Search for sterile neutrino mixing using ICAL detector at INO

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Introduction

The phenomena of neutrino (ν) oscillation among three active neutrino flavors (ν_e, ν_μ, ν_τ) has been established by several neutrino experiments e.g., solar, atmospheric, reactor and accelerator experiments beyond any doubt.However, the results, obtained from the short-baseline experiments, namely LSND, MiniBooNE indicate the possible existence of new kind of ν, different from the three active flavors. Their results cannot be explained within the standard three active ν oscillation formalism and require additional νs with masses at the eV scale. Such νs cannot participate in the weak interaction due to the constraint on invisible width of the Z boson [1] and are therefore called "sterile" νs. There have been several attempts to interpret the results of LSND and MiniBooNE in terms of 3+N ν oscillation models involving three active νs and N additional sterile νs [2]. In the atmospheric neutrino sector, the down-going ν_μ and $\bar{\nu}_\mu$ fluxes can be significantly altered due to the presence of eV^2-scale active-sterile oscillations, which is analysed in details [3] using the proposed iron calorimeter (ICAL) detector at the India-based Neutrino Observatory (INO).
In this work, we carry out a detailed study of sterile ν mixing using μ^- and μ^+ events at ICAL.

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Simulation

The survival probability $\nu_\mu \to \nu_\mu$ is estimated using 3+1 ν oscillation formula which is reduced to 2-ν oscillation probability as given in Eq.(1) due to higher value of squared mass difference. The survival probability used here is given by,

$$P = 1 - sin^2 2\Theta_{\mu\mu} sin(\frac{1.27\Delta m^2 L}{E}) \qquad (1)$$

where L is the source to detector distance in km, E is energy of νs in GeV, $\Theta_{\mu\mu}$ is given by $\sin^2 2\Theta_{\mu\mu} = 4\ |U_{\mu 4}|^2(1\text{-}|U_{\mu 4}|^2)$ and U is the 4×4 neutrino mixing matrix. In addition, the ν production height distribution in the atmosphere as a function of zenith angle and energy of ν is implemented by using Gaussian smearing of path length as given in [5]. We generate unoscillated muon events using NUANCE duly modified for INO. To reduce statistical fluctuation, we generate 1000 years of data which are normalized to required exposure during the statistical analysis. Those events are further made oscillated using a reweighting algorithm discussed in [6], which is based on the acceptance-rejection method. Finally, the oscillated events are smeared with detector response, using gaussian function, given by INO collaboration [7], to get the final reconstructed muon events at ICAL. Fig. 1 shows a typical muon spectrum integrated over a fixed cos θ_z bin. The black curve shows the sterile unoscillated events where as the red curve is obtained after oscillation with parameters as given in the figure caption.

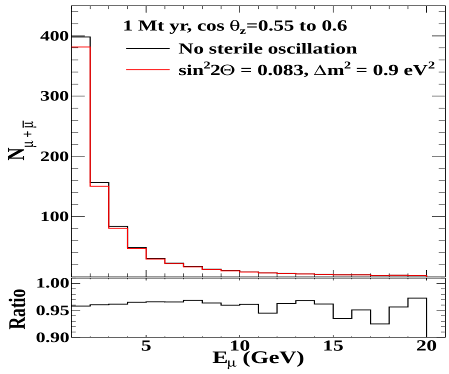

FIG. 1: Muon event spectrum vs energy integrated over the cos θ_z bin between 0.55 to 0.6 with(red line) and without(black line) two-flavor sterile oscillation. Detector resolution includes 10° in angle and 15% in energy respectively. Bottom figure shows the ratio of oscillated to unoscillated events.

χ^2 estimation

To study the sensitivity on sterile ν mixing, we used standard definition of χ^2 with Poissonian error distributions [6]. The χ^2 is minimized over a set of pull variables which includes five systematic uncertainties such as 20% overall flux normalization error , 10% error for overall normalization of cross-section, 5% error due to both tilt factor and zenith angle dependence of the flux and finally 5% overall systematic error [8]. For the calculation of χ^2, we have considered 38 energy and 36 cos θ_z bins.

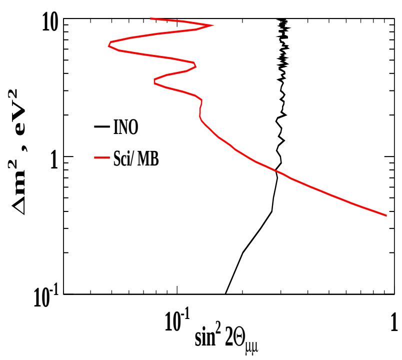

FIG. 2: Comparison of exclusion curve using INO ICAL detector and SciBooNE/ MiniBooNE [9] at 90 %CL with combined $N_{\mu^-} + N_{\mu^+}$ events

Results and Discussions

The survival probability of the down going atmospheric neutrinos will be effected by the active-sterile oscillation. The sensitivity on sterile neutrino mixing for an exposure of 1Mt.yr is shown in Fig. 2. The black line shows the plot using INO-ICAL detector resolution table given for different angle and energy bins. It is found that for the ICAL detector at INO, the exclusion limit for $\sin^2 2\Theta_{\mu\mu}$ can be ~ 0.13 at 90% CL for an exposure of 1 Mt.yr. The red curve in Fig.2 corresponds to the sensitive plot for SciBooNE/ MiniBooNE [9] which is shown for comparison. It is found that at lower values of Δm^2, the ICAL detector has better sensitivity compared to SciBooNE/ MiniBooNE, a short-baseline experiment, due to variable path length and energy of down going atmospheric neutrinos. The present study has been carried out for muon events using INO ICAL detector resolutions. The sensitivity study for neutrino events is in progress.

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