Gallium and Reactor Neutrinos Anomaly

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- Neutrinos are special in the Standard Model: the only neutral fermions
- 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 $\sim \overline{f_R^C} f_R$

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 (Gallium) and $\bar{\nu}_e$ (Reactor) disappearance

Gallium Anomaly

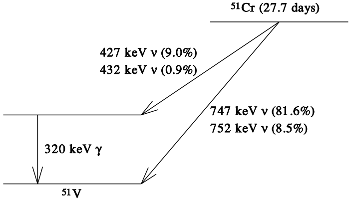
Gallium radioactive source experiments

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

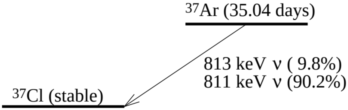
$$\nu_e + {}^{71}\mathrm{Ga} \to {}^{71}\mathrm{Ge} + e^-$$

$$e^- + {}^{51}\mathrm{Cr} \to {}^{51}\mathrm{V} + \nu_e \qquad e^- + {}^{37}\mathrm{Ar} \to {}^{37}\mathrm{Cl} + \nu_e$$

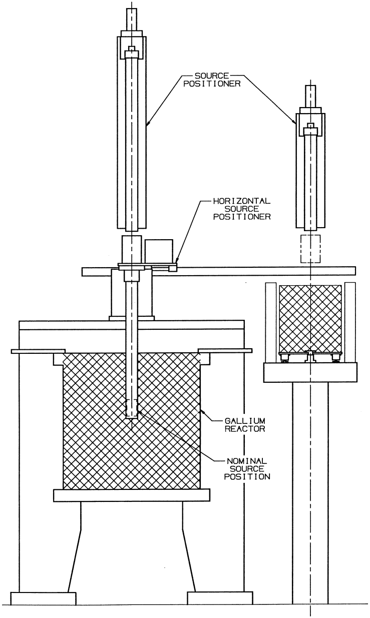
	^{51}Cr				^{37}Ar	
E [keV]	747	752	427	432	811	813
B.R.	0.8163	0.0849	0.0895	0.0093	0.902	0.098



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



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



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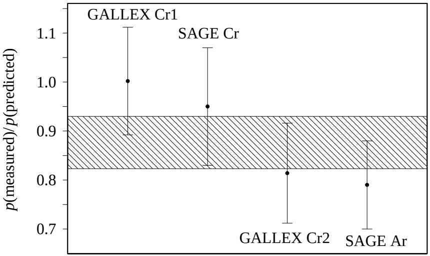


[SAGE, PRC 73 (2006) 045805, nucl-ex/0512041]

	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	

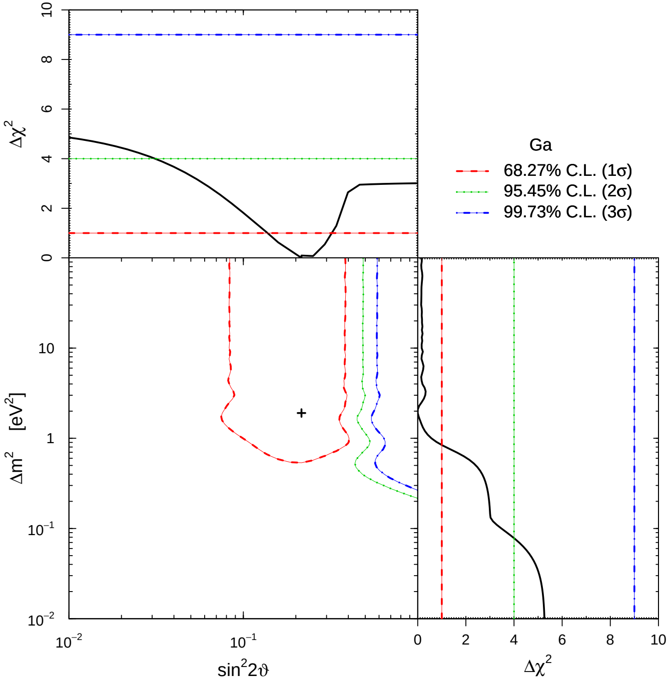
$$R_{\text{Ga}} = 0.88 \pm 0.05$$

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

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

$$L_{\text{osc}} \lesssim 0.5 \quad \text{m} \quad \Longrightarrow \quad \Delta m^2 \gtrsim 4\,\text{eV}^2 \quad \Longrightarrow \quad \nu_e \to \nu_s$$

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



$\chi^2_{\min} = 2.90$

NdF $= 2$

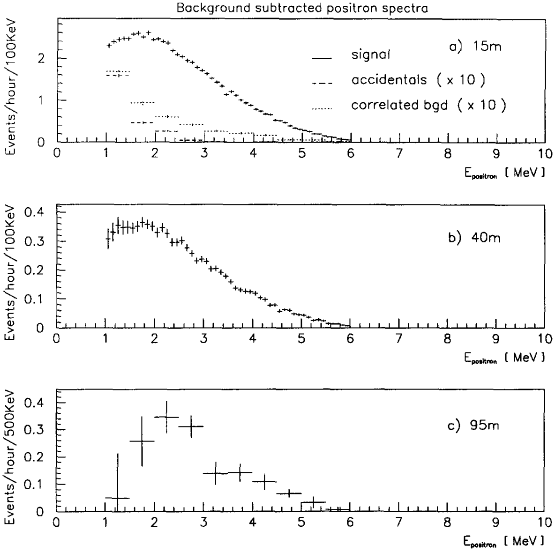
GoF $= 0.23$

$\sin^2 2\vartheta = 0.22$

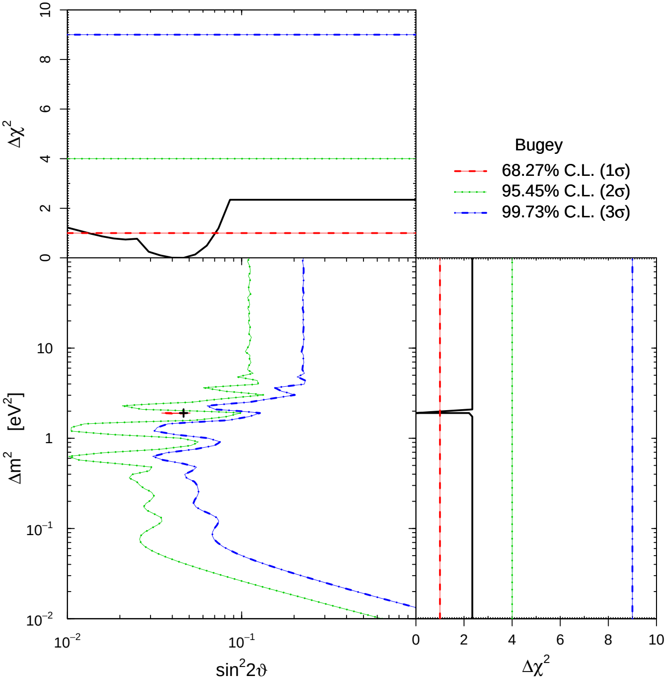
$\Delta m^2 = 1.91\,\mathrm{eV}^2$

[arXiv:0711.4222]

Bugey



[Bugey, NPB 434 (1995) 503]



$\chi^2_{\rm min} = 46.55$

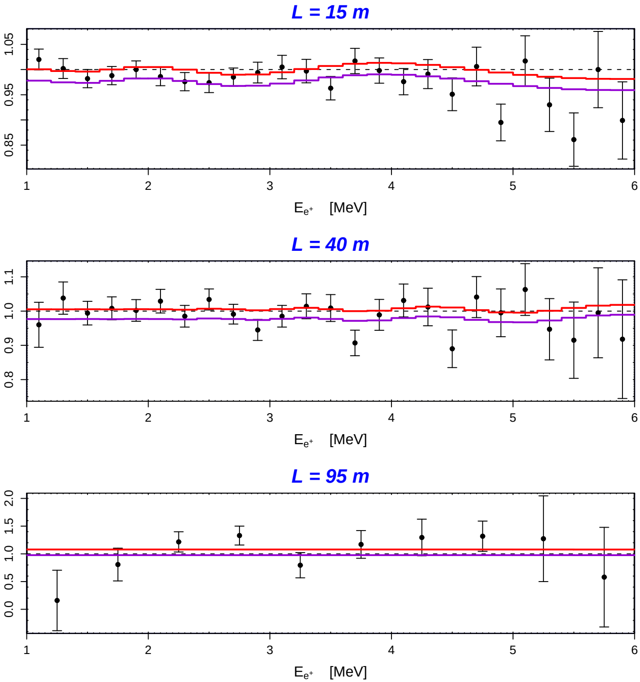
$\mathrm{NdF} = 53$

$\mathrm{GoF} = 0.72$

$\sin^2 2\vartheta = 0.044$

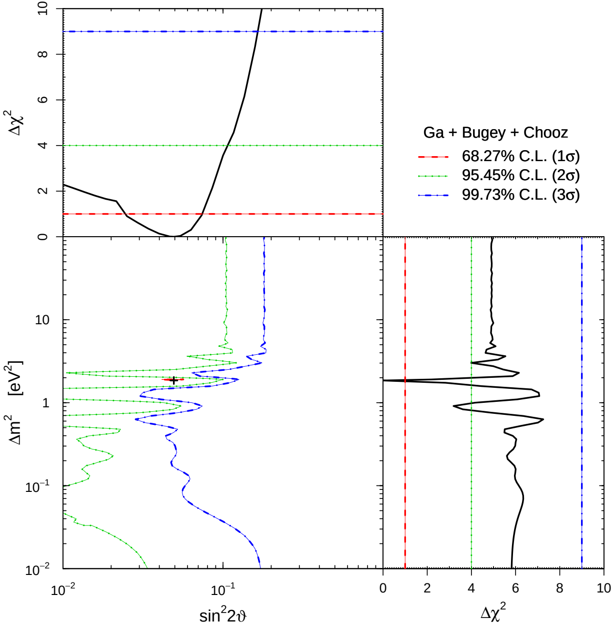
$\Delta m^2 = 1.85\,\mathrm{eV}^2$

[arXiv:0711.4222]



L = 15 m
1.05
0.95
0.85
1
2
3
4
5
6
E_{e^+} [MeV]
L = 40 m
1.1
1.0
0.9
0.8
1
2
3
4
5
6
E_{e^+} [MeV]
L = 95 m
2.0
1.5
1.0
0.5
0.0
1
2
3
4
5
6
E_{e^+} [MeV]

Gallium + Bugey + Chooz



$\chi^2_{\text{min}} = 53.47$

$\text{NdF} = 58$

$\text{GoF} = 0.64$

$\sin^2 2\vartheta = 0.049$

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

[arXiv:0711.4222]

Conclusions

- The Gallium anomaly may be due to $\nu_e \to \nu_s$ oscillations with $\sin^2 2\vartheta \gtrsim 0.04$ and $\Delta m^2 \gtrsim 0.1\,\text{eV}^2$
- These transitions are compatible with the $\bar{\nu}_e$ survival probability measured in reactor experiments (Bugey and Chooz)
- Bugey data present a weak indication in favor of neutrino oscillations with $\sin^2 2\vartheta \simeq 0.04$ and $\Delta m^2 \simeq 1.8\,\text{eV}^2$
- These surprising indications of new physics beyond the Standard Model may be explored by
  - 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)
  - Experiments with a $\bar{\nu}_e$ beam produced in recoiless nuclear decay and detected in recoiless nuclear antineutrino capture (Mossbauer neutrinos)
  - The LENS detector with an artificial Megacurie ν_e source