Simulation of neutron background for DINO Dark Matter search experiment

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Introduction

The goal of the proposed Dark Matter (DM) search experiment DINO (Dark matter@INO) is to search for the Weakly Interacting Massive Particles (WIMP) as candidates of Dark Matter. WIMPs are expected to interact with the detector nuclei via elastic scattering, resulting in nuclear recoils. DINO experiment proposes to use suitable scintillation detectors operated at cryogenic temperature for the detection of recoiling nuclei. Such rare event search needs high sensitivity and complete knowledge about the possible radiation background that can interfere with the experiment.

The inorganic scintillating crystals CsI and $Gd_3Ga_3Al_2O_{12}$ (GGAG) have been considered as possible detector materials. These materials show good scintillation properties. The light yield of CsI(Tl) is about 54 photons/keV and that of GGAG is about 45 photons/keV [1, 2]. One of the main factors affecting the sensitivity of the detector is the background. It is important to understand the sensitivity of these materials to different background radiation.

Most of the cosmogenic background will be reduced significantly in underground laboratories. But cosmic ray muons, natural and induced radioactivity in the cavern add to the background. Some of these background can be reduced by active and passive shielding. Since the neutrons interact with the detector in the same way as WIMPs, the knowledge of the flux of neutrons and the energy spectra at the site are very essential. In underground laboratories, neutrons can be generated mainly by spontaneous fission of U and by U / Th (α, n) reactions on the rock materials and interaction of cosmic ray muons with rock and shielding materials. The low energy neutron flux from radioactivity at the proposed India-based Neutrino Observatory site at Theni has been calculated by N. Dokania et al. using Monte Carlo simulations [3]. We have done a simulation to study the flux of neutrons both of cosmogenic origin i.e. by muon interaction and of radiogenic origin i.e from spontaneous fission and the (α, n) reactions in the Jaduguda rock.

Simulation using GEANT4

The Jaduguda rock composition, obtained from rock sample analysis, is given in Table I. The density of the rock is about 2.85 g/cm^3. The rock contains 8 ppm of U and 16 ppm of Th ([4]). The rock sample was collected by core drilling at 555 m depth.

Geant4.9.6 (patch 02)([5]) based code which uses Shielding physics list, has been used for generation and propagation of particles through rock volume. Secondary particle production cuts are set to 0.7mm for gammas and e^+/e^-. A rock block of dimension (1 m $\times$ 1 m $\times$ 0.25 m) is used as the target through which 10^7 monoenergetic muons at fixed angle are passed. Simulation is repeated for different muon energies. Muons are generated ran-

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TABLE I: The composition of Jaduguda rock

Material	Conc(%)	Material	Conc(%)
SiO_2	66.45	K_2O	2.61
Al_2O_3	18.20	TiO_2	0.59
Fe_2O_3	0.26	P_2O_5	0.18
FeO	4.61	MnO	0.03
CaO	1.82	U_3O_8	0.005
MgO	1.39	Mo	0.002
Na_2O	1.60	H_2O	0.25

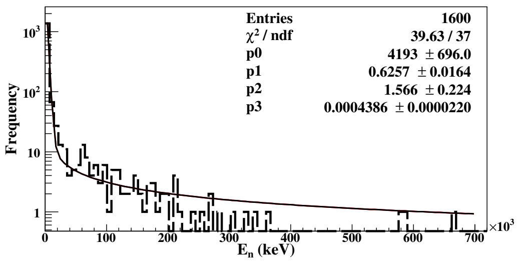

FIG. 1: The energy distribution of neutrons from 10 GeV muons after propagating through rock.

domly on a plane of dimension (1 m × 1m) at one end of the rock block. The spectra of neutrons produced in the interaction of muons are recorded. These neutrons are allowed to propagate through rock volume and the energy distribution of neutrons after propagating through 0.25 m of rock is also found.

Results and discussion

Figure 1 shows the energy distribution of neutrons from muon interaction after propagating through rock (dashed curve). The distribution is fitted with a function $p_0\ (E_n^{-p_1}\ +\ p_2\ e^{-p_3 E_n})$ (solid curve). This distribution is used to generate neutrons for studying the response of scintillating crystals to neutrons. Though the production of neutrons increases as muon energy increases, this becomes less as muon energy further increases as they leave the rock without interaction. It is observed that about 60% of the neutrons produced from muons of energy between 5 GeV – 20 GeV have been absorbed in the rock with thickness 0.25 m.

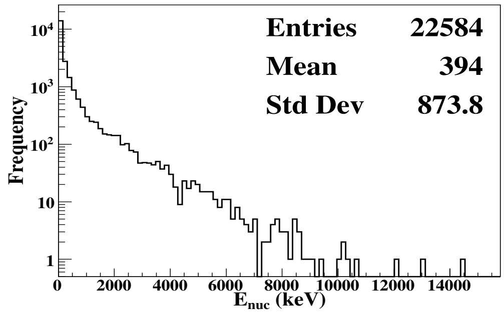

FIG. 2: Distribution of kinetic energy of all the recoiling nuclei of GGAG.

The neutrons, generated using ROOT([6]) according to the above distribution for different muon energies, have been passed through the crystals to study their response. 10^5 neutrons in the energy range (0.01–50) MeV has been generated. A cube of GGAG with side 1 cm is used as a target and the neutrons are propagated through it. The distribution of initial kinetic energy of all the recoiling nuclei is shown in Fig. 2, which is obtained using neutron spectra for 10 GeV muons. This contains the nuclei from elastic scattering, inelastic scattering and radioactive decay. The recoil energy of individual nuclei in the crystal is also studied. It is found that the interactions are more in GGAG compared to CsI which gives more number of recoil nuclei in GGAG. The number of recoil nuclei reduces as the neutron energy increases for both crystals. The absorption of neutrons is more in GGAG.

References

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