Anti-neutrinos from nuclear reactors Chasing θ_{13}

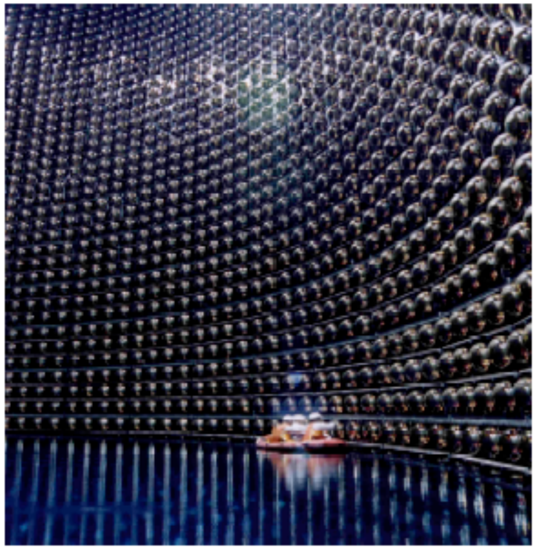
Double Chooz

H. de Kerret
APC / Collège de France

ICEPP, 18th of December 2006

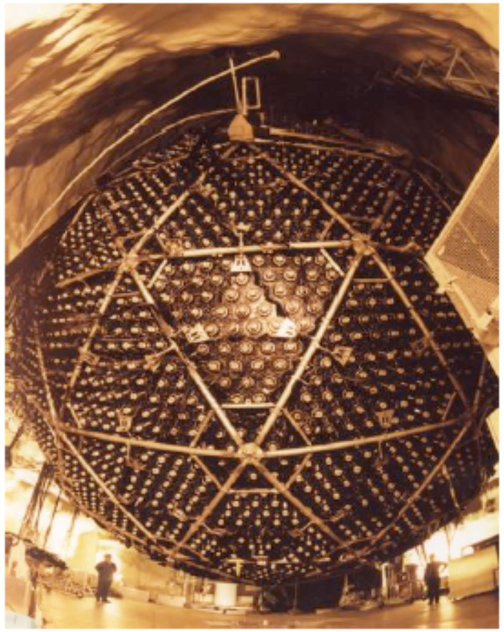
Recent discoveries in Neutrino Physics

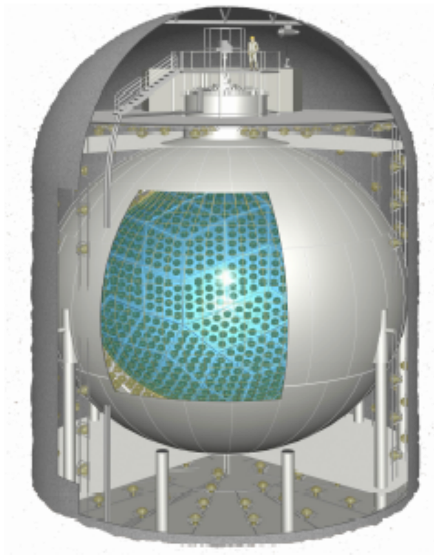
Non-accelerator experiments have changed our understanding of neutrinos



Atmospheric+Solar ν
(Super-K)

Solar (SNO)



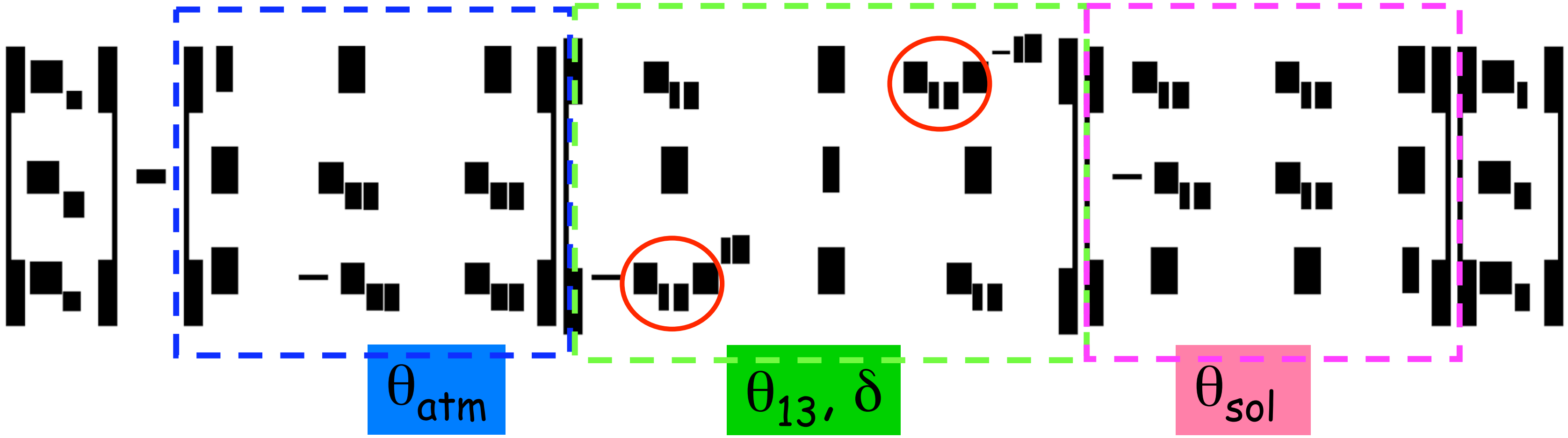


Reactor
(KamLAND)

- Neutrinos are <u>not massless</u> (mass is small: $m_{\nu e} < 0.0000059\ m_e$)
- <u>Evidence</u> for neutrino flavor conversion $\nu_e \leftrightarrow \nu_\mu \leftrightarrow \nu_\tau$
- Combination of experimental results show that <u>*neutrinos oscillate*</u>

Neutrino oscillations

Neutrino mass matrix



Constraining the neutrino sector

$$[\Delta m^2_{21} - \theta_{12}] - [\Delta m^2_{32} - \theta_{23}] - \underbrace{\text{sign}(\Delta m^2_{32}) - \theta_{13} - \delta}$$

solar ν
+
KamLAND
+
reactor ν ?

↓

MSW-LMA

$\Delta m^2_{12} \sim O(10^{-4/-5})$ eV^2
$\sin^2(2\theta_{12}) \sim 0.8$
(large angle)

atmospheric ν
+
K2K
+
MINOS - Superbeams ...

↓

$\Delta m^2_{32} \sim 2\text{-}3\ 10^{-3}$ eV^2
$\sin^2(2\theta_{23}) \sim 1$
(maximal angle)

superbeam ν
+
reactor ν

↓

$\sin^2(2\theta_{13}) < 0.20$ (CHOOZ) ➔ θ_{13} ?
(small angle)

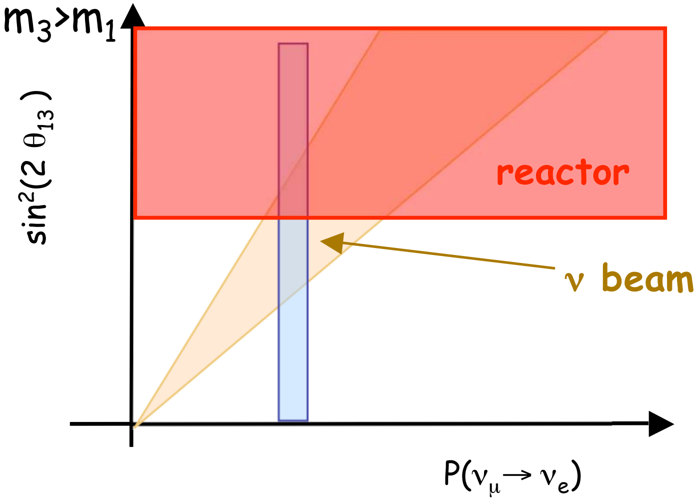
Hierarchy ➔ sign(Δm^2_{32}) ?

CP violation ➔ δ phase ?

But no absolute mass scale coming from oscillation experiments --> β & $\beta\beta 0\nu$ decays ?

θ_{13} & beam experiments

LBL ν_μ disappearance : $\sin^2(2\theta_{23})$ ➔ 2 solutions : θ_{23} & $\pi/2-\theta_{23}$
$|\Delta m^2_{13}|$ ➔ 2 solutions $m_1>m_3$ or $m_3>m_1$



Appearance probability :

$$P(\nu_\mu \rightarrow \nu_e) \sim K_1 \sin^2(\theta_{23}) \sin^2(2\theta_{13}) + K_2 \sin(2\theta_{23}) \sin(\theta_{13}) \,\mathrm{sign}(\Delta m^2_{31}) \cos(\delta) \pm K_3 \sin(2\theta_{23}) \sin(\theta_{13}) \sin(\delta) + \ldots$$

- K_1, K_2, K_3: constants known with experimental errors
- dependence in $\sin(2\theta_{23})$, $\sin(\theta_{23})$ ➔ 2 solutions
- dependence in $\mathrm{sign}(\Delta m^2_{31})$ ➔ 2 solutions
- δ-CP phase ε $[0,2\pi]$ ➔ interval of solutions

θ_{13} & reactor experiments

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

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

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

  ➔ weak dependence in Δm^2_{21}

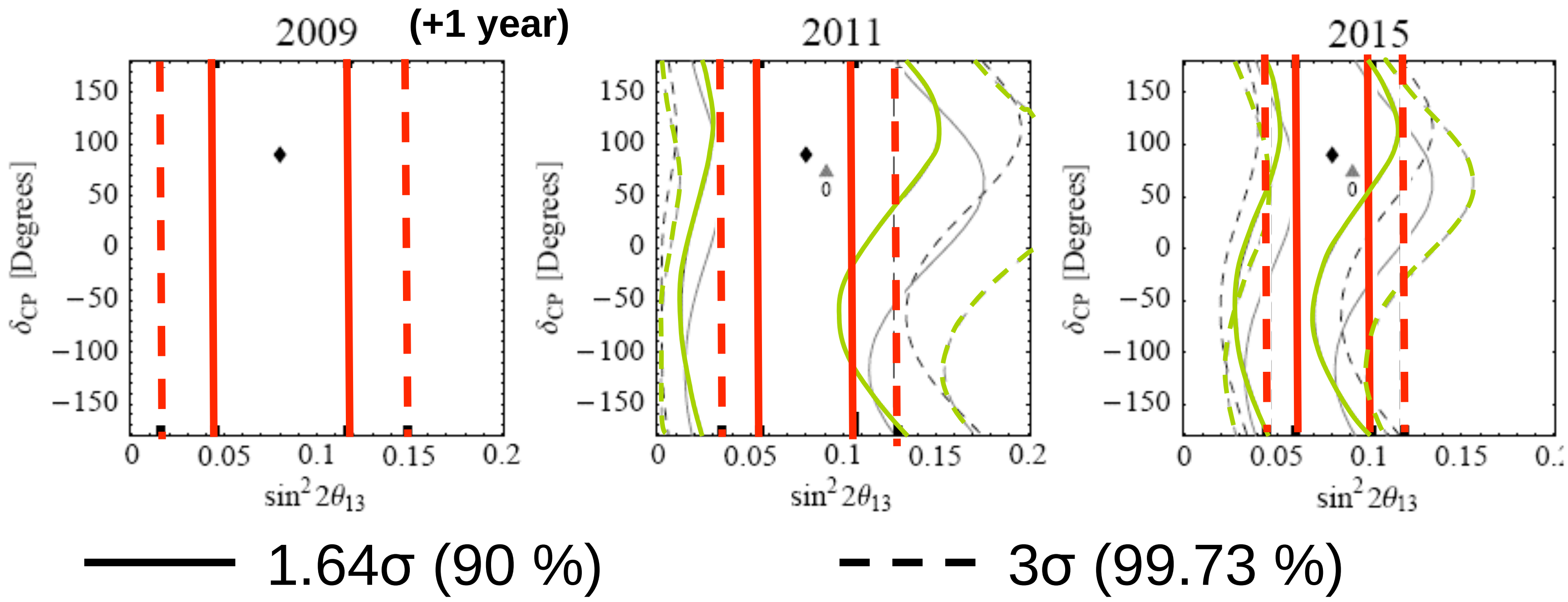
- a few MeV ν_e + short baselines → negligible matter effects ($O[10^{-4}]$)

➔ $\sin^2(2\theta_{13})$ measurement independent of $\mathrm{sign}(\Delta m^2_{13})$

Complementarity with T2K

Assumptions:

- Double Chooz starts 2009 (2 detectors)
- T2K starting with full intensity 2011-2012
- $\sin^2(2\Theta_{13}) = 0.08$, $\Delta m^2_{23} = 2.0 \cdot 10^{-3}\ \mathrm{eV}^2$

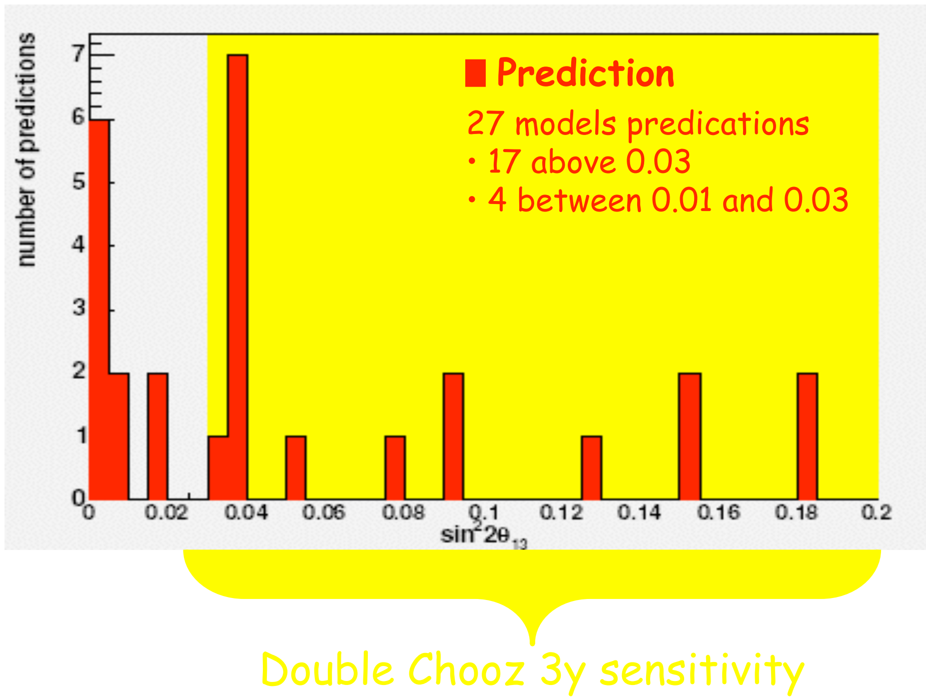


θ_{13} seems in reach …

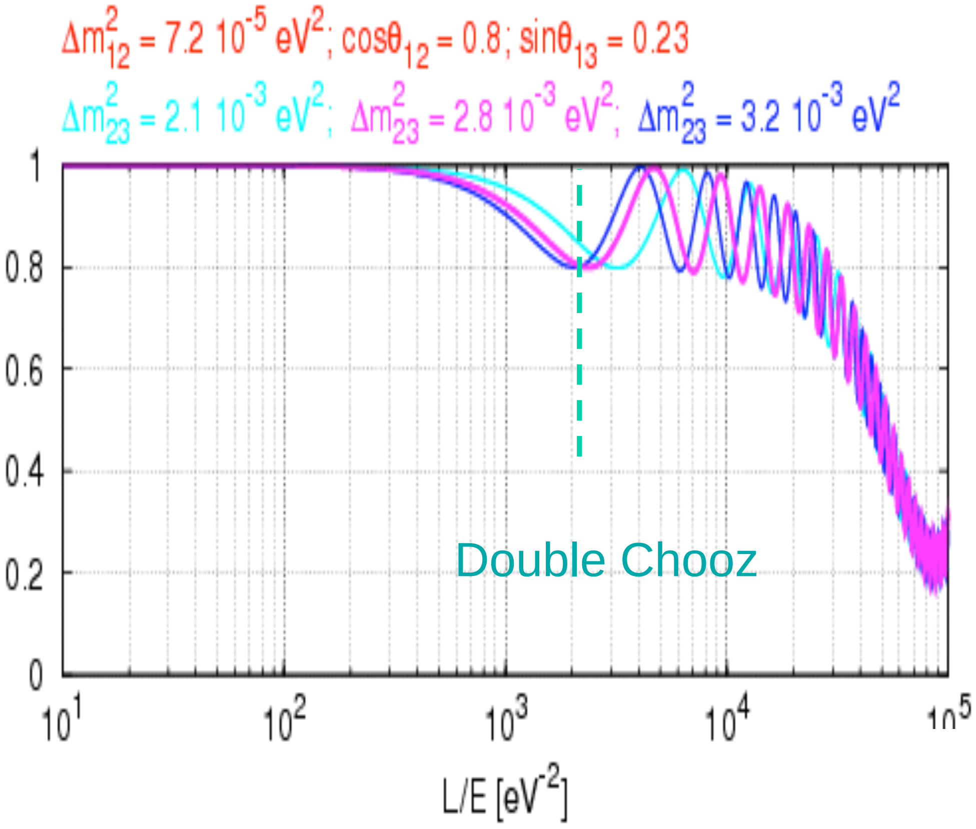
Reference	$\sin\theta_{13}$	$\sin^2 2\theta_{13}$
SO(10)		
Goh, Mohapatra, Ng [40]	0.18	0.13
Orbifold SO(10)		
Asaka, Buchmüller, Covi [41]	0.1	0.04
SO(10) + flavor symmetry		
Babu, Pati, Wilczek [42]	$5.5 \cdot 10^{-4}$	$1.2 \cdot 10^{-6}$
Blazek, Raby, Tobe [43]	0.05	0.01
Kitano, Mimura [44]	0.22	0.18
Albright, Barr [45]	0.014	$7.8 \cdot 10^{-4}$
Maekawa [46]	0.22	0.18
Ross, Velasco-Sevilla [47]	0.07	0.02
Chen, Mahanthappa [48]	0.15	0.09
Raby [49]	0.1	0.04
SO(10) + texture		
Buchmüller, Wyler [50]	0.1	0.04
Bando, Obara [51]	0.01 .. 0.06	$4 \cdot 10^{-4}$ .. 0.01
Flavor symmetries		
Grimus, Lavoura [52, 53]	0	0
Grimus, Lavoura [52]	0.3	0.3
Babu, Ma, Valle [54]	0.14	0.08
Kuchimanchi, Mohapatra [55]	0.08 .. 0.4	0.03 .. 0.5
Ohlsson, Seidl [56]	0.07 .. 0.14	0.02 .. 0.08
King, Ross [57]	0.2	0.15
Textures		
Honda, Kaneko, Tanimoto [58]	0.08 .. 0.20	0.03 .. 0.15
Lebed, Martin [59]	0.1	0.04
Bando, Kaneko, Obara, Tanimoto [60]	0.01 .. 0.05	$4 \cdot 10^{-4}$ .. 0.01
Ibarra, Ross [61]	0.2	0.15
3×2 see-saw		
Appelquist, Piai, Shrock [62, 63]	0.05	0.01
Frampton, Glashow, Yanagida [64]	0.1	0.04
Mei, Xing [65] (normal hierarchy)	0.07	0.02
(inverted hierarchy)	> 0.006	$> 1.6 \cdot 10^{-4}$
Anarchy		
de Gouvêa, Murayama [66]	> 0.1	> 0.04
Renormalization group enhancement		
Mohapatra, Parida, Rajasekaran [67]	0.08 .. 0.1	0.03 .. 0.04

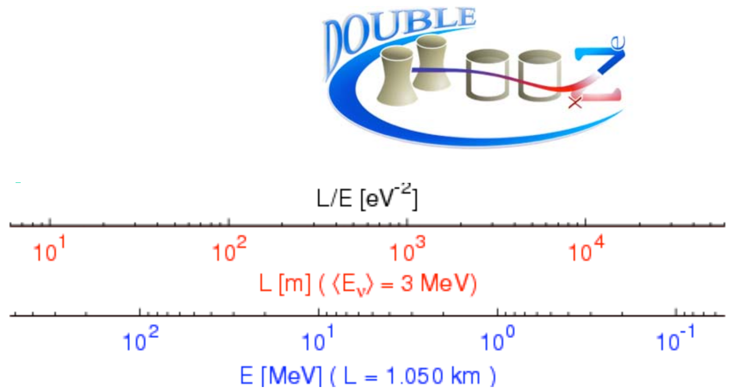
Table 1: Incomplete selection of predictions for θ_{13}. The numbers should considered as order of magnitude statements.

A Theoretician joke?

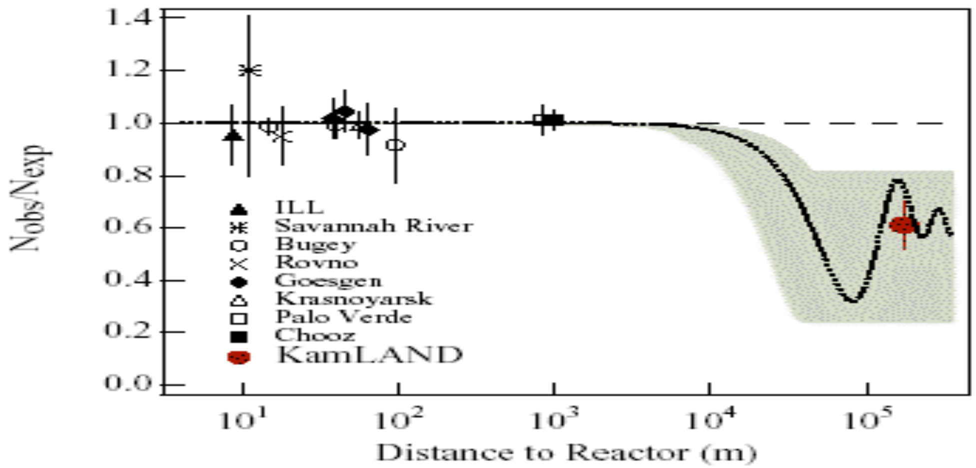


Neutrino oscillation from a reactor: as it was detected





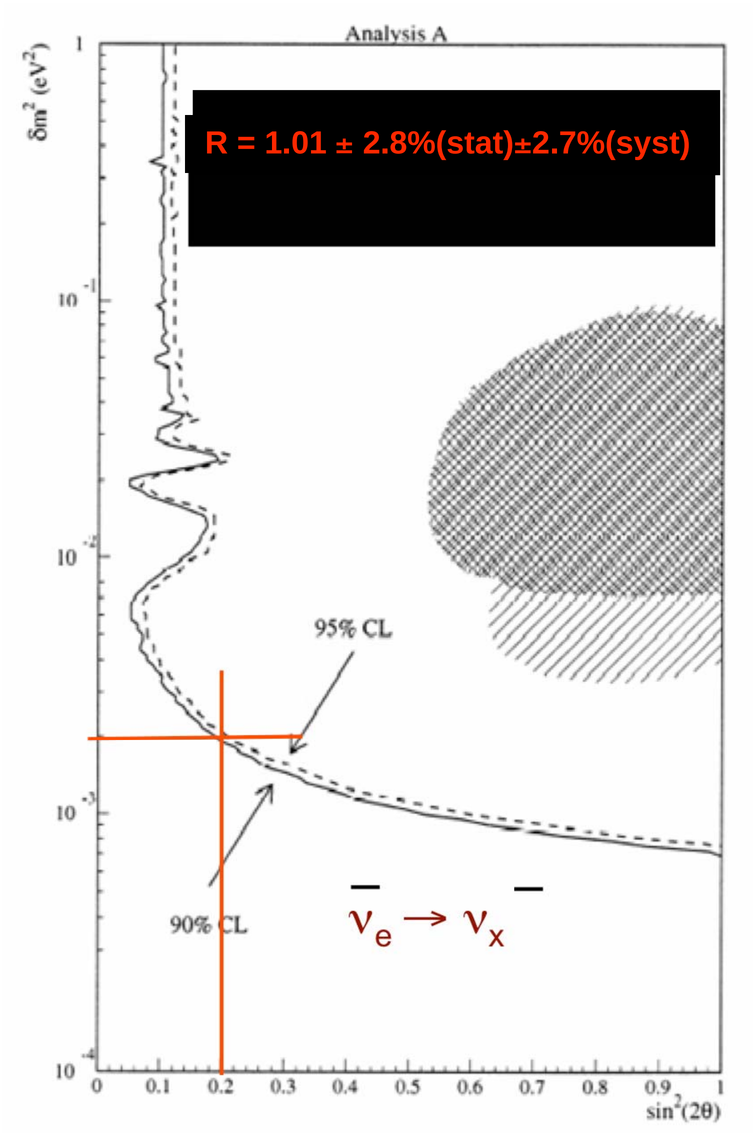
KAMLAND

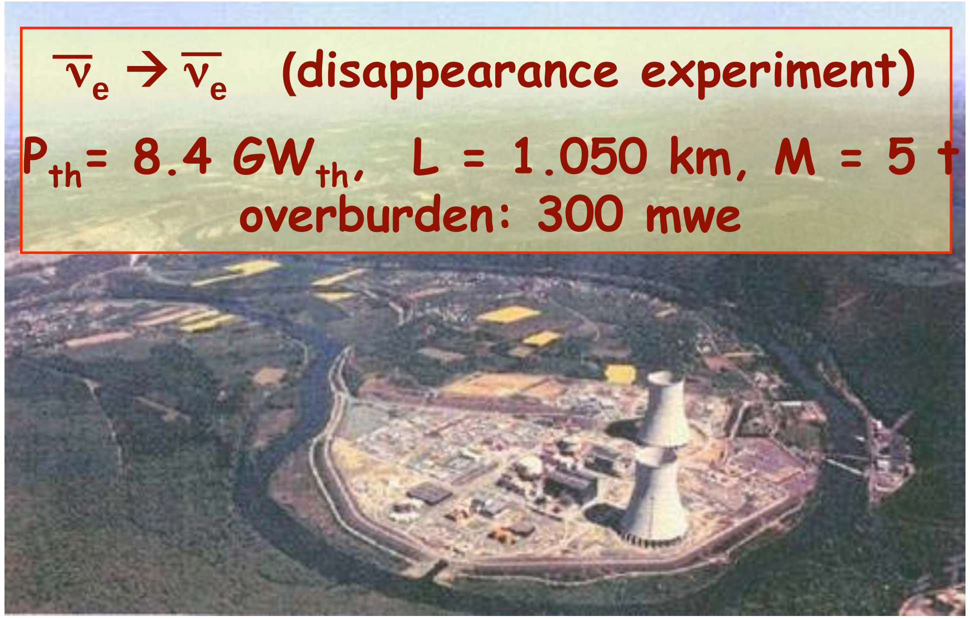


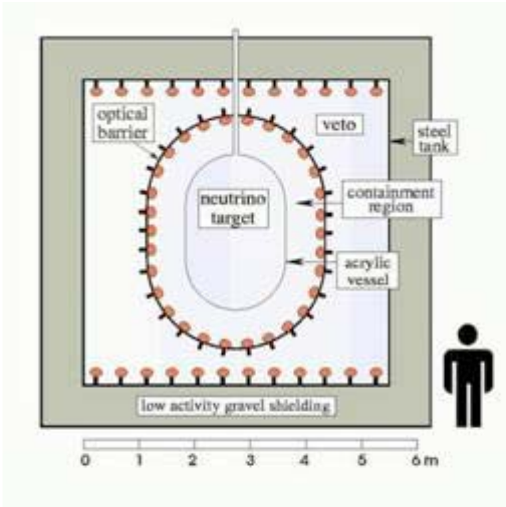
50 Years of detector developments

- Huge progress:
  - from 10 meters of the reactor core till 170 km (4 orders of magnitude; 8 orders on signal)
  - Signal/Background ~20 – 100 in recent experiment
  - Backgrounds are well understood
- Slower progress
  - Loaded scintillator: stability issue
  - Reconstruction
    - From PMTs signal, computes event position (timing, charge balance)
    - neutrino direction (neutron brings some direction memory:
      e+ and neutron position build a direction vector

Best current constraint: CHOOZ







World best constraint !

@Δm^2_{atm} = 2.7 10^{-3} eV^2

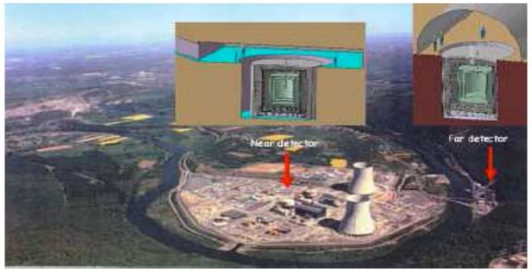
$\sin^2(2\theta_{13}) < 0.12$

(90% C.L)

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

2004-2006: Publications

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



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

Version 5.0

April 28, 2004

EU Letter of Intent
hep-ex/0406032

- White book
- Main physicist streams
  - bugey:declais,boucshez,dekerret shoenert oberauer hagner
  - Kamland:suzuki,suekane
  - Savannah:soebel,svoboda
  - Russia: skorokhvatov

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

arXiv:hep-ex/0606025 v2 20 Jun 2006

F. Ardellier[19] I. Barabanov[10] J. C. Barrière[19] F. Beißel[1]
S. Berridge[23] L. Bezrukov[10] A. Bernstein[14] T. Bolton[12]
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E. Caden[6] C. Cattadori[7,17] S. Cazaux[19] M. Cerrada[5] B. Chevis[23]
H. Cohn[23] J. Coleman[15] S. Cormon[21] B. Courty[4] A. Cucoanes[1]
M. Cribier[4,19] N. Danilov[11] S. Dazeley[15] A. Di Vacri[7]
Y. Efremenko[23] A. Etenko[13] M. Fallot[21] C. Fernández-Bedoya[5]
F. von Feilitzsch[22] Y. Foucher[21] T. Gabriel[23] P. Ghislain[4]
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C. Hagner[8] W. Hampel[16] T. Handler[23] F. X. Hartmann[16]
G. Horton-Smith[12] P. Huber[22†] J. Jochum[24] Y. Kamyshkov[23]
D. M. Kaplan[9] H. de Kerret[4] T. Kirchner[21] V. Kopeikin[13]
J. Kopp[22] A. Kozlov[23] T. Kutter[15] Yu. S. Krylov[11] D. Kryn[4]
T. Lachenmaier[24] C. Lane[6] T. Lasserre[4,19*] C. Lendvai[22] Y. Liu[2]
A. Letourneau[19] D. Lhuillier[19] M. Lindner[22] J. LoSecco[18]
I. Machulin[13] F. Marie[19] J. Martino[21] D. McKee[2] R. McNeil[15]
F. Meigner[19] G. Mention[19] W. Metcalf[15] L. Mikaelyan[13]
A. Milsztajn[19] J. P. Meyer[19] D. Motta[19] L. Oberauer[22]
M. Obolensky[4] C. Palomares[5] P. Perrin[19] W. Potzel[22]
J. Reichenbacher[3] B. Reinhold[1] D. Reyna[3] M. Rolinec[22]
L. Romero[5] S. Roth[1] S. Schoenert[16] U. Schwan[16] T. Schwetz[22]
L. Scola[19] V. Sinev[13,19] M. Skorokhvatov[13] A. Stahl[1] I. Stancu[2]
N. Stanton[12] S. Sukhotin[4,13] R. Svoboda[14,15] A. Tang[12]
A. Tonazzo[4] D. Underwood[3] F.J. Valdivia[5] D. Vignaud[4]
D. Vincent[4] W. Winter[22‡] K. Zbiri[21] R. Zimmermann[8]

20th June 2006

Proposal
hep-ex/0606025

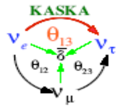
Proposal for U.S. participation in
Double-CHOOZ:
A New θ_{13} Experiment at the Chooz Reactor

S. Berridge[g], W. Bugg[g], J. Busenitz[a], S. Dazeley[e],
G. Drake[b], Y.Efremenko[g], M. Goodman[b*], J. Grudzinski[b],
V. Guarino[b], G. Horton-Smith[d], Y. Kamyshkov[g], T. Kutter[e]
C. Lane[c], J. LoSecco[f], R. McNeil[e], W. Metcalf[e],
D. Reyna[b], I. Stancu[a], R. Svoboda[e*], R. Talaga[b]

October 14, 2004

[a] University of Alabama, [b] Argonne National Laboratory, [c] Drexel University,
[d] Kansas State University, [e] Louisiana State University,
[f] University of Notre Dame, [g] University of Tennessee
* US Contacts: phsvob@lsu.edu, maury.goodman@anl.gov

US Letter of Intent
hep-ex/0410081

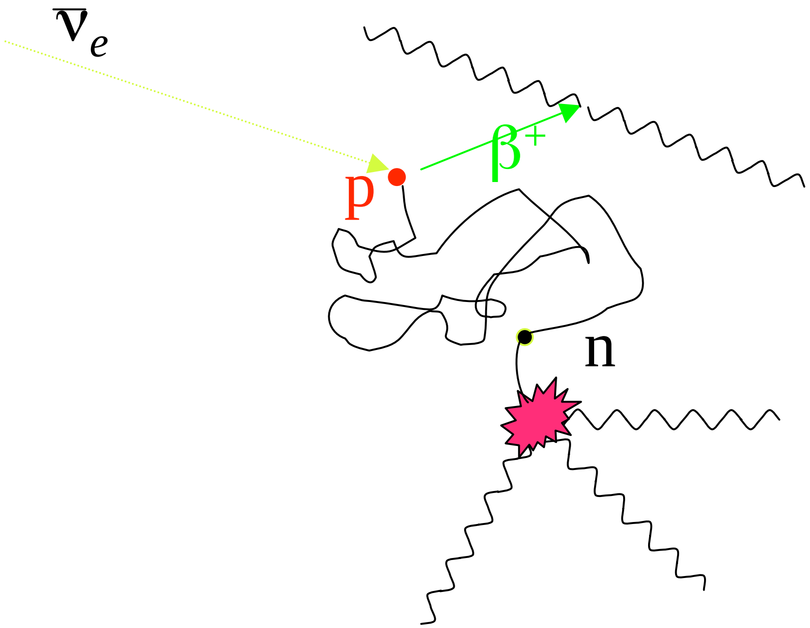


Letter of Intent for KASKA
High Accuracy Neutrino Oscillation Measurements
with $\bar{\nu}_e$s from
*Ka*shiwazaki-*Ka*riwa Nuclear Power Station.

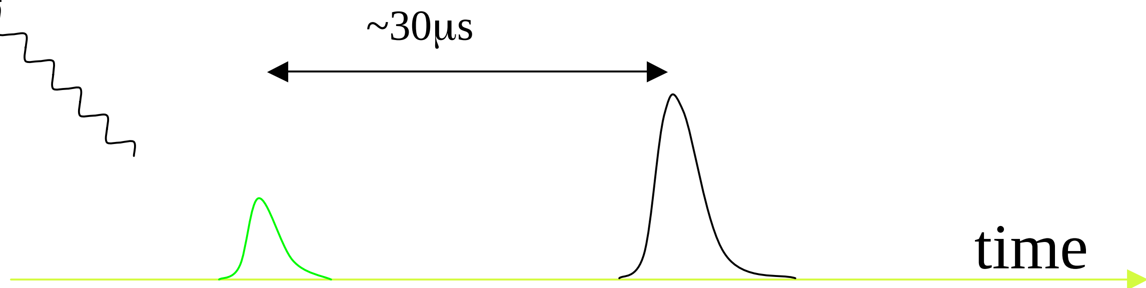
M. Aoki[5] K. Akiyama[4,a] Y. Fukuda[4] A. Fukui[3,b]
Y. Funaki[9] H. Furuta[9] T. Hara[3] T. Haruna[10]
N. Ishihara[2] T. Iwabuchi[5,c] T. Kawasaki[5]
M. Katsumata[5] M. Kuze[9] J. Maeda[9] K. Matsubara[9]
T. Matsumoto[10,d] H. Minakata[10] H. Miyata[5]
Y. Nagasaka[1] T. Nakagawa[10] N. Nakajima[5]
H. Nakano[5] K. Nitta[9] M. Nomachi[6] K.Sakai[5]
Y. Sakamoto[8] K. Sakuma[10,e] M. Sasaki[5] F. Suekane[7]
H. Sugiyama[2] T. Sumiyoshi[10] Y.Tabata[7] N. Tamura[5]
M. Tanimoto[5] Y. Tsuchiya[7] R. Watanabe[5]
and O. Yasuda[10]

The events

proton-rich liquid scintillator
is both a target and detector



Add Gd to reduce neutron
capture time, increase
capture energy



Ev = Ee+ +1.8 Mev

prompt

β^+ signal:

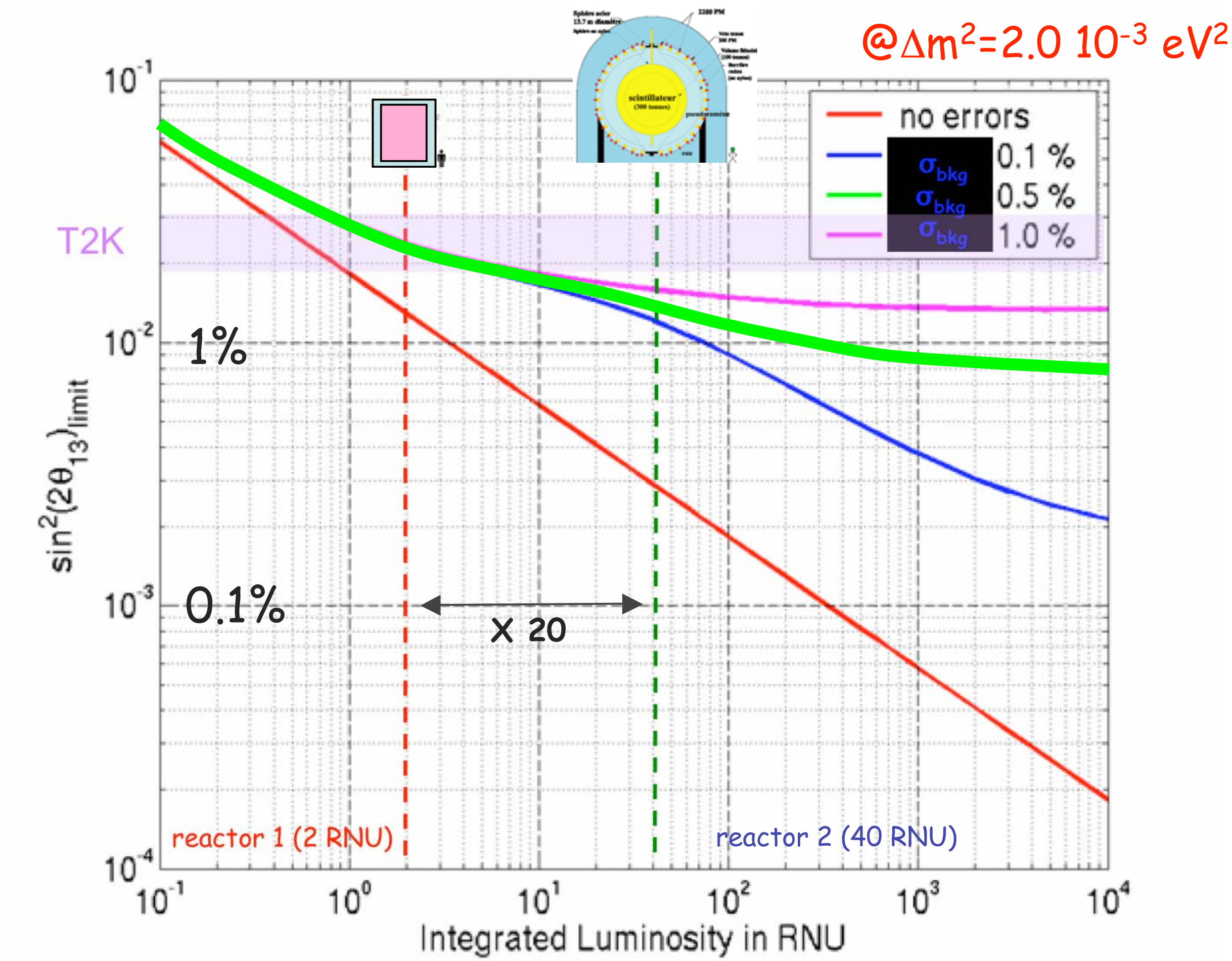
E_ν - 0.8MeV

delayed

n capture:

~ 8MeV

90% C.L. sensitivity if $\sin^2(2\theta_{13})=0$



Huber, Lindner, Schwetz & Winter: hep-ph/0303232

G. Men tion & T. L.

RNU = Reactor Neutrino Unit : 1 RNU = 10^{31} free H GW_{th} year

Reactor$_1$ (0.5 km, 2.3 km): ~13 tons$_{PXE}$ x 10 GW x 3 years ➔ **$\sin^2(2\theta_{13})$<~0.02**, 90% C.L

Reactor$_2$ (0.5 km, 2.3 km): ~270 tons$_{PXE}$ x 10 GW x 3 years ➔ **$\sin^2(2\theta_{13})$<~0.01**, 90% C.L

Daya Bay

China/US collaboration

Four reactor cores

- ✓ P=4 x 2.9 = 1.6 GW_{th}
- ✓ + two new cores for 6 GW_{th} in 2011

Civil construction

- ✓ Near: 1 km tunnel + laboratory
- ✓ Far: 2 km tunnel + laboratory

~10 tons detector modules

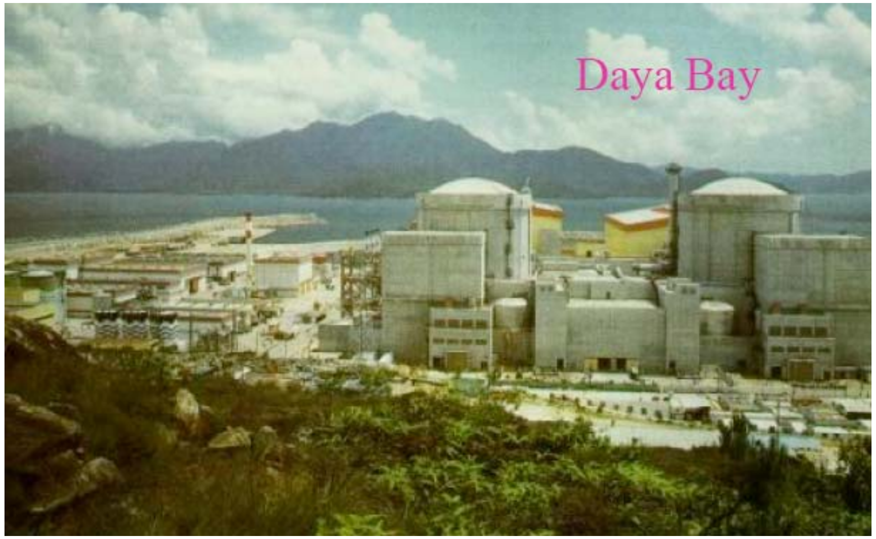
- ✓ Near: 25 tons - 300 m – 200 mwe
- ✓ Far: 50 tons - 1.5-1.8 km - 700 mwe
- ✓ Movable detector concept

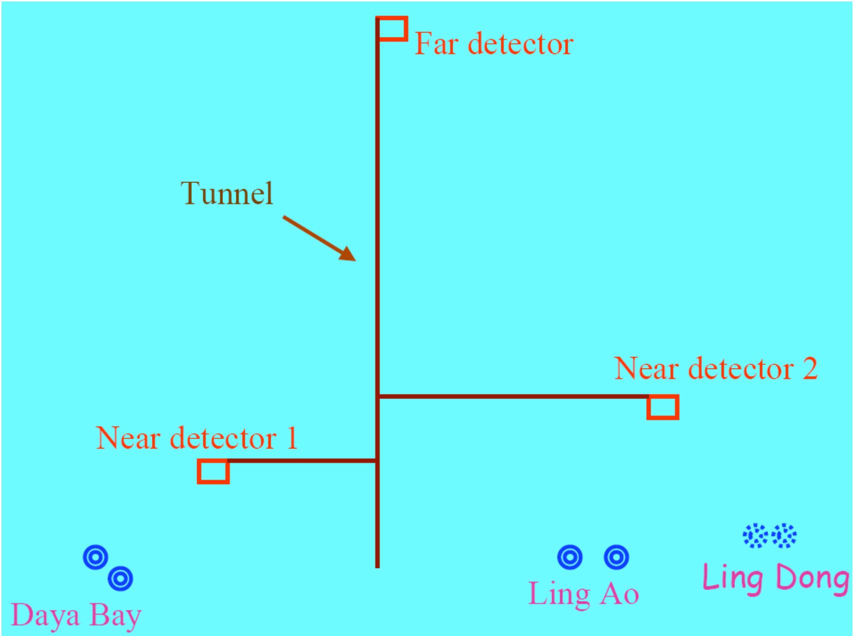
Sensitivity

- ✓ 0.4% systematic error
- ✓ $\sin^2(2\theta_{13}) < \sim 0.01$ (90% C.L.) ?

Prospects (not yet approved)

- ✓ 2004-05: R&D, 2006-07: Construction
- ✓ 1 Near detector running in 2008
- ✓ *Geological & safety studies ongoing*





DOUBLE CHOOZ

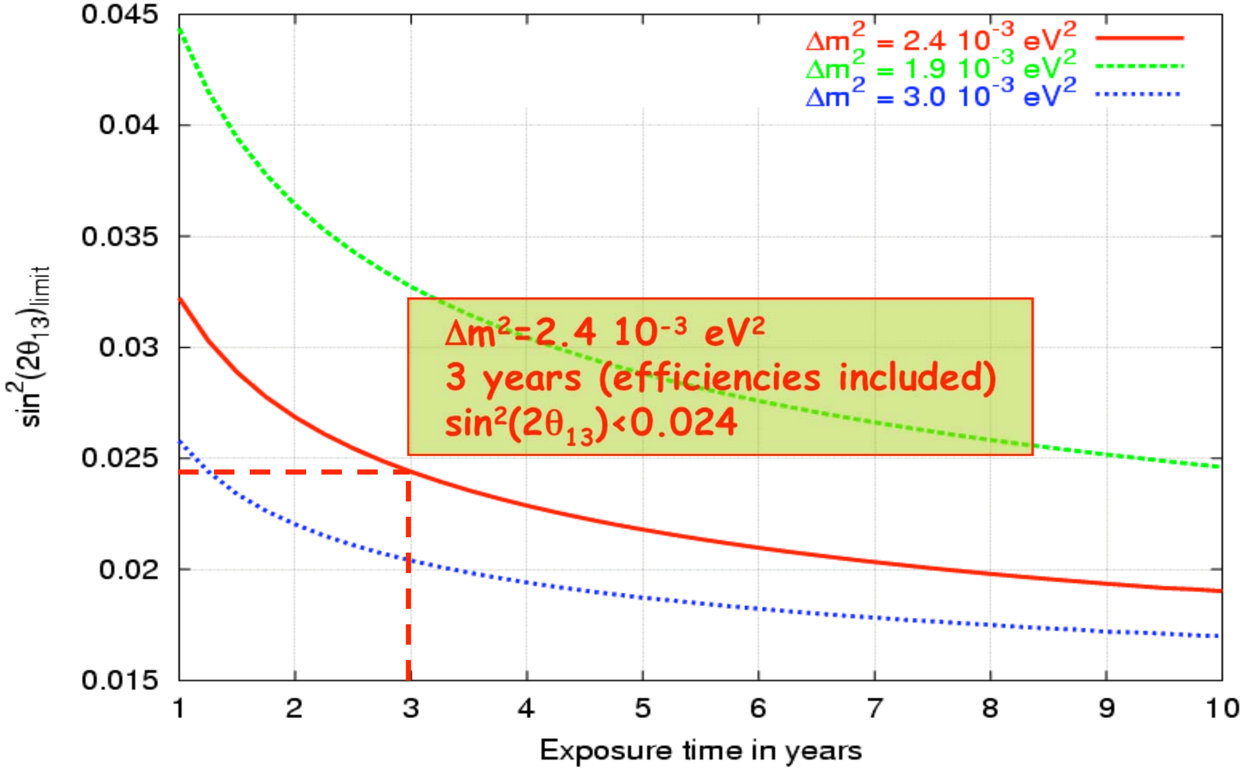
collaboration

- Japan
  - Tohoku Univ.
  - Tokyo Metropolitan Univ.
  - Niigata Univ.
  - Tokyo Institute of Technology
  - Kobe Univ.
  - Tohoku Gakuin Univ.
  - Miyagi University of Education
  - Hiroshima Inst. of Technology
- USA
  - Livermore nat lab
  - Argonne
  - Columbia Univ
  - Chicago Univ
  - Kansas U
  - Notre Dame U
  - Tennesse U
  - Alabama U
  - Drexel U
  - Illinois Inst tech
- France
  - Saclay
  - APC (collège de France)
  - Subatech Nantes
- Germany
  - Max planck Heidelberg
  - Munich U
  - Hamburg U
  - Tubingen U
  - Aachen U
- Spain
  - CIEMAT Madrid
- England
  - Oxford
  - Sussex Univ
- Russia
  - Kurchatov inst
  - Sc. Acad.

At Chooz, June 06

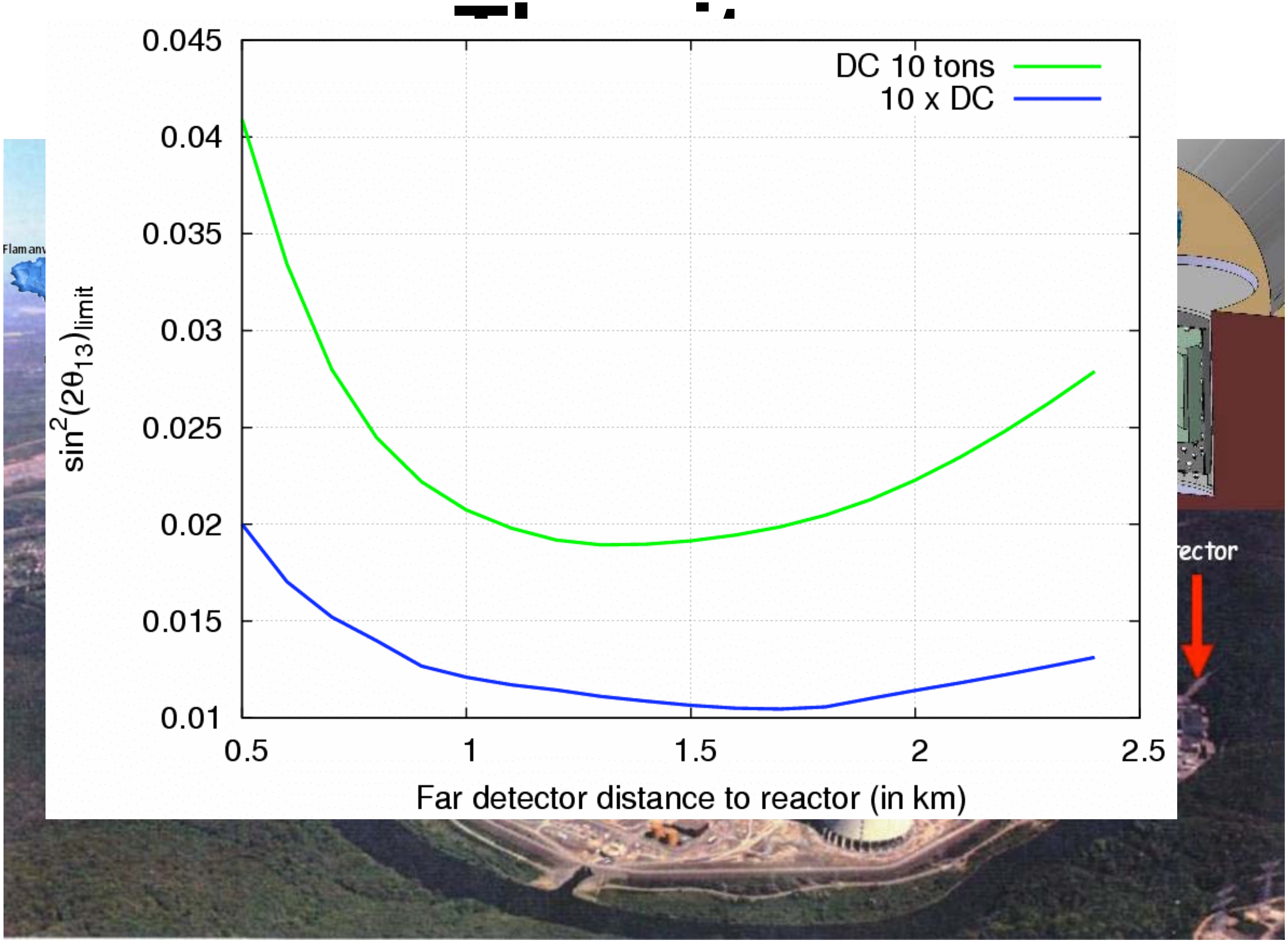
France, Germany,Spain funded. England, US and Japan expected before Summer 07
Already started building…

Potential limit if $\sin^2(2\theta_{13})=0$



- Efficiencies included
- 1% of background in Near & Far detectors
- Syst. uncert.:

σ_{abs} = 2.0%
σ_{rel} = 0.6%
σ_{scl} = 0.5%
σ_{shp} = 2.0%
$\sigma_{\Delta m^2}$ = 20%

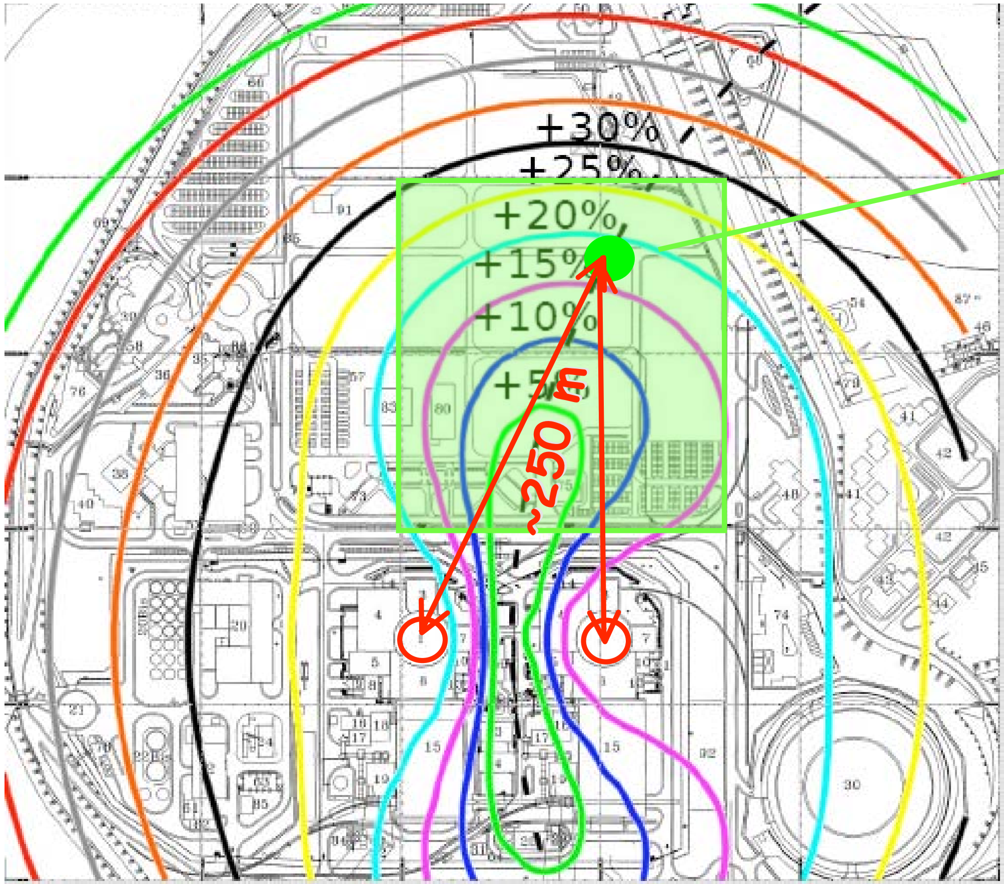


DC 10 tons
10 x DC
$\sin^2(2\theta_{13})_{limit}$
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.5
1
1.5
2
2.5
Far detector distance to reactor (in km)

Near detector location

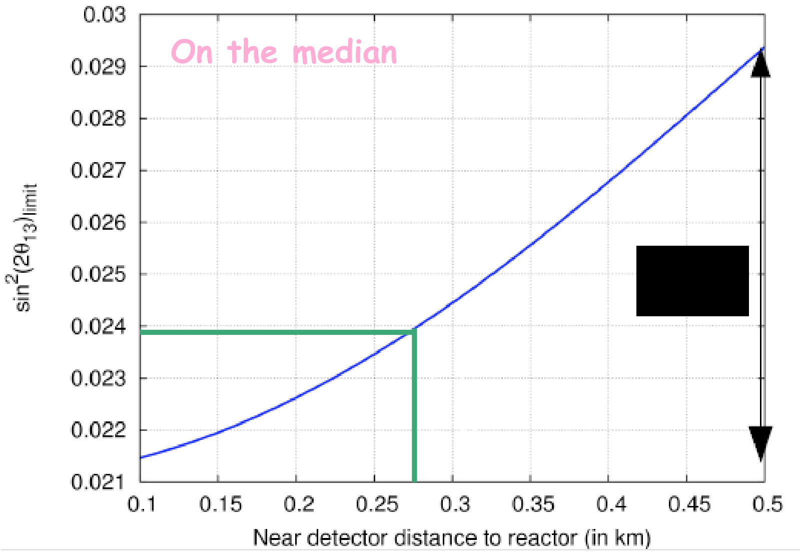
- Uncorrelated fluctuations included
- Relative Error : 0.6%
- Spectral shape uncertainty 2%
- Δm^2 known at 20%
- Power flucutation of each core: 3%

$$\chi^2 = \min_{\{\alpha_{i,k}^{D,R}\}} \left\{ \sum_{D=N,F} \sum_{i=1}^{NBins} \left[\left(\frac{\sum_{R=R_1,R_2} \left[O_i^{D,R} - T_i^{D,R} - \sum_{k=1}^{K} \alpha_{i,k}^{D,R} S_{i,k}^{D,R} \right]}{U_i^D} \right)^2 + \sum_{R=R_1,R_2} \sum_{k=1}^{K} c_{i,k}^{D,R} \left(\frac{\alpha_{i,k}^{D,R}}{\sigma_k^{D,R}} \right)^2 \right] \right\}$$



Available and suitable area

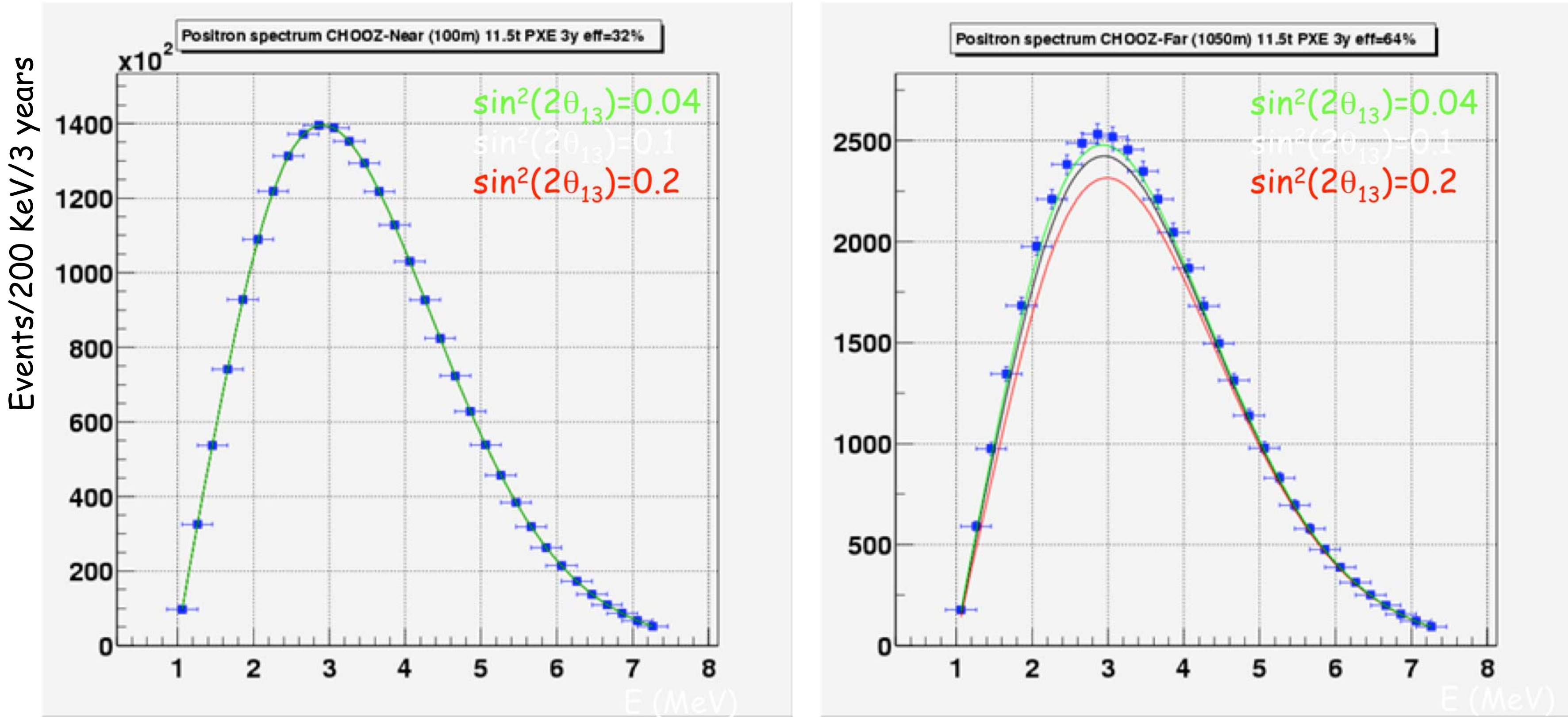
Spent fuel effect under study kopeikin and al.



3 years data taking

Observable: e^+ spectrum

$\Delta m^2_{atm} = 2.0\ 10^{-3}$ eV2



Near Detector: ~ 3 10^6 events/3y

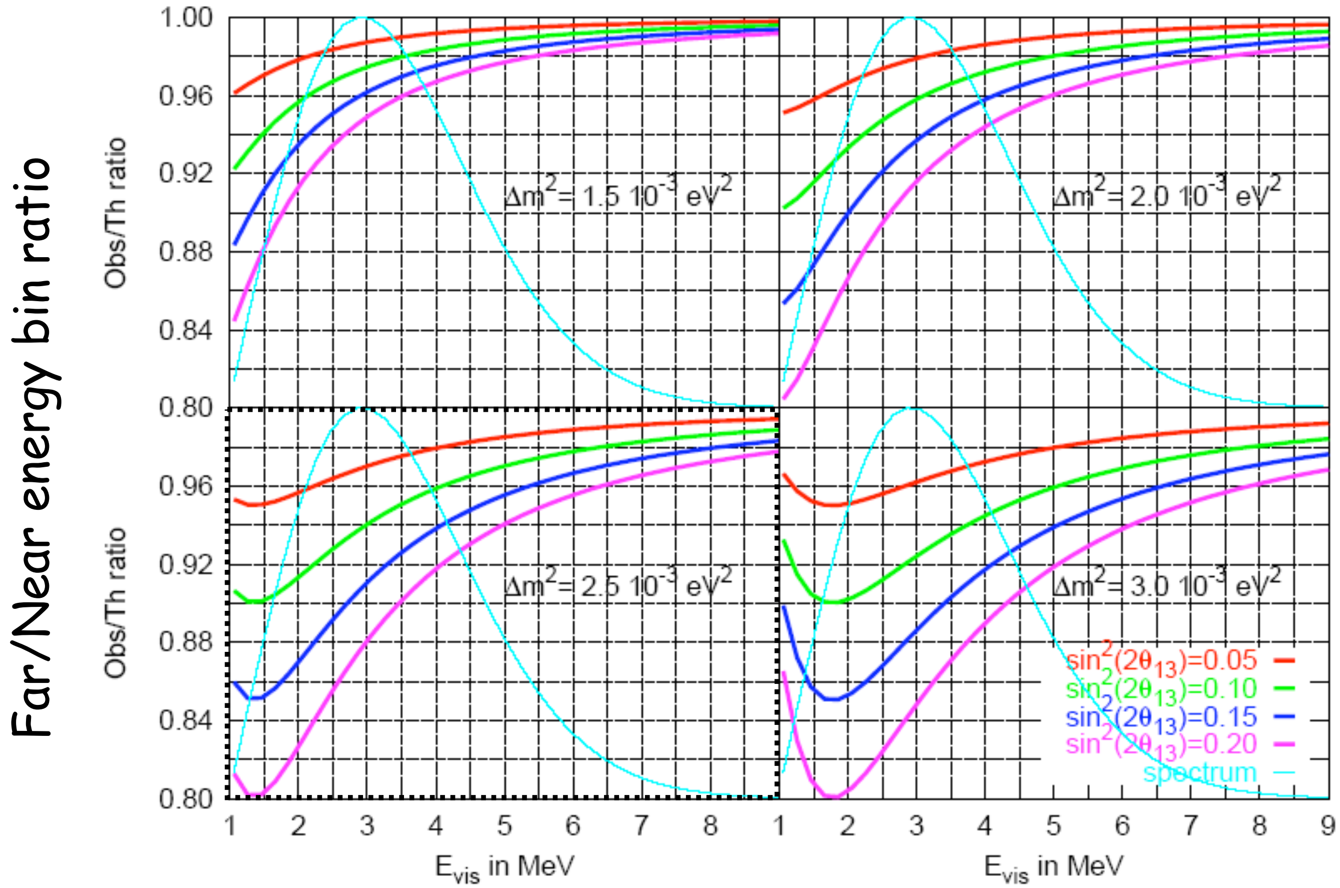
-Reactor efficiency:	80%
-Detector efficiency:	80%
-Dead time:	50%

Far Detector: ~ 60 000 events/3y

-Reactor efficiency:	80%
-Detector efficiency:	80%

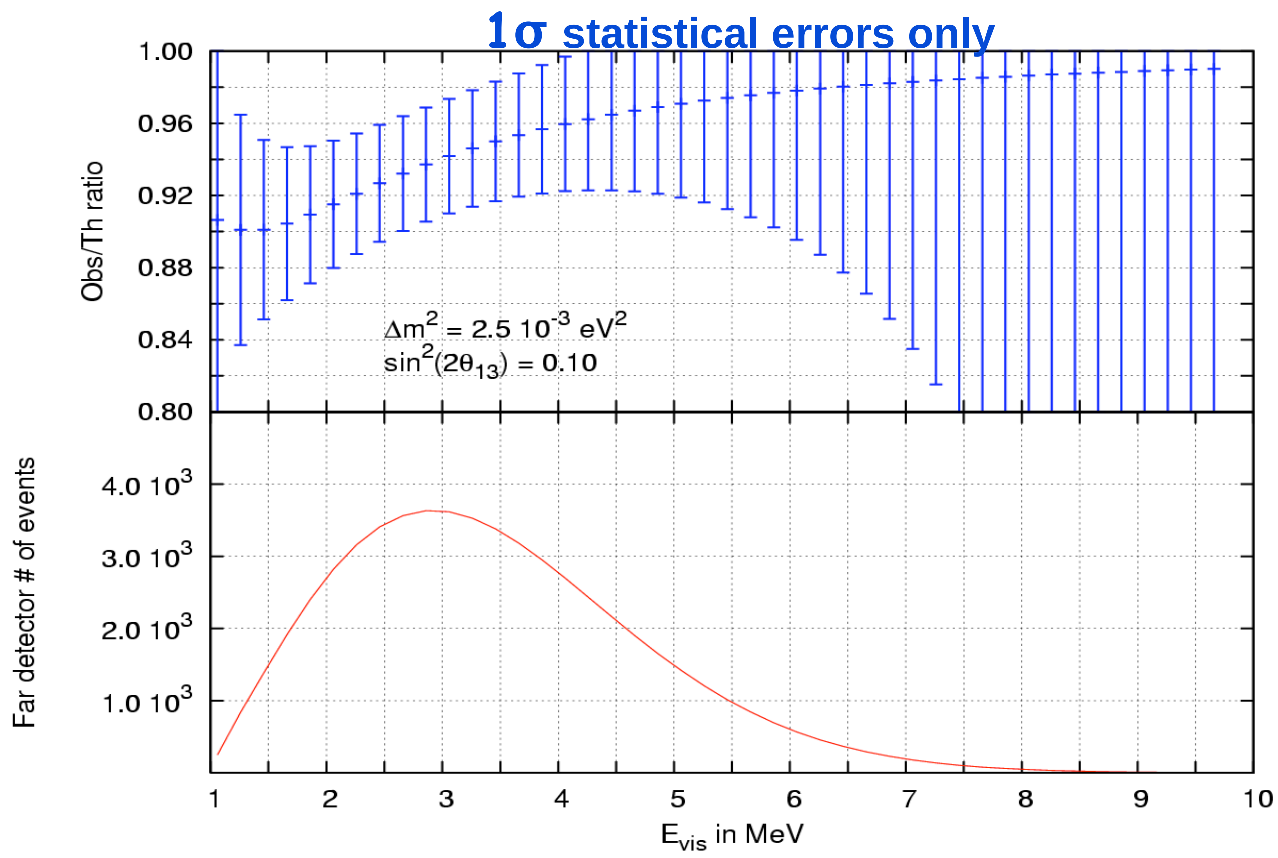
Expected signal

Rate + shape information if θ_{13} not too small



Note: optimum baseline between ~1.2km and 1.8 km

Spectrum deformation information



rate info:

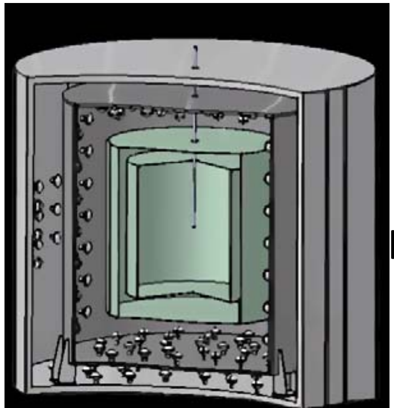
no-osc excluded
@ 2.66σ

shape info:

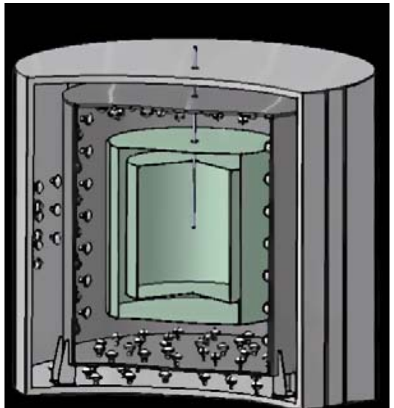
flat shape excluded
@ 5.98σ

The Double-Chooz concept

$\overline{\nu}_e$



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



D_1 = 100-200 m

D_2 = 1,050 m

8.4 GW_{th}
Chooz PWR power station

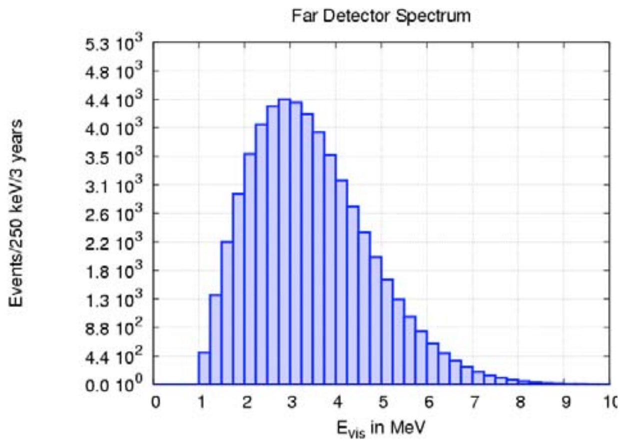
Near detector

Far detector

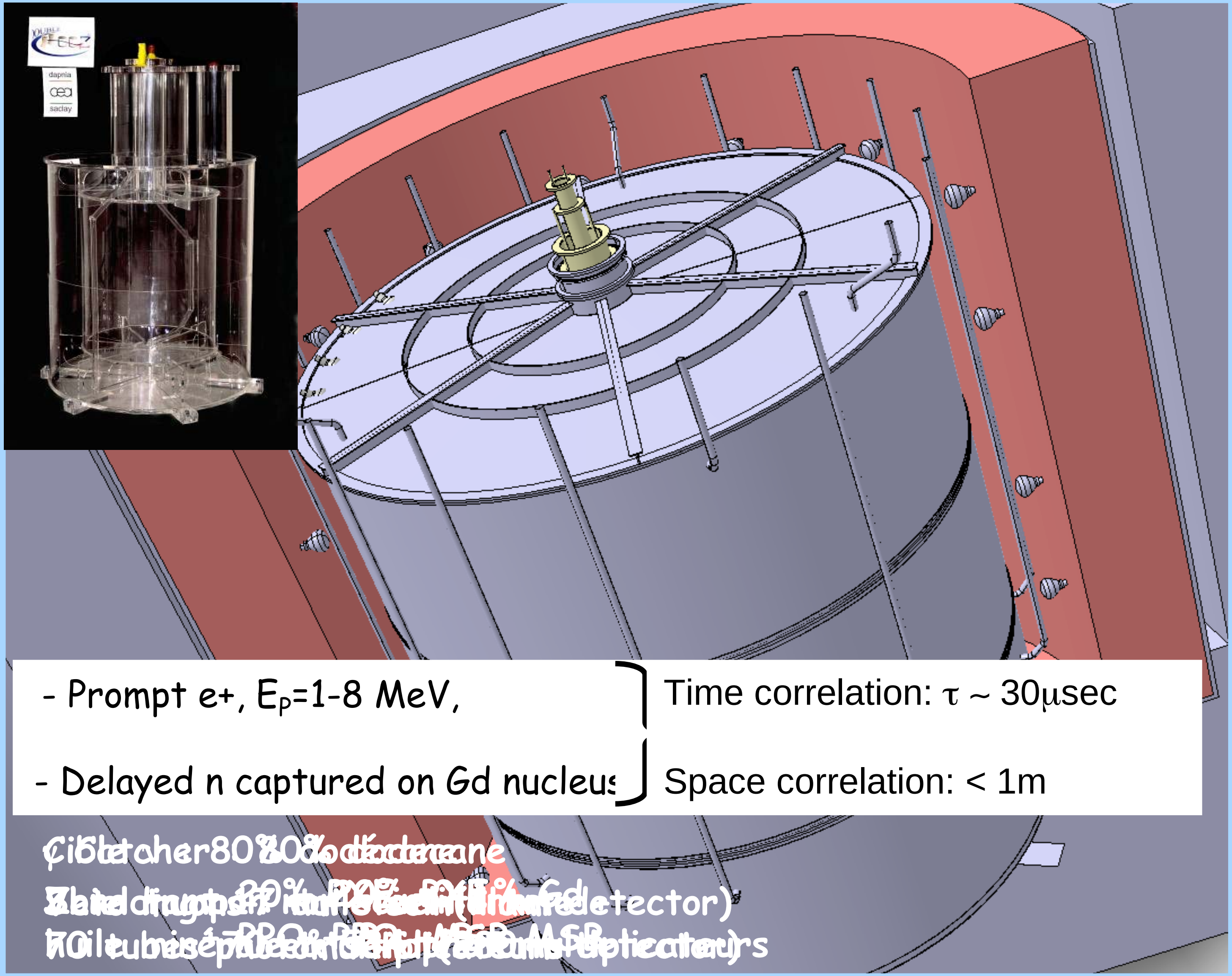
✓ anti-ν_e flux (uranium 235, 238 & plutonium 239, 241)
✓ Reaction: $\overline{\nu}_e + p \rightarrow e^+ + n$, <E>~ 4 MeV, $E_{threshold}$ =1.8 MeV
✓ Disappearance experiment: search for a departure from the $1/D^2$ behavior and shape distortion

improve Chooz sensitivity ➔ 0.03

➔ **Improve the detector concept**
➔ **and backgrounds rejection**

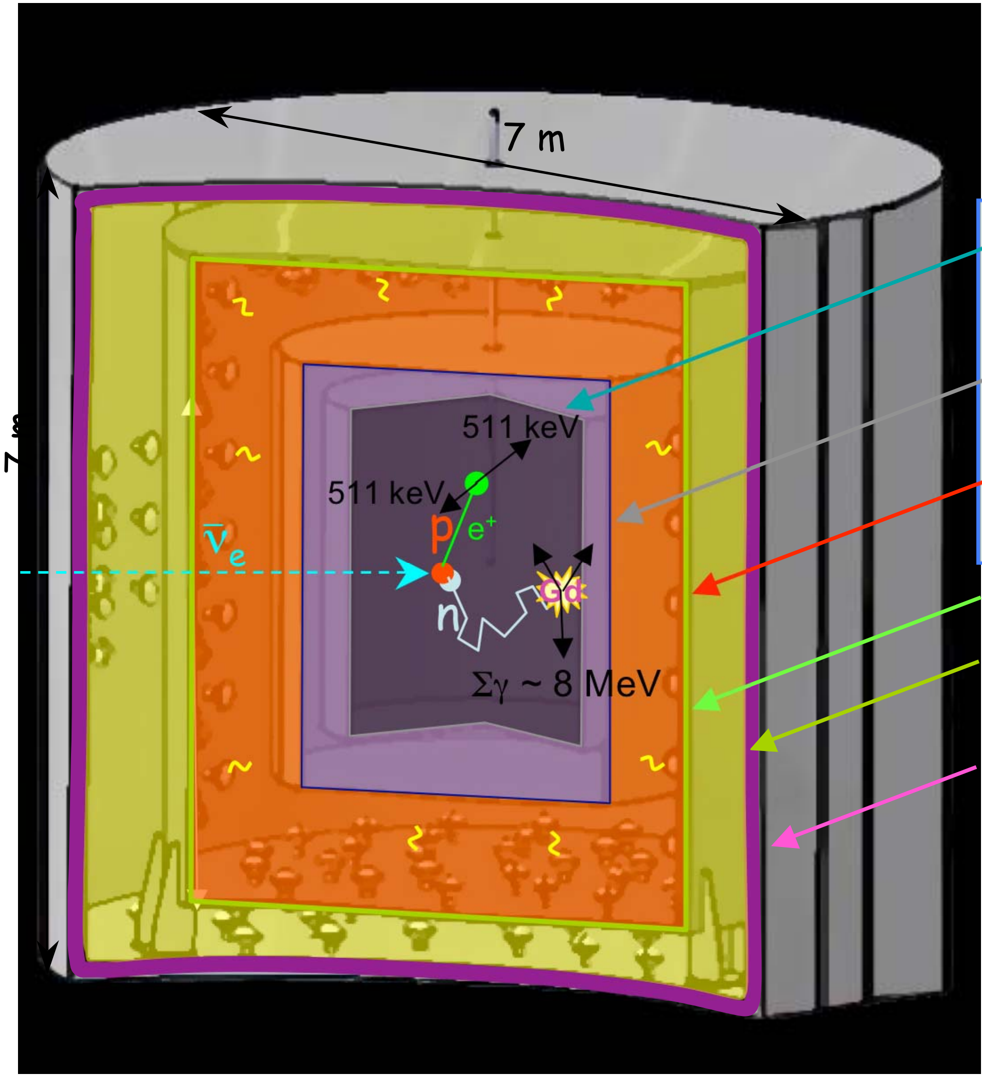


2004-2005: Detector design



- Prompt e+, E_P=1-8 MeV, — Time correlation: $\tau \sim 30\mu sec$
- Delayed n captured on Gd nucleus — Space correlation: < 1m

New detector design



ν target: **80% dodecane + 20% PXE + 0.1% Gd**
(acrylic, r = 1,2 m, h = 2,8 m, 12,7 m³)

γ-catcher: **80% dodecane + 20% PXE**
(acrylic, r+0,6m – V = 28,1 m³)

Non-scintillating buffer: **same liquid (+ quencher?)**
(r+0.95m, , V = 100 m³)

PMTs supporting structure

Muon VETO: **scintillating oil**
(r+0.6 m – V = 110 m³)

Shielding: **0,15 m steel**

The Double-Chooz sites

Improving CHOOZ
- Statistical error -

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

✓ <u>**Luminosity increase**</u> $L = \Delta t \times P(GW) \times V_{target}$

	CHOOZ	Double-Chooz
Target volume	5,55 m^3	12,67 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 : 60 000/3 y CHOOZ-near: >3 10^6/3 y
Statistical error	2,7%	0,4%

Improving CHOOZ
- Systematical error -

@CHOOZ : σ_{sys}=2.7%

✓ **Decreasing systematical error**

1. Improve the detector concept
2. Two identical detectors ➔ towards $\sigma_{relative}$~0,6%
3. Backgrounds – improve S/B>100 ➔ error<1%

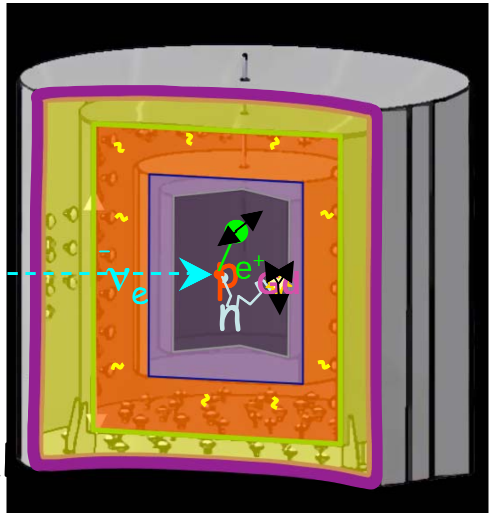
	Chooz	Double-Chooz
Reactor cross section	1.9 %	—
Number of protons	0.8 %	0.2 %
Detector efficiency	1.5 %	0.5 %
Reactor power	0.7 %	—
Energy per fission	0.6 %	—

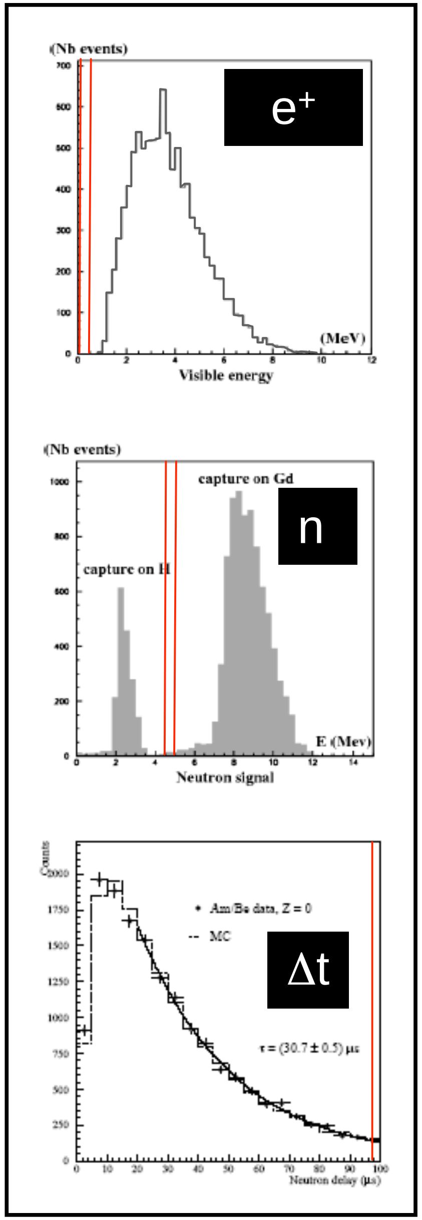
Relative Normalization: Analysis

✓ @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 accidental
- Δt (e+ - n)

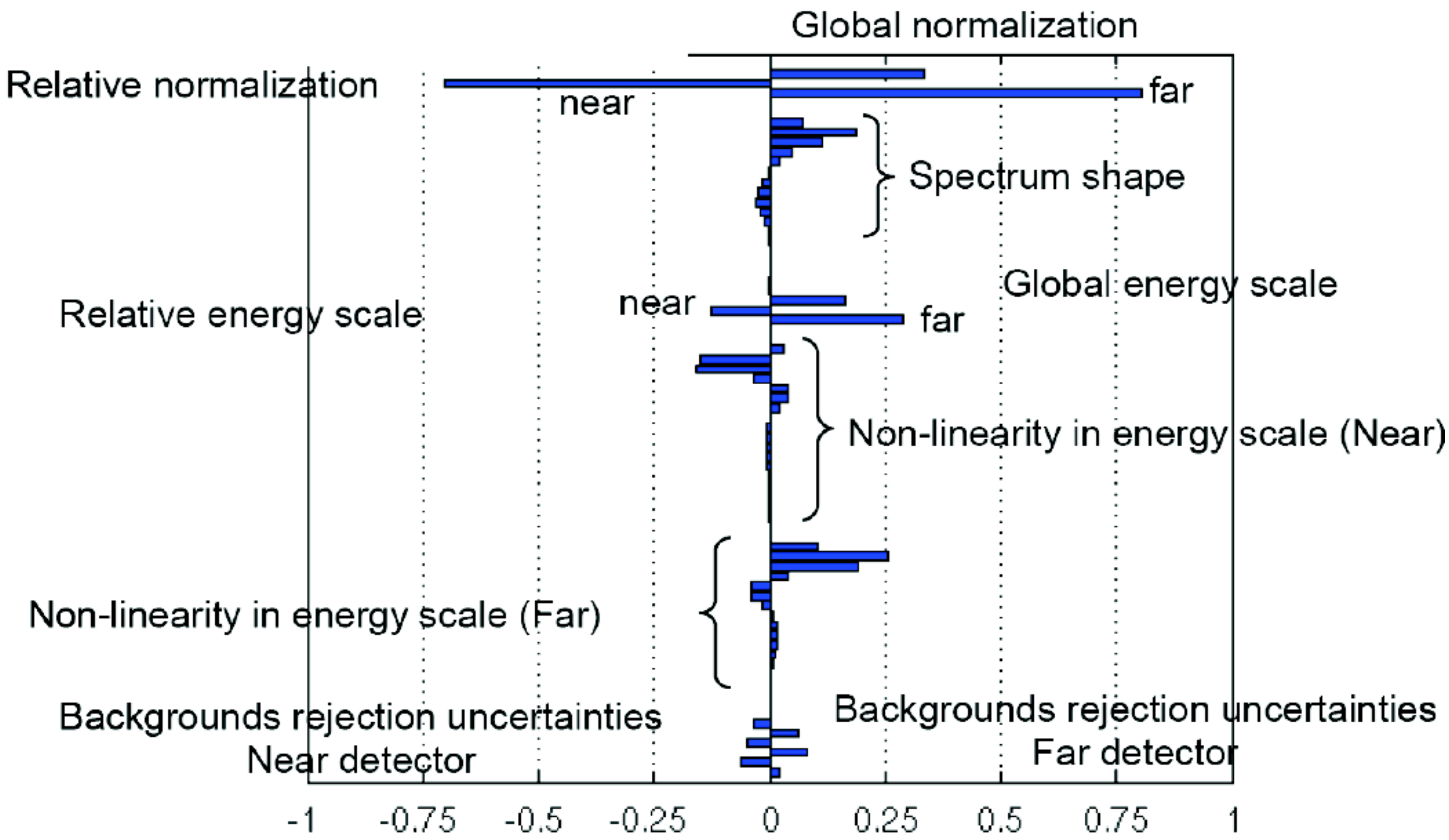




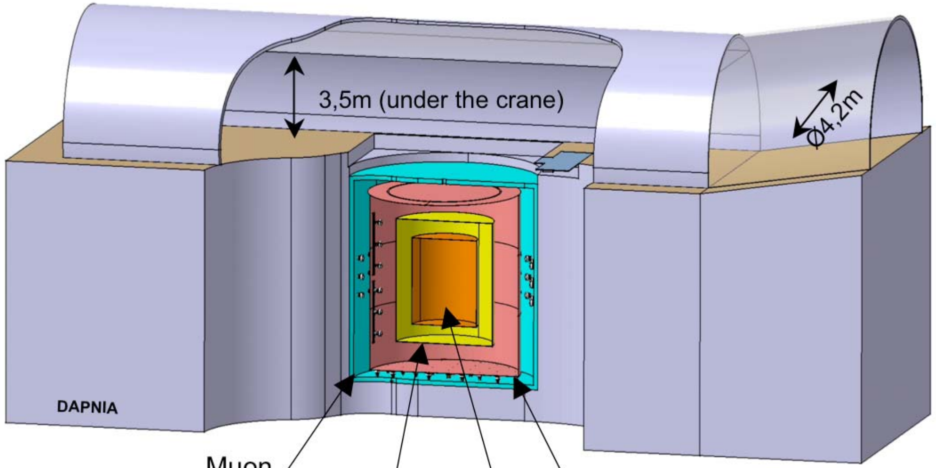
	CHOOZ	Double-CHOOZ	
selection cut	rel. error (%)	rel. error (%)	Comment
positron energy*	0.8	0	not used
positron-geode distance	0.1	0	not used
neutron capture	1.0	0.2	Cf calibration
capture energy containment	0.4	0.2	Energy calibration
neutron-geode distance	0.1	0	not used
neutron delay	0.4	0.1	—
positron-neutron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

Systematics Pull X^2 analysis

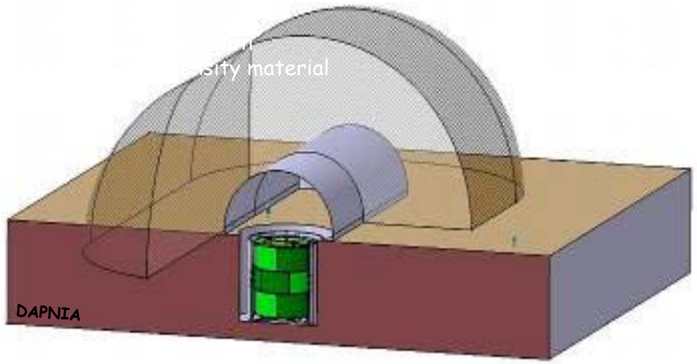


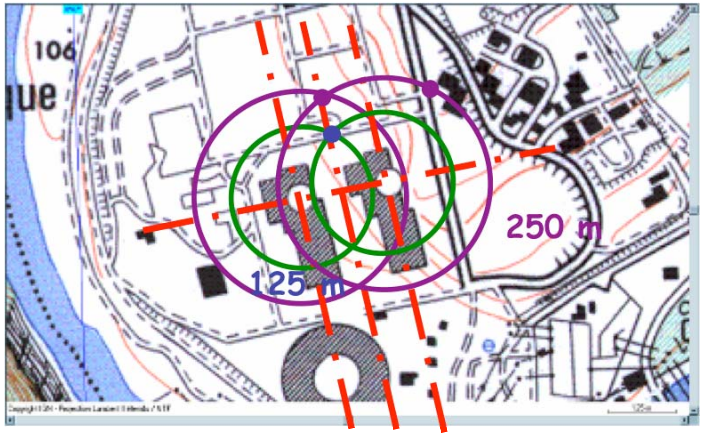
Far site



Near site

Distance Reactor-detector	Required overburden (m.w.e)
100	45-53
150	55-65
200	67,5-80





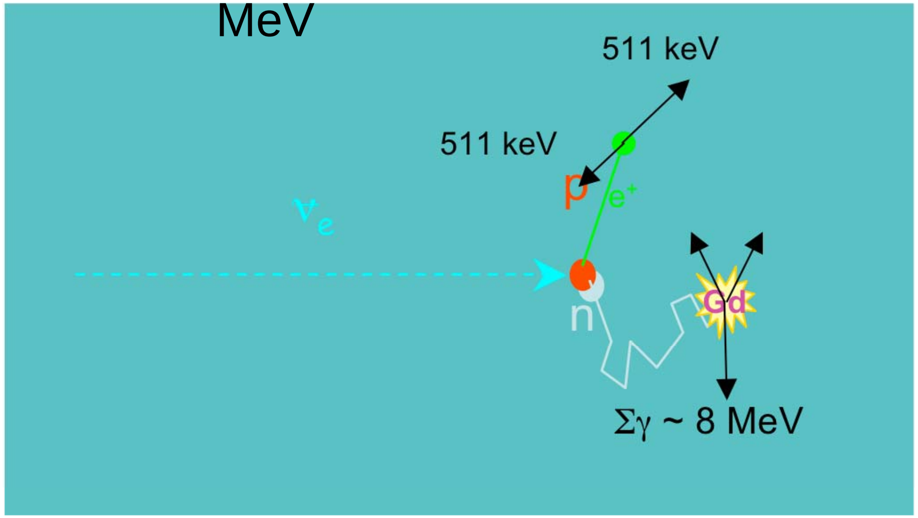
BACKGROUNDS

ν

Backgrounds

neutrino identification (signal)

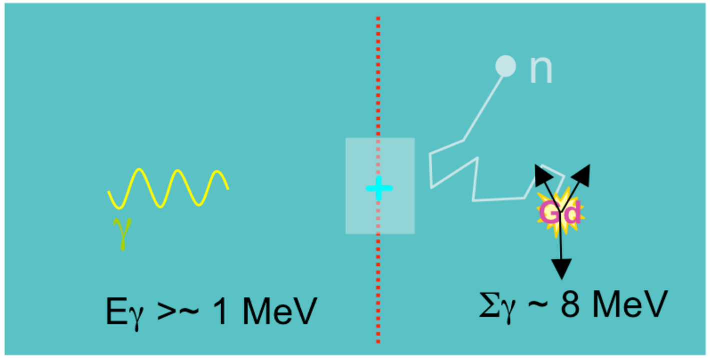
$E\nu = E_{e+} + 1.8$ MeV



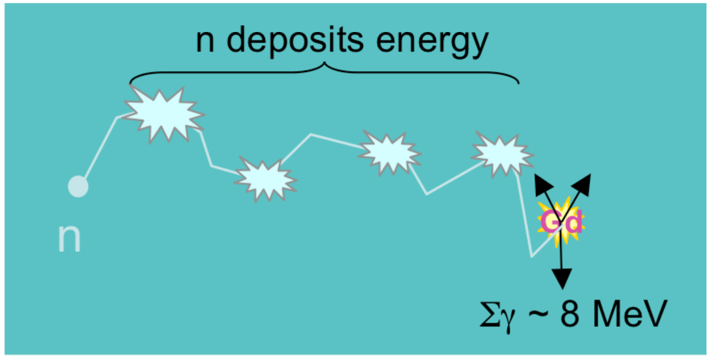
prompt signal (e^+ + 2 * 511 keV
+ n capture on Gd (H_2,Li,B,)

Distance e^+-n ~ 6cm with some memory
Of the neutrino direction

accidental background (uncorrelated)



correlated background



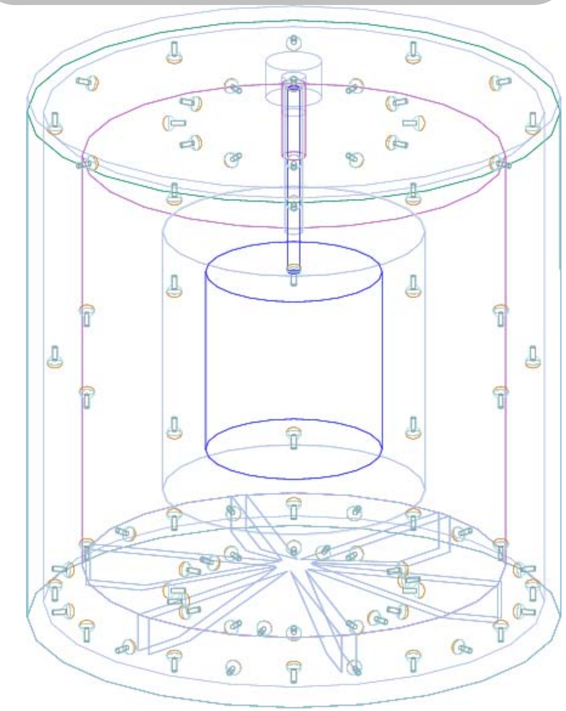
+β-n cascades

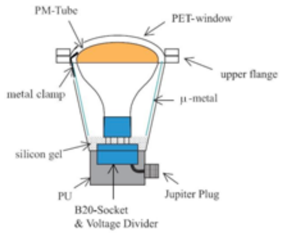
Bkg reduction: Veto systems

INNER VETO

crucial for bkg rejection

- Tag μ and secondaries
- Very high ε (~ 99%)



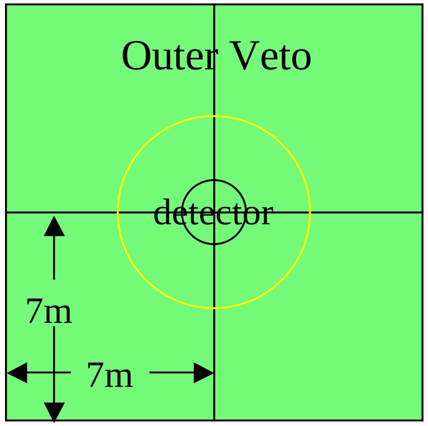


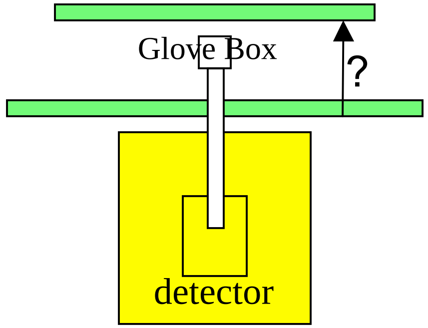
Baseline:

- 50 cm, scintillating mineral oil
- 60 – 100 PMTs
- Reflective walls (paint + Tyvek)

OUTER VETO

- Tag "near miss" μ
- Redundancy for higher rejection power





Baseline:
MINOS like
scintilator planes

Neutron Induced Background

✓**Cosmic muons** create fast neutrons through

- ✓ **Spallation** in the rock surrounding the detector
- ✓ **muon capture** in the detector materials

✓Fast neutron slows down by scattering into the scintillator; it could deposit between 1-8 MeV and be later captured on Gd !

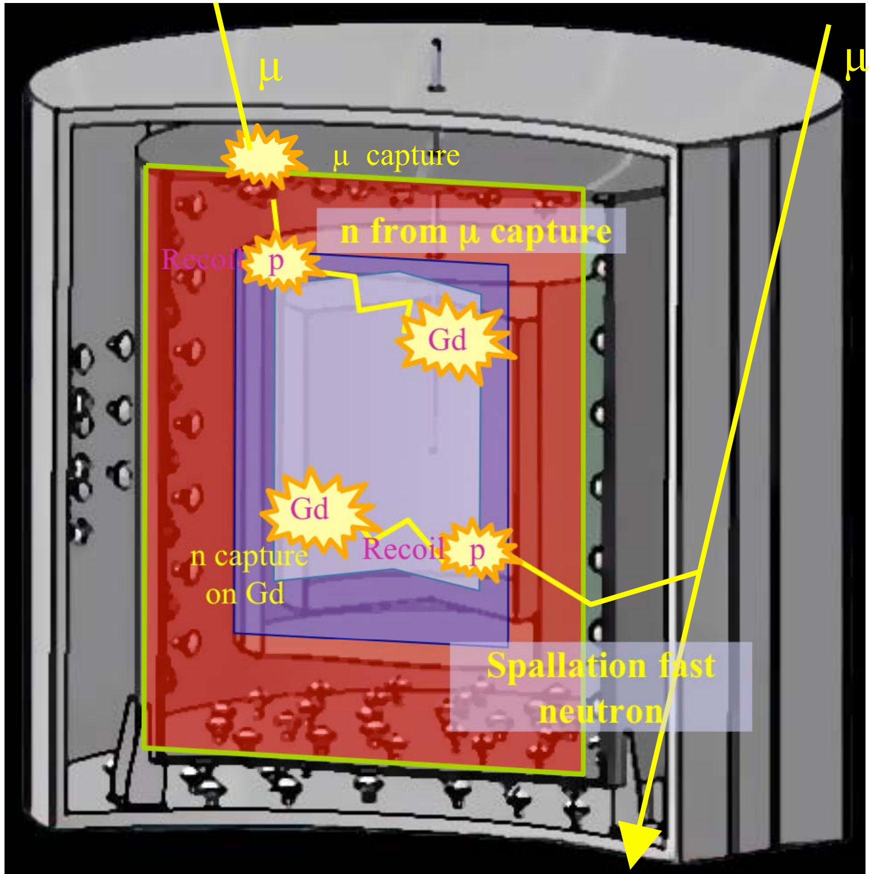
✓Full simulation – Geant + Fluka

✓Old Chooz simulation: 300 m.w.e. 31hours – MC is reliable !

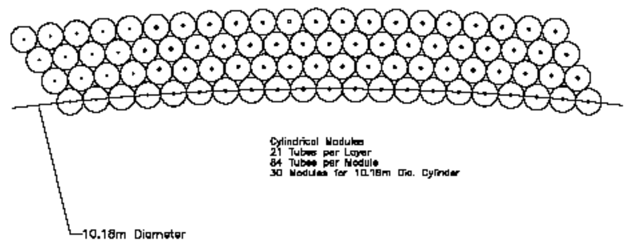
- Simulated: N_b<1.6 evts/day (90% C.L.)
- Measured in-situ: N_b=1.1 evts/day

✓Double-Chooz simulation:

- 338 10^6 μ tracked – 580 10^3 neutrons tracked
- 1 neutron created a muon event
- Far detector: N_b<0.5 evt/day (90% C.L.)
- Near detector: N_b<3.2 evts/day (90%C.L.)

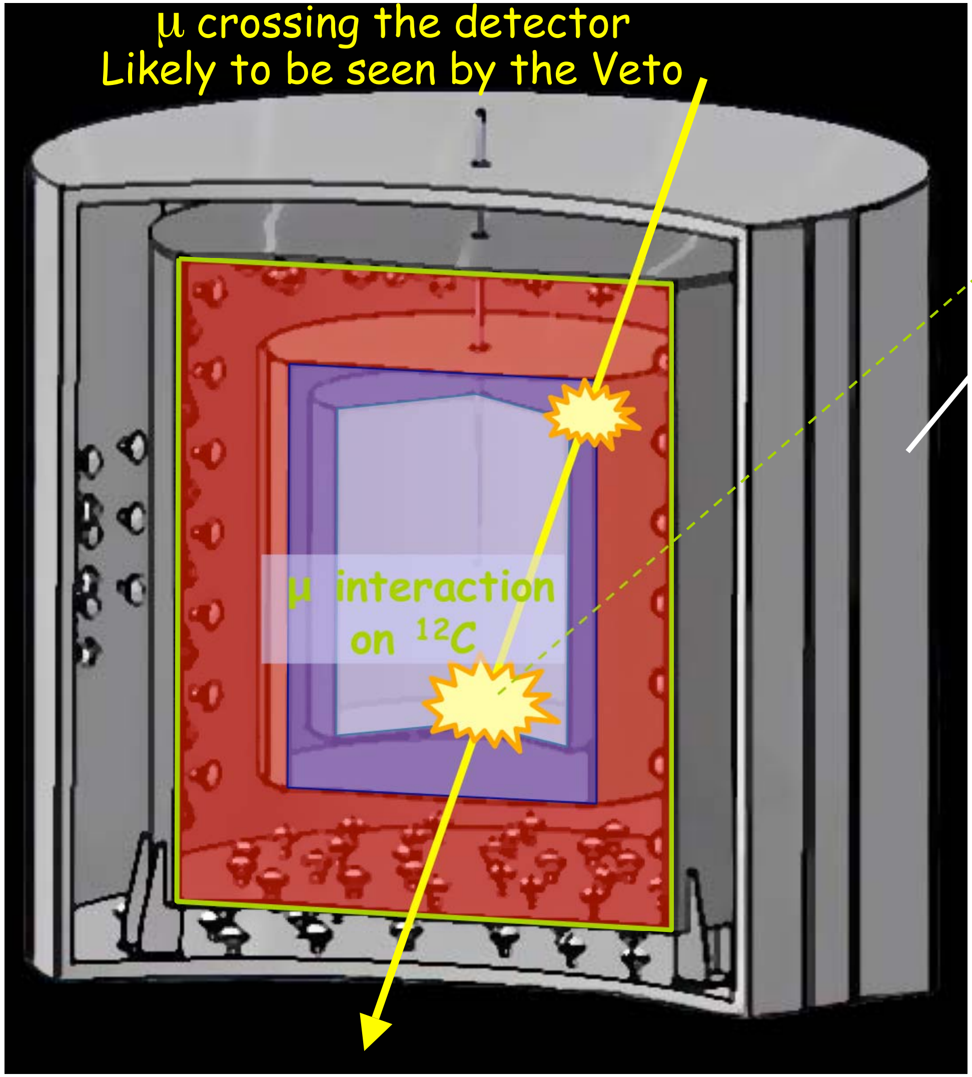


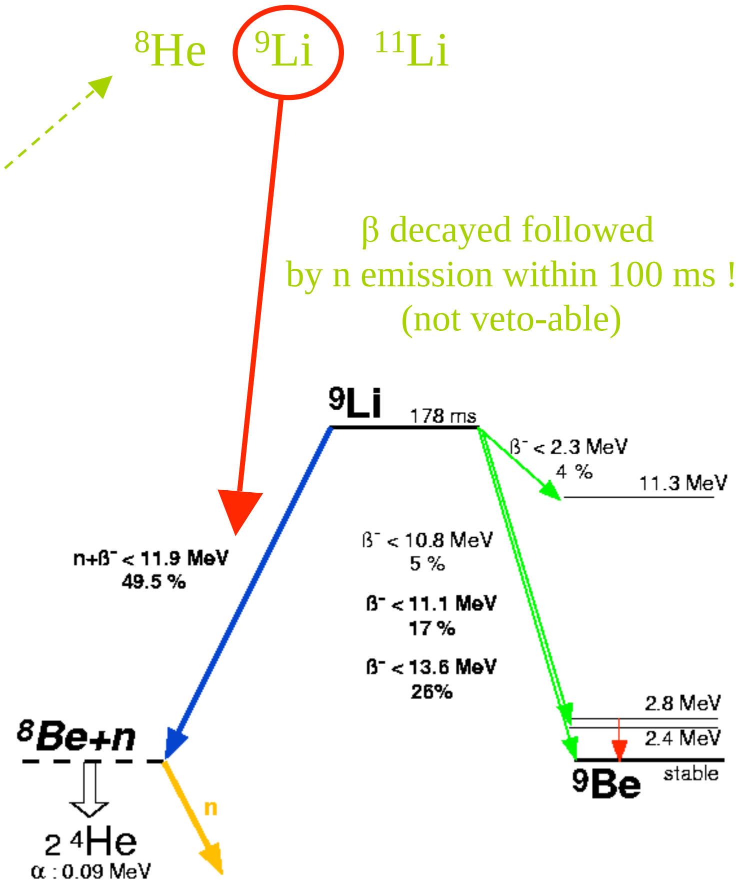
An outer muon veto will surround it, to tag near miss muons.



β-neutron cascades (cosmogenics)

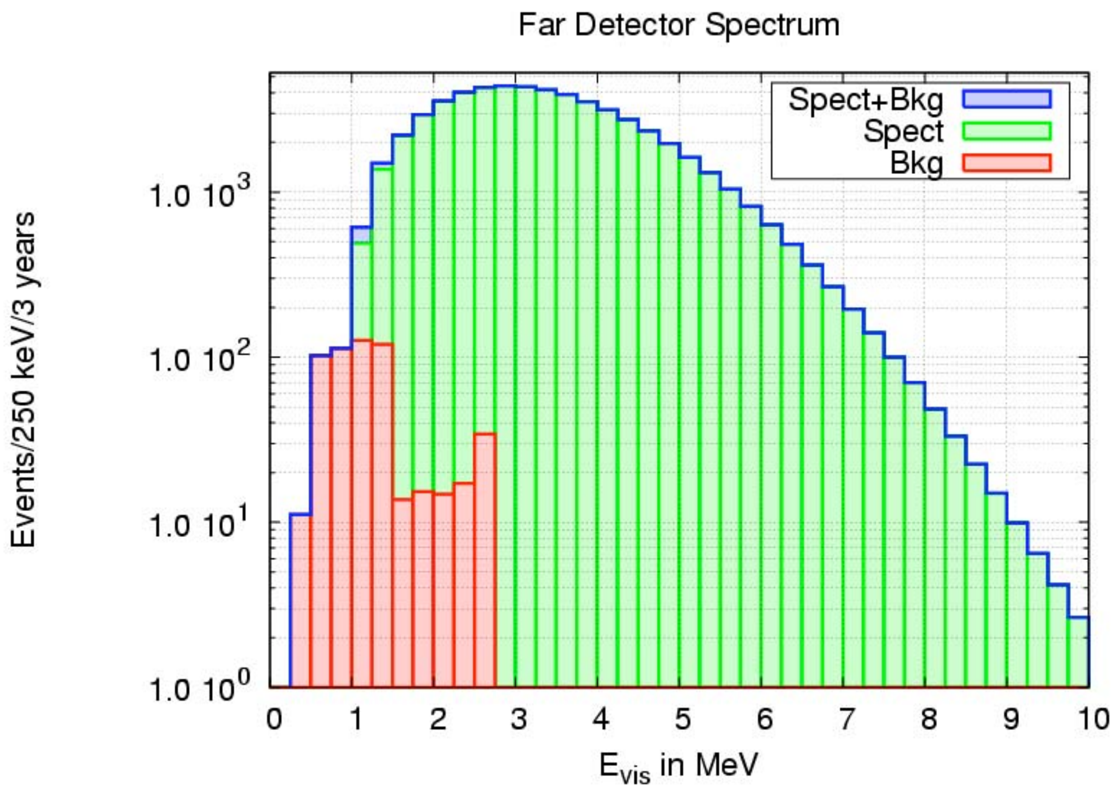
From Kamland





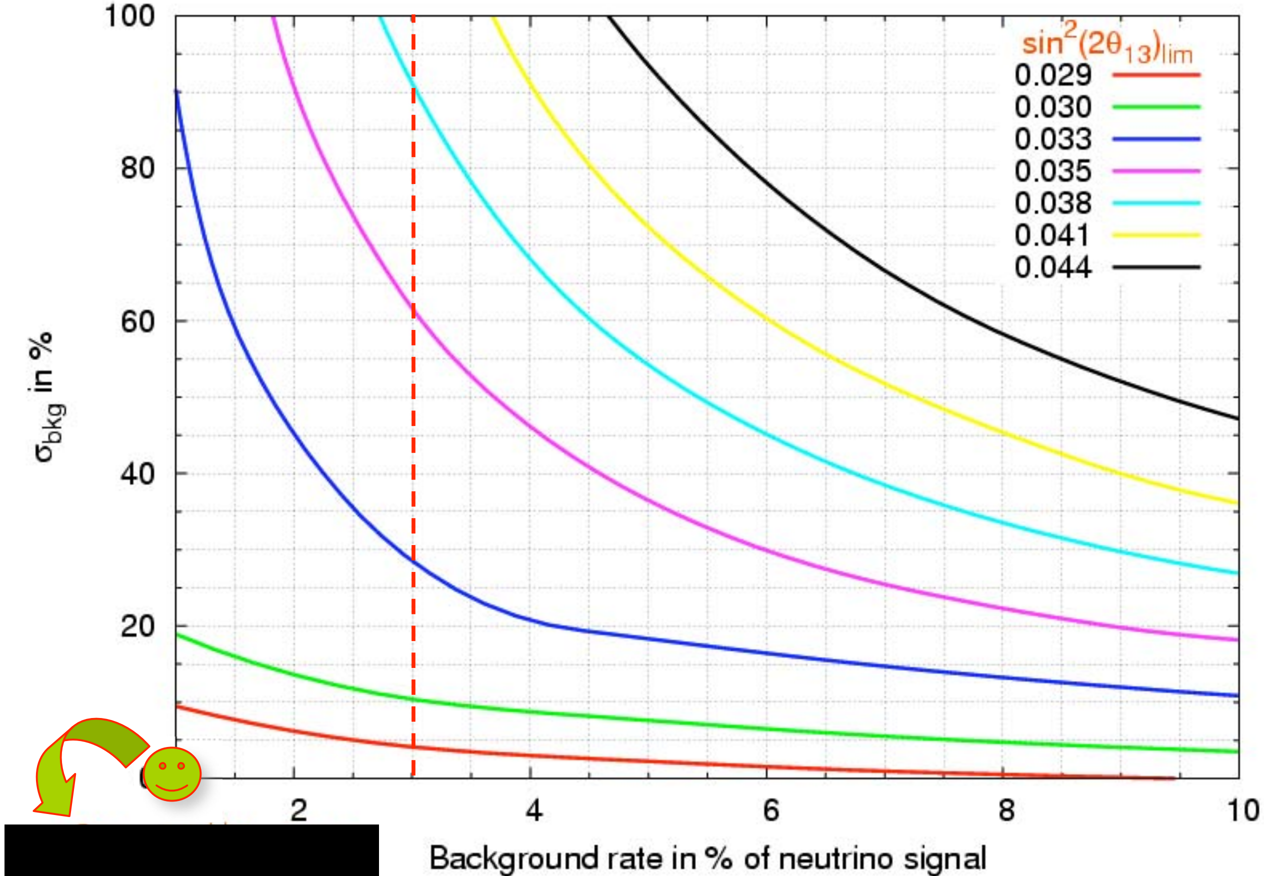
RECONSTRUCT THE μ TRACK
(outer veto+inner veto+central detector)

Far detector spectrum with PMTs background



PMTs background shape rejection: How far ?

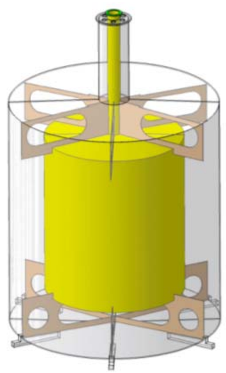
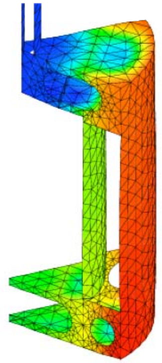
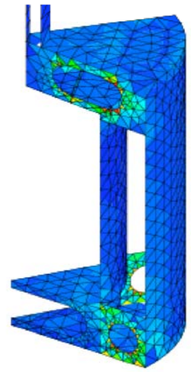
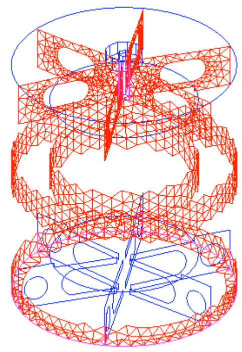
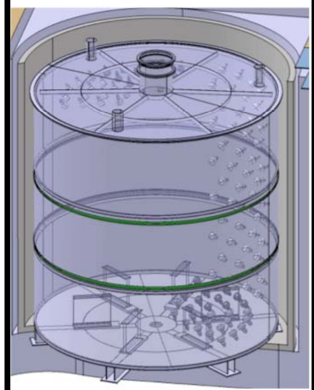
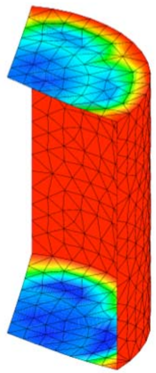
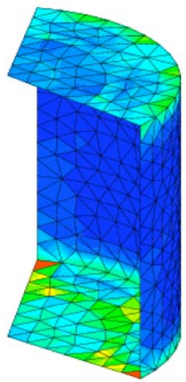
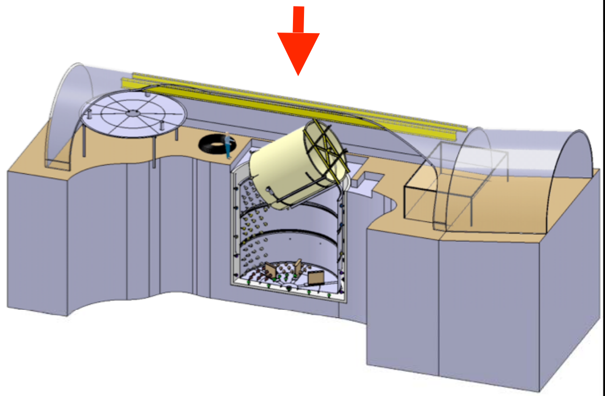
Contours of sensitivity loss



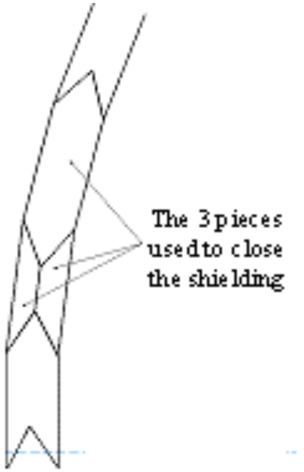
[redacted]

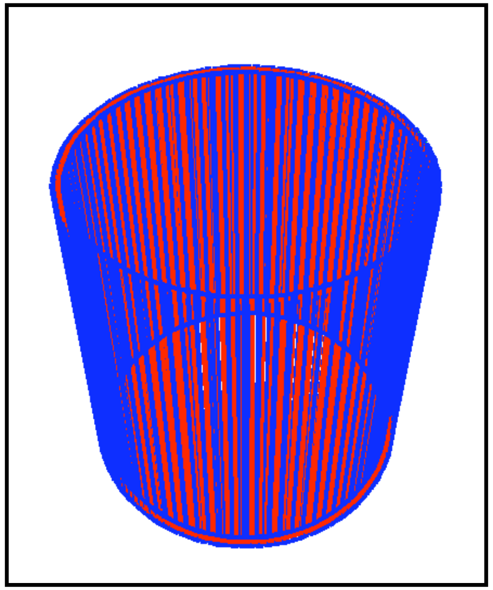
Detector definition

Mechanics: Acrylics and Buffer

Vessel	Dimension	Distortion	Stress	Transport & Integration
	***Inputs :*** *Target : 8 mm* *γ catcher : 12 m* ***Loads =** dead load*	 distortion : <1 mm	 VM stress: 1 MPa	 
	***Inputs :*** *Buffer : 3 m* ***Loads =*** *2 kg / pmts + dead load*	 distortion : 4.1 mm	 VM stress: 23 MPa	**Truck freq. <7 Hz BUT Eigen freq. ~ 8 Hz Impose a precise integration scenario (last gluing on site)** 

Mechanics: γ ray shiedling





• γ's from rock radioactivity dominate the single rate in the Target+GC (no shield)

•Optimum shielding with 17 cm of low radioactive steel (G3 & G4)

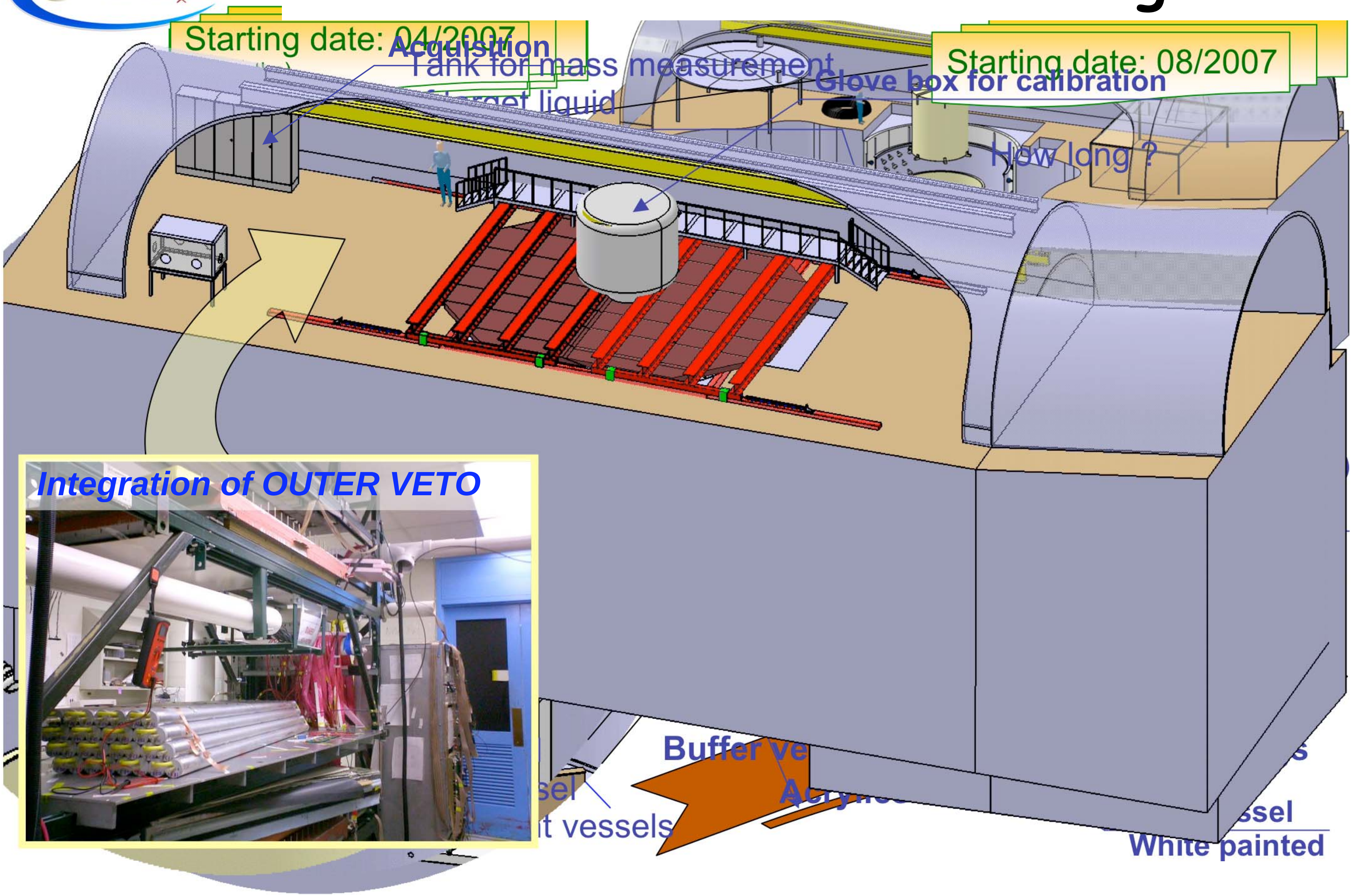
• Cracks → a few % effect

• 250 tons of steel to be assembled in bars.

•A 1 cm steel vessel guarantees the veto tightness

Will be demagntized in lab

Far Detector Integration



Gd doped scintillator development

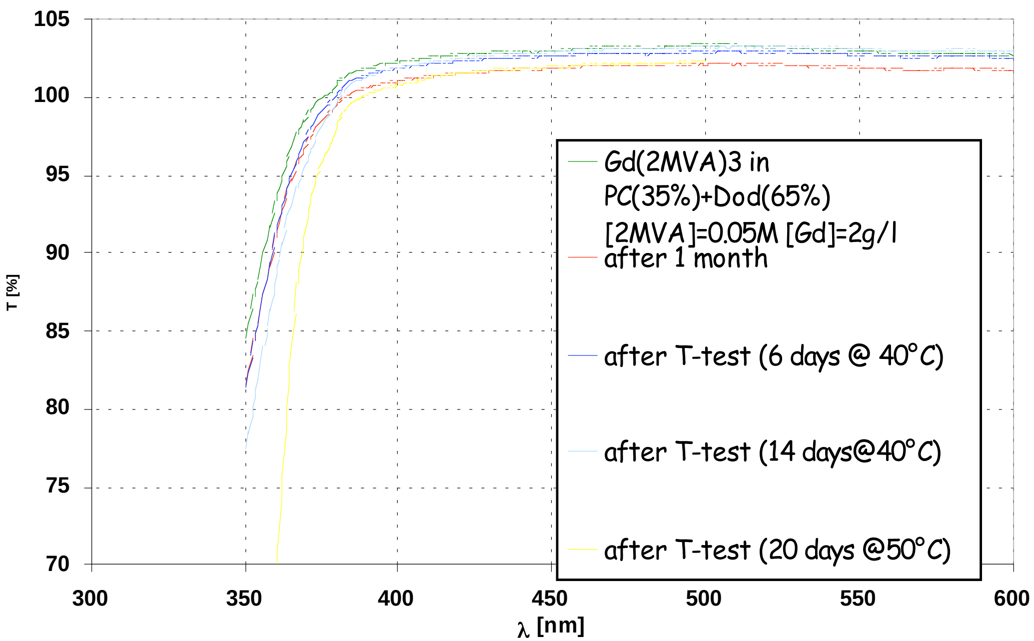
✓**Goal: 0.1% Gd loaded scintillator (follow up of LENS**

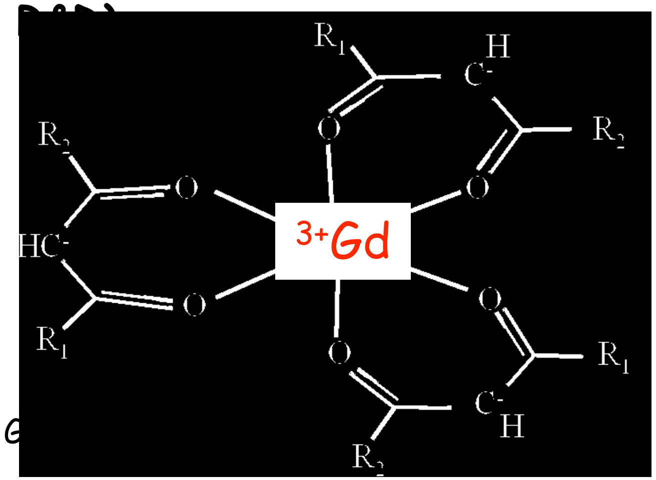
- Light yield ~8000 γ/MeV + attenuation length > 5m
- STABLE & Compatible with acrylic

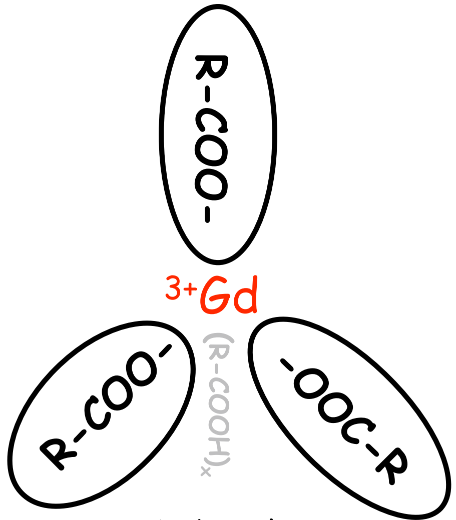
✓ **Ongoing:** **1/ Long term stability**

→ 2004 **2/ scintillator-acrylic compatibility**

- 400 days Ageing test @30-50º [x2-4 each 10º]
- Material compatibility test + acrylic design







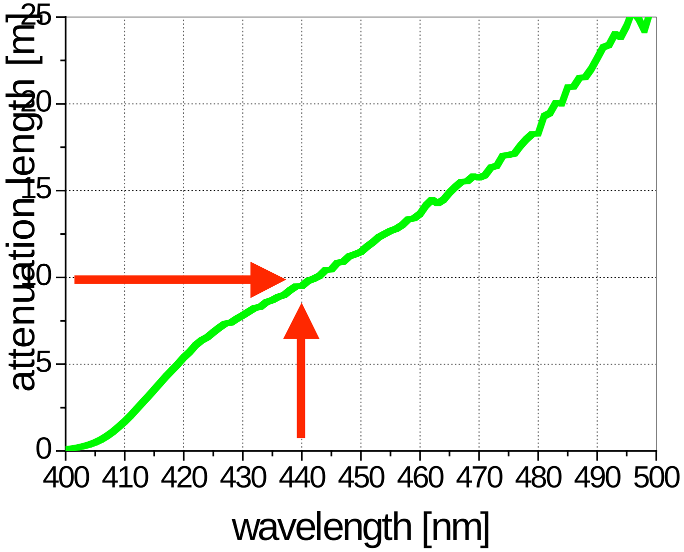
Carboxylate

Scintillator status

(russia-LNGS-heidelberg)

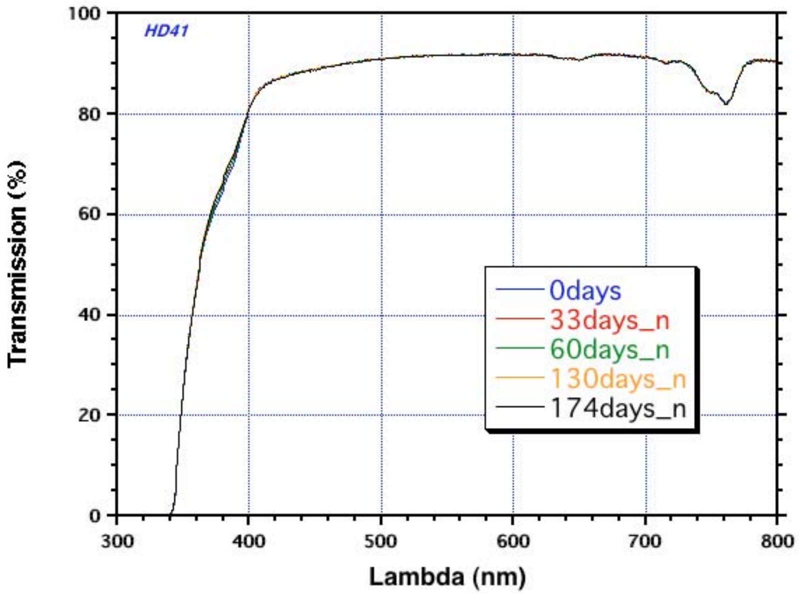
- Gd-loading: 1g/l
- solvent: PXE/dodecane (20:80 by vol.)
- Scintillator development and tests started 2003

Carboxylate scintillator:



Light yield: 89 % of unloaded

Beta-Diketonate scintillator:

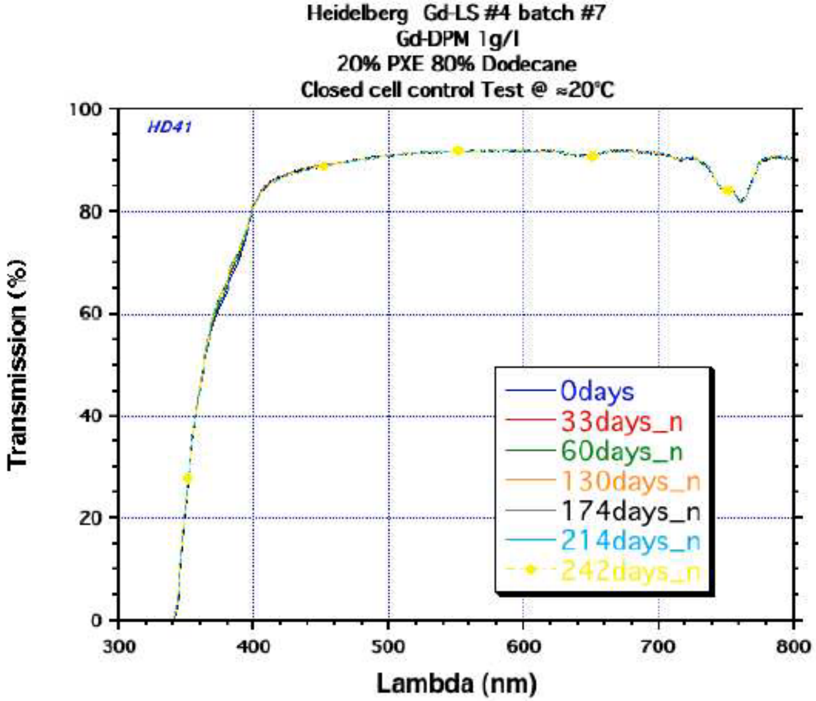


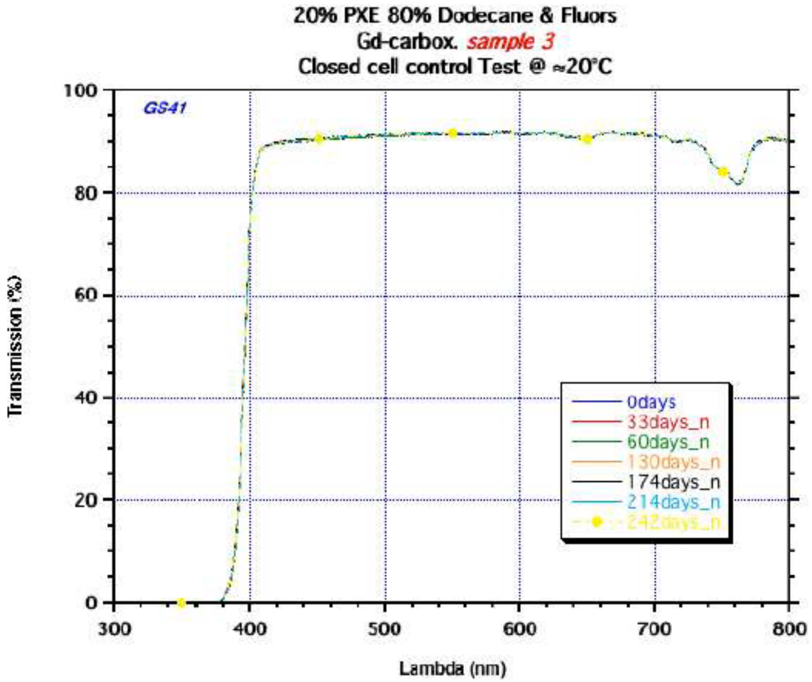
Light yield: 80 % of unloaded

Survey Scintillator Stability

Double Chooz R&D: 2 generation of Gd-Loaded scintillator

- 1st generation < 2004 : Gd-CBX → some failures at 20 °C
- 2nd generation > 2004 Gd-CBX & Gd-Beta-Dikotonates (Gd-dpm)
  - Improved stability and optics (suitable for Double Chooz)
  - R&D finalization phase → Validation on ~100 l scale with a Double Chooz mockup



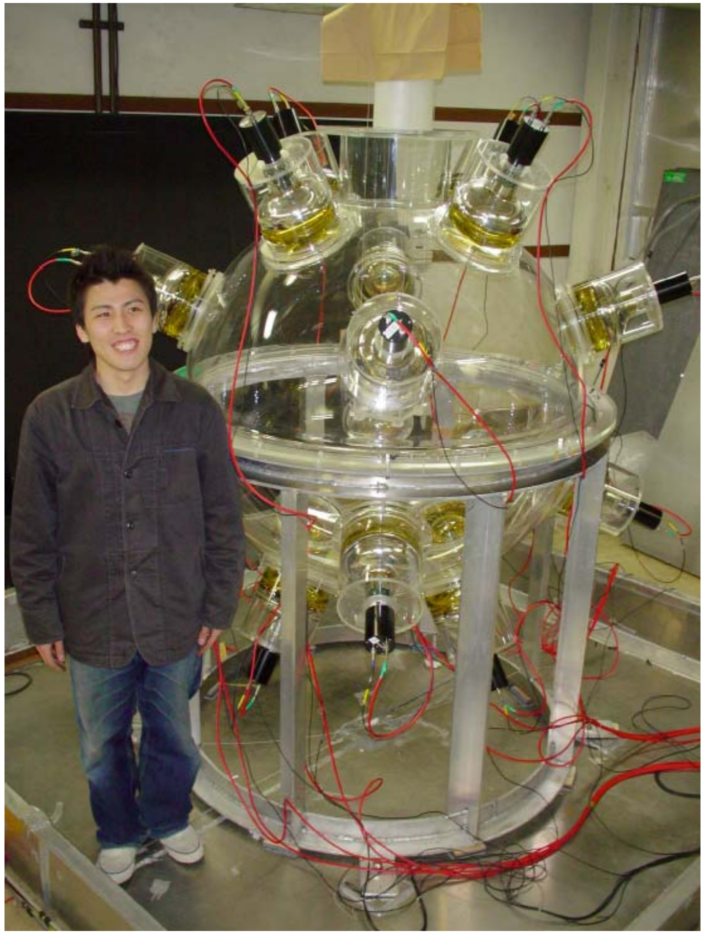


UV-VIS-IR scintillator attenuation length

- Transition to industrial production (100kg is needed): MPIK Heidelberg is constructing a new building for storage and purification of all scintillators for both detectors.
- On-site storage tanks for scintillators in Chooz

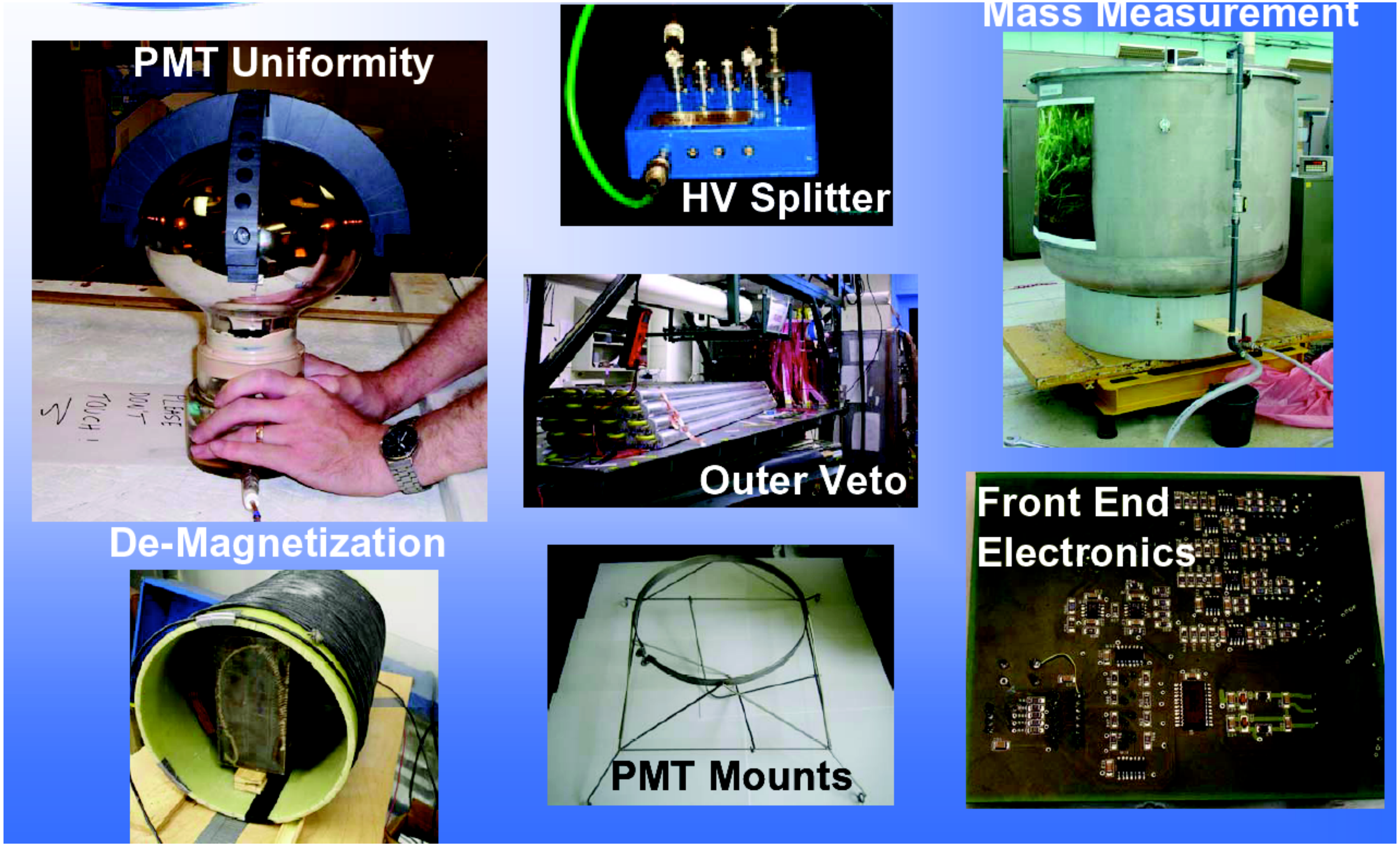
Mockups

- Physical one in Japan (instrumented)



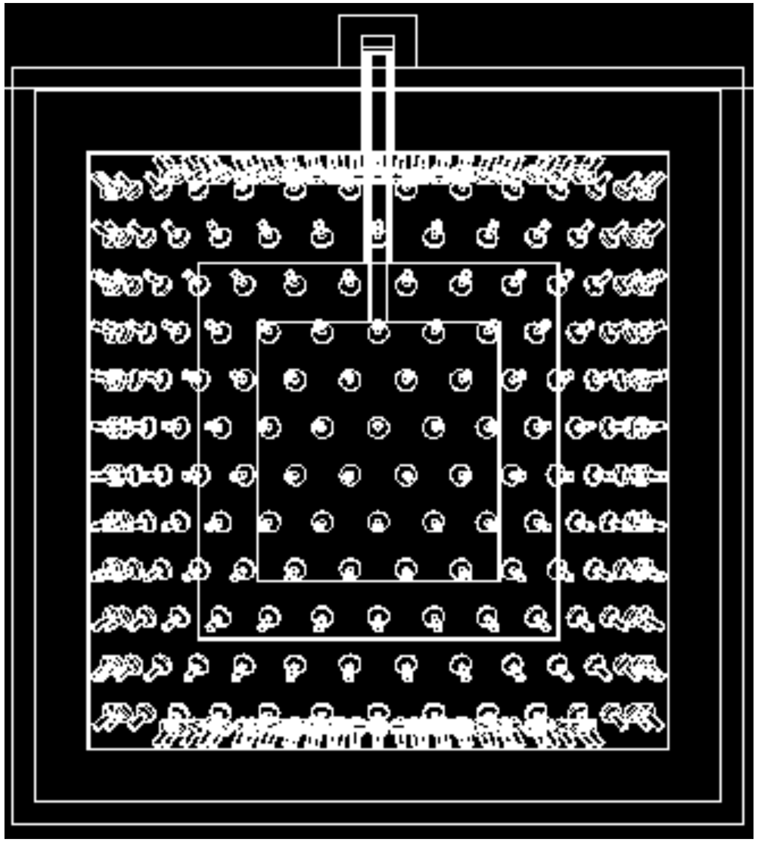
Mechanical on in france

Testing & prototyping



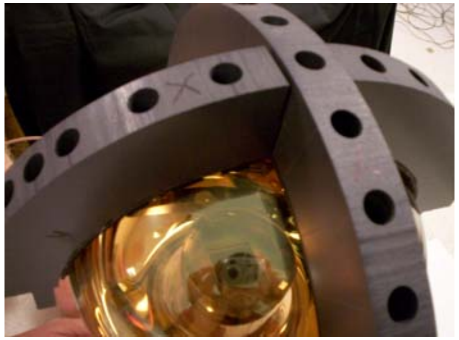
Phototubes baseline

- 8" / 10" Ultra low background tubes
- 534 / 330 PMTs
- ~13 % coverage (200 p.e. Mev)
- Energy resolution goal: 7 % at 1 MeV

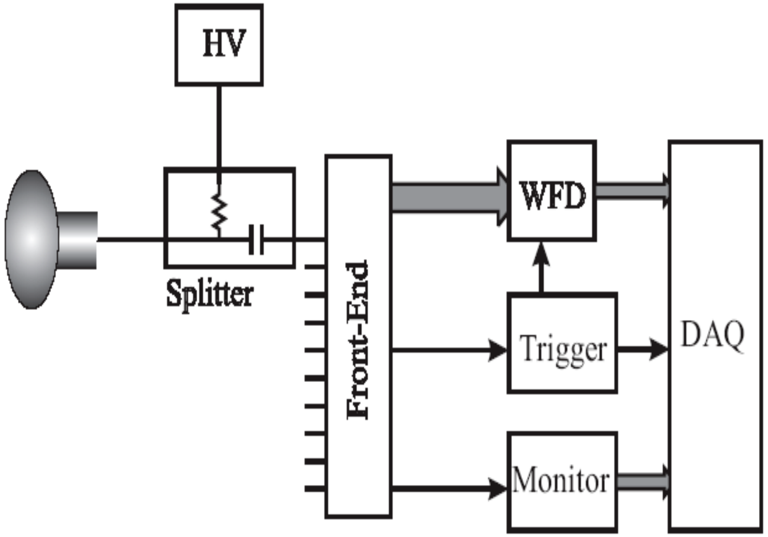


- Current work:
  - PMT selection (size, radiopurity)
    - ETL 9354KB, Hamamatsu, Photonis
  - Angular sensitivity, Concentrators?
  - Magnetic shielding (yes)
    →design study
  - Tilting tube options
  - Cabling & Tightness (done)

tilted	pe/MeV	Ratio
no	191,2	
yes	196,2	1,026



Electronics & DAQ



Hardware digitization
8 channels : Waveform module
125 modules
7 VME crates
18 modules/crate

V1721 developped DC/CAEN

Total 11 GB/d

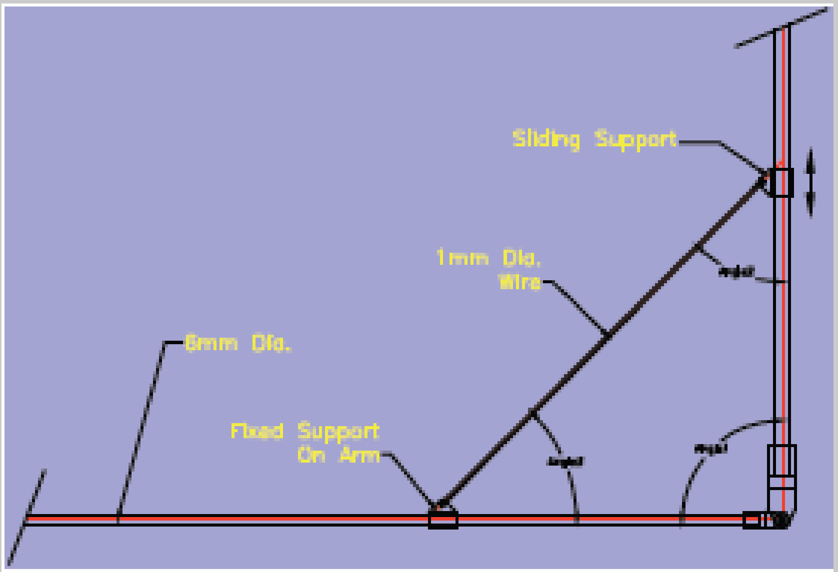
First level trigger (hardware) on single light : coincidences performed by software

Trigger:
- Detect coincidences
- Detect neutrinolike events (2 singles with E < 50MeV)
- Keep more data for neutrinolike than for other events

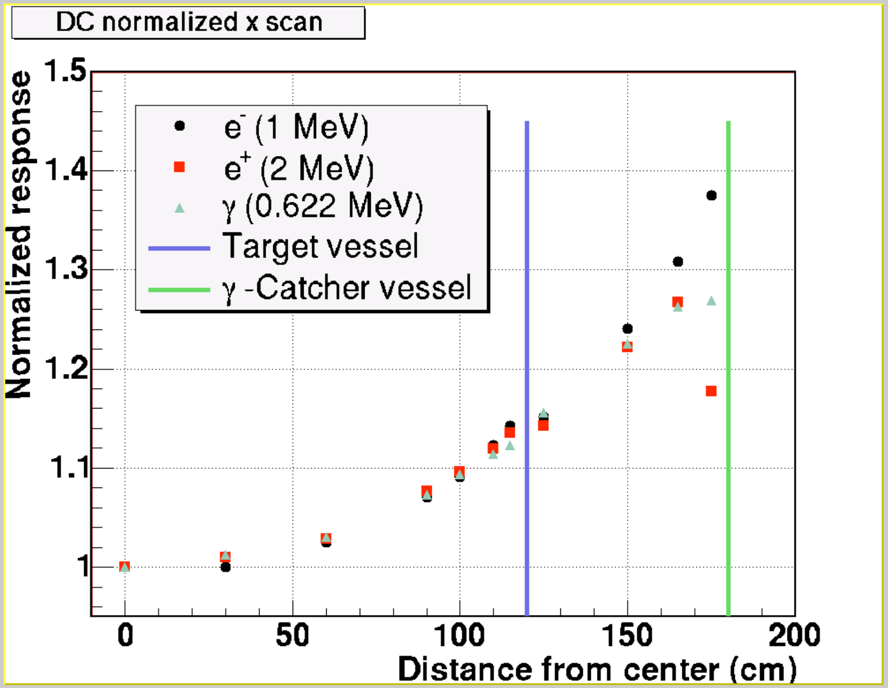
Monitoring
- Artificial triggers:
- Pulser
- Laser
- Fission chamber (neutron source)

Calibration

- Target region:
Articulated arm
(2-3 cm accuracy)
- γ-catcher and buffer:
Wire driven sources
(guide tubes)



Simulated detector response for various sources:



By products:
Non proliferation effort

Non proliferation effort
reactor monitoring

✓ IAEA: International Agency for Atomic Energy

✓ Missions: Safety & Security, Science & Technology, Safeguard & Verification

Control that member states do not use civil installations with military goals (production of plutonium !)

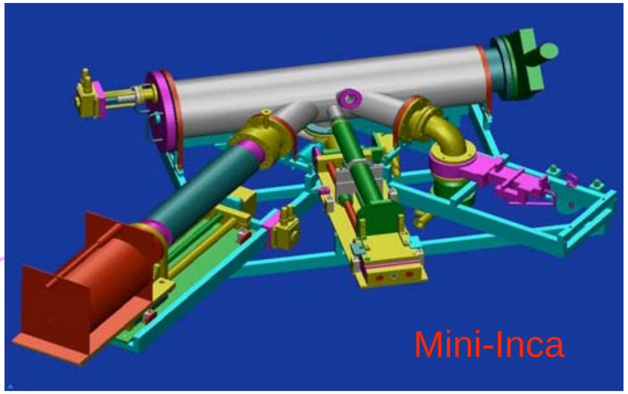
- Control of the nuclear fuel in the whole fuel cycle *
- Fuel assemblies, rods, containers * (*Anti-neutrinos could play a role!)
- Distant & unexpected controls of the nuclear installations *

✓ Why IAEA is interested to antineutrino ?

- IAEA wants the « state of the art » methods for the future

✓ IAEA wants a feasibility study on antineutrinos

- Monitoring of the reactors with a Double-Chooz like detector
- Monitoring a country – new reactors "à la KamLAND"



✓ **Double-Chooz-IAEA:**

- Perform new antineutrino spectrum measurement @ILL reactor (Mini-Inca + β-spectrometer)
- Use Double-Chooz near as a 'prototype' for nuclear reactor monitoring
- Other studies like large and very large underwater antineutrino detectors …
- Collaboration with Los Alamos, Livermore, Sandia

Byproducts: geoneutrinos

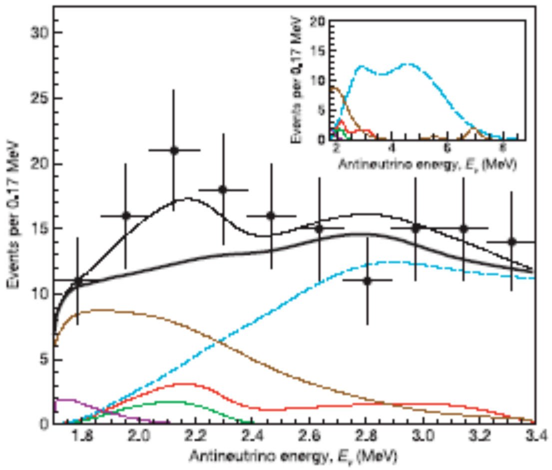
-> Recent kamland result

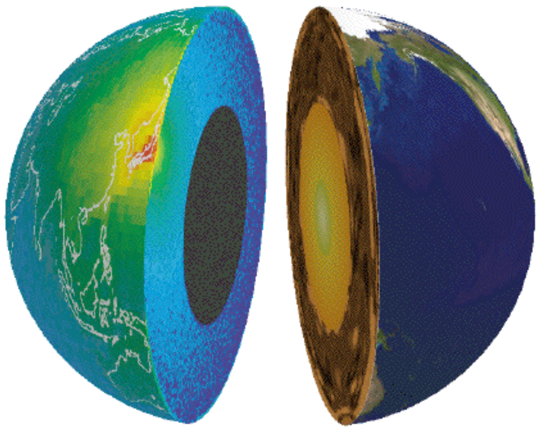
Double Chooz is too small to see them,

But can help study the measurement

Idea: neutron keeps track of the direction

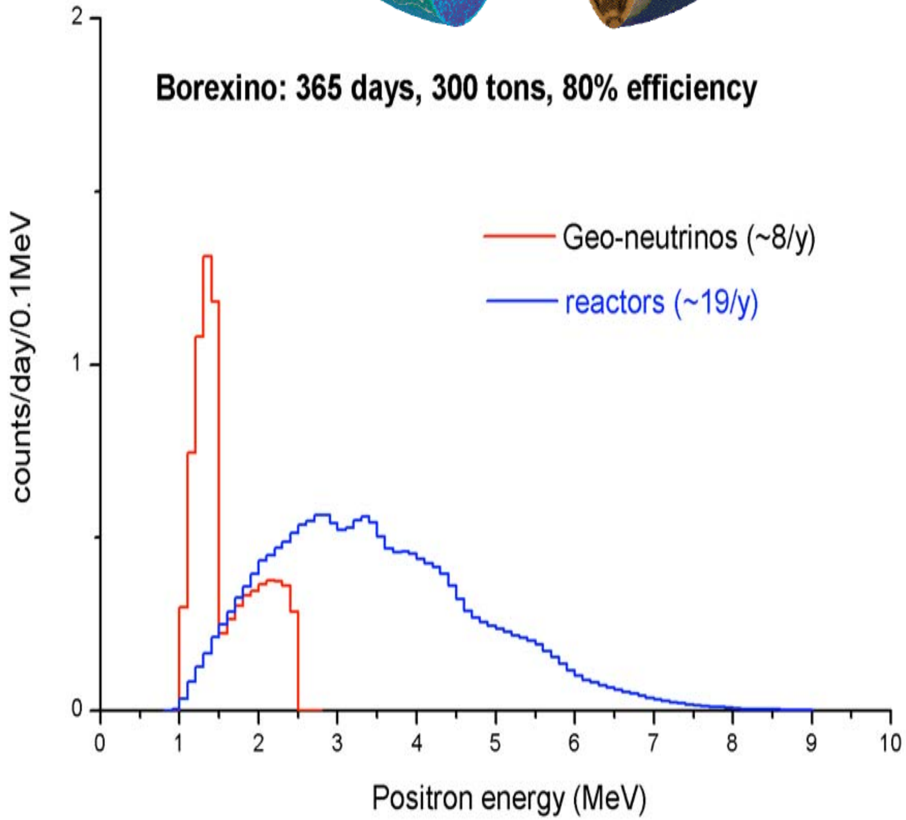
Recontruct e+ and n position



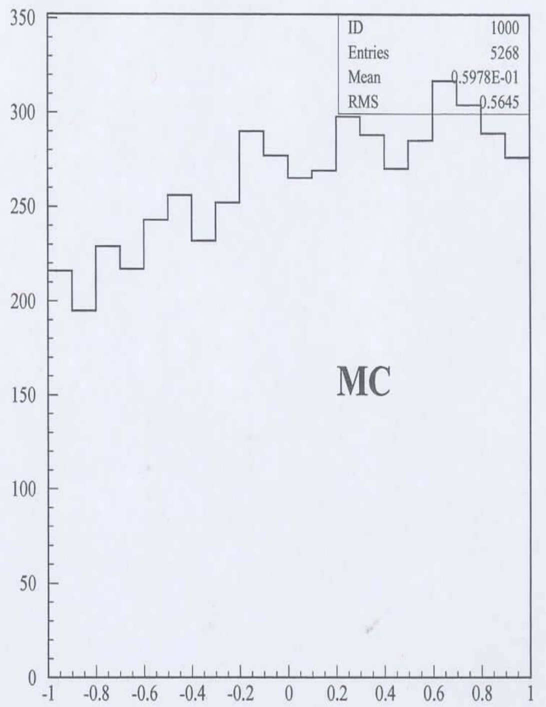


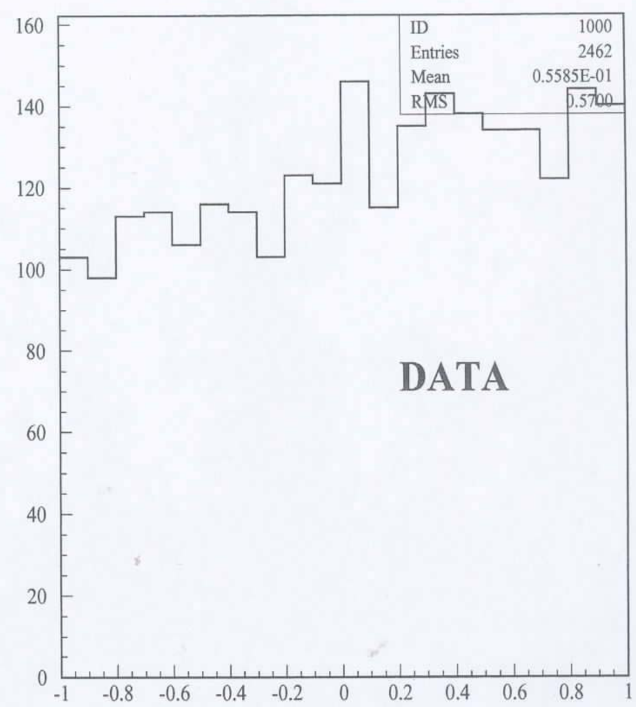
First evidence: kamland

Need neutrino direction measurement



To find the direction of incoming neutrinos, compare the GLOBAL angular ditribution with MC





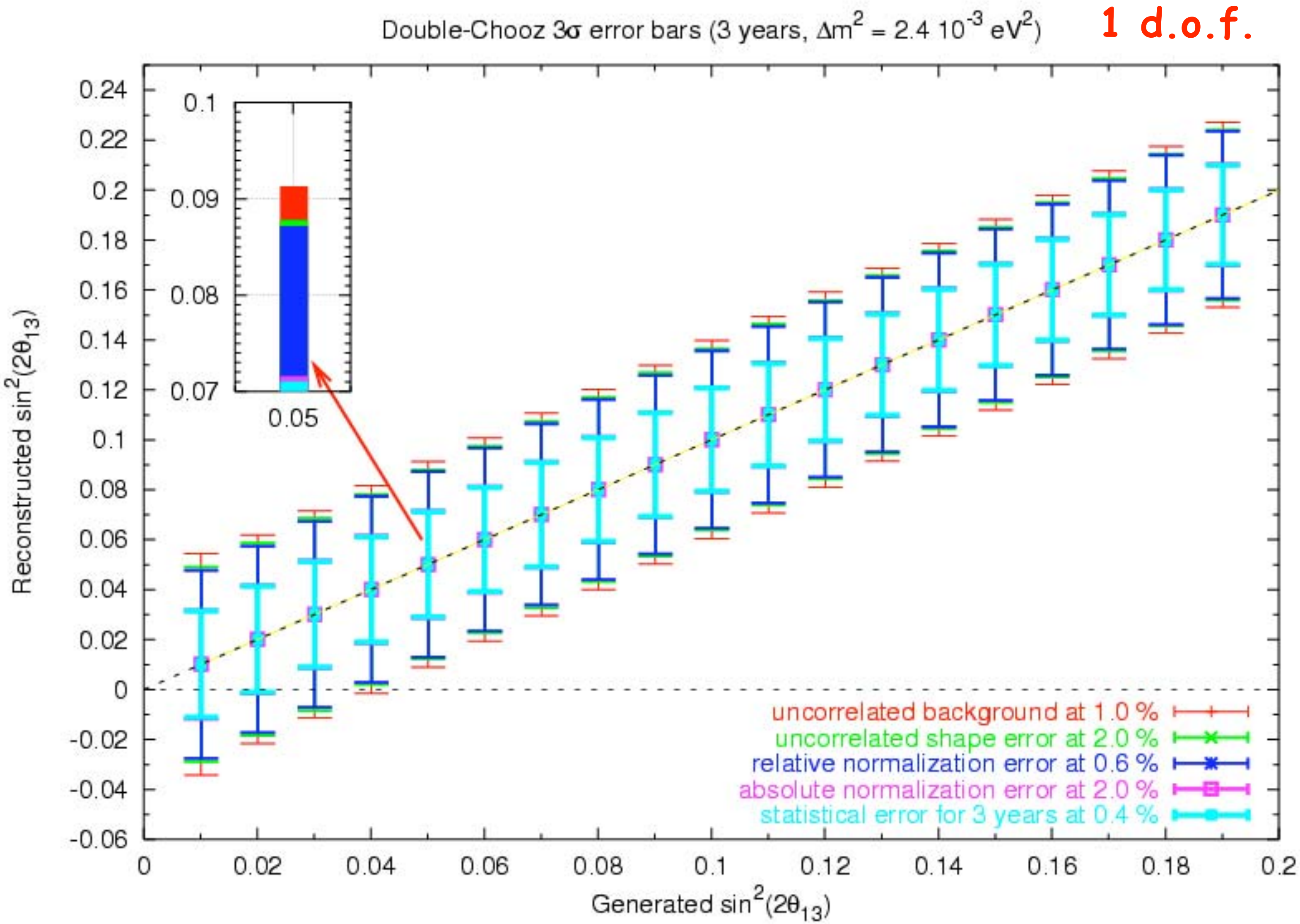
	$\mid\vec{p}\mid$	ϕ	θ	Uncertainty
Data	0.055	$-70°$	$103°$	$18°$
MC	0.052	$-56°$	$100°$	$19°$

Chooz first experiment
Ex/9906011 :

Double Chooz: large numbers of neutrinos with known direction, which will allow to improve algorythr

conclusions

Discovery potential

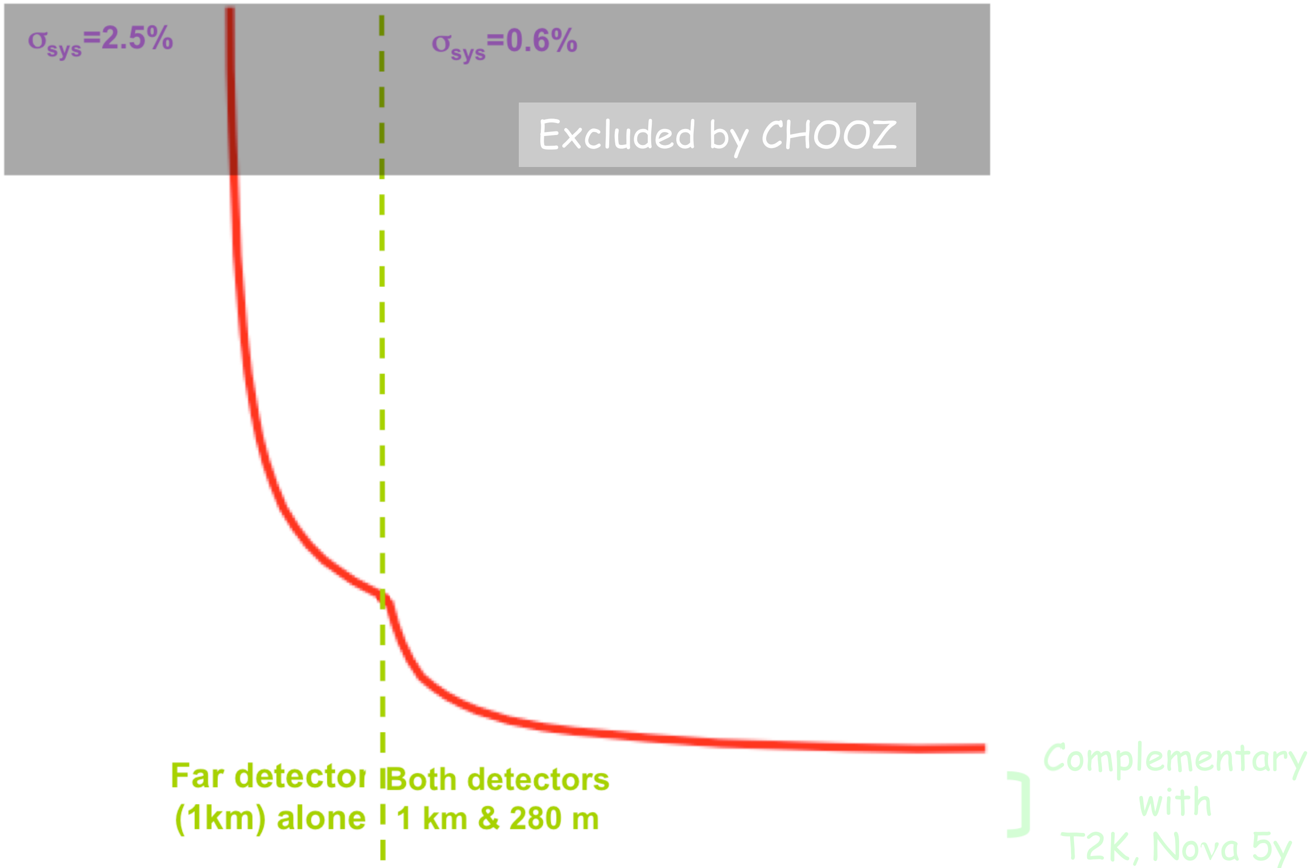


2008-2013: Data taking

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

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

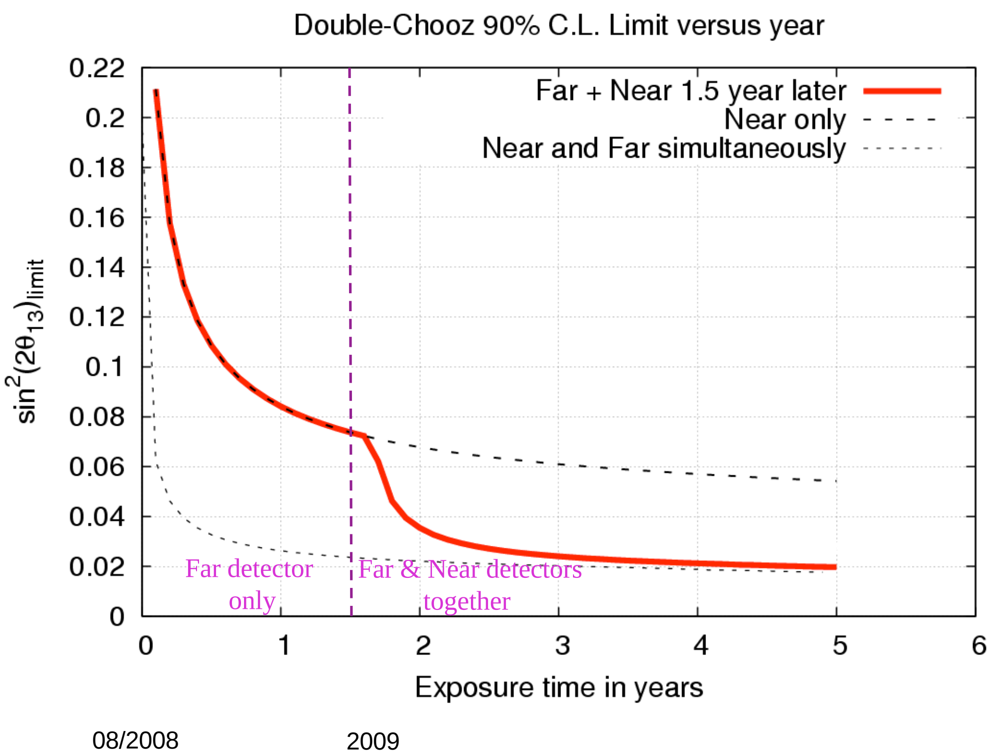
- Efficiencies included
- 1% 'bin to bin' uncorrelated error on background subtraction.
- Systématiques:
  - $\sigma_{abs} = 2.0\%$
  - $\sigma_{rel} = 0.6\%$
  - $\sigma_{scl} = 0.5\%$
  - $\sigma_{shp} = 2.0\%$
  - $\sigma_{\Delta m^2} = 20\%$



Sensitivity 2007-2012

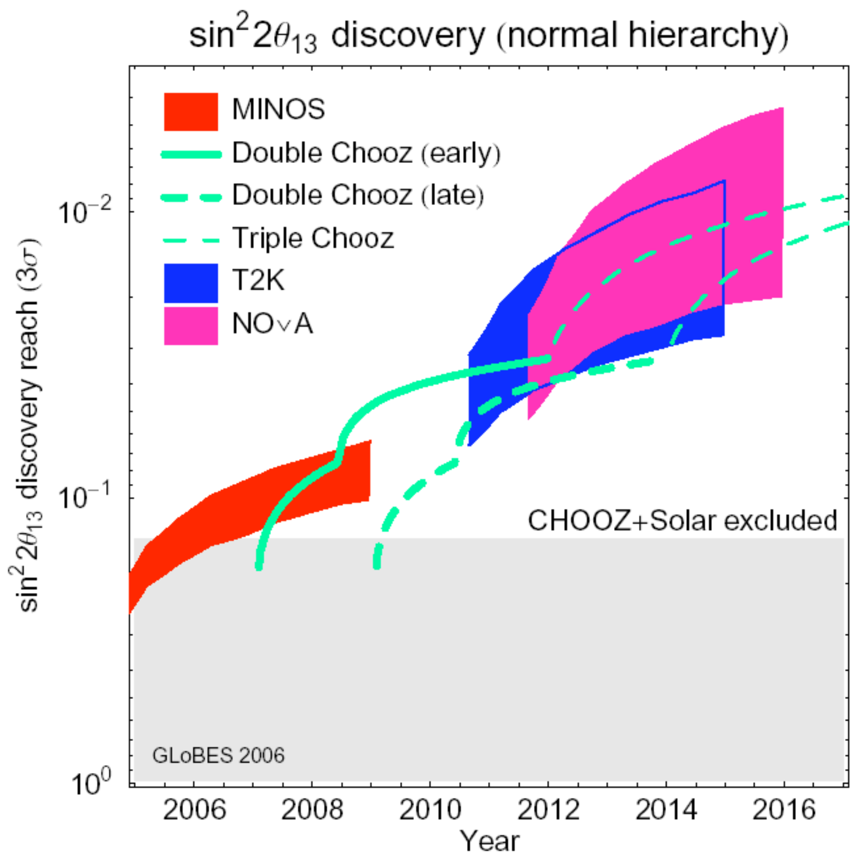
Double-Chooz Far Detector starts in 2007
Double-Chooz Far detector follows 16 months later

90% C.L. contour if $\sin^2(2\theta)=0$
Δm^2_{atm} = 2.8 10^{-3} eV^2 is supposed to be known at 20% by MINOS

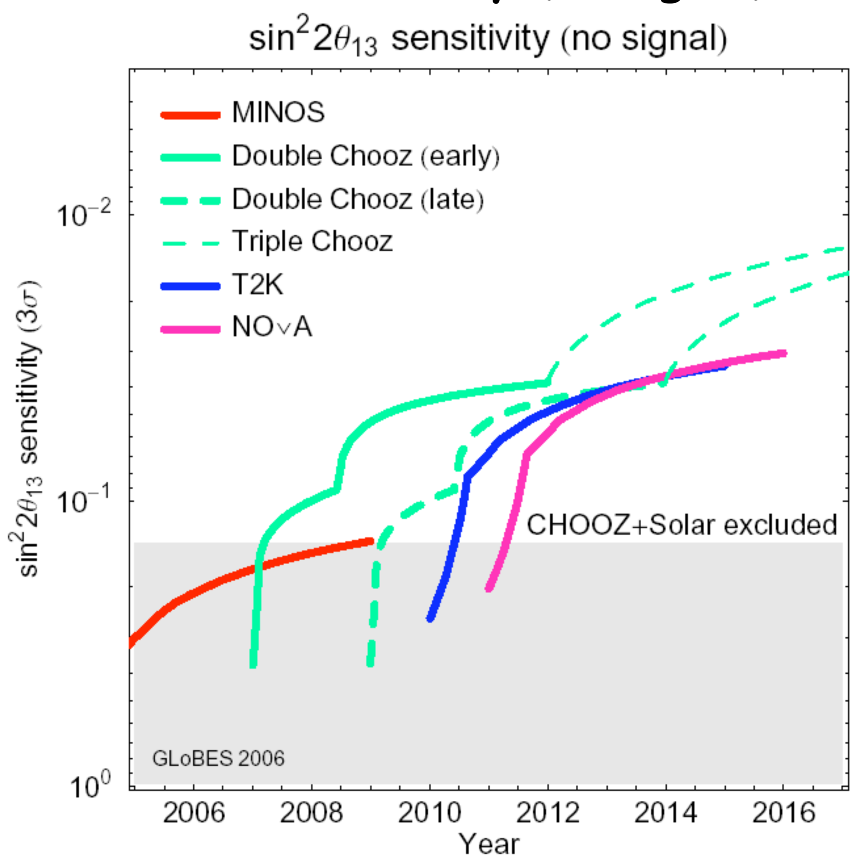


Experimental context

3σ discovery potential



3σ sensitivity (no signal)



Conclusions & outlook

Double Chooz ready to go! Moving towards the construction phase …

- *2007* → *Start of the integration*
- *2008* → *Start of phase I : Far 1 km detector alone – 1 km*

  $\sin^2(2\theta_{13}) < 0.06$ in 1,5 year

  World best sensitivity foreseen from 2008?
- *2009* → *Start of phase II : Both near and far detectors - 280 m + 1 km*

  $\sin^2(2\theta_{13}) < 0.025$ in 3 years

  Complementarity with Superbeam experiments: T2K, Nova

If oscillation found, build a new project to check it : a big detector at a powerful site ..