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.

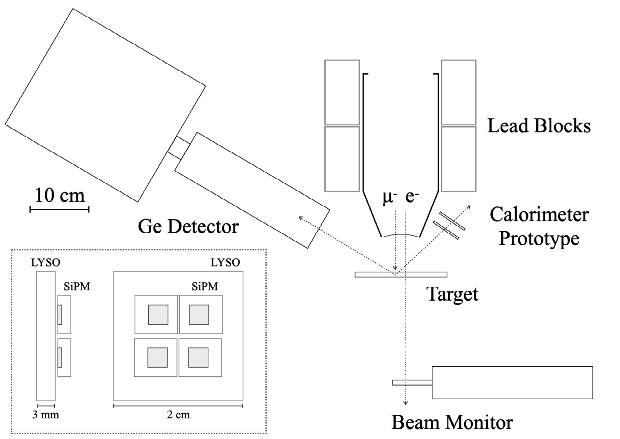

Fig. 1. Experimental setup. The inset shows the structure of the prototype.

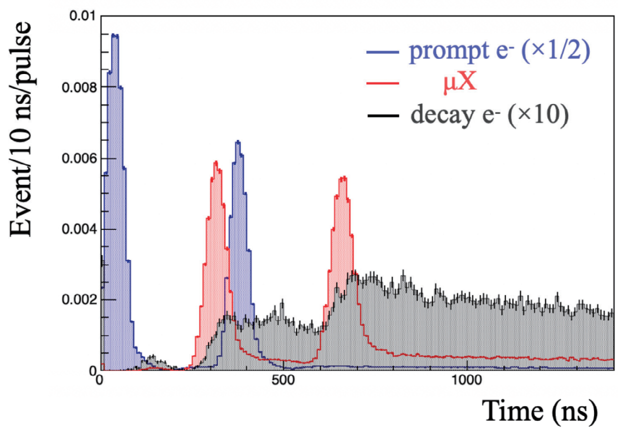

Fig. 2. Electron and X-rays time spectra. The prompt electrons were detected by the beam monitor.

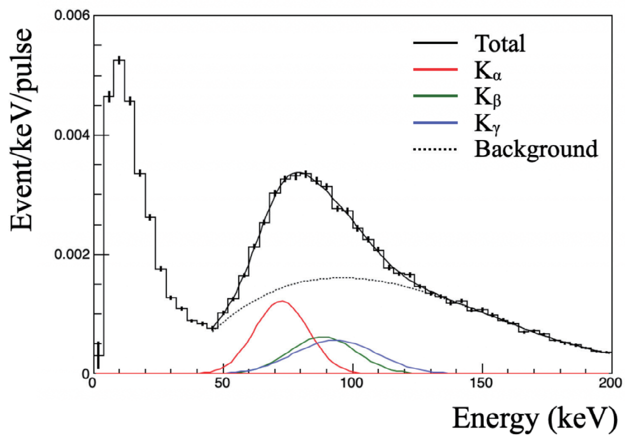

Fig. 3. X-ray energy spectrum obtained by the calorimeter prototype.

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.

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