VI. ORGANIZATION AND ACTIVITIES OF RIKEN NISHINA CENTER (Activities and Members)

1. Organization

1.1 Organization Chart as of April 1, 2013

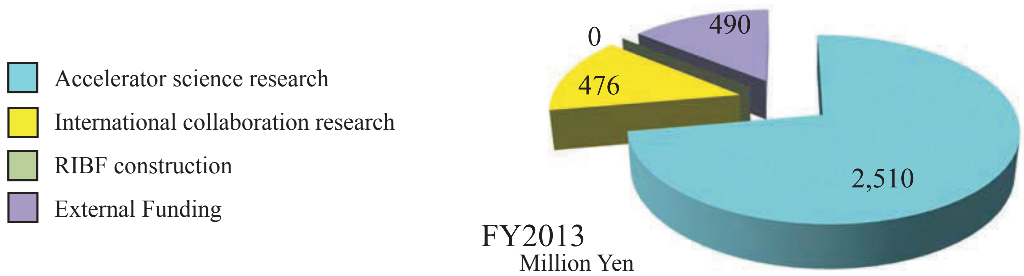
1.2 Topic in FY2013

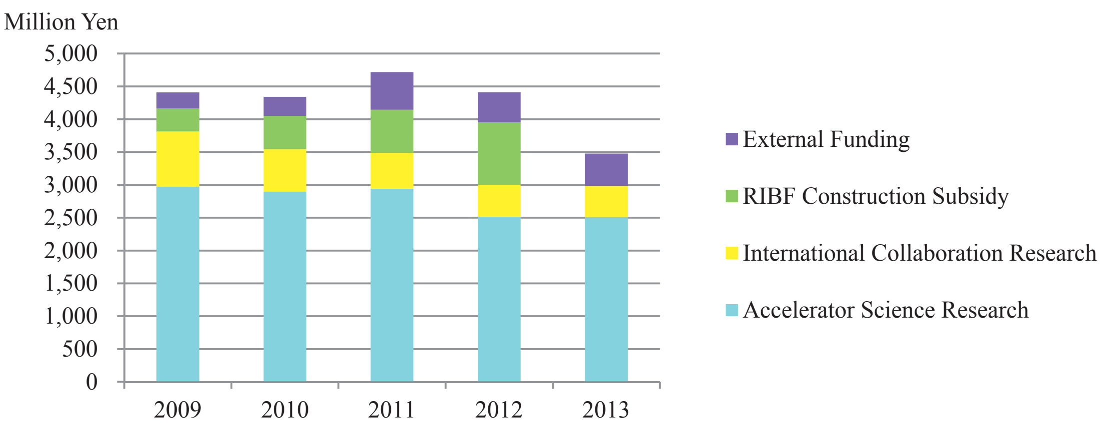
Apr. 1, 2013	Start of **Nuclear Spectroscopy Laboratory** Start of **Research Group for Superheavy Element**, taking over Superheavy Element Laboratory, associated with following two teams **Superheavy Element Production Team** **Superheavy Element Device Development Team** Personnel Change Deputy Director of RNC: Hiroyosi SAKURAI Director of RBRC: Samuel H. ARONSON Team Leader of User Support Office: Ken-ichiroYONEDA Team Leader of SAMURAI Team: Hiromi SATO New Appointment Deputy Group Director of Accelerator Group (Energy Efficient Management): Masayuki KASE Senior Adviser: Walter F. HENNING
Nov. 1, 2013	New Appointment Deputy Director of RBRC: Robert PISARSKI

2. Finances

Breakdown expenses of the RNS FY2013 budget and transition for past five years are shown in following figures.

Due to the budgetary limitation caused by the aftermath of Tohoku earthquake and Fukushima nuclear disaster, beam time for the RIBF users as recommended in NCAC2011 is not able to be provided sufficiently at present. For FY2013, RNC managed to realize 3.5 month operation by receiving additional President's Discretionary Fund and cancelling accelerator operation in autumn which was replaced by a consecutive operation from the year-end to the next fiscal year.

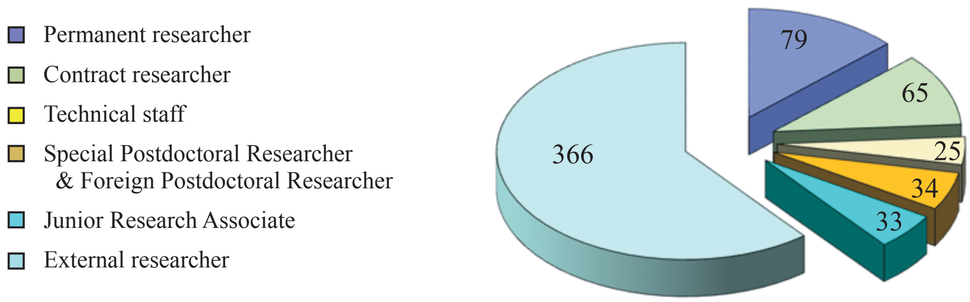


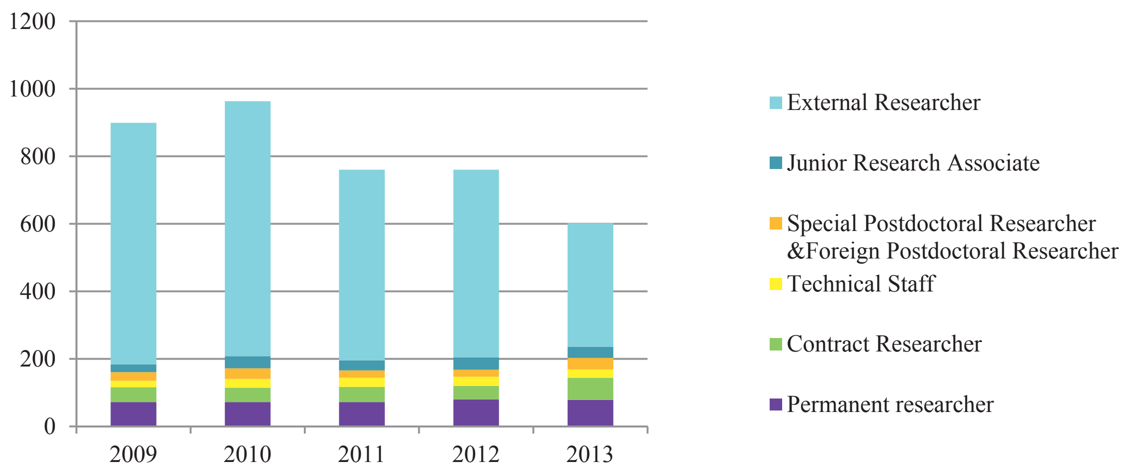


3. Staffing

Having reached a consensus within RIKEN on the issue of supplementing additional permanent staff to the Accelerator Group, RNC now have a better outlook for solving personnel shortage problem. RNC eagerly anticipate additional permanent staff to join the Accelerator Group in the near future, with one new arrival in FY2013, another one to be selected for FY2014. On the other hand, while there is several permanent staffs that underwent career shift from research to research support, the number is still not enough. To further promote an increase in permanent research support staff, RNC are recruiting from entire RIKEN for qualified candidates.

Breakdown to six personnel categories in FY2013 and transition for past five years are shown in following figures.





4. Management

RIKEN Nishina Center for Accelerator-Based Science (**RNC**) is now composed of, under RNC Director Hideto En'yo,

10 Laboratories,
1 Research unit,
7 Groups with 20 Teams,
2 overseas research center with 3 Groups.

There are also three 'Partner Institutes' which conduct research in the laboratories arranged in RNC.

RNC is managed by its Director through the majority decision in the RNC Coordination Committee. Accelerator Research Promotion Section which carries out administrative function of RNC under the President of RIKEN is set close to RNC.

In order to support the management of RNC, there are

Scientific Policy Committee,
Program Advisory Committee,
Safety Review Committee,
RIBF Machine Time Committee, and
Public Relations Committee.

There are also committees to support the President of RIKEN or the Director of RNC.

RBRC Management Steering Committee (MSC) and Nishina Center Advisory Council, which has two subcommittees.

RBRC Scientific Review Committee (SRC) and
Advisory Committee for the RIKEN-RAL Muon Facility.

Nishina Center for Accelerator-based Science

Executive Members (as of March 31, 2014)

Hideto EN'YO	Director, RNC; Chief Scientist, Director of Radiation Laboratory
Tetsuo HATSUDA	Deputy Director (Theoretical Research), RNC; Chief Scientist, Director of Quantum Hadron Physics Laboratory
Hiroyoshi SAKURAI	Deputy Director (RIBF Research), RNC; Chief Scientist, Director of Radioactive Isotope Physics Laboratory
Tohru MOTOBAYASHI	RIBF Synergetic-Use Coordinator
Walter F. HENNING	Senior Advisor
Yasushige YANO	Senior Advisor
Minami IMANISHI	Assistant

RNC Coordination Committee

Following subjects relating to RNC management are deliberated under the chairmanship of RNC Director.

Establishment of the new organization or reorganization in RNC,
Personnel management of RNC researchers,
Research themes and research budget
Approval of the Partner Institutes,
Evaluation as to the management of RNC and the response to recommendations by external evaluation.

RNC Coordination Committee is held monthly.

Members (as of March 31, 2014)

Hideto EN'YO	Director, RNC; Chief Scientist, Director of Radiation Laboratory
Hiroyoshi SAKURAI	Deputy Director, RNC; Chief Scientist, Director of Radioactive Isotope Physics Laboratory
Tetsuo HATSUDA	Deputy Director, RNC; Chief Scientist, Director of Quantum Hadron Physics Laboratory
Walter F. HENNING	Senior Advisor
Tohru MOTOBAYASHI	RIBF synergetic-use coordinator
Yasushige YANO	Senior Advisor
Masahiko IWASAKI	Chief Scientist, Director of Advanced Meson Science Laboratory
Tomohiro UESAKA	Chief Scientist, Director of Spin isospin Laboratory
Hideki UENO	Chief Scientist, Director of Nuclear Spectroscopy Laboratory; Deputy Group Director, User Liaison and Industrial Cooperation Group
Toru TAMAGAWA	Associate Chief Scientist, Director of High Energy Astrophysics Laboratory
Takashi NAKATSUKASA	Associate Chief Scientist, Director of Theoretical Nuclear Physics Laboratory
Emiko HIYAMA	Associate Chief Scientist, Director of Strangeness Nuclear Physics Laboratory
Koji HASHIMOTO	Associate Chief Scientist, Director of Mathematical Physics Laboratory
Kosuke MORITA	Group Director, Research Group for Superheavy Element; Team Leader, Superheavy Element Production Team
Osamu KAMIGAITO	Group Director, Accelerator Group
Hideyuki SAKAI	Group Director, User Liaison and Industrial Cooperation Group
Hiroki OKUNO	Deputy Group Director, Accelerator Group; Team Leader, Accelerator R&D Team; Team Leader, Cryogenic Technology Team
Nobuhisa FUKUNISHI	Deputy Group Director, Accelerator Group; Team Leader, Beam Dynamics & Diagnostics Team
Masayuki KASE	Deputy Group Director, Accelerator Group; Team Leader, Infrastructure Management Team
Tomoko ABE	Group Director, Accelerator Applications Research Group; Team Leader, Radiation Biology Team
Yoshitomo UWAMINO	Group Director, Safety Management Group
Toshiyuki KUBO	Group Director, Research Instruments Group; Team Leader, Detector Team
Masanori WAKASUGI	Group Director, Instrumentation Development Group; Team Leader, Rare RI-ring Team; Team Leader, SCRIT Team
Eiji IKEZAWA	Team Leader, RILAC Team
Takashi ICHIHARA	Team Leader, Computing and Network Team
Naruhiko SAKAMOTO	Team Leader, Cyclotron Team
Hiromi SATO	Team Leader, SAMURAI Team (-Mar. 2014), Team Leader, Detector Team (Apr. 2014-)
Takahide NAKAGAWA	Team Leader, Ion Source Team
Hiromitsu HABA	Team Leader, RI Applications Team
Koji MORIMOTO	Team Leader, Superheavy Element Device Development Team
Atsushi YOSHIDA	Team Leader, Industrial Cooperation Team
Koichi YOSHIDA	Team Leader, BigRIPS Team
Ken-ichiro YONEDA	Team Leader, User Support Office
Michiharu WADA	Team Leader, SLOWRI Team
Yasuyuki Akiba	Vice Chief Scientist, Radiation Laboratory; Group Leader, Experimental Group, RIKEN BNL Research Center
Katsuhiko ISHIDA	Vice Chief Scientist, Advanced Meson Science Laboratory
Tsukasa TADA	Vice Chief Scientist, Quantum Hadron Physics Laboratory
Yuko MOTIZUKI	Research Unit Leader, Astro-Glaciology Research Unit
Akihiko UEDA	Senior Manager; Director, Head of Accelerator Research Promotion Section

Accelerator Research Promotion Section

The scope of business of Accelerator Research Promotion Section is Planning and coordination as to research program and research system of RNC, Planning and management of budget use of RNC, Public relations activity.

Members (as of March 31, 2014)

Akihiko UEDA	Senior Manager; Director, Head of Accelerator Research Promotion Section
Mitsuru KISHIMOTO	Manager, Accelerator Research Promotion Section
Hayato NISHIMURA	Deputy Manager (-May 2014)
Kazunori MABUCHI	Deputy Manager
Yukari ONISHI	Chief
Kumiko SUGITA	Special Administrative Employee
Yuko OKADA	Task-Specific Employee
Yukiko SATO	Task-Specific Employee
Kyoji YAMADA	Special Temporary Employee
Yoshio OKUIZUMI	Temporary Employee
Masatoshi MORIYAMA	Consultant for Advisory Committee, Research Review, etc.
Rie KUWANA	Temporary Staff

Scientific Policy Committee

Scientific Policy Committee deliberates on Research measures and policies of RNC, Administration of research facilities under RNC's control. Committee members are selected among professionals within and without RNC. The Committee is held annually.

Members (as of March 31, 2014)

Hirokazu Tamura	Chair Prof., Graduate School of Science, Tohoku University
Yujiro IKEDA	Director, J-PARC Center
Akira UKAWA	Prof., Faculty of Pure and Applied Sciences, University of Tsukuba
Takaharu OTSUKA	Director, Center for Nuclear Study (CNS), University of Tokyo
Hideo OHNO	Research Advisor, Japan Synchrotron Radiation Research Institute (JASRI)
Ryosuke KADONO	PI, Muon Science Laboratory, Institute of Materials Structure Science, High Energy Accelerator Research Organization (KEK)
Takashi NAKANO	Director of Research Center for Nuclear Physics (RCNP), Osaka University
Hirohiko TSUJII	Fellow, National Institute of Radiological Sciences (NIRS)
Tomofumi NAGAE	Prof. Graduate School of Science, Kyoto University
Hitoshi NAKAGAWA	Auditor, Japan International Research Center for Agricultural Sciences
Yoshiyuki FUJII	Project Prof., Arctic Environment Research Center, National Institute of Polar Research
Yasuhiko FUJII	Director, Research Center for Neutron and Technology, Comprehensive Research Organization for Science and Society (CROSS-TOKAI)
Shoji FUTATSUGAWA	Executive Director, Japan Radioisotope Association
Masanori YAMAUCHI	Director, Institute of Particle and Nuclear Studies, High Energy Accelerator Research Organization (KEK)
Kazuyoshi YAMADA	Director, Institute of materials Structure Science, High Energy Accelerator Research Organization (KEK)
Kazuo SHINOZAKI	Director, Center for Sustainable Resource Science, RIKEN
Ryutaro HIMENO	Director, Advanced Center for Computing and Communication, RIKEN

The meeting of FY2013 was held on July 11, 2013 at Tokyo Liaison Office of RIKEN.

Program Advisory Committee

Program Advisory Committee reviews experimental proposals submitted by researchers and reports the acceptance or the denial of the adaptation of proposals to RNC Director. The Committee also reports to RNC Director the available period (days) of RIBF or Muon Facility at RAL allotted to researchers.

The name and scope of the Committees are follows;

(1) Nuclear Physics Experiments at RIBF (NP-PAC): academic research for nuclear physics,
(2) Materials and Life Science Researches at RNC (ML-PAC): academic research for material science and life science,
(3) Industrial Program Advisory Committee (In-PAC): non-academic research

Program Advisory Committee for Nuclear Physics Experiments at RI Beam Factory (NP-PAC)

Members

Muhsin N. HARAKEH	Chair Prof. KVI (Kernfysisch Versneller Instituut), University of Groningen, Netherlands
Yanlin YE	Prof. State Key Lab. of Nucl. Phys. and Tech., School of Physics, Peking University, Chaina

Christoph SCHEIDENBERGER	Head, NuSTAR/ENNA Department, GSI, Germany
Friedrich-K. THIELEMANN	Prof. Department of Physics, University of Basel, Switzerland
Rick F. CASTEN	Physics Department, Yale University, USA
Christopher J. (KIM) LISTER	Prof. Department of Physics and Applied Physics, University of Massachusetts, Lowell, USA
Hans EMLING	GSI, Germany
Hironori IWASAKI	Assistant Professor of Physics, National Superconducting Cyclotron Laboratory, Michigan State University, USA
Walter D. LOVELAND	Full Prof. Department of Chemistry, Oregon State University, USA
Thomas NILSSON	Prof. Department of Fundamental Physics, Chalmers Univ. of Technology, Sweden Chair of BFC (Board of FAIR Collaborations)
Bradley. M.SHERRILL	FRIB Chief Scientist, Michigan State University, USA
Olivier SORLIN	Grand Accélérateur National d'Ions Lourds (GANIL), France
Satoshi N. NAKAMURA	Associate Prof. Nuclear Experiment Group, Faculty of Science, Tohoku University
Atsushi TAMII	Associate Prof. Experimental Nuclear Physics Division, Research Center for Nuclear Physics, Osaka University
Yutaka UTSUNO	Frontier Research on Heavy Element System, Advanced Science Research Center, JAEA
Masanobu YAHIRO	Prof. Fundamental particle physics, Department of Physics, Faculty of Sciences, Kyushu University
Takashi NAKATSUKASA	Associate Chief Scientist, Director of Theoretical Nuclear Physics Laboratory, RNC, RIKEN

Program Advisory Committee for Materials and Life Science Researches at RIKEN Nishina Center (ML-PAC)

Members

Jean-Michel POUTISSOU	Chair Senior research scientist Emeritus, TRIUMF, Canada
Alex AMATO	Muon Spin Spectroscopy, Paul Scherrer Institute, Switzerland
Douglas E. MACLAUGHLIN	(University of California, Riverside, USA)
Sadamichi MAEKAWA	(JAEA, JAPAN)
Kenya KUBO	Prof. The College of Liberal Arts, International Christian University
Adrian HILLIER	ISIS, RAL, UK
Philippe MENDELS	Laboratorie de Physique des Solides, Universite Paris-SUD, France
Xu-Guang ZHENG	Saga University
Hiroyuki YAMASE	(NIMS, JAPAN)
Ryosuke KADONO	PI, Muon Science Laboratory, Institute of Materials Structure Science, High Energy Accelerator Research Organization (KEK)
Norimichi KOJIMA	University of Tokyo, JAPAN)
Toshiyuki AZUMA	Chief Scientist, Atomic, Molecular & Optical Physics Laboratory, RIKEN
Atsushi KAWAMOTO	(Hokkaido University, JAPAN)
Shigeo YOSHIDA	(Yokohama City University, JAPAN)

Industrial Program Advisory Committee (In-PAC) Members (July 1, 2012--March 31, 2014)

Members

Akihiro IWASE	Chair Prof. Graduate School of Engineering, Osaka Prefecture University
Kenya KUBO	Prof. The College of Liberal Arts, International Christian University
Hitoshi NAKAGAWA	Auditor, Japan International Research Center for Agricultural Sciences
Nobuhiko NISHIDA	Full time research fellow, Toyota Physical and Chemical Research Institute
Toshinori MITSUMOTO	Chief Engineer, Quantum Equipment Division, Sumitomo Heavy Industries, Ltd
Toshiyuki AZUMA	Chief Scientist, Atomic, Molecular & Optical Physics Laboratory, RIKEN

Safety Review Committee

Safety Review Committee is composed of two sub committees, Safety Review Committee for Accelerator Experiments and Hot-Labo Safety Review Committee. These Committees review the safety of the usage scenario about radiation generating equipment submitted to RNC Director from the spokesperson of the approved experiment.

Safety Review Committee for Accelerator Experiments

Members

Takashi KISHIDA	Chair, Sakurai Radioactive Isotope Physics Laboratory
Kouji MORIMOTO	Superheavy Element Research Device Development Team
Eiji IKEZAWA	RILAC Team
Hiromitsu HABA	RI Applications Team
Shinichiro MICHIMASA	Assistant Prof., Center for Nuclear Study, University of Tokyo
Hidetoshi YAMAGUCHI	Lecturer, Center for Nuclear Study, University of Tokyo
Hiroshi WATANABE	Lecturer, KEK
Hiromi SATO	Detector Team

Atsushi YOSHIDA	Industrial Cooperation Team
Koichi YOSHIDA	BigRIPS Team
Naoki FUKUDA	BigRIPS Team
Naruhiko SAKAMOTO	Cyclotron Team
Hisao SAKAMOTO	Safety Management Group
Yoshitomo UWAMINO	Safety Management Group
Kanenobu TANAKA	Safety Management Group

Hot-Labo Safety Review Committee

Members

Masako IZUMI	Chair, Radiation Biology Team
Yoshitomo UWAMINO	Safety Management Group
Hisao SAKAMOTO	Safety Management Group
Hiroki MUKAI	Safety Management Group
Kanenobu TANAKA	Safety Management Group
Hiromitsu HABA	RI Applications Team

RIBF Machine Time Committee

Upon request of RNC Director, RIBF Machine Time Committee deliberates the operating program of RIBF and returns the results to him.

Members

Hideyuki SAKAI	Chair, User Liaison and Industrial Cooperation Group
Tomoko ABE	Group Director, Accelerator Applications Research Group
Nobuhisa FUKUNISHI	Deputy Group Director, Accelerator Group
Osamu KAMIGAITO	Group Director, Accelerator Group
Masayuki KASE	Deputy Group Director, Accelerator Group
Toshiyuki KUBO	Group Director, Research Instruments Group
Kouji MORIMOTO	Team Leader, Superheavy Element Research Device Development Team
Hiroki OKUNO	Deputy Group Director, Accelerator Group
Hiroyoshi SAKURAI	Chief Scientist, Sakurai Radioactive Isotope Physics Laboratory
Hideki UENO	Chief Scientist, Nuclear Spectroscopy Laboratory
Tomohiro UESAKA	Chief Scientist, Spin isospin Laboratory
Yoshitomo UWAMINO	Group Director, Safety Management Group
Masanori WAKASUGI	Group Director, Instrumentation Development Group
Ken-ichiro YONEDA	Team Leader, User Support Office
Susumu SHIMOURA	Professor, Center for Nuclear Study, University of Tokyo
Hidetoshi YAMAGUCHI	Lecturer, Center for Nuclear Study, University of Tokyo
Hiroari MIYATAKE	Professor, KEK

Public Relations Committee

Upon request of RNC Director, Public Relations Committee deliberates and coordinates following matters.
(1) Construction of the public relation system of the overall RNC,
(2) Prioritization of the public relation activities of the overall RNC,
(3) Other basic matters and important matters concerning the public relations of the overall RNC.

Members

Akihiko UEDA	Chair, Senior Manager; Director, Head of Accelerator Research Promotion Section (-Mar. 2014)
Hiroyoshi SAKURAI	Deputy Director, RNC; Chief Scientist, Director of Radioactive Isotope Physics Laboratory
Tetsuo HATSUDA	Deputy Director, RNC; Chief Scientist, Director of Quantum Hadron Physics Laboratory
Tohru MOTOBAYASHI	RIBF synergetic-use coordinator
Walter F. HENNING	Senior Advisor
Yasushige YANO	Senior Advisor
Masahiko IWASAKI	Chief Scientist, Director of Advanced Meson Science Laboratory
Tomohiro UESAKA	Chief Scientist, Director of Spin isospin Laboratory
Hideki UENO	Chief Scientist, Director of Nuclear Spectroscopy Laboratory; Deputy Group Direcotr, User Liaison and Industrial Cooperation Group
Toru TAMAGAWA	Associate Chief Scientist, Director of High Energy Astrophysics Laboratory
Takashi NAKATSUKASA	Associate Chief Scientist, Director of Theoretical Nuclear Physics Laboratory
Emiko HIYAMA	Associate Chief Scientist, Director of Strangeness Nuclear Physics Laboratory
Koji HASHIMOTO	Associate Chief Scientist, Director of Mathematical Physics Laboratory
Kosuke MORITA	Group Director, Research Group for Superheavy Element; Team Leader, Superheavy Element Production Team

Osamu KAMIGAITO	Group Director, Accelerator Group
Hideyuki SAKAI	Group Director, User Liaison and Industrial Cooperation Group

RBRC Management Steering Committee (MSC)

RBRC MSC is set up according to Memorandum of Understanding Between RIKEN and BNL concerning the collaboration on the Spin Physics Program at the Relativistic Heavy Ion Collider (RHIC).

Members

Maki KAWAI	Executive Director, RIKEN
Shoji NAGAMIYA	Science Advisor, RIKEN
Hideto EN'YO	Director, RNC
Peter BOND	Senior Advisor, BNL
David LISSAUER	Deputy Chair, Physics Department, BNL
Satoshi OZAKI	Senior Advisor, BNL

Nishina Center Advisory Council

The charge to NCAC is set by the Terms of Reference presented by the Director of the RIKEN and the RNC Director on the fundamental issues about research activities and research administration. NCAC submits its report to the President of RIKEN, and to the Director of Nishina Center if necessary. The members of NCAC are recommended by the Director of Nishina Center to the President of RIKEN from among highly knowledgeable individuals and experts worldwide. NCAC has two sub-councils for the RBRC and the RAL Muon Facility respectively.

Members

Robert TRIBBLE	Chair Deputy Director for Science and Technology, BNL, USA
Juha ÄYSTÖ	Director of Helsinki Institute of Physics, Finland
Angela BRACCO	Prof., Department of Physics, the University of Milan, Italy
Ken'ichi IMAI	Prof., Emeritus (Kyoto Univ.), Group Leader, Research Group for Hadron Physics, Advanced Science Research Center, JAEA
Marek LEWITOWICZ	Deputy Director, Grand Accélérateur National d'Ions Lourds, France
Lia MERMINGA	Head, Accelerator Division, TRIUMF, Canada
Witold NAZAREWICZ	Prof., Department of Physics and Astronomy, the University of Tennessee, USA
Susumu SHIMOURA	Prof., Center for Nuclear Study (CNS), University of Tokyo
Matthias SCHÄDEL	Group Leader, Research Group for Superheavy Elements, Advanced Science Research Center, JAEA. (Visiting Scientist, GSI, Germany)
GuoQing XIAO	Director, Institute of Modern Physics, Chinese Academy of Sciences, Chaina
Akira YAMAMOTO	Head, Linear Collider Project Office, Department of Advanced Accelerator Technologies, KEK
Wolfram WEISE	Director, European Center for Theoretical studies in Nuclear Physic and Related Areas, Italy
Masaki FUKUSHIMA	Prof., Institute for Cosmic Ray Research, University of Tokyo
Jun SUGIYAMA	Principal Research Scientist, Toyota Central R&D Labs., INC
Richard MILNER	Prof., Director, Laboratory for Nuclear Science, MIT, USA
Hirokazu TAMURA	Prof., Department of Physics, Graduate School of Science, Tohoku University
Muhsin N. HARAKEH	Prof., Emeritus, KVI (Kernfysisch Versneller Instituut), University of Groningen, Netherlands
Jean-Michel POUTISSOU	Senior research scientist Emeritus, TRIUMF, Canada
Andrew TAYLOR	Executive Director, STFC National Laboratories, UK

RBRC Scientific Review Committee (SRC)

Members

Richard MILNER	Chair Prof., Director, Laboratory for Nuclear Science, MIT, USA
Shinya AOKI	Prof. Yukawa Institute for Theoretical Physics, Kyoto University
Ken'ich IMAI	Group Leader, Research Group for Hadron Physics, Advanced Science Research Center, JAEA Prof. emeritus, Kyoto University
Tetsuo MATSUI	Prof. Department of Basic Science, Graduate School of Arts and Sciences, Komaba, University of Tokyo
Alfred MUELLER	Prof. Department of Physics, Columbia University, USA
Peter Braun-MUNZINGER	Prof. Dr. GSI Helmholtzzentrum für Schwerionenforschung, Germany
Charles PRESCOTT	Prof. Stanford Linear Accelerator Center, USA
Akira UKAWA	Prof. Graduate School of Pure and Applied Science, University of Tsukuba

Advisory Committee for the RIKEN-RAL Muon Facility

Members

Andrew TAYLOR	Chair Executive Director, STFC National Laboratories, UK
Jean-Michel POUTISSOU	Senior research scientist Emeritus, TRIUMF, Canada
Klaus P. JUNGMANN	Prof. University of Groningen, Netherlands
Roberto De RENZI	Prof. Department of Physics and Earth Sciences, University of Parma, Italy
Yasuyuki MATSUDA	Asso. Prof. Graduate School of Arts and Sciences, the University of Tokyo
Jun SUGIYAMA	Principal Research Scientist, Toyota Central R&D Labs., INC

5. International Collaboration

Country	Partner Institute	Objects	RNC contact person
Belgium	Katholieke Universiteit te Leuven	Framework	Michiharu Wada, Team Leader, SLOWRI Team
Bulgaria	the Institute for Nuclear Research and Nuclear Energy (INRNE)	Framework	Hedeki Ueno, Chief Scientist, Nuclear Spectroscopy Laboratory
Canada	TRIUMF	Accelerator-based Science	Hiroyoshi Sakurai, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
China	China Nuclear Physics Society	The creation of the council for China -Japan research collabortion on nuclear physics	Hiroyoshi Sakurai, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
	Peking University	Nuclear Science	Hiroyoshi Sakurai, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
	Peking University	Strategic cooperation (Nishina School)	Hiroyoshi Sakurai, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
	Shanghai Jiao Tong University	International Joint Graduate School Program	Takashi Nakatsukasa, Associate chief scientist, Theoretical Nuclear Physics Laboratory
	ZHEJIANG University	International Joint Graduate School Program	Isao Watanabe, Advanced Meson Science Laboratoy
	Institute of Modern Physics	Physics of heavy ions	Hiroyoshi Sakurai, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
	School of Nuclear Science and Technology, Lanzhou University	Framework	Yue MA, Advanced Meson Science Laboratory
	School of Physics, Nanjing University	Framework	Emiko Hiyama, Associate chief scientist, Strangeness Nuclear Physics Laboratory
EU	European Gamma-Ray Spectroscopy Pool Owners Committee	The use of Euroball ditector at RIKEN	Shunji Nishimura, Radioactive Isotope Physics Laboratory
	European Center for Theoretical Studies in Nuclear Physics and Related Areas (ECT*)	Theoretical physics	Tetsuo Hatsuda, Deputy Director, Chief Scientist, Quantum Hadron Physics Laboratory
	CERN	RD-51:R&D programme for micro-pattern gas detectors (MPGD)	Satoshi Yokkaichi, Senior Research Scientist, Radiation Laboratory
Finland	University of Jyvaskyla	Basic nuclear physics and related instrumentation	Michiharu Wada, Team Leader, SLOWRI Team
France	GANIL	The creation of an associated international laboratory (LIA)	Tohru Motobayashi, RIBF synergetic-use coordinator
	DSM/IRFU, GANIL, IN2P3/IPNO	The preparation and realization for the MUST2 campaign of experiments at RIKEN	Hiroyoshi Sakurai, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory

Country	Partner Institute	Objects	RNC contact person
France	Natioanl Institute of Nuclear Physics and Particle Physics (IN2P3)	Physics of heavy ions	Tohru Motobayashi, RIBF synergetic-use coordinator
	SIMEM Graduate School, Department of Physics,Caen University	Framework	Tomohiro Uesaka, Chief Scientist, Spin Isospin Laboratory
	CEA-DSM	The use of MINOS device at RIKEN	Tomohiro Uesaka, Chief Scientist, Spin Isospin Laboratory
Germany	Technische Universität München	Nuclear physucs, hadron physics, nuclear astrophysics	Emiko Hiyama, Associate chief scientist, Strangeness Nuclear Physics Laboratory
	Max-Planck Gesellschaft	Comprehensive agreement	Hiroyoshi Sakurai, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
	GSI	Physics of heavey ions and accelerator	Hiroyoshi Sakurai, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
Hungary	the Institute of Nuclear Reseach of the Hungarian Academy of Sciences (ATOMKI)	Nuclear physics, Atomic Physics	Tomohiro Uesaka, Chief Scientist, Spin Isospin Laboratory
Italy	Natinal Institute of Nuclear Physics (INFN)	Physics of heavy ions	Tohru Motobayashi, RIBF synergetic-use coordinator
	Applied Physics Division, National Institute for New Technologies, Energy and Environment (ENEA)	Research program with the Radiation Laboratory	Tohru Motobayashi, RIBF synergetic-use coordinator
Indonesia	ITB, UNPAD, ITS, UGM	Material science using muons at the RIKEN-RAL muon facility	Isao Watanabe, Advanced Meson Science Laboratoy
	UNPAD	International Joint Graduate School Program	Isao Watanabe, Advanced Meson Science Laboratoy
	ITB	International Joint Graduate School Program	Isao Watanabe, Advanced Meson Science Laboratoy
Korea	Seoul National University	Nishina School	Hiroyoshi Sakurai, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
	Seoul National University	International Joint Graduate School Program	Itaru Nakagawa, Radiation Laboratory
	Institute of Basic Science, Rare Isotope Science Project	Rare ion accelerator and related fields	Hiroyoshi Sakurai, Shunji Nishimura
	College of Natural Sciences of Kyungpook National University	International Joint Graduate School Program	Tomohiro Uesaka, Chief Scientist, Spin Isospin Laboratory
	Department of Physics, Kyungpook National University	Framework	Tomohiro Uesaka, Chief Scientist, Spin Isospin Laboratory
	College of Science, Yonsei University	Spin physics and High energy heavy ion physics	Yasuyuki Akiba, Radiation Laboratory
	Department of Physics, Yonsei University	International Joint Graduate School Program	Yasuyuki Akiba, Radiation Laboratory
	Department of Physics, Korea University	High energy physics, heavy ion physics	Yuji Goto, Radiation Laboratory
Malaysia	Universiti Sains Malaysia	Muon Science	Isao Watanabe, Advanced Meson Science Laboratoy
Poland	the Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences(IFJ PAN)	Nuclear physics and related subjects	Hiroyoshi Sakurai, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
Romania	"Horia Hulubei" National Institute of Physics and Nuclear Engineering Bucharest-Magurele, Romania	Nuclear physics and related subjects	Tomohiro Uesaka, Chief Scientist, Spin Isospin Laboratory
Russia	Joint Institute for Nuclear Research (JINR)	Framework of scientific and technical cooperarion	Tomohiro Uesaka, Chief Scientist, Spin Isospin Laboratory
	Russion Research Center "Kurchatov Institute"	Nuclear physics, Atomic Physics	Hiroyoshi Sakurai, Tomohiro Uesaka, Osamu Kamigaito, Masanori Wakasugi

Country	Partner Institute	Objects	RNC contact person
Switzerland	Paul Scherrer Institute	Improve the performance and reliability of accelerator systems	Osamu Kamigaito, Group Director, Chief Scientist, Accelerator Group
UK	The Science and Technology Facilities Council	Muon science using the ISIS Facility at the Rutherford Appleton Laboratory	Director of RIKEN-RAL muon facility
	University of Liverpool	International Joint Graduate School Program	Hiroyoshi Sakurai, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
USA	BNL	The Spin Physics Program at the Relativistic Heavy Ion Collider(RHIC)	Director of RNC
	Columbia University	The development of QCDCQ	Taku Izubuchi, Group Leader, Computing Group, RBRC
	Michigan State University	Comprehensive	Tomohiro Uesaka, Chief Scientist, Spin Isospin Laboratory
		TPC(Time Projection Chamber)	Hiroyoshi Sakurai Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory & Tadaaki ISOBE, Radioactive Isotope Physics Laboratory
Vietnam	Vietnam Atomic Evergy Commission	Nuclear Science	Tohru Motobayashi, RIBF synergetic-use coordinator
	Institute for Nuclear Sciences and Technique	Nuclear Physics	Hiroyoshi Sakurai, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
	Hanoi University of Science	International Joint Graduate School Program	Hiroyoshi Sakurai, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
	Institute of Physics, Vietnam Academy of Science and Technology	Academic exhange	Hiroyoshi Sakurai, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory

Theoretical Research Division
Quantum Hadron Physics Laboratory

1. Abstract

Atomic nuclei are made of protons and neutrons bound by the exchange of Yukawa's pion and other mesons. Also, protons and neutrons are made of quarks bound by the exchange of gluons. These strong interactions are governed by the non-Abelian gauge theory called the quantum chromodynamics (QCD). On the basis of theoretical and numerical analyses of QCD, we study the interactions between the nucleons, properties of the dense quark matter realized at the center of neutron stars, and properties of the hot quark-gluon plasma realized in the early Universe. Strong correlations common in QCD and cold atoms are also studied theoretically to unravel the universal features of the strongly interacting many-body systems. Developing perturbative and non-perturbative techniques in quantum field theory and string theory are of great importance not only to solve gauge theories such as QED and QCD, but also to find the theories beyond the standard model of elementary particles. Various theoretical approaches along this line have been attempted.

2. Major Research Subjects

(1) Nucleon structure and nuclear force from QCD
(2) Theory of spontaneous symmetry breaking
(3) QCD under extreme conditions
(4) Non-perturbative study of supersymmetric quantum field theories and string theories
(5) QED calculation of the lepton anomalous magnetic moments
(6) Physics of particles with resonant interactions

3. Summary of Research Activity

(1) Nucleon structure and nuclear force from QCD

(1-1) Nucleon structure from lattice QCD

The structure of nucleon is a crucial quantity to understand the low energy behaviors of QCD, and to detect the possible sign of physics beyond the standard model. In particular, the precise values of scalar matrix elements are required for the dark matter search experiments, and we performed the lattice QCD calculation for strangeness and charmness scalar matrix elements using chiral fermions. The so-called "spin crisis" is one of the most challenging issues in nucleon structure. Its lattice QCD study is also challenging since the computation of the disconnected insertions and glue matrix elements are required. We developed a novel method to calculate these components and performed the first complete lattice calculation for the nucleon spin.

(1-2) Lattice nuclear force

While the nuclear force serves as the cornerstone in nuclear physics, theoretical understanding of them from the underlying theory, QCD, has not been established yet. Our HAL QCD Collaboration has been developing the lattice QCD method to determine the nuclear forces. The method has been successfully applied to various hadron-hadron interactions including the hyperon forces. The physical origin of the repulsive core was revealed as the quark Pauli blocking effect. The equation of state based on lattice nuclear forces was studied and the saturation of nuclear matter was observed for the first time. Of particular interest is the determination of the three-nucleon forces from lattice QCD. Facing the challenge of the enormous computational cost for this study, we developed a novel algorithm which reduces the cost by a factor of 192. The lattice QCD results indicate that repulsive three-nucleon forces exist at short distance.

(2) Theory of spontaneous symmetry breaking

The general counting rule for Nambu-Goldstone (NG) modes is derived using Mori's projection operator method in non-Lorentz invariant systems at zero and finite temperatures. We classified NG modes into two types: One is the same type (Type-I or A) as that in relativistic systems. The other is type-II or B NG mode that is characterized by the expectation value of $[Q_a, Q_b]$, where Q_a and Q_b are broken charges. The motion of the type-II NG mode is precessional, while that of type-I NG mode is harmonic. The total number of Nambu-Goldstone modes is equal to the number of broken charges minus half the rank of the expectation value of $[Q_a, Q_b]$.

(3) QCD under extreme conditions

(3-1) QCD under strong magnetic field

We discussed the fate of chiral symmetry in an extremely strong magnetic field B, taking into account not only quark fluctuations but also neutral meson effects. The former would enhance the chiral-symmetry breaking at finite B according to the Magnetic Catalysis, while the latter would suppress the chiral condensate once B exceeds the scale of the hadron structure. Using a chiral model we demonstrate how neutral mesons are subject to the dimensional reduction and the low dimensionality favors the chiral-symmetric phase. We pointed out that this effect, the Magnetic Inhibition, can be a feasible explanation for recent lattice QCD data indicating the decreasing behavior of the chiral-restoration temperature with increasing B. We also discussed the behavior of vector-meson mass and the possibility of its condensation in a strong magnetic field. Several hadronic models show that the mass of the charged vector meson degreases as the magnetic field increases, and at some critical magnetic field, the charged vector meson condenses. We, however, showed, by using the Vafa-Witten theorem, that the vector meson condensation does not happen in QCD. We also performed the numerical analysis for the meson mass and condensation in lattice QCD. The lattice QCD data confirmed no charged vector meson condensation in a magnetic field.

(3-2) Relativistic hydrodynamics

We studied relativistic hydrodynamics in the linear regime, based on Mori's projection operator method. In relativistic hydrodynamics, it is considered that an ambiguity about the fluid velocity occurs from a choice of a local rest frame: the Landau and Eckart frames. We derived hydrodynamic equations in the both frames by the projection operator method. We found that the difference of the frames was not the choice of the local rest frame, but rather that of dynamic variables in the linear regime.

(4) Non-perturbative study of supersymmetric quantum field theories and string theories

(4-1) Lattice formulation of the N=2 supersymmetric Landau-Ginzburg model and numerical simulation

Noting the fact that a simple momentum cutoff applied to an off-shell supersymmetric multiplet does not break supersymmetry (SUSY), we constructed a lattice formulation of the two-dimensional N=2 supersymmetric Wess-Zumino (WZ) model that preserves manifest SUSY. Although the locality is broken with this lattice formulation, one can argue that the locality is restored in the continuum limit because of the preserved SUSY. Using this formulation, we further carried out a numerical simulation of a massless WZ model with a cubic superpotential, which is believed to become an N=2 superconformal field theory in the infrared limit. We measured a scaling dimension and the central charge in the infrared limit and obtained values consistent with the theoretical conjecture.

(4-2) Theoretical basis for a lattice formulation of the four-dimensional N=1 supersymmetric Yang-Mills (SYM) theory

Since there is no lattice formulation of the four-dimensional N=1 SYM theory that can preserve manifest SUSY, it is important to understand how SUSY is restored in the continuum limit. In a precise theoretical treatment, this issue should be addressed in terms of the Ward-Takahashi (WT) relation associated with SUSY. We pointed out there was a flaw in past treatments of the WT relation and provided a proper analysis of the WT relation by using a generalized BRS transformation that treats the chiral symmetry, SUSY and the translational invariance in a unified way. Since the lattice regularization breaks the infinitesimal translation, it is not straightforward to construct the EMT, a Noether correct associated with the translational invariance. We pointed out that in lattice formulations of the four-dimensional N=1 SYM theory, there is a natural method to define an EMT in view of the Ferrara-Zumino supermultiplet, a supermultiplet that contains the supercurrent and the EMT. In the continuum limit, because of the restored SUSY, the EMT also restores the conservation law.

(4-3) Lattice EMT using the Yang Mills gradient flow

Although the EMT is a fundamentally important object in quantum field theory, its construction in lattice field theory is not straightforward because there the translational invariance is explicitly broken. The difficultly of the problem comes from the fact that a composite operator generally contains the ultraviolet (UV) divergence and its definition inevitably depends on the UV regularization adopted. Here, noticing the UV finiteness of composite operators defined through the so-called Yang-Mills gradient flow, we construct a formula for the EMT in the lattice formulation of the pure Yang-Mills theory. The formula reproduces a correctly-normalized conserved EMT in the continuum limit.

(4-4) Matrix model for a type-IIA superstring and the non-perturbative SUSY breaking

We studied analytically and numerically a matrix model that is supposed to provide a non-perturbative definition of a type IIA superstring in a two-dimensional spacetime. We found that the spacetime SUSY in the system, although it does not contain the translations, is spontaneously broken as a result of a non-perturbative dynamics. This is the first example in which one can concretely address a non-perturbative spontaneous breaking of the spacetime SUSY in superstring theory.

(4-5) Novel quantum effects on non-perturbative dynamics of string theory

While perturbative aspects of string theories are well understood by the worldsheet calculations applying powerful techniques of conformal field theories, non-perturbative dynamics are difficult to comprehend. An exception would be the non-critical string in less-than one-dimension, which can be formulated non-perturbatively with matrix models. Therefore, studies of matrix models are potentially important to the understanding non-perturbative dynamics of string theory, in this regard. To represent the dynamics of non-critical string, the potential of the corresponding matrix model is tuned so that it exhibits the second-order critical point. Thus, the matrix model which composes discretized strings becomes continuous smooth string theory. It is found, however, with a certain type of the potential, a matrix model can manifest the first order transition. This phenomenon is due to the quantum effect known as the resonant tunneling. This effect has not been considered in the studies of matrix models so far. Incorporating these kinds of quantum effects into the study of matrix models may reveal novel dynamics of string theory.

(4-6) Investigations of string duality through worldsheet dynamics

String duality is a powerful concept that has been leading us to better understandings of the non-perturbative aspects of string theory. One type of duality is particularly of interest, namely open-closed duality. Open string corresponds to gauge theories while closed one shows gravity. Thus, open-closed duality suggests relation between gauge theories and the theory of gravity. This relation could be behind another duality, AdS/CFT correspondence. The difference between open string and closed string is, from the view point of the world sheet of string theory, nothing but the difference of the boundary condition of the worldsheet field theory. Since the difference is predetermined by the boundary condition, investigating directly the relation between open and closed string is a difficult task. Recently, it is found that certain quantum systems exhibit the change from the closed-boundary vacuums to open-boundary ones through the spatial modulation of the couplings. This procedure is called Sine-Square Deformation (SSD). Since open string may become closed one through SSD, it is interesting to investigate SSD in the context of string theory. We found a divergence in the worldsheet metric and also degenerated vacua other than the ordinary sl(2,C) invariant vacuum.

(5) QED higher-order calculation of lepton anomalous magnetic moments

The electron and muon anomalous magnetic moments (g-2) were precisely measured at Harvard and at Brookheaven, respectively. Comparing the measurements to the theoretical predictions of g-2, we are able to test the standard model of elementary particles in rigorous ways and find a possible window to new physics. To carry out such tests the tenth-order contribution of the perturbation theory of Quantum Electrodynamics (QED), which consists of 12,671 Feynman diagrams, must be known. About ten years ago we started the project calculating all QED contributions of the tenth order by numerical means. With help of the code-generator developed by ourselves, we made all computer programs necessary to determine the tenth-order g-2. In 2012 we have finally obtained the preliminary values of the tenth-order g-2 for both electron and muon and announced them publicly. Improvement of numerical evaluation has also been attempted to meet the precision proposed by the on-going new experiments of both electron and muon g-2's.

(6) Physics of particles with resonant interactions

(6-1) Universal physics of particles with resonant interactions

We investigated the universal physics that arises in presence of resonant interactions, in particular the Efimov effect for three particles which can bind them into a trimer. Efimov trimers are characterised by a parameter called the three-body parameter. Performing calculations using realistic helium-4 atomic interactions, we have shown that helium-4 atoms follows the van der Waals universality of the Efimov three-body parameter previously observed in ultracold atom experiments. This universality has then been explained by the universality of the atomic pair correlation, using pair models and separable potentials. It has been generalized to other short-range interactions, such as interactions in nuclear physics and condensed matter, making predictions for the trimer energies in these systems. It was also investigated the case of mass-imbalanced three-body systems where one particle is significantly lighter than the other two. Depending on the mass ratio and scattering length, the three-body system can form universal trimers determined solely by the scattering length, or Efimov trimers determined by the three-body parameter. Using numerical calculations, we have mapped out the crossover between these two limits.

(6-2) Coherent photoassociation of a Bose-Einstein condensate

Photoassociation is the process of binding a pair of atoms by shining light onto it. It usually results in incoherent losses, but some years ago we predicted the conditions for the observation of coherent oscillations when a Bose-Einstein condensate of atoms is photoassociated. This prediction has been successfully observed by experimentalists at Rice University with whom we have collaborated to analyze the experimental data.

Head

Tetsuo HATSUDA (Chief Scientist)

Members

Tsukasa TADA (Vice Chief Scientist) (Apr. 1, 2013 -)
Hiroshi SUZUKI (Senior Research Scientist) (- Aug. 31, 2013)
Takumi DOI (Research Scientist)
Yoshimasa HIDAKA (Research Scientist)
Pascal Raphaël Gabriel NAIDON (Research Scientist)

Nishina Center Research Scientist

Makiko NIO

Special Postdoctoral Researchers

Daisuke KADOH (- Mar. 31, 2013)
Arata YAMAMOTO (- Mar. 31, 2014)
Kanabu NAWA
Yuji SAKAI
Akihiko MONNAI (Apr. 1, 2013 – Jul., 2013)
Kazuhiko KAMIKADO (Apr. 1, 2013 -)
Takashi SANO (Apr. 1, 2013 -)

Foreign Postdoctoral Researchers

Michael Gordon ENDRES (- Sep. 14, 2013)
Gergely Peter FEJOES

Postdoctoral Researchers

Yoichi IKEDA
Taichi KAWANAI (Apr. 1, 2013 -)
Shinsuke YOSHIDA (Apr. 1, 2013 -)
Daisuke SATO (Apr. 1, 2013 -)
Koich HATTORI (Feb. 1, 2014 -)

Visiting Scientists

Motoi TACHINBANA (Faculty of Science and Engineering, Saga University)
Toichiro KINOSHITA (Physics Department, Cornell University)
Sinya AOKI (Yukawa Institute for Theoretical Physics, Kyoto University)
Taichi KAWANAI (Graduate School of Science, University of Tokyo) - Mar. 31, 2013
Masahito UEDA (Graduate School of Science, University of Tokyo)
Tatsuyuki TAKATSUKA (Faculty of Humanities and Social Science, Iwate University)
Hong MAO (Hangzhou Normal University, China)
Sho OZAKI (Yonsei University, Korea)
Takashi OKA (Graduate School of Science, University of Tokyo)
Shoichi SASAKI (Graduate School of Science, Tohoku University)
Keitaro NAGATA (IPNS, KEK)
Takashi INOUE (College of Bioresource Science, Nihon University)
Yoshitaka HATTA (Yukawa Institute for Theoretical Physics, Kyoto University)
Teiji KUNIHIRO (Graduate School of Science, Kyoto University)
Kenji MORITA (Yukawa Institute for Theoretical Physics, Kyoto University)
Kazuyuki KANAYA (Graduate School of Pure and Applied Science University of Tsukuba)

Makoto TAKIZAWA (Showa Pharmaceutical University)
Sachiko TAKEUCHI (Faculty of Social Welfare, Japan College of Social Work)
Yuji HIRONO (Graduate School of Science, University of Tokyo)
Hiroshi TOKI (RCNP, Osaka University) Apr. 1, 2013 -
Masashi HAYAKAWA (Graduate School of Science, Nagoya University)
Kenji SASAKI (Center for Computational Sciences, University of Tsukuba)
Takayuki MATSUKI (Department of Environmental Science and Education, Tokyo Kasei University)
Daisuke KADOH (IPNS, KEK) - Apr. 30, 2013
Hiroshi SUZUKI (Faculty of Sciences, Kyushu University) Sep. 1, 2013 -

Visiting Researcher
Takashi SANO (Japan Society for the Promotion of Science) - Mar. 31, 2013

Research Consultant
Hiroshi TOKI (RCNP, Osaka University) - Mar. 31, 2013

Junior Research Associate
Masaru HONGO (Graduate School of Science, University of Tokyo) Apr. 1, 2013 -

Short-term Program for International Program Associate
Robert Friedrich LANG (Department of Physics, Technical University of Munich) Oct. 7, 2013 – Feb. 12, 2014

Student Trainees
Bruno CHARRON (Graduate School of Science, University of Tokyo)
Akihiko MONNAI (Graduate School of Science, University of Tokyo) - Mar. 31, 2013
Yasufumi ARAKI (Graduate School of Science, University of Tokyo)
Yusuke HAMA (Graduate School of Science, University of Tokyo)
Tomoya HAYATA (Graduate School of Science, University of Tokyo)
Yasuki TACHIBANA (Graduate School of Science, University of Tokyo)
Koichi MURASE (Graduate School of Science, University of Tokyo)
Kota MASUDA (Graduate School of Science, University of Tokyo)
Masaru HONGO (Graduate School of Science, University of Tokyo) - Mar. 31, 2013
Yuya TANIZAKI (Graduate School of Science, University of Tokyo)
Ryuichi KURITA (Graduate School of Science, University of Tokyo)
Sho KAMATA (Graduate School of Science, Rikkyo University)
Masanori YAMADA (Graduate School of Pure and Applied Science, University of Tsukuba)
Koichiro HIRANUMA (Graduate School of Science & Engineering, Tokyo Institute of Technology)
Simpei ENDO (Graduate School of Science, University of Tokyo)

Assistants
Yoko FUJITA
Yuri TSUBURAI

Theoretical Research Division
Theoretical Nuclear Physics Laboratory

1. Abstract

Nuclei are finite many-particle systems composed of protons and neutrons. They are self-bound in femto-scale (10^{-15}m) by the strong interaction (nuclear force) whose study was pioneered by Hideki Yukawa. Uncommon properties of the nuclear force (repulsive core, spin-isospin dependence, tensor force, etc.) prevent complete microscopic studies of nuclear structure. There exist number of unsolved problems even at present. In addition, radioactive beam facilities reveal novel aspects of unstable nuclei. We are tackling these old problems and new issues in theoretical nuclear physics, developing new models and pursuing large-scale calculations of quantum many-body systems. We are also strongly involved in research on other quantum many-body systems, to resolve mysteries in the quantum physics.

2. Major Research Subjects

(1) Nuclear structure and quantum reaction theories
(2) First-principle calculations with the density functional theory for many Fermion systems
(3) Computational nuclear physics

3. Summary of Research Activity

(1) Energy-density-functional calculation including proton-neutron mixing

We have performed mean-field calculation based on the Skryme energy density functional (EDF) including arbitrary mixing between protons and neutrons. Isobaric analogue states (IASs) were calculated using the isocraking method. Through the calculations for IASs in A=14 and 40-56 isobars, we demonstrated that our model is capable of qualitative description of the excited IASs. The T=1 IAS in the A=14 exhibits asymmetry between the relative energy of the T_z=1 state and that of the T_z=-1 states measured from the T_z=0 state, which may be related to charge asymmetry and independence of the NN interaction. To investigate this point, we also started a systematic calculation of the T = 1 triplets in the A=10-58 region. We also performed a benchmark calculation by comparing the results obtained with our 3D EDF solver and those obtained with an axial EDF solver.

(2) Finite amplitude method in covariant density functional theory

The ^{22}C nucleus is currently of significant interest, since its halo structure with extremely weak binding was suggested by experiments. We have performed the Glauber analysis on this nucleus based on the density distribution calculated with the Skyrme energy density functional. To reproduce the large experimental cross section, we need to readjust the t_0 parameter of the Skyrme functional. It is desirable to have new experimental data on the reaction cross section with higher bombarding energy which should be available in current RIBF. In addition, we calculated the electric dipole modes of excitation with the RPA using the finite amplitude method (FAM). The computer code was previously developed, however, we need a very large space to treat such a weakly bound nucleus. The calculation with the 3D coordinate space of radius of 100 fm has been carried out, thanks to available high performance computing systems. It suggests that a very strong low-energy peak does not consist only of weakly bound s-wave neutrons, but also of sizable amount of d-wave components.

(3) Reaction cross section and electric dipole excitations in ^{22}C

The ^{22}C nucleus is currently of significant interest, since its halo structure with extremely weak binding was suggested by experiments. We have performed the Glauber analysis on this nucleus based on the density distribution calculated with the Skyrme energy density functional. To reproduce the large experimental cross section, we need to readjust the t_0 parameter of the Skyrme functional. It is desirable to have new experimental data on the reaction cross section with higher bombarding energy which should be available in current RIBF. In addition, we calculated the electric dipole modes of excitation with the RPA using the finite amplitude method (FAM). The computer code was previously developed, however, we need a very large space to treat such a weakly bound nucleus. The calculation with the 3D coordinate space of radius of 100 fm has been carried out, thanks to available high performance computing systems. It suggests that a very strong low-energy peak does not consist only of weakly bound s-wave neutrons, but also of sizable amount of d-wave components.

(4) Systematic study on pygmy dipole strength in heavy isotopes

We have systematically studied the low-lying electric dipole mode, so-called the pygmy dipole resonances (PDR) in neutron-rich isotopes in a region of nuclei with N<90, using the linear response calculation with the Skyrme energy density functional. The strong neutron shell effects have been found, which suggest several magic numbers for the enhancement of the PDR strength. We also investigate the deformation effect on the PDR. The K=0 component of E1 strength become dominant in Sr and Zr isotopes with prolate deformation. However, it is not associated with the orientation dependence of the neutron skin thickness. In fact, it is opposite, namely, the neutron skin thickness along the symmetry axis si smaller than that in the perpendicular directions. The close examination of the PDR strength in nuclei beyond N=82 indicates different characters for the peaks at E > 5 MeV and those at E < 5 MeV. The low-energy dipole states appearing at very low energies (E < 5 MeV) indicates no hindrance of the E1 strength from the pure single-particle strength. This suggests that these PDR peaks are completely decoupled from the giant dipole resonance (GDR).

(5) Deformed nuclei in the black-sphere approximation

In order to study the value of the density derivative L of the symmetry energy of nearly symmetric nuclear matter, the total reaction cross section, σ_R, of neutron-rich nuclei is one of the most important observables. We focus on the reactions involving the isotopes of Ne and Mg using the black-sphere approximation of nuclei. In this region of nuclei, we have to face the nuclear deformation. We change the black sphere into a spheroid of the same volume in order to take into account nuclear deformation before the discussion of L dependence. The values of the deformation parameter, β, are taken from microscopic nuclear structure models. Before drawing conclusion, we have to check the interaction dependence by adopting SkM*, SLy4, KTUY etc. The study is now in progress.

(6) Giant dipole resonance in ^{88}Mo at finite temperature and angular momentum

The line shapes of giant dipole resonance (GDR) in the decay of the compound nucleus 88Mo, which is formed after the fusion-evaporation reaction 48Ti + 40Ca at various excitation energies E* from 58 to 308 MeV, are generated by averaging the GDR strength functions predicted within the phonon damping model (PDM) using the empirical probabilities for temperature and angular momentum. The average strength functions are compared with the PDM strength functions calculated at the mean temperature and mean angular momentum, which are obtained by averaging the values of temperature and angular momentum using the same temperature and angular-momentum probability distributions, respectively. It is seen that these two ways of generating the GDR linear line shape yield very similar results. It is also shown that the GDR width approaches a saturation at angular momentum J ≥ 50ħ at T= 4 MeV and at J ≥ 70ħ at any T.

The evolution of the GDR width and shape at finite temperature T and angular momentum J is described within the the PDM. The PDM description is compared with the established experimental systematics obtained from heavy-ion fusion and inelastic scattering of light particles on heavy target nuclei, as well as with predictions by other theoretical approaches. Extended to include the effect of angular momentum J, its strength functions have been averaged over the probability distributions of T and J for the heavy-ion fusion-evaporation reaction, which forms the compound nucleus ^{88}Mo at high T and J. The results of theoretical predictions are found in excellent agreement with the experimental data. The predictions by PDM and the heavy-ion fusion data are also employed to predict the viscosity of hot medium and heavy nuclei.

(7) Study of pygmy dipole resonance with the exact treatment of the pairing

The strength functions of giant dipole resonance (GDR) in oxygen $^{18-24}$O, calcium $^{50-60}$Ca, and tin $^{120-130}$Sn isotopes are calculated within the phonon damping model under three approximations: without superfluid pairing, including BCS pairing, and exact pairing gaps. The analysis of the numerical results shows that exact pairing decreases the two-neutron separation energy in light nuclei, but increases it in heavy nuclei as compared to that obtained within the BCS theory. In neutron-rich medium and heavy nuclei, exact pairing significantly enhances the strength located at the low-energy tail of the GDR, which is usually associated with the pygmy dipole resonance (PDR). The line shape of the GDR changes significantly with increasing the neutron number within an isotopic chain if the model parameter is kept fixed at the value determined for the stable isotope.

(8) Microscopic analysis of fusion hindrance in heavy systems

We study the reaction mechanism of fusion reactions and analyze origins of fusion hindrance in heavy systems with microscopic time-dependent Hartree-Fock (TDHF) theory. We have developed a method to directly extract nucleus-nucleus potential and energy dissipation from the relative motion of colliding nuclei to nuclear intrinsic excitations in fusion reactions from TDHF trajectories. We show that the Coulomb barrier disappears in potentials obtained in heavy systems and they monotonically increase as relative distance decreases, which are different from those of light, medium-mass systems. Further analysis shows that main origin of fusion hindrance is a dynamical change of extracted potential at short relative distance.

(9) Nuclear β-decay half-lives and r-process matter flow

Nucleosynthesis via rapid neutron capture, i.e., the r-process, is a major mechanism for producing the elements heavier than Fe in Universe. Understanding this process requires knowledge of properties such as masses, β-decay half-lives, and neutron-capture cross sections for a large number of extremely neutron-rich nuclei far from the stability line. In order to reliably predict the β-decay half-lives of thousands of unknown nuclei relevant to the r-process, the full self-consistency of the quasi-particle RPA (QRPA) approach is essential. Meanwhile, the proton-neutron pairing correlations in both isovector (T = 1) and isoscalar (T = 0) channels must be taken into account properly. In a very recent work, we established a fully self-consistent charge-exchange QRPA with both T = 1 and T = 0 proton-neutron pairing, based on the relativistic Hartree-Fock-Bogoliubov (RHFB) framework. Then, we systematically investigated the β-decay half-lives of neutron-rich even-even nuclei with 20 ≤ Z ≤ 50. It is shown that the available data are well reproduced, where the isospin-dependent T = 0 proton-neutron pairing is one of the most important ingredients. With the calculated β-decay half-lives, a classical r-process calculation has been performed with neutron density n_n = 1022-1024 cm^{-3} and temperature T = 1.5×109 K, and a remarkable speeding up of r-matter flow is predicted. This leads to enhanced r-process abundances of elements with A ≥ 140, an important result for understanding the origin of heavy elements in Universe.

(10) Pseudospin symmetry in nuclear single-particle spectra

In nuclear single-particle spectra, pairs of single-particle states with quantum numbers (n-1, l+2, j=l+3/2) and (n, l, j=l+1/2) are always found to be quasi-degenerate. Arima et al. and Hecht et al. introduced in 1969 the so-called pseudospin symmetry (PSS) to explain this phenomenon. Although it has been already more than 40 years since the suggestion of PSS in atomic nuclei and comprehensive efforts have been made, the origin of PSS is still a puzzle. Recently, we suggested that it is promising to understand PSS and its breaking mechanism in a fully quantitative way by combining the similarity renormalization group technique, supersymmetric (SUSY) quantum mechanics, and perturbation theory. We took the Schrödinger equation as an example, which corresponds to the lowest-order approximation in transforming a Dirac equation into a diagonal form by using the similarity renormalization group. It is shown that while the spin symmetry-conserving term appears in nuclear single-particle Hamiltonian, the PSS-conserving term appears naturally in its SUSY partner Hamiltonian. The eigenstates of these two Hamiltonians are exactly identical except for the so-called intruder states, which have no pseudospin partners. In such a way, the origin of PSS deeply hidden in the original Hamiltonian can be traced in its SUSY partner.

Head
Takashi NAKATSUKASA (Associate Chief Scientist)

Member
Akihisa KOHAMA (Senior Research Scientist)

Nishina Center Research Scientist
Nguyen Dinh DANG

Special Postdoctoral Researchers
Koichi SATO
Kohei WASHIYAMA

Foreign Postdoctoral Researcher
Haozhao LIANG (Jan. 1, 2014 -)

Research Consultants
Akitsu IKEDA (- Mar. 31, 2014)
Kenichi MATSUYANAGI (- Mar. 31, 2014)

Visiting Researcher
Haozhao LIANG (JSPS) (- Dec. 31, 2013)

Visiting Scientists
Takashi ABE (Univ. of Tokyo)
Wataru HORIUCHI (Hokkaido Univ.) - Mar. 31, 2013
Kei IIDA (Kochi Univ.)
Kiyomi IKEDA (Niigata Univ.)
Naoyuki ITAGAKI (Kyoto Univ.)
Kaori KAKI (Shizuoka Univ.)
Lu GUO (Univ. of Chinese Academy) - Mar. 31, 2013
Nguyen Quang HUNG (Tan Tao Univ.) Aug., 2013 – Sep., 2013, Feb. 1, 2014 -
Kazuyuki OGATA (Osaka Univ.)
Kazuhiro OYAMATSU (Aichi Shukutoku Univ.)
Yasuyuki SUZUKI (Niigata Univ.)
Kazuko TANABE (Otsuma Women's Univ.)
Yasutaka TANIGUCHI (Univ. of TSUKUBA) - Mar. 31, 2013

Assistants
Keiko SUZUKI
Noriko KIYAMA (- Aug. 31, 2013)
Mitsue YAMAMOTO (Sep. 1, 2013 -)

Theoretical Research Division
Strangeness Nuclear Physics Laboratory

1. Abstract

We proposed accurate calculation method called 'Gaussian Expansion Method using infinitesimally shifted Gaussian lobe basis function'. When one proceeds to four-body systems, calculation of the Hamiltonian matrix elements becomes much laborious. In order to make the four-body calculation tractable even for complicated interactions, the infinitesimally-shifted Gaussian lobe basis function has been proposed. The GEM with the technique of infinitesimally-shifted Gaussians has been applied to various three-, four- and five-body calculations in hypernuclei, the four-nucleon systems, and cold-atom systems. As results, we succeeded in extracting new understandings in various fields.

2. Major Research Subjects

(1) Hypernuclear structure from the view point of few-body problem
(2) Structure of exotic hadron system
(3) Baryon-baryon interaction based on lattice QCD
(4) Structure of three- and four-body ^{4}He atom systems

3. Summary of Research Activity

(1) By a addition of Λ particle to neutron-rich Λ hypernuclei, we found that states of the $^7{}_\Lambda$He and $^6{}_\Lambda$H became more stable. Especially, in $^7{}_\Lambda$He, our prediction for the ground state is not inconsistent with the observed data within the error bar. The calculated result in $^6{}_\Lambda$H did not find any bound state, which is inconsistent with the observed data. To understand the observed data for $^6{}_\Lambda$H, theoretically it is requested to calculate reaction cross section of ^{6}Li(π^+,K^+) $^6{}_\Lambda$H.

(2) As one of nuclear response by addition of Λ particle, we found that Λ-separation energy was dependent on the degree of deformation of core nuclei. Especially, energy gain by the Λ-particle addition in super-deformed state is much smaller than that in normal-deformed state in $^{10}{}_\Lambda$Be and $^{41}{}_\Lambda$Ca.

(3) By solving ^{4}He trimer and tetramer systems accurately, we succeeded in exploring their level structure and a universality between those atomic systems and few-nucleon systems. Furthermore, we succeeded in explaining some fundamental results of the cold atom experiments using alikali atoms (Li, K, Rb, Cs) on account of the universality between ^{4}He atoms and the alkali atoms.

Head
Emiko HIYAMA (Associate Chief Scientist)

Researcher (appointment across AICS)
Hiroya SUNO

Contract Researcher
Yasuro FUNAKI

Foreign Postdoctoral Researcher
Philipp Gubler

Special Postdoctoral Researcher
Masahiro ISAKA (Apr. 1, 2013 -)

Postdoctoral Researchers
Kenji FUKUKAWA (- 2013/10)
Naoyuki SAKUMICHI (JSPS) (Apr. 1, 2013 -)

Visiting Scientists
Takayuki MYO (Osaka Institute of Technology)
Taiichi YAMADA (Kanto Gakuin University)
Tetsuo HYODO (YITP, Kyoto University)
Makoto OKA (Tokyo Institute of Technology)
Tomokazu FUKUDA (Osaka Electro-Communication University)
Daisuke JIDO (Tokyo Metropolitan University)
Hidekatsu NEMURA (University of Tsukuba)
Soichi ISHIKAWA (Hosei University)
Takenori FURUMOTO (Ichinoseki National College of Technology) -Mar. 31,2014
Atsushi HOSAKA (RCNP, Osaka University)
Shoji SHINMURA (Gifu University)
Akinobu DOTE (High Energy Accelerator Research Organization, KEK)
Thomas RIJKEN (Radboud University Nijmegen)
Kazuma NAKAZAWA (Gifu University)

Atsushi UMEYA (Nihon Institute of technology)
Toru SATO (Osaka University)
Satoru HIRENZAKI (Nara Women's University)
Masayuki ASAKAWA (Osaka University)
Masakiyo KITAZAWA (Osaka Univeristy)
Wolfram WEISE (Technical University of Munich)
Keiko MURANO (YITP, Kyoto University)
Jinjiu HU (Peking University)
Yoshikazu FUJIWARA (Kyoto University) -Mar. 31,2014
Shuichi GOJUKI (SGI Japan Ltd.)

Research Consultants
Yasuo YAMAMOTO
Toshio MOTOBA

Short-term Program for International Program Associate
Bo ZHOU (Nanjng University) (Jan. 11, 2013 – May 31, 2013)

Junior Research Associate
Shota Ohnishi (Grad. Sch. Sci. & Eng., Tokyo Institute of Technology)

Student Trainees
Akira YOKOTA (Grad. Sch. Sci. & Eng., Tokyo Institute of Technology)
Saori MAEDA (Grad. Sch. Sci. & Eng., Tokyo Institute of Technology)
Tetsuya YOSHIDA (Grad. Sch. Sci. & Eng., Tokyo Institute of Technology)
Yongwoo CHOI (Kyungpook National University)
Hana GIL (Kyungpook National University)

Assistants
Yoko FUJITA
Yuri TSUBURAI

Theoretical Research Division
Mathematical Physics Laboratory

1. Abstract

The aim of mathematical physics laboratory is to apply mathematical scheme to resolve long-standing issues in various subjects of physics. Mathematics, in particular that originates in superstring theory, has universal feature which is common to wide range of physics. This covers elementary particle physics, hadron physics, nuclear physics, cosmology, general relativity and condensed matter physics. We apply mathematical scheme such as superstring theory, D-branes, AdS/CFT correspondence, solitons, statistical mechanics and integrable systems. Topics which the laboratory covers currently include non-perturbative analysis of quantum chromo-dynamics, superstrings, and models beyond the standard model of particle physics, and soliton physics.

2. Major Research Subjects

(1) Application of Superstring Theory
(2) Non-perturbative analyses of strongly-coupled gauge theories
(3) Physics of Black Holes and Cosmology
(4) Solitons physics
(5) Mathematical physics
(6) Lattice gauge theory

3. Summary of Research Activity

Interplay between mathematics and physics is indispensable, as any physics law is described in terms of mathematics. However, the present status of various theoretical physics does not fully appreciate the usefulness of mathematics, as each topics goes into details and has less interaction with other subjects even nearby. We integrate various subjects of physics, by applying recent development of mathematics and mathematical physics, to solve long-standing issues in physics. In particular, mathematical methods in superstring theory has been developed and is mature enough to be applied to other physics. We put efforts on the application as described below, in addition to some other mathematical techniques such as numerical simulations, solitons and integrable systems.

(1) Application of superstring theory

1) AdS/CFT correspondence and nuclear physics

The renowned AdS/CFT correspondence, which was initiated in superstring theory, is a useful and powerful tool for analyzing strongly-coupled gauge theories. This has been applied to QCD, the dynamics of quarks. We studied how this powerful tool can have an impact on nuclear physics. We computed an effective action of multi-baryon systems, which should serve as a basic quantum action for nuclear physics. This turned out to reproduce nicely nuclear forces and baryon spectrum. In addition, three-body nuclear force was computed.

2) Vacuum Instability in Electric Fields via AdS/CFT: Euler-Heisenberg Lagrangian and Planckian Thermalization

We analyze vacuum instability of strongly coupled gauge theories in a constant electric field using AdS/CFT correspondence. The model is the N=2 1-flavor supersymmetric large N_c QCD in the strong 't Hooft coupling limit. We calculate the Euler-Heisenberg effective Lagrangian L(E), which encodes the nonlinear response and the quantum decay rate of the vacuum in a background electric field E, from the complex D-brane action in AdS/CFT. We find that the decay rate given by Im L(E) becomes nonzero above a critical electric field set by the confining force between quarks. A large-E expansion of Im L(E) is found to coincide with that of the Schwinger effects in QED, replacing its electron mass by the confining force. Then, the time-dependent response of the system in a strong electric field is solved non-perturbatively, and we observe a universal thermalization at a shortest timescale "Planckian thermalization time" t ~ 1/T ~ E^{-1/2}. Here, T is an effective temperature which quarks feel in the nonequilibrium state with nonzero electric current, calculated in AdS/CFT as a Hawking temperature. Stronger electric fields accelerate the thermalization, and for a realistic value of the electric field in RHIC experiment, we obtain t ~ 1 [fm/c], which is consistent with the believed value.

(2) Cosmology

1) Primordial spectra from sudden turning trajectory

Effects of heavy fields on primordial spectra of curvature perturbations are discussed in inflationary models with a sudden turning trajectory. When heavy fields are excited after the sudden turn and oscillate around the bottom of the potential, the following two effects are generically induced: deformation of the inflationary background spacetime and conversion interactions between adiabatic and isocurvature perturbations, both of which can affect the primordial density perturbations. In this paper, we calculate primordial spectra in inflationary models with sudden turning potentials taking into account both of the two effects appropriately. We find that there are some non-trivial correlations between the two effects in the power spectrum and, as a consequence, the primordial scalar power spectrum has a peak around the scale exiting the horizon at the turn. Though both effects can induce parametric resonance amplifications, they are shown to be canceled out for the case with the canonical kinetic terms. The peak feature and the scale dependence of bispectra are also discussed.

2) A Parallel World in the Dark

The baryon-dark matter coincidence is a long-standing issue. Interestingly, the recent observations suggest the presence of dark radiation, which, if confirmed, would pose another coincidence problem of why the density of dark radiation is comparable to that of photons. These striking coincidences may be traced back to the dark sector with particle contents and interactions that are quite similar, if not identical, to the standard model: a dark parallel world. It naturally solves the coincidence problems of dark matter and dark radiation, and predicts a sterile neutrino(s) with mass of (0.1−1)eV, as well as self-interacting dark matter made of the counterpart of ordinary baryons. We find a robust prediction for the relation between the abundance of dark radiation and the sterile neutrino, which can serve as the smoking-gun evidence of the dark parallel world.

(3) Lattice gauge theory

1) Phase structure of 2-dimensional topological insulators by lattice strong coupling expansion

The phase structure of 2-dimensional topological insulators under a sufficiently strong electron-electron interaction is investigated. The effective theory is constructed by extending the idea of the Kane-Mele model on the graphenelike honeycomb lattice, in terms of U(1) lattice gauge theory (quantum electrodynamics, QED). We analyze the phase structure by the techniques of strong coupling expansion of lattice gauge theory. As a result, we find that the topological phase structure of the system is modified by the electron-electron interaction. There evolves a new phase with the antiferromagnetism not parallel to the direction pointed by the spin-orbit coupling, in between the conventional and the topological insulator phases. We also discuss the physical implication of the new phase structure found here, in analogy to the parity-broken phase in lattice quantum chromodynamics (QCD), known as "Aoki phase".

(4) Mathematical physics

1) Non-Lagrangian Theories from Brane Junctions

In this article we use 5-brane junctions to study the 5D T_N SCFTs corresponding to the 5D N=1 uplift of the 4D N=2 strongly coupled gauge theories, which are obtained by compactifying N M5 branes on a sphere with three full punctures. Even though these theories have no Lagrangian description, by using the 5-brane junctions proposed by Benini, Benvenuti and Tachikawa, we are able to derive their Seiberg-Witten curves and Nekrasov partition functions. We cross-check our results with the 5D superconformal index proposed by Kim, Kim and Lee. Through the AGTW correspondence, we discuss the relations between 5D superconformal indices and n-point functions of the q-deformed W_N Toda theories.

2) SUSY breaking by nonperturbative dynamics in a matrix model for 2D type IIA superstrings

We explicitly compute nonperturbative effects in a supersymmetric double-well matrix model corresponding to two-dimensional type IIA superstring theory on a nontrivial Ramond-Ramond background. We analytically determine the full one-instanton contribution to the free energy and one-point function, including all perturbative fluctuations around the one-instanton background. The leading order two-instanton contribution is determined as well. We see that supersymmetry is spontaneously broken by instantons, and that the breaking persists after taking a double scaling limit which realizes the type IIA theory from the matrix model. The result implies that spontaneous supersymmetry breaking occurs by nonperturbative dynamics in the target space of the IIA theory. Furthermore, we numerically determine the full nonperturbative effects by recursive evaluation of orthogonal polynomials. The free energy of the matrix model appears well-defined and finite even in the strongly coupled limit of the corresponding type IIA theory. The result might suggest a weakly coupled theory appearing as an S-dual to the two-dimensional type IIA superstring theory.

3) Conditionally valid uncertainty relations

It is shown that the well-defined unbiased measurement or disturbance of a dynamical variable is not maintained for the precise measurement of the conjugate variable, independently of uncertainty relations. The conditionally valid uncertainty relations on the basis of those additional assumptions, which include most of the familiar Heisenberg-type relations, thus become singular for the precise measurement. We clarify some contradicting conclusions in the literature concerning those conditionally valid uncertainty relations: The failure of a naive Heisenberg-type error-disturbance relation and the modified Arthurs-Kelly relation in the recent spin measurement is attributed to this singular behavior. The naive Heisenberg-type error-disturbance relation is formally preserved in quantum estimation theory, which is shown to be based on the strict unbiased measurement and disturbance, but it leads to unbounded disturbance for bounded operators such as spin variables. In contrast, the Heisenberg-type error-error uncertainty relation and the Arthurs-Kelly relation, as conditionally valid uncertainty relations, are consistently maintained.

4) W_3 irregular states and isolated N=2 superconformal field theories

We explore the proposal that the six-dimensional (2,0) theory on the Riemann surface with irregular punctures leads to a four-dimensional gauge theory coupled to the isolated N=2 superconformal theories of Argyres-Douglas type, and to two-dimensional conformal field theory with irregular states. Following the approach of Gaiotto-Teschner for the Virasoro case, we construct W_3 irregular states by colliding a single SU(3) puncture with several regular punctures of simple type. If n simple punctures are colliding with the SU(3) puncture, the resulting irregular state is a simultaneous eigenvector of the positive modes L_n, ..., L_{2n} and W_{2n}, ..., W_{3n} of the W_3 algebra. We find the corresponding isolated SCFT with an SU(3) flavor symmetry as a nontrivial IR fixed point on the Coulomb branch of the SU(3) linear quiver gauge theories, by confirming that its Seiberg-Witten curve correctly predicts the conditions for the W_3 irregular states. We also compare these SCFT's with the ones obtained from the BPS quiver method.

5) A Landscape in Boundary String Field Theory: New Class of Solutions with Massive State Condensation

We solve the equation of motion of boundary string field theory allowing generic boundary operators quadratic in X, and explore string theory non-perturbative vacua with massive state condensation. Using numerical analysis, a large number of new solutions are found. Their energies turn out to distribute densely in the range between the D-brane tension and the energy of the tachyon vacuum. We discuss an interpretation of these solutions as perturbative closed string states. From the cosmological point of view, the distribution of the energies can be regarded as the so-called landscape of string theory, as we have a vast number of non-perturbative string theory solutions including one with small vacuum energy.

Head
Koji HASHIMOTO (Associate Chief Scientist)

Special Postdoctoral Researchers
Toshifumi NOUMI
Masato TAKI
Shingo TORII

Postdoctoral Researchers
Johannes SCHMUDE (-Sep. 30,2013)
Taro KIMURA (JSPS)
Yuki MINAMI

Senior Visiting Scientist
Koichi YAZAKI

Visiting Scientists
Tatsumi AOYAMA (Nagoya Univ.)
Minoru ETO (Yamagata Univ.) Aug. 1,2013 -
Kazuo FUJIKAWA (Univ. of Tokyo)
Masanori HANADA(KEK)
Masashi HAYAKAWA (Nagoya Univ.) - Mar. 31, 2013
Tetsutaro HIGAKI(KEK) Jan. 1, 2014 -
Keiji IGI(Univ. of Tokyo)
Hideaki IIDA (Kyoto Univ.) - Mar. 31, 2013
Norihiro IIZUKA (CERN) - Mar. 31, 2013
Nobuyuki ISHIBASHI (Univ. of Tsukuba)
Hiroshi ITOYAMA (Osaka City Univ.)
Yu MAEZAWA(Universiät Bielefeld)
Shoichi MIDORIKAWA (Aomori Univ.)
Muneto NITTA (Keio Univ.) - Mar. 31, 2013
Noriaki OGAWA(KIAS) - Mar. 31, 2013
Kazutoshi OHTA (Meiji Gakuin Univ.)
Makoto SAKAGUCHI (Keio Univ.)
Norisuke SAKAI (Tokyo Women's Christian Univ.)
Yuuichirou SHIBUSA (Nagasaki Inst. of Applied Science)
Asato TSUCHIYA (Shizuoka Univ.)
Yoshio YAMAGUCHI (Univ. of Tokyo)
Tamiaki YONEYA (The Open Univ. of Japan) - Mar. 31, 2013

Assistants
Keiko SUZUKI
Noriko KIYAMA (- Aug. 31, 2013)
Mitsue YAMAMOTO (Sep. 1, 2013 -)

Sub Nuclear System Research Division
Radiation Laboratory

1. Abstract

Nucleons, such as protons and neutrons, are a bound state of constituent quarks glued together with gluons. The detail structure of nucleons, however, is not well understood yet. Especially the mechanism to build up the spin of proton, which is 1/2, is a major problem in physics of the strong force. The research goal of Radiation Laboratory is to solve this fundamental question using the world first polarized-proton collider, realized at RHIC in Brookhaven National Laboratory (BNL) in USA. RHIC stands for Relativistic Heavy Ion Collider, aiming also to create Quark Gluon Plasma, the state of Universe just after the Big Bang. RIKEN-BNL Research Center (RBRC) directed by N. Samios, and recently by S. Aronson carries our core team at BNL for those exciting researches using the PHENIX detector. We have found that the proton spin carried by gluons is indeed small, which is a very striking finding beyond our expectations. Recently we successfully identified W boson in the electron/positron decay channel, with which we established the method to determine how much anti-quarks carry the proton spin. Other than the activities at RHIC we are preparing new experiments at SPring-8, J-PARC and Fermilab to study the nature of hadron. We are also performing technical developments such as novel ion sources, fine-pitch silicon pixel detectors and high-performance trigger electronics. We also have developed neutron optical devices, whose know-how has been transferred to the other new research center where Neutron Beam Technology Team was newly established.

2. Major Research Subjects

(1) Spin physics with relativistic polarized-proton collisions at RHIC
(2) Study of nuclear matter at high temperature and/or at high density
(3) Technical developments on radiation detectors and accelerators

3. Summary of Research Activity

(1) Experimental study of spin structure of proton using RHIC polarized proton collider

[See also RIKEN-BNL Research Center Experimental Group for the activities at BNL]

After the establishment of small gluon polarization inside the proton, we are investigating the antiquark spin and partonic orbital motion inside the proton with polarized proton collisions at RHIC using the PHENIX detector in order to understand the last piece of the proton-spin puzzle. We have collected W-boson production data to extract flavor-separated antiquark polarizations. The data analysis is ongoing to obtain the final results of the antiquark polarization. The Drell-Yan process (quark-antiquark annihilation) with polarized proton collisions is one of the key measurements to investigate the orbital motion in the proton. We are proposing to perform such measurement by upgrading the PHENIX detector. As a pilot measurement, some of us are participating in the Fermilab SeaQuest experiment which has been collecting $\mu^+\mu^-$ pairs using a 120-GeV unpolarized proton at Fermilab. By measuring unpolarized Drell-Yan process, we can study quark spin-orbit effects which supplement what can be learned in the polarized Drell-Yan process.

(2) Experimental study of quark-gluon plasma using RHIC heavy ion collider

[See also RIKEN-BNL Research Center Experimental Group for the activities at BNL]

We have completed several key measurements in the study of quark-gluon plasma at RHIC. As the top of them, we lead the analysis of the first thermal photon measurement in heavy ion collisions. The measurement indicates that the initial temperature reached in the central Au+Au collision at 200 GeV is about 350MeV, far above the expected transition temperature Tc~170MeV, from hadronic phase to quark-gluon plasma. This work was rewarded by Nishina Memorial Prize in 2011. Using the same "virtual photon" method used in the thermal photon measurement, we measured direct photons in d+Au collisions. The results show that there is little cold nuclear effects in direct photons. This supports that the large enhancement of direct photons observed in Au+Au is indeed due to hot quark-gluon plasma formed in Au+Au collisions.

We also measured the elliptic flow strength, v2, of direct photons in Au+Au collisions. The results show surprisingly large v2, which means the source of those photons expands elliptically. This is one of the most interesting results from RHIC in the last three years. One of the JRA students of Radiation Laboratory led this important analysis. Also, the most recent measurements of high p_T π^0 suppression in Au+Au collisions show that the suppression reduces at very high pT (pT~20GeV). Analysis of heavy quark using the silicon vertex detector is ongoing. The first preliminary results from the 2011 Au+Au run and 2012 p+p run was reported in the Quark Matter 2012 conference. We are now finalizing the results for publication.

In Wako we are operating a cluster computer system specialized to analyze huge data sets taken with the PHENIX detector. It consists of 28 nodes (18 old nodes and 10 new nodes) each of which has two CPUs and 10 sets of local disk for data repository (old node: quad-core CPU, 1TB disk, new node: six-core CPU, 2TB disk). There are 264 CPU cores and 380 TB disks in total. This configuration ensures the fastest disk I/O when the jobs are assigned to the nodes where the required data sets are stored. It is also important that this scheme doesn't require an expensive RAID system and network. Through this development we have established a fast and cost-effective solution in analyzing massive data.

(3) Study of properties of mesons and exotic hadrons with domestic accelerators

Preparation of the experiment E16 at J-PARC 50-GeV PS is underway with the Grant-in-Aid for Scientific Research on Innovative Areas (MEXT). This experiment aims to perform a systematic study of the mass modification of low-mass vector mesons in nuclei to explore the chiral symmetry breaking in dense nuclear matter, namely, the mechanism proposed by Nambu to generate the major part of hadron mass.

Gas Electron Multiplier (GEM) technology is adopted for the two key detectors, GEM Tracker (GTR) and Hadron-blind Cherenkov detector (HBD). With cooperation with Japanese industries, GEM foils with a world-largest size (30cm x 30cm) are newly developed.

Through the beam tests at ELPH, J-PARC, LEPS, and RIKEN RIBF, the followings are achieved and proven; 1) required position resolution of 0.1 mm, and 2) stable operation under the hadron-background environment, typically 30 times higher rate than that expected in the J-PARC experimental area. The design parameters of the GTR and HBD were finalized and the mass-production of GTR GEM started. HBD GEM is under the final tuning to achieve the required stability, efficiency and pion-rejection power.

For the readout electronics of GEM, a preamp using the APV25 ASIC chip is developed and tested. For the digitization and the data transfer, the SRS system developed by CERN is also tested and adopted. Another preamp-ASIC for the trigger signal from GEM foils is also developed and tested. Trigger logic boards, which are developed by Belle II, are tested with the firmware customized for this experiment.

The development phase of the detector components is just finished and we are moving to the production phase. For the electronics, mass production will start in a year after some remained tests. The construction of the beam line is finally funded in KEK and started at J-PARC in 2013. It will be completed by March 2016. The spectrometer construction at the beam line is planned to start in March 2015 and the commissioning with a primary beam will be performed in early 2016.

(4) Detector development for PHENIX experiment

After 7 years of hard work, we finally completed and installed the silicon vertex tracker (VTX) into the PHENIX detector at RHIC in December 2010. VTX is a 4-layer silicon tracker to measure heavy quark (charm and bottom) production in p+p and heavy ion collisions at RHIC. The detector was funded by RIKEN and the US DOE. We and RIKEN BNL Research Center are responsible for construction and operation of the inner two pixel detectors. The VTX was successfully commissioned during the 500 GeV p+p run in the 2011 of RHIC. Subsequently, we collected 5 billion Au+Au events in the 2011 run, 11/pb of p+p data at 510 GeV, 3/pb of p+p data at 200 GeV, 110/μb of U+U data at 193 GeV, and 2.9/nb of Cu+Au at 200 GeV. We are now analyzing those datasets to study the interaction between heavy quarks and the quark-gluon plasma.

During the 2011 run, part of the pixel detector was damaged due to thermal stress on the detector. We improved the operation procedure and there is no additional damage on the detector since 2012. We repaired the damaged pixel detectors in 2012 to 2013, and this repair work has been completed. The detector was re-installed in PHENIX before the 2014 run and has been successfully re-commissioned. We will have a long (~15 weeks) of Au+Au run at 200 GeV and we expect that we have high quality data with much higher statistics than the 2011 Au+Au run.

Sea quark polarization measurement via W-boson production is one of the highlight of PHENIX spin program. In order to detect high momentum muons from W-decay, we developed the momentum-sensitive trigger system for the PHENIX forward muon arms with collaborators from KEK, Kyoto and Rikkyo University. Together with new hadron absorber, W-boson measurement was successfully carried out using the new high momentum trigger. We accumulated high-integrated luminosity of about $250\mathrm{pb}^{-1}$ in Run13 and almost achieved our goal. The intensive analysis is underway towards the publication.

(5) Neutron optics

Cold or thermal neutron beam is a high-sensitivity probe to study not only the structure of condensed matter, but also fundamental physics. Recently interests arise to apply those neutrons for the internal imaging of industrial material, sometimes at the fabrication stage or sometimes after aging. RANS (RIKEN Accelerator-driven compact neutron source) has been developed at the K1 space of RIBF building, and became operational in January 2013. By bombarding protons accelerated to 7MeV onto the beryllium target, neutrons are produced in low-energy nuclear reactions, Be(p,n)B. Fast and slow neutrons are detected at the end of the beam line, 5m away from the target. The large-area neutron imaging detectors, the combination of plastic scintillators and MPPCs, have been developed for the non-destructive inspections of the large scale structures such as bridges. Initial imaging experiments were successful with thermal and cold neutrons, and also in neutron-induced prompt gamma-ray analysis. Instrumentations for the polarized-neutron imaging and pulsed-neutron imaging are under construction.

The technology for a neutron interferometer using multilayer mirrors is adopted for differential phase imaging, to see an internal structure of a bulk. We have demonstrated that an internal crack in an acrylic plate is observable.

These activities were transferred to Neutron Beam Technology Team in RIKEN Center for Advanced Photonics.

(6) Development of beam source

Under the collaboration with BNL, we are developing various techniques for a laser ion source (LIS) to provide high quality heavy-ion beams to the accelerators at present or in the future. We have demonstrated the instantaneous beam intensity of more than 70 mA with highly-charged carbon and aluminum. This is the highest-current heavy-ion beam produced by any methods. The technical developments are well accumulated and now being applied to the DIGITAL accelerator in KEK. The beam commissioning of this new system is expected in 2014 with fully-stripped carbon beam. We have also established stable operation of low charge state heavy ion beams with an extremely low emittance.

We just installed another new LIS at the most upstream of the RHIC accelerator complex in BNL. The new LIS allows rapid switching among a wide variety of beam species so that the complex can be operated with large flexibility.

At Wako, the development of a next-generation electron beam source was performed using the novel photocathode based on a super-lattice semiconductor with negative electron affinity (NEA) surface. This activity was transferred to Nagoya University.

Head
Hideto EN’YO (Chief Scientist; Director, RNC)

Members
Yasuyuki AKIBA (Vice Chief Scientist)
Yuji GOTO (Senior Research Scientist)
Itaru NAKAGAWA (Senior Research Scientist)
Yoshie OTAKE (Senior Research Scientist) (- Mar. 31, 2013)
Yasushi WATANABE (Senior Research Scientist)
Satoshi YOKKAICHI (Senior Research Scientist)
Ralf SEIDL (Senior Research Scientist)
Hiroaki ONISHI (concurrent; Senior Research Scientist)

Special Postdoctoral Researcher
Yoshichika SEKI

Contract Researchers
Takashi HACHIYA
Hisayuki TORII (May 1, 2013 – Mar. 31, 2014)

Postdoctoral Researchers
Yoki ARAMAKI (- Mar. 31, 2014)
Yoshimasa IKEDA (- Mar. 31, 2014)
Yoshimitsu IMAZU (- Jun. 30, 2013)
Daisuke KAWAMA (JSPS)
Takayuki SUMITA (May 1, 2013 -)
Tomonori TAKAHASHI (- Mar. 31, 2014)
Yuhei MORINO (May 1, 2013 -)

Senior Visiting Scientists
Toshiaki SHIBATA (Grad. Sch. of Sci. and Eng., Tokyo Inst. of Tech.)
Takashi NAKANO (RCNP, Osaka University)

Visiting Scientists
Kazuya AOKI (Inst. of Particle and Nuclear Studies, KEK) Jun. 1, 2013 -
Alexander BAZILEVSKY (BNL, USA) Jul. 15, 2013 -
Wolfgang BENTZ (Tokai Univ.)
Akitomo ENOKIZONO (Grad. Sch. of Sci., Rikkyo Univ.)
Hirotsugu FUJII (Grad. Sch./College of Arts and Sciences, Univ. of Tokyo) - Mar. 31, 2013
Yoshinori FUKAO (Inst. of Particle and Nuclear Studies, KEK)
Kenji FUKUSHIMA (Keio Univ.)
Haruhiko FUNAHASHI (Grad. Sch. of Sci., Kyoto Univ.) - Mar. 31, 2013
Taku GUNJI (CNS, Univ. of Tokyo) Jul. 1, 2013 -
Noriyosu HAYASHIZAKI (Tokyo Inst. Tech.)
Masanori HIRAI (Tokyo Univ. of Science)
Kensuke HOMMA (Grad. Sch. of Sci., Hiroshima Univ.) - Mar. 31, 2013
Ryo ICHIMIYA (KEK) Jun. 1, 2013 -
Noriyoshi ISHII (Grad. Sch. of Pure and Applied Sci., Univ. of Tsukuba)
Robert JAMESON (Goethe Universitat Frankfurt, Germany) - Mar. 31, 2013
Masashi KANETA (Tohoku Univ.) Oct. 1, 2013 -
Hirotsugu KASHIWAGI (Takasaki Advanced Radiation Res. Inst., JAEA)
Shunzo KUMANO (Inst. of Particle and Nuclear Studies, KEK)
Teiji KUNIHIRO (Grad. Sch. of Sci., Kyoto Univ.) - Mar. 31, 2013
Makoto KUWAHARA (Nagoya Univ.)
Youngil KWON (Yonsei Univ., Korea) Jul. 22, 2013 -
Yoshikazu MAEDA (RCNP, Osaka Univ.) - Mar. 31, 2013
Yajun MAO (Peking Univ., China) - Mar. 31, 2013
Tsutomu MIBE (KEK)
Yoshiyuki MIYACHI (Tokyo Inst. Tech.) - Mar. 31, 2013
Norihito MURAMATSU (RCNP, Osaka Univ.) - Mar. 31, 2013
Ryotaro MUTO (KEK)
Tomofumi NAGAE (Grad. Sch. of Sci., Kyoto Univ.) - Mar. 31, 2013
Atsushi NAKAMURA (Information Media Center, Hiroshima Univ.) May 1, 2013 -
Tomoaki NAKAMURA (ICEPP, Univ. of Tokyo) - Mar. 31, 2013
Kenichi NAKANO (Tokyo Inst. Tech.)
Megumi NARUKI (KEK) Jul. 1, 2013 -
Masayuki NIIYAMA (Grad. Sch. of Sci., Kyoto Univ.) - Mar. 31, 2013
Tomohiro NISHITANI (Nagoya University)

Munehisa OHTANI (Kyorin Univ.)
Masahiro OKAMURA (BNL, USA)
Kyoichiro OZAWA (KEK)
Petra RIEDLER (CERN, Switzerland) - Mar. 31, 2013
Naohito SAITO (J-PARC, KEK) - Mar. 31, 2013
Hiroyuki SAKO (JAEA) - Mar. 31, 2013
Murad SARSOUR (Georgia State University) - Mar. 31, 2013
Susumu SATO (JAEA)
Shin-ya SAWADA (Inst. of Particle and Nuclear Studies, KEK)
Michiko SEKIMOTO (Inst. of Particle and Nuclear Studies, KEK)
Maya SHIMOMURA (Iowa State University)
Kazutaka SUDO (Inst. of Particle and Nuclear Studies, KEK) - Mar. 31, 2013
Mizuki SUMIHAMA (RCNP, Osaka Univ.) - Mar. 31, 2013
Taneja SWADHIN (SUNY at Stony Brook) - Mar. 31, 2013
Masao TABUCHI (Nagoya Univ.) - Mar. 31, 2013
Junpei TAKANO (KEK)
Kiyoshi TANIDA (Seoul National Univ., Korea)
Feng WEI (New Mexico State Univ., USA) Jul.1, 2013 – Jul. 24, 2013
Yorito YAMAGUCHI (CNS, Univ. of Tokyo)
Satoru YAMASHITA (ICEPP, Univ. of Tokyo) - Mar. 31, 2013
Imuran YOUNUS (Univ. of New Mexico, USA) - Mar. 31, 2013

Student

Junior Research Associates

Yasuhiro FUWA (Grad. Sch. of Sci., Kyoto Univ.) Apr. 1, 2013 -
Shinichi HAYASHI (CNS, Univ. of Tokyo)
Tomoya HOSHINO (Grad. Sch. of Sci., Hiroshima Univ.) Apr. 1, 2013 -
Shunsuke Ikeda (Tokyo Inst. Tech.) Apr. 1, 2013 -
Kouki KANNO (Fac. Sci., Univ. of Tokyo) Apr. 1, 2013 -
Yuya KOMATSU (Fac. Sci. , Univ. of Tokyo)
Masafumi KUMAKI (Fac. Sci. and Eng., Waseda Univ.) Apr. 1, 2013 -
Sanshiro MIZUNO (Grad. Sch. of Pure and Applied Sci., Univ. of Tsukuba)
Hiroshi NAKAGOMI (Grad. Sch. of Pure and Applied Sci., Univ. of Tsukuba) Apr. 1, 2013 -
Wataru NAKAI (Fac. Sci., Univ. of Tokyo) Apr. 1, 2013 -
Masaya NIHASHI (Grad. Sch. of Sci., Hiroshima Univ.) - Mar. 31, 2013
Yuko SEKIGUCHI (CNS, Univ. of Tokyo) Apr. 1, 2013 -
Megumi SEKINE (Tokyo Inst. Tech.)
Takahito TODOROKI (Grad. Sch. of Pure and Applied Sci., Univ. of Tsukuba) - Mar. 31, 2013
Tomoya TSUJI (CNS, Univ. of Tokyo)
Daisuke WATANABE (Univ. of Tsukuba) Apr. 1, 2013 -
Satoshi YANO (Grad. Sch. of Sci., Hiroshima Univ.) Apr. 1, 2013 –

International Program Associates

Chong KIM (Korea Univ., Korea) Dec. 10, 2013 -
Taebong MOON (Yonsei Univ., Korea) Jul. 1, 2013 -
Sanghwa PARK (Seoul National Univ., Korea)
Inseok YOON (Seoul National Univ., Korea)

Student Trainees

Nobuaki AMANO (Grad. Sch. of Sci., Kyoto Univ.) - Mar. 31, 2013
Nerangika Sadeera BANDARA (Univ. of Massachusetts, Amherst, USA) Jul. 1, 2013 – Jul. 23, 2013
Michael BEAUMIER (Univ. of California, Riverside, USA) Jul. 8, 2013 – Aug. 4, 2013
Jeongsu BOK (New Mexico State Univ., USA) Jun. 30, 2013 – Jul. 11, 2013
Kazuya HAYASE (Tokyo Univ. of Science) - Mar. 31, 2013
Daniel JUMPER (Univ. of Illinois at Urbana Champaign, USA) Jul. 8, 2013 – Jul. 26, 2013
Sotaro KANDA (Fac. Sci., Univ. of Tokyo) - Mar. 31, 2013
Aaron KEY (Univ. of New Mexico, USA) Jul. 1, 2013 – Jul. 21, 2013
Paul KLINE (Dept. of Physics, SUNY at Stony Brook, USA) - Mar. 31, 2013
Yukiyoshi KON (RCNP, Osaka Univ.) - Mar. 31, 2013
Andrew MANION (Dept. of Physics, SUNY at Stony Brook, USA) - Mar. 31, 2013
Shinichi MASUMOTO (Fac. Sci., Univ. of Tokyo) - Mar. 31, 2013
Abraham MELES (New Mexico State Univ., USA) Jul. 1, 2013 – Jul. 20, 2013
Shou MIYASAKA (Tokyo Inst. Tech.) - Mar. 31, 2013
Pedro MONTUENGA (Univ. of Illinois at Urbana Champaign, USA) Jul. 8, 2013 – Jul. 29, 2013
Hikari MURAKAMI (Fac. Sci., Univ. of Tokyo) Nov. 1, 2013 -
Kazuya NAGASHIMA (Grad. Sch. of Sci., Hiroshima Univ.)
Shoichiro NISHIMURA (Fac. Sci., Univ. of Tokyo) - Mar. 31, 2013
Yuki OBARA (Fac. Sci., Univ. of Tokyo)

Hideyuki OIDE (Fac. Eng., Univ. of Tokyo) - Mar. 31, 2013
Yusuke OYA (Grad. Sch. of Sci., Hiroshima Univ.)
Gonaduwage PERERA (New Mexico State Univ., USA) Jul. 1, 2013 – Jul. 20, 2013
Joshua PERRY (Iowa State Univ., USA) Jul. 2, 2013 – Jul. 31, 2013
Dai SAKURAI (Grad. Sch. of Eng., Tokyo Univ. of Science) - Mar. 31, 2013
Takahiro SAWADA (RCNP, Osaka Univ.) - Mar. 31, 2013
Takuya SHIBUKAWA (Fac. Sci., Univ. of Tokyo) Apr. 1, 2013 -
Akihisa TAKAHARA (CNS, Univ. of Tokyo) - Mar. 31, 2013
Yosuke WATANABE (Fac. Sci., Univ. of Tokyo) - Mar. 31, 2013
Yuki WATANABE (Tokyo Univ. of Science) - Mar. 31, 2013
Haiwang YU (Peking Univ., China) Jul. 7, 2013 – Aug. 4, 2013

Interns
Hidemitsu ASANO (Fac. of Sci., Kyoto Univ.) - Mar. 31, 2014
Ciprian GAL (Dept. of Physics , SUNY at Stony Brook) Jun. 28, 2013 – Aug. 4, 2013
Minjung KIM (Seoul National Univ., Korea) Jul. 1, 2013 – Aug. 31, 2013
Katsuro NAKAMURA (Grad. Sch. of Sci., Kyoto Univ.) - Mar. 31, 2013
Masako YAMADA (Grad. Sch. of Sci., Kyoto Univ.) - Mar. 31, 2013
Takayuki YAMAMOTO (Waseda Univ.) - Mar. 31, 2013

Part-time Staff (Research Assistance)
Ryoji AKIMOTO (CNS, Univ. of Tokyo)
Kimiaki HASHIMOTO (Fac. of Sci., Rikkyo Univ.)
Takeru IGURI (Rikkyo Univ.)
Toru NAGASHIMA (Rikkyo Univ.)
Wataru SAITO (Rikkyo Univ.)

Assistants
Keiko SUZUKI
Noriko KIYAMA (- Aug. 31, 2013)
Mitsue YAMAMOTO (Sep. 1, 2013 -)

Sub Nuclear System Research Division
Advanced Meson Science Laboratory

1. Abstract

Particles like muons, pions, and kaons have finite life times, so they do not exist in natural nuclei or matters. By implanting these particles into nuclei/matters, exotic phenomena in various objects can be studied from new point of view.

Kaon is the second lightest meson which has strange-quark as a constituent quark. It is expected that if one embed mesons into nuclei, the sizes of the nuclei become smaller and one can form a high density object beyond the normal nuclear density. Study of this object could lead to better understanding of the origin of the mass of the matter, and may reveal the quark degree of freedom beyond the quark-confinement. The other example is the weak interaction in nuclear matter. It can only be studied by the weak decay of hypernuclei, which have Lambda particle in the nuclei.

Muon provides even wider scope of studies, covering condensed matter physics as well as nuclear and atomic physics, and we are trying to extend the application field further into chemical and biological studies. For instance, stopping positively charged muon in a material, we obtain information on the magnetic properties or the local field at the muon trapped site (μSR). Injecting negatively charged muon to hydrogen gas, muonic hydrogen atom (μp) is formed. We are planning to measure μp hyperfine splitting energy to measure proton magnetic radius, which is complementary quantity to the proton charge radius and its puzzle lately attracts strong interest. We are also interested in precision measurement of muon property itself, such as muon anomalous magnetic moment (g-2).

In our research, we introduce different kind of impurities into nuclei / matters, and study new states of matter, new phenomena, or the object properties.

2. Major Research Subjects

(1) Study of meson property and interaction in nuclei
(2) Origin of matter mass / quark degree of freedom in nuclei
(3) Condensed matter and material studies with muon
(4) Nuclear and particle physics studies via muonic hydrogen
(5) Development of ultra cold muon beam, and its application from material science to particle physics

3. Summary of Research Activity

(1) Hadron physics at J-PARC, RIKEN-RIBF, GSI and SPring-8

Kaon and pion will shed a new insight to the nuclear physics. The recent discovery of deeply bound pionic atom enables us to investigate the properties of mesons in nuclear matter. At RIKEN-RIBF, we are preparing precise experimental study of the pionic atom. We have also started next generation kaon experiments (E15 and E31) at J-PARC. In these experiments, we are aiming at precise determination of the $K^{bar}N$ interaction, and clarify the nature of kaon in nuclei and the nature of Λ(1405), which could be K^-p bound state. At Spring-8 and at GSI, we are also aiming to study ω and η' nuclei. By these experiments, we aim to be a world-leading scientific research group using these light meta-stable particles.

(1-A) Deeply bound kaonic nuclei

We have performed experimental exploration of theoretically predicted deeply bound kaonic nuclear states, such as the $<K^-pp>$ bound state. One of the most interesting features of the kaonic nucleus is the strong attraction of the $K^{bar}N$ interaction. Because of this strong attraction, the kaon in nucleus will attract surrounding nucleons resulting in extremely high-density object, which is several times larger than normal nuclear density. Measurement of the kaon properties at such high energy density will provide precious information on the origin of hadron masses and the chiral symmetry breaking and its partial restoration.

The experiment J-PARC E15 aims to identify the nature of the $<K^-pp>$ bound state by the in-flight $^3He(K^-, n)$ reaction, which allows us to investigate such state both in the formation via the missing-mass spectroscopy using the emitted neutron, and in its decay via the invariant-mass spectroscopy by detecting decay particles from $<K^-pp>$. For the experiment, we constructed a dedicated spectrometer system at the secondary beam-line, K1.8BR, in the hadron hall of J-PARC.

The first physics data-taking was carried out in March and May, 2013 with 6×10^9 kaons on ^3He target, corresponding to a ~1% of the approved proposal. We successfully obtained semi-inclusive $^3He(K^-, n)$ X missing-mass spectrum, and found a tail structure just below the mass threshold of $(K^- + p + p)$ which cannot be explained by well-known processes and backgrounds. We also demonstrated an exclusive analysis by reconstructing $^3He(K^-, \Lambda p)$ n events. To derive more information on the $K^{bar}N$ interaction by the exclusive measurement, we are planning to perform the second physics-run, in which 10 times more data will be accumulated.

(1-B) Precision X-ray measurement of kaonic atom

Simultaneously with the above experiment (1), we have performed an X-ray spectroscopy of atomic $3d \rightarrow 2p$ transition of negatively charged K mesons captured by helium atoms. Many Kaonic atom x-rays are measured and most of them can be explained by theoretical calculation, however, very large deviation exist on kaonic helium (and the oxygen) which can never been explained in the present theoretical scheme. Therefore, a new and high precision data have been long awaited for. This large deviation could be due to the existence of deeply bound kaonic states in nuclei, well below the atomic levels of kaons in energy. Very recently, we performed a kaonic helium X-ray measurement. We have achieved much more precise X-ray measurement, resulting in the shift to be 2 ± 2 (stat.) ± 2 (syst.) eV, which is in good agreement with the theoretical calculation. Therefore, previous data should be replaced by the present value, and the so called "kaonic helium puzzle" has been dissolved.

Another important X-ray measurement of kaonic atom would be $2p \rightarrow 1s$ transition of kaonic deuteron. We have measured same transition of kaonic hydrogen, but the width and shift from electro-magnetic (EM) value reflect only isospin average of the $K^{bar}N$

interaction. We can resolve isospin dependence of the strong interaction by the measurement. We are presently preparing a proposal to J-PARC PAC to measure kaonic deuteron X-ray.

(1-C) Deeply bound pionic atoms and η' mesic nuclei

We have been working on precision spectroscopy of pionic atoms systematically, that leads to understanding of the origin of hadron mass. The precision data set stringent constraints on the chiral condensate at nuclear medium. We are presently conducting the precision measurement at RIBF. The first measurement is aiming at pionic tin 121 as the first step for the systematic spectroscopy. A pilot experiment was performed in 2010, and the first main experiment was performed in 2014 showing a very good performance of the system. We have been analyzing the data to improve experimental setup of the pionic atom spectroscopy at the RIBF in RIKEN. We expect to achieve better experimental resolution with much reduced systematic errors.

We are also working on spectroscopy of η' mesic nuclei in GSI/FAIR. Theoretically, peculiarly large mass of η' is attributed to UA(1) symmetry and chiral symmetry breaking. As a result, large binding energy is expected for η' meson bound states in nuclei (η'-mesic nuclei). From this measurement, we can access information about partial restoration of chiral symmetry in nuclear media via the binding energy and decay width of η'-nuclear bound state.

(1-D) Hadron physics at SPring-8/LEPS2

Photo production of meson in nuclei is known to be a powerful tool to investigate property of the hadron in nuclear media. For this study, we started a new experimental project named LEPS2 (Laser Electron Photon at SPring-8 II) in this RIKEN Mid-term. The experimental hutch for LEPS2 at SPring-8 was constructed in March 2011, lead by RIKEN. The Large solenoid spectrometer magnet (2.96 m inner diameter x 2.22 m length) was successfully transported from BNL (US) to SPring-8 and installed into LEPS2 hutch in 2011.

One of the first physics programs is photo-production of η' in nuclei. Especially (γ, p) is most important reaction channel, where we can perform missing mass spectroscopy by detecting forward going proton. One of the big advantages of photo-production reaction is that the initial reaction is expected to be much cleaner than the hadron channel.

Detector construction for the first physics program is in progress. The 4π Electro-Magnetic calorimeter has been constructed and proton counter to detect forward going proton produced via (γ,p) reaction was partially installed in November 2013. Engineering run for the first experiment was performed in December 2013 to confirm performance of our detector system. Full set of the detector will be installed by mid April 2014 and we are planning to perform first physics data taking run starting from mid April 2014 to end of July 2014.

(2) Muon science at RIKEN-RAL branch

The research area ranges over particle physics, condensed matter studies, chemistry and life science. Our core activities are based on the RIKEN-RAL Muon Facility located at the Rutherford Appleton Laboratory (UK), which provides intense pulsed-muon beam. We have variety of important research activities such as particle / nuclear physics studies with muon's spin and condensed matter physics by muon spin rotation / relaxation / resonance (μSR).

(2-A) Condensed matter/materials studies with μSR

We are going to serve new μSR spectrometer named CHRONUS to collaborative experiments from the May-June cycle in 2014. To have higher affinity on μSR studies with ISIS muon facility, common data acquisition (DAQ) system with ISIS standard DAQ (DAEIII) and front-end control system (SEKI) have been installed and optimized along with other equipment in Port-4. Installations of an experimental platform over Port-4 and a pillar crane have been completed. Thus, we can perform two independent μSR experiments in Port-2 and 4 at the same time, switching double-pulse to share beam between the two.

Among our scientific activities on μSR studies from year 2011 to 2013, following six subjects of material sciences are most important achievements at the RIKEN-RAL muon facility:

1) One-dimensional diffusive motion of spin-excited states in the spin liquid of molecular magnet, $EtMe_3Sb[Pd(dmit)_2]_2$, has been found. The data shows that this material could be the first example that realized one-dimensional resonating valence bond state.
2) A static ordering of small Ir moments in the pyrochlore iridate, $Nd_2Ir_2O_7$, was examined. We found that this system is located close to the quantum critical point.
3) A static ordering of Yb moment in pyrochlore structure of $Yb_2Ti_2O_7$ crystal has been confirmed. This ordering can be explained by the Higgs mechanism.
4) Spontaneous small static internal fields in the superconducting state of URu_2Si_2 have been measured. From the data and its crystal structure, we obtained a scenario to explain superconducting mechanism of this system.
5) The universality class of the Mott transition in $EtMe_3P[Pd(dmit)_2]_2$ has been confirmed by pressure dependences of transportation properties.
6) Muon sites in La_2CuO_4 crystal have been evaluated based on ab-initio calculation on spatial distribution of the potential energy, taking into account the Cu spin spatial distribution effect.

(2-B) Nuclear and particle physics studies via ultra cold muon beam and muonic atoms

If we can improve muon beam-emittance, beam-timing and energy dispersion (*so-called* "ultra-slow muon"), then the capability of μSR study will be drastically improved. The ultra-slow muon beam can be stopped in thin foils, multi-layered materials and artificial lattices and we can apply the μSR techniques to surface and interface science. The development of ultra-slow muon beam is also very important as the source of ultra-cold (pencil-like small emittance) muon beam for muon g-2 measurement. Therefore, we have been working on R&D study.

We had been working on the "ultra-slow muon" generation based on the following technique, namely, positive muon beam with thermal energy has been produced by laser ionization of muoniums in vacuum (bound system of μ^+ and electron) emitted from the hot tungsten surface by stopping "surface muon beam" at Port-3. However, the muon yield and obtained emittance was far from satisfactory, and remained to be far from any kind of realistic application.

Therefore, in this mid-term, we decided to start developing two key components first, namely high efficiency muonium generator at room temperature and high intensity ionization laser. The study of muonium generator has been done in collaboration with TRIUMF. Very recently, we demonstrated tremendous increase of the muonium emission efficiency by fabricating fine laser drill-holes on the surface of silica aerogel. We also developed a high power Lyman-α laser in collaboration with laser group at RIKEN. In this laser development, we succeeded to synthesize novel laser crystal Nd:YGAG, which has an ideal wave-length property for laser amplification to generate Lyman-α by four wave mixing in Kr gas cell. The developed new laser will ionize muoniums 100 times more efficiently for slow muon beam generation. In order to fully apply these new developments to slow muon generation, we are designing a new beam line based on microscope optics.

(3) Theoretical Researches

(3-A) Physics of Quantum Hall system

We have investigated the interlayer phase coherence and the Josephson currents in the bi-layer quantum Hall system based on the non-commutative geometrical approach. We have demonstrated that the Josephson in-plane current provokes anomalous behaviors in the Hall resistance in counter flow and drag experiments. Furthermore, we investigate the condition on the input current for the tunneling current to be coherent and dissipation less. Our results explain quite well the experimental report on the input current due to the von Klitzing group [Phys. Rev. Lett. 104 (2010) 116802]. We have predicted also how the condition changes when the sample is tilted in the magnetic field.

Head

Masahiko IWASAKI (Chief Scientist)

Members

Katsuhiko ISHIDA (Vice Chief Scientist)
Kenta ITAHASHI (Senior Research Scientist)
Yue MA (Research Scientist)
Hiroaki OHNISHI
Haruhiko OUTA (Senior Research Scientist)
Fuminori SAKUMA (Senior Research Scientist)
Tsukasa TADA (Vice Chief Scientist - Mar. 31, 2013)
Isao WATANABE (Senior Research Scientist)

Special Postdoctoral Researcher

Ikuto KAWASAKI

Contract Researchers

Yu OISHI
Shinji OKADA
Masaharu SATO (Apr. 1, 2013 -)

Special Temporary Employee

Teiichiro MATSUZAKI

Senior Visiting Scientist

Kazuhiro TANAKA (IPNS, KEK)

Visiting Scientists

Tadashi ADACHI (Grad. Grad. Sch. Eng., Tohoku Univ.)
Jun AKIMITSU (Coll. Sci. Eng., Aoyama Gakuin Univ.)
Kunio AWAGA (Grad. Sch. Sci., Nagoya Univ.)
Pavel BAKULE (IPS AS CR, Czech)
Ayi BAHTIAR (UNPAD, Indonesia)
George BEER (Univ. of Victoria, Canada)
HyoungChan BHANG (Seoul Natl Univ., Korea)
Graeme BLAKE (Univ. of Groningen, Netherlands)
N. Ludmila BOGDANOVA (ITEP, Russia)
Kwang Yong CHOI (Chung-Ang Univ., Korea)
Lee CHOW (UCF, USA)
Catalina CURCEANU (INFN, Italy)
Prasad Tara DAS (SUNY, USA)
Irwan DHARMAWAN (UNPAD, Indonesia)
Yasuaki EINAGA (Fac. Sci & Tech., Keio. Univ.)
Masaya ENOMOTO (Fac. Sci., Tokyo Univ. of Sci.)
Zyun Francis EZAWA (Grad. Sch. Sci., Tohoku Univ.)
Mark FAYFMAN (Kurchatov Inst., Russia)
Donald FLEMING (Univ. of British Columbia/TRIUMF)
Yutaka FUJII (Fac. Eng., Fukui Univ.)
Hiroyuki FUJIOKA (Grad. Sch. Sci., Kyoto Univ.)
Masaki FUJITA (IMR, Tohoku Univ.)

Hideto FUKAZAWA (Grad. Sch. Sci., Chiba Univ.)
Takayuki GOTO (Fac. Sci. & Tech., Sophia Univ.)
Kazuo HAYAKAWA (Fac of Sci. & Tech., Shizuoka Inst. Sci. & Tech.)
Ryugo S. HAYANO (Grad. Sch. Sci., Univ. of Tokyo)
Wataru HIGEMOTO (ASRC, JAEA)
Yuki HIGUCHI (Toyota Central R&D Labs.)
Satoru HIRENZAKI (Fac. Sci., Nara Women's Univ.)
Masahiko HIROI (Fac. Sci., Kagoshima Univ.)
Koichi ICHIMURA (Fac. of Eng., Hokkaido Univ.)
Youichi IGARASHI (IPNS, KEK)
Hiromi IINUMA (IPNS, KEK)
Masami IIO (CSC, KEK)
Susumu IKEDA (IMSS, KEK)
Yutaka IKEDO (IMSS, KEK)
Rintaro INOUE (ICR, Kyoto Univ.)
Takayuki ISHIDA (Grad. Sch. Infor. & Eng., Univ. Elect. Commu.)
Yasuyuki ISHII (Dept. Phys., Tokyo Medical Univ.) - Mar. 31. 2014
Shigeru ISHIMOTO (IPNS, KEK)
Tomoichi ISHIWATARI (SMI, Austria)
Ryosuke KADONO (IMSS, KEK)
Kazuya KAMAZAWA (Toyota Central R&D Labs.)
Toshiji KANAYA (ICR, Kyoto Univ.)
Roland KAWAKAMI (UC Riverside, USA)
Takayuki KAWAMATA (Grad. Sch. Eng., Tohoku Univ.)
Naritoshi KAWAMURA (IMSS, KEK)
Seiko KAWAMURA (J-PARC, JAEA)
Kenji KAWASHIMA (Coll. Sci. Eng., Aoyama Gakuin Univ.) - Mar. 31. 2014
Hikomitsu KIKUCHI (Grad. Sch. Eng., Univ. of Fukui)
Yasushi KINO (Fac. Sci., Tohoku Univ.)
Wataru KOBAYASHI (Grad. Sch. Pure & Applied Sci., Univ. of Tsukuba)
Yoshio KOBAYASHI (Grad. Sch. of Info. & Eng., Univ. of Elec.-Com.)
Akihiro KODA (IMSS, KEK)
Yoh KOHORI (Fac. Sci., Chiba Univ.)
Yoji KOIKE (Grad. Sch. Eng., Tohoku Univ.)
Kenji KOJIMA (IMSS, KEK)
Norimichi KOJIMA (Grad. Sch. Arts & Sci., Univ. of Tokyo)
Kenya KUBO (Grad. Sch. Sci., ICU)
Shoko KUME (Grad. Sch. Sci., Univ. of Tokyo)
Yoshitaka KUNO (Grad. Sch. Sci., Osaka Univ.)
Takuya KURAHASHI (IMS, NINS)
Haruhiko KUROE (Fac. Sci. & Tech., Sophia Univ.)
Guido LANGOUCHE (NVAO, Netherlands)
Shunsuke MAKIMURA (IMSS, KEK)
Hirotaka MANAKA (Grad. Sch. Sci. & Eng., Kagoshima Univ.)
Kenji MATSUDA (Grad. Sch. Sci. &Eng. for Edu., Univ. of Toyama)
Yasuyuki MATSUDA (Grad. Sch. Arts & Sci., Univ. of Tokyo)
Tsutomu MIBE (IPNS, KEK)
Mototsugu MIHARA (Grad. Sch. Sci., Osaka Univ.)
Yasuhiro MIYAKE (IMSS, KEK)
Jun MIYAZAKI (Fac. Sci. Div., Nihon Univ.) - Mar. 31. 2014
Soichiro MIZUSAKI (Coll. Sci. & Eng., Aoyama Gakuin Univ.)
Mohamed Ismail MOHAMED IBRAHIM (USM, Malaysia)
Kazuhiko MUKAI (Toyota Central R&D Labs.) - Mar. 31. 2014
Yujiro NAGATA (Coll. Sci. Eng., Aoyama Gakuin Univ.)
Takashi NAGATOMO (IMSS, KEK) - Dec. 31, 2013
Hiroyuki NAKAMURA (Grad. Sch. Eng., Kyoto Univ.)
Jin NAKAMURA (Grad. Sch. Infor. & Eng., Univ. Elect. Commu.)
Satoshi NAKAMURA (Grad. Sch. Sci., Tohoku Univ.)
Takashi NAKAMURA (Grad. Sch. Sci. & Eng., Tokyo Tech.)
Takayoshi NAKAMURA (RIES, Hokkaido Univ.)
Takehito NAKANO (Grad. Sch. Sci., Osaka Univ.)
Saburou NASU (Grad, Sch. Eng. & Sci., Osaka Univ.)
Kazuhiko NINOMIYA (Grad. Sch. Sci., Osaka Univ.)
Nobuhiko NISHIDA (Fac. Sci., Tokyo Tech.)
Katsuhiko NISHIMURA (Grad. Sch. Sci.&Eng. for Edu., Univ. of Toyama)
Kusuo NISHIYAMA (IMSS, KEK)
Hiroyuki NOUMI (RCNP, Osaka Univ.)
Hiroshi NOZAKI (Toyota Central R&D Labs.) - Mar. 31. 2014

Yasuo NOZUE (Grad. Sch. Sci., Osaka Univ.)
Agung NUGROHO (ITB, Indonesia)
Kazuki OHISHI (CROSS Tokai)
Yoshitaka OHKUBO (KURRI, Kyoto Univ.)
Atsushi OKAZAWA (Grad. Sch. Arts & Sci., Univ. of Tokyo)
Leonid PONOMAREV (Kurchatov Institute, Russia)
Francis PRATT (RAL, UK)
Risdiana (UNPAD, Indonesia)
Lusy SAFRIANI (UNPAD, Indonesia)
Naohito SAITO (IPNS, KEK)
Shin-ichi SAKAMOTO (J-PARC, JAEA)
Tobat SARAGI (Univ. of Kassel, Germany)
Kazuhiko SATO (Grad. Sch. Sci. & Eng., Saitama Univ.)
Masaharu SATO (Grad. Sch. Sci., Univ. of Tokyo)
Ralph SCHEICHER (Michigan Tech. Univ., USA)
Ryoichi SEKI (California State Univ., Northridge, USA)
Hexi SHI (Grad. Sch. Sci., Univ. of Tokyo) - Mar. 31. 2014
Kouichirou SHIMOMURA (IMSS, KEK)
Ichiro SHIRAKI (Grad. Sch. Medi. & Eng. Sci., Univ. of Yamanashi)
Patrick STRASSER (IMSS, KEK)
Hiroyuki SUGAI (ASRC, JAEA)
Jun SUGIYAMA (Toyota Central R&D Labs.) - Mar. 31. 2014
Shukri SULAIMAN (USM,, Malaysia)
Hiroyuki SUZUKI (AKTD, NIMS)
Ken SUZUKI (SMI, Austria)
Soh SUZUKI (CRC, KEK)
Takao SUZUKI (Shibaura Inst. of Tech.)
Takatoshi SUZUKI (Grad. Sch. Sci., Univ. of Tokyo)
Yoshikazu TABATA (Grad, Sch. Eng. & Sci., Kyoto Univ.)
Shigeru TAKAGI (Grad, Sch. Sci., Tohoku Univ.)
Kazuyuki TAKAI (Grad. Sch. Sci. & Eng., Tokyo Tech.)
Nao TAKESHITA (NeRI, AIST)
Yoichi TANABE (WPI, Tohoku Univ.)
Manobu TANAKA (IPNS, KEK)
Hiroshi TANIDA (Grad. Sch. Adv. Sci. Matter, Hiroshima Univ.)
Harry TOM (UC Riverside, USA)
Dai TOMONO (Grad. Sch. of Sci., Kyoto Univ.)
Eiko TORIKAI (Grad. Sch. Medi. & Eng. Sci., Univ. of Yamanashi)
Akihisa TOYODA (IPNS, KEK)
Kyo TSUKADA (Grad. Sch. Sci., Tohoku Univ.)
Satoshi TSUTSUI (JASRI) - Mar. 31. 2014
Masatomo UEHARA (Grad. Sch. Eng., Yokohama Natl.Univ.)
Kazuki UENO (IPNS, KEK)
Izumi UMEGAKI (Toyota Central R&D Labs.)
Helmut WEICK (GSI, Germany)
Eberhard WIDMANN (SMI, Vienna)
Zhuan XU (Zhejiang Univ. China)
Eiichi YAGI (Fac. Sci. & Eng., Waseda Univ.)
Yasuhiro YAMADA (Fac. Sci., Tokyo Univ. of Sci.)
Ichihiro YAMAUCHI (IMSS, KEK) - Mar. 31. 2014
Toshimitsu YAMAZAKI (Grad. Sch. Sci., Univ. of Tokyo)
Koji YOKOYAMA (Queen Marry Univ., UK)
Makoto YOKOYAMA (Coll. Sci., Ibaraki Univ.)
Yutaka YOSHIDA (Fac of Sci. & Tech., Shizuoka Inst. Sci. & Tech.)
Masaru YOSOI (RCNP, Osaka Univ.)
Arkady YUKHINCHUK (VNIIEF, Russia)
Johann ZMESKAL (SMI, Austria)

Visting Technicians

Yuya FUJIWARA (Grad. Sch. Sci., Univ. of Tokyo)
Shinji KAI (Tanaka Kikinzoku Kogyo K.K.)
Kazuo OOYAMA (JOHO com.)
Kunihiro SHIMA (Tanaka Kikinzoku Kogyo K.K.)

Research Consultants

Yoshinori AKAISHI
Atsuko ITO
Masayasu KAMIMURA

Hironari MIYAZAWA

Junior Research Associates

Hirotomo HAMANO (Grad. Sch. Sci., Osaka Univ.) Apr. 1, 2013 -
Sohtaro KANDA (Grad. Sch. Sci., Univ. of Tokyo) Apr. 1, 2013 – Mar. 31, 2014
Yuki NOZAWA (Grad. Sch. Sci., Kyoto Univ.)
Yuta SADA (Grad. Sch. Sci., Kyoto Univ.) - Mar. 31, 2013
Makoto TOKUDA (Grad. Sch. Sci. & Eng., Tokyo Tech.) - Mar. 31, 2013

International Program Associates

Noraina Binti ADAM (USM, Malaysia) Feb. 15, 2014 -
Budi ADIPERDANA (UNPAD, Indonesia) - Nov. 29, 2013
Hanjie GUO (Zhejiang Univ., China) - Dec. 20, 2013
Edi SUPRAYOGA (Bandung Inst. Tech., Indonesia) Apr. 1, 2013 -
Zhang QI (Lanzhou Univ., China) Feb. 3,2013 -

Student Trainees

Malik Anjelh BAQIYA (Sch. Eng., Tohoku Univ.)
Shun ENOMOTO (Grad, Sch. Sci., Osaka Univ.)
Kenji FUJIMURA (Grad. Sch. Sci. & Eng., Ibaraki Univ.)
Daisuke FURUSAWA (Grad. Sch. Eng., Kyoto Univ.)
Yoshiyuki FURUYA (Fac. Sci., Tokyo Univ. Sci.)
Hanjie GUO (Zhejiang Univ., China)
Tadashi HASHIMOTO (Grad. Sch. Sci., Univ. of Tokyo)
Fuminao HOSOMI (Fac. Sci., Univ. of Tokyo)
Suguru IGARASHI (Grad. Sch. Sci. & Eng., Aoyama Gakuin Univ.)
Takuya INABE (Grad. Sch. Eng., Tohoku Univ.)
Kentaro INOUE (Grad. Sch. Sci., Osaka Univ.)
Wataru ITO (Grad. Sch. Sci. & Eng., Aoyama Gakuin Univ.)
Richika KATO (Grad. Sch. Sci., ICU)
Shingo KAWASAKI (Grad. Sch. Sci., Osaka Univ.)
Taehyung KIM (Fac. Sci., Univ. of Toyama)
Ryo KITAMURA (Grad. Sch. Sci., Univ. of Tokyo)
Hiroaki KOBAYASHI (Grad. Sch. Arts & Sci., Univ. of Tokyo)
Sajjad MARI (IUT, Iran)
Kazuki MATSUI (Fac. Sci.& Tech., Sophia Univ.)
Go MISHIMA (Grad. Sch. Sci., Univ. of Tokyo)
Ryo MIYATANI (Fac. Sci., Tokyo Univ. o f Sci.)
Saidah Sakinah bt MOHD JAJUDIN (Univ. Saints Malaysia, Malaysia)
Yohei MURAKAMI (Grad. Sch. Sci., Univ. of Tokyo)
Daiki NATORI (Fac. Info & Eng., Univ. of Elec.-Com.)
Takahiro NISHI (Grad. Sch. Sci., Univ. of Tokyo)
Ayumi OCHIAI (Fac. Sci., Tokyo Univ. o f Sci.)
Shinji OGAWA (Fac. Sci., Univ. of Tokyo)
Kaori OTAKE (Coll. of Liberal Arts, ICU)
Anba Datt PANT (Grad. Sch. Sci. & Eng., Yamanashi Univ.)
Ainul Fauzeeha Binti ROZLAN (Univ. Saints Malaysia, Malaysia)
Yuta SADA (Grad. Sch. Sci., Kyoto Univ.)
Daisuke SAKATE (Grad. Sch. Sci. & Eng. Saitama Univ.)
Yukiko SATO (Fac. Info. & Eng., Univ. of Elec.-Com.)
He Xi SHI (Grad. Sch. Sci., Univ. of Tokyo)
Kazuma SHIGA (Fac. Sci., Tokyo Univ. of Sci.)
Ryo SHIMIZU (Fac. Sci., Tokyo Univ. of Sci.)
SUNARYONO (ITS, Indonesia)
Edi SUPRAYOGA (ITB, Indonesia)
Miho SATOU (Fac. Sci., Tokyo Univ. Sci.)
Kensuke SUZUKI (Grad. Grad. Sch. Eng., Tohoku Univ.)
Masato SUZUKI (Fac. Info. & Eng., Univ. of Elec.-Com.)
Kenichi TANABE (Fac. Sci., Tokyo Univ. Sci.)
Yoshiki TANAKA (Grad. Sch. Sci., Univ. of Tokyo)
Hiroki TAKEDA (Grad. Sch. Sci. & Eng., Aoyama Gakuin Univ.)
Ahmad TANFIQ (ITS, Indonesia)
Makoto TOKUDA (Grad. Sch. Sci. & Eng., Tokyo Inst. of Tech.)
Shotaro TANIGAWA (Fac. Info. & Eng., Univ. of Elec.-Com.)
Natsuki TOMIDA (Grad. Sch. Sci., Kyoto Univ.)
Yuni WATANABE (Grad. Sch. Sci., Univ. of Tokyo)
Takumi YAMAGA (Grad. Sch. Sci., Osaka Univ.)
Hiroyuki YAMADA (Grad. Sch. Sci., Univ. of Tokyo)

Hiroki YAMAKAMI (Grad. Sch. Sci., Kyoto Univ.)
Shingo YAMADA (Grad. Sch. Sci. & Eng., Aoyama Gakuin Univ.)
Sungwon YOON (Catholic Univ., Korea)
Xingliang XU (Grad. Sch. Sci. & Eng., Saga Univ.)
Ruidong ZHU (Fac. Sci., Univ. of Tokyo)

Part-time Workers

Toshihiko HIRAIWA (Grad. Sch. Sci., Kyoto Univ.) - Mar. 31, 2013
Yuko KATO (Grad. Sch., Tokyo Gakugei Univ.) Mar. 21, 2013 – Sep. 30, 2013
Yuta SADA (Grad. Sch. Sci., Kyoto Univ.) Apr. 1, 2013 – Mar. 31, 2014
Makoto TOKUDA (Grad. Sch. Sci. & Eng., Tokyo Inst. of Tech.) Apr. 1, 2013 -

Assistants

Yoko FUJITA
Yuri TSUBURAI

Sub Nuclear System Research Division
RIKEN-BNL Research Center

1. Abstract

The RIKEN BNL Research Center was established in April 1997 at Brookhaven National Laboratory with Professor T. D. Lee of Columbia University as its initial Director. It is funded by the Rikagaku Kenkyusho (RIKEN, The Institute of Physical and Chemical Research) of Japan. The Center is dedicated to the study of strong interactions, including spin physics, lattice QCD and RHIC physics through the nurturing of a new generation of young physicists. Professor Lee was succeed by BNL Distinguished Scientist, N. P. Samios, who served until 2013. The current director is Dr. S. H. Aronson. Support for RBRC was initially for five years and has been renewed three times, and presently extends to 2018. The Center is located in the Physics Department. The RBRC Theory Group activities are closely and intimately related to those of the Nuclear Theory, High Energy Theory, and Lattice Gauge Theory Groups at BNL. The RBRC Experimental Group works closely with the DOE RHIC Spin Group, the RIKEN Spin Group at BNL, and the PHENIX heavy ion groups. BNL provides office space, management, and administrative support. In addition, the Computer Science Center (CS) and Information Technology Division (ITD) at BNL provides support for computing, particularly the operation and technical support for the RBRC 400 Teraflop QCDCQ (QCD Chiral Quark) lattice gauge theory computer. The Deputy Director of RBRC is R. Pisarski (BNL). L. McLerran (BNL) is leader of the Theory Group. Y. Akiba (RIKEN) is Experimental Group leader with A. Deshpande (Stony Brook) deputy. T. Izubuchi (BNL) is Computing Group leader.

2. Major Research Subjects

Major research subjects of the theory group are
- (1) Heavy Ion Collision
- (2) Perturbative QCD
- (3) Phenomenological QCD

Major research subjects of the computing group are
- (1) Search for new law of physics through tests for Standard Model of particle and nuclear physics
- (2) Dynamics of QCD and related theories
- (3) Theoretical and algorithmic development for lattice field theories, QCD machine design

Major research subject of the experimental group are
- (1) Experimental Studies of the Spin Structure of the Nucleon
- (2) Study of Quark-Gluon Plasma at RHIC
- (3) PHENIX detector upgrades

3. Summary of Research Activity

Summary of Research Activities of the three groups of the Center are given in the sections of each group.

Director

Samuel H. ARONSON (Ph. D)

Deputy Director

Robert PISARSKI (Ph. D)

Administrative Staff

Mituru KISHIMOTO (Administration Manager, Accelerator-based Research Promotion Section)
Kazunori MABUCHI (Deputy Administration Manager, RBRC)
Colleen MICHAEL (Secretary)
Taeko ITO (Assistant to Account Manager for Administration)

Sub Nuclear System Research Division
RIKEN-BNL Research Center
Theory Group

1. Abstract

The efforts of the RBRC theory group are concentrated on the major topics of interest in High Energy Nuclear Physics. This includes: understanding of the Quark-Gluon Plasma; the nature of dense quark matter; the initial state in high energy collisions, the Color Glass Condensate; its evolution through a Glasma; spin physics, as is relevant for polarized hadronic collisions; physics relevant to electron-hadron collisions.

Theory Group hosted many joint tenure track positions with universities in U.S. and Japan.

2. Major Research Subjects

(1) Heavy Ion Collision
(2) Perturbative QCD
(3) Phenomenological QCD

3. Summary of Research Activity

(1) Spin Physics

The experimental program at RBRC is strongly focused on determining the origin of spin in the proton and neutron. To extract the spin content of nucleon requires both precise data and precise computation. Dr. Jianwei Qiu of the Nuclear Theory group is one of the world's leading theorists in perturbative QCD, and leading the effort at BNL in spin physics. Their effort will continue to concentrate on computing perturbative QCD effects to sufficient precision that one can reliably extract information from the evolving experimental program. In addition they are developing ideas which might be tested in an electron-hadron collider, such as the one proposed to be built by adding an electron ring to RHIC.

(2) Matter at High Energy Density

The RHIC experimental heavy ion program is designed to study the properties of matter at energy densities much greater than that of atomic nuclei. This includes the initial state of nucleus-nucleus collisions, the Color Glass Condensate, the intermediate state to which it evolves, the Glasma, and lastly the thermal state to which it evolves, the Quark-Gluon Plasma. Theorists at the RBRC have made important contributions to all of these subjects.

Matter at high temperature has been studied by a variety of techniques involving both numerical and analytic methods. Much of the high precision work on numerical simulations of lattice QCD at nonzero temperature and density such matter have been done by members of the Lattice Gauge Theory Group at BNL, including Frithjof Karsch, Peter Petreczsky, Swagato Mukherjee, and postdoctoral assistants. These groups, along with collaborators at Columbia University, the University of Bielefeld, and other groups, have computed numerous properties of QCD in thermodynamic equilibrium. This includes the equation of state for physical quark masses, susceptibilies with respect to quark chemical potentials, and transport coefficients.

Phenomenological theories of the Quark-Gluon Plasma, based upon results from lattice simulations, have been developed by R. Pisarski of the Nuclear Theory Group, in collaboration with Dr. Y. Hidaka (previously of RBRC/BNL, and now a permanent member at RIKEN in Waco), Shu Lin, Daisuke Sato, and other postdoctoral research assistants at RBRC/BNL.

The theory of the Color Glass Condensate and Glasma was largely developed by RBRC scientists. This theory has been successfully applied to a wide variety of experimental results involving high energy collisions of hadrons, electrons and nuclei. There is recent data on heavy ion collisions that are naturally explained by such matter, including data on proton (or deuteron) nucleus collisions. Much of the effort here will be aimed towards excluding or verifying the Color Glass Condensate and Glasma hypothesis in RHIC and LHC experiments.

Thermal matter at high temperature and baryon density has been traditionally conjectured to be of two phases: confined and deconfined, with a direct correlation between deconfinement and the restoration of chiral symmetry. RBRC scientists have recently conjectured a third phase, of quarkyonic matter. This is baryonic matter at energy densities very high compared to the QCD scale. It has a pressure and energy density typical of quarks, yet it is confined. The name arises because it shares properties of confined baryonic matter with unconfined quark matter. This hypothesis is new and predicts new classes of phenomena that might be observed in collisions of nuclei of relatively low energy at RHIC. There are a number of first principle theoretical issues also to be understood.

Efforts on RHIC phenomenology proceed on a broad front. Recent efforts include improving hydrodynamic computations using state of the art equations of state derived from lattice gauge theory. Understanding the nature of matter at high baryon number density has generated the idea of Quarkyonic Matter, that may have implications for an upcoming low energy run at RHIC and eventual experiments in the future at FAIR and NICA. An issue being studied is the nature of mass generation and the breaking of translational invariance. A central focus of work at RBRC, the Color Glass Condensate and the Glasma, matter that controls the high energy limit of QCD, is being realized in experiments at RHIC. Much activity focuses on the relation between observations at LHC and the implications made at RHIC.

Group Leader
Larry McLERRAN

Deputy Group Leader
Robert PISARSKI (concurrent)

Members
RHIC Physics Fellows
Adrian DUMITRU (- Mar. 31, 2014)
Cecilia LUNARDINI (-Mar. 31, 2013)
Anna STASTO (-Mar. 31, 2013)
Jinfeng LIAO
Fedor BEZRUKOV
HoUng YEE

Research Associates
Adam BZDAK
Daniel PITONYAK (Sep. 3, 2013 -)
Shu LIN (RIKEN FPR)
Sergey SYRITSYN (RIKEN FPR) (Oct. 1, 2013-)

Special Postdoctoral Researchers
Koji KASHIWA (- Mar. 31, 2014)
Akihiko MONNAI (Apr. 1, 2013-)

Visiting Scientists
Taku IZUBUCHI (RBRC Computing Group)
Miklos GYULASSY
Robert L. JAFFE
Edward SHURYAK
Testufumi HIRANO
Feng YUAN

Secretarial Staff
Pamela ESPOSITO (Theory Group Secretary)

Sub Nuclear System Research Division
RIKEN-BNL Research Center
Computing Group

1. Abstract

The computing group founded in 2011 as a part of the RIKEN BNL Research Center established at Brookhaven National Laboratory in New York, USA, and dedicated to conduct researches and developments for large scale physics computations important for particle and nuclear physics. The group was forked from the RBRC Theory Group.

The main mission of the group is to provide important numerical information that is indispensable for theoretical interpretation of experimental data using the theories of particle and nuclear physics. Their primary area of research is lattice quantum chromodynamics (QCD), which describes the sub-atomic structures of hadrons, which allow us the ab-initio investigation for strongly interacting quantum field theories beyond pertrubative analysis.

The RBRC group and its collaborators have emphasized the necessity and importance of precision calculations, which will precisely check the current understandings of nature, and will have a potential to find a physics beyond the current standard model of fundamental physics. We have therefore adopted techniques that aim to control and reduce any systematic errors. This approach has yielded many reliable results.

The areas of the major activities are R&D for high performance computers, developments for computing algorithms, and researches of particle, nuclear, and lattice theories. Since the inception of RBRC, many breakthroughs and pioneering works has carried out in computational forefronts. These are the use of the domain-wall fermions, which preserve chiral symmetry, a key symmetry for understanding nature of particle nuclear physics, the three generations of QCD devoted supercomputers, pioneering works for QCD calculation for Cabibbo-Kobayashi-Maskawa theory, QCD+QED simulation for isospin breaking, novel algorithm for error reduction in general lattice calculation. Now the chiral quark simulation is performed at the physical up, down quark mass, the precision for many basic quantities reached to accuracy of sub-percent, and the group is aiming for further important and challenging calculations, such as the full and complete calaution for $K\to\pi\pi$ decay, ε'/ε, or hadronic contributions go muon's anomalous magnetic moment, or Nucleon's shape and structures.

2. Major Research Subjects

(1) Search for new law of physics through tests for Standard Model of particle and nuclear physics, especially in the framework of the Cabibbo–Kobayashi–Maskawa (CKM), hadronic contributions to the muon's anomalous magnetic moment (g-2).
(2) Dynamics of QCD and related theories, including study for the structures of nucleons
(3) Theoretical and algorithmic development for lattice field theories, QCD machine design

3. Summary of Research Activity

In 2011, QCD with Chiral Quarks (QCDCQ), a third-generation lattice QCD computer that is a pre-commercial version of IBM's Blue Gene/Q, was installed as an in-house computing resource at the RBRC. The computer was developed by collaboration among RBRC, Columbia University, the University of Edinburgh, and IBM. Two racks of QCDCQ having a peak computing power of 2 × 200 TFLOPS are in operation at the RBRC. In addition to the RBRC machine, one rack of QCDCQ is owned by BNL for wider use for scientific computing. In 2013, 1/2 rack of Blue Gene/Q is also installed by US-wide lattice QCD collaboration, USQCD. The group has also used the IBM Blue Gene supercomputers located at Argonne National Laboratory and BNL (NY Blue), and RICC, the cluster computers at RIKEN (Japan), Fermi National Accelerator Laboratory, the Jefferson Lab, and others.

Such computing power enables the group to perform precise calculations using up, down, and strange quark flavors with proper handling of the important symmetry, called chiral symmetry, that quarks have. Several projects are ongoing: flavor physics in the framework of the CKM theory for kaons and B mesons; the electromagnetic properties of hadrons; hadronic contributions to the muon's anomalous magnetic moment; the proton's and neutron's electric dipole moments; proton decay; nucleon form factors, which are related to the proton spin problem; and QCD thermodynamics in finite temperature/density systems such as those produced in heavy-ion collisions at the Relativistic Heavy Ion Collider. Major breakthroughs on important problems such as the direct CP violation process ($K \to \pi\pi$, ε'/ε) will be attempted using this computer.

The RBRC group and its collaborators have emphasized the necessity and importance of precision calculations, which will precisely check the current understandings of nature, and will have a potential to find physics beyond the current standard model of fundamental physics. We have therefore adopted techniques that aim to control and reduce any systematic errors. This approach has yielded many reliable results.

The group also delivers an algorithmic breakthrough, which speed up generic lattice gauge theory computation typically by a factor of 20 or more. In this novel technique called All Mode Averaging (AMA), the whole calculation is divided into frequent approximated calculations, and infrequent expensive and accurate calculation using lattice symmetries.

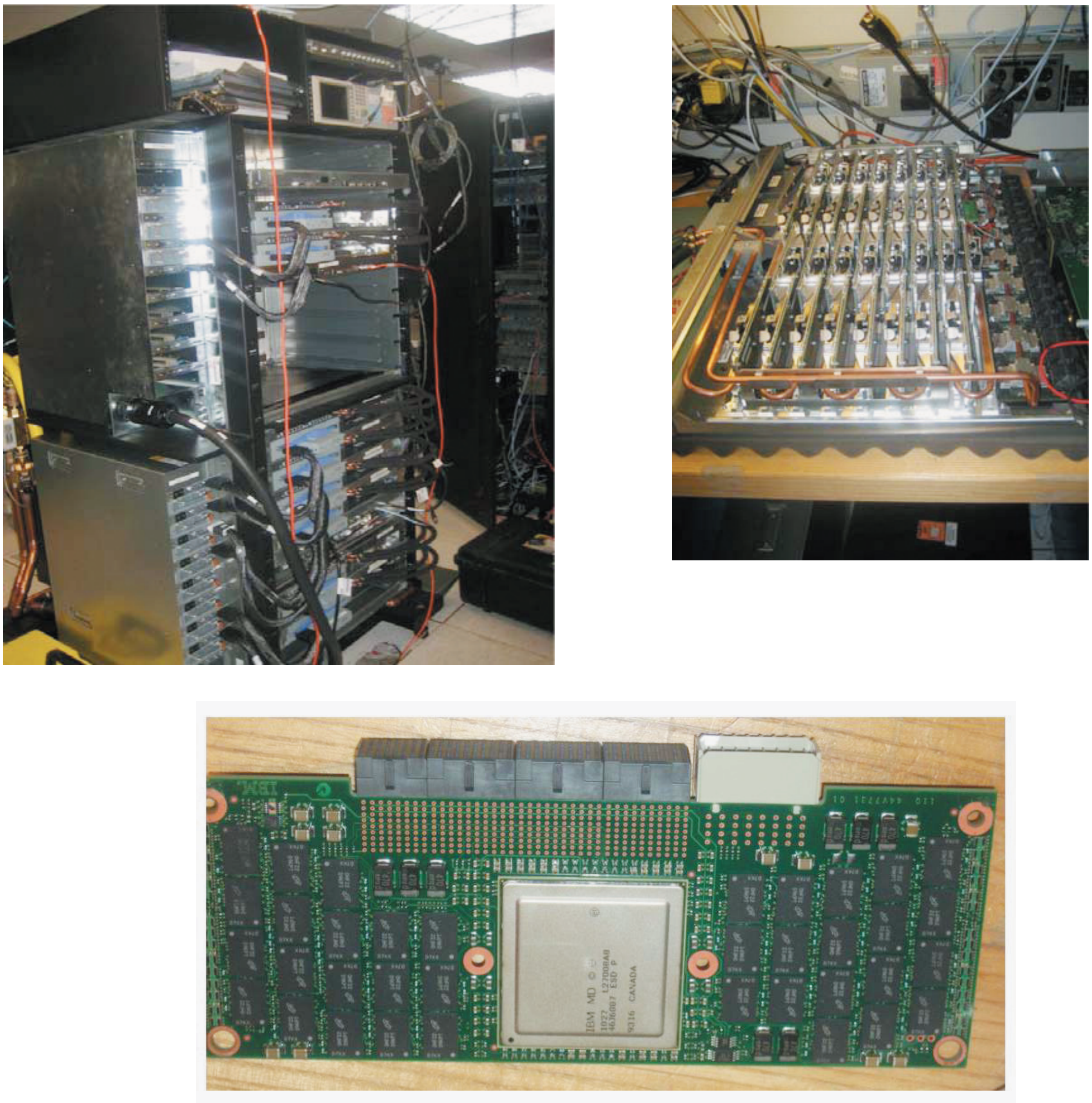


Fig. The rack, motherboard, and chips of QCDCQ

Group Leader
Taku IZUBUCHI

Members
RIKEN BNL Fellow
Tomomi ISHIKAWA (Apr. 1,2013 -)

RHIC Physics Fellow
Brian TIBURZI
Ethan NEIL (Sep. 1, 2013 -)

Research Associates
Eigo SHINTANI (- Sep. 30, 2013)
Christoph LEHNER (RIKEN FPR)
Christopher KELLY (RIKEN FPR)(Sep. 1,2013-)

Visiting Scientists
Robert MAWHINNEY (Columbia Univ., USA)
Shigemi OHTA (KEK)
Yasumichi AOKI (Nagoya Univ.) Apr. 1, 2013-
Meifeng LIN (Yale Univ.) Apr. 1,2013-
Hyung-Jin KIM (BNL)
Chulwoo JUNG (BNL)
Takeshi YAMAZAKI (Nagoya Univ.)
Thomas Blum (University of Connecticut)

Sub Nuclear System Research Division
RIKEN-BNL Research Center
Experimental Group

1. Abstract

RIKEN BNL Research Center (RBRC) Experimental Group studies the strong interactions (QCD) using RHIC accelerator at Brookhaven National Laboratory, the world first heavy ion collider and polarized p+p collider. We have three major activities: Spin Physics at RHIC, Heavy ion physics at RHIC, and detector upgrades of PHENIX experiment at RHIC. We study the spin structure of the proton using the polarized proton-proton collisions at RHIC. This program has been promoted by RIKEN's leadership. The first focus of the research is to measure the gluon spin contribution to the proton spin. Our recent data analysis has shown that the proton spin carried by the gluons is small, which is a very striking finding beyond our expectations. The aim of Heavy ion physics at RHIC is to re-create Quark Gluon Plasma (QGP), the state of Universe just after the Big Bang. Two important discoveries, jet quenching effect and strong elliptic flows, have established that new state of dense matter is indeed produced in heavy ion collisions at RHIC. We are now studying the property of the matter. Recently, we have measured direct photons in Au+Au collisions for $1<p_T<3$ GeV/c, where thermal radiation from hot QGP is expected to dominate. The comparison between the data and theory calculations indicates that the initial temperature of 300 MeV to 600 MeV is achieved. These values are well above the transition temperature to QGP, which is calculated to be approximately 170 MeV by lattice QCD calculations.

We have major roles in detector upgrades of PHENIX experiment, namely, the silicon vertex tracker (VTX) and muon trigger upgrades. Both of the upgrade is now complete. VTX detector was installed in PHENIX in 2011 and we are taking data since then. Muon trigger was complete and it was essential for W→μ measurement in 2013.

2. Major Research Subjects

(1) Experimental Studies of the Spin Structure of the Nucleon
(2) Study of Quark-Gluon Plasma at RHIC
(3) PHENIX detector upgrades

3. Summary of Research Activity

We study the strong interactions (QCD) using the RHIC accelerator at Brookhaven National Laboratory, the world first heavy ion collider and polarized p+p collider. We have three major activities: Spin Physics at RHIC, Heavy ion physics at RHIC, and detector upgrades of PHENIX experiment.

(1) Experimental study of spin structure of proton using RHIC polarized proton collider

How is the spin of proton formed with 3 quarks and gluons? This is a very fundamental question in Quantum Chromodynamics (QCD), the theory of the strong nuclear forces. The RHIC Spin Project has been established as an international collaboration between RIKEN and Brookhaven National Laboratory (BNL) to solve this problem by colliding two polarized protons for the first time in history. This project also has extended the physics capabilities of RHIC.

The first goal of the Spin Physics program at RHIC is to determine the gluon contribution to proton spin. It is known that the spin of quark accounts for only 25% of proton spin. The remaining 75% should be carried either by the spin of gluons or the orbital angular momentum of quarks and gluons. One of the main goals of the RHIC spin program has been to determine the gluon spin contribution. Before the start of RHIC, there was little experimental constraint on the gluon polarization, ΔG.

PHENIX measures the double helicity asymmetry (A_{LL}) of π^0 production to determine the gluon polarization. Our publication from 2006 run has shown that the gluon polarization in the proton is small and only about half of proton spin can be accounted by gluon spin in the measured region of gluon momentum in proton. Figure 1 shows our most recent results of π^0 ALL measurement, which has just submitted to Physical Review D. The figure shows the combined results of RUN5, RUN6, and RUN9. The new data give even stronger constraint on the gluon spin. RBRC exp. G led the gluon spin analysis in PHENIX. K. Bolye, a fellow of RBRC experimental group has a major role in this paper.

RHIC achieved polarized p+p collisions at 500 GeV in 2009. The collision energy increased to 510 GeV in 2012 and 2013. We have recorded The main goal of these high energy p+p run is to measure anti-quark polarization via single spin asymmetry AL of the W boson production. We have published the first results on W→e measurement at mid-rapidty from 2009 dataset in 2011. We upgraded the muon trigger system to measure W→m decays in the forward direction. With the measurement of W→ e and W→μ, we can cover a wide kinematic range in anti-quark polarization measurement. The 2013 run is the main spin run at 510 GeV. PHENIX has recorded more than 150/pb of data in the run. Combined with the datasets in 2009 (8.6/pb), 2011(18/pb), and 2012(~30/pb), we will have a definite measurement of anti-quark spin.

Figure 2 show the results of the AL measurement from the 510 GeV polarized proton run in 2012. This is approximately 1/5 of the data that was recorded in the 2013 run. Much improved results are expected in the combined data set. The analysis of the data is in progress.

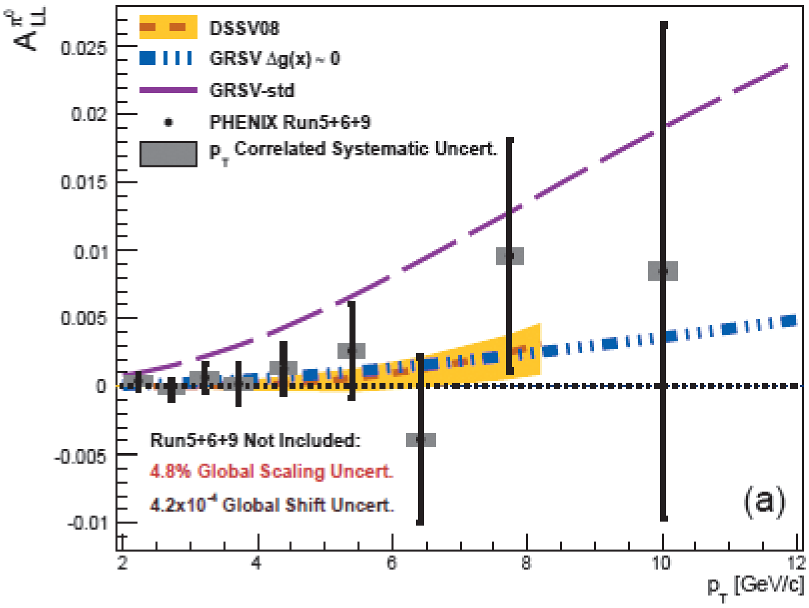


Figure 1 Double spin asymmetry ALL in π^0 production as function of transverse momentum pT compared with expectations for different gluon polarization ΔG(x). Submitted to Physical Review D (arXiv:1402.6296 (2014)).

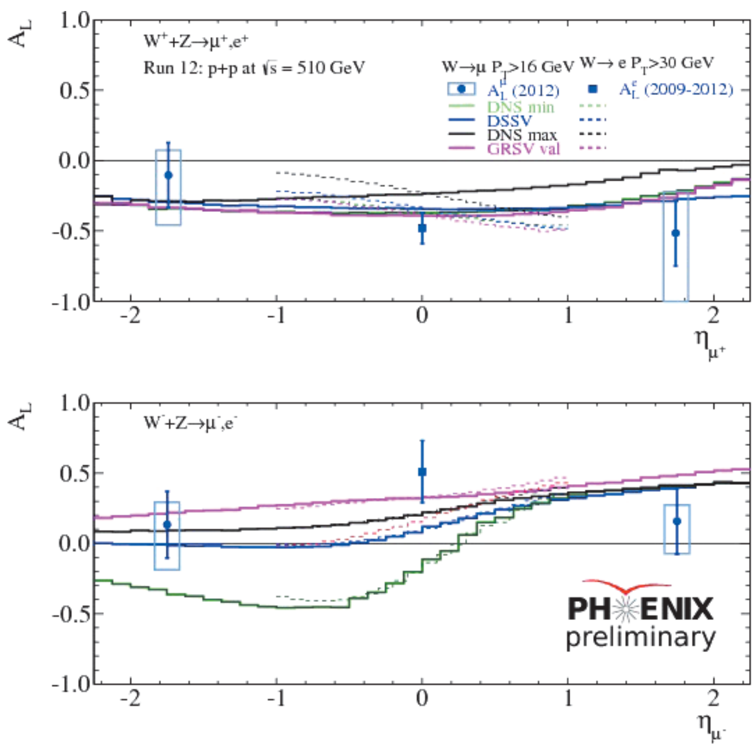


Figure 2 Single spin asymmetry AL of W→e and W→μ measured by PHENIX in the 2012 polarized proton run

(2) Experimental study of Quark-Gluon Plasma using RHIC heavy-ion collider

The goal of high energy heavy ion physics at RHIC is study of QCD in extreme conditions i.e. at very high temperature and at very high energy density. Experimental results from RHIC have established that dense partonic matter is formed in Au+Au collisions at RHIC. The matter is very dense and opaque, and it has almost no viscosity and behaves like a perfect fluid. These conclusions are primarily based on the following two discoveries:

- Strong suppression of high transverse momentum hadrons in central Au+Au collisions (jet quenching)
- Strong elliptic flow

These results are summarized in PHENIX White paper, which has over 1700 citations to date.

The focus of the research in heavy ion physics at RHIC is now to investigate the properties of the matter. RBRC have played the leading roles in some of the most important results from PHENIX in the study of the matter properties. These include (1) measurements of heavy quark production from the single electrons from heavy flavor decay (2) measurements of J/Psi production (3) measurements of di-electron continuum and (4) measurements of direct photons.

The most important recent result is the measurement of direct photons for $1<p_T<5$ GeV/c in p+p and Au+Au through their internal conversion to e+e- pairs. If the dense partonic matter formed at RHIC is thermalized, it should emit thermal photons. Observation of thermal photon is direct evidence of early thermalization, and we can determine the initial temperature of the matter. It is predicted that thermal photons from QGP phase is the dominant source of direct photons for $1<p_T<3$ GeV/c at the RHIC energy. We measured the direct photon in this p_T region from measurements of quasi-real virtual photons that decays into low-mass e+e- pairs. Strong enhancement of direct photon yield in Au+Au over the scaled p+p data has been observed. Several hydrodynamical models can reproduce the central Au+A data within a factor of two. These models assume formation of a hot system with initial temperature of Tinit = 300 MeV to 600 MeV. This is the first measurement of initial temperature of quark gluon plasma formed at RHIC. These results are recently published in Physical Review Letters. Y. Akiba is the leading person of the analysis and the main author of the paper. He received 2011 Nishina memorial Prize mainly based on this work.

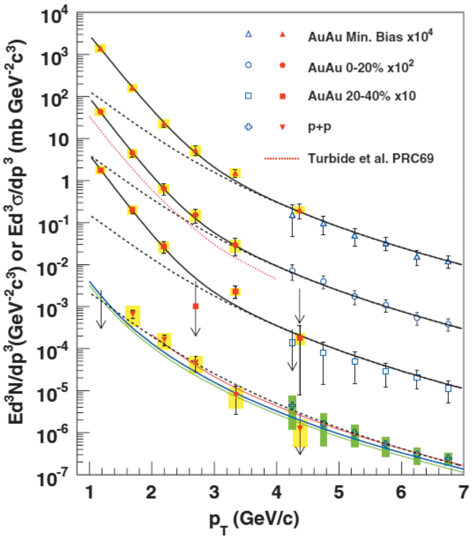


Figure 3 Invariant cross section (p+p) and invariant yield (Au+Au) of direct photons as function of pT. Published in Phys. Rev. Lett. 104, 132301 (2010).

(3) PHENIX detector upgrade

The group has major roles in several PHENIX detector upgrades, namely, the silicon vertex tracker (VTX) and muon trigger upgrades.

VTX is a high precision charged particle tracker made of 4 layers of silicon detectors. It is jointly funded by RIKEN and the US DOE. The inner two layers are silicon pixel detectors and the outer two layers are silicon strip detectors. Y. Akiba is the project manager and A. Deshpande is the strip system manager. The VTX detector was completed in November 2010 and subsequently installed in PHENIX. The detector started taking data in the 2011 run. With the new detector, we are measuring heavy quark (charm and bottom) production in p+p, A+A collisions to study the properties of quark-gluon plasma.

Muon trigger upgrades are needed for W→μ measurement at 500 GeV. New trigger electronics (Muon Trigger FEE) and new Muon trigger detectors using RPC technology were installed in PHENIX muon arms. Additional hadron absorbers were installed in front of the muon arms to reduce the background. These upgrades were essential for the high statistic W→μ measurement in 2013 run. Over 150/pb of data was recorded in the run. I. Nakagawa is the leading person of the installation of the Muon Trigger FEE, and R. Seidl have major role in the RPC project. He is also leading the W→μ analysis.

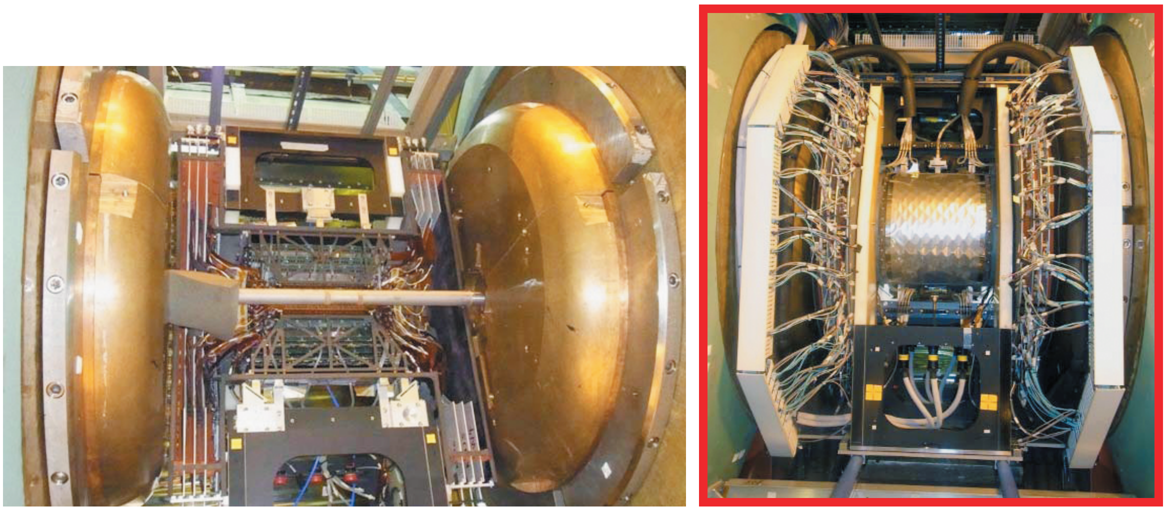


Figure 4 Left: a picture of West half of VTX detector installed in PHENIX experiment. The interior of the detector can be seen. Right: The VTX detector completed with all cables, cooling tubes and dry gas connections.

Group Leader
Yasuyuki AKIBA

Deputy Group Leader
Abhay DESHPANDE

Members
Yuji GOTO (concurrent)
Itaru NAKAGAWA (concurrent)
Takashi ICHIHARA (concurrent)
Atsushi TAKETANI (concurrent)
Yasushi WATANABE (concurrent)
Satoshi YOKKAICHI (concurrent)

RIKEN BNL Fellows
Kieran BOYLE
Josef SEELE (- Feb. 7, 2014)

RHIC Physics Fellows
Stefan BATHE
Xiaorong WANG

Research Associates
John KOSTER (RIKEN FPR) (- May 23, 2013)
Chin-Hao CHEN

Special Postdoctoral Researcher
Maki KUROSAWA (- Mar. 31, 2014)

Visiting Members
Zheng LEE (BNL)
Kiyoshi TANIDA (Seoul Univ.)
Akio OGAWA (BNL)
Masahiro OKAMURA (BNL)
Rachid NOUICER (BNL)
Ady HERSHCOVITCH (BNL)

Intern
Minjung KIM (- Jun. 10, 2013)

Sub Nuclear System Research Division
RIKEN Facility Office at RAL

1. Abstract

Our core activities are based on the RIKEN-RAL Muon Facility located at the Rutherford Appleton Laboratory (UK), which provides intense pulsed-muon beam. Muons have their own spins with 100% polarization, and can detect very precisely local magnetic fields and their fluctuations at muon stopping sites. The method to study characteristic of materials by observing time dependent changes of muon spin polarization is called “Muon Spin Rotation, Relaxation and Resonance (μSR method), and is applied to studies of electro-magnetic proerties of insulating, metallic, magnetic, superconducting systems. Muons reveal static and dynamic properties of electronic state of materials in the zero-field condition which is the ideal magnetic condition for reasearches on the magnetism. We have carried out μSR investigations on frustrated organic system which has a triangular spin network. We found the one dimensional properties of the spin-spin correlations in the system. This proves the first example which has the one-dimensional resonating spin state in real materials.

Positive muon beam with thermal energy has been produced by laser ionization of muoniums (bound system of mu+ and electron) emitted from hot tungsten surface with stopping surface muon beam at Port-3. The ultra-slow muon beam can be stopped in thin foils, multi-layered materials and artificial lattices and we can apply the μSR techniques to surface and interface science. The development of ultra-slow muon beam is also very important as the source of ultra-cold (pencil-like small emittance) muon beam for muon g-2 measurement. We have been developing muonium generators to create more muoniums in vacuum even at room temperature. Very recently, we demonstrated tremendous increase of the muonium emission efficiency by fabricating fine laser drill-holes on the surface of silica aerogel. We also developed a high power Lyman-alpha laser in collaboration with laser group at RIKEN. The new laser will ionize muoniums 100 times more efficiently for slow muon beam generation.

2. Major Research Subjects

(1) Materials science by muon-spin-relaxation method
(2) Hyperfine interactions at muon sites studied by the computation science
(3) Nuclear and particle physics studies via muonic atoms and ultra cold muon beam

3. Summary of Research Activity

(1) Material Science at the RIKEN-RAL Muon Facility

Muons have their own spins with 100% polarization, and can detect very precisely local magnetic fields and their fluctuations at muon stopping sites. The method to study characteristic of materials by observing time dependent changes of muon spin polarization is called “Muon Spin Rotation, Relaxation and Resonance (μSR method), and is applied to studies of newly fabricated materials. Muons with their own spin polarization enable us to conduct (1) material studies under external zero field condition, (2) magnetism studies with samples without nuclear spins, and (3) measurements of muon spin relaxation changes at wide temperature range with same detection sensitivity. The detection time range of local field fluctuations by μSR is 10^{-6} to 10^{-11} second, which is medium region between neutron scattering method (10^{-10}-10^{-12} second) and Nuclear Magnetic Resonance (NMR) (longer than 10^{-6} second). At port-2 of the RIKEN-RAL Muon Facility, we have been performing μSR researches on newly fabricated strong correlated-electron systems, organic molecules and biological samples to study electron structures, superconductivity, magnetism, molecular structures and crystal structures.

In the period from 2011 to 2013, we have obtained excellent results, and the highlights are listed in the following,

1) One-dimensional diffusive motion of spin-excited states in the spin liquid state of molecular magnet, $EtMe_3Sb[Pd(dmit)_2]_2$
2) Static ordering of small Ir moments in the pyrochlore iridate, $Nd_2Ir_2O_7$
3) Static ordering of Yb moment on the corner of the pyrochlore structure of $Yb_2Ti_2O_7$ which can be explained by the Higgs mechanism.
4) Spontaneous small static internal fields in the superconducting state of URu_2Si_2.
5) Universality class of the Mott transition in $EtMe_3P[Pd(dmit)_2]_2$.
6) Finding new muon sites in La_2CuO_4 and success to explain those sites from the potential view point on the basis of a newly developed calculation method taking into account an effect of the special distribution of Cu spin.
7) International collaborations to organize new μSR experiments and to develop a group to work on muon-site calculations by using computational technique.

Soft matters with small spins like organic molecules are now good target for the pulsed muon beam to be applied. The one-dimensional diffusive motion in the two-dimensional crystal structure has been observed. This indicates a strong possibility to observe the one-dimensional RVB state appears in the frustrated spin liquid state in organic molecules (result-1). Solid observations of a static magnetically ordered state of corner-shared magnetic moments on pyrochlore systems gave us new interpretations to understand exotic phenomena (result-2 and 3). We measured an increase of static internal fields at the muon site in the zero-field condition just below the superconducting transition temperature of URu_2Si_2. This could give a light on the mechanism of the superconductivity which has been a long-standing problem of this system (result-4). We have been developing gas-pressurized high-pressure apparatus which can be not only be used for μSR but also other purposes. We have applied this pressure system to $EtMe_3P[Pd(dmit)_2]_2$ and have found that pressure dependent resistivity and thermoelectric effect measurements have shown that the Mott transition belongs to the Ising universality class even in two-dimensional states (result-5). Well known and deeply investigate La_2CuO_4 did open a new scheme of the Cu spin. Taking into account the effect of the distribution of Cu spin, we succeeded to explain newly found muon sites and hyperfine fields at those sites (result-6). We have been very keen to develop muon activities in Asian countries. We have formed MOU with Universiti Sains Malaysia (USM) in order to develop activities on the muon-site calculation. We have newly started to collaborate in μSR experiments on strongly correlated systems with researchers from Taiwan and Korea including the student acceptance (result-7).

A new μSR spectrometer "Chronus" which has finely multi-segmented forward and backward μ-e counter arrays (303 counters each) is now being used for real muon experiments. Software systems which control the data acquisition and experimental conditions are well working in Port-4. The same data acquisition system with that being used in the ISIS muon facility (DAE-III) was adopted. Muon signals more than 70 million events per hour have been recorded even in the single-pulse mode by using DAE-III system in Port-4.

(2) Ultra Slow (low energy) Muon Beam Generation and Applications

Positive muon beam with thermal energy has been produced by laser ionization of muoniums (bound system of μ^+ and electron) emitted from hot tungsten surface with stopping surface muon beam at Port-3. The method generates positive muon beam with acceleration energy from several 100 eV to several 10 keV, small beam size (a few mm) and good time resolution (less than 8 nsec). By stopping the ultra-slow muon beam in thin foils, multi-layered materials and artificial lattices, we can precisely measure local magnetic field in the materials, and apply the μSR techniques to surface and interface science. Since there has been no appropriate probe to study magnetism at surface and interface, the ultra-slow muon beam will open a new area of these research fields. In addition, the development of ultra-slow muon beam is very important as the source of ultra-cold (pencil-like small emittance) muon beam for muon g-2 measurement.

It is essential to increase the slow muon beam production efficiency by 100 times for these applications. There are three key techniques in ultra-slow muon generation: production of thermal muonium, high intensity Lyman-alpha laser and the ultra-slow muon beam line.

In the period from 2011 to 2013, we developed a high power Lyman-alpha laser in collaboration with laser group at RIKEN. The new laser will ionize muoniums 100 times more efficiently for slow muon beam generation. This development was funded mostly by the Grant-in-Aid for Scientific Research on Innovative Areas "Frontier in Materials, Life and Particle Science Explored by Ultra Slow Muon Microscope". This Grant-in-Aid research group is a complex of research institutions from universities together with J-PARC muon group and RIKEN. Therefore, the new laser system should be installed to J-PARC slow muon beam line. On the other hand, we succeeded to synthesize novel ceramic-based Nd:YGAG crystal in this development, and this crystal can also be applicable to the flash-lamp based Lyman-alpha laser system of RIKEN-RAL to realize substantial improvement of the laser power at a much reduced cost based on the experiences.

Another plan in 2011-2013 was to achieve drastic improvements in the ultra-slow muon source with much reduced emittance. We have been developing muonium generators to create more muoniums in vacuum even at room temperature. Very recently, we demonstrated tremendous increase of the muonium emission efficiency by fabricating fine laser drill-holes on the surface of silica aerogel. The measurement was carried out at TRIUMF in collaboration with J-PARC muon g-2 group. Analysis is in progress and the result will be published soon. We believe that the better efficiency and beam quality can be achieved in ultra-slow muon generation by using this new muonium source.

Based on these two new key components, we are planning to feed these new techniques to RIKEN-RAL ultra-slow muon beam line to realize further development of ultra-slow muon technology. The present muonium production target section, which had been designed with hot tungsten, will be rebuilt to use advantage of the new room temperature target, such as no need of thermal shielding etc. Also, we adopt an all-cylindrical beam-transport design, because of its simpler optics and better manufacture precision, which will contribute to the ultimate cold muon source required for muon g-2. We plan the construction and testing be finished in time for the RIKEN-RAL muon beam recovery in Feb 2015 after ISIS shutdown.

(3) Other topics

Muon catalyzed fusion has been one of the main subject of studies since the start of the RIKEN-RAL Muon Facility. It has produced many new results by using the advantage of the high-intensity pulsed muon beam and the advanced tritium handling facility as was reported in previous RIKEN-RAL IACs. Even though, huge increase of the catalysis rate that is enough for energy production is yet difficult to achieve. Considering the limited funds and human resources maintaining the tritium facility, we plan the safe closure of the tritium facility well before 2018. We have started discussion of safe removal of the tritium handling facility. The decommissioning is planned in early 2015.

New demand is emerging utilizing the muon beam for electronics chips radiation effect studies. Recent progress of semiconductor devices has produced electronics chips with very fine structure. It is concerned that the single memory upset by the ionization effect of single muon may result in malfunction or errors of advanced electronics. Muon is the main component of the cosmic ray in our ordinal life and difficult to be removed. Measurements are being performed at RIKEN-RAL to measure such an error rate. There is also measurement to test the electronics chips in a condition equivalent to the high radiation environment in accelerator experiment.

A new proposal was submitted recently to measure the proton radius by using the hyperfine splitting of the 1S states of muonic hydrogen. This is in contrast to the recent measurement at PSI using 2S-2P energy splitting. The hyperfine transition measurement needs a high intensity laser so it needs to be matched with pulsed muon beam. Design of the hydrogen target, the laser, and the detector is in progress.

Director

Philip KING

Member

Isao WATANABE (concurrent)

Administration Manager

Mitsuru KISHIMOTO

RIBF Research Division
Radioactive Isotope Physics Laboratory

1. Abstract

This laboratory explores exotic nuclear structures and dynamics in exotic nuclei that have never been investigated before, such as those with largely imbalanced proton and neutron numbers. Our aim is to develop new experimental techniques utilizing fast RI beams to discover new phenomena and properties in exotic nuclei. Another important subject is the equation-of-state in asymmetric nuclear matter, and its association with the origin of elements and with neutron stars. For instance, we are making attempts to the better understand underlying mechanism for exotic stability-enhancements of very neutron-rich fluorine isotopes, the large deformation of the nucleus Mg-34 with N=22 in spite of its vicinity to the N=20 magic neutron number and anomalous collectivity in C-16. We are further extending these studies to medium- and heavy-mass regions by developing facilities, detectors and unique methods at RIBF, thereby leading on the challenging task to find new exotic phenomena. We also perform numerical simulations of nucleosynthesis under the environment of core-collapse supernovae, and moreover quest for footprints of supernovae and solar activities in the past, embedded in Antarctic ice core.

2. Major Research Subjects
(1) Study of structure and dynamics of exotic nuclei through developments of new tools in terms of reaction- and technique-based methodology
(2) Research on EOS in asymmetric nuclear matter via heavy-ion induced reactions
(3) Detector developments for spectroscopy and reaction studies

3. Summary of Research Activity
(1) In-beam gamma spectroscopy

In the medium and heavy mass region explored at RIBF, collective natures of nuclei are one of important subjects, which are obtained through production and observation of high excited and high spin states. To populate such states, heavy-ion induced reactions such as fragmentation, fission are useful. So far, we have developed two-step fragmentation method as an efficient method to identify and populate excited states, and lifetime measurements to deduce transition strength.

Devices utilized for the in-beam gamma spectroscopy are ZeroDegree Spectrometer (ZDS) and a NaI array DALI2. Since the end of 2008, the first spectroscopy on nuclei island-of-inversion region was performed, we have explored step-by-step new and unknown regions in the nuclear chart. The second campaign in 2009 was organized to study background components originating from atomic processes in a heavy target. Neutron-rich nuclei at N=20 to 28 were studied in 2010. In 2011-2013, we conducted experiment programs for Ca-54, Ni-78, neutron-rich nuclei at N=82 and neutron-deficient nuclei at Z=50.

A multitude of data obtained with inelastic, nucleon knock-out, fragmentation channels have been analyzed and published. In 2011-2013, collective natures of Mg-36, 38 and Si-42 were both published in PRL. Excited states firstly observed in Ca-54 were reported in Nature to demonstrate a new nuclear magic number of 34. Fragmentation reaction has been found efficient for nuclei with A>100 and low-lying excited state in Pd-126 has been successfully observed and reported in PRC.

To further strengthen the in-beam gamma spectroscopy at RIBF, we have proposed a new setup of MINOS + DALI2 to search for the 1st excited states in even-even neutron-rich nuclei with Z~20 to 40. The program was submitted to the PAC 2013 as a new category "proposal for scientific program" and was S-ranked. A dedicated collaboration "SEASTAR" has been established as a subset of in-beam gamma collaboration "SUNFLOWER". The first campaign will be organized in April 2014 to study neutron-rich Cr, Fe and Ni isotopes.

Concerning a next generation detector, a construction proposal of a LaBr3 array "SHOGUN", was submitted to the PAC 2009, and an international workshop was organized in Feb. 2011 to form the SHOGUN collaboration. A technical development with small sized crystals is now in progress.

(2) Decay spectroscopy

Beta- and isomer-spectroscopy is an efficient method for studying nuclear structure, especially for non-yrast levels. We had accumulated experimental techniques at the RIPS facility to investigate nuclear structure in light mass region via beta-gamma and beta-p coincidence. Concerning the medium and heavy mass region available at RIBF, we have developed two position-sensitive active-stoppers, strip-silicon detectors and a cylindrical active stopper called CAITEN, to achieve a low-background measurement by taking correlation between heavy ion stop position and beta-ray emission position. A site of decay-spectroscopy at the new facility of RIBF is the final focal plane of ZDS, where high precision of TOF in particle identification is obtained due to a long flight path from BigRIPS to ZDS.

At the end of 2009, the first decay spectroscopy was organized with a minimum setup of four clover gamma detectors and silicon strip detectors, to study neutron-rich nuclei with A~110. The first campaign was found successful and efficient to publish four letter articles in 2011, two PRL's and two PLB's. One of the PRL papers is associated to the r-process path where half-lives for 18 neutron-rich nuclei were determined for the first time. The other PRL paper reported a finding of deformed magic number 64 in the Zr isotopes.

The success of the first decay-spectroscopy campaign stimulated to form a new large-scale collaboration "EURICA", where a twelve Euroball cluster array is coupled with the silicon-strip detectors to enhance gamma efficiency by a factor of 10. A construction proposal of "EURICA" was approved in the PAC 2011, and the commissioning was successfully organized in spring 2012. Since then, physics runs have been conducted for programs approved to survey nuclei of interest as many as possible, such as Ni-78, Pd-128, Sn-100. So far, three papers, two PRL's and one PRC, were published. One of the highlights is discovery of a seniority isomer in Pd-128, of which cascade gamma decay gives the energy of 1st excited state and robustness of N=82 magic number.

Beta-delayed neutron emission probability of medium and heavy neutron-rich nuclei is important to understand nuclear structure and the r-process path. In 2013, a new collaboration "BRIKEN" has been established to form a He-3 detector array. A present design of the array has neutron efficiency as high as 70% up to 3 MeV. The array will be coupled with the AIDA silicon strip system. A construction proposal was approved at the PAC 2013 and physics proposals will be discussed at the PAC 2014.

The CAITEN detector was successfully tested with fragments produced with a Ca-48 beam in 2010.

(3) Equation-of-state via heavy-ion central collisions

Equation-of-state in asymmetric nuclear matter is one of major subjects in physics of exotic nuclei. Pi-plus and pi-minus yields in central heavy ion collisions at the RIBF energy are considered as one of EOS sensitive observables at the RIBF energy. To observe charged pions, a TPC for the SAMURAI spectrometer is being constructed under an international collaboration “SPiRIT”. Construction proposal was submitted at the PAC 2012, and physics proposals were approved at the PAC 2012 and 2013. Physics runs are scheduled in 2015.

An international symposium “NuSYM” on nuclear symmetry energy was organized at RIKEN July 2010 to invite researchers in three sub-fields, nuclear structure, nuclear reaction and nuclear astrophysics, and to discuss nuclear symmetry energy together. Since then, the symposium series have been held every year and been useful to encourage theoretical works and to strengthen the collaboration.

(4) Nucleon correlation and cluster in nuclei

Nucleon correlation and cluster in nuclei are matters of central focus in a “beyond mean-field” picture. The relevant programs with in-beam gamma and missing-mass techniques are to depict nucleon condensations and correlations in nuclear media as a function of density as well as temperature. Neutron-halo and –skin nuclei are objects to study dilute neutron matter at the surface. By changing excitation energies in neutron-rich nuclei, clustering phenomena and role of neutrons are to be investigated.

In 2013, two programs were conducted at the SAMURAI spectrometer. One is related to proton-neutron correlation in the C-12 nucleus via p-n knockout reaction with a carbon target. The other is to search for a cluster state in C-16, which was populated via inelastic alpha scattering. The data is being analyzed.

(5) Nuclear data for nuclear waste of long-lived fission products

The nuclear waste problem is an inevitable subject in nuclear physics and nuclear engineering communities. Since the Chicago Pile was established in 1942, nuclear energy has become one of major sources of energy. However, nowadays the nuclear waste produced at nuclear power plants has caused social problems. Minor actinide components of the waste have been studied well as a fuel in fast breeder reactors or ADS. Long-lived fission products in waste, on the other hand, have not been studied extensively. A deep geological disposal has been a policy of several governments, but it is difficult to find out location of the disposal station in terms of security, sociology and politics. To solve the social problem, a scientific effort is necessary for nuclear physics community to find out efficient methods for reduction of nuclear waste radioactivity.

In 2013, we have started up a new project to take nuclear data for transmutation of long-lived fission products to obtain cross section data needed for designing a nuclear waste treatment system. In 2014, we will make the first attempt to measure fragmentation reaction data with Cs-137 and Sr-90 beams at 200A MeV.

(6) Missing mass method

Missing mass technique is one of fundamental spectroscopy methods at RIBF. Detection of recoil particles from target is essential in excitation energy determination of particle unbound states without any assumption of particle- and gamma-decay processes, and also giving transfer angular momentum from the angular distribution measurement. We have developed a solid hydrogen target as well as a detector system called ESPRI for proton-(in)elastic scattering. In 2010, the ESPRI system was placed at GSI to measure proton elastic scattering with Ni isotope beams. In addition, the first missing mass spectroscopy was performed at RIBF, where the start-of-art detector MUST2 was invited from France to investigate O-24 and its neighboring nuclei. The (p,2p) reaction study for the light neutron-rich nuclei was carried out with the Kappa spectrometer installed at the new facility of RIBF.

The missing mass activity based on direct reactions has been moved to Spin-Isospin Laboratory in RNC since Uesaka was appointed as a chief scientist in April 2011.

(7) Interdisciplinary study for nuclear astrophysics

To understand the origin of elements beyond ion, interdisciplinary works are important in linking data from nuclear physics programs. In this respect, we did promote the ice core analysis activity to find out historical supernovae and to estimate event rates of supernovae.

This activity has been moved to Astro-Glaciology Research Unit in RNC since Motizuki was appointed as a unit leader in July 2011.

(8) Laser spectroscopy of radioactive isotope atoms

Electromagnetic moment is one of the most important quantities for studying nuclear structures because they are directly correlated with the quantum states and configurations of valence nucleons. Precision laser spectroscopy of radioisotope atoms (RI atoms) reveals these nuclear properties through the measurement of atomic level structures affected by hyperfine interactions. We have been developing a novel laser spectroscopic method for RI atoms named “*OROCHI* (Optical RI-atom Observation in Condensed Helium as Ion-catcher).” It is a combination of superfluid helium (He II) as a stopper of energetic RI beam with several tens MeV/u and in situ laser-microwave/-RF double resonance spectroscopy of stopped RI atoms. We expect that this method is applicable to a wide variety of atomic species whose yields are as low as 10 pps.

The laser spectroscopy activity has been moved to Nuclear Spectroscopy Laboratory in RNC since Ueno was appointed as a chief scientist in April 2013.

Head
Hiroyoshi SAKURAI (Chief Scientist; Deputy Director, RNC)

Members
Takashi ICHIHARA (Vice Chief Scientist)
Yoichi NAKAI (Senior Research Scientist)
Hideaki OTSU (Senior Research Scientist)
Takashi KISHIDA (Senior Research Scientist)
Shunji NISHIMURA (Senior Research Scientist)
Hiu Ching LEE (Research Scientist)
Tadaaki ISOBE (Research Scientist)
Pieter DOORNENBAL (Research Scientist)

Contract Researcher
Satoshi TAKEUCHI (Apr. 1, 2013 -)

Foreign Postdoctoral Researchers
Giuseppe LORUSSO
Paer-Anders SOEDERSTROEM (Feb. 1, 2014 -)

Postdoctoral Researchers
Paer-Anders SOEDERSTROEM (Oct. 18, 2013 – Jan. 31, 2014)
Paer-Anders SOEDERSTROEM (JSPS) (- Oct. 17, 2013)
Ann-Kathrin PERREVOORT (JSPS) (Apr. 1, 2013 – Feb. 3, 2014)

Senior Visiting Scientists
Shigeru KUBONO (University of Tokyo)
Kengo OGAWA (Chiba Univ.)

Visiting Scientists
Nori AOI (RCNP, Osaka University)
Dam Nguyen BINH (Institue of Physicks, Vietnam Academy of Science and Technology) - Mar. 31, 2013
Silivio CHERUBINI (University of Catania, Italy)
Alessia DI (INFN Laboratori Nazionali del Sud,Catania,Itary) Jun. 1, 2013 – Mar. 31, 2014
Pierpaolo FIGUERA (INFN Laboratori Nazionali del Catania,Italy) Jun. 1, 2013 – Mar. 31, 2014
Daiki NISHIMURA (Tokyo University of Science)
Mitsunori FUKUDA (Osaka University)
Adrian GELBERG (Universitat zu Köln, Germany) - Aug. 12, 2013
Mikhail GOLOVKOV (Flerov Lab. of Nuclear Reaction, JINR) - Mar. 31, 2014
Andrey FOMICHEV (Flerov Lab. of Nuclear Reaction, JINR) - Mar. 31, 2014
Atsushi HATAKEYAMA (Tokyo University of Agriculture and Technology) - Mar. 31, 2014
Chuangye HE (China Institute of Atomic Energy) - Mar. 31, 2013
Byungsik HONG (Korea University) Feb. 24, 2014 -
Kazuo IEKI (Rikkyo University)
Hyo Soon JUNG (University of Notre Dame)
Le Hong KHIEM (Institue of Physicks, Vietnam Academy of Science and Technology)
Nobuyuki KOBAYASHI (School of Science, the University of Tokyo)
Yosuke KONDO (Tokyo Institute of Technology) -Mar. 31, 2013
Nikolaus Ludwig KURZ (GSI) -Mar. 31, 2013
Yukari MATSUO (Hosei University)
Indranil MAZUMDAR (GSI)
Takamasa MOMOSE (The University of British Columbia, Canada)
Tetsuya MURAKAMI (Graduate School of Science, Kyoto University)
Takashi NAKAMURA(Tokyo Institute of Technology) -Mar. 31, 2013
Megmi NIIKURA (the University of Tokyo)
Evgueni NIKOLSKI (RRC Kurchatov Institute, Institute of General and Nuclear Physics, Russia)
Alexey OGLOBLIN (RRC Kurchatov Institute, Institute of General and Nuclear Physics, Russia)
Hooi Jing ONG (RCNP)
Naohiko OTSUKA (International Atomic Energy Agency, Austria)
Paul PAPKA (Department Fisika, Universiteit Stellenbosch) Aug. 1,2013 – Mar. 31, 2014
Toshiyuki SUMIKAMA (Tohoku University)
Maya TAKECHI (GSI) - Mar. 31, 2013
Xiaolong WANG (Kyoto Univ.) - Mar. 31, 2014
Hiroshi WATANABE (Beihang University)

Visiting Technician
Andrey BEZBAKH (Flerov Lab. of Nuclear Reaction, JINR) Sep. 1, 2013 - Mar. 31, 2014
Alexander KNYAZEV (Flerov Lab. of Nuclear Reaction, JINR) Sep. 1, 2013 - Mar. 31, 2014

Ivan KOJOUHAROV (GSI Helmholtzzentrum fuer Schwerionenforschung GMBH)
Sergey KRUPKO (Flerov Lab. of Nuclear Reaction, JINR) Sep. 1, 2013 - Mar. 31, 2014
Sergey SIDORCHUK (Flerov Lab. of Nuclear Reaction, JINR) Sep. 1, 2013 - Mar. 31, 2014
Roman SLEPNEV (Flerov Lab. of Nuclear Reaction, JINR) Sep. 1, 2013 - Mar. 31, 2014

Research Associates
Mizuki NISHIMURA (- Mar. 31, 2014)
Satoshi TAKEUCHI (- Mar. 31, 2013)

Junior Research Associates
Shintaro GO - Mar. 31, 2014
Yoshiaki SHIGA

International Program Associates
Xiaofei YANG (Peking Univ., China) -Feb. 16, 2014
Hongna LIU (Peking Univ., China)
Jin WU
Frank BROWNE - Sep. 30, 2013
Zena PATEL Mar. 21, 2013 - Sep. 30, 2013
Simon RICE Mar. 31, 2013 – Jul. 7, 2014
William POWELL
Laura SINCLAIR Apr. 19, 2013 – Oct. 19, 2013
Daniel LUBOS May 22, 2013 – Dec. 14, 2013

Research Consultant
Masayasu ISHIHARA

Consultant
Tateaki TORII

Part-time worker
Zhengyu XU (- Mar. 31, 2014)

Intern
Takatoshi MATSUKURA (Tokyo Metropolitan College of Industrical Technology) Aug. 22, 2013 – Sep. 13, 2013

Student Trainees
Jin-hee CHANG (Korea University)
Rie DAIDO (Osaka University)
Justin ESTEE (Michigan State University)
Yifan FANG (Osaka University)
Tomomi FUJITA (Osaka University)
Lauren HEILBORN (Texas A&M University)
Hisaya HOTAKA (Tohoku Univ.)
Tomoki ISHIGAKI (Osaka University)
Rachel HODGES (Michigan State University)
Akira HOMMA (Niigata University)
Jongwon HWANG (Seoul National Univ.)
Kei IMAMURA (Meiji University)
Yasuto KAMISHOU (Osaka Univ.)
Masanori KANEKO (Kyoto University)
Sunji KIM (Soul Univ., Korea)
Shumpei KINNO (The Tokyo University of Science)
Kazuma KOBAYASHI (Rikkyo University)
Akihiro KOJIMA (Tohoku Univ.)
JungWoo LEE (Korean University)
Keishi MATSUI (The University of Tokyo)
Hideyuki MATSUZAWA (Rikkyo University)
Takuya MIYAZAKI (The University of Tokyo)
Yosuke MITSUYA (Meiji Univ.)
Satoru MOMIYAMA (The University of Tokyo)
Shouta MORIMOTO (Osaka University)
Yosuke MORITA (Osaka University)
Motoki MURATA (Kyoto University)
Daiki MUROOKA (Niigata University)
Kotomi MUTO (Tohoku Unversity)
Masayuki NAGASHIMA (Nigata University)
Junichi OHNO (Osaka University)

Noritsugu NAKATSUKA (Kyoto University)
Hiroki NISHIBATA (Osaka University)
Ippei NISHIZUKA (Tohoku University)
Masami SAKO (Kyoto University)
Philipp SCHROCK (Technical University Darmstadt)
Hirotaka SUZUKI (Osaka University)
Tadashi TAKO (Tohoku University)
Kohei TAKENAKA (Kyoto University)
Mana TANAKA (Osaka University)
Suwat TANGWANCHAROEN (Michigan State University)
Ryo TANIUCHI (The University of Tokyo)
Keisuke TASHIRO (Nigata University)
Takumi USUKURA (Rikkyo University)
He WANG (Peking University)
Daisuke WATANABE (The Tokyo University of Science)
Kouta WATANABE (Osaka University)
Jack WINKELBAUER (Michigan State University)
Zhengyu XU (The University of Tokyo)
Ayumi YAGI (Osaka University)
Tetsuya YAMAMOTO (Osaka University)
Shintoro YAMAOKA (Osaka University)
Takamasa YOSHIDA (Rikkyo University)
Kenta YOSHINAGA (The Tokyo University of Science)
Andrew ZARRELLA (Texas A&M University)
Yifan ZHU (The Tokyo University of Science)

Assistant

Yu NAYA
Tomoko FUJII (- Mar. 31, 2013)

RIBF Research Division
Spin isospin Laboratory

1. Abstract

The Spin Isospin Laboratory pursues research activities putting primary focus on interplay of spin and isospin in exotic nuclei. Investigations on isospin dependences of nuclear equation of state, spin-isospin responses of exotic nuclei, occurrence of various correlations at low-densities, evolution of spin-orbit coupling are main subjects along the line. One of our goals is to elucidate a variety of nuclear phenomena in terms of interplay of spin and isospin.

Establishment of storage-ring science in Japan is another big goal of our laboratory. We are leading, in collaboration with the Wakasugi group, the Rare RI Ring project to achieve precision mass measurement of r-process nuclei.

2. Major Research Subjects

(1) Direct reaction studies of neutron-matter equation of state
(2) Study of spin-isospin responses with RI-beams
(3) Production of spin polarized protons and its application to RI-beam experiments
(4) R-process nucleosynthesis study with heavy-ion storage ring
(5) Development of special targets for RI-beam experiments

3. Summary of Research Activity

(1) Direct reaction studies of neutron matter equation of state

Direct reactions induced by light-ions serve as powerful tools to investigate various aspects of nuclei. We are advancing experimental programs to explore equation of state of neutron matter, via light-ion induced reactions with RI-beams.

(1-a) Determination of a neutron skin thickness by proton elastic scattering

A neutron skin thickness is known to have strong relevance to asymmetry terms of nuclear equation of state, especially to a term proportional to density. The ESPRI project aims at determining density distributions in exotic nuclei precisely by proton elastic scattering at 200−300 MeV/nucleon. An experiment for ^{132}Sn that is a flagship in this project is planned to be performed in 2015. Prior to the ^{132}Sn experiment, we have applied the ESPRI setup that consists of a solid hydrogen target and recoil proton detectors to ^{16}C in 2012.

(1-b) Asymmetry terms in nuclear incompressibility

Nuclear incompressibility represents stiffness of nuclear matter. Incompressibility of symmetric nuclear matter is determined to be 230±20 MeV, but its isospin dependence still has a large uncertainty at present. A direct approach to the incompressibility of asymmetric nuclear matter is an experimental determination of energies of isoscalar giant monopole resonances (GMR) in heavy nuclei. We have developed, in close collaboration with Center for Nuclear Study (CNS) of University of Tokyo, an active gas target for deuteron inelastic scattering experiments to determine GMR energies. The active gas target has been already tested with oxygen and xenon beams at HIMAC and will be applied to a ^{132}Sn experiment in 2015.

(1-c) Multi-neutron andα-cluster correlations at low densities

Occurrences of multi-neutron andα-cluster correlations are other interesting aspects of nuclear matter and define its low-density behavior. The multi-neutron andα-cluster correlations can be investigated with the large-acceptance SAMURAI spectrometer. The SAMURAI has been already applied to experiments to explore light neutron-rich nuclei close to the dripline. We plan to reinforce experimental capabilities of the SAMURAI by introducing advanced devices such as MINOS (Saclay) and NeuLAND (GSI).

(1-d) Fission barrier heights in neutron-rich heavy nuclei

The symmetry energy has a strong influence on fission barrier heights in neutron-rich nuclei. Knowledge on the fission barrier heights, which is quite poor at present, is quite important for our proper understanding on termination of the r-process. We are planning to perform, in collaboration with the TU Munich group, (p,2p)-delayed fission experiments at the SAMURAI to determine the fission barrier heights in neutron-rich nuclei in Pb region.

(2) Study of spin-isospin responses with RI-beams

The study of spin-isospin responses in nuclei forms one of the important cores of nuclear physics. A variety of collective states, for example isovector giant dipole resonances, isobaric analogue states, Gamow-Teller resonances, have been extensively studied by use of electromagnetic and hadronic reactions from stable targets.

The research opportunities can be largely enhanced with light of availabilities of radioactive isotope (RI) beams and of physics of unstable nuclei. There are three possible directions to proceed. The first direction is studies of spin-isospin responses of unstable nuclei via inverse-kinematics charge exchange reactions. A neutron-detector array WINDS has been constructed, under a collaboration of CNS, Tokyo and RIKEN, for inverse kinematics (*p*,*n*) experiments at the RI Beam Factory. We have already applied WINDS to the (*p*,*n*) experiments for ^{12}Be, ^{132}Sn and plan to extend this kind of study to other exotic nuclei.

The second direction is studies with RI-beam induced charge exchange reaction. RI-beam induced reactions have unique properties which are missing in stable-beam induced reactions and can be used to reach the yet-to-be-discovered states. We have constructed the SHARAQ spectrometer and the high-resolution beam-line at the RI Beam Factory to pursue the capabilities of RI-beam induced reactions as new probes to nuclei. One of the highlights is an observation of β^+ type isovector spin monopole resonances (IVSMR) in ^{208}Pb and ^{90}Zr via the (t, ^{3}He) reaction at 300 MeV/nucleon.

The third direction is studies of neutron- and proton-rich nuclei via stable-beam induced charge exchange reactions, which is conducted under collaboration with Research Center for Nuclear Physics (RCNP), Osaka University. We have performed the double charge exchange ^{12}C(^{18}O, ^{18}Ne)^{12}Be reaction at 80 MeV/nucleon to investigate structure of a neutron-rich ^{12}Be nucleus. Peaks corresponding to ground and excited levels in ^{12}Be have been clearly observed.

(3) Production of spin-polarized protons and its application to RI-beam experiments

Recent experimental and theoretical studies have revealed that spin degrees of freedom play a vital role in exotic nuclei. Tensor force effects on the evolution of shell and possible occurrence of p-n pairing in the proton-rich region are good examples of manifestations of spin degrees of freedom.

In exploring the spin effects in exotic nuclei, scattering with polarized protons should be a powerful tool. We have constructed a novel polarized proton solid target aiming to shed light of polarization on the physics of exotic nuclei. A distinguished feature of the target system is that it works under a low magnetic field of 0.1 T and temperature higher than 100 K, which exhibits a striking contrast to standard DNP targets working in extreme conditions of several Tesla and sub-Kelvin. It should be noted that we have recently achieved a proton polarization of 40% at room temperature in a pentacene-d_{14} doped p-terphenyl crystal.

The polarized proton target was applied, for the first time, to measurement of vector analyzing power in the proton elastic scattering of neutron-rich ^{6,8}He nuclei at 71 MeV/nucleon at RIPS, RIKEN. At RI Beam Factory, a hole-state spectroscopy via the (p, 2p) knockout reaction from unstable oxygen isotopes was performed with the polarized target.

(4) R-process nucleosynthesis study with heavy-ion storage ring

Most of the r-process nuclei become within reach of experimental studies for the first time at RI Beam Factory at RIKEN. The Rare RI Ring at RIBF is the unique facility with which we can perform mass measurements of r-process nuclei. Construction of the Rare RI Ring started in FY2012 in collaboration with Tsukuba and Saitama Universities. A major part of the ring has been completed and the commissioning run is planned in FY2014.

We are planning to start precise mass measurements of r-process nuclei in 2015. A series of experiments will start with nuclei in the A=80 region and will be extended to heavier region.

(5) Development of special targets for RI-beam experiments

For the research activities shown above, we are developing and hosting special targets for RI-beam experiments listed below:

a) Polarized proton target
b) Thin solid hydrogen target
c) MINOS (developed at Saclay and hosted by the Spin Isospin Laboratory)

Head

Tomohiro UESAKA (Chief Scientist)

Members

Masaki SASANO (Research Scientist)
Juzo ZENIHIRO (Research Scientist)

Postdoctoral Researchers

Masanori DOZONO - Mar. 31, 2014
Valerii PANIN Dec. 1, 2013-

Senior Visiting Scientists

Hiroyuki SAGAWA (Aizu University) - Mar. 31, 2014
Didier BEAUMEL (IPN) Apr. 1, 2013 -

Visiting Researcher

Alexandre OBERTELLI (JSPS) Sep. 2, 2013 -

Research Associate

Kenichiro TATEISHI Apr. 1, 2013 -

Junior Research Associates

Keiichi KISAMORI
Yuki KUBOTA Apr. 1, 2013 -
CheongSoo LEE Apr. 1, 2013 -
Fumi SUZAKI Apr. 1, 2013 -

International Program Associates

Sergey S. CHEBOTARYOV Jun 1, 2013 -
Sylvain R. LEBLOND Mar. 6, 2013 – Sep. 3, 2013
Evgeniy V. MILMAN Apr. 1, 2013 -
Clementine A. SANTAMARIA Sep. 3, 2013 – Sep. 22, 2013
Chao WEN Oct. 25, 2013 -

Visiting Scientists

Anna CORSI (CEA Saclay) Jun. 24, 2013 -
Alain GILLIBERT (CEA Saclay) Feb. 24, 2014 -
Yosuke KONDO (Graduate School, Tokyo Institute of Technology)

Attila KRASZNAHORKAY (ATOMKI) Mar. 15, 2014 -
Yohei MATSUDA (RCNP) May 1, 2013 -
Kenjiro MIKI (RCNP) Apr. 1, 2013 -
Dennis MUECHER (TU Munchen) Dec. 15, 2013 -
Takashi NAKAMURA (Graduate School, Tokyo Institute of Technology)
Kimiko SAKAGUCHI (Graduate School, Tohoku University)
Satoshi SAKAGUCHI (Kyusyu University)
Yasuhiro TOGANO (Graduate School, Tokyo Institute of Technology)
Takashi WAKUI (Tohoku University)
Takayuki YAMAGUCHI (Saitama University)

Visiting Technicians

Gilles AUTHELET (CEA Saclay) Jun. 25, 2013 -
Denis CALVET (CEA Saclay) Oct. 14, 2013 -
Frederic CHATEAU (CEA Saclay) Oct. 14, 2013 -
Alain DELBART (CEA Saclay) Oct. 14, 2013 -
Arnaud GIGANON (CEA Saclay) Oct. 14, 2013 -
Caroline LAHONDE-HAMDOUN (CEA Saclay) Oct. 14, 2013 -
Jean-Marc GHELLER (CEA Saclay) Jun. 25, 2013 -
Cedric PERON (CEA Saclay) Jun. 25, 2013 -
Alan PEYAUD (CEA Saclay) Oct. 14, 2013 -
Jean-Yves ROUSSE (CEA Saclay) Jun. 25, 2013 -

Research Consultant

Harutaka SAKAGUCHI

Interns

SungHan BAE Aug. 6, 2013 - Aug. 16, 2013
Sungha BAEK Aug. 6, 2013 - Aug. 16, 2013
JiHwan BHYUN Aug. 6, 2013 - Aug. 16, 2013
ZhenXing CHEN Aug. 6, 2013 - Aug. 16, 2013
Seungbum CHUNG Aug. 6, 2013 - Aug. 16, 2013
BaoShan HU Aug. 6, 2013 - Aug. 16, 2013
ZhiMeng HU Aug. 6, 2013 - Aug. 16, 2013
Wei JIANG Aug. 6, 2013 - Aug. 16, 2013
WeiGuang JIANG Aug. 6, 2013 - Aug. 16, 2013
JaeSung KIM Aug. 6, 2013 - Aug. 16, 2013
JinHa KIM Aug. 6, 2013 - Aug. 16, 2013
YoungHoon LIM Aug. 6, 2013 - Aug. 16, 2013
LanDiao LIU Aug. 6, 2013 - Aug. 16, 2013
FaFu NIU Aug. 6, 2013 - Aug. 16, 2013
Seongho SHIN Aug. 6, 2013 - Aug. 16, 2013
YiWen WEN Aug. 6, 2013 - Aug. 16, 2013
ZhaoRu ZHANG Aug. 6, 2013 - Aug. 16, 2013
TongKe ZHAO Aug. 6, 2013 - Aug. 16, 2013
WenJie ZHU Aug. 6, 2013 - Aug. 16, 2013

Student Trainees

Sergey Chebotaryov (Kyung pook National University) Jun. 30, 2013 – Jul. 15, 2014
Naruki INABA (University of Tsukuba) Apr. 1, 2013 -
Yuki ISHII (Kyoto University) Apr. 25, 2013 -
Tomomi KAWAHARA (Toho University) - Mar. 31, 2013
Tatsuo BABA (Kyoto University) Apr. 1, 2013 - Mar. 31, 2014
Taku FUKUNAGA (Kyusyu University) Apr. 1, 2013 - Mar. 31, 2014
Shota FUKUOKA (University of Tsukuba) Apr. 1, 2013 -
Tatsuya FURUNO (Kyoto University) Apr. 1, 2013 - Mar. 31, 2014
Shuhei GOTANDA (University of Miyazaki) Apr. 1, 2013 -
Tomosuke KADOYA (Tohoku University) - Mar. 31, 2013
Yoshihisa KANAYA (University of Miyazaki) Apr. 1, 2013 -
Junpei KOUNO (Saitama University) Apr. 1, 2013 - Mar. 31, 2014
Satoshi MATSUNAGA (Saitama University) Apr. 1, 2013 -
Ryogo MINAKATA (Tokyo Institute of Technology) Apr. 1, 2013 - Mar. 31, 2014
Hiroshi MIURA (Saitama University) May 27, 2013 -
Takuma NISHIMURA (Saitama University) May 27, 2013 -
Shun OGOSHI (Tokyo Institute of Technology) Apr. 1, 2013 - Mar. 31, 2014
Syunichirou OHMIKA (Saitama University) May 27, 2013 -
Muduki ONO (Saitama University) May 27, 2013 - Mar. 31, 2014
Kazuki SAWAHATA (Tokyo Institute of Technology) May 1, 2013 -

Mizuki SHIKATA (Tokyo Institute of Technology) May 1, 2013 -
Chihiro SHIMURA (Saitama University) May 27, 2013 - Mar. 31, 2014
Yuuta SHIOKAWA (Tohoku University) Apr. 1, 2013 - Mar. 31, 2014
Takahiro TAGUCHI (Tohoku University) - Mar. 31, 2014
Megumi TAKAHASHI (Tohoku University) - Mar. 31, 2013
Yuuki TAKEUCHI (Saitama University) May 27, 2013 -
Zhengyang TIAN (Peking University) - Mar. 31, 2014
Junichi TSUBOTA (Tokyo Institute of Technology) May 1, 2013 -
Miho TSUMURA (Kyoto University) Apr. 1, 2013 - Mar. 31, 2014
Yasunori WADA (Tohoku University) Apr. 1, 2013 - Mar. 31, 2014
Hidetomo WATANABE (Tohoku University) - Mar. 31, 2013
Junpei YASUDA (Kyusyu University) Apr. 1, 2013 -

Part-time workers

Tomomi KAWAHARA Apr. 1, 2013 -
Reiko KOJIMA - May 31. 2013

Assistant

Emiko ISOGAI
Yu Naya
Tomoko FUJII (- Mar. 31, 2013)

RIBF Research Division
Nuclear Spectroscopy Laboratory

1. Abstract
The group has conducted nuclear-physics studies utilizing stopped/slowed-down radioactive-isotope (RI) beams at the RIKEN RIBF facility based on the technique of nuclear spectroscopy that takes advantage of intrinsic nuclear properties such as nuclear spins, electromagnetic moments, and decay modes. In particular, by combining the techniques and devices for the production of spin-controlled RI beams to spectroscopic studies, high-sensitivity measurements to spin precessions/resonances have been conducted through a change in the angular distribution of radiations. The nuclear structures and properties of far-unstable nuclei are discussed based on thus determined spin-related observables. The methods are also applied to condensed matter studies, such as semiconductors, ferromagnets, fullerenes, and systems with dilute magnetic impurities, by exploiting RIs as microscopic probes.

2. Major Research Subjects
(1) Nuclear spectroscopy with stopped/slowed-down RI beams
(2) R&D studies on the production of spin-oriented RI beam
(3) Application of RI probes
(4) Fundamental physics: Study of symmetry

3. Summary of Research Activity
(1) Nuclear spectroscopy with stopped/slowed-down RI beams

Measurements of static electromagnetic nuclear moments over a substantial region of the nuclear chart have been conducted for structure studies on the nuclei far from the β-decay stability. Utilizing nuclear spin orientation phenomena of RIs created in the projectile-fragmentation reaction, ground- and excited-state nuclear moments of nuclei far from the stability have been determined by means of the β-ray-detected nuclear magnetic resonance (β-NMR) and γ-ray time differential perturbed angular distribution (γ-TDPAD) methods. To extend these observations to extremely rare RIs, a new method has been developed based on the laser spectroscopy which makes use of characteristic atomic properties of RIs surrounded by liquid helium.

(2) R&D studies on the production of spin-oriented RI beams

A new method has been developed for controlling spin in a system of rare RIs, taking advantage of the mechanism of the two-step projectile fragmentation reaction combined with the momentum-dispersion matching technique. This success allows us to utilize spin-controlled world's highest intensity rare RIBs delivered from BigRIPS for researches on the nuclear structure of species situated outside the traditional region of the nuclear chart. In parallel with this work, the development of a new apparatus to produce highly spin-polarized RI beams will be conducted by extending the atomic beam resonance method to fragmentation-based RI beams.

(3) Application of RI probes

The application of RI and heavy ion beams as a probe for condensed matter studies is also conducted by the group. The microscopic material dynamics and properties have been investigated through the deduced internal local fields and the spin relaxation of RI probes based on various spectroscopies utilizing RI probes such as the β-NMR/nuclear quadrupole resonance (NQR) methods, in-beam Mössbauer spectroscopy and the γ-TDPAC spectroscopy.

(4) Fundamental physics: Study of symmetry

The nuclear spins of stable and unstable isotopes sometimes play important roles in fundamental physics research. New experimental methods and devices have been developed for studies of the violation of time reversal symmetry (T-violation) using spin-polarized nuclei. These experiments aim to detect the small frequency shift in the spin precession arising from new mechanisms beyond the Standard Model.

Head

Hideki UENO (Chief Scientist)

Members

Yuichi ICHIKAWA (Oct. 1, 2013-) (Research Scientist)
Aiko NAKAO (May 1, 2013-) (Senior Research Scientist)

Research Consultant

Takuya OKADA

Visiting Scientists

Hisazumi AKAI (Osaka Univ.)
Koichiro ASAHI (Tokyo Tech)
Dimiter BALABANSKI (Bulgarian Academy of Sciences)
Takeshi FURUKAWA (Tokyo Metropolitan Univ.)
Atsushi HATAKEYAMA (Tokyo Univ. of Agriculture and Technology)
Yuichi ICHIKAWA (Tokyo Institute of Technology) - Sep. 30, 2013
Radomira LOZEVA (CNRS/IN2P3)
Yukari MATSUO (Hosei Univ.)

Kensaku MATSUTA (Osaka Univ.)
Takamasa MOMOSE (Kyoto Univ.)
Jiro MURATA (Rikkyo Univ.)
Wataru SATO (Kanazawa Univ.)
Makoto UCHIDA (Tokyo Tech)
Xiaolong WANG (Kyoto Univ.) -Mar. 31, 2014
Akihiro YOSHIMI (Okayama Univ.)

Junior Research Associates
Yoko ISHIBASHI (Univ. of Tsukuba) - Mar. 31, 2014
Kei IMAMURA (Meiji Univ.)

Student Trainees
Aleksey GLADKOV (Kyungpook National University) -Mar. 31, 2014
Miki HAYASAKA (Tokyo Gakugei Univ.)
Ryosuke KANBE (Osaka Univ.) -Mar. 31, 2014
Yuki KANNO (Tokyo Tech)
Shota KISHI (Tokyo Gakugei Univ.) -Mar. 31, 2014
Shuichiro KOJIMA (Tokyo Tech) -Mar. 31, 2014
Yuichi OHTOMO (Tokyo Tech) -Mar. 31, 2014
Tsubasa SAGAYAMA (Tokyo Gakugei Univ.) -Mar. 31, 2014
Yu SAKAMOTO (Tokyo Tech)
Tomoya SATO (Tokyo Tech)
Yonggeun SEON (Kyungpook National University)
Hazuki SHIRAI (Tokyo Tech) -Mar. 31, 2014
Takahiro SUZUKI (Tokyo Tech)
Masaomi TANAKA (Osaka Univ.)
Masato TSUCHIYA (Tokyo Tech)

Assistant
Emiko ISOGAI

RIBF Research Division
High Energy Astrophysics Laboratory

1. Abstract

In the immediate aftermath of the Big Bang, the beginning of our universe, only hydrogen and helium existed. However, nuclear fusion in the interior of stars and the explosion of supernovae in the universe over the course of 13.8 billion years led to the evolution of a world brimming with the many different elements we have today. By using man-made satellites to observe X-rays and gamma-rays emitted from celestial objects, we are observing the synthesis of the elements at their actual source. Our goal is to comprehensively elucidate the scenarios for the formation of the elements in the universe, together with our research on sub-atomic physics through the use of an accelerator.

2. Major Research Subjects

(1) Nucleosynthesis in Stars and Supernovae
(2) Particle Acceleration Mechanism in Astronomical Objects
(3) Physics in Extremely Strong Magnetism and Gravity
(4) Research and Development of Innovative X-ray and Gamma-ray detectors

3. Summary of Research Activity

High Energy Astrophysics Laboratory started on April 2010. The goal of our research is to reveal the mechanism of nucleosynthesis in the universe, and to observe exotic physical phenomena in extremely strong magnetic and/or gravitational field. We have observed supernova remnants, strongly magnetized neutron stars, pulsars, black holes and galaxies with X-ray astronomical satellites.

We showed that the expansion of ejecta in Tycho's supernova remnant was consistent with a spherically symmetric shell, based on Suzaku (Japanese X-ray observatory) measurements of the Doppler broadened X-ray emission lines. This is the first direct measurement of the expansion velocity of the elements produced in the thermonuclear expansion supernova. This information tells us the stratified structure of the elements, implying that the heavier elements such as Fe are produced deeper interior of the explosion.

We discovered the emission line of aluminum in supernova remnant G344.7-0.1 for the first time. Aluminum is produced in the neutron rich environment of supernova explosions. We also found manganese, which is enriched in the environment of neutron excess, in some supernova remnants. A systematic study of those lines emitted from the neutron rich elements will be a good tool to explore the nucleosynthesis in the interior of star explosions.

High-energy X-rays from radioactive Ti-44, which is a direct tracer of the supernova blast, was first imaged with the focusing telescope, NuSTAR. The map of Ti-44 in Cassiopeia A does not show spherical or axial symmetry, but asymmetry, supporting a mildly asymmetric explosion model with low-mode convection. This is the first astronomical image with nuclear gamma-rays and new observational evidence to understand the mechanism of supernova explosion and nucleosynthesis.

Gamma-ray emission up to 10 MeV was detected from thundercloud, suggesting that the detected gamma-rays were produced by relativistic electrons via bremsstrahlung. Those relativistic electrons are probably accelerated through an electrical potential difference in the thundercloud. This observation gives us a hint of the particle acceleration probably occurred near the neutron stars.

We continue to construct the Gravity and Extreme Magnetism Small Explorer (GEMS) under the collaboration with NASA Goddard Space Flight Center (USA). GEMS is the first dedicated satellite for the X-ray polarimetry, which is opening a new field in Astrophysics and Astronomy. The construction of an engineering model and basic performance studies of an X-ray polarimeter were carried out in FY2010, and the semiflight model of the detector was built in FY2012 and tested in FY2013. Unfortunately, NASA stops the GEMS project due to an expected cost overrun in 2012, but we will repropose the mission in 2014 with some modification. RIKEN will become a co-principal investigator institute and takes more responsibility on the X-ray polarimeter system and science.

Head
Toru TAMAGAWA (Associate Chief Scientist)

Contract Researcher
Goro SATO

Special Postdoctoral Researchers
Satoru KATSUDA
Shin'ya YAMADA
Asami HAYATO
Kumi ISHIKAWA

Postdoctoral Researcher
Takao KITAGUCHI

Visiting Scientists
Aya BAMBA (ISAS/JAXA)
Naohisa INADA (Univ. of Tokyo)

Madoka KAWAHARADA (ISAS/JAXA)
Atsushi SENDA (JST)
Poshak GANDHI (ISAS/JAXA)
Ken OHSUGA (NAOJ)
Toru MISAWA (Shinshu Univ.)
Yujin NAKAGAWA (Waseda Univ.)
Rohta TAKAHASHI (Tomakomai Nat'l College of Tech.)
Yukikatsu TERADA (Saitama Univ.)
Harufumi TSUCHIYA (JAEA)
Masaki WAKABAYASHI (Jakulin commercial company LC)
Hiroya YAMAGUCHI (CfA/Harvard Univ.)

Visiting Researchers (JSPS)
Teruaki ENOTO (Stanford Univ.)
Wataru IWAKIRI (Saitama Univ.)

Part-time Workers
Shigeru ENDO
Megu KUBOTA
Rie YOSHII

Student Trainees
Takanori IWAHASHI (Tokyo Univ. of Science)
Saori KONAMI (Tokyo Univ. of Science)
Wataru IWAKIRI (Saitama Univ.)
Fumi ASAMI (Tokyo Univ. of Science)
Kenta KANEKO (Kogakuin Univ.)
Kenichi IWATA (Shibaura Institute of Technology)
Megu KUBOTA
Yoko TAKEUCHI (Tokyo Univ. of Science)
Rie YOSHII (Tokyo Univ. of Science)
Akifumi YOSHIKAWA (Tokyo Univ. of Science)

Assistant
Yu NAYA

RIBF Research Division
Astro-Glaciology Research Unit

Our Astro-Glaciology Research Unit, organized in July 2011, promotes both theoretical and experimental studies to open up a new interdisciplinary research field between astrophysics and glaciology. On the theoretical side, we numerically simulate:

(1) Changes in the chemical composition of the stratosphere induced by high-energy photons and/or particles emitted from explosive astronomical phenomena, such as solar proton events and galactic supernovae, and

(2) The explosive nucleosynthesis, including the rapid neutron capture process (the r-process) for the creation of the elements heavier than iron, arising in the environment of core-collapse supernova explosions.

Subjects (1) and (2) themselves are very important in solar–terrestrial research and nuclear astrophysics, respectively; furthermore, the items (1) and (2) are intended to be coupled with experimental studies described below.

On the experimental side, we analyze the ice cores drilled at the Dome Fuji station in Antarctica in collaboration with the National Institute of Polar Research, Tokyo. These ice cores correspond to time capsules of the past. In particular, the ice cores obtained at Dome Fuji are known to be unique because they contain much more information on conditions in the stratosphere than any other ice cores recovered from other locations in either hemisphere. This means that the Dome Fuji ice cores may have an original advantage to study astronomical phenomena of the past, since γ-rays and high-energy protons emitted from astronomical events affect the chemical and isotopic compositions in the stratosphere and not those in the troposphere. Accordingly, we measure:

(3) Variations in the nitrate ion (NO_3^-) concentrations in the ice cores, in order to seek the proxy of past solar activity and the footprints of supernovae in our galaxy,

(4) Variations in the water isotopes (^{18}O and ^{2}H) in the ice cores, in order to reconstruct past temperature changes on the earth, and

(5) Variations in the nitrate isotope (^{15}N) in the ice cores, in order to investigate the possibility of this isotope becoming a new and a more stable proxy for solar activity and/or galactic supernovae.

Items (3), (4), and (5) have been analyzed with Dome Fuji ice cores with a temporal resolution of about 1 year. By comparing the results for items (3) and (4), we aim to understand the correlation between solar activity and climate changes in the past on the millennium scale. The basis for item (4) is already established in glaciology. Item (5) will be the one of very first measurements taken in ice cores. The theoretical studies related to items (1) and (2) will provide a background for distinguishing the characteristics of the astronomical events from meteorological noise that usually appears in the ice core data. Finally, we note that the supernova rate in our galaxy is crucial to understand the r-process nucleosynthesis but yet remains unknown. Our item (3) is also intended to diagnose the galactic supernova rate ultimately.

Head

Yuko MOTIZUKI (Research Unit Leader)

Members

Kazuya TAKAHASHI (Concurrent: Senior Research Scientist)
Yoichi NAKAI (Concurrent: Senior Research Scientist)

Contract Researcher

Kentaro SEKIGUCHI (- Mar. 31, 2013)

Postdoctoral Researcher

Sachiko OKAMOTO (- Mar. 31, 2014)

Visiting Scientists

Hideharu AKIYOSHI (National Institute for Environmental Studies)
Bradley MEYER (Clemson Univ., USA) - Mar. 31, 2013
Sachiko AMARI (Washington Univ.,USA) - Mar. 31, 2013
Akira HORI (Kitami Institute of Technology)
Hiroyuki KOURA (Japan Atomic Energy Agency) - Mar. 31, 2013
Hideki MADOKORO (Mitsubishi Heavy Industries, Ltd.)
Takahiro TACHIBANA (Waseda High Sch., Waseda Univ.) - Mar. 31, 2013
Kohji TAKAHASHI (Universite Libre de Bruxelles) - Mar. 31, 2013

Junior Research Associate

Satomi KIKUCHI (Saimata University) - Mar. 31, 2013

Student Trainees

Daiti SUZUKI - Mar. 31, 2013

Part-time Workers

Keiko FUKUSHIMA
Manami MARUYAMA
Yuri OBI

Ai TANEICHI

Assistants

Yoko FUJITA
Yuri TSUBURAI

RIBF Research Division
Research Group for Superheavy Element

1. Abstract

The elements with their atomic number Z>103 are called as trans-actinide or superheavy elements. The chemical properties of those elements have not yet been studied in detail. Those elements do not exist in nature. Therefore, they must be produced by artificially for the scientific study of those elements. In our laboratory, we have been studying the physical and chemical properties of the superheavy elements utilizing the accelerators in RIKEN and various methods of efficient production of the superheavy elements.

2. Major Research Subjects

(1) Search for new superheavy elements
(2) Decay spectroscopy of the heaviest nuclei
(3) Study of the chemical properties of the heaviest elements
(4) Study of the reaction mechanism of the fusion process (theory)

3. Summary of Research Activity

(1) Searching for new elements

To expand the periodic table of elements and the nuclear chart, we will search for new elements.

(2) Spectroscopic study of the nucleus of heavy elements

Using the high sensitivity system for detecting the heaviest element, we plan to perform a spectroscopic study of nuclei of the heavy elements.

(3) Chemistry of superheavy elements

Study of chemistry of the trans-actinide (superheavy element) has just started world-wide, making it a new frontier in the field of chemistry. Relativistic effects in chemical property are predicted by many theoretical studies. We will try to develop this new field.

(4) Study of a reaction mechanism for fusion process

Superheavy elements have been produced by complete fusion reaction of two heavy nuclei. However, the reaction mechanism of the fusion process is still not well understood theoretically. When we design an experiment to synthesize nuclei of the superheavy elements, we need to determine a beam-target combination and the most appropriate reaction energy. This is when the theory becomes important. We will try to develop a reaction theory useful in designing an experiment by collaborating with the theorists.

(5) Research Highlight

The discovery of a new element is one of the exciting topics both for nuclear physicists and nuclear chemists. The elements with their atomic number Z>103 are called as trans-actinides or superheavy elements. The chemical properties of those elements have not yet been studied in detail. Since those elements do not exist in nature, they must be produced by artificially, by using nuclear reactions for the study of those elements. Because the production rate of atoms of those elements is extremely small, an efficient production and collection are key issues of the superheavy research. In our laboratory, we have been trying to produce new elements, studying the physical and chemical properties of the superheavy elements utilizing the accelerators in RIKEN.

Although the Research Group for Superheavy element has started at April 2013, the Group is a renewal of the Superheay Element Laboratory started at April 2006, based on a research group which belonged to the RIKEN accelerator research facility (RARF), and had studied the productions of the heaviest elements. The main experimental apparatus is a gas-filled recoil ion separator GARIS. The heaviest elements with their atomic numbers, 107 (Bohrium), 108 (Hassium), 109 (Meitnerium), 110 (Darmstadtium), 111 (Roentogenium), and 112 (not yet named) were discovered as new elements at Helmholtzzentrum für Schwerionenforschung GmbH (GSI), Germany by using ^{208}Pb or ^{209}Bi based complete fusion reactions, so called "cold fusion" reactions. We have made independent confirmations of the productions of isotopes of 108th, 110th, 111th, and 112th elements by using the same reactions performed at GSI. After these work, we observed an isotope of the 113th element, ^{278}113, in July 2004, in April, 2005, and in August 2012. The isotope, ^{278}113, has both the largest atomic number, (Z = 113) and atomic mass number (A = 278) which have determined experimentally among the isotopes which have been produced by cold fusion reactions. We could show the world highest sensitivity for production and detection of the superheavy elements by these observations.

We decided to make one more recoil separator GARIS-II, which has an acceptance twice as large as existing GARIS, in order to realize higher sensitivity. The design of GARIS-II has finished in 2008. All fabrication of the separator will be finished at the end of fiscal year 2008. It will be ready for operation in fiscal year 2009 after some commissioning works.

Preparatory work for the study of the chemical properties of the superheavy elements has started by using the gas-jet transport system coupled to GARIS. The experiment was quite successful. The background radioactivity of unwanted reaction products has been highly suppressed. Without using the recoil separator upstream the gas-jet transport system, large amount of unwanted radioactivity strongly prevents the unique identification of the event of our interest. This new technique makes clean and clear studies of chemistry of the heaviest elements promising.

The spectroscopic study of the heaviest elements has started by using alpha spectrometry. New isotope, ^{263}Hs (Z=108), which has the smallest atomic mass number ever observed among the Hassium isotopes, had discovered in the study. New spectroscopic information for ^{264}Hs and its daughters have obtained also. The spectroscopic study of Rutherfordium isotope ^{261}Rf (Z=104) has done and 1.9-s isomeric state has directly produced for the first time.

Preparatory works for the study of the new superheavy elements with atomic number 119 and 120 have started in 2013. We measured the reaction products of the ^{248}Cm(^{48}Ca, xn)$^{296\text{-}x}$Lv(Z=116) previously studied by Frelov Laboratory of Nuclear Reaction, Russia, and GSI.

We observed 5 isotopes in total which tentatively assigned to ^{293}Lv, and ^{292}Lv.

Head
Kosuke MORITA (Group Director)

Visiting Scientist
Kunihiro FUJITA (Kyushu University) Nov. 1, 2013-

Student Trainees
Yoshihiro NARIKIYO
Taiki TANAKA - Mar 31, 2014
Shoya YAMAMOTO - Mar 31, 2014

Assistant
Yu NAYA

RIBF Research Division
Research Group for Superheavy Element
Superheavy Element Production Team

For this year, see the section of Research Group for Superheavy Element.

Head
Kosuke MORITA (Group Director)

Member
Kouji MORIMOTO (concurrent)

Nishina Center Research Scientist
Daiya KAJI (concurrent)

Nishina Center Technical Scientist
Akira YONEDA

Special Postdoctoral Researcher
Yasuo WAKABAYASHI

Visiting Scientist
Hiroyuki KOURA (JAEA)

Research Consultant
Kenji KATORI (- Mar. 31, 2014)

Part-time Worker
Kengo TANAKA

Students
Junior Research Associate
Mirei TAKEYAMA

Student Trainees
Yukiko KOMORI (Osaka Univ.) - Mar 31 ,2014
Takuya YOKOKITA (Osaka Univ.) - Mar 31 ,2014
Kengo TANAKA (concurrent)

RIBF Research Division
Research Group for Superheavy Element
Superheavy Element Device Development Team

1. Abstract

A gas-filled recoil ion separator has been used as a main experimental device for the study of superheavy elements. This team is in charge of maintain, improve, develop and operate the separators and rerated devices. There are two gas-filled recoil ion separators installed at RILAC experimental hall. One is GARIS that is designed for symmetric reaction such as cold-fusion reaction, and the other is newly developed GARIS-II that is designed for asymmetric reaction such as hot-fusion reaction. New element $^{278}113$ were produced by ^{70}Zn + ^{209}Bi reaction using GARIS. Further the new element search Z > 118 are preparing by using GARIS-II.

2. Major Research Subjects

(1) Maintenance of GARIS and development of new gas-filled recoil ion separator GARIS-II.
(2) Maintenance and development of detector and DAQ system for GARIS and GARIS-II.
(3) Maintenance and development of target system for GARIS and GARIS-II.

3. Summary of Research Activity

The GARIS-II is newly developed which has an acceptance twice as large as existing GARIS, in order to realize higher sensitivity. It will be ready for operation in fiscal year 2014 after some commissioning works. We will also offer user-support if a researcher wishes to use the devices for his/her own research program.

Head
Kouji MORIMOTO (Team Leader)

Nishina Center Research Scientist
Daiya KAJI

Nishina Center Technical Scientist
Akira YONEDA (concurrent)

Visiting Scientist
Fuyuki TOKANAI (Yamagata University)

Part-time Worker
Sayaka YAMAKI (- Mar. 31, 2014)

Student Trainee
Sayaka YAMAKI (concurrent)

RIBF Research Division
Accelerator Group

1. Abstract

The accelerator group, consisting of seven teams, pursues various upgrade programs of the world-leading heavy-ion accelerator facility, RI-Beam Factory (RIBF), to enhance the accelerator performance and operation efficiency. The programs include the R&D of superconducting ECR ion source, charge stripping systems, beam diagnostic devices, radiofrequency systems, control systems, and beam simulation studies. We are also maintaining the large infrastructure to realize effective operation of the RIBF, and are actively promoting the applications of the facility to a variety of research fields.

Our primary mission is to supply intense, stable heavy-ion beams for the users through effective operation, maintenance, and upgrade of the RIBF accelerators and related infrastructure. The director members shown below govern the development programs that are not dealt with by a single group, such as intensity upgrade and effective operation. We also promote the future plans of the RIBF accelerators along with other laboratories belonging to the RIBF research division.

2. Major Research Subjects

(1) Intensity upgrade of RIBF accelerators (Okuno)
(2) Effective and stable operation of RIBF accelerators (Fukunishi)
(3) Operation and maintenance of infrastructures for RIBF (Kase)
(4) Promotion of the future projects (Kamigaito, Fukunishi, Okuno)

3. Summary of Activity

(1) The stripping schemes for Xe and U beams have been renewed.
(2) The intensity of the xenon beam reached 38 pnA.
(3) The beam availability exceeded 90 %.
(4) The large infrastructure was properly maintained based on a well-organized cooperation among the related sections.
(5) A new upgrade plan was proposed for further enhancement of the beam intensity. Basic study is in progress.

Group Director
Osamu KAMIGAITO (Chief Scientist)

Deputy Group Directors
Hiroki OKUNO (Intensity upgrade)
Nobuhisa FUKUNISHI (Stable and efficient operation)
Masayuki KASE (Energy-efficiency management)

International Program Associate
Vasileios TZOGANIS (University of Liverpool)

Visiting Scientists
Akira GOTO (Yamagata University)
Toshiyuki HATTORI (Tokyo Institute of Technology)

Assistant
Karen SAKUMA

RIBF Research Division
Accelerator Group
Accelerator R&D Team

1. Abstract

We are developing the key hardware in upgrading the RIBF accelerator complex. Our primary focus and research is charge stripper which plays an essential role in the RIBF accelerator complex. Charge strippers remove many electrons in ions and realize efficient acceleration of heavy ions by greatly enhancing charge state. The intensity of uranium beams is limited by the lifetime of the carbon foil stripper conventionally installed in the acceleration chain. The improvement of stripper lifetimes is essential to increase beam power towards the final goal of RIBF in the future. We are developing the low-Z gas stripper. In general gas stripper is free from the lifetime related problems but gives low equilibrium charge state because of the lack of density effect. Low-Z gas stripper, however, can give as high equilibrium charge state as that in carbon foil because of the suppression of the electron capture process. Another our focus is the upgrade of the world's first superconducting ring cyclotron.

2. Major Research Subjects

(1) Development of charge strippers for high power beams (foil, low-Z gas)
(2) Upgrade of the superconducting ring cyclotron
(3) Maintenance and R&D of the electrostatic deflection/inflection channels for the beam extraction/injection

3. Summary of Research Activity

(1) Development of charge strippers for high power beams (foil, low-Z gas)

(Hasebe, H., Imao, H. Okuno., H.)

We are developing the charge strippers for high intensity heavy ion beams. We are focusing on the developments on carbon or berrilium foils and gas strippers including He gas stripper.

(2) Upgrade of the superconducting ring cyclotron

(Ohnishi, J., Okuno, H.)

We are focusing on the upgrade of the superconducting ring cyclotron.

(3) Maintenance and R&D of the electrostatic deflection/inflection channels for the beam extraction/injection

(Ohnishi, J., Okuno, H.)

We are developing high-performance electrostatic channels for high power beam injection and extraction.

Team Leader

Hiroki OKUNO (Deputy Group Director)

Members

Jun-ichi OHNISHI (Senior Technical Scientist)
Hiroshi IMAO (Research Scientist)

Nishina center Technical Scientist

Hiroo HASEBE

Special Postdoctoral Researcher

Hironori KUBOKI (- Mar. 31, 2014)

Visiting Scientists

Noriyosu HAYASHIZAKI (Tokyo Institute of Technology)
Mitsuhiro FUKUDA (RCNP, Osaka Univ.) - Mar. 31, 2013
Andreas ADELMANN (PSI, Switzerland)

Research Consultants

Yoshiaki CHIBA - Mar. 31, 2013
Isao YAMANE - Mar. 31, 2013

RIBF Research Division
Accelerator Group
Ion Source Team

1. Abstract

Our aim is to operate and develop the ECR ion sources for the accelerator-complex system of the RI Beam Factory. We focus on further upgrading the performance of the RI Beam Factory through the design and fabrication of a superconducting ECR heavy-ion source for production of high-intensity uranium ions.

2. Major Research Subjects

(1) Operation and development of the ECR ion sources
(2) Development of a superconducting ECR heavy-ion source for production of high-intensity uranium ions

3. Summary of Research Activity

(1) Operation and development of ECR ion sources

(T. Nakagawa, M. Kidera, Y. Higurashi, K. Ozeki, T. Nagatomo, H. Haba, and T. Kageyama)

We routinely produce and supply various kinds of heavy ions such as zinc and calcium ions for the super-heavy element search experiment as well as uranium ions for RIBF experiments. We also perform R&D's to meet the requirements for stable supply of high-intensity heavy ion beams.

(2) Development of a superconducting ECR ion source for use in production of a high-intensity uranium beam

(T. Nakagawa, J. Ohnishi, M. Kidera, Y. Higurashi, K. Ozeki and T. Nagatomo)

The RIBF is required to supply uranium beams with very high intensity so as to produce RI's. We have designed and are fabricating an ECR ion source with high magnetic field and high microwave- frequency, since the existing ECR ion sources have their limits in beam intensity. The coils of this ion source are designed to be superconducting for the production of high magnetic field. We are also designing the low-energy beam transport line of the superconducting ECR ion source.

Team Leader
Takahide NAKAGAWA

Member
Takeshi NAGATOMO (Technical Scientist)

Nishina Center Research Scientists
Masanori KIDERA
Yoshihide HIGURASHI

Contract Researcher
Kazutaka OHZEKI

Postdoctral Researcher
Tatsuya URABE (- Mar. 31, 2014)

Temporary Employee
Tadashi KAGEYAMA (- Mar. 31, 2014)

Part-time Worker
Yumi KURAMITSU

RIBF Research Division
Accelerator Group
RILAC Team

1. Abstract

The operation and maintenance of the RIKEN Heavy-ion Linac (RILAC) have been carried out. There are two operation modes: one is the stand-alone mode operation and the other is the injection mode operation. The RILAC has been used especially as an injector for the RIKEN RI- Beam Factory accelerator complex. The RILAC is composed of the ECR ion source, the frequency-variable RFQ linac, six frequency-variable main linac cavities, and six energy booster cavities (CSM).

2. Major Research Subjects

(1) The long term high stability of the RILAC operation.
(2) Improvement of high efficiency of the RILAC operation.

3. Summary of Research Activity

The RILAC was started to supply ion beams for experiments in 1981. Thousands hours are spent in a year for delivering many kinds of heavy-ion beams to various experiments.

The RILAC has two operation modes: one is the stand-alone mode operation delivering low-energy beams directly to experiments and the other is the injection mode operation injecting beams into the RRC. In the first mode, the RILAC supplies a very important beam to the nuclear physics experiment of “the research of super heavy elements”. In the second mode, the RILAC plays a very important role as upstream end of the RIBF accelerator complex.

The maintenance of these devices is extremely important in order to keep the log-term high stability and high efficiency of the RILAC beams. Therefore, improvements are always carried out for the purpose of more stable and more efficient operation.

Team Leader
Eiji IKEZAWA

Member
Yutaka WATANABE (Senior Technical Scientist)

Research Consultants
Toshiya CHIBA (- Mar. 31, 2014)
Masatake HEMMI (- Mar. 31, 2014)

RIBF Research Division
Accelerator Group
Cyclotron Team

1. Abstract
Together with other teams of Nishina Center accelerator division, maintaining and improving the RIBF cyclotron complex. The accelerator provides high intensity heavy ions. Our mission is to have stable operation of cyclotrons for high power beam operation. Recently, stabilization of the rf system is a key issue to provide 10 kW heavy ion beam.

2. Major Research Subjects
(1) RF technology for Cyclotrons
(2) Operation of RIBF cyclotron complex
(3) Maintenance and improvement of RIBF cyclotrons
(4) Single turn operation for polarized deuteron beams
(5) Development of superconducting cavity for the rebuncher system

3. Summary of Research Activity
Development of the rf system for a reliable operation
Development of highly stabilized low level rf system
Development of superconducting rebuncher cavity
Development of the intermediate-energy polarized deuteron beams.

Team Leader
Naruhiko SAKAMOTO

Nishina Center Research Scientist
Kenji SUDA

Foreign Postdoctoral Researcher
Liang LU (-July 31, 2013)

Research Consultant
Yoshiaki CHIBA (-Mar.31, 2014)

RIBF Research Division
Accelerator Group
Beam Dynamics and Diagnostics Team

1. Abstract

The cascaded cyclotrons used in RIKEN RI Beam Factory (RIBF) requires not only severe matching of the beam but also high stability of all the accelerator components in order to establish stable operation of the world's most intense heavy-ion beams. Beam Dynamics and Diagnostics Team is responsible for power supplies, beam instrumentation, computer control and beam dynamic studies of the RIBF accelerator complex and strongly contributes to the performance upgrade of the RIBF.

2. Major Research Subjects

(1) Seeking the best operation method of the RIBF accelerator complex based on the beam dynamics study.
(2) Maintenance and development of the beam instrumentation, especially non-destructive monitors.
(3) Upgrade of the computer control system of the RIBF accelerator complex.
(4) Maintenance and improvements of the magnets and power supplies.

3. Summary of Research Activity

(1) The world-first beam current monitor with a high-Tc current sensor and SQUID has been developed.
(2) The bending power of the fixed-frequency Ring Cyclotron has been upgraded to 700 MeV. It enables us to accelerate $^{238}U^{64+}$ ions obtained by the helium gas stripper and contributes to stable and high-intensity operation of RIBF.
(3) An EPICS-based control system and a homemade beam interlock system have been stably working. Replacement of the existing legacy control system used in the old half of our facility is ongoing. Construction of the new control system for the new injector RILAC2 was successfully completed, where the embedded EPICS system running on F3RP61-2L CPU module, developed by KEK and RIKEN control group, was used.
(4) We replaced some dated power supplies of RIKEN Ring Cyclotron by new ones, which have better long-term stability than the old ones. The other existing power supplies (~900) are stably operated owing to elaborate maintenance work.
(5) We have contributed to RILAC2 construction, especially in its beam diagnosis, control system, magnet power supplies, vacuum system, high-energy beam transport system etc.

Team Leader
Nobuhisa FUKUNISHI (Deputy Group Director)

Members
Masaki FUJIMAKI (Senior Technical Scientist)
Keiko KUMAGAI (Senior Technical Scientist)
Tamaki WATANABE (Senior Technical Scientist)
Kazunari YAMADA (Senior Technical Scientist)

Nishina Center Technical Scientists
Misaki KOBAYASHI-KOMIYAMA
Akito UCHIYAMA

Postdoctral Researcher
Takuya MAEYAMA

Temporary Employee
Makoto NAGASE (- Mar. 31, 2014)

Visiting Scientists
Hiromichi RYUTO (Photonics and Electronics Science and Engineering Center, Kyoto University)
Jun-ichi ODAGIRI (Accelerator Laboratory, High Energy Accelerator Research Organization (KEK))
Shin-ichiro HAYASHI (Faculty of Health Science, Hiroshima International University) - Mar. 31, 2014

RIBF Research Division
Accelerator Group
Cryogenic Technology Team

1. Abstract

We are operating the cryogenic system for the superconducting ring cyclotron in RIBF. We are operating the helium cryogenic system in the south area of RIKEN Wako campus and delivering the liquid helium to users in RIKEN. We are trying to collect efficiently gas helium after usage of liquid helium.

2. Major Research Subjects

(1) Operation of the cryogenic system for the superconducting ring cyclotron in RIBF
(2) Operation of the helium cryogenic plant in the south area of Wako campus and delivering the liquid helium to users in Wako campus.

3. Summary of Research Activity

(1) Operation of the cryogenic system for the superconducting ring cyclotron in RIBF
(Okuno, H., Dantsuka, T., Nakamura, M., Maie, T.,)
(2) Operation of the helium cryogenic plant in the south area of Wako campus and delivering the liquid helium to users in Wako campus.
(Dantsuka, T., Tsuruma, S., Okuno, H.).

Team Leader
Hiroki OKUNO (Deputy Group Director)

Member
Masato NAKAMURA (Senior Technical Scientist)

Nishina Center Technical Scientist
Takeshi MAIE

Technical Staff-I
Tomoyuki DANTSUKA

Temporary Employee
Kumio IKEGAMI (- Mar. 31, 2014)

Part time Worker
Shizuho TSURUMA

RIBF Research Division
Accelerator Group
Infrastructure Management Team

1. Abstract

The RIBF facility is consisting of many accelerators and its infrastructure is very important in order to make an efficient operation of RIBF project. We are maintaining the infrastructure of the whole system and to support the accelerator operation with high performance. We are also concerning the contracts of gas- and electricity-supply companies according to the annual operation plan. The contracts should be reasonable and also flexible against a possible change of operations. And we are searching the sources of inefficiency in the operation and trying to solve them for the high-stable machine operation.

2. Major Research Subjects

(1) Operation and maintenance of infrastructure for RIBF accelerators.
(2) Renewal of the old equipment for the efficient operation.
(3) Support of accelerator operations.

Team Leader
Masayuki KASE (Deputy Group Director)

Members
Shu WATANABE (Senior Technical Scientist)
Hiromi YAMASAWA (Manager)

Research Consultant
Shin-ichi WATANABE (- Mar. 31, 2014)

Temporary Employee
Tadashi FUJINAWA (-Mar. 31, 2014)

Visiting Scientist
Hideshi MUTO (Tokyo Univ. of Sci. Suwa)

RIBF Research Division
Instrumentations Development Group

1. Abstract

This group develops core experimental installations at the RI Beam factory. Experimental installations currently under construction include designs containing common elements enabling multiple use (SLOWRI), as well as others that are highly program specific (SCRIT and Rare-RI Ring). All are designed to maximize the research potential of the world's most intense RI beams, made possible by the exclusive equipment available at the RI Beam Factory. Beam manipulation techniques, such as a beam accumulation and a beam cooling etc., will be able to provide opportunities of new experimental challenges and the foundation for future developments of RIBF.

2. Major Research Subjects

(1) SCRIT Project
(2) SLOWRI Project
(3) Rear RI Ring Project

3. Summary of Research Activity

We are developing beam manipulation technology in carrying out above listed project. They are the high-quality slow RI beam production (SCRIT and SLOWRI), the beam cooling and stopping (SCRIT and SLOWRI), and the beam accumulation technology (Rare RI Ring). The technological knowhow accumulated in our projects will play a significant role in the next generation RIBF. Future Plan for each project is described in subsections. SCRIT is now partially under construction and the system has been already tested using stable isotopes. ISOL system for SCRIT experiment (ERIS) is now under development. Rare RI Ring construction has been started in 2012 and we succeeded in the first beam circulation using alpha particle in this year. There are many things we have to do to make it ready for starting mass measurement, but it is now ready for operation. SLOWRI is now under construction.

Group Director
Masanori WAKASUGI

Senior Visiting Scientist
Akira OZAWA

Student Trainees
Saki MATSUO
Yohei SUMI
Mamoru TOGASAKI

Assistants
Yoshiko SAKATA
Noriko KIYAMA

RIBF Research Division
Instrumentations Development Group
SLOWRI Team

1. Abstract

Construction of a next-generation stopped and low-energy radioactive ion beam facility (SLOWRI) which will provide low-energy, high-purity and small emittance ion beams of all elements has been started in FY2013 as one of the principal facilities at the RIKEN RI-beam factory (RIBF). High-energy radioactive ion beams from the projectile fragment separator BigRIPS are thermalized in a large He gas catcher cell (RFC cell) or in a small Ar gas catcher cell (PALIS cell). In the RFC cell, thermalized ions in buffer gas are guided and extracted to a vacuum environment by a combination of dc electric fields and inhomogeneous rf fields (rf carpet ion guide). The PALIS cell will be placed in the vicinity of the second focal plane slits of BigRIPS and can be used continuously during other experiments. From these gas cells, the low-energy ion beams will be delivered via mass separators and switchyards to various devices: such as an ion trap, a collinear fast beam apparatus, and a multi-reflection time of flight mass spectrograph. In the R&D works at the present ring cyclotron facility, an extraction efficiency of 33% for a 100A MeV ^{8}Li ion beam from the projectile fragment separator RIPS was achieved and the dependence of the efficiency on the ion beam intensity was investigated.

First spectroscopy experiment at the prototype SLOWI was performed on Be isotopes. Energetic ions of ^{7,10,11}Be from the RIPS were trapped and laser cooled in a linear rf trap and precision spectroscopy was performed. The evaluated ion temperature of <10 mK demonstrates that a reduction of more than 15 orders of magnitude for the kinetic energy of radioactive Be was achieved online. The ground state hyperfine constants of all Be isotopes have been measured precisely by laser and microwave. These precision measurements will be used to confirm the anomalous mean radius of the valence neutron of the so called neutron halo nucleus. Other laser spectroscopy experiments using the slow RI-beams are also under progress in off-line setups. A collinear fast beam apparatus for nuclear charge-radii measurements was build and tested with stable Ar^{+} ion beams.

A multi-reflection time-of-flight mass spectrograph (MRTOF) has been developed and tested online for radioactive lithium isotope, ^{8}Li. A high mass resolving power of 170,000 has been obtained for an isobaric doublet of ^{40}K and ^{40}Ca with a very short flight time of 2 ms. This performance allowed accurate mass determination of $<10^{-7}$ accuracy by a single isobaric reference. Two mass measurement projects using MRTOF mass spectrographs have been started: one is for trans uranium elements at the GARIS facility and the other is for r-process nuclides at SLOWRI facility.

Resonance ionization spectroscopy has been tested during the offline development of PALIS gas cell. Stable isotopes of Co, Cu, Fe, Ni, Ti, Nb, Sn, In, and Pd were resonantly ionized by excimer pumped dye lasers or Nd:YAG laser pumped Ti:Sapphire lasers with the prototype gas cell setup. The resonance spectra are in many cases sufficient to resolve the hyperfine structures. Nuclear spins and magnetic moments will be determined for various isotopes obtained during other experiments.

2. Major Research Subjects

(1) Construction of stopped and low-energy RI-beam facility, SLOWRI.
(2) Laser spectroscopy of trapped radioactive Beryllium isotopes.
(3) Development of a multi-reflection time-of-flight mass spectrograph for precision mass measurements of short-lived nuclei.
(4) Development of parasitic slow RI-beam production method using resonance laser ionization.
(5) Development of ion-surfing gas cell.

3. Summary of Research Activity

(1) Construction of stopped and low-energy RI-beam facility (SLOWRI)

(WADA, Michiharu, SONODA, Tetsu, KATAYAMA, Ichiro, SCHURY, Peter, ITO, Yuta, ARAI, Fumiya, ARAI, Shigeaki, KUBO, Toshiyuki, KUSAKA, Kensuke, FUJINAWA Tadashi, MAIE Takeshi, YAMASAWA Hideyuki, WOLLNIK, Hermann,)

Installation of SLOWRI has been started in FY2013. It consists of two gas catchers (RF Carpet gas cell and PALIS gas cell), mass separators a 50-m beam transport line, a beam cooler-buncher, an isobar separator, and a laser system. The RFCarpet gas cell will be installed at the exit of the D5 dipole magnet of BigRIPS. The gas catcher contains a large cryogenic He gas cell with a large traveling wave rf-carpet. It will convert main beams of BigRIPS to low-energy, low-emittance beams without any restrictions on the chemical properties of the elements. The PALIS gas cell will be installed in the vicinity of the second focal plane slit of BigRIPS. It will provide parasitic RI-beams from those ions lost in the slits during other experiments. In this gas catcher, thermalized RI ions quickly become neutral and will be re-ionized by resonant laser radiations. These gas catchers will be tested off-line in FY2014. The 50 m beam transport line consists of four dipole magnets (SD1 to SD4), two focal plane chambers, 62 electrostatic quadrupole singlets, 11 electrostatic quadrupole quartets (EQQ1 to EQQ11) and 7 beam profile monitors (BPM). SD1 and SD2, located right after the gas catchers will be used for isotope separation. After eliminating contaminant ions at the focal plane chamber, the low energy beam will be transported by FODO lattice structure with phase space matching using EQQs. The EQQs have multipole elements made of 16 rods on which various potentials can be applied to produce 6-pole and 8 pole fields, simultaneously, for compensation of ion optical aberrations. This multipole element can also produce dipole fields for steering and scanning the beam. The BPM have a classical cross-wire beam monitor as well as a channel electron multiplier with a pinhole collimator. Combining the scanning capability of the EQQs and the pinhole detector, we can observe a beam profile even for a very low-intensity RI-beams. Off- and on-line commissioning will take place in FY2014 and the low-energy RI-beams will be provided for users in FY2015.

(2) Laser spectroscopy of trapped radioactive beryllium isotope ions

(WADA, Michiharu, TAKAMINE, Aiko, SCHURY Peter, SONODA Tetsu, OKADA, Kunihiro, KANAI, Yasuyuki, YOSHIDA, Atsushi, KUBO, Toshiyuki, WOLLNIK, Hermann, SCHUESSLER, Hans, Shunsuke, KATAYAMA Ichiro)

As a first application of the prototype SLOWRI setup, we applied hyperfine structure spectroscopy to the beryllium isotopes to determine in particular the anomalous radius of the valence neutron of the neutron halo nucleus ^{11}Be, and to determine the charge radii of these beryllium isotopes through laser-laser double resonance spectroscopy of laser-cooled ions. Laser cooling is an essential prerequisite for these planned experiments. The first laser spectroscopy experiments for beryllium isotopes were performed to measure the resonance frequencies of 2s $^2S_{1/2}$ - 2p $^2P_{3/2}$ transition of ^{7}Be+, ^{9}Be+, ^{10}Be$^+$ and ^{10}Be+ ions and the nuclear charge radii of these isotopes were determined. The hyperfine structures of ^{11}Be$^+$ and ^{7}Be$^+$ ions using the laser-microwave double resonance spectroscopy were also performed and the magnetic hyperfine constants of ^{7}Be$^+$ and ^{11}Be$^+$ ions were determined with accuracies of better than10^{-7}.

(3) Development of a multi-reflection TOF mass spectrograph for short-lived nuclei

(WADA, Michiharu, SCHURY Peter, ITO, Yuta, ARAI Fumiya, SONODA Tetsu, WOLLNIK, Hermann, MORIMOTO, Koji, KAJI, Daiya, HABA, Hiromitsu, KOURA, Hiroyuki)

The atomic mass is one of the most important quantities of a nucleus and has been studied in various methods since the early days of physics. Among many methods we chose a multi-reflection time-of-flight (MR-TOF) mass spectrometer. Slow RI beams extracted from the RF ion-guide are bunch injected into the spectrometer with a repetition rate of ~100 Hz. The spectrometer consists of two electrostatic mirrors between which the ions travel back and forth repeatedly. These mirrors are designed such that energy-isochrononicity in the flight time is guaranteed during the multiple reflections while the flight time varies with the masses of ions. A mass-resolving power of 170,000 has been obtained with a 2 ms flight time for 40K and 40Ca isobaric doublet. This mass-resolving power should allow us to determine ion masses with an accuracy of 10^{-7}. An online mass measurement for radioactive lithium isotope has been carried out at the prototype SLOWRI setup.

The MR-TOF mass spectrograph has been placed under the GARIS-II separator aiming at direct mass measurements of trans-uranium elements. A small cryogenic gas catcher cell will be placed at the focal plane box of GARIS-II and a bunched low-energy heavy ion beam can be transported to the trap of MR-TOF. An online commissioning experiment is planned in FY2014.

(4) Development of collinear fast beam apparatus for nuclear charge radii measurements

(WADA, Michiharu, SCHUESSLER, Hans, IIMURA, Hideki, SONODA, Tetsu, SCHURY, Peter, TAKAMINE, Aiko, OKADA, Kunihiro, WOLLNIK, Hermann)

The root-mean-square charge radii of unstable nuclei have been determined exclusively by isotope shift measurements of the optical transitions of singly-charged ions or neutral atoms by laser spectroscopy. Many isotopes of alkaline, alkaline-earth, noble-gases and several other elements have been measured by collinear laser spectroscopy since these ions have all good optical transitions and are available at conventional ISOL facilities. However, isotopes of other elements especially refractory and short-lived ones have not been investigated so far.

In SLOWRI, isotopes of all atomic elements will be provided as well collimated mono-energetic beams. This should expand the range of applicable nuclides of laser spectroscopy. In the first years of the RIBF project, Ni and its vicinities, such as Ni, Co, Fe, Cr, Cu, Ga, Ge are planned to be investigated. They all have possible optical transitions in the ground states of neutral atoms with presently available laser systems. Some of them have so called recycle transitions which enhance the detection probabilities noticeably. Also the multistep resonance ionization (RIS) method can be applied to the isotopes of Ni as well as those of some other elements. The required minimum intensity for this method can be as low as 10 atoms per second.

We have built an off-line mass separator and a collinear fast beam apparatus with a large solid-angle fluorescence detector. A 617 nm transition of the metastable Ar+ ion at 20 keV was measured with both collinear and anti-collinear geometry that allowed us to determine the absolute resonant frequency of the transition at rest with more than 10^{-8} accuracy. Such high accuracy measurements for Ti and Ni isotopes are in progress.

(5) Development of parasitic slow RI-beam production scheme using resonance laser ionization

(SONODA Tetsu, IIMURA Hideki, WADA Michiharu, KATAYAMA Ichiou, ADACHI Yoshitaka, NOTO Takuma, TAKATSUKA Takaaki, TOMITA Hideki, WENDT Klaus, ARAI Fumiya, ITOU Yuta, SCHURY Peter, FUKUDA Naoki, INABE Naohito, KUBO Toshiyuki, KUSAKA Kensuke, TAKEDA Hiroyuki, SUZUKI H., WAKASUGI Masanori, YOSHIDA Koichi)

More than 99.9% of RI ions produced in projectile fission or fragmentation are simply dumped in the first dipole magnet and the slits. A new scheme, named PALIS, to rescue such dumped precious RI using a compact gas catcher cell and resonance laser ionization was proposed as a part of SLOWRI. The thermalized RI ions in a cell filled with Ar gas can be quickly neutralized and transported to the exit of the cell by gas flow. Irradiation of resonance lasers at the exit ionizes neutral RI atoms efficiently and selectively. The ionized RI ions can be further selected by a magnetic mass separator and transported to SLOWRI experimental area for various experiment. The resonance ionization scheme itself can also be a useful method to perform hyperfine structure spectroscopy of RI of many elements.

A prototype setup has been tested for resonance ionization scheme of several elements, extraction from the cell, and transport to a high vacuum chamber. An online setup, which will be placed at the second focal plane (F2) of BigRIPS, has been fabricated in FY2013 and commissioning is scheduled in FY2014.

Team Leader
Michiharu WADA

Member
Hideyuki YAMAZAWA (concurrent)

Nishina Center Research Scientists
Tetsu SONODA
Kensuke KUSAKA (concurrent)

Nishina Center Technical Scientist
Takeshi MAIE (concurrent)

Contract Researcher
Peter SCHURY

Research Associate
Yuta ITO (- Mar. 31, 2014)

Research Consultant
Hirokane KAWAKAMI (- Mar. 31, 2014)

Visiting Scientists
Hideki IIMURA (Japan Atomic Energy Agency)
Kunihiro OKADA (Sophia University)
Hans SCHUESSLER (Texas A&M University)
Aiko TAKAMINE (Aoyama Gakuin University) - Mar. 31, 2014
Hideki TOMITA (Graduate School of Engineering, Nagoya University)
Klaus WENDT -Mar. 31, 2014
Hermann WOLLNIK (University of Giessen) - Mar. 31, 2014

Part-time Workers
Shigeaki ARAI
Ichirou KATAYAMA
Tadashi FUJINAWA (-Mar. 31, 2014)

Student Trainees
Takuma NOTO
Takaaki TAKATSUKA - Mar. 31, 2014
Fumiya ARAI
Yoshitaka ADACHI - Mar. 31, 2014
Takahide TAKAMATSU - Mar. 31, 2014

RIBF Research Division
Instrumentations Development Group
Rare RI-ring Team

1. Abstract

Mass measurement is one of the most important contributions to a nuclear property research especially for short-lived unstable nuclei far from the beta-stability line. In particular, a high-precision mass measurement for nuclei located around the r-process pass (rare-RI) is required in nucleosynthesis point of view. We chose a method of isochronous mass spectrometry (IMS) to make a measurement time shorter than 1 ms. Heavy-ion storage ring named "Rare-RI RIng (R3)" is now under construction at RIKEN RI Beam Factory. Our target performance in the mass determination is to achieve an accuracy of the order of 10^{-6} (~100 keV) even if we get only one event. Since an isochronism in R3 is established over a wide range of the momentum, rare-RIs with a large momentum spread, $\Delta p/p=0.5$ %, are acceptable. Another significant feature of the R3 system is an individual injection scheme in which a produced rare-RI itself triggers the injection kicker. Design study for R3 has been continued from more than ten years ago, and the construction has been started in 2012. Construction of the infrastructures and fabrication of major parts of hardware relating to R3 have already been roughly completed. We are now setting up and testing all equipment including the power supplies, the control system, the vacuum system, and so on, toward the first commissioning planed in 2014.

2. Major Research Subjects

Developments of isochronous storage ring to measure mass of rare RI.

3. Summary of Research Activity

Since the lattice design of R3 is based on the cyclotron motion, it can provide an isochronism in a wide range of the momentum. We expect a great improvement in mass resolution in IMS as long as the isochronous field is precisely formed in R3. Therefore, IMS using R3 is capable of both a high-precision measurement and a fast measurement. All the devices in R3 was designed under the assumption that an incoming beam has an energy of 200 MeV/u and a charge to mass ratio, m/q, of less than 3. The ring structure was designed with a similar concept of a separate-sector ring cyclotron. It consists of six sectors and 4.02-m straight sections, and each sector consists of four rectangular bending magnets. They are reused magnets used in TARN-II, which was constructed at INS Tokyo University more than 20 years ago. A radially homogeneous magnetic field is produced in the magnet, and a magnetic rigidity is 6.5 Tm at maximum. Main coils of all the bending magnets are connected in series, and the current of 3000 A is required for rare-RIs, for instance, ^{78}Ni with the magnetic rigidity of 5.96 Tm. Two magnets at both ends of each sector are additionally equipped with ten trim coils to form a precise isochronous magnetic field. For $\Delta p=0$ particle, the circumference is 60.35 m and the betatron tunes are $\nu x=1.21$ and $\nu y=0.84$ in horizontal and vertical directions, respectively. The momentum acceptance is $\Delta p/p=0.5$ % and the transverse acceptances are 20π mmmrad and 10π mmmrad in horizontal and vertical directions, respectively. Although the transverse acceptances of the R3 itself are actually larger than these values, they are limited by that of the injection beam line. Of special note is that the isochronism is precisely fulfilled in a wide range of momentum (full width 1 %) due to a cyclotron-motion based lattice design.

Another performance required for R3 is to efficiently seize hold of an opportunity of the measurement for rare-RIs produced unpredictably. We adopted an individual injection scheme in which the produced rare-RI itself triggers the injection kicker magnets. Full activation of the kicker magnetic field has to be completed within the flight time of the rare-RI from an originating point of the trigger signal to the kicker position in R3. Development of an ultra-fast response kicker system is a key issue for establishing the individual injection scheme. Performances required for the kicker system are an ultra-fast response, a fast charging, and a full-time charging. Output current of our kicker power supply rises at 250 ns and the center of the flat top of the magnetic field is at smaller than 500 ns from the trigger input.

We provided ordinary beam diagnostic devices such as a screen monitor and a beam position monitor based on triangle pickup electrodes. Although five sets of these monitors distributed along the orbit in R3 are useful in a machine tuning process using a high-intensity primary beam. They, however, are incapable for rare-RIs because of the poor sensitivity. Therefore, we inserted high-sensitive monitors, which are applicable even for a single particle circulation. One of them is a cavity type of Schottky pick-up. A resonance frequency is designed to be 172 MHz, which corresponds to the harmonic number of 56, and a measured quality factor is over 7000 and shunt impedance is 400 kΩ. We can detect single ion circulation of $^{78}Ni^{28+}$ with only a few ms measurement. Another is a timing monitor, which detects secondary electrons emitted from thin carbon foil placed on the accumulation orbit. The thickness of the foil will be 50 $\mu g/cm^2$. The rare-RI with the energy of 200 MeV/u survives only for first 1000 turns because of an energy loss at the foil.

Major components of R3 have already been fabricated and the ring components were precisely arraigned. We are now setting up and testing every device individually, and we advance all preparations towards the commissioning scheduled in 2014.

Team Leader
Masanori WAKASUGI (Group Director)

Members
Tamaki WATANABE (concurrent)
Yutaka WATANABE (concurrent)
Naohito INABE (concurrent)
Yoshiyuki YANAGISAWA (concurrent)
Hideyuki YAMAZAWA (concurrent)

Nishina Center Research Scientist
Yoshitaka YAMAGUCHI

Nishina Center Technical Scientists
Takeshi MAIE (concurrent)
Misaki KOMIYAMA (concurrent)

Junior Research Associate
Yasushi ABE (University of Tsukuba)

Visiting Scientists
Daisuke NAGAE (Inst. Phys., Univ.of Tsukuba)
Tetsuro KOMATSUBARA (University of Tsukuba) - Mar. 31, 2014

Research Consultant
Akira NODA (- Mar. 31, 2014)

Student Trainees
Ayano ENOMOTO
Shunsuke OKADA - Mar. 31, 2014
Yuta SAITO - Mar. 31, 2014

RIBF Research Division
Instrumentations Development Group
SCRIT Team

1. Abstract

The SCRIT Electron Scattering Facility is now under construction at RIKEN RIBF. This aims at investigation of internal nuclear structure for short-lived unstable nuclei by means of electron scattering. SCRIT (Self-Confining RI Ion Target) is a novel method to form internal targets in an electron storage ring. This technique has made electron scattering experiments for unstable nuclei possible. Construction of the facility has been started in 2009. This facility consists of an electron accelerator (RTM), a SCRIT-equipped electron storage ring (SR2), an electron-beam-driven RI separator (ERIS), and a detector system for scattered electrons. Operation of accelerators, RTM and SR2, was started in 2010, performance test of the SCRIT system using stable isotopes, ^{133}Cs and ^{132}Xe, was successfully done in 2011 and 2012. Construction of ERIS was started in 2011 and it was commissioned in 2012. The first RI beams from ERIS were supplied in 2013, and the ion source is now under improvement. The detector system consisting of a high-resolution magnetic spectrometer, drift chambers, trigger scintillators, and luminosity monitors is now under construction. We are going to perform the first experiment of electron scattering from unstable nuclei within a fiscal year 2014.

2. Major Research Subjects

Development of SCRIT electron scattering technique and construction of the SCRIT electron scattering facility.

3. Summary of Research Activity

Development of an electron scattering experimental system for short-lived unstable nuclei using a novel internal target of unstable nuclei (SCRIT).

(Wakasugi, Ohnishi, Kurita, Suda, Tamae, Hori, Hara, Ichikawa)

SCRIT is novel technique to form internal target in an electron storage ring. Positive ions are confined in the electron beam axis by transverse focusing force given by the circulating electron beam. This is well known "ion trapping" phenomenon. The created ion cloud in which RI ions injected from outside are confined works as a target of electron scattering.

In 2010, we successfully commissioned electron accelerators RTM and SR2. Current of electron beams stored in SR2 and its storage lifetime have been reached to 300 mA and 2 hours, respectively, in the energy range of 150-300 MeV that is required in electron scattering experiments. In test experiments of the SCRIT system performed in 2011 and 2012, we used stable isotopes, ^{133}Cs and ^{132}Xe, and revealed many details of the SCRIT performance. The luminosity of 10^{27} /(cm^{2}s) was obtained in case of the number of injected ions of 10^8. The lifetime of the ion confinement was obtained to be over 1 s. They are performances satisfactory to the electron scattering experiment. In fact, we succeeded in measurements of angular distributions of scattered electrons from the target ions trapped in the SCRIT device.

Development of ERIS is one of the most important issues in the facility construction. RIs are generated by photo-fission process of ^{238}U, which is driven by the 150-MeVelectron beams from RTM. ERIS consists of a target ion source including UCx targets and a mass separation system. ERIS was constructed in 2011 and performances such as the extraction efficiency of 21 % and the mass resolving power of 1660 were obtained in the commissioning in 2011. We developed production method of UCx targets by ourselves. The first RI production was succeeded in last year, and $^{126\text{-}132}$Sn and $^{138\text{-}141}$Xe isotopes were extracted. Since the yield of extracted RIs is still below our expectation and there is some problem in durability of the ion source, the target ion source is now under improvement. A cooler buncher system connected to the ERIS beam line is indispensable, because the continuous beam from ERIS has to be converted to pulsed beam for ion injection to the SCRIT device. We are now developing the cooler buncher based on a RFQ linear trap. This was constructed in 2013 and is now under testing offline. This will be installed within this year.

In last year, we constructed a new detector for scattered electrons. This consists of a high-resolution magnetic spectrometer, a beam tracking system using drift chambers, trigger scintillators, and a luminosity monitor. This has a solid angle of 100 msr, energy resolution of 10^{-3}, and the scattering angle coverage of 30-60 degrees. A wide range of momentum transfer, 80-300 MeV/c, is covered by changing the electron beam energy from 150 to 300 MeV. This detector system is now under setting up offline and they are expected to be available soon.

Team Leader

Masanori WAKASUGI (Group Director)

Member

Tetsuya OHNISHI (Senior Technical Scientist)

Senior Visiting Scientist

Toshitada HORI (Hiroshima University)

Visiting Scientists

Toshimi SUDA (Research Center of Electron Photon Science, Tohoku Univ.)

Shuo WANG (Research Center of Electron Photon Science, Tohoku Univ.) - Jun. 30, 2013

Research Consultants

Takeshi EMOTO (-Mar. 31, 2014)
Shin-ichi ICHIKAWA (-Mar. 31, 2014)
Masahiro HARA (-Mar. 31, 2014)
Tadaaki TAMAE (-Mar. 31, 2014)

Student Trainees

Takaya MIYAMOTO - Mar. 31, 2014
Yuto SHIMAKURA - Mar. 31, 2014
Yuji HARAGUCHI
Shunpei YONEYAMA
Teruaki TSURU

RIBF Research Division
Research Instruments Group

1. Abstract

The research instruments group is the driving force at RI Beam Factory (RIBF) for continuous enhancement of activities and competitiveness of experimental research. Consisting of five teams, we are in charge of the design, construction, operation and improvement of the core research instruments at RIBF, such as BigRIPS separator, ZeroDegree spectrometer, GARIS spectrometer and SAMURAI spectrometer, and the related infrastructure and equipment. The group also conducts related experimental research as well as R&D studies on the research instruments.

2. Major Research Subjects

Design, construction, operation and improvement of the core research instruments at RIBF and related R&D studies. Experimental studies on exotic nuclei

3. Summary of Research Activity

The current research subjects are summarized as follows:

(1) Design, construction, operation, and improvement of the core research instruments at RIBF and their related infrastructure and equipment for continuous enhancement of activities and competitiveness of experimental research
(2) R&D studies on technical issues of the core research instruments and related equipment at RIBF
(3) Experimental research on exotic nuclei using the core research instruments at RIBF

Group Director
Toshiyuki KUBO

Senior Visiting Scientist
Toshio KOBAYASHI (Tohoku University)

Junior Research Associate
Daichi MURAI

Student Trainee
Katrina KOEHLER

Research Supporting Staff (part time Worker)
Meiko UESAKA

Assistant
Emiko ISOGAI

RIBF Research Division
Research Instruments Group
BigRIPS Team

1. Abstract

This team is in charge of design, construction, development and operation of BigRIPS in-flight separator and its related research instruments at RI beam factory (RIBF). They are employed not only for the production of RI beams but also the experimental studies using RI beams.

2. Major Research Subjects

Design, construction, development and operation of BigRIPS in-flight separator, RI-beam transport lines, and their related research instruments.

3. Summary of Research Activity

This team is in charge of design, construction, development and operation of BigRIPS in-flight separator, RI-beam transport lines, and their related research instruments such as ZeroDegree spectrometer at RI beam factory (RIBF). They are employed not only for the production of RI beams but also various kinds of experimental studies using RI beams.

The research subjects may be summarized as follows:

(1) General studies on RI-beam production using in-flight scheme.
(2) Studies on ion-optics of in-flight separators, including particle identification of RI beams
(3) Simulation and optimization of RI-beam production.
(4) Development of beam-line detectors and their data acquisition system.
(5) Experimental studies on production reactions and unstable nuclei.
(6) Experimental studies of the limits of nuclear binding.
(7) Development of superconducting magnets and their helium cryogenic systems.
(8) Development of a high-power production target system.
(9) Development of a high-power beam dump system.
(10) Development of a remote maintenance and remote handling systems.
(11) Operation, maintenance and improvement of BigRIPS separator system, RI-beam transport lines and their related research instruments such as ZeroDegree spectrometer and so on.
(12) Experimental research using RI beams.

Team Leader
Koichi YOSHIDA

Members
Naohito INABE (Senior Technical Scientist)
Masao OHTAKE (Senior Technical Scientist)
Yoshiyuki YANAGISAWA (Senior Research Scientist)
Kanenobu TANAKA (concurrent)

Nishina Center Research Scientists
Kensuke KUSAKA
Naoki FUKUDA
Hiroyuki TAKEDA

Contract Researcher
Daisuke KAMEDA

Postdoctoral Researchers
Deuk Soon AHN
Hiroshi SUZUKI

Part-time Worker
Hidekazu KUMAGAI (- Mar. 31, 2014)

Senior Visiting Scientist
Jerry NOLEN (ANL)

Visiting Scientists
Bradley SHERRILL (NSCL, Michigan State Univ., USA)

Daniel BAZIN (NSCL, Michigan State Univ., USA)
Oleg TARASOV (NSCL, Michigan State Univ., USA)
David MORRISSEY (NSCL, Michigan State Univ., USA)
Mauricio PORTILLO (NSCL, Michigan State Univ., USA)
Hans GEISSEL (GSI, Germany)
Martin WINKLER (GSI, Germany)
Michael FAMIANO (Western Michigan Univ., USA)
Yutaka MIZOI (Osaka Electro-Commnication Univ.)
Naohito IWASA (Tohoku Univ.)
Sadao MOMOTA (Kochi University of Technology)
Kazuo IEKI (concurrent) (Rikkyo Univ.) - Mar. 31, 2013

Student Trainee

Yohei OHKODA (Tohoku Univ.) - Mar. 31, 2014

RIBF Research Division
Research Instruments Group
SAMURAI Team

1. Abstract

In collaboration with research groups in and outside RIKEN, the team designs, develops and constructs the SAMURAI spectrometer and relevant equipment that are and will be used for reaction experiments using RI beams at RI Beam Factory. The SAMURAI spectrometer consists of a large superconducting dipole magnet and a variety of detectors to measure charged particles and neutrons. After the commissioning experiment in March 2012, the team prepared and conducted, in collaboration with researchers in individual experimental groups, the first series of experiments with SAMURAI in May 2012. The team also provides basis for research activities by, for example, organizing collaboration workshops by researchers who are interested in studies or plan to perform experiments with the SAMURAI spectrometer.

2. Major Research Subjects

Design, operation, maintenance and improvement of the SAMURAI spectrometer and its related research instruments.

Help and management for SAMURAI-based research programs.

3. Summary of Research Activity

The current research subjects are summarized as follows:

(1) Operation, maintenance and improvement of a large superconducting dipole magnet that is the main component of the SAMURAI spectrometer

(2) Design, development and construction of various detectors that are used for nuclear reaction experiments using the SAMURAI spectrometer.

(3) Preparation for planning experiments using SAMURAI spectrometer.

(4) Maintenance and improvement of the SAMURAI beam line.

(5) Formation of a collaboration platform called "SAMURAI collaboration"

Team Leader

Hiromi SATO

Member

Ken-ichiro YONEDA (concurrent: Deputy Team Leader)

Research Associate

Yohei SHIMIZU

Visiting Scientists (JST)

Bertis Charles RASCO (Louisiana State University, USA)

Julien Didier GIBELIN (JSPS: LPC-Caen, France) -Aug. 8, 2013

Visiting Technician

Nobuyuki CHIGA (Tohoku University) -Mar. 31, 2014

RIBF Research Division
Research Instruments Group
Computing and Network Team

1. Abstract

This team is in charge of development, management and operation of the computing and network environment, mail and information servers and data acquisition system and management of the information security of the RIKEN Nishina Center.

2. Major Research Subjects

(1) Development, management and operation of the general computing servers
(2) Development, management and operation of the mail and information servers
(3) Development, management and operation of the data acquisition system
(4) Development, management and operation of the network environment
(5) Management of the information security

3. Summary of Research Activity

This team is in charge of development, management and operation of the computing and network environment, mail and information servers and data acquisition system and management of the information security. The details are described elsewhere in this progress report.

(1) Development, management and operation of the general computing servers

We are operating Linux/Unix NIS/NFS cluster system for the data analysis of the experiments and general computing. This cluster system consists of eight computing servers with 28 CPU cores and totally 200 TB RAID of highly-reliable Fibre-channel HDD. We have replaced the data analyses servers and RAID file systems for the experimental data in the spring of 2012. Approximately 600 user accounts are registered on this cluster system. We are adopting the latest version of the Scientific Linux (X86_64) as the primary operating system, which is widely used in the accelerator research facilities, nuclear physics and high-energy physics communities in the world.

(2) Development, management and operation of the mail and information servers

We are operating RIBF.RIKEN.JP server as a mail/NFS/NIS server. This server is a core server of RIBF Linux/Unix cluster system. This server was replaced in the summer of 2011 since it passed more than five years from the installation. Postfix has been used for mail transport software and dovecot has been used for imap and pop services. These software packages enable secure and reliable mail delivery. Sophos Email Security and Control (PMX) installed on the mail front-end servers tags spam mails and isolates virus-infected mails. The probability to identify the spam is approximately 95-99%. We are operating several information servers such as WWW servers, Integrated Digital Conference (INDICO) server, Wiki servers, Groupware servers, Windows Media and Quick Time streaming servers, and an anonymous FTP server (FTP.RIKEN.JP).

(3) Development, management and operation of the data acquisition system

We have developed the standard data-acquisition system named as RIBFDAQ. This system can process up to 40 MB/s data. By using parallel readout from front-end systems, the dead time could be small. To synchronize the independent DAQ systems, the time stamping system has been developed. The resolution and depth of the time stamp are 10 ns and 48 bit, respectively. This time stamping system is very useful for beta decay experiments such as EURICA and BRIKEN projects. The current main task is the DAQ coupling, because detector systems with dedicated DAQ systems are transported to RIBF from foreign facilities. In case of SAMURAI Silicon (NSCL/TUM/WUSTL), the readout system is integrated into RIBFDAQ. The projects of MUST2 (GANIL), MINOS (CEA Saclay), and NeuLAND (GSI) cases, data taken by their DAQ systems are transferred to RIBFDAQ. For SPIRIT (RIKEN/GANIL/CEA Saclay/NSCL), RIBFDAQ data are sent to GET system that is a large-scale signal processing system for the time projection chamber. These cases, data are merged in online. On the other hand, EURICA (GSI) and BRIKEN (GSI/Univ. Liverpool/IFIC) projects, we adopt the time stamping system to use individual trigger for each detector system. In this case, data are merged in offline. In addition to the development DAQ system, we are developing intelligent circuits based on FPGA. Mountable Controller (MOCO) is a very fast readout controller for VME modules. General Trigger Operator (GTO) is an intelligent triggering NIM module. These new circuits are successfully working.

(4) Development, management and operation of the network environment

We have been managing the network environment collaborating with Advanced Center for Computing and Communications (ACCC). All the Ethernet ports of the information wall sockets are capable of the Gigabit Ethernet connection (10/100/1000BT). Approximately 60 units of wireless LAN access points have been installed to cover the almost entire area of Nishina Center.

(5) Management of the information security

It is essential to take proper information security measures for information assets.

We are managing the information security of Nishina Center collaborating with ACCC.

Team Leader
Takashi ICHIHARA (concurrent)

Member
Yasushi WATANABE (concurrent)

Nishina Center Research Scientist
Hidetada BABA

Student Trainee
Ryousuke TANUMA - Mar. 31, 2014

RIBF Research Division
Research Instruments Group
Detector Team

1. Abstract
This team is in charge of development, fabrication, and operation of various detectors used for nuclear physics experiments at RIBF. Our current main mission is maintenance and improvement of beam-line detectors which are used at BigRIPS separator and its succeeding beam lines for beam diagnosis and particle identification of RI beams. We are also engaged in research and development of new detectors that can be used for higher-intensity RI beams.

2. Major Research Subjects
Development, fabrication, and operation of various detectors for nuclear physics experiments, including beam-line detectors which are used for the production and delivery of RI beams (beam diagnosis and particle identification).

3. Summary of Research Activity
The current research subjects are summarized as follows:

(1) Maintenance and improvement of the beam-line detectors which are used at BigRIPS separator and its succeeding beam lines.
(2) Development of new beam-line detectors with radiation hardness and tolerance for higher counting rates
(3) Development of a high dynamic range preamplifier for silicon strip detectors

Team Leader
Toshiyuki KUBO (Group Director)

Special Postdoctoral Researcher
Yuki SATO

Visiting Scientist
Kohei FUJIWARA (Tokyo Metropolitan Industrial Technology Research Institute)

Research Consultant
Hiroyuki MURAKAMI (- Mar. 31, 2014)

Students
Junior Research Associate
Hiroyuki MIYA - Mar. 31, 2014

RIBF Research Division
Accelerator Applications Research Group

1. Abstract

This group promotes various applications of ion beams from RI Beam Factory. Radiation Biology Team studies various biological effects of fast heavy ions and develops new technology to breed plants and microbials by heavy-ion irradiations. RI Applications Team studies production and application of radioisotopes for various research fields, development of trace element analysis and its application, and development of chemical materials for ECR ion sources.

2. Major Research Subjects

Research and development in biology, chemistry and materials science utilizing heavy-ion beams from RI Beam Factory.

3. Summary of Research Activity

(1) Biological effects of fast heavy ions.
(2) Development of heavy-ion breeding.
(3) Production and application of radioisotopes.
(4) Developments of trace elements analyses

Group Director
Tomoko ABE

Assistants
Yoshiko SAKATA
Noriko KIYAMA

RIBF Research Division
Accelerator Applications Research Group
Radiation Biology Team

1. Abstract

Radiation biology team studies various biological effects of fast heavy ions. It also develops new technique to breed plants by heavy-ion irradiations. Fast heavy ions can produce dense and localized ionizations in matters along their tracks, in contrast to photons (X rays and gamma rays) which produce randomly distributed isolated ionizations. This localized and dense ionization can cause double-strand breaks of DNA which are not easily repaired and result in mutation more effectively than single-strand breaks. A unique feature of our experimental facility at the RIKEN Ring Cyclotron (RRC) is that we can irradiate living tissues in atmosphere since the delivered heavy-ion beams have energies high enough to penetrate deep in matter. This team utilizes a dedicated beam line (E5B) of the RRC to irradiate microbes, plants and animals with beams ranging from carbon to iron. Its research subjects cover physiological study of DNA repair, genome analyses of mutation, and development of mutation breeding of plants by heavy-ion irradiation. Some new cultivars have already been brought to the market.

2. Major Research Subjects

(1) Study on the biological effects by heavy-ion irradiation
(2) Studies on ion-beam breeding and genome analysis
(3) Innovative application of heavy-ion beams

3. Summary of Research Activity

We study biological effects of fast heavy ions from the RIKEN Ring Cyclotron using 135A MeV C, N, Ne ions, 95A MeV Ar ions and 90A MeV Fe ions. We also develop breeding technology of microbes and plants. Main subjects are:

(1) Study on the biological effects by heavy-ion irradiation

Heavy-ion beam deposits a concentrated amount of dose at just before stop with severely changing the LET. The peak of LET is achieved at the stopping point and known at the Bragg peak (BP). It is well known to be good for cancer therapy to adjust the BP to target malignant cells. On the other hand, a uniform dose distribution is a key to the systematic study, and thus to the improvement of the mutation efficiency. Therefore plants and microbes are treated using ions with stable LET. We investigated the effect of LET ranging from 22.5 to 640 keV/μm, on mutation induction using the model plant *Arabidopsis thaliana*. The most effective LET (LETmax) was 30.0 keV/μm. In the case of microbe (*Mesorhizobium lothi*), the results showed a higher incidence of deletion mutations for Fe ions at 640 KeV/μm than for C ions at 23-40 keV/μm. Thus, the LET of ion beams seems to be an important factor affecting mutagenesis.

(2) Study on ion-beam breeding and genome analysis

In contrast to X rays and gamma rays, fast heavy ions are found to be useful for plant breeding since they only cause localized damage on DNA and can induce mutations more effectively with lower dosage. Our team utilizes beams of fast heavy ions from the RRC to develop heavy-ion breeding techniques. LETmax is effective for breeding because of its very high mutation frequency. Since most mutations are small deletions, these are sufficient to disrupt a single gene. Thus, irradiation can efficiently generate knockout mutants of a target gene, and can be applied to reverse genetics. Higher LET (> 290 keV/μm) was shown to efficiently generate large deletions ranging from several to several tens of kbp. Many genes in the *Arabidopsis* genome (> 10%) are composed of tandem duplicated genes that share functions. Previous studies demonstrated that large deletions were required to knockout tandem arrayed genes, and the appropriate deletion size was estimated to be approximately 5–10 kbp, based on gene density in *Arabidopsis*. No method is currently available to efficiently generate deletion mutants of this size. As such, higher LET irradiation is promising as a new mutagen suitable for the functional analysis of tandem duplicated genes.

(3) Innovative application of heavy-ion beams

We have formed a consortium for ion-beam breeding. It consisted of 24 groups in 1999. In 2013 it consisted of 164 groups from Japan and 18 from overseas. Breeding was performed previously using mainly flowers and ornamental plants. We have recently put a new Japanese barnyard millet cultivar with low amylose content and short culm, ‘Nebarikko No. 2’ on the market. Beneficial variants have been grown for various plant species, such as high yield rice, semi-dwarf early rice, semi-dwarf buckwheat, hypoallergenic peanut, spineless oranges, non-flowering Eucalyptus and lipids-hyperaccumulating unicellular alga. We also successfully isolated 4 salt-resistant lines of rice from 325 progeny lines. We collaborate with Miyagi prefecture and Tohoku University to breed salt-resistant lines in the more delicious commercial rice varieties, ‘Hitomebore’ and ‘Manamusume’, that will grow normally and retain their good taste in saline paddy fields affected by the recent tsunami. The target of heavy-ion breeding is extended from flowers to crops like grains so that it will contribute to solve the global problems of food and environment.

Team Leader
Tomoko ABE (Group Director)

Members
Katsunori ICHINOSE (Senior Technical Scientist)
Masako IZUMI (Senior Research Scientist)
Tokihiro IKEDA (Senior Research Scientist)
Kazuhide TSUNEIZUMI (Senior Research Scientist)
Teruyo TSUKADA (Senior Research Scientist)
Ryouhei MORITA (Technical Scientist)

Postdoctoral Researcher
Kotaro ISHII

Technical Staff I
Yoriko HAYASHI
Sachiko KOGURE (-Mar. 31, 2014)

Technical Staff II
Sumie OHBU

Visiting Scientists
Ryutaro AIDA (Natl. Inst. Floricult. Sci.) -Mar. 31, 2013
Mari AMINO (Tokai University Hospital) -Mar. 31, 2013
Chang-Hyu BAE (Sunchon Natl. Univ., Korea) -Mar. 31, 2013
Hiroyuki DAIMON (Osaka Pref. Univ.) -Mar. 31, 2013
Ali FERJANI (Tokyo Gakugei Univ.)
Makoto FUJIWARA (Grad. Sch., Col. Arts Sci., Univ. of Tokyo)
Eitaro FUKATSU (Forest tree beeding Cet.)
Yoshiya FURUSAWA (Natl. Inst. Radiol. Sci.) -Mar. 31, 2013
Toshinari GODO (Botanic Gardens Toyama)
Misako HAMATANI (Hiroshima City Agric. Forest. Promot. Cen.) -Mar. 31, 2013
Yasuhide HARA (Kanagawa Inst. Agric. Sci.) -Mar. 31, 2013
Masanori HATASHITA (Wakasa Wan Energy Res. Cen.) -Mar. 31, 2013
Atsushi HIGASHITANI (Grad. Sch. Life Sci., Tohoku Univ.) -Mar. 31, 2013
Ryoichi HIRAYAMA (Natl. Inst. Radiol. Sci.) -Mar. 31, 2013
Akiko HOKURA (Tokyo Denki Univ.)
Ichiro HONDA (Natl. Agric. Res. Cen.) -Mar. 31, 2013
Mitsugu HORITA (Hokuren Agri. Res. Inst.) -Mar. 31, 2013
Hiroyuki ICHIDA (Meiji Univ.)
Yuji ITO (Natl. Agric. Res. Cen., Hokkaido Region)
Akihiro IWASE (Grad. Sch. Engin., Osaka Pref. Univ.)
Hiroshi KAGAMI (Shizuoka Citrus Exp. Station) -Mar. 31, 2013
Tetsuya KAKO (Suntory Flowers, Ltd.) -Mar. 31, 2013
Tsutomu KUBOYAMA (Ibaraki Univ.) -Mar. 31, 2013
Norihiko MISHIMA (Fukuda Denshi Co., Ltd.) -Mar. 31, 2013
Yutaka MIYAZAWA (Grad. Sch. Life Sci., Tohoku Univ.)
Kazumitsu MIYOSHI (Fac. Bioresour. Sci., Akita Pref. Univ.)
Toshikazu MORISHITA (Inst. Rad. Breeding, Natl. Inst. Agric. Res.)
Koji MURAI (Fukui Pref. Univ.)
Francesco MUSUMECI (Catania Univ.) -Mar. 31, 2013
Koichiro NISHIKAWA (FLORSAIKA CIA. LTDA.) -Mar. 31, 2013
Norihiro OHTSUBO (Natl. Inst. Floricult. Sci.)
Tomo OOMIYA (Hokkaido Ornamental Plants Veg. Res. Cen.) -Mar. 31, 2013
Masaya SAKAI (Fukuda Denshi Co., Ltd.) -Mar. 31, 2013
Kouichi SAKAMOTO (YUKIGUNI AGURI Co., Ltd.) -Mar. 31, 2013
Katsutomo SASAKI (National Agriculture and Food Research Organization)
Mikio SHIMADA (Kyoto Univ.) -Mar. 31, 2013
In-Ja SONG (Jeju National University)
Fumio SUGAWARA (Tokyo Univ. of Sci.) -Mar. 31, 201
Masao SUGIYAMA (Hokko Chem. Ind. Co., Ltd.) -Mar. 31, 2013
Keita SUGIYAMA (Nat. Inst. Veg.Tea Sci.) -Mar. 31, 2013
Ryuji SUGIYAMA (Ajinomoto, Co., INC.) -Mar. 31, 2013
Kazunori SUZUKI (Plant Biotech. Inst. Ibaraki Agric. Cen.) -Mar. 31, 2013
Masao SUZUKI (Natl. Inst. Radiol. Sci.) -Mar. 31, 2013
Kenichi SUZUKI (Suntory Flowers, Ltd.) -Mar. 31, 2013
Kunio SUZUKI (Technoflora, Co., Ltd.)
Hinako TAKEHISA (Natl. Inst. Agric. Sci.)

Sachie TANAKA (Tokai Univ.) -Mar. 31, 2013
Teruhiko TERAKAWA (Hokko Chem. Ind. Co., Ltd.) -Mar. 31, 2013
Ken TOKUHARA (Dogashima Orchid Cen.) -Mar. 31, 2013
Masanori TOMITA (CRIEPI)
Tomojiro KOIDE (RIKEN VITAMIN Co., Ltd.)
Hisashi TSUJIMOTO (Fac. Agri., Tottori Univ.)
Kozo TSUKADA (Nippon Veterinary and Life-sci. Univ.) -Mar. 31, 2013
Makoto UBUKATA (Hokkaido Univ.)
Masao WATANABE (Fac. Agri., Tohoku Univ.)
Yasuko YOSHIHARA(Japan Atomic Energy Agency) -Mar. 31, 2013
Koichiro YOSHIOKA (Tokai University Hospital) -Mar. 31, 2013

Visting Technicians

Tomojirou KOIDE (Riken Vitamin Co., Ltd.)
Takuji YOSHIDA (Takii Seed Co., Ltd.)

Research Fellows

Hideki ASAUMI (Ehime Agricultural Experiment Station) -Mar. 31, 2013
Masataka CHAYA (Nagasaki Agr. Forest. Exp. Station) -Mar. 31, 2013
Fumiko HIDAKA (Kagoshima Pref. Inst. for Agric. Dev.) -Mar. 31, 2013
Takeya ICHIKI - Mar. 31, 2014
Shunsuke IMANISHI (Natl. Inst.Veg. and Tea Sci.) - Mar. 31, 2014
Hiroaki KISAKA (Ajinomoto, Co., INC.) -Mar. 31, 2013
Yuri KURUMATANI (Chiba Pref. Agr. Res. Cent.) -Mar. 31, 2013
Chikara KUWATA (Chiba Pref. Agr. Res. Cent.) -Mar. 31, 2013
Tadanori MINO (Wadomari Cho Agr. Exp. Station) -Mar. 31, 2013
Miyuki NISHI (Saga Agricultural Experiment Station) -Mar. 31, 2014
Kyousuke NIWA (Hyogo Pref. Res. Inst.) -Mar. 31, 2014
Tadahito OOTUBO (Wadomari Cho Agr. Exp. Station) -Mar. 31, 2013
Yoshihide SAKITA (Wadomari Cho Agr. Exp. Station) -Mar. 31, 2013
Tsukasa SHIRAO (Kagoshima Biotechnology Inst.) -Mar. 31, 2013
Keiichi TAKAGI (Wakasa-wan Energy Research Center) -Mar. 31, 2013
Tomihiro TAKESHITA -Mar. 31, 2014
Kei-ichiro UENO (Kagoshima Biotechnology Inst.) -Mar. 31, 2013
Naoji WAKITA (Wadomari Cho Agr. Exp. Station) -Mar. 31, 2013

Consultant

Hiroyuki SAITO (-Mar. 31, 2013)

Part-time Workers

Yuki SHIRAKAWA
Hideo TOKAIRIN
Taeko WAKANA
Satoko YASUDA
Mieko YAMADA
Anju MATSUNAGA (- Apr. 5, 2013)
Honami OOHASHI (Aug.22, 2013-Sep. 6, 2013)

Students

Junior Research Associate

Liqiu MA (Grad. Sch. Sci. & Engin., Saitama Univ.) -Mar. 31, 2013

Student Trainees

Kentaro FUJITA
Hiroki KAWAMOTO -Mar. 31, 2014
Kana MIYOSHI
Takuto TAKAHASHI -Mar. 31, 2014
Fumitaka TAMEZAWA
Megumi UTSUGI
Fumitaka YAMAGISHI

RIBF Research Division
Accelerator Applications Research Group
RI Applications Team

1. Abstract

The RI Applications Team develops production technologies of radioisotopes (RIs) at RIKEN RI Beam Factory (RIBF) for application studies in the fields of physics, chemistry, biology, medicine, and pharmaceutical and environmental sciences. We use the RIs mainly for nuclear and radiochemical studies such as development of RI production technologies and chemistry of superheavy elements. The purified RIs such as ^{65}Zn and ^{109}Cd are delivered to universities and institutes through Japan Radioisotope Association. We also develop new technologies of mass spectrometry for the trace-element analyses using accelerator technology and apply them to the research fields such as cosmochemistry, environmental science, archaeology and so on. We also develop chemical materials for ECR ion sources of the RIBF accelerators.

2. Major Research Subjects

(1) Research and development of RI production technology at RIBF
(2) RI application researches
(3) Development of trace element analysis using accelerator techniques and its applications to geoscience and environmental science
(4) Development of chemical materials for ECR ion sources of RIBF accelerators

3. Summary of Research Activity

RI Applications Team utilizes RIBF heavy-ion accelerators for following research subjects:

(1) Research and development of RI production technology at RIBF and RI application studies

Due to its high sensitivity, the radioactive tracer technique has been successfully applied for investigations of the behavior of elements in the fields of chemistry, biology, medicine, engineering, and environmental sciences. We have been developing production technologies of useful radiotracers at RIBF and conducted their application studies in collaboration with many researchers in various fields. With 14-MeV proton, 24-MeV deuteron, and 50-MeV alpha beams from the AVF cyclotron, we presently produce about 30 long-lived radiotracers from ^{7}Be to ^{206}Bi. Among them, ^{65}Zn, ^{109}Cd, and ^{88}Y are delivered to Japan Radioisotope Association for fee-based distribution to the general public in Japan. On the other hand, radionuclides of a large number of elements are simultaneously produced from metallic targets such as ^{nat}Ti, ^{nat}Ag, ^{nat}Hf, and ^{197}Au irradiated with a 135-MeV nucl.$^{-1}$ ^{14}N beam from the RIKEN Ring Cyclotron. These multitracers are also supplied to universities and institutes as collaborative researches.

In 2013, we installed a new RI production system having an effective shield on the beam line of AVF to increase production yields of RIs by intense beam irradiations. We produced ^{65}Zn, ^{109}Cd, and ^{88}Y for our scientific researches on a regular schedule and supplied the surpluses through Japan Radioisotope Association to the general public. In 2013, we have accepted 14 orders of ^{65}Zn with a total activity of 72.7 MBq, 5 orders of ^{109}Cd with 14.15 MBq, and 1 order of ^{88}Y with 30 kBq. We also developed production technologies for new radioisotopes such as ^{28}Mg, ^{75}Se, ^{85}Sr, ^{99}Mo, and ^{124}I which were strongly demanded but lack supply sources in Japan. We also investigated the excitation functions for the ^{nat}Ni(d,x), ^{nat}Zn(d,x), ^{nat}Zr(d,x), ^{nat}Zr(α,x), ^{nat}Hf(d,x), and ^{nat}Pt(d,x) reactions to effectively produce useful RIs.

(2) Superheavy element chemistry

Chemical characterization of newly-discovered superheavy elements (SHEs, atomic numbers $Z \geq 104$) is an extremely interesting and challenging subject in modern nuclear and radiochemistry. We are developing SHE production systems as well as rapid single-atom chemistry apparatuses at RIBF. Using heavy-ion beams from RILAC and AVF, long-lived SHEs such as ^{261}Rf, ^{262}Db, and ^{265}Sg are produced, and their chemical properties are investigated.

We have been developing a gas-jet transport system at the focal plane of the gas-filled recoil ion separator GARIS at RILAC. This system is a promising approach for exploring new frontiers in SHE chemistry: (i) the background radioactivity of unwanted reaction products are strongly suppressed, (ii) the intense beam is absent in the gas-jet chamber and hence high gas-jet efficiency is achieved, and (iii) the beam-free condition also allows for investigations of new chemical systems. In 2013, the isotope of ^{262}Db was produced in the reaction of ^{248}Cm(^{19}F,5n)^{262}Db, and the decay properties of ^{262}Db and its α-decay daughter ^{258}Lr were investigated in detail using the rotating wheel apparatus MANON for α/SF spectrometry. Toward the SHE chemistry behind GARIS, we also developed a gas-chromatograph apparatus directly coupled to GARIS, which enabled in-situ complexation and gas-chromatographic separation of a large variety of volatile compounds of SHEs. In 2013, a cryogenic gas-chromatograph apparatus developed by the GSI-Mainz Univ. group was shipped to RIKEN, and the gas-phase chemistry with the organo-metallic compound of $Sg(CO)_6$ was successfully conducted in collaboration with Helmholtz-Institut Mainz, GSI, Mainz Univ., JAEA, Bern Univ., PSI, IMP, Hirosima Univ., Kyushu Univ., Niigata Univ., UC Berkeley, LBNL, and Saitama Univ.

At the AVF cyclotron, an automated hydroxide precipitation apparatus was developed in collaboration with Osaka Univ. Using the apparatus, the hydroxide complexation of ^{261}Rf was investigated with its homologues ^{85}Zr and ^{169}Hf. A batch-type solid-liquid extraction apparatus for a repetitive extraction experiment of SHEs was also developed in the HCl-TIOA system with Osaka Univ. using ^{85}Zr and ^{169}Hf. In 2013, a reversed-phase TTA extraction of ^{261}Rf and its homologues ^{85}Zr and ^{169}Hf was conducted in HF/HNO_3 solutions using Automated Rapid Chemistry Apparatus (ARCA) developed at GSI-Mainz Univ.-JAEA. In collaboration with Niigata Univ. and JAEA, a reversed-phase TBP extraction experiment of ^{90}Nb and ^{170}Ta were conducted using ARCA for the future ^{262}Db chemistry.

(3) Applications of RIKEN RI technologies for the Fukushima accident in 2011

Since the Fukushima Dai-ichi power plant accident in 2011, we have contributed radioactivity measurements of various samples such as soils and foods, and developed a low-cost radiation detector for foods.

(4) Development of trace element analysis using accelerator techniques and its application to geoscience and environmental science

We developed new mass spectrometry technologies for trace element analyses as an application of accelerator technology to various fields such as cosmochemistry, environmental science, and archaeology. ECRIS-AMS is a new type of accelerator mass spectrometry at RILAC equipped with an ECR ion source. This system is available for measuring trace elements (10^{-14}–10^{-15} level) and is expected to be especially effective for measurements of low-electron-affinity elements such as ^{26}Al, ^{41}Ca, and ^{53}Mn. In 2013, we have renovated the detection system and examined the sensitivity and mass resolution power. We also attempted to develop another technology by customizing a mass spectrometer equipped with a stand-alone ECR ion source for analyses of elemental and isotopic abundances. Furthermore, we analyzed sulfur and lead isotope ratios for cinnabar samples from ancient tombs in Japan to elucidate the origin of cinnabar.

(5) Development of chemical materials for ECR ion sources of RIBF

In 2013, we investigated a production method of $^{238}U(C_8H_8)_2$ for the ECR ion source of RIBF. We also prepared metallic ^{238}U and $^{238}UO_2$ on a regular schedule.

Team Leader
Hiromitsu HABA

Member
Kazuya TAKAHASHI (Senior Research Scientist)

Postdoctoral Researcher
Minghui HUANG (- Mar. 31, 2014)

Technical Staff I
Jumpei KANAYA (- Mar. 31, 2014)

Research Consultant
Seiichi SHIBATA (- Mar. 31, 2014)

Junior Research Associate
Masashi MURAKAMI (Niigata Univ.)

Part-time Worker
Michiko KITAGAWA

Visiting Scientists
Mayeen Uddin KHANDAKER (Univ. Malaya)
Hidetoshi KIKUNAGA (Tohoku Univ.)
Kazuhiro OOE (Niigata Univ.)
Hiroshi SHIMIZU (Rissho University)
Miho TAKAHASHI (Tokyo Univ. Marine Sci. and Tech.)
Masayoshi TODA (Tokyo Univ. Marine Sci. and Tech.)
Takahiro YAMADA (Japan Radiation Association)
Akihiko YOKOYAMA (Kanazawa Univ.)

Visting Technicians
Yuichiro WAKITANI (Japan Radiation Association)
Shinya YANOU (Japan Radiation Association)

Student Trainees
Ryuji AONO (Niigata Univ.) -Mar. 31, 2014
Yoshiki FUKUDA (Kanazawa Univ.) -Mar. 31, 2014
Naoya GOTO (Niigata Univ.) -Mar. 31, 2014
Kazunori HAYASHI (Kanazawa Univ.) -Mar. 31, 2014
Junichi HIRATA (Tokyo Univ. Marine Sci. and Tech.)
Hajime KIMURA (Kanazawa Univ.) -Mar. 31, 2014
Yuuta KITAYAMA (Kanazawa Univ.) -Mar. 31, 2014
Takumi KOYAMA (Niigata Univ.) -Mar. 31, 2014
Eita MAEDA (Kanazawa Univ.) -Mar. 31, 2014
Kouhei NAKAMURA (Osaka Univ.) -Mar. 31, 2014
Yuri OBI (Tokyo Univ. Marine Sci. and Tech.) -Mar. 31, 2014
Daisuke SATO (Niigata Univ.) -Mar. 31, 2014
Yudai SHIGEKAWA (Osaka Univ.) -Mar. 31, 2014
Yuuki SHIGEYOSHI (Kanazawa Univ.) -Mar. 31, 2014
Takumi TANIGUCHI (Kanazawa Univ.) -Mar. 31, 2014
Keigo TOYOMURA (Osaka Univ.) -Mar. 31, 2014

Shohei TSUTO (Niigata Univ.) -Mar. 31, 2014
Shingo UENO (Kanazawa Univ.) -Mar. 31, 2014

RIBF Research Division
User Liaison and Industrial Cooperation Group

1. Abstract

The essential mission of the “User Liaison and Industrial Cooperation (ULIC) Group” is to maximize the research activities of RIBF by attracting users in various fields with a wide scope.

The ULIC Group consists of two teams.

The User Support Team provides various supports to visiting RIBF users through the User’s Office. The Industrial Cooperation Team supports potential users in industries who use the beams for application purposes or for accelerator related technologies other than basic research. Production of various radioisotopes by the AVF cyclotron is also one of the important missions. The produced radioisotopes are distributed to researchers in Japan for a charge through the Japan Radioisotope Association.

In addition the ULIC Group takes care of laboratory tours for RIBF visitors from public. The numbers of visitors amounts to 2,300 per year.

Group Director
Hideyuki SAKAI

Deputy Group Director
Hideki UENO (concurrent: User Support)

Members
Mieko KOGURE (Technical Assistant) (-Mar. 31, 2014)
Aiko NAKAO (Senior Research Scientist) (Feb. 1, 2013-Apr. 30, 2013)

Special Temporary Employee
Tadashi KAMBARA

Senior Visiting Scientists
Ikuko HAMAMOTO (The Lund University)
Munetake ICHIMURA (The University of Tokyo)

Assistants
Yoshiko SAKATA (- Oct. 31, 2013)
Noriko KIYAMA
Tomoko IWANAMI
Katsura IWAI
Emiko ISOGAI (- Mar. 31,2013)

RIBF Research Division
User Liaison and Industrial Cooperation Group
User Support Office

1. Abstract

To enhance synergetic common use of the world-class accelerator facility, the Radioisotope Beam Factory (RIBF), it is necessary to promote a broad range of applications and to maximize the facility's importance. The facilitation and promotion of the RIBF are important missions charged to the team. Important operational activities of the team include: i) the organization of international Program Advisory Committee (PAC) meetings to review experimental proposals submitted by RIBF users, ii) RIBF beam-time operation management, and iii) promotion of facility use by hosting outside users through the RIBF Independent Users program, which is a new-user registration program begun in FY2010 at the RIKEN Nishina Center (RNC) to enhance the synergetic common use of the RIBF. The team opened the RIBF Users Office in the RIBF building in 2010, which is the main point of contact for Independent Users and provides a wide range of services and information.

2. Major Research Subjects

(1) Facilitation of the use of the RIBF
(2) Promotion of the RIBF to interested researchers

3. Summary of Research Activity

(1) Facilitation of the use of the RIBF

The RIBF Users Office, formed by the team in 2010, is a point of contact for user registration through the RIBF Independent User program. This activity includes:

- registration of users as RIBF Independent Users,
- registration of radiation workers at the RIKEN Wako Institute,
- provision of an RIBF User Card (a regular entry permit) and an optically stimulated luminescence dosimeter for each RIBF Independent User, and
- provision of safety training for new registrants regarding working around radiation, accelerator use at the RIBF facility, and information security, which must be completed before they begin RIBF research.

The RIBF Users Office is also a point of contact for users regarding RIBF beam-time-related paperwork, which includes:

- contact for beam-time scheduling and safety review of experiments by the In-House Safety Committee,
- preparation of annual Accelerator Progress Reports, and
- maintaining the above information in a beam-time record database.

In addition, the RIBF Users Office assists RIBF Independent Users with matters related to their visit, such as invitation procedures, visa applications, and the reservation of on-campus accommodation.

(2) Promotion of the RIBF to interested researchers

- The team has organized an international PAC for RIBF experiments; it consists of leading scientists worldwide and reviews proposals in the field of nuclear physics (NP) purely on the basis of their scientific merit and feasibility. The team also assists another PAC meeting for material and life sciences (ML) organized by the RNC Advanced Meson Laboratory. The NP and ML PAC meetings are organized twice a year.
- The team coordinates beam times for PAC-approved experiments and other development activities. It manages the operating schedule of the RIBF accelerator complex according to the decisions arrived at by the RIBF Machine Time Committee.
- To promote research activities at RIBF, proposals for User Liaison and Industrial Cooperation Group symposia/mini-workshops are solicited broadly both inside and outside of the RNC. The RIBF Users Office assists in the related paperwork.
- The team is the point of contact for the RIBF users' association. It arranges meetings at RNC headquarters for the RIBF User Executive Committee of the users' association.
- The Team conducts publicity activities, such as arranging for RIBF tours, development and improvement of the RNC official web site, and delivery of RNC news via email and the web.

Team Leader
Ken-ichiro YONEDA

Deputy Team Leader
Yasushi WATANABE (concurrent)

Technical Staff I
Narumasa MIYAUCHI

Visiting Scientists
Yoshiteru SATO (Seoul National University) - Aug. 31, 2013
Masayuki YAMAGAMI (University of Aizu) - Aug. 31, 2013

RIBF Research Division
User Liaison and Industrial Cooperation Group
Industrial Cooperation Office

1. Abstract

Industrial cooperation team handles non-academic activities at RIBF corresponding to industries and to general public.

2. Major Research Subjects

(1) Fee-based distribution of radioisotopes produced at RIKEN AVF Cyclotron
(2) Support of industrial application using the RIBF accelerator beam and its related technologies including novel industrial applications.
(3) Development of real-time wear diagnostics of industrial material using RI beams

3. Summary of Research Activity

(1) Fee-based distribution of radioisotopes

This team handles fee-based distribution of radioisotopes Zn-65, Y-88 and Cd-109 from 2007, which are produced by the RI application team at the AVF cyclotron, to nonaffiliated users under a Material Transfer Agreement between Japan Radioisotope Association and RIKEN. In 2013, we delivered five shipments of Cd-109 with a total activity of 14.15 MBq and 14 shipments of Zn-65 with a total activity of 72.7 MBq. In addition, we delivered the first shipment of Y-88 with an activity of 0.03 MBq. The final recipients of the RIs were eight universities, two research institutes and one private company.

(2) Support of Industrial application using RIBF

In November 2009, RNC started a new project "Promotion of applications of high-energy heavy ions and RI beams" as a grant-in-aid program of MEXT "Sharing Advanced Facilities for Common Use Program". In this project, RNC opens the old part of the RIBF facility, which includes the AVF cyclotron, RILAC, RIKEN Ring Cyclotron and experimental instruments like RIPS, to non-academic proposals from users including private companies. This MEXT program was terminated in September 2010, but RNC succeed and promote this facility sharing program after that. The proposals are reviewed by a program advisory committee, industrial PAC. The proposals which have been approved by the industrial PAC are allocated with beam times and the users pay RIKEN the beam time fee. The intellectual properties obtained by the use of RIBF belong to the users. In order to encourage the use of RIBF by those who are not familiar with utilization of ion beams, the first two beam times of each proposal can be assigned to trial uses which are free of beam time fee.

The industrial PAC met for the first time in January 2010, and reviewed and approved two proposals as trial uses. The beam times of both proposals were executed successfully in 2010 at the RIKEN Ring Cyclotron and RILAC. The second meeting held in June 2010 reviewed four proposals and approved three of them as trial uses. Beam times of two of the proposals were successfully executed in 2010 and 2011 at the RIKEN Ring Cyclotron. The third meeting held in July 2012 reviewed one proposal and approved it.

(3) Development of real-time wear diagnostics using RI beams

We are promoting a method for real-time wear diagnostics of industrial material using RI beams as tracers. This new method was developed by a close collaboration with Sumitomo Heavy Industry, which led to an application of a patent. For that purpose, very intense RI beams of 7Be (T1/2=52 days) at 4.1 MeV/u and 22Na (T1/2=2.6 years) at 3.7 MeV/u were produced via the (p,n) reaction at the CRIB separator using beams from the AVF cyclotron. In the past, those RIs were produced at the RIPS separator using beams from the RRC, which are constantly used for the academic research. The RI beam production by the AVF cyclotron alone increases flexibility in the beam-time scheduling and more importantly leads to reduce the production cost for industrial users.

As we can provide RI beams of different nuclides and control the implantation depth, we have developed a novel method of wear diagnostics in collaboration with Sumitomo Heavy Industry (SHI) Examination & Inspection Ltd., SHI Technology Research Center and CNS and jointly applied for a patent. Implantation of different RI for both machine parts contacting each other, one can distinguish the wear-loss rate of both interacting parts simultaneously. Implantation of one or a few RIs with controlling its depth profile, it can be applicable for processing a wear-loss gauge on a machine part. We are also developing a new method to determine the spatial distribution of positron-emitting RIs on periodically-moving objects in a closed system, which can be used for real-time evaluation of wear loss in a running machine. This is based on the same principle as the medical PET systems but is simpler and less expensive.

Team Leader
Atsushi YOSHIDA

Members
Hiroshige TAKEICHI (Senior Research Scientist)
Aiko NAKAO (-Jan. 31, 2013)

Visiting Scientists
Shuhei TATEMICHI (Fuji Electric Systems)
Masanori INOUE (Fuji Electric Systems)

RIBF Research Division
Safety Management Group

1. Abstract

The RIKEN Nishina Center for Accelerator-Based Science possesses one of the largest accelerator facilities in the world, which consists of two heavy-ion linear accelerators and five cyclotrons. This is the only site in Japan where uranium ions are accelerated. The center also has electron accelerators of microtron and synchrotron storage ring. Our function is to keep the radiation level in and around the facility below the allowable limit and to keep the exposure of workers as low as reasonably achievable. We are also involved in the safety management of the Radioisotope Center, where many types of experiments are performed with sealed and unsealed radioisotopes.

2. Major Research Subjects

(1) Safety management at radiation facilities of Nishina Center for Accelerator-Based Science
(2) Safety management at Radioisotope Center
(3) Radiation shielding design and development of accelerator safety systems

3. Summary of Research Activity

Our most important task is to keep the personnel exposure as low as reasonably achievable, and to prevent an accident. Therefore, we daily patrol the facility, measure the ambient dose rates, maintain the survey meters, shield doors and facilities of exhaust air and wastewater, replenish the protective supplies, and manage the radioactive waste. Advice, supervision and assistance at major accelerator maintenance works are also our task.

We revised the safety interlock system of RIBF building to meet the requirement due to the installations of SLOWRI and R3 detectors. Four neutron monitors were additionally placed around the rooms, and connected with the interlock system to stop the ion beam when radiation level rose. The local shields in the experiment vaults were partly modified.

A new experiment room for measurement of short-half-life radionuclide was made in the pump room of the linac building, and an exhaust system with a high-efficiency particulate air (HEPA) filter was installed there. Contamination test apparatuses were installed.

For the above modifications we applied for the government license 5 times, and underwent the government inspections 4 times.

We developed ionization chambers which were fairly resistant to radiation, and installed them in the SRC vault. The real-time dose rate values are shown at the entrance of the vault.

Group Director
Yoshitomo UWAMINO

Deputy Group Director
Kanenobu TANAKA (Technical Scientist)

Nishina Center Technical Scientists
Hisao SAKAMOTO
Rieko HIGURASHI HIRUNUMA
Takeshi MAIE (concurrent)

Technical Staff I
Atsuko AKASHIO
Tomoyuki DANTSUKA (concurrent)

Assistant
Tomomi OKAYASU

Assigned Employee
Hiroki MUKAI

Temporary Staffing
Hiroyuki FUKUDA (- Mar. 31, 2014)
Satoshi HASHIGUCHI (- Mar. 31, 2013)
Mamoru TAKEKOSHI (Apr. 1, 2013 -)
Yoshiyuki YAMAUCHI (Apr. 1, 2013 -)

Research Consultant
Masaharu OKANO

Visiting Scientists
Takashi NAKAMURA (Shimizu Corporation)
Koji OHISHI (Shimizu Corporation)
Noriaki NAKAO (Shimizu Corporation)

Part-time Workers

Hiroko AISO
Shin FUJITA
Kimie IGARASHI
Satomi IIZUKA
Hiroshi KATO
Kazushiro NAKANO (- Mar. 31, 2014)
Tsutomu YAMAKI (- Mar. 31, 2013)

Partner Institution

The Nishina Center established the research partnership system in 2008. This system permits an external institute to develop its own projects at the RIKEN Wako campus in equal partnership with the Nishina Center. At present, three institutes, Center for Nuclear Study of the University of Tokyo (CNS), Institute of Particle and Nuclear Studies of KEK (KEK), and Department of Physics, Niigata University (Niigata) are conducting research activities under the research partnership system.

CNS and the Nishina Center signed the partnership agreement in 2008. Until then, CNS had collaborated in joint programs with RIKEN under the "Research Collaboration Agreement on Heavy Ion Physics" (collaboration agreement) signed in 1998. The partnership agreement redefines procedures related to the joint programs while keeping the spirit of the collaboration agreement. The joint programs include experimental nuclear physics activities using CRIB, SHARAQ, GRAPE at RIBF, theoretical nuclear physics activities with ALPHLEET, accelerator development, and activities at RHIC PHENIX.

The partnership agreement with the Niigata University was signed in 2010. The activity includes theoretical and experimental nuclear physics, and nuclear chemistry.

KEK started low-energy nuclear physics activity at RIBF in 2011 under the research partnership system. The newly constructed isotope separator KISS will be available for the users in near future.

The activities of CNS, Niigata, and KEK are reported in the following pages.

Partner Institution
Center for Nuclear Study, Graduate School of Science
The University of Tokyo

1. Abstract
The Center for Nuclear Study (CNS) aims to elucidate the nature of nuclear system by producing the characteristic states where the Isospin, Spin and Quark degrees of freedom play central roles. These researches in CNS lead to the understanding of the matter based on common natures of many-body systems in various phases. We also aim at elucidating the explosion phenomena and the evolution of the universe by the direct measurements simulating nuclear reactions in the universe. In order to advance the nuclear science with heavy-ion reactions, we develop AVF upgrade, CRIB and SHARAQ facilities in the large-scale accelerators laboratories RIBF. We started a new project OEDO for a new energy-degrading scheme is proposed, where a RF deflector system is introduced to obtain a good quality of low-energy beam. We promote collaboration programs at RIBF as well as RHIC-PHENIX and ALICE-LHC with scientists in the world, and host international meetings and conferences. We also provide educational opportunities to young scientists in the heavy-ion science through the graduate course as a member of the department of physics in the University of Tokyo and through hosting the international summer school.

2. Major Research Subjects
(1) Accelerator Physics
(2) Nuclear Astrophysics
(3) Nuclear spectroscopy of exotic nuclei
(4) Quark physics
(5) Nuclear Theory
(6) SHARAQ project
(7) Active Target Development

3. Summary of Research Activity
(1) Accelerator Physics

One of the Major tasks of the accelerator group is the AVF upgrade project that includes development of ion sources, upgrading the AVF cyclotron of RIKEN and the beam line to CRIB. Development of ECR heavy ion sources is to provide a new HI beams, higher and stable beams of metallic ions, and to improve the control system. The Hyper ECR and the Super ECR sources provide all the beams for the AVF cyclotron and support not only CRIB experiments but also a large number of RIBF experiments. Injection beam monitoring and control are being developed and studied. Detailed study of the optics from the ion sources are expected to improve transmission and qualities of beams for the RIBF facility.

(2) Nuclear Astrophysics

The nuclear astrophysics group in CNS is working for experiments using the low-energy RI beam separator CRIB.

In September, 2013, beta-delayed alpha decay of 16N, which is relevant for the astrophysical 12C(a,g) reaction rate,was measured at CRIB using an active target system (GEM-MSTPC).
Many decay events were detected from 16N beam particles stopped in the active target. 15O and 10Be beams were produced for the first time at CRIB, and both beams will be used for resonant scattering experiments.
Based on recent collaboration on nuclear astrophysics at CRIB, two memorunda of understanding on the collaborated research have been made between CNS and IBS (Korea), and CNS, INFN-LNS (Italy) and CNS-SKKU (Korea).

(3) Nuclear structure of exotic nuclei

The NUSPEQ (NUclear SPectroscopy for Extreme Quantum system) group studies exotic structures in high-isospin and/or high-spin states in nuclei. The CNS GRAPE (Gamma-Ray detector Array with Position and Energy sensitivity) is a major apparatus for high-resolution in-beam gamma-ray spectroscopy. Missing mass spectroscopy using the SHARAQ is going to start as another approach on exotic nuclei. In 2013, the following progress has been made.

Experimental programs under the EURICA collaboration were performed for studying evolution of deformation in neutron-rich Z~60 nuclei, which are being analyzed now. High-spin states in A~40 nuclei were measured at Tandem ALTO facility at IPN Orsay by using fusion reaction, where a new candidate of superdeformed states were found in ^{35}S.

Gamow-Teller transitions of ^{8}He were studied by the (p,n) reaction in inverse kinematics, where a prominent sharp peak at Ex~8 MeV was found to be the Gamow-Teller resonance. Exothemic charge exchange reactions (^{8}He,^{8}Li*(1+)) on ^{12}C and ^{4}He are being analyzed now. Experiment on the tetra-neutron system via the ^{4}He(^{8}He,^{8}Be)4n reaction is being analyzed, where several tens of events were identified to be candidates of the 4n system just above the threshold.

The readout system of 14 detectors of the CNS GRAPE was upgraded, where digital pulse data taken by sampling ADCs are analyzed by FPGAs on boards.

Experimental setup of studying tetra neutron system using the double-charge exchange reaction ^{4}He(^{8}He,^{8}Be)4n at 200 A MeV was prepared for the measurement in April 2012.

(4) Quark Physics

Main goal of the quark physics group is to understand the properties of hot and dense nuclear matter created by colliding heavy nuclei at relativistic energies. The group has been involved in the PHENIX experiment at Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory, and the ALICE experiment at Large Hadron Collider (LHC) at CERN.

As for PHENIX, the group has been concentrating on the physics analysis involving leptons and photons; dark photon searches in low mass Dalitz decays, J/ψ production in ultra-peripheral Au+Au collisions, and electron measurement from semi-leptonic decay of heavy flavor mesons which uses the Si VTX detector subsystem.

As for ALICE, the group has involved in the data analyses, which include production of multi-particle correlation in Pb+Pb collisions, nuclear modification of energetic neutral pions in Pb+Pb collisions, and measurement of low-mass lepton pairs in Pb+Pb and p+Pb collisions. The group started to involve in the ALICE-TPC upgrade using a Gas Electron Multiplier (GEM) in 2012. Systematic studies of gain stability, ion back flow, and energy resolutions with various field configurations are underway at CNS and at CERN. Performance evaluation of the COBRA-GEM for the ALICE-TPC upgrade is underway.

R&D of GEM and related techniques has been continuing. Development of resistive GEM with resistive anodes and GEM with glass insulator have been progressing in collaboration with the Tamagawa group of RIKEN.

(5) Nuclear Theory

The nuclear theory group has been promiting the RIKEN-CNS Collaboration project on large-scale nuclear structure calculations since 2001 and maintain its PC cluster. Based on this experience and its achievements, we participated in activities of HPCI Strategic Programs for Innovative Research (SPIRE) Field 5 “The origin of matter and universe” since 2011. The SPIRE project aims at an integral understanding of the origin and structure of matter and the universe utilizing the K computer.

In the SPIRE project, we are in charge of the elucidation of nuclear prop-erties using ultra large-scale simulations of quantum many-body systems and its applications. In order to perform large-scale shell-model calcu- lations, we developed an efficient computer program of the Monte Carlo Shell Model (MCSM) method for massive parallel computation, and per- formed benchmark calculations at K computer. We have studied both the medium-heavy and light nuclei with large model space on K computer in 2013. In medium-heavy nuclei, we successfully describe the shape coexis- tence for 68Ni. In light nuclei, systematic calculations have been performed with increasing the number of the major shells. The α cluster structure in Be isotopes has been also studied.

(6) SHARAQ project

A main subject of the SHARAQ program is charge-exchange reactions induced by heavy-ion beams, with which a variety of selectivities in transferred quantum numbers, ΔS, ΔT, ΔTz, ΔL etc, are available.

This year SHARAQ group made preparations for the coming two experiments.
One was for the develpment of parity-transfer probe (^{16}O, ^{16} F(g.s.)) reaction.
A MWDC was installed at the exit of the first dipole magnet of SHARAQ to track the proton produced from the instant decay of ^{16} F(g.s.) → ^{15} F + p.
The other was for the mass measurement around A~50 isotopes including ^{54}Ca by the Bρ-TOF method.
For this purpose, a set of CVD diamond detectors was developed and we attained a time resolution of 27~ps.
Also a detector system for tagging the isomers at the final focal plane of the SHARAQ was developed.

As a project of near future, a letter of intent was submitted to NP-PAC aiming at studying spin-isospin response of isomers by (p,n) reaction.

(7) Active Target Development

In a project of active target development launched as an intergroup collaboration in 2009, two types of active target have been developed. Technical development such as a capability of gating operation of GEM has been done for one active target and the alpha emission following the beta decay of ^{16}N was measured with the same active target. The development for the high intensity beam injection is being performed for the other active target. The test experiment with a high intensity ^{132}Xe beam was performed.

Director

Takaharu OTSUKA

Scientific Staff

Susumu SHIMOURA (Professor)
Hideki HAMAGAKI (Professor)
Kentaro YAKO (Associate Professor)
Noritaka SHIMIZU (Project Associate Professor)
Hidetoshi YAMAGUCHI (Lecturer)
Shin'ichiro MICHIMASA (Assistant Professor)
Taku GUNJI (Assistant Professor)
Shinsuke OTA (Assistant Professor)

Guest Scientists

Hiroaki UTSUNOMIYA (Guest Professor)
Yutaka UTSUNO (Guest Associate Professor)

Technical Staff
Norio YAMAZAKI
Yukimitsu OHSHIRO

Techinical Assistants
Shin-ichi WATANABE (~3.2013)
Hiroshi KUREI
Takehiko SENOO
Akira YOSHINO
Shoichi YAMAKA
Kazuyuki YOSHIMURA
Masahiko TANAKA

Project Research Associates
Hisayuki TORII (~3.2013)
Tooru YOSHIDA
Yoritaka IWATA (1.2013~)

Post Doctoral Associates
Shuichiro EBATA (~3.2013)
Yorito YAMAGUCHI
Taro NANAO
David, STEPPENBECK
Tomoaki TOGASHI (3.2013~)

Graduate Students
David. M KAHL
Masashi, MATSUSHITA
Akihisa TAKAHARA
Hiroyuki MIYA
Ryoji AKIMOTO (~3.2013)
Hiroshi TOKIEDA
Tomoya TSUJI
Shintaro GO (~3.2013)
Shoichiro KAWASE
ShinIchi HAYASHI
KeiIchi KISAMORI
Motonobu TAKAKI
Tang T. LEUNG (~3.2013)
Yuko SEKIGUCHI
Rin YOKOYAMA
Yuki KUBOTA
CheongSoo LEE
Kohei TERASAKI
Motoki KOBAYASHI
Kentaro YUKAWA (4.2013~)

Administration Staff
Hiroshi YOSHIMURA
Ikuko YAMAMOTO
Takako ENDO
Yukino KISHI
Toshiko ITAGAKI
Yuko SOMA

Partner Institution
Center for Radioactive Ion Beam Sciences, Institute of Natural Science and Technology Niigata University

1. Abstract

The Center for Radioactive Ion Beam Sciences, Niigata University, aims at uncovering the properties of atomic nuclei and heavy elements and their roles in the synthesis of elements, with use of the advanced techniques of heavy ion and radioactive ion beam experiments as well as the theoretical methods. Main research subjects include the measurements of various reaction cross sections and moments of neutron- or proton-rich nuclei, synthesis of super-heavy elements and radio-chemical studies of heavy nuclei, and theoretical studies of exotic nuclei based on quantum many-body methods and various nuclear models. In addition, we promote interdisciplinary researches related to the radioactive ion beam sciences, such as applications of radioactive isotopes and radiation techniques to material sciences, nuclear engineering and medicine. Many of them are performed in collaboration with RIKEN Nishina Center and with use of the RIBF facilities. The center emphasizes also its function of graduate education in corporation with the Graduate School of Science and Technology, Niigata University, which invites three researchers in RIKEN Nishina Center as visiting professors.

2. Major Research Subjects

(1) Reaction cross section and radii of neutron-rich nuclei
(2) Production of superheavy nuclei and radiochemistry of heavy elements
(3) Nuclear theory

3. Summary of Research Activity

(1) Reaction cross section and radii of neutron-rich nuclei

The experimental nuclear physics group has studied nuclear structure with the RI beam. One of our main interests is the interaction/reaction cross section measurements. They are good probes to investigate nuclear matter radii and nuclear matter distributions including halo or skin structure. Recently we have measured the interaction sections of Ne, Na, Mg and Al isotopes from stable region to neutron drip line with BigRIPS in RIBF. We found a large enhancement of cross section at ^{31}Ne. It suggests that ^{31}Ne nucleus has a neutron halo. It is consistent with the soft E1 excitation measurement. We also found an enhancement at ^{37}Mg. For odd-Z nuclei, Na and Al, we did not find such a large enhancement from neighbor isotopes. The systematics of observed interaction/reaction cross sections shows the changing of nuclear structure from stable region to neutron drip line via island of inversion.

(2) Production of superheavy nuclei and radiochemistry of heavy elements

The nuclear chemistry group has been investigating decay properties of super-heavy nuclei, measured the excitation functions of rutherfordium isotopes, and clarified the ambiguity of the assignment of a few-second spontaneously fissioning isotope of 261Rf. The new equipment designed for measurement of short-lived alpha emitters is under development.
For the chemistry research of super-heavy elements, preparatory experiments, such as solvent extraction for the group 4, 5, and 6th elements and gaseous phase chemistry for group-4 elements, have been performed using radioisotopes of corresponding homolog elements.

(3) Nuclear theory

One of the main activities of the nuclear theory group concerns with developments of the nuclear density functional theory and exploration of novel correlations and excitations in exotic nuclei. A fully selfconsistent scheme of the quasiparticle random phase approximation (QRPA) on top of the Skyrme-Hartree-Fock-Bogoliubov mean-field for deformed nuclei has been developed in the group. The versatility of this method to describe the deformation splitting of the giant resonances associated with the onset of deformation has been demonstrated for the first time by the intensive numerical calculation performed for Nd and Sm isotopes. The same method is further extended to describe the spin-isospin modes of excitation in deformed neutron-rich nuclei. A successful description of the Gamov-Teller beta-decay transition rate in the neutron-rich Zr isotopes is achieved with this method. Another correlation of interest in neutron-rich nuclei is the pair correlation, for which the spatial di-neutron correlation has been a key topic. Applying the continuum QRPA to the pairing modes of excitation in neutron-rich Sn isotopes, we predict the emergence of an anomalous pair vibration for isotopes with A>132. Furthermore the new mode is predicted to exhibits the di-neutron character. In addition to these studies, activities related to the proton-neutron pairing, the di-neutron correlation in the asymptotic tail in drip-line nuclei, the quasiparticle resonances in unbound odd-N nuclei are under way. Cluster structure and the ab initio studies of light nuclei are also important research subjects of the theory group.

Director

Masayuki MATSUO (Professor)

Scientific Staff

Hisaaki KUDO (Professor)
Takashi OHTSUBO (Associate Professor)
Shin-ichi GOTO (Associate Professor)
Shigeyoshi AOYAMA (Associate Professor)
Takuji IZUMIKAWA (Associate Professor)
Kenichi YOSHIDA (Assistant Professor)
Kazuhiro OOE (Assistant Professor)

Jun GOTO (Assistant Professor)

Post Doctoral Associate
Hirotaka SHIMOYAMA

Graduate Students
Kazuya HIROKAWA
Yoshihiko KOBAYASHI
Junpei ANZAI
Sho KANESAWA

Partner Institution
Radioactive Nuclear Beam Group, IPNS (Institute for Particle and Nuclear Studies) KEK (High Energy Accelerator Research Organization)

1. Abstract

The on-line tests of the KISS (KEK Isotope Separation System) were performed by using ^{56}Fe and ^{124}Xe beam from RIKEN Ring Cyclotron. The performance (overall extraction efficiency and selectivity) with increasing those beam intensities was investigated. Especially in the test using the ^{124}Xe beam, the target (^{198}Pt)-recoils were successfully extracted as singly charged ions. Although the overall efficiency achieved so far was smaller by about one order of magnitude than expected, measurements of lifetime of beta-decaying Pt-like recoils are to be performed, while further developing the performance by using ^{136}Xe beam. Some other activities related to the research subjects itemized below are also included.

2. Major Research Subjects

(1) Radioactive isotope beam production and manipulation for nuclear experiments.
(2) Explosive nucleosyhnthesis (rp- and r-process).
(3) Heavy ion reaction mechanism for producing heavy neutron-rich nuclei.
(4) Single particle states of neutron-rich nuclei by isobaric analog resonances.
(5) Development of RNB probes for materials science applications.

3. Summary of Research Activity

The KISS is an element-selective isotope separator using a magnetic mass separator combined with in-gas-cell resonant laser ionization. The gas cell filled with argon gas of 50 kPa is a central component of the KISS for extracting only the element of interest as ion beam for subsequent mass separation. In the cell, the element primarily produced by low-energy heavy ion reactions is stopped (thermalization and neutralization), transported by buffer gas (argon gas-flow of ~50 kPa in the present case), and then re-ionized by laser irradiation just before the exit. Therefore, it is desirable that the gas cell would keep high performance of extraction efficiency and selectivity (ratio of the number of ions extracted with laser operation to that without laser operation) throughout these processes. The absolute extraction efficiency and selectivity of the gas cell was investigated in the on-line test experiments where stable beams of ^{56}Fe and ^{124}Xe were directly injected for providing the gas cell with controlled number of atoms (^{56}Fe case) and energetic target (a thin foil of ^{198}Pt irradiated by ^{124}Xe)-like recoils, respectively. Also investigated were the so-called plasma effects which are thought to degrade the performance due to the plasma formed in the cell by the primary beam injection.

Injecting into the cell the ^{56}Fe beam of 90 MeV/nucleon from the RRC after being properly energy-degraded to 1.5 MeV/nucleon for complete stop around the center of the cell, we extracted laser-ionized ^{56}Fe atoms. Here, we have used a modified gas-cell, which was originally designed to reduce the plasma effect, but more deeply bent for better shadowing the beam irradiation region (plasma formation region) than previously used. The extraction efficiency for ^{56}Fe was measured to be about 0.25% and almost constant with increasing primary beam intensity (increasing number of injected iron atoms). The selectivity of about 50 was achieved, though showing a moderate deterioration by beam intensity of up to 4 pnA. Although the gas cell was well baked (outgassed) for the test, additional contamination was observed due to the beam irradiation, by which the laser-ionized ^{56}Fe atoms were fragmented into ^{56}Fe (A=56), ^{56}Fe (H_2O) (A=74) and $^{56}Fe\ Ar_2$ (A=136) at the same intensity. Once the contamination could be removed, the extraction efficiency for ^{56}Fe would be restored accordingly.

After successfully demonstrating the performance of the KISS with iron, a series of online tests are planned to check the universality of the performance (if the performance demonstrated is element-independent). In a first test along the line, we used the ^{198}Pt atoms introduced into the gas cell as recoils out of the ^{198}Pt target by elastic scattering of ^{124}Xe of 10.75 MeV/nucleon from the RRC. The transformation of those laser-ionized ^{198}Pt atoms to sidebands was different from what was observed for ^{56}Fe; the laser-ionized-^{198}Pt - related ions were mostly observed as ions of ^{198}Pt, ^{198}Pt (H_2O), and $^{198}Pt\ Ar_2$ in the intensity ratio of 1:4:10. The extraction efficiency for ^{198}Pt in the form of $^{198}Pt\ Ar_2$ was estimated to be about 0.15% from the cross section of elastic scattering between ^{198}Pt and ^{124}Xe. Even with the present efficiency of 0.15%, the beta-decay half-lives of more than 20 unknown nuclei around N = 126 and Z<82 would be measured. While addressing the current development issues, we are going to measure the lifetime of beta-decaying Pt-like recoils in the year of 2014.

For the beta-decay lifetime measurements of the nuclei, mostly having $Q\beta$ values as small as 2 MeV, two double-layered plastic scintillators holding the implantation spot on a tape transport station in-between will be used. Two 0.5-mm and 1.0-mm thick scintillators with a size of 20-cm wide and 14-cm height were fabricated and tested. Almost full solid angle can be covered with the size (geometrical acceptance of 80%). When we measured the detection efficiency of the thinner scintillator wrapped with the aluminized Mylar, we found a rather large position dependency of the detection efficiency. While using instead a reflection sheet which is often used for the liquid crystal display, the position dependence as well as the detection efficiency was improved. Due to the thinness of the tested, multi-reflection of the scintillation lights in the scintillator seemed to make the efficiency worse. Using the $^{90}Sr/^{90}Y$ source, the coincidence efficiency of the two layers was observed to be 60% which is consistent with the GEANT simulation. The remaining 20% were almost stopped in the first layer, indicating the absolute efficiency of close to 100%. The tape transport station equipped with the plastic scintillators will be installed in the beginning of the 2014.

As a continuing effort for search for effective laser ionization scheme of elements of our interest (Z<82), a reference cell was fabricated, and is currently being used to search for auto ionizing states in Ta, W, and etc…

In order to investigate the feasibility of the multi-nucleon transfer (MNT) in the reaction system of ^{136}Xe on ^{198}Pt for producing heavy neutron-rich isotopes around the mass number of 200 with the neutron magic number of 126, the analysis of the data taken at GANIL in March 2012 is under progress. Using the elastic scattering data for ^{136}Xe, special efforts are currently being paid for extracting the absolute cross sections of projectile-like MNT channels, as well as of target-like fragments (TLFs) identified by their de-excitation gamma-rays. Some of the results, especially the cross sections of TLFs, would be directly compared to those estimated from the ongoing test experiments of the KISS as mentioned above.

The systematics of the single particle structure of even-odd nuclei along isotopic and/or isotonic chains give insights into the evolution of the relevant nuclear shell structure. We have investigated the first three bound states of ^{31}Mg by measuring their isobaric analog resonances through the proton resonance elastic scattering off ^{30}Mg in order to pin down the underlying mechanism of the island of inversion. The experiment was performed by using the post-accelerator REX-ISOLDE at CERN. A thick polyethylene target of 5.6 mg/cm^2 was impinged on by the ^{30}Mg ion beam accelerated up to 2.92 MeV/nucleon. The excitation function of the protons scattered around 0 degree in the laboratory frame was measured. The angular momenta (l) and spectroscopic factors (S^{pp}) of the first three bound states in ^{31}Mg were deduced. The l values are consistent with those previously assigned by the beta decay. Comparing the S^{pp} with the spectroscopic factors for the N=19 nuclei ^{37}Ar and ^{35}S measured by the (d, p) reaction shows that the S^{pp} for the positive parity states in ^{31}Mg were largely quenched. This means that the overlap between the wave function of the positive parity state and that of the neutron coupled to the ground state of ^{30}Mg is small, demonstrating that the border of the island of inversion is placed between ^{30}Mg and ^{31}Mg.

We have developed a nanoscale diffusion measurement method using alpha-emitting radioactive ^{8}Li tracer. In the method, while implanting a pulsed ^{8}Li beam of 8 keV, the alpha particles emitted at a small angle ($\theta = 10\pm1^\circ$) relative to a sample surface were detected as a function of time. The method has been successfully applied to measure the lithium diffusion coefficients for an amorphous Li4SiO4 - Li3VO4 (LVSO) of several hundreds nm in thickness, well demonstrating that the present method has a sensitivity to the diffusion coefficients down to a value of 10^{-12} cm^2/s, more sensitive by about two orders magnitude than previously achieved. It should be noted that in the previous method sensitive to microscale diffusion the angles subtended by the α-particle detectors were within $63 \pm 14^\circ$ and the incident energy of ^{8}Li was about 4 MeV. The present method is therefore supposed to be sensitive to nanoscale Li diffusion as compared to the previous method where tracer atoms were deeply implanted (several micrometers).

Group Leader
Hiroari MIYATAKE

Members
Yoshikazu HIRAYAMA
Nobuaki IMAI
Yutaka WATANABE
Hironobu ISHIYAMA
Sunchan JEONG
Michihiro OYAIZU
Yung-Hee KIM (PhD. Student, Seoul National University)
Momo MUKAI (D. Student, Tsukuba University)
Sota KIMURA (D. Student, Tsukuba University)

Events (April 2013 - March 2014)

RNC

2013	Apr. 1	Start of Nuclear Spectroscopy Laboratory, taking over Polarized RI Beam Team Start of Research Group for Superheavy Element
	Apr. 20	Wako Open campus
	May 7	RBRC Managing and Steering Committee held in Wako Campus
	May 28	New-Comers Seminar
	May 30	Effect of MOU between College of Science, Yonsei Univ. (Korea) and RNC
	Jun. 5	Effect of MOU between RNC and Department of Physics, Kyungpook National University (Korea)
	Jun. 26 - 27	RIBF Users Meeting 2013
	Jun. 28 - 29	RNC NP-PAC
	Jul. 2-3	RNC ML-PAC
	Jul. 11	Scientific Policy Committee (FY2013)
	Aug. 6 - 16	Nishina School
	Aug. 19 - 23	HPCI,京大基研、計算基礎科学連携拠点共催サマースクール「クォークから超新星爆発まで―基礎物理の理想への挑戦―」
	Aug. 28	Effect of MOU between Department of Physics, Korea Univ. and RNC
	Sep. 12	Effect of MOU For the use of MINOS device at RIKEN between CEA-DSM and RNC
	Oct. 2	President of Vietnam National University of Hanoi-Hanoi University of Science visits RNC
	Oct. 16	Effect of MOU between Institute of Basic Science, Rare Isotope Science Project, Korea and RNC for research collaboration in the area of rare ion accelerator and related fields
	Oct. 23	Effect of Agreement for International Joint Graduate School Program between RIKEN and Department of Physics, Yonsei University (Korea)
	Oct. 31 - Nov. 1	RBRC Scientific Review Committee
	Nov. 9 - 10	Participation in Science Agora 2013 held in Odaiba
	Dec. 13 - 14	RNC NP-PAC
	Dec. 27	Effect of Addendum No.26 to the Memorandum of Understanding for the RD51 Collaboration Participation of the Nishina Center for Accelerator-Based Science, RIKEN
2014	Jan. 30	Effect of Extension of MoU between RNC and Michigan State University
	Feb. 4	Effect of Memorandum of Understanding for Research Collaboration between RNC and the "Horia Hulubei" National Institute of Physics and Nuclear Engineering Bucharest-Magurele, Romania
	Feb. 20	Associate Chief Scientist Interim Review Program (Dr. Emiko HIYAMA)
	Feb. 26	Effect of Statement of Work for MOU between RNC and MSU

CNS

2013	Aug. 28 - Sep. 03	The 12th CNS international Summer School (CNSS13) http://indico.cns.s.u-tokyo.ac.jp/conferenceDisplay.py?confId=81

Awards (April 2013 - March 2014)

Awardee	Laboratory	Award	Organization	Date
Hiroshi Imao	Accelerator R&D Team	ACFA-IPAC13 Accelerator Prize	The Asian Committee for Future Accelerators	May 16
Emiko Hiyama	Strangeness Nuclear Physics Laboratory	The 33rd annual Saruhashi Award	The Association for the Bright Future of Women Scientists	May 25
Kimiko Sekiguchi	Visiting Scientist Spin Isospin Laboratory	15th Morita Fellowship Award	Japanese Association of University Women	May 25
Hiroshi Imao, Hiroki Okuno & Hironori Kuboki	Accelerator R&D Team / Accelerator Group / Special Postdoctoral Researcher, Accelerator Group	PASJ Award for Technical Contributions	Particle Accelerator Society of Japan	Aug. 4
Tomoko Abe & 7 others	Accelerator Applications Research Group	Excellent Presentation Award: 123rd Meeting of The Japanese Society of Breeding	Japanese Society of Breeding	Aug. 4
Tomoko Abe	Accelerator Applications Research Group	The BSJ Special Prize for Botanical Research	The Botanical Society of Japan	Sep. 14
Tomoko Abe & 3 others	Accelerator Applications Research Group	Excellent Presentation Award: 124th Meeting of The Japanese Society of Breeding	Japanese Society of Breeding	Nov. 19
Nobuyuki Chiga	Visiting Technician Research Instruments Group	FY2013 Technical Division Award: Graduate School of Science	Technical Division Graduate School of Science Tohoku University	Nov. 28
Yasushi Watanabe, et al.	RIKEN Nishina Center for Accelerator-Based Science	Science Agora Award	Japan Science and Technology Agency	Dec. 26

Press Releases (April 2013 - March 2014)

RNC

Apr. 4	Unvail the last 1/100 seconds of mass falling into a black hole – the first discovery of the high energy X-rays from a gas just falling into a black hole	Shin'ya Yamada, et al. (High-Energy Astrophysics Lab.)
Jul. 17	Development of high precision mass spectrometry for short-lived nuclei, MRTOF --- sub ppm precision with a few millisecond flight times ---	Michiharu Wada, et al. (SLOWRI Team)
Sep. 14	From quarks to the structure of neutron stars – intimate relation between the quark mass and the neutron-star mass is revealed –	Takumi Doi, et al. (Quantum Hadron Physics Lab.)
Oct. 9	Discovery of exotic isomers with a magic number	Hiroshi Watanabe, Shunji Nishimura & Hiroyoshi Sakurai (Radioactive Isotope Physics Lab.)
Oct. 10	Evidence for a new nuclear ‘magic number’ of 34 --- a key to access a dream region of ‘island-of-stability’	David Steppenbeck & Satoshi Takeuchi (Radioactive Isotope Physics Lab.)
Oct. 11	Harvest of salt-tolerance rice in saline paddy field	Tomoko Abe (Radiation Biology Team)
Nov. 20	‘Magic numbers’ disappear and expand area of nuclear deformation	Pieter Doornenbal ＆ Hiroyoshi Sakurai (Radioactive Isotope Physics Lab.)
Feb. 20	Asymmetric explosion of core-collapse supernovae – the first mapping of radioactive 44Ti nuclei in Cassiopeia A	Takao Kitaguchi (High-Energy Astrophysics Lab.)