Analysis of Neutrino Oscillation experiments

Mario Andrés Acero Ortega

Università degli Studi di Torino , LAPTH - Université de Savoie

Second Year - Seminar

Torino, Italy

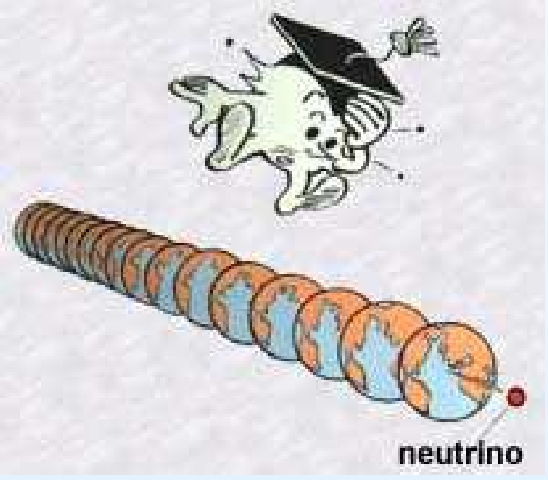
January 15th, 2008

Tutor: Carlo Giunti (INFN - Torino)

Co-Tutor: Julien Lesgourgues (LAPTH - Annecy)

1. Outline

- Neutrino oscillations
- Analysis of Neutrino Experimental Data
  - Gallium experiments
  - Reactor experiments
- Conclusions
- What is coming...



2. Neutrinos oscillations

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

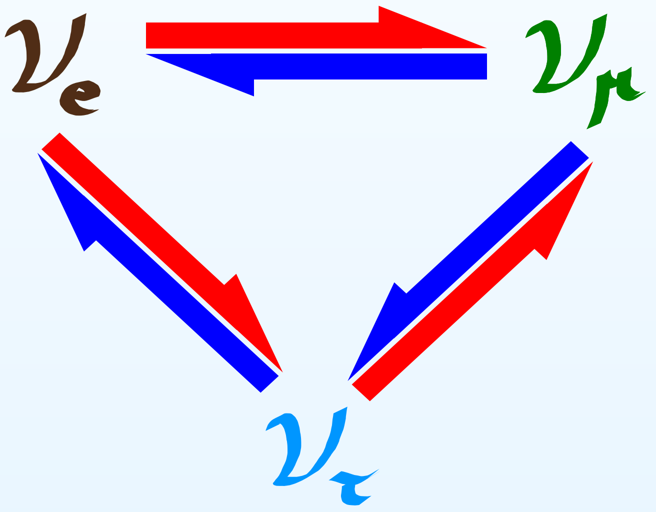
Oscillations between active neutrino flavors

$\Updownarrow$

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

We can detect νs through

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



3. Analysis of Neutrino Experimental Data

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

$$\Delta m^2_{\text{sol}} = (8.0^{+0.6}_{-0.4}) \times 10^{-5}\text{eV}^2 \qquad \Delta m^2_{\text{atm}} \simeq 2 - 3 \times 10^{-3}\text{eV}^2$$

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

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

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

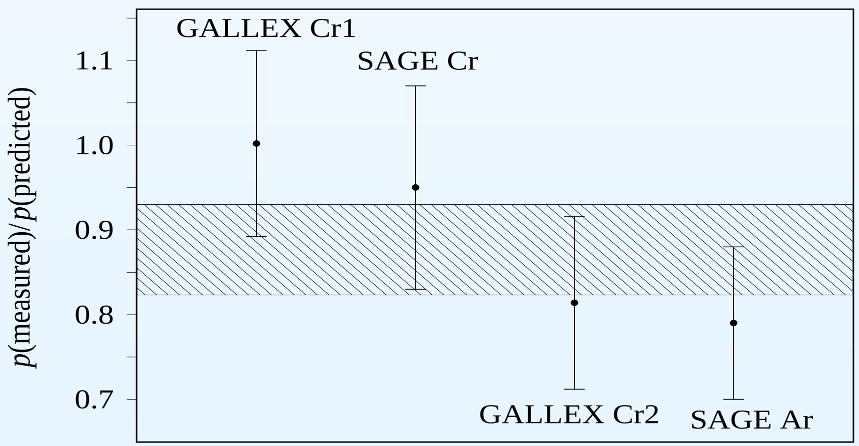
$\Downarrow$

Two Neutrino Mixing framework.

3.1 Ga experiments: GALLEX and SAGE

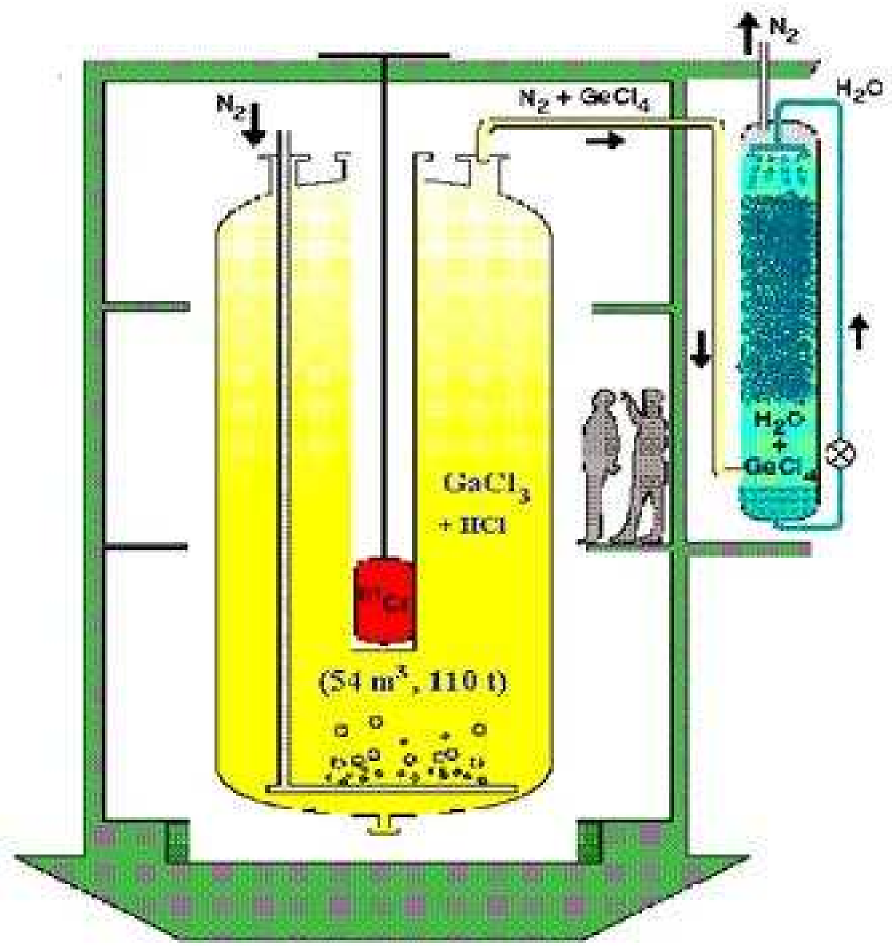
Electron neutrinos come from the decay of ^{51}Cr and ^{37}Ar radioactive sources which decay through electron capture emiting monoenergetic ν_e detected through the reaction

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



Weighted average
$\mathbf{R = 0.88 \pm 0.05}$.

Solar Seutrino Experiments



3.2 Ga experiments

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

$$P_{\nu_e \to \nu_e}(L, E) = 1 - \sin^2(2\theta)\sin^2\left(1.27\frac{\Delta m^2(eV^2)L(m)}{E(MeV)}\right),$$

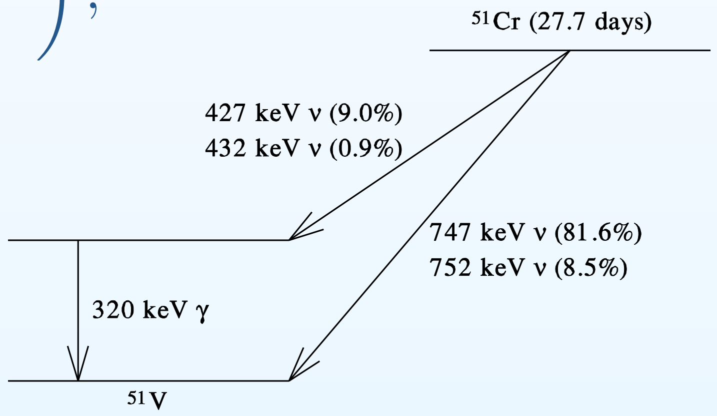
For the analysis we use the theoretical ratio, R_{th}, of the predicted ^{71}Ge production rates with and without neutrino oscillations:

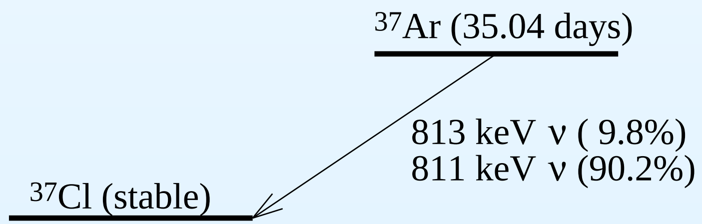
$$R_{th} = \frac{\int dV L^{-2} \sum_i B_i \sigma_i P_{\nu_e \to \nu_e}(L, E_i)}{\sum_i B_i \sigma_i \int dV L^{-2}},$$

which is to be compared with the measured ratios.

Electron capture

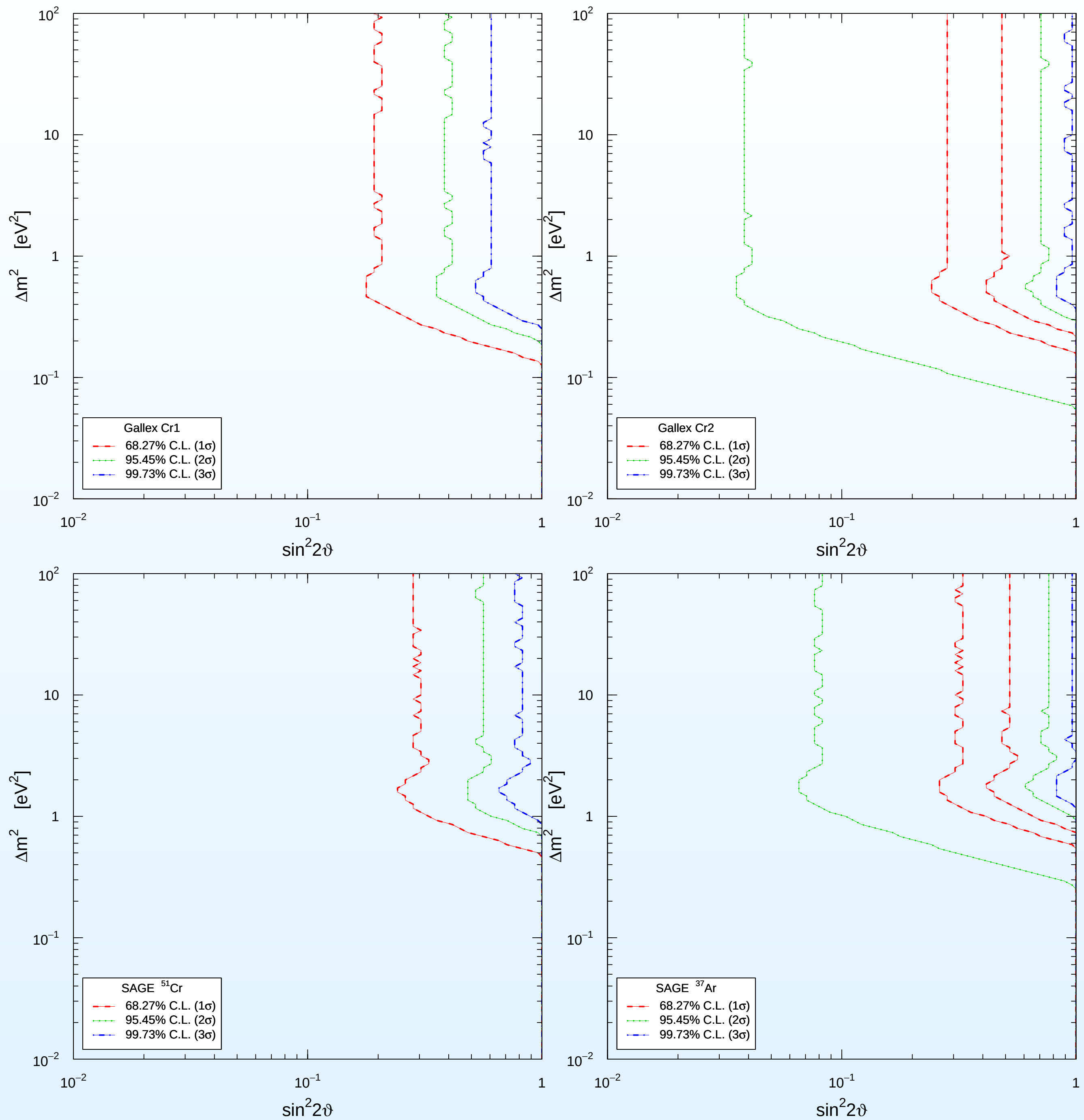
$$\mathbf{{}^{51}_{24}Cr + e^- \to {}^{51}_{23}V + \nu_e}$$





3.3 Ga experiments

2σ allowed bands for GALLEX-Cr2 and SAGE ^{37}Ar, with $\Delta m^2 \gtrsim 1\,\mathrm{eV}^2$.



3.4 Ga experiments

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

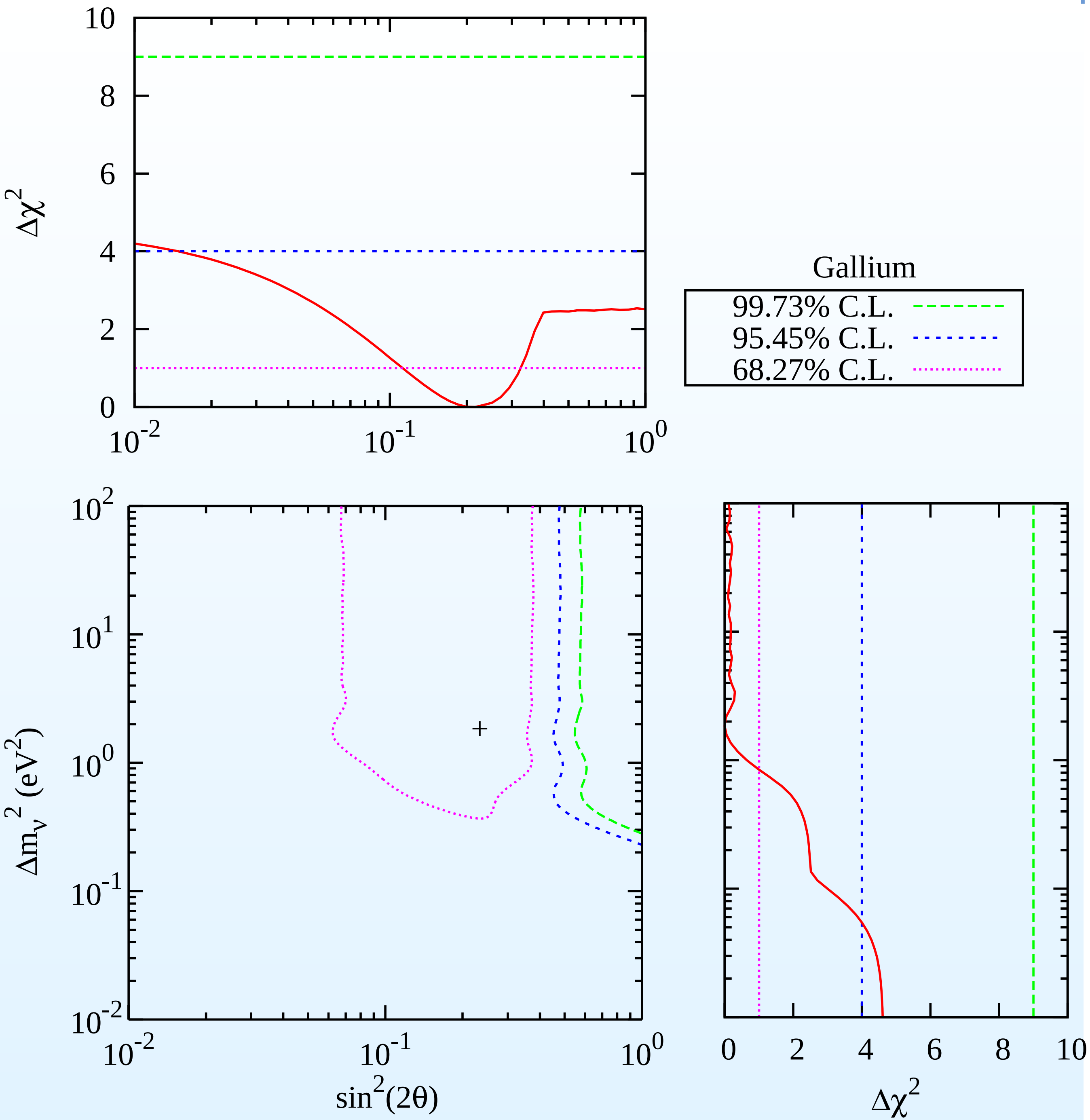
$$\mathbf{\Delta m^2_{bf} = 2.03\,eV^2}$$

$$\sin^2(2\theta)_{bf} = 0.23$$

and at 1σ (68.27 % C.L.)

$$\mathbf{\Delta m^2 > 0.84\,eV^2}$$

$$\sin^2(2\theta)_{bf} = 0.13 - 0.34$$

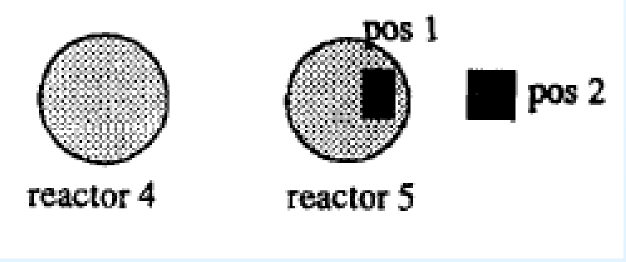


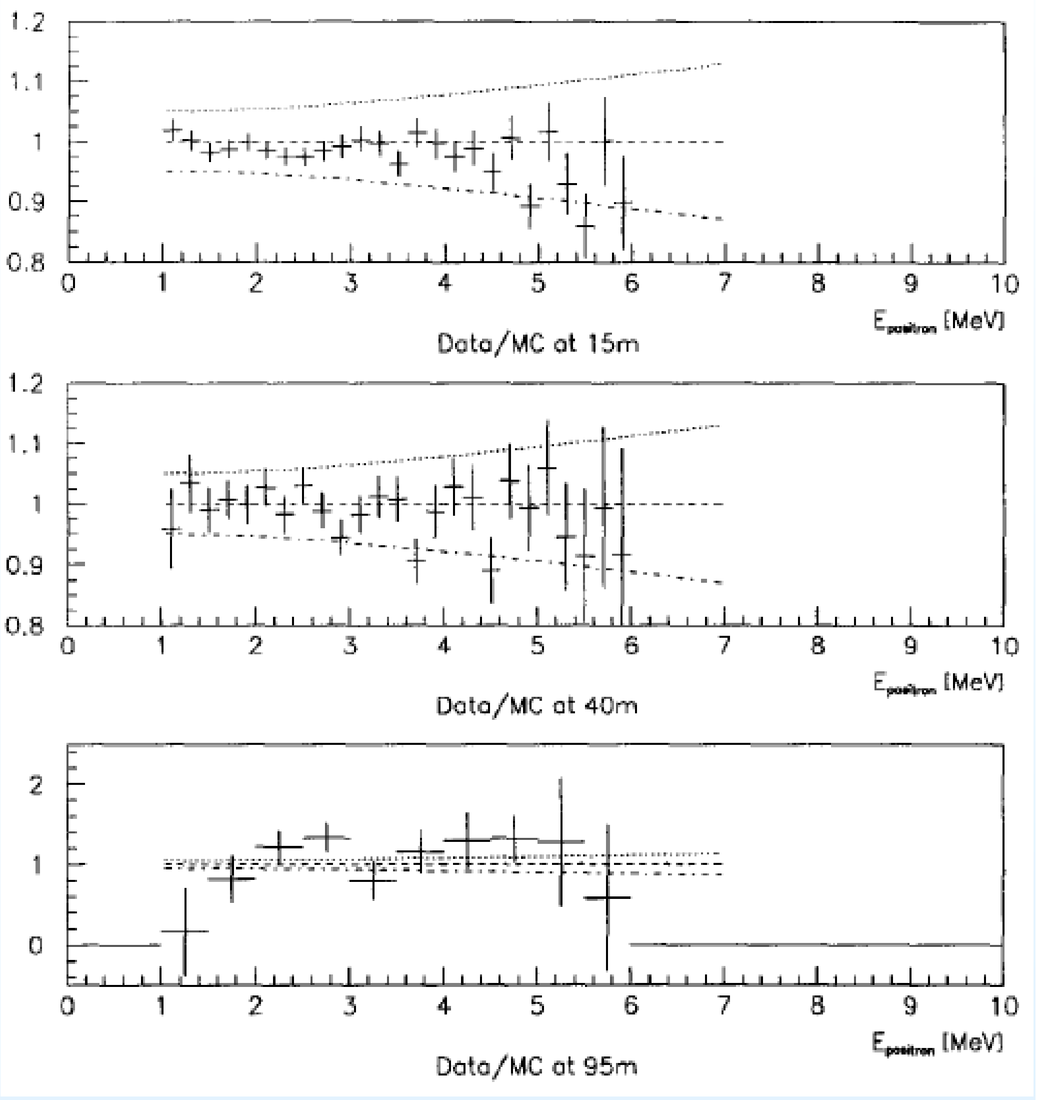
4. Reactor experiments

Electron antineutrino detected through the inverse beta decay process

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

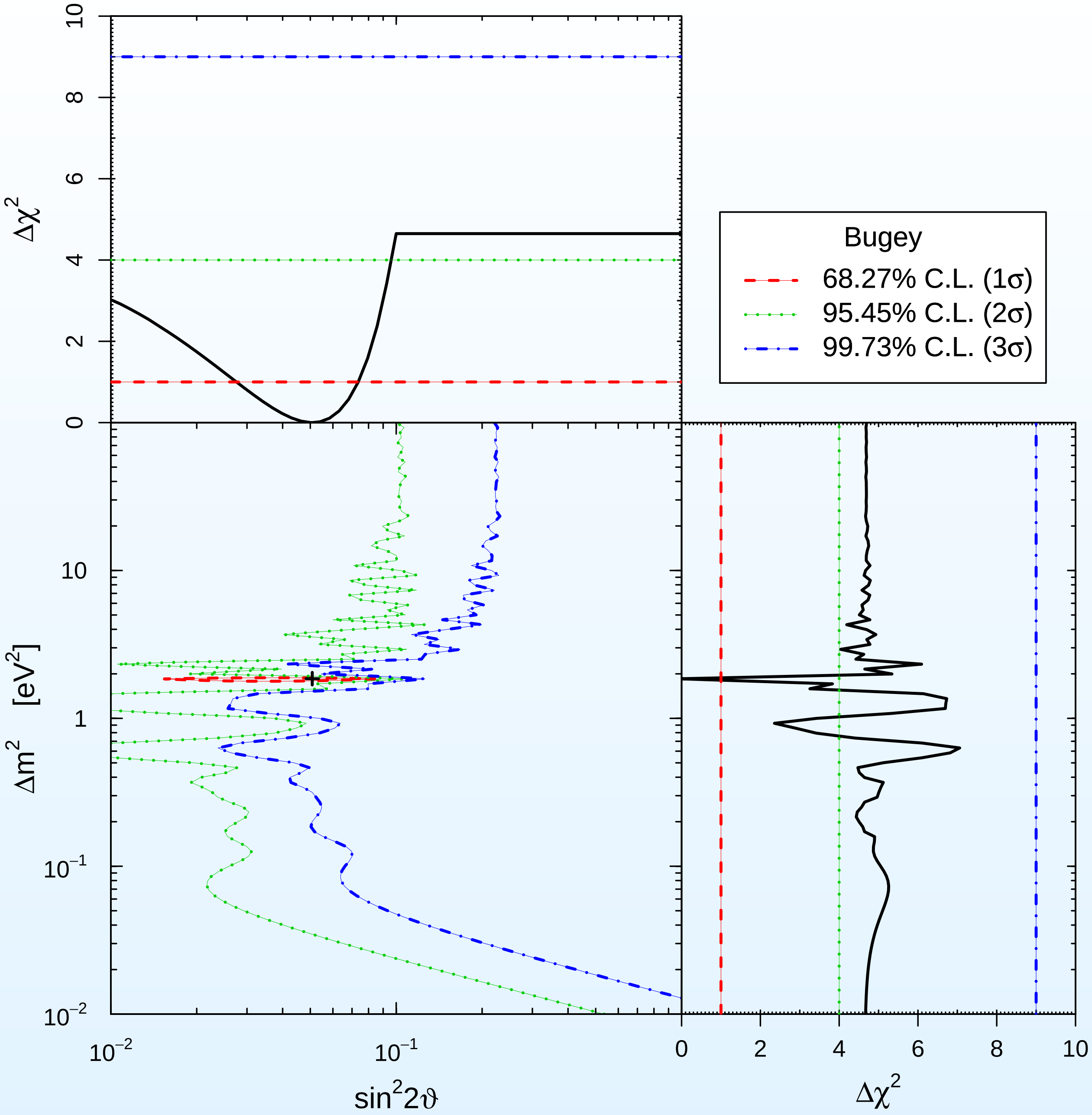
with the energy relation $E_\nu = E_{e^+} + 1.8$MeV.
The **Bugey** experiment searches for $\bar{\nu}_e$ disappearance at the three distances ($L_j = 15, 40, 95$ m) and collected $N_j = 25, 25, 10$ (for $j = 1, 2, 3$) energy bins (data).





4.1 Bugey

Narrow 1σ allowed region with Δm^2 around $1.85eV^2$ and $0.02 \lesssim \sin^2 2\theta \lesssim 0.08$

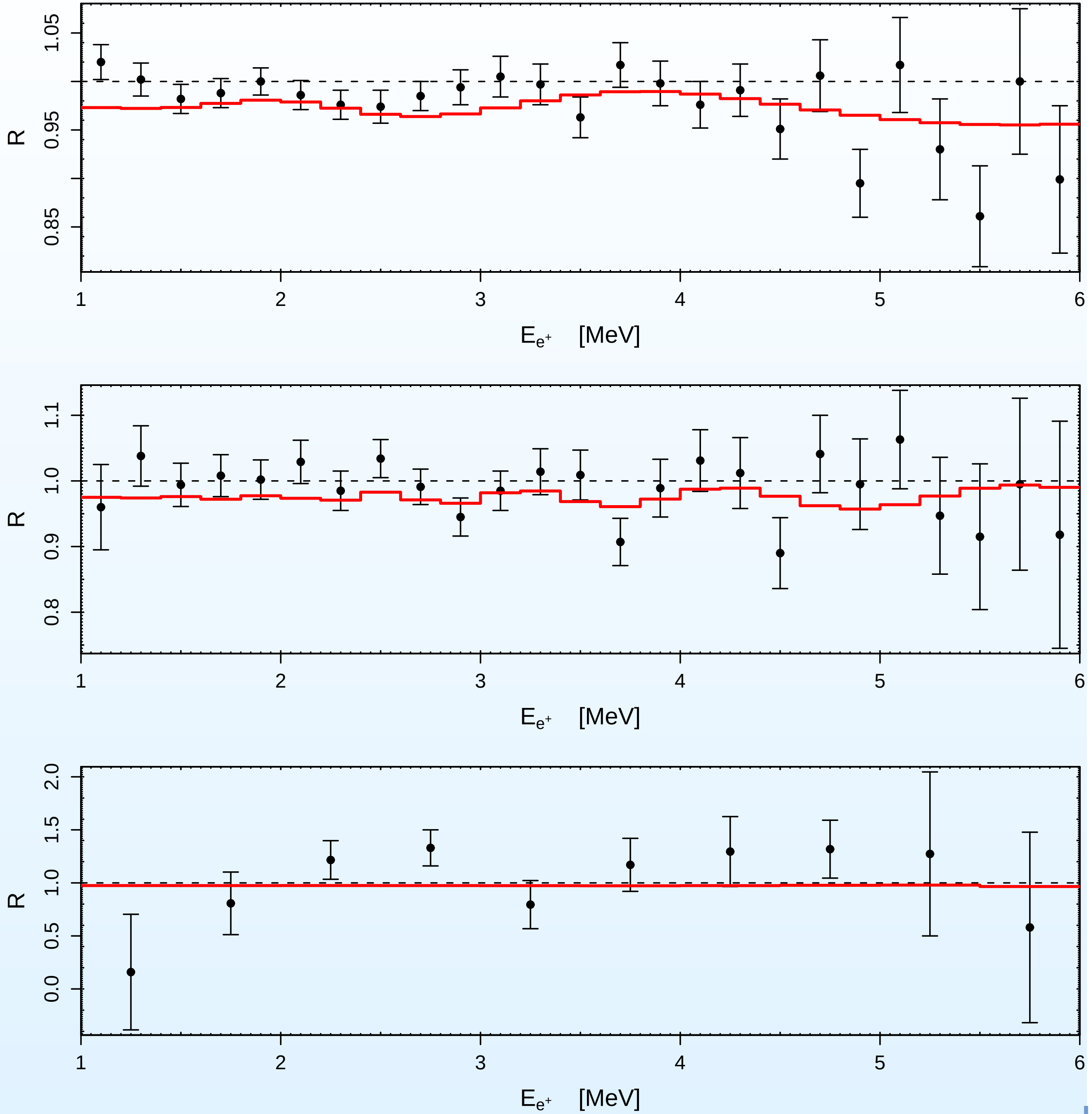


4.2 Bugey spectra

Histogram relative to the best fit against the Bugey experimental data

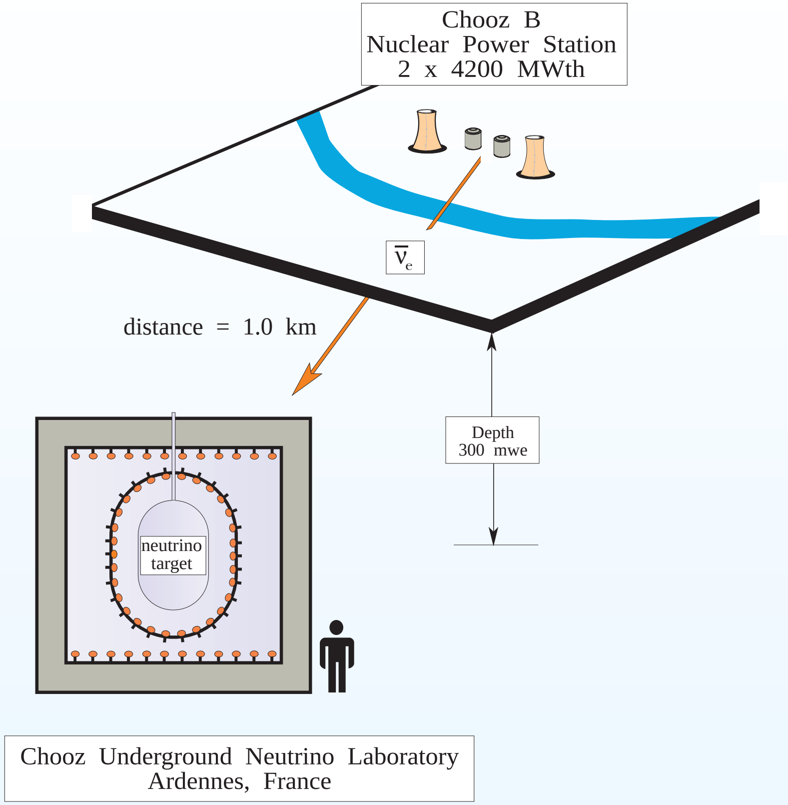
$$\sin^2 2\theta_{\text{bf}} = 0.051$$

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



4.3 Chooz

The ratio of the number of observed to the expected events (in absence of oscillations) is $R_{\text{Chooz}} = 1.01 \pm 0.04$.



$$P_{\nu_e \to \nu_e}(L,E) = 1 - \sin^2(2\theta)\sin^2\left(1.27\frac{\Delta m^2(eV^2)L(m)}{E(MeV)}\right)$$

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).

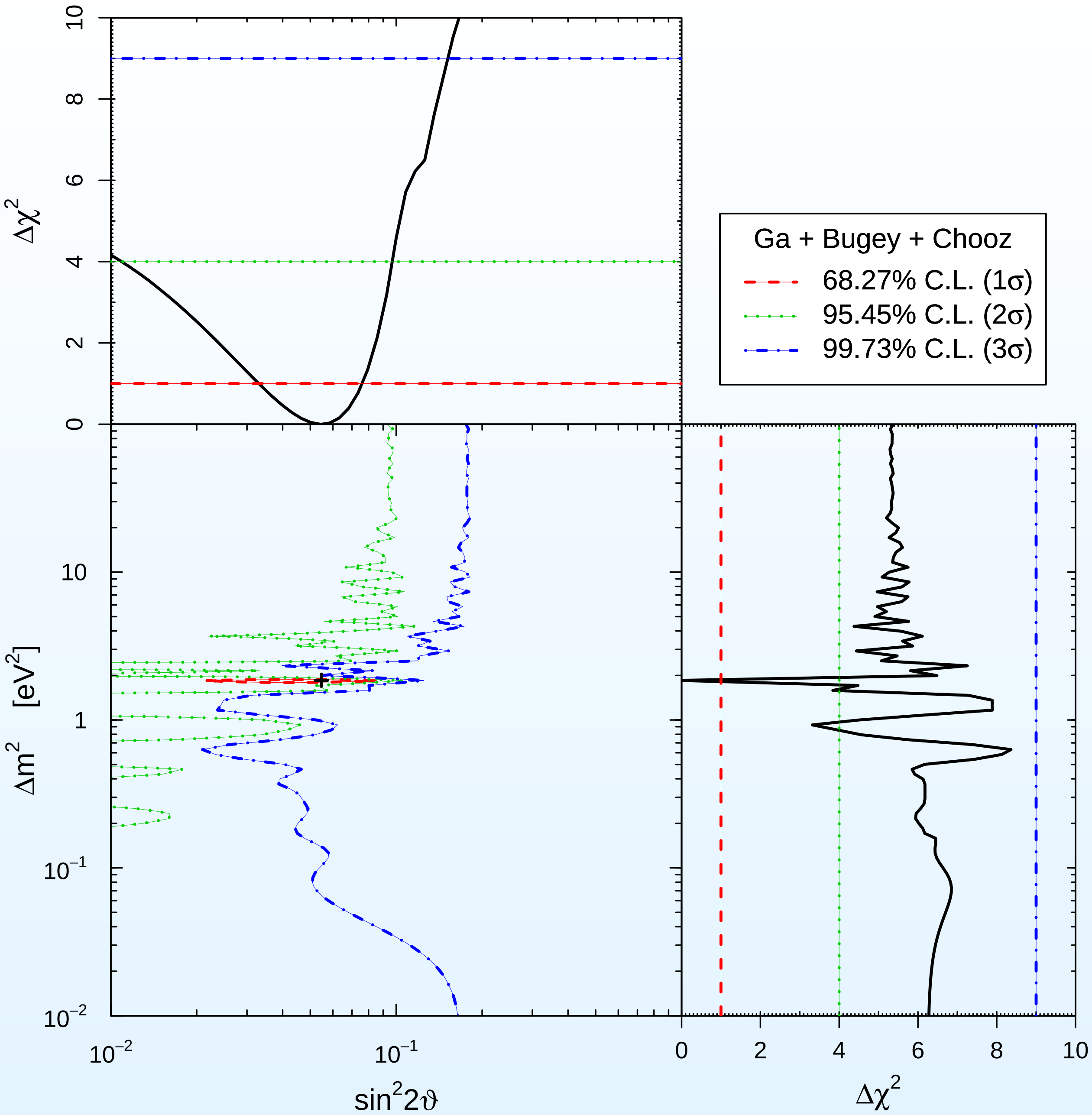
4.3 Global fit

Weak indication in favor of neutrino oscillations with

$$\mathbf{\Delta m^2 \simeq 1.85 eV^2}$$

and

$$\mathbf{0.02 \lesssim \sin^2 2\theta \lesssim 0.08.}$$



6. Conclusions

- From Gallium experiments, **we found and indication of neutrnio disappearance due to neutrino oscillations** with $\sin^2 2\theta \gtrsim 0.04$ and $\Delta m^2 \gtrsim 0.1$ eV^2.
- The Bugey data present a **weak indication in favor of neutrino oscillations** with $0.02 \lesssim \sin^2 2\theta \lesssim 0.08$ and $\Delta m^2 \simeq 1.85$ 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.

Work published:
M.A., C. Giunti, M. Laveder, ***Limits on ν_e and $\bar{\nu}_e$ disappearance from Gallium and reactor experiments***, arXiv:0711.4222

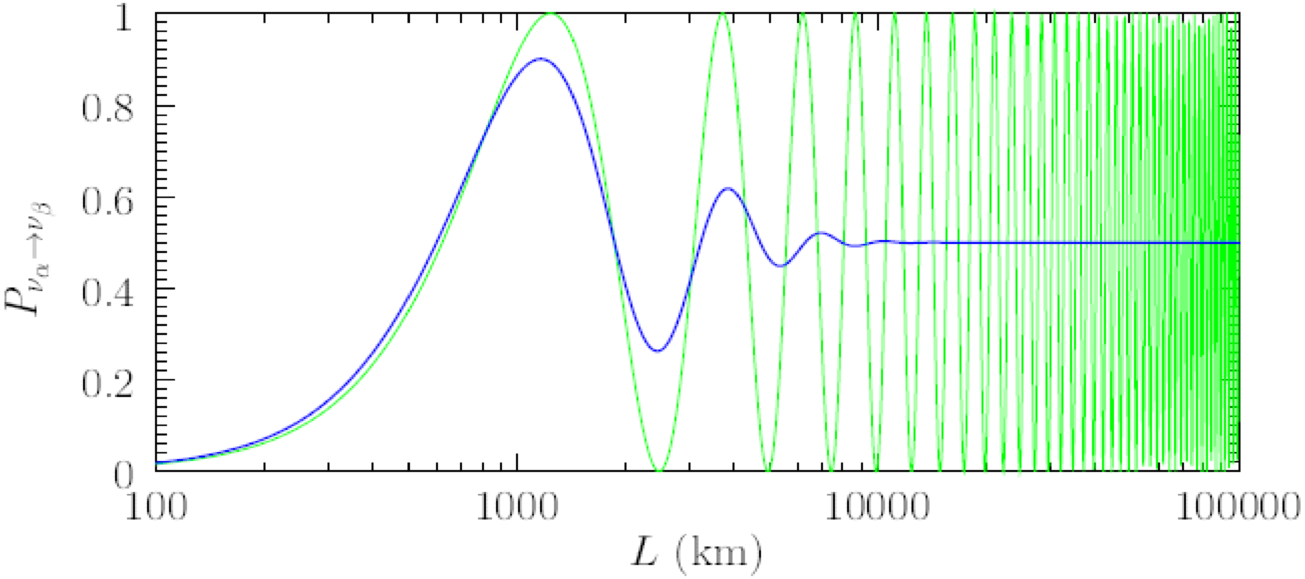
Future work

- Extending the data analysis including some other reactor experiments, which show anomalies that could be indication of neutrino oscillations.
  - CHOOZ (complete analysis)
  - Savannah River Site
  - Institute Laue Langevin (I.L.L)
  - Gösgen
- Studying constrains in sterile neutrinos, coming from cosmological data (work under the supervision of Julien Lesgourgues and Carlo Giunti)

Thanks!

Average over Energy Resolution of the Detector

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



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

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