Global analyses of neutrino data and implications for future

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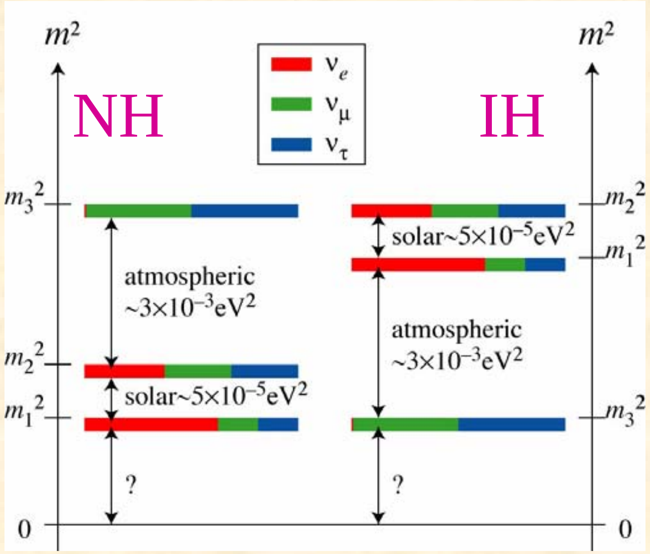
Introduction

Leptons low energy phenomenology: masses and mixing angles

•Three-flavor neutrino oscillation parameters

•The MNSP matrix for leptons is analogous to the CKM matrix for quarks

- We know:
  - Three charged lepton masses, Δm^2_{12}, and Δm^2_{23}
  - part of the neutrino mass hierarchy: $m_1 < m_2$
  - limits on the absolute mass scale (cosmology, tritium endpoint, neutrino less double-beta decay)
  - θ_{12} and θ_{23} from neutrino mixing



- We don't know:
  - The absolute neutrino mass scale
  - part of the neutrino mass hierarchy: m_2 <?> m_3
  - θ_{13} and δ_{CP} values
  - Nature of the neutrino: Dirac or Majorana (δ_{12}, δ_{13} values)

Outline

- $\Delta m^2_{12}, \theta_{12}$ oscillations (*Solar*, *and Reactors*)
- $\Delta m^2_{23}, \theta_{23}$ oscillations (*Atmospheric*, *and Accelerators*)
- θ_{13} limits (*Reactors*, *Accelerators*, *Atmospheric and Solar)*
- Overview: global fits
- Neutrino-less Double Beta Decay
- Cosmological limits
- LSND oscillations?
- Near future (10 years?)
  - *Conventional Beams*
  - *Reactors*
  - *Super-Beams*

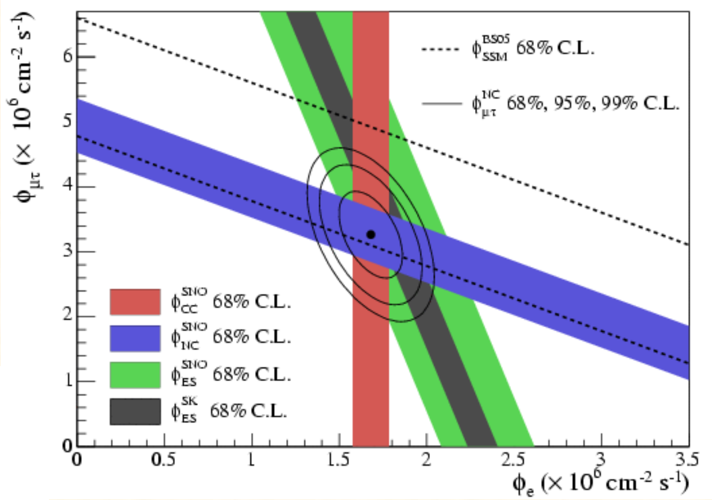
Solar mixing: Δm_{12}^2, θ_{12}

Solar experiments (Homestake, SAGE, GNO, Super-K, and SNO) and KamLAND

New KamLAND and SNO results in the last year

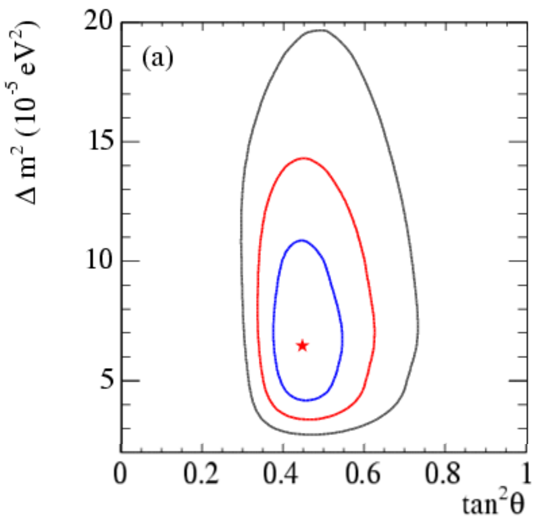
- KamLAND: Observed shape distortion

- SNO: Final salt results

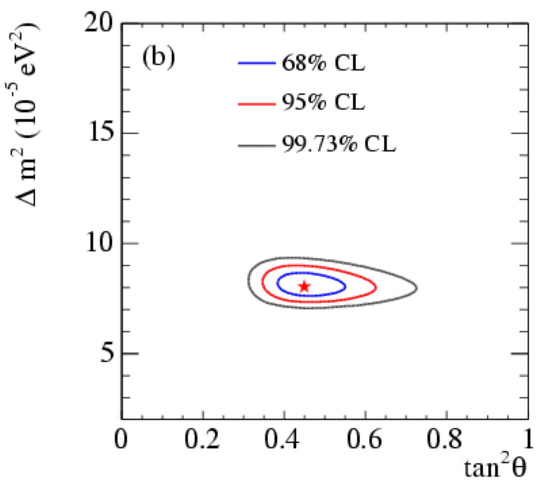


Flavor flux constraints

All-solar data fit by SNO



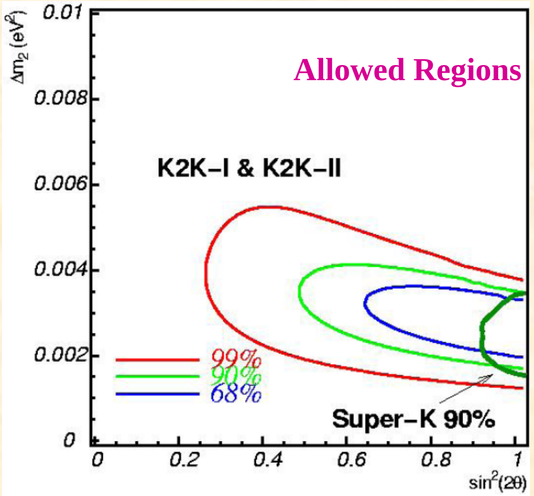
Global 2 neutrino fit by SNO



Atmospheric mixing: Δm_{23}^2, θ_{23}

Oscillation signals from →

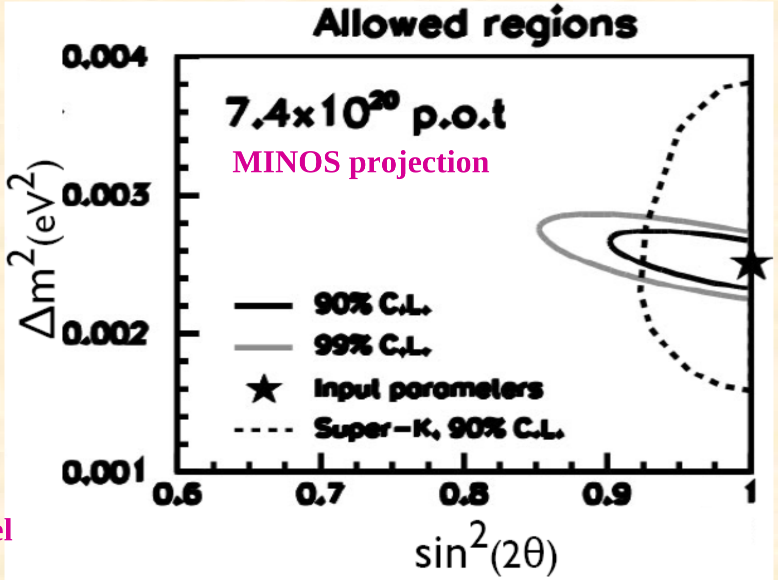
- Super-K (atmospheric)
- K2K (accelerator)



Thomas Kutter

MINOS is now running

- first events last year
- 3-year expectation plot →
- already have ~2 years of atmospheric data



Brian Rebel

θ_{13} limits (*Reactors, Atmospheric, Accelerators, and Solar)*

- Looking for a small oscillation on a ~km scale
- Reactors: antineutrino disappearance through θ_{13} oscillation has no contributions from unknown parameters

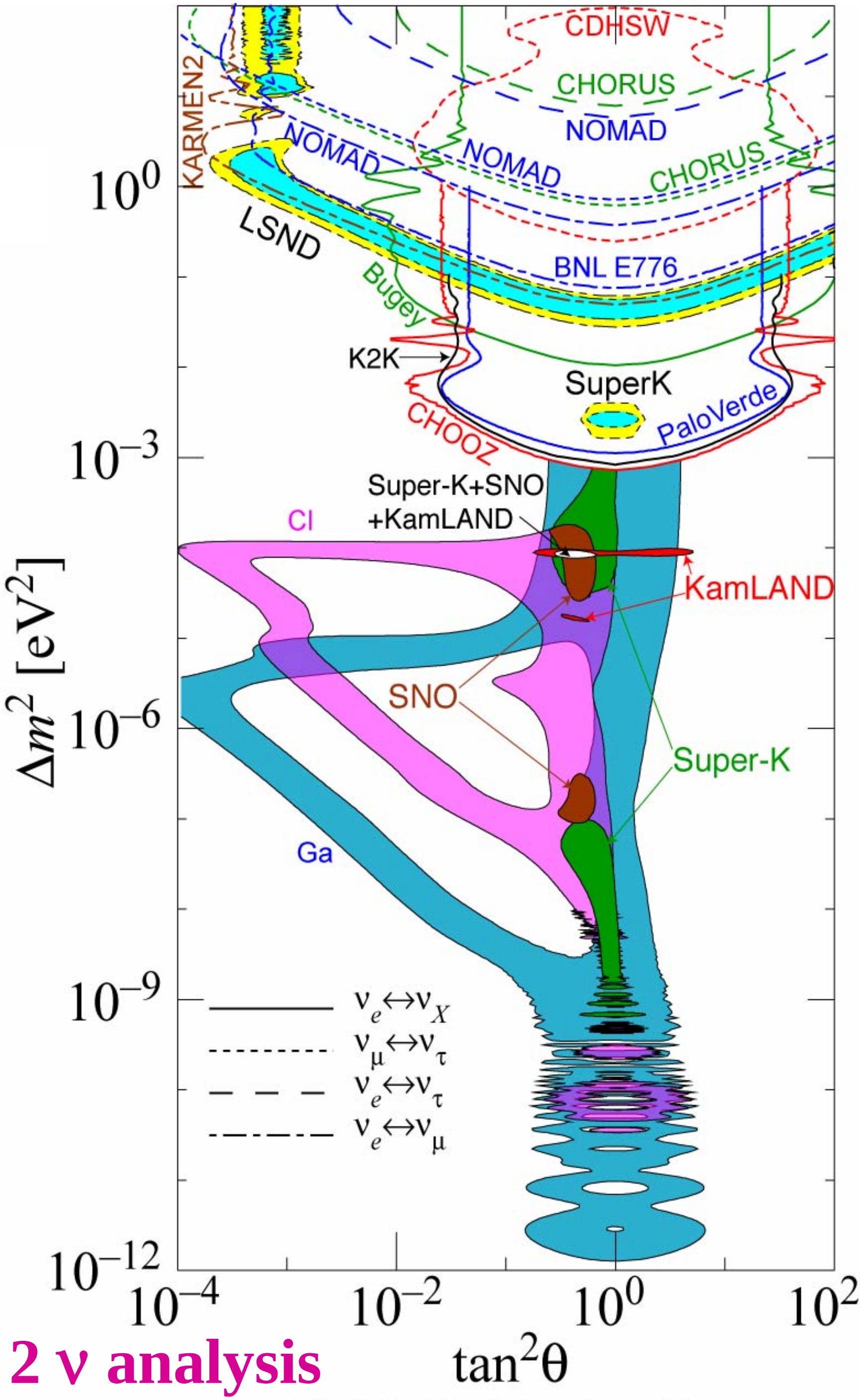
- BNL E776: Excluded region on anti-$\nu_\mu \rightarrow$ anti-ν_e [1]
- Bugey: Limit on anti-ν_e disappearance [2]
- CDHSW: Excluded region on ν_μ disappearance [3]
- CHOOZ: Limit on anti-ν_e disappearance [4]
- CHORUS: Excluded region on $\nu_e \rightarrow \nu_\tau$ or $\nu_\mu \rightarrow \nu_\tau$ appearance [5]
- Palo Verde: Limit on anti-ν_e disappearance [13]
- see full refs [1-16]

$$\sin^2\theta_{13} < \begin{cases} 0.029\ (0.067)\ \text{CHOOZ+atmospheric+K2K} \\ 0.041\ (0.079)\ \text{solar+KamLAND} \\ 0.021\ (0.046)\ \text{global data} \end{cases}$$

Global fits

Three neutrino analysis

	-3σ	-2σ		$+2\sigma$	$+3\sigma$
Δm^2_{12} (10^{-5} eV^2)	6.9	7.2	7.9	8.7	9.0
$\sin^2\theta_{12}$	0.24	0.27	0.31	0.36	0.40
Δm^2_{23} (10^{-3} eV^2)	1.5	1.8	2.3	2.9	3.2
$\sin^2\theta_{23}$	0.31	0.34	0.47	0.63	0.67
$\sin^2\theta_{13}$ (10^{-2})			<	2.1	4.6



2 ν analysis

http://hitoshi.berkeley.edu/neutrino

Global fits: experiments

All excluded regions are at 90% CL unless noted otherwise

- BNL E776: Excluded region on anti-$\nu_\mu \rightarrow$ anti-ν_e [1]
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- CHORUS: Excluded region on $\nu_e \rightarrow \nu_\tau$ or $\nu_\mu \rightarrow \nu_\tau$ appearance [5]
- Palo Verde: Limit is on anti- ν_e disappearance [13]
- Cl (Homestake): Preferred region on ν_e disappearance [6]
- Ga (SAGE and GALLEX): Preferred region ν_e disappearance at 95%CL [7]
- KamLAND: Pref. region on anti-ν_e disappearance at 95% CL [8]
- KARMEN2: Excluded region on anti- $\nu_\mu \rightarrow$ anti-ν_e appearance [9]
- K2K: Excluded region on $\nu_\mu \rightarrow \nu_e$ appearance [10]
- LSND: Preferred region on anti- $\nu_\mu \rightarrow$ anti- ν_e appearance [11]
- NOMAD: Excluded region on $\nu_e \rightarrow \nu_\tau$ or $\nu_\mu \rightarrow \nu_\tau$ appearance [12]
- SNO: Preferred region on ν_e disappearance at 95% CL [14]
- Super-Kamiokande (solar): Preferred region on ν_e disappearance at 95% CL [15]
- Super-Kam. (atmospheric): Preferred region on ν_μ disappearance at 90% and 99% CL [16]

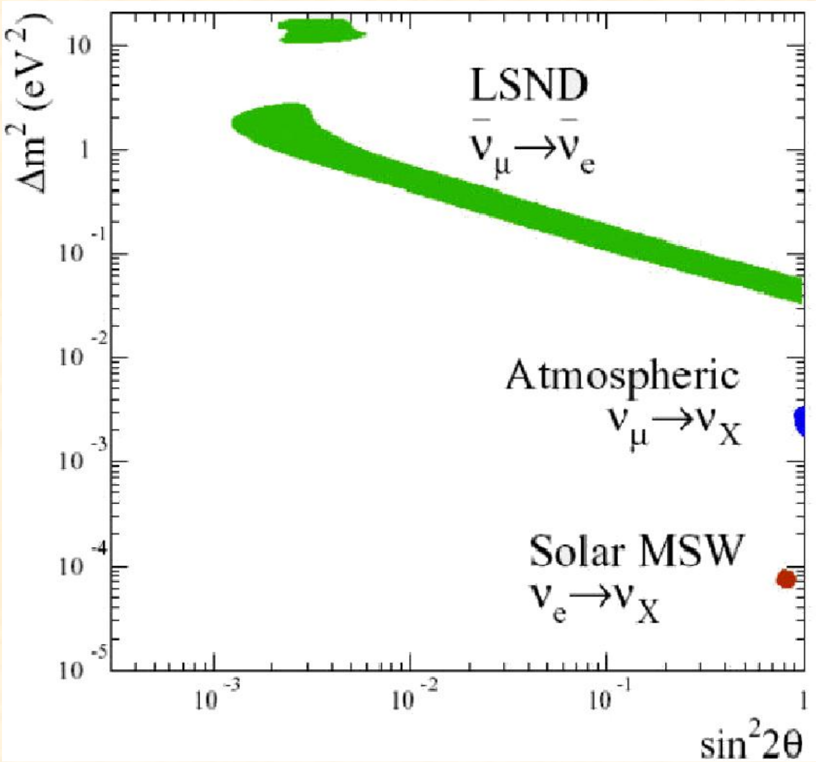
Global fits: references

1 L. Borodovsky et al., Phys. Rev. Lett. 68, 274-277 (1992)
2 B. Achkar et al., Nucl. Phys. B434, 503-534 (1995).
3 F. Dydak et al., Phys. Lett. B134, 281 (1984).
4 M. Apollonio et al., Eur. Phys. J. C27, 331-374 (2003), Fig. 55 Analysis A
5 E. Eskut et al., Phys. Lett. B497, 8-22 (2001).
6 based on hep-ex/0208004 by Michael Smy.
7 based on G.L. Fogli et al., hep-ph/0506083 (2 dof.)
8 Kamland coll., Phys. Rev. Lett. 94 081801 (2005), hep-ex/0406035
9 A. Armbruster et al., Phys. Rev. D65, 112001 (2002), hep-ex/0203021
10 K2K coll., Phys. Rev. Lett. 93 051801 (2004), hep-ex/0402017
11 A. Aguilar et al., Phys. Rev. D64, 112007 (2001), at 90% and 99% CL.
12 P. Astier et al., hep-ex/0106102, Nucl. Phys. B611, 3-39 (2001).
13 F. Boehm et al., hep-ex/0107009, Phys. Rev. D64, 112001 (2001), Fig. 7, solid curve.
14 nucl-ex/0502021, Fig. 34.
15 hep-ex/0508053, Fig. 55, left. The combination of Super-Kamiokande, SNO and KamLAND at the 95% CL from Fig. 56(b), light gray region.
16 Talk presented by Masato Shiozawa at International School of Nuclear Physics, 27th Course, "Neutrinos in Cosmology, in Astro, Particle, and Nuclear Physics", Erice, Sicily, 16-24 September, 2005.

LSND oscillations?

• The LSND result (4σ!) does not fit into the standard three flavor picture

• Three Δm^2s are not consistent with only three neutrino masses



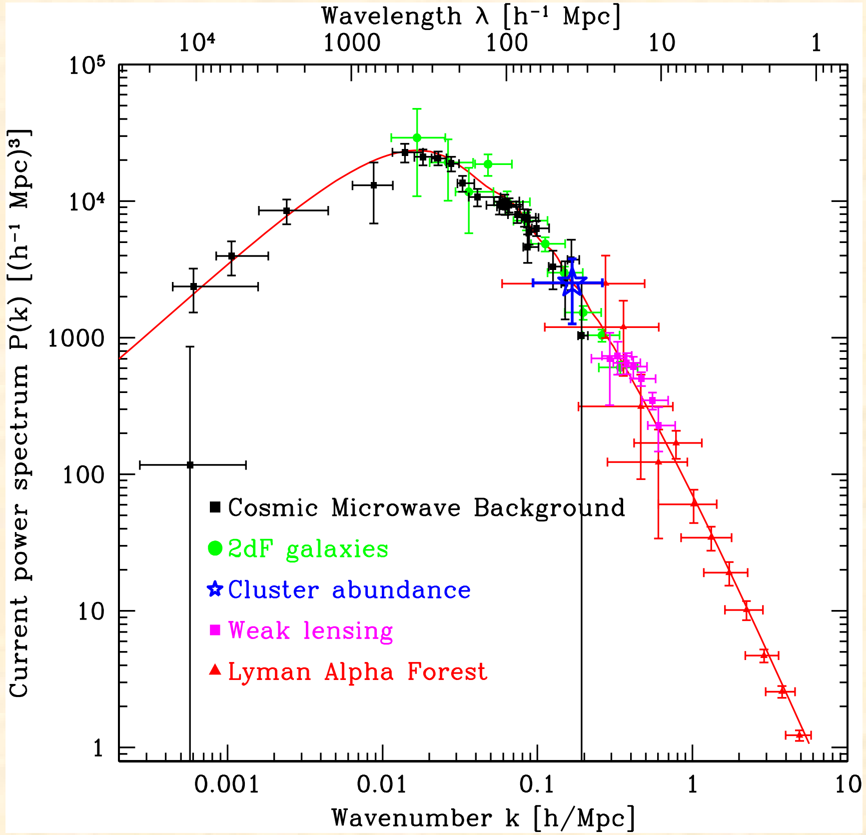
• MiniBooNE is looking for the same signal at a higher energy, same L/E, different systematic errors

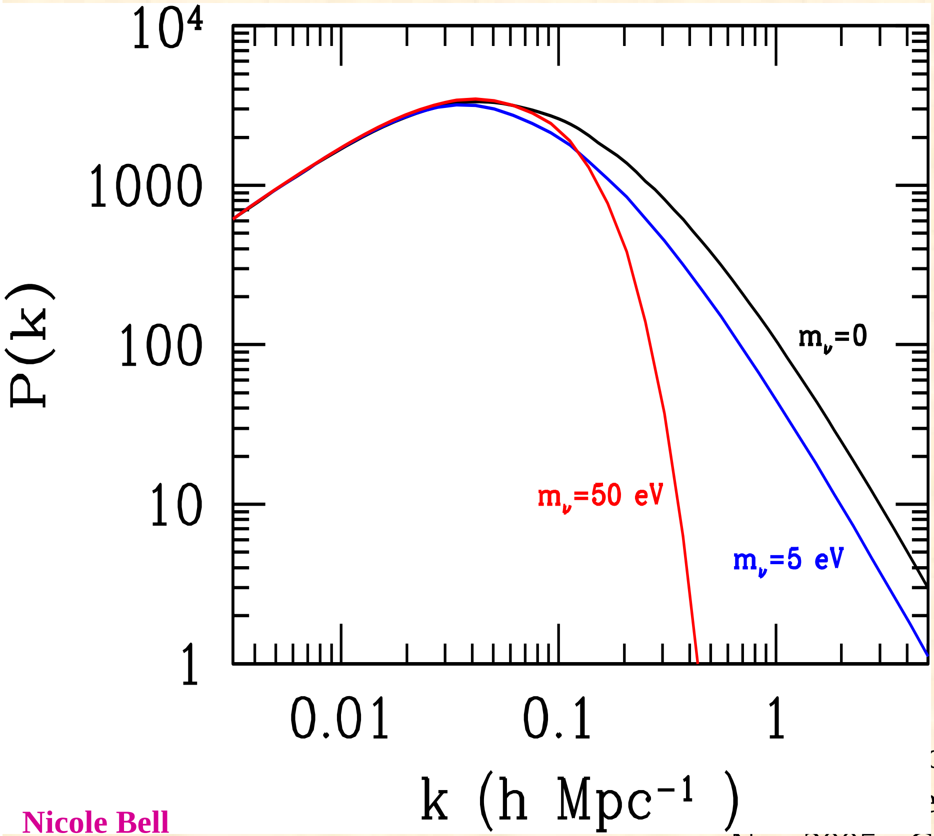
• Blind analysis: box to be open in late 2005/early 2006

Cosmological limits

• The cosmological effects of neutrino mass are seen in the large-scale structure of the universe

• The *standard* neutrinos cosmological fits constrain the sum of the neutrino masses: $\Sigma m_\nu < \sim 1$ eV

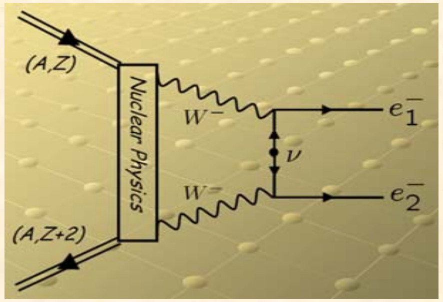




• There are models where effects on large-scale structure are greatly reduced: they evade these limits (Neutrinoless Universe!)

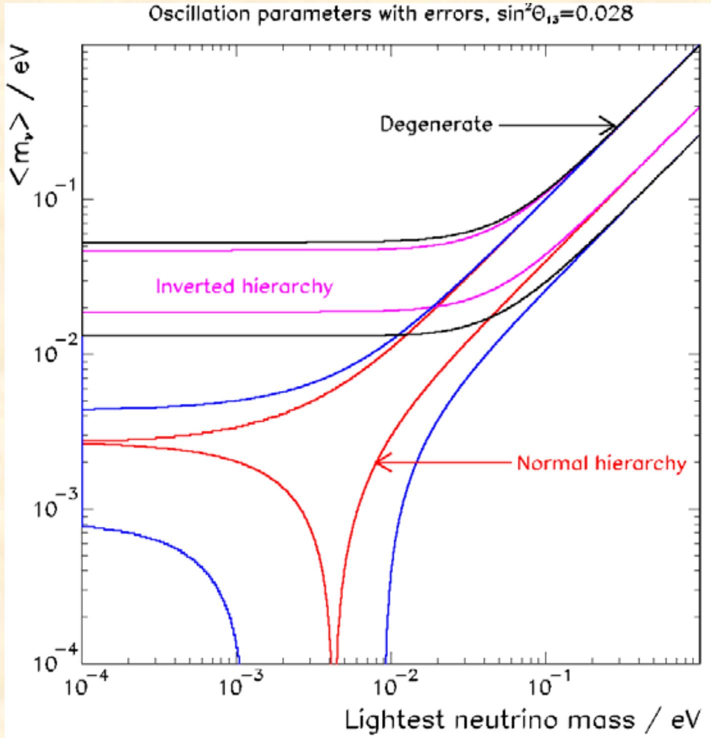
Absolute mass and Neutrino-less Double Beta Decay

• If neutrinos are Majorana (neutrinos are their own antiparticles), double-beta decay can proceed by a loop diagram with no neutrinos in the final state



• This process is sensitive to a Majorana mass

$$\boxed{\langle m_{\beta\beta} \rangle = \sum_{i=1}^{3} |U_{ei}|^2 m_i \varepsilon_i}$$

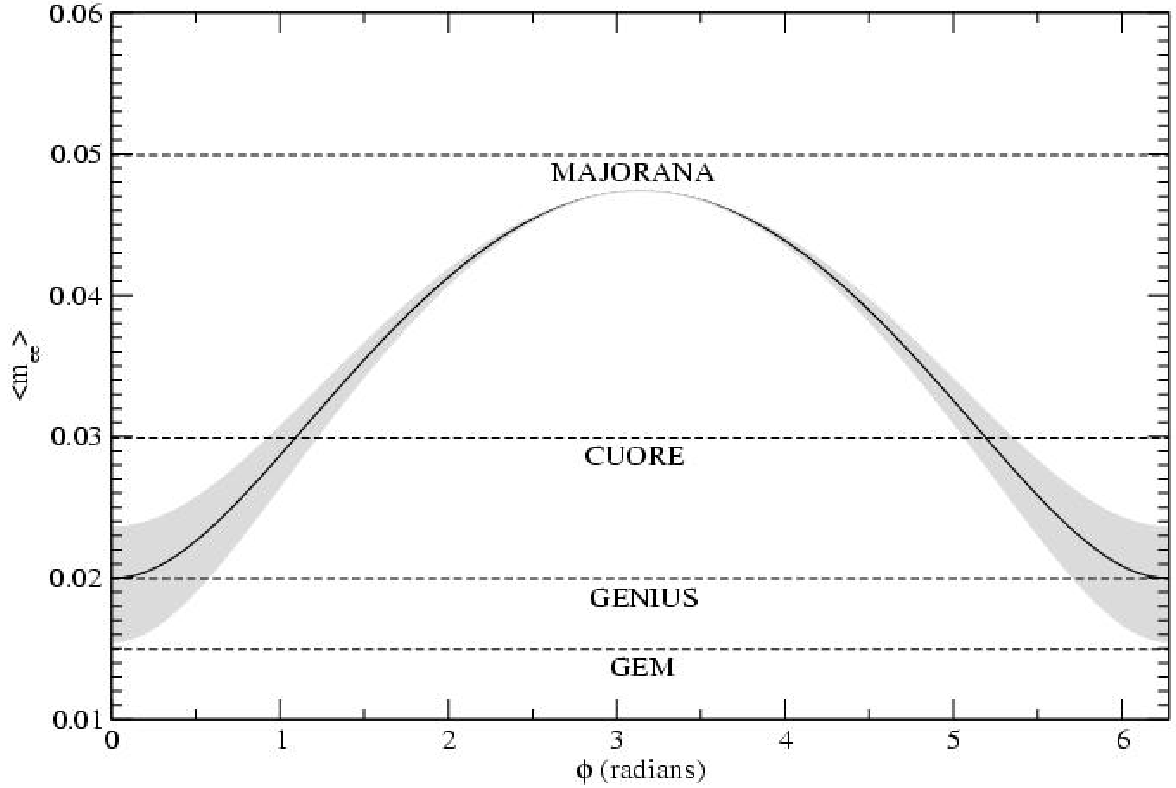


• Very nice related **ΔL=2** processes
see *hep-ph/0502163* Phys.Rev. D71 (2005) 115001

• In the inverted hierarchy, there is a minimum Majorana mass

An example: Vanishing Determinant and θ_{13}

Inverted Hierarchy



B. C. Chauhan, J. Pulido, M.P. hep-ph/0510272

The near future:
(*Conventional Beams, Reactors, Super-Beams*)

- Conventional beams:

•MINOS	735km	3 GeV	5yr	$\nu_\mu \to \nu_\mu, \nu_e$
•ICARUS	732km	17 GeV	5yr	$\nu_\mu \to \nu_\mu, \nu_e, \nu_\tau$
•OPERA	732km	17 GeV	5yr	$\nu_\mu \to \nu_\mu, \nu_e, \nu_\tau$

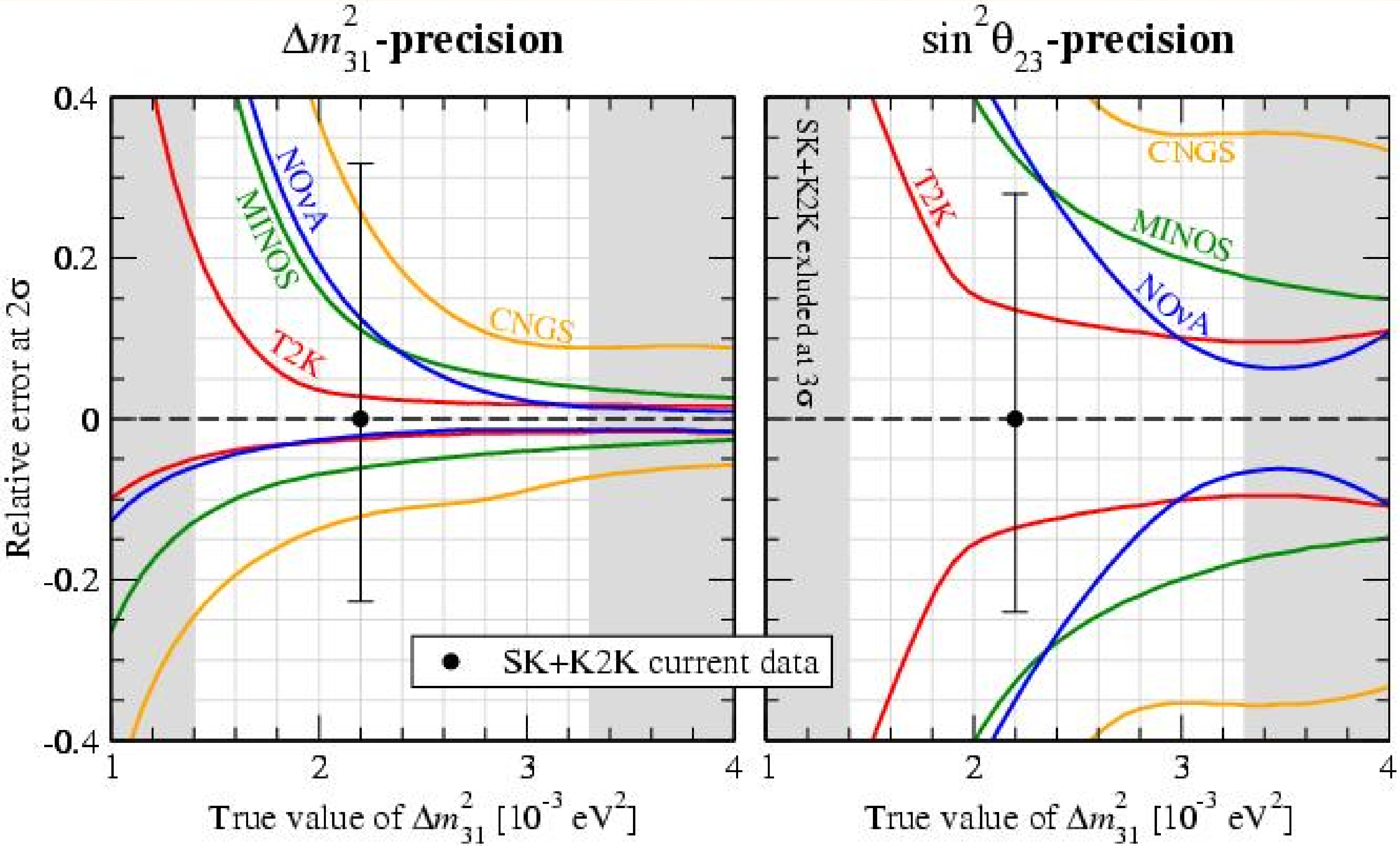
- Reactors with near and far detectors:

•D-CHOOZ	1.05km	4 MeV	3yr	anti-$\nu_e \to$ anti-ν_e
•Reactor-II	1.70km	4 MeV	5yr	anti-$\nu_e \to$ anti-ν_e

- Off-axis super-beams:

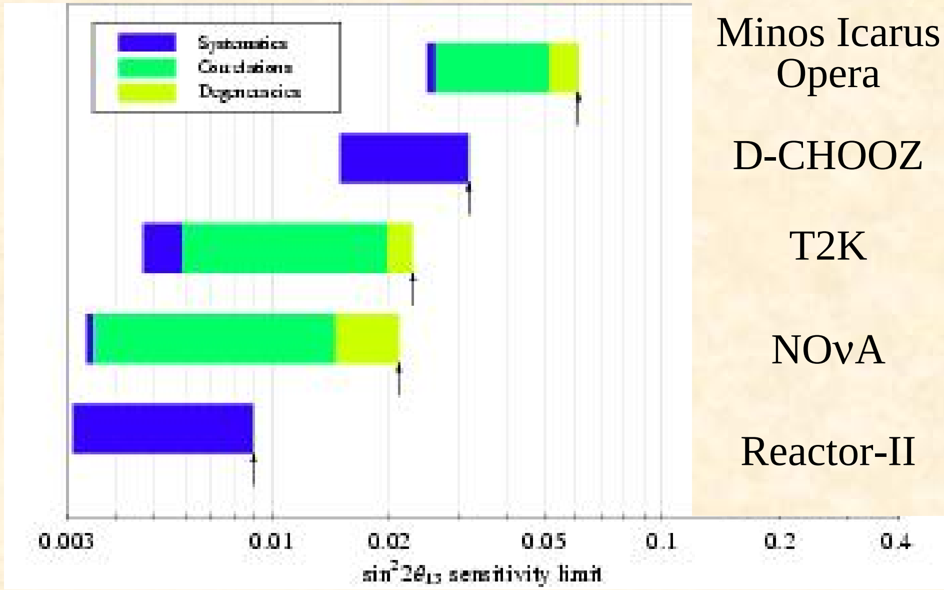
•T2K	295km	760 MeV	5yr	$\nu_\mu \to \nu_e, \nu_\mu$
•NOνA	812km	2.22GeV	5yr	$\nu_\mu \to \nu_e, \nu_\mu$

Improvements for Δm_{31}^2 and $\sin^2\theta_{23}$

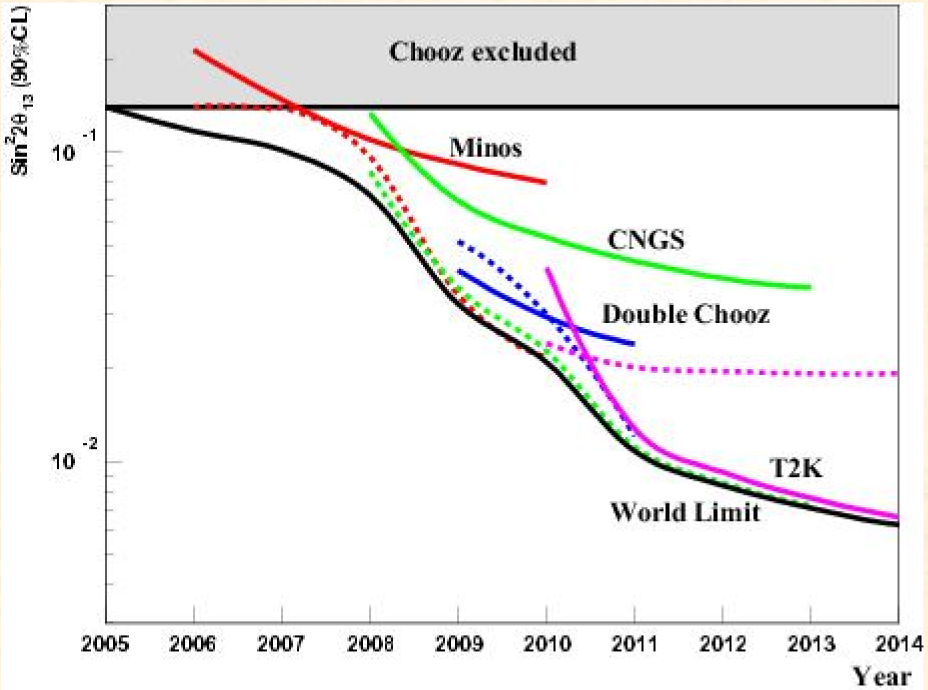


Lindner hep-ph/0503101

Limits on θ_{13}



$\Delta m_{31}^2 = 2\ 10^{-3} eV^2$ $\sin^2\theta_{23}=1$ $\Delta m_{12}^2 = 7\ 10^{-5} eV^2$ $\sin^2\theta_{12}=0.8$



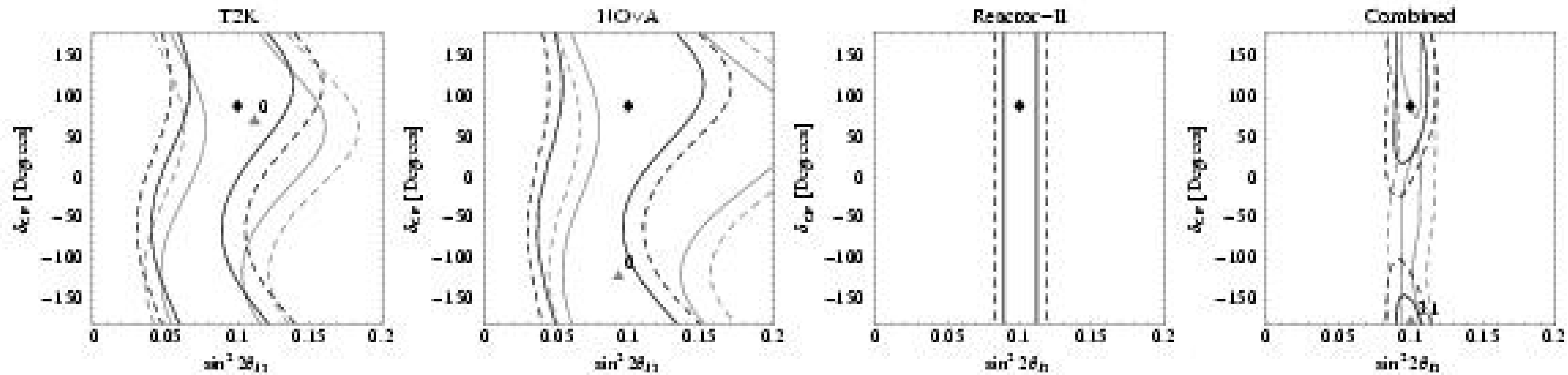
Large θ_{13} and phases

•Reactors with near and far detectors: Accurate measurement of θ_{13}

•D-CHOOZ	1.05km	4 MeV	3yr	anti-$\nu_e \rightarrow$ anti-ν_e
•Reactor-II	1.70km	4 MeV	5yr	anti-$\nu_e \rightarrow$ anti-ν_e

•Off-axis super-beams: Strong correlation between θ_{13} and δ_{CP}

•T2K	295km	760 MeV	5yr	$\nu_\mu \rightarrow \nu_e, \nu_\mu$
•NOνA	812km	2.22GeV	5yr	$\nu_\mu \rightarrow \nu_e, \nu_\mu$



•Mass hierarchy determination

•No information on CP violation

Schwetz hep-ph/0510331

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