Discrimination of Low Energy Neutrons with Time Differentiated Signals

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INTRODUCTION

The low energy nuclear reactions producing extreme low energy neutrons in the exit channel have a renewed interest due to their larger involvement in nuclear astrophysics and radiation dosimetry. Most of the reactions in this range belongs to direct reactions only and those neutrons are not accompanied by any γs. Hence the exploration of these reactions requires the measurement of neutrons produced. Even though the neutron detection is successful, these counts are not used for absolute measurement of cross sections due to the non smooth behavior of the intrinsic efficiency and broad response in pulse height spectrum. Further, the neutron scintillators are highly sensitive to the γ events also. However, the cross-section analysis using neutrons has to be established for the analysis of neutron-producing direct reactions. Since the neutron distribution is expected to be monoenergetic or in a lower energy domain, the issue of accounting for efficiency has been more or less solved. However, the accurate discrimination of neutron and γ bands at lower energies is the existing issue.

The neutrons are interacting in the scintillating medium through the elastic scattering with the nuclei. This produce recoiling of charged particles while γ interactions produce electronic recoils through Compton process. Due to the difference in the linear energy transfer between recoiled electrons and recoiled protons, the population ratio of triplet to the singlet states is different. As these states are holding their peculiar characteristics on decay time, the effect is highly reflected in the pulse shapes. Since the signals from neutron events are considered, it has a higher contribution in the tail region, due to the decay of triplet states. However, the low energy neutrons interact through the radiative capture, due to the higher capture cross sections. These γs produced through the radiative capture process also interacting with the scintillator medium and produce a significant level of energy deposition.

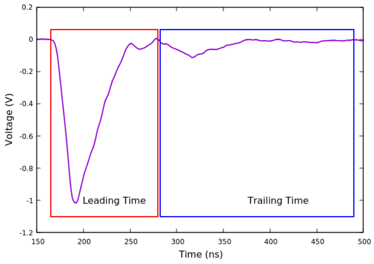

Figure 1: *The time differentiated pulse shape from BC501A liquid scintillator.*

The conventional pulse shape discriminators are using the methodology of a short gate to long gate ratio for the pulse shape discrimination[1]. These methods are very much successful for the high energy neutrons having light output above 500 keV$_{ee}$. As the neutron energies below 500 keV are considered, there produces a significant level of overlapping between neutron and γ in the ADC-PSD correlations. This effect significantly affects the efficiency of neutron detection which makes huge uncertainties in the final cross-section. The cross-section is much lesser compared to normal reactions. As a solution to this, a novel pulse shape discriminator concept has been introduced and implemented through the digitizer-based data acquisition system. The effectiveness of this method for low energy neutrons is validated by measuring the neutron spectrum from ^{19}F(α,n) reaction. The details are in the following sections.

Materials and Methods

The numerically differentiated pulse from the dynode of the liquid scintillator crosses the baseline corresponding to the time of peak amplitude and starting point of the decay of the triplet state. This timing information has been utilized for the n-γ discrimination. The dynode signal of the neutron scintillator carries two charge colonies corresponding to the decay from singlet and triplet states, with a discrete boundary. This boundary is accurately determined by estimating the zero crossing time differentiated signal. The time difference between the signal trigger time and this boundary is taken as the rising time and the difference between the boundary point and the set end point is taken as the trailing time. From this, a pulse shape parameter is derived as trailing time to the total time. This holds the concept as the triplet state population is higher, it produces more trailing time which acts as a signature of neutrons. For γ events, this trailing time is considerably smaller. Considering the neutron capture events with neutron energy of more than 100 keV, there will be a significant level of recoil. These recoils also will contribute to the population of the triplet state along with the intense singlet state contribution. This information is used to identify the low energy neutrons in the present study.

For testing the setup, the dynode output of the BC501A is connected to the DT5743 digitizer. A low energy neutron source generating neutrons through $^{19}F(\alpha$,n) reactions have been used. The natural terrestrial γ events provide the γ signal. The events were recorded for a long time and the peak voltage, charge, leading time and trailing time parameters etc; are measured by configuring the differential waveform in the digitizer. The PSD is generated corresponding to each event by the trailing time to total time ratio of the signal and a correlation plot with peak voltage to PSD is made. The neutron and γ bands were identified in the correlation plot. The time-differentiated pulse shape from BC501A is illustrated in Figure 1 with marking for the rising time domain and trailing time domain. The 2D spectrum between ADC and PSD, generated from the ratio of trailing time and the total signal time, is represented in Figure 2.

The 2D plot is gated for the neutron colony and projected on the ADC axis for getting the response spectrum. The response spectrum is linearly calibrated with Compton edge of ^{137}Cs γs and unfolded using RooUnfold utilizing the response matrix for BC501A [2].

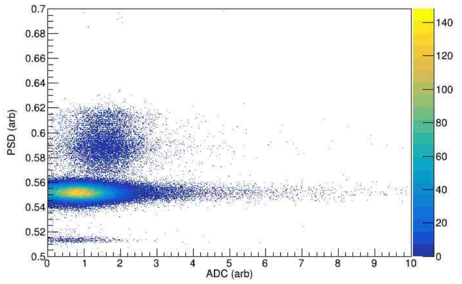

Figure 2: *The 2D correlation plot between voltage and pulse shape parameter.*

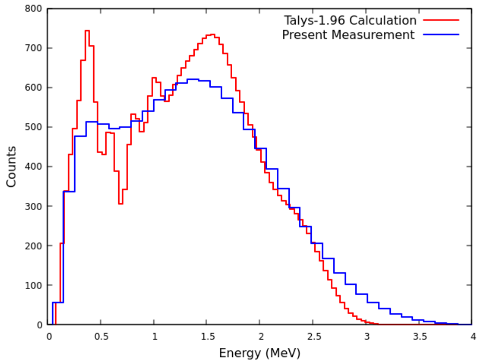

Figure 3: *Measured neutron spectrum of $^{19}F(\alpha$,n) along with Talys calculation.*

Results and Discussion

Figure 2 shows a clear separation between γ and neutron bands than the conventional zero cross time, which is provided by the long gate to short gate methods. The obtained spectrum is compared with the neutron spectrum from a thick LiF sample calculated using the Talys-1.96 nuclear reaction code. The unfolded spectrum of neutrons, compared with the theoretical spectrum is illustrated in Figure 3. This shows that the spectrum is similar and the low energy with a starting point of 100 keV is well measured. The experiment shows that this method clearly discriminates low energy neutrons and γs and can be effectively utilized for the situations of nuclear astrophysics where low energy neutrons in the exit channel are present.

References

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