Mauro Mezzetto
Istituto Nazionale di Fisica Nucleare, Sezione di Padova

" Rassegna Sperimentale sulle Oscillazioni dei Neutrini"

Entirely devoted to θ_{13}:

- Introduction
- Results from T2K and Minos at accelerators and Double Chooz, Daya Bay and RENO at reactors.
- Long term perspectives: Leptonic CP violation.
- Sterile neutrinos and experimental perspectives: see G. Sirri talk later this morning.

θ_{13} measurement is a milestone in HEP

- θ_{13} was one of the few standard model parameters still unknown.
- It is one of the most discriminant parameters to select neutrino mass matrixes, a key ingredient to decide grand unified theories (if any).
- Non-zero θ_{13} is necessary to build-up leptonic CP violation. The value (order of magnitude) of θ_{13} is necessary to optimize new facilities to measure leptonic CP violation.

Reactors vs Accelerators

Accelerators: ν_e appearance

$$P_{\nu_\mu \to \nu_e} = 4c_{13}^2 s_{13}^2 s_{23}^2 \sin^2 \frac{\Delta m_{13}^2 L}{4E} \times \left[1 \pm \frac{2a}{\Delta m_{13}^2}(1-2s_{13}^2)\right] \qquad \theta_{13} \text{ driven}$$

$$+ 8c_{13}^2 s_{12} s_{13} s_{23}(c_{12}c_{23}\cos\delta - s_{12}s_{13}s_{23}) \cos\frac{\Delta m_{23}^2 L}{4E} \sin\frac{\Delta m_{13}^2 L}{4E} \sin\frac{\Delta m_{12}^2 L}{4E} \text{CPev}$$

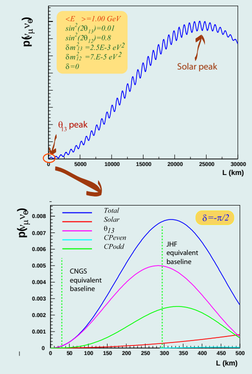
$$\mp 8c_{13}^2 c_{12} c_{23} s_{12} s_{13} s_{23} \sin\delta \sin\frac{\Delta m_{23}^2 L}{4E} \sin\frac{\Delta m_{13}^2 L}{4E} \sin\frac{\Delta m_{12}^2 L}{4E} \qquad \text{CPodd}$$

$$+ 4s_{12}^2 c_{13}^2 \{c_{13}^2 c_{23}^2 + s_{12}^2 s_{23}^2 s_{13}^2 - 2c_{12}c_{23}s_{12}s_{23}s_{13}\cos\delta\} \sin\frac{\Delta m_{12}^2 L}{4E} \qquad \text{solar driven}$$

$$\mp 8c_{12}^2 s_{13}^2 s_{23}^2 \cos\frac{\Delta m_{23}^2 L}{4E} \sin\frac{\Delta m_{13}^2 L}{4E} \frac{aL}{4E}(1-2s_{13}^2) \qquad \text{matter effect (CP odd)}$$

Reactors: $\overline{\nu}_e$ disappearance

$$1 - P_{\overline{\nu}_e - \overline{\nu}_e} \simeq \sin^2 2\theta_{13} \sin^2(\Delta m_{31}^2 L/4E) + (\Delta m_{21}^2/\Delta m_{31}^2)^2 (\Delta m_{31}^2 L/4E)^2 \cos^4\theta_{13} \sin^2 2\theta_{12}$$



$$p(\nu_\mu \to \nu_e) = 4c^2_{13}s^2_{13}s^2_{23}\sin^2\frac{\Delta m^2_{13}L}{4E} \times \left[1 \pm \frac{2a}{\Delta m^2_{13}}(1-2s^2_{13})\right] \qquad \theta_{13}\ \text{dri}$$

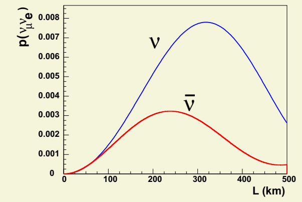
$$+\,8c^2_{13}s_{12}s_{13}s_{23}(c_{12}c_{23}\cos\delta - s_{12}s_{13}s_{23})\cos\frac{\Delta m^2_{23}L}{4E}\sin\frac{\Delta m^2_{13}L}{4E}\sin\frac{\Delta m^2_{12}L}{4E} \quad \text{CPev}$$

$$\mp\,8c^2_{13}c_{12}c_{23}s_{12}s_{13}s_{23}\sin\delta\sin\frac{\Delta m^2_{23}L}{4E}\sin\frac{\Delta m^2_{13}L}{4E}\sin\frac{\Delta m^2_{12}L}{4E} \qquad \text{CPodd}$$

$$+\,4s^2_{12}c^2_{13}\{c^2_{13}c^2_{23} + s^2_{12}s^2_{23}s^2_{13} - 2c_{12}c_{23}s_{12}s_{23}s_{13}\cos\delta\}\sin\frac{\Delta m^2_{12}L}{4E} \qquad \text{solar driven}$$

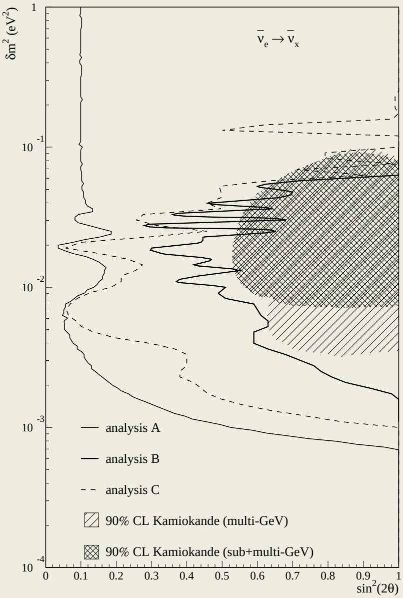
$$\mp\,8c^2_{12}s^2_{13}s^2_{23}\cos\frac{\Delta m^2_{23}L}{4E}\sin\frac{\Delta m^2_{13}L}{4E}\frac{aL}{4E}(1-2s^2_{13}) \qquad \text{matter effect (CP odd)}$$

θ_{13} discovery requires a signal ($\propto \sin^2 2\theta_{13}$) greater than the solar driven probability



Leptonic CP discovery requires

$$A_{CP} = \frac{P(\nu_\mu\to\nu_e) - P(\overline{\nu}_\mu\to\overline{\nu}_e)}{P(\nu_\mu\to\nu_e) + P(\overline{\nu}_\mu\to\overline{\nu}_e)} \neq 0$$



CHOOZ final results

- **Analysis A** $\overline{\nu}_e$ spectrum after background subtraction. Both the absolute rate and the spectrum are used.
- **Analysis B** Uses the different baseline ($\Delta L = 117.7\ m$) of the two reactors. Many systematic errors cancel, but statistical errors are bigger and the Δm^2 sensitivity is reduced by the shorter baseline.
- **Analysis C** Only spectrum information is used.

1450 citations:
the top cited null result in hep ever !

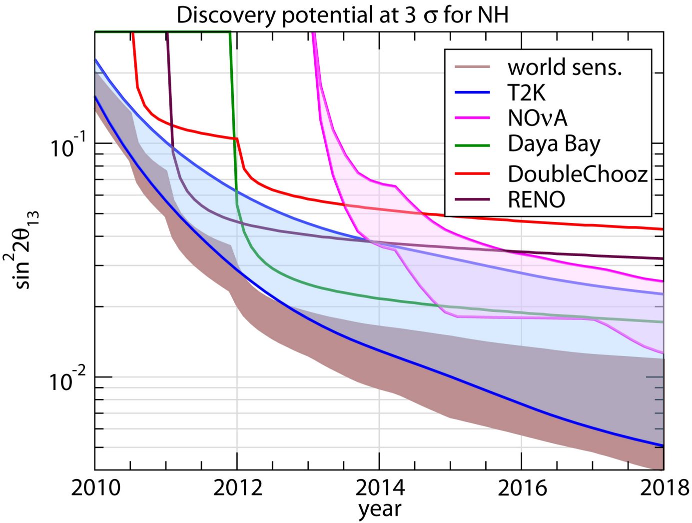
1998 - 2011

No experiment had been able to improve the Chooz sensitivity.
Even if 3 neutrino oscillation long-baseline projects had been setup in 3 continents:

- **K2K**: KEK to SuperKamiokaNDE: the first check of the discovery of neutrino oscillation in atmospheric neutrinos by using an artificial neutrino beam. The proton intensity was not enough to achieve a competitive sensitivity to θ_{13}.
- **MINOS**: NuMI neutrino beam from Fermilab to the Minos detector. Aimed to improve the precision of the measurement of the atmospheric oscillation parameters θ_{23} and Δm^2_{23}. The iron magnetized Minos detector was not optimized for the detection of electrons. Recently achieved a sensitivity on θ_{13} similar to the CHOOZ sensitivity.
- **CNGS:** CNGS neutrino beam from CERN to the Opera and Icarus detectors at LNGS. The beam setup had been optimized for the ν_τ appearance searches and for this reason was not optimal for θ_{13} searches.

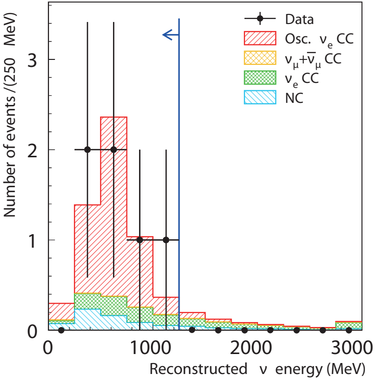
Predictions before exp. results

M.M. and T. Schwetz, J.Phys.G G37 (2010) 103001

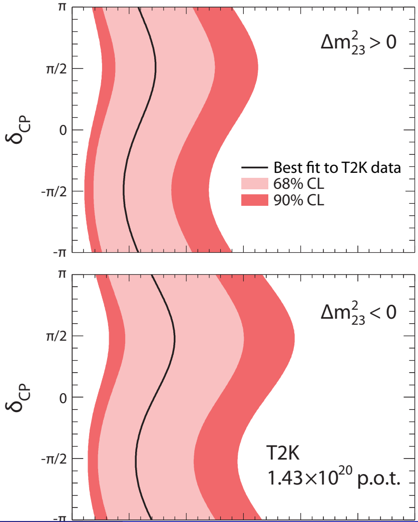


The T2K Experiment

T2K result, PRL 107 (2011) 041801



Expected: 1.5 +/- 0.3
Measured: 6

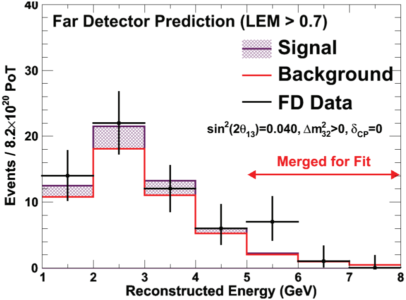


Systematic errors

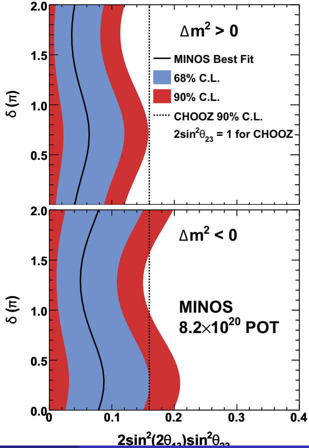
Source	$\sin^2 2\theta_{13} = 0$	$\sin^2 2\theta_{13} = 0.1$
(1) neutrino flux	± 8.5%	± 8.5%
(2) near detector	$^{+5.6}_{-5.2}$%	$^{+5.6}_{-5.2}$%
(3) near det. statistics	± 2.7%	± 2.7%
(4) cross section	± 14.0%	± 10.5%
(5) far detector	± 14.7%	± 9.4%

MINOS, PRL 107 (2011) 181802

Results on appearance of electron-neutrinos with 8.2x10[20] POT

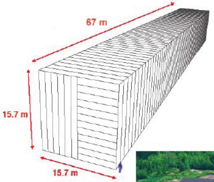


	MINOS	T2K
pot	8.2 10^{20}	1.45 10^{20}
tjoule	1.57	0.07
tjoule kton	7.85	1.57

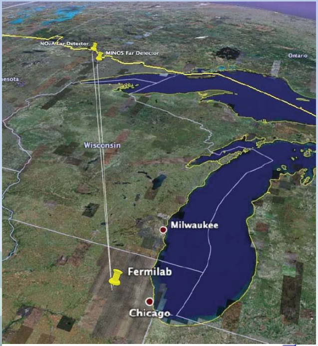


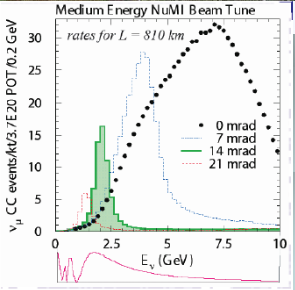
Year	pot	Expected	Detected
2009	3.1 10^{20}	27	35
2010	7.0 10^{20}	49	54
2011	8.2 10^{20}	49	62

NOvA



- 14 kt total mass, 70% scintillator
- 930 planes
- ~3 m water equivalent earth overburden of barite and concrete



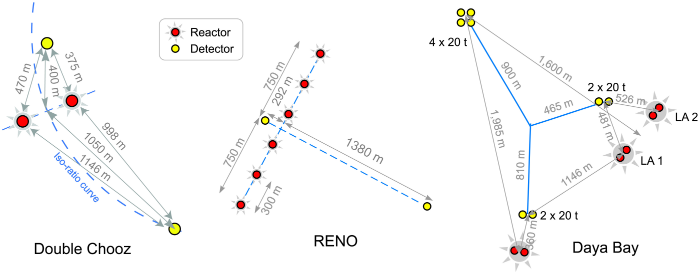


- FNAL NuMI off-axis beam
- Power upgrade 320kW→700kW
  - Recycler: anti-proton → proton
  - Rep cycle 2.2s → 1.33s
- New 14kton liquid scintillator fine grained detector @810km
- Far detector will complete and start taking data in 2014

7

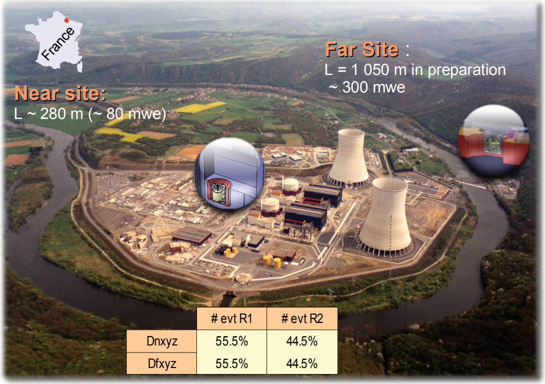
The three reactor players

Setup	P_{Th} [GW]	L [m]	m_{Det} [t]	Events/year	Backgrounds/day
Daya Bay	17.4	1700	80	$10 \cdot 10^4$	0.4
Double Chooz	8.6	1050	8.3	$1.5 \cdot 10^4$	3.6
RENO	16.4	1400	15.4	$3 \cdot 10^4$	2.6



Double Chooz

Talk by J. Dawson



	# evt R1	# evt R2
Dnxyz	55.5%	44.5%
Dfxyz	55.5%	44.5%

2 cores – 1 site – 8.5 GW_{th}

1 near position, 1 far

- target: 2 x 8.3 t

Civil engineering

- 1 near lab ~ Depth 40 m, Ø 6 m
- 1 available lab

Statistics (including ε)

- far: ~ 40 evts/day
- near: ~ 460 evts/day

Systematics

- reactor : ~ 0.2%
- detector : ~ 0.5%

Backgrounds

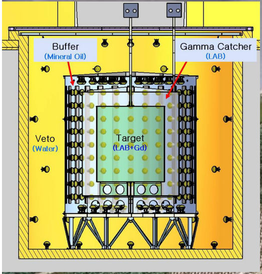
- σ_{b2b} at far site: ~ 1%
- σ_{b2b} at near site: ~ 0.5%

Planning

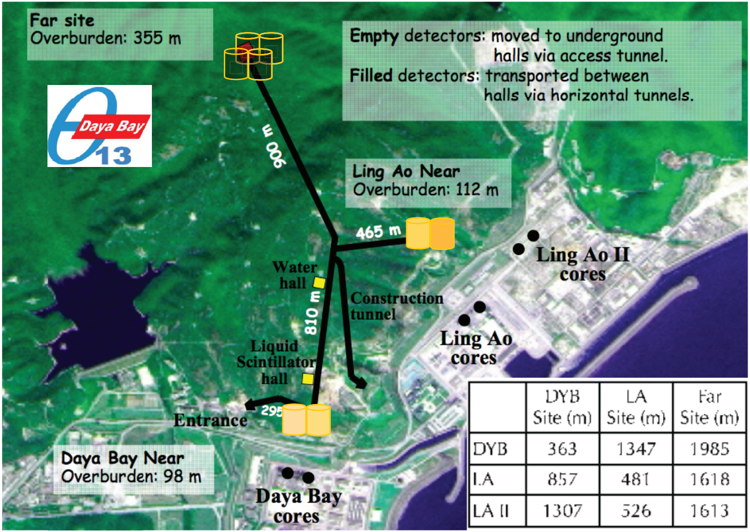
1. Far detector only
   - Sensitivity (1.5 ans) ~ 0.06
2. Far + Near sites
   - available from 2010
   - Sensitivity (3 years) ~ 0.025

RENO

	Location	Thermal Power	Distances Near/Far (m)	Depth (mwe)	Target Mass (tons)	Cost
RENO	Korea	17.3 GW	290/1380	120/450	16/16 ton	~10M$



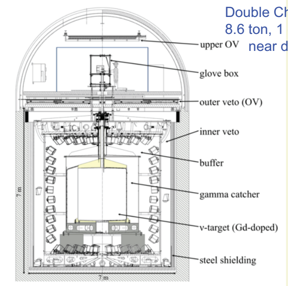
Daya Bay

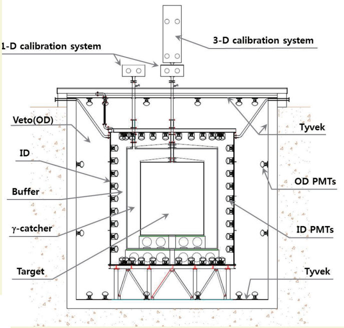


	DYB Site (m)	LA Site (m)	Far Site (m)
DYB	363	1347	1985
LA	857	481	1618
LA II	1307	526	1613

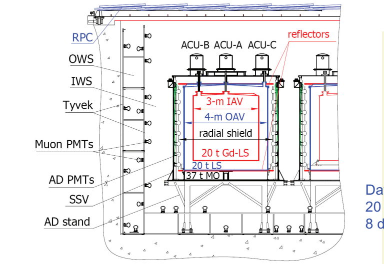
Reactor detectors

Double Chooz
8.6 ton, 1 detector (far)
near detector by 2013





RENO
16 ton, 2 detectors (near + far)



Daya Bay
20 ton, 6 detectors (3 far, 3 near)
8 detectors by 2013 (4+4)

Experimental Results

T2K ($\theta_{13} > 0$ @ 2.5σ)
Expected events: 1.5, Detected 6

Double Chooz (1.3σ)
Expected events: 4344, Detected 4101
$R_{DC} = 0.944 \pm 0.016(\text{stat}) \pm 0.040(\text{syst})$

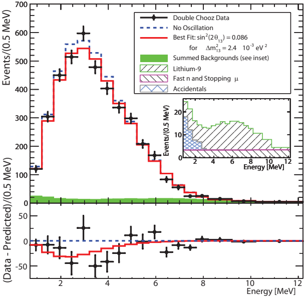
Daya Bay (5.2σ)
Expected events: 85506, Detected 80376
$R_{DB} = 0.940 \pm 0.011(\text{stat}) \pm 0.004(\text{syst})$

RENO (4.9σ)
Expected events:149905, Detected 137912
$R_R = 0.920 \pm 0.009(\text{stat.}) \pm 0.014(\text{syst.})$

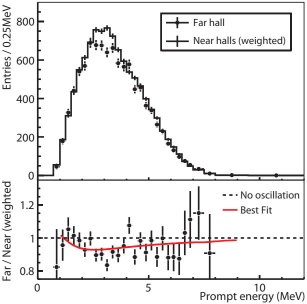
Spectral information

Not used in the fit

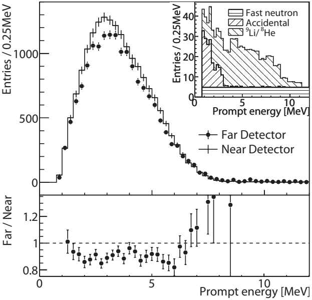
Double Chooz



Daya Bay

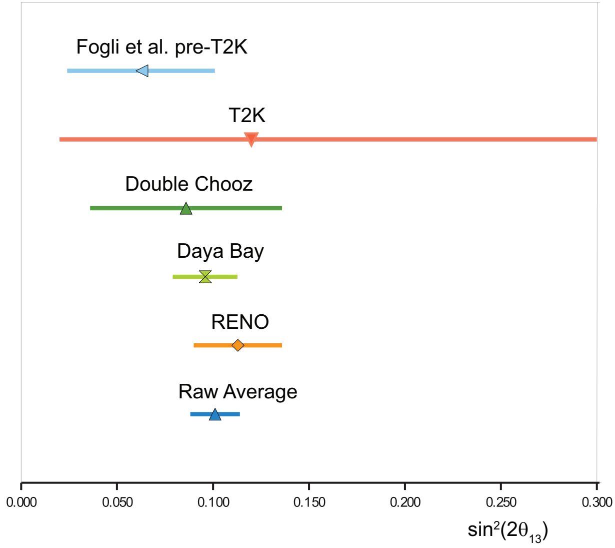


RENO

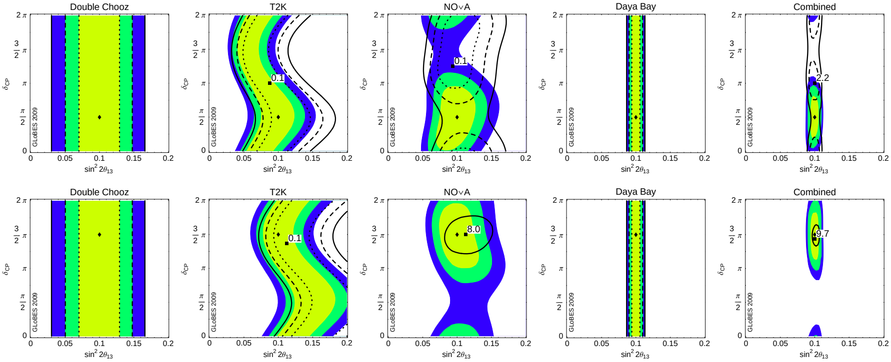


Summary of θ_{13} results

Computed for $\Delta m^2_{23} = 2.4 \cdot 10^{-3}$ eV^2



P. Huber et al., JHEP 0911:044,2009.
Fit at $\sin^2 2\theta_{13} = 0.1$ (1,2,3 σ)



Necessary conditions to have LCPV detectable

The third necessary condition has just been fulfilled !

ν_μ-ν_e oscillations in a 3 ν scheme

$$p(\nu_\mu \rightarrow \nu_e) = 4c_{13}^2 s_{13}^2 s_{23}^2 \sin^2 \frac{\Delta m_{13}^2 L}{4E} \times \left[1 \pm \frac{2a}{\Delta m_{13}^2}(1 - 2s_{13}^2)\right] \quad \theta_{13} \text{ driven}$$

$$+ 8c_{13}^2 s_{12} s_{13} s_{23}(c_{12}c_{23}\cos\delta - s_{12}s_{13}s_{23}) \cos\frac{\Delta m_{23}^2 L}{4E} \sin\frac{\Delta m_{13}^2 L}{4E} \sin\frac{\Delta m_{12}^2 L}{4E} \quad \text{CPeven}$$

$$\mp 8c_{13}^2 c_{12} c_{23} s_{12} s_{13} s_{23} \sin\delta \sin\frac{\Delta m_{23}^2 L}{4E} \sin\frac{\Delta m_{13}^2 L}{4E} \sin\frac{\Delta m_{12}^2 L}{4E} \quad \text{CPodd}$$

$$+ 4s_{12}^2 c_{13}^2 \{c_{13}^2 c_{23}^2 + s_{12}^2 s_{23}^2 s_{13}^2 - 2c_{12}c_{23}s_{12}s_{23}s_{13}\cos\delta\} \sin\frac{\Delta m_{12}^2 L}{4E} \quad \text{solar driven}$$

$$\mp 8c_{12}^2 s_{13}^2 s_{23}^2 \cos\frac{\Delta m_{23}^2 L}{4E} \sin\frac{\Delta m_{13}^2 L}{4E} \frac{aL}{4E}(1 - 2s_{13}^2) \quad \text{matter effect} \quad (\text{CP odd})$$

The third necessary condition has just been fulfilled !

ν_μ-ν_e oscillations in a 3 ν scheme

$$p(\nu_\mu \to \nu_e) = 4c_{13}^2 s_{13}^2 s_{23}^2 \sin^2\frac{\Delta m_{13}^2 L}{4E} \times \left[1 \pm \frac{2a}{\Delta m_{13}^2}(1-2s_{13}^2)\right] \qquad \theta_{13} \text{ driven}$$

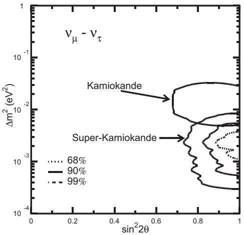
$$+\, 8c_{13}^2 s_{12}s_{13}s_{23}(c_{12}c_{23}\cos\delta - s_{12}s_{13}s_{23}) \cos\frac{\Delta m_{23}^2 L}{4E} \sin\frac{\Delta m_{13}^2 L}{4E} \sin\frac{\Delta m_{12}^2 L}{4E} \quad \text{CPeven}$$

$$\mp\, 8c_{13}^2 c_{12}c_{23}s_{12}s_{13}s_{23} \sin\delta \sin\frac{\Delta m_{23}^2 L}{4E} \sin\frac{\Delta m_{13}^2 L}{4E} \sin\frac{\Delta m_{12}^2 L}{4E} \qquad \text{CPodd}$$

$$+\, 4s_{12}^2 c_{13}^2\{c_{13}^2 c_{23}^2 + s_{12}^2 s_{23}^2 s_{13}^2 - 2c_{12}c_{23}s_{12}s_{23}s_{13}\cos\delta\} \sin\frac{\Delta m_{12}^2 L}{4E} \qquad \text{solar driven}$$

$$\mp\, 8c_{12}^2 s_{13}^2 s_{23}^2 \cos\frac{\Delta m_{23}^2 L}{4E} \sin\frac{\Delta m_{13}^2 L}{4E} \frac{aL}{4E}(1-2s_{13}^2) \qquad \text{matter effect} \quad (\text{CP odd})$$

SK, PRL 81 (1998) 1562 (3558 citations)



Necessary conditions to have LCPV detectable

The third necessary condition has just been fulfilled !

ν_μ-ν_e oscillations in a 3 ν scheme

$$p(\nu_\mu \to \nu_e) = 4c_{13}^2 s_{13}^2 s_{23}^2 \sin^2\frac{\Delta m_{13}^2 L}{4E} \times \left[1 \pm \frac{2a}{\Delta m_{13}^2}(1 - 2s_{13}^2)\right] \quad \theta_{13} \text{ driven}$$

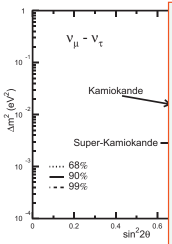
$$+ 8c_{13}^2 s_{12}s_{13}s_{23}(c_{12}c_{23}\cos\delta - s_{12}s_{13}s_{23}) \cos\frac{\Delta m_{23}^2 L}{4E} \sin\frac{\Delta m_{13}^2 L}{4E} \sin\frac{\Delta m_{12}^2 L}{4E} \quad \text{CPeven}$$

$$\mp 8c_{13}^2 c_{12}c_{23}s_{12}s_{13}s_{23} \sin\delta \sin\frac{\Delta m_{23}^2 L}{4E} \sin\frac{\Delta m_{13}^2 L}{4E} \sin\frac{\Delta m_{12}^2 L}{4E} \quad \text{CPodd}$$

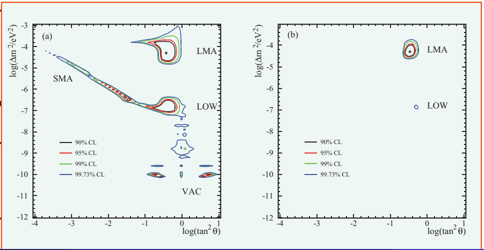
$$+ 4s_{12}^2 c_{13}^2 \{c_{13}^2 c_{23}^2 + s_{12}^2 s_{23}^2 s_{13}^2 - 2c_{12}c_{23}s_{12}s_{23}s_{13}\cos\delta\} \sin\frac{\Delta m_{12}^2 L}{4E} \quad \text{solar driven}$$

$$\mp 8c_{12}^2 s_{13}^2 s_{23}^2 \cos\frac{\Delta m_{23}^2 L}{4E} \sin\frac{\Delta m_{13}^2 L}{4E} \frac{aL}{4E}(1 - 2s_{13}^2) \quad \text{matter effect (CP odd)}$$

SK, PRL 81(1998) 1562 (3558 citations)



SNO, PRL 89 (2002) 011302 (1934 citations)



Necessary conditions to have LCPV detectable

The third necessary condition has just been fulfilled !

ν_μ-ν_e oscillations in a 3 ν scheme

$$p(\nu_\mu - \nu_e) = 4c_{13}^2 s_{13}^2 s_{23}^2 \sin^2 \frac{\Delta m_{13}^2 L}{4E} \times \left[1 \pm \frac{2a}{\Delta m_{13}^2}(1 - 2s_{13}^2)\right]$$ θ_{13} driven

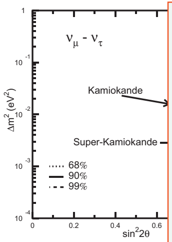
$$+ 8c_{13}^2 s_{12} s_{13} s_{23} (c_{12} c_{23} \cos\delta - s_{12} s_{13} s_{23}) \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E}$$ CPeven

$$\mp 8c_{13}^2 c_{12} c_{23} s_{12} s_{13} s_{23} \sin\delta \sin \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E}$$ CPodd

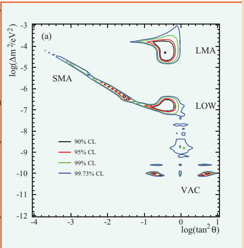
$$+ 4s_{12}^2 c_{13}^2 \{ c_{13}^2 c_{23}^2 + s_{12}^2 s_{23}^2 s_{13}^2 - 2c_{12} c_{23} s_{12} s_{23} s_{13} \cos\delta \} \sin \frac{\Delta m_{12}^2 L}{4E}$$ solar driven

$$\mp 8c_{12}^2 s_{13}^2 s_{23}^2 \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \frac{aL}{4E} (1 - 2s_{13}^2)$$ matter effect (CP odd)

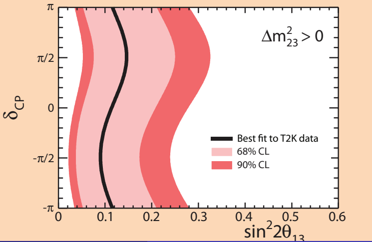
SK, PRL 81(1998) 1562 (3558 citations)



SNO, PRL 89 (2002) 01

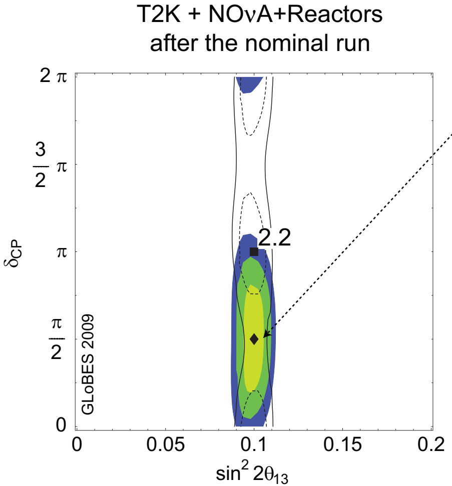


T2K, arXiv:1106.2822



Status after this generation of LBL experiments: CPV

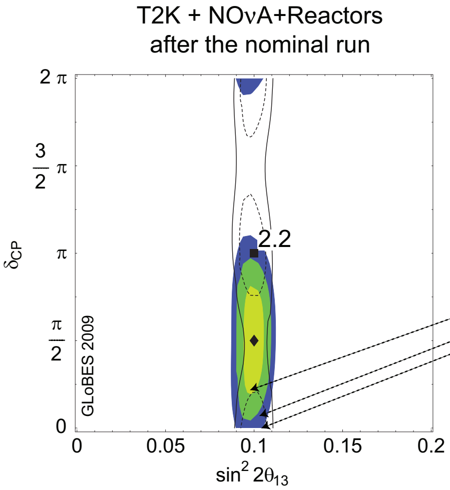
From P. Huber et al., JHEP 0911:044,2009.



1) Choose a test point, this is the most favorable: max δ_{CP} and max θ_{13}

Status after this generation of LBL experiments: CPV

From P. Huber et al., JHEP 0911:044,2009.

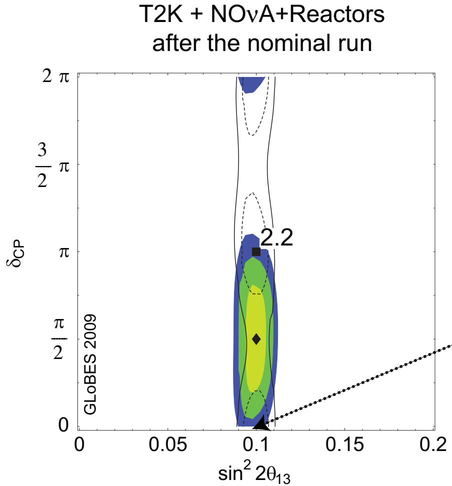


1) Choose a test point, this is the most favorable: max δ_{CP} and max θ_{13}

2) Fit to the expected sensitivity of the experiments: 1σ, 2σ, 3σ

Status after this generation of LBL experiments: CPV

From P. Huber et al., JHEP 0911:044,2009.



1) Choose a test point, this is the most favorable: max δ_{CP} and max θ_{13}

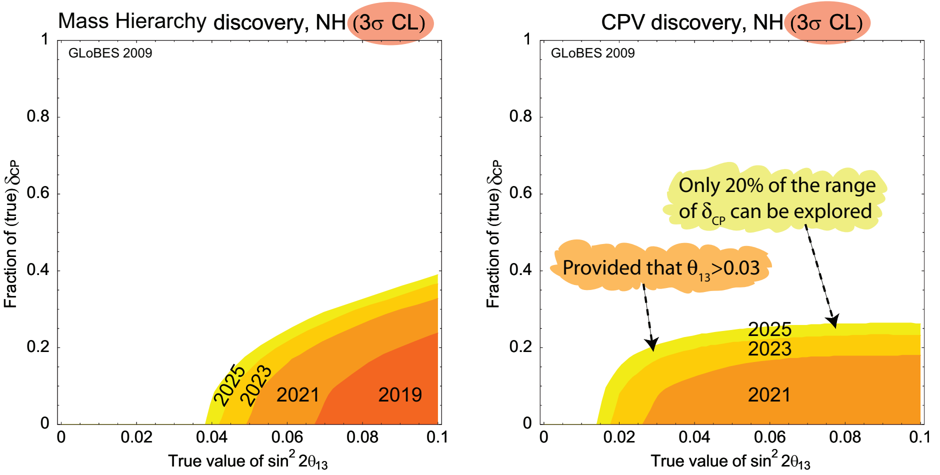
2) Fit to the expected sensitivity of the experiments: 1σ, 2σ, 3σ

3) Null CP is compatible with data already at 2σ

Status after accelerator upgrades

From P. Huber et al., JHEP 0911:044,2009.

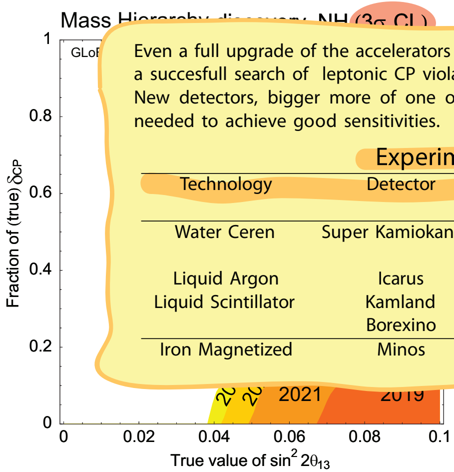
Prediction of sensitivity including a **fully optimized global run** (antineutrinos in T2K and NOνA) and **full upgrade of the accelerators**: 1.6 MW at J-PARC and 2.4 MW at FNAL (Project-X)

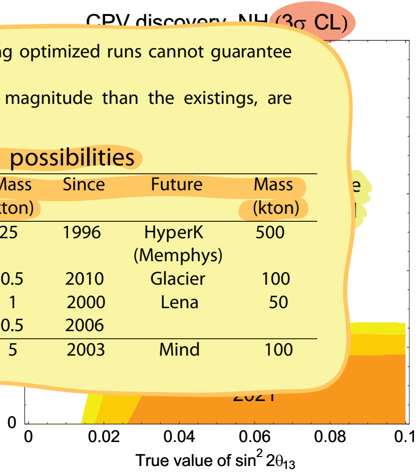


Status after accelerator upgrades

From P. Huber et al., JHEP 0911:044,2009.

Prediction of sensitivity including a **fully optimized global run** (antineutrinos in T2K and NOνA) and **full upgrade of the accelerators**: 1.6 MW at J-PARC and 2.4 MW at FNAL (Project-X)





Even a full upgrade of the accelerators and long optimized runs cannot guarantee a succesfull search of leptonic CP violation.
New detectors, bigger more of one order of magnitude than the existings, are needed to achieve good sensitivities.

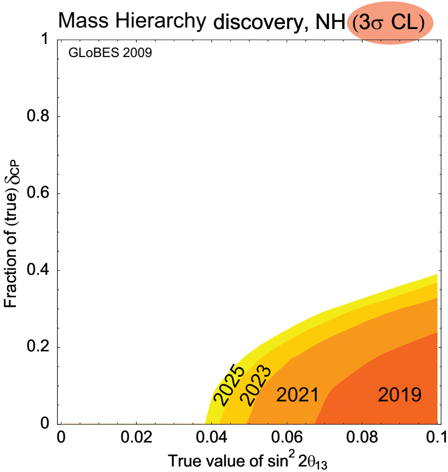
Experimental possibilities

Technology	Detector	Mass (kton)	Since	Future	Mass (kton)
Water Ceren	Super Kamiokande	25	1996	HyperK (Memphys)	500
Liquid Argon	Icarus	0.5	2010	Glacier	100
Liquid Scintillator	Kamland	1	2000	Lena	50
	Borexino	0.5	2006		
Iron Magnetized	Minos	5	2003	Mind	100

Status after accelerator upgrades

From P. Huber et al., JHEP 0911:044,2009.

Prediction of sensitivity including a **fully optimized global run** (antineutrinos in T2K and NOνA) and **full upgrade of the accelerators**: 1.6 MW at J-PARC and 2.4 MW at FNAL (Project-X)

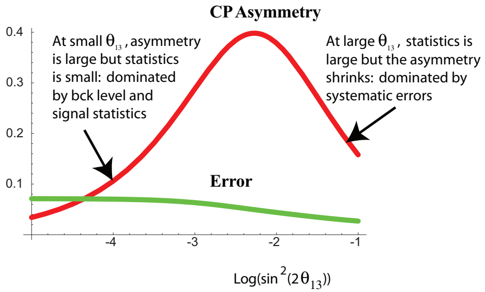


Regarding mass hierarchy

Additional information will come by atmospheric neutrinos:
SK can improve its sensitivity by analyzing the full statistics and plugging the right value of θ_{13}.
INO can measure mass hierarchy on its own (but a standalone measurement would require 1 Mton yr exposure for 3 σ according to Gandhi et al arXiv:07071723)
Global fits including beam and atmospherics not yet fully studied.

Measuring Leptonic CP violation

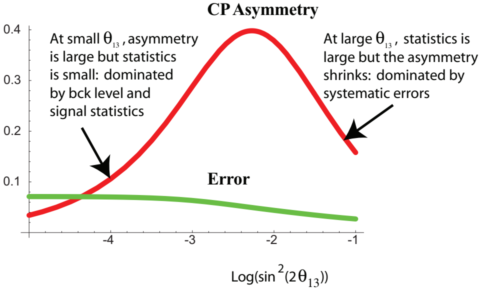
$$A_{CP} = \frac{P(\nu_\mu \to \nu_e) - P(\overline{\nu}_\mu \to \overline{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\overline{\nu}_\mu \to \overline{\nu}_e)}$$



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.

Measuring Leptonic CP violation

$$A_{CP} = \frac{P(\nu_\mu \to \nu_e) - P(\overline{\nu}_\mu \to \overline{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\overline{\nu}_\mu \to \overline{\nu}_e)}$$

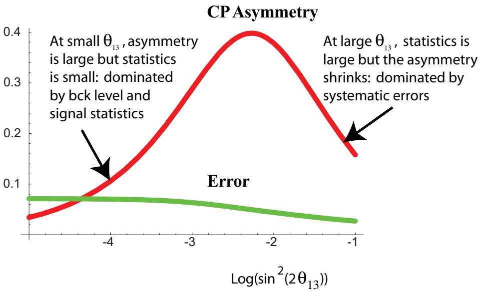


LCPV asymmetry at the first oscillation maximum, $\delta = 1$, Error curve: dependence of the statistical+systematic (2%) computed for a beta beam the fixed energy $E_\nu = 0.4$ GeV, $L = 130$ km.

- **The detection of such asymmetry is an evidence of Leptonic CP violation only in absence of competitive processes (i.e. matter effects, see following slides) $\Rightarrow$ "short" Long Baseline experiments**

Measuring Leptonic CP violation

$$A_{CP} = \frac{P(\nu_\mu \to \nu_e) - P(\overline{\nu}_\mu \to \overline{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\overline{\nu}_\mu \to \overline{\nu}_e)}$$



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.

- **The detection of such asymmetry is an evidence of Leptonic CP violation only in absence of competitive processes (i.e. matter effects, see following slides) $\Rightarrow$ "short" Long Baseline experiments**
- Statistics and systematics play different roles at different values of $\theta_{13} \Rightarrow$ impossible to optimize the experiment without a prior knowledge of θ_{13}
- Contrary to the common belief, the highest values of θ_{13} are not the easiest condition for LCPV discovery

Possible Strategies

"Short" Long Baselines: HyperKamiokaNDE, CERN-Frejus

Measure mass hierarchy and θ_{23} octant with atmospheric neutrinos in a gigantic water Cerenkov detector.
Measure CPV with beam neutrinos at short baselines, where any $\nu - \overline{\nu}$ asymmetry is entirely due to leptonic CP violation (negligible matter effects).

"Long" Long Baselines: LBNE, CERN-Phyasalmi

Measure mass hierarchy and leptonic CP violation with beam neutrinos (what about θ_{23} octant degeneracy?) achieving very good sensitivity on mass hierarchy with some compromise with CPV sensitivity.

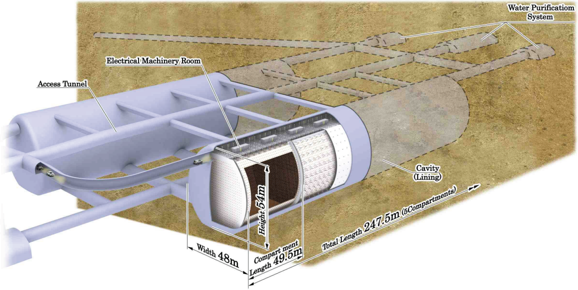
Strong interest on new concepts for future facilities like Beta Beams and Neutrino Factories.

HyperKamiokaNDE

Letter of Intent: arXiv:1109.3262

J-Parc 30 GeV proton accelerator upgraded at 1.66 MW

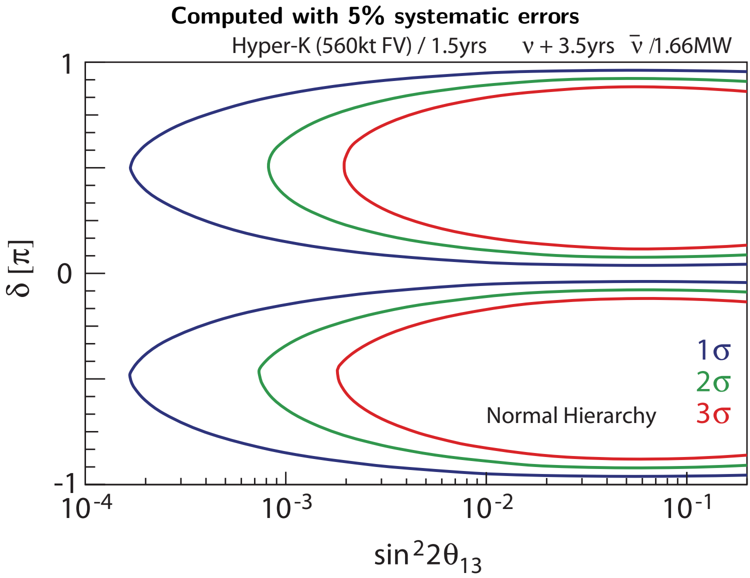
540 kton water Cerenkov detector built at the same distance and off-axis angle as Super Kamiokande.



Challenge: push systematic errors at 5% (T2K first result published with 16% systematic errors)

Outstanding performances for proton decays, solar neutrinos, supernova neutrinos etc.

HyperKamiokaNDE: CPV sensitivity



European Super Beam Options

CERN-Frejus:

- A 570 kton water Cerenkov detector at Frejus, Memphys (130 km from CERN)
- A neutrino super beam by the SPL 4MW Linac.
- Eventually fire a Beta Beam to the same detector.

CERN-Phyasalmi:

- A 100 kton liquid argon detector at Phyasalmi (2290 km from CERN)
- A neutrino super beam by a 1.6 MW, 50 GeV, synchrotron.
- As a first stage build a 10 kton LAr detector and fire a CNGS like neutrino beam (maybe using SPS protons)

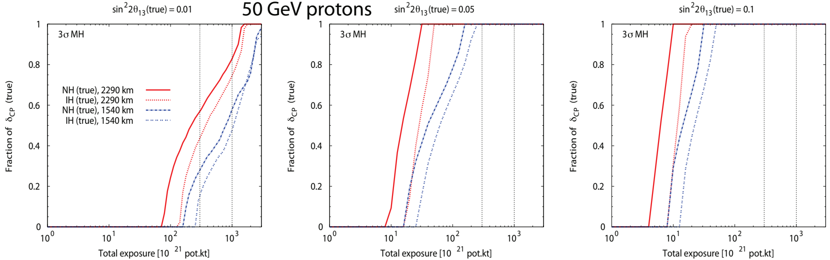
No serious study about **CP at LNGS** so far (but just wait for the NuTurn workshop at LNGS, 8-10 May, 2012).

None of the two accelerators is in the LHC upgrade plan so far.

CERN-Phyasalmi (arXiv:1109.6526)

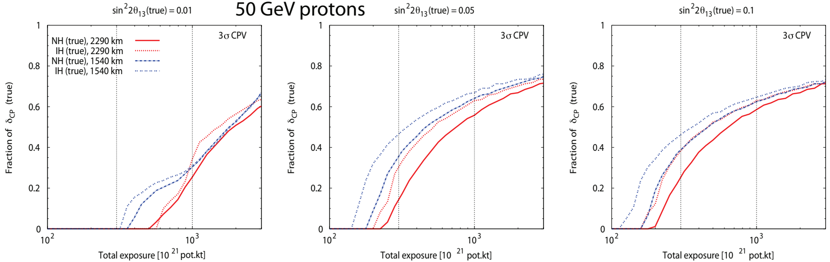
First stage: mass hierarchy with a 10-20 kton LAr detector

50 GeV protons



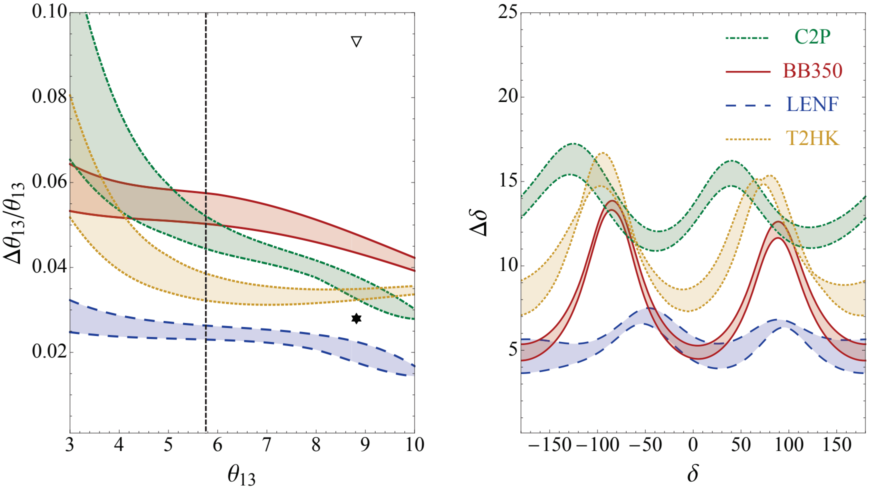
Second stage: CPV with a 100 kton LAr detector

50 GeV protons



Precision on measuring δ_{CP}

From P. Coloma et al., arXiv:1203.565



Conclusions

The measurement of θ_{13} solves one of the few question marks still left in the standard model. Among the many fondamental consequences, it opens the door to future long-baseline neutrino experiments addressing leptonic CP violation.

Five experimental results in the past 9 months, coming from accelerators and reactors, provided exciting information about θ_{13}.

Leptonic CP violation, measurable only at accelerators, will require challenging experimental improvements. The optimization of future facilities is now possible by knowing the θ_{13} value.

A worldwide effort is ongoing with multiple proposals in three different continents.