Characterization of the BC501A Neutron Detector

M. K. Singh[1,2✠], V. Singh[1*], V. S. Subramanyam[1], H. T. Wong[2]
[1.] Department of Physics, Institute of Science, Banaras Hindu University, Varanasi - 221005, INDIA
[2.] Institute of Physics, Academia Sinica, Taipei - 11529, TAIWAN
**Email: venkaz@yahoo.com, ✠*singhmanoj59@gmail.com

Now-a-days, most of the dark matter results are limited due to neutron background. Therefore, related experiments are addressing this issue especially to the reduction and tagging of neutrons background. In this direction we have also started neutron background study. This paper is focused on the characterization of the BC501A neutron detector.

1. Introduction and Physics Motivation

Identification of dark matter candidate is among the most important and long standing open problems in modern physics. In astronomy and cosmology, dark matter is matter that is inferred to exist from gravitational effects on visible matter and background radiation, but is undetectable by emitted or scattered electromagnetic radiation. On the basis of all the observations and model calculations the composition of the universe is understood to be only 4% visible matter, 73% Dark energy and 23% dark matter. Various dark matter candidates have been proposed by several models in support of the presence of dark matter but till date dark matter candidate is not yet discovered.

Fast neutrons are a particular problem for the dark matter search experiments. Fast neutrons can mimic signatures of these rare events, often with significantly higher frequency than the desired event [1, 2]. Due to the weak nature, Weakly Interacting Massive Particles (WIMP) is proposed to interact via nuclear recoils. This gives WIMP dark matter searches a powerful tool for discriminating between background signals and potential WIMP signals. Many detectors are able to separate the two recoil types by measuring multiple modes of energy transfer: light, heat, or ionization. Electronic recoils, from gammas and electrons, deposit energy in different ratios of these quantities than nuclear recoils. By detecting at least two of these quantities for each event, it is possible to effectively distinguish between electron and nuclear recoils which play important role to control the most common background in the dark matter search experiments [1, 2, 3]. However, fast neutrons will not be rejected by this technique, since they too interact via nuclear recoils. Thus it is vitally important to know the fast neutron background in the lab so that it can be shielded against. Fast neutrons are generated by a few distinct sources:

(I) Spontaneous Fission of Heavy Nuclei: Spontaneous fission is a process in which a nucleus, without external intervention, breaks apart into many fragments. These fission events can emit multiple neutrons along with gammas and lighter nuclei. Though rare, spontaneous fission isotopes can be found in the decay chains of uranium and thorium. The most common spontaneous fission neutron source is ^{252}Cf, which has a short half-life of 2.65 years.

(II) Radioisotope (α, n) Reactions: Fast neutrons is generating through (α, n) reactions, an example of such reaction is: $^{4}\alpha_{2} + {}^{9}\mathrm{Be}_{4} \rightarrow {}^{12}\mathrm{C}_{6} + {}^{1}\mathrm{n}_{0}$ (+ 5.71 M eV). The above reaction show that an energetic alpha is captured by a Be nucleus, which then emits an energetic neutron. These reactions occur naturally in material that contains trace amounts of uranium and thorium. The decay chains of these two elements emit numerous alpha particles, which can then interact with light nuclei in the surrounding material. These are the most common neutrons found in underground environments where the low background experiments operate.

(III) Cosmic-Ray Induced Spallation: The high energy neutrons are produced from spallation by high energy particles. This occurs naturally from high energy cosmic rays interacting in the atmosphere and high energy muons interacting underground. When energetic cosmic rays are incident on the upper atmosphere, they rapidly lose their energy through collisions with the molecules in the air. These collisions trigger air-showers that can exceed hundreds of meters in diameter when they reach sea-level. While propagating down, various particles are created, including protons, neutrons, electrons, gammas, pions, kaons, and muons. These secondary particles are the source of the ambient radioactivity at the surface.

(IV) Muon-Induced Reactions: Muons created by cosmic rays are deeply penetrating and are one of the largest backgrounds for underground experiments. Muons may interact directly in a detector, or induce radioactivity as it interacts with the local material. Muon-induced neutrons are generated by either spallation, like the cosmic-ray interactions, or through negative-muon capture.

2. Neutron Detector Characteristics

Neutron detector has a hybrid structure, bringing two different types of target material to operate at the same time. These materials are frequently used and well known scintillators, namely BC501A, which is sensitive for fast neutrons, and BC702, sensitive to thermal neutrons. BC501A is an organic liquid scintillator containing 4.82×10^{22} and 3.98×10^{22} atoms of hydrogen and carbon per cm^3. High density of hydrogen atoms in its compound makes it a good target material for neutron detection through neutron-proton elastic scattering for the fast neutrons in the MeV range. BC501A has the pulse shape discrimination property [1], i.e. it yields different signals for proton recoil and electron recoil events, due to which it is possible to distinguish neutron hit events from that of gammas as shown in Figure 1.

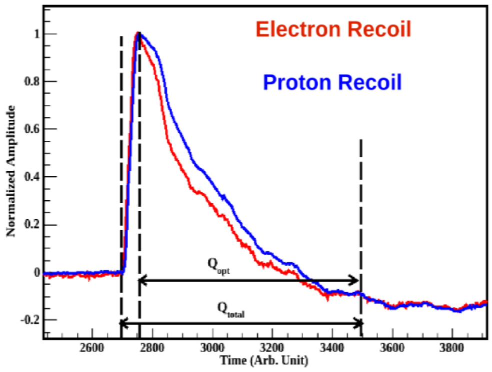

FIG. 1: Average pulse shape with typical integral range for pulse shape PSD variables.

The two signals shown have the same total integral, but the longer tail of the neutron signal. BC702 is sensitive for slow/thermal neutrons, which are present in the background environment mostly as a result of moderation of the fast neutrons via elastic scattering in the shielding and other materials.

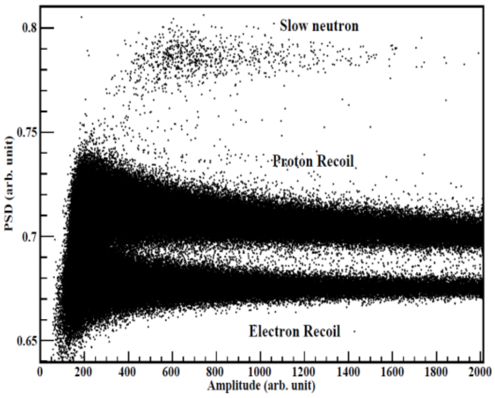

FIG. 2: Distribution of events for PSD variable with respect to light output in arb. unit.

For each event, the total charge in two integration regions, Q_{opt} and Q_{total} can be calculated as shown in Figure 1. By comparing the charge in the short (Q_{opt}) and long (Q_{total}) regions using equation, $PSD = (Q_{total} - Q_{opt}) / Q_{total}$, neutron and gamma interactions will be effectively separated. Figure 2 shows distribution of events for calculated PSD variable versus light output in arbitrary unit. Continue R & D efforts are going on, via the optimizations of hardware configurations and software pulse shape discrimination techniques.

References

[1] J. Qin et al., Applied Radiation and Isotopes **104**, 1524 (2015).

[2] D. -M. Mei et al., NIM **A 606**, 651660 (2009).

[3] Chen YongHao et al., Sci. China-Phys Mech Astron, **57**(10), 18851890 (2014).