NEUTRON DETECTOR ARRAY BASED ON STILBENE CRYSTALS FOR THE ACCULINNA AND ACCULINNA-2 SEPARATORS*

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(Received December 13, 2013)

The investigation of light neutron-rich nuclei is planned by means of the ACCULINNA separator and at the newly constructed ACCULINNA-2 separator. Fast neutron detection techniques in presence of γ-rays background play an important role in such investigations. Therefore, a prototype of the neutron detector array based on stilbene crystals has been designed for further studies. Stilbene scintillators have excellent n–γ discrimination, competitive to the liquid scintillators, used in the past experiments at ACCULINNA. The first results of n–γ separation obtained with stilbene crystals are presented.

DOI:10.5506/APhysPolB.45.519
PACS numbers: 29.40.Mc, 29.25.Dz

1. Introduction

Fast neutron detectors are used extensively in a wide range of nuclear physics experiments [1]. Their range of application covers nearly all the

* Presented at the XXXIII Mazurian Lakes Conference on Physics, Piaski, Poland, September 1–7, 2013.

topics in basic and applied nuclear research. Fast neutron detectors often serve as ancillary detectors for powerful in-beam spectroscopy arrays and during the reaction studies with radioactive nuclei.

Most recent experiments at the ACCULINNA separator [2] have been focused on the reconstruction of the spectra of the light-dripline nuclei with a large neutron excess like ^{4,5}H [3], $^{8-10}$He [4, 5]. Fast neutrons have to be detected in order to identify the reactions channels and reconstruct the complete kinematics. It was already done during a few studies using European Neutron Array "DEMON" modules, based on a NE213 organic liquid scintillator [6] at the ACCULINNA. Promising results of the experiments using DEMON and interest in further studies of the structure of light neutron-rich nuclei resulted in the construction of a new neutron detector array to be used at the ACCULINNA and ACCULINNA-2 separators [7].

In experimental studies of neutron-rich nuclei at low and intermediate energy reactions, one has to face the problem of detection of fast neutrons, in the presence of γ rays. The materials which have the best spectrometry characteristics in neutron detection are organic single crystals (anthracene, trans-stilbene, p-terphenyl, and p-quaterphenyl). In a group of organics crystals, stilbene is known for its excellent n–γ discrimination properties. An example of pulse shapes generated by neutrons and γ rays is presented in Fig. 1. Stilbene crystals have selective response for neutrons and γ rays due to the differences in the pulse shape of scintillation signals. Nevertheless, stilbene single crystals are not so frequently used because it is difficult to grow them to large sizes (above one inch) [8]. Liquid scintillators are more frequently used than stilbene crystals as they are relatively low cost materials (much cheaper than stilbene) which allow to build large volume detectors. Recently, promising alternative for the detection of fast neutrons was found, namely the composite scintillators [9, 10], having good n–γ discrimination. Composite scintillators are representing a new type of organic scintillators

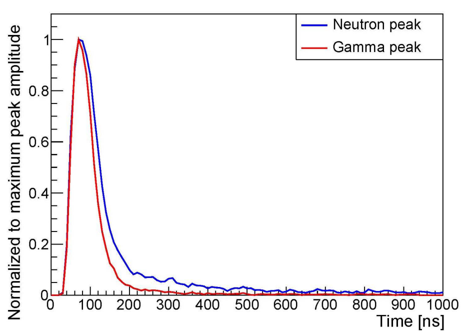
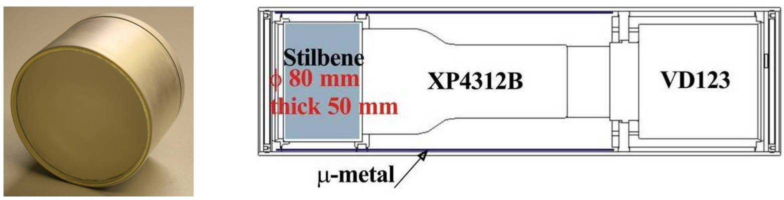


Fig. 1. Typical neutron and γ-ray pulses, for stilbene scintillator. The curves are normalized at their maximum values.

— crystals in grains. These are relatively low cost materials offering the properties of organic scintillators for large volume detectors. In this work, we present a new neutron detector array based on stilbene single crystals.

2. Neutron detector array

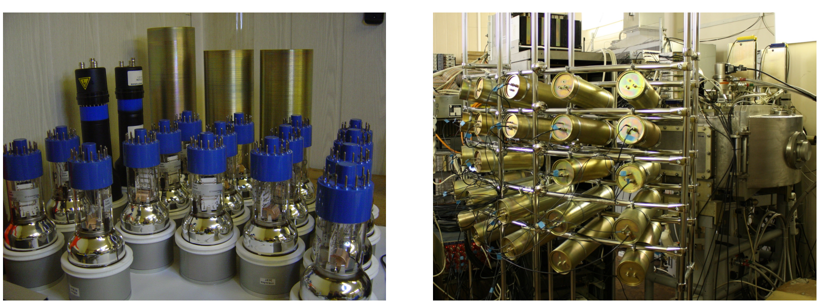
The new neutron detector array is based on 32 stilbene organic scintillators manufactured by company Amcrys-H from Kharkov, Ukraine. Each detection module consists of a stilbene organic scintillator, 80 mm in diameter and 50 mm thick (Fig. 2 (a)). The compact size of stilbene crystal



(a) (b)

Fig. 2. (a) Stilbene scintillator of 80 mm in diameter and 50 mm thick encapsulated into an aluminum housing. (b) A scheme of a detection module.

and a very good amplitude resolution, in comparison to neutron detectors based on liquid scintillators, make this type of detectors advantageous from the point of view of the angular, time, and energy resolution. The stilbene scintillators are coupled with Photonis 9822B or Enterprise ET9305KB photomultipliers (PMT) by RTV-615 optical resin and placed into custom made housing. A schematic view of a detection module is shown in Fig. 2 (b). Stilbene scintillators with PMTs and the neutron detection wall are shown in Fig. 3 (a), (b), respectively. A typical block diagram for neutron-γ separation system is shown in Fig. 4.



(a) (b)

Fig. 3. (a) Stilbene crystals and PMTs. (b) A layout of the neutron detection array in the measurement room.

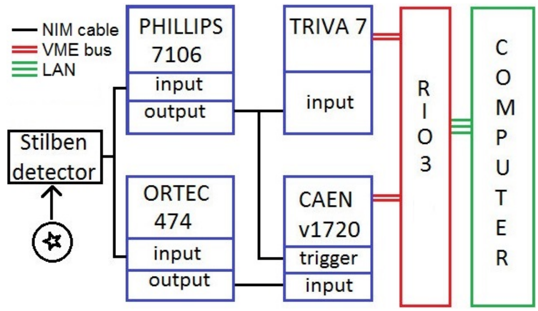


Fig. 4. Block diagram of a typical neutron–γ separation experiment.

3. Energy calibration

Compton scattering is the dominant interaction of γ rays with matter, in the energy range of γ rays about 1 MeV. In such interactions, a fraction of the incident γ-ray energy is deposited, so full-energy peaks are not observed in typical spectra [11]. The light output of electron is linear with its energy in the range of 0.04 MeV $\leq E_e \leq$ 1.6 MeV [12], so the Compton electrons are used to perform the energy calibration. The energy is usually described in keVee, where ee stands electron–equivalent unit. The Compton edge is determined by using the formula [13]

$$N_{\mathrm{c}} = N_{\mathrm{p}} + 1.177\sigma\,, \tag{1}$$

where N_{c} is the channel number of the Compton edge, N_{p} is the channel number of the edge peak, σ is a standard deviation of the edge peak. The energy of the Compton edge for ^{137}Cs and ^{60}Co are 478 keV and 1041 keV,

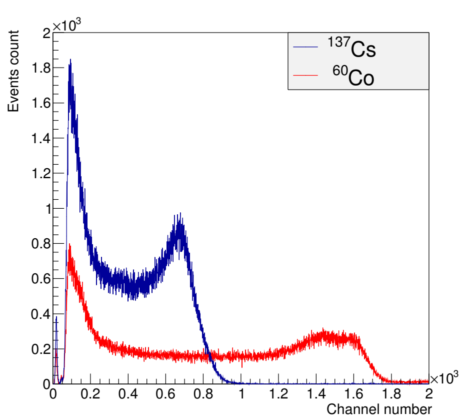


Fig. 5. The scintillation amplitude spectra for the stilbene crystal irradiated by γ rays from ^{137}Cs and ^{60}Co sources.

respectively. In measurements, the energies of the Compton edge for ^{137}Cs and ^{60}Co are corresponding to 696 and 1549 channels, respectively. The calibration spectra for both sources are shown in Fig. 5.

4. Pulse shape discrimination of neutron–γ signals

The energy threshold of the n–γ discrimination for stilbene scintillators has been obtained using the pulse shape discrimination method (PSD) [14]. In general, the PSD method is based on the determination of the ratio of two parts of the signal: a peak and its tail. An example of PSD spectra is shown in Fig. 6 (a). A quantity that is used for representing the discrimination power of PSD method is called figure of merit (FOM), calculated for various, narrow pulse height cuts. The definition of FOM is given by the formula

$$\mathrm{FOM} = \frac{T_{n-\gamma}}{W_n + W_\gamma}\,, \tag{2}$$

where $T_{n-\gamma}$ is the distance between the γ ray and neutron peak, W_γ is the FWHM of γ rays, and W_n is the FWHM of neutrons. It is known that spectra are discriminated when FOM is equal 1.27 [15]. For such FOM value, the n–γ peaks are separated at 99.5% of the confidence level.

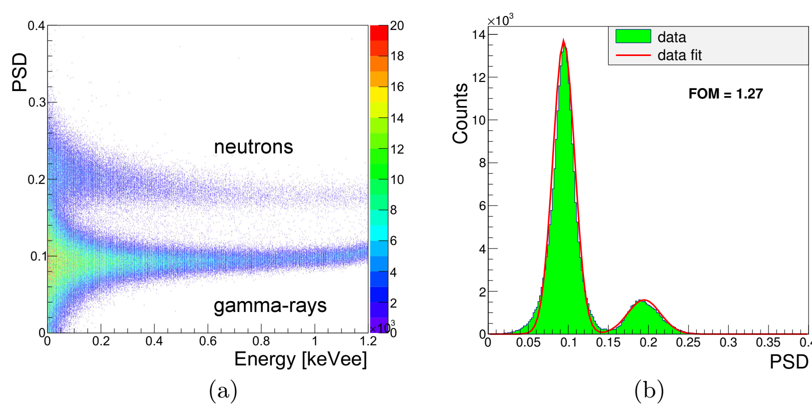


Fig. 6. (a) An example of neutron–γ discrimination plot obtained with a stilbene scintillator under irradiation of ^{252}Cf source; (b) FOM value for the lower energy threshold $\sim$ 75 keVee. Data fit is performed by a default ROOT build in procedure using a Gaussian function.

The important aspect of the PSD procedure is determination of a dividing point ("the border") between the peak and the tail. More generally, the dividing point is a function of pulse energy chosen to maximize a FOM value. The PSD algorithm is based on a few step procedure. For a given energy threshold, the borders for light signal integration are chosen to maximize the FOM value. Three different procedures to determine the borders of integration of the peak and the tail of the signal have been applied. To get the energy separation threshold the procedure of searching the best FOM value have been repeated for different energies. The energy separation threshold for given signal border have been determined as the lowest energy for which the FOM value is 1.27. At 75 keVee, the dividing point between peak and tail is 120 ns.

After the PSD procedure the value of the threshold for the n–γ discrimination was estimated as $\sim$ 75 keVee. Time resolution of the stilbene detectors was found by measuring γ rays from ^{137}Cs γ source with a pair of stilbene modules. Data analysis was done by means of procedures by using the ROOT scripts. The time resolution obtained for all 32 units was determined as 600 ps.

5. Summary

A new neutron detection array based on 32 stilbene organic crystals has been constructed. The test measurements of the neutron array with ^{252}Cf source using a simple DAQ system, resulted in determination of the energy separation threshold (75 keVee) for n–γ discrimination at the confidence level of 99.5%. The new front end electronics for Photonis 9822B and Enterprise ET9305KB PMTs and electronic modules in NIM standard for generating gates are being developed. The neutron detection array will be extended to 64 stilbene modules for future experiments at the ACCULINNA and ACCULINNA-2 fragment separators.

The work was partially supported by JINR grant No. 13-502-03 and the Russian RFBR Grant No. 11-02-00657-a.

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