Latest 3+1 and 3+2 fits

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Included data sets (red=new!)

Neutrinos:

- Miniboone ν_e
- NOMAD
- NuMI
- CCFR84
- CDHS
- **Gallex** (coming soon)

Antineutrinos:

- LSND
- Miniboone $\bar{\nu}_e$ **(updated)**
- KARMEN
- Bugey **(including reactor anomaly)**
- Chooz **(including reactor anomaly)**
- **MINOS NC**
- **MINOS CC**

Reference for 2009 fits by Georgia: arXiv:0906.1997v2

Fit parameters:

Oscillation Probabilities:

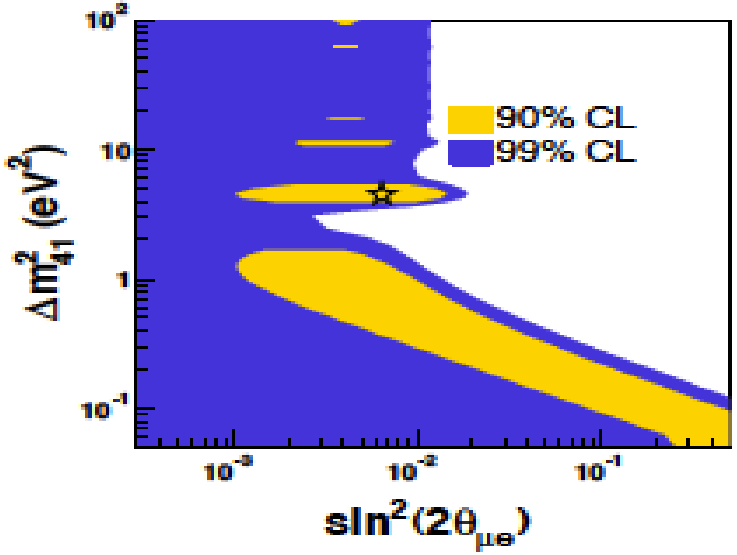
- Appearance: $P(\nu_\alpha \rightarrow \nu_{\beta \neq \alpha}) = \sin^2 2\theta_{\alpha\beta} \sin^2[1.27\ \Delta m^2\ (L/E)]$
- Disappearance: $P(\nu_\alpha \rightarrow \nu_\alpha) = \sin^2 2\theta_{\alpha\alpha} \sin^2[1.27\ \Delta m^2\ (L/E)]$

3+1 Fit parameters: Δm^2_{41}, $U_{\mu 4}$, and U_{e4}

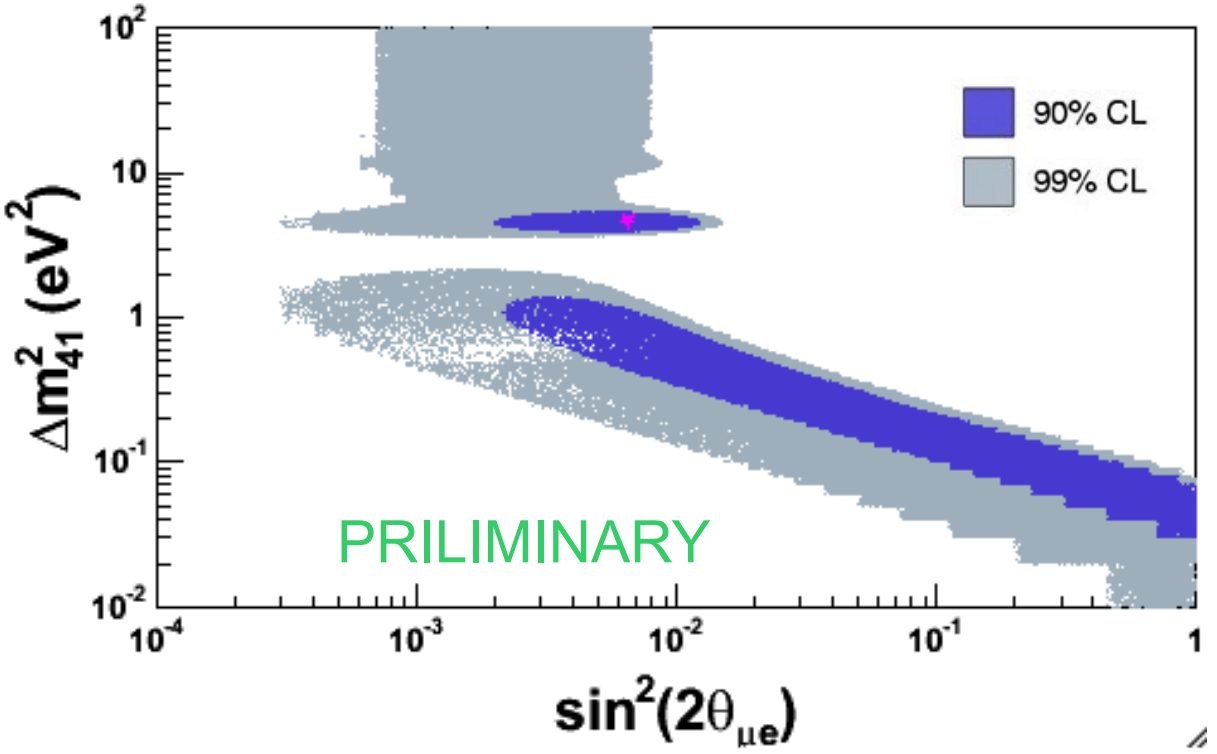
- $\sin^2 2\theta_{\mu e} = 4\ U_{e4}^2\ U_{\mu 4}^2$
- $\sin^2 2\theta_{\mu\mu} = 4\ U_{\mu 4}^2\ (1 - U_{\mu 4}^2)$
- $\sin^2 2\theta_{ee} = 4\ U_{e4}^2\ (1 - U_{e4}^2)$

Miniboone nubar update

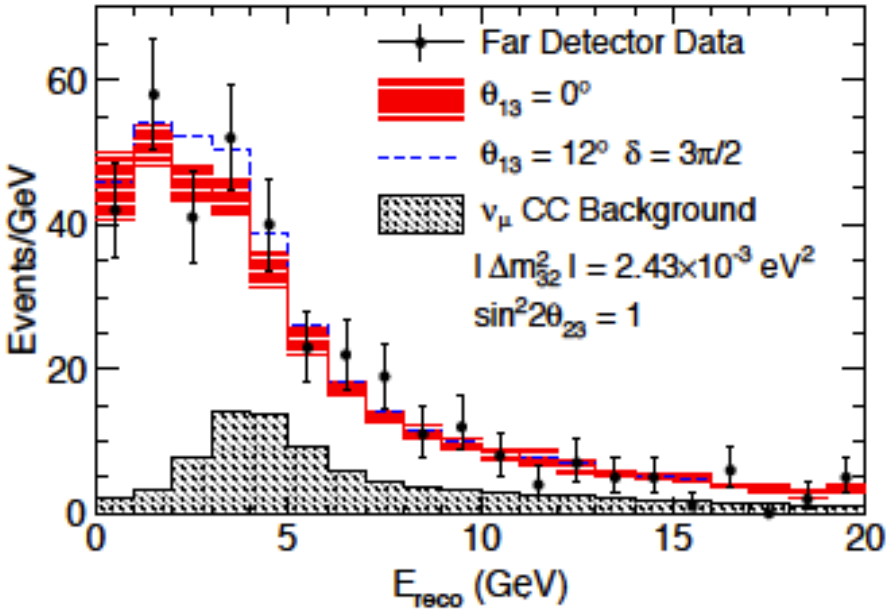
arXiv:0906.1997v2



2010 data release update



Minos NC: arXiv:1001.0336v3



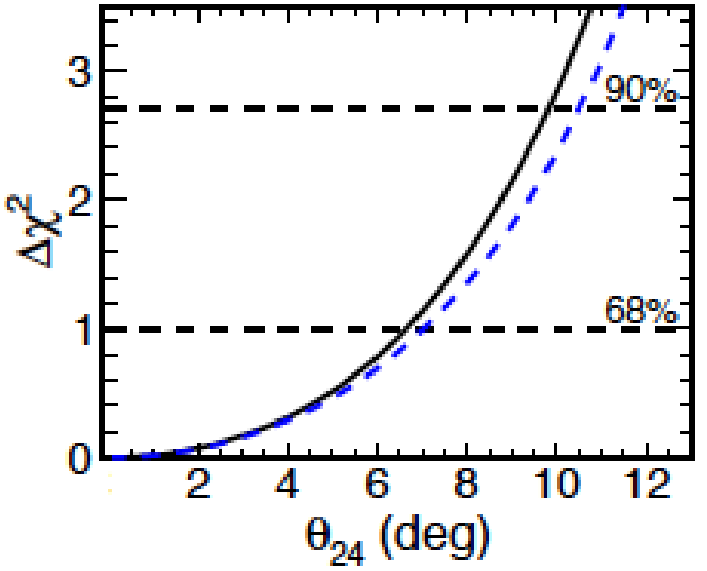
$$f_s \equiv \frac{P_{\nu_\mu \to \nu_s}}{1 - P_{\nu_\mu \to \nu_\mu}}.$$

Assumptions:
$\theta_{14}=0$, $\delta_2=0$

$$P_{\nu_\mu \to \nu_\mu} = 1 - 4\Big\{|U_{\mu 3}|^2\left(1 - |U_{\mu 3}|^2 - |U_{\mu 4}|^2\right)\sin^2\Delta_{31} + \frac{|U_{\mu 4}|^2}{2}(1 - |U_{\mu 4}|^2)\Big\},$$

$$P_{\nu_\mu \to \nu_\alpha} = 4\mathcal{R}\Big\{\left(|U_{\mu 3}|^2|U_{\alpha 3}|^2 + U^*_{\mu 4}U_{\alpha 4}U_{\mu 3}U^*_{\alpha 3}\right)\sin^2\Delta_{31} + \frac{|U_{\mu 4}|^2|U_{\alpha 4}|^2}{2}\Big\}, \quad (13)$$

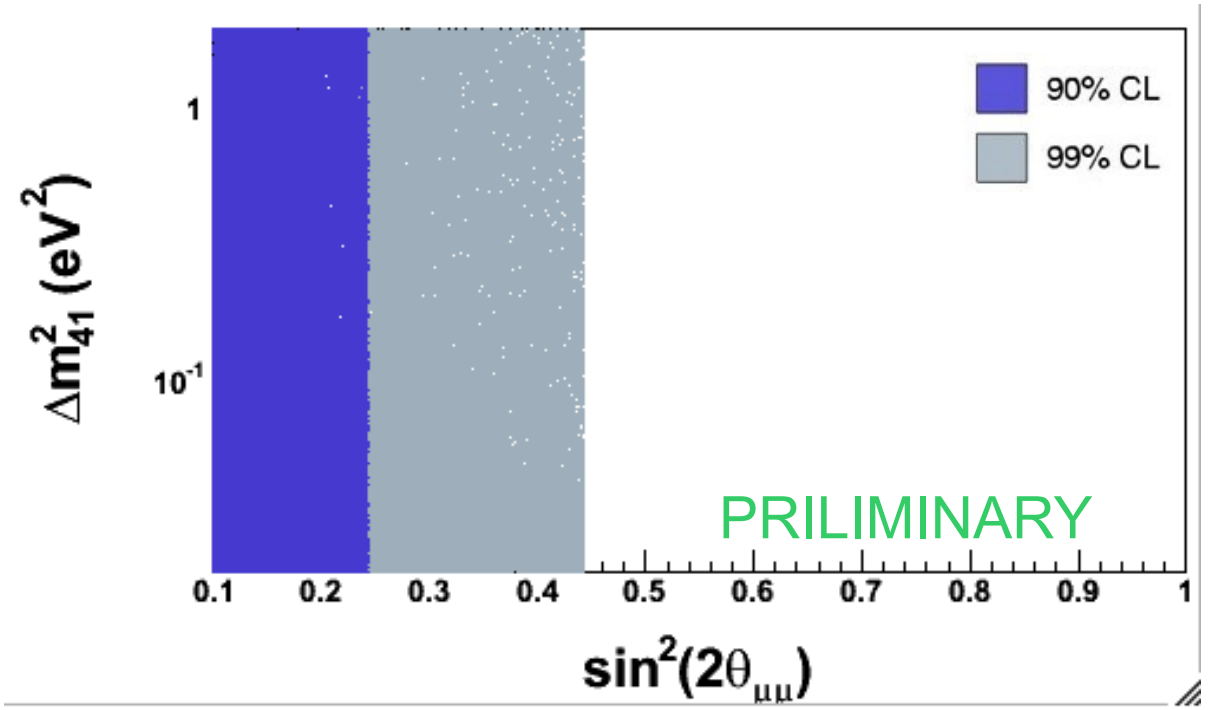
Model	θ_{13}	χ^2/D.O.F.	θ_{23}	θ_{24}	θ_{34}	f_s
$m_4 = m_1$	0	47.5/39	$45.0^{+9.0}_{-8.9}$		$0.1^{+28.7}_{-0.1}$	0.51
	12	46.2/39	$47.1^{+8.8}_{-11.0}$		$23.0^{+22.6}_{-24.1}$	0.55
$m_4 \gg m_3$	0	47.5/38	$45.0^{+9.0}_{-8.9}$	$0.0^{+7.2}_{-0.0}$	$0.1^{+28.7}_{-0.1}$	0.52
	12	46.2/38	$47.1^{+8.8}_{-11.0}$	$0.0^{+7.2}_{-0.0}$	$23.0^{+22.6}_{-24.1}$	0.55



$U_{\mu 4} = \cos\theta_{14}\sin\theta_{24}\exp(-i\delta_2) = \sin\theta_{24}$

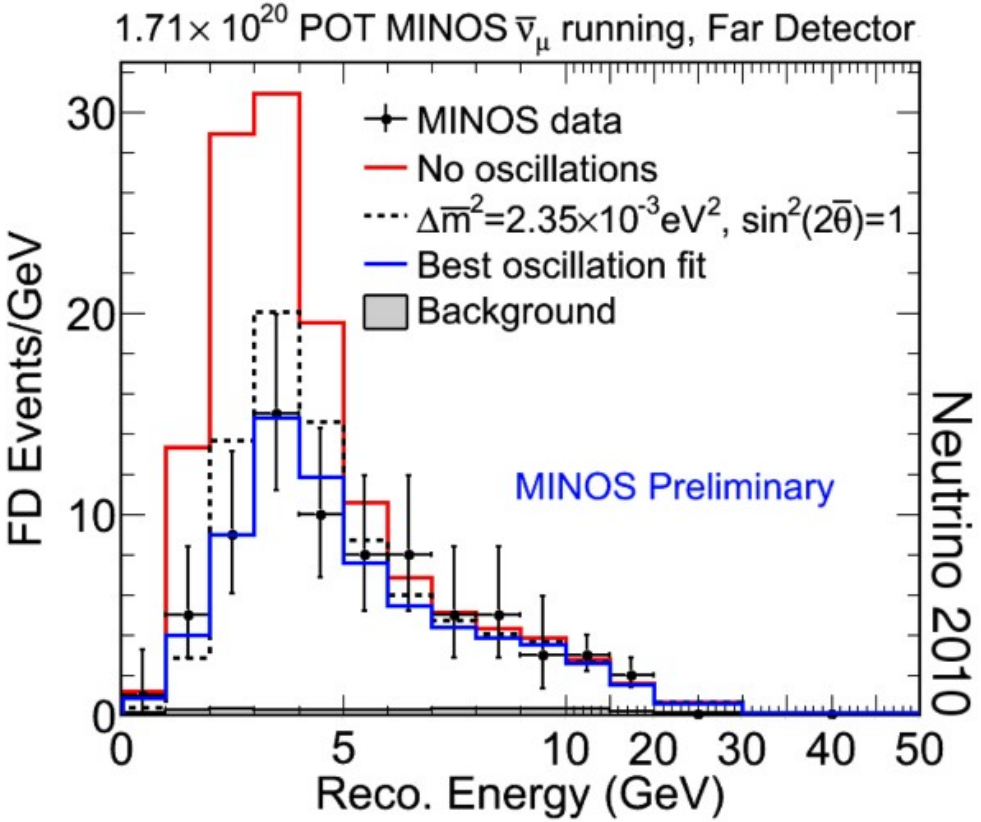
$U_{\mu 4}$ is what we fit for, so we use their fit for θ_{24} to constrain $U_{\mu 4}$.

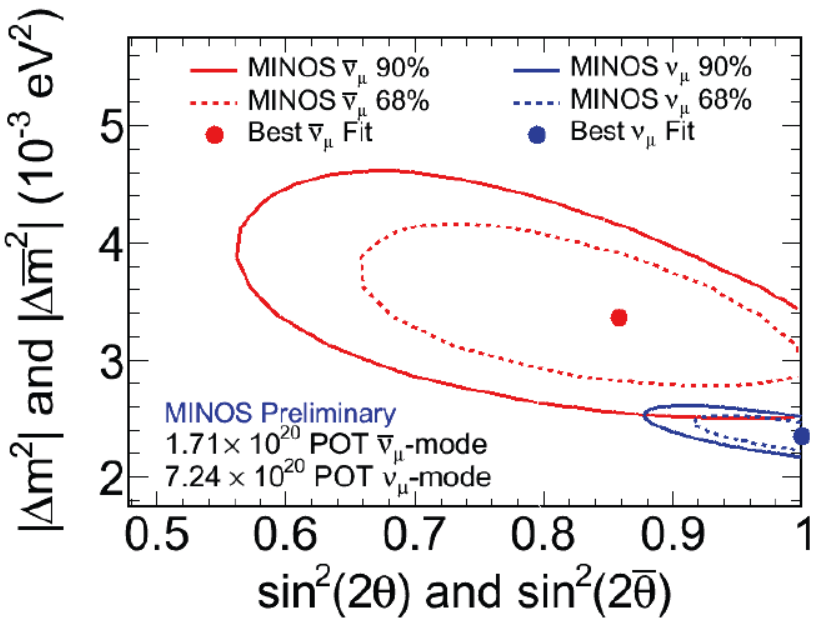
MINOS NC: 3+1 fit



- $\sin^2 2\theta_{\mu\mu} = 4\, U_{\mu 4}^{\,2}\,(1 - U_{\mu 4}^{\,2})$
- $U_{\mu 4} = \sin\theta_{24}$

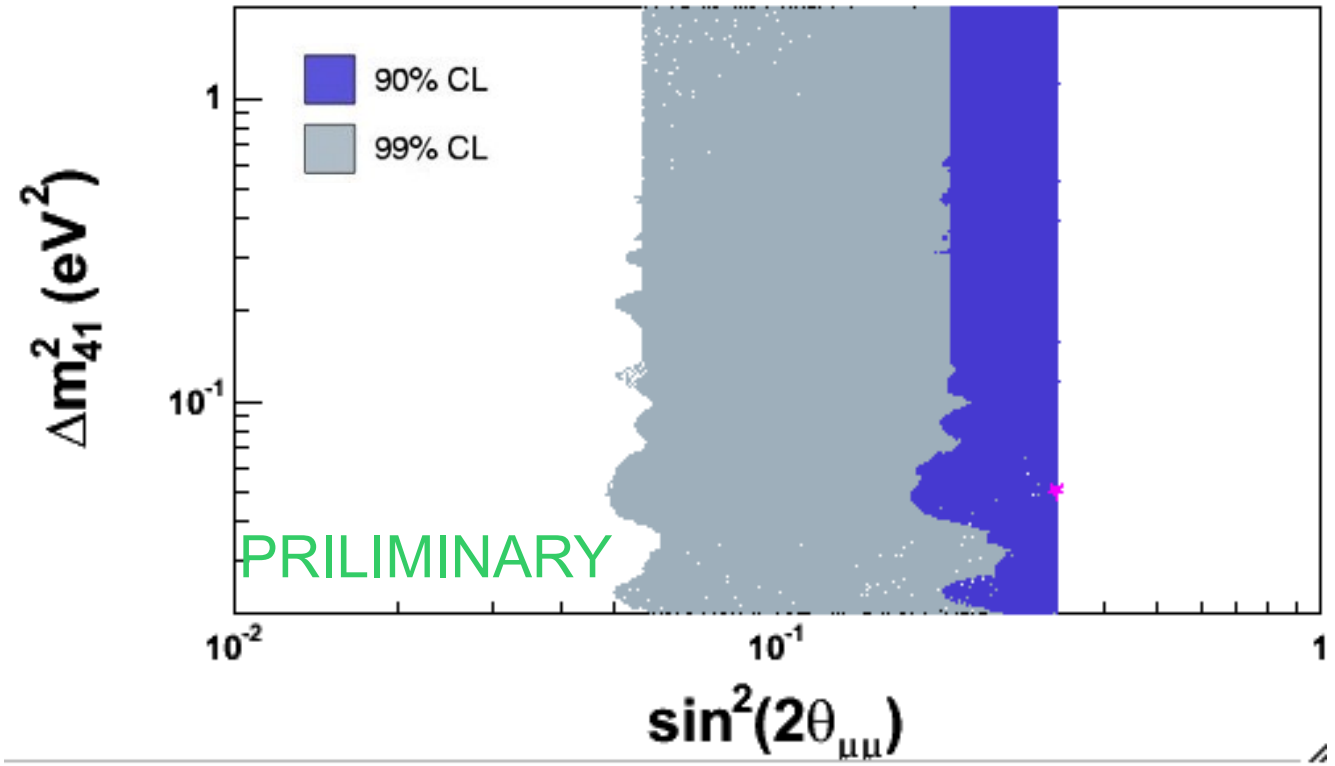
MINOS CC: arXiv:1104.0344v1





- We use the binned data from the histogram for our fits

MINOS CC 3+1 Fit

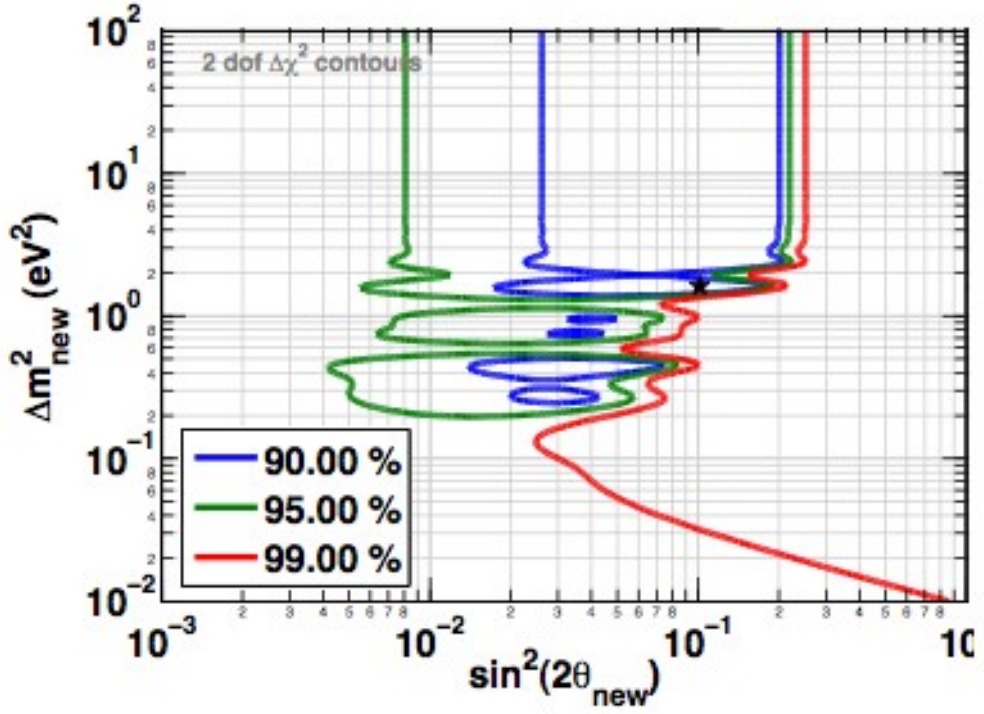


χ^2	dof	Probability	Δm^2_{41}	$\sin^2 2\theta_{\mu\mu}$
27.1	12	7%	0.50	0.330

Note: Umax explicitly constraint to be <0.3 (unitarity)

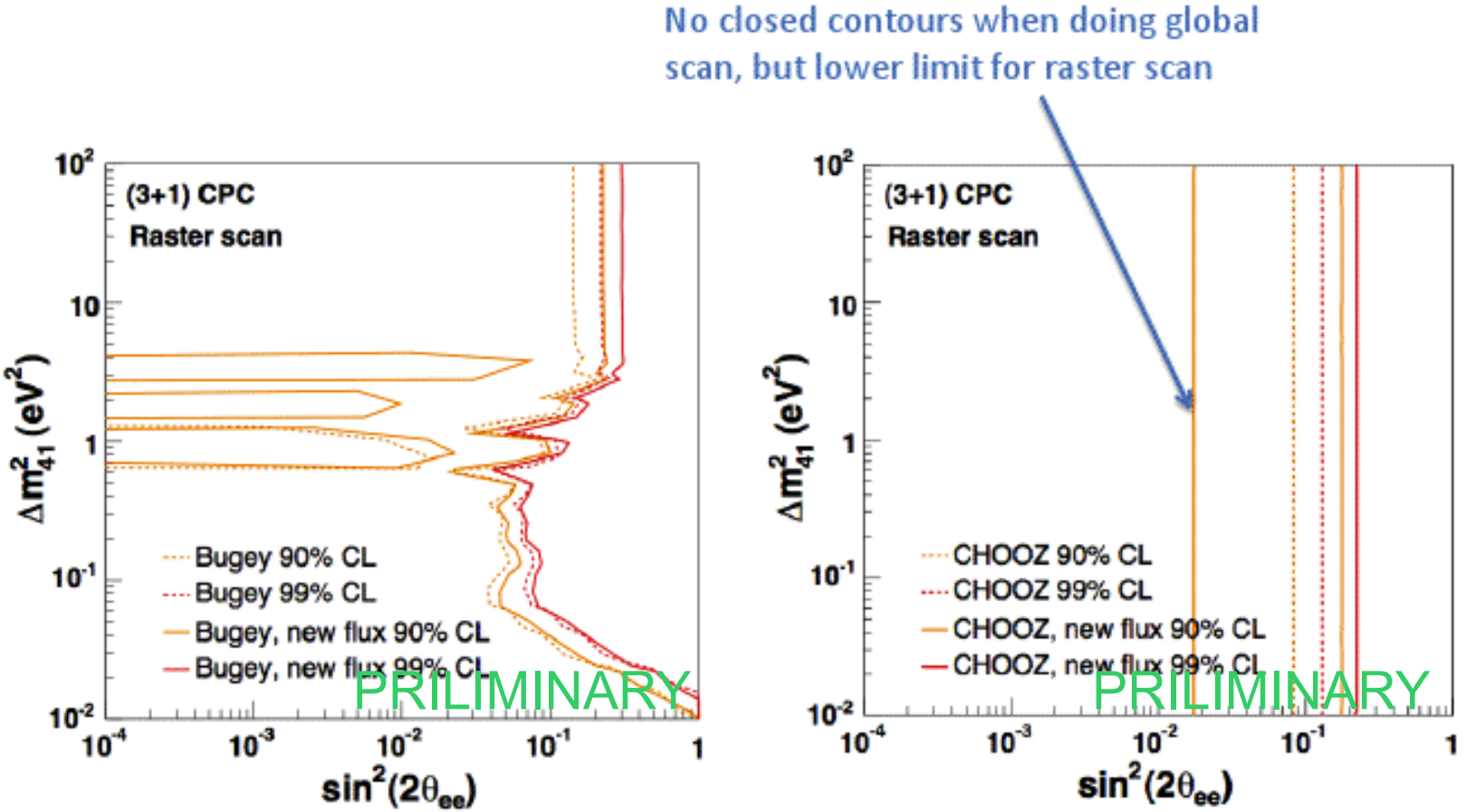
Reactor Anomaly: arXiv:1101.2755

- New reactor flux predictions correspond to a deficit of ~3%



- Fit from paper to reactor experiments: Bugey, Krasnoyarsk, Rovno, SRP
- Bestfit Δm^2 around 2 eV^2,

Bugey and Chooz 3+1 fits



- Fits by Georgia

3+2 fits

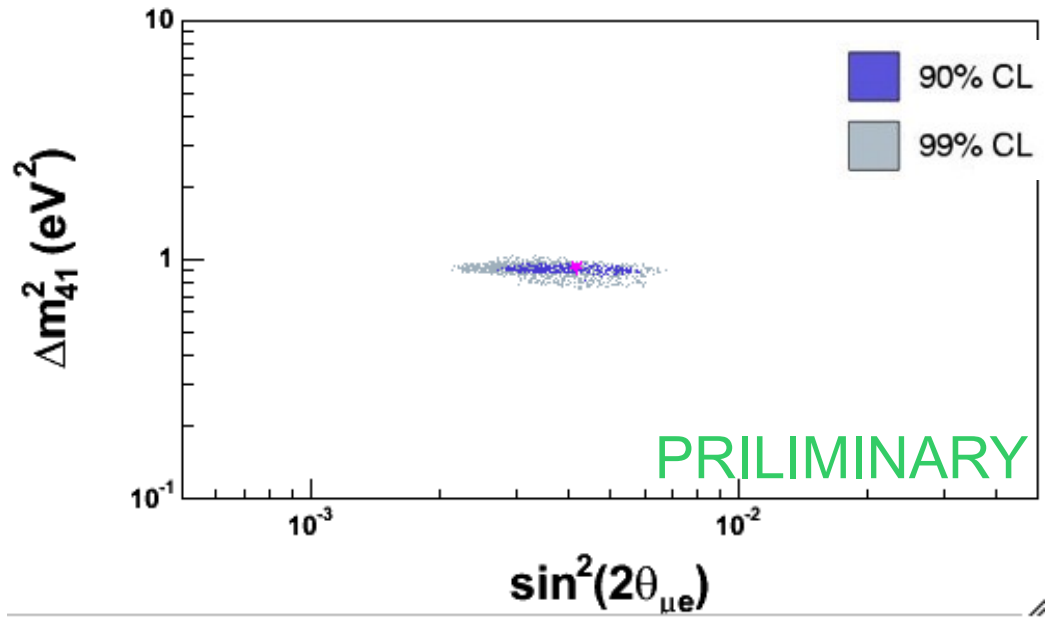
	Dataset	CP	X^2 (ndf)	gof	$\Delta m^2 41$	$\Delta m^2 51$	Ue4	Uμ4	Ue5	Uμ5	φ45
Old	**all SBL+ atm**	**CPC**	186.1 (193)	62%	0.92	23.8	0.13	0.13	0.083	0.14	0
		CPV	182.6 (192)	67%	0.92	26.6	0.14	0.14	0.077	0.15	1.7
New	**all SBL+ atm**	**CPC**	191.5 (193)	52%	0.92	24.0	0.12	0.14	0.070	0.14	0
		CPV	189.3 (192)	54%	0.92	26.5	0.13	0.13	0.078	0.15	1.7

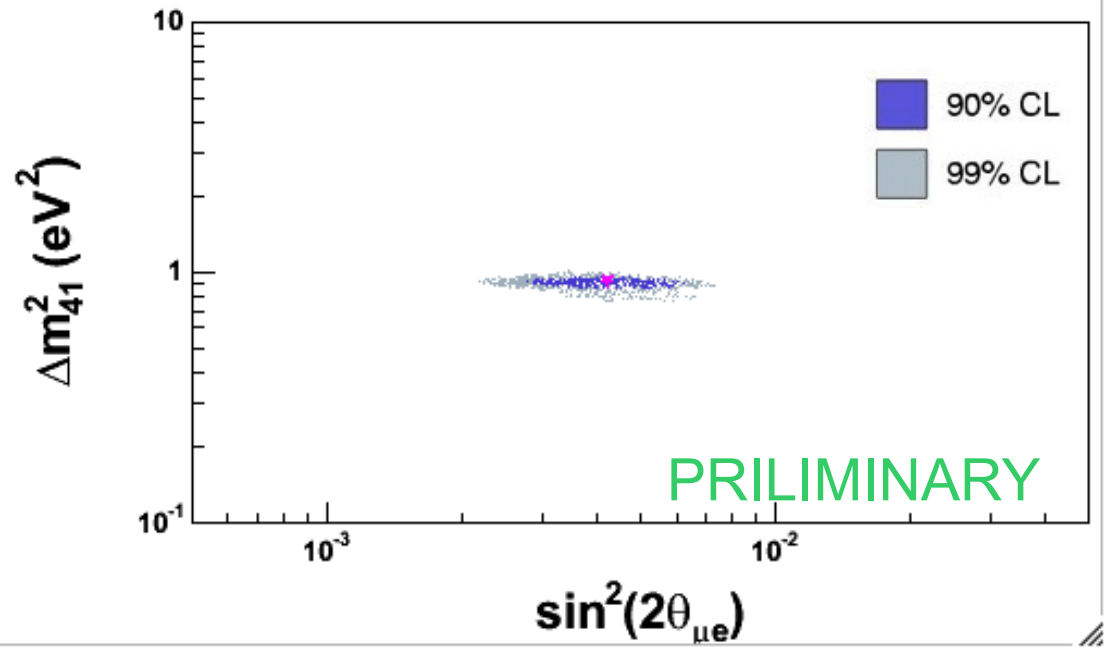
PRILIMINARY

OLD: PRD 80 073001 (2009)
NEW: includes updated MiniBooNE antineutrino appearance dataset, and new reactor flux predictions

- Fits by Georgia

Global nubar fits: before and after reactor anomaly





Umax explicitly constraint to be <0.3 (unitarity)

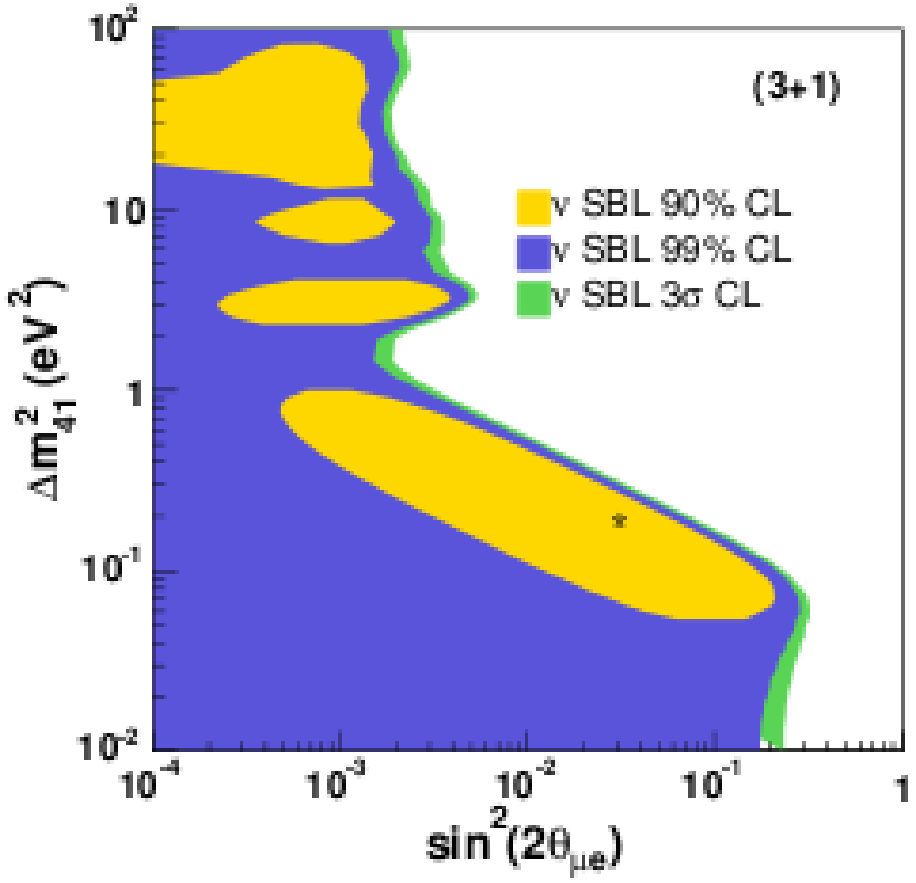
Previous fit:

X^2:	91.9
Dof:	103
Probability:	77.5%
Δm_{41}^2:	0.91
$\sin^2 2\theta_{\mu e}$:	0.0043
$\sin^2 2\theta_{\mu\mu}$:	0.30

Including Reactor Anomaly:

X^2:	90.4
Dof:	103
Probability:	77.5%
Δm_{41}^2:	0.92
$\sin^2 2\theta_{\mu e}$:	0.0042
$\sin^2 2\theta_{\mu\mu}$:	0.22

Global nu fits: from Georgia's paper

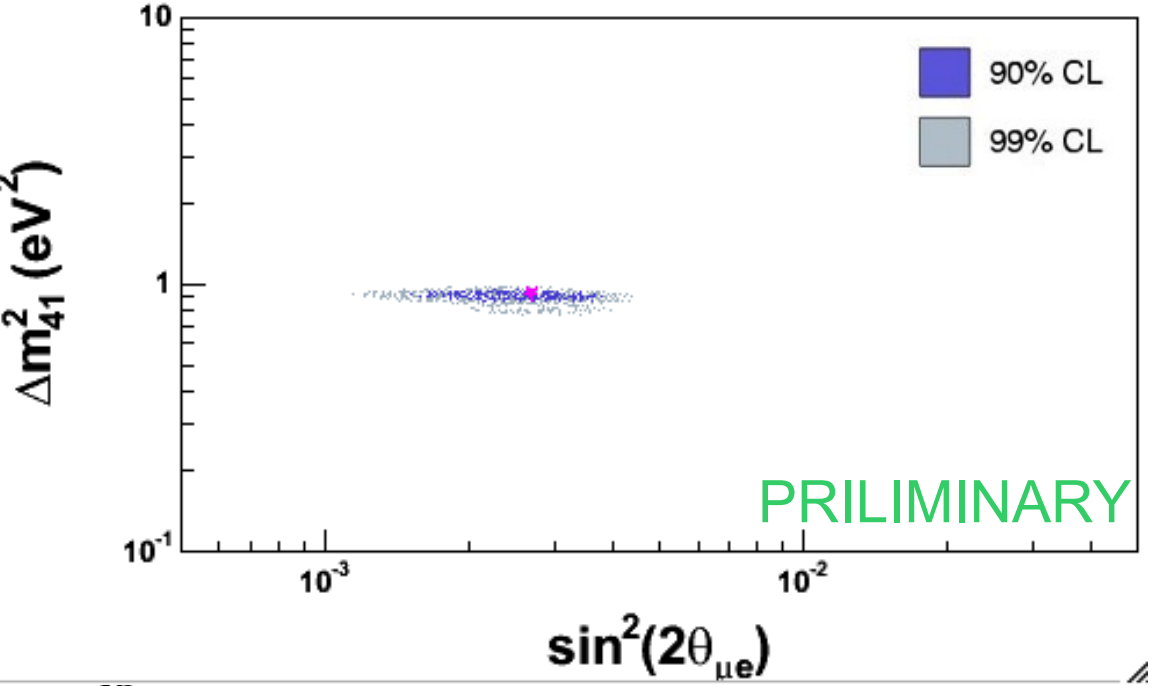


χ^2	dof	Probability	Δm^2_{41}	$\sin^2 2\theta_{\mu e}$	$\sin^2 2\theta_{\mu\mu}$
91	90	47%	0.19	0.031	0.031

Note: Umax was not constrained to be <0.3 for this fit so the χ^2 would actually be worse than this for comparing to the fits in the rest of this talk (where Umax is constrained)

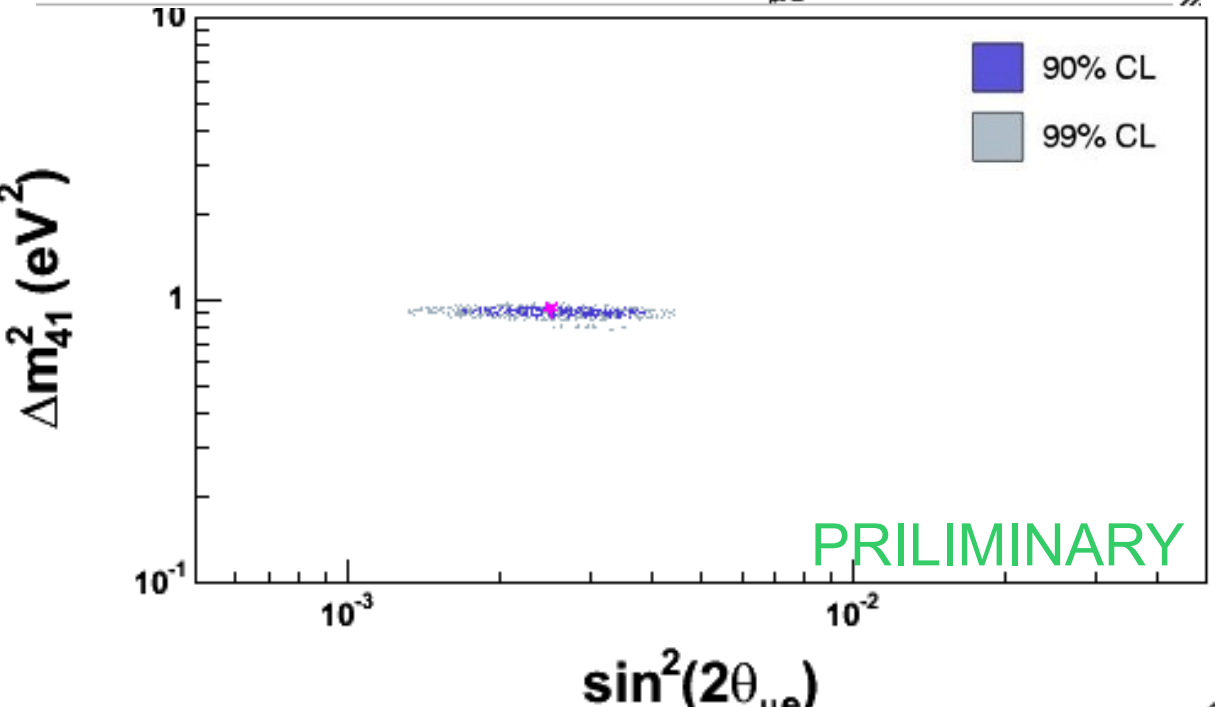
nu+nubar

Umax explicitly constraint to be <0.3 (unitarity)



Previous fit:

X^2:	203
Dof:	196
Probability:	35%
Δm_{41}^2:	0.92
$\sin^2 2\theta_{\mu e}$:	0.0027
$\sin^2 2\theta_{\mu\mu}$:	0.14

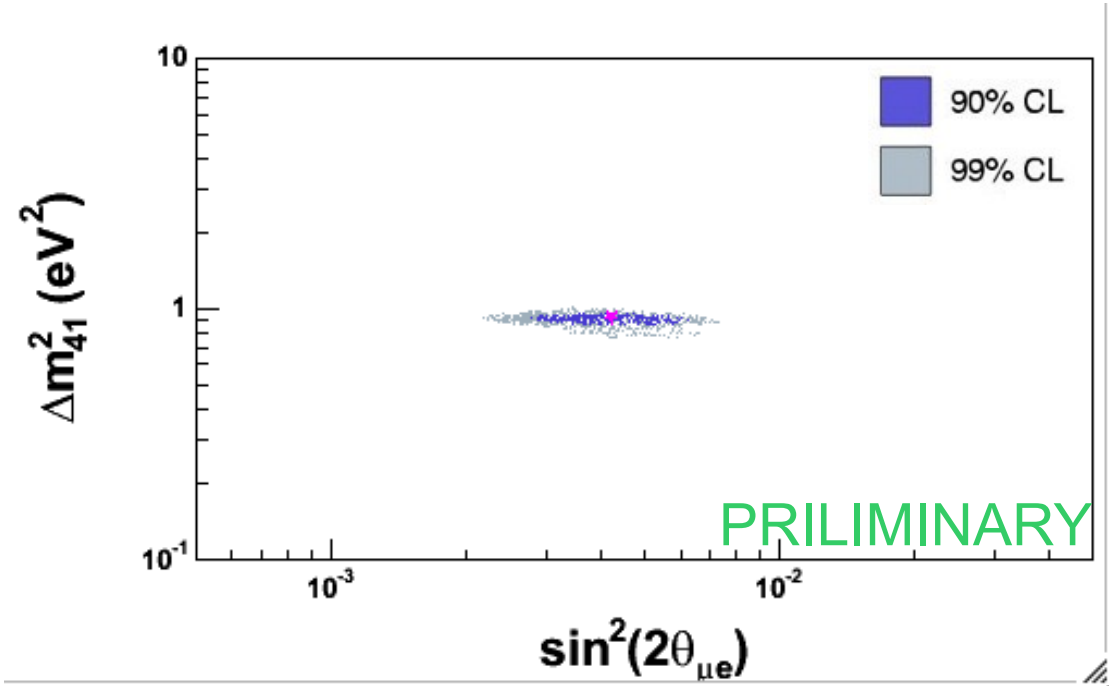


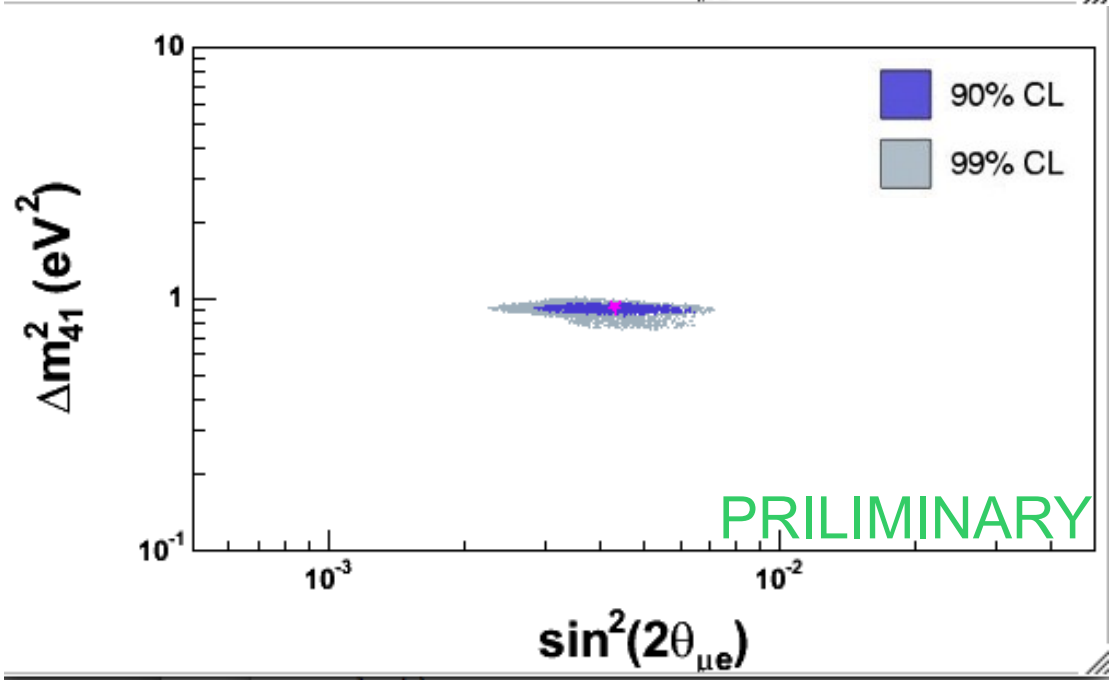
Including reactor anomaly:

X^2:	199
Dof:	196
Probability:	43%
Δm_{41}^2:	0.92
$\sin^2 2\theta_{\mu e}$:	0.0025
$\sin^2 2\theta_{\mu\mu}$:	0.11

Global nubar fits: including MINOS

Umax explicitly constrained to be <0.3





Previous (with Reactor Anomaly):

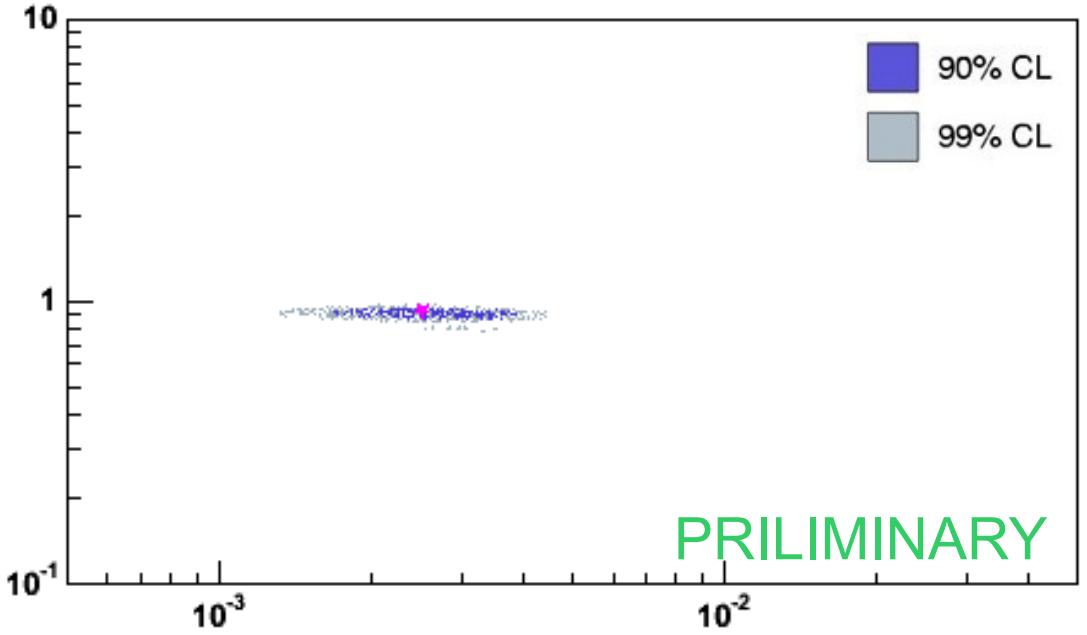
X^2:	90.4
Dof:	103
Probability:	77.5%
$\Delta m_{41}{}^2$:	0.92
$\sin^2 2\theta_{\mu e}$:	0.0042
$\sin^2 2\theta_{\mu\mu}$:	0.22

Including MINOS

X^2:	125.8
Dof:	117
Probability:	27%
$\Delta m_{41}{}^2$:	0.92
$\sin^2 2\theta_{\mu e}$:	0.0043
$\sin^2 2\theta_{\mu\mu}$:	0.24

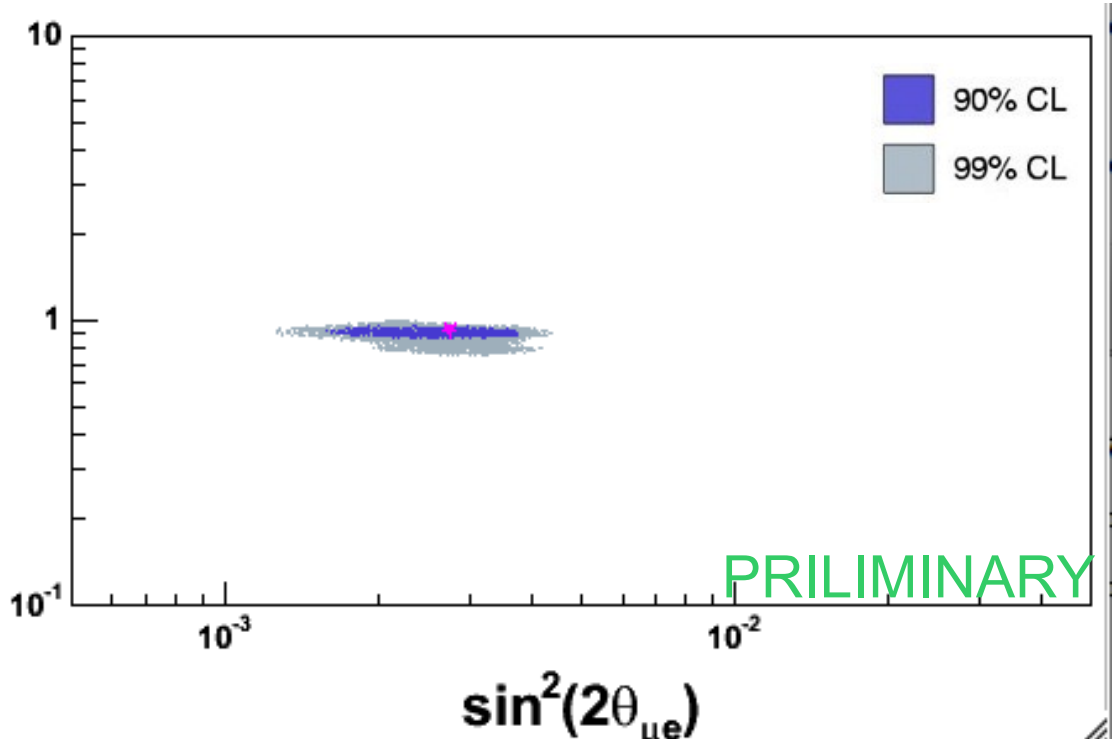
Global nu + nubar fit with MINOS

Umax explicitly constrained to be <0.3



Previous (inc reactor anomaly)

X^2:	199
Dof:	196
Probability:	43%
Δm_{41}^2:	0.92
$\sin^2 2\theta_{\mu e}$:	0.0025
$\sin^2 2\theta_{\mu\mu}$:	0.11



Including MINOS::

X^2:	239
Dof:	210
Probability:	8.3%
Δm_{41}^2:	0.92
$\sin^2 2\theta_{\mu e}$:	0.0028
$\sin^2 2\theta_{\mu\mu}$:	0.14

Summary

- Reactor Anomaly seems to slightly decrease tension, especially in 3+2 CPV fits
- MINOS is not very compatible with global fits
- We are in the middle of this but will have a paper soon
- Still need to:
  - Include Gallex
  - Calculate Compatibilities
  - 3+2 plots
  - Do more fits

Backup

Parameter Goodness of Fit

- Tests how well different data sets agree

$$\chi^2_{PG} = \chi^2_{min,all} - \sum_i \chi^2_{min,i}$$

i runs over individual experiments

- Compatibility is then calculated from χ^2_{PG} and the common underlying fit parameters (i.e. mixing parameters and mass splittings) as the degrees of freedom

Reference: M. Maltoni and T. Schwetz 2003
arXiv:hep-ph/0304176

$$U = \begin{bmatrix} U_{e1} & U_{e2} & c_{14}s_{13}e^{-i\delta_1} & s_{14} \\ U_{\mu 1} & U_{\mu 2} & -s_{14}s_{13}e^{-i\delta_1}s_{24}e^{-i\delta_2} + c_{13}s_{23}c_{24} & c_{14}s_{24}e^{-i\delta_2} \\ U_{\tau 1} & U_{\tau 2} & -s_{14}c_{24}s_{34}s_{13}e^{-i\delta_1} - c_{13}s_{23}s_{34}s_{24}e^{i\delta_2} + c_{13}c_{23}c_{34} & c_{14}c_{24}s_{34} \\ U_{s1} & U_{s2} & -s_{14}c_{24}c_{34}s_{13}e^{-i\delta_1} - c_{13}s_{23}c_{34}s_{24}e^{i\delta_2} - c_{13}c_{23}s_{34} & c_{14}c_{24}c_{34} \end{bmatrix}.$$