

Report on T2K Result:

<http://jnusrv01.kek.jp/public/t2k/index.php>

Paper: <http://arxiv.org/abs/1106.1238>

Talk: <http://jnusrv01.kek.jp/public/t2k/sites/default/files/t2k-nue1st.pdf>

Press: http://www.kek.jp/intra-e/press/2011/J-PARC_T2Kneutrino.html

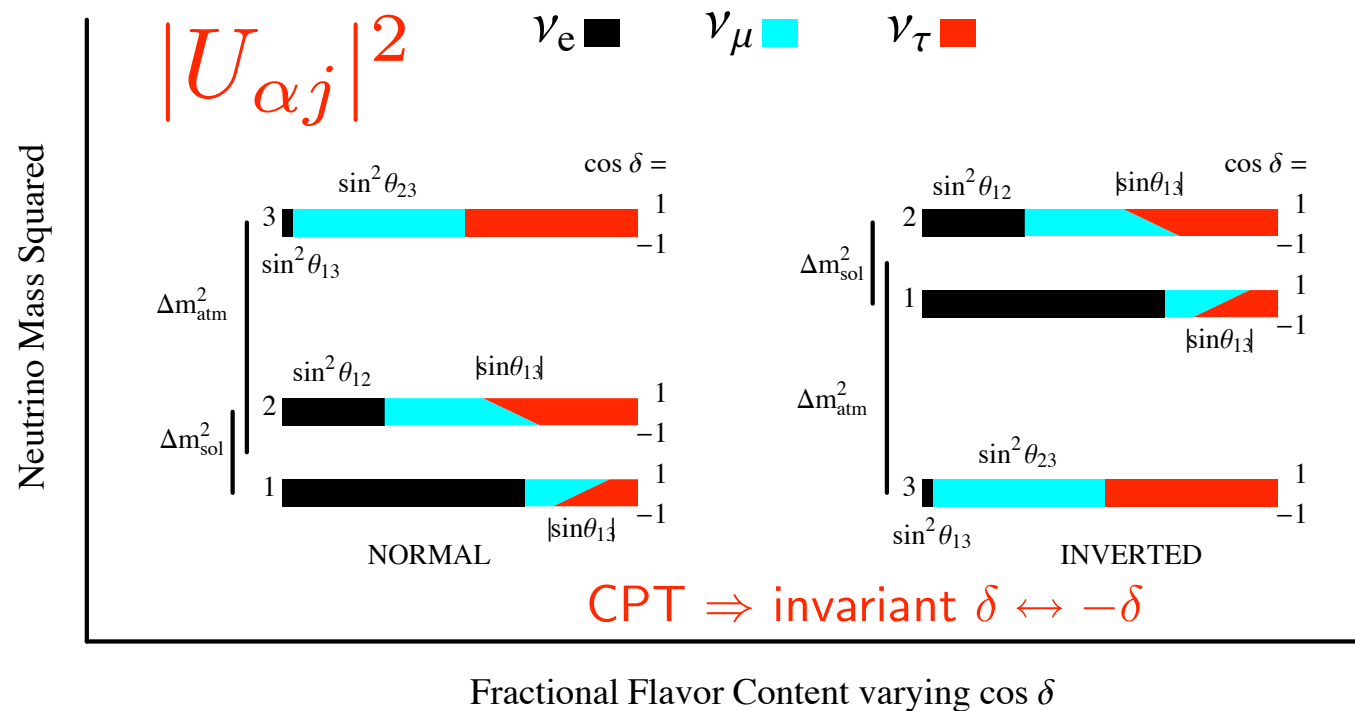


T2K Main Goals:

- ★ Discovery of $\nu_\mu \rightarrow \nu_e$ oscillation (ν_e appearance)
- ★ Precision measurement of ν_μ disappearance

Neutrino Masses & Mixings:

$$\sin^2 \theta_{13} \equiv |U_{e3}|^2, \quad \sin^2 \theta_{12} \equiv \frac{|U_{e2}|^2}{(1 - |U_{e3}|^2)}, \quad \sin^2 \theta_{23} \equiv \frac{|U_{\mu 3}|^2}{(1 - |U_{e3}|^2)}$$



$$\delta m_{sol}^2 = +7.6 \times 10^{-5} \text{ eV}^2$$

$$|\delta m_{atm}^2| = 2.4 \times 10^{-3} \text{ eV}^2$$

$$|\delta m_{sol}^2|/|\delta m_{atm}^2| \approx 0.03$$

$$\sqrt{\delta m_{atm}^2} = 0.05 \text{ eV} < \sum m_{\nu_i} < 0.5 \text{ eV} = 10^{-6} * m_e$$

$$\sin^2 \theta_{12} \sim 1/3$$

$$\sin^2 \theta_{23} \sim 1/2$$

$$\sin^2 \theta_{13} < 3\%$$

$$0 \leq \delta < 2\pi$$

Chooz
Minos

- $\theta_{13} \neq 0$ allows ν_e to oscillate at the Atmospheric scale 500km/GeV !!!
(as well as the Solar scale 15,000km/GeV)

- CPV and Mass Hierarchy

Vacuum LBL:

$$\nu_{\mu} \rightarrow \nu_e$$

$$P_{\mu \rightarrow e} \approx \left| \sqrt{P_{atm}} e^{-i(\Delta_{32} \pm \delta)} + \sqrt{P_{sol}} \right|^2$$

$$\Delta_{ij} = \delta m_{ij}^2 L / 4E$$

CP violation !!!

where $\sqrt{P_{atm}} = \sin \theta_{23} \sin 2\theta_{13} \sin \Delta_{31}$

and $\sqrt{P_{sol}} = \cos \theta_{23} \sin 2\theta_{12} \sin \Delta_{21}$

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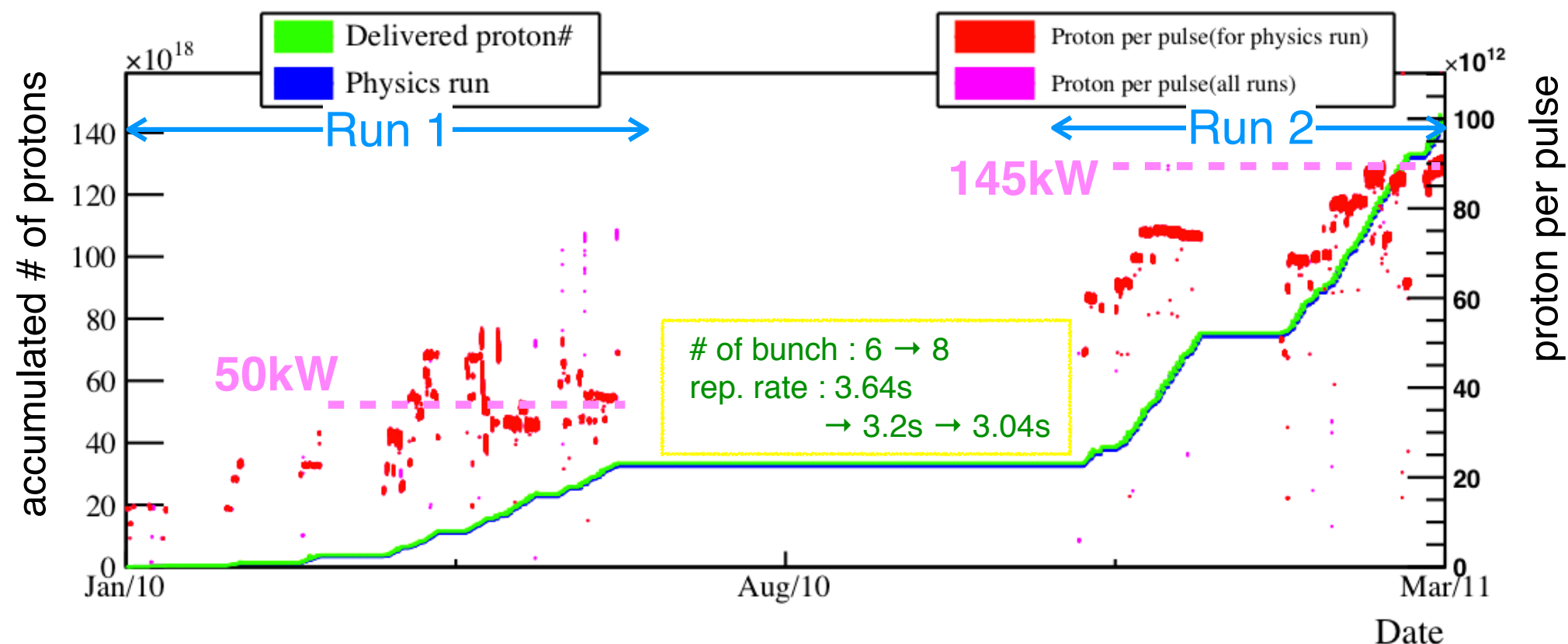
and $\sqrt{P_{sol}} = \cos \theta_{23} \sin 2\theta_{12} \sin \Delta_{21}$

$$P_{\mu \rightarrow e} \approx P_{atm} + 2\sqrt{P_{atm}P_{sol}} \cos(\Delta_{32} \pm \delta) + P_{sol}$$

only CPV

$$\cos(\Delta_{32} \pm \delta) = \cos \Delta_{32} \cos \delta \mp \sin \Delta_{32} \sin \delta$$

Total # of protons used for analysis



Run 1 (Jan. '10 - June '10)

- 3.23×10^{19} p.o.t. for analysis
- 50kW stable beam operation

Run 2 (Nov. '10 - Mar. '11)

- 11.08×10^{19} p.o.t. for analysis
- ~145kW beam operation

Total # of protons used for this analysis is 1.43×10^{20} pot
 2% of T2K's final goal and ~5 times exposure of the previous report

The expected number of events for $\sin^2 2\theta_{13}=0$

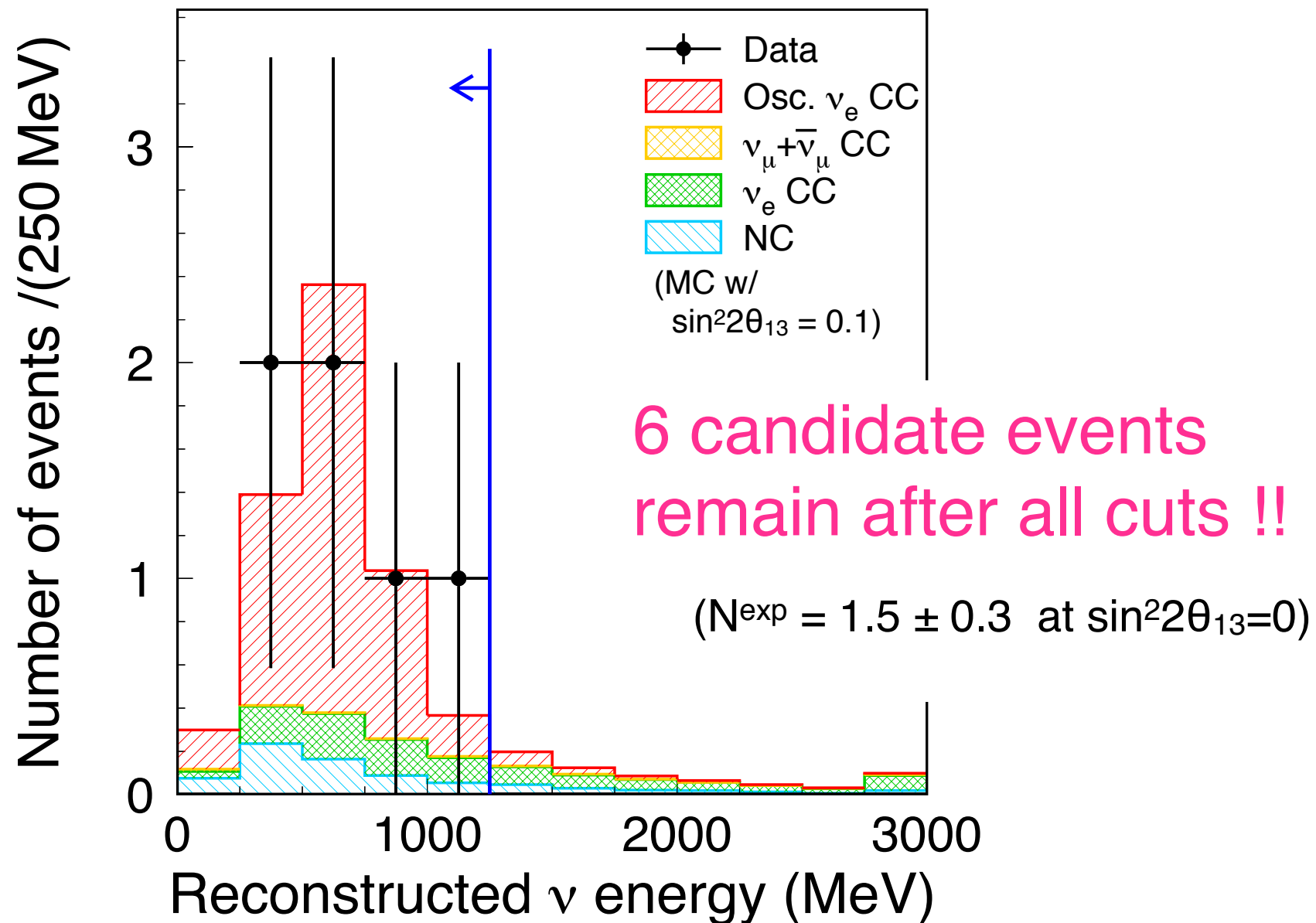
The expected number of events with 1.43×10^{20} p.o.t.

$$N^{\text{exp}}_{\text{SK tot.}} = 1.5 \text{ events}$$

	Beam ν_e background	NC background	Oscillated $\nu_\mu \rightarrow \nu_e$ (solar term)	Total
<i>The expected # of events at SK</i>	0.8	0.6	0.1	1.5

Results for ν_e appearance search with 1.43×10^{20} p.o.t.

Reconstructed ν energy cut ($E_{\text{rec}} < 1250$ MeV) : *Final cut*



Under the $\theta_{13}=0$ hypothesis, the probability to observe six or more candidate events is 0.007 (equivalent to 2.5σ significance)

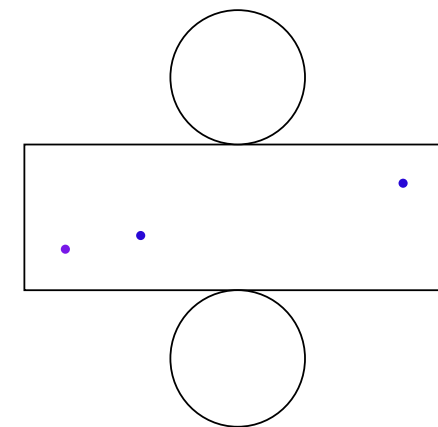
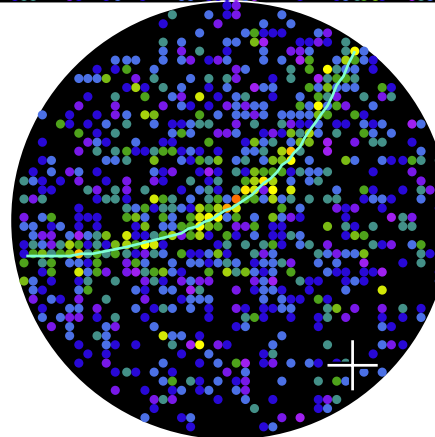
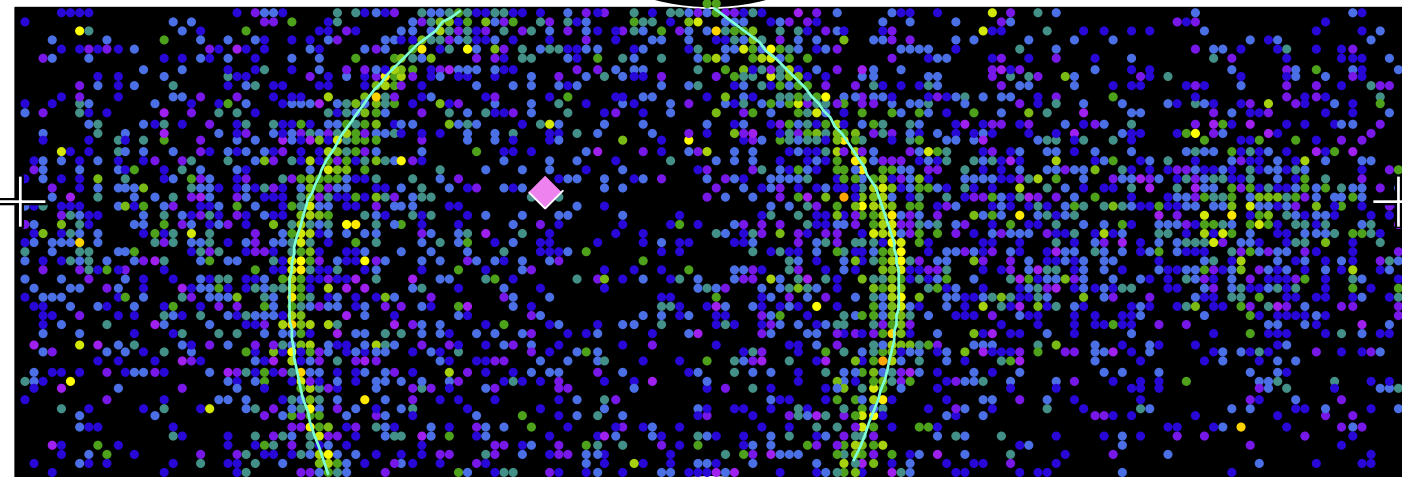
ν_e candidate event

Super-Kamiokande IV

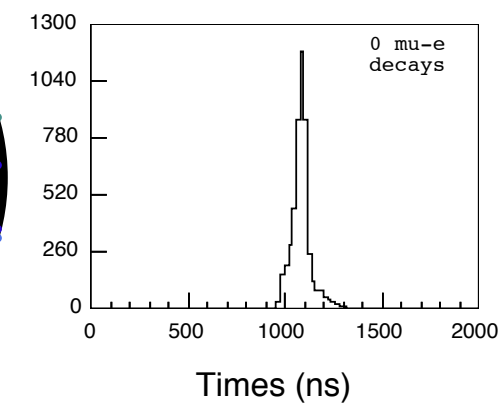
T2K Beam Run 0 Spill 1039222
Run 67969 Sub 921 Event 218931934
10-12-22:14:15:18
T2K beam dt = 1782.6 ns
Inner: 4804 hits, 9970 pe
Outer: 4 hits, 3 pe
Trigger: 0x80000007
D_{wall}: 244.2 cm
e-like, p = 1049.0 MeV/c

Charge (pe)

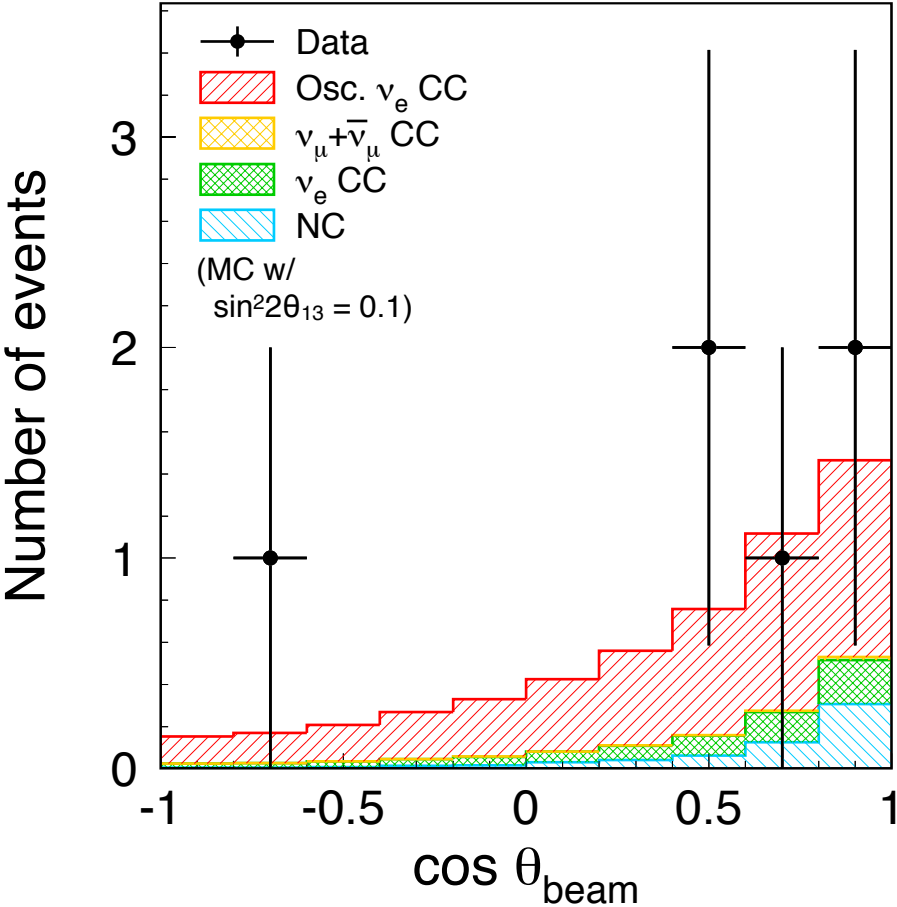
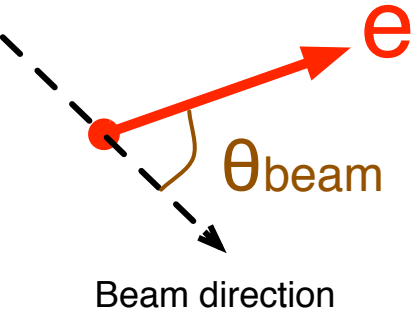
- >26.7
- 23.3-26.7
- 20.2-23.3
- 17.3-20.2
- 14.7-17.3
- 12.2-14.7
- 10.0-12.2
- 8.0-10.0
- 6.2- 8.0
- 4.7- 6.2
- 3.3- 4.7
- 2.2- 3.3
- 1.3- 2.2
- 0.7- 1.3
- 0.2- 0.7
- < 0.2



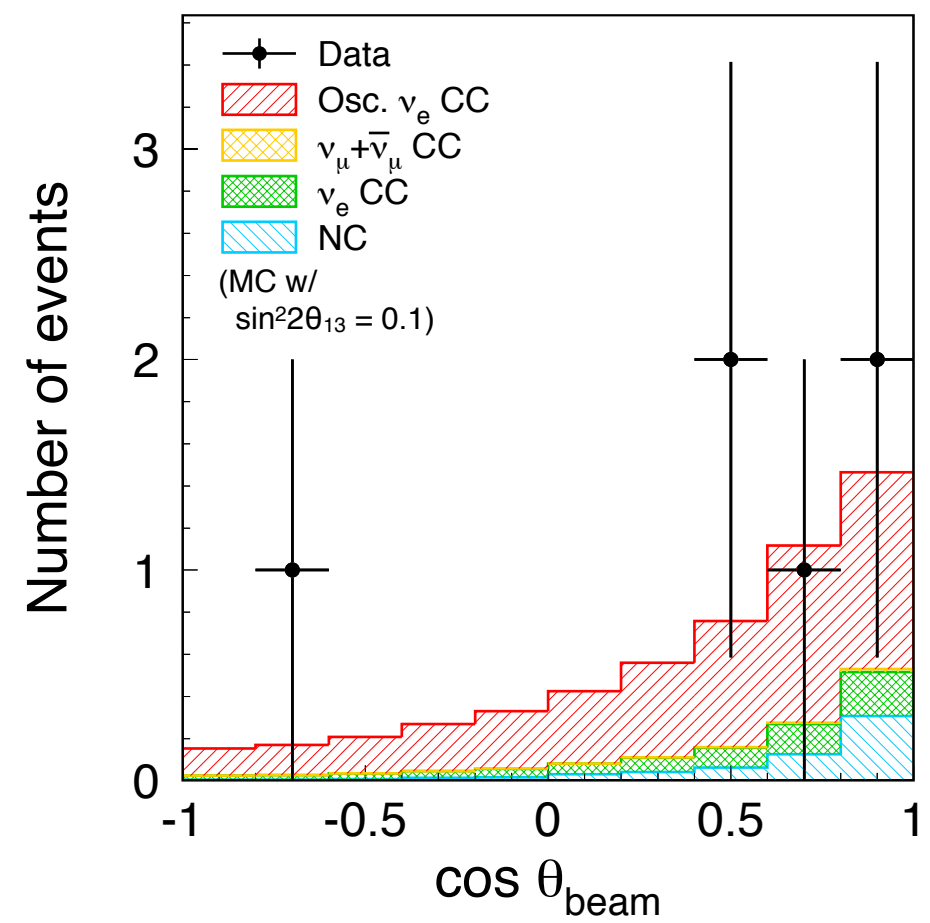
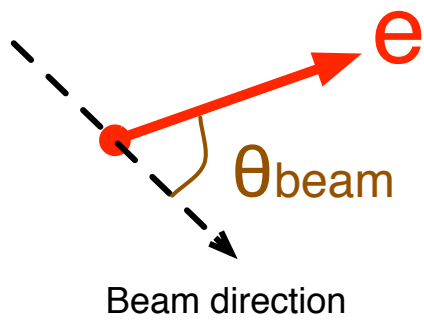
visible energy : 1049 MeV
of decay-e : 0
2 γ Inv. mass : 0.04 MeV/c²
recon. energy : 1120.9 MeV



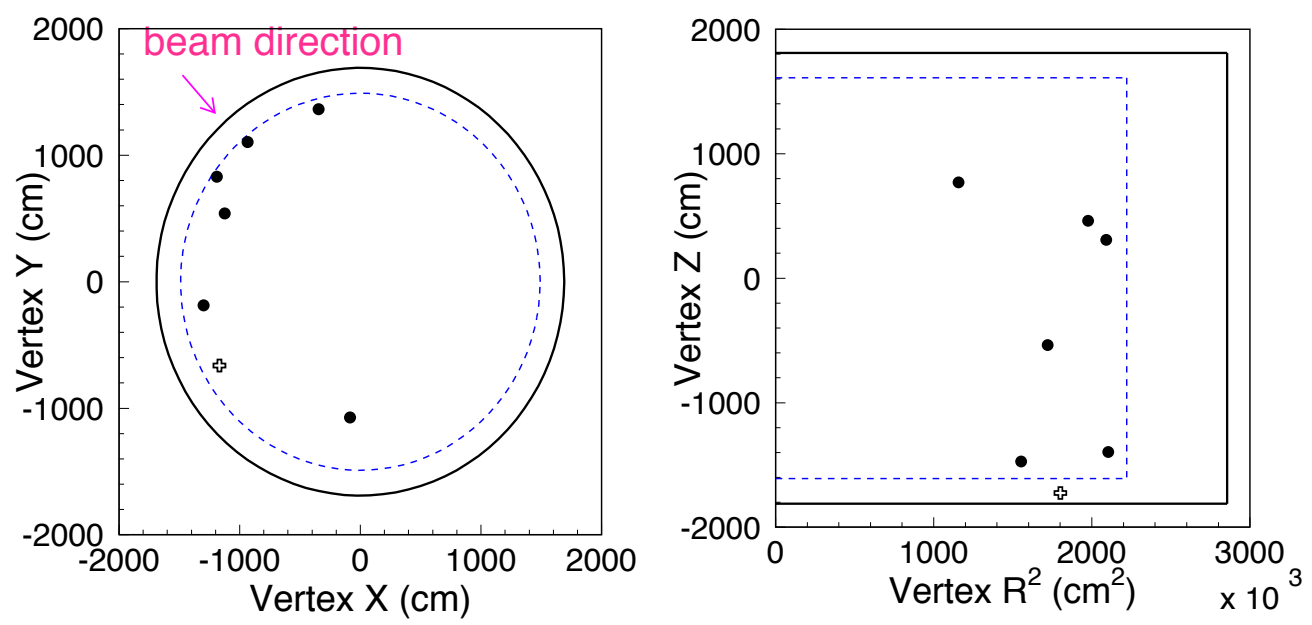
Check several distribution of ν_e candidate events



Check several distribution of ν_e candidate events



Vertex distribution of ν_e candidate events

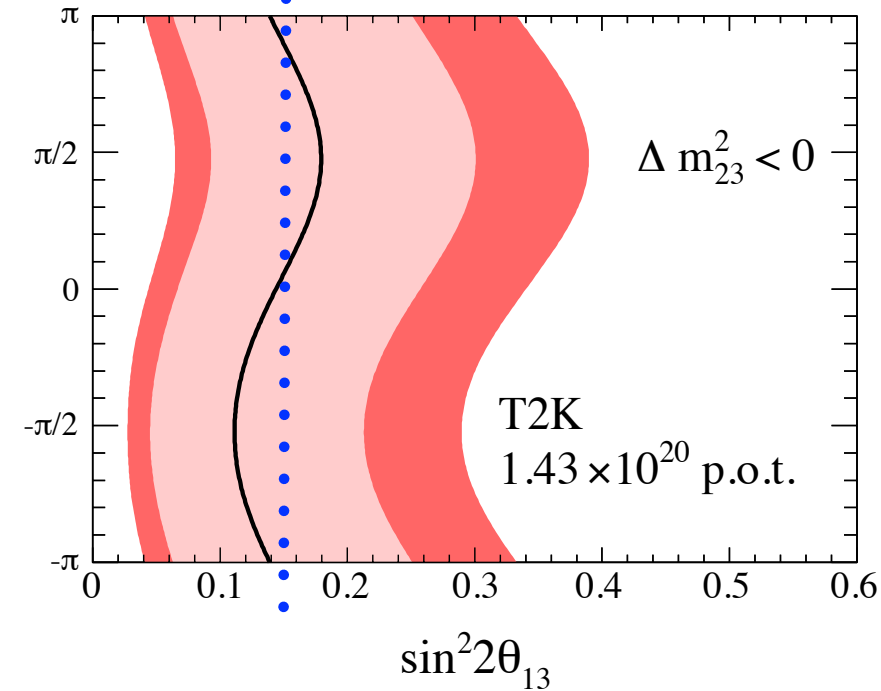
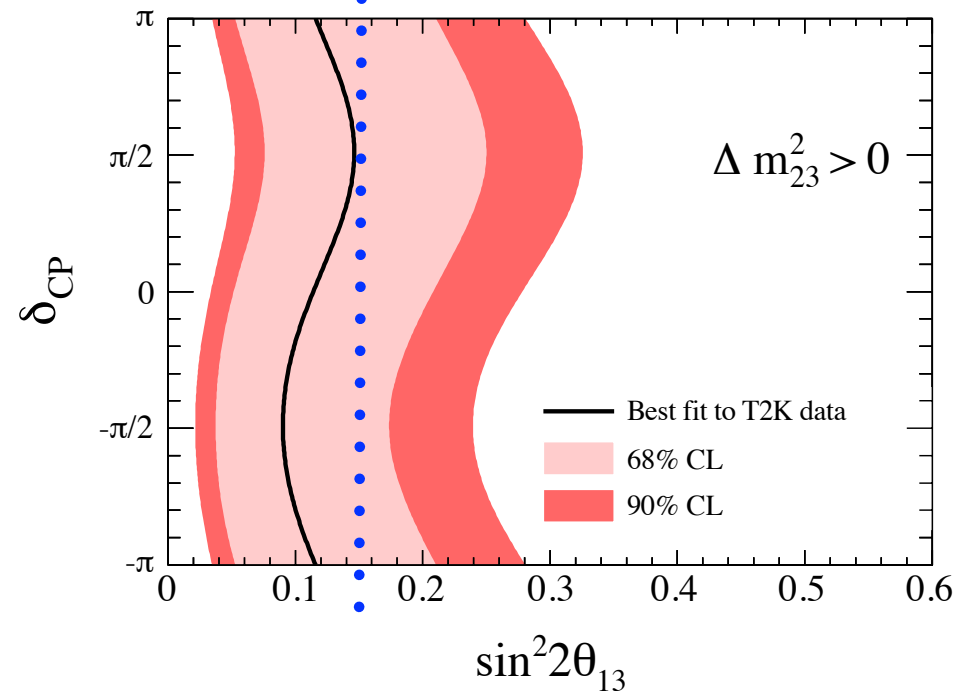


These events are clustered at large R
→ Perform several checks. for example

- * Check distribution of events outside FV → no indication of BG contamination
- * Check distribution of OD events → no indication of BG contamination
- * K.S. test on the R^2 distribution yields a p-value of 0.03

Allowed region of $\sin^2 2\theta_{13}$ as a function of δ_{CP}

(assuming $\Delta m_{23}^2 = 2.4 \times 10^{-3} \text{ eV}^2$, $\sin^2 2\theta_{23} = 1$)



90% C.L. interval & Best fit point (assuming $\Delta m_{23}^2 = 2.4 \times 10^{-3} \text{ eV}^2$, $\sin^2 2\theta_{23} = 1$, $\delta_{CP} = 0$)

$$0.03 < \sin^2 2\theta_{13} < 0.28$$

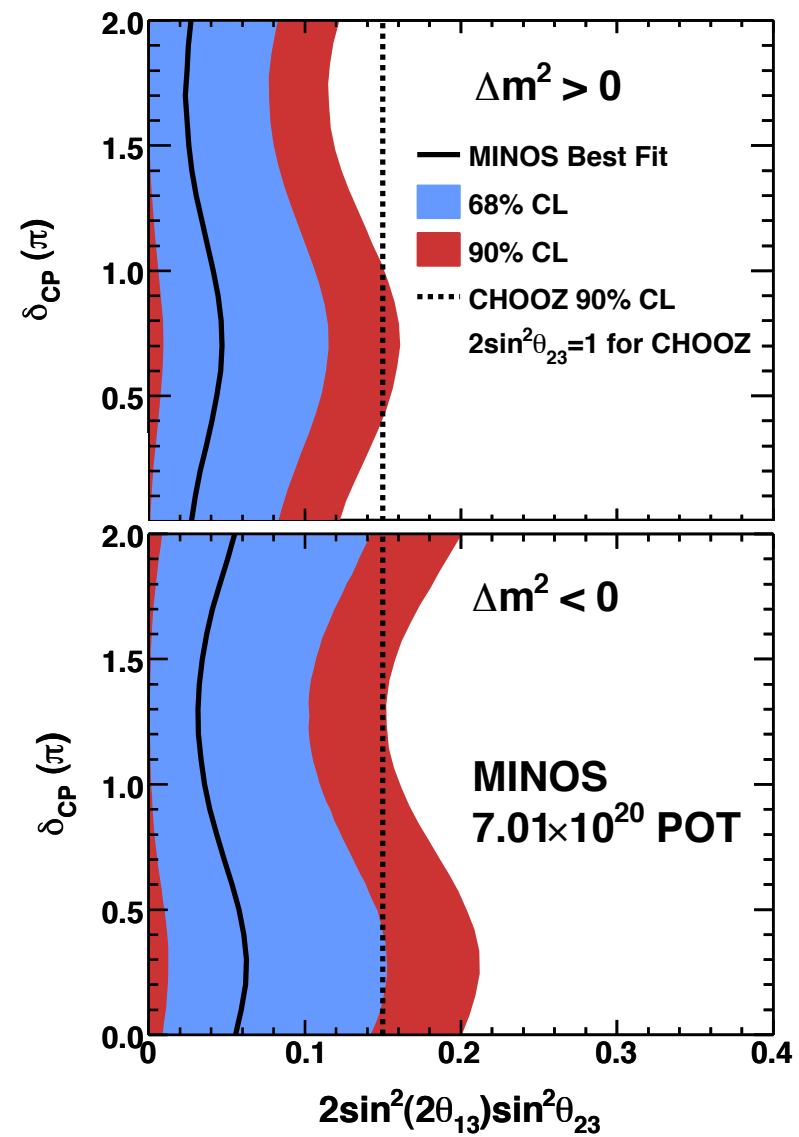
$$\sin^2 2\theta_{13} = 0.11$$

$$0.04 < \sin^2 2\theta_{13} < 0.34$$

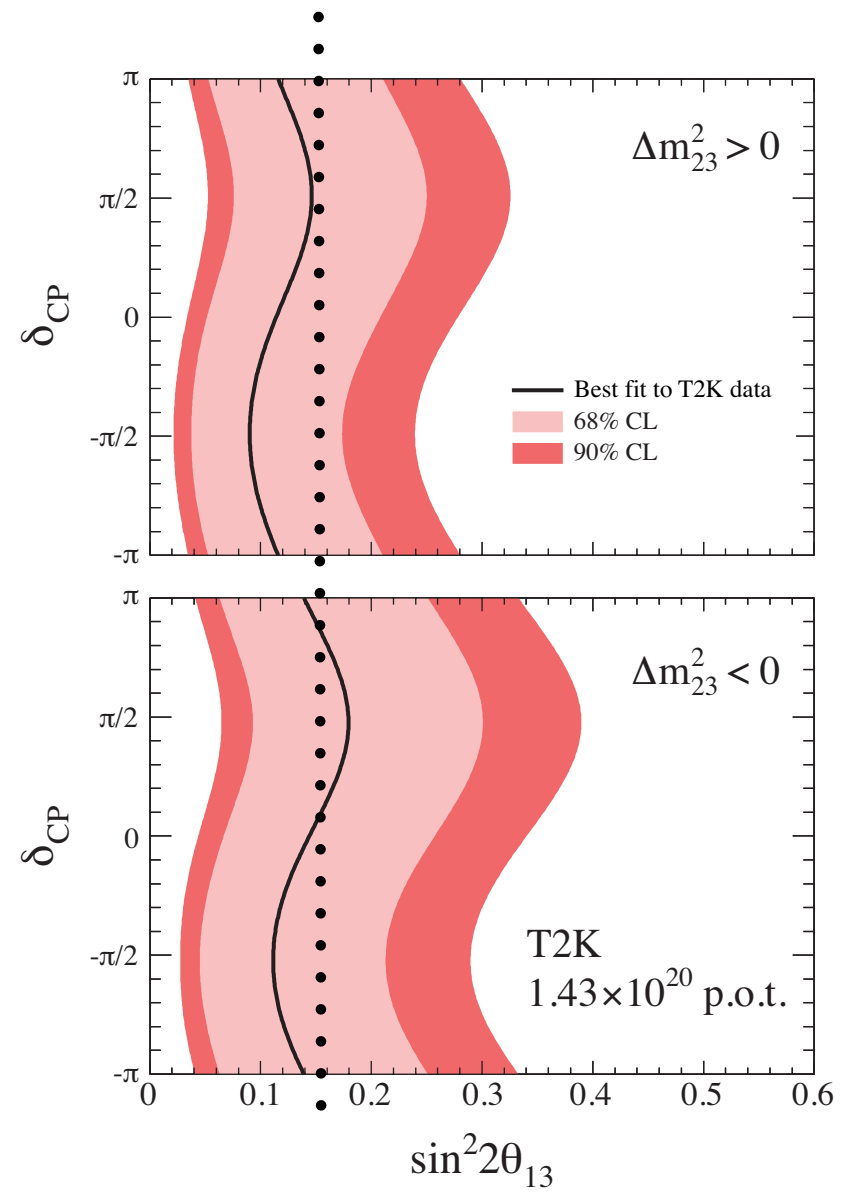
$$\sin^2 2\theta_{13} = 0.14$$

Chooz bound assuming $\sin^2 \theta_{23} = \frac{1}{2}$

MINOS:



T2K:



Chooz bound assuming $\sin^2 \theta_{23} = \frac{1}{2}$

Combining T2K and MINOS results

Joachim Kopp

June 17, 2011

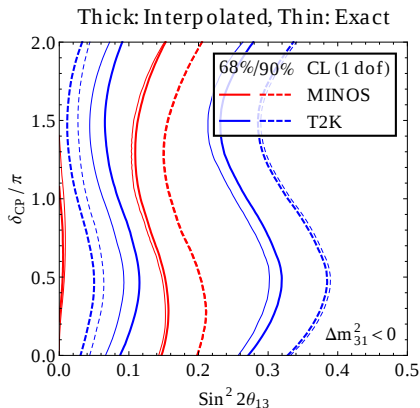
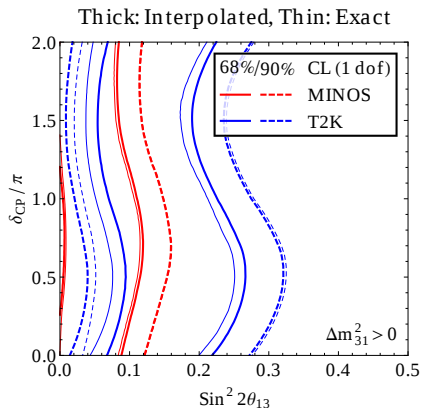


Method

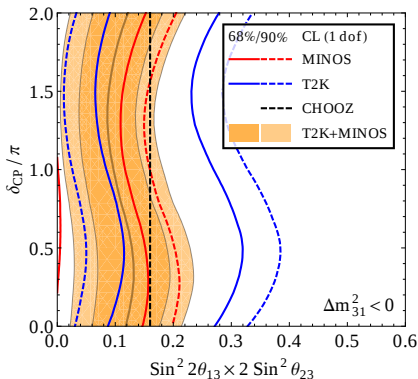
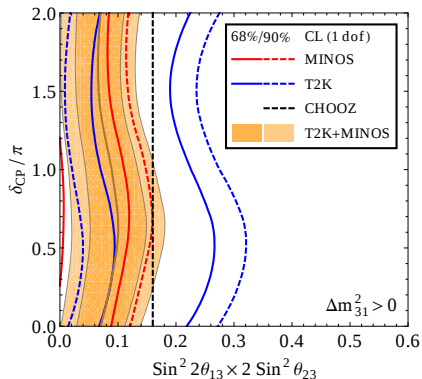
A **very rudimentary** approach:

- Digitize **T2K** and **MINOS** plots.
- At each δ , fit a parabola between the contours to obtain **crude approximations** to the **likelihood manifolds**
- **Add** the two log-likelihoods

Comparison of exact contours vs. our approximation

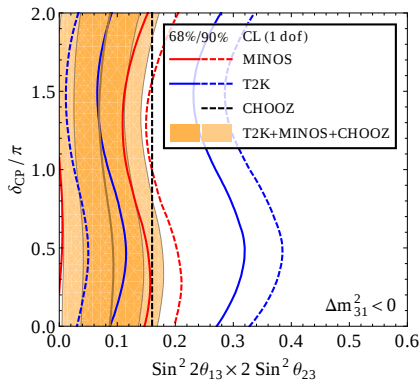
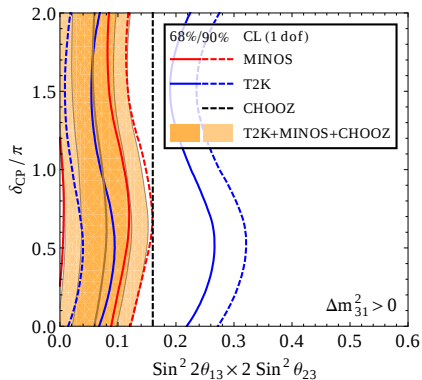


Combining MINOS and T2K results



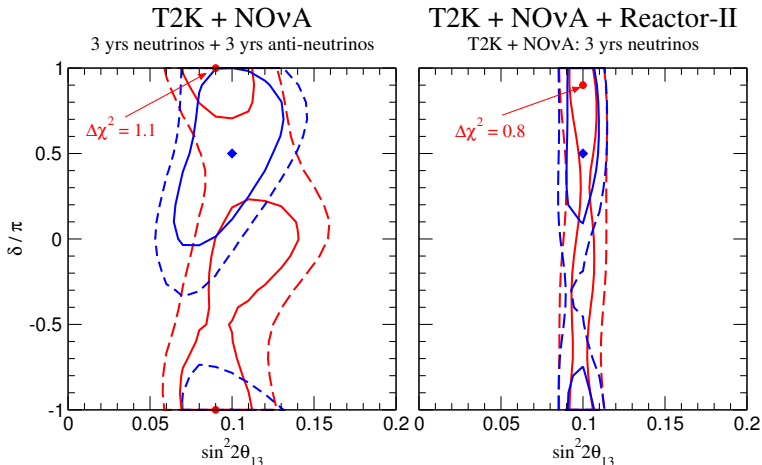
- Upper limit on θ_{13} dominated by MINOS
- Lower limit dominated by T2K
- Significance of $\theta_{13} \neq 0$ reduced in combination
- *Method not accurate enough for quantitative statements!*

Including CHOOZ



Implications of $\theta_{13} \neq 0$ for future experiments

- Can expect constraints on δ_{CP} from T2K, NO ν A, reactors
- Need anti-neutrino runs

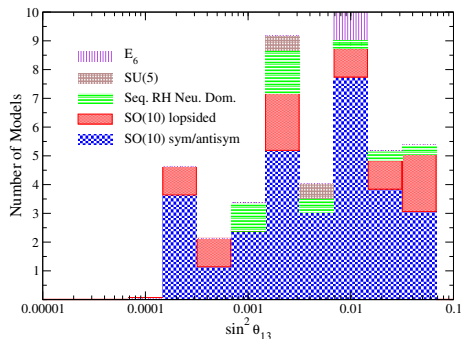
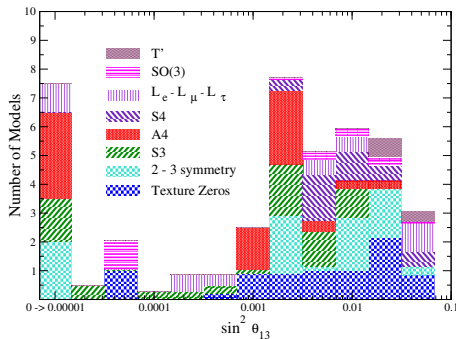


Contours: 90%, 3 σ ; blue: NH, red: IH

Huber Lindner Rolinec Schwetz Winter, hep-ph/0412133

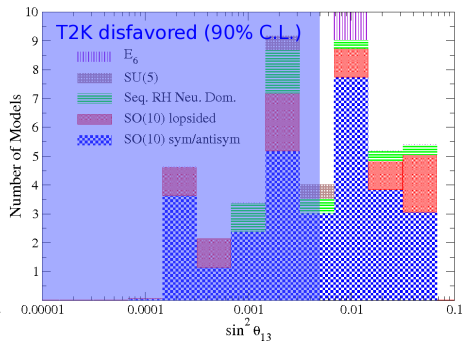
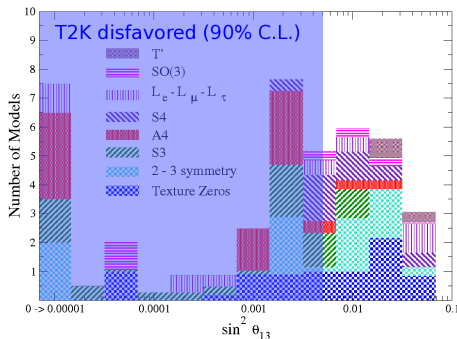
Implications of T2K for models

Albright arXiv:0911.2437



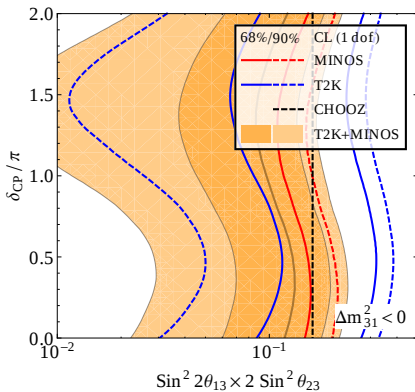
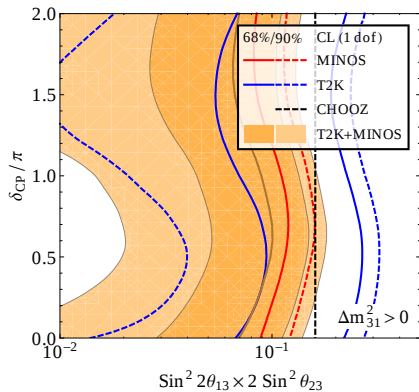
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Backup slides

Combining MINOS and T2K results (log scale)



Combining MINOS, T2K and CHOOZ (log scale)

