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Digital pulse shape discrimination between fast neutrons and gamma rays with para-terphenyl scintillator

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Abstract. In the presented work, we investigated several digital methods of a discrimination signals from fast neutrons and gamma quanta. The experimental setup consists of a Pu-Be neutron source, a scintillation detector with an organic para-terphenyl monocrystal, and a digitizer (CAEN DT5730, 500 MS/s). Mixed waveform sequences were stored and then separated by pulse shape. Four methods were used for signals separation. Comparison of the traditional and the new methods of Figure of Merit (FOM) calculation is given. FOM $=1.5$ was obtained in our setup for the minimum threshold value. A scintillation detector with a para-terphenyl crystal was used to measure neutron yield in the neutron generator with carbon nanotubes.

1. Introduction

A registration of fast neutrons flux against the background of gamma radiation is an important task both for the case of low particle intensity (measurement of the neutron and gamma background in neutrino and dark matter particle detectors \cite{1}, environmental monitoring) and for the case of high mixed fluxes of neutrons and gamma rays (neutron flux from neutron generators \cite{2, 3} and particle accelerators, monitoring of spent nuclear fuel). To detect fast neutrons, scintillation detectors with organic scintillators are widely used. In such scintillators, two components of de-excitation are present: the fast and the slow. Intensity of the slow component in such scintillators depends on the type of the detected particle. A modern technique of digital acquisition with the following digital processing of the output pulses from a scintillation detector allows to discriminate signals from gamma quanta and neutrons.

2. Experimental setup

The experimental setup includes a Pu-Be neutron source, a scintillation detector with an organic crystal, CAEN DT5730 (8 channels, 14 bit, 500 MS/s, bandwidth 250 MHz) digitizer and personal computer. The scintillation detector contains a para-terphenyl single crystal (formula C$_{18}$H$_{14}$, density 1.23 g/cm$^3$) of a cylindrical shape 25x25mm. The Hamamatsu R6094 photoelectric multiplier (PMT) registers scintillation photons from a para-terphenyl crystal. Signals from the PMT are fed to the
The analog input of the digitizer [4]. The impedance of the analog inputs of the digitizer is 50 Ohm. The digitizer can acquire a different number of samples per event. We stored 500 samples per event. Waveform signals together with the time stamp per each sample were recorded in a data file via USB interface. The time stamp which is fixed relatively the external or internal trigger is important feature which is critical while the following tasks are performed: 1) a monitoring of neutron and gamma background near accelerators and pulsed neutron generators [5, 6]; a registration of gamma spectra in intervals between irradiation pulses [7, 8]. The distance from the Pu-Be neutron source to the scintillation detector was varied between 10 to 22 cm. An energy calibration of the scintillation detector was done by $^{137}$Cs and $^{60}$Co gamma sources.

3. The efficiency of neutron-gamma discrimination by the pulse shape
The intensity of the slow component of the light flash from the para-terphenyl scintillator is larger when the fast neutrons is detected in comparison with the case of gamma quanta detection [9, 10]. This phenomena allows to discriminate the signals from neutrons and gamma quanta by analysis of the pulse shapes.

Several digital methods for fast neutrons and gamma quanta pulse shape discrimination have been used. Original application software was developed for this purpose. The most simple method is based on the analysis of the dependence of the area of pulsed signals on their amplitudes (Figure 1). As can be seen from Figure 1, the signals form two separate branches. The disadvantage of this method appears in the poor discrimination at low energies. Other methods use a calculation of the areas in short $S_{\text{short}}$ and long $S_{\text{long}}$ gates for each pulsed signal (Figure 2). The length and time position of both gates are optimized. The dependence of $S_{\text{short}}$ from $S_{\text{long}}$ allows to separate neutrons from gamma quanta (Figure 3). This method shows the same problem of poor separation of signals at low energies.
The best signal discrimination was achieved by using the following criteria - PSD (Pulse Shape Discrimination) = (Slong - Sshort) / Slong. Figure 4 shows the dependence of the PSD parameter on the total area of the signals. It can be seen that this method makes it possible to separate the signals, including for low energies of neutrons and gamma quanta.

The quantitative criterion for the efficiency of PSD procedure is the value of Figure of Merit (FOM). The value of FOM = (max n - max γ) / (FWHM n + FWHM γ). The FOM value is traditionally estimated by fitting peaks on the PSD histogram by the sum of two Gaussian distributions. However, such an approximation could be incorrect rather often. We use for this task spline approximation of the peaks (Figure 5). Figure 5 shows the discrimination of neutrons and gamma quanta at different threshold levels: “no threshold”, 100 keVee, 200 keVee, and 300 keVee. The efficiency of the gamma-neutron PSD increases from FOM = 1.5 (without a threshold) to FOM = 1.8 (threshold = 300 keVee).
4. Conclusion
A scintillation detector with a para-terphenyl crystal is a good instrument to solve the problem of fast neutrons detecting against a background of gamma radiation. Digital methods of pulse shape analysis make it possible to achieve an effective discrimination of the signals from neutrons and gamma quants. The value of FOM = 1.5 was obtained in our setup for the minimum threshold, while FOM ≈ 1 for the known BC-501A liquid scintillator. The scintillation detector with the p-terphenyl crystal was used by us to measure the neutron yield in the newly developing neutron generator based on carbon nanotubes.

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