An investigation of stilbene organic scintillators for fast neutron detection at Acculinna-2

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Overview

The energy and time resolution in accordance with neutron registration efficiency, $n-\gamma$ separations and light output responses to electrons and charged ions of stilbene scintillators are presented in this work. The measurements are carried out by the use of neutron and gamma sources together with Monte Carlo simulations in the Geant4 toolkit framework.

Introduction

- A neutron spectrometer based on stilbene crystals coupling with fast photomultiplier tubes, has been crucially developed and routinely employed in our research for the demand of studying a set of resonant states of neutron-rich nuclei ($^{5-7}\mathrm{H}, ^{7,9}\mathrm{He}$ and $^{10}\mathrm{Li}$) lately at ACCULINNA-2 [1-2].

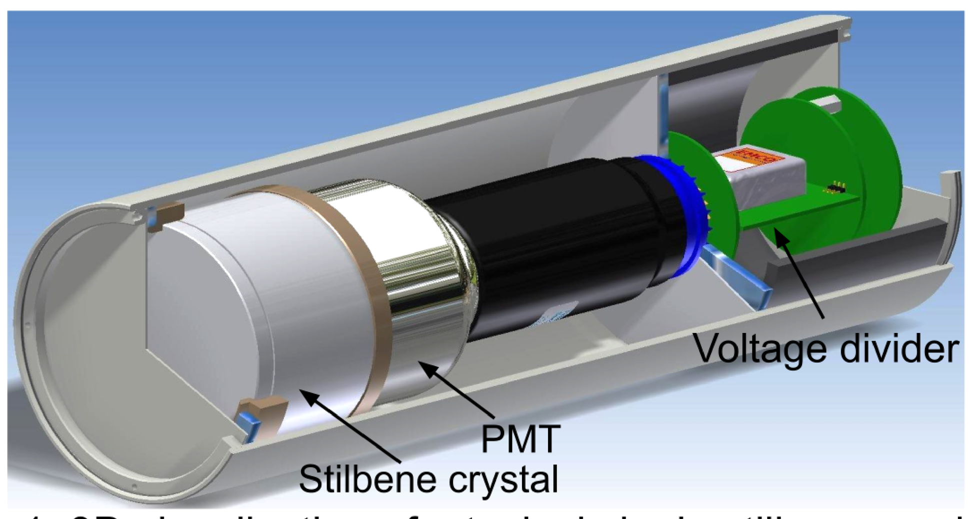

Fig. 1: 3D visualization of a typical single stilbene module.

- Typical assembling of a stilbene module is a $\varnothing$ 80 $\times$ 50 mm stilbene crystal ($C_{14}H_{12}$) coupling optically with a 3" ET-Enterprise 9822B PMT and is encapsulated in a thin-walled aluminum housing, as depicted in Fig. 1.

γ-measurements

1. **Energy calibration**
   - The response of a stilbene scintillator is regularly calibrated by means of $^{22}\mathrm{Na}$ and $^{137}\mathrm{Cs}$ γ-ray sources. The photopeak cannot be attained owing to the low atomic number of organic scintillators, hence we utilize the Compton Edge (CE) technique [2] for such energy calibrations.

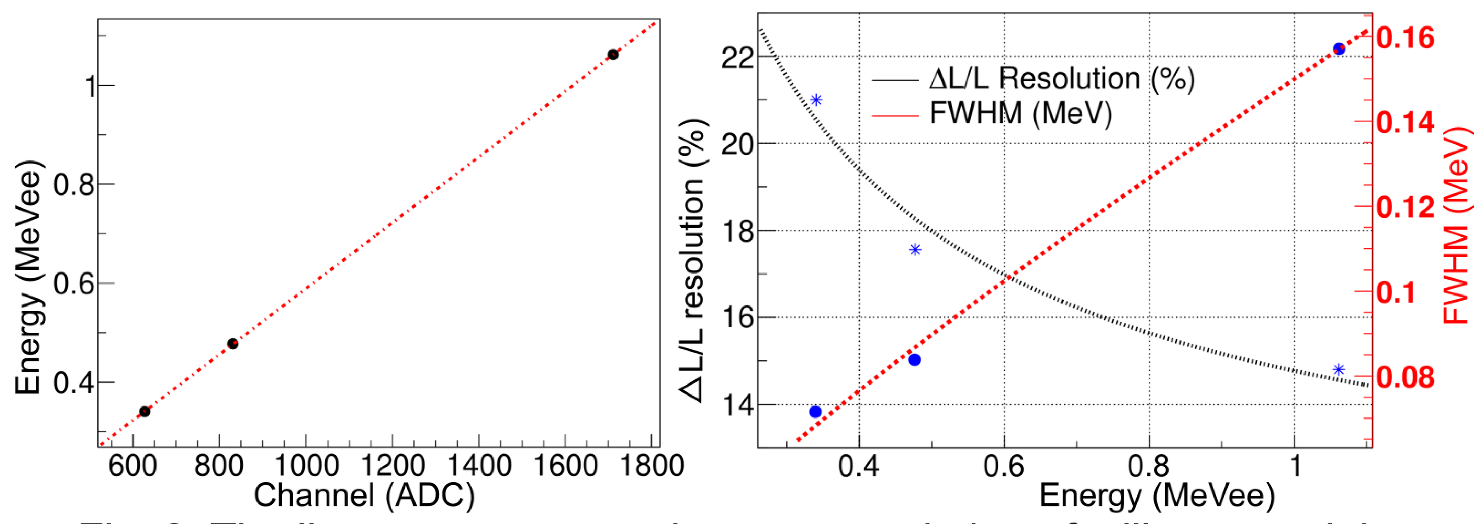

Fig. 2: The linear response and energy resolution of stilbene module.

   - The first derivative of measured spectra is to precisely determine the CE positions and later on the spectra are to be compared with Geant4 simulations so as to extract its energy resolution, presented in Fig. 2.

2. **Time resolution**
   - Time resolution is performed by use of $^{60}\mathrm{Co}$ source, decaying a cascade of two γ-quanta. Coincidence measurements are done with 04 independent stilbene modules that have similar amplitude and timing properties.

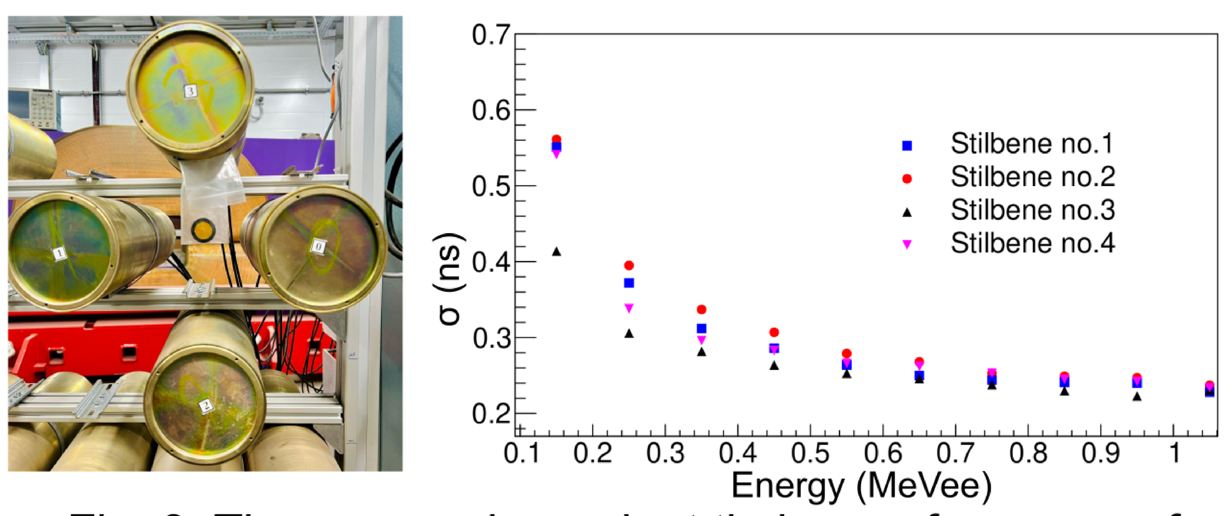

Fig. 3: The energy dependent timing performance of each individual module in a set of 04 stilbene detectors.

   - Utilizing a set of matrices to solve at least 04 linear equations, the energy dependent time resolution for each module is depicted in Fig. 3, different range of the data derives from disparate signal sizes.

Neutron measurements

A typical monoenergetic fast neutron beam from $\mathrm{d-T}$ reaction originated by a continuous neutron flux generator ING-27 [3] is used in this work.

1. **Neutron gamma discrimination (NGD)**
   - In Fig. 4, 2D plot PSD versus energy indicates the $n-\gamma$ discrimination of stilbene detector at different range of energies. The Figure-of-Merit (FOM) factor is to specify which detector is better for neutron detection, the higher the FOM, the better the $n-\gamma$ separations.

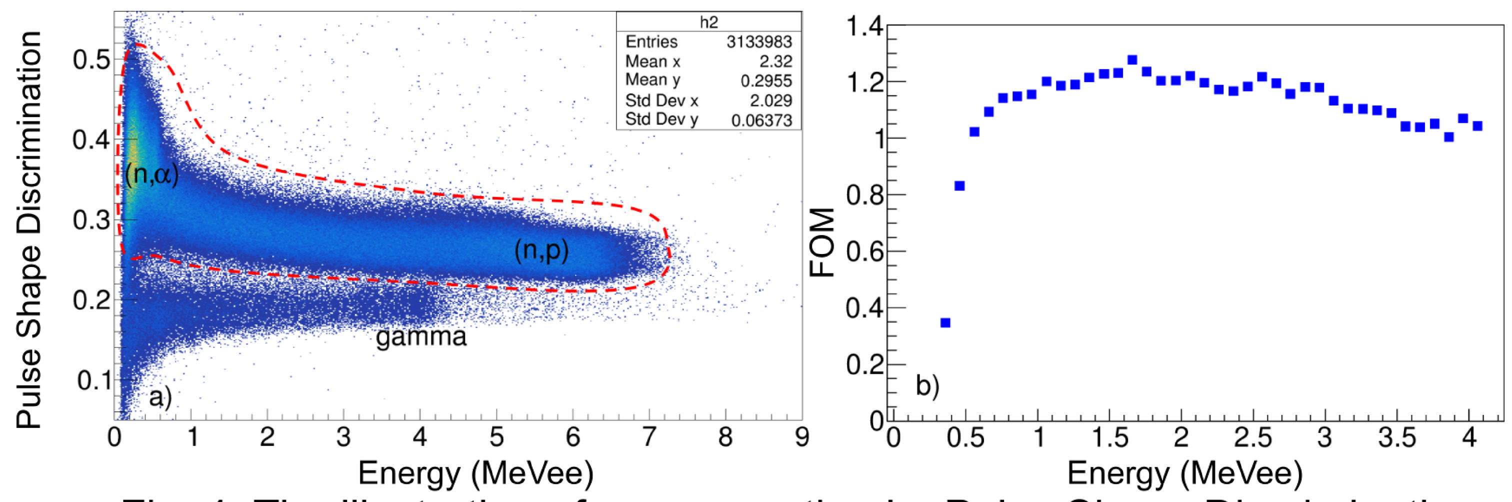

Fig. 4: The illustration of n-γ separation by Pulse Shape Discrimination and the energy dependent FOM from 0.3-4 MeVee.

2. **Light output responses to heavy charged particles**
   - Light production differs for each type of scintillator and also relies on the sort of charged particle ionizing inside the materials.

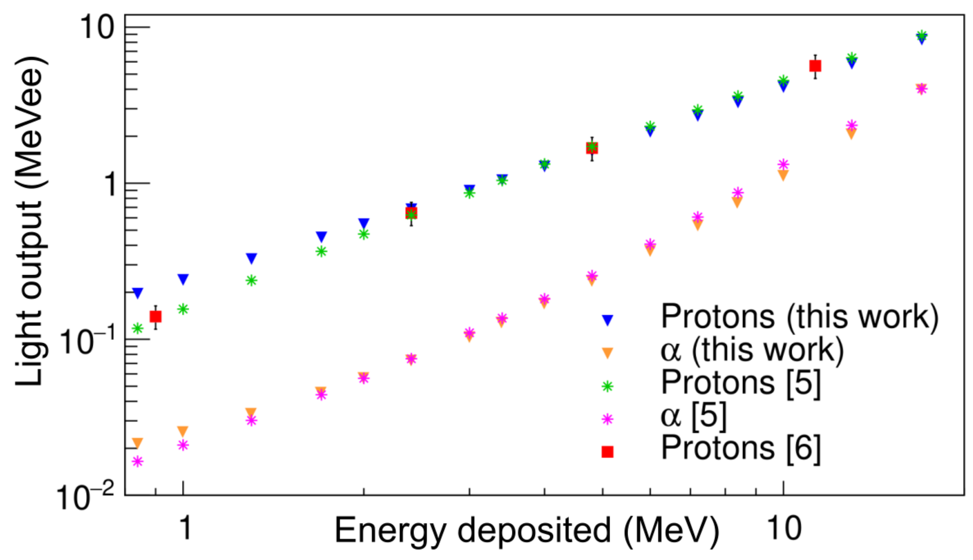

Fig. 5: Light output as a function of recoil particle energy in stilbene.

   - Fitting the measured responses to charged paticles of stilbene detector with Geant4 simulation, we reconstruct the light output function of recoil proton + α-particles, and compare with other studies in Fig. 5.
   - Possessing the same initial energy, electrons tend to generate more light than heavier particles when they stop in organic scintillators.

3. **Neutron registration efficiency**
   - The neutron detection efficiency is experimentally defined as the amount of observed neutron-α coincidences divided by the total number of only incoming α-particles reaching the 64-pixel silicon detector.

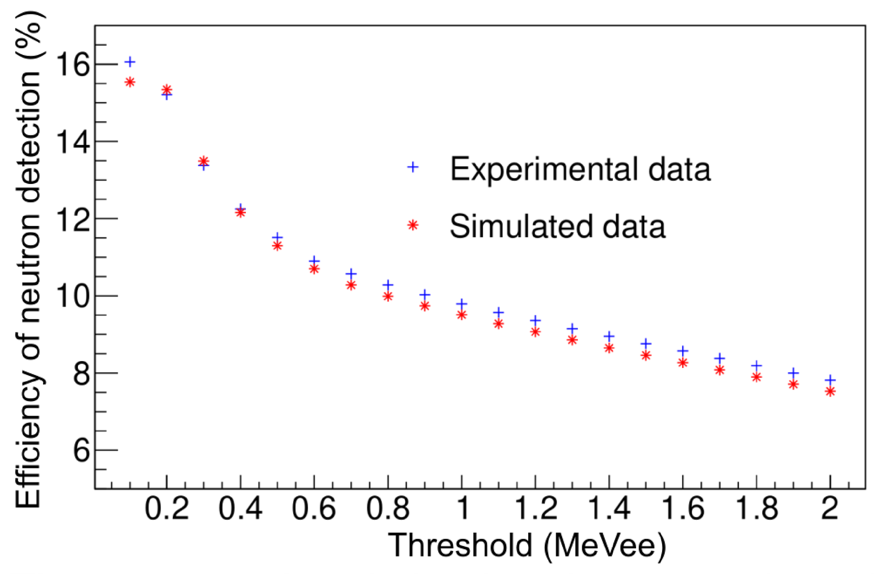

Fig. 6: The measured and simulated neutron detection efficiency dependent thresholds in stilbene scintillator.

   - The simulated neutron registration is calculated by integrating the response function of stilbene in Geant4 and is compared with measured data at different threshold levels in Fig. 6.

Summary

- The characterization of stilbene detectors in terms of neutron registration efficiency, $n-\gamma$ separation capability along with time and energy resolution were examined in this work.
- It is pivotal to investigate thoroughly a typical stilbene detector performance so as to optimize and advance later our neutron spectroscopy at ACCULINNA-2 to a qualitatively higher level.

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