Rassegna sperimentale oscillazioni di neutrino

Passato, Presente e Futuro

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The Golden Age of Neutrino oscillation from 1998 to 2006: **the PDG Indicator**

PDG 1997 edition

Neutrinos 5pg
No. of Light Neutrino Types from Collider Expts. 2pg
Massive Neutral Leptons & Effects of Nonzero Neutrino Masses 5pg
Limits from Neutrinoless Double-beta Decay 2pg
Solar neutrinos 8pg

PDG 1999 edition

Neutrino mass	16pg
No. of Light Neutrino Types from Collider Expts.	2pg
Searches for Massive Neutrinos	5pg
Limits from Neutrinoless Double-beta Decay	2pg
Solar neutrinos	8 pg

PDG 2000 edition

Neutrino mass	17 pg
No. of Light Neutrino Types from Collider Expts.	2 pg
Searches for Massive Neutrinos	(5 pages)
Two-flavor Oscillation Parameters and Limits	(2 pages)
Limits from Neutrinoless Double-beta Decay	(3 pages)
Solar neutrinos	(11 pages)

PDG 2002 edition

Electron, muon, and tau neutrinos (New)	3pg
Neutrino Physics as Explored by Flavor Change (New)	24pg
Understanding Two-Flavor Oscillation Parameters and Limits (Rev.)	6pg
Two-Flavor Oscillation Parameters and Limits (plots) (Rev.)	4pg
No. of Neutrino Types from Collider Expts. (Rev.)	2pg
Solar neutrinos (Rev.)	14pg
Limits from Neutrinoless Double-beta Decay (Rev.)	4pg

PDG 2004 edition

Electron, muon, and tau neutrinos (Rev.)	3pg
Neutrino mass, mixing, and flavor change (Rev.)	24pg
Number of Light Neutrino Types from Collider Expts.	2pg
Understanding Two-Flavor Oscillation Parameters and Limits	5pg
Limits from Neutrinoless Double-beta Decay (Rev.)	4pg
Solar neutrinos (Rev.)	18pg

PDG 2006 edition

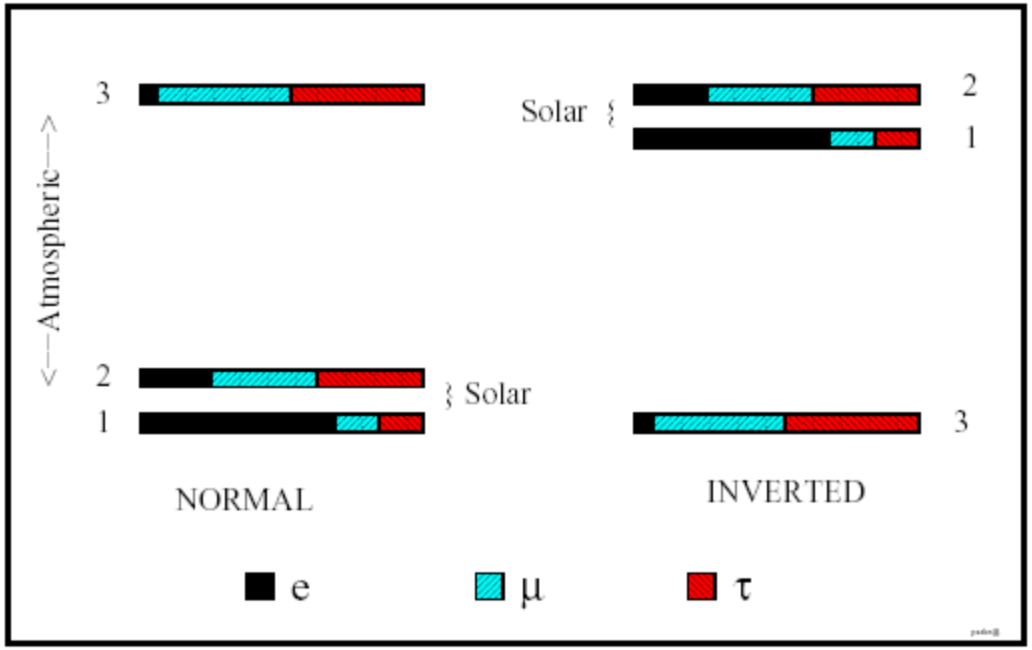
Standard Model and Related Topics	
Quantum chromodynamics (Rev.) errata	(25 pages)
Electroweak model and constraints on new physics (Rev.) errata	(50 pages)
Cabibbo-Kobayashi-Maskawa quark-mixing matrix (New) erratum	(20 pages)
CP violation (Rev.)	(28 pages)
Neutrino mass, mixing, and flavor change (Rev.)	(23 pages)
Quark model (Rev.) erratum	(20 pages)
Grand Unified Theories (Rev.)	(20 pages)
Structure Functions (Rev.; see below for more figures)	(15 pages)
Structure Functions--additional figures (Rev.; see above) errata	(8 pages)
Fragmentation Functions (Rev.)	(26 pages)
Tests of Conservation Laws (Rev.) errata	(5 pages)
CPT Invariance Tests in Neutral Kaon Decay (Rev.)	(4 pages)
CP Violation in K_S -> 3pi	(1 page)
CP Violation in K_L Decays (Rev.)	(12 pages)
V(ud), V(us), Cabibbo Angle, and CKM Unitarity (New)	(11 pages)
Determination of V(cb) and V(ub) (New)	(39 pages)

The importance of pursuing neutrino oscillation studies

- Neutrino oscillations are the sole body of experimental evidence for physics beyond the Standard Model
- The observed tiny mass and the large flavour mixing are believed to be consequences of phenomena occurred at the Bing Bang
  - Neutrino oscillation physics is complementary to high-energy collider physics
- The precision measurement of the oscillation parameters and the discovery of LCPV will have important consequences on astrophysics and cosmology
- Furthermore, if the presence of massive sterile neutrinos is proved, it will contribute to clarify the Dark Matter problem
- For a detailed discussion of these topics we refer to arXiv: 0710.4947 and references therein (The ISS Working Group); hep-ph/0606054 A. Strumia and F. Vissani

Notation

- Mixing parameters: $U = U(\theta_{12}, \theta_{13}, \theta_{23}, \delta)$ as for CKM matrix
- Mass-gap parameters: $M^2 = \Delta m^2_{12}\ ,\ \pm\,\Delta m^2_{23}$



The absolute neutrino mass scale should be set by direct mass measurements:

- β-decay
- 0ν2β-decay
- "W-MAP"

Outline

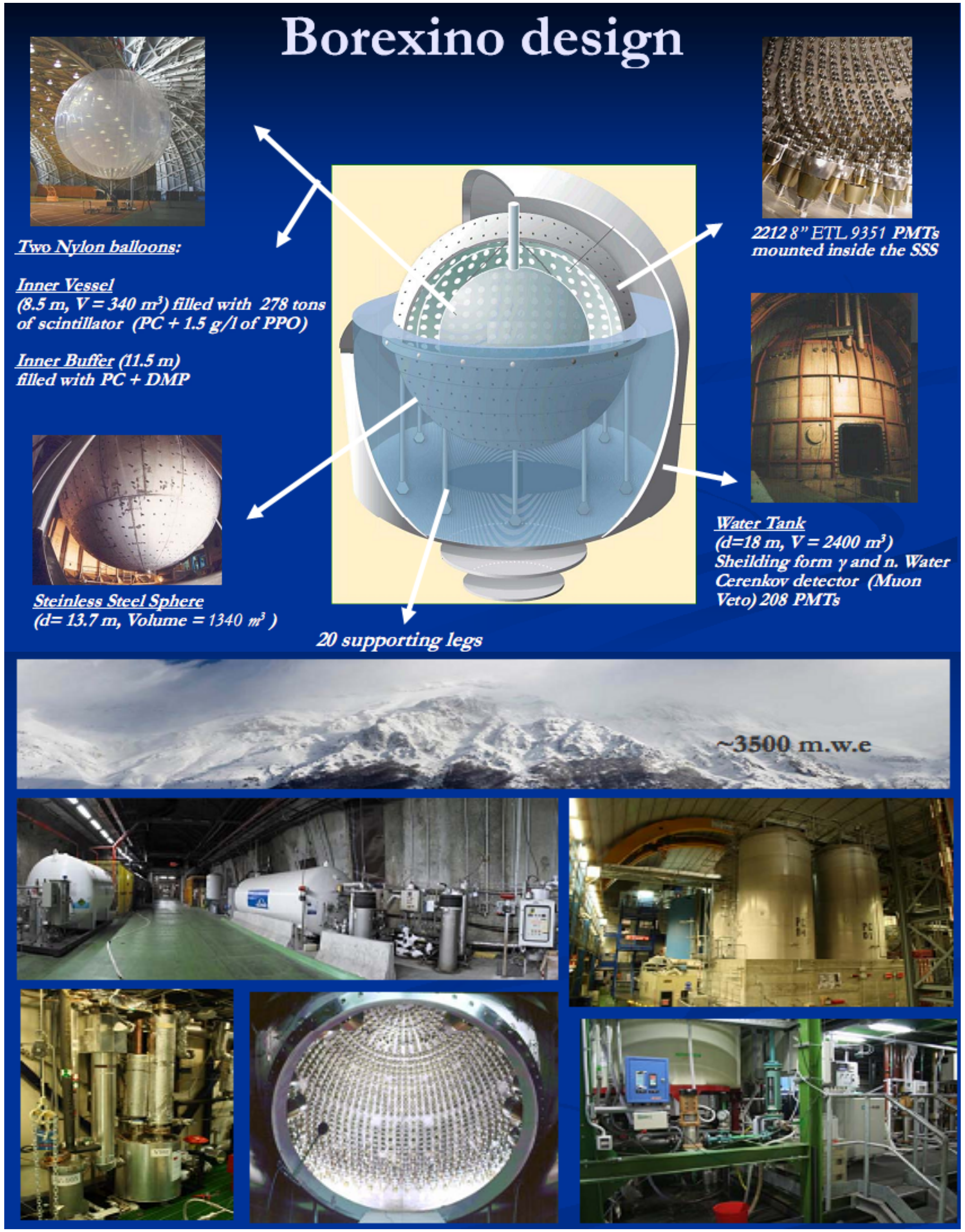
- Past: recent results
  - Borexino, MINOS and SNO
  - Global fit
- Present: on-going experiments
  - MINOS, OPERA, T2K, Reactor experiments
- Future: European (with a focus on Italian) perspectives

Past: recent results

Borexino, MINOS and SNO

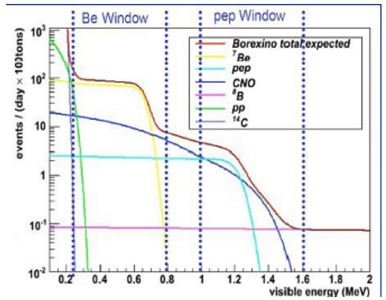
Globaf fit results

Borexino

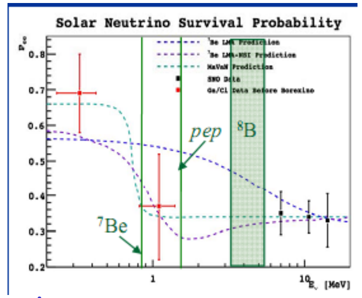


Goals of the experiment:

- First real time observation of the sub-MeV solar neutrinos (mainly from ^{7}Be)



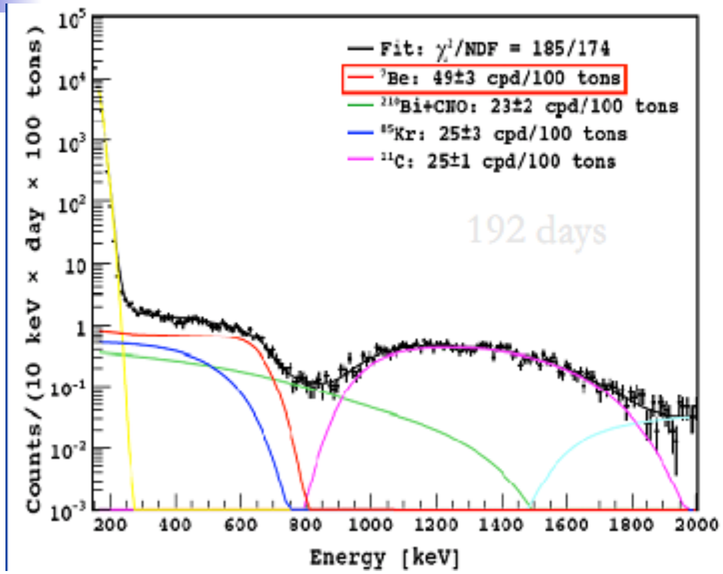
- Low threshold observation of ^{8}B neutrinos
- Test of the matter-vacuum transition of the neutrino oscillations with ^{7}Be, ^{8}B and possibly pep neutrinos

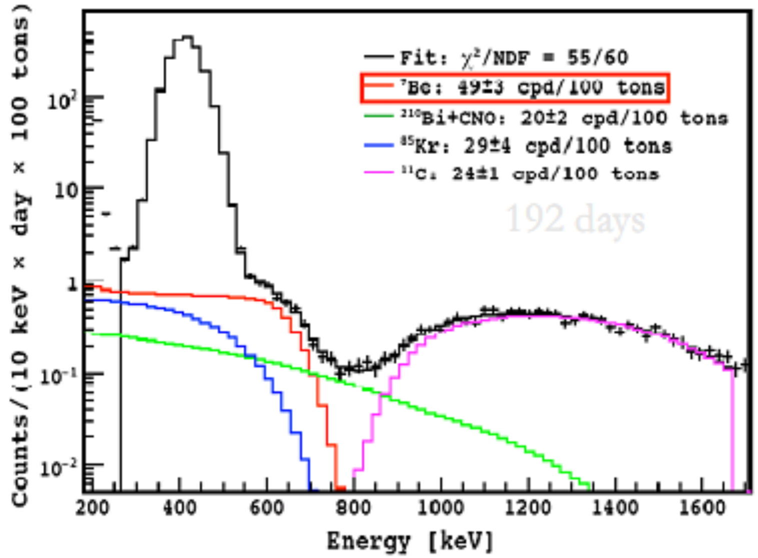


- Study of solar spettroscopy: test of the solar metallicity
- First evidence of geo-neutrinos at 3σ

Direct measurement of ^{7}Be neutrinos

(PRL 101, 091302 (2008))





	NO oscillations BPS07 (High-Z)	BPS07(GS98) High-Z	BPS07(AGS05) Low-Z
Expected rate (cpd/100 t)	74 ± 4	48 ± 4	44 ± 4

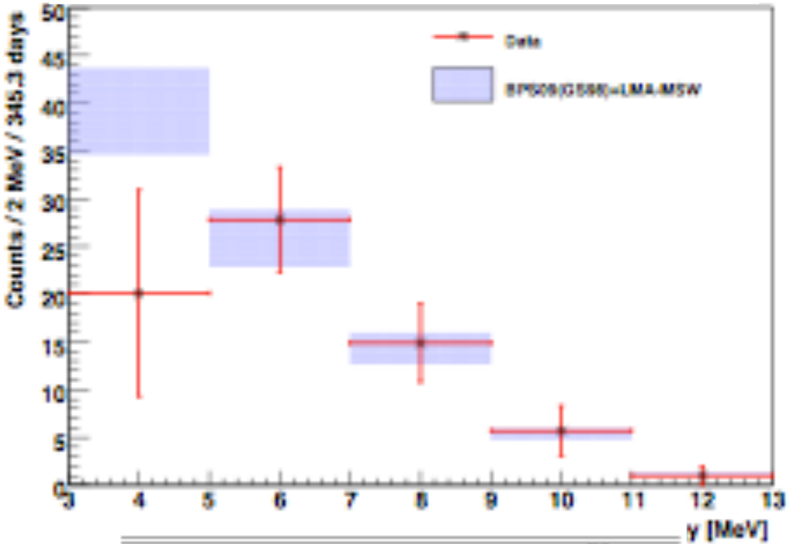
$$R(^7Be) = 49 \pm 3_{stat} \pm 4_{sys} \text{ cpd/100 ton} \quad [\pm 10\%]$$

The NO oscillation hypothesis is rejected at 4σ level!

No clue on the metallicity problem due to the large errors

^{8}B solar neutrinos

First observation of ^{8}B neutrinos with a threshold at 2.8 MeV



	Threshold [MeV]	$\Phi^{ES}_{^8B}$ [10^6 cm^{-2} s^{-1}]
SuperKamiokaNDE I [5]	5.0	$2.35\pm0.02\pm0.08$
SuperKamiokaNDE II [2]	7.0	$2.38\pm0.05^{+0.16}_{-0.15}$
SNO D_2O [3]	5.0	$2.39^{+0.24}_{-0.23}{}^{+0.12}_{-0.12}$
SNO Salt Phase [25]	5.5	$2.35\pm0.22\pm0.15$
SNO Prop. Counter [26]	6.0	$1.77^{+0.24}_{-0.21}{}^{+0.09}_{-0.10}$
Borexino	3.0	$2.4\pm0.4\pm0.1$
Borexino	5.0	$2.7\pm0.4\pm0.1$

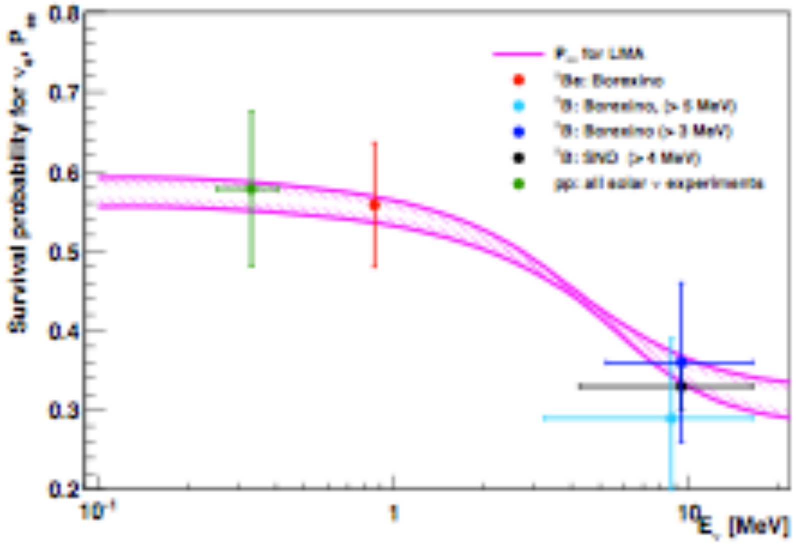
Very recently the SNO Collaboration published the total ^{8}B flux with a low threshold (3.5 MeV) analysis.

1. Model-independent measure of the ^{8}B flux:

   Φ_{NC} = 5.140 +4.0 -3.8 %

2. Measure of the ^{8}B flux assuming unitarity:

   Φ_{8B} = 5.046 +3.8 -3.9 %



Under the assumption of the high Z SM

P_{ee} (^{7}Be) = 0.56 ± 0.10 (0.862 MeV)
P_{ee} (^{8}B) = 0.35 ± 0.10 (8.6 MeV)

P_{ee} (^{7}Be) / P_{ee} (^{8}B) $\neq 1$ @ 1.8 σ

Borexino confirms @ 1.8 σ the presence of the transition zone between the low energy vacuum-driven and high-energy matter-driven solar neutrino oscillations predicted by the MSW-LMA.

Geoneutrinos

Inverse beta decay reaction. Correlated in space and time pair of signals.

$$\bar{\nu}_e + p \rightarrow n + e^+$$

E_{th}=1.806 MeV

1) *Prompt signal:* Positron + 2 γ from annihilation with e^-, E_γ=0.511 MeV

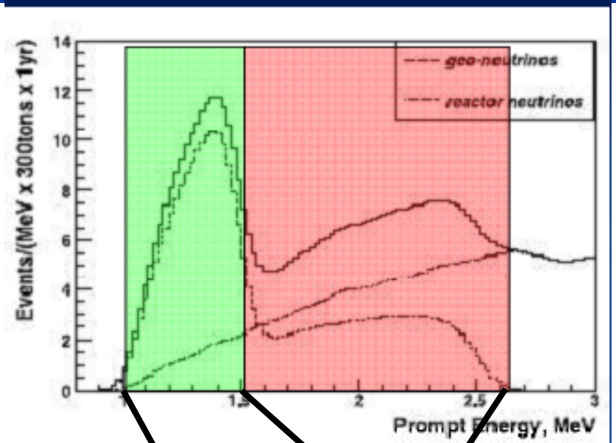
After t~250μs

2) *Delayed signal:* Neutron capture on Hydrogen - γ of E_γ=2.2 MeV

The expected anti-ν signal comes mainly from the reactors and from the β decays of long-lived radioactive isotopes (^{238}U, ^{232}Th) naturally present in the Earth's interior (geo-neutrinos).

Detection technique

à la Reines&Cowan



	1-1.5	1.5-2.6	2.6-10
Geo ^{232}Th	1.2	0	0
Geo ^{238}U	2.1	2.3	0
Reactor	0.5	3.3	8.5
Total	3.8	5.6	8.5
Random	0.3	0.2	0.0

Expected in 300 t in 1 year

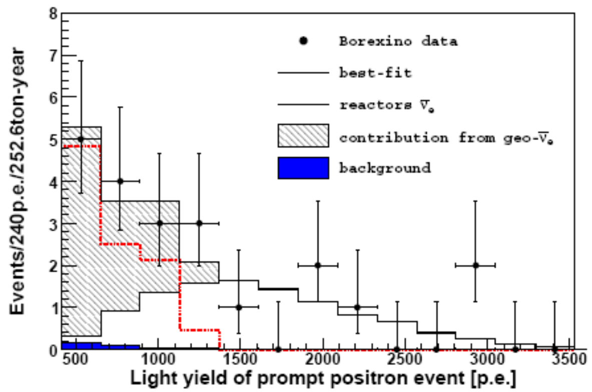


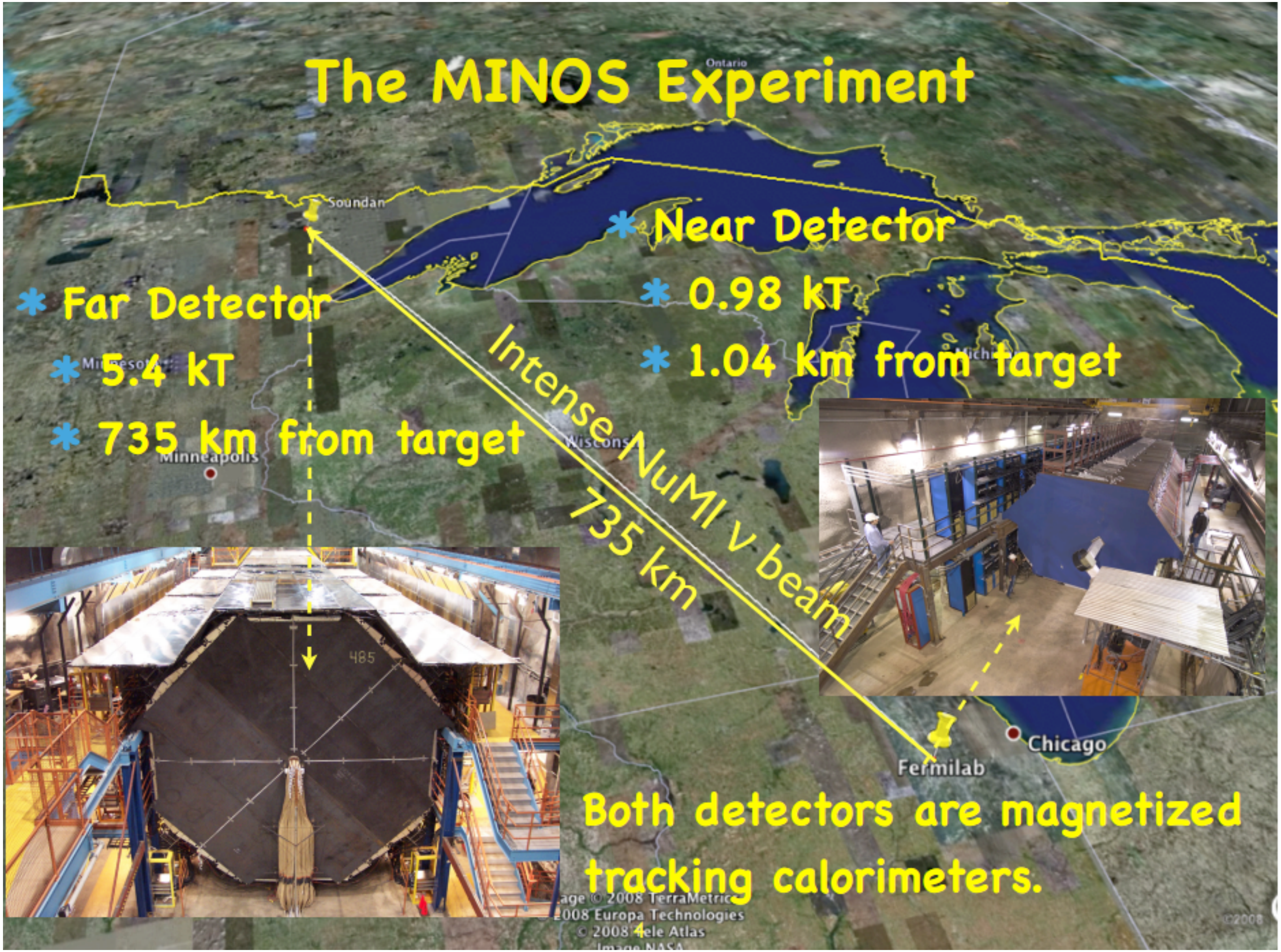
Table 3: Comparison the Borexino measurement of geo–$\bar{\nu}_e$ with predictions. See text for details.

Source	Geo–$\bar{\nu}_e$ Rate [events/(100 ton·yr)]
Borexino	$3.9^{+1.6}_{-1.3}$
BSE [16]	$2.5^{+0.3}_{-0.5}$
BSE [30]	2.5±0.2
BSE [5]	3.6
Max. Radiogenic Earth	3.9
Min. Radiogenic Earth	1.6

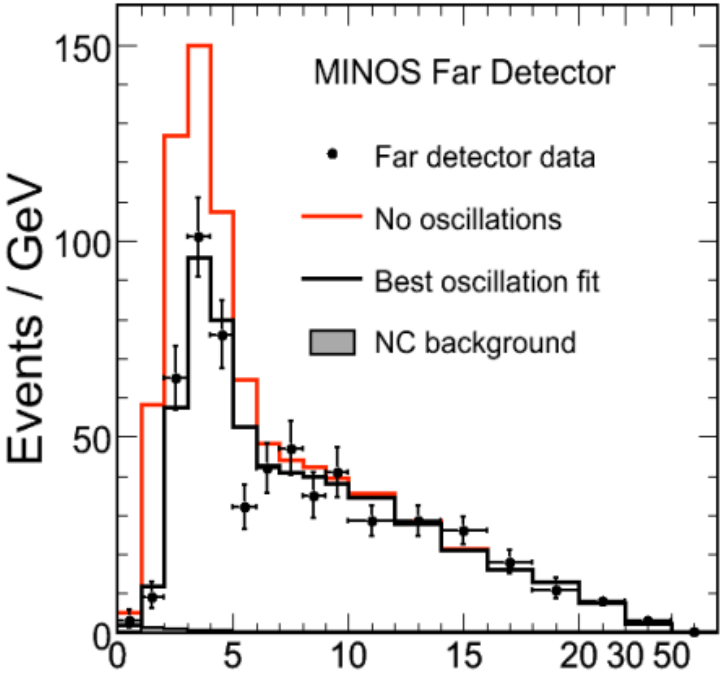
The #evts detected by Borexino is

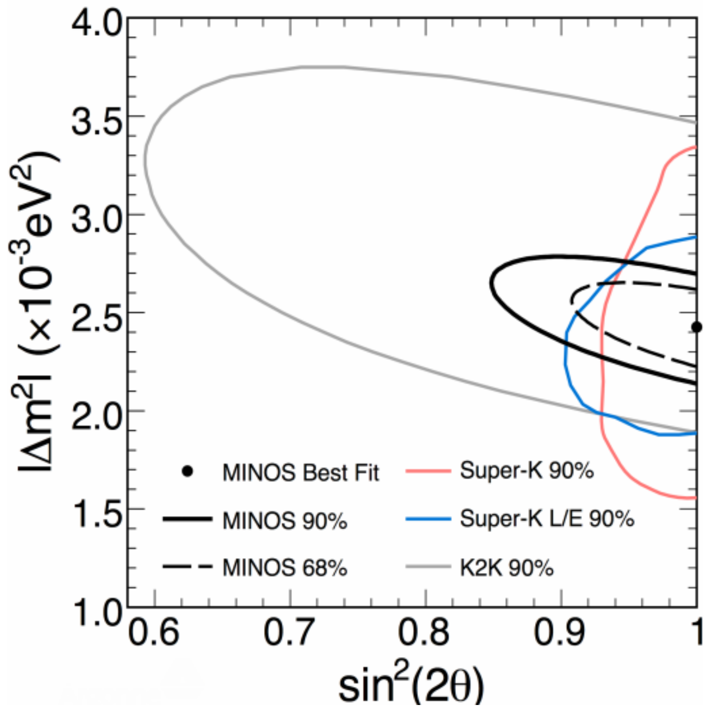
$9.9_{-3.4}^{+4.1}(_{-8.2}^{+14.6})$ at 68.3% (99.73%)

The null hypothesis is rejected at 99.997% C.L.


The MINOS Experiment
Ontario
Soundan
* Far Detector
* 5.4 kT
* 735 km from target
Minneapolis
* Near Detector
* 0.98 kT
* 1.04 km from target
Intense NuMI ν beam
735 km
485
Chicago
Fermilab
Both detectors are magnetized
tracking calorimeters.
Image © 2008 TerraMetrics
© 2008 Europa Technologies
© 2008 Tele Atlas
Image NASA

Precision measurement of Δm^2 and $\sin^2 2\theta$

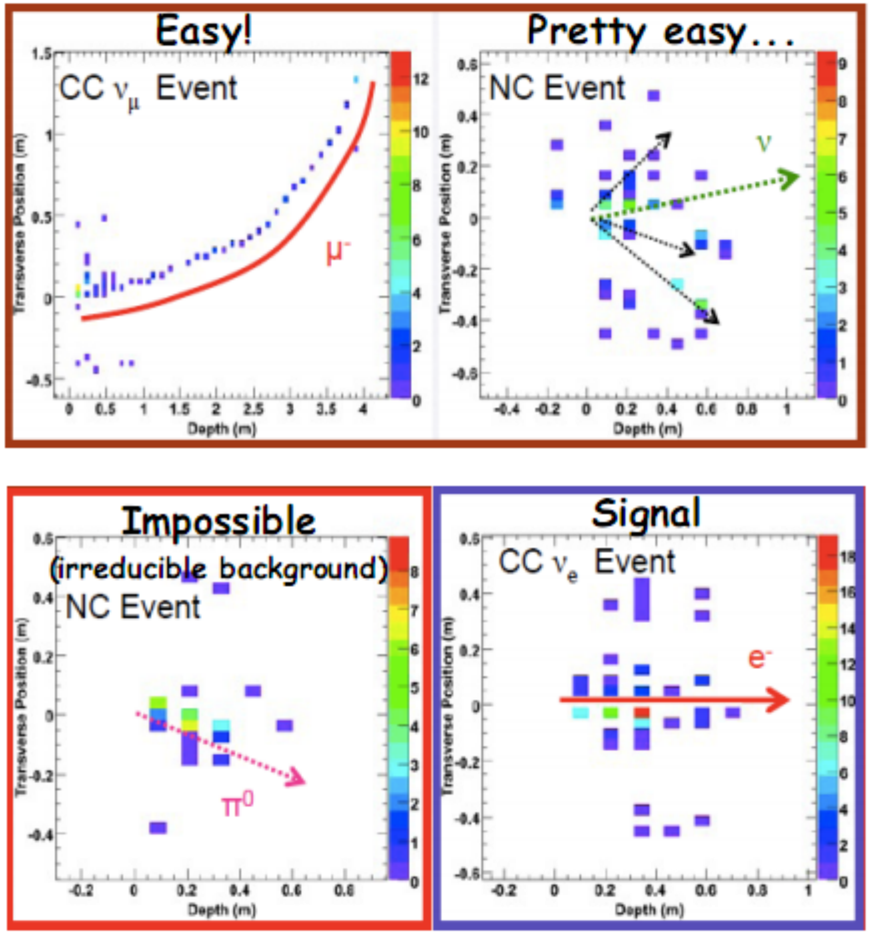




* FD energy spectrum is only looked at after performing:
  * low-level data quality checks
  * procedural checks
* 848 events observed in the FD
* 1065 ± 60 expected with no oscillations

* Constrained fit:
  * $\Delta m^2 = (2.43 \pm 0.13) \times 10^{-3}\ eV^2$ (68% CL)
  * $\sin^2(2\theta) > 0.90$ (90% CL)
  * $\chi^2/ndof = 90/97$

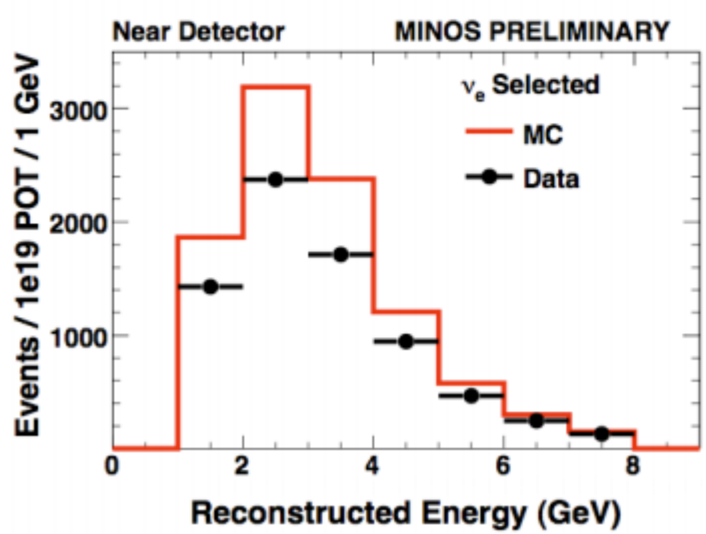
Search for ν_e appearance



Important the neutrino beam understanding

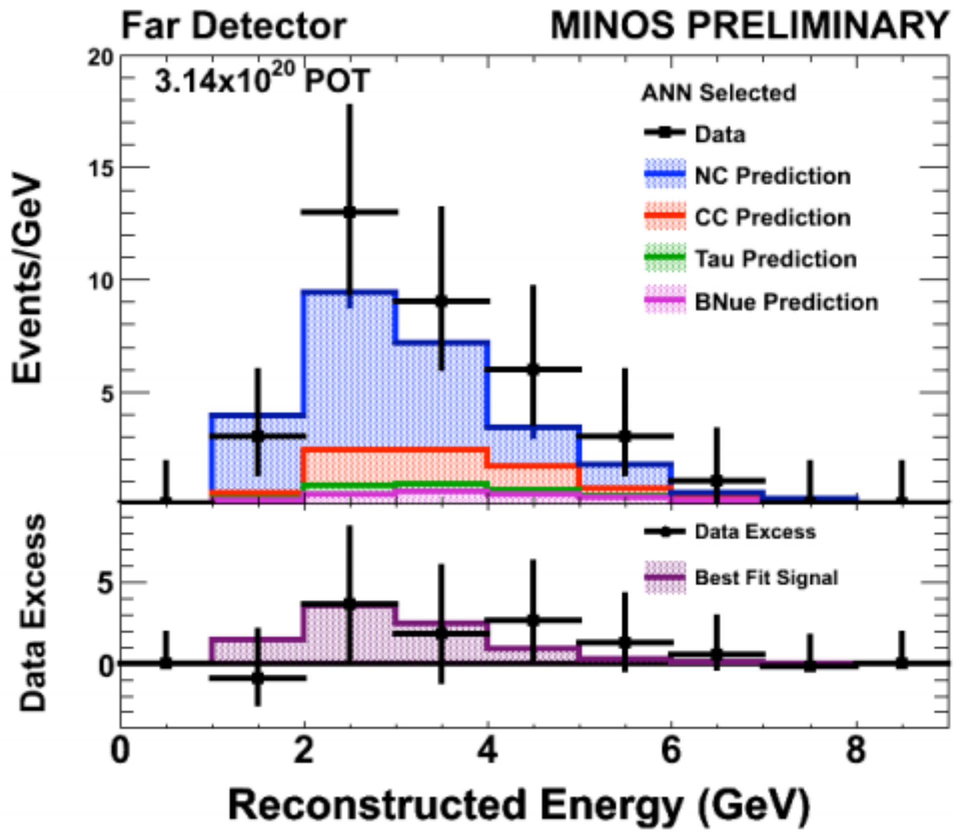
→Analysis of the near detector data

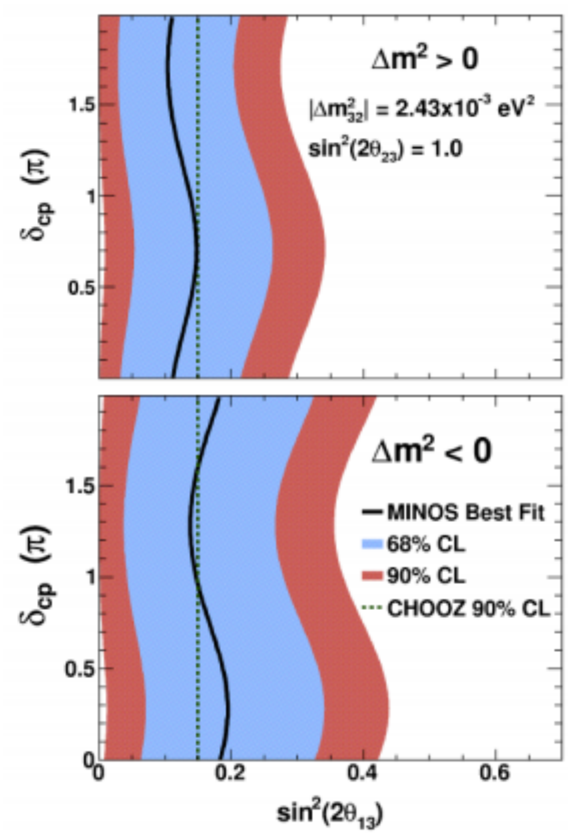
Large discrepancy seen!



Given the detector granularity signal to noise discrimination is very difficult

Results





35 events have been observed with an expectation of 25±5±2 events

There is an excess at 1.5σ; θ_{13}=0 is included at 92% C.L.

Constraints from a global 3ν analysis

M. C. Gonzalez-Garcia, M. Maltoni and J. Salvado, ``Updated global fit to three neutrino mixing: status of the hints of theta13 > 0,'' arXiv:1001.4524 [hep-ph].

High-Z: GS98 with Gallium cross-section from [17]	Low-Z and SAGE meas.: AGSS09 with modified Gallium cross-section [13]	
$\Delta m^2_{21} = 7.59 \pm 0.20 \, (^{+0.61}_{-0.69}) \times 10^{-5}$ eV^2	Same	(<10%)
$\Delta m^2_{31} = \begin{cases} -2.40 \pm 0.11 \, (^{+0.37}_{-0.39}) \times 10^{-3} \text{ eV}^2 \text{ (inverted)} \\ +2.51 \pm 0.12 \, (^{+0.39}_{-0.36}) \times 10^{-3} \text{ eV}^2 \text{ (normal)} \end{cases}$	Same	(~15%)
$\theta_{12} = 34.4 \pm 1.0 \, (^{+3.2}_{-2.9})$	$34.5 \pm 1.0 \, (^{+3.2}_{-2.8})$	(~10%)
$\theta_{23} = 42.3^{+5.3}_{-2.8} \, (^{+11.4}_{-7.1})$	Same	(~30%)
$\theta_{13} = 6.8^{+2.6}_{-3.6} \, (\leq 13.2)$ — $\theta_{13} \neq 0$ at 1.9σ	$\theta_{13} \neq 0$ at 1.5σ — $5.7^{+3.0}_{-3.9} \, (\leq 12.7)$	
$[\sin^2\theta_{13} = 0.014^{+0.013}_{-0.011} \, (\leq 0.052)]$	$[0.010^{+0.013}_{-0.009} \, (\leq 0.049)]$	
$\delta_{CP} \in [0, 360]$	Same	

Why θ_{13} is important?

$$P_{\nu_\mu \to \nu_e} \cong \sin^2 2\theta_{13} \sin^2 \theta_{23} \frac{\sin^2\left[\left(1-\hat{A}\right)\Delta\right]}{\left(1-\hat{A}\right)^2}$$

$$\mp \alpha \sin\theta_{13} \xi \sin\delta_{CP} \sin\Delta \frac{\sin\left(\hat{A}\Delta\right)}{\hat{A}} \frac{\sin\left[\left(1-\hat{A}\right)\Delta\right]}{\left(1-\hat{A}\right)}$$

$$+ \alpha \sin\theta_{13} \xi \cos\delta_{CP} \cos\Delta \frac{\sin\left(\hat{A}\Delta\right)}{\hat{A}} \frac{\sin\left[\left(1-\hat{A}\right)\Delta\right]}{\left(1-\hat{A}\right)}$$

$$+ \alpha^2 \cos^2\theta_{23} \sin^2 2\theta_{12} \frac{\sin^2\left(\hat{A}\Delta\right)}{\hat{A}^2}$$

$$\equiv O_1 + O_2(\delta) + O_3(\delta) + O_4$$

$-$ for ν

$+$ for $\bar{\nu}$

$\hat{A} \propto$ Matter effects

$$\alpha = \frac{\Delta m_{21}^2}{\left|\Delta m_{31}^2\right|}$$ small (~1/30) but non negligible

$\xi \propto \theta_{12}$

If θ_{13} is vanishing or too small the possibility to observe CP violation in the leptonic sector vanishes!!!

The clone problem

- The Eightfold Degeneracy in (θ_{13}, δ) Measure (Barger01,Burguet02)

$$N_i^{\pm}(\bar\theta_{13}, \bar\delta; \bar s_{atm}, \bar s_{oct}) = N_i^{\pm}(\theta_{13}, \delta; s_{atm}, s_{oct})$$

One has to solve ALL the following systems of equations:

intrinsic ambiguity

$$N_i^{\pm}(\bar\theta_{13}, \bar\delta; \bar s_{atm}, \bar s_{oct}) = N_i^{\pm}(\theta_{13}, \delta; s_{atm} = \bar s_{atm}, s_{oct} = \bar s_{oct})$$

sign ambiguity $(\pm\Delta m^2_{23})$

$$N_i^{\pm}(\bar\theta_{13}, \bar\delta; \bar s_{atm}, \bar s_{oct}) = N_i^{\pm}(\theta_{13}, \delta; s_{atm} = -\bar s_{atm}, s_{oct} = \bar s_{oct})$$

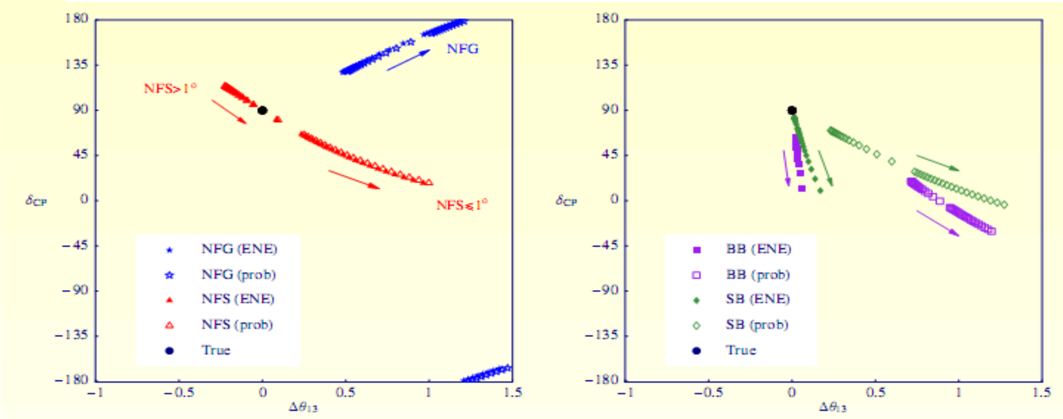
octant ambiguity $[\theta_{23}, \pi/2 - \theta_{23}]$

$$N_i^{\pm}(\bar\theta_{13}, \bar\delta; \bar s_{atm}, \bar s_{oct}) = N_i^{\pm}(\theta_{13}, \delta; s_{atm} = \bar s_{atm}, s_{oct} = -\bar s_{oct})$$

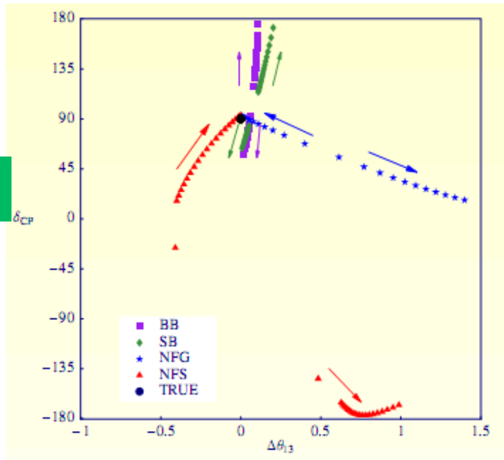
mixed ambiguity

$$N_i^{\pm}(\bar\theta_{13}, \bar\delta; \bar s_{atm}, \bar s_{oct}) = N_i^{\pm}(\theta_{13}, \delta; s_{atm} = -\bar s_{atm}, s_{oct} = -\bar s_{oct})$$

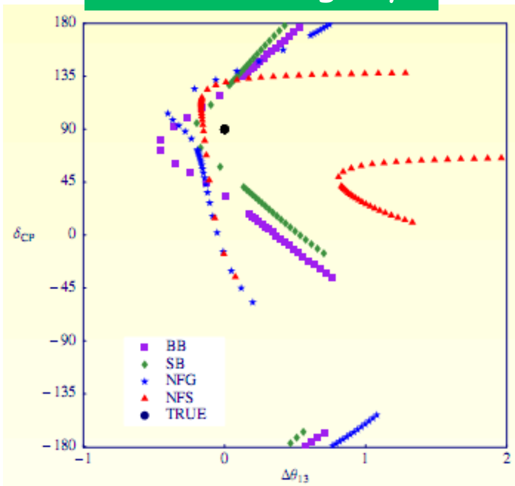
Intrinsic ambiguity



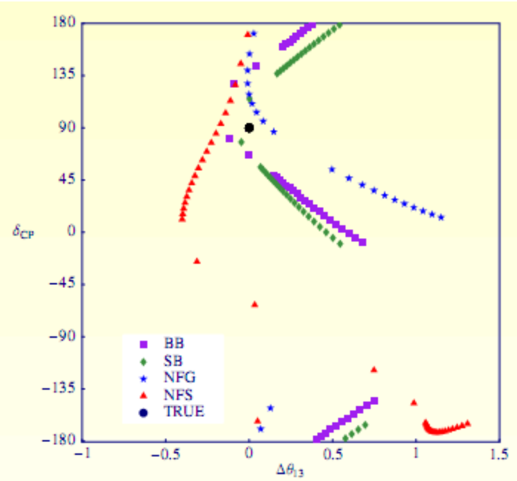
Sign ambiguity



Octant ambiguity

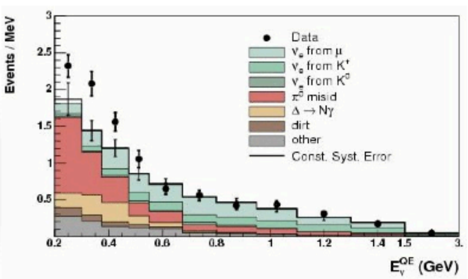


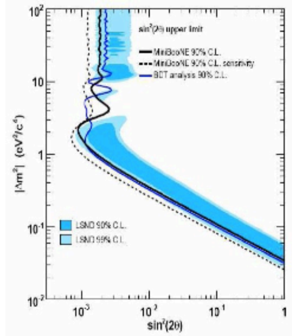
Mixed ambiguity



The LSND saga

Appearance results (neutrino mode)





- Analysis based on 6.46E20 POT
- No oscillations at LSND L/E region (> 475 MeV)
- Observed 3σ excess of events in low-energy region (< 475 MeV)

Lett. 102, 101802 (2009)

Anomaly Mediated Neutrino-Photon Interactions
Harvey, Hill, & Hill, arXiv:0905.029

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CP-Violation 3+2 Model
Maltoni & Schwetz, arXiv:0705.0107; T. Goldman, G. J. Stephenson Jr., B. H. J. McKellar, Phys. Rev. D75 (2007) 091301

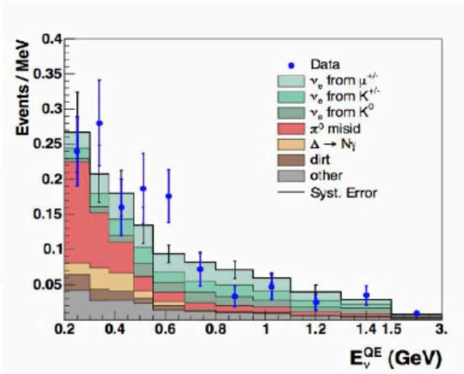
Lorentz Violation
Katori, Kostelecky, & Tayloe, Phys. Rev. D74 (2006) 105009

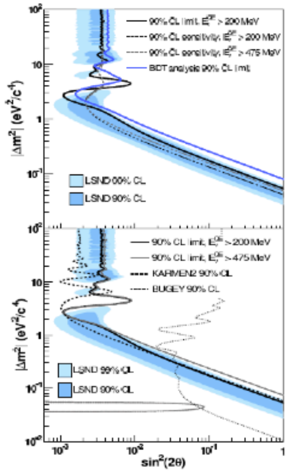
CPT Violation 3+1 Model
Barger, Marfatia, & Whisnant, Phys. Lett. B576 (2003) 303

VSBL Electron Neutrino Disappearance
Giunti and Laveder arXiv:0902.1992

New Gauge Boson with Sterile Neutrinos
Ann E. Nelson & Jonathan Walsh, arXiv:0711.1363

Appearance results (anti-neutrino mode)





- Analysis based on 3.386E20 POT
- No low energy excess
- Currently work on combined $\nu - \bar{\nu}$ analysis
- More data will provide additional information

Phys. Rev. Lett. 103, 111801 (2009)

Moriond EW 2010, La Thuile, Italy — *11 of 16*

MicroBooNE @FNAL on the BooNE and NUMI beams, DoubleLAr recently proposed to run on a refurbished PS neutrino beam. OscSNS will exploit the SNS neutrino beam with a oil–scintillator detector to check the LSND signal

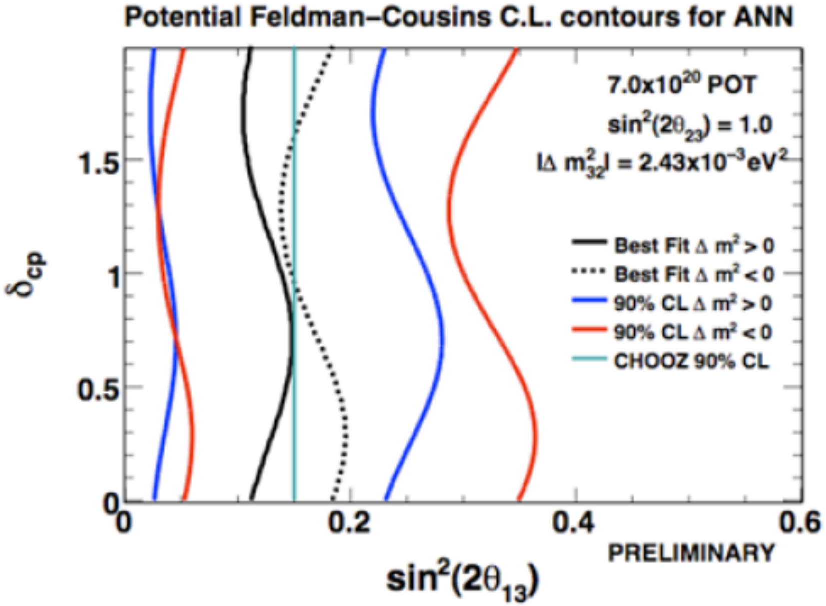
Comments

- The size of θ_{13} is crucial to assess CP violation in the leptonic sector
- None of currently running facilities will be able to extract (even in the most optimistic case of a θ_{13} close to the CHOOZ limit) full information
- On the other hand it is very difficult to plan the future not knowing this parameter
- So far there is no evidence for neutrino oscillations in the "appearance" channel. LSND, Karmen and MiniBoone exploited the appearance but the results are rather controversial…

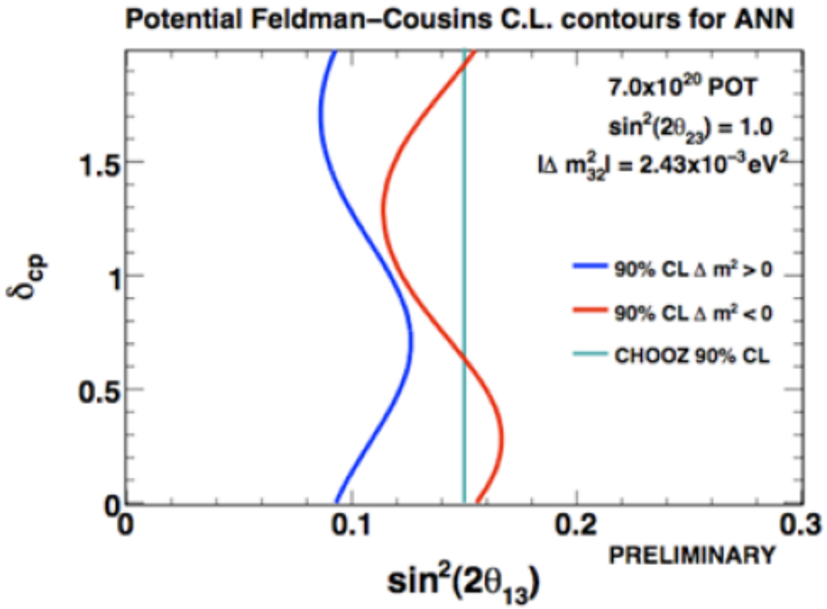
Present: on-going experiments

MINOS
OPERA
T2K
Reactor experiments

MINOS perspectives



If excess remains with new data

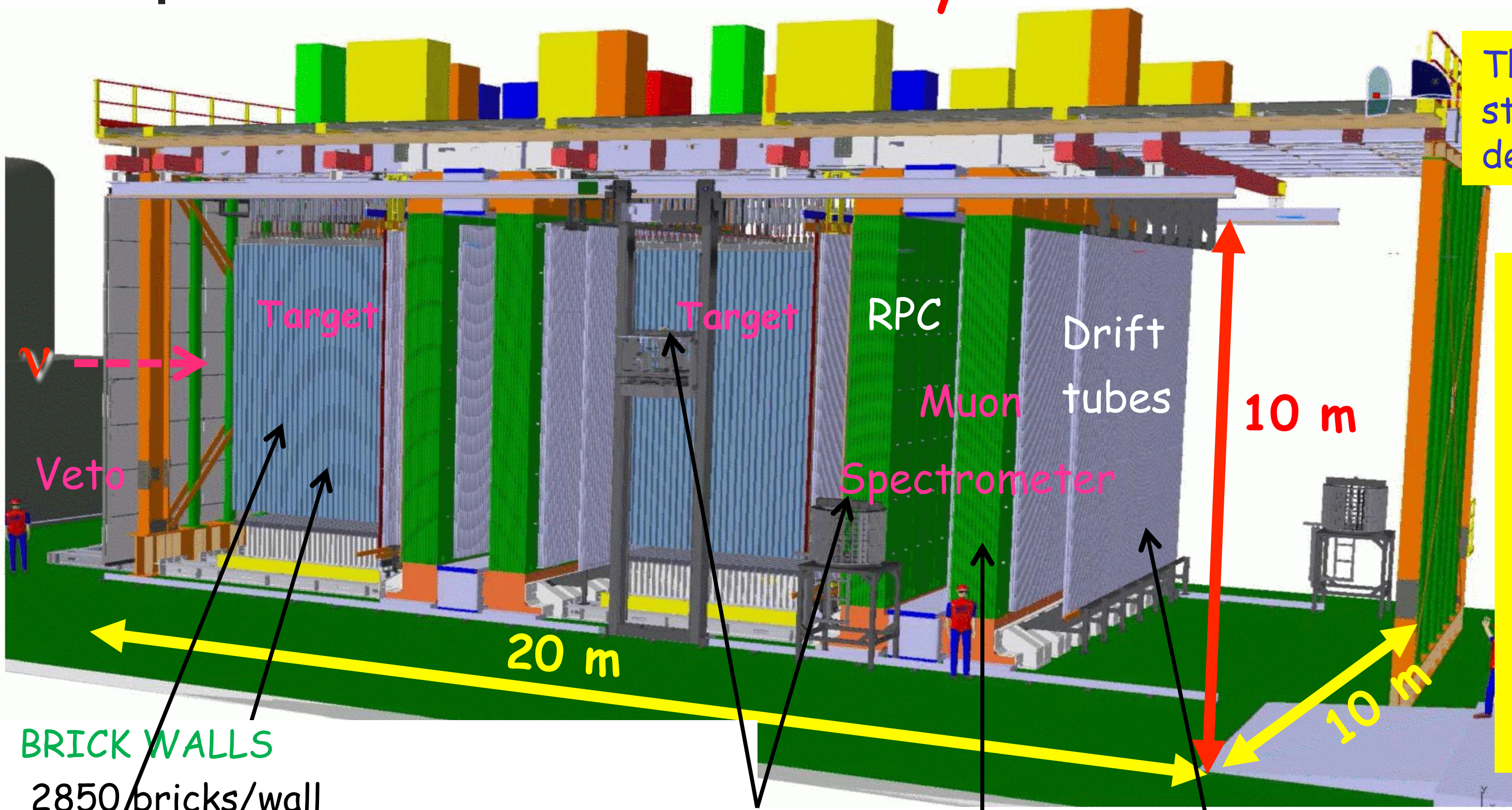


If excess goes away with new data

Twice ofthe statistics is on tape and is being analyzed (the results are going to be presented at FNAL today).

In the best case (the excess is confirmed) a null value of θ_{13} is disfavoured at 2σ

The OPERA hybrid detector



The bricks are stand-alone passive detectors

→ **Electronic Detectors** are needed for:

- Triggering, Timing
- Neutrino interactions Location
- Hadronic calorimetry
- Muon I.D. and Spectrometry

BRICK WALLS

2850 bricks/wall

- 53 walls : 150000 bricks ~ 1.25 kton

TARGET TRACKERS

- 2x31 scintillator strips walls
- 256+256 X-Y strips/wall
- WLS fiber readout
- 64-channel PMTs
- 63488 channels
- 0.8 cm resololution, 99% ε
- rate 20 Hz/pixel @1 p.e.

BMS

Brick Manipulator System

HIGH PRECISION TRACKERS

6 drift-tube layers/spectrometer

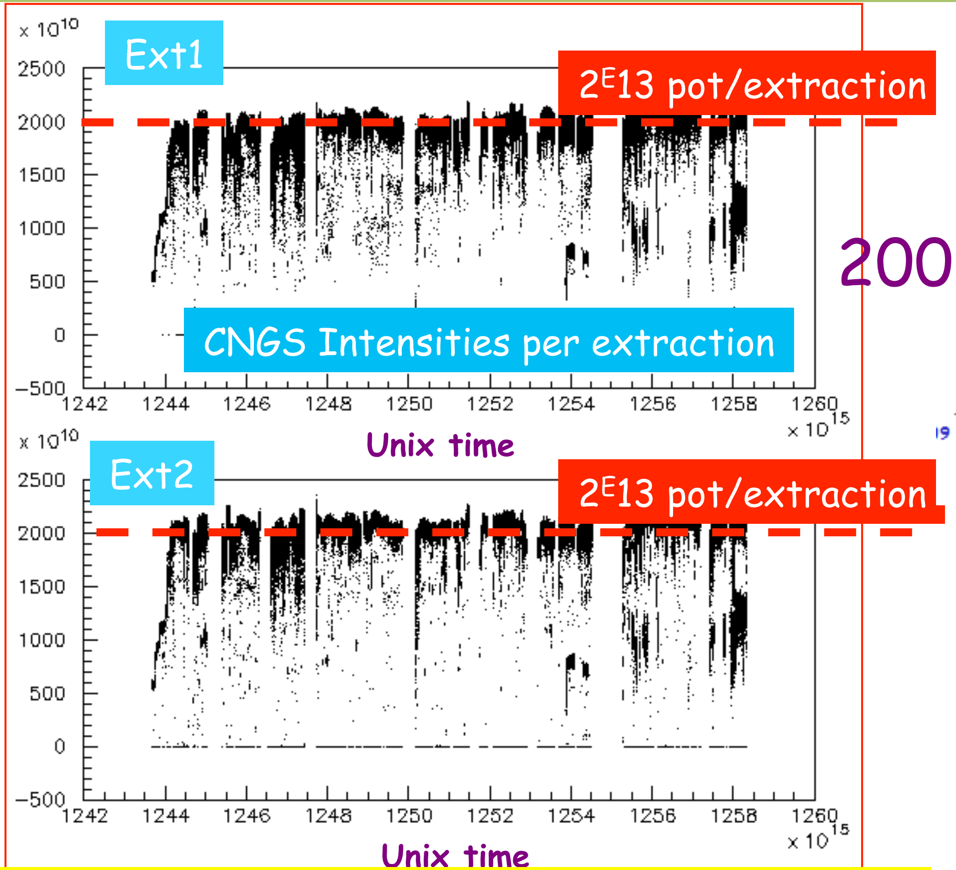
spatial resolution < 0.5 mm

INNER TRACKERS

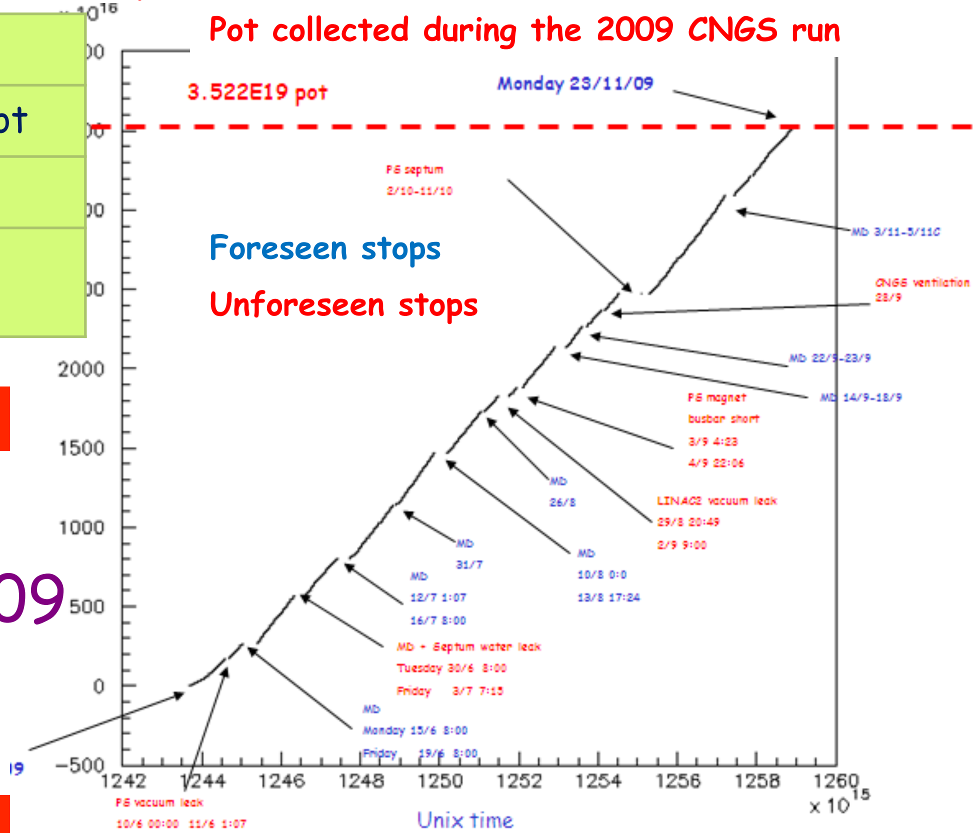
- 990-ton dipole magnets (B= 1.55 T), 5cm thick iron plates instrumented with 22 RPC planes
- 3050 m^2, ~1.3 cm res.

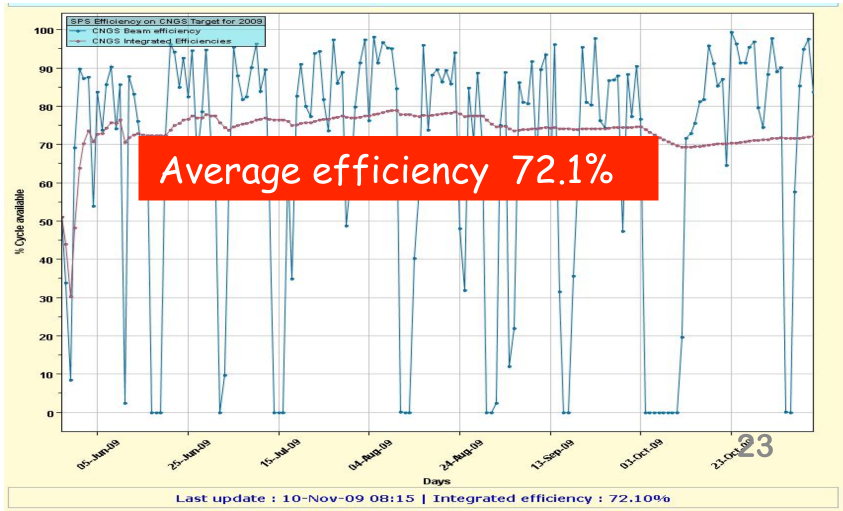
CNGS beam performance: Physics runs 2008-2009

	2008 run	2009 run
Protons on target	1.782E19 pot	3.522E19 pot
On-time events	10122	21428
Candidate interactions in the target	1698	3693



2009



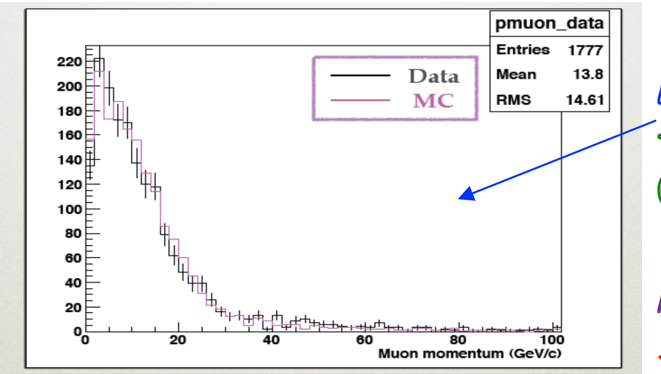


Nominal performance: 2.4E13 pot/extraction

4.5E19 pot/year

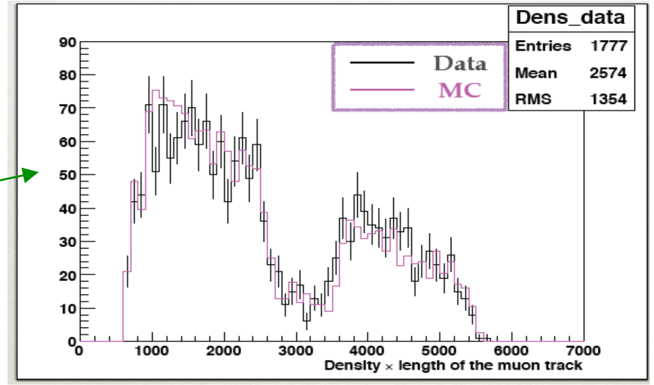
ν_μ CC events : quantities measured in the ED

Muon reconstruction and hadronic showers behaviour in reasonable agreement data/MC for ν_μ CC events



Muon momentum

Track length x density (range for muon id)

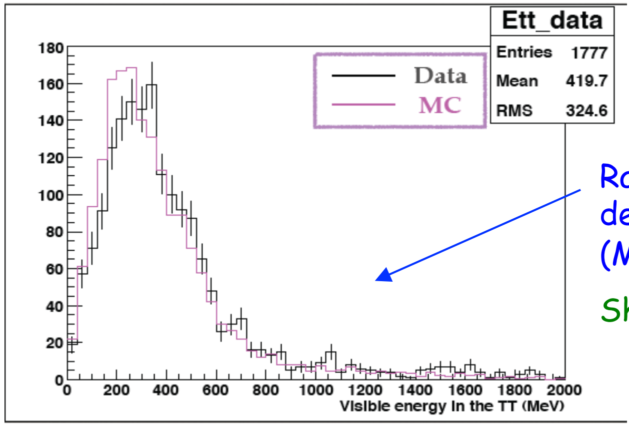


Muon identification:

✓Range cut

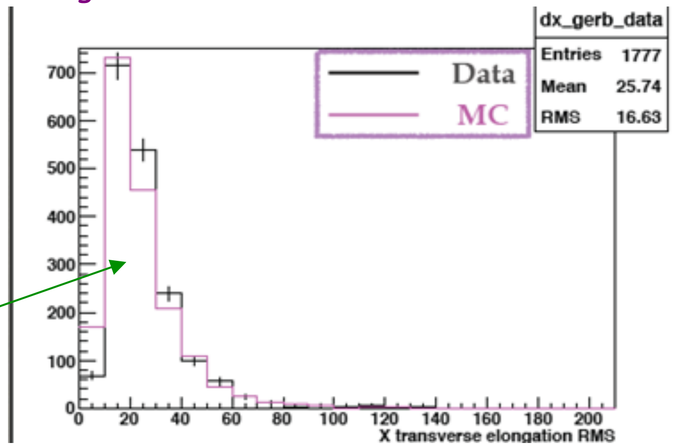
✓Range vs momentum measured in bricks with MCS

✓Best brick-ED angular matching



Raw hadronic energy deposited in TT scintillator (MeV)

Shower transverse profile

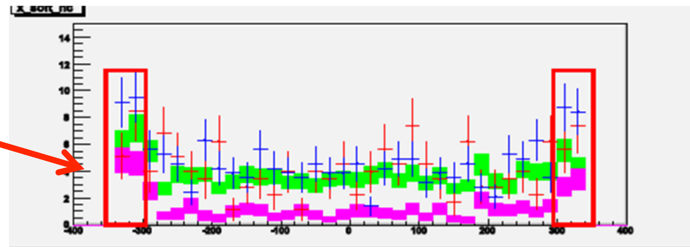


NC/CC ratio measurement after removal of external bck accumulation at target borders:

Data 2008: NC/CC= 0.230 ± 0.014 (stat.)

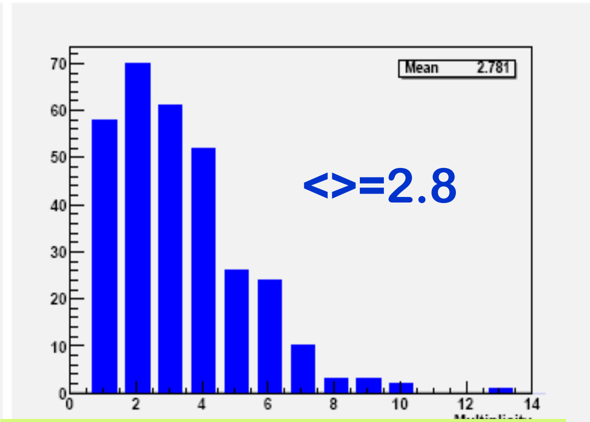
Data 2009: NC/CC= 0.230 ± 0.009 (stat.)

MC: NC/CC= 0.236 ± 0.005 (stat.)

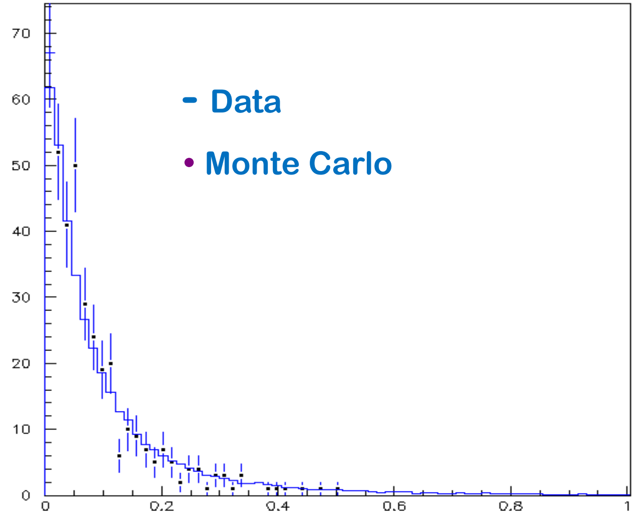


Reconstructed tracks and momenta in bricks

Reconstructed tracks at the primary vertex for ν_μ CC events



Event track multiplicity distribution



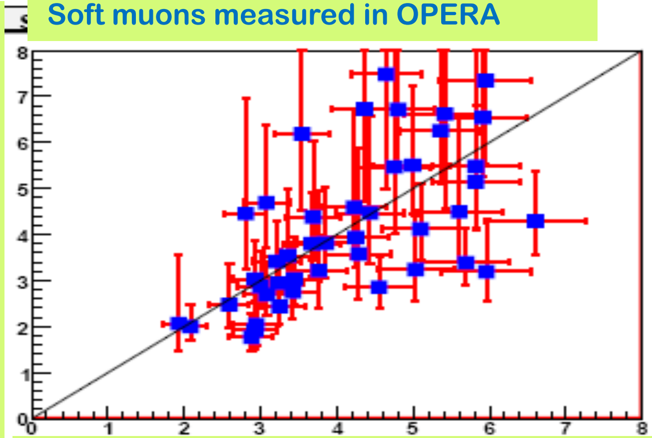
Track slope (rad)

Muon slopes measured at primary vertex compared to MC

(at generator level !)

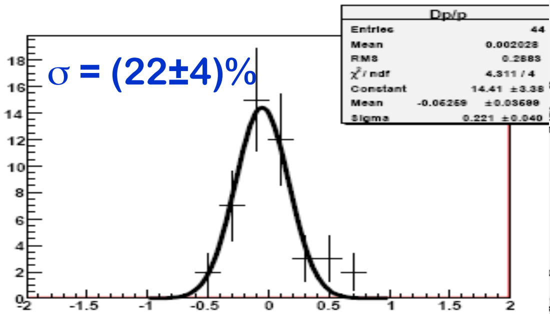
MCS measurement of soft muons (p<6 GeV) in order to validate the technique for kinematical measurements and compare to momenta reconstructed with ED

Soft muons measured in OPERA



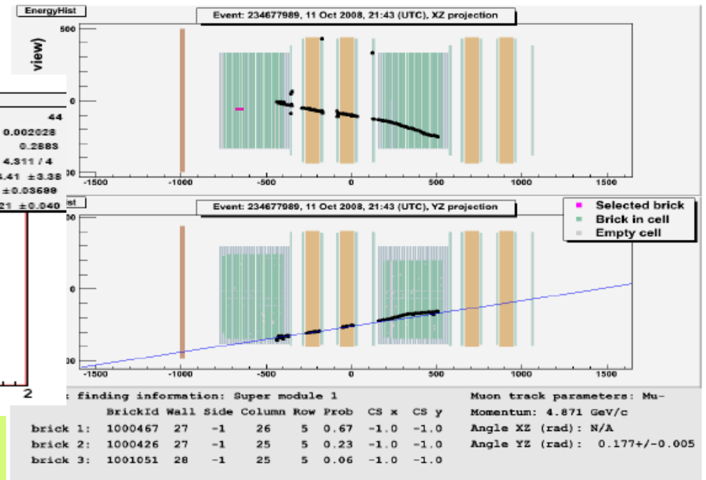
Momentum from MCS (GeV/c)

Momentum from electronic detector (GeV/c)



$\frac{\text{Pmcs-Pspectro}}{\text{Pspectro}}$

$\frac{\Delta p}{p}$



Decay search

Scanning activities (till fall 2009) were focused on vertex location

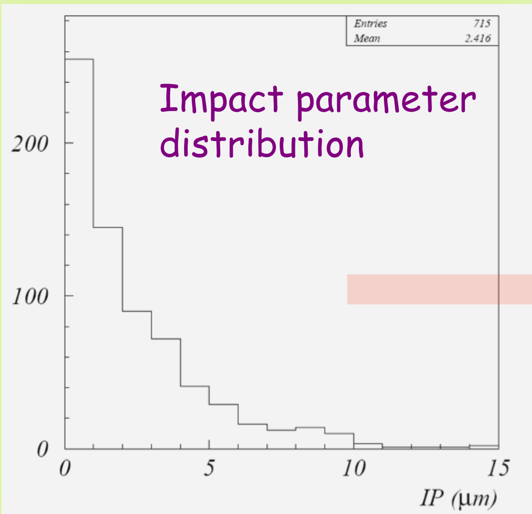
→ A systematic DECAY SEARCH was started on 2008 and 2009 data in order to find all possible decay topologies

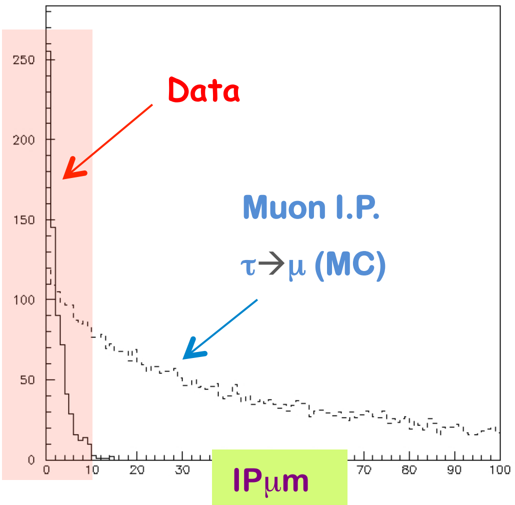
1) improvement of the vertex definition and IP distribution

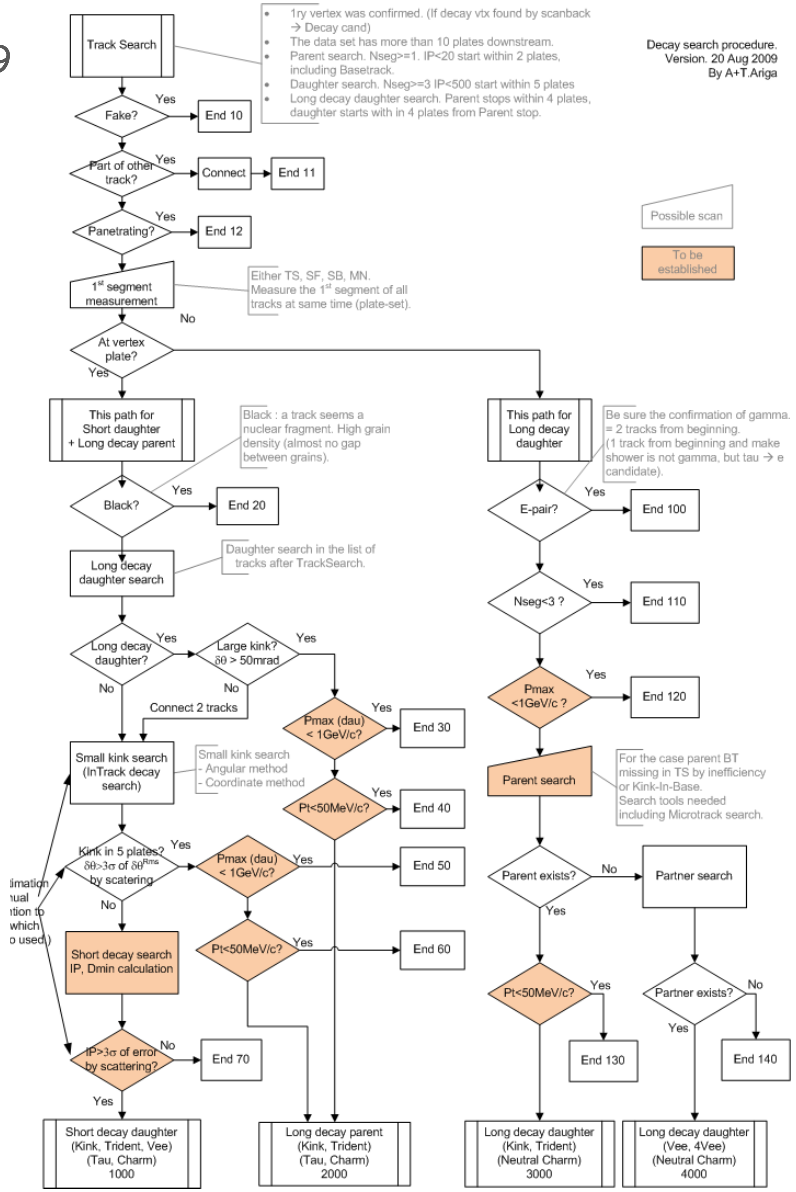
2) detection of possible kink topologies (on tracks attached to primary vertex)

3) search for extra tracks from decays not attached to primary vertex

20 charm candidates were found so far (in good part with the scan-back and vertex location procedures).
Charm events are the control sample for decay search
→ completion of systematic decay search for final evaluation







Events location summary for 2008 run

	0mu	1mu	All
Events predicted by the electronic detector	406	1292	1698
Found in CS	271	1045	1316
Vertices located in bricks	151	792	943
Vertices located in dead materials	6	38	44
Interactions in the upstream brick	6	33	39

Events location summary for 2009 run (in progress)

	0mu	1mu	All
Events predicted by the electronic detector	865	2297	3162
Extracted CS	829	2211	3040
CS Scanned	666	1802	2468
Found in CS	376	1139	1515
Vertices located in bricks	67	371	438
Vertices located in dead materials	2	11	13
Interactions in the upstream brick	3	36	39

About 1400 neutrino interaction vertices localized

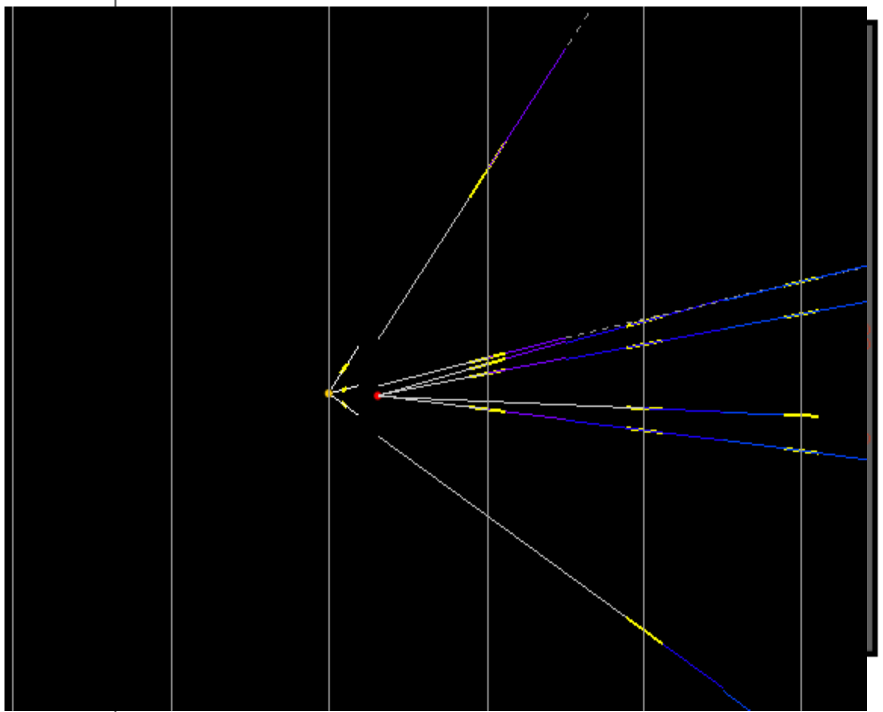
Topological identification and kinematical confirmation of a charm event

A D^0 4 prongs decay candidate:

All units are in microns !

Event 234654975

Brick 85405



VERTEX 1

	Impact Parameter
Track 1	1,36
Track 2	0,88
Track 7	0,51

X	66716,60
Y	49892,8
Z	90,9

Primary vertex

VERTEX 2

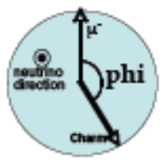
	Impact Parameter
Track 3	1,13
Track 4	1,81
Track 5	1,99
Track 6	1,39

X	66710,10
Y	49899
Z	403,9

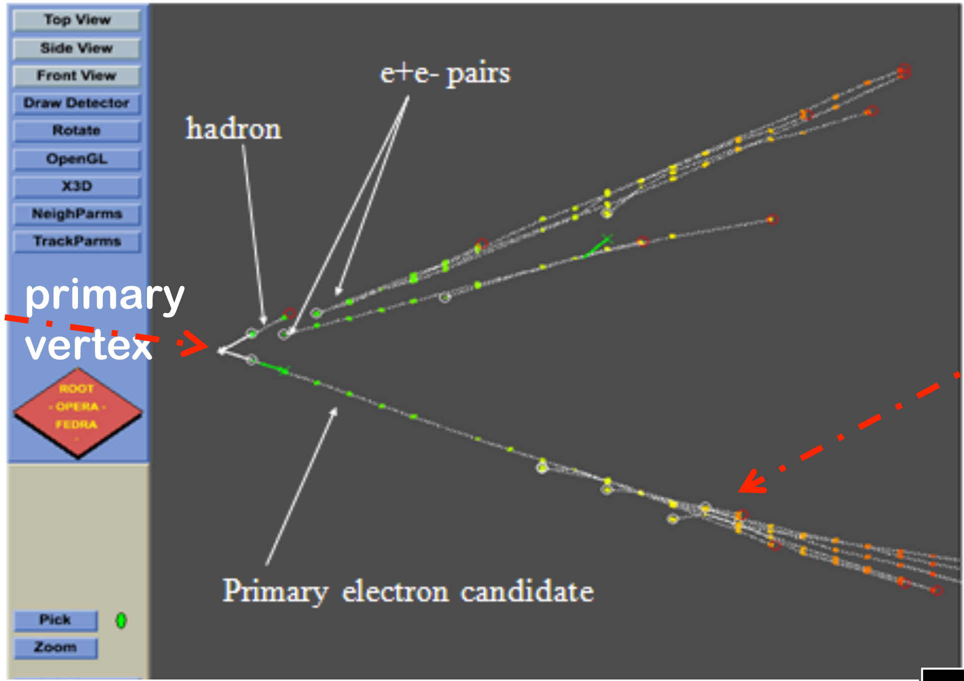
Decay vertex

D^0

Tx	Ty	Flight Length (μm)	phi	minimum mass (GeV/c²)
-0,0207	0,0198	313,1	173,2°	1,7



Electrons and photons reconstruction



A ν_e CC interaction candidate

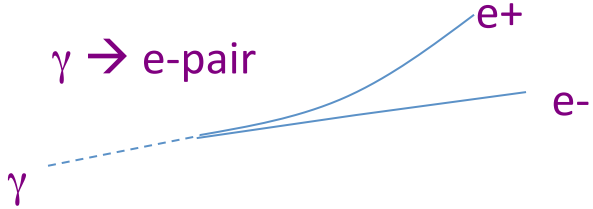
electromagnetic shower

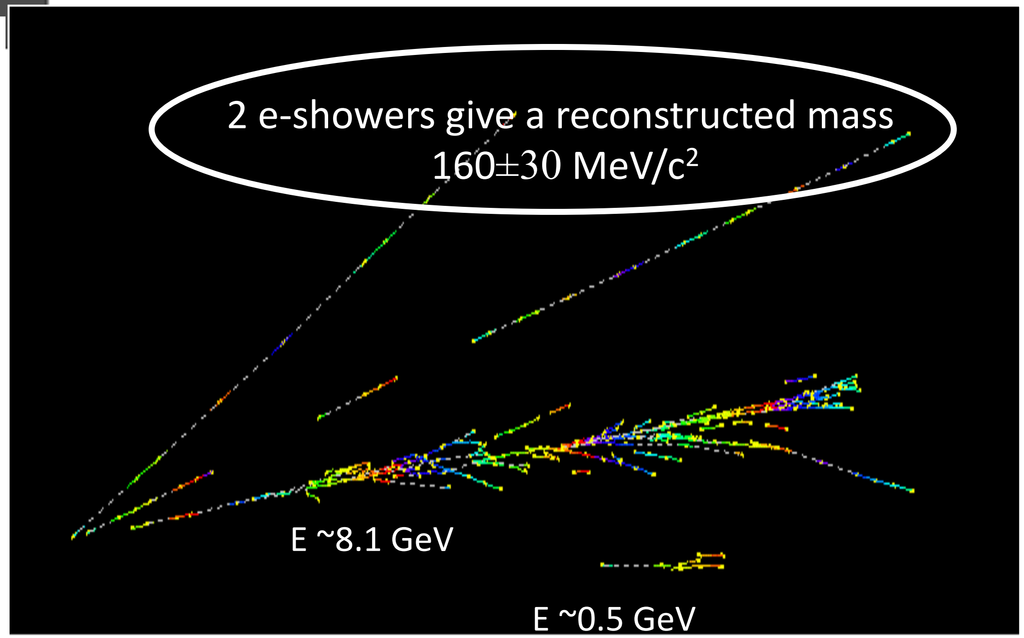
A ν_μ CC interaction with π^0 production

70% of 1-prong hadronic τ decays include one or more π^0 → important to detect gamma from tau decays to improve S/N.

Gamma detection:

- **detection of shower**
- **detection e-pair at start point**

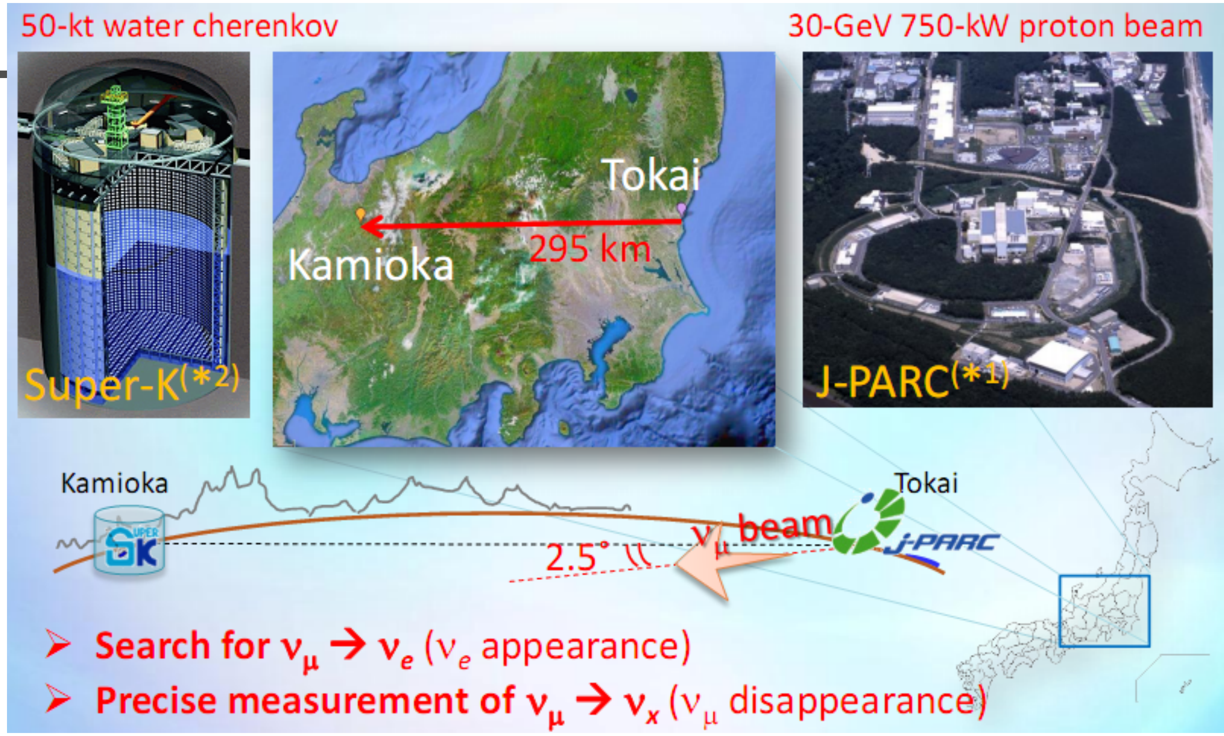




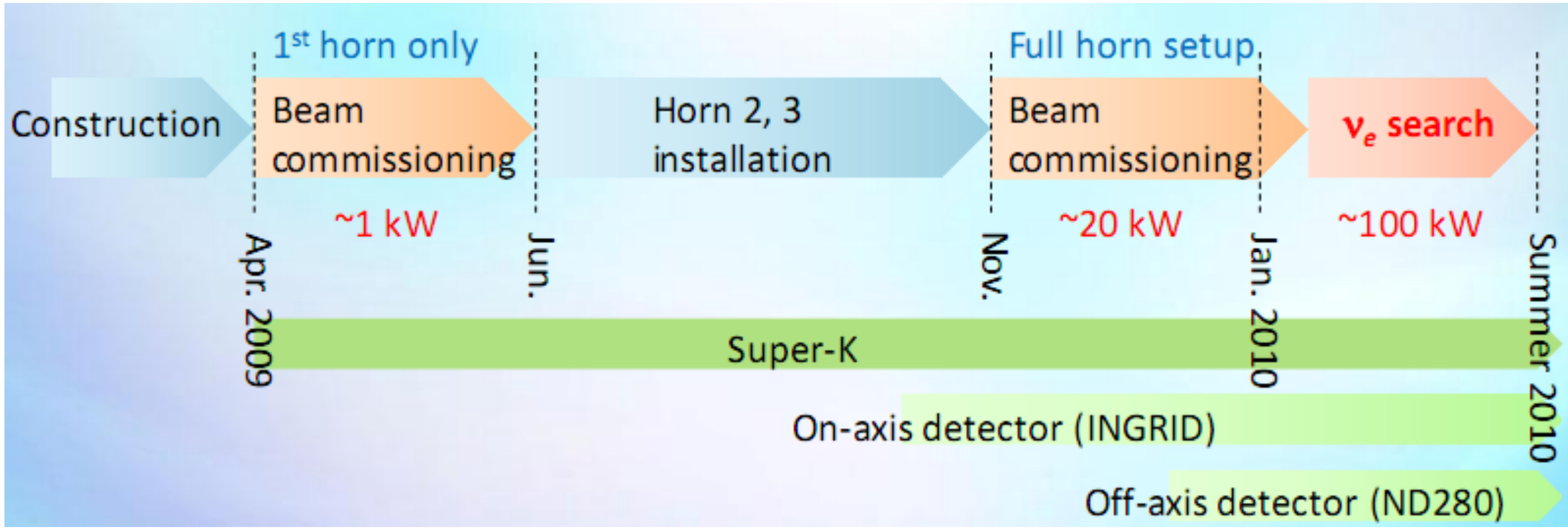
OPERA summary

- OPERA has taken data in 2008 and 2009 for 5.3E19 pot, proving the full chain of events handling/analysis
- Electronic detectors performance reliable and well understood
- A systematic decay search was started on all 2008 (and then 2009) events in order to find all possible decay topologies
- Several charm events found as expected
- Global analysis well in progress, ongoing studies on events kinematics and hadronic interactions background
- The 2010 run will start on the 29th April → hoping to achieve this year the nominal CNGS performance
- No tau signal seen yet, stay tuned !

T2K

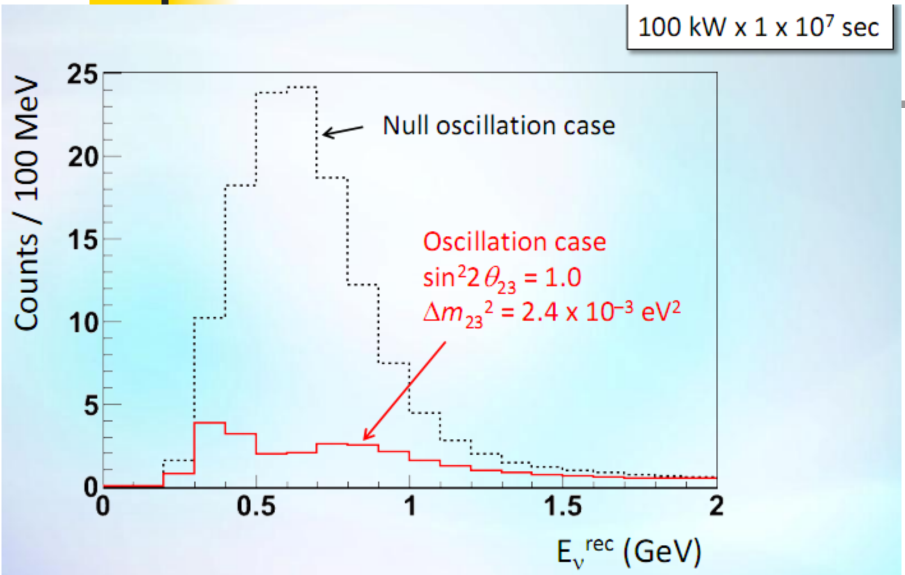


50-kt water cherenkov
30-GeV 750-kW proton beam
Super-K(*2)
Tokai
Kamioka
295 km
J-PARC(*1)
Kamioka
Tokai
ν_μ beam
2.5°
J-PARC
➢ Search for $\nu_\mu \rightarrow \nu_e$ (ν_e appearance)
➢ Precise measurement of $\nu_\mu \rightarrow \nu_x$ (ν_μ disappearance)



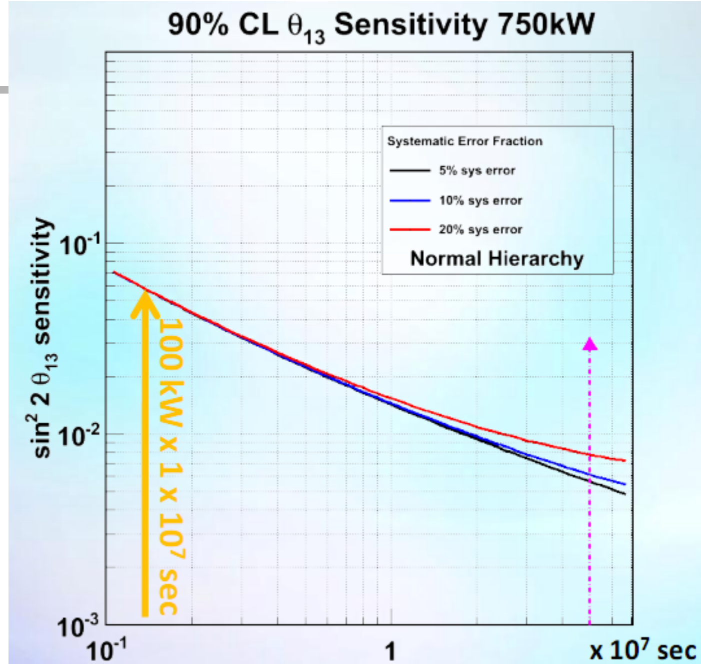
1st horn only
Full horn setup
Construction
Beam commissioning
Horn 2, 3 installation
Beam commissioning
ν_e search
~1 kW
~20 kW
~100 kW
Apr. 2009
Jun.
Nov.
Jan. 2010
Summer 2010
Super-K
On-axis detector (INGRID)
Off-axis detector (ND280)

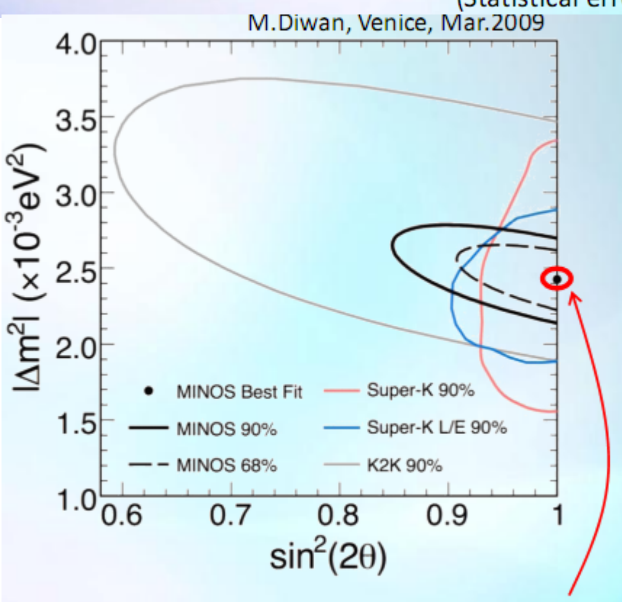
T2K prospects for 2010 and beyond



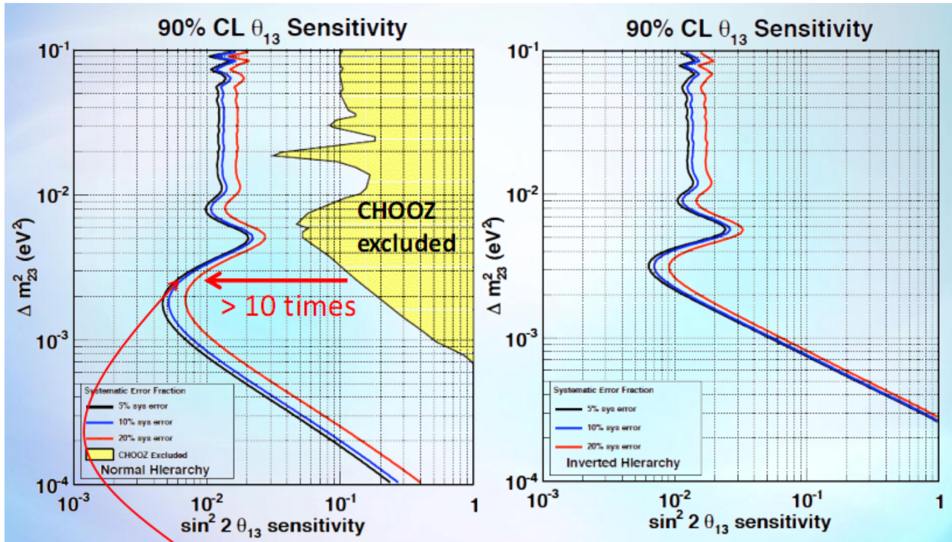
→ $\delta(\sin^2 2\theta_{23}) \approx 0.1$, $\delta(\Delta m_{23}^2) \approx 4 \times 10^{-4}$ eV^2 (90% CL)

(Statistical error only)





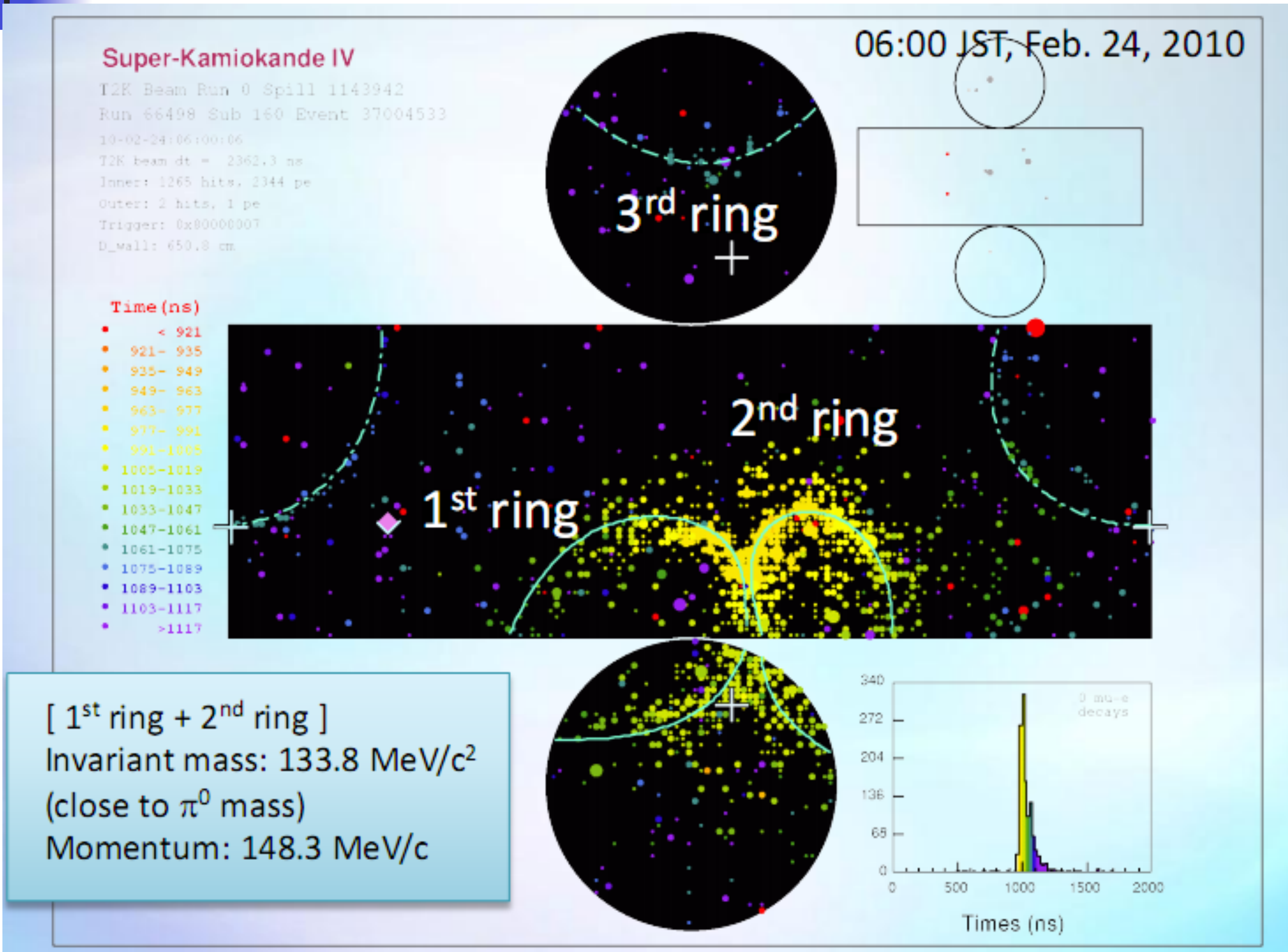
$\delta(\sin^2 2\theta_{23}) \approx 0.01$, $\delta(\Delta m_{23}^2) < 10^{-4}$ eV^2



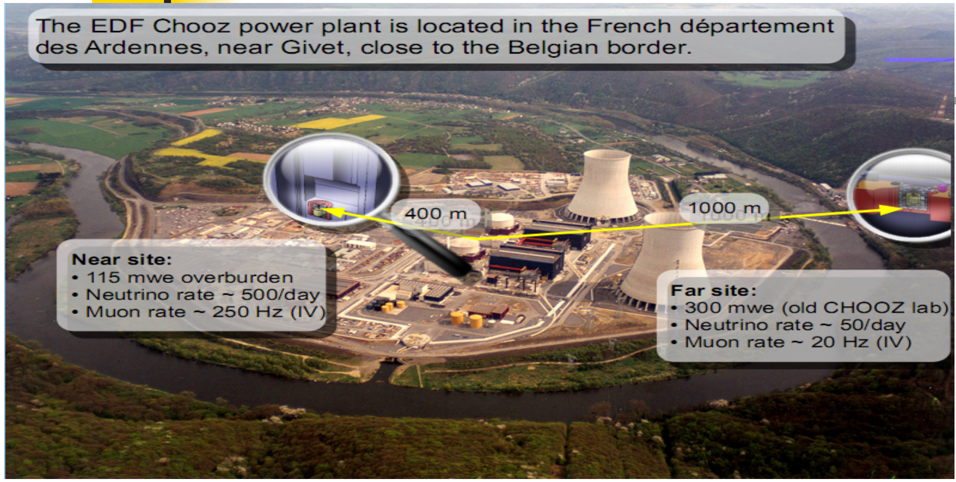
0.0060 @ $\Delta m_{23}^2 = 2.4 \times 10^{-3}$ eV^2

(for a 10% sys. error)

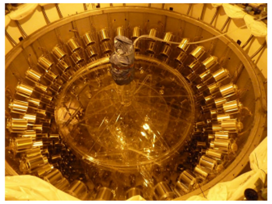
T2K 1st neutrino event in SK



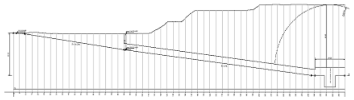
Reactor experiments



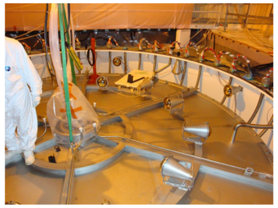
- Far detector closing imminent
  - Electronics installation ongoing
  - Awaiting fluid delivery
  - Commissioning run ~ May
  - In parallel: closing of steel shield and outer veto installation
- Near laboratory construction starting
  - Fully funded
  - Design approved by EDF
  - To be finished till end 2010



Acrylics integration, 10/2009

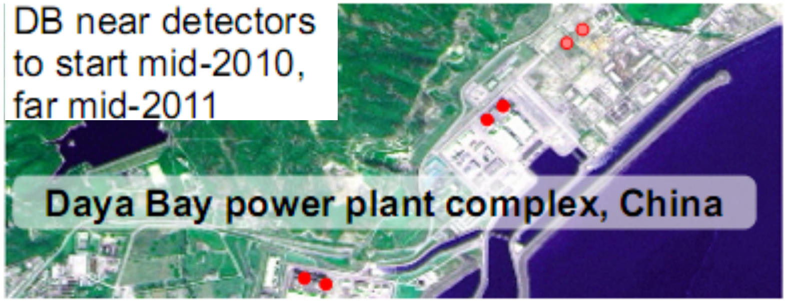


Side view of near lab planning sketch



Top veto PMT installation, 1/2010

DB near detectors to start mid-2010, far mid-2011

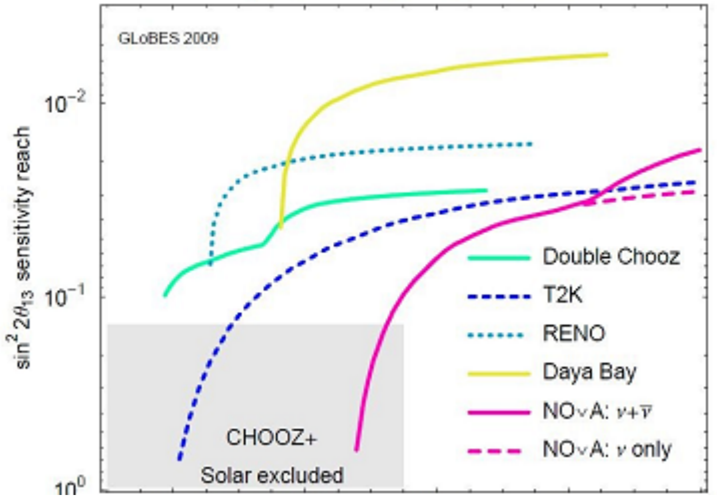


Reno expects to start mid-2010

Power $[GW_{th}]$	L_{near} [m]	L_{Far} [m]	M_{target} [t]	s_{stat} [%]	s_{syst} [%]	$\sin^2 2\theta_{13}$ > (90 % CL)
8.6	400	1050	8.3	0.5	0.6	0.03
17.3	290	1380	16	0.3	0.5	0.02
17.4	360 (500)	1990 (1620)	80	0.2	0.4	0.01

Double Chooz   Reno   Daya Bay

$\sin^2 2\theta_{13}$ sensitivity limit (NH, 90% CL)



Future plans

How to discover CP violation and perform PMNS precision measurements

What approach in Europe?

- Many ideas have been put on the market
  - Different accelerator technologies (SuperBeam, NuFact, BB)
  - Different baselines
  - Different detector technologies
- We think that Phase II in Europe should be part of a common effort of the Elementary Particle community
  - ☞ Exploit as much as possible technologies common to other fields (e.g. LHC upgrades, EURISOL)
  - ☞ Exploit already existing infrastructure (e.g. LNGS halls)
  - ↳ Costs reduction!

For an extensive review

e-Print: **arXiv:0912.3372, to be published on La Rivista del Nuovo Cimento**

European facilities for accelerator neutrino physics: perspectives for the decade to come

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[b] I.N.F.N., Sezione di Padova, Padova, Italy
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Abstract

Very soon a new generation of reactor and accelerator neutrino oscillation experiments - Double Chooz, Daya Bay, Reno and T2K - will seek for oscillation signals generated by the mixing parameter θ_{13}. The knowledge of this angle is a fundamental milestone to optimize further experiments aimed at detecting CP violation in the neutrino sector. Leptonic CP violation is a key phenomenon that has profound implications in particle physics and cosmology but it is clearly out of reach for the aforementioned experiments. Since late 90's, a world-wide activity is in progress to design facilities that can access CP violation in neutrino oscillation and perform high precision measurements of the lepton counterpart of the Cabibbo-Kobayashi-Maskawa matrix. In this paper the status of these studies will be summarized, focusing on the options that are best suited to exploit existing European facilities (firstly CERN and the INFN Gran Sasso Laboratories) or technologies where Europe has a world leadership. Similar considerations will be developed in more exotic scenarios - beyond the standard framework of flavor oscillation among three active neutrinos - that might appear plausible in the occurrence of anomalous results from post-MiniBooNE experiments or the CNGS.

$\theta_{13} \geq 8°$ ($Sin^2 2\theta_{13} \geq 0.08$)				
Source	**Detector technology in Hall C**	**Detector technology in an extended site at LNGS**	**Schedule**	**Competitors**
Conventional Beam	OPERA: prolongation of the run with an upgraded CNGS	LAr technology Mass 20 kton	>2012	T2K and Nova
θ_{13}>~2° ($Sin^2 2\theta_{13}$>~0.005)				
Conventional beam	---	---		Mton Water Cerenkov in Japan and/or USA
BetaBeam high-Q	Magnetized iron calorimeter Mass 40 kton	LAr technology Mass 100 kton	~2020	
Neutrino Factory based at RAL	Magnetized iron calorimeter Mass 40 kton	LAr technology+Spectrometer Mass 100 kton	~2020	Wordwide (INO, NuFact in USA)
Neutrino Factory based at CERN	Detector à la OPERA Mass 5-10 kton LAr technology+Spectrometer Mass 5-10 kton		~2020	Wordwide (INO, NuFact in USA)
θ_{13}~<2° ($Sin^2 2\theta_{13}$~<0.005)				
In this scenario the options that could be exploited are: Neutrino Factory, High-Q BetaBeam				
Outside the standard framework there is room for low mass LAr detectors to clarify the miniBooNE low energy excess and check the still alive LSN oscillation signal: MicroBooNE @FNAL on the BooNE and NUMI beams, DoubleLAr recently proposed to run on a refurbished PS neutrino beam. OscSNS will exploit the SNS neutrino beam with a oil–scintillator detector to check the LSND signal				

Conclusion

- The last decade has established the occurrence of neutrino oscillations and seen enormous progresses in the measurement of the PMNS matrix. Next round of experiments is rather challenging and demands for huge investments and worldwide collaborations
- Present: INFN has
  - the leadership in the solar sector studies with Borexino;
  - the opportunity to announce with OPERA the first evidence of neutrino oscillation in the appearance channel;
  - unfortunately the contribution to θ_{13} quest is marginal
- Future: although the time-scale is rather long (≈2020), INFN has the detector technologies, the skill and the infrastructures to play a leading role
- E. Fermi "invented" the neutrino and B. Pontecorvo the neutrino oscillations phenomenon. It is a must for Italian Physics Community to play a major role in future neutrino experiments