Reactor Antineutrinos :

Status of θ_{13} experiments
&
Reactor Antineutrino Anomaly

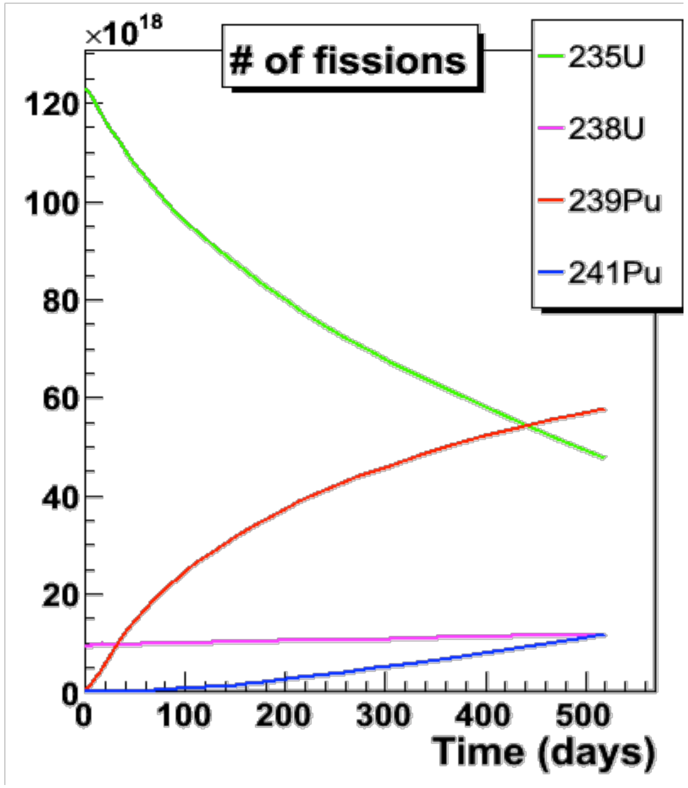
Th. Lasserre (CEA-Saclay, Irfu APC & SPP)
EPS HEP 2011

Reactor Neutrino Overview

- **Electron antineutrinos emitted through Decays of Fission Products of ^{235}U, ^{238}U, ^{239}Pu, ^{241}Pu**
- **Nuclear reactors** : $1\ \mathrm{GW_{th}} \Leftrightarrow 2\ 10^{20}\ \bar{\nu}/\mathrm{s}$
- **Neutrino Luminosity** : $N_{\bar{\nu}} = \gamma(1+k)P_{\mathrm{th}}$

  γ: reactor constant

  k : fuel evolution correction up to 10%



- **Common Detection**
  - Inverse Beta-Decay reaction (xsec: $\sigma_{V\text{-}A}$)

    $$\bar{\nu}_e + p \longrightarrow e^+ + n$$

  - Threshold 1.8 MeV. E_ν extend to 10 MeV
  - Measure anti-ν_e of interaction rate

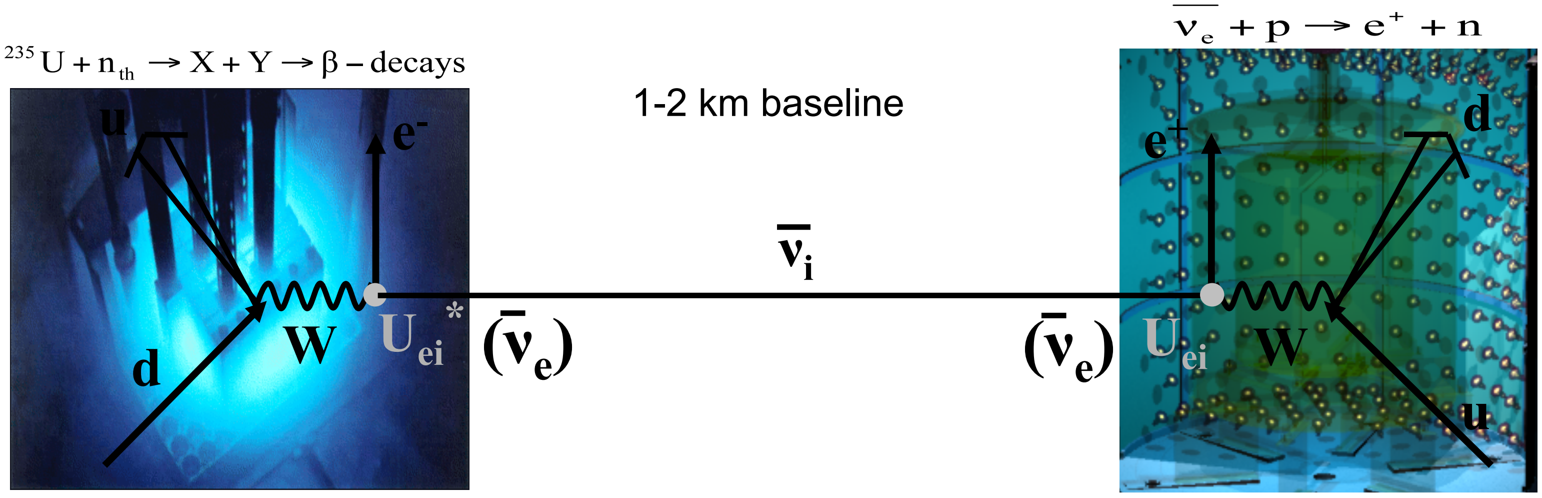
$$n_\nu = \frac{1}{4\pi R^2}\frac{P_{\mathrm{th}}}{\langle E_f\rangle}N_p\varepsilon\sigma_f \longrightarrow \sigma_f^{\mathrm{meas.}} = \frac{4\pi R^2 n_\nu^{\mathrm{meas.}}}{N_p\varepsilon}\frac{\langle E_f\rangle}{P_{\mathrm{th}}}$$

$$\updownarrow$$

- Comparison of σ_f to prediction

$$\sigma_f^{\mathrm{pred.}} = \int_0^\infty \phi_f^{\mathrm{pred.}}(E_\nu)\sigma_{\mathrm{V\text{-}A}}(E_\nu)\mathrm{d}E_\nu$$

Reactor Neutrino Oscillation Physics (θ_{13})



Reactor core

Target free H

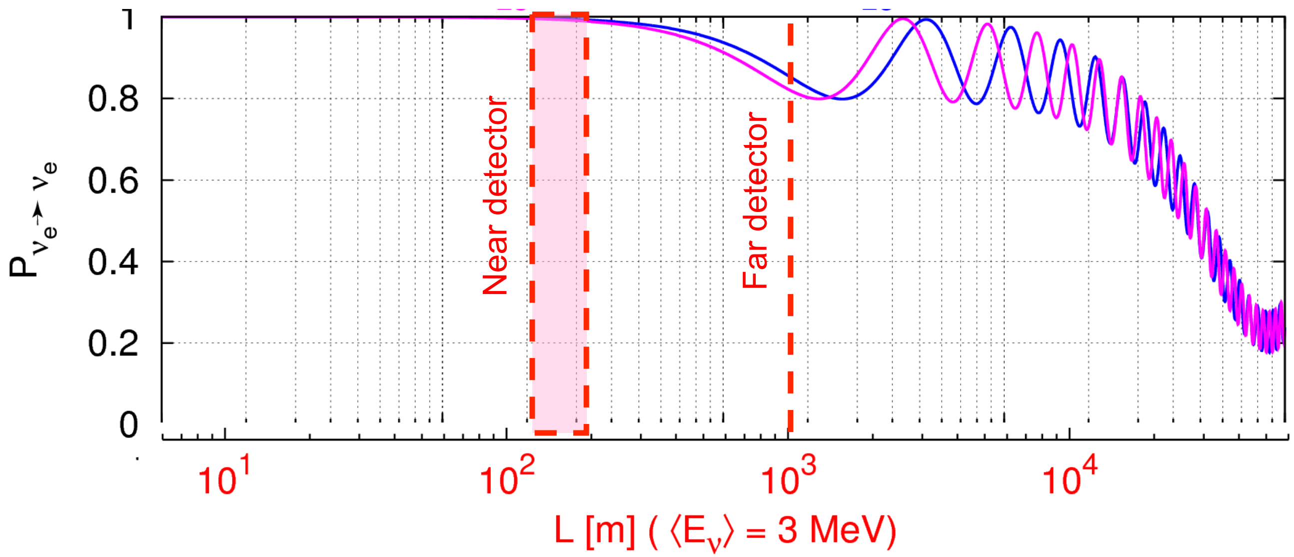
$$P(\overline{\nu}_e \rightarrow \overline{\nu}_e) = 1 - \sin^2(2\theta_{13})\left[\sin\left(1.27\frac{\Delta m^2_{atm}\ (eV^2) L\ (m)}{E\ (MeV)}\right) + O\left(\frac{\Delta m^2_{sol}}{\Delta m^2_{atm}}\right)\right]$$

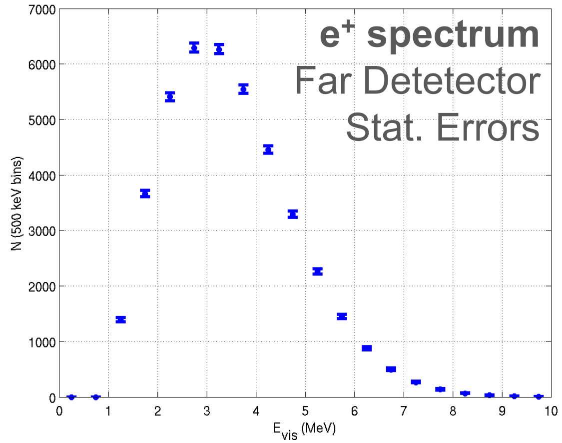
- **Straightforward oscillation formula** : weak dependence on Δm_{sol}^2
- MeV electron antineutrinos : only **disappearance** experiments
- $\sin^2(2\theta_{13})$ measurement **independent of δ-CP**
- $\sin^2(2\theta_{13})$ measurement **independent of sign(Δm^2_{13})**

} **‘clean’** information on θ_{13}

The concept from Lev Mikaelyan (Kurchatov, 2000)

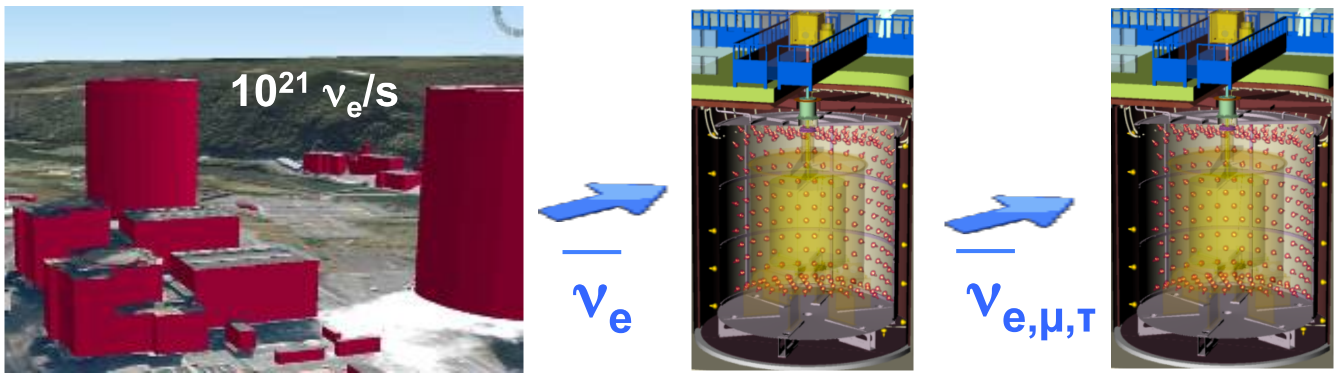
$$P(\nu_e \rightarrow \nu_e) = 1-\sin^2(2\theta_{13})\sin^2(\Delta m^2_{31}L/4E)$$





Δm^2_{atm}= 3.0 10^{-3} eV^2

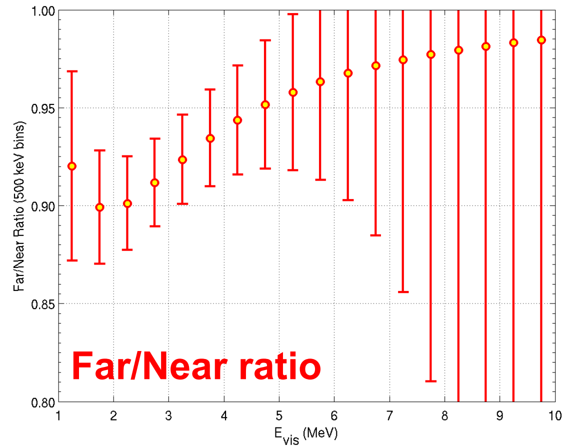
$\sin^2(2\theta_{13})$=0.12

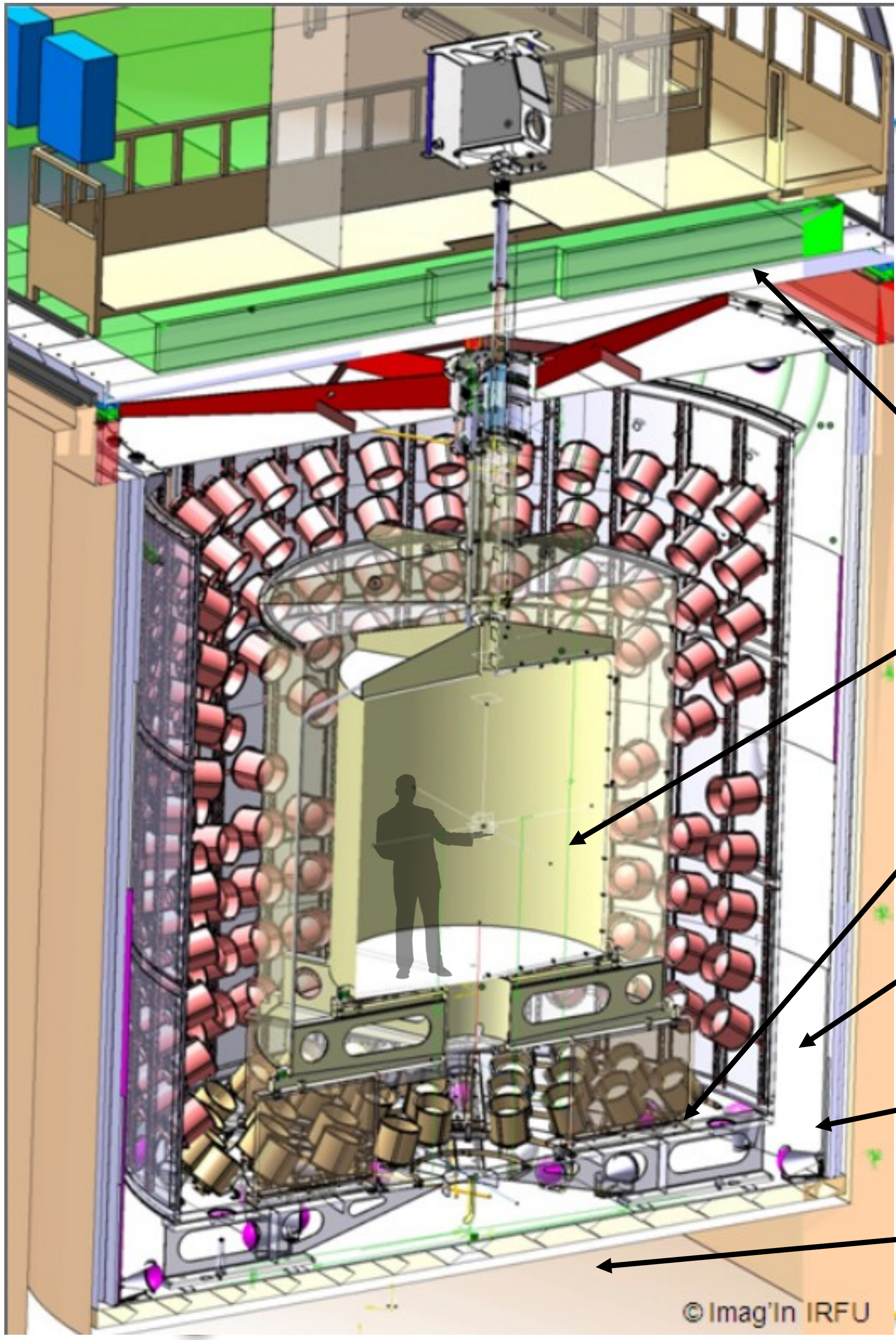


Chooz Nuclear Power Station
2 cores of 4.3 GW_{th} each

Near detector
400 m

Far detector
1050 m





Similar Detector Designs

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

http://bama.ua.edu/~busenitz/rnu2003_talks/lasserre1.doc
http://bama.ua.edu/~busenitz/rnu2003_talks/suekane1.pdf

Outer Veto: plastic scintillator strips (400 mm)

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

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

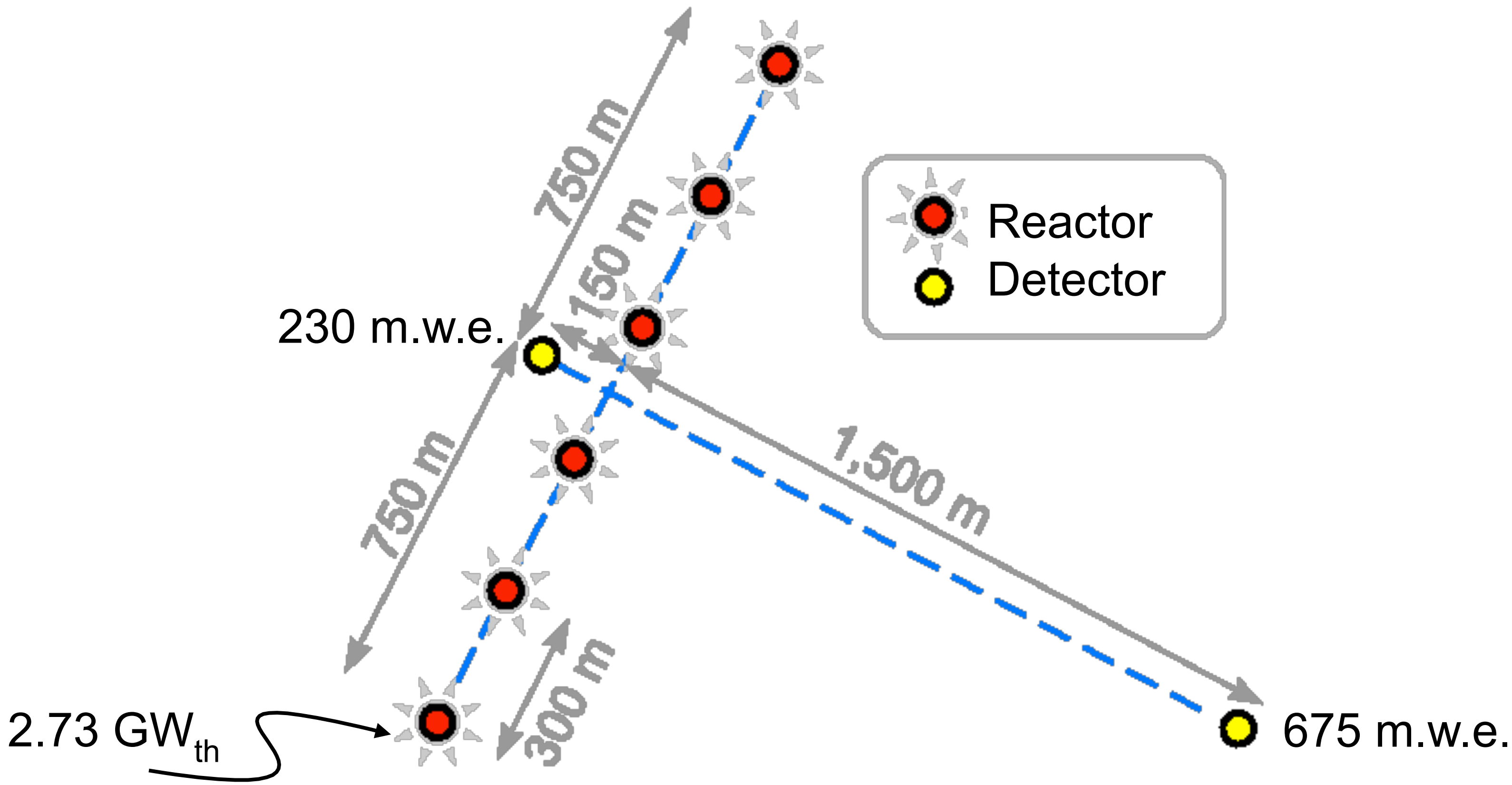
Buffer: 110 m^3 of mineral oil in a stainless steel vessel (3 mm) viewed by 390 PMTs

Inner Veto: 90m^3 of scintillator in a steel vessel equipped with 78 PMTs

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

RENO

Courtesy : S. B. Kim



Yong gwang nuclear power station in Korea

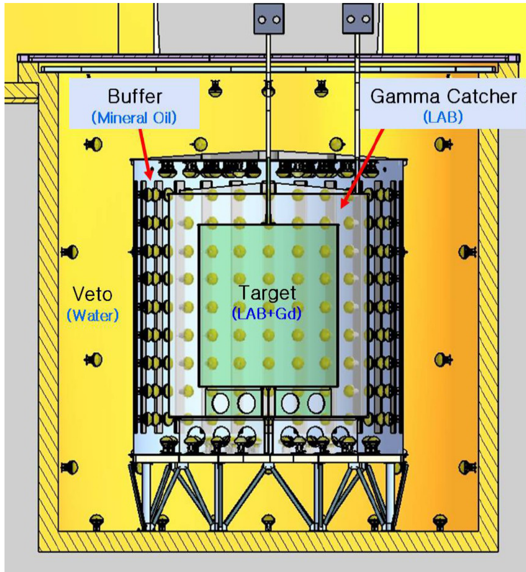
Status of RENO

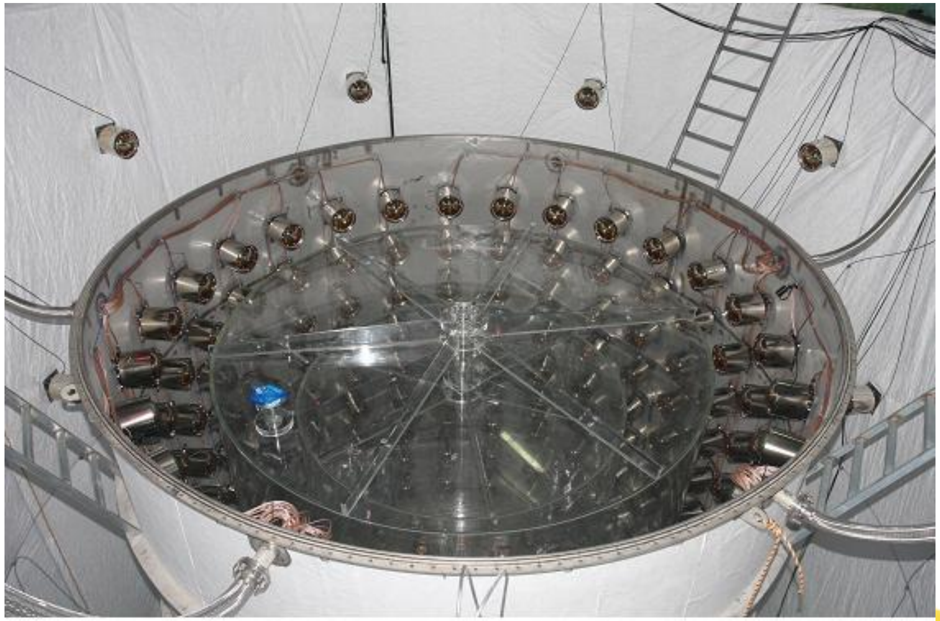
- **Site: Youngwang, Korea**
  Tunnel + halls ready
  6 cores, 16 GW (aligned)

- **Two 20 ton (Gd-LS) detectors**
  Near: 20 tons - 350 m – 200 mwe
  Far: 20 tons - 1.4 km - 700 mwe

- **Sensitivity**
  0.5% systematic error
  $\sin^2(2\theta_{13}) < 0.02$ (90% C.L.), 3 y

- **Status**
  Two detector almost filled
  Data taking by August 2011





RENO: Detector Filling

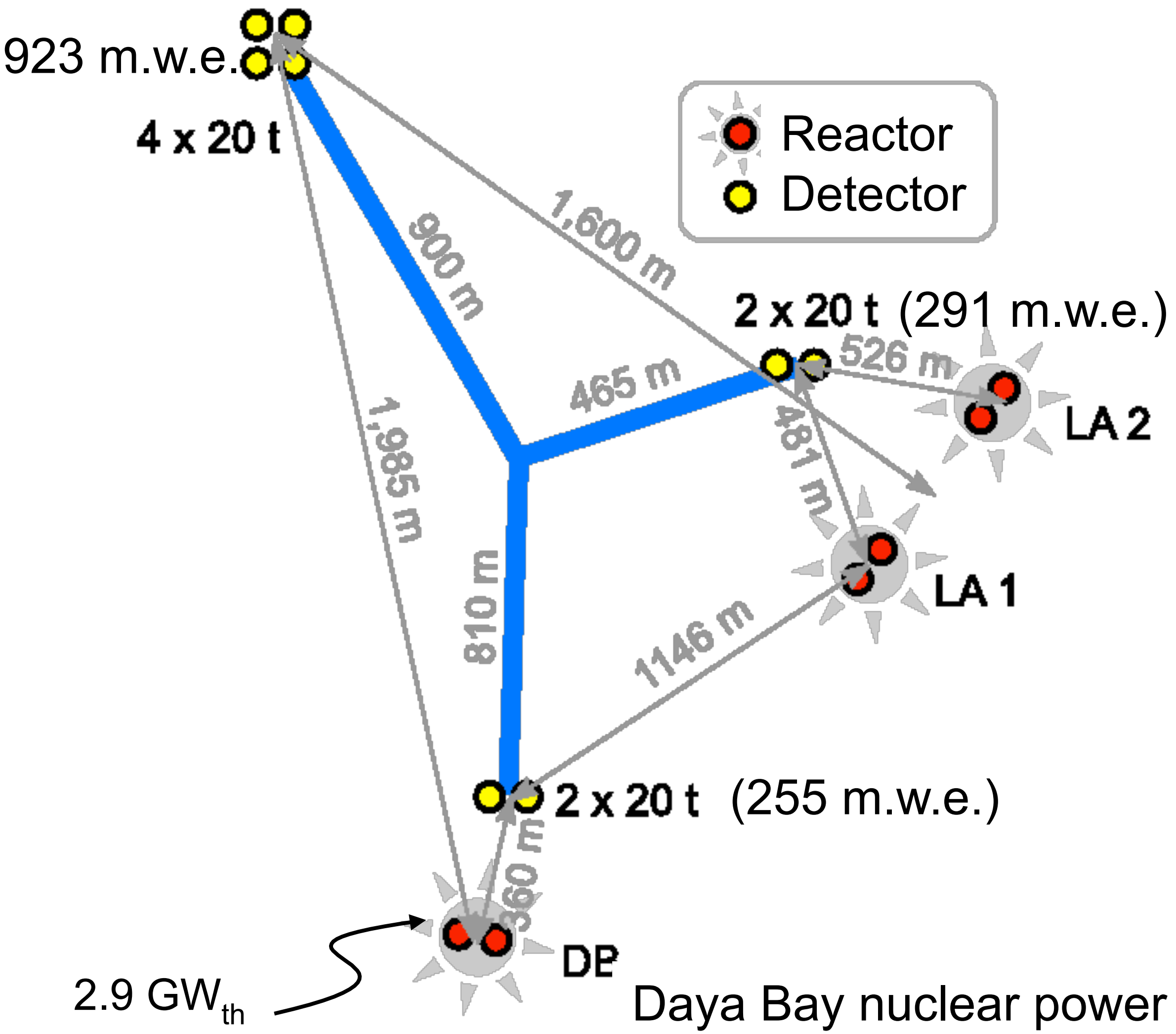
- Both near and far detectors are filled with Gd-LS, LS & Mineral Oil
- Veto water filling will be completed by the end of July 2011.

Target

Gamma Catcher

Daya Bay

Courtesy : K. B. Luk



Daya Bay nuclear power station in China

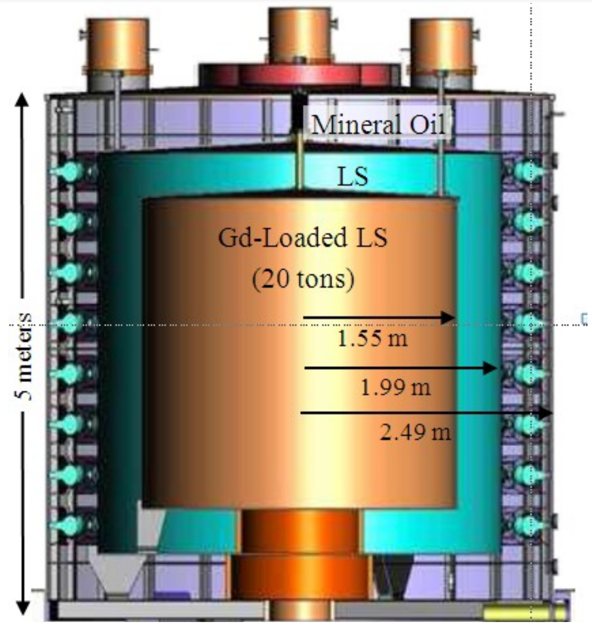
Status of Daya Bay

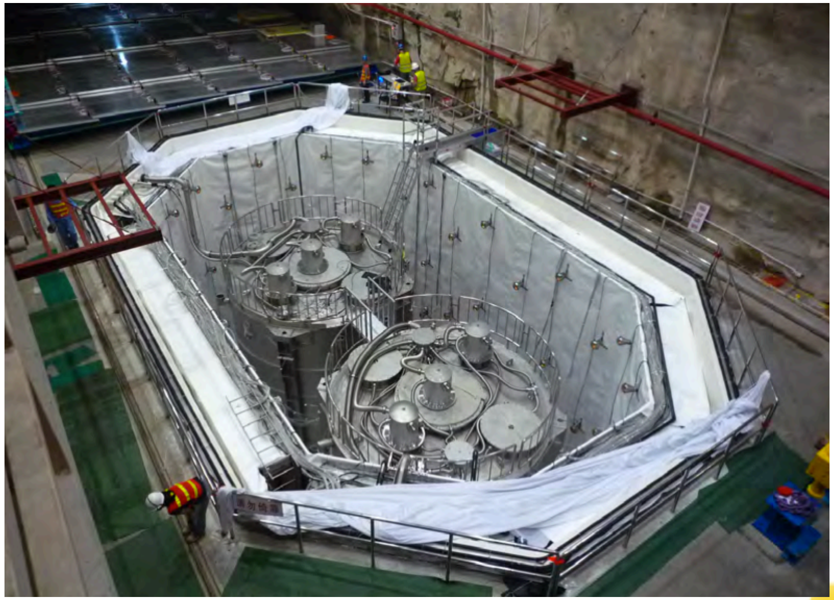
- **Site:** Daya Bay Plant (11.6+6 GW_{th}), China
  Near: 1 km tunnel + laboratory
  Far: 2 km tunnel + laboratory

- **8x20 tons detector modules (Gd-LS)**
  Near: 4x20 tons – 360-500 m – 200 mwe
  Far: 4x20 tons - 1.6-1.9 km – 1000 mwe
  Movable detector concept (in water pools)

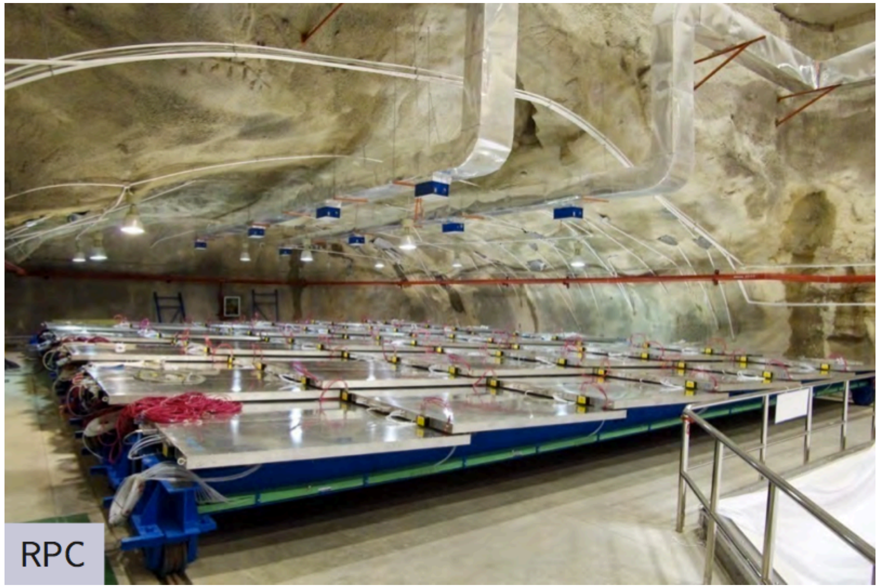
- **Expected Sensitivity**
  0.36% systematic error (relative)
  5 years, $\sin^2(2\theta_{13}) < 0.01$ (90% C.L.)

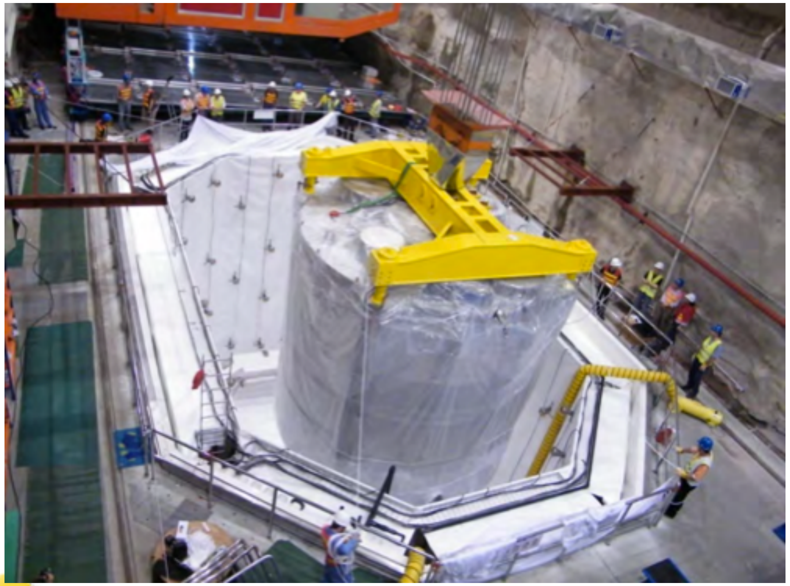
- **Status**
  2 near det. running by summer 2011
  8 detectors to run in summer 2012

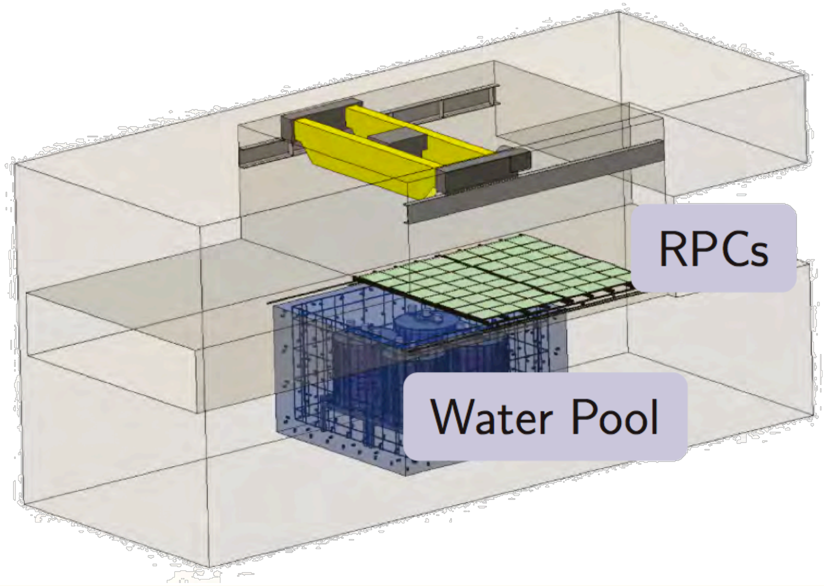




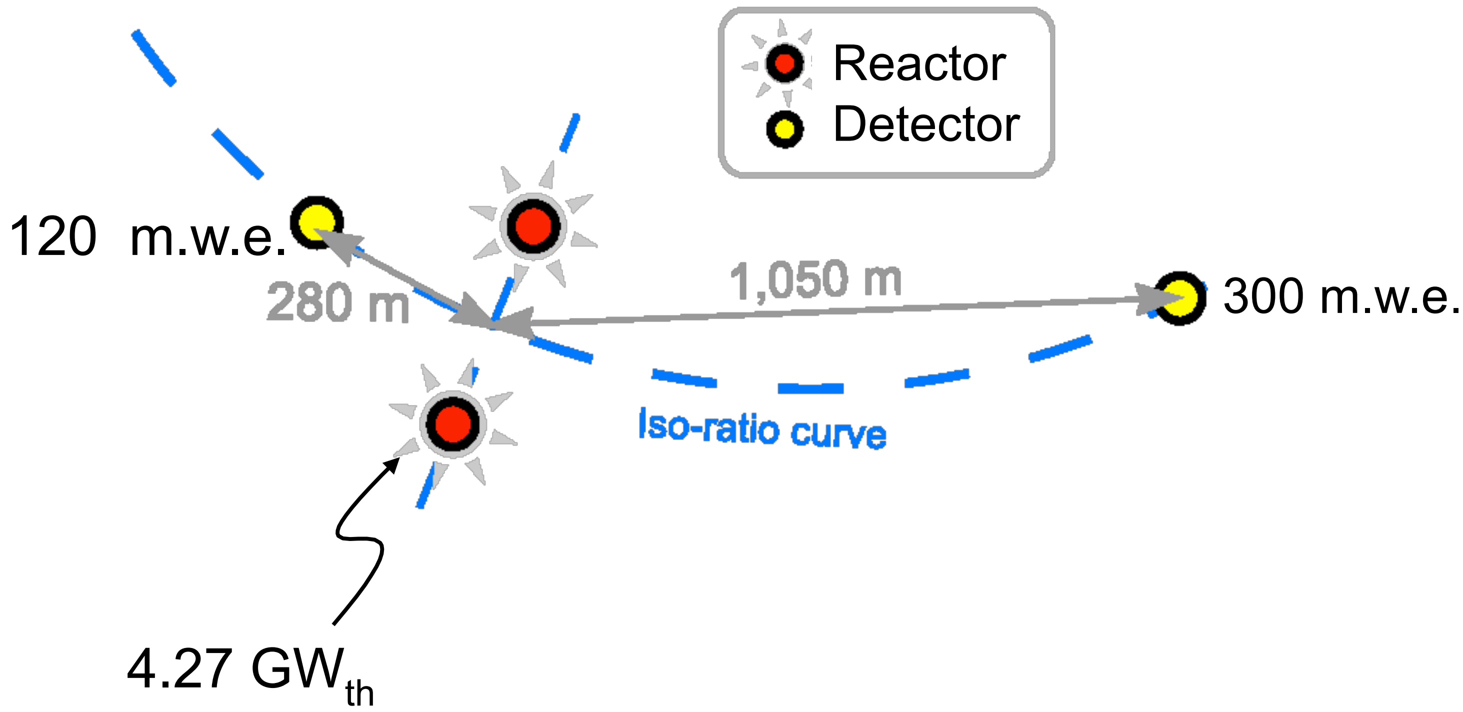
Status of Daya Bay (see Poster)



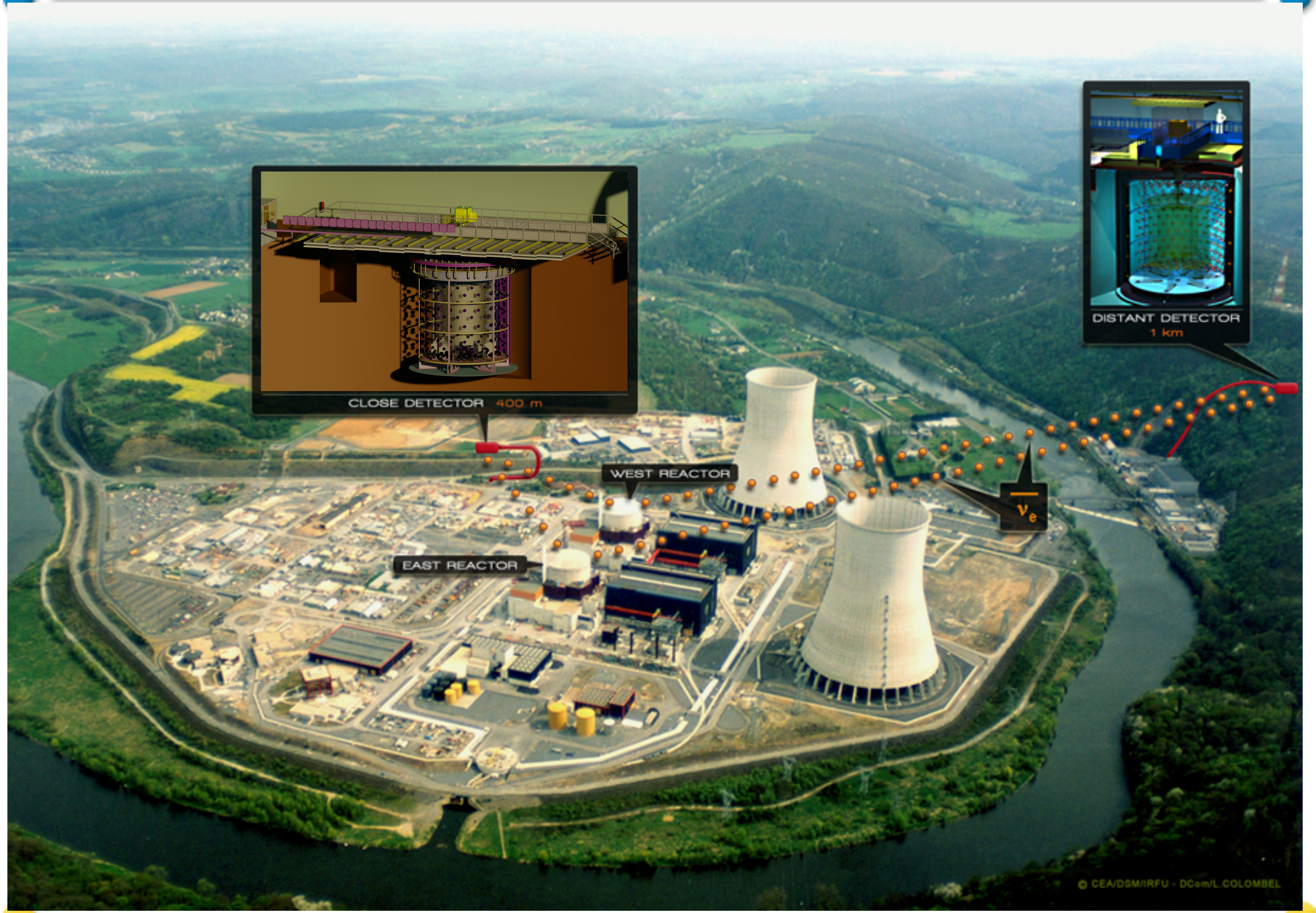




Double Chooz



Double Chooz Sites (France)



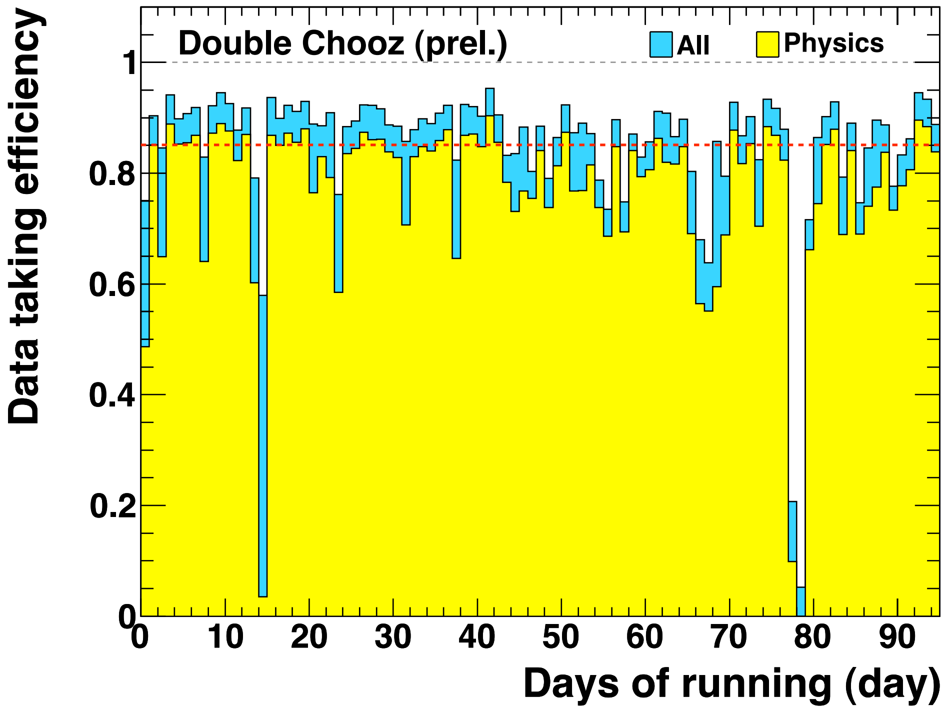
Near Laboratory Excavation

- Started Apr. 2011
- Lab delivery Apr. 2012
- Near detector End 2012
- Baseline ~ 400 m
- Overburden ~120 mwe

Far Detector Construction 2008-10

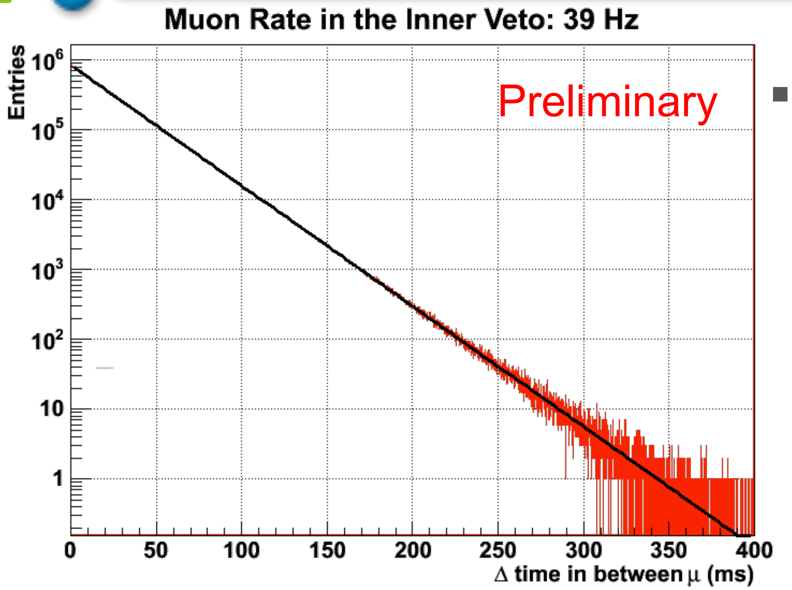
Challenging "4-layer vessel" detector concept,
invented by Double Chooz in 2002 has proved to be possible

Stable Data Taking since April 13th 2011

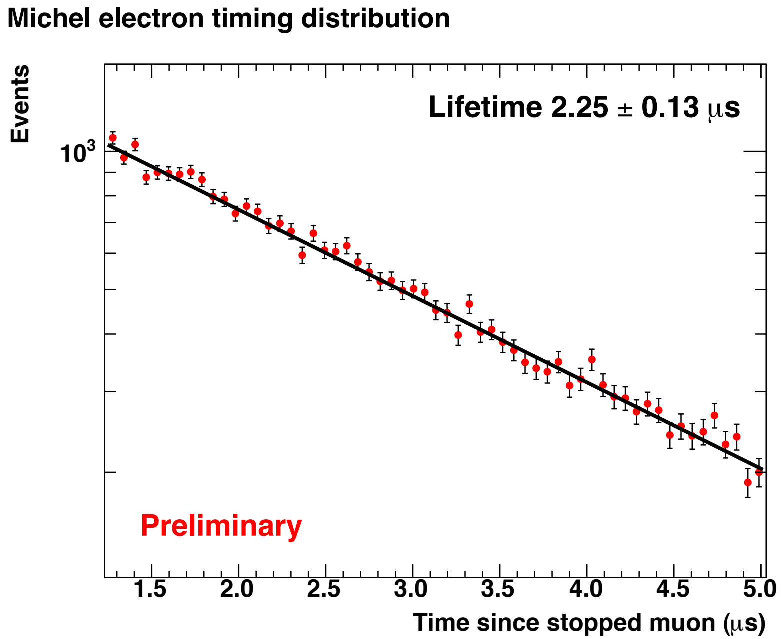


- >70 full days of physics (Physics Run Eff. 75%)
- Trigger rate 120 Hz - Trigger threshold < 0.6 MeV
- Calibration runs 10% of the time (light injection through embedded fiber)
- Outer Veto Muon & Source Calibration Deployment being commissioned

Muon & Michel Electron Data

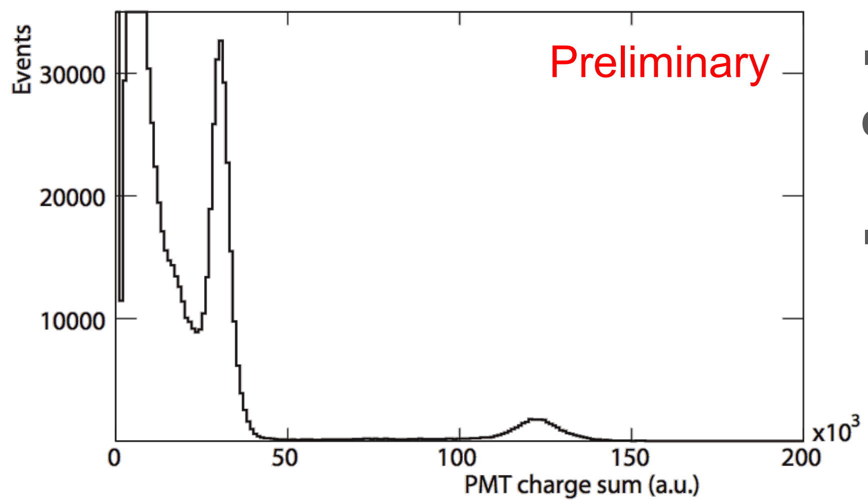


- **Muons**
  - Δt time between two muon events (ms)
  - ~40Hz of muons tagged by Inner Veto
  - ~10Hz of muons tagged by Inner Detector



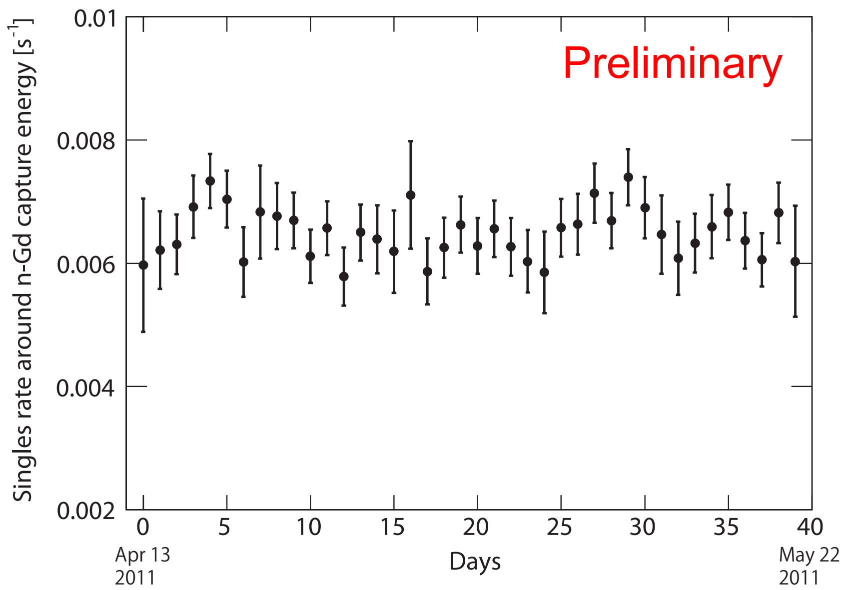
- **Michel Electrons**
  - Time since stopped muon (μs) + Energy Selection Criteria
  - Stat. error only
  - Delayed coincidence well tagged

Neutron Data



- **Charge spectrum for muon-correlated events in Gd-capture time window**

- Peaks of neutron capture
  - on Hydrogen (2.2MeV)
  - on Gadolinium (~8MeV).



- **Stability of singles rate in delayed energy window**
  - After vetoing muon-correlated events

- **Caveat:**
  - RAW data, no gain calibration, no energy calibration, no vertex correction

Detector Performances & Sensitivity

- **We saw instrumental light from PMTs. These noise events are under control.**

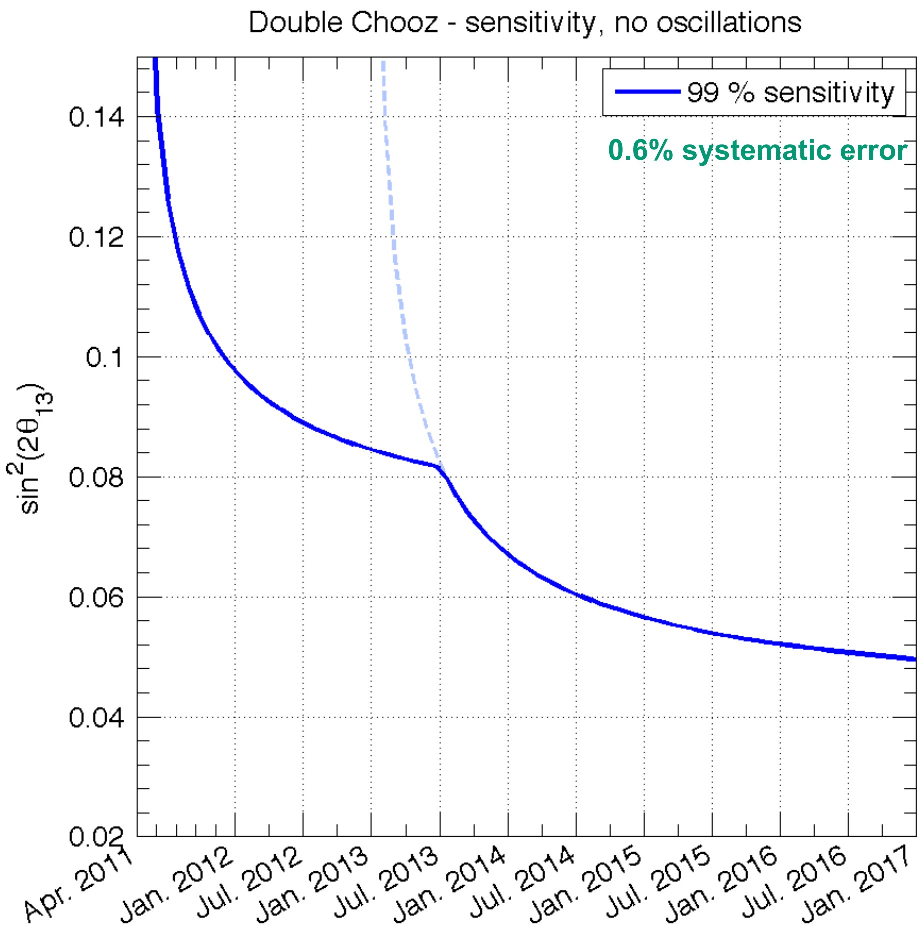
- **Singles rates**
  - after vetoing muon-correlated events
  - ~10 Hz in [0.7, 12] MeV → ~DC proposal
  - <0.01 Hz in [6, 12] MeV → < ½ DC proposal
  - Promising sign for low Accidental rate
- **Neutron-capture as expected**
  - on Gd (Target) & H (T+GC)

→These data support DC should have a clean set of neutrino candidates

- **Correlated backgrounds under study**

- **Neutrino oscillation analysis on-going**

- **T2K's central values to be addressed at 99% CL with 2011 data**



The Reactor Antineutrino anomaly

Phys. Rev. D83, 073006, 2011

http://irfu.cea.fr/en/Phocea/Vie_des_labos/Ast/ast_visu.php?id_ast=3045

New Reactor Antineutrino Spectra

- **Accurate e⁻ measurements, ILL reactor (1980-89):**
  - Irradiation of ^{235}U, ^{239}Pu, ^{241}Pu foils in intense n_{th} flux from the ILL core
  - High resolution magn. spectrometer, normalization uncertainty of 1.8%

- **Thousands of β-branches involved…**

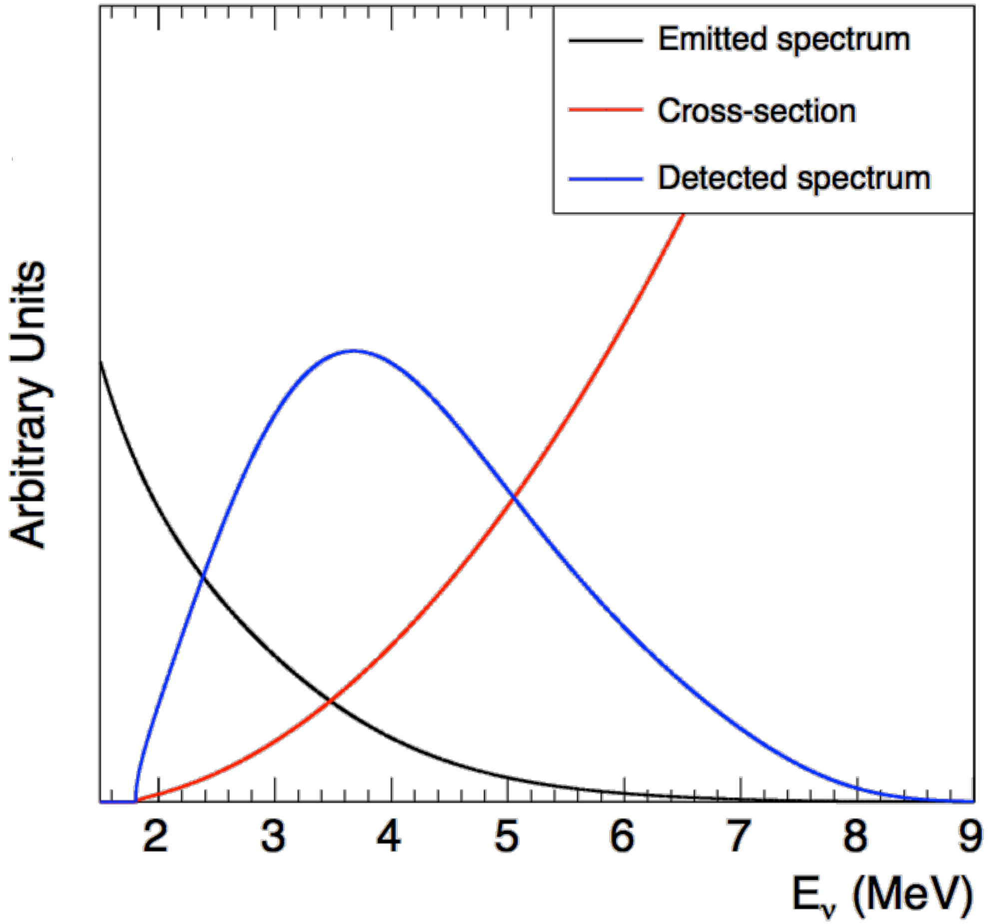
- **From electron to neutrino spectra: need a conversion**

  - **Old Method:**
    - Fit integral e^- spectrum with a sum of 30 effective β-branches
    - Conversion of the effective branches to ν spectra
    - Effective correction on the ν-spectra ($A_{C,W}$)

  - **New Method (Phys. Rev. C83, 054615, 2011)**
    - Conversion with "true" distribution of β-branches reproducing >90% of ILL e^- data + five effective branches to the remaining 10%
    - **Net 3% upward shift in energy-averaged neutrino fluxes with respect to old ν-spectrum for ^{235}U, ^{239}Pu, ^{241}Pu (confirmed by arXiv:1106.0687)**

Computing the expected rate/spectrum

$$\sigma_f^{pred} = \int_0^{\infty} S_{tot}(E_\nu)\sigma_{\mathrm{V-A}}(E_\nu)dE_\nu = \sum_k f_k \sigma_{f,k}^{pred}$$



- **Inverse Beta Decay:**

  $\bar{\nu}_e + p \rightarrow e^+ + n$

- **V-A cross section**

  $\sigma_{\mathrm{V-A}}(E_e) = \kappa\, p_e E_e$
  $(1 + \delta_{rec} + \delta_{wm} + \delta_{rad})$

- **The pre-factor κ (cm^2 MeV^{-2})**

  - Can be related to neutron life time
  - Vogel-Beacom 1999 : κ = 0.952 10^{-42}
  - RAA : PDG τ_n : κ = 0.956 10^{-42}
  - Evolution in 2011 κ=0.961 10^{-42}

  <τ_n> revision +0.5%

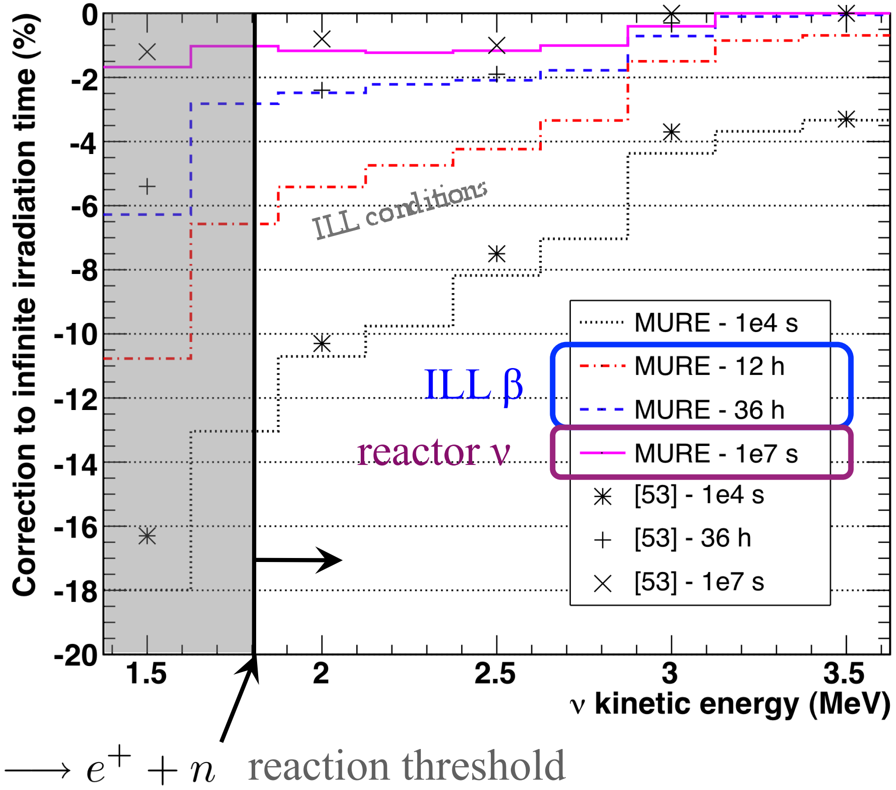
Off-Equilibrium Effects

- **10% of fission products have a β-decay life-time long enough to keep accumulating after several days**
  - ILL electron reference spectra : 12 hours to 1.8 days irradiation time
  - Neutrino reactor experiments irradiation time >> months

- **Correction included by default in our new reference model**

- Not included before CHOOZ

- Relative change of ν-spectrum w.r.t. infinite irradiation time

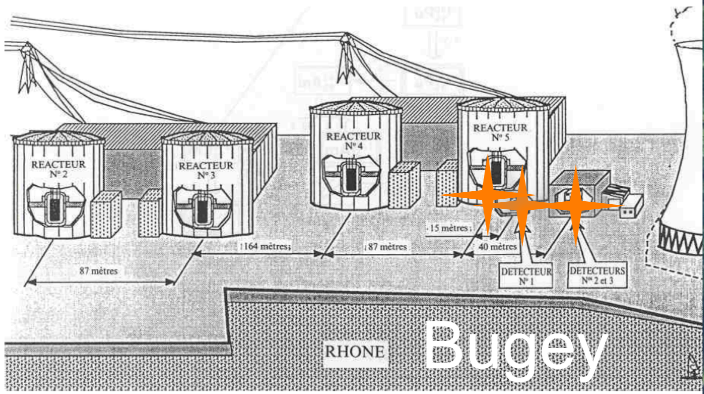


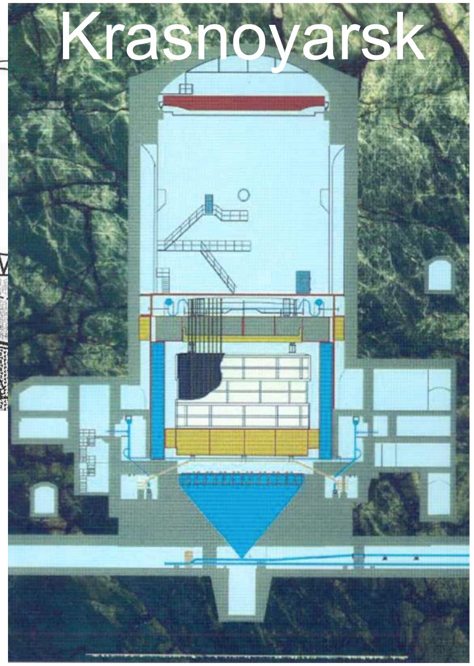
The New Cross Section Per Fission

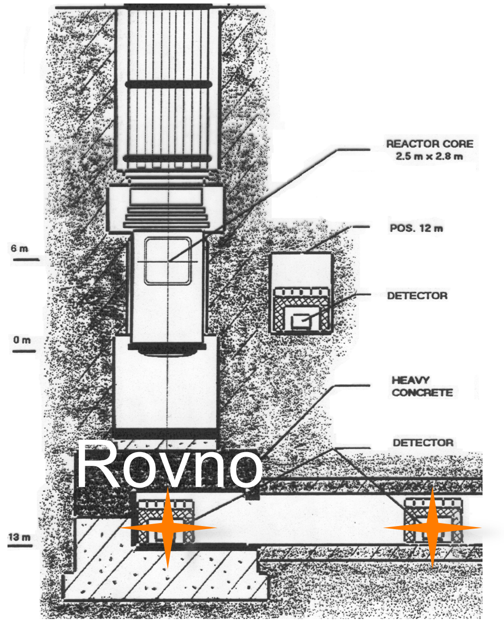
- ν-flux: ^{235}U +2.5%, ^{239}Pu +3.1%, ^{241}Pu +3.7%, ^{238}U +9.8% (σ_f^{pred} ↗)
- Off-equilibrium corrections now included (σ_f^{pred} ↗)
- Neutron lifetime decrease by a few % (σ_f^{pred} ↗) $\sigma_{\text{V-A}}(E_\nu) \propto 1/\tau_n$
- Slight evolution of the phase space factor (σ_f^{pred} →)
- Slight evolution of the energy per fission per isotope (σ_f^{pred} →)
- Burnup dependence: $\sigma_f^{pred} = \sum_k f_k \sigma_{f,k}^{pred}$ (σ_f^{pred} →)
- New Results:

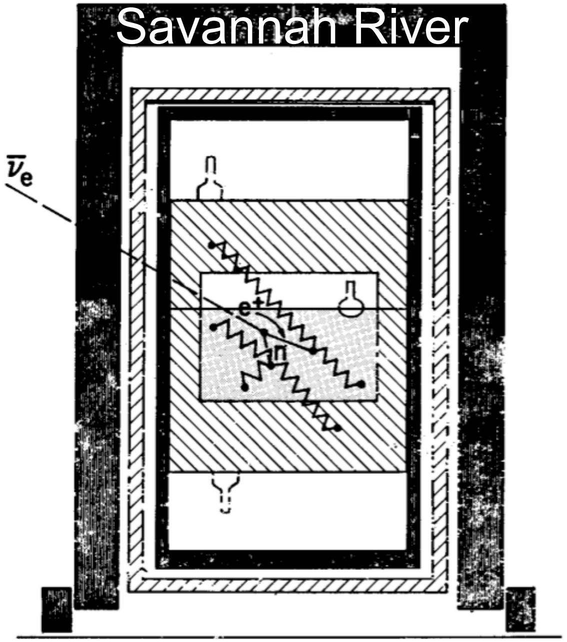
	old [3]	new	new/old
$\sigma_{f,^{235}U}^{pred}$	6.39±1.9%	6.61±2.11%	+3.4%
$\sigma_{f,^{239}Pu}^{pred}$	4.19±2.4%	4.34±2.45%	+3.6%
$\sigma_{f,^{238}U}^{pred}$	9.21±10%	10.10±8.15%	+9.6%
$\sigma_{f,^{241}Pu}^{pred}$	5.73±2.1%	5.97±2.15%	+4.2%

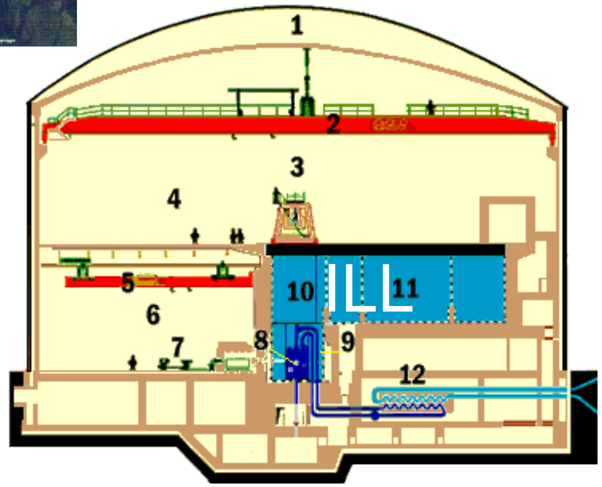
19 Experimental Results below 100 m











Measured cross sections are taken at their face values

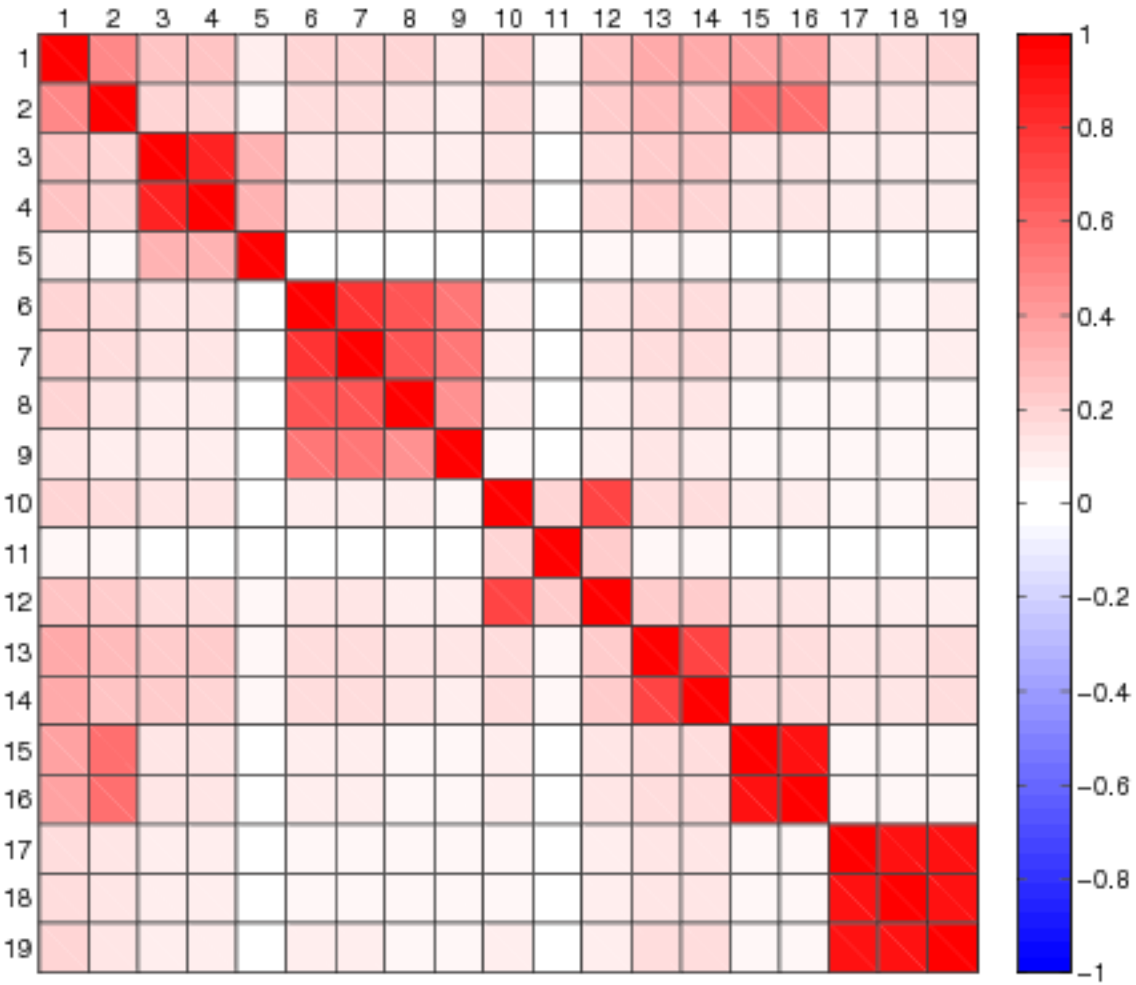
19 Experimental Results Revisited (L<100m)

#	result	Det. type	τ_n (s)	^{235}U	^{239}Pu	^{238}U	^{241}Pu	old	new	err(%)	corr(%)	L(m)
1	Bugey-4	^{3}He+H_2O	888.7	0.538	0.328	0.078	0.056	0.987	0.942	3.0	3.0	15
2	ROVNO91	^{3}He+H_2O	888.6	0.614	0.274	0.074	0.038	0.985	0.940	3.9	3.0	18
3	Bugey-3-I	^{6}Li-LS	889	0.538	0.328	0.078	0.056	0.988	0.946	4.8	4.8	15
4	Bugey-3-II	^{6}Li-LS	889	0.538	0.328	0.078	0.056	0.994	0.952	4.9	4.8	40
5	Bugey-3-III	^{6}Li-LS	889	0.538	0.328	0.078	0.056	0.915	0.876	14.1	4.8	95
6	Goesgen-I	^{3}He+LS	897	0.620	0.274	0.074	0.042	1.018	0.966	6.5	6.0	38
7	Goesgen-II	^{3}He+LS	897	0.584	0.298	0.068	0.050	1.045	0.992	6.5	6.0	45
8	Goesgen-II	^{3}He+LS	897	0.543	0.329	0.070	0.058	0.975	0.925	7.6	6.0	65
9	ILL	^{3}He+LS	889	$\simeq 1$	—	—	—	0.832	0.802	9.5	6.0	9
10	Krasn. I	^{3}He+PE	899	$\simeq 1$	—	—	—	1.013	0.936	5.8	4.9	33
11	Krasn. II	^{3}He+PE	899	$\simeq 1$	—	—	—	1.031	0.953	20.3	4.9	92
12	Krasn. III	^{3}He+PE	899	$\simeq 1$	—	—	—	0.989	0.947	4.9	4.9	57
13	SRP I	Gd-LS	887	$\simeq 1$	—	—	—	0.987	0.952	3.7	3.7	18
14	SRP II	Gd-LS	887	$\simeq 1$	—	—	—	1.055	1.018	3.8	3.7	24
15	ROVNO88-1I	^{3}He+PE	898.8	0.607	0.277	0.074	0.042	0.969	0.917	6.9	6.9	18
16	ROVNO88-2I	^{3}He+PE	898.8	0.603	0.276	0.076	0.045	1.001	0.948	6.9	6.9	18
17	ROVNO88-1S	Gd-LS	898.8	0.606	0.277	0.074	0.043	1.026	0.972	7.8	7.2	18
18	ROVNO88-2S	Gd-LS	898.8	0.557	0.313	0.076	0.054	1.013	0.959	7.8	7.2	25
19	ROVNO88-3S	Gd-LS	898.8	0.606	0.274	0.074	0.046	0.990	0.938	7.2	7.2	18

Experiments correlation matrix

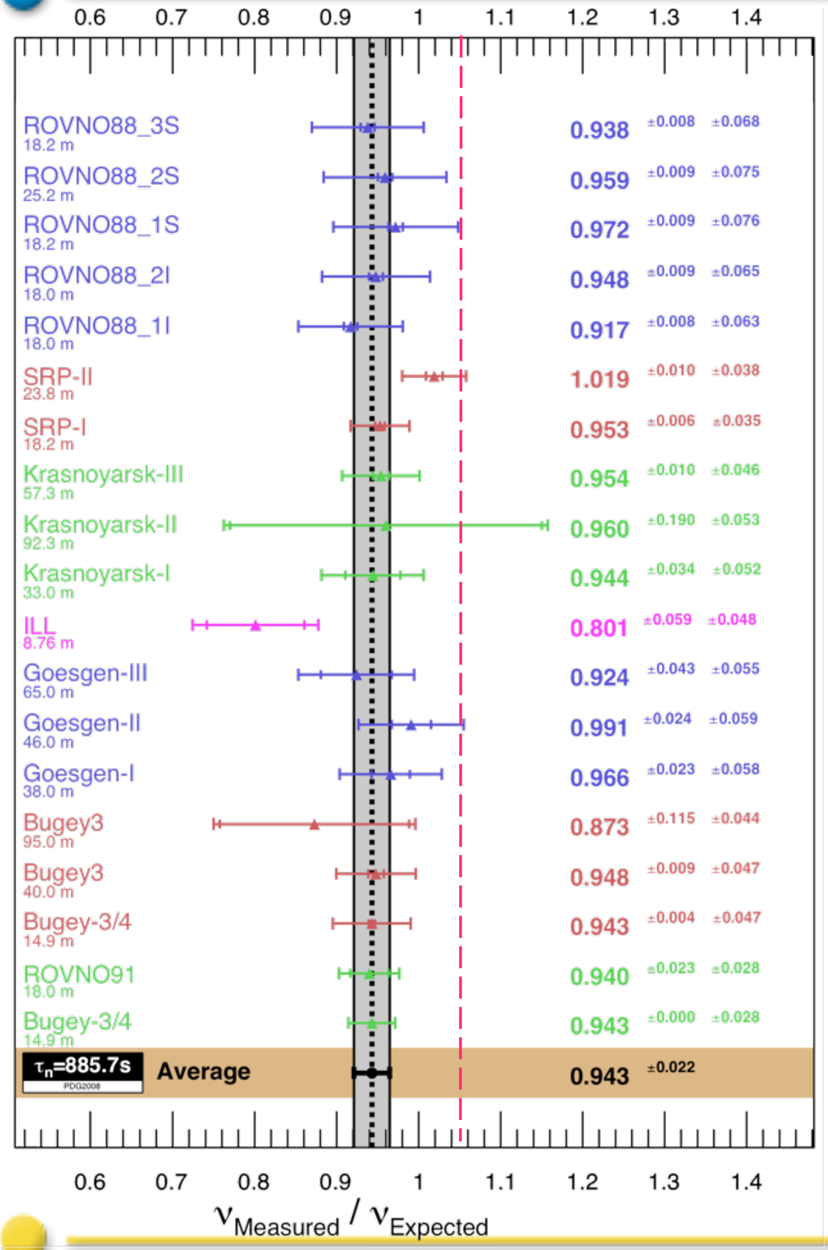
$\vec{R}$	$\Sigma_{tot.}$ (in %)	$\Sigma_{cor.}$ (in %)
Bugey-4 15m	3.0	3.0
Rovno91 18m	3.9	3.0
Bugey-3 15m	5.0	5.0
Bugey-3 40m	5.1	5.0
Bugey-3 92m	14.1	5.0
Goesgen 38m	6.5	6.0
Goesgen 45m	7.6	6.0
Goesgen 65m	9.5	6.0
ILL 9m	5.1	4.1
Krasno 33m	5.1	4.1
Krasno 92m	20.3	4.1
Krasno 57m	4.1	4.1
SRP I 18m	3.7	3.7
SRP II 25m	3.8	3.7
Rovno88 1I 18m	6.9	6.9
Rovno88 2I 18 m	6.9	6.9
Rovno88 1S 18m	7.8	7.2
Rovno88 2S 25m	7.8	7.2
Rovno88 3S 18m	7.2	7.2

C (correlation matrix on Ratios)



- Main pink color comes from the 2% systematic on ILL β-spectra normalization uncertainty
- The experiment block correlations come from identical detector, technology or neutrino source

The reactor antineutrino anomaly



$$\chi^2 = \left(r - \vec{R}\right)^T W^{-1} \left(r - \vec{R}\right)$$

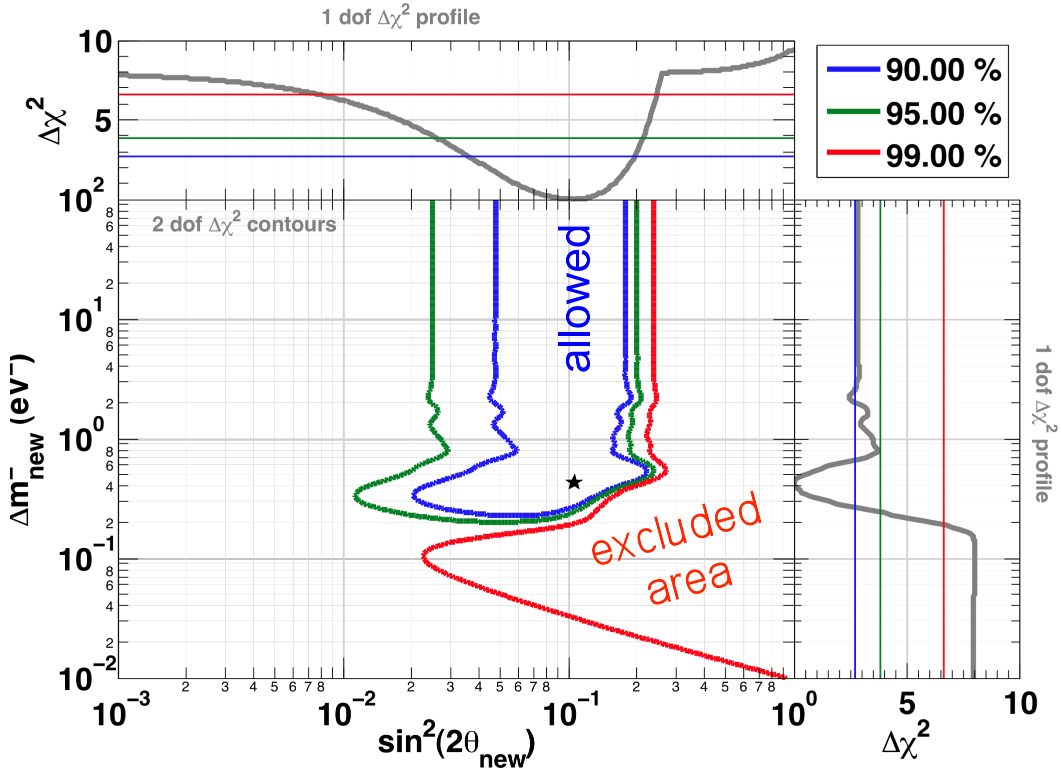
- **Best fit : μ = 0.943±0.023** (χ^2 = 19.6/19)
- **Deviation from unity**
  - Naïve Gaussian : 99.3% C.L.
  - Toy MC: 98.6% C.L. (10^6 trials)
- **No hidden covariance**
  - 18% of Toy MC have $\chi^2_{min}<19.6$
- **At least three alternatives:**
  - Wrong prediction of ν-spectra ?
  - Bias in all experiments ?
  - New physics at short baselines: Mixing with 4th ν-state ? θ_{new} and Δm^2_{new}

The 4th neutrino hypothesis

- Combine all rate measurements, no spectral-shape information
- Fit to anti-ν_e disappearance hypothesis

$$\begin{pmatrix} \nu_e \\ \nu_s \end{pmatrix} = \begin{pmatrix} \cos\theta_{\text{new}} & \sin\theta_{\text{new}} \\ -\sin\theta_{\text{new}} & \cos\theta_{\text{new}} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_{\text{new}} \end{pmatrix}$$

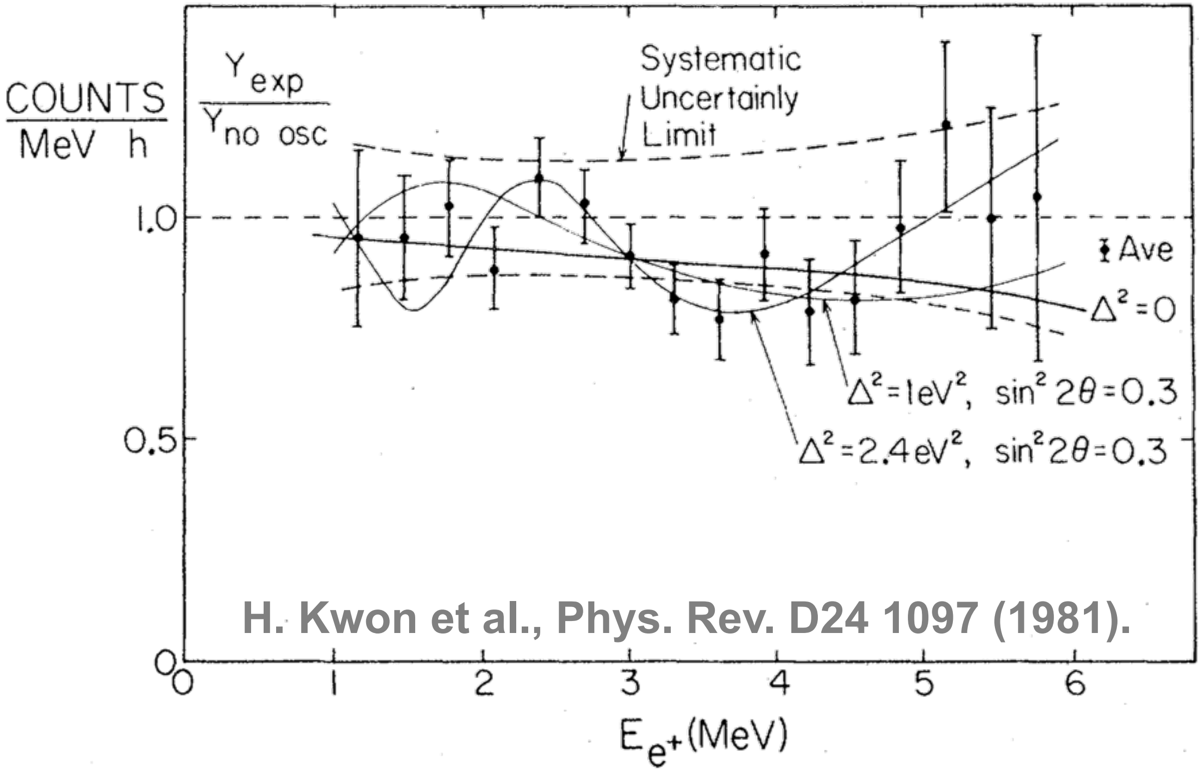
$$P_{\nu_e\to\nu_e}(L,E) = |\langle\nu_e(L)|\,\nu_e(L=0)\rangle|^2 = 1 - \sin^2(2\theta_{\text{new}})\sin^2\left(\frac{\Delta m^2_{\text{new}}L}{E}\right)$$



- Absence of oscillation is disfavored at 98.6% C.L.

The 1981 ILL Grenoble neutrino experiment

- ILL Reactor : **Almost pure ^{235}U ; Compact core**
- Detector **8.8 m** from core
- Reanalysis in 1995 by part of the collaboration to account for overestimation of flux at ILL reactor by 10%... Affects the rate only

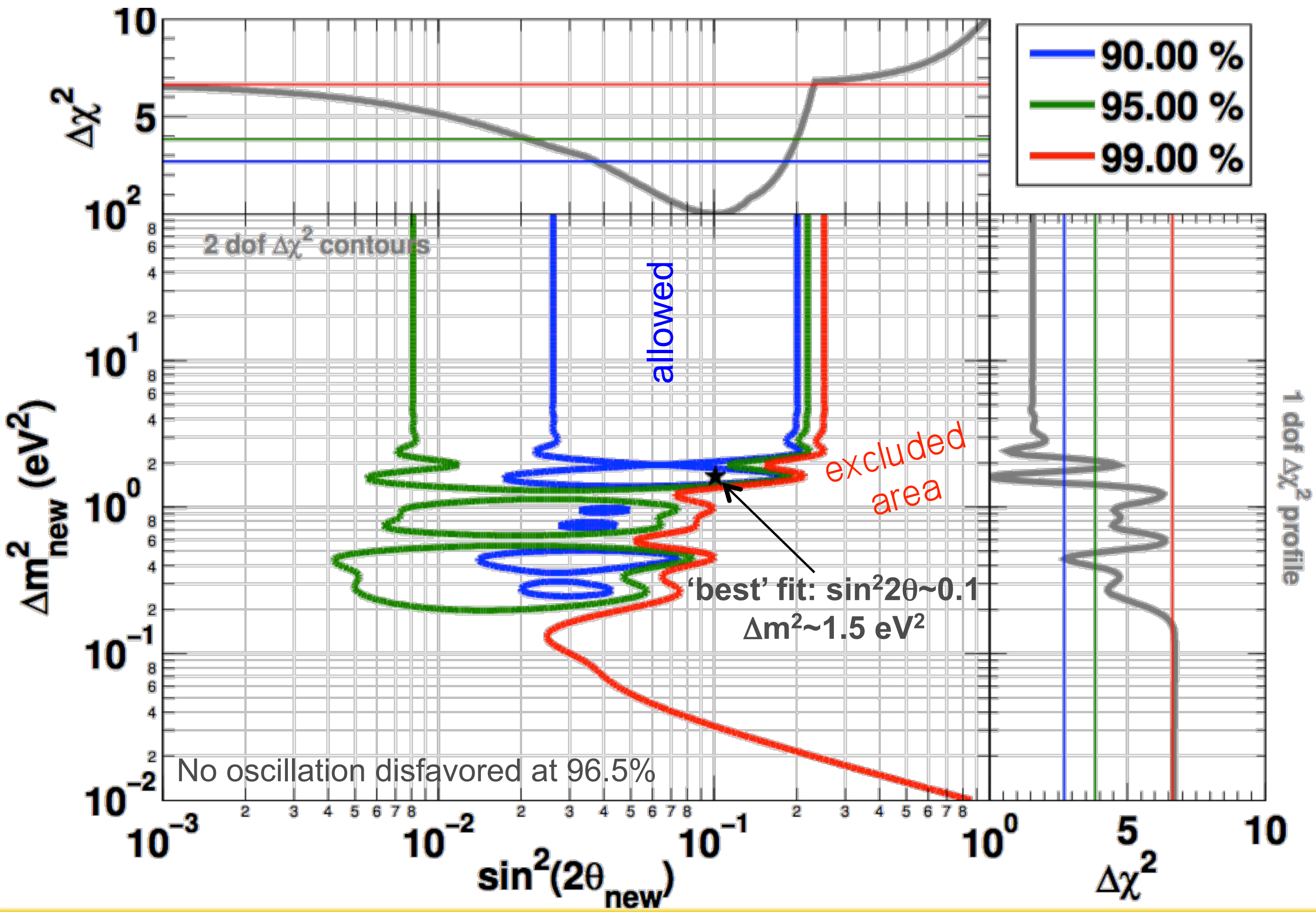


H. Kwon et al., Phys. Rev. D24 1097 (1981).

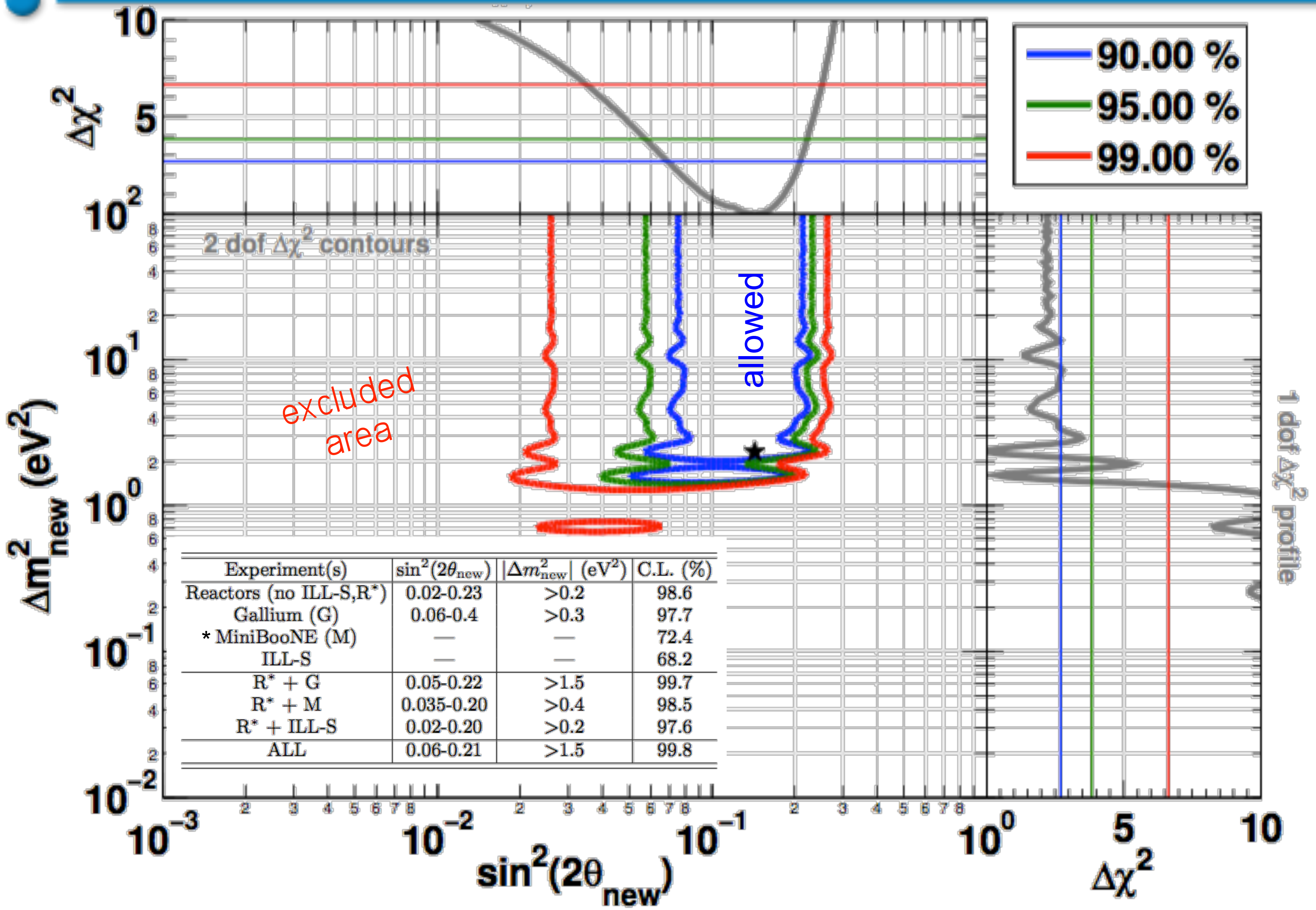
- Large errors, but a striking pattern is seen by eye ?

Combined Reactor Rate+Shape contours

Including original Bugey-3 & ILL Energy Spectra constraints



Combining reactor rates + shape + Gallium Anomaly



Experiment(s)	$\sin^2(2\theta_{new})$	$\lvert\Delta m^2_{new}\rvert$ (eV^2)	C.L. (%)
Reactors (no ILL-S,R*)	0.02-0.23	>0.2	98.6
Gallium (G)	0.06-0.4	>0.3	97.7
* MiniBooNE (M)	—	—	72.4
ILL-S	—	—	68.2
R* + G	0.05-0.22	>1.5	99.7
R* + M	0.035-0.20	>0.4	98.5
R* + ILL-S	0.02-0.20	>0.2	97.6
ALL	0.06-0.21	>1.5	99.8

The no-oscillation hypothesis is disfavored at 99.8% CL

* Miniboone re-analysis of : C. Giunti, M. Laveder, Phys. Rev. D82 (2010) 053005

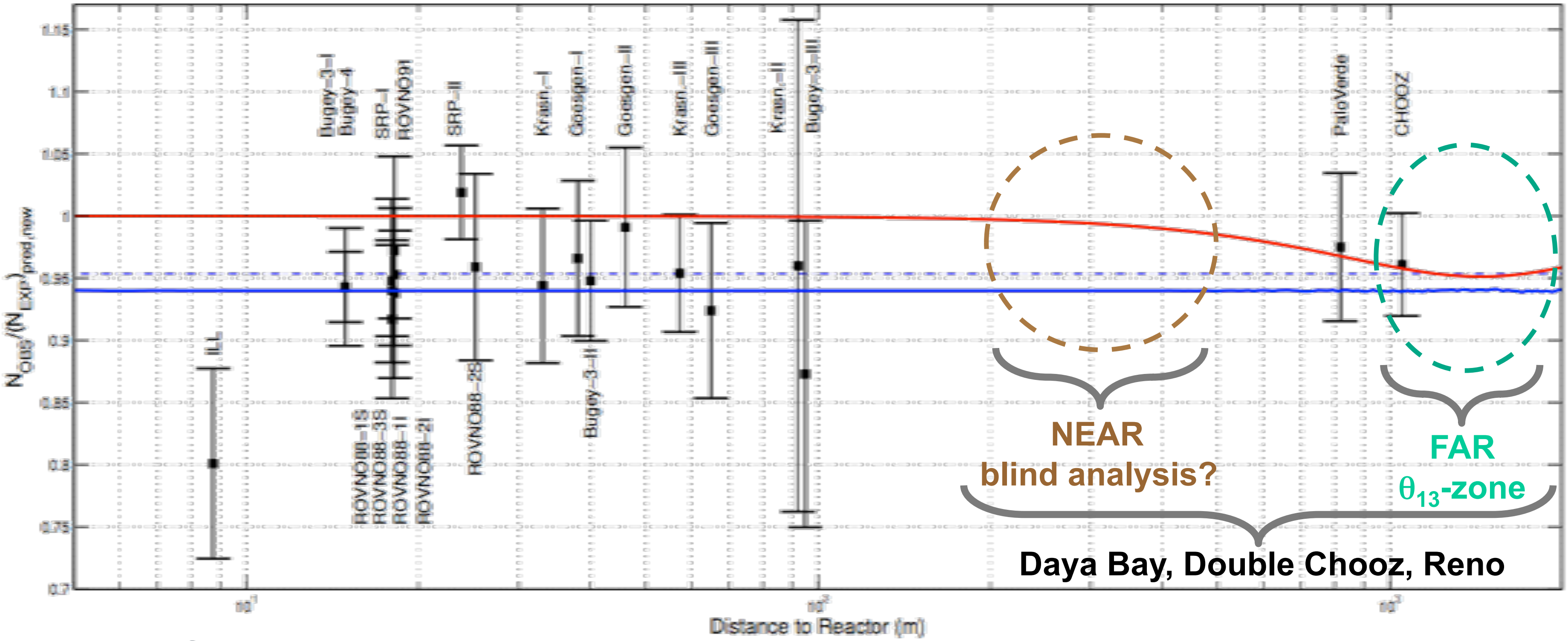
Implication of the reactor antineutrino anomaly for θ_{13} search at reactors

Implication for θ_{13} at 1-2 km baselines

- The choice of normalization is crucial for reactor experiments looking for θ_{13} without near detector

  $\sigma_f^{pred,new}$: new prediction of the antineutrino fluxes

  σ_f^{ano} or σ_f^{bugey} : experimental cross section



- A deficit observed at 1-2 km can either be induced by θ_{13} induced oscillation BUT also by other explanations (experimental, biased-ϕ, …)

Single Baseline Experiments: Normalization

- Experiments with baselines > 500 m
- How do you normalize the expected flux, knowing the fuel composition?
- **If near + far detector, not an issue anymore**

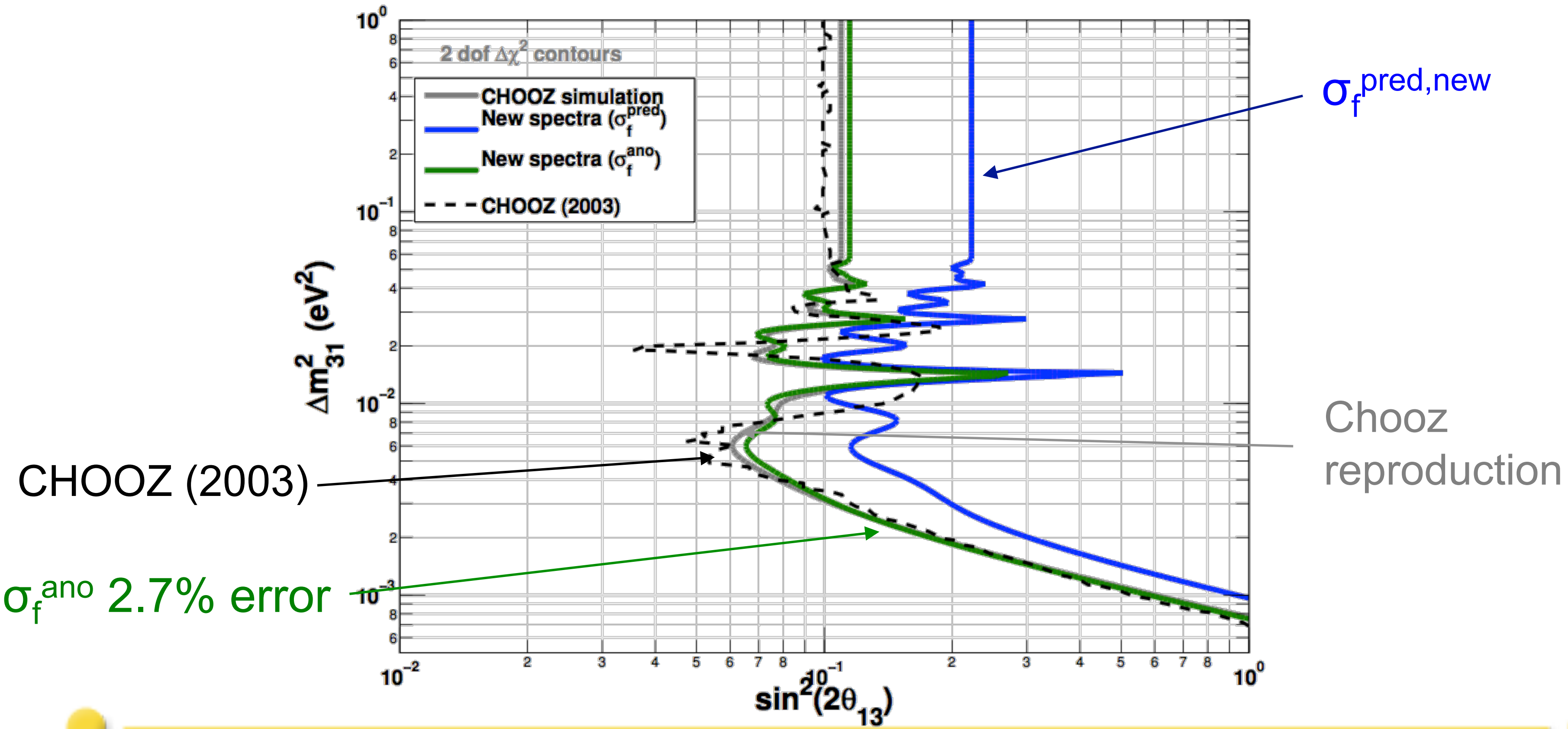
Choices

- **σ_f^{pred}**
  - Use $\sigma_f^{pred,new}$ =6.102 10^{-43} cm^2/fission ± 2.7%
  - Use $\sigma_f^{pred,old}$=5.850 10^{-43} cm^2/fission ± 2.7%
- **σ_f^{exp}**
  - Use σ_f^{exp} Bugey-4=5.750 10^{-43} cm^2/fission ± 1.4%
    Chooz's choice: use lower error (total 2.7% instead of 3.3%)
    Double Chooz Phase-I plans using $\sigma_f^{exp,bugey4}$
  - Use $\langle\sigma_f^{exp}\rangle=\boldsymbol{\sigma_f^{ano}}$=5.750 10^{-43} cm^2/fission ± 1% + ?% (syst.)
    Average over short-baseline expts.

in this slide assume Bugey-4 fuel comp.

CHOOZ reanalysis

- The choice of σ_f changes the limit on θ_{13}
- Chooz original choice was σ_f^{exp} from Bugey-4 with low error
- If $\sigma_f^{pred,new}$ is used, limit is worse by factor of 2
- If σ_f^{ano} is used with 2.7%, we obtain the original limit



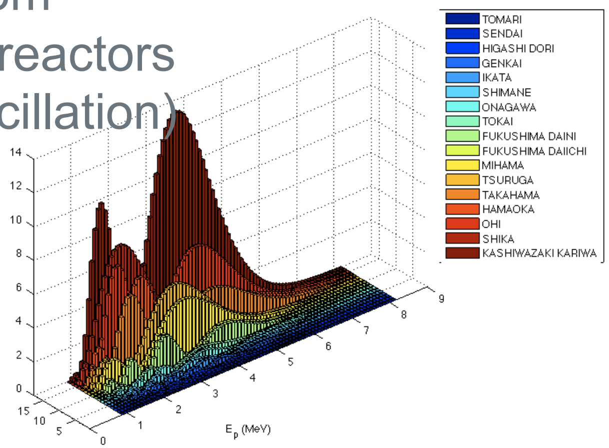
Reanalysis of KamLAND's 2010 results

arXiv:1009.4771v2 [hep-ex]

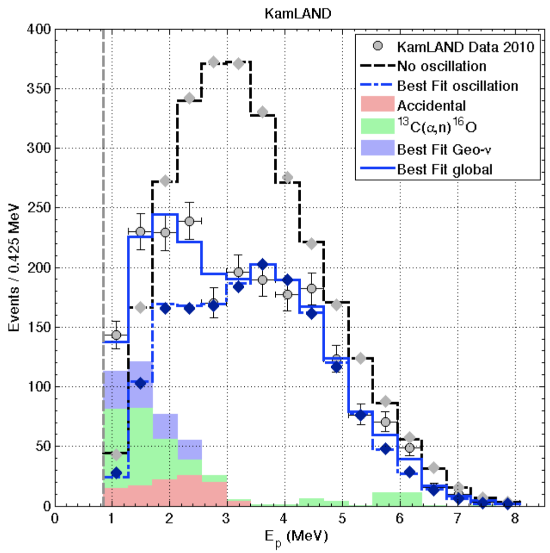
Systematics

	Detector-related (%)		Reactor-related (%)	
Δm^2_{21}	Energy scale	1.8 / 1.8	$\overline{\nu}_e$-spectra [31]	0.6 / 0.6
Rate	Fiducial volume	1.8 / 2.5	$\overline{\nu}_e$-spectra	2.4 / 2.4
	Energy scale	1.1 / 1.3	Reactor power	2.1 / 2.1
	$L_{cut}(E_p)$ eff.	0.7 / 0.8	Fuel composition	1.0 / 1.0
	Cross section	0.2 / 0.2	Long-lived nuclei	0.3 / 0.4
	Total	2.3 / 3.0	Total	3.3 / 3.4

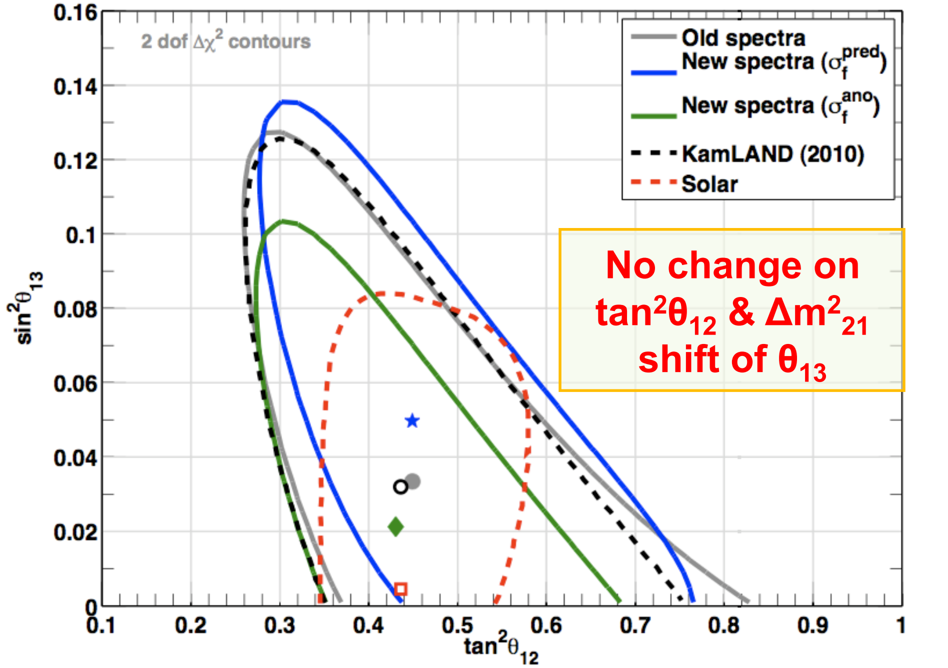
Spectra from Japanese reactors (with ν_e oscillation)



Reproduced KamLAND spectra within 1% in [1-6] MeV range



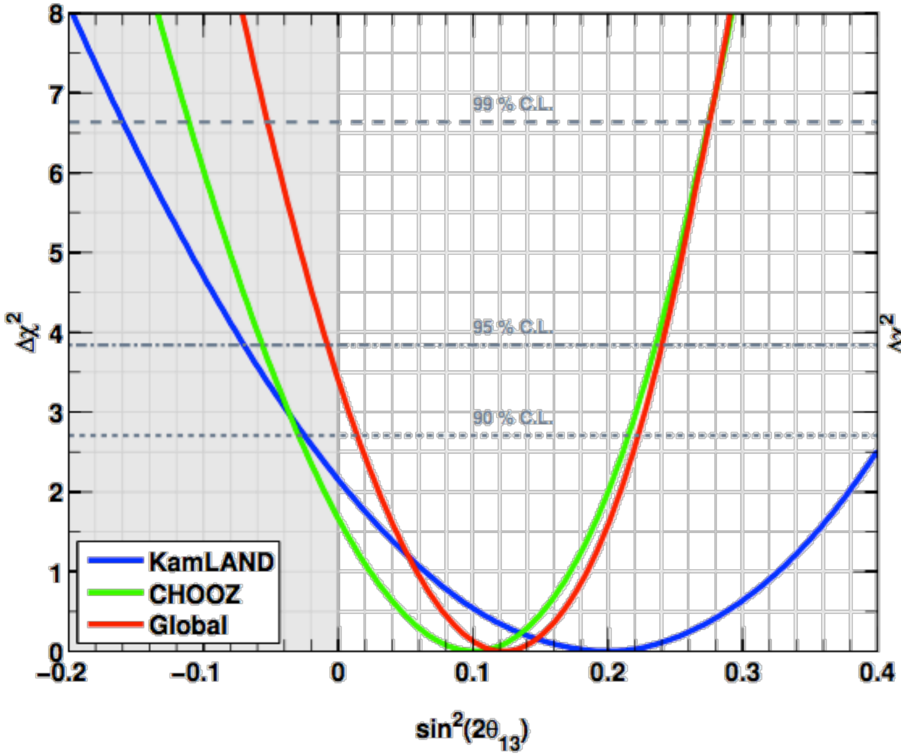
With new spectra predictions



CHOOZ and KamLAND combined limit on θ_{13}

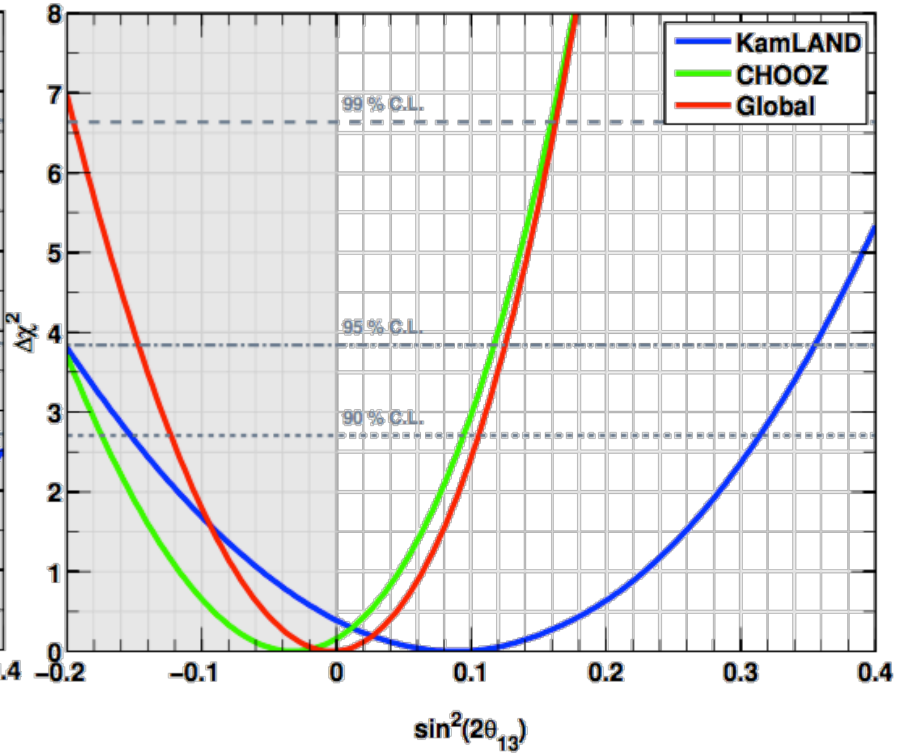
Normalization with $\sigma_f^{pred,new}$

3-ν framework & 2.7% uncertainty



Normalization using σ_f^{ano}

3-ν framework & 2.7% uncertainty

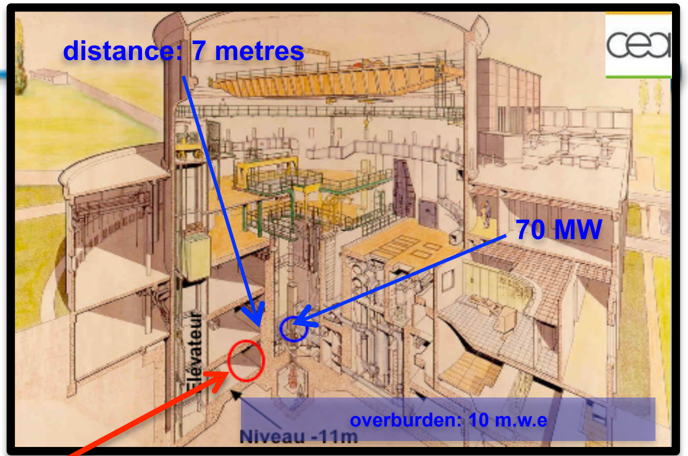


- Constraint on θ_{13} with 1-baseline experiment prediction dependent (Arxiv:1103:0734)
  - **Proven method : using $\sigma_f^{bugey-4}$** (Eur. Phys. J. C27, 331-374 (2003)) → **DC-phase1**
  - **Multi-detector experiments are not affected**

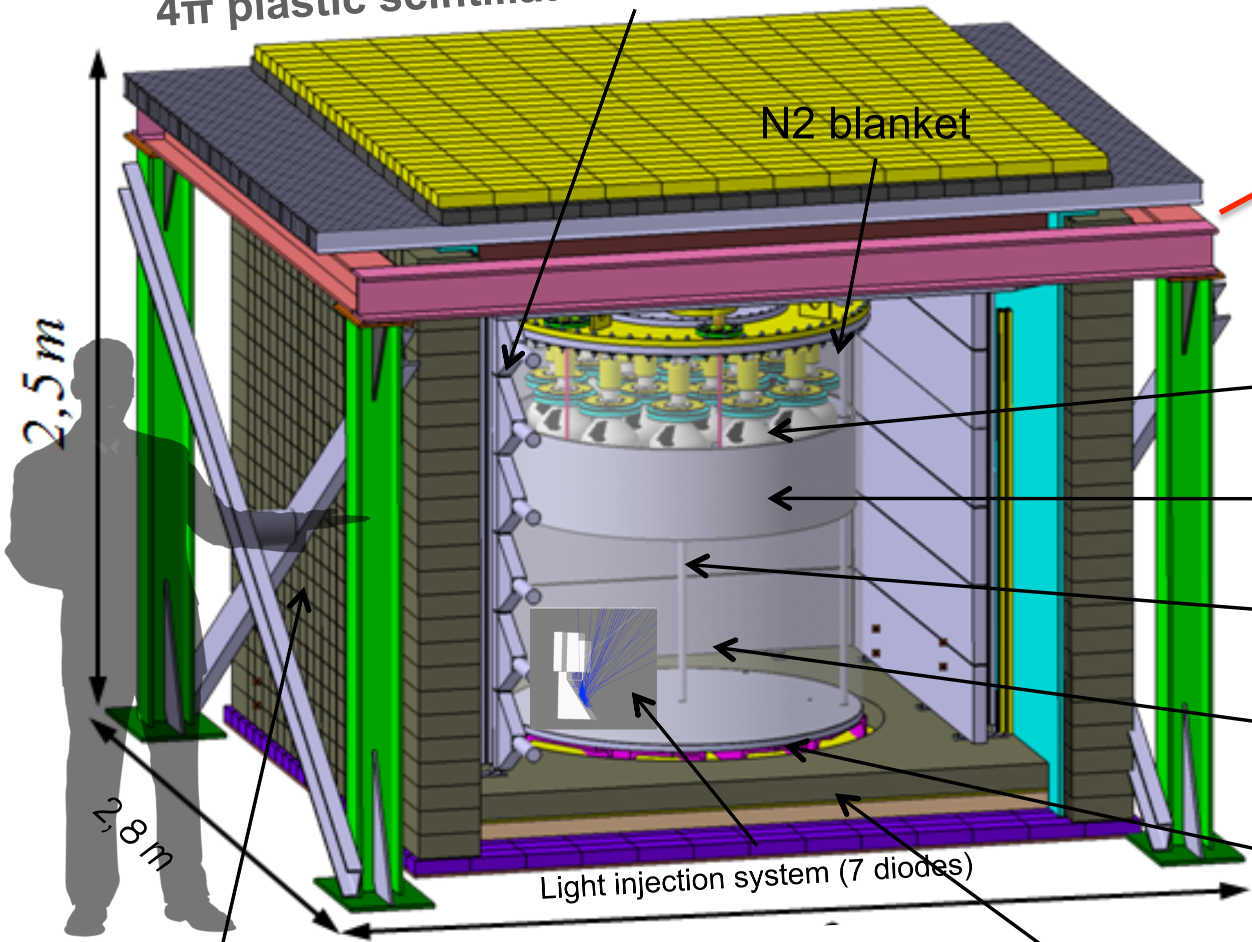
Possible Experimental Tests

The Nucifer Reactor Exp.

First goal: Non Proliferation
Thermal Power Measurement
Fuel Composition Measurement U/Pu



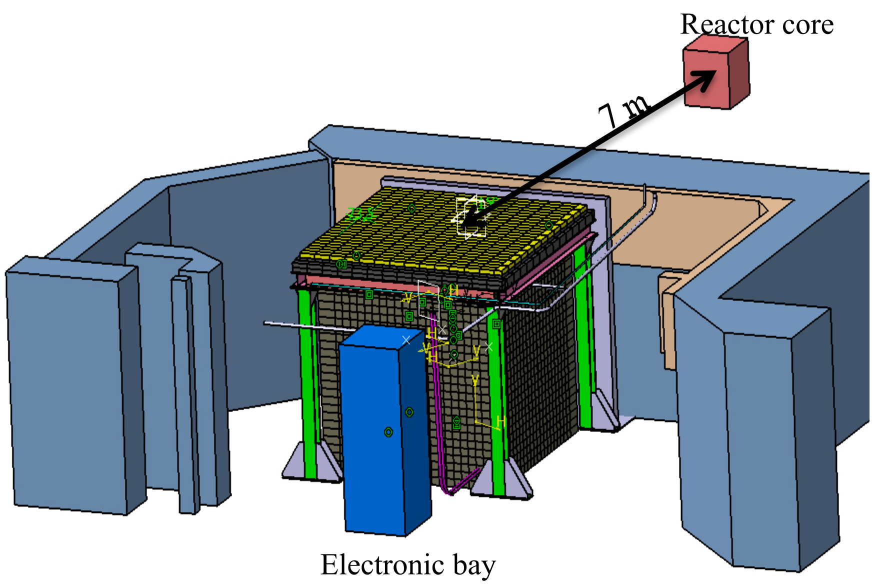
Osiris research reactor
CEA-Saclay (600 ν/d)
CEA – IN2P3 coll.

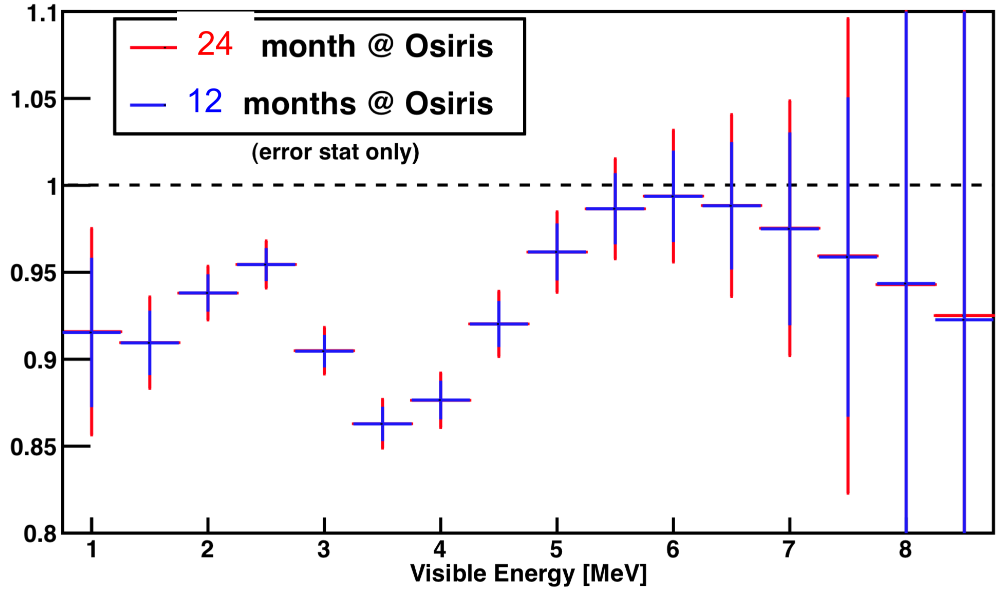


NUCIFER Test of the Reactor Neutrino Anomaly

- **Osiris Research Reactor :** Core Size: 57x57x60 cm
- **Nucifer Detector Size** : 1.2x0.7m (850l)
- **Baseline :** <L>=7.0 m, σ=0.3 m → eV^2 oscillations are not washed out

- Folding Nucifer Geant4 Monte Carlo detector response
- $\Delta m^2 = 2.4$ eV^2 & $\sin^2(2\theta)=0.15$
- No backgrounds. Thus to be taken with a grain of salt …

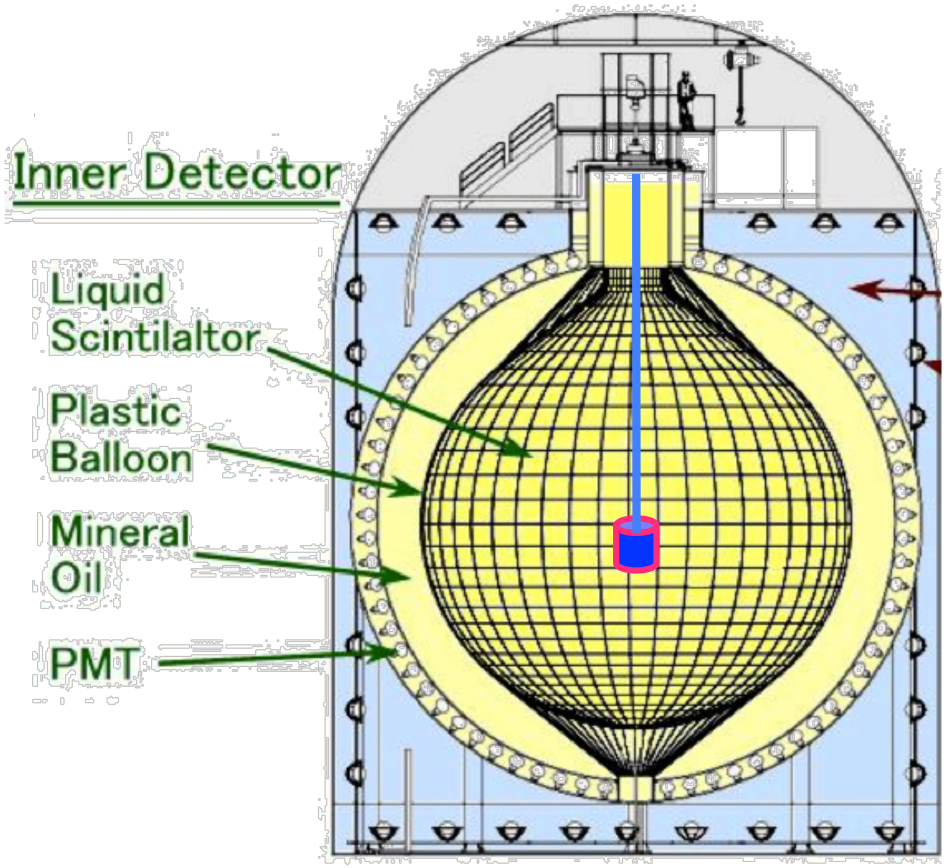




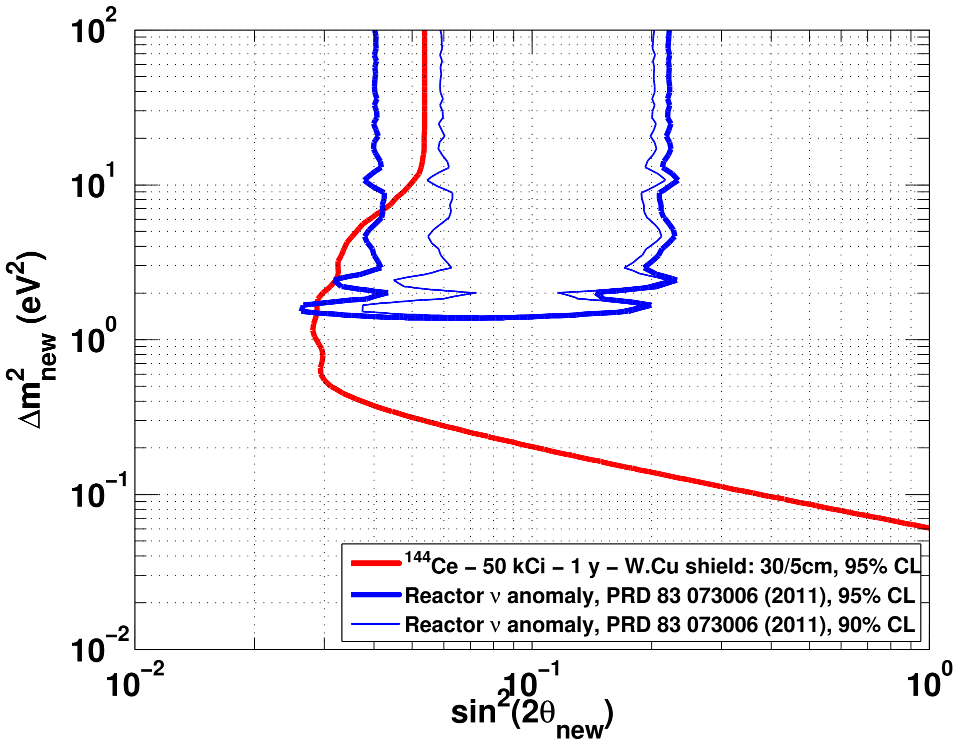
- Such pattern could not be seen at Bugey-3 (extended core & L=14 m)

A ^{144}Ce kCi Anti-neutrino Source Experiment

- A 50 kCi anti-ν source (10 g of ^{144}Ce) in the middle of a large LS detector
- Inside a thick 35 cm W-Cu shielding → background free
- Energy-dependent oscillating pattern in event spatial distribution



M. Cribier, M Fechner, T. Lasserre, et al.
arXiv:1107.2335



Conclusion and perspectives

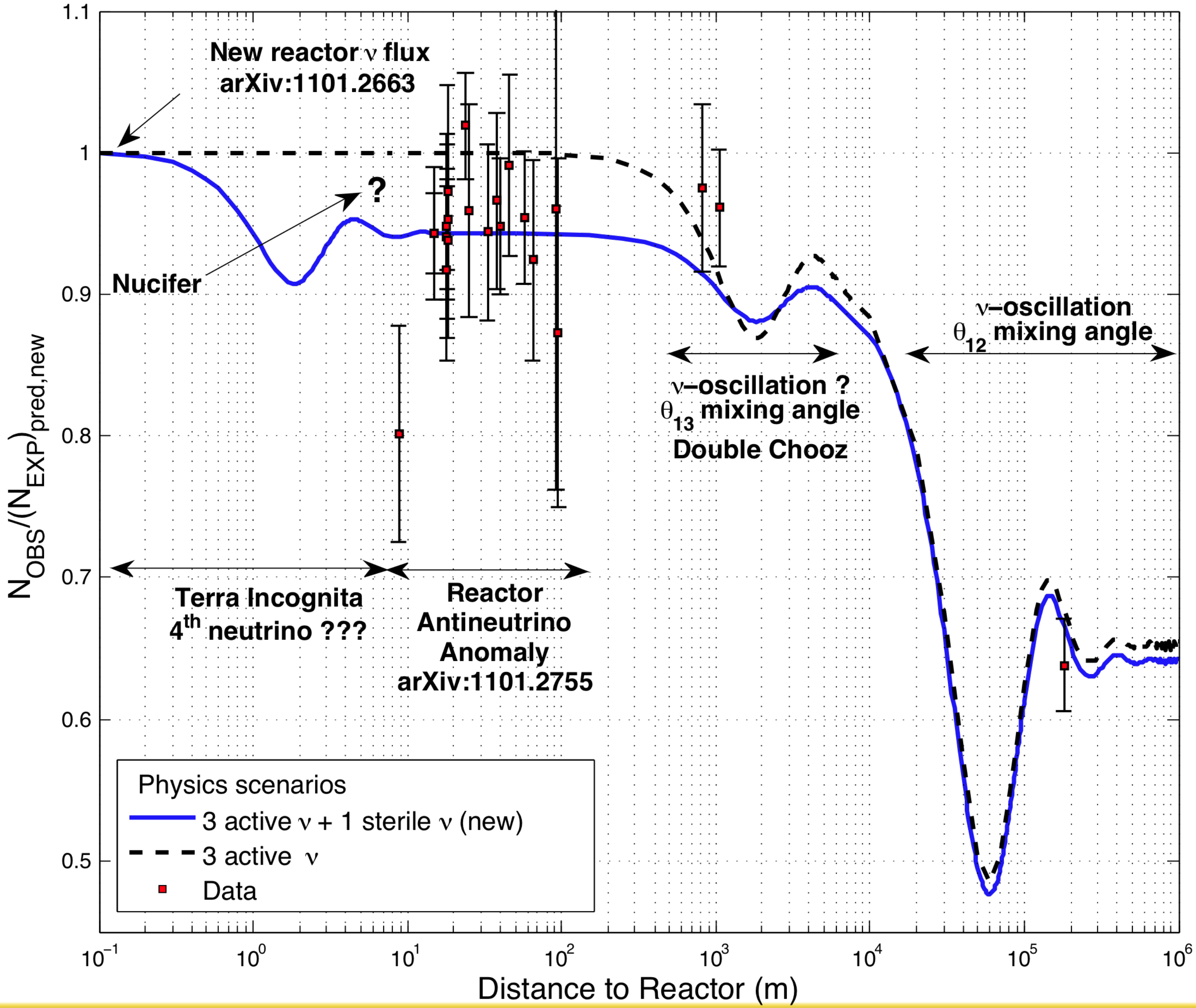
- **Great perspective for θ_{13} Reactor Experiments**
  - Two Daya Bay Near detectors starting this summer
  - RENO near & far detectors start data taking this summer
  - Double Chooz is taking data since April 2011 – Near Detector end 2012
- **Reactor Project for θ_{12} :** Daya Bay Proposal (Wang, Neutel 2011)

- **New Reactor Antineutrino Anomaly**
  - Experimental bias should be deeply investigated.
  - Hypothesis : a 4^{th} neutrino ($\Delta m^2 \approx eV^2$). No-oscillation disfavored at 99.8%

- **New experimental input is needed:**
  - L/E ≈ few m/MeV
    - Nucifer (Saclay/IN2P3), Scraam (LLNL), or new project at ILL reactor (Saclay/TUM/LAPP)
    - New source experiments (Borexino, 'Gavrin Neutel 2011, arXiv:1107.2335**, …)**
  - L/E ≈ km/GeV
    - Icarus detector moved to CERN, new neutrino beam, near detector (C. Rubbia)
    - T2K near detector

Backup

Need for new experimental inputs !



Double Chooz Instrumental Light

- Unexpected PMT light emission was found

- The rate is the same level of magnitude as the ‘singles’ rate, which is in line with the proposal

- The events are rather different from the ‘singles’

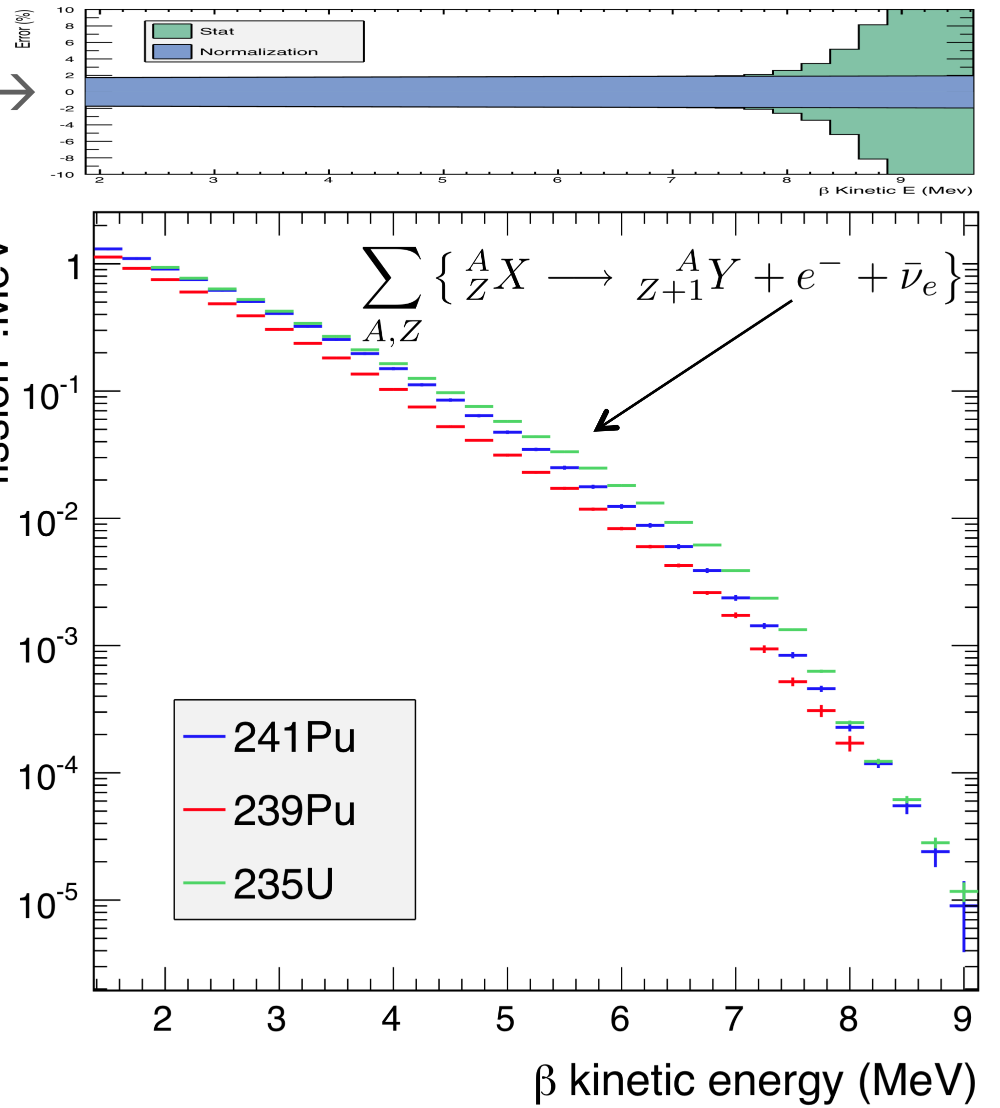
- Set of cuts brings it at a level much lower than the ‘singles’

- Analysis work is ongoing to assess systematics

The ILL electron Data Anchorage

Unique reference to be met by any other measurement or calculation

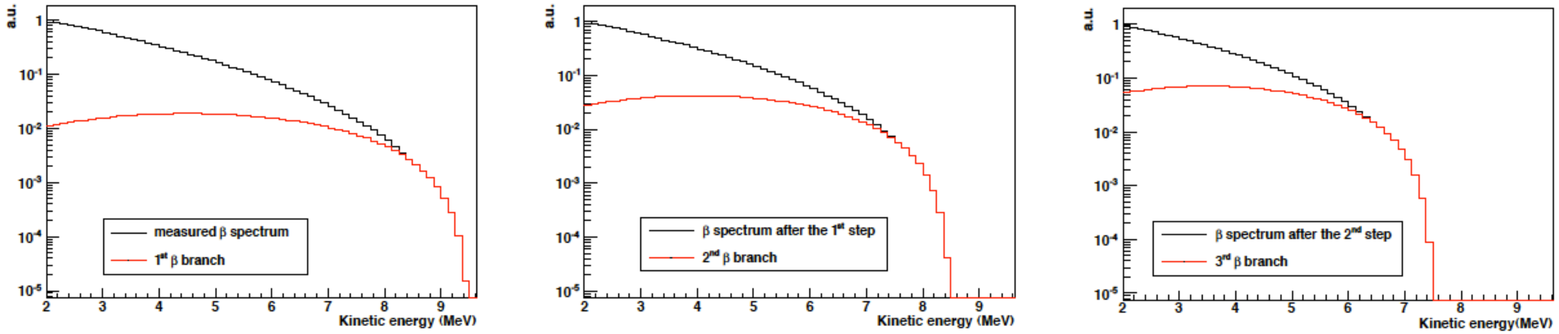
uncertainty →



- Accurate e⁻ measurements @ ILL' (1980-89):
  - High resolution magn. spectrometer
  - Intense and pure thermal n spectrum from the core
  - Extensive use of reference internal conversion electron lines → Normalization (1.8%)

ILL data: conversion to ν spectra

- **Fit e⁻ spectrum with a sum of 30 effective branches**
- **Conversion of the effective branches to ν spectra**



- **All theory included in these effective branches but:**

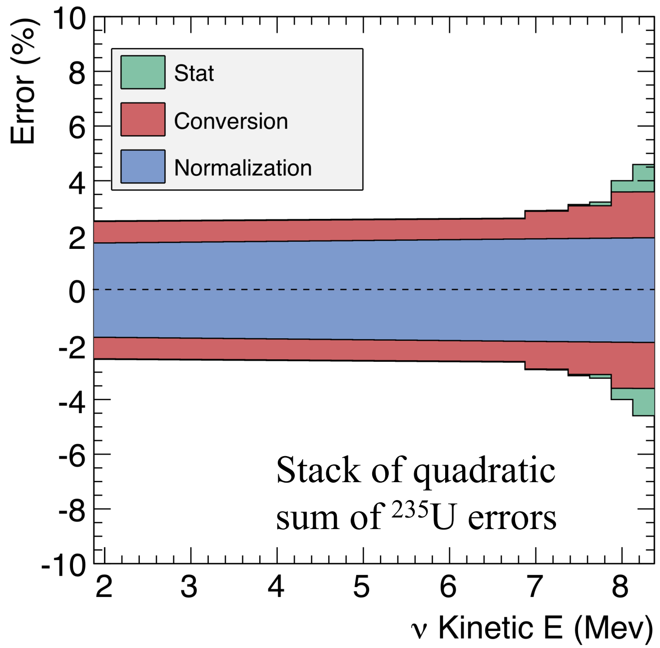
  - What Z? : Mean fit on nuclear data *Z=f(E0)*

$$Z(E_0) \approx 49.5 - 0.7E_0 - 0.09E_0^2, \quad Z \geq 34$$

  - What A_{CW}? : effective correction on the ν-spectra

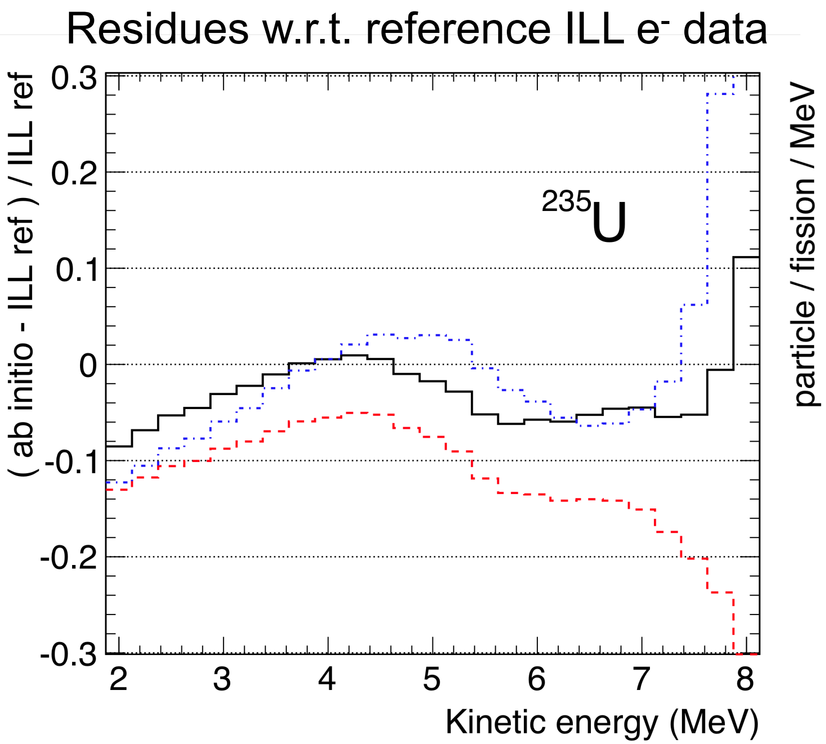
$$DN_n^{C,W}(E_n) \approx 0.65 \times (E_n - 4MeV) \quad \%$$

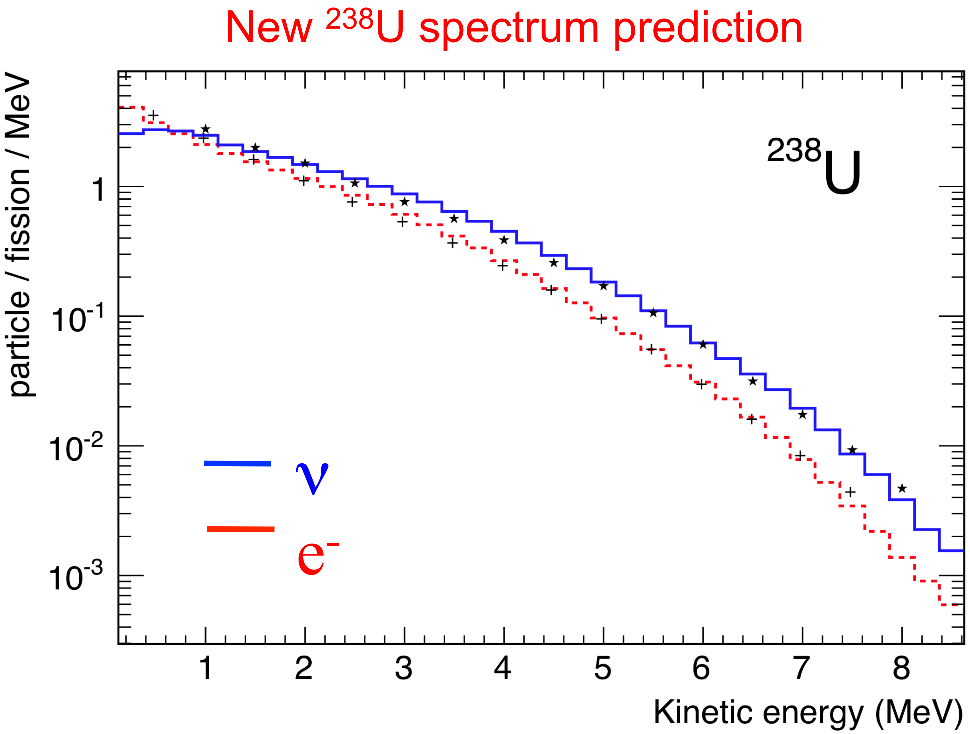
- **Conversion error from envelop of numerical studies**



The Full *Ab Initio* Attempt (electron data)

- MURE evolution code: core composition and off equilibrium effects
- BESTIOLE code: build up database of ~800 nuclei and 10000 β-branches

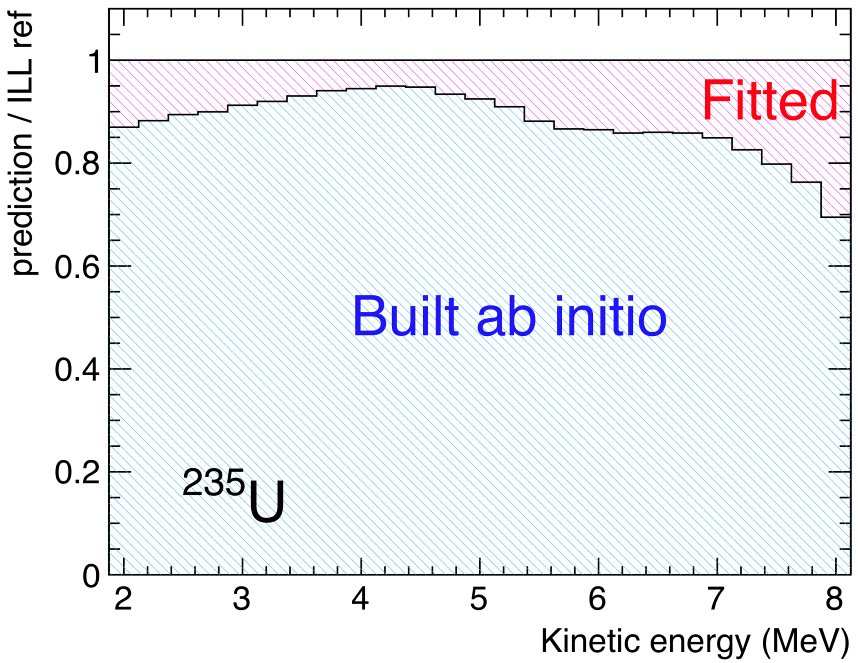


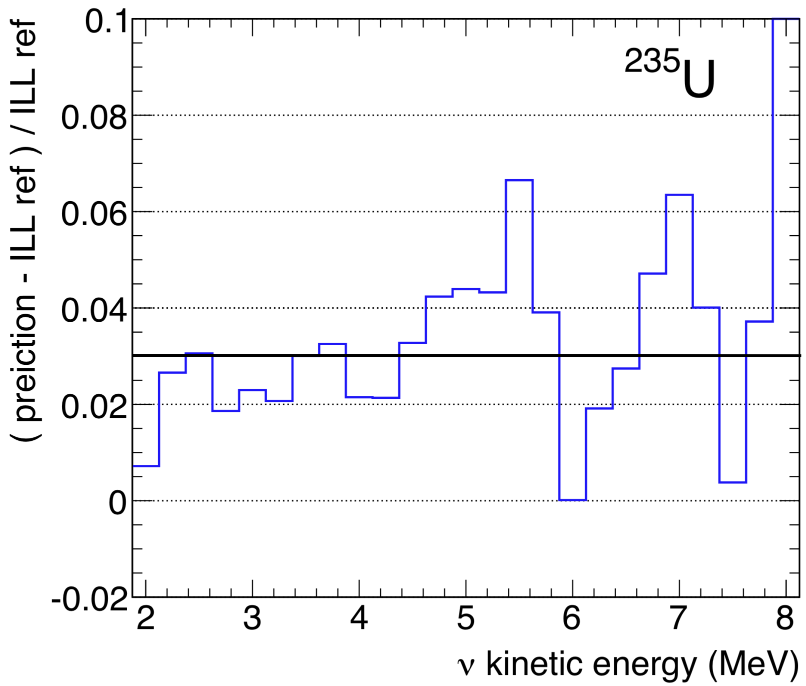


→ 95+/-5% of the spectrum reproduced but still not meeting required precision
→ Useful estimate of ^{238}U spectrum which couldn't be measured @ ILL
→ Measurement at FRMII ongoing (N. Haag & K Schreckenbach)

The New Mixed Conversion Approach

1. **SAME** ILL e- data Anchorage
2. Ab-Initio: “true” distribution of β-branches reproduces >90% of ILL e^- data.
3. Old-procedure: five effective anchorage-branches to the remaining 10%.





- **+3% normalization shift with respect to old ν spectrum**
- **Similar result for all isotopes (^{235}U, ^{239}Pu, ^{241}Pu)**
- **Stringent Test Performed – Origin of the bias identified**