Double Chooz

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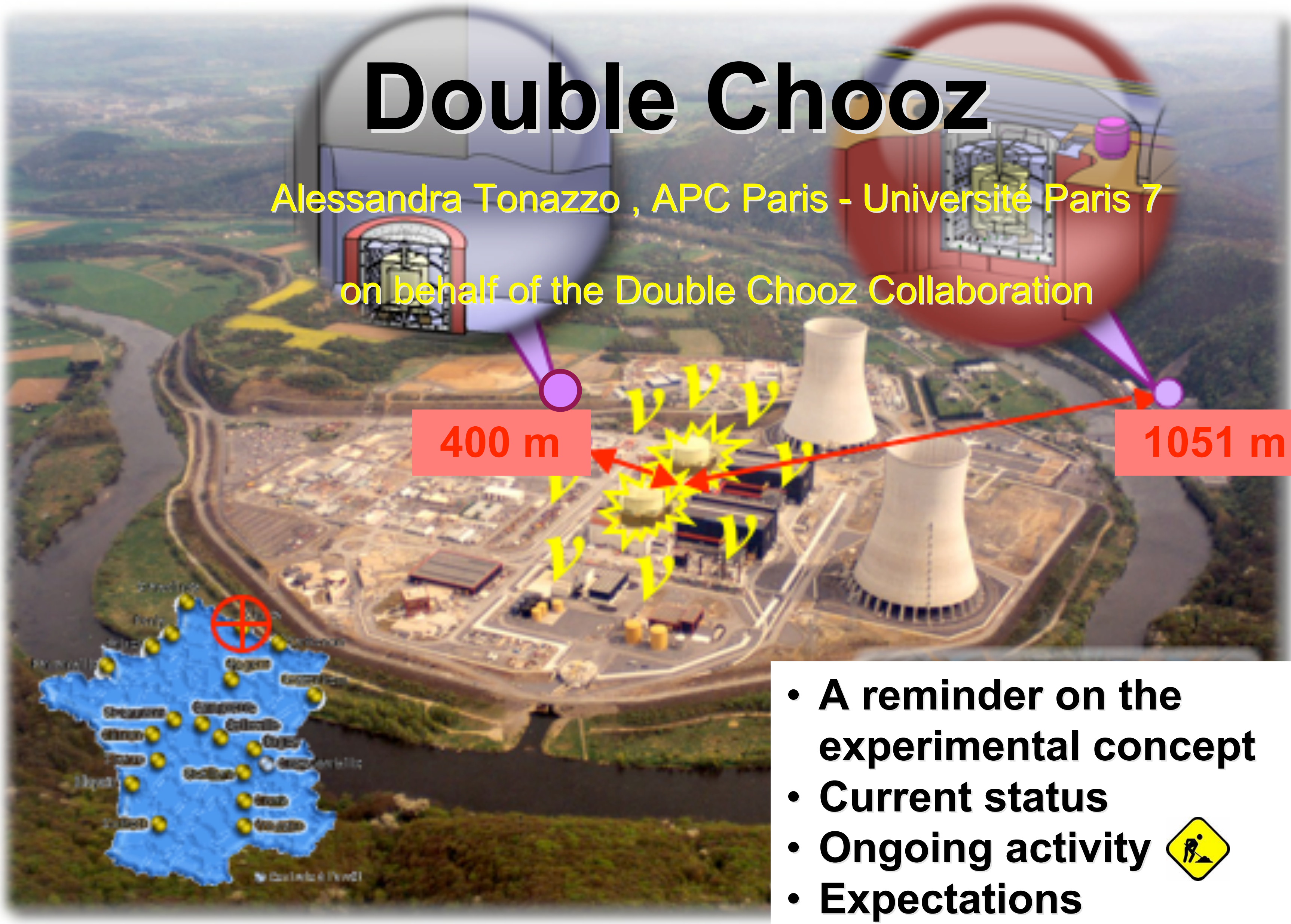
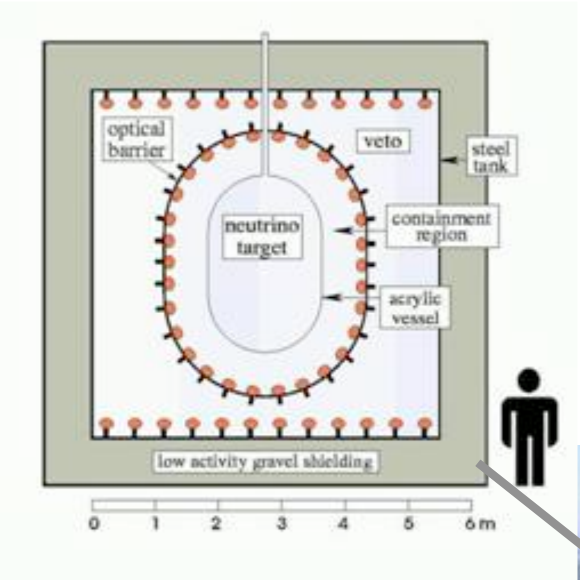
on behalf of the Double Chooz Collaboration

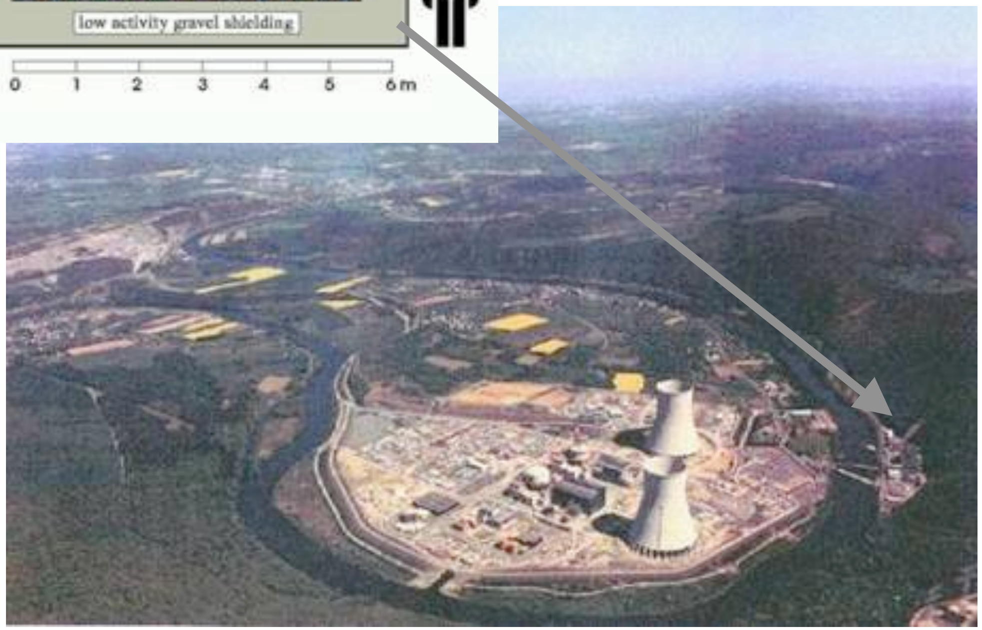


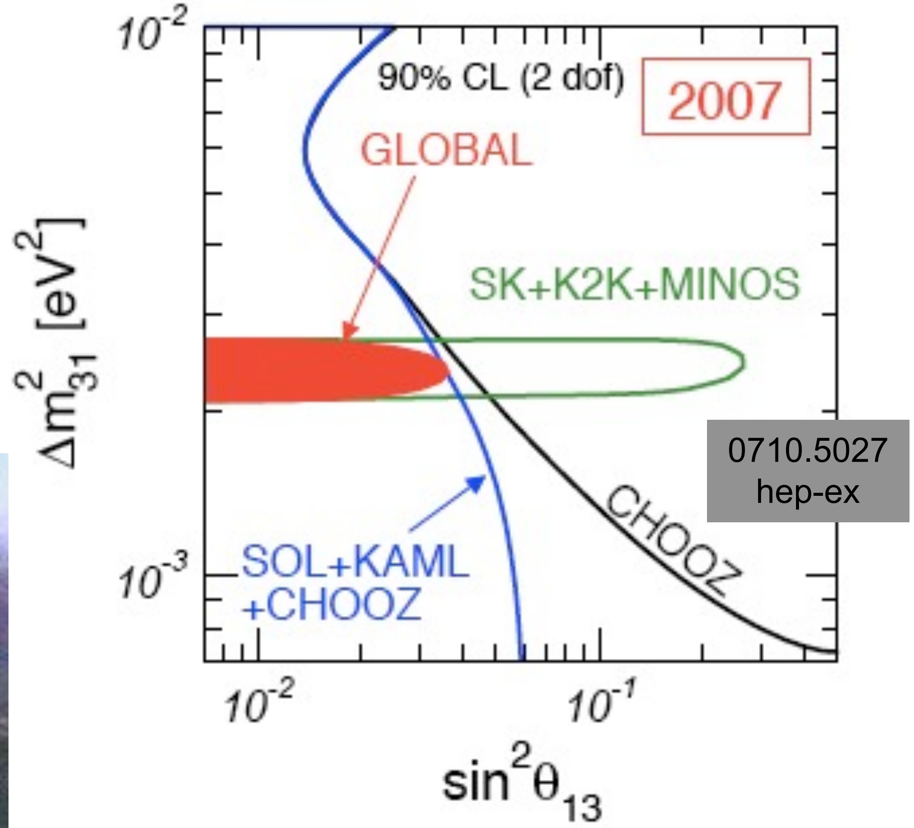
- A reminder on the experimental concept
- Current status
- Ongoing activity
- Expectations

θ_{13} : what we know



The CHOOZ Experiment





0710.5027 hep-ex

CHOOZ (+atm+LBL)
$\sin^2(2\theta_{13})$<0.11 [90%CL]
dominates combined limit

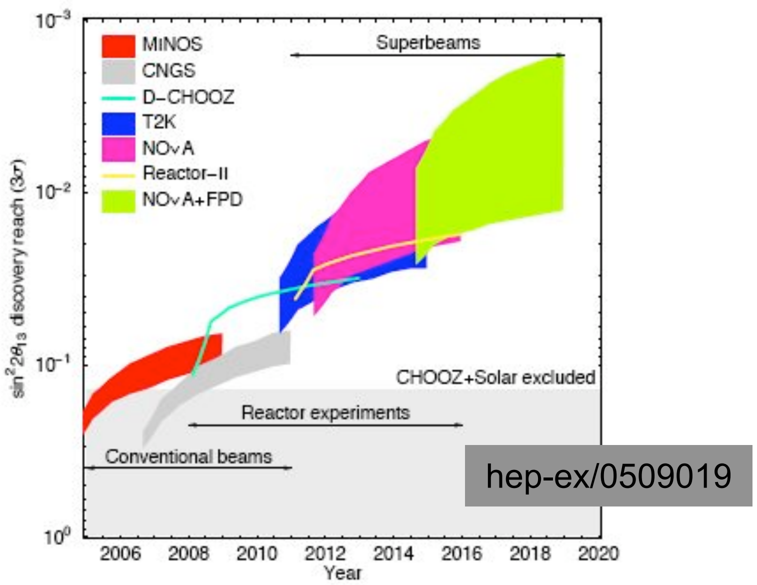
M.Apollonio et. al., Eur.Phys.J. C27 (2003) 331-374

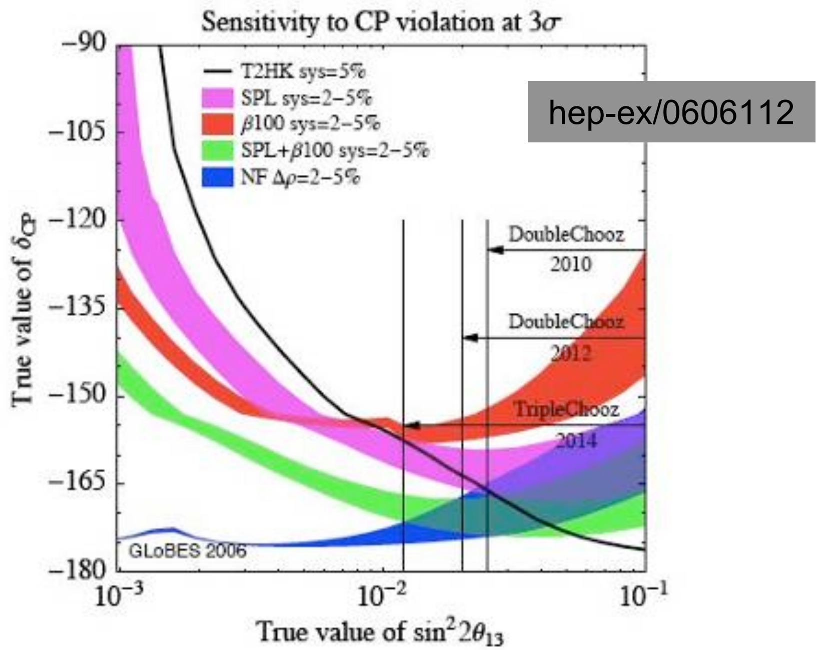
θ_{13} at reactors

- $\bar{\nu}_e$ disappearance : independent of δ-CP, weak dependence on Δm^2_{21}
- O(MeV) + small distances ⇒ Matter effects negligible ⇒ measurement independent of $sign(\Delta m^2_{13})$

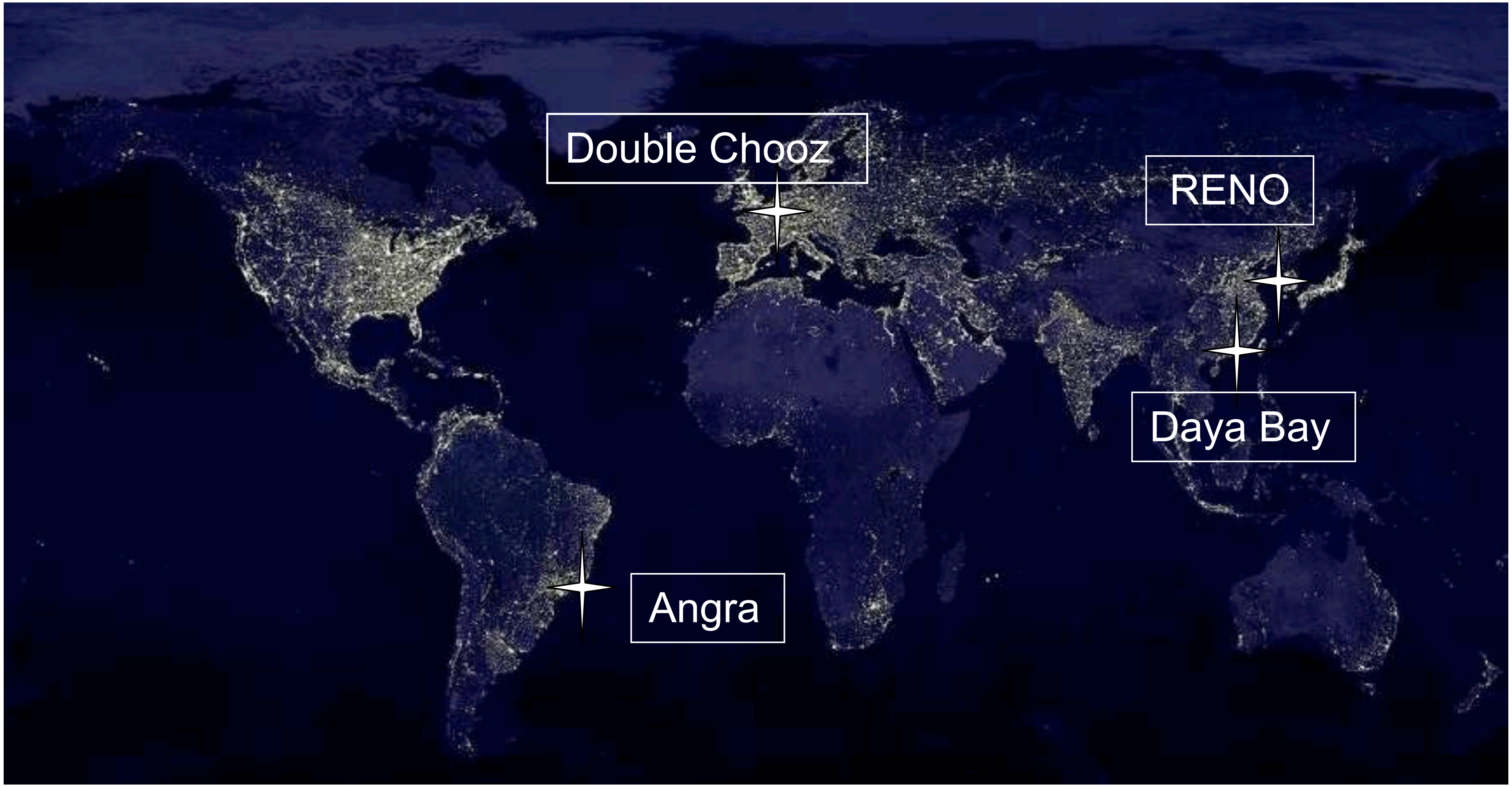
➡ "Clean" θ_{13} measurement, complementary to beams
(break correlations and degeneracies)

➡ Experiments can be carried out on a short time scale and for relatively low cost ⇒ input on roadmap for future beams





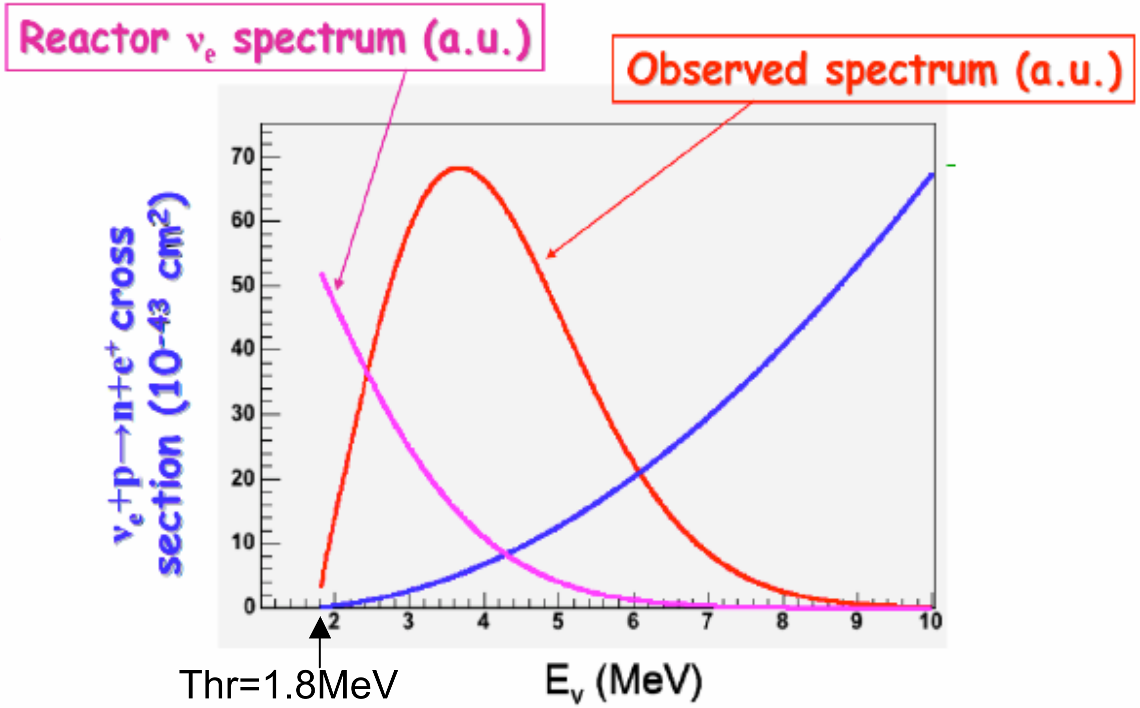
Reactor θ_{13} projects «today»



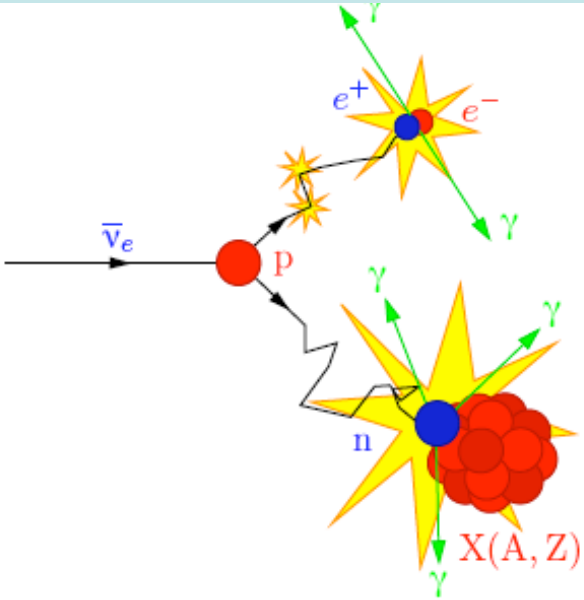
ν detection at reactor experiments

$$N_\nu\left(s^{-1}\right) = 6N_{Fiss}\left(s^{-1}\right) \approx 2\times10^{11}P\left(s^{-1}\right)$$

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



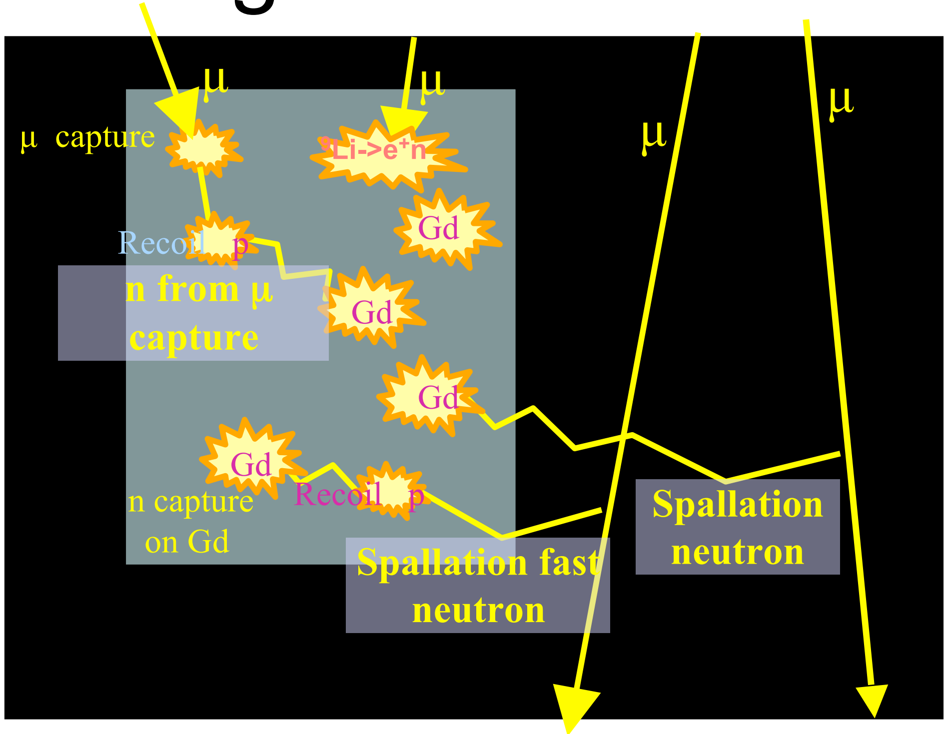
Detection by "inverse beta"
$\bar{\nu}_e + p \rightarrow e^+ + n$
in scintillator



Prompt photons from e^+ annihilation
$E_{VIS} \approx \mathbf{E}_\nu - (M_n - M_p) + m_e$

Delayed photons from **n** capture
on H : $\Delta t \sim 200\mu s$ E~2MeV
on dedicated nuclei (Gd): $\Delta t \sim 30\mu s$ E~8MeV

θ_{13} at reactors : Backgrounds



Accidental bkg:

- e⁺-like signal: radioactivity from materials, PMTs, surrounding rock (^{208}Tl). (Rate=R_e)
- n signal: n from cosmic μ spallation, thermalised in detector and captured on Gd (R_n);

  γ mimicking n

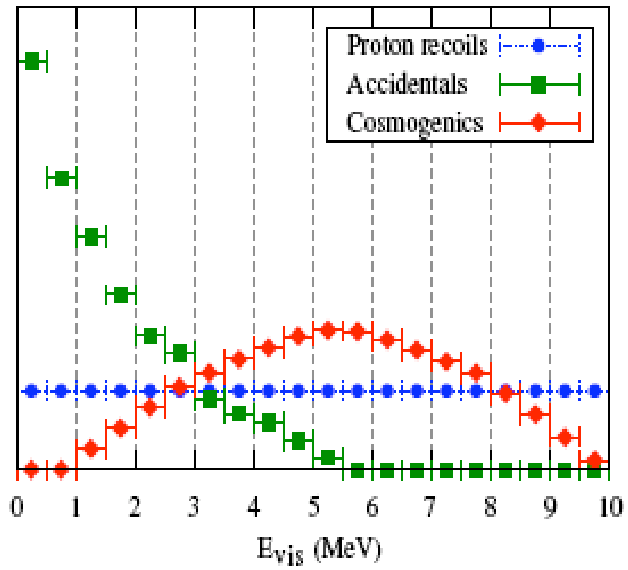
➡ Accidental coincidence

Rate = $R_e \times R_n \times \Delta t$

Correlated bkg:

➡ fast n (by cosmic μ) recoil on p (low energy) and captured on Gd

➡ long-lived (^{9}Li, ^{8}He) β+n-decaying isotopes induced by μ

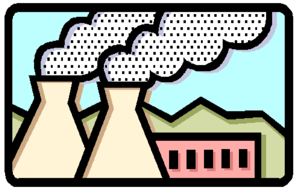


Expect Signal/Bkg > 50

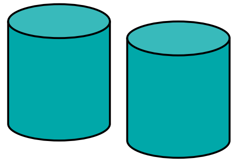
How can we improve experiments?

CHOOZ : R_{osc} = 1.01 ± 2.8% (stat) ± 2.7% (syst)

- Statistics
  - Larger detection volume
  - Longer exposure



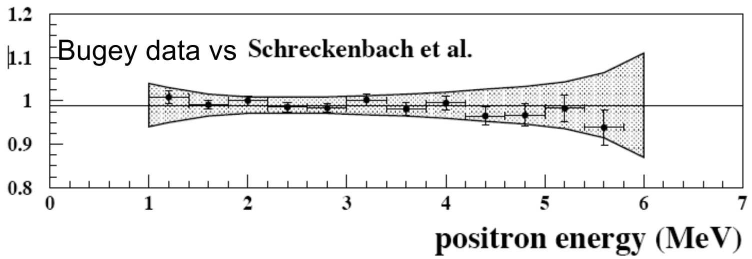
- Experimental error: ν flux and cross-section uncertainty
  - Detectors at different distances from reactors
  - Identical detectors to reduce inter-detector systematics (efficiency, inter-calibration)



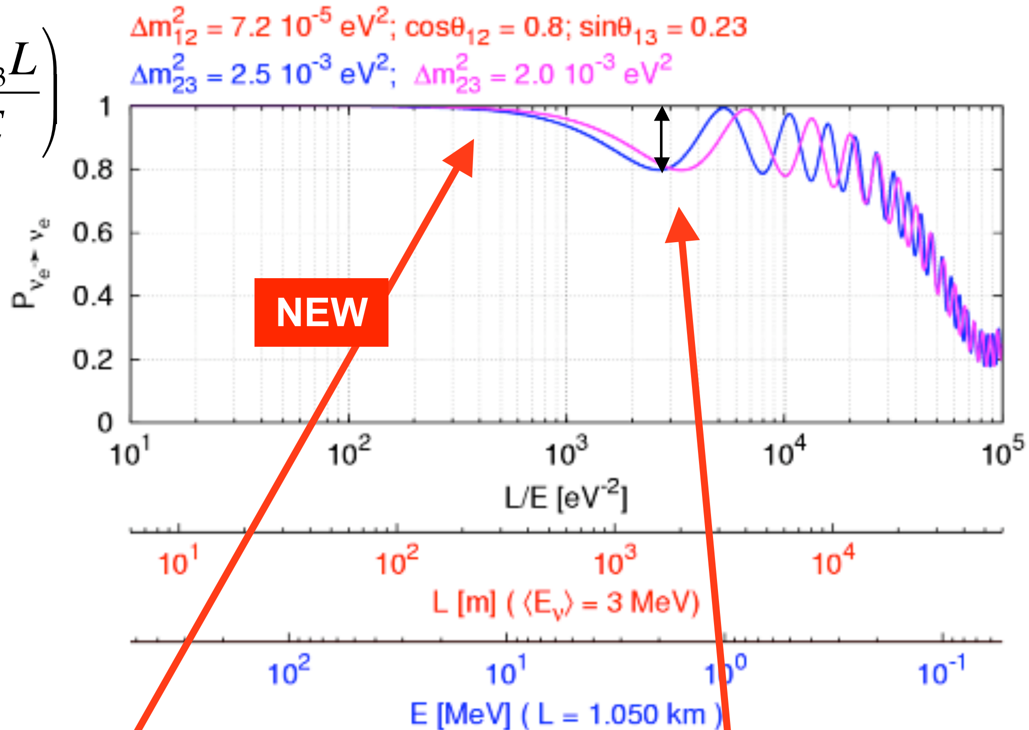
- Experimental error: Detector
  - Improve detector design : E(e+) threshold, e+ and n efficiency
  - Improve detector knowledge : calibration
- Experimental error: Background
  - Reduce accidentals by improving detector design: shielding, radiopurity
  - Reduce correlated and accidentals by increasing overburden
  - Improve background knowledge by direct measurement

The experimental concept

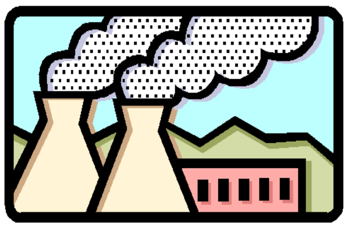
$$P(\bar{\nu}_e \to \bar{\nu}_e) \cong 1 - \sin^2(2\theta_{13})\sin^2\left(\frac{\Delta m^2_{23} L}{4E}\right)$$



~~Imperfect knowledge of physical processes in reactors : error ~2%~~

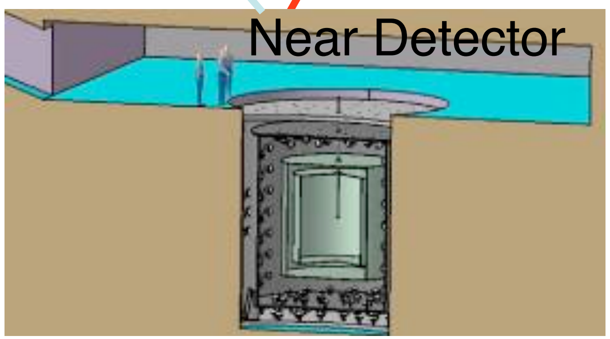


Reactor



$\bar{\nu}_e$ →

Near Detector

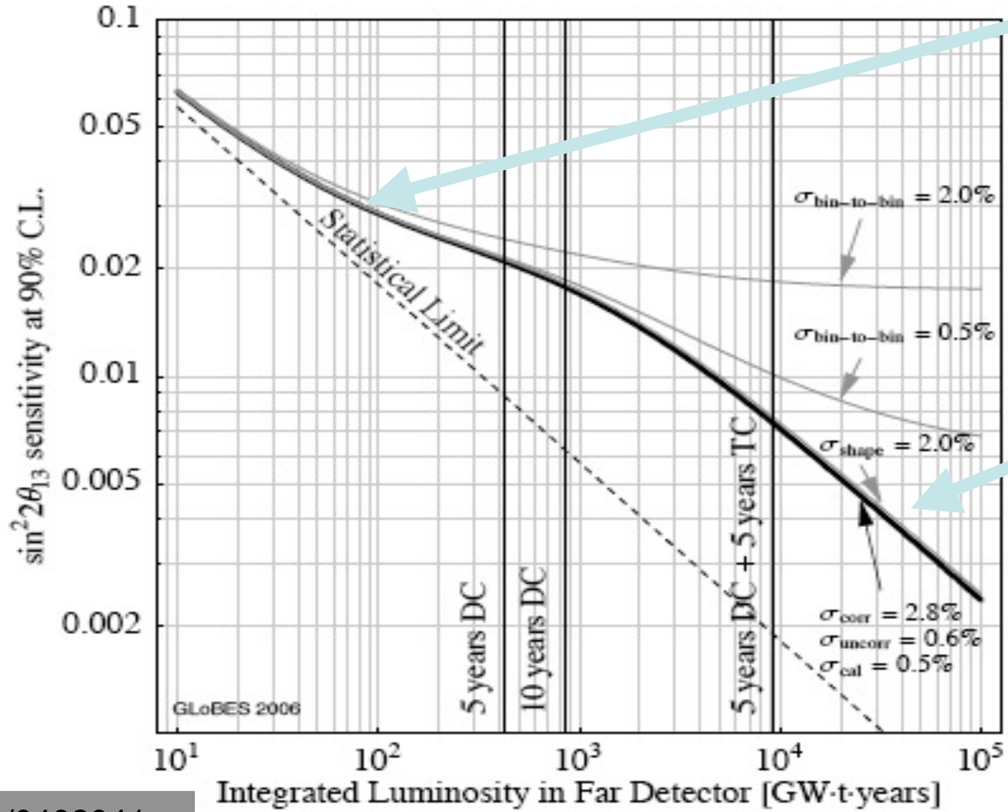


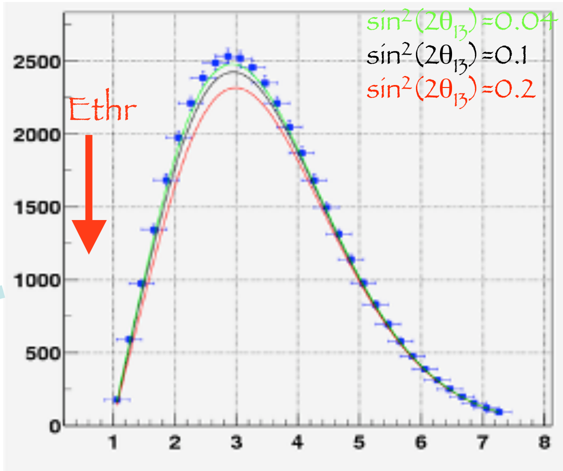
$\bar{\nu}_e$? →

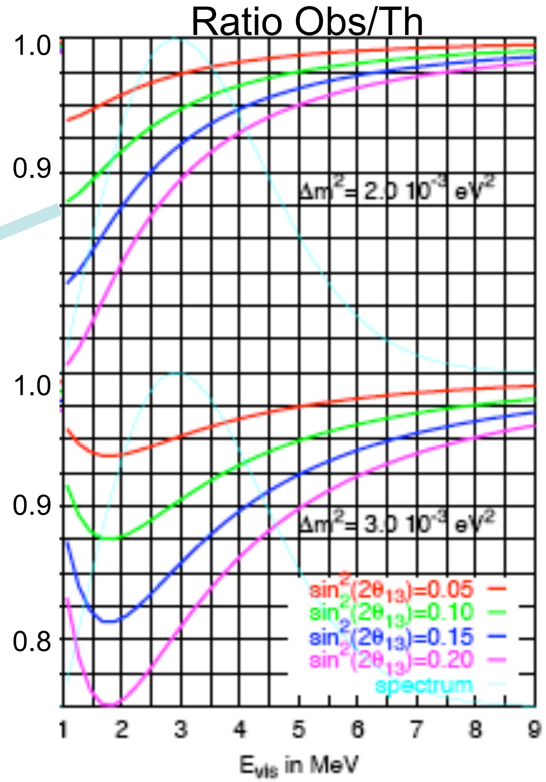
Far Detector

The experimental concept

Far vs Near :
two independent sets of information
Normalisation / Spectrum distortion
Dominating at low / high statistics resp.







hep-ex/0402041
hep-ex/0606112
Mention+Lasserre

The Double Chooz Collaboration

- France: CEA/IRFU Saclay, APC Paris, Subatech Nantes, Strasbourg
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- Japan: Tohoku U., Niigata U., Tokyo Metropolitan U., Tokyo Inst.Tech., Kobe U., Tohoku Gakuin U., Hiroshima I Inst.Tech., Miyagi U. of Education
- Russia: RAS, Kurchatov Institute (Moscow)
- Spain: CIEMAT (Madrid)
- UK: Sussex
- USA: Alabama, ANL, Chicago, Columbia, Drexel, Kansas State, LSU, LLNL, Notre Dame, Tennessee, IIT, U.C.Davis
- Brazil: CBPF, UNICAMP

Proposal: hep/ex 0606025

arXiv:hep-ex/0606025 v2 20 Jun 2006

Double Chooz: A Search for the Neutrino Mixing Angle θ_{13}

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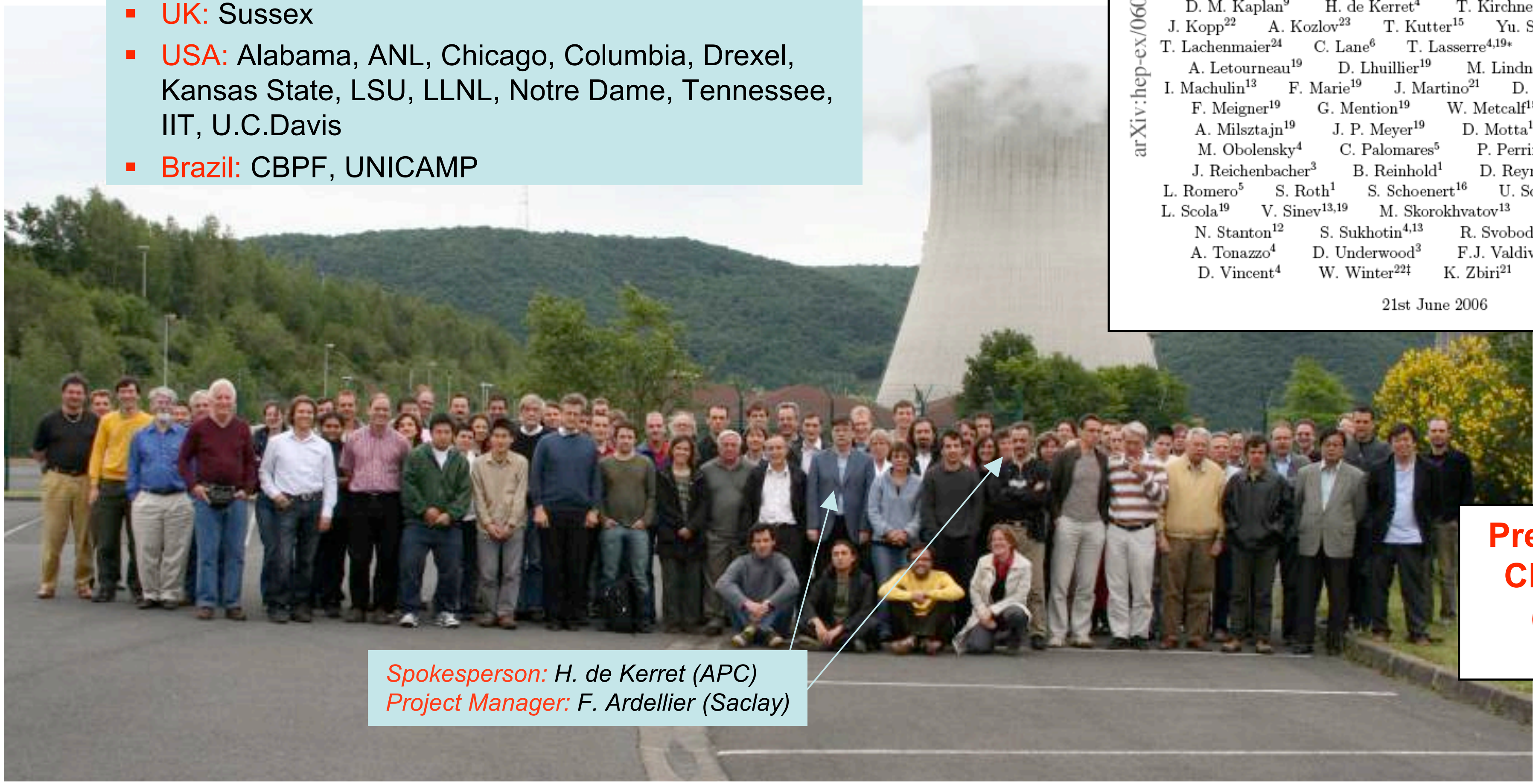
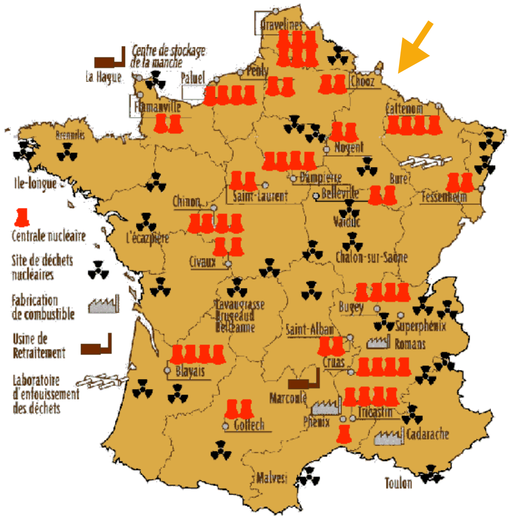
21st June 2006

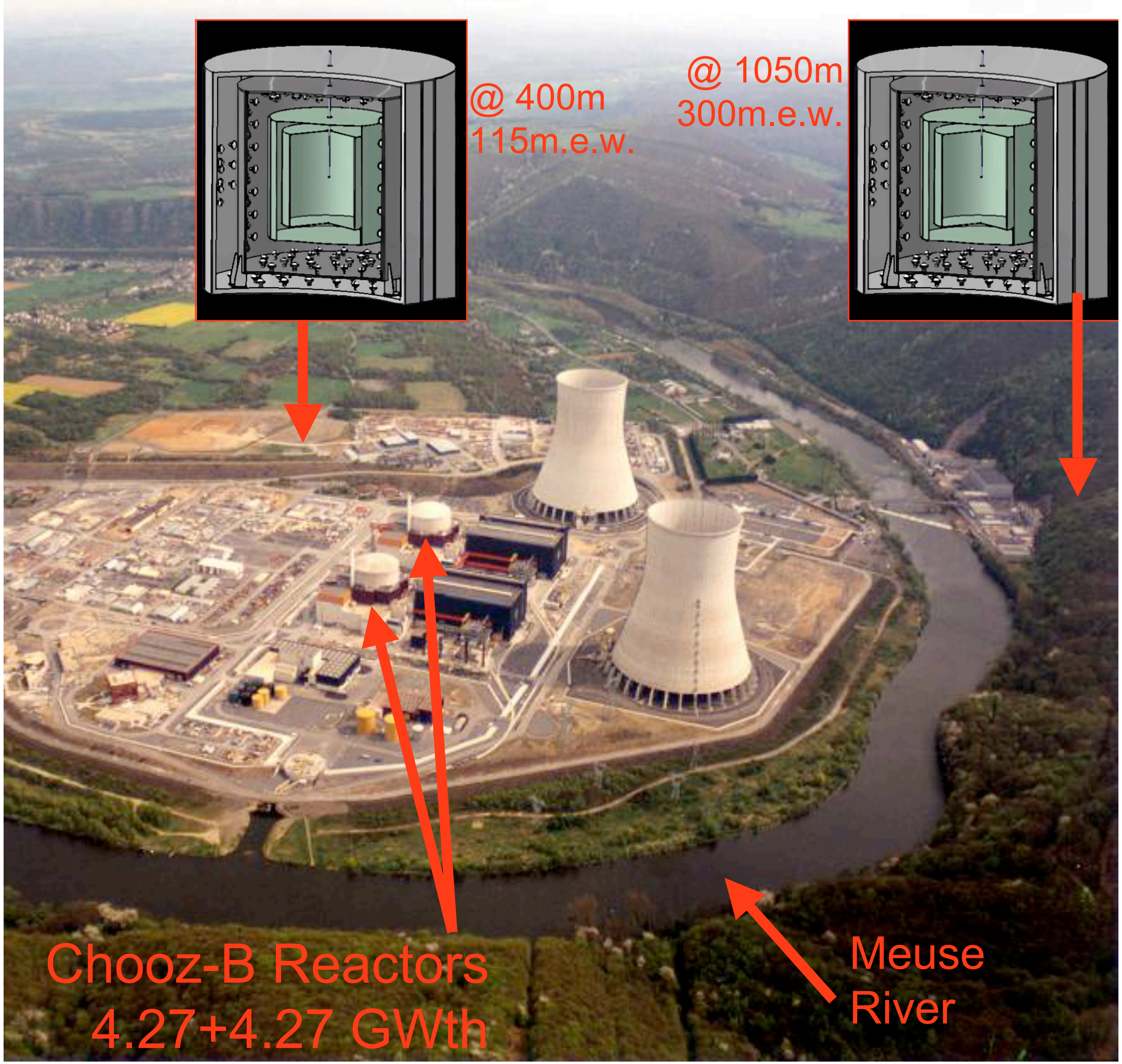


Spokesperson: *H. de Kerret (APC)*
Project Manager: *F. Ardellier (Saclay)*

Press release CEA+CNRS (France) 19/09/06

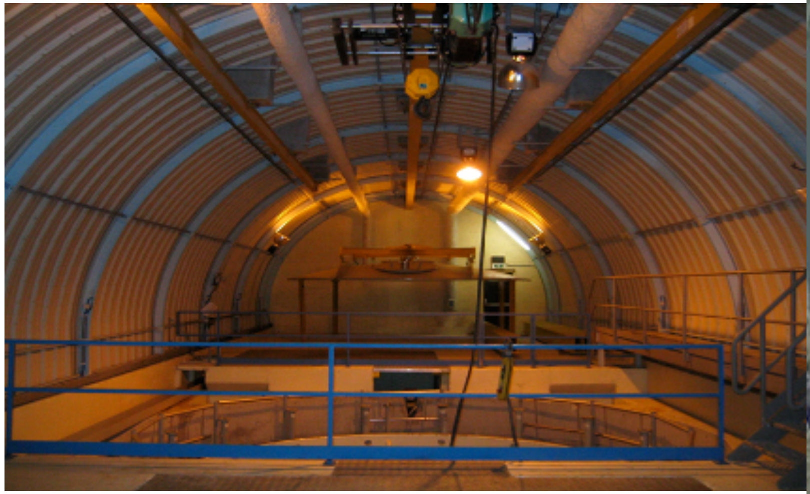
The Chooz site in the Ardennes





Neutrino labs

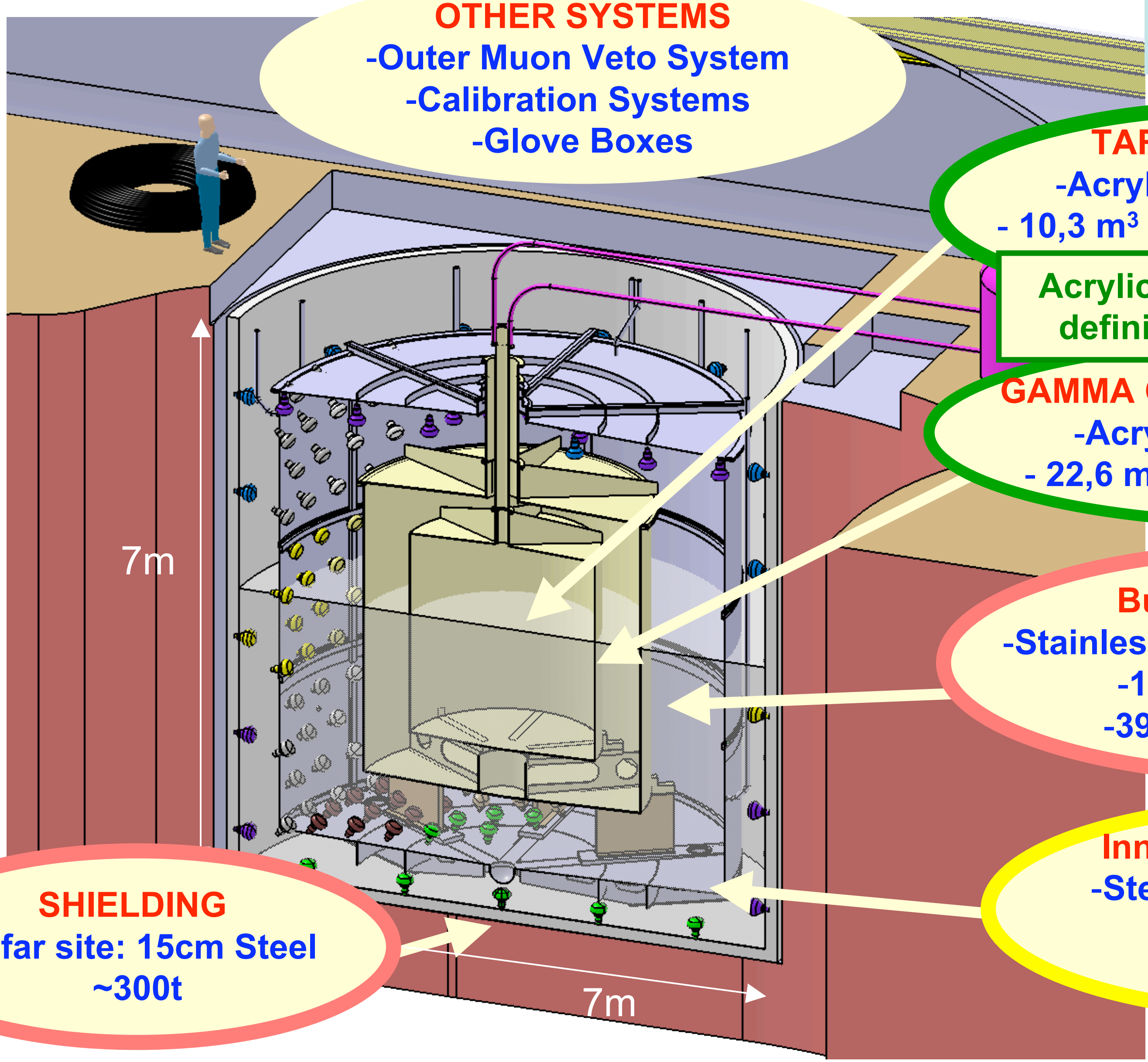
Far site:
Existing experimental hall+pit of the Chooz experiment will be used
d = 1050 m
overburden ~ 300 m.w.e. hill
~70 neutrino events/day



Near site: Location defined: NEW
under a small natural hill
<d> = 400 m
overburden >114m.w.e., nearly flat
~500 neutrino events/day

The detector(s)

Active nu target +
Active shielding +
Passive shielding



OTHER SYSTEMS
-Outer Muon Veto System
-Calibration Systems
-Glove Boxes

TARGET : (th=2,3m)
-Acrylic vessel (th=8mm)
- 10,3 m^3 LS doped with 1g/l Gd

Acrylic vessels ➔ «hardware» definition of fiducial volume

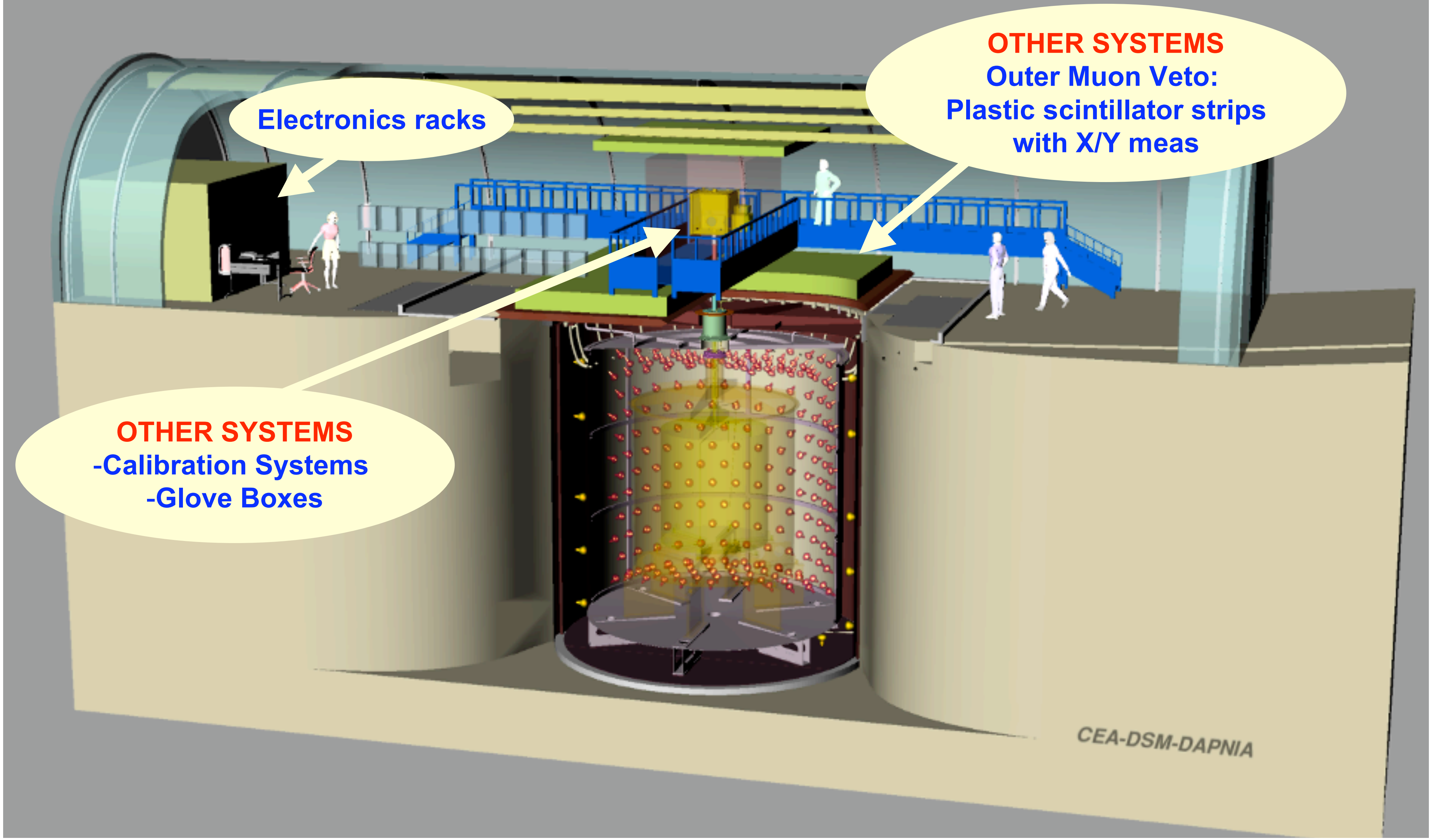
GAMMA CATCHER : (th. = 0,55m)
-Acrylic vessel (th= 8mm)
- 22,6 m^3 LS (identical to target)

Buffer : (th.=1,05m)
-Stainless steel vessel (th = 3 mm)
-114,2 m^3 mineral oil
-390 PMTs (10 inches)

Inner VETO: (th = 0,5 m)
-Steel vessel (th = 10 mm)
-~80 m^3 LS
78 PMTs

SHIELDING
@ far site: 15cm Steel
~300t

The detector(s)



Background studies

Accidentals

- radioactivity (dominated by PMTs) + neutrons induced by cosmic muons
- request singles rate ~5Bq (above 0.7 MeV)

Radiopurity constraints on detector materials single rate <0.1 Hz from each contribution

Less stringent than KamLAND and Borexino, but needs care

	^{40}K g/g	^{238}U g/g	^{232}Th g/g	^{60}Co mBq/Kg
Target LS	10^{-10}	10^{-13}	10^{-13}	—
Target Acrylics	10^{-8}	10^{-11}	10^{-11}	—
GC LS	10^{-10}	10^{-13}	10^{-13}	—
GC Acrylics	10^{-8}	10^{-11}	10^{-11}	—
Buffer Oil	—	10^{-12}	10^{-12}	—
Buffer Vessel	—	10^{-9}	10^{-9}	15
Veto LS	—	10^{-10}	10^{-10}	—

hep-ex/0606025

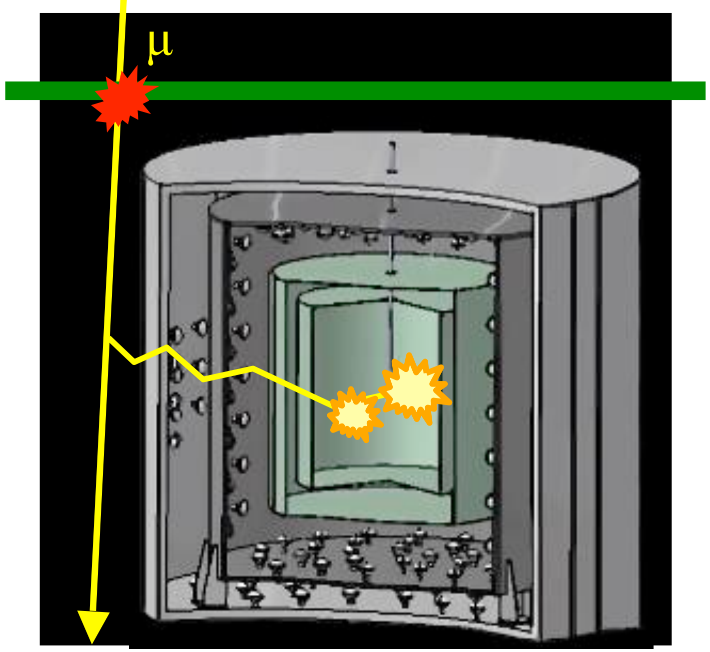
Correlated

old Chooz reactor-off data = ~1.5d^{-1}

~50%fast-n/~50%^{9}Li

- validate simulation (Geant-4, Fluka)
- extrapolate to Far and Near detector

Measurements in correlation with muon signal in the Outer Veto will provide important information



Background studies

Signal/Bkg >50

Detector	Site		Background				
			Accidental		Correlated		
			Materials	PMTs	Fast n	μ-Capture	^{9}Li
CHOOZ		Rate (d^{-1})	—	—	—	—	0.6 ± 0.4
(24 ν/d)		Rate (d^{-1})	0.42 ± 0.05		$1.01 \pm 0.04(stat) \pm 0.1(sys)$		
	Far	bkg/ν	1.6%		4%		
		Systematics	0.2%		0.4%		
Double Chooz		Rate (d^{-1})	0.5 ± 0.3	1.5 ± 0.8	0.2 ± 0.2	< 0.1	1.4 ± 0.5
(69 ν/d)	Far	bkg/ν	0.7%	2.2%	0.2%	<0.1%	1.4%
		Systematics	<0.1%	<0.1%	0.2%	<0.1%	0.7%
Double Chooz		Rate (d^{-1})	5 ± 3	17 ± 9	1.3 ± 1.3	0.4	9 ± 5
(1012 ν/d)	Near	bkg/ν	0.5%	1.7%	0.13%	<0.1%	1%
		Systematics	<0.1%	<0.1%	0.2%	<0.1%	0.2%

estimates with "old" near detector location
= conservative
(with new location: $N_\nu/2$, $N_\mu/3$)

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Systematic uncertainties

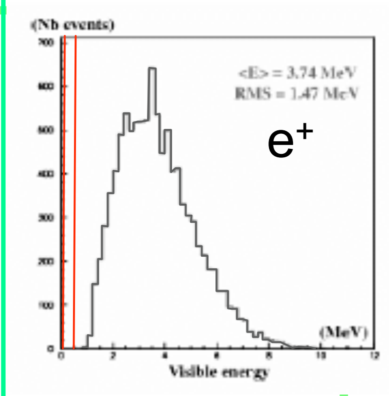
- Backgrounds
  - B/S reduced by larger buffers + outer veto + overburden
  - Threshold lower than start of e+ spectrum
  - Double acrylics vessel ⇒ no need for fiducial volume cut

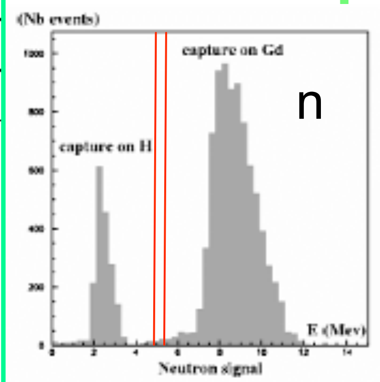
- Analysis

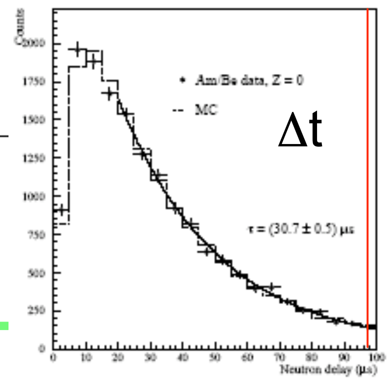
	CHOOZ	Double-CHOOZ	
selection cut	rel. error (%)	rel. error (%)	Comment
* positron energy*	0.8	0	not used
positron-geode distance	0.1	0	not used
* neutron capture	1.0	0.2	Cf calibration
capture energy containment	0.4	0.2	Energy calibration
neutron-geode distance	0.1	0	not used
* neutron delay	0.4	0.1	—
positron-neutron distance	0.3	0 – 0.2	0 if not used
neutron multiplicity*	0.5	0	not used
combined*	1.5	0.2-0.3	—

*average values

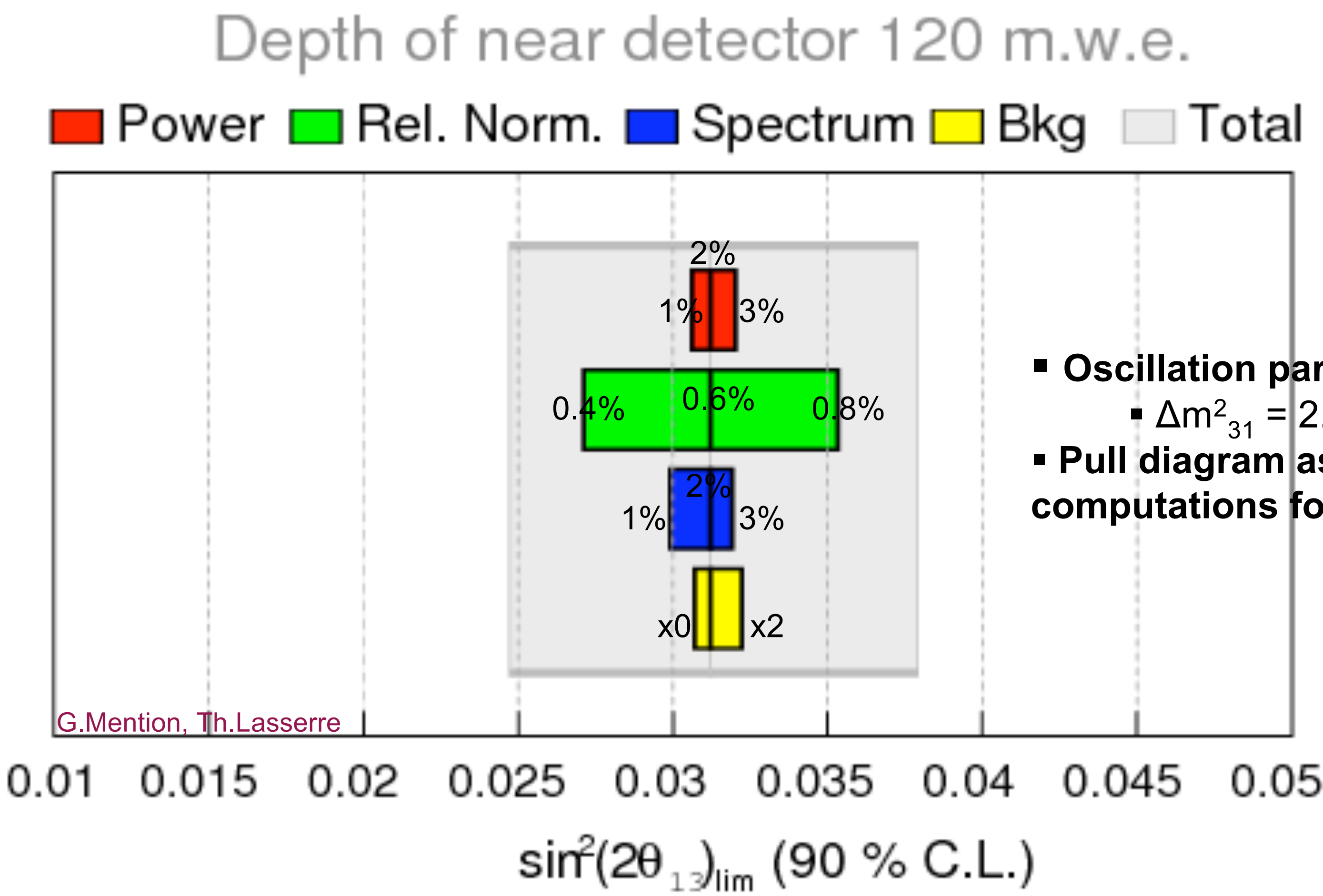
* Easier to control near vs far than absolute







Systematic uncertainties



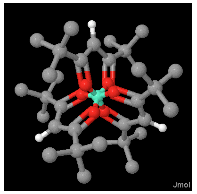
- **Oscillation parameters**
  - $\Delta m^2_{31} = 2.5\ 10^{-3}\ eV^2$
- **Pull diagram assumptions: computations for 3 y data taking**

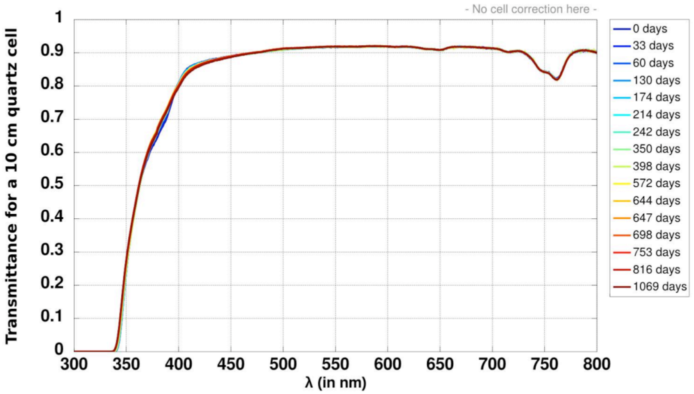
Total systematics: <~ 0.6%

Statistics: 60000 neutrino events @ Far Detector

R&D + Testing

Gd-doped scintillator



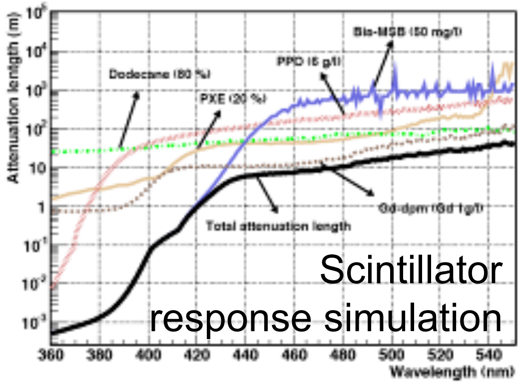


Acrylic vessels

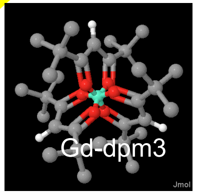
L1 trigger board

DAQ with no dead time. fADCs

CAEN V1721
500 MHz - 8bit



R&D + Testing

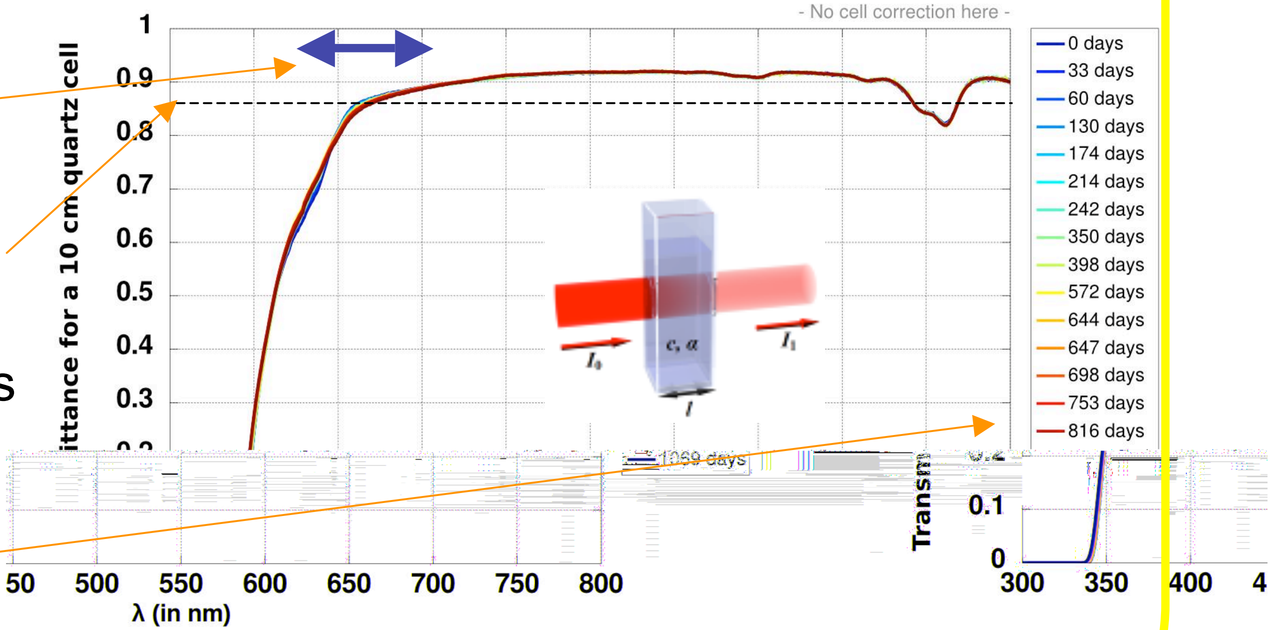


Gd-doped scintillator

20%PXE + 80%Dodecane
+ 1g/l Gd beta-diketonate
(+PPO +bis-MSB)

Requirements:

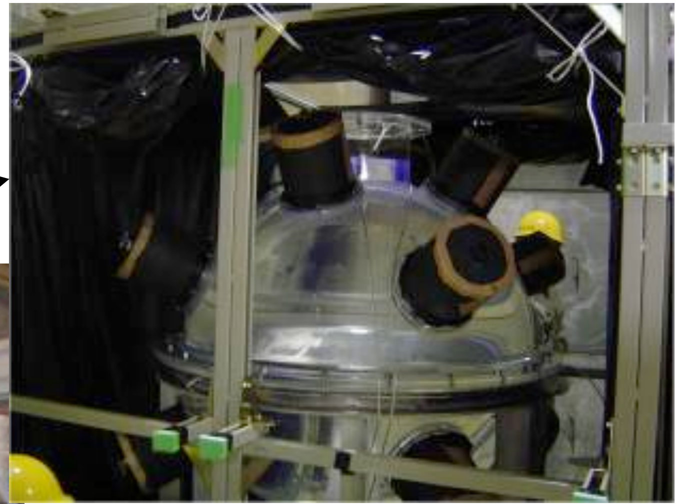
- light transmission in PMT sensitivity window
- attenuation length >~10m
- Stability over experiment's lifetime (remember CHOOZ problem...) tested for 3yrs @20°C and at 40° C (catalyzed)
- Radiopurity

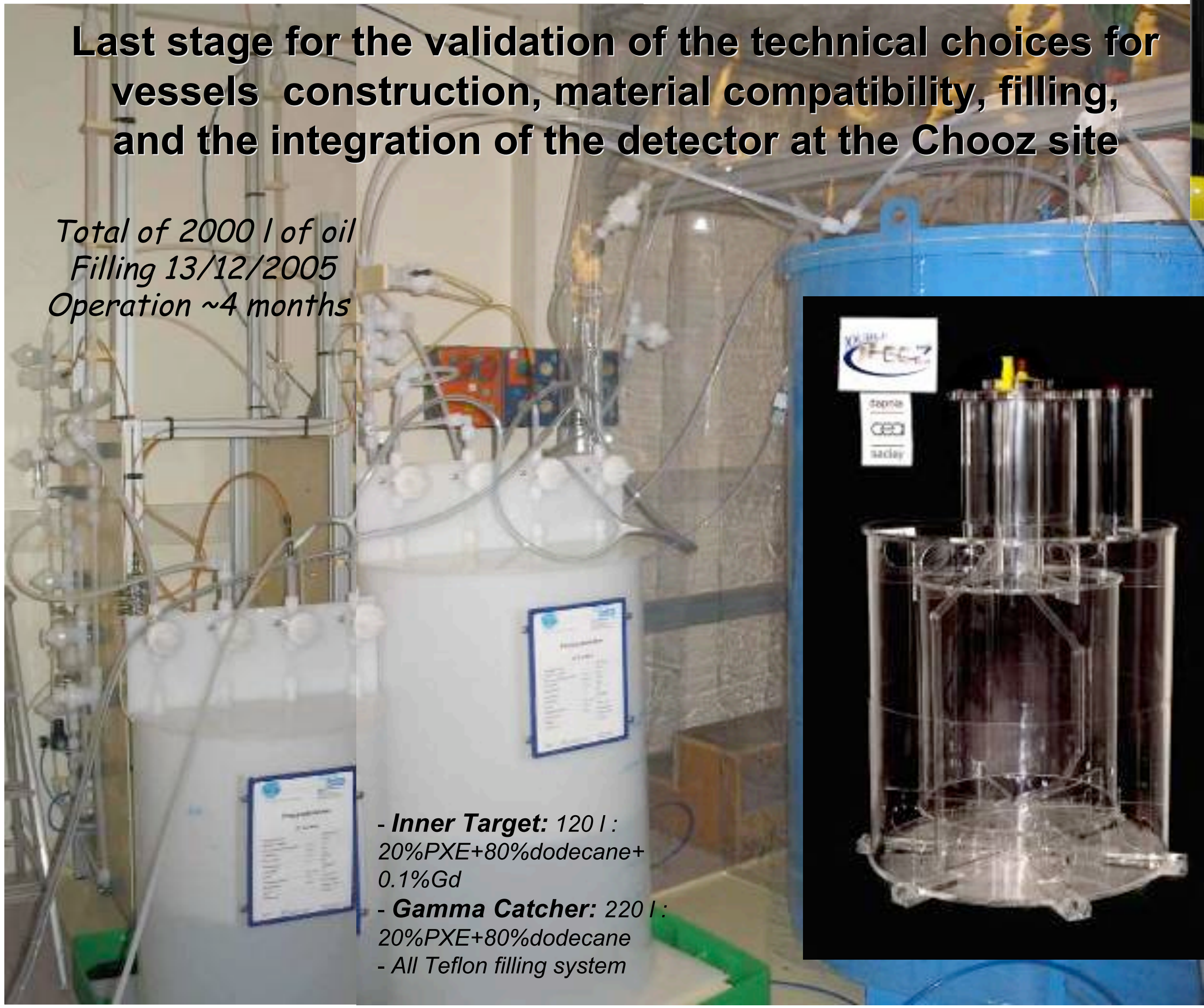


Prototyping

1) Scale 1/5 Double Chooz detector

2) Detection of neutrino at JoJo reactor (Japan) with Kaska prototype



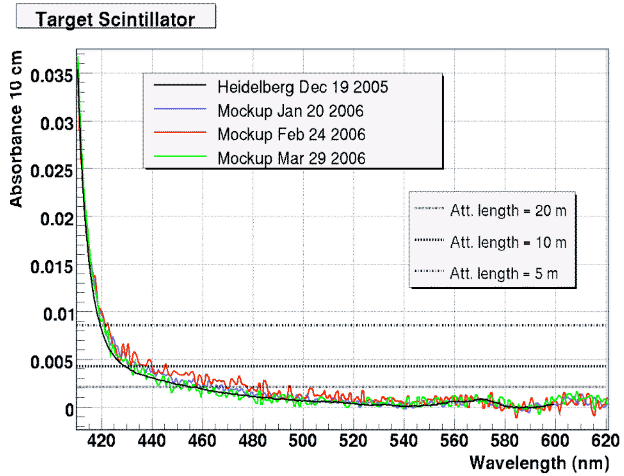


Last stage for the validation of the technical choices for vessels construction, material compatibility, filling, and the integration of the detector at the Chooz site

Total of 2000 l of oil
Filling 13/12/2005
Operation ~4 months

- ***Inner Target:*** *120 l : 20%PXE+80%dodecane+ 0.1%Gd*
- ***Gamma Catcher:*** *220 l : 20%PXE+80%dodecane*
- *All Teflon filling system*

Results on scintillator stability in realistic operation conditions, although on short term, are encouraging



Current activity: Far lab integration

Civil engineering work completed:

Pit refurbished

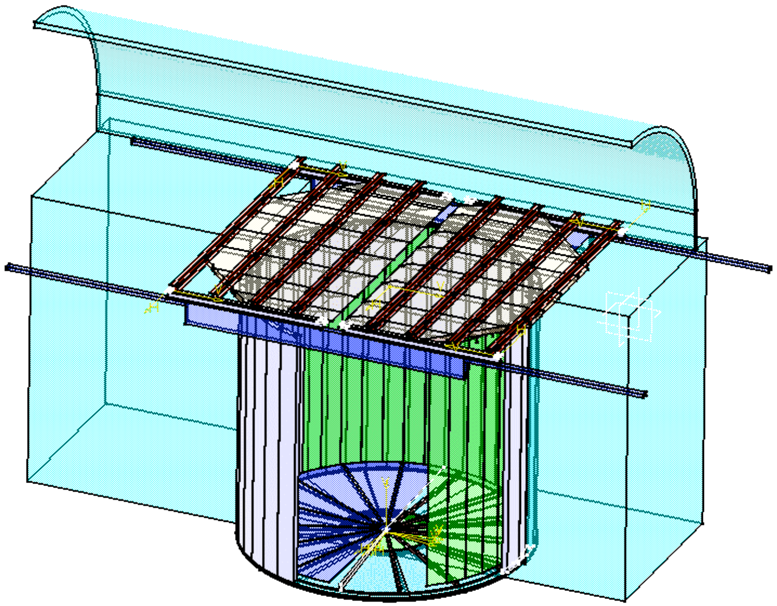
Access adapted

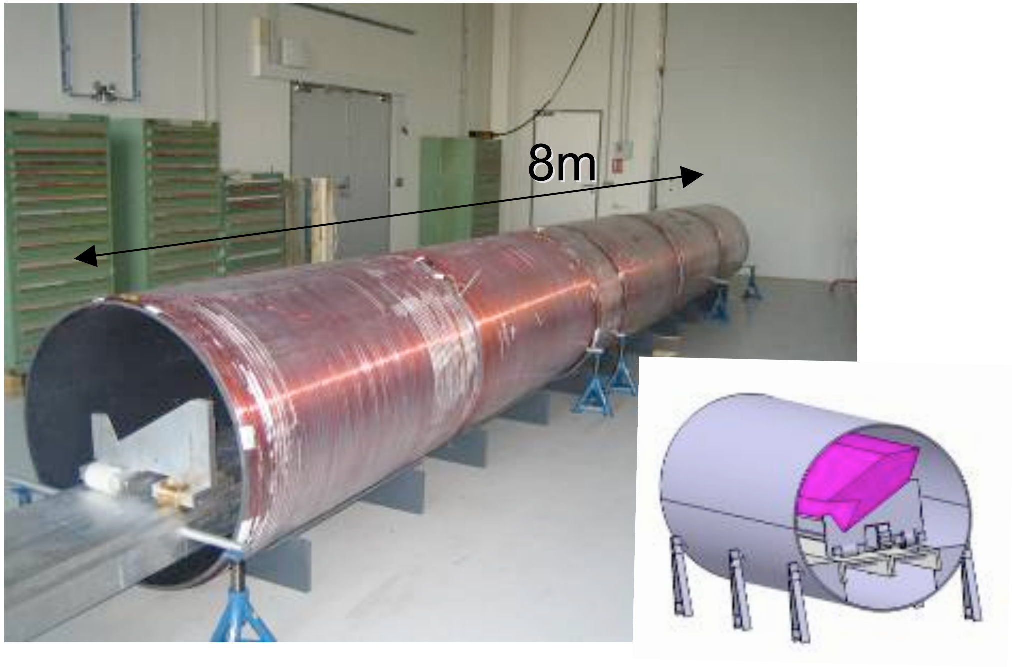
Cleanliness + radiopurity measurements ongoing

Current activity : Far detector shield

Steel shielding bars
(~300t, low radioactivity)

demagnetization in progress

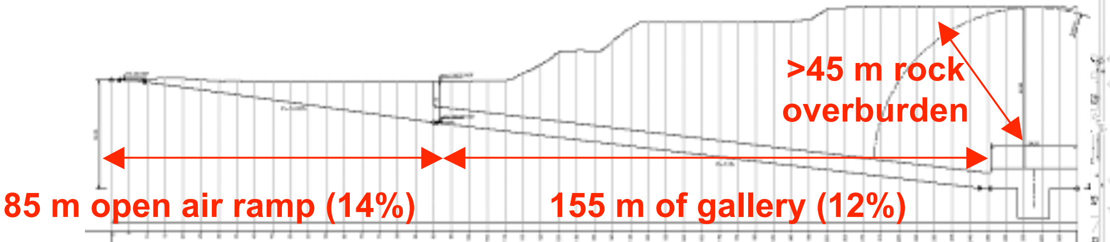


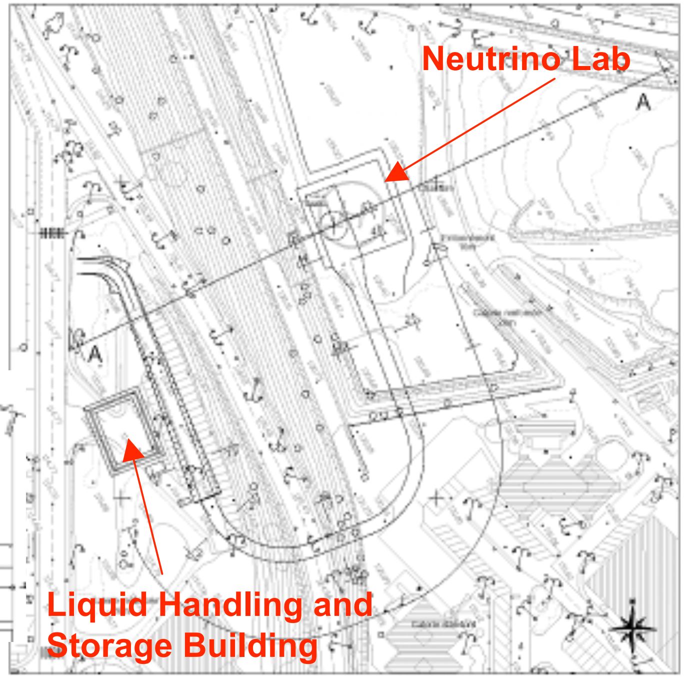


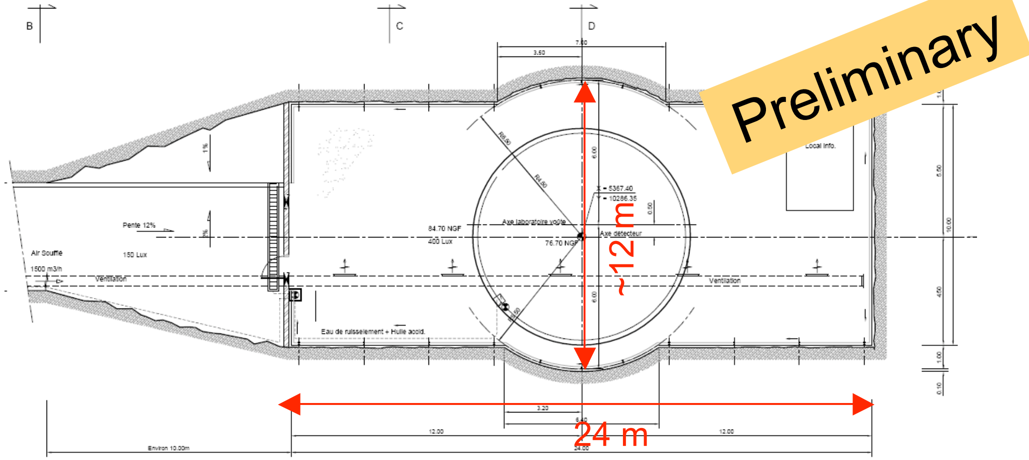
Current activity : Near lab

Geological survey done

Finalization of access tunnel + lab excavation design

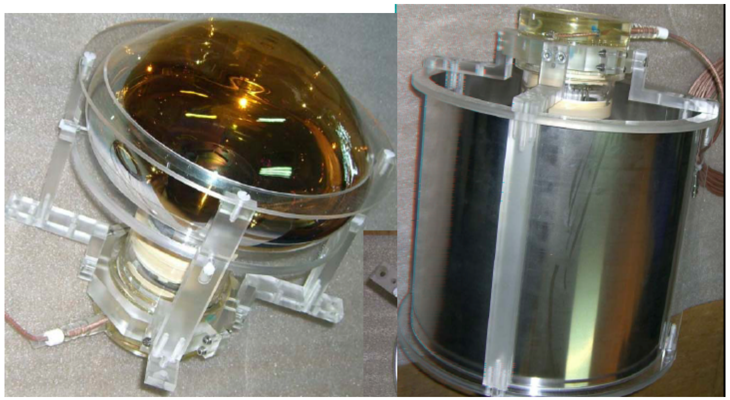




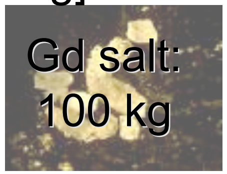


Current activity : Production

PMT support+shield



Scintillator production:
main components needed for
both detectors have been
delivered & checked
[@Heidelberg]

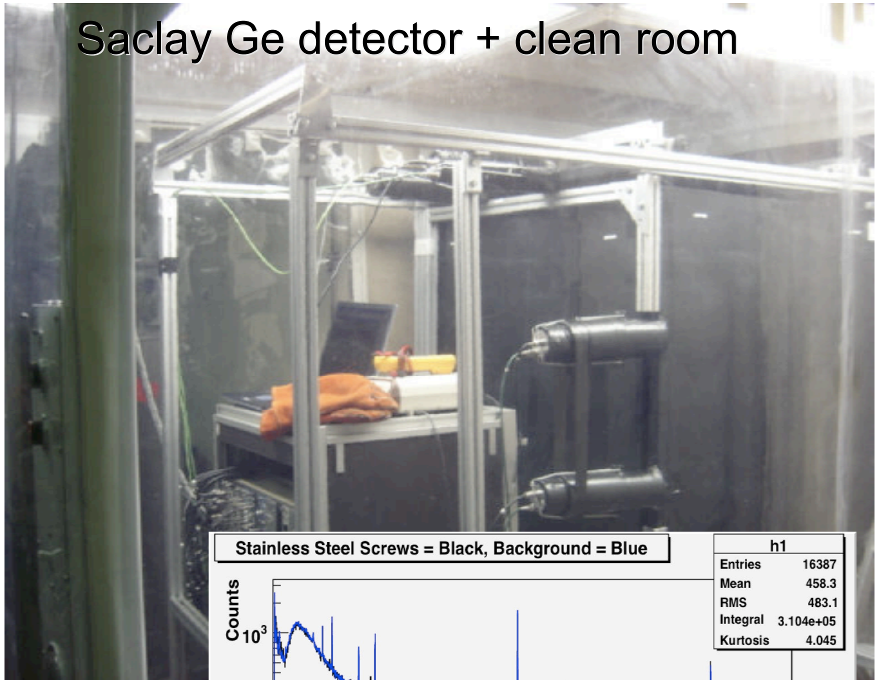


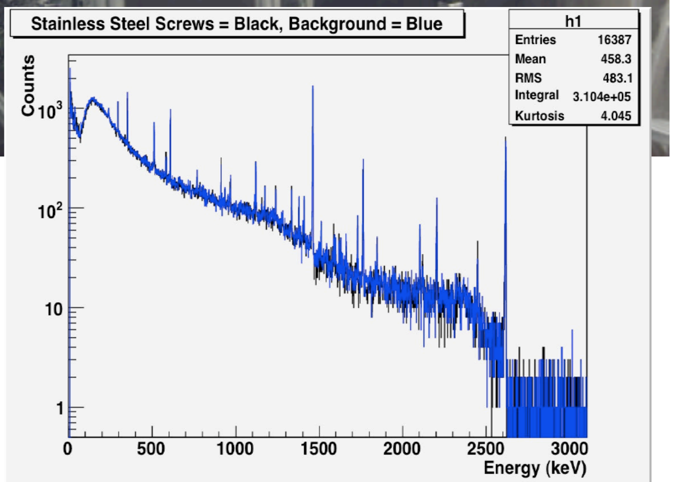
Mixing to be done in one batch
then transported to site for each detector

Current activity : Measurements

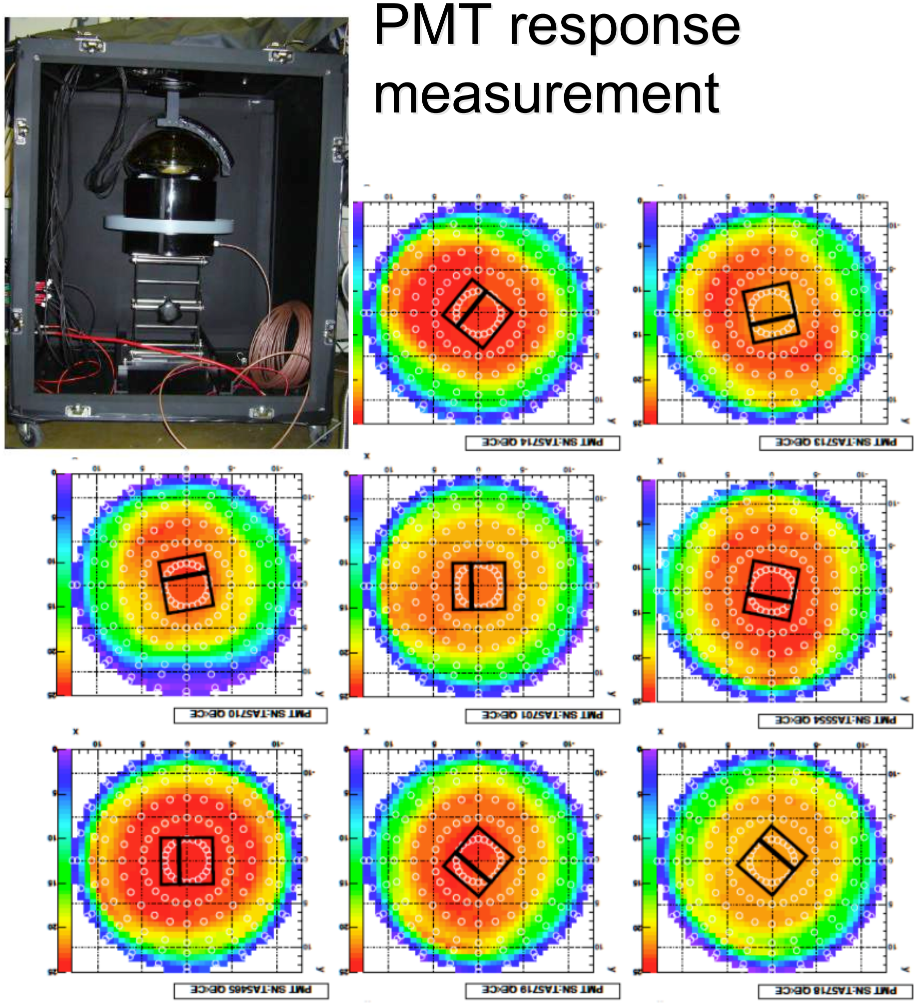
Material radioactivity measurements
@LNGS, Modane,Oroville, Saclay

Saclay Ge detector + clean room

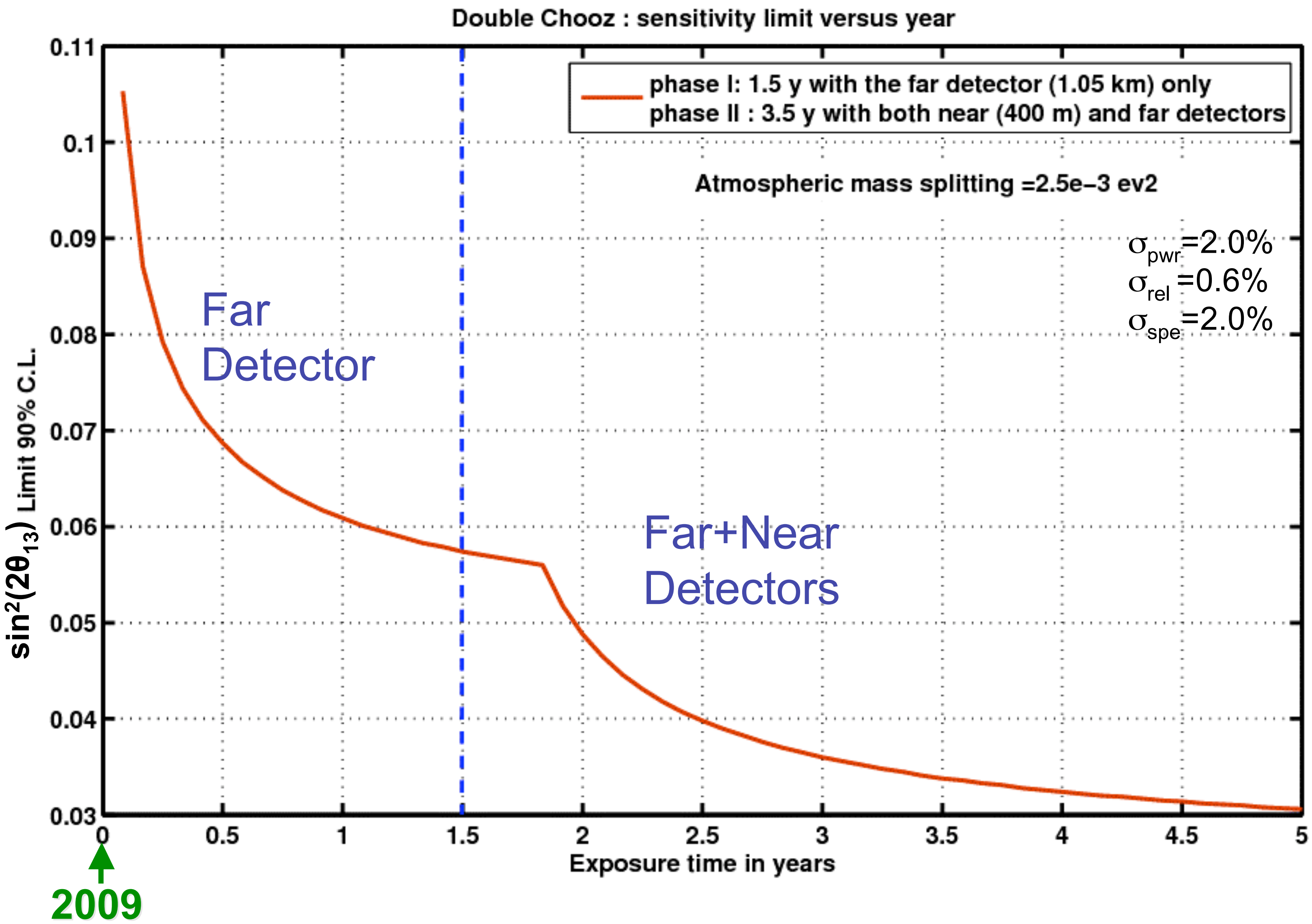




PMT response
measurement



DC timescale



Other potentials

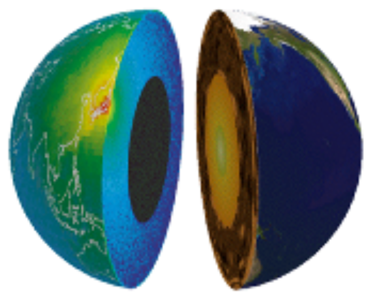
Double Chooz can do more than just measure neutrino oscillations.

Studies to use Gd-LS detectors for :

- Measurement of reactor thermal power
  - Independent of methods used by electric companies
- Non proliferation
  - Neutrinos as a new safeguard tool ("Neutrinos for Peace")
  - Monitor isotopic composition to ensure that civilian nuclear facilities are not used for military purposes (^{239}Pu)

IAEA
International Atomic Energy Agency

- Neutrinos' directionality
  - for Geo-Neutrino measurements
  - cfr **Kamland, Nature 436, 499-503 (28 July 2005)**



Summary and outlook

- Double Chooz aims at being the first of a new generation of neutrino experiments using identical detectors at different distances from a reactor to measure θ_{13}

→ Entering the precision era for neutrino oscillation measurements

- Ongoing activity
  - We are in the construction phase

- It's coming soon !
  - 2008: starting installation of far detector
  - 2009: start data taking with far detector
  - 2010: near detector installation
  - 2013: reach target sensitivity $\sin^2 2\theta_{13}$~0.03 (for $\Delta m^2_{31}=2.5\text{x}10^{-3}\ eV^2$)

(... unless ...)

Backup: 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 %	
	Volume	0.3 %	0.2 %	Precise target mass measurement
	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 %	Spill in/out compensate to ~1%
	Live time	?	0.25 %	Difference near/far is relevant !
Analysis	From 7 to 3 cuts	1.5 %	0.2 - 0.3 %	(see previous slide)
	Total	**2.7 %**	**< 0.6 %**	