NUFACT 2012— WG1SUMMARY REPORT

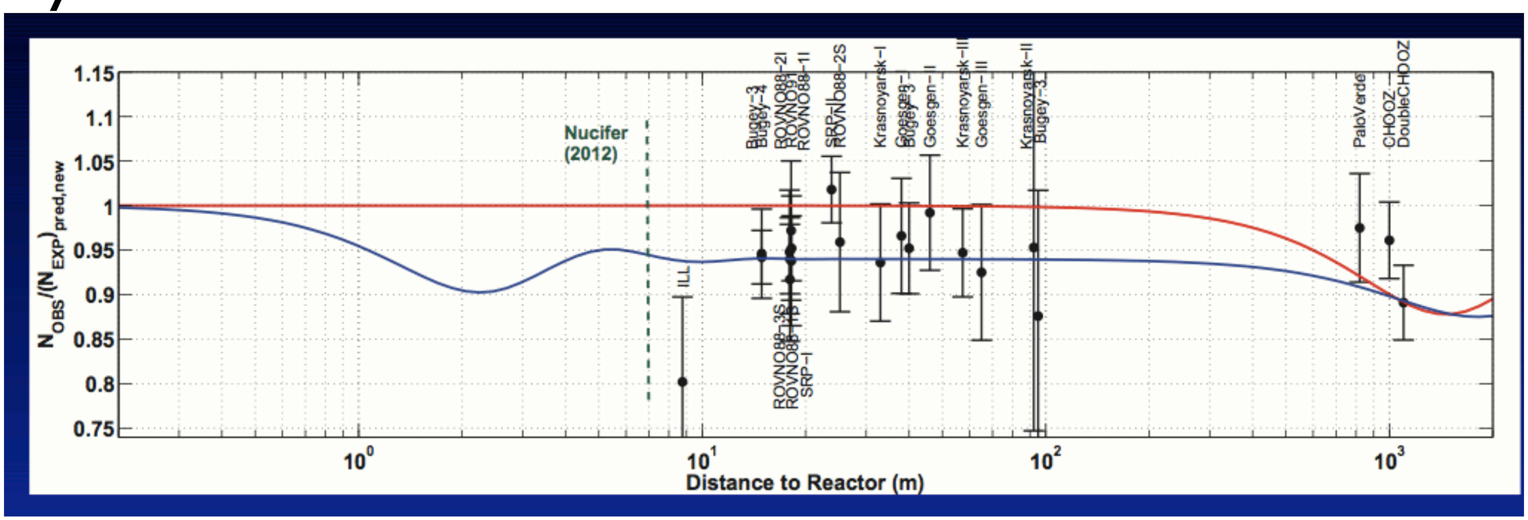
P. Vahle, E. Fernandez Martinez, T. Nakadaira

Questions Addressed

- The issue of the sterile neutrino
  - Can we continue to do precision 3 flavor oscillation physics without solving the mystery of the sterile?
  - How do we go about solving the mystery?
- How can we over-constrain the three flavor oscillation system?
- What do we do, now we know θ_{13}=0.09
  - What role will systematics play?
  - Are there better ways to optimize existing plans?
  - Are there better plans?

The Sterile Question

- P. Huber—Many 3 sigma-ish hints that there's something unexpected going on
  - Reactor Anomaly—6% deficit of anti-nue at short distances
  - Gallium Anomaly—25% deficit of nue from radioactive sources at short distances
  - Cosmology—relativistic energy density suggests 4 neutrinos
- Caution: A lot of hidden, hard to control systematic and theory errors



Miniboone and LSND

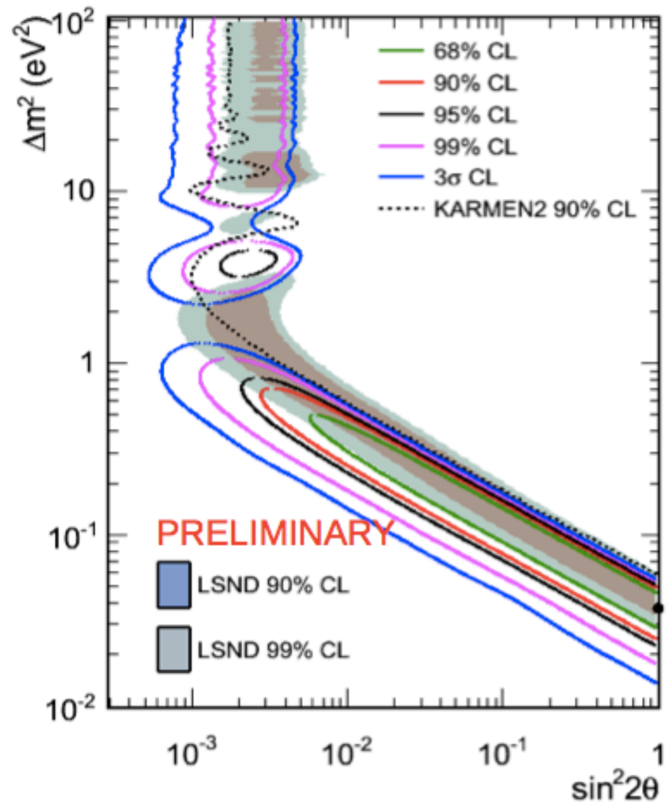
Z. Pavlovic

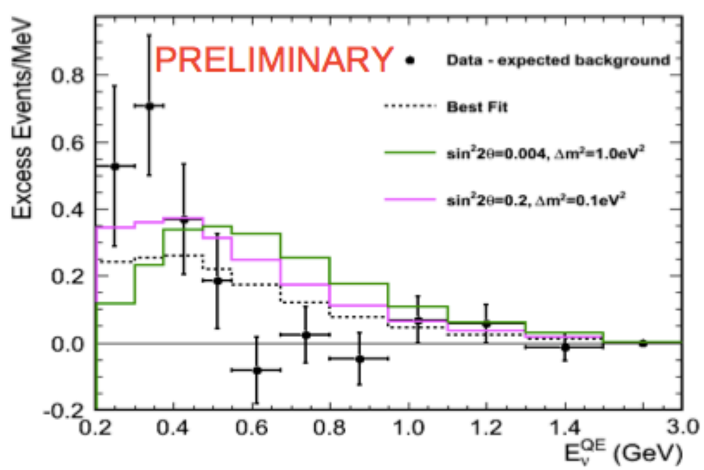
Combined ν and $\bar{\nu}$ analysis

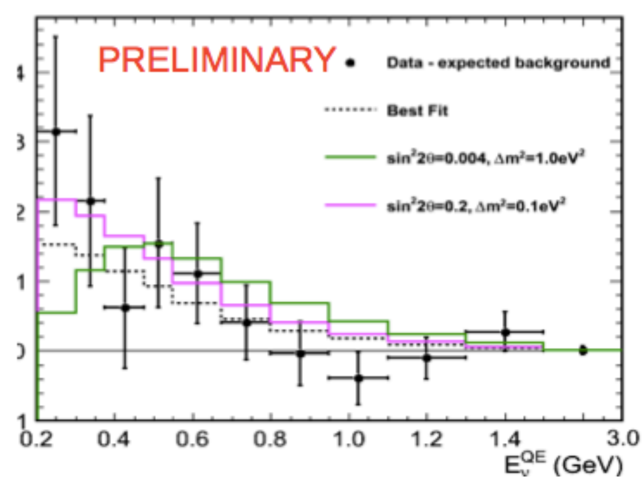
4

- Consistent treatment of WS
- Full correlated systematic error matrix
- Excess (200-1250): 240±34.5±52.6 (3.8σ)
- Best Fit preferred over null at 3.6σ

combined	E > 200 MeV	E > 475 MeV
χ^2(null)	42.53	12.87
Prob(null)	0.1%	35.8%
χ^2(bf)	24.72	10.67
Prob(bf)	6.7%	35.8%







No appearance without Disappearance

In general, in a 3+N sterile neutrino oscillation model one finds that the energy averaged probabilities obey the following inequality

$$P(\nu_\mu \to \nu_e) \leq 4P(\nu_e \to \nu_e)P(\nu_\mu \to \nu_\mu)$$

-- P. Huber

- There is tension between appearance and disappearance observations

G. Karagiorgi

Global Fits

P. Vahle, NuFACT 2012

- $\overset{(-)}{\nu}_e$ appearance
  - **LSND**
    [Phys. Rev. D 64, 112007 (2001)]
  - **MiniBooNE (BNB) $\bar{\nu}$ app**
    [hep-ex/1207.4809]
  - **MiniBooNE (BNB) ν app**
    [hep-ex/1207.4809]
  - **MiniBooNE (NuMI)**
    [Phys. Rev. Lett. 102, 211801 (2009)]
  - **NOMAD**
    [Phys. Lett. B 570, 19 (2003)]
  - **KARMEN**
    [Phys. Rev. D 65, 112001 (2002)]

- $\overset{(-)}{\nu}_e$ disappearance
  - **Bugey**
    [Nucl. Phys. B 434, 503 (1995)]
  - **Gallex/Sage**
    [Phys. Rev. D 78, 073009 (2008)]
  - **KARMEN/LSND xsec**
    [Phys. Rev. D 85, 013017 (2012)]

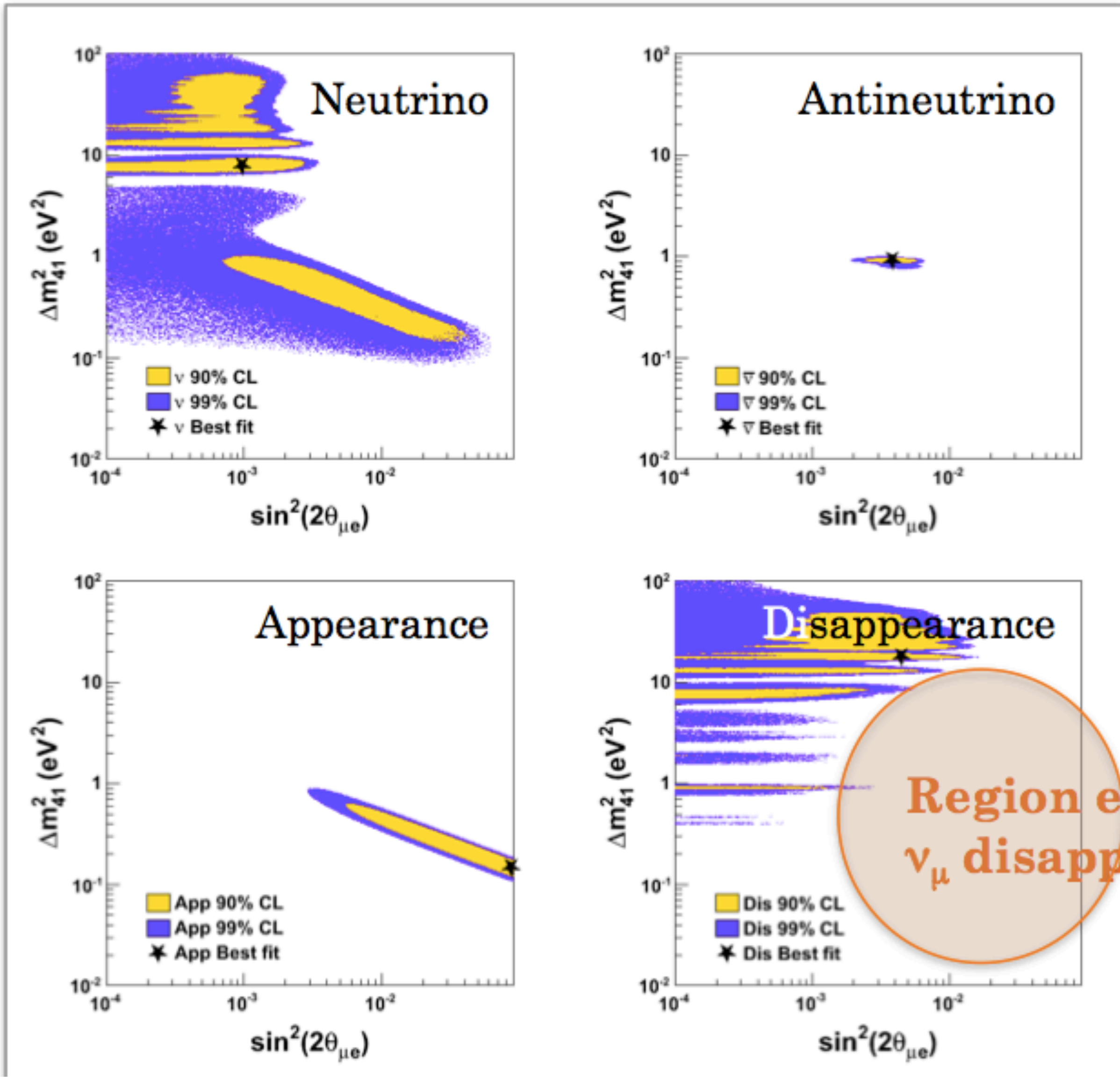
- $\overset{(-)}{\nu}_\mu$ disappearance
  - **CCFR84**
    [Z. Phys. C 27, 53 (1985)]
  - **CDHS**
    [Phys. Lett. B 134, 281 (1984)]
  - **MINOS**
    [hep-ex/1202.2772 (2012), hep-ex/1108.1509 (2012)]
  - **MiniBooNE ν dis**
    [Phys. Rev. Lett. 103, 061802 (2009)]
  - **Atmospheric**
    [New J. Phys. 6, 122 (2004)]

Reviewed Anomalies

Null experiments with sensitivity to sterile neutrinos

(3+1): Incompatibilities

G. Karagiorgi



Region excluded from ν_μ disappearance experiments

In (3+1) model:
PG ($\nu,\bar{\nu}$) = 0.14%

PG (app,dis) = 0.013%

In (3+2) model:
PG ($\nu,\bar{\nu}$) = 5.3%
PG (app,dis)= 0.0082%

In (3+3) model:
PG(nu,antinu)=53%
PG(app,dis)=0.0081%

"Appearance and disappearance data sets still incompatible even under a (3+3) scenario"

J. Evslin

Cosmological Constraints

- High sterile mass has tension with cosmological constraints
- 2 different modifications to cosmology can evade the bounds, at least in the 3+1 models
  - time varying dark energy
  - sterile neutrino mass proportional to density of the medium
- (3+3) fits prefer dm2's>10 eV^2—difficult to allow such high masses even with these modifications?

Minimal Sterile Neutrino Model

J. Lopez-Pavon

- Mini-seesaw model (very low scale Majorana mass) De Gouvea et al 05

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \mathcal{L}_{\rm kin} - \frac{1}{2}\overline{\nu_{si}} M_{ij} \nu_{sj}^c - (Y)_{i\alpha} \overline{\nu_{si}} \widetilde{\phi}^\dagger L_\alpha + {\rm h.c.}$$

- Minimal extension of the SM that accounts for neutrino masses and naturally includes sterile neutrinos (MM).

- More predictive than the phenomenological models (PM). In 3+2 models:

Model	# Δm^2	# Angles	# Phases
3 ν	2	3	1
3+2 MM	4	4	3
3+2 PM	4	9	5

→ ...and, in the MM, sterile mixing depends on the mass parameters

Effect of Steriles on 3flavor phys

- Theory motivated global fits reduce the degrees of freedom
- Relate new mixing angles to the standard 3 mixing angles
- Goodness of fits from theory motivated models are comparable to best phenomenological fits
- Best fits can pull standard mixing angles
  - e.g. Value of theta_13 changes by 20% in the MM model compared to 3 flavor fits.

--J. Lopez-Pavon

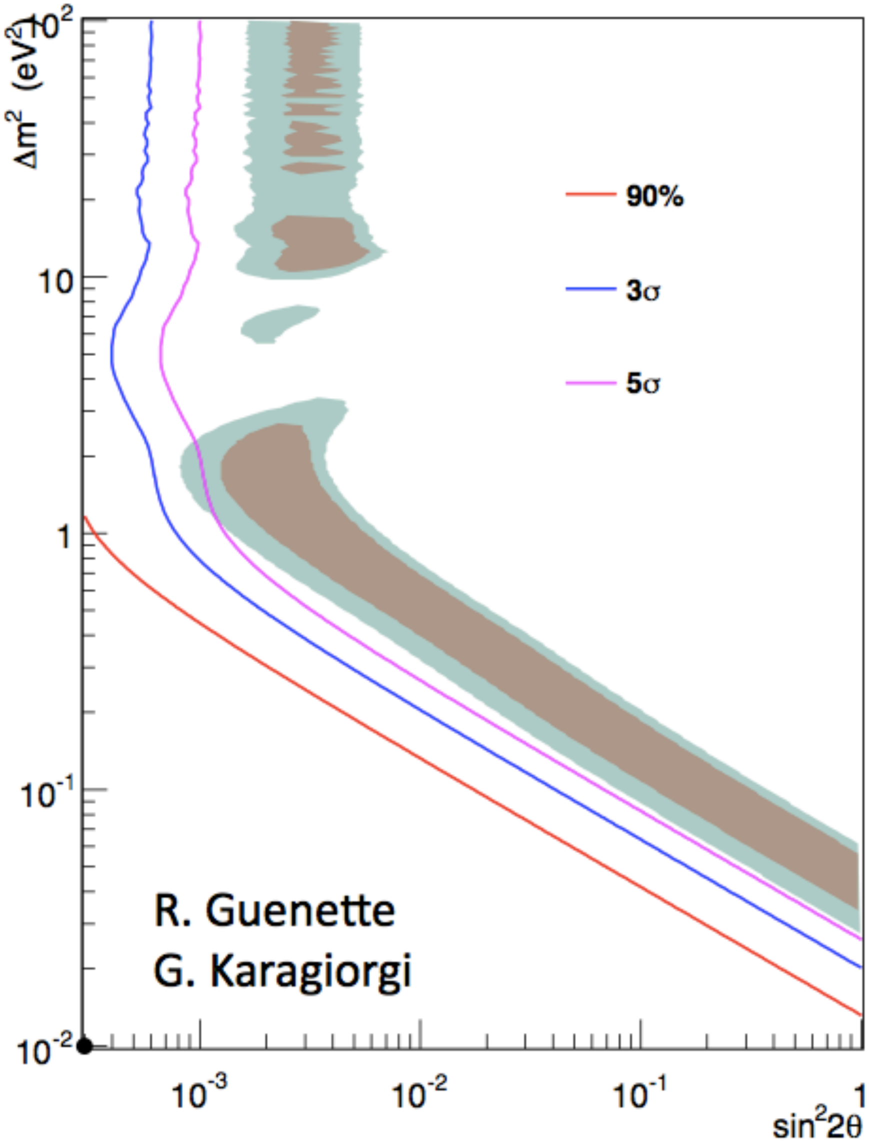
Where to from here?

- Measure reactor rates at really Near Detectors
  - 7 experiments proposed, 1 taking data now (NUCIFER at Saclay)
- Measure rates from sources inserted in neutrino detectors
  - another 7 proposals
- Spallation sources

--B. Fleming

LAr1 sensitivity* to MiniBooNE anti-neutrino anomalies

Reference configuration: MicroBooNE at 200m and LAr1 at 700m



3-5 years with present running conditions

Fiducial volumes assumed for MicroBooNE and Lar1 are 61t and 695t respectively.

* 3+1 neutrino model

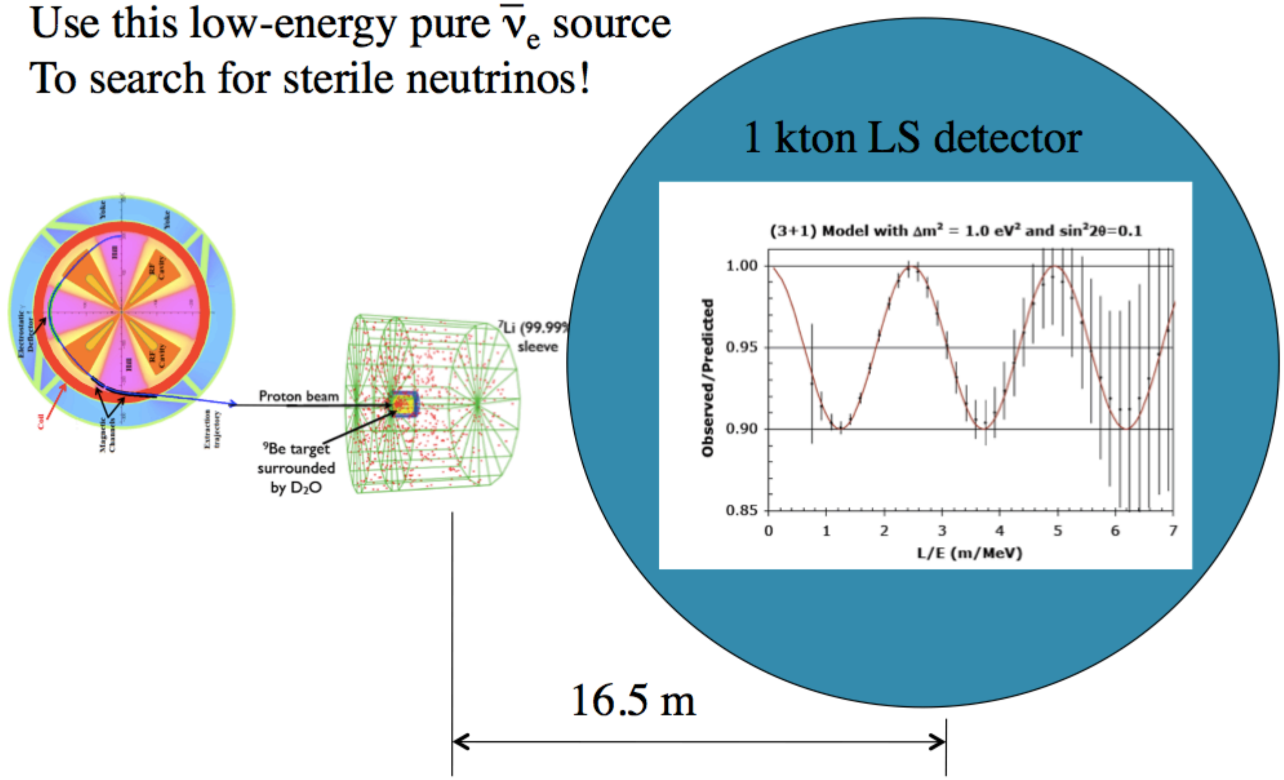
--B. Fleming

J. Conrad

IsoDAR

- Use 60 MeV protons from cyclotron to make isotopes that beta decay at rest

Use this low-energy pure $\overline{\nu}_e$ source
To search for sterile neutrinos!



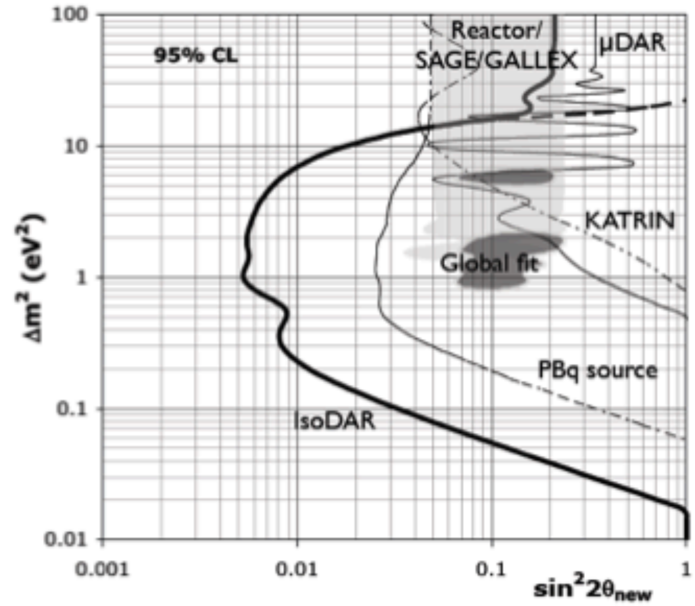
Potential locations: KamLAND and SNO+

IsoDAR

J. Conrad

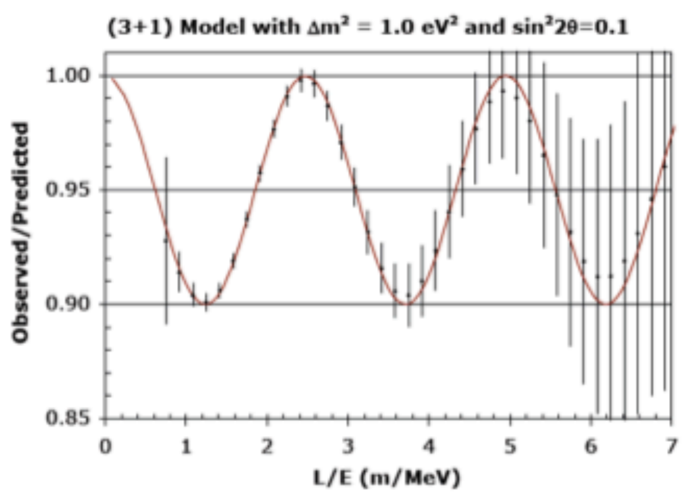
Outstanding sensitivity!

> 5σ in <2 years of running

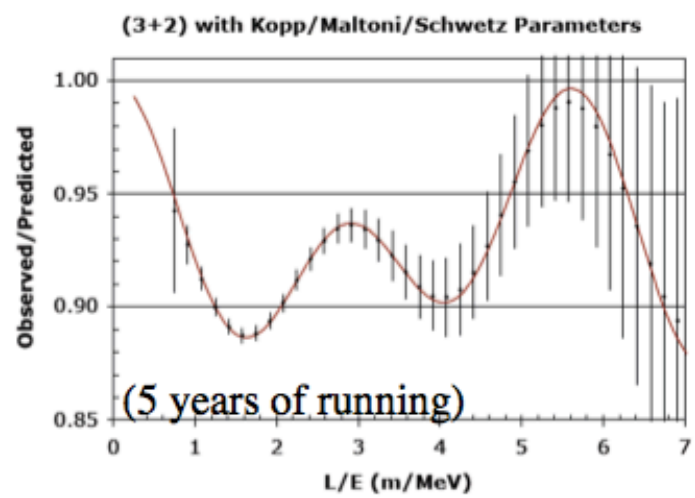


Ability to discriminate between models!

3+1



3+2

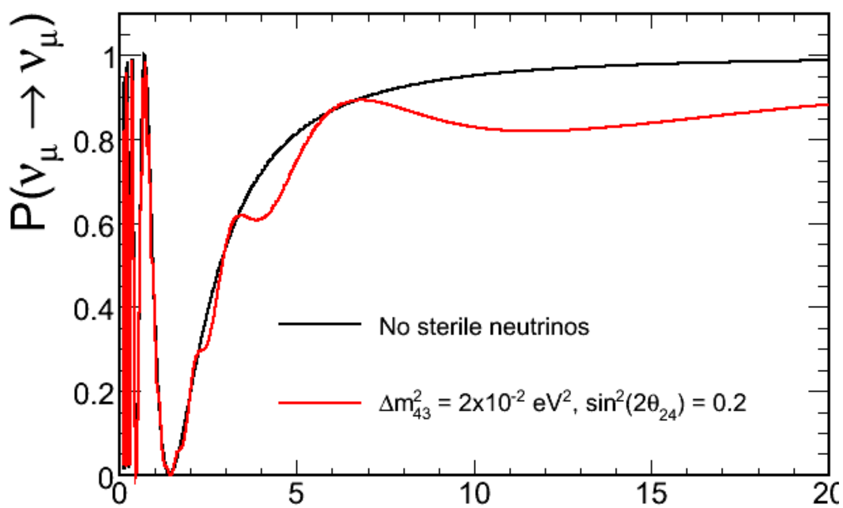


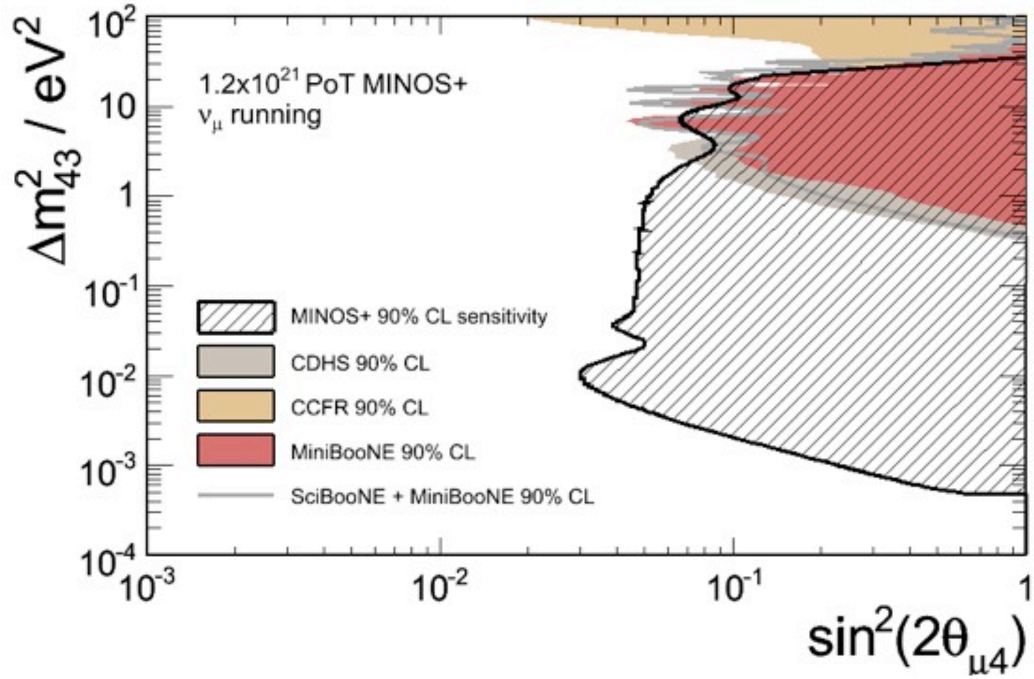
IsoDAR is a stepping stone on the way to Daedulus which can study CP violation via anti-numu to anti-nue oscillations

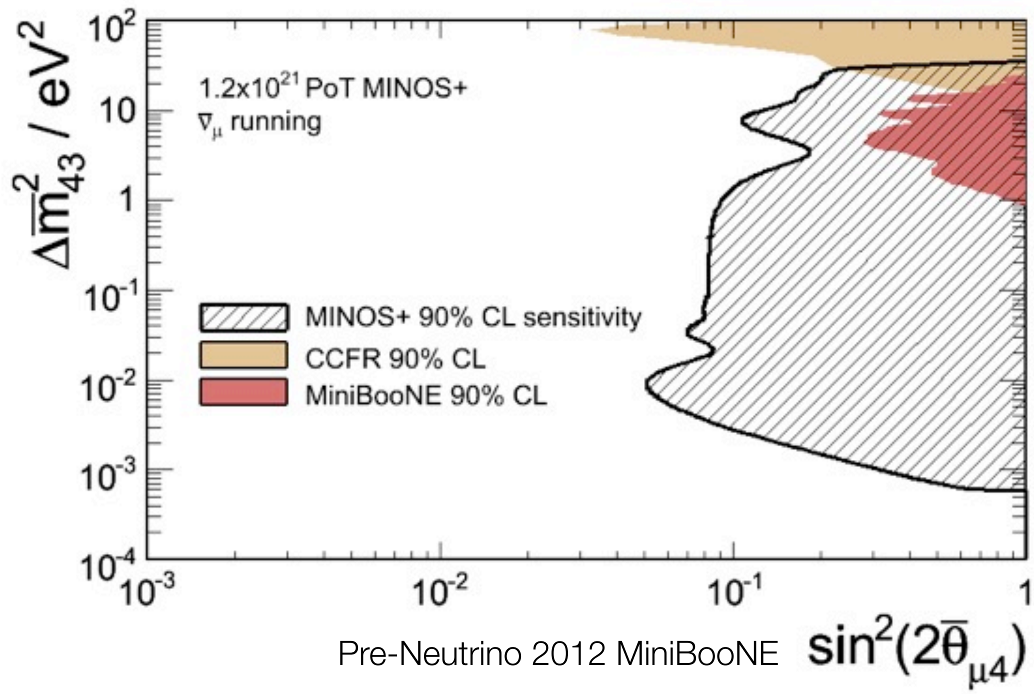
R. Nichol

Sterile Neutrino Search

- Sterile mixing is a proxy for any new physics
- Shows up as a distortion to the (oscillated) CC and NC Far Detector spectra







Pre-Neutrino 2012 MiniBooNE

R. Nichol

The MINOS+ vs LSND vs MiniBooNE Plot

- Can not have appearance without disappearance
- MINOS+ will (most likely) place limits on:

$\sin^2 2\theta_{24}$ (vs Δm^2_{41})

- Bugey (and other reactor experiments) placed limits on:

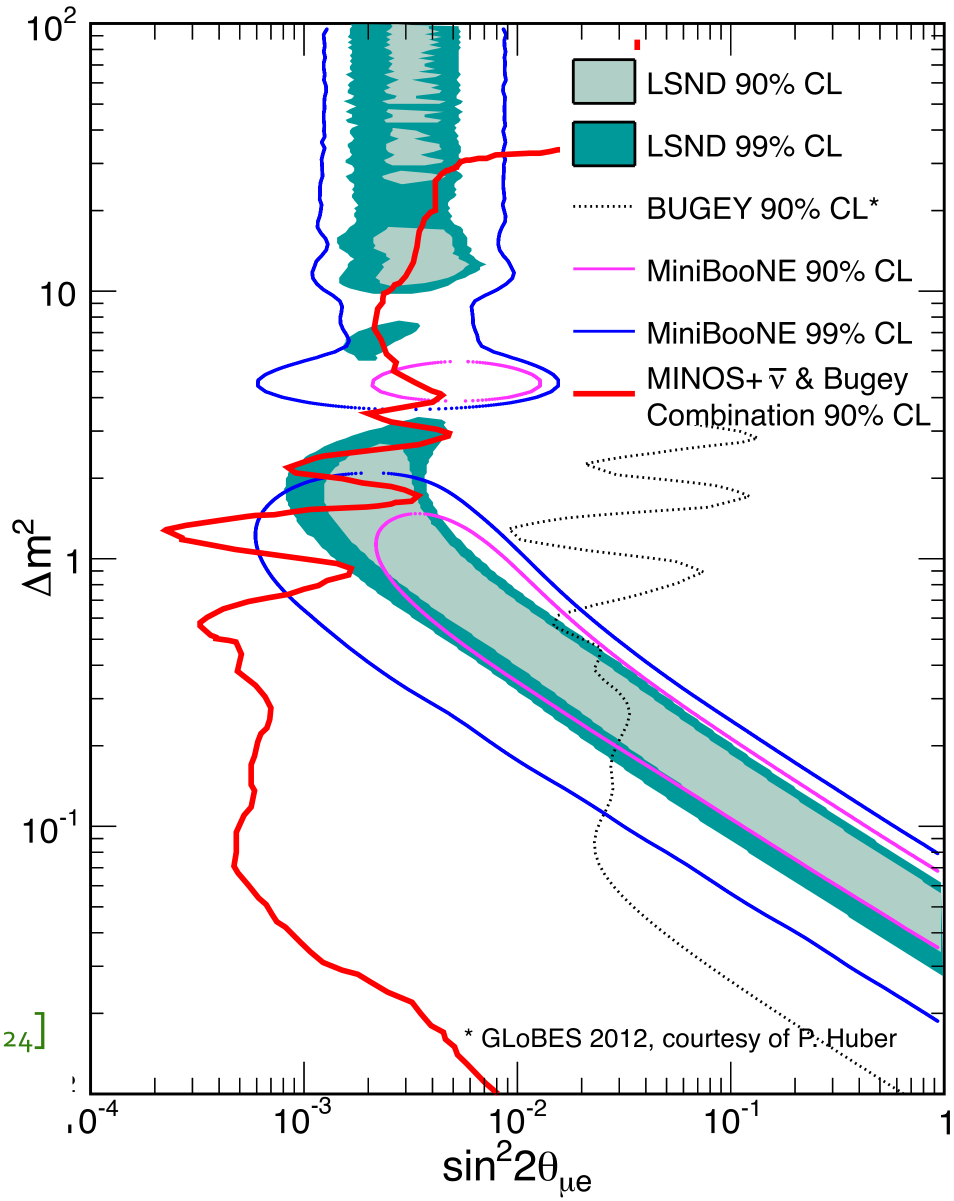
$\sin^2 2\theta_{14}$ (vs Δm^2_{41})

- LSND/MiniBoone measure:

$\sin^2 2\theta_{\mu e} = 4|U_{e4}|^2 x |U_{\mu 4}|^2 = 4\,[\sin^2\theta_{14}]\,x\,[\cos^2\theta_{14}\sin^2\theta_{24}]$

$= \sin^2 2\theta_{14}\, x \sin^2\theta_{24}$

- Combine Bugey&MINOS+




Don't forget nuStorm

Constraining Theories—testing sum rules

MC Chen

Predictions: a SUSY SU(5) x T´ Model

- Neutrino Sector (2 parameters): $M_{RR} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix} S_0 \qquad M_D = \begin{pmatrix} 2\xi_0+\eta_0 & -\xi_0 & -\xi_0 \\ -\xi_0 & 2\xi_0 & -\xi_0+\eta_0 \\ -\xi_0 & -\xi_0+\eta_0 & 2\xi_0 \end{pmatrix} \zeta_0\zeta_0' v_u$
- Seesaw mechanism:

$$U_{TBM}^T M_\nu U_{TBM} = \mathrm{diag}((3\xi_0+\eta_0)^2, \eta_0^2, -(-3\xi_0+\eta_0)^2)\frac{(\zeta_0\zeta_0' v_u)^2}{s_0\Lambda}$$

- Prediction for MNS matrix:

$$U_{\mathrm{MNS}} = V_{e,L}^\dagger U_{\mathrm{TBM}} = \begin{pmatrix} 1 & -\theta_c/3 & * \\ \theta_c/3 & 1 & * \\ * & * & 1 \end{pmatrix} \begin{pmatrix} \sqrt{2/3} & 1/\sqrt{3} & 0 \\ -\sqrt{1/6} & 1/\sqrt{3} & -1/\sqrt{2} \\ -\sqrt{1/6} & 1/\sqrt{3} & 1/\sqrt{2} \end{pmatrix}$$

$$\theta_{13} \simeq \theta_c/3\sqrt{2}$$ ← CGs of SU(5) & T´

$$\tan^2\theta_\odot \simeq \tan^2\theta_{\odot,TBM} + \frac{1}{2}\theta_c\cos\delta$$

neutrino mixing angle; 1/2; quark mixing angle

→ complex CGs: leptonic Dirac CPV

δ = 227 degrees

⇒ connection between leptogenesis & leptonic CPV at low energy

- sum rule among absolute masses:

$$m_2^2 - m_1^2 = (\eta_0^4 - (3\xi_0+\eta_0)^4)\frac{(\zeta_0\zeta_0' v_u)^2}{S_0} > 0$$

$$m_3^2 - m_1^2 = -24\eta_0\xi_0(9\xi_0^2+\eta_0^2)\frac{(\zeta_0\zeta_0' v_u)^2}{S_0}$$

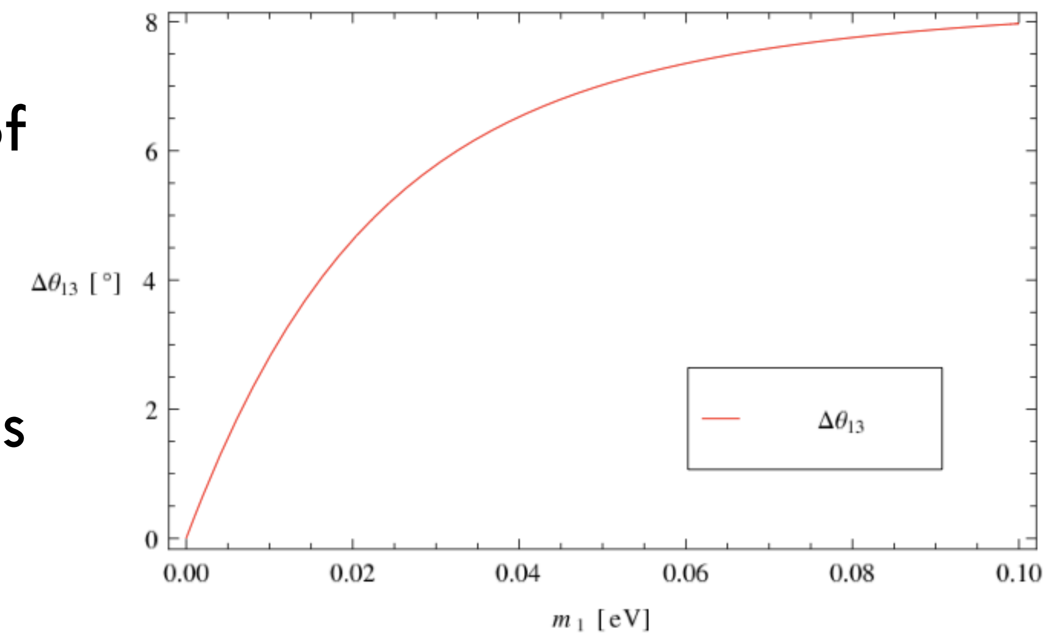
normal hierarchy predicted

M. Ratz

Tribimaximal Mixing

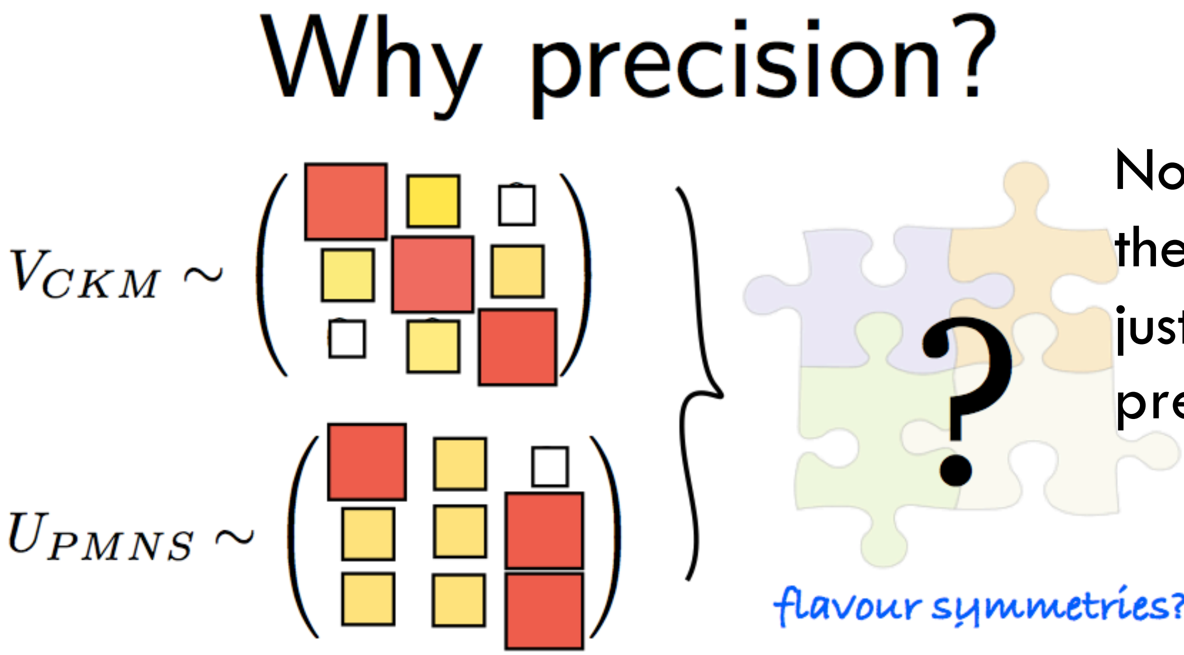
- Is Tribimaximal Mixing still appealing now that we know theta13 is large?
- In short, it can still be accommodated by "Kahler Corrections"

☞ $\Delta\theta_{13}$ for Kähler coefficient $\kappa_V = 1, v/\Lambda = 0.2$



- In general, predictions based on symmetries of subsectors are subject to sizeable corrections
- There are large theoretical uncertainties in classes of popular constructions

Precision

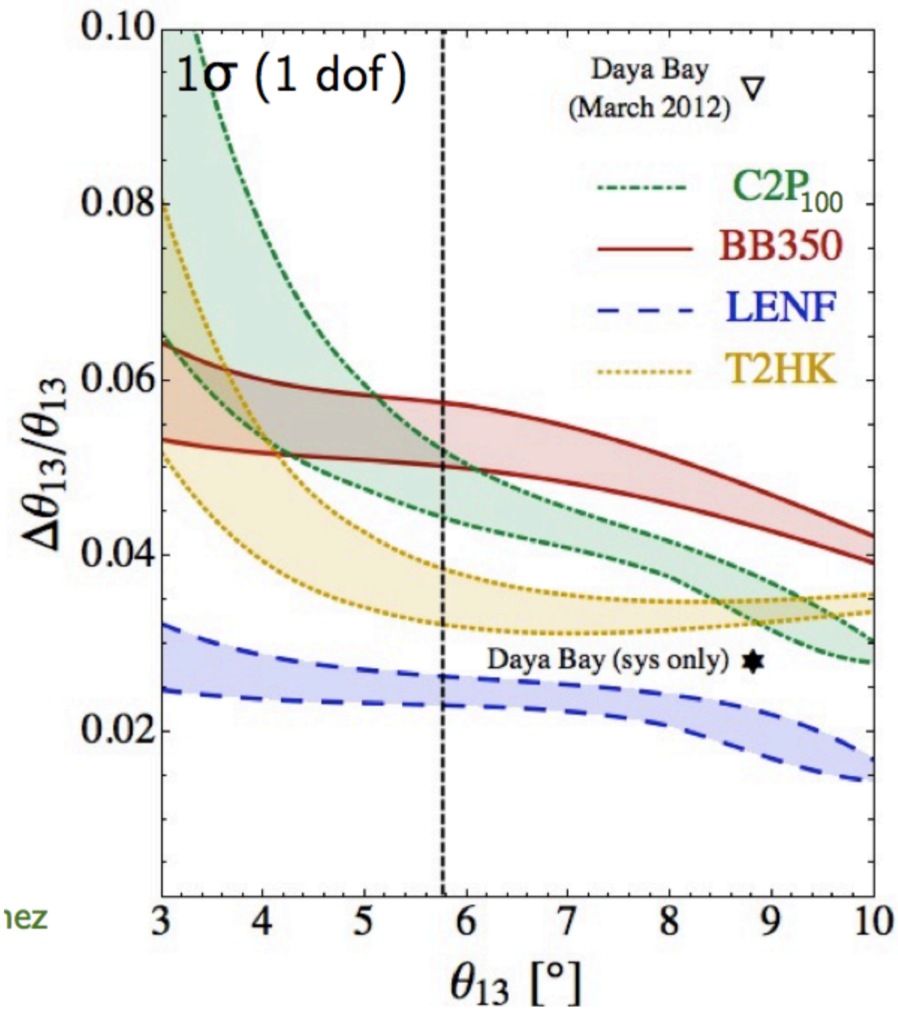


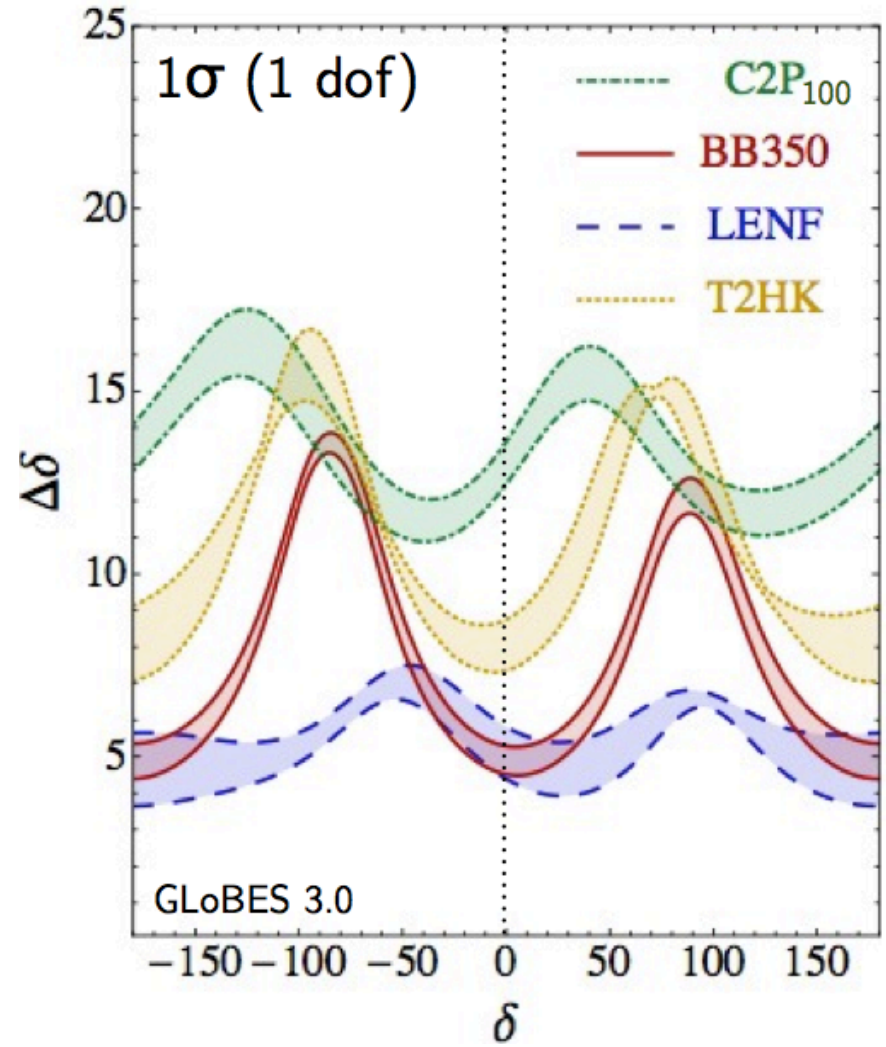
Now that we know that theta13 is large, its not just about discovery, but precision

Parameter	Value (neutrino PMNS matrix)	Value (quark CKM matrix)
θ_{12}	$34 \pm 1^{\circ}$	$13.04 \pm 0.05^{\circ}$
θ_{23}	$43 \pm 4^{\circ}$	$2.38 \pm 0.06^{\circ}$
θ_{13}	$9 \pm 1^{\circ}$	$0.201 \pm 0.011^{\circ}$
Δm^2_{21}	$+(7.58 \pm 0.22) \times 10^{-5}$ eV^2	
$\lvert\Delta m^2_{32}\rvert$	$(2.35 \pm 0.12) \times 10^{-3}$ eV^2	$m_3 >> m_2$
δ_{CP}	unknown	$67 \pm 5^{\circ}$

Table from Bishai's talk at PXPS

Precision of facilities



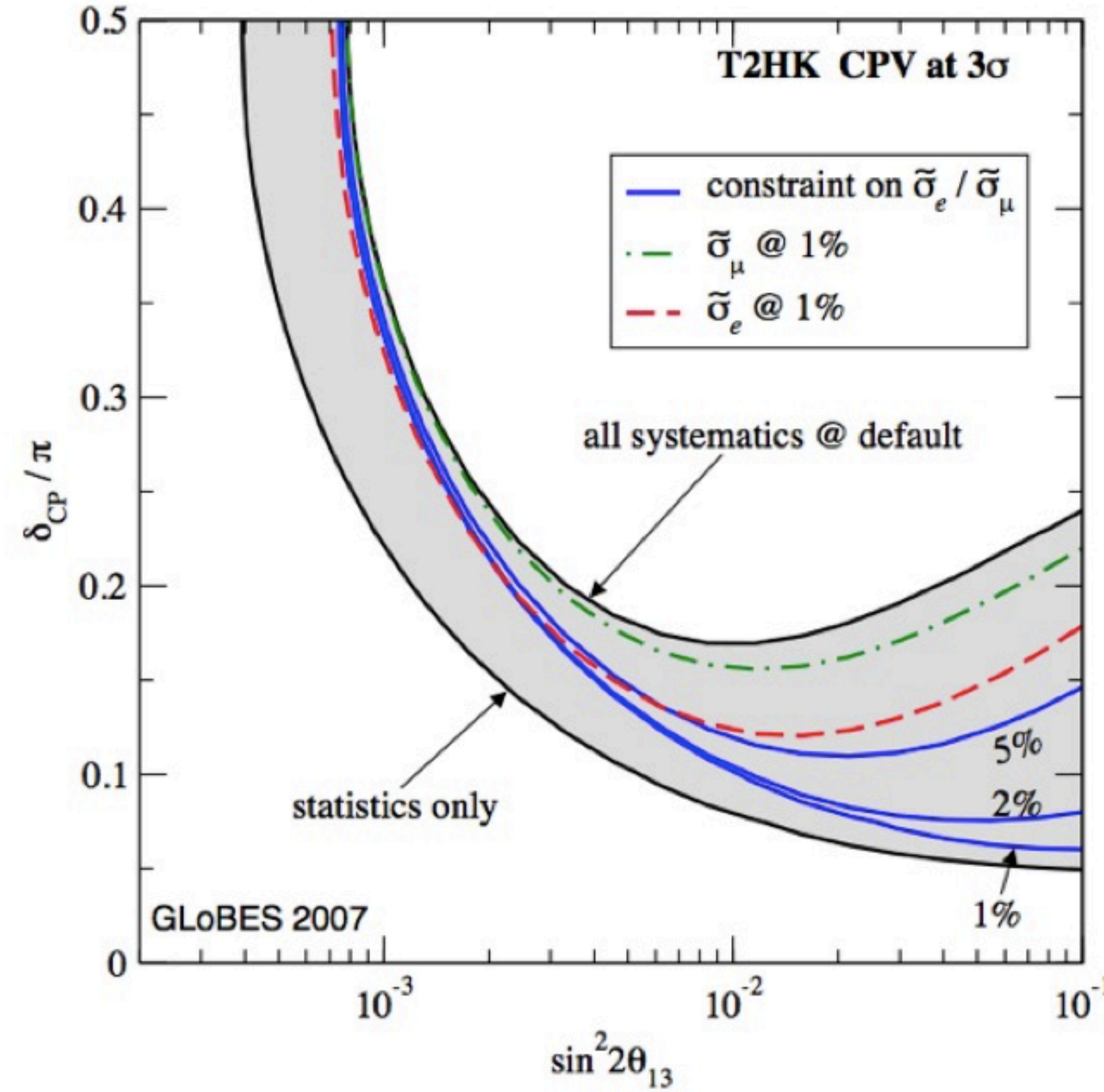


ıez

P. Coloma

Systematics matter

- Large theta 13 mean we have to be careful of systematics



Huber, Mezzetto, Schwetz, 0711.2950 [hep-ph]

P. Coloma

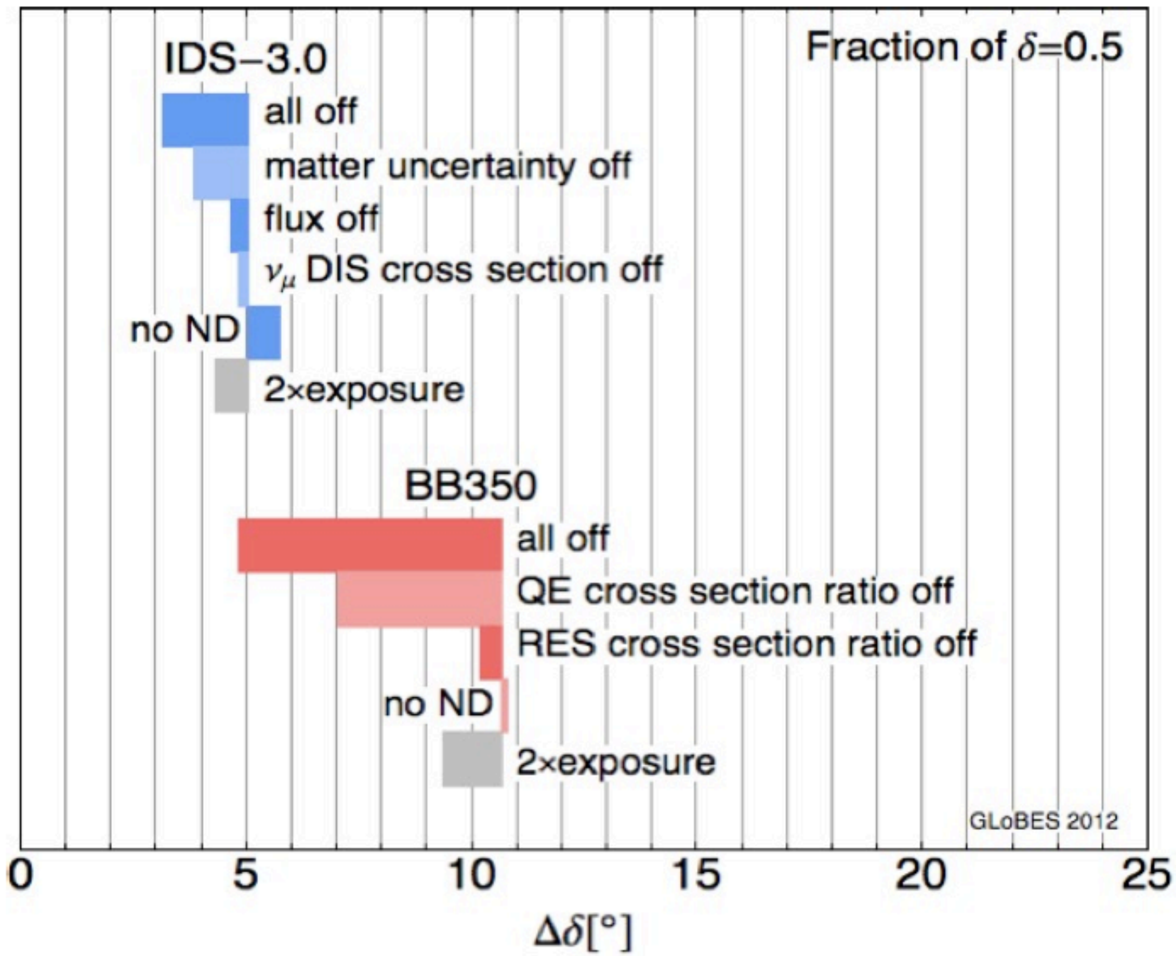
Systematics

	SB			BB			NF		
Systematics	Opt.	Def.	Cons.	Opt.	Def.	Cons.	Opt.	Def.	Cons.
Fiducial volume ND	0.2%	0.5%	1%	0.2%	0.5%	1%	0.2%	0.5%	1%
Fiducial volume FD (incl. near-far extrap.)	1%	2.5%	5%	1%	2.5%	5%	1%	2.5%	5%
Flux error signal ν	5%	7.5%	10%	1%	2%	2.5%	0.1%	0.5%	1%
Flux error background ν	10%	15%	20%		correlated			correlated	
Flux error signal $\bar{\nu}$	10%	15%	20%	1%	2%	2.5%	0.1%	0.5%	1%
Flux error background $\bar{\nu}$	20%	30%	40%		correlated			correlated	
Background uncertainty	5%	7.5%	10%	5%	7.5%	10%	10%	15%	20%
Cross secs × eff. QE†	10%	15%	20%	10%	15%	20%	10%	15%	20%
Cross secs × eff. RES†	10%	15%	20%	10%	15%	20%	10%	15%	20%
Cross secs × eff. DIS†	5%	7.5%	10%	5%	7.5%	10%	5%	7.5%	10%
Ratio ν_e/ν_μ QE*	3.5%	11%	–	3.5%	11%	–	3.5%	11%	–
Ratio ν_e/ν_μ RES*	2.7%	5.4%	–	2.7%	5.4%	–	2.7%	5.4%	–
Ratio ν_e/ν_μ DIS*	2.5%	5.1%	–	2.5%	5.1%	–	2.5%	5.1%	–
Matter density	1%	2%	5%	1%	2%	5%	1%	2%	5%

theoretical constraint

P. Coloma

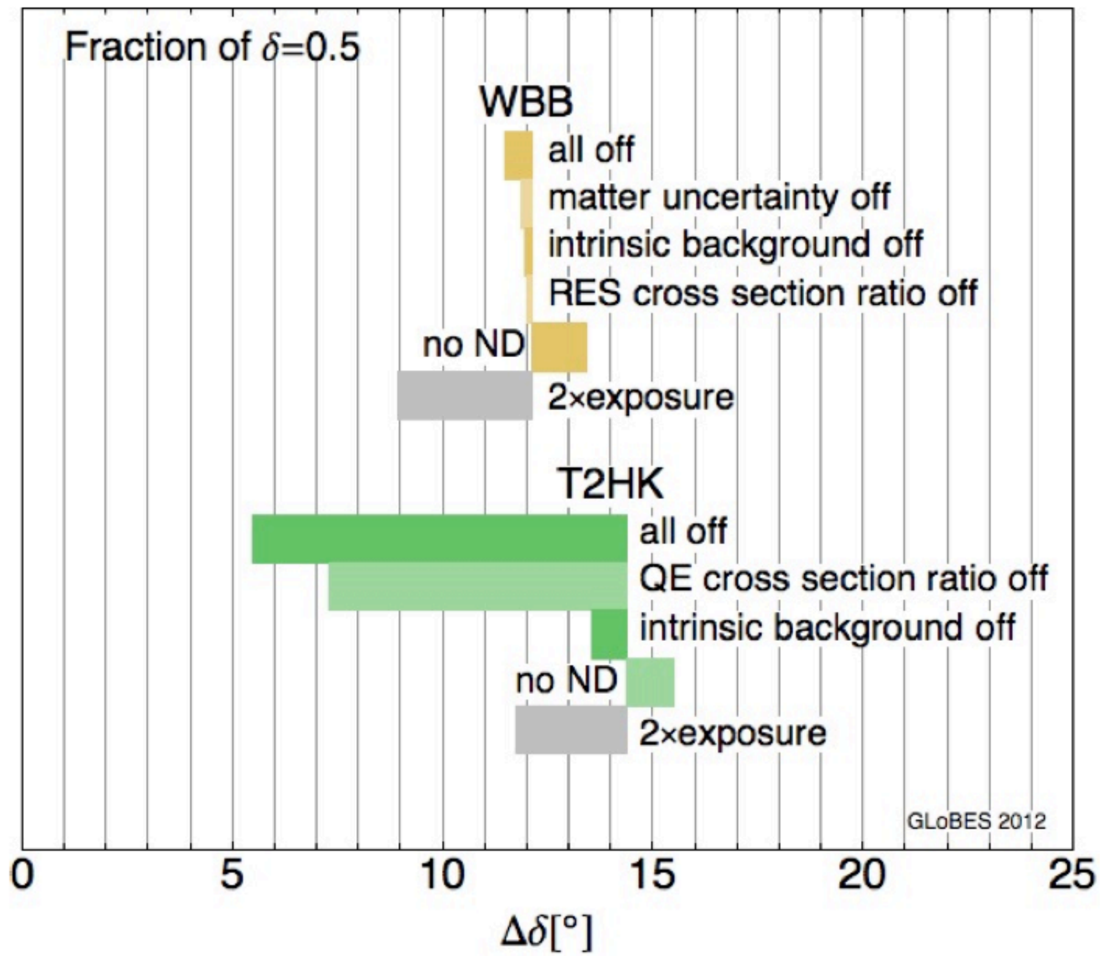
Systematics



Coloma, Huber, Kopp, Winter, In preparation

P. Coloma

Systematics



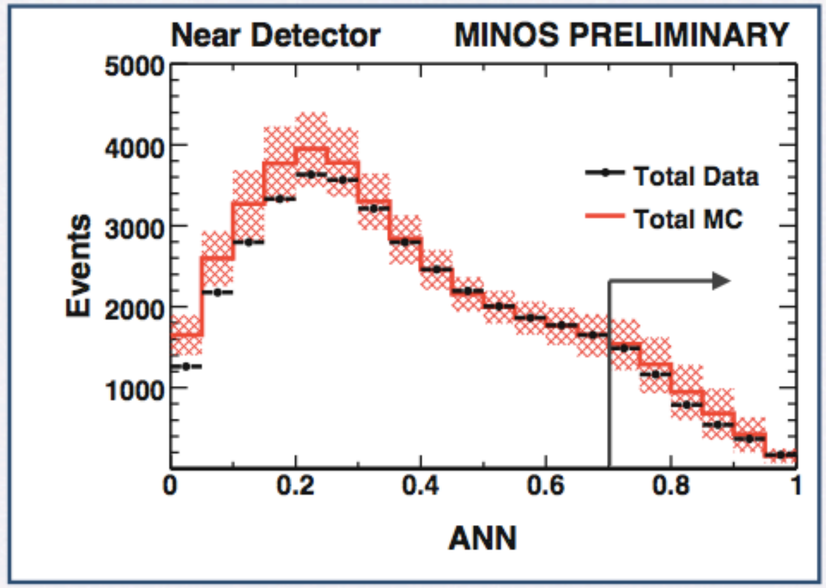
Coloma, Huber, Kopp, Winter, In preparation

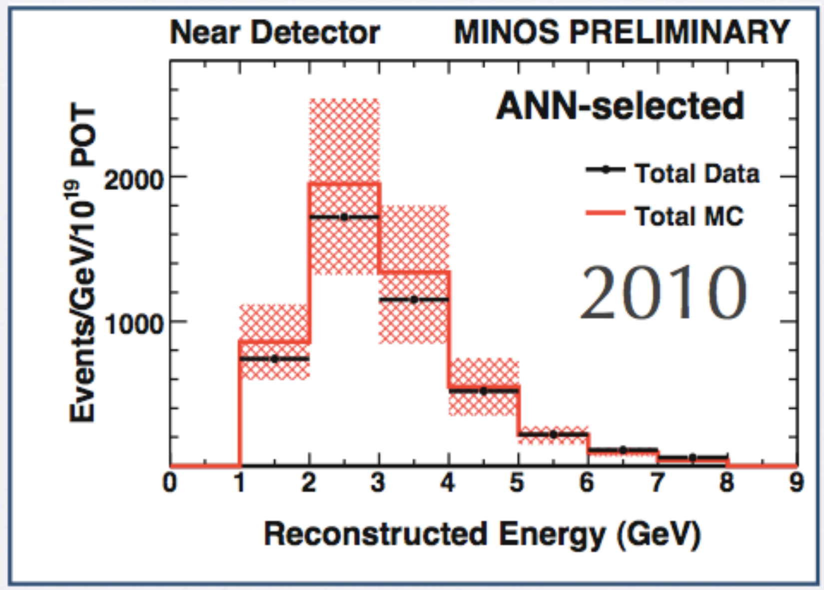
- Conclusion: one can get away without a ND if one uses disappearance measurements in FD to constrain systematics
- Some of us were very surprised by this conclusion…

MINOS systematics

M. Sanchez

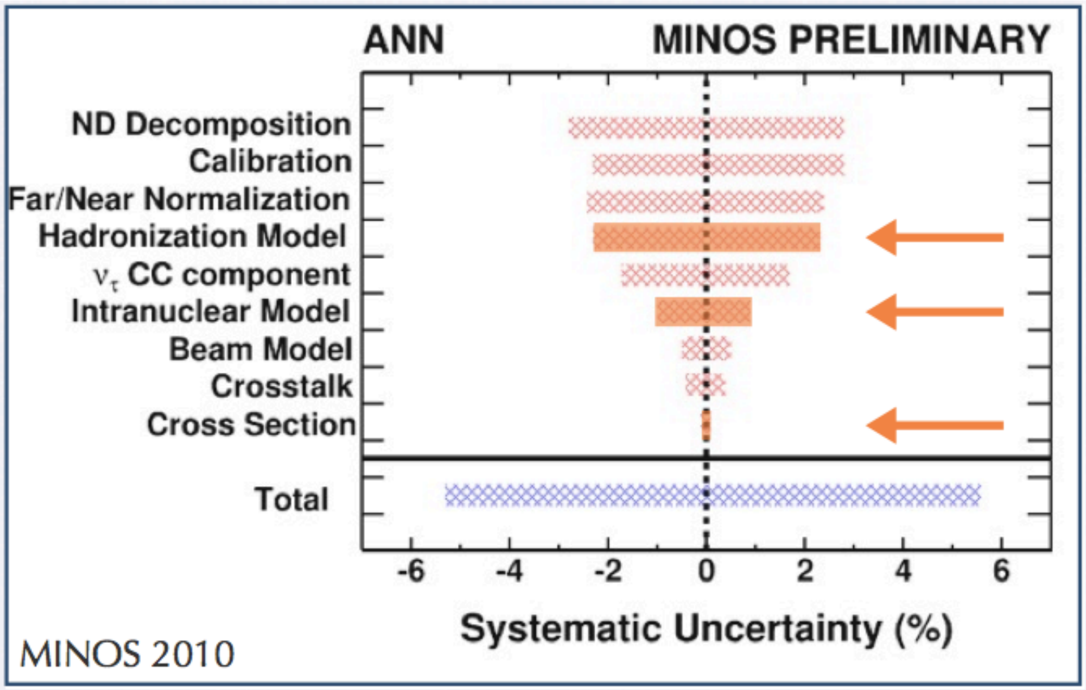
- Hadronization and FSI uncertainties cause sizeable systematic errors in MINOS ND nue selected sample…





FD Prediction Systematics

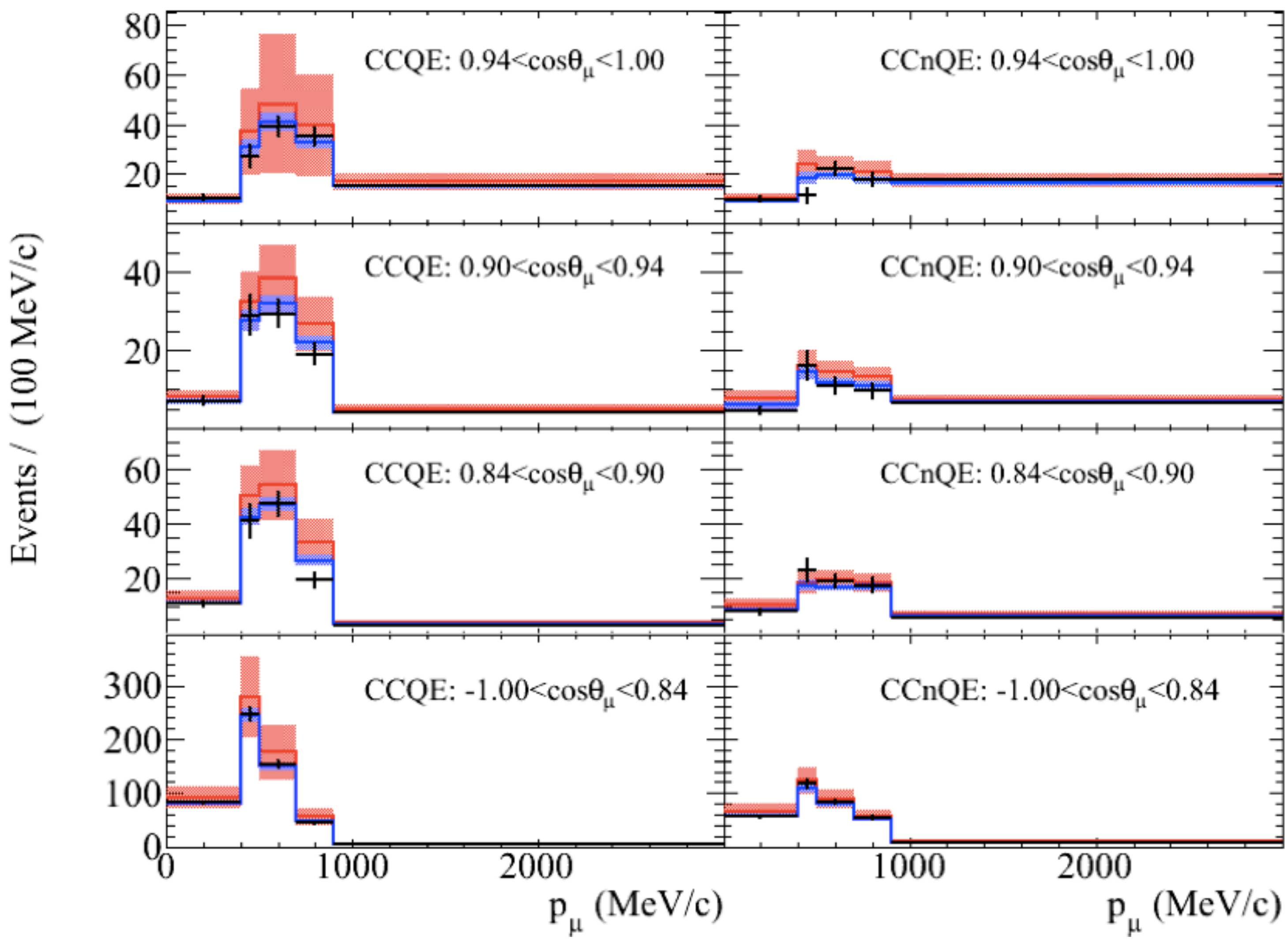
- …But they largely cancel in the extrapolation



- For the main background components the hadronization model systematic is corrected to about 4%, while intranuclear and cross sections are down to 1% or less.
- More recent analyses have these below 2.5%.

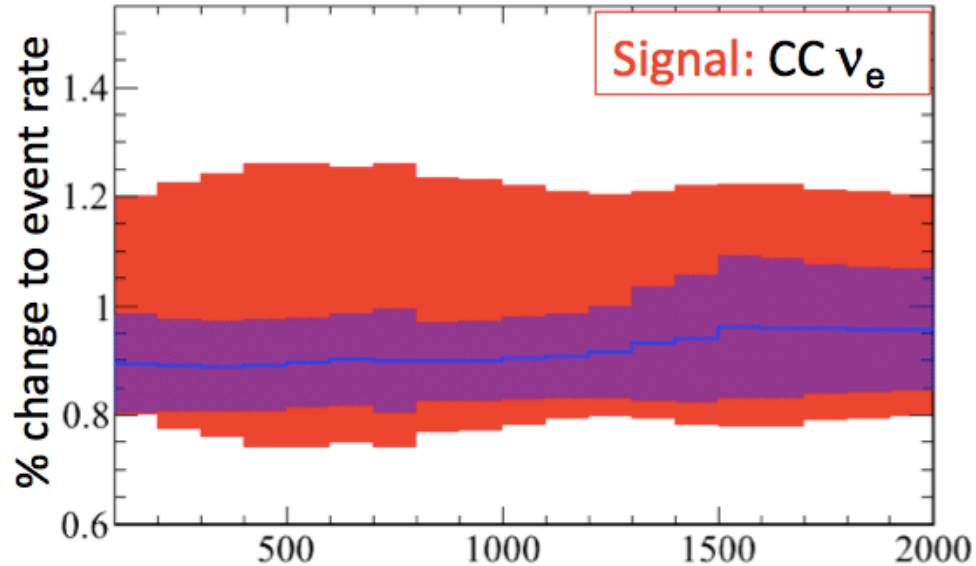
T2K ND and systematics

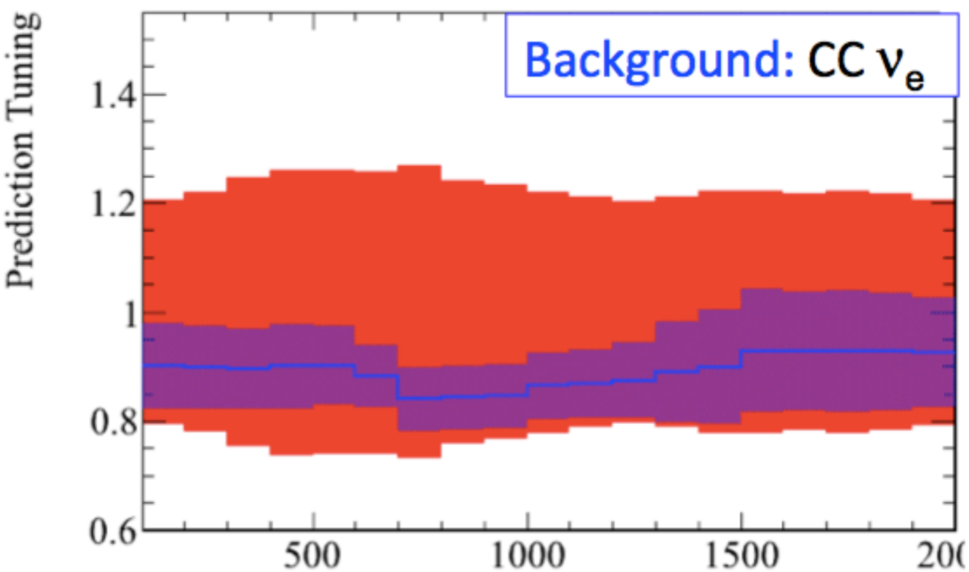
Data
without ND information
with ND information

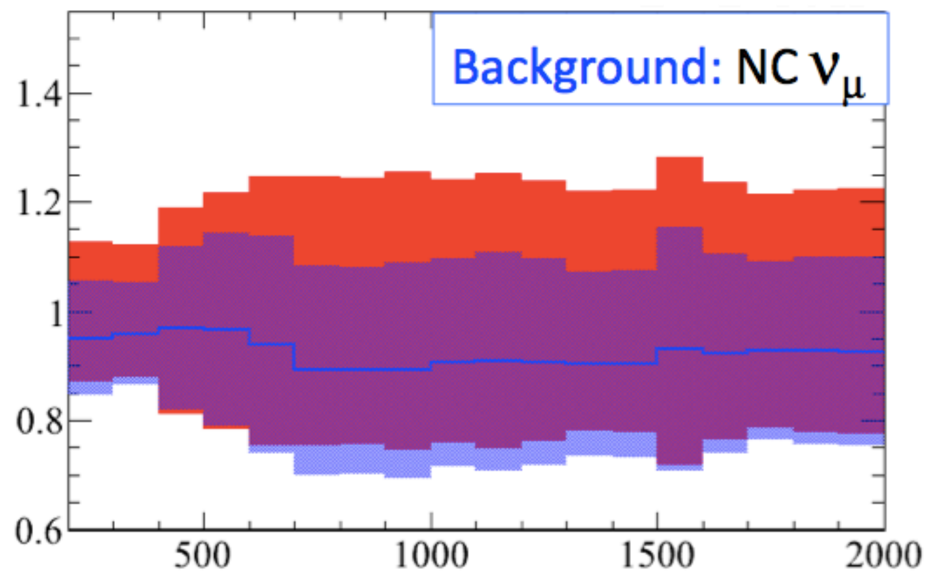


K. Mann

- Rate of ν_e signal and backgrounds without ND measurement and with ND measurement
- Uncertainty envelope from constrained flux, cross section parameters
- Includes correlation between flux and cross section at ND, SK





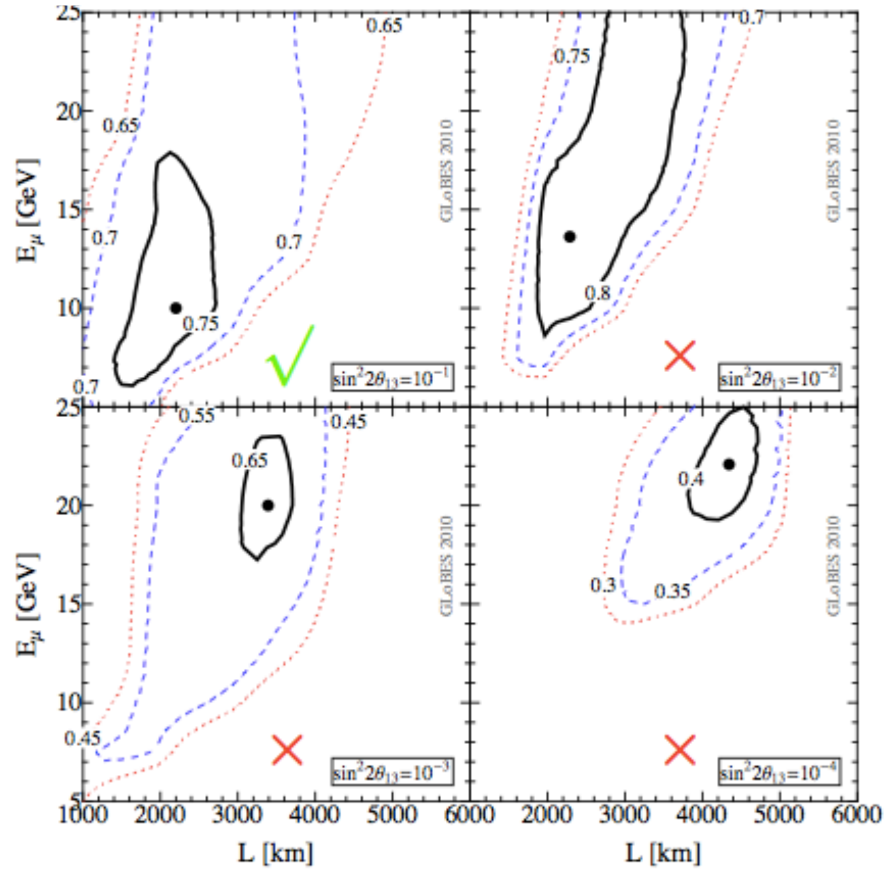


Action Item for experimentalists: Review systematics inputs for future facilities and the implications of having no ND

R. Bayes

New nufact optimization

- Physics priorities shift to measurement of CP violation.
- For measurement of θ_{13} used
  - Two baselines: 4000 km and 7500 km
  - 25 GeV stored μ energy.
- Re-optimization of baseline and beam energy required
- Measurement of δ_{CP} achieved with
  - Single 2000 km baseline.
  - 10 GeV stored μ energy.



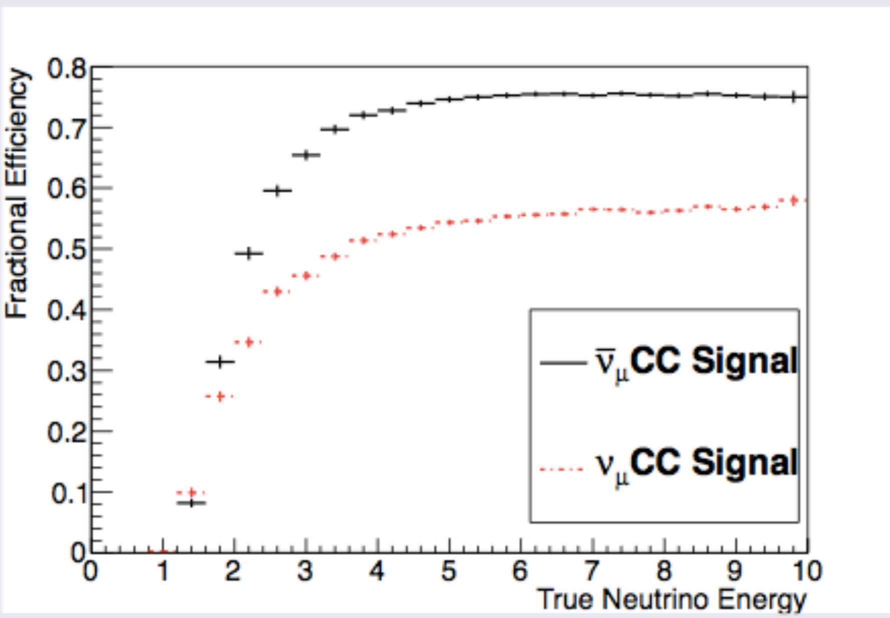
From IDS-NF-020, Interim Design Report

- MIND simulation used to examine sensitivities with these specifications.

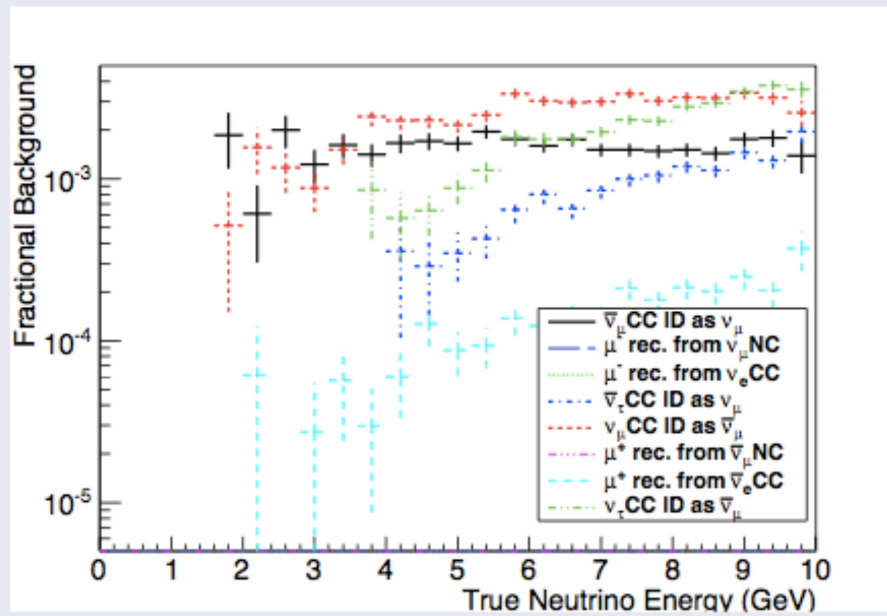
R. Bayes

Rethinking MIND

Signal Efficiencies



Background



- All reconstruction efficiencies at or above 50%.
- Background suppressed by parts in 10^3.
- NC backgrounds completely suppressed.

- Events simulated with GENIE.
- Full geometry & $\vec{B}$ field in GEANT 4
- Realistic field map generated by Bob Wands at FNAL

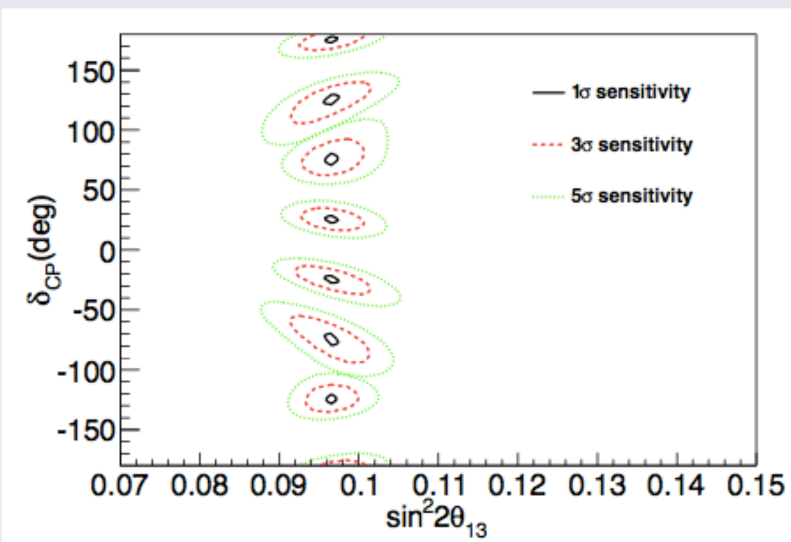
R. Bayes

MIND Sensitivity

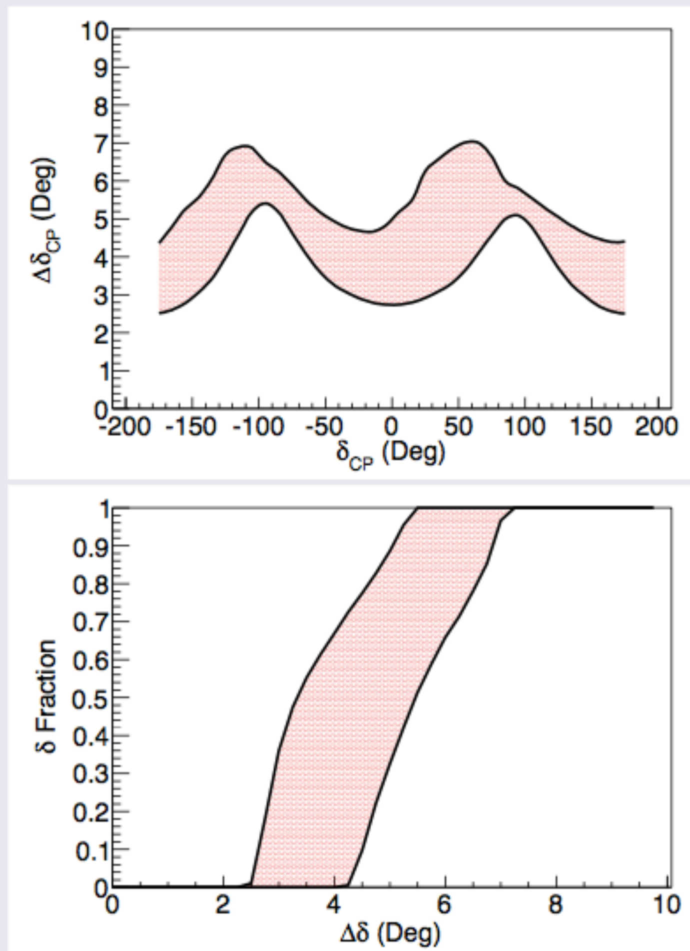
Assuming 10 GeV Factory, 10 years Running, 0.5×10^{21} μ^+ + 0.5×10^{21} μ^- per year

- Uses cuts-based analysis.
- Consider μ^+ and μ^- focussing
- Systematic variations shown (σ_A, σ_X)=(1%, 1%)→(2.5%, 3%).

χ^2 Contours; Arbitrary δ_{CP}, $\theta_{13} = 9°$

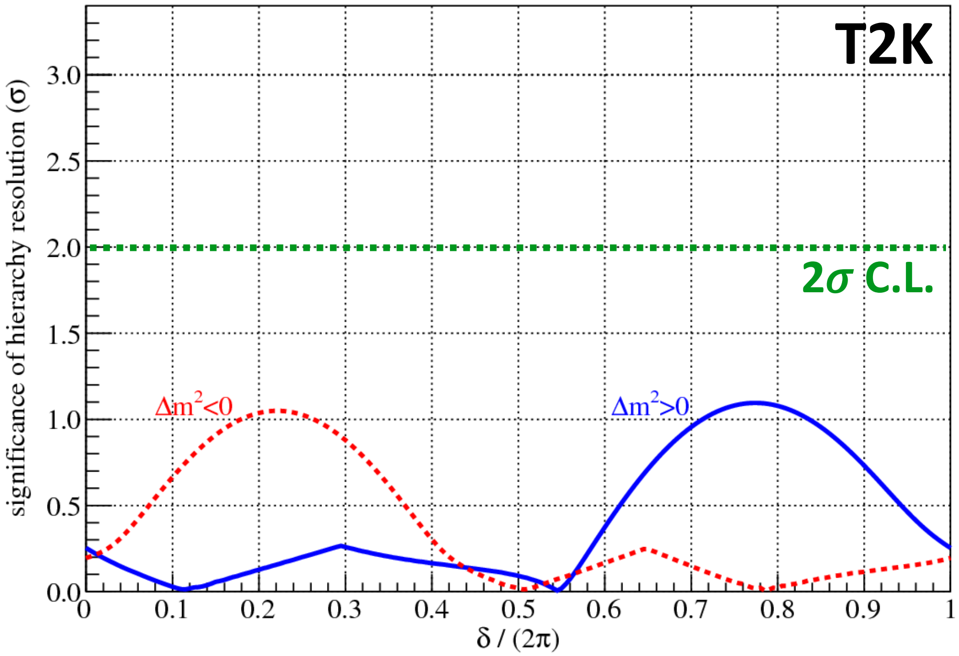


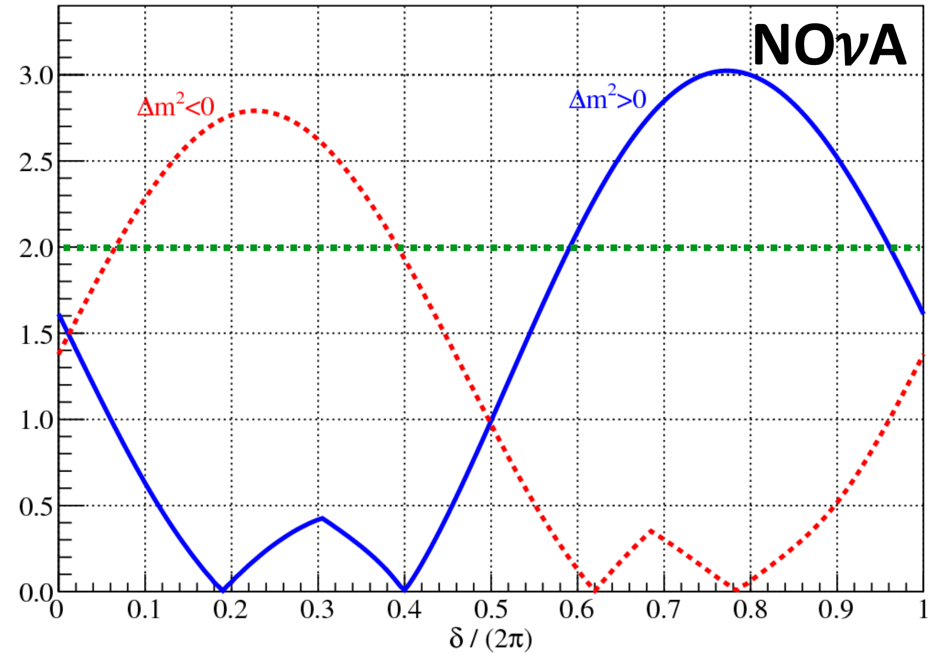
Error in δ_{CP} from 1 σ curves



Hierarchy resolution at the end of 2019.
Even split of ν and $\bar{\nu}$ running at both expts.

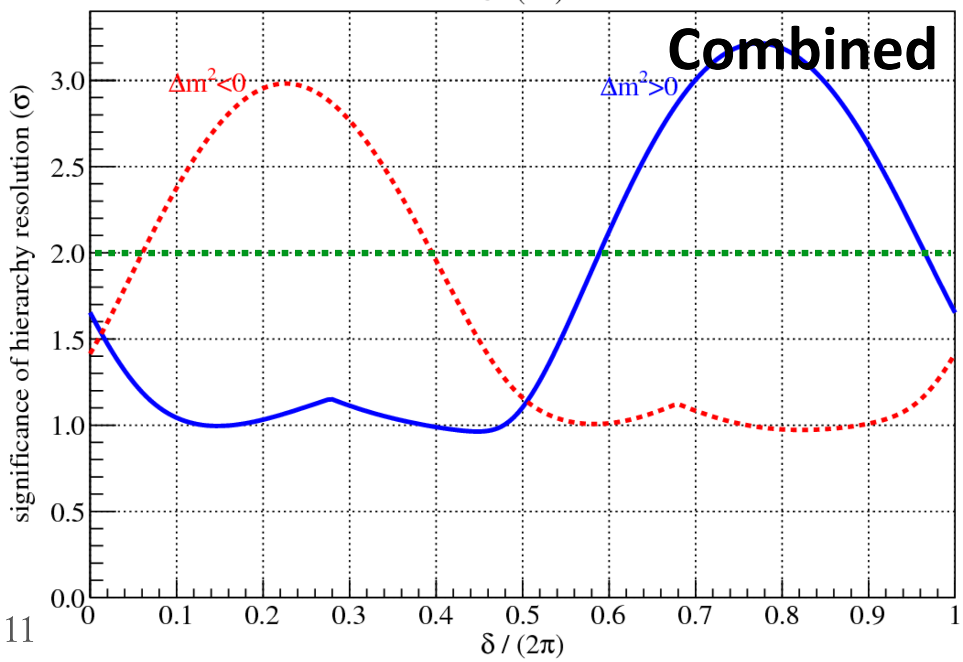
For test scenario of $\sin^2(2\theta_{13})=0.095$, $\sin^2(2\theta_{23})=1$





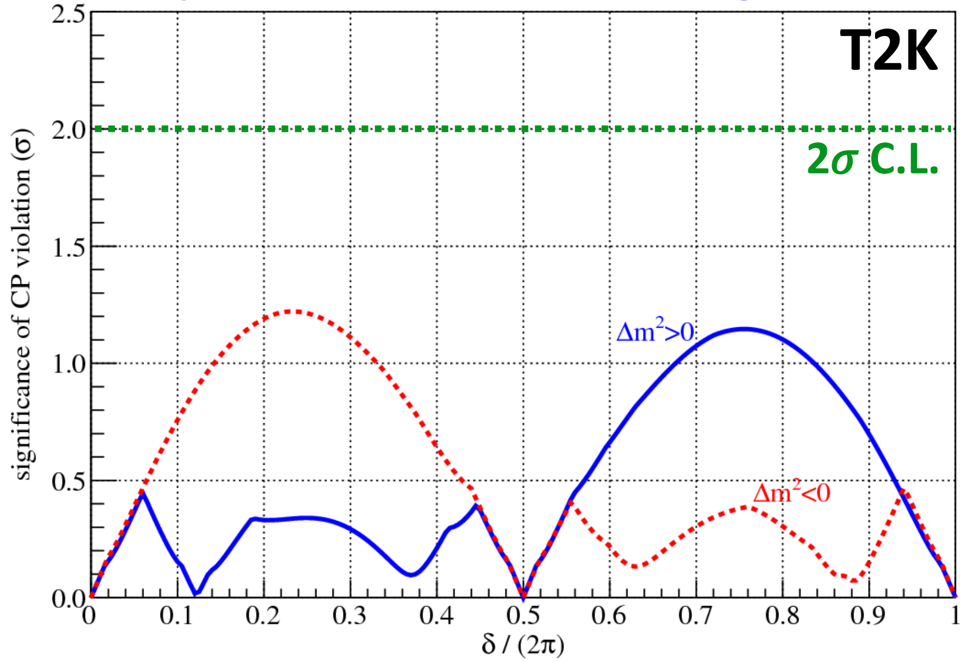
- **2σ C.L. (~95% C.L.) marked in green**
- **T2K baseline** too short for hierarchy
- **<u>NOνA alone:</u>** 37% of δ range covered
- **<u>NOνA+T2K:</u>** 38% of δ range covered
- *But:* note that the **combination is greater than the sum of its parts** in the "degenerate" region (reaching a modest 1σ everywhere)

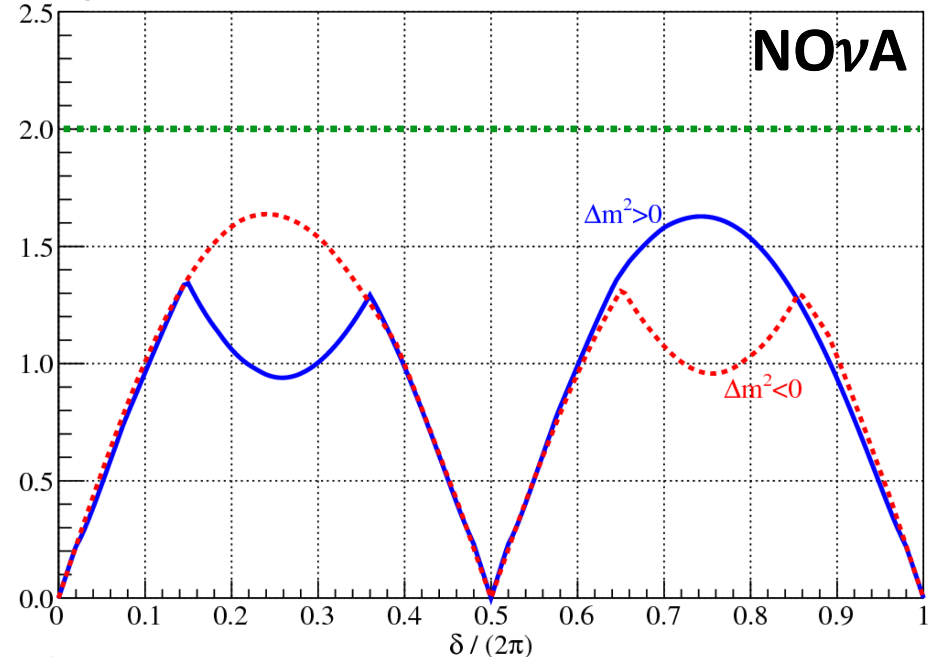
R. Patterson

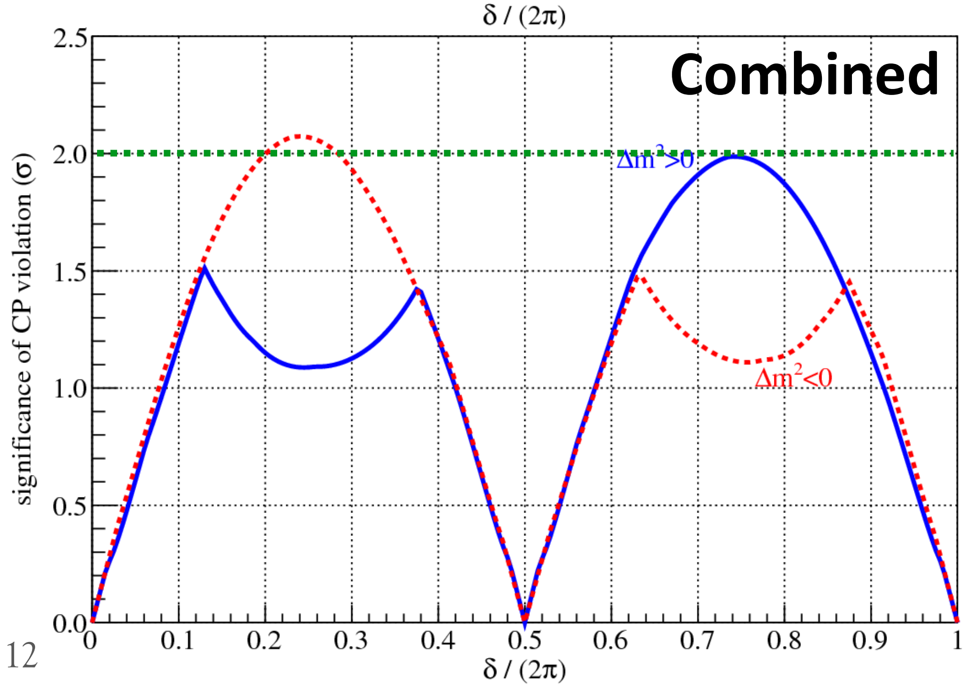


CP violation determination at the end of 2019.
Even split of ν and $\overline{\nu}$ running at both expts.

For test scenario of
$\sin^2(2\theta_{13})$=0.095, $\sin^2(2\theta_{23})$=1





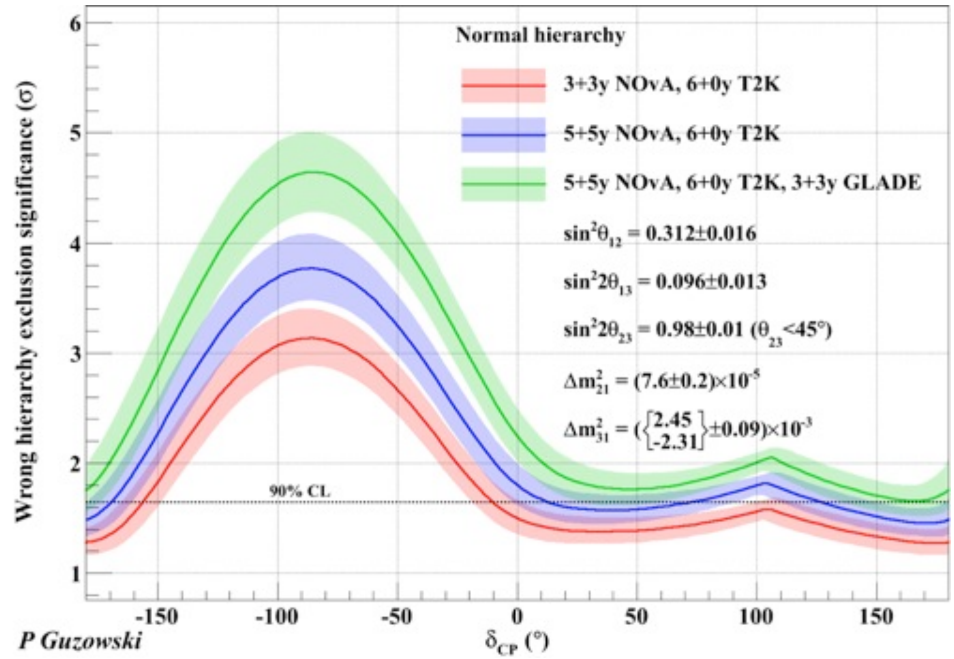


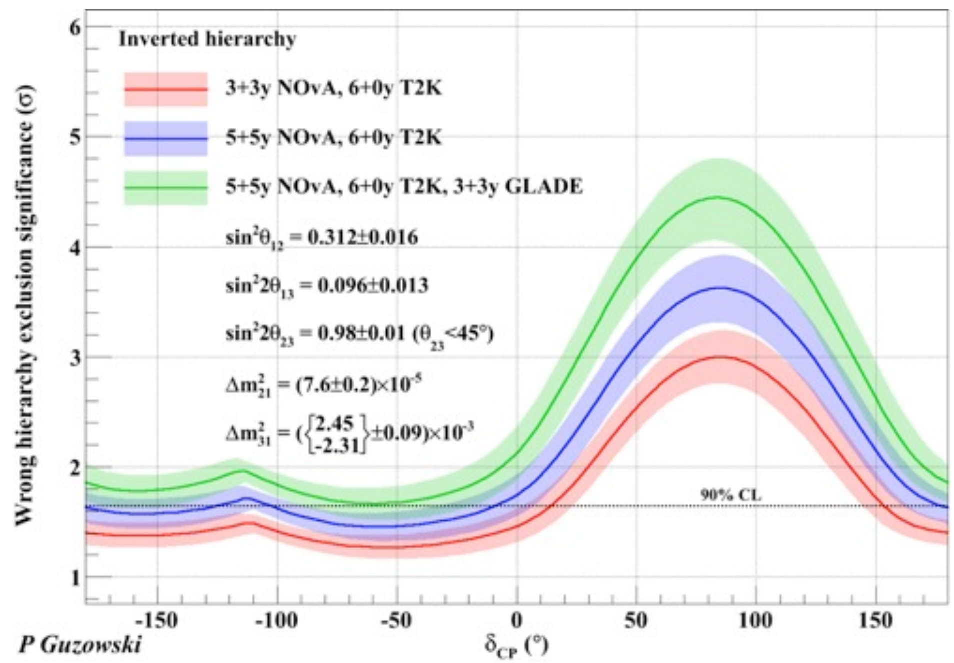
- **CPv tough all around!**
- Essentially **no coverage at 2σ**, but a good start over much of δ
- <u>Note:</u> unlike the hierarchy reach, this **can be arbitrarily hard**, depending on the true answer

R. Patterson

Mass Hierarchy

- Physics reach of GLADE is similar to NOvA
    - NOvA+GLADE = 2 NOvA
- Sensitivities assume we know $\sin^2 2\theta_{23}$ to 0.01 by 2020
- The (less sensitive) lower octant is assumed
- Extends the three sigma reach of NOvA+T2K, but need to get lucky

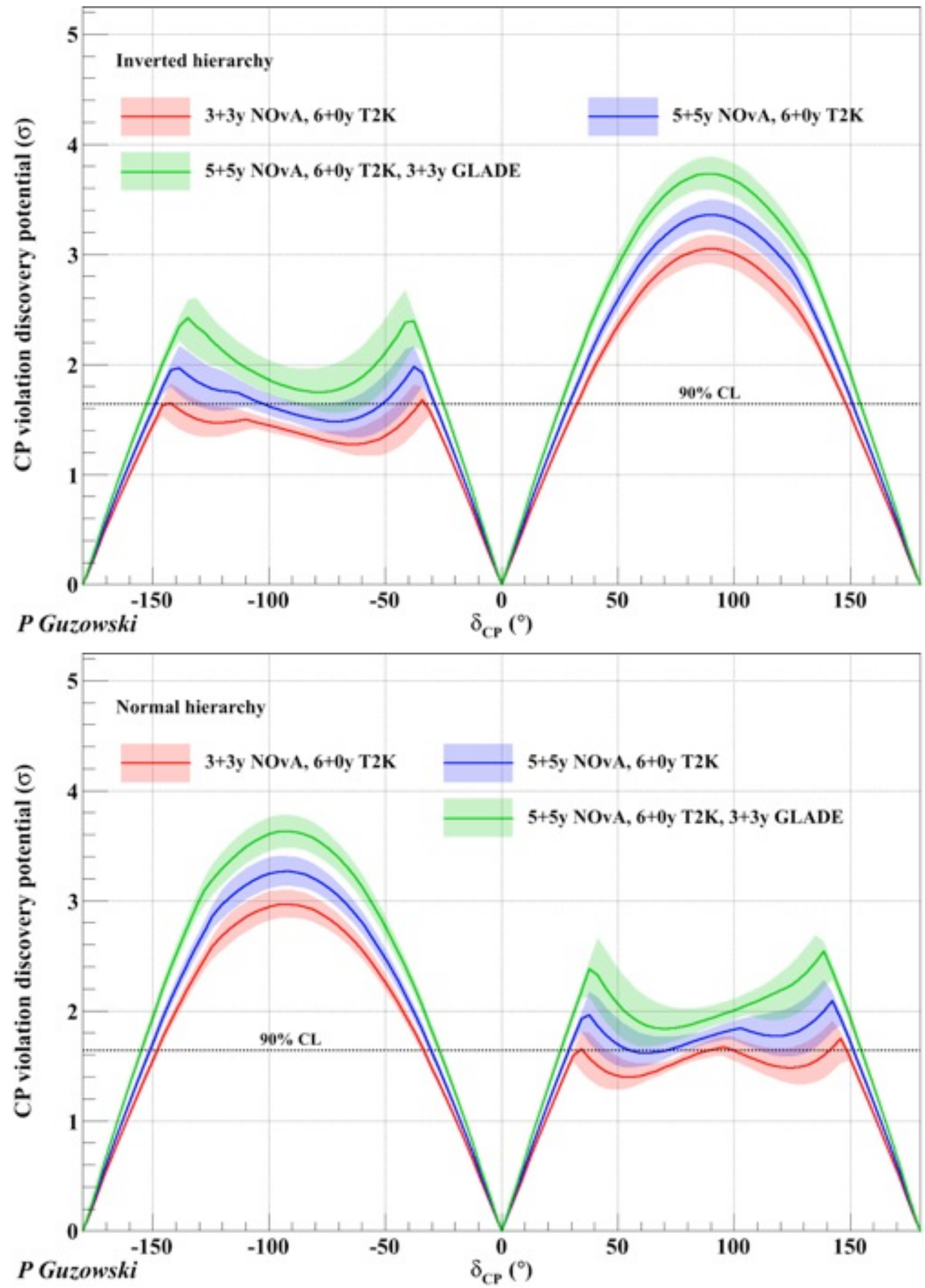




R. Nichol

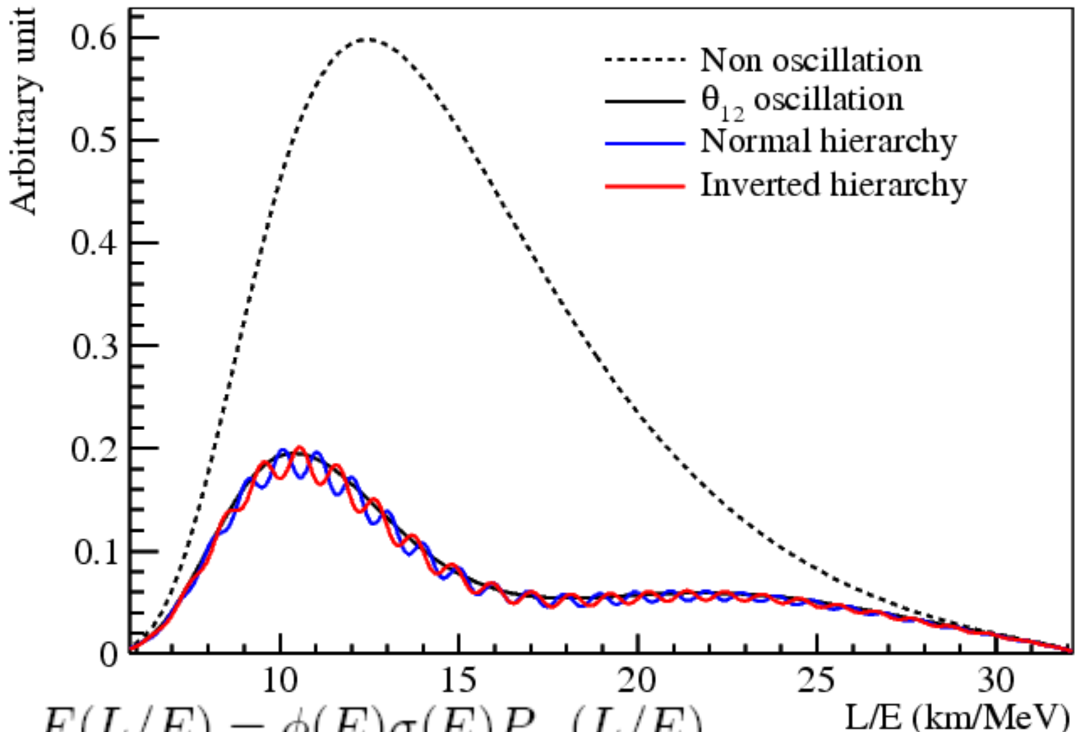
CP Violation

- Physics reach of GLADE is similar to NOvA
    - NOvA+GLADE = 2 NOvA
- Sensitivities assume we know $\sin^2 2\theta_{23}$ to 0.01 by 2020
- The (less sensitive) lower octant is assumed
- Addition of GLADE provides some 90% sensitivity in the less favourable sectors



R. Nichol

Daya Bay2



$$F(L/E) = \phi(E)\sigma(E)P_{ee}(L/E)$$

$$\begin{aligned} P_{ee}(L/E) &= 1 - P_{21} - P_{31} - P_{32} \\ P_{21} &= \cos^4(\theta_{13})\sin^2(2\theta_{12})\sin^2(\Delta_{21}) \\ P_{31} &= \cos^2(\theta_{12})\sin^2(2\theta_{13})\sin^2(\Delta_{31}) \\ P_{32} &= \sin^2(\theta_{12})\sin^2(2\theta_{13})\sin^2(\Delta_{32}) \end{aligned}$$

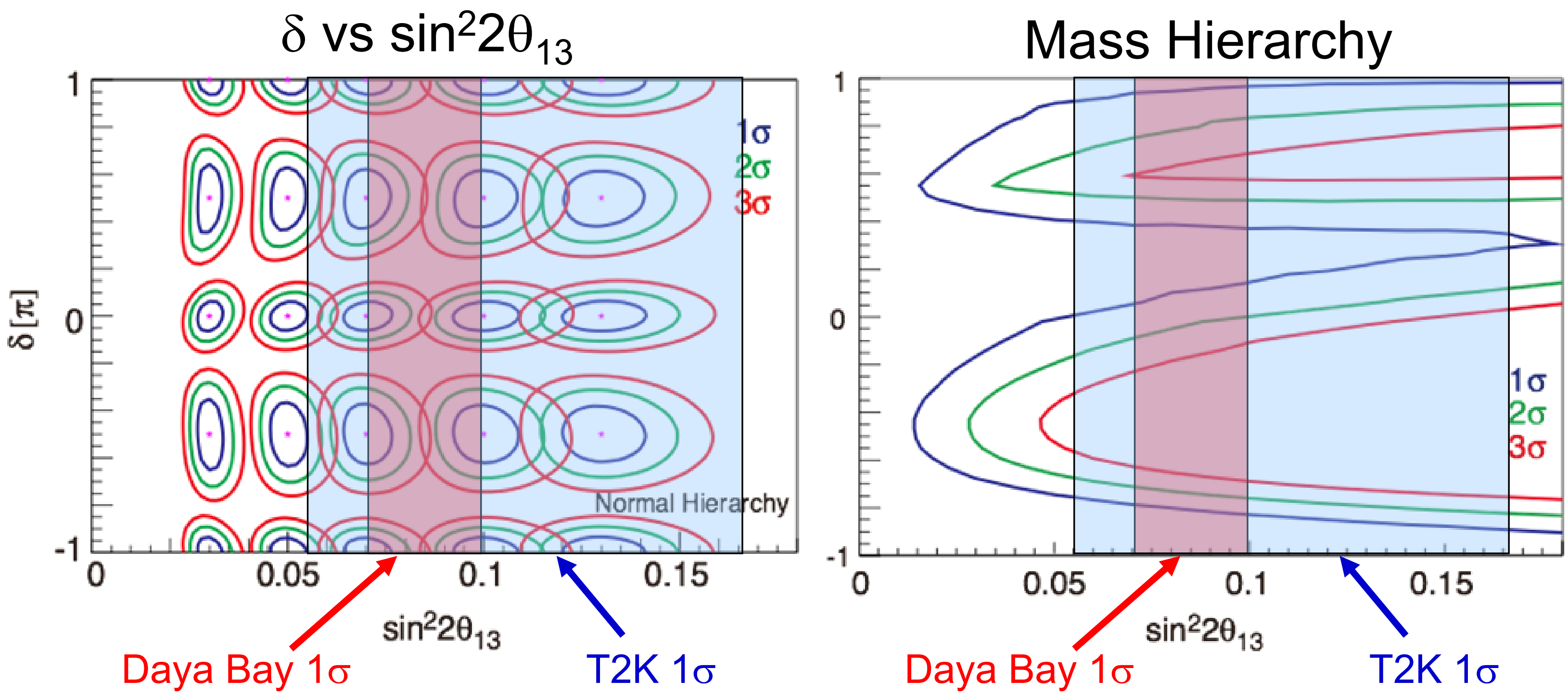
- Requires careful baseline selection
  - 1-2 km window
  - multiple baselines need to be understood
- Requires good energy resolution ~3%

Y. Hayato

HyperK

Neutrino beam from J-PARC (0.75 MW)

10 yrs of running (ν 3 yrs. + $\bar{\nu}$ 7 yrs., 1 yr ≡ 10^7 sec.)

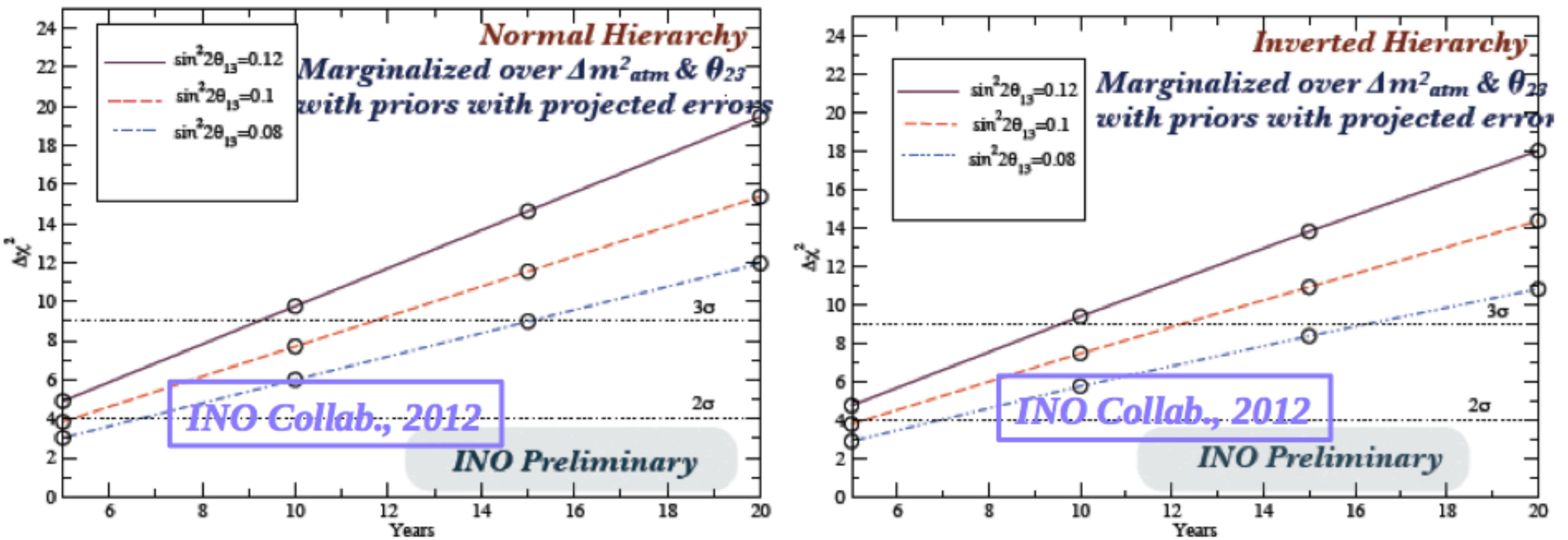


• CP phase parameter precision (w/ hierarchy info.) < 18°

• Chance to determine the mass hierarchy ~ 43%

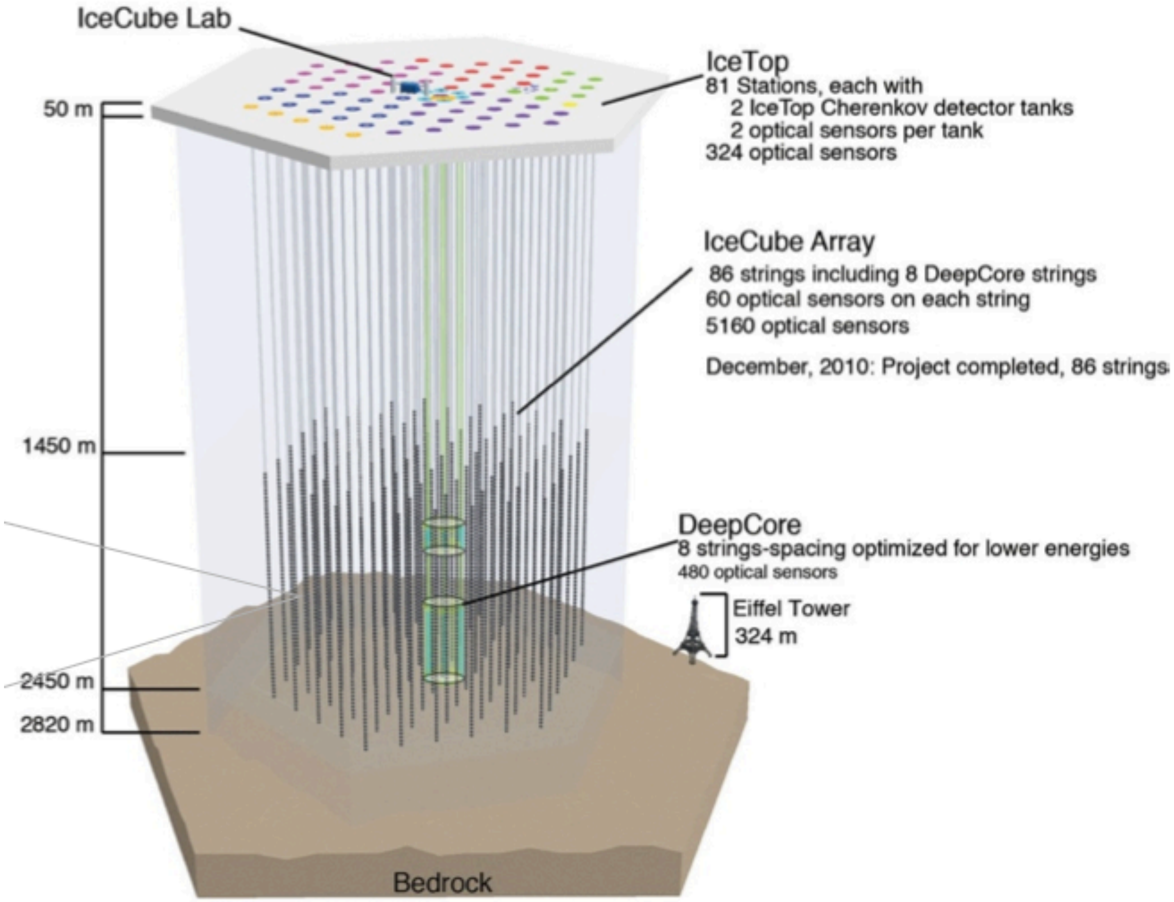
A. Dighe

INO


Normal Hierarchy
Marginalized over Δm^2_{atm} & θ_{23}
with priors with projected errors
$\sin^2 2\theta_{13}$=0.12
$\sin^2 2\theta_{13}$=0.1
$\sin^2 2\theta_{13}$=0.08
$\Delta\chi^2$
Years
3σ
2σ
INO Collab., 2012
INO Preliminary
Inverted Hierarchy
Marginalized over Δm^2_{atm} & θ_{23}
with priors with projected error
$\sin^2 2\theta_{13}$=0.12
$\sin^2 2\theta_{13}$=0.1
$\sin^2 2\theta_{13}$=0.08
$\Delta\chi^2$
Years
3σ
2σ
INO Collab., 2012
INO Preliminary

D. Cowen

Deep Core

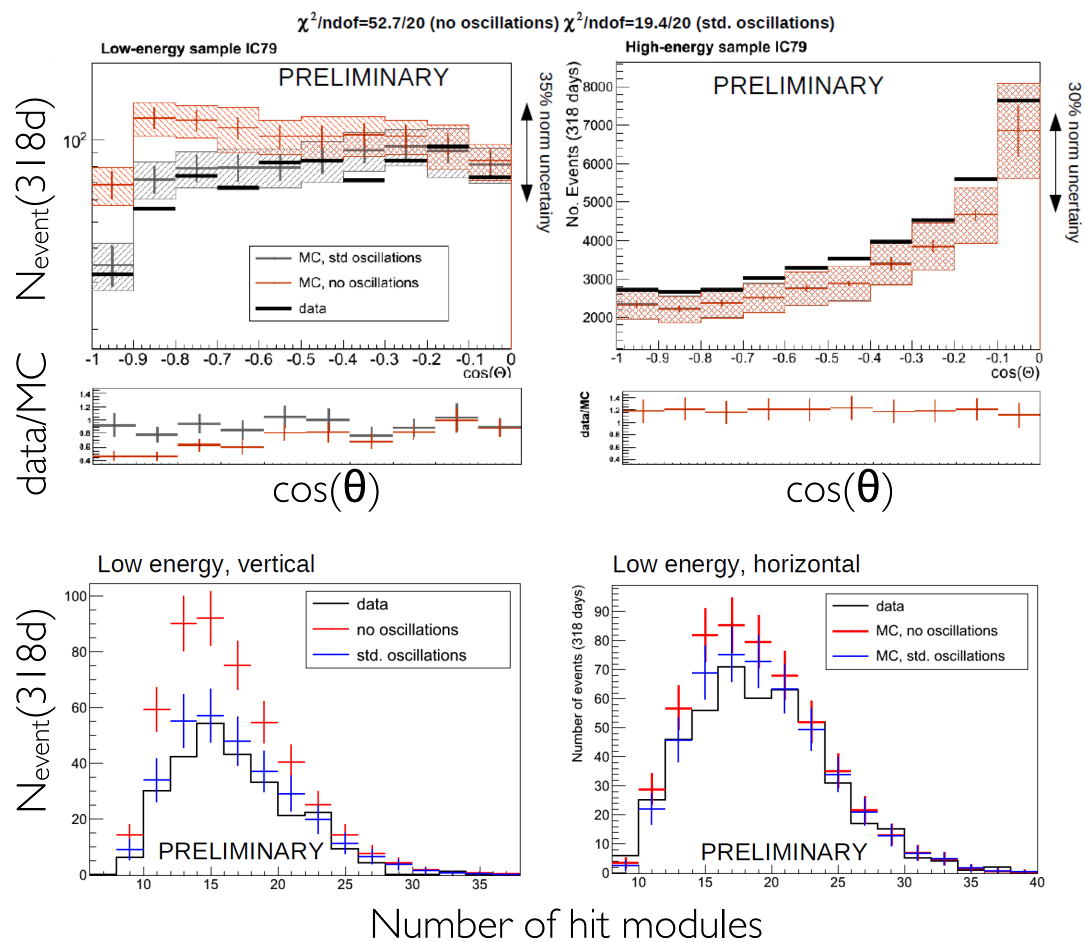


- 30 Mton effective mass (yes, Mega)
- ~10 GeV threshold
- Enriched cascade (read nue+NC) sample
- Observes atmospheric oscillations

D. Cowen

Second Result from DeepCore

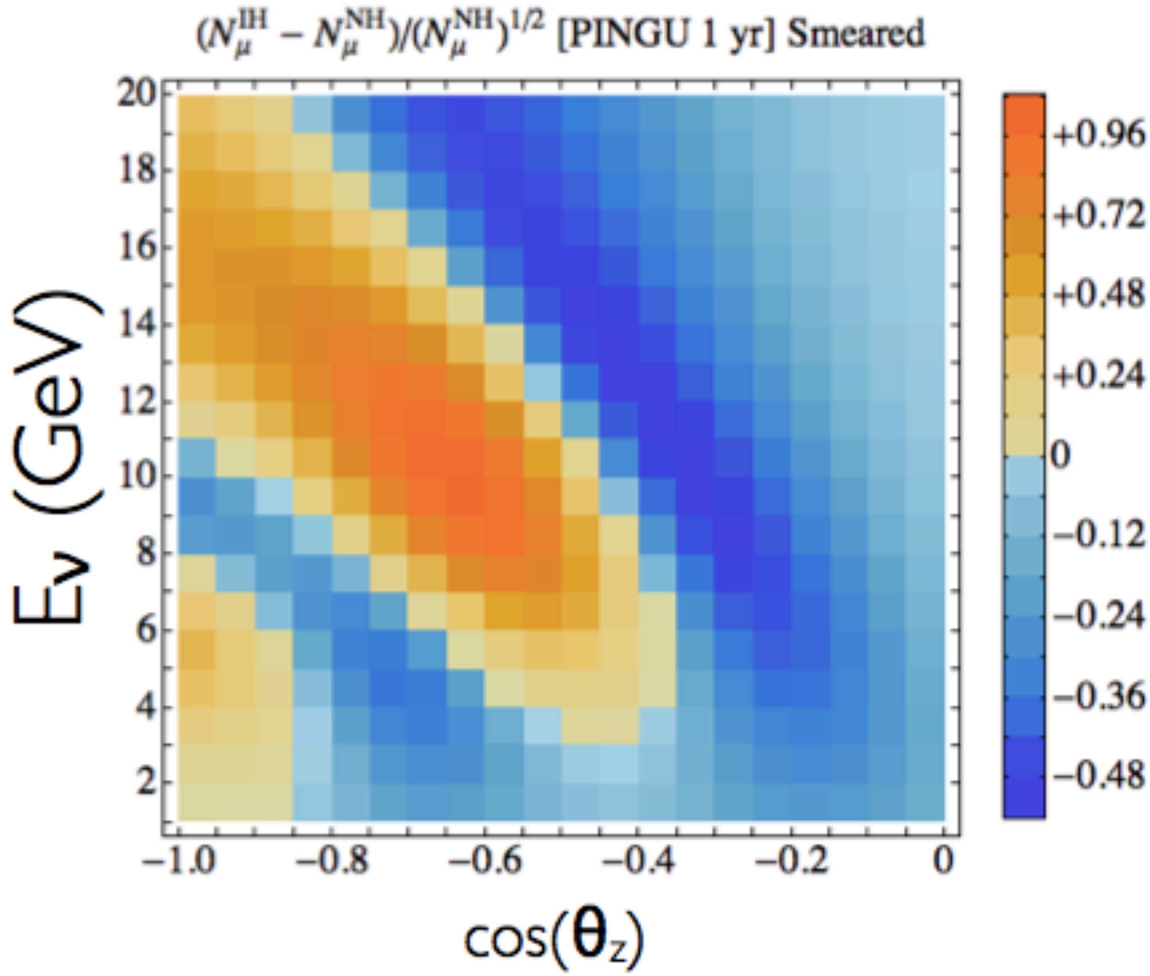
- Looked for (expected) atmospheric ν_μ oscillations at highest energies ever
- Oscillations seen
- Analysis was not designed to measure oscillation parameters
  - Ruled out no-disappearance hypothesis



Next step—Pingu

D. Cowen

- Increase string density
- Lower threshold to ~1GeV
- Effective volume 10 Mton at 10 GeV
- Sensitivity to matter effects



Impact of smearing: summed significance drops to 10σ (no systematics), 7σ (5% uncorr. syst.), 4.5σ (10% uncorr. syst.).

D. Cowen

Even better

P. Vahle, NuFACT 2012

- Assumptions:
  - 20% ν_μ CC misID
  - No energy resolution
    - A counting experiment!
  - Include irreducible backgrounds
    - intrinsic beam, NC events, ν_τ
  - signal & bkgd. systematics uncorrelated
- Conclusions:
  - 18σ effect (stat. only)
  - With particle ID, might be also sensitive to CP

NUMI beam at 10^{21} PoT

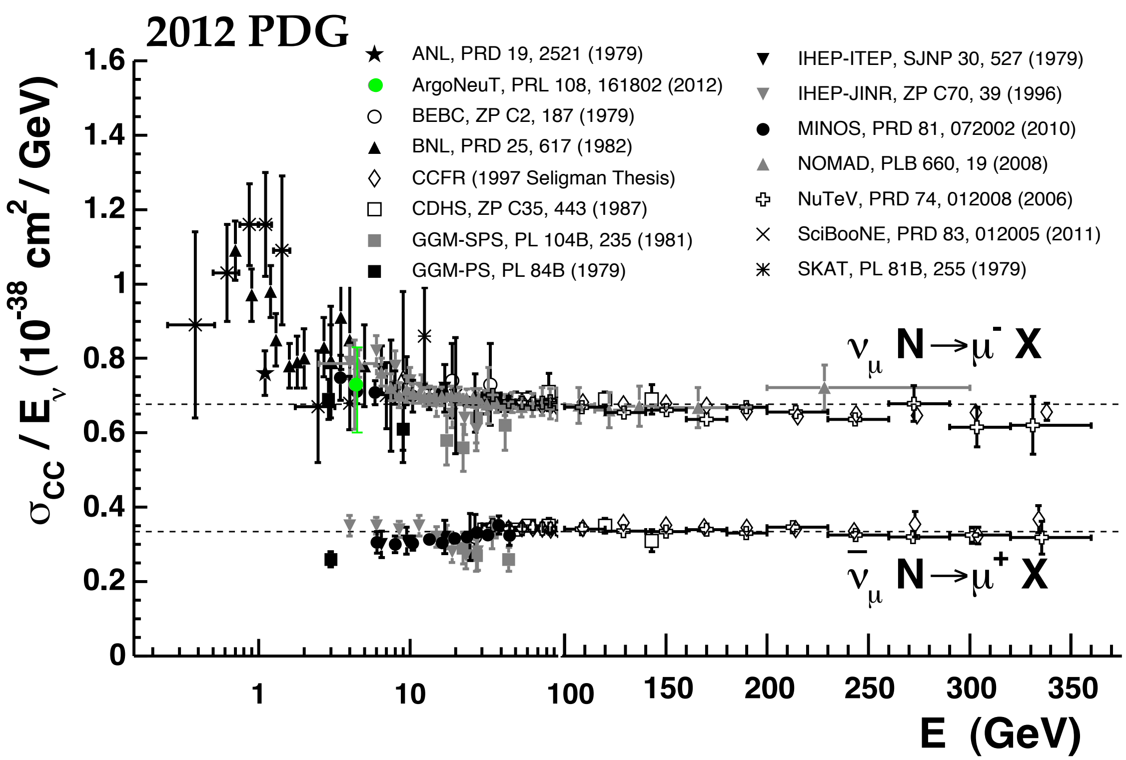
	Normal hier.	Inv. hierarchy
Signal	**1560**	**54**
Backgrounds:		
ν_e beam	39	59
Disapp./track mis-ID	511	750
ν_τ appearance	3	4
Neutral currents	2479	2479
Total backgrounds	3032	3292
Total signal+backg.	4592	3346

Table courtesy W. Winter. See also Tang and Winter, JHEP 1202 (2012) 028.

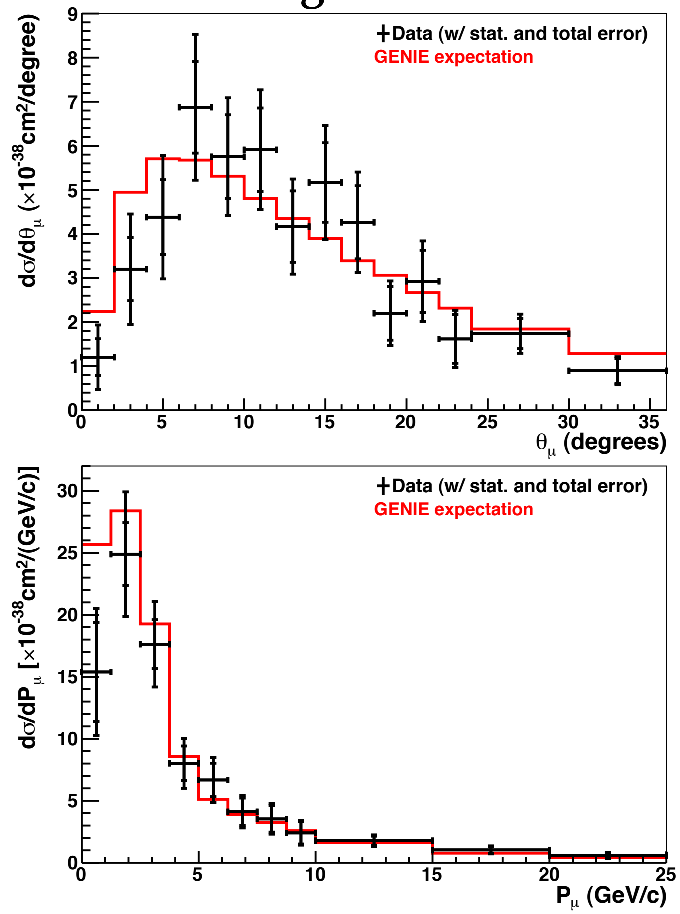
- Beam from FNAL has to point down 66 degrees…

Lar Development

P. Vahle, NuFACT 2012



ArgoNeuT



Inclusive CC cross-section

Refs:

1.) ***First Measurements of Inclusive Muon Neutrino Charged Current Differential Cross Sections on Argon*, C. Anderson et al., PRL 108 (2012) 161802, arXiv:1111.0103**

2.) *Neutrino cross section measurements*, J. Beringer et al. (Particle Data Group), Phys. Rev. D**86**, 010001 (2012)

Questions for next year

- For how long do we need to run T2K+Nova to reach the systematic/background limit? How much significance can they provide when they reach that limit?
- Evaluate the sensitivity of facilities for the different sources of systematic errors at future facilities. Which of these sources are uncorrelated between neutrino and antineutrinos? Are these systematic errors reasonable assumptions?
- Can we do precision experiments without a ND?
- How much significance for the mass hierarchy can we expect from atmospheric neutrinos and cosmology? Do we need a dedicated accelerator experiment to reach the 5 sigma level for any value of delta?

More questions

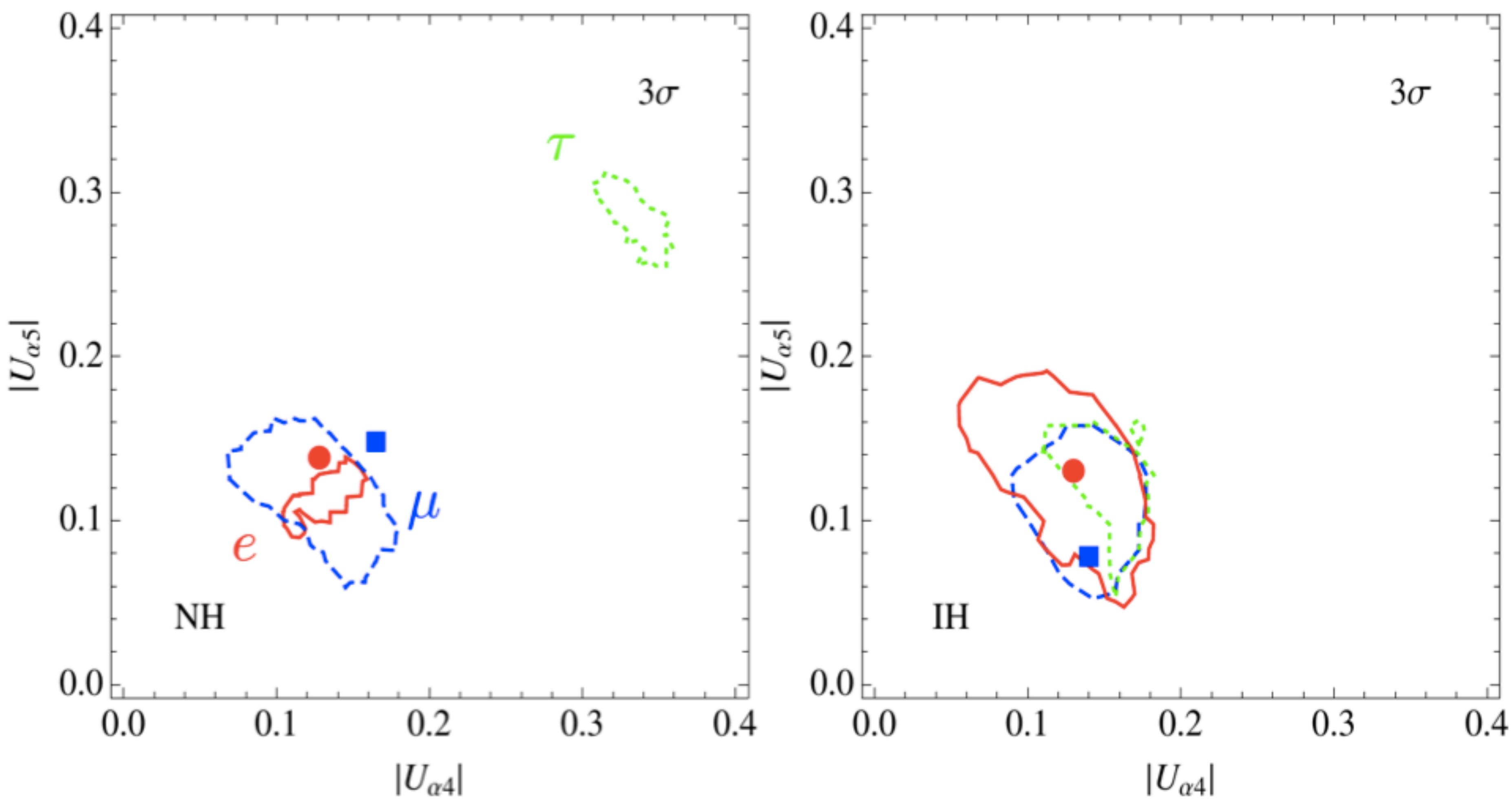
- What can we learn about the Majorana nature of neutrinos from a measurement of the mass hierarchy combined with neutrinoless double beta decay probes? If the hierarchy is inverted and we don't find 0nubb decays are neutrinos Dirac particles?
- Can we reoptimize the design of future facilities for large theta_13?
- Are off axis beams still interesting for large theta_13?
- Evaluate expected sensitivity to deviations of theta_23 from maximality and to its octant at different facilities.
- What are target precisions in each of the mixing parameters that could usefully constrain/rule out different theories?

Backup

Minimal Sterile Neutrino Model

J. Lopez-Pavon

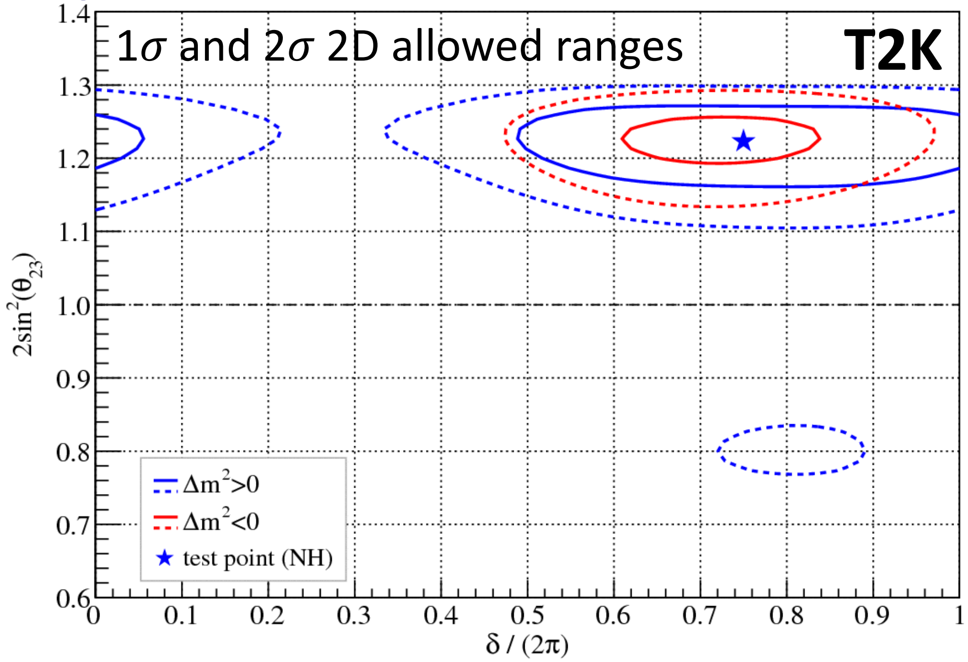
Prediction: large tau-mixing with extra states for NH!

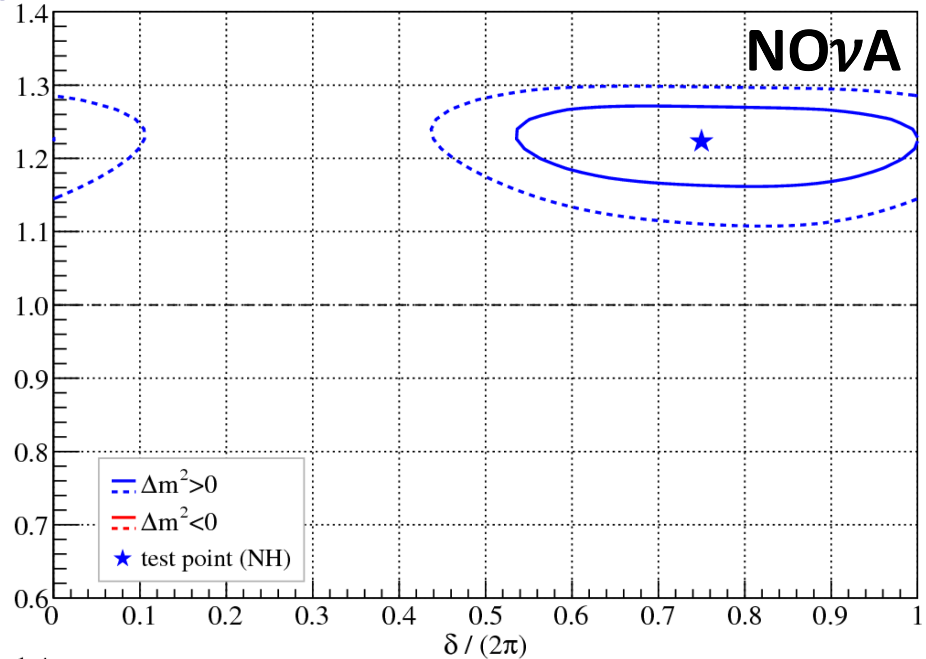


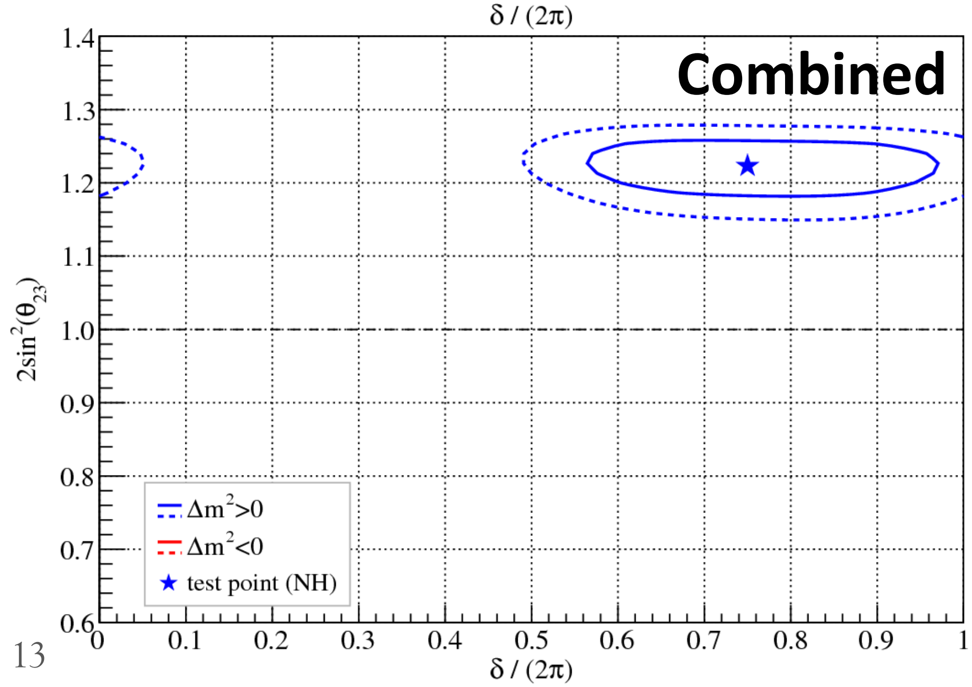
Donini, Hernandez, JLP, Maltoni, Schwetz 2012; arXiv:1205.5230

Simultaneous δ, θ_{23}, and hierarchy information expected at the end of 2019. Even split of ν, $\overline{\nu}$.

For starred point shown and $\sin^2(2\theta_{13})$=0.095



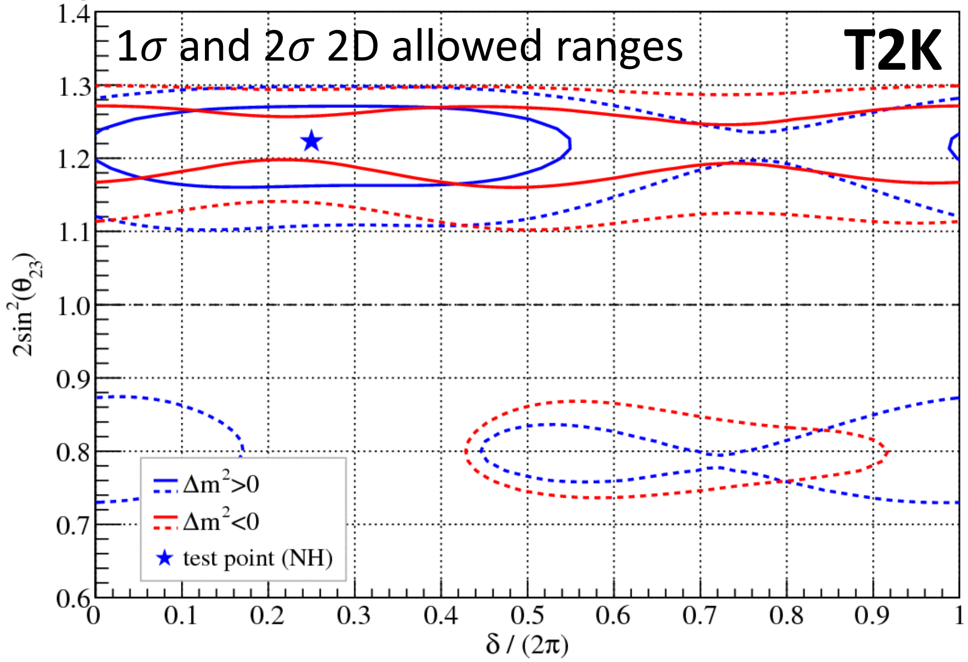


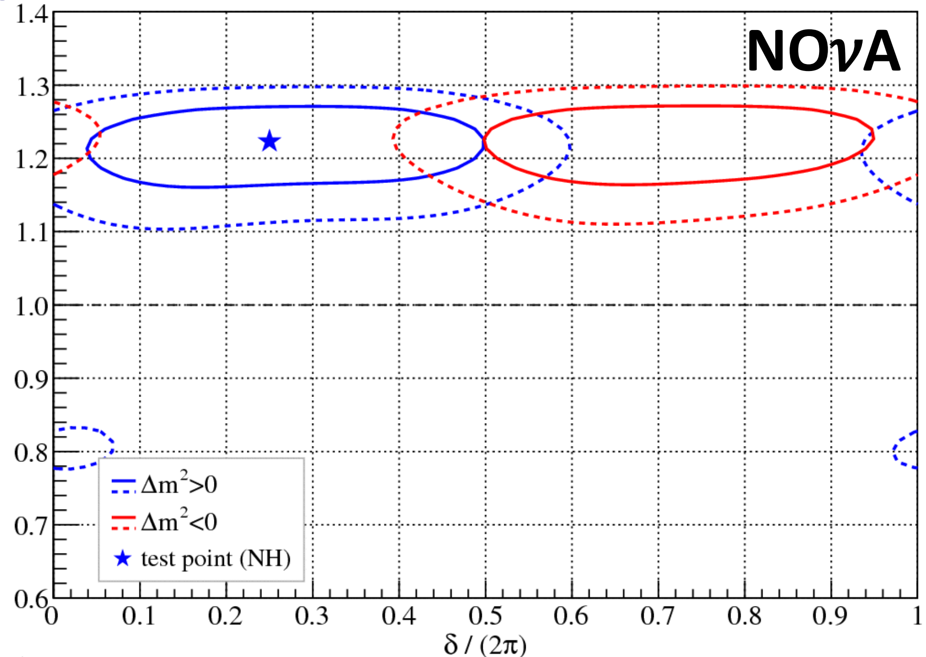


- **Non-maximal mixing scenario:** $\sin^2(2\theta_{23})$=0.95, $\theta_{23}>\pi/4$
- **Octant resolved** in NOνA and combined cases at >2σ.
- **Note:** this includes the ν_μ disappearance constraints on θ_{23}

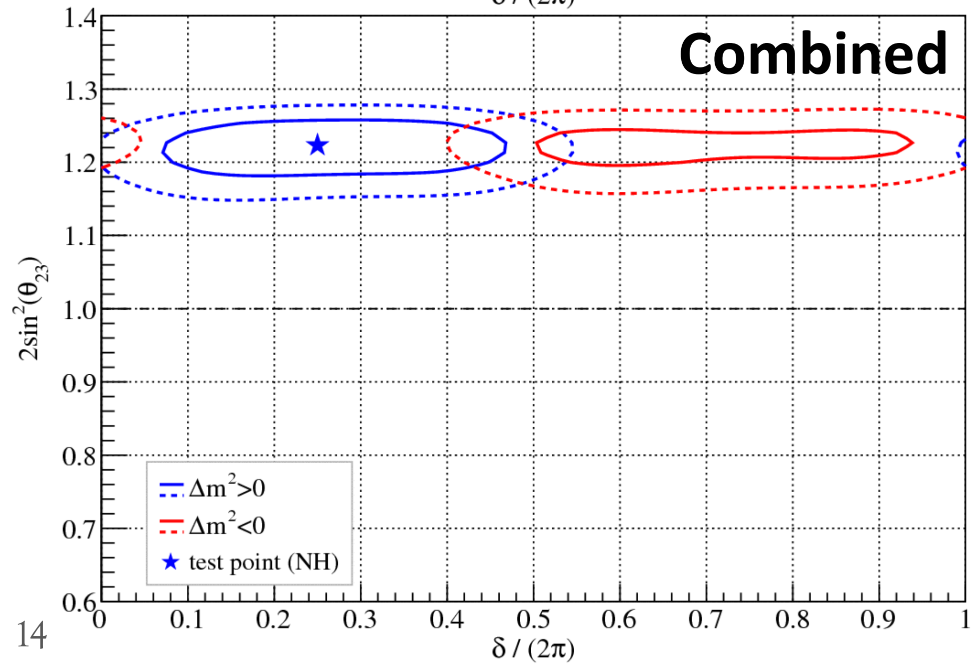
Simultaneous δ, θ_{23}, and hierarchy information expected at the end of 2019. Even split of ν, $\bar{\nu}$.

For starred point shown and $\sin^2(2\theta_{13})=0.095$

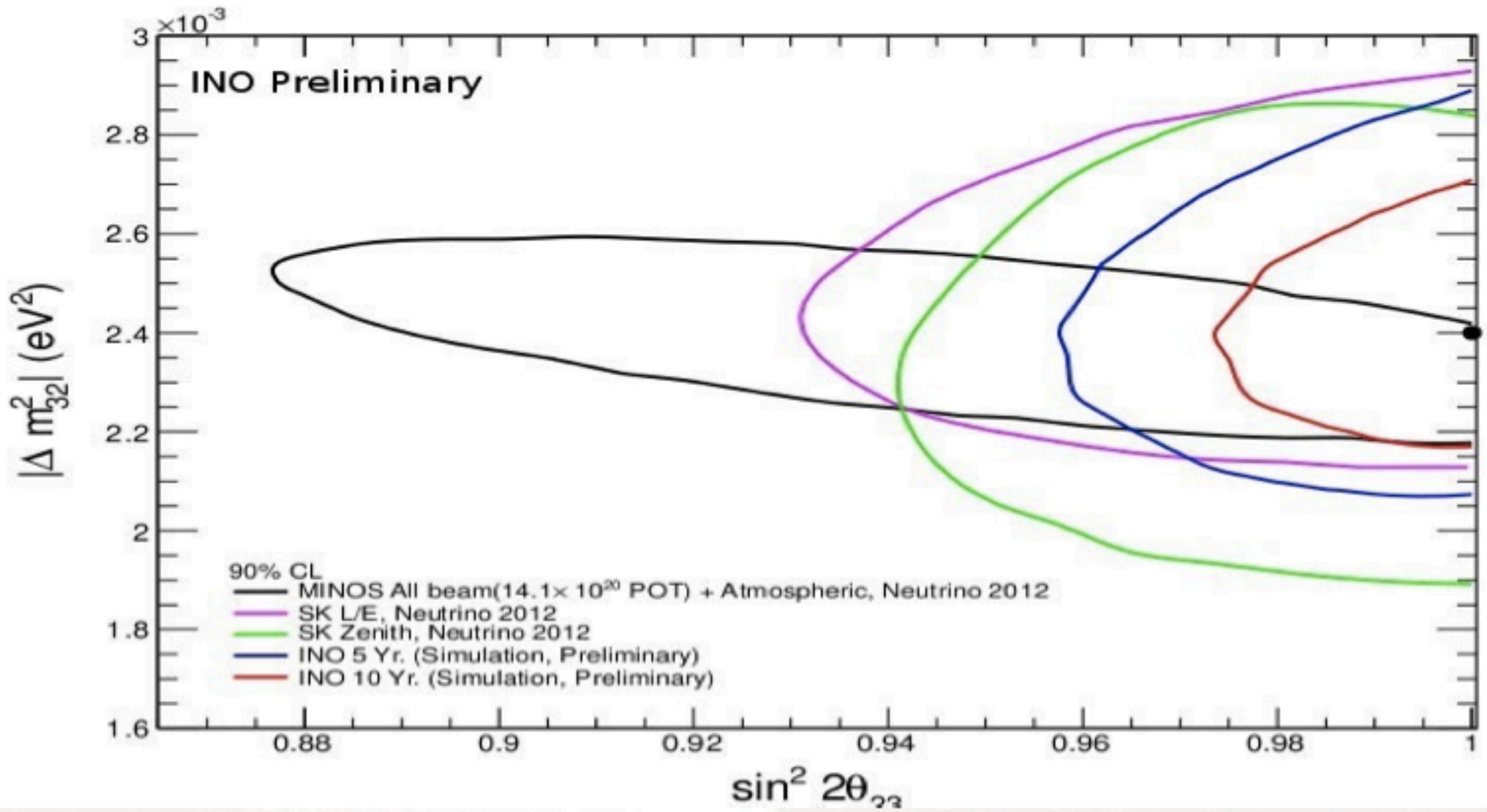




- **Non-maximal mixing scenario:**
  $\sin^2(2\theta_{23})=0.95$, $\theta_{23}>\pi/4$
- **…with unfavorable δ this time**
- **Octant still resolved** at >2σ, despite "degeneracy"
- ***This is a general point:*** *octant determination is largely insensitive to hierarchy and δ*



INO


INO Preliminary
$\times 10^{-3}$
3
2.8
2.6
2.4
2.2
2
1.8
1.6
$|\Delta m^2_{32}|$ (eV^2)
0.88
0.9
0.92
0.94
0.96
0.98
1
$\sin^2 2\theta_{23}$
90% CL
MINOS All beam(14.1× 10²⁰ POT) + Atmospheric, Neutrino 2012
SK L/E, Neutrino 2012
SK Zenith, Neutrino 2012
INO 5 Yr. (Simulation, Preliminary)
INO 10 Yr. (Simulation, Preliminary)

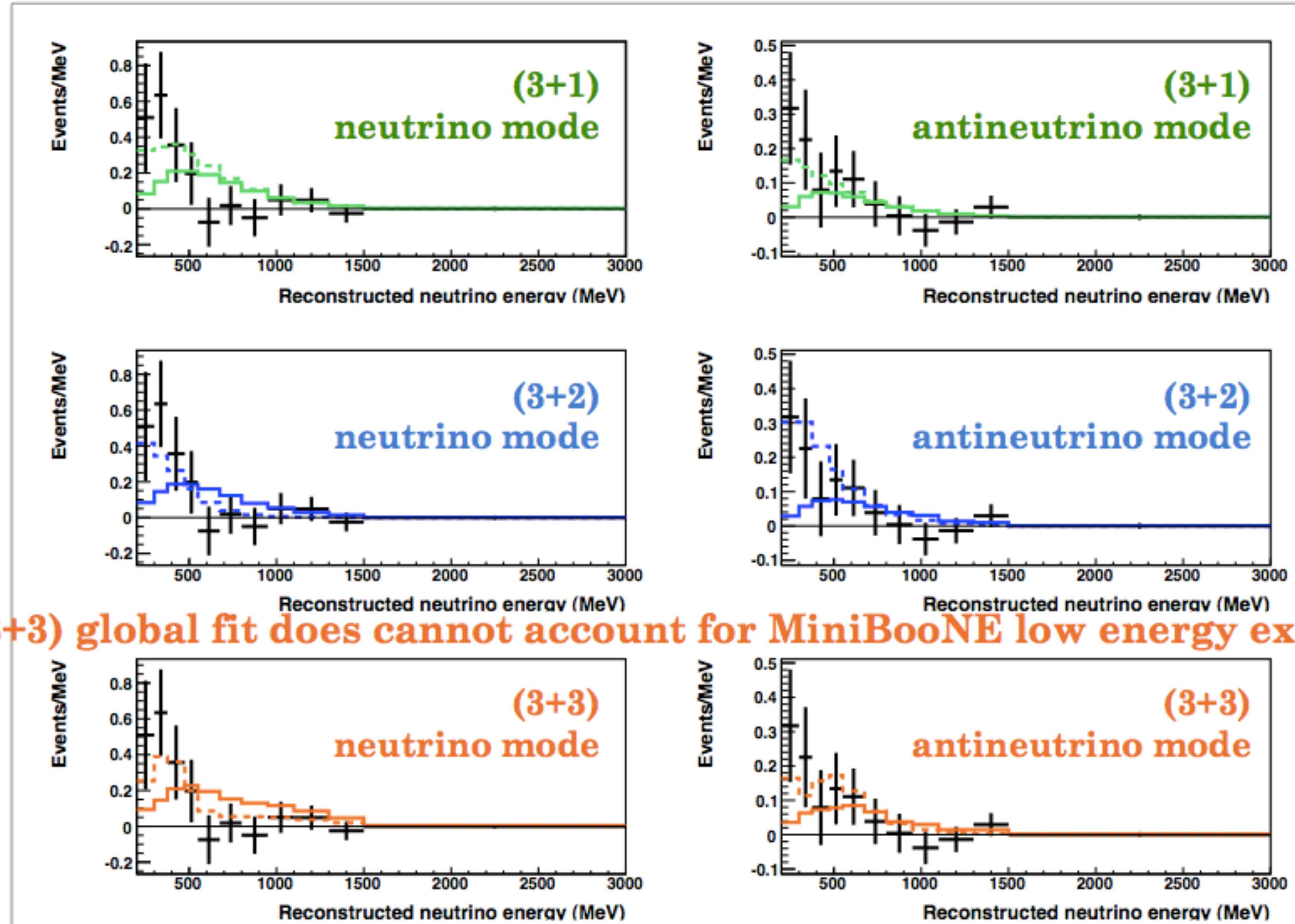
(3+3): Incompatibilities

G. Karagiorgi

—— All SBL
- - - - App SBL

- Appearance fits largely driven by MiniBooNE:

2



(3+3) global fit does cannot account for MiniBooNE low energy excess