Study of Muon-induced neutron background for rare events

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Introduction

Understanding and mitigation of the muon-induced neutron background is an important aspect of rare decay searches such as neutrinoless double beta decay (NDBD) or dark matter [1, 2]. Such backgrounds are also limiting factors for rare nuclear decays like forbidden alpha/beta decay or other decays to excited nuclear states [3]. These decays to excited states can be probed using high-purity germanium (HPGe) detectors. Techniques like coincident detection of gamma rays in decay cascades and suppression of Compton-scattered gammas (anti-Compton shield, ACS) are generally employed to improve the signal-to-noise ratio. The ACS shield, comprising high-Z material for enhanced detection efficiency, can also be a source of muon-induced background. With this motivation, the study of muon-induced background in BGO ACS has been initiated in the low-background setup at TIFR.

Experimental setup

The Cryo-cooled detector for RAre Decay and Low Background Experiment (CRADLE) setup consists of a carbon fiber body, low-background High Purity Germanium (HPGe) detector. The HPGe detector (C1) is a GEM series coaxial, p-type detector (GEM30P4-83-RB) with 36% relative efficiency and is operated with a CFG-X-COOL-III-230 cooler. To reduce ambient background, it is surrounded by two layers of lead shielding: an inner 5 cm layer of low-activity lead (< 0.3 Bq/kg) and an outer 5 cm layer of moderate-activity lead (< 19 Bq/kg). For the detection of muons, two plastic scintillators (P_1 and P_2) of 50 x 50 cm^2 area and 1 cm thickness are mounted on top of the CRADLE. An annular Bismuth Germanate (BGO) ACS of 2.5 cm thickness is mounted around the HPGe detector (inside the lead shielding).

Data was recorded using a CAEN N6724 digitizer (14-bit, 100 MS/s). The HPGe detector was calibrated with a ^{56}Co source up to 3.5 MeV. To understand the gamma-ray background arising from the BGO, data was taken with and without the BGO for 18.3 days each. It should be noted that the BGO was used as a passive target in this measurement and not as an ACS. A pulser (10 Hz) was added to the HPGe detector as a monitor for the DAQ. Neutrons produced from muon interactions in the lead shielding and/or BGO can further induce (n, γ) reactions in the BGO. These secondary γ rays can be detected by the HPGe. Muon-induced interactions were selected as coincidence events between P_1 and P_2 within ± 100 ns and with C1 within a time window of ± 500 ns.

Analysis and results

Figure 1 shows the singles (top panel) and muon-coincident (bottom panel) gamma-ray spectra with (red solid line) and without (blue dotted line) the BGO detector. In the singles spectra, it is observed that the BGO attenuates most of the characteristic ambient background gammas (e.g., 2615 keV). The continuum background level shows an increase below 2000 keV and a reduction above that. The background increases by approximately 19% in the 100-1000 keV range and 16% in the 1000-2000 keV range, while in the 2000-2800 keV range, the background is reduced by about 11%. Detailed simulations are needed to understand this. It should be noted that

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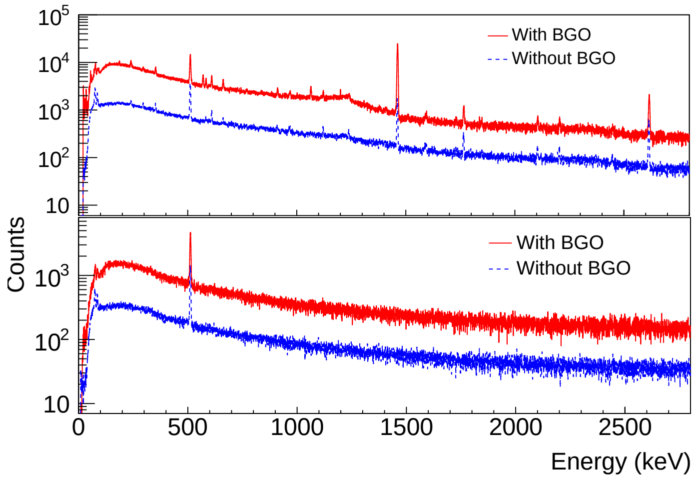

FIG. 1: Comparison of singles (top panel) and muon-coincident (bottom panel) gamma ray spectra with (red solid line) and without (blue dotted line) the BGO detector. The spectra with BGO are scaled by a factor of 5 for better visibility.

the intensity of the 1460 keV line showed an almost 200% increase, perhaps due to the presence of PMT glass.

In the muon-coincident spectra, the presence of the BGO reduced the continuum gamma background over the entire region by about 15%. The yield of the 511 keV line is expected to increase due to enhanced pair production in the surrounding high-Z material (lead and BGO). However, these gammas appear to be well shielded from the HPGe detector (C1), and the intensity of the 511 keV line shows a reduction of 25%. This is an important observation for positron double beta decay studies, where BGO could be used to improve sensitivity in the HPGe spectrum without contributing additional background in the 511 keV line. No new lines are observed in the coincident spectra, and further data collection to improve statistics and sensitivity is in progress. Geant4-based simulations for muon-induced (n, γ) reactions [4] are in progress. The simulation results and comparisons with experimental data will be presented.

Conclusion

Muon-coincident gamma-ray spectra were studied in the CRADLE setup with and without the annular BGO passive shield for about 18 days. Within the available statistics, no new gamma rays were observed due to the presence of the BGO. The BGO effectively reduces the intensity of the 511 keV peak, which may be important for improving the sensitivity of positron double beta decay. Simulations to understand the detailed behavior of the spectrum are in progress.

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