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Working out the position resolution on large scintillating detectors, through the "light attenuation method"

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In this work we present the results of the application of the "light attenuation" method to extract position information out of a large bi-dimensional scintillating plate, to be used as a neutron detector.

Keywords: Neutron spectroscopy; scintillation detectors; elastic neutron scattering.

En este trabajo se detalla el método de extracción de la información en posición para la detección de neutrones por una placa bidimensional grande de material centelleador por atenuación de luz.

Descriptores: Espectroscopia de Neutrones; detectores de centelleo; dispersión elástica.

PACS: 29.30.Hs; 29.40.Mc; 25.40.Dn

1. Introduction

The motivation of this work comes from the recent interest in the precise measurement of angular distribution of mono-energetic neutron elastic scattering on heavy targets at small angles ($<$ 10 deg) [1–4].

A nice review of the past and present status of "neutron spectrometry" can be found in [5].

It is well known that mono-energetic neutron fluxes are produced as a product of a primary nuclear reaction (typically d(d, n) or d(t, n)) [6], with intensities around a few hundred and up to a few thousand neutrons per second. It is then of paramount importance, in order to proceed successfully with a study of neutron scattering off any target, using a flux as low as those, to have the largest solid angle coverage to detect every scattered neutron.

Large detector arrays highly segmented, known as "hodoscopes" have been used, but in this work we develop a device that is much simpler in its implementation, much less expensive in its construction, and requires less associated electronics (for further information on position sensitive detectors see [7]).

As a particle traverses a scintillating material, a spark of light is produced at that spot. This light is "viewed" by an array of photomultipliers placed at different locations around the active scintillating material. However, the amount of light reaching each detector is different. This "attenuation" is a function of the distance from the spark to each photomultiplier, a combination of the intrinsic light attenuation (absorption) and the variation with distance of the solid angle presented by each photomultiplier.

In this work we present a careful study of such distance dependent light attenuation, for two different scintillating material geometries, with the goal of developing a two dimensional position sensitive detector for neutrons.

Although we will not deal in this work with the "spectrometric" information (energy deposition or pulse height), it is worth at this point mentioning that all position reconstruction algorithms rely on the knowledge of the initial amplitude of the signal, which has to be recovered as well. In that sense, the spectroscopic information is part of the information provided by the detection system we are proposing here.

2. Experimental procedure

Although the detector we aim to build is intended for neutron detection, it is much easier for developing and testing purposes to work with gamma rays, since low activity commercial sources are available. At a latter stage, the uniform cosmic ray (mainly muons) and neutrons will be used.

The data we are presenting in this work was obtained with the gamma radiation from a ^{60}Co source. It is well known that this isotope emits two photons in cascade (that is one after the other in the same event). The first one of energy 1.1732 MeV and the second one of 1.3325 MeV.

The scintillating material we used is a commercial plastic by Bicron (BC-416). Some of its main characteristics, relevant for this work are (see [8] for full details): Polyvinyl Toluene based, 1.032 g/cm^3 density, 4 ns light pulse decay time, 5.25 and 4.73 ($\times 10^{22}$) Hydrogen and Carbon atoms/cm3 respectively, intrinsic light attenuation coefficient (down to Io/e) 210 cm.

Because of the low atomic number of this material, the probability of photoelectric interaction is very small, since it goes approximately like $Z^n/E_\gamma^{3.5}$ [9] (Z being the atomic number of the material and E_γ the photon energy, the light produced in the detector will come from molecular excitations induced by moving electrons from Compton Scattering of the two gamma rays in the material.

Figure 2 (see below) shows a collection of such "typical" Compton Scattering spectra.

Light produced by the interaction of charged particles ("Compton electrons" in our case) with the scintillating material is converted into a current (or voltage) pulse by one or several photomultipliers (RCA 4523 in our study), that are optically coupled to the active detecting volume usually with the help of a light guide, or just optical grease or glue.

Figure 1 shows schematically the setup used along our measurements. The electric pulses from the photomultipliers are handled by standard NIM electronics (also shown schematically in Fig. 1), and by a CAMAC-based data acquisition system developed by our group at IFUNAM [10]. The scintillating material was shaped in two ways; i) an hexagonal prism 30 cm long, 10 cm apothem (a geometry we have already studied [11, 12], and ii) a plate 150 long, 60 cm wide and 5 cm high. In both cases one single photomultiplier is coupled to them.

The ^{60}Co radioactive source is placed in a small lead collimator on top of each detector at different distances from the photomultiplier. In the results we show below, a larger value of this distance means further away from the photomultiplier.

3. Results

Figure 2 shows the spectra obtained by the hexagonal geometry. The well known form of the Compton scattering appears. And as expected, the spectrum "moves" towards the lower channels as the source moves away from the photomultiplier. Because the intrinsic attenuation length (210 cm) is larger than the distances measured and shown in Fig. 2, this position dependence has to be qualitatively understood in terms of the change in solid angle presented by the photocathode to the light spot. Due to light reflections in the plastic walls, the specific form of this dependence is complicated. A full simulation (Geant-4) is required to understand this phenomenon. Such work is currently underway and results will be published soon elsewhere.

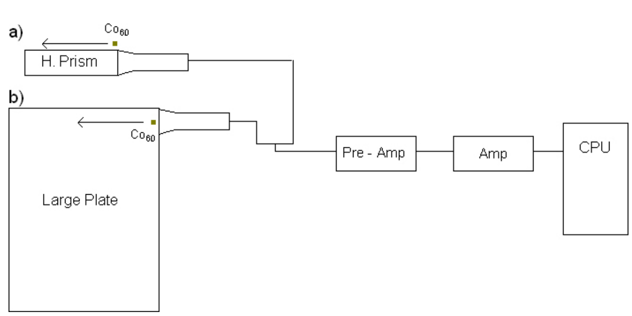

FIGURE 1. Schematic representation of the experimental setup used in this work. Frame (a) the hexagonal prism, (b) the plate.

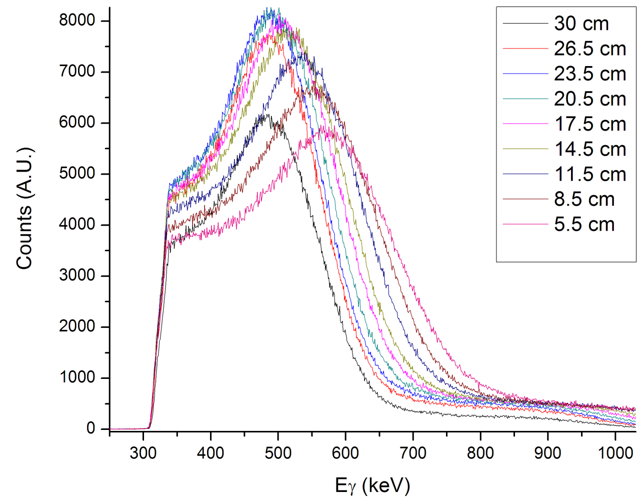

FIGURE 2. Energy spectrum from the detection of gamma rays from a ^{60}Co source by the hexagonal configuration. All spectra were taken by counting a constant time (300 s). Each curve corresponds to a different distance between the source and the photomultiplier as shown in the insert.

Figure 3 shows a summary of this measurement where the channel corresponding to the "Compton edge" of each spectrum, is plotted against the distance of the gamma source to the photomultiplier. The smooth curve corresponds to an exponential function fitted to the data.

It is never enough stressing of the importance of geometrical details. The results just shown correspond to the case where the faces of the prism are not well polished, in order to disrupt large internal reflection patterns. If, on the other hand, the surfaces of the prism are well polished, reflections set up internally and the position information is totally destroyed. Figure 4 shows the equivalent to Fig. 3, but with polished faces.

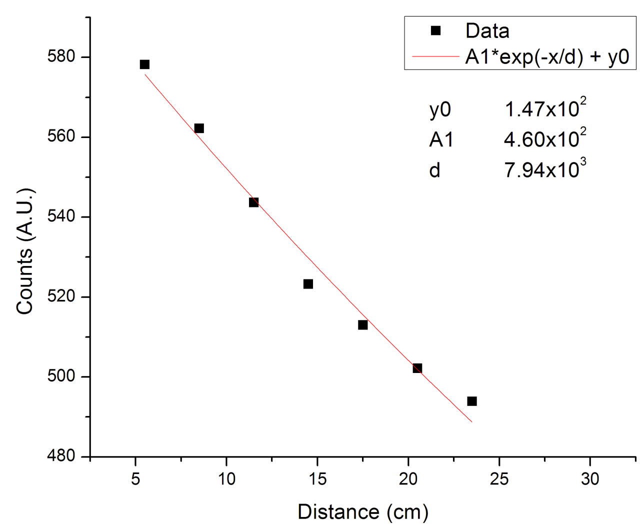

FIGURE 3. For the hexagonal prism configuration, this plot shows the channel number corresponding to the "Compton Edge" for each spectrum as a function of the distance between the ^{60}Co source to the photomultiplier. The fit corresponds to a pure exponential decay law.

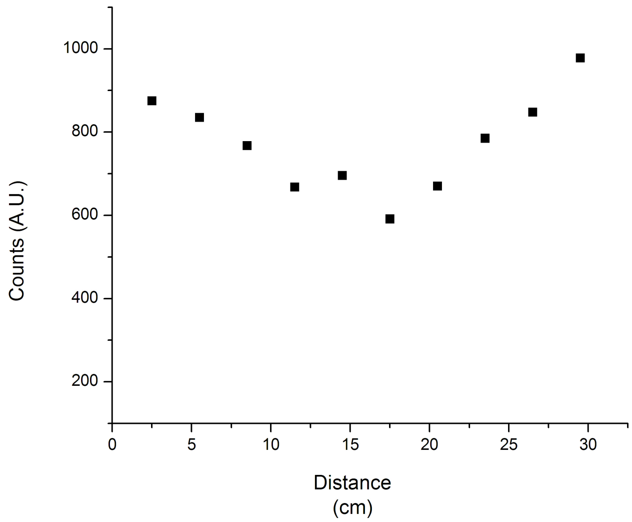

FIGURE 4. For the hexagonal prism configuration, WITH POLISHED FACES, this plot is the equivalent to that in figure 3 for a prism whose faces have been "sanded out".

A similar procedure is carried out with the large plate configuration. The gamma source is placed on top of the scintillating plate along a line perpendicular to the photocathode of the photomultiplier at different distances. Pulse high spectra are taken for each distance.

Figure 5 corresponds to the plot of the total integral of the spectrum of each distance (proportional to the total number of photons detected) versus that distance.

Similarly to the hexagonal prism case, a strong, position dependence is observed.

4. Discussion

The data presented above shows strong position dependence in the response of our detection system in both geometries studied. An attempt to fit of this dependence with a single exponential decay yields "attenuation coefficients" (80 cm for the prism and 6.4 cm for the large plate) inconsistent with each other and with the intrinsic attenuation length value (210 cm), a clear indication that the main factor in the position dependence of our signals is NOT the intrinsic absorption.

In Fig. 5, besides the fit to an exponential function, two other curves are shown corresponding to fits to (A+Bx^n) for "n" equals -1 (hyperbola) and -2 (inverse square law). In the case we consider the intrinsic attenuation negligible, those curves represent the approximated functional dependence of the solid angle with distance for two dimensions (negligible thickness plate) and three dimensions (volume) propagation of light within the plastic scintillator.

An interesting feature is that the position dependence obtained is stronger for the large plate than it is for the hexagonal prism, a fact that can very well be put to practice in order to obtain good position resolution in a two dimensional detector, as planed.

Figure 6, shows the result of a calculation where the large plate has 4 photomultipliers optically coupled to the corners cut at 45^a angle. Most of the active area of the detector is shown to provide position resolution better than $\pm$ 1 cm, other regions with worst resolution (near each corner) are also shown, in the darkest areas the resolution is quite poor (up to $\pm$ 5 cm).

This situation can be significantly improved by adding more photomultipliers to the configuration.

Ambiguities arising from multi-hit events (more than one particle being detected simultaneously), are also solved with more photomultipliers "viewing" the plate.

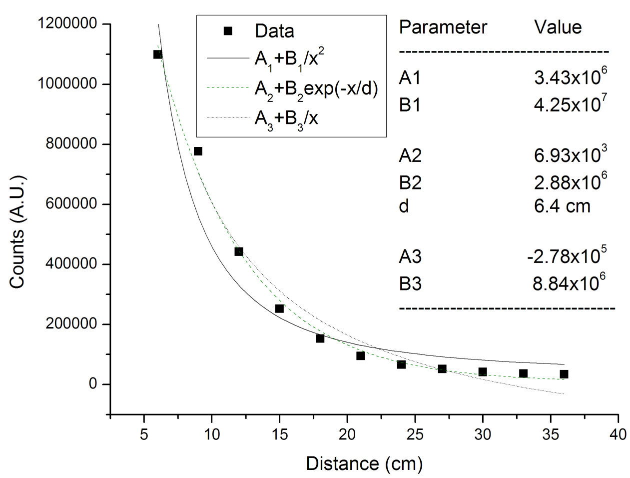

FIGURE 5. For the large plate configuration, this plot shows the integral of each spectrum as a function of the distance between the ^{60}Co source to the photomultiplier. The two fits correspond to a pure exponential and an inverse square law.

5. Conclusions

Position information out of a large scintillating piece of material can be obtained through the attenuation suffered by the light as it travels from the spot it is produced to the detecting (photomultiplier) device.

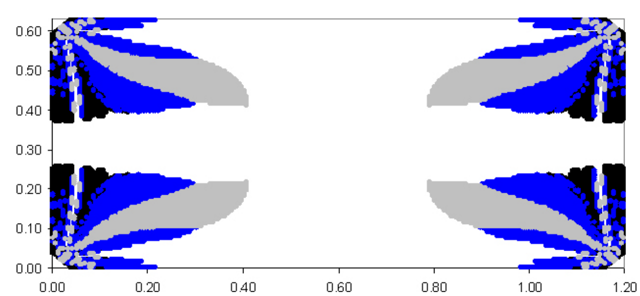

FIGURE 6. Calculation. For the large plate configuration hypothetically viewed by 4 photomultipliers placed in the corners cut at 45 deg. A 1% pulse high resolution is assumed. Position information with a sensitivity better than 1 cm is obtained throughout most of the active area, near the photomultipliers, it degrades to better than 2, 3 and 5 cm as we move closer to the Photomultipliers and the edge of the detector.

The main attenuation factor is not the intrinsic absorption, but instead losses by solid angle coverage of the detecting device (photomultiplier).

Care must be taken in all specific geometric details. In particular polishing or not the surfaces of the faces of the active detection material is critical. It has been shown how much this position information can be destroyed in one case.

Bi-dimensional information (x, y) can be extracted from a rectangular large plate, provided sufficient number of photomultipliers are viewing the active volume from different directions.

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