High Efficiency Large Volume Multiparametric Neutron Detector for Nuclear Physics and Nuclear Astrophysics Measurements

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Abstract

Monitoring neutron emission with efficient detectors is the most straightforward way to study physics problems such as fission of heavy nuclei, where neutrons are preferentially emitted because of the Coulomb barrier, the (α,n) reactions among them we mention ^{13}C(α, n) ^{16}O and ^{26}Ne$(\alpha, n)^{25}$Mg that are essential to understand the evolution of AGB (asymptotic giant branch) stars and the production of elements heavier than Fe via slow neutron capture s-process. A large volume (more than 5 l) neutron detector has been realized by organic liquid scintillator: the detector shows a very good performance for high efficiency measurements at low and very low neutron rate in the 0.03-10 MeV energy range. γ-n discrimination has been jointly performed by standard pulse shape discrimination and the digital charge comparison method, the results obtained by the two techniques are presented and discussed. A very good γ-n discrimination down to 100 kee with good efficiency has been achieved.

Key words: neutron spectroscopy, detectors radiation, scintillation detectors
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1. Introduction

The main problem in detecting low energy low rate neutrons is the discrimination between the relatively few neutrons and the large electromagnetic background. Charged background can be easily cut down by veto scintillators

placed around the neutron detector. The first requirement of experimentalists is for high efficiency detector which implies a large size and hence a good n-γ discrimination even if neutron counting rate is a small fraction of the electromagnetic background. n-γ discrimination with neutron counting rate that is some 10^3 smaller than the γ's flux has been successfully reported (see ref.[1]) by large volume liquid scintillator. The second important requirement is that the neutron detector must be fairly robust and not too expensive. Here we describe a neutron detector based on liquid scintillator that fulfils all of these requirements. n-γ discrimination is usually done by pulse shape discrimination (PSD), but this technique does not allow to go down to 500-600 kee (keV electron equivalent energy) with a reasonable efficiency. Exploiting the difference in the intensity of the slow component of the light pulse related to the space density of the charge carriers produced by different types of ionizing particles [2], excellent n-γ discriminations have been measured using the charge comparison method. The charge comparison method compares directly the intensity of the slow component to the total light pulse produced by incident ionizing radiation or the recoil protons and electrons. One charge-to-digital converter (QDC) at the opening of the gate signal integrates the charge corresponding to the total pulse and another QDC, triggered by the delay gate signal, collects only the charge of the slow component. Plotting in two dimensional display the results from the two QDCs the γ's and the neutrons are observed to occupy two well separated regions of the plot. This separation can be observed down to 100 kee energy, with a significant improvement with respect to the standard PSD. The detector is a thin-walled (3 mm) aluminum cylinder 160 mm diameter and 420 mm length filled with around 5 l of NE213 liquid scintillator. The inside of the aluminum container is coated by white highly reflecting paint. NE213 should be oxygen-free as far as possible in order to obtain a good PSD performance, for this reason dry argon was made to pass through the liquid scintillator before sealing the detector. By X-ray analysis it has been checked that the aluminum can is "bubble free" and completely filled with NE213. Two photomultipliers Hamamatsu R1250, 5" diameter view the scintillator through 10 mm thick Pyrex glass plates placed on opposite sides of the cylinder.

2. n-γ discrimination

All the measurements were carried out with an Am-Be source that delivers neutrons with energy up to around 10 MeV with an average value of

around 4 MeV and different γ lines. The light emission mechanism of NE213 has two component: a prompt component, which starts in approximately the first 5 ns after excitation and a delayed component which occurs in the subsequent 20-25 ns. The prompt component is quenched in regions of high density excitation (around the path of a particle with high $\Delta E/dx$) in such a way that the proportion of light emitted in the prompt component changes with $\Delta E/dx$. Pulse shape discrimination of NE213 relies on the relative proportion of these components. A NIM pulse shape discriminator module (Canberra 2160A) operating on the anode pulse of the two photomultipliers viewing the liquid scintillator separates γ from neutron events. The coincidence of the two photomultipliers gives the strobe signal of all the analog electronic chain. A two dimensional scatter plot showing the obtained γ-n discrimination is presented in Fig. 1: it plots the time distributions of the PSD Canberra 2160A module for the lower photomultiplier vs that for the upper one. The contamination of γ's in the neutron area was estimated to be less than 10%. But n-γ discriminations has been also performed by charge comparison method. Fig. 2 shows the block diagram of the experimental arrangement. The typical time relation between photomultiplier pulse and gates at the inputs of QDC is shown in the lower part of Fig. 2. The optimal position of the gate at the slow component and its width are critical points for achievement of a good n-γ discrimination. The optimisation process was carried out for neutrons and γ's accepted in a narrow energy gate ($\Delta E/E = 5\%$) at 300 kee. At this energy both peaks are well resolved in the n-γ discrimination spectrum and are almost Gaussian.

3. Results and discussions

Fig. 3 is a typical two-dimension scatter plot of the charge at the slow component vs the total charge measured with an Am-Be source, displayed in linear scale. A good n-γ discriminations down to about 100 kee energy of recoil electrons and a well defined γ component is achieved: this means a high photoelectron yield is produced in the tested large volume scintillation and a high fraction is collected even if we have an unfavorable scintillator diameter (160 mm) compared to the photomultiplier diameter (127 mm). The wide and asymmetrical distribution of the neutron component in the two dimensional plot seems to reflect a multiple scattering of neutrons on protons which is very likely for a large scintillator. It is well known that the fraction of light at the slow component [2] decreases when the proton energy increases and

we can see this effect very well in Fig. 3. The γ component is almost linear while neutron component is bent, thus we think the light pulse corresponding to neutron detected in double scattering process will be characterized by a more intense slow component than that due to neutrons detected in the single scattering process. The events observed in the valley between γ and neutron components are larger than the background observed above the neutron component. We think the latter events are due to pile-up effect while the events in the valley cannot be interpreted in this way for typical counting rate of $6 \div 8 \times 10^3$ count/s. According to MCNP simulation code[3] the present detector has an efficiency larger than 55% for 10 MeV neutrons and about 50% for γ's of 1275 keV. Since a Am-Be source placed very close to the scintillator was used for these measurements, the coincidence summing of neutrons and γ's de-exciting the 4.4 MeV level in ^{12}C emitted in the prompt coincidence from Am-Be source is expected. The sum pulse due to recoil protons and electrons is expected to be seen in the valley between n and γ lines. This working hypothesis was tested by moving away the source and reducing the neutron flux with paraffin absorber, the percent of event in the valley between neutrons and γ's was drastically reduced. A quantitative estimation of n-γ discrimination can be made by analyzing one dimensional spectra for narrow energy gates set on the total charge (energy) axis. Fig. 4 shows n-γ discrimination spectrum at 100 kee gate measured with a higher gain of the photomultiplier. The shown good separation of γ and neutron peaks means that a very effective n-γ discrimination is achieved down to 100 kee . From Fig. 4 the γ's contamination in the neutron area is evaluated to be less than 4%. Comparing the γ-n discrimination obtained by standard PSD method based on Canberra 2160A module and the digital charge comparison method we have seen that the latter gives the best results both from the amount of the γ's contamination under the neutron peak (10% against 4%) and the lower limit of energy reached (500 kee against 100 kee). We think that the main limitation of n-γ discrimination comes from the photoelectron statistics, that is directly related to the quality of the scintillator and the photoelectron yield of the photomultiplier. This latter is influenced by geometrical factors, i.e. the larger exit of the scintillator than the photomultiplier diameter and a larger absorption of light that effects large volume detectors. Monitoring neutron emission with efficient detectors is the most straightforward way to study physics problems such as fission of heavy nuclei, where neutrons are preferentially emitted because of the Coulomb barrier, the (α,n) reactions among them we mention ^{13}C(α, n) ^{16}O and ^{26}Ne$(\alpha, n)^{25}$Mg that are essential

to understand the evolution of AGB (asymptotic giant branch) stars and the production of elements heavier than Fe via slow neutron capture s-process. The present detector has been studied in order to match the needs of future research projects in Nuclear Astrophysics [4].

References

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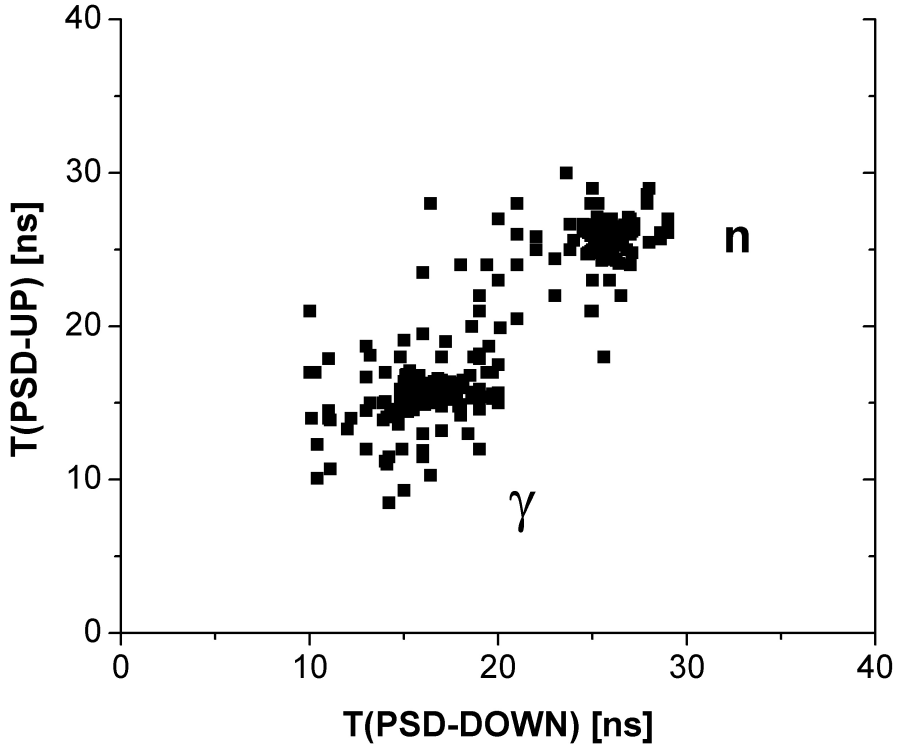

Figure 1: Two dimensional spectrum of the time distribution of the PSD Canberra 2160A module: the vertical and horizontal axis shows the upper and lower photomultiplier respectively. The γ-n discrimination from Am-Be source can be noticed.

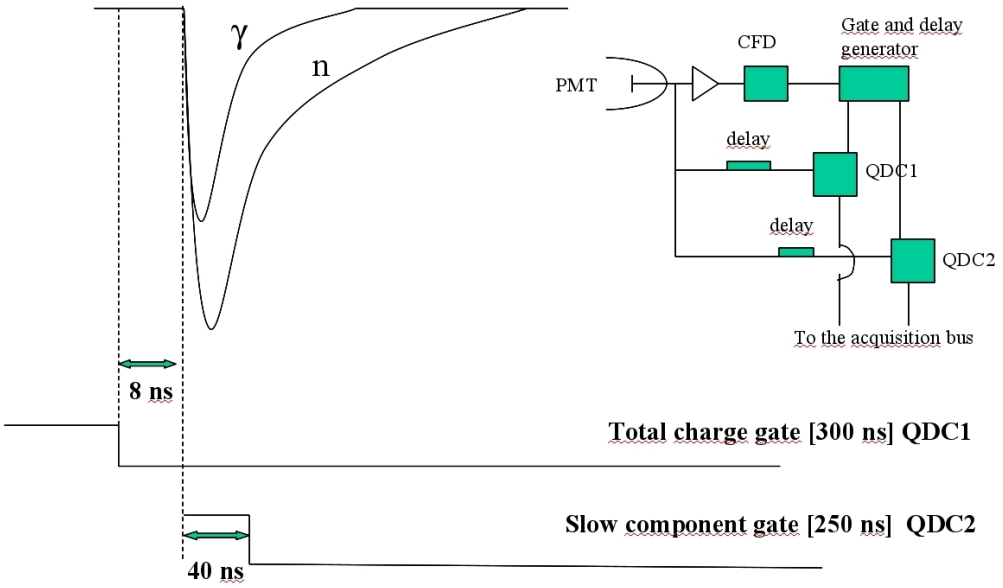

Figure 2: NIM Electronic block diagram and time relation between photomultiplier pulse and gates at the input of QDCs used to measure γ-n discrimination by digital-charge comparison method.

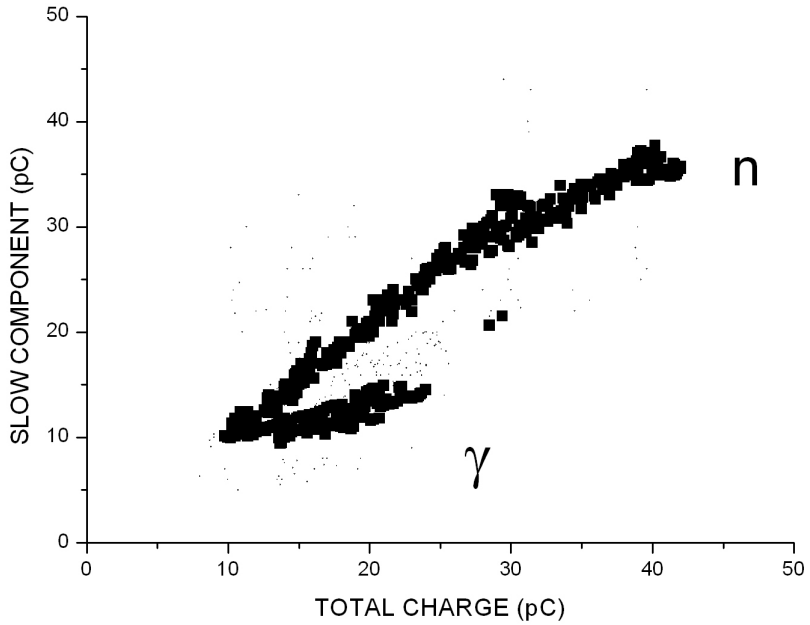

Figure 3: Two dimensional scatter plot of the charge in the slow component vs the total charge (pC) collected by QDC from an Am-Be source.

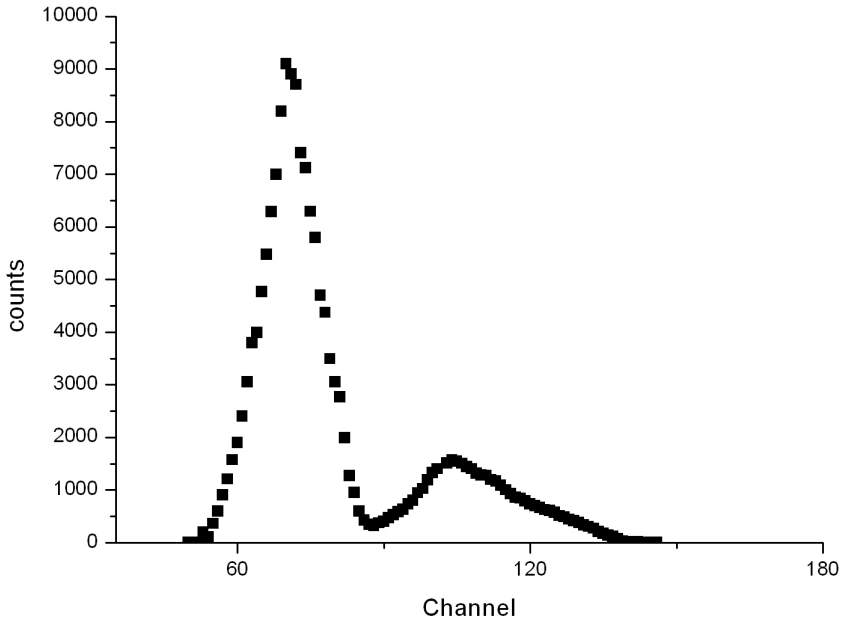

Figure 4: γ-n discrimination spectrum measured with the gate set at 100 kee. Note the good separation between the γ peak (the higher and thinner one) and the neutron peak