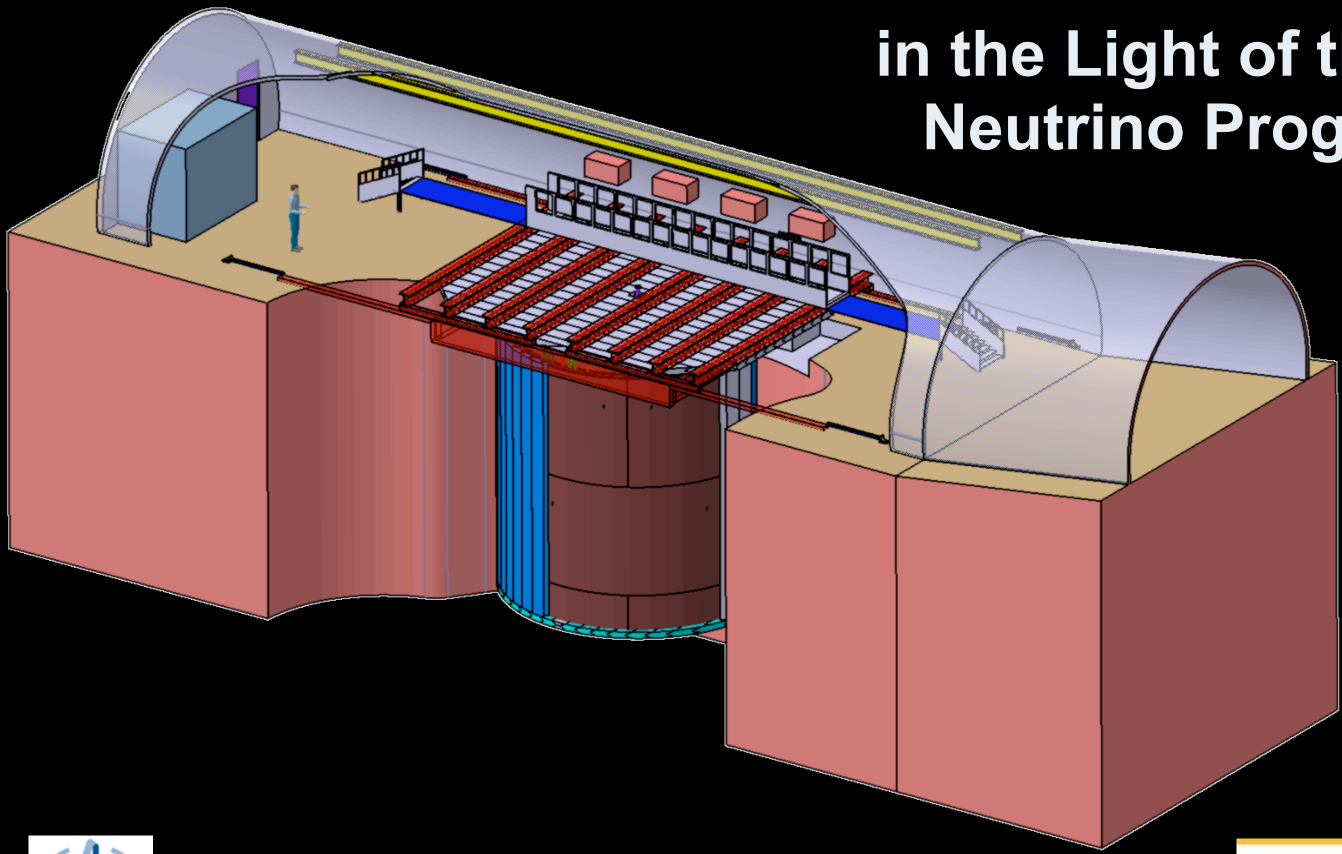
Double Chooz

in the Light of the Reactor Neutrino Program for θ_{13}



Thierry Lasserre (CEA/Saclay & APC/Paris)

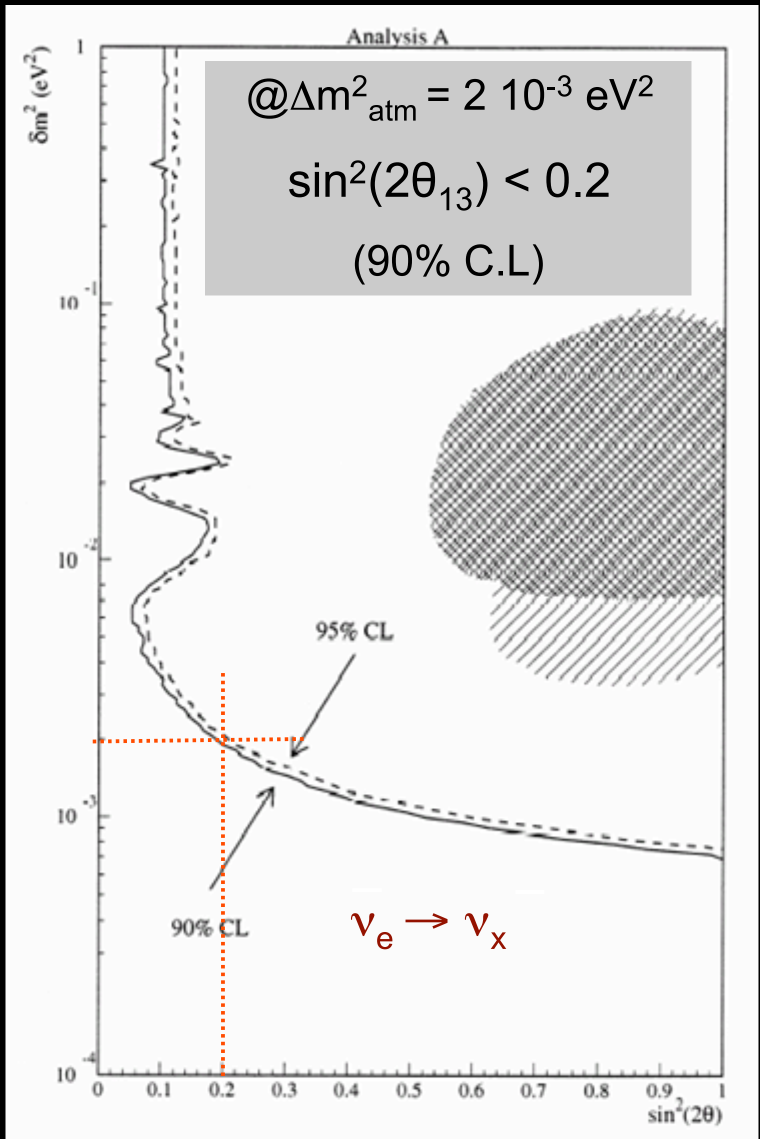
6th KEK Topical Conference

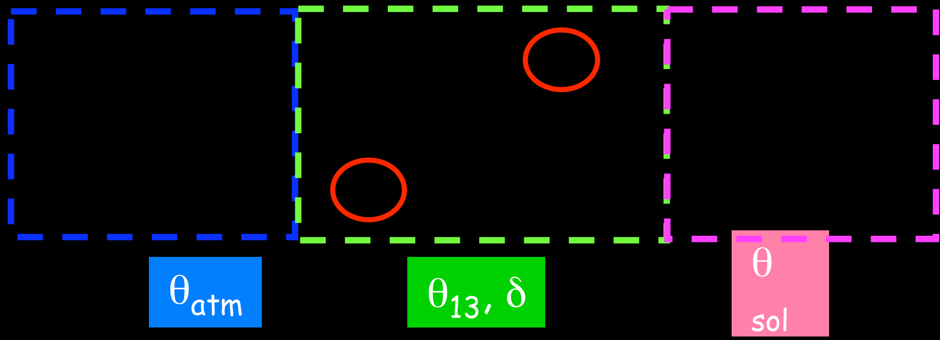
Frontiers in Particle Physics and Cosmology (KEKTC6)

Feb. 6 (Tue) - 8(Thu), 2007

http://doublechooz.in2p3.fr/

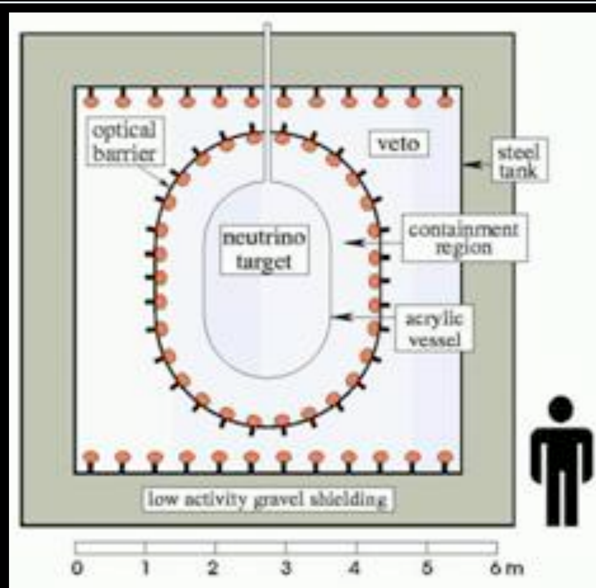
Best current constraint: CHOOZ





$\overline{\nu}_e \rightarrow \overline{\nu}_e$ (disappearance experiment)

P_{th} = 8.4 GW_{th}, L = 1.050 km, M = 5 t
overburden: 300 mwe



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

θ_{13} & beam experiments

Appearance probability : **$P(\nu_\mu \to \nu_e)$**

$$\begin{aligned} P_{\rm app} &\simeq \sin^2 2\theta_{13}\sin^2\theta_{23}\frac{\sin^2[(1-\hat{A})\Delta]}{(1-\hat{A})^2} \\ &\pm \alpha\sin 2\theta_{13}\,\xi\sin\delta_{CP}\sin(\Delta)\frac{\sin(\hat{A}\Delta)}{\hat{A}}\frac{\sin[(1-\hat{A})\Delta]}{(1-\hat{A})} \\ &+ \alpha\sin 2\theta_{13}\,\xi\cos\delta_{CP}\cos(\Delta)\frac{\sin(\hat{A}\Delta)}{\hat{A}}\frac{\sin[(1-\hat{A})\Delta]}{(1-\hat{A})} \\ &+ \alpha^2\cos^2\theta_{23}\sin^2 2\theta_{12}\frac{\sin^2(\hat{A}\Delta)}{\hat{A}^2}, \end{aligned}$$

$$\hat{A}\Delta = \frac{\sqrt{2}}{2}G_F n_e L$$

$$\begin{aligned} \alpha &= \frac{\Delta m^2_{21}}{\Delta m^2_{31}} \simeq 0.03, \\ \Delta &\equiv \frac{\Delta m^2_{31}L}{4E}, \\ \xi &\equiv \sin 2\theta_{12}\sin 2\theta_{23}. \end{aligned}$$

➔ other dependences: $\sin(2\theta_{23})$, $\sin(\theta_{23})$, sign(Δm^2_{31}), δ-CP phase in $[0,2\pi]$

θ_{13} & reactor experiments

- $\langle E_\nu \rangle$ ~ a few MeV ➔ only disappearance experiments

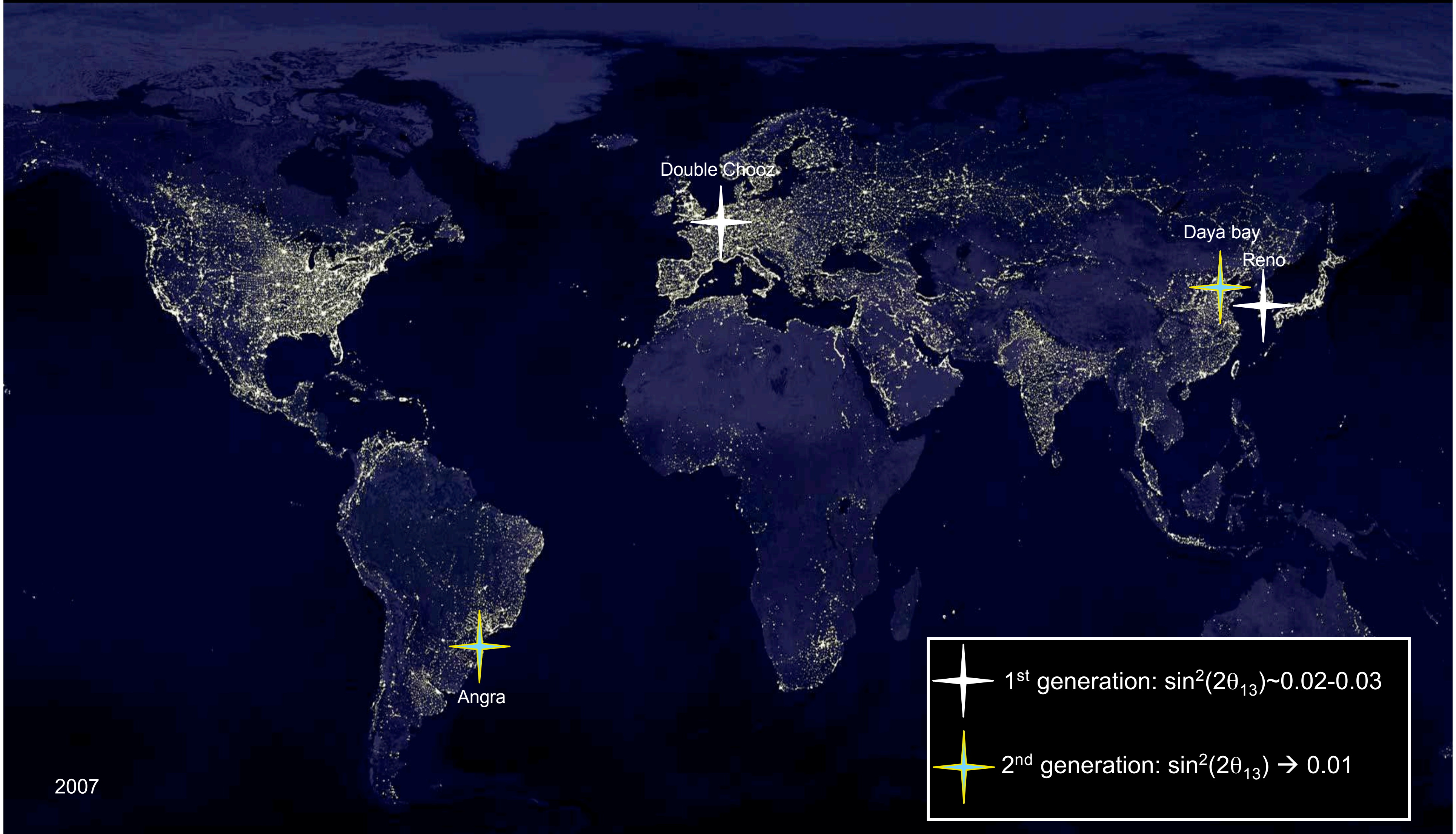
➔ $\sin^2(2\theta_{13})$ measurement independent of δ-CP

- **$1-P(\nu_e \to \nu_e) = \sin^2(2\theta_{13})\sin^2(\Delta m^2_{31}L/4E) + O(\Delta m^2_{21}/\Delta m^2_{31})$**

➔ weak dependence in Δm^2_{21}

- a few MeV ν_e + short baselines → negligible matter effects ($O[10^{-4}]$) ➔ $\sin^2(2\theta_{13})$ measurement independent of sign(Δm^2_{13})

2007: Remaining proposals …



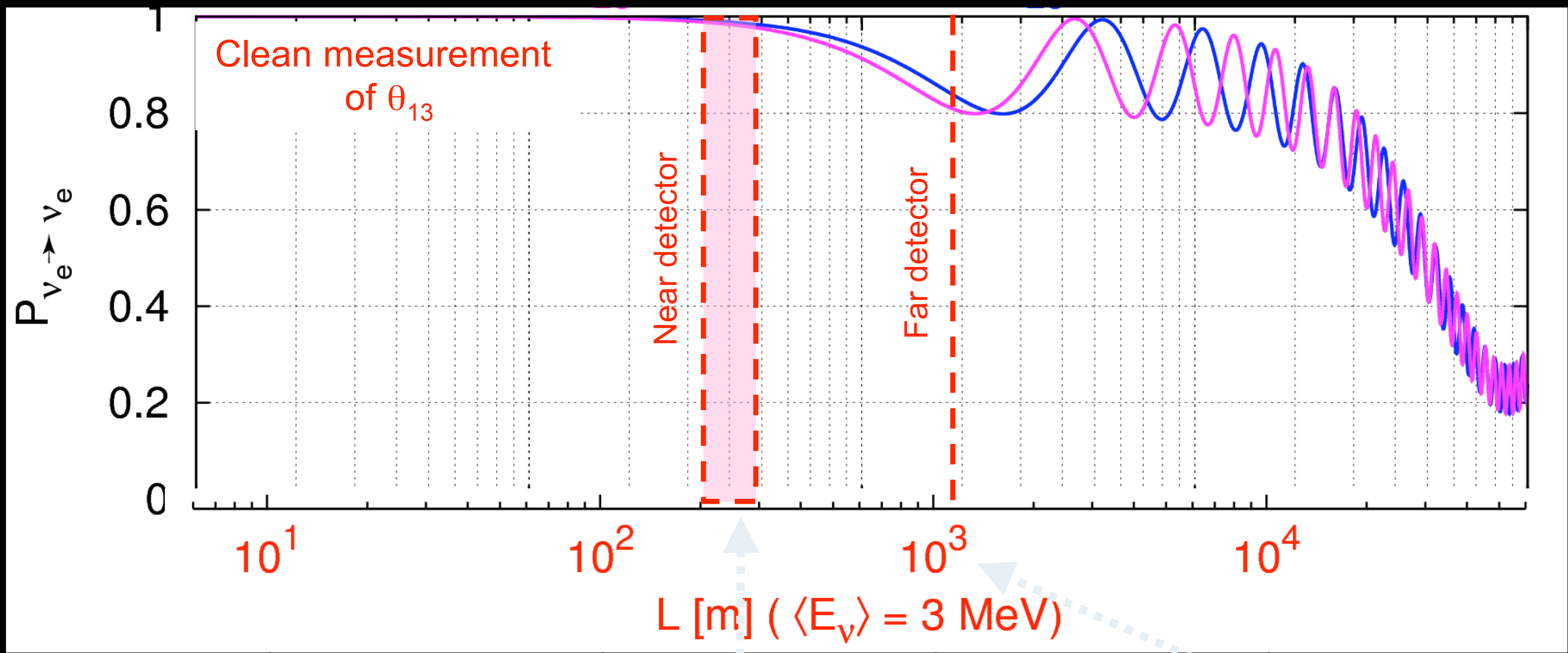
Double Chooz Collaboration

Double Chooz Institutions

University of Aachen	University of Alabama	AstroParticule et Cosmologie (APC)
Argonne National Laboratory	CIEMAT, Centro de Investigaciones Energeticas MedioAmbientales y Tecnologicas	Drexel University
Universität Hamburg	Max Planck Institut für Kernphysik Heidelberg	**Hiroshima Institute of technology**
Illinois Institute of Technology	Institute for Nuclear Research RAS	Institute of Physical Chemistry RAS
Kansas State University	**Kobe University**	RRC Kurchatov Institute
Lawrence Livermore National Laboratory	University of Columbia	Louisiana State University
Miyagi University of Education	**Niigata University (KEK collaboration)**	University of Notre Dame
DAPNIA CEA/Saclay	Sandia National Laboratories	Subatech Nantes
Tohoku University	**Tohoku Gakuin University**	**Tokyo Institute of Technology**
Tokyo Metropolitan University	Eberhard-Karls Universität Tübingen	University of Tennessee
University of Oxford	University of Sussex	University of Chicago

The - new - concept

$P(\nu_e \rightarrow \nu_e) = 1 - \sin^2(2\theta_{13})\sin^2(\Delta m^2_{31} L/4E)$

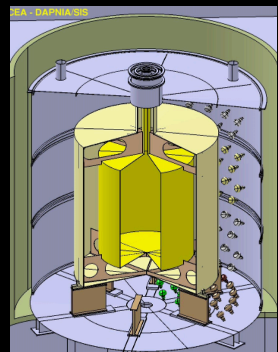


Nuclear power station
2 cores: 4.27 GW_{th}

Électron antineutrinos
flux : 10^{21} $\bar{\nu}_e$/s

$\bar{\nu}_e$

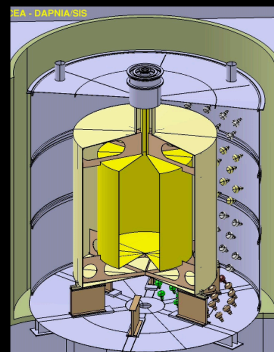
Near detector



~250 m

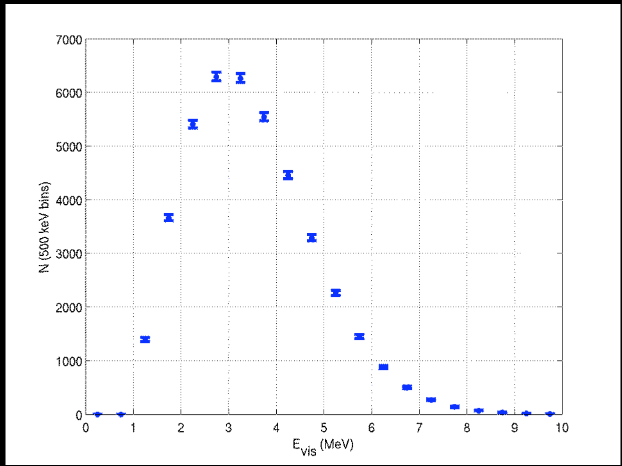
$\bar{\nu}_{e,\mu,\tau}$

Far detector

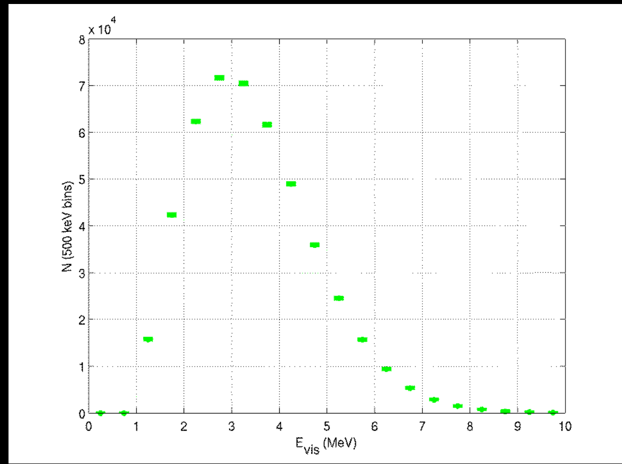


1050 m

Expected Oscillation Signal



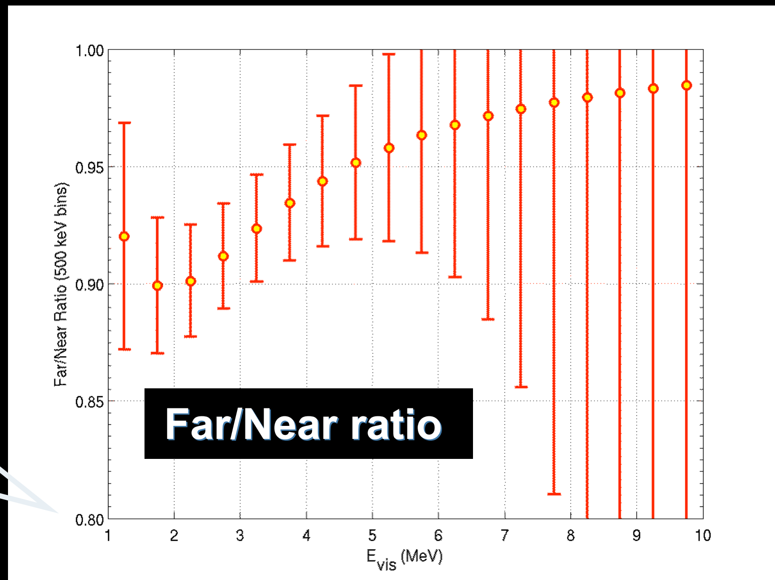
Far Spectrum



Near Spectrum

$\Delta m^2_{atm} = 3.0\ 10^{-3}\ eV^2$

$\sin^2(2\theta_{13})=0.12$

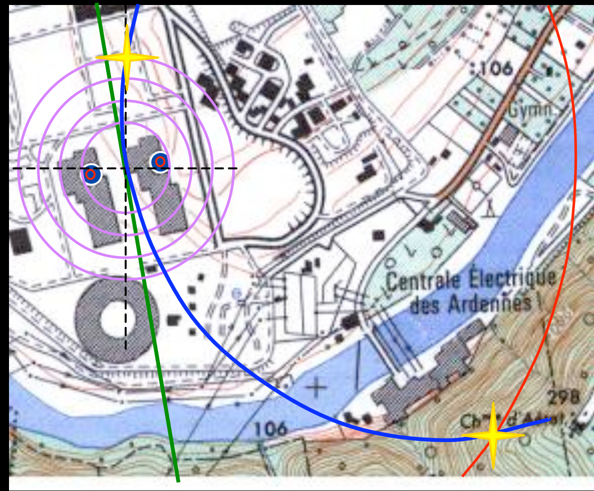


The Chooz site in French Ardennes

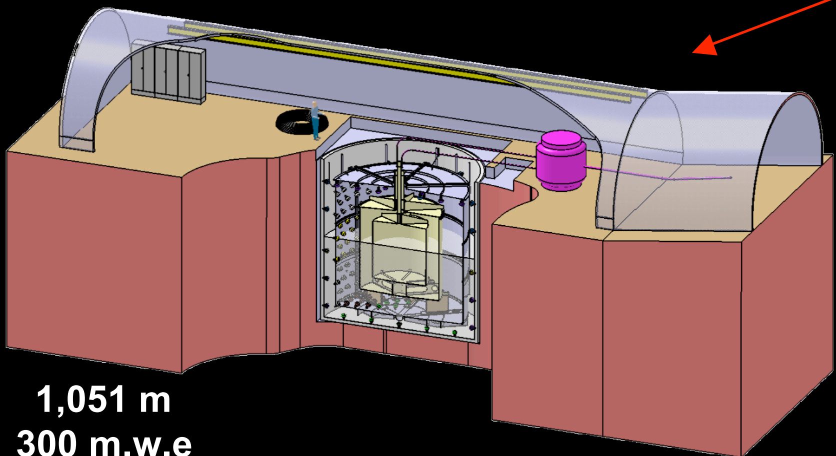
1 km site

274 m site

Integration to start mid-2007

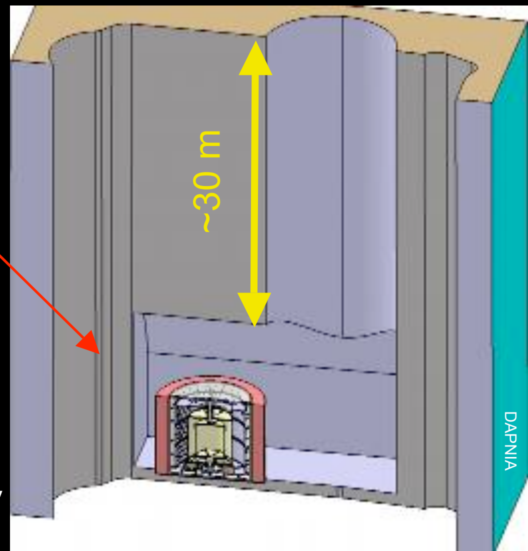


μ flux x ~10



1,051 m
300 m.w.e
15 200 events/y

274 m
80 m.w.e
162 260 events/y



Integration end of 2009

Improving CHOOZ: summary

@CHOOZ: R = 1.01 ± 2.8%(stat)±2.7%(syst)

– Statistical error –

	CHOOZ	Double-Chooz
Target volume	5,55 m^3	10,3 m^3
Target composition	6,77 10^{28} H/m^3	6,82 10^{28} H/m^3
Data taking period	Few months	3-5 years
Event rate	2700	CHOOZ-far : 40 000/3 y CHOOZ-near: >1 10^6/3 y
Statistical error	2,7%	0,5%

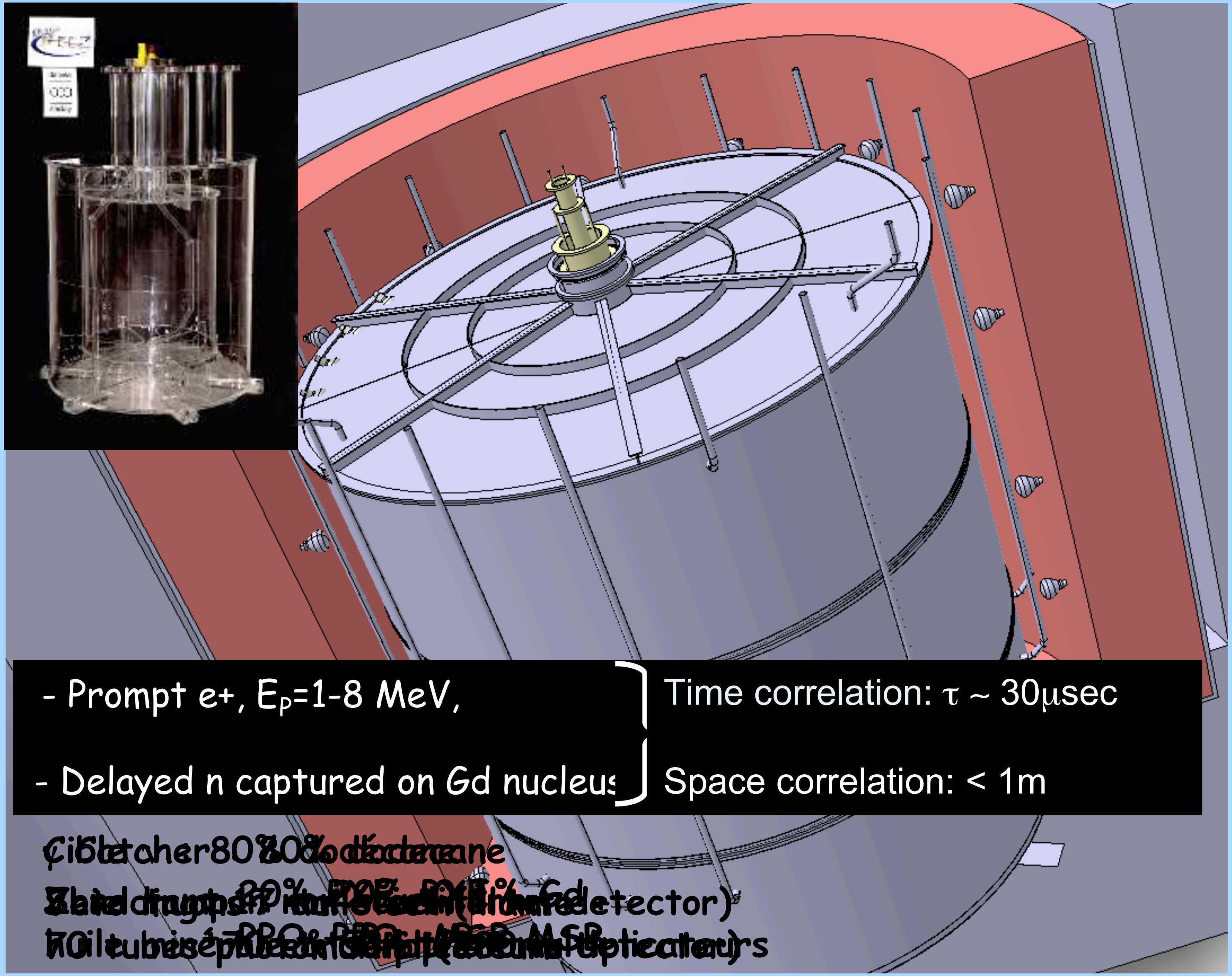
Luminosity incerase L = Δt x P(GW) x Np

– Systematic & Background errors –

	Chooz	Double-Chooz
Reactor cross section	1.9 %	—
Number of protons	0.8 %	0.2 %
Detector efficiency	1.5 %	0.5 %
Reactor power	0.7 %	—
Energy per fission	0.6 %	—

Improve the detector concept
Two identical detectors ➔ towards $\sigma_{relative}$<0,6%
Careful backgrounds control ➔ error<1%

2002-2005: Detector design



- Prompt e+, E_P=1-8 MeV,
- Delayed n captured on Gd nucleus

Time correlation: $\tau \sim 30\mu sec$

Space correlation: < 1m

2004-2007: Detector design

Calibration Glove-Box :

Outer Veto :
Scintillator panels

Target ν : 10,3 m^3
80% $C_{12}H_{26}$+ 20% PXE +0,1% Gd
+ PPO + Bis-MSB

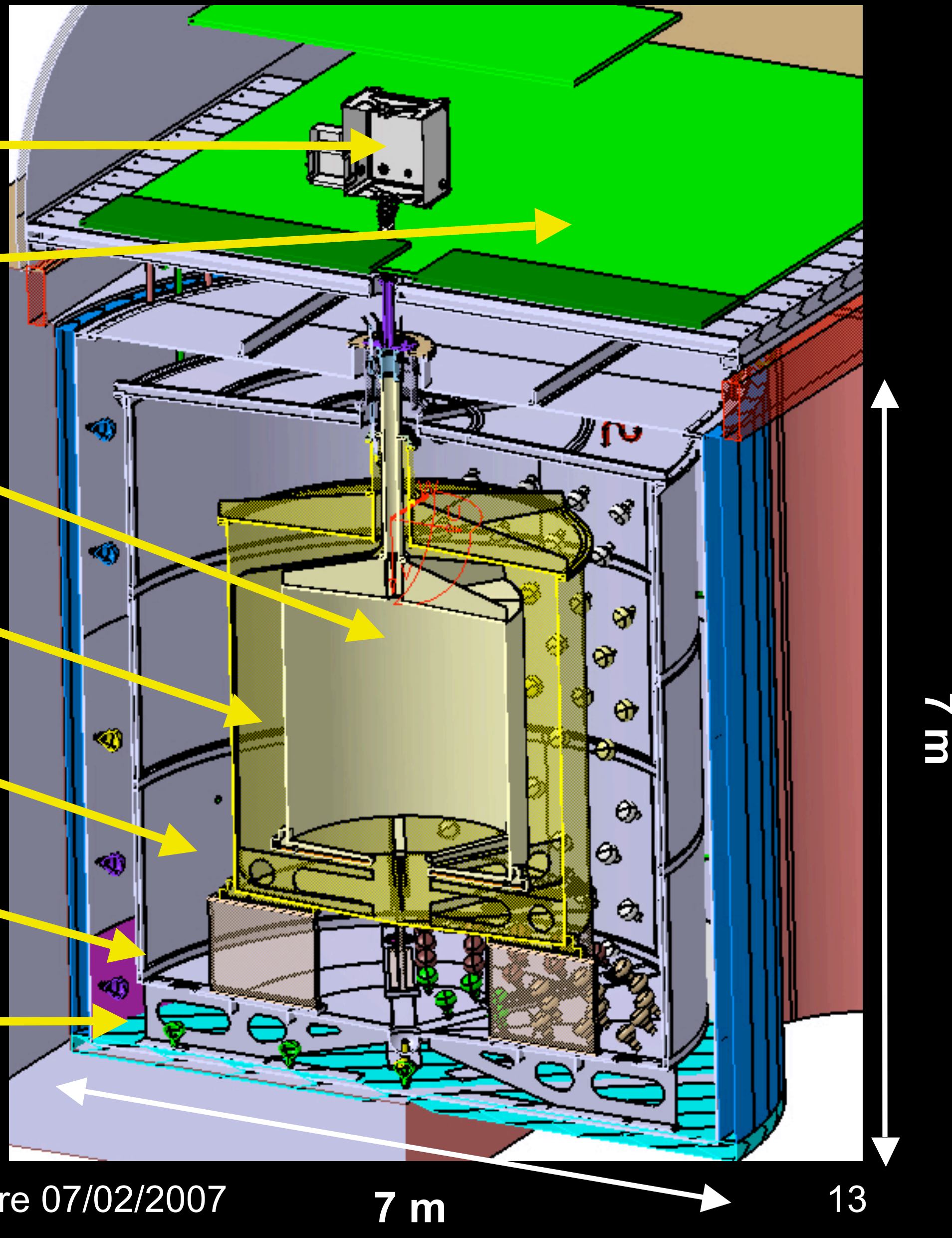
γ Catcher : 22,6 m^3
80% $C_{12}H_{26}$ + 20% PXE + PPO + Bis-MSB

Non scintillating Buffer : 114 m^3
mineral oil

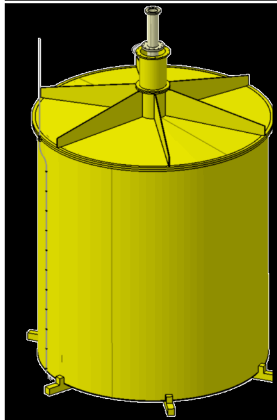
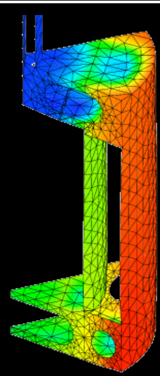
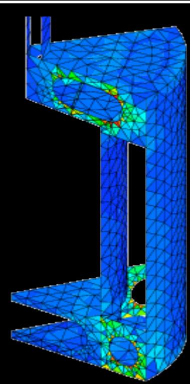
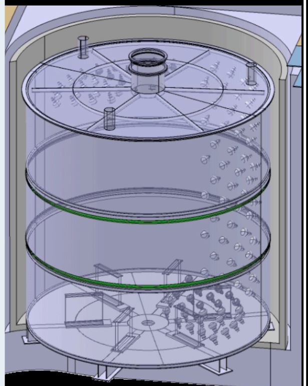
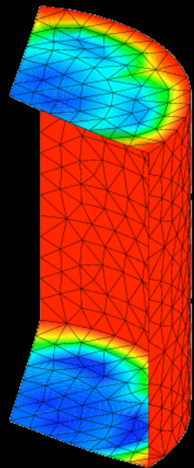
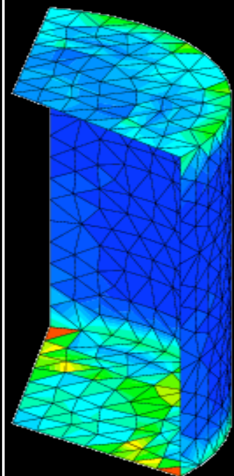
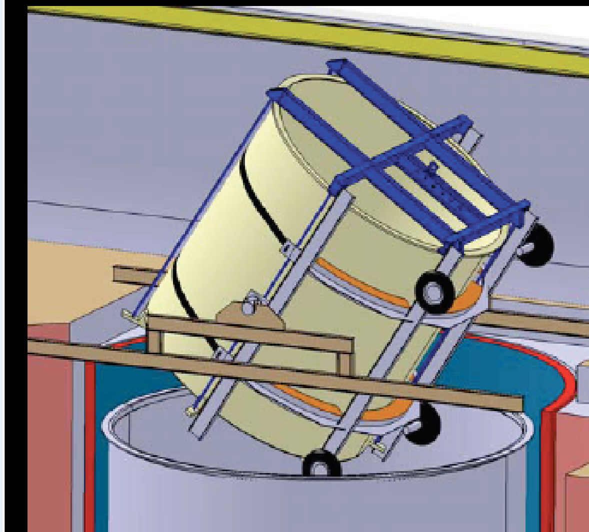
Buffer vessel & 360 10'' PMTs :
Stainless steel 3 mm

Inner Muon Veto : 90 m^3
mineral oil + 70 8'' PMTs

Steel Shielding :
17 cm steel, All around



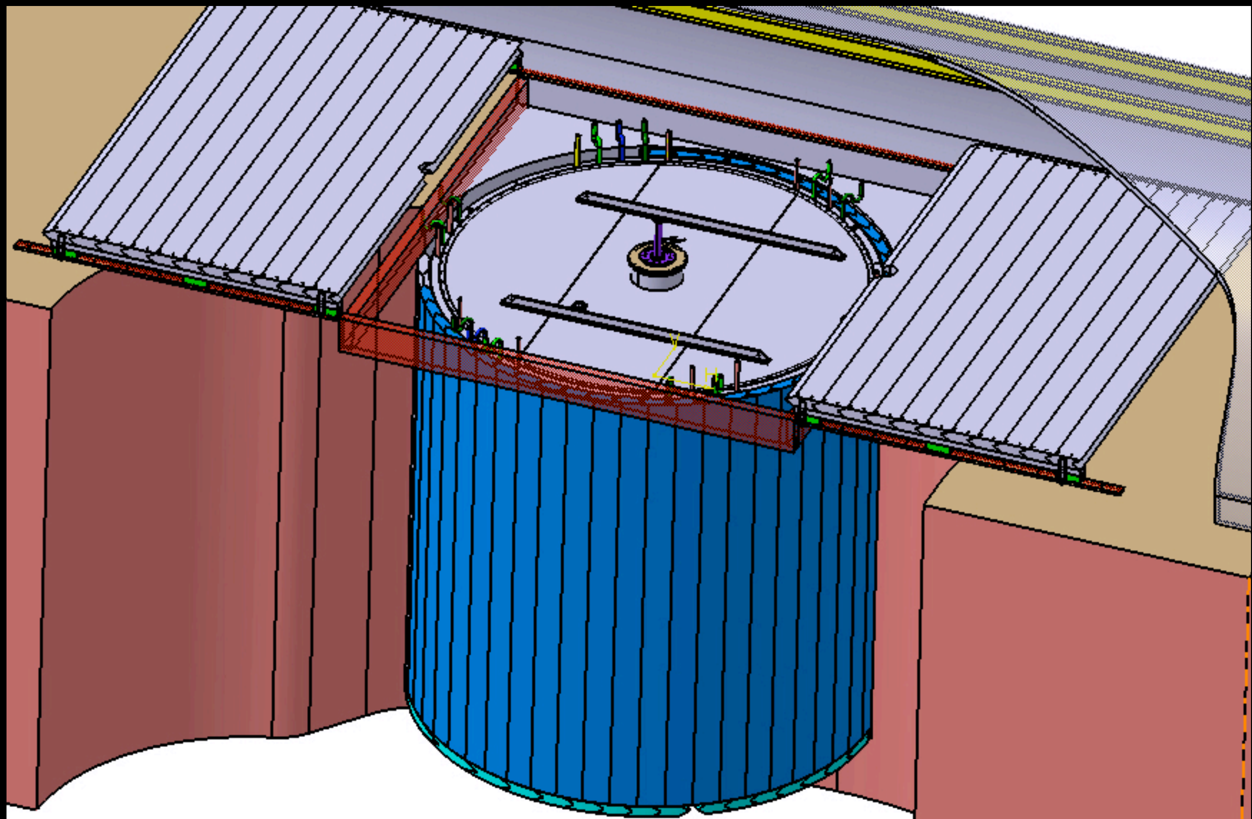
Mechanics: Acrylics and Buffer

Vessel	Dimension	Distortion	Stress	Transport & Integration
	***Inputs :*** *Target : 12 mm* *γ catcher : 12 m* ***Loads =** dead load* **Closing R&D** **Radiopurity test** **Contract 2007/8**	 distortion : <1 mm	 VM stress: 1 MPa	
	***Inputs :*** *Buffer : 3 mm* ***Loads =*** *2 kg / pmts +* *dead load* ***Stainless steel delivered*** ***Radiopurity OK*** ***- 10^{-9} g/g U/th &*** ***- <20 mBq/kg Co***	 distortion : 4.1 mm	 VM stress: 23 MPa	

γ ray shiedling & Outer Veto

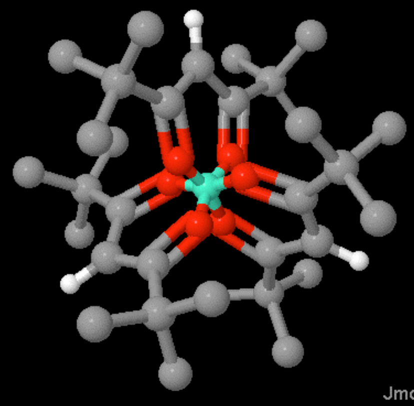
- γ's from rock radioactivity dominate the single rate in the Target+GC (no shield)
- Shielding with 17 cm of low radioactive steel
  - → 250 tons of steel to be assembled in bars & 1 cm thick steel vessel guarantees the tightness

- Steel bars demagnetization under preparation
- Call for the bid December 2006 → order to company soon

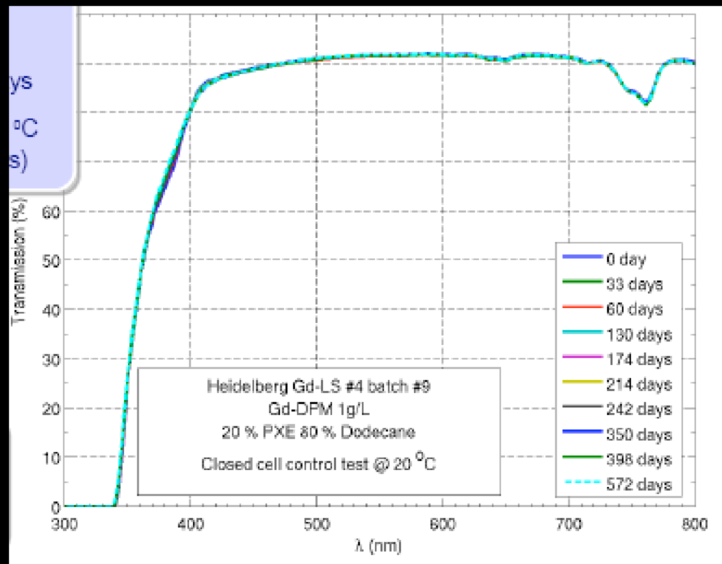


Gd doped scintillator

- **Solvant: 20% PXE – 80% Dodecane**
- **Gd loading: being developed @MPIK**
  - 0.1% Gd loading of Gd-dmp (Beta Dikitonate)
  - Long term Stability promising
  - LY ~7000 ph/MeV: 6 g/l PPO + 50 mg/l Bis-MSB
  - Attenuation length: 5-10 m meters at 420 nm
  - Radiopurity → U: 10^{-12} g/g - Th: 10^{-12} g/g - K: 10^{-9} g/g



Gd(dpm)$_3$



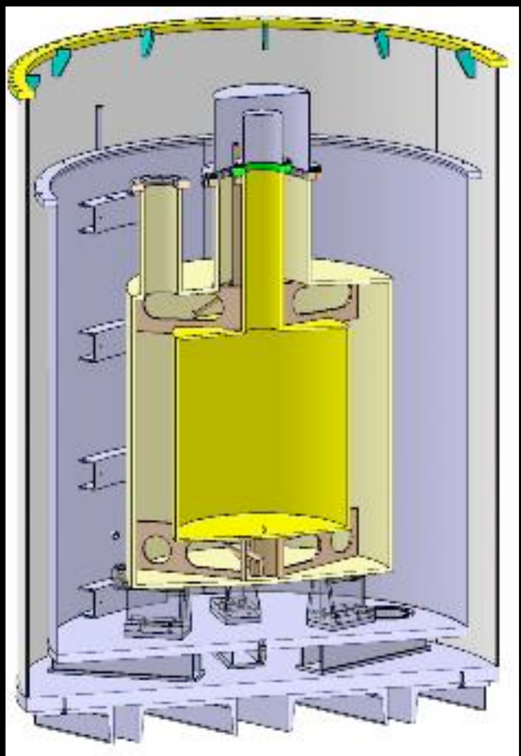
UV-VIS-IR scintillator transmission

- Heidelberg MPIK →Transition to industrial production of 100 kg of Gd → summer 2007
- On-site storage building *available* at Chooz → Upgrade will be done in 2007

Technical 1/5 mockup at Saclay

Validation of the technical choices for the vessels : construction, material compatibility, filling, and the integration

Total of 2000 l of oil
Filling 13/12/2005
Stable in the detector

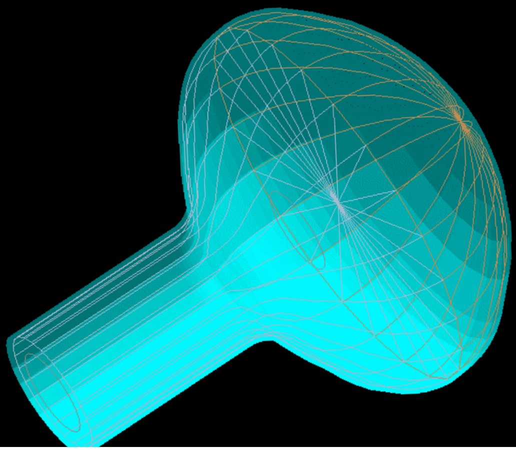


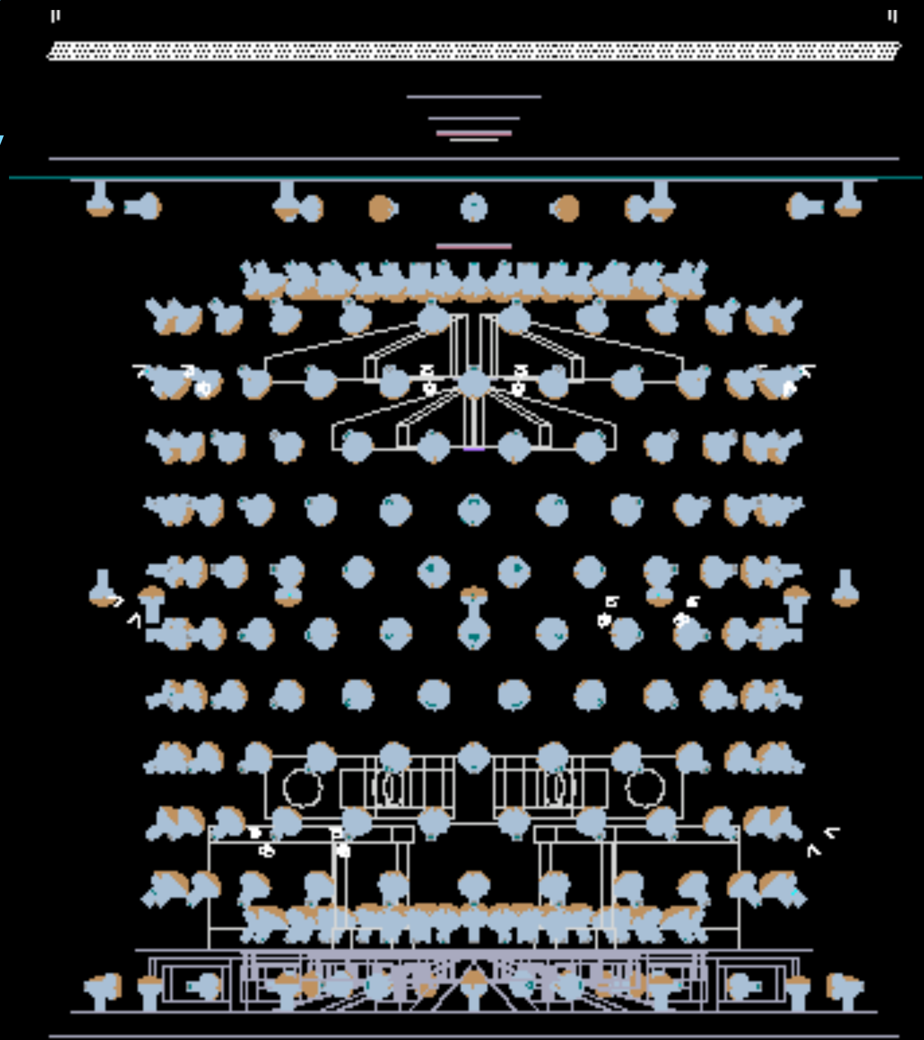
- ***Inner Target:*** *120 l : 20%PXE+80%dodecane+0.1%Gd*
- ***Gamma Catcher:*** *220 l : 20%PXE+80%dodecane*

Phototubes baseline

- 10“ Ultra low background tubes + HV
- ~400 PMTs → ~15 % coverage
- Energy resolution goal: 7 % at 1 MeV

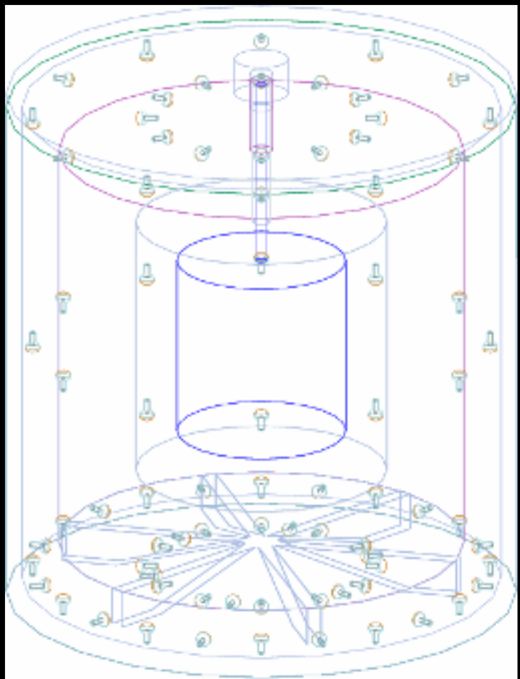
- Current work :
  - PMT selection ongoing
  - Radiopurity
  - Angular sensitivity
  - Magnetic shielding
  - Tilting tube options (done)
  - Cabling & Tightness (done)
  - Light concentrator?

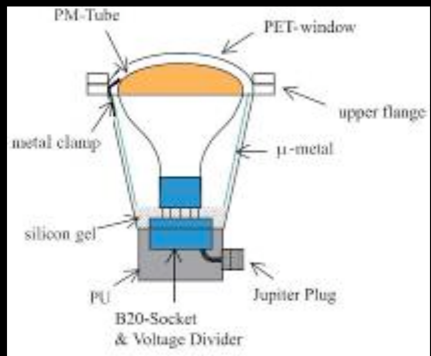




Inner and Outer Veto systems

Inner Veto : Tag μ and secondaries. Very high ε (>99.5%)

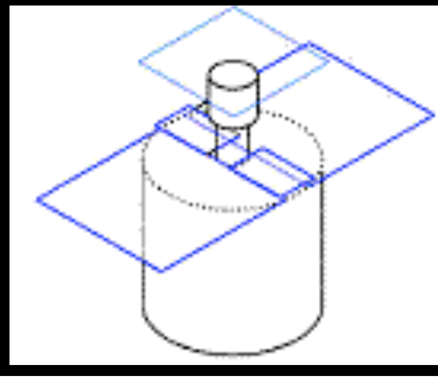




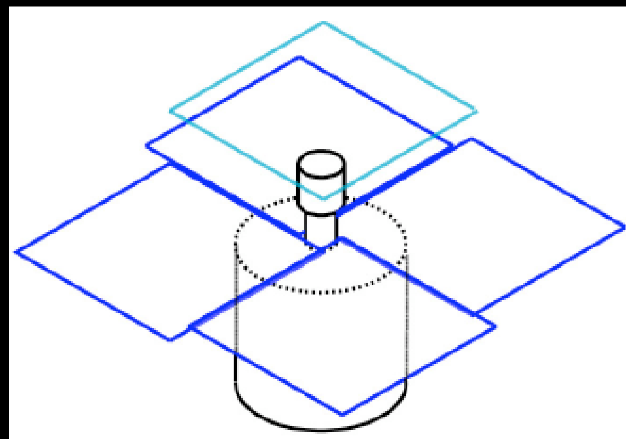
- 50 cm, scintillating mineral oil
- ~70 PMTs (8 inches)
- Reflective walls (paint + Tyvek)

Outer Veto : Tag "near miss" μ.
Redundancy for higher rejection power

Panels of strips of coextruded plastic scintillator +TiO_2 reflector with 1.2 mm diameter wavelength shifting fiber



Far detector

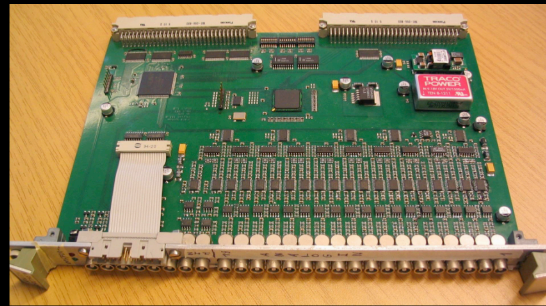


Near detector

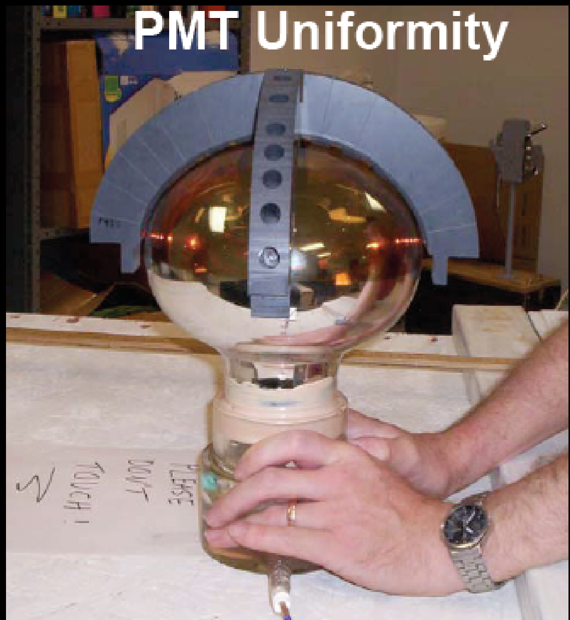
Testing & prototyping


Helmholtz-Coils

Demagnetization

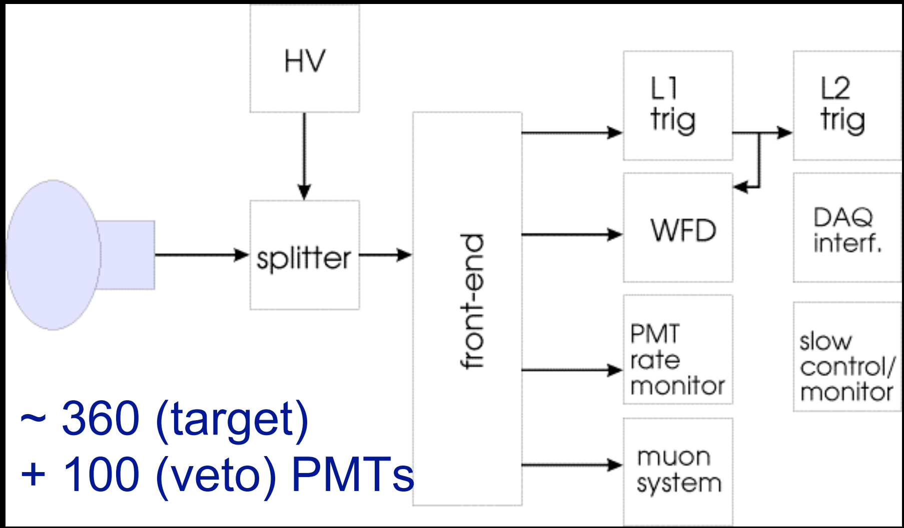

L1 Trigger Board

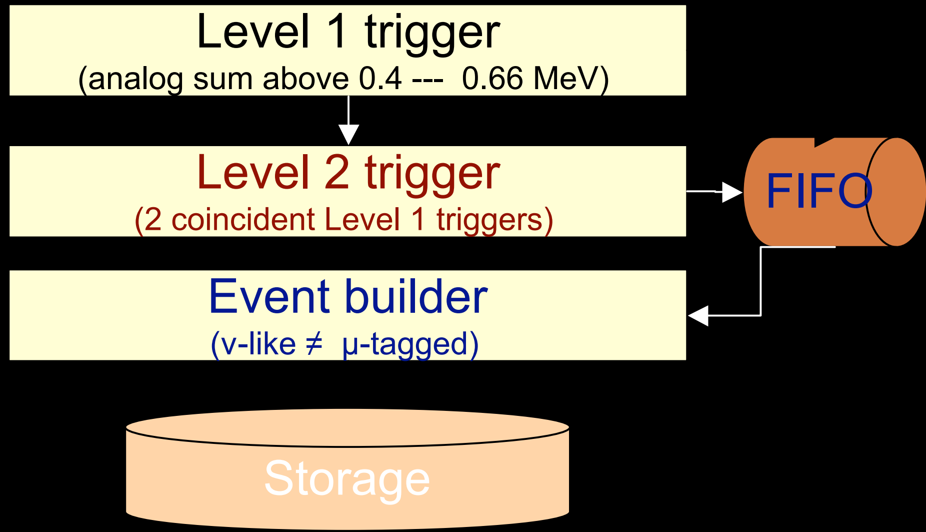
PMT Uniformity




Mass Measurement

Electronics & DAQ





Zero dead-time DAQ

HV+Front-End:

- Single cable for HV + PMT signal
- Amplification x15 – Pulse shape – Baseline correction
- Handle high energy muons
- Analog Pulse Summation for Level 1 Trigger

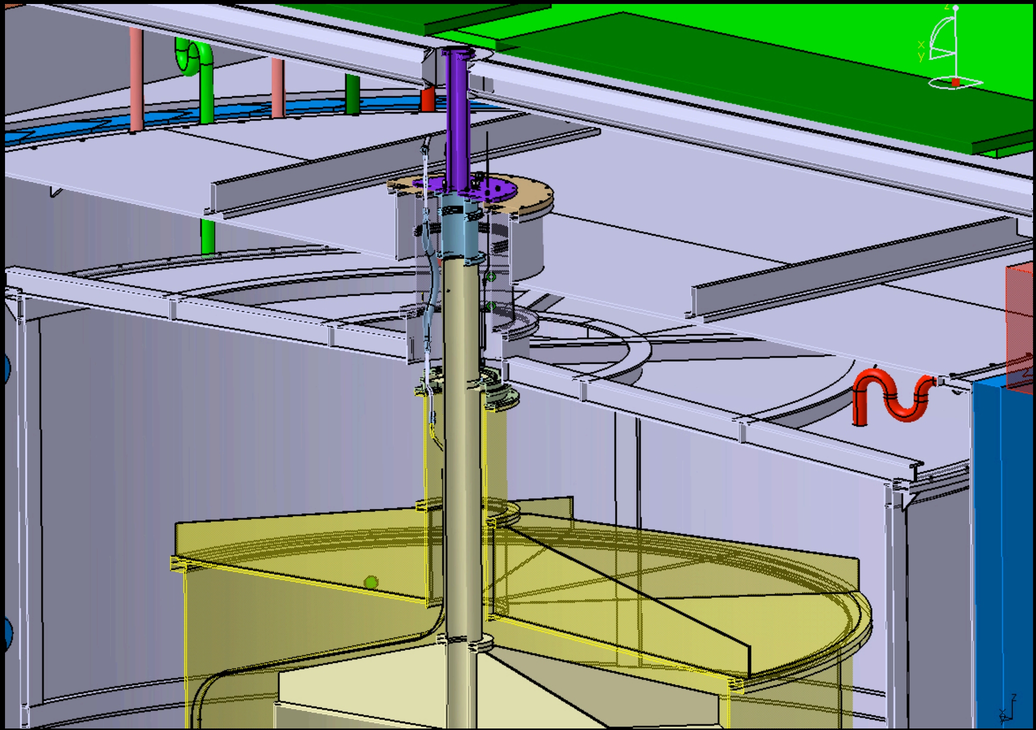
Flash-ADC

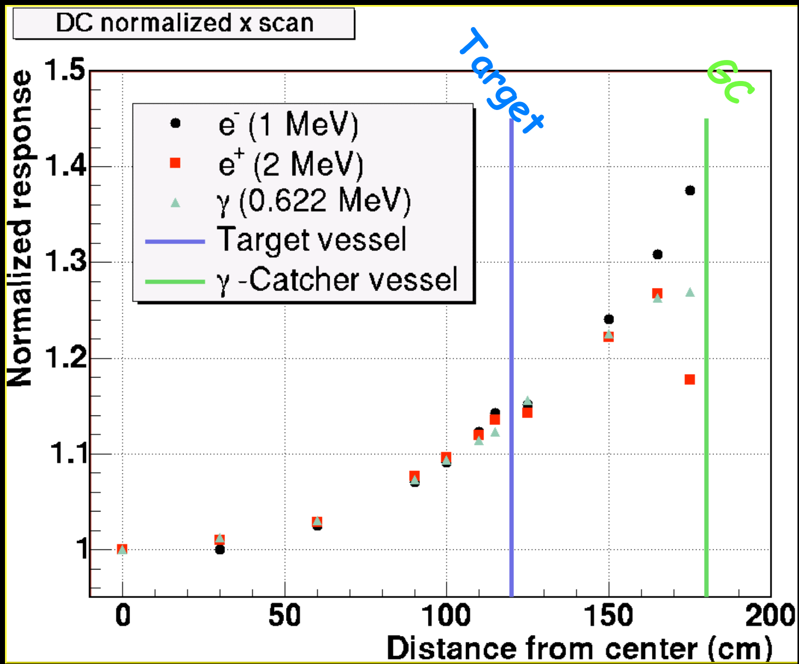
- Wave-form sampling @ 500MHz
- 8-bit ADC (few PEs/ch for ν-events)
- Developed between APC & CAEN

➡ **Prototype FADC being tested**

Detector Calibration

- **Estimate relative Near/far detection efficiency to within 0.5%**
- **Measure relative Near/Far positron energy scale to within 1%**
- **Radioactive sources + Laser & LEDs →** devices:
  - Target: Articulated Arm → 1 cm positioning accuracy
  - CG and Buffer: Wire driven sources (guide tubes)
  - Deployment of laser light sources and Tagged neutron source on z-axis.





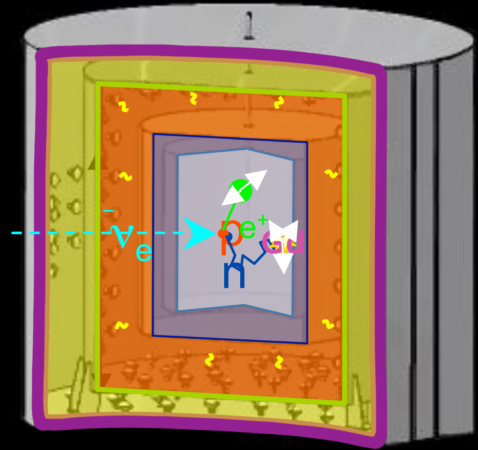
Detector response to e^-, e^+, γ's
Along a radial scan

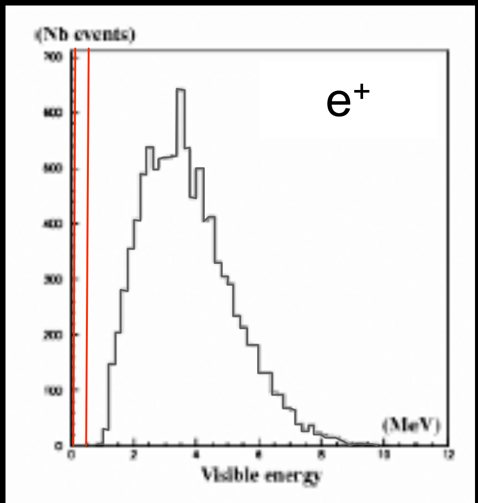
Systematics

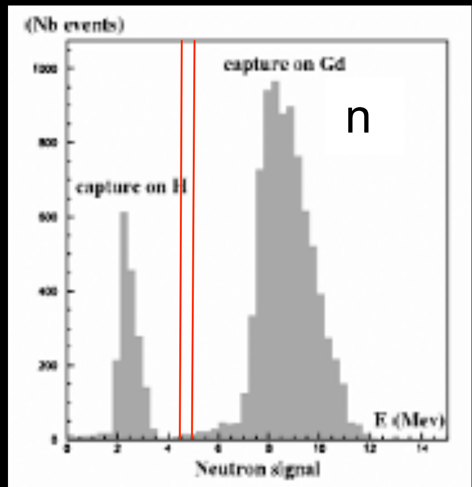
		Chooz	Double-Chooz	
Reactor-induced	ν flux and σ	1.9 %	<0.1 %	Two ''identical'' detectors, Low bkg
	Reactor power	0.7 %	<0.1 %	
	Energy per fission	0.6 %	<0.1 %	
Detector - induced	Solid angle	0.3 %	<0.1 %	Distance measured @ 10 cm + monitor core barycenter
	Target Mass	0.3 %	0.2 %	Same weight sensor 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 %	(see next slide)
	Total	**2.7 %**	**< 0.6 %**	**(Total ~0.45% without contigency ....)**

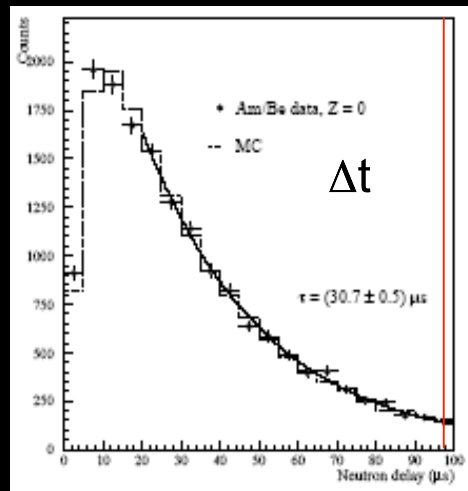
Relative Normalization: Analysis

- ✓ @Chooz: 1.5% syst. err.
  - 7 analysis cuts
  - Efficiency ~70%
- ✓ Goal Double-Chooz: ~0.3% syst. err.
  - 2 to 3 analysis cuts
- ✓ Selection cuts
  - neutron energy
  - (- distance e+ - n) [level of accidentals]
  - Δt (e+ - n)

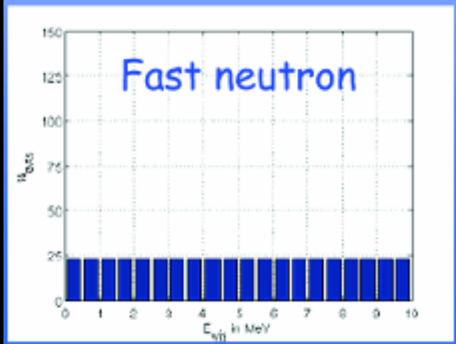


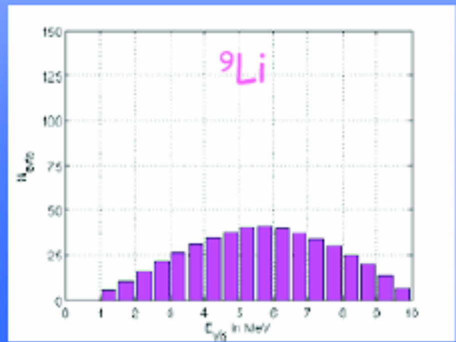


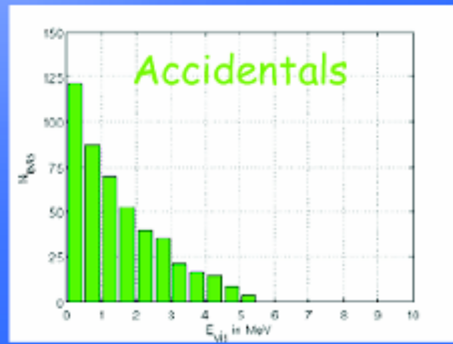




Backgrounds







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%

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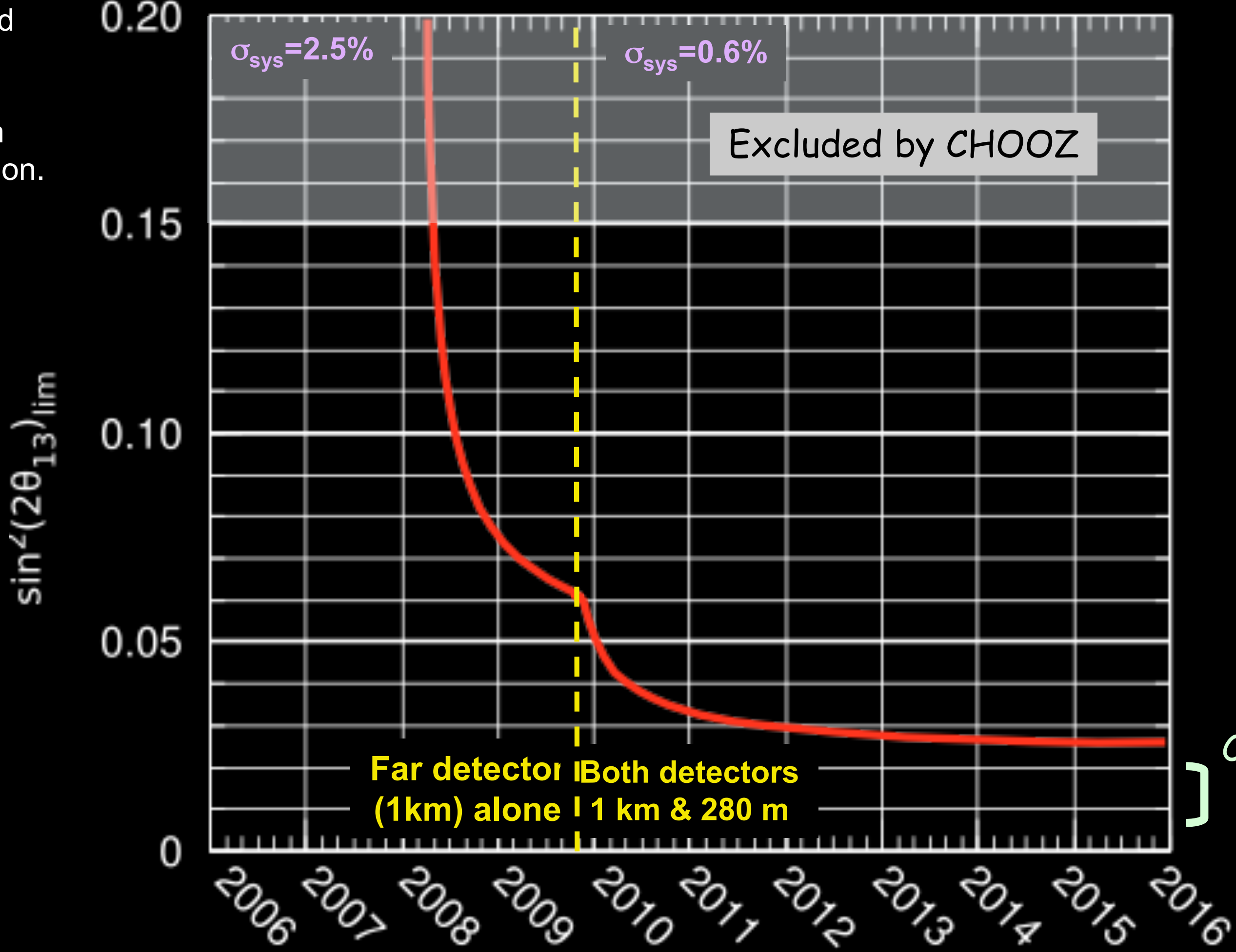
90% C.L. limit if $\sin^2(2\theta)=0$

- Efficiencies included
- 1% 'bin to bin' uncorrelated error on background subtraction.
- Systématiques:
  - σ_{abs} = 2.0%
  - σ_{rel} = 0.6%
  - σ_{scl} = 0.5%
  - σ_{shp} = 2.0%
  - $\sigma_{\Delta m^2}$ = 20%

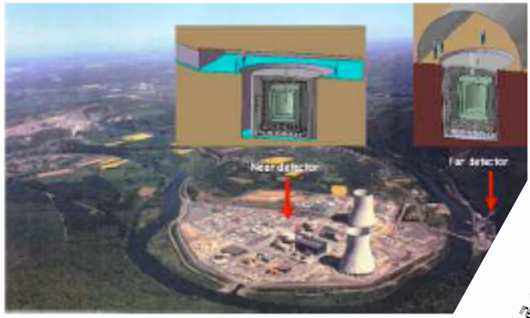
$\Delta m^2_{atm} = 2.5\ 10^{-3}\ eV^2$ (20% uncertainty)



Complementary with T2K, Nova 5y

2004-2006: Publications

Letter of Intent for Double-CHOOZ: a search for the mixing angle θ_{13}



APC, Paris - RAS, Moscow - DAPNIA, Saclay - EKU-Tü
INFN, Assergi & Milano - INR, Moscow -MPI, Heidelberg -RP
TUM-München - University of l'Aquila -Universität

Version 5.0

April 28, 2004

EU Lette[...]
hep-ex[...]

COMMUNIQUE DE PRESSE

Le 19 septembre 2006

Lancement de l'expérience « Double Chooz »

Le CEA/Dapnia[1] et le CNRS/IN2P3[2] ont décidé de lancer la construction de l'expérience Double Chooz, destinée à étudier les neutrinos, ces particules élémentaires produites en abondance dans les étoiles, l'atmosphère, et les cœurs des centrales nucléaires[3]. Deux détecteurs identiques seront placés près de la centrale EDF de Chooz (Ardennes), à des distances différentes des réacteurs. Cette expérience permettra de mesurer avec précision la dernière propriété encore mal connue des neutrinos : l'oscillation.

CEA & CNRS Press Release for The Double Chooz Launching
September 19 2006

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

20th June 2006

Proposal
hep-ex/0606025

[...]ne 2007

Conclusions & outlook

- Funding has been established in Europe
  → Request in Japan and US

- First goal: measurement of θ_{13}
  Double Chooz moving towards the construction phase !

  - *2007-08 → Detector construction & integration*
  - *2008 → Start of phase I : Far 1 km detector alone*
    $\sin^2(2\theta_{13}) < 0.06$ in 1,5 year (90% C.L.)
  - *2009 → Start of phase II : Both near and far detectors*
    $\sin^2(2\theta_{13}) < 0.025$ in 3 years (90% C.L.)
    Complementarity with Superbeam experiments: T2K, Nova

- Faisability study on non proliferation
  Reactor ν's track the Pu isotopic content of reactors → new beta spectra measurement & small detector deployed close to nuclear cores

  - 2009-10 → Near detector at 280 m = prototyping of a futur AIEA monitor?

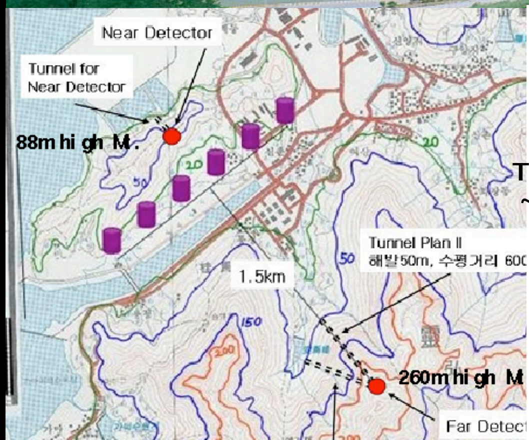
Daya Bay (hep-ex/0701029)

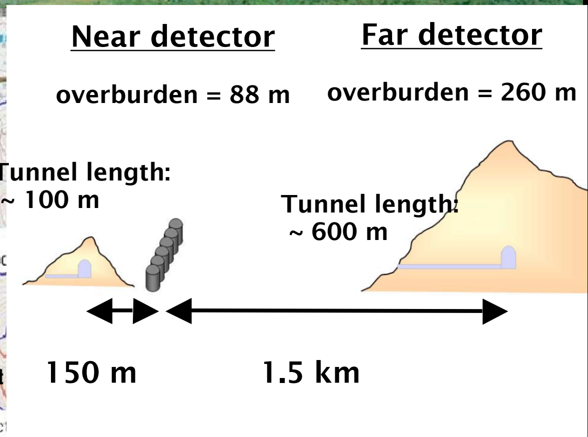
In Daya Bay, China

- **4 cores – 2 sites – 11.6 GWth**
  ⇨ 6 cores in 2011- with 17.4 GWth
- **2 near positions, (1 mid), 1 far**
  - far: 4 modules of 20 t
  - near: 2 modules of 20 t each
- **Civil Engineering**
  - ~ 3.4 km tunnels
  - 5 laboratories to be build
- **Statistics (including ε)**
  - far: 70 evt/day/mod
  - mid-site: 200 evts/day/mod
  - near: 600 evts/day/mod
- **Mobile modules** ⇨ swapping (Theo.)
- **Systematics**
  - reactors : ~ 0.1% - detectors : ~ 0.38%
- **Backgrounds**
  - B/S @ near sites: ~0.5% @ far site: ~0.2%
- **Sensitivity goal & Planning**
  1. Fast Measurement (Phase I)
     - DYB+Mid-site, 2008-2009
     - Sensitivity (1 year) ~ 0.035
  2. Complete measurement
     - DYB+LA+Far, from 2010
     - Sensitivity (3 years) < 0.008

RENO (http://neutrino.snu.ac.kr/RENO)

In South Corea Yongwang,

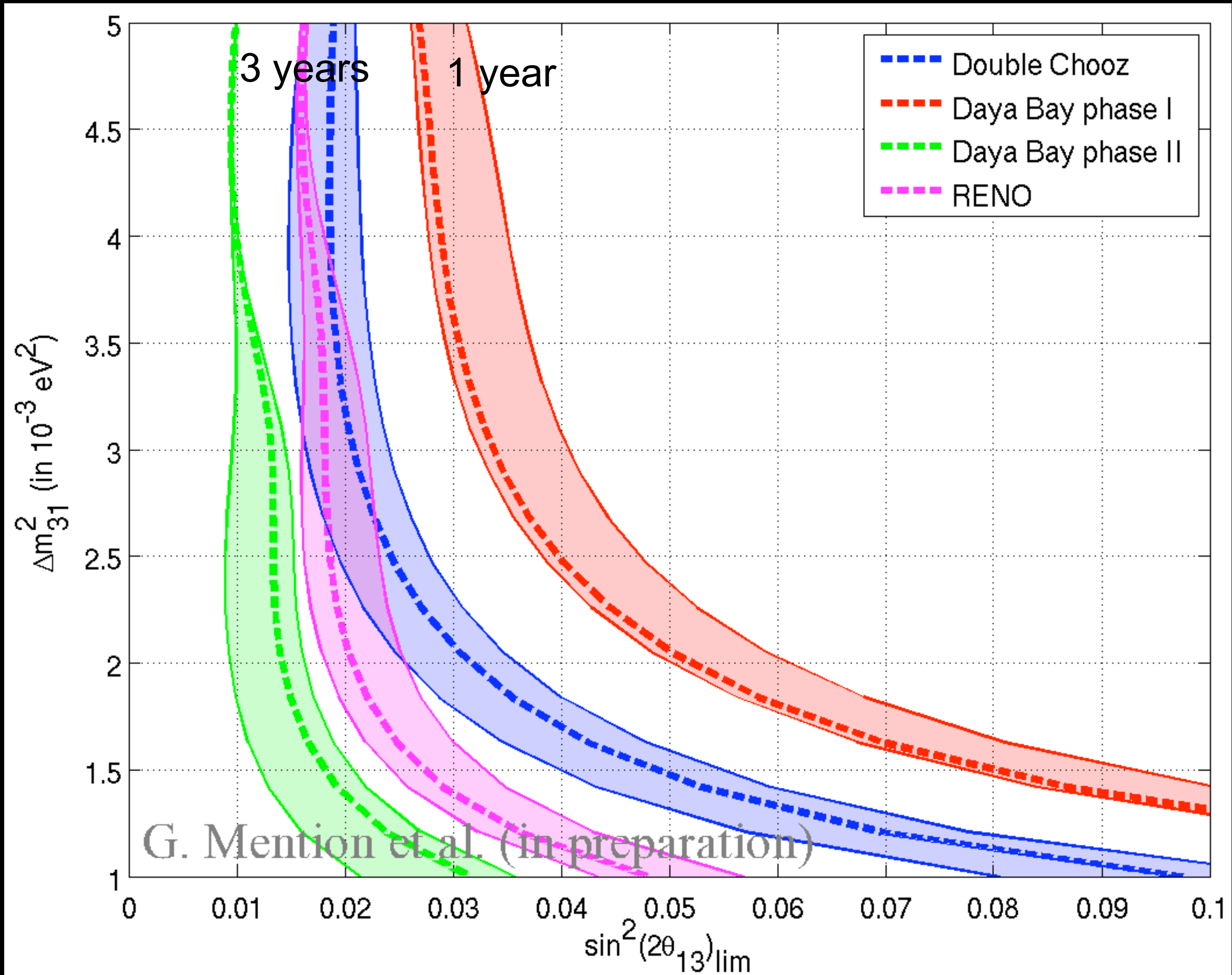




- **6 cores – 1 site – 16.4 GW_{th}**
- **1 near site, 1 far,**
- **3 *"very near"* sites**
  - target: 2 x 20 t
  - + target: 3 x ~ 200-300 kg
- **Civil Engineering**
  - ~ 700 m tunnels
  - 2 laboratories to be build
- **Statistics (including ε)**
  - Far: ~ 70 evts/day
  - Near: ~ 1,700 evts/day
- **Systematics**
  - total: ~ 0.5-1%
- **Overburden**
  - Far: ~ 700 mwe
  - Near: ~ 240 mwe
- **Sensitivity & Planning**
  - Start construction in 2007
  - Sensitivity: ~ <u>0.02</u>

Unified Analysis of current projects

(G. Mention & T.L.)



data/theory *"distance"* — systematic biases

$$\chi^2 = \min_{\{\alpha^D_{i,k}\}} \left\{ \sum_{D=N,F} \sum_{i=1}^{NBins} \left(\frac{O_i^D - T_i^D - \sum_{k=1}^{K} \alpha_{i,k}^D S_{i,k}^D}{U_i^D} \right)^2 + \sum_{k=1}^{K} c_{i,k}^{D,R} \left(\frac{\alpha_{i,k}^D}{\sigma_k^D} \right)^2 \right\}$$

both detectors — all rate/spectral information — systematic knowledge weights

Worst limit
(prediction too optimistic)

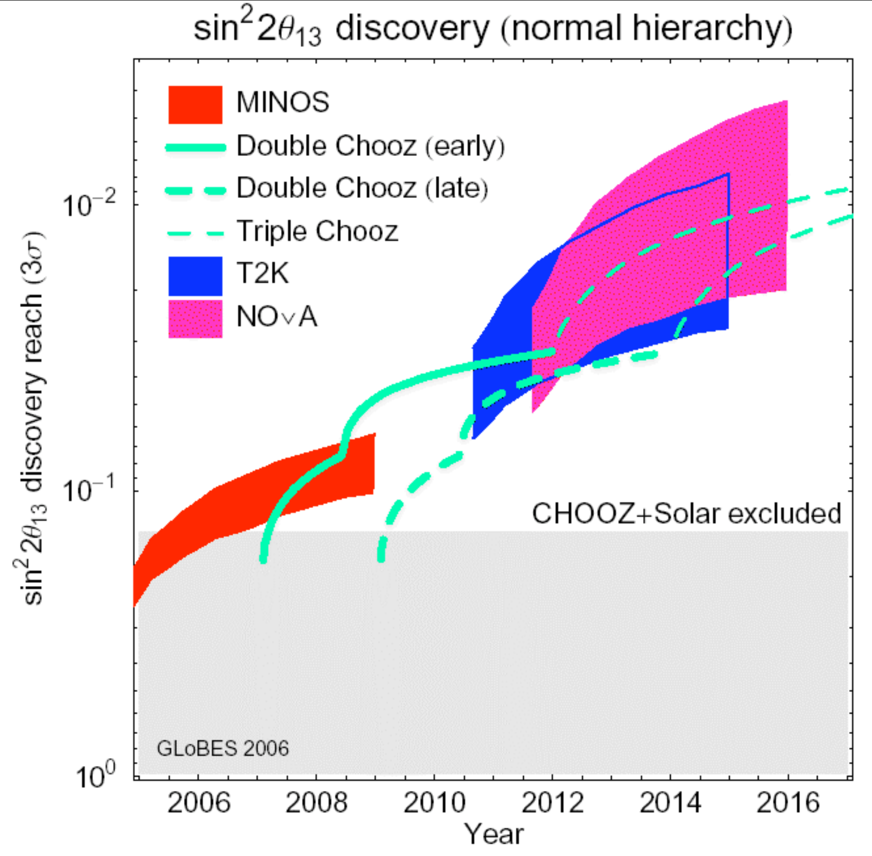
σ_{rel} = 0.18 %
σ_{pwr} = 2.0 %
σ_{abs} = 2.0 %

Best Limit
(prevision pessimistic)

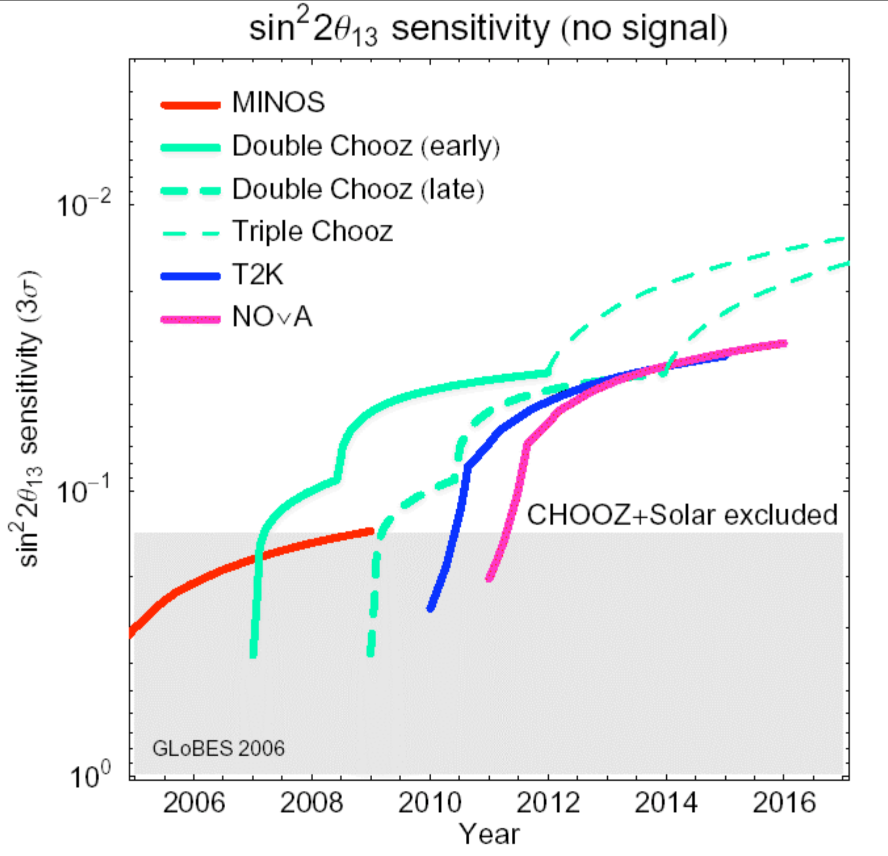
σ_{rel} = 0.6 %
σ_{pwr} = 3.0 %
σ_{abs} = 3.0 %

Experimental context

3σ discovery potential



3σ sensitivity (no signal)



Lindner et al. (Globes 2006)