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List of acronyms and abbreviations

PVT	polyvinyltoluene
PPO	2,5-diphenyloxazole
INFN-LNS	Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali del Sud
R&D	Research and Development
DCE	Double Carge Exchange
NRP	Nuclear Reactions and astrophysics process in Plasmas
ToF	Time of Flight
SiPM	Silicon Photo Multiplier
PSD	Pulse Shape Discrimination
PMT	Photo Multiplier Tube
FOM	Figure Of Merit
FWHM	Full Width at Half Maximum

Executive Summary

Introduction

In the past scintillation detectors have been used in several nuclear physics studies [1-3] and applications [4, 5]. Recently, the possibility of manufacturing plastic scintillators with efficient neutron/gamma discrimination has been developed with a new polyvinyltoluene (PVT) polymer matrix loaded with a scintillating dye, 2,5-diphenyloxazole (PPO) [6].
Recently at INFN-LNS two research topics are fostering R&D on these scintillators, the study of Double Charge Exchange (DCE) in peripheral nuclear reactions [7] and Nuclear Reactions and astrophysics process in Plasmas (NRP) [8].
The exploration of detailed nuclear structure through DCE has historically got great benefits by the use of magnetic spectrometers. Recently large acceptance and high resolution spectrometers have been installed in leading European laboratories for fundamental nuclear physics with a major impact on the progress of knowledge in several branches of nuclear structure and reaction mechanisms.
Important upgrading of the existing facilities can be foreseen, especially in the view of emerging detection technologies, in order to extend the application of magnetic spectrometry to the more and more challenging experiments required by the present and future nuclear science. Among these, the MAGNEX spectrometer [9] of LNS has been coupled to organic scintillators neutron detector array, EDEN [10,11], to perform a better selection of reaction mechanisms. The improvement of PPO technology could be very useful to these topics.
NRP is a new field of studies related to recent laser technology advances, which in the near future can give the opportunity to investigate nuclear reactions and fundamental process in plasma under extreme conditions. Also for this contest, the “ideal” neutron detection module must have: i) high efficiency; ii) good discrimination of gammas from neutrons; iii) good timing performance for ToF neutron energies reconstruction.
In addition, laser-plasma experiments require detector able to work in hard environmental conditions. These requirements may be met by configuration based on plastic scintillators coupled with new solid state devices, Silicon Photomultiplier, SiPM [12-14], and a totally digital acquisition for the multi-hit signals expected from reactions events in plasma.
A possibility of manufacturing plastic scintillators with efficient neutron/gamma pulse shape discrimination is demonstrated using a system of a PVT polymer matrix loaded with a PPO. According to a commonly accepted mechanism [15, 16], both gamma and neutron induced pulses contain a fast decay (prompt) component and a slow decay (delayed) fluorescence one.

Pulse Shape Discrimination for EJ301 and EJ299 scintillator

In order to characterize the Pulse Shape Discrimination (PSD) for the two detectors the following experimental set-up was done.

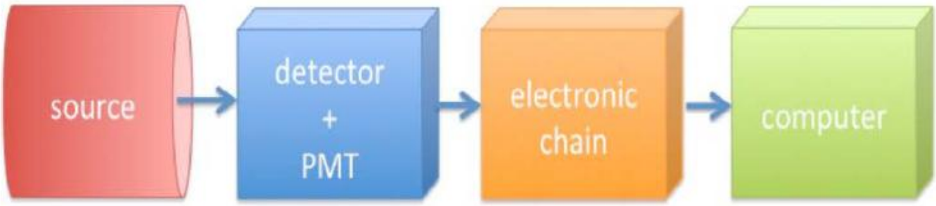

Figure 1: A sketch of the experimental setup.

The first test on detectors was performed on liquid scintillator EJ301 + PMT (Photo Multiplier Tube) Hamamatsu R 1250 (14 stages). The liquid scintillator has been assembled and oriented towards the Am-Be source collimated through an aluminium plate 2 cm thick with a hole of 5 mm diameter, in order to keep less than 5% the difference in the path length of particles impinging in the detectors.

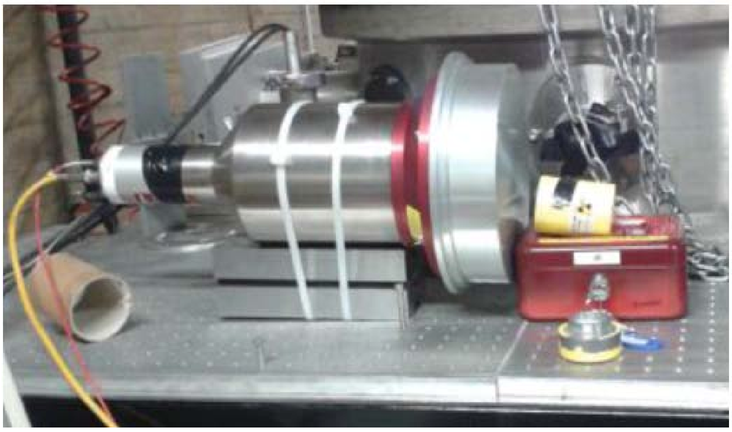

Figure 2. Scintillator EJ301 coupled with phototube.

The second test was performed on plastic scintillator EJ299 + PMT Hamamatsu R 1924 (10 stages) . The plastic scintillator has been assembled and oriented in front of Am-Be source, collimator thickness of 2 cm and a diameter of 3 mm, to minimize the discrepancy path of the particles in the sparkling part, less than 5%.

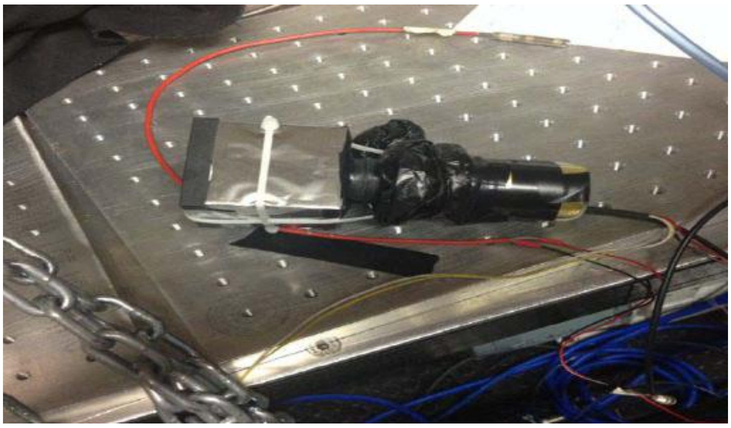

Figure 3. Scintillator EJ299 assembled with phototube.

The circuit is based on an analog fast stretcher generating highly performing signals for PSD and timing purposes. A beam test has demonstrated a low detection threshold, a good pulse-shape discrimination even at low energies and a wide dynamic range for measurement of the neutrons energy [10]. The voltage generated by the photon interaction of PMT are sent to BaF Pro [17,18].

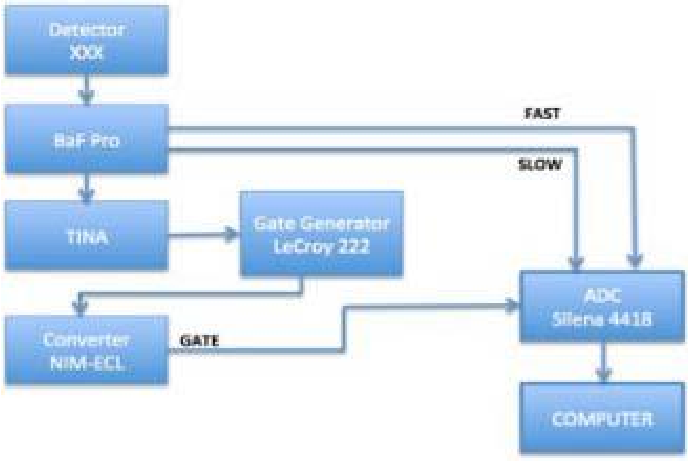

Figure 4. Block diagram of the electronic for the PSD.

The 16-channel BaF-pro module makes use of a sophisticated analog fast stretcher circuit to determine the fast component of the light output of the scintillator (hereafter indicated as ''fast'') and an integration section that provides the total energy of the signal (hereafter indicated as ''slow'').
Finally, a computer recorded the Fast and Slow components produced by the light collection system.
Techniques for accurate discrimination between neutrons and photons interacting with scintillators have been established for a long time. The PSD techniques used to distinguish between the pulses from neutrons and the pulses from gamma rays rely on the differences in the pulse shapes produced.
The goal of this research effort was to test the ability of a polyvinyltoluene research sample to produce recordable, distinguishable signals in response to gamma rays and neutrons. PSD was performed to identify if the signal was generated by a gamma ray or a neutron.

Analysis and Results

The typical signal of EJ301 and EJ299 [19] coupled with PMT are shown in figure 5 and figure 6 respectively.

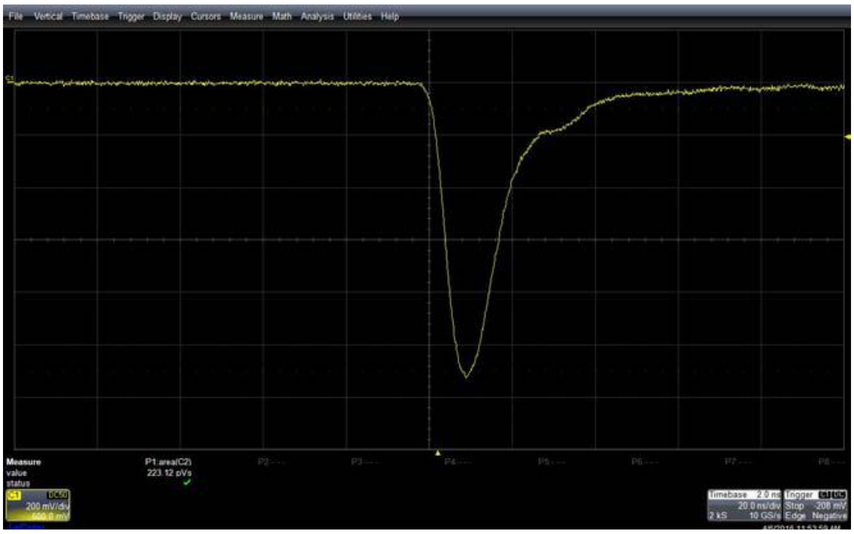

Figure 5. Signal of EJ301 + PMT from oscilloscope LeCroy. Time base is 20 ns/division.

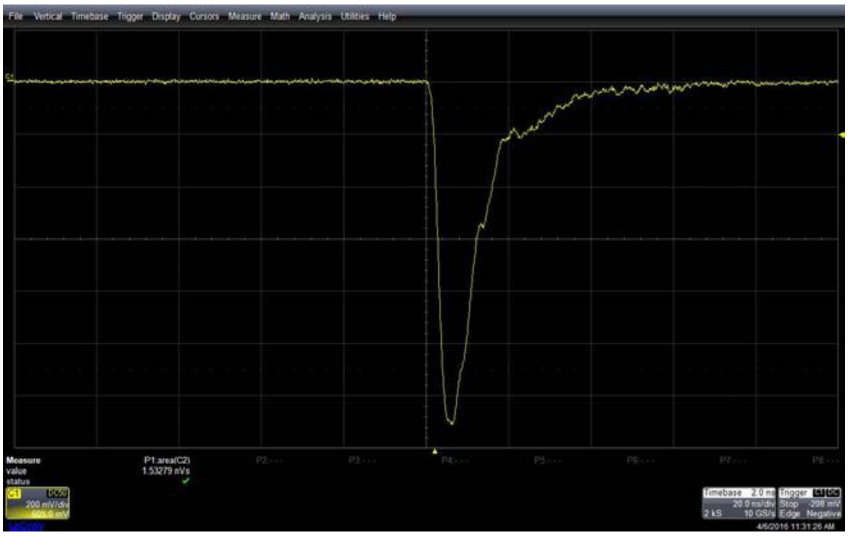

Figure 6. Signal of EJ299 + PMT from oscilloscope LeCroy. Time base is 20 ns/division.

We observed that the response of liquid scintillator is characterized by decay times of the order of 3-4 ns. The results of PSD analisys are shown in figure 7 and figure 8 for EJ301 and EJ299 respectively (neutrons are bounded in a red polygon).

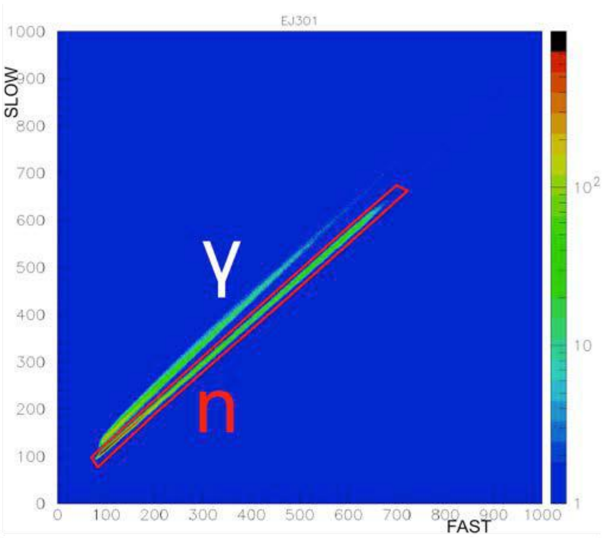

Figure 7. PSD performance for EJ301.

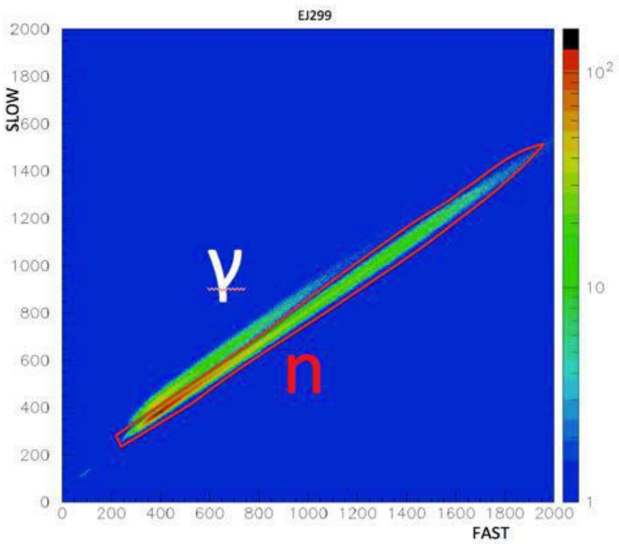

Figure 8. PSD performance for EJ299.

Pulse shape analysis allowed the definition of a figure of merit as an indicative parameter for the neutron/gamma discrimination. Any detector with a Figure Of Merit (FOM) above 0.58 [20], that is FOM: $FOM=S/(\delta_{neutrons} + \delta_{gammas})$ where S is the separation between gamma and neutron peaks, and $\delta_{neutrons}$, δ_{gammas} are full width at half maximum (FWHM) of the corresponding peaks, can be considered to have adequate PSD capability for fast neutron detection in the presence of gamma rays. Both detectors exceed this FOM.
The separation S was calculated as the difference between the mean delayed light, for neutrons and gammas taken as a normal distribution in PSD over a specified energy range.

Conclusion

A plastic scintillator prototype has been fully built, equipped and tested, thus making this deliverable fully accomplished. In particular in this document we have described the activity made at INFN-LNS on the plastic scintillator EJ299 in comparison with the most traditional liquid scintillator EJ301 used in several nuclear physics experiments.

One of the advantages of plastic scintillators include fairly high light output, with a decay time of 2-4 nanoseconds, but one of the major advantages is their flexibility; they are easily machined by normal means and shaped to desired forms.
A special focus on the PSD capability of this material, which is characterized by low toxicity and low volatility, has been addressed.
PSD analysis allowed the definition of a FOM as an indicative parameter for the neutron/gamma discrimination. Any detector with a FOM above 0.58 can be considered to have adequate PSD capability for fast neutron detection in the presence of gamma rays. Both detectors exceed this FOM.

ANNEX