Sterile neutrino search in the STEREO Experiment

NBI Summer School - Tuesday 2nd of August 2016

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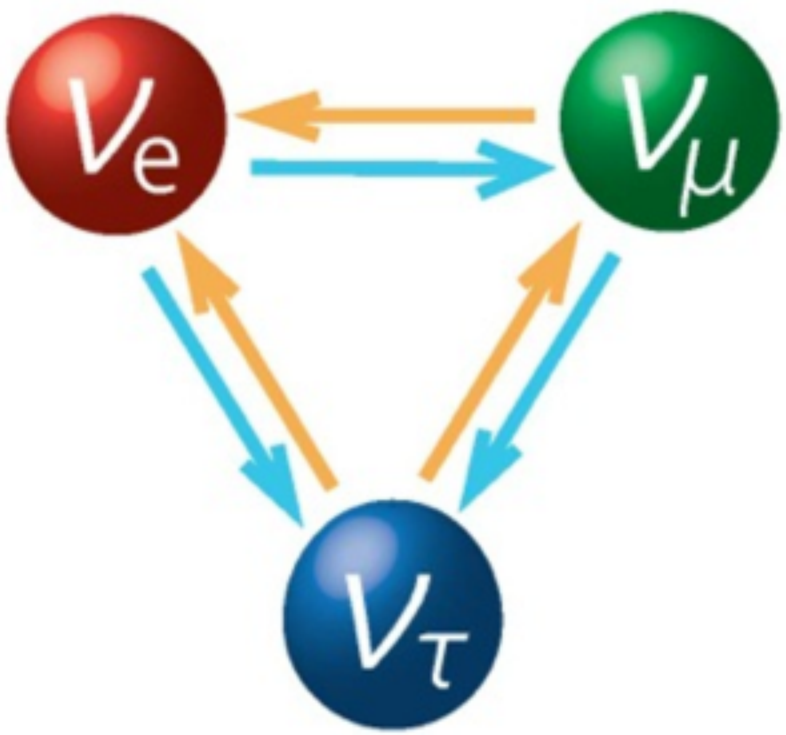
Neutrino Oscillations



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** $\frac{m_i^2}{2E}L$ → Act. flavor ES oscillates as neutrino propagates

Low mass approximation

PMNS Matrix

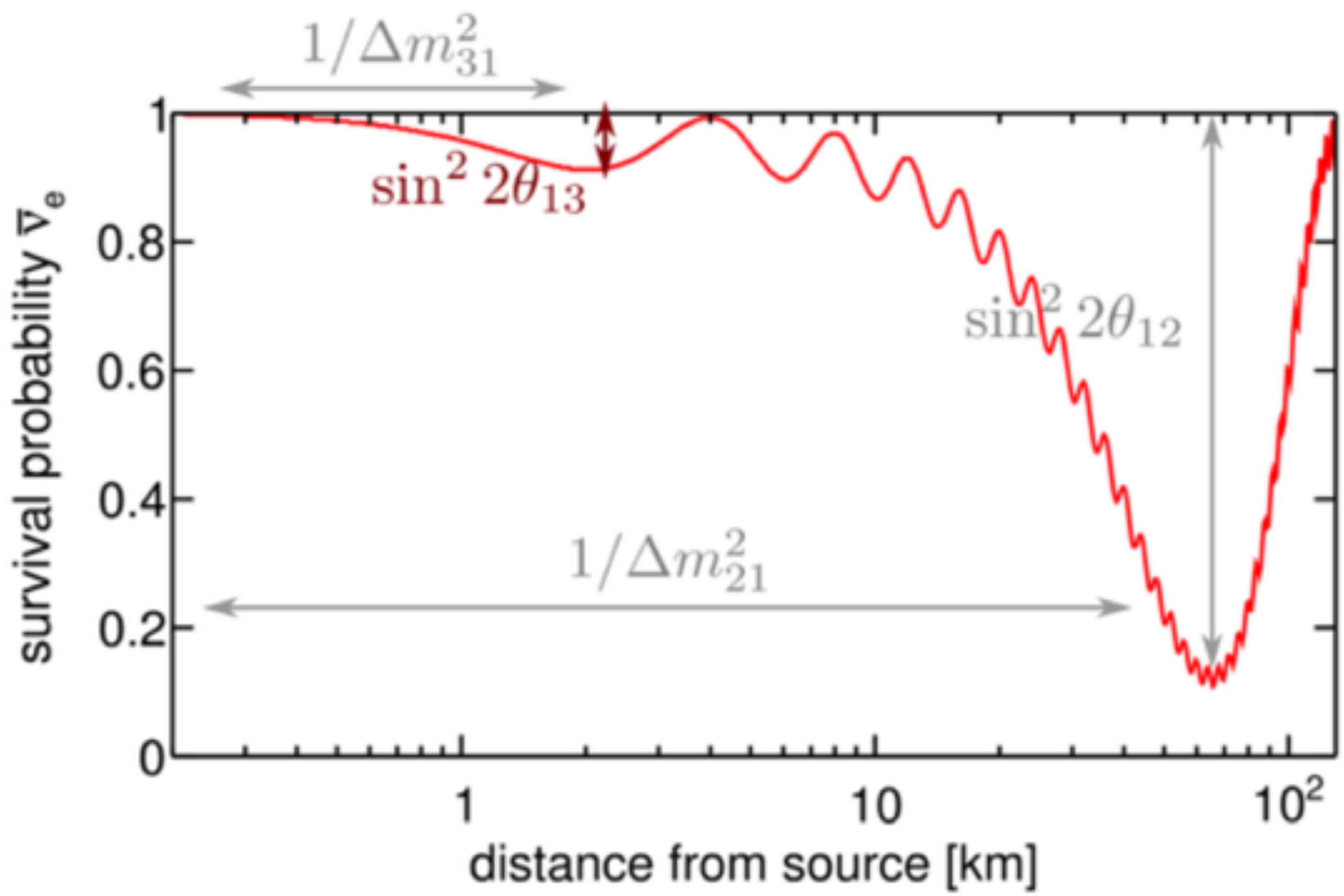
Definite act. flavor basis → $\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U_{PMNS} \cdot \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$ ← Definite mass basis

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

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



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

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

Weak interacting families

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

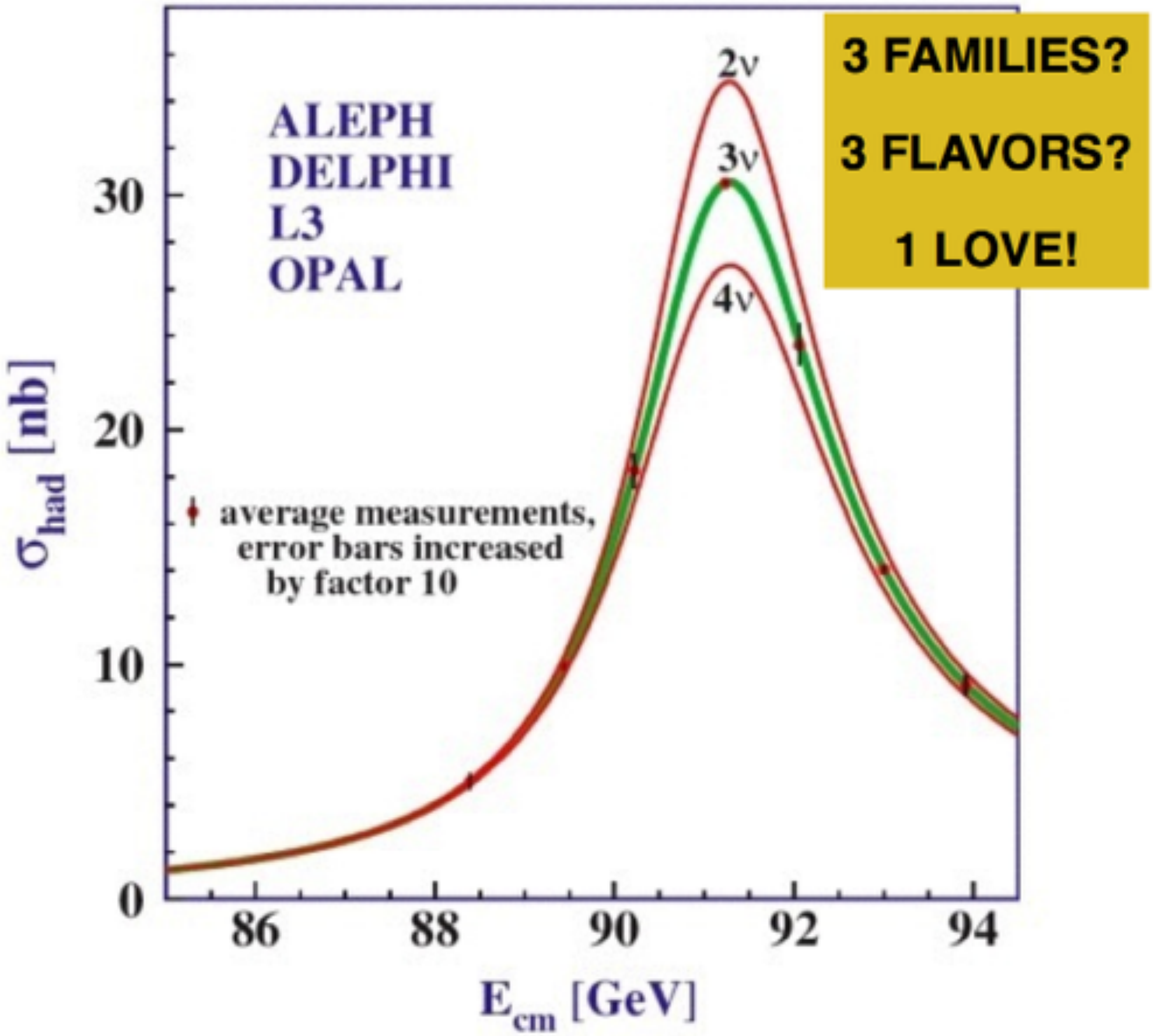
Experiments at **LEP** found that:

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

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

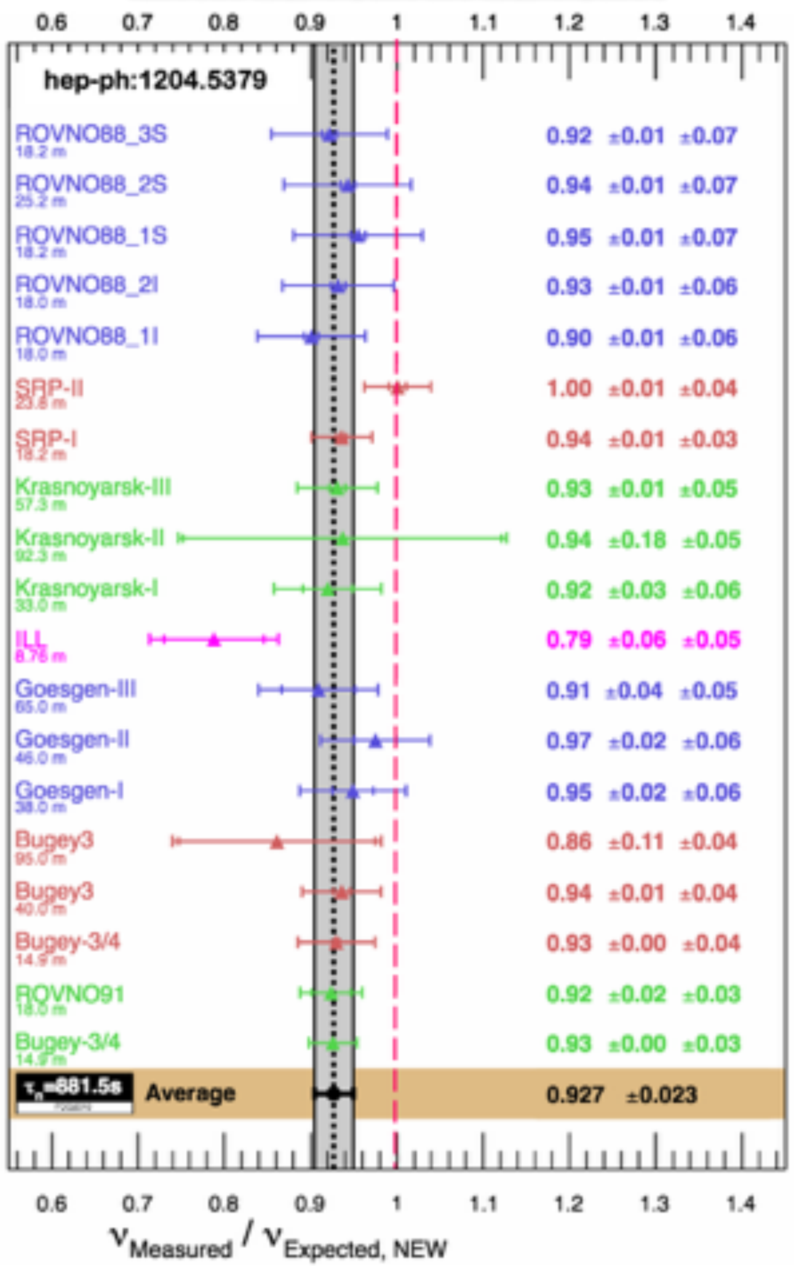


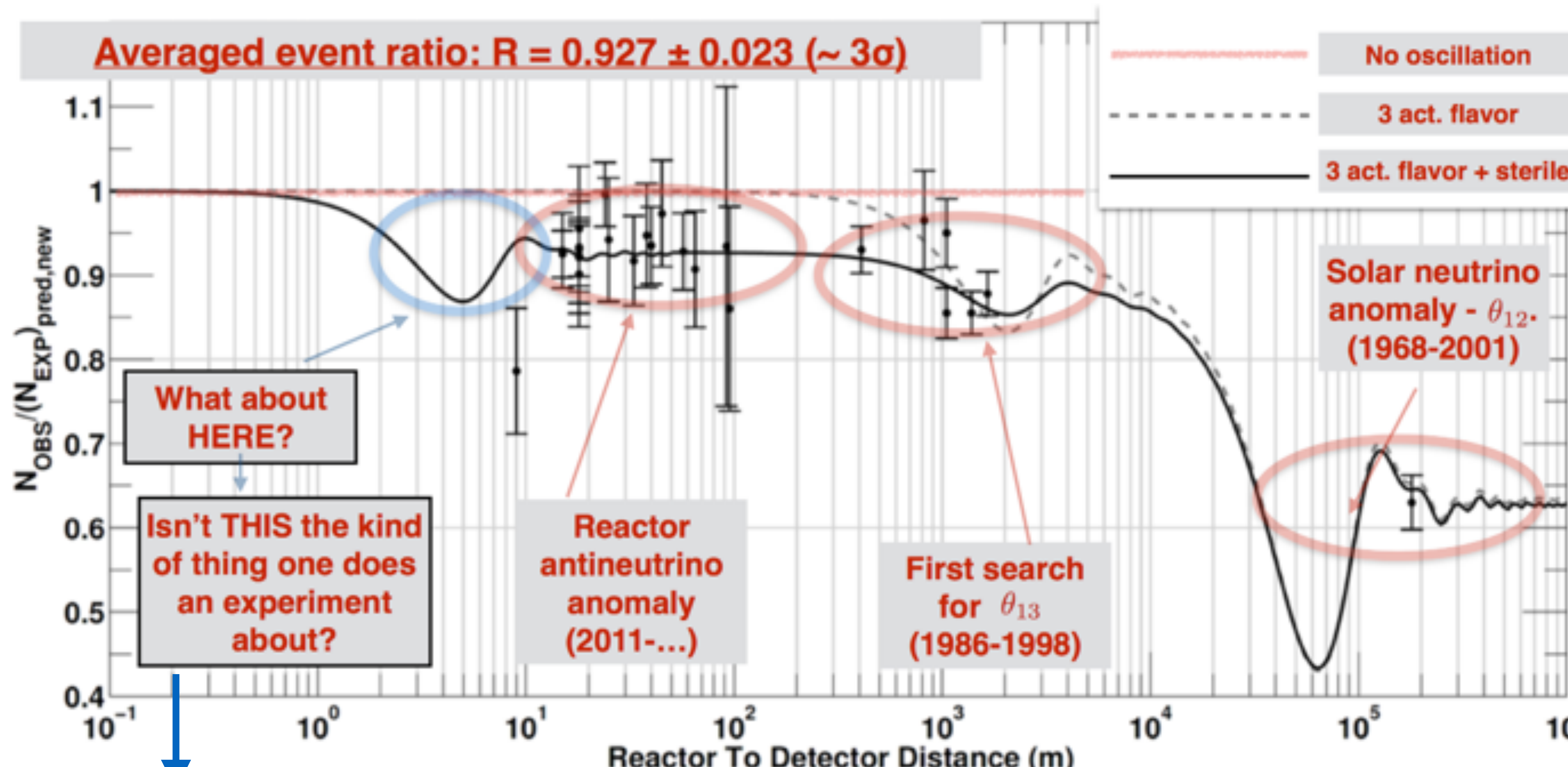
Observing $\bar{\nu}_e$ disappearance

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

Summary of short baseline experiments

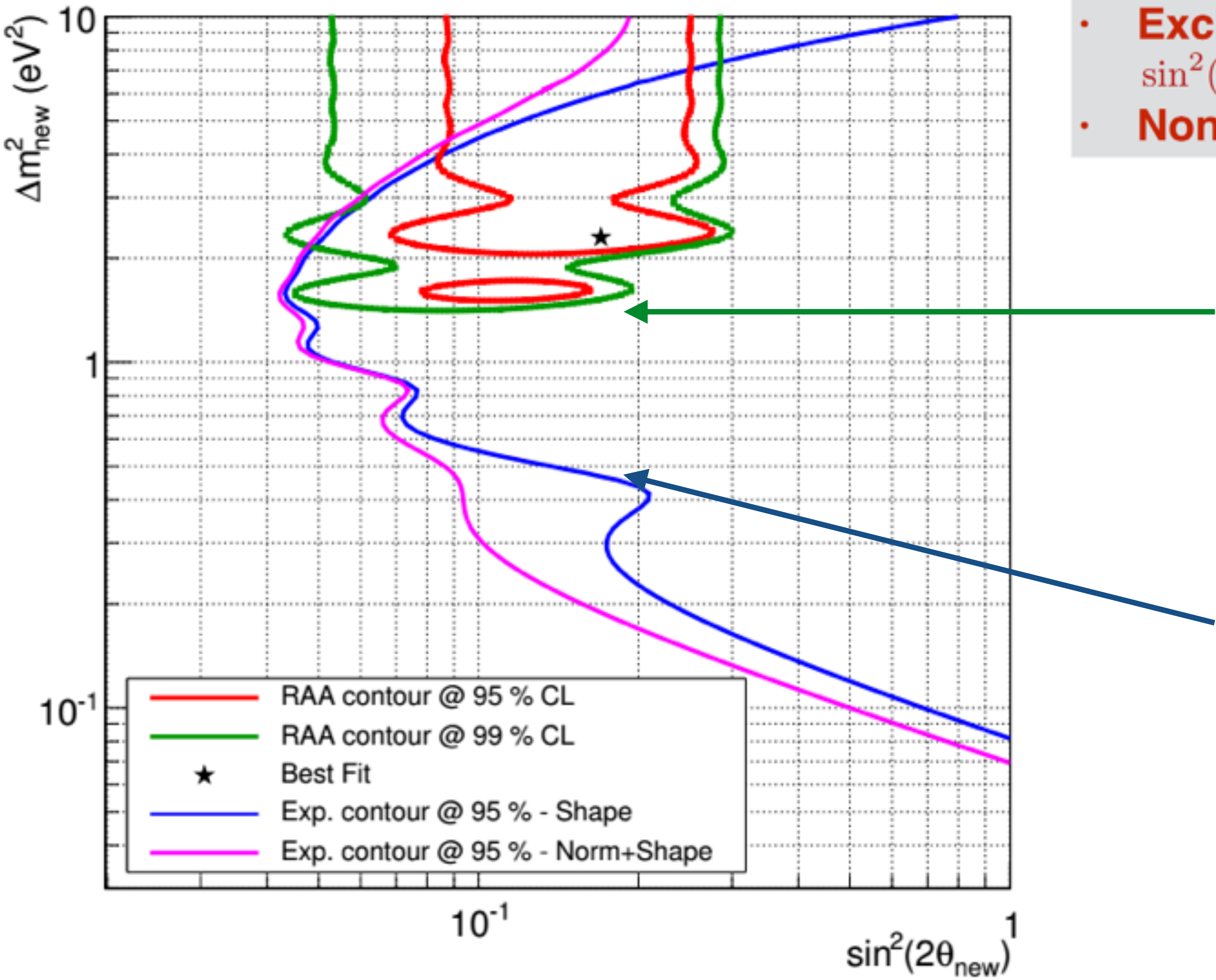
- Less neutrinos than expected are observed in RAA region… **hidden oscillation?**
- To fit observations at LEP: 4th type of neutrino must be **STERILE**





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

Discovery potential of Stereo



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

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

Expected parameter's space available in Stereo

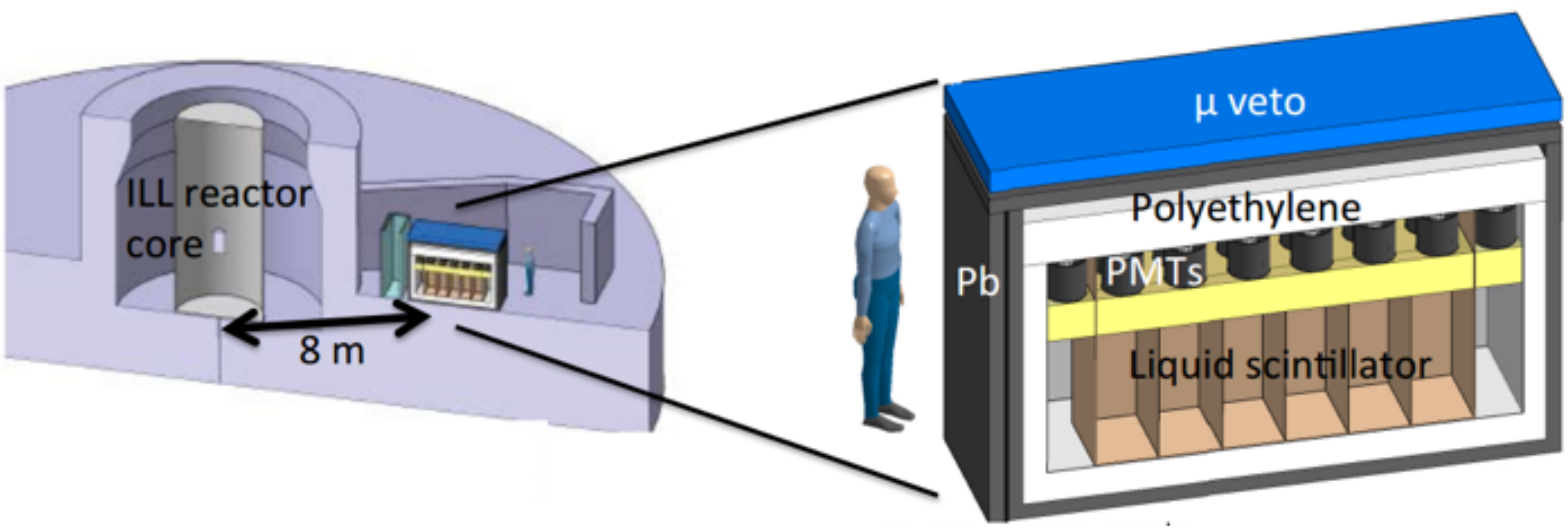
Sterile Neutrinos

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

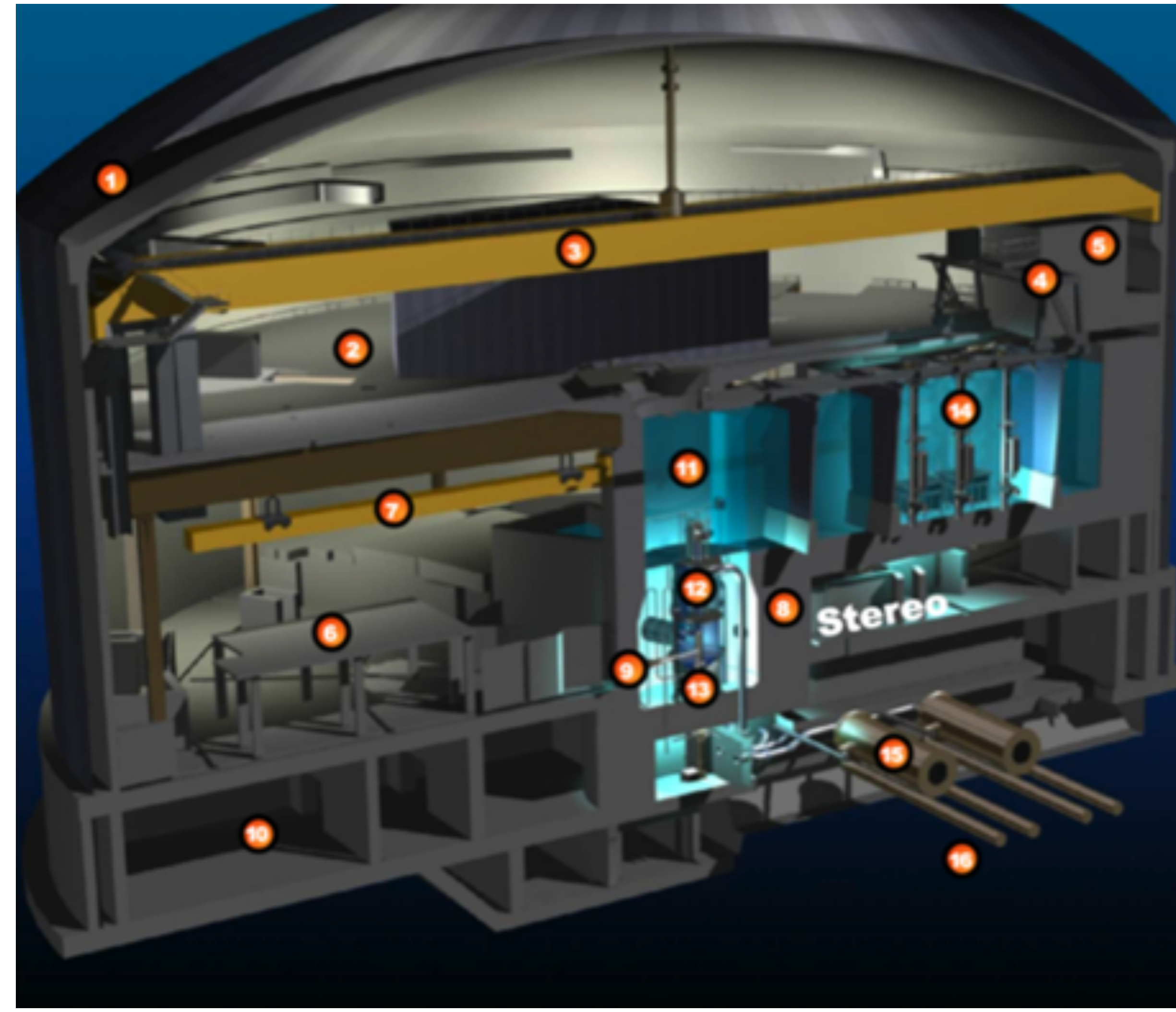


ILL Reactor Plant

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**

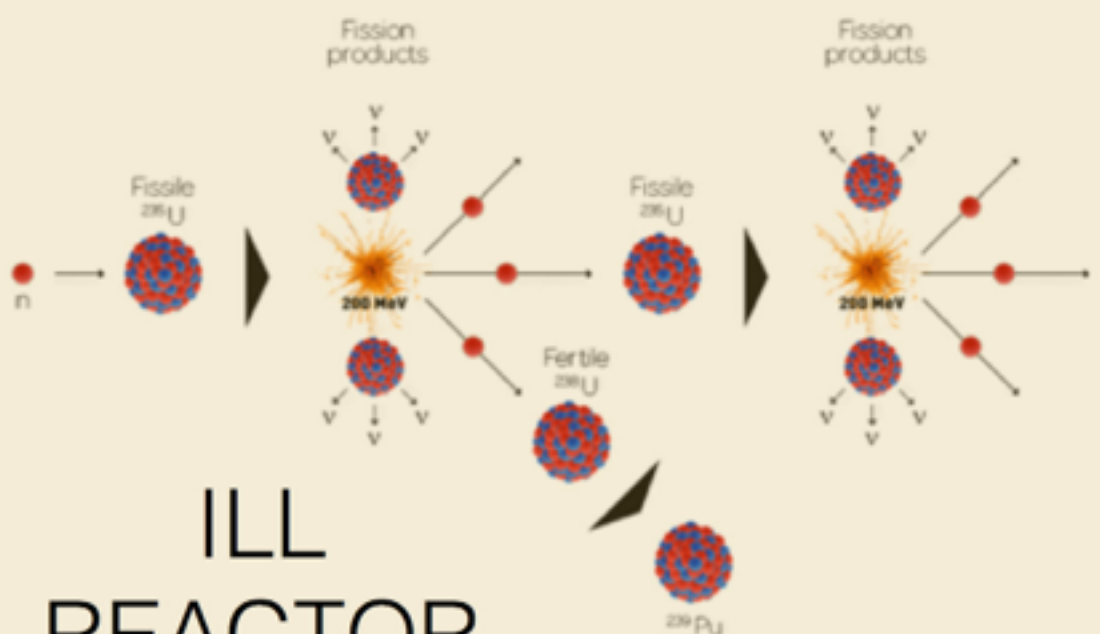
Production Spectra + IBD cross section combine

[3] Inverse beta decay
the **scintillator**
$\bar{\nu}_e + p \rightarrow e^+ + n$

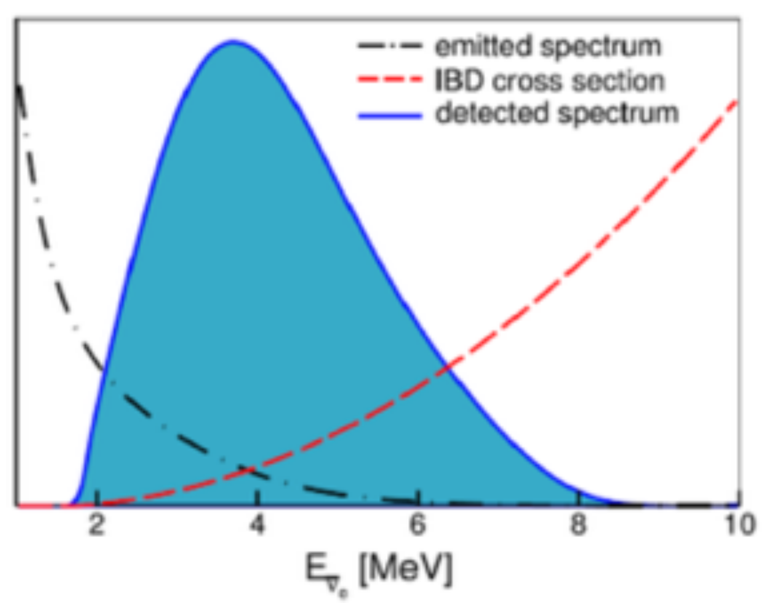
PRODUCTION

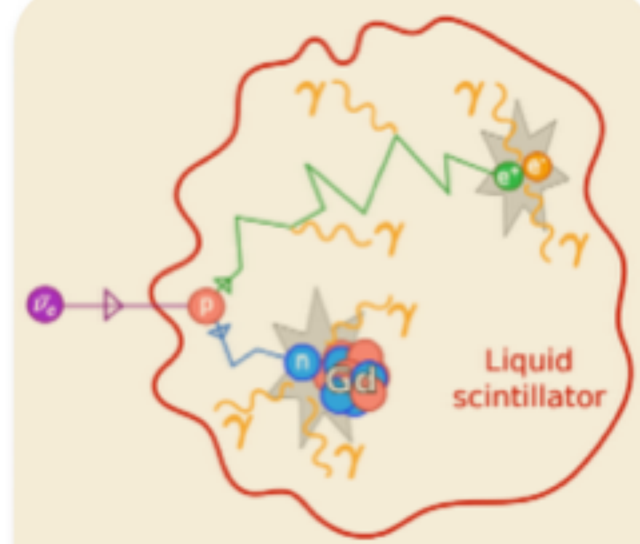
SPECTRA

DETECTION



ILL
REACTOR



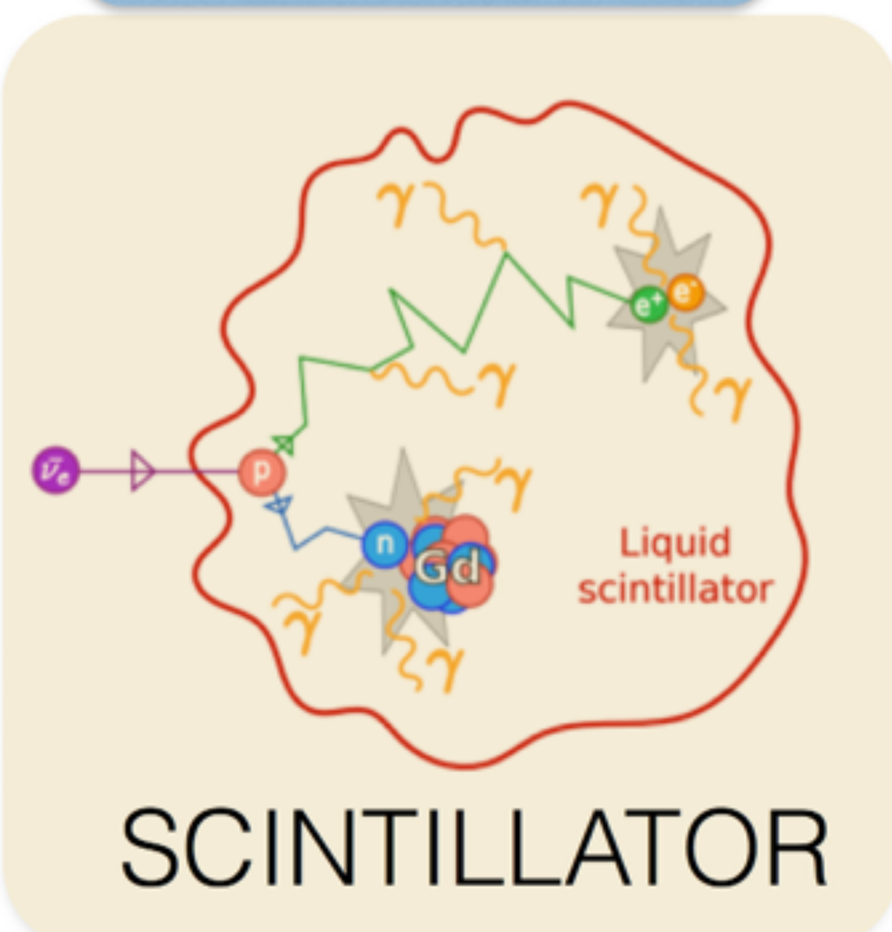


SCINTILLATOR

Physical process

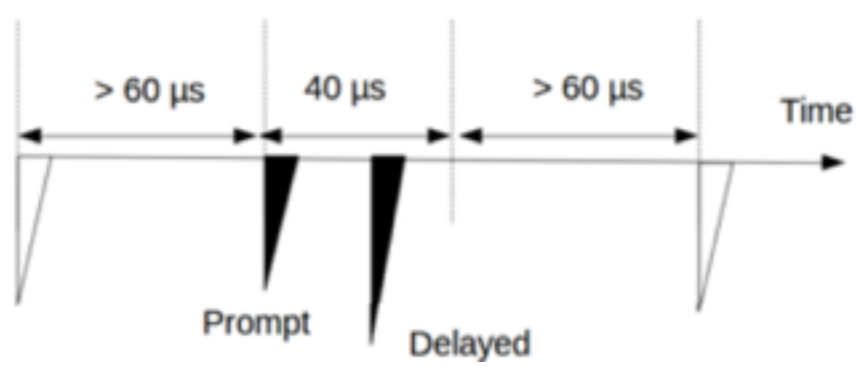
[3] Inverse beta decay the **scintillator**

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

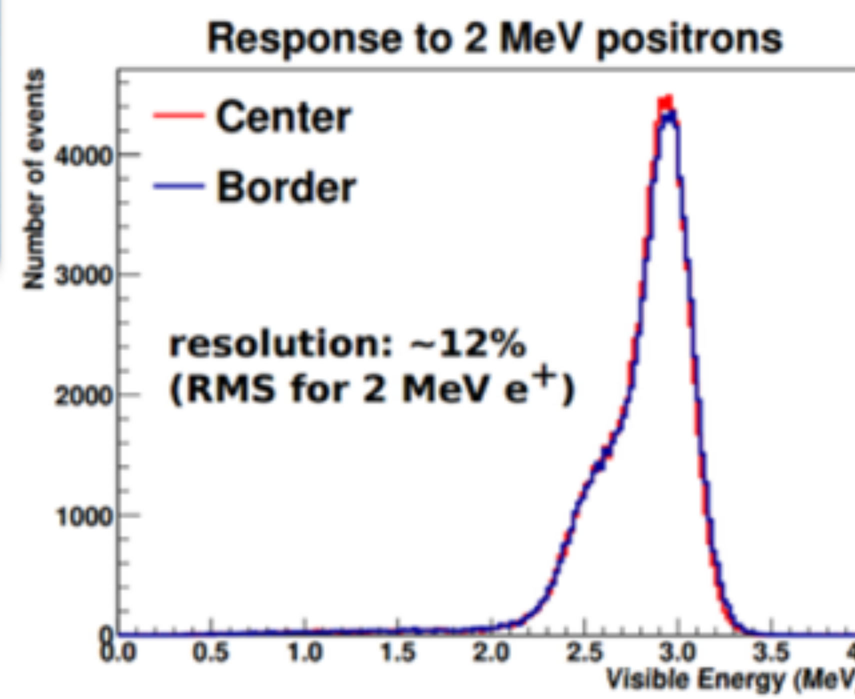


[4] Electron losses energy until **annihilation**: **Prompt signal**

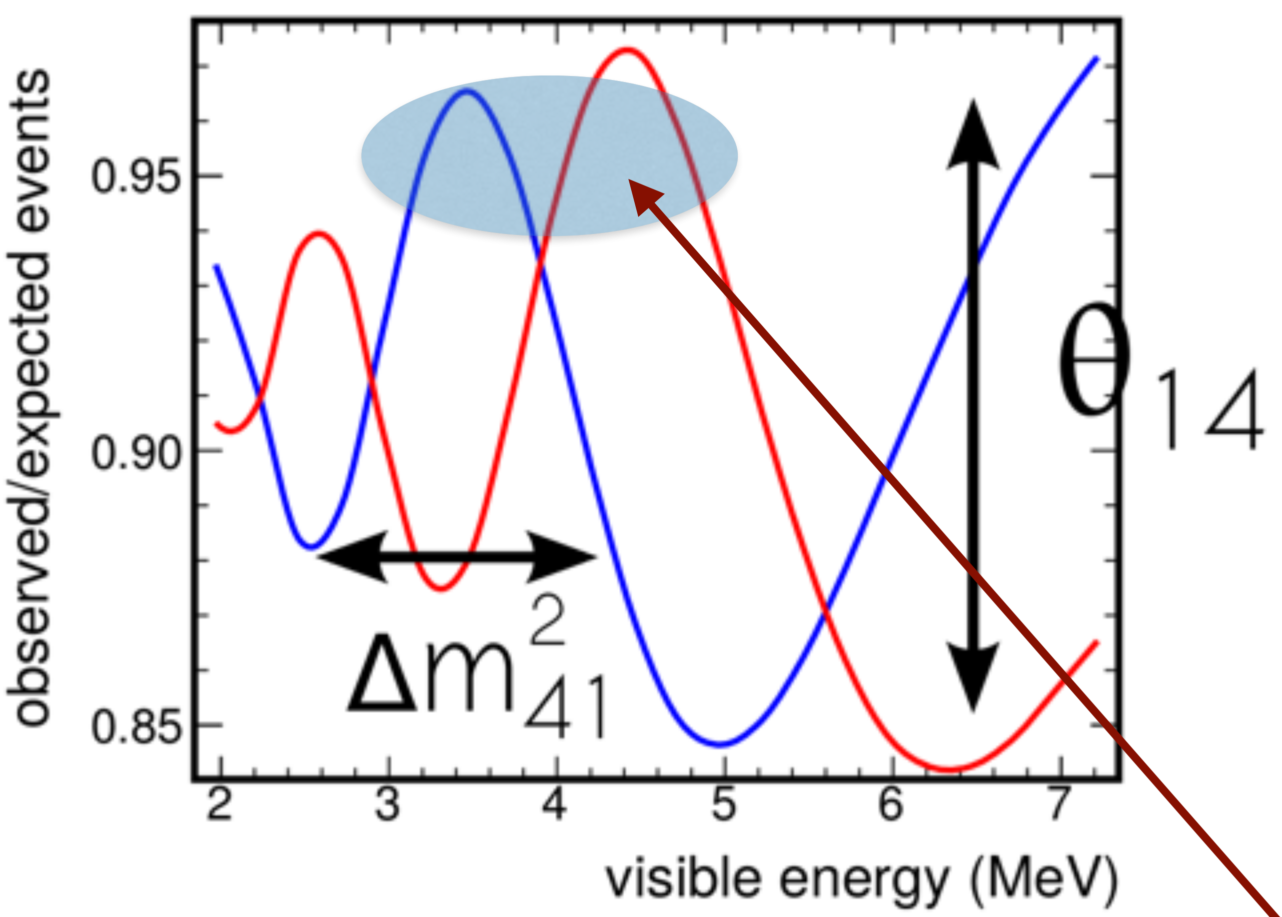
[5] Neutron Catcher (Gd): emits **gammas** summing up 8MeV **Delayed signal**

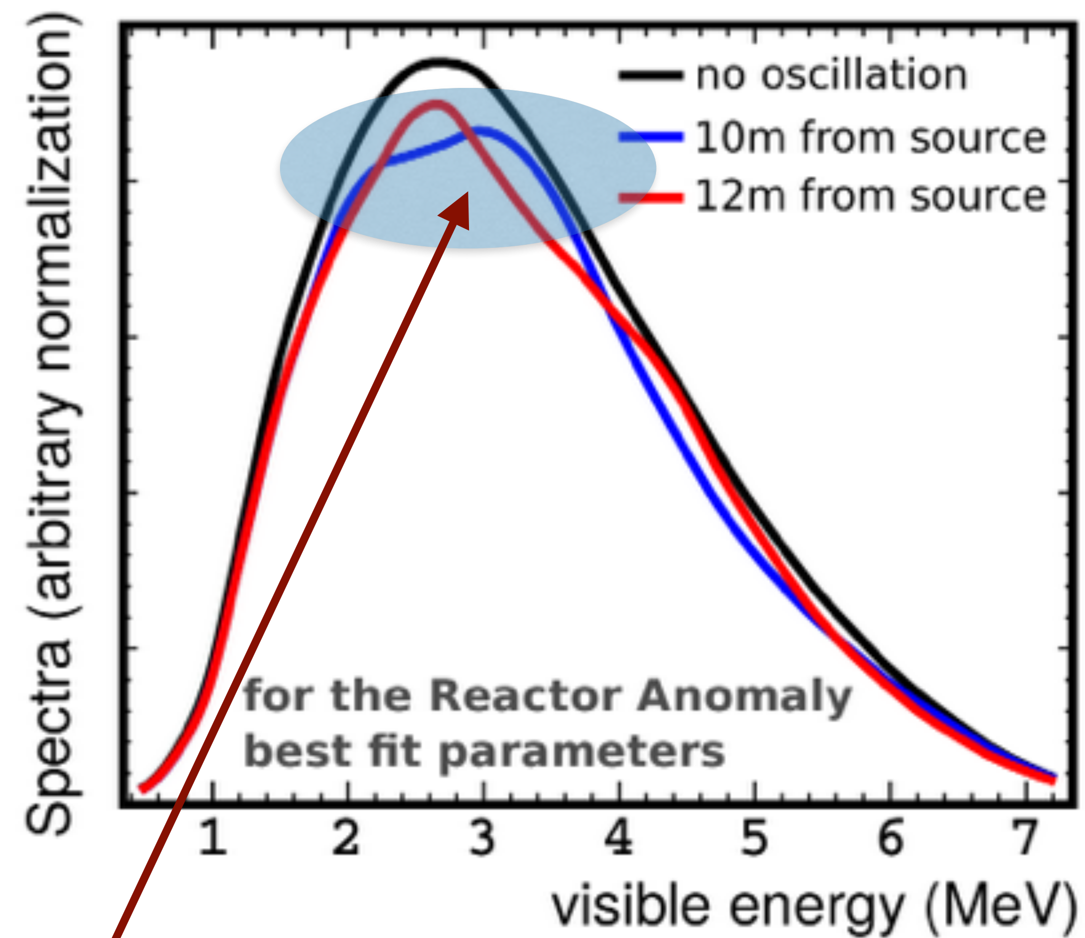


What do we see?
Energy of the **prompt signal**, necessarily in coincidence with **delayed signal**:



Sterile ν signature





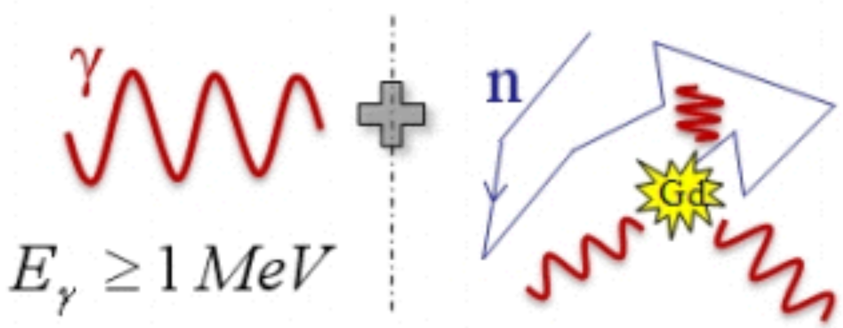
Furthest Cell

Closest Cell

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

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

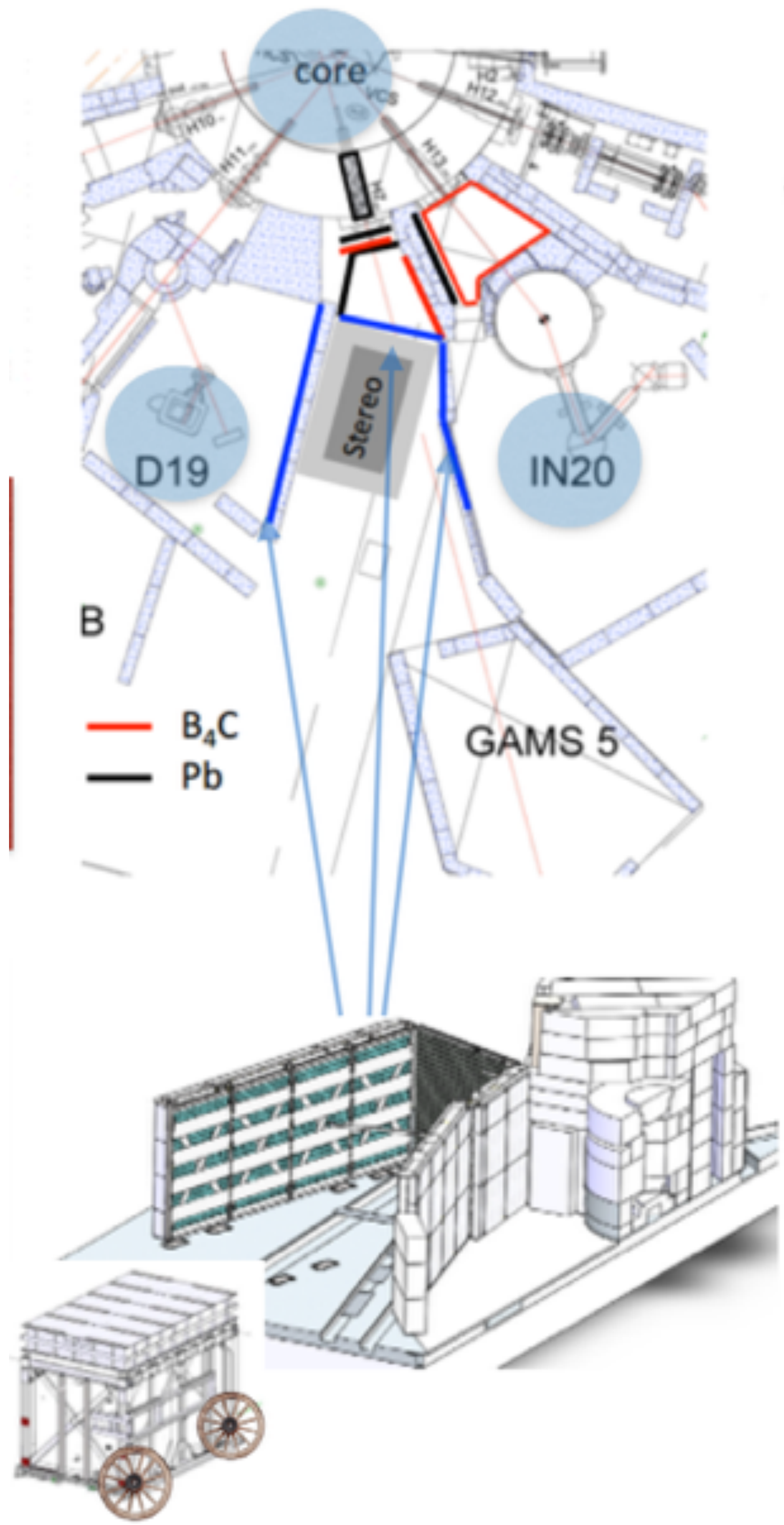
Dealing with background

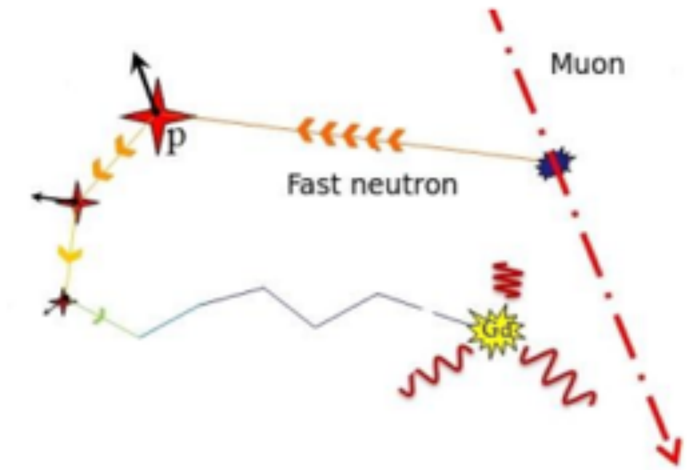


Random related

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



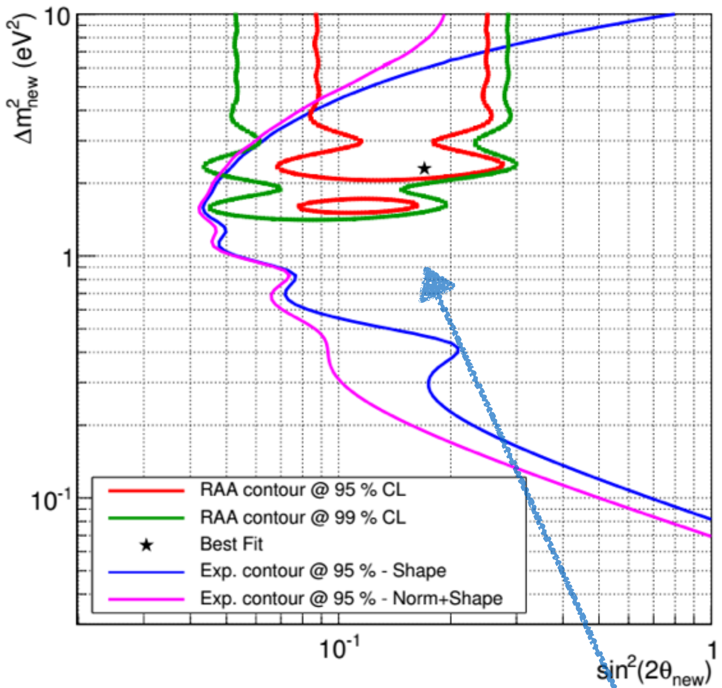


Cosmic background

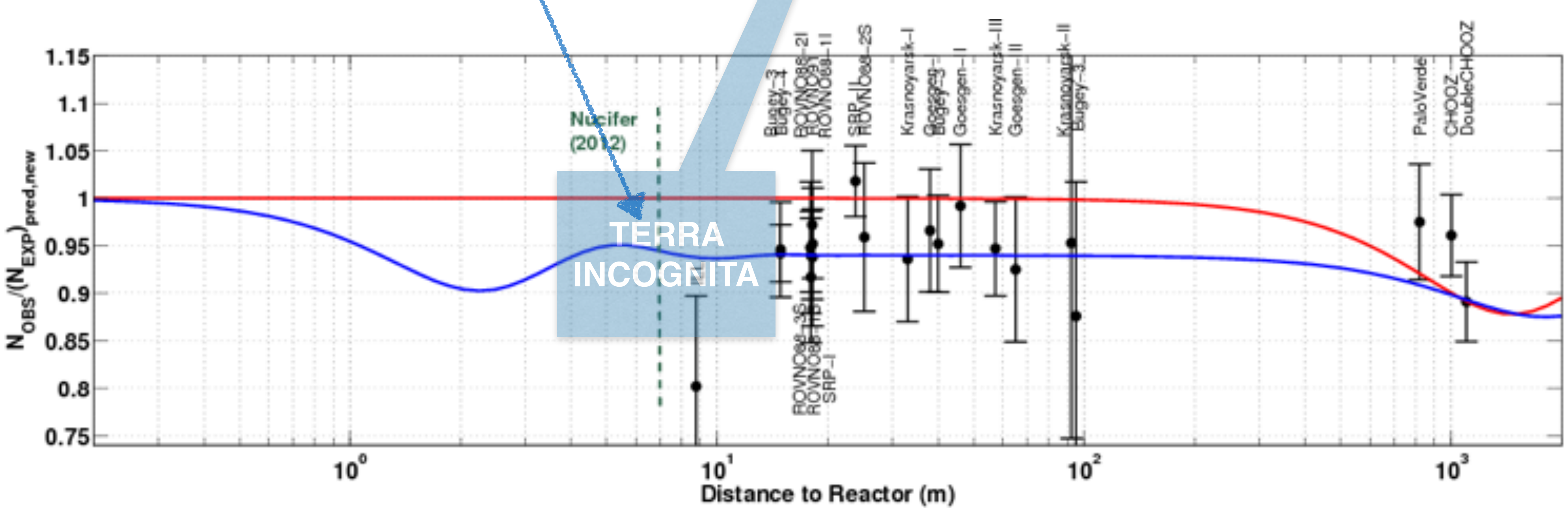
Fast n scatters with H+ and recoil energy creates prompt signal. Slowed down n generates delayed signal.

- 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