Development of position and pulse shape discriminant neutron detector modules

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There are many applications for fast neutron detectors including fundamental physics, astrophysics, and stewardship science [1,2]. Many conventional detectors with neutron/gamma discrimination capabilities use liquid scintillators that are dangerous due to toxicity and volatility and do not offer great position resolution. A push for more modern detectors with greater energy resolution and efficiency has driven the development of many new dense detector systems that use solid organic scintillators. One such detector array is being developed here at the Texas A&M University Cyclotron Institute (CI). The Texas Neutron detector, TexNeut, is being constructed here using novel pseudo-bar detector modules. In past annual reports, we presented simulations that guide R&D [3] and also the results of construction and characterization of these modules [3-5]. Each module was shown to offer 2 cm position discrimination (xD) with a reasonably low threshold, and the modules retain the exceptional pulse shape discrimination (PSD) capability of the *p*-terphenyl scintillator. During 2020-2021, we continued to characterize the detector modules, worked on optimization, and began the design of the TexNeut array using these neutron detector modules.

Because TexNeut will be operated in a time-of-flight (TOF) mode it is important to understand the timing resolution of the device. At the CI, analog electronics were setup to characterize the timing resolution of the pseudo-bar modules using a ^{22}Na source as shown in Fig. 1. The electronics setup consisted of a constant fraction discriminator (CFD), time-to-digital converter (TDC), and charge-to-digital converter (QDC) to record pulse times and energies. The ^{22}Na source produces β^{+} which annihilate readily with electrons in the environment creating 511 keV γ-rays which are emitted at 180° from each other. Two cesium fluoride (CsF) detectors, which have sub-ns rise times, were positioned to detect the coincident gammas, with a single pseudo-bar module. One CsF (stop) was placed at the same location as the pseudo-bar, 20 cm from the ^{22}Na source. The other CsF (start) was placed 20 cm opposite the ^{22}Na source.

We used the QDC and TDC to record energy and timing information for all detectors. γ-Ray timing and energy information was recorded with the start and stop CsF. This information was used to understand the timing resolution of the CsF detectors. The timing resolution of the CsF detectors was found to be 364 ps FWHM. Using lead bricks, we collimated the γ-rays to expose each crystal in the pseudo-bar separately. This allowed us to measure the timing resolution all the way down to any threshold created in the electronics, even beyond the xD threshold established in [4] of 300 keVee.

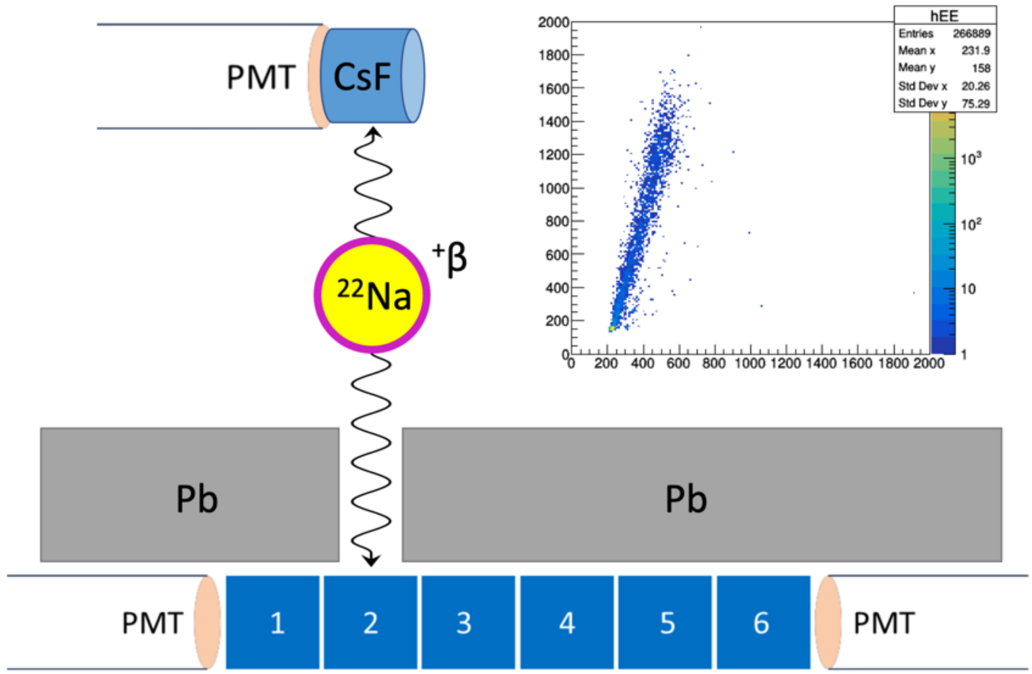

Fig. 1. Sketch of the CsF and pseudo-bar placement during the timing characterization experiments. The placement of the stop CsF detector is not shown here. The histogram inset shows the energy spectrum from both PMTs, E_{left} vs E_{right}, with γ-rays only being exposed to crystal-2 as shown in the diagram. Units in the inset histogram are ADC channel.

After deconvoluting the CsF timing contribution from each pseudo-bar timing spectrum we were able to extract the timing resolution for the pseudo-bar on its own. This was done for the entire data set, but also for events only above the 300 keVee xD threshold. Additionally, the timing information from both left and right PMTs was combined using a weighted average, to give optimal resolution. Two weighted averaging methods were used – a bulk weighted average of all events (labeled "W-Avg in Fig. 2), which gives the singles timing resolution, and an event-by-event weighted average ("E-by-E" in Fig. 2), which simulates the procedure used in a time-of-flight experiment. The single crystal timing as well as the results of both weighted average methods are shown in Fig. 2.

To conclude, between this work and [3-5], the relevant detector properties have been fully characterized, with a timing resolution of 400-700 ps FWHM. The results from this work, as well as [3-5] are currently under review for publication with *Nuclear Instrumentation and Methods A.* Moving forward we plan to construct the TexNeut array using these pseudo-bar modules and commision the detector in conjuction with TexAT [6], exploring the low-level structure of ^{10}Li by studying highly excited states in ^{10}Be that are isobaric analogues those low-level resonances in ^{10}Li.

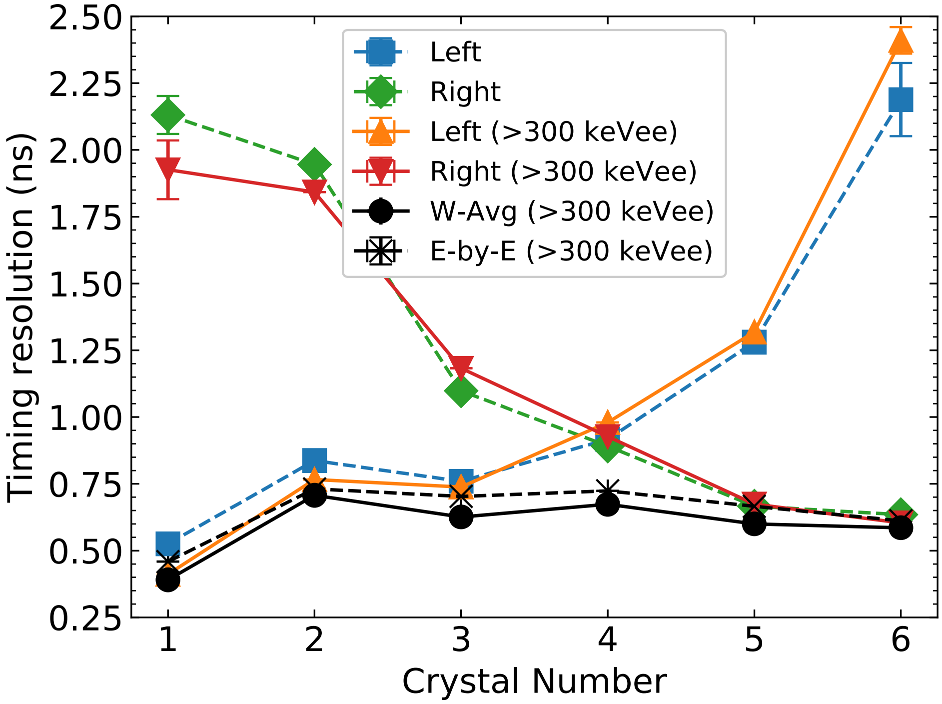

Fig. 2. The timing resolution measured for each crystal (colored polygons) as well as the timing found by using weighted averaging (black circle/x).

[1] E. Aboud *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2019-2020), p. IV-121.

[2] E. Aboud *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2018-2019), p. IV-39.

[3] D.P. Scriven *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2018-2019), p. IV-55.

[4] D.P. Scriven *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2019-2020), p. IV-112.

[5] C.E. Parker *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2018-2019), p. IV-52.

[6] E. Koshchiy *et al.*, Nuclear Inst. and Methods in Phys. Res. **A957**, 163398 (2020).

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