Mauro Mezzetto
Istituto Nazionale di Fisica Nucleare, Sezione di Padova

" Experimental status and perspectives of neutrino physics "

- Present status
- Medium term perspectives: Mass Hierarchy.
- Long term perspectives: Leptonic CP violation.
- Sterile Neutrinos
- ICARUS-Nessie

Leptons are VERY different from quarks. (I)

Neutrinos $U_{MNSP} \sim \begin{pmatrix} 0.8 & 0.5 & ? \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix}$

Quarks $V_{CKM} \sim \begin{pmatrix} 1 & 0.2 & 0.005 \\ 0.2 & 1 & 0.04 \\ 0.005 & 0.04 & 1 \end{pmatrix}$

Solar+Atmospherics indicate a quasi bi-maximal mixing matrix, **VERY DIFFERENT from CKM matrix (almost diagonal)!**

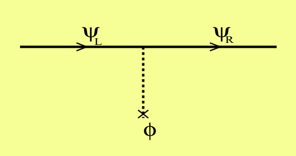
$$U_{MNSP} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13} e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13} e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix},$$

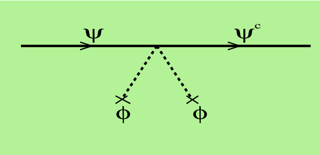
$\theta_{13} \to 0 \quad \Rightarrow \quad$ The 3x3 mixing matrix becomes a trivial product of two 2x2 matrixes.

θ_{13} drives $\nu_\mu \to \nu_e$ subleading transitions $\Rightarrow$
the necessary milestone for any subsequent search: neutrino mass hierarchy and leptonic CP searches.

$u \sim 5$ MeV	$c \sim 1$ GeV	$t \sim 175$GeV	$e \sim 0.5$ MeV	$\mu \sim 0.1$ GeV	$\tau \sim 2$GeV
$d \sim 8$ MeV	$s \sim 0.1$ GeV	$b \sim 5$GeV	$\nu_e \leq \mathcal{O}(1\ eV)$	$\nu_\mu \leq \mathcal{O}(1\ eV)$	$\nu_\tau \leq \mathcal{O}(1\ eV)$

How can the same model generate mass ratio so different?

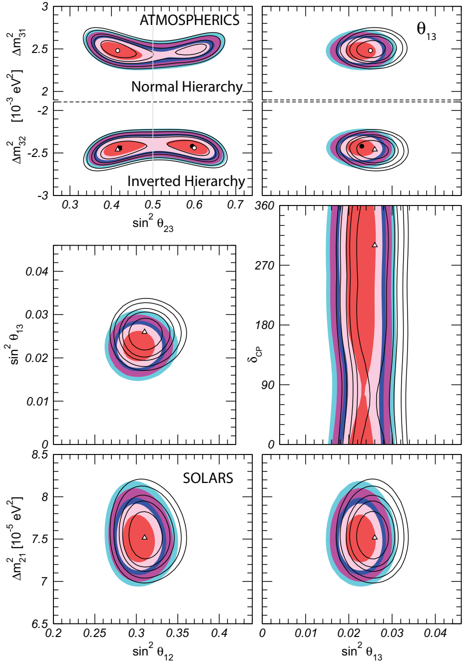




$$\lambda_\nu \overline{\Psi}_R \Phi \Psi_L + h.c.$$
$$m_f = \lambda_f v$$
$$L$$

$$\frac{\alpha_\nu}{M} \nu_L^T C \tilde{\Phi}^T \tilde{\Phi} \nu_L + h.c.$$
$$m_f = \alpha_\nu \frac{v^2}{M}$$
$$\not{L}$$

A new physics scale, M, can explain the new hierarchy (if at the GUT scale) and is associated to the breaking of a global symmetry of the SM: total lepton number L.


ATMOSPHERICS
Normal Hierarchy
Inverted Hierarchy
θ13
SOLARS
Δm^2_{31}
Δm^2_{32}
$[10^{-3}\ eV^2]$
$\sin^2\theta_{23}$
$\sin^2\theta_{13}$
δ_{CP}
$\Delta m^2_{21}\ [10^{-5}\ eV^2]$
$\sin^2\theta_{12}$
$\sin^2\theta_{13}$

Shopping list for future experiments

δm^2_{12} ✓ SOLARS+KAMLAND $\delta m^2_{12} = (7.9 \pm 0.7)\ 10^{-5}\ eV^2$

θ_{12} ✓ SOLARS+KAMLAND $\sin^2(2\theta_{12}) = 0.82 \pm 0.055$

Addressed by accelerator neutrino experiments

δm^2_{23} ✓ ATMOSPHERICS $\delta m^2_{23} = (2.4 \pm 0.4)\ 10^{-3}\ eV^2$

θ_{23} ✓ ATMOSPHERICS $\sin^2(2\theta_{23}) > 0.95$

θ_{13} ✓ $\sin^2 2\theta_{13} = 0.1$

LSND/Steriles ?

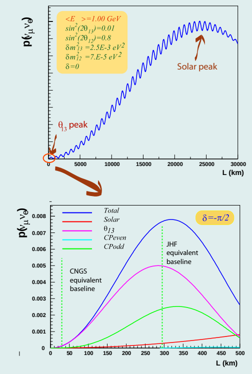
δ_{CP}

Mass hierarchy

Σm_ν BETA DECAY END POINT $\Sigma m_\nu < 6.6$ eV

Dirac/Majorana

Sub leading $\nu_\mu - \nu_e$ oscillations



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

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

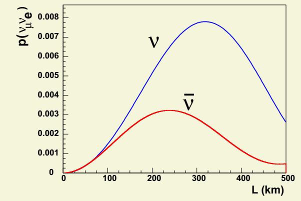
$$\mp\, 8c_{13}^2 c_{12} c_{23} s_{12} s_{13} s_{23} \sin\delta \sin \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E}$$ CPodd

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

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

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

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



Reactors vs Accelerators

Accelerators: ν_e appearance

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

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

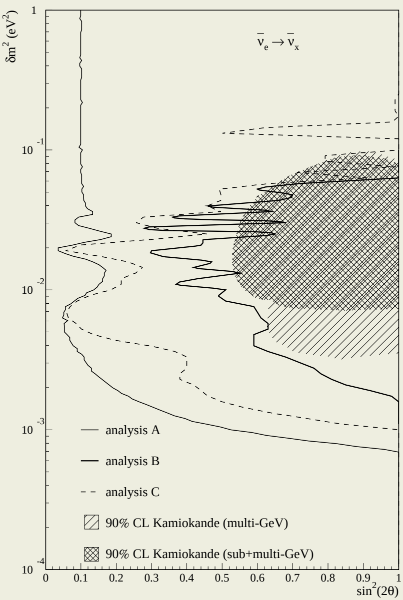
$$\mp 8c_{13}^2 c_{12}c_{23}s_{12}s_{13}s_{23}\sin\delta\sin\frac{\Delta m_{23}^2 L}{4E}\sin\frac{\Delta m_{13}^2 L}{4E}\sin\frac{\Delta m_{12}^2 L}{4E} \qquad \text{CPodd}$$

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

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

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

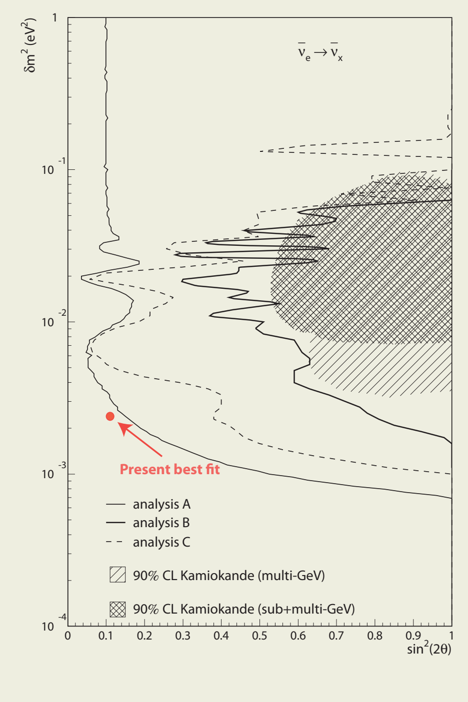
$$1 - P_{\overline{\nu}_e-\overline{\nu}_e} \simeq \sin^2 2\theta_{13}\,\sin^2(\Delta m_{31}^2 L/4E) + (\Delta m_{21}^2/\Delta m_{31}^2)^2\,(\Delta m_{31}^2 L/4E)^2\cos^4\theta_{13}\,\sin^2 2\theta_{12}$$



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 !



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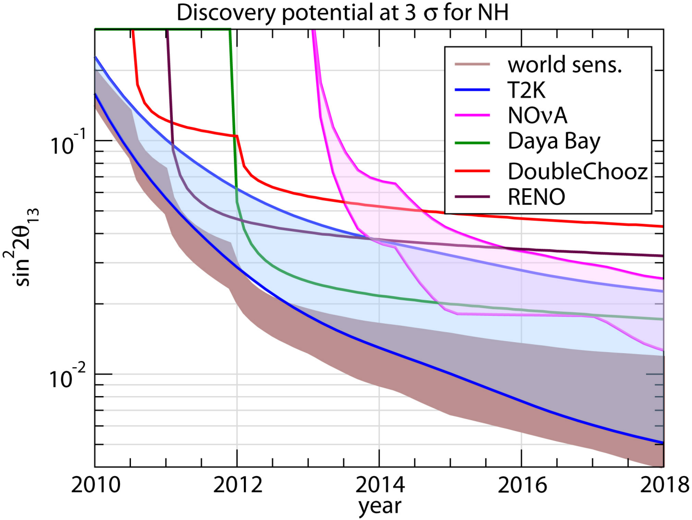
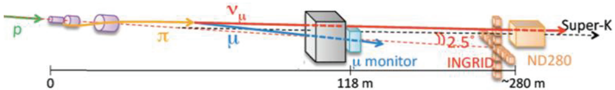
Predictions before exp. results

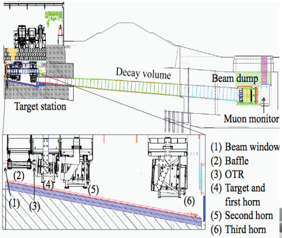
M.M. and T. Schwetz, J.Phys.G G37 (2010) 103001



The T2K Experiment

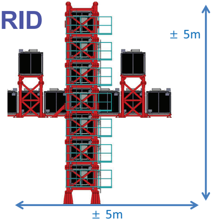


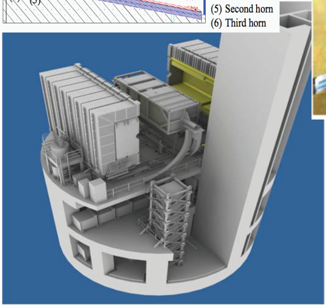
JPARC Accelerator @ Tokay



SuperKamiokaNDE

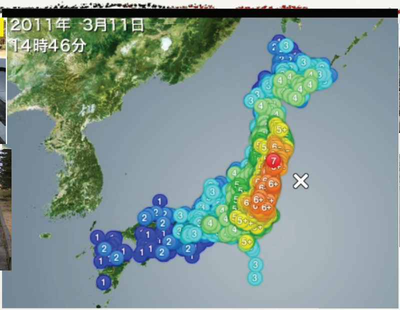
INGRID





ND280

T2K/J-PARC recovery after the BIG earthquake in March 11, 2011



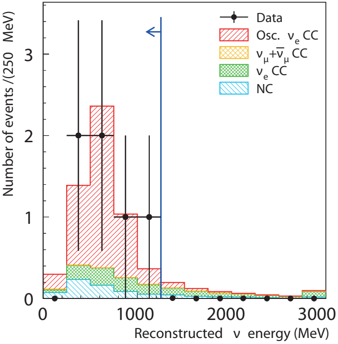
09:30 Key was on.

On Dec.9, 2011, J-PARC LINAC operation restarted!!!
On Dec.24, 2011, Neutrino events were observed at T2K-ND280!!

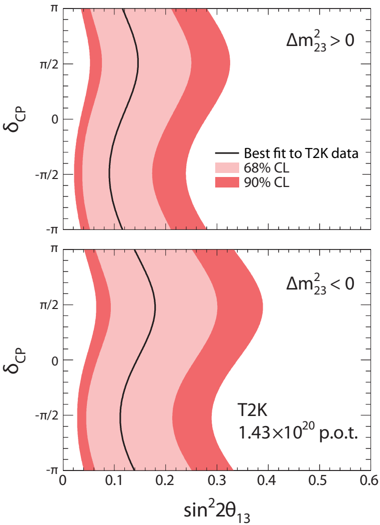
- ***Heartfelt gratitude to the tremendous supports to J-PARC and T2K from all over the world.***

12年6月5日火曜日

T2K result, PRL 107 (2011) 041801



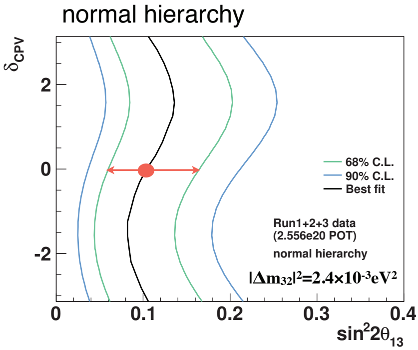
Expected: 1.5 +/- 0.3
Measured: 6

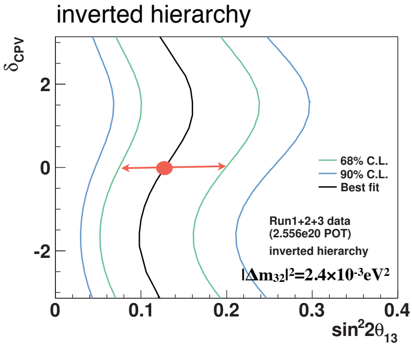


Systematic errors

Source	$\sin^2 2\theta_{13} = 0$	$\sin^2 2\theta_{13} = 0.1$
(1) neutrino flux	$\pm$ 8.5%	$\pm$ 8.5%
(2) near detector	$^{+5.6}_{-5.2}$%	$^{+5.6}_{-5.2}$%
(3) near det. statistics	$\pm$ 2.7%	$\pm$ 2.7%
(4) cross section	$\pm$ 14.0%	$\pm$ 10.5%
(5) far detector	$\pm$ 14.7%	$\pm$ 9.4%
Total $\delta N^{exp}_{SK}/N^{exp}_{SK}$	$^{+22.8}_{-22.7}$%	$^{+17.6}_{-17.5}$%

Final Results: ν_e appearance evidence at 3.2 σ

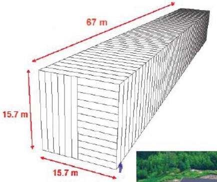




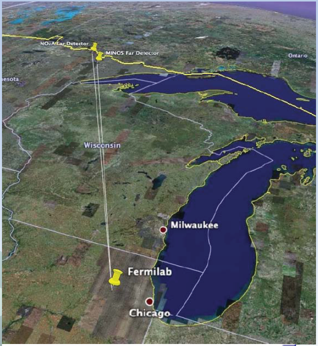
$\sin^2 2\theta_{13}=0.104\,^{+0.060}_{-0.045}$ @$\delta_{CP}=0$

$\sin^2 2\theta_{13}=0.128\,^{+0.070}_{-0.055}$ @$\delta_{CP}=0$

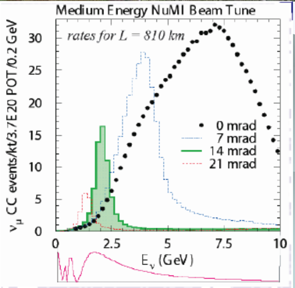
NOvA



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



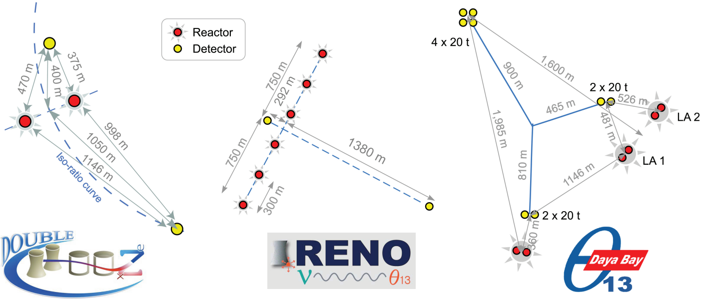
- FNAL NuMI off-axis beam
- Power upgrade 320kW→700kW
  - Recycler: anti-proton → proton
  - Rep cycle 2.2s → 1.33s
- New 14kton liquid scintillator fine grained detector @810km
- Far detector will complete and start taking data in 2014



7

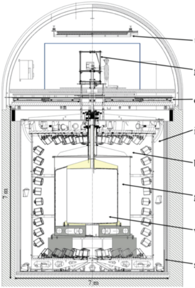
The three reactor players

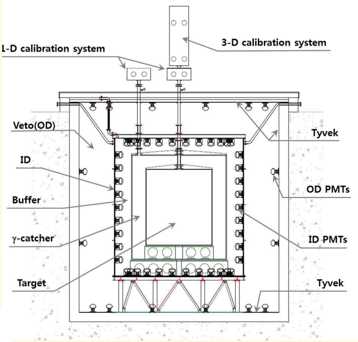
Setup	$P_{\rm Th}$ [GW]	L [m]	$m_{\rm Det}$ [t]	Events/year	Backgrounds/day
Daya Bay	17.4	1700	80	$10 \cdot 10^4$	0.4
Double Chooz	8.6	1050	8.3	$1.5 \cdot 10^4$	3.6
RENO	16.4	1400	15.4	$3 \cdot 10^4$	2.6



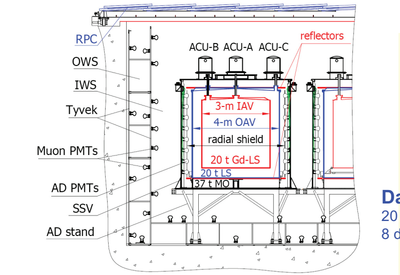
Reactor detectors

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



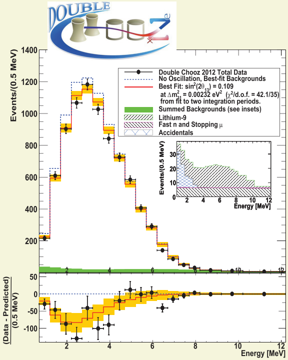


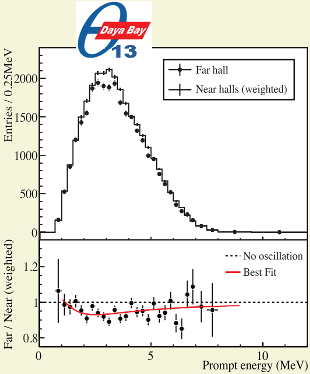
RENO
16 ton, 2 detectors (near + far)

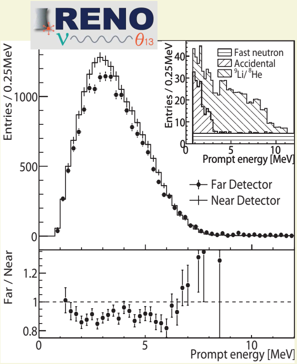


Daya Bay
20 ton, 6 detectors (3 far, 3 near)
8 detectors by 2013 (4+4)

Experimental Results







$\sin^2 2\theta_{13} = 0.109 \pm 0.030(\mathrm{stat}) \pm 0.025(\mathrm{syst})$

R=0.944 +/- 0.007 (stat) +/- 0.003 (syst)

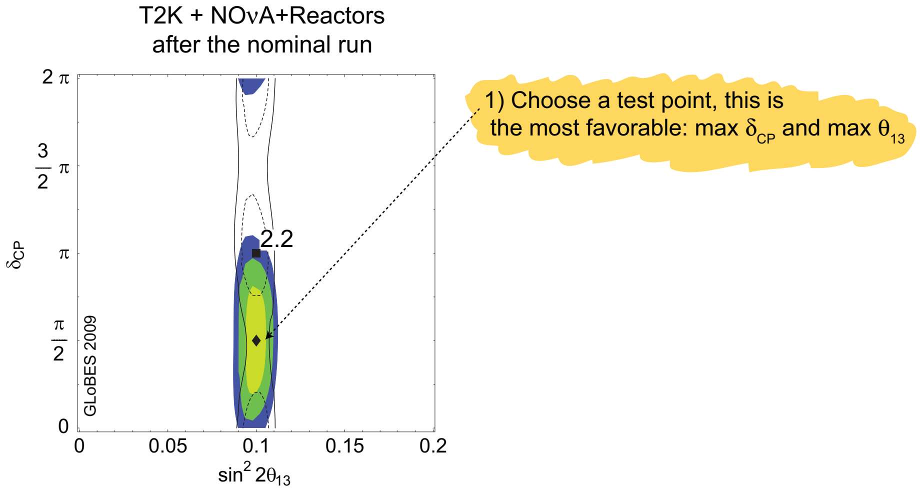
$\sin^2 2\theta_{13} = 0.089 \pm 0.010\ (\mathrm{stat}) \pm 0.005\ (\mathrm{syst})$

R=0.920 +/- 0.009 (stat) +/- 0.014 (syst)

$\sin^2 2\theta_{13} = 0.113 \pm 0.013(stat) \pm 0.019(syst)$

Status after this generation of LBL experiments: CPV

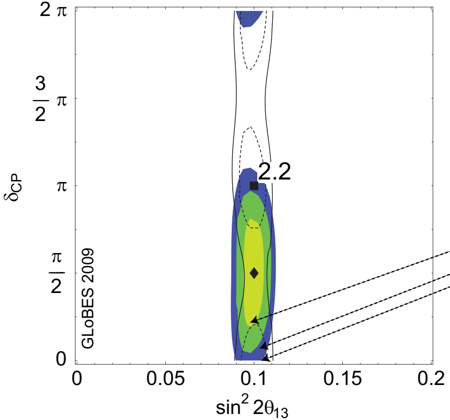
From P. Huber et al., JHEP 0911:044,2009.



Status after this generation of LBL experiments: CPV

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

T2K + NOνA+Reactors
after the nominal run

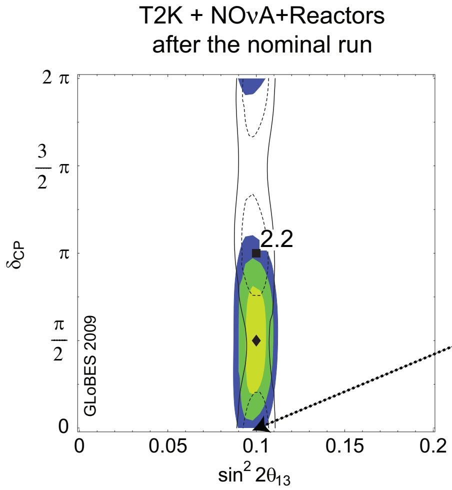


1) Choose a test point, this is the most favorable: max δ_{CP} and max θ_{13}

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}

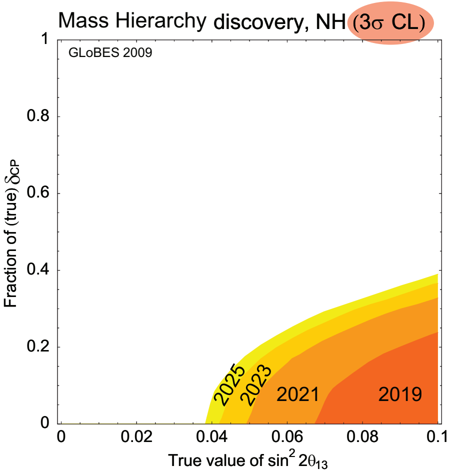
2) Fit to the expected sensitivity of the experiments: 1σ, 2σ, 3σ

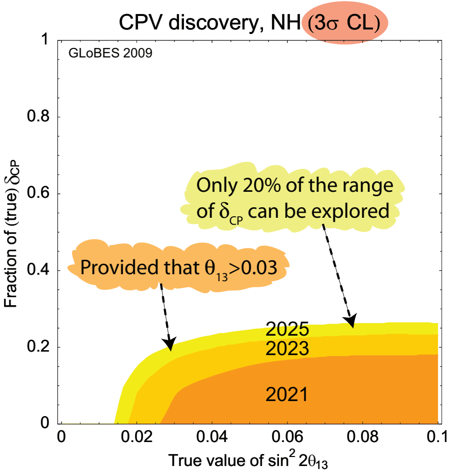
3) Null CP is compatible with data already at 2σ

Status after accelerator upgrades

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

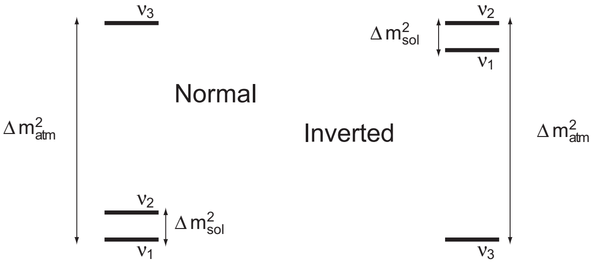
Prediction of sensitivity including a **fully optimized global run** (antineutrinos in T2K and NOνA) and **full upgrade of the accelerators**: 1.6 MW at J-PARC and 2.4 MW at FNAL (Project-X)





Measuring mass hierarchy

An internal degree of freedom of neutrino masses is the sign of Δm^2_{31}: $\mathrm{sign}(\Delta m^2_{13})$.

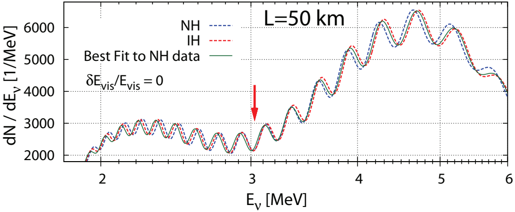


This parameter decides how mass eigenstates are coupled to flavor eigenstates with important consequences to direct neutrino mass and double beta decay experiments.

Large θ_{13} allows mass hierarchy searches using reactor and atmospheric neutrinos (accelerator neutrinos could measure MH even at small θ_{13}).

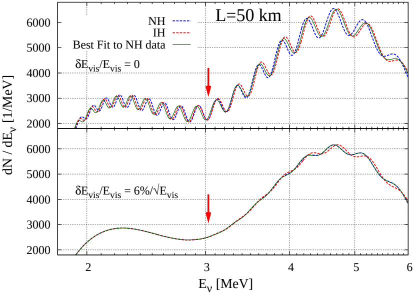
MH at reactors

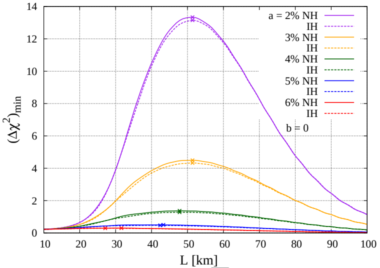
$$P_{ee} = 1 - \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2(\Delta_{21}) - \sin^2 2\theta_{13}\sin^2(|\Delta_{31}|)$$
$$- \sin^2\theta_{12}\sin^2 2\theta_{13}\sin^2(\Delta_{21})\cos(2|\Delta_{31}|)$$
$$\pm\frac{\sin^2\theta_{12}}{2}\sin^2 2\theta_{13}\sin(2\Delta_{21})\sin(2|\Delta_{31}|),$$



- The MH term $\propto \Delta m^2_{12}$: 50 km baseline
- The MH term $\propto \sin^2 2\theta_{13}$: the interest on this technique revamped after the T2K result
- The MH term goes to zero at the max solar probability and changes sign crossing the zero point. An important feature for the MH fits
- Note the the mass hierarchy has just two possible, known values, +/- 1, this implies that the gaussian statistic is not adequate to discriminate among the two values (see arXiv:1210.3651)

MH at reactors:experimental challenges

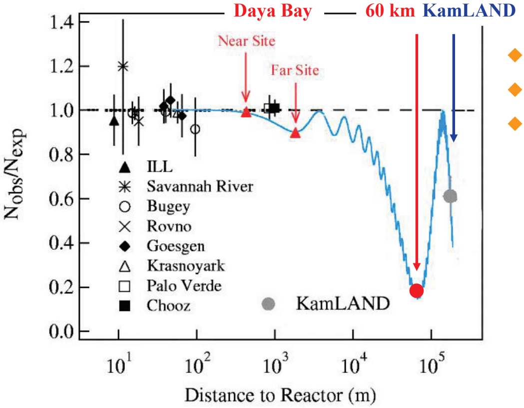




- Requires excellent energy resolution to keep the wiggles, goal: $3\%\sqrt{E}$: $2 \times$ Kamland
- Requires excellent linearity: goal 0.1% $10 \times$ Kamland
- Requires statistics: 20 kton liquid scintillator detector, $10 \times$ Kamland
- "Far" reactors can spoil the wiggles, the effective optimal baseline is shorter than the optimal baseline according to oscillations (to increase the signal/noise ratio)
- Background rates induced by cosmics are more dangerous than Daya-Bay-I (longer distance from reactors), not too shallow depth mandatory.
- The distance of the detector from the reactors must be uniform (the wiggles correspond to 1 km baseline), not too much freedom on the choice of the location of the far detector

Daya Bay-II Experiment

Giant Detector located at 60 km from Daya Bay reactors, the 1st maximum of θ_{12} oscillation.

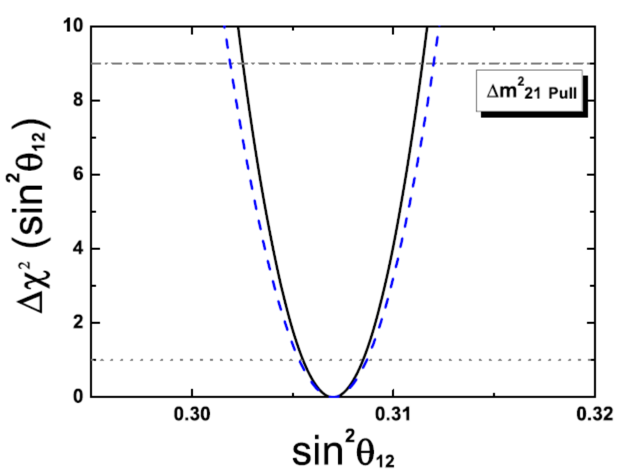


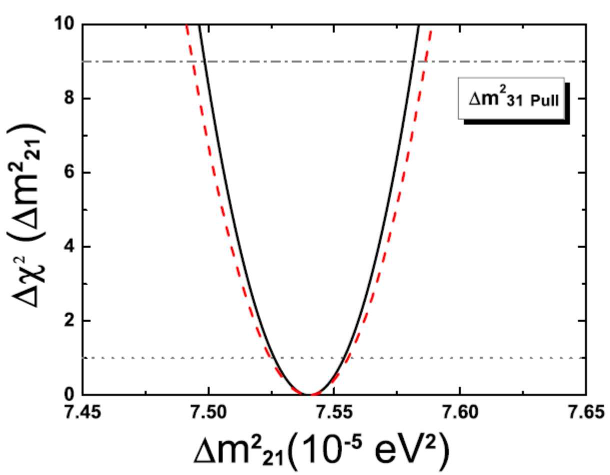
- **20 kton detector**
- **3% energy resolution**
- Rich physics possibilities
  - **Mass hierarchy**
  - **Precision measurement of 4 mixing parameters**
  - **Supernovae neutrino**
  - **Geoneutrino**
  - **Sterile neutrino**
  - **Abnormal magnetic moment**
  - **Possible CPV**

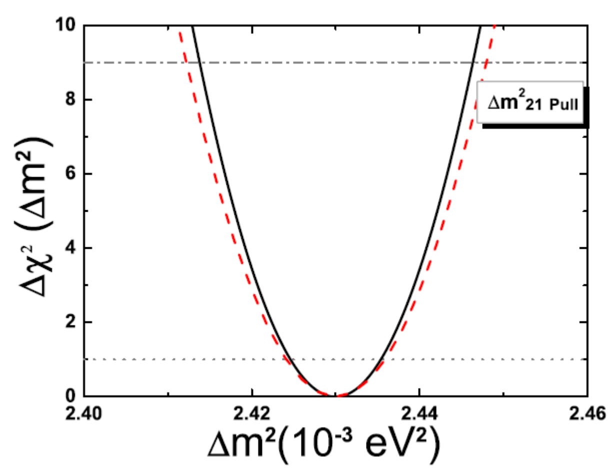
Precision Measurements

- Fundamental to the Standard Model and beyond
- Probing the unitarity of U_{PMNS} to ~1% level !

	Current	Daya Bay II
Δm^2_{12}	3%	0.26%
Δm^2_{23}	5%	0.30%
$\sin^2\theta_{12}$	6%	0.63%
$\sin^2\theta_{23}$	20%	N/A
$\sin^2\theta_{13}$	14% ➔ 4%	~ 15%







THREE-FLAVOR EFFECTS IN ATMOSPHERIC NEUTRINOS

- *Incomplete list of the literature:*

Petcov (1998), Chizov, Maris, Petcov (1998), Akhmedov (1999),Akhmedov,Dighe,Lipari,Smirnov (1999),Kim (1998),Peres,Smirnov(1999),Bernabeu, Palomares-Ruiz, Perez, Petcov, (2002), Gonzalez-Garcia, Maltoni (2003), Bernabeu, Palomares-Ruiz, Petcov (2003), Peres, Smirnov (2004), Indumathi, Murthy (2004), Gandhi, Ghoshal, Goswami, Mehta, Sankar (2004), Gonzalez-Garcia, Maltoni, Smirnov (2004), Palomares-Ruiz, Petcov (2005), Choubey, Roy (2005), Fogli, Lisi, Marrone, Palazzo (2005); Huber, Maltoni, Schwetz (2005), T. Kajita (2005); E. K. Akhmedov, M. Maltoni and A. Y. Smirnov (2005), Petcov, Schwetz (2006), S. Choubey (2006); Indumathi, Murthy, Rajasekaran, Sinha (2006), E. K. Akhmedov, M. Maltoni and A. Y. Smirnov (2007), R. Gandhi, P. Ghoshal, S. Goswami, P. Mehta, S. U. Sankar and S. Shalgar (2007), E. K. Akhmedov, M. Maltoni and A. Y. Smirnov (2008), Gandhi, Ghoshal, Goswami, Sankar (2008), Mena, Mocioiu, Razzaque (2008), Peres, Smirnov (2009), Gandhi, Ghoshal, Goswami, Sankar (2009), Samanta (2006 - 10), Samanta, Smirnov (2010), Conrad, de Gouvea, Shalgar (2010), Gonzalez-Garcia, Maltoni, Salvado (2011), Barger, Gandhi, Ghoshal, Goswami, Marfatia, Prakash, Raut, Sankar (2012), Blennow, Schwetz (2012), Akhmedov, Razzaque, Smirnov (2012), ...

- *My apologies if your name is missing here -*

Monolith

CERN-SPSC-2001-019, CERN-SPSC-M-657

See also T. Tabarelli de Fatis: "Prospects of measuring $sin^2 2\theta_{13}$ and the sign of Δm^2 with a massive magnetized detector for atmospheric neutrinos." Eur.Eur.Phys.J. C24 (2002) 43-50

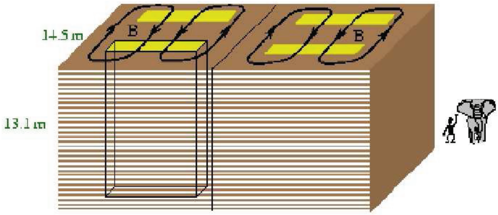
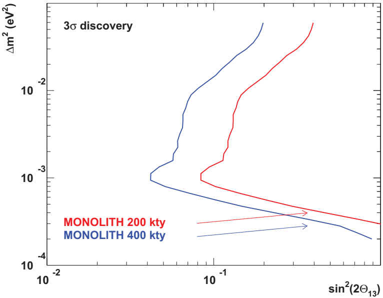
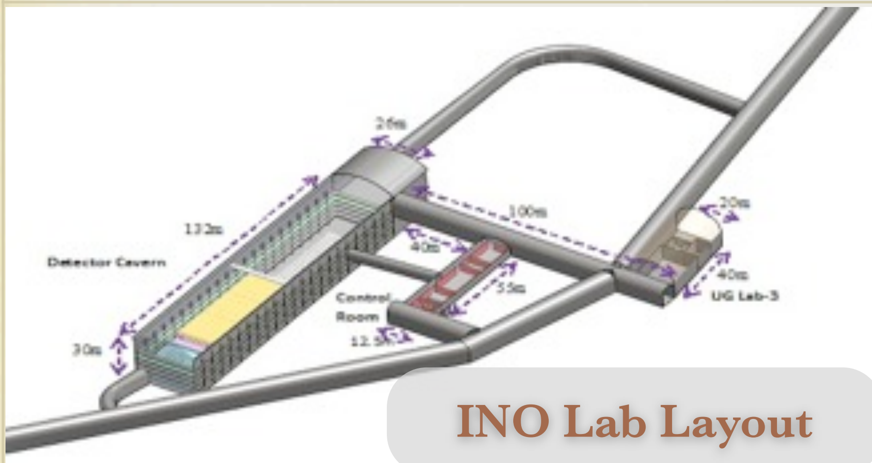


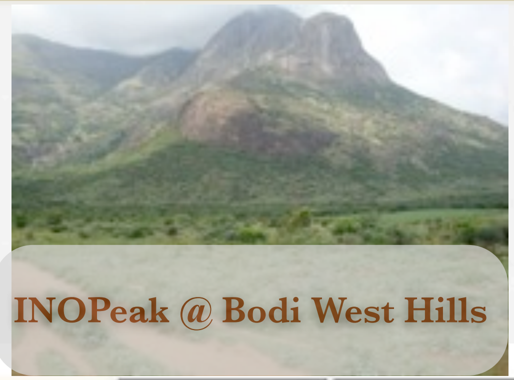
Fig. 3. Schematic view of the MONOLITH detector. The arrangement of the magnetic field is also shown.



INDIA-BASED NEUTRINO OBSERVATORY (INO)

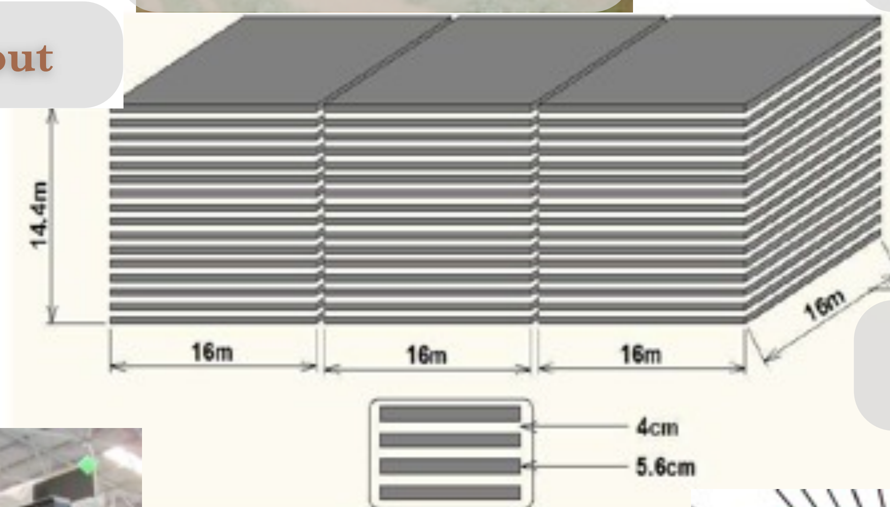


INO Lab Layout



INOPeak @ Bodi West Hills

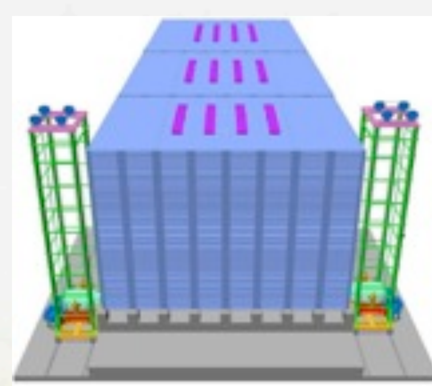
RPC Test stand at TIFR

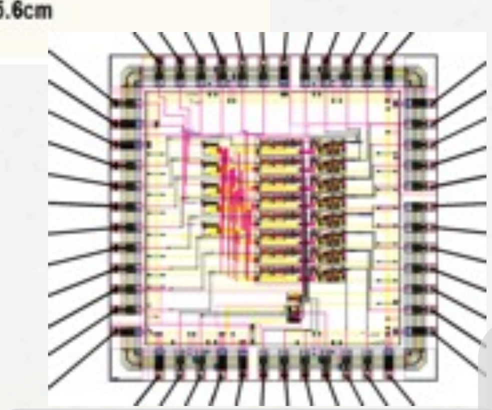


Prototype ICAL at VECC

RPC fabrication at TIFR

RPC fabrication at Asahi Glass Co.



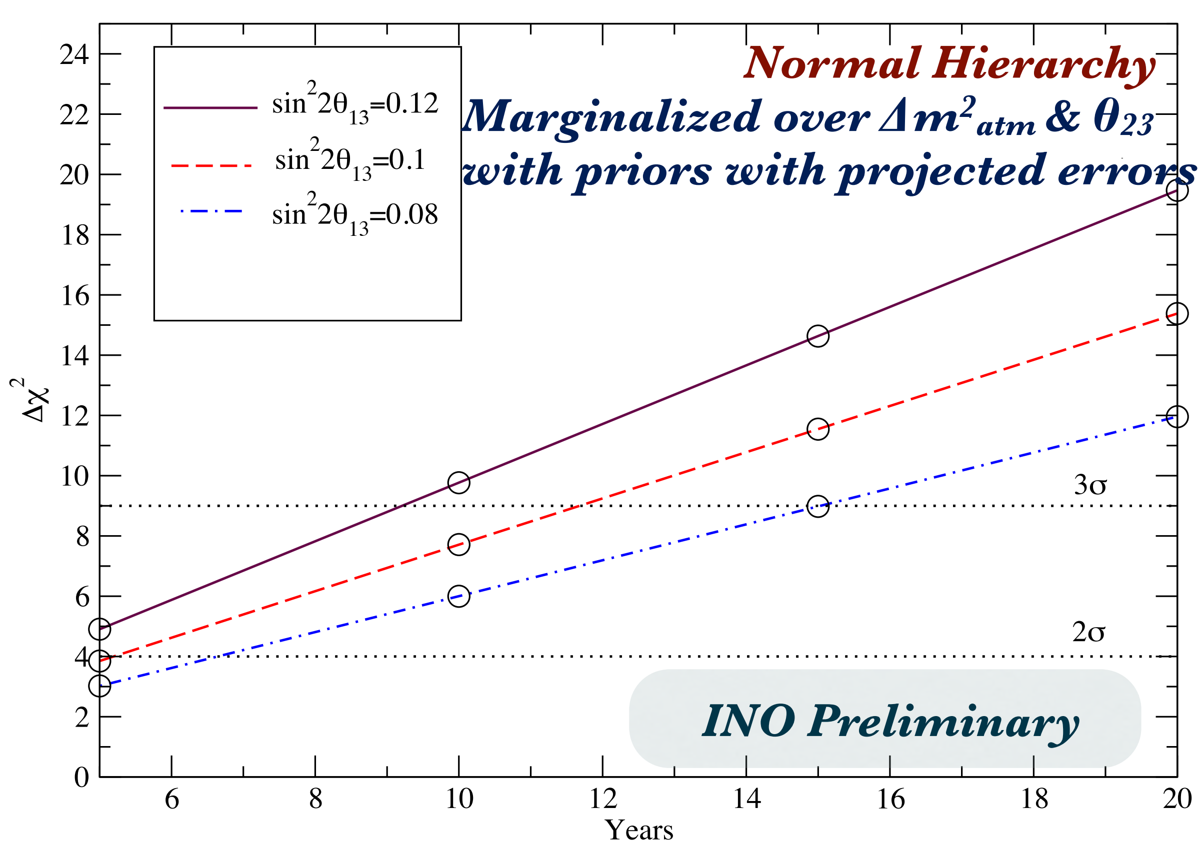


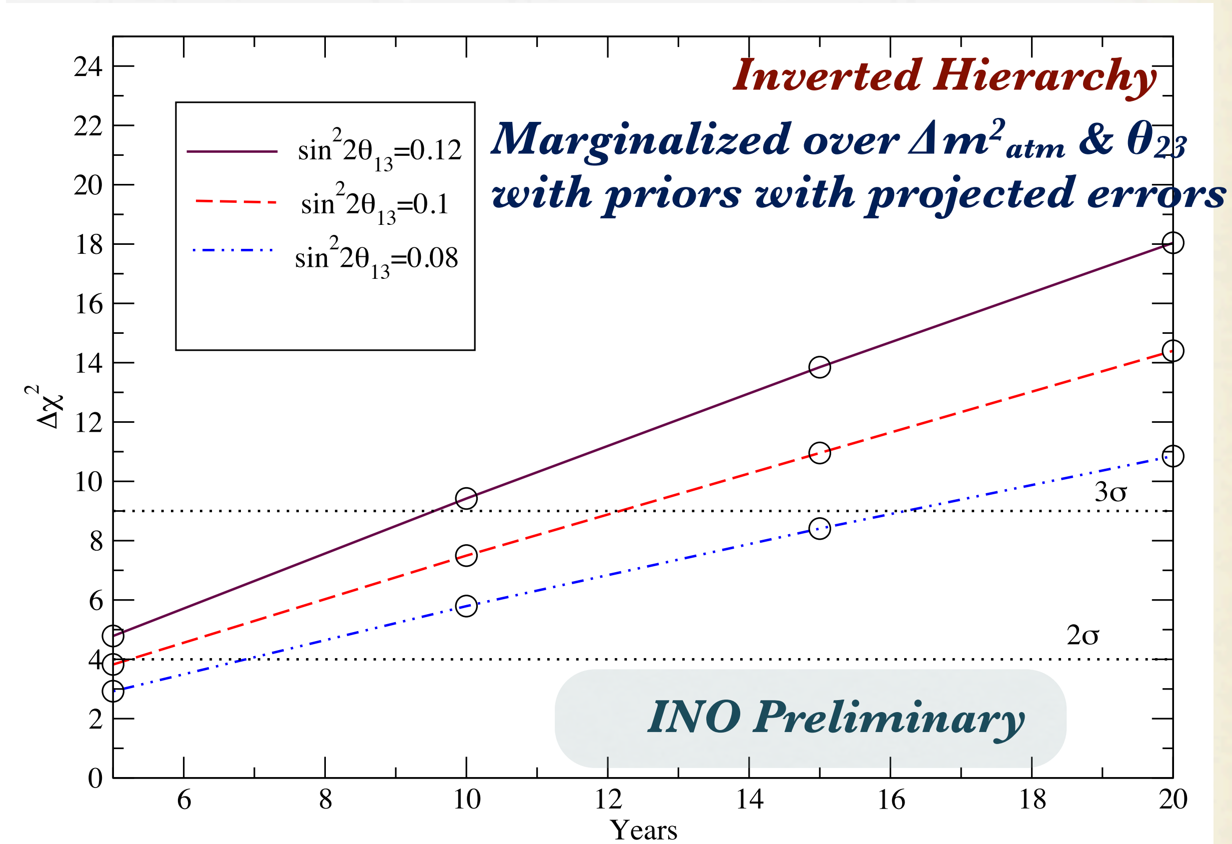
ASIC for RPC designed at BARC

2mx2m RPC stand at TIFR

MASS HIERARCHY @ INO

- Events generated using Nuance and ICAL resoln in E and $\cos\theta_{zenith}$





INO Collab, 2012

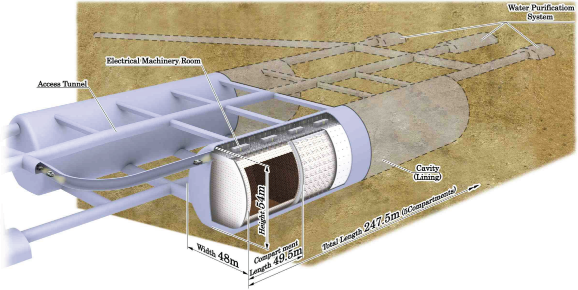
- ~2σ sensitivity for $\sin^2\theta_{23}=0.5$, $\sin^2 2\theta_{13}=0.1$ by 2022 (5 yrs)
- ~2.7σ sensitivity for $\sin^2\theta_{23}=0.5$, $\sin^2 2\theta_{13}=0.1$ by 2027 (10 yrs)

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.

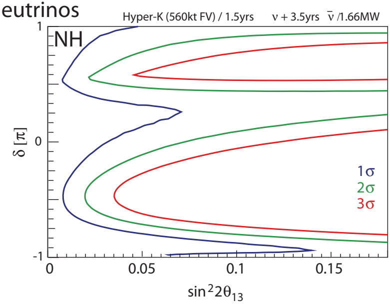


Challenge: push systematic errors at 5% (T2K first result published with 16% systematic errors)

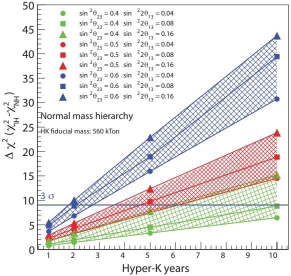
Outstanding performances for proton decays, solar neutrinos, supernova neutrinos etc.

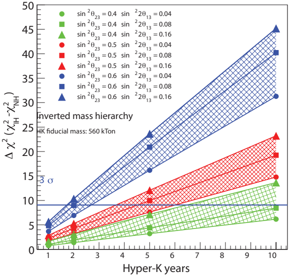
HyperKamiokaNDE: mass hierarchy sensitivity

Beam neutrinos only



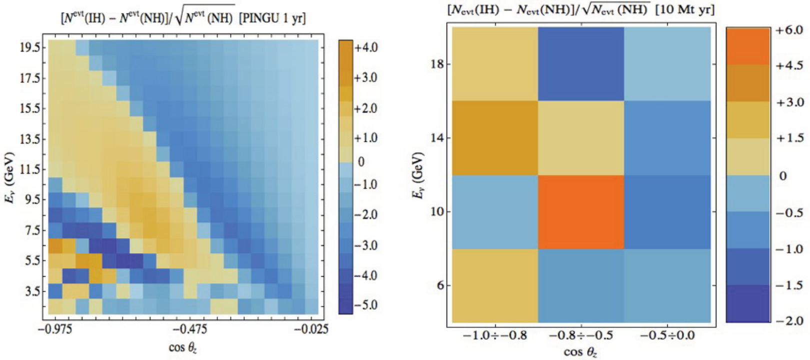
Atmospheric neutrinos only





Mass Hierarchy at Neutrino Telescopes

Akhmedov, Razzaque, Smirnov, arXiv:1205.7071



- **PINGU:** 20 more strings inside IceCube, very close each other
- **ORCA:** redesign km3 to decrease the energy threshold well below 10 GeV.

Neutrino Oscillations in Matter

$$P_{\theta_{13}} = \sin^2(2\theta_{13})\sin\theta_{23}{}^2\sin^2((\hat{A}-1)\hat{\Delta})/(\hat{A}-1)^2;$$
$$p_{\sin\delta} = \alpha\sin(2\theta_{13})\zeta\sin\delta\sin(L\hat{\Delta})\sin(\hat{A}\hat{\Delta})\sin((1-\hat{A})\hat{\Delta})/((1-\hat{A})\hat{A});$$
$$p_{\cos\delta} = \alpha\sin(2\theta_{13})\zeta\cos\delta\cos\hat{\Delta}\sin(\hat{A}\hat{\Delta})\sin(1-\hat{A}\hat{\Delta})/((1-\hat{A})\hat{A});$$
$$p_{\mathrm{solar}} = \alpha^2\cos\theta_{23}{}^2\sin^2 2\theta_{12}\sin^2(\hat{A}\hat{\Delta})/\hat{A}^2;$$

$\alpha = \mathrm{Abs}(\Delta m^2_{21}/\Delta m^2_{31})$; $\hat{\Delta} = \frac{L\Delta m^2_{31}}{4E}$ $\zeta = \cos\theta_{13}\sin 2\theta_{12}\sin 2\theta_{23}$
$\boldsymbol{\hat{A} = \pm a/\Delta m^2_{31}}$; $a = 7.6\cdot 10^{-5}\rho\cdot E_\nu(GeV)$ $\rho = \text{matter density (g cm}^{-3})$
The $\hat{A}$ term changes sign with $\mathrm{sign}(\Delta m^2_{13})$

Matter effects require long “long baselines"

Neutrino Oscillations in Matter

$$P_{\theta_{13}} = \sin^2(2\theta_{13})\sin\theta_{23}{}^2\sin^2((\hat{A}-1)\hat{\Delta})/(\hat{A}-1)^2;$$
$$p_{\sin\delta} = \alpha\sin(2\theta_{13})\zeta\sin\delta\sin(L\hat{\Delta})\sin(\hat{A}\hat{\Delta})\sin((1-\hat{A})\hat{\Delta})/((1-\hat{A})\hat{A});$$
$$p_{\cos\delta} = \alpha\sin(2\theta_{13})\zeta\cos\delta\cos\hat{\Delta}\sin(\hat{A}\hat{\Delta})\sin(1-\hat{A}\hat{\Delta})/((1-\hat{A})\hat{A});$$
$$p_{\mathrm{solar}} = \alpha^2\cos\theta_{23}{}^2\sin^2 2\theta_{12}\sin^2(\hat{A}\hat{\Delta})/\hat{A}^2;$$

$\alpha = \mathrm{Abs}(\Delta m^2_{21}/\Delta m^2_{31})$; $\hat{\Delta} = \frac{L\Delta m^2_{31}}{4E}$ $\zeta = \cos\theta_{13}\sin 2\theta_{12}\sin 2\theta_{23}$
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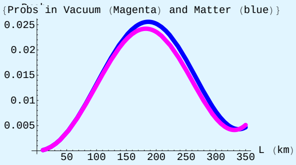
The $\hat{A}$ term changes sign with $\mathrm{sign}(\Delta m^2_{13})$

Matter effects require long "long baselines"

$\boldsymbol{E_\nu = 0.35\mathrm{GeV}\ L \simeq 130}$ **km**

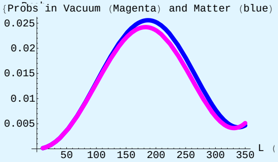


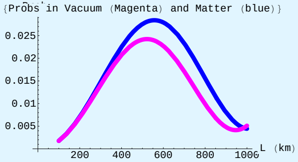
Neutrino Oscillations in Matter

$$P_{\theta_{13}} = \sin^2(2\theta_{13})\sin\theta_{23}{}^2\sin^2((\hat{A}-1)\hat{\Delta})/(\hat{A}-1)^2;$$
$$p_{\sin\delta} = \alpha\sin(2\theta_{13})\zeta\sin\delta\sin(L\hat{\Delta})\sin(\hat{A}\hat{\Delta})\sin((1-\hat{A})\hat{\Delta})/((1-\hat{A})\hat{A});$$
$$p_{\cos\delta} = \alpha\sin(2\theta_{13})\zeta\cos\delta\cos\hat{\Delta}\sin(\hat{A}\hat{\Delta})\sin(1-\hat{A}\hat{\Delta})/((1-\hat{A})\hat{A});$$
$$p_{\mathrm{solar}} = \alpha^2\cos\theta_{23}{}^2\sin^2 2\theta_{12}\sin^2(\hat{A}\hat{\Delta})/\hat{A}^2;$$

$\alpha = \mathrm{Abs}(\Delta m^2_{21}/\Delta m^2_{31})$; $\hat{\Delta} = \frac{L\Delta m^2_{31}}{4E}$ $\zeta = \cos\theta_{13}\sin 2\theta_{12}\sin 2\theta_{23}$
$\boldsymbol{\hat{A} = \pm a/\Delta m^2_{31}}$; $a = 7.6\cdot 10^{-5}\rho\cdot E_\nu(GeV)$ $\quad\rho = \mathrm{matter\ density}\ (\mathrm{g\,cm^{-3}})$
The $\hat{A}$ term changes sign with $\mathrm{sign}(\Delta m^2_{13})$

Matter effects require long "long baselines"
$E_\nu = 0.35\mathrm{GeV}$ $L \simeq 130$ km **$E_\nu = 1\mathrm{GeV}$ $L \simeq 500$ km**



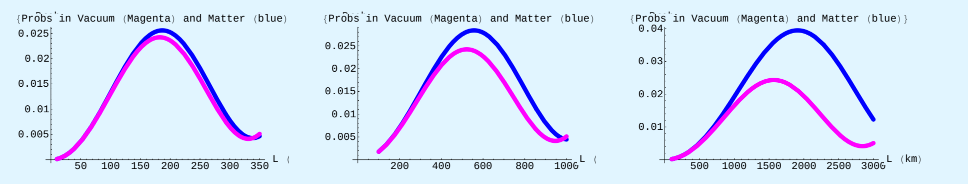


Neutrino Oscillations in Matter

$$P_{\theta_{13}} = \sin^2(2\theta_{13})\sin\theta_{23}{}^2\sin^2((\hat{A}-1)\hat{\Delta})/(\hat{A}-1)^2;$$
$$p_{\sin\delta} = \alpha\sin(2\theta_{13})\zeta\sin\delta\sin(L\hat{\Delta})\sin(\hat{A}\hat{\Delta})\sin((1-\hat{A})\hat{\Delta})/((1-\hat{A})\hat{A});$$
$$p_{\cos\delta} = \alpha\sin(2\theta_{13})\zeta\cos\delta\cos\hat{\Delta}\sin(\hat{A}\hat{\Delta})\sin(1-\hat{A}\hat{\Delta})/((1-\hat{A})\hat{A});$$
$$p_{\mathrm{solar}} = \alpha^2\cos\theta_{23}{}^2\sin^2 2\theta_{12}\sin^2(\hat{A}\hat{\Delta})/\hat{A}^2;$$

$\alpha = \mathrm{Abs}(\Delta m^2_{21}/\Delta m^2_{31})$; $\hat{\Delta} = \frac{L\Delta m^2_{31}}{4E}$ $\zeta = \cos\theta_{13}\sin 2\theta_{12}\sin 2\theta_{23}$
$\boldsymbol{\hat{A} = \pm a/\Delta m^2_{31}}$; $a = 7.6\cdot 10^{-5}\rho\cdot E_\nu(GeV)$ $\rho = \text{matter density (g cm}^{-3})$
The $\hat{A}$ term changes sign with $\mathrm{sign}(\Delta m^2_{13})$

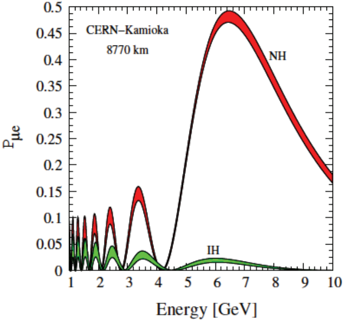
Matter effects require long "long baselines"
$\boldsymbol{E_\nu = 0.35\mathrm{GeV}\ L \simeq 130\ \mathrm{km}}$ $\boldsymbol{E_\nu = 1\mathrm{GeV}\ L \simeq 500\ \mathrm{km}}$ $\boldsymbol{E_\nu = 3\mathrm{GeV}\ L \simeq 1500\ \mathrm{km}}$

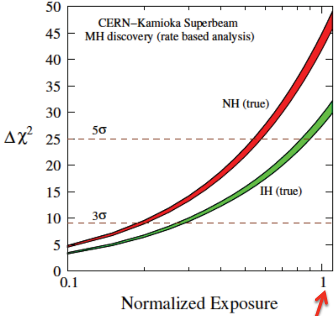


Computed for 50 GeV/c proton beam. At 400 GeV/c and 700 kw apparently requires 3-5 years to have 5 sigmas

CERN-Super-K (8870 km)

Agarwalla-Hernandez April 12





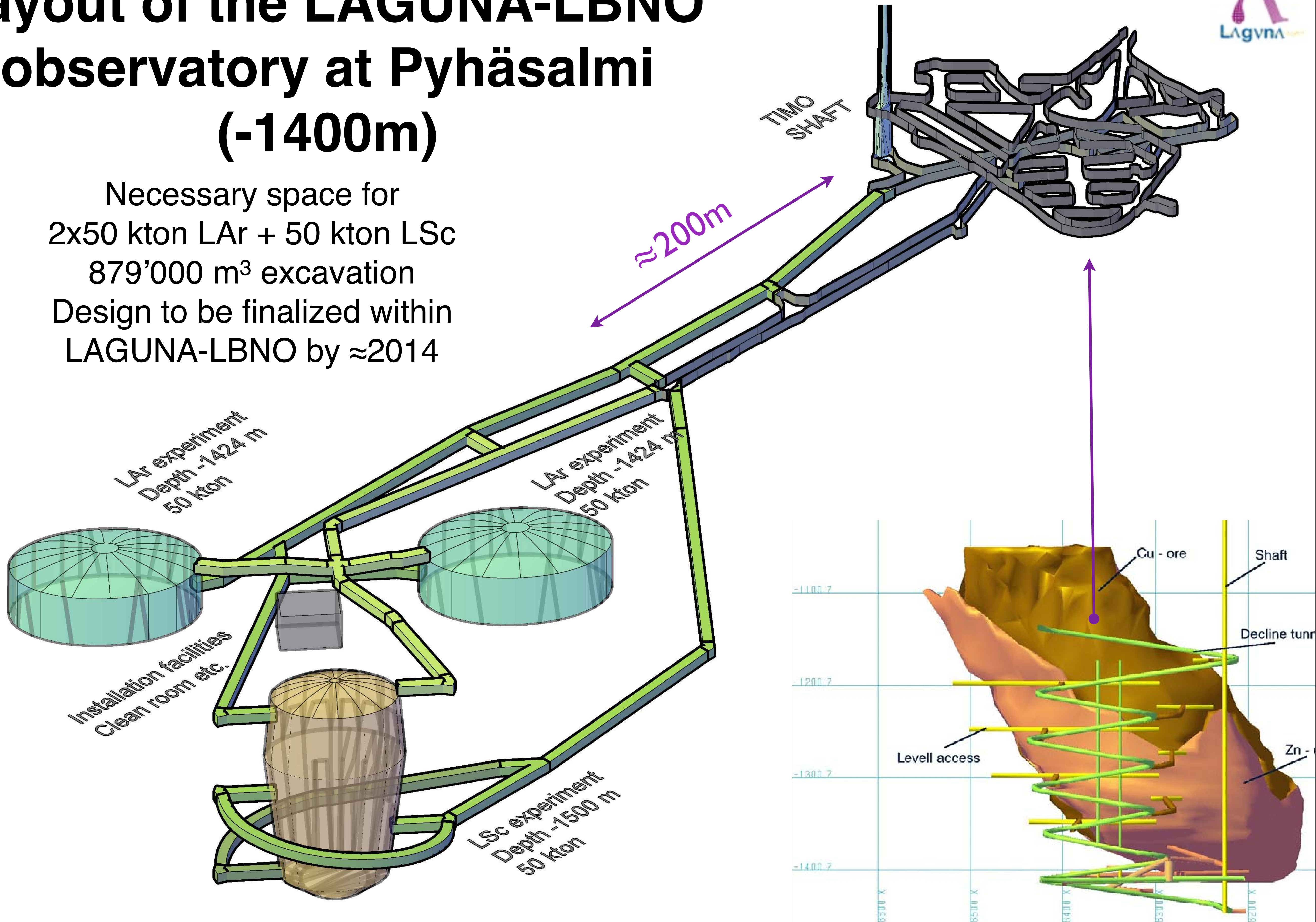
5×10^{21} pot.

Channel	CERN-Kamioka (8870 km) Signal CC-1 ring	CERN-Kamioka (8870 km) Background Int+Mis-id+NC = Total
$\nu_\mu \to \nu_e$ (NH)	**44**	1+2+16=**19**
$\nu_\mu \to \nu_e$ (IH)	**2**	1+3+16=**20**
$\nu_\mu \to \nu_\mu$ (NH)	**83**	**2**
$\nu_\mu \to \nu_\mu$ (IH)	**91**	**2**

May 8-10, 2012 NuTURN@

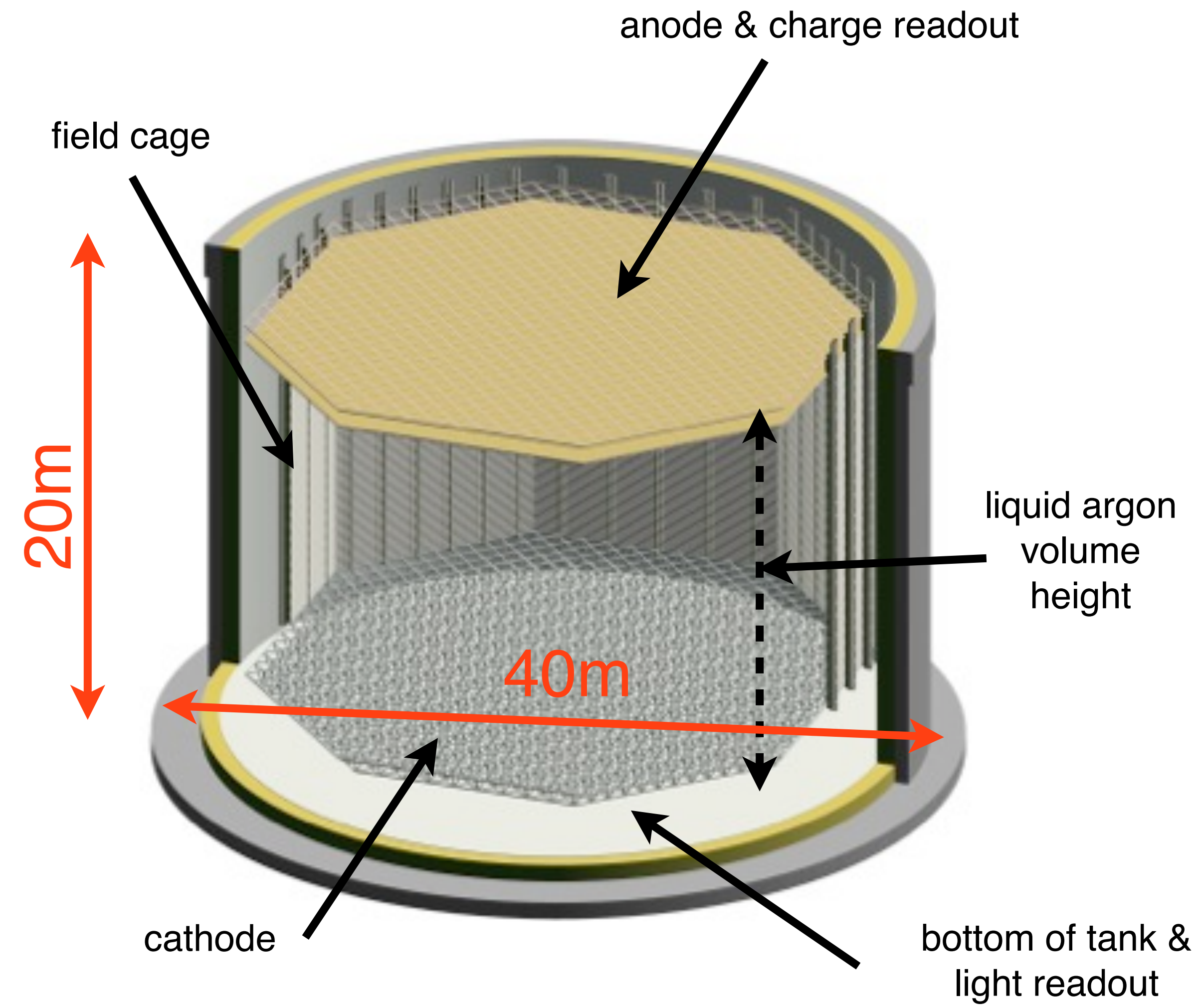
Layout of the LAGUNA-LBNO observatory at Pyhäsalmi (-1400m)

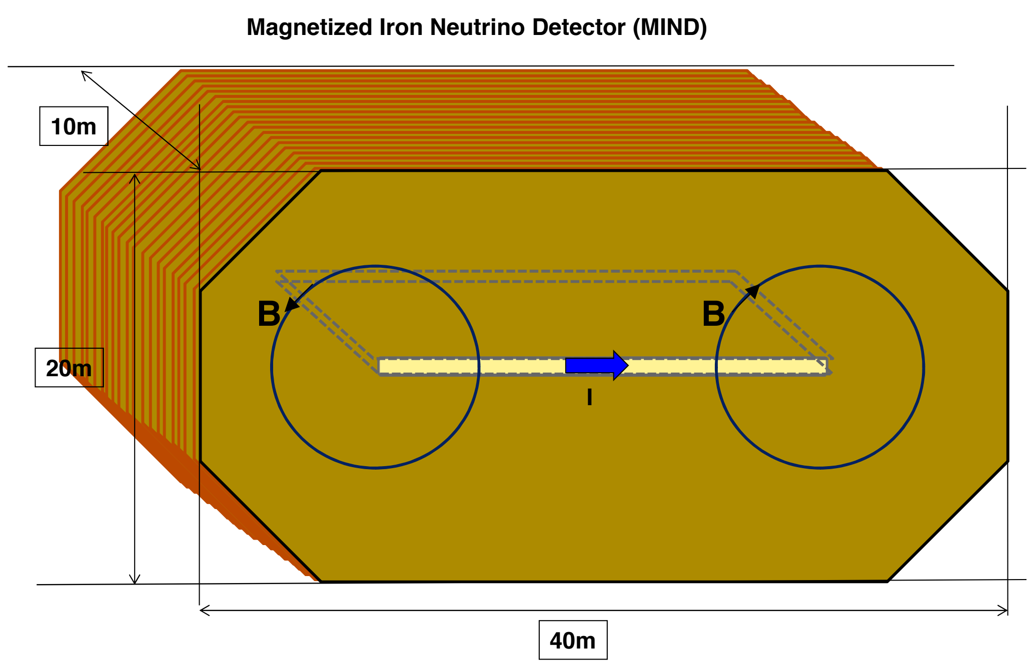
Necessary space for
2x50 kton LAr + 50 kton LSc
879’000 m^3 excavation
Design to be finalized within
LAGUNA-LBNO by ≈2014



Far underground detectors

- **20 kton double phase LAr LEM TPC (GLACIER): best detector for electron appearance measurements with excellent energy resolution and small systematic errors**
  - Exclusive final states, low energy threshold on all particles
  - Excellent ν energy resolution and reconstruction ability from sub GeV to a few GeV, from single prong to high multiplicity
    - ➡ Suitable for spectrum measurement with needed wide energy coverage
  - Excellent π^0/electron discrimination
    - ➡ Wide band On-Axis beam is tolerable
- **35 kton magnetized Muon Detector (MIND): conventional and well-proven detector for muon CC, and NC**
  - muon momentum & charge determination, inclusive total neutrino energy
  - rsμ/wsμ with Neutrino Factory
  - 3cm Fe plates, 1cm scintillator bars, B=1.5-2.5 T



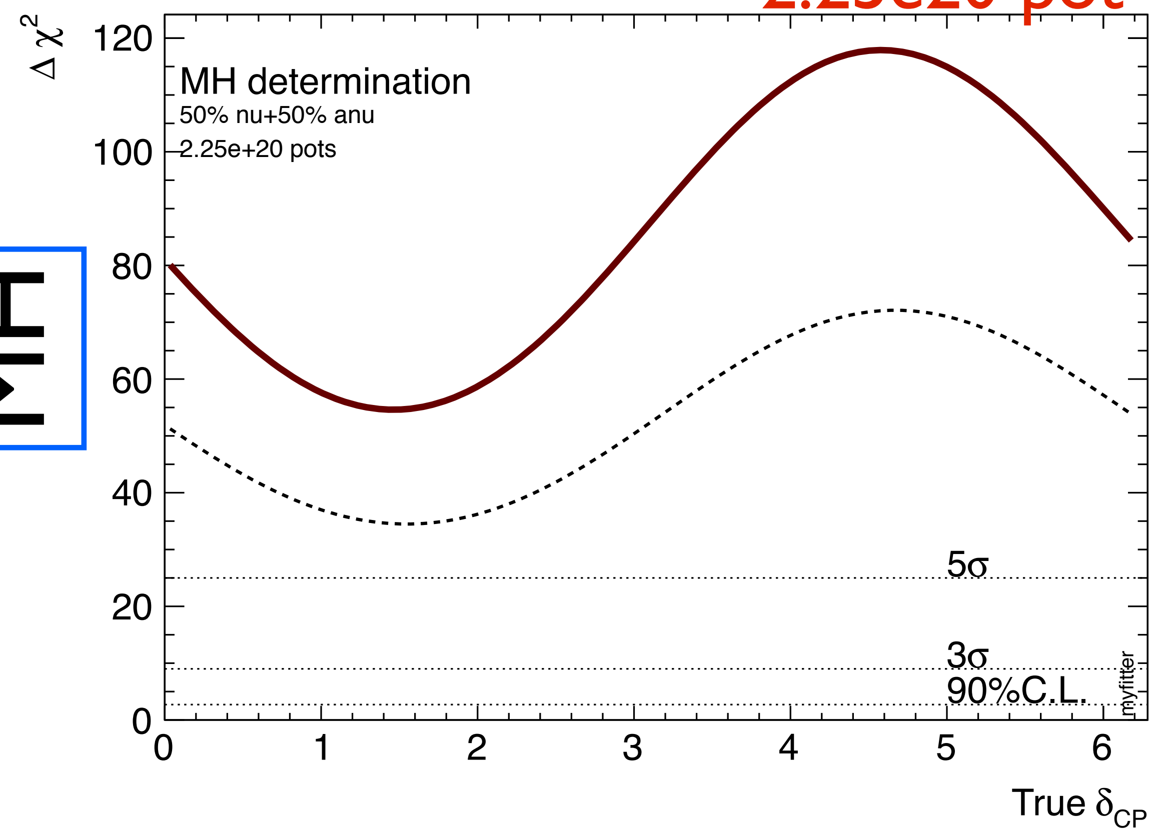


MH & CPV sensitivities

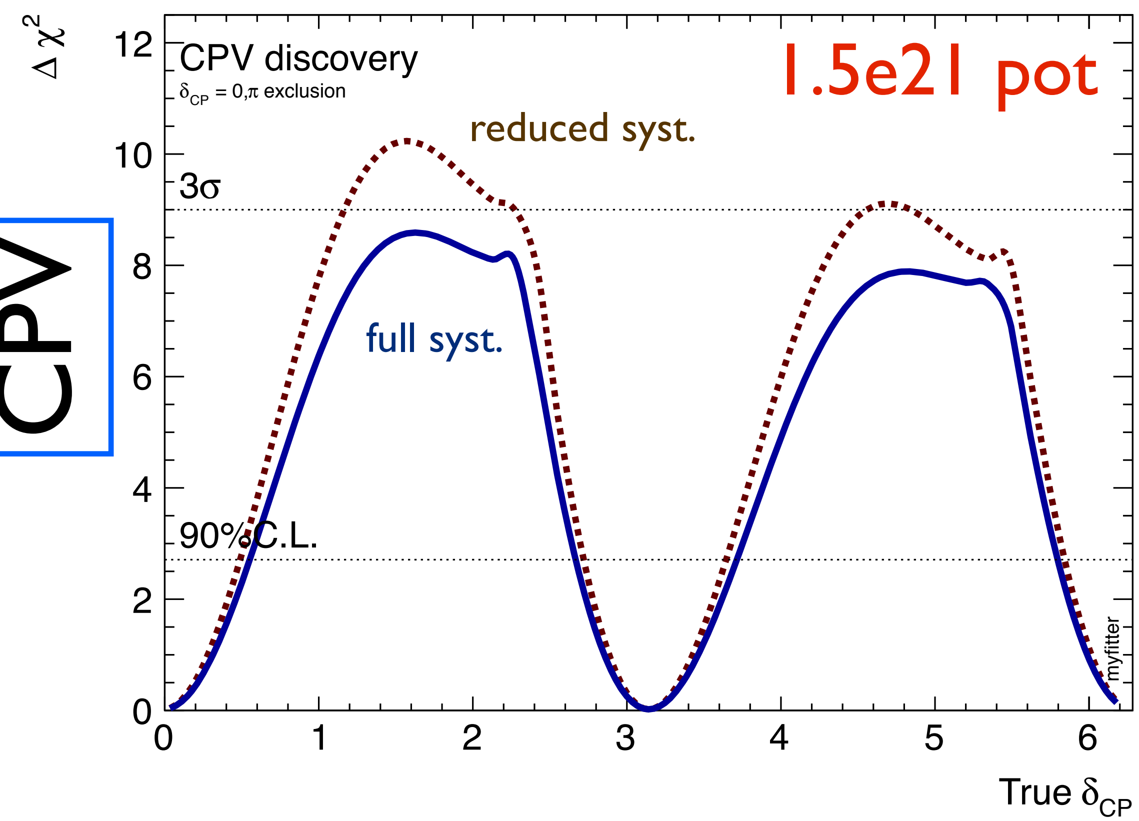
- Estimation using all systematic errors mentioned previously.
- Nominal beam power scenarios (700kW).
- For $\sin^2 2\theta_{13}$=0.1, approximately (at 90%C.L.):
  - MH: 100% coverage at >5σ in a few years of running
  - CPV: ≈60% coverage and evidence for maximal CP (π/2, 3π/2) at 2.9σ in 10 years
- CPV coverage already sensitive to systematic errors.
- With more details studies and a better definition of the near detector, hadron production measurements, and other auxiliary measurements, they might be reduced.
- In case of negative result, the CPV sensitivity can be improved with longer running periods and/or an increase in beam power and far detector mass. For instance, CPV becomes accessible at > 3σ's C.L. for 75% of the δ_{CP} parameter space with a three-fold increase in exposure, provided that systematic errors can be controlled well below the 5% level.

2.25e20 pot

MH



CPV



DayaBay II	reactor 60km	20 kt LS	3 σ in 6 years	R&D on E-reso. my guess 2020	Karsten Heegner	
ICAL@INO	atmos.	50 kt MID (RPCs)	2.7 σ in 10 years	2027	Sandhya Choubey	
HyperK	atmos.	1 Mt Water Cerenkov	3 σ in 5 years 4 σ in 10 years	2027/28 2033/34	Sandhya Choubey	LoI submitted
T2HK	LBL accel. 295 km	1 Mt Water Cerenkov	0..3 σ in 10 years	2028	Masashi Yokoyama	
PINGU	atmos.	Ice (South pole)	3...11 σ in 5 years	feasibility study ongoing.	Sandhya Choubey Poster	Systematics ?
MINOS+	LBL accel. 735 km	MID 5.4 kt	no claim on mass hierarchy	---	speaker on question	
GLADE	LBL accel. 810 km	LAr 5 kt	In combination with NOνA and T2K ≤ 2 σ	Letter-of-Intent	André Rubbia, Poster	
NOνA	LBL AshRiver 810 km	TASD 14 kt	0...3 σ in 6 years depending on δ	2020	Ryan Patterson	under construction starts 2014
LBNE	LBL Homestake LBL Soudan LBL AshRiver	LAr 10 kt LAr 15 kt LAr 30 kt	1.5...7 σ in 10 y 0...3 σ in 10 y 0.5...5σ in 10 y	2030	Bob Swoboda	range gives dependence on δ
GLACIER	LBL accel. 2300 km	LAr 20 kt	> 5σ in a few y.	2025 + number of years to the decision	André Rubbia	
LENA	LBL accel. 2300 km	Liq. Scint. 50 kt	5 σ in 10 years	2028 + number of years to the decision	Lothar Oberauer	

The information is collected from talks given at the NEUTRINO2012 conference in Kyoto in June 2012.
The following transparencies are extracted from the corresponding talks (speakers listed in the 6th column).

Achim Stahl – RWTH Aachen University

Necessary conditions to have LCPV detectable

The third necessary condition has just been fulfilled !

ν_μ-ν_e oscillations in a 3 ν scheme

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

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

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

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

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

Necessary conditions to have LCPV detectable

The third necessary condition has just been fulfilled !

ν_μ-ν_e oscillations in a 3 ν scheme

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

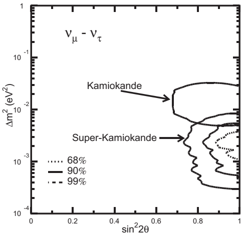
$$+ 8c_{13}^2 s_{12} s_{13} s_{23} (c_{12} c_{23} \cos\delta - s_{12} s_{13} s_{23}) \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E} \quad \text{CPeven}$$

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

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

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

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



The third necessary condition has just been fulfilled !

ν_μ-ν_e oscillations in a 3 ν scheme

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

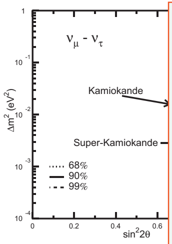
$$+ 8c_{13}^2 s_{12}s_{13}s_{23}(c_{12}c_{23}\cos\delta - s_{12}s_{13}s_{23}) \cos\frac{\Delta m_{23}^2 L}{4E} \sin\frac{\Delta m_{13}^2 L}{4E} \sin\frac{\Delta m_{12}^2 L}{4E} \quad \text{CPeven}$$

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

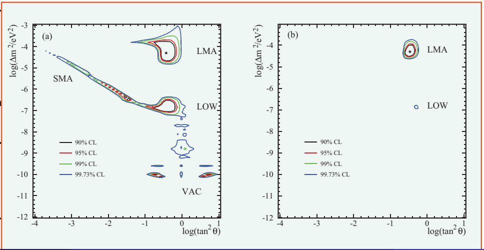
$$+ 4s_{12}^2 c_{13}^2\{c_{13}^2 c_{23}^2 + s_{12}^2 s_{23}^2 s_{13}^2 - 2c_{12}c_{23}s_{12}s_{23}s_{13}\cos\delta\} \sin\frac{\Delta m_{12}^2 L}{4E} \quad \text{solar driven}$$

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

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

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

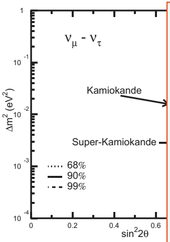
$$+ 8c_{13}^2 s_{12} s_{13} s_{23}(c_{12}c_{23}\cos\delta - s_{12}s_{13}s_{23}) \cos\frac{\Delta m_{23}^2 L}{4E} \sin\frac{\Delta m_{13}^2 L}{4E} \sin\frac{\Delta m_{12}^2 L}{4E} \quad \text{CPeven}$$

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

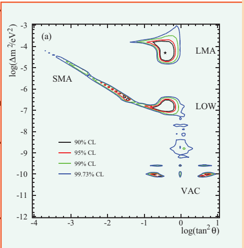
$$+ 4s_{12}^2 c_{13}^2 \{c_{13}^2 c_{23}^2 + s_{12}^2 s_{23}^2 s_{13}^2 - 2c_{12}c_{23}s_{12}s_{23}s_{13}\cos\delta\} \sin\frac{\Delta m_{12}^2 L}{4E} \quad \text{solar driven}$$

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

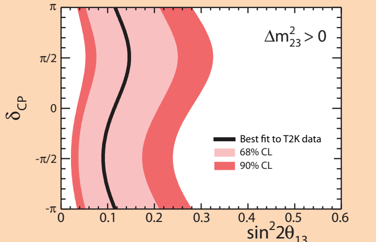
SK, PRL 81(1998) 1562 (3558 citations)



SNO, PRL 89 (2002) 01



T2K, arXiv:1106.2822

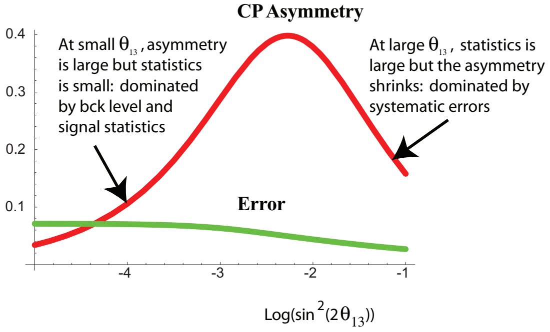


The largest θ_{13} is not the best value for LCPV

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

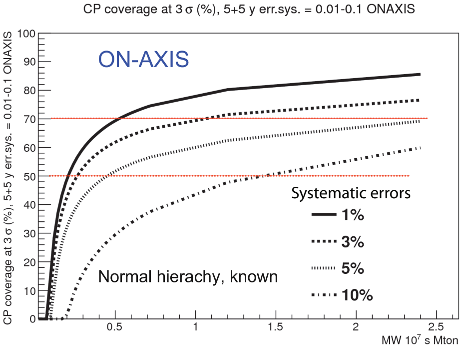
Signal statistics is maximum BUT $\nu - \overline{\nu}$ asymmetry is minimum
In other terms systematic errors dominate

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.

Systematic errors vs. experimental exposure

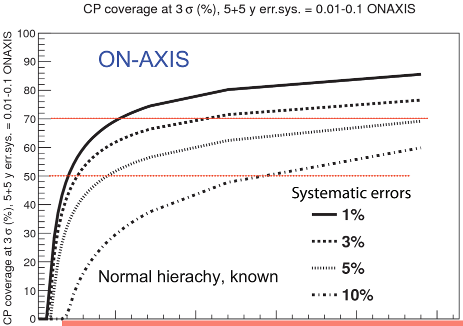


From A. Longhin talk at nuTurn 2012

Exposure [MW ·107 s · Mt] for 3σ

Systematics	1%	3%	5%	10%
50% Coverage	0.2	0.25	0.5	1.5
70% Coverage	0.5	1	2.5	/

Systematic errors vs. experimental exposure



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Exposure [MW ·107 s · Mt] for 3σ

Systematics	1%	3%	5%	10%
50% Coverage	0.2	0.25	0.5	1.5
70% Coverage	0.5	1	2.5	/

Why are we struggling for the largest possible LAr detector and not for the smallest possible systematic errors?

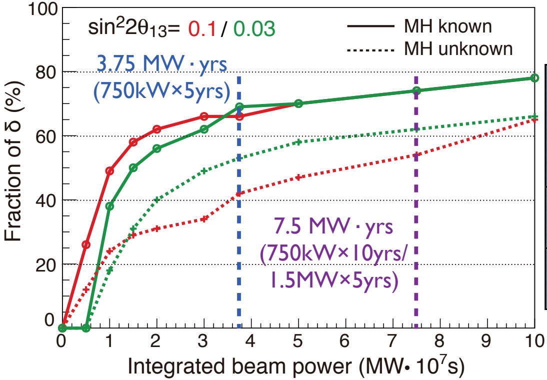
Couldn't we take the lesson from reactor experiments?

Any comparison of different facilities at fixed systematic error is meaningless

Isn't it premature to stop thinking about Beta Beams and Neutrino Factories?

Fraction of δ (%) for CPV discovery

Fraction of δ in % for which expected CPV ($\sin\delta \neq 0$) significance is $>3\sigma$



$\sin^2 2\theta_{13}=0.1$

(MW× yrs)	Mass hierarchy	
	known	unknown
3.75	69%	42%
7.5	74%	54%

- Effect of unknown mass hierarchy is limited
  - Input from atm ν and other experiments also expected for MH

The "Modular" approach

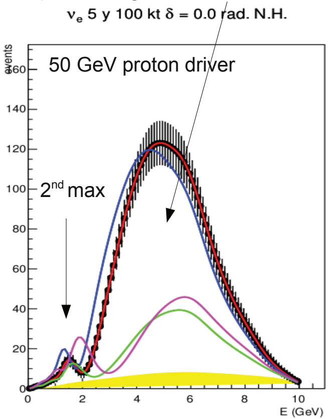
- The most naïve design would assume a single (may be ≈100 kton) LAr container of a huge size. But the dimensions of most events under study (beam-ν, cosmic ray-ν, proton decays) are of much smaller dimensions.
- For instance, the whole volume of ultra-pure LAr will be totally contaminated even by a tiny accidental leak (ppb). A spare container vessel for ≈100 kton are unrealistic.
- Fortunately increasing the size of a single container does not introduce significant physics arguments in its favour.
- A modular structure with several separate vessels, each of a few thousand tons, is to us a more realistic solution.
- A reasonable single volume unit could be of 8 x 8 m^2 cross section, a drift gap of 4 m and a length of about 60 m, corresponding to 3840 m^3 of liquid or 5370 t of LAr.
- Two units should be located side to side with 10 kt mass.

A first cost estimate, based on ICARUS know-how

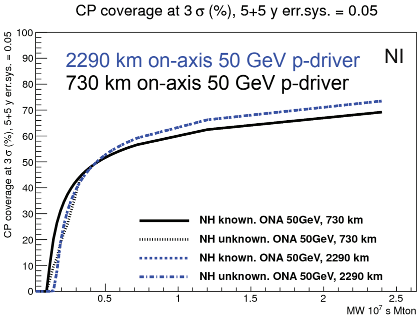
- Based on the long experience with ICARUS and a firm cooperation with industries in the realization of the detectors, a relatively firm estimate of the costs may be given.
- The cost, including contingencies, based on the above list of items 1-7 is as follows:
  - Engineering design and prefabrication costs: 10 M€
  - Construction and installation of first 10 kt: 40 M€
  - Scale reduction and other 4 modules (40 kt): 120 M€
  - LAr procurement for 50 kt fiducial mass 40 M€
- Total construction cost for a 50 kt fiducial mass 210 M€
- Total with additional extension of + 20 kt 285 M€
- Excavated volume for 50 kt fiducial mass 1.25×10^5 m^3

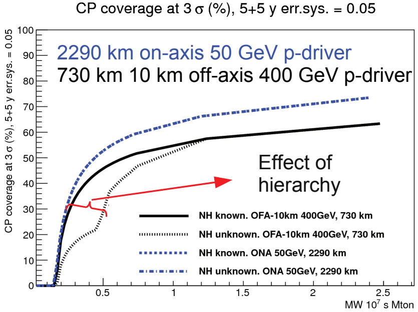
2290 ↔ 730 km

- MH: 2290 km is superior (large matter effects), no ambiguities from MH knowledge



- CP violation: not a huge difference
- Higher coverage at 2290 at high exposures (where 2nd max starts to play a role)





νTURN, LNGS. 8-10 May 2012

Exercise: low-E + short baseline (~100 km) ?

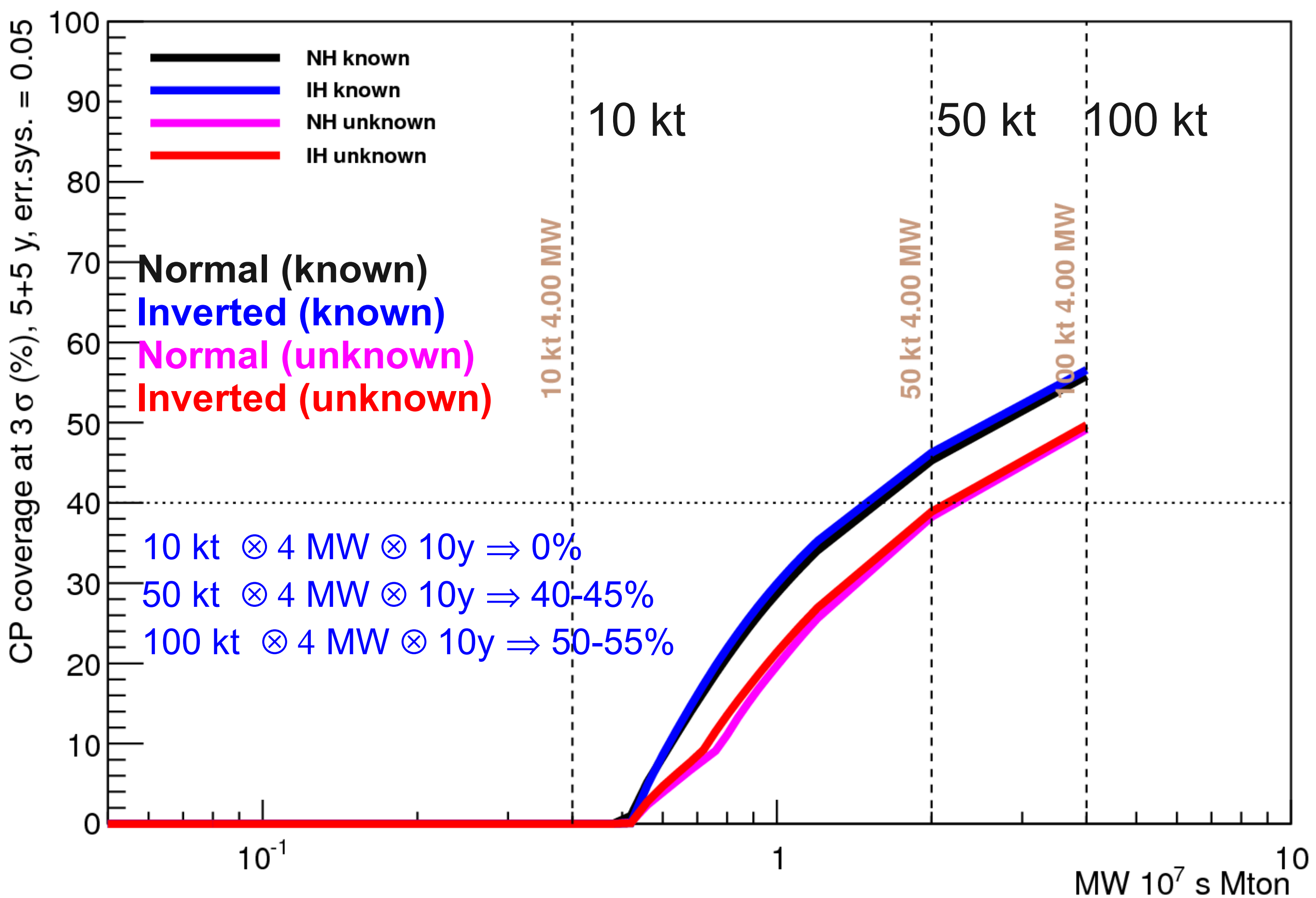
New J.Phys. 4 (2002) 8
JHEP 0704 (2007) 003
E.P.J.C 71:1745, 2011

Philosophy of SPL-Fréjus (L=130 km) E_p = 4.5 GeV, 4 MW SPL

Despite better performances of LAr quite large masses are still required to get a reasonable coverage even with a 4 MW driver.

NB. original design is 440 kt of water

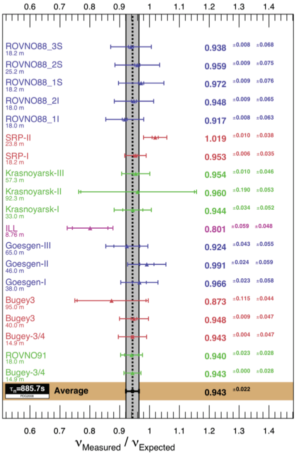
CP coverage at 3 σ (%), 5+5 y, err.sys. = 0.05 SPL

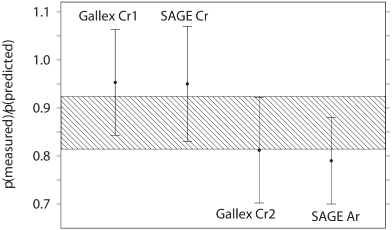


Not suited for existing underground. Would need an external site (and p-driver).

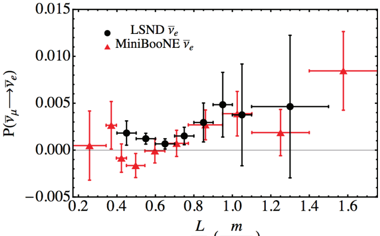
Sources

Reactors

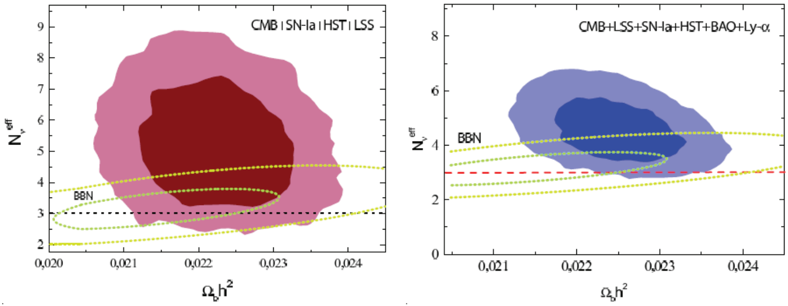




Accelerators



Hints for sterile neutrinos from cosmology ?



Gianpiero Mangano, Alessandro Melchiorri, Olga Mena, Gennaro Miele, Anze Slosar
Journal-ref: JCAP0703:006,2007

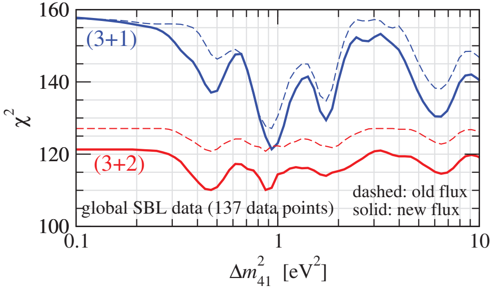
Cosmological Fits

From Sterile Neutrinos White Paper, arXiv:1204.5379

Table III. A selection of recent constraints on N_{eff}, with 68% (95%) uncertainties. W-5 and W-7 stand for WMAP 5-year and 7-year data respectively, H_0 refers to the constraint $H_0 = 74.2 \pm 3.6$ km s^{-1} from [347], LRG the halo power spectrum determined from the luminous red galaxy sample of the SDSS data release 7 [348], while CMB denotes a combination of small-scale CMB experiments such as ACBAR, BICEP and QUaD.

Model	Data	N_{eff}	Ref.
N_{eff}	W-5+BAO+SN+H_0	$4.13^{+0.87(+1.76)}_{-0.85(-1.63)}$	[346]
	W-5+LRG+H_0	$4.16^{+0.76(+1.60)}_{-0.77(-1.43)}$	[346]
	W-5+CMB+BAO+XLF+f_{gas}+H_0	$3.4^{+0.6}_{-0.5}$	[349]
	W-5+LRG+maxBCG+H_0	$3.77^{+0.67(+1.37)}_{-0.67(-1.24)}$	[346]
	W-7+BAO+H_0	$4.34^{+0.86}_{-0.88}$	[338]
	W-7+LRG+H_0	$4.25^{+0.76}_{-0.80}$	[338]
	W-7+ACT	5.3 ± 1.3	[343]
	W-7+ACT+BAO+H_0	4.56 ± 0.75	[343]
	W-7+SPT	3.85 ± 0.62	[344]
	W-7+SPT+BAO+H_0	3.85 ± 0.42	[344]
	W-7+ACT+SPT+LRG+H_0	$4.08^{(+0.71)}_{(-0.68)}$	[350]
	W-7+ACT+SPT+BAO+H_0	3.89 ± 0.41	[351]
$N_{eff}+f_\nu$	W-7+CMB+BAO+H_0	$4.47^{(+1.82)}_{(-1.74)}$	[352]
	W-7+CMB+LRG+H_0	$4.87^{(+1.86)}_{(-1.75)}$	[352]
$N_{eff}+\Omega_k$	W-7+BAO+H_0	4.61 ± 0.96	[351]
	W-7+ACT+SPT+BAO+H_0	4.03 ± 0.45	[352]
$N_{eff}+\Omega_k+f_\nu$	W-7+ACT+SPT+BAO+H_0	4.00 ± 0.43	[351]
$N_{eff}+f_\nu+w$	W-7+CMB+BAO+H_0	$3.68^{(+1.90)}_{(-1.84)}$	[352]
	W-7+CMB+LRG+H_0	$4.87^{(+2.02)}_{(-2.02)}$	[352]
$N_{eff}+\Omega_k+f_\nu+w$	W-7+CMB+BAO+SN+H_0	$4.2^{+1.10(+2.00)}_{-0.61(-1.14)}$	[353]
	W-7+CMB+LRG+SN+H_0	$4.3^{+1.40(+2.30)}_{-0.54(-1.09)}$	[353]

3+2 global fit



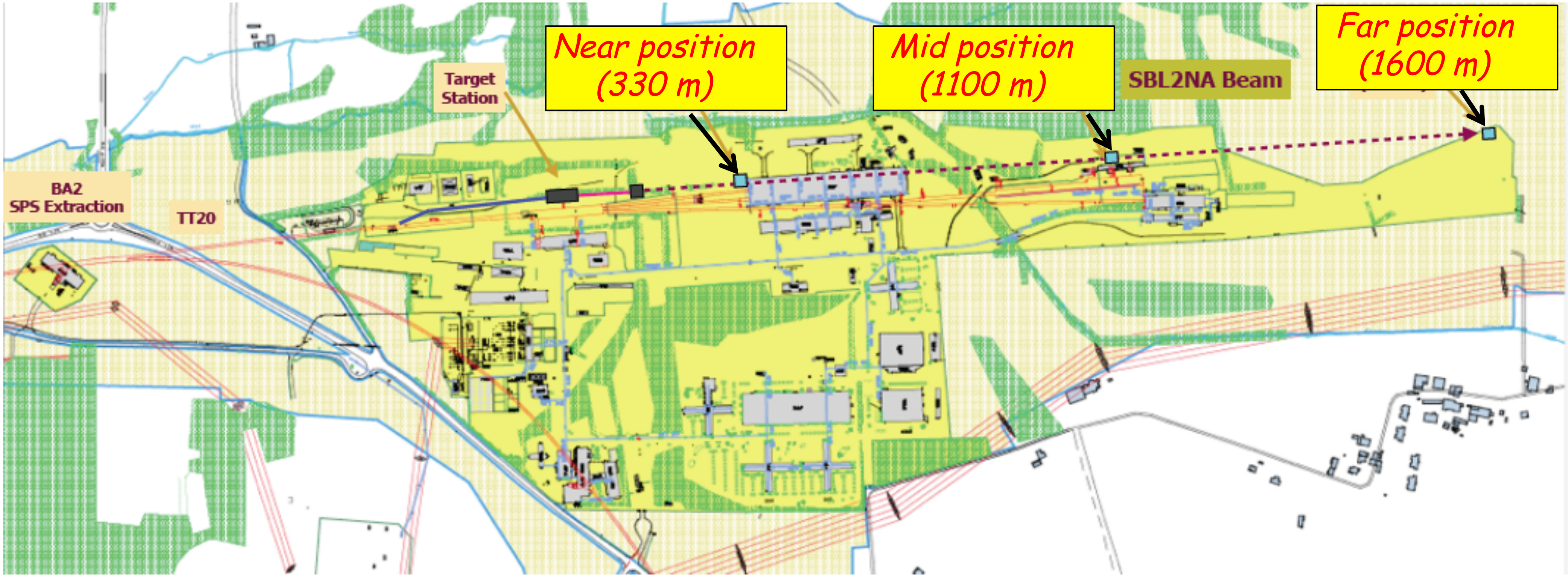
- $\Delta\chi^2_{3+2}$ (old vs new fluxes) $= 11.1$
- $\Delta\chi^2$ (3+1 vs 3+2) $= 11.2$ (97.6% CL, 4 dof)
  6.3 for old flux

Kopp, Maltoni, TS, 11

Experimental Goals

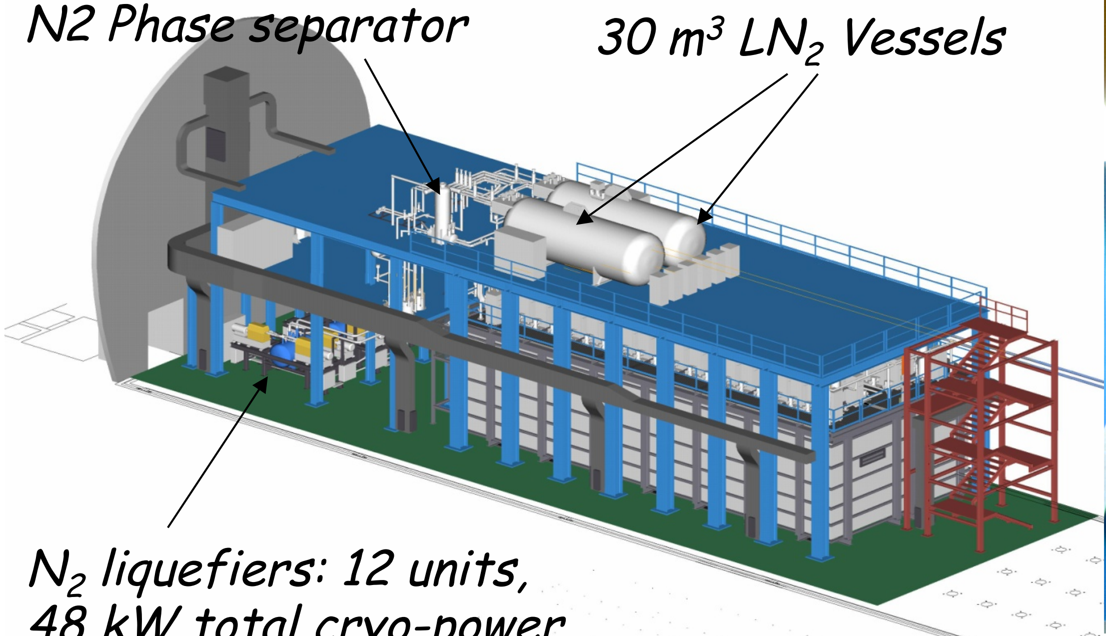
- Bring anomalies (ν_e-ν_e, ν_μ-ν_e) to evidences or get rid of them definitely.
- Demonstrate they are **sterile neutrinos** (NC disappearance).
- Confirm the model (ν_μ disappearance):
  - One or two more neutrinos?
  - **CP violation?**

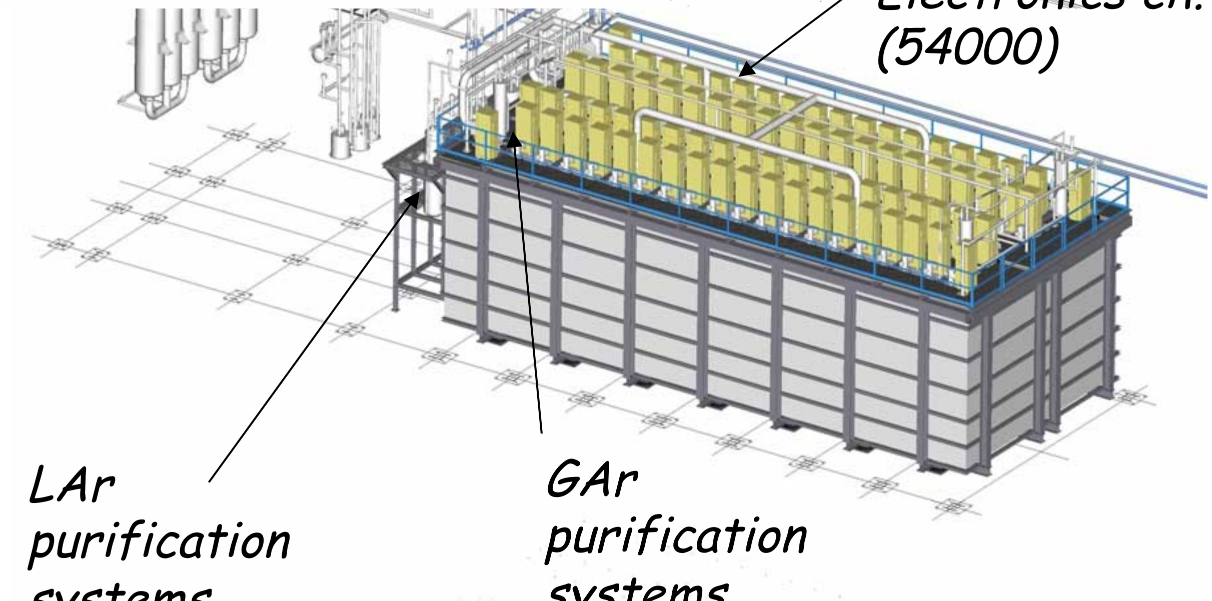
New Neutrino Facility in the CERN North Area



100 GeV primary beam fast extracted from SPS; target station next to TCC2; decay pipe l =100m, ø = 3m; beam dump: 15m of Fe with graphite core, followed by μ stations.
Neutrino beam angle: pointing upwards; at -3m in the far detector ~5mrad slope.

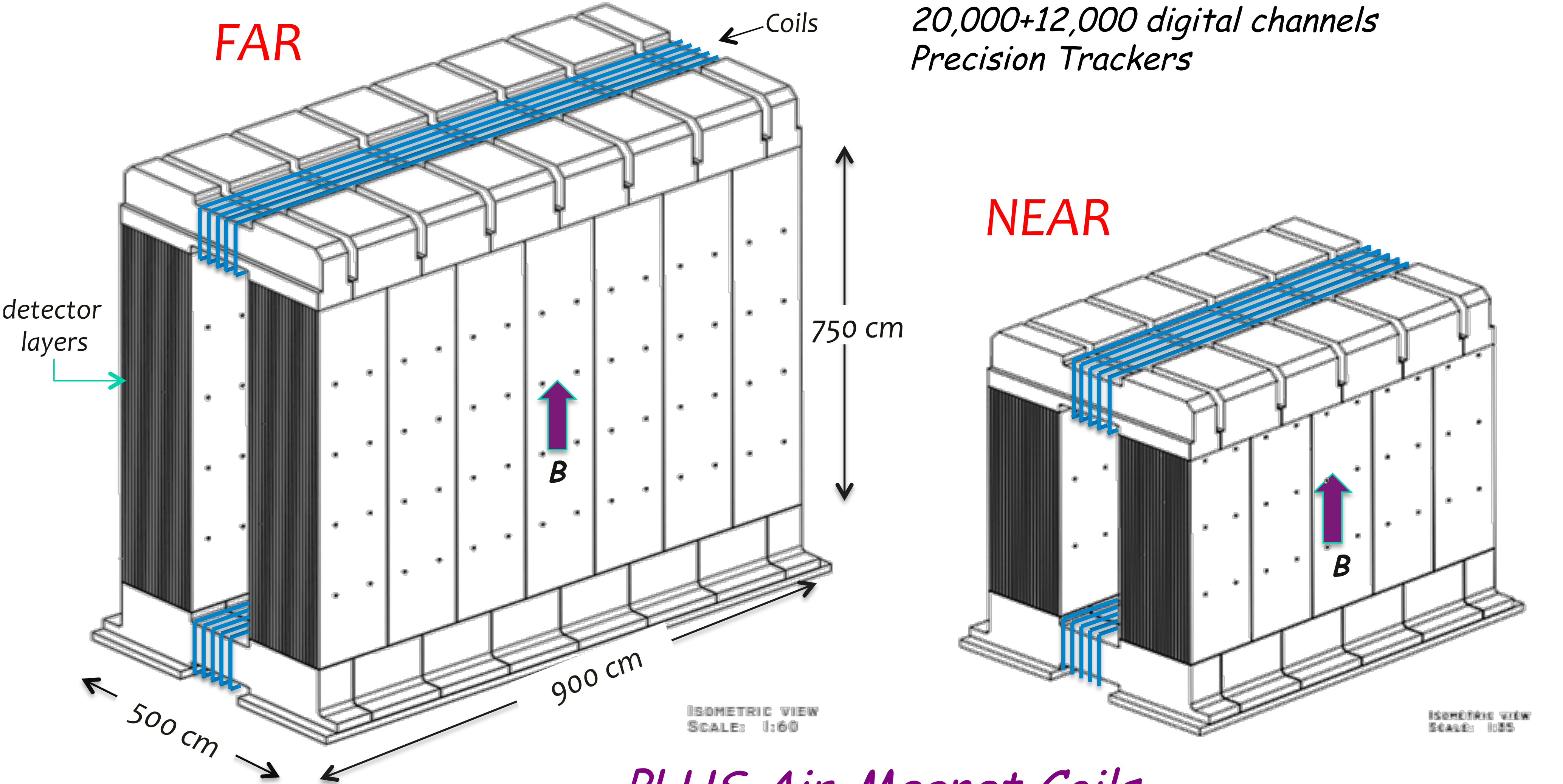
ICARUS-T600 @LNGS: 0.77 kton LAr-TPC





NESSiE Iron Spectrometers

1800 + 700 m² of RPC
20,000+12,000 digital channels
Precision Trackers



PLUS Air-Magnet Coils

Conclusions

In the short term, short baseline experiments can guarantee an excellent case of physics for neutrino experiments. They can also be the ideal testbench for the development of future gigantic liquid argon detectors.

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.

In the medium term, mass hierarchy can be addressed by long baseline experiments. However non accelerator experiment could achieve similar sensitivities in a cheaper and faster way.

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.

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XV International Workshop on Neutrino Telescopes

Istituto Nazionale di Fisica Nucleare

Europe/Rome timezone

11-15 March 2013 *Palazzo Franchetti, Istituto Veneto di Scienze, Lettere ed Arti*

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Support

The “Neutrino Telescopes” is one of the most prestigious international event in the field of Physics. It takes place every two years and dates back to 1988 when Prof. Milla Baldo Ceolin conceived it and launched the first edition. It became soon a crucial event and it is now considered a consolidated appointment where to discuss the latest discoveries and the fascinating future scenarios in topics that range from Neutrinos to Astrophysics and Cosmology.

The program will be structured in plenary sessions with invited talks followed by discussions. There will be also a poster session, aiming at involving particularly, but not limited to, young researchers with new brilliant ideas on the workshop’s topics of interest.

The Workshop will take place from March 12th to March 15th, 2013. Registration will open on March 11th. Secretariat desk will be available from 15.00 to 18.00