High-resolution hadronic-atom X-ray spectroscopy with superconducting transition-edge-sensor microcalorimeters

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Hadronic atoms provide a unique laboratory to study the strong interaction between the hadron and atomic nucleus at the low-energy limit. Effects of the strong interaction are experimentally extracted by performing characteristic X-ray-emission spectroscopy of the most tightly bound energy levels, which are most perturbed by strong forces. As for kaonic atoms, many experiments have collected data on a variety of targets[1]; however, the energy resolution of conventional semiconductor X-ray spectrometers employed in the past measurements has been insufficient to detect small spectral effects attributed to the strong interaction. As a result, the depth of the K^--nucleus potential at zero energy remains still unknown. This is closely related to the recent investigations of bound states of the kaon in the nucleus and is one of the greatest concerns in the recent strangeness nuclear physics[2].

With the aim of providing a breakthrough to the current situation, we are preparing an ultra-high resolution X-ray measurement of kaonic atoms using a novel cryogenic X-ray detector, i.e., an array of superconducting transition-edge-sensor (TES) microcalorimeters which has been recently developed at NIST[3,4]. The energy resolution is about two orders of magnitude better than that of converntional silicon drift detectors (SDDs).

To demonstrate the feasibility of the X-ray spectroscopy with TES in a hadron beam environment, we recently performed a pioneering experiment by measuring pionic carbon X rays with a 240-pixel TES array using 173 MeV/c π^- beam at the πM1 beamline of Paul Scherrer Institute. Figure 1 shows the preliminary results of (a) a correlation plot of the measured X-ray time versus energy distributions for π^- triggered events, and (b) and (c) show the projections. A sharp peak from the pionic carbon 4-3 X-ray transition was successfully observed at 6.43 keV with a clear timing correlation with the beam. The characteristic X rays of Fe Kα1 (6.404 keV) and Fe Kα2 (6.391 keV) that are uncorrelated with beam timing originate from surrounded materials that are excited using an X-ray tube. The achieved average energy resolution is 5 eV (FHWM) at 6 keV in "beam-off" condition, and 8 eV in "beam-on" condition, while the energy resolution of a SDD used as a reference in this experiment is ~165 eV as shown in Fig. 1 (d).

This demonstration is the world's first application of a TES spectrometer to the hadronic-atom X-ray spectroscopy and a key milestone toward more general use of high-resolution microcalorimeter spectrometers at charged-particle beam lines.

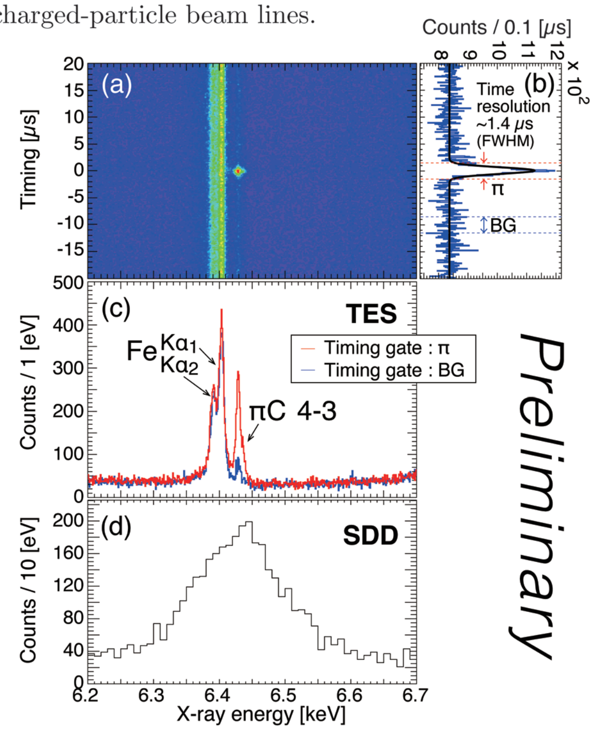

Fig. 1. Preliminary results of the measured X-ray time and energy distributions for π triggered events. (a) A correlation plot of the time difference between pion arrival and X-ray detection vs the X-ray energy measured by the TES array. (b) The projections on the time axis. (c) The projection on the energy axis. The energy spectra with two time gates, pions ("π") and background ("BG") indicated in (b), are shown. (d) An X-ray energy spectrum measured by the reference SDD.

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