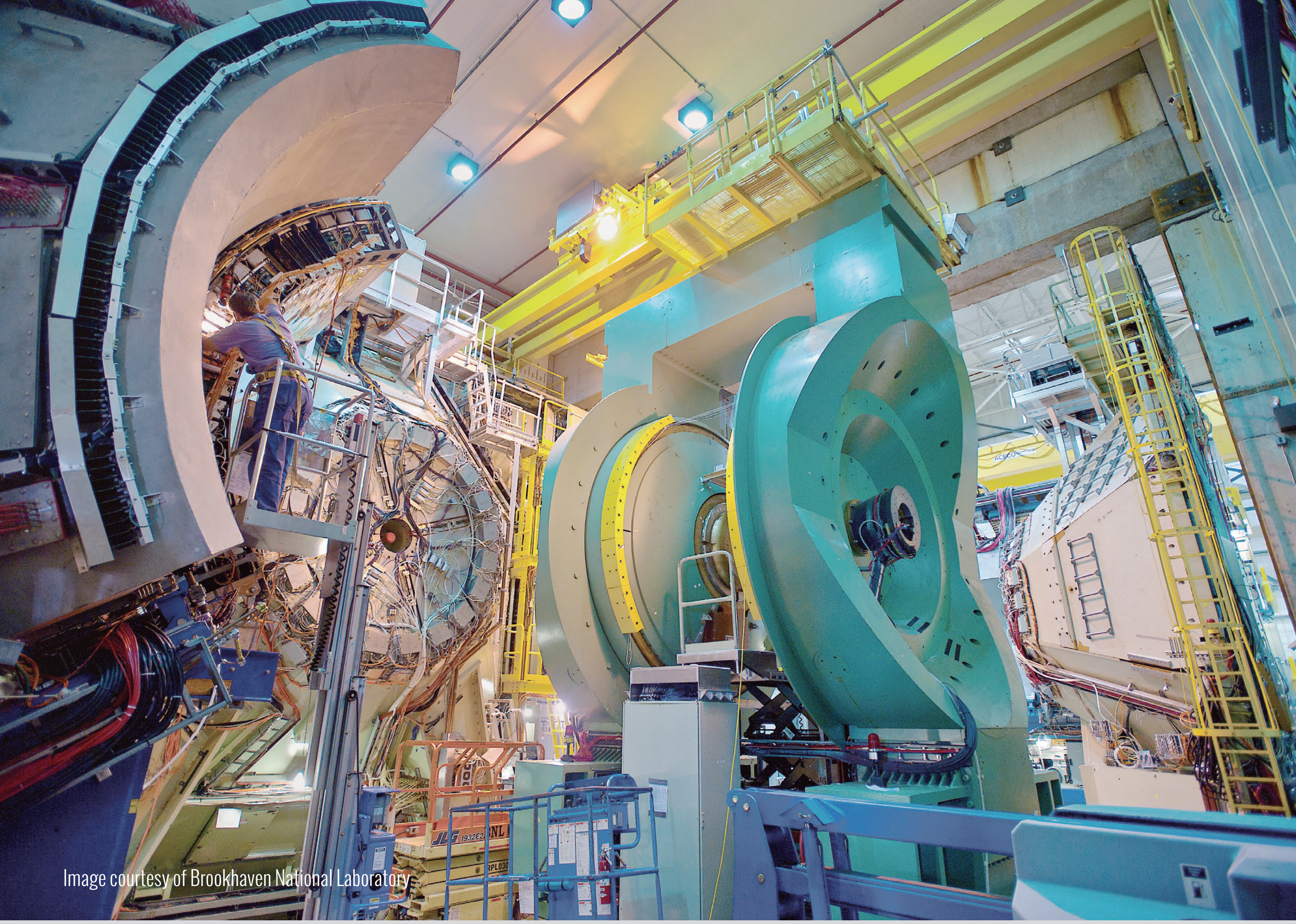

PHENIX

- looking at hot and cold nuclear matter and resurrecting itself again and again

The Relativistic Heavy Ion Collider, RHIC, at Brookhaven National Laboratory on Long Island, NY, was built to study the conditions in an early universe shortly after the Big Bang. In that epoch the temperature of the universe was so hot, that quarks and gluons, mediators of the strong interaction, were not yet condensated into hadrons such as protons and neutrons. This phase of the universe is known as the quark-gluon plasma (QGP). Its existence was predicted and RHIC was set to discover it which it eventually did.

At the same time also the internal structure of the most fundamental building blocks of the visible world today, protons and neutrons was not understood well and particularly the spin composition between quarks, gluons and their orbital angular momenta were at odds with earlier nucleon models. RHIC was also set to understand the role of gluon spins and sea quarks. The spin program was realized at the initiative and with substantial support of RIKEN and greatly improved our understanding of cold nuclear matter and brought in turn new surprises.

PHENIX

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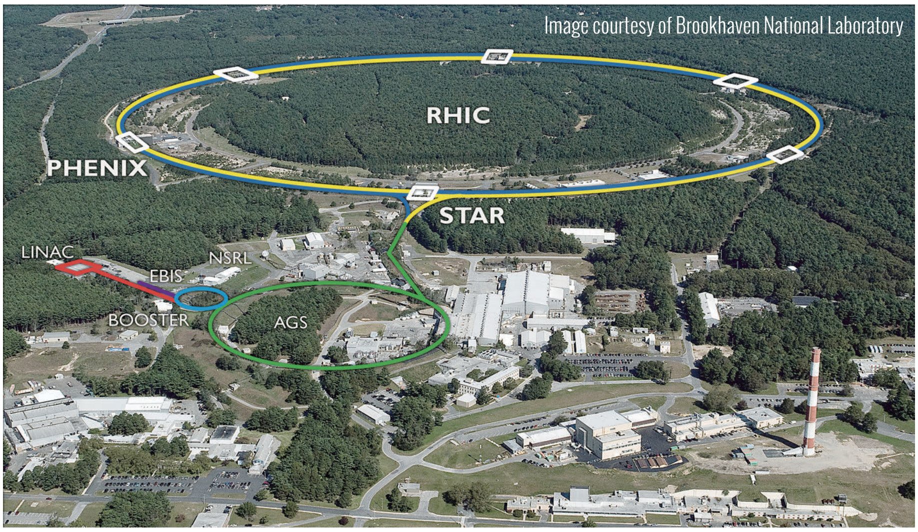

Figure 1: Aerial view of the RHIC accelerator complex including pre-accelerators and locations of currently operating detectors.

While at the beginning of RHIC one typical collider detector was already approved to be built, several other proposals for more dedicated detectors were initially rejected out of funding constraints. As a result these rejected proposals worked together and, like the fabled bird, rose from the ashes being appropriately named PHENIX (though the official name stands for Pioneering High Energy Nuclear Interaction eXperiment). PHENIX's strong points were the rather precise central detectors, especially electromagnetic calorimetry, forward muon detectors and high rate data taking capabilities at the expense of coverage. Currently about 400 collaborators from 78 institutions (including 11 Japanese) in 14 countries are participating in the PHENIX experiment.

With this initial detector configuration, it was possible to both find the QGP [1] and learn about its properties. One telltale sign of the QGP was the suppression of hadrons and jets at higher energies due to the additional interactions within the hot, dense QGP medium. In contrast, high energetic photons were not suppressed as they are only interacting electromagnetically. These features are summarized in Figure 2.

One of the main surprises was that this QGP does not behave like a gas but more like a perfect liquid with a very small viscosity. With the help of light emitted inside the plasma it was even possible to roughly determine the temperature of the QGP [2] within models which led to the 2011 Nishina

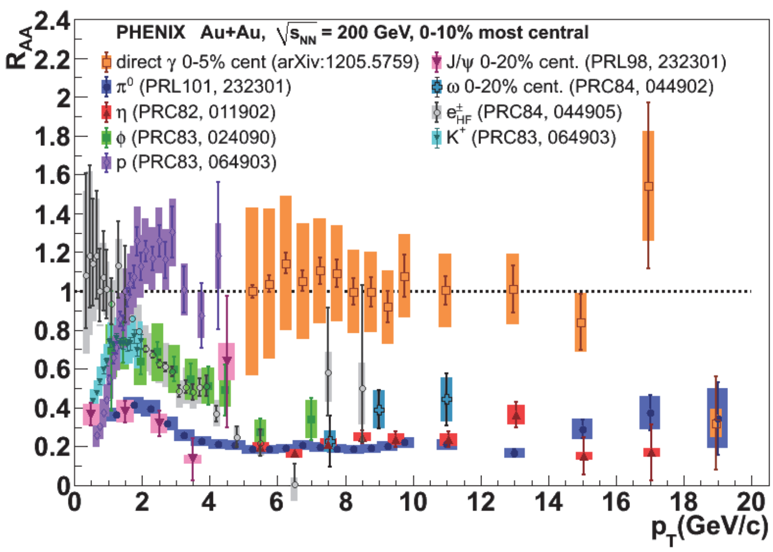

Figure 2: Summary of cross section ratios between most central AuAu collisions and proton proton collisions. All hadrons seem to be suppressed at high transverse momenta as expected when traversing the Quark-gluon plasma.

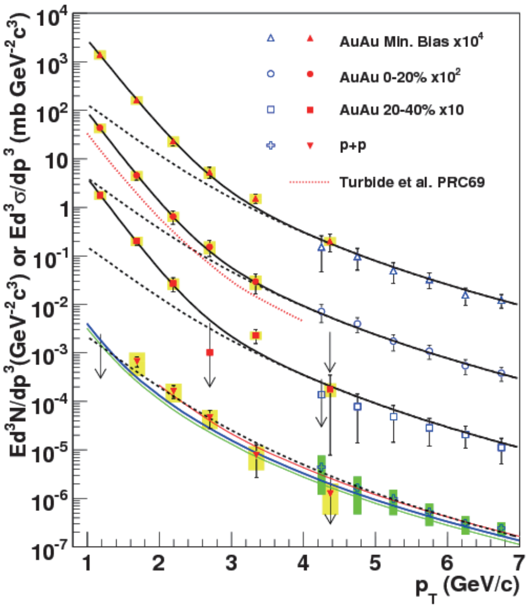

Figure 3: Photon cross sections in AuAu and proton proton collisions. An enhancement indicates the thermal radiation of the Quark-gluon plasma and allows estimating its temperature.

Memorial Prize [3]. The low-energetic photon spectra are shown in Figure 3 for Au-Au collisions at various centralities in comparison to “cold” proton-proton collisions and display an additional contribution due to the thermal radiation within the QGP.

In recent years the focus moved towards studying QGP properties using heavy quarks which required the installation of a silicon vertex tracker. A large part of this upgrade was performed by RIKEN.

For the study of the spin structure of the nucleon for a long time spin double spin asymmetries in polarized proton-proton collisions were small, ruling out extreme gluon spin contributions to the spin of the nucleon as suggested by early models (i.e., contributing several units of $\hbar$ to be mostly compensated by opposite orbital angular momentum). With the high statistics data sets in the years 2009 [4] at a collision energy of 200GeV and 2012/2013 [5] for energies of 510GeV it is now established that the gluon spin plays a substantial and potentially even dominant role [6] in the proton spin. Figure 4 displays the current knowledge of the total gluon spin contribution as a function of the minimum Bjorken variable x. To extend our knowledge to even lower x, more forward measurements are ongoing at RHIC while eventually an electron-ion collider will reach the lowest fractional momenta similar to HERA in the unpolarized case.

To evaluate the contribution of sea quarks the parity violation of the weak interaction was used in proton-proton collisions to select their contribution in real W boson production. Their contributions appear to be nonzero and not symmetric between up- and down-type flavors.

Furthermore, many transverse spin effects, originally expected to be low-energy phenomena, continue to surprise to the highest collisions energies available at RHIC with the RHIC experiments slowly unraveling its origins.

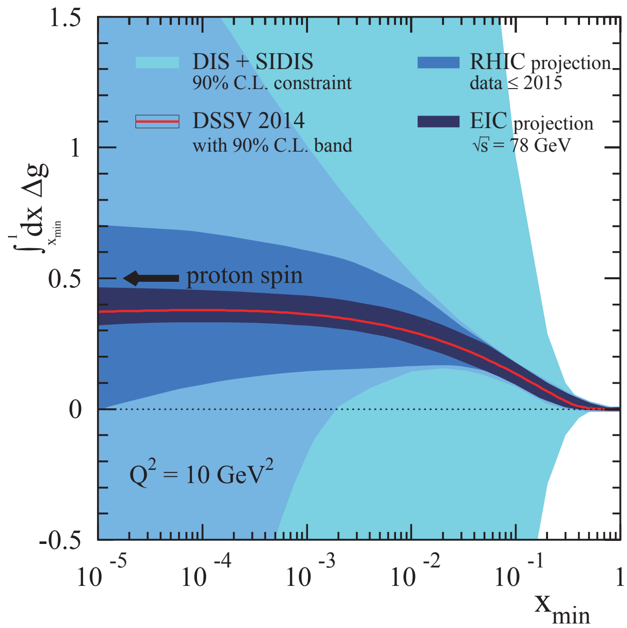

Figure 4: Running integral of the gluon spin contribution to the proton spin from non RHIC data (light blue), including published RHIC data, expected improvements and an eventual electron ion collider (in successively darker shades of blue). The RHIC data first showed a rather substantial contribution. [7]

As the name suggests, PHENIX has re-emerged already once and it is bound to do the same once more right now. The Heavy Ion physics interest at RHIC moves towards jets, and heavy quark-antiquark states to provide complementary measurements to the LHC heavy ion program. Also the study of the spin structure is interested to look at forward rapidities which allows to access transverse spin effects unique to RHIC at higher momentum fractions while also looking at lower momentum fractions to pin down the gluon spin in regions not covered yet.

As such, PHENIX is currently re-inventing itself as sPHENIX and forward sPHENIX concentrating on jet detection at central and forward rapidities with electromagnetic and hadronic calorimetry, tracking and the former BABAR 1.5 Tesla solenoid magnet being already transferred to BNL. These mostly new systems could then even re-rise yet again in the case the electron ion collider (EIC) is built at BNL as a zero-day EIC detector currently dubbed as ePHENIX.

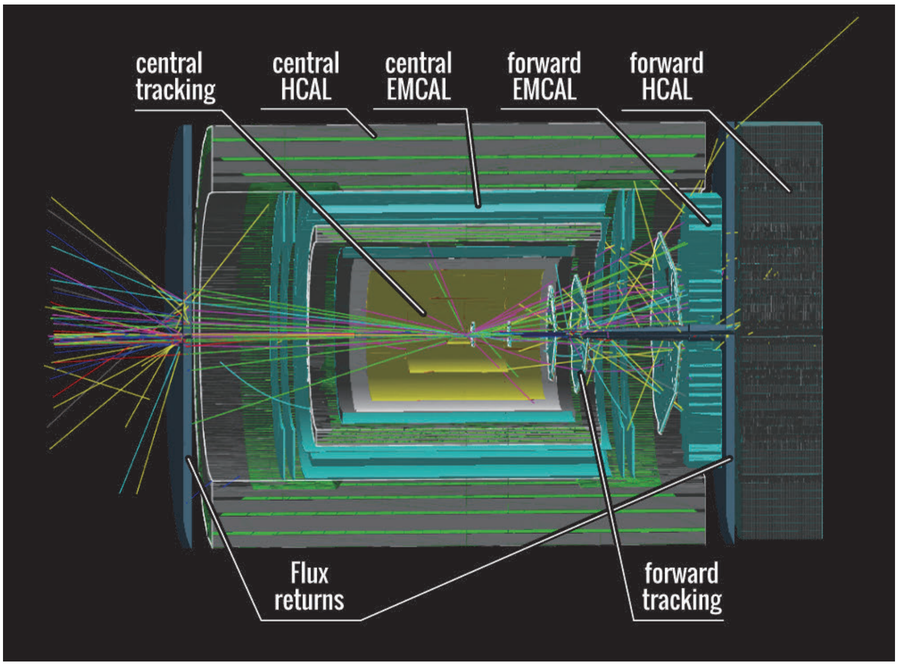

Figure 5: GEANT4 Rendering of the sPHENIX detector including forward upgrades currently under consideration in a 500 GeV proton-proton collision event.

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