Reactor Neutrinos

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NExT meeting, University of Southampton, 4th May 2011

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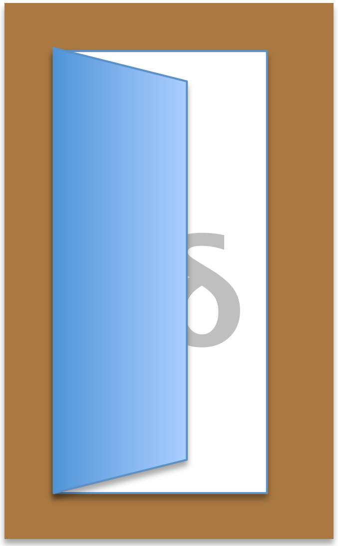
- Introduction
- Current status of upcoming detectors
- Reactor anomaly

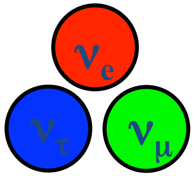
Part I/III

INTRODUCTION

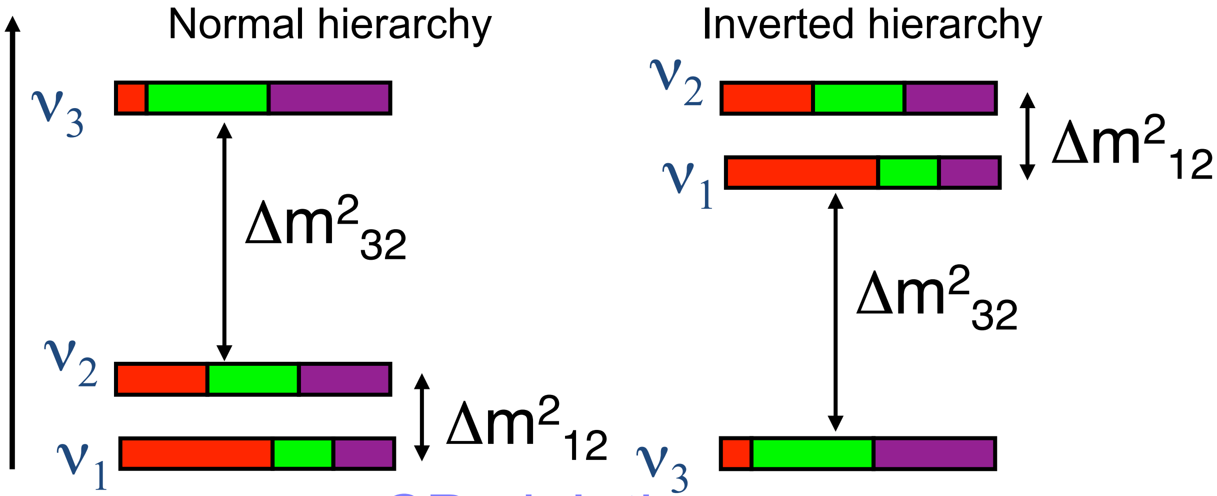
Neutrino oscillations



Θ_{13}: portal to CP violation



(mass)^2



"Atmospheric" Well measured

~Unknown

CP-violation phase

"Solar" Well measured

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

$\theta_{23} = (45 \pm 7)^o$

$\Delta m^2_{32} = 2.4 \times 10^{-3}\ \mathrm{eV}^2$

θ_{13} <~ 10^o

$\Delta m^2_{31} \sim \Delta m^2_{32}$

$\theta_{12} = (34 \pm 3)^o$

$\Delta m^2_{12} = 7.6 \times 10^{-5}\ \mathrm{eV}^2$

Two approaches

LBL accelerator experiments:

- Look for appearance ($\nu_\mu \to \nu_e$) in pure ν_μ beam vs. *L* and *E*
- Near detector to measure background ν_es (beam + mis-id)
- $P(\nu_\mu \rightarrow \nu_e) = f(\delta, \text{sign}(\Delta m_{31}^2))$

Reactor experiments:

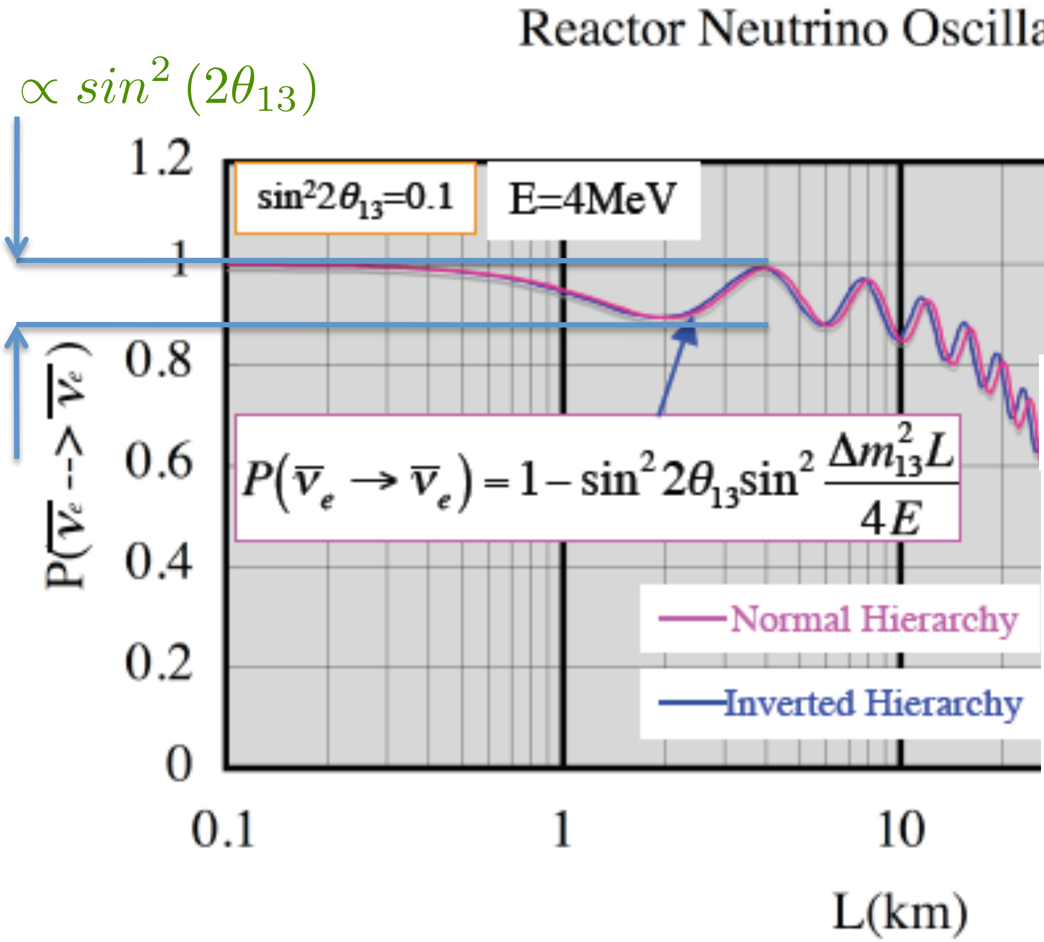
- Look for disappearance ($\overline{\nu}_e \to \overline{\nu}_e$) as a fnc of *L* and *E*
- Near detector to measure unoscillated flux
- $P(\overline{\nu}_e \rightarrow \overline{\nu}_e)$ independent of δ; matter effects small

Combination of appearance and disappearance very powerful if comparable sensitivity

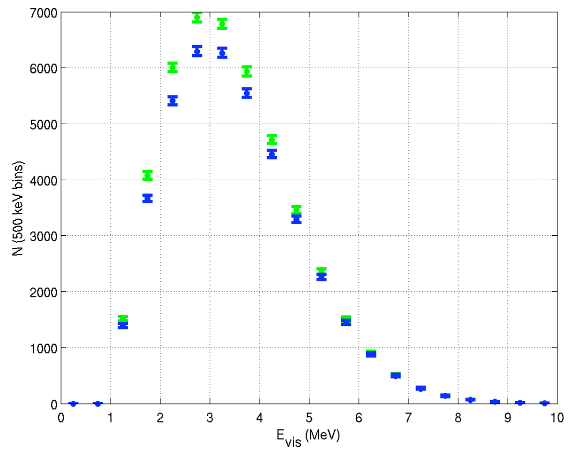
T2K, MINOS, NOνA

Double Chooz, Daya Bay, RENO

Reactor experiments



Spectral change:
only small difference



Double Chooz
3 yrs, $\sin^2 2\theta_{13} = 0.1$,
$\Delta m^2 = 2.5\times10^{-3}$
arXiv:hep-ex/0606025

- *No degeneracies*
- *No matter effects*
- *No correlations*

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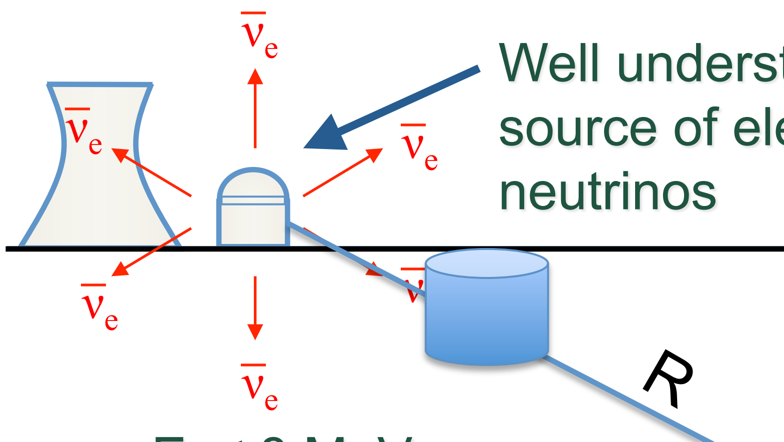
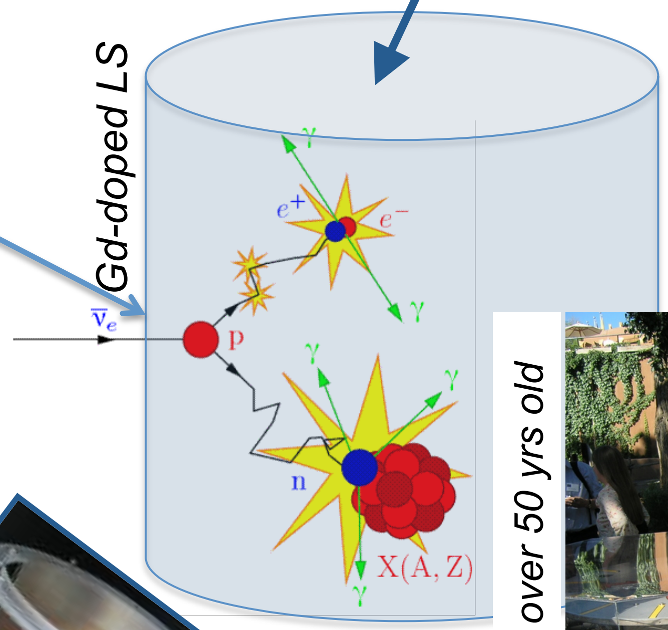
Reactor experiments

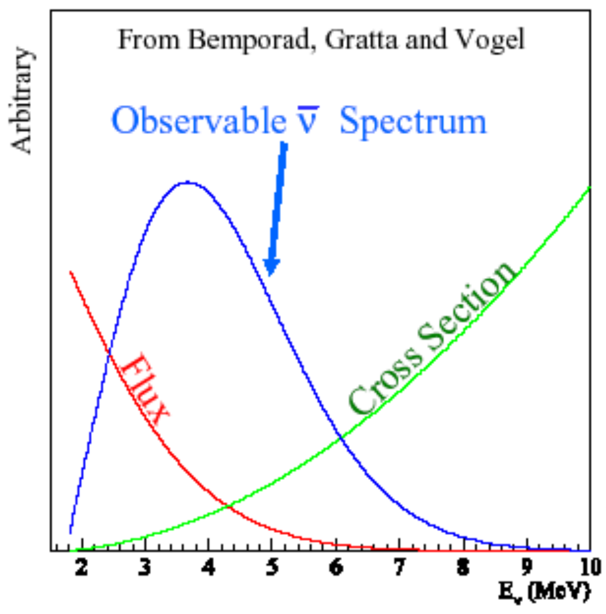


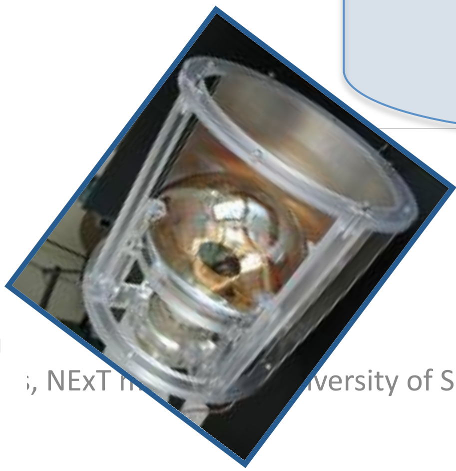


Well understood*, isotropic source of electron anti-neutrinos

$E_\nu \leq 8$ MeV

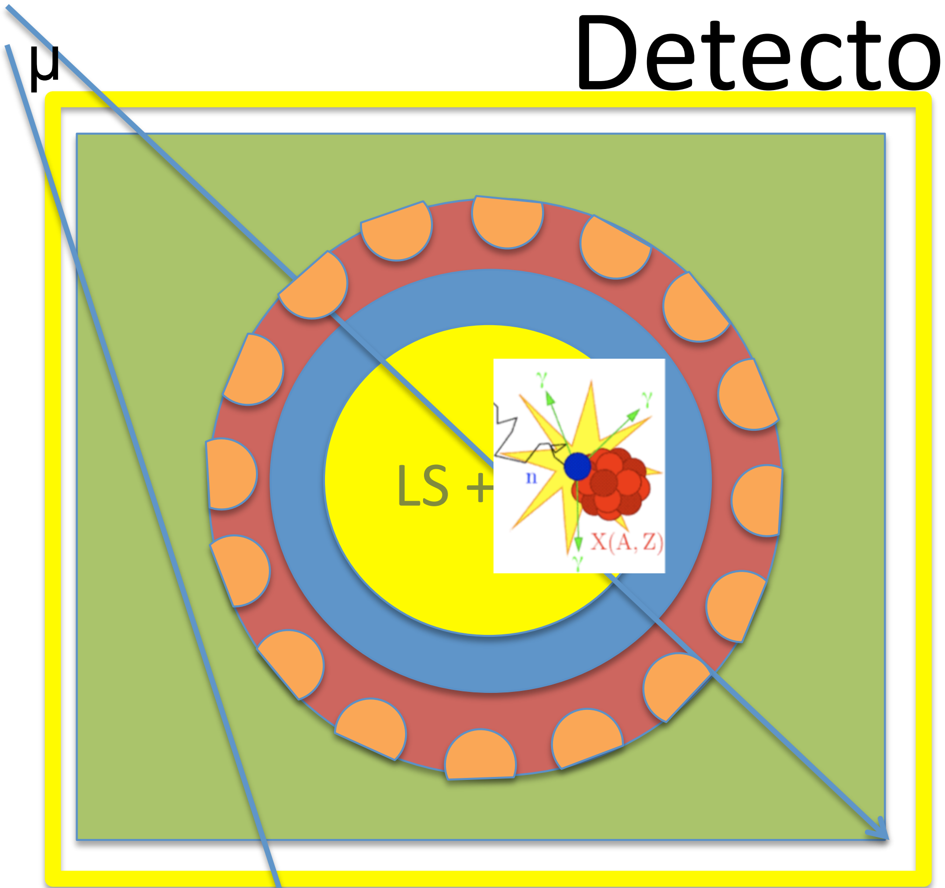
Oscillations observed as **disappearance** of $\overline{\nu}_e$

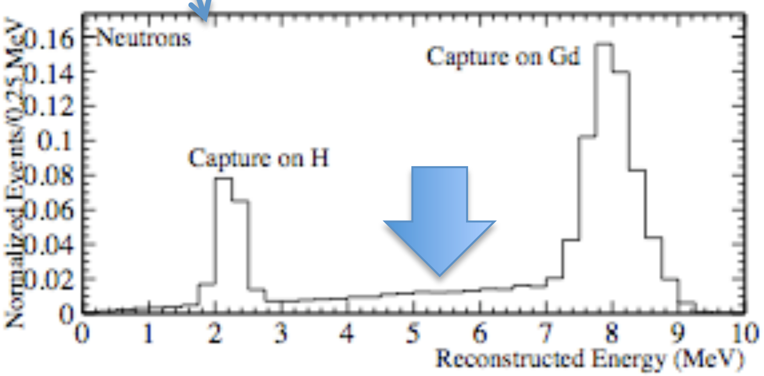




Design concept over 50 yrs old

Detector design





- Keep geometry simple *(as simple as possible)*
- Light collection (energy resolution)
- Size matters: counting vs shape measurement
- Active muon shielding
- Depth: reduce muon rate
- Detect passing muons
- Gamma catcher
  - Catch escaping gammas from neutron captures on Gd: reduce tail
- Backgrounds
  - materials (Gd complex)
  - (PMT, rock) shielding

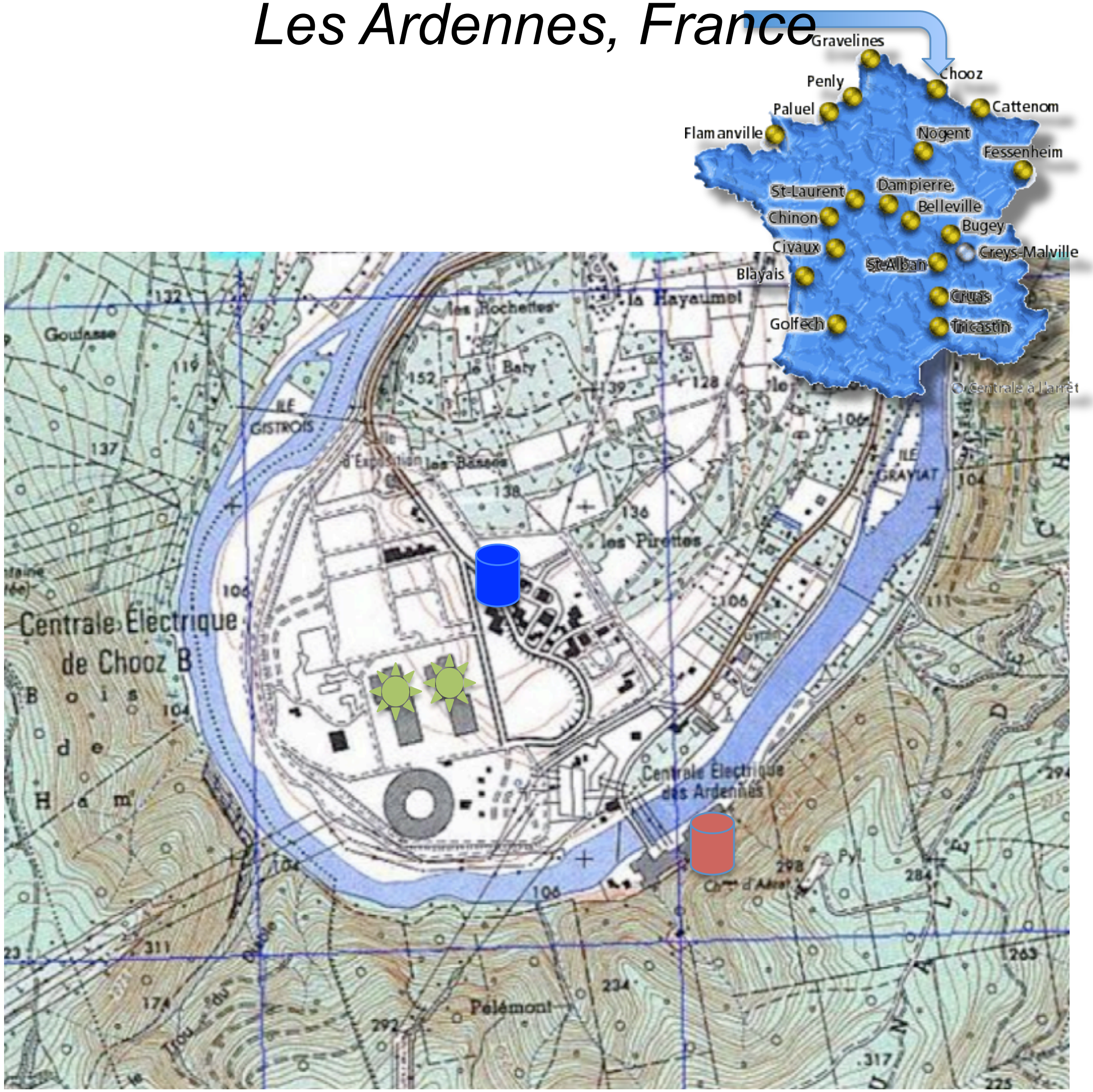

braidwood.uchicago.edu

Part II/III

STATUS

Double Chooz overview

Les Ardennes, France



2 cores:

8.5 GW_{th}

Near detector:

|D| ~ 400 m

Overburden ~115 m.w.e.

(flat topology)

Far detector:

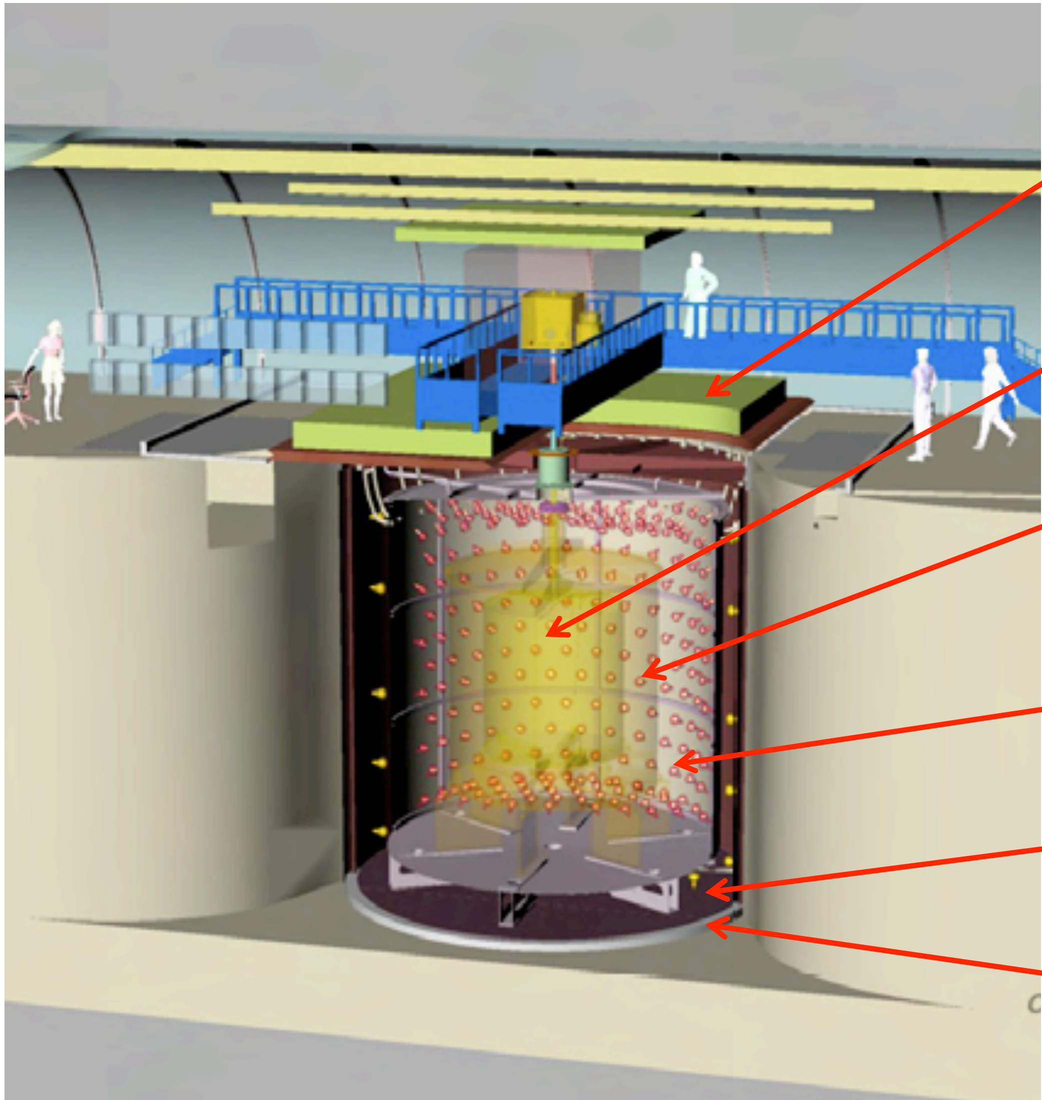
D ~ 1.05 km

Overburden ~300 m.w.e.

(hill topology)

Existing (Chooz) pit at far detector

Detector design: Double Chooz



Outer Veto:
Plastic scintillator or RPCs

ν Target:
Liquid scintillator doped with 0.1% Gd

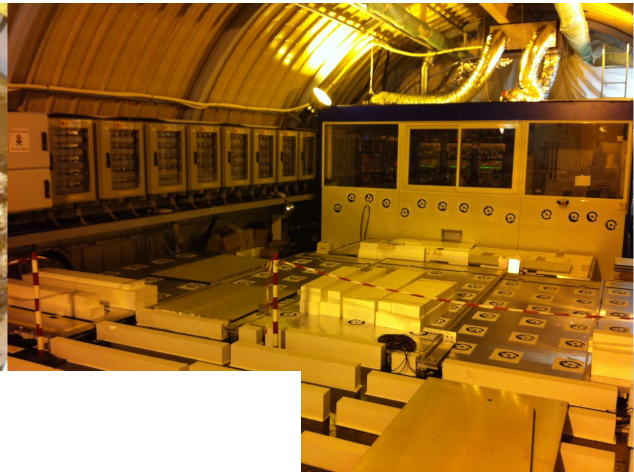
γ Catcher:
Liquid scintillator (undoped)

Buffer:
Mineral oil; PMTs

Inner Veto:
Liquid scintillator or water; PMTs

Shielding:
Steel or water

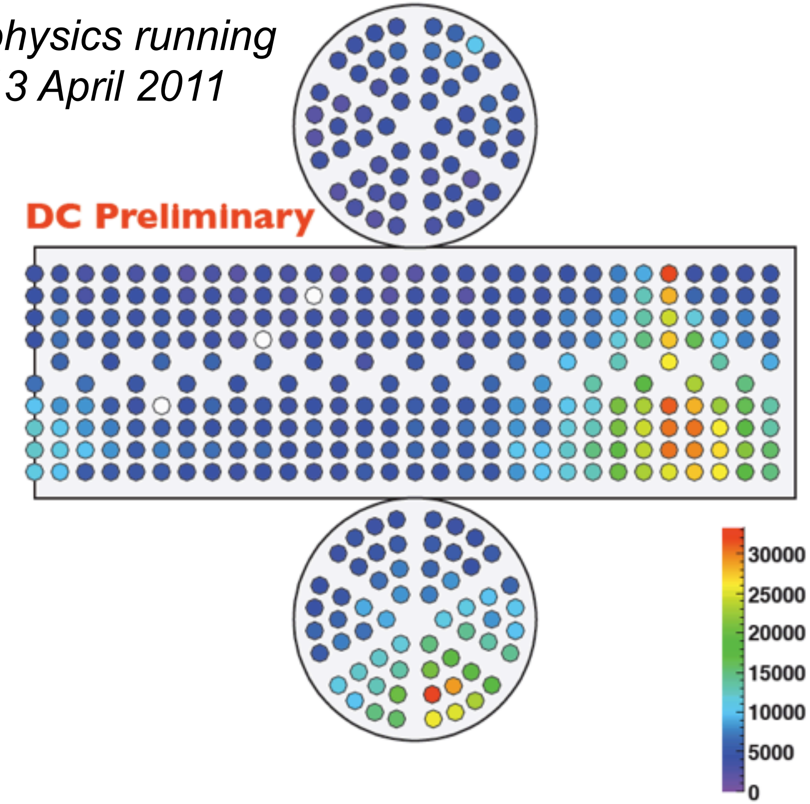
Double Chooz: status



veto being installed

ground breaking near site: 29 April 2011

physics running 13 April 2011



Daya Bay

This year:

6 reactors/17.4 GW

Far site

L = 1615 m/1985 m
350 m overburden
~90 events/day/detector

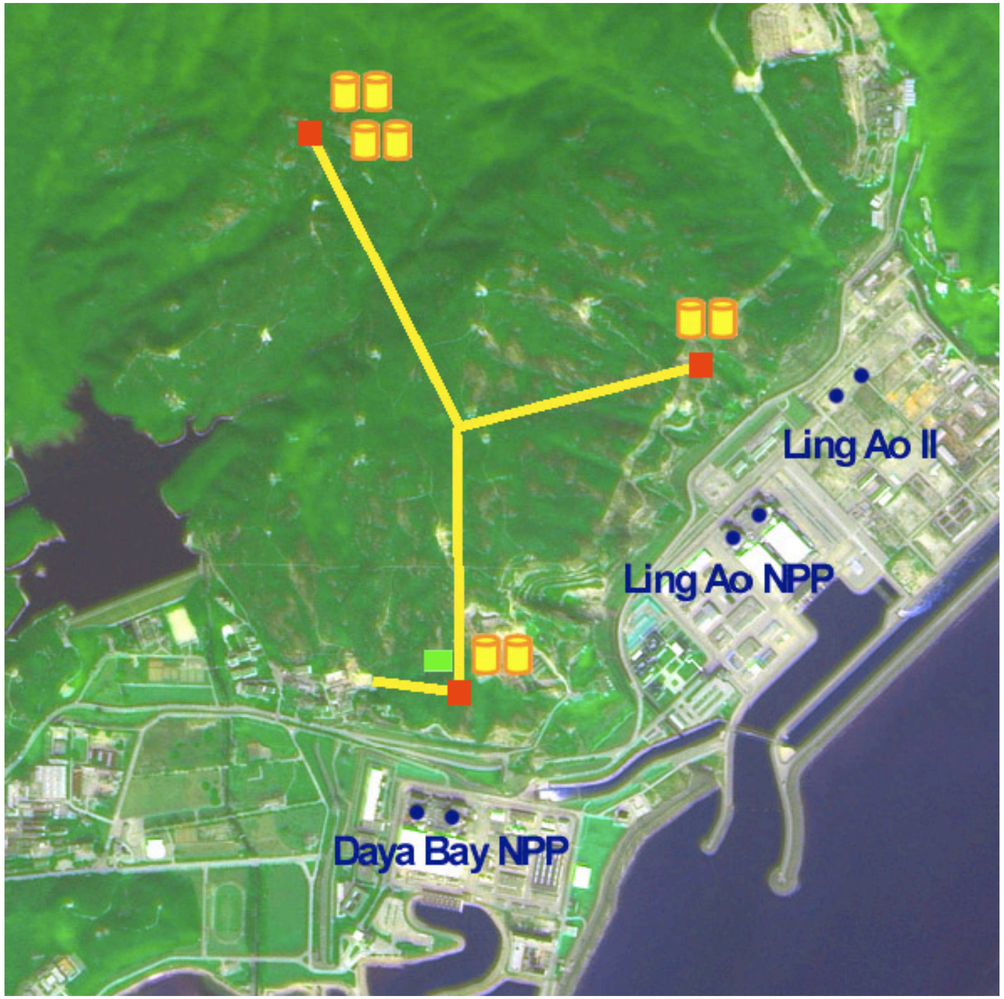
DB near site

L = 363 m/1145 m
98 m overburden
~930 events/day/detector

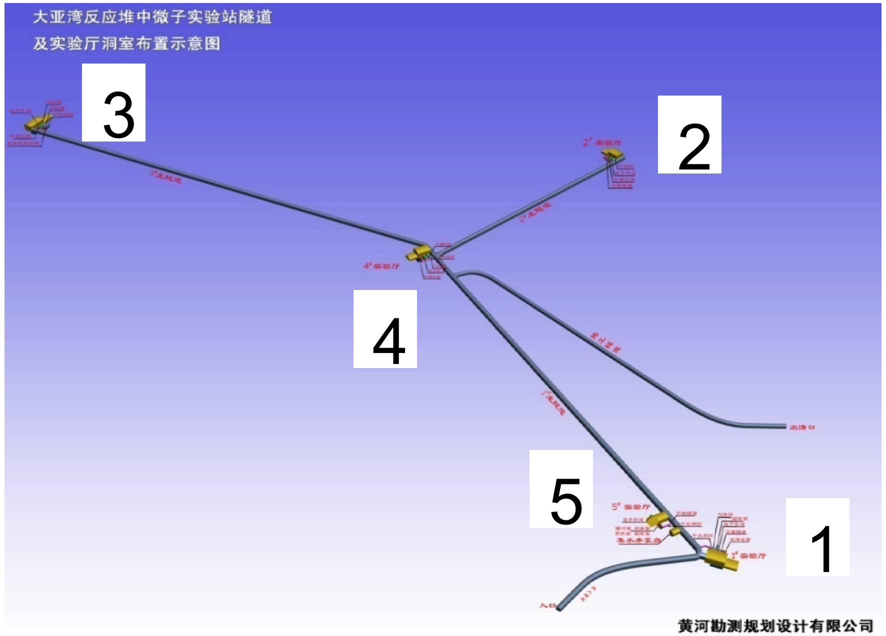
LA near site

L = 481 m/526 m
112 m overburden
~760 events/day/detector

Target mass 8 x 20 ton



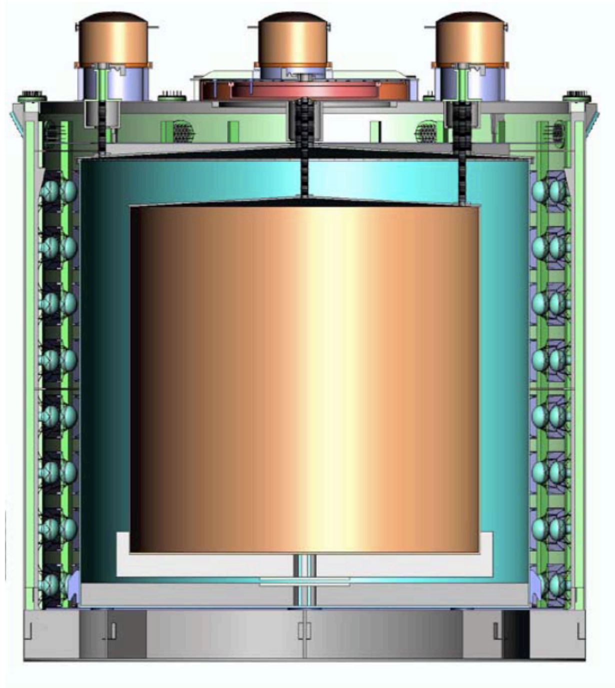
Daya Bay



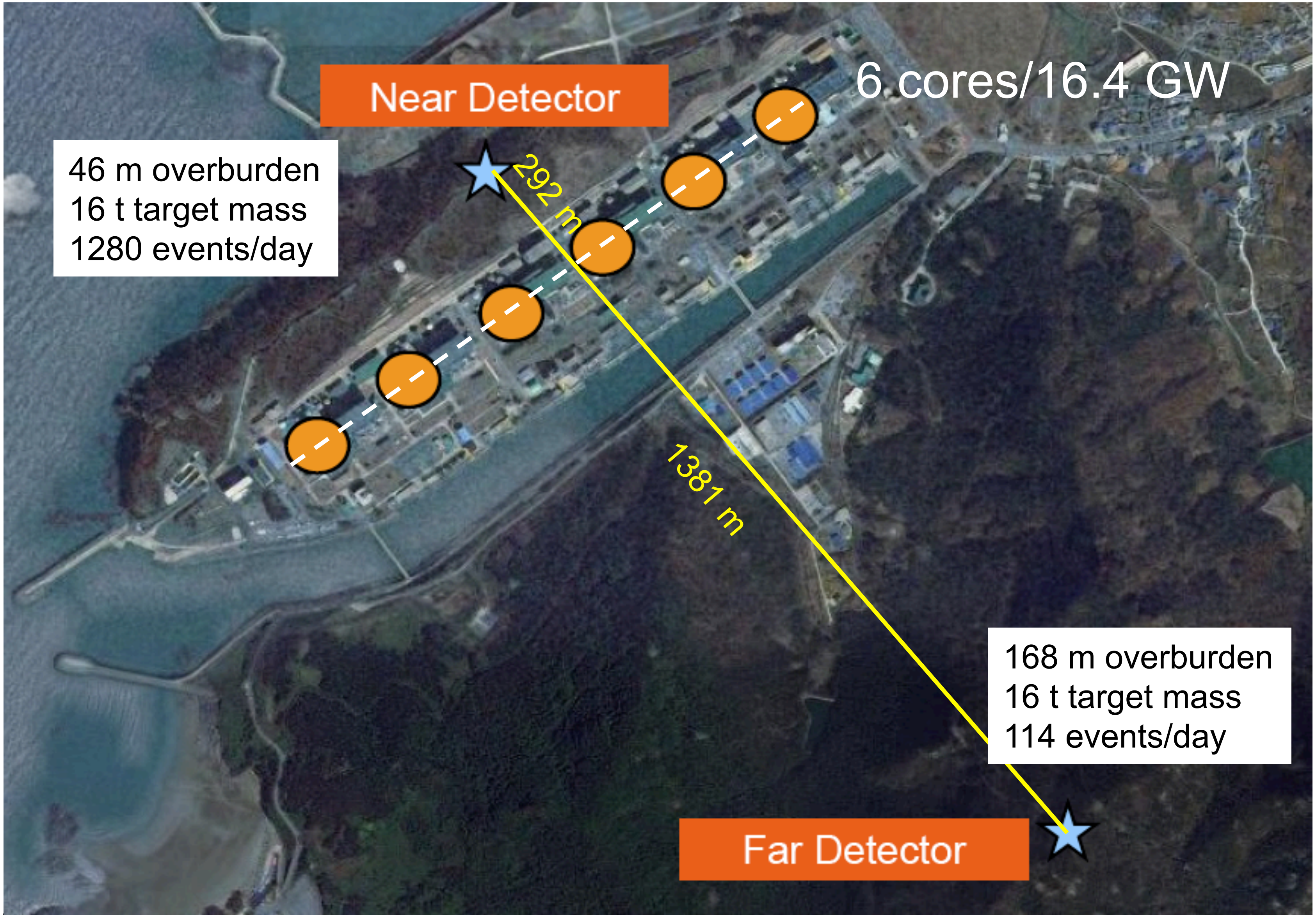
- Tunnels completed
- All halls except no. 3 completed
- Hall 3 to be completed this summer (2011)

Daya Bay

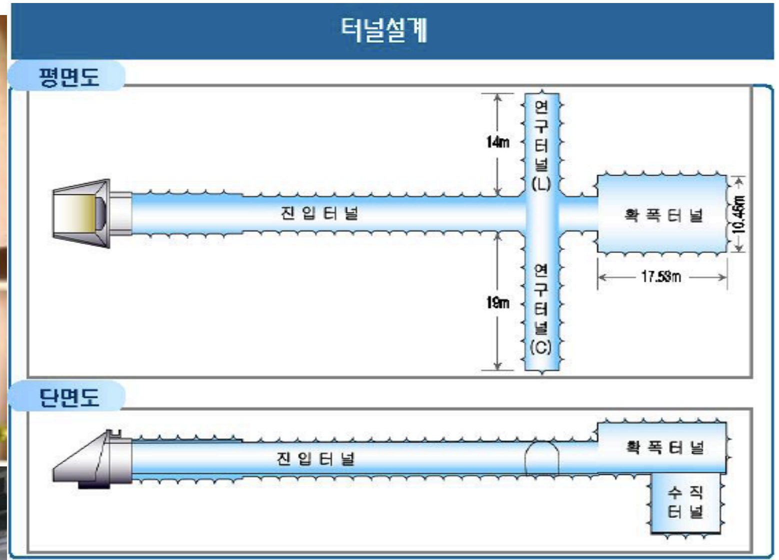
- Two detectors completed and dry-run tested
- Remaining to be completed by next spring
- Electronics, trigger, DAQ ready for Hall 1; RPC and water vetos nearly ready
- Liquid scintillator filling of Hall 1 detectors to start this month



Reno


Near Detector
6 cores/16.4 GW
46 m overburden
16 t target mass
1280 events/day
292 m
1381 m
168 m overburden
16 t target mass
114 events/day
Far Detector

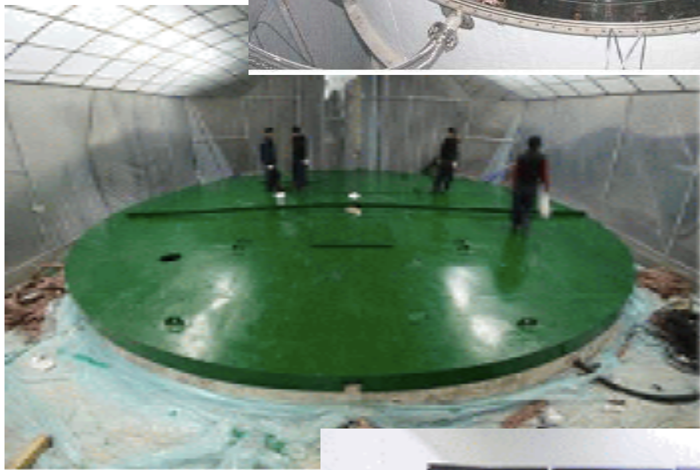
Reno

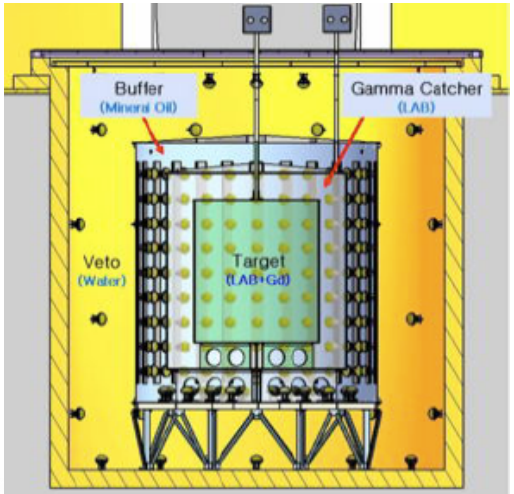


- Tunnels, detector halls completed
- Infrastructure in place: control room, liquid production system, offices

RENO

- Both detectors completed
- DAQ installed; dry runs under way
- LS production + filling: May – June 2011
- Data-taking: July 2011





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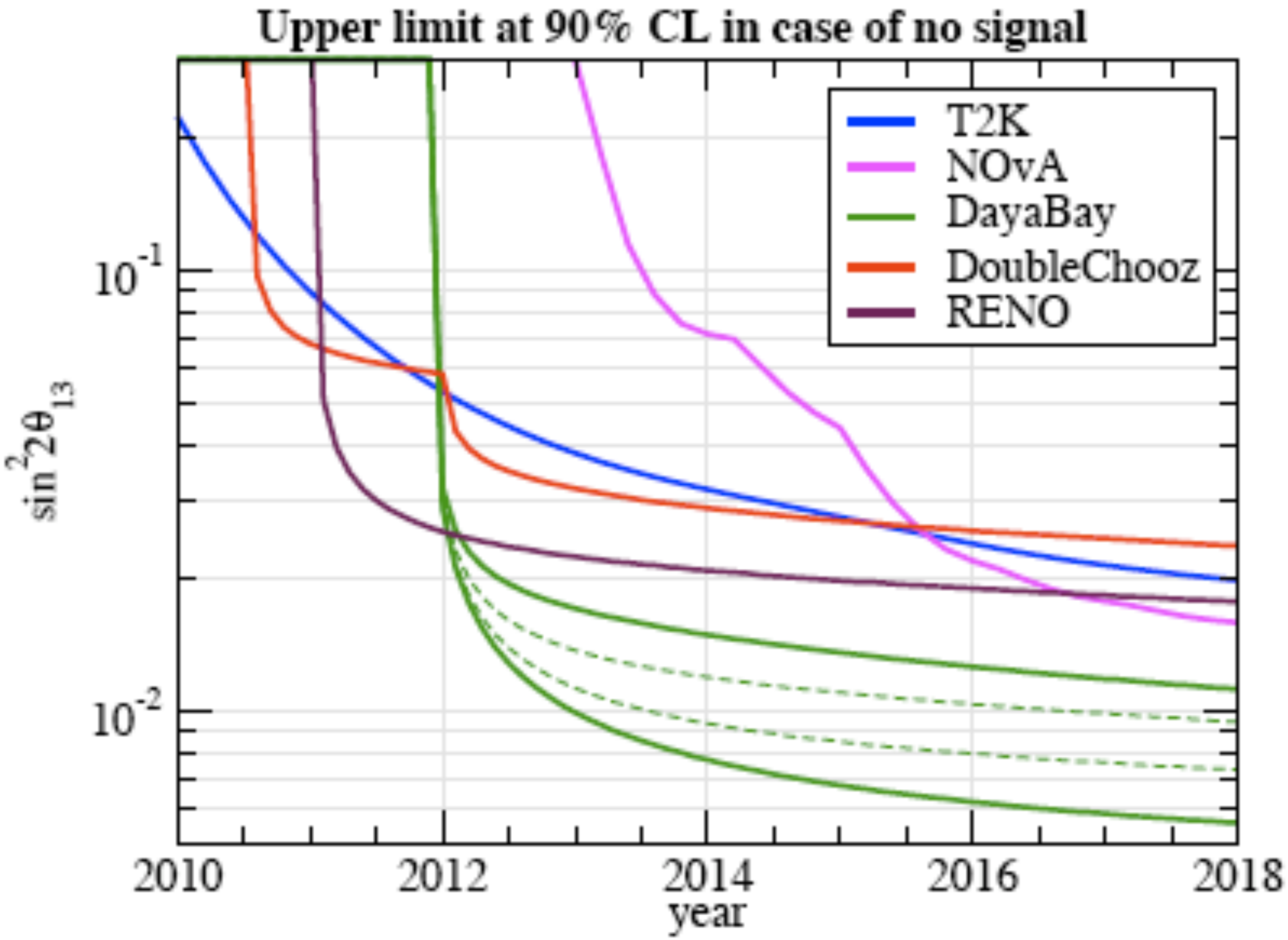
A comparison

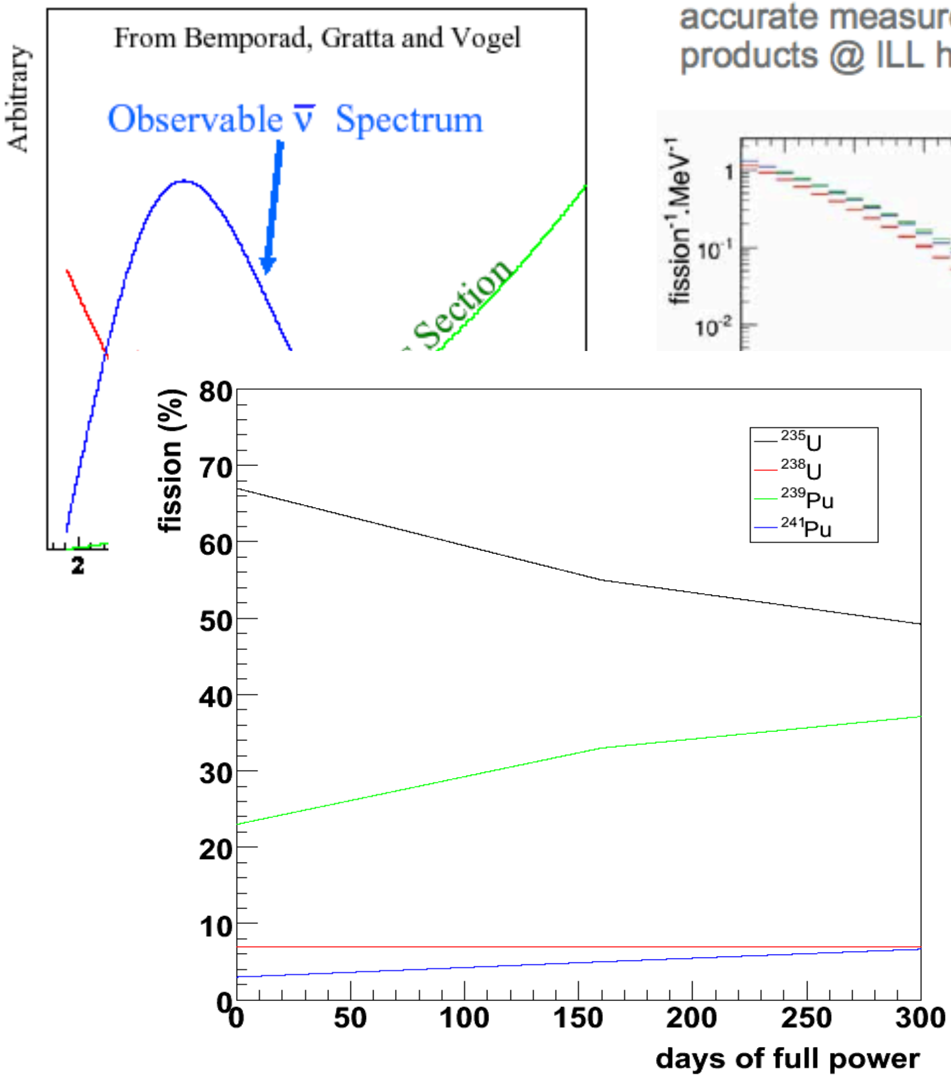


M. Mettezzo and T. Schwetz, arXiv:1003.5800v1

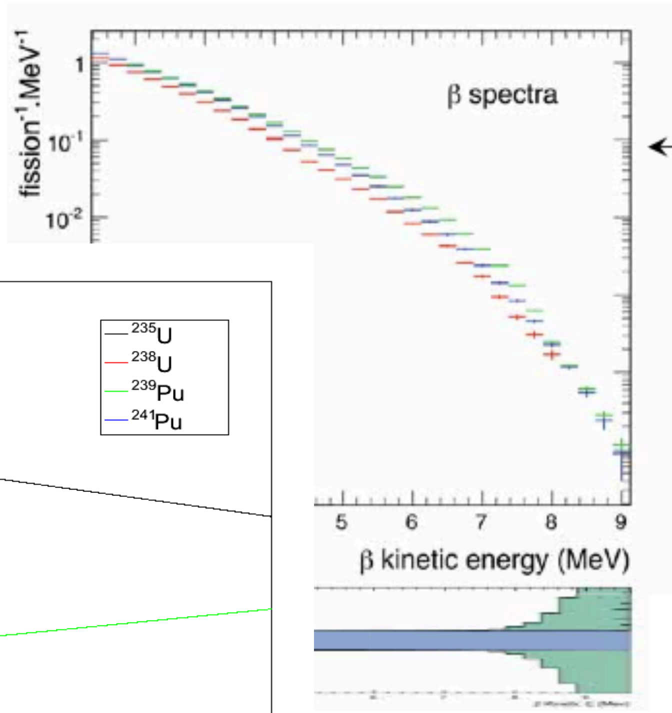
Part III/III

REACTOR ANOMALY

Flux calculation 101



accurate measurements of β-spectra of ^{235}U, ^{239}Pu, ^{241}Pu fission products @ ILL high resolution magnetic spectrometer in the 80's



$$\sum_{A,Z}\{\,{}^{A}_{Z}X \longrightarrow {}_{Z+1}^{\;\;A}Y + e^- + \bar{\nu}_e\}$$

Total electron spectra from the β-decays of ^{235}U, ^{239}Pu and ^{241}Pu fission products.

Normalization of data known at ~**2%** level.

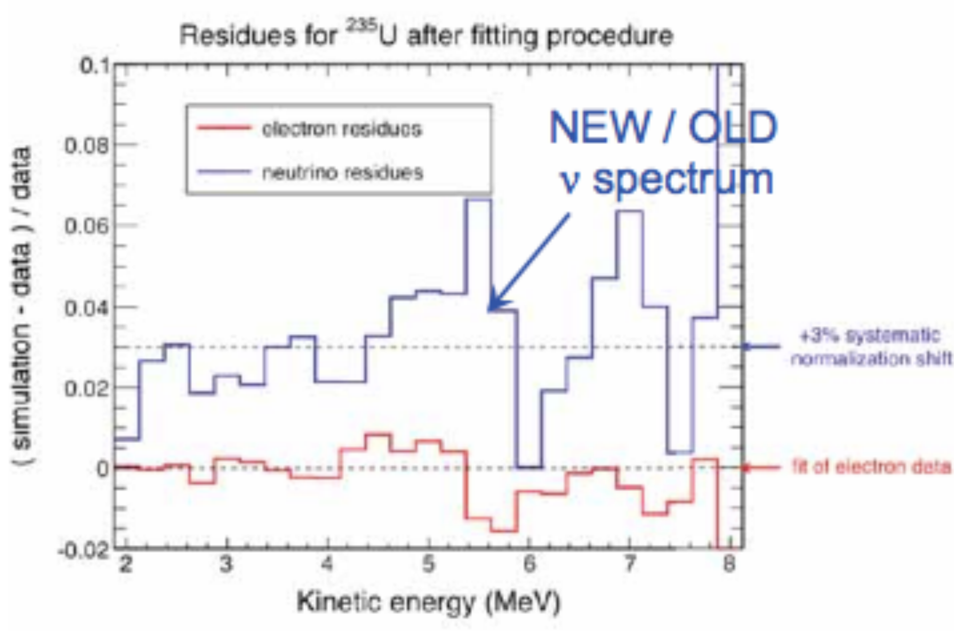
Recalculation of reactor fluxes

arXiv:1101.2663

- Beta spectra measured @ ILL 1980s (^{235}U)
- Included more decays in ab initio calculations

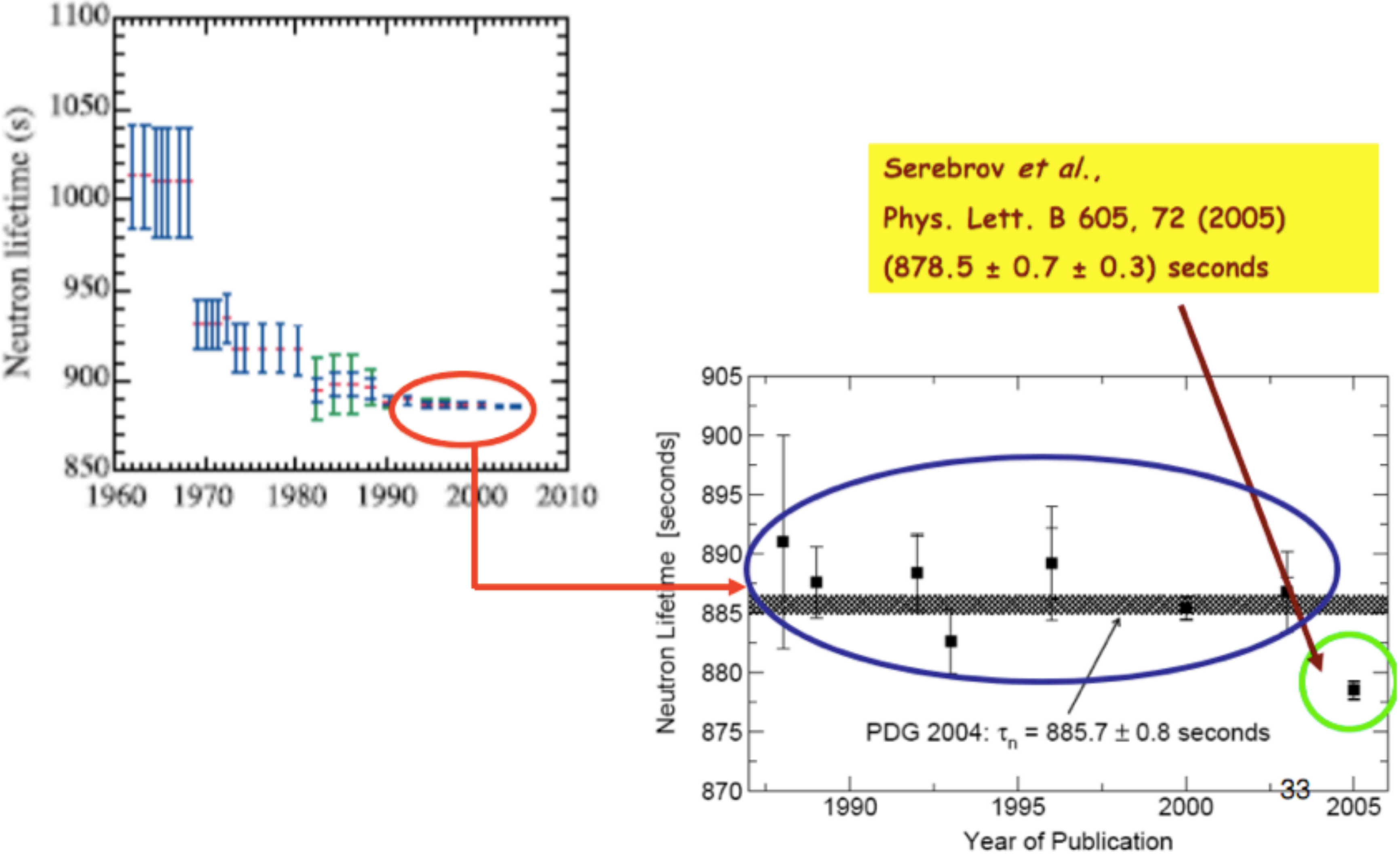
…

- Updated neutron lifetime (see next slide)
- Long lived betas – taken better into account
- Improved error/correlation propagation



same for other isotopes (238U, 239/241Pu)

Neutron lifetime



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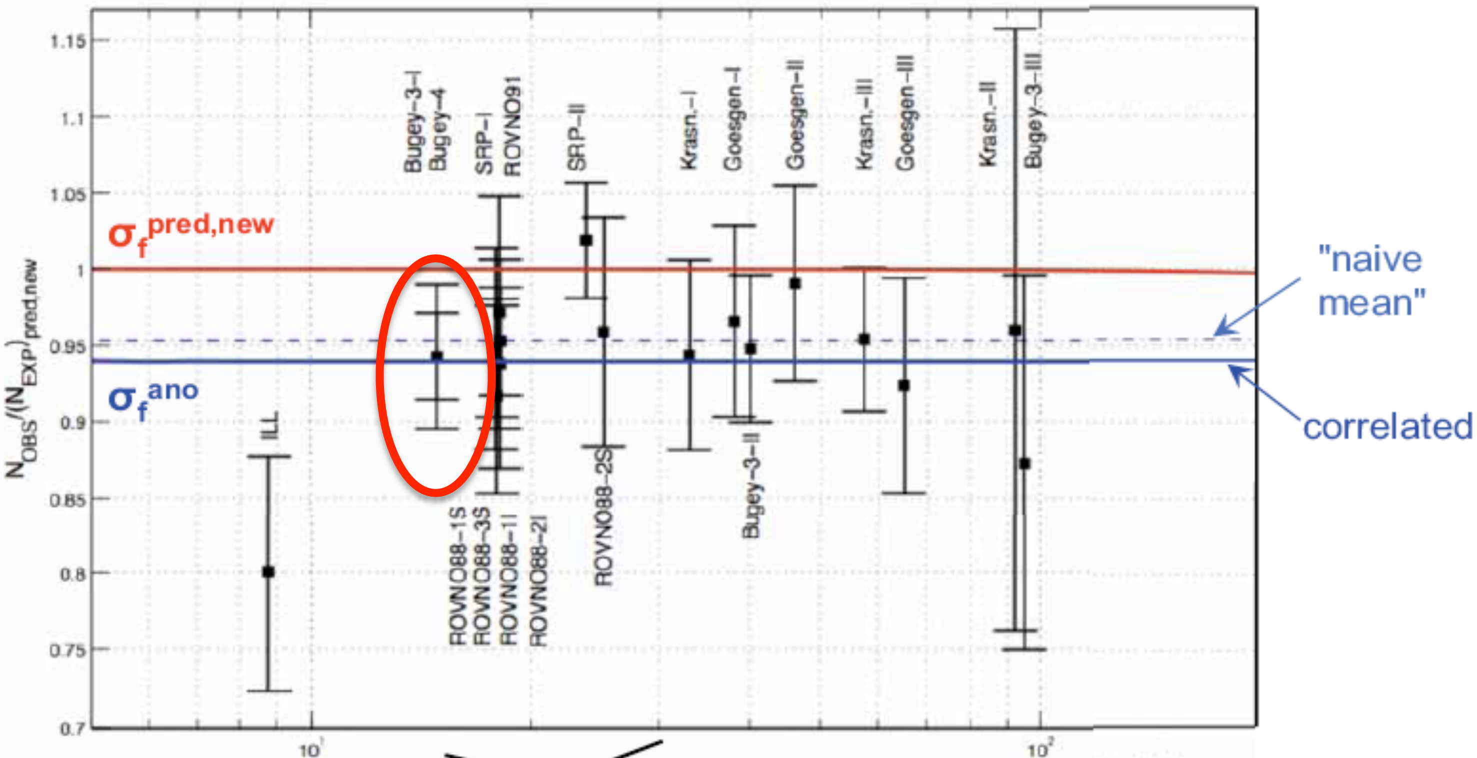
Consequences for short baseline experiments



(naive weighted mean) σ_f^{ano} = ~~(0.95±0.01)~~ $\sigma_f^{pred,new}$

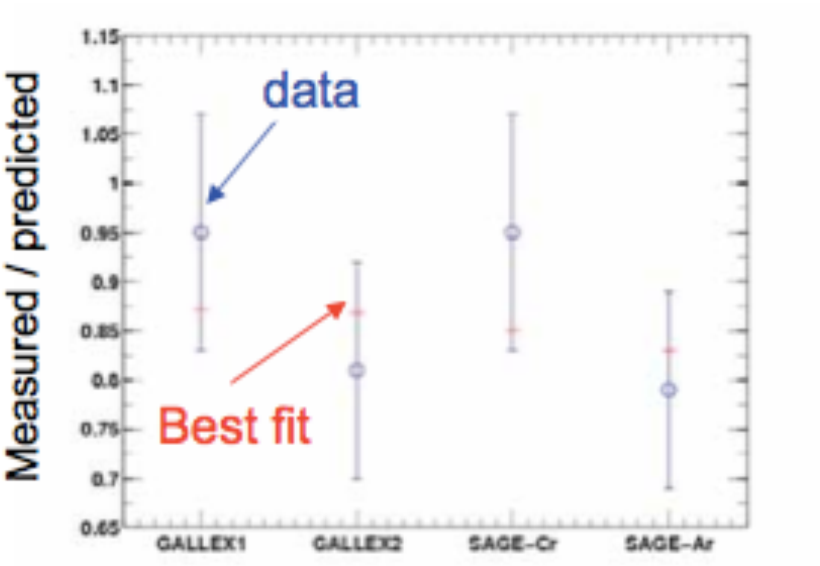
(correlated weighted mean) $\sigma_f^{ano} = (0.943 \pm 0.023)\ \sigma_f^{pred,new}$

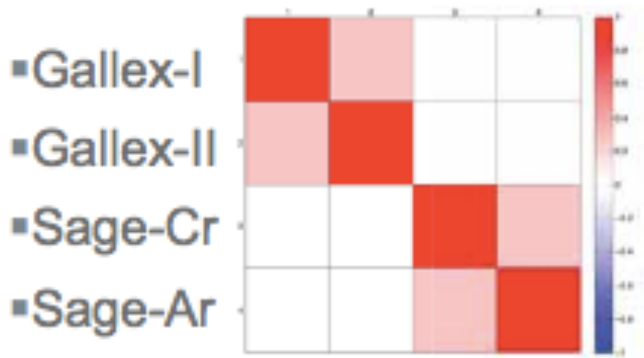
mean value of measured quantities

from new flux conversion from ILL β-spectra

Consistent with Ga anamoly

Radiochemical neutrino experiments using Ga (SAGE/GALLEX) used MCi radioactive sources (^{51}Cr and ^{37}Ar) for calibration purposes: observed lower rate than expected!!

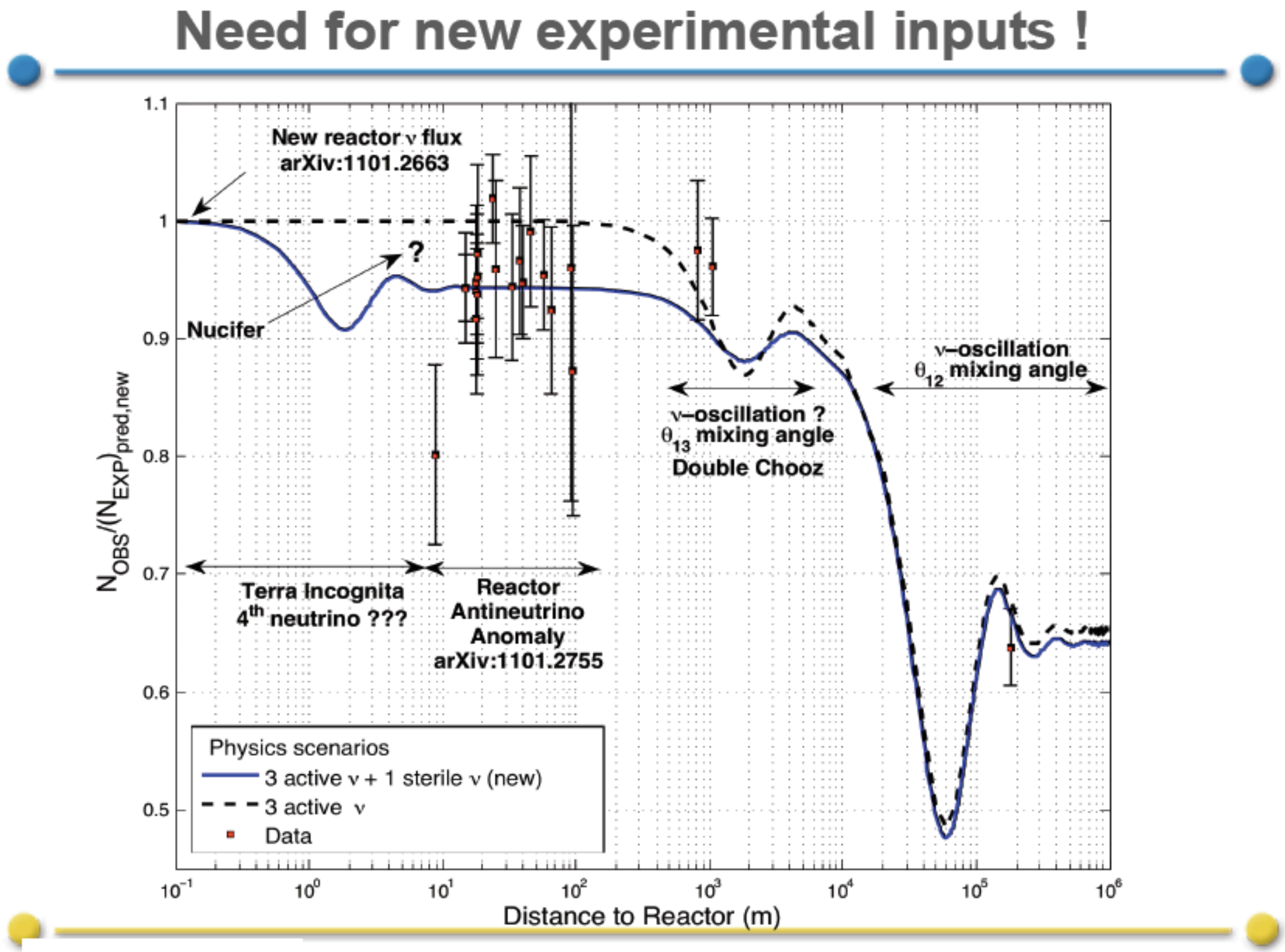




R = meas./pred. rates = 0.86 ± 0.06 (1σ)

Guinti, Lavender PRD82 053005 (2010)

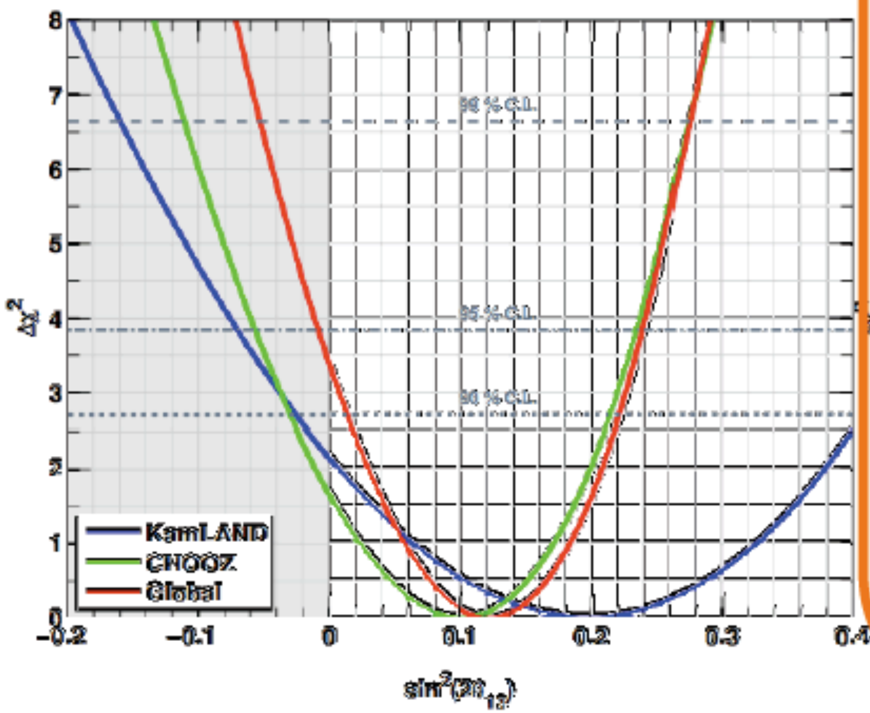
Interpretation ArXiv:1101.2755



CHOOZ and KamLAND combined limit on θ_{13}

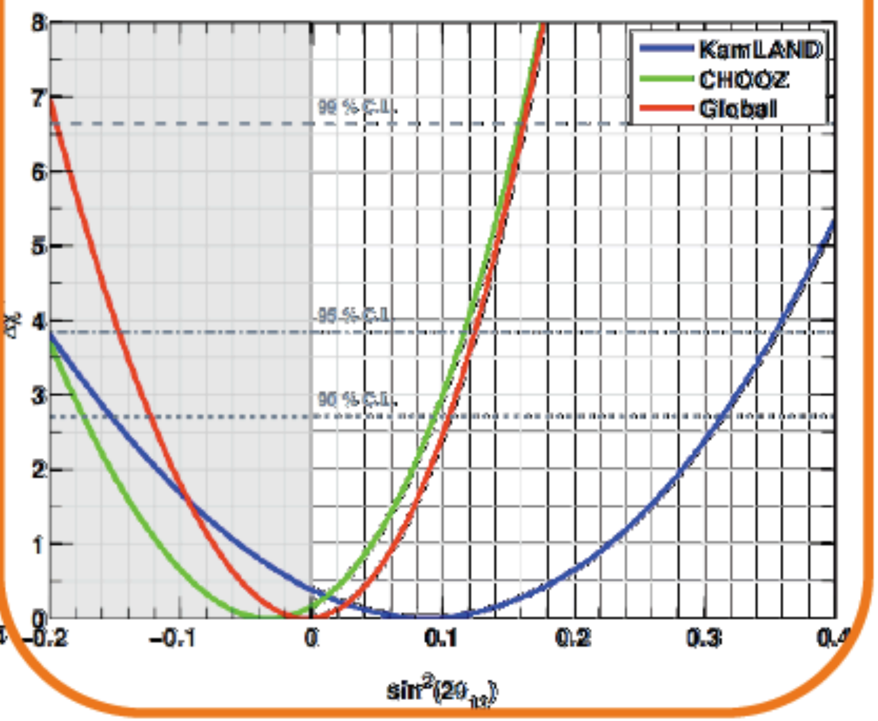
Normalization with $\sigma_f^{pred,new}$

3-ν framework & 2.7% uncertainty



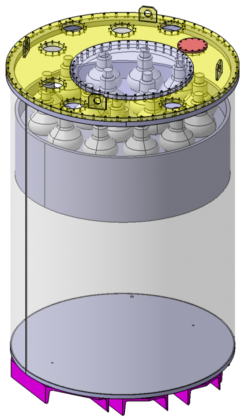
Normalization using σ_f^{ano}

3-ν framework & 2.7% uncertainty

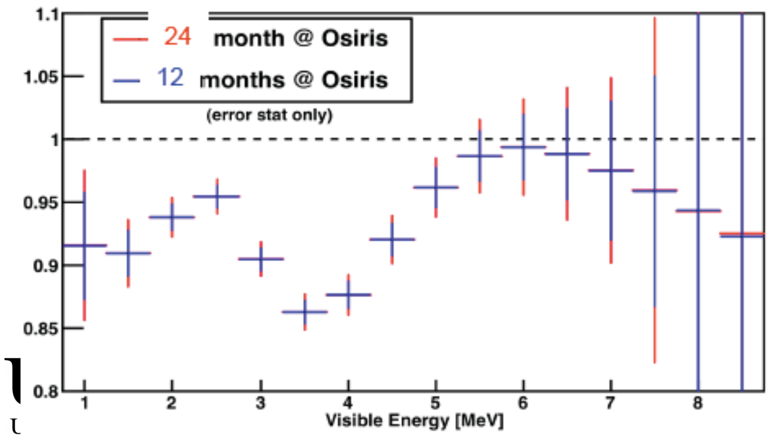


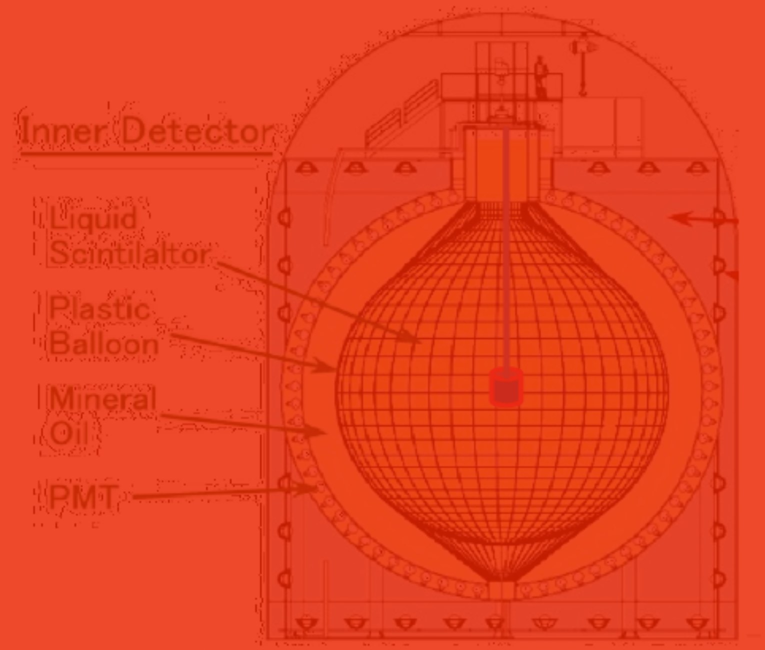
- **Our interpretation** (different from Arxiv:1103:0734 for KamLAND-$\sigma_f^{pred,new}$, T. Schewtz's talk)
  - No hint on θ_{13}>0 from reactor experiments : $\sin^2(2\theta_{13})<0.11$ (90%C.L., 1dof)
  - CHOOZ 90 % CL limit stays identical to Eur. Phys. J. C27, 331-374 (2003)
  - Multi-detector experiments are not affected

Possible checks



- NUCIFER
  - Non-proliferation experiment at Saclay
  - Compact core 57 x 57 x 60 cm
  - <L> = 7.0 m

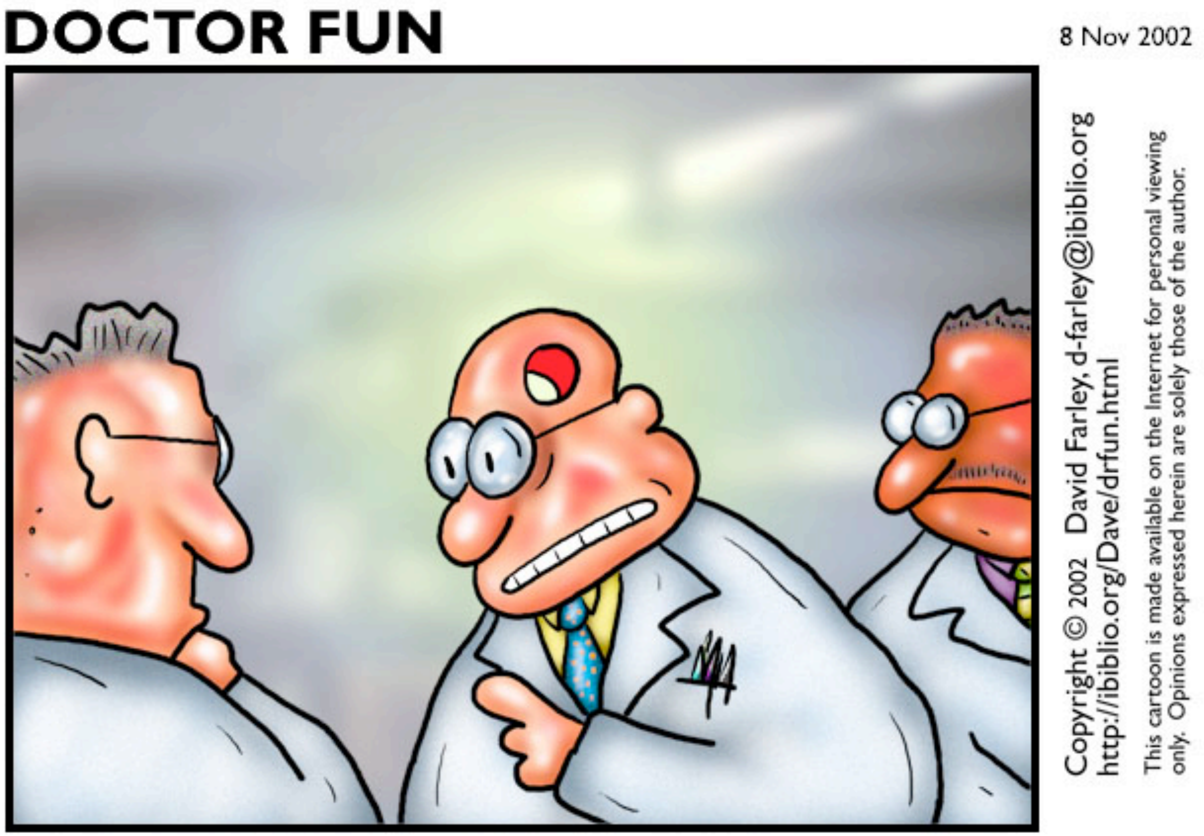




- MCi ν source in LS detector
  - Position resolution ~20 cm
  - KamLAND, SNO+, Borexino
- ICARUS @ CERN PS ν beam…?

Conclusion

Exiting times ahead!



The discovery of the "biggie" neutrino