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“ Prospettive future per esperimenti di neutrini short e long baseline”

- Introduction
- New results of T2K
- Evidences of $\theta_{13} \neq 0$
- 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)!**

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

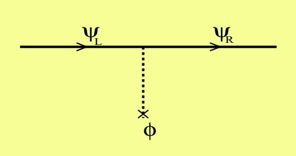
$\theta_{13} \to 0 \quad \Rightarrow$ The 3x3 mixing matrix becomes a trivial product of two 2x2 matrixes.

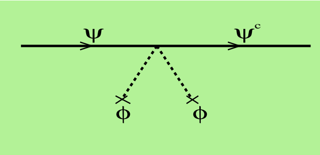
θ_{13} drives $\nu_\mu \to \nu_e$ subleading transitions $\Rightarrow$
the necessary milestone for any subsequent search:
neutrino mass hierarchy and leptonic CP searches.

Leptons are VERY different from quarks. (II)

$u \sim 5$ 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.

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

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.

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

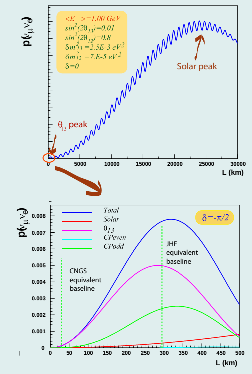
$$p(\nu_\mu \to \nu_e) = 4c_{13}^2 s_{13}^2 s_{23}^2 \sin^2 \frac{\Delta m_{13}^2 L}{4E} \times \left[1 \pm \frac{2a}{\Delta m_{13}^2}(1-2s_{13}^2)\right] \quad \theta_{13} \text{ dri}$$

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

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

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

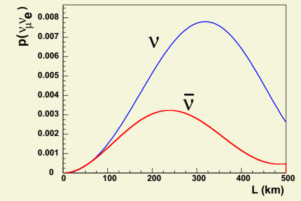
$$\mp 8c_{12}^2 s_{13}^2 s_{23}^2 \cos\frac{\Delta m_{23}^2 L}{4E} \sin\frac{\Delta m_{13}^2 L}{4E} \frac{aL}{4E}(1-2s_{13}^2) \quad \text{matter effect (CP odd)}$$



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

Leptonic CP discovery requires

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



Reactors vs Accelerators

Accelerators: ν_e appearance

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

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

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

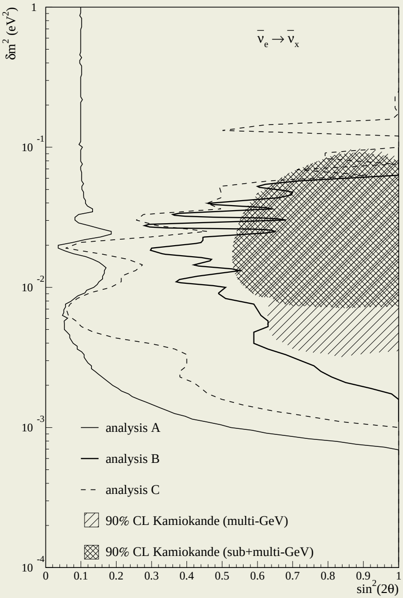
$$+\,4s_{12}^2 c_{13}^2\{c_{13}^2 c_{23}^2 + s_{12}^2 s_{23}^2 s_{13}^2 - 2c_{12}c_{23}s_{12}s_{23}s_{13}\cos\delta\}\sin^2\frac{\Delta m_{12}^2 L}{4E} \qquad \text{solar driven}$$

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

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

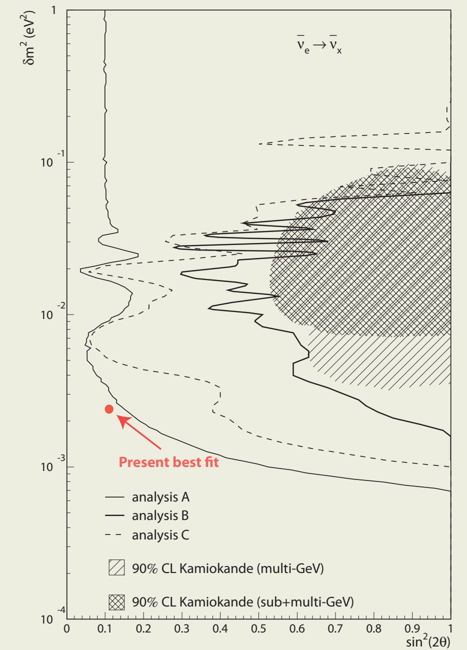
$$1-P_{\overline{\nu}_e-\overline{\nu}_e}\simeq\sin^2 2\theta_{13}\,\sin^2(\Delta m_{31}^2 L/4E) + (\Delta m_{21}^2/\Delta m_{31}^2)^2\,(\Delta m_{31}^2 L/4E)^2\cos^4\theta_{13}\,\sin^2 2\theta_{12}$$

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 !



CHOOZ final results

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1998 - 2011

Until 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.

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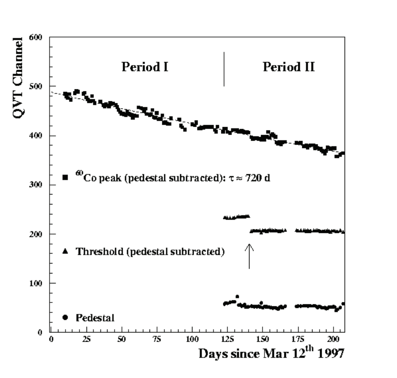
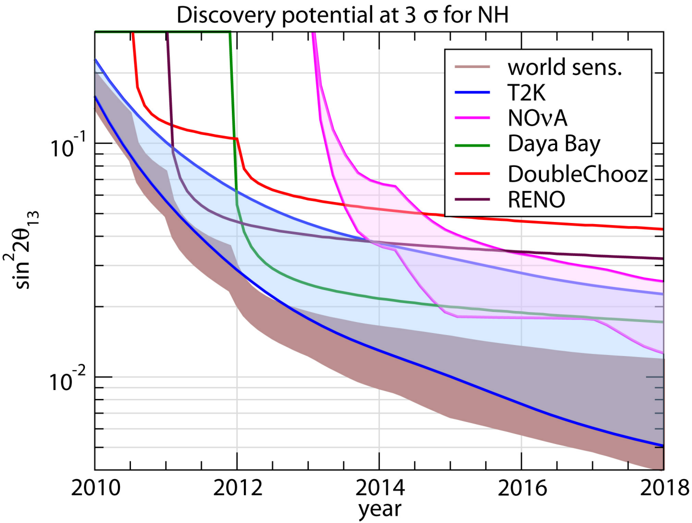


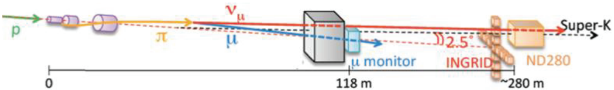
Fig. 24. Peak associated with the ^{60}Co 2.5 MeV line, as a function of time, as measured by means of a Lecroy QVT. The detected charge follows an exponential decrease, with deca y time ≈ 720 d.

Predictions before exp. results

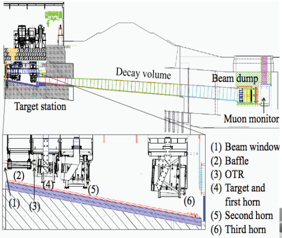
M.M. and T. Schwetz, J.Phys.G G37 (2010) 103001



The T2K Experiment



JPARC Accelerator @ Tokay



SuperKamiokaNDE

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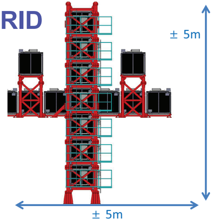

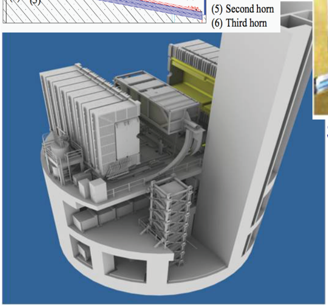

ND280

T2K Collaboration

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Kulkarni,[31] R. Kurjata,[55] T. Kutter,[31] J. Lagoda,[2] K. Laihem,[42] M. Laveder,[24] K. P. Lee,[50] P. T. Le,[34] J. M. Levy,[37] C. Licciardi,[40] I. T. Lim,[9] T. Lindner,[5] R. P. Litchfield,[56,28] M. Litos,[4] A. Longhin,[8] G. D. Lopez,[34] P. F. Loverre,[25] L. Ludovici,[25] T. Lux,[19] M. Macaire,[8] K. Mahn,[52] Y. Makida,[18,†] M. Malek,[21] S. Manly,[41] A. Marchionni,[15] A. D. Marino,[10] J. Marteau,[32] J. F. Martin,[51,§] T. Maruyama,[18,†] T. Maryon,[29] J. Marzec,[55] P. Masliah,[21] E. L. Mathie,[40] C. Matsumura,[35] K. Matsuoka,[28] V. Matveev,[26] K. Mavrokoridis,[30] E. Mazzucato,[8] N. McCauley,[30] K. S. McFarland,[41] C. McGrew,[34] T. McLachlan,[50] M. Messina,[3] W. Metcalf,[31] C. Metelko,[47] M. Mezzetto,[24] P. Mijakowski,[2] C. A. Miller,[52] A. Minamino,[28] O. Mineev,[26] S. Mine,[7] A. D. Missert,[10] G. Mituka,[50] M. Miura,[49] K. Mizouchi,[52] L. Monfregola,[20] F. Moreau,[14] B. Morgan,[56] S. Moriyama,[49] A. Muir,[46] A. Murakami,[28] M. 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+ J. Caravaca, Y. Kanazawa, P. Sinclair, O. Perevozchikov

2

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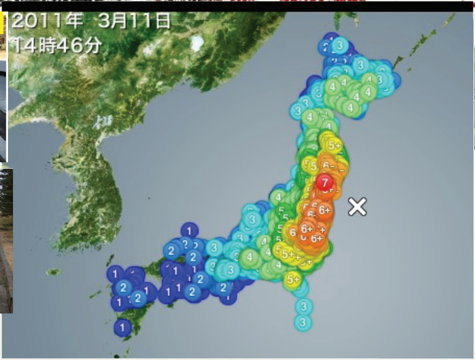
~500 physicists from 12 countries

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



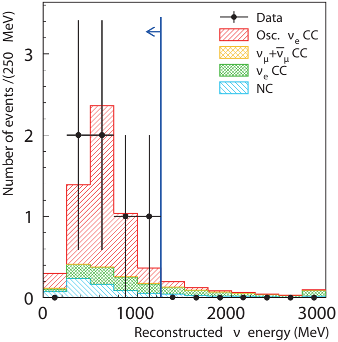
09:30 Key was on.

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

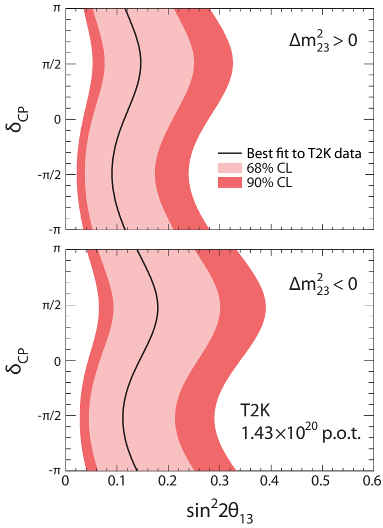
- *Heartfelt gratitude to the tremendous supports to J-PARC and T2K from all over the world.*

3

T2K result, PRL 107 (2011) 041801



Expected: 1.5 +/- 0.3
Measured: 6

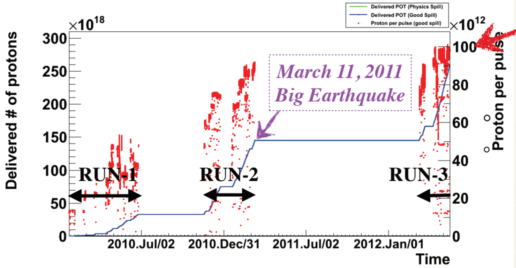


Systematic errors

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 $\delta N^{exp}_{SK}/N^{exp}_{SK}$	$^{+22.8}_{-22.7}\%$	$^{+17.6}_{-17.5}\%$

Shot 97455 at 12/06/01 16:31:33
202.34 kW 12/06/01 16:31:34

Data collected and Analyzed



up to 190 kW

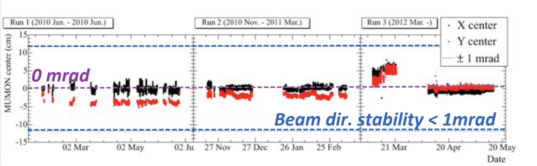
w/ >1×10^{14} protons per pulse (world record)

Analysis by May 15th, 2012

2.56×10^{20} POT (Protons On Target)

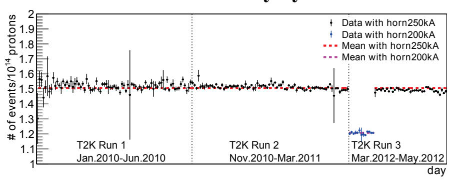
- **RUN-1 (2010): 0.32×10^{20} POT**
- **RUN-2 (2010-2011): 1.11×10^{20} POT**
  - **ND280 RUN-1+2 data used for oscillation analysis**
- **RUN-3 (2012): 1.12×10^{20} POT**
  - **including 0.21×10^{20} POT with 200kA horn operation (13% flux reduction at peak)**
  - **ND280 RUN-3data was checked for consistency with RUN1+2.**

Stability of the beam direction (Muon monitor)



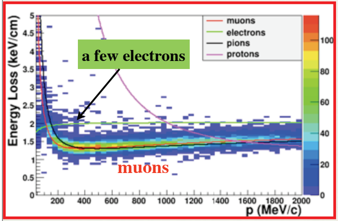
Performance of ND280

ν event rate stability by INGRID

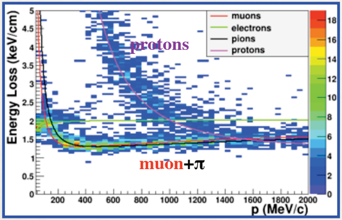


TPC PID

negative track

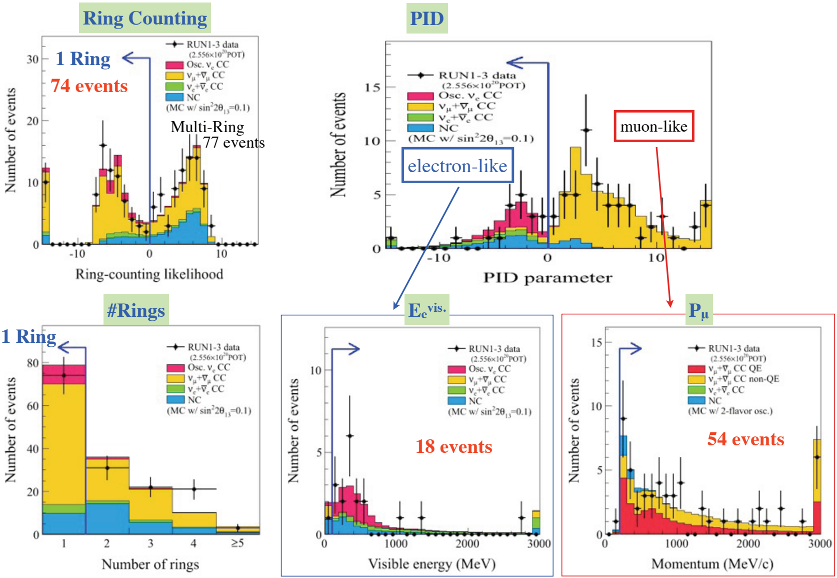


positive track



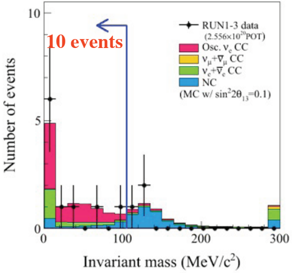
- INGRID [RUN 1-3 data]
  - ν rate stability
  - beam direction:
    - -0.01±0.33 mrad (x)
    - -0.11±0.37 mrad (y)
- ND280 [RUN 1-2 data]
  - excellent PID and tracking capability
  - identification of the neutrino interactions.

Data Reduction (simple cut analysis)

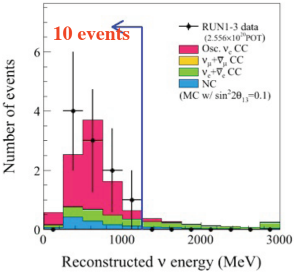


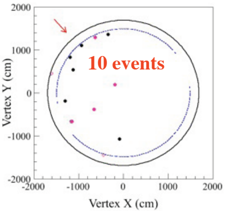
Further ν_e selection

Invariant mass of assumed two rings (<105MeV/c^2) [POLfit]



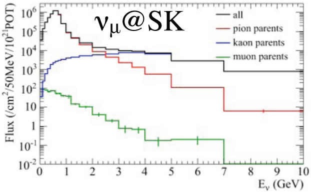
Reconstructed E_ν < 1250MeV



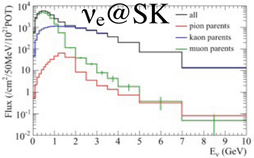


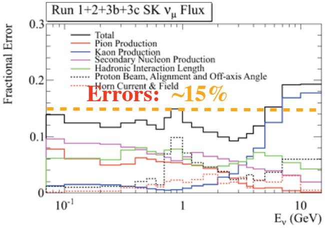
RUN 1+2+3 2.556×10^{20} POT	Data	MC Expectation w/ $\sin^2 2\theta_{13}=0.1$				
		Signal $\nu_\mu \to \nu_e$	BG total	CC ($\nu_\mu+\bar{\nu}_\mu$)	CC($\nu_e+\bar{\nu}_e$)	NC
e-like	19	8.70	13.23	2.30	4.07	6.86
E_{vis}>100MeV	18	8.50	11.47	1.49	4.03	5.94
No decay-e	13	7.31	8.56	0.28	3.19	5.09
POLfit mass	10	6.82	3.67	0.07	2.21	1.39
E_ν^{rec}<1250MeV (MC $\sin^2 2\theta_{13}=0$ case)	10	6.61 (0.15)	2.47 (2.58)	0.05 (0.05)	1.36 (1.47)	1.06 (1.06)
Efficiency [%]		60.7	1.0	0.0	20.0	0.9

Neutrino flux prediction w/CERN NA61

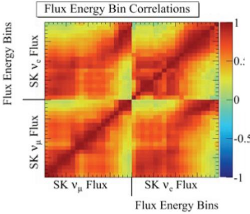


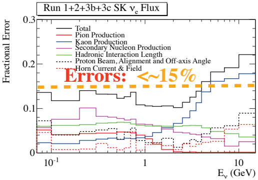
ν_μ, ν_e, anti-ν_μ, anti-ν_e energy dependent errors with full correlations @SK and @ND280 are taken in the FIT!





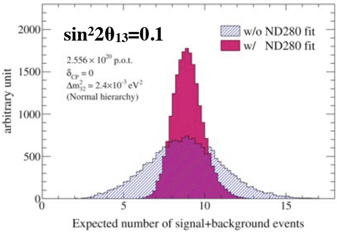
ν_μ and ν_e Flux Energy Correlations

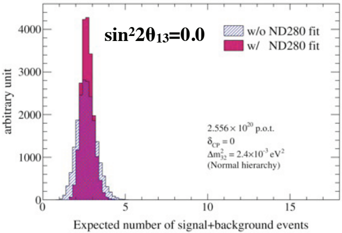




Errors: 10~15%

Event Prediction





#Events prediction

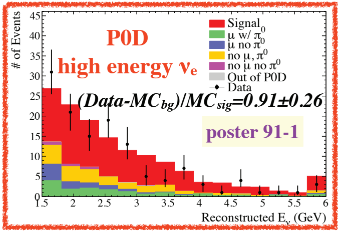
	$\sin^2 2\theta_{13}=0.1$	$\sin^2 2\theta_{13}=0.0$
Total	**9.07±0.93**	**2.73±0.37**
ν_e signal	6.60	0.15
ν_e background (beam org.)	1.32	1.42
ν_μ background (~NCπ^0)	1.02	1.02
anti-ν background	0.13	0.14

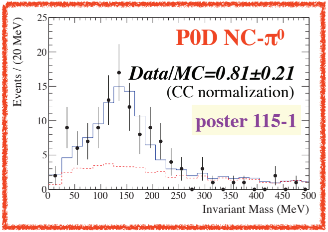
Systematic Errors

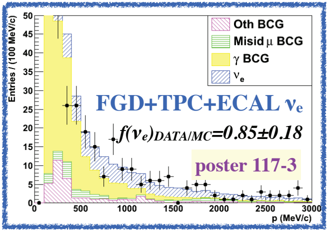
	$\sin^2 2\theta_{13}=0.1$	$\sin^2 2\theta_{13}=0.0$
Flux+Xsec in T2K fit	5.7%	8.7%
Xsec (from other exp.)	7.5%	5.9%
SK + FSI	3.9%	7.7%
Total	**10.3%**	**13.4%**

Big improvement from the 2011 result:
~18%($\sin^2 2\theta_{13}$=0.1) ~23% ($\sin^2 2\theta_{13}$=0.0)

Close Detector cross checks







- Dominant backgrounds for Electron Neutrino Appearance are measured in ND280.
- Measurements of both CC-ν_e and NC-π^0 are consistent with the MC prediction.

- ***Check the background events at ND280 for ν_e appearance.***

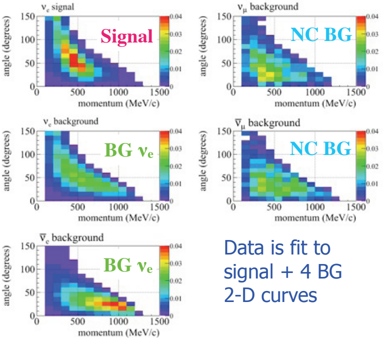
Oscillation Analysis FIT (3 methods)

$$\mathcal{L}(N_{obs.}, \boldsymbol{x}, \boldsymbol{o}, \boldsymbol{f}) = \mathcal{L}_{norm}(N_{obs.}; \boldsymbol{o}, \boldsymbol{f}) \times \mathcal{L}_{shape}(\boldsymbol{x}; \boldsymbol{o}, \boldsymbol{f}) \times \mathcal{L}_{syst.}(\boldsymbol{f})$$

measurements, **oscillation parameters** **systematic parameters**

- **Method-1**: Maximum likelihood Fit w/ **Rate + (p_e, θ_e)**
- **Method-2**: Maximum likelihood Fit w/ **Rate + reconstructed E_ν**
- **Method-3**: **Feldman&Cousins** for Rate only

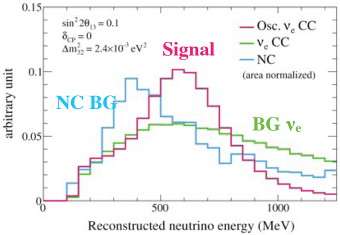
Method-1



Data is fit to signal + 4 BG 2-D curves

$$E^{rec} = \frac{m_p^2 - (m_n - E_b)^2 - m_e^2 + 2(m_n - E_b)E_e}{2(m_n - E_b - E_e + p_e \cos\theta_e)}$$

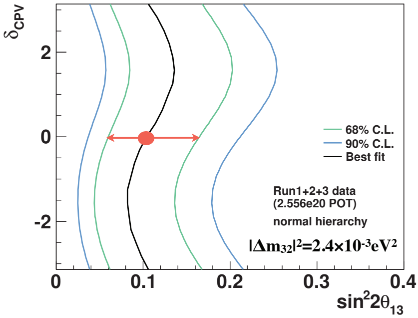
Method-2



Data is fit to signal + 2 BG 1-D curves

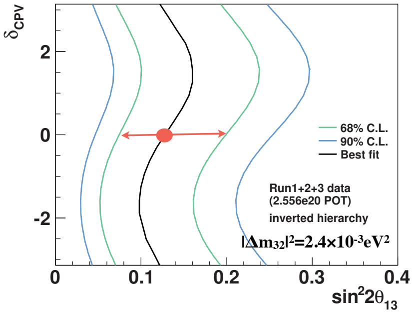
Final Results: ν_e appearance evidence at 3.2 σ

normal hierarchy



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

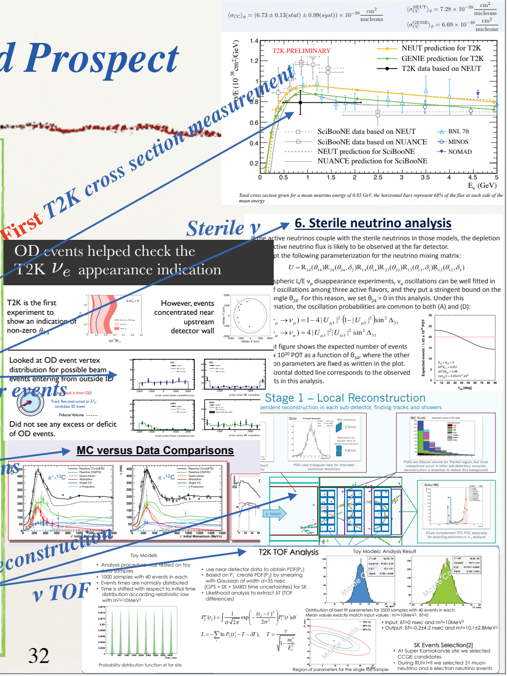
inverted hierarchy



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

7. More T2K results and Prospect

82 - 1	An Optical Transition Radiation Monitor for the T2K Proton Beam Line
83 - 2	Measurement of Pion and Kaon production cross sections with NA61/SHINE for T2K
84 - 3	Hadron Production Measurements with the T2K Replica Target in NA61/SHINE for the T2K Neutrino Flux Prediction
85 - 1	Performance of the Muon Monitor in the T2K Experiment
86 - 2	Improvement and recent status of the beam monitoring with T2K neutrino beam monitor INGRID
87 - 3	Measurement of the flux averaged Inclusive Charged Current cross-section
90 - 3	First Muon-Neutrino Disappearance Study with the T2K Off-Axis Beam
91 - 1	Measurement of the ν_e Component of T2K's ν_μ Beam in the ND280 P0D
92 - 2	Sterile neutrino search at T2K using NC nuclear de-excitation gamma-rays
93 - 3	Outer Detector Events at T2K
94 - 1	T2K ν_e appearance analysis using energy spectrum
95 - 2	Recent Result of numu disappearance analysis in T2K experiment
115 - 1	Measurement of NC1π^0 production using the ND280 P0D
116 - 2	Pion Final State Interactions in NEUT
117 - 3	Measurement of the ν_e flux of T2K's beam in the tracker of ND280
118 - 1	Measurement of CC inclusive cross-section on Iron in a few GeV neutrino beam at the T2K
119 - 2	Constraining neutrino interaction parameters in T2K using MiniBooNE data
120 - 3	Measurement of the Muon Neutrino Spectrum at the T2K Near Detector
160 - 1	T2K neutrino time of flight study
162 - 3	Reconstruction in the ND280 at T2K



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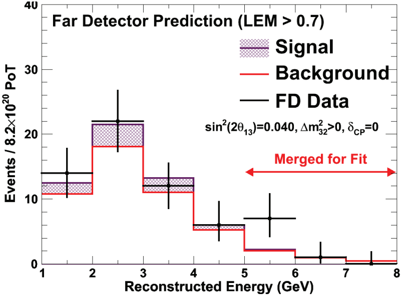
T2K Prospect

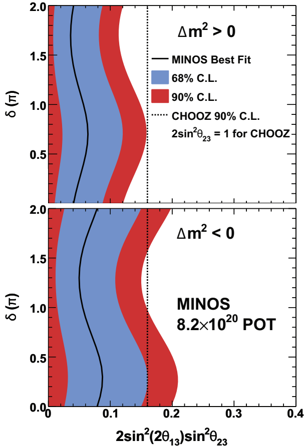
- Results from data collected by June 2012 are expected soon.
- Update on results from ν_μ disappearance coming shortly: T2K can significantly improve the precision on the atmospheric parameters, to a level where sub-leading terms become detectable.
- Collected data expected to increase with new runs at higher beam power: $8 \cdot 10^{20}$ p.o.t. (2013) $\Rightarrow$ $12 \cdot 10^{20}$ p.o.t. (2014) $\Rightarrow$ $18 \cdot 10^{20}$ p.o.t. (2015)
- More precise measurements of $P(\nu_\mu \rightarrow \nu_e)$: a tool to assess sub-leading effects such as CP violation, matter effects (mass hierarchy), possible new physics manifesting from ν_e appearance.

MINOS, PRL 107 (2011) 181802

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

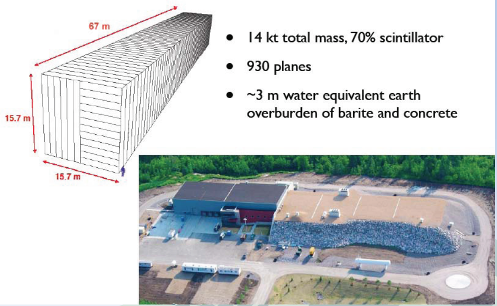


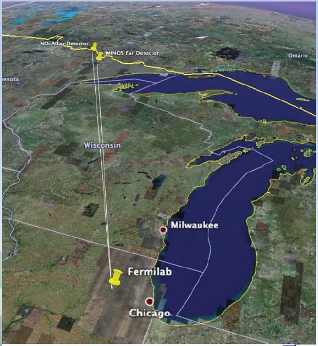
	MINOS	T2K
pot	8.2 10^{20}	1.45 10^{20}
tjoule	1.57	0.07
tjoule kton	7.85	1.57



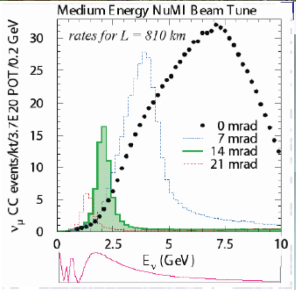
Year	pot	Expected	Detected
2009	3.1 10^{20}	27	35
2010	7.0 10^{20}	49	54
2011	8.2 10^{20}	49	62

NOvA





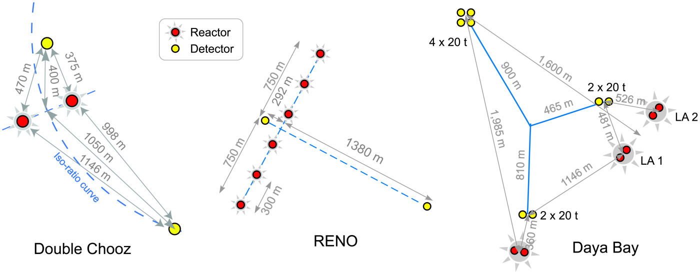
- FNAL NuMI off-axis beam
- Power upgrade 320kW→700kW
  - Recycler: anti-proton → proton
  - Rep cycle 2.2s → 1.33s
- New 14kton liquid scintillator fine grained detector @810km
- Far detector will complete and start taking data in 2014



7

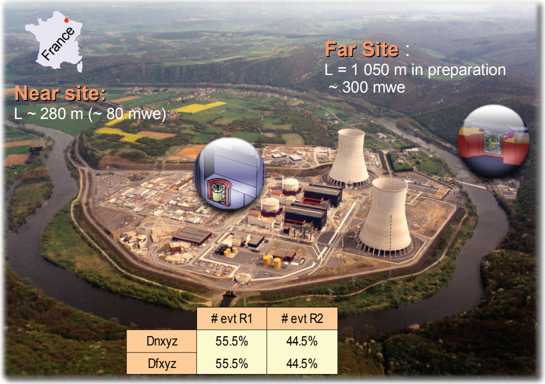
The three reactor players

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



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

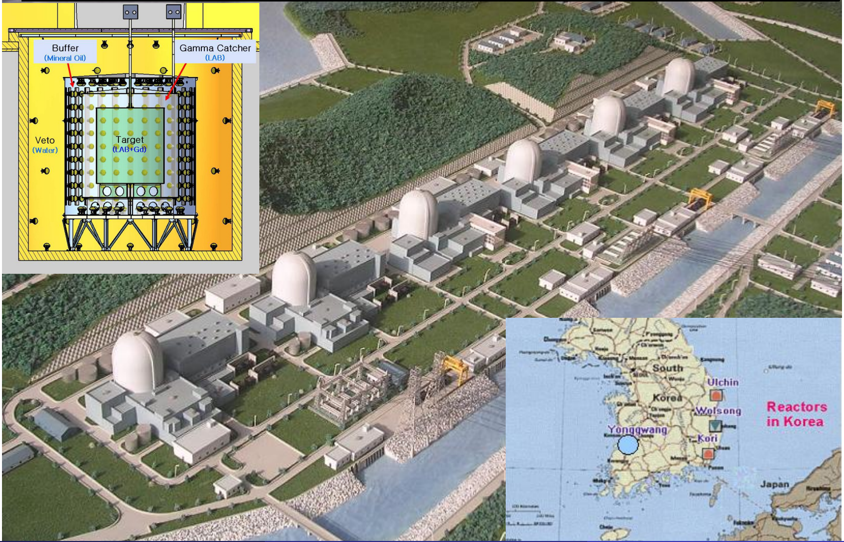
- σ_{b2b} at far site: ~ 1%
- σ_{b2b} at near site: ~ 0.5%

Planning

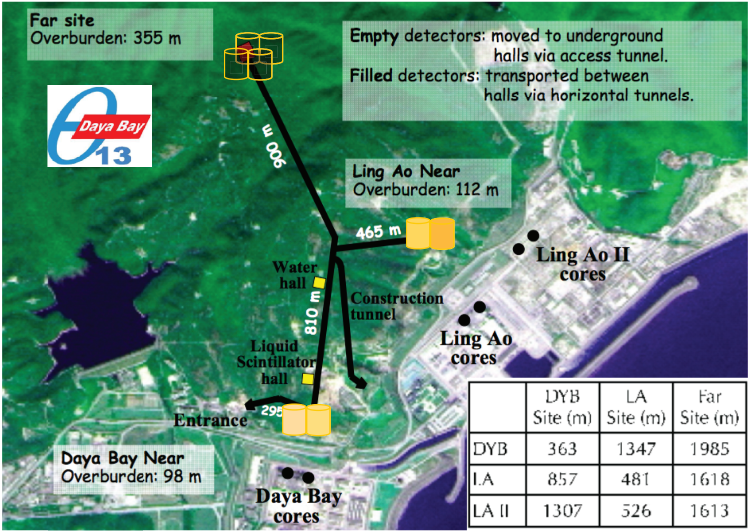
1. Far detector only
   - Sensitivity (1.5 ans) ~ 0.06
2. Far + Near sites
   - available from 2010
   - Sensitivity (3 years) ~ 0.025

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$

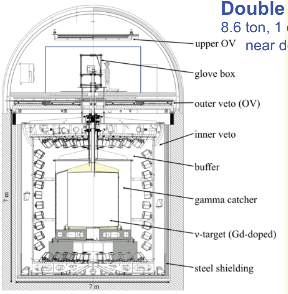


Daya Bay

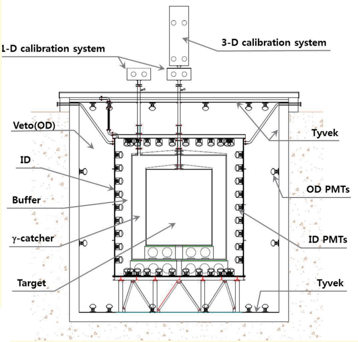


	DYB Site (m)	LA Site (m)	Far Site (m)
DYB	363	1347	1985
LA	857	481	1618
LA II	1307	526	1613

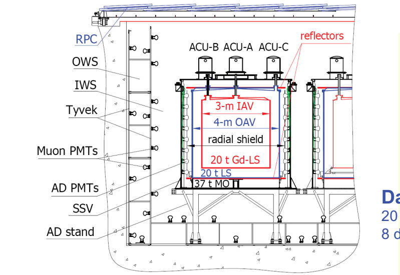
Reactor detectors



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)

θ_{13} is large!

with SBL data:

$$\sin^2\theta_{13} = 0.022^{+0.0033}_{-0.0030}$$
$$\sin^2 2\theta_{13} = 0.086 \pm 0.012$$
$$\theta_{13} = (8.5^{+0.62}_{-0.61})^\circ$$

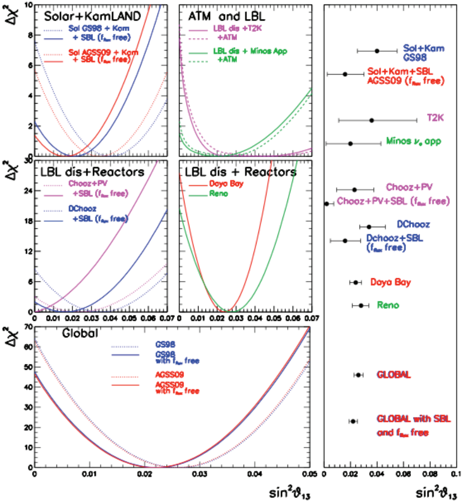
6.9σ significance

without SBL data using 2011 flux pred.:

$$\sin^2\theta_{13} = 0.026^{+0.0034}_{-0.0032}$$
$$\sin^2 2\theta_{13} = 0.101^{+0.013}_{-0.012}$$
$$\theta_{13} = (9.3 \pm 0.59)^\circ$$

8.0σ significance

Gonzalez-Garcia, Maltoni, Salvado, TS, in prep.



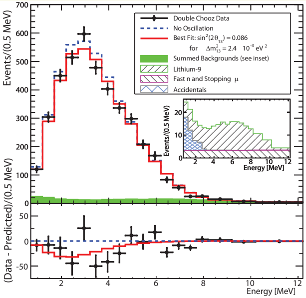
T. Schwetz

2

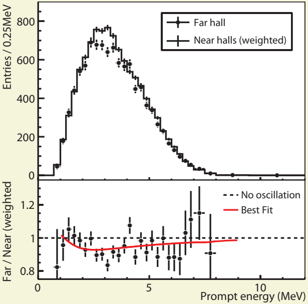
Spectral information

Not used in the fit so far by DB and RENO

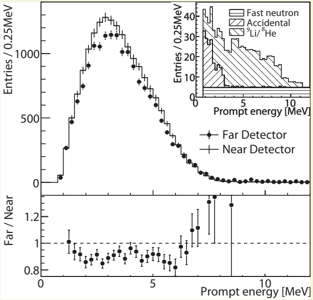
Double Chooz



Daya Bay

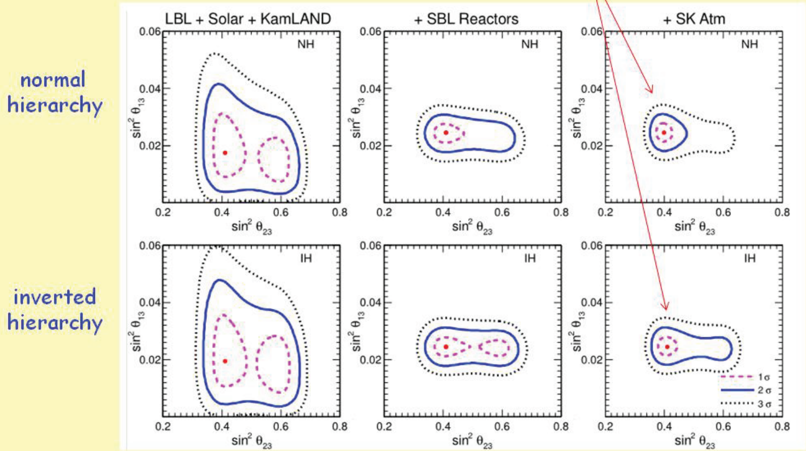


RENO



Global fits are providing stimulating insights

Adding SK atm data: the preference for θ_{23} in the 1st octant is corroborated



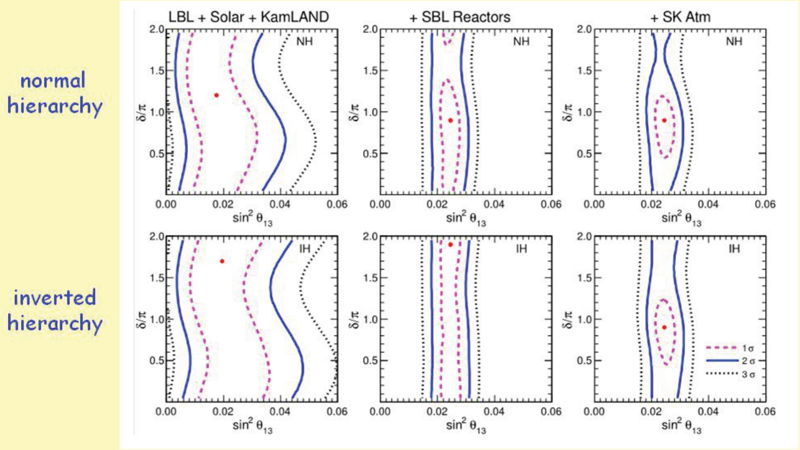
Gianluigi Fogli

νTURN 2012, Laboratori Nazionali del Gran Sasso, May 9, 2012

24

Global fits are providing stimulating insights

Adding SK atmospheric data:



We find a ~ 1σ preference for θ ~ π as in the early analysis of hep-ph/0506083.

Necessary conditions to have LCPV detectable

The third necessary condition has just been fulfilled !

ν_μ-ν_e oscillations in a 3 ν scheme

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

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

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

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

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

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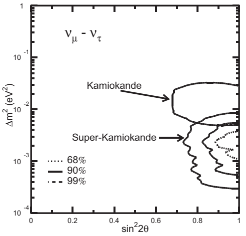
SK, PRL 81(1998) 1562 (3558 citations)



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

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

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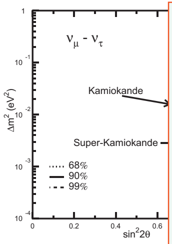
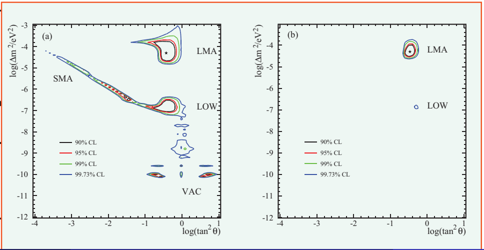


SNO, PRL 89 (2002) 011302 (1934 citations)



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

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

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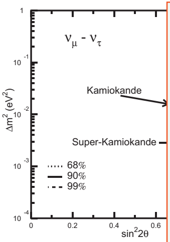
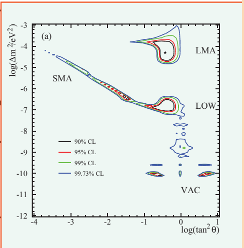
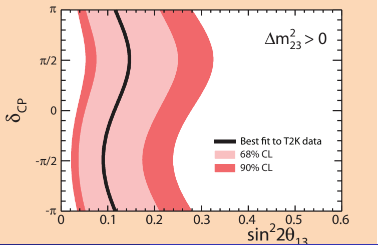


SNO, PRL 89 (2002) 01

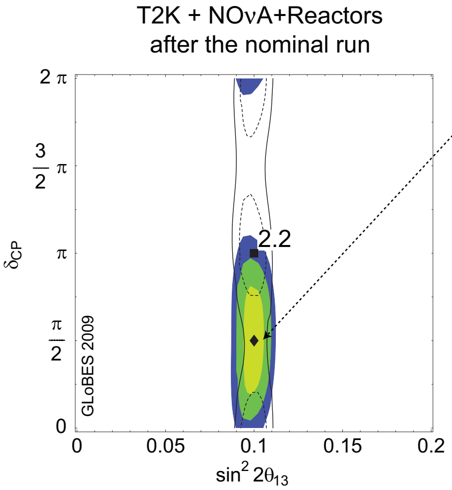


T2K, arXiv:1106.2822



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}

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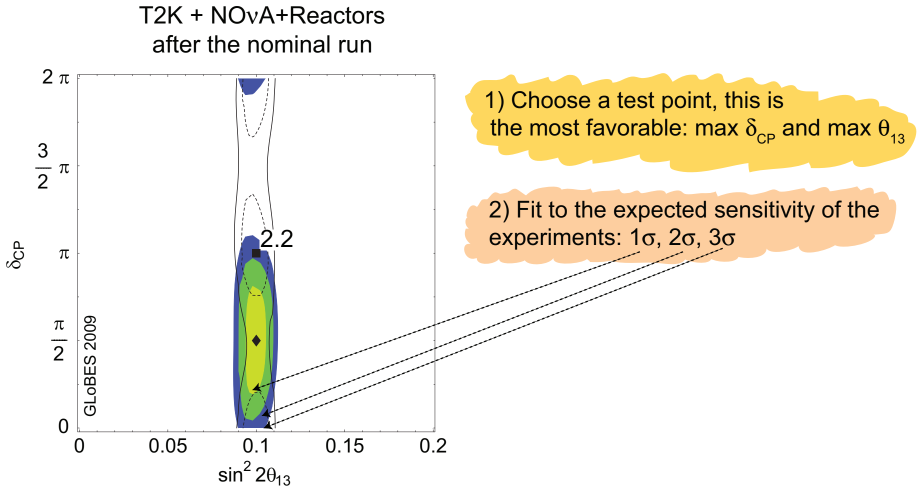

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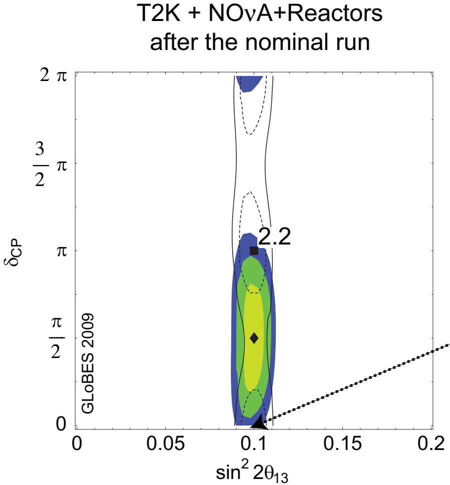


1) Choose a test point, this is the most favorable: max δ_{CP} and max θ_{13}

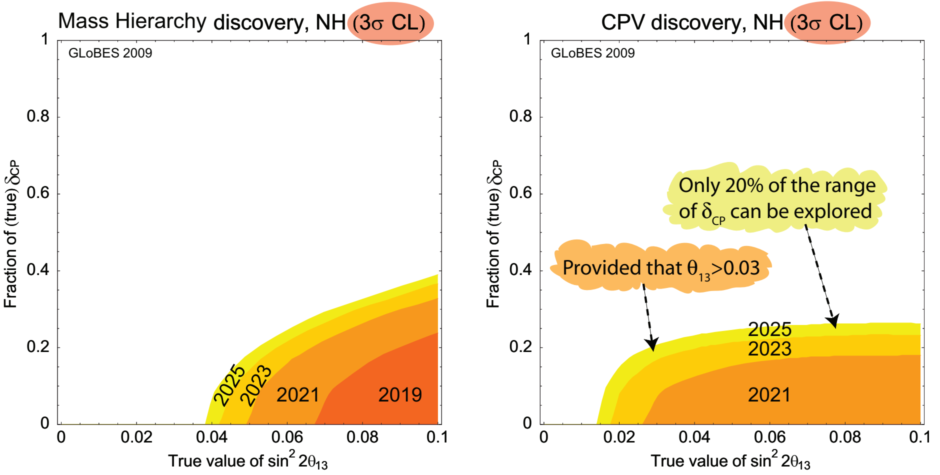
2) Fit to the expected sensitivity of the experiments: 1σ, 2σ, 3σ

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

Status after accelerator upgrades

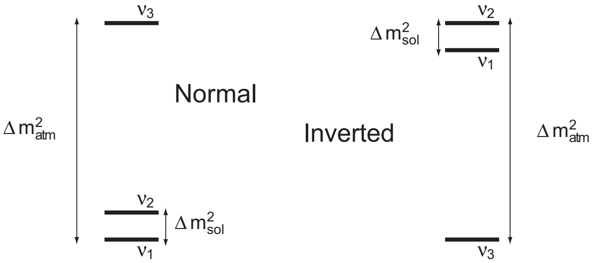
From P. Huber et al., JHEP 0911:044,2009.

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}).

INO (Identifying the Neutrino mass Ordering)

How does the global situation improve if atmospheric data from the India-based Neutrino Observatory (INO) is combined with NOvA+T2K+reactors? Blennow, TS, 1203.3388

- *INO starts 2017 with 50kt or 100kt*
- *muon threshold of 2 GeV*
- *zenith angle region -1 < cosθ < -0.1*
- *~230 (neutrino+antineutrino) events per 50 kt yr (no osc)*
- *for energy and direction reconstruction consider "low" (15%, 15°) and "high" (10%, 10°) resolution scenario*
- *assume $\sin^2 2\theta_{13} = 0.09 \pm 0.017$*

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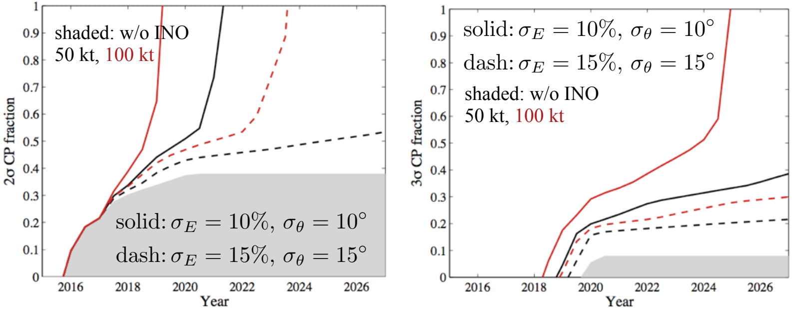
INO (Identifying the Neutrino mass Ordering)

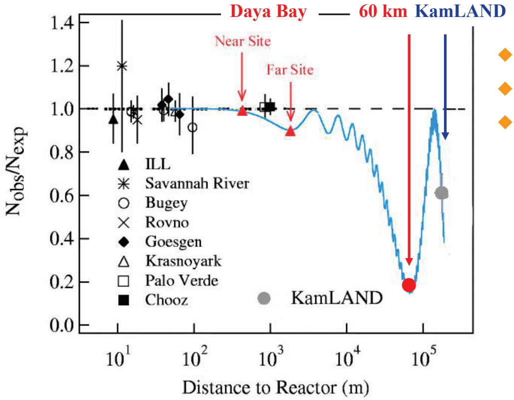


Blennow, TS, 1203.3388

T. Schwetz

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**

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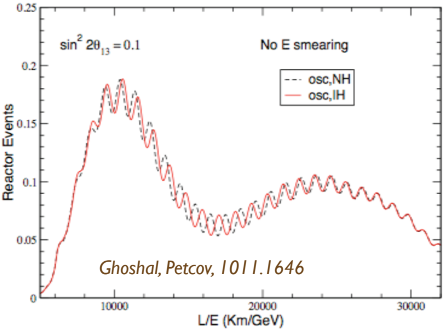
Hierarchy from a reactor experiment

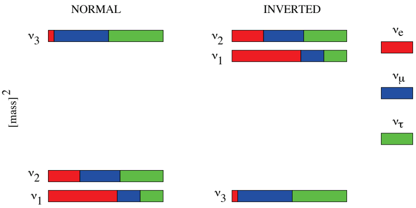
Petcov, Piai, hep-ph/0112074

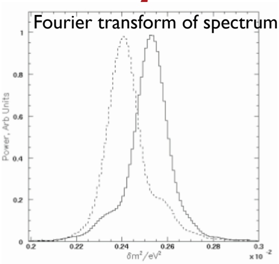
$$\overline{P}(\overline{\nu}_e \rightarrow \overline{\nu}_e) = 1 - \frac{1}{2}\sin^2 2\theta_{13}\left[1 - \left(c_{12}^2 \cos 2\Delta_{31} + s_{12}^2 \cos 2\Delta_{32}\right)\right] - \sin^2 2\theta_{12} c_{13}^4 \sin^2 \Delta_{21}$$



Daya Bay II

Hierarchy from a reactor experiment





Learned, Dye, Pakvasa, Svoboda, 06
Zhan, Wang, Cao, Wen, 08

- *there are two large frequencies: Δm^2_{31} and Δm^2_{32}*
- *θ_{12} is non-maximal and we know the sign of Δm^2_{21}*
- *for NH (IH) the larger (smaller) frequency dominates*

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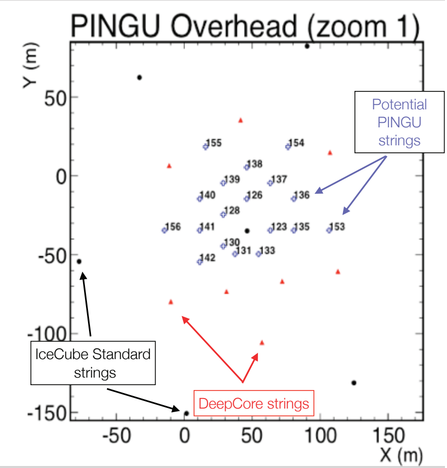
PINGU: Possible Geometry

- IceCube
- DeepCore
- **Beyond DeepCore**

- Add 18-20 strings into DeepCore volume
- One of many possible geometries
- R & D for future water/ice cerenkov detectors



The mass hierarchy from the ice?

IceCube → DeepCore → ***PINGU***

- *~20 additional strings within DeepCore*
- *lower threshold to few GeV*
- *~10 Mt effective volume*
- *construction within 1 yr, ~$25 M*

Doug Cowen, NuSky, ICTP, June 2011

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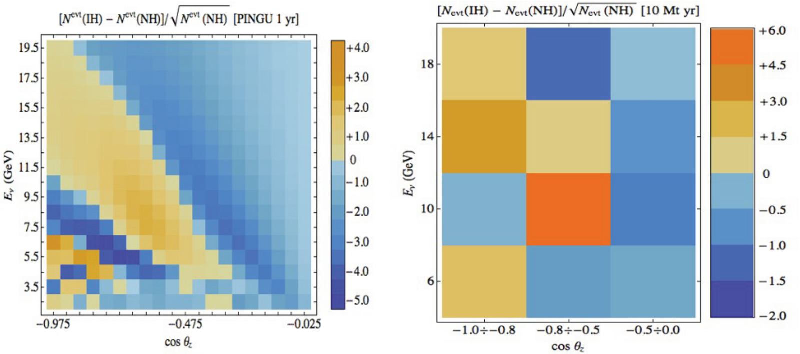
Mass hierarchy from PINGU



Akhmedov, Razzaque, Smirnov, in prep.

T. Schwetz

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Neutrino Oscillations in Matter

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

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

Matter effects require long “long baselines"

$$P_{\theta_{13}} = \sin^2(2\theta_{13})\sin\theta_{23}{}^2\sin^2((\hat{A}-1)\hat{\Delta})/(\hat{A}-1)^2;$$
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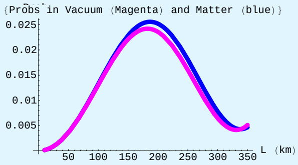
Matter effects require long "long baselines"
$\boldsymbol{E_\nu = 0.35\mathrm{GeV}\ L \simeq 130\ \mathrm{km}}$



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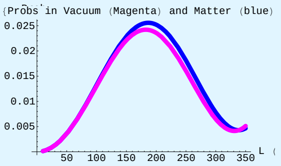
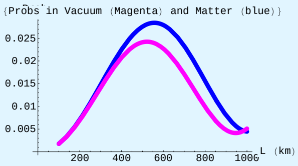
The $\hat{A}$ term changes sign with $\mathrm{sign}(\Delta m^2_{13})$

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**





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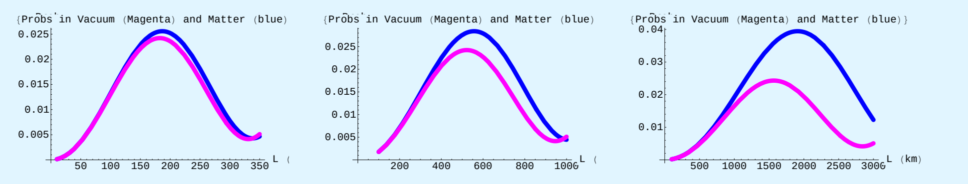
$\boldsymbol{\hat{A} = \pm a/\Delta m^2_{31}}$; $a = 7.6 \cdot 10^{-5} \rho \cdot E_\nu(GeV)$ $\rho = \text{matter density } (\mathrm{g\,cm^{-3}})$

The $\hat{A}$ term changes sign with $\mathrm{sign}(\Delta m^2_{13})$

Matter effects require long "long baselines"

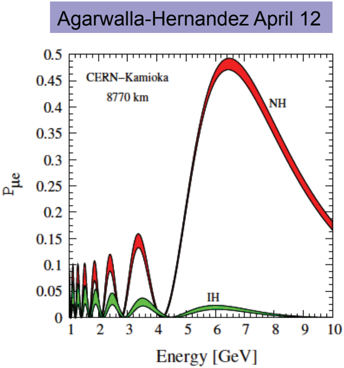
$\boldsymbol{E_\nu = 0.35\mathrm{GeV}\ L \simeq 130}$ **km** $\boldsymbol{E_\nu = 1\mathrm{GeV}\ L \simeq 500}$ **km** $\boldsymbol{E_\nu = 3\mathrm{GeV}\ L \simeq 1500}$ **km**

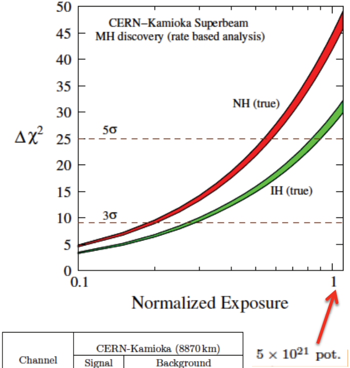


SPS to SK

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)



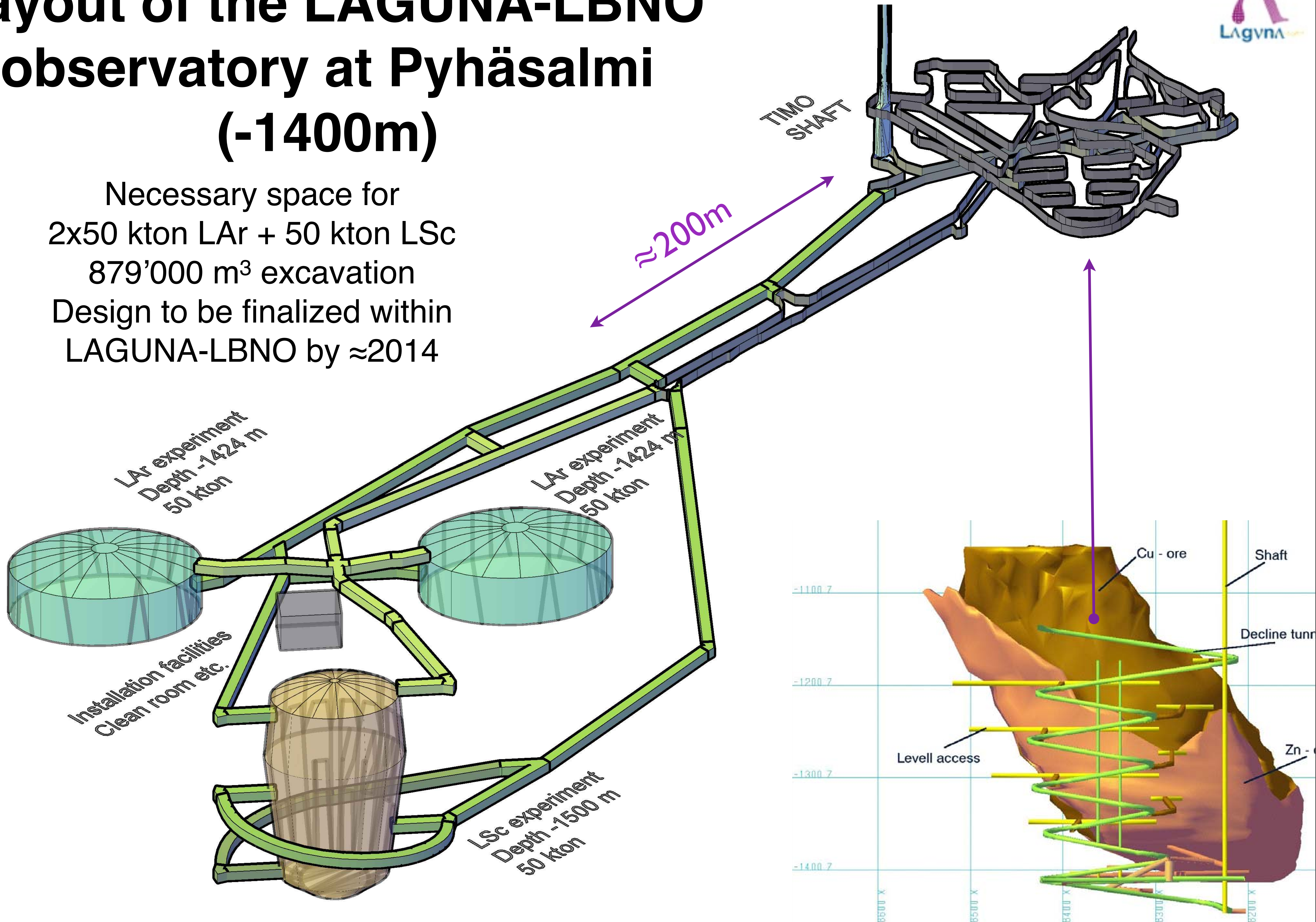


Channel	CERN-Kamioka (8870 km) Signal CC-1 ring	Background Int+Mis-id+NC = Total
$\nu_\mu \to \nu_e$ (NH)	**44**	1+2+16=**19**
$\nu_\mu \to \nu_e$ (IH)	**2**	1+3+16=**20**
$\nu_\mu \to \nu_\mu$ (NH)	**83**	**2**
$\nu_\mu \to \nu_\mu$ (IH)	**91**	**2**

May 8-10, 2012 NuTURN@

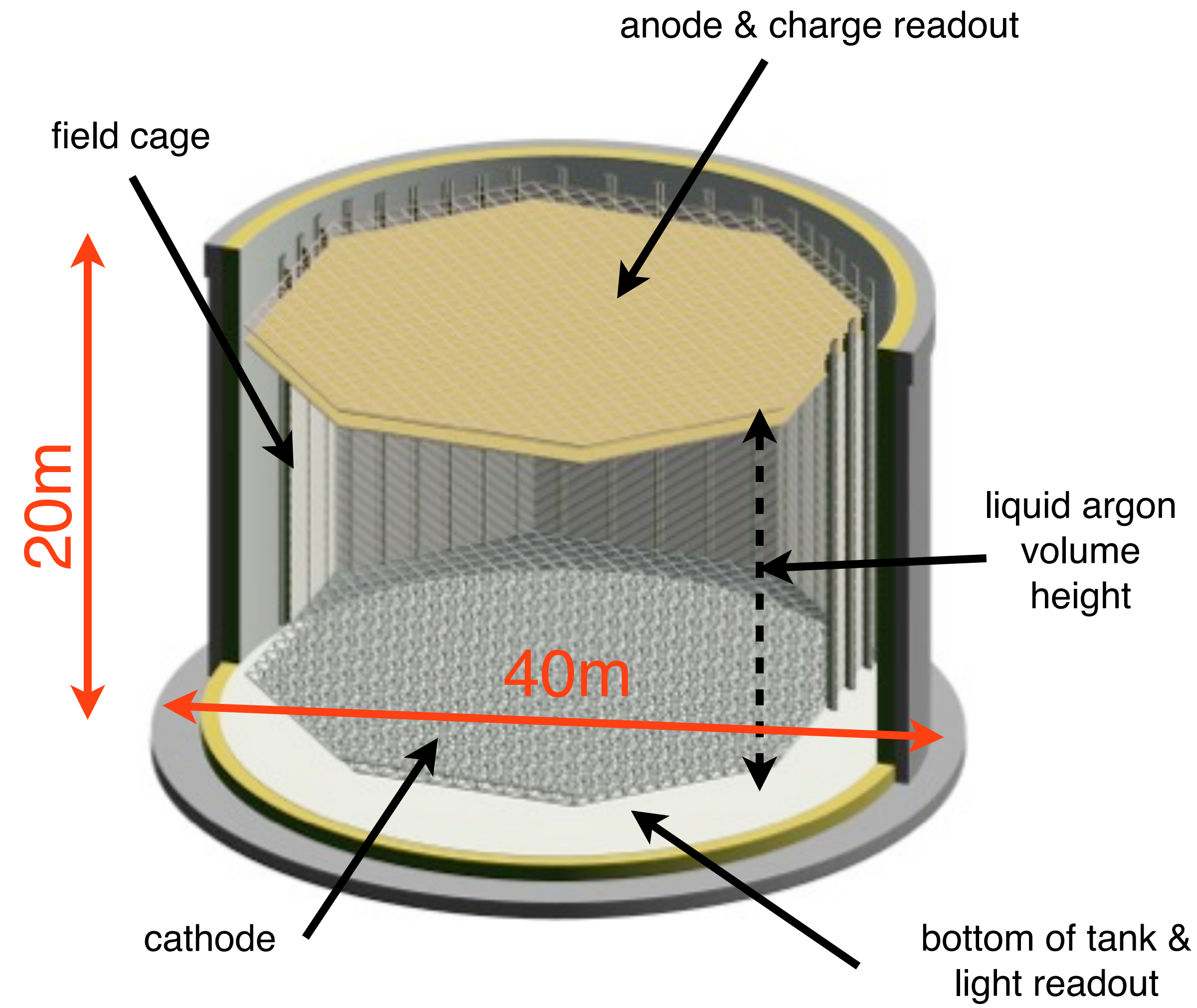
Layout of the LAGUNA-LBNO observatory at Pyhäsalmi (-1400m)

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

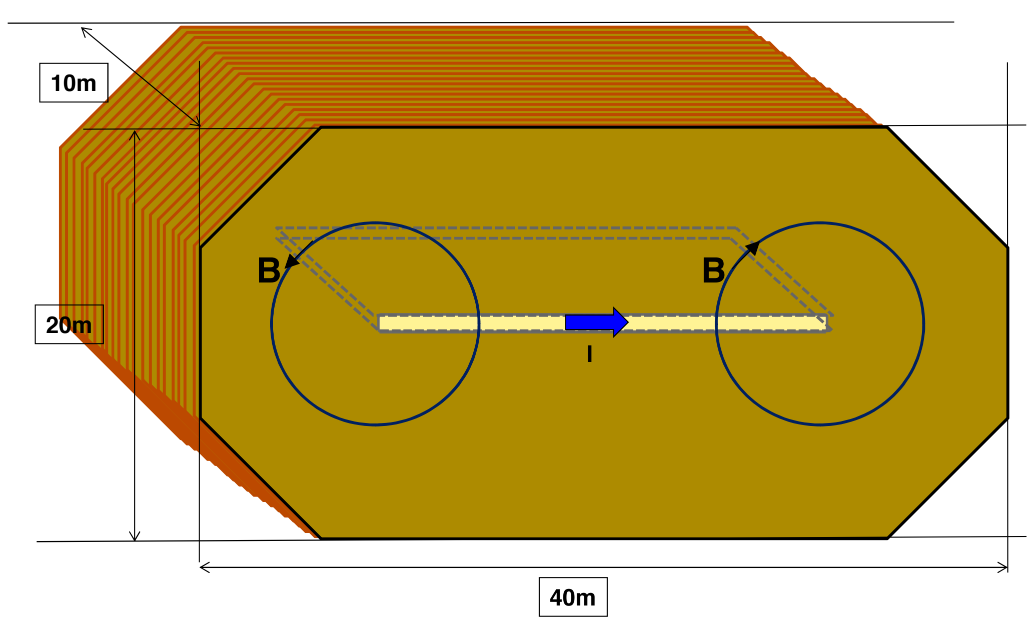


Far underground detectors

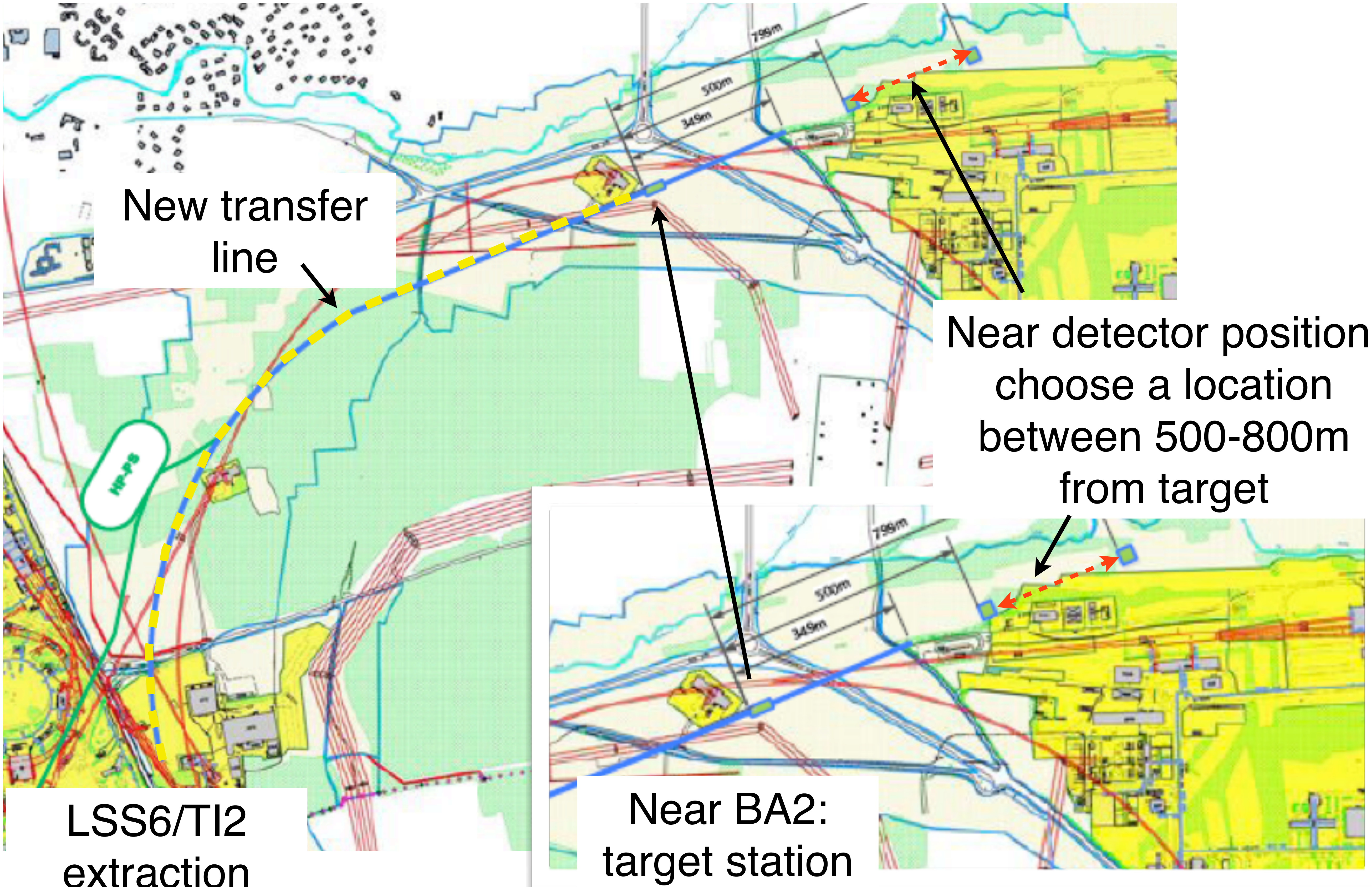
- **20 kton double phase LAr LEM TPC (GLACIER): best detector for electron appearance measurements with excellent energy resolution and small systematic errors**
  - Exclusive final states, low energy threshold on all particles
  - Excellent ν energy resolution and reconstruction ability from sub GeV 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

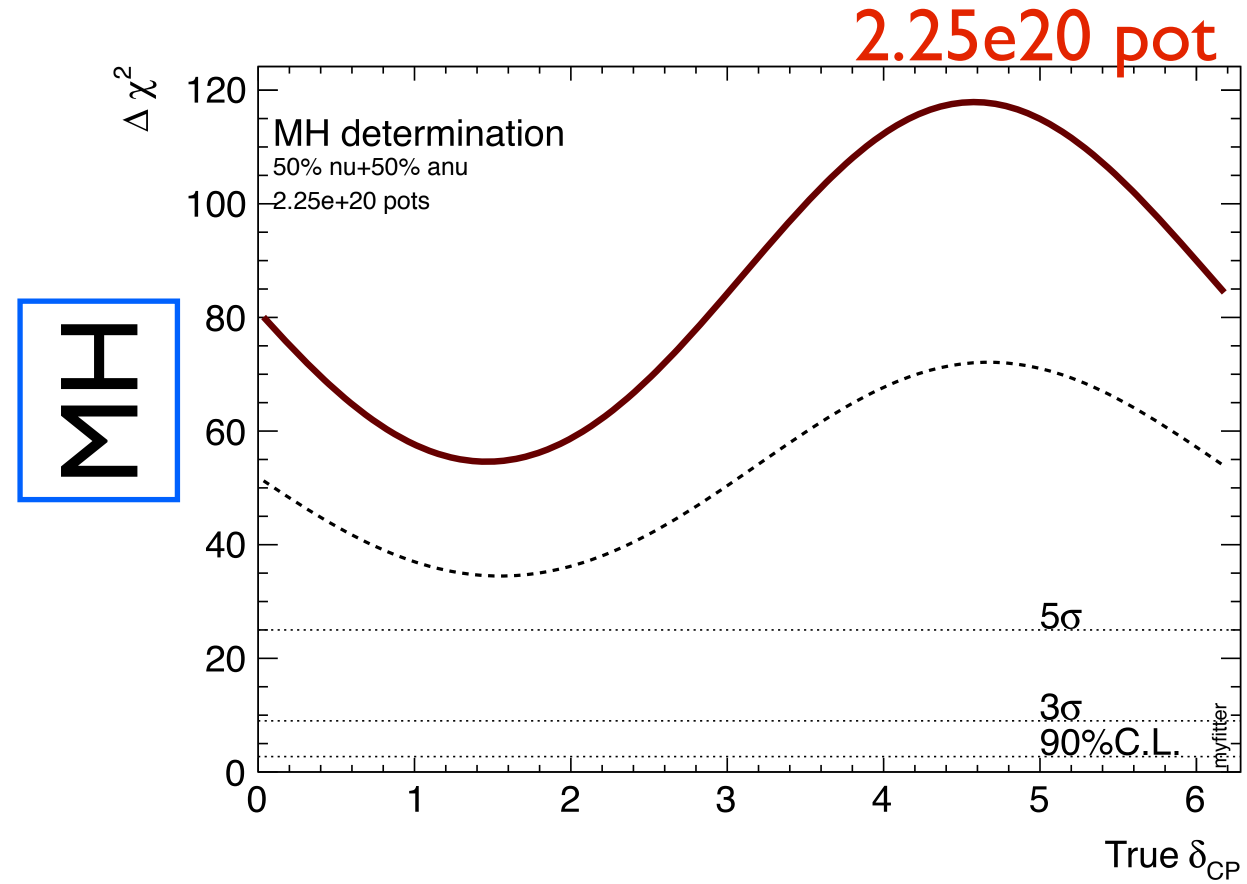


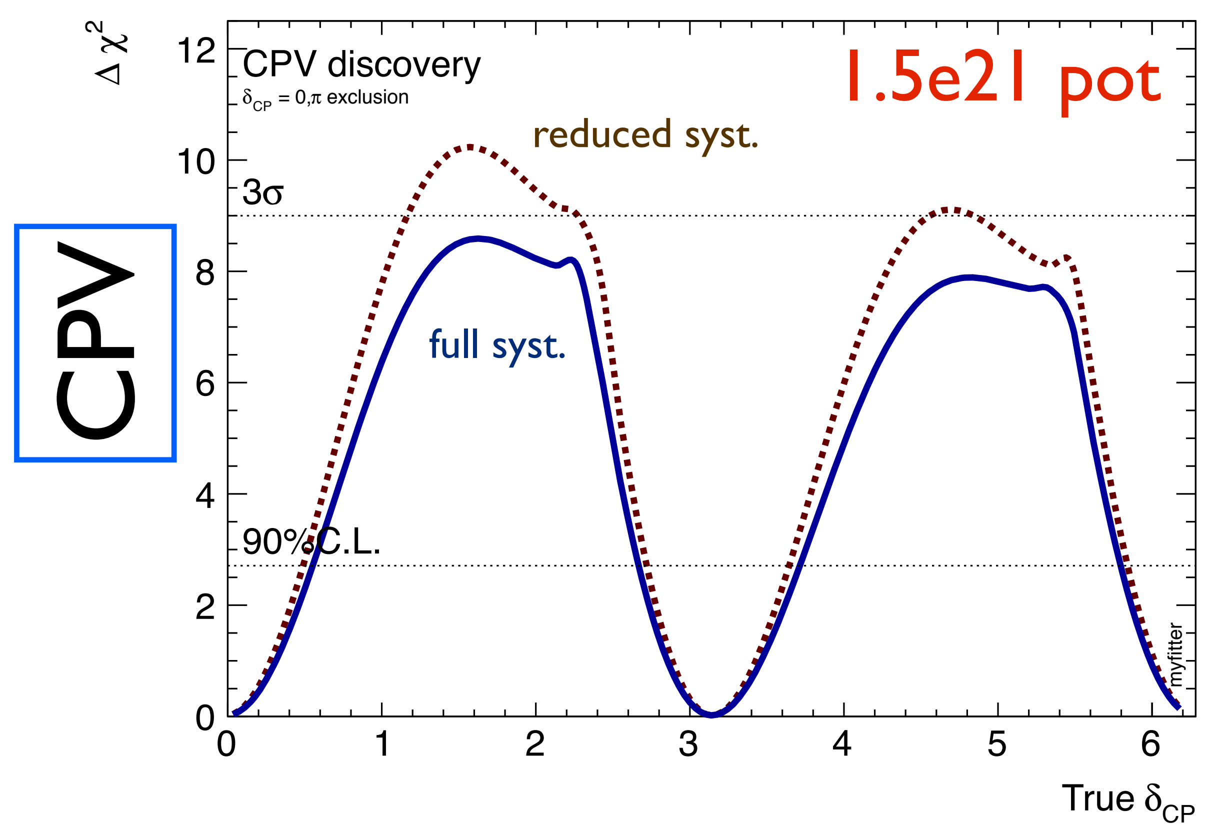
Detailed view of CN2PY layout : Option A



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.





Milestones - Timescale

LAGUNA Design Study funded for site studies:	**2008-2011**
Categorize the sites and down-select:	**Sept. 2010**
Start of LAGUNA-LBNO	**2011**
Submission of LBNO EoI to CERN	**2012**
End of LAGUNA-LBNO DS: technical designs, layouts, liquids handling&storage, safety, ...	**2014**
Critical decision	**2015 ?**
Excavation-construction (incremental):	**2016-2021 ?**
Phase 1 LBL physics start:	**2023 ?**
Phase 2 incremental step implementation:	**>2025 ?**

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 $\leq 2\ \sigma$	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).

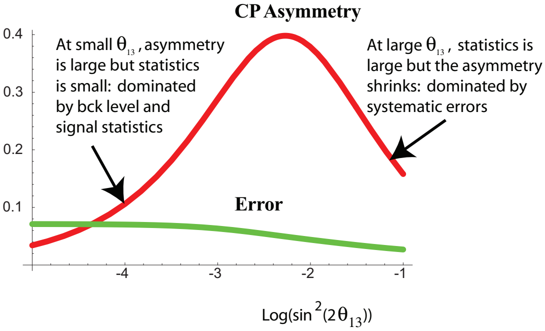
Achim Stahl – RWTH Aachen University

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

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

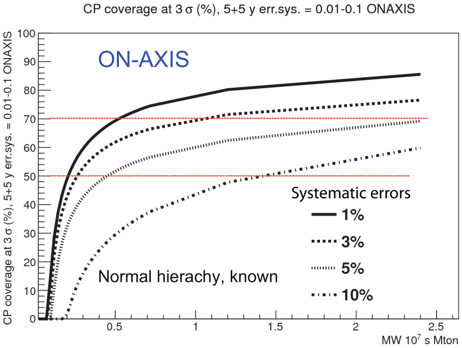
Signal statistics is maximum BUT $\nu - \overline{\nu}$ asymmetry is minimum
In other terms systematic errors dominate

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

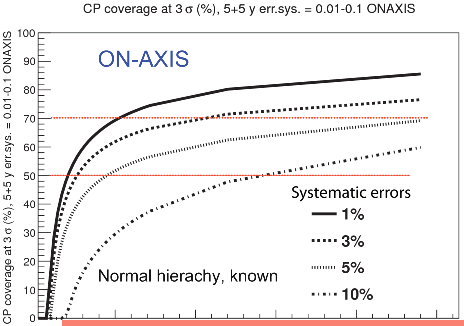


From A. Longhin talk at nuTurn 2012

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



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	/

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?

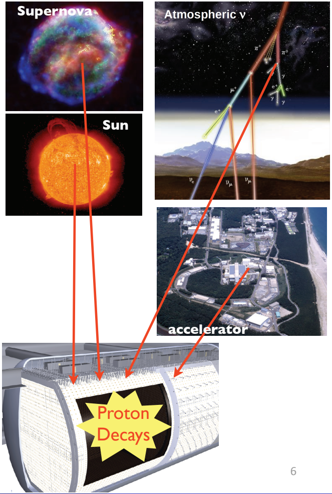
Any comparison of different facilities at fixed systematic error is meaningless

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

Hyper-K WG,
arXiv:1109.3262 [hep-ex]

Multi-purpose detector, Hyper-K

- Total (fiducial) volume is 1 (0.56) million ton
  - 25 × Super-K
- Explore full picture of neutrino oscillation parameters.
  - Discovery of leptonic CP violation (Dirac δ)
  - ν mass hierarchy determination(Δm^2_{32}>0 or <0)
  - θ_{23} octant determination ($\theta_{23}<\pi/4$ or $>\pi/4$)
- Extend nucleon decay search sensitivity
  - $\tau_{proton}=10^{34}\sim10^{35}$ years
- Neutrinos from astrophysical objects
  - 200 ν's / day from Sun
  - 250,000 (50) ν's from Supernova @Galactic-center (Andromeda)
  - 830 ν's / 10 years Supernova relic ν
  - WIMP ν, solar flare ν, etc



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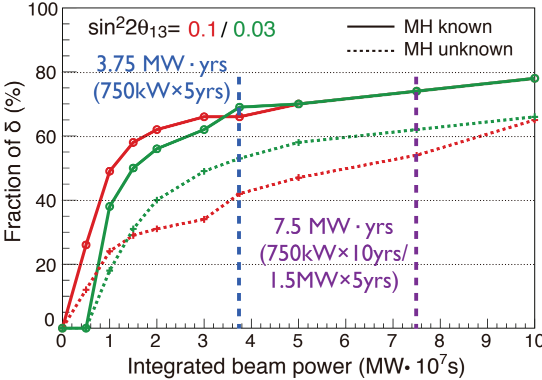
Fraction of δ (%) for CPV discovery

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

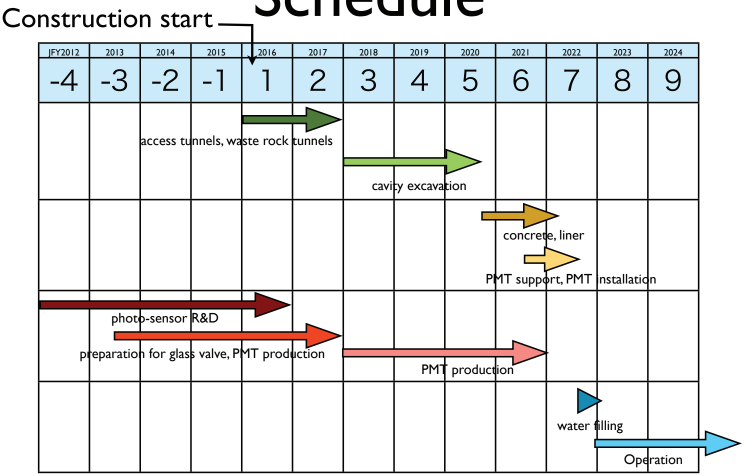


$\sin^2 2\theta_{13}=0.1$

(MW× yrs)	Mass hierarchy known	Mass hierarchy 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

Schedule



assuming budget being approved from JPY2016

The "Modular" approach

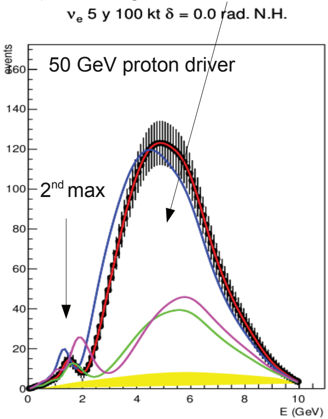
- The most naïve design would assume a single (may be ≈100 kton) LAr container of a huge size. But the dimensions of most events under study (beam-ν, cosmic ray-ν, proton decays) are of much smaller dimensions.
- For instance, the whole volume of ultra-pure LAr will be totally contaminated even by a 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

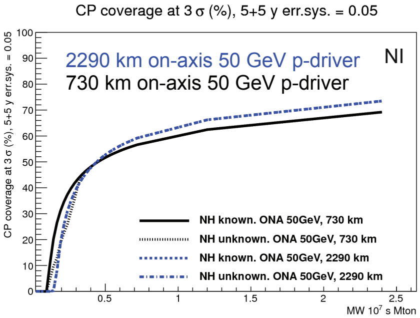
- Based on the long experience with ICARUS and a firm cooperation with industries in the realization of the detectors, a relatively firm estimate of the costs may be given.
- The cost, including contingencies, based on the above list of items 1-7 is as follows:
  - Engineering design and prefabrication 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

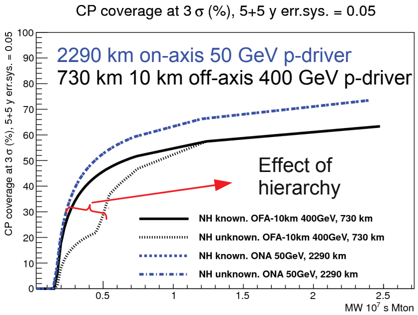
2290 ↔ 730 km

- 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

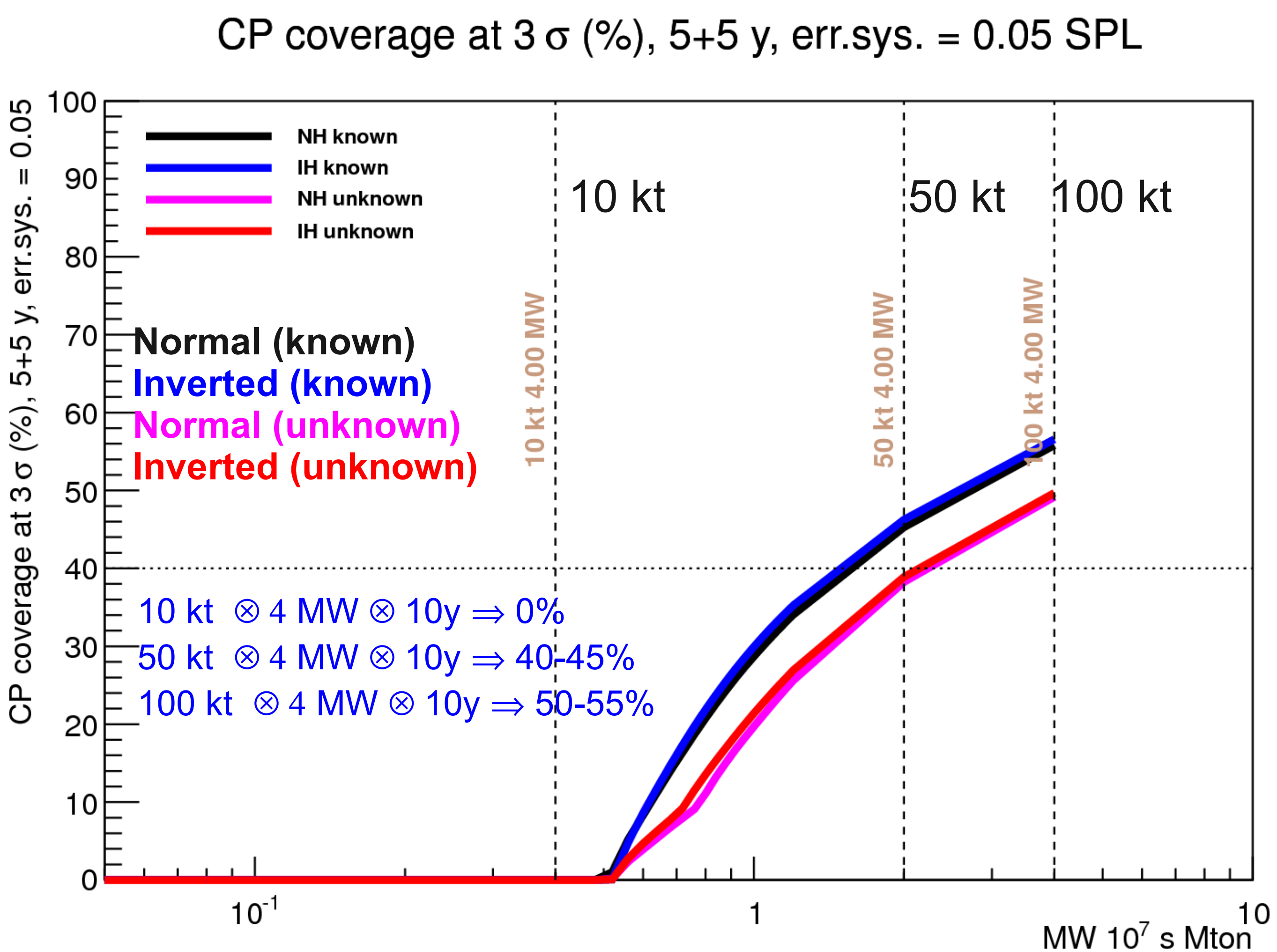
Exercise: low-E + short baseline (~100 km) ?

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



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

Conclusions (not the last slide)

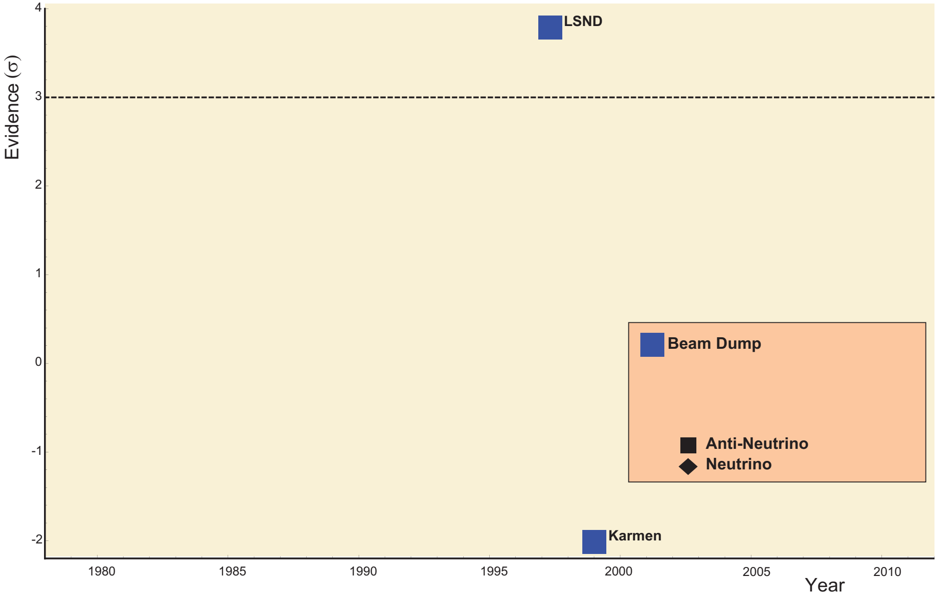
The measurement of θ_{13} solves one of the few question marks still left in the standard model. Among the many fondamental consequences, it opens the door to future long-baseline neutrino experiments addressing leptonic CP violation.

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

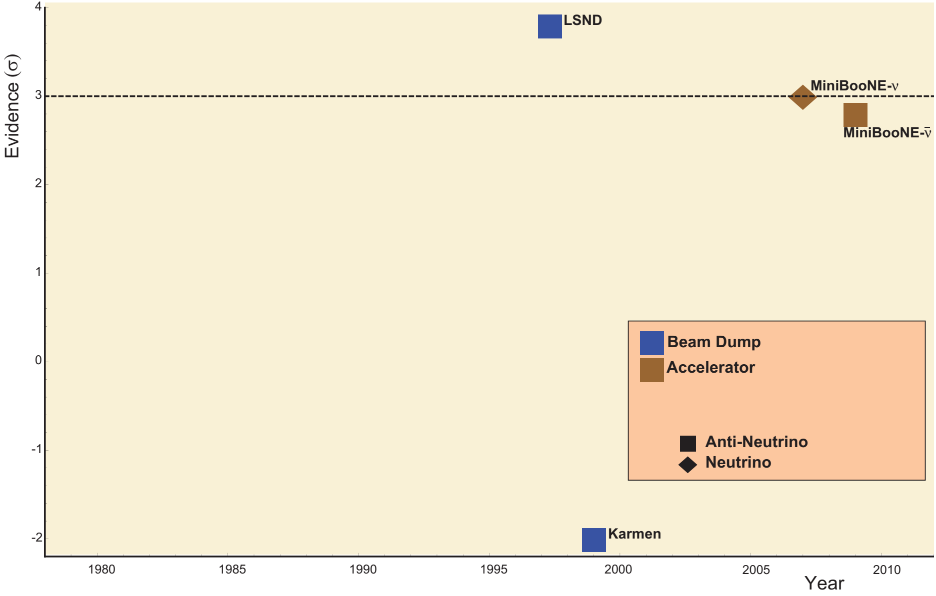
Leptonic CP violation, measurable only at accelerators, will require challenging experimental improvements. The optimization of future facilities is now possible by knowing the θ_{13} value.

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

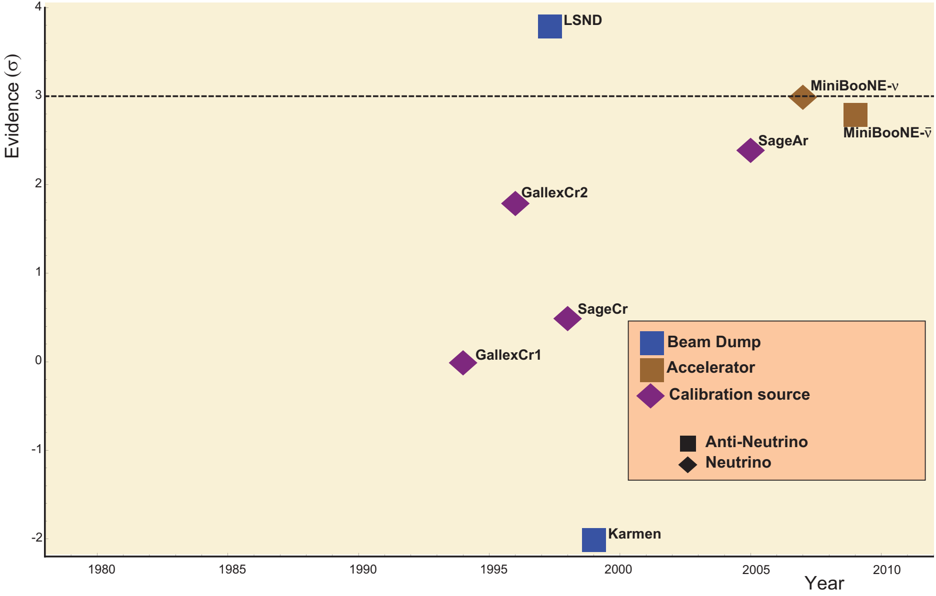
A long standing set of anomalies



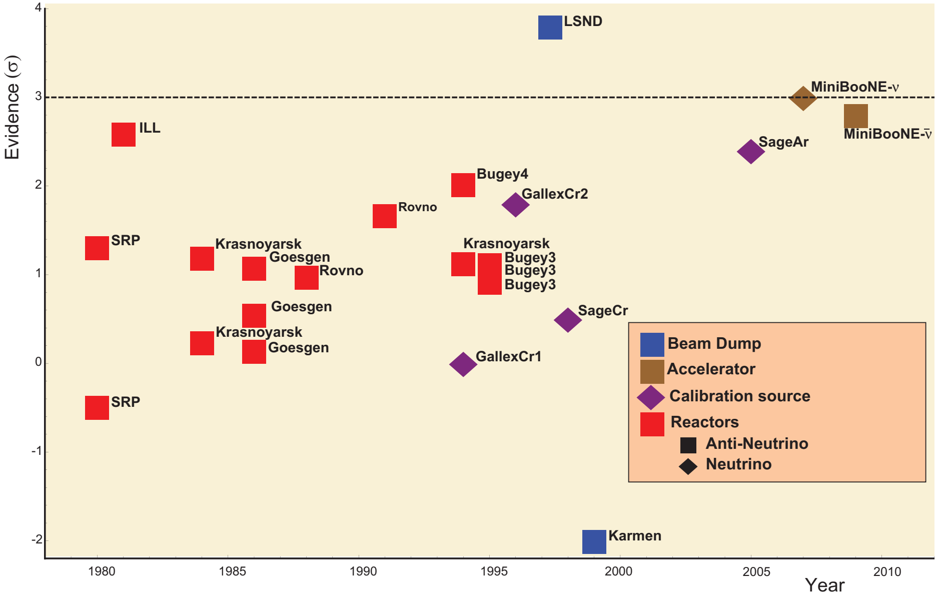
A long standing set of anomalies



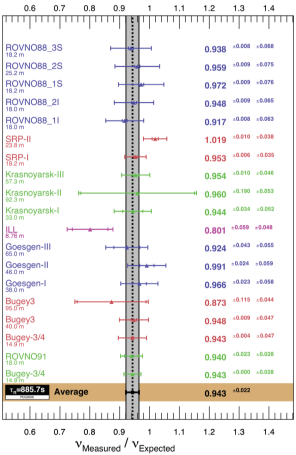
A long standing set of anomalies



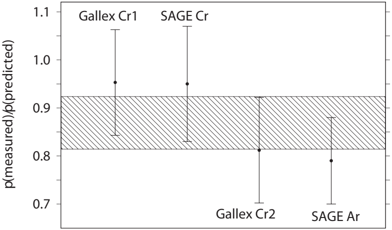
A long standing set of anomalies



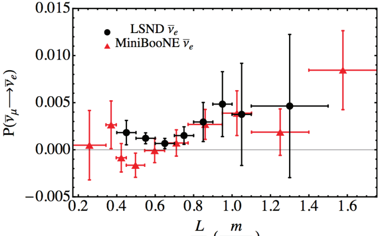
Reactors



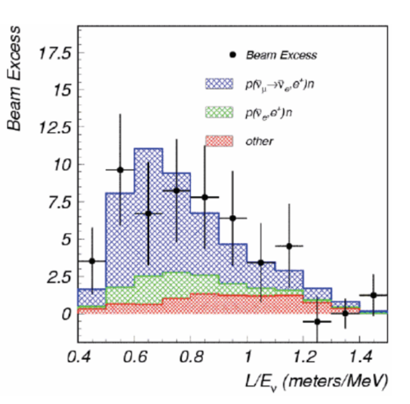
Sources



Accelerators



The LSND Result



•$\bar{\nu}_e$ candidate excess:
87.9 ± 22.4 ± 6.0 (3.8σ)

•If interpreted as oscillations:
$P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e) = (0.264 \pm 0.067 \pm 0.045)\%$

PRD 64, 112007 (2001)

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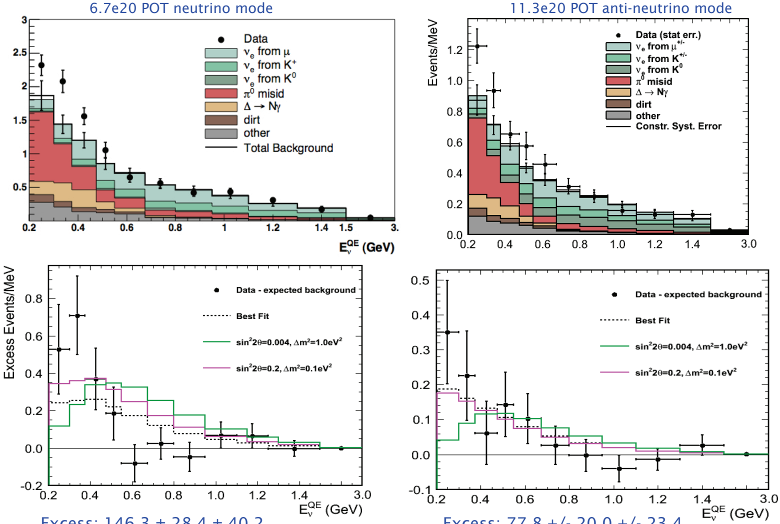
The MiniBooNE result

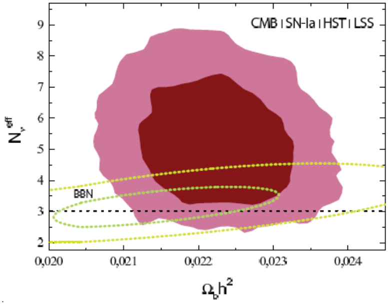
From M. Sorel talk at Beyond3nu

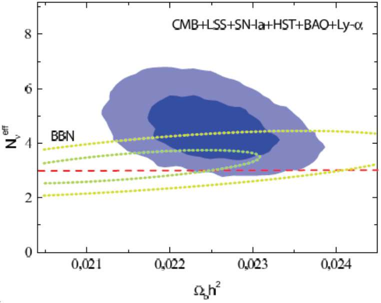


Excess: 146.3 ± 28.4 ± 40.2

Excess: 77.8 +/- 20.0 +/- 23.4

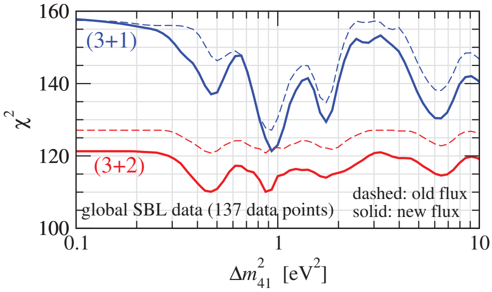
Hints for sterile neutrinos from cosmology ?





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

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

No evidence of steriles whatsoever

- Steriles are not necessary to build up $\nu_\mu \to \nu_e$ transitions or ν_e disappearance
- They are invoked to accommodate a fourth δm^2 faking the LEP limit on three neutrinos.

Experimental Goals

- Bring anomalies to evidences or get rid of them definitely.
- Demonstrate they are **sterile neutrinos**.
- Confirm the model
  - New neutrinos **are more than one**
  - **CP is violated.**
  - alternatively: NSI (non standard neutrino interactions), CPT violation, quantum decoherence . . . ..

The signature of Steriles

The main signature of steriles is **NC disappearance**

Looked for by SuperKamiokanDE and MINOS, whose limits are going to become interesting.

Possible only at accelerators (look at $P(\nu_\mu \rightarrow \nu_\mu)$ in the following)

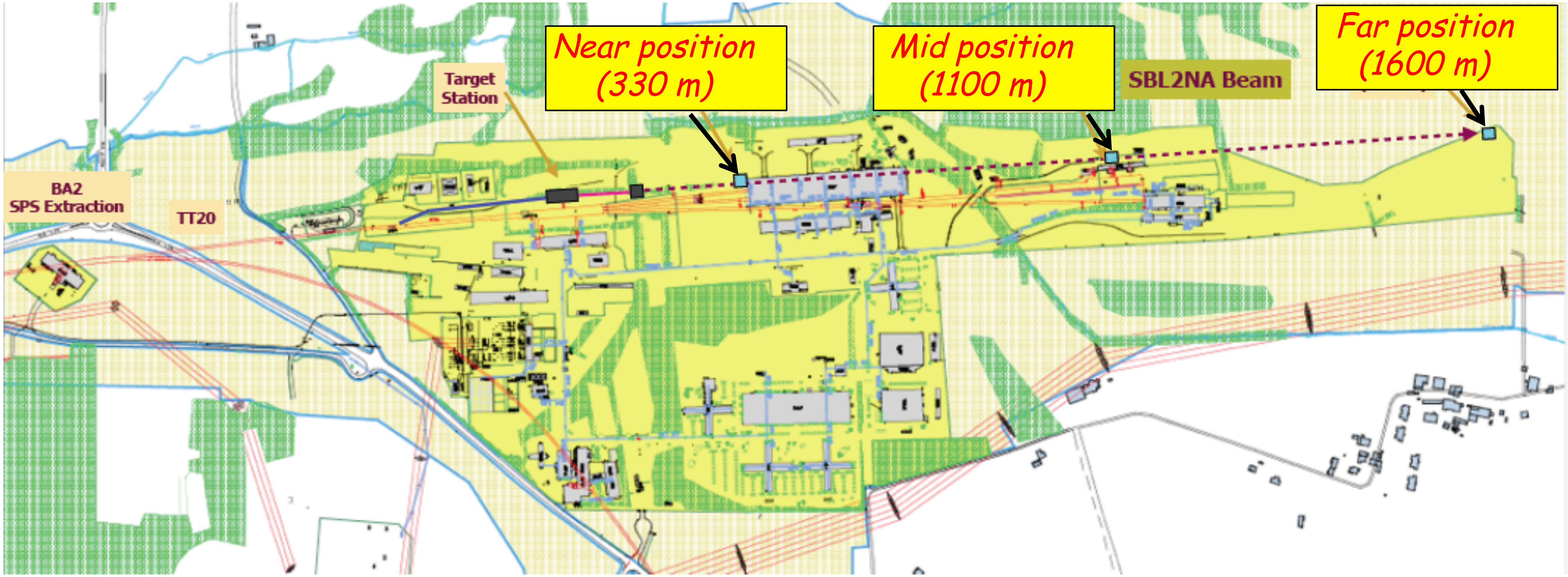
Requires a detector capable to unambiguously select no-muon events and possibly to tag some NC exclusive topologies and needs to be normalized by the ν_μ spectrum.

Mandatory to keep systematics at the 5% level or below

The ICARUS-NESSIE Collaborators

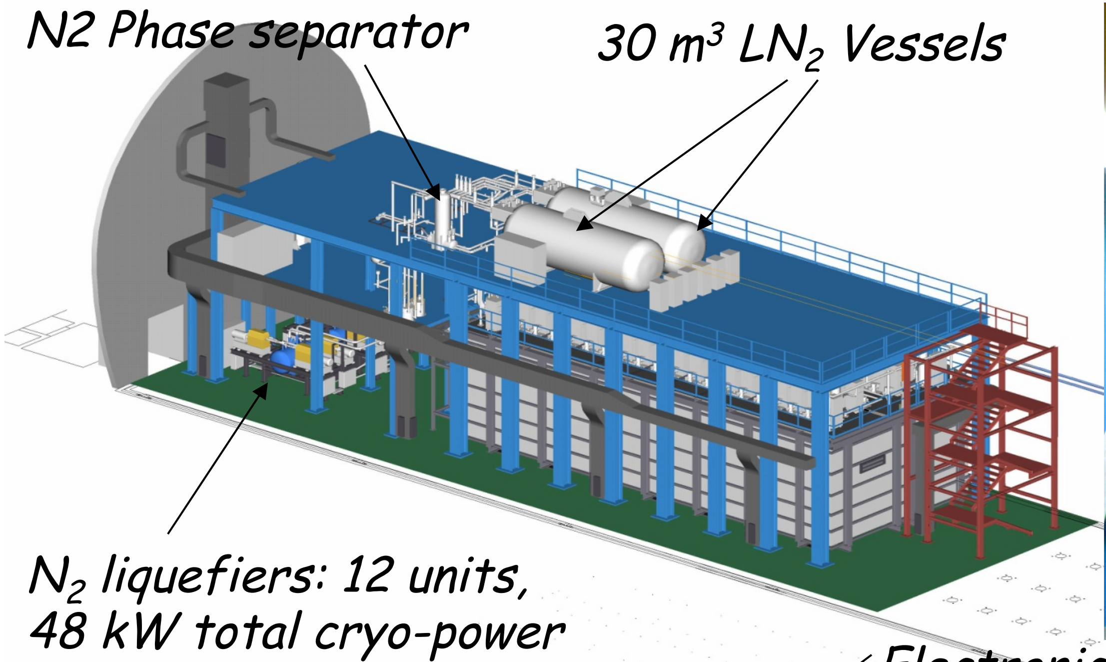
M. Antonello[1], D. Bagliani[2], B. Baibussinov[5], M. Benettoni[5], P. Bernardini[25,26], A. Bertolin[5], H. Bilokon[6], F. Boffelli[8], M. Bonesini[9], C. Bozza[31], R. Brugnera[4,5], E. Calligarich[8], N. Canci[1], A. Cecchetti[6], S. Cecchini[24], S. Centro[4,5], A. Cesana[10], K. Cieslik[11], D. B. Cline[12], A. G. Cocco[14], G. Collazuol[5,6], P. Creti[26], F. Dal Corso[5], I. De Mitri[25,26], D. Dequal[4,5], A. Dermenev[15], G. De Robertis[22], M. De Serio[22], L. Degli Esposti[24], D. Di Ferdinando[24],R. Dolfini[7,8], M. De Gerone[2,3], U. Dore[28,29], S. Dusini[5], S. Dussoni[2,3], P. Fabbricatore[3], C. Fanin[5], C. Farnese[4], A. Fava[5], A. Ferrari[16], R. A. Fini[22], G. Fiore[26], G. Fiorillo[13,14], A. Garfagnini[4,5], G. T. Garvey[17], F. Gatti[2,3], G. Giacomelli[23,24], R. Giacomelli[24], D. Gibin[4,5], S. Gninenko[15], G. Grella[30], C. Guandalini[24], F. Guber[15], M. Guerzoni[i24], A. Guglielmi[5], M. Haranczyk[11], J. Holeczek[18], A. Ivashkin[15], M. Kirsanov[15], J. Kisiel[18], I. Kochanek[18], U. Kose[5], A. Kurepin[15], J. Łagoda[19], G. Laurenti[24], M. Laveder[4,5], I. Lippi[5], F. Loddo[22], A. Longhin[6], P. Loverre[28,29], G. Lucchini[9], W. C. Louis[17], G. Mancarella[25,26], G. Mandrioli[24], S. Mania[18], G. Mannocchi[6], S. Marchini[5], A. Margiotta[23,24], G. Marsella[26,27], V. Matveev[15], N. Mauri[6], E. Medinaceli[4,5], A. Menegolli[7,8], G. Meng[5], A. Mengucci[6], M. Mezzetto[5], R. Michinelli[24], G. B. Mills[17], C. Montanari[8], M. T. Muciaccia[21,22], M. Nicoletto[5], D. Orecchini[6], S. Otwinowski[12], T. J. Palczewski[19], A. Paoloni[6], G. Passardi[16], A. Pastore[21,22], L. Patrizii[24], F. Perfetto[13,14], P. Picchi[6], F. Pietropaolo[5], P. Płoński[20], M. Pozzato[23,24], A. Rappoldi[8], G. L. Raselli[8], R. Rescigno[30], G. Rosa[28,29], M. Rossella[8], C. Rubbia[1,16], P. Sala[10], A. Scaramelli[10], E. Segreto[1], S. Simone[21,22], M. Sioli[23,24], G. Sirri[24], M. Spurio[23,24], L. Stanco[5], S. Stellacci[30], D. Stefan[1], J. Stepaniak[19], R. Sulej[19], A. Surdo[26], O. Suvorova[15], M. Tenti[23,24], M. Terrani[10], D. Tlisov[15], V. Togo[24], R. G. Van de Water[17], G. Trinchero[6], M. Turcato[5], F. Varanini[4], M. Ventura[6], S. Ventura[5], C. Vignoli[1], H. G. Wang[12], X. Yang[12], M. Zago[5], A. Zani[8] and K. Zaremba[20].

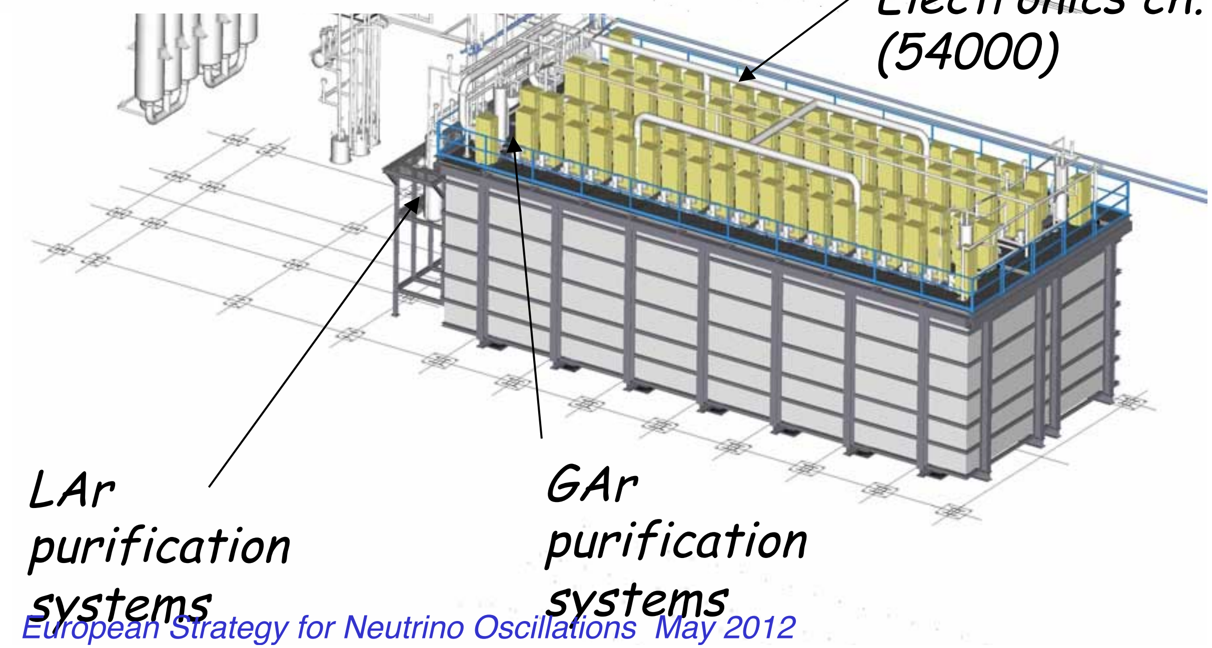
New Neutrino Facility in the CERN North Area



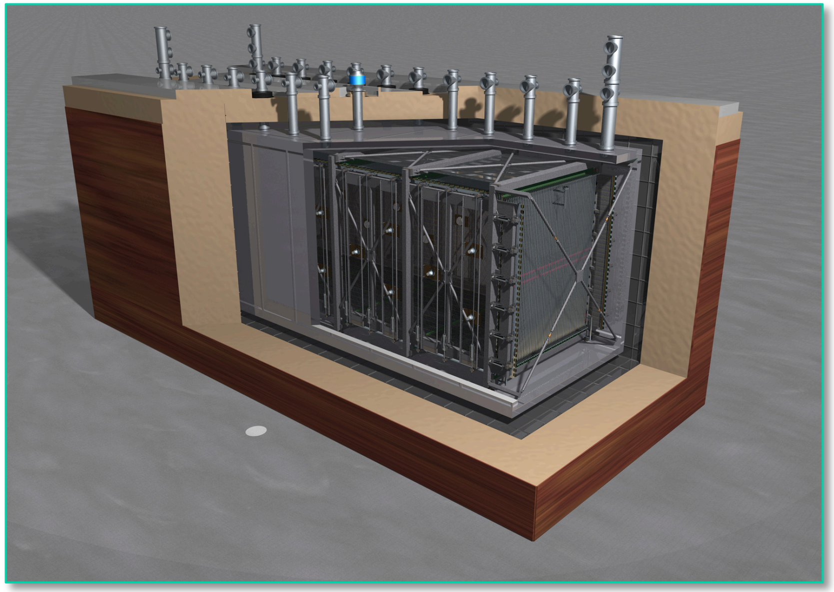
100 GeV primary beam fast extracted from SPS; target station next to TCC2; decay pipe l =100m, ø = 3m; beam dump: 15m of Fe with graphite core, followed by μ stations.
Neutrino beam angle: pointing upwards; at -3m in the far detector ~5mrad slope.

ICARUS-T600 @LNGS: 0.77 kton LAr-TPC



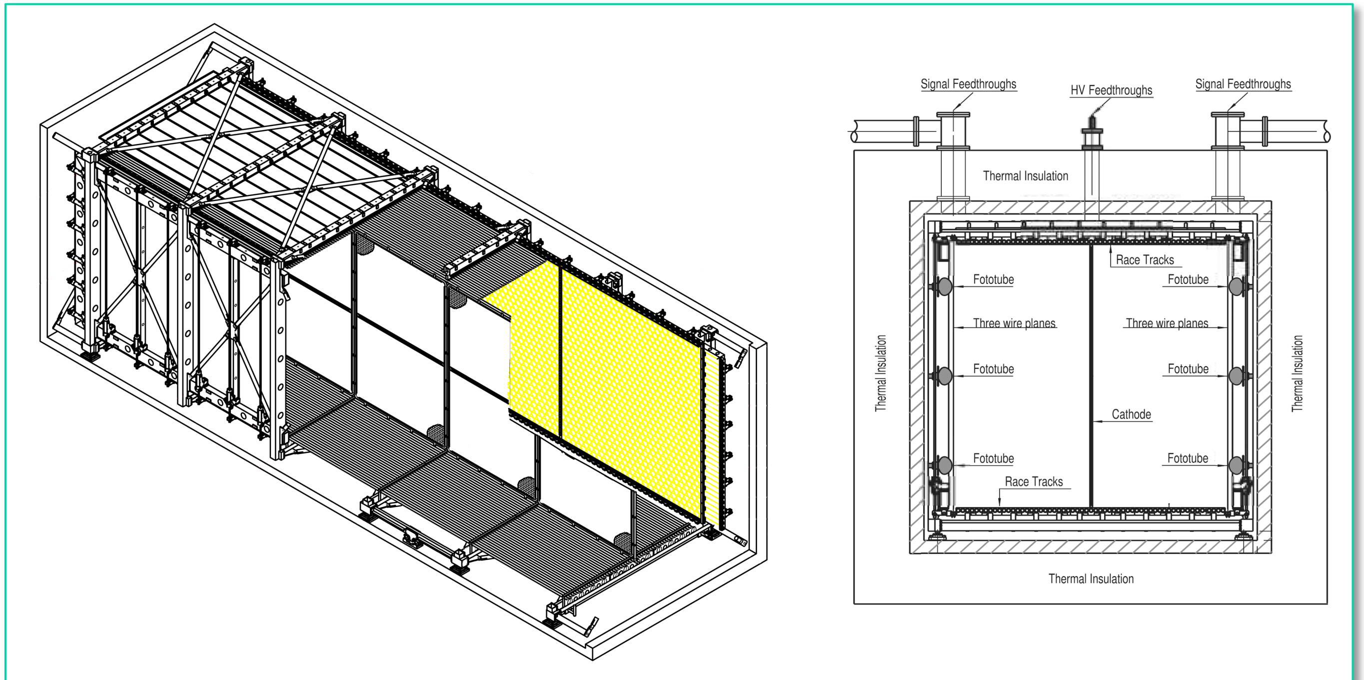


New T150 LAr-TPC



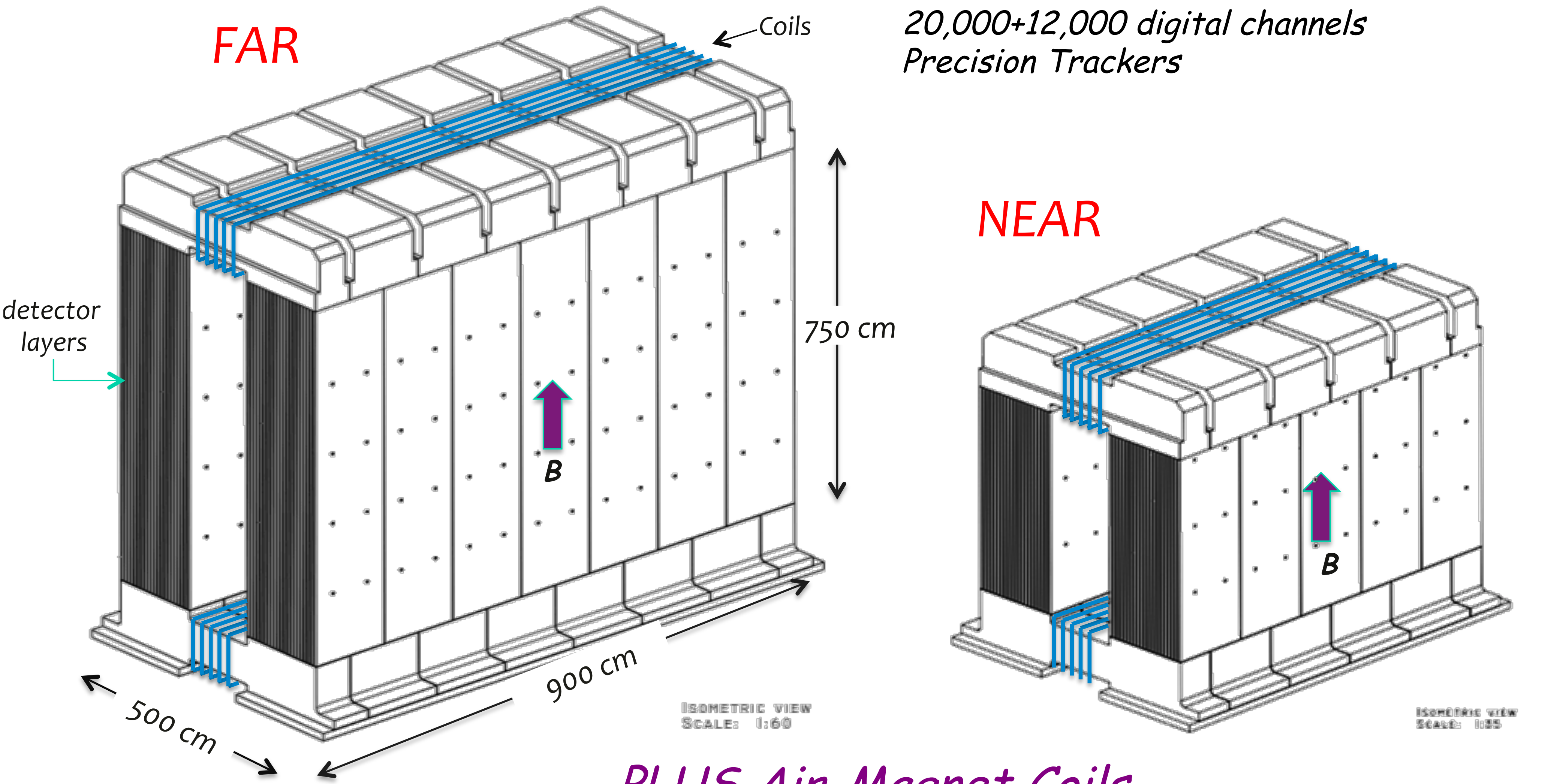
The present design of the T600 is extended to the basic structure of the T150 module. The module contains a high precision, high stability stainless steel structure independent of the container that supports two wire chambers, with three read-out planes each, the field shaping electrodes and one cathode, separating the two 1.5 m drift regions.

Most of the solutions already successfully adopted for the T600 at LNGS will be used. Existing equipment will be conveniently re-used (wiring tables, cleaning tools, etc.).



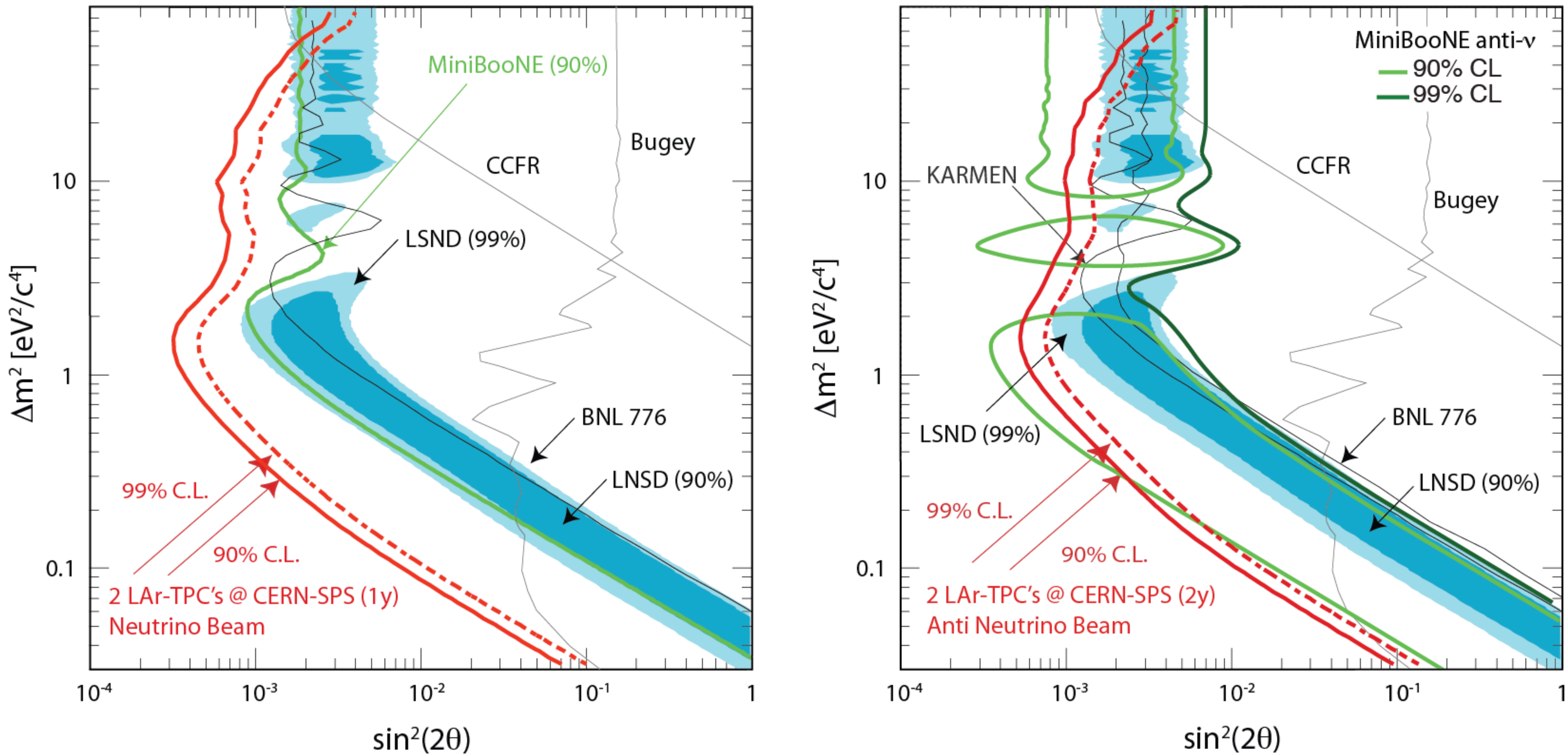
NESSiE Iron Spectrometers

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



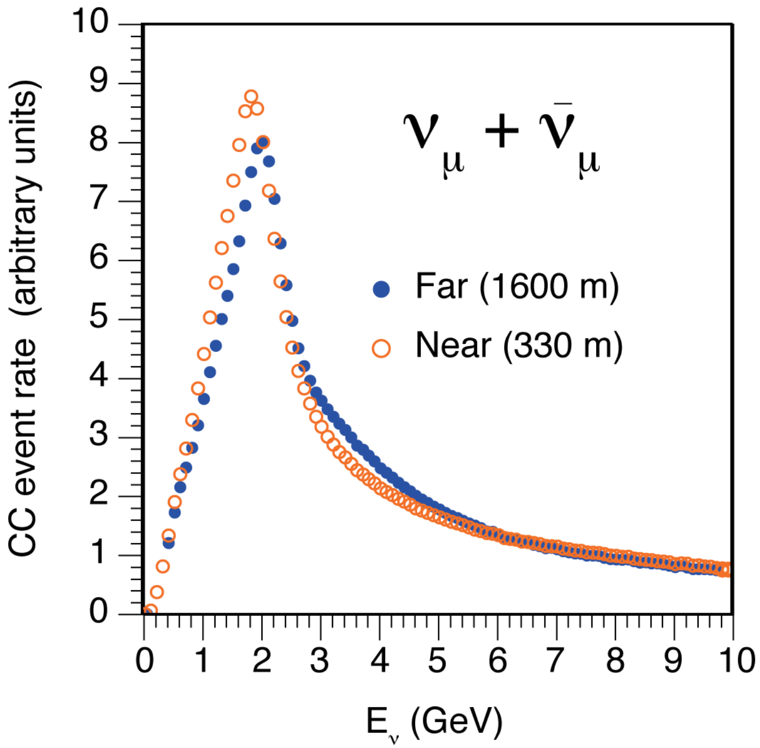
PLUS Air-Magnet Coils

Comparing LSND sensitivities

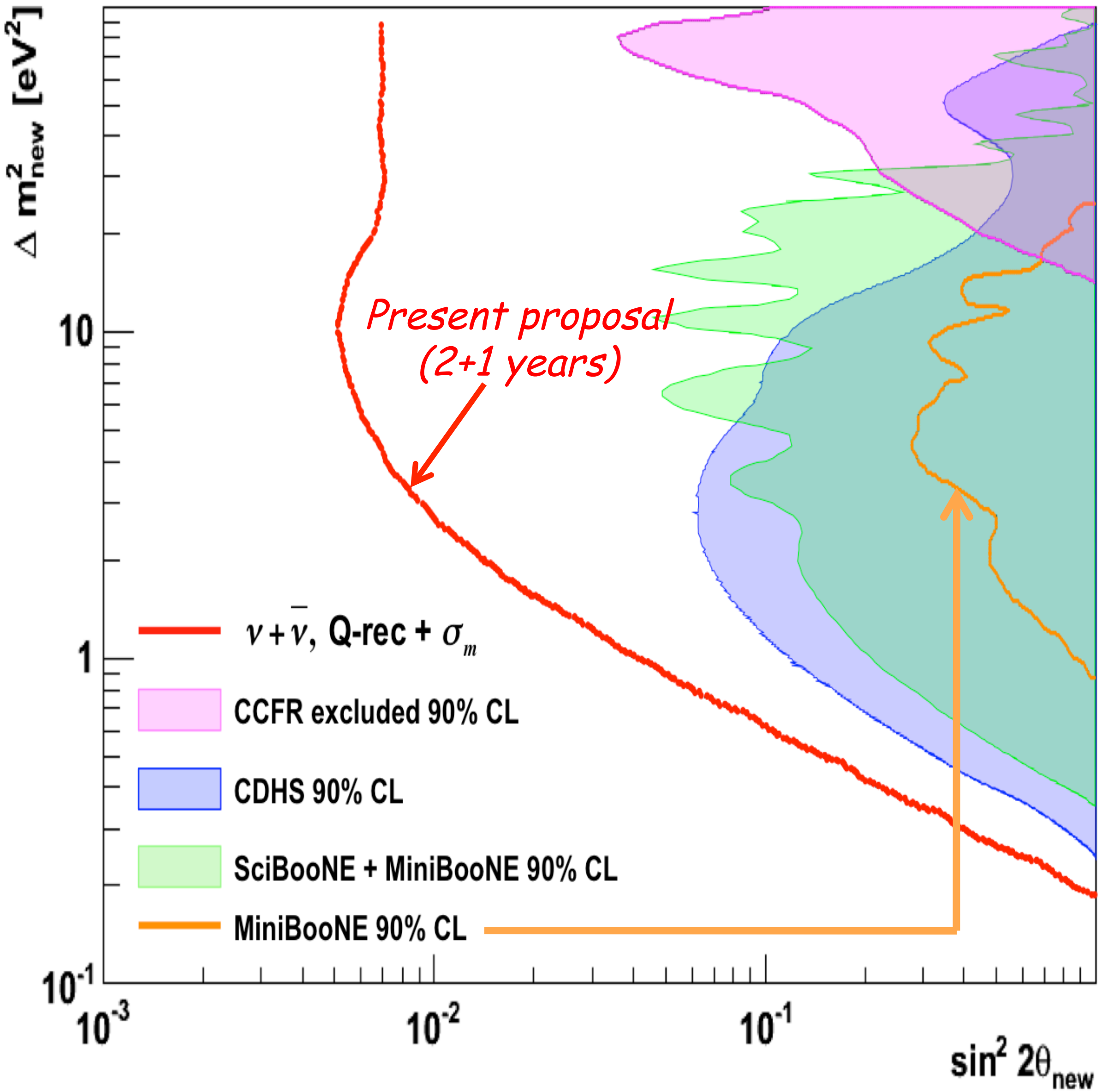


Expected sensitivity for the proposed experiment: ν_μ beam (left) and anti-ν_μ (right) for 4.5 10^{19} pot (1 year) and 9.0 10^{19} pot (2 years) respectively. LSND allowed region is fully explored in both cases.

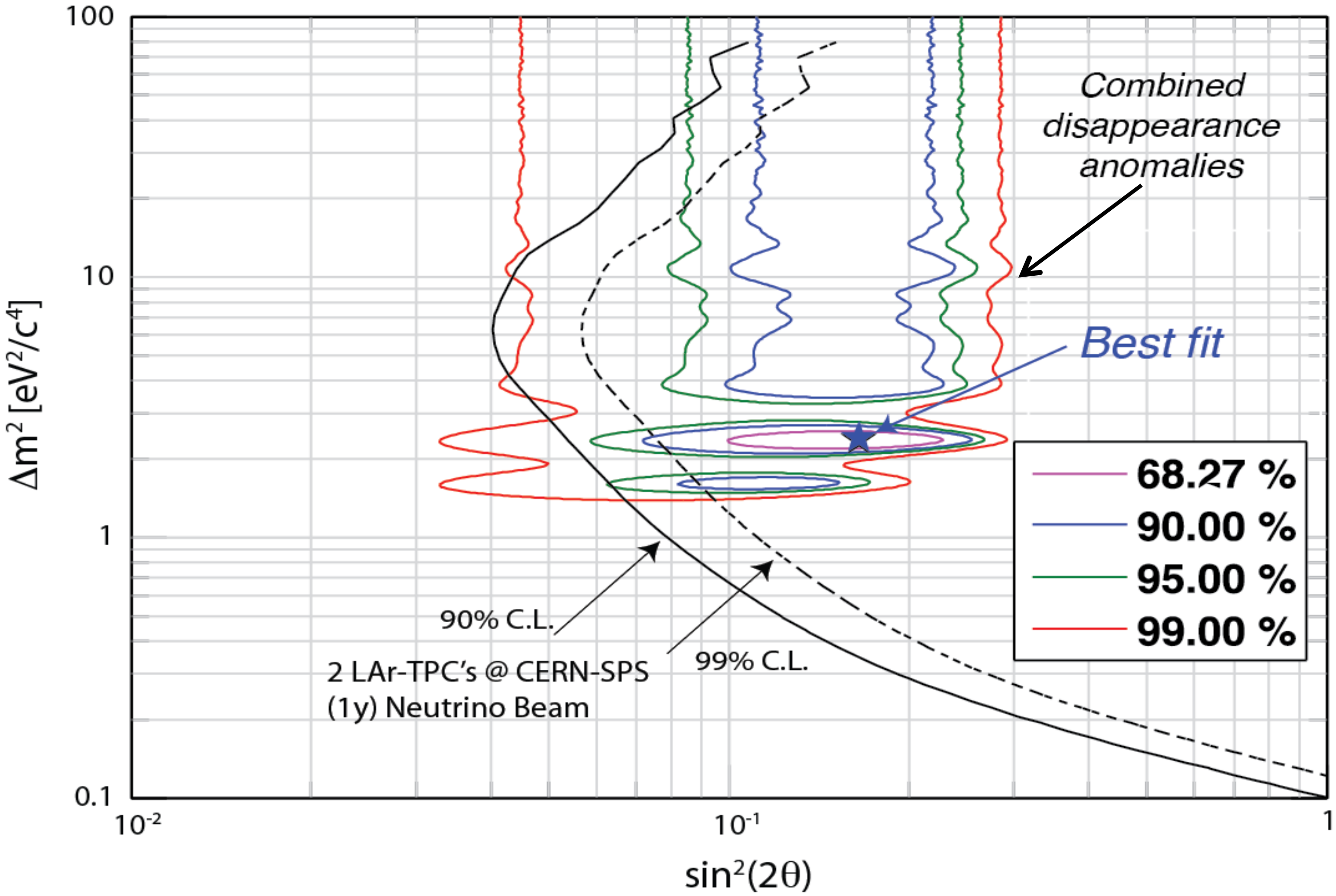
Sensitivity to ν_μ disappearance



90% C.L. sensitivity for 2 years anti-ν + 1 year ν
Exclusion limits :
CCFR, CDHS, SciBooNE + MiniBooNE



Sensitivity to ν_e disappearance anomalies



- *Oscillation sensitivity in $\sin^2(2\theta_{new})$ vs. Δm^2_{new} distribution for CERN-SPS neutrino beam (1 year). A 3% systematic uncertainty on energy spectrum is included. See also combined "anomalies" from reactor neutrino, Gallex and Sage experiments.*

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.

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.

The ultimate goal of accelerator neutrino experiments is leptonic CP violation.
The only realistic project on the floor so far is T2HK.
A worldwide effort is ongoing with multiple proposals in three different continents.