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Performance of the trigger-veto detector for Korea Experiments on Magnetic Monopole

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Magnetic monopoles have not been observed despite decades of efforts. KoreA Experiment on Magnetic Monopole (KAEM) is an experimental search for fundamental magnetic monopoles in the low-mass and low-charge regions. KAEM is configured with a thin aluminum target, ^{22}Na source, two 1 T·m solenoids, about 3 m long vacuum chamber, two electromagnetic calorimeters, and the trigger-veto detector. The LYSO, CsI, and CsI(Tl) crystals, used widely in nuclear/particle physics experiments, are candidates for the trigger-veto detector and electromagnetic calorimeters. We investigated the characteristics and the performance of those crystals to decide which type of crystal satisfies the requirements of our experiment. In addition, these crystals were tested with a customized DAQ system and ^{22}Na, ^{137}Cs, and ^{60}Co radioactive sources. This talk will present the characteristics of several types of crystals and beam test results obtained with the customized DAQ system.

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1. Introduction

KoreA Experiment on Magnetic Monopole (KAEM) is proposed to search for elementary magnetic monopoles where mass is below the electron mass (m_e) and charge below the electron charge (e). For this purpose, we designed an experiment that can measure the magnetic charge down to 100 times smaller than the electron charge, by accelerating the magnetic charge in a 1.0 Tesla-meter field. The putative magnetic charge is produced in electron-positron at rest. As depicted in Fig. 1, it is configured with a ^{22}Na source for a low-energy positron and a thin aluminum target for electron-positron annihilation in the center of a long magnetic solenoid. In addition, the electromagnetic calorimeter consisting of scintillation crystals coupled with SiPM arrays are placed at each end of the solenoid. Inside the vacuum chamber, the trigger-veto detector surrounding the ^{22}Na source detects 1.275 MeV γ as a trigger signal. The scintillator is required to have a fast exponential decay time and excellent time resolution (< 300 ps), well matched to photodetectors at the peak wavelength emission and high light yield for good energy resolution.

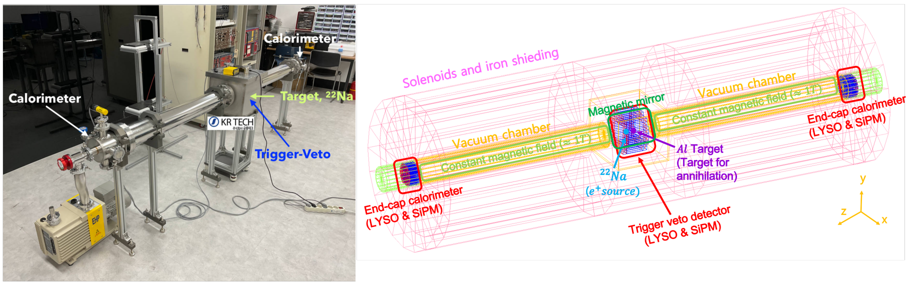

Figure 1: Picture and geometry of experimental design.

2. Measurement of Scintillator Characteristics

The LYSO, CsI, and CsI(Tl) crystals, used widely in nuclear/particle physics experiments, are candidates for the trigger-veto detector and electromagnetic calorimeters. In order to decide on a scintillator that satisfies the requirement of our experiment, we measured the scintillator characteristics of these crystals of dimension 2 cm $\times$ 2 cm $\times$ 12 cm: emission wavelength, decay time, and gamma energy spectra from 511 keV to 1.33 MeV using the experimental set-up presented in Fig. 2. The energy resolution and linearity were also investigated. Based on these measurement results, LYSO crystal is most appropriate for our use.

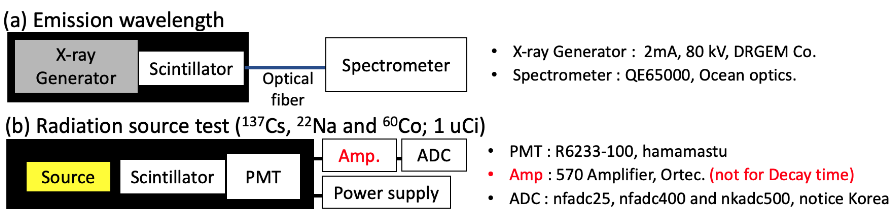

Figure 2: Experimental setup for (a) emission wavelength and (b) radiation source tests.

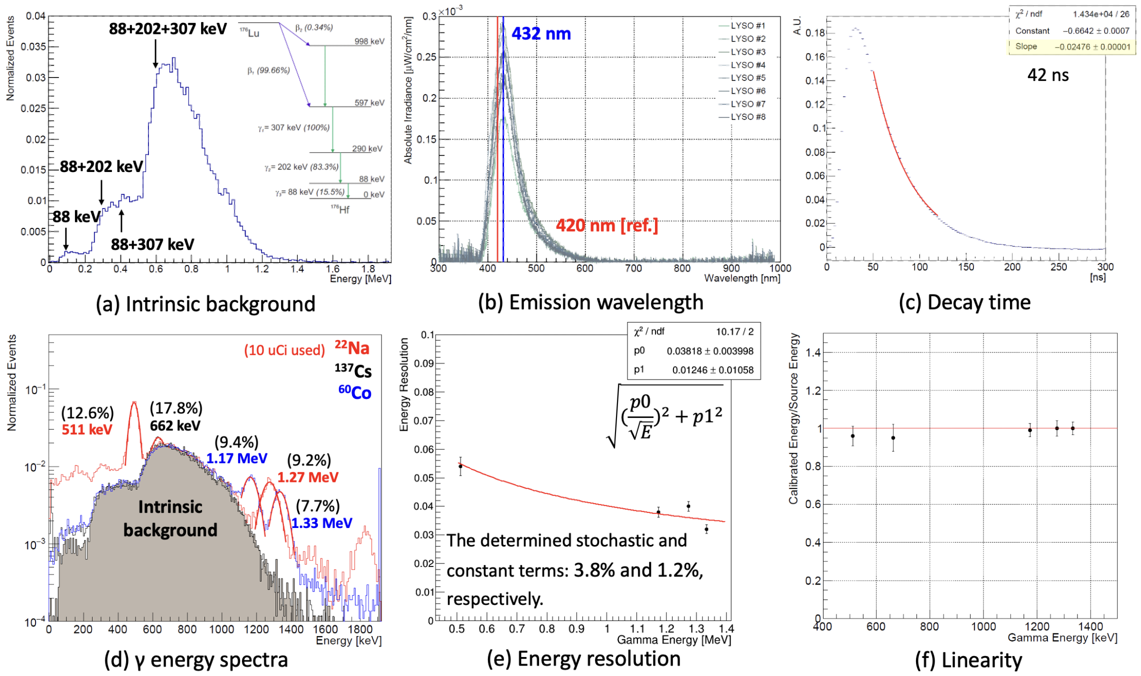

Figure 3: Measurement results of LYSO scintillator characteristics.

Figs. 3(a)−(f) show the measurement results with LYSO scintillator of intrinsic background distribution due to ^{176}Lu, emission wavelength, decay time, gamma energy spectra, energy resolution, and linearity from 511 keV to 1.33 MeV, respectively.

The LYSO scintillator has intrinsic background from the 2.6% of ^{176}Lu in the LYSO crystal. The measured intrinsic background distribution and decay scheme of ^{176}Lu are presented in Fig. 3(a). The background distribution agrees well with the corresponding energy from the decay scheme and is comparable to the results in reference [1]. We reproduced the emission wavelength and decay time of LYSO scintillators provided by Saint-Gobain [1]. As shown in Fig. 3(b) and Fig. 3(c), these results are a measured wavelength emission of 432 nm and a single exponential decay time of 42 ns. Then, tests are performed with LYSO coupled to PMT and radiation sources such as ^{22}Na, ^{137}Cs, and ^{60}Co, producing gammas in the energy range from 511 keV to 1.33 MeV. The measured energy spectra calibrated using 1.27 MeV gammas are shown in Fig. 3(d). As depicted in Fig. 3(d), a gray area, red, black, and blue lines mean energy spectrum of intrinsic background, ^{22}Na, ^{137}Cs, and ^{60}Co, respectively. The peaks at 511 keV, 662 keV, 1.17 MeV, 1.27 MeV and 1.33 MeV are fitted with a Gaussian function and calculated FWHM energy resolution shown in brackets for each. In Fig. 3(e), energy resolution is fitted with the formula shown in the figure. The stochastic and constant terms are determined as 3.8% and 1.2%, respectively. The energy resolution of 4.8% at 662 keV is consistent with 8.5% (FWHM) from Saint-Gobain [1]. Fig. 3(f) shows good linearity in energy range from 511 keV to 1.33 MeV, and the measured energy is constant within 5% despite intrinsic background.

3. Energy Measurement with Trigger-veto Detector System

The customized DAQ system made by Notice Korea, with DRS4 chip which has a sampling rate of up to 5 GHz, and waveform digitization stored in 1024 sampling cells per channel, can cover 160 channels with SiPMs coupled to both sides of the LYSO crystal. As shown in Fig. 4, the energy spectra were measured with SiPMs attached to the left and right side of the LYSO crystal, ^{22}Na source, and the customized DAQ system, which has optimized gain to measure energy up to 7 MeV. As a result, the energy resolutions of the left and right SiPMs are measured as 16.7% and 14.3%, respectively.

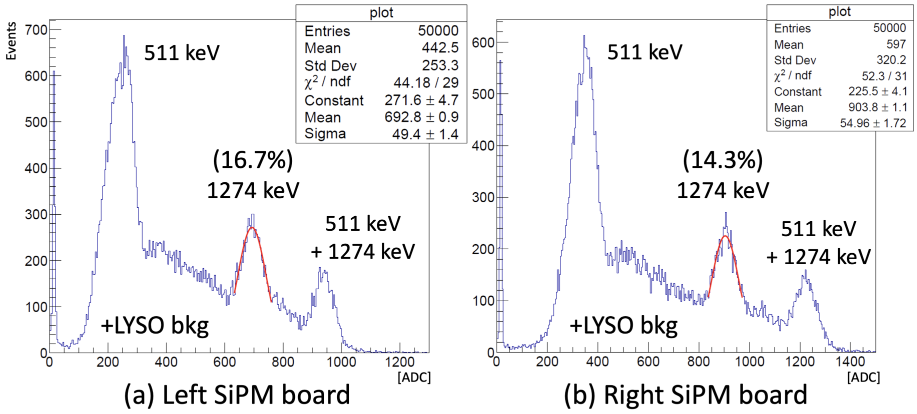

Figure 4: γ energy spectra with LYSO scintillator couple with SiPM, and customized DAQ system.

4. Next Steps

Performance tests of LYSO, CsI, and CsI(Tl) crystals were done for our experiment, and we decided to use the LYSO crystal for the trigger-veto system based on performance test results. Additionally, a customized DAQ system for the trigger-veto was tested. With radiation sources, LYSO coupled to SiPMs, and DAQ system, time resolution will be measured. Also, the responses from different size crystals of 1 cm × 1 cm × 6 cm for ECAL will be performed.

Acknowledgement

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References

[1] "LYSO Scintillation Crystal", https://www.crystals.saint-gobain.com/radiation-detection-scintillators/crystal-scintillators/lyso-scintillation-crystals, Last Accessed Sep. 30th, 2022.