Double Chooz

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for the Double Chooz Collaboration
Neutrinos and Dark Matter 2009
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Neutrino Mixing

- best fits:

$$\boxed{\begin{gathered}\theta_{23} = 45^{+4.}_{-3.4} \\ \left|\Delta m^2_{13}\right| = 2.40 \pm 0.12 \times 10^{-3}\, eV^2\end{gathered}}$$

SK+K2K+MINOS

Solar+KamLand

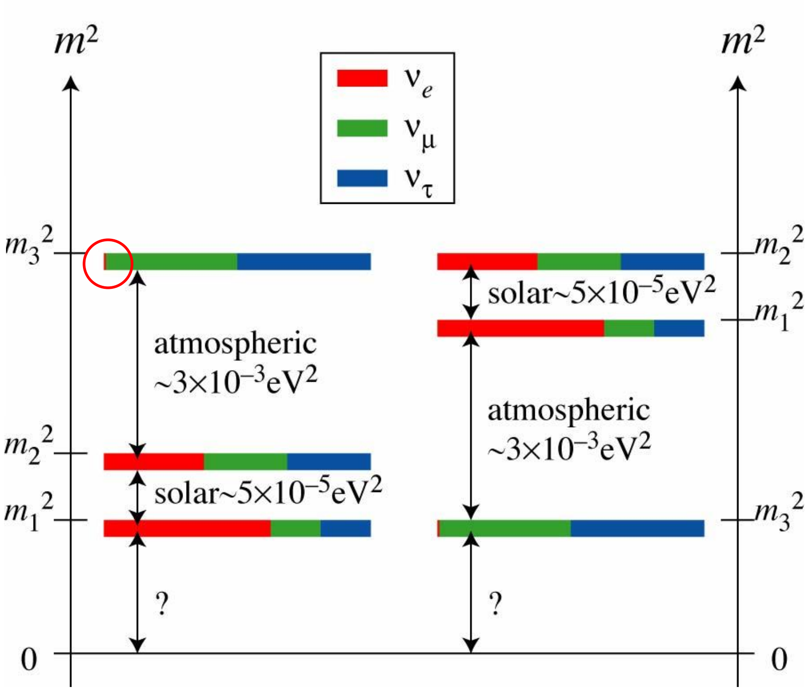
$$\boxed{\begin{gathered}\theta_{12} = 33.5^{+1.3}_{-1.0} \\ \Delta m^2_{12} = 7.65^{+0.23}_{-0.20} \times 10^{-5}\, eV^2\end{gathered}}$$

@1σ arXiv:0808.2016

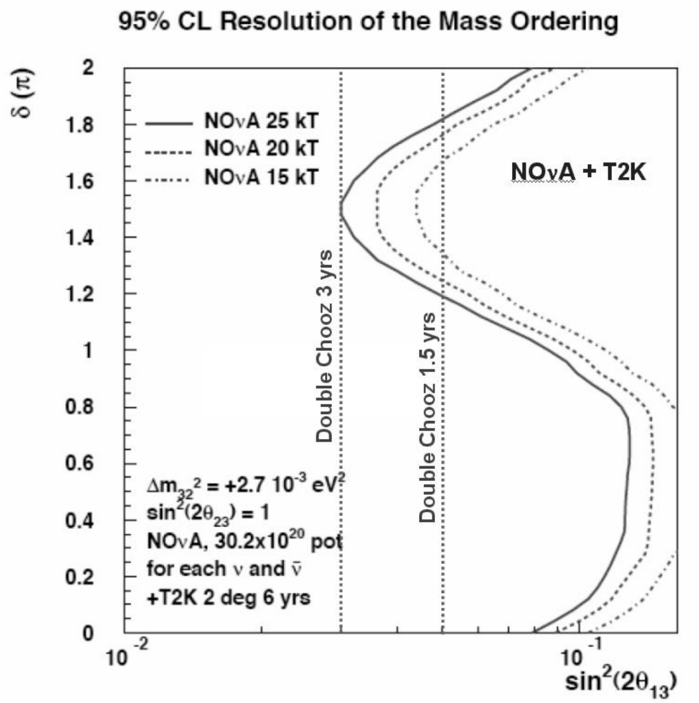
- what is ν_e component of ν_3?

$$U = \begin{pmatrix} U_{e1} & U_{e2} & \bigcirc\!\!\!\!\!\!U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} = \begin{pmatrix} Big & Big & Small\,? \\ Big & Big & Big \\ Big & Big & Big \end{pmatrix}$$

$$= \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \times \begin{pmatrix} \cos\theta_{13} & 0 & e^{-i\delta_{CP}}\sin\theta_{13} \\ 0 & 1 & 0 \\ -e^{i\delta_{CP}}\sin\theta_{13} & 0 & \cos\theta_{13} \end{pmatrix} \times \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix}$$

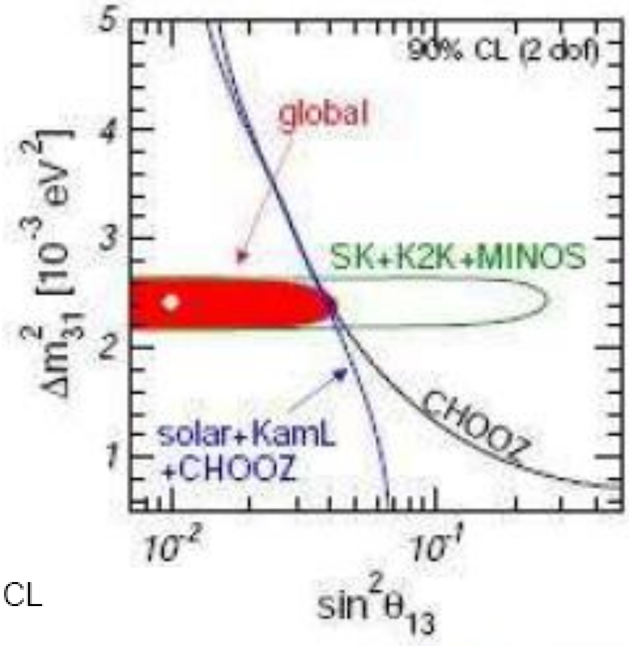


Motivation



- Reactor experiment provides clean measurement of θ_{13}:

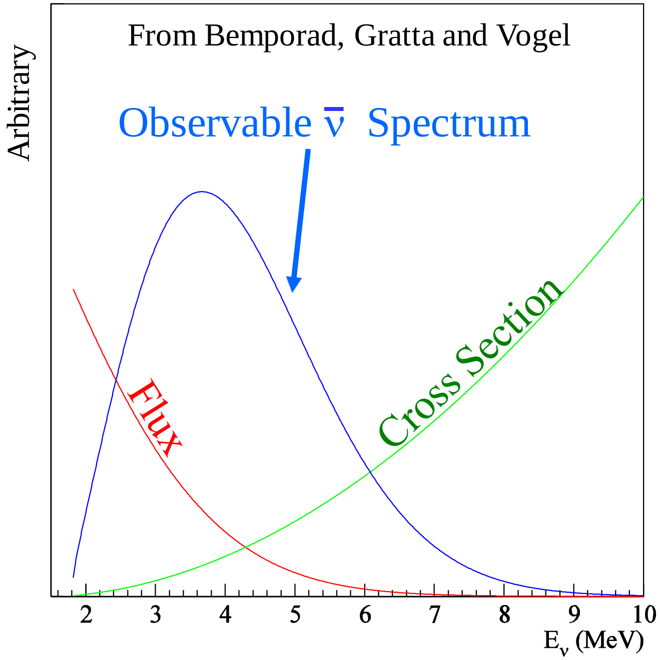
$$P(\bar{\nu_e} \rightarrow \bar{\nu_e}) \simeq 1 - \sin^2 2\theta_{13} \sin^2 \left(\frac{1.27 \Delta m^2_{13} L}{E_\nu} \right)$$

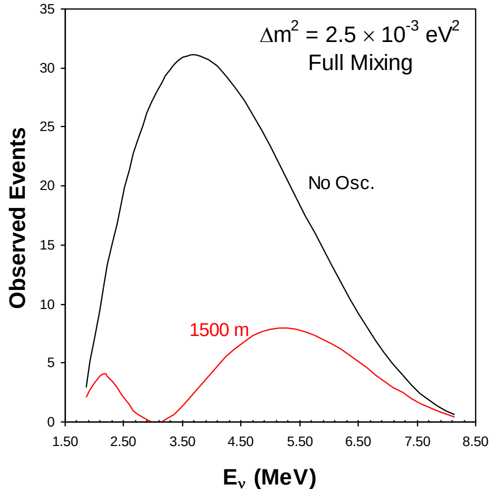


- Value of θ_{13} :
  - Mass hierarchy and scale
  - CP violation
  - CHOOZ 1997 → $\boxed{\theta_{13} < 9.5\,\mathrm{deg}}$ @ 90% CL

Reactor Neutrinos

- Nuclear reactors are intense $\bar{\nu}_e$ sources with a well–measured flux and spectrum
    - 3 GW → 6×10^{20} $\bar{\nu}_e$/sec
      700 events /year/ton at 1500 m
    - visible spectrum peak at ~ 3.7 MeV
    - oscillation max. for $\Delta m^2=2.5\times10^{-3}$ eV^2 at L ~1500 m

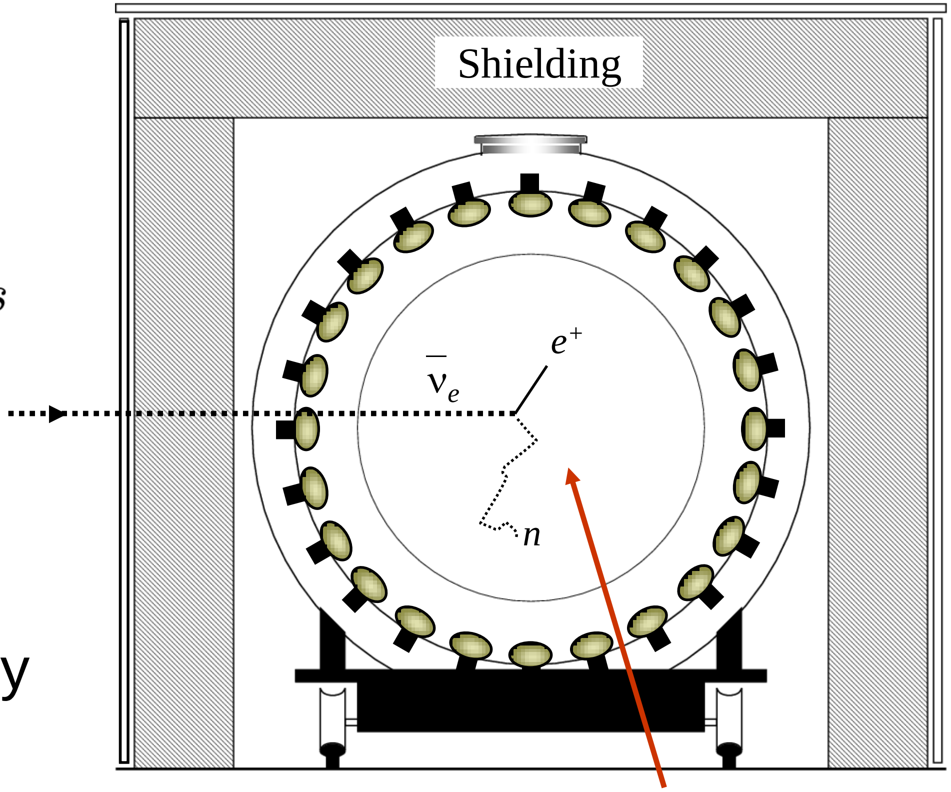




- Disappearance measurement:
    - look for small deviation between near (~200m) and far (~1500m) detectors:
        - counting = number of events
        - shape = energy spectra

Detection

- Inverse β–decay:
  - $\bar{\nu}_e + p \rightarrow e^+ + n$
- ^{155}Gd,^{157}Gd capture:
  - $n + Gd \rightarrow 8 \text{ MeV of } \gamma s$
  - $\tau \sim 30\ \mu\text{sec}$
    (0.1% Gd concentration)
- Events selected by coincidence
- ν energy spectrum given by visible e^+ energy:
  - $E_\nu = E_{vis} + 1.8 \text{ MeV} - 2m_e$



Liquid Scintillator
with Gadolinium

= Photomultiplier Tube

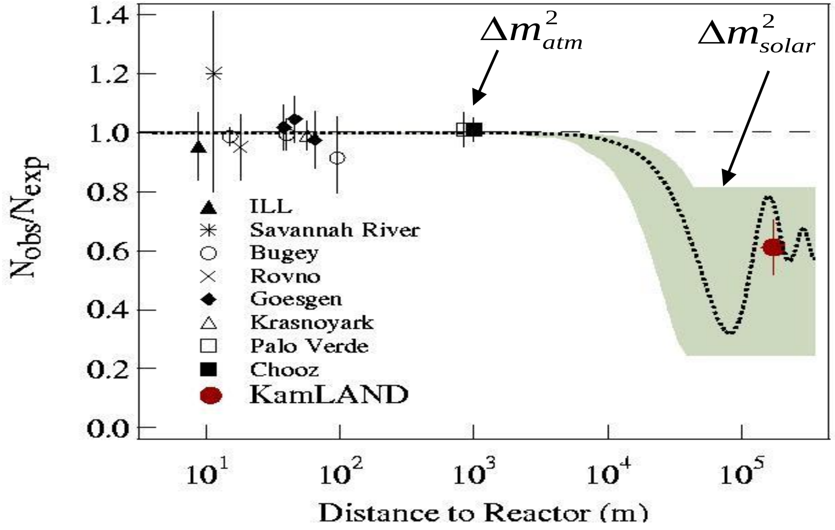
θ_{13} Limits

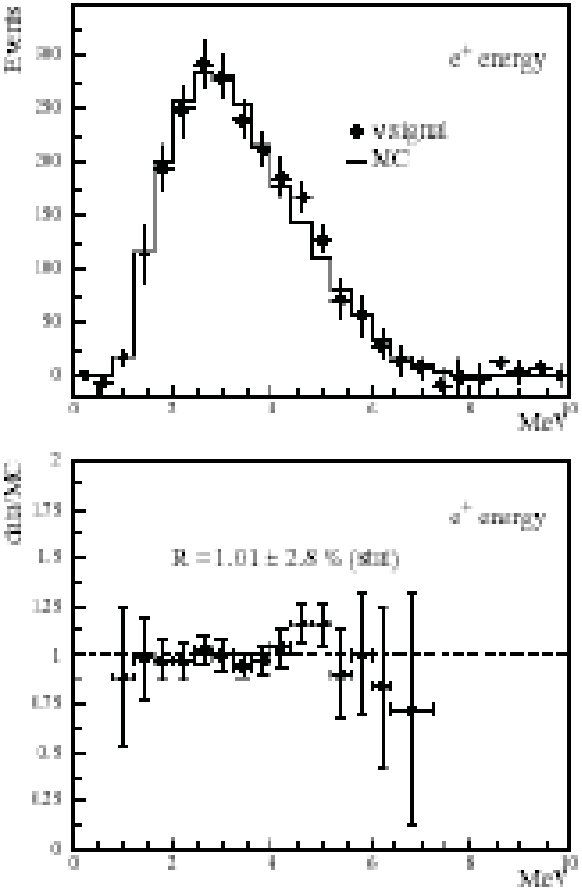
CHOOZ: $R = N_{meas}/N_{exp} = 1.01 \pm 2.8\%\ (stat) \pm 2.7\%\ (sys)$

$\theta_{13} < 9.5\ \mathrm{deg}$ @ 90% CL

CHOOZ:

- 5.55 m^3 doped target in single detector @ 1050m
- ~3 months data-taking
- 2% systematic on reactor flux

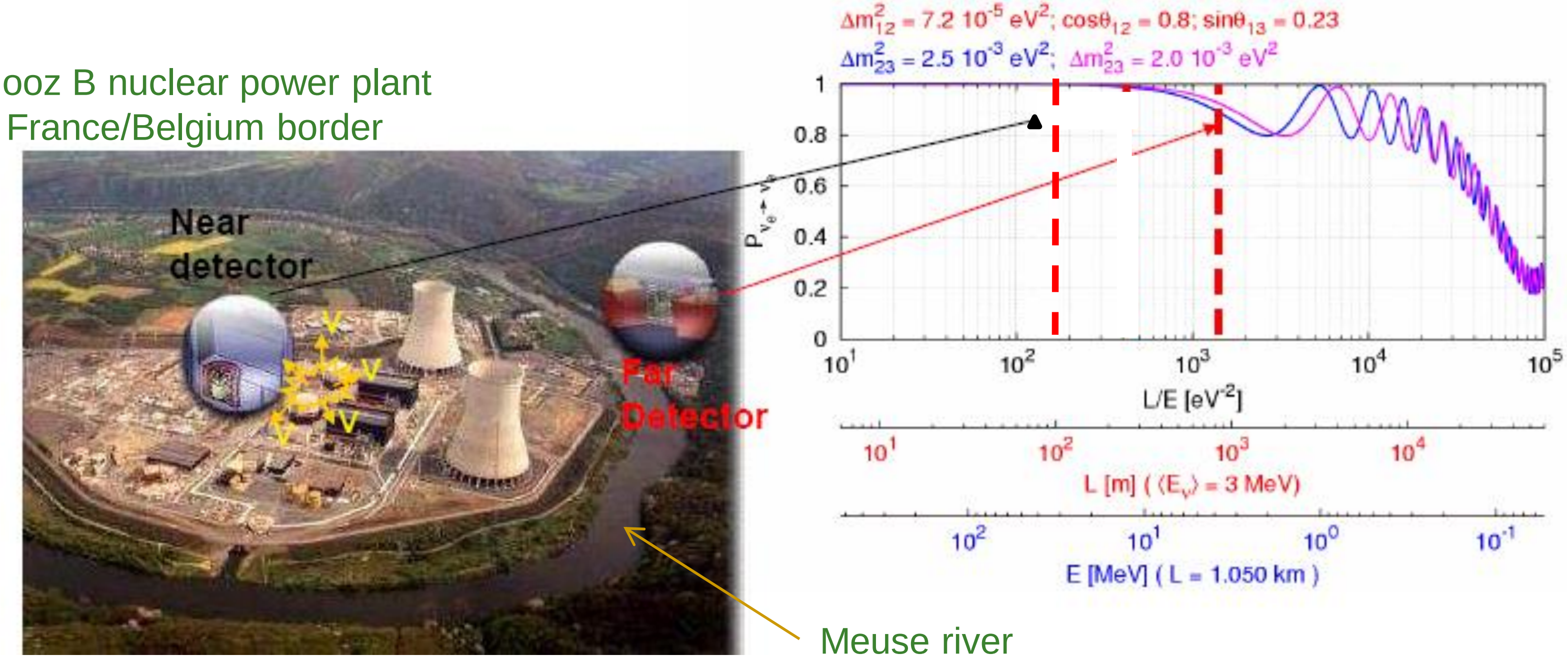




Improve Limits

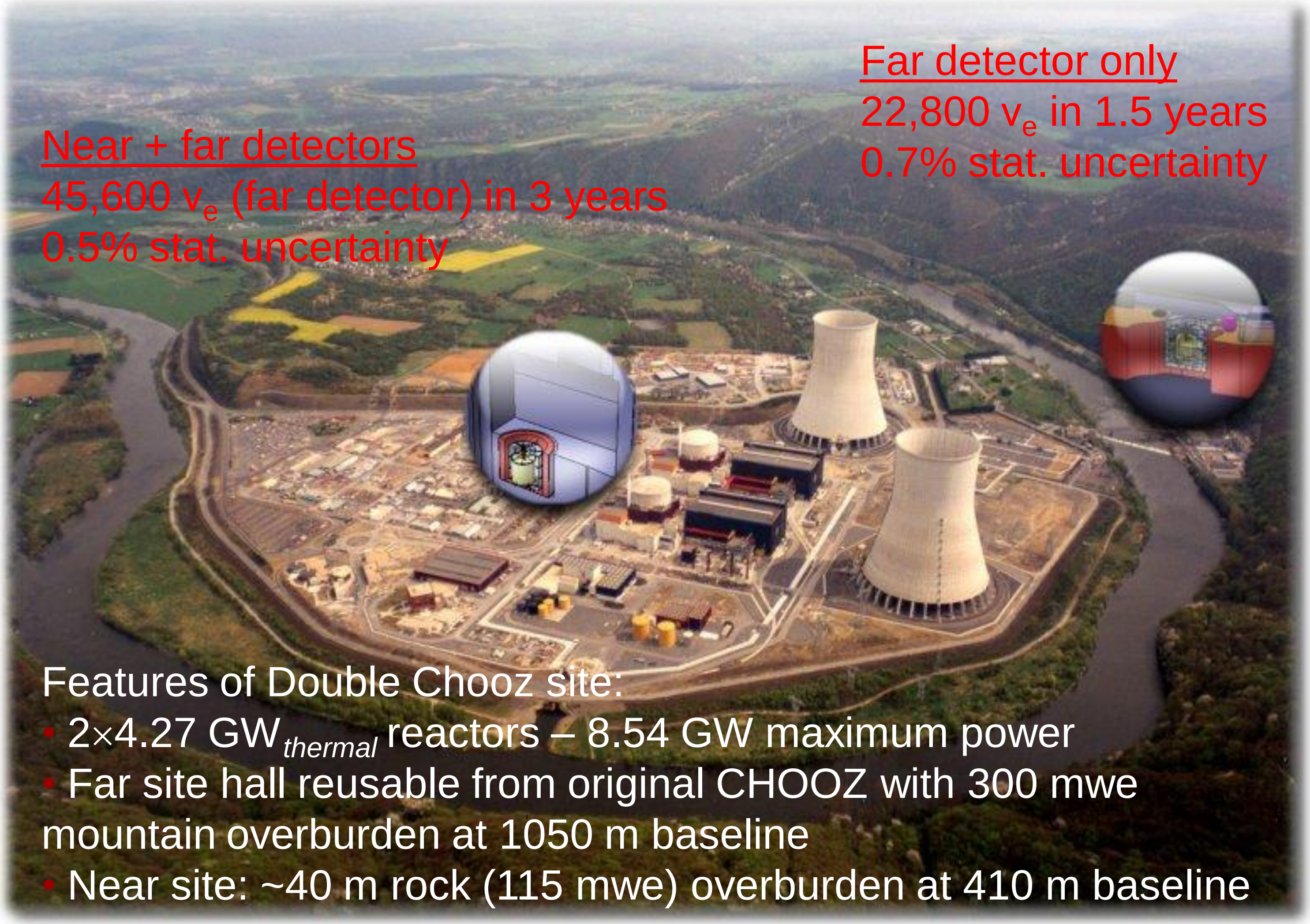
- Add identical near detector: need only relative acceptance
  - remove systematics from reactor neutrino flux, energy
- New detector design
  - low radioactivity PMTs protected by mineral oil
  - addition of non-doped “gamma-catcher” defines target volume
- New Gd scintillator mixture: instability in CHOOZ scintillator attenuation
- Reduce cosmogenic backgrounds: add outer detectors

Chooz B nuclear power plant
on France/Belgium border



Meuse river

Double Chooz



Far detector only

22,800 ν_e in 1.5 years

0.7% stat. uncertainty

Near + far detectors

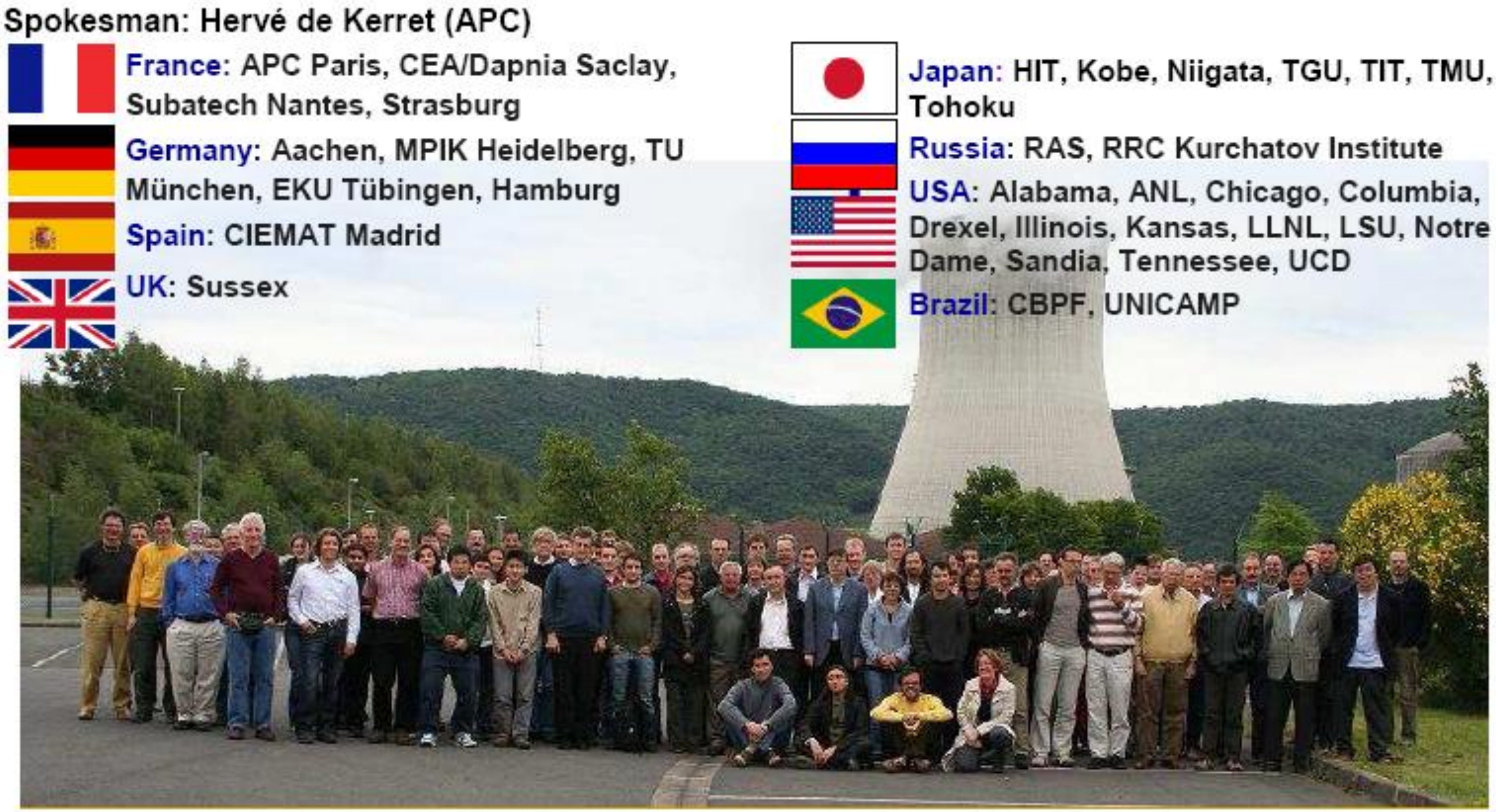
45,600 ν_e (far detector) in 3 years

0.5% stat. uncertainty

Features of Double Chooz site:

- 2×4.27 $GW_{thermal}$ reactors – 8.54 GW maximum power
- Far site hall reusable from original CHOOZ with 300 mwe mountain overburden at 1050 m baseline
- Near site: ~40 m rock (115 mwe) overburden at 410 m baseline

Collaboration



Spokesman: Hervé de Kerret (APC)

France: APC Paris, CEA/Dapnia Saclay, Subatech Nantes, Strasburg

Germany: Aachen, MPIK Heidelberg, TU München, EKU Tübingen, Hamburg

Spain: CIEMAT Madrid

UK: Sussex

Japan: HIT, Kobe, Niigata, TGU, TIT, TMU, Tohoku

Russia: RAS, RRC Kurchatov Institute

USA: Alabama, ANL, Chicago, Columbia, Drexel, Illinois, Kansas, LLNL, LSU, Notre Dame, Sandia, Tennessee, UCD

Brazil: CBPF, UNICAMP

Phase 1: Far detector only

Systematic	% Error
Reactor Power	1.9
Energy per fission	0.6
ν_e/fission	0.2
ν cross section	0.1

Reactor

- 2.0% total systematic
- based on CHOOZ analysis
- dominates Phase 1 errors

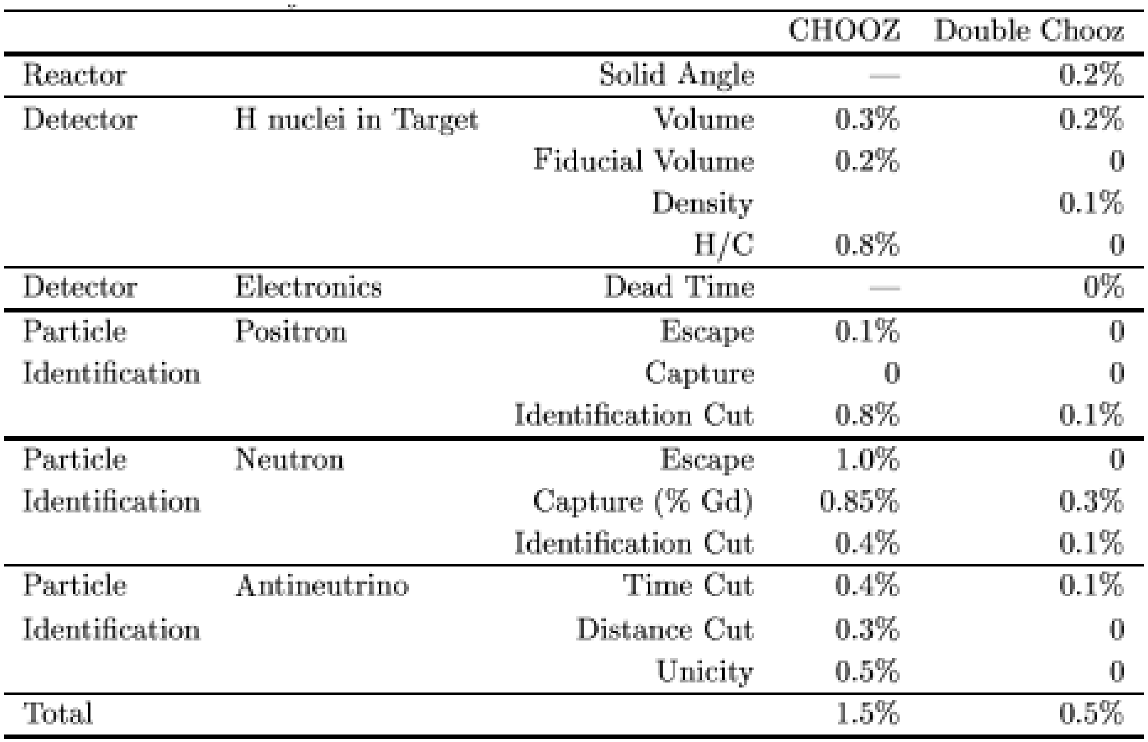
Systematic	% Error
Detector volume	0.2
Scintillator density	0.01
H/C composition	< 0.5
Gd concentration	0.3
Deadtime	0
e+ energy cut	0.1
n loss (spill in/out)	< 1.0
n energy cut	0.1
Time cut	0.4

Detector and data selection

- < 1.3% total systematic (CHOOZ analysis: 1.5% total)

Phase 2: Near + Far Detectors

Systematic errors on the relative normalization

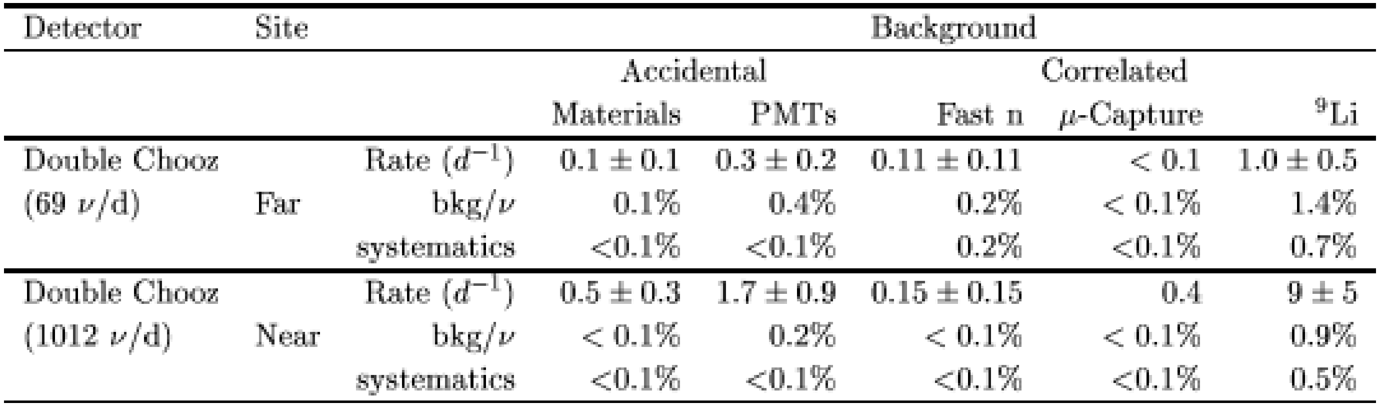


			CHOOZ	Double Chooz
Reactor		Solid Angle	—	0.2%
Detector	H nuclei in Target	Volume	0.3%	0.2%
		Fiducial Volume	0.2%	0
		Density		0.1%
		H/C	0.8%	0
Detector	Electronics	Dead Time	—	0%
Particle Identification	Positron	Escape	0.1%	0
		Capture	0	0
		Identification Cut	0.8%	0.1%
Particle Identification	Neutron	Escape	1.0%	0
		Capture (% Gd)	0.85%	0.3%
		Identification Cut	0.4%	0.1%
Particle Identification	Antineutrino	Time Cut	0.4%	0.1%
		Distance Cut	0.3%	0
		Unicity	0.5%	0
Total			1.5%	0.5%

- PMT radioactivity protected by oil buffer (CHOOZ: 60 Hz, DC: 1.5 Hz)
- cosmogenic neutron background reduced by improved vetos
- *in situ* calibrations improve energy scale for selection cuts

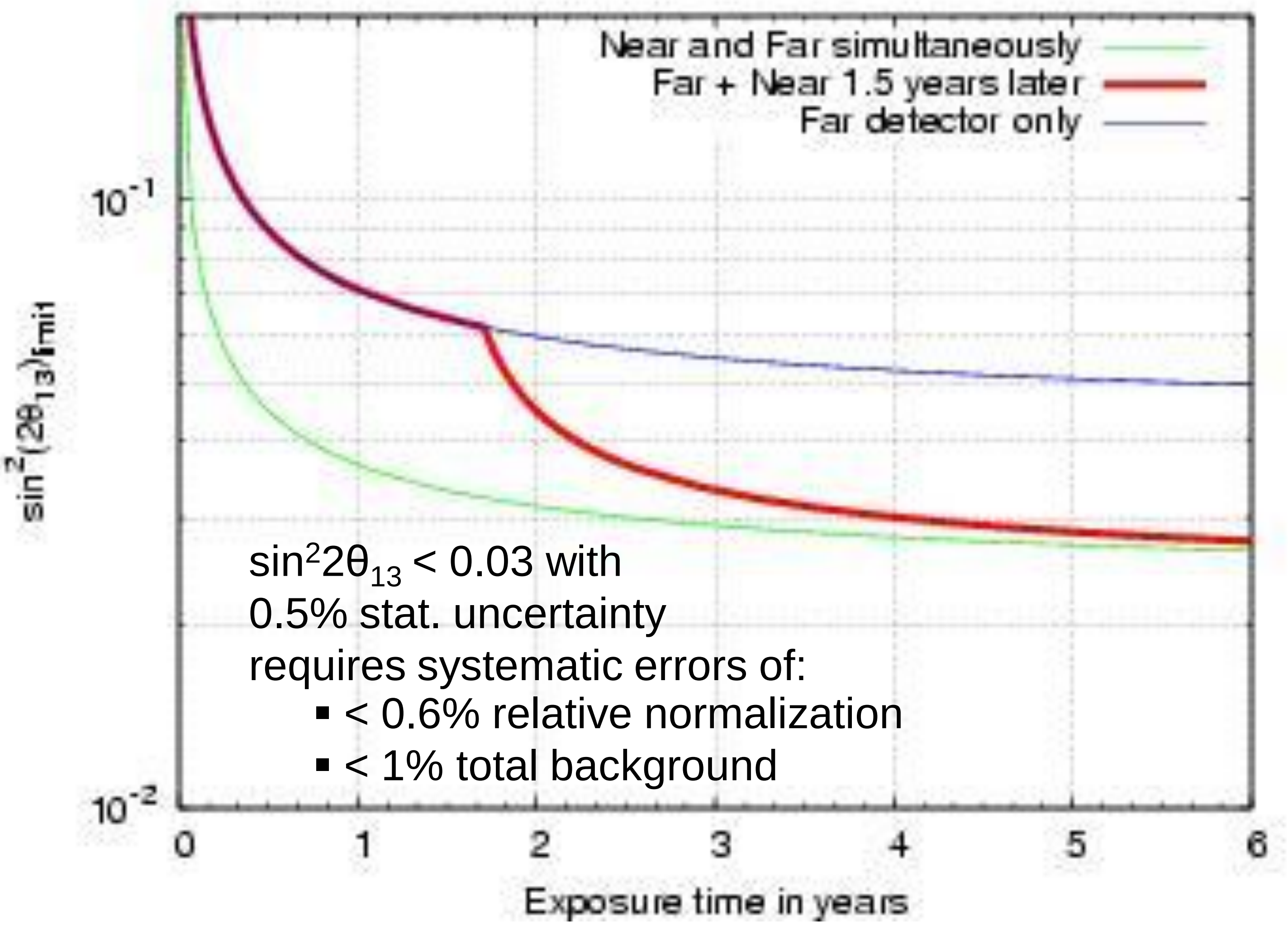
Backgrounds

- Accidental
  - random coincidences between two different events (*e.g*. radioactive decay plus cosmogenic neutron) together fake IBD signal
- Correlated
  - fast neutron – from muon showers near detector. A single neutron can elastically scatter in the target and subsequently capture on Gd
  - muon capture – on nuclei in dead material along muon track can produce several high-energy neutrons
  - 9Li – production by muon spallation inside target. Production mechanism not well-understood. About 50% of β decays produce a neutron. 178 ms half life causes prohibitive deadtime if vetoed by muon track in target.



Detector	Site		Background				
			Accidental		Correlated		
			Materials	PMTs	Fast n	μ-Capture	^{9}Li
Double Chooz		Rate (d^{-1})	0.1 ± 0.1	0.3 ± 0.2	0.11 ± 0.11	< 0.1	1.0 ± 0.5
(69 ν/d)	Far	bkg/ν	0.1%	0.4%	0.2%	$< 0.1\%$	1.4%
		systematics	<0.1%	<0.1%	0.2%	<0.1%	0.7%
Double Chooz		Rate (d^{-1})	0.5 ± 0.3	1.7 ± 0.9	0.15 ± 0.15	0.4	9 ± 5
(1012 ν/d)	Near	bkg/ν	$< 0.1\%$	0.2%	$< 0.1\%$	$< 0.1\%$	0.9%
		systematics	<0.1%	<0.1%	<0.1%	<0.1%	0.5%

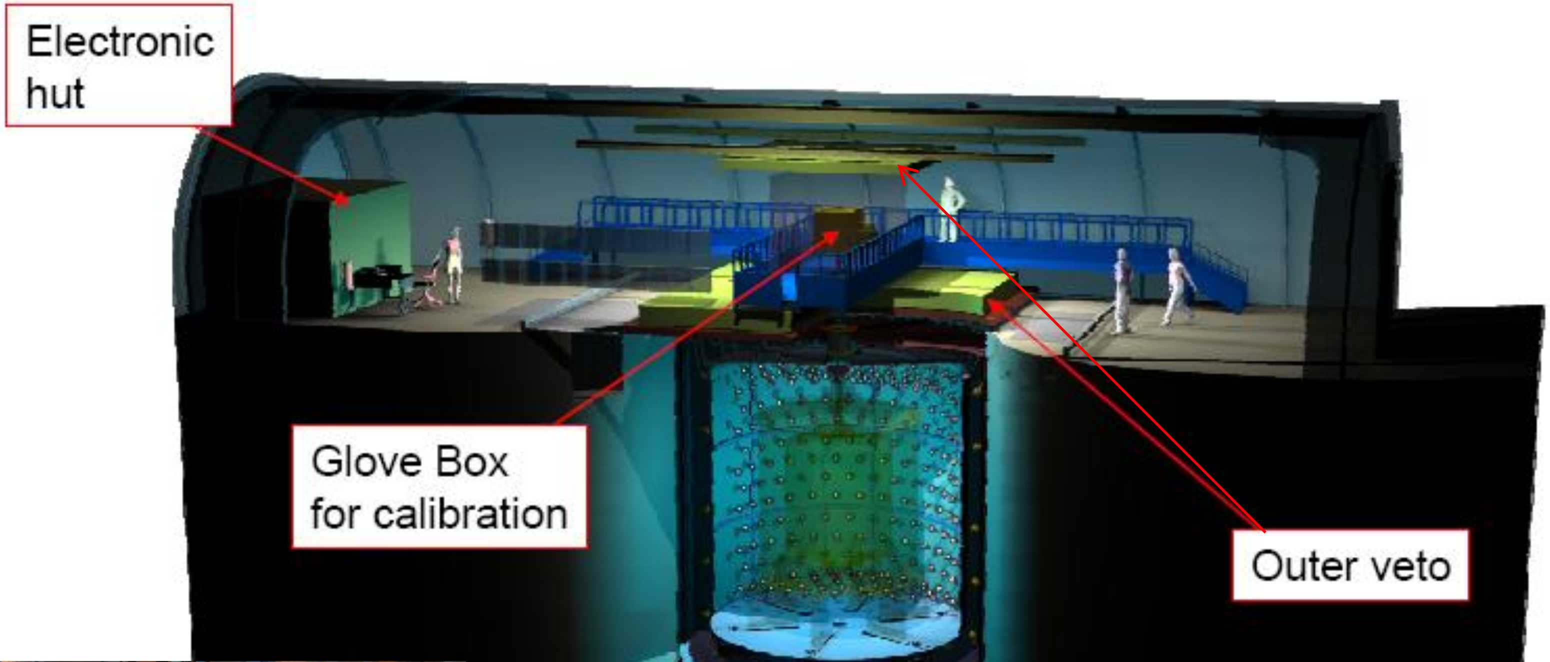
Expected Sensitivity



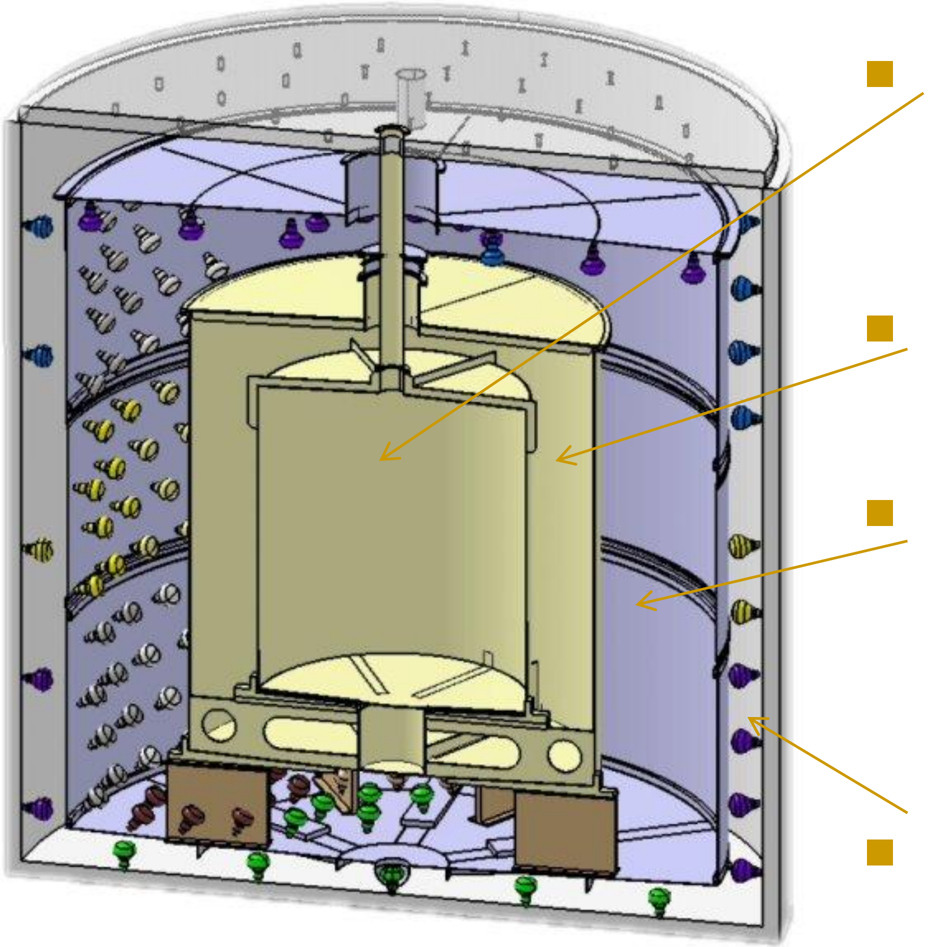
$\sin^2 2\theta_{13} < 0.03$ with
0.5% stat. uncertainty
requires systematic errors of:

- < 0.6% relative normalization
- < 1% total background

Far Site Hall



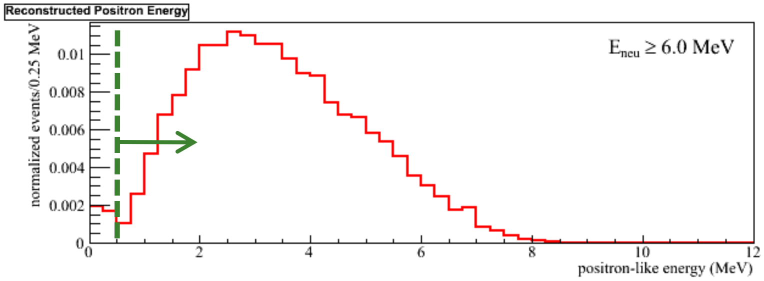
Inner Detectors

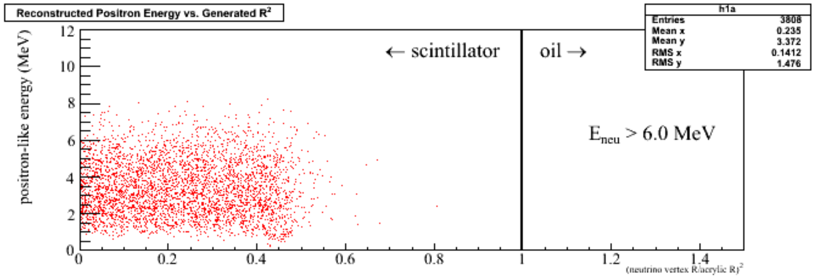


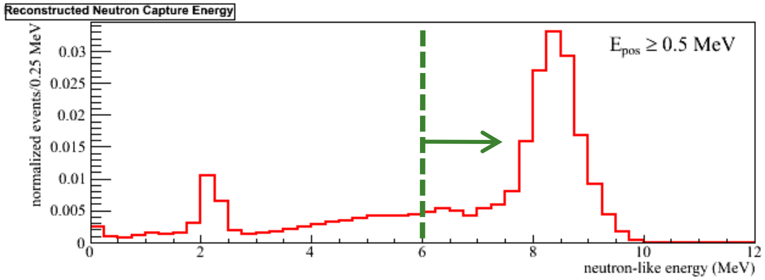
- Target
  h = 2458mm
  d = 2300mm
  - $10.3\ m^3$ (8.8 tonnes) of 0.1% Gd-doped LS
- Gamma-catcher
  h = 3574mm
  d = 3392mm
  - ~50 cm ($22.6\ m^3$) of LS
- Buffer
  h = 5674mm
  d = 5516mm
  - 105 cm of nonscintillating organic liquid ($114.2\ m^3$)
  - 390 10” Hamamatsu PMTs
- Inner Veto
  h = 6640mm
  d = 6590mm
  - $90\ m^3$ LS with 78 8” PMTs

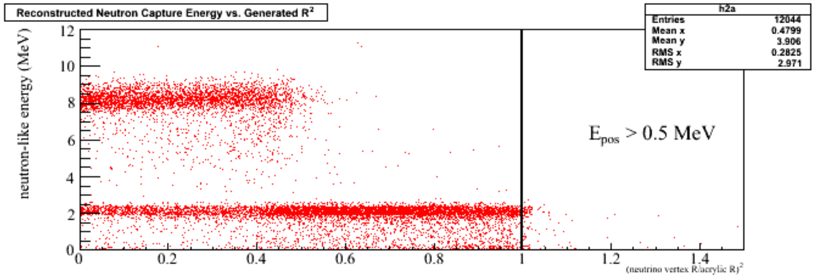
Detector Simulation

- Geant4-based Monte Carlo with ROOT output
  - detailed detector geometry and pulse modeling
  - $\bar{\nu}_e$ events generated throughout central detectors
  - two reconstructed events within 100 μsec window

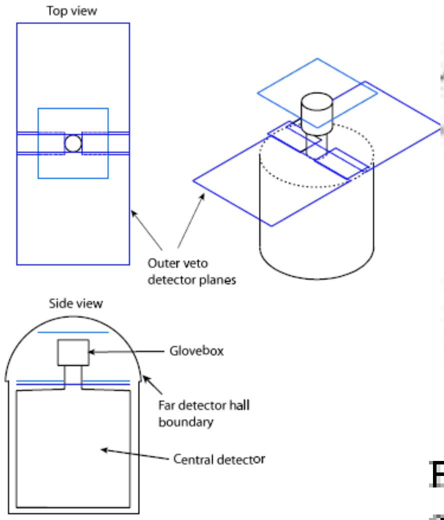


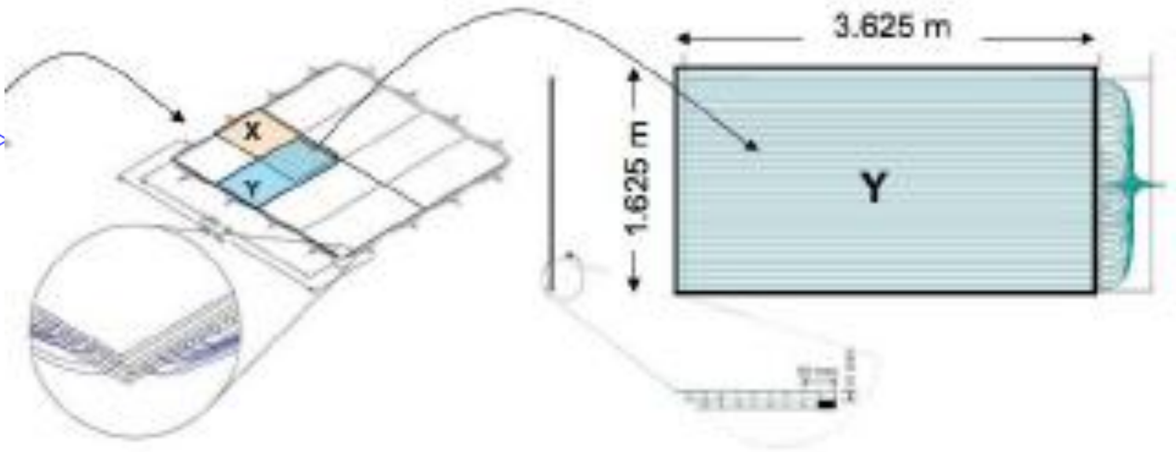






Outer Veto





Each plane is fully active and consists of modules oriented in both X and Y directions

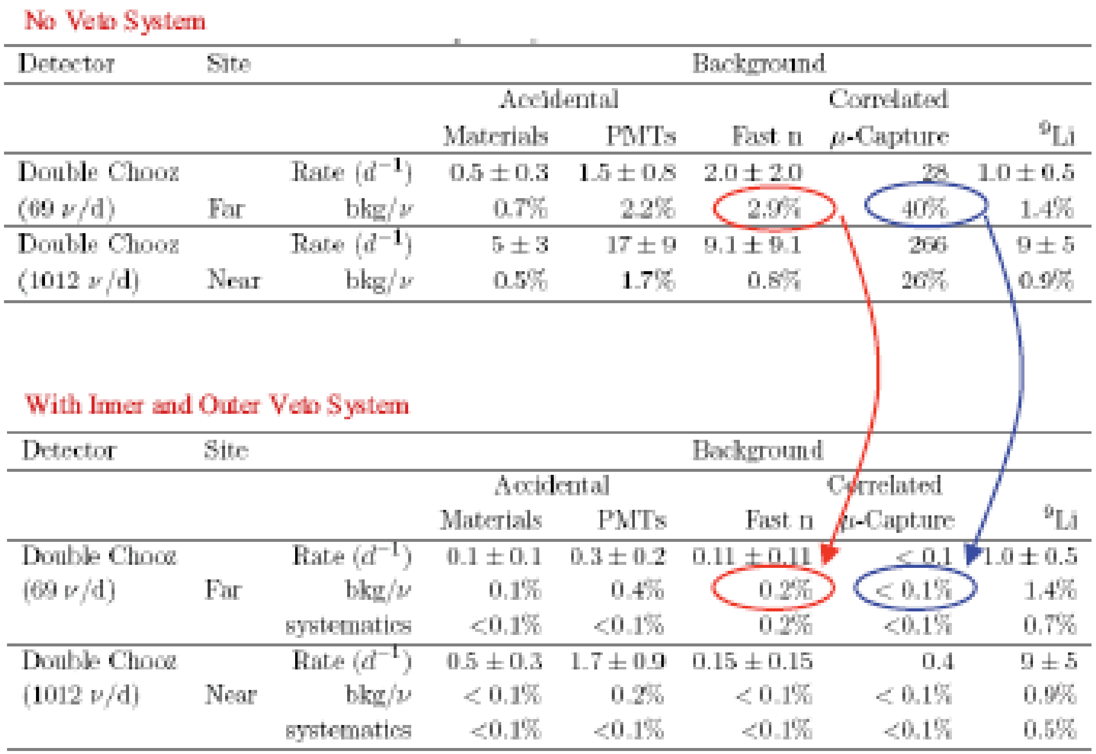
OV modules consist of 2 layers of 64 scintillator strips with WLS fibers connected to a multi-anode PMT

LAYOUT

- two 7.0 x 7.2 meter panels ~1 m above the inner detectors
  - overlapped vertically for continuous active coverage
  - mounted to retractable steel shielding
- one 3.6 x 3.6 m upper panel above glove box
  - protects neck and provides tracking

	Raw muon rates
Near	5.9 Hz/m^2
Far	0.62 Hz/m^2

Veto Effect

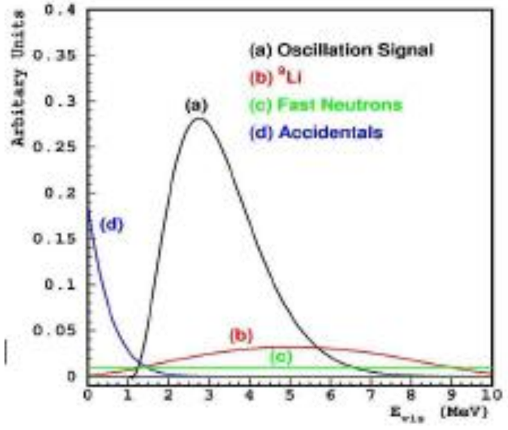


No Veto System

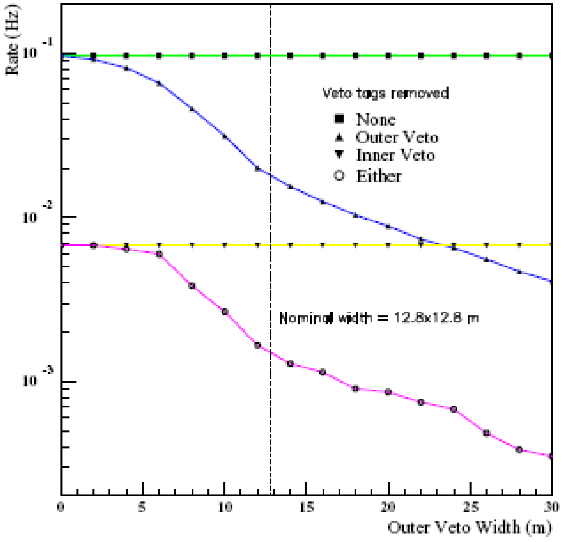
Detector	Site		Background				
			Accidental		Correlated		
			Materials	PMTs	Fast n	μ-Capture	^{9}Li
Double Chooz		Rate (d^{-1})	0.5 ± 0.3	1.5 ± 0.8	2.0 ± 2.0	28	1.0 ± 0.5
(69 ν/d)	Far	bkg/ν	0.7%	2.2%	2.9%	40%	1.4%
Double Chooz		Rate (d^{-1})	5 ± 3	17 ± 9	9.1 ± 9.1	266	9 ± 5
(1012 ν/d)	Near	bkg/ν	0.5%	1.7%	0.8%	26%	0.9%

With Inner and Outer Veto System

Detector	Site		Background				
			Accidental		Correlated		
			Materials	PMTs	Fast n	μ-Capture	^{9}Li
Double Chooz		Rate (d^{-1})	0.1 ± 0.1	0.3 ± 0.2	0.11 ± 0.11	< 0.1	1.0 ± 0.5
(69 ν/d)	Far	bkg/ν	0.1%	0.4%	0.2%	< 0.1%	1.4%
		systematics	<0.1%	<0.1%	0.2%	<0.1%	0.7%
Double Chooz		Rate (d^{-1})	0.5 ± 0.3	1.7 ± 0.9	0.15 ± 0.15	0.4	9 ± 5
(1012 ν/d)	Near	bkg/ν	< 0.1%	0.2%	< 0.1%	< 0.1%	0.9%
		systematics	<0.1%	<0.1%	<0.1%	<0.1%	0.5%



Near site, 100% efficient detectors



Background candidate neutron study →

- rate of neutrons (from “near-miss” muons) entering the central detector as a function of OV width
  - muons which deposit energy in the central detectors are removed
- FLUKA generated muon sample

Far Detector Construction

Original CHOOZ hall and pit refurbished and new cleanliness standards achieved

October 2008

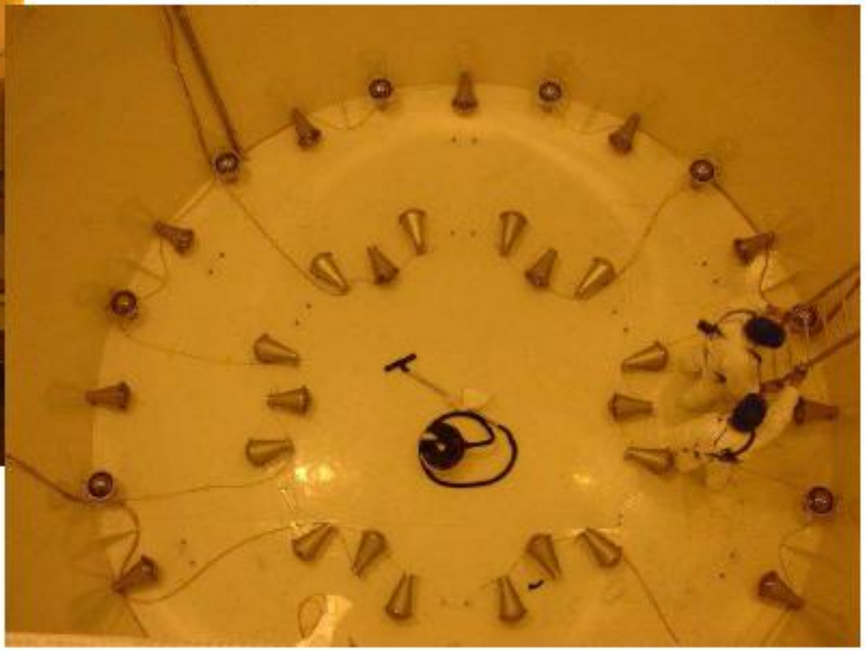
Shield of 15 cm demagnetized iron

Construction pictures from CEA/CNRS/IRFU

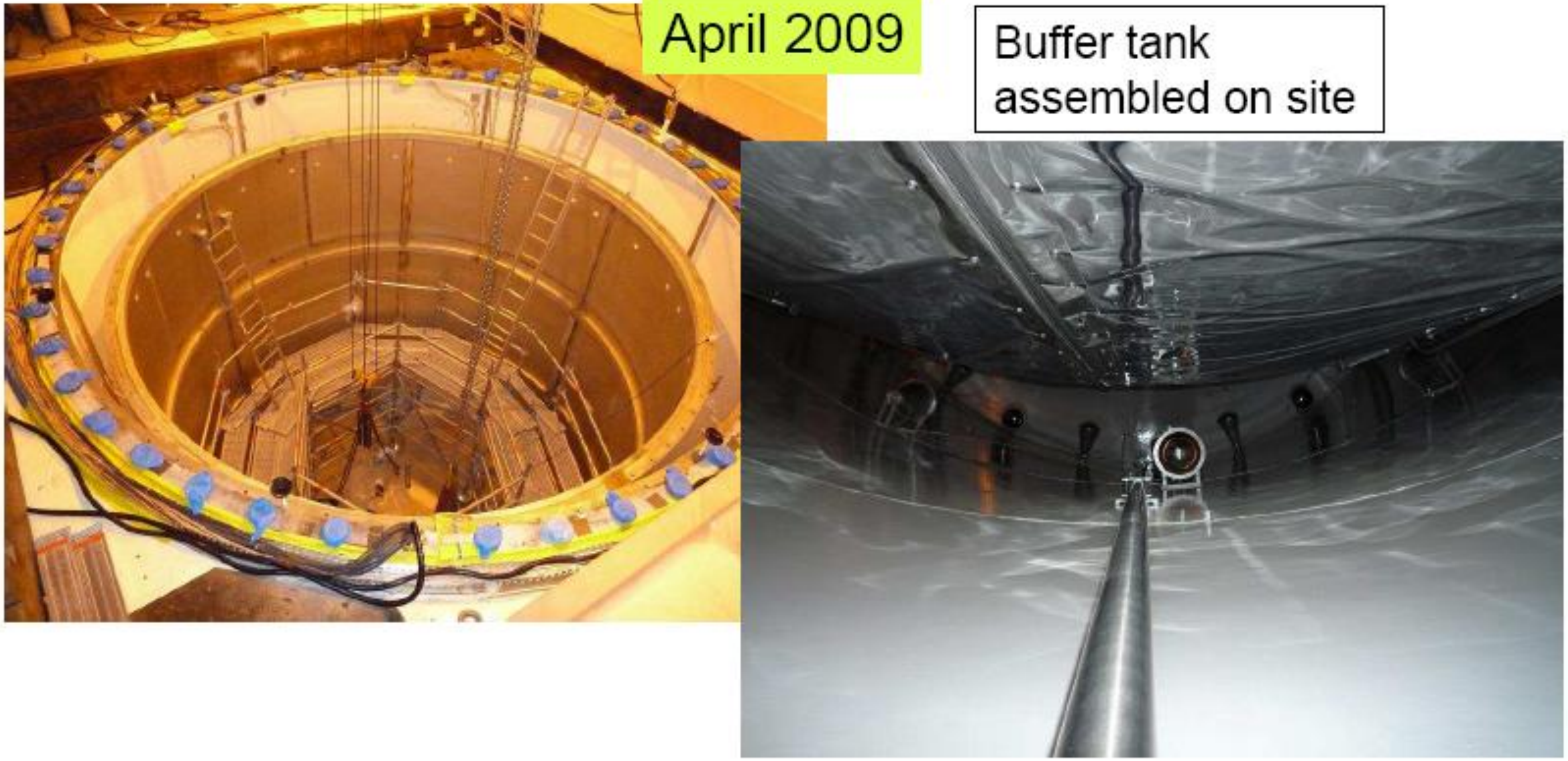
Far Detector Progress

February 2009

Inner Veto PMTs
Installation completed



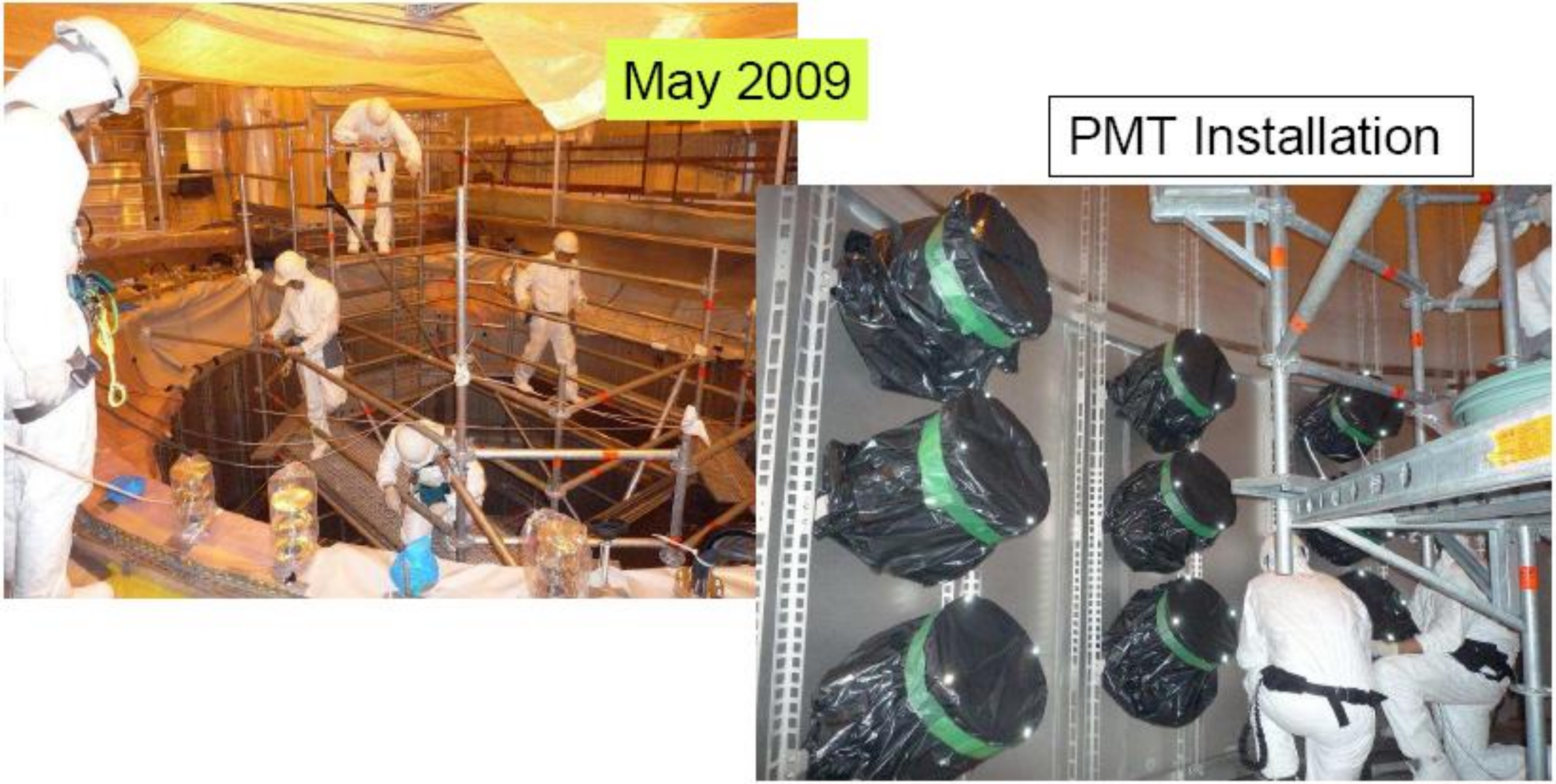
Far Detector Progress



April 2009

Buffer tank assembled on site

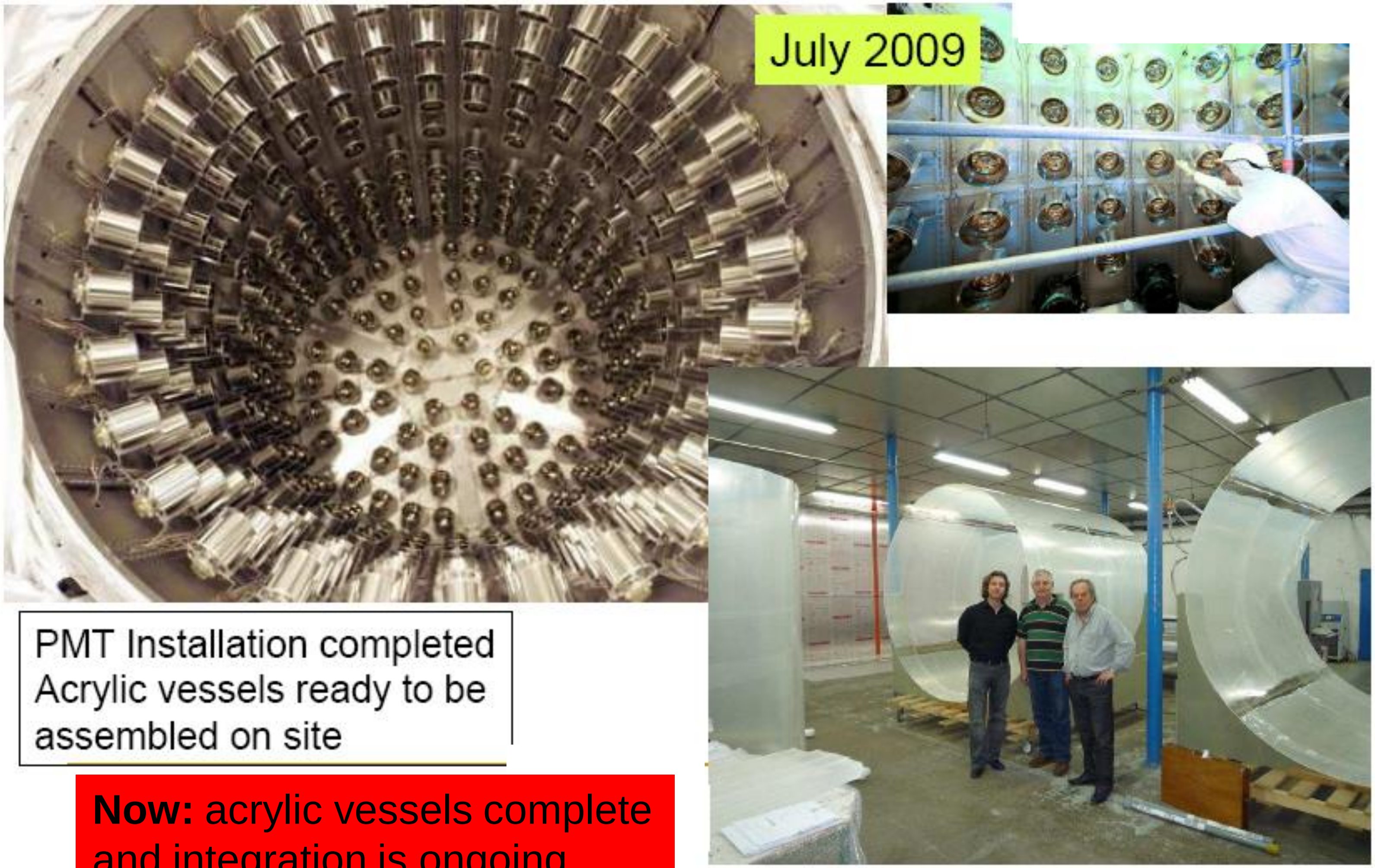
Far Detector Progress



May 2009

PMT Installation

Far Detector Current Status

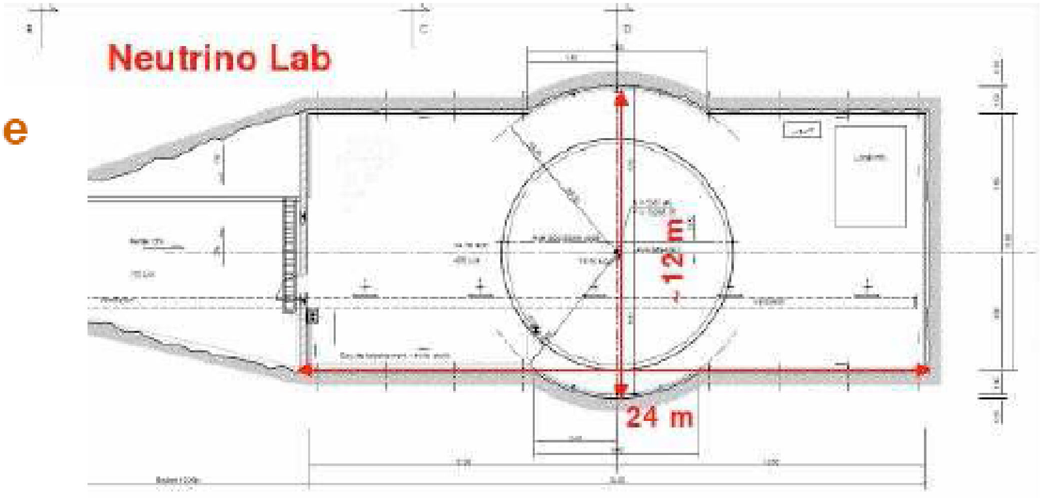


PMT Installation completed
Acrylic vessels ready to be assembled on site

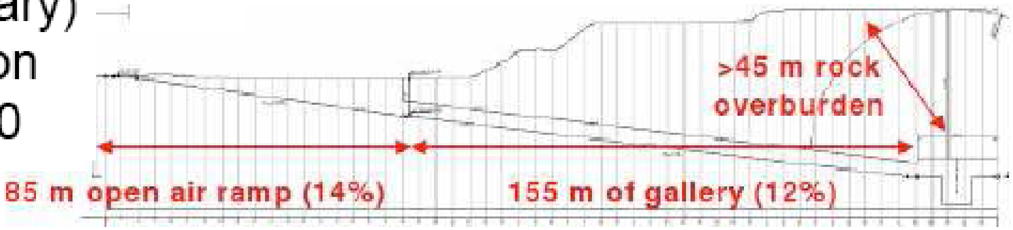
Now: acrylic vessels complete and integration is ongoing.

Near Detector Status

May 20th the **agreement for the Near laboratory construction** has been signed.
The agreement includes the region Champagne-Ardennes, EDF and French agencies.



Preliminary

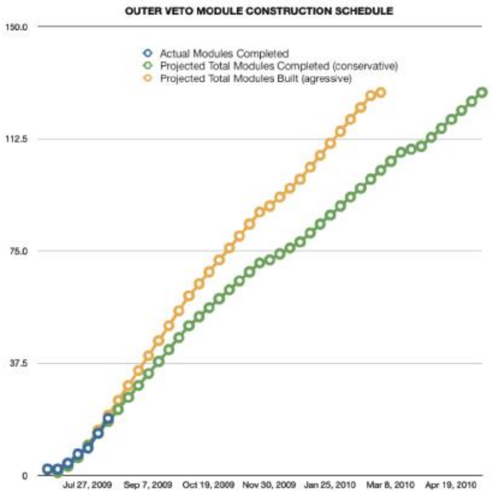


Schedule

- Geological study done (February)
- Tender process for construction
- Constructed at the end of 2010

Schedule

- Geological survey completed for near lab February 2009
- Far detector
    - Now installing acrylic vessels
    - Outer veto module construction on schedule →
    - Inner detector closed at the end of 2009
    - Liquid scintillator filling through April 2010
    - Begin data-taking with inner far detector in April
    - Outer veto installed after filling (not required for inner detector data taking)
- Near hall construction begins end of 2010
- Near detector data taking in 2011



Conclusion

- Double Chooz will be the first new generation detector reactor neutrino experiment to measure θ_{13}
- April 2010 begin far detector data taking
  - achieve current limit of $\sin^2 2\theta_{13} < 0.15$ at 90% CL with approximately one month of data
- near detector data taking in 2011
- five years after start of data taking (3 yrs of two detectors): $\sin^2 2\theta_{13} < 0.03$ at 90% CL