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Development of electron detectors for the BRAND experiment

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ABSTRACT

The BRAND experiment employs detectors that utilize gas ionization and plastic scintillators, integrated with custom-designed front-end electronics, aimed at measuring the correlation coefficients in neutron beta decay. This article focuses on the characterization and performance of a newly developed electron detector prototype featuring custom-designed front-end electronics. The characterization results indicate an weak gain dependency of the scintillator when exposed to a radioactive source, varying along its length and width.

1. Introduction

The correlation coefficients of neutron and nuclear beta decays are pivotal tools for probing physics beyond the Standard Model (BSM) in a low-energy regime. The BRAND experiment is an innovative initiative aimed at the simultaneous measurement of 11 correlation coefficients (*a, A, B, D, H, L, N, R, S, U,* and *V*) in neutron decay, with particular emphasis on *H, L, S, U,* and *V*, which have not been previously measured. These coefficients require the determination of four vectors: the momentum and spin polarization of the electron, as well as the momentum of the proton and the spin polarization of the decaying neutron. The electron detection system includes a MultiWire Drift Chamber (MWDC) tracker [1,2], scintillator detectors for energy measurement and triggering, and a Mott scattering target for electron spin analysis. The proton detection system comprises an accelerating electric field, an electron-to-proton converter foil and a thin scintillator with SiPM readout. The decay vertex will be reconstructed using data from the tracker, the proton hit position, and the time-of-flight information from the proton detector.

This article shows the response function of 1 m long plastic scintillator readout by two PMTs attached to both scintillator ends and charge sensitive preamplifiers with charge-to-time converter front end electronics.

2. Electron detector

The advanced version of BRAND-II will utilize a long plastic scintillator bar ($100 \times 10 \times 1$ cm^3) for the measurement of energy deposited by the electrons originating from neutron decay (direct and Mott-scattered electrons). The commercially available EJ200 scintillator is particularly suitable for this application due to its significant light attenuation length of 380 cm [3]. Two Hamamatsu PMTs (R1828-01 [4]) are coupled to the scintillator at both ends via light guide as illustrated in Fig. 1. To enhance light collection, the light guide adapter and three faces of the scintillator are wrapped with a 98% reflective film (3M ESR [5]), while the front face is wrapped with aluminized Mylar (thickness ∼ 6 μm). The scintillator was scanned with a ^{241}Am source (59 keV gamma, dia ∼2 mm) and ^{207}Bi source (two conversion electron line groups around 480 and 1000 keV, dia ∼0.5 mm). These sources were directly placed on the scintillator front face.

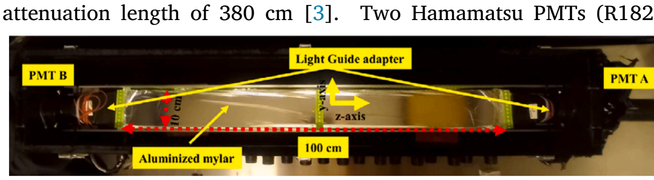

Fig. 1. The plastic scintillator detector with description of axis orientation.

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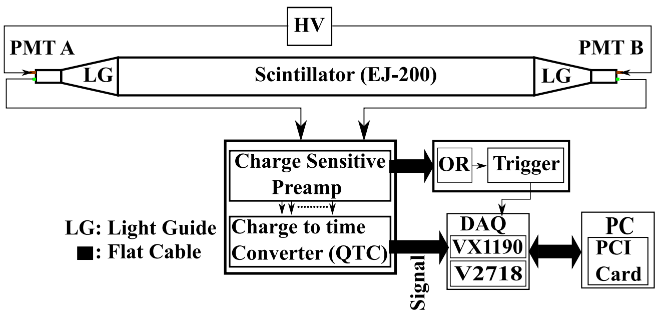

Fig. 2. Block diagram of characterization setup.

Fig. 2 shows the block diagram of utilizing charge-sensitive preamplifier with charge-to-time converter. It offers a robust solution for simultaneously measuring the timing and energy deposited in the detector. Traditionally, Analog-to-Digital Converter (ADC) and Time-to-Digital Converter (TDC) modules are employed to measure the deposited energy and timing of corresponding channels. However, if the integrated signal charge information is encoded in the signal time width, the use of ADC modules becomes redundant.

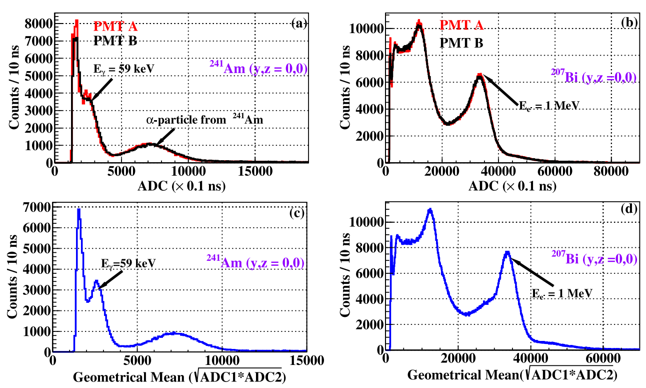

Fig. 3. Spectra of ^{241}Am and ^{207}Bi were obtained by positioning the sources at the center of the scintillator. Panel (a) and (b) display the superimposed spectra from PMT A and PMT B, respectively. Panel (c) and (d) present spectra of the geometric mean of the signal charges from PMT A and PMT B.

Fig. 3 shows typical spectra of ^{241}Am and ^{207}Bi located at the center of scintillator. A systematic scan was carried out along z-axis at y = 0 cm.

Fig. 4 shows the measured response using ^{241}Am (59 keV gamma) and ^{207}Bi (1 MeV conversion electron), demonstrating an almost uniform distribution with a maximum deviation of approximately 2% along the z-axis within a range of ±40 cm (see bottom panel).

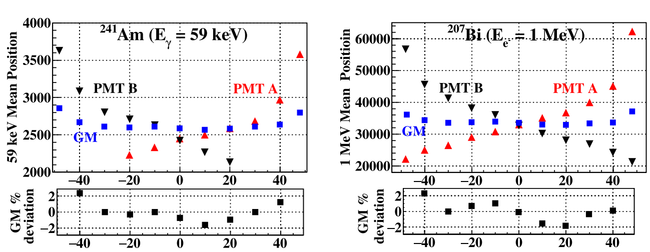

Fig. 4. Measured scintillator response for ^{241}Am and ^{207}Bi along z-axis (y = 0). The bottom panels shows percentage deviation in geometrical mean (GM) with respect to the average value.

Similar scans were conducted along the periphery of the scintillator. Fig. 5 displays the scan along z-axis for different y-positions. Table 1 lists the average values of 59 keV and 1 MeV geometric mean peak positions within a range of $z = \pm 40$ cm. Along the y-axis, the response deviation is approximately 2% for the 59 keV gamma rays and around 6% for the 1 MeV conversion electrons which is probably due to active source dimensions.

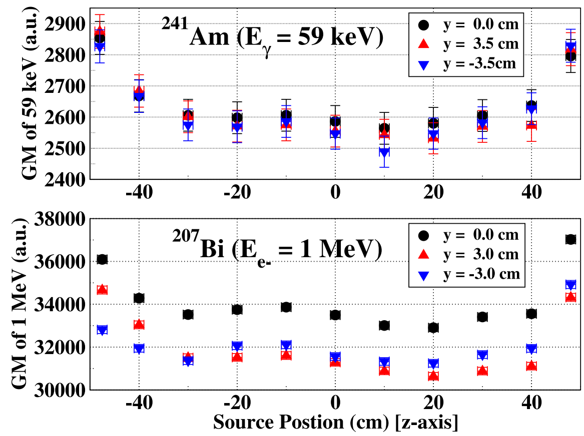

Fig. 5. Measured scintillator response for ^{241}Am and ^{207}Bi along z-axis for various y-positions.

Table 1
The average value of geometrical peak positions within range of z = ±40 cm (square bracket shows position for 1 MeV peak).

y-position (cm)	<59 keV (GM)> (× 0.1 ns)	<1 MeV (GM)> (× 0.1 ns)
−3.5 [−3.0]	2577 ± 51	31 689 ± 343
0.0 [0.0]	2606 ± 31	31 387 ± 419
+3.5 [+3.0]	2578 ± 44	33 532 ± 347

Consequently, it is essential to perform gain mapping and implement it into the data analysis of the BRAND experiment to account for these variations.

3. Summary

The scan shows fairly uniform response over entire scintillator surface. However, gain mapping over the scintillator surface is essential for a precision measurement. In the next step, the energy resolution map will be measured. Such a study requires recording the scintillator hits in coincidence with electron tracker signals.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Dagmara Rozpedzik reports financial support was provided by National Science Centre Poland. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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