Very-Short-BaseLine Electron Neutrino Disappearance

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Standard Model: Massless Neutrinos

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

  (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:

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

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

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
$\nu_e \to \nu_\mu, \nu_\tau$

Reactor
$\bar{\nu}_e$ disappearance

Homestake
Kamiokande
GALLEX/GNO & SAGE
Super-Kamiokande
SNO
BOREXino

(KamLAND)

$$\to \begin{cases} \Delta m^2_{\text{SOL}} \simeq (7.6 \pm 0.2) \times 10^{-5}\,\text{eV}^2 \\ \tan^2 \vartheta_{\text{SOL}} \simeq 0.47 \pm 0.06 \end{cases}$$

Atmospheric
$\nu_\mu \to \nu_\tau$

Accelerator
ν_μ disappearance

Kamiokande
IMB
Super-Kamiokande
MACRO
Soudan-2

(K2K & MINOS)

$$\to \begin{cases} \Delta m^2_{\text{ATM}} \simeq (2.4 \pm 0.1) \times 10^{-3}\,\text{eV}^2 \\ \sin^2 \vartheta_{\text{ATM}} \simeq 0.50 \pm 0.07 \end{cases}$$

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

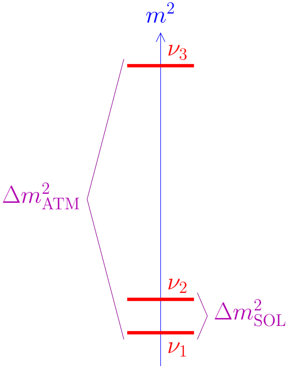
three massive fields: ν_1, ν_2, ν_3

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

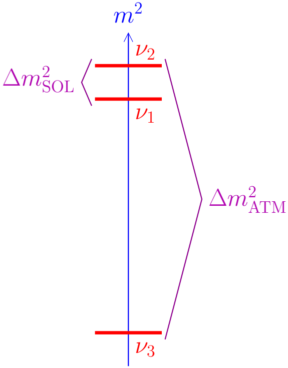
$$\Delta m^2_{\text{SOL}} = \Delta m^2_{21} \simeq (7.6 \pm 0.2) \times 10^{-5} \, \text{eV}^2$$

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

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

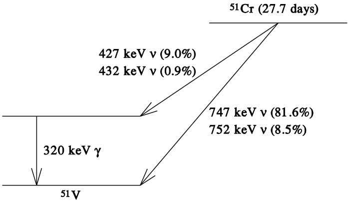
Gallium Radioactive Source Experiments

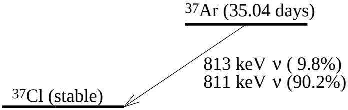
Tests of the solar neutrino detectors GALLEX (Cr1, Cr2) and SAGE (Cr, Ar)

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

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

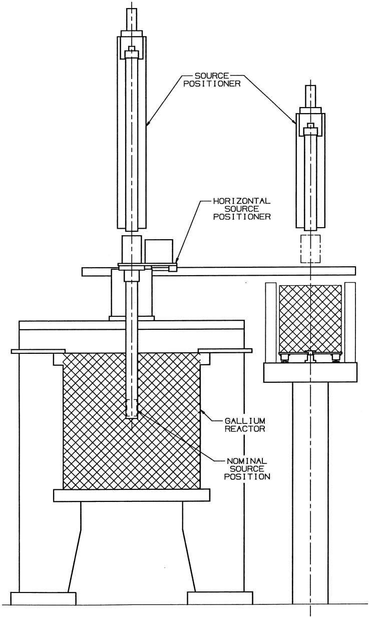
	^{51}Cr				^{37}Ar	
E [keV]	747	752	427	432	811	813
B.R.	0.8163	0.0849	0.0895	0.0093	0.902	0.098



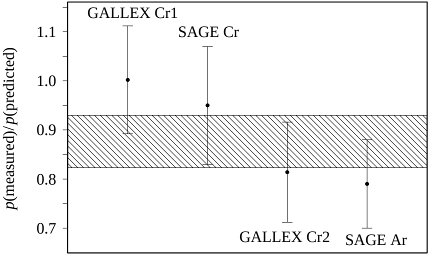


[SAGE, PRC 73 (2006) 045805, nucl-ex/0512041]

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



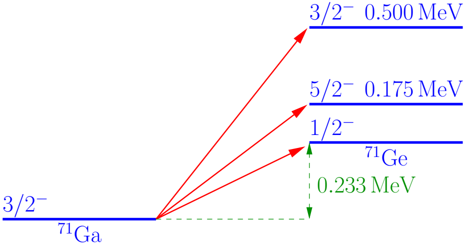
[SAGE, PRC 59 (1999) 2246, hep-ph/9803418]



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

$$\boxed{R_{\text{Ga}} = 0.88 \pm 0.05}$$

- 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 $\sigma(e^- + {}^{71}\text{Ge} \to {}^{71}\text{Ga} + \nu_e)$:

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

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

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

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

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

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

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

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

- 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 ${}^{71}\text{Ge}$. The calculation predicts destructive interference between the (p, n) spin and spin-tensor matrix elements.”

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

	GALLEX		SAGE	
	Cr1	Cr2	Cr	Ar
R	1.00 ± 0.10	0.81 ± 0.10	0.95 ± 0.12	0.79 ± 0.10
$\langle L \rangle$	1.9 m		0.6 m	

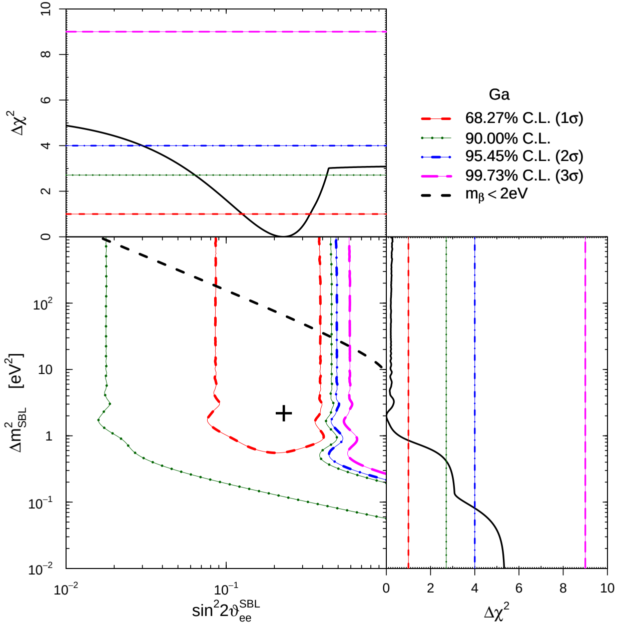
$$\boxed{R_{\text{Ga}} = 0.88 \pm 0.05}$$

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

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

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

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



$\chi^2_{\mathrm{min}} = 2.94$

$\mathrm{NdF} = 2$

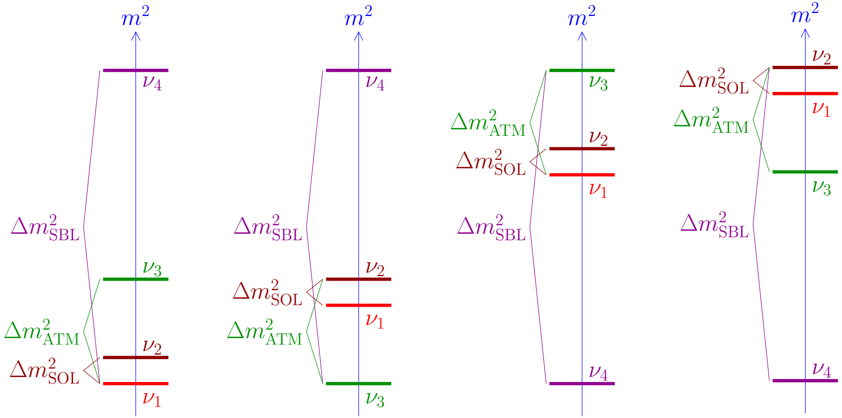
$\mathrm{GoF} = 23\%$

$\sin^2 2\vartheta = 0.22$

$\Delta m^2 = 1.98\,\mathrm{eV}^2$

[Acero, C.G, Laveder, PRD 78 (2008) 073009, arXiv:0711.4222]

3+1 Four-Neutrino Mixing



"normal" "3ν-inverted" "4ν-inverted" "fully-inverted"

$|U_{e4}|^2 \ll 1$ $|U_{\mu 4}|^2 \ll 1$ $|U_{\tau 4}|^2 \ll 1$ $|U_{s4}|^2 \simeq 1$

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

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

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

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

$$U = \left(\begin{array}{ccc|c|} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ U_{\mu1} & U_{\mu2} & U_{\mu3} & U_{\mu4} \\ U_{\tau1} & U_{\tau2} & U_{\tau3} & U_{\tau4} \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} \end{array}\right)$$

$\uparrow$

SBL

$$\sin^2 2\vartheta^{\text{SBL}}_{ee} \simeq 0.22 \Rightarrow |U_{e4}|^2 \simeq 0.06$$

$$\sin^2 2\vartheta^{\text{SBL}}_{ee} \gtrsim 0.02 \Rightarrow |U_{e4}|^2 \gtrsim 0.005$$

Tritium Beta-Decay

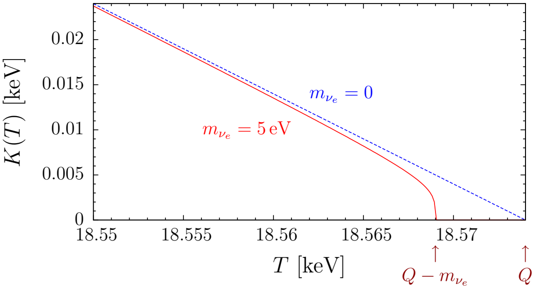
$^3H \to {}^3He + e^- + \bar{\nu}_e$

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

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

Kurie plot

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



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

Mainz & Troitsk

[Weinheimer, hep-ex/0210050]

future: KATRIN (start 2010)

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

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

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

4ν-inverted and fully-inverted schemes

$$|U_{e1}|^2 + |U_{e2}|^2 + |U_{e3}|^2 \simeq 1 \qquad\qquad |U_{e4}|^2 \ll 1$$

$$m_\beta \simeq m_1 \simeq m_2 \simeq m_3 \simeq \sqrt{\Delta m^2_{\text{SBL}}}$$

$$\boxed{\Delta m^2_{\text{SBL}} \lesssim 5\,\text{eV}^2}$$

Normal and 3ν-inverted schemes

$$m_\beta \lesssim 2\,\text{eV} \quad \Longrightarrow \quad |U_{e4}|^2 m_4^2 \lesssim 4\,\text{eV}^2$$

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

$$\Delta m^2_{\text{SBL}} \lesssim 4|U_{e4}|^{-2}\,\text{eV}^2$$

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

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

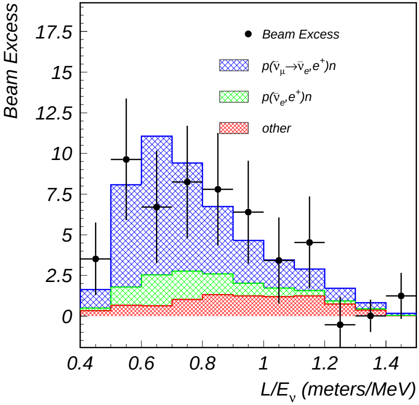
$$\boxed{\Delta m^2_{\text{SBL}} \lesssim \frac{8}{1 - \sqrt{1 - \sin^2 2\vartheta_{ee}^{\text{SBL}}}}\,\text{eV}^2}$$

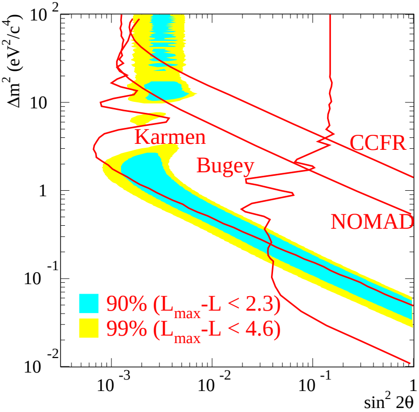
$$\sin^2 2\vartheta_{ee}^{\text{SBL}} \gtrsim 0.02 \Rightarrow \Delta m^2_{\text{SBL}} \lesssim 800\,\text{eV}^2$$

LSND

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

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



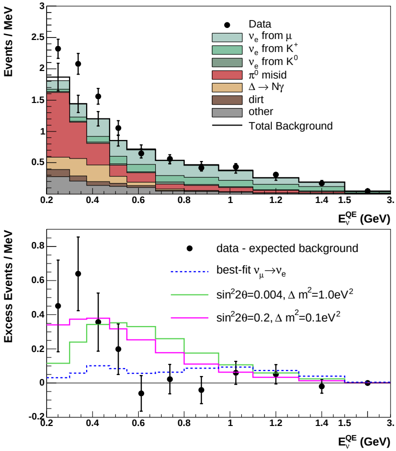


$$\Delta m^2_{\mathrm{LSND}} \gtrsim 0.2\,\mathrm{eV}^2 \qquad (\gg \Delta m^2_{\mathrm{ATM}} \gg \Delta m^2_{\mathrm{SOL}})$$

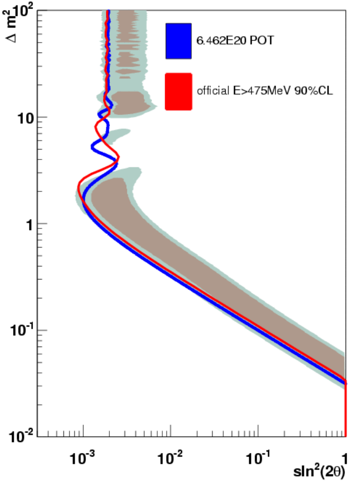
MiniBooNE

[PRL 98 (2007) 231801]

$\nu_\mu \to \nu_e$ $L \simeq 541\,\mathrm{m}$ $475\,\mathrm{MeV} \le E \lesssim 3\,\mathrm{GeV}$



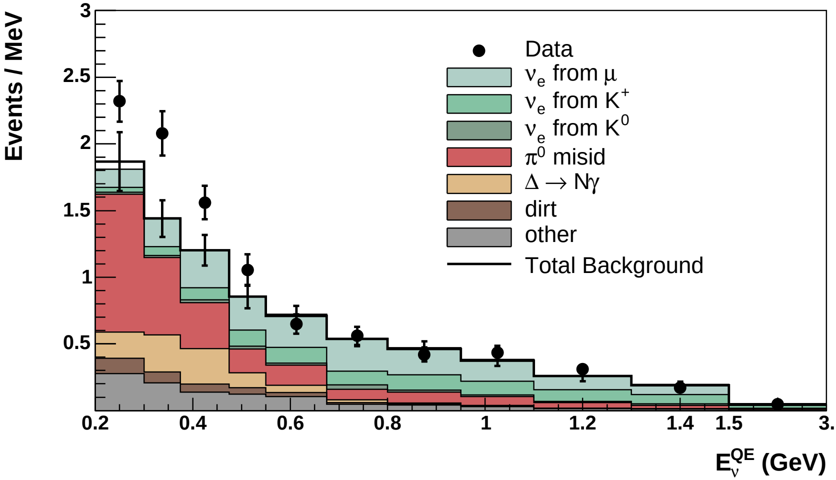
[PRL 102 (2009) 101802, arXiv:0812.2243]



[arXiv:0901.1648]

Low-Energy Anomaly!

MiniBooNE Low-Energy Anomaly



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

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

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

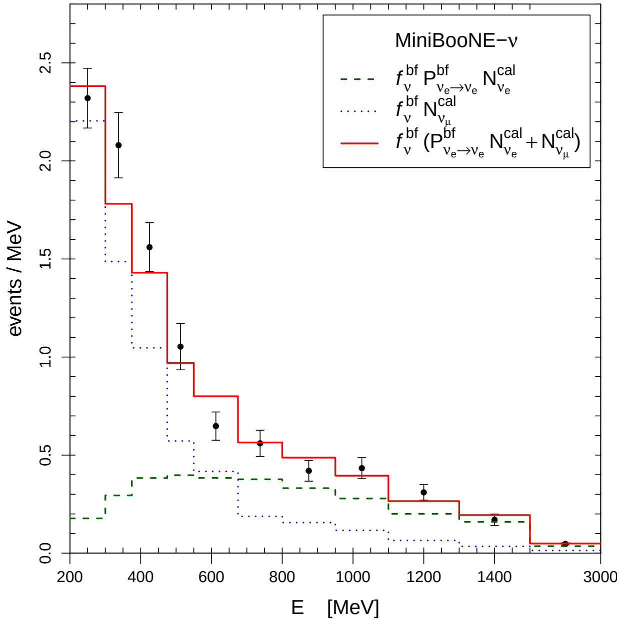
- Estimated 15% uncertainty of the calculated neutrino flux [MiniBooNE, PRD 79 (2009) 072002, arXiv:0806.1449] is consistent with measured ratio 1.21 ± 0.24 of detected and predicted charged-current quasi-elastic ν_μ events [MiniBooNE, PRL 100 (2008) 032301, arXiv:0706.0926]

- We consider $\Delta m^2_{\text{SBL}} \to \Delta m^2_{\text{VSBL}} \gtrsim 20\,\text{eV}^2$
  - $P_{\nu_e\to\nu_e}$ is practically constant in MiniBooNE

$$L^{\text{MB}}_{\text{osc}} = \frac{4\pi E}{\Delta m^2} \lesssim 400\,\text{m} \quad < \quad L^{\text{MB}} \simeq 541\,\text{m}$$

  - Very-Short-BaseLine (VSBL) because oscillation length in Gallium Radioactive Source Experiments and Reactor Neutrino Experiments is extremely small:

$$L_{\text{osc}}(1\,\text{MeV}) \lesssim 10\,\text{cm}$$



No Osc.

$\chi^2_{\rm min} = 27.2$

$\rm NdF = 10$

$\rm GoF = 0.2\%$

$f_\nu = 1.15$

Osc.

$\chi^2_{\rm min} = 17.7$

$\rm NdF = 9$

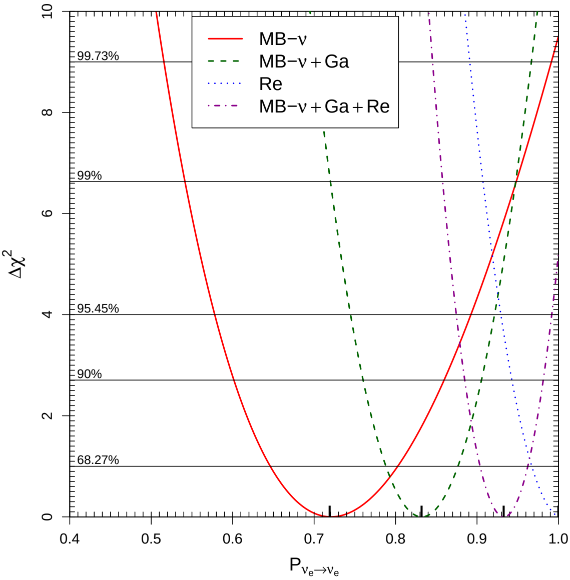
$\rm GoF = 3.8\%$

$f_\nu = 1.31$

$P_{\nu_e\to\nu_e} = 0.72$

[C.G, Laveder, PRD 80 (2009) 013005, arXiv:0902.1992]

MiniBooNE-ν + Gallium + Reactors



[C.G, Laveder, PRD 80 (2009) 013005, arXiv:0902.1992]

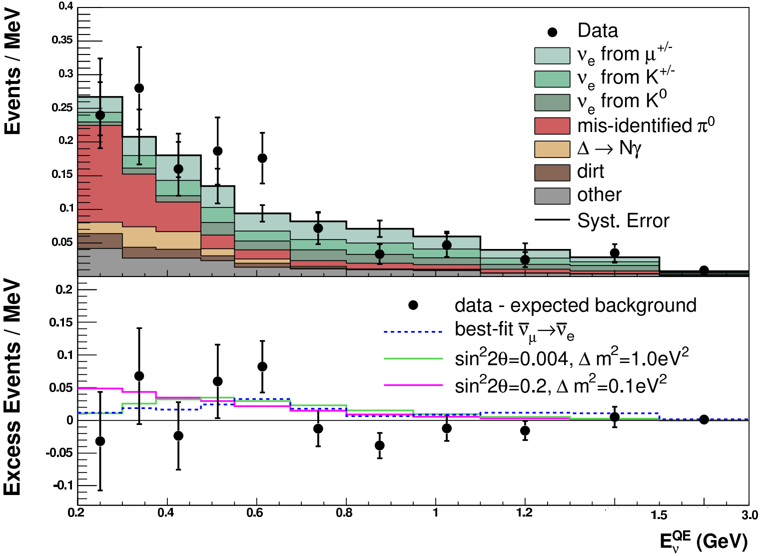
		MB-ν	MB-ν+Ga	Re	MB-ν+Ga+Re
No Osc.	$\chi^2_{\rm min}$	27.2	34.0	2.9	36.9
	NDF	10	11	7	18
	GoF	0.2%	0.04%	89.8%	0.5%
	$f_\nu^{\rm bf}$	1.15	1.15		1.15
Osc.	$\chi^2_{\rm min}$	17.7	20.1	2.9	31.7
	NDF	9	10	6	17
	GoF	3.8%	2.8%	82.7%	1.7%
	$P^{\rm bf}_{\nu_e\to\nu_e}$	0.72	0.83	1.0	0.93
	$f_\nu^{\rm bf}$	1.31	1.24		1.19
PG	$\Delta\chi^2_{\rm min}$		2.4		11.1
	NDF		1		2
	GoF		12.4%		0.4%

[C.G, Laveder, PRD 80 (2009) 013005, arXiv:0902.1992]

PG = Parameter Goodness-of-fit

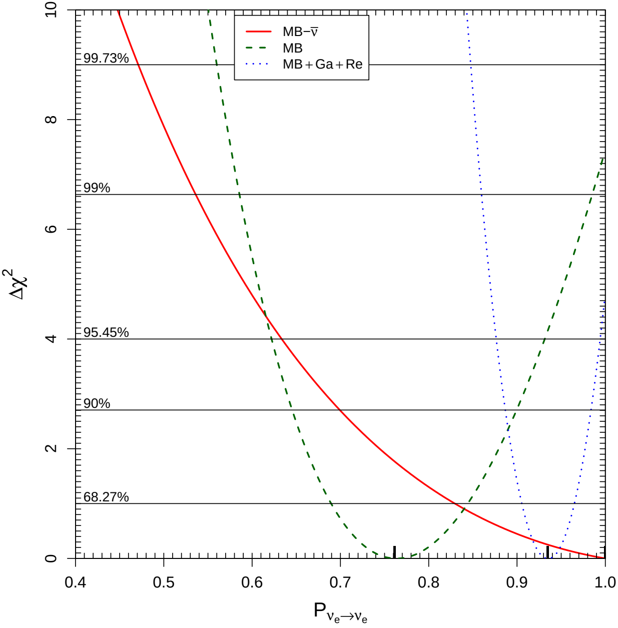
[Maltoni, Schwetz, PRD 68 (2003) 033020, hep-ph/0304176]

MiniBooNE Antineutrino Data



[PRL 103 (2009) 111801, arXiv:0904.1958]

No Low-Energy Anomaly!



[C.G, Laveder, PRD 80 (2009) 013005, arXiv:0902.1992]

		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%
	$f_{\bar{\nu}}^{\text{bf}}$	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
	$f_{\bar{\nu}}^{\text{bf}}$	1.08	1.08	1.19	1.10
	f_{ν}^{bf}			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%

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

[C.G, Laveder, PRD 80 (2009) 013005, arXiv:0902.1992]

Tension between neutrino and antineutrino data could be due to:

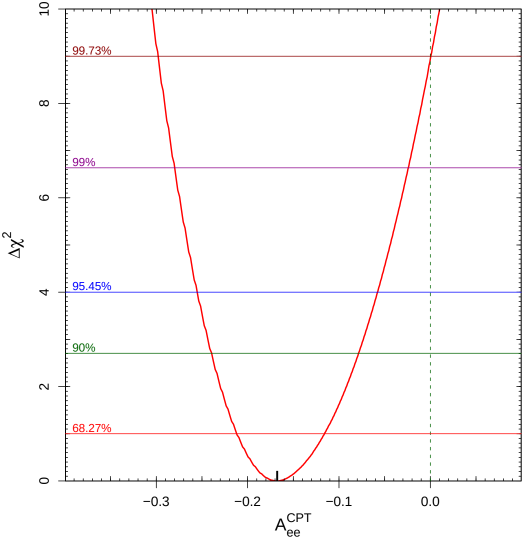
- Statistical fluctuations.
- Underestimate of systematic uncertainties.
- Our hypothesis of VSBL ν_e disappearance is excluded.
- Violation of CPT symmetry: $P_{\nu_e \to \nu_e} \neq P_{\bar{\nu}_e \to \bar{\nu}_e}$.

$$\nu_\alpha \to \nu_\beta \quad \xrightarrow{\text{CP}} \quad \nu_{\bar{\alpha}} \to \nu_{\bar{\beta}} \quad \xrightarrow{\text{T}} \quad \nu_{\bar{\beta}} \to \nu_{\bar{\alpha}}$$

$$\text{CPT} \quad \Longrightarrow \quad \boxed{P_{\nu_\alpha \to \nu_\beta} = P_{\nu_{\bar{\beta}} \to \nu_{\bar{\alpha}}}}$$

$$\alpha = \beta \quad \Longrightarrow \quad \boxed{P_{\nu_\alpha \to \nu_\alpha} = P_{\bar{\nu}_\alpha \to \bar{\nu}_\alpha}}$$

CPT Violation?



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

$$\chi^2_{\mathrm{min}} = 39.9$$

$$\mathrm{NdF} = 26$$

$$\mathrm{GoF} = 4.0\%$$

$$A_{ee}^{\mathrm{CPT}} = -0.17$$

[C.G, Laveder, PRD 80 (2009) 013005, arXiv:0902.1992]

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:

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

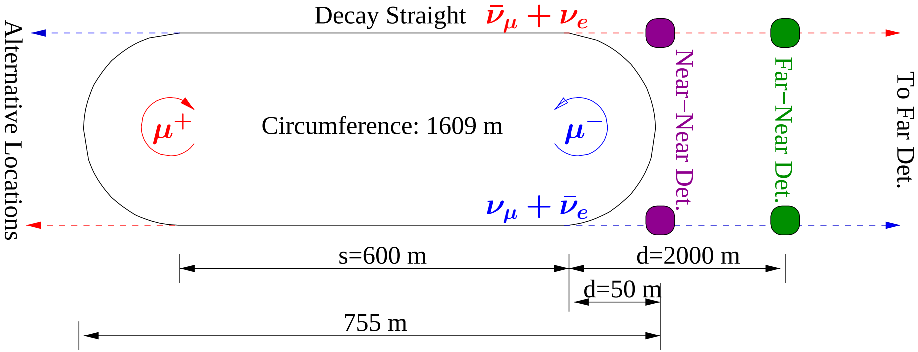
$$N(A,Z) \to N(A,Z-1) + e^+ + \nu_e \qquad (\beta^+)$$

- Neutrino Factory experiments:

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

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

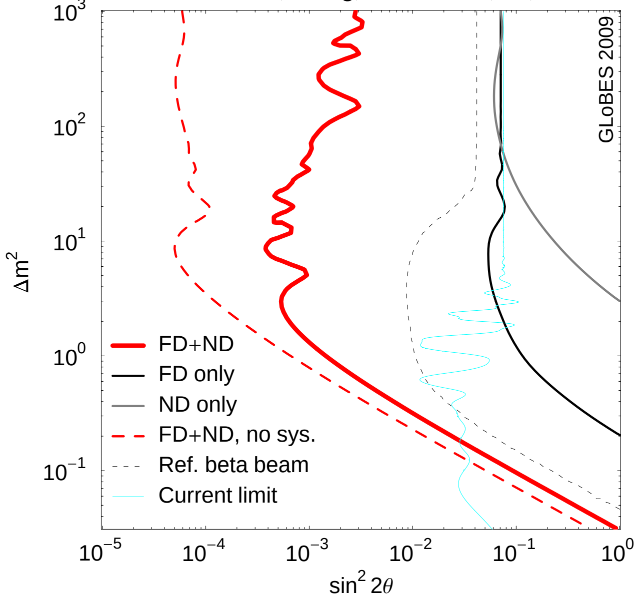
Neutrino Factory



[C.G, 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

d=50m (200kg) + d=2km (32t)



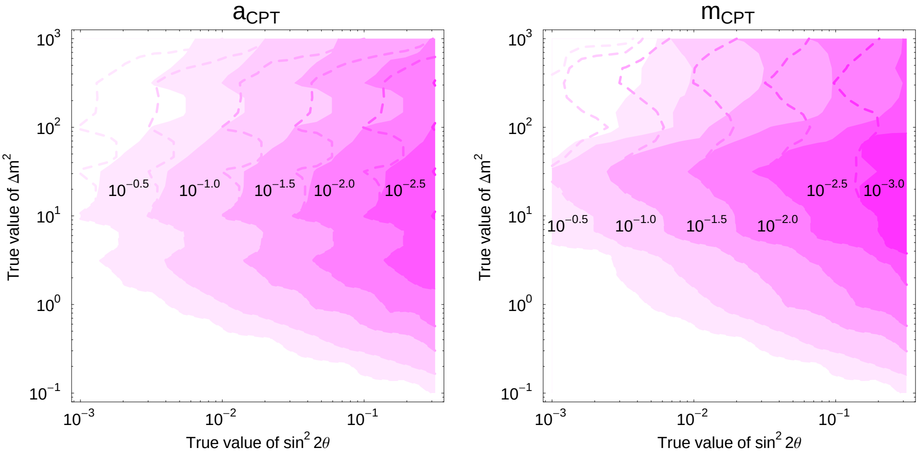
[C.G, Laveder, Winter, PRD 80 (2009) 073005, arXiv:0907.5487]

CPT Violation?

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

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

$$a_{\text{CPT}} \equiv \frac{\vartheta_{\nu} - \vartheta_{\bar{\nu}}}{\vartheta_{\nu} + \vartheta_{\bar{\nu}}} \qquad\qquad m_{\text{CPT}} \equiv \frac{\Delta m^2_{\nu} - \Delta m^2_{\bar{\nu}}}{\Delta m^2_{\nu} + \Delta m^2_{\bar{\nu}}}$$



[C.G, Laveder, Winter, PRD 80 (2009) 073005, arXiv:0907.5487]

$10^{-0.5} \simeq 0.3 \qquad 10^{-1.5} \simeq 0.03 \qquad 10^{-2.5} \simeq 0.003$

dashed lines: no averaging over decay straights

Conclusions

- The Gallium anomaly may be due to $\nu_e \to \nu_s$ oscillations with $\sin^2 2\vartheta \gtrsim 0.1$ and $1\,\text{eV}^2 \lesssim \Delta m^2 \lesssim 800\,\text{eV}^2$
- These transitions may explain the MiniBooNE Low-Energy-Anomaly
- Tension between neutrino and antineutrino data could be an indication of CPT violation ($P_{\nu_e \to \nu_e} \neq P_{\bar{\nu}_e \to \bar{\nu}_e}$)
- (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), which can test also CPT violation.