Simulation studies for false positive event rate due to muon-induced neutral particles for a shallow depth ICAL detector

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Introduction

The India-based Neutrino Observatory (INO) is proposed to house Iron Calorimeter (ICAL) detector and will be located at Bodi West Hills in the southern part of India. At the chosen location the detector will be covered from all the sides by about 1 km of rock. The rock overburden reduces the cosmic muon flux by a factor of 10^6. The same level of cosmic muon background reduction can be achieved by a combination of a Shallow depth (of about 100 m depth) ICAL (SICAL) and Cosmic Muon Veto Detector with veto efficiency 99.99%. The feasibility study of CMVD has already been done as discussed in [1]. In the case of SICAL, the investigation of muon-induced neutral background becomes crucial as these neutrals can mimic neutrino events. In this paper, a GEANT4 based study is done to estimate the rate of such false positive signals in SICAL.

Simulation Framework

The propagation of all the secondaries produced in muon-nuclear interaction along the full length of 100 m of rock would take a lot of computational time. Also, the neutrals produced only in the last part of the rock will be able to come out, therefore, the simulation is done in three parts. In the first part, a cube of dimensions 100 m × 100 m × 100 m and rock as material, was constructed in GEANT4. The muons with incident energy (E_μ) varied randomly from 0.01 GeV to 500 GeV were propagated downwards from surface A as shown in Fig. 1. The energy of the muon after traversing 100 m of rock (E'_μ) was then plotted as a function of E_μ. The full incident energy range was divided into bins of width $\Delta E = 1$ GeV and the corresponding (E'_μ) spectrum was fitted to Crystal Ball fit function.

In the second part, a cuboid of dimensions

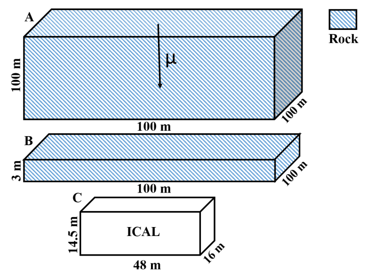

FIG. 1: A schematic showing configuration of the geometry used in the simulation.

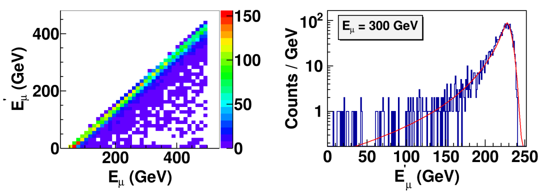

FIG. 2: 2D histogram showing E'_μ vs E_μ (left) and E'_μ distribution 300 GeV (right) incident muon energy fitted to Crystal Ball fit function (right).

100 m × 100 m × 3 m made up of rock was considered and muons were incident from top of surface B as shown in Fig. 1. Incident energy spectrum was generated with CORSIKA and was shifted according to Fig. 2 (left). For every input E_μ from CORSIKA, E'_μ was generated randomly from the corresponding Crystal Ball fit function. One such fit function

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for E_μ=300GeV is shown in Fig. 2 (right). For simulating the muon-nuclear interaction of muon with SiO_2 of density 2.65 gm/cc, Kokoulin model [2] was used and all the secondaries produced were propagated in rock. In the third part, the secondaries with their (E,θ) distributions coming out of the rock from the second part of the simulation were propagated in ICAL simulation code.

Results and Discussion

In the simulation, the most frequently produced secondary in the muon-nuclear interaction was the neutron. So, it becomes important to study its propagation in ICAL. However, K_L^0 has a decay mode $K_L^0 \rightarrow \pi^\pm \mu^\pm \nu_\mu$ with a decay fraction of (27.04 $\pm$ 0.07)% which directly gives muons which can generate false positive events in SICAL.

	neutron	
	No. of Events	No. of Particles
N(all E)	29378181	83254316
N_{out}(all E)	6670889	12579456
N_{out}(E > 1 GeV)	485790	511498
N'_{out}(E > 1 GeV)	111	111
	K_L^0	
	No. of Events	No. of Particles
N(all E)	273864	316862
N_{out}(all E)	80852	87059
N_{out}(E > 1 GeV)	46770	49475
N'_{out}(E > 1 GeV)	10	11

TABLE I: Distribution of neutron and K_L^0

Table 1 shows the events and particles distribution of neutrons and K_L^0 for 10^{10} muons incident on 3 m of rock. In the table, N denotes the total number of events (or particles) produced, N_{out} denotes the number of events and particles coming out of the rock with energy more 1 GeV and N'_{out} denotes the number of events and particles coming out of the rock without any accompanying charged particle of energy more than 50 MeV.

The secondaries were propagated in ICAL code and the fraction of times a track-like signal (F_{trk}) with a condition of minimum 5 layers having hit and $\chi^2/ndf < 10$ was obtained to be 2×10^{-3}. The fraction of times a false positive signal occurs in SICAL is given by $F_{FP} = N_{out} \times F_{trk} \times (\epsilon_{veto})^{n_q}$, where $\epsilon_{veto} = 10^{-4}$ from [1] is the veto inefficiency and n^q is the number of charged particle coming out of rock along with neutral particle. F_{FP} is calculated for different configuration and is tabulated in Table 2. For an ICAL sized detector, the false positive rate comes out to be 0.002/day. The neutrino event rate is about 3/day which $\sim$1000 times more than the false positives rate.

Configuration	N_{out} (E > 1 GeV)	F_{FP}
0 q & 1 n	120	2.4×10^{-1}
0 q & 2 n	1	2×10^{-3}
0 q & 3 n	0	0
1 q & 1 n	119381	2.3×10^{-2}
1 q & 2 n	0	0
1 q & 3 n	0	0
2 q & 1 n	70430	1.4×10^{-6}
2 q & 2 n	4636	9.3×10^{-8}
2 q & 3 n	0	0
Others	329818	0
Total	524386	2×10^{-1}

TABLE II: Break up of events with a specified number of charged (q) and neutral (n) particles.

Conclusion

The false positive event rate for SICAL, due to muon induced neutral particles in rock comes out to be $\sim$1000 times smaller than the neutrino event rate at proposed ICAL detector. According to the simulation, SICAL seems to be a good prospect, however, a feasibility study should be done for experimental verification of the simulation.

Acknowledgments

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References

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