GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN

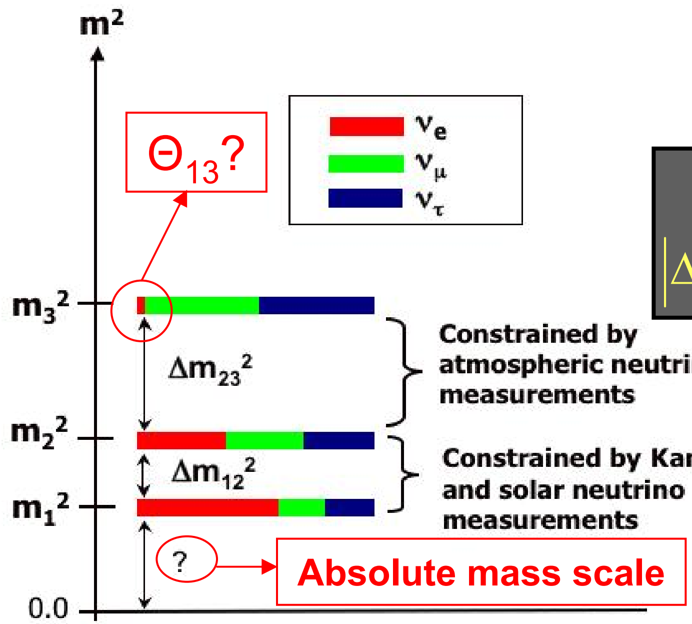
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

DOUBLE CHOOZ

Double-Chooz Neutrino Experiment

Carmen Palomares (Ciemat, Spain)
for Double-Chooz Collaboration

Current knowledge on neutrino oscillation



$$\theta_{23} = 45.0^{+15.3}_{-14.2}$$

$$|\Delta m^2_{13}| = 2.40 \pm 0.12 \times 10^{-3} eV^2$$

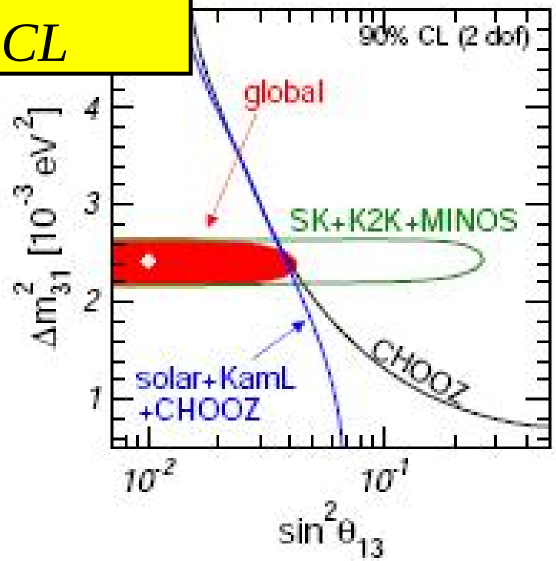
$$\theta_{12} = 34.3^{+7.9}_{-5.4}$$

$$\Delta m^2_{12} = 7.59^{+0.23}_{-0.18} \times 10^{-5} eV^2$$

@1σ arXiv:0808.2016

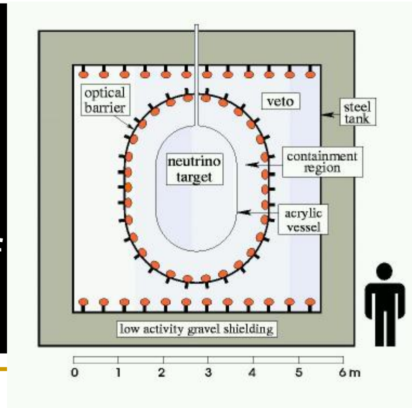
$\theta_{13} < 10.5\,\mathrm{deg}$

$90\%CL$

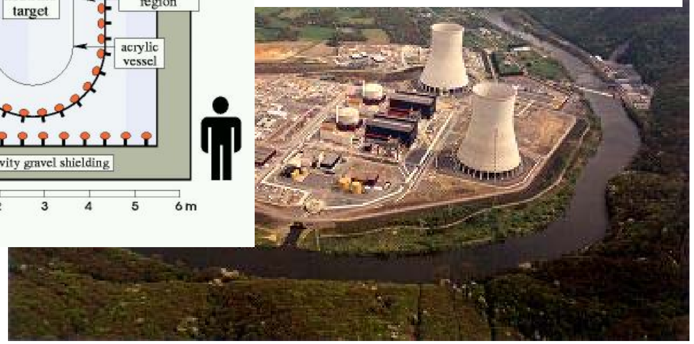


The main goal of upcoming experiments is the determination of θ_{13}:

- CP violation depends on non-zero value of θ_{13}
- Any realistic possibility to determine the sign of Δm_{31} relies on a not-too-small θ_{13}



The main limit comes from CHOOZ reactor experiment ´97

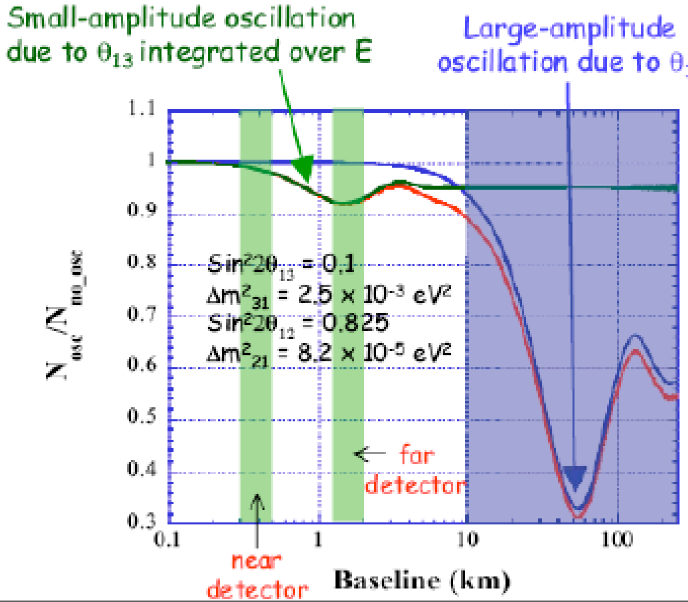


Experimental methods to measure θ_{13}

Long-Baseline Accelerators: Appearance (νμ→νe)
Oscillation probability complicated and dependent not only on θ_{13} but also:
CP violation parameter, sign of Δm_{31} , size of $\sin^2\theta_{23}$

Nuclear reactors: Disappearance ($\bar{\nu}_e \rightarrow \bar{\nu}_e$)

- L/E match Δm_{31}^2 (L~1 Km)
- θ_{13} independent of CP-violation
- Weak dependence on Δm_{12}
- Negligible matter effects

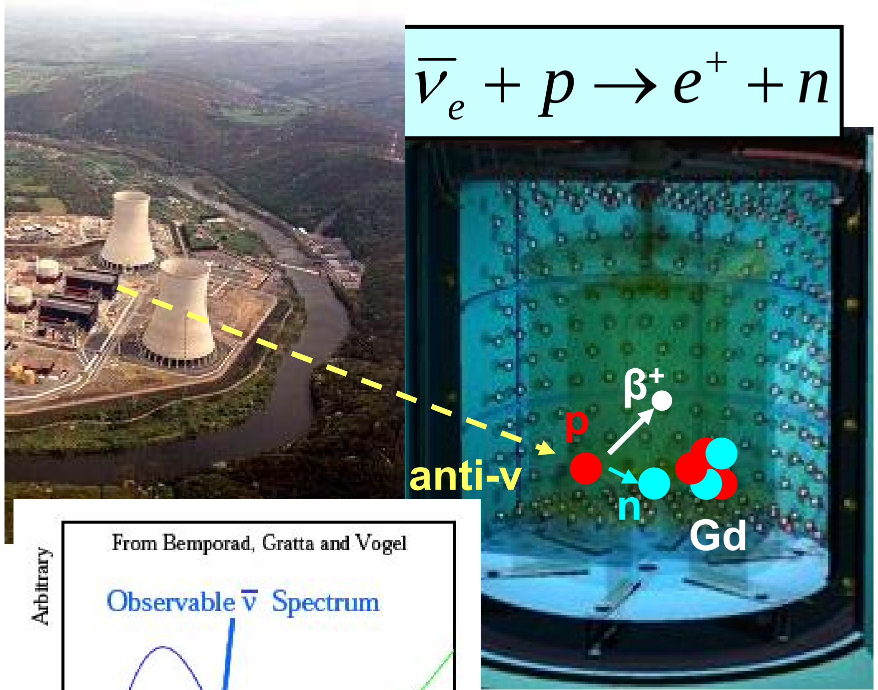


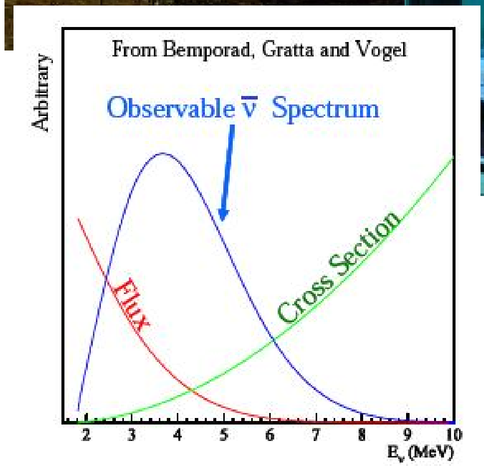
- Unambiguous measurement of Θ_{13} complementary to beams
- The only limitation comes from systematic errors
- These experiments must be carried out on a short time scale to provide an input for future beams

$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = 1 - \sin^2 2\theta_{13} \sin^2 \frac{\Delta m_{13}^2 L}{4E} + \left(\frac{\Delta m_{21}^2 L}{4E_\nu}\right)^2 \cos^4\theta_{13} \sin^2 2\theta_{12}$$

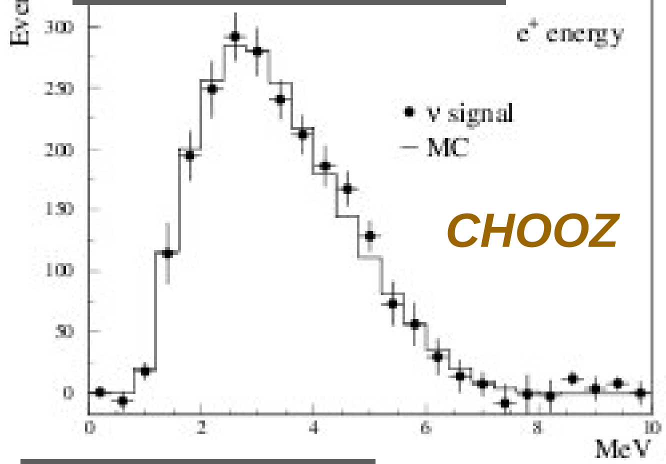
Nuclear reactor experiments

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

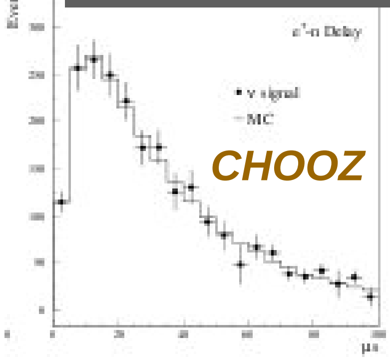




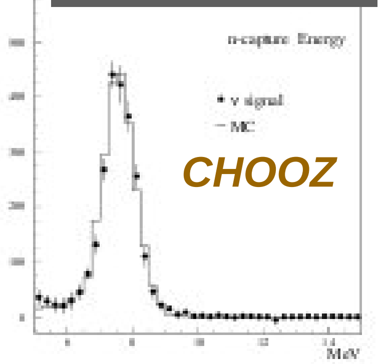
Ee+ = Ev-(Mn-Mp)



ΔT:Gd deexcited after n capture



n-capture on Gd



Improving CHOOZ

CHOOZ: $R = N_{meas}/N_{exp} = 1.01 \pm 2.8\%\ (stat) \pm 2.7\%\ (sys)$

Statistical error

	CHOOZ	Double Chooz
Target volume	5.55 m3	10.3 m3
Data taking period	Few months	3-5 years
Event rate	2700	Chooz-far 60000/3y
Statistical error	2.8%	0.5%

Systematic error

	CHOOZ	Double Chooz
Reactor uncertainties ν flux and reactor power	2.1%	←
Number of protons	0.8%	0.2%
Detector Efficiency	1.5%	0.5%

The Double Chooz Collaboration

Spokesman: Hervé de Kerret (APC)

France: APC, CEA/DSM/IRFU, IN2P3(Subatech, IPHC), ULB

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

Spain: CIEMAT

UK: Sussex

Japan: HIT, Kobe U., Niigata U., TGU, Tokyo IT, Tokyo MU, Tohoku U., Hiroshima IT.

Russia: RAS, RRC Kurchatov Institute

USA: U. Alabama, ANL, U. Chicago, Columbia U, Drexel U, ITT, MIT, Kansas S U, LLNL, U. Notre Dame, Sandia NL, U. Tennessee, UCDavis

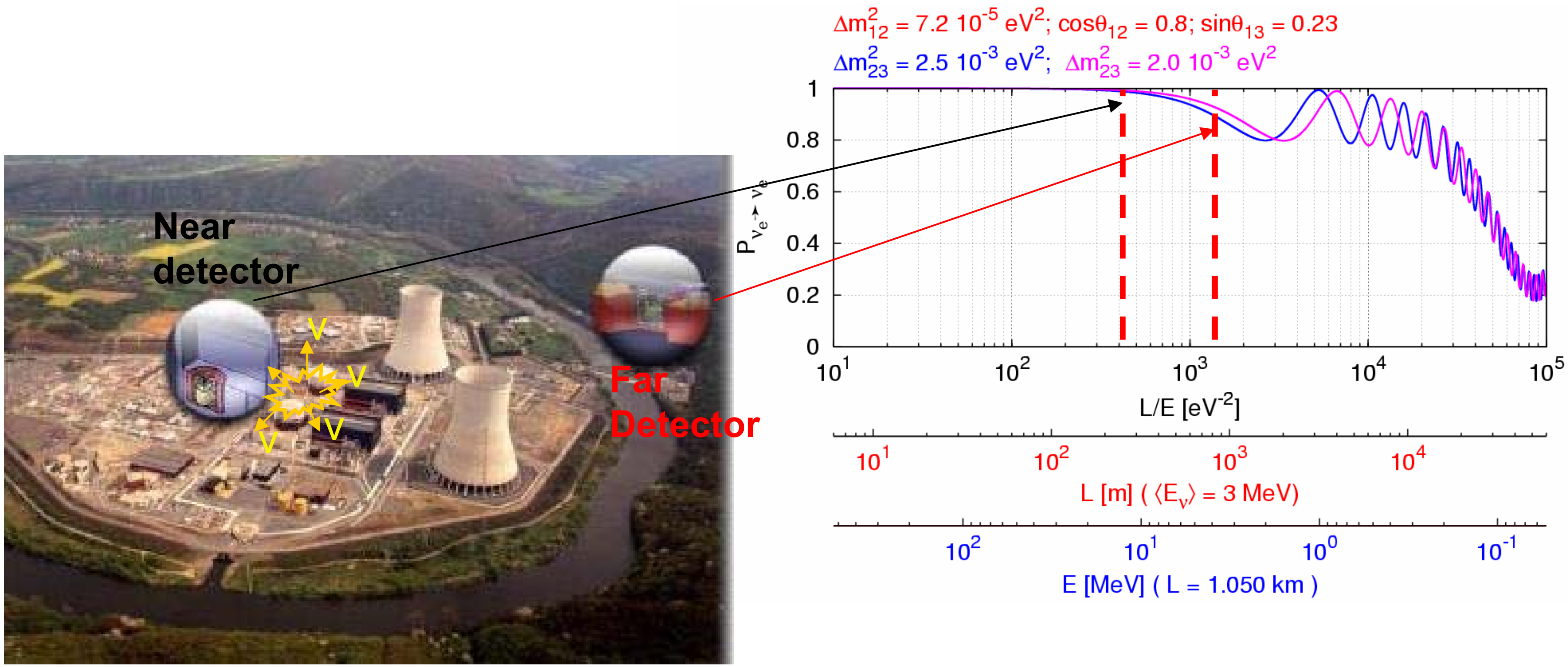
Brazil: CBPF, UNICAMP,UFABC

Double Chooz Concept

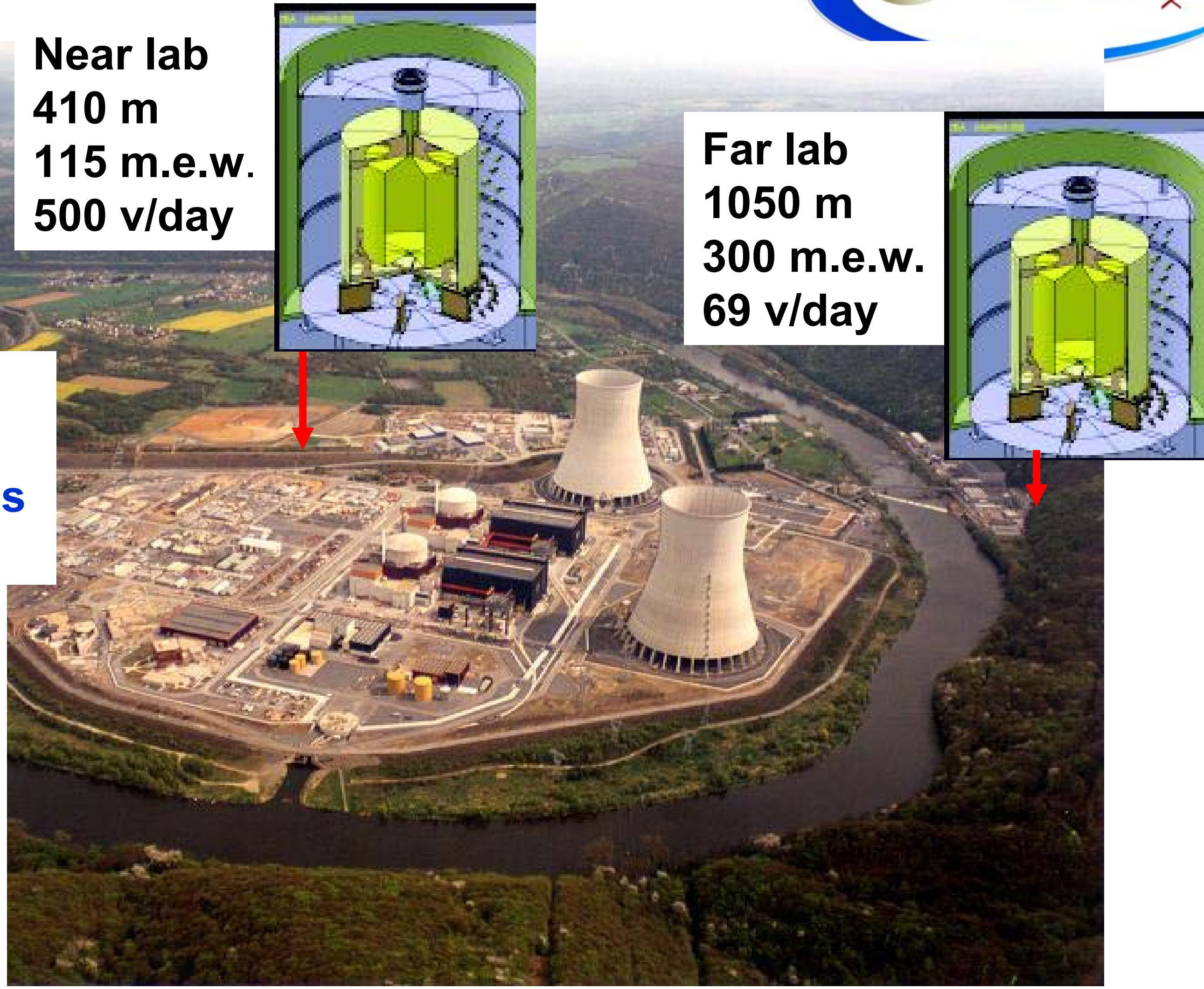
To look for non-zero values of Θ_{13}

Beyond the previous systematic limitations:

1. **Two detectors** to remove uncertainties of the reactor flux
2. **Identical detectors** to reduce errors due to detector acceptance



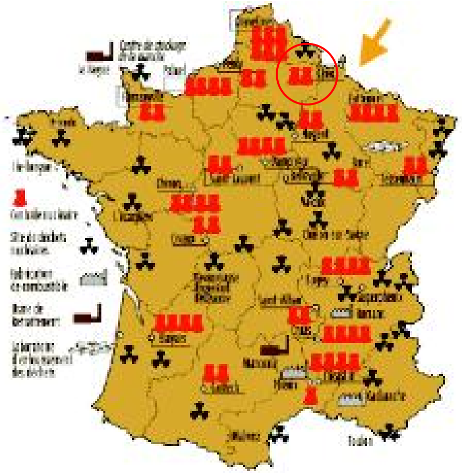
The Chooz site:



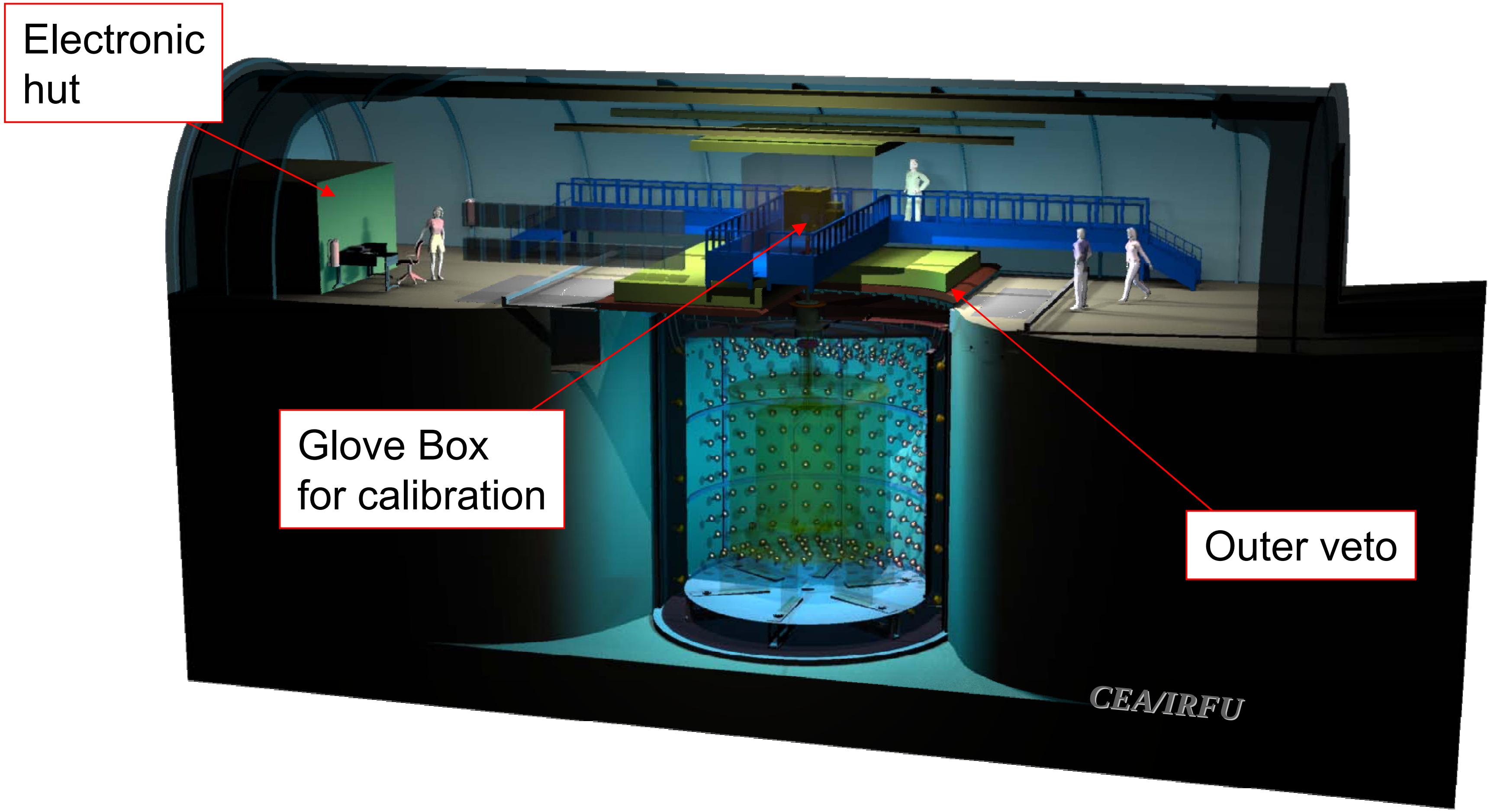
Near lab
410 m
115 m.e.w.
500 v/day

Far lab
1050 m
300 m.e.w.
69 v/day

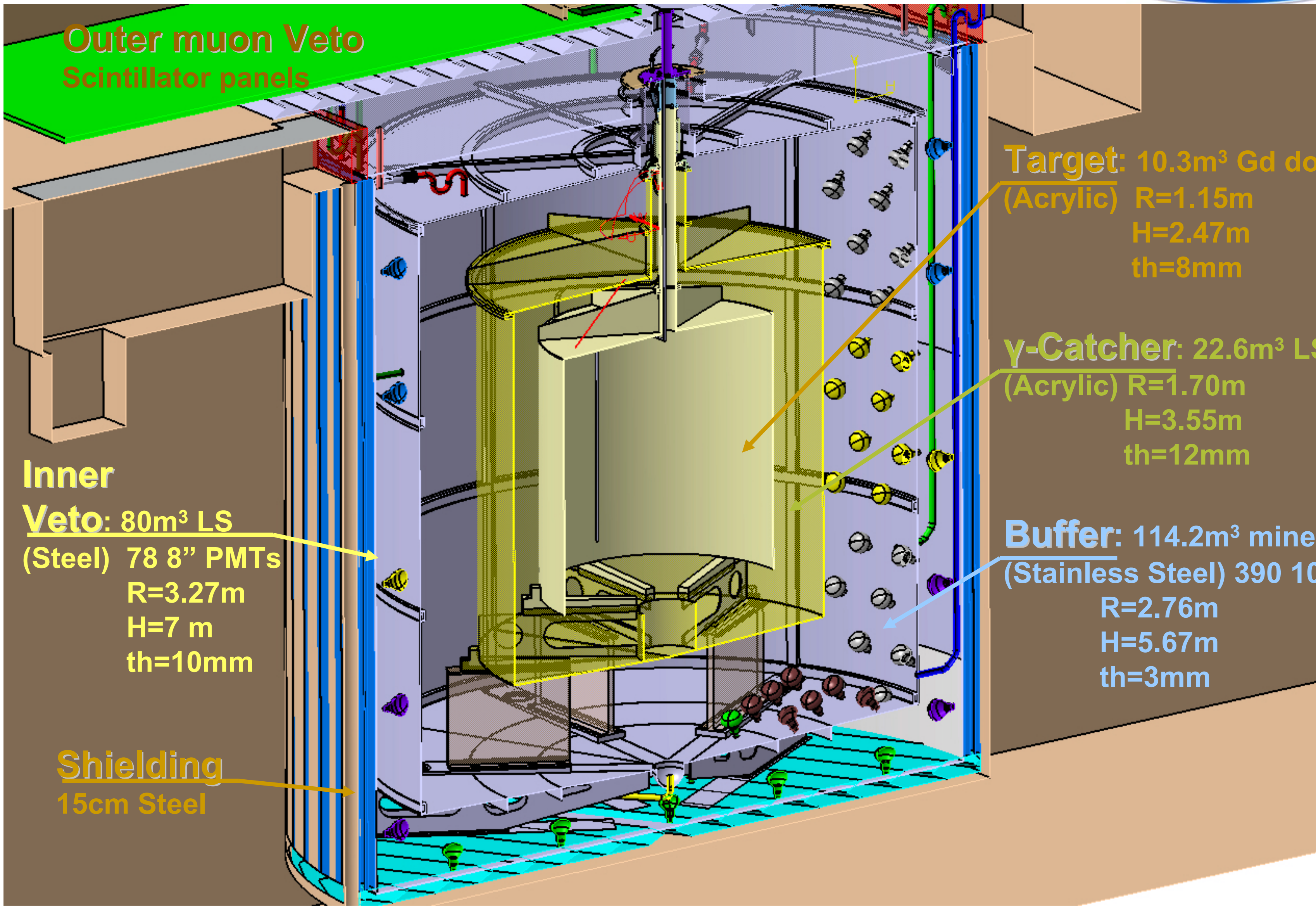
Chooz-B reactors
8.4 GWth
Placed in the Ardennes (France)



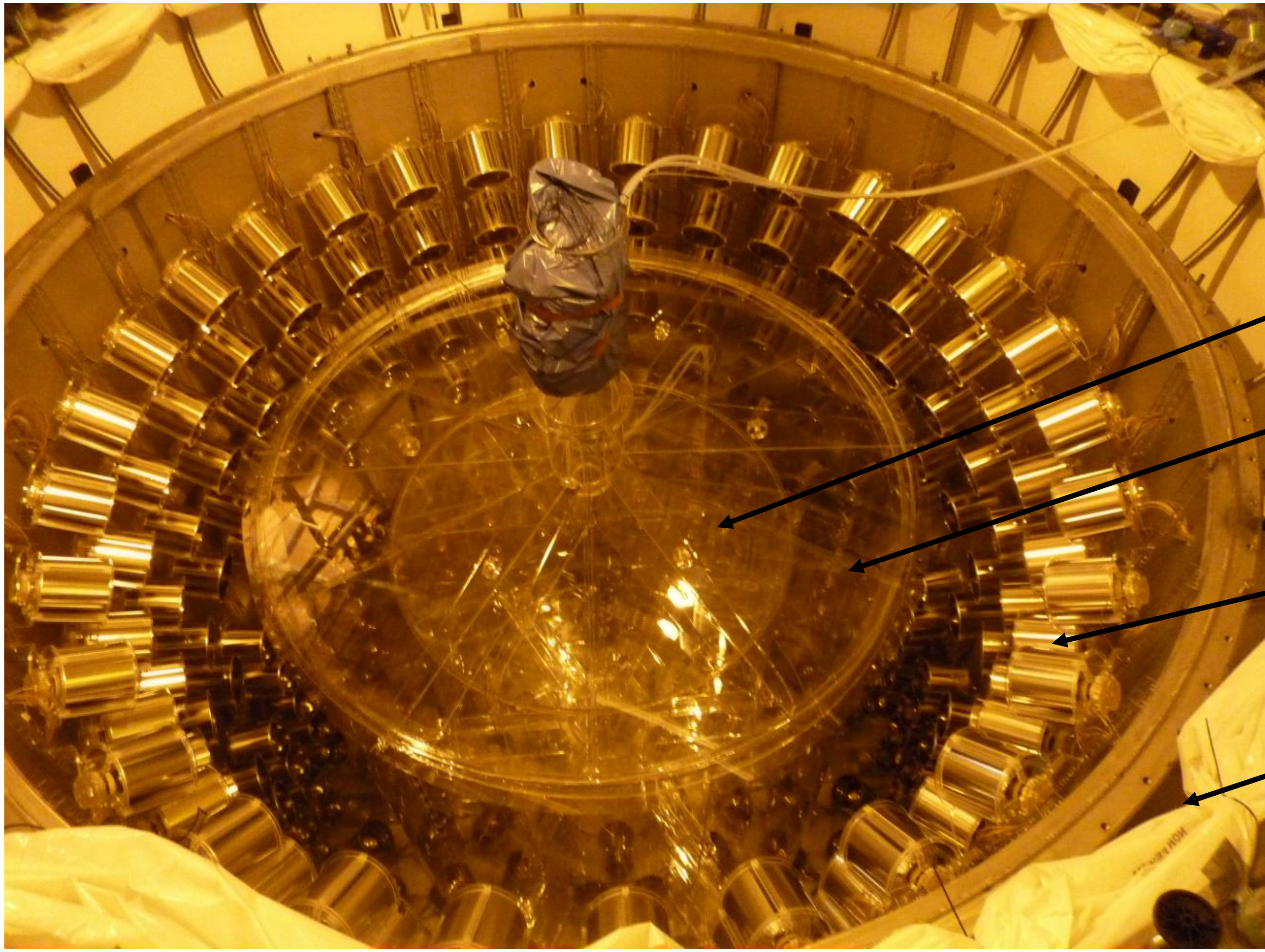
The Double Chooz Laboratories



The Detector(s)

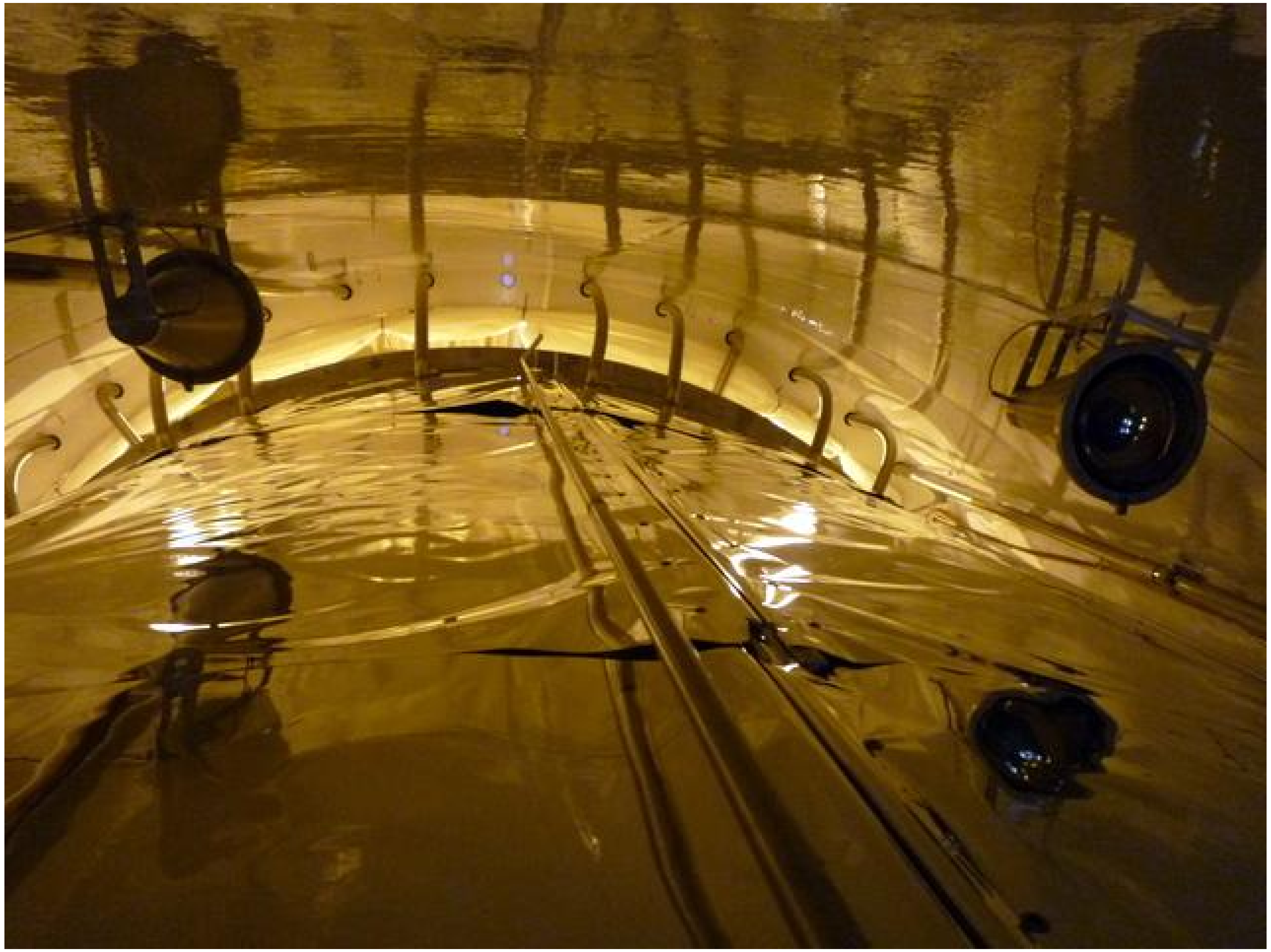


Inner detector

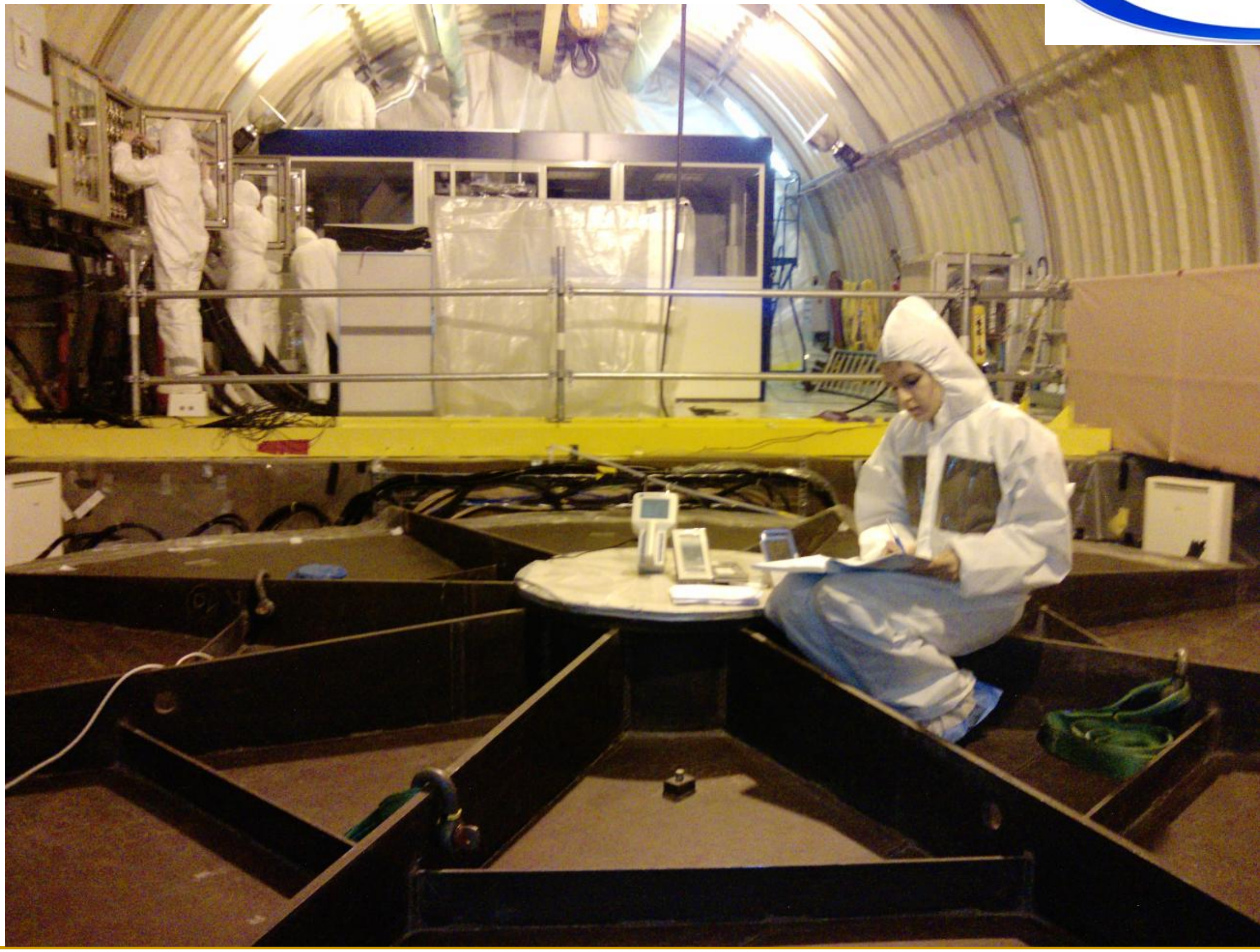


Inner detector

Inner muon veto

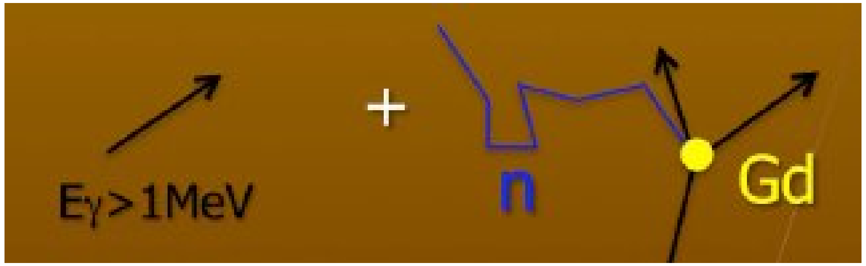


Detector close and filled



Backgrounds

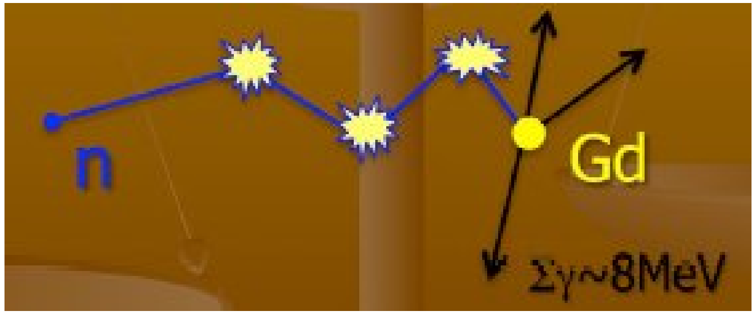
Accidental



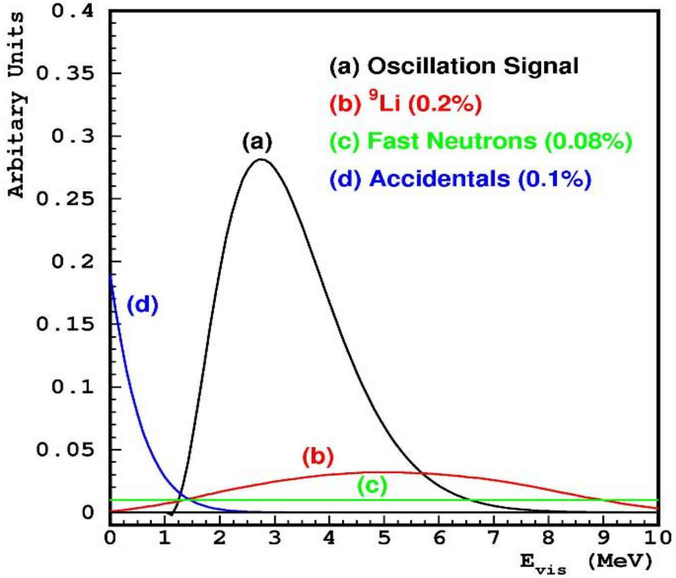
Natural Radioactivity

Spallation n captured on Gd

Correlated

- 

Fast n recoil on p (low energy) and captured on Gd



- long-lived (9Li, 8He) β-decaying isotopes induced by μ

Improving CHOOZ

BACKGROUND

- **Single e^+-like** reduced:
  - ☺ PMT very low radioactive glass
  - ☺ PMT is not in contact with liquid scintillator

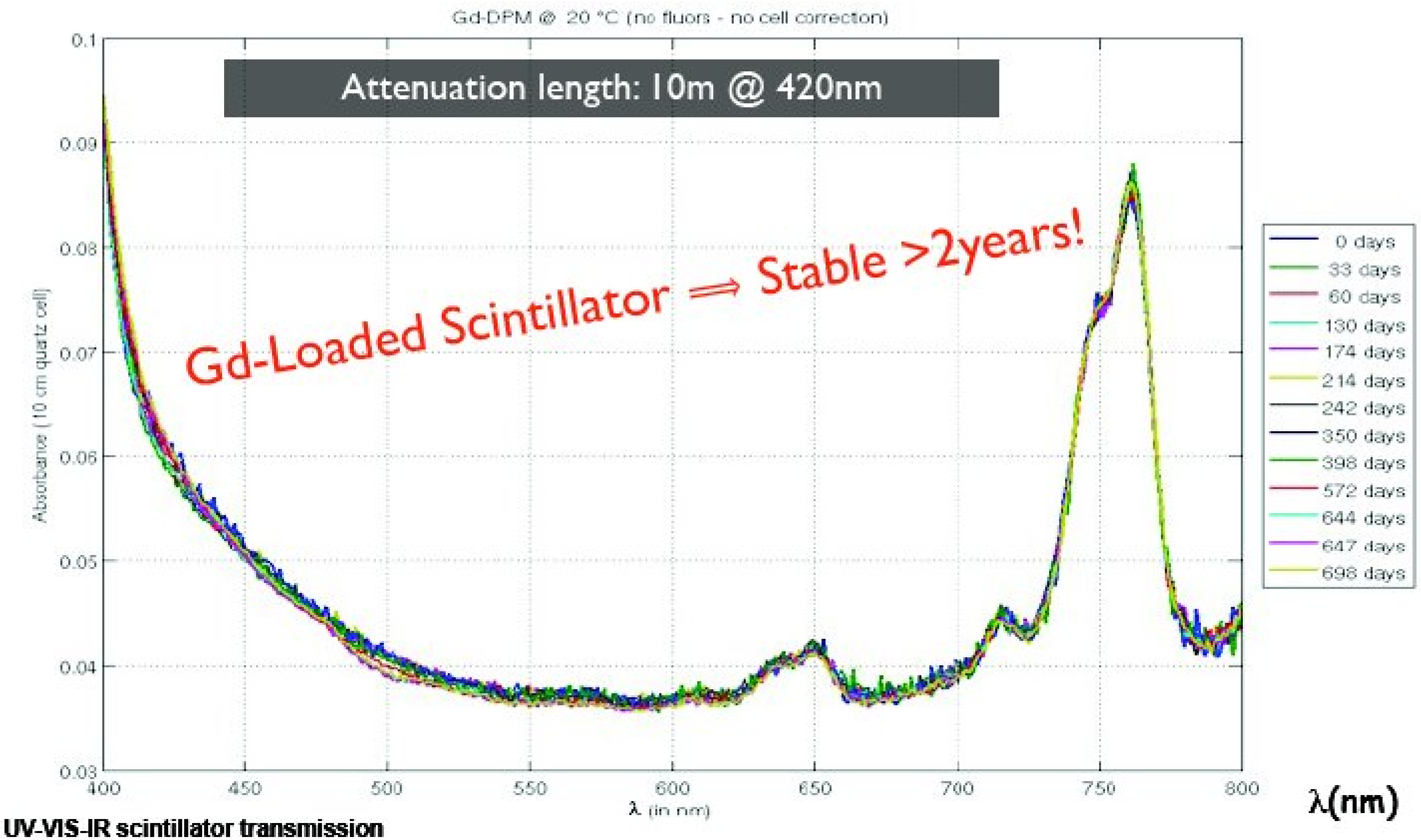
    (PMT single rate CHOOZ: ~60 Hz. Double-Chooz ~1.2 Hz)
  - ☺ Detector shielded by 15 cm iron
- **Neutron rate** reduced by using a **more efficient cosmic muon veto system**

DETECTOR PERFORMANCE

Calibration relative detection efficiency between near and far detector should be known with an uncertainty <0.5%

Detector stability liquid scintillator stability tested over 3 years

Gd doped liquid scintillator stability

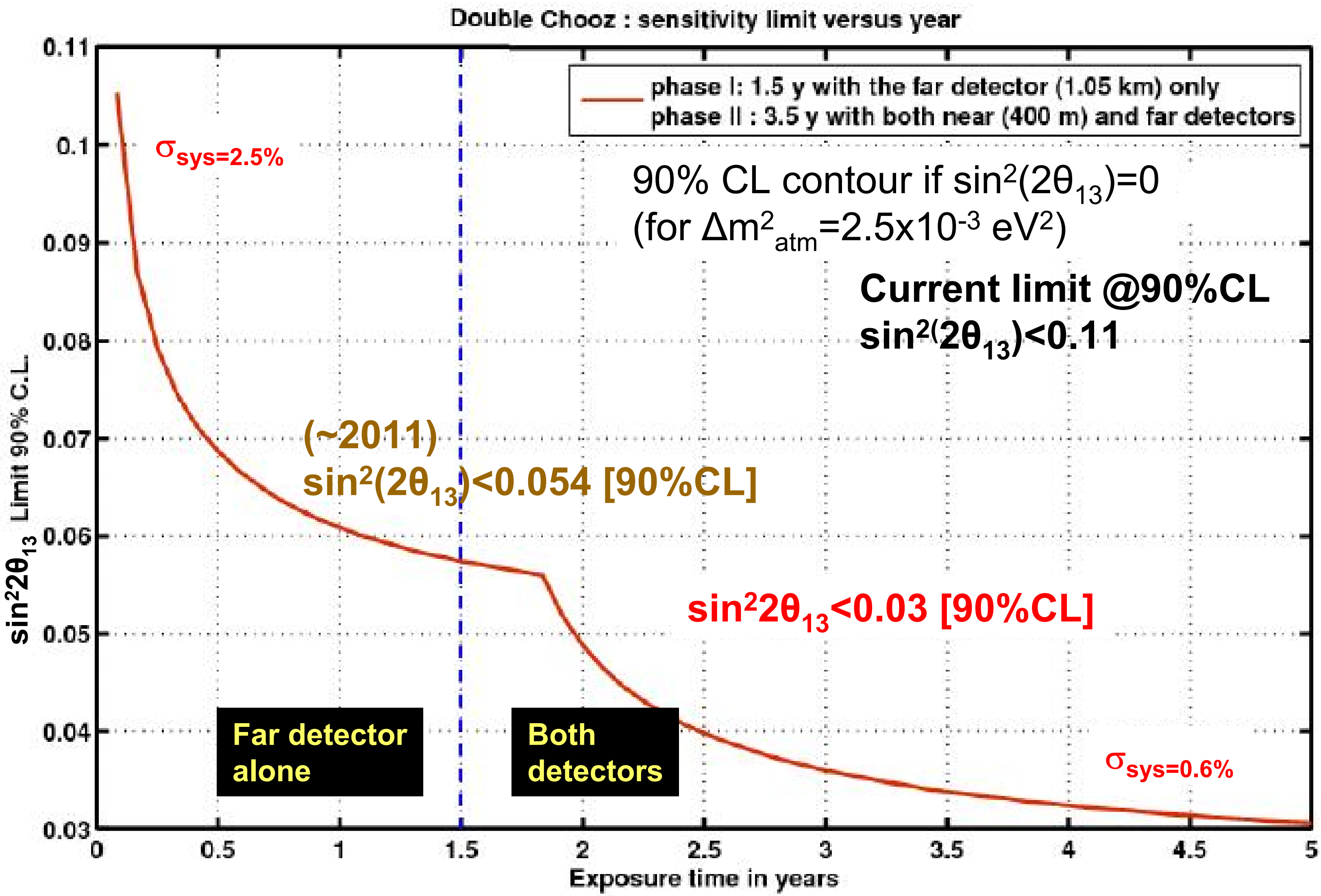


UV-VIS-IR scintillator transmission

Status and Schedule

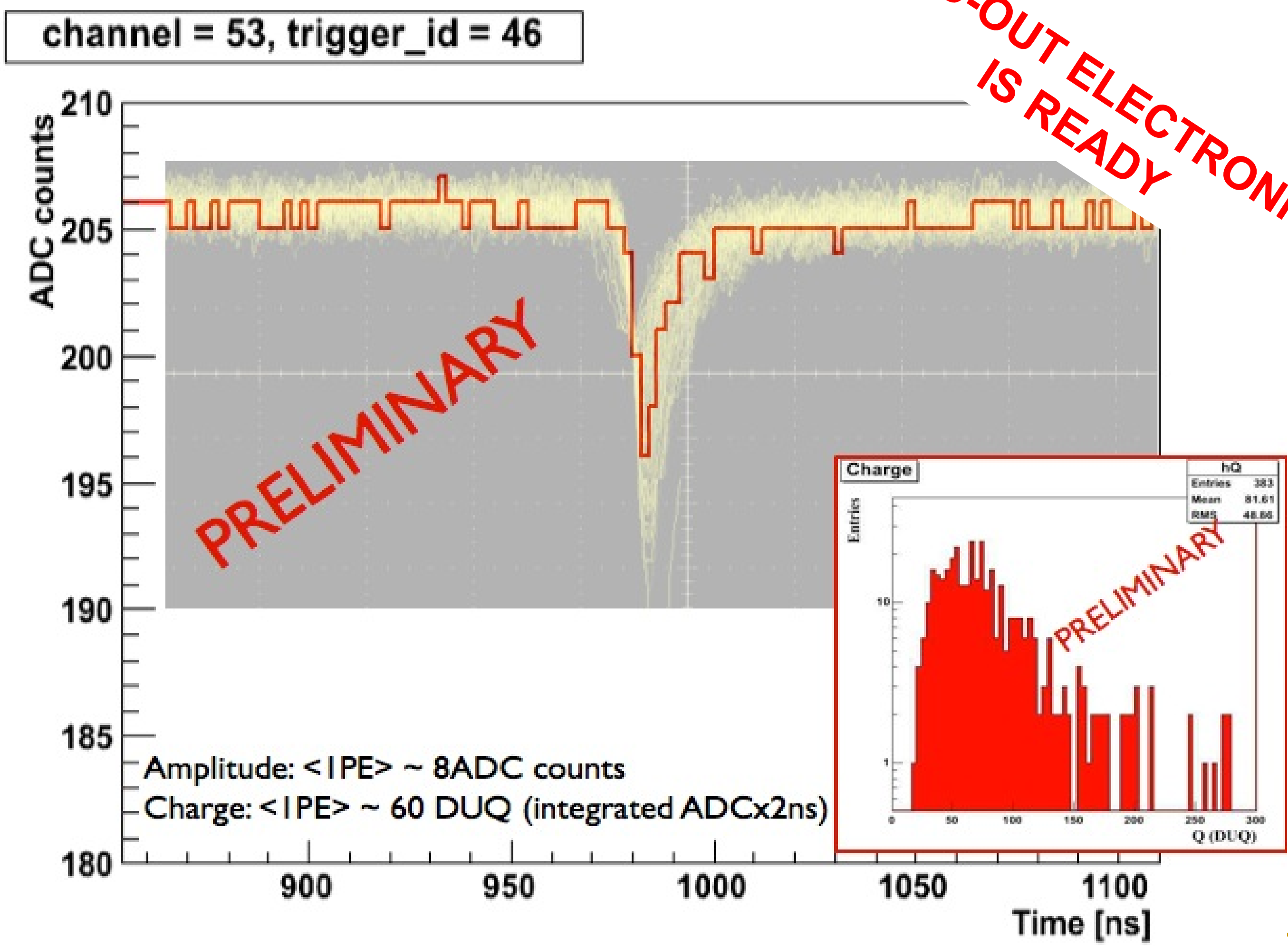
- Far detector filled and almost ready !!!
- First neutrino by Christmas
- 2011 Data taking with Far detector
- 2011 Construction of Near Lab
- 2012 Construction of Near detector and data taking with both detectors by fall.

Expected Sensitivity



First data with dry detector

READ-OUT ELECTRONICS IS READY



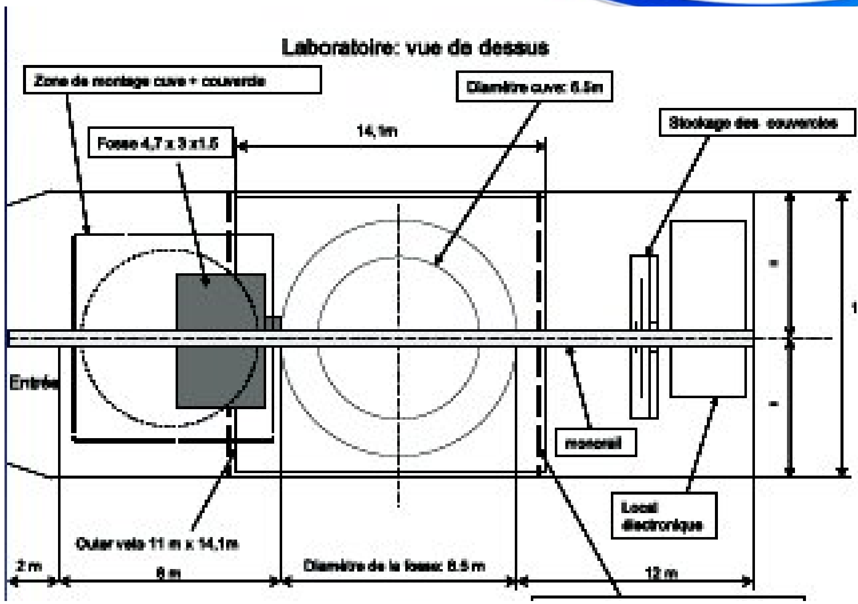
Near Detector

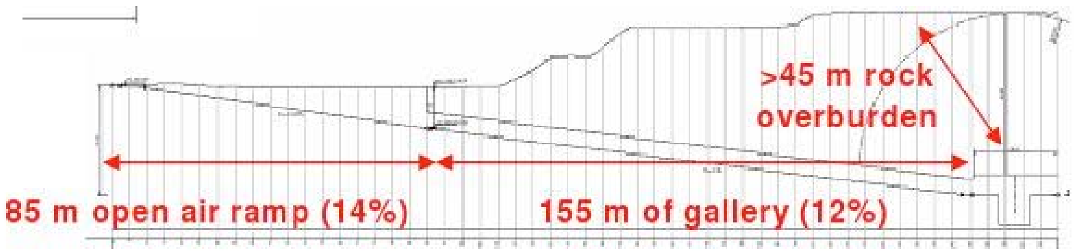
Authorisations and funding secured by the region Champagne-Ardennes, EDF and French agencies.

Involvement of EDF on the construction

Schedule

- Tender process for construction is over
- Lab available fall 2011
- Near D. construction 30 weeks
- Data taking by fall 2012



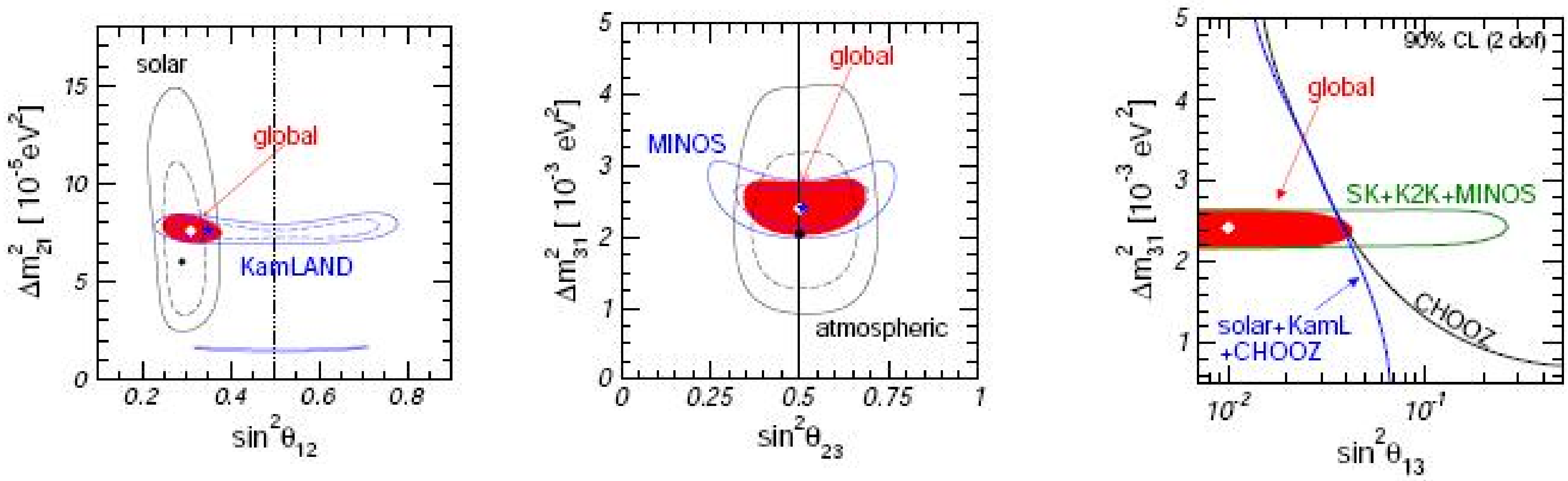


Summary

- **Double Chooz** will be the first of a new generation of neutrino experiments **using identical detectors at different distances** from a reactor to measure Θ_{13}
- **First neutrino event just round the corner !!**
- Running far detector: current limit $\sin^2 2\Theta_{13} < 0.11$ @ 90% CL in few weeks and <0.06 running 1 year
- **2012 start of data taking with both detectors**
- Detector stability will allow a **long data taking period**
- **Three years running both detectors:** **$\sin^2 2\Theta_{13} < 0.03$ @ 90% CL**

Backup

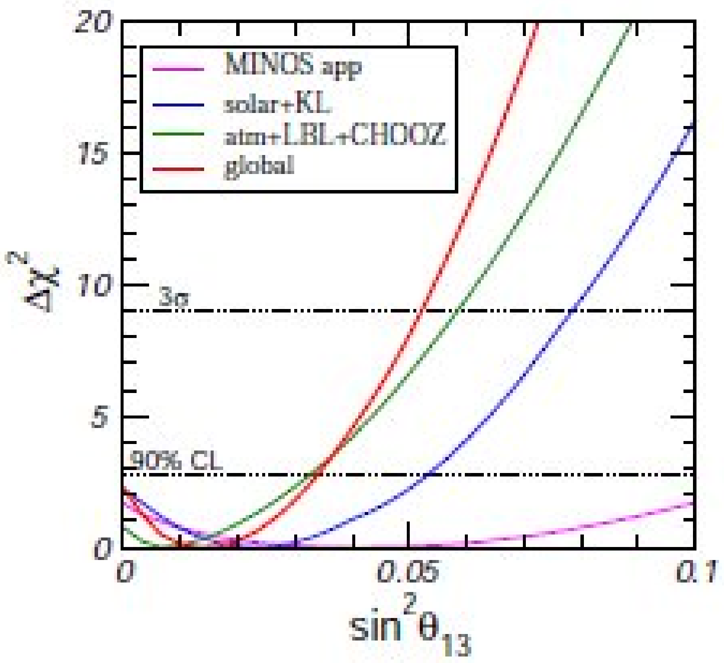
Neutrino oscillations: present status



arXiv:0808.2016

Θ_{13} Determination

A non-zero value for θ_{13} ?



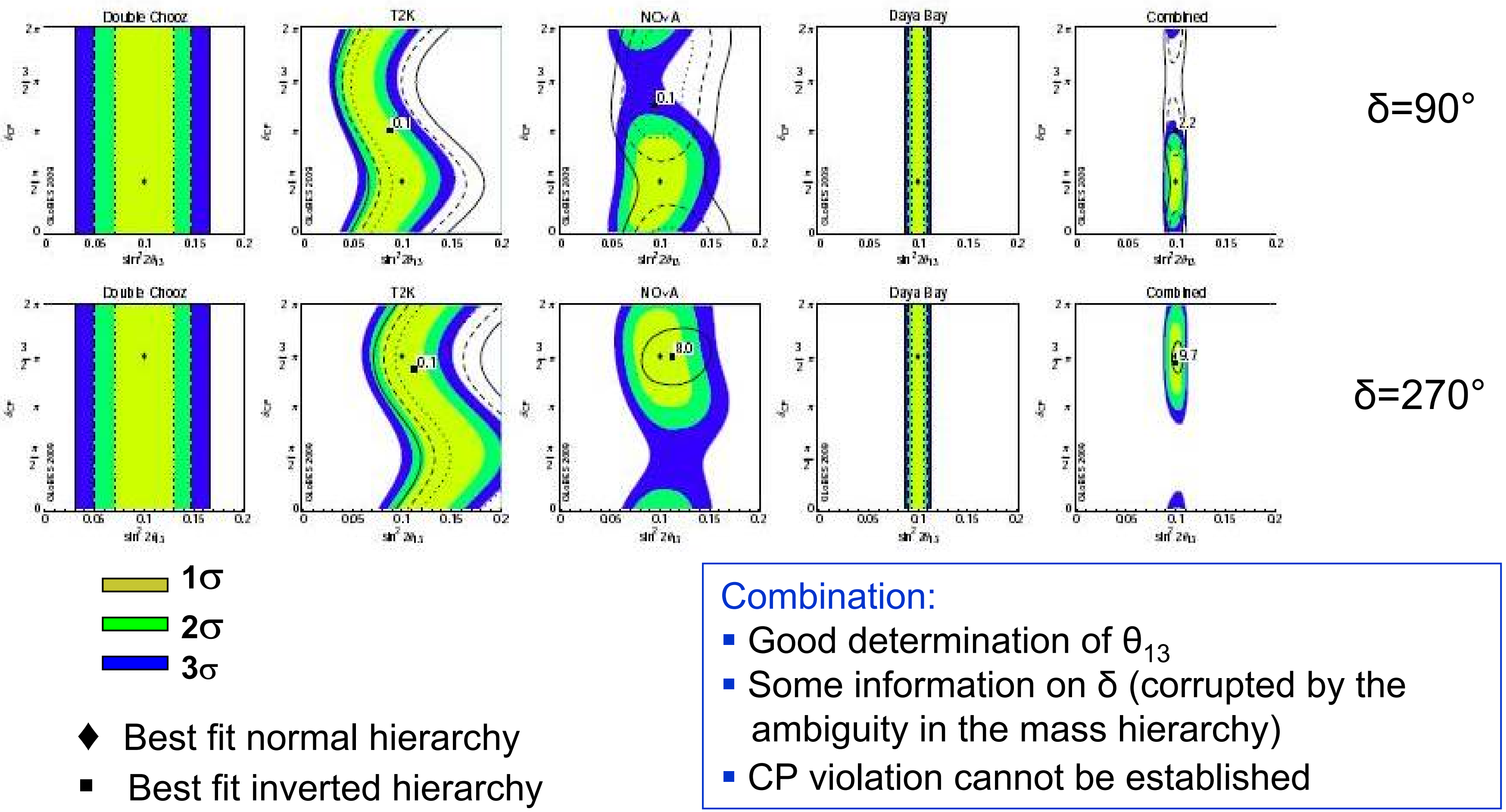
- Solar + KamLAND data lead to a hint for non-zero θ_{13} (1.5σ)
- However, the CHOOZ + atmospheric data give a smaller value.
- **The global combination including the MINOS appearance data gives a non-zero best fit value of θ_{13}**

$$\sin^2\theta_{13} = 0.013^{+0.013}_{-0.009}$$

arXiv:0808.2016

Θ_{13} Determination

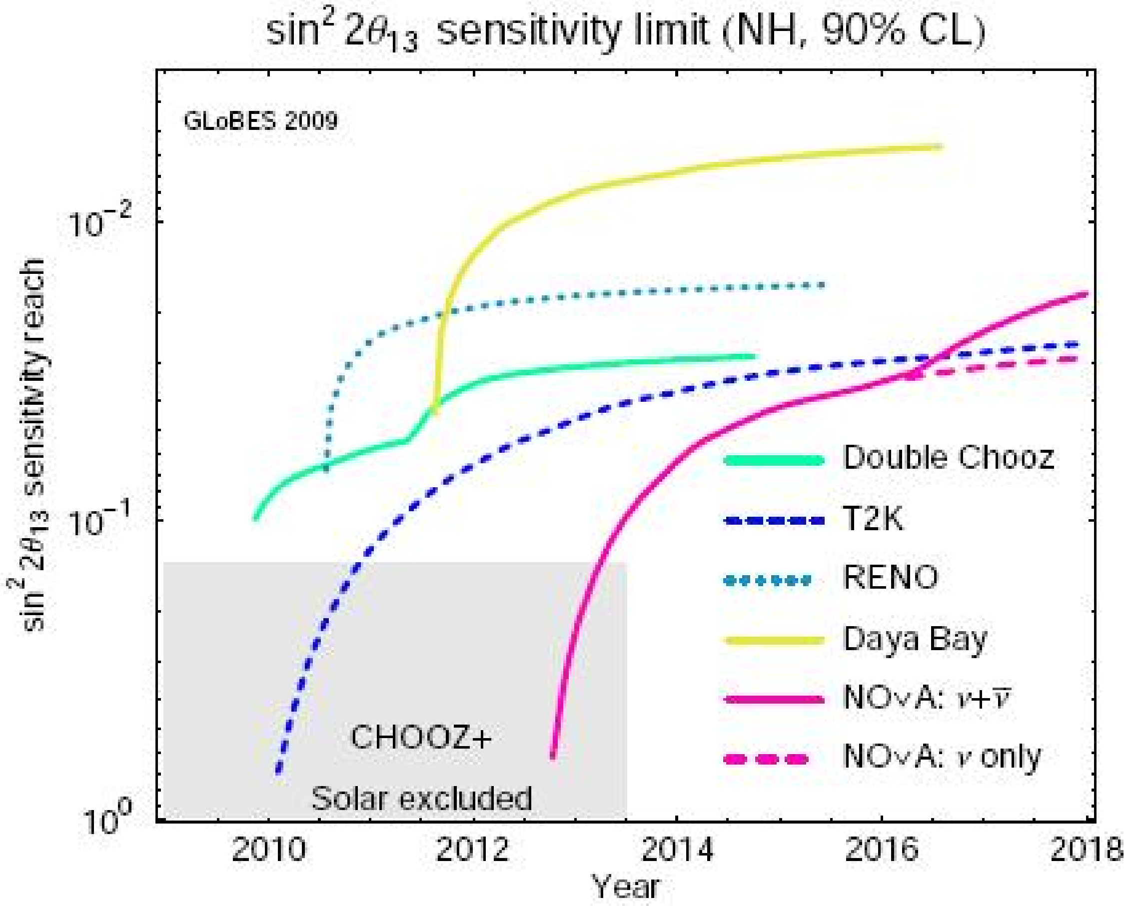
$\sin^2 2\theta_{13}$—δ plane for the true values $\sin^2 2\theta_{13}=0.1$ arXiv:0907.1896



Combination:

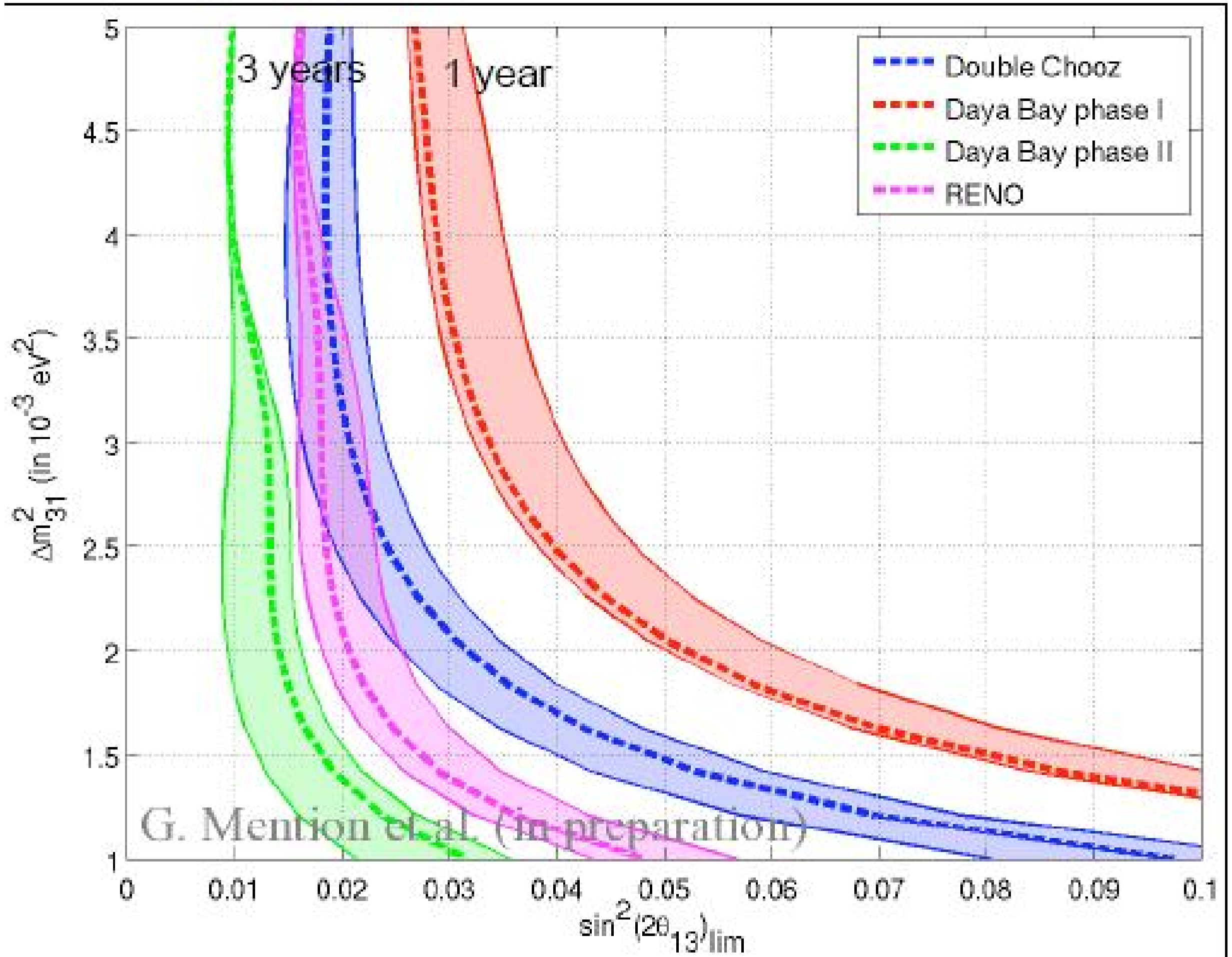
- Good determination of θ_{13}
- Some information on δ (corrupted by the ambiguity in the mass hierarchy)
- CP violation cannot be established

Θ_{13} Determination



arXiv:0907.1896

Reactor experiments proposals



Reactor and antineutrino spectrum

Raw reactor data

Power, mass, # fissions
Operation mode (refueling and enrichments)
Monitoring of the power vs time

Reactor evolution code
MURE / DRAGON

Isotope mass
Isotope fission rate

Predicted neutrino spectrum

Neutrino energy spectra
of U and Pu
(Simulation code)

Double-Chooz: Systematic errors

		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
	Target Mass	0.3 %	0.2 %	Same weight sensor for both det.
	Density	0.3 %	<0.1 %	Accurate T control (near/far)
	H/C ratio & Gd concentration	1.2 %	<0.2%	Same scintillator batch + Stability
	Spatial effects	1.0 %	<0.1 %	"identical" Target geometry & LS
	Live time	few %	0.25 %	Measured with several methods
Analysis	From 7 to 3 cuts	1.5 %	0.2 - 0.3 %	
	Total	**2.7 %**	**< 0.6 %**	**(Total ~0.45% without contigency ....)**

Background

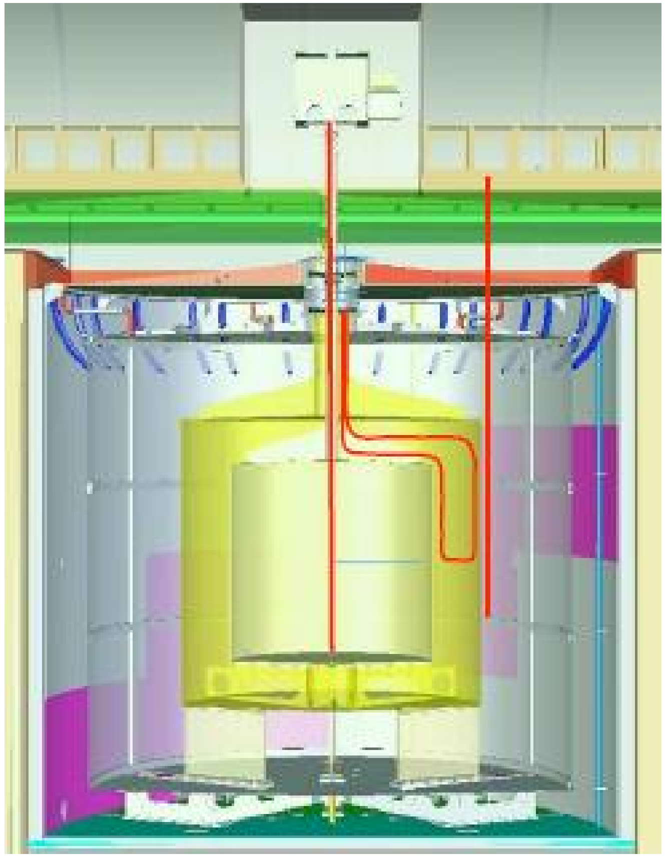
No Veto System

Detector	Site		Background				
			Accidental		Correlated		
			Materials	PMTs	Fast n	μ-Capture	^{9}Li
Double Chooz		Rate (d^{-1})	0.5 ± 0.3	1.5 ± 0.8	2.0 ± 2.0	28	1.0 ± 0.5
(69 ν/d)	Far	bkg/ν	0.7%	2.2%	2.9%	40%	1.4%
Double Chooz		Rate (d^{-1})	5 ± 3	17 ± 9	9.1 ± 9.1	266	9 ± 5
(500 v / d)	Near	bkg/ν	0.5%	1.7%	0.8%	26%	0.9%

Inner and Outer Veto

Detector	Site		Background				
			Accidental		Correlated		
			Materials	PMTs	Fast n	μ-Capture	^{9}Li
Double Chooz		Rate (d^{-1})	0.1 ± 0.1	0.3 ± 0.2	0.11 ± 0.11	< 0.1	1.0 ± 0.5
(69 ν/d)	Far	bkg/ν	0.1%	0.4%	0.2%	< 0.1%	1.4%
		systematics	<0.1%	<0.1%	0.2%	<0.1%	0.7%
Double Chooz		Rate (d^{-1})	0.5 ± 0.3	1.7 ± 0.9	0.15 ± 0.15	0.4	9 ± 5
(500 v / d)	Near	bkg/ν	< 0.1%	0.2%	< 0.1%	< 0.1%	0.9%
		systematics	<0.1%	<0.1%	<0.1%	<0.1%	0.5%

Calibration System



Deployment of radioactive sources:

Articulated arm (Target)

Guide tubes (Gamma-catcher)

Buffer tubes

Z-axis system

Light Injection:

LED systems IV and buffer

Laser (Z-axis)