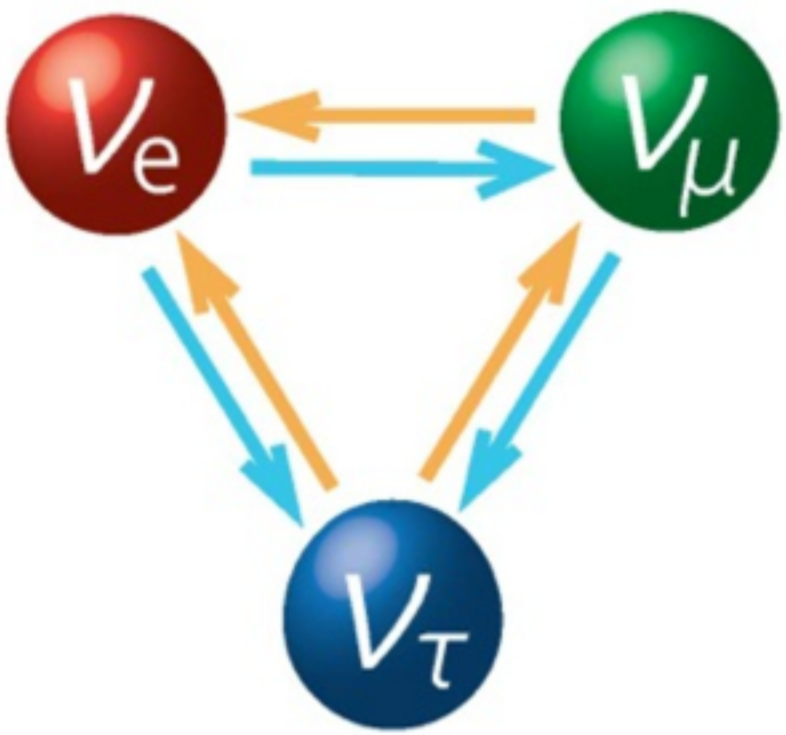
Sterile neutrino search in the STEREO Experiment

MAX-PLANCK-INSTITUT
FÜR KERNPHYSIK
HEIDELBERG

STEREO

Summer School on the Standard Model and beyond - Corfu
Friday 2nd of September 2016

Christian Roca - Max Planck Institut für Kernphysik



From active flavour ES to mass ES

A change of basis in the Hilbert space by using the 3x3 unitary matrix U called PMNS matrix:

$$|\nu_\alpha(t)\rangle = \sum_i U_{\alpha i} |\nu_i(t)\rangle$$

$$|\nu_i(t)\rangle = \sum_\alpha U^\dagger_{i\alpha} |\nu_\alpha(t)\rangle$$

Act. flavor ES as mass ES superposition

each mass ES propagate

with different phase $\frac{m_i^2}{2E}L$

Low mass approximation

Act. flavor ES oscillates as neutrino propagates

PMNS Matrix

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Definite act. flavor basis → $\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U_{PMNS} \cdot \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$ ← Definite mass basis

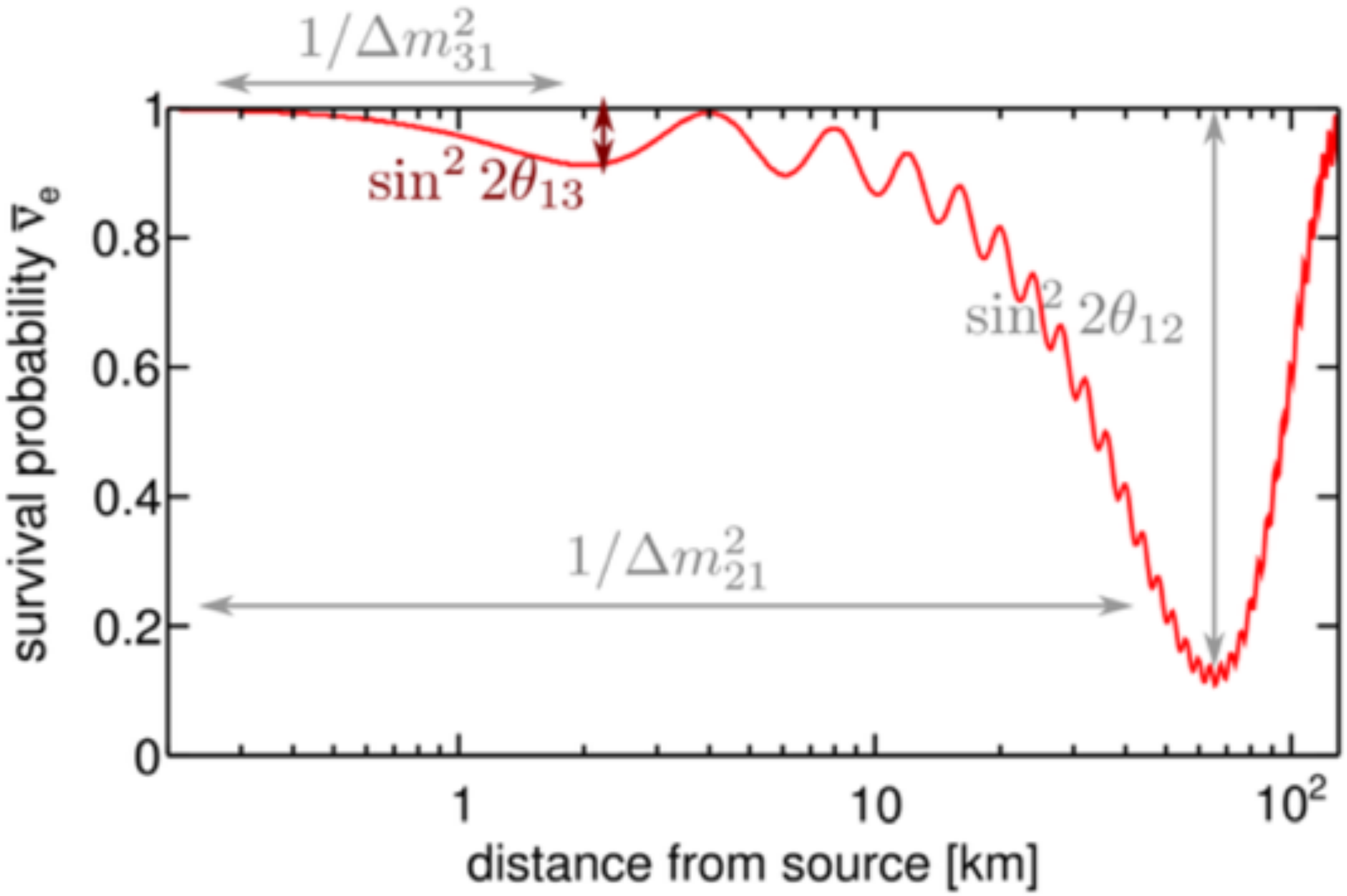
4 free parameters: 3 mixing angles + complex phase

$$U_{\text{PMNS}} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{bmatrix} \cdot \begin{bmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{bmatrix} \cdot \begin{bmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Atmospheric	Reactor	Solar
$\theta_{23} \sim 33^o$	$\theta_{13} \sim 9^o$	$\theta_{12} \sim 45^o$

Oscillation of $\bar{\nu}_e$

- Nuclear reactors are **sources** of $\bar{\nu}_e$.
- $\bar{\nu}_e$ **oscillate**.
- **Survival probability** after traveling a distance L?



$$P(\overline{\nu}_e \to \overline{\nu}_e, L) = 1 - 4\cos^2(\theta_{12})\cos^2(\theta_{13})\sin^2(\theta_{12})\sin^2(\theta_{13})\sin^2\left(\frac{\Delta m^2_{21} L}{4E}\right)$$
$$-4\cos^2(\theta_{12})\cos^2(\theta_{13})\sin^2(\theta_{13})\sin^2\left(\frac{\Delta m^2_{31} L}{4E}\right)$$
$$-4\sin^2(\theta_{12})\cos^2(\theta_{13})\sin^2(\theta_{13})\sin^2\left(\frac{\Delta m^2_{32} L}{4E}\right)$$

Mixing angle: amplitude of oscillation
Mass difference: frequency of oscillation

Weak interacting families

BUT! Why ONLY **three** active flavors?

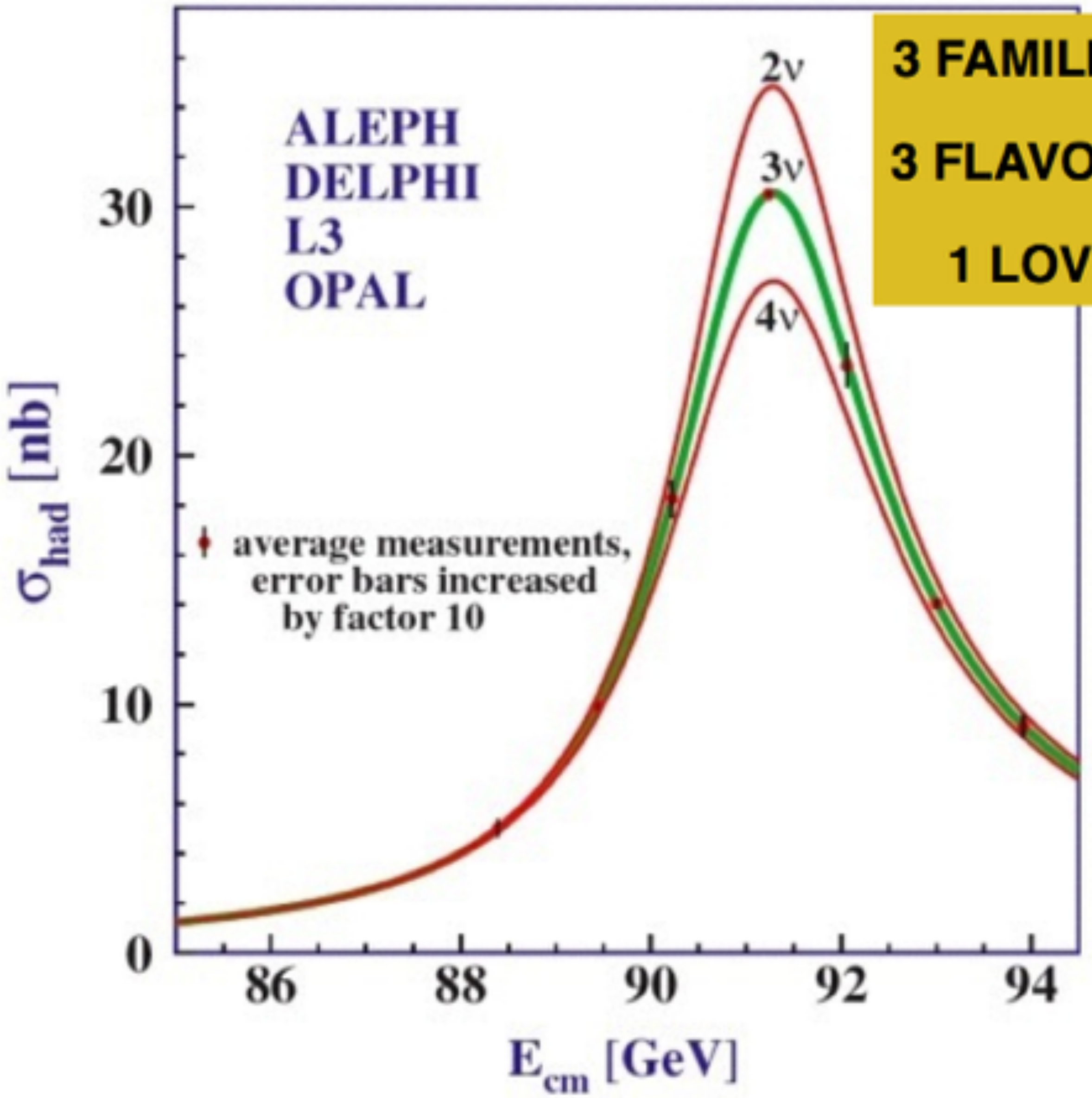
Experiments at **LEP** found that:

$$N_\nu = 2.9840 \pm 0.0023$$

Best fit for the **Z boson decay width**
NOTE: Those are the number of families interacting weakly!

BUT! BUT! Is this in complete **agreement** with other observations?

Z boson decay width to hadrons @ LEP



3 FAMILIES?

3 FLAVORS?

1 LOVE!

Observing $\bar{\nu}_e$ disappearance

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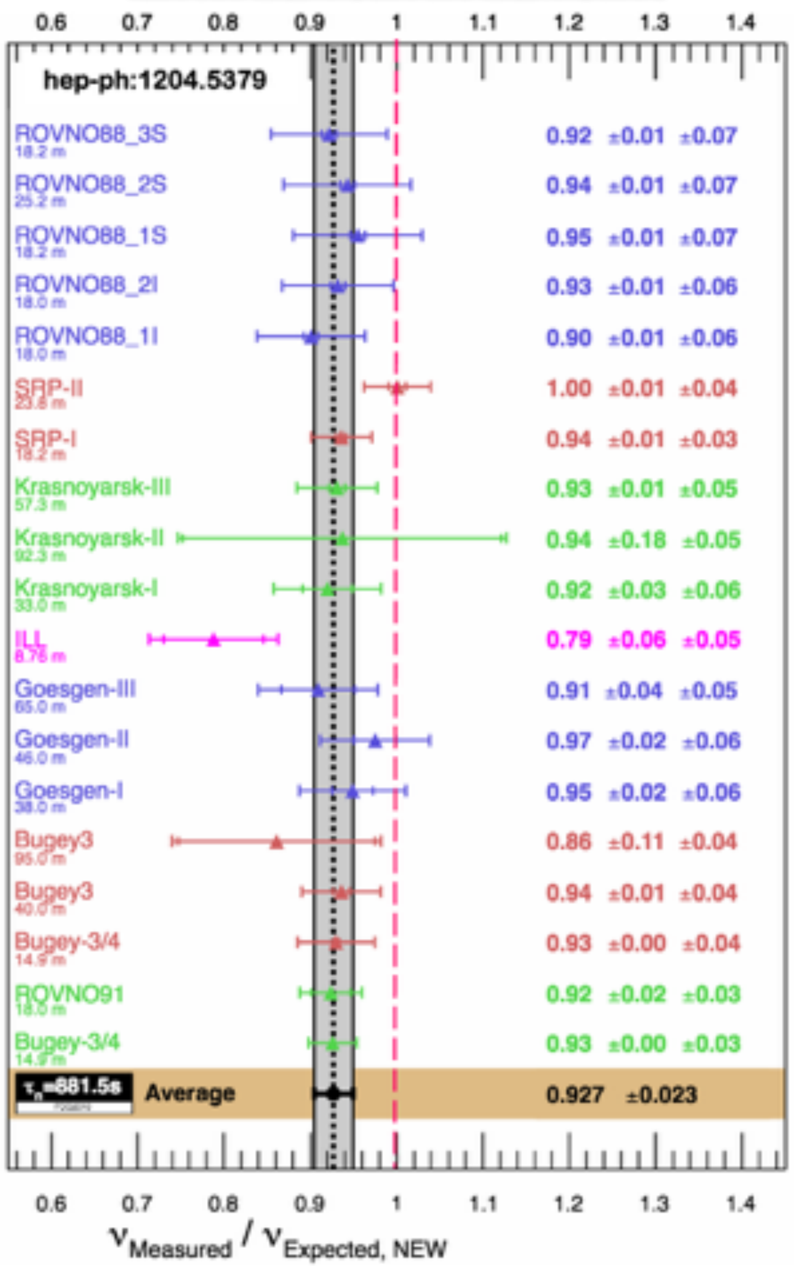
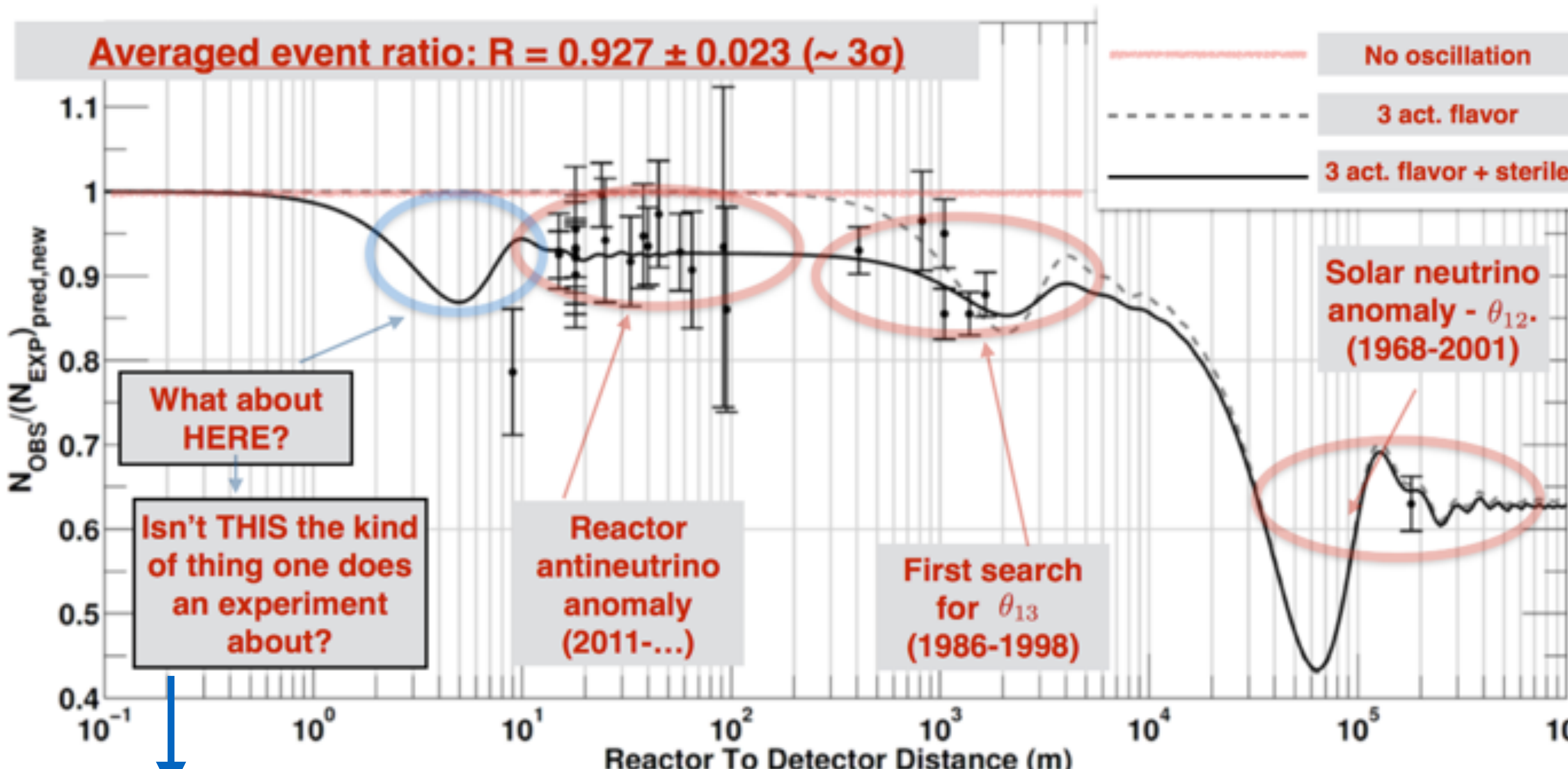
Summary of short baseline experiments

- Less neutrinos than expected are observed in RAA region… **hidden oscillation?**
- To fit observations at LEP: 4th type of neutrino must be **STERILE**

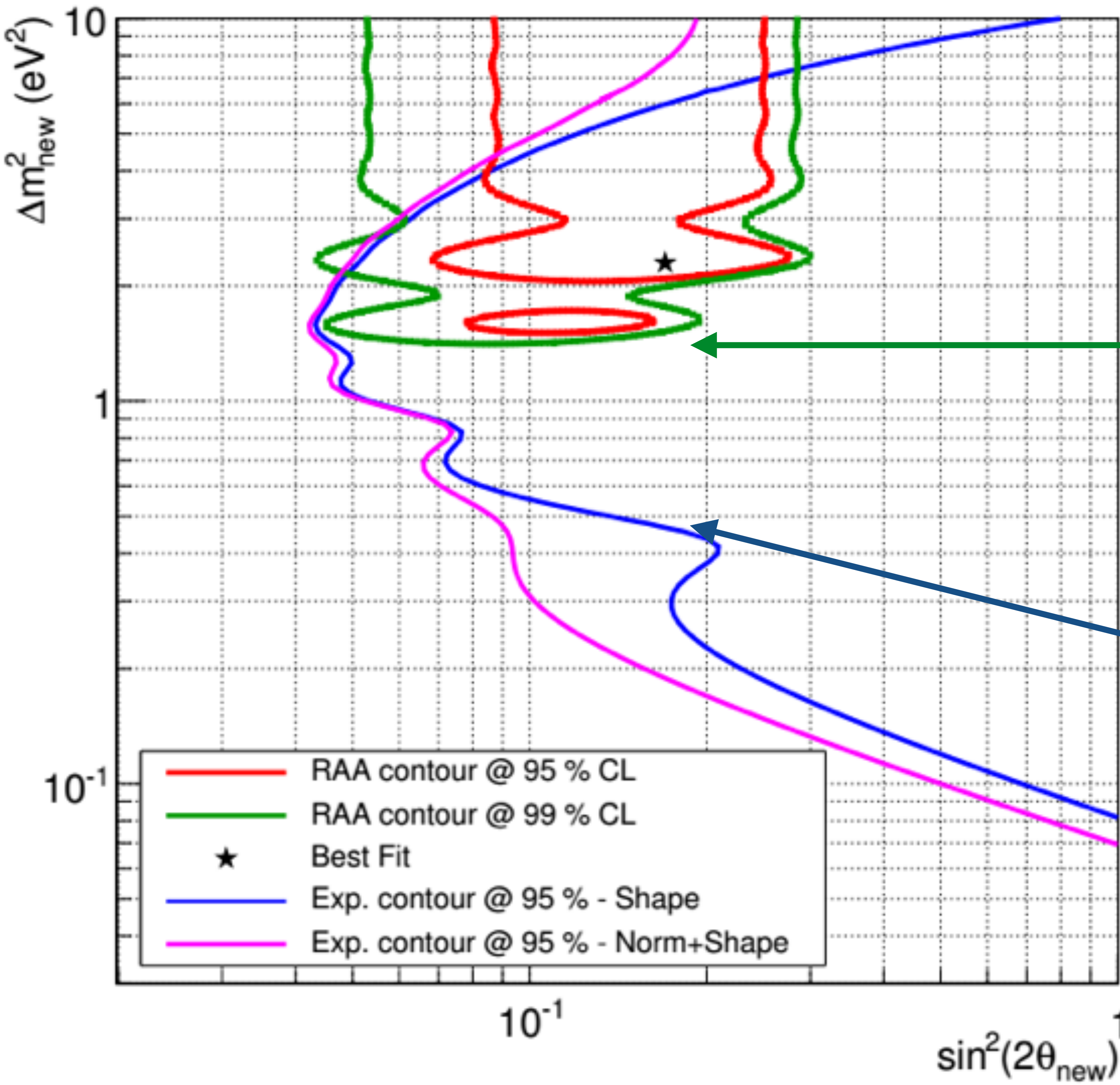




- No information available for < 10m baseline.
- Clear signature of oscillation available.
- Stereo wants to know!

Discovery potential of Stereo

- **Exclusion plot:** $\Delta m^2_{new} \approx 2\text{eV}^2$, $\sin^2(2\theta_{new}) \approx 0.15$
- **Non-exploited baseline: ~ 10 m**



Reactor Antineutrino Anomaly (RAA) + MiniBooNE, Gallex, SAGE… contour's plot

Expected parameter's space available in Stereo

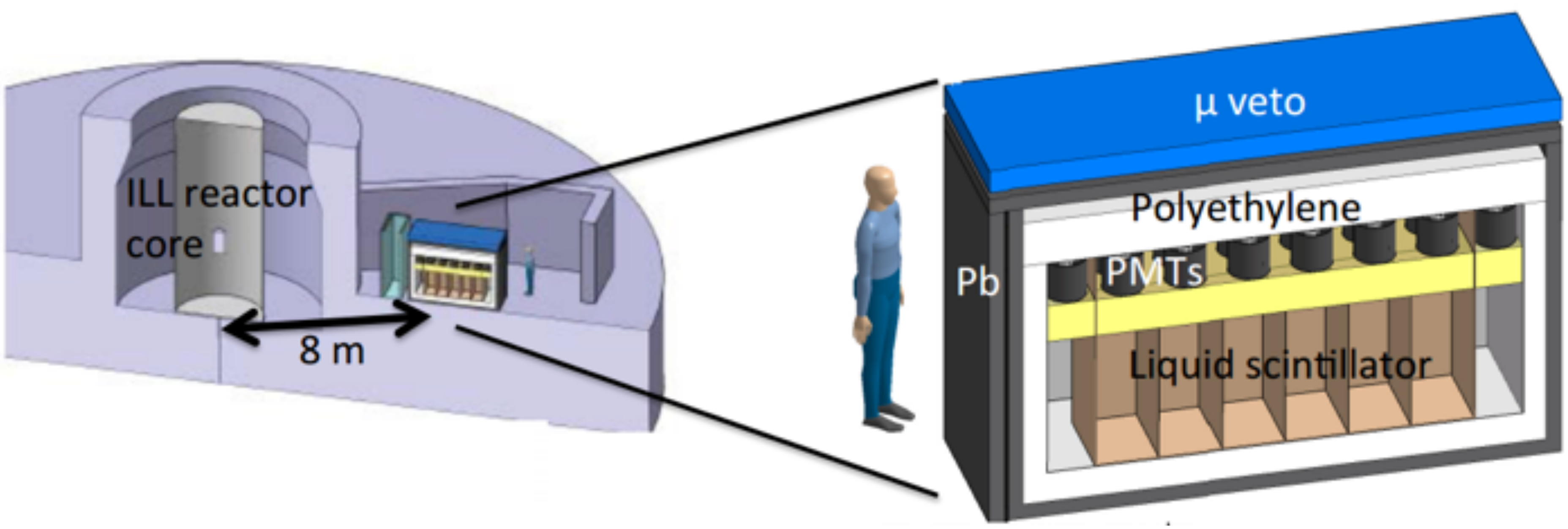
Stereo Experiment

WHAT? Variable short baseline neutrino segmented 6-cell detector

WHERE? 8-11m from ILL Nuclear Reactor Core - Grenoble (France)

HOW? IBD in liquid scintillator: PMT measure e+ and n signals

WHO? cea, LAPP, LPSC Grenoble, ILL Neutrons for Science, Max-Planck-Institut für Kernphysik Heidelberg

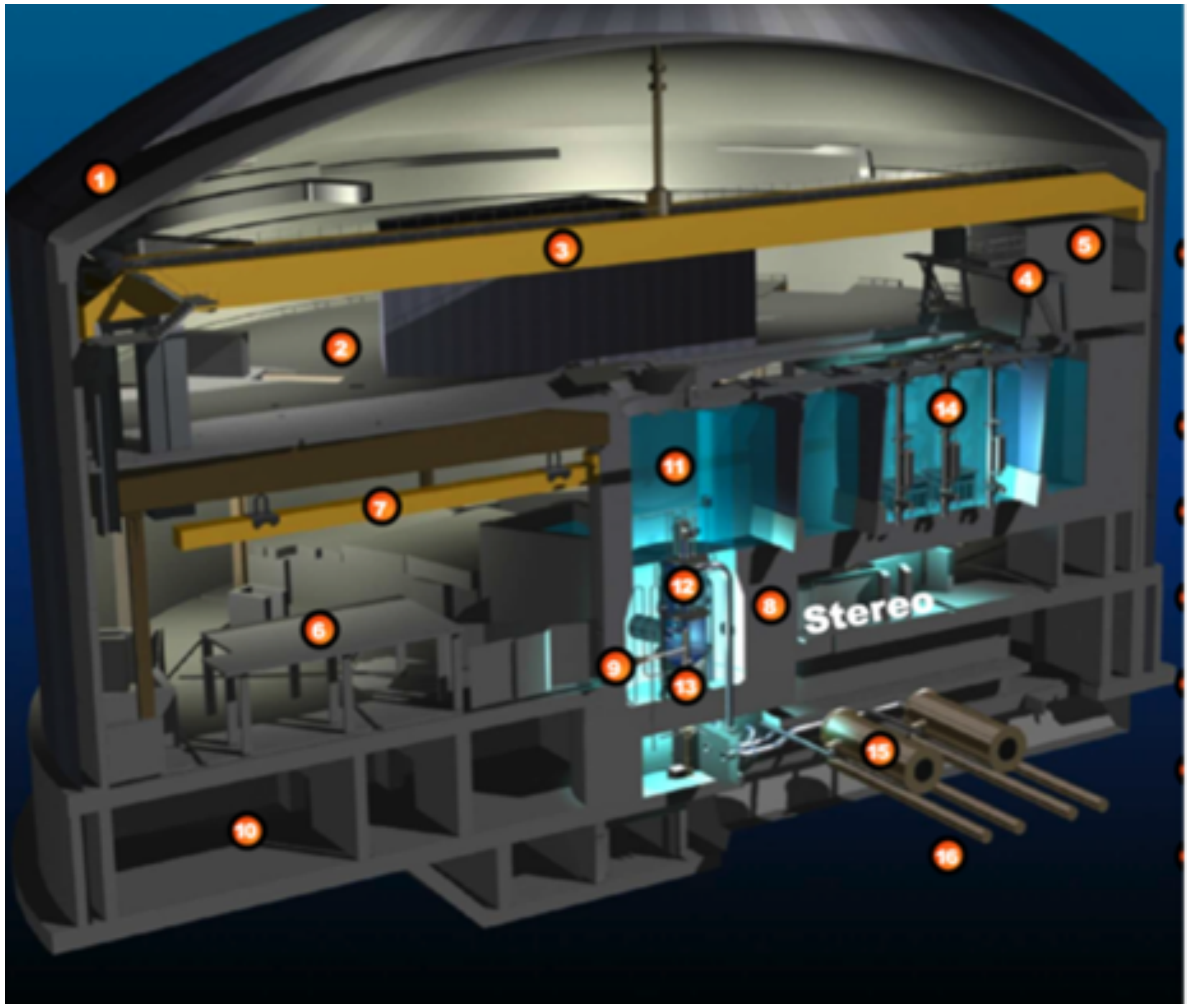


ILL Reactor Plant

Institut Laue-Langevin, Grenoble FRANCE

Reactor core needs to be very compact

- Source as point-like as possible
- Detector located very close to the source
- ILL with core's diameter of 9cm



- 58 MW of power.
- Highly enriched U-235.
- Measuring ~ 50% Reactor ON time.
- 8m minimum distance from detector.
- Challenging reactor-related BG.

Physical process

[1] U-235 controlled fission stimulated with neutrons

[2] Fission products disintegrate via beta decay emitting **antineutrinos**

Production Spectra + IBD cross section combine

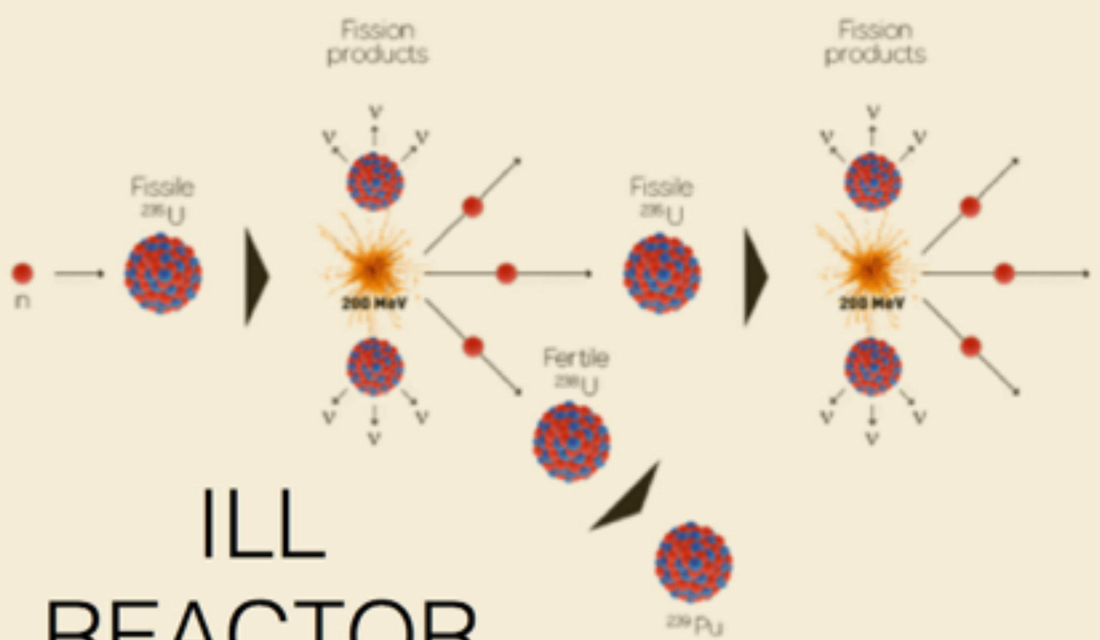
[3] Inverse beta decay within the **scintillator**

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

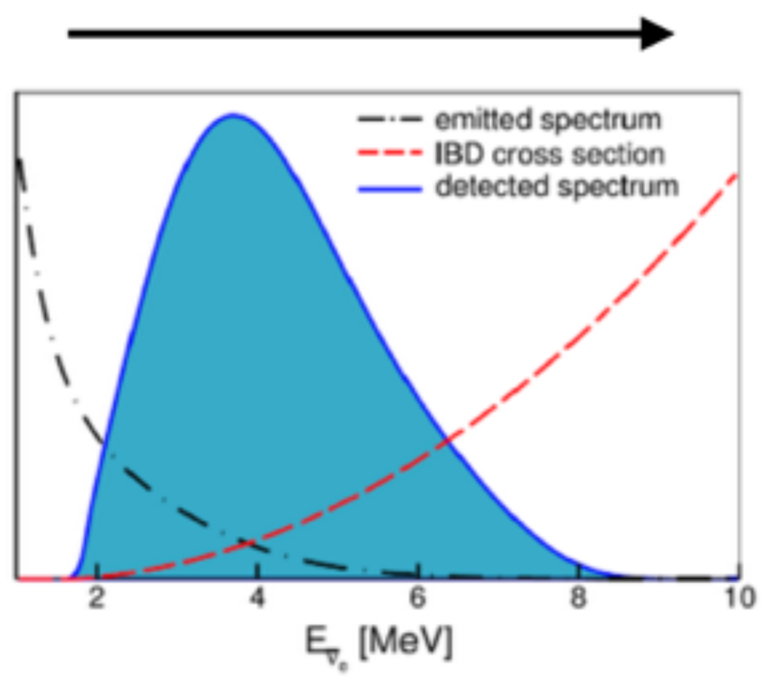
PRODUCTION

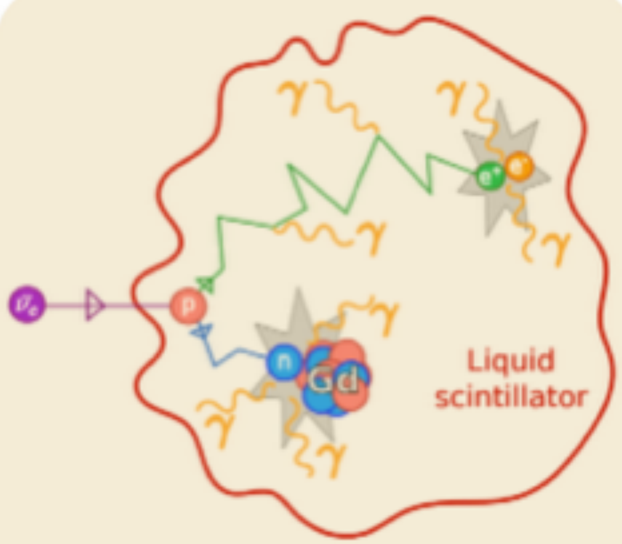
SPECTRA

DETECTION



ILL REACTOR



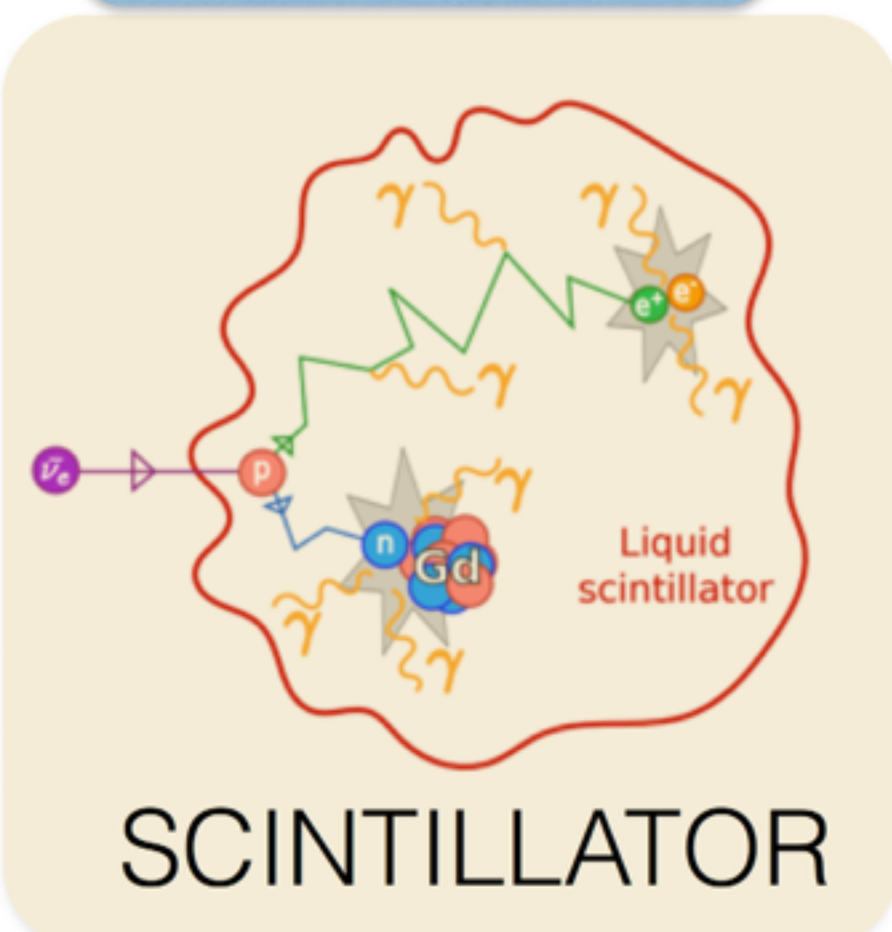


SCINTILLATOR

Physical process

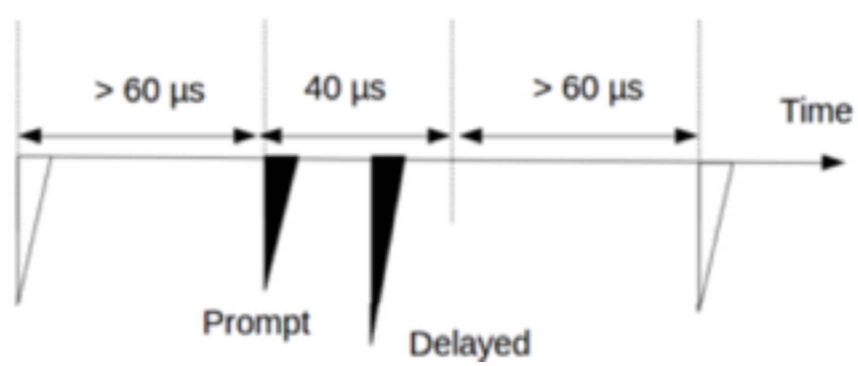
[3] Inverse beta decay within the scintillator

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

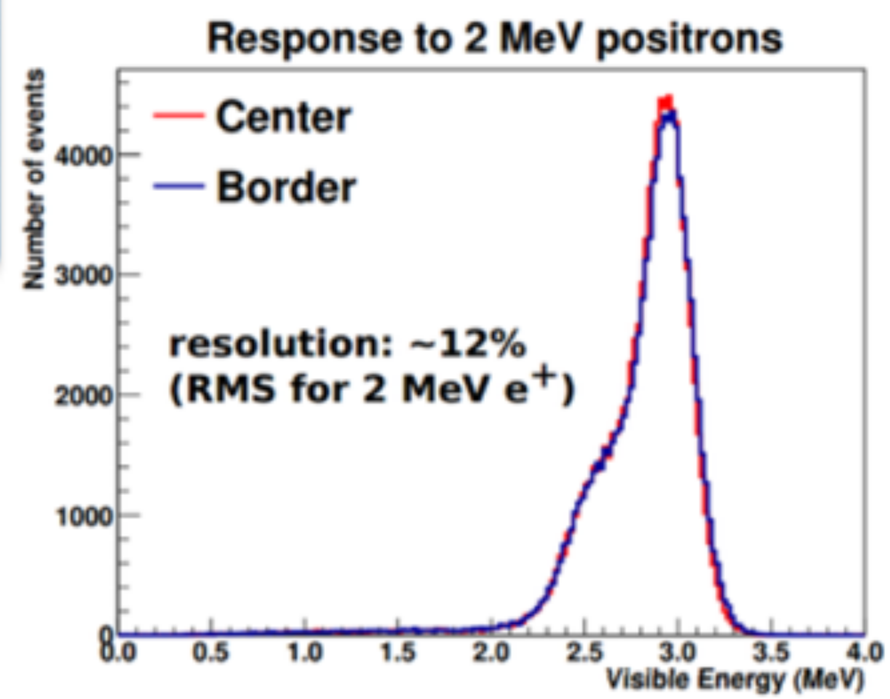


[4] Positron losses energy until **annihilation**: **Prompt signal**

[5] Neutron Catcher (Gd): emits **gammas** summing up 8MeV **Delayed signal**



What do we see? Energy of the **prompt signal**, necessarily in coincidence with **delayed signal**:

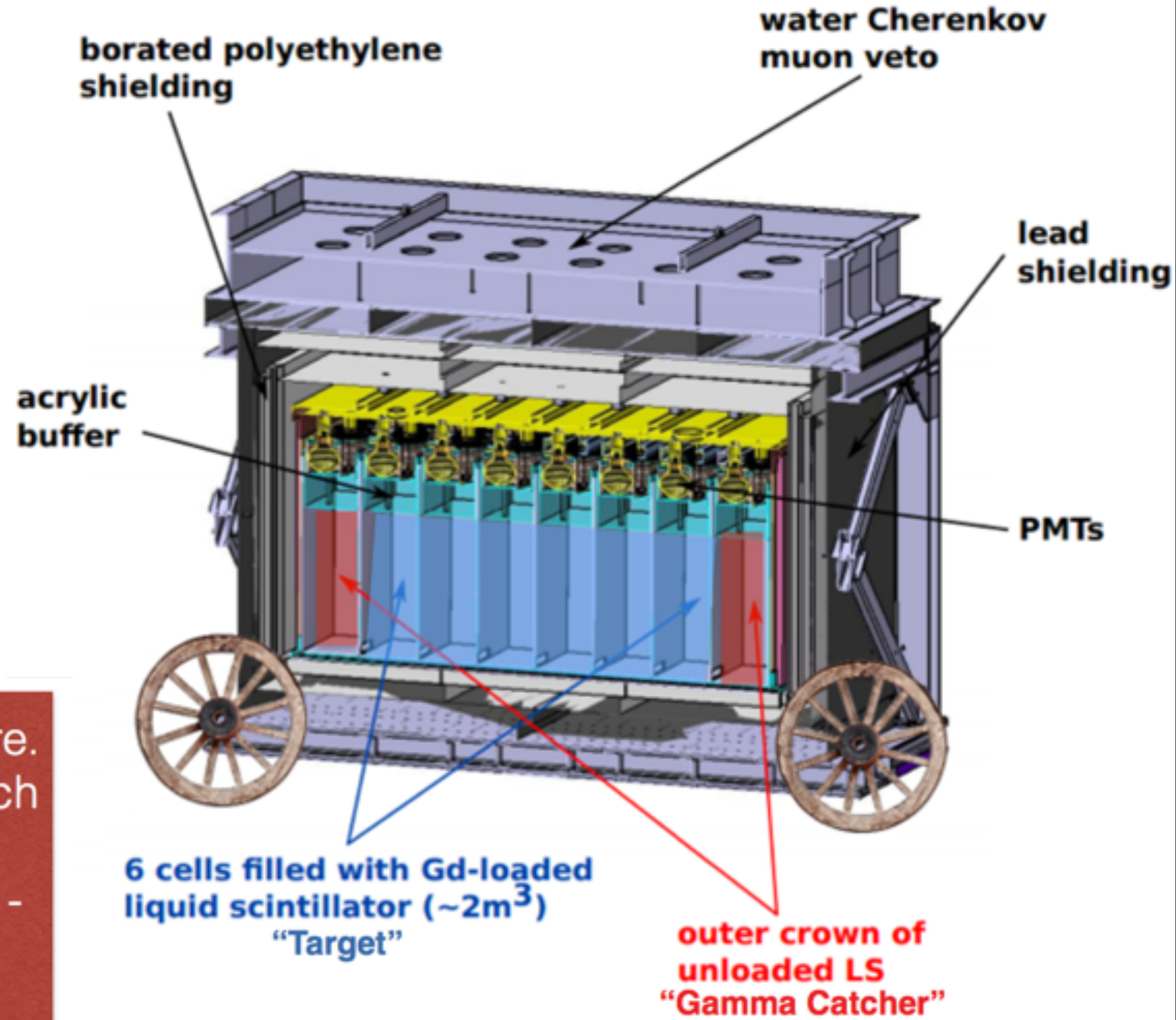


Stereo Detector

Target PMTs

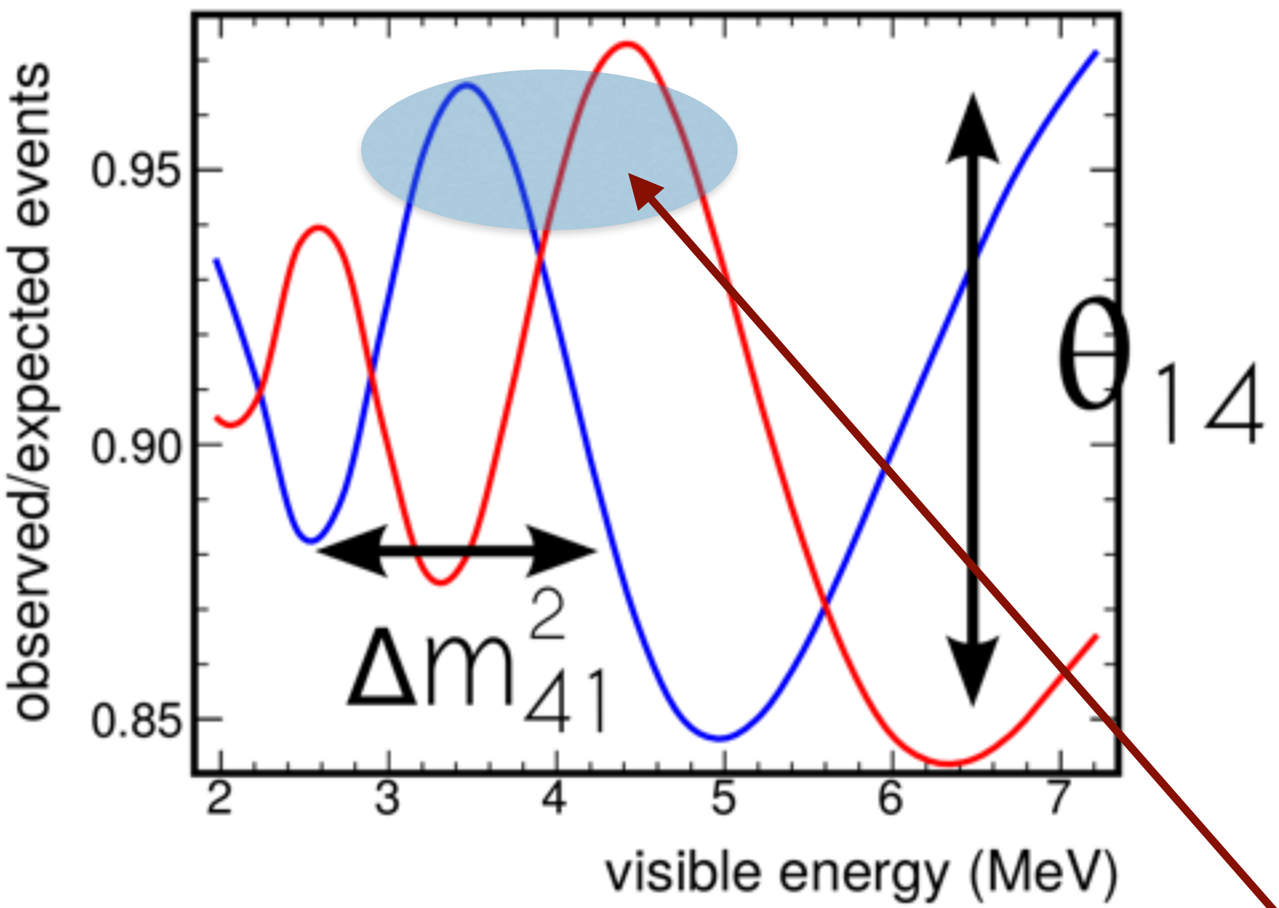
Scintillator

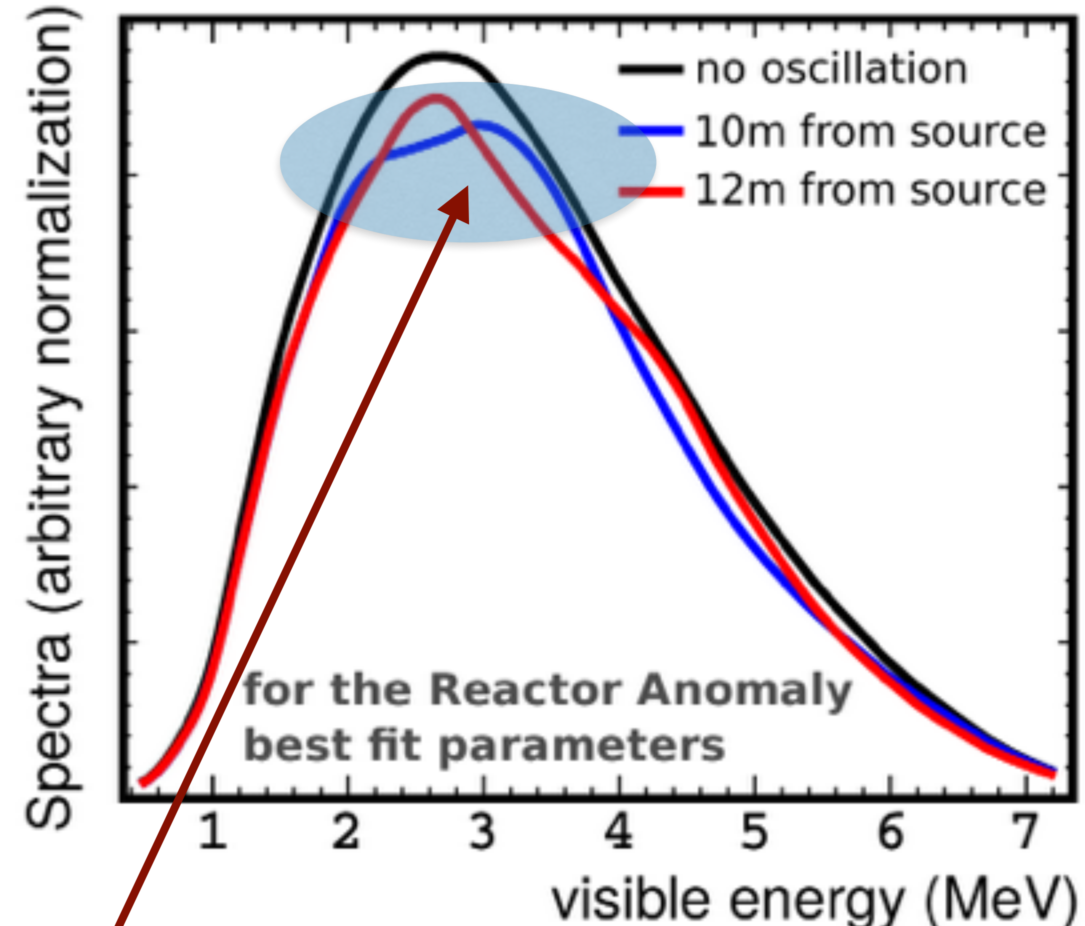
- **LAB** 75% + **PXE** 20% + DIN 5%
- **Wave Length Shifters**: PPO and Bis-MSB
- **Transparency** (at ~420 nm): attenuation length ~ 6m



- **Target** Volume loaded with Gd for n-capture.
- **Gamma catcher** surrounding target to catch escaping .
- **Acrylic buffer** screens radiation from PMT - increases resolution.
- 48 x 8" **PMTs** collect photons ~ 420nm.

Sterile ν signature





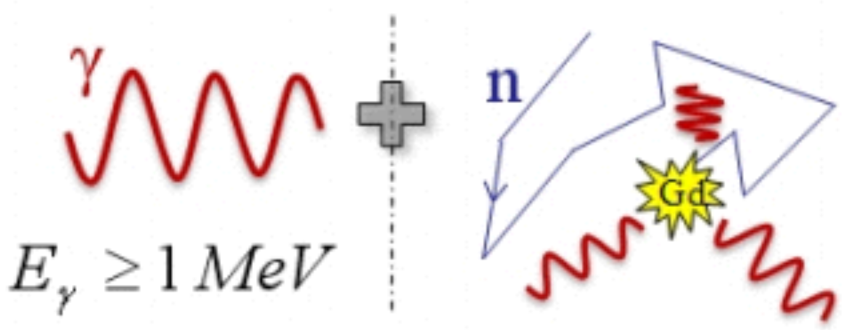
Furthest Cell (red)

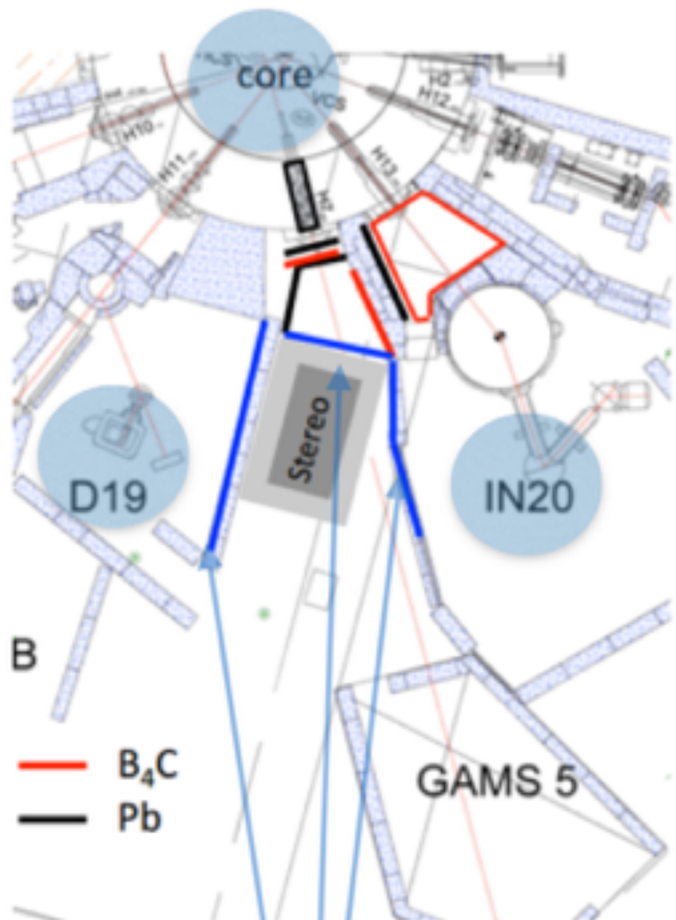
Closest Cell (blue)

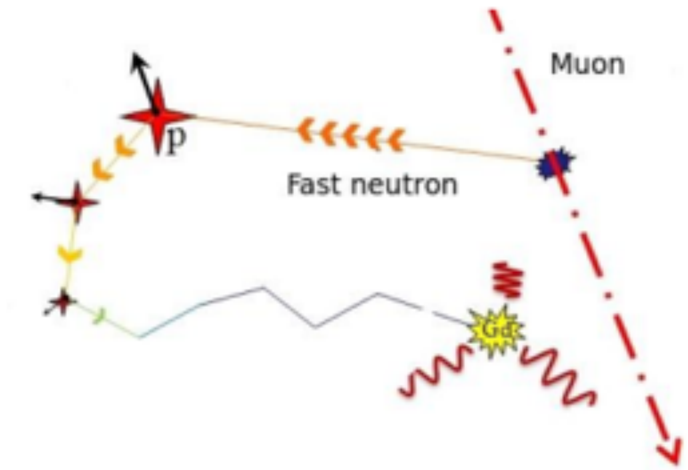
Survival probability depends on L/E - Difference in flux between cells must be visible

$$P(\bar{\nu}_e \rightarrow \bar{\nu}_s) \sim \sin^2 2\theta_{14} \cdot \sin^2(1.27\Delta m^2_{41}\frac{L}{E})$$

Dealing with background



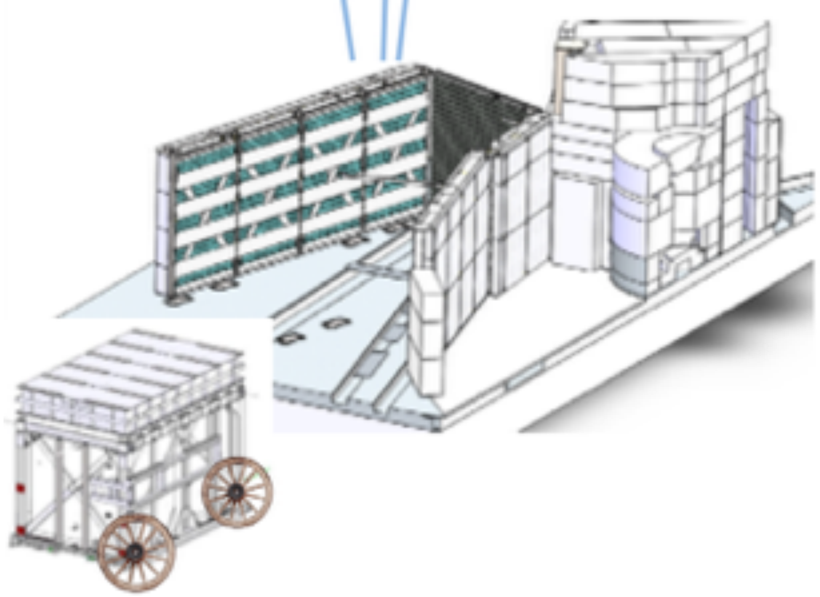




Random related

Emission of ɣ and n from reactor (core) and nearby experiments (D19, IN20) accidentally produce random coincidence

- Nearby sources shielded with borated polyethylene (**B4C**) and lead (**Pb**)
- **Perimeter** shielding

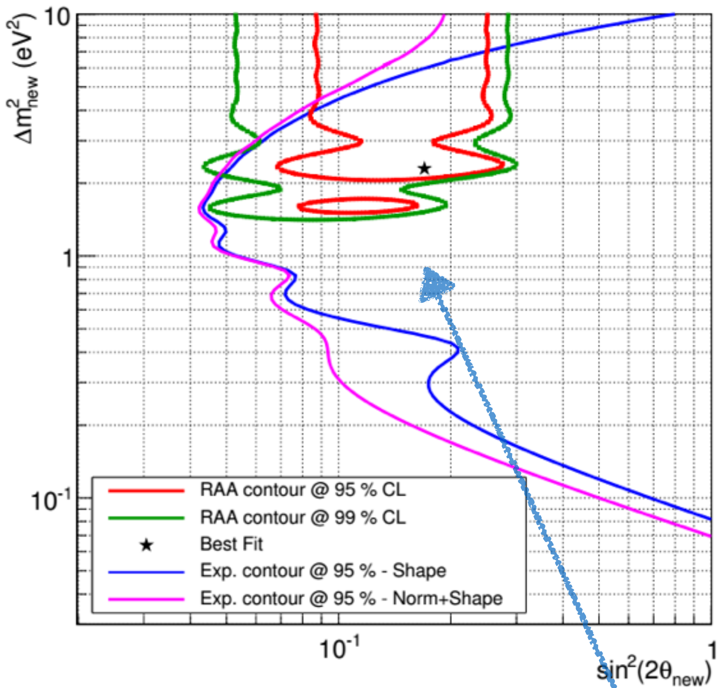


Cosmic background

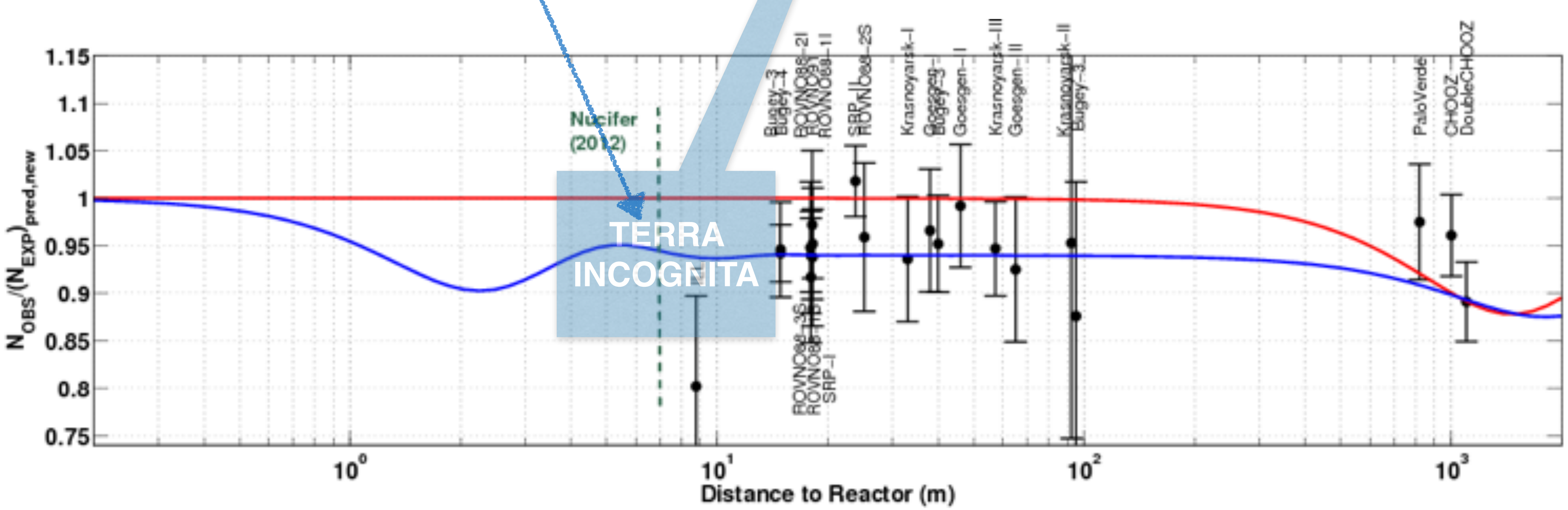
Fast n scatters with H+ and recoil energy creates prompt signal. Slowed down n generates delayed signal.

- Muon Veto
- Water channel overburden
- Reactor OFF measurement
- Pulse Shape Discrimination (PSD) capabilities

Oscillations towards sterile



Stereo is sailing towards Terra Incognita!



Data taking **Fall 2016!**

Thanks for watching!

"This is not even wrong!" Wolfgang Ernst Pauli