Sterile neutrinos

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School on Dark Matter and Neutrino Detection
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Summary of the talk

1) New neutrino states

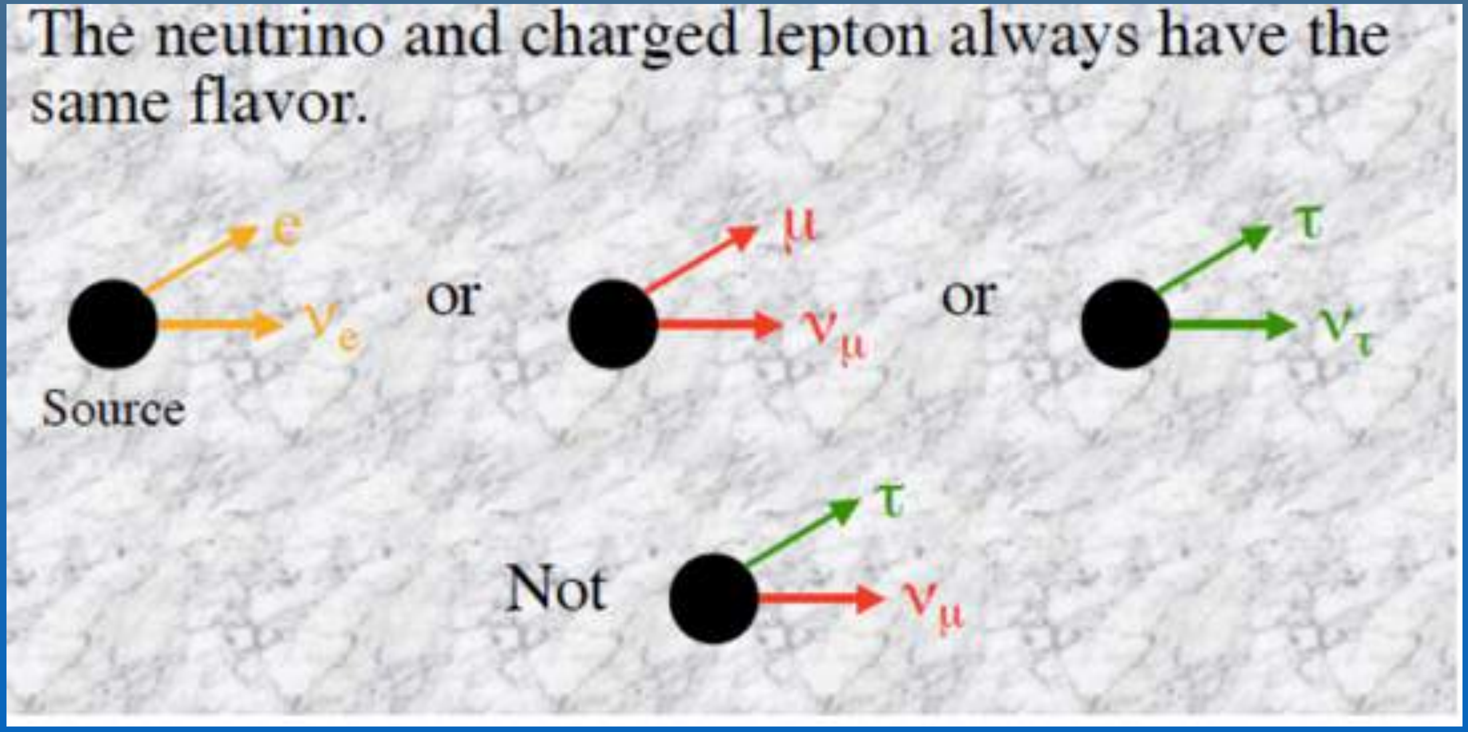
2) How to search for Sterile neutrinos?

3) Hints of sterile neutrinos

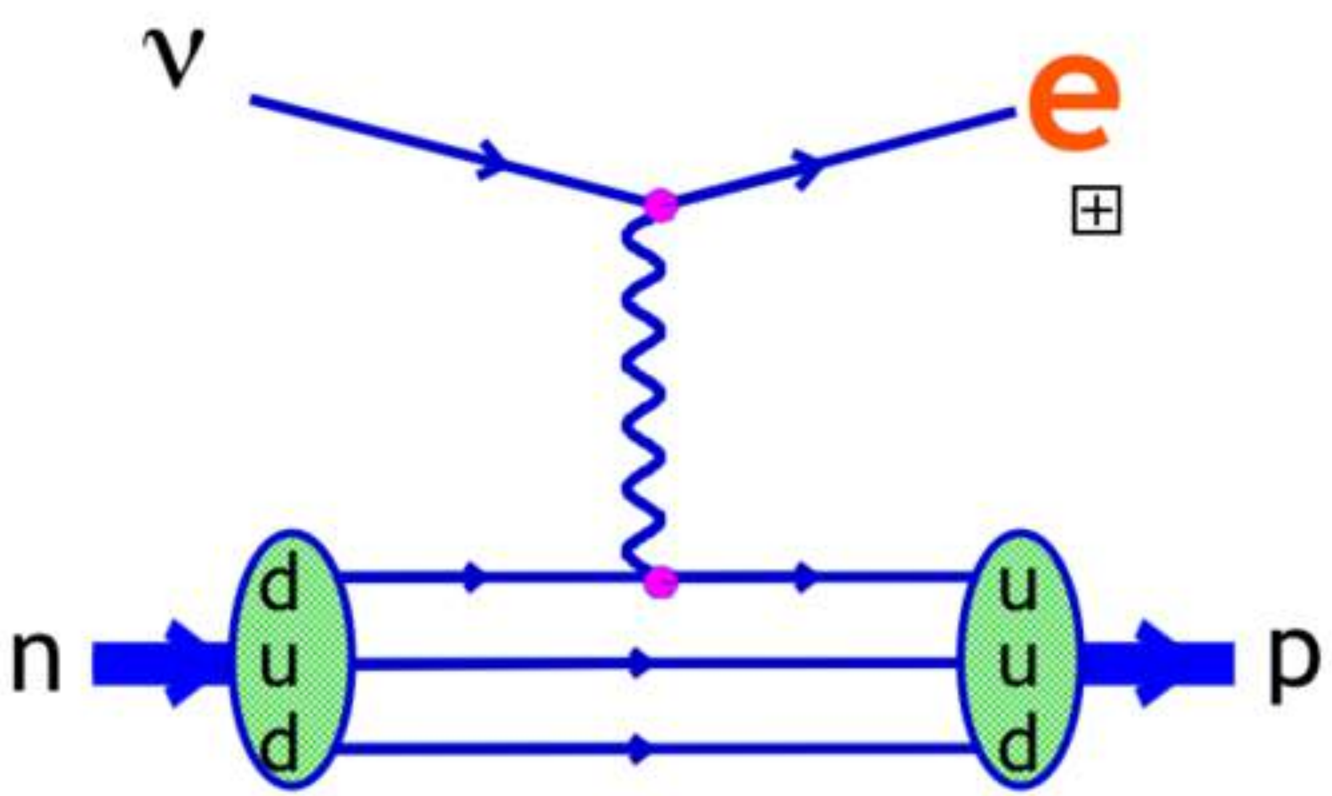
4) Constrains on sterile neutrinos

5) Present search for sterile neutrinos

Neutrinos in XX century

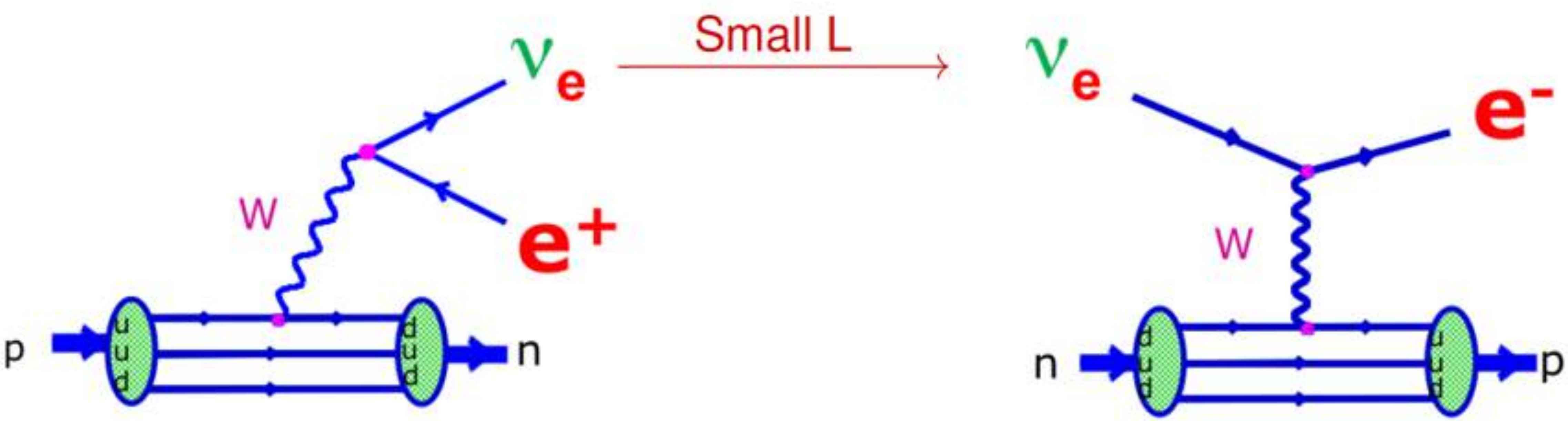


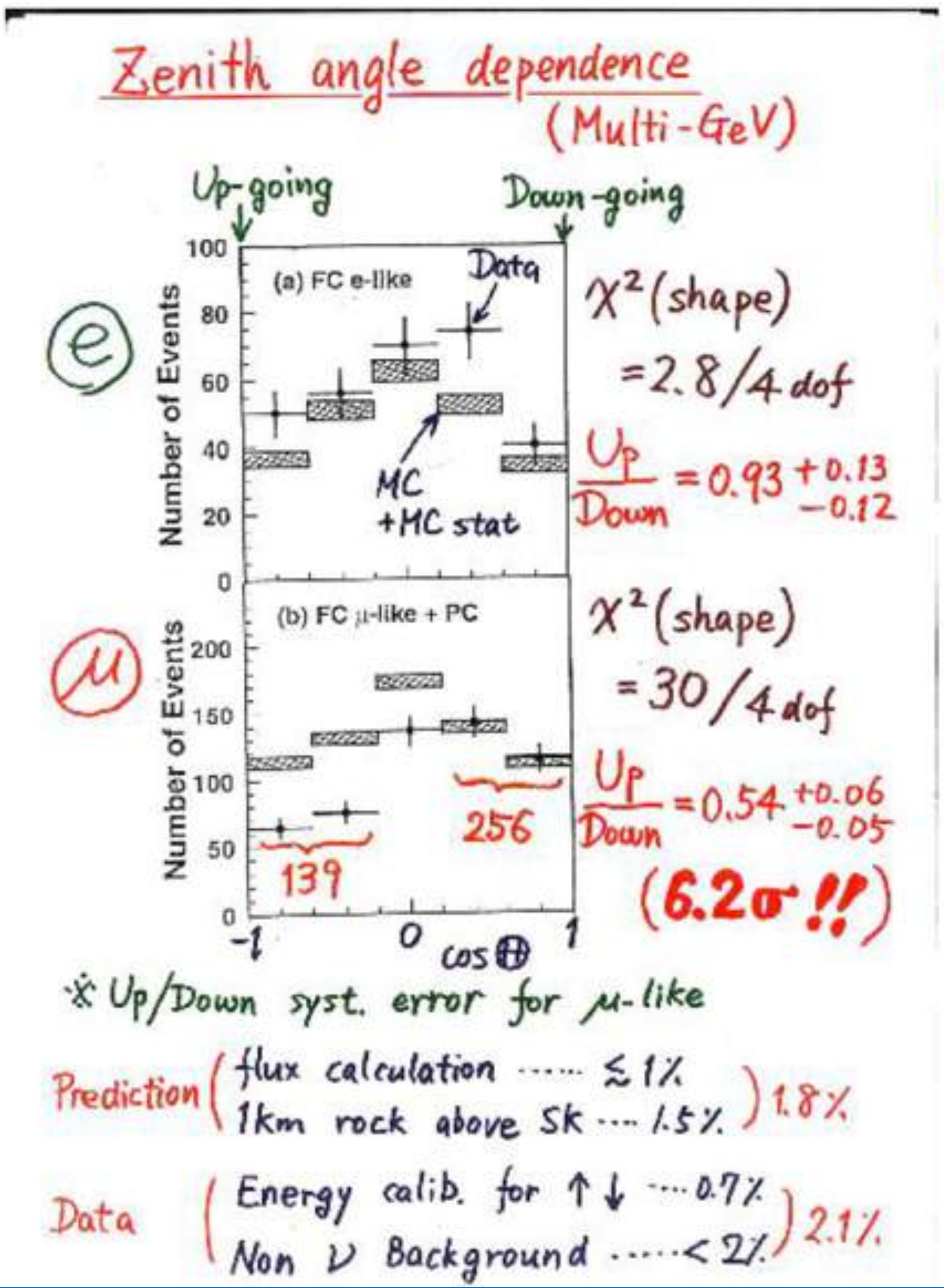
We don't see neutrinos: Weak interaction changes flavour



Usually *label* the neutrino state producing an electron as *electron neutrino*

In early experiments (over short distances) a ν_e at source would always interact as a ν_e producing an e^-

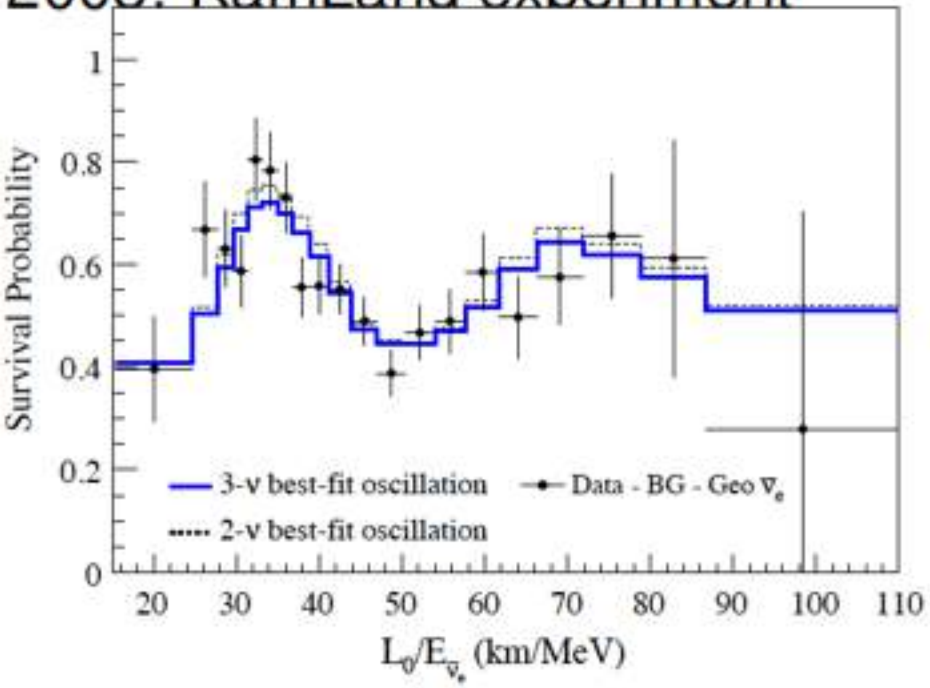




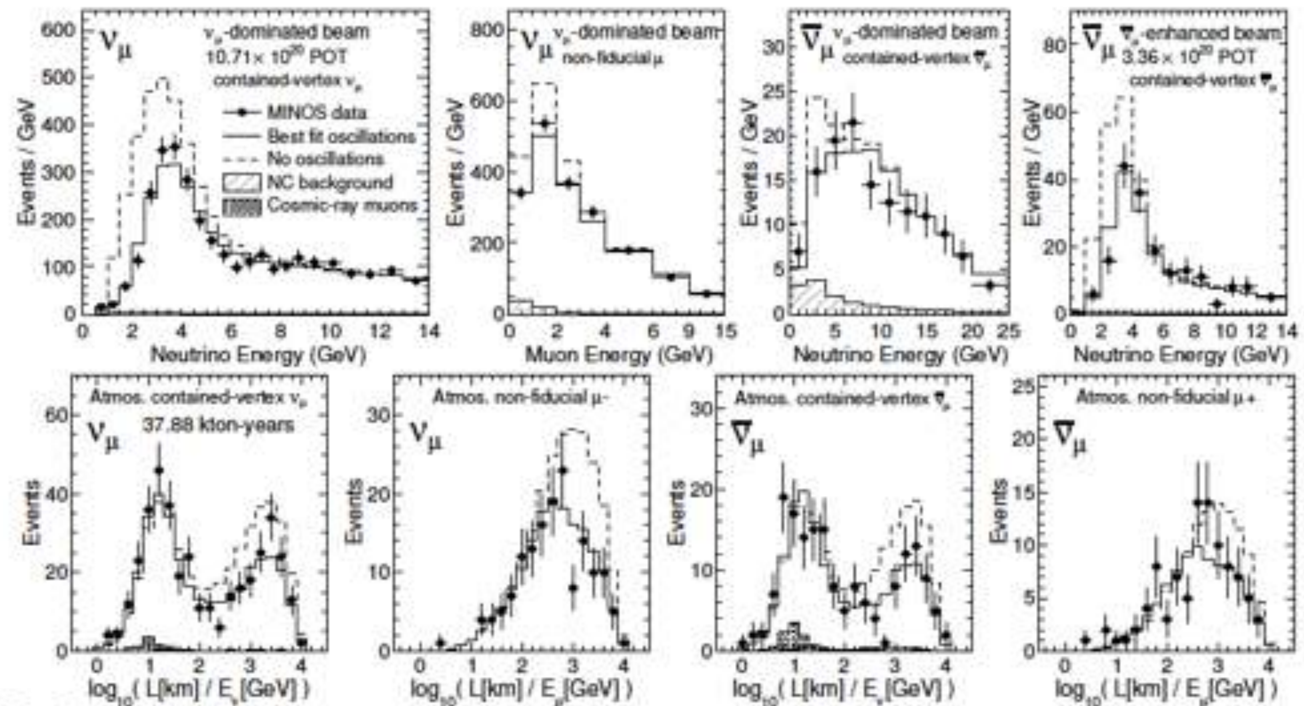
In 1998, Kajita show this slide:

Muonic Neutrinos change flavor: neutrinos are disappearing.

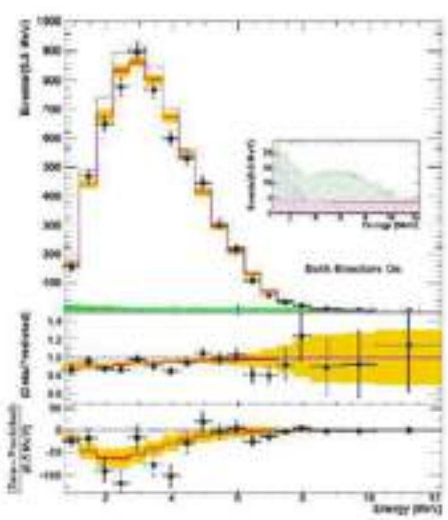
2008: KamLand experiment



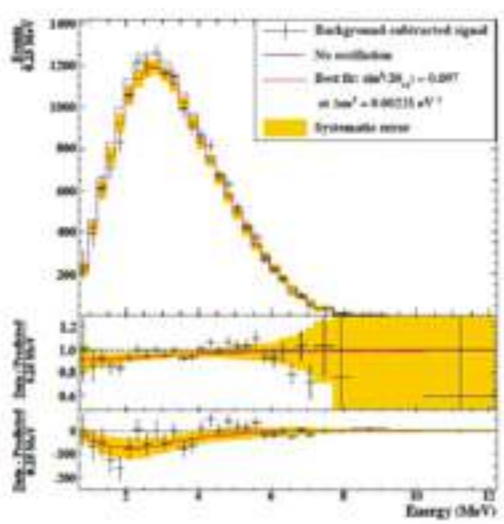
MINOS experiment 2010: UFG/USP/UNICAMP



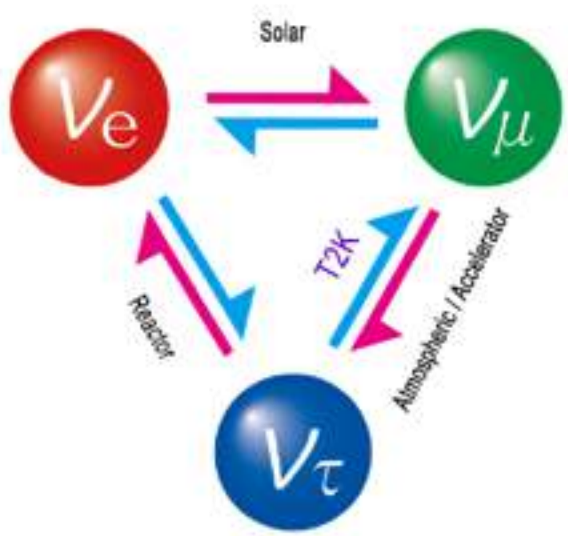
Double Chooz 2013: UNICAMP/UFABC/CBPF



Gd-capture



H-capture



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• Pontecorvo(1958) :

Flavor of Neutrinos, ν_e ν_μ ν_τ are a linear combination of states with well defined mass, ν_1 ν_2 ν_3

we have

$$\nu_e = +\cos\theta\,\nu_1 + \sin\theta\,\nu_2$$

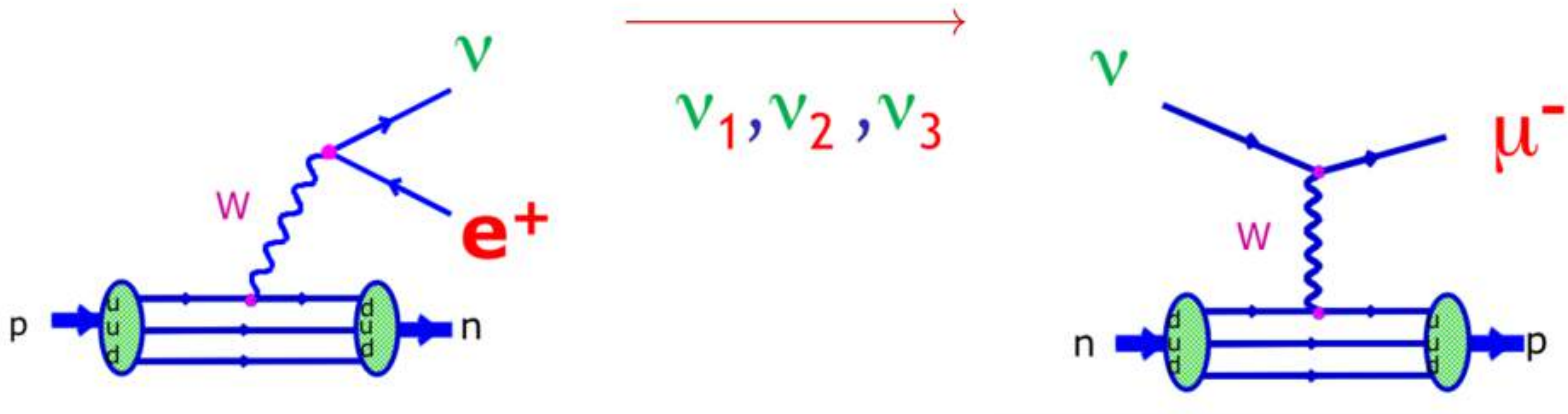
$$\nu_\mu = -\sin\theta\,\nu_1 + \cos\theta\,\nu_2$$

the states ν_1 e ν_2 are mass eigenstates

Symmetry Magazine

Over larger distances we have

Not use ν_e, the fundamental particles are ν_1, ν_2, ν_3



Coherent Quantum Mechanics superposition

$$|\nu(t)\rangle = U_{e1} e^{-iE_1 t}\,|\nu_1\rangle + U_{e2} e^{-iE_2 t}\,|\nu_2\rangle + U_{e3} e^{-iE_3 t}\,|\nu_3\rangle$$

The Nobel Prize in Physics 2015

Photo: A. Mahmoud

Takaaki Kajita

Prize share: 1/2

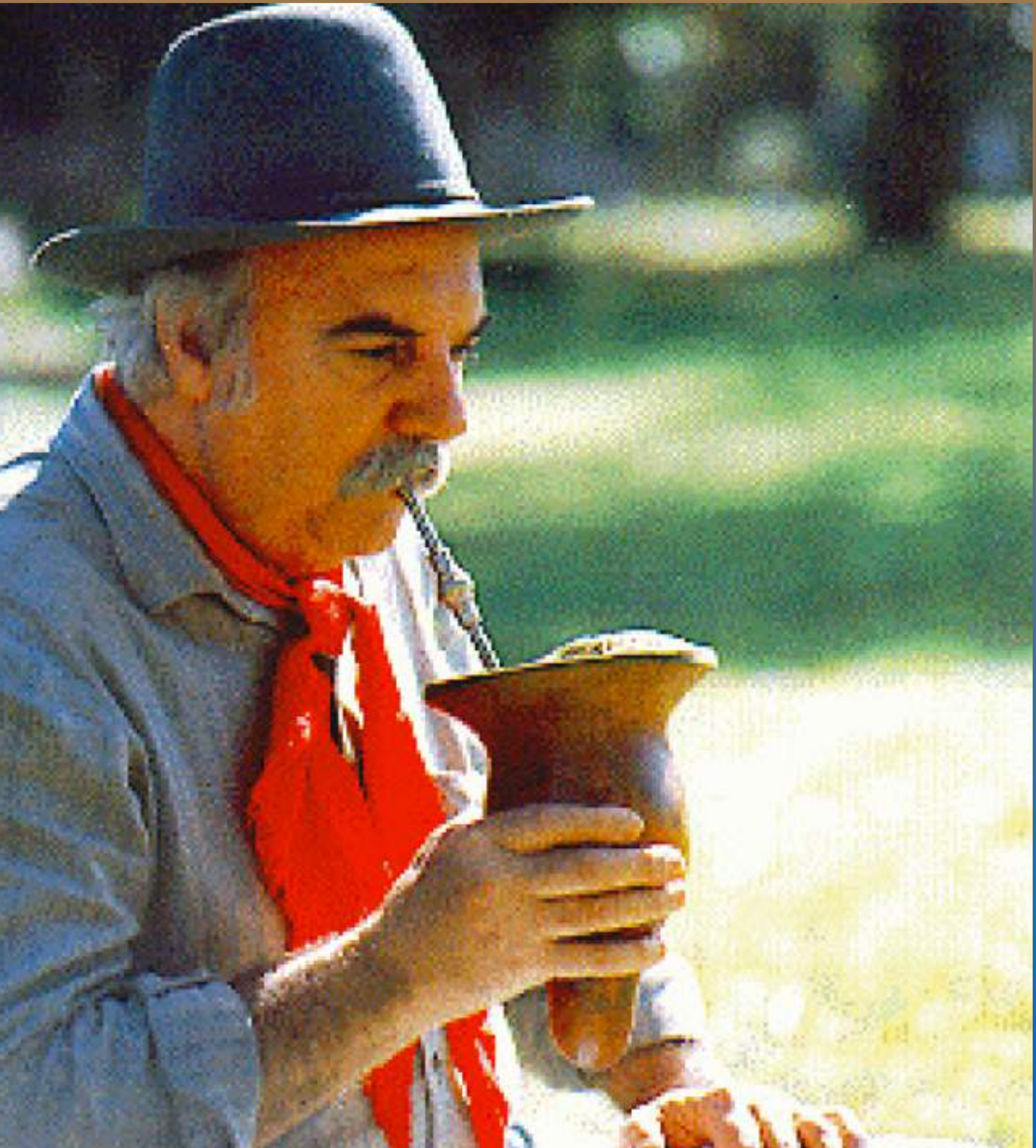
Photo: A. Mahmoud

Arthur B. McDonald

Prize share: 1/2

The first discovery in particle physics
of new phenomena beyond the Standard Model.

The Nobel Prize in Physics 2015 was awarded jointly to Takaaki Kajita and Arthur B. McDonald *"for the discovery of neutrino oscillations, which shows that neutrinos have mass"*



What to do now?

New types of neutrinos

Is possible to have other neutrino states?

More probably not: more copies of the flavour neutrinos are not allowed.

Experimental result: only three neutrinos interact.

What happened with neutrinos that don't interact?

No bound.

[History of Poltergeist experiment]

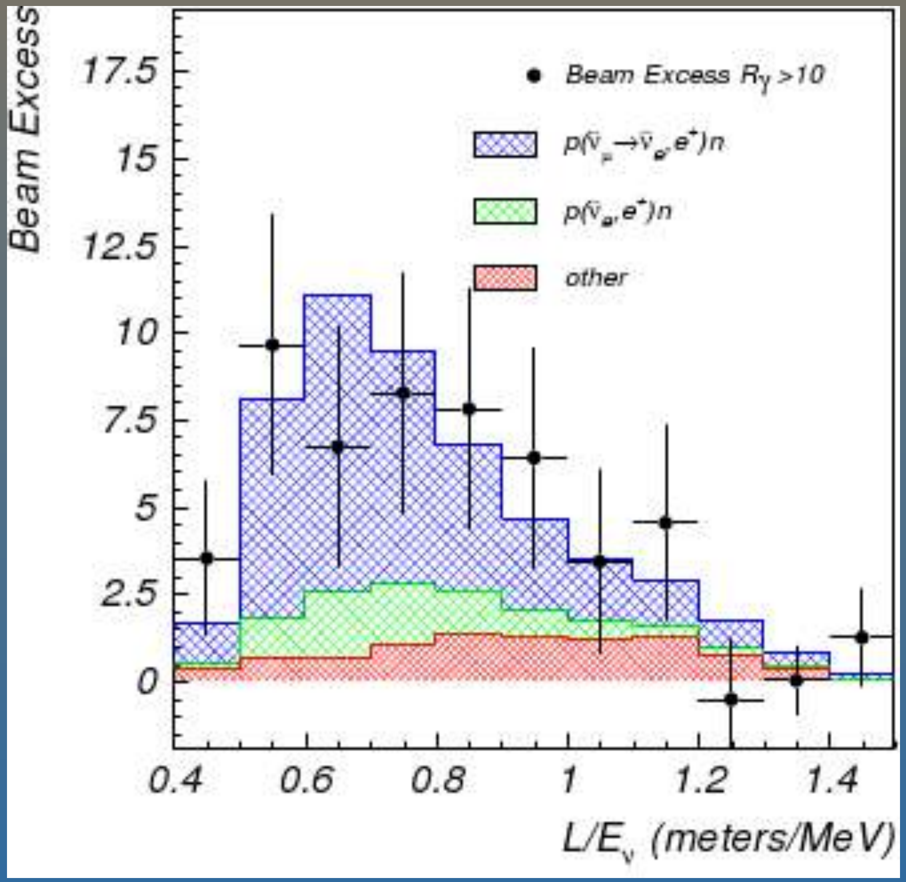
How to detect sterile neutrinos?

Poltergeist experiment

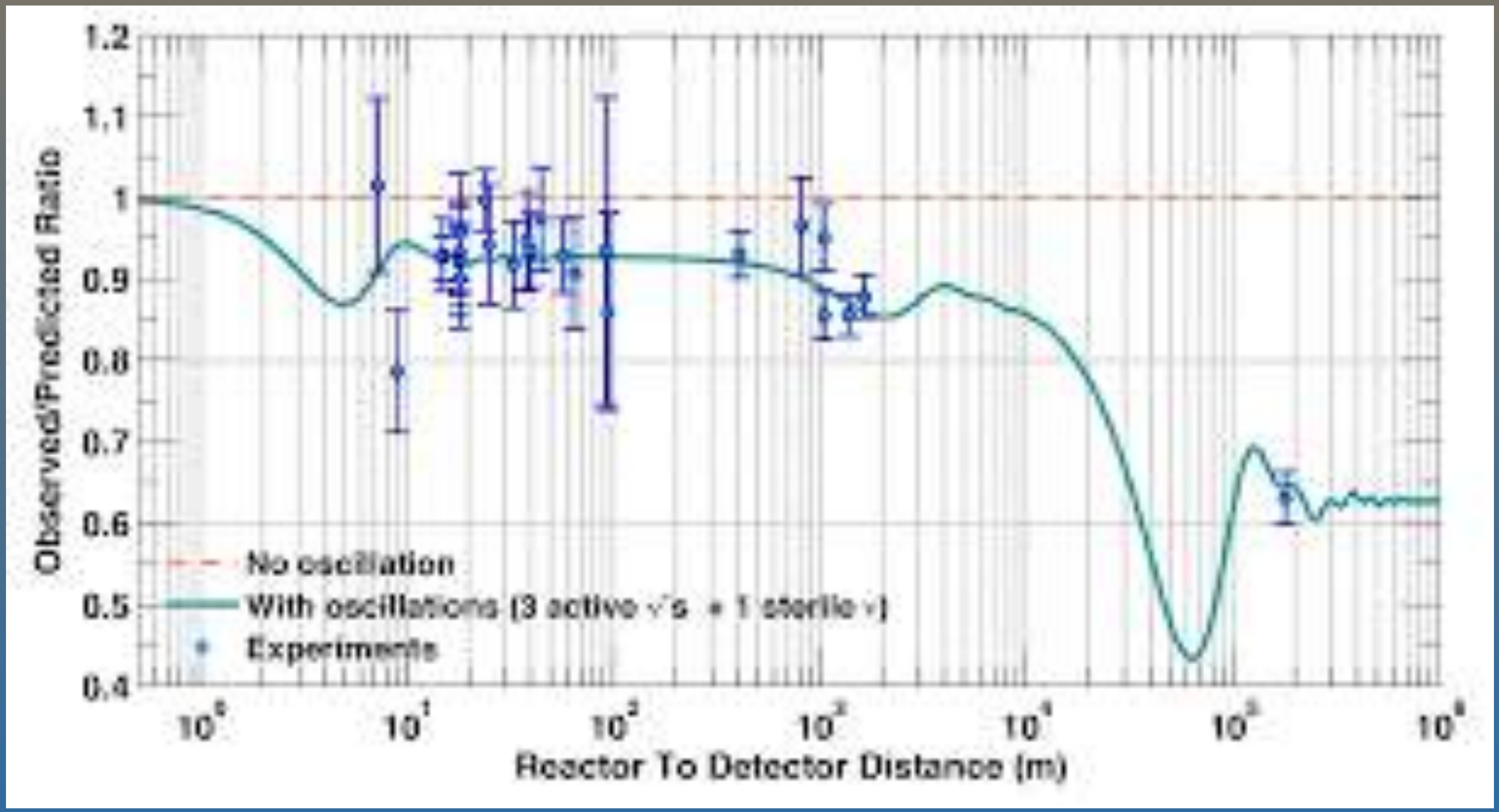
Janet Conrad: experimental physicist

First round: short-baseline experiments

LSND Experiment

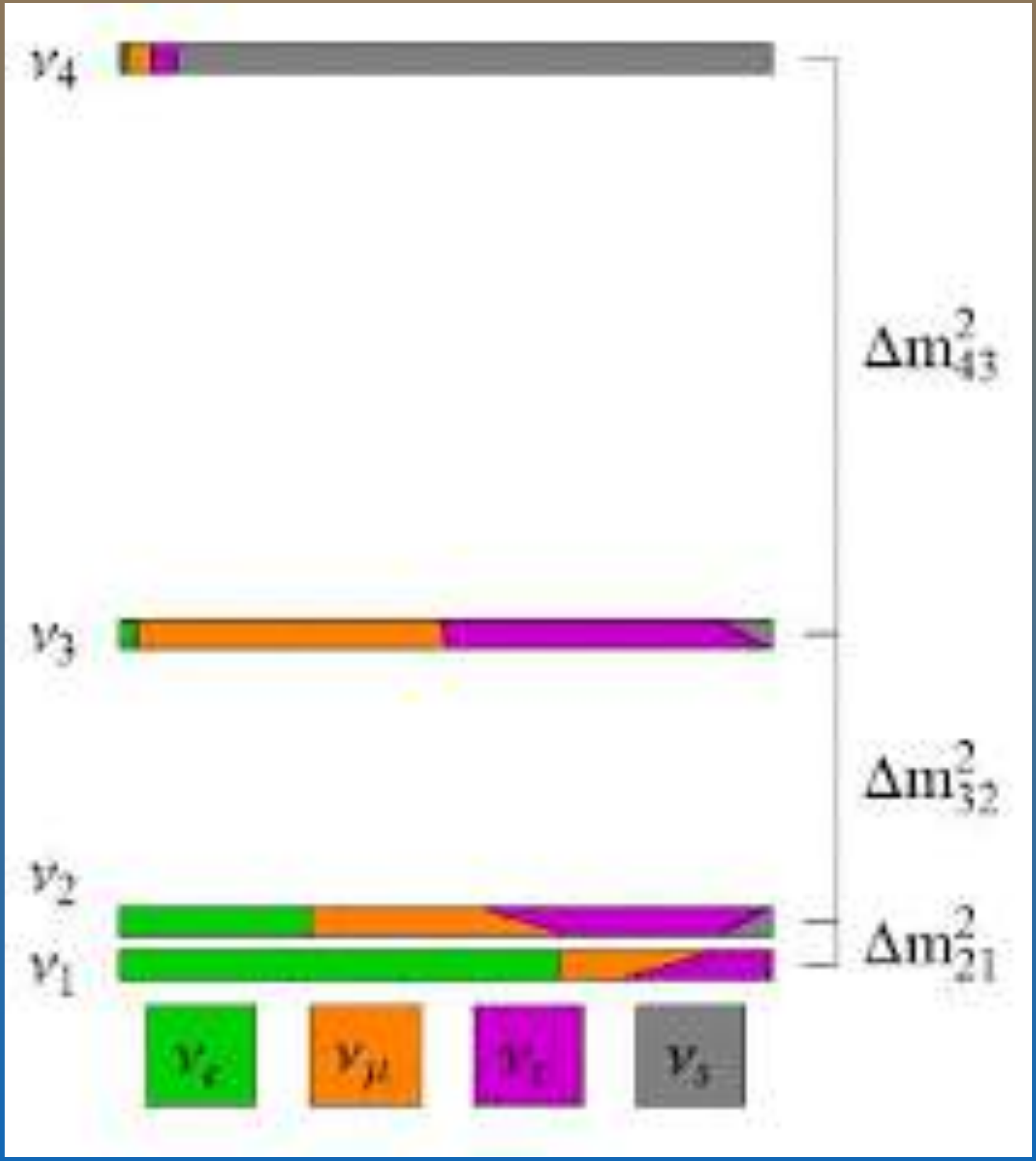


Reactor anomaly



$$P(\nu_\mu \to \nu_e) = \sin^2(2\theta_{\mu e}) \sin^2\left(\frac{\Delta m^2 L}{4E}\right) \qquad \Delta m^2 \sim (0.1 - 1.0)\ \mathrm{eV}^2$$

Simplest sterile model



3+1 mass scheme

$$P(\nu_\mu \to \nu_e) = \sin^2(2\theta_{\mu e}) \sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$

$$P(\nu_\mu \to \nu_\mu) = 1 - \sin^2(2\theta_{\mu\mu}) \sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$

$$P(\nu_e \to \nu_e) = 1 - \sin^2(2\theta_{ee}) \sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$

$$\sin^2(2\theta_{\mu e}) = 4|U_{\mu 4}|^2|U_{e4}|^2$$

$$\sin^2(2\theta_{\mu\mu}) = 4|U_{\mu 4}|^2(1 - |U_{\mu 4}|^2)$$

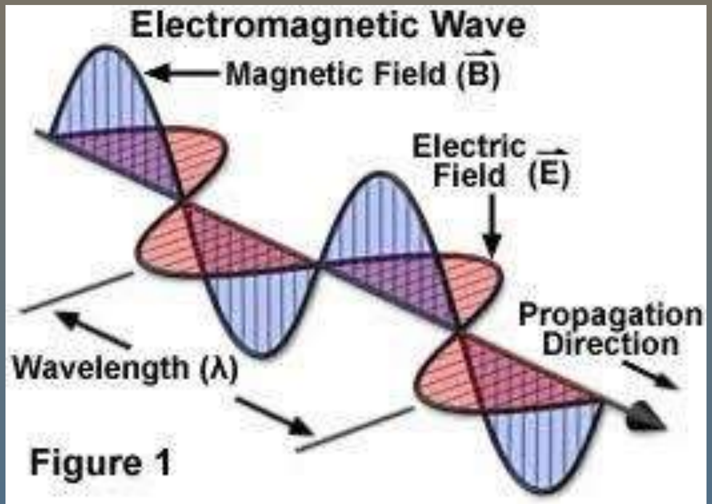
$$\sin^2(2\theta_{ee}) = 4|U_{e4}|^2(1 - |U_{e4}|^2)$$

$$\sin^2(2\theta_{\mu e}) \sim \frac{\sin^2(2\theta_{\mu\mu}) \sin^2(2\theta_{ee})}{4}$$

Search for $\nu_\mu \to \nu_\mu$ disappearence : No oscillation

Neutrinos in a medium

Analogy: electromagnetic waves in dielectric media



→ **Harmonic oscillator**

Acceleration → **EM wave**

$$\mathbf{c} \to \mathbf{v} = \frac{\mathbf{c}}{\mathbf{n}} \quad \text{refraction index}$$

Refraction of neutrinos in matter

Effective mass for neutrinos

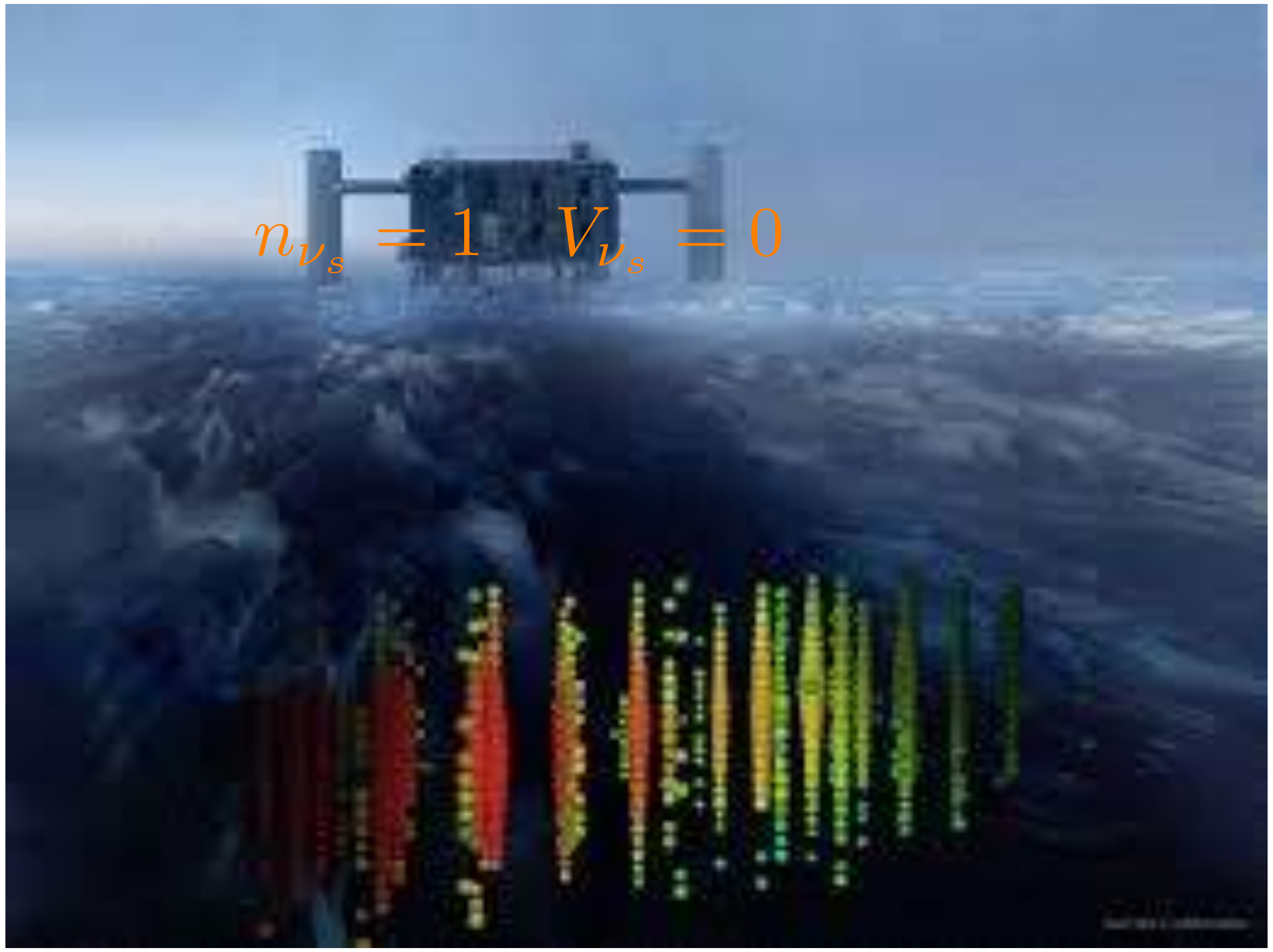
Wolfenstein, Mikheyev and Smirnov (MSW) 1986

$$n_{\nu_e} \neq 1 \quad V_{\nu_e} = \sqrt{2} G_f n_e - \sqrt{2} G_f n_n / 2$$

$$n_{\nu_\mu} \neq 1 \quad V_{\nu_\mu} = -\sqrt{2} G_f N_n / 2$$

$$n_{\nu_s} = 1 \quad V_{\nu_s} = 0$$

ICECUBE test of sterile oscillation

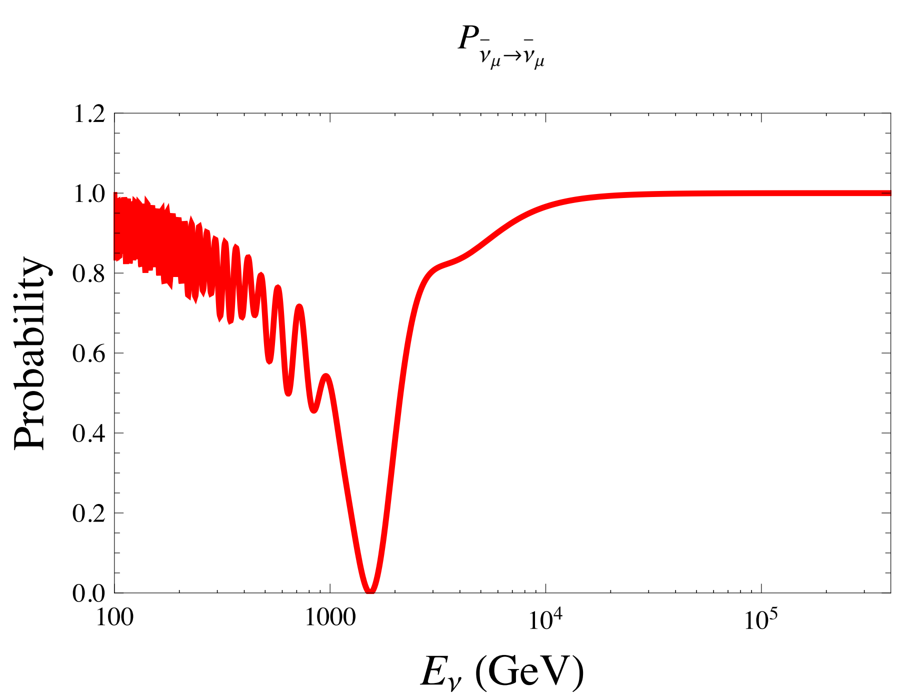


Atmospheric neutrino detector

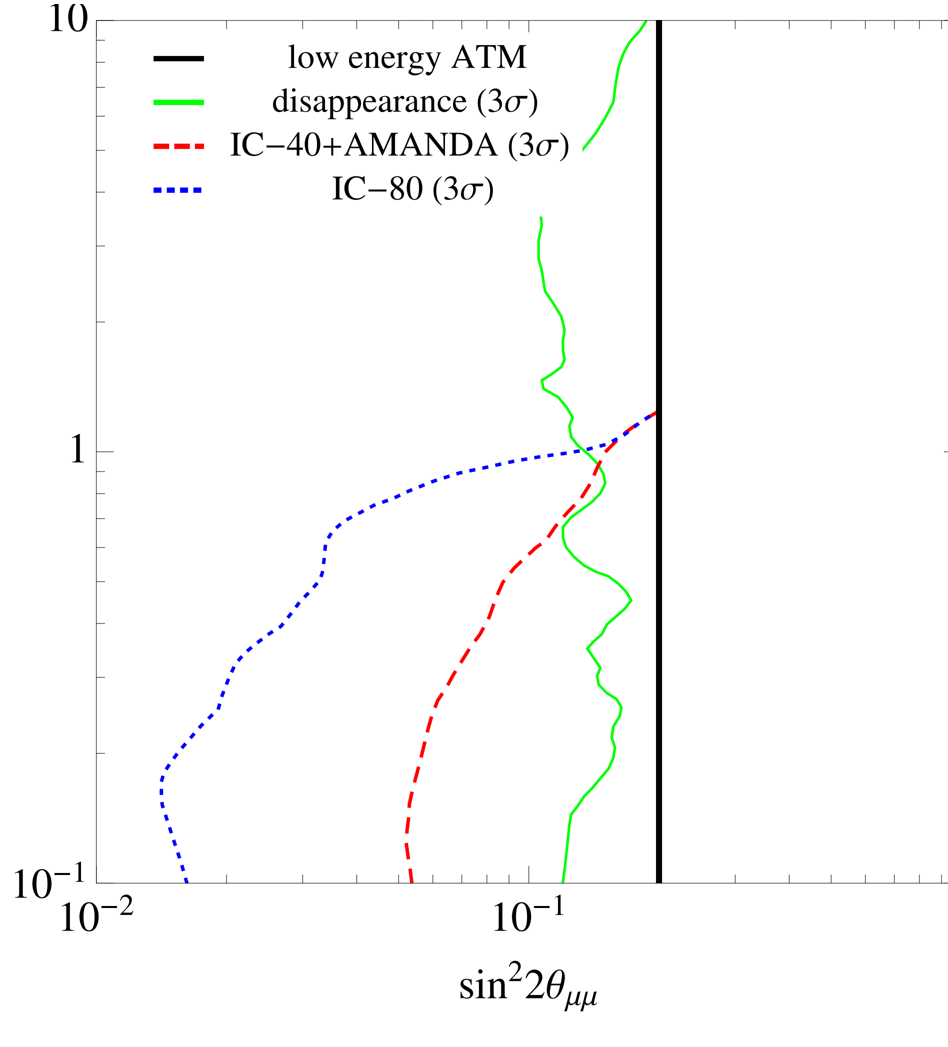
$$n_{\nu_e} \neq 1 \quad V_{\nu_e} = \sqrt{2}G_f n_e - \sqrt{2}G_f n_n/2$$

$$n_{\nu_\mu} \neq 1 \quad V_{\nu_\mu} = -\sqrt{2}G_f N_n/2$$

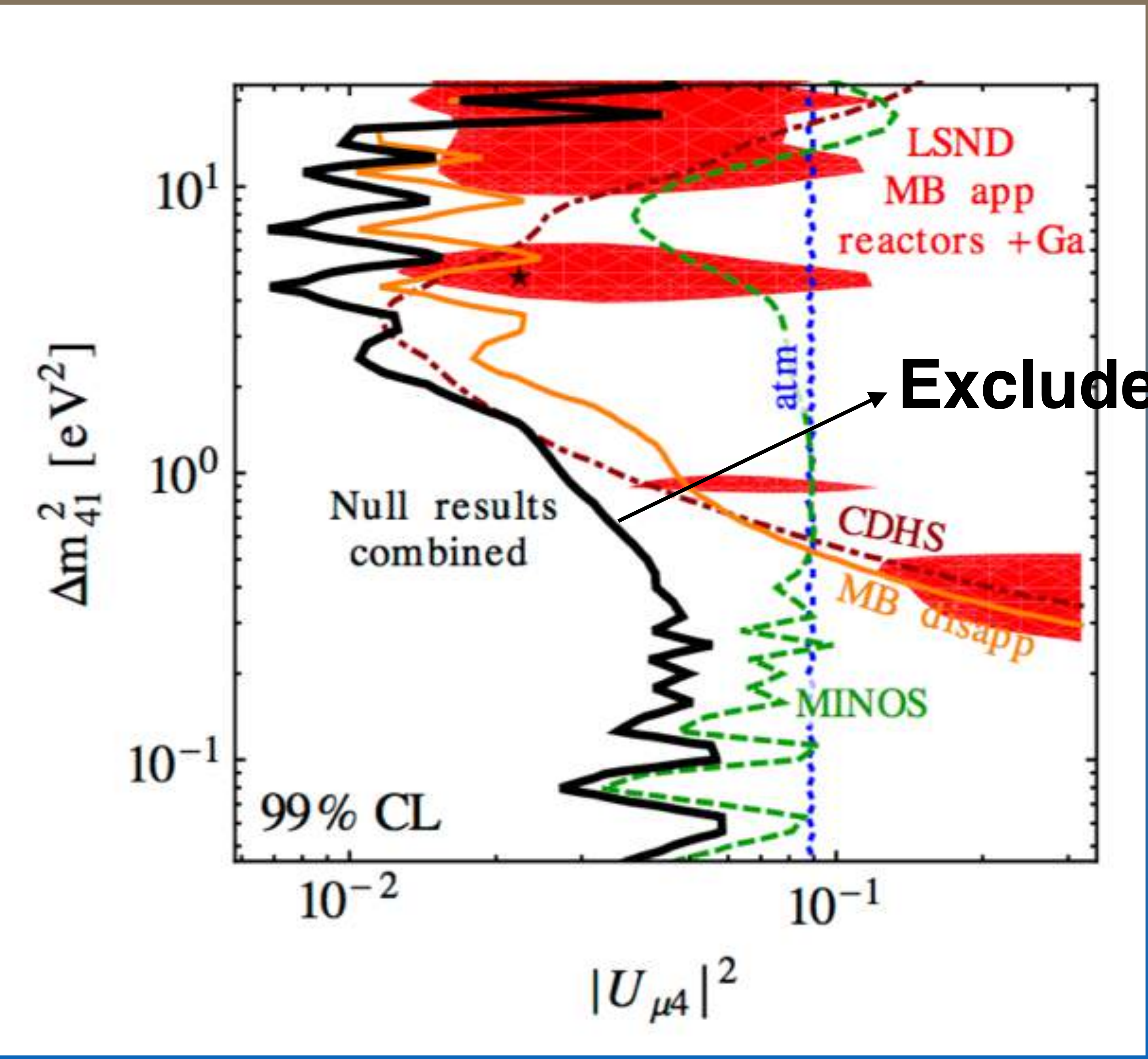
$$n_{\nu_s} = 1 \quad V_{\nu_s} = 0$$



Matter effect for sterile neutrino

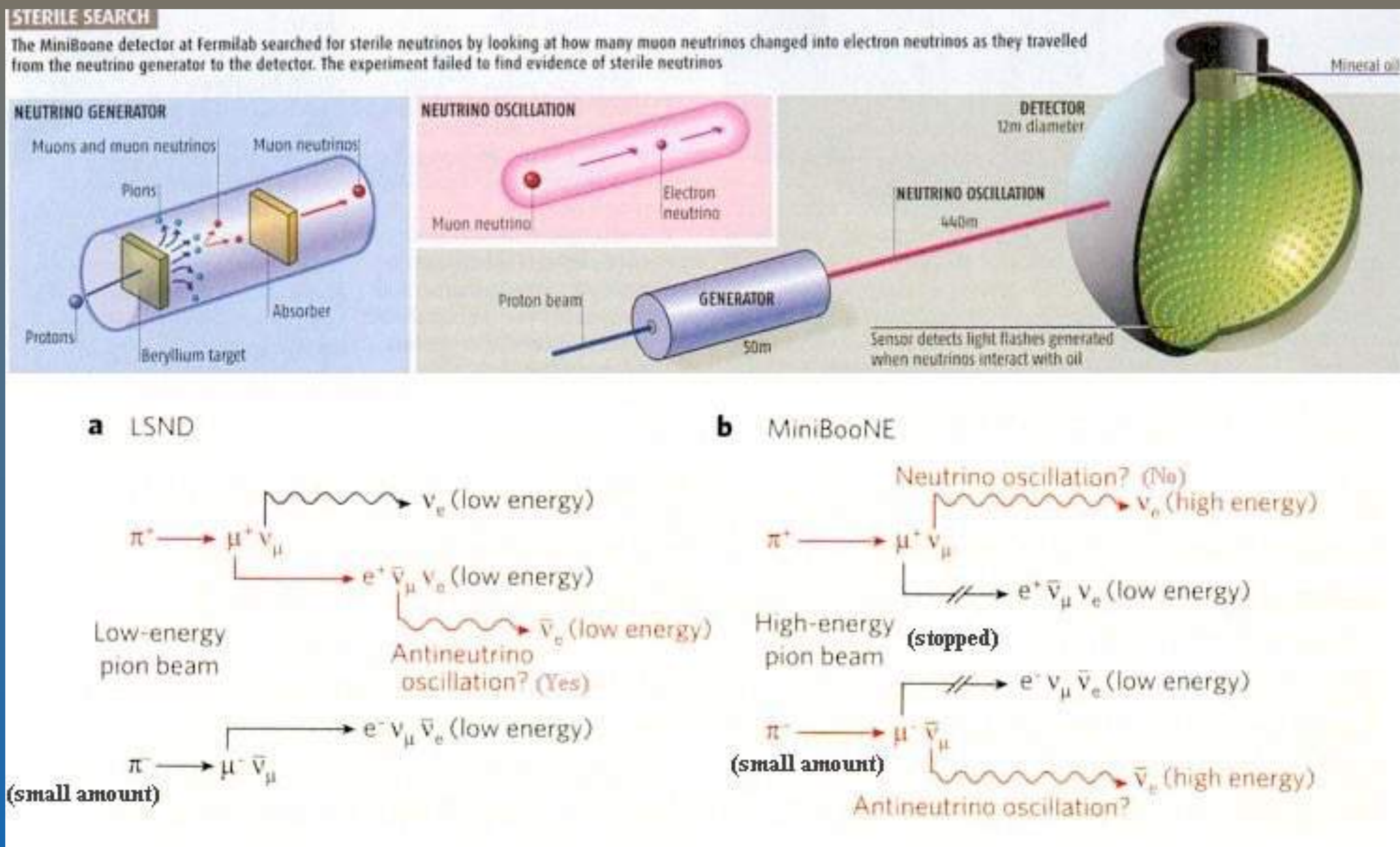


Sterile model in 3+1

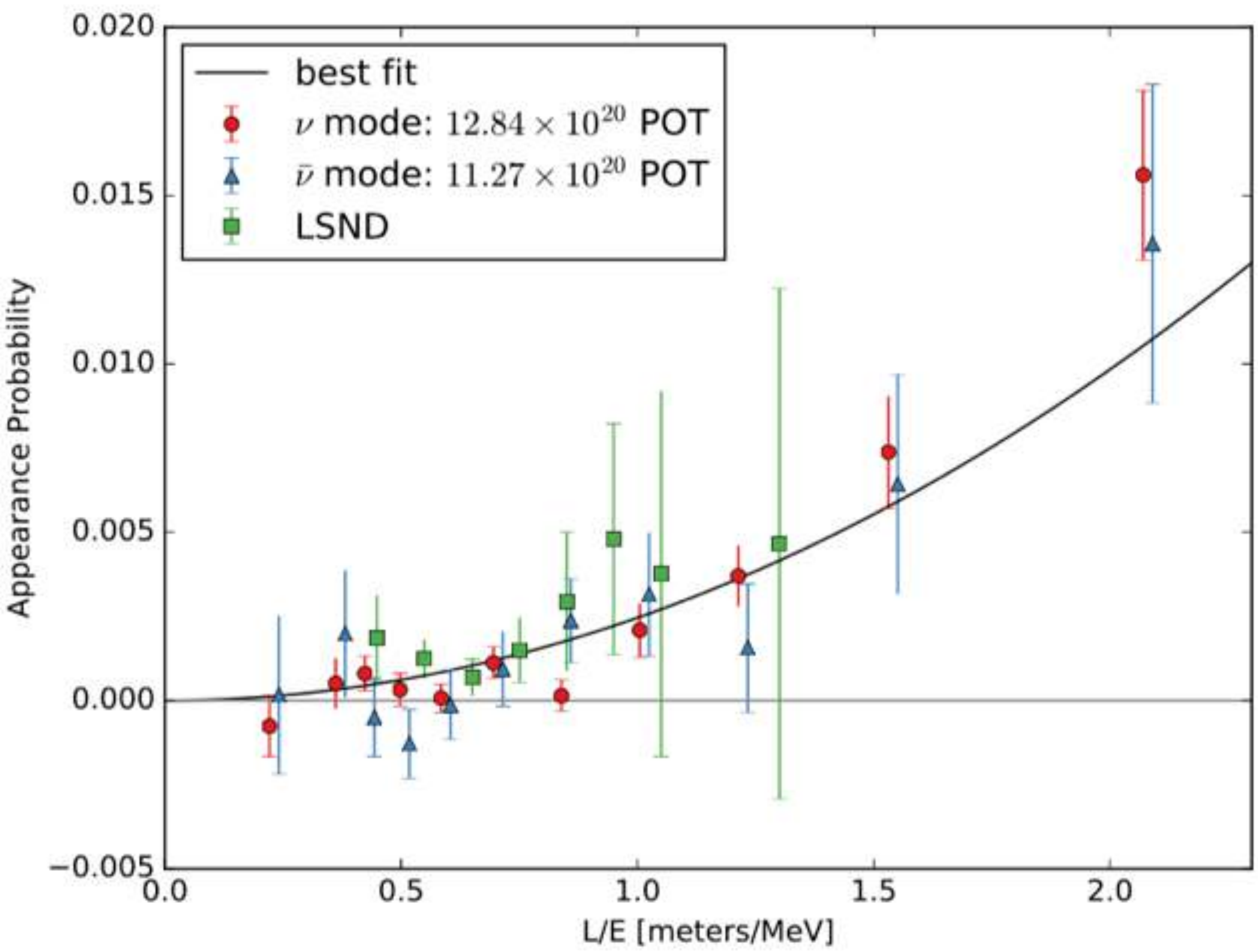


Contradictory statements!

MINI-BOONE 2018



MINI-BOONE RESULTS IN 2018



4.5σ effect

Sterile neutrinos?

Strong hint of sterile neutrinos in MINI-BOONE (small hint in LSND/reactor anomaly)

We should understand about the conflict of muon disappearance and electron appearance

Possible alternatives: experimental error?, another explanation for such small appearance probabilities?

Conflict with cosmology: **too heavy neutrino and too many**

UNICAMP

São Paulo School of Advanced Science on Experimental Neutrino Physics

December 03 – 14, UNICAMP - Campinas - Brazil

São Paulo School of Advanced Science on Experimental Neutrino Physics

The São Paulo School of Advanced Science on Experimental Neutrino Physics (SP – SASEN) proposes to disseminates information and methods in the area, especially to young students and researchers interested in neutrino physics. It will present a general view on key topics with the aid of renowned specialists.

There will be seven main topics:

- Neutrino oscillation phenomenology
- Long baseline neutrino experiments
- Short baseline neutrino experiments
- Sterile neutrinos
- Supernova neutrinos
- Neutrino mass measurements
- Experimental techniques for neutrino detection

There will also be offered hands on activities in which discussion on new technologies will be stimulated. The participants will also be able to present their works in the form of posters during the school. A visit to the Laboratório Nacional de Luz Sincroton (LNLS) is also planned.