

First Results from the Double Chooz experiment



Glenn Horton-Smith

KANSAS STATE
UNIVERSITY

High Intensity Frontier Workshop
Rockville, MD – December 1, 2011



Double Chooz collaboration



Brazil

CBPF
UNICAMP
UFABC



France

APC
CEA/DSM/IRFU:
SPP
SPhN
SEDI
SIS
SENAC
CNRS/IN2P3:
Subatech
IPHC
ULB/VUB



Germany

EKU Tübingen
MPIK Heidelberg
RWTH Aachen
TU München
U. Hamburg



Japan

Tohoku U.
Tokyo Inst. Tech.
Tokyo Metro. U.
Niigata U.
Kobe U.
Tohoku Gakuin U.
Hiroshima Inst
Tech.



Russia

INR RAS
IPC RAS
RRC Kurchatov



Spain

CIEMAT-Madrid



UK

Sussex

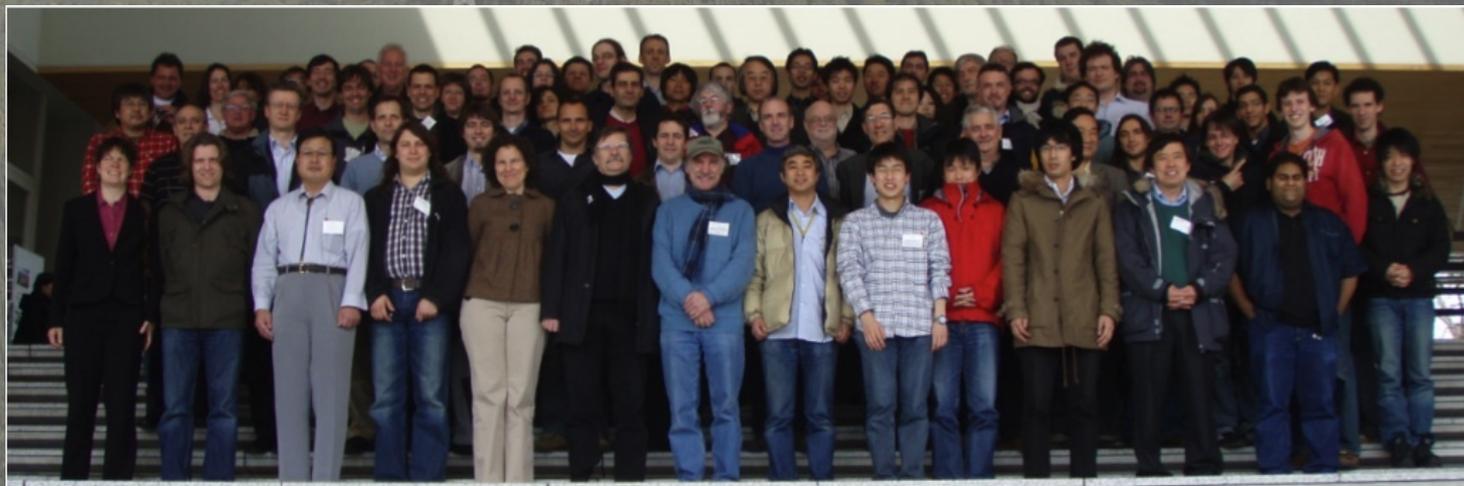


USA

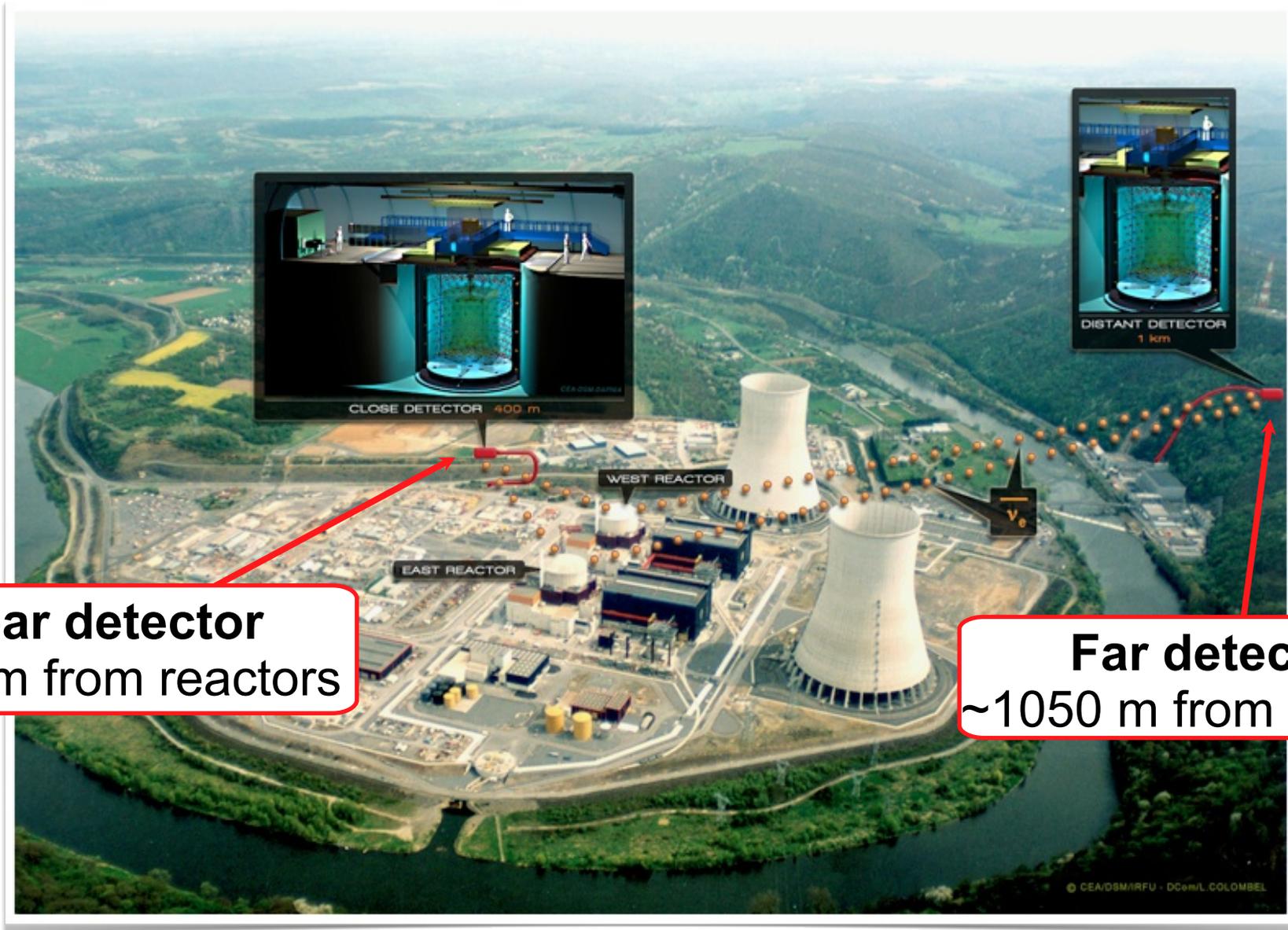
U. Alabama
ANL
U. Chicago
Columbia U.
UCDavis
Drexel U.
IIT
KSU
LLNL
MIT
U. Notre Dame
Sandia National
Laboratories
U. Tennessee

Spokesperson: H. de Kerret (IN2P3)
Project Manager: Ch. Veyssièrre (CEA-Saclay)

Web Site: www.doublechooz.org/



Double Chooz Overview

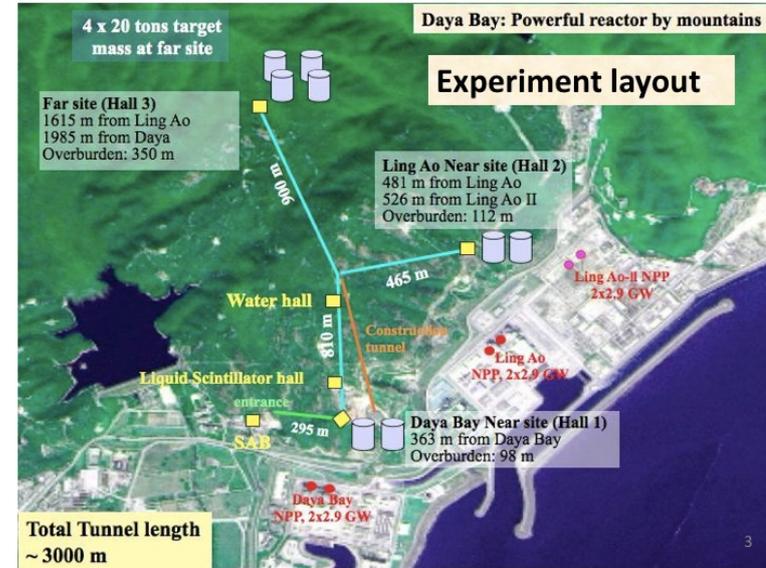


Near detector
~400 m from reactors

Far detector
~1050 m from reactors

Similar experiments

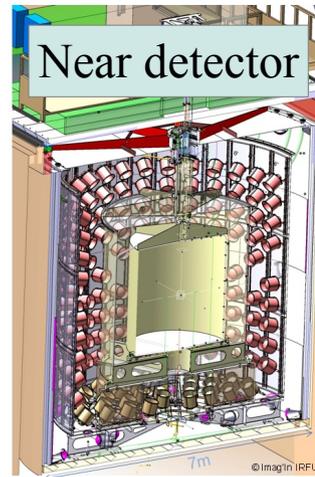
- Daya Bay (in China)
 - 4 → 6 reactors
 - Multiple detectors
 - Two near sites, one far
 - 363~526 m / ~1800 m
- RENO (in Korea)
 - 6 reactors
 - 290 m / 1380 m



Concept

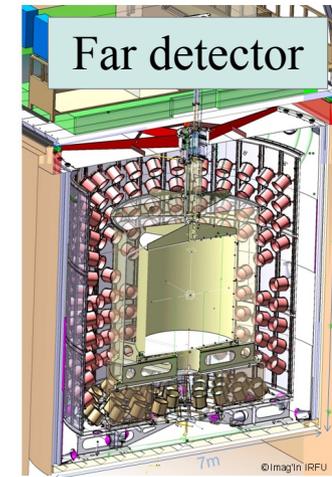


Very little
oscillation



L=400 m

Significant
oscillation



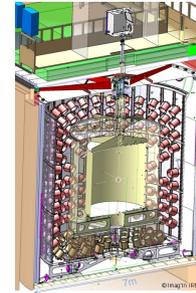
L=1050 m

$$P_{\bar{\nu}_e \rightarrow \bar{\nu}_e}(L) = |\langle \bar{\nu}_e(L) | \bar{\nu}_e(0) \rangle|^2 \simeq 1 - \sin^2(2\theta_{13}) \sin^2\left(\frac{\Delta m_{13} L}{4E}\right)$$

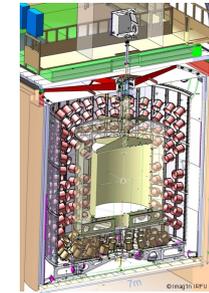
Oscillation signature to look for

$$P_{\bar{\nu}_e \rightarrow \bar{\nu}_e}(L) \simeq 1 - \sin^2(2\theta_{13}) \sin^2\left(\frac{\Delta m_{13} L}{4E}\right), \quad L/E \ll 2000 \text{ m/MeV}$$

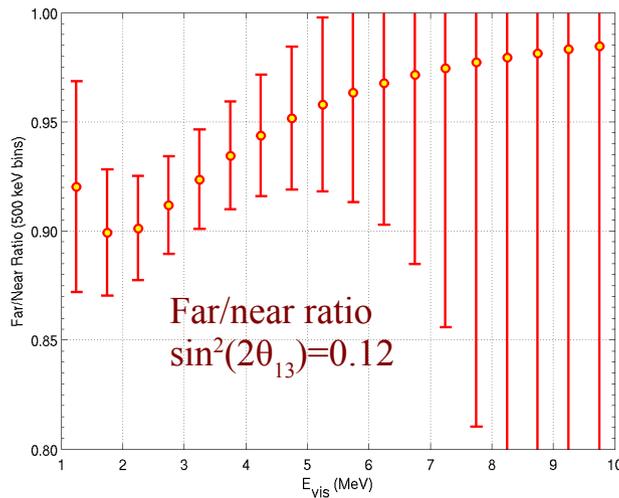
$$P_{\bar{\nu}_e \rightarrow \bar{\nu}_e}(L) \simeq 1 - \sin^2(2\theta_{12}) \sin^2\left(\frac{\Delta m_{12} L}{4E}\right), \quad L/E \gg 2000 \text{ m/MeV}$$



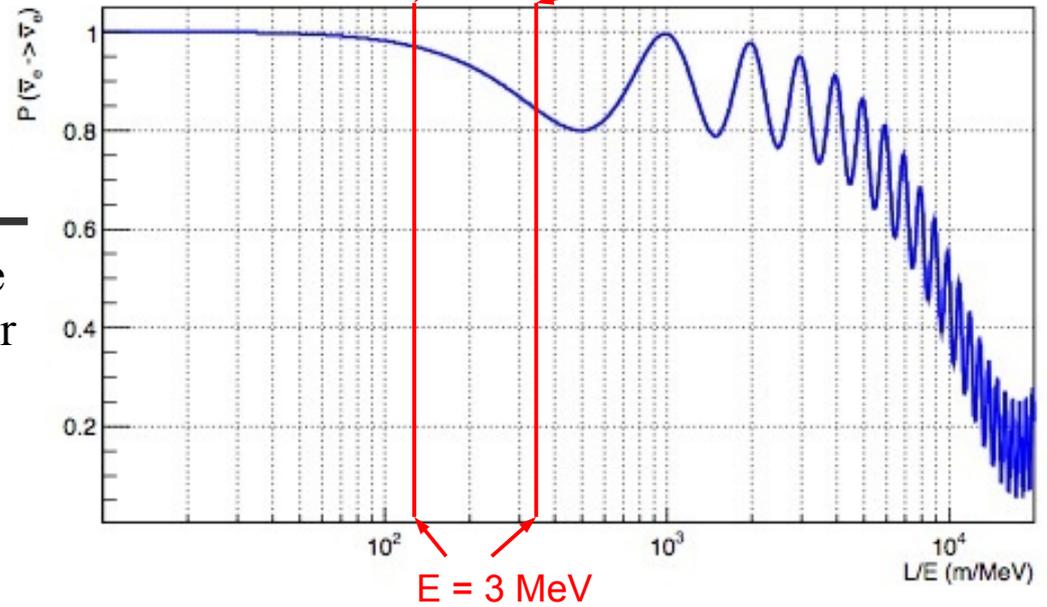
L=400 m



L=1050 m



← Compare near to far



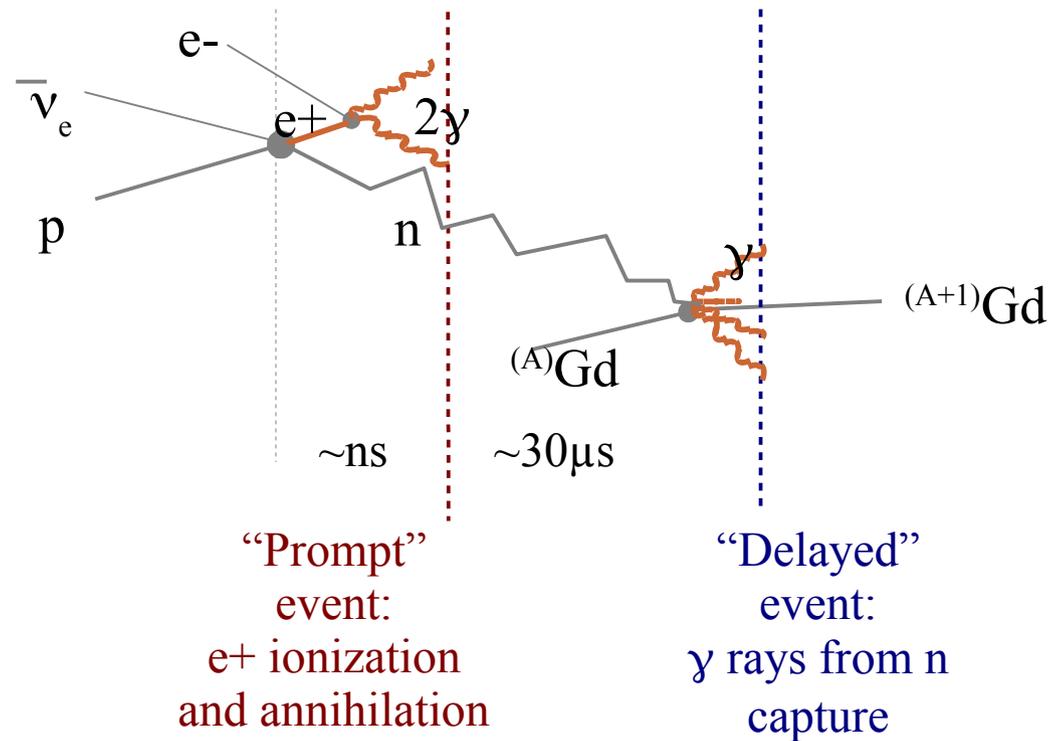
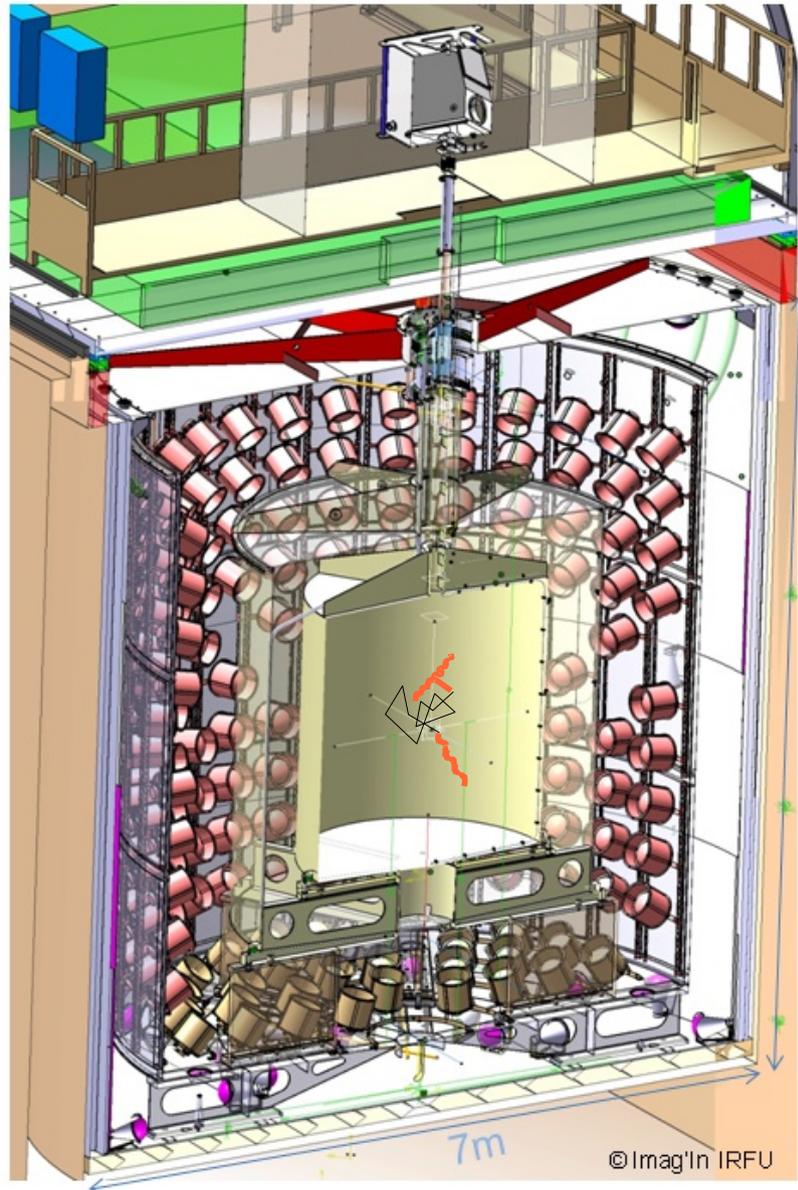
$$\Delta m_{23}^2 = 2.5 \times 10^{-3} \text{ eV}^2 \quad \Delta m_{12}^2 = 7 \times 10^{-5} \text{ eV}^2$$

$$\sin^2(2\theta_{13}) = 0.2 \quad \cos^2(\theta_{12}) = 0.7$$

Some features of reactor-based θ_{13} experiments

- The disappearance is insensitive to the value of the δ -CP phase \rightarrow clean measurement of θ_{13} .
- Short baseline (order of 1 km) is insensitive to matter effects.
- Dependence on Δm_{21}^2 is weak: $O(\Delta m_{21}^2 / \Delta m_{31}^2)$.
 - \rightarrow Complementary to accelerator long-baseline experiments.

How we detect the antineutrinos: the inverse beta decay signal

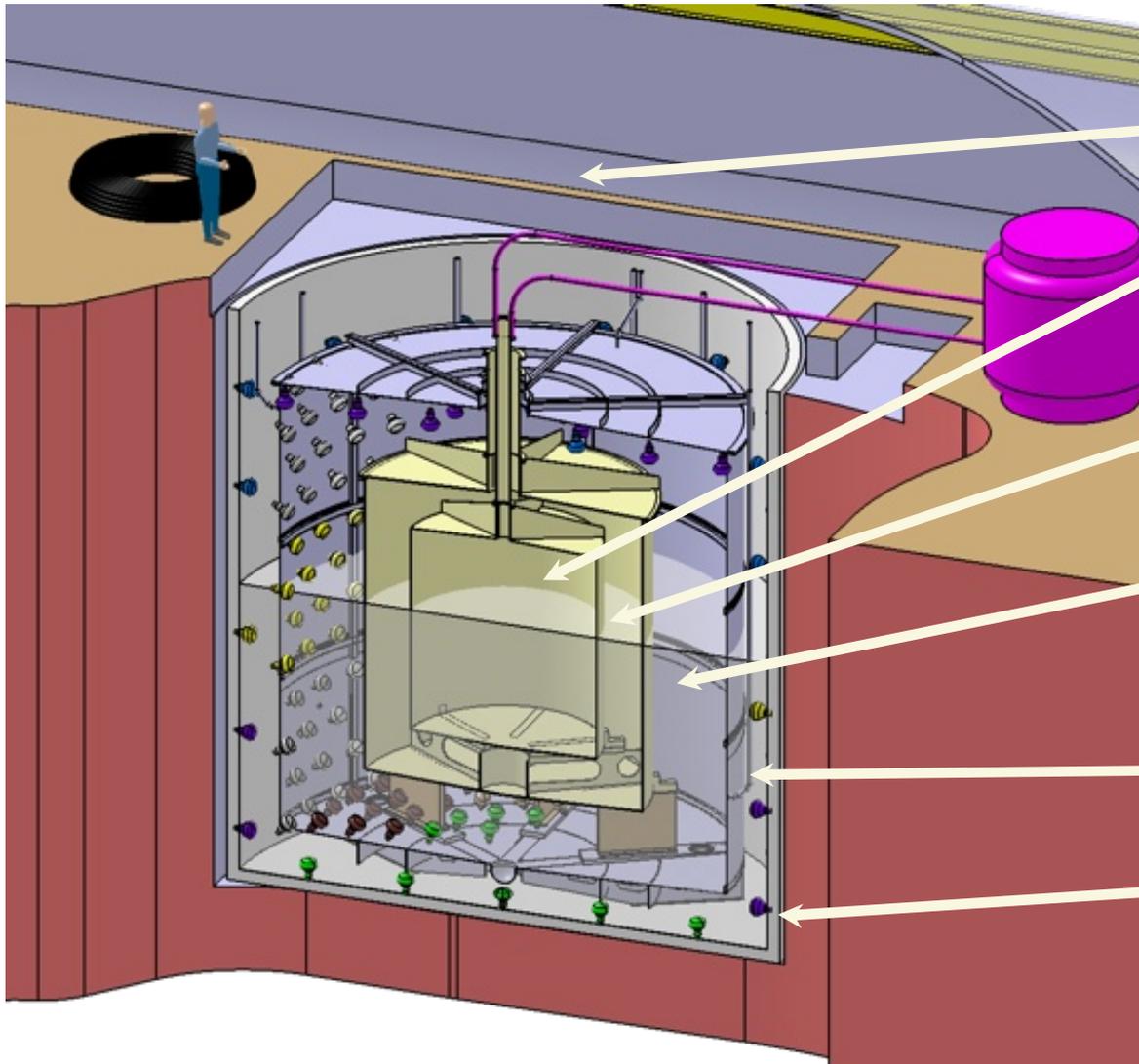


Expected rates:

65 interactions/day in far detector target

450 interactions/day in near detector target

Detector design



Outer Veto: plastic scintillator strips

ν -Target: 10.3 m³ of organic liquid scintillator, Gd-doped, in acrylic vessel (8 mm).

γ -Catcher: Liquid scintillator, no Gd, in acrylic (12 mm).

Buffer: Non-scintillating liquid, 390 PMTs (10"), stainless steel vessel.

Inner Veto: Scintillator in steel vessel. 78 PMTs (8").

Shielding: about 250t steel shielding ~150 mm thick

Milestones – Far Detector

- May 2008 - October 2010
 - Far detector construction.
- December 2010
 - Far detector filling completed.
- **April 2011**
 - Far detector commissioned.
 - **Start physics data taking with far detector.**
- July 2011
 - Outer veto commissioned.
- **November 2011**
 - **FIRST RESULT presented at LowNu 2011**
(uses far detector only)

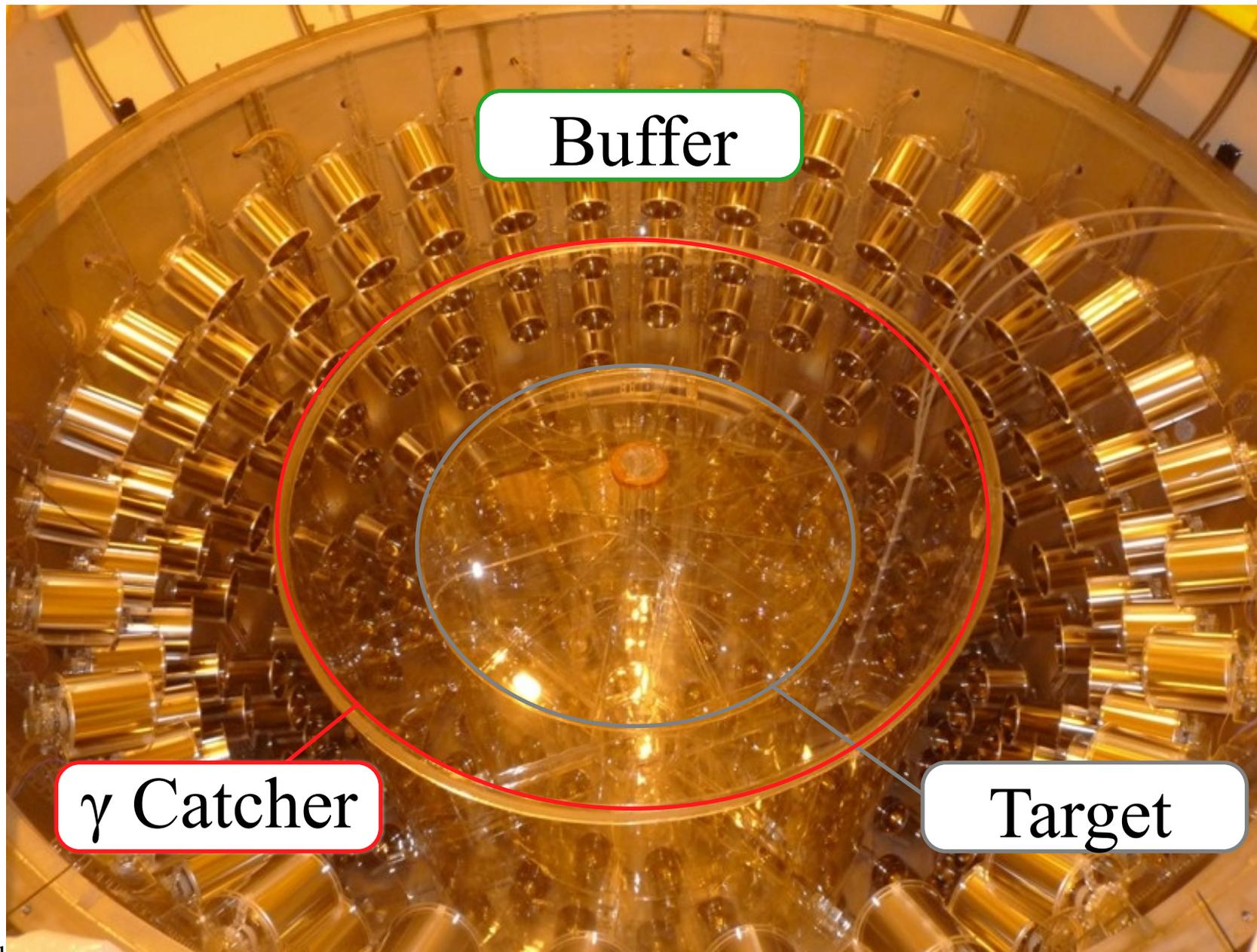
Milestones – Near Detector

- **April 2011**
 - Near laboratory construction started.
- ~June 2012
 - Near laboratory expected delivery.
- ~Beginning 2013
 - Near detector expected.
- After commissioning
 - Data taking with two detectors.

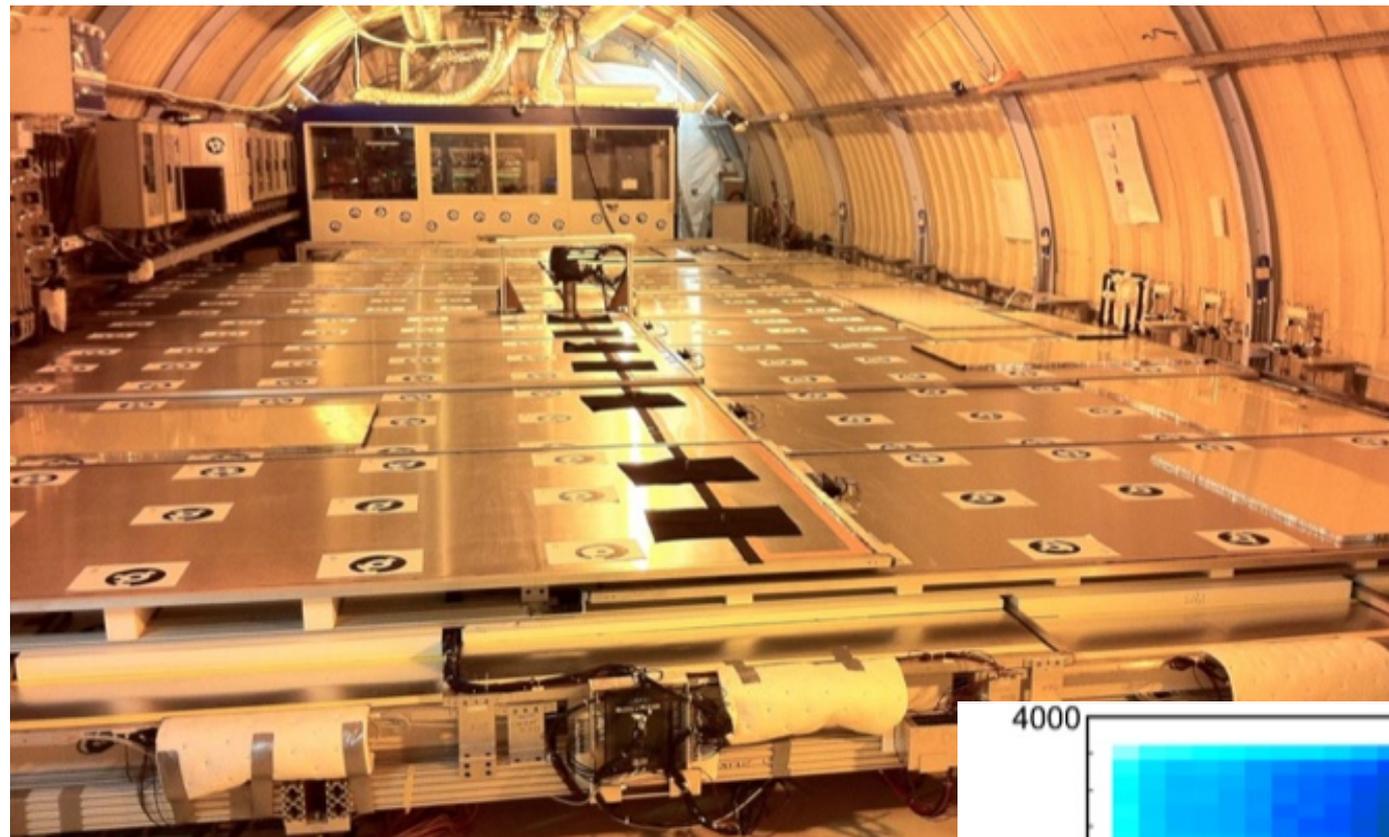
Near Detector Lab Under Construction



Far Detector During Installation

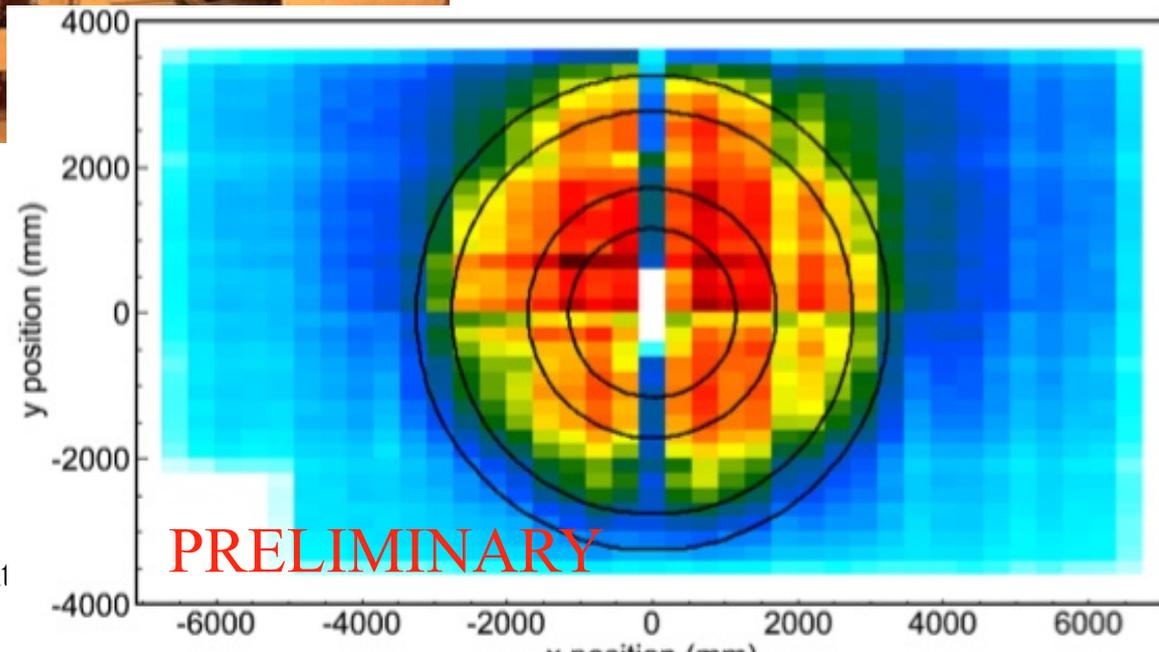


After OV Installation Complete



Outer Veto

Muons seen by both
Outer-Veto and Neutrino
Detector (“shadow”)

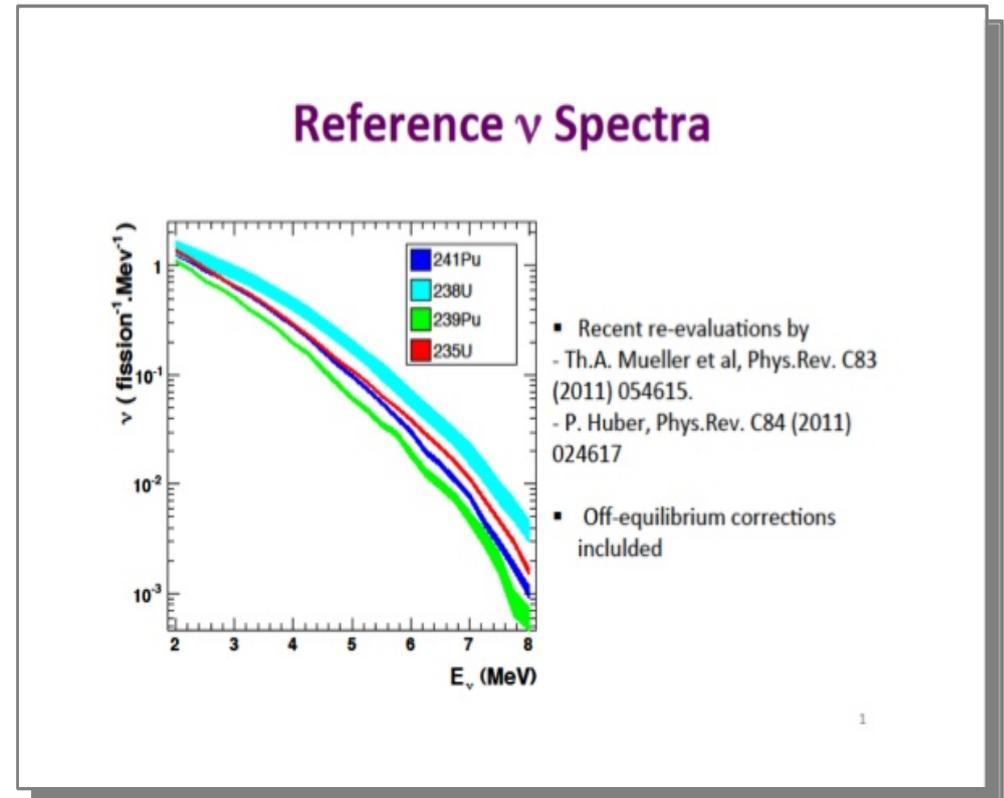


December 1, 2011

G. Horton-Smit

Reactor Neutrino Flux

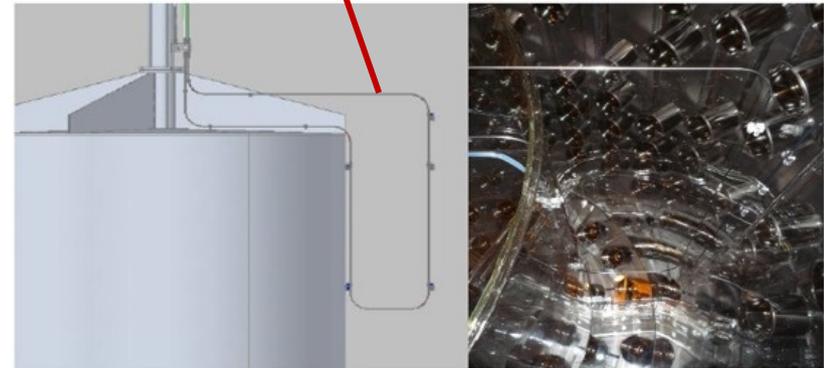
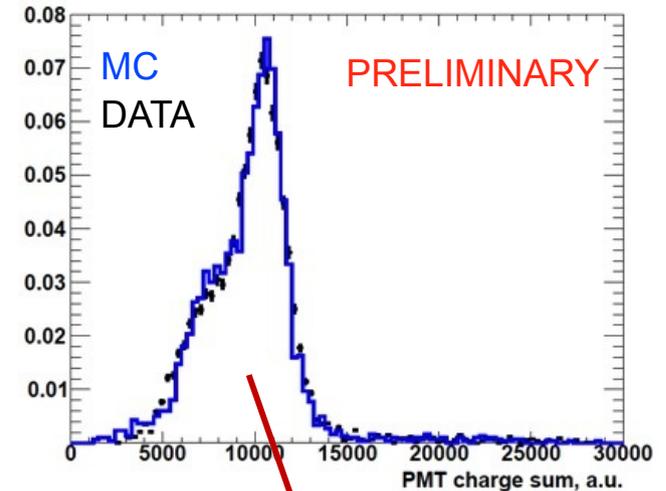
- Recent work defines new reference for the neutrino flux prediction.



- “Anchors” for total cross-section * overall flux:
 - Far-only data: Bugey 4 data. (Same as CHOOZ.)
 - Near+far phase: near detector data.

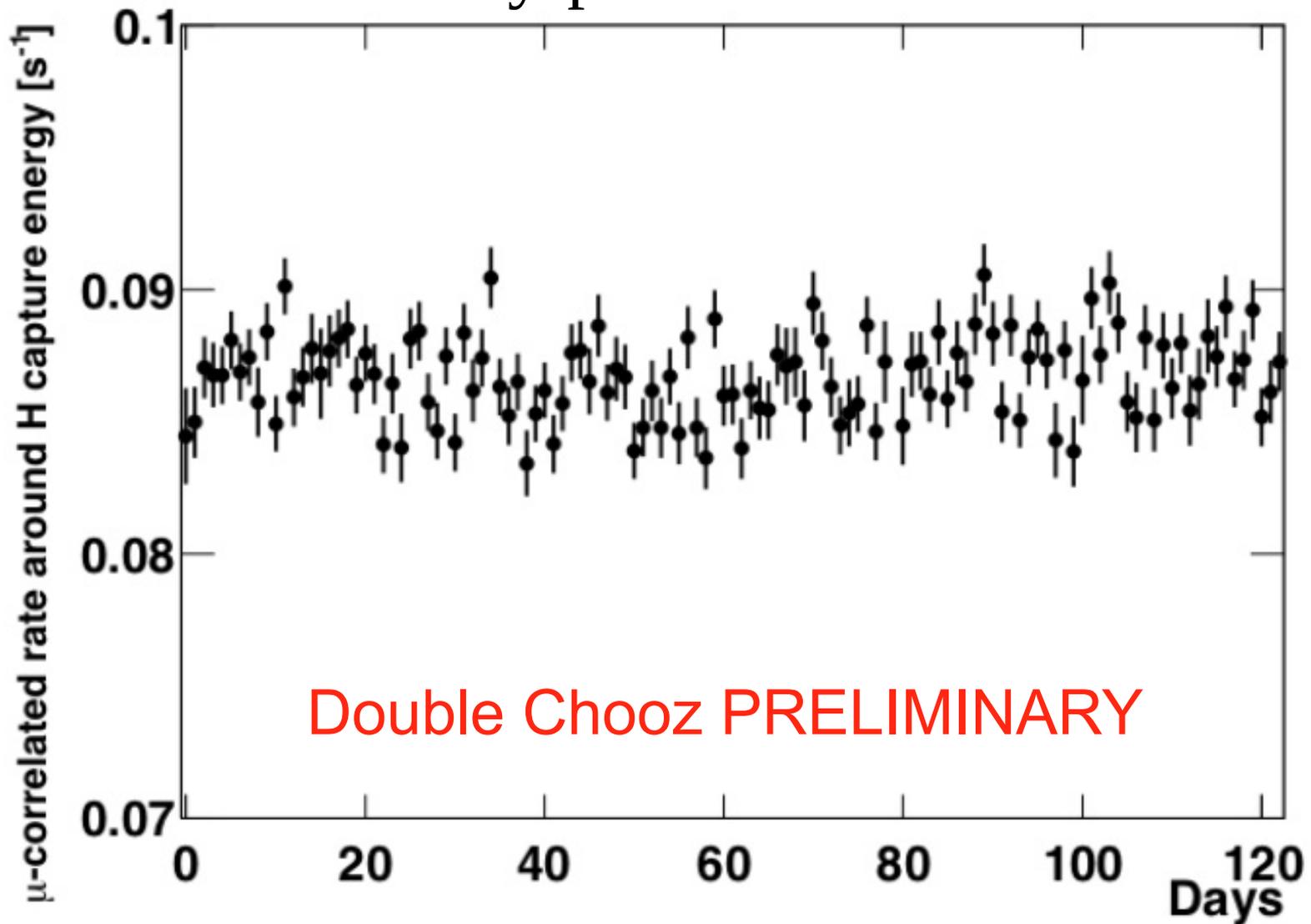
Calibration

- Light injectors
 - inner-detector and inner-veto
- Laser (UV and green)
- Sources (^{68}Ge , ^{137}Cs , ^{60}Co , ^{252}Cf)
- Deployment systems
 - vertical axis (target)
 - guide tube (gamma catcher)
 - articulated arm (future)



Detector Stability

cosmic-ray-produced neutrons



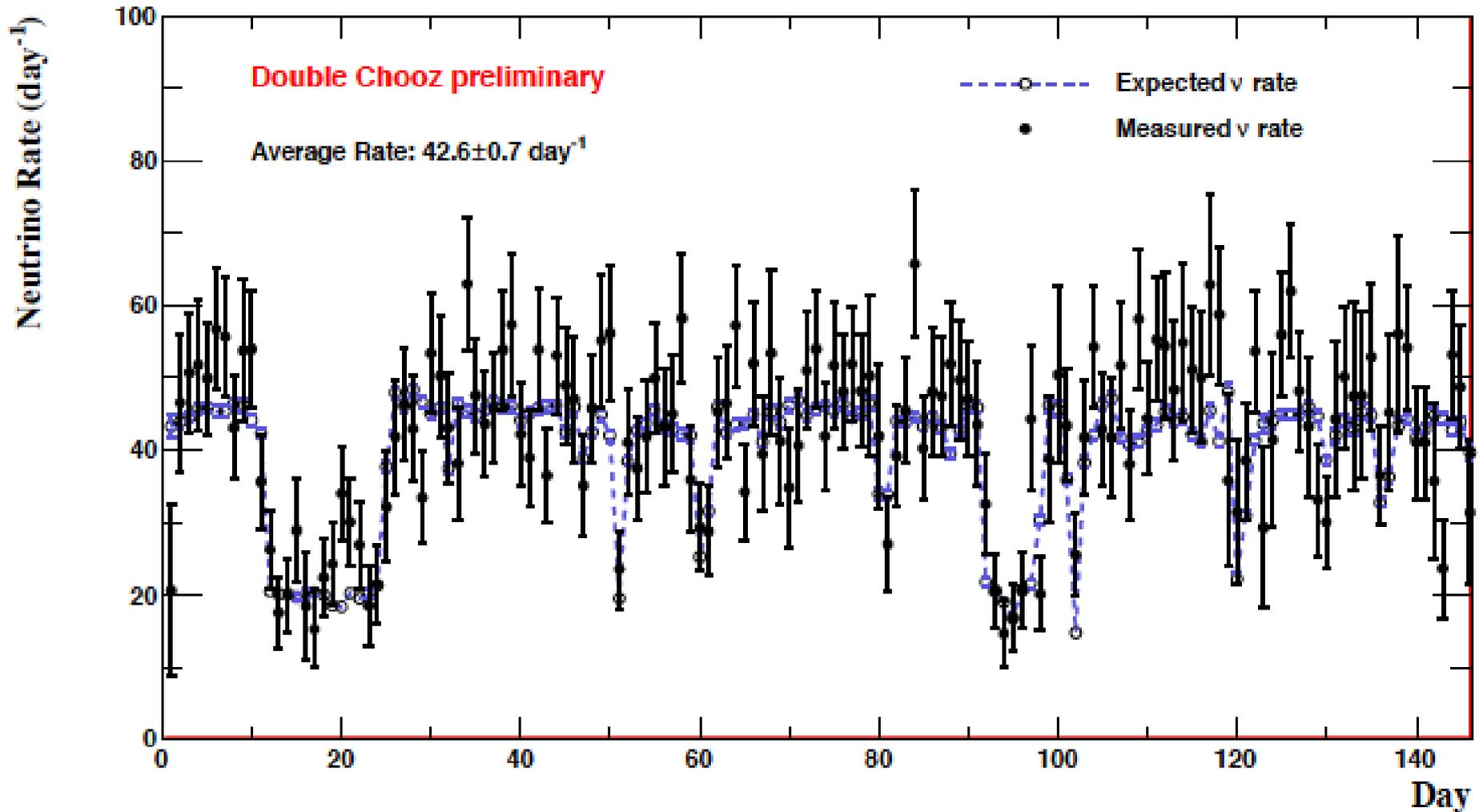
Neutrino Candidate Selection

- Cut 1 ms after each muon tagged by inner-veto or inner-detector
- Cut out PMT spontaneous light emission
 - Use ratio $Q_{\max}/Q_{\text{total}}$ to cut triggers having $>9\%$ of light in one PMT.
 - Use RMS of arrival times at PMTs to cut triggers with light spread over > 40 ns.
- **Prompt signal within [0.7, 12] MeV**
- **Delayed signal within [6, 12] MeV**
- **Prompt-delay coincidence within [2, 100] μs**
- Multiplicity condition
 - No trigger ($E > 500\text{keV}$) within $100 \mu\text{s}$ before prompt.
 - Only one trigger ($E > 500\text{keV}$) within $400 \mu\text{s}$ after the prompt.

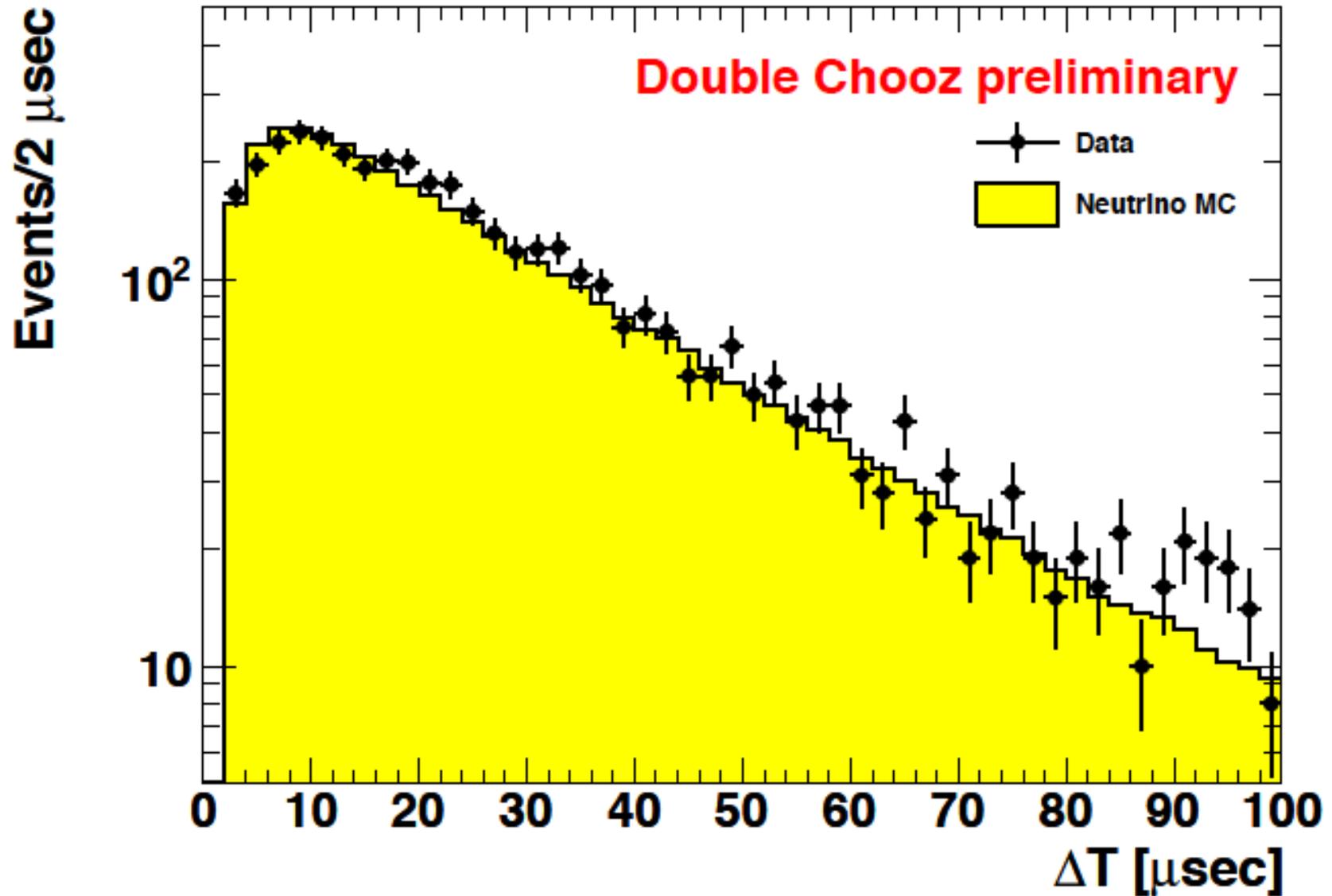
Candidate Rate vs Time

Neutrino candidates rate

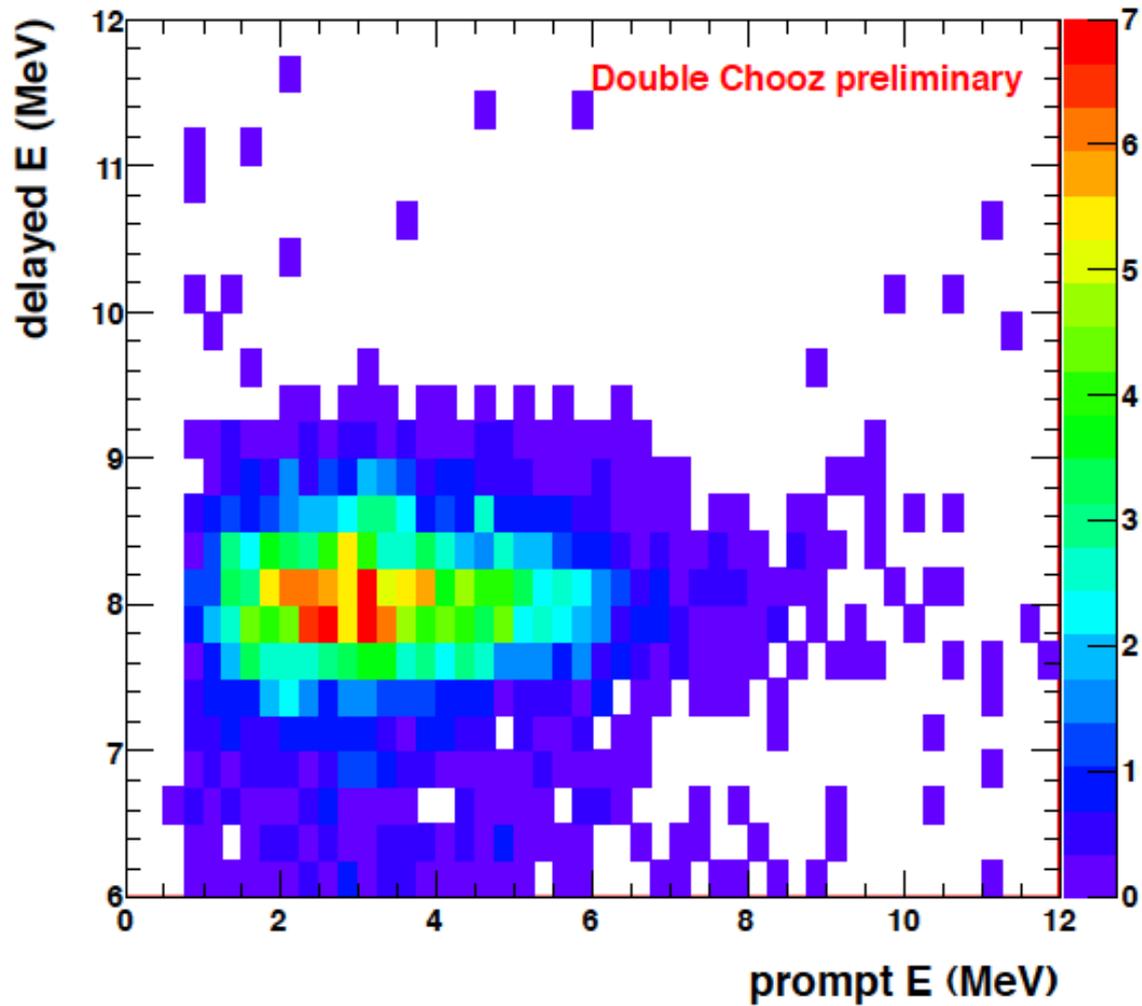
no background subtraction



Time Correlation



Prompt vs Delayed Energies

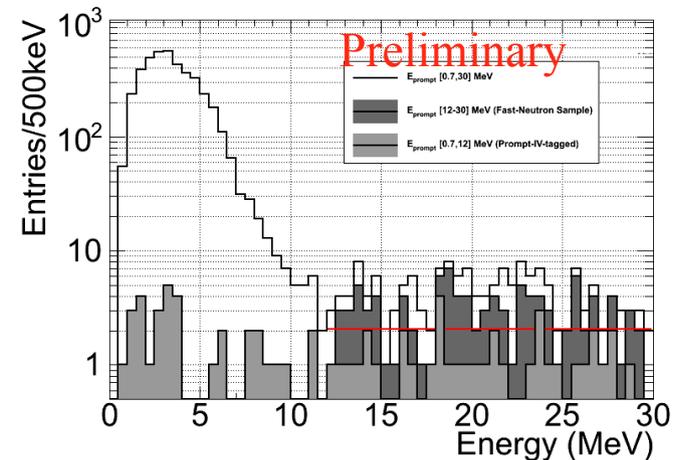
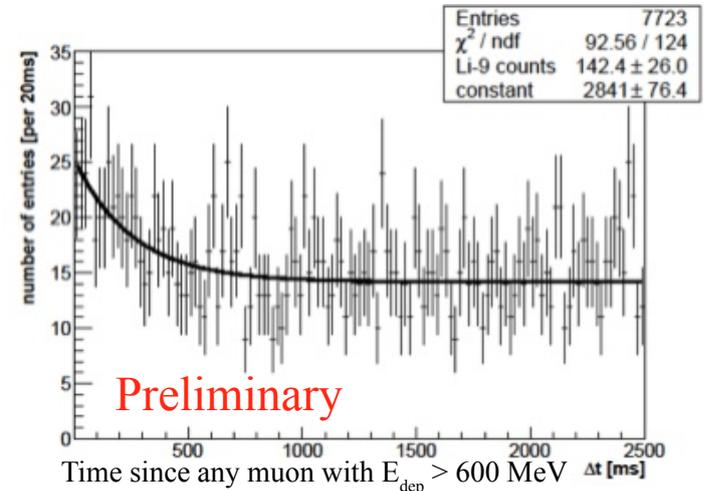


Backgrounds

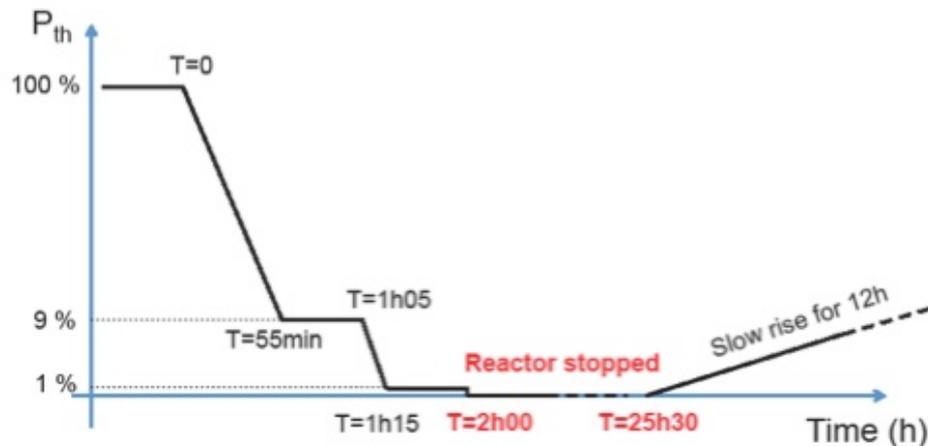
- **Correlated backgrounds:**
 - **Fast neutrons** (by cosmic μ) give recoil protons (low energy) and are captured on Gd.
 - **Stopping muons** followed by muon-decay (Michel electron/positron).
 - **Long-lived $\beta+n$ -decaying isotopes** (^9Li , ^8He) induced by μ .
- **Accidental backgrounds:**
 - Prompt and delayed triggers from unrelated radioactive decays and neutrons.

Background measurements

- **Accidentals**,
from off-time windows:
 $(0.332 \pm 0.004) \text{ day}^{-1}$
- **$^9\text{Li}/^8\text{He}$** ,
from muon correlation:
 $(2.3 \pm 1.2) \text{ day}^{-1}$
- **Spallation neutrons**,
from $>12\text{MeV}$ spectrum:
 $(0.7 \pm 0.5) \text{ day}^{-1}$



The Day Both Reactors Stood Still



(Having only two reactors can be a good thing!)

- One reactor off for refueling, 2 months.
- During this time, the other reactor went off for tests, 1 day.
- 3 events < 30 MeV, 2 of them < 12 MeV.
- Consistent with our background estimates.

Theta-13 Preliminary Results

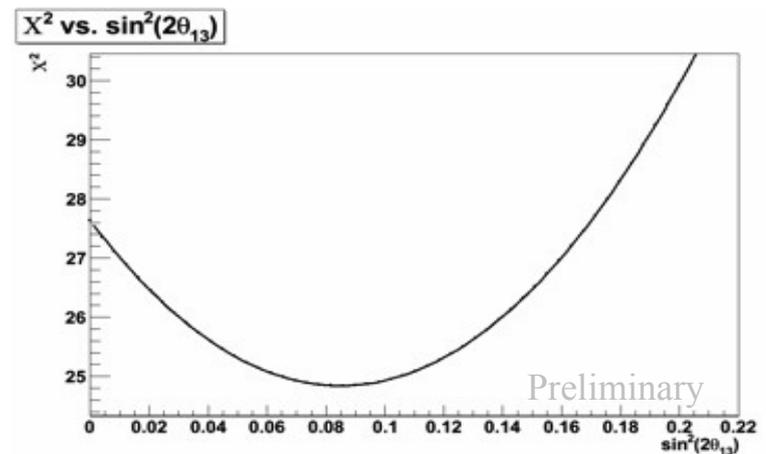
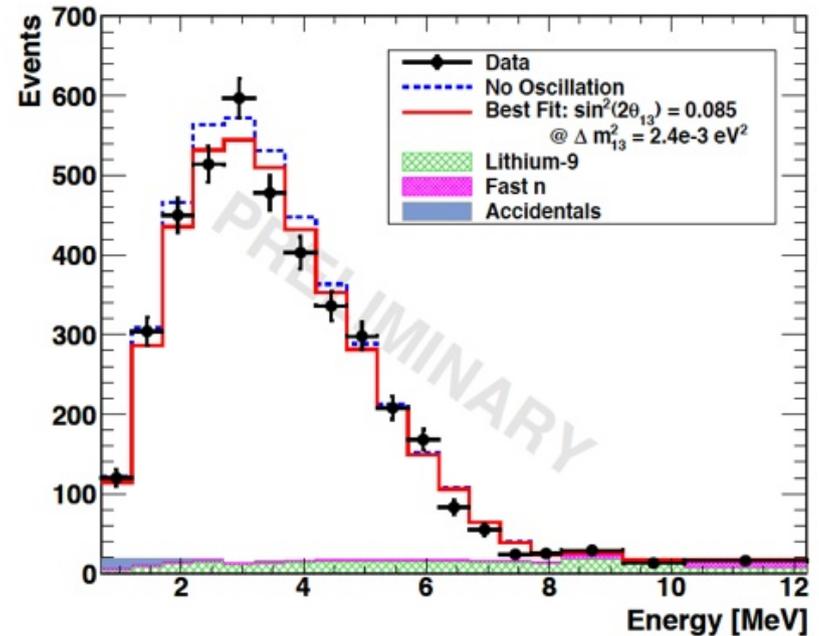
- Far detector data only

Rate + Shape Analysis:

$$\sin^2(2\theta_{13}) = 0.085 \pm 0.051$$

Rate Only Analysis:

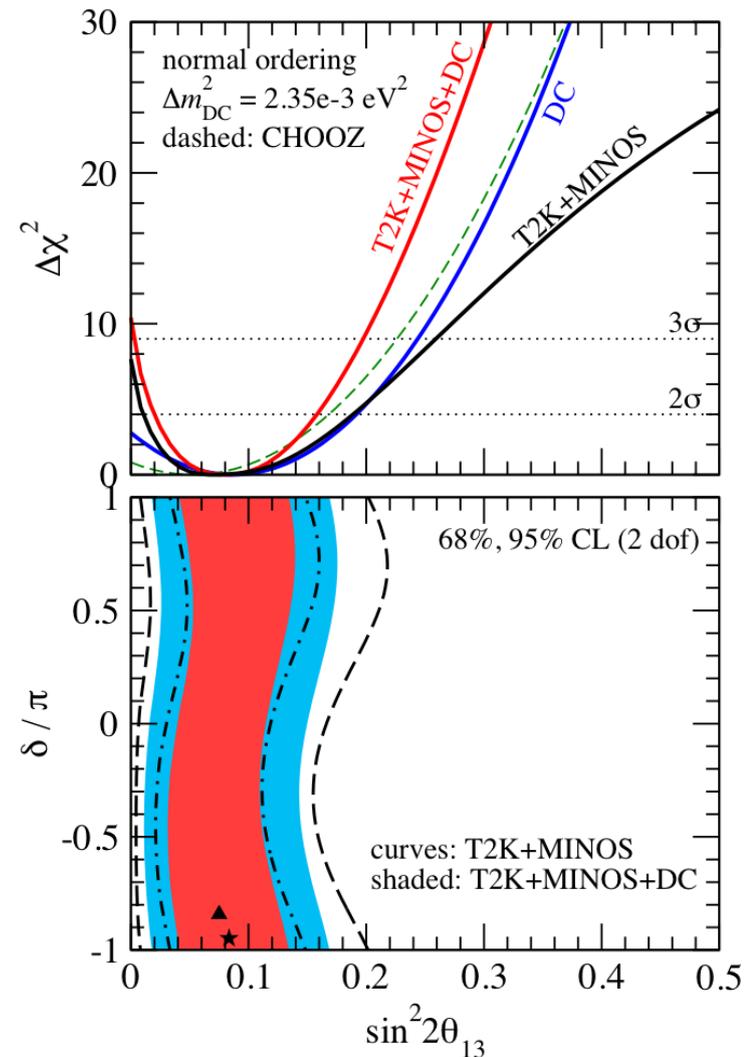
$$\sin^2(2\theta_{13}) = 0.093 \pm 0.079$$



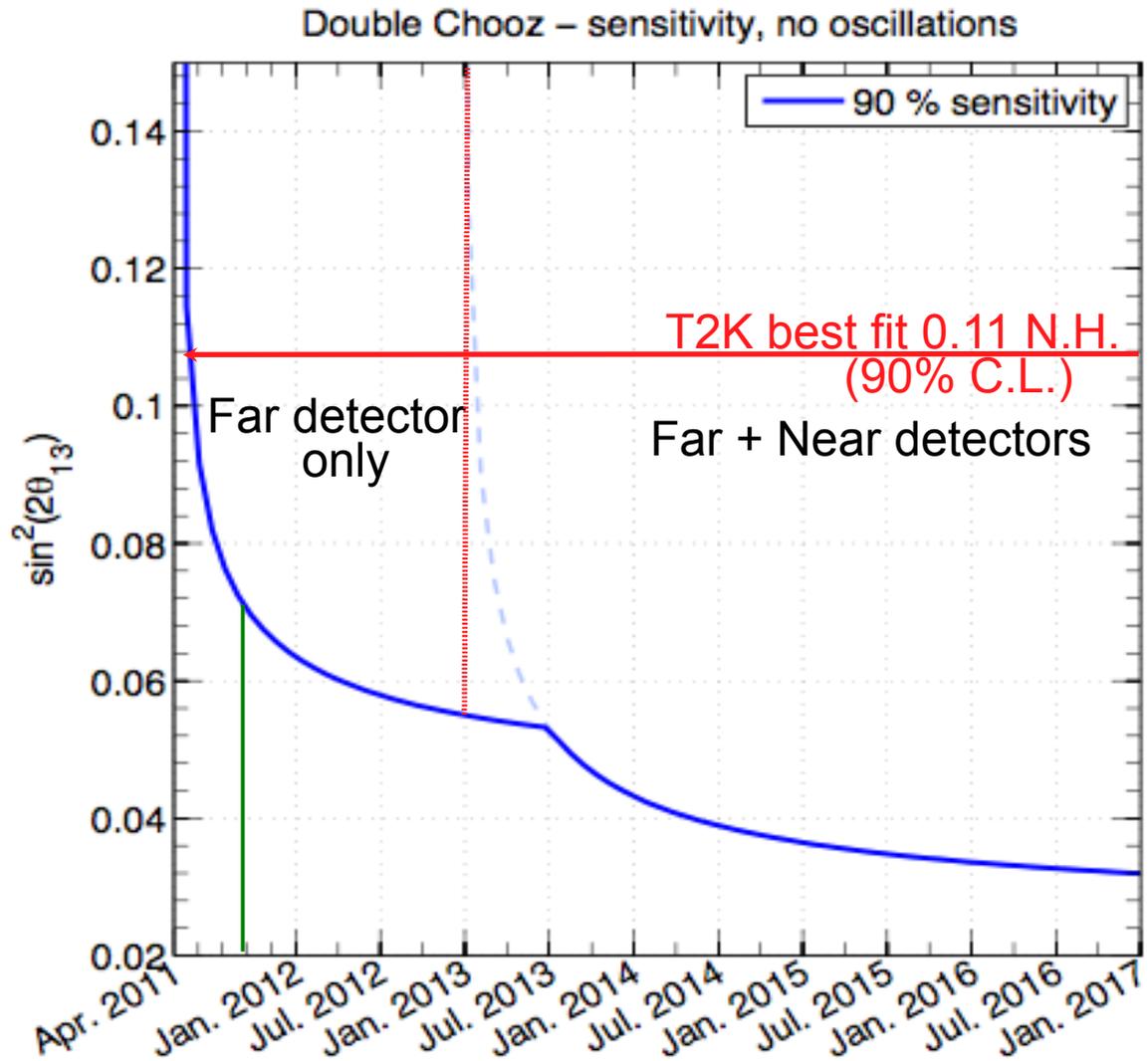
Global Theta-13 Fits

- DC results consistent with T2K, MINOS.
- Significantly improves knowledge of θ_{13} .
- Combined effect: $\theta_{13} > 0$ at 3σ .

The plots at left were made by T. Schwetz for normal hierarchy. Similar plots can be found in arXiv:1111.3330v1 [hep-ph] by Machado, Minakata, Nunokawa, and Funchal.

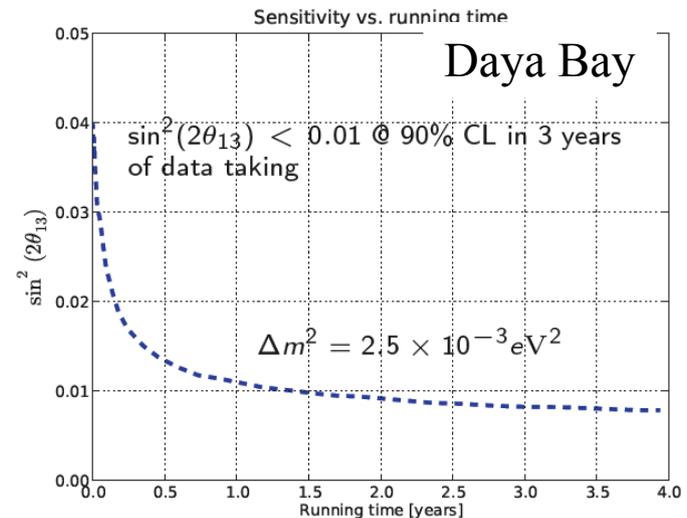
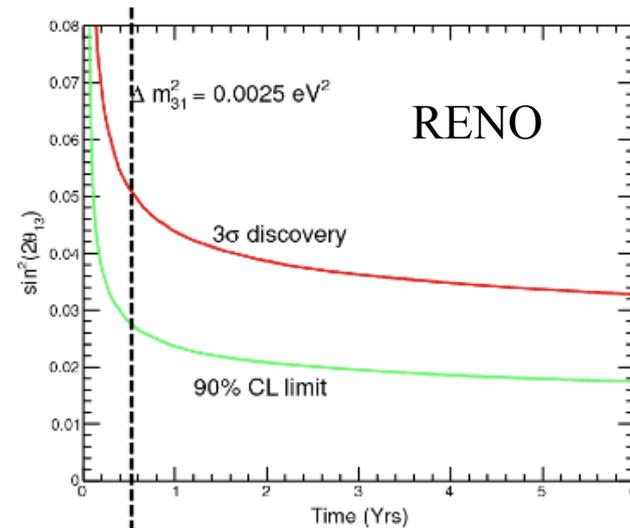


Timeline and sensitivity: Double Chooz



More Timelines and Sensitivities

- **RENO** is taking data with far AND near since August 1, aims for first result by Neutrino 2012 (June, 2012).
- **Daya Bay** aims to start taking data at all sites in **summer 2012**. Precision after 1 year already beats all other experiments.



Conclusion

Now

First Double Chooz oscillation result

$$\sin^2(2\theta_{13}) = 0.085 \pm 0.051 \text{ (68\% CL)}$$

This summer

RENO expects to deliver result, approx. factor of 2 better precision.

Next

Daya Bay expects to start operating with full detector complement as early as this summer, Double Chooz by early 2013.

Daya Bay's sensitivity goal brings “precision neutrino physics” to θ_{13} .

Non-DC image and plot attributions

- Photo of Chooz chimneys (slide 5): Google Earth/Panoramio user “fab59650”
- 3D Cutaway model of Double Chooz detector, © Imag'IN IRFU.
- Daya Bay layout: Haoqi Lu's talk at LowNu 2011
- RENO layout and sensitivity curve: K.K.Ju's talk at LowNu 2011.
- Daya Bay sensitivity curve: courtesy K.Heeger

See also

- Longer talk given at LowNu 2011 by Herve deKerret: <http://doublechooz.in2p3.fr/>

See also

- Longer talk given at LowNu 2011 by Herve deKerret: <http://doublechooz.in2p3.fr/>
- Even longer seminar given at Saclay by Thierry Lasserre,
http://irfu.cea.fr/en/Phocea/Vie_des_labos/Seminaires/index.php?y=2011&id=2688