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Separation of signals from neutrons and gamma quanta by the method of normalized signals

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Abstract. The solution of the problem how to register fast neutrons in the presence of intense gamma radiation is required when solving such fundamental and applied problems as registration of the neutron and gamma background in underground low-background experiments (the low background detectors of the neutrino and dark matter); beam diagnostic at particle accelerators; radiation monitoring at nuclear facilities, nuclear medicine; environmental monitoring. To separate signals from neutrons and gamma quanta, scintillation detectors with organic scintillators are used. The best scintillators are organic crystals of stilbene and p-terphenyl. The efficiency of separating signals from neutrons and gamma quanta can be increased using various methods of digital signal processing of the pulse shapes of the registered signals. A parameter traditionally called the Figure of Merit (FOM) is used to compare these methods. The experimental setup consisted of a Pu-Be neutron source, a scintillation detector with organic crystal p-terphenyl, a Hamamatsu R6094 photomultiplier, a CAEN DT5730 Digitizer (500 MHz, 14bit), which store the shape of each pulse for the following digital processing. A new "method of normalized signals" was developed. Three variants of the new method of normalized signals are described, which give the following FOM values: 1.6, 1.7, and 2.1. The traditional method of signals separation on the same array of experimental data showed the efficiency FOM = 1.6. The new method of signal separation is used to register fast neutrons in the installation dedicated for the development of a compact neutron generator, which is necessary for the calibration of low-background detectors of neutrinos and dark matter particles.

1. Introduction
To register fast neutrons in the presence of intense gamma radiation, scintillation detectors with organic scintillators are used. The best scintillators for solving this problem are stilbene and p-terphenyl crystals [1-3]. Analysis of the pulse shape of a scintillation detector with an organic crystal makes it possible to separate signals from neutrons and gamma quanta. We investigated a new method that increases the efficiency of discrimination of signals from neutrons and gamma rays.

2. Experimental setup

To study pulse shape discrimination algorithms, we used the Pu-Be neutron source in a lead container with a wall thickness of 10 mm. The experimental setup includes a scintillation detector with an organic cylindrical crystal of p-terphenyl with 25 mm diameter and 25 mm height [4-5], CAEN DT5730 digitizer (8 channels, 14 bit, 500 MS/s, bandwidth 250 MHz) and a personal computer. Signals from R6094 photomultiplier go directly to the digitizer [6, 7]. The digitizer stores signal waveforms from the detector into the file. The time stamp of each signal is stored in the same file also. This parameter is important to register neutron and gamma quanta near accelerators [8-11].

3. Method of normalized signals

Typically, the Pulse Shape Discrimination (PSD) histogram method is used to discriminate signals from neutrons and gamma quanta according to the pulse shape corresponding to the particle type fixed by the scintillation detector. This method is based on a calculation of the different areas of the signals limited in time by predefined gates. The gates most often used, so called short S_{short} and long S_{long} gates, are shown at Figure 1. Next step of the method is to find the value of the PSD parameter $PSD=(S_{long}-S_{short})/S_{long}$ and to plot the PSD histogram (Figure 2) which typically contains two peaks corresponding to two different particle types.

A quantitative criterion for the efficiency of peaks separation from neutrons and gamma quanta is the Figure of Merit (FOM) value. To determine the FOM, we fitted the top of each peak corresponding for neutrons ($_n$) and gammas quanta ($_\gamma$) with a Gaussian curve (Figure 2). The value $FOM = (max_n - max_\gamma) / (FWHM_n + FWHM_\gamma)$. We obtained the value FOM = 1.62 ± 0.07 for neutrons from a Pu-Be source using the traditional PSD method.

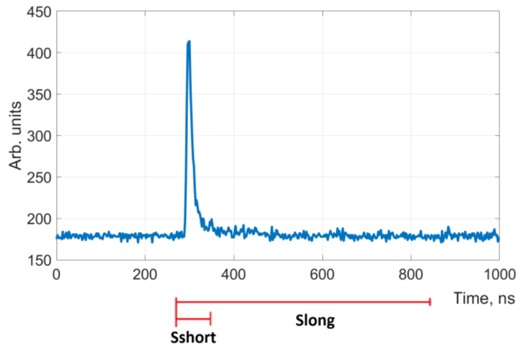

Figure 1. Pulse oscillogram with short and long gates shown.

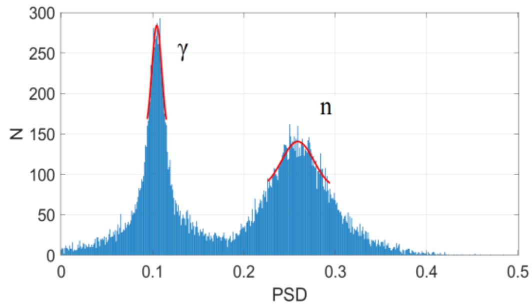

Figure 2. PSD histogram with fitted top of each peak with a Gaussian curve.

We propose a new method of signal discrimination - the method of normalized signals. The results of a study of three variants of this method are the following.

In the new method, each pulse acquired from the scintillation detector is normalized to the area of this pulse. The example of the group of normalized signals is shown in Figure 3.

We have studied two types of gates (Figure 3). The first gate type Gate 1 captures the area of the pulse maximum. A histogram of the areas of normalized signals with Gate 1 is shown in Figure 4. The value of FOM= 1.57 ± 0.07 was calculated for this type of gate.

The second gate type was Gate 2 which captures the tail of the pulse. A histogram of the areas of normalized signals with Gate 2 is shown in Figure 5. The FOM value for the second type of gate is FOM = 1.71 ± 0.10.

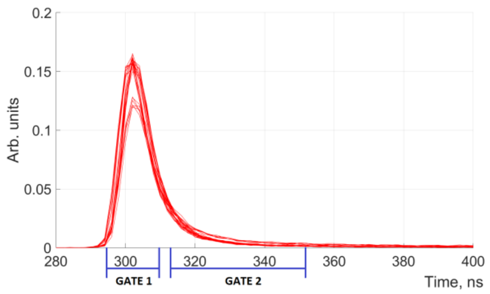

Figure 3. Oscillogram of a group of normalized signals.

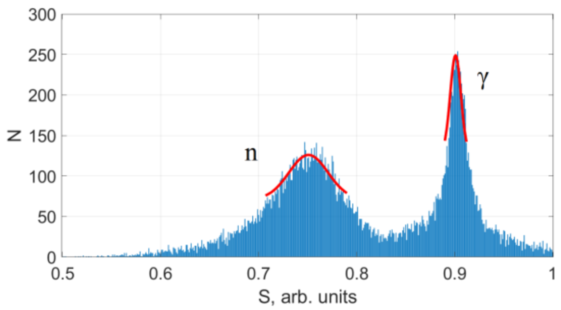

Figure 4. Histogram of signal areas at Gate 1.

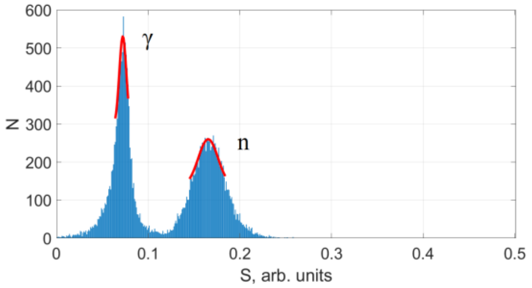

Figure 5. Histogram of signal areas at Gate 2.

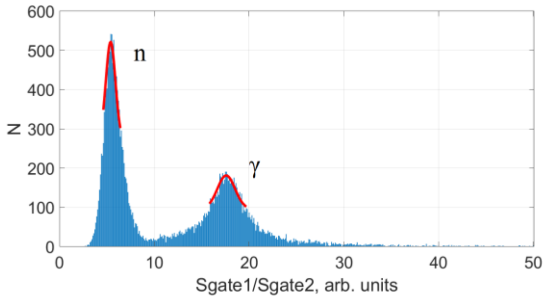

Figure 6. Sgate1/Sgate2 ratio histogram.

The third variant of the normalized signal method is to use the ratio of areas of the signals at Gate 1 and Gate 2. Figure 6 shows a histogram of the Sgate1/Sgate2 ratio. In this case, the efficiency of signal discrimination reaches the highest value FOM = 2.12 ± 0.10.

4. Conclusion

In comparison with the traditional method, the new method of normalized signals increases the efficiency of signal discrimination from FOM = 1.6 to FOM = 2.1.

The method of normalized signals is used to register fast neutrons in an installation for the development of a compact neutron generator [12-14]. A small-sized monochromatic neutron generator is required to calibrate low-background detectors of neutrinos and dark matter particles.

Acknowledgments

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