Simulation for cosmogenic neutron background for the PICO experiment at SNOLAB

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Introduction

The PICO experiment searches for nuclear recoil signals expected to be produced by WIMP (Weakly Interacting Massive Particle) candidates of dark matter (DM) using bubble chamber filled with fluorine-rich superheated liquids [1, 2]. PICO detector is located in the SNOLAB underground laboratory at a depth of approximately 6.01 km.w.e. Due to the predicted small WIMP-nucleon scattering cross section, the challenges of the experiment is to build the large enough detectors to produce adequate event rates and reduce/eliminate backgrounds to isolate the DM signals. As nuclear recoils of keV energies originating in the elastic scattering due to fast neutrons mimic the WIMP-nucleus interactions, these are one of the limitations in improvement of the sensitivity of PICO detector.

In underground laboratory, main source of MeV neutrons is the natural radioactivity, such as (α,n) reaction and spontaneous fission, due to presence of U/Th in the rock or in the detector materials. In contrast, neutrons produced through interaction of high energy cosmic-ray muons with matter are of energies upto several GeV. Due to the higher energies, it is difficult to moderate and/or absorb the cosmogenic neutrons using hydrogen-rich shielding materials. In addition, these high energy neutron could produce secondary neutrons via interaction with other materials, even from the detector materials. All these makes the evaluation of the accurate neutron flux a crucial task to understand the neutron backgrounds via a Monte Carlo simulation. It is essential to include the actual experimental setup and all physics processes in the simulation. The motivation of the present simulation is to obtain the flux, energy spectrum and angular distribution of muon induced neutrons at the rock/experimental hall boundary of SNOLAB.

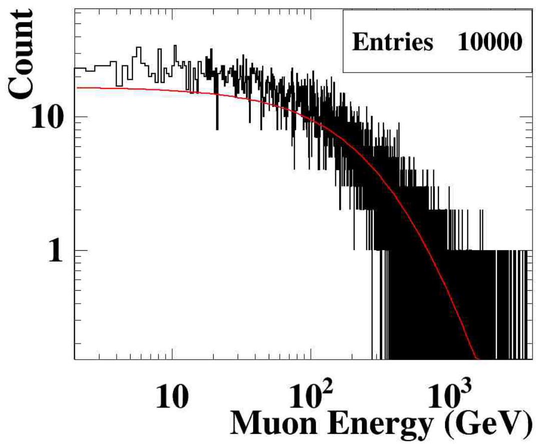

FIG. 1: Energy spectrum of primary μ^- in the incident surface.

Simulation

Geant4 simulation toolkit [3] based code has been used in the present work. An experimental hall of dimension 15 m× 15 m × 20 m has been created within which the PICO detector is situated. This hall is filled with air of density 1.293 kg/m^3 and is surrounded from all sides by 200 m thick norite rock. The density

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of norite rock is taken to be 2.894 gm/cm^3. The energy spectrum and angular distribution of primary muon have been simulated with the help of the approach used by D.-M. Mei *et al.* [4]. In the simulation ten thousand μ^- are incident within the norite rock in a hemispherical surface of radius 17.0 m from the center of the hall. The surface area of the incident plane is 1815 m^2. The energy spectrum of the muon follows the expression [4, 5],

$$\frac{\mathrm{dN}}{\mathrm{dE}_\mu} = \mathrm{Ae}^{-\mathrm{bh}\,(\gamma_\mu - 1)}[\mathrm{E}_\mu + \epsilon_\mu(1 - \mathrm{e}^{-\mathrm{bh}})]^{-\gamma_\mu} \qquad (1)$$

where A is the normalization constant, E_μ is the muon energy after crossing h (km.w.e), b = 0.4/km.w.e. [6], γ_μ = 3.77 and ϵ_μ= 693 GeV [7].

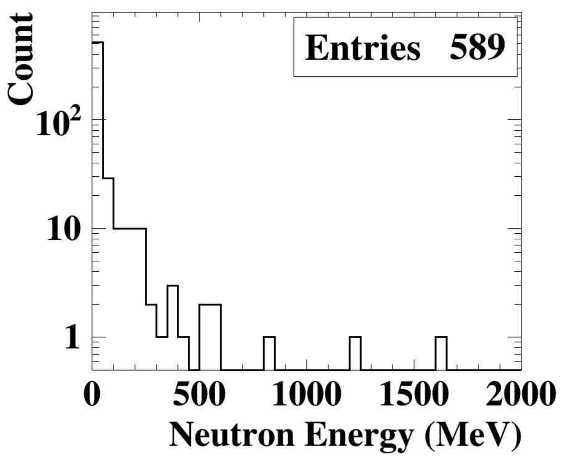

FIG. 2: Energy spectrum of μ^--induced neutron at rock/experimental hall boundary.

Cosmic-ray muons produce neutrons via muon spallation, photo-nuclear interactions, hadron inelastic interaction, μ^- capture. All of these physics processes are implemented in the simulation through "Shielding" physics list. This physics list uses the Fritiof parton model along with Precompound model (FTFP) and the Bertini cascade model for the high (4 GeV to 100 TeV) and low energy ranges (up to 5 GeV) respectively in case of hadron-nucleus inelastic processes. For photonuclear process, Bertini cascade model is used in the energy range less than 3.5 GeV, whereas above 3 GeV Quark-gluon String model with Precompound (QGSP) is used. Muon spallation interaction is handled by 'G4MuonVDNuclearModel' for the energy range 0 eV to 1 PeV.

Results and Discussions

The energy spectrum of primary μ^- at the incident surface is shown in Fig 1. The red line in Fig 1 is obtained by fitting the simulated distribution by Eq. (1). The average μ^--induced neutron flux at the rock/experimental hall boundary is obtained to be about (0.029± 0.004)× 10^{-9} cm^{-2}sec^{-1}. It is observed that the most of neutrons are in the forward direction compared to incident muons. The energy spectrum of cosmogenic neutron at the boundary is shown in Fig 2. It is observed that about 20% neutrons have energy greater than 10 MeV.

References

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