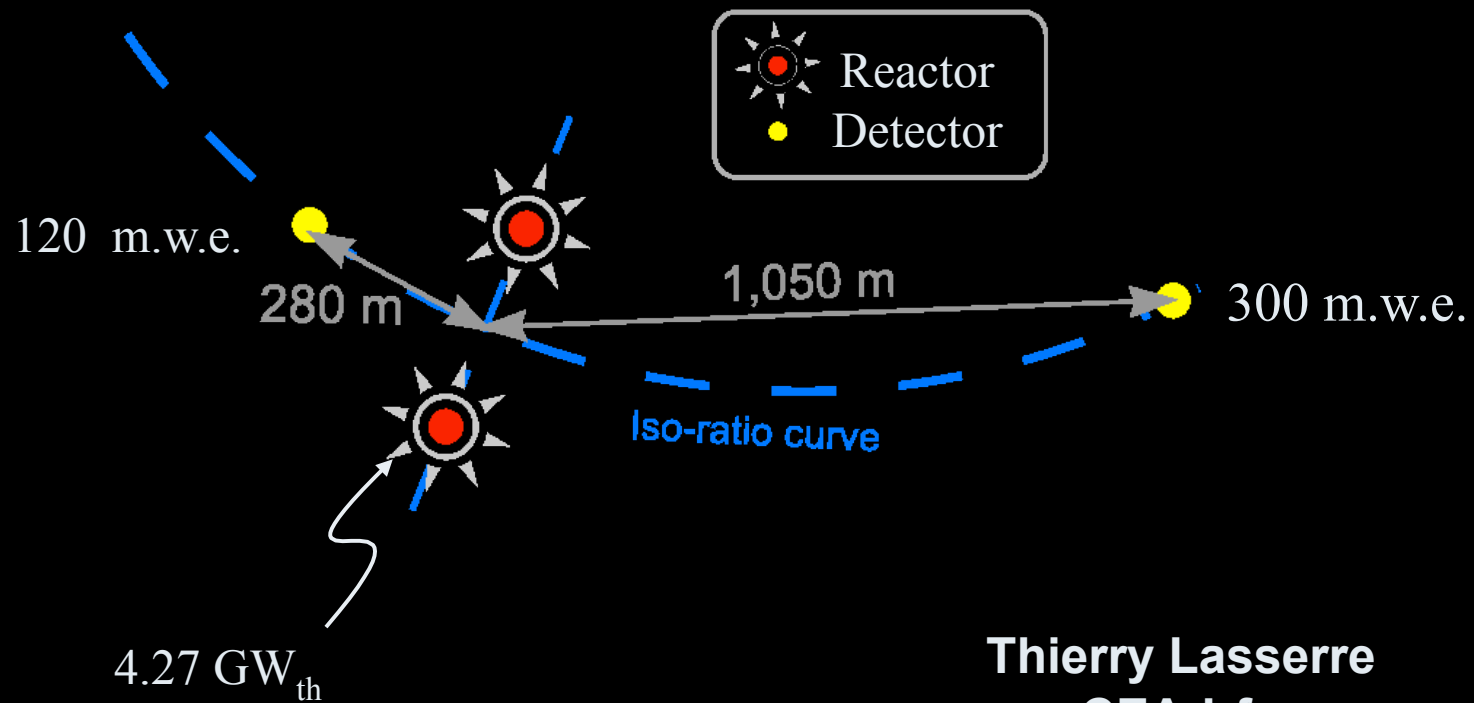
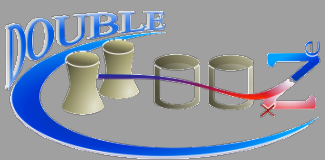


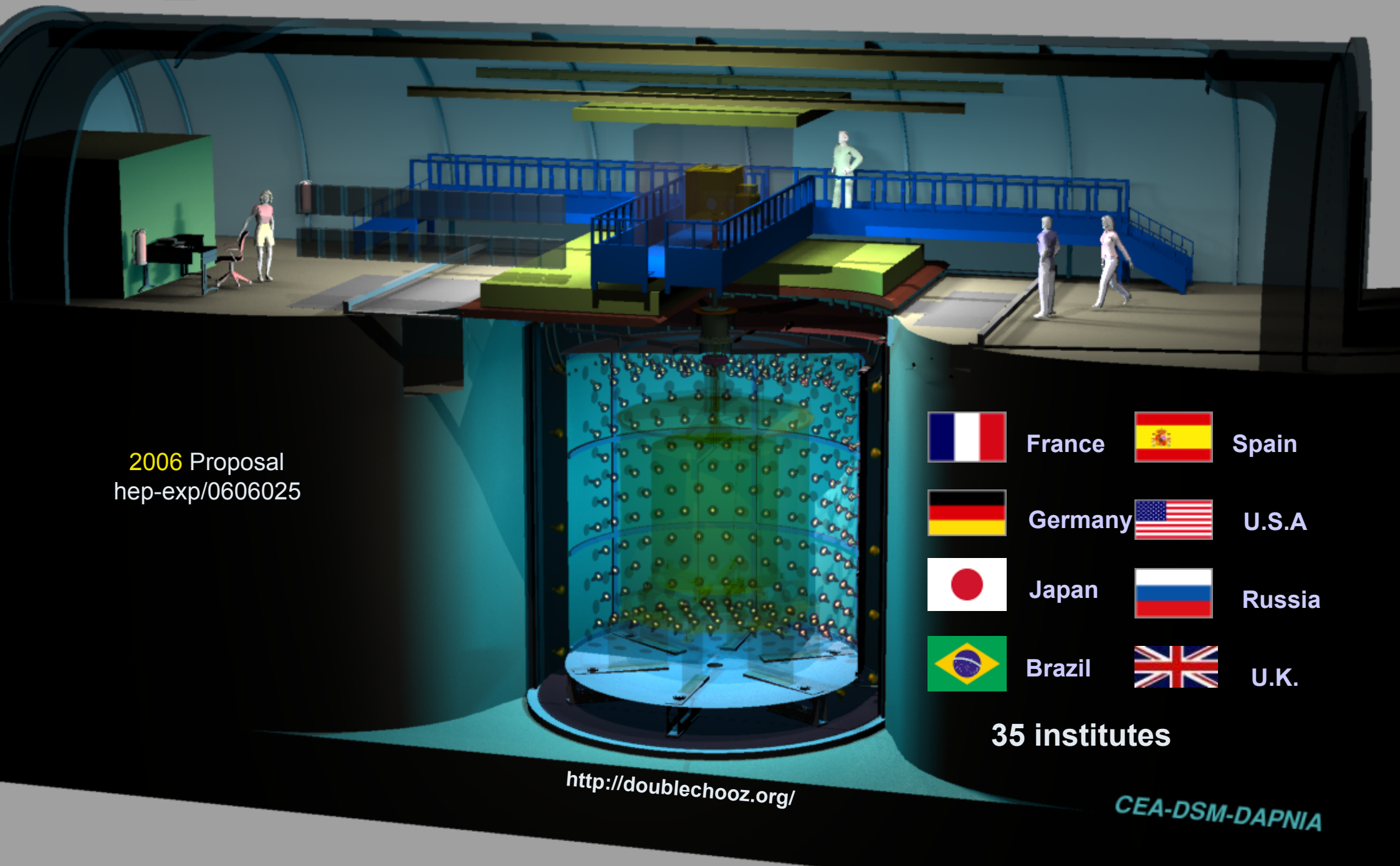
Double Chooz



Thierry Lasserre
CEA-Irfu
Annecy, Feb. 4th 2011



Double Chooz



2006 Proposal
hep-exp/0606025



France



Spain



Germany



U.S.A



Japan



Russia



Brazil

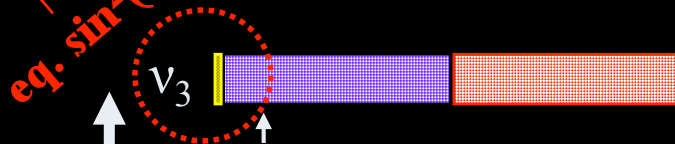


U.K.

35 institutes

<http://doublechooz.org/>

CEA-DSM-DAPNIA

θ_{13} $|U_{e3}|^2$
 $\approx \sin^2(2\theta_{13})$  $(\text{Mass})^2$

$$\Delta m_{\text{atm}}^2 = 2.5 \cdot 10^{-3} \text{ eV}^2$$

 ν_2 ν_1

$$\Delta m_{\text{sol}}^2 = 8 \cdot 10^{-5} \text{ eV}^2$$

$$\nu_e \quad \text{yellow} \quad |U_{ei}|^2 \quad \nu_\mu \quad \text{purple} \quad |U_{\mu i}|^2 \quad \nu_\tau \quad \text{red} \quad |U_{\tau i}|^2$$

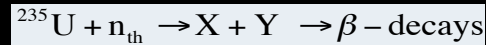
The Current Central Role of θ_{13}

- **θ_{13} is the last neutrino oscillation parameter to be measured**
 - θ_{12} & $\theta_{23} \gg \theta_{13} \rightarrow$ a guideline for oscillation models
 - Improvement of mass parameters (m_e , $m_{\beta\beta}$) & astrophysical sources
- **Quest for $\theta_{13} \rightarrow 2015 \rightarrow$ Quest for CP violation in the electroweak sector.**
 - $\sin^2(2\theta_{13}) > 0.02 \rightarrow$ conventional neutrino beam ($\pi \rightarrow \mu \nu$, 1% contamination)
 - $\sin^2(2\theta_{13}) < 0.02 \rightarrow$ neutrino factories ($\mu \rightarrow \nu$ or $A X \rightarrow e + \nu$, pure beams)
- **Experimentally: need to connect the ν_e flavour with the isolated neutrino (Δm_{atm}^2)**
 - **@Reactor: $L \sim 1$ km, $E \sim \text{MeV}$**
 - Disappearance expt. ; (Double Chooz, Daya Bay, Reno)
 - θ_{13} only $\rightarrow$ 'clean'
 - **@Beam: $L \sim 1000$ km, $E \sim \text{GeV}$**
 - Appearance expt. ; (T2K, Nova)
 - (θ_{13} , NH/IH, δ_{CP}) $\rightarrow$ correlations & degeneracies

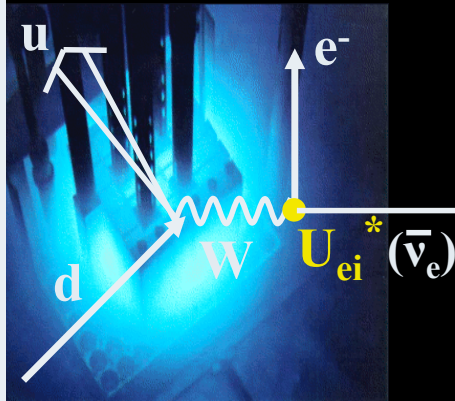
$\rightarrow$ Complementary projects

Double Chooz Oscillation Physics

$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) =$$



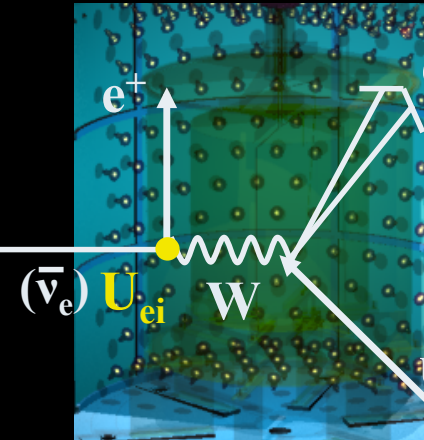
$$\left[\sum_{i=1,2,3} \text{Ampl}_i \right]$$



Reactor core

$$e^{-im_i^2 \frac{L}{2E}}$$

$\bar{\nu}_i$



Target H

$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = \left[\sum_i U_{ei}^* e^{-im_i^2 \frac{L}{2E}} U_{ei} \right]^2 = 1 - \sin^2(2\theta_{13}) \left[\sin \left(1.27 \frac{\Delta m_{\text{atm}}^2 (\text{eV}^2) L (\text{m})}{E (\text{MeV})} \right) + O \left(\frac{\Delta m_{\text{sol}}^2}{\Delta m_{\text{atm}}^2} \right) \right]$$

- Simple oscillation formula

→ depends $\sin^2(2\theta_{13})$ & Δm_{atm}^2 , weakly on Δm_{sol}^2

- MeV antineutrinos → disappearance experiment

→ independent of δ -CP

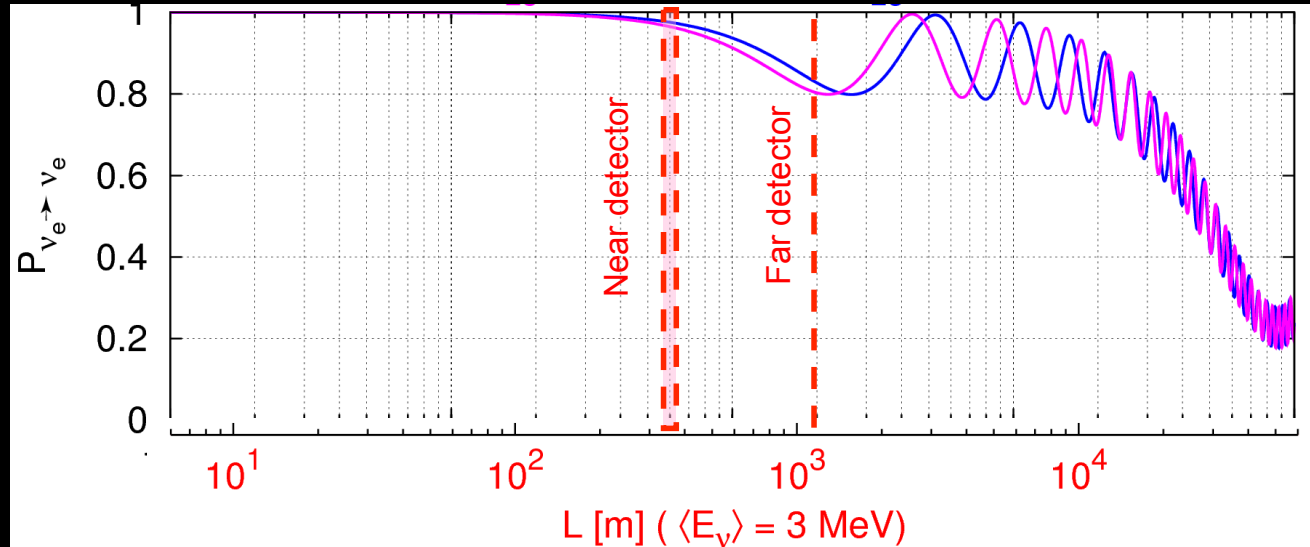
- MeV neutrinos + 1 km baseline → matter effects $O[10^{-4}]$

→ independent of $\text{sign}(\Delta m_{13}^2)$

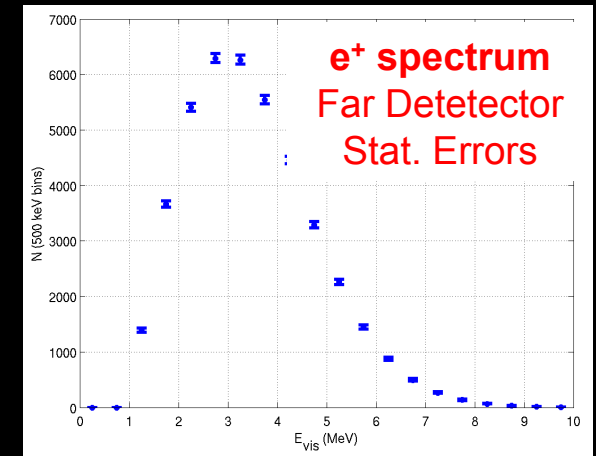
‘clean’ θ_{13}
information

The experimental concept

$$P(\nu_e \rightarrow \nu_e) = 1 - \sin^2(2\theta_{13}) \sin^2(1.27 \Delta m_{31}^2 L/E)$$

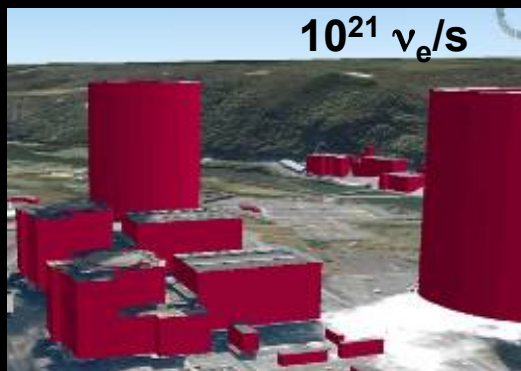


Ardellier et. al, hep-ex/0405032

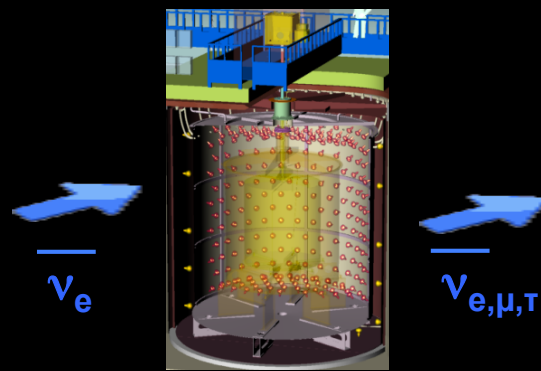


$$\Delta m_{\text{atm}}^2 = 3.0 \cdot 10^{-3} \text{ eV}^2$$

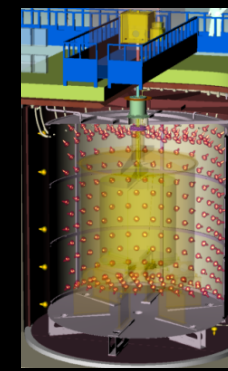
$$\sin^2(2\theta_{13}) = 0.12$$



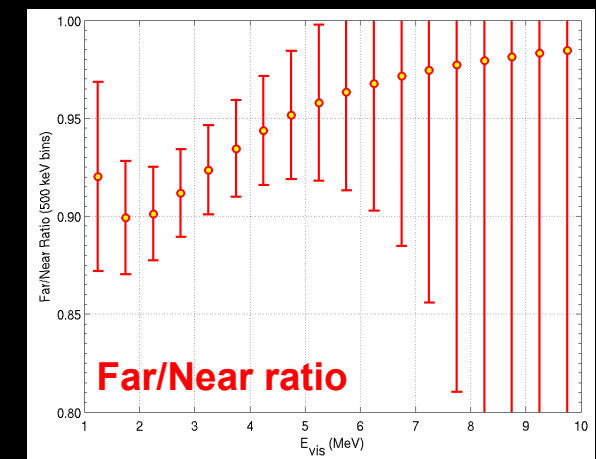
Chooz Nuclear Power Station
2 cores of 4.27 GW_{th} each



Near detector
400 m

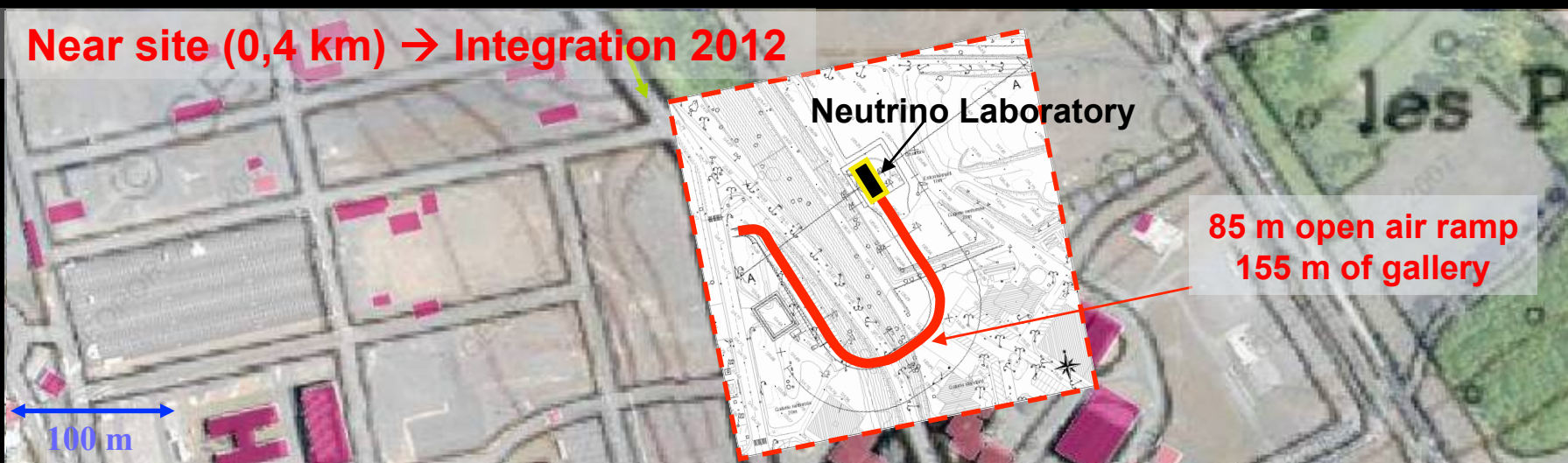
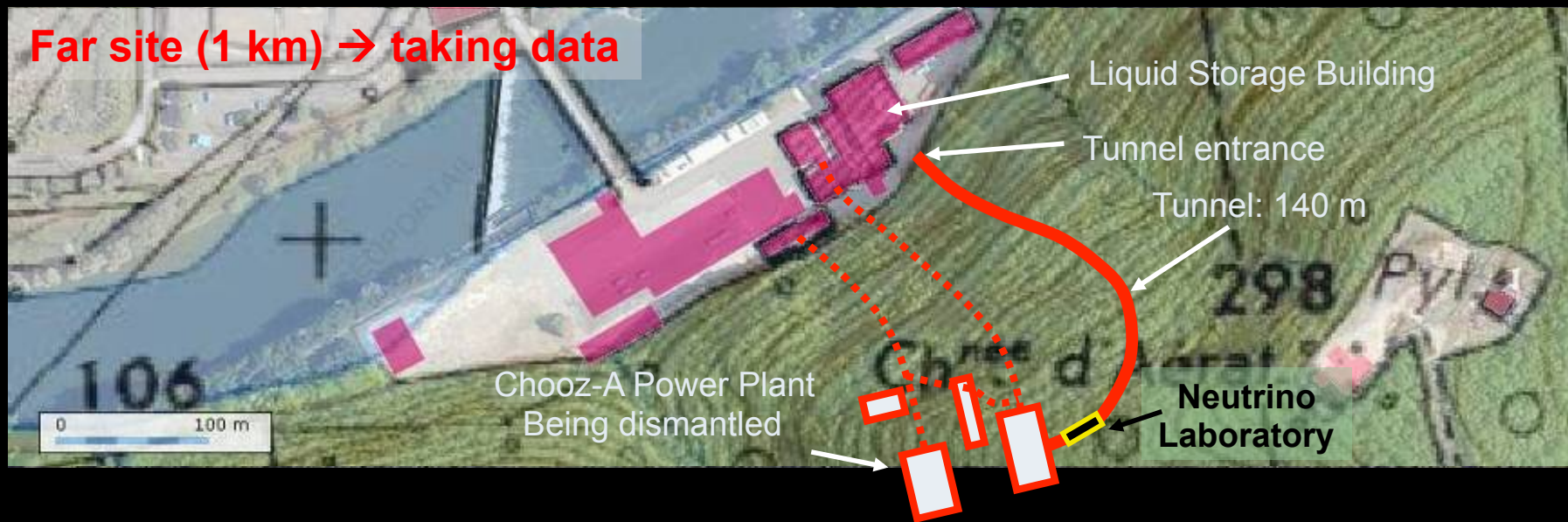


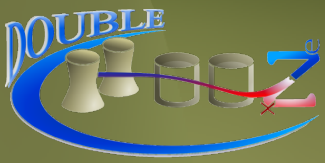
Far detector
1050 m



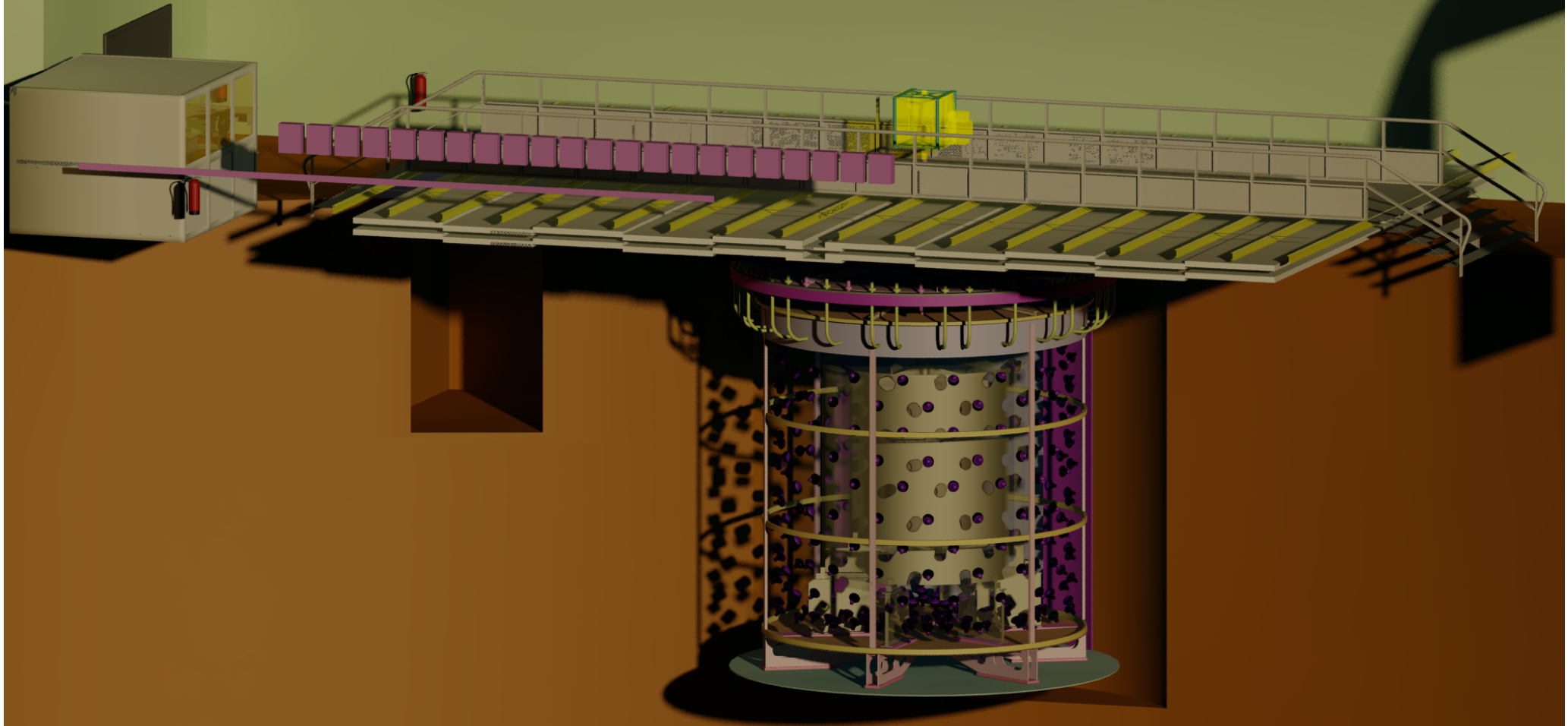


Underground Sites



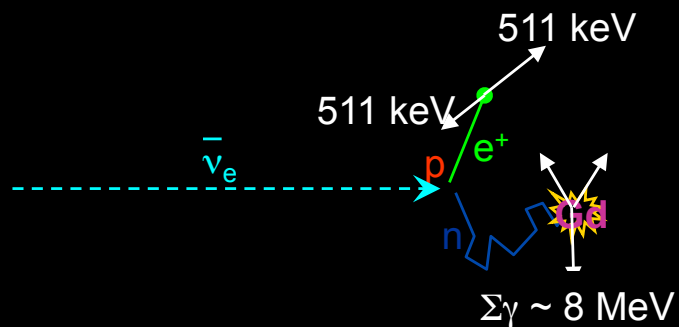


Near Detector Construction (2011-12)



Background & Signal

e^- antineutrino Signature



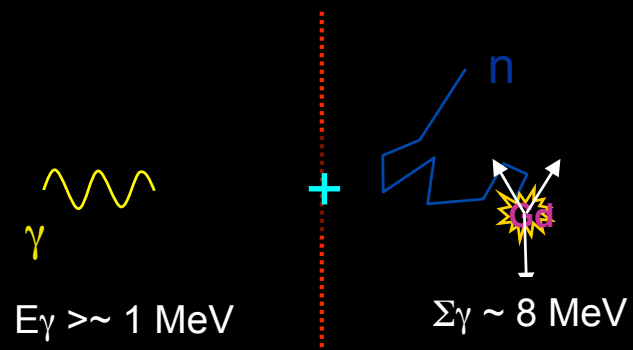
Prompt e^+ (1-8 MeV) Delayed n Gd-capture (8 MeV)

Time correlation: $\tau \sim 30 \mu\text{s}$

Space correlation: $< 1 \text{ m}$

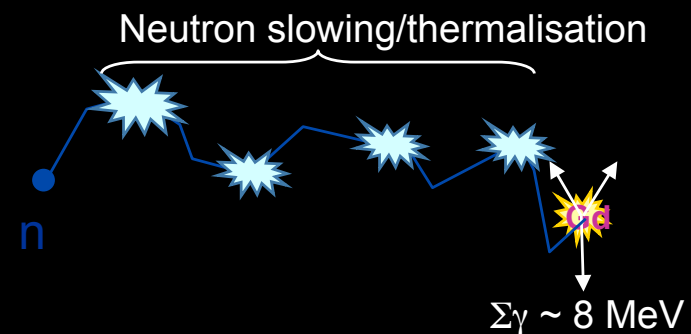
Far: 70 neutrinos d^{-1}
Near: 500 neutrinos d^{-1}

Accidental Background



Far: 2 neutrinos d^{-1}
Near: 11 neutrinos d^{-1}

Correlated Background



Far: 1.6 neutrinos d^{-1}
Near: 5.2 neutrinos d^{-1}

Improving w/r CHOOZ

- **Best Sensitivity @CHOOZ:** $R = 1.01 \pm 2.8\%(\text{stat}) \pm 2.7\%(\text{syst})$

- **Luminosity increase:**

- $L = 3\text{-}5 \text{ years} \times 8.4 \text{ GW} \times (10 \text{ m}^3 \times 6.10^{28} \text{ H/m}^3)$
- 40000 events $\rightarrow$ 0.5% systistical error goal

- **Reducing Systematics:**

- 2 detector concept
- New detector design
 - Improved calibration capabilities
 - Less backgrounds
 - neutron & gamma shielding
 - radiopurity & cleanliness
 - Improved background rejection
- **0.6% sys. rel systematics goal** $\longrightarrow$

Systematics	CHOOZ	Double Chooz
Reactor	1.9%	---
Target H	0.8%	0.2%
Efficiency	1.5%	0.5%



Detector

New 4-region large detector concept
from Double Chooz Coll. (2003)

http://bama.ua.edu/~busenitz/rnu2003_talks/lasserre1.doc

Outer Veto: plastic scintillator strips (400 mm)

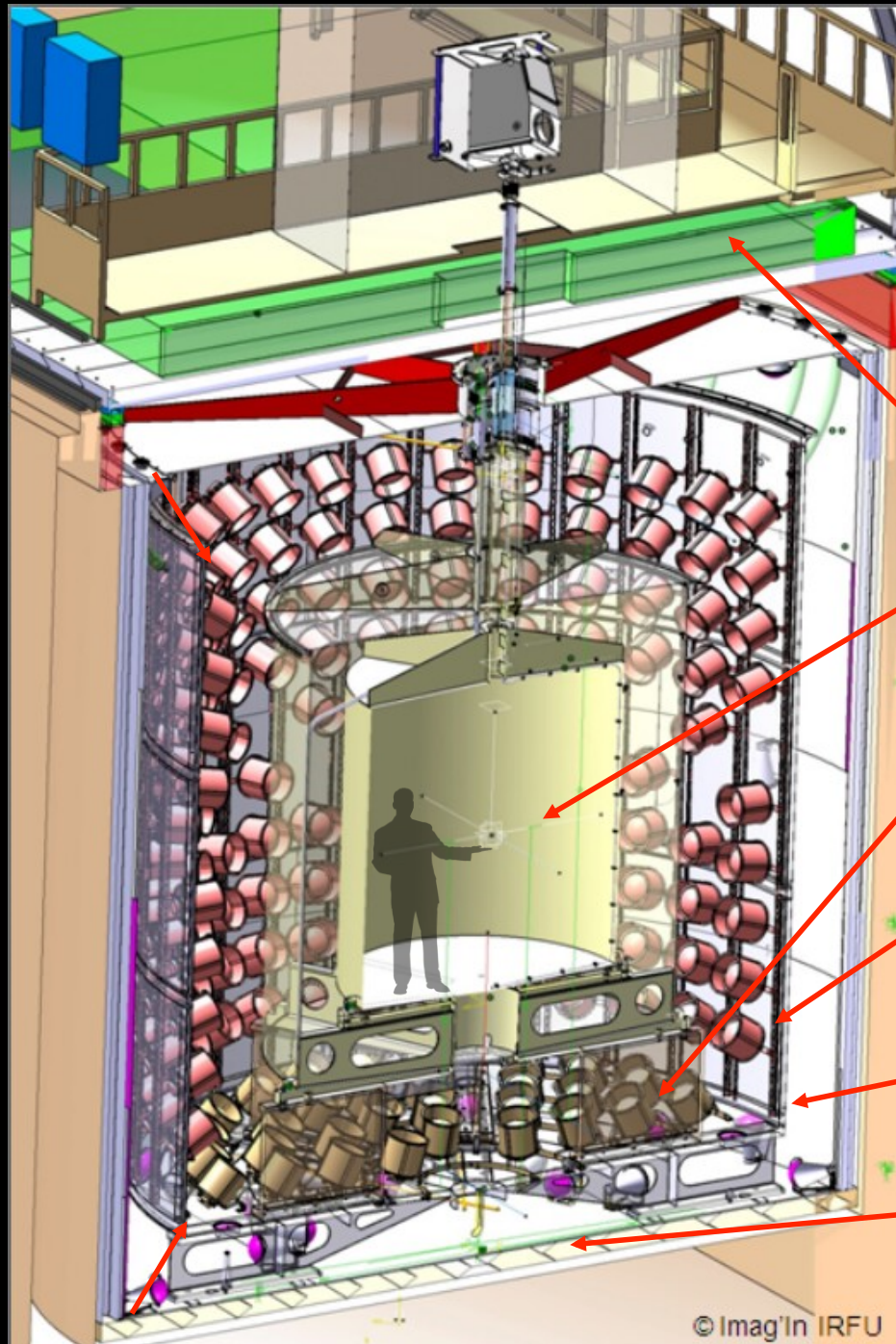
ν -Target: 10,3 m³ scintillator doped with 1g/l of Gd compound in an acrylic vessel (8 mm)

γ -Catcher: 22,3 m³ scintillator in an acrylic vessel (12 mm)

Buffer: 110 m³ of mineral oil in a stainless steel vessel (3 mm) viewed by 390 PMTs

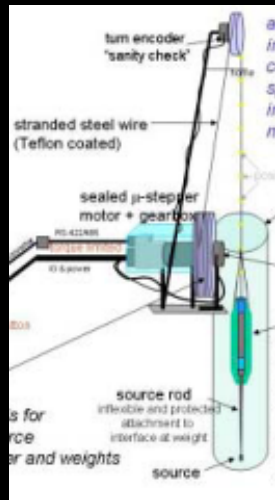
Inner Veto: 90m³ of scintillator in a steel vessel equipped with 78 PMTs

Veto Vessel (10mm) & Steel Shielding (150 mm)



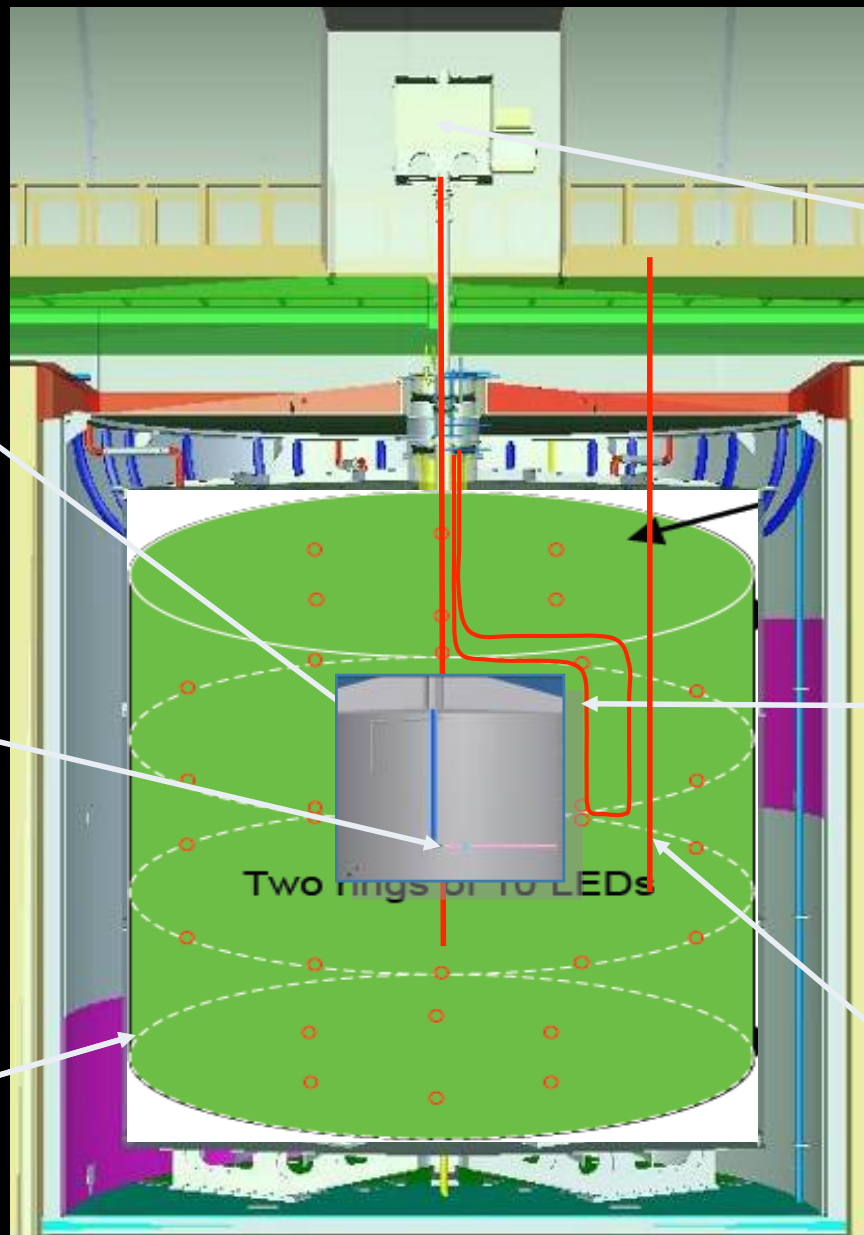
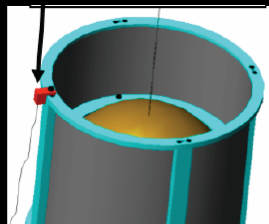
Detector Calibration Systems

Fish-line



Articulated Arm

Embedded LED calibration system
385, 420, 470 nm



Glove Box



GC guide Tube



Buffer guide Tube

250 ton Steel Shielding



T. Lasserre 08/10/2009

Inner Muon Veto



T. Lasserre 08/10/2009



Inner Veto PMTs & Buffer Vessel

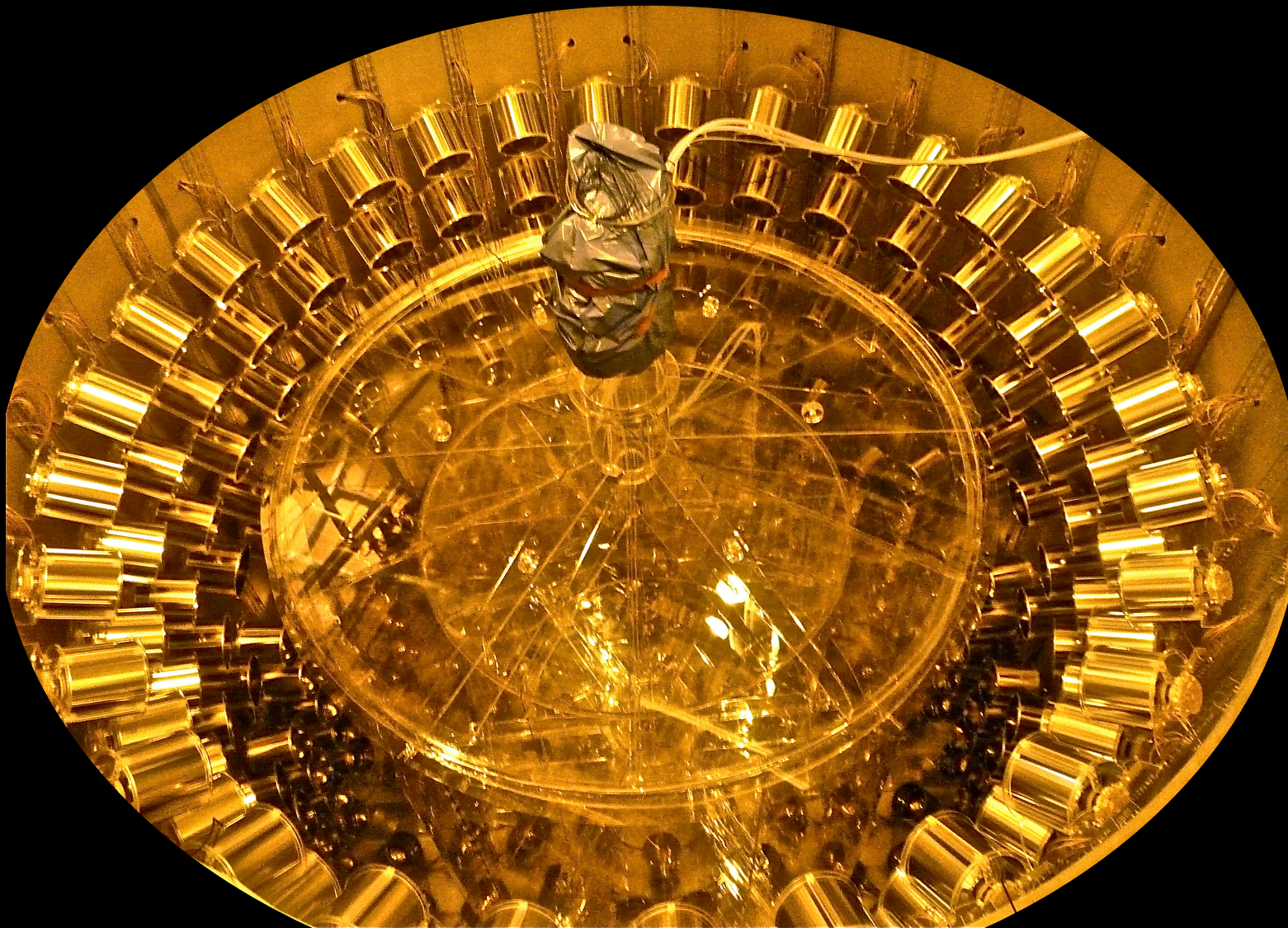


T. Lasserre 08/10/2009

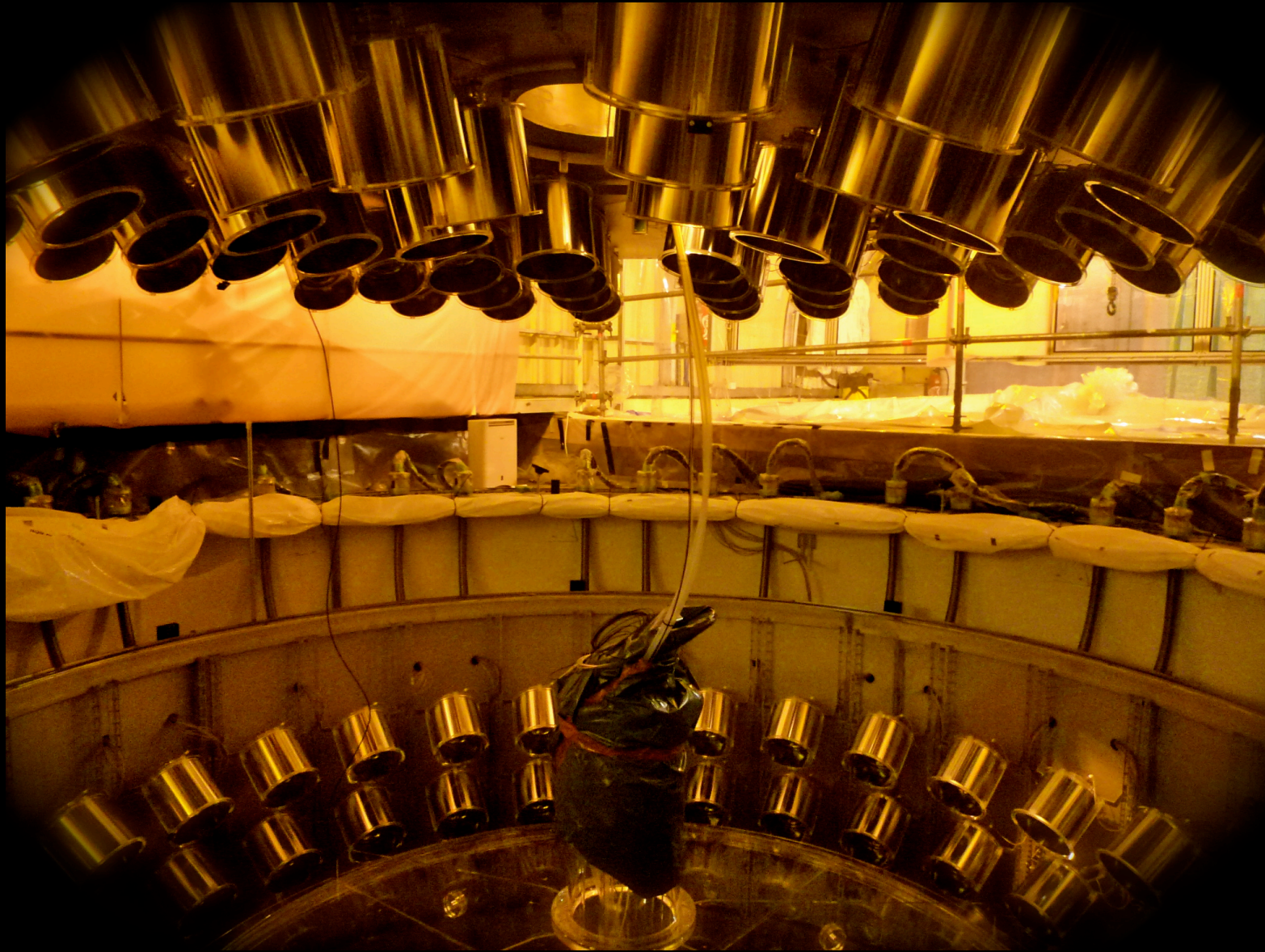




Detector Interior



Detector Closing



Detector Filling



Detector Filling: October-December 2010

T. Lasserre - 04/02/2011

21

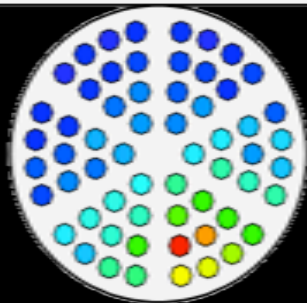
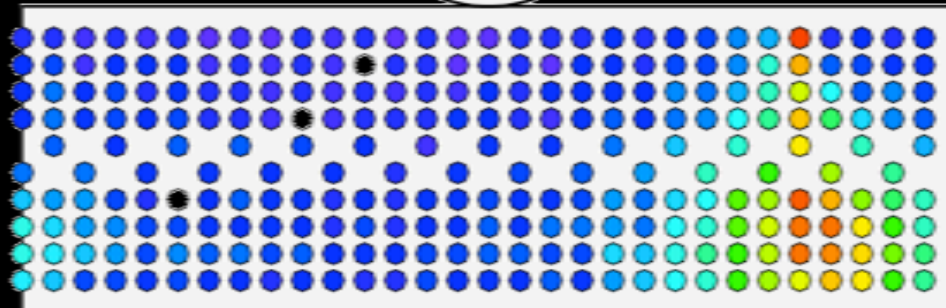
Top Shielding



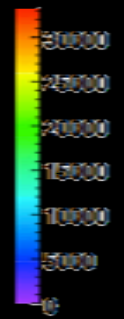
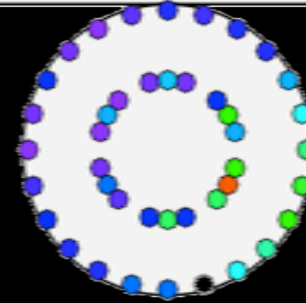
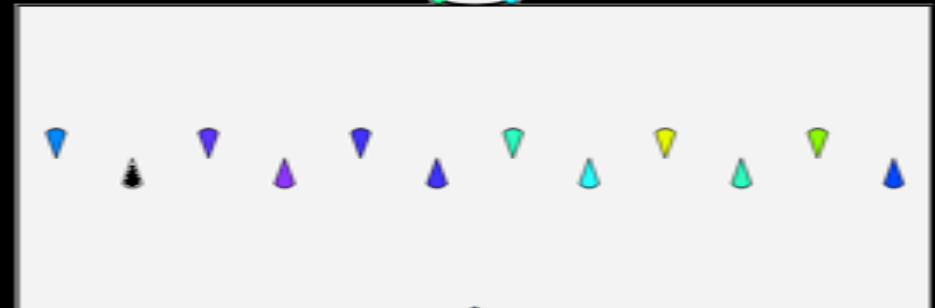
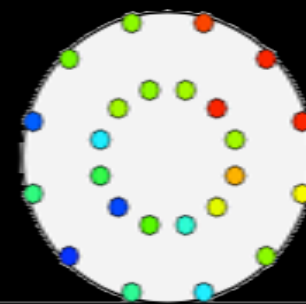
Next: Outer Muon Veto, Glove Box for in situ Calibration (Feb-June 2010)

Muon Candidate

Inner Detector
Event Display

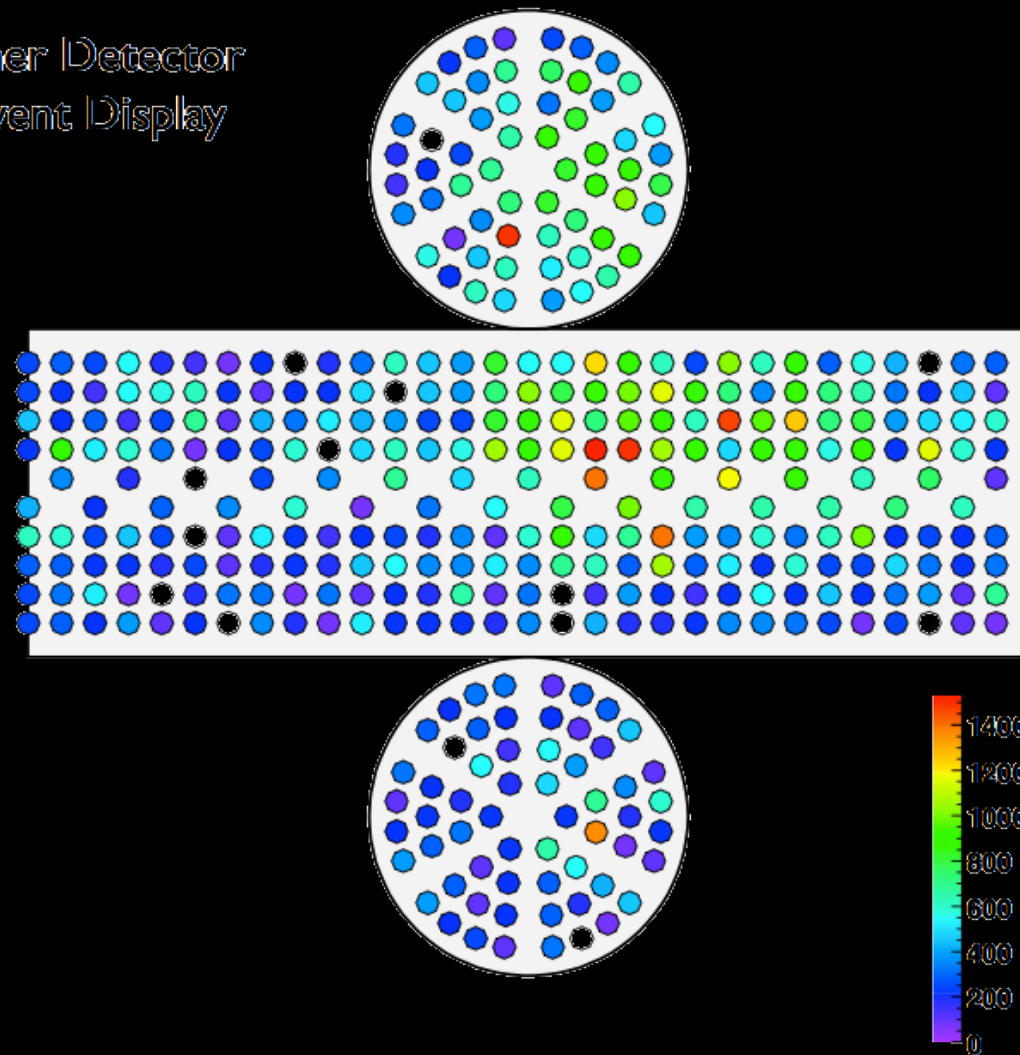


Inner Veto
Event Display

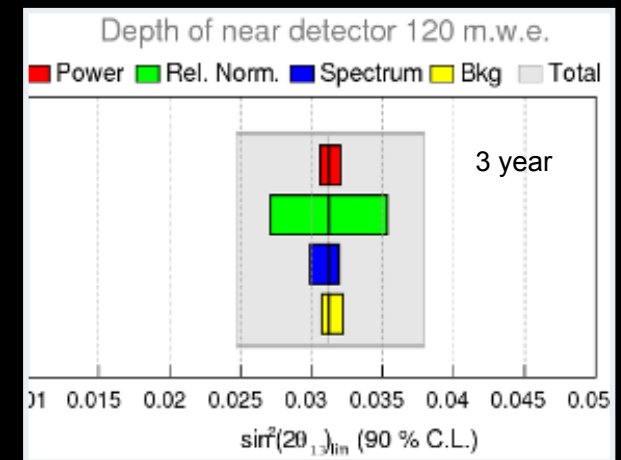
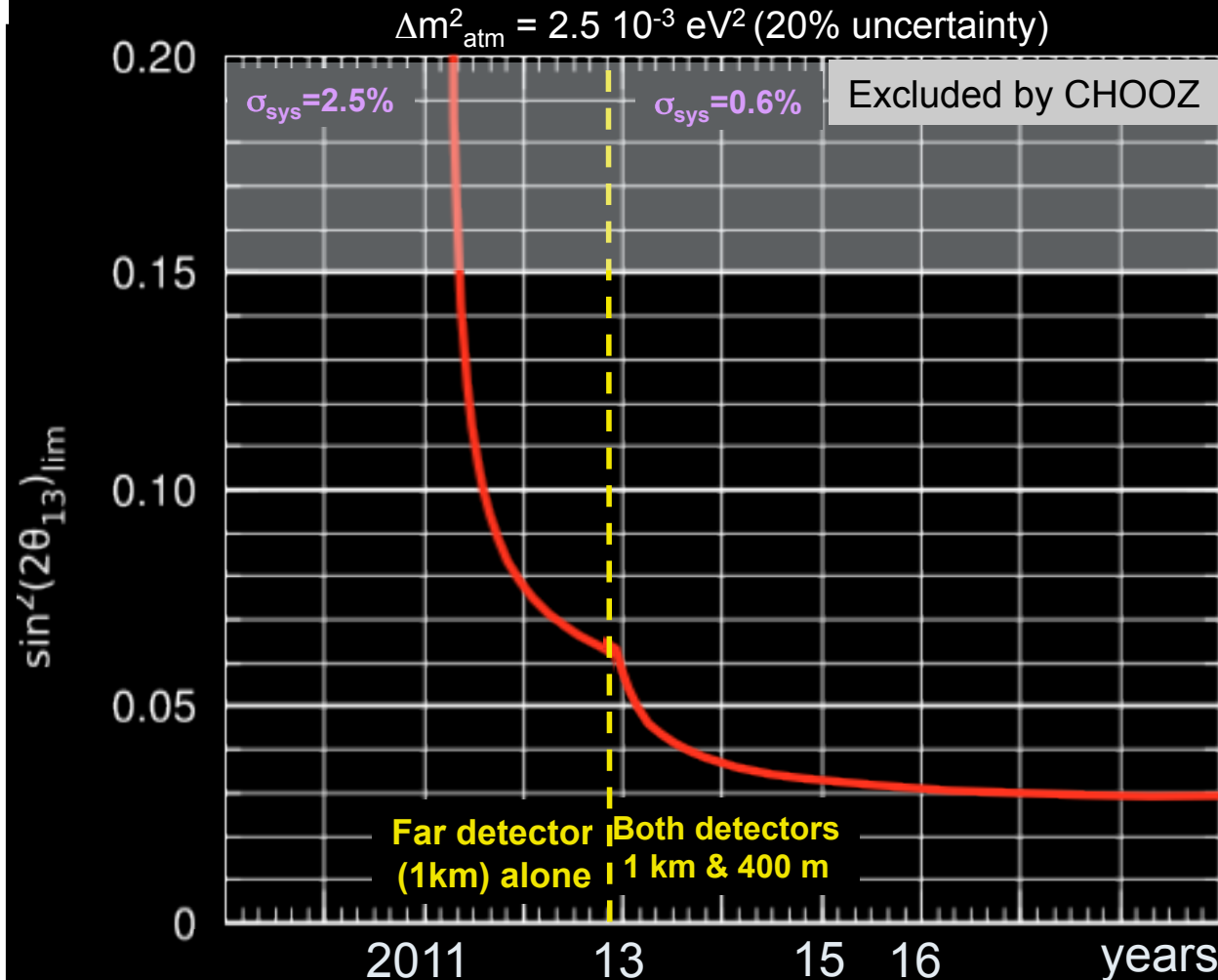


Contained Single Event

Inner Detector
Event Display



Sensitivity (Limit) Timeline



	Best	Central	Worst
Power	1.0%	2.0%	3.0%
Rel. Norm.	0.4%	0.6%	0.8%
Spectrum	1.0%	2.0%	3.0%
Background rates	X 0	X 1	X 2

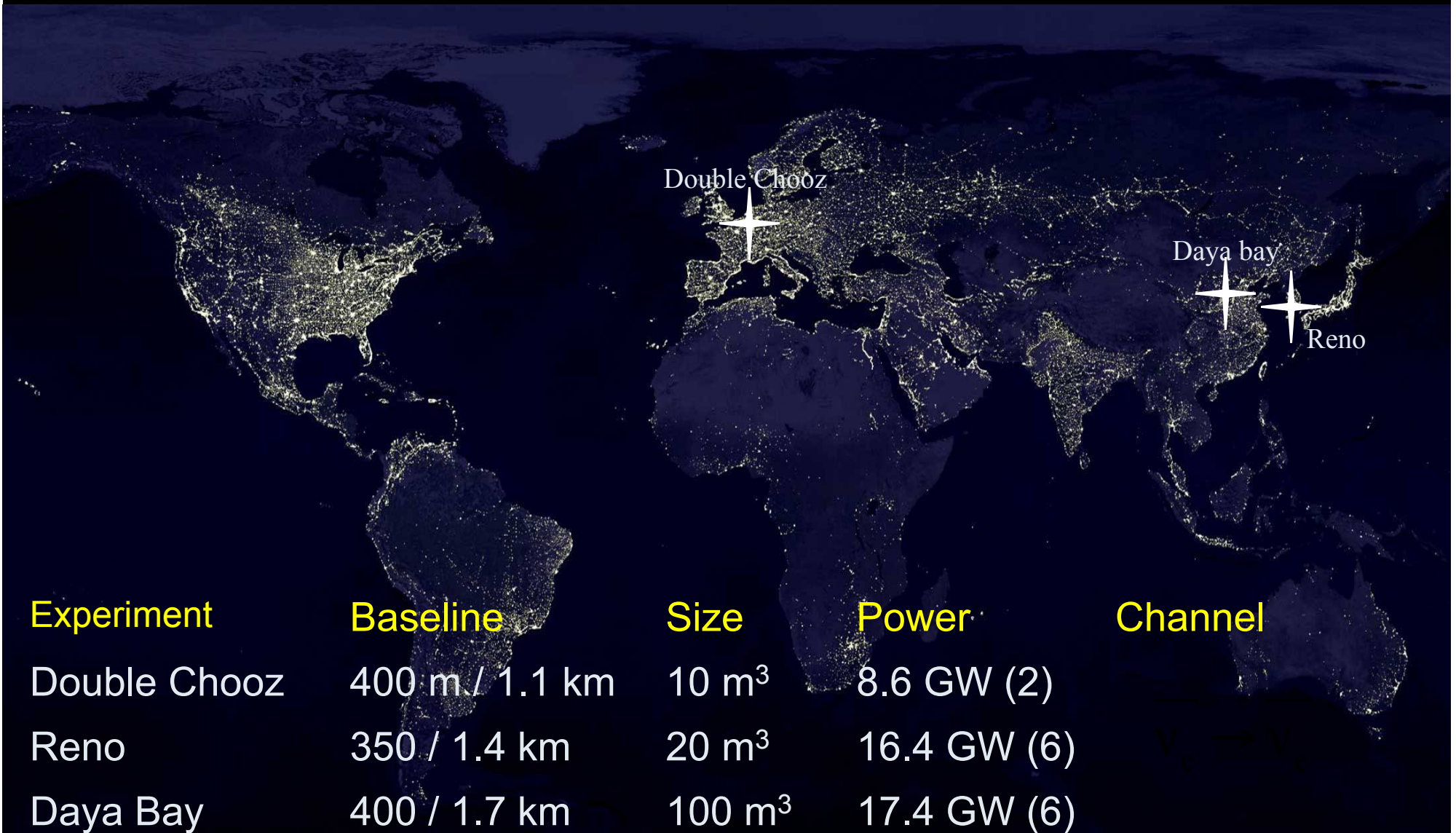
G. Mention, T. Lasserre, D. Motta,
[hep-ex/arXiv:0704.0498](https://arxiv.org/abs/hep-ex/0704.0498)



Double Chooz Status

- **2009** → Far detector construction & intégration
- **12/2010** → Start of phase I : Far 1 km detector alone
 $\sin^2(2\theta_{13}) < 0.06$ after 1,5 y (90% C.L.) if no-oscillation
- **2011** → Near Lab Excavation
→ Near Detector Integration
- **End 2012** → Start of phase II : both near and far detectors
 $\sin^2(2\theta_{13}) < 0.03$ after 3 y (90% C.L.) if no-oscillation

Reactor Neutrino Experiments



Double Chooz

Daya bay

Reno

Experiment	Baseline	Size	Power	Channel
Double Chooz	400 m / 1.1 km	10 m ³	8.6 GW (2)	$\bar{\nu}_e \rightarrow \bar{\nu}_e$
Reno	350 / 1.4 km	20 m ³	16.4 GW (6)	
Daya Bay	400 / 1.7 km	100 m ³	17.4 GW (6)	

- **New 4-region large detector concept from Double Chooz Coll. (2003)**

(http://bama.ua.edu/~busenitz/rnu2003_talks/lasserre1.doc)

Concept adopted by Daya Bay and Reno **BUT**

Double Chooz syst: 0.6% RENO sys: 0.45%

Daya Bay sys: 0.38%
(without det. Swaping)

→ Different expected sensitivities ...

- **Double Chooz**

- Cons: Shorter baseline
- Pros: 2 cores → reactor OFF periods, calibration, accidental bkg

- **Daya Bay**

- Cons: 9 baselines / 6 nuclear cores
- Pros: 160 tons of active volume, opt. baseline, corr. bkg

- **RENO**

- Cons: Near/Far assymetric configuration, accidental bkg, calibration
- Pros: Infrastructure ready