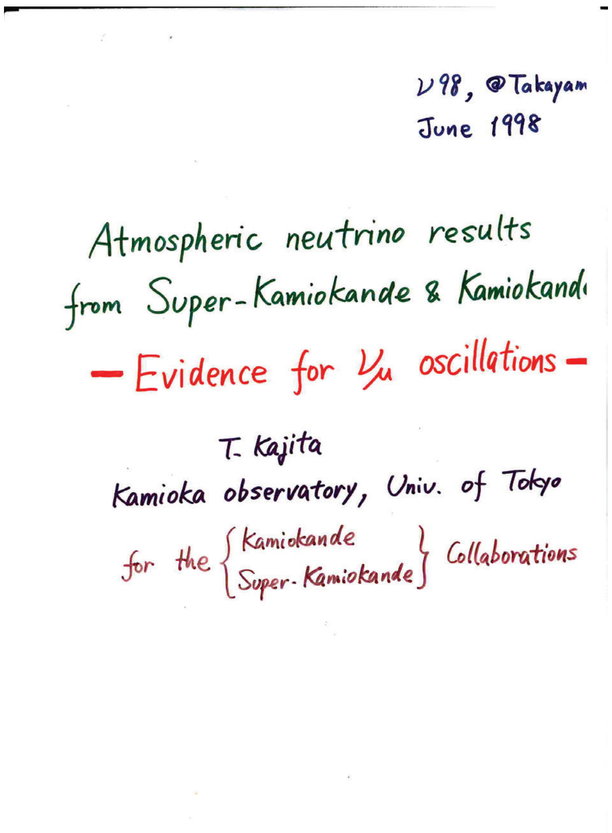
What Next Neutrini, Padova, 1 Dicembre 2014

M. Mezzetto
INFN-Padova

16 anni di oscillazioni di neutrini: what next

16 years of neutrino oscillations



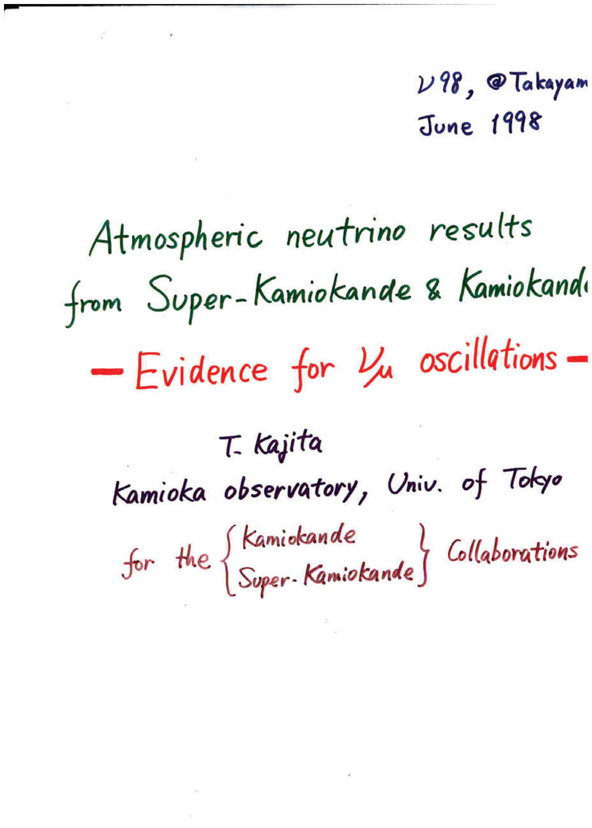
ν98, @Takayam
June 1998

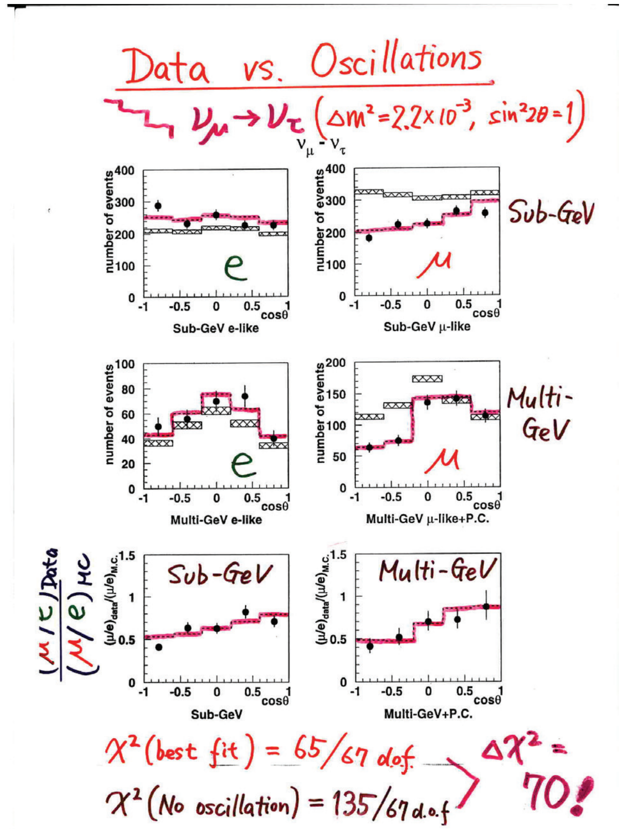
Atmospheric neutrino results
from Super-Kamiokande & Kamiokand

— Evidence for ν_μ oscillations —

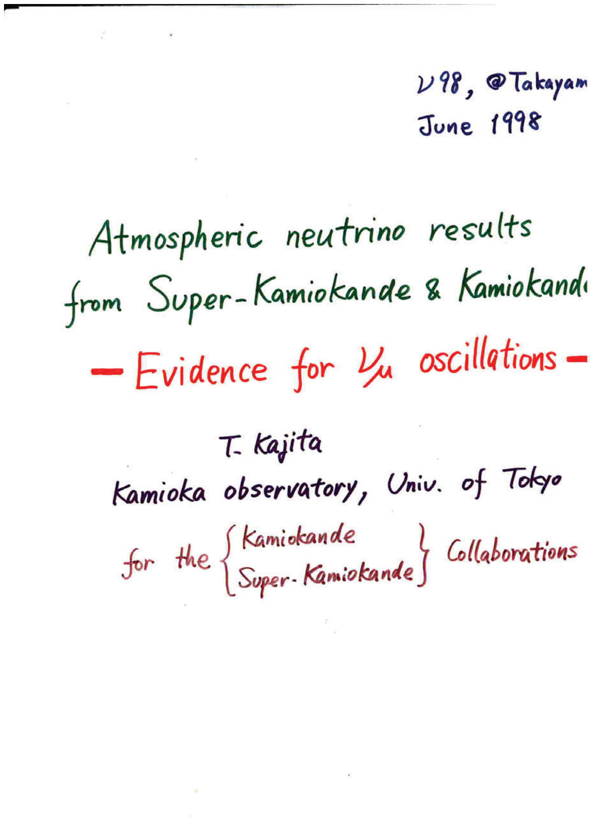
T. Kajita
Kamioka observatory, Univ. of Tokyo
for the {Kamiokande / Super-Kamiokande} Collaborations

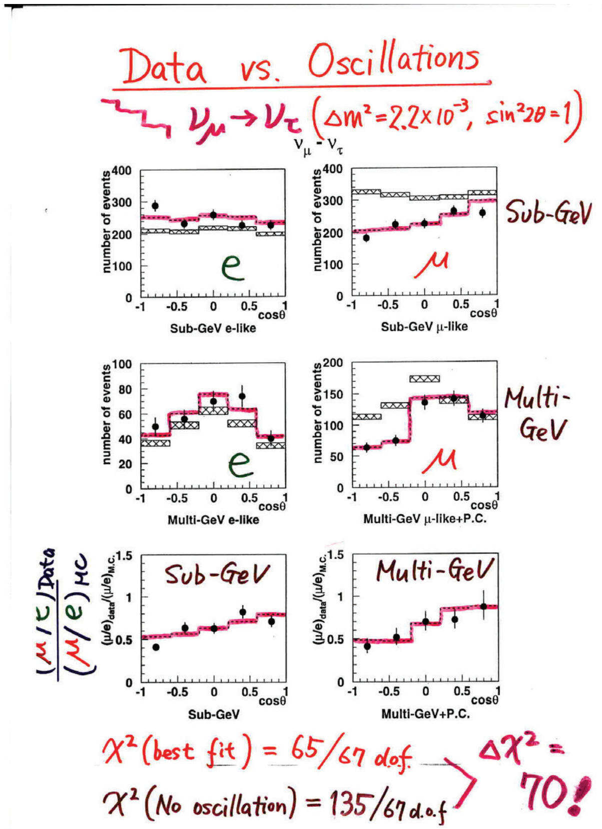
16 years of neutrino oscillations

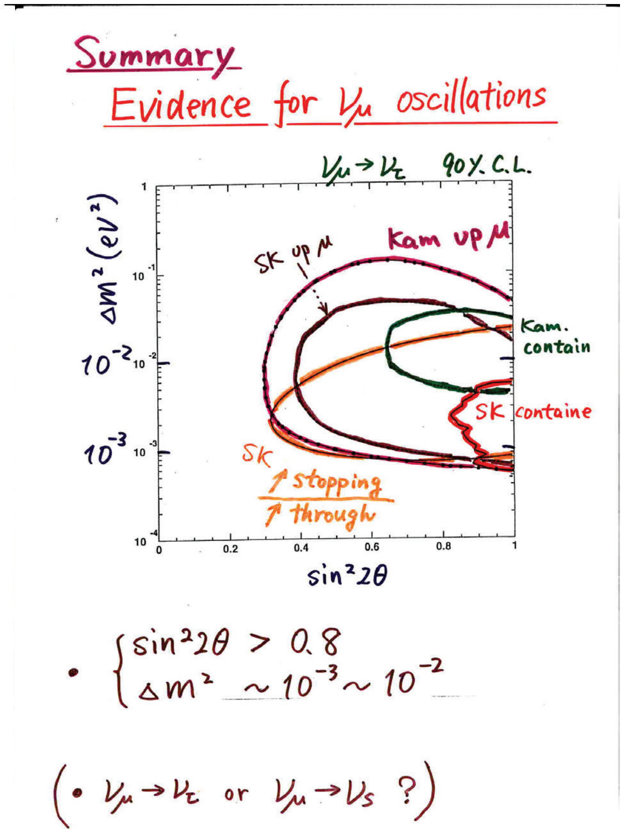




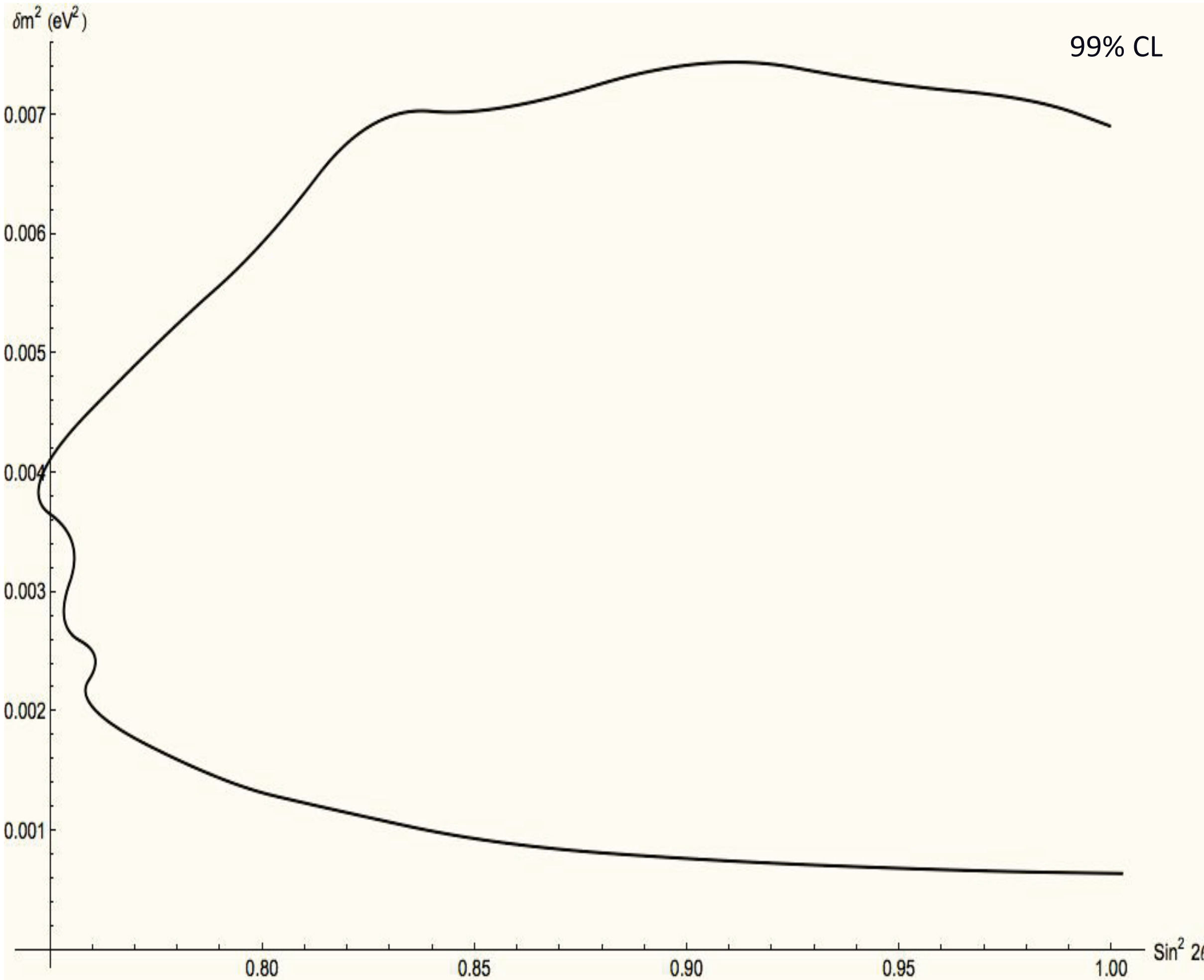
16 years of neutrino oscillations





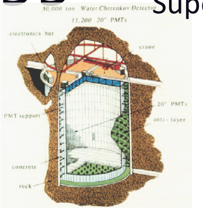


The progress in atmospheric parameters



1999

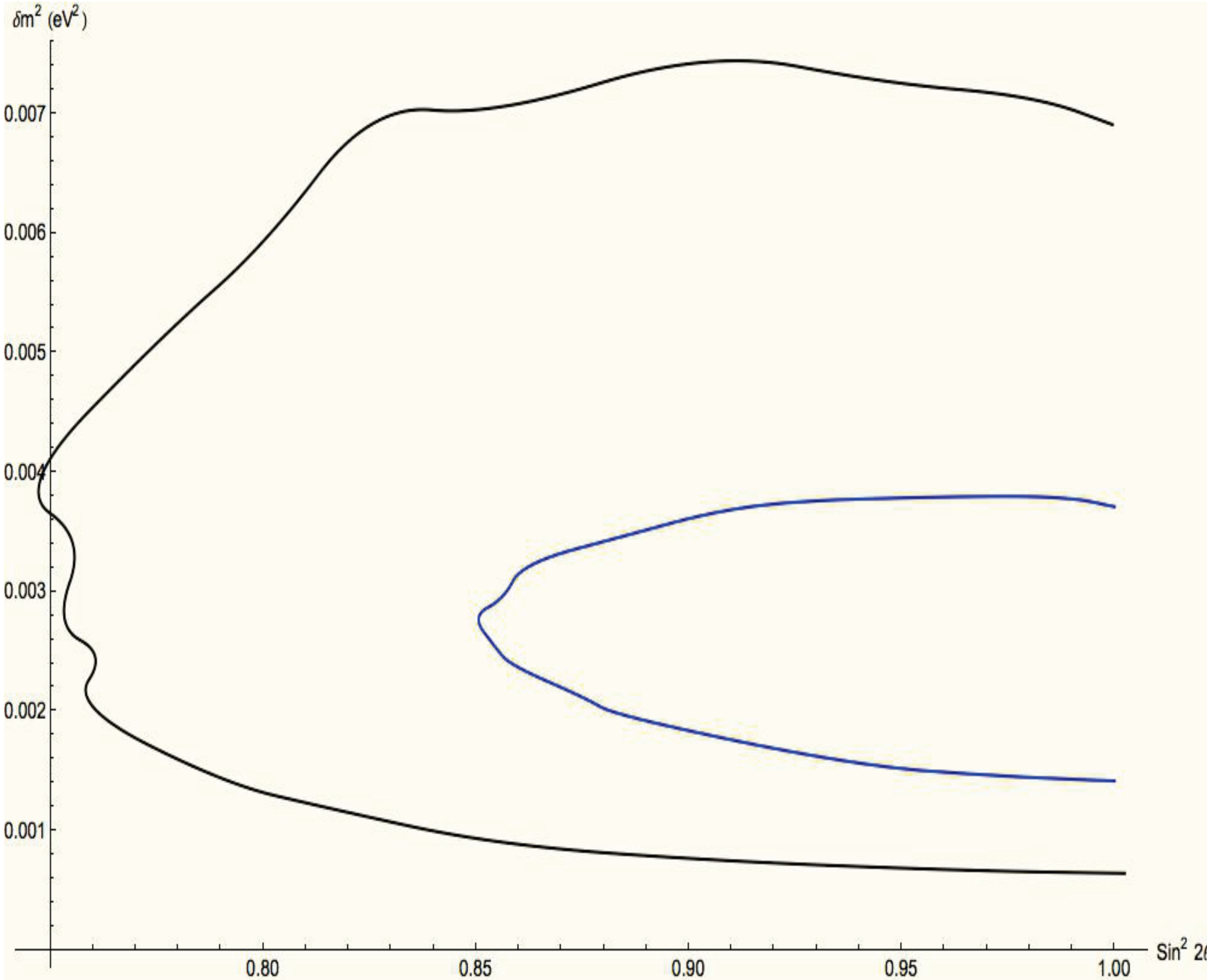
SuperK



MACRO at GRAN SASSO

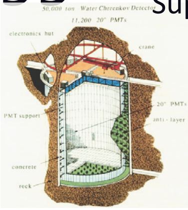
Monopole, Astrophysics, and Cosmic Ray Observatory

The progress in atmospheric parameters



1999

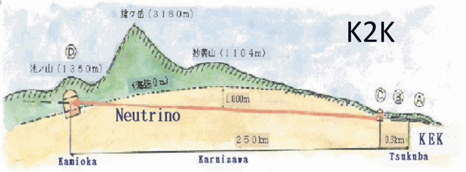
SuperK



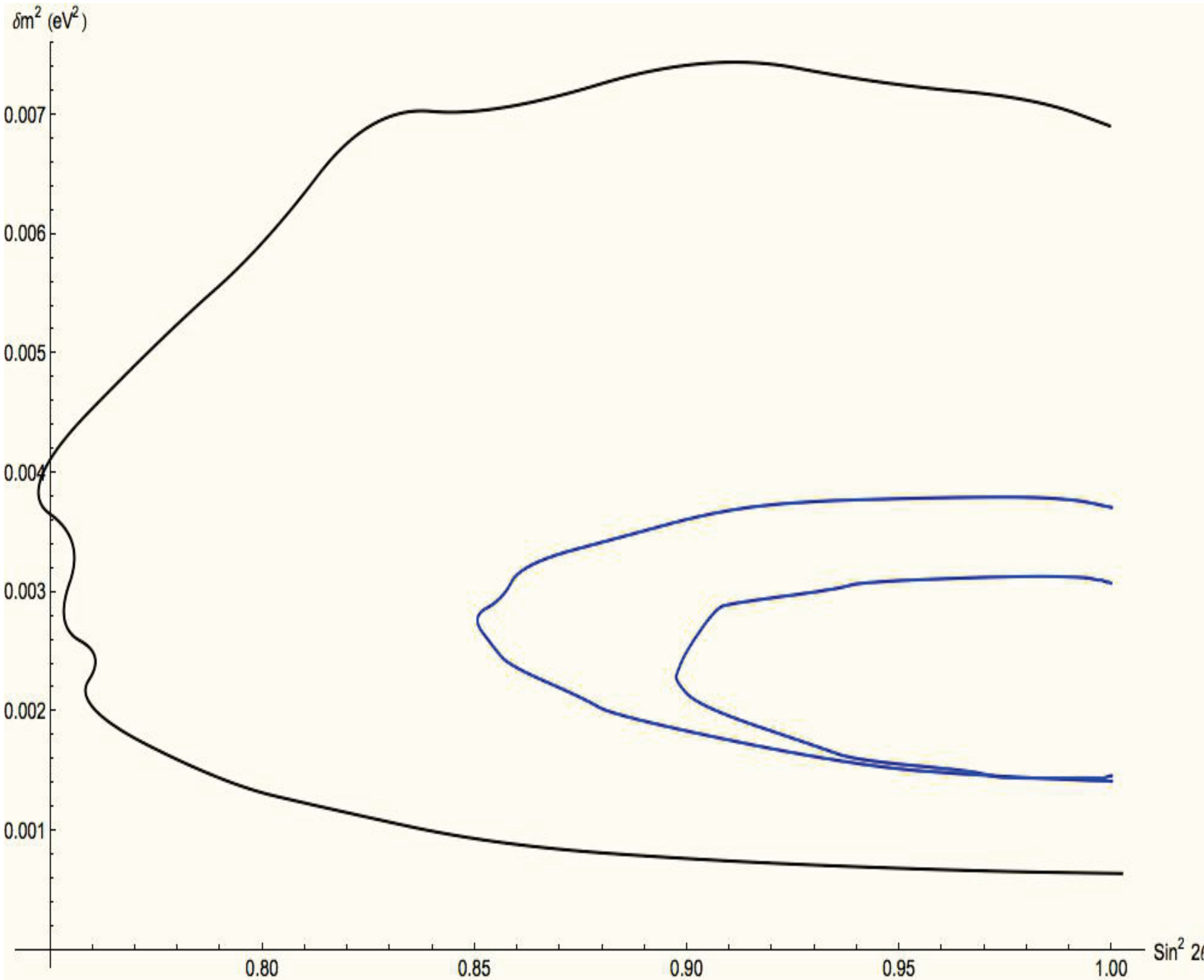
MACRO at GRAN SASSO

Monopole, Astrophysics, and Cosmic Ray Observatory

2002



The progress in atmospheric parameters



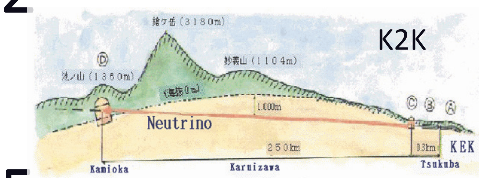
1999

SuperK

Monopole, Astrophysics, and Cosmic Ray Observatory

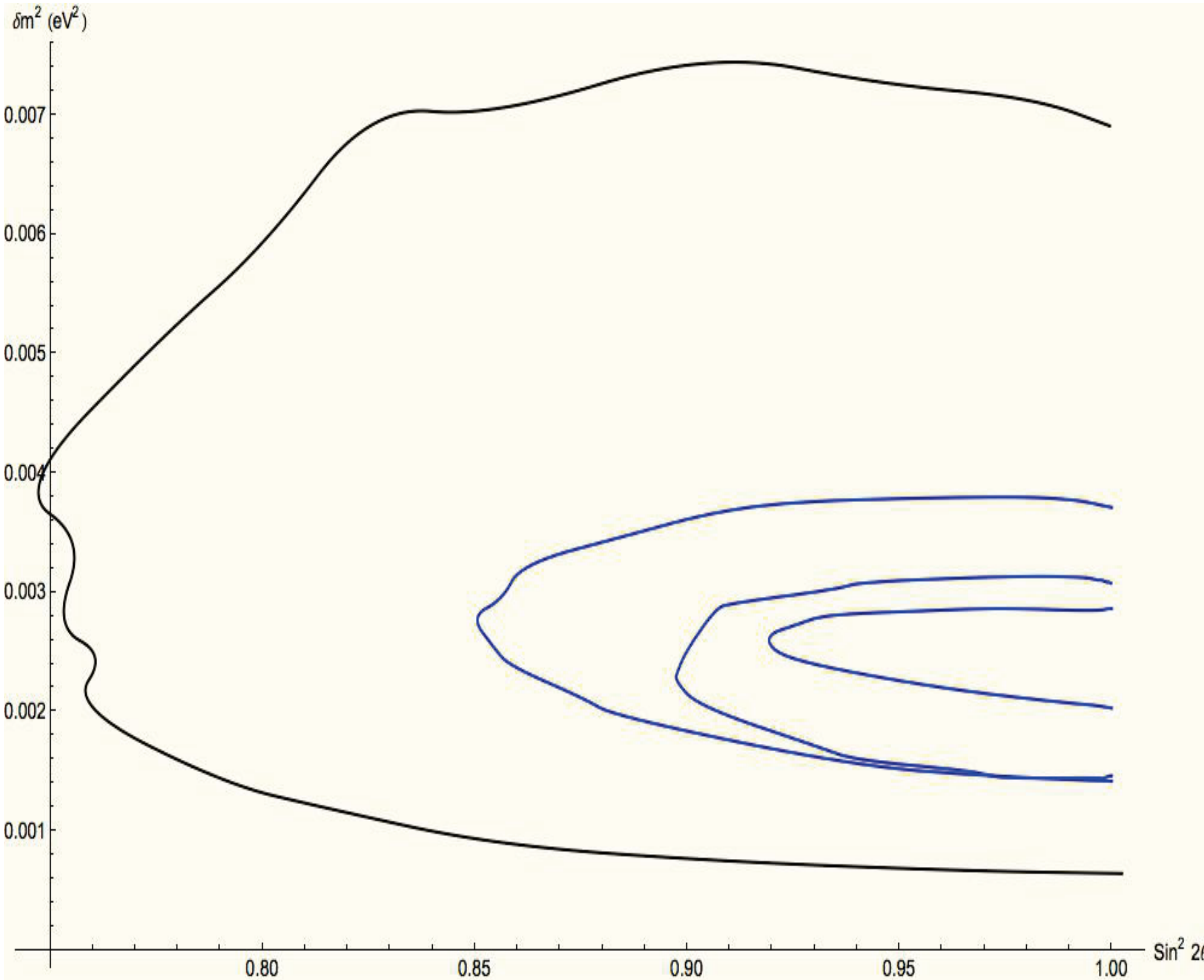
MACRO at GRAN SASSO

2002



2005

The progress in atmospheric parameters



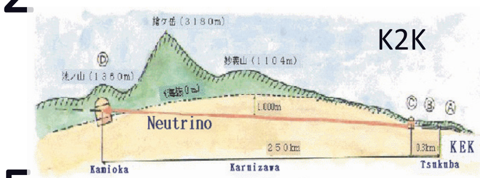
1999

SuperK

MACRO at GRAN SASSO

Monopole, Astrophysics, and Cosmic Ray Observatory

2002

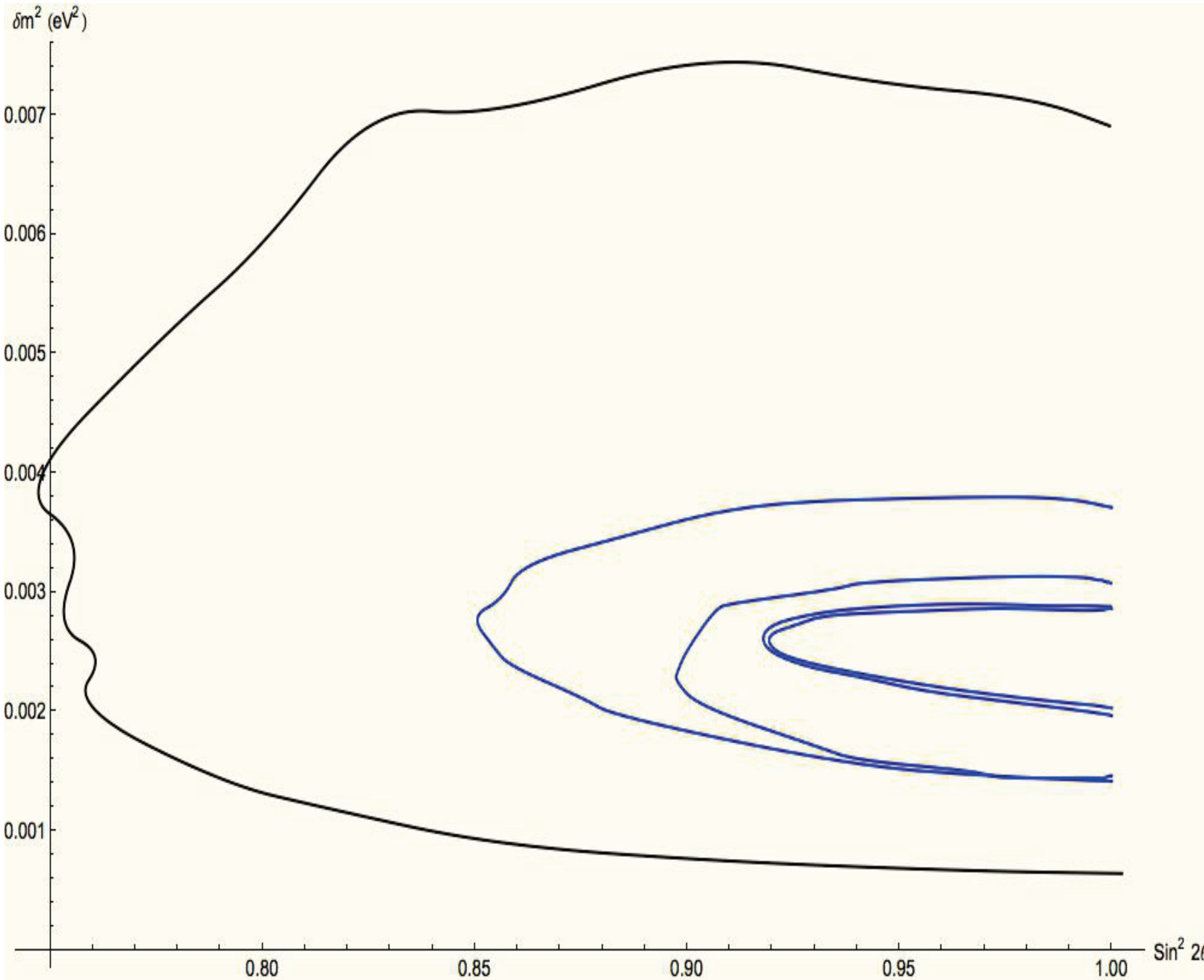


2005

2008

MINOS

The progress in atmospheric parameters



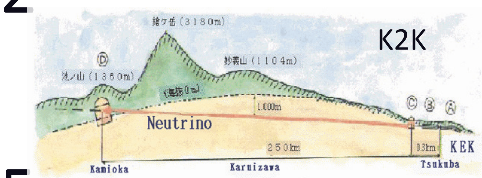
1999

SuperK

MACRO at GRAN SASSO

Monopole, Astrophysics, and Cosmic Ray Observatory

2002



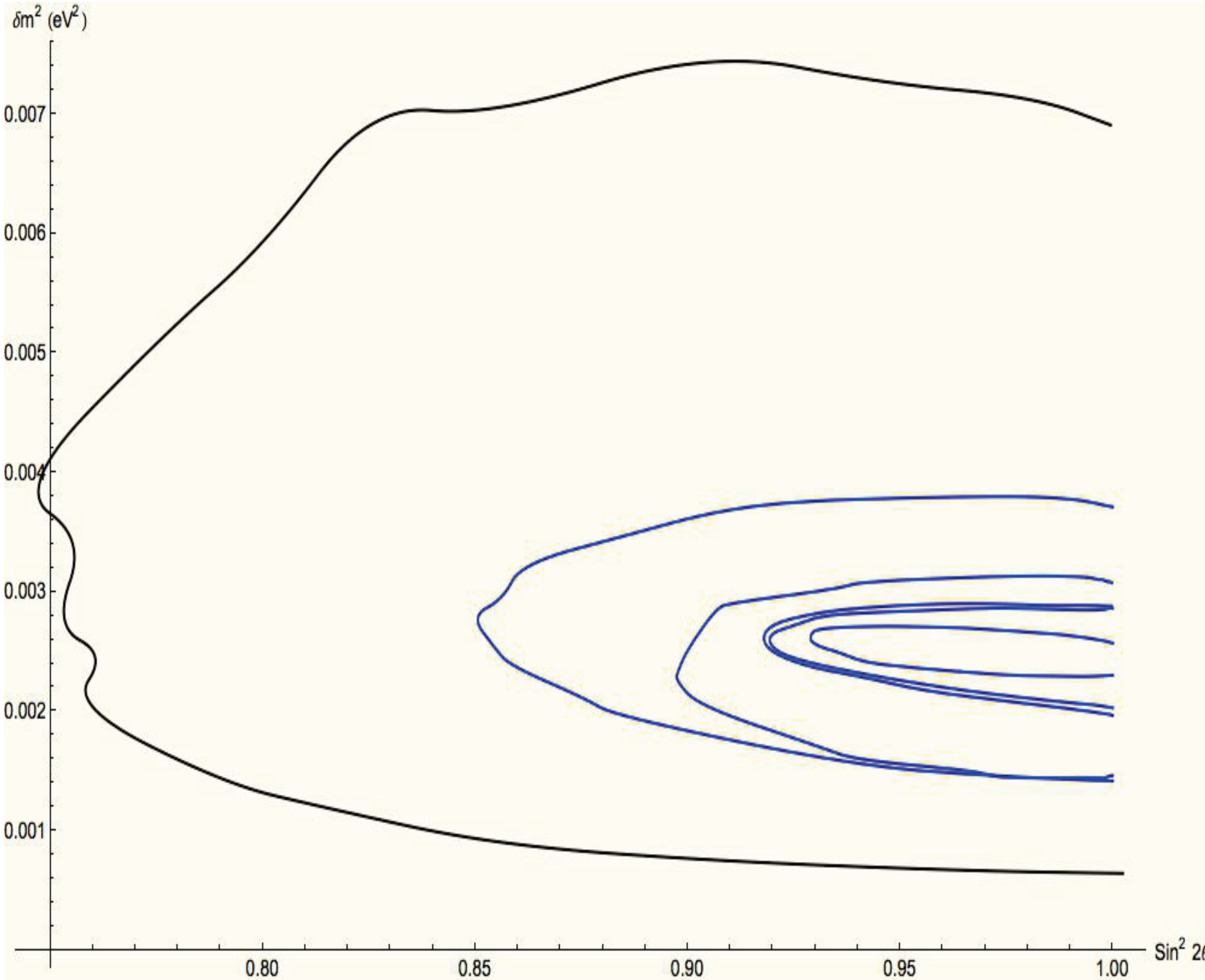
2005

2008

MINOS

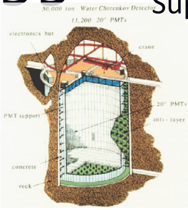
2010

The progress in atmospheric parameters

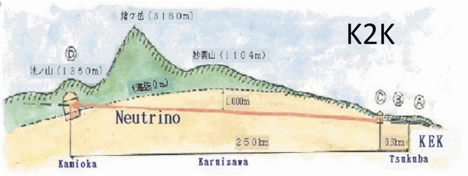


1999

SuperK



2002



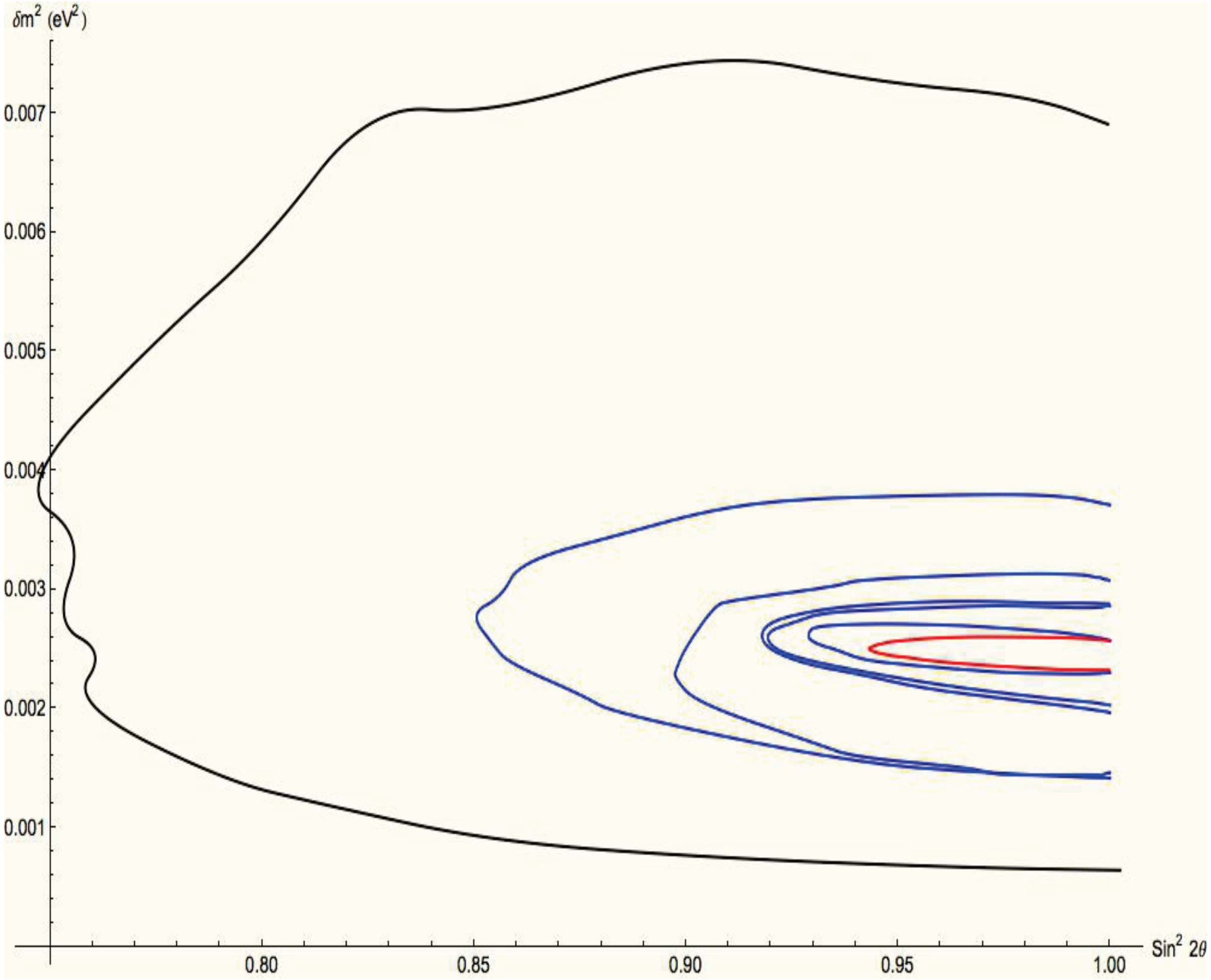
2005

2008

2010

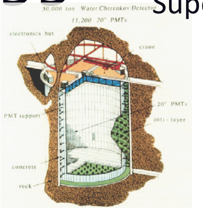
2012

The progress in atmospheric parameters



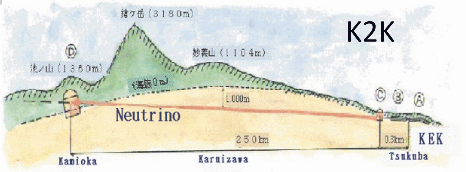
1999

SuperK



MACRO at GRAN SASSO
Monopole, Astrophysics, and Cosmic Ray Observatory

2002



2005

2008

MINOS

2010

2012

2014

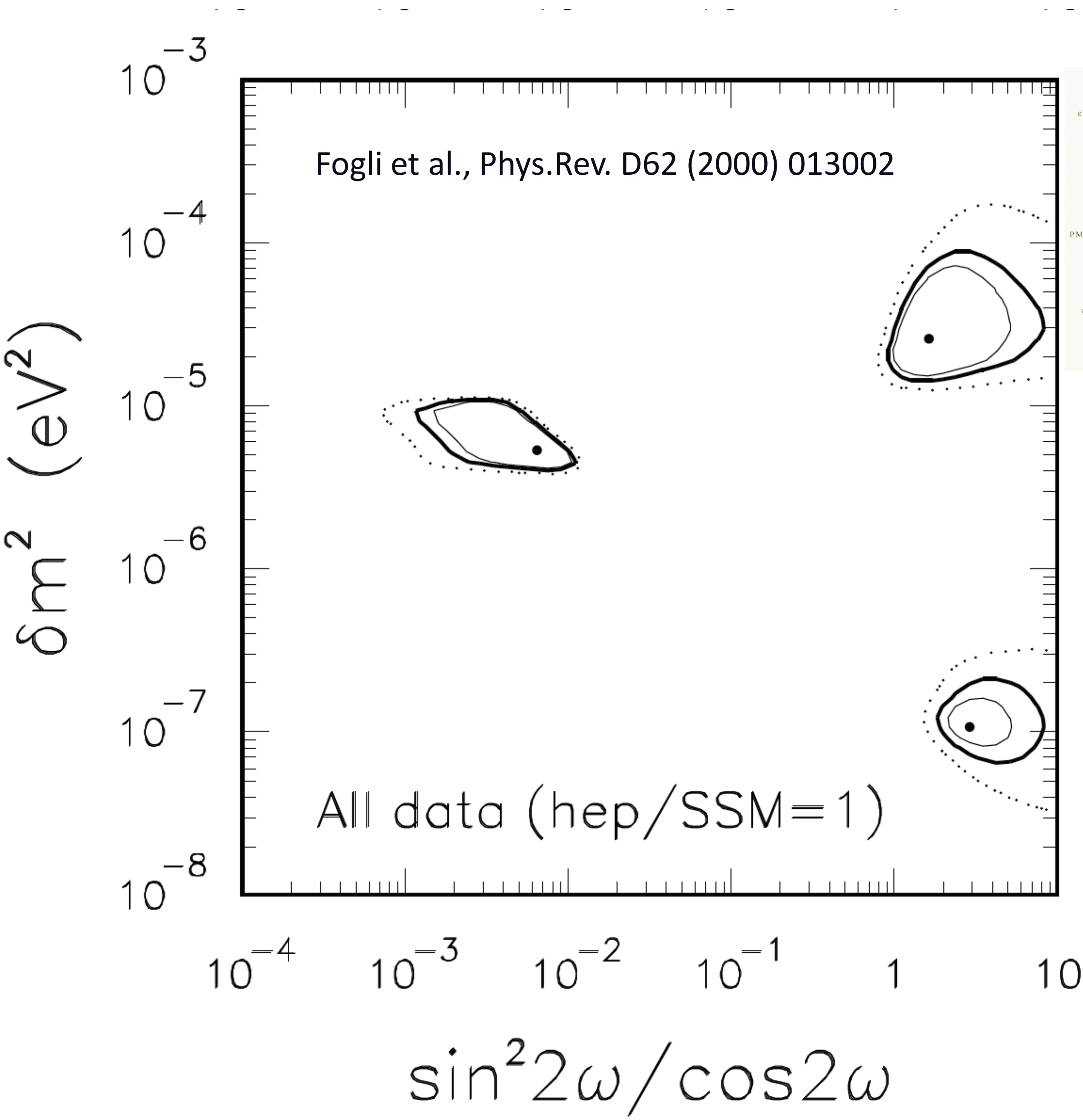
T2K

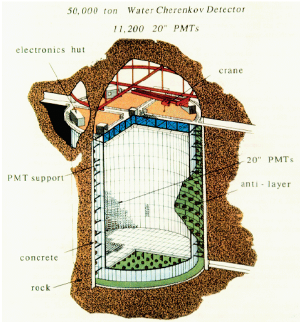
Along time changed variables, fitting methods, conventions, assumptions ….

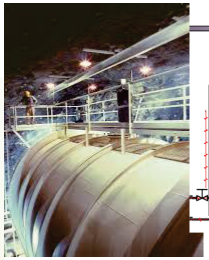
Results also from Opera, Antares, IceCube ….

The progress in solar parameters

1999

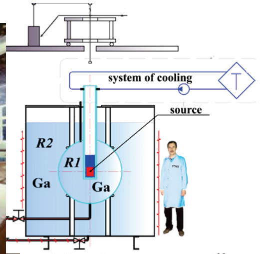


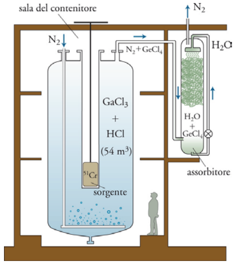




Homestake

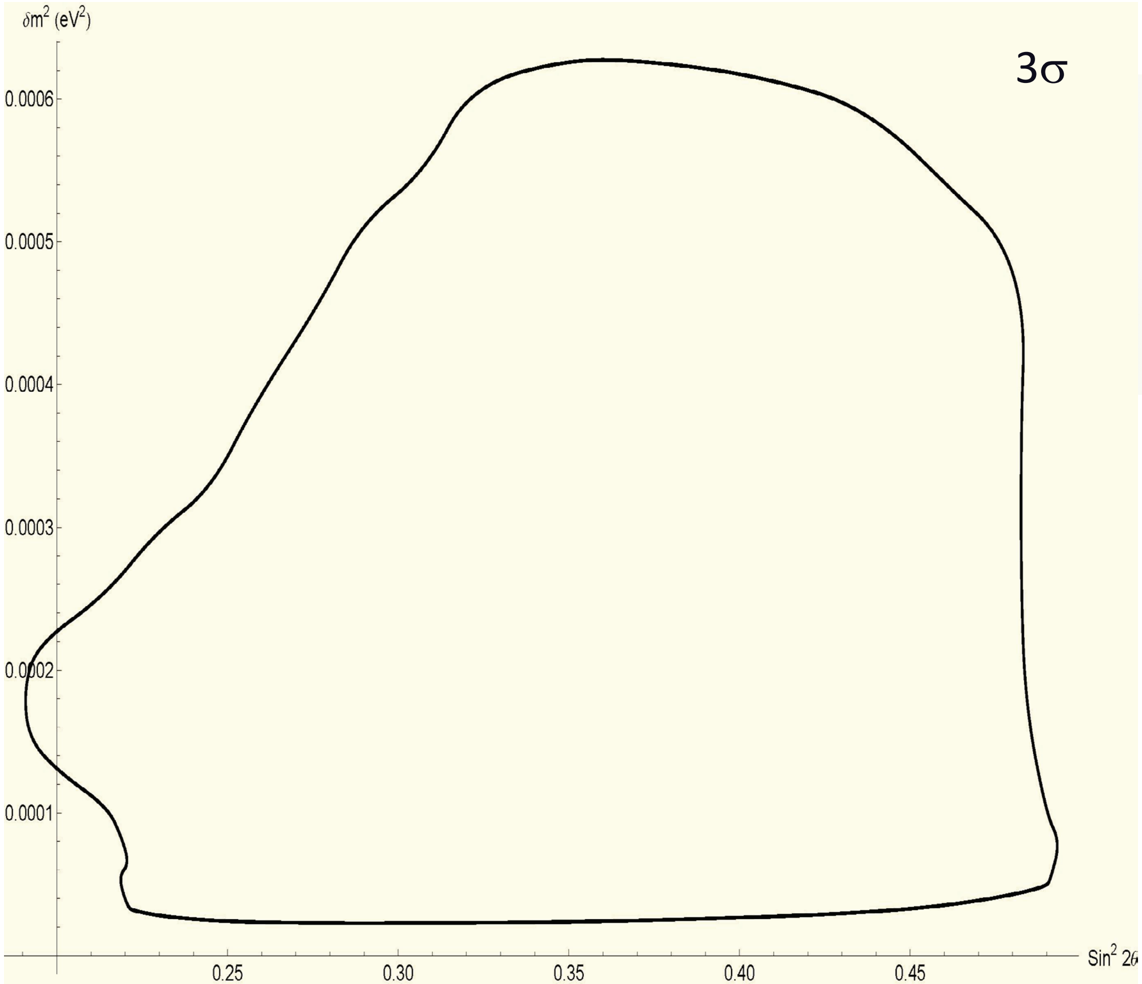
SAGE



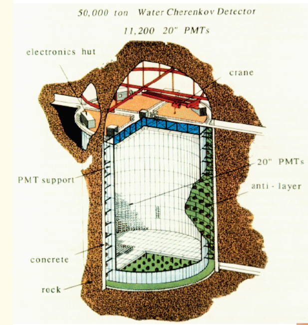


Gallex/GNO

The progress in solar parameters



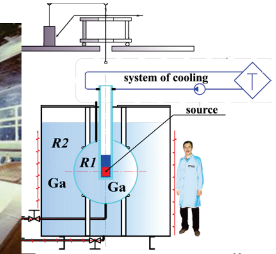
1999

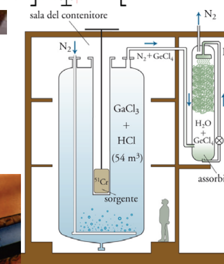


2002

Homestake

SAGE

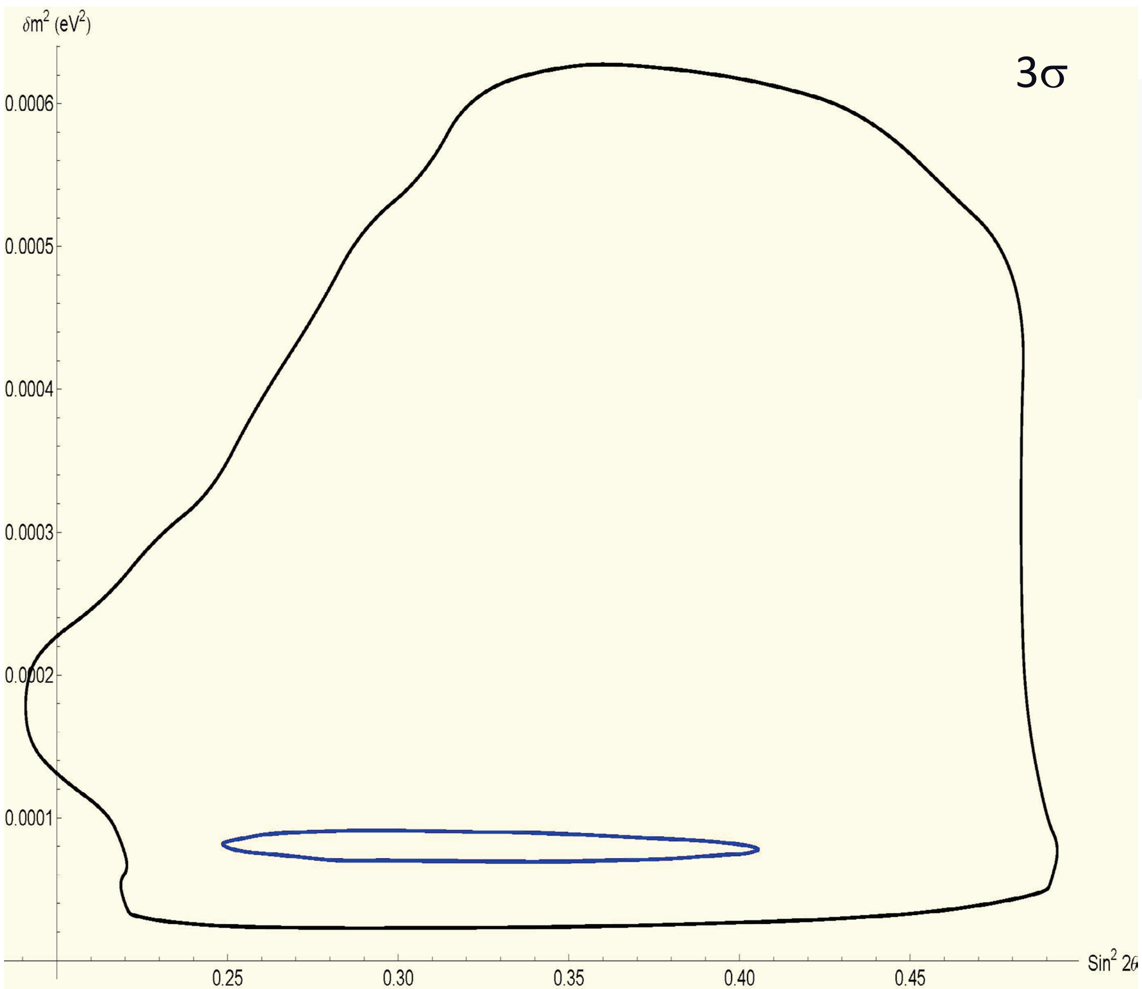




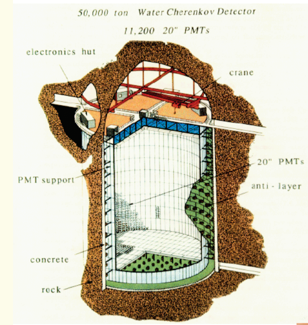
Gallex/GNO

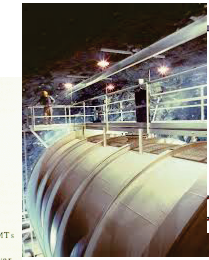
SNO

The progress in solar parameters



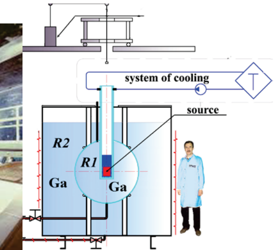
1999





Homestake

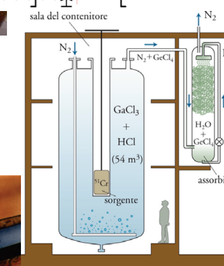
SAGE



2002

Kam
LAND

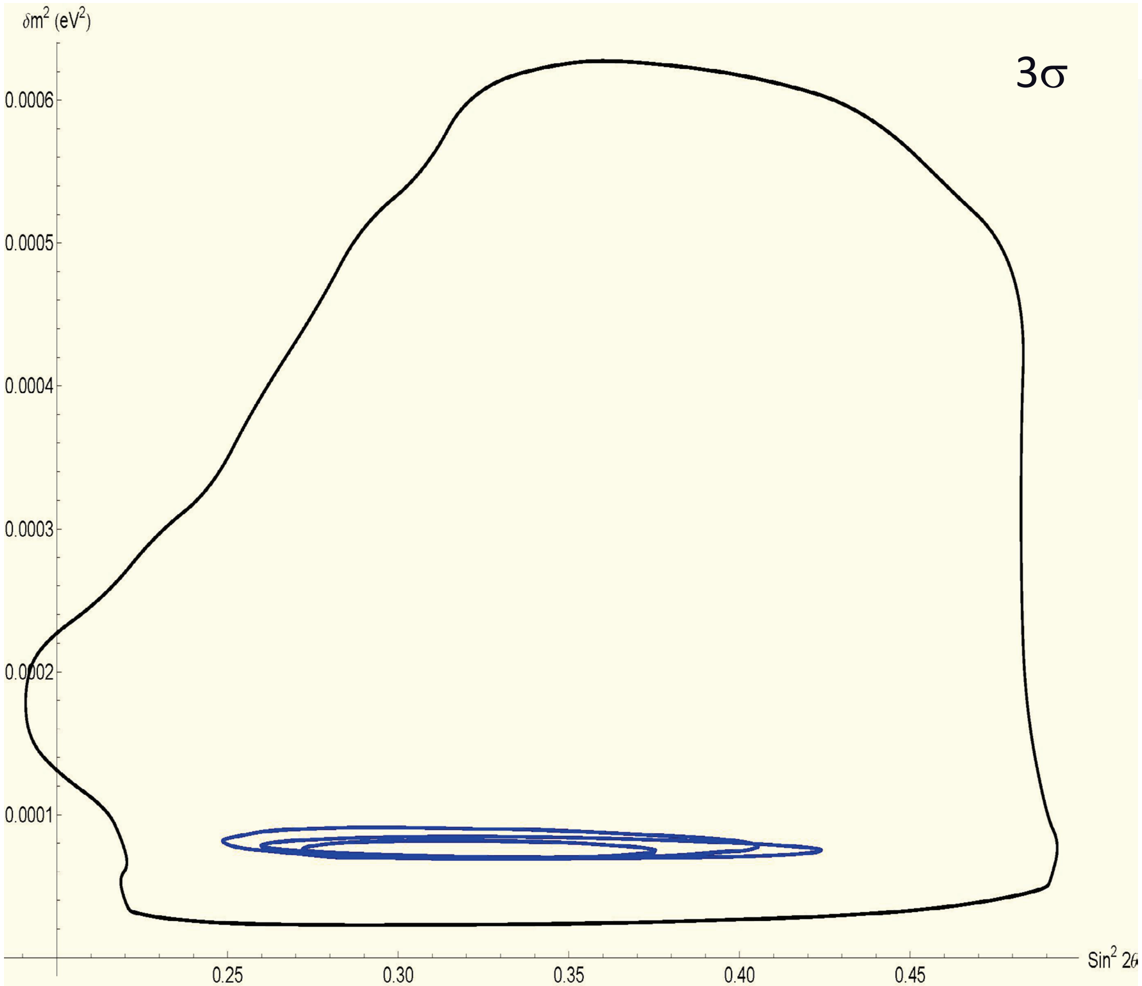
SNO



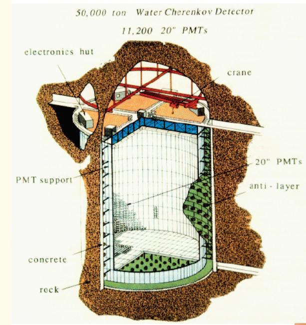
Gallex/GNO

2005

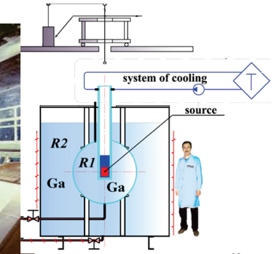
The progress in solar parameters

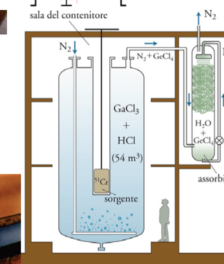


1999



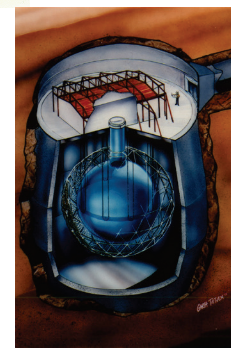

Homestake

SAGE




Gallex/GNO

2002

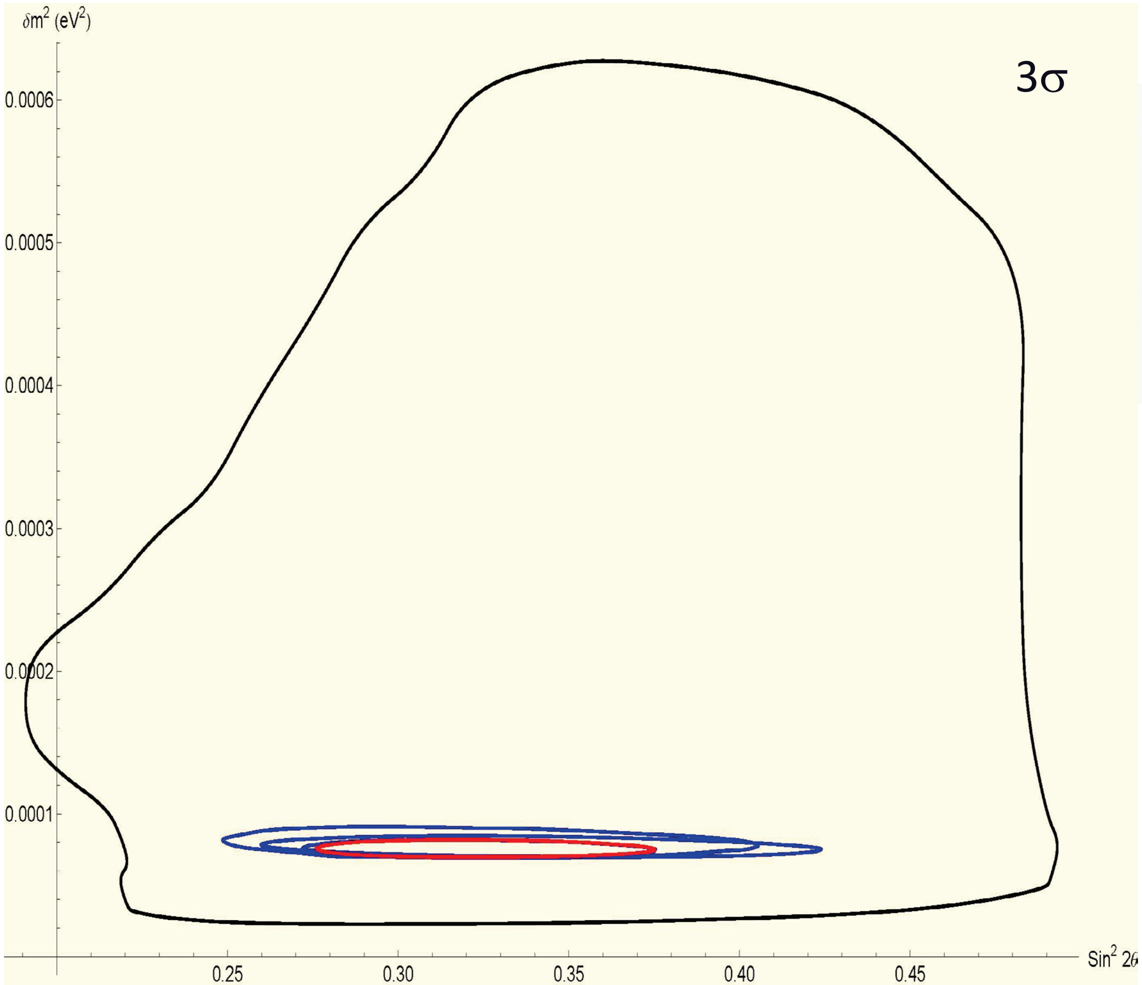

SNO

2005

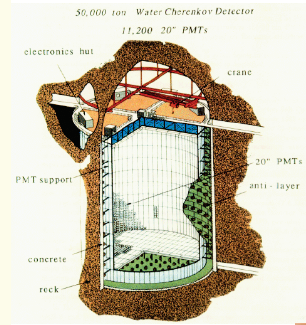
2008

2010

The progress in solar parameters

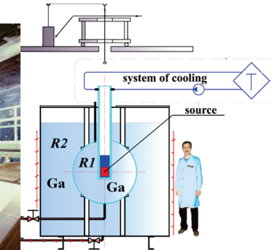


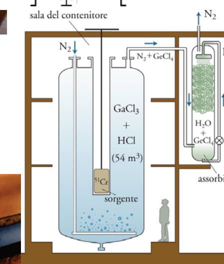
1999



Homestake

SAGE



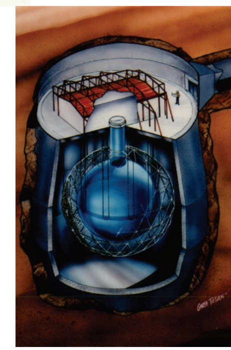


Gallex/GNO

2002

Kam LAND

Kamioka Liquid scintillator Anti-Neutrino Detector



SNO

2005

2008

2010

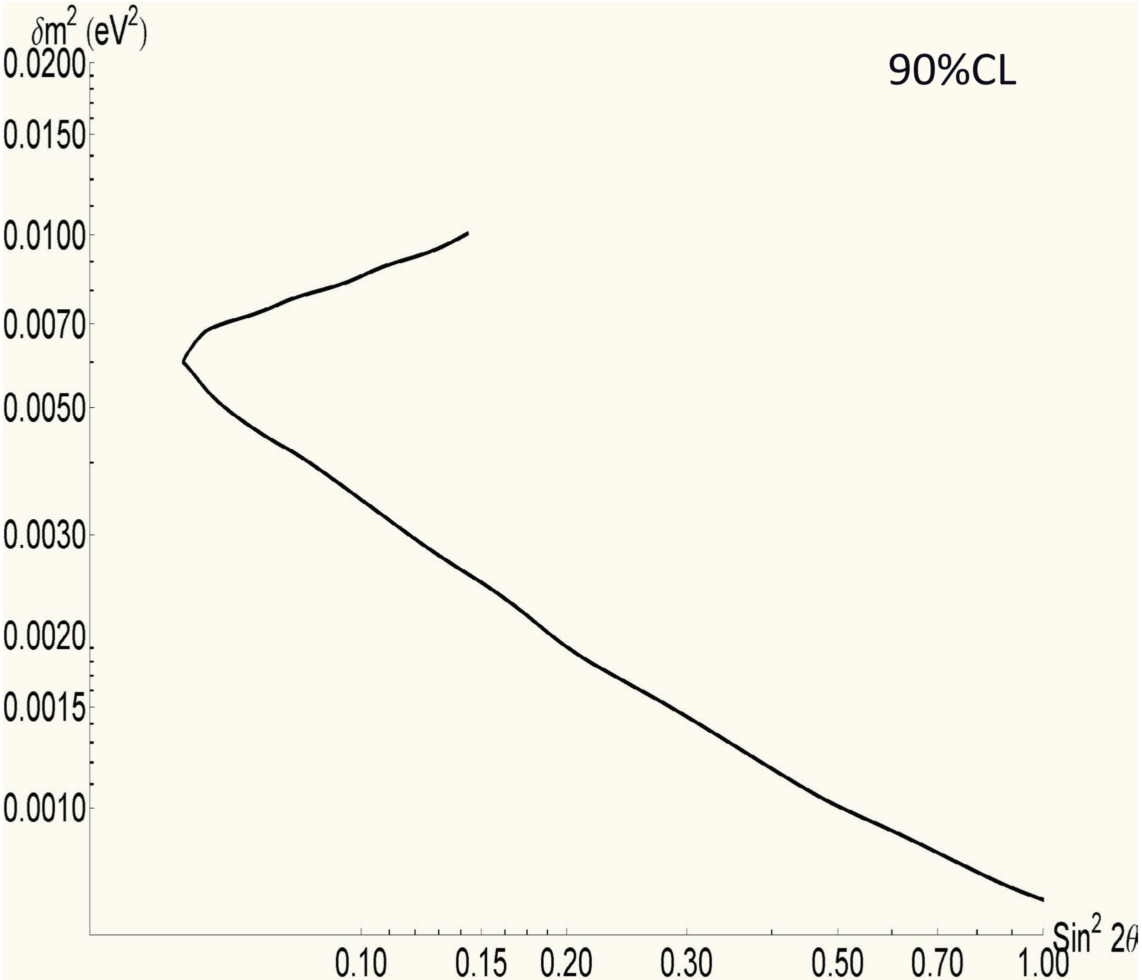
2012

2014

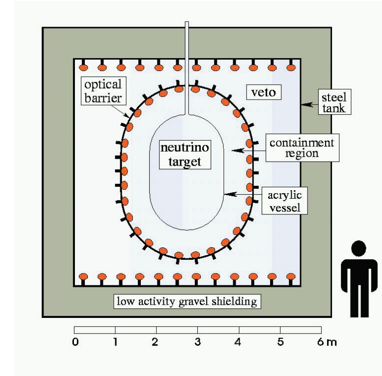
BOREXINO GRAN SASSO

Along time changed variables, fitting methods, conventions, assumptions …. And also some important cross section both at the source and the detector, not to mention the new evaluation of reactor antineutrino rates.

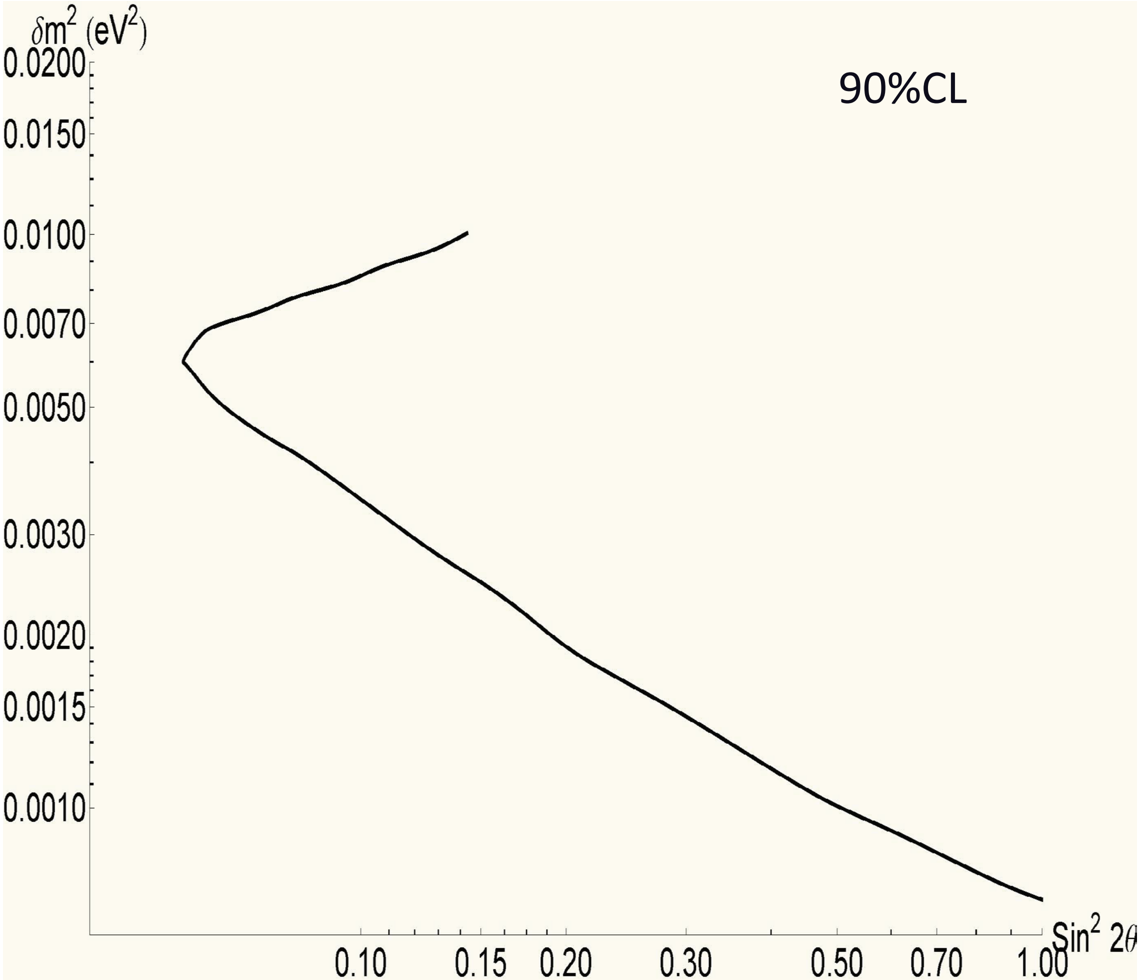
The progress in θ_{13}



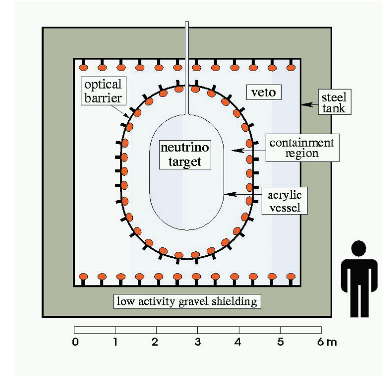
1999



The progress in θ_{13}



1999



2002

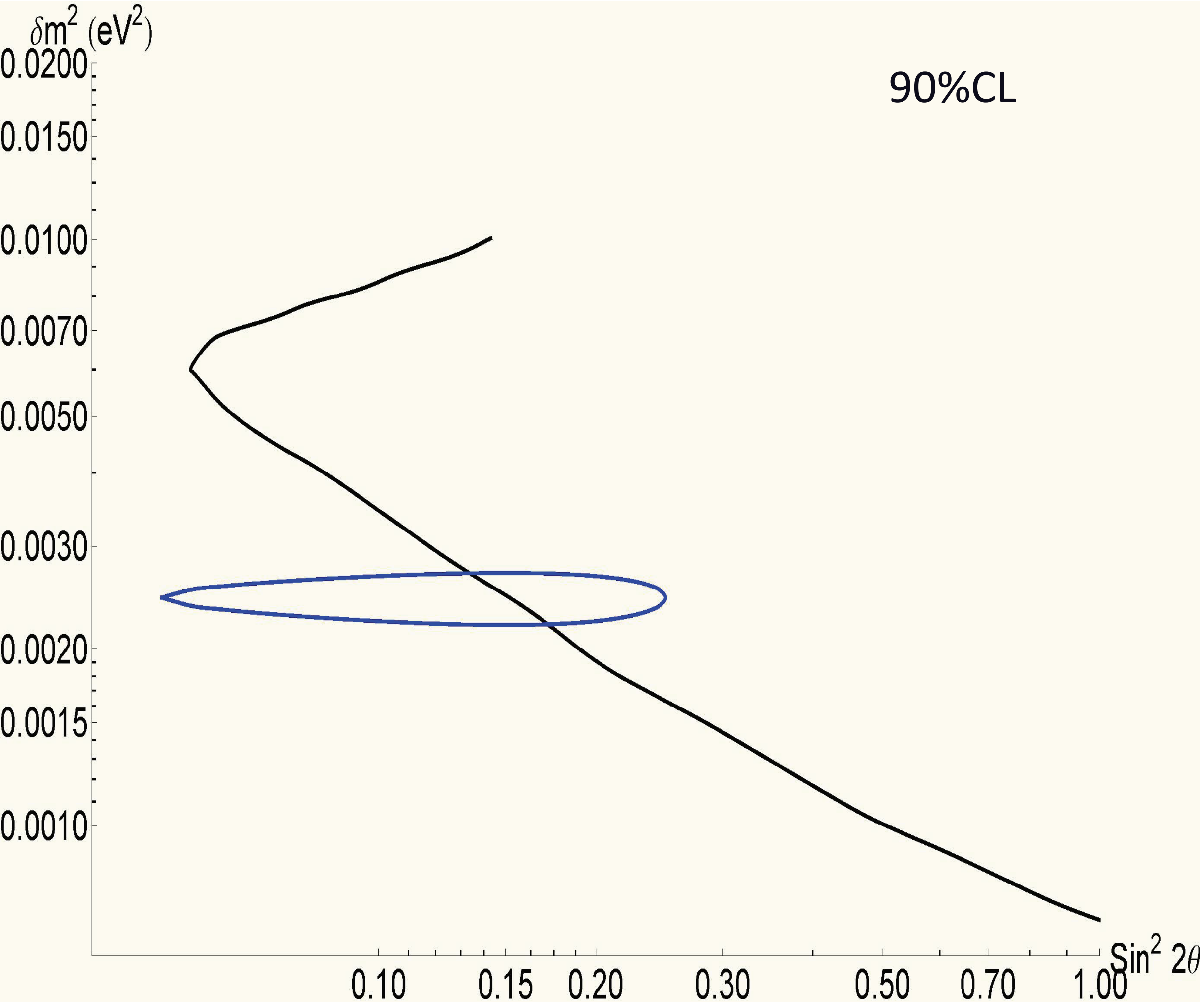
2005

2008

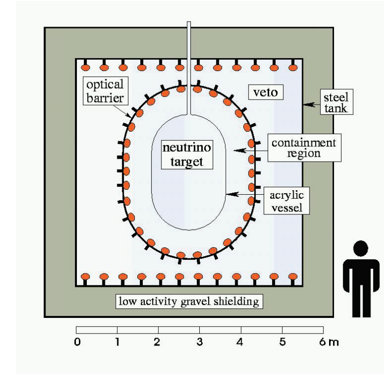
2009

At Neutel 2009 Fogli et al. start claiming that global fits favour $\sin^2 2\theta_{13}$=0.1 at 1.5σ

The progress in θ_{13}



1999



2002

2005

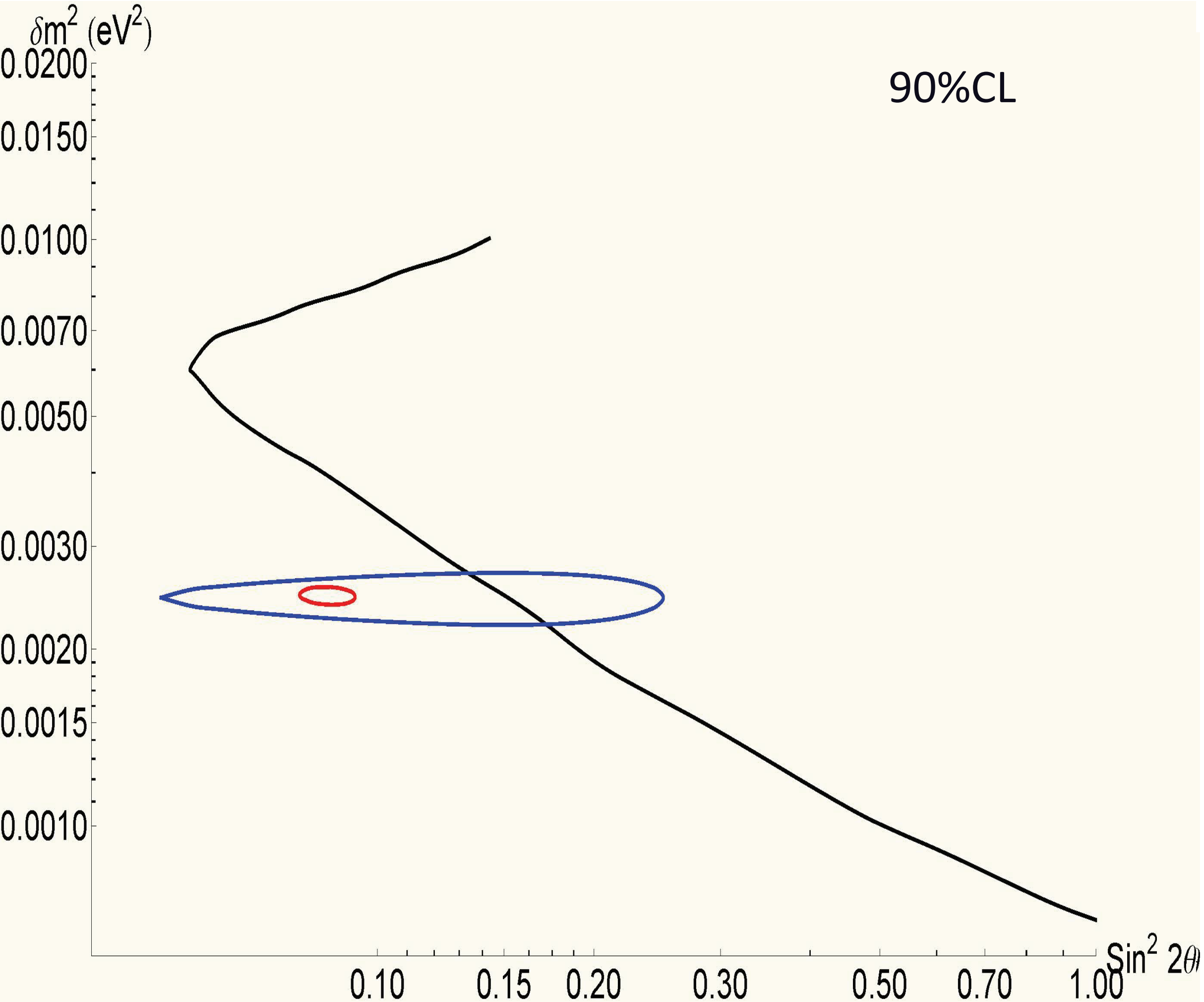
2008

2010

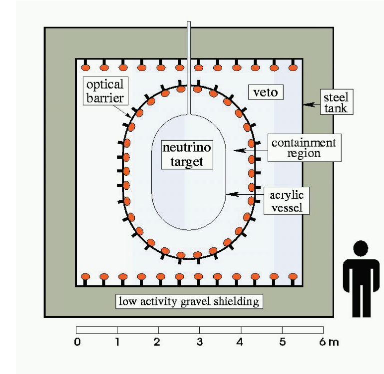
At Neutel 2010 Fogli et al.
Start claiming that global fits
Favour $\sin^2 2\theta_{13}$=0.1 at 1.5σ

2011

The progress in θ_{13}



1999



2002

2005

2008

2010 At Neutel 2010 Fogli et al. Start claiming that global fits Favour $\sin^2 2\theta_{13}=0.1$ at 1.5σ

2011 T2K

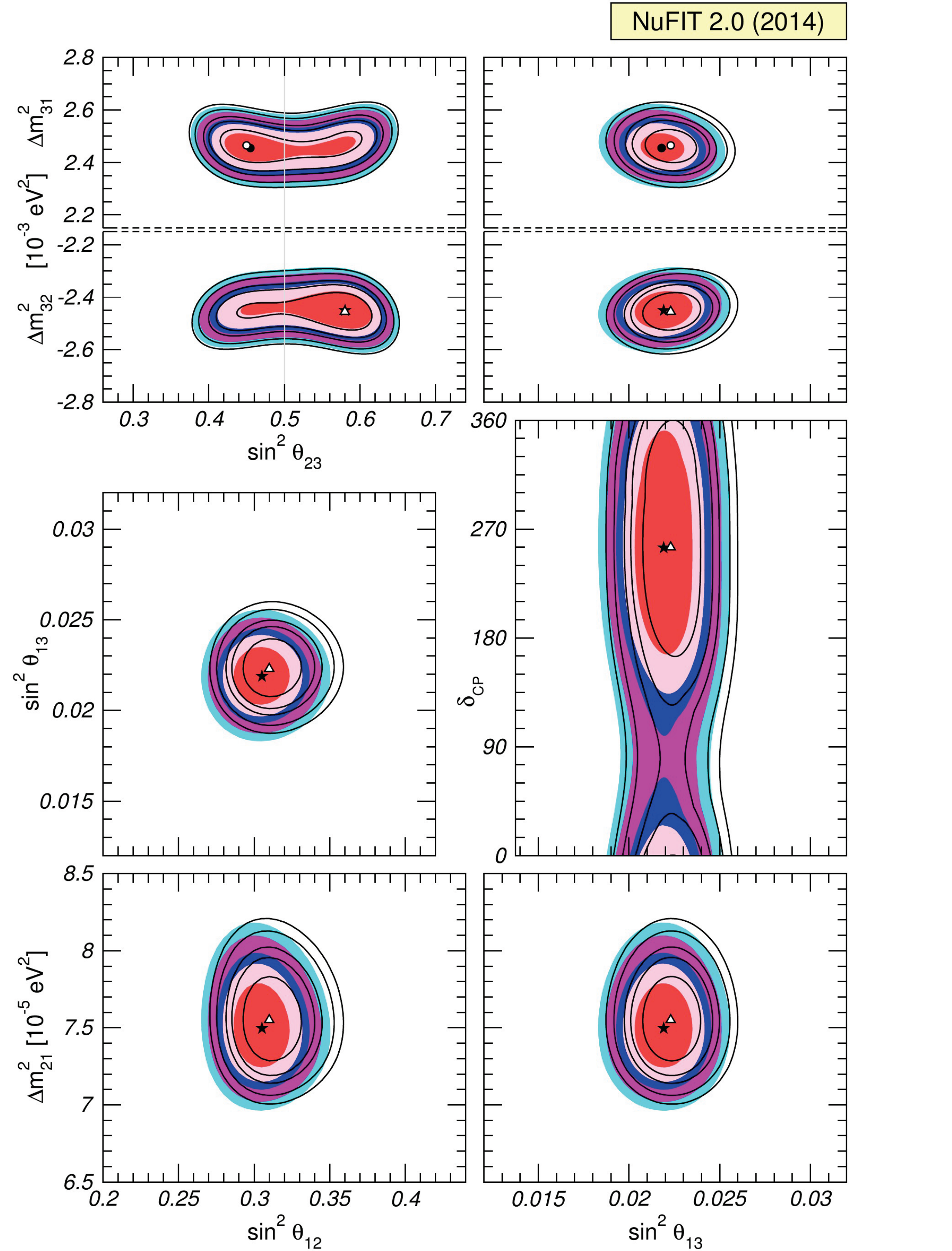
2012 RENO, Daya Bay, Double Chooz

What went wrong with θ_{13} ?

Why 12 years to improve Chooz?

Present situation

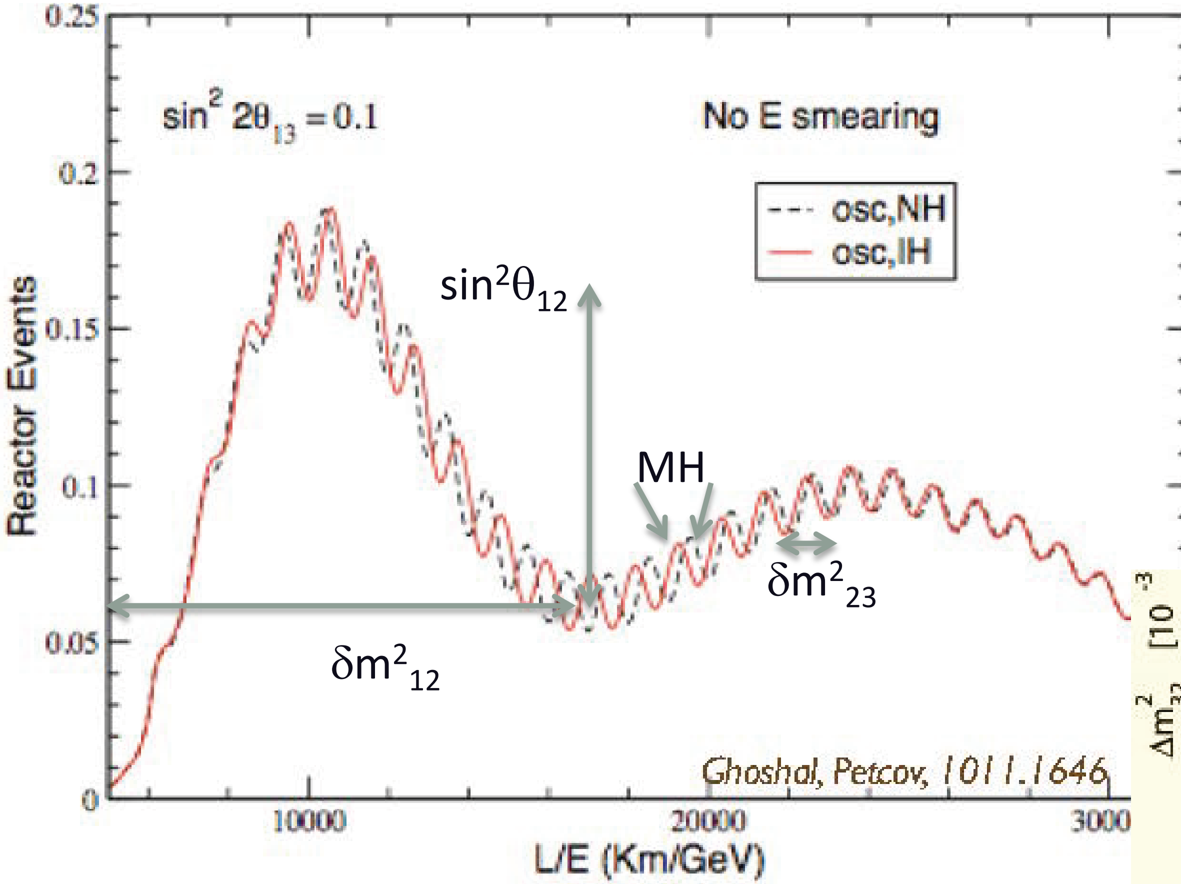
- Precision era started
- Can precision constrain new physics?
- What about unitarity ? (It's assumed in all these plots)

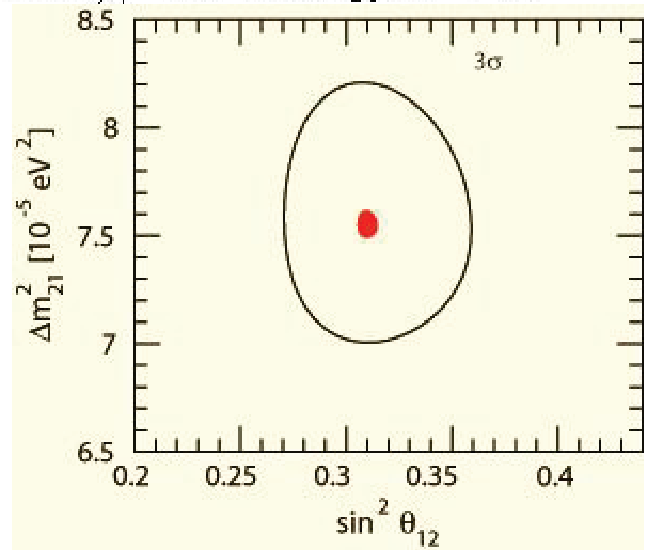


JUNO

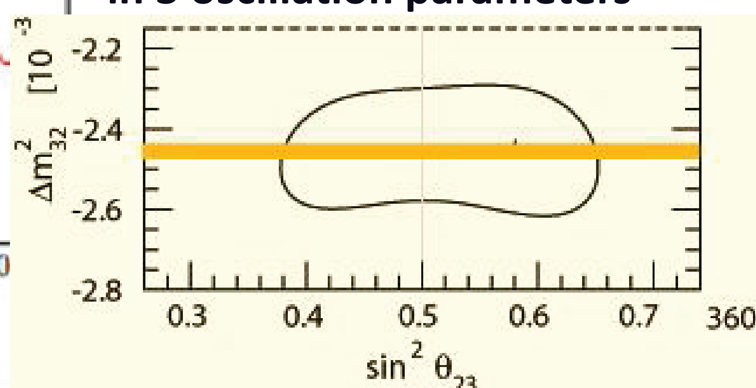
Petcov, Piai, hep-ph/0112074

$$P(\overline{\nu}_e \to \overline{\nu}_e) = 1 - \frac{1}{2}\sin^2 2\theta_{13}\left[1 - \left(c_{12}^2 \cos 2\Delta_{31} + s_{12}^2 \cos 2\Delta_{32}\right)\right] - \sin^2 2\theta_{12} c_{13}^4 \sin^2 \Delta_{21}$$





Factor 10 better precision in 3 oscillation parameters

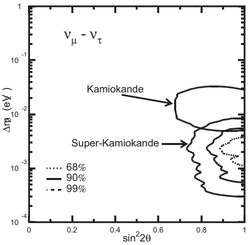


A detectable Leptonic CP Violation is not "natural"

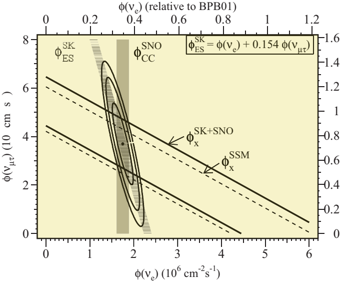
The CP odd term in oscillation formulas is

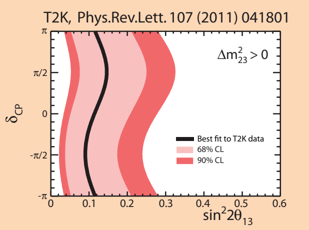
$$\propto \sin 2\theta_{23} \sin 2\theta_{12} \sin 2\theta_{13} \sin \delta \sin \frac{\Delta m^2_{13} L}{4E}$$

SuperKamiokande PRL 81(1998) 1562



SNO + SK, Phys.Rev.Lett. 87 (2001) 071301





Please note:

- SuperKamiokande protagonist in all the three discoveries
- Water Cerenkov the only experimental technique in these business.

PMNS CP Phase and Leptogenesis

Leptogenesis and Low Energy CP Violation in Neutrino Physics

Nucl.Phys. B774 (2007) 1-52

S. Pascoli [a], S.T. Petcov[b] [1] and A. Riotto[c,d]

[a] *IPPP, Dept. of Physics, University of Durham, DH1 3LE,UK*
[b] *SISSA and INFN-Sezione di Trieste, Trieste I-34014, Italy*
[c] *CERN Theory Division, Geneve 23, CH-1211, Switzerland*
[d] *INFN, Sezione di Padova, Via Marzolo 8, Padova I-35131, Italy*

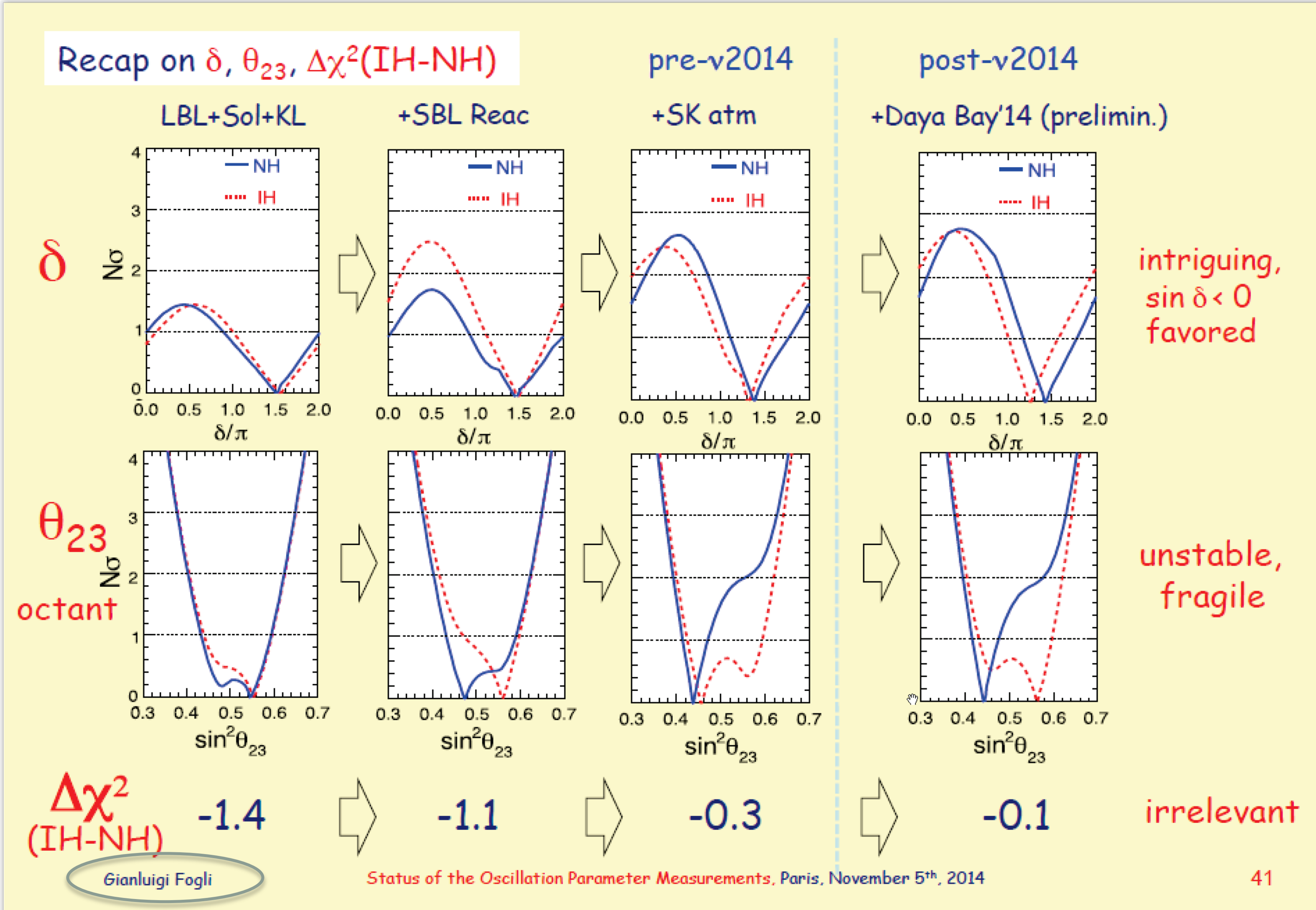
Abstract

Taking into account the recent progress in the understanding of the lepton flavour effects in leptogenesis, we investigate in detail the possibility that the CP-violation necessary for the generation of the baryon asymmetry of the Universe is due exclusively to the Dirac and/or Majorana CP-violating phases in the PMNS neutrino mixing matrix U, and thus is directly related to the low energy CP-violation in the lepton sector (e.g., in neutrino oscillations, etc.). We first derive the conditions of CP-invariance of the neutrino Yukawa couplings

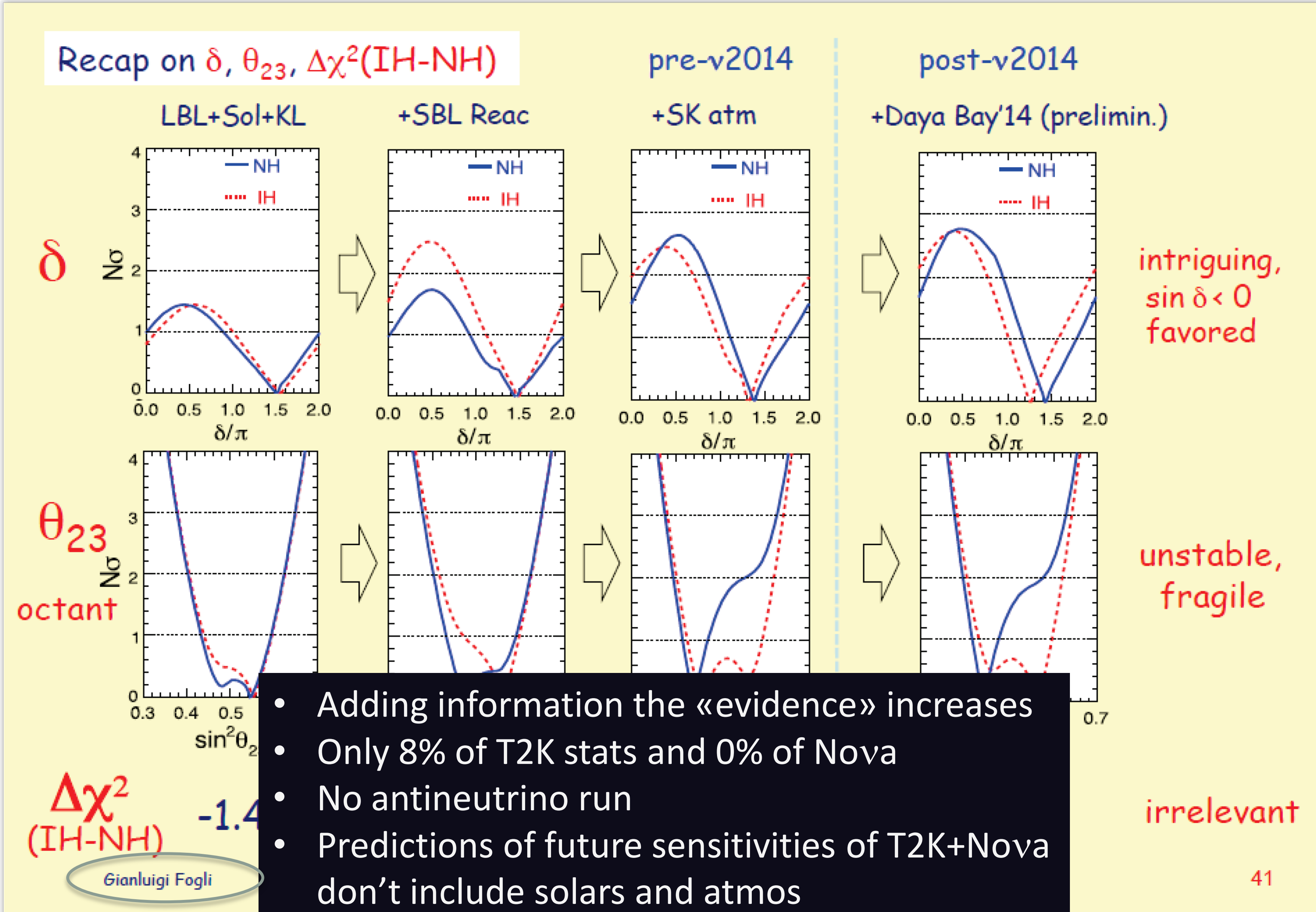
Given that $s_{13}|\sin\delta| \lesssim 0.2$, the lower bound in this inequality can be satisfied only for $M_1 \gtrsim 2.9 \times 10^{11}$ GeV. Recalling that the flavour effects in leptogenesis of interest are fully developed for $M_1 \lesssim 5 \times 10^{11}$ GeV, we obtain a *lower bound on the values of* $|s_{13}\sin\delta|$ *and* s_{13} *for which we can have successful leptogenesis in the case considered:*

$$|\sin\theta_{13}\,\sin\delta| \gtrsim 0.11\,, \quad \sin\theta_{13} \gtrsim 0.11\,. \qquad (93)$$

Hint of CP violation?



Hint of CP violation?



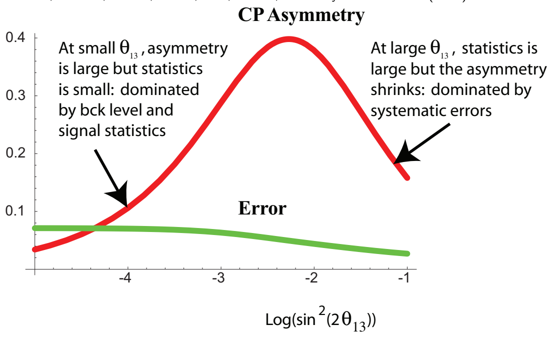
- Adding information the «evidence» increases
- Only 8% of T2K stats and 0% of Nova
- No antineutrino run
- Predictions of future sensitivities of T2K+Nova don't include solars and atmos

The largest θ_{13} is not the best value for LCPV

$$A_{CP} = \frac{P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\bar{\nu}_\mu \to \bar{\nu}_e)} \propto \frac{1}{\sin\theta_{13}}$$

Signal statistics is maximum BUT $\nu - \bar{\nu}$ asymmetry is minimum
In other terms systematic errors dominate

Blondel, Cervera, Donini, Huber, MM, Strolin, Acta Phys. Polon. B **37** (2006) 2077

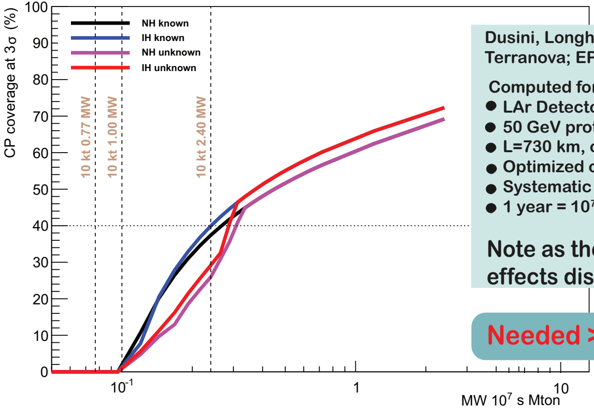


LCPV asymmetry at the first oscillation maximum, $\delta = 1$, Error curve: dependence of the statistical+systematic (2%) computed for a beta beam the fixed energy $E_\nu = 0.4$ GeV, $L = 130$ km.

Defining LCPV target performances

5 σ with 50% coverage **(3 σ with 70% coverage)**

CP coverage at 3 σ (%), 5+5 y, err.sys. = 0.05 ONAXIS



Dusini, Longhin, MM, Patrizii, Sioli, Sirri, Terranova; EPJ C73 (2013) 2392

Computed for:

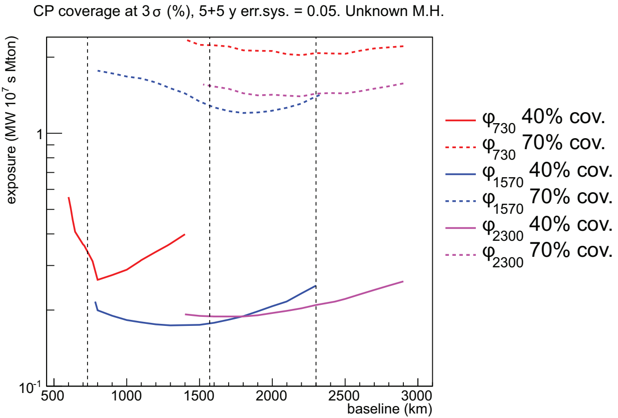
- LAr Detector
- 50 GeV proton beam
- L=730 km, on-axis
- Optimized optics
- Systematic errors: 5%
- 1 year = 10^7 s

Note as the MH degeneracy effects disappear with exposure

Needed >1 Mton x MW x year

There are no magic baselines for CP searches

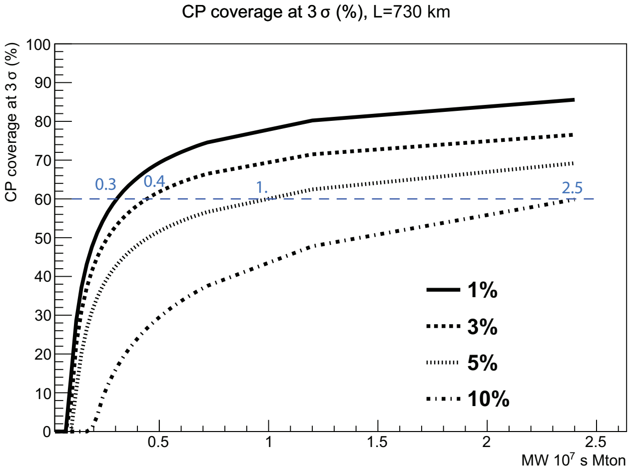
Dusini et al., EPJ C73 (2013) 2392



- LAr detector, 50 GeV/c proton accelerator
- Beam optics optimized with the same algorithm for 3 baselines: 732, 1570, 2300 km.
- For each optimization the baseline has been moved in a range
- Curves are for 40% and 70% coverage (3σ)

Systematic errors play a decisive role

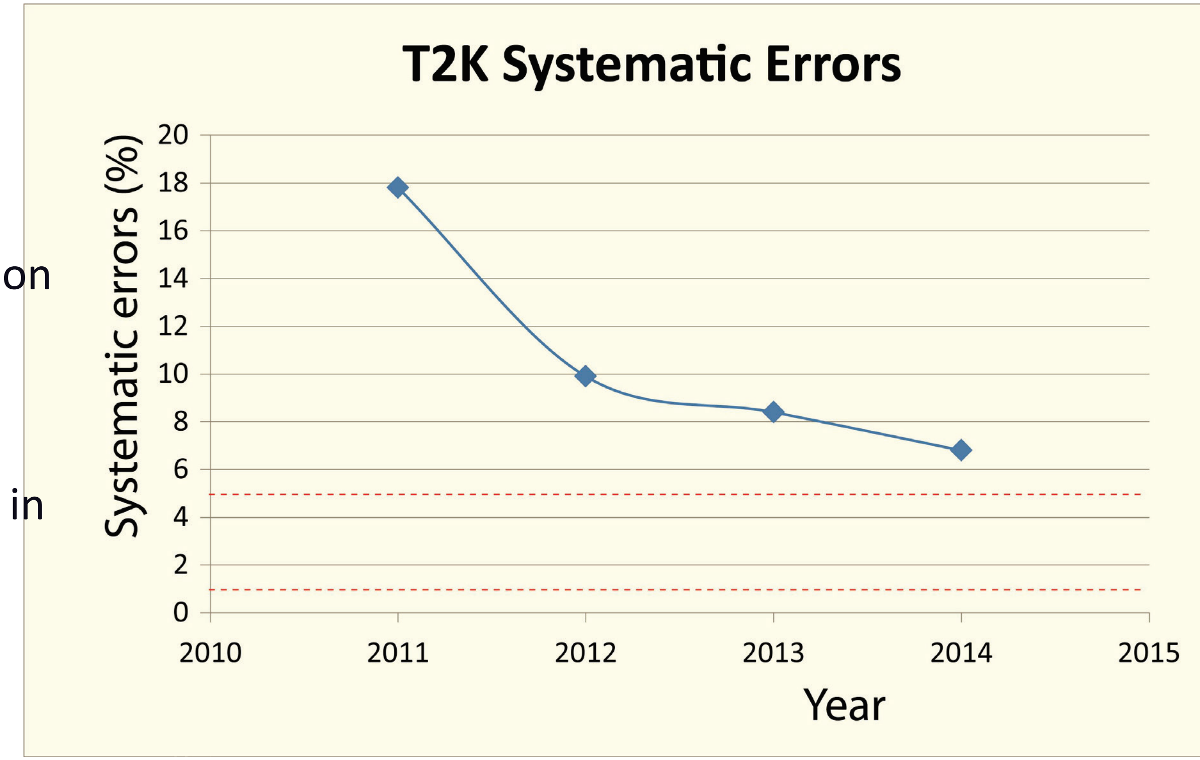
Dusini et al., EPJ C73 (2013) 2392



Again on systematic errors

The experience of T2K

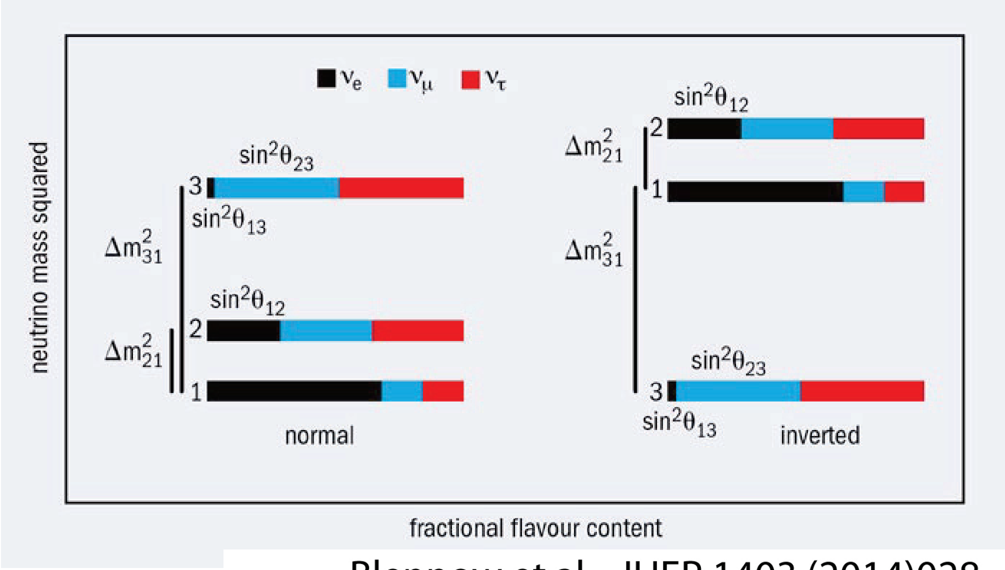
- A sophisticated close detector station: ND280 + Ingrid
- The best quality hadroproduction data ever produced (NA61) already included
- A huge, qualified, effort by the largest collaboration ever seen in neutrino physics
- At present limited by statistics



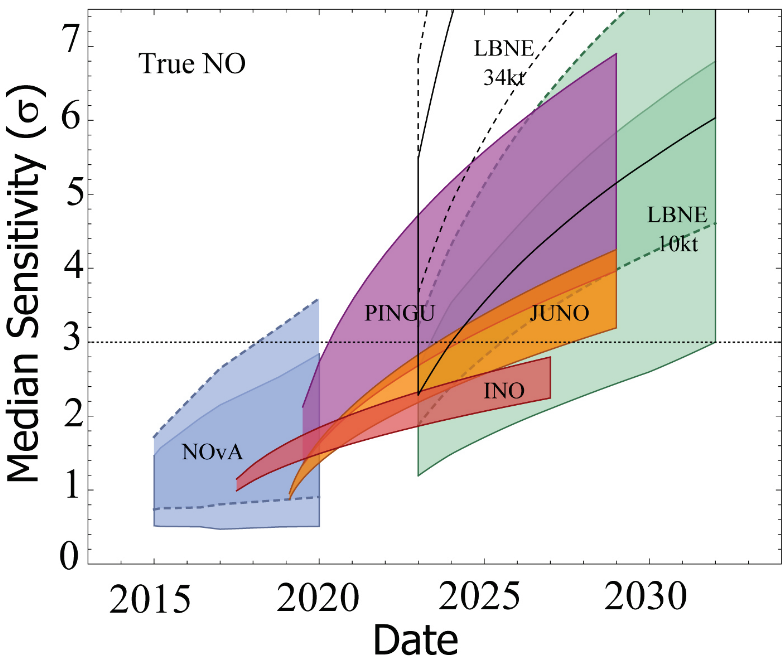
- The 1% goal cannot be achieved by just designing a «better» close detector
- It will probably require a step in neutrino beam technology
- So far proposed Nustorm and a **Tagged Neutrino Beam**

Mass Hierarchy

- An internal degree of freedom in neutrino masses
- Important in double beta decay (only if inverted)
- Which role in cosmology?
- Which role in BSM?



Blennow et al., JHEP 1403 (2014)028



- Pure oscillation effects in ν_e disappearance: **Juno**
- Matter effects in ν_μ disappearance: **INO**, Pingu, Orca, HK
- Matter effects in ν_e appearance: **NOνA**, LBNF, T2HK

Conclusions

- After 16 years neutrino oscillations are healthy and lively
- They can guarantee valuable input in several foundamental aspects of high energy physics
- The international interest in neutrino oscillation is extremely high
- Excellent opportunities for the INFN community
- Past mistakes should help in better programming future activities.