Simulation of neutron background for DINO experiment

Meghna. K. K[1],* Pijushpani Bhattacharjee[2], Satyaki Bhattacharya[2], Debasish Das[2], Mala Das[2], Chandi Charan Dey[2], Sayan Ghosh[2], Biswajit Karmakar[2], Debasish Majumdar[2], Pratik Majumdar[2], Bedangadas Mohanty[1], Naba Kumar Mondal[2], Satyajit Saha[2], Susnata Seth[2], and Manoj Kumar Sharan[2]
[1]*National Institute of Science Education and Research, HBNI, Jatni 752050, Odisha, INDIA and*
[2]*Saha Institute of Nuclear Physics, HBNI, Kolkata 700064, INDIA*

Introduction

Various cosmological observations such as rotation curve of galaxies, gravitational lensing etc. establish the existence of a non-luminous matter known as Dark Matter which constitutes about 27% of the matter content of the universe[1]. Despite the evidence for the existence of dark matter, its constituents are still unknown. Weakly Interacting Massive Particles (WIMPs) are one of the most prominent dark matter candidates. Dark matter at INO (DINO) is an upcoming direct dark matter search experiment at proposed India-based Neutrino Observatory[2]. DINO will be looking for WIMP interaction with the detector material via elastic scattering resulting in recoil of nuclei which in turn, produces scintillation in the detection media. The first phase of the experiment is expected to be done in Jaduguda mine of UCIL at the depth of 555 m from the surface. Since the event rate of such rare event search is expected to be very small, the accurate determination of background is crucial. Neutrons are one of the most important background since they interact with the detector materials in the same way as the WIMPs. The response of detector materials to neutrons is studied previously using GEANT4[3]. In underground laboratories, neutrons can be generated mainly by spontaneous fission of U and radiogenic processes, such as by U / Th (α, n) reactions on the rock materials and by cosmogenic processes, such as interaction of cosmic ray muons with rock and shielding materials. We have estimated the flux of both the cosmogenic and the radiogenic neutrons for Jaduguda laboratory facility.

*Electronic address: meghna@niser.ac.in

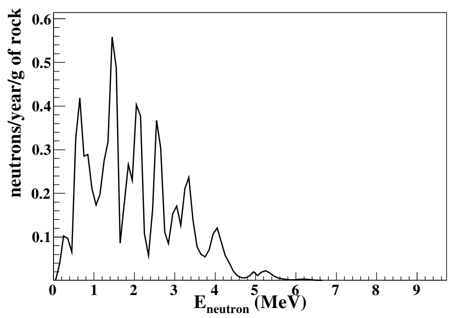

FIG. 1: Neutron flux induced by (α, n) reaction in 1g of Jaduguda rock.

Neutrons from (α, n) reactions

The Jaduguda rock composition is obtained from rock sample analysis. 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. Neutron production rate through (α, n) reaction for different elements have been calculated by D.M. Mei et al. [5]. This data has been used to determine the flux of neutron at Jaduguda laboratory. The total neutrons flux from (α, n) reactions in the main Jaduguda rock materials have been obtained as 0.727 neutrons/year/g of rock/ppm of U-238 and 0.285 neutrons/year/g of rock/ppm of Th-232. Neutron flux induced by (α, n) reaction in 1g of Jaduguda rock is given in Fig. 1.

Muon induced neutrons

A GEANT4 [6] simulation is done for finding the flux of muon induced neutrons in the laboratory. The muon induced neutron in the detector can be tagged using muon veto. But, the neutrons produced by muons which are missed by veto cannot be tagged and can act as WIMP. Hence the ac-

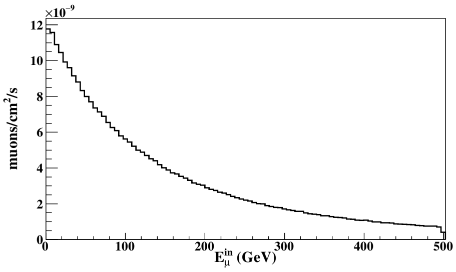

FIG. 2: The muon flux at the rock surface.

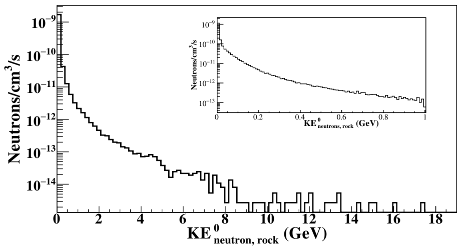

FIG. 3: Flux of neutron produced in rock. Flux for energy less than 1 GeV is shown in the inset.

curate determination of flux is very crucial. The angular distribution of neutrons is also important to estimate the path length of neutrons inside the detector. A Monte Carlo code has been used for generating muon flux underground. Gaissers formula [7] is used to obtain energy (E_μ) and angular (θ_μ and ϕ_μ) distribution for muon events at the surface. These muons have been propagated to the underground site. The slant depth is calculated using topographic map of Jaduguda for each value of θ_μ and ϕ_μ by using 2D interpolation for calculating the energy loss. The muon charge ratio can be described using "pika" model [8] which is derived from Gaisser's formula for μ^+ and μ^- separately. The parameterization obtained by MINOS experiment by fitting data to "pika" model has been used here for generating μ^+ and μ^- events. The events are generated at the five faces of rock block of 2m thickness : top, left, right, front and back. The muons flux for three months with energies up tp 500 GeV at the lab are generated. It is found that the cosmic ray muon flux in the lab is nearly 3.14×10^{-7}/cm^2/s with an average energy of about 140 GeV. The muon flux obtained is shown in Fig. 2.

The geometry of the rock and the detector set up is described in GEANT4. The detector set up consists of cylindrical CsI crystal with a diameter 22 mm and height 40 mm surrounded by cylindrical layers of shielding materials at all the sides with various thickness as follows: Teflon (0.5mm), copper (6 mm), lead (30 cm), polypropylene (40 cm). There is rectangular rock block with thickness 2 m surrounding this detector set up with 1 m air gap between them. The muon events are generated at the outer surface of the rock block and are propagated. As the muons interact with the rock they produce neutrons and other shower particles which then reach the detector setup. The muons and other secondaries can interact with the detector and further produce neutrons.

The flux of neutrons produced in the rock in all directions is shown in Fig. 3. The neutrons produced in each layer is given in Table I and neutrons at the surface of each layer given in Table II.

TABLE I: The neutrons produced in each layer.

Material	# of neutrons	/cm$^3/s$
Rock	651376	$1.766(\pm 0.002) \times 10^{-09}$
Poly	933	$5.443(\pm 0.001) \times 10^{-11}$
Pb	11312	$6.27(\pm 0.05) \times 10^{-09}$

TABLE II: The neutrons at the surface of each layer.

Material	# of neutrons	/cm$^2/s$
Poly	24082	$3.02(\pm 0.02) \times 10^{-08}$
Pb	9581	$5.86(\pm 0.06) \times 10^{-08}$
Cu	176	$2.5(\pm 0.2) \times 10^{-07}$
CsI	47	$1.7(\pm 0.2) \times 10^{-07}$

Acknowledgments

DAE is acknowledged for financial support.

References

[1] P. A. R. Ade et al., Astron. Astrophys. **594**, A13 (2016).
[2] (ICAL Collaboration) Pramana 88, 79 (2017).
[3] K. K Meghna et al., Proceedings of the DAE-BRNS Symp. on Nucl. Phys. 61 (2016) 934.
[4] Jaduguda rock analysis results, AMD, Hyderabad.
[5] D.M. Mei et al., NIM A 606 (2009) 651.
[6] http://geant4.cern.ch/
[7] K. Nakamura et al., (PDG), JP G **37**, 075021 (2010).
[8] P. A Schreiner et al., Astroparticle Physics 32 (2009) 61–71.