GEANT4 simulation Study with converter coated gas based neutron detectors

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Introduction

Monte Carlo based GEANT4 simulations have been carried out to estimate the efficiency of neutron detector using Boron-10 and Gadolinium as a Converter material. The choice of converter material is pivotal in neutron detector for its fabrication and performance in the radiation fields. Cross-section of different converter materials for thermal neutron are listed in table 1. Neutrons that can be detected using these converter coatings requires a hybrid system with a separate gas amplification stage. The goal is to build a converter coated Gas electron Multiplier (GEM) based gas detector that can perform the job of neutron detection. GEM detector consists of three GEM foils and a drift and readout plane. Coatings can be introduced on the drift plane as well as on the surfaces of each GEM foil. The later one is practically very complicated to achieve. In this report, we present the simulation results by implementing coatings of various thickness on inside of the drift plane. The conversion products, Lithium or Helium, which leave the Boron, deposit a fraction of the total kinetic energy of up to 2.7 MeV ionizing the counter gas. The objective of simulation is to obtain the optimum thickness of the coating so as to achieve maximum efficiency of the counter. $^{10}\mathbf{B}$ as converter material based detectors have advantages because of low gamma sensitivity. Gadolinium (Gd) as a converter material is advantageous because of its high cross-section for neutron.

Boron Converters

Neutrons are converted into ion fragments by boron-10 via a nuclear reaction with the two branches:

S. No.	Neutron Sensitive converter Material	cross-section for thermal neutrons (barns)
1.	$^{155}\mathbf{Gd}$, $^{157}\mathbf{Gd}$	27000
2.	$^{3}\mathbf{He}$	5400
3.	$^{10}\mathbf{B}$	3840
4.	$^{6}\mathbf{Li}$	940

TABLE I: Microscopic cross-section of different converter materials for thermal neutron detection[1].

$$^{10}\mathbf{B} + n \longrightarrow {}^{7}\mathbf{Li}(0.84MeV) + \alpha(1.475MeV) + \gamma(0.48MeV)$$
$$\longrightarrow {}^{7}\mathbf{Li}(1.013MeV) + \alpha(1.776MeV)$$

First branch of reaction have branching ratio of 94% .

Gd as converter material

$$^{155}\mathbf{Gd} + n \longrightarrow {}^{156}\mathbf{Gd} + \gamma + ICe^{-} + 8.5MeV$$

$$^{157}\mathbf{Gd} + n \longrightarrow {}^{158}\mathbf{Gd} + \gamma + ICe^{-} + 7.9MeV$$

We are planning a neutron detector which is based on thin films of 99 % enriched $^{10}\mathbf{B}$. The conversion products create a signal by ionization in the active detection volume filled with the standard counting gas $Ar : CO_2$ of mixtures from (70:30).

Simulation

In our simulation we have considered a single particle mono energetic neutron beam incident perpendicular on the front face of the detector as shown in figure. All the necessary

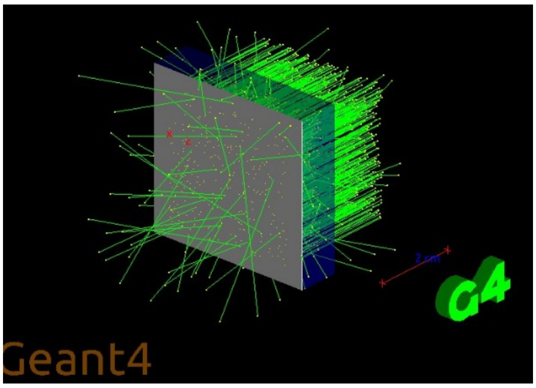

FIG. 1: Snapshot of GEANT4 simulation for boron (white color) coated on Ar(70%)/CO_2(30%) gas mixture (Blue) detector in planar configuration.

PhysicsList Class that takes care of the interaction of particles in medium in GEANT4 have been included for simulations. In real life, there neutron emission is associated with gamma background. Suitable threshold cuts on the energy deposited are employed to discriminate the neutrons against this background. We refer these cuts as Low level discriminator (LLD).

Results

As shown in Fig. 2, the maximum efficiency for a neutron energy of 1 eV at 1 KeV LLD value(top curve in the figure) is around 1.52 % at a thickness of 10 μm and for 60 keV LLD value (bottom curve), maximum efficiency is around 1.15 %. The detection efficiency is observed to first increase and reach to maximum at a certain thickness after which it almost saturates with a slight decrease.

The maximum efficiency as observed in simulation for 1 keV incident neutron energy at 1 keV LLD value is 0.018 % at a thickness of 20 μm as shown in fig 3. Efficiency increases first like the previous case and then almost saturates. Similar studies with Gadolinium converter has been carried out. Simulation results for varying neutron energies starting

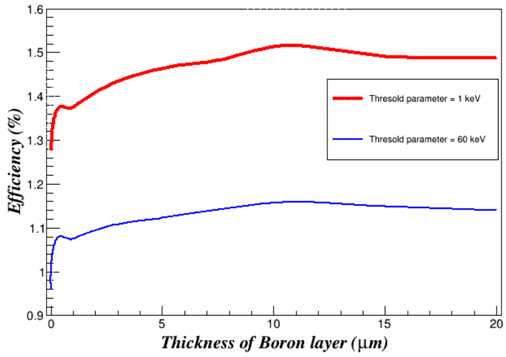

FIG. 2: Variation of efficiency of neutron detection with thickness of ^{10}**B** as converter material for 1 eV incident neutron energy at 1 keV threshold parameter for Energy deposition (Red) and 60 keV threshold parameter (blue).

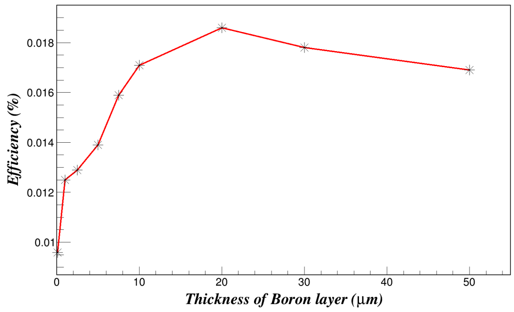

FIG. 3: Variation of efficiency of neutron detection with thickness of Boron layer as converter material for 1 keV incident neutron energy at 1 keV Threshold value.

from thermal energies and for different threshold cuts along with studies for different gas mixtures will be presented and discussed.

References

[1] M.K. Parida, et.al.**Nuclear Instruments and Methods in Physics Research Section A:**, 951:162978 (2020).