Short-BaseLine Electron Neutrino Disappearance

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GDR neutrino a l'X, École Polytechnique, Palaiseau, France

work in collaboration with

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Standard Model: Massless Neutrinos

- Standard Model: ν_L, ν_R^c $\Longrightarrow$ no Dirac mass term $\mathcal{L}^{\text{D}} \sim m^{\text{D}} \nu_L \nu_R$
- Majorana Neutrino: $\nu^c = \nu$
- $\nu_R^c = \nu_R$ $\Longrightarrow$ Majorana mass term $\mathcal{L}^{\text{M}} \sim m^{\text{M}} \nu_L \nu_R^c$
- Standard Model: Majorana mass term not allowed by $\text{SU}(2)_L \times \text{U}(1)_Y$

  (no Higgs triplet)

- Neutrinos are special in the Standard Model: the only neutral fermions
- In extensions of the SM neutrinos can mix with non-SM fermions:

$$L_L = \begin{pmatrix} \nu_{eL} \\ e_L \end{pmatrix} \left({I=1/2 \atop Y=-1} \right) \quad \Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} \left({I=1/2 \atop Y=+1} \right) \quad \widetilde{\Phi} = i\tau_2\,\Phi^* \left({I=1/2 \atop Y=-1} \right)$$

non-SM chiral fermion field $f_R = f_L^C \left({I=0 \atop Y=0} \right)$

Dirac mass term $\sim \overline{L_L}\widetilde{\Phi} f_R \quad + \quad$ Majorana mass term $\sim \overline{f_R^C} f_R$

in some models f_R is called right-handed neutrino: $f_R \to \nu_R$

- If these non-SM fermions are light, they are called sterile neutrinos:

$$\nu_{sL} \equiv \nu_R^C$$

- Active neutrinos $(\nu_e, \nu_\mu, \nu_\tau)$ can oscillate into sterile neutrinos (ν_s)
- Extremely interesting window on physics beyond the SM
- Observable: disappearance of active neutrinos
- Many $\overset{(-)}{\nu}_e$ and $\overset{(-)}{\nu}_\mu$ disappearance experiments
- We focus on ν_e and $\bar{\nu}_e$ disappearance
- Gallium and MiniBooNE ν_e anomalies and reactor $\bar{\nu}_e$ data

Experimental Evidences of Neutrino Oscillations

Solar $\nu_e \to \nu_\mu, \nu_\tau$	Homestake Kamiokande GALLEX/GNO & SAGE Super-Kamiokande SNO BOREXino	→	$\Delta m^2_{\text{SOL}} \simeq (7.6 \pm 0.2) \times 10^{-5}\,\text{eV}^2$ $\tan^2\vartheta_{\text{SOL}} \simeq 0.47 \pm 0.06$
Reactor $\bar{\nu}_e$ disappearance	(KamLAND)		
Atmospheric $\nu_\mu \to \nu_\tau$	Kamiokande IMB Super-Kamiokande MACRO Soudan-2	→	$\Delta m^2_{\text{ATM}} \simeq (2.4 \pm 0.1) \times 10^{-3}\,\text{eV}^2$ $\sin^2\vartheta_{\text{ATM}} \simeq 0.50 \pm 0.07$
Accelerator ν_μ disappearance	(K2K & MINOS)		

Two scales of Δm^2: $\Delta m^2_{\text{ATM}} \simeq 30\,\Delta m^2_{\text{SOL}}$

Large mixings: $\vartheta_{\text{ATM}} \simeq 45^\circ$, $\vartheta_{\text{SOL}} \simeq 34^\circ$

Three-Neutrino Mixing

$$\nu_{\alpha L} = \sum_{k=1}^{3} U_{\alpha k} \, \nu_{kL} \qquad (\alpha = e, \mu, \tau)$$

three flavor fields: ν_e, ν_μ, ν_τ

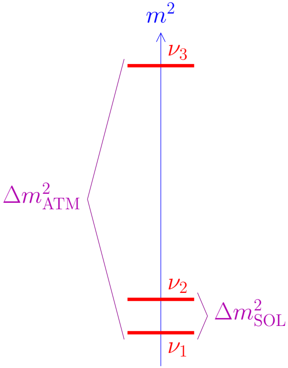
three massive fields: ν_1, ν_2, ν_3

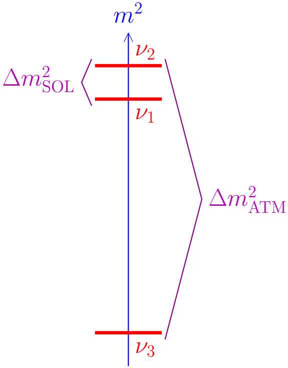
$$\Delta m^2_{21} + \Delta m^2_{32} + \Delta m^2_{13} = m^2_2 - m^2_1 + m^2_3 - m^2_2 + m^2_1 - m^2_3 = 0$$

$$\Delta m^2_{\text{SOL}} = \Delta m^2_{21} \simeq (7.6 \pm 0.2) \times 10^{-5} \, \text{eV}^2$$

$$\Delta m^2_{\text{ATM}} \simeq |\Delta m^2_{31}| \simeq |\Delta m^2_{32}| \simeq (2.4 \pm 0.1) \times 10^{-3} \, \text{eV}^2$$

Allowed Three-Neutrino Schemes





"normal" "inverted"

different signs of $\Delta m^2_{31} \simeq \Delta m^2_{32}$

absolute scale is not determined by neutrino oscillation data

Gallium Anomaly

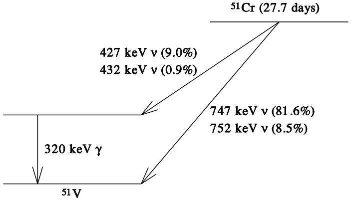
Gallium Radioactive Source Experiments

Tests of the solar neutrino detectors GALLEX (Cr1, Cr2) and SAGE (Cr, Ar)

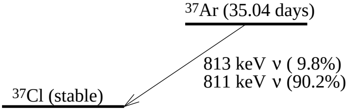
Detection Process: $\nu_e + {}^{71}\text{Ga} \to {}^{71}\text{Ge} + e^-$

ν_e Sources: $e^- + {}^{51}\text{Cr} \to {}^{51}\text{V} + \nu_e$ $e^- + {}^{37}\text{Ar} \to {}^{37}\text{Cl} + \nu_e$

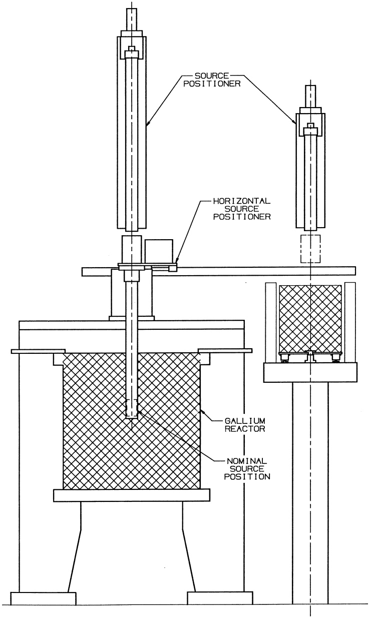
	^{51}Cr				^{37}Ar	
E [keV]	747	752	427	432	811	813
B.R.	0.8163	0.0849	0.0895	0.0093	0.902	0.098



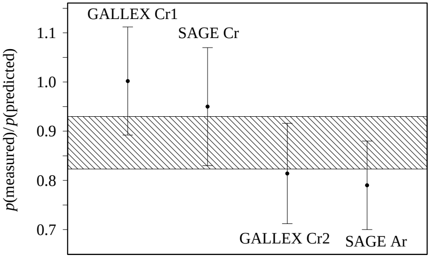
[SAGE, PRC 59 (1999) 2246, hep-ph/9803418]



[SAGE, PRC 73 (2006) 045805, nucl-ex/0512041]



[SAGE, PRC 59 (1999) 2246, hep-ph/9803418]

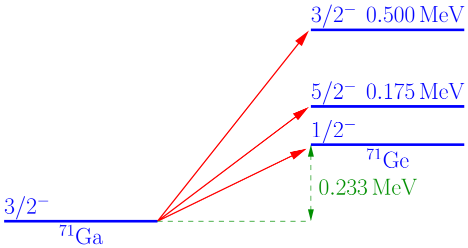


[SAGE, PRC 73 (2006) 045805, nucl-ex/0512041]

$$R_{\mathrm{Ga}} = 0.88 \pm 0.05$$

- Deficit could be due to overestimate of $\sigma(\nu_e + {}^{71}\text{Ga} \to {}^{71}\text{Ge} + e^-)$

- Calculation: Bahcall, PRC 56 (1997) 3391, hep-ph/9710491



- $\sigma_{\text{G.S.}}$ related to measured $\sigma(e^- + {}^{71}\text{Ge} \to {}^{71}\text{Ga} + \nu_e)$:

$$\sigma_{\text{G.S.}}({}^{51}\text{Cr}) = 55.3 \times 10^{-46}\,\text{cm}^2\,(1 \pm 0.004)_{3\sigma}$$

- $\sigma({}^{51}\text{Cr}) = \sigma_{\text{G.S.}}({}^{51}\text{Cr}) \left(1 + 0.669\,\dfrac{\text{BGT}_{175\,\text{keV}}}{\text{BGT}_{\text{G.S.}}} + 0.220\,\dfrac{\text{BGT}_{500\,\text{keV}}}{\text{BGT}_{\text{G.S.}}}\right)$

- Bahcall: [Bahcall, PRC 56 (1997) 3391, hep-ph/9710491]

  from $p + {}^{71}\mathrm{Ga} \to {}^{71}\mathrm{Ge} + n$ measurements [Krofcheck et al., PRL 55 (1985) 1051]

$$\frac{\mathrm{BGT}_{175\,\mathrm{keV}}}{\mathrm{BGT}_{\mathrm{G.S.}}} < 0.056 \Rightarrow \frac{\mathrm{BGT}_{175\,\mathrm{keV}}}{\mathrm{BGT}_{\mathrm{G.S.}}} = \frac{0.056}{2} \qquad \frac{\mathrm{BGT}_{500\,\mathrm{keV}}}{\mathrm{BGT}_{\mathrm{G.S.}}} = 0.146$$

3σ lower limit: $\frac{\mathrm{BGT}_{175\,\mathrm{keV}}}{\mathrm{BGT}_{\mathrm{G.S.}}} = \frac{\mathrm{BGT}_{500\,\mathrm{keV}}}{\mathrm{BGT}_{\mathrm{G.S.}}} = 0$

3σ upper limit: $\frac{\mathrm{BGT}_{175\,\mathrm{keV}}}{\mathrm{BGT}_{\mathrm{G.S.}}} < 0.056 \times 2 \qquad \frac{\mathrm{BGT}_{500\,\mathrm{keV}}}{\mathrm{BGT}_{\mathrm{G.S.}}} = 0.146 \times 2$

$$\sigma({}^{51}\mathrm{Cr}) = 58.1 \times 10^{-46}\,\mathrm{cm}^2 \left(1^{+0.036}_{-0.028}\right)_{1\sigma}$$

- Haxton: [Hata, Haxton, PLB 353 (1995) 422, nucl-th/9503017; Haxton, PLB 431 (1998) 110, nucl-th/9804011]

  "a sophisticated shell model calculation is performed ... for the transition to the first excited state in ${}^{71}\mathrm{Ge}$. The calculation predicts destructive interference between the (p, n) spin and spin-tensor matrix elements."

$$\sigma({}^{51}\mathrm{Cr}) = 63.9 \times 10^{-46}\,\mathrm{cm}^2\,(1 \pm 0.106)_{1\sigma}$$

	GALLEX		SAGE	
	Cr1	Cr2	Cr	Ar
R	0.953 ± 0.11	$0.812^{+0.10}_{-0.11}$	0.95 ± 0.12	$0.79 \pm {}^{+0.09}_{-0.10}$
$\langle L \rangle$	1.9 m		0.6 m	

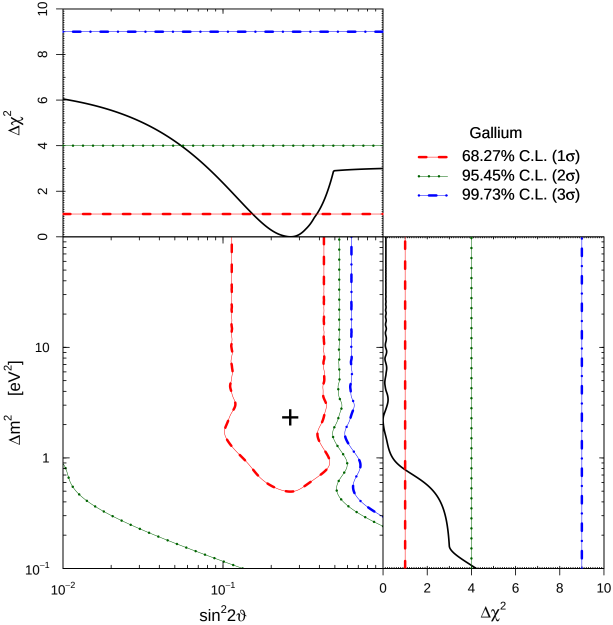
$$\boxed{R_{\text{Ga}} = 0.87 \pm 0.05}$$

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

$$L_{\text{osc}} \lesssim 0.5 \quad \text{m} \quad \Longrightarrow \quad \Delta m^2_{\text{SBL}} \gtrsim 1\,\text{eV}^2 \quad \Longrightarrow \quad \nu_e \to \nu_s$$

$$R = \frac{\int \mathrm{d}V \, L^{-2} \sum_i (\text{B.R.})_i \, \sigma_i \, P_{\nu_e \to \nu_e}(L, E_i)}{\sum_i (\text{B.R.})_i \, \sigma_i \int \mathrm{d}V \, L^{-2}}$$

[Acero, Giunti, Laveder, PRD 78 (2008) 073009, arXiv:0711.4222]



No Osc.

$\chi^2_{\min} = 8.3$

$\mathrm{NdF} = 2$

$\mathrm{GoF} = 8.1\%$

Osc.

$\chi^2_{\min} = 1.8$

$\mathrm{NdF} = 2$

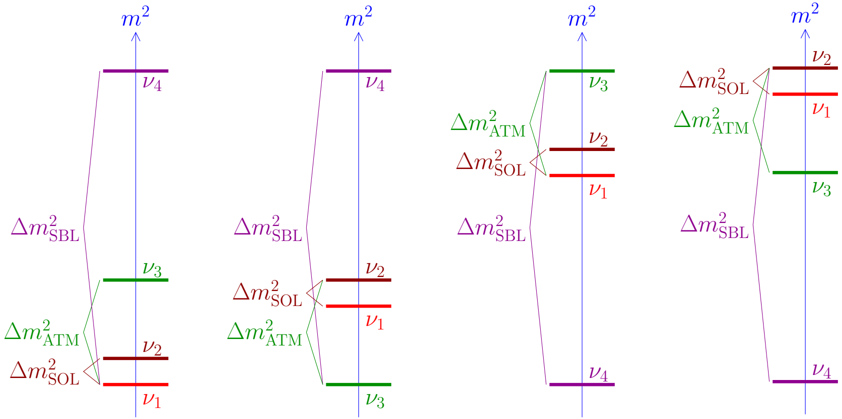
$\mathrm{GoF} = 40\%$

$\sin^2 2\vartheta = 0.26$

$\Delta m^2 = 2.20\,\mathrm{eV}^2$

[Acero, Giunti, Laveder, PRD 78 (2008) 073009, arXiv:0711.4222]

3+1 Four-Neutrino Mixing



"normal"	"3ν-inverted"	"4ν-inverted"	"fully-inverted"
$\|U_{e4}\|^2 \ll 1$	$\|U_{\mu4}\|^2 \ll 1$	$\|U_{\tau4}\|^2 \ll 1$	$\|U_{s4}\|^2 \simeq 1$

$$P^{\mathrm{SBL}}_{\nu_\alpha\to\nu_\beta} = \sin^2 2\vartheta^{\mathrm{SBL}}_{\alpha\beta} \sin^2\left(\frac{\Delta m^2_{\mathrm{SBL}} L}{4E}\right) \quad (\alpha \neq \beta)$$

$$\sin^2 2\vartheta^{\mathrm{SBL}}_{\alpha\beta} = 4|U_{\alpha 4}|^2 |U_{\beta 4}|^2$$

$$P^{\mathrm{SBL}}_{\nu_\alpha\to\nu_\alpha} = 1 - \sin^2 2\vartheta^{\mathrm{SBL}}_{\alpha\alpha} \sin^2\left(\frac{\Delta m^2_{\mathrm{SBL}} L}{4E}\right)$$

$$\sin^2 2\vartheta^{\mathrm{SBL}}_{\alpha\alpha} = 4|U_{\alpha 4}|^2 \left(1 - |U_{\alpha 4}|^2\right)$$

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & \boxed{U_{e4}} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & \boxed{U_{\mu 4}} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & \boxed{U_{\tau 4}} \\ U_{s1} & U_{s2} & U_{s3} & \boxed{U_{s4}} \end{pmatrix}$$

↑ SBL

$$\sin^2 2\vartheta^{\mathrm{SBL}}_{\alpha\alpha} \ll 1$$

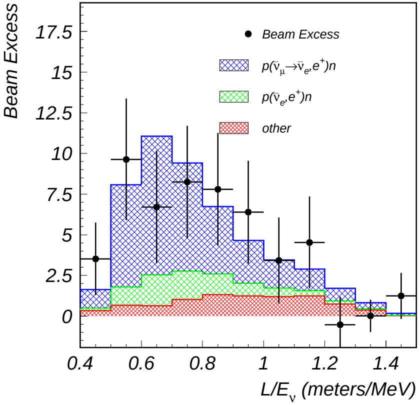
$$\Downarrow$$

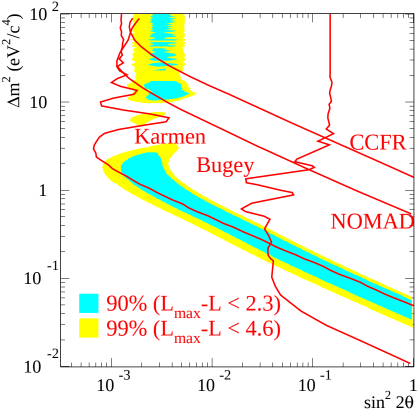
$$|U_{e4}|^2 \simeq \frac{\sin^2 2\vartheta^{\mathrm{SBL}}_{\alpha\alpha}}{4}$$

LSND

[PRL 75 (1995) 2650; PRC 54 (1996) 2685; PRL 77 (1996) 3082; PRD 64 (2001) 112007]

$\bar{\nu}_\mu \to \bar{\nu}_e \qquad L \simeq 30\,\text{m} \qquad 20\,\text{MeV} \le E \le 200\,\text{MeV}$



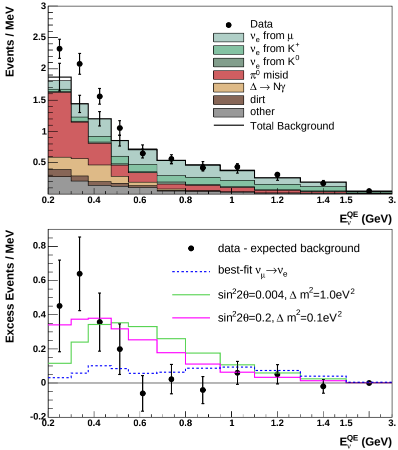


$\Delta m^2_{\text{LSND}} \gtrsim 0.2\,\text{eV}^2 \qquad (\gg \Delta m^2_{\text{ATM}} \gg \Delta m^2_{\text{SOL}})$

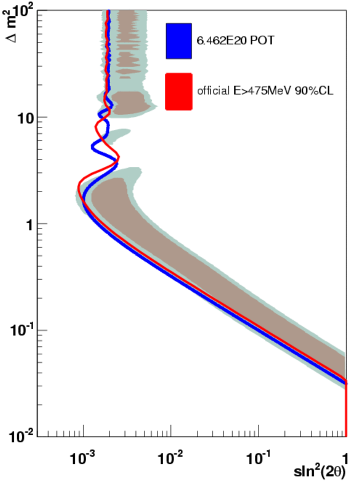
MiniBooNE

[PRL 98 (2007) 231801]

$\nu_\mu \to \nu_e$ $\quad L \simeq 541\,\text{m}$ $\quad 475\,\text{MeV} \leq E \lesssim 3\,\text{GeV}$



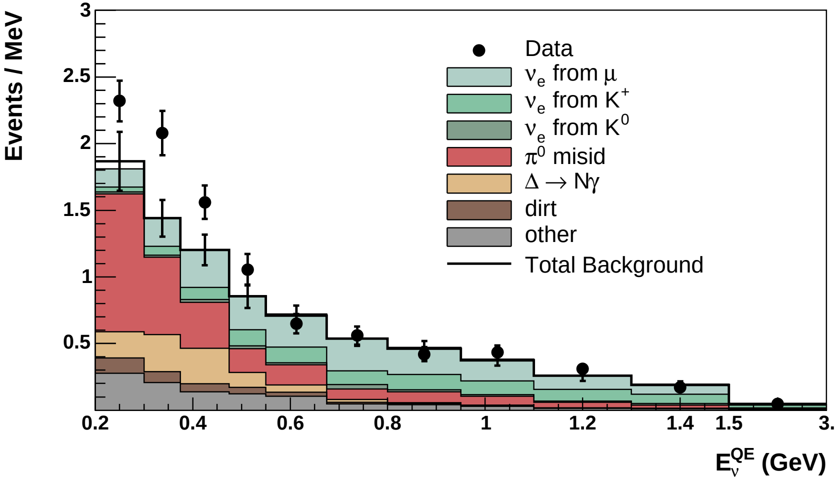
[PRL 102 (2009) 101802, arXiv:0812.2243]



[arXiv:0901.1648]

Low-Energy Anomaly!

MiniBooNE Low-Energy Anomaly



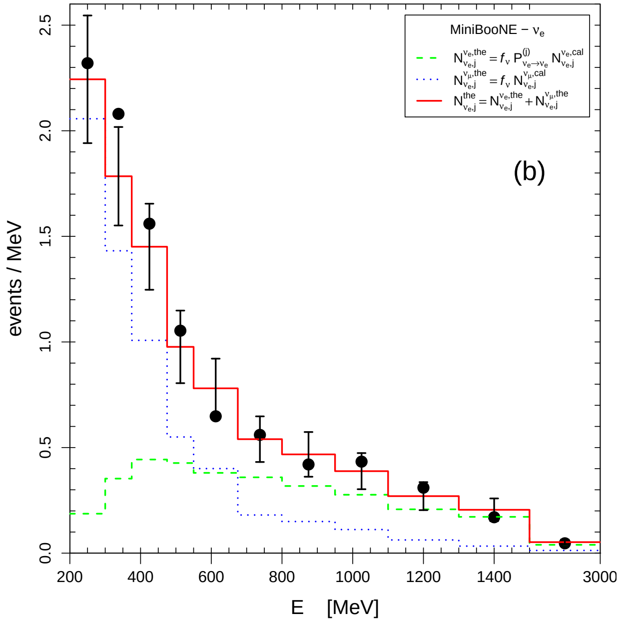
[PRL 102 (2009) 101802, arXiv:0812.2243]

Our Hypothesis: $N_{\nu,j}^{\text{the}} = f_\nu \left(P_{\nu_e \to \nu_e} N_{\nu_e,j}^{\text{cal}} + N_{\nu_\mu,j}^{\text{cal}} \right)$

[Giunti, Laveder, PRD 77 (2008) 093002, arXiv:0707.4593; PRD 80 (2009) 013005, arXiv:0902.1992]

$$N^{\text{the}}_{\nu,j} = f_\nu \left(P_{\nu_e \to \nu_e} N^{\text{cal}}_{\nu_e,j} + N^{\text{cal}}_{\nu_\mu,j} \right)$$

- Estimated 15% uncertainty of the calculated neutrino flux [MiniBooNE, PRD 79 (2009) 072002, arXiv:0806.1449] is consistent with measured ratio 1.21 ± 0.24 of detected and predicted charged-current quasi-elastic ν_μ events [MiniBooNE, PRL 100 (2008) 032301, arXiv:0706.0926]
- We fit MiniBooNE ν_e and ν_μ data using the info at http://www-boone.fnal.gov/for_physicists/data_release/lowe/



No Osc. & $f_\nu = 1$

$\chi^2_{\min} = 14.3 + 5.4$

$\mathrm{NdF} = 3 + 16$

$\mathrm{GoF} = 41\%$

Our Hypothesis

$\chi^2_{\min} = 2.0 + 7.6$

$\mathrm{NdF} = 16$

$\mathrm{GoF} = 89\%$

$f_\nu = 1.26$

$\sin^2 2\vartheta = 0.32$

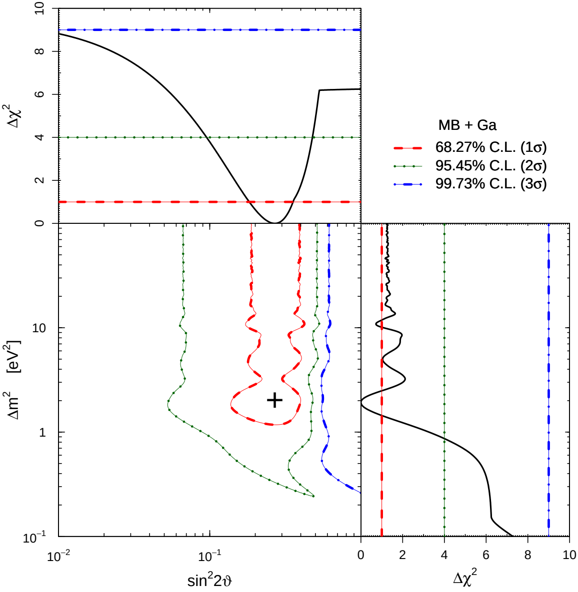
$\Delta m^2 = 1.84\,\mathrm{eV}^2$

[Giunti, Laveder, 2010, in preparation]

- Note similar best-fit values of $\sin^2 2\vartheta$ and Δm^2
- Gallium best fit: $\sin^2 2\vartheta = 0.26$ and $\Delta m^2 = 2.20\,\text{eV}^2$
- MiniBooNE best fit: $\sin^2 2\vartheta = 0.32$ and $\Delta m^2 = 1.84\,\text{eV}^2$
- Parameter Goodness of Fit of combined analysis:

$$\Delta\chi^2_{\text{min}} = 0.14 \qquad \text{NDF} = 2 \qquad \text{GoF} = 93\%$$

MiniBooNE + Gallium



$\chi^2_{\text{min}} = 2.3 + 9.2$

$\text{NdF} = 20$

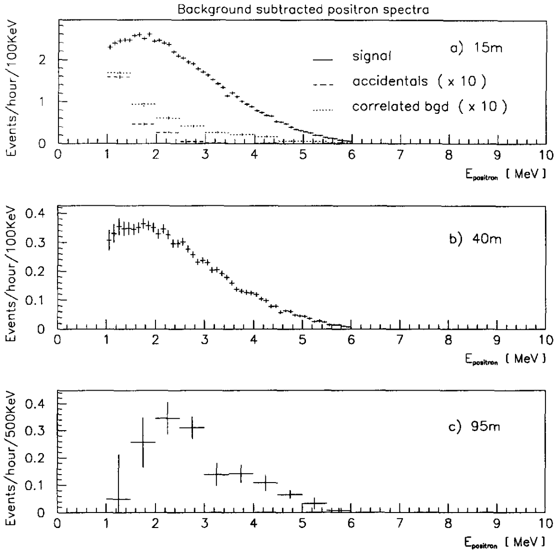
$\text{GoF} = 93\%$

$\sin^2 2\vartheta = 0.27$

$\Delta m^2 = 1.92\,\text{eV}^2$

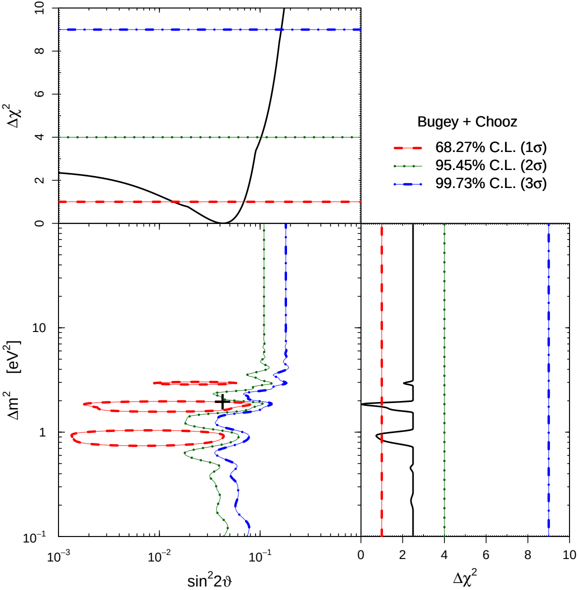
[Giunti, Laveder, 2010, in preparation]

Bugey



[Bugey, NPB 434 (1995) 503]

Bugey + Chooz



$\chi^2_{\rm min} = 48.5$

$\mathrm{NdF} = 54$

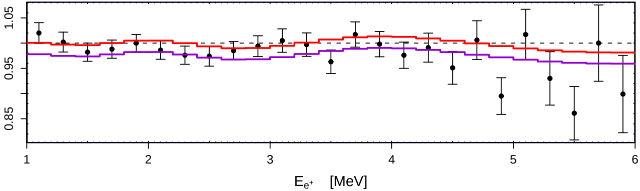
$\mathrm{GoF} = 69\%$

$\sin^2 2\vartheta = 0.042$

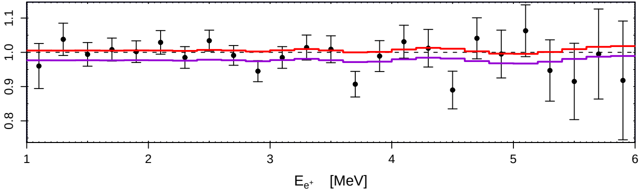
$\Delta m^2 = 1.85\,\mathrm{eV}^2$

[Acero, Giunti, Laveder, PRD 78 (2008) 073009, arXiv:0711.4222]

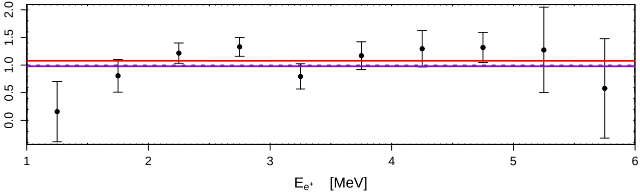
L = 15 m



L = 40 m



L = 95 m



Note similar best-fit values of Δm^2 but different $\sin^2 2\vartheta$:

- Gallium+MiniBooNE best fit: $\Delta m^2 = 1.92\,\text{eV}^2$ and $\sin^2 2\vartheta = 0.27$
- Reactors best fit: $\Delta m^2 = 1.85\,\text{eV}^2$ and $\sin^2 2\vartheta = 0.042$

Tritium Beta-Decay

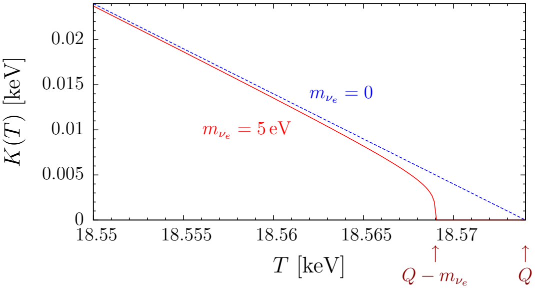
$^3\text{H} \to {}^3\text{He} + e^- + \bar{\nu}_e$

$$\frac{d\Gamma}{dT} = \frac{(\cos\vartheta_C G_F)^2}{2\pi^3} |\mathcal{M}|^2 F(E)\, pE\, (Q-T) \sqrt{(Q-T)^2 - m_{\nu_e}^2}$$

$$Q = M_{^3\text{H}} - M_{^3\text{He}} - m_e = 18.58\,\text{keV}$$

Kurie plot

$$K(T) = \sqrt{\frac{d\Gamma/dT}{\frac{(\cos\vartheta_C G_F)^2}{2\pi^3} |\mathcal{M}|^2 F(E)\, pE}} = \left[(Q-T) \sqrt{(Q-T)^2 - m_{\nu_e}^2} \right]^{1/2}$$



$m_{\nu_e} \lesssim 2.2\,\text{eV}$ (95% C.L.)

Mainz & Troitsk

[Weinheimer, hep-ex/0210050]

future: KATRIN

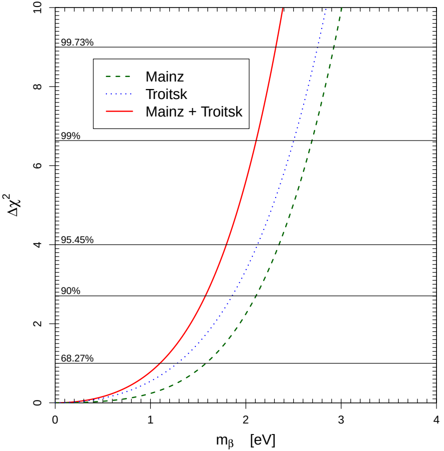
[hep-ex/0109033] [hep-ex/0309007]

sensitivity: $m_{\nu_e} \simeq 0.2\,\text{eV}$

Neutrino Mixing: $m_{\nu_e} \Longrightarrow m_\beta = \sqrt{\sum_k |U_{ek}|^2 m_k^2}$

Mainz: $m_\beta^2 = -0.6 \pm 2.2 \pm 2.1\,\text{eV}^2$

Troitsk: $m_\beta^2 = -2.3 \pm 2.5 \pm 2.0\,\text{eV}^2$



95% C.L. Upper Limits

Mainz:	2.3 eV
Troitsk:	2.0 eV
Mainz+Troitsk:	1.8 eV

Normal and 3ν-inverted schemes

$$m_\beta \lesssim \widetilde{m}_\beta \, \text{eV} \quad \Longrightarrow \quad |U_{e4}|^2 m_4^2 \lesssim \widetilde{m}_\beta^2$$

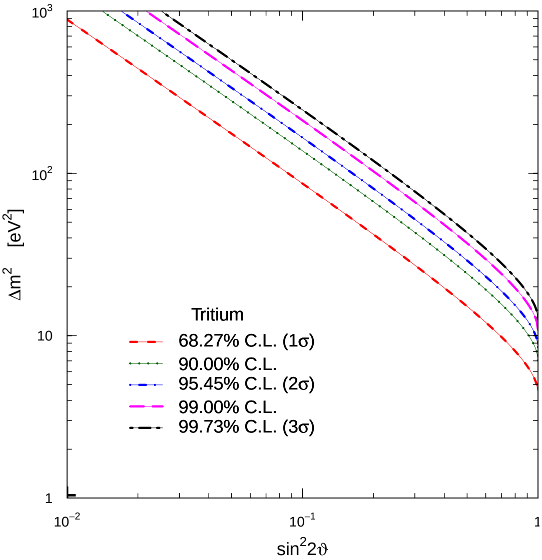
$$m_4 \gg m_1, m_2, m_3 \quad \Longrightarrow \quad m_4^2 \simeq \Delta m^2_{\text{SBL}}$$

$$\Delta m^2_{\text{SBL}} \lesssim |U_{e4}|^{-2} \widetilde{m}_\beta^2$$

$$\sin^2 2\vartheta_{ee}^{\text{SBL}} = 4|U_{e4}|^2 \left(1 - |U_{e4}|^2\right) \Longrightarrow |U_{e4}|^2 = \frac{1}{2}\left(1 \pm \sqrt{1 - \sin^2 2\vartheta_{ee}^{\text{SBL}}}\right)$$

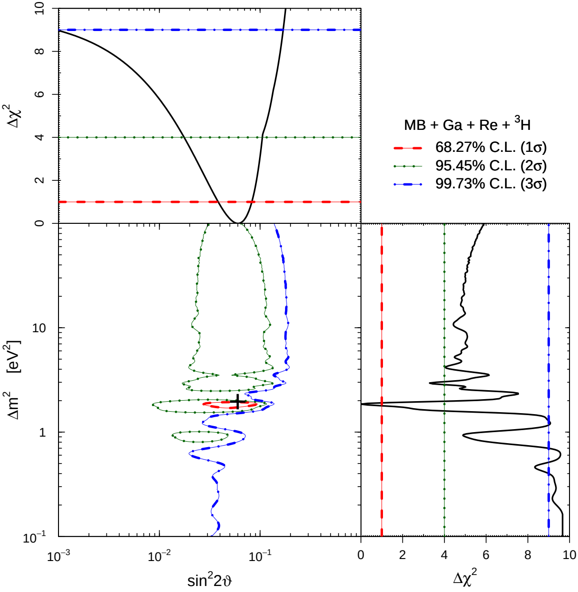
$$|U_{e4}|^2 < \frac{1}{2} \quad \Longrightarrow \quad |U_{e4}|^2 = \frac{1}{2}\left(1 - \sqrt{1 - \sin^2 2\vartheta_{ee}^{\text{SBL}}}\right)$$

$$\boxed{\Delta m^2_{\text{SBL}} \lesssim \frac{2\widetilde{m}_\beta^2}{1 - \sqrt{1 - \sin^2 2\vartheta_{ee}^{\text{SBL}}}}}$$



[Giunti, Laveder, 2010, in preparation]

MiniBooNE + Gallium + Reactors + Tritium



$\chi^2_{\rm min} = 4.1 + 58.6$

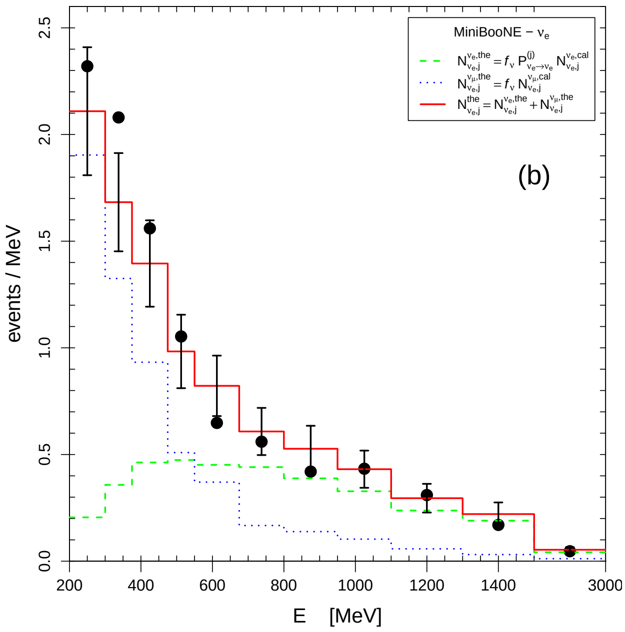
$\text{NdF} = 78$

$\text{GoF} = 90\%$

$\sin^2 2\vartheta = 0.06$

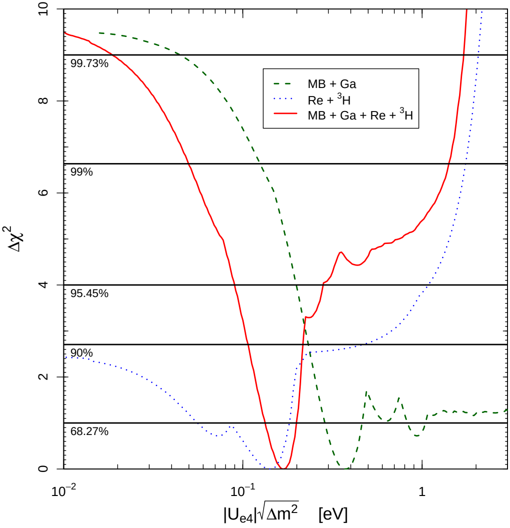
$\Delta m^2 = 1.85\,\text{eV}^2$

[Giunti, Laveder, 2010, in preparation]



MiniBooNE − ν_e
$N^{\nu_e,\mathrm{the}}_{\nu_e,j} = f_\nu \, P^{(j)}_{\nu_e\to\nu_e} \, N^{\nu_e,\mathrm{cal}}_{\nu_e,j}$
$N^{\nu_\mu,\mathrm{the}}_{\nu_e,j} = f_\nu \, N^{\nu_\mu,\mathrm{cal}}_{\nu_e,j}$
$N^{\mathrm{the}}_{\nu_e,j} = N^{\nu_e,\mathrm{the}}_{\nu_e,j} + N^{\nu_\mu,\mathrm{the}}_{\nu_e,j}$
(b)
events / MeV
E [MeV]
0.0
0.5
1.0
1.5
2.0
2.5
200
400
600
800
1000
1200
1400
3000

Prediction for Beta-Decay Experiments



[Giunti, Laveder, 2010, in preparation]

$$m_\beta = \sqrt{\sum_{k=1}^{4} |U_{ek}|^2 m_k^2}$$

$$m_\beta \geq |U_{e4}| m_4$$

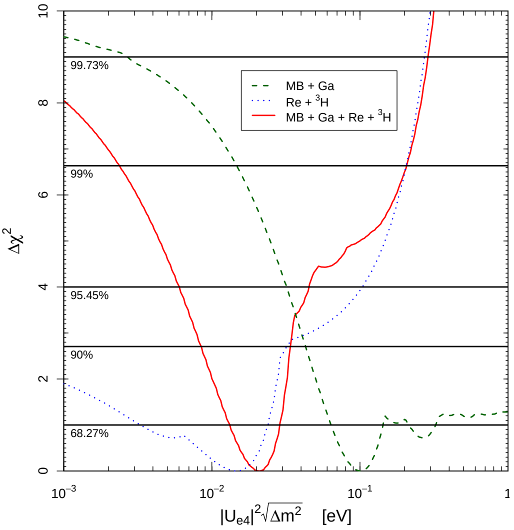
$$m_\beta \geq |U_{e4}| \sqrt{\Delta m^2}$$

$$\left(|U_{e4}|\sqrt{\Delta m^2}\right)_{\text{bf}} = 0.17\,\text{eV}$$

At 95% C.L.

$$|U_{e4}|\sqrt{\Delta m^2} \in [0.093, 0.28]\,\text{eV}$$

Prediction for Neutrinoless Double-Beta Decay



$$m_{2\beta} = \sum_{k=1}^{4} U_{ek}^2 m_k$$

$$\left(|U_{e4}|^2 \sqrt{\Delta m^2}\right)_{\rm bf} = 0.021\,\text{eV}$$

95% C.L. Interval

$[0.006, 0.044]$ eV

[Giunti, Laveder, 2010, in preparation]

Future Tests of (V)SBL ν_e and $\bar{\nu}_e$ Disappearance

The hypothesis of VSBL ν_e disappearance can be tested with high accuracy by future experiments with pure well-known electron neutrino beams:

- SAGE collaboration is planning a new source experiment (ν_e)
- Beta-Beam experiments:

$$N(A,Z) \to N(A,Z+1) + e^- + \bar{\nu}_e \qquad (\beta^-)$$

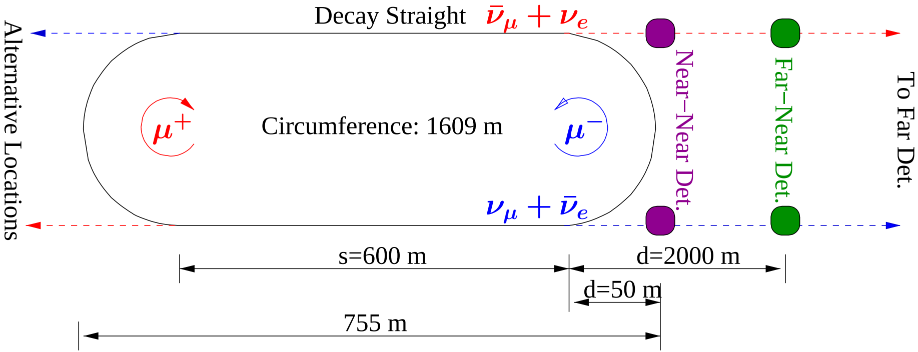
$$N(A,Z) \to N(A,Z-1) + e^+ + \nu_e \qquad (\beta^+)$$

- Neutrino Factory experiments:

$$\mu^+ \to \bar{\nu}_\mu + e^+ + \nu_e$$

$$\mu^- \to \nu_\mu + e^- + \bar{\nu}_e$$

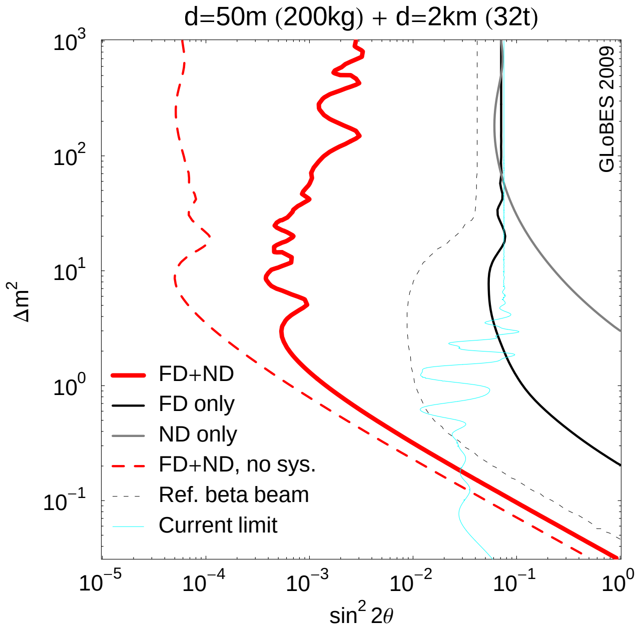
Neutrino Factory



[Giunti, Laveder, Winter, PRD 80 (2009) 073005, arXiv:0907.5487]

Near Detectors: Scintillator or Iron Calorimeter with perfect flavor identification

Systematic Uncertainties: Cross Section, Detector Normalization, Energy Resolution and Calibration, Backgrounds



[Giunti, Laveder, Winter, PRD 80 (2009) 073005, arXiv:0907.5487]

Conclusions

- The Gallium anomaly may be due to $\nu_e \to \nu_s$ oscillations with $\sin^2 2\vartheta \gtrsim 0.1$ and $\Delta m^2 \gtrsim 1\,\text{eV}^2$
- These transitions may explain the MiniBooNE Low-Energy-Anomaly and fit the Bugey reactor data
- Interesting coincidence of best-fit values of Δm^2 at about $2\,\text{eV}^2$ from Gallium, MiniBooNE and Reactor data
- Combined fit indicates $\sin^2 2\vartheta \approx 0.06$ and $\Delta m^2 \approx 1.85\,\text{eV}^2$
- Interesting predictions: $m_\beta \approx 0.1 - 0.2\,\text{eV}$ and $m_{2\beta}$ could be as large as about $0.04\,\text{eV}$
- (V)SBL ν_e and $\bar{\nu}_e$ disappearance can be checked in future
  - Beta-Beam experiments (pure ν_e or $\bar{\nu}_e$ beam from nuclear decay)
  - Neutrino Factory experiments (ν_e and $\bar{\nu}_\mu$ from μ^+ decay, or $\bar{\nu}_e$ and ν_μ from μ^- decay)