DOE Review
May 2006

Neutrino Theory at Fermilab

- Scientists: Boris Kayser, Stephen Parke, Chris Quigg
- Post Doc: Mu-Chen Chen, Olga Mena
- Users: Andre de Gouvea and Carl Albright

Nu Research Papers:

Neutrino **Coannihilation on Dark-Matter Relics?**
Gabriela Barenboim (**Valencia U.**) , **Olga Mena Requejo**, **Chris Quigg** (**Fermilab**) . **FERMILAB-PUB-06-050-T, Apr 2006. 5pp.**
e-Print Archive: astro-ph/0604215

What fraction of boron-8 solar neutrino**s arrive at the earth as a nu(2) mass eigenstate?**
Hiroshi Nunokawa (**Rio de Janeiro, Pont. U. Catol.**) , **Stephen J. Parke** (**Fermilab**) , **Renata Zukanovich Funchal** (**Sao Paulo U.**) . **FERMILAB-PUB-05-049-T, Jan 2006. 23pp.**
Dedicated to the memory of John Bahcall who championed solar neutrinos for many lonely years.
e-Print Archive: hep-ph/0601198

Super-NOnuA: A Long-baseline neutrino **experiment with two off-axis detectors.**
Olga Mena Requejo (**Fermilab**) , **Sergio Palomares-Ruiz** (**Vanderbilt U.**) , **Silvia Pascoli** (**CERN**) . **CERN-PH-TH-2005-050, FERMILAB-PUB-05-050-T, Apr 2005. 17pp.**
Published in Phys.Rev.D72:053002,2005
e-Print Archive: **hep-ph/0504015**

Determining the neutrino **mass hierarchy and CP violation in NoVA with a second off-axis detector.**
Olga Mena (**Fermilab**) , **Sergio Palomares-Ruiz** (**Vanderbilt U.**) , **Silvia Pascoli** (**CERN & Durham U., IPPP**) .
CERN-PH-TH-2005-195, IPPP-05-63, DCPT-05-126, FERMILAB-PUB-05-461-T, Oct 2005. 20pp.
Published in Phys.Rev.D73:073007,2006
e-Print Archive: hep-ph/0510182

Physics potential of the Fermilab NuMI beamline.
Olga Mena, **Stephen J. Parke** (**Fermilab**) .
FERMILAB-PUB-05-196-T, May 2005. 22pp.
Published in Phys.Rev.D72:053003,2005
e-Print Archive: **hep-ph/0505202**

Theory of neutrino**s: A White paper.**
R.N. Mohapatra *et al.* **FERMILAB-TM-2342-T, SLAC-PUB-11622, Oct 2005. 143pp.**
e-Print Archive: hep-ph/0510213

Neutrino physics.
Boris Kayser (**Fermilab**) . **SSI-2004-L004, FERMILAB-PUB-05-236-T, Jun 2005. 21pp.**
Lectures given at 32nd SLAC Summer Institute on Particle Physics (SSI 2004): Natures Greatest Puzzles, Menlo Park, California, 2-13 Aug 2004.
Published in eConf C040802:L004,2004
e-Print Archive: hep-ph/0506165

Conference Proceedings:

many ...

Committees:

Kayser; APS(hep/nucl), NuSAG, Fermilab PAC, P5

Academic Lectures:

Boris Kayser (4) and Stephen Parke (4)

Studies:

Proton Driver: Parke and Mena

FNAL Experiments:

MINOS, mini-BOONE

NOvA

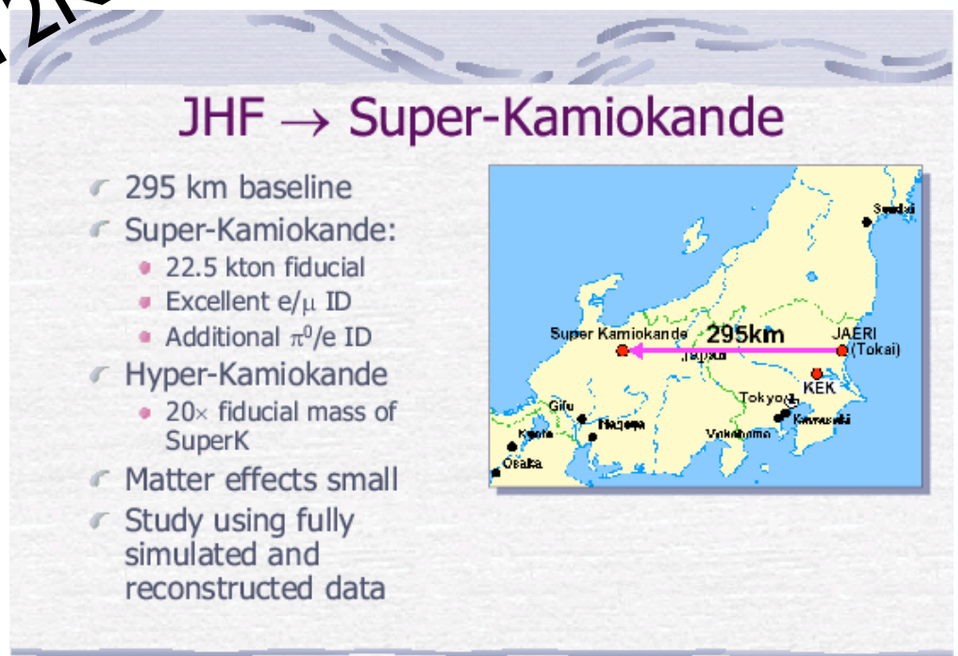
Hierarchy Determination: Counting Expts at First Osc. Max.

- Neutrino ν Anti-Neutrino NOvA Expt.

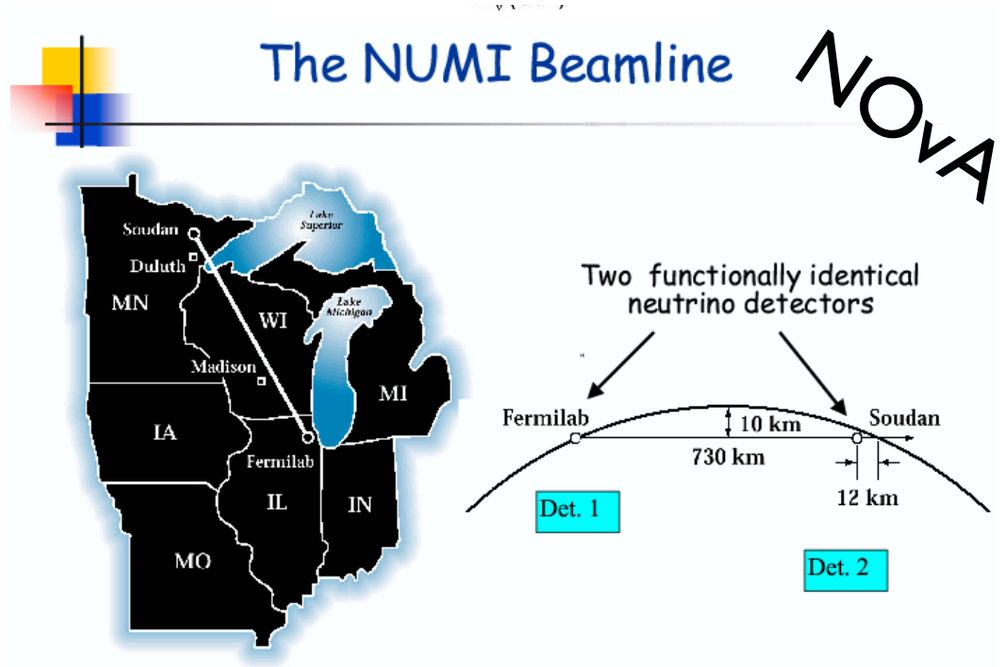
- Neutrino ν Neutrino Two Expts Different L's and EQUAL E/L's: NOvA+T2K

- Neutrino ν Anti-Neutrino Two Expts Different L's: NOvA+T2K

T2K

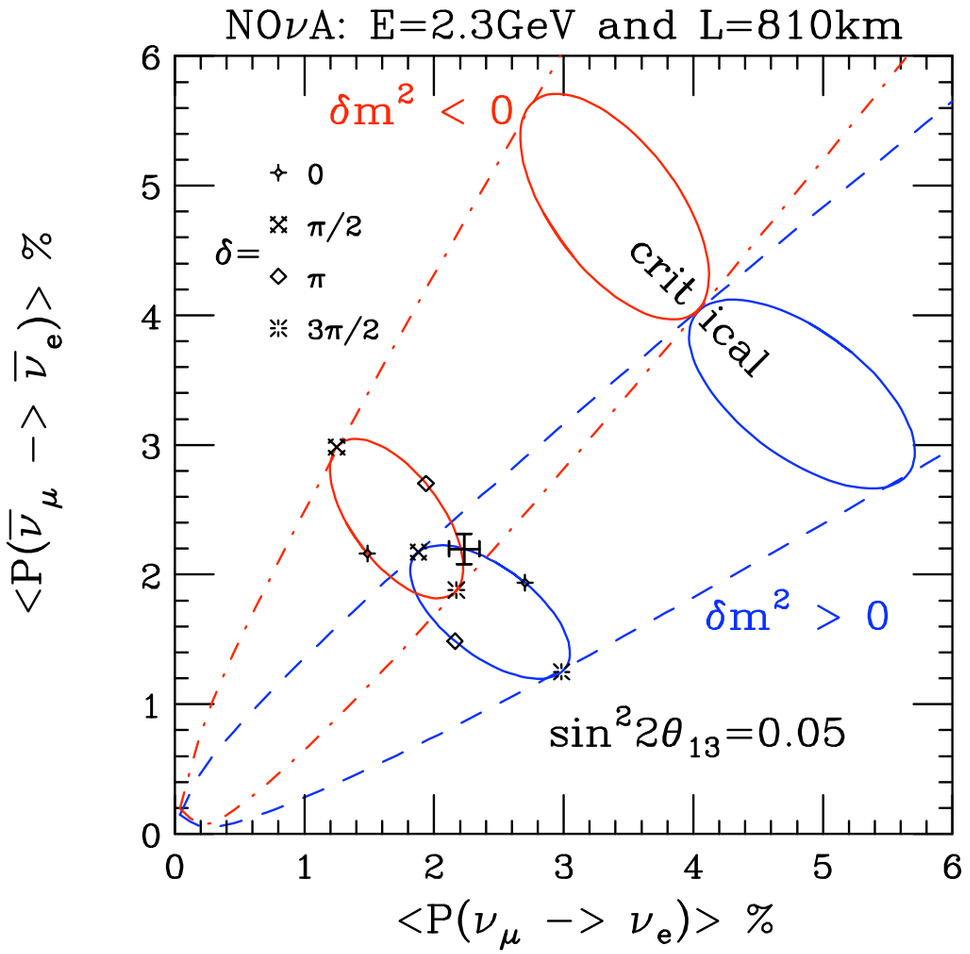


NOvA



I PHYSICS POTENTIAL OF THE FERMILAB NUMI BEAMLINE

Olga Mena, Stephen J. Parke hep-ph/0505202



S: 4 +4 yrs

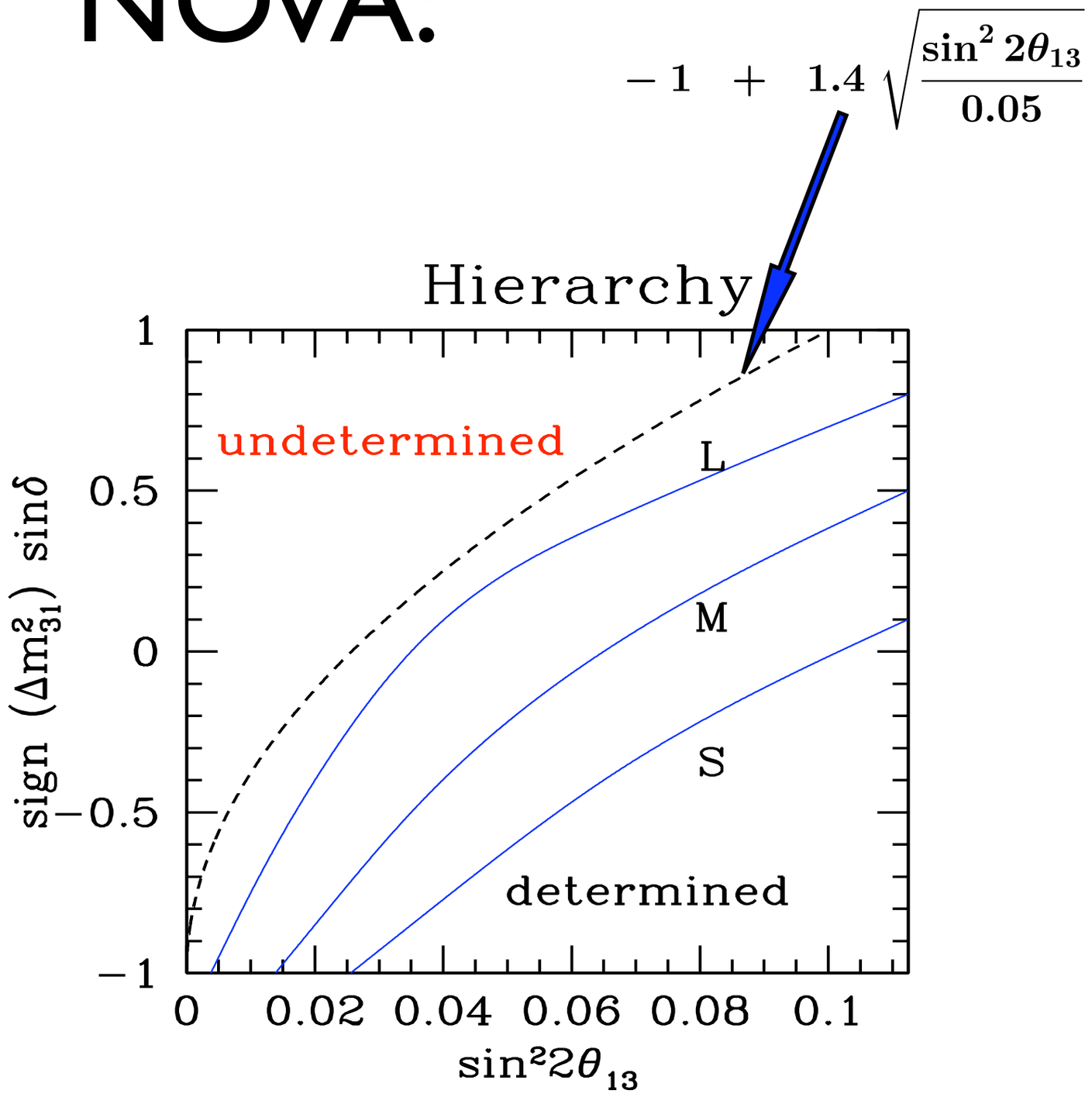
M (=5*S):

Proton Driver

L (=5*M):

PD + Liquid Argon

NOvA:

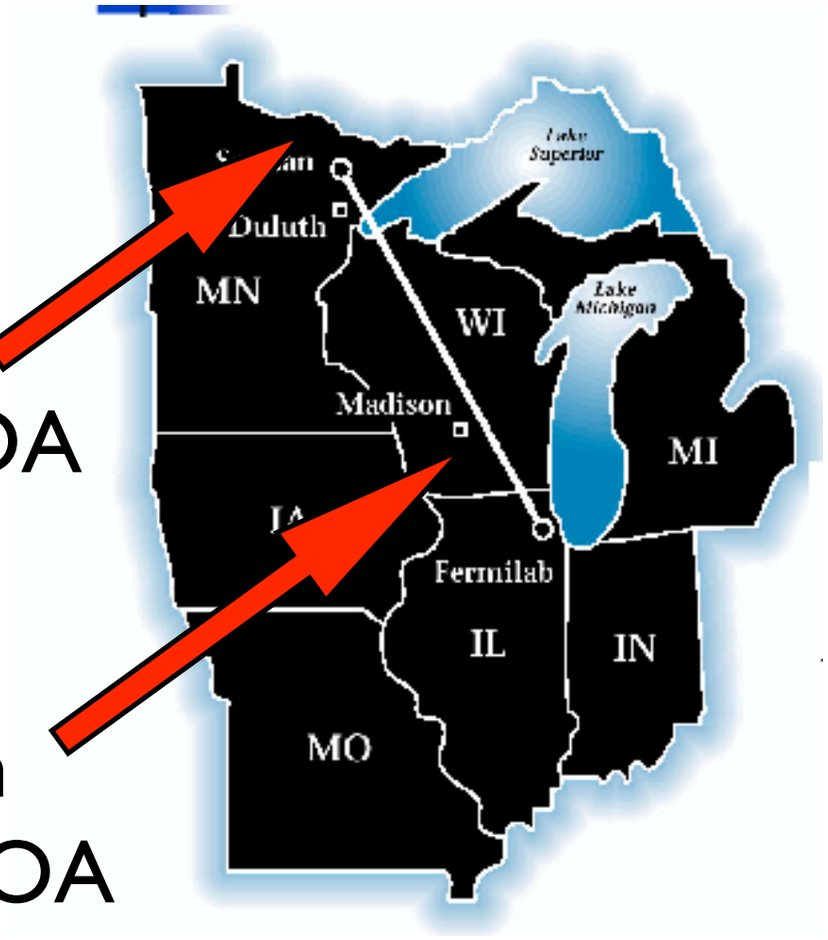


II Super-NOvA: Olga Mena with S. Palomares-Ruiz and S. Pascoli

hep-ph/0504015 & 05101182

NOvA plus "NEAR" DETECTOR

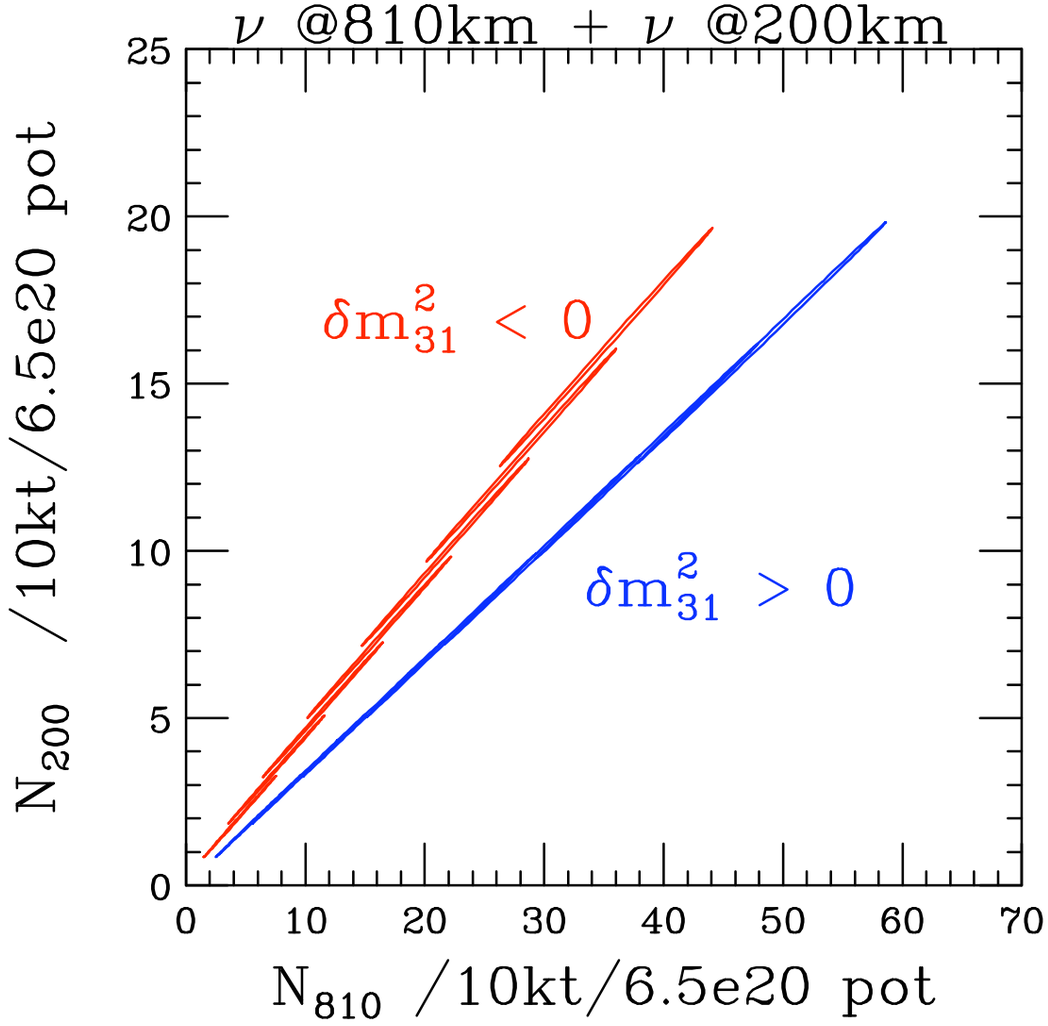
810km
@ 10 km OA
2.3 GeV



200km
@ 8 km OA
0.7 GeV

approx same
E/L

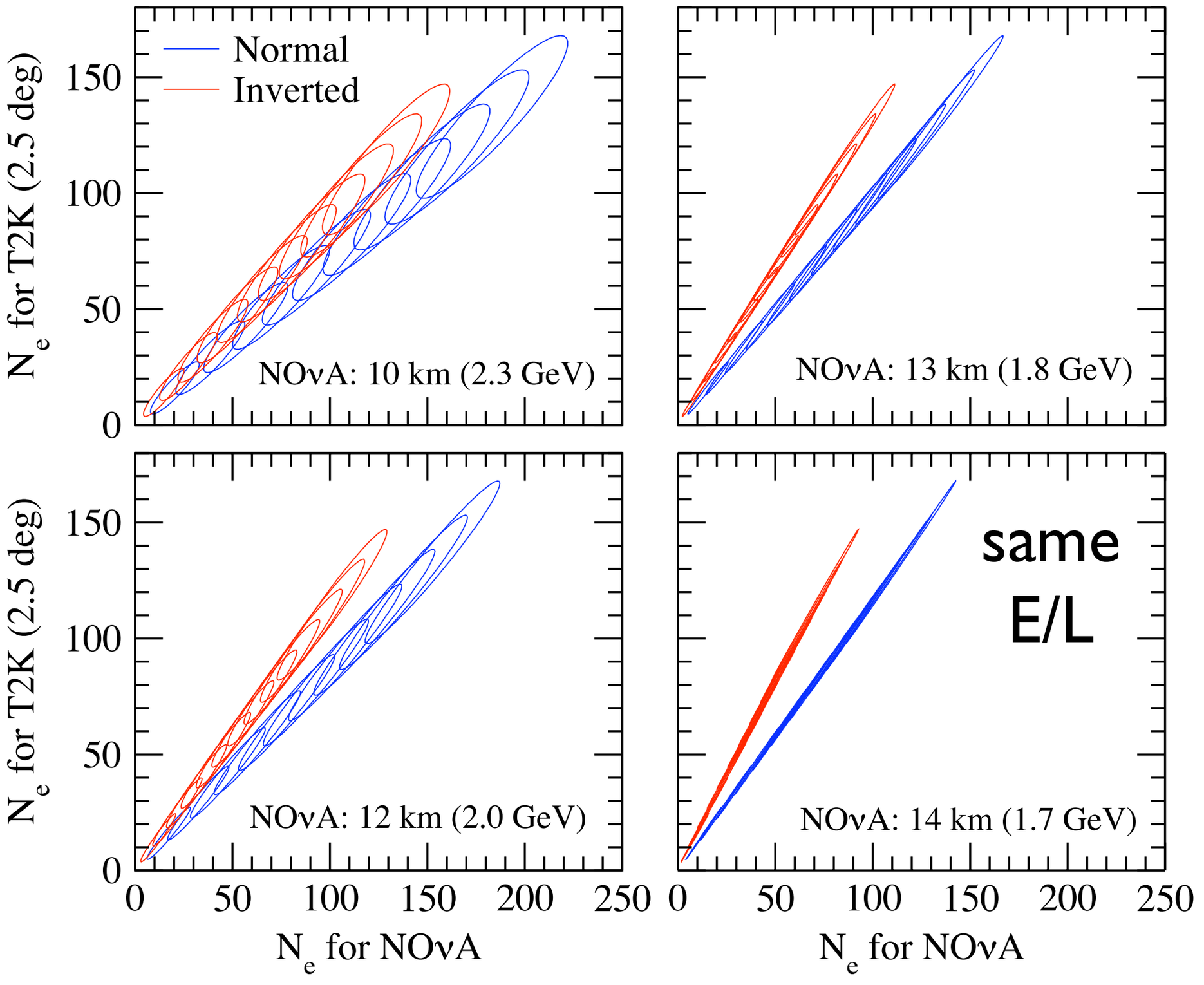
Neutrino - Neutrino



$\sin^2 2\theta_{13}=(1,\ 2,\ 3,\ 4.3,\ 6,\ 7.4,\ 9.5)\ 10^{-2}$

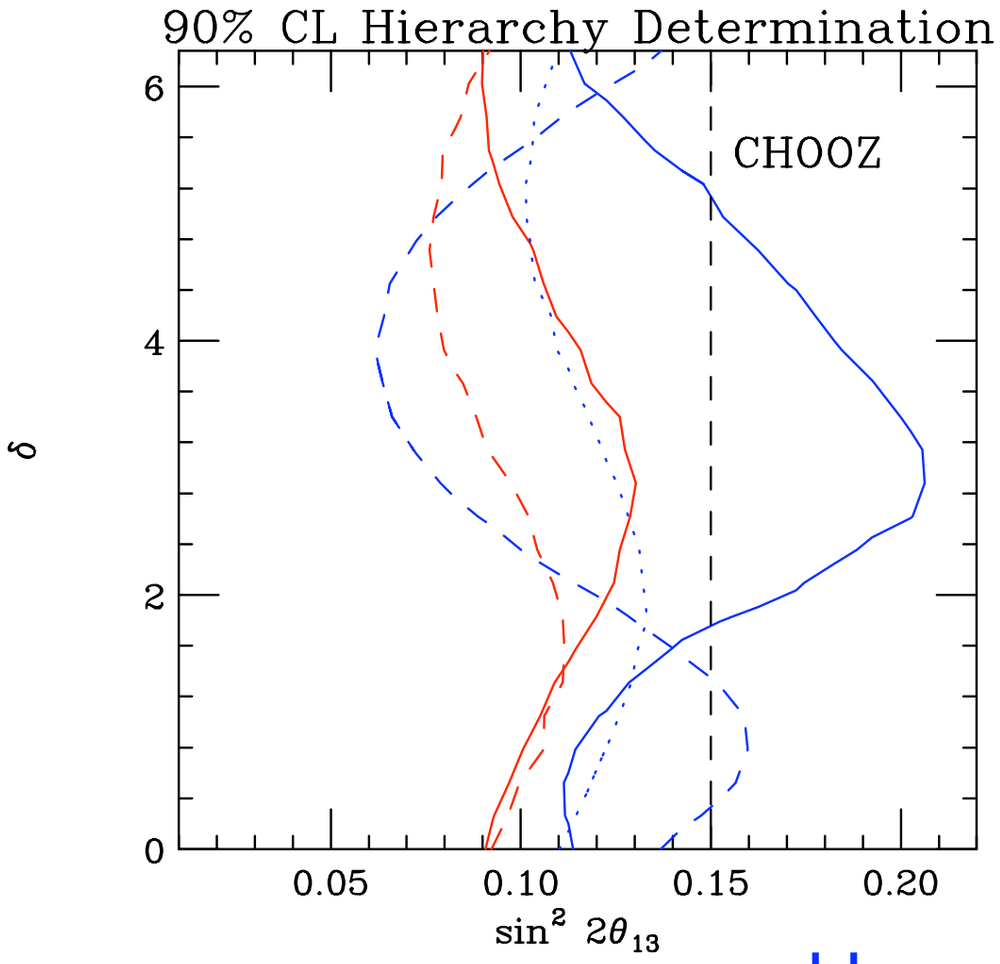
Mena + Parke: hep-ph/0606nnn

What about combining T2K and NOvA?
Neutrinos Only

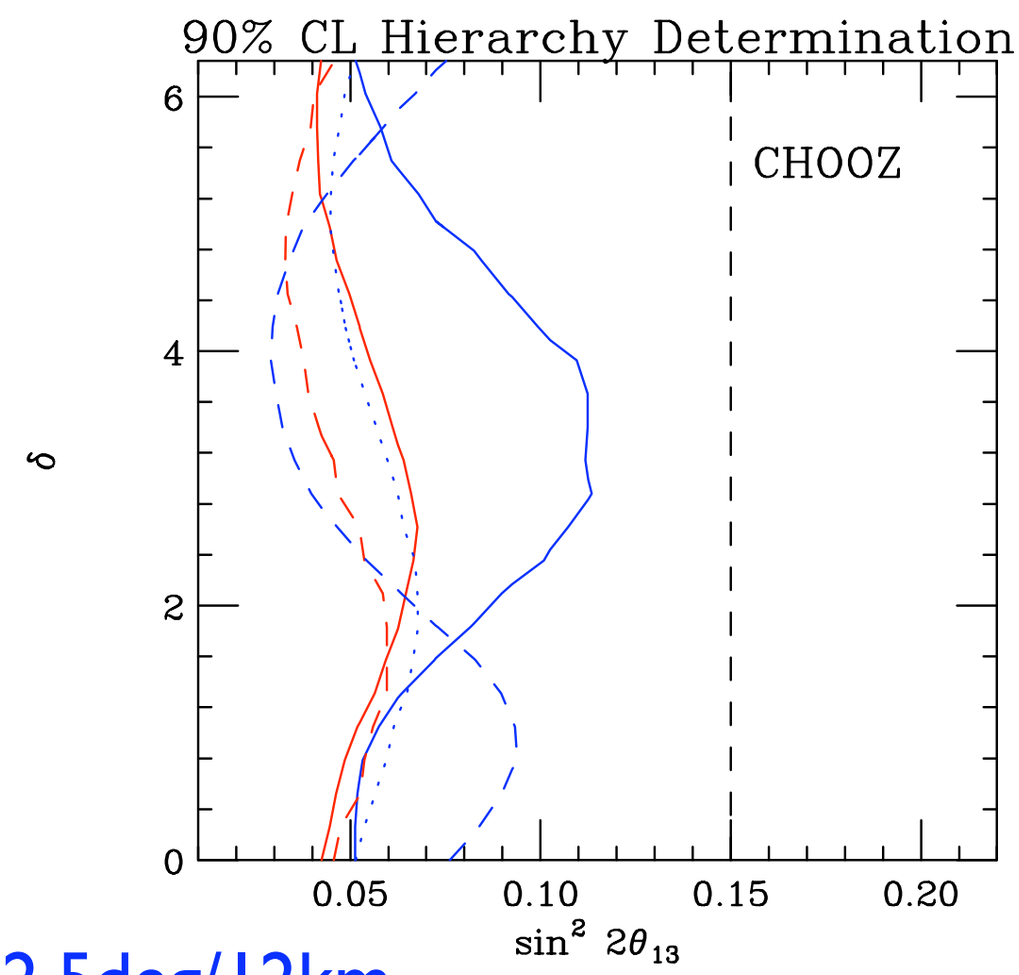


T2K (deg) + NOvA (km)
Off Axis:

phase I



phase II



blue solid 2.5deg/12km

red solid 2.5deg/13km

red dashed 2.5deg/14km

blue dashed 2.5 deg/16km

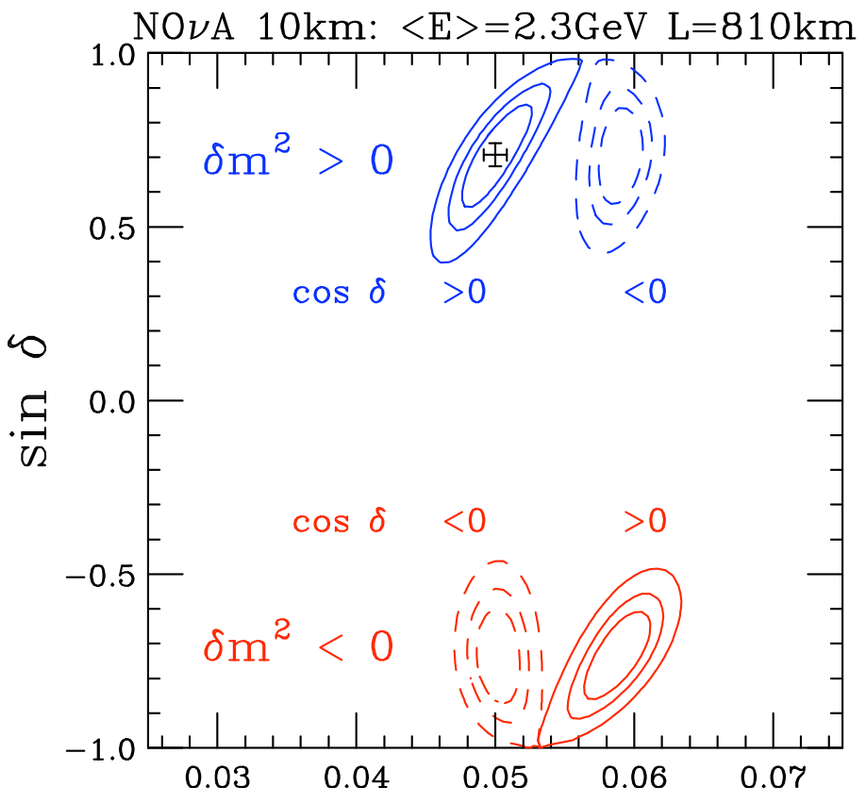
blue dotted 2.0deg/12km

III

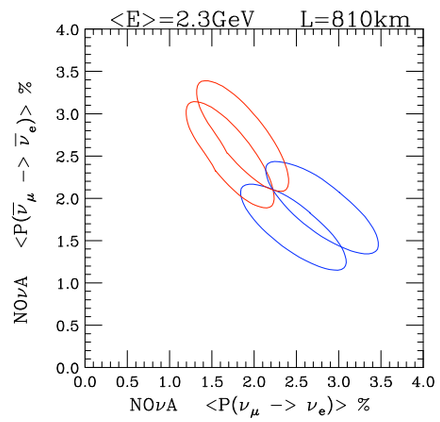
UNTANGLING CP VIOLATION AND THE MASS HIERARCHY IN LONG BASELINE EXPERIMENTS.

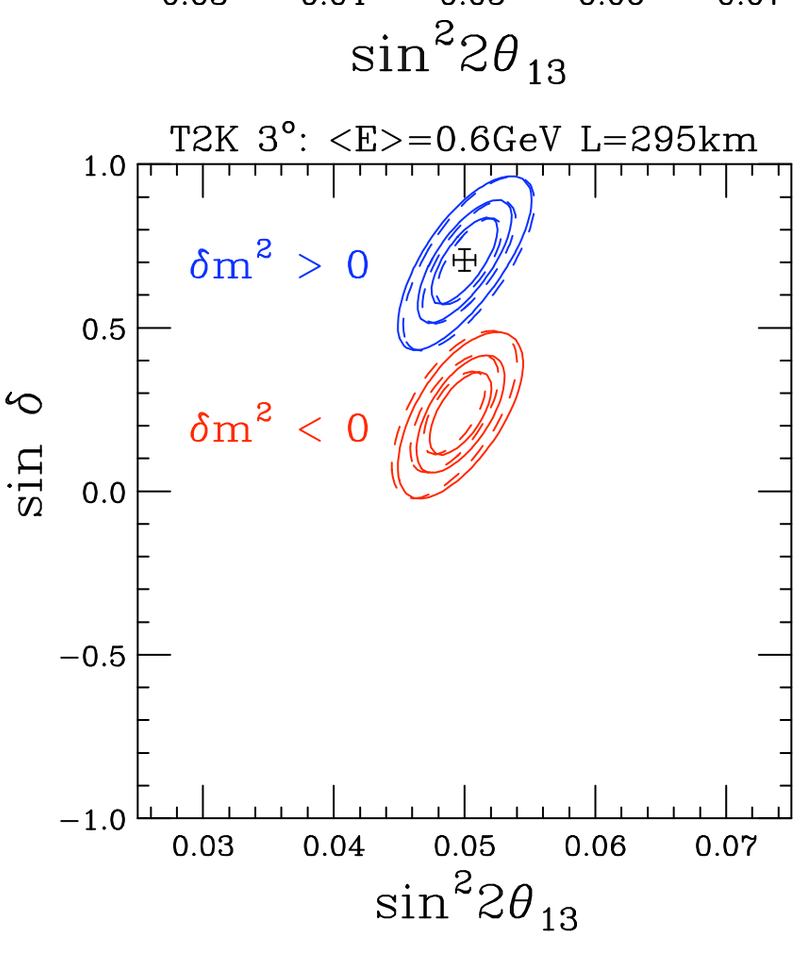
Olga Mena, Stephen J. Parke

hep-ph/0408070



$$\langle \sin\delta \rangle_+ - \langle \sin\delta \rangle_- \;=\; 1.41\sqrt{\frac{\sin^2 2\theta_{13}}{0.05}} \qquad \text{for NO}\nu\text{A.}$$





$$\langle \sin\delta \rangle_+ - \langle \sin\delta \rangle_- \;=\; 0.47\sqrt{\frac{\sin^2 2\theta_{13}}{0.05}} \qquad \text{for T2K}$$

$$\left| \langle \sin\delta \rangle^{\boldsymbol{T2K}}_{\boldsymbol{fake}} - \langle \sin\delta \rangle^{\boldsymbol{NO\nu A}}_{\boldsymbol{fake}} \right| \;=\; 0.94\sqrt{\frac{\sin^2 2\theta_{13}}{0.05}}.$$

For an "early" determination of the Neutrino Mass Hierarchy,

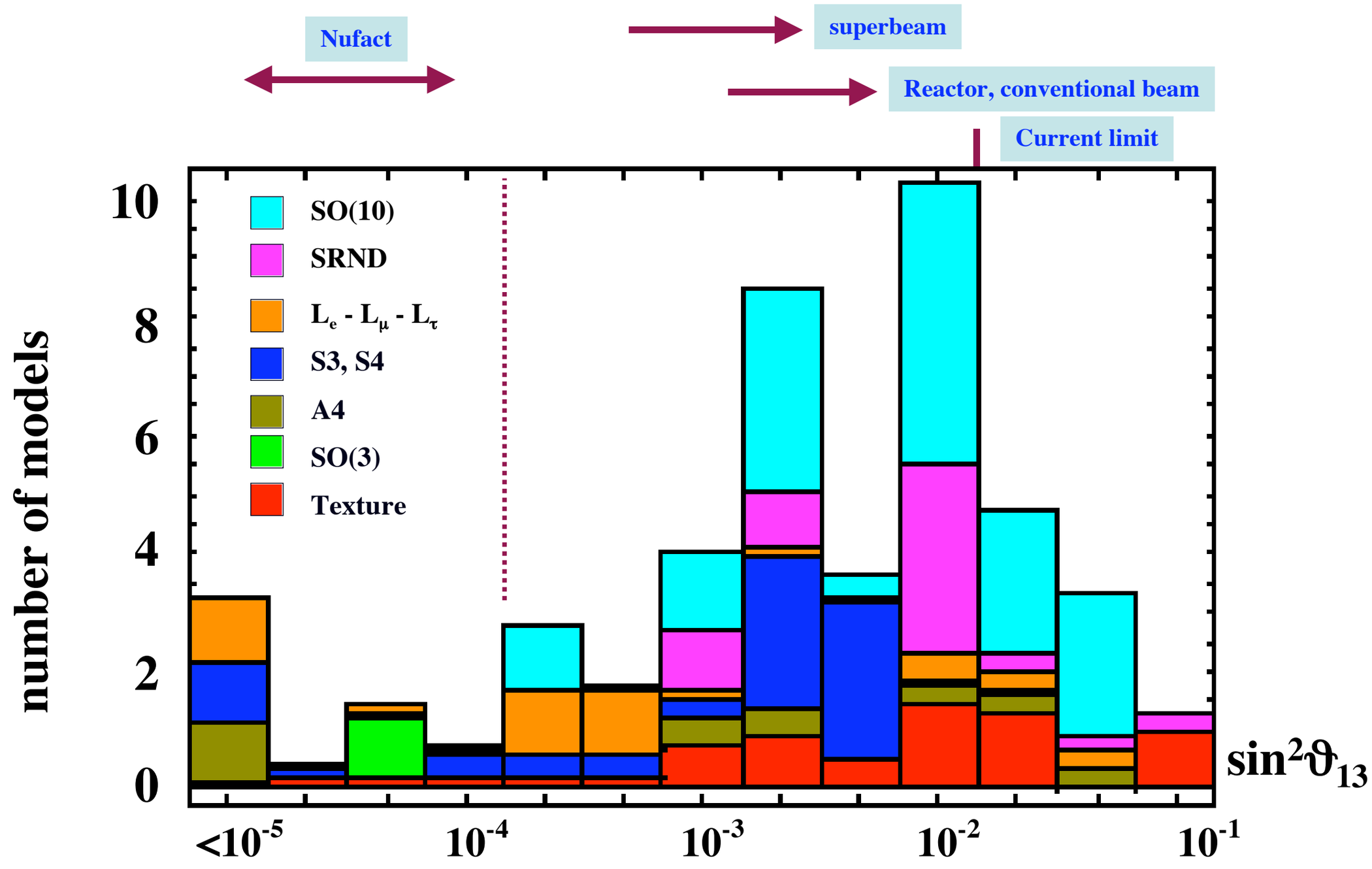
NOvA

is an Essential Ingredient.

Albright & Chen:

Predictions of all 46 models for 1-3 mixing:

C. Albright & M.-C.C. (2006)



What Fraction of ^{8}Boron Solar Neutrinos arrive at the Earth as a ν_2 mass eigenstate?[1]

Stephen Parke, Hiroshi Nunokawa & Renata Zukanovich-Funchal
hep-ph/0601198

$$\delta m^2_\odot = 8.0 \times 10^{-5} eV^2$$

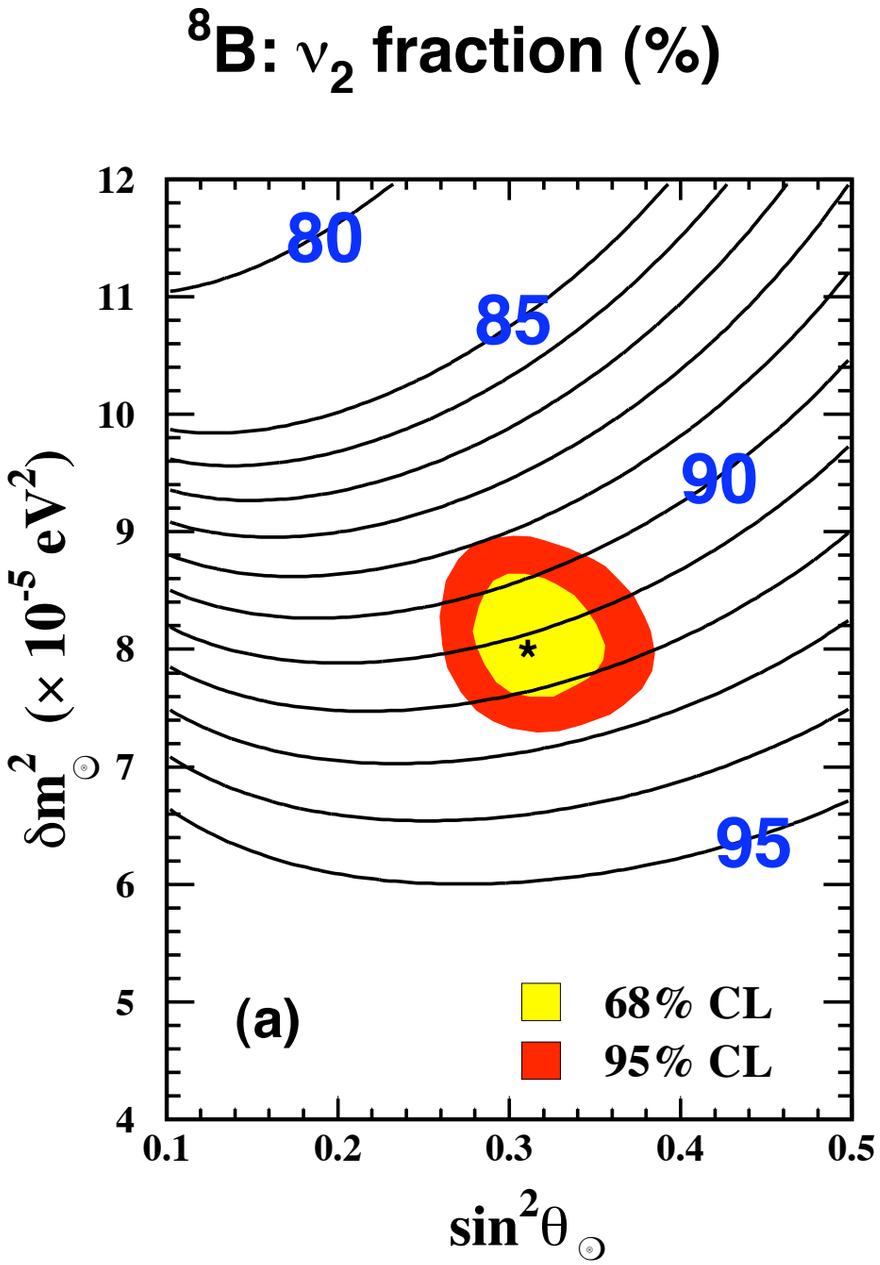
$$\sin^2\theta_\odot = 0.31$$

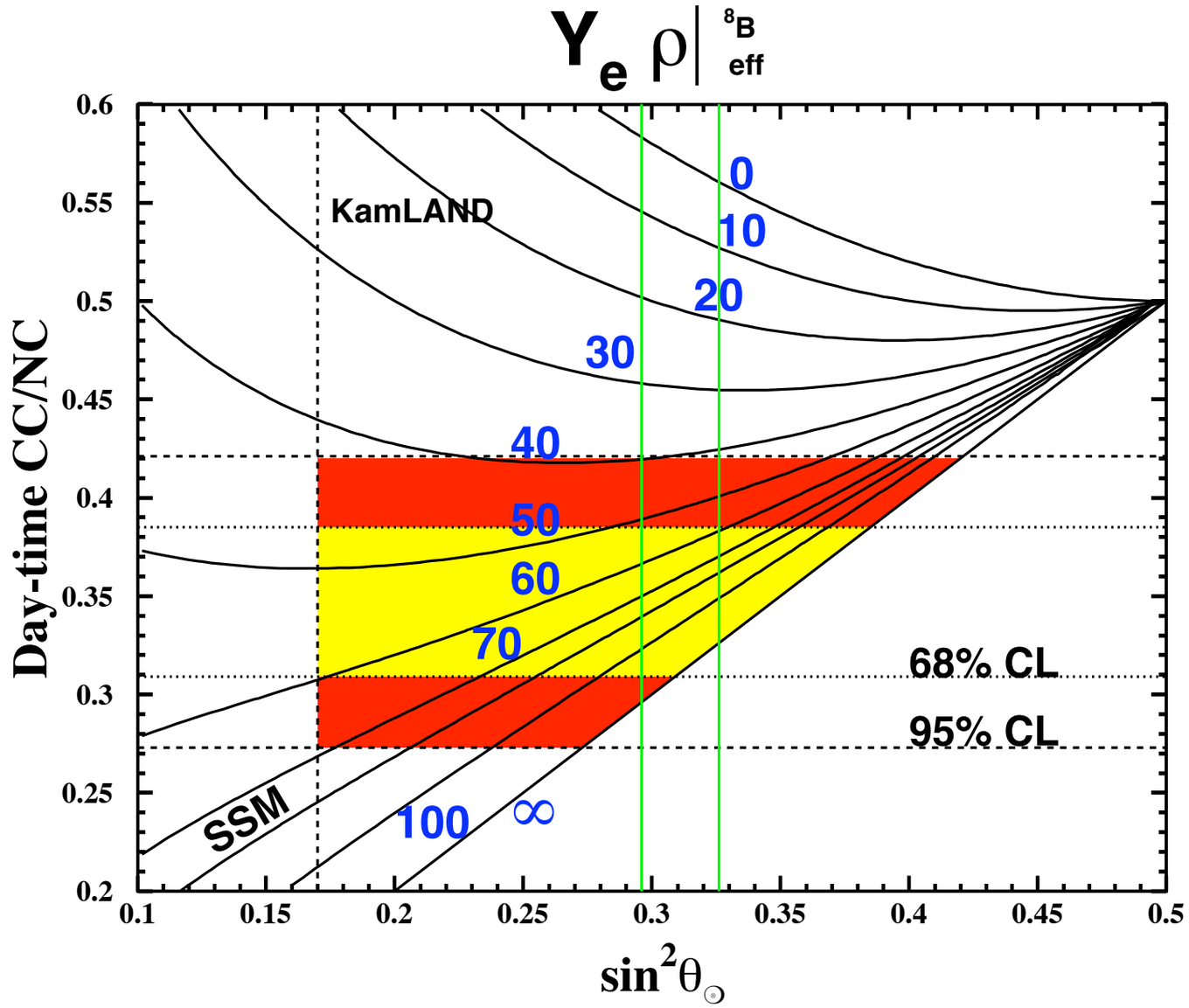
$$\nu_2 \sim \frac{1}{\sqrt{3}}(\nu_e + \nu_\mu + \nu_\tau)$$

$$L_{osc} = \frac{4\pi E}{\delta m^2_\odot} = 300km\left(\frac{E}{10MeV}\right) \quad \text{OR} \quad \Delta \equiv \frac{\delta m^2_\odot L}{4E} = 10^6\left(\frac{10MeV}{E}\right)$$

Effectively Incoherent !!!

What Fraction of ^{8}Boron Solar Neutrinos arrive at the Earth as a ν_2 mass eigenstate?[1]





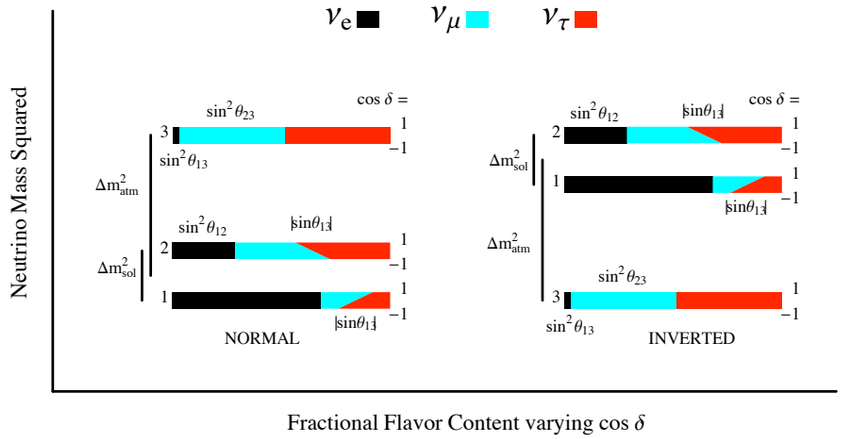
91+/-2 %

3 flavor fractions:

$$\mathcal{F}_1 \approx f_1 = 0.09 \mp 0.02,$$

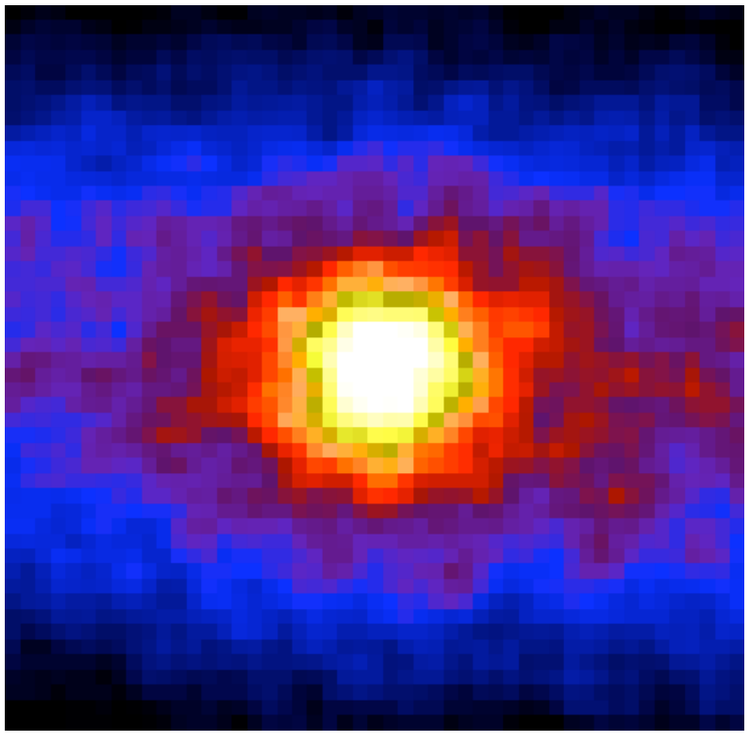
$$\mathcal{F}_2 = f_2 - \sin^2\theta_{13} \approx 0.91 \pm 0.02 - \sin^2\theta_{13},$$

$$\mathcal{F}_3 = \sin^2\theta_{13}.$$



$$|U_{e2}|^2 \approx \sin^2\theta_{\odot}^{8B} + (0.53^{+0.06}_{-0.04})\sin^2\theta_{13}.$$

SK



These are ν_2 Neutrinos !!!

extras:

Neutrino Coannihilation on Dark-Matter Relics?

Gabriela Barenboim,[1,*] Olga Mena Requejo,[2,†] and Chris Quigg[2,‡]

astro-ph/0604215

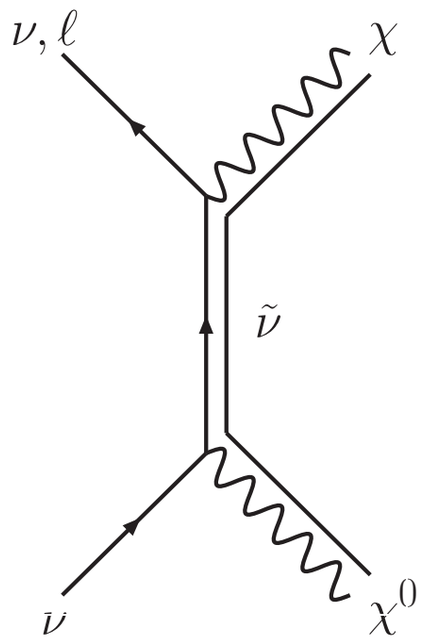


FIG. 1: Resonant sneutrino formation in neutrino–neutralino collisions. Double lines denote superpartners.

detector in the vicinity of Earth

$$1.3 \times 10^{-21} \text{ events cm}^{-2} \text{ y}^{-1}.$$