Study of Secondary Neutron Production by Cosmic Muons interaction in Lead

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Introduction

The primary cosmic rays consisting of protons, alpha particles and heavier nuclei continuously bombard the Earth with a rate of 1000 particles/m^2-sec at the top of the Earth atmosphere. Upon entering the atmosphere, the primary cosmic radiations interact with the air molecules, mainly oxygen and nitrogen nuclei, and produce pions, kaons and other hadrons. These hadrons decay to muons which finally reach the Earths surface. These muons are known as cosmic-ray muons.

Fast neutrons produced from cosmic-ray muons interaction in matter represent an important background for low-energy underground experiments such as measurements of neutrino oscillations, experimental searches for double beta decay and dark matter experiments. Unlike charged hadrons which can be tagged by a veto detector system, neutrons usually cannot be identified until they are finally captured, mimicking the signal. The occasional neutron scattering with the sensitive material of the detector and the long lifetime of neutrons in surrounding materials and in detector further complicate the situation.

In this paper production of secondary neutrons by interaction of cosmic muons with Lead (Pb) is studied, since Pb is one of the most common material used for detector shielding. Cosmic muons with realistic energy distribution are propagated through a test detector assembly having Pb and scintillator material using simulation package Geant4 [1]. The energy, timing and multiplicity distributions are obtained for produced neutrons. Finally effect of Pb width on neutron multiplicity is studied.

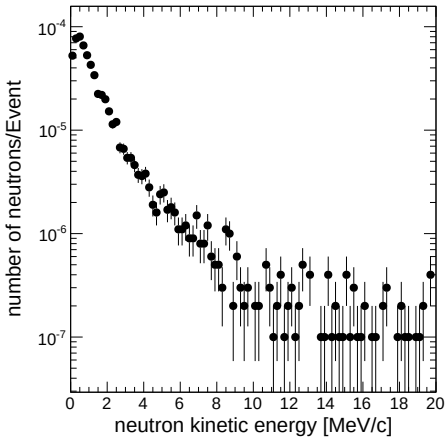

FIG. 1: The kinetic energy distribution of secondary neutrons produced from cosmic muon interaction in a Pb slab of 10 cm width.

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The energy of cosmic muons reaching earth in vertical direction have a range starting from few MeV to several TeV. The energy distribution of vertical cosmic muons can be parameterized with a power law function [2]. In our simulations we use power law with an exponent α =-2.7 to generate cosmic muon energy distribution at Earths surface.

$$I \propto E^{\alpha} \quad (1)$$

The energy of cosmic muons is taken in the range of 0.3 GeV to 100 GeV. These muons are then simulated through the detector geometry and all the produced particles are tracked through the material traversed by them. Several characteristics of these particles like ki-

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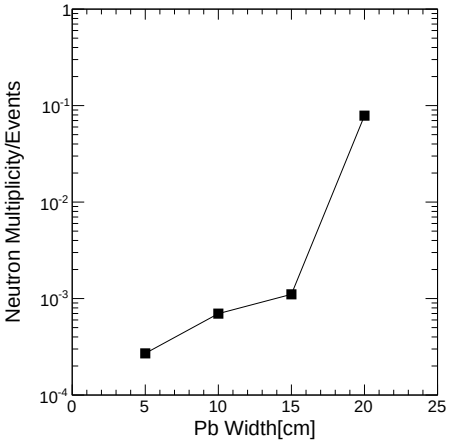

FIG. 2: The secondary neutron multiplicity as a function of length of material traveled by cosmic muon.

netic energy, momentum, production time etc. are studied.

Figure 1 shows the distribution of kinetic energy of neutrons produced in the interaction of muons with a Pb slab of 50cm×50cm×10cm dimension. The produced neutrons have maximum energy up to 20 MeV. These neutrons can enter the active region of detector and mimic a signal event.

Figure 2 shows the neutron multiplicity distribution as a function of length of Pb traversed by the muon. The neutron multiplicity increases approximately linearly with the length of Pb traversed by the muon up to the Pb width of 15cm. A more rapid increase in neutron multiplicity is observed for Pb width more than 15cm. This can be the effect of increase in the multiple scatterings inside the material. Table I shows the effect of the cosmic muons pathlength on produced neutrons average kinetic energy and per event multiplicity. The average kinetic energy of neutrons decreases with the muon traverse path up to the Pb width of 15 cm and then increases slightly while the multiplicity increases with the Pb width.

TABLE I: Effect of cosmic muons pathlength inside Pb on average kinetic energy of produced neutrons and per event neutron multiplicity.

Pb width (cm)	$<$ K.E. $>$ of neutrons (MeV)	(neutron multiplicity)$\times 10^{-4}$ (per Event)
5	1.713±0.067	2.703±0.078
10	1.606±0.043	6.978±0.134
15	1.365±0.031	11.065±0.171
20	1.392±0.004	786.490±1.873

Conclusions

In this paper the production of secondary neutrons by cosmic muons inside Pb material has been analyzed. The realistic power law energy distribution of cosmic muons is used for the simulations. The kinetic energy and per event multiplicity distributions of produced neutrons are studied as a function of length of Pb traversed by muons. It is observed that the average kinetic energy of produced neutrons decreases with the length traversed by muons up to the Pb width of 15 cm and then increases slightly. The neutron multiplicity is found to increases with the increase of Pb width, slowly up to the Pb width of 15 cm and then a more rapid increase is observed.

References

[1] S. Agostinelli *et al.* [GEANT4 Collaboration], "GEANT4: A Simulation toolkit," Nucl. Instrum. Meth. A **506**, 250 (2003).

[2] P. Shukla, "Energy and angular distributions of atmospheric muons at the Earth," arXiv:1606.06907 [hep-ph].