Measurements at low energy threshold with CsI detector using pulse shape techniques

Kirtikesh Kumar[1],* R. Sehgal[1], S.P. Behera[1,3], P.K. Netrakanti[1], D.K. Mishra[1,3], G. D. Patra[2], S. G. Singh[2,3], S. Sen[2,3], and V. Jha[1,3]
[1]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA*
[2]*Technical Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA and*
[3]*Homi Bhabha National Institute, Anushaktinagar, Mumbai - 400094, INDIA*

Introduction

Coherent Elastic Neutrino-Nucleus Scattering (CEνNS) measurements using reactor antineutrinos and low - mass direct Dark Matter (DM) search experiments rely on the detection of nuclear recoils produced in these rare event interactions. These recoils typically carry very low energies, often below few keV, due to the relatively small masses and kinetic energies of the incident particles. As majority of the recoil energy is dissipated as heat, only a small fraction ($\sim$ 25%) is detectable as ionization or scintillation. Hence, achieving ultra-low detection thresholds is critical to improving sensitivity in these experiments [1].

Inorganic scintillators, particularly those with Pulse Shape Discrimination (PSD) capabilities and high light yield, are well-suited for meeting some of these stringent requirements. With careful selection of scintillator materials and control over the crystal growth process high levels of radiopurity can be achieved, reducing internal backgrounds. However, scintillator selections are also dictated by the recoil energies which depend on the atomic mass of the constituent elements. Furthermore, PSD enables the effective distinction between electron and nuclear recoils, essential for identifying genuine signals. In this study, we present our efforts to achieve a O(keVee) threshold using an indigenous CsI(Tl) detector.

Experimental Details

We use a 3"(ϕ) × 4"(h) size CsI(Tl) crystal, grown at CTL, TPD, BARC, coupled to a 3" Hamamatsu R1307 photo multiplier tube (PMT) in this study. A CAEN 1730 14 bit 500 MS/s digitizer with DPP-PSD Firmware is used to generate triggers and analyze the waveform. The signal is collected via CoMPASS software which stores the ADC channel, timestamp and waveform of triggered pulses in a ROOT file for further analysis. We use ^{241}Am as source of low energy γ and X-rays in this study.

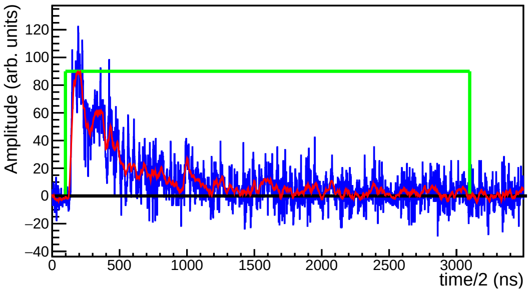

FIG. 1: Waveform of anode signal in CsI(Tl) crystal. (blue) original waveform, (red) smoothed waveform, (green) gate for charge integration

Waveform Description

Figure 1 shows a typical waveform of anode pulse from the CsI(Tl) detector when recorded with ^{241}Am source. The measured decay time constant of the pulse is 700 ns, characteristic of the CsI(Tl) detector. The triggered events can be classified into following four categories based on their waveforms (i) Signal events are those recorded from 300 ns before trigger and

---

*Electronic address: `kirtikesh@barc.gov.in` have decay time of ~750 ns. (ii) PMT noise pulses which are within 100 ns, generally appearing at low energies due to PMT bases. (iii) Digitizer noise events triggered due to electronic noise in digtal filters are the major cause of low energy noise events. (iv) Incomplete charge integration due to trigger holdoff from previous pulse.

Methodology

The methodology adopted by us effectively extracts signal events from the acquired data. A pulse shape discrimination (PSD) parameter defined using the integrated charge in short (Q_s over 800ns) and long (Q_l over 6μs) gates as PSD $= 1 - Q_s/Q_l$ is used to select gamma events. The selected event waveforms are then transformed using a 32 sample moving average as shown in Fig. 1. The mean (μ) and standard deviation (σ) of the amplitude at each sampling time of these pulses are then evaluated. A cut on number of outlier samples ($|\text{amplitude}| > \mu + 4\sigma$) effectively removes digitizer noise. For the signals passing this cut, an amplitude weighted mean time parameter [1, 2] is defined by $log(< t >) = log(\sum t_i.a_i/\sum a_i)$, where a_i is the amplitude of the pulse at time t_i from the start of the gate with sum running till the end of gate. A plot of Energy vs this parameter is shown in Fig. 2. The band in $2.37 < log(< t >) < 2.45$ corresponds to signal events. PMT noise lies below this band. Thus a stringent cut on this parameter allows for obtaining ADC Spectra as shown in Fig. 3. The bump seen in 100-400 ADC channel range may arise due to 14-22 keV X-rays from Neptunium produced in α-decay of ^{241}Am.

Conclusion

Tests with a CsI(Tl) detector show a large number of fast events at low energies. A suitable filtering technique has been designed to extract signal events from this type of noise. Using external triggering to reduce digitizer noise events is planned to achieve lower thresholds.

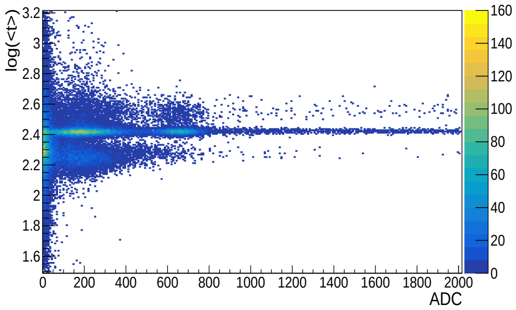

FIG. 2: $log(< t >)$ vs ADC for event filtering

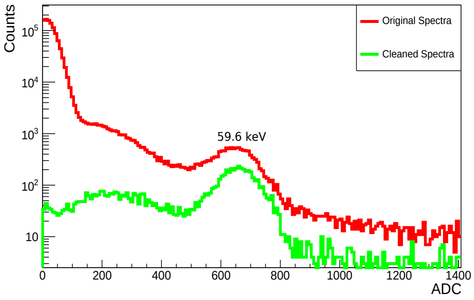

FIG. 3: ADC Spectra of gamma and X-ray using ^{241}Am source with and without filtering

References

[1] G. Adhikari et al., Astropart. Phys. 130 (2021) 102581

[2] G.H. Yu et al., arXiv:2408.14688