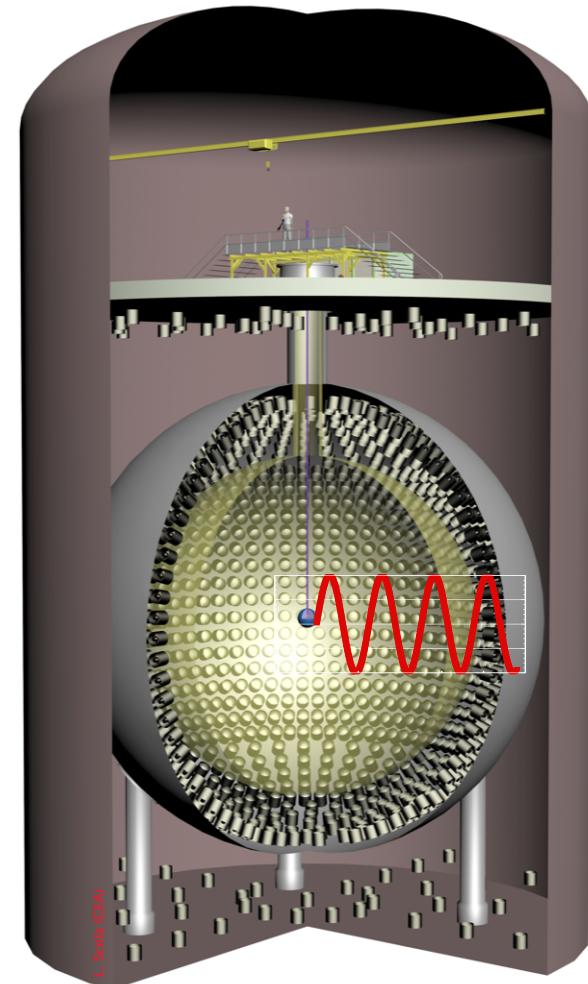


GDR Neutrino, June 21, 2012

CeLAND

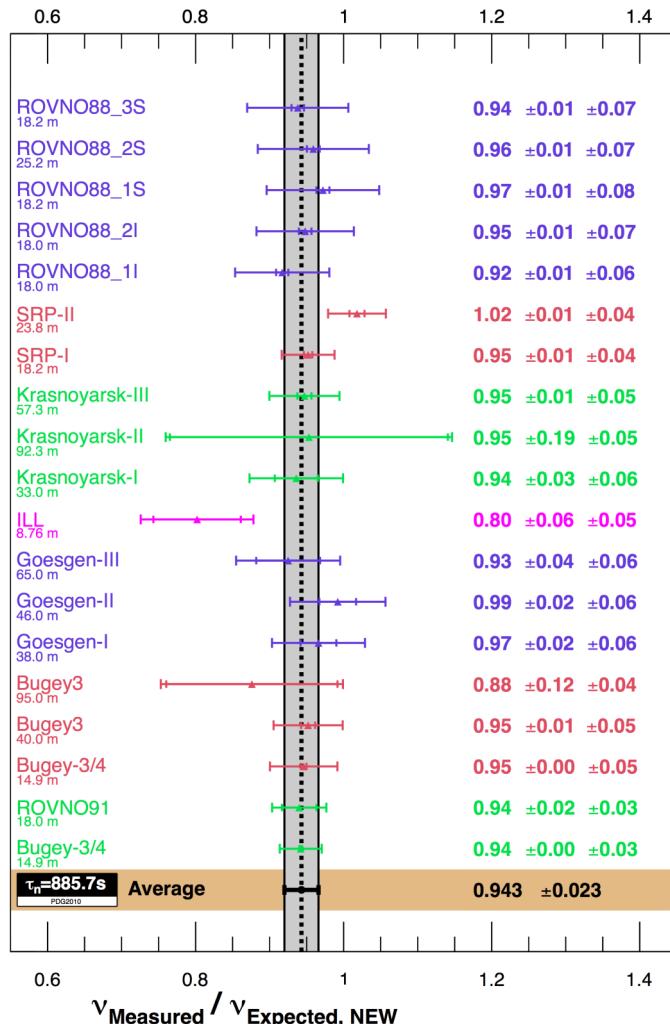
Testing the fourth neutrino hypothesis with an antineutrinos generator

Michel Cribier
CEA/DSM Irfu/SPP & APC-Paris



Need a fourth neutrino ?

The Reactor Antineutrino Anomaly



❖ G. Mention et al.

Phys. Rev. D83, 073006 (2011)

❖ New antineutrino flux from nuclear reactors : + 3,5 %

- Th. Mueller et al.

Phys. Rev C 83, 054615 (2011)

❖ Neutron lifetime ...

... Cross section : + 1%

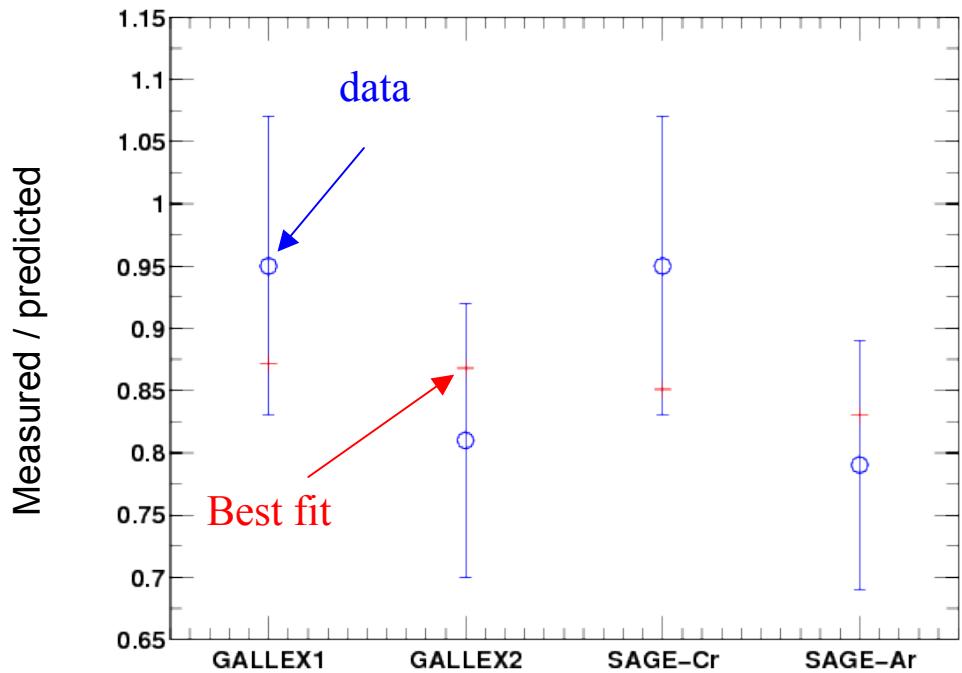
❖ Long lived isotopes in reactors : + 1%

❖ An overall deficit : **$7.3 \pm 2.3 \%$**

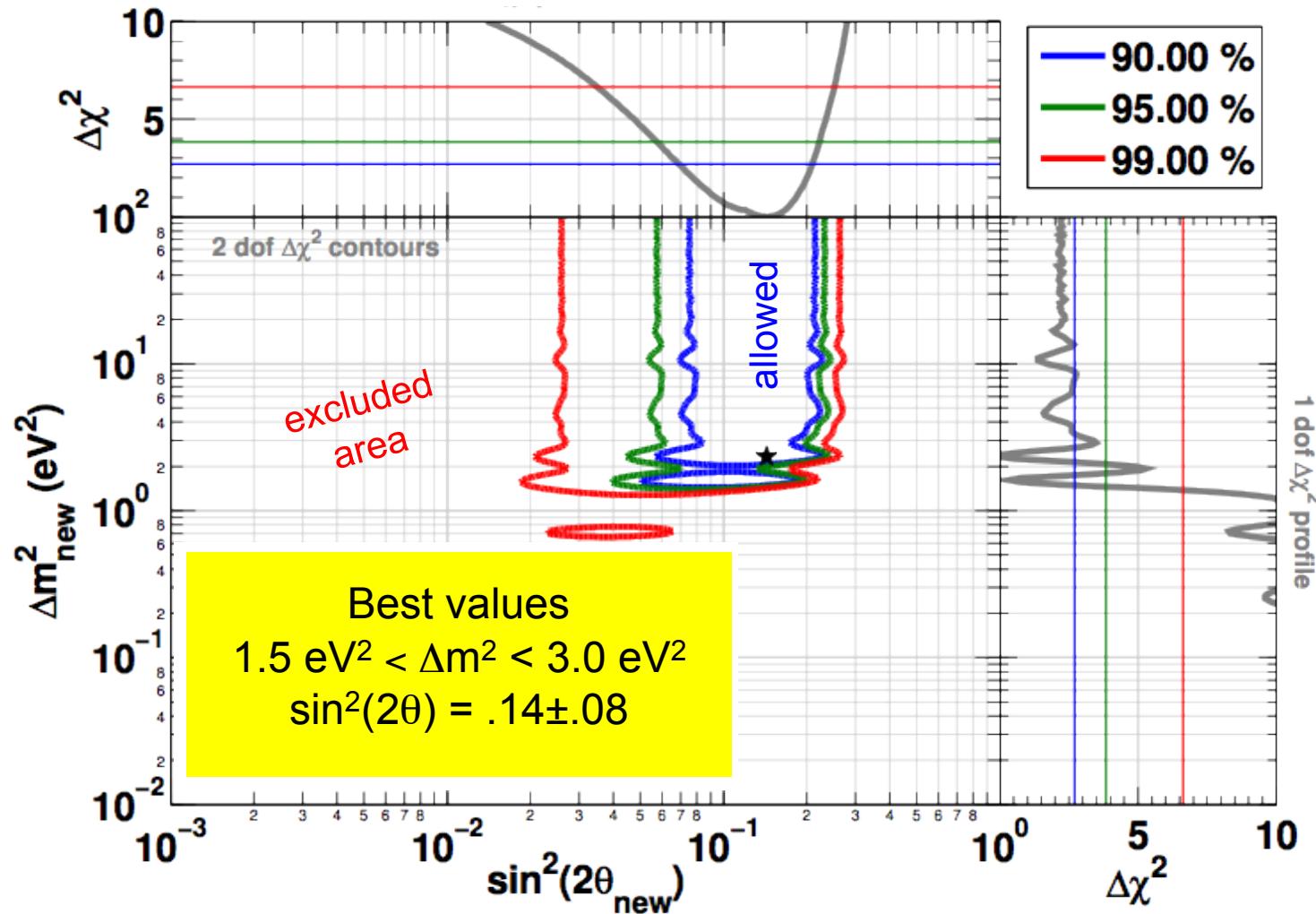
The Gallium Anomaly

- ❖ C. Giunti & M. Laveder
Phys. Rev C 83, 065504 (2011)
- ❖ Calibration of solar neutrino experiments
 - Distance ≈ 1 m
- ❖ Gallex
 - 2 ^{51}Cr ν sources
- ❖ Sage
 - 1 ^{51}Cr ν source
 - 1 ^{37}Ar ν source
- ❖ Overall deficit : **14 \pm 6 %***

- Not using reevaluation of $^{71}\text{Ga}(\nu_e, e) ^{71}\text{Ge}$ cross section following D.Frekers et al. *Phys. Lett. B* 706 (2011) 134



Reactors and Gallium

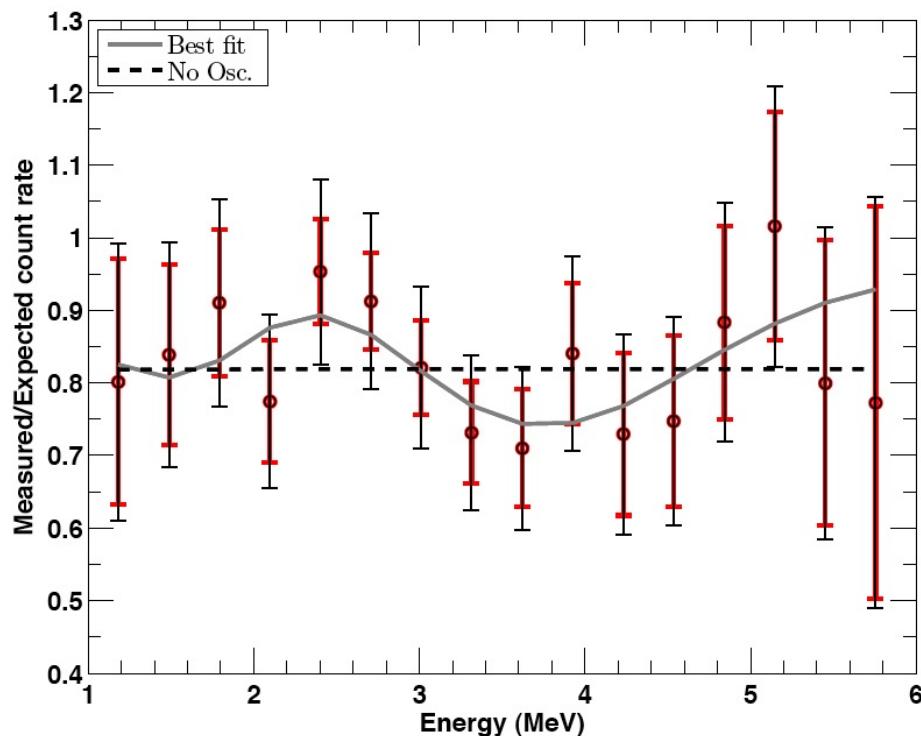


The no-oscillation hypothesis is disfavored at 99.8% CL

An intriguing result 1st ILL experiment

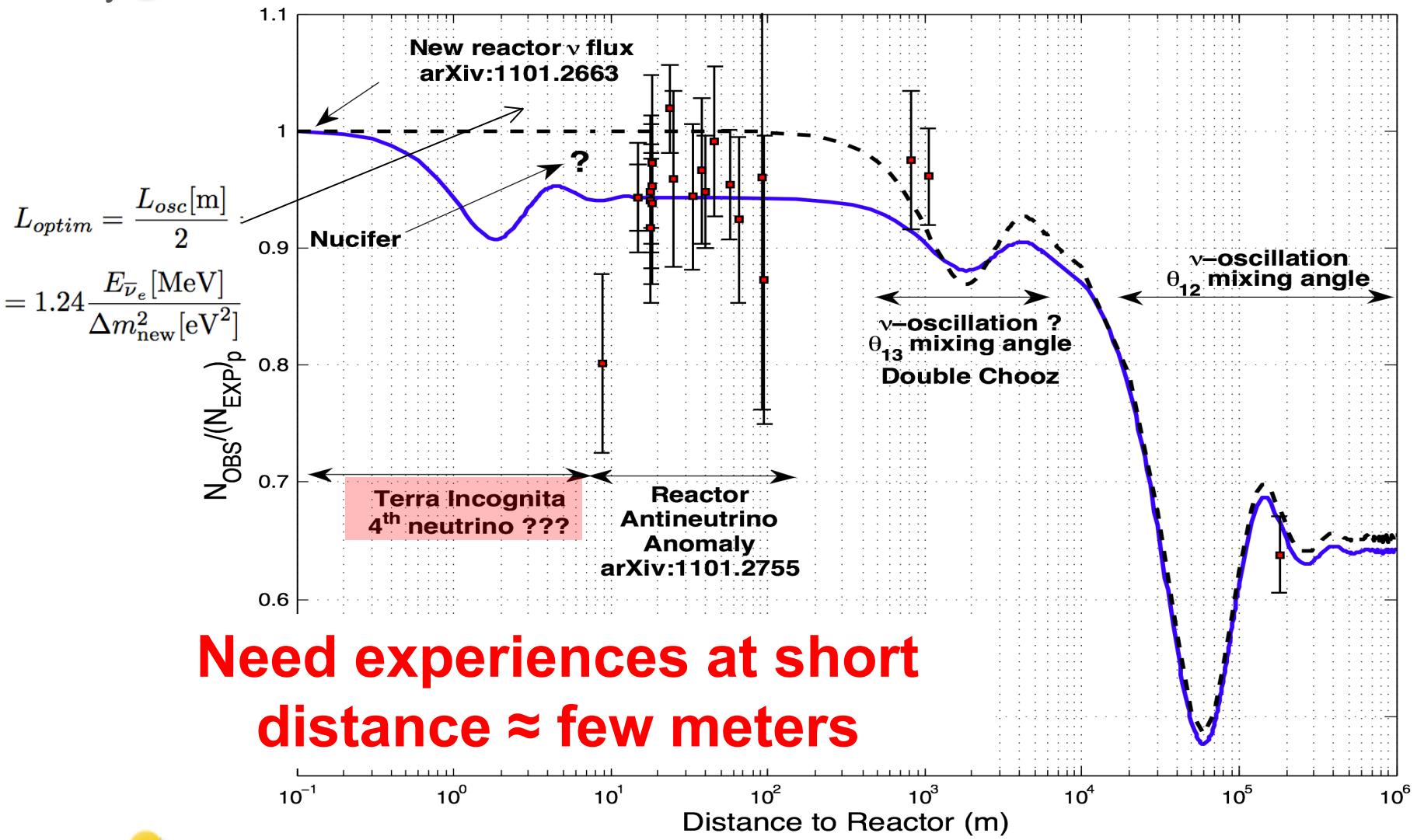


- ❖ Performed in 1980 at ILL reactor in Grenoble @ < 9 m
- ❖ Reevaluation in 1990 by 9.5 % of the reactor power
- ❖ Reanalysed in 1995



Fit with
 $\Delta m^2 = 2.3 \text{ eV}^2$
 $\sin^2(2\theta) = .24$

We need new experimental input !



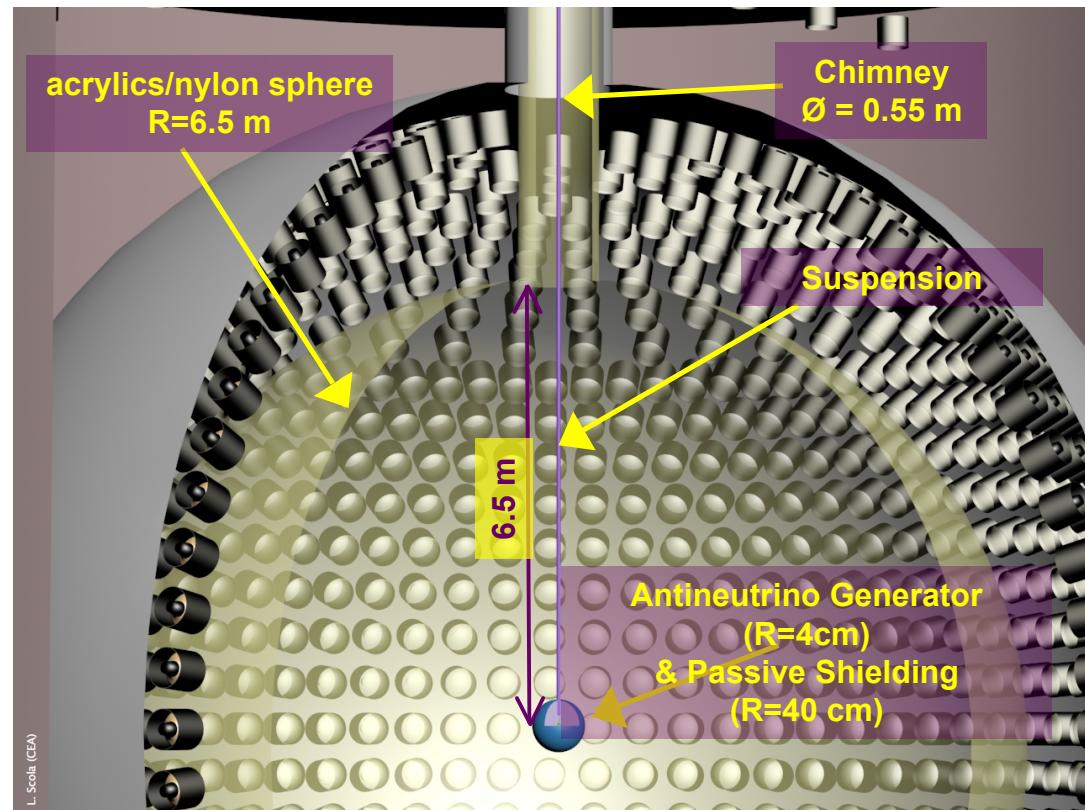
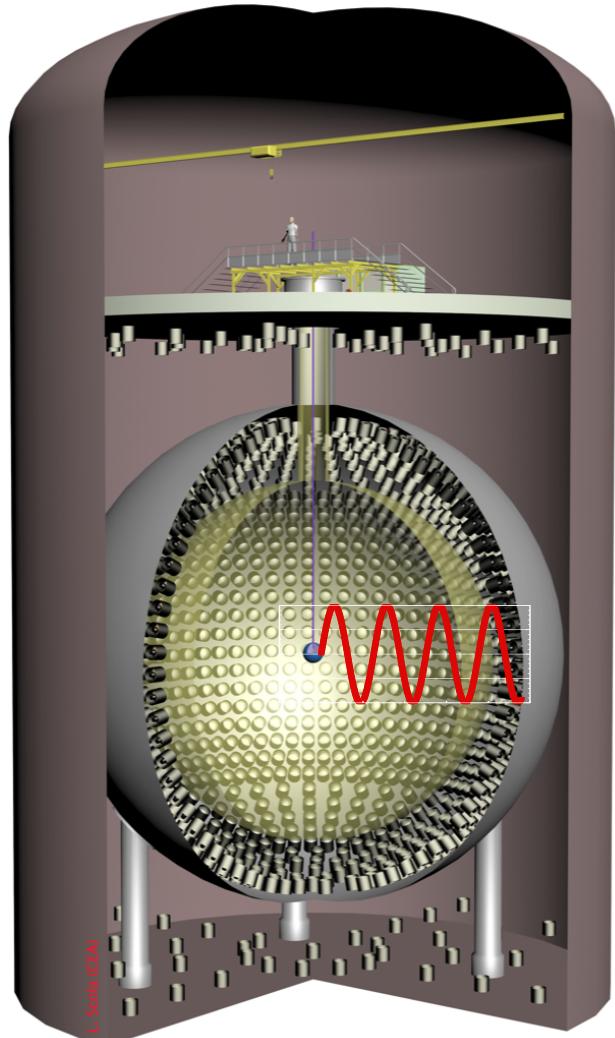
Need experiences at short
distance \approx few meters

A proposed search for a fourth neutrino with a PBq anti-neutrino source

*M. Cribier, M. Fechner, T. Lasserre, D. Lhuillier, A. Letourneau, G.
Mention, D. Franco, S. Schoenert, V. Kornoukhov*

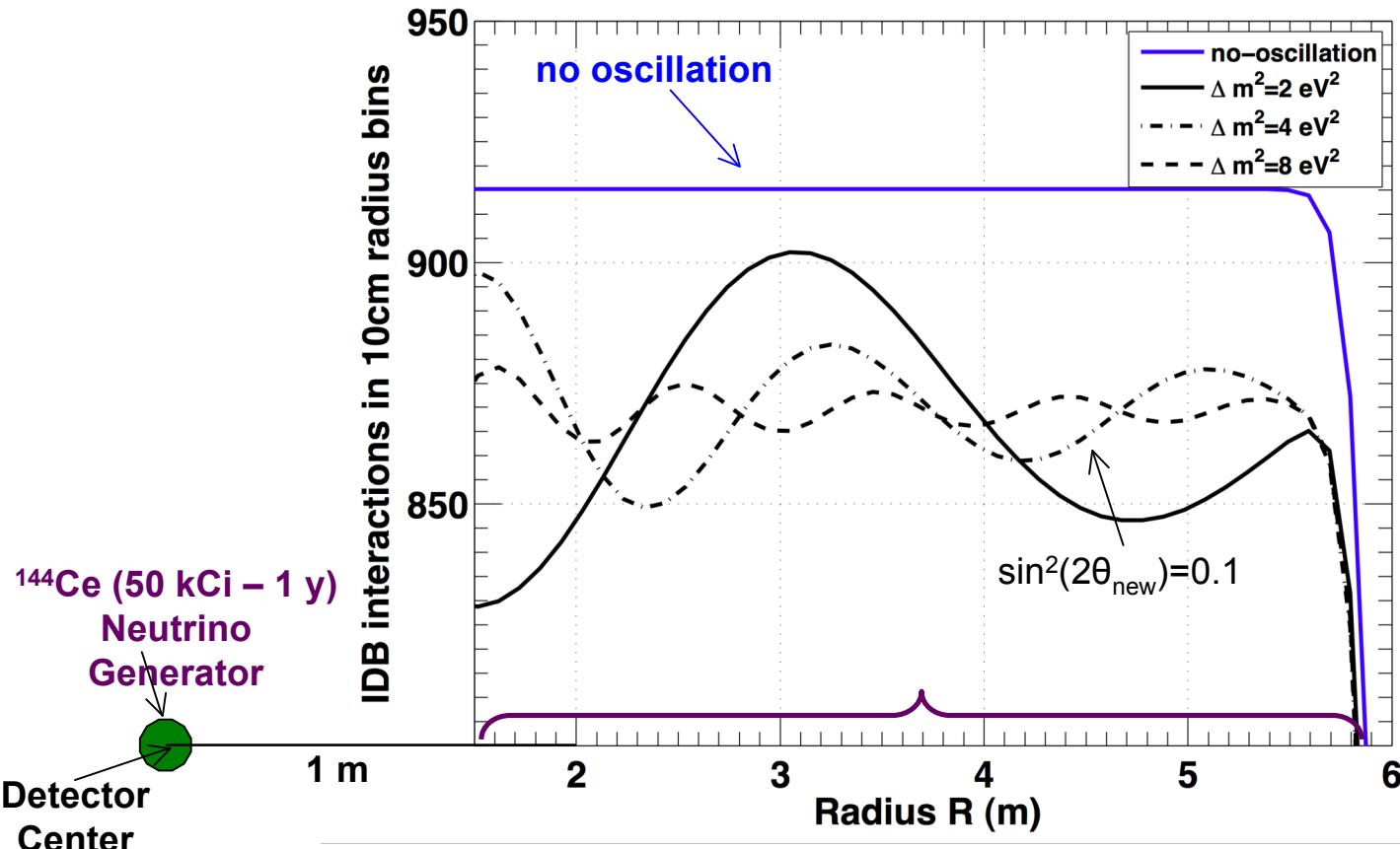
Phys. Rev. Lett. 107, 201801 (2011)

Concept



An Unambiguous Proof

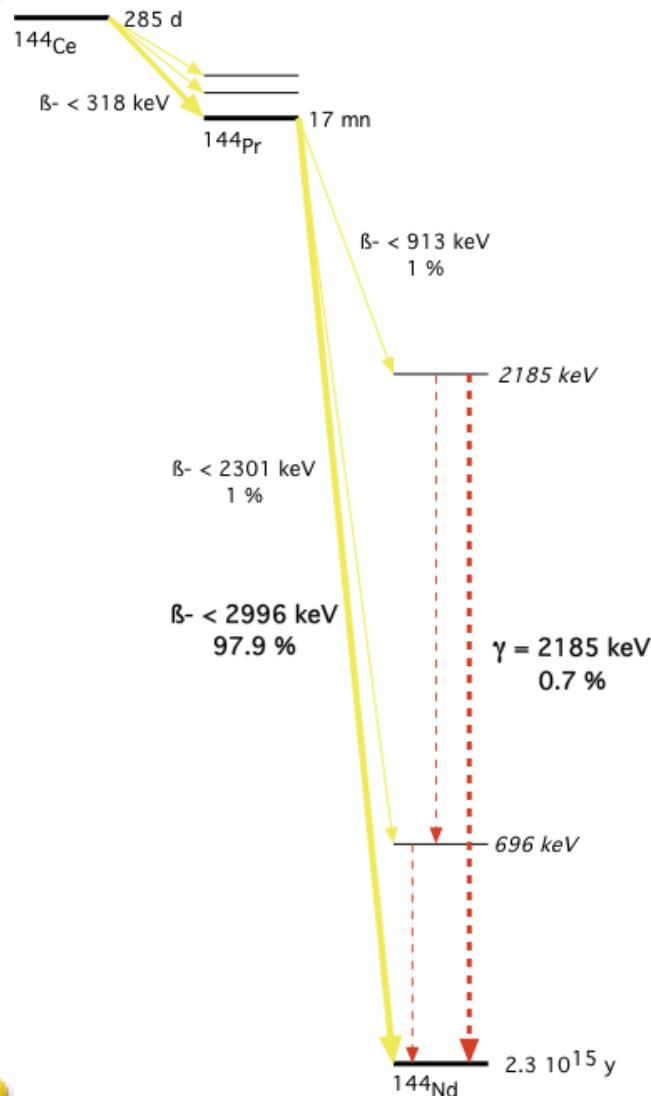
$$\frac{dN}{dR}(R,t) \propto \frac{A(t)}{4\pi R^2} \times \langle\sigma\rangle \times N_p \times 4\pi R^2 \times P_{ee} \left(\frac{\Delta m^2 R}{\langle E \rangle} \right)$$



Advantages of antineutrinos

- ❖ Antineutrino detection via inverse beta-decay
 - High cross section ($\approx 10^{-43} \text{ cm}^2$) : from **MCi to kCi** !
 - Antineutrino must have **$E_\nu > 1.8 \text{ MeV}$**
 - Long Lifetime for production, transport and measurement
 - $e^+ - n$ delayed coincidence : **background free experiment**
- ❖ Antineutrino source must involve
 - a long-lived low-Q nucleus...
 - ... that decays into a short-lived high-Q nucleus
 - Possible candidates
 - $^{90}\text{Sr}-^{90}\text{Y}$, **$^{144}\text{Ce}-^{144}\text{Pr}$** , $^{106}\text{Ru}-^{106}\text{Rb}$, $^{42}\text{Ar}-^{42}\text{K}$
 - Easy to produce

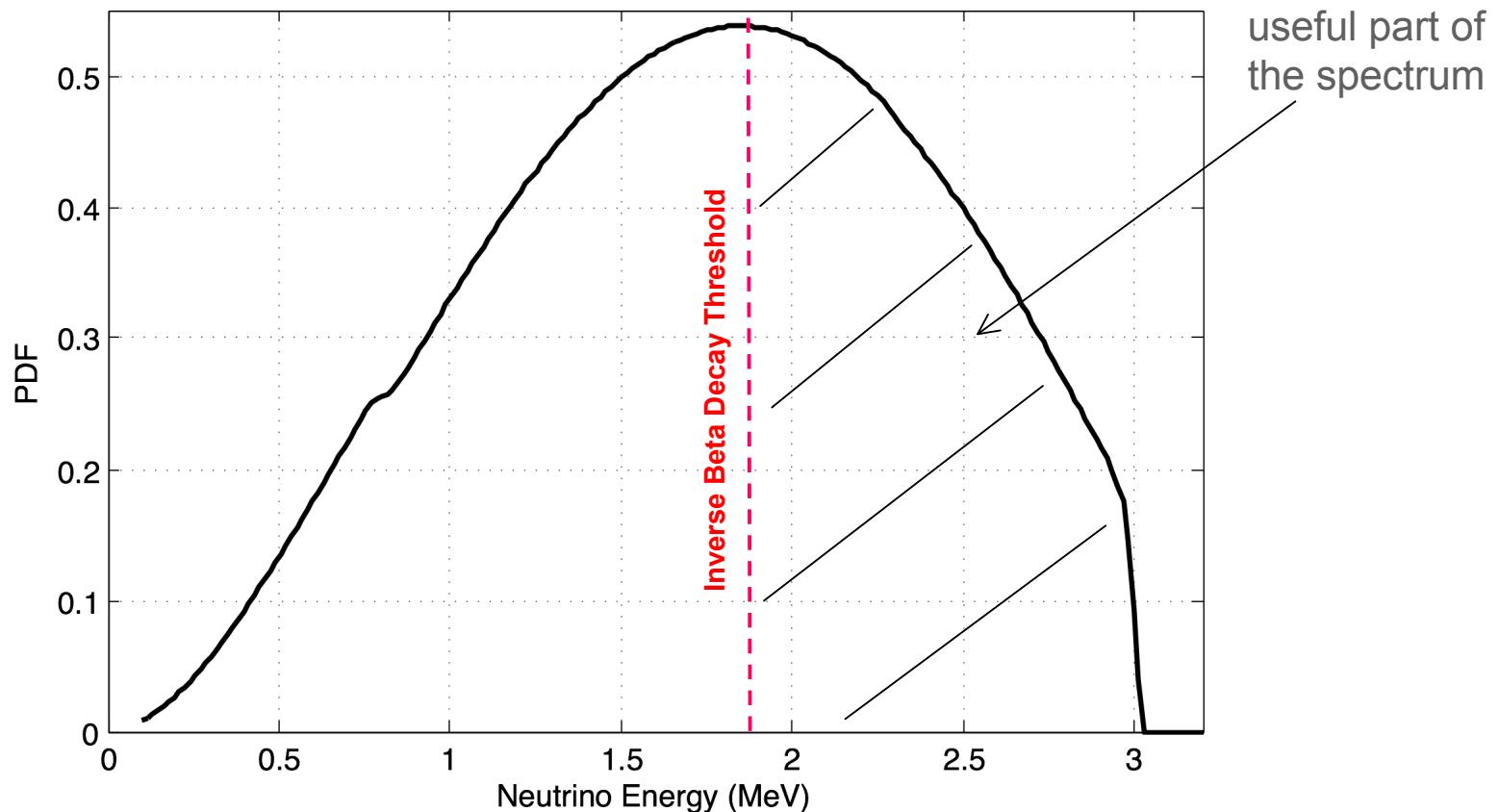
^{144}Ce - ^{144}Pr



- ❖ Ce : Cerium
- ❖ Pr : Praseodymium
- ❖ Mean life : 411.01 d
- ❖ 50 kCi (1.85 PBq)
 - 16 g of ^{144}Ce
- ❖ 50 kCi \Rightarrow 382 W
 - $\langle \text{power} \rangle 1\text{y} = 225 \text{ W}$
 - 7.64 W/kCi
- ❖ A well identified background
 - γ @ 2.185 MeV ; BR: 7 %
 - Need a 10^{-12} reduction

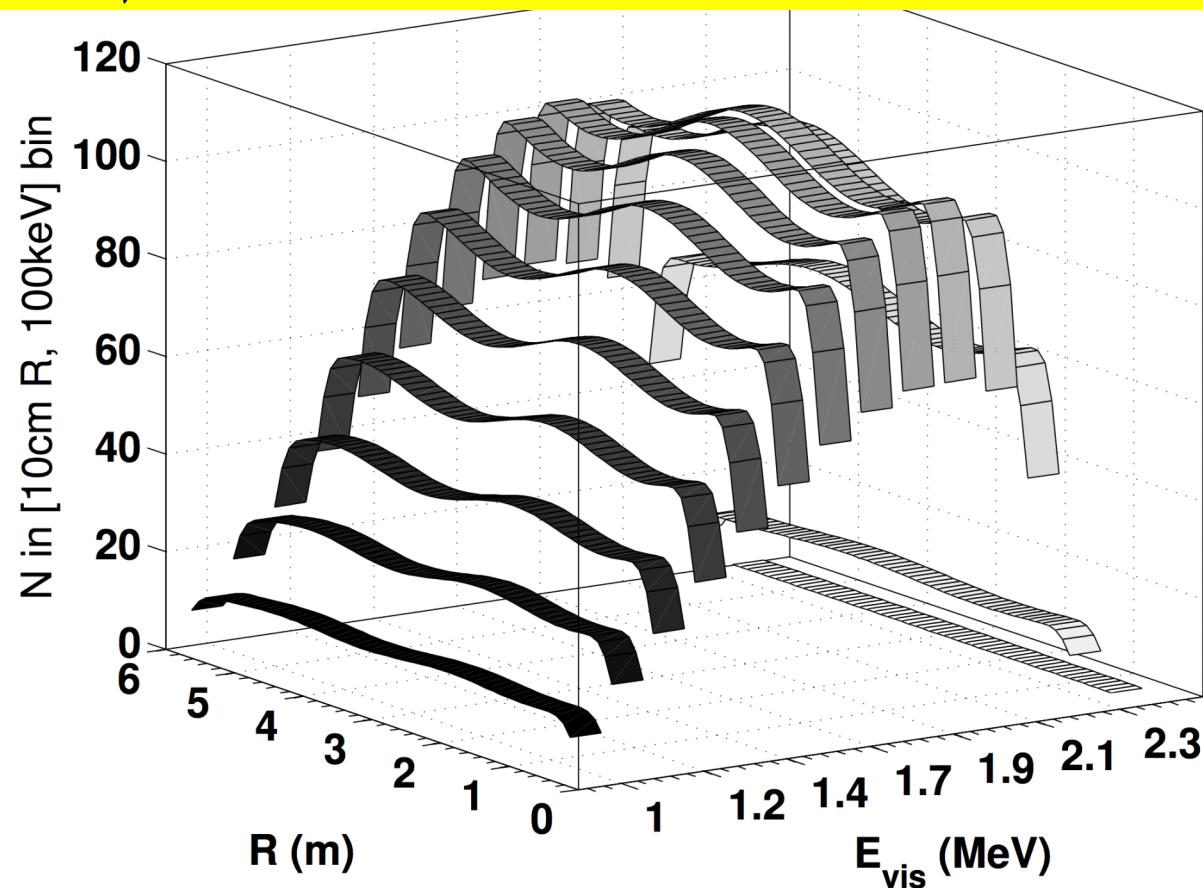
Good utilisation of antineutrinos

- ❖ 48.75 % of antineutrinos emitted above IBD threshold



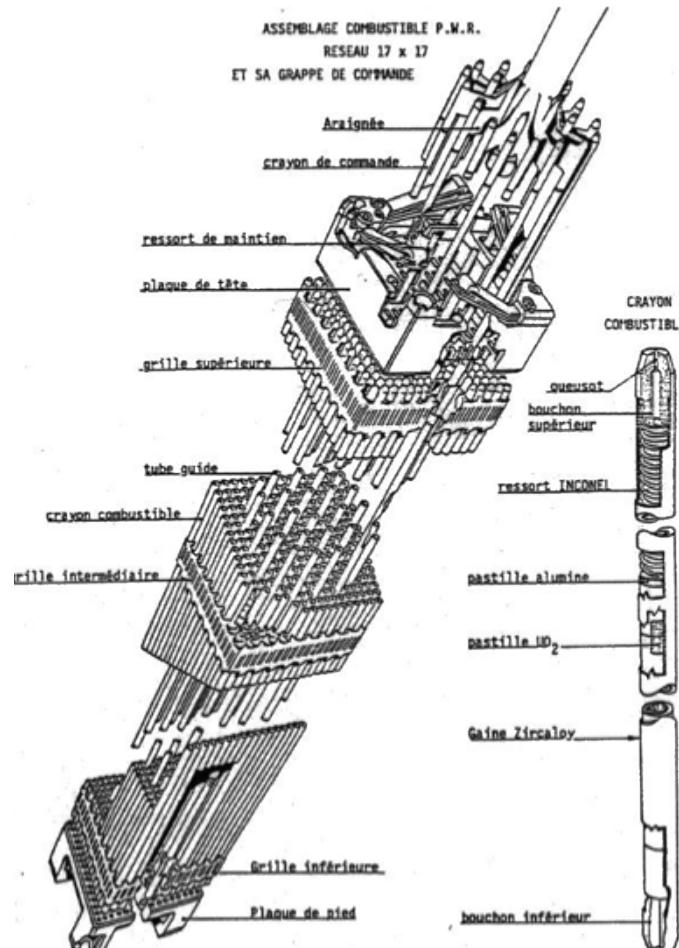
2-D imprint in E_ν, R space

$$\frac{d^3N(R, E_\nu, t)}{dR dE_\nu dt} = A_0 \times n \times \sigma(E_\nu) \times S(E_\nu) \times P(R, E_\nu) \times e^{-t/\tau_{ce}}$$



Making an antineutrino generator

Cerium an abundant fission product



- ❖ 1 ton of spent fuel
 - Fission products : 44 kg
 - Rare earth : 15 kg
 - Cerium : 4 kg
 - ¹⁴⁴Ce : 22 g ie 80 kCi
- ❖ Extraction process
 - Displacement chromatography
 - French experts tested at lab scale
- ❖ Need the required industrial capability
 - La Hague type
- ❖ Constraint on radioactive impurities

Characteristics of the antineutrino generator

- ❖ Cerium is in the chemical form of CeO_2
 - ^{144}Ce remain mixed with stable Cerium isotope
- ❖ A powder of apparent density $\approx 2\text{-}3 \text{ g/cm}^3$
- ❖ Operations
 - Mixing of the $\approx 3 \text{ kg}$ of powder
 - Cold or hot pressing to reach $\approx 3\text{-}4 \text{ g/cm}^3$
 - In hot cell with remote handling
- ❖ The $^{144}\text{Ce}-^{144}\text{Pr}$ antineutrino generator (AvG)
 - a spherical object of 7.1 cm in radius R
 - Cerium powder enclosed in a steel enveloppe
 - Compact : $R \ll L_{\text{osc}}$



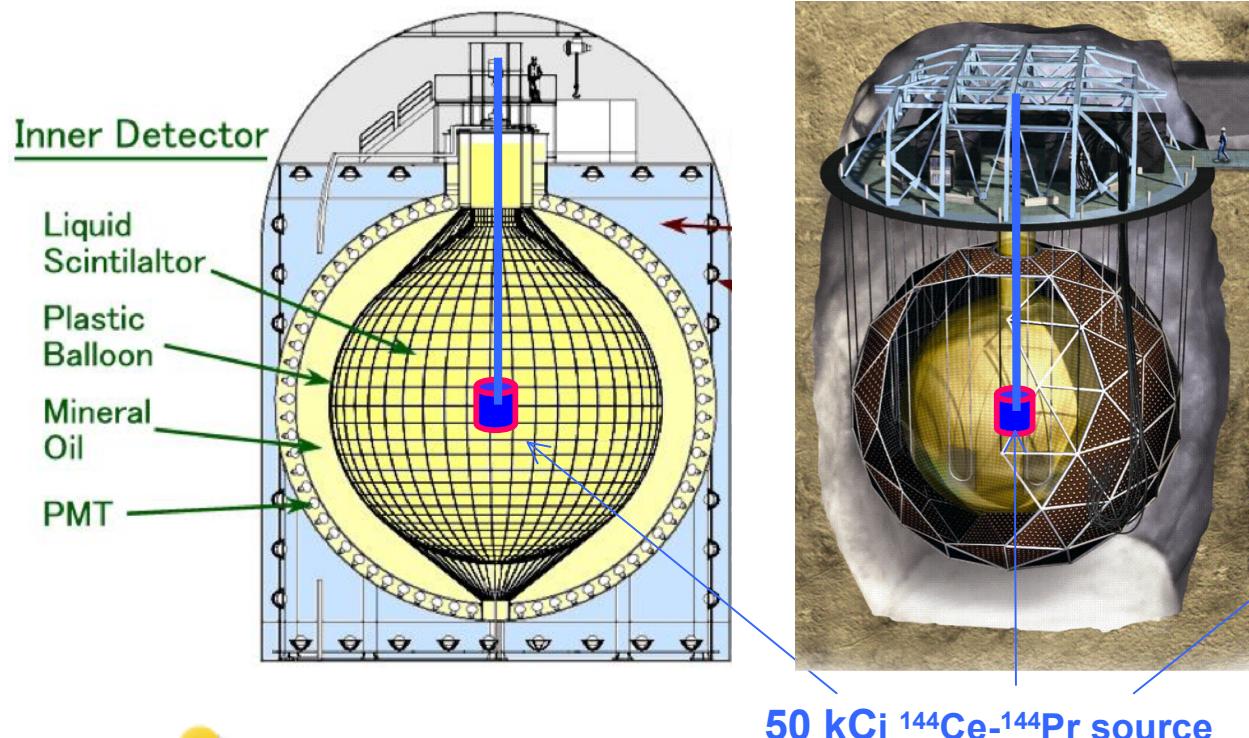
Activity measurements

- ❖ Differential calorimetry in hot cells
 - 1.5 % accuracy
 - Needs 3-4 days for thermalization and counting
 - Technique used in Sage
- ❖ Sampling and counting @ Saclay
 - Sampling, dissolution, large dilution
 - Shipment to external labs
 - Counting in Ge-counter
 - needs << 1% mass measurements
- ❖ Not a limiting factor for the experiment

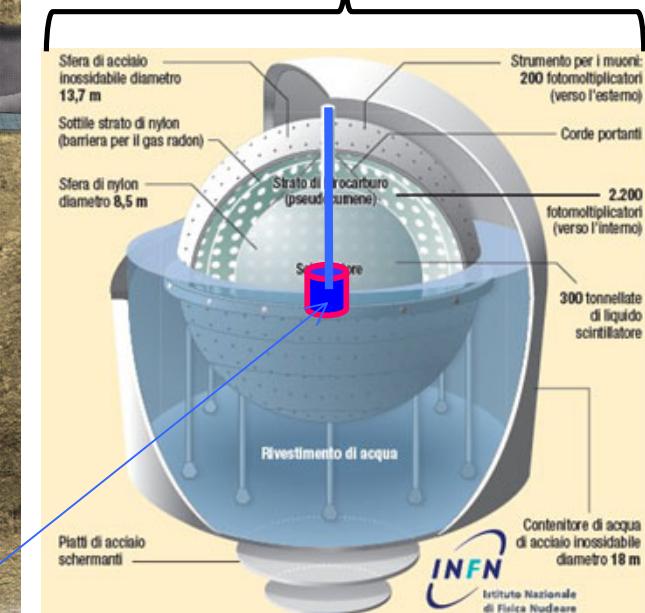
Solving experimental constraints

Large liquid scintillator detectors ?

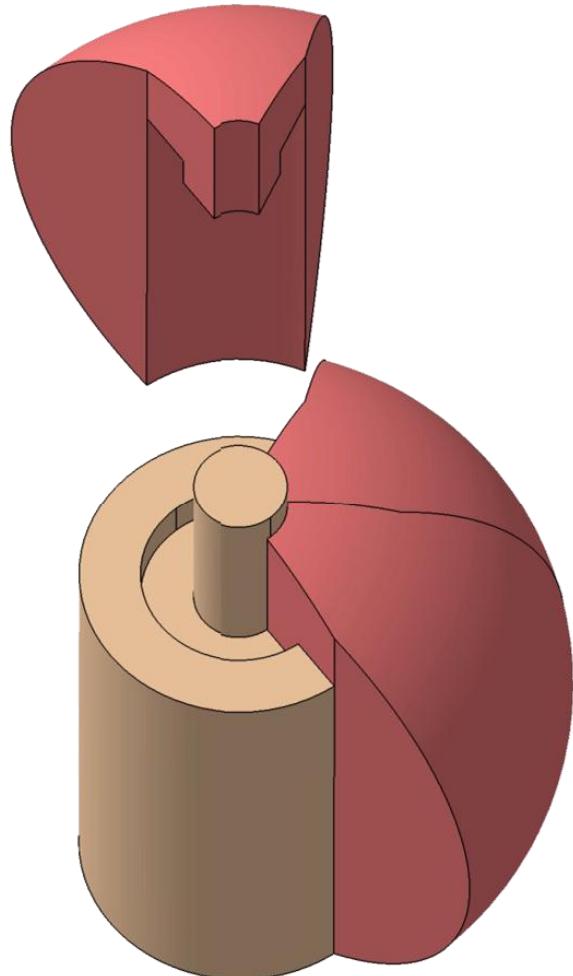
- ❖ 3 possible candidates : Borexino, KamLAND, SNO+
 - Interferences with the present experimental programs
 - Technical issues : size of chimney, liquid purity, electronics...
 - Good energy resolution : 5 %
 - Good position resolution : $\approx 15 \text{ cm} \ll L_{\text{osc}}$



+ internal initiative
by Borexino Collaboration



Shielding

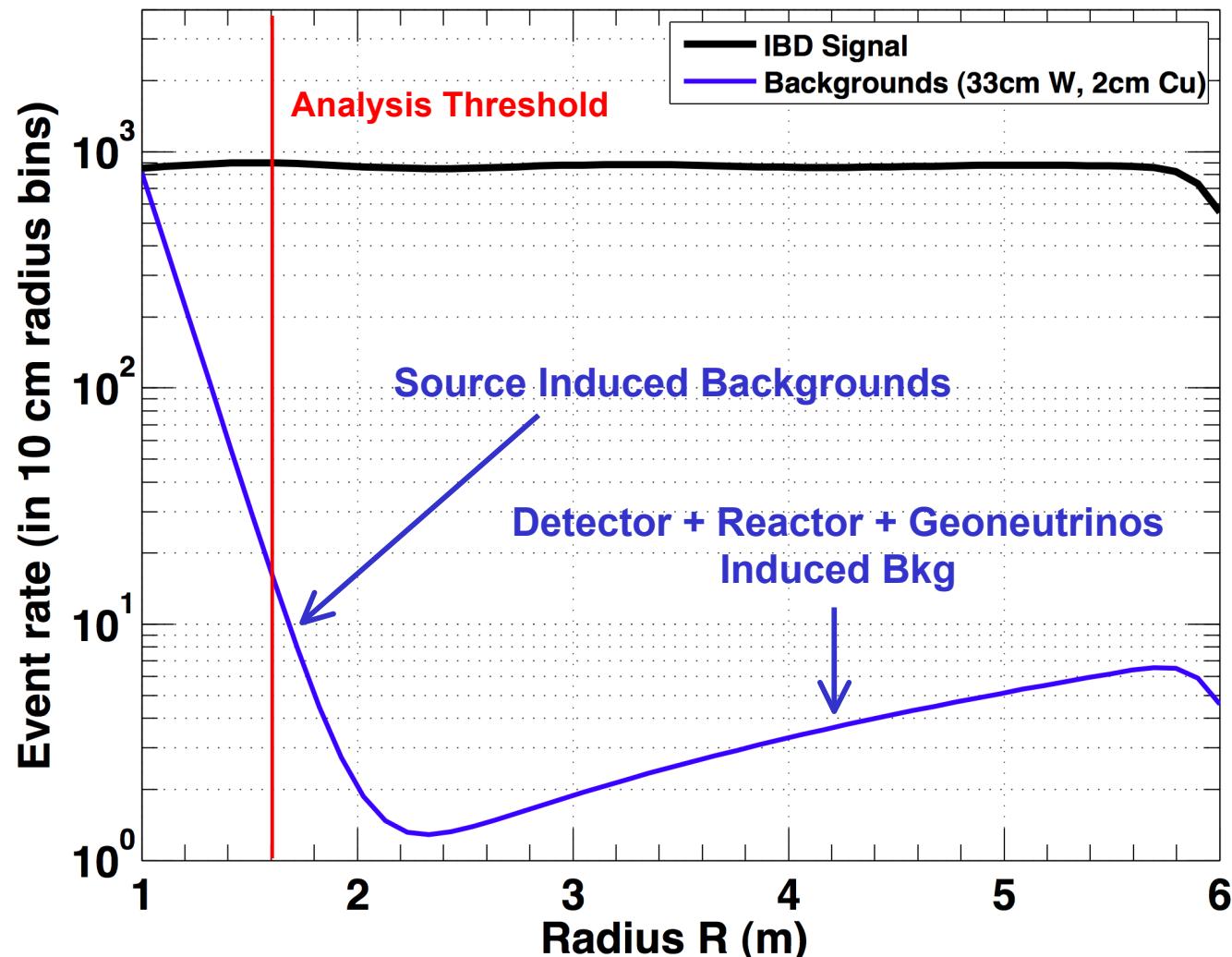


- ❖ Experimental requirements well above legal safety constraints
- ❖ Reduce the 2.2 MeV γ to avoid accidental backgrounds
- ❖ 40 cm of tungsten :
 - ≈ 5 tons
- ❖ 7 pieces to insert and assemble through chimney
 - Like a boat in a bottle...
- ❖ Impurities in tungsten ?
 - Test @ Saclay
 - Previous tests for Gerda
- ❖ Discussion with industry (Plansee)
 - Looks possible

Signal and Backgrounds

- ❖ 50 kCi ^{144}Ce - ^{144}Pr
 - ❖ 40 000 evts in 1 year
 - 1 mHz
 - ❖ Inverse β -decay coinc.
 - $E_{\text{prompt}} > 0.9 \text{ MeV}$
 - $E_{\text{delayed}} > 2.0 \text{ MeV}$
 - $\Delta t < 750 \mu\text{s}$
 - $\Delta V < 10 \text{ m}^3$
 - ❖ Background from ^{144}Pr
 - After 1m in liquid. scint.
 - $R_{\text{prompt}} = 2.5 \text{ Hz}$
 - $R_{\text{delayed}} = 0.6 \text{ Hz}$
 - $R_{\text{accident}} = 1 \text{ mHz}$
- S/B ≈ 1**
- After 1.5 m : S/B = 100
 - ❖ 3 cm of tungsten
bkgd rate divided by 10
 - ❖ W induced bkgd
 - From measures by Gerda
 - Bkgd $\ll \gamma$ from ^{144}Pr
 - to be rechecked with actual W

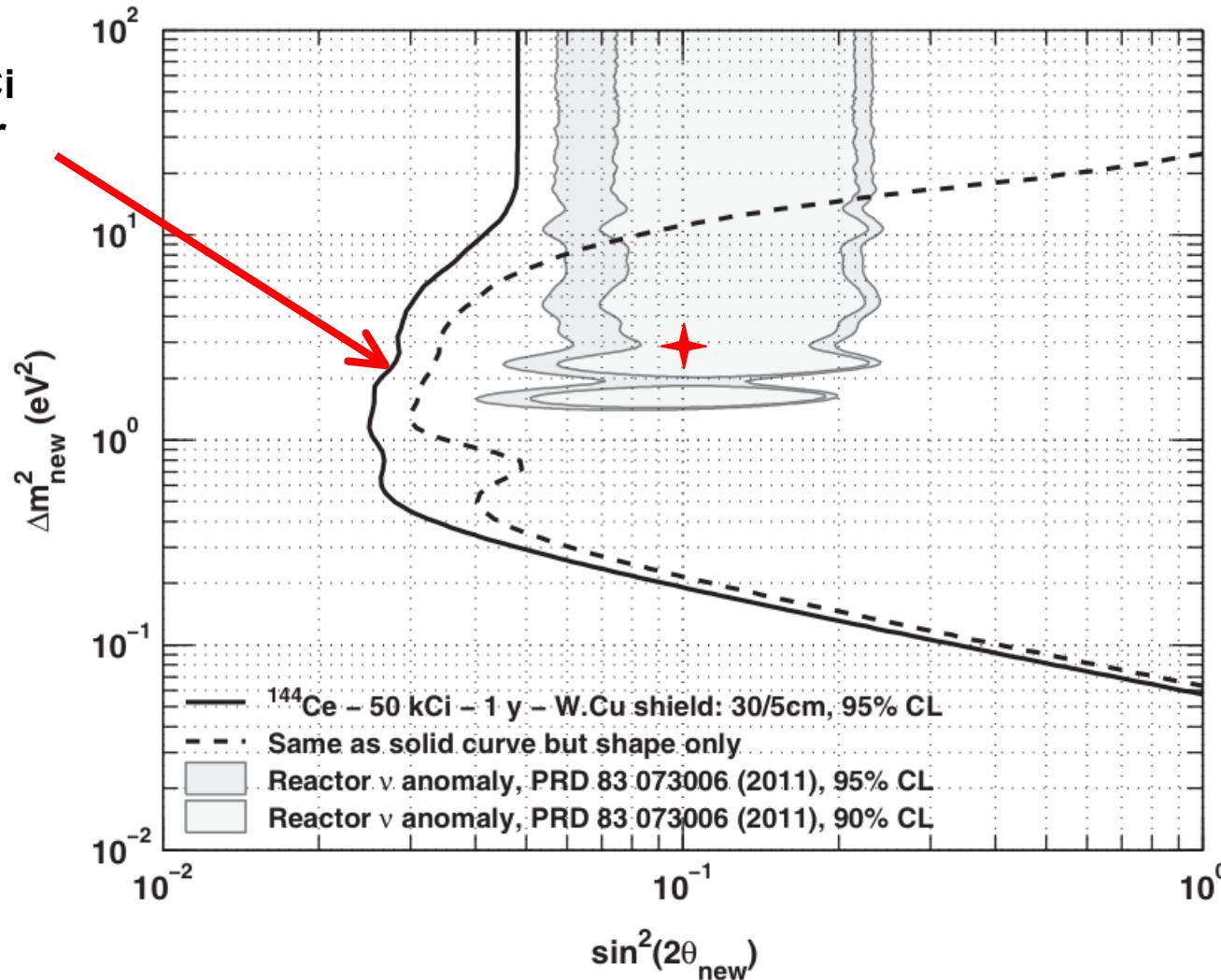
Backgrounds



Fourth neutrino the decisive test

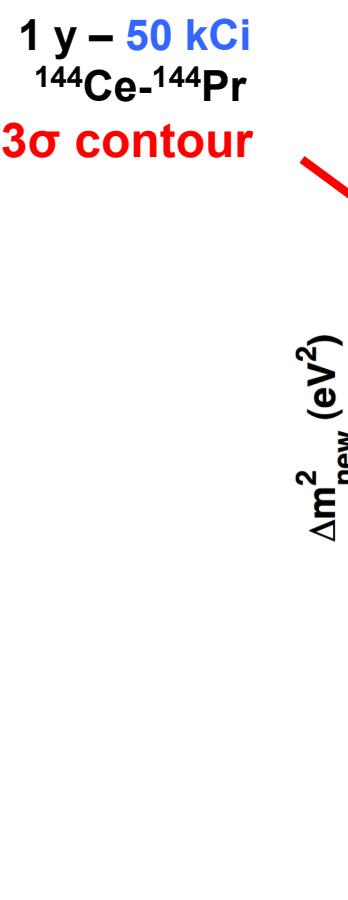
Full range of parameters

1 y – 50 kCi
 ^{144}Ce - ^{144}Pr
95%CL



Discovery potential

$\sin^2 2\theta = 0.1$ & $\Delta m^2 = 2.2 \text{ eV}^2$ tagged at 3σ



Conclusions

- ❖ Do we need a fourth neutrino ?
 - Intriguing anomalies in reactors experiments, Gallium,...
 - A possible revolution in physics
- ❖ An elegant experimental answer : ^{144}Ce - ^{144}Pr
 - Able to cover the full range of expected parameters
 - Rather easy to realise
 - Advance contacts with russian nuclear industry
 - Contacts for tungsten shielding encouraging
 - Discussions with Borexino and KamLAND
 - Could be made in the 3-4 years to come
 - Few technical uncertainties
 - Mainly regulation issues to solve
- ❖ **Five years funding from European Research Council granted to Thierry Lasserre**

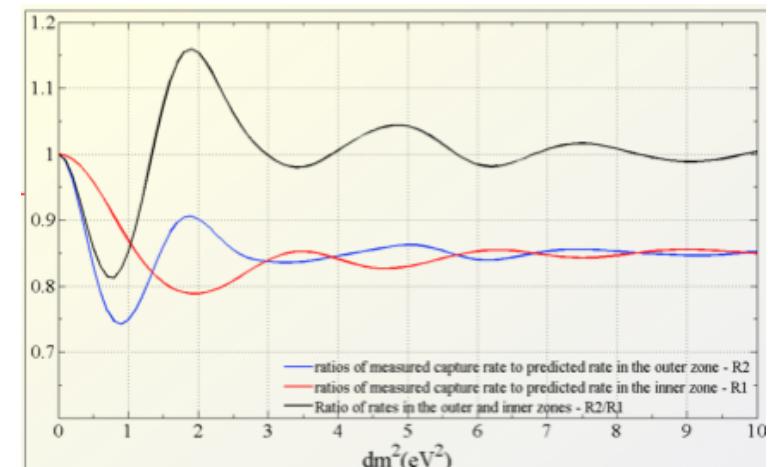
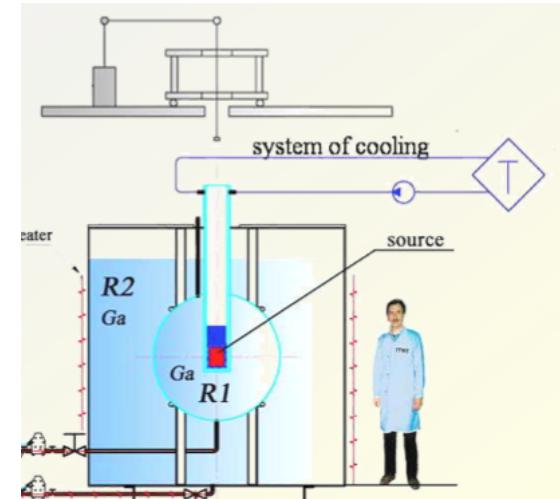


Just do it.

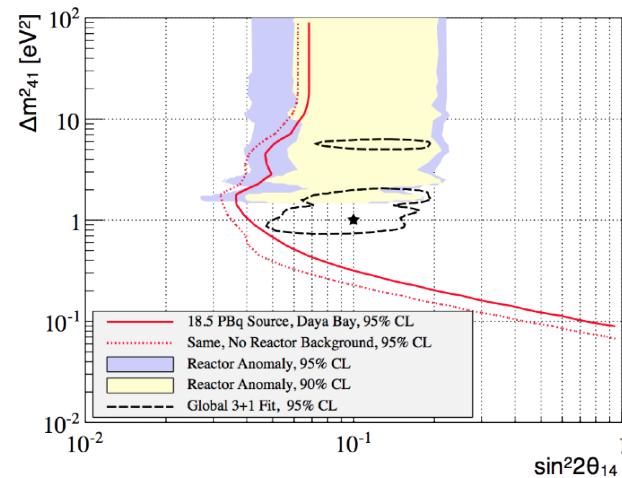
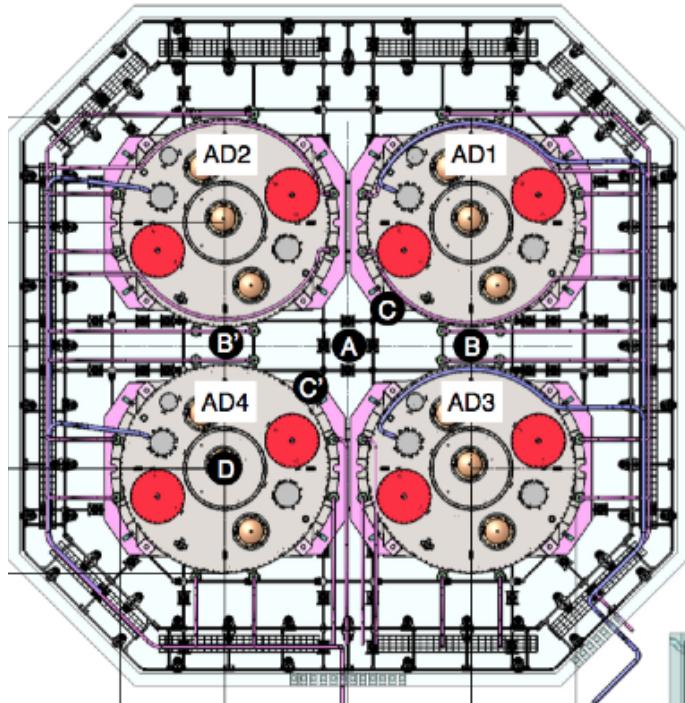
Backup slides

The Baksan proposal

- ❖ **New Gallium experiment**
 - well known technology
 - zone 1 : 8 t
 - zone 2 : 42 t
- ❖ **Source**
 - ^{51}Cr - 3 Mci
 - 50 days irradiation in research reactor SM3
- ❖ **Well known background**
 - Solar neutrinos
- ❖ **Partial sensitivity to the reactor anomaly**
- ❖ **arXiv:1006.2103**



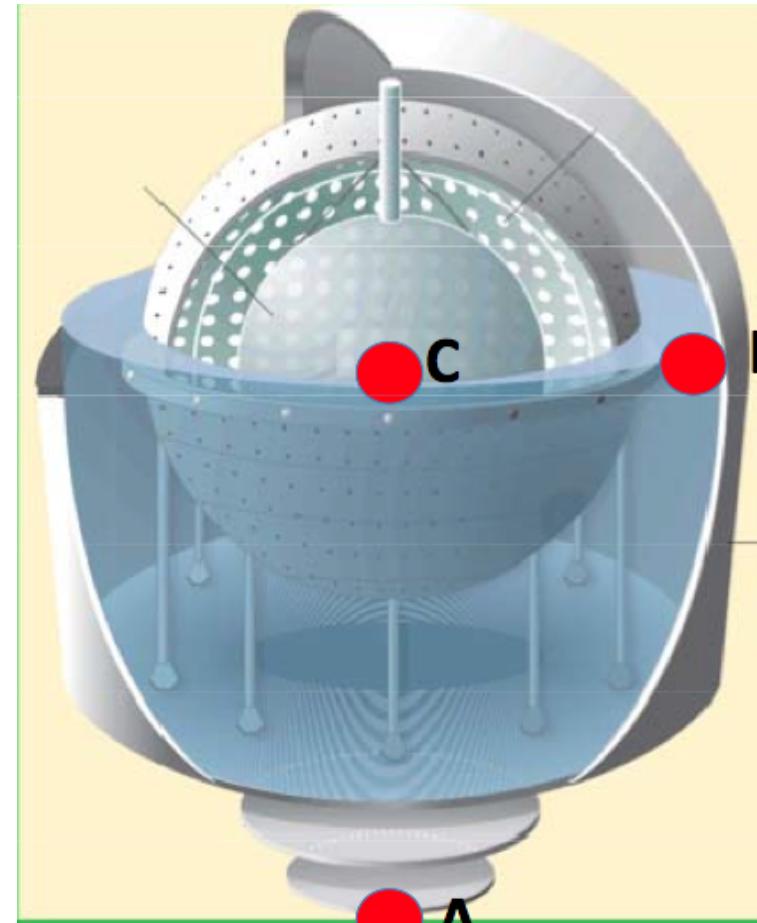
The Daya Bay proposal



- ❖ D. Dwyer et al. arXiv:1109.6036
- ❖ Based on our PRL paper
- ❖ 500 kCi ^{144}Ce - ^{144}Pr source in the Daya Bay FD pool
- ❖ Realisation ?
 - no fuel reprocessing in the US

The Borexino proposal

- ❖ **Significant Effort**
- ❖ **Sources**
 - ^{51}Cr : > 5 MCi
 - ^{90}Sr – spent fuel
 - ^{144}Ce – spent fuel
- ❖ **Gallex enriched Cr still available in Saclay**
- ❖ **3 locations studied**
 - A – Pit
 - B – Water Buffer
 - C – Center



Proposal sensitivities

