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Future of Atmospheric Neutrino Measurements

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Abstract

Discovery of large θ_{13} has opened up the possibility of determining the neutrino mass hierarchy and θ_{23} octant through earth matter effects. The atmospheric neutrinos pick up large earth matter effects both in the ν_e and ν_μ channels, which if observed could lead to the determination of the mass hierarchy and θ_{23} octant using this class of experiments in the near future. In this talk I review the status and prospects of future atmospheric neutrino measurements in determining the mass hierarchy and octant of θ_{23}.

Keywords: neutrino oscillations, atmospheric neutrinos

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1. Introduction

We now have more than 10σ signal for non-zero θ_{13} from global neutrino data [1, 2, 3]. The T2K experiment was the first to report the observation of θ_{13} driven oscillations in their data [4]. This hint was corroborated by data from the MINOS [5] and Double Chooz [6], and finally confirmed beyond all doubts first by the Daya Bay [7] and then by the RENO [8] experiments. All these experiments confirmed their first results with more statistics at this conference.

With the question regarding size of θ_{13} answered the remaining outstanding questions in neutrino physics include: (i) the sign of Δm^2_{31} (neutrino mass hierarchy), (ii) hints of θ_{23} being non-maximal, (iii) if θ_{23} is indeed non-maximal then its octant, and (iv) CP violation in the lepton sector. Of these, the first three could be probed from measurements of atmospheric neutrino measurements in bigger and better experiments in the future.

2. Reach of T2K, NOνA and Reactor experiments

Before discussing the prospects of determining the hitherto unknown neutrino parameters using future atmospheric neutrino measurements, it is pertinent to review the reach of the current long baseline experiments, T2K and NOvA, and reactor experiments Double Chooz, Daya Bay and RENO. Projected sensitivity reach of the combined data from these experiments to neutrino mass hierarchy, CP violation, and octant of θ_{23} was performed in [9]. The experimental specifications and time lines for these experiments were taken from the respective Letter of Intent and/or DPR of these experimental proposals. The details of the assumed specifications for each of the experiments and the method of analysis can be found in [9]. Here we present two sample plots from that paper which show the combined reach of these experiments to mass hierarchy, CP violation and θ_{23} octant. We show the mass hierarchy (left panels) and CP violation (right panel) sensitivity plots in Fig. 1. The top panels are for normal hierarchy as taken as true while the bottom panels are when inverted hierarchy is taken to be true. Each color defines the area in the $\sin^2 2\theta_{13}$-fraction of δ_{CP} zone for which mass hierarchy (left plots) and CP violation (right plots) determination is possible at the 90% C.L.. One can see that for $\sin^2 2\theta_{13} = 0.1$ mass hierarchy will be determined only for 50% of the true δ_{CP} values even at 90% C.L.. At 3σ C.L. these plots are essentially empty.

In Fig. 2 we show the sensitivity to θ_{23} octant, which can be seen to be rather good for $\sin^2 2\theta_{13} = 0.1$. This good sensitivity basically comes from the complimentarity between the accelerator-based long baseline experiments which essentially measure the combination $\sin^2\theta_{23}\sin^2 2\theta_{13}$ and the reactor experiments which

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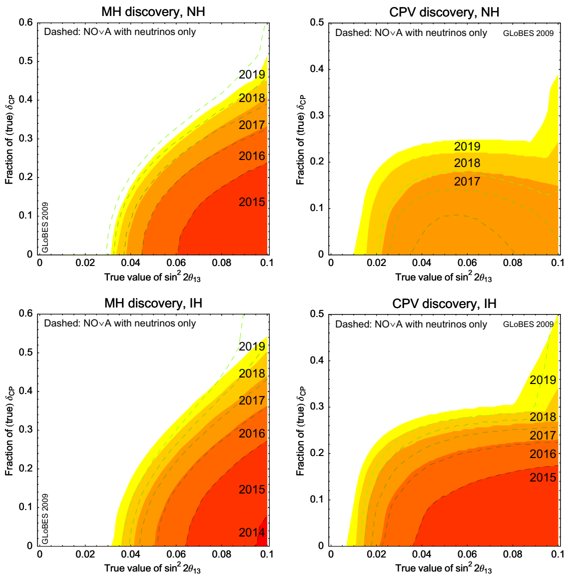

Figure 1: Mass hierarchy (left panels) and CP violation (right panels) discovery potentials as a function of true $\sin^2 2\theta_{13}$ and fraction of true δ_{CP} at the 90% C.L. from T2K, NOvA and the reactor data. Top panels are for true normal hierarchy (defined as $\Delta m^2_{31} > 0$) while bottom panels are for true inverted hierarchy ($\Delta m^2_{31} < 0$). The different shadings correspond to different points of time, as marked in the plots (note that 2015 here means mid 2015). The dashed curves refer to NOvA with neutrino running only, whereas the shaded contours refer to the nominal NOvA neutrino-antineutrino plan. Taken from [9].

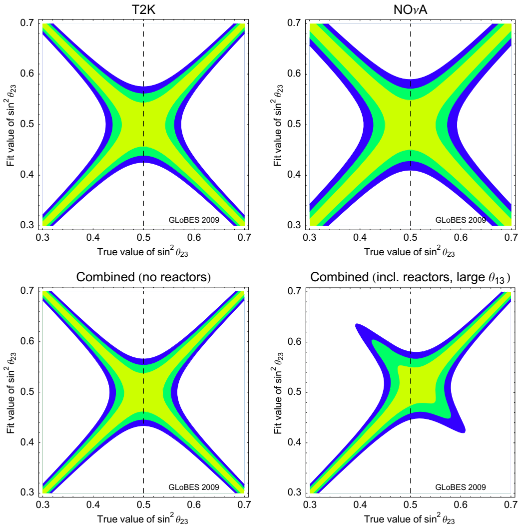

Figure 2: The 1σ, 2σ and 3σ fit range of $\sin^2\theta_{23}$ shown as a function of the true $\sin^2\theta_{23}$ from different experiments. The upper left and right, and the lower left panels are computed for for $\sin^2 2\theta_{13} = 0$ while the lower right panel is computed for $\sin^2 2\theta_{13} = 0.1$. Taken from [9].

measure pure $\sin^2 2\theta_{13}$.

3. Future Atmospheric neutrino experiments

We give in Fig. 3 the comparison between the different atmospheric neutrino detectors.

4. The India-based Neutrino Observatory

There will be an underground lab at Theni (9° 58 N, 77°16 E), with ∼ 1 km all-round rock cover accessed through a 2 km long tunnel. There will be one large cavern for the 50 kton magnetized Iron CALorimeter (ICAL) and several small caverns to facilitate many other experimental programs. The detector is expected to go into construction soon and is planned to start operations in around 2017. The detector will have dimensions 48.4 m in length, 16 m in width and 14.4 in height with a layered structure with 150 layers of 5.6 cm iron slabs interleaved with glass Resistive Plate Chambers (RPC) acting as the active detector element.

Simulations for ICAL@INO are done according to the following prescription. Atmospheric neutrino events are generated using the Nuance event generator V3.000 customized for ICAL@INO. These events are then passed through the GEANT V4 based detector simulation code. The data from this is then digitized and finally the muon tracks and hadron showers reconstructed. The INO collaboration have performed detailed studies of the detector performance for both the muons passing through the detector as well as the detector response to hadrons. We show in Fig. 4 a snapshot of the detector efficiencies and resolutions for muons in ICAL@INO as a function of the muon energy. These results have been obtained by including the inhomogeneous field map-