A LYSO calorimeter prototype for muonic X-ray detection

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The Weinberg angle is an energy-dependent parameter that describes the mixing of electromagnetic and weak interactions. Measurements of the Weinberg angle at various energy scales are important as a precision test of the standard model and a search for new physics. The Weinberg angle can be determined via neutral current interactions. The most precise result was obtained at a low-energy scale by observing the atomic parity violation (APV) in cesium atoms.1)

When a nuclear Coulomb potential captures a negative muon, the muon forms an exotic bound state called a muonic atom. An APV experiment using muonic atoms provides a unique opportunity to search for physics beyond the standard model. In the 1990s, several experiments were conducted at the Paul Scherrer Institute.2) However, no parity-odd transition was observed because of difficulties in the experiment.

A new experiment using a high-intensity pulsed muon beam and a segmented calorimeter has been proposed to revisit this topic. The process of interest is the transition from the 2S state to the 1S state, which involves a one-photon emission. In the experiment, a segmented calorimeter consisting of Ce: LYSO crystals and silicon photomultipliers (SiPMs) detects X-rays from muonic atoms. The target energy resolution is 10% (FWHM) at 75 keV. As the first stage of the project, a calorimeter prototype was developed and tested at Port4 of the RIKEN-RAL muon facility.

Figure 1 illustrates the experimental setup. Muonic X-rays and decay electrons from a graphite target were detected using the prototype detector. The detector has two layers, each consisting of a 2-cm-square, 3-mm-thick crystal attached to four SiPMs (Hamamatsu S13360-3050CS) with an active area of 3-mm-square. The signals were amplified and shaped using EASIROC-based electronics and recorded with a waveform digitizer using DRS4.

Figure 2 shows the time spectra of electrons and X-rays. Since electrons penetrate the two detector layers, the coincidence analysis allowed us to distinguish between electron and X-ray events. Figure 3 shows an energy spectrum of muonic X-rays. The energy was calibrated with the 81 keV line of $^{133}$Ba. The peak structure was consistent with K X-rays of muonic carbon atoms. While the prototype demonstrated a sufficient time resolution, there is room for improvement in the energy resolution. A new version with improved light collection efficiency is under fabrication.

The authors thank Dr. Adrian Hillier and Ms. Bethany Hampshire for their kind assistance in preparation for the experimental setup at RAL. This experiment was conducted under the user program RB1970126 at the RIKEN-RAL muon facility. This work was supported by Japanese JSPS KAKENHI Grant Number 19H04618.

References