Digital Gamma-Neutron Discrimination with Organic Plastic Scintillator EJ 299-33

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The neutron/gamma pulse shape discrimination (PSD) is measured for the newly discovered plastic scintillator EJ 299-33 using a fast digitizer DDC10. This plastic scintillator (EJ 299-33) discovered by Lawrence Livermore National Laboratory(LLNL) is now commercially available by Eljen Technology. Some of its properties include light output emission efficiency of 56/100 (of Anthracene), wavelength of maximum emission of 420 nm, C:H ratio of 1:1.06 and density of 1.08 g/cm^3. The PSD between neutrons and gamma rays in this plastic scintillator is studied using a 5.08-cm diameter by 5.08-cm thick sample irradiated by a neutron-gamma source AmBe-241 and employing charge integration method. The results show that EJ 299-33 has a very good PSD, having a figure of merit of approximately 0.80, 2.5 and 3.09 at 100 KeVee, 450 KeVee and 750 KeVee light outputs respectively. The performance of this new material is compared to that of a liquid scintillator with a well proven excellent PSD performance NE213, having a figure of merit of 0.93, 2.95 and 3.30 at 100 KeVee, 450 KeVee and 750 KeVee respectively. The PSD performance of EJ 299-33 is found to be comparable to that of NE 213.

1 Introduction

For several years efforts to develop plastic scintillators with efficient neutron/gamma discrimination yielded little success [1, 2]. Plastic scintillators are preferred over liquid scintillators for a number of attractive features including low cost, self-containment, and ease of machining. This is why the invention of the plastic scintillator EJ 299-33 [3], with a very good PSD capability has generated a great interest in the community [4–8].

Applications of this type of scintillator in complex nuclear physics experiments or in homeland security and nonproliferation and safeguards are now possible. The goal of this paper is to report our recent off-line evaluation of PSD capability of EJ 299-33.

2 Experimental method

The experiment was performed at Nuclear Science Research Laboratory in Rochester. This experiment was done prior to our in-beam experiment at Laboratori Nazionali del Sud (LNS) in Catania [8]. It was meant to test the response of the organic plastic scintillator EJ 299-33, the same scintillator used in the in-beam experiment. Our results from the in-beam experiments have since been published elsewhere [8].

The experiment was done using a fast digital signal processing module, DDC10 made by SkuTek instruments [9]. The DDC10 is fashioned with 10 analog inputs, each of which is capable of a 14bit analog to digital conversions operating at 100 Ms/s. The neutron/gamma study was performed using neutron-gamma source AmBe-241, shielded with a 5.0-cm lead block which reduced the γ rates to a magnitude comparable to that of neutrons, to irradiate the 5.08-cm diameter × 5.08-cm thick EJ 299-33 sample. The plastic scintillator EJ 299-33 was coupled to the photomultipler(PMT) Hamamatsu R7724 and PMT base of ELJEN model VD23N-7724 operated at 1750 Volts. The liquid scintillator NE-213 was however coupled to PMT XP-2041 operated at 1750 Volts.

In order to separate neutrons from γ-rays, integration is performed in two parts of the pulse from the digital waveforms. The first integration is done from the beginning of the pulse rise time and the other integration is done over the tail part. These two integrals are designated Q_{total} and Q_{tail} respectively. The ratio between them is used to separate neutrons from γ-rays. Thus PSD is defined as

$$PSD = \frac{Q_{tail}}{Q_{total}}. \tag{1}$$

The point where the tail begins can be optimized for better neutron/gamma separation. For this case, the tail begins 40-ns after the rise time.

The quantitative evaluation of PSD was made using figures of merit (FOM) defined below.

$$FOM = \frac{\Delta X}{(\delta_{gamma} + \delta_{neutron})}, \tag{2}$$

where ΔX is the separation between the gamma and neutron peaks, and δ_{gamma} and $\delta_{neutron}$ are the full width at half maximum of the corresponding peaks (see Figs. 2A-F). The separation, ΔX was calculated as the difference between the mean delayed light fraction $\frac{Q_{tail}}{Q_{total}}$, for neutrons and gamma-rays taken as a normal distribution in PSD over a specified energy range [3]

A reference parameter to define a good PSD in the tested sample is arrived at by noting that a reasonable definition

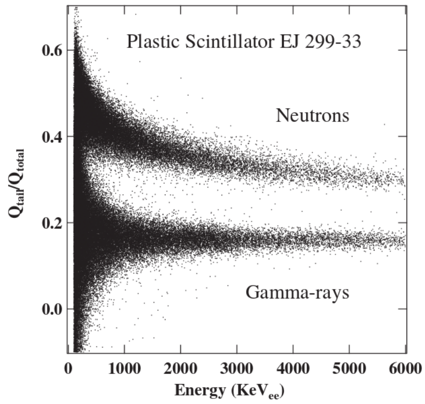

Fig. 1A: Pulse shape discrimination patterns for γ-rays and neutrons obtained using charge integration method for the plastic scintillator EJ 299-33.

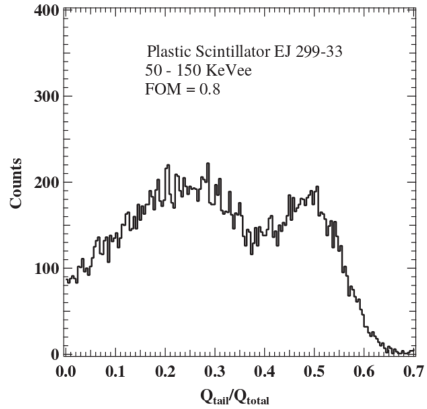

Fig. 2A: PID pattern obtained with organic plastic scintillator EJ 299-33 showing n/γ separation for the light output cut 50-150 KeVee.

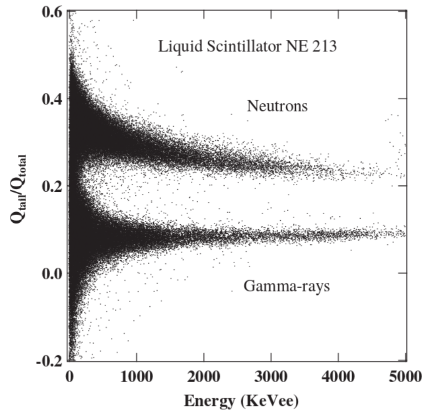

Fig. 1B: Pulse shape discrimination patterns for γ-rays and neutrons obtained using charge integration method for the liquid scintillator NE213.

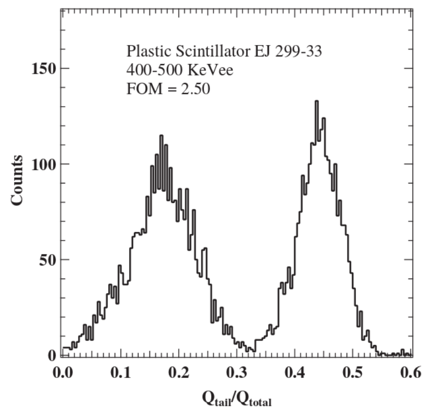

Fig. 2B: PID pattern obtained with organic plastic scintillator EJ 299-33 showing n/γ separation for the light output cut 400-500 KeVee.

for well separated Gaussian distributions of similar populations sizes is $\Delta X > 3(\sigma_{gamma} + \sigma_{neutron})$, where σ is the standard deviation for each corresponding peak. Considering that full width at half maximum for each peak is related to the standard deviation by the expression, FWHM$\approx 2.36\sigma$, FOM$\geq 3(\sigma_{gamma} + \sigma_{neutron})/2.36(\sigma_{gamma} + \sigma_{neutron}) \approx 1.27$ is considered a good PSD [3].

3 Experimental results

The main experimental results are represented in Figs. 1A-1B and Figs. 2A-2F. The quality of PSD achieved with the plastic scintillator EJ 299-33 is illustrated in Fig. 1A, where one observes a very good separation of intensity ridges due to γ-rays (effectively recoil electrons) and neutrons(effectively recoil protons). Fig. 1B illustrates similar result but for the standard liquid scintillator NE 213 with proven excellent PSD capability for purposes of comparison. As one observes in 1A-B, the degree of separation of neutrons from γ-rays for the EJ 299-33 and NE 213 is comparable. This excellent PSD capability is what makes this new scintillator unique among the plastic scintillators and is a welcome feature from the point of neutron detection and identification in the presence of gamma-ray background.

The quality of particle identification(PID) i.e. separation of neutrons and γ-rays is further evidenced by the figure of merit(FOM) as illustrated in Figs. 2A-2C for EJ 299-33 for the energy cuts 100 KeVee, 450 KeVee and 750 KeVee respectively, as indicated by the labels. Figs. 2D-2F show similar results but this case for the liquid scintillator NE 213 included for the purpose of comparison. In order to calculate the FOM, we make energy cut and project only the points within the energy cut along the y-axis. The resulting plot has a PSD along the x-axis and counts on the y-axis as shown in Figs. 2A-2F. The obtained figures of merit suggest the per-

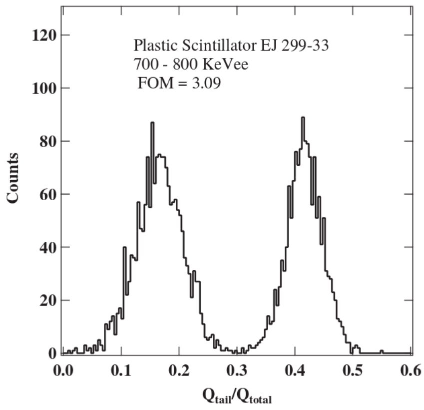

Fig. 2C: PID pattern obtained with organic plastic scintillator EJ 299-33 showing n/γ separation for the light output cut 700-800 KeVee.

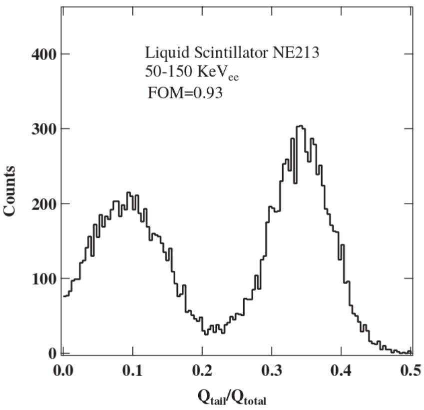

Fig. 2D: PID pattern obtained with organic liquid scintillator NE213 showing n/γ separation for the light output cut 50-150 KeVee.

formance of the standard liquid scintillator NE 213 and the new plastic scintillator are comparable. This results suggest that the replacement of liquid scintillators by plastic scintillators for applications challenged by the well known problems of liquids such as toxicity, flammability, high freezing points, among others is now possible [3, 4].

4 Summary

The results show excellent PSD capability of the new plastic scintillator EJ 299-33 to a level useful for practical applications in complex nuclear physics experiments, nuclear forensics etc. Along with its good charged particle identification [8], EJ 299-33 is expected to provide a viable alternative to the widely used CsI(Tl)detetctor.

Acknowledgements

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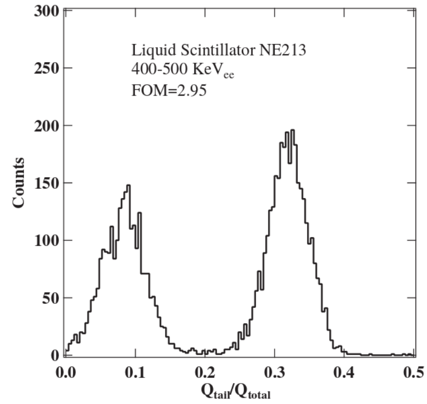

Fig. 2E: PID pattern obtained with organic liquid scintillator NE213 showing n/γ separation for the light output cut 400-500 KeVee.

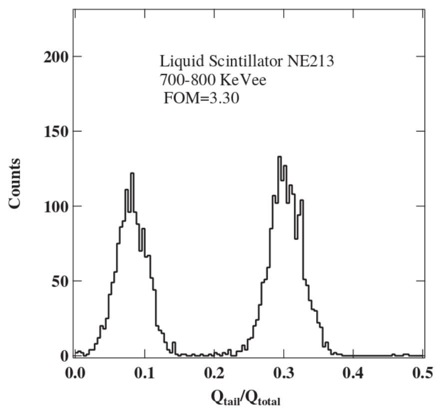

Fig. 2F: PID pattern obtained with organic liquid scintillator NE213 showing n/γ separation for the light output cut 700-800 KeVee.

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References

1. Birks J. B. The theory and Practice of Scintillation Counting. Pergamon Press, London, 1963.
2. Knoll G. F. Radiation Detection and Measurements. John Wiley and Sons, Inc. 2007.
3. Zaitzeva N., Benjamin L. P., Iwona P., Andrew G., Paul H. M., Leslie C., Michele F., Nerine C., Stephen P. *Nuclear Instruments and Methods in Physics Research*, 2012, v. A668, 88–93.
4. Pozzi S. A., Bourne M. M., Clarke S. *Nuclear Instruments and Methods in Physics Research*, 2013, v. A723, 19–23.
5. Cester D., Nebbia G., Pino F., Viesti G. *Nuclear Instruments and Methods in Physics Research*, 2014, v. A748, 33–38.
6. Preston R. M., Eberhard J. E., Tickner J. R. *Journal of Instrumentation*, 2013, issue 8, P12005.
7. Favalli A. *IEEE Nuclear Science*, 2013, v. 60, 1053.
8. Nyibule S., Henry E., Tõke J.,Schöder U. W. *Nuclear Instruments and Methods in Physics Research*, 2013, v. A728, 36–39.
9. http://www.skutek.com