GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN

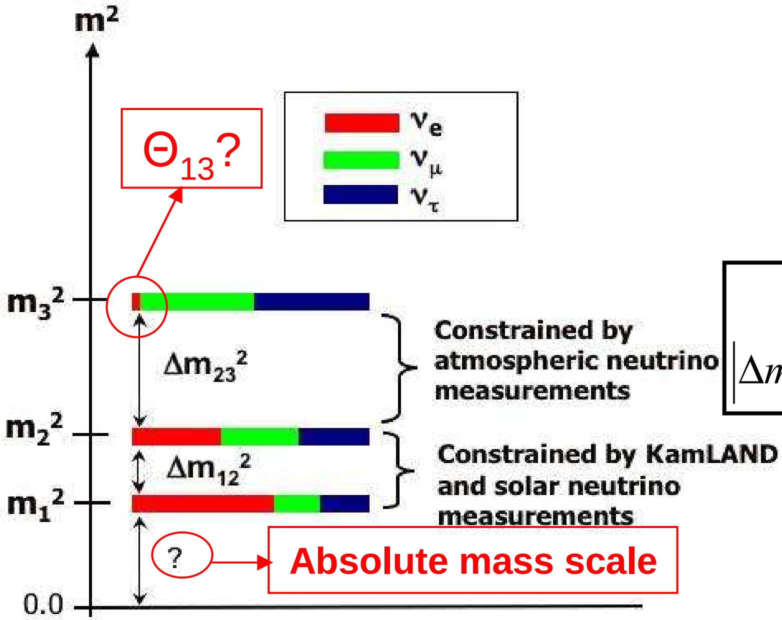
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Double-Chooz Neutrino Experiment

Carmen Palomares (Ciemat, Spain)

for Double-Chooz Collaboration

Current knowledge



$\theta_{13} < 9.5\,\mathrm{deg}$ @ 90% CL

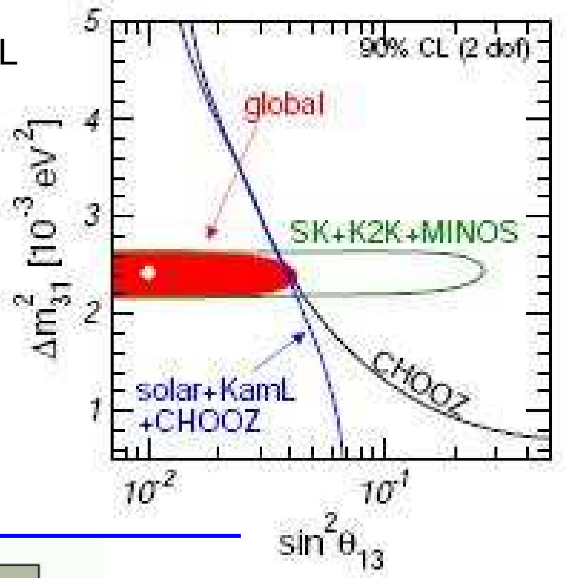
$$\theta_{23} = 45^{+4.}_{-3.4}$$

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

$$\theta_{12} = 33.5^{+1.3}_{-1.0}$$

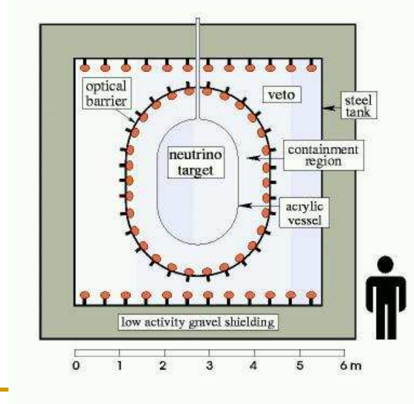
$$\Delta m^2_{12} = 7.65^{+0.23}_{-0.20} \times 10^{-5}\,eV^2$$

@1σ arXiv:0808.2016

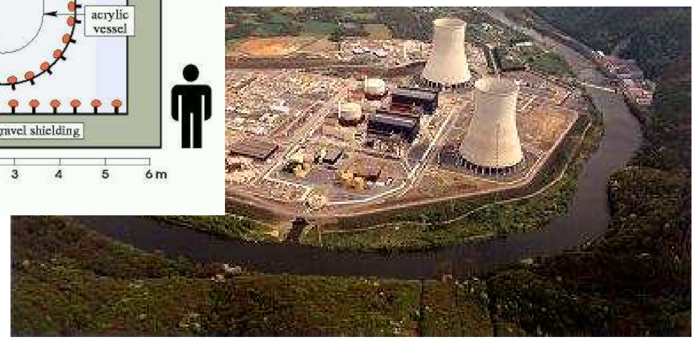


Open questions:
- Mass hierarchy
- Absolute mass scale
- CP violation effects
- Size of θ_{13}

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



The main limit comes from CHOOZ reactor experiment ´97

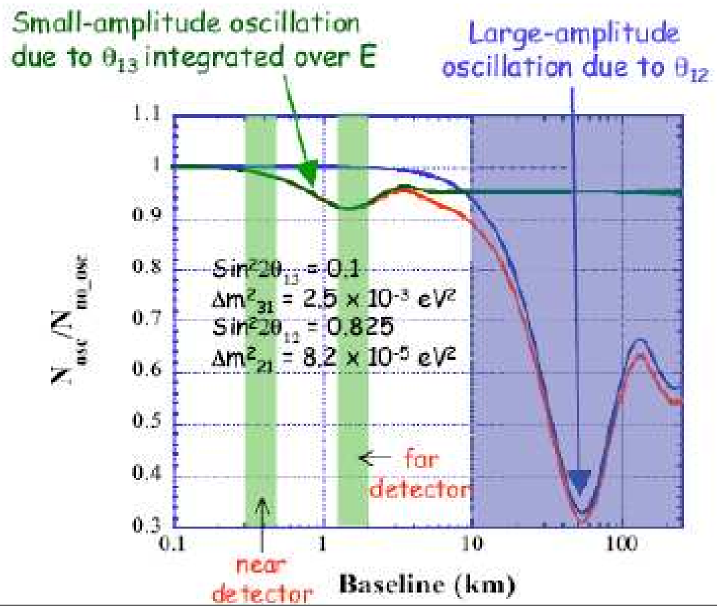


Experimental methods to measure θ_{13}

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

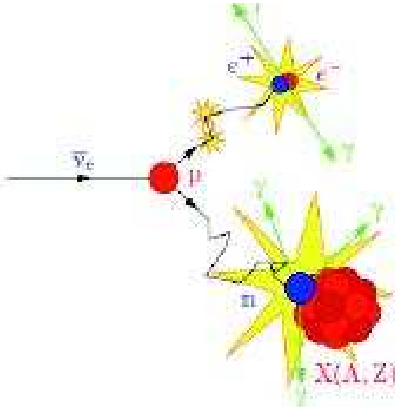


$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = 1 - \sin^2 2\theta_{13} \sin^2 \frac{\Delta m^2_{13} L}{4E} + \cancel{\left(\frac{\Delta m^2_{21} L}{4E_\nu}\right)^2 \cos^4\theta_{13} \sin^2 2\theta_{12}}$$

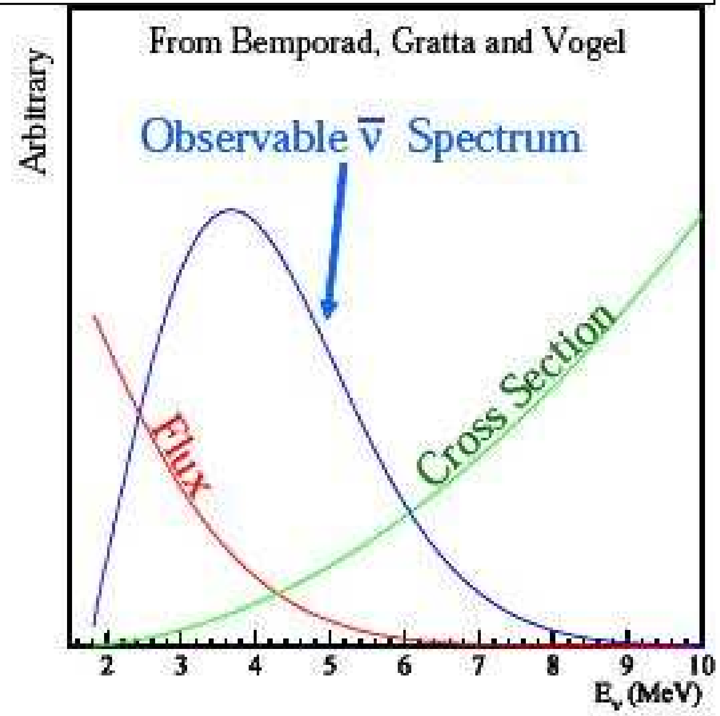
Neutrino detection at nuclear reactor experiments

Detection by inverse β-decay

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



Using β spectra measurements for ^{235}U, ^{239}Pu, and ^{241}Pu can calculate the ν_e flux to ~1.5%.



Signature→ Delay coincidence of:

Prompt **e⁺** annihilation $E_{e+} = E_\nu-(M_n-M_p)$

Photons from **n** capture on H E= 2 MeV

on dedicated nuclei (Gd) E = 8 MeV

Backgrounds

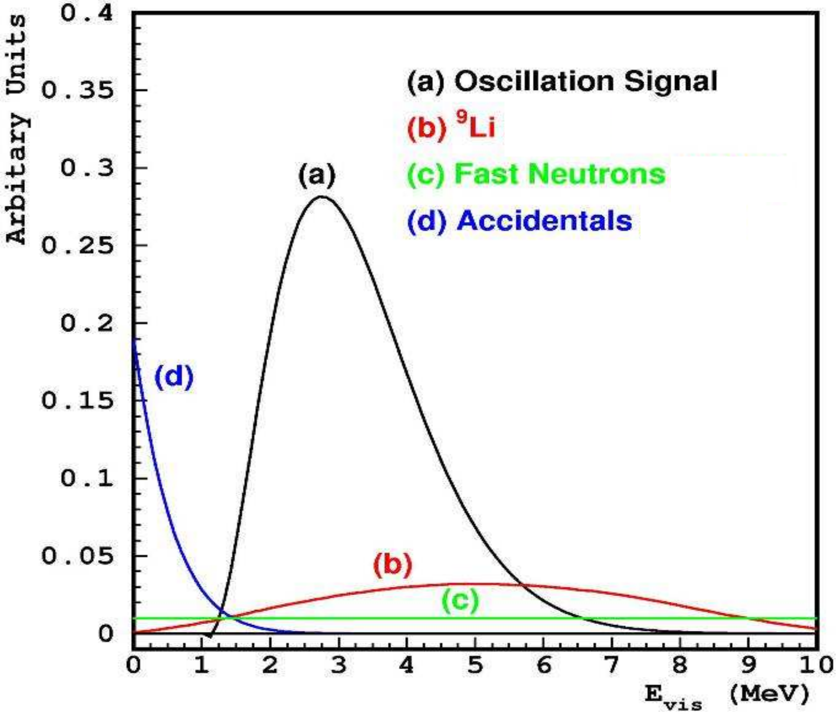
Accidental:

- 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

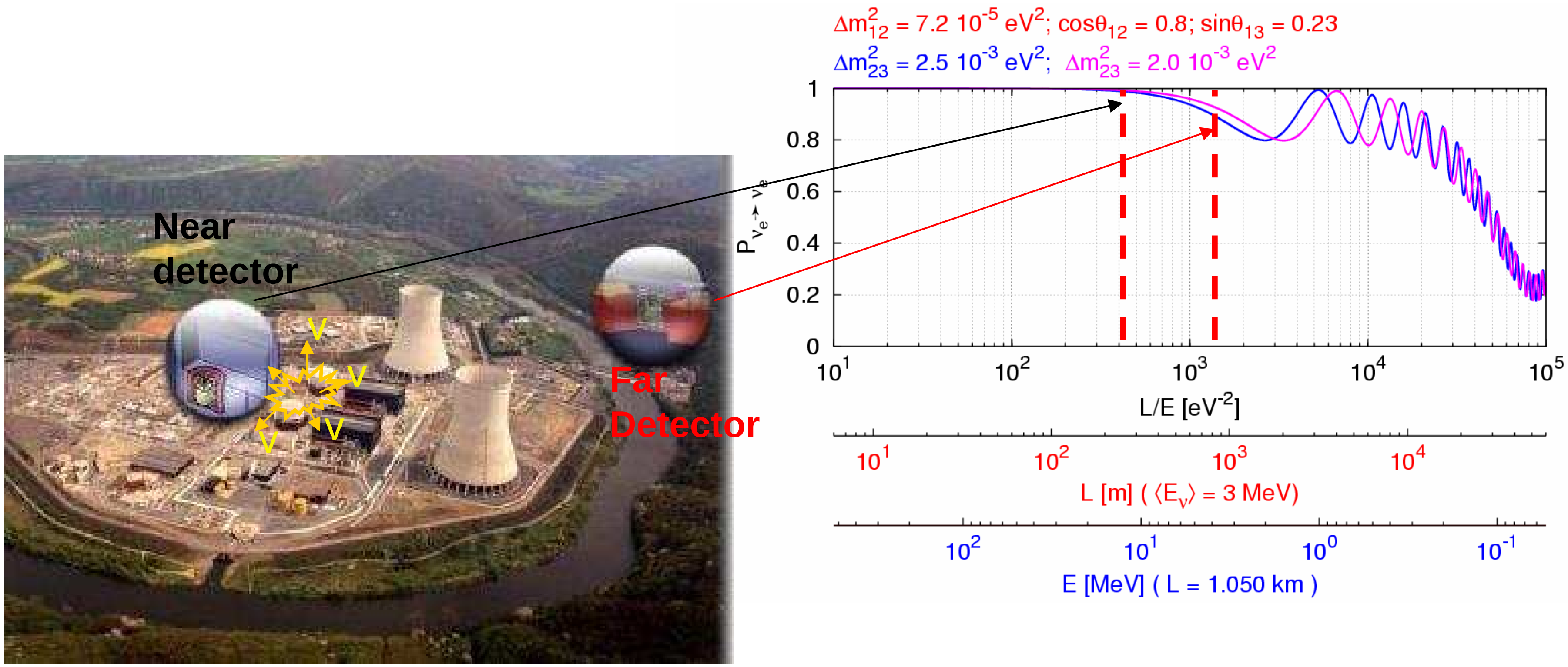


Double Chooz Concept

To look for non-zero values of Θ_{13}

Beyond the previous systematic limitations:

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



Improving CHOOZ

CHOOZ: $R=N_{meas}/N_{exp}$ = 1.01 ± 2.8% (stat) ± 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%

Improving CHOOZ

Background

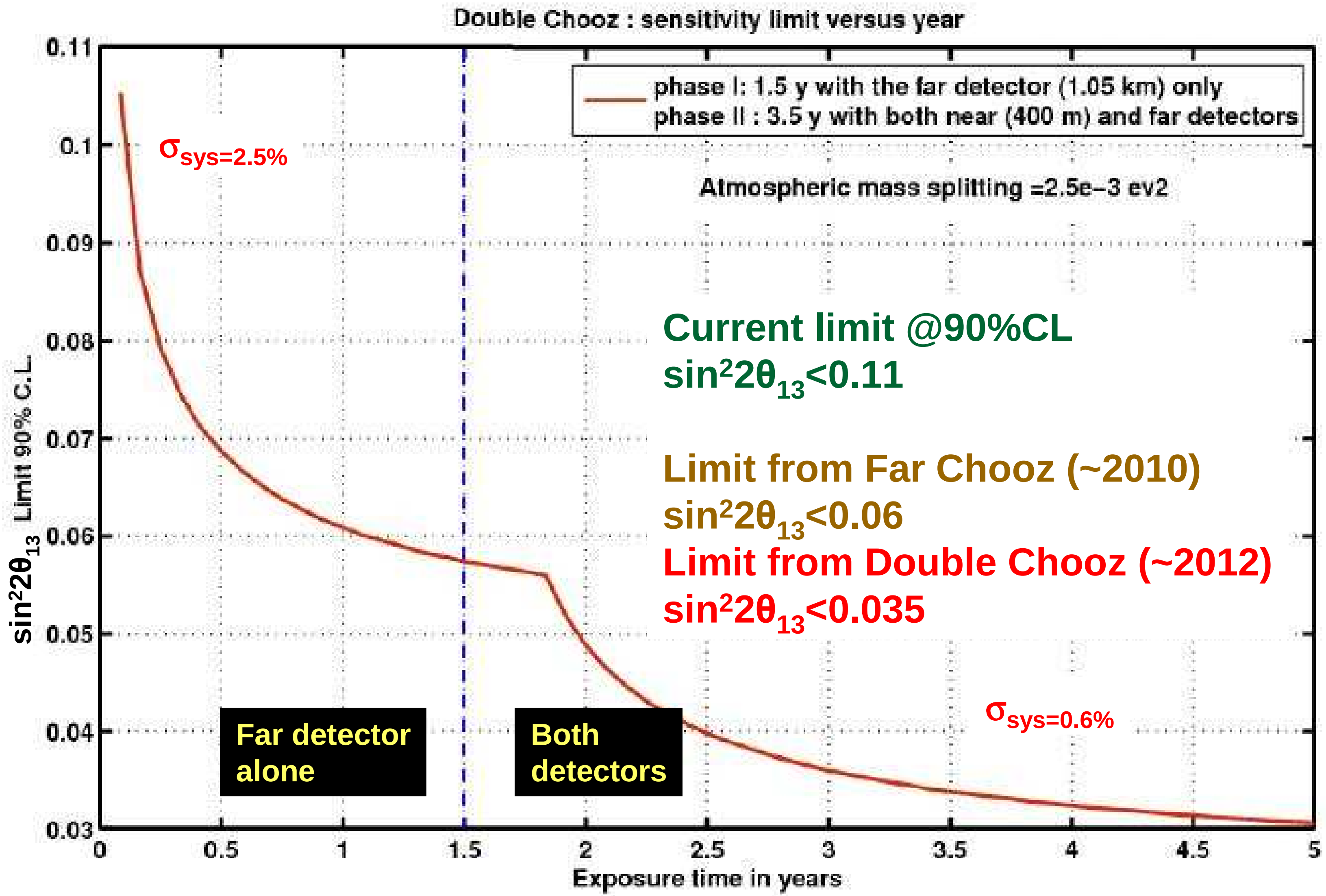
- **Single e^+-like** reduced: PMT very low radioactivity glass
  PMT is not in contact with liquid scintillator
  (PMT single rate
  CHOOZ: ~60 Hz. Double-Chooz ~1.5 Hz)
  Detector shielded by 15 cm iron
- **Neutron rate** reduced by using a
  more efficient cosmic muon veto system

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

Expected Sensitivity



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

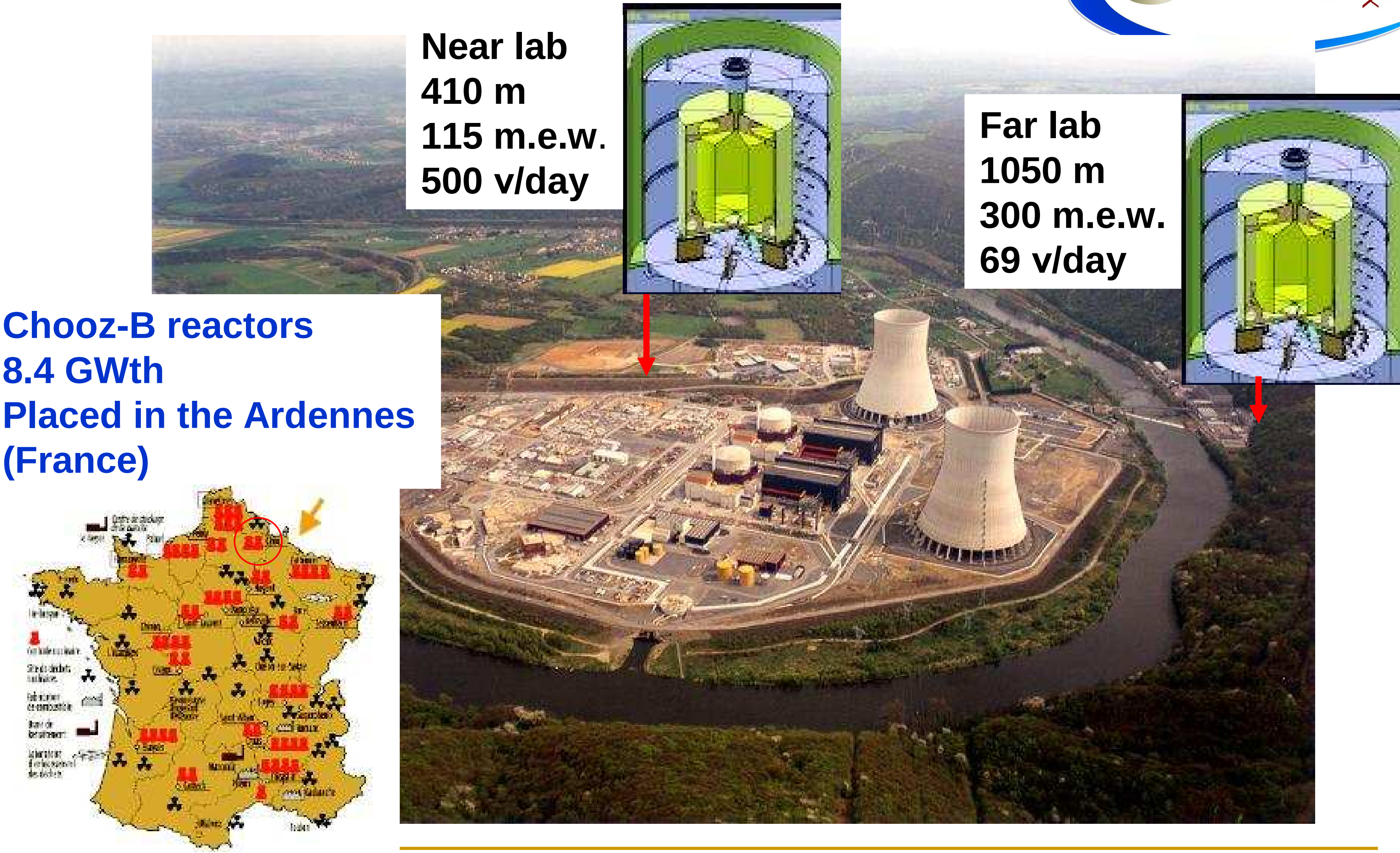
Japan: HIT, Kobe, Niigata, TGU, TIT, TMU, Tohoku

Russia: RAS, RRC Kurchatov Institute

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

Brazil: CBPF, UNICAMP

The Chooz site:

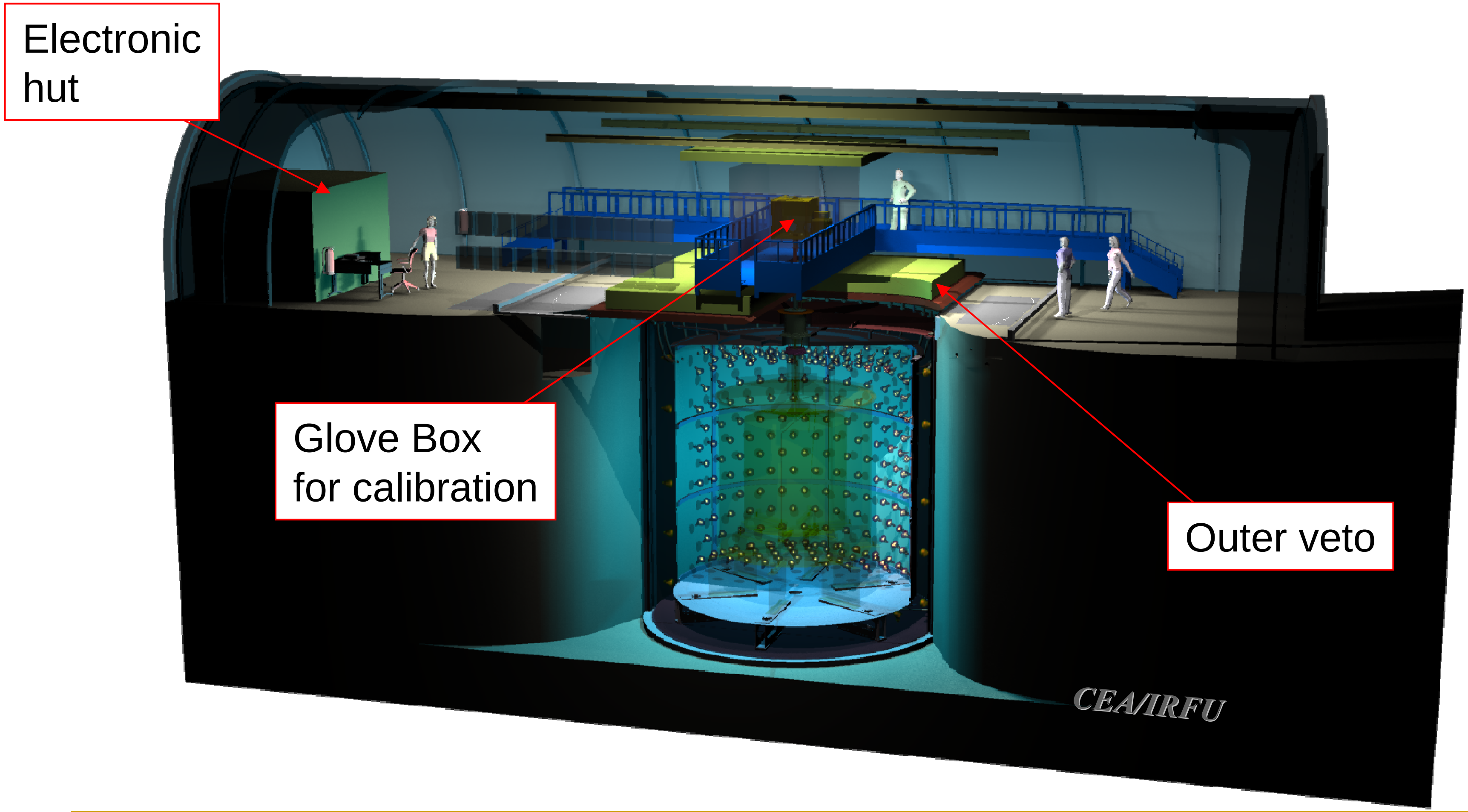


Near lab
410 m
115 m.e.w.
500 ν/day

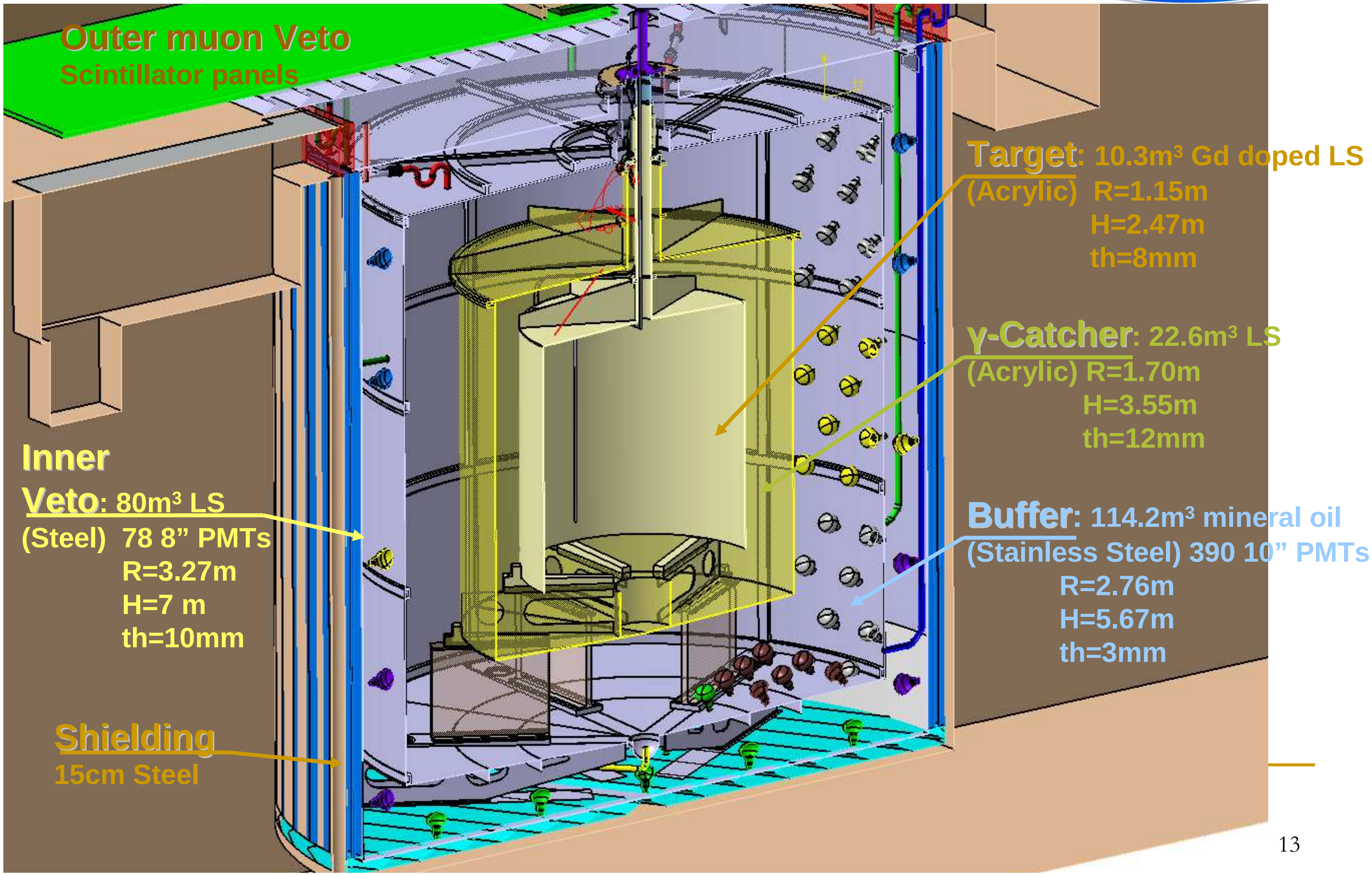
Far lab
1050 m
300 m.e.w.
69 ν/day

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

The Double Chooz Laboratories



The Detector(s)



Far Detector Construction

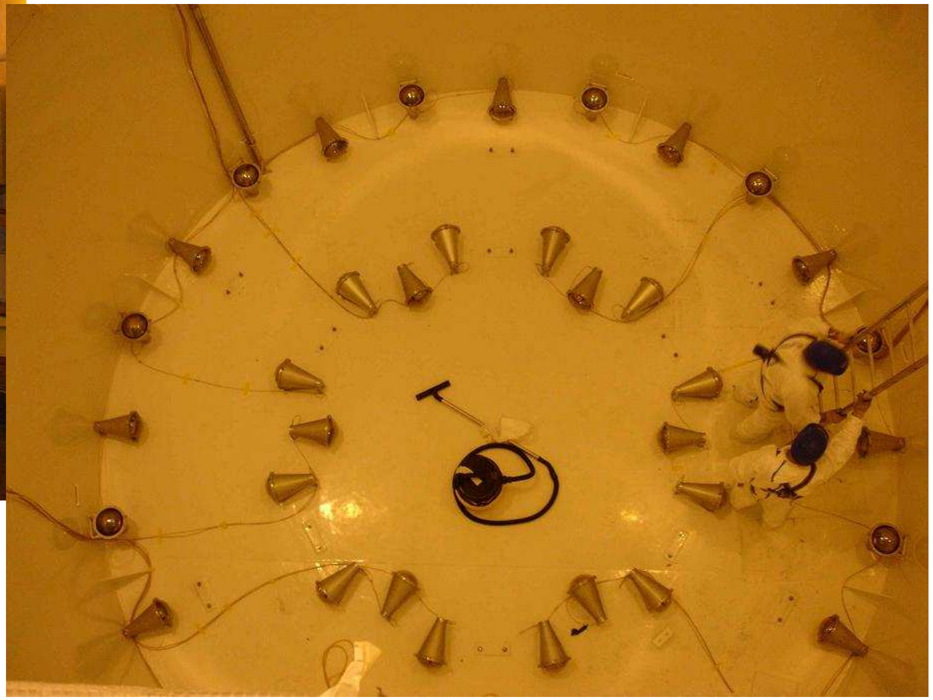
After refurbishment of the pit, the detector construction started in the second half of 2008.

Shield of 15 cm demagnetized iron

Far Detector Construction

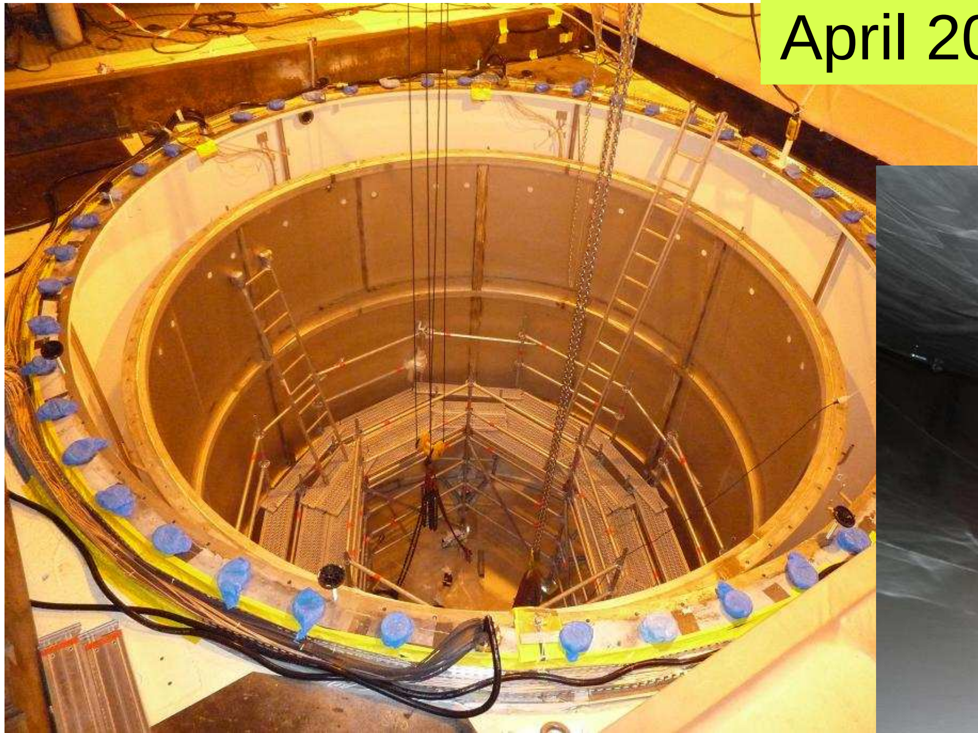
February 2009

Inner Veto PMTs
Installation completed



Far Detector Construction

April 2009



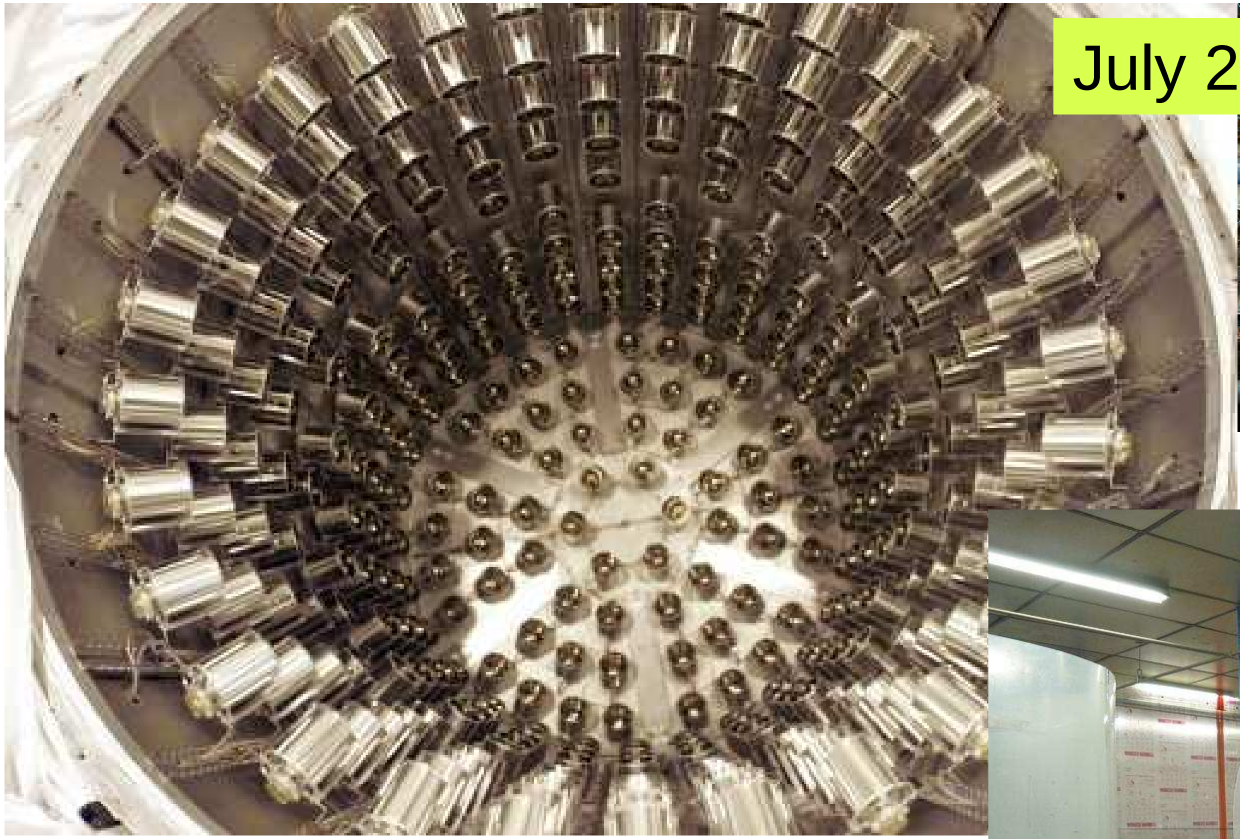
Buffer tank
assembled on site

Far Detector Construction

May 2009

PMT Installation

Current Status



July 2009

PMT Installation completed
Acrylic vessels ready to be assembled on site

Schedule

- Far Detector will be finished at the end of 2009

  Inner Veto and buffer PMT installation in the upper lid

  Electronics

- Filling and commissioning beginning of 2010

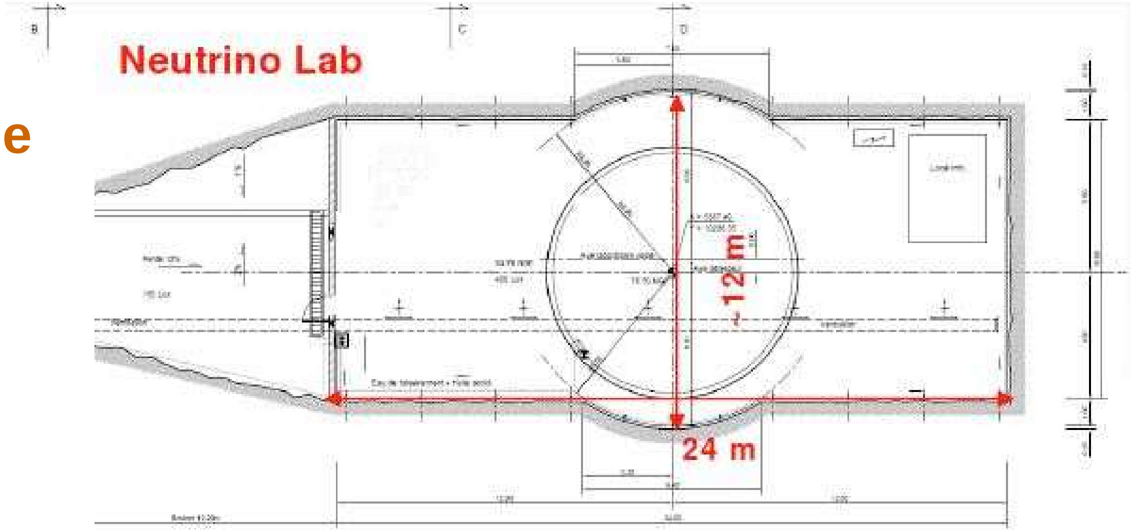
- Outer veto will be installed in April 2010

  (not indispensable for running)

From April 2010 a 4 months stop of one of the reactors
(possibility to get a stop of both reactors during some weeks)

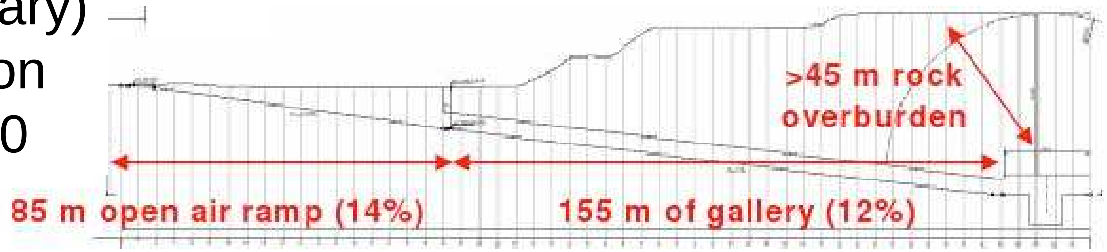
Near Detector

May 20th the **agreement for the Near laboratory construction** has been signed.
The agreement includes the region Champagne-Ardennes, EDF and French agencies.



Schedule

- Geological study done (February)
- Tender process for construction
- Constructed at the end of 2010

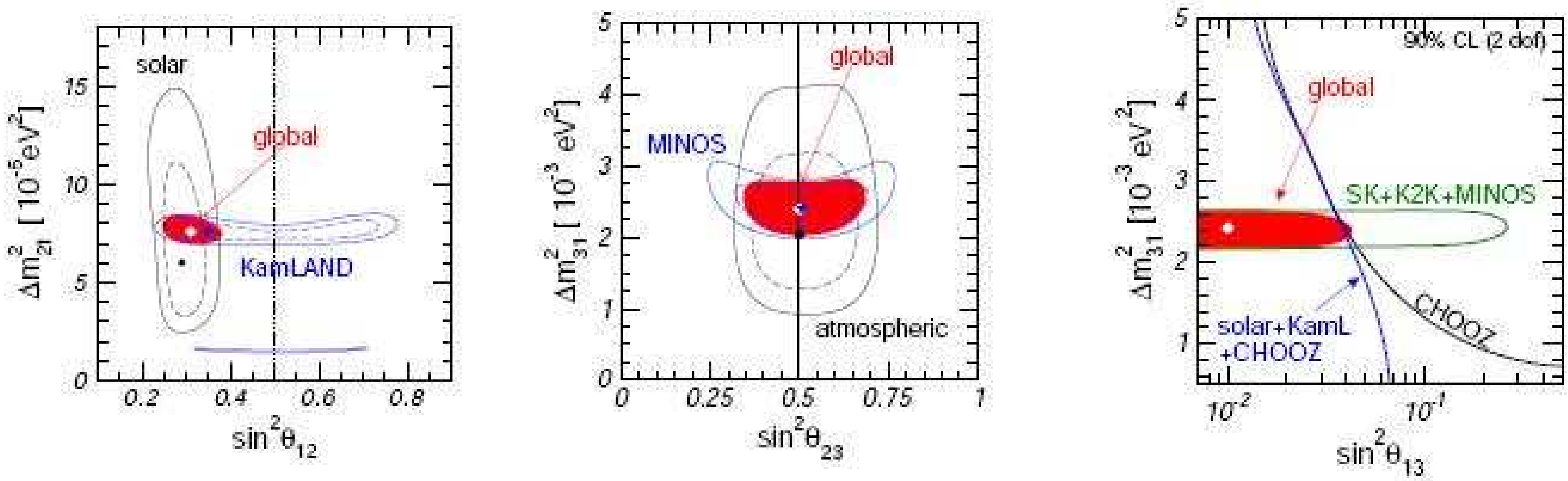


Summary

- **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 quarter of **2010 start of data taking** with far detector: current limit $\sin^2 2\Theta_{13} < 0.11$ @ 90% CL in few weeks and <0.06 running 1 year
- **2011 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

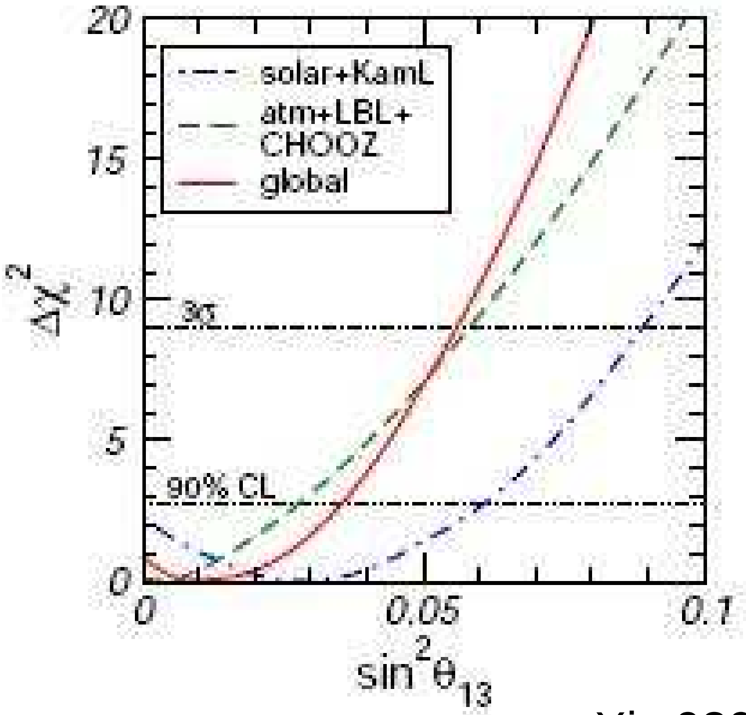
Neutrino oscillations: present status



arXiv:0808.2016

Θ_{13} Determination

A non-zero value for θ_{13} ?



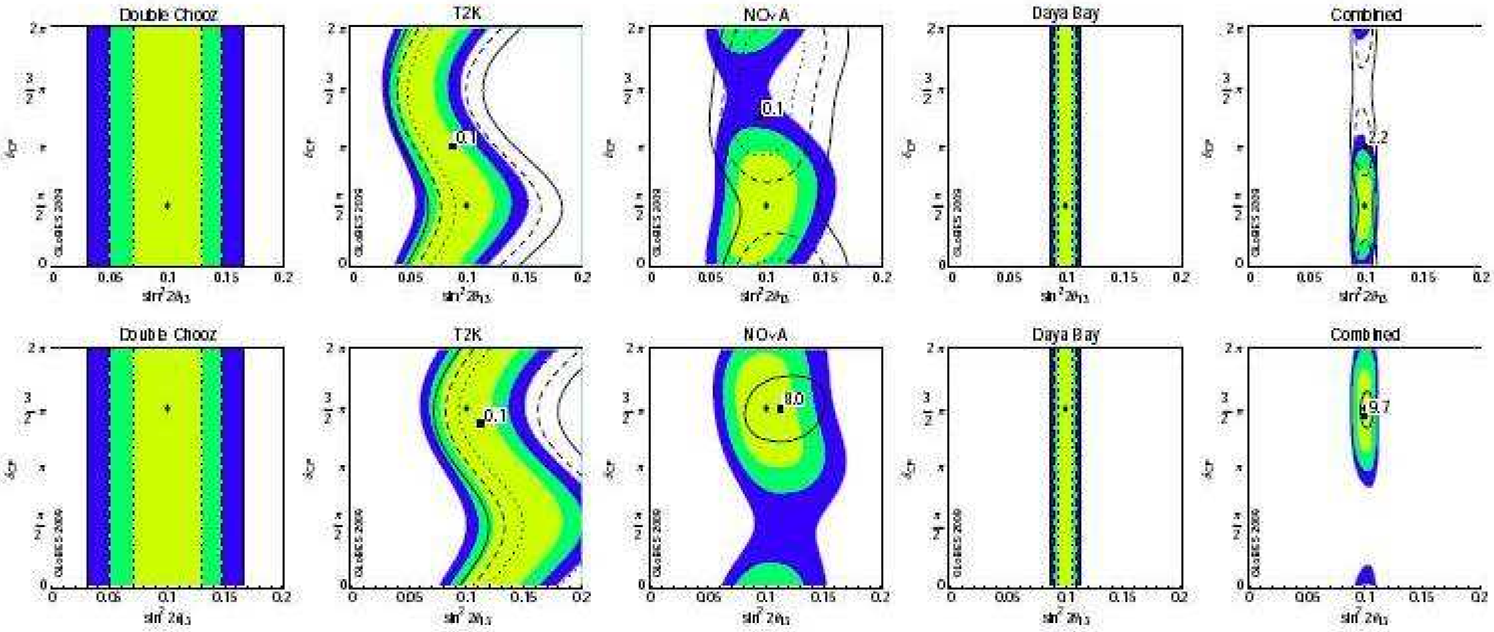
arXiv:0808.2016

- Solar + KamLAND data lead to a hint for non-zero θ_{13} (1.5σ)
- Therefore, the CHOOZ + atmospheric data give a smaller value.

At present no significant hint for a non-zero θ_{13}

Θ_{13} Determination

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



$\delta=90°$

$\delta=270°$

1σ
2σ
3σ

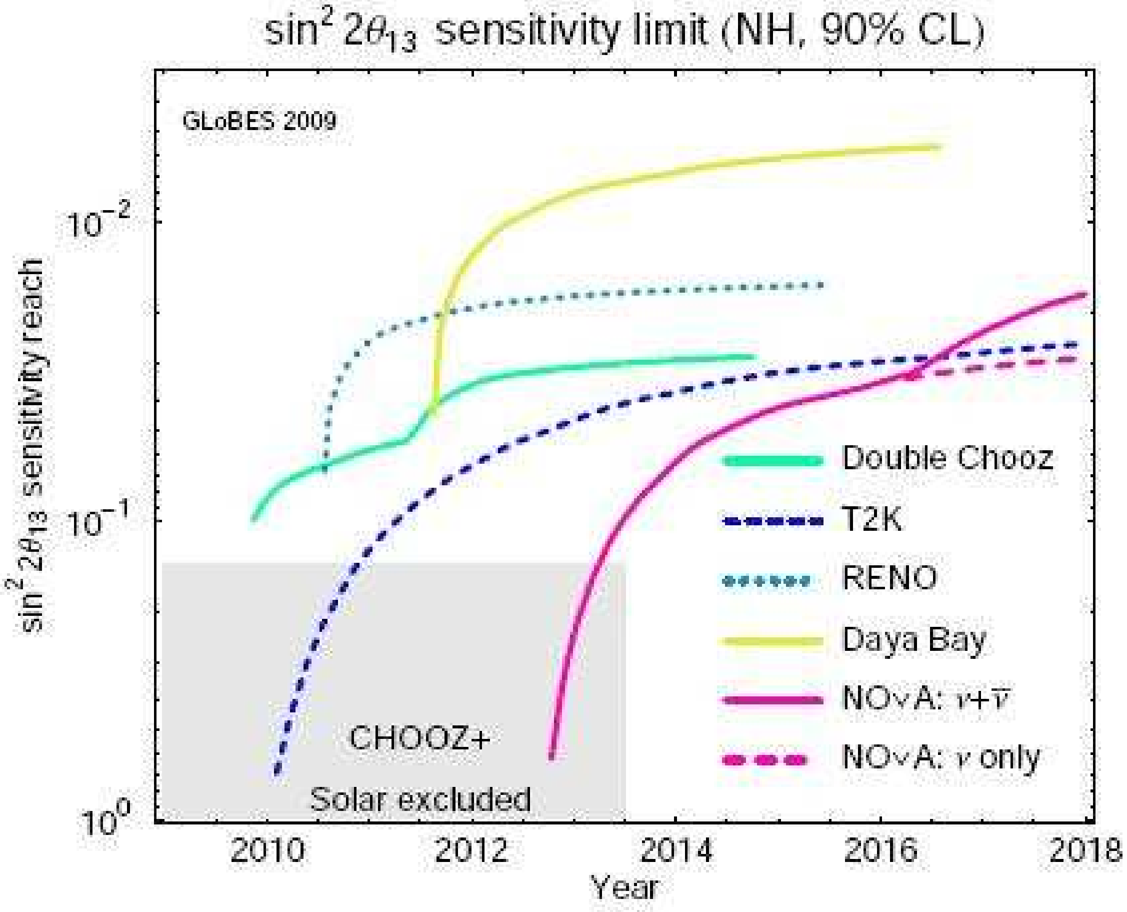
♦ Best fit normal hierarchy

▪ Best fit inverted hierarchy

Combination:

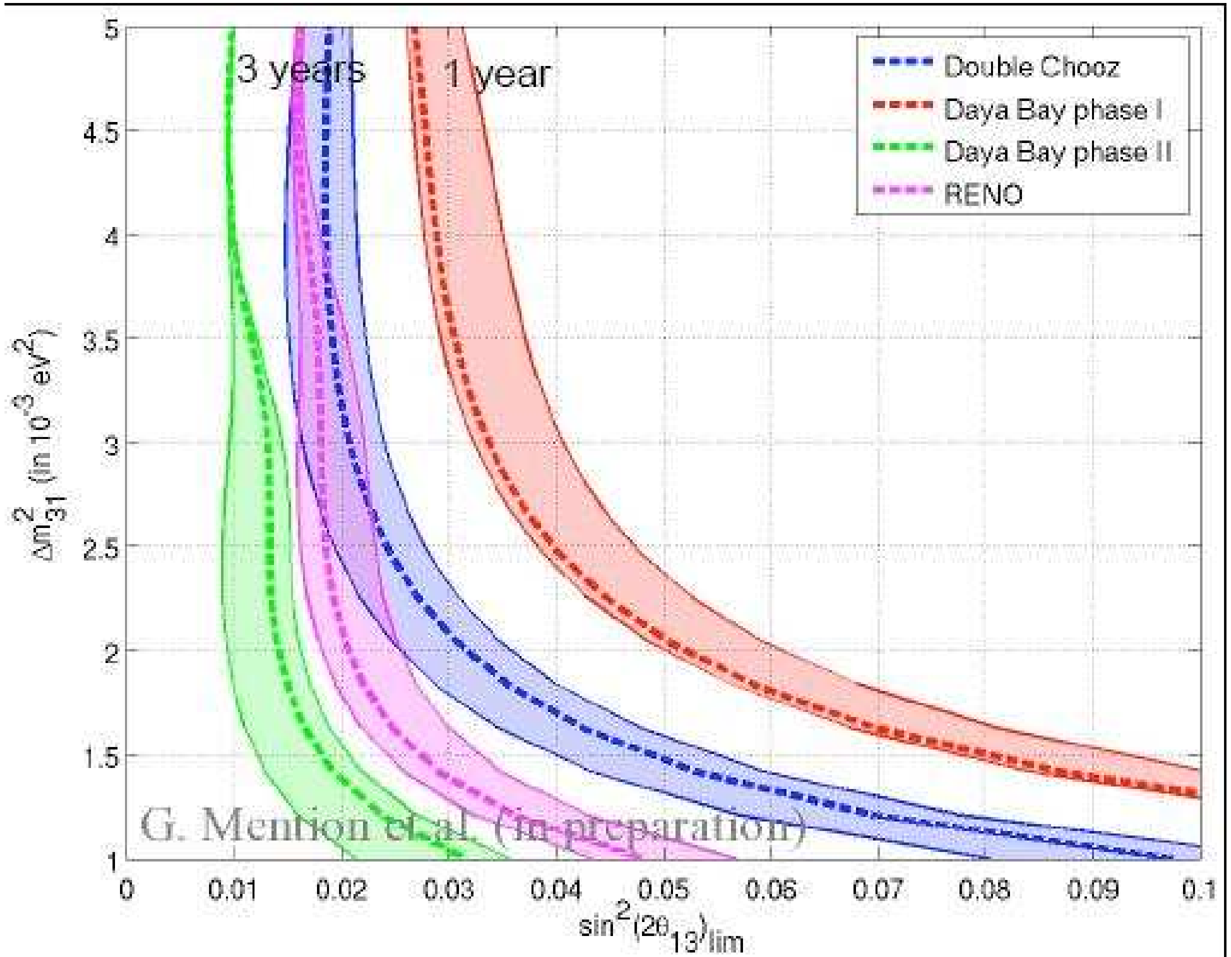
- Good determination of θ_{13}
- Some information on δ (corrupted by the ambiguity in the mass hierarchy)
- CP violation cannot be established

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

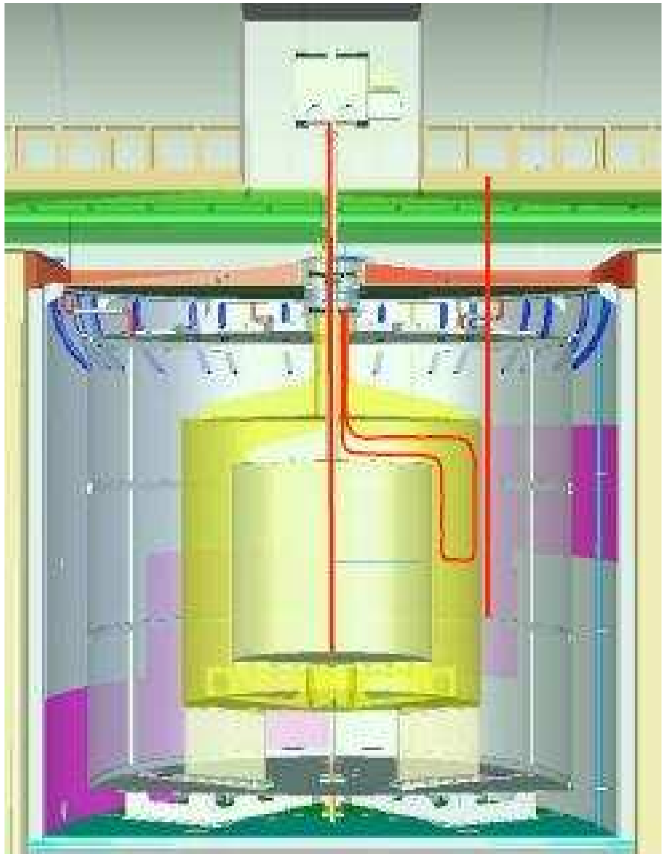
No Veto System

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 ν / 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 ν / 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)

Target and G-Catcher

Three targets finished

Cylinder glued

Lid construction: gluing support and filling tube

Target and G-Catcher

Gamma catcher construction divided between Néotec site and Chooz power plant to avoid heavy transportation:

Néotec: Cylinders parts constructed
Lids constructed and glued

Chooz: gluing of the cylinder
gluing of cylinder, lids and filling tubes