The first result of the Double CHOOZ experiment.

Sergey Sukhotin – NRC “Kurchatov Institute”

on behalf of Double CHOOZ collaboration.

December-2011 Dubna

Neutrino oscillations

U=matrice PMSN : 3 angles,1 CP phase + 2 mass differences

atmospheric ν   leptonic ~~CP~~ phase δ   solar ν

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \begin{pmatrix}1&0&0\\ 0&c_{23}&s_{23}\\ 0&-s_{23}&c_{23}\end{pmatrix}\begin{pmatrix}c_{13}&0&s_{13}e^{-i\delta}\\ 0&1&0\\ -s_{13}e^{+i\delta}&0&c_{13}\end{pmatrix}\begin{pmatrix}c_{12}&s_{12}&0\\ -s_{12}&c_{12}&0\\ 0&0&1\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

Super-K+K2K+MINOS
P(νμ→νμ)

Solar+KAMLAND
P(νe→νx)

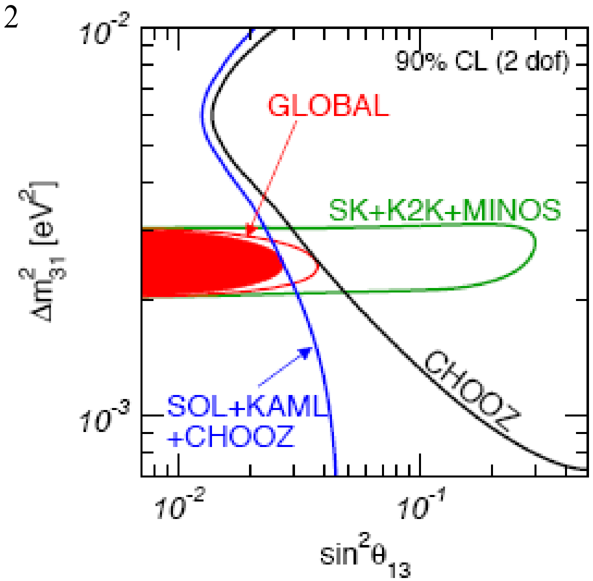
CHOOZ
sin2(2θ13)<0.2

$$\sin^2\Theta_{23} = 0.51 \pm 0.06$$

$$\Delta m^2_{31} = (2.45 \pm 0.09)\times 10^{-3}\, eV^2$$

$$\sin^2\Theta_{12} = (0.312^{+0.017}_{-0.015})$$

$$\Delta m^2_{21} = (7.59^{+0.20}_{-0.18})\times 10^{-5}\, eV^2$$



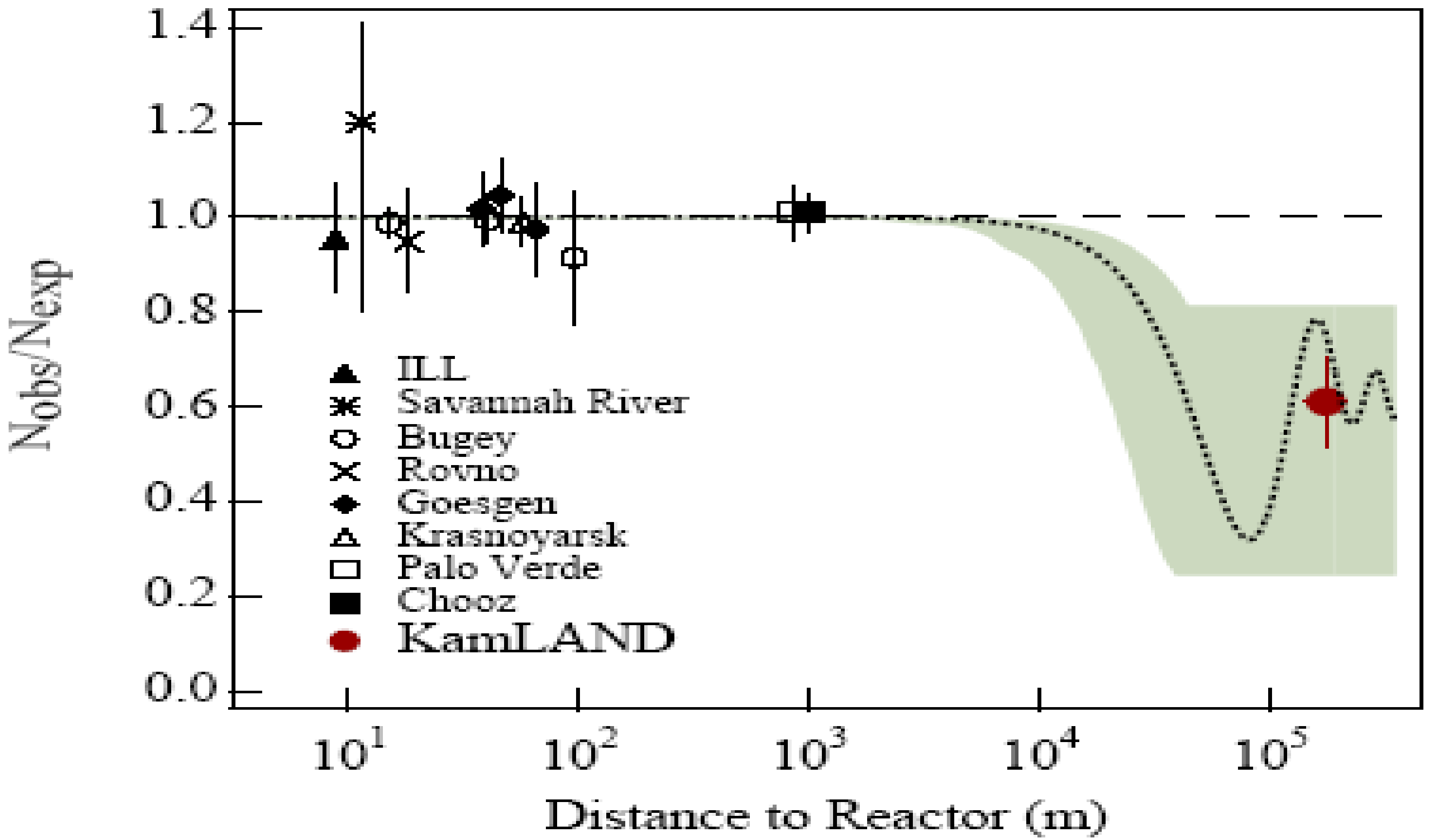
arXiv:1103.0734v2

The future quest for θ13

Accelerators

Reactors

50 years of the neutrino experiments at nuclear reactors.

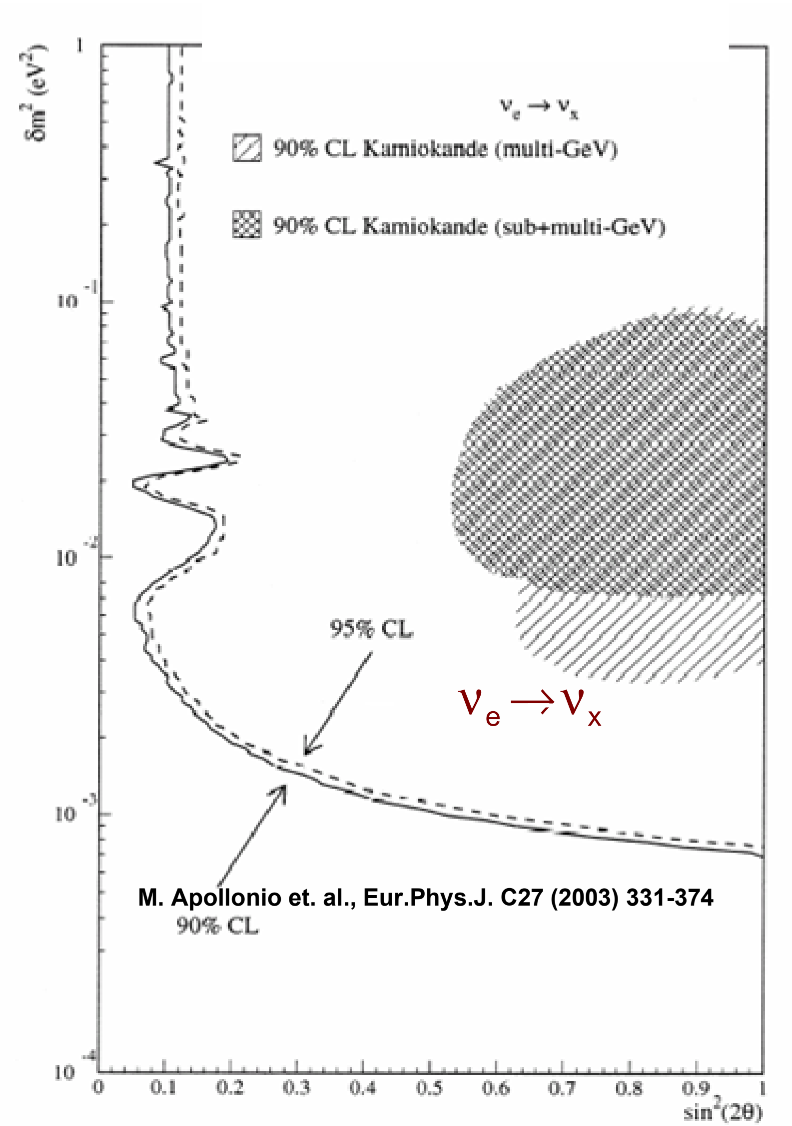


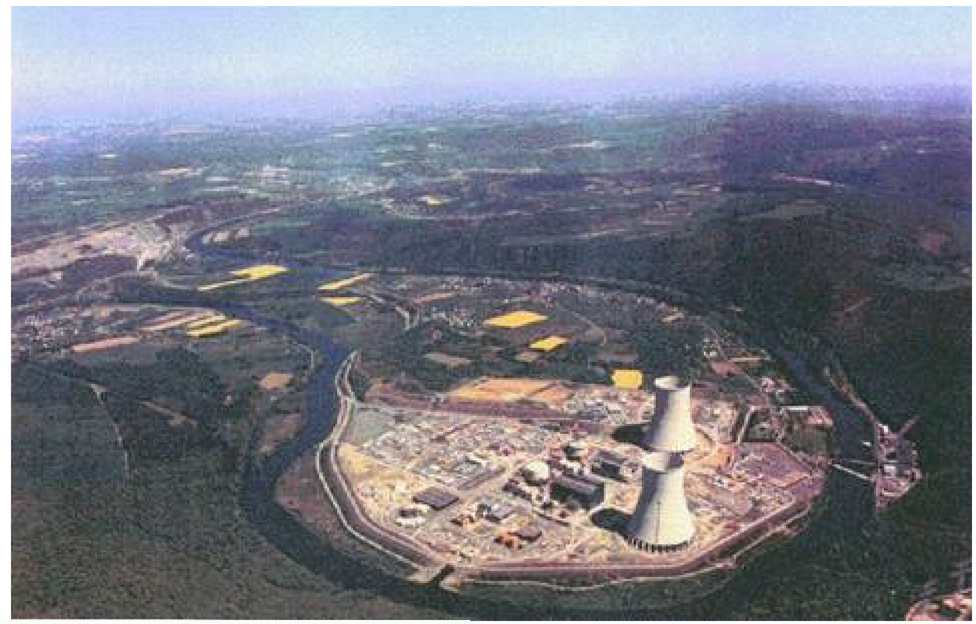
Chooz experiment (1995-1998)

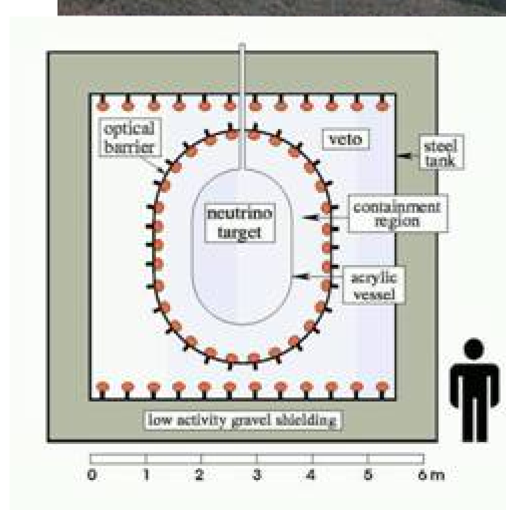
R = 1.01 ± 2.8% (stat) ± 2.7% (syst.)

Disappearance experiment
P=8.4GW. L=1.05 km. M=5 t @300 m.w.e.

$$\bar{\nu}_e \rightarrow \bar{\nu}_e$$







@Δm^2_{13} = 2*10^{-3} eV^2

$\sin^2(2\theta_{13}) < 0.2$

(90% C.L)

Data taking - CHOOZ experiment

Reactor 1	Reactor 2	Time (days)
ON	**ON**	**64,3**
ON	**OFF**	**85,8**
OFF	**ON**	**49,5**
OFF	**OFF**	**142,5**

Background: (2.02 ± 0.12) ev./day   Effect / Bkg > 10

Main problem: instability of the Gd-loaded scintillator

New concept of the reactor experiment:

how to improve the results of CHOOZ

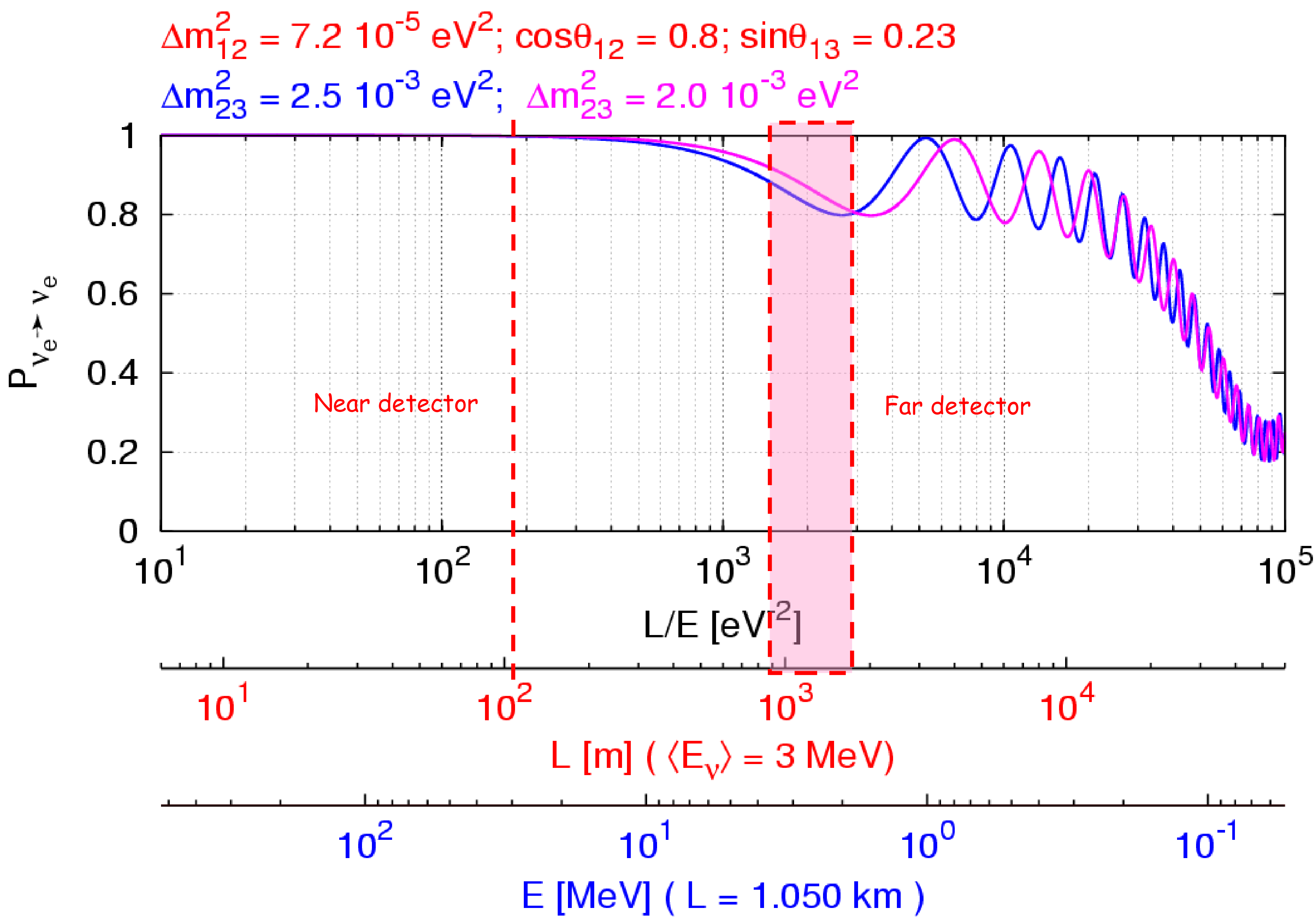
L.A.Mikaelyan and V.VSinev arXiv:hep-ex/9908047v1 11-Aug-1999
Talk given at the International Conference on Non-Accelerator New Physics, NANP-99, Dubna, (28/06-03/07)-1999.

The White Paper «A new reactor neutrino experiment to measure θ_{13}» hep-ex/0402041 (2002)

Double CHOOZ Proposal hep-ex/0606025 v2 20-June-2006

Two identical detectors

$$P(\bar{\nu}_e \to \bar{\nu}_e) = 1 - \sin^2 2\theta_{13} \sin^2 \frac{\Delta m_{13}^2 L}{4E}$$



Double Chooz systematic uncertainties

		Chooz	Double-Chooz	
Reactor-induced	ν flux and σ	1.9 %	<0.1 %	Two "identical" detectors, Low bkg
	Reactor power	0.7 %	<0.1 %	
	Energy per fission	0.6 %	<0.1 %	
Detector - induced	Solid angle	0.3 %	<0.1 %	Distance measured @ 10 cm + monitor core barycenter
	Volume	0.3 %	0.2 %	Precise control of detector filling
	Density	0.3 %	<0.1 %	Accurate T control (near/far)
	H/C ratio & Gd concentration	1.2 %	<0.1 %	Same scintillator batch + Stability
	Spatial effects	1.0 %	<0.1 %	Identical detectors and monitoring
	Live time	-----	0.25 %	Special electronic systems and monitoring
Analysis	From 7 to 3 cuts	1.5 %	0.2 - 0.3 %	Simplified cuts due to detector design
	Total	2.7 %	< 0.6 %	

The Double Chooz Collaboration

Spokesman: Hervé de Kerret (APC)

France: APC Paris, CEA/Dapnia Saclay, Subatech Nantes, Strasburg

Germany: Aachen, MPIK Heidelberg, TU München, EKU Tübingen, Hamburg

Spain: CIEMAT Madrid

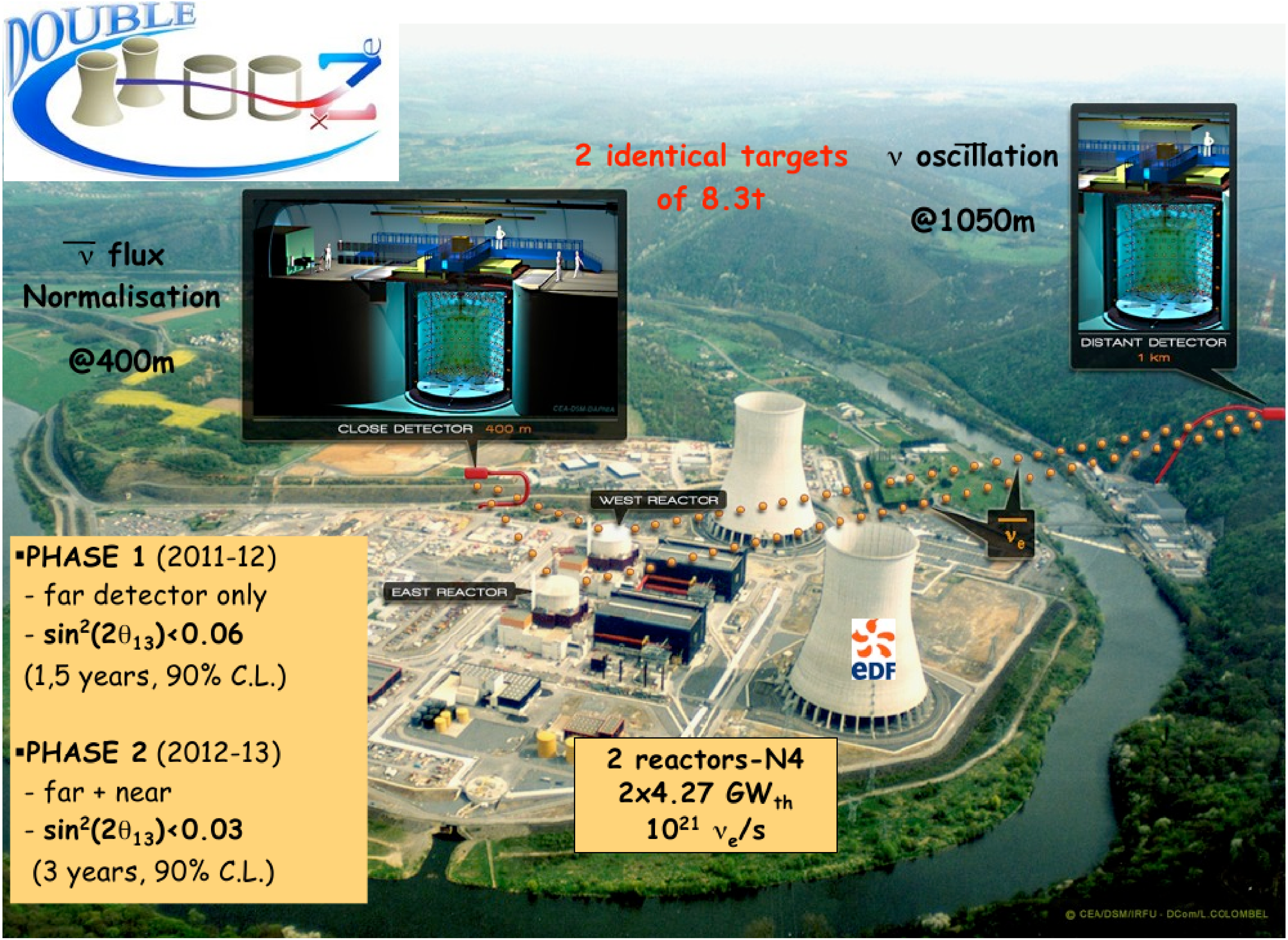
UK: Sussex

Japan: HIT, Kobe, Niigata, TGU, TIT, TMU, Tohoku

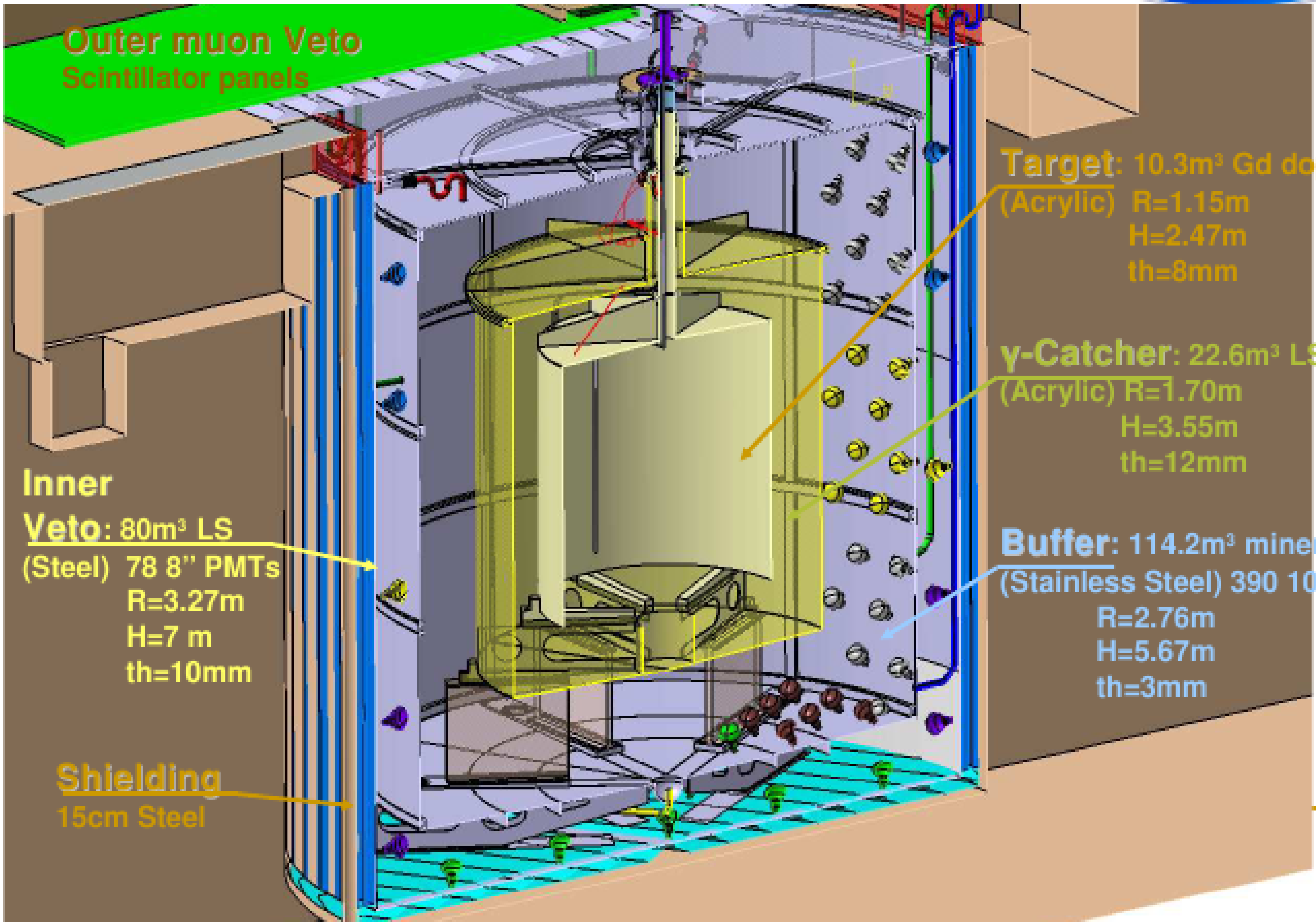
Russia: RAS, RRC Kurchatov Institute

USA: Alabama, ANL, Chicago, Columbia, Drexel, Illinois, Kansas, LLNL, LSU, Notre Dame, Sandia, Tennessee, UCD

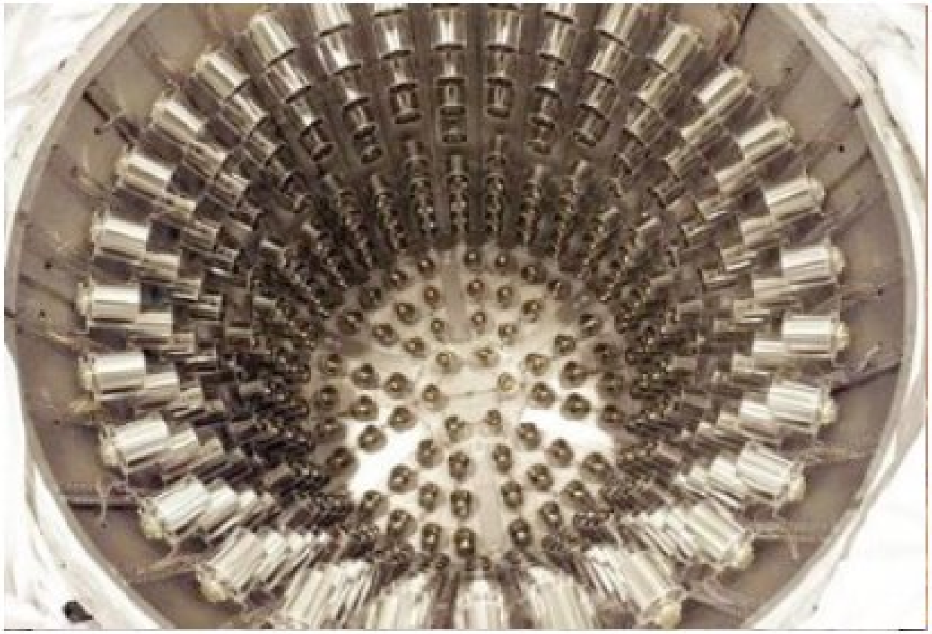
Brazil: CBPF, UNICAMP

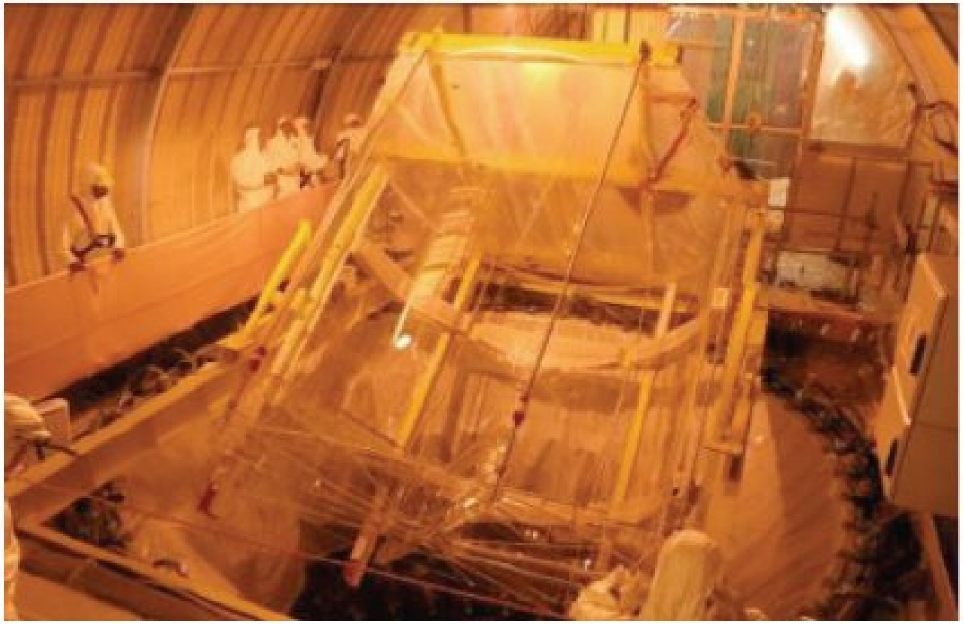

2 identical targets of 8.3t
ν oscillation
@1050m
$\overline{\nu}$ flux
Normalisation
@400m
CLOSE DETECTOR 400 m
DISTANT DETECTOR
1 km
WEST REACTOR
EAST REACTOR
$\overline{\nu}_e$
▪PHASE 1 (2011-12)
- far detector only
- $\sin^2(2\theta_{13})<0.06$
(1,5 years, 90% C.L.)
▪PHASE 2 (2012-13)
- far + near
- $\sin^2(2\theta_{13})<0.03$
(3 years, 90% C.L.)
2 reactors-N4
2x4.27 GW_{th}
10^{21} ν_e/s
eDF
© CEA/DSM/IRFU - DCom/L.COLOMBEL

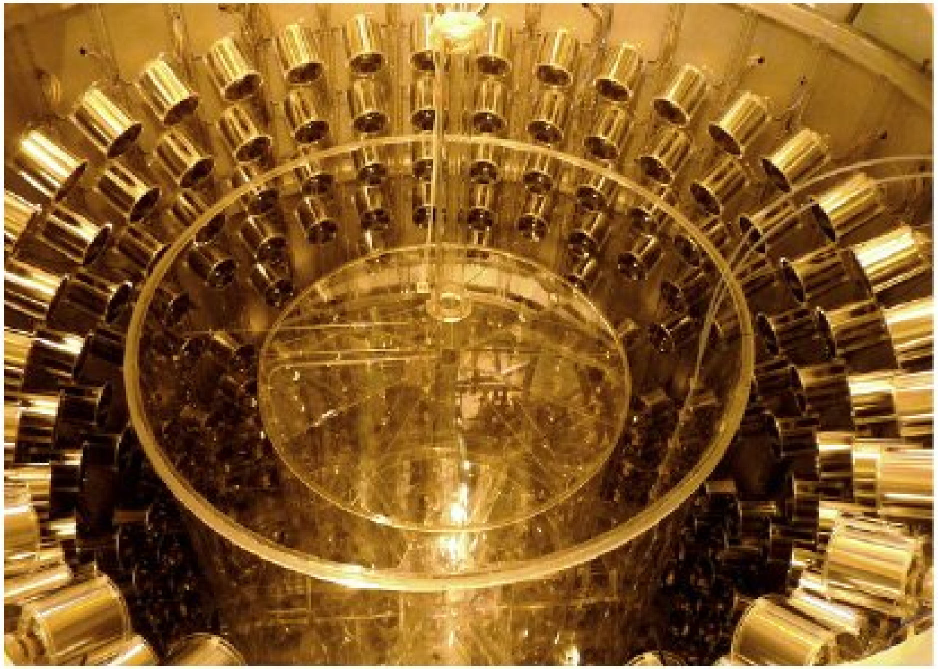
The Detector(s)



Far Detector Installation

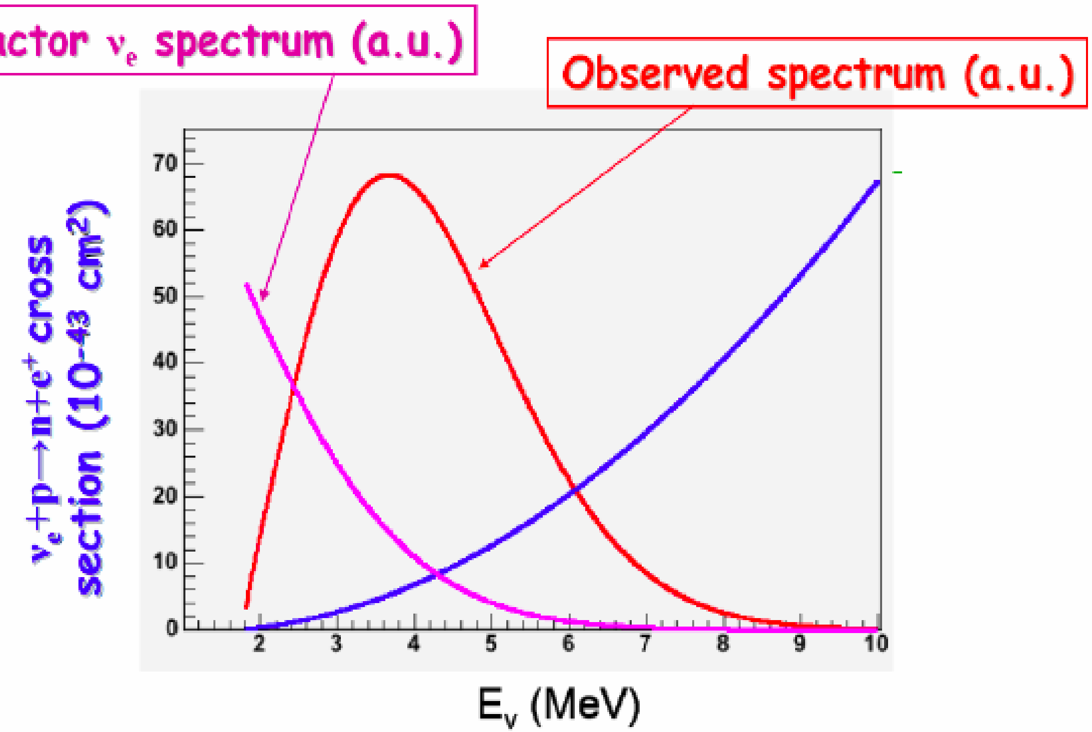






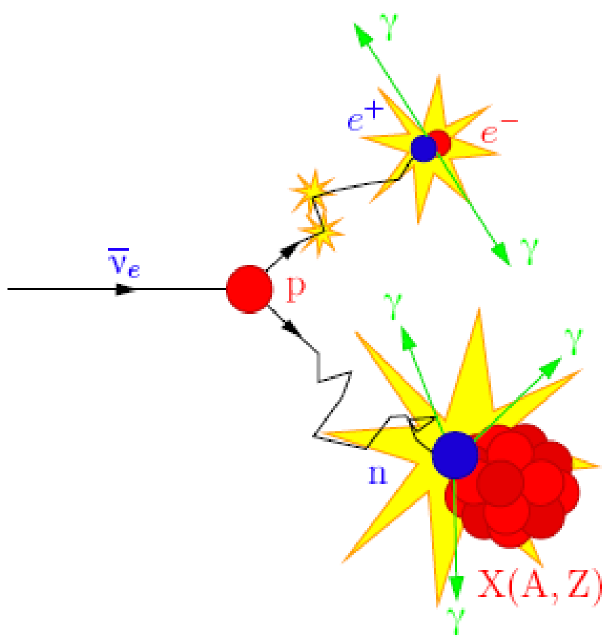
$\bar{\nu}_e$ detection at reactor experiments

P=8GW $\Rightarrow N_\nu \sim 10^{21} s^{-1}$ on all solid angle



Detection by "inverse beta"

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



Prompt photons from e^+ and two annihilation gammas (2 * 511 keV)

$E_{vis} = E_\nu$ - 0.78 MeV + $O(E_e/m_n)$

Delayed photons from **n** capture on dedicated nuclei (Gd)

$\Delta t \sim 30\ \mu s$ $\quad$ <E> ~ 8 MeV

Far detector status

- Filling of the detector was finished at the end of 2010.
- Detector commissioning is completed in April 2011.
- More than 100 full days of physics collected.
- Outer veto is installed and commissioned in May 2011.
- Singles rates (after vetoing muon-correlated events):

  ~10 Hz in the [0.7÷12] MeV - prompt signal

  < 0.01 Hz in the [6÷12] MeV - delayed signal

Antineutrino Candidates Selection

- Discard all triggers in 1 ms after each muon (mainly tagged by inner veto)
- Prompt signal within [0.7 – 12] MeV
- Delayed signal within [6 – 12] MeV
- Time coincidence window between prompt and delayed [2 – 100] μs
- Multiplicity condition:
  - No trigger (E > 500 keV) within 100 μs before prompt signal
  - Only one trigger (E > 500 keV) within 400 μs after prompt signal

Backgrounds

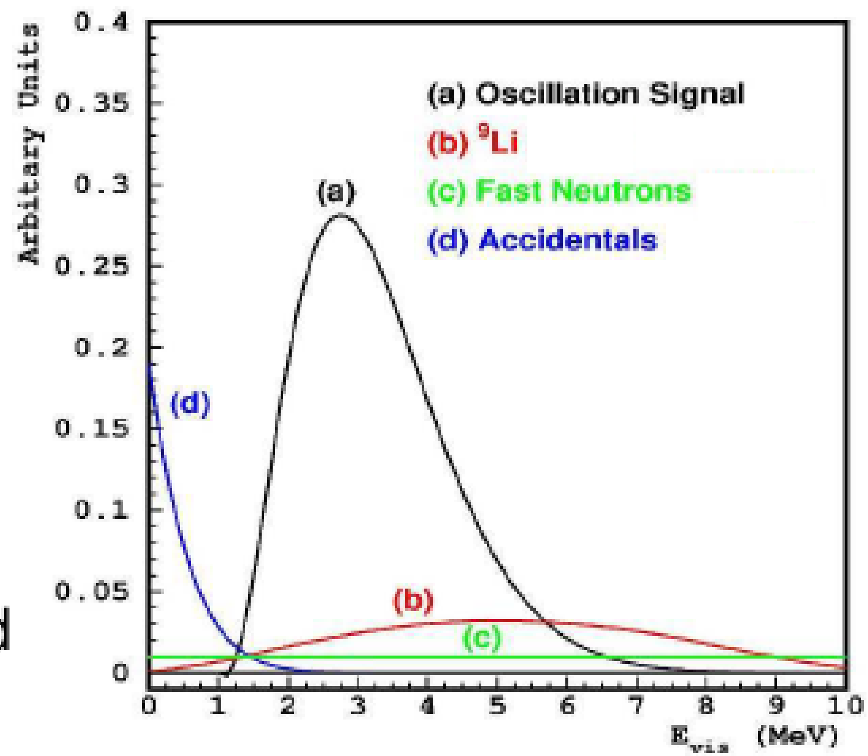
Accidental:

- e+-like signal: radioactivity from materials and surrounding rock.
- n signal: n from cosmic μ spallation, thermalized in detector and captured on Gd.

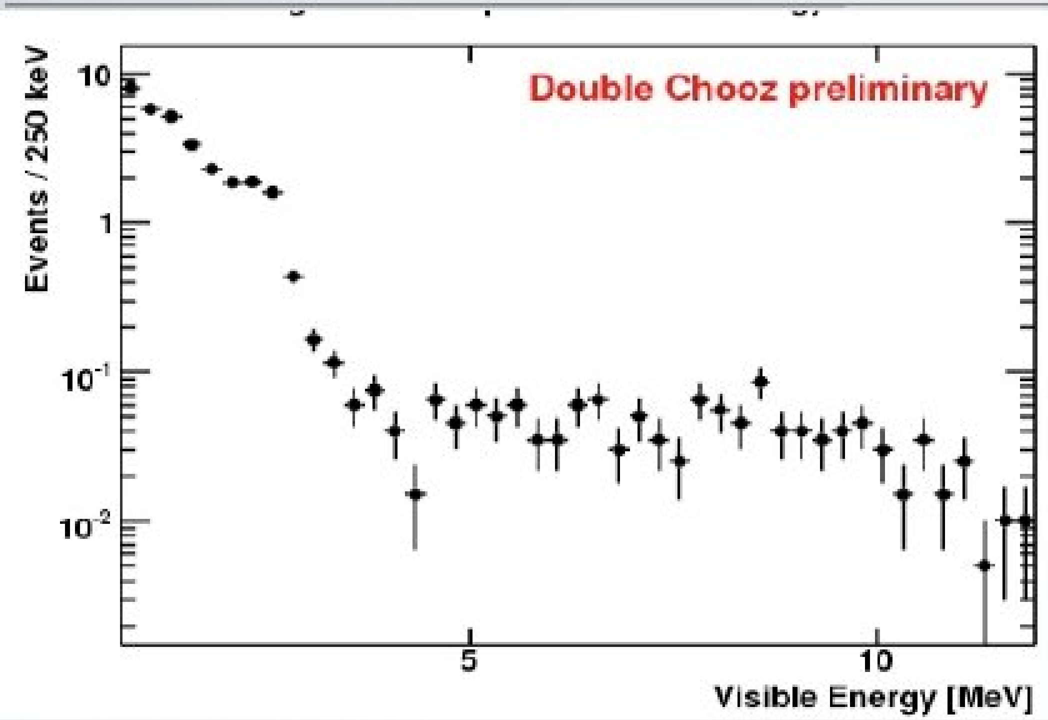
  Or another radioactivity event

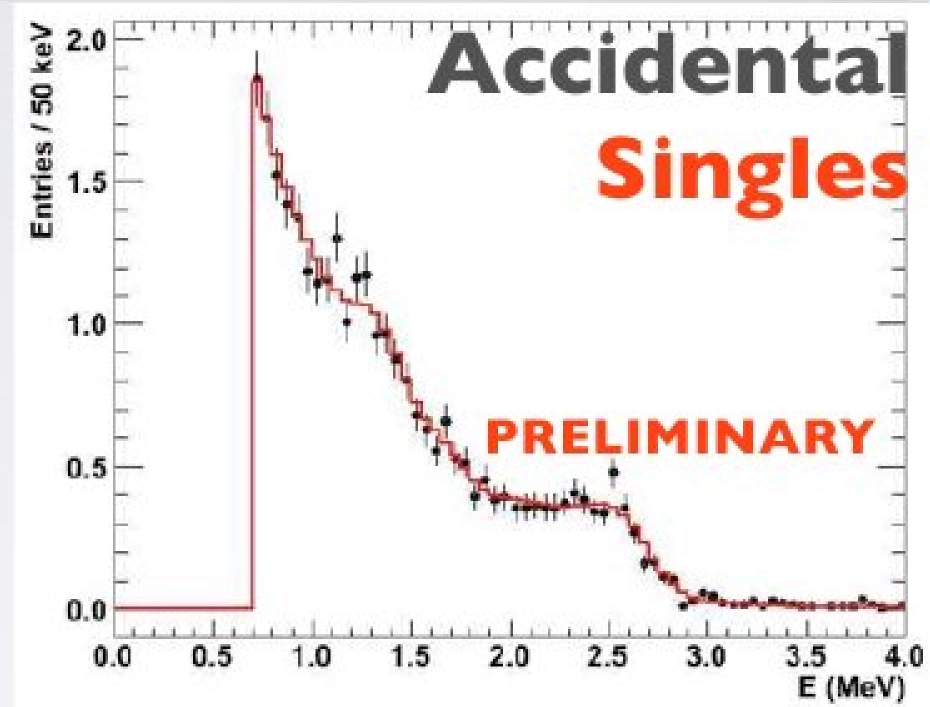
Correlated:

- fast n (by cosmic μ) recoil on p (low energy) and captured on Gd
- long-lived (^{9}Li, ^{8}He) β-decaying isotopes induced by μ



Accidental BG



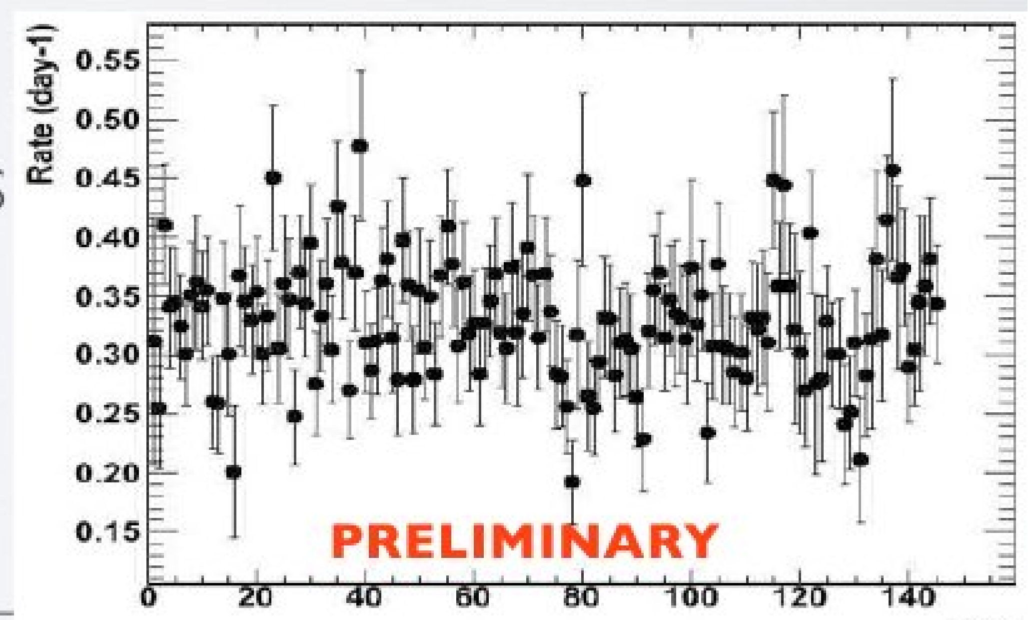


analysis method

off time-window from [1,100]ms

including multiplicity condition

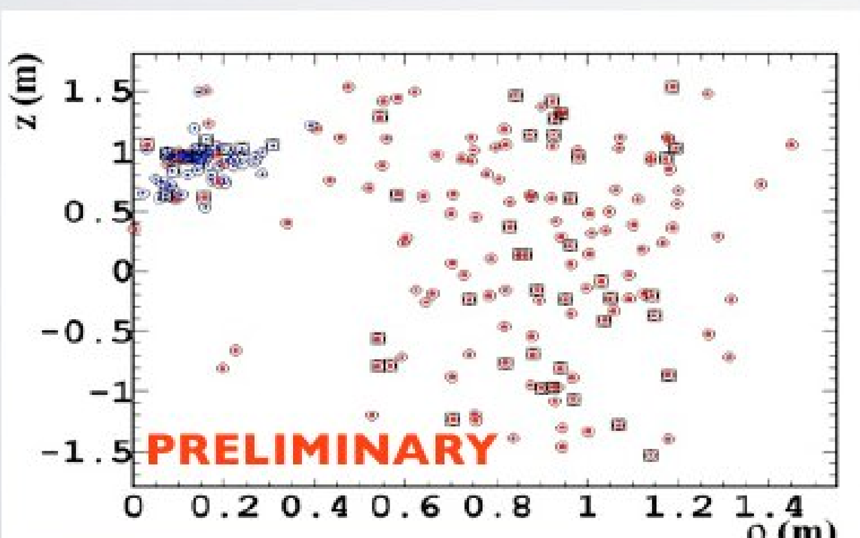
Rate=$(0.332\pm0.004)\mathrm{day}^{-1}$

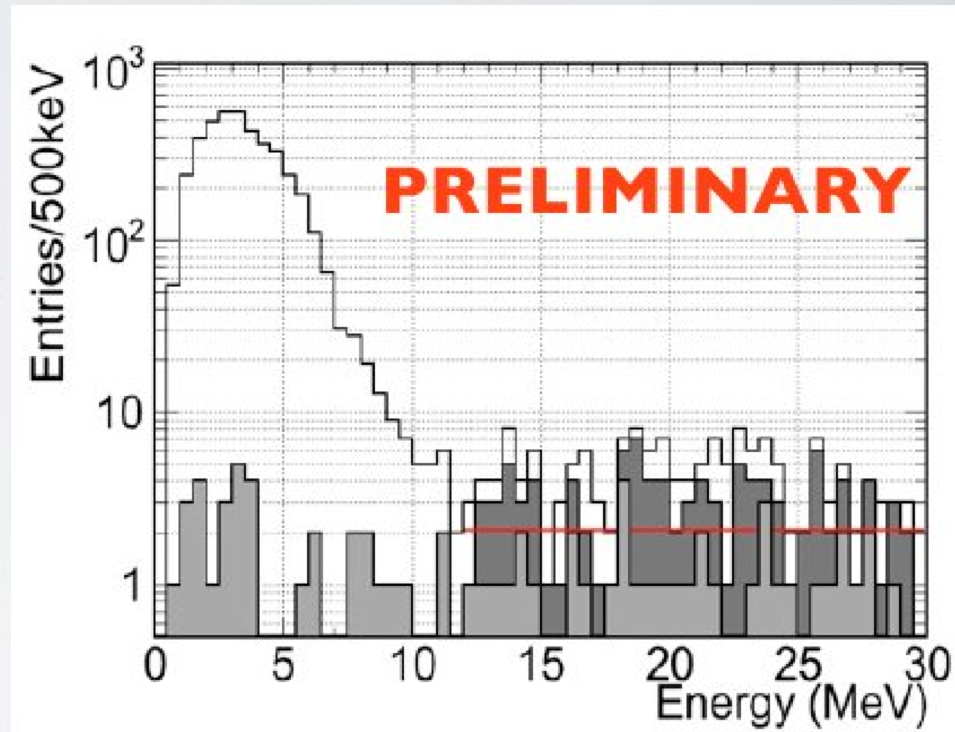


Spallation Neutrons

analysis method

extrapolation as flat energy spectrum from high-energies to prompt energy-window using IV-tagging



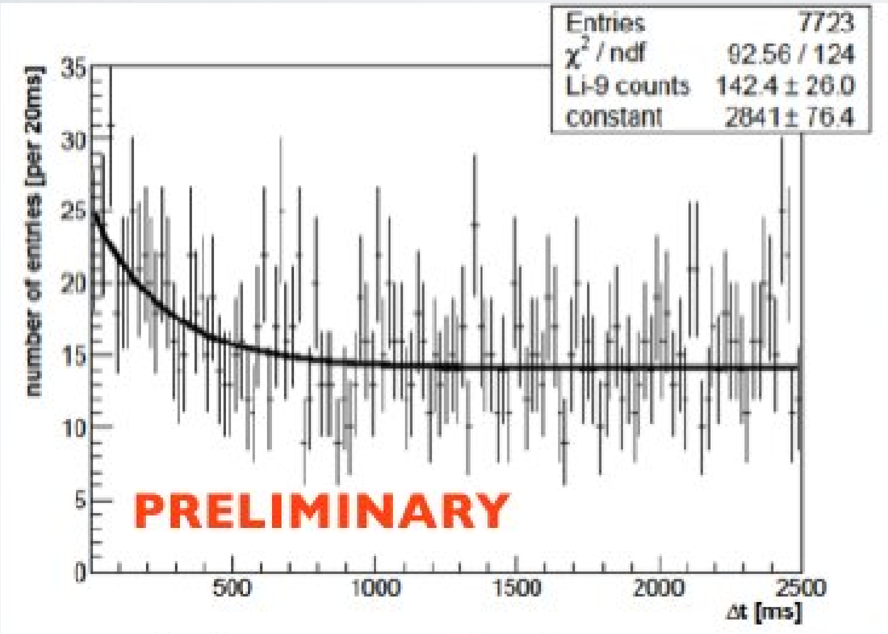


Flat energy spectrum used for θ_{13} fit, deviations taking as spectral uncertainties

Rate=(0.7±0.5)day $^{-1}$

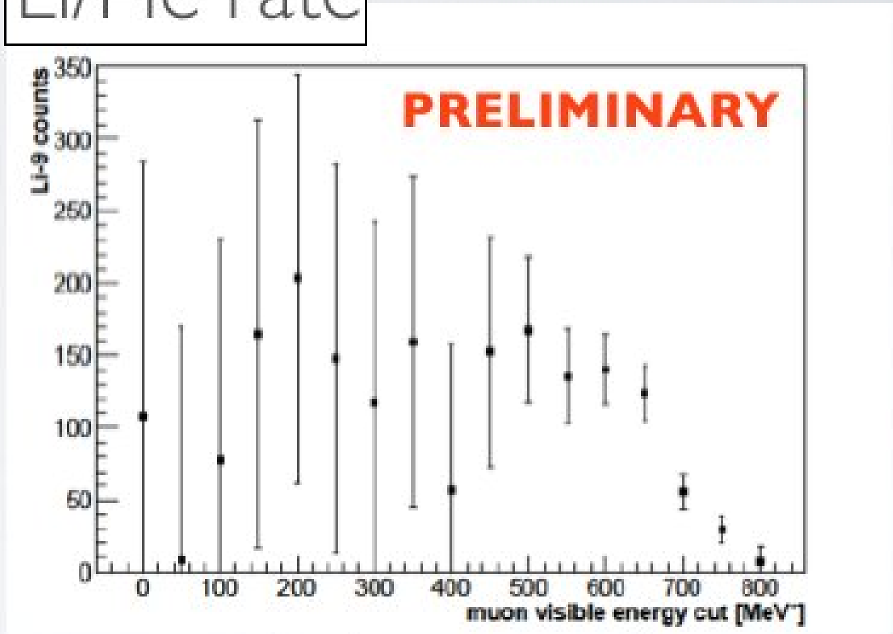
$^{9}Li/^{8}He$ BG

A Li/He production upon showering muons
(identified by large deposited E & high neutron multiplicity)



(example) correlation to last muons E_{dep}>600MeV

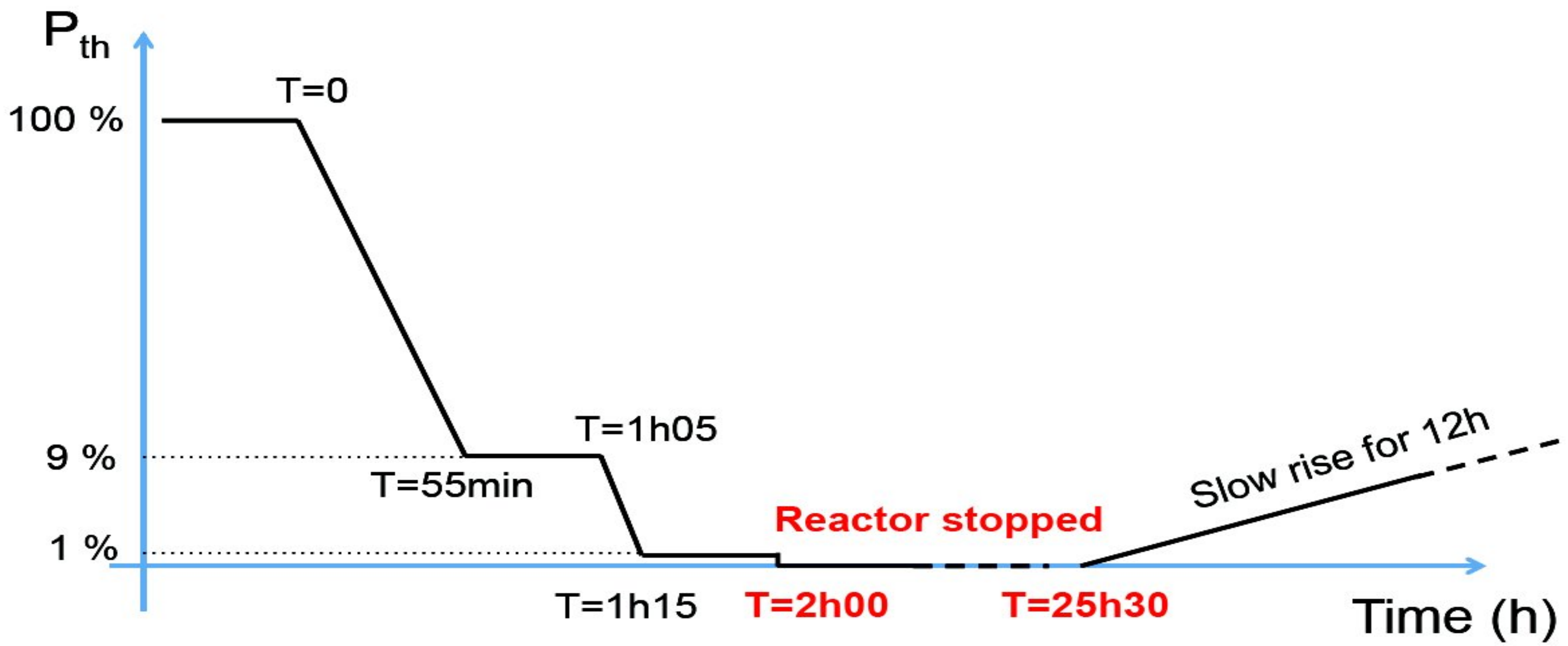
Li/He rate



extrapolation to all muons (low deposited energy)

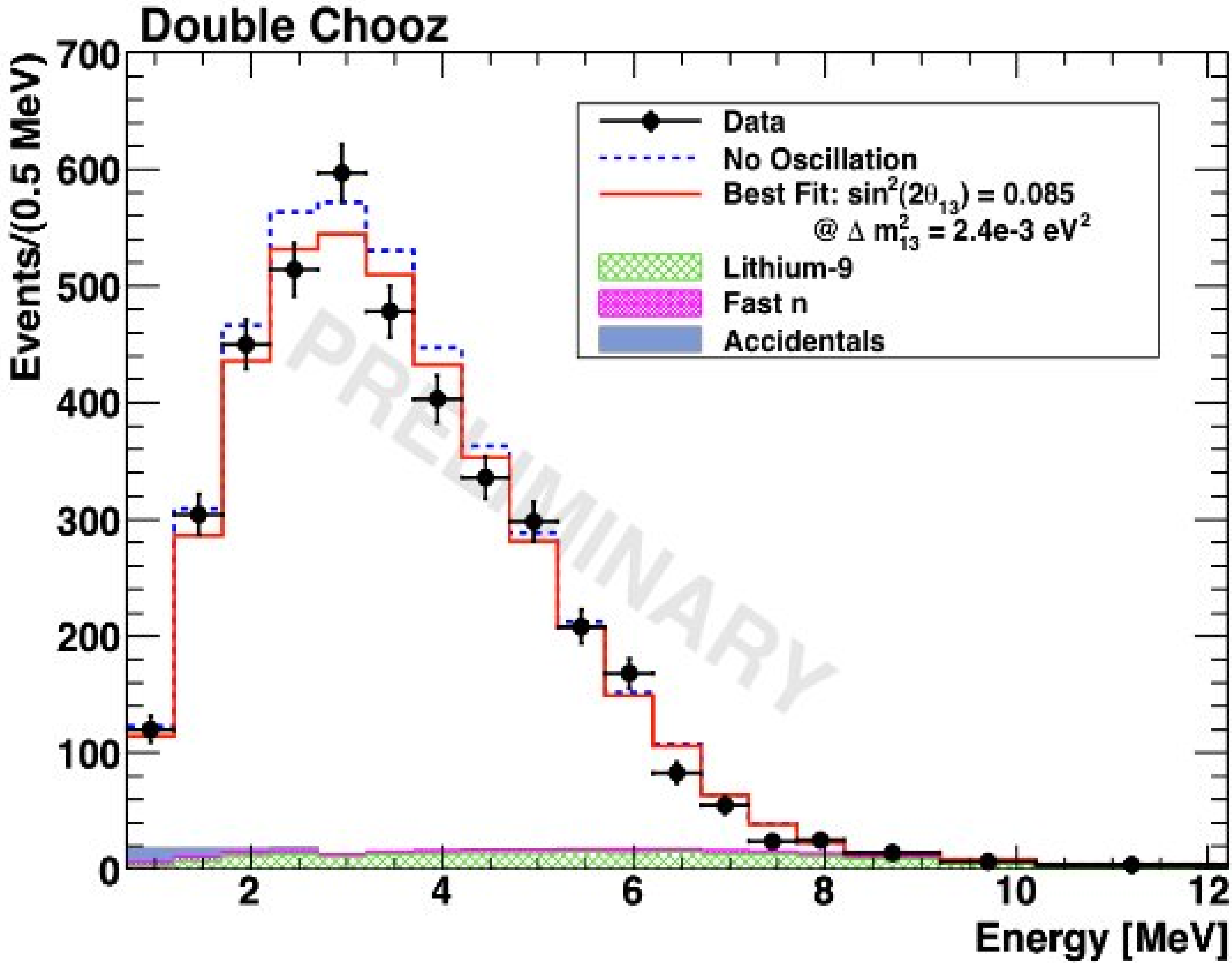
Rate=(2.3±1.2)day $^{-1}$

October-2011: Both reactors OFF (~ 1 day) : 3 events found



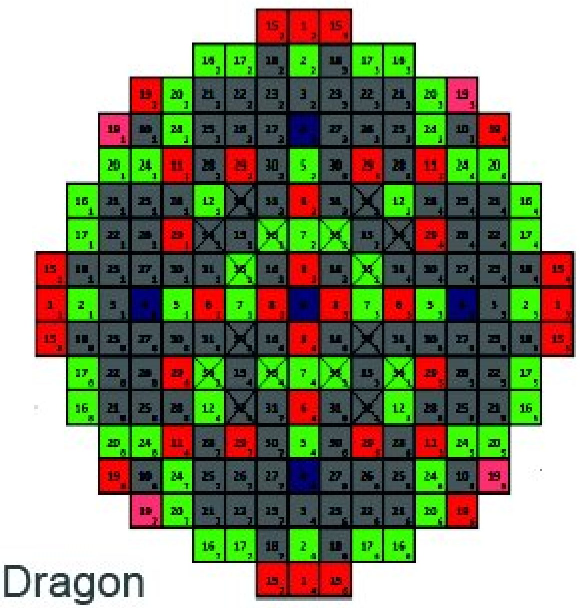
Estimated background (~100 days) = (3.3 ± 1.3) ev./day

to be compared: CHOOZ (142.5 days) = (2.02 ± 0.12) ev./day


Double Chooz
Events/(0.5 MeV)
0
100
200
300
400
500
600
700
2
4
6
8
10
12
Energy [MeV]
Data
No Oscillation
Best Fit: $\sin^2(2\theta_{13}) = 0.085$
@ $\Delta m^2_{13} = 2.4\text{e-}3\ \text{eV}^2$
Lithium-9
Fast n
Accidentals
PRELIMINARY

Reactor Evolution Code

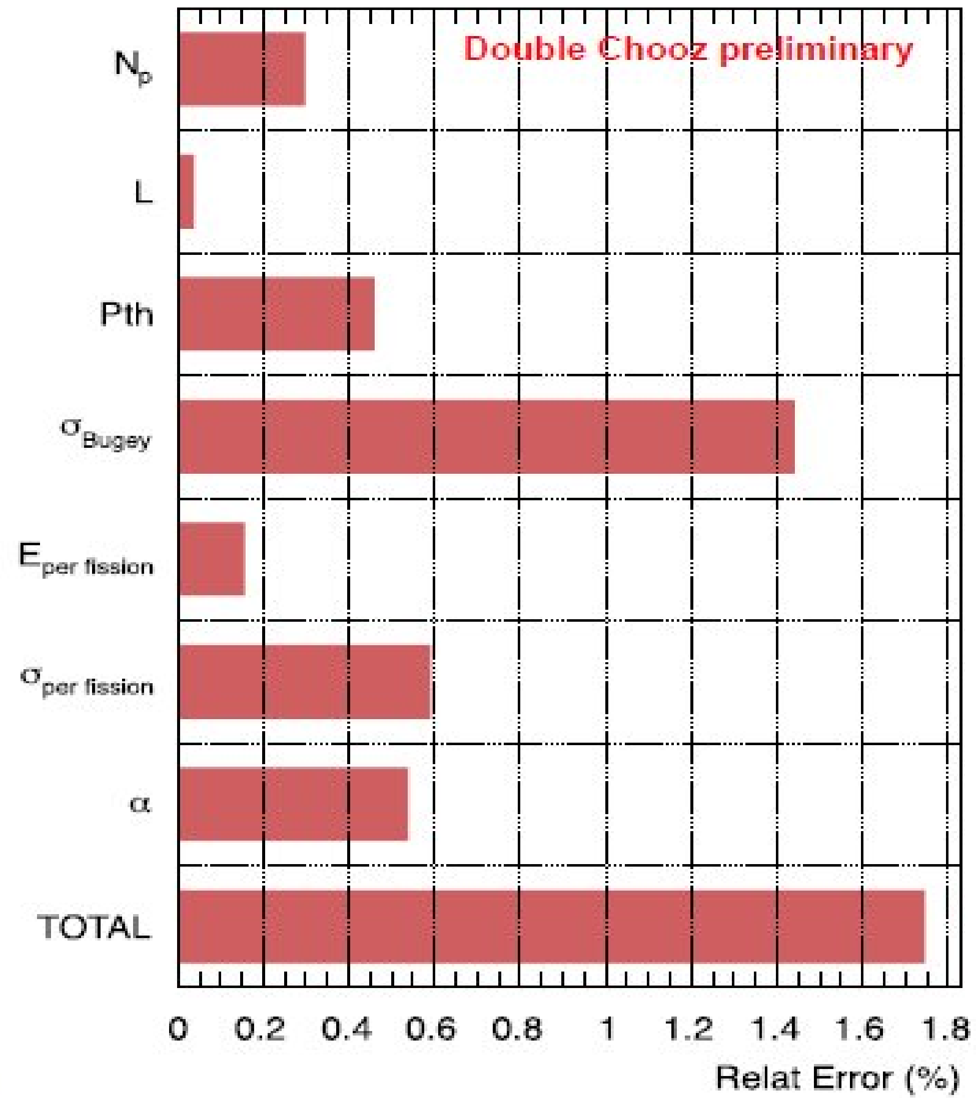
Development of full core simulation with MURE Code (Subatech).



- A lot of EDF inputs (initial fuel loading, geometry, power history,…)
- Validation with independent calculation (Dragon code, EDF calculations, Takahama benchmark).
- Complete error budget based on uncertainty on reactor parameters, code comparison, nuclear database inputs.

Error on Reactor Predictions

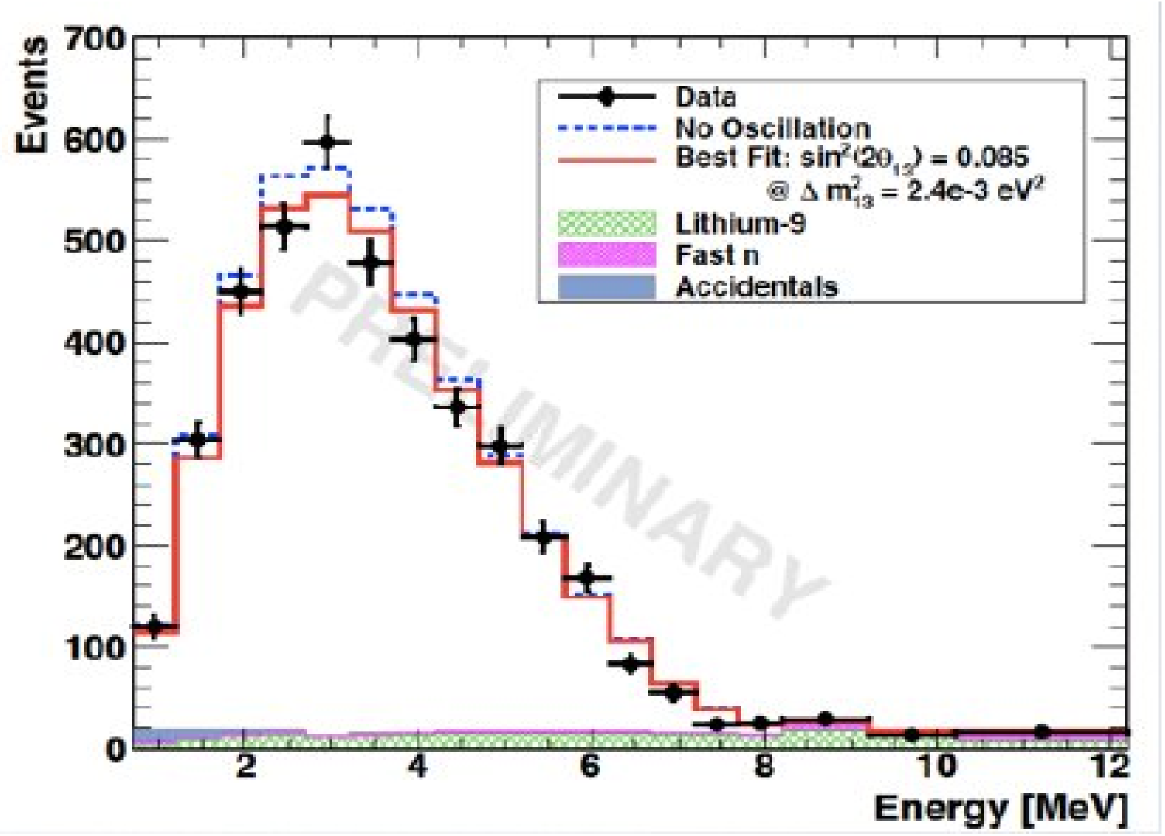
- Anchor point of Bugey4 measurement suppresses sensitivity to reference spectra ($\sigma_{\text{per fission}}$)
- Accurate reactor simulation with MURE keep contribution of the uncertainty on fission rates low.



1.7% total error

(2.7% if no Bugey4 anchor)

Analysis with far detector only



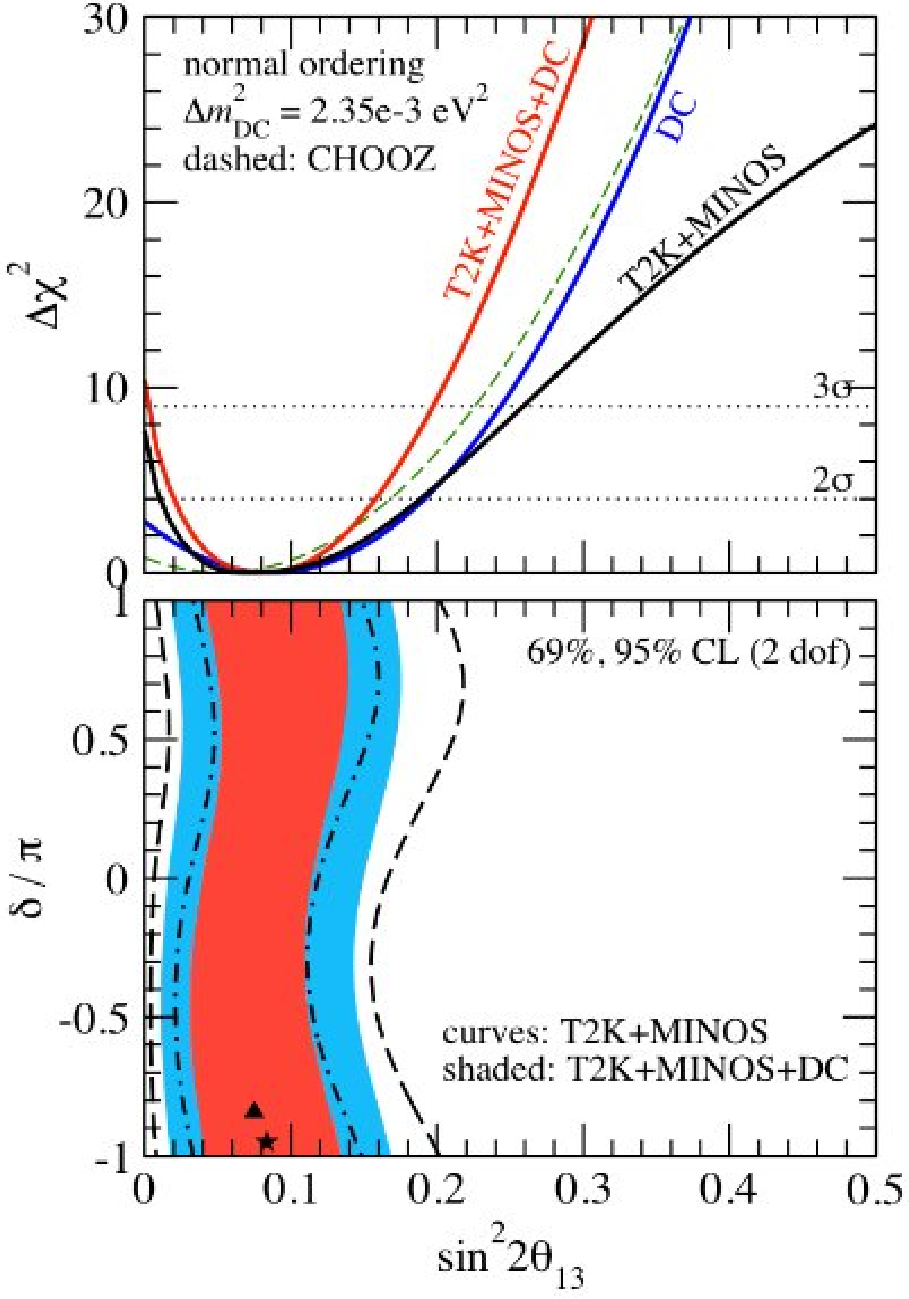
Rate + Shape analysis:

$$\sin^2(2\Theta_{13}) = 0.085 \pm 0.029(stat) \pm 0.042(sys) @ 68\% CL$$

Rate only:

$$\sin^2(2\Theta_{13}) = 0.093 \pm 0.029(stat) \pm 0.073(sys) @ 68\% CL$$

Combined analysis: DCHOOZ + T2K + MINOS



The probability $\Theta 13 = 0$ is excluded @ 3σ level

▲ **- T2K + MINOS**

★ **- DCHOOZ + T2K + MINOS**

Near Lab. construction started 29th of April.

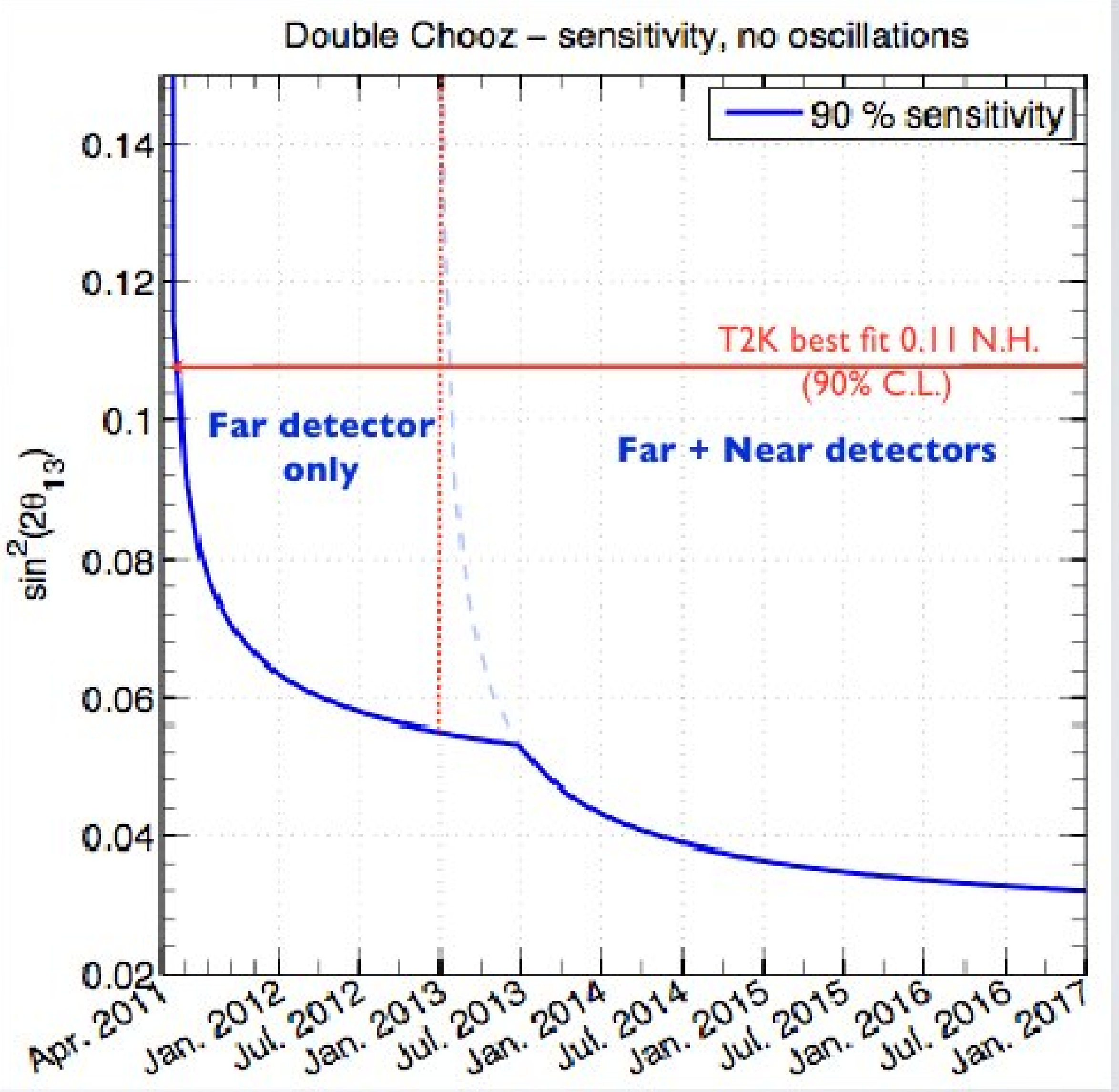
Near detector expected to be ready at the end of 2012.

Near Laboratory

delivery by June 2012

Timeline & Sensitivity

Normalisation to the Bugey-4 cross-section with far detector only to be independent on the flux prediction (not to be affected by the reactor neutrino anomaly).



Conclusions

- November 2011: First Double Chooz result was presented

$$\sin^2(2\Theta_{13}) = 0.085 \pm 0.029(stat) \pm 0.042(sys) @ 90\% CL$$

- The Near Detector will be operational by early 2013
- With only 2 reactors, Double Chooz will have a chance to measure the background

Backup slides

Summary

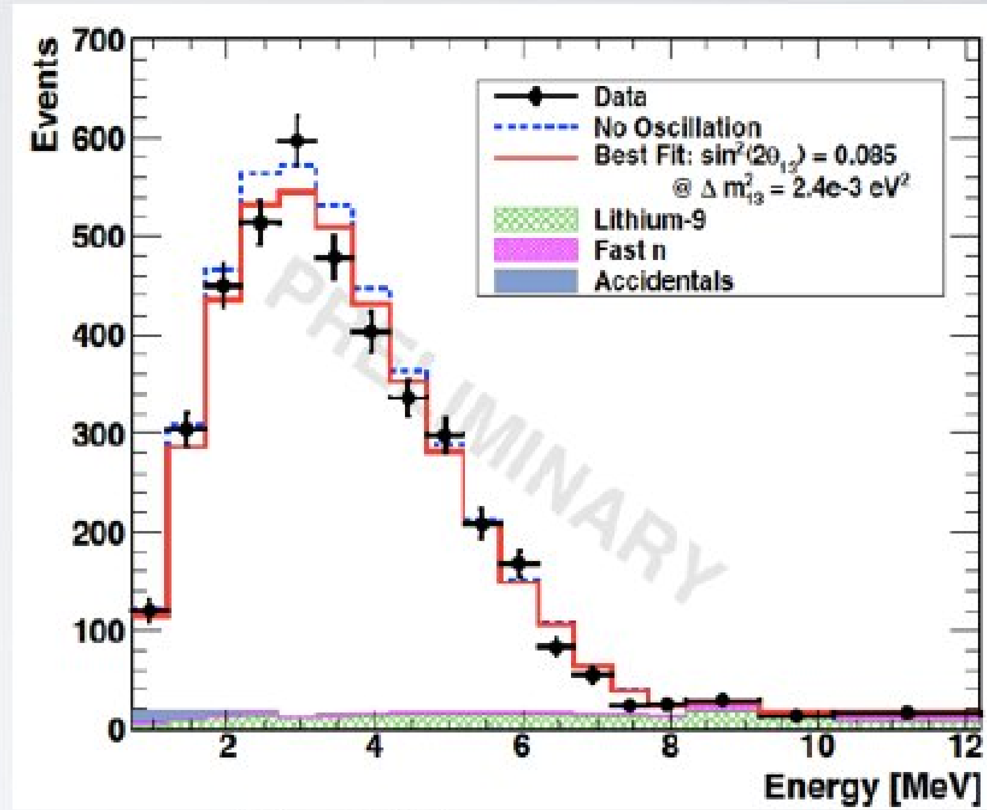
- The experiment is progressing steadily
  - Daya Bay Hall: started taking data since Aug 15, 2011
  - Ling Ao Hall: under commissioning.
  - Far Hall: almost done with installing the infrastructure.
  - Status of ADs:
    - 4 ADs have been finished.
    - AD5 and 6 assembly nearly finish
    - AD7 and 8 completion in spring 2012
- Schedule:
  - Summer 2012: Full experiment running !
  - Stay tuned!

Summary of RENO Status

- Construction of both near and far detectors at RENO are completed in Feb. 2011
- All the liquids including Gd-LS are produced and filled by end of July 2011
- Regular data-taking with NEAR & FAR detectors began from August 1, 2011
  - Preliminary result shows satisfactory detector performance
  - Detector calibration and comparison of ND & FD are performed
- Data reduction, source calibration, and Monte-Carlo reconstruction efforts are on progress & going on smoothly

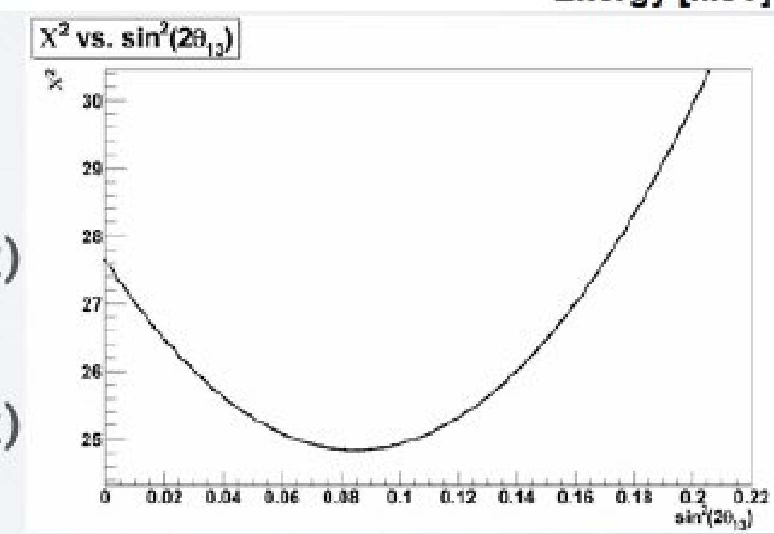
θ13 Preliminary Results

First neutrino oscillation data release of DC at <u>LowNu11</u> @ Seoul (Korea)



Far detector data only

No-Oscillation:
reactor flux prediction



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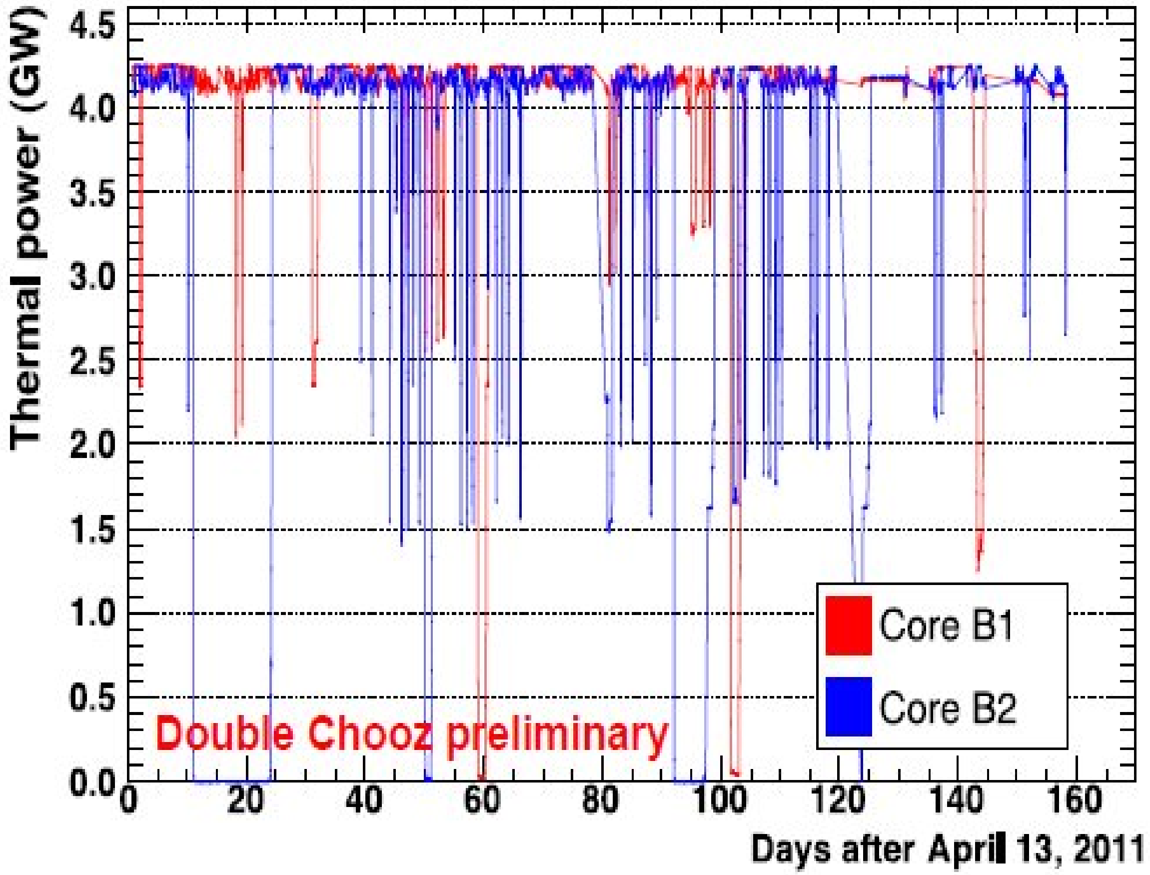
Rate Only:
$\sin^2(2\theta_{13}) = 0.093 \pm 0.029(stat) \pm 0.073(syst)$

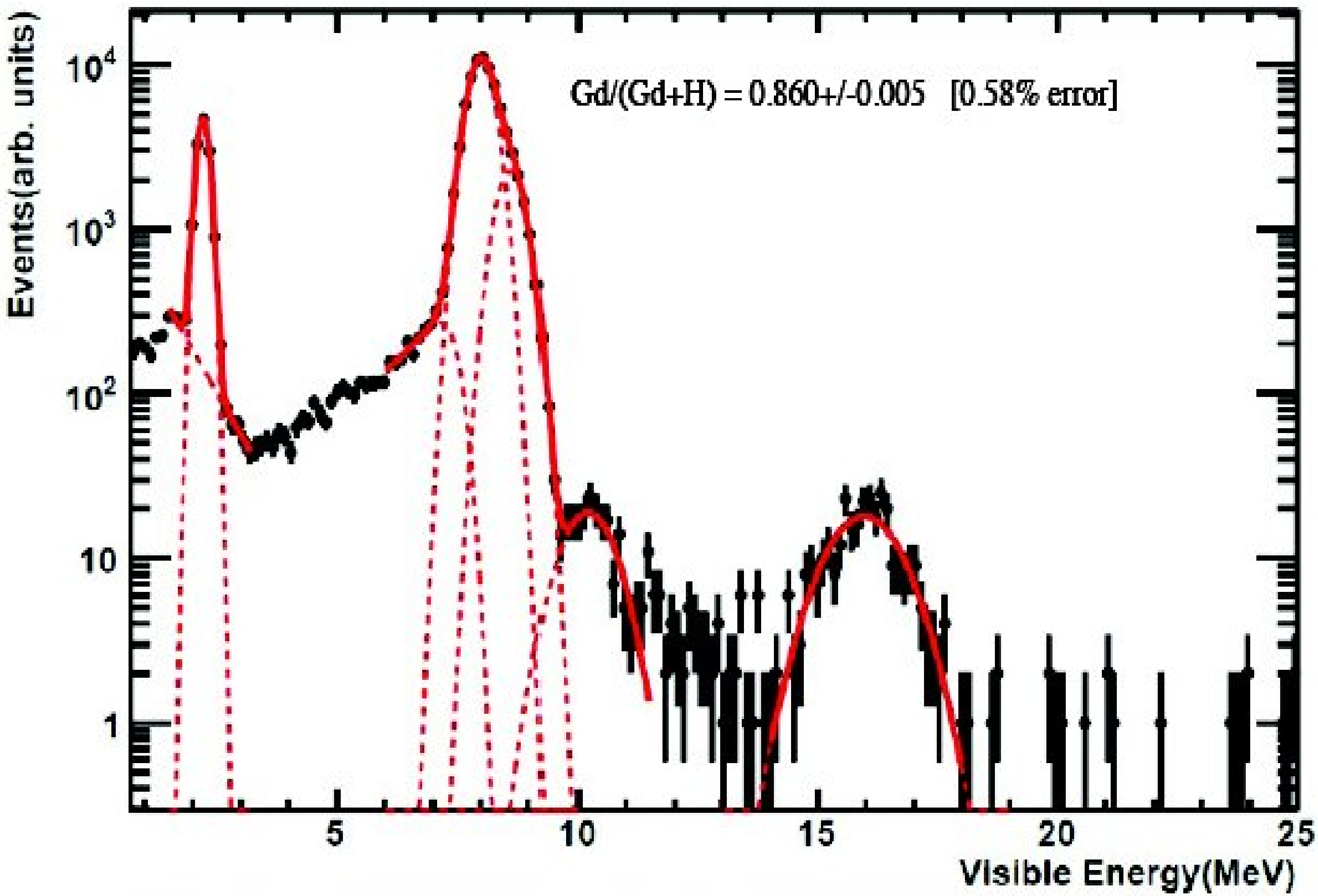


$\delta P_{th}/P_{th} = 0.46\%$

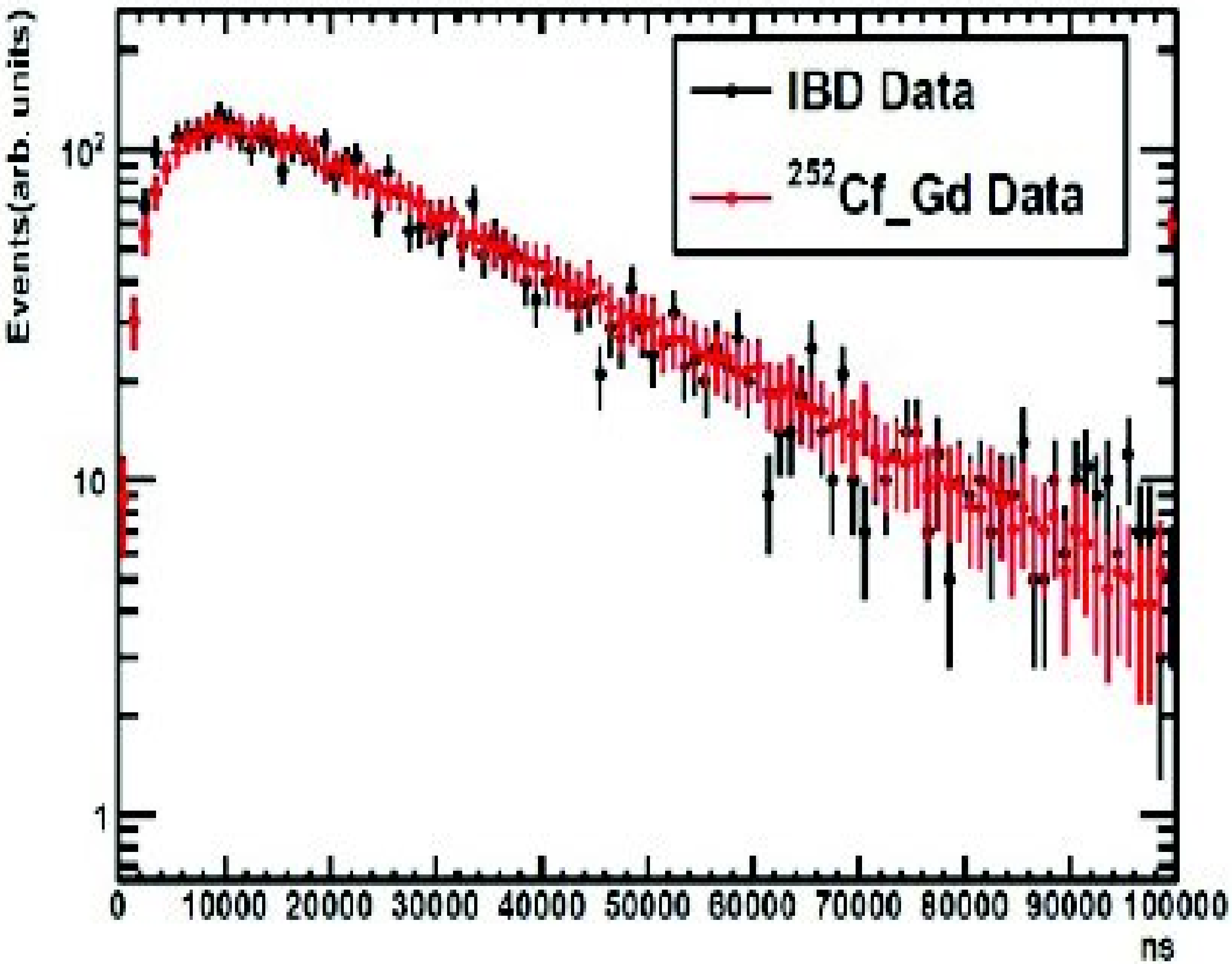
(1 sigma)

- Precise weekly anchor points by enthalpic balance at steam generators.
- Monitoring every minute, based on temperature in primary loop.
- Full error treatment in EDF note (HP1C-2011-2007-FR, Y. Caffari, J.M. Favennec)

^{252}Cf Data Delayed Signal



Delta T Distribution



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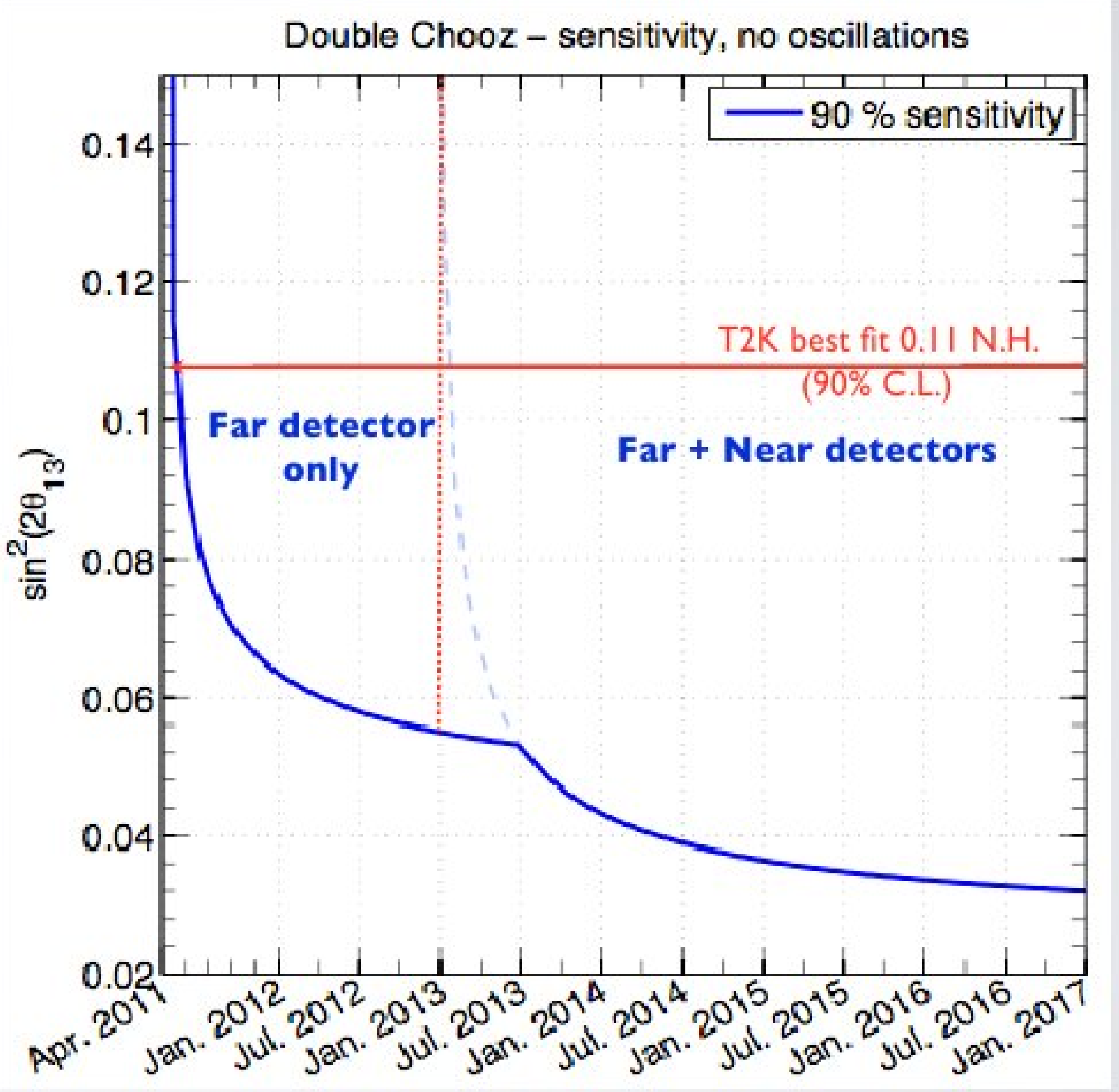
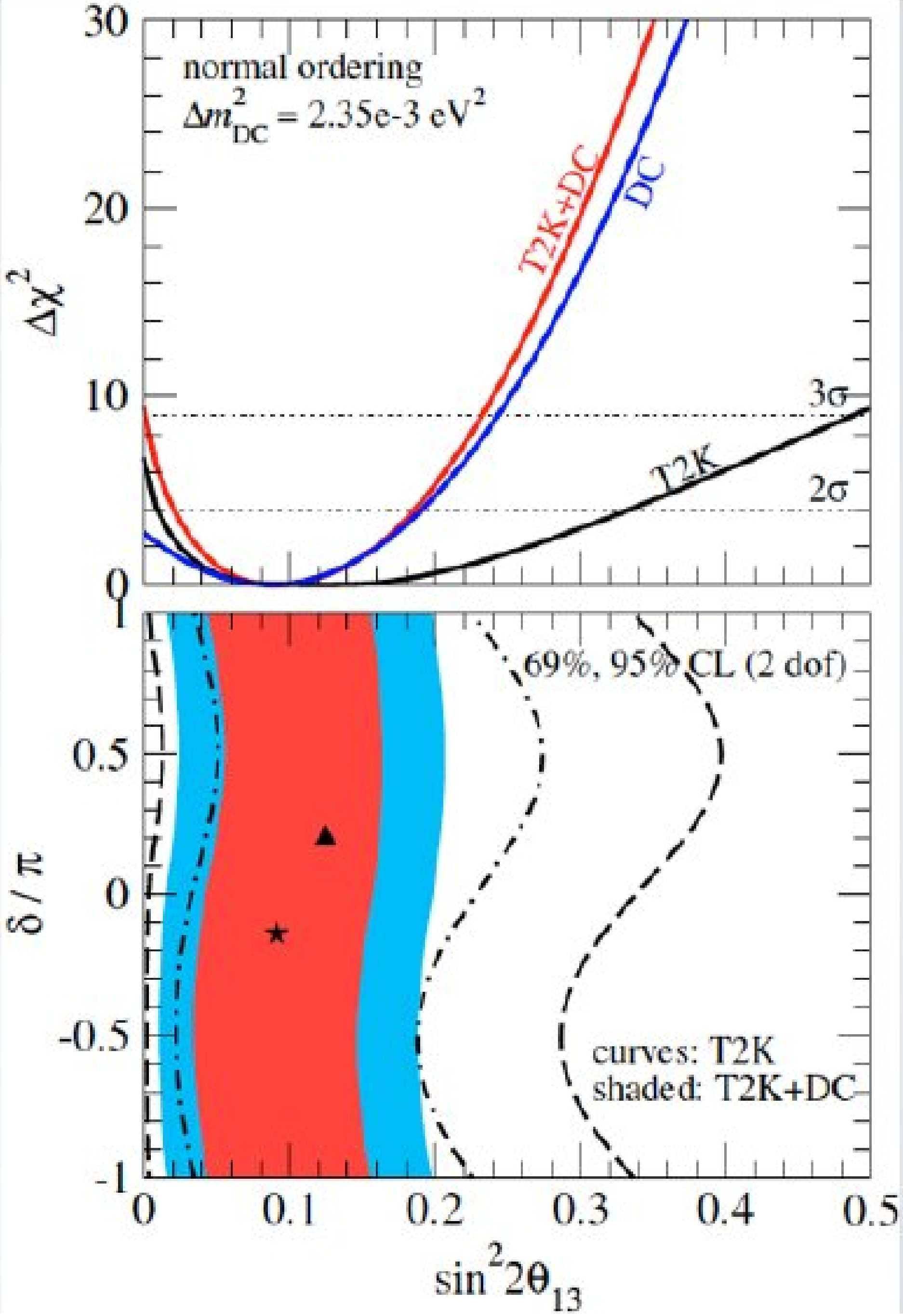


Global θ_{13} Hunt

DC results consistent with T2K results

Major impact in θ_{13} knowledge today by DC

Combined effect: $\sin^2(2\theta_{13}) > 0$ @ 3σ



Site in French Ardennes