Phenomenology with sterile neutrinos

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SUSY 2011, September 1, 2011

Fermilab

based on work done in collaboration with
Carlos Arguëlles, Roni Harnik, Pedro Machado,
Michele Maltoni, Stephen Parke, Thomas Schwetz

Outline

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Short baselines anomalies

An intriguing accumulation of inconclusive hints . . .

The reactor anti-neutrino anomaly

- Recent reevaluation of expected reactor $\bar{\nu}_e$ flux is $\sim 3.5\%$ higher than previous prediction Mueller et al. arXiv:1101.2663 vs. Schreckenbach 1985
- Method: Use measured β-spectra from ^{238}U, ^{235}U, ^{241}Pu fission at ILL and convert to $\bar{\nu}_e$ spectrum
- Problem: Requires knowledge of Q-values for all contributing decays.

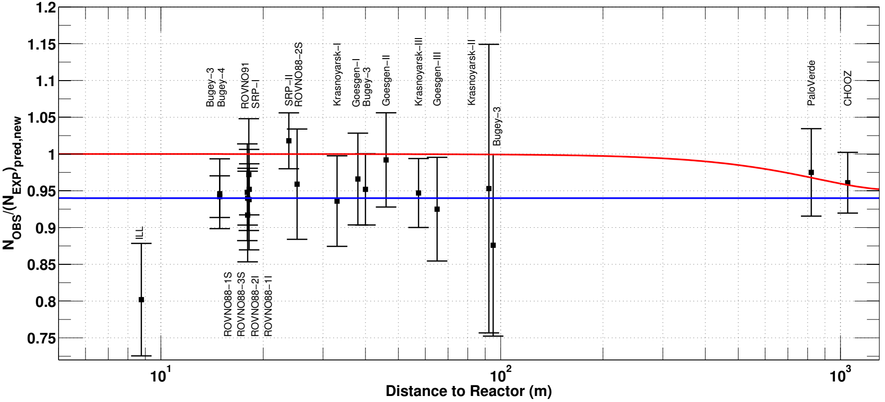
Old method Schreckenbach 1985	New method Mueller et al. arXiv:1101.2663
30 effective branches	Uses nuclear databases (90% of $\bar{\nu}_e$ flux)
	5 effective branches (remaining 10%)
	Error propagation, correlation matrix
	Off-equilibrium corrections (short irradiation time at ILL $\rightarrow$ not all β-branches in equilibrium

Mueller et al.'s results recently confirmed using independent method: P. Huber, arXiv:1106.0687

…but also mentions possibly poorly understood nculear effects (weak magnetism) in nuclei with large log *ft* as a possible source of the anomaly.

The reactor anti-neutrino anomaly (2)

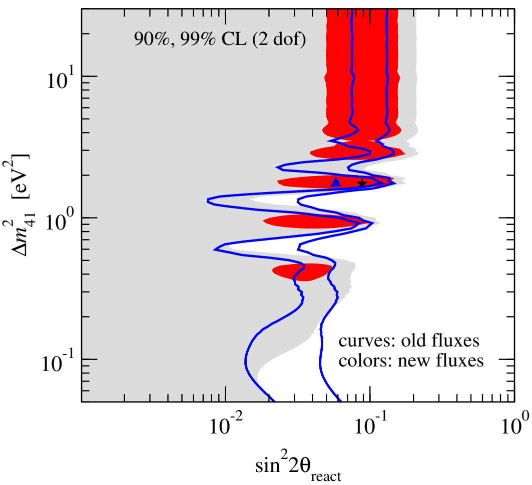
- Have short-baseline reactor experiments observed an event deficit?



Mention et al. arXiv:1101.2755

Fit to reactor anti-neutrino data in a 3+1 model

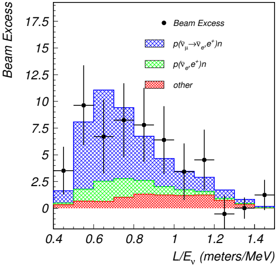
Assume 3 active neutrinos + 1 sterile neutrino
($\rightarrow$ $\bar{\nu}_e$ can oscillate into sterile neutrinos)



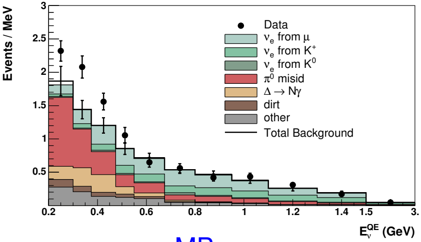
plot by Thomas Schwetz

LSND, KARMEN, MiniBooNE

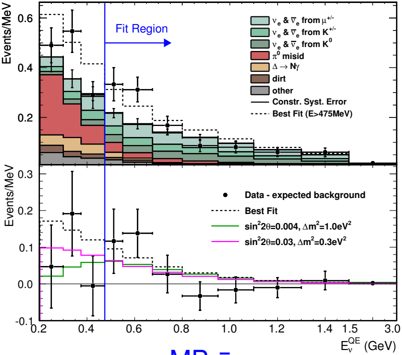
- LSND:
  - $\bar{\nu}_e$ appearance in $\bar{\nu}_\mu$ beam from stopped pion source
- MiniBooNE:
  - $\bar{\nu}_e$ appearance in accelerated $\bar{\nu}_\mu$ beam
  - No similar appearance in ν_e mode
    $\rightarrow$ CP violation?
- KARMEN:
  - Very similar to LSND, but no excess



LSND $\bar{\nu}_e$



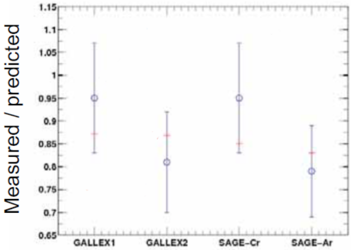
MB ν_e



MB $\bar{\nu}_e$

The Gallium anomaly (not included in our fits)

- Calibration measurements for the GALLEX and SAGE solar neutrino detectors using intense radioactive ν_e sources (^{51}Cr and ^{37}Ar)
- Neutrino detection via $^{71}\text{Ga} + \nu_e \to {}^{71}\text{Ge} + e^-$
- Result: Measurements consistently lower than expectation from other calibration methods



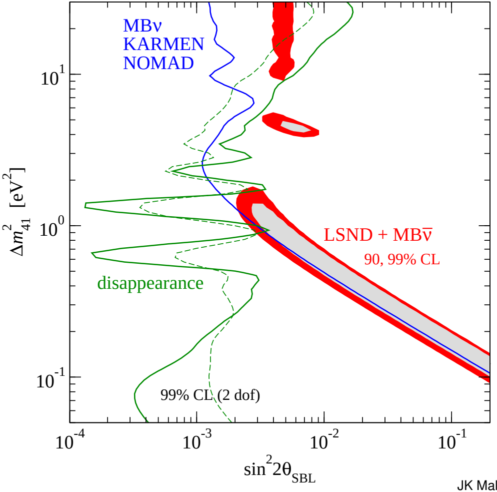
Giunti Laveder arXiv:1005.4599, arXiv:1006.3244
Mention et al. Moriond 2011 talk

- Question: How well are efficiencies of the radiochemical method understood?

Outline

Fit to SBL data in a 3+1 model

- Short baseline: Standard oscillations ineffective (Δm^2 too small)
- Add extra (sterile) neutrino $\rightarrow$ 3+1 model (effectively a 2-flavor problem)
- Fit does not work well (no CP violation)

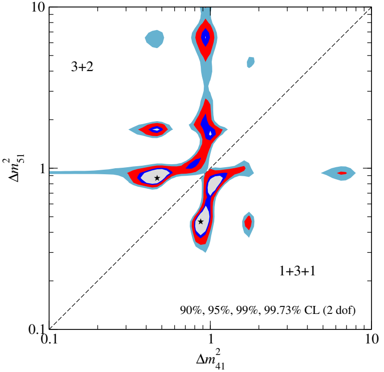


JK Maltoni Schwetz, arXiv:1103.4570

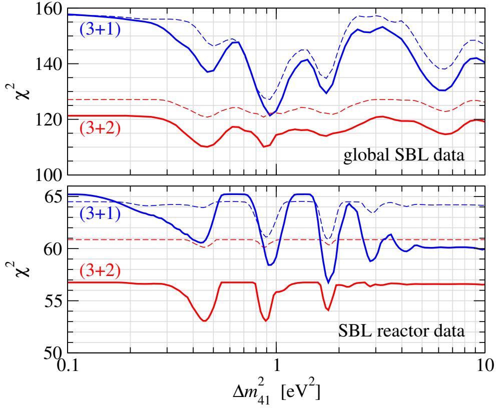
Global fit in a 5-flavor framework

Why 5 flavors?

- Need at least 2 sterile neutrinos to have CP violation at short baseline for MiniBooNE ν_e vs. $\bar{\nu}_e$ (in 3+1, SBL oscillations are effectively 2-flavor)



JK Maltoni Schwetz, arXiv:1103.4570;
see Giunti Laveder arXiv:1107.1452 for another global fit



Parameter goodness of fit: Test compatibility of 2 data sets by comparing global $\chi^2_{\rm min}$ to $\chi^2_{\rm min}$ for separate fits

Global fit in a 5-flavor framework

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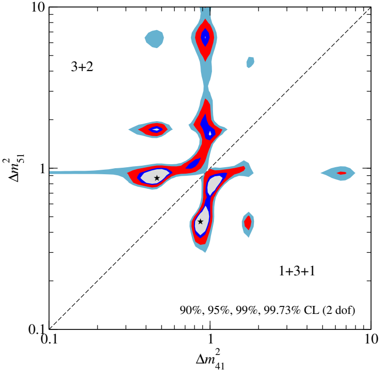

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	Δm^2_{41}	$\lvert U_{e4}\rvert$	$\lvert U_{\mu 4}\rvert$	Δm^2_{51}	$\lvert U_{e5}\rvert$	$\lvert U_{\mu 5}\rvert$	δ/π	χ^2/dof
3+2	0.47	0.128	0.165	0.87	0.138	0.148	1.64	110.1/130
1+3+1	0.47	0.129	0.154	0.87	0.142	0.163	0.35	106.1/130

Best fit point

	LSND+MB($\bar{\nu}$) vs rest		appearance vs disapp.	
	old	new	old	new
$\chi^2_{\mathrm{PG},3+2}$/dof	25.1/5	19.9/5	19.9/4	14.7/4
PG_{3+2}	10^{-4}	0.13%	5×10^{-4}	0.53%
$\chi^2_{\mathrm{PG},1+3+1}$/dof	19.6/5	16.0/5	14.4/4	10.6/4
PG_{1+3+1}	0.14%	0.7%	0.6%	3%

Parameter goodness of fit test

Parameter goodness of fit: Test compatibility of 2 data sets by comparing global $\chi^2_{\min}$ to $\chi^2_{\min}$ for separate fits

Outline

Sterile neutrinos and direct dark matter detection

- Solar and atmospheric neutrinos are a well-known background to future direct dark matter searches

  see e.g. Gütlein et al. arXiv:1003.5530

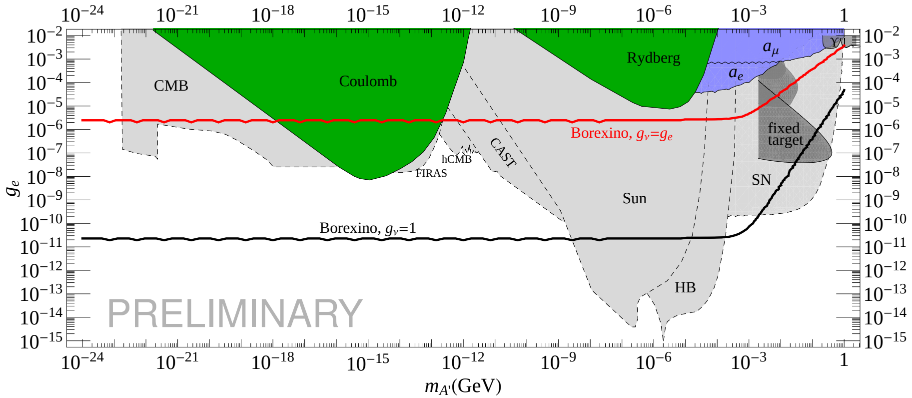
- If low-energy neutrino interactions are enhanced by new physics, this background can be significantly enhanced
  $\rightarrow$ Possible explanation of DM anomalies?

  Pospelov arXiv:1103.3261, Harnik JK Machado (work in progress)

- Phenomenologically, this is easiest to achieve in models with sterile neutrinos

Sterile neutrinos and direct dark matter detection (2)

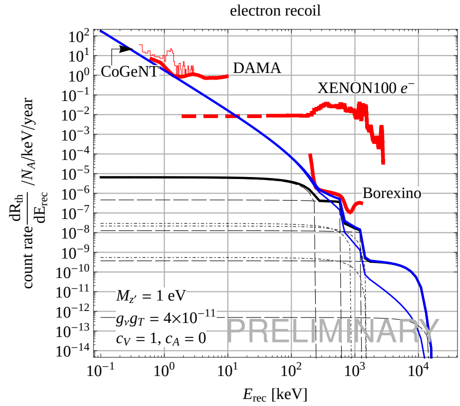
- Introduce a sterile neutrino + a light ($\ll 1$ eV) gauge boson, weakly coupled to electrons, but not too weakly coupled to sterile neutrinos



Ringwald et al., Harnik JK Machado (work in progress)

Sterile neutrinos and direct dark matter detection (2)

- Introduce a sterile neutrino + a light ($\ll$ 1 eV) gauge boson, weakly coupled to electrons, but not too weakly coupled to sterile neutrinos
- $\mathcal{O}$(MeV) sterile neutrinos produced in the Sun through oscillation
- Can potentially explain CoGeNT excess through ν_s–e^- scattering



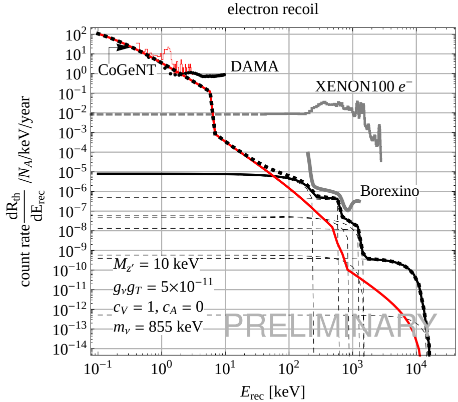
Harnik JK Machado (work in progress)

- With several sterile neutrinos, oscillations can lead to annual modulation

Sterile neutrinos and direct dark matter detection (3)

An alternative model

- Assume mass of sterile neutrino to be slightly below the solar Be-7 line
  - Easier to avoid Borexino constraint
  - Xenon-100 electron background may still be a problem

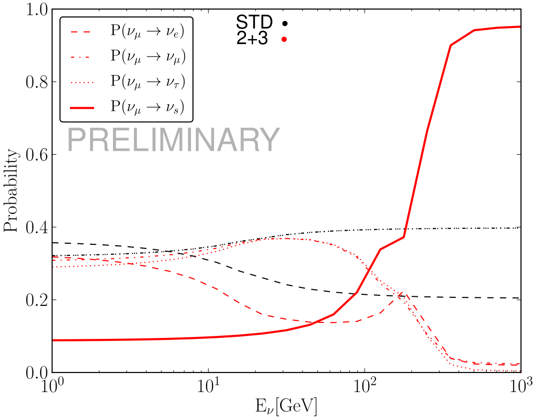


Harnik JK Machado (work in progress)

Outline

Sterile neutrinos and indirect dark matter search

- IceCube and Super-Kamiokande limits on neutrinos from dark matter annihilation in the Sun depend crucially on oscillation physics.
- If sterile neutrinos exist, new MSW resonances can lead to strong conversion of active neutrinos into sterile neutrinos in the Sun



Arguëlles JK (work in progress)

Outline

Conclusions

- Several interesting, but inconclusive hints for sterile neutrinos
  - LSND and MiniBooNE
  - Reactor anti-neutrino anomaly
  - Gallium anomaly
- Global fit favors $3+2$ scenario with $\Delta m^2_{41} \sim 0.47\ \mathrm{eV}^2$, $\Delta m^2_{51} \sim 0.87\ \mathrm{eV}^2$
- But tension remains in the fit
- We need a conclusive $\geq 5\sigma$ result in short-baseline neutrino physics

Far-reaching implications of existence of sterile neutrinos. For instance:

- Potential new signals in direct dark matter searches.
  Possible explanation for CoGeNT excess in terms of
  sterile neutrinos + new light gauge force?
- Limits on neutrinos from dark matter annihilation in the Sun can become much weaker

Thank you!

Our fitting procedure

- Atmospheric neutrinos: Eight classes of events: Sub-GeV e, μ ($p < 400$ GeV/c), Sub-GeV e, μ ($p > 400$ GeV/c), Multi-GeV e, μ, Upward stopping μ, upward throughgoing μ, 10 zenith angle bins each
- Reactor experiments: Bugey 3 (incl. spectrum), Bugey 4, Chooz (incl. spectrum), Goesgen 1–3, ILL, Krasnoyarsk 1–3, Palo Verde, Rovno
- SBL ν_e appearance experiments: LSND, KARMEN, MiniBooNE (ν and $\bar{\nu}$, consider only $E > 475$ MeV, i.e. low-E excess in ν_e sample not included)
- Gallium anomaly not included
- SBL ν_μ disappearance experiments: CDHS, NOMAD
- All codes reproduce the individual fits from the respective experiments and have been used and tested in many previous projects.