VSBL Electron Neutrino Disappearance

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Madrid - 11 December 2009

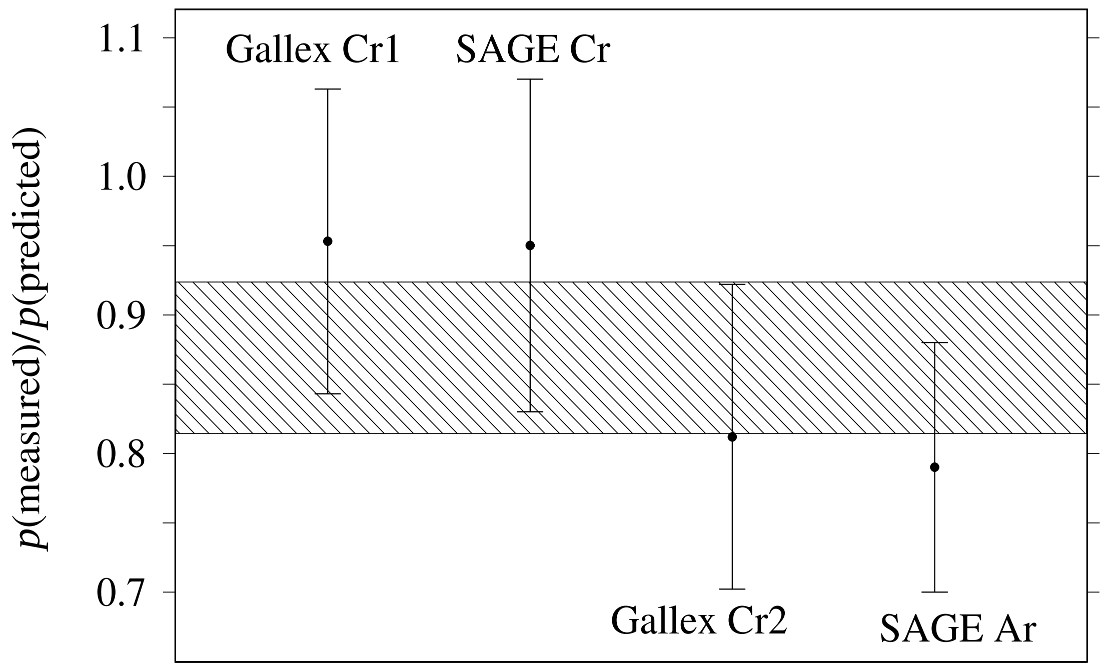
work in collaboration with Carlo Giunti [arXiv:0902.1992]

and with Carlo Giunti & Walter Winter [arXiv:0907.5487]

Active-Sterile ν mixing ?

- Charged massive spin 1/2 particles can have only a Dirac mass term
- According to Majorana neutral massive spin 1/2 particles can coincide with their antiparticles having a Majorana mass term.
- Non-SM right-handed neutral particles can have both Dirac and Majorana mass terms.
- If these non-SM right-handed neutral particles are light (sterile neutrinos ν_s) can mix with ordinary active neutrinos.
- The observable effect is a disappearance of active neutrinos.
- We focus on SBL Gallium, Miniboone and Reactors experiments.

ν_e Disappearance in Gallium radioactive source experiments



$R \equiv$ wheighted average value of the ratio of measured and predicted ^{71}Ge production rates (p) :

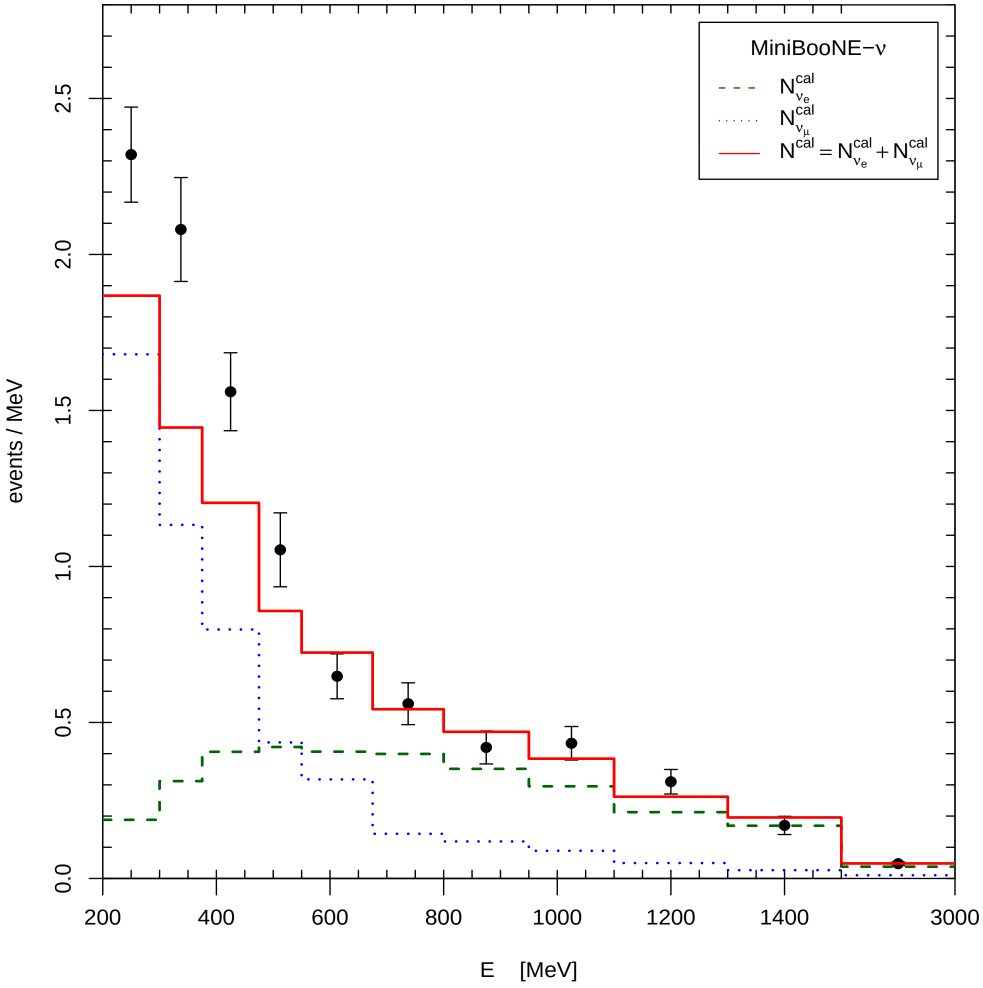
$$R \equiv \frac{\mathrm{p(measured)}}{\mathrm{p(predicted)}} = 0.87 \pm 0.05$$

arXiv:0901.2200[nucl-ex]

Ga radioactive source exp. results may be interpreted as an indication of the disappearance of ν_e due to active-sterile oscillations!

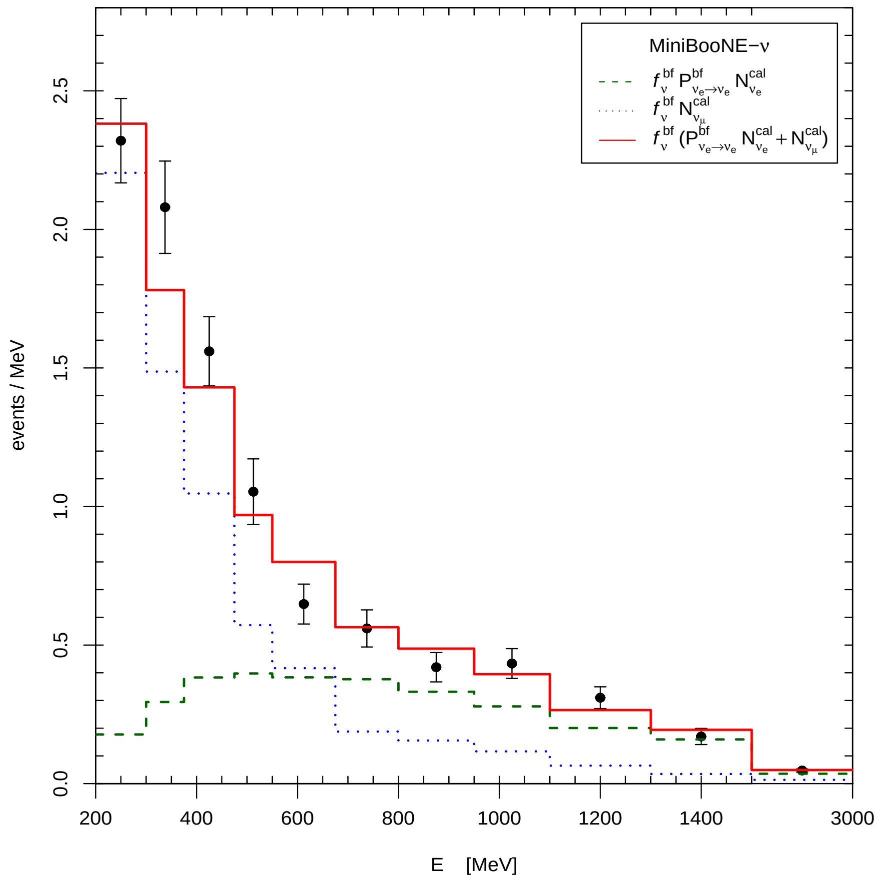
hep-ph/0610352 Carlo Giunti & ML

Miniboone-ν data : Low Energy Excess or ...



arXiv:0812.2243

ν_e Disappearance in Miniboone-ν data



Phys. Rev. D 77, 093002 (2008) C.Giunti & ML

A renormalization of the absolute event rate by a constant factor f_ν ($\Delta f_\nu = 0.15$) with a simultaneous disappearance of the ν_e in the beam .

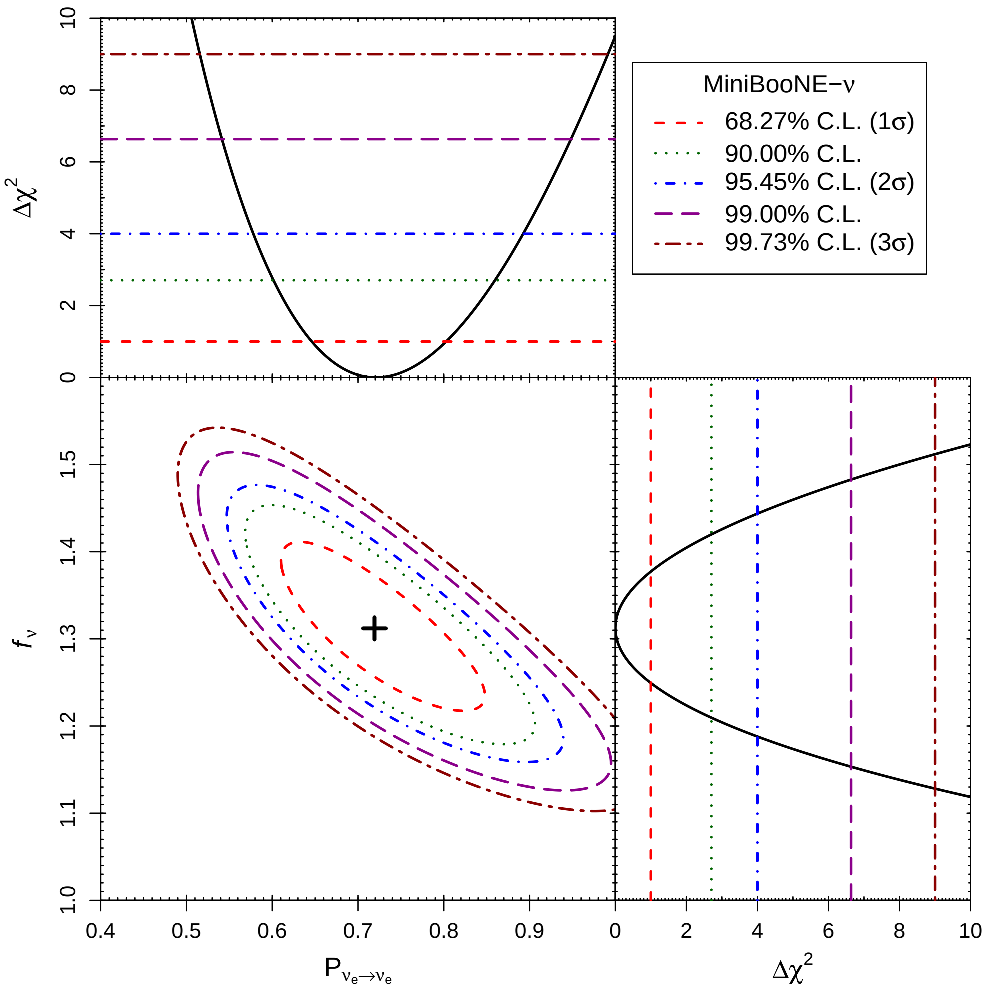
A constant $P_{\nu_e\to\nu_e} \leftrightarrow \Delta m^2 \gtrsim 20\,\mathrm{eV}^2$.

j	Energy Range [MeV]	$N^{\text{cal}}_{\nu_e,j}$	$N^{\text{cal}}_{\nu_\mu,j}$	$N^{\text{cal}}_{\nu,j}$	$N^{\text{exp}}_{\nu,j}$
1	$200-300$	24.2	162.4	186.7	232
2	$300-375$	21.8	86.4	108.2	156
3	$375-475$	39.4	81.2	120.6	156
4	$475-550$	29.5	34.5	64.1	79
5	$550-675$	47.0	42.4	89.4	82
6	$675-800$	47.0	19.7	66.7	70
7	$800-950$	49.1	20.0	69.1	64
8	$950-1100$	41.8	16.4	58.2	65
9	$1100-1300$	41.2	12.1	53.3	63
10	$1300-1500$	29.1	9.7	38.8	34
11	$1500-3000$	54.5	18.2	72.7	73

We calculate the best fit values of the parameters $P_{\nu_e\to\nu_e}$ and f_ν by minimizing the least-square function :

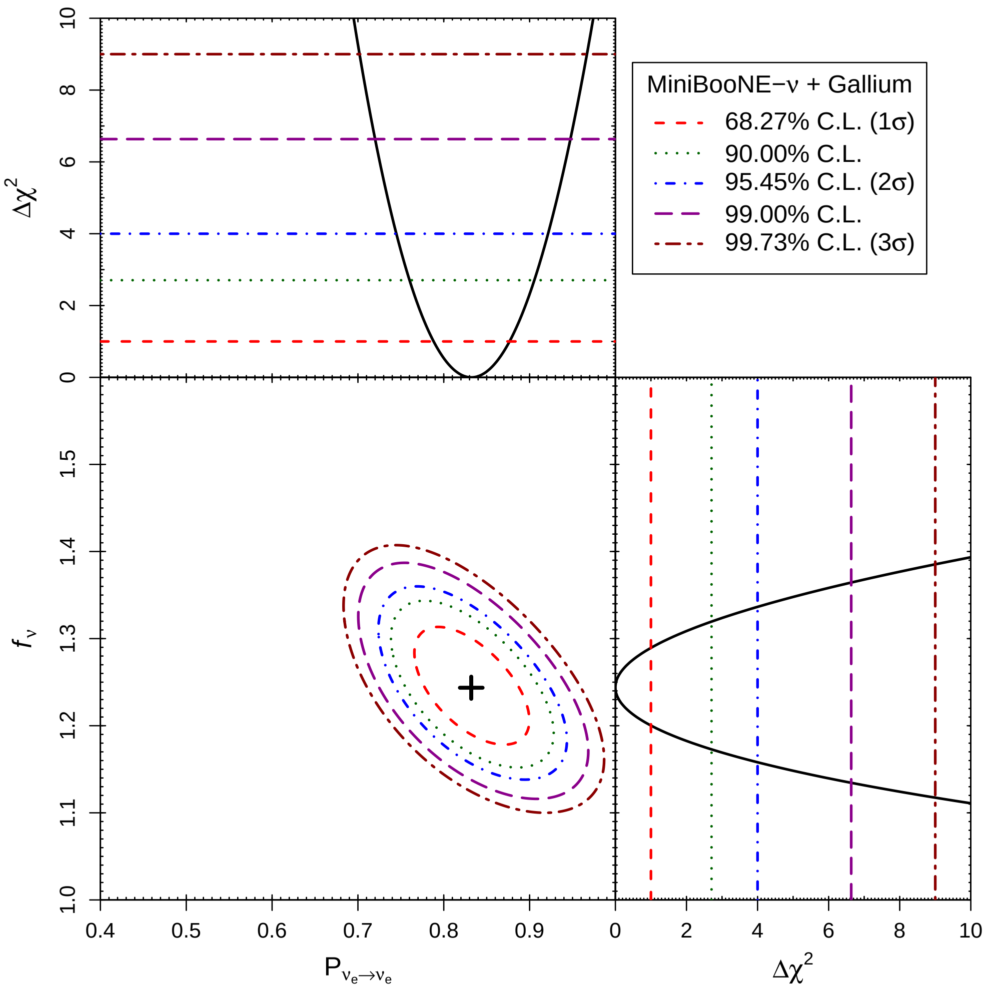
$$\chi^2_{\text{MB-}\nu} = \sum_{j=1}^{11} \frac{\left(N^{\text{the}}_{\nu,j} - N^{\text{exp}}_{\nu,j}\right)^2}{N^{\text{the}}_{\nu,j}} + \left(\frac{f_\nu - 1}{\Delta f_\nu}\right)^2, \qquad N^{\text{the}}_{\nu,j} = f_\nu \left(P_{\nu_e\to\nu_e} N^{\text{cal}}_{\nu_e,j} + N^{\text{cal}}_{\nu_\mu,j}\right)$$

Fit to Miniboone-ν data



$\chi^2_{min} = 17.7/(9\,\mathrm{dof})$ $\quad GoF = 3.8\%$ $\quad P^{bf}_{\nu_e\to\nu_e} = 0.72^{+0.08}_{-0.07}$ $\quad f^{bf}_{\nu} = 1.31^{+0.07}_{-0.06}$

Fit to Miniboone-ν & Gallium data



$\chi^2_{min} = 20.1/(10\,\mathrm{dof}) \quad GoF = 2.8\% \qquad P^{bf}_{\nu_e\to\nu_e} = 0.83 \pm 0.04 \quad f^{bf}_{\nu} = 1.24^{+0.05}_{-0.04}$

Miniboone-ν & Gallium : Osc vs No Osc

		MB-ν	MB-ν+Ga
	χ^2_{min}	27.2	34.0
No Osc.	NDF	10	11
	GoF	0.2%	0.04%
	f_ν^{bf}	1.15	1.15
	χ^2_{min}	17.7	20.1
	NDF	9	10
Osc.	GoF	3.8%	2.8%
	$P^{\text{bf}}_{\nu_e \to \nu_e}$	0.72	0.83
	f_ν^{bf}	1.31	1.24
	$\Delta\chi^2_{\text{min}}$		2.4
PG	NDF		1
	GoF		12.4%

Active-Sterile ν_e mixing !

- The parameter goodness-of-fit of 12.4% implies that the results of the MiniBooNE neutrino and the Gallium radioactive source experiments are compatible in the framework of the ν_e disappearance hypothesis.
- The goodness of fit of 2.8% is acceptable and much better than the 0.04% obtained without ν_e disappearance.
- $P_{\nu_e \to \nu_e} = 1$ is disfavored at more than 3σ (the precise value is 99.98% CL).

The large disappearance of ν_e found in Gallium and in Miniboone-ν data, may be due to oscillations into sterile neutrinos $\nu_e \longrightarrow \nu_s$ since

- $\nu_e \longrightarrow \nu_\mu$ transitions are restricted by the results of CCFR , KARMEN , NOMAD and MINIBOONE ;
- $\nu_e \longrightarrow \nu_\tau$ transitions are limited by the results of CHORUS and NOMAD .

SBL Reactor $\overline{\nu}_e$ experiments

$R^{(\mathrm{d})}$ denotes the ratio of measured and predicted event rates at the source-detector distance d:

Gosgen :

$$R^{(37.9\,\mathrm{m})}_{\mathrm{Gosgen}} = 1.018 \pm 0.019(\mathrm{stat}) \pm 0.015(\mathrm{uncorr}) \pm 0.060(\mathrm{corr})\,, \qquad (1)$$

$$R^{(45.9\,\mathrm{m})}_{\mathrm{Gosgen}} = 1.045 \pm 0.019(\mathrm{stat}) \pm 0.015(\mathrm{uncorr}) \pm 0.060(\mathrm{corr})\,, \qquad (2)$$

$$R^{(64.7\,\mathrm{m})}_{\mathrm{Gosgen}} = 0.975 \pm 0.036(\mathrm{stat}) \pm 0.030(\mathrm{uncorr}) \pm 0.060(\mathrm{corr})\,, \qquad (3)$$

Bugey :

$$R^{(15\,\mathrm{m})}_{\mathrm{Bugey}} = 0.988 \pm 0.004(\mathrm{stat}) \pm 0.05(\mathrm{syst})\,, \qquad (4)$$

$$R^{(40\,\mathrm{m})}_{\mathrm{Bugey}} = 0.994 \pm 0.010(\mathrm{stat}) \pm 0.05(\mathrm{syst})\,, \qquad (5)$$

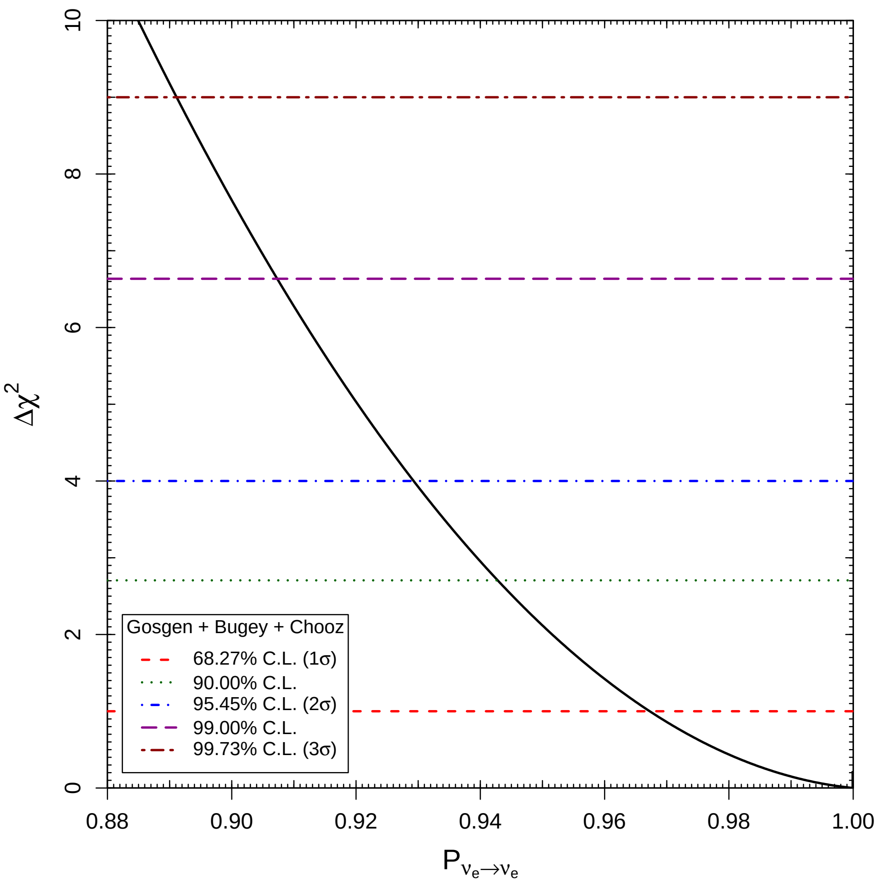
$$R^{(95\,\mathrm{m})}_{\mathrm{Bugey}} = 0.915 \pm 0.132(\mathrm{stat}) \pm 0.05(\mathrm{syst})\,. \qquad (6)$$

Chooz :

$$R^{(1\,\mathrm{km})}_{\mathrm{Chooz}} = 1.01 \pm 0.028(\mathrm{stat}) \pm 0.036(\mathrm{syst})\,. \qquad (7)$$

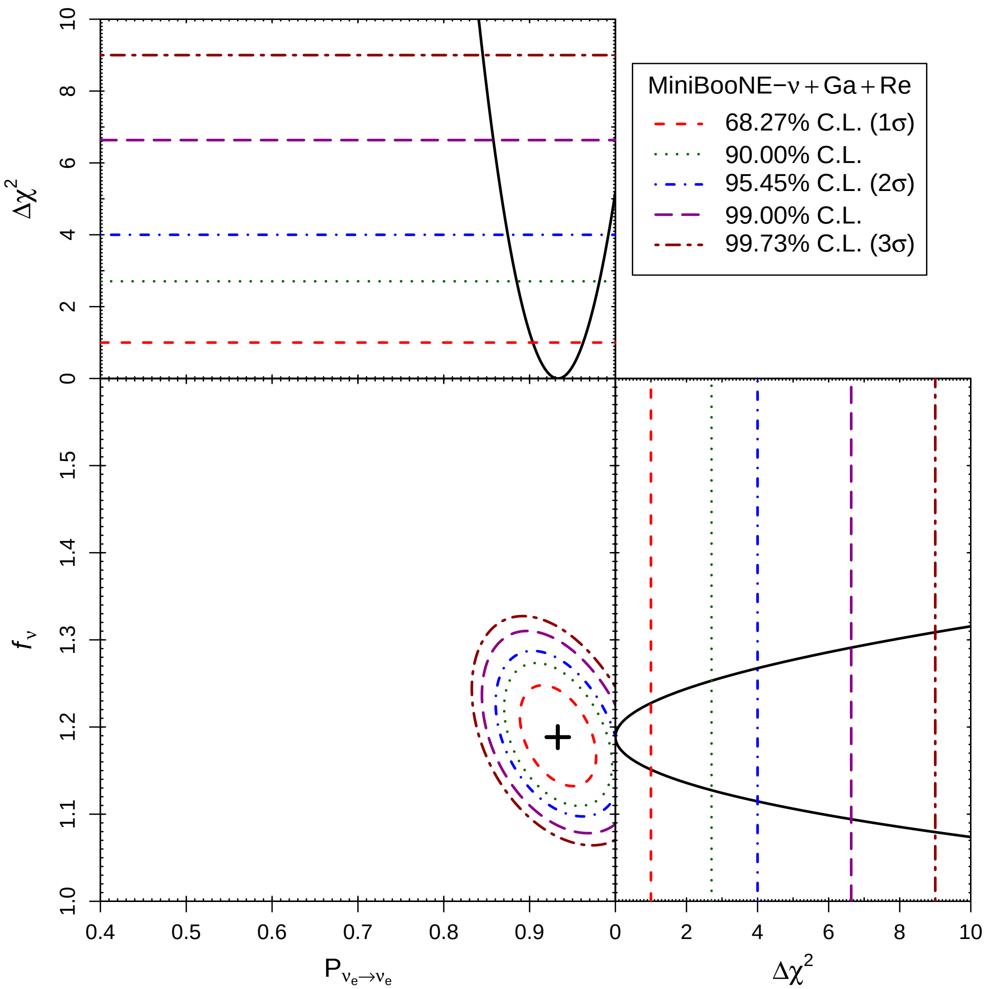
N.B. The Chooz systematic uncertainty of the reactor neutrino flux has the same value as that of Gosgen and Bugey, i.e. approximately 3% (ILL value).

Fit to SBL Reactor $\overline{\nu}_e$ data



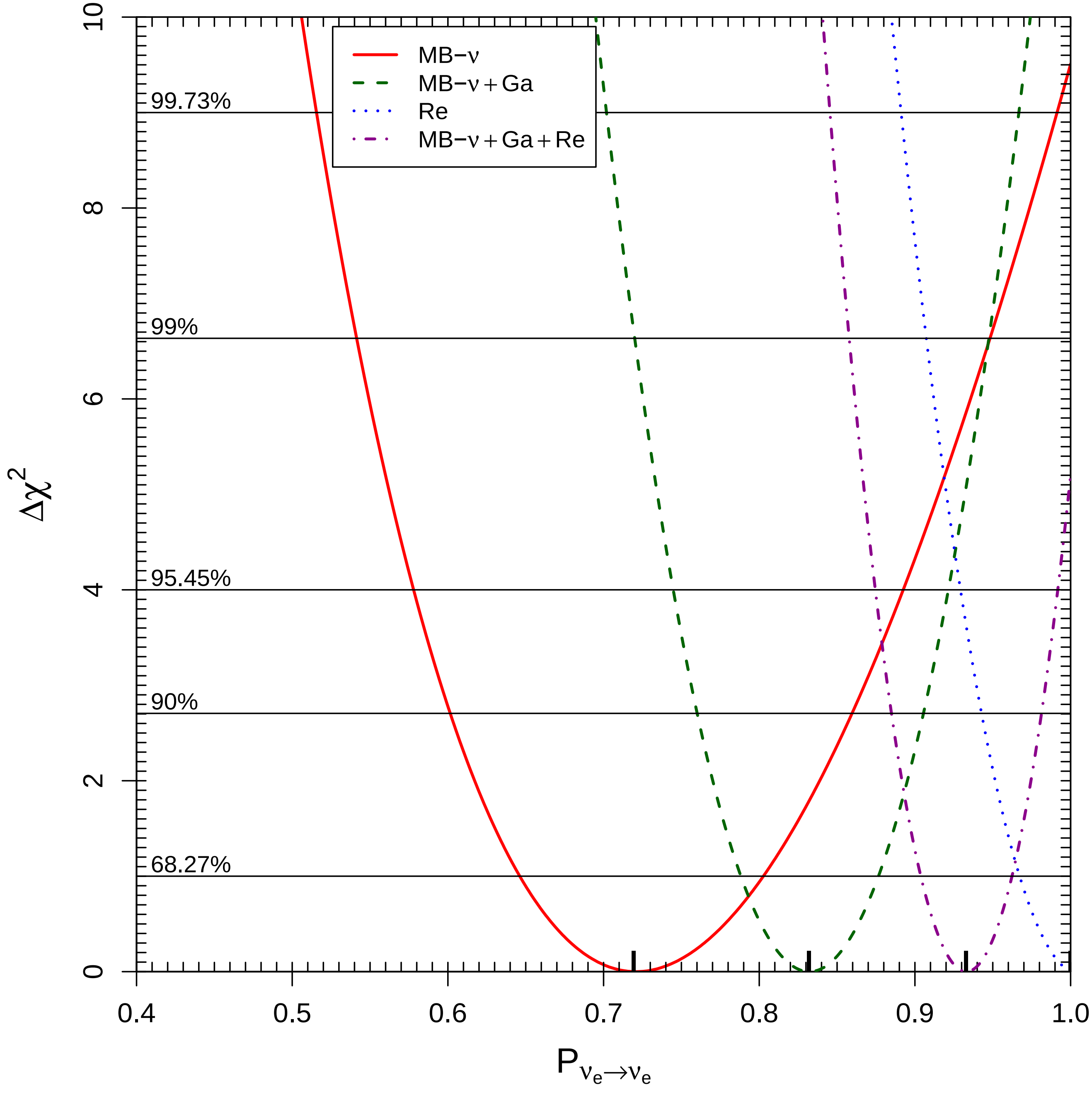
The lower limits for $P_{\nu_e \to \nu_e}$ indicate that reactor data allow a small $\bar{\nu}_e$ disappearance. Therefore, we tried a combined analysis of MiniBooNE neutrino, Gallium and reactor data under the hypothesis of ν_e disappearance with $P_{\nu_e \to \nu_e} = P_{\bar{\nu}_e \to \bar{\nu}_e}$.

Combined fit of Miniboone-ν & Gallium & Reactor (1)



$$\chi^2_{min} = 31.7/(17\,\mathrm{dof}) \quad GoF = 1.7\% \quad P^{bf}_{\nu_e \to \nu_e} = 0.93 \pm 0.03 \quad f^{bf}_{\nu} = 1.19 \pm 0.04$$

Combined fi t of Miniboone-ν & Gallium & Reactor (2)



Miniboone-ν & Gallium & Reactor : Osc vs No Osc

		MB-ν	MB-ν+Ga	MB-ν+Ga+Re
	χ^2_{min}	27.2	34.0	36.9
No Osc.	NDF	10	11	18
	GoF	0.2%	0.04%	0.5%
	f_ν^{bf}	1.15	1.15	1.15
	χ^2_{min}	17.7	20.1	31.7
	NDF	9	10	17
Osc.	GoF	3.8%	2.8%	1.7%
	$P^{\text{bf}}_{\nu_e \to \nu_e}$	0.72	0.83	0.93
	f_ν^{bf}	1.31	1.24	1.19
	$\Delta\chi^2_{\text{min}}$		2.4	11.1
PG	NDF		1	2
	GoF		12.4%	0.4%

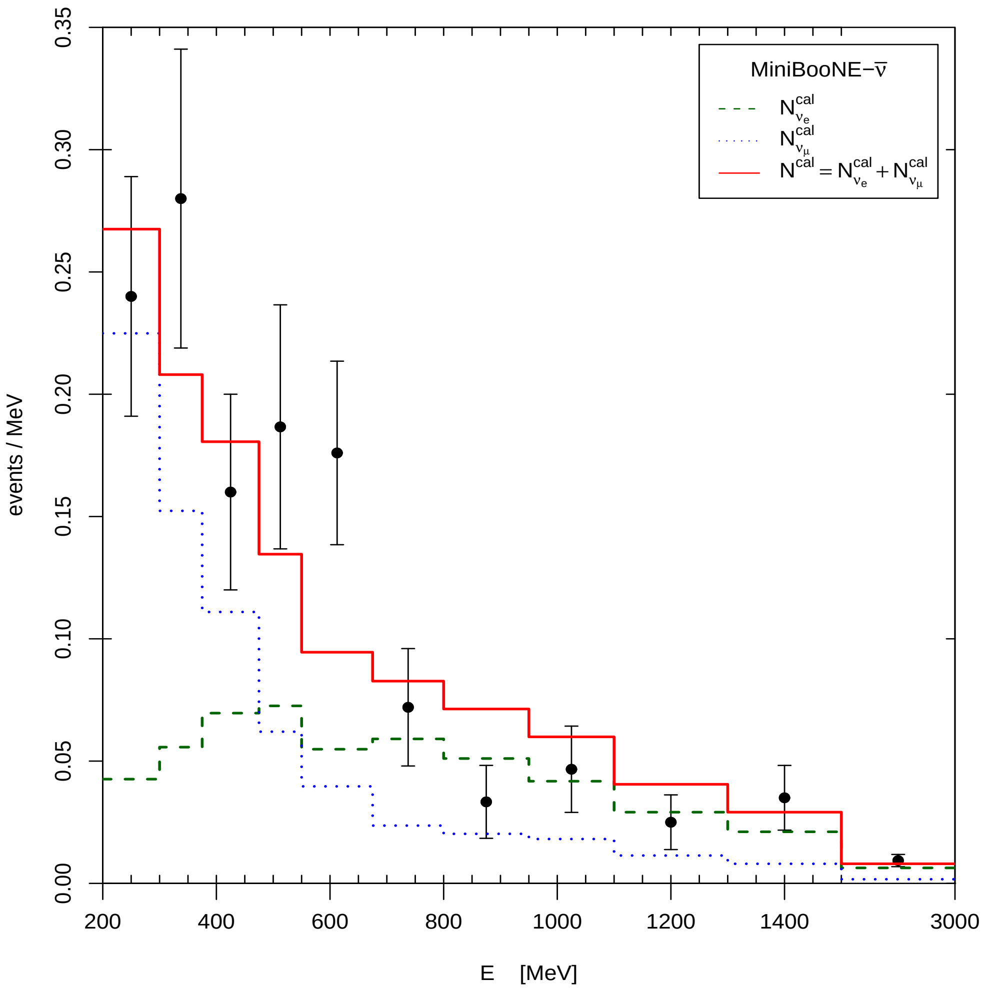
Tension between ν_e and $\overline{\nu}_e$data

- The rather low parameter goodness-of-fi t, 0.4% , shows that there is tension between MiniBooNE and Gallium neutrino data on one side and reactor antineutrino data on the other side.
- The goodness of fi t of 1.7% is acceptable and it is better than the 0.5% obtained without ν_e disappearance.
- $P_{\nu_e \to \nu_e} = 1$ is disfavored at more than 2σ (97.74% CL).

Possible explanations of this tension could be:

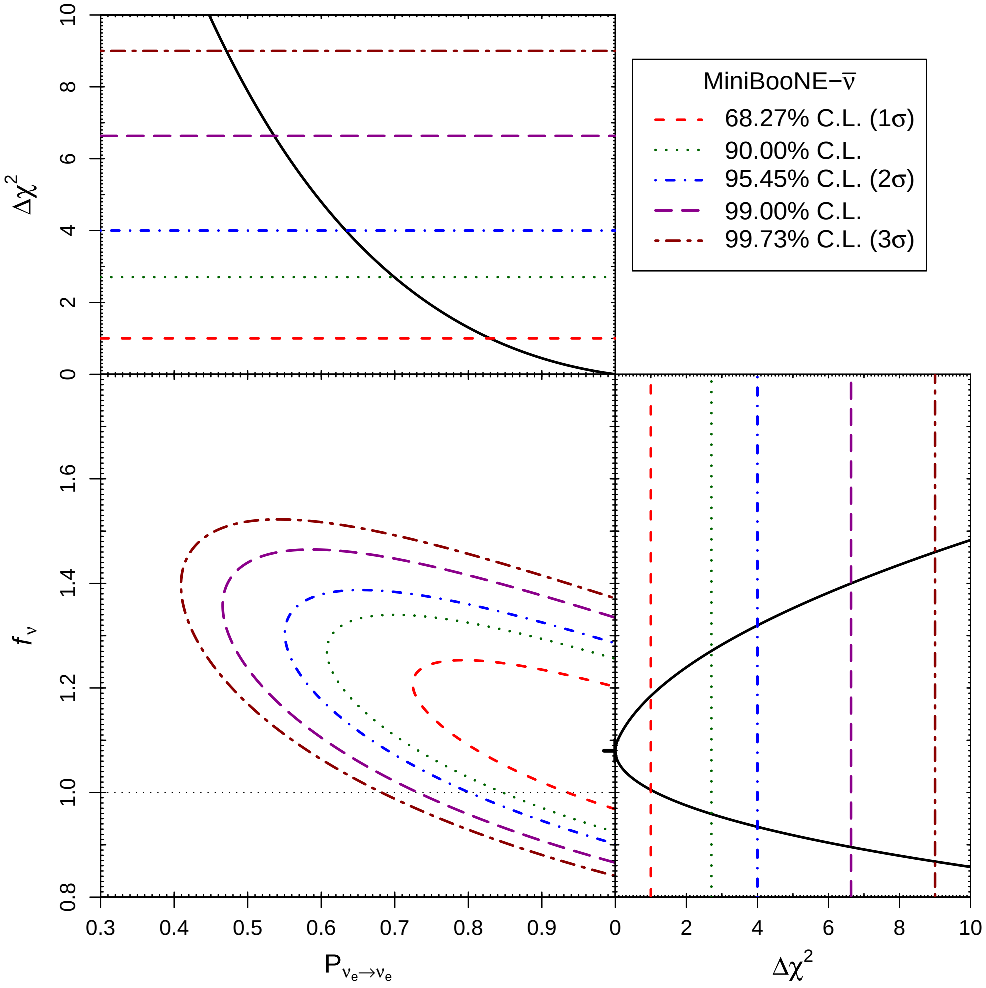
1. Statistical fluctuations.
2. Systematic uncertainties have been underestimated.
3. Our hypothesis of ν_e disappearance is excluded.
4. There is a violation of CPT symmetry leading to $P_{\nu_e \to \nu_e} \neq P_{\bar{\nu}_e \to \bar{\nu}_e}$.

More data : Miniboone-$\bar{\nu}$



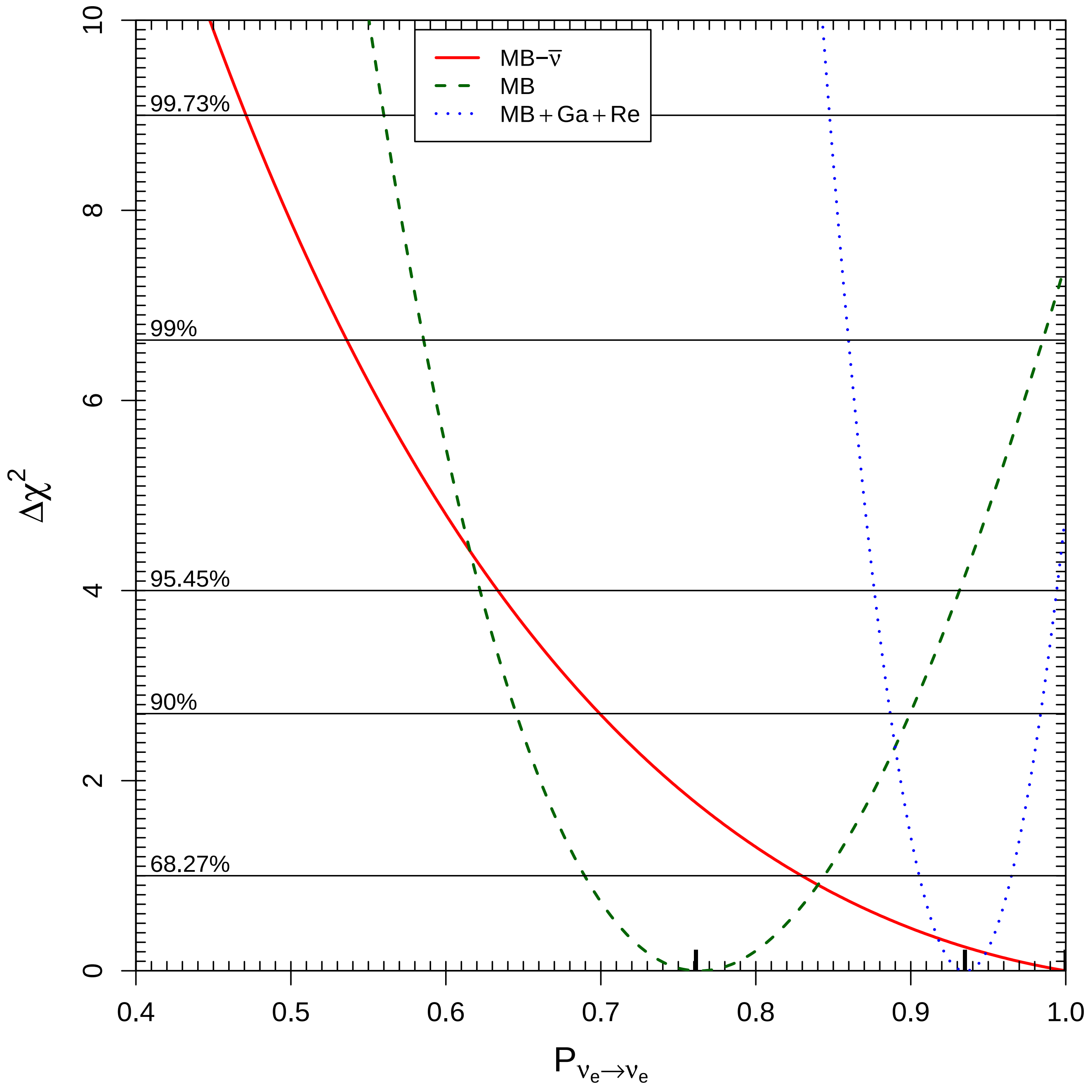
Karagiorgi talk @ FNAL dec 2008

Fit to Miniboone-$\bar{\nu}$ data



$$\chi^2_{min} = 16.9/(9\,\mathrm{dof}) \qquad GoF = 5.0\% \qquad P^{bf}_{\nu_e\to\nu_e} = 1.00^{+0.00}_{-0.17} \qquad f^{bf}_{\bar{\nu}} = 1.08^{+0.10}_{-0.08}$$

Combined fi t of Miniboone & Gallium & Reactor



Miniboone & Gallium & Reactor : Osc vs No Osc

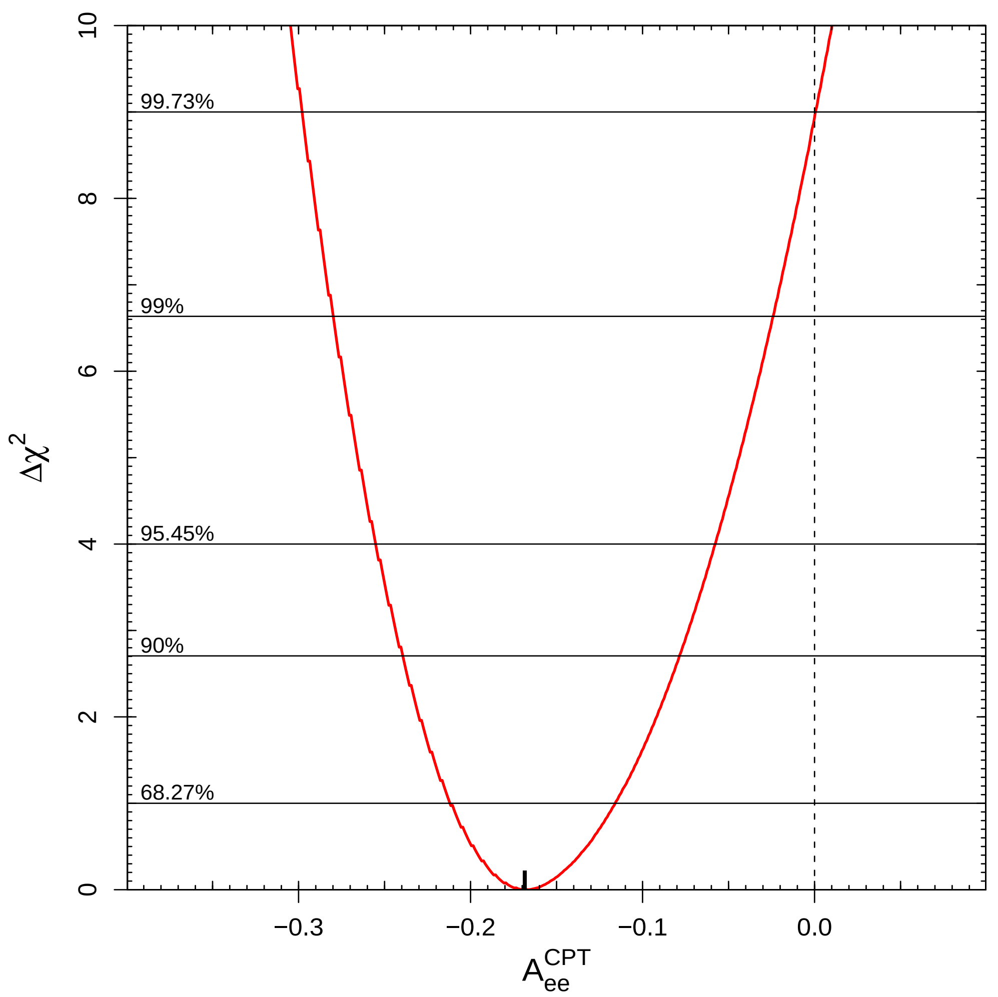
		MB-ν	MB-ν+Ga	MB-ν+Ga+Re	MB+Ga+Re
	$\chi^2_{\rm min}$	27.2	34.0	36.9	53.8
No Osc.	NDF	10	11	18	29
	GoF	0.2%	0.04%	0.5%	0.3%
	$f_{\nu}^{\rm bf}$	1.15	1.15	1.15	1.15
	$f_{\bar{\nu}}^{\rm bf}$				1.08
	$\chi^2_{\rm min}$	17.7	20.1	31.7	48.9
	NDF	9	10	17	27
Osc.	GoF	3.8%	2.8%	1.7%	0.6%
	$P^{\rm bf}_{\nu_e \to \nu_e}$	0.72	0.83	0.93	0.93
	$f_{\nu}^{\rm bf}$	1.31	1.24	1.19	1.19
	$f_{\bar{\nu}}^{\rm bf}$				1.10
	$\Delta\chi^2_{\rm min}$		2.4	11.1	8.3
PG	NDF		1	2	3
	GoF		12.4%	0.4%	4.1%

Tension between ν_e and $\overline{\nu}_e$data

- The parameter goodness-of-fit of 4.1% do not allow us to reject the compatibility of the data under the hypothesis of ν_e disappearance. This results indicate that the possibility that the tension between MiniBooNE neutrino and Gallium data on one side and reactor data on the other side is due to statistical fluctuations may be correct.
- The goodness of fit of 0.6% is rather low and it is better than the 0.3% obtained without ν_e disappearance.
- $P_{\nu_e \to \nu_e} = 1$ is disfavored at more than 2σ (97.04% CL).
- Next we consider a possible violation of the CPT equality $P_{\nu_e \to \nu_e} = P_{\bar{\nu}_e \to \bar{\nu}_e}$ as a possible explanation of the tension between MiniBooNE and Gallium neutrino data on one side and reactor antineutrino data on the other side under the hypothesis of ν_e disappearance.
- We quantify the amount of CPT violation through the asymmetry

$$A_{ee}^{\text{CPT}} \equiv P_{\nu_e \to \nu_e} - P_{\bar{\nu}_e \to \bar{\nu}_e} \,.$$

CPTV fi t of Miniboone & Gallium & Reactor



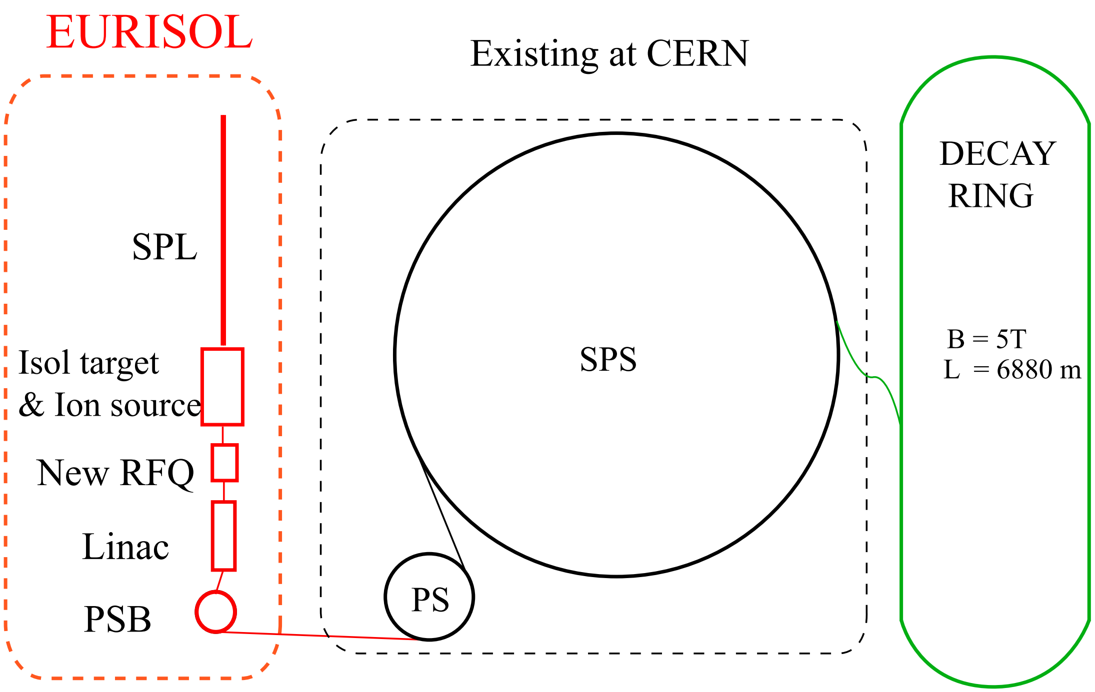
$\chi^2_{min} = 38.3/(26\,\mathrm{dof})$ $\quad GoF = 5.7\%$ $\quad A_{ee}^{\mathrm{CPT}} = -0.165^{+0.05}_{-0.04}$

Interesting results !

- The relatively low goodness of fi t of 5.7% is due to the relatively low goodness of fi t of the MiniBooNE neutrino (3.8%) and antineutrino (5.0%) data.
- There is an indication of CPT violation ($A_{ee}^{\text{CPT}} < 0$) at 99.71% CL.
- Since the indication of CPT violation that we have found has been obtained under the hypothesis of ν_e disappearance into sterile neutrinos, it could be due to very exotic CPT-violating properties of the sterile neutrinos.
- Let us emphasize that the possibility of CPT violation is extremely interesting and should be explored in future experiments by measuring the CPT asymmetries:

$$A_{\alpha\beta}^{\text{CPT}} \equiv P_{\nu_\alpha \to \nu_\beta} - P_{\bar{\nu}_\beta \to \bar{\nu}_\alpha} \qquad \alpha, \beta = e, \mu.$$

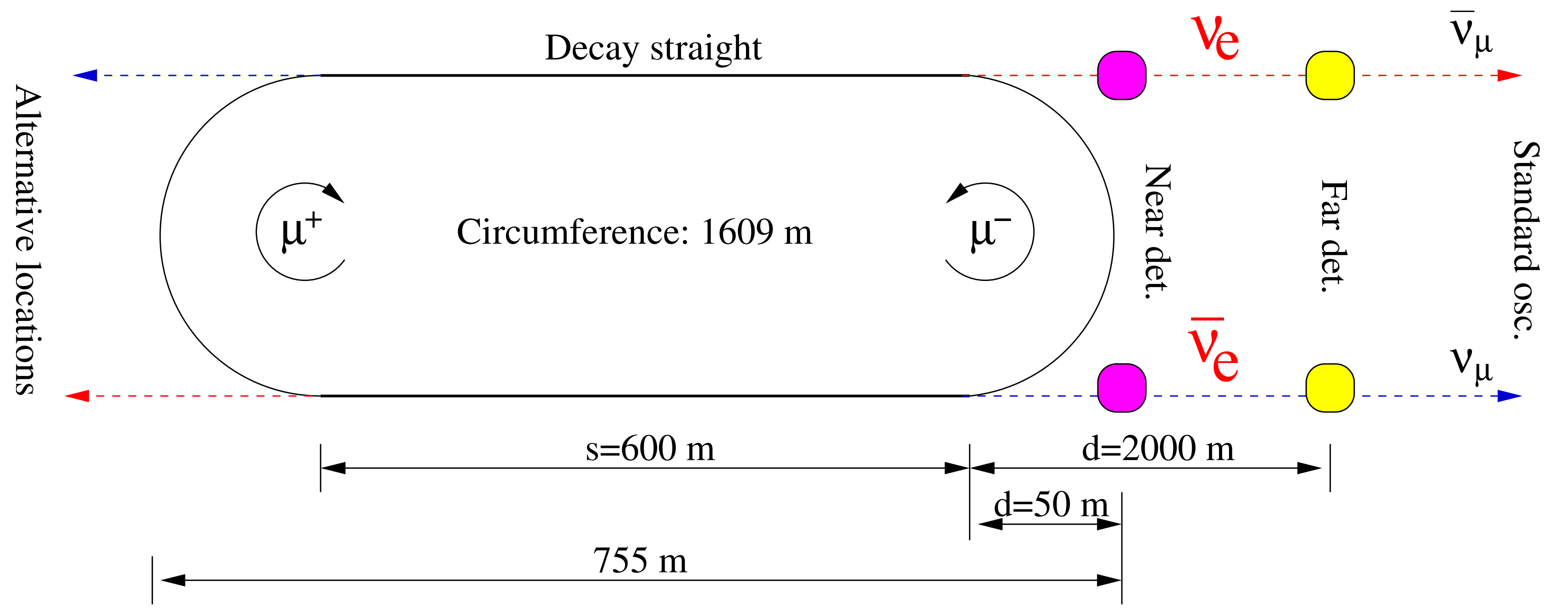
Future SBL experimental CPT tests with a β beam



Future SBL Beta-Beam experiments [P.Zucchelli PLB 532 (2002) 166]

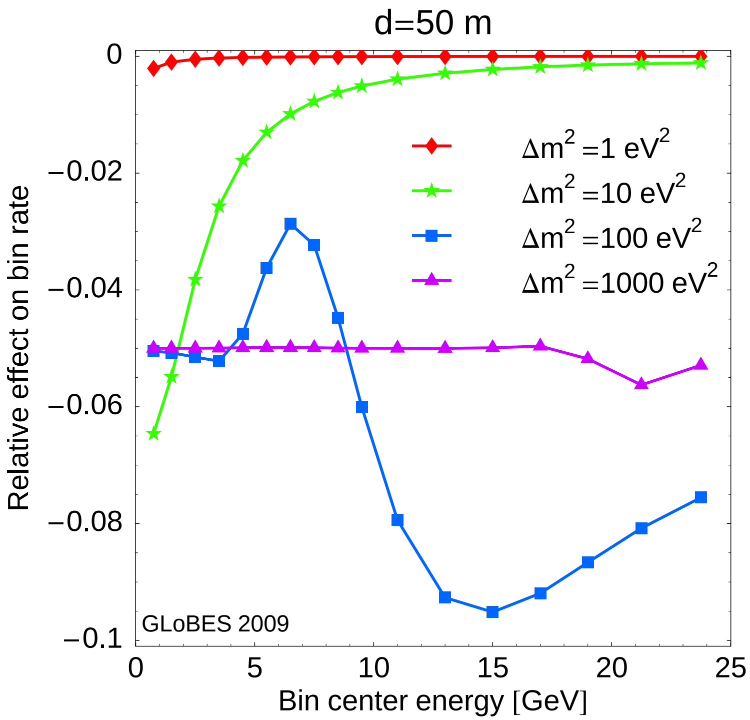
with a pure ν_e or $\bar{\nu}_e$ beam from nuclear decay of accelerated ions have the potentiality to check the possible SBL disappearance of ν_e and $\bar{\nu}_e$ with high accuracy .

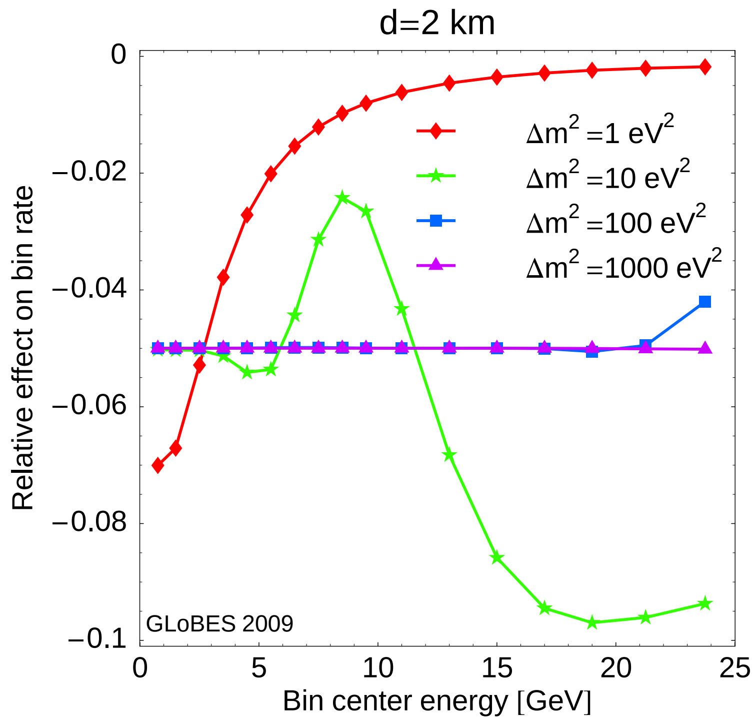
Future SBL experimental CPT tests with a ν factory



Future SBL ν factory experiments C.Giunti, ML and W.Winter [arXiv:0907.5487] with pure ν_e AND $\bar{\nu}_e$ beams from muon decay of accelerated muons have the capability to check the possible SBL disappearance of ν_e and $\bar{\nu}_e$ with very high accuracy. Non standard interactions studied from [A.Rubbia, ML et al. JHEP06(2001)032] $\longrightarrow$ [J.Tang and W.Winter arXiv:0903.3039].

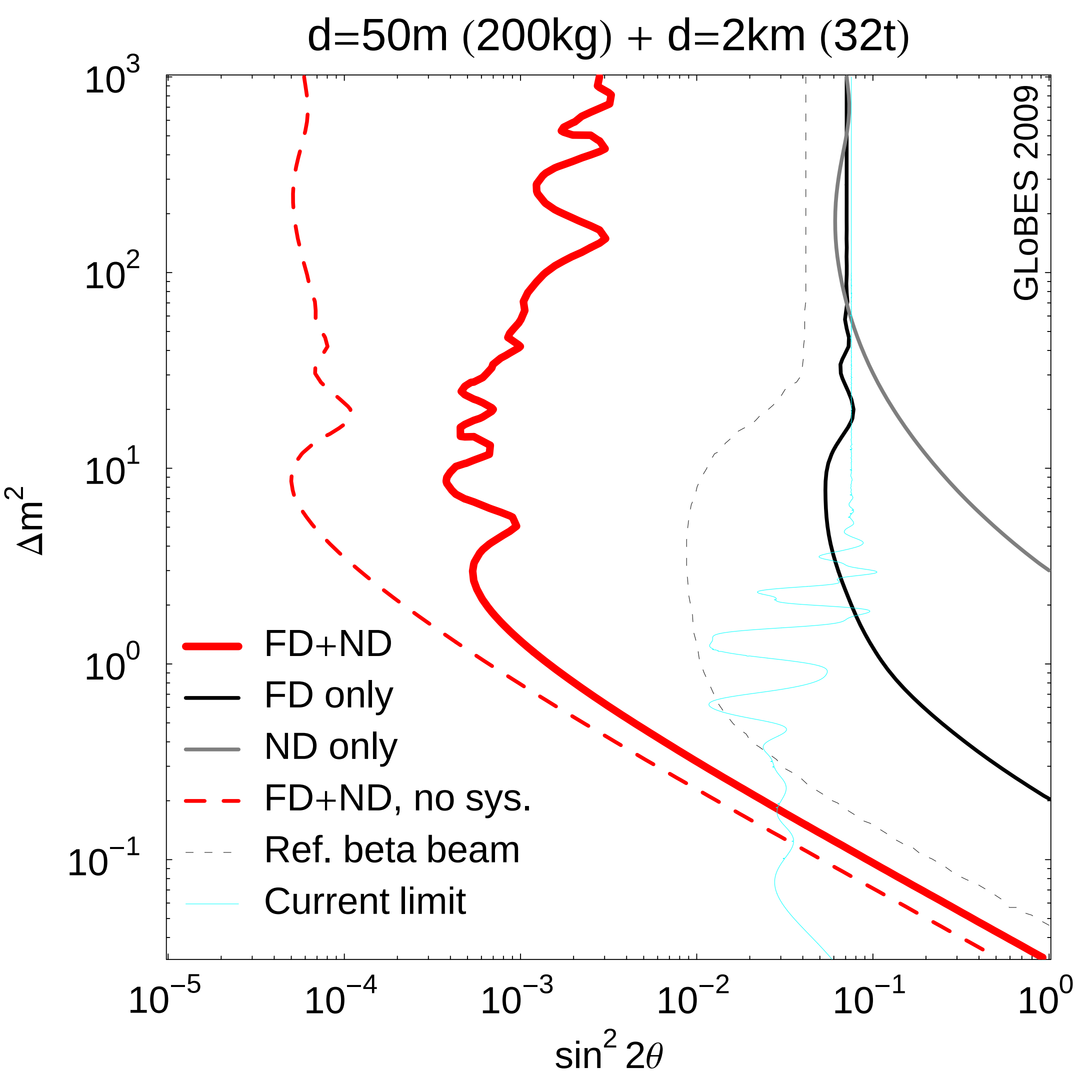
Oscillated event rates at 2 distances





Relative effect on the binned (neutrino) event rates for several values of Δm^2, and $\sin^2 2\theta = 0.1$, in the near (left) and far (right) detectors. For each energy bin we plotted $(R - R_0)/R_0$ where R and R_0 are the expected rates with and without oscillations.

CPT tests at a ν factory : Sensitivity



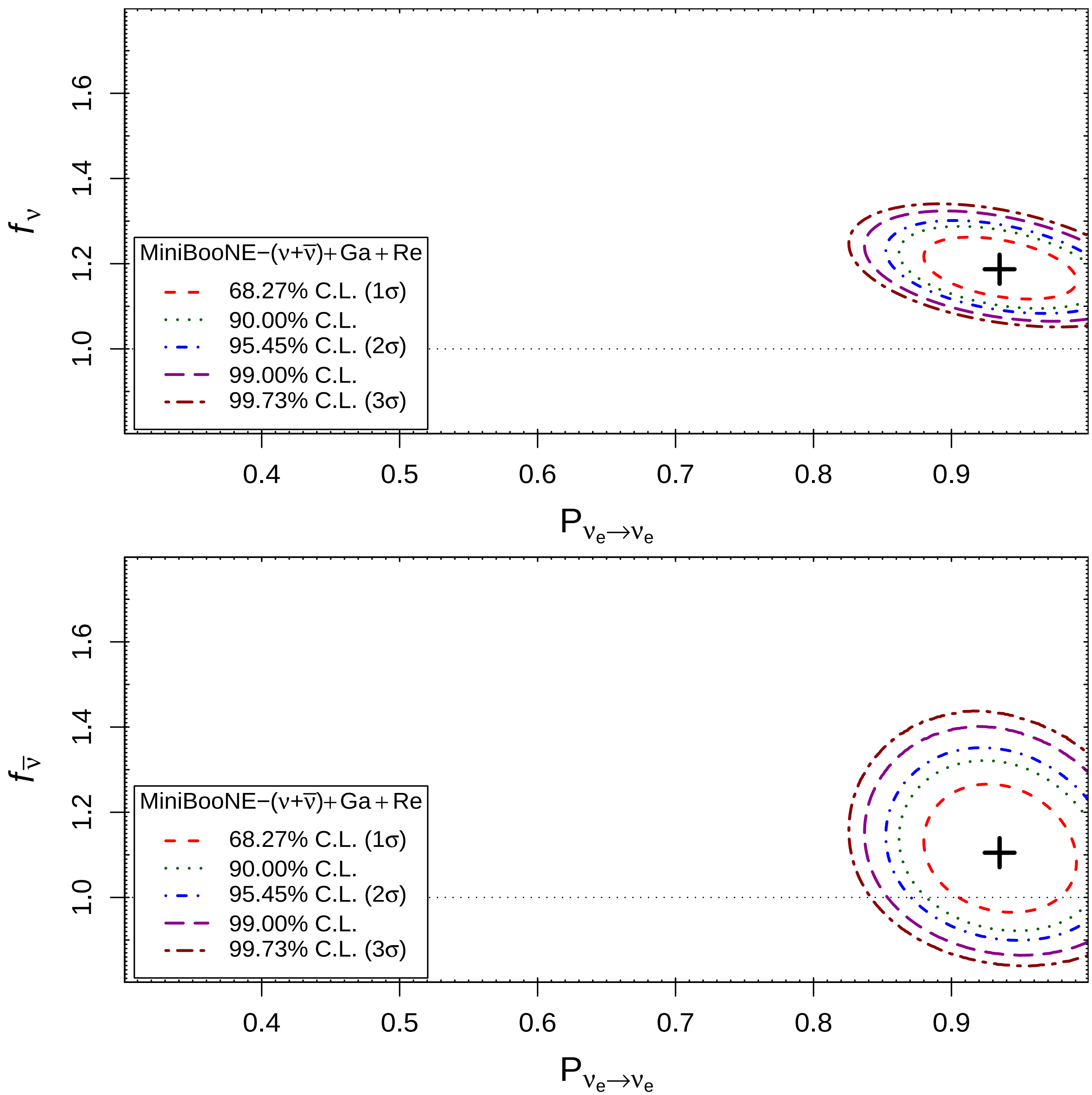
$$A_{ee}^{\text{CPT}} = -0.165^{+0.05}_{-0.04} \Rightarrow \sin^2 2\theta = 0.33^{+0.10}_{-0.08}$$

... if they are roses they'll flower...

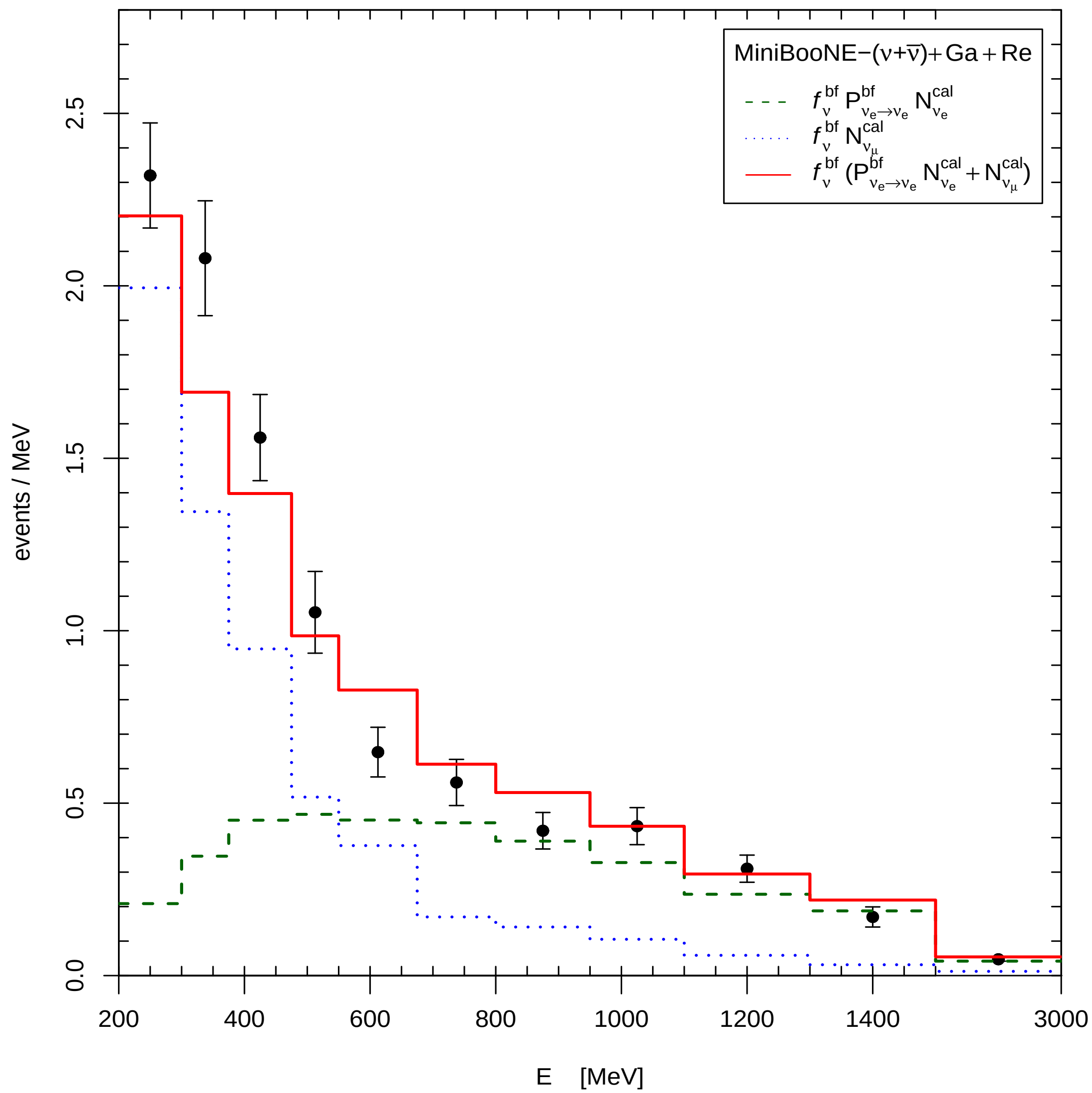
... A BRIGHT FUTURE for Majorana ν physics !!!

Backup slides

Combined fi t of Miniboone & Gallium & Reactor



Best fi t of Miniboone & Gallium & Reactor vs Miniboone-ν data



	BF	68.27%	90%	95.45%	99%	99.73%
MB-ν	0.72	0.65 - 0.80	0.60 - 0.86	0.58 - 0.89	0.54 - 0.95	0.52 - 0.99
MB-ν+Ga	0.83	0.79 - 0.88	0.76 - 0.91	0.75 - 0.92	0.72 - 0.95	0.70 - 0.97
Re	1.00	0.97 - 1.00	0.94 - 1.00	0.93 - 1.00	0.91 - 1.00	0.89 - 1.00
MB-ν+Ga+Re	0.93	0.90 - 0.96	0.89 - 0.98	0.88 - 0.99	0.86 - 1.00	0.85 - 1.00
MB-$\bar{\nu}$	1.00	0.83 - 1.00	0.70 - 1.00	0.63 - 1.00	0.54 - 1.00	0.47 - 1.00
MB-$\bar{\nu}$+Re	1.00	0.97 - 1.00	0.95 - 1.00	0.93 - 1.00	0.91 - 1.00	0.89 - 1.00
MB	0.76	0.69 - 0.84	0.65 - 0.90	0.62 - 0.93	0.59 - 0.98	0.56 - 1.00
MB+Ga+Re	0.93	0.91 - 0.96	0.89 - 0.98	0.88 - 0.99	0.86 - 1.00	0.85 - 1.00

Table 1: Best-fit values (BF) and allowed ranges of $P_{\nu_e \to \nu_e}$ at the indicated value of confidence level.

		MB-$\bar{\nu}$	MB-$\bar{\nu}$+Re	MB	MB+Ga+Re
	χ^2_{min}	16.9	19.8	44.1	53.8
No Osc.	NDF	10	17	21	29
	GoF	7.6%	28.5%	0.2%	0.3%
	$f^{\text{bf}}_{\bar{\nu}}$	1.08	1.08	1.08	1.08
	χ^2_{min}	16.9	19.8	36.7	48.9
	NDF	9	16	19	27
Osc.	GoF	5.0%	23.0%	0.9%	0.6%
	$P^{\text{bf}}_{\nu_e\to\nu_e}$	1.00	1.00	0.76	0.93
	$f^{\text{bf}}_{\bar{\nu}}$	1.08	1.08	1.19	1.10
	f^{bf}_{ν}			1.28	1.19
	$\Delta\chi^2_{\text{min}}$		0.0	2.1	8.3
PG	NDF		1	1	3
	GoF		100.0%	14.8%	4.1%

Table 2: Values of χ^2, number of degrees of freedom (NDF) and goodness-of-fi t (GoF) for the fi t of MiniBooNE antineutrino (MB-$\bar{\nu}$), MiniBooNE antineutrino and reactor (MB-$\bar{\nu}$+Re), MiniBooNE neutrino and antineutrino (MB) and MiniBooNE neutrino and antineutrino, Gallium and reactor (MB+Ga+Re) data. The fi rst four lines correspond to the case of no oscillations (No Osc.). The following six lines correspond to the case of oscillations (Osc.). The last three lines give the parameter goodness-of-fi t (PG) .

Parameter Goodness-of-fi t (PG)

- The goodness-of-fit is the probability to obtain a worse fit under the assumption that the model under consideration is correct. It is the standard statistic used for the estimation of the quality of a fit obtained with the least-squares method, assuming the validity of the approximation in which χ^2_{min} has a χ^2 distribution with NDF $= N_{\text{D}} - N_{\text{P}}$ degrees of freedom, where N_{D} is the number of data points and N_{P} is the number of fitted parameters. The fit is usually considered to be acceptable if the goodness-of-fit is larger than about 1%.
- The value of $(\Delta\chi^2_{\text{min}})_{\text{A+B}}$ corresponding to the Parameter Goodness-of-fit (PG) of two experiments A and B is given by $(\chi^2_{\text{min}})_{\text{A+B}} - [(\chi^2_{\text{min}})_{\text{A}} + (\chi^2_{\text{min}})_{\text{B}}]$. It has a χ^2 distribution with number of degrees of freedom NDF $= P_{\text{A}} + P_{\text{B}} - P_{\text{A+B}}$, where P_{A}, P_{B} and $P_{\text{A+B}}$ are, respectively, the number of parameters in the fits of A, B and A+B data.
  [M. Maltoni and T. Schwetz, Phys. Rev. D68 (2003) 033020 (hep-ph/0304176).]