NEUTRINO PHYSICS FROM NEW MEASUREMENTS

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Emergence of neutrino physics is fueled by the recent growth in quality and quantity of experimental data, yet, there are still open questions. How much can the determination of mixing parameters be improved? Can we improve bounds on θ_{13} before experiments designed specifically for this parameter start? How well can we determine or limit sterile fraction of neutrino flux from sun and sterile mixing angle? We examine the impact of outcome from new measurements in the context of providing answers to these questions.

It is well established that, solar neutrinos primarily change into another active flavor[1]. Experimental evidences from solar[1,2], atmospheric[3], reactor[4,5,6] and long-baseline[7] experiments can be accommodated into the framework of neutrino mass, oscillations, and neutrino mixing. In this formalism, it is known that solar mixing angle, θ_{12}, is large[8,9], but not maximal, and atmospheric mixing angle, θ_{23}, is large, even maximal. Matter effects probably plays a role in this transformation[10].

The size of the third mixing angle, θ_{13}, is currently best limited by combined CHOOZ reactor experiment and SK atmospheric data. In Fig. 1, we present bounds on θ_{13} under certain considerations. The horizontal shaded regions are 90% C. L. and 99% C. L. bounds on δm^2_{23} from SuperK atmospheric data. The thick (thin) dashed curve is the 90% C. L. (3σ) CHOOZ bound. The 99% C. L. region on δm^2_{23} extends as low as $1 \times 10^{-3}\mathrm{eV}^2$. At the lower end of this region, θ_{13} is poorly constrained by CHOOZ. The solid curves in Fig. 1 are bounds from from CHOOZ, KamLAND and solar data at 90% C. L. and 3σ. Our analysis shows that, the upper bound on θ_{13} from KamLAND and solar neutrino data gets stronger (especially in the region with small δm^2_{23} where CHOOZ reactor bound is relatively weak), and even dominates as this data gets refined. In order to examine the possible impact of new NC and CC measurements from NCD phase of SNO experiment, we add two new hypothetical measurements with 1-σ uncertainties of 5.5% and 6.4%, and vary the corresponding central values by 1-σ around their salt-phase determinations. The shaded curved bands, showing how 90% C. L. and 3σ bounds vary upon addition of these hypothetical data, suggest that the impact could be further improvement of the bounds on θ_{13}.

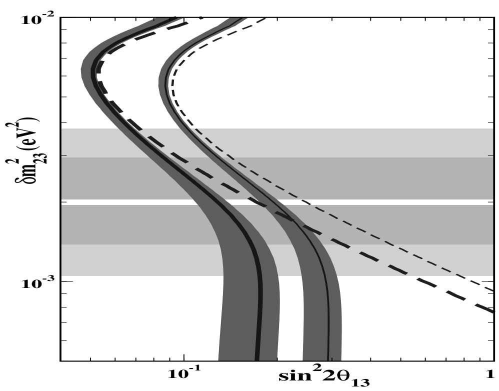

Fig. 1. The horizontal shaded regions are 90% C. L. and 99% C. L. bounds on δm^2_{23} from SuperK atmospheric data. The thick (thin) dashed curve is the 90% C. L. (3σ) CHOOZ bound. The solid curves are bounds from from CHOOZ, KamLAND and solar data at 90% C. L. and 3σ and the shaded curved bands show the possible impact of new NC and CC measurements at each confidence level.

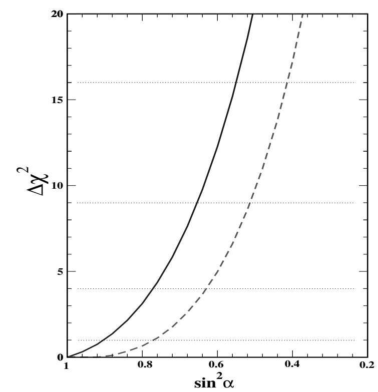

Fig. 2. $\Delta\chi^2$ vs. $\sin^2\alpha$ from analyses, all solar and KamLAND data (solid line) and just SNO and KamLAND data (dashed line). The horizontal dotted lines are at the $\Delta\chi^2 = n^2$ indicating n-σ confidence levels. ^{8}B flux is free.

In simple 4-neutrino mixing scenarios, electron neutrinos change into some linear combination of active (non-electron) and sterile neutrinos,

$$\nu_e \to \cos\alpha\, \nu_s + \sin\alpha\, \nu_{\mu,\tau}\,. \tag{1}$$

This is based on the assumption that the electron flavor is distributed among two eigenstates only. The sterile admixture is described by sterile mixing angle, α. The fraction of oscillating neutrinos changing into active (sterile) flavor is given by $\sin^2\alpha$ ($\cos^2\alpha$). The average survival probability of electron neutrinos, P_e, for SNO experiment can be calculated as,

$$P_e = \frac{\int \lambda(E_\nu)\sigma^{SNO}_{CC}(E_\nu)P_{e\to e}(E_\nu, \delta m^2_{12}, \theta_{12})dE_\nu}{\int \lambda(E_\nu)\sigma^{SNO}_{CC}(E_\nu)dE_\nu}\,, \tag{2}$$

where λ is ^8B spectrum and σ^{SNO}_{CC} is CC cross section. The energy dependent survival probability, $P_{e\to e}$, is a function of both neutrino energy, E_ν, and mixing parameters, δm^2_{12} and θ_{12}, which can be taken from KamLAND experiment. Matter effects has little effect on calculation of P_e in the model we applied here (especially when sterile fraction is small). SNO experiment measures CC, $\Phi_{CC} \sim P_e \Phi_{^8B}$, and NC, $\Phi_{NC} \sim P_a \Phi_{^8B}$ where P_a is active fraction of the total flux and $\Phi_{^8B}$ is solar ^8B neutrino flux. It is estimated that P_e can be known up to 7% uncertainty[11], while Φ_{NC} and Φ_{CC} can be measured with 5.5%, 6.4% uncertainties in NCD phase of SNO[12]. The fraction of oscillating neutrinos changing into active flavor can be cast into the form,

$$\sin^2\alpha = \frac{\Phi_{NC} - \Phi_{CC}}{\Phi_{^8B} - \Phi_{CC}}\,. \tag{3}$$

We examine the fractional error, $\sigma_{\sin^2\alpha}/\sin^2\alpha$, which requires access to the value of ^8B flux. Adapting SSM value, which has over 20% uncertainty, yields almost 30% fractional uncertainty on $\sin^2\alpha$. An alternative way is extracting, ^8B flux from SNO CC measurement, through the relation $\Phi_{^8B} = \Phi_{CC}/P_e$. We see that fractional uncertainty on $\sin^2\alpha$ can be reduced below 20% by this substitution[13]. This result is independent of solar model uncertainties.

Another method to determine the uncertainty on $\sin^2\alpha$ is to perform a statistical analysis based on the oscillation formulae, where $\sin^2\alpha$ is a fit parameter. We present results of such global analyses in Fig. 2 projected on $\sin^2\alpha$ and marginalized over all other mixing parameters. The results consistent with non existence of sterile component in solar neutrino flux. The 1-σ bound for the analysis, in which solar and KamLAND data is considered (the solid line in Fig. 2), yields about 10% uncertainty on $\sin^2\alpha$. When only SNO and KamLAND data is considered (the dashed line in Fig. 2), the uncertainty on $\sin^2\alpha$ increases to about 20% (which is comparable to the bound we obtained in simpler approach we utilized earlier, using P_e determination from KamLAND and NC, CC measurements from SNO). To conclude, oscillation of solar neutrinos into pure sterile flavor is not allowed but the possibility of a small sterile component in solar flux cannot be eliminated within the current precision of model dependencies. In the long run, solar model model independent measurements, like NC determination by SNO experiment, are the preferred way for studying the sterile neutrino fraction and/or sterile mixing angle in both simple approaches (like the one we presented) and full statistical analysis based on the oscillation formulae.

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