



T2K–Super-K Combined Fit Study

θ_{23} Octant Discrimination and Mass Hierarchy Determination

J. Imber

SUNY at Stony Brook

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Outline



Introduction

Inputs to the Study

Combined χ^2 Plots

Summary and Future Plans

Motivation



- ▶ The present measurements of oscillation parameters from individual experiments can be improved by a combination of these datasets. This could be critical to make advancements using current experiments.
- ▶ What additional sensitivity to the $\sin^2 \theta_{23}$ octant and/or the mass hierarchy can be gained by combining a T2K ν_e appearance and ν_μ disappearance joint fit with the Super-K 3-flavour atmospheric fit?

- ▶ T2K
 - ▶ Narrow spectrum, fixed baseline
 - ▶ ν_μ Disappearance and ν_e appearance channels → sensitivity to many parameters
- ▶ Super-K
 - ▶ Broad spectrum, wide range of baselines
 - ▶ Multiple event categories → sensitivity to many parameters inc. Mass Hierarchy
- ▶ Daya Bay
 - ▶ High statistics $\bar{\nu}_e$ disappearance measurement
 - ▶ Strong constraint on $\sin^2(\theta_{13})$

T2K Monte Carlo Input



- ▶ T2K MC normalized to 10^{21} POT (approx. Spring 2014)
- ▶ Bin T2K ν_e and ν_μ event selections in reconstructed ν energy, bin width 50MeV
- ▶ Fixed Parameters
 - ▶ $\sin^2 2\theta_{12} = 0.87$
 - ▶ $\Delta m_{12}^2 = 7.6 \times 10^{-5} \text{eV}^2$
- ▶ Calculate N_{exp} over range of remaining 4 oscillation parameters
- ▶ N_{obs} based on 'Truth' point parameter values
 - ▶ $\sin^2 \theta_{13} = 0.025$
 - ▶ $\Delta m_{32}^2 = 2.4 \times 10^{-3} \text{eV}^2$
 - ▶ $\delta_{cp} = 0$
 - ▶ $\sin^2 \theta_{23} = 0.45, 0.5, 0.55$

T2K inputs cont.



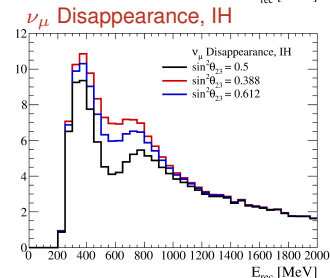
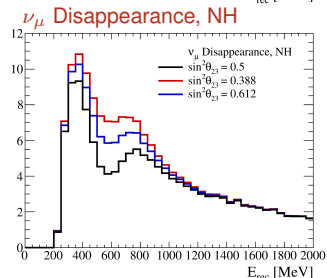
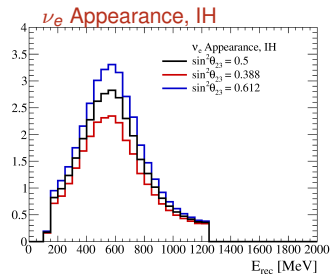
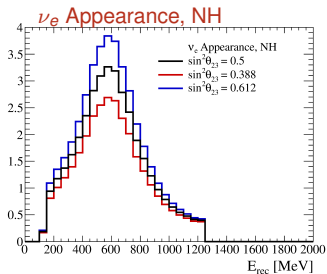
- ▶ Form χ^2 using the following equation

$$\chi^2 = \chi_{T2K,\nu_e}^2 + \chi_{T2K,\nu_\mu}^2 + \chi_{T2K,sys}^2$$

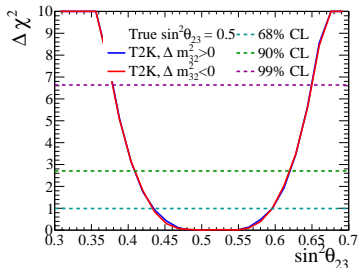
$$\chi^2 = -2 \sum_{E_{\nu_e}} \ln P(E_{\nu_e}; f \cdot N_{exp}^{\nu_e} > 0, N_{obs}^{\nu_e}) - 2 \sum_{E_{\nu_\mu}} \ln P(E_{\nu_\mu}; f \cdot N_{exp}^{\nu_\mu} > 0, N_{obs}^{\nu_\mu}) + (1-f) \cdot \mathbf{C}^{-1} \cdot (1-f)$$

- ▶ Where \mathbf{C} is a covariance matrix relating the error on each energy bin and f is a vector systematic shifts

T2K reconstructed energy spectra

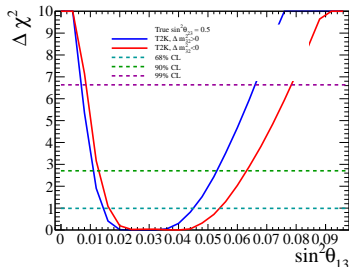
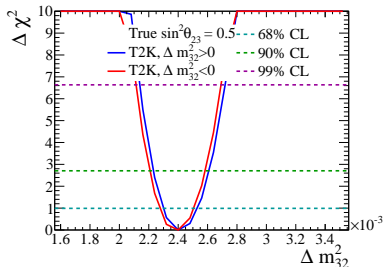


T2K Fit Results



T2K MC Truth
Normal Hierarchy

$$\sin^2 \theta_{23} = 0.5$$



Super-K Input

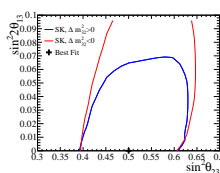
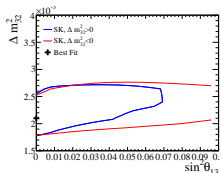
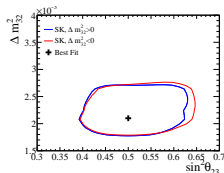
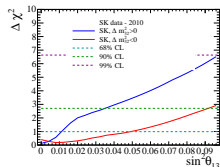
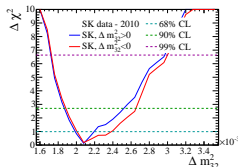
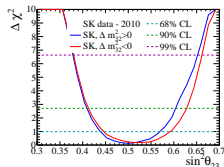


- ▶ Super-K I,II and III result published in 2010

R. Wendell et al., Phys Rev D, 81 092004

- ▶ Add final Super-K χ^2 to T2K χ^2

$$\chi^2 = \chi_{T2K,\nu_e}^2 + \chi_{T2K,\nu_\mu}^2 + \chi_{T2K,sys}^2 + \chi_{SK,data}^2$$



Daya Bay Input

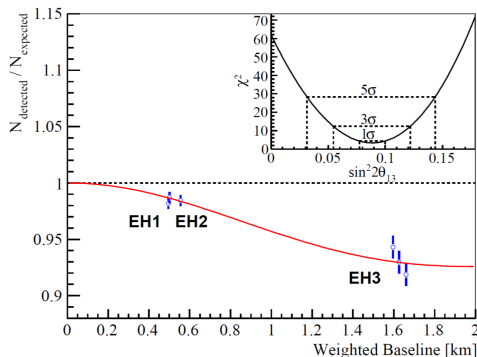


- ▶ Daya Bay result constrains $\sin^2 \theta_{13}$

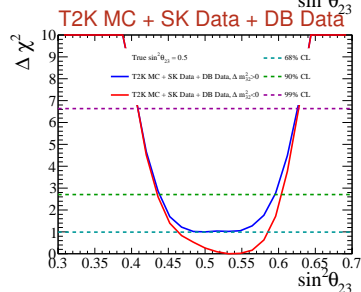
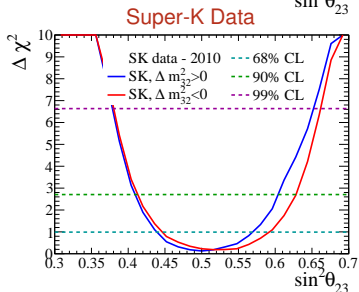
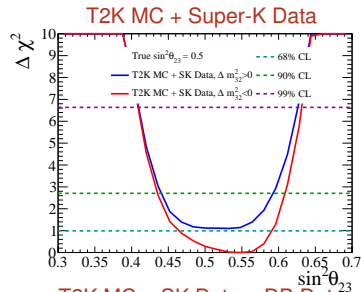
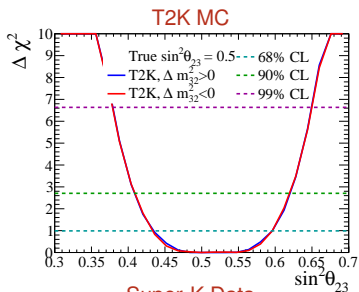
F. P. An et al., Chinese Phys. C 1, 011001 (2013).

- ▶ Add Daya Bay χ^2

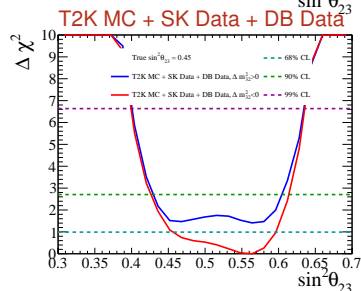
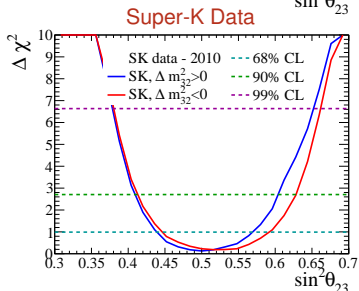
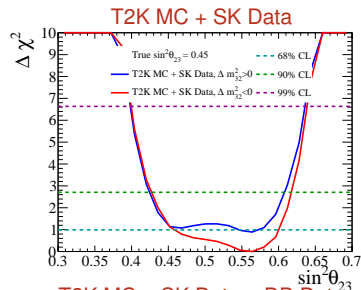
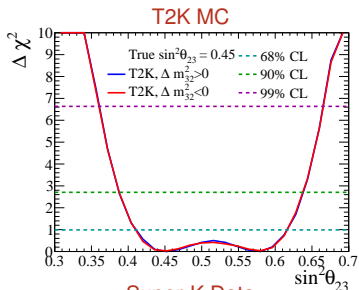
$$\chi^2 = \chi_{T2K, \nu_e}^2 + \chi_{T2K, \nu_\mu}^2 + \chi_{T2K, \text{sys}}^2 + \chi_{SK, \text{data}}^2 + \chi_{DB, \text{data}}^2$$



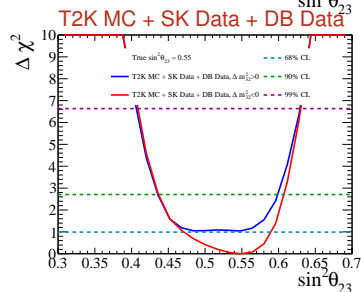
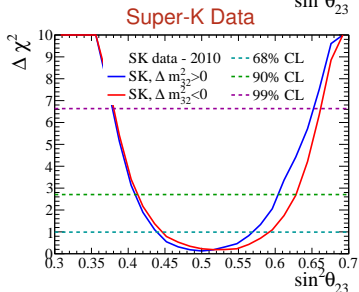
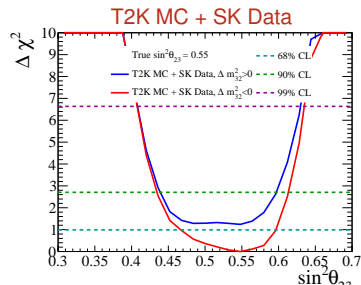
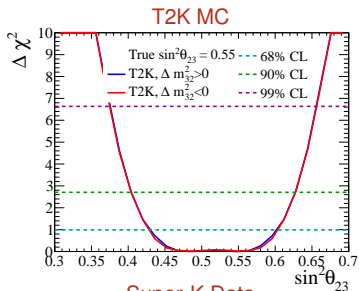
T2K MC Truth - Normal Hierarchy, $\sin^2 \theta_{23} = 0.5$



T2K MC Truth - Normal Hierarchy, $\sin^2 \theta_{23} = 0.45$



T2K MC Truth - Normal Hierarchy, $\sin^2 \theta_{23} = 0.55$



Summary



- ▶ We see a benefit in combining these experimental results.
- ▶ As expected from the 2012 Super-K atm. fit, constraining $\sin^2 \theta_{13}$ results in a weak hierarchy preference of ~ 1 unit $\Delta\chi^2$
- ▶ Mixture of MC and data makes it more difficult to draw conclusions

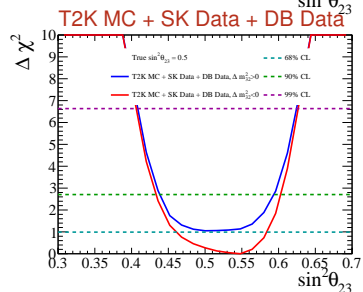
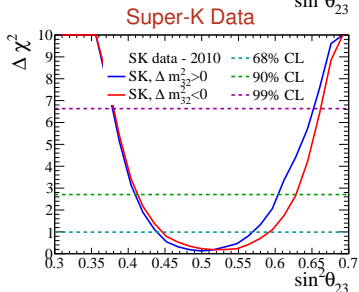
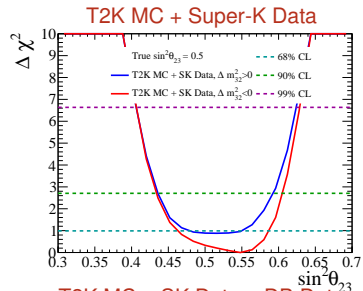
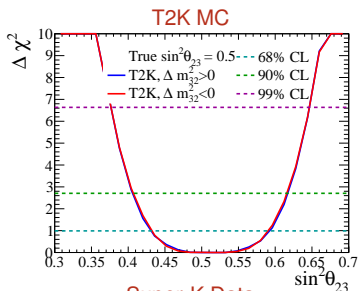
Future Plans



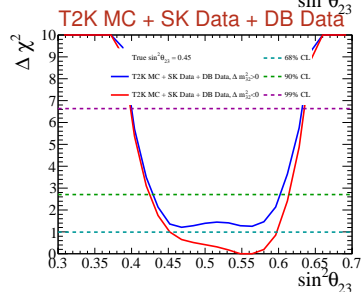
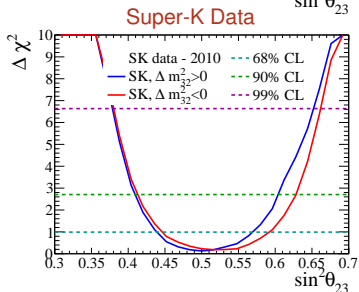
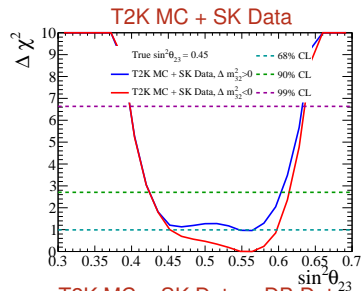
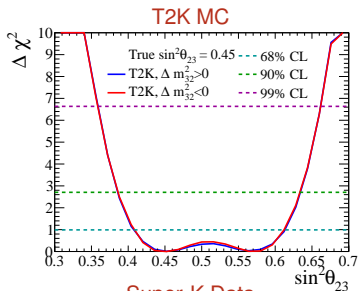
- ▶ Study future sensitivities by combining T2K MC with Super-K MC for various data scenarios
- ▶ Further integrate the analyses
 - ▶ Common error calculation for T2K and Super-K samples
 - ▶ correlated detector, cross section and FSI/SI errors
- ▶ Combined fit using available data (requires formal agreement between collaborations)

Backup

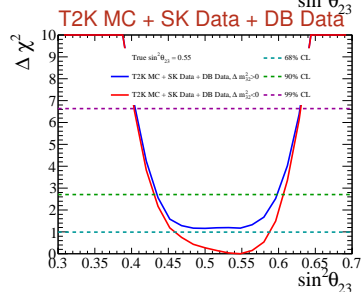
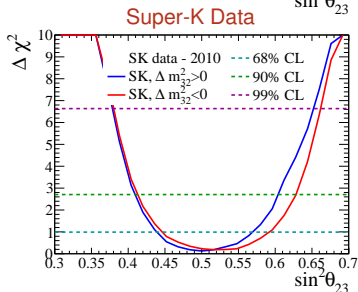
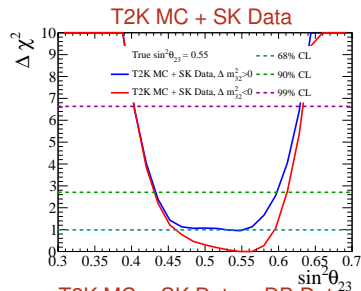
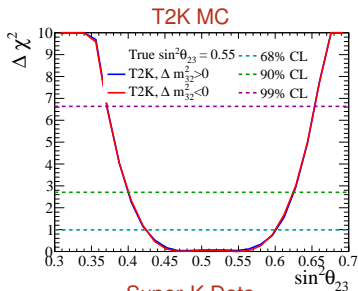
T2K MC Truth - Inverted Hierarchy, $\sin^2 \theta_{23} = 0.5$



T2K MC Truth - Inverted Hierarchy, $\sin^2 \theta_{23} = 0.45$



T2K MC Truth - Inverted Hierarchy, $\sin^2 \theta_{23} = 0.55$

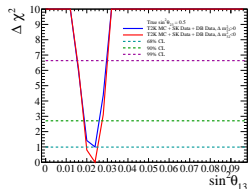
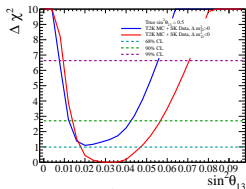
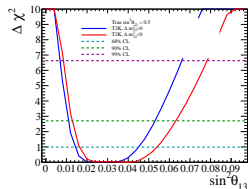
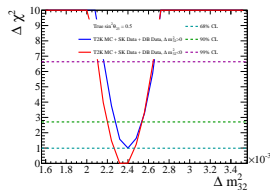
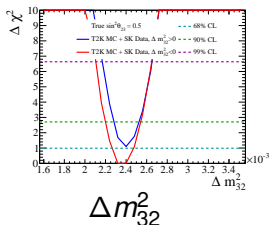
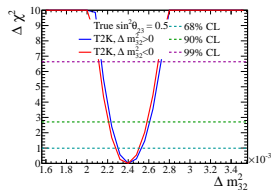


T2K MC Truth - Normal Hierarchy, $\sin^2 \theta_{23} = 0.5$

T2K

T2K + SK

T2K + SK + DB

 $\sin^2(\theta_{13})$ 

Super-K atm. Event Samples

R. Wendell et al., Phys Rev D, 81 092004

