Electron (anti)neutrino disappearance in Gallium and reactor experiments

Mario Andrés Acero Ortega

INFN and Università degli Studi di Torino

LAPTH - Université de Savoie

Neutrinos in Particle, in Nuclear and in Astrophysics

Trento, Italy

18 November, 2008

Work in collaboration with

Carlo Giunti and Marco Laveder

Neutrinos oscillations

Quantum mechanical phenomenon $\Rightarrow$ interference of different massive νs.

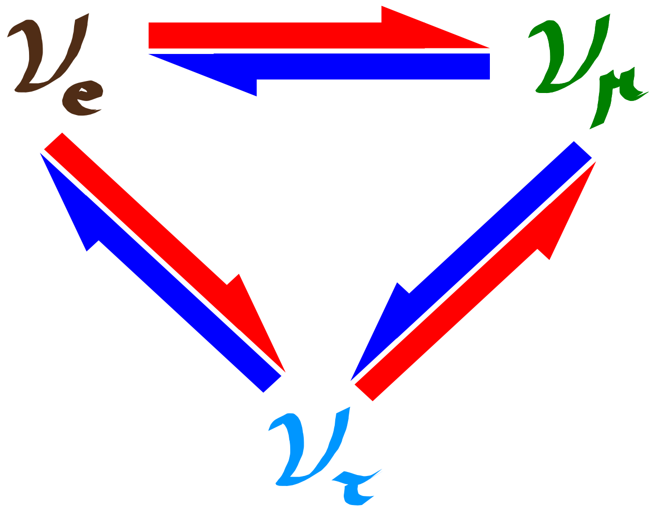
Oscillations between active neutrino flavors

$\Updownarrow$

they are **massive** and **mixed**.

We can detect νs through

- Charged- or neutral current processes ($\nu_e + {}^{71}$Ga $\rightarrow {}^{71}$Ge $+ e^-$ used in gallium experiments);
- Elastic scattering $\nu + e^- \rightarrow \nu + e^-$.



Analysis of Neutrino Experimental Data

Experimental evidence of three-neutrino mixing from solar and atmospheric neutrino experiments:

$$\Delta m^2_{\text{sol}} = (7.59 \pm 0.21) \times 10^{-5}\ \text{eV}^2 \quad \text{[KamLAND PRL 100, 221803 (2008)]}$$

$$\Delta m^2_{\text{atm}} = (2.43 \pm 0.13) \times 10^{-3}\ \text{eV}^2 \quad \text{[MINOS PRL 101, 131802 (2008)]}$$

But... $\rightarrow$ Anomalies which can be interpreted as **exotic neutrino mixing**:

- LSND (but with MiniBOONE...),
- Gallium radioactive source experiments $\rightarrow$ GALLEX, SAGE.

Possible explanation: disappearance of electron neutrinos due to neutrino oscillation ($\nu_e \rightarrow \nu_s$).
Then we analyze the Gallium experiment data and study its compatibility with the data from Bugey and CHOOZ reactor experiments

$\Downarrow$

Two Neutrino Mixing framework.

Gallium radioactive source experiments

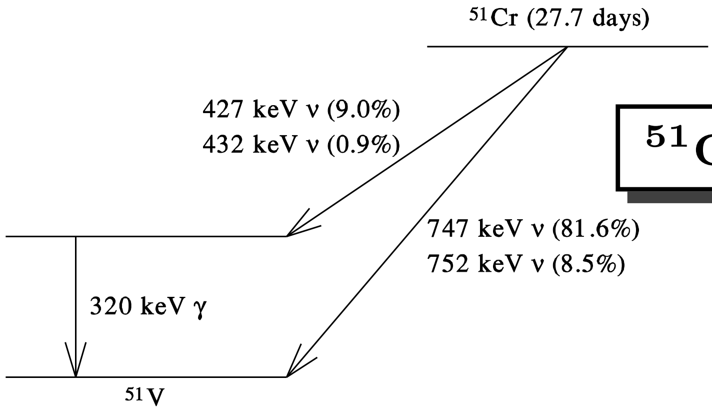
- Designed and performed to test the detectors used in Solar neutrino experiments, to eliminate any doubt on their results.
- Intense radioactive neutrino sources were used (^{51}Cr and ^{37}Ar), with well determined activity, located inside the detector used in Solar neutrino experiments (Gallium).
- Measurement of the source activity with different methodes:
  - Calorimetry,
  - Gamma ray spectroscopy.
- Experimental conditions as close as possible to those for the solar neutrino experiments.

	GALLEX		SAGE	
	Cr1	Cr2	Cr	Ar
R	1.00 ± 0.10	0.81 ± 0.10	$0.95 \pm 0, 12$	0.79 ± 0.10

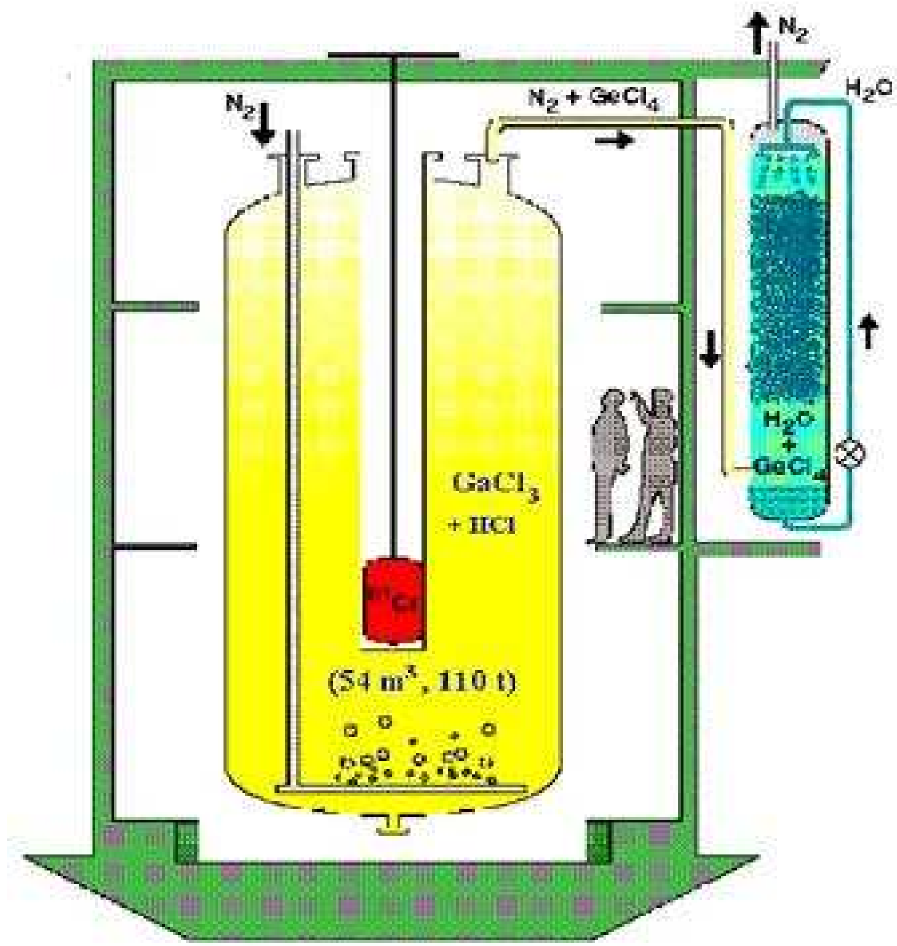
Gallium experiments: GALLEX and SAGE

Electron neutrinos come from the decay of ^{51}Cr and ^{37}Ar radioactive sources which decay through electron capture emitting monoenergetic ν_e detected through the reaction

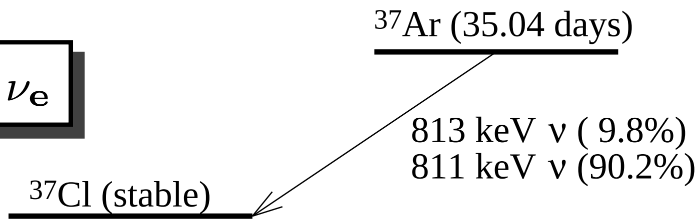
$$\nu_e + {}^{71}\text{Ga} \to {}^{71}\text{Ge} + e^- .$$



$$\mathbf{{}^{51}Cr + e^- \to {}^{51}V + \nu_e}$$



$$\mathbf{{}^{37}Ar + e^- \to {}^{37}Cl + \nu_e}$$



Gallium experiments

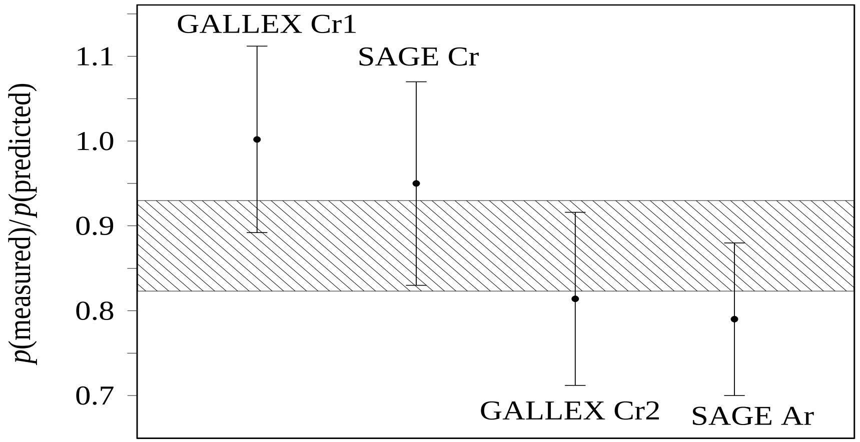
The survival probability of electron (anti)neutrinos with energy E at a distance L from the source is

$$P_{\nu_e \to \nu_e}(L, E) = 1 - \sin^2(2\theta)\sin^2\left(\frac{\Delta m^2 L}{4E}\right),$$

For the analysis we use the theoretical ratio, R_{th}, of the predicted ^{71}Ge production rates with and without neutrino oscillations:

$$R_{th} = \frac{\int dV L^{-2} \sum_i (B.R.)_i \sigma_i P_{\nu_e \to \nu_e}(L, E_i)}{\sum_i (B.R.)_i \sigma_i \int dV L^{-2}},$$

which is to be compared with the measured ratios.



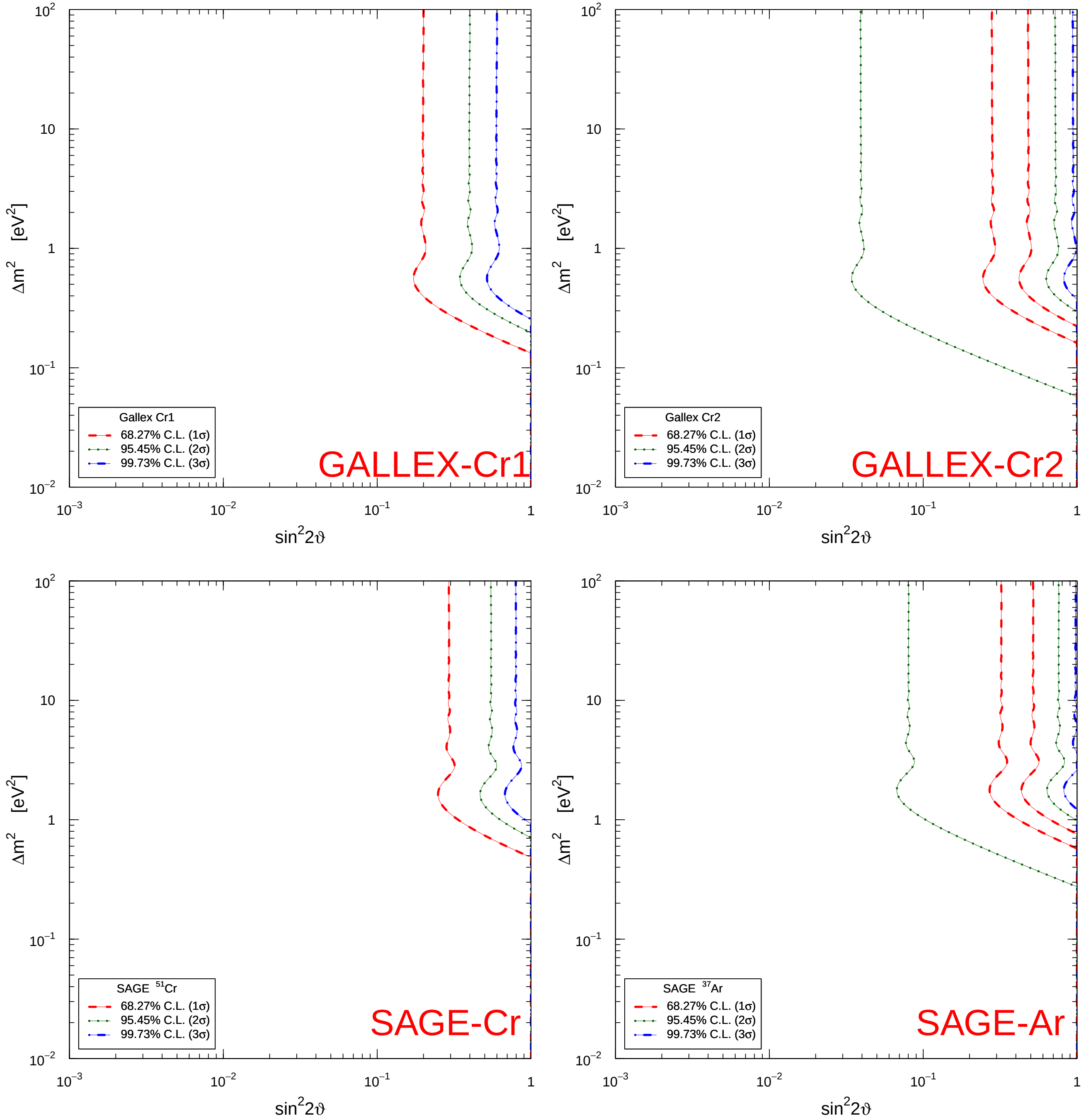
Weighted average

$$\mathbf{R = 0.88 \pm 0.05}$$

[SAGE, PRC 73 (2006) 045805]

Gallium experiments

Upper limits from GALLEX-Cr1 and SAGE ^{51}Cr, while 2σ allowed bands for GALLEX-Cr2 and SAGE ^{37}Ar, with $\mathbf{\Delta m^2 \gtrsim 1\,eV^2}$ (Table).

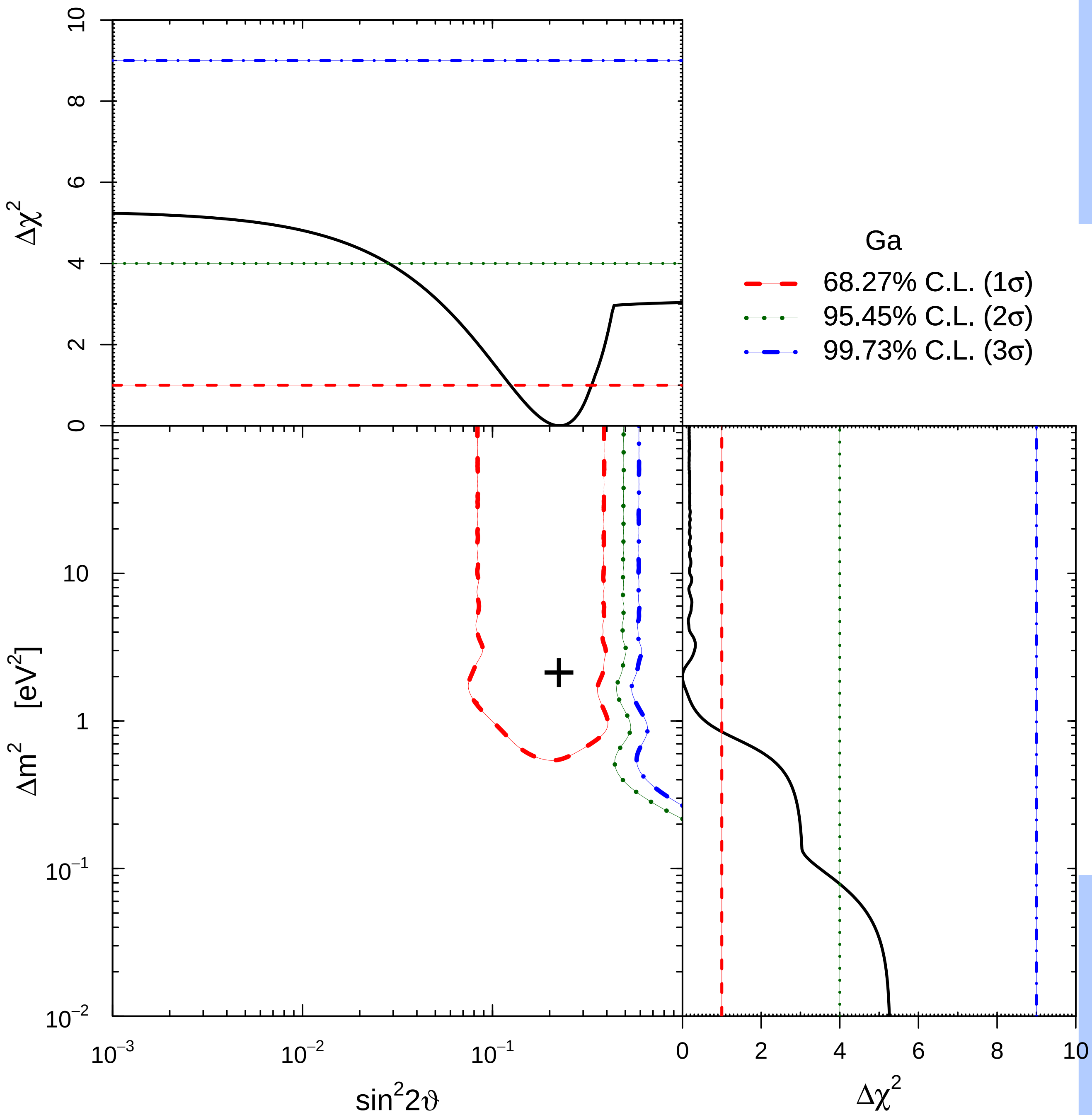


Gallium experiments

Combined least-squares analysis for the Gallium experiments. It shows a 1σ allowed region, and we find

$$\chi^2_{\text{min}} = 2.94$$
$$\text{NDF} = 2$$
$$\text{GoF} = 0.23$$
$$\sin^2 2\theta = 0.22$$
$$\Delta m^2 = 1.98 \text{ eV}^2$$

[PRD 78 (2008) 073009, arXiv:0711.422]



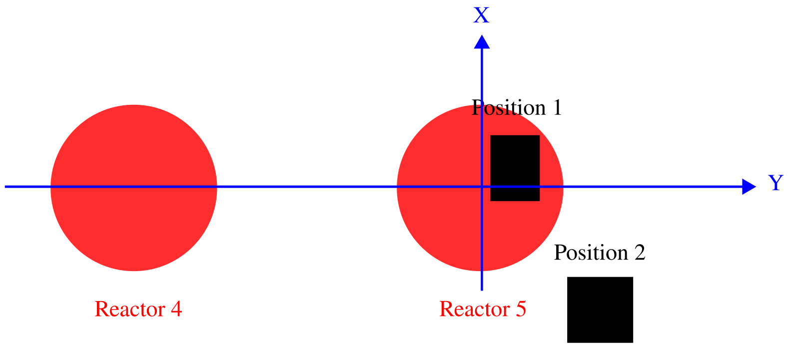
Reactor experiments

Electron antineutrino detected through the inverse beta decay process

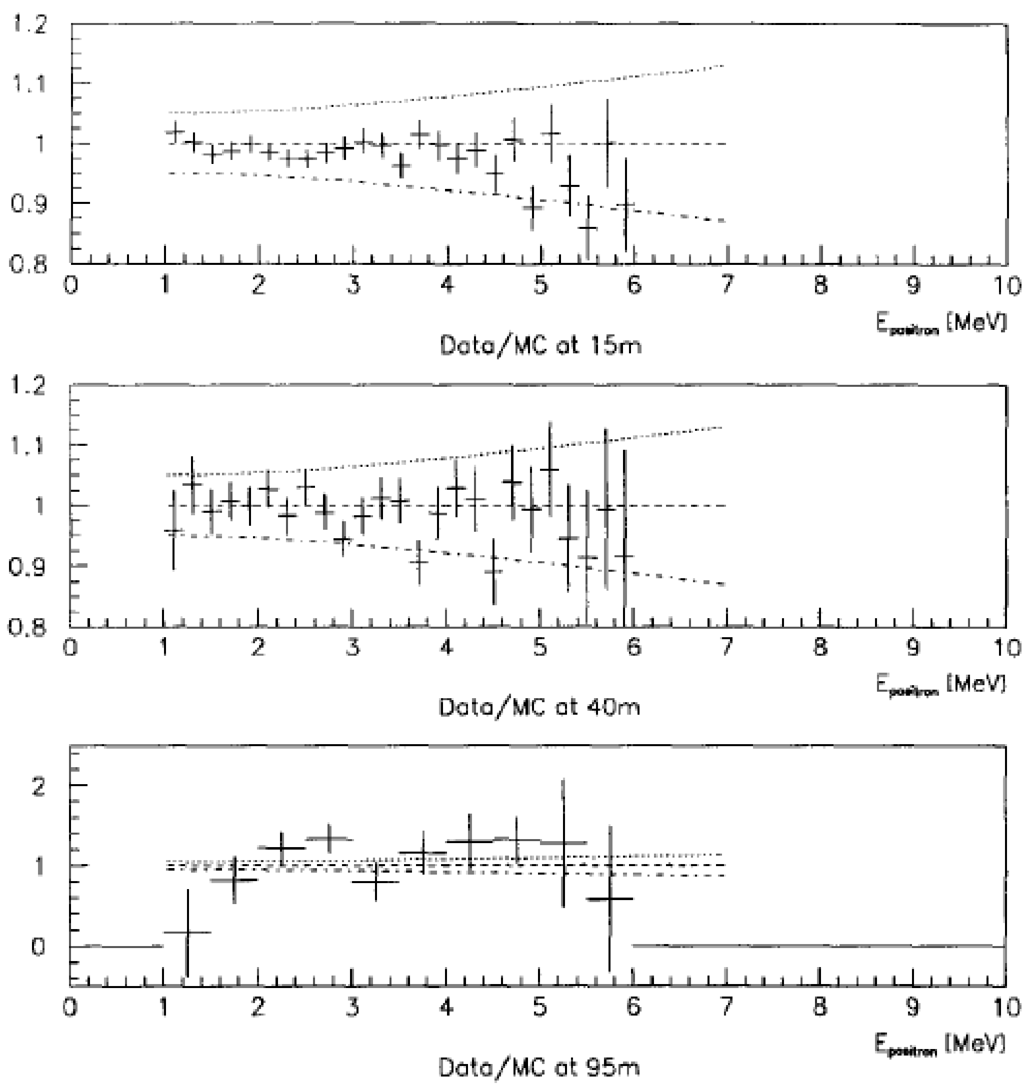
$$\bar{\nu}_e + p \to n + e^+$$

with the energy relation $E_\nu = E_{e^+} + 1.8$MeV.

The **Bugey** experiment searches for $\bar{\nu}_e$ disappearance at the three distances ($L_j = 15, 40, 95$ m) and collected $N_j = 25, 25, 10$ (for $j = 1, 2, 3$) energy bins (data).



Bugey, NPB 434 (1995) 503



Bugey

Narrow 1σ allowed region with Δm^2 around 0.9 eV^2, 1.85 eV^2 and 3.0 eV^2 and

$\chi^2_{\text{min}} = 47.97$

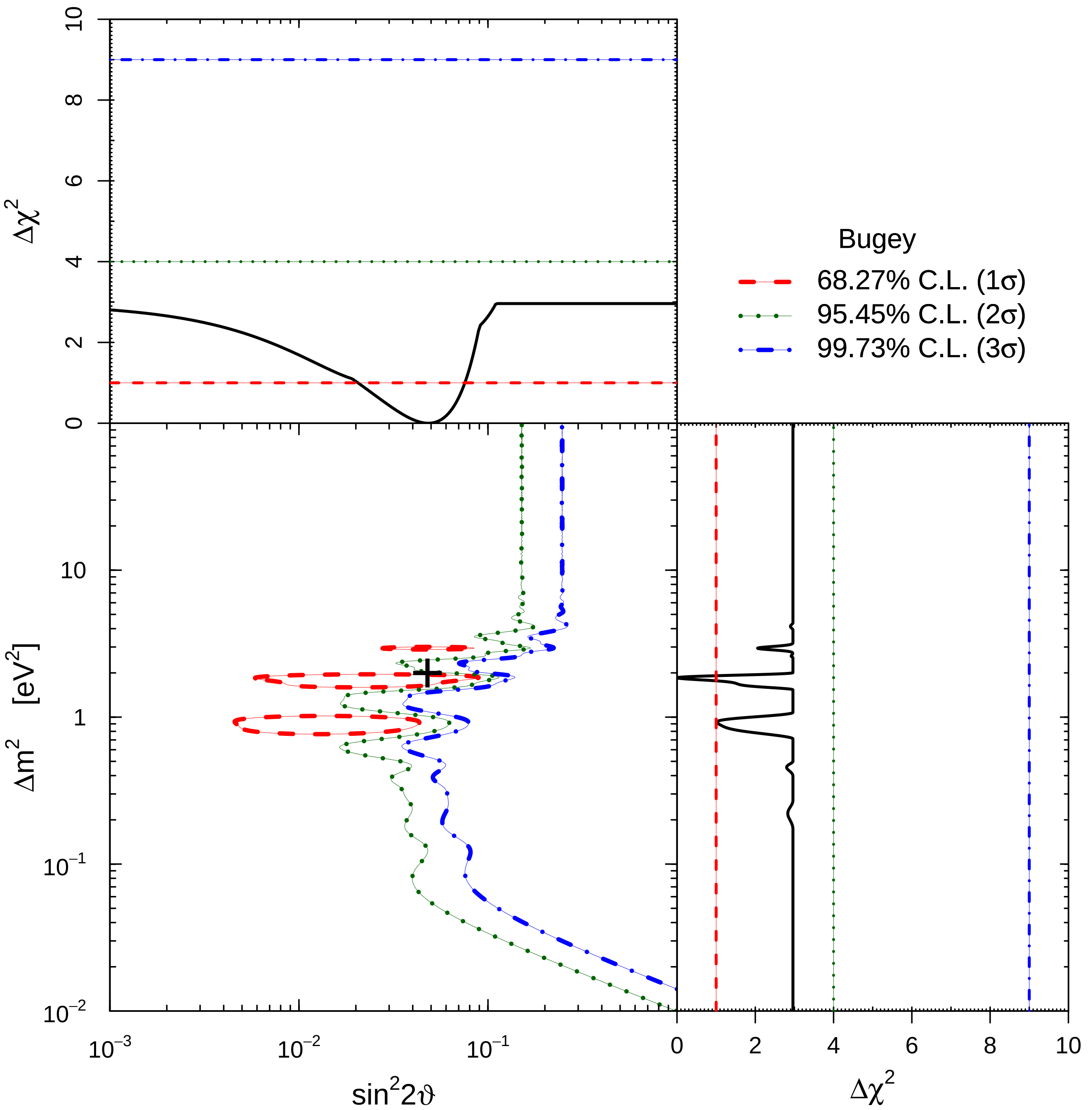
NDF $= 53$

GoF $= 0.67$

$\sin^2 2\theta = 0.048$

$\Delta m^2 = 1.85$ eV^2

[PRD 78 (2008) 073009, arXiv:0711.422]

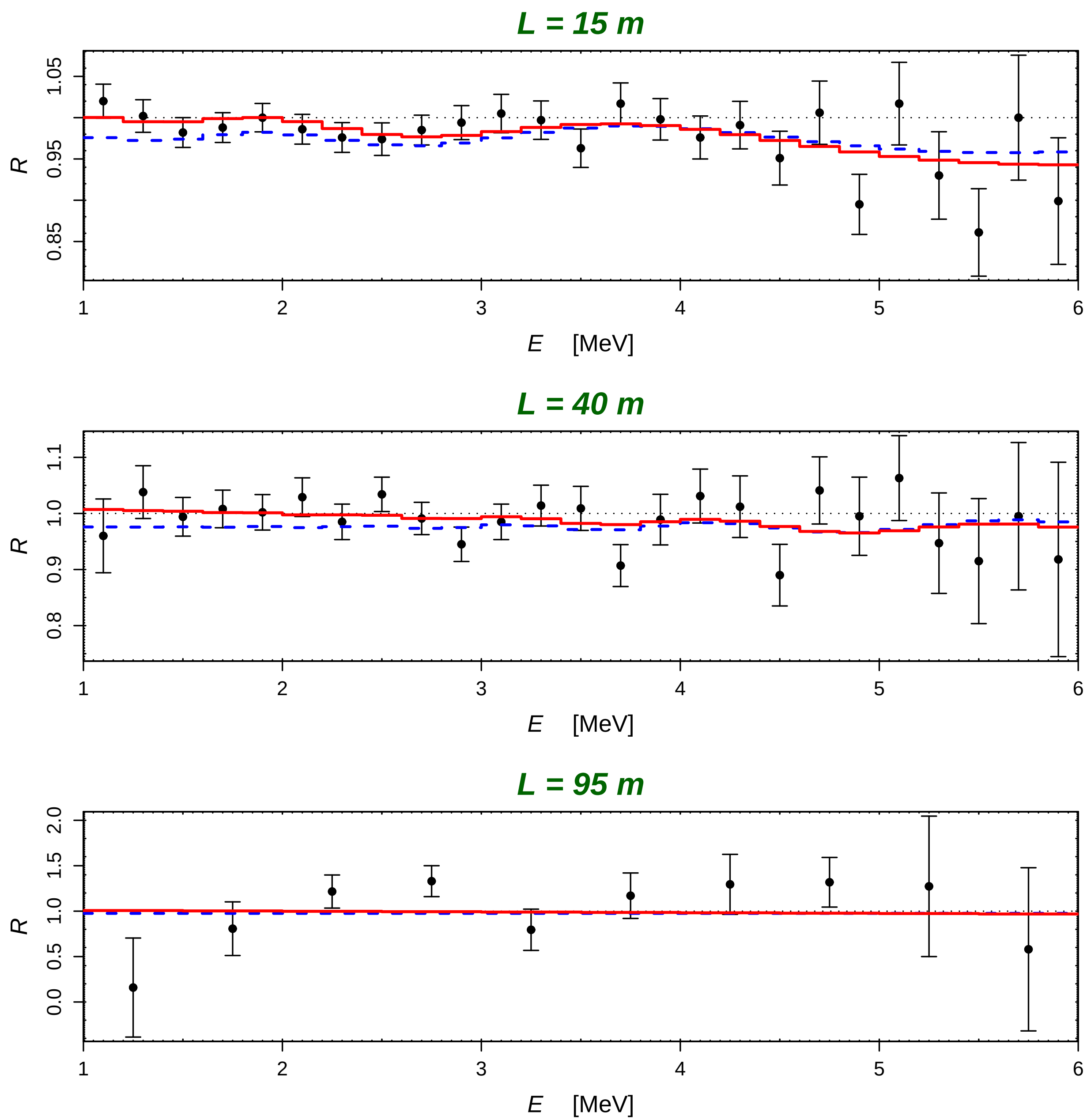


Bugey spectra

Histogram relative to the best fit against the Bugey experimental data

$$\sin^2 2\theta_{\mathrm{bf}} = 0.048$$

$$\Delta m^2_{\mathrm{bf}} = 1.85\ \mathrm{eV}^2$$



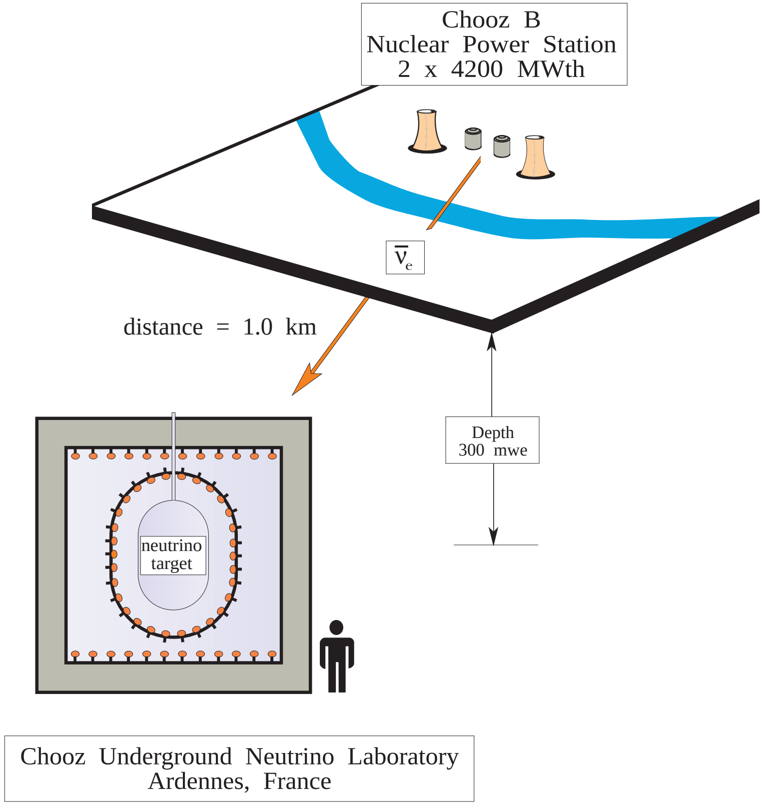
Chooz

The ratio of the number of observed to the expected events (in absence of oscillations) is $R_{\text{Chooz}} = 1.01 \pm 0.04$ [Chooz, EPJ C 27 (2003) 331].

$$P_{\bar{\nu}_e \to \bar{\nu}_e}(L, E) = 1 - \sin^2(2\theta)\sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$

average to

$$\langle P_{\bar{\nu}_e \to \bar{\nu}_e} \rangle = 1 - \frac{1}{2}\sin^2 2\theta,$$



Experiment	L	E	Δm^2
Bugey (SBL)	$\sim$ 10 m	$\sim$ 1 MeV	$\sim$ 0.1 eV^2
Chooz (LBL)	$\sim$ 1 km	$\sim$ 1 MeV	$\sim 10^{-3}$ eV^2

Which is then combined with the previous analysis, in the Δm^2 scale we are interested in ($\Delta m^2 \sim 1$ eV^2).

Global fit

Weak indication in favor of neutrino oscillations with

$\chi^2_{\text{min}} = 54.80$

$\text{NDF} = 58$

$\text{GoF} = 0.60$

$\sin^2 2\theta = 0.054$

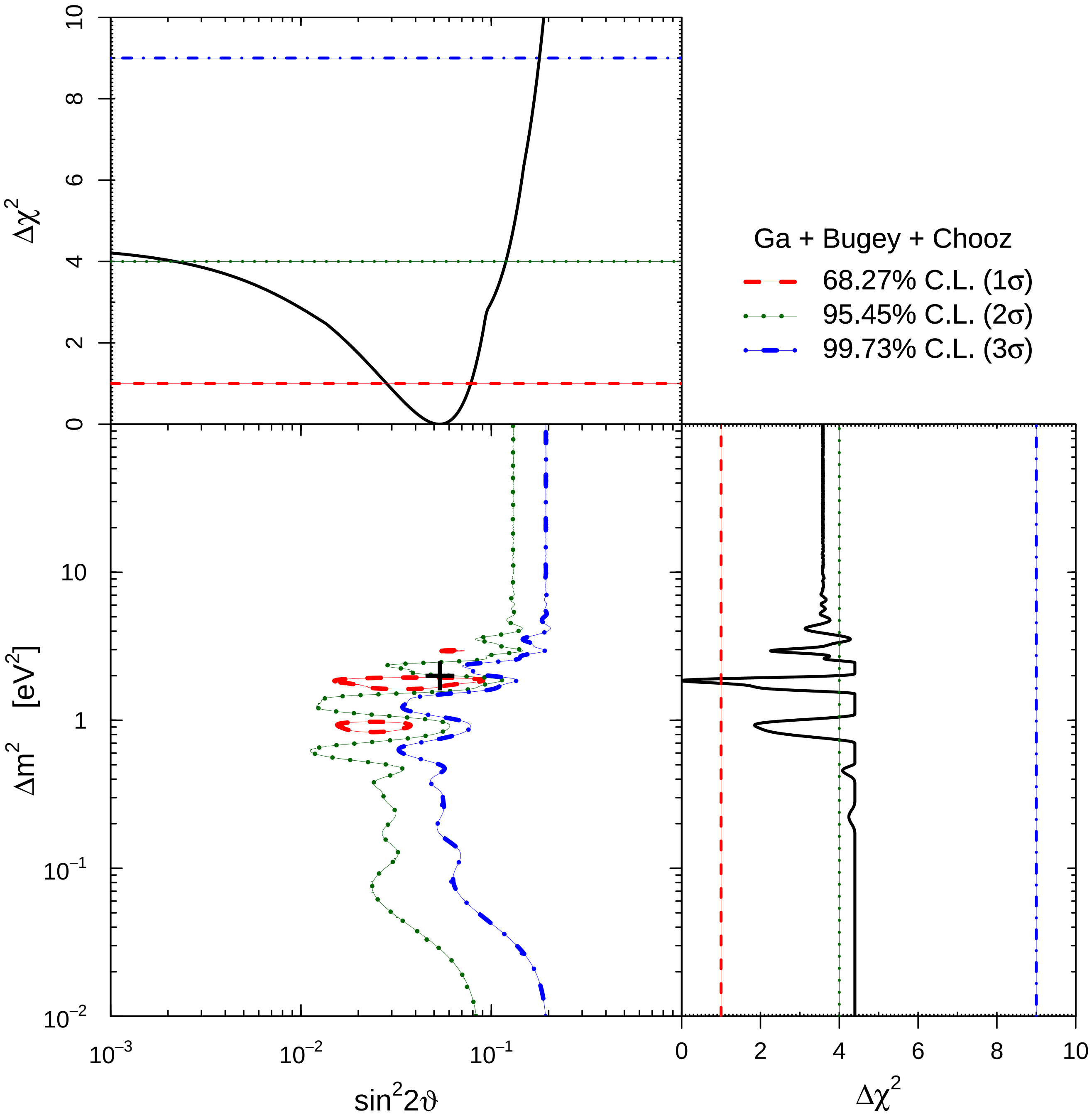
$\Delta m^2 = 1.85\ \text{eV}^2$

$\Delta\chi^2_{\text{min}} = 3.85$

$\text{NDF} = 3$

$\text{PGoF} = 0.28$

[PRD 78 (2008) 073009, arXiv:0711.422]

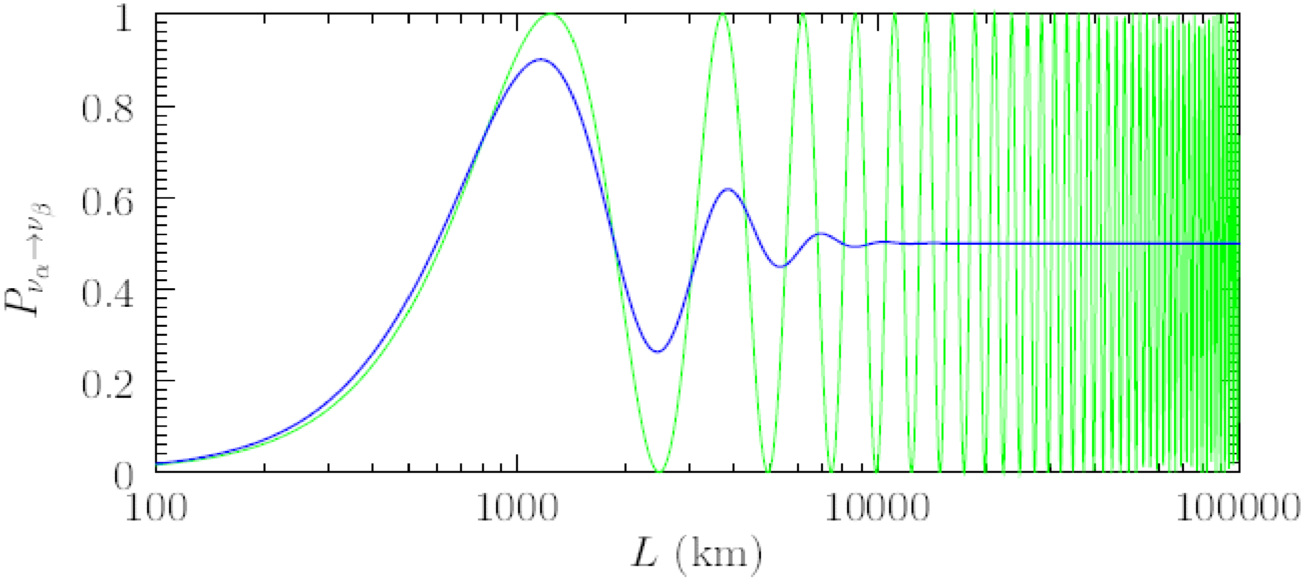


Conclusions

- From Gallium experiments, **we found and indication of neutrino disappearance due to neutrino oscillations** with $\sin^2 2\theta \gtrsim 0.03$ and $\Delta m^2 \gtrsim 0.1$ eV^2 at $\sim 70 - 90\%$ C.L.
- The Bugey data present a **weak indication in favor of neutrino oscillations** with $0.02 \lesssim \sin^2 2\theta \lesssim 0.08$ and $\Delta m^2 \simeq 1.8$ eV^2.
- In the combined analysis of the Gallium, Bugey and CHOOZ data, the **weak indication persists**, with **compatible results** between the Bugey-Gallium, Bugey-CHOOZ and Gallium-CHOOZ data analysis.
- These indications of new physics may be explored by
  - Beta-beam experiments,
  - Neutrino Factory experiments,
  - The LENS detector with an artificial Megacurie ν_e source.

Average over Energy Resolution of the Detector

$$P_{\nu_\alpha \to \nu_\beta}(L,E) = \sin^2 2\vartheta \sin^2\left(\frac{\Delta m^2 L}{4E}\right) = \frac{1}{2}\sin^2 2\vartheta \left[1 - \cos\left(\frac{\Delta m^2 L}{2E}\right)\right]$$



$\Delta m^2 = 10^{-3}\,\text{eV}$ $\quad \sin^2 2\vartheta = 1$ $\quad \langle E \rangle = 1\,\text{GeV}$ $\quad \Delta E = 0.2\,\text{GeV}$

$$\langle P_{\nu_\alpha \to \nu_\beta}(L,E) \rangle = \frac{1}{2}\sin^2 2\vartheta \left[1 - \int \cos\left(\frac{\Delta m^2 L}{2E}\right) \phi(E)\, \mathrm{d}E\right] \qquad (\alpha \neq \beta)$$