Double Chooz

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on behalf of the Double Chooz collaboration

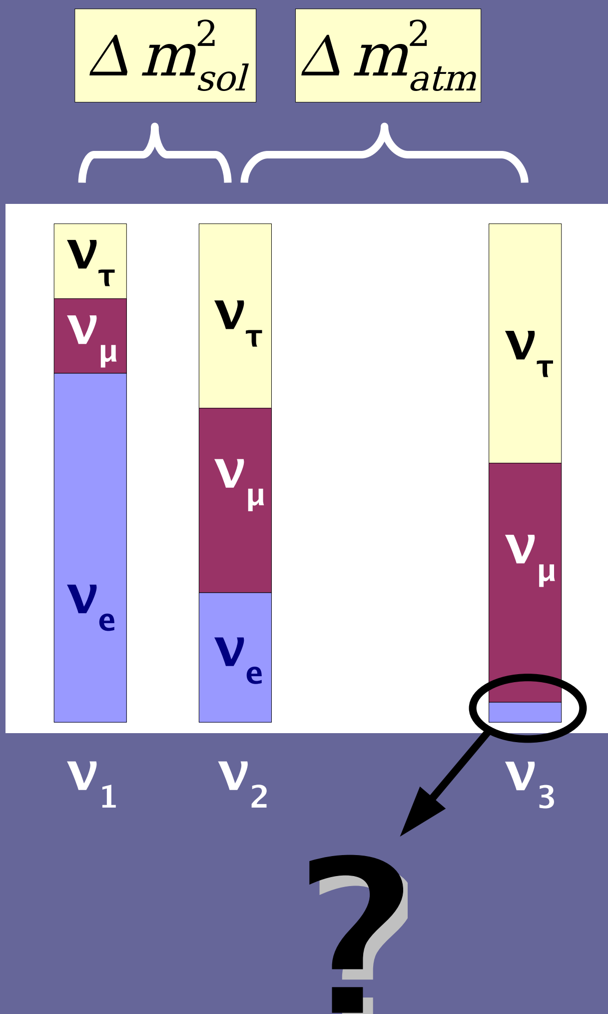
6th Rencontres du Vietnam
Hanoi, August 6-12 2006

What and Why ?

A reminder from the overview talk

(the first time I can refer to my own review talk at a conference !)

Neutrino mixing : how much of ν_e is in ν_3 ?



$$U_{MNSP} = U_{atm} \times \begin{pmatrix} \cos\theta_{13} & 0 & e^{-i\delta_{cp}}\sin\theta_{13} \\ 0 & 1 & 0 \\ -e^{i\delta_{cp}}\sin\theta_{13} & 0 & \cos\theta_{13} \end{pmatrix} \times U_{sol} \times U^{diag}_{Maj}$$

θ_{13} is the key parameter to access:

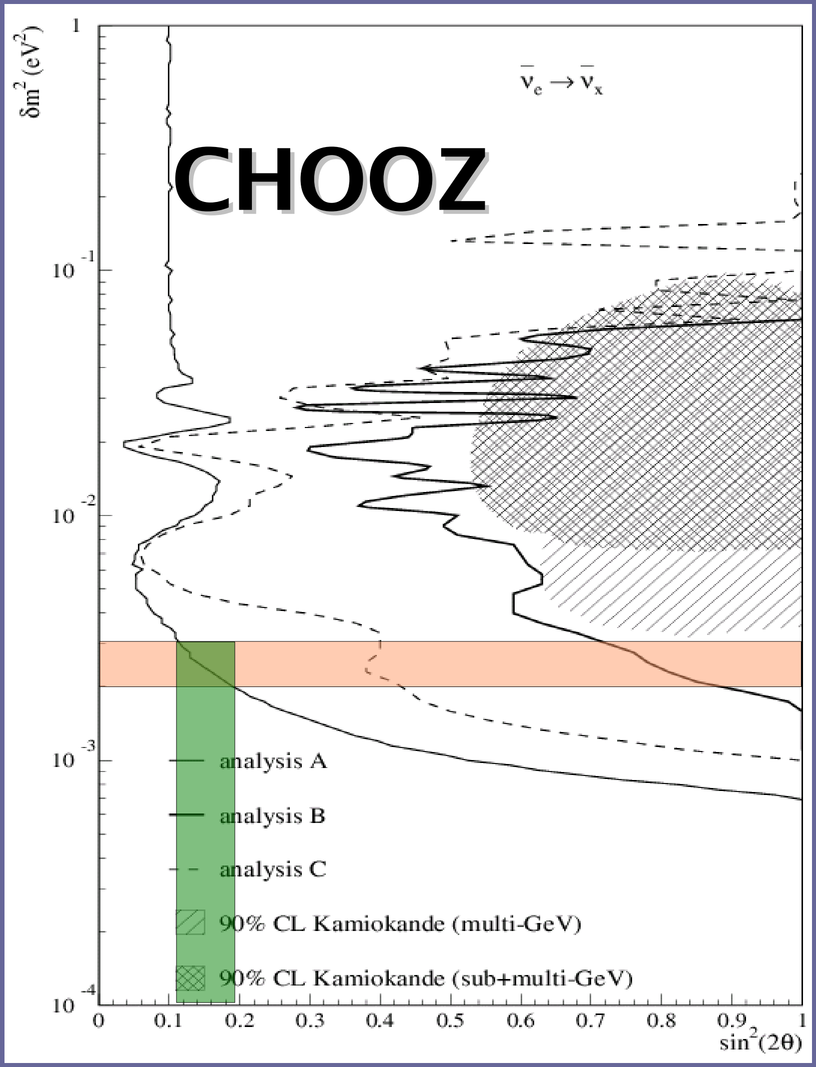
➔ genuine 3-flavors effects

➔ CP-violating phase δ

parameter	bf±1σ	1σ acc.	2σ range	3σ range
Δm^2_{21} $[10^{-5}\text{eV}^2]$	7.9 ± 0.3	4%	$7.3 - 8.5$	$7.1 - 8.9$
$\lvert\Delta m^2_{31}\rvert$ $[10^{-3}\text{eV}^2]$	$2.5^{+0.20}_{-0.25}$	10%	$2.1 - 3.0$	$1.9 - 3.2$
$\sin^2\theta_{12}$	$0.30^{+0.02}_{-0.03}$	9%	$0.26 - 0.36$	$0.24 - 0.40$
$\sin^2\theta_{23}$	$0.50^{+0.08}_{-0.07}$	16%	$0.38 - 0.64$	$0.34 - 0.68$
$\sin^2\theta_{13}$	–	–	≤ 0.025	≤ 0.041

(Thomas Schwetz, fit to global data, hep-ph/0606060)

Current constraint (90 % C.L.)



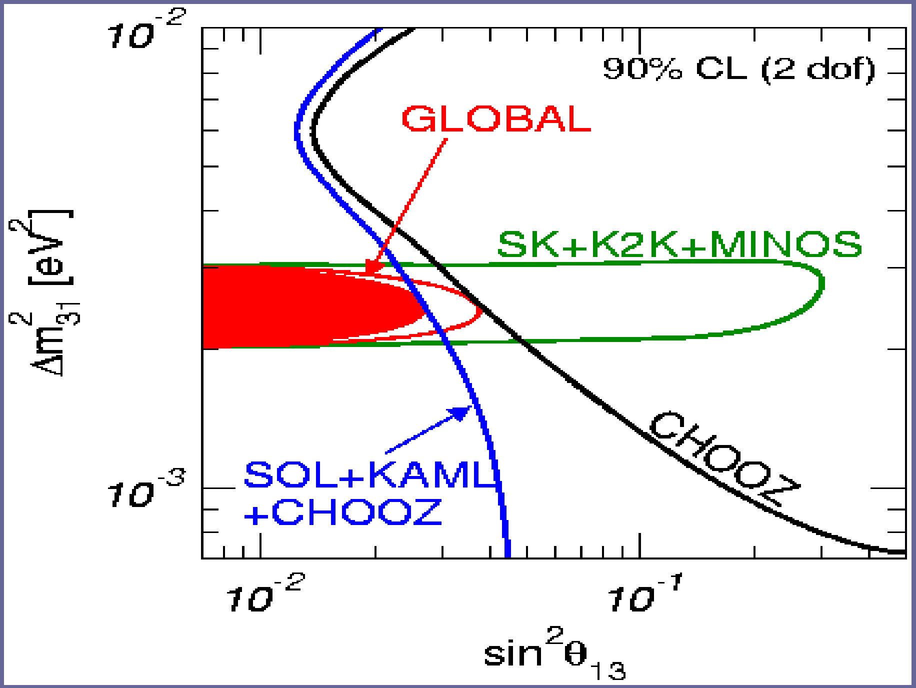
(M. Apollonio et. al., Eur.Phys.J. C27 (2003), 331)

$\sin^2 2\theta_{13} \lesssim 0.12 - 0.20$

(CHOOZ + allowed Δm^2)

$\sin^2 2\theta_{13} \lesssim 0.12$

(global analysis + best fit Δm^2)



(Thomas Schwetz, hep-ph/0606060)

How to improve CHOOZ ?

From CHOOZ to Double Chooz

- ✔ **Statistical error : 2.8 % → ~ 0.5 %**
- ✔ **Knowledge of source & detector : 2.7 % → ~ 0.6 %**

➔ **Sensitivity to $\sin^2 2\theta_{13}$ (90% C.L.) : ~ 0.15 → ~ 0.03**

Proposed approach

- ✔ Improve statistics by running longer with a larger target mass
- ✔ Cancel most of the systematics with a 2-detector concept
- ✔ Improve experimental design to control detector-related systematics

- "White Paper Report on Using Nuclear Reactors to search for a value of θ_{13}", hep-ex/0402041 (125 authors, 40 Institutions, Editor: M. Goodman)
- "LOI for Double Chooz: a search for the mixing angle θ_{13}", hep-ex/0405032 (52 authors, 14 Institutions)
- Proposal, hep-ex/0606025 (113 authors, 24 Institutions)

The Concept

Near site (to build)

- L ~ 280 m , ~ 80 mwe
- ~ 1000 $\bar{\nu}$ interactions/day in target

Far site (existing!)

- L = 1050 m , ~ 300 mwe
- ~ 70 $\bar{\nu}$ interactions/day in target

Detector layout

Within the constraint of the existing pit, maximize :

- ✔ target mass (statistics)
- ✔ shielding (low background)
- ✔ E-containment (decrease systematics)

$\bar{\nu}$ **Target** (~ 8.2 tons Gd-doped scintillator)

γ-**catcher** (t=55 cm, undoped scintillator)

Buffer (t= 105 cm, mineral oil)

Veto (t=50 cm, mineral oil + fluors)

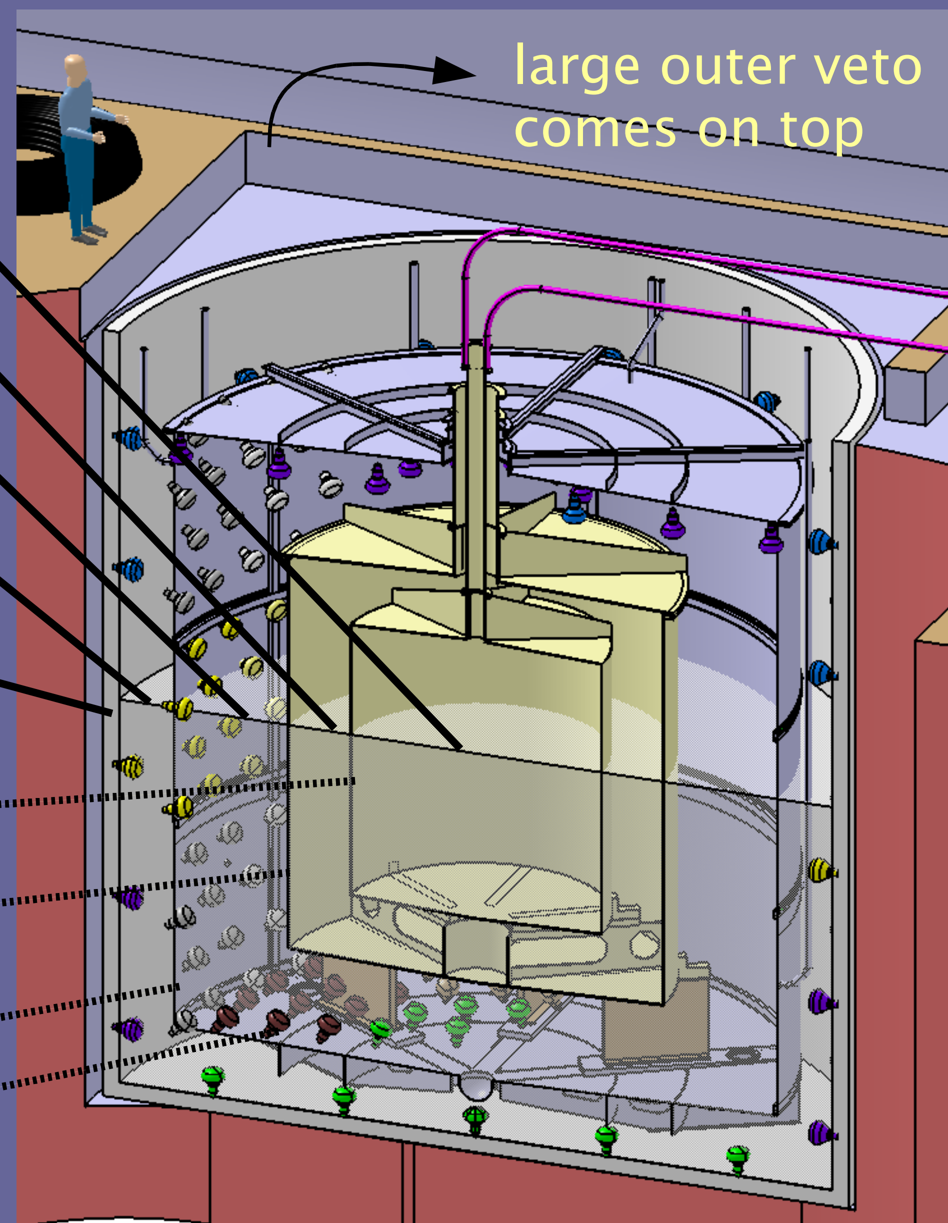
Shielding (17 cm steel)

Acrylic target vessel

Acrylic γ-catcher vessel

Buffer tank (stainless steel) & PMT support structure

PMTs (534 + 80, 8")



Who ?

Double Chooz Collaboration

France	APC, Paris CEA/DAPNIA, Saclay Subatech, Nantes
Germany	MPI Kernphysik, Heidelberg Technische Universität, München Universität Tübingen Universität Hamburg Universität Aachen
Spain	CIEMAT, Madrid
Italy	LNGS, Gran Sasso
England	Oxford
Russia	Institute for Nuclear Research RAS Institute of Physical Chemistry RAS RRC Kurchatov Institute
USA	University of Alabama Argonne National Laboratory Drexel University Kansas State University Lawrence Livermore National Laboratory Louisiana State University University of Notre Dame University of Tennessee

France

- Detector Mechanics
- Near and Far Laboratory Infrastructure
- Technical Coordination and Detector Integration
- Ageing Tests & Chemical Compatibility
- Digitization/DAQ

Germany

- Scintillators
- Fluid Handling System
- Inner Muon Veto
- Level 1 Trigger System

Spain

- Inner Detector Photo-Detection and associated Mechanics

England

- Light PMT Light Concentrators
- Laser/LED Calibration

Russia

- Calibration
- Scintillator Development

(with INFN-Gran Sasso, Italy)

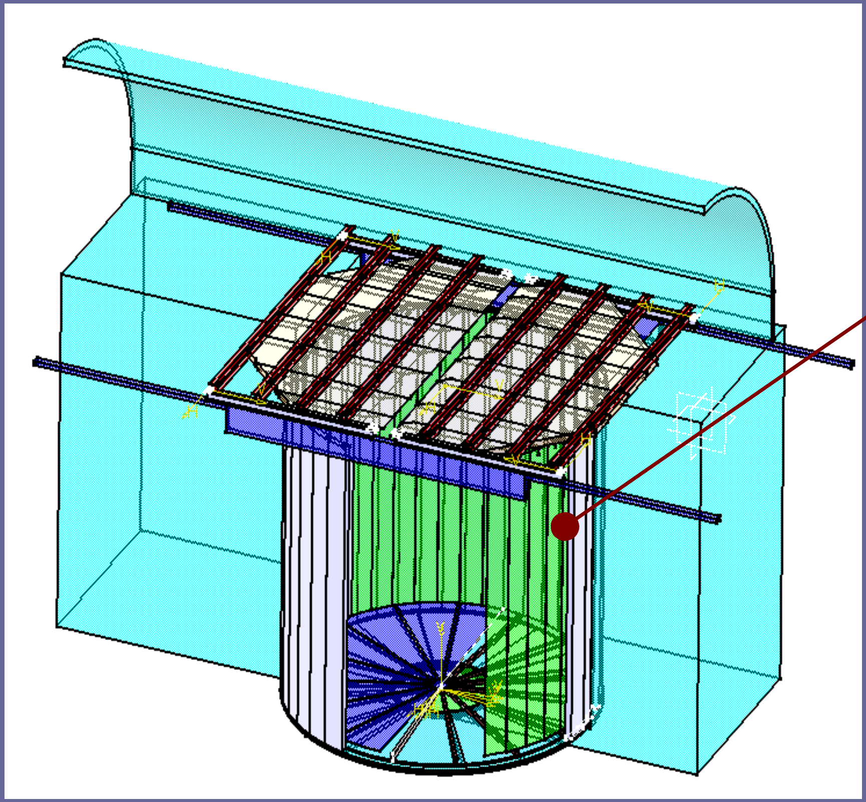
USA (pending fundings)

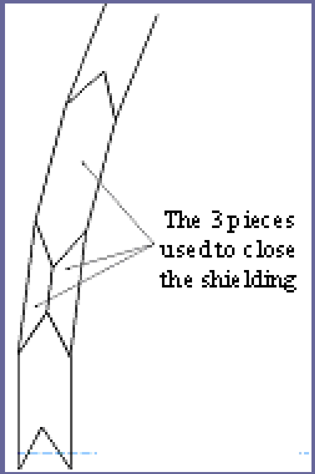
- Inner PMTs
- Front-End Electronics and HV System
- Calibration System
- Slow Control
- Outer Muon Veto

Highlights of Design, Integration and R&D

Steel shielding

(17 cm, optimized by MC)





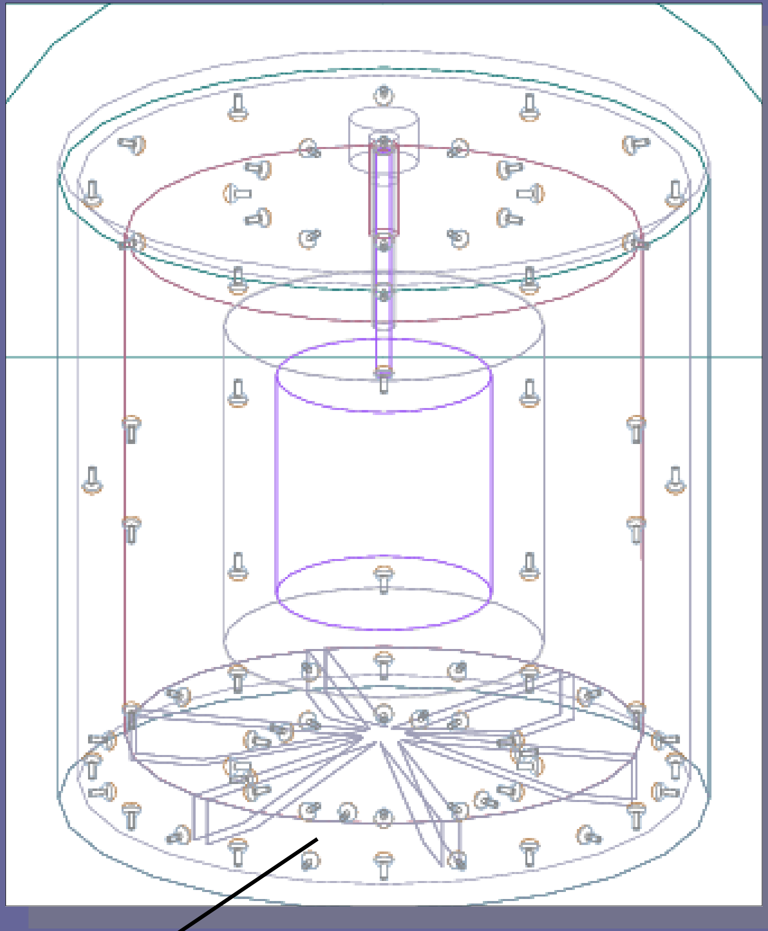
Study of demagnetization

(strong residual magnetic fields would spoil the PMT performance)

More compact and effective than the CHOOZ shielding (75 cm low radio-activity sand)

Inner Veto

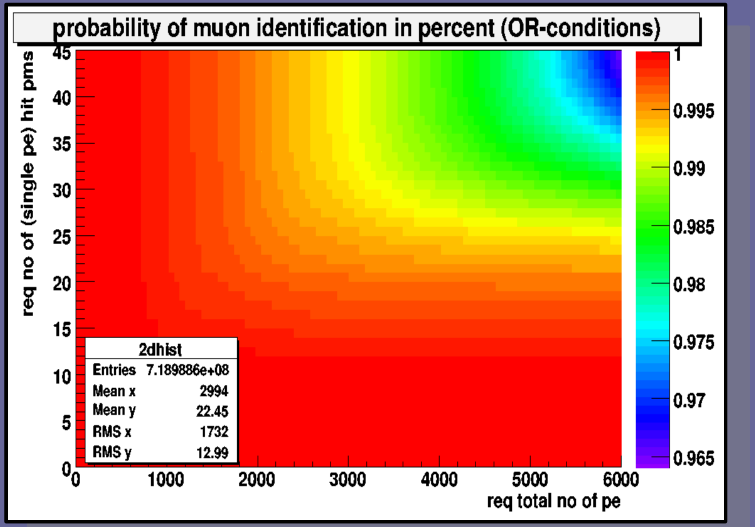
(50 cm, scintillating oil, white-painted steel, 84 8″ PMTs)

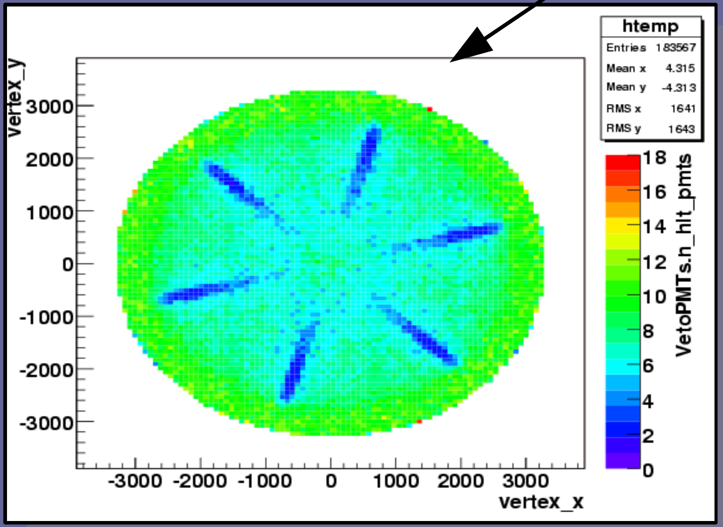


Detailed Monte Carlo studies

- ✔ PMT placements – trigger conditions to optimize μ identification efficiency
- ✔ Study of light shadowing from support structures
- ✔ Response to μ and n

Efficiency vs trigger condition (simulated μ flux at far detector)

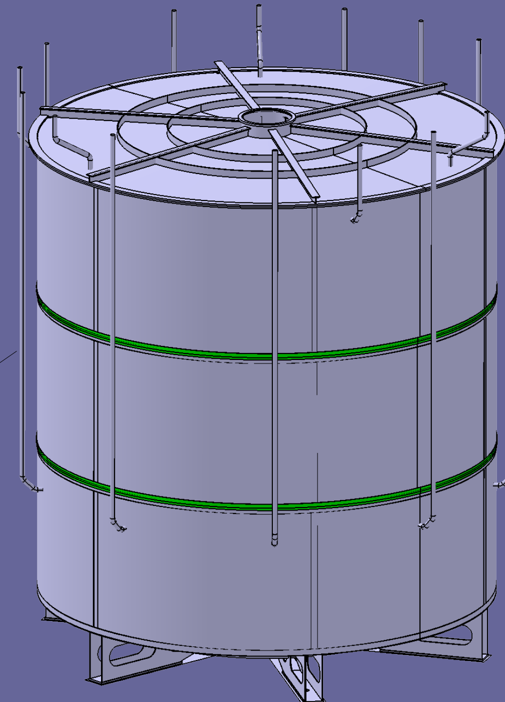




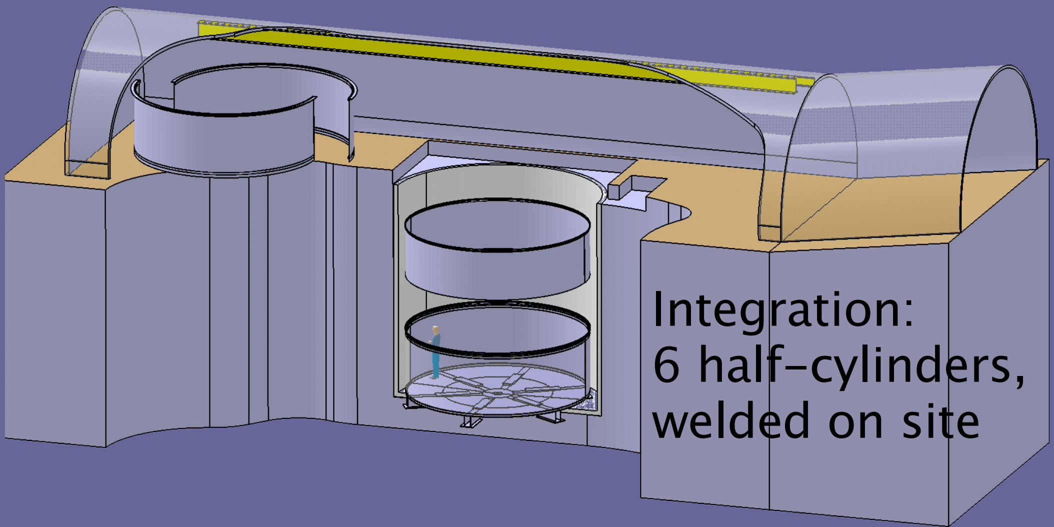
Response to local energy depositions of 5 MeV by minimum ionizing particles at detector bottom

Buffer

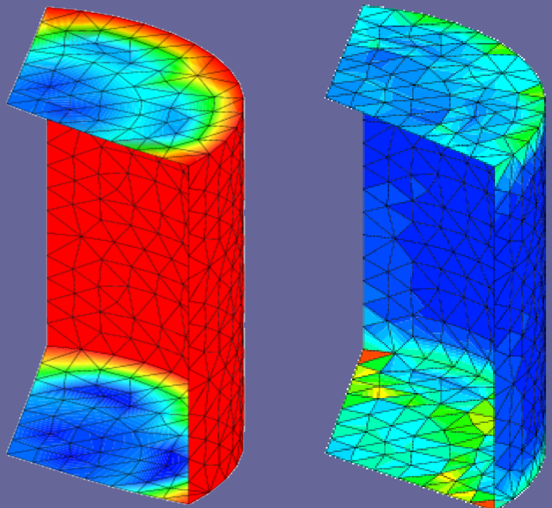
(3 mm stainless steel tank,
105 cm mineral oil, 534 8″ PMTs)

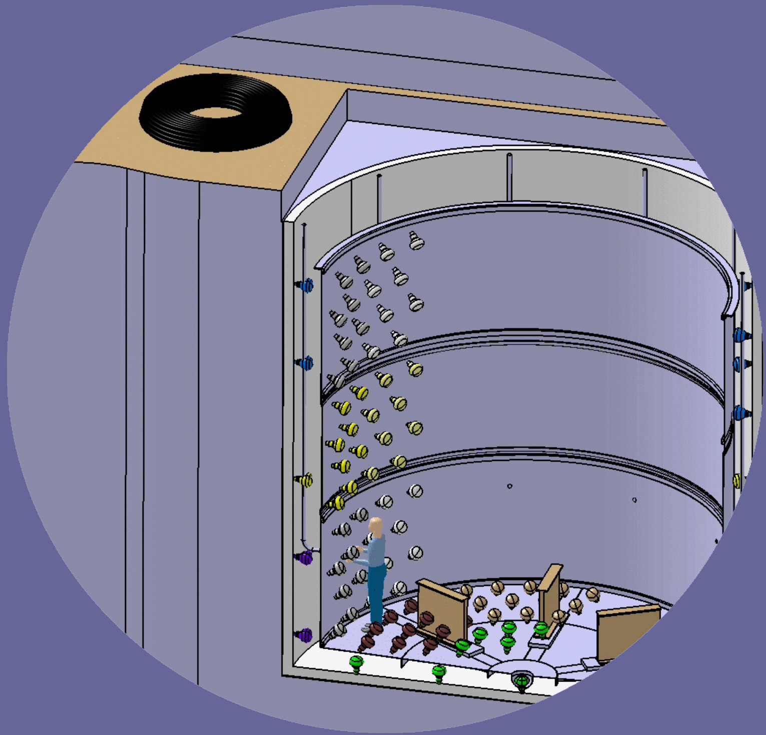


PMT cable
conduits



Integration:
6 half-cylinders,
welded on site

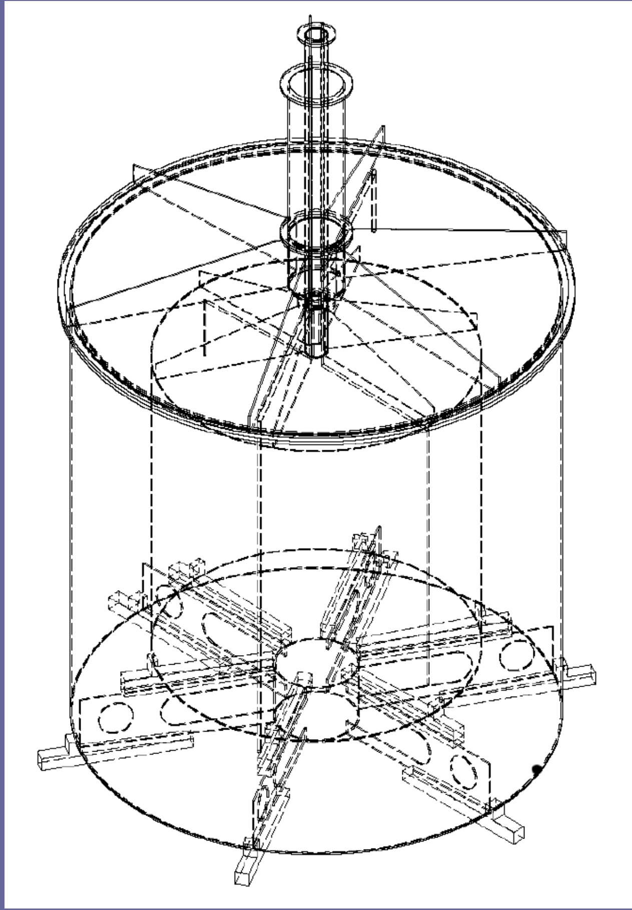




Mechanics validated by
deformation & stress
simulations.
Safety factor ~ 10

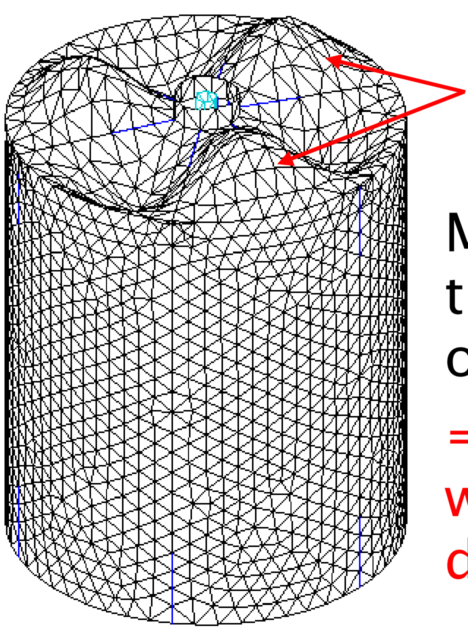
Acrylic Vessels

- **Target:** 10.2 m^3, thick. = 8 mm
- **γ-Catcher:** 55 cm, thick. = 12 mm



✔ Acrylic selection upon several compatibility tests with Double Chooz scintillators

✔ Simulations of the mechanics

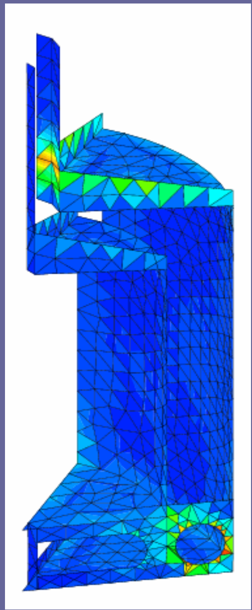


1st oscillation mode

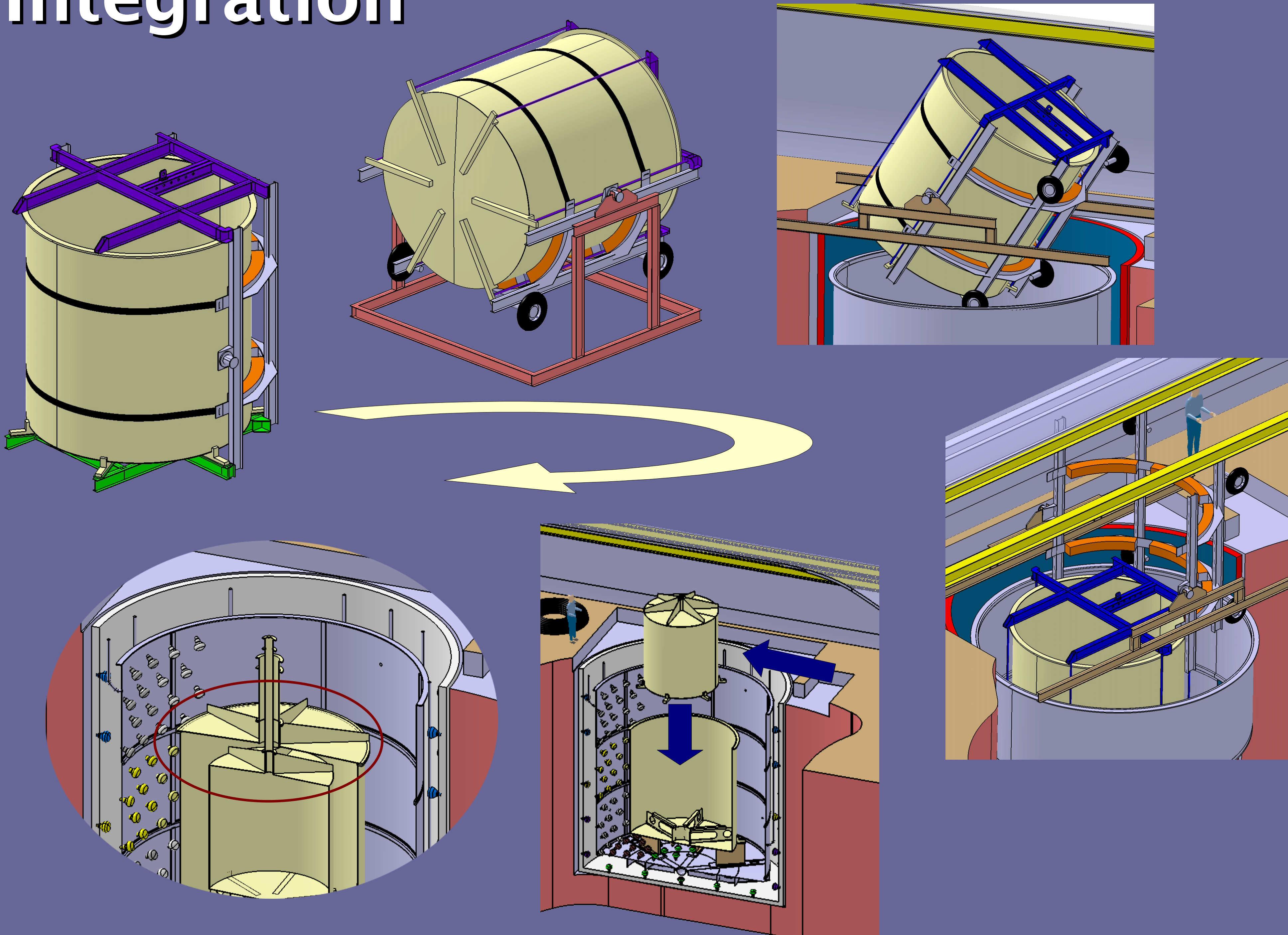
Mechanical analysis of the oscillation modes of a double vessel.

⇒Possible resonances with truck dumpers during transport !

Calculation of deformation & stress at dead load and during filling.
Safety factor ~ 10



Integration



Gd-loaded Scintillators

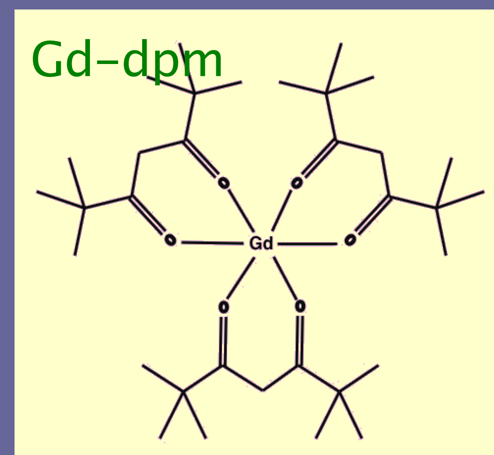
$\nu_e + p \rightarrow e^+ + n$ (Q = 1.8 MeV)

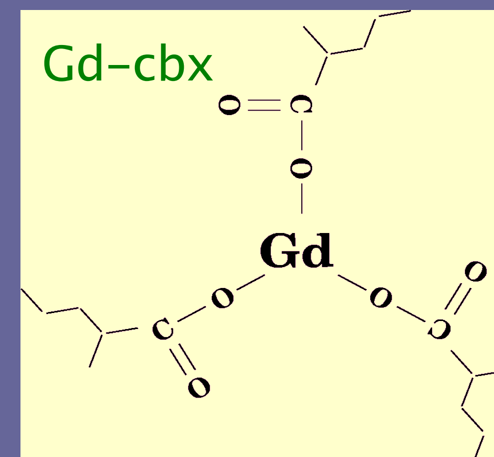
$n_{th} + Gd \rightarrow Gd^* \rightarrow Gd + \sim 8$MeV

- **Scintillator base (driven by compatibility and safety issues)**

  20 % PXE + 80 % Dodecane + PPO (~ 6 g/l) + bis-MSB (~ 20 mg/l)

- **Gd-Compound (Gd 1 g/l)**
  - Gd carboxylate (+ stabilizers)
  - Gd beta-diketonate (dpm)

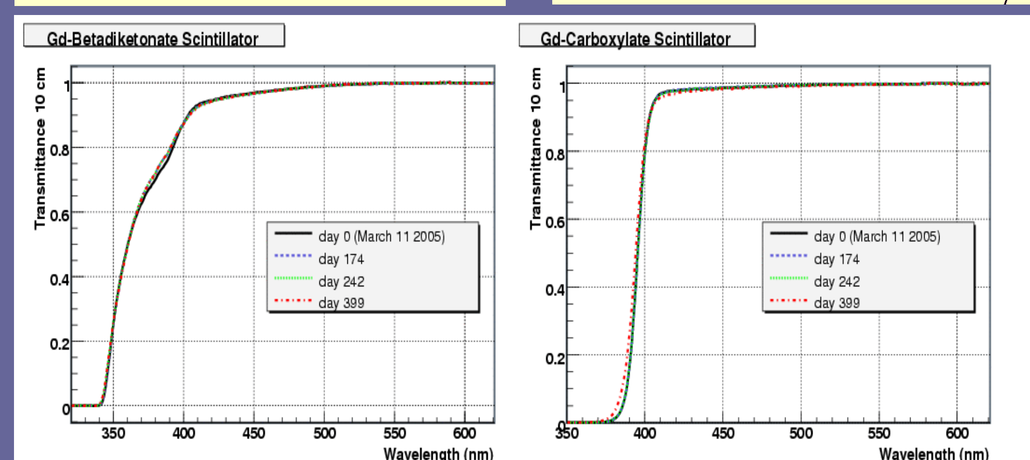




✔ Both formulations of Gd-doped LS developed and proved to be sound

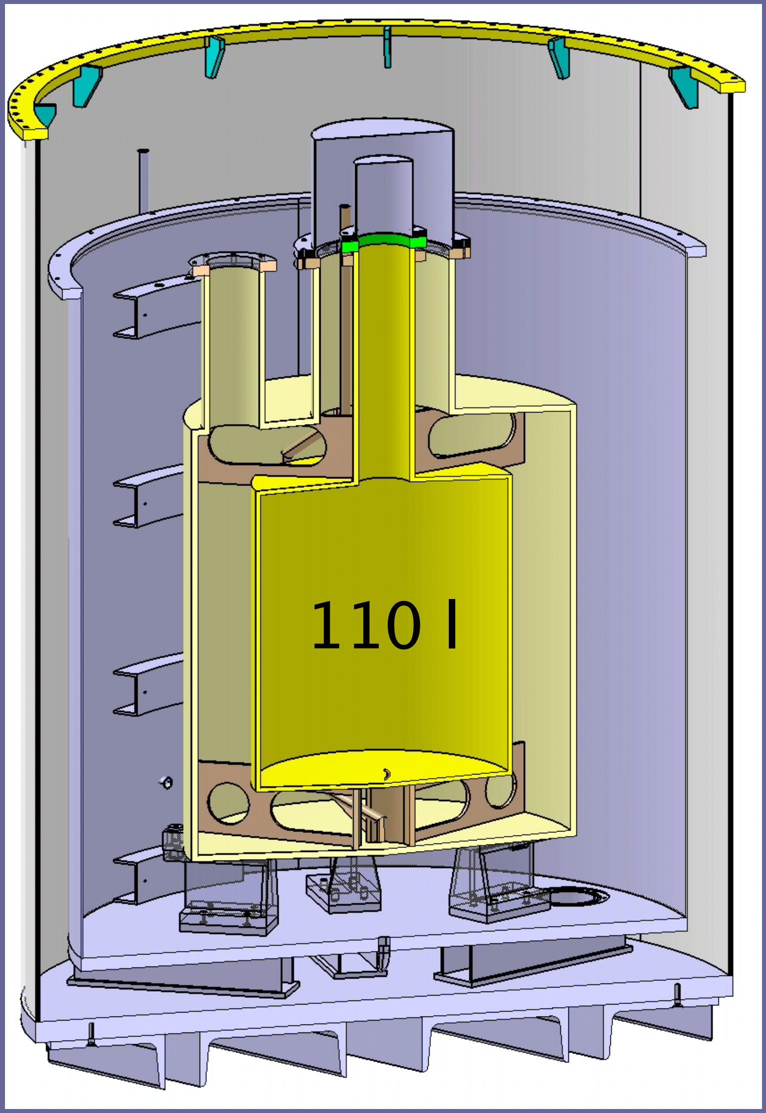
✔ Chemical project now scaling from ~ 100 l test to <u>industrial production</u>

✔ Building for scintillator purification and storage under construction at MPI-Heidelberg



Test of the long-term stability of Gd-doped LS samples

Technical validation with 1/5 prototype



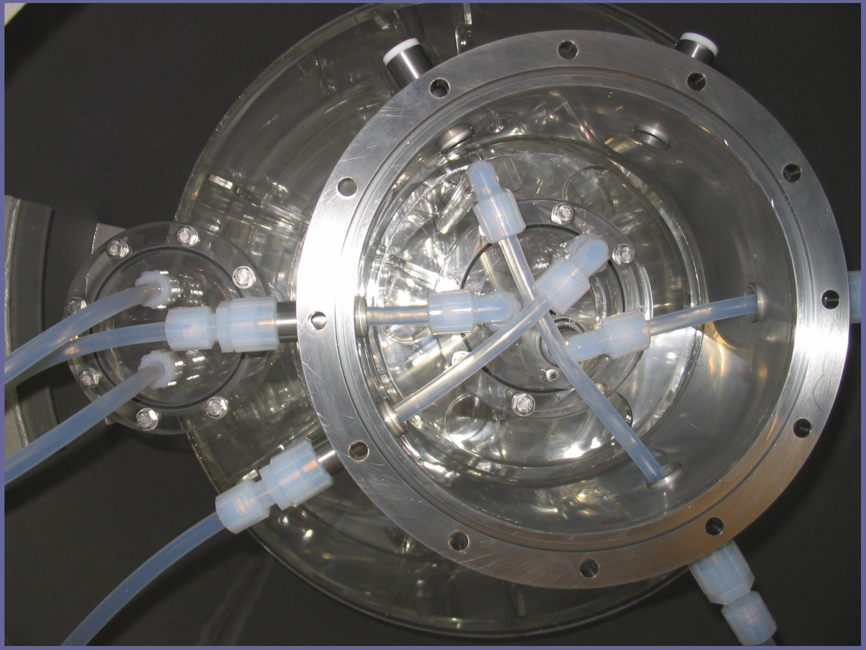
Technical Goals

- ➔ *Validate* design of acrylic vessels
- ➔ *Validate* mechanical solutions
- ➔ *Validate* detector integration scenario
- ➔ *Final Check* of material compatibility
- ➔ *Define* control procedures for vessels
- ➔ *Define* interfaces for liquid handling
- ➔ P*repare* the filling procedure

Additional benefits

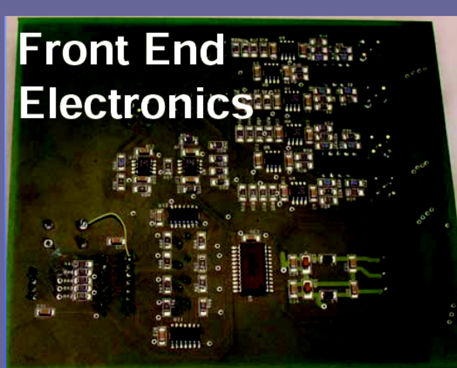
- ✔ Test run for the assembly in the real detector
- ✔ Finalize the definition of interfaces
- ✔ Finalize the assign-ment of responsibilities

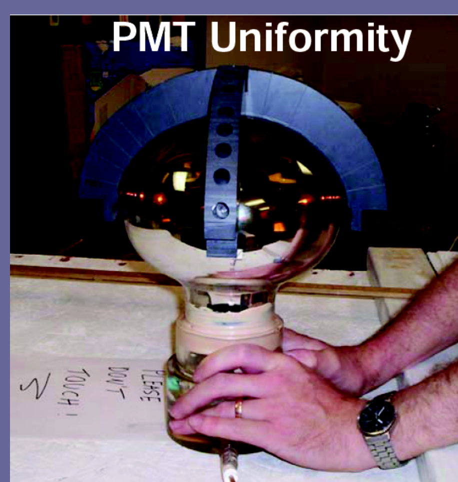
A learning experience ...

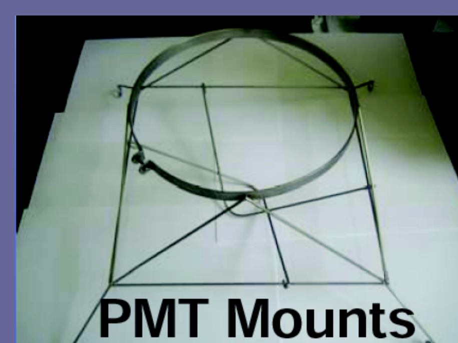


• Complete filling on Dec 2005
• Succesfull coordination of people and groups with different expertise
• Some technical solutions for the acrylic mechanics need revision
• Tightness of the filling system is not trivial
• Interfaces are difficult

... And a lot more testing and prototypes





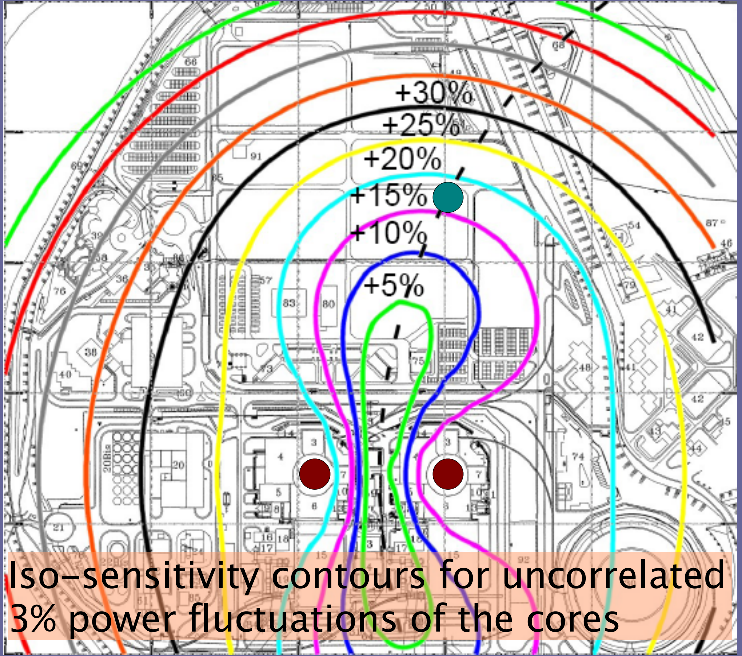


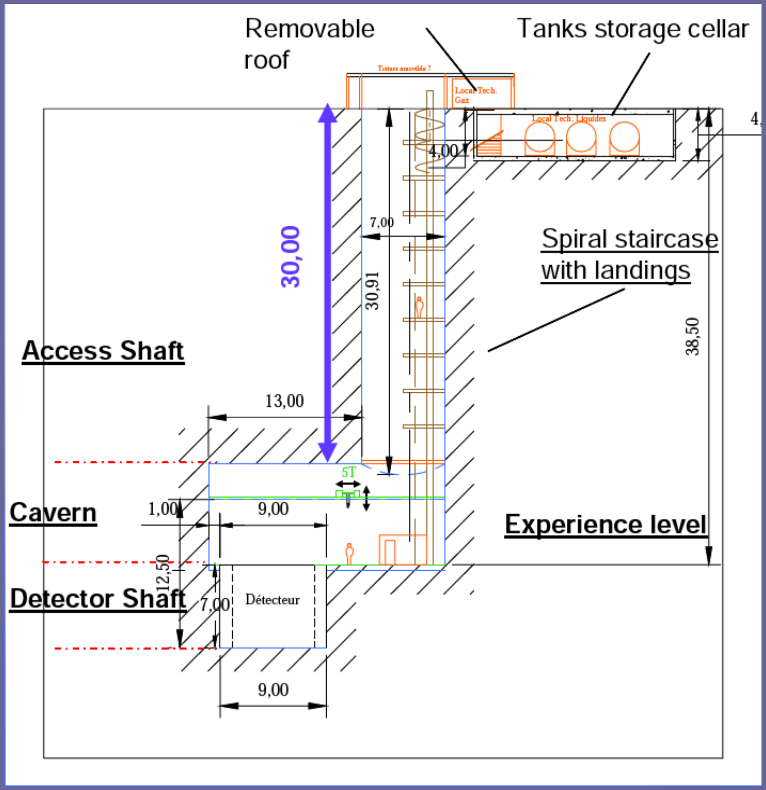
News from the near lab

Pre-study for the design and optimization of the near laboratory carried out by Double Chooz physicists and engineers in collaboration with engineers from EDF.

Result:

- ➔ location: 280 m, on the line of equal flux ratio between the two cores as in the far lab
- ➔ design: 30 m shaft with lateral cavity and pit.
- ➔ overburden: > 80 mwe, flat topography





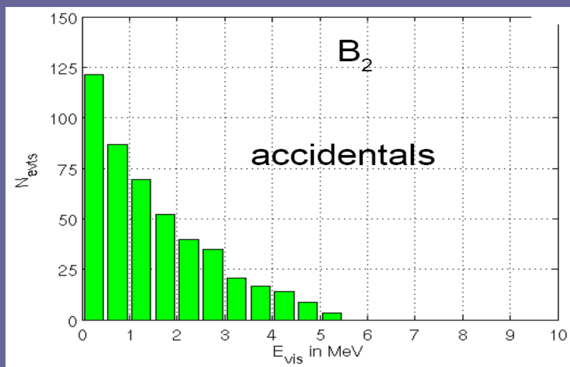
Next steps

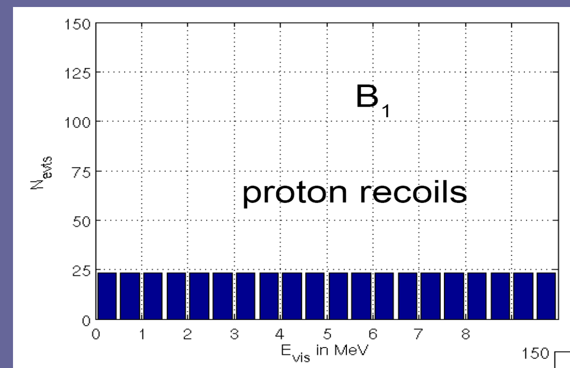
- preliminary study by EDF civil engineers to be concluded by fall 2006
- at this time, cost estimation at ± 20%
- design finalization in 2007
- construction in 2008
- lab availability in spring 2009
- detector commissioning by fall 2009

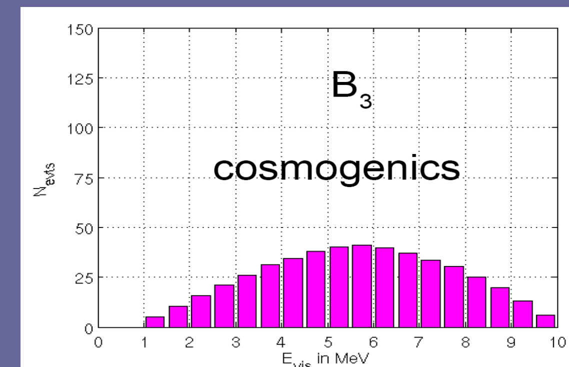
Overview of the systematics

		CHOOZ (single far detector)	Double Chooz	Comments
Reactor	Power	~ 2 %	negligible	same flux composition @ Far and Near
	E/fission	0,6%	negligible	identical detectors
	ν/fission	0,2%	negligible	identical detectors
	σ	0,1%	negligible	identical detectors
	Distances & finite size	negligible	0,2%	distances known at 10 cm
	Tot Reactor	2,2%	0,2%	
# target p	Total	0,8%	0,2%	same batch of scintillator only error on target M (relative)
Efficiency	e^+ energy cut	0,8%	0,1%	low threshold, γ-catcher
	Gd/H captures	1,0%	0,2%	identical detectors
	n energy cut	0,4%	0,2%	identical detectors, γ-catcher
	e^+ – n distance	0,3%	not necessary	lower single rate (buffer)
	e^+ – n delay	0,4%	0,1%	identical detectors
	n multiplicity	0,5%	negligible	lower single rate (buffer)
	dead-time near		0,2%	Measured with several methods
	Tot efficiency	1,5%	0,4%	
	Grand Total	**2,7%**	**≲0,5%**	

Overview of the backgrounds

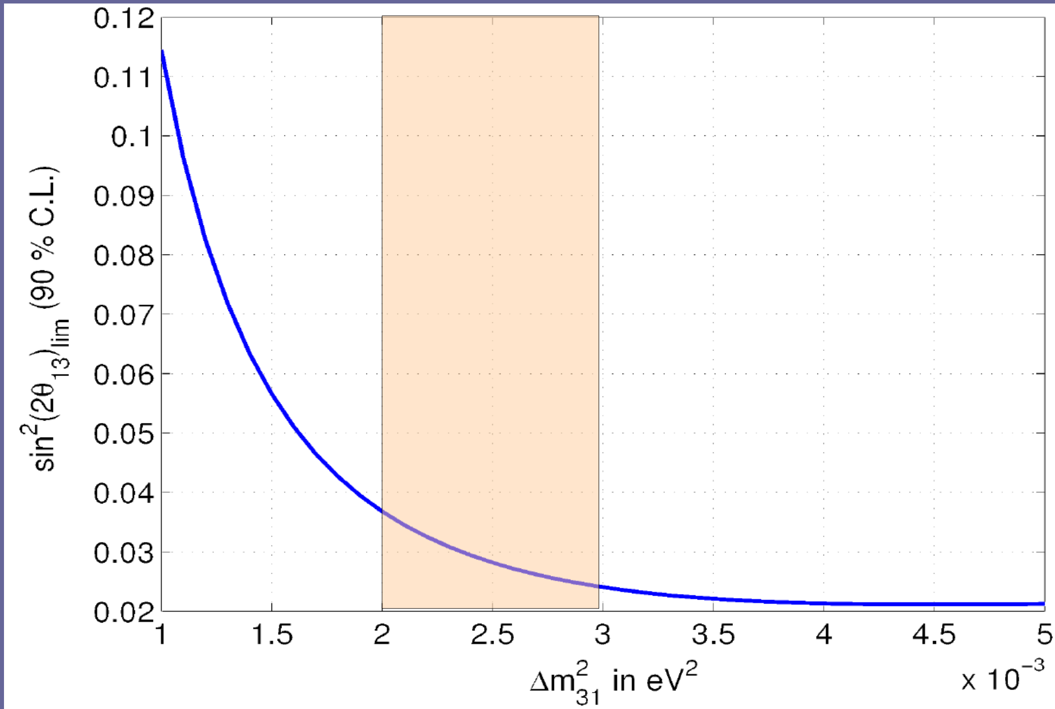






Detector	Site		Background				
			Accidental		Correlated		
			Materials	PMTs	Fast n	μ-Capture	^{9}Li
CHOOZ		Rate (d^{-1})	—	—	—	—	0.6 ± 0.4
(24 ν/d)		Rate (d^{-1})	0.42 ± 0.05		$1.01 \pm 0.04(stat) \pm 0.1(sys)$		
	Far	bkg/ν	1.6%		4%		
		Systematics	0.2%		0.4%		
Double Chooz		Rate (d^{-1})	1 ± 0.1	1 ± 0.1	0.15 ± 0.15	0.42 ± 0.2	1 ± 0.5
(69 ν/d)	Far	bkg/ν	1.4%	1.4%	0.2%	0.6%	1.4%
		Systematics	0.2%	0.2%	0.2%	0.3%	0.7%
Double Chooz		Rate (d^{-1})	7.2 ± 1.0	7.2 ± 1.0	1.4 ± 0.14	2.6 ± 1.2	5.2 ± 3.2
(990 ν/d)	Near	bkg/ν	0.7%	0.7%	0.14%	0.26%	0.6%
		Systematics	0.1%	0.1%	0.2%	0.1%	0.3%

Sensitivity

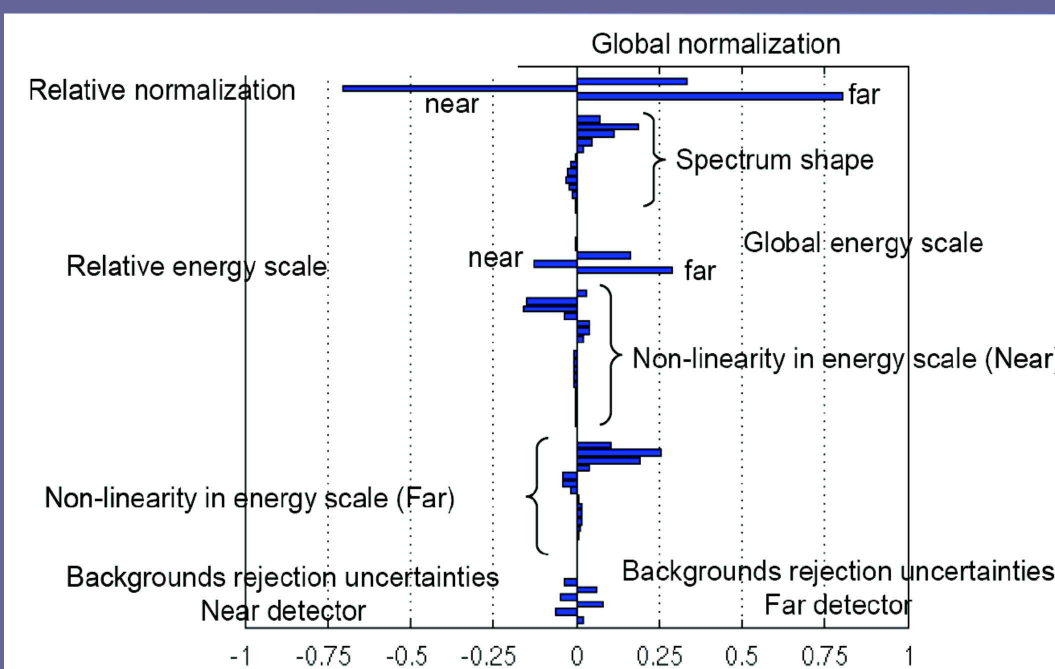


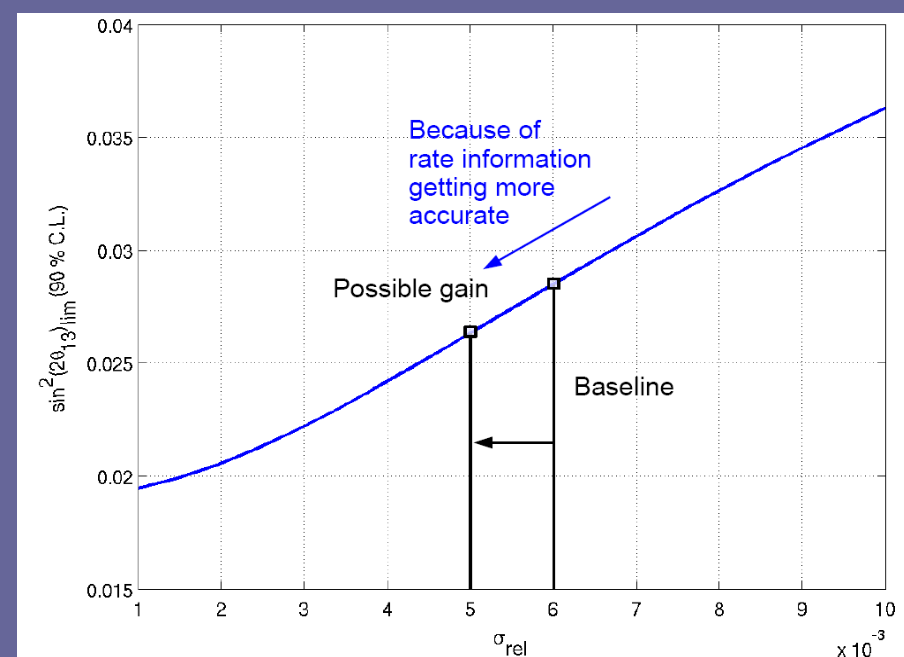
data/theory *"distance"* — systematic biases

$$\chi^2 = \min_{\{\alpha^D_{i,k}\}} \left\{ \sum_{D=N,F} \sum_{i=1}^{NBins} \left(\left(\frac{O_i^D - T_i^D - \sum_{k=1}^{K} \alpha^D_{i,k} S^D_{i,k}}{U_i^D} \right)^2 + \sum_{k=1}^{K} c^{D,R}_{i,k} \left(\frac{\alpha^D_{i,k}}{\sigma^D_k} \right)^2 \right) \right\}$$

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

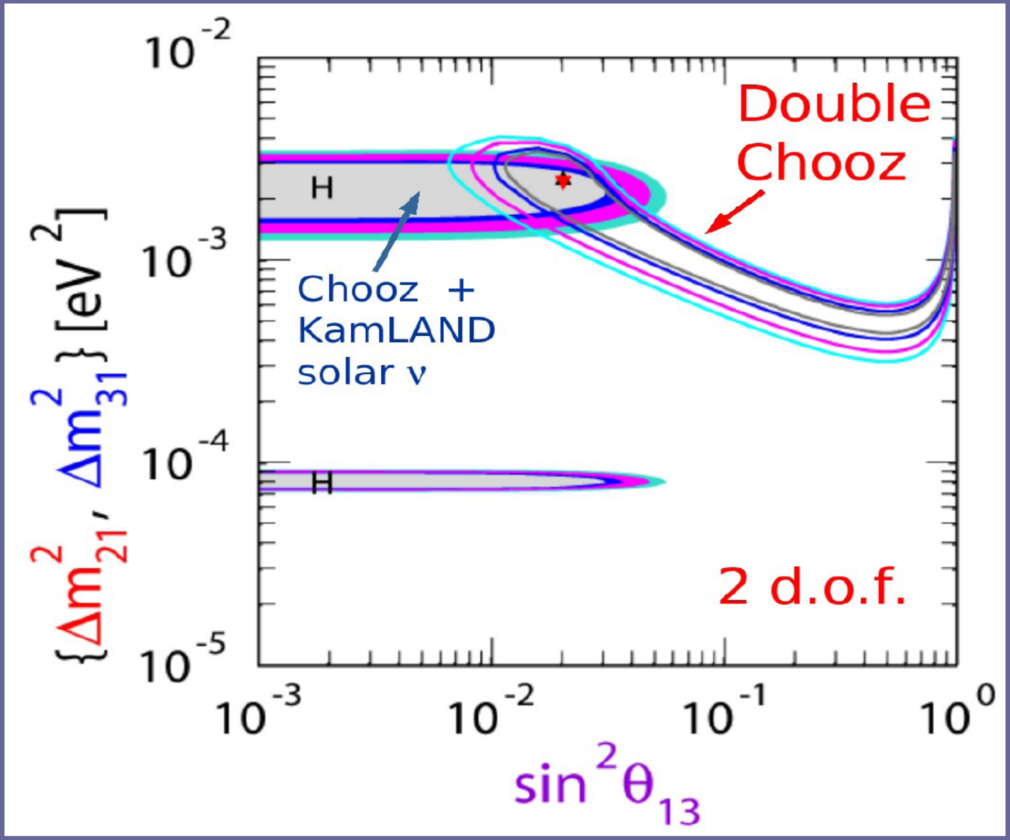
pulls of the systematics in the χ^2 analysis



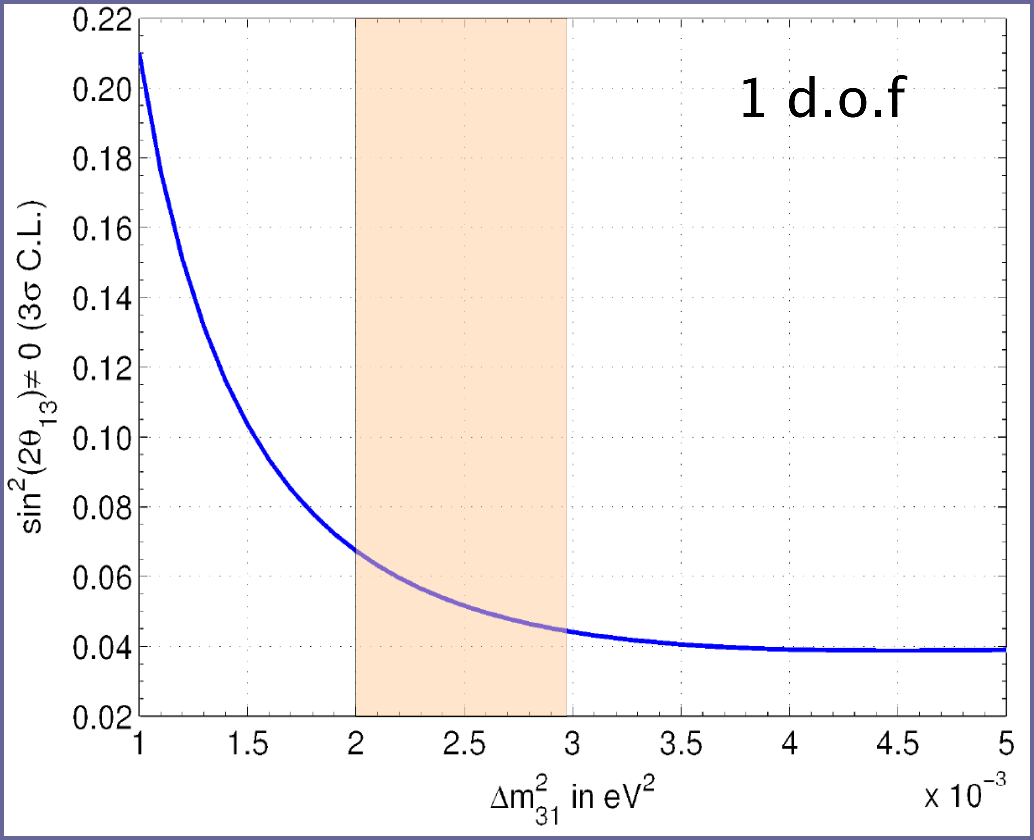


Discovery potential

Example of measurement for $\sin^2 2\theta_{13}=0.08$



Lowest true value for which $\sin^2 2\theta_{13}=0$ excluded at $\geq 3\sigma$



Conclusions & Outlook

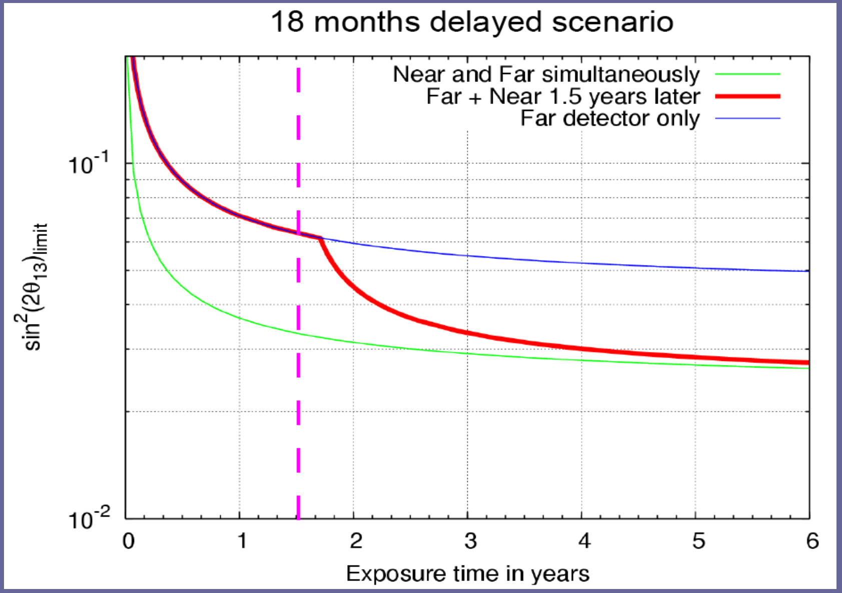
✔ Double Chooz approved and funded in France

✔ Funded by Max Planck Society. First approvals by German BMBF, Spain.

✗ DOE rejected the US R&D proposal (stating there is not enough money for a participation in both Double Chooz and Daya Bay)

✔ The reaction of the French agencies was doubling their initial investment ... Strong French commitment to not delay the project

✔ New collaborators: Madrid, Oxford



06/2008

The largest part of the **funding is secured**
R&D is concluded

Project shifting now to construction phase

- Proposal: hep-ex/0606025 (157 pages, 113 authors, 24 institutions)
- now → 2007: material procurement
- Oct 2007: start far detector construction
- June 2008: far detector commissioning
- 2008: near lab construction
- Spring 2009: near lab available
- Fall 2009: near detector commissioning