Identification of neutrons and gamma rays using a combination of three algorithms for separating signals of the scintillation detector

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Identification of neutrons and gamma rays using a combination of three algorithms for separating signals of the scintillation detector

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Abstract. Scintillation detectors with organic scintillators are widely used for fast neutrons detection in high gamma ray background. The peculiarity of this type of detector is that the pulse shape depends on the type of the detected particle. Traditionally, the Pulse Shape Discrimination (PSD) histogram is used to determine the number of detected neutrons. The PSD parameter is calculated from the shape of the detector pulse and assigned to each pulse. A typical PSD histogram contains two peaks corresponding to neutrons and gamma rays that overlap in the region between the peaks. With this approach, it is impossible to identify each individual signal in the area between the peaks. Therefore, it is not possible to calculate the overall signal identification coefficient. We have proposed a new method for the identification of neutrons and gamma quanta, which includes a combination of three signal separation algorithms: the traditional histogram PSD, the dependence of the area of signals on their amplitude, Tau histogram (tau means the fall constant of the detector pulses). This combination of three algorithms makes it possible to calculate the value of the signal identification coefficient. To test a new method for identifying neutrons and gamma quanta, we used a Pu-Be neutron source, a scintillation detector with a p-terphenyl crystal and a CAEN DT5730 Digitizer (14 bit, 500 MHz). When a scintillation detector registered neutron from a Pu-Be source, the signal identification coefficient was 91.6%. A new method for identifying signals from a scintillation detector is used to register neutrons at the light ion accelerator.

1. Introduction

Scintillation detectors with organic scintillators are widely used for fast neutron detection in conditions of high level of gamma ray background. The shape of the output pulse in such detectors depends on the type of the detected particle. So, the analysis of the pulse shape of a scintillation detector with an organic scintillator makes it possible to discriminate signals from neutrons and gamma quanta.

Traditionally, the discrimination of neutrons and gamma quanta is performed by using a PSD (Pulse Shape Discrimination) histogram method. The areas of the signal per each pulse in the short Sshort and long Slong gates are calculated as shown at Figure 1. The PSD parameter is determined as the value of the following ratio: PSD = (Slong - Sshort) / Slong. Figure 2 shows a PSD histogram that contains two peaks with a spline approximation. The “separation point” corresponds to the minimum between the peaks in the PSD histogram. The pulses located to the right of the “separation point” are considered to be neutrons while pulses to the left are considered to be initiated by gamma quanta, although the superposition of the peaks introduces an uncertainty in identifying signals between the peaks. An effective way to reduce uncertainty in particle type identification is to apply a combination of different signal discrimination algorithms to each fixed pulse. The combination of more than one algorithm makes it possible to calculate the value of the signal identification coefficient.

2. Experimental setup

To study pulse shape discrimination algorithms, we used a scintillation detector with an organic cylindrical crystal of p-terphenyl with 25 mm diameter and 25 mm height [1-6]. The experimental setup includes a Pu-Be neutron source, a scintillation detector, a CAEN DT5730 digitizer (8 channels, 14 bit, 500 MS / s, bandwidth 250 MHz) and a personal computer. The Pu-Be neutron source is in a lead container with a wall thickness of 10 mm. Signals from R6094 PMT are fed directly to the analog input of the digitizer CAEN DT5730 [7, 8]. Waveforms of signals from the digitizer are written to the data file. The time stamp of each signal from the detector is fixed in the same file also. This information is necessary for solving a number of problems, such as registration of neutron and gamma radiation near accelerators and neutron generators [9-12].

Direct digital processing of the pulse shape of a scintillation detector makes it possible to separate signals from neutrons and background gamma quanta.

3. Combination of three algorithms for separating signals of the scintillation detector

In order to improve the efficiency of identifying signals from the scintillation detector, we used a combination of three algorithms: traditional PSD and two more independent signal discrimination algorithms.

The second algorithm (TAU) is based on the analysis of the falling age of each pulse. The falling edge of each pulse is fitted by an exponential function a*exp(-b*t) where coefficient $b=1/\tau$ and τ is the signal decay constant. Then a histogram of $1/\tau$ values is plotted. Similarly, to the PSD histogram, there is a “separation point” on the $1/\tau$ histogram (Figure 3). The neutrons are to the left of the dividing point while are gamma quanta are to the right.

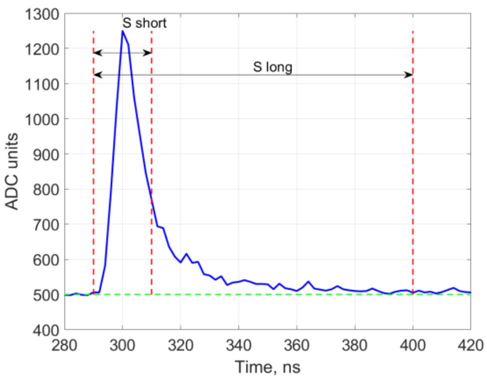

Figure 1. Typical pulse oscillogram with shown short and long gate parameters.

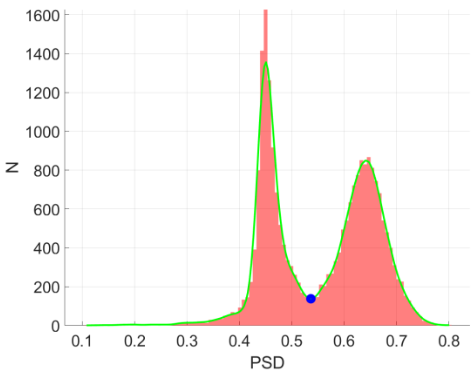

Figure 2. PSD histogram with spline approximation of the two peaks and “separation point”.

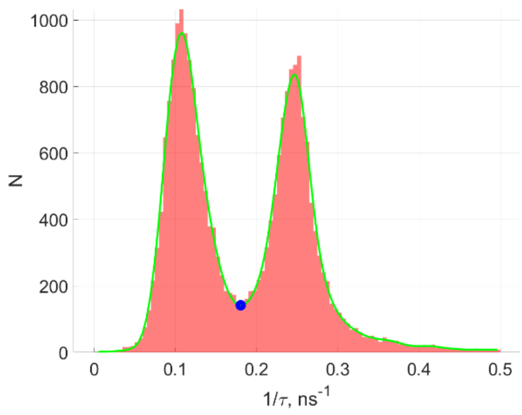

Figure 3. 1/τ histogram with spline approximation of the two peaks and "separation point".

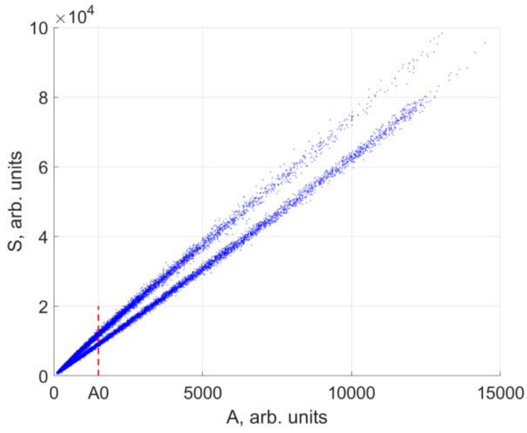

Figure 4. Signal area (S) versus its amplitude (A)

The third algorithm uses a plot of signal area versus amplitude (Figure 4). In this case, signal discrimination is performed by using Principal Component Analysis (PCA) [13]. Using plot of signal area versus amplitude, we select such value of the pulses amplitude (A0), to the right of which there is a complete discrimination of the signals. Then it is necessary to construct a covariance matrix for signals whose amplitude is greater than A0. The eigenvector corresponding to the largest eigenvalue of the constructed matrix is called the first principal component (PC1), the next called the second principal component (PC2). Let's move on to the new coordinates, which are more efficient in terms of signal discrimination (Figure 5). The first main component runs between two sets of signals and is a dividing line between the two types of signals. Next, for all signals, we again build the dependence of the signal area on the amplitude and draw a dividing line (Figure 6). All points above the dividing line are neutrons, and below are gamma quanta.

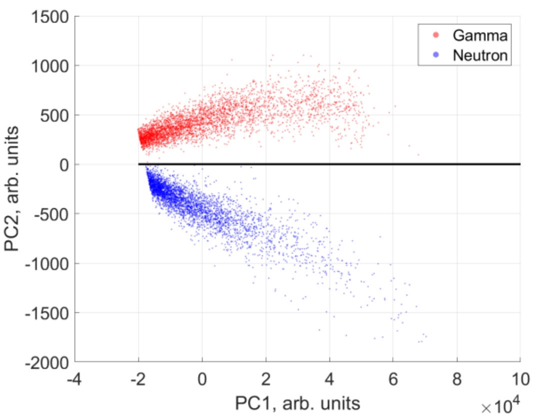

Figure 5. A set of signals in the coordinates of the principal components.

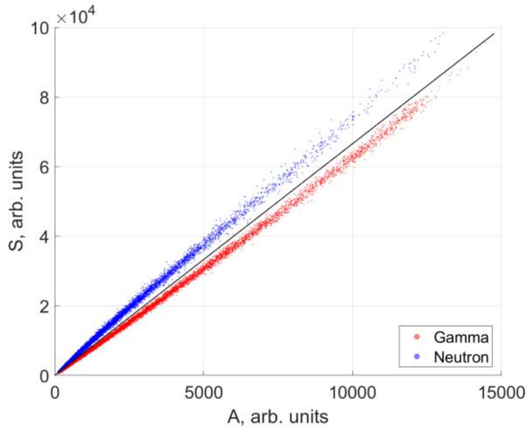

Figure 6. Dependence of the signal area on the amplitude with a dividing line.

The use of three independent signal discrimination algorithms makes it possible to increase the efficiency of identification of neutrons and gamma quanta. The result of the combination of the three signal discrimination algorithms is shown in Table 1. The top line of Table 1 shows 8 possible combinations of signal identification results for each separate algorithm. The bottom line contains the relative number of all signals (in percent) corresponding to the corresponding combination of the application of the three algorithms.

Table 1. The result of a combination of three signal separation algorithms.

PSD - γ PCA - γ TAU - γ	PSD - γ PCA - γ TAU - N	PSD - γ PCA - N TAU - γ	PSD - γ PCA - N TAU - N	PSD - N PCA - γ TAU - γ	PSD - N PCA - γ TAU - N	PSD - N PCA - N TAU - γ	PSD - N PCA - N TAU - N
44.09	1.40	0.37	0.19	3.02	1.95	1.46	47.51

Table shows that three independent algorithms indicate the same particle type for 47.51+44.09=91.6% of the detected signals.

4. Conclusion

The use of three signal discrimination algorithms simultaneously improves the identification of fast neutrons. The coefficient of agreement of the three algorithms when detecting neutrons from a Pu-Be source with a scintillation detector was 91.6%. The method of three algorithms for signal separation is used to register fast neutrons with scintillation detectors at the HELIS light ion accelerator [14, 15].

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