New physics and astrophysics with coherent neutrino scattering

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Neutrino-nucleus coherent scattering

Coherent effects of a weak neutral current

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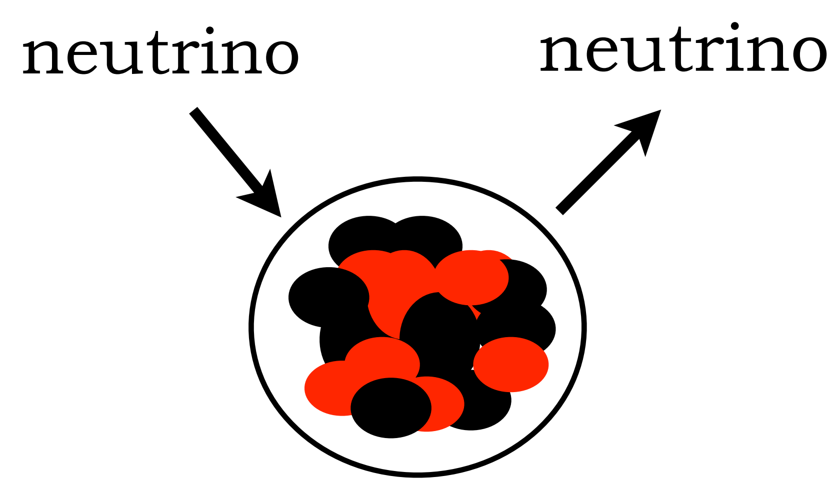
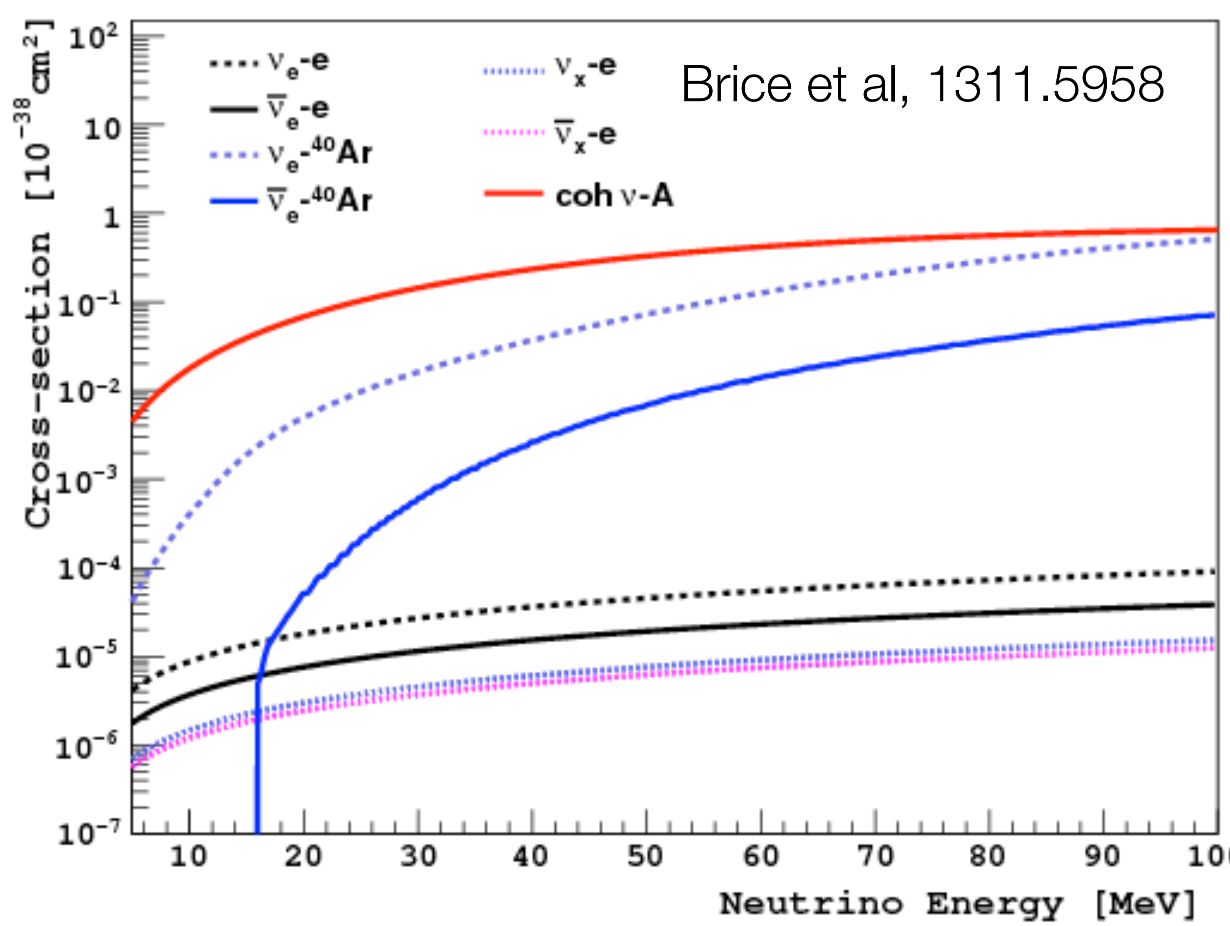
(Received 15 October 1973; revised manuscript received 19 November 1973)

If there is a weak neutral current, then the elastic scattering process $\nu + A \to \nu + A$ should have a sharp coherent forward peak just as $e + A \to e + A$ does. Experiments to observe this peak can give important information on the isospin structure of the neutral current. The

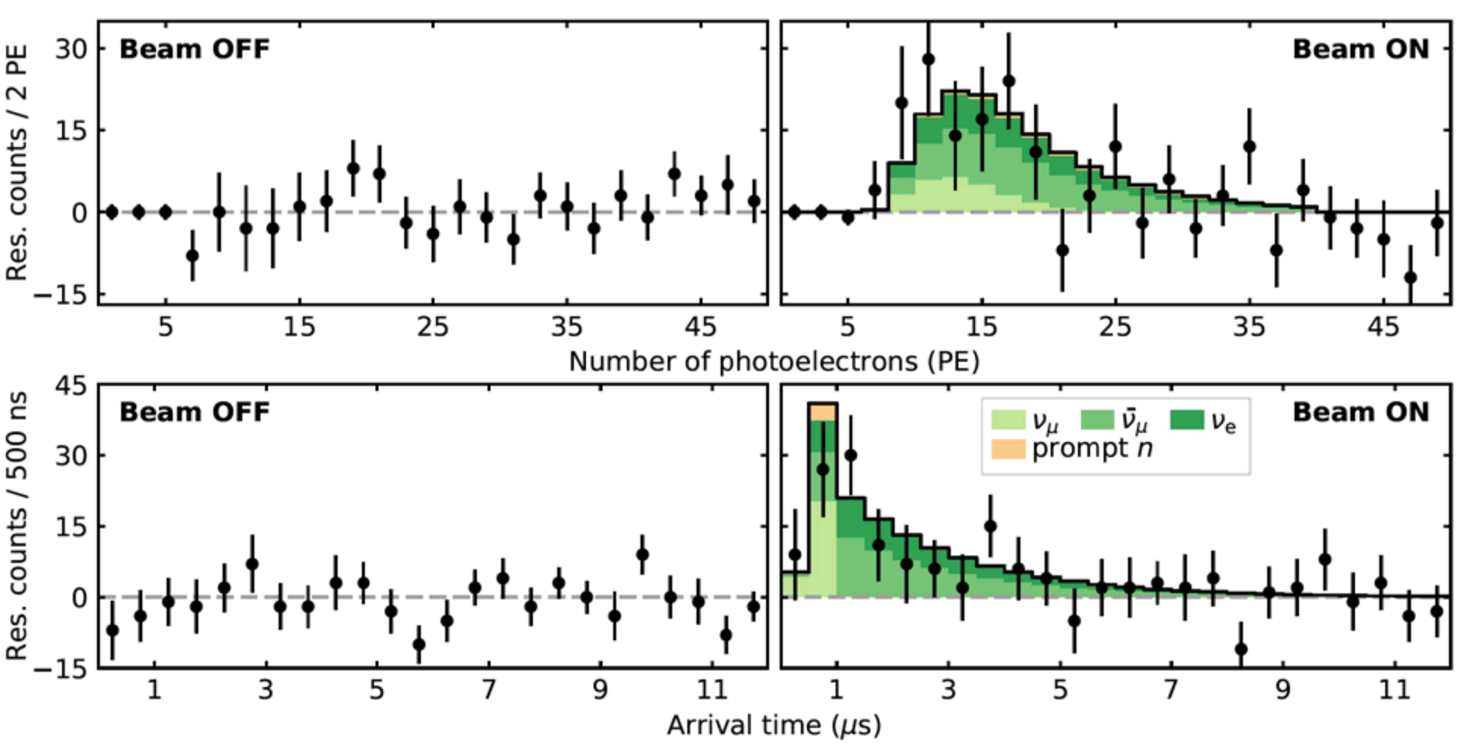


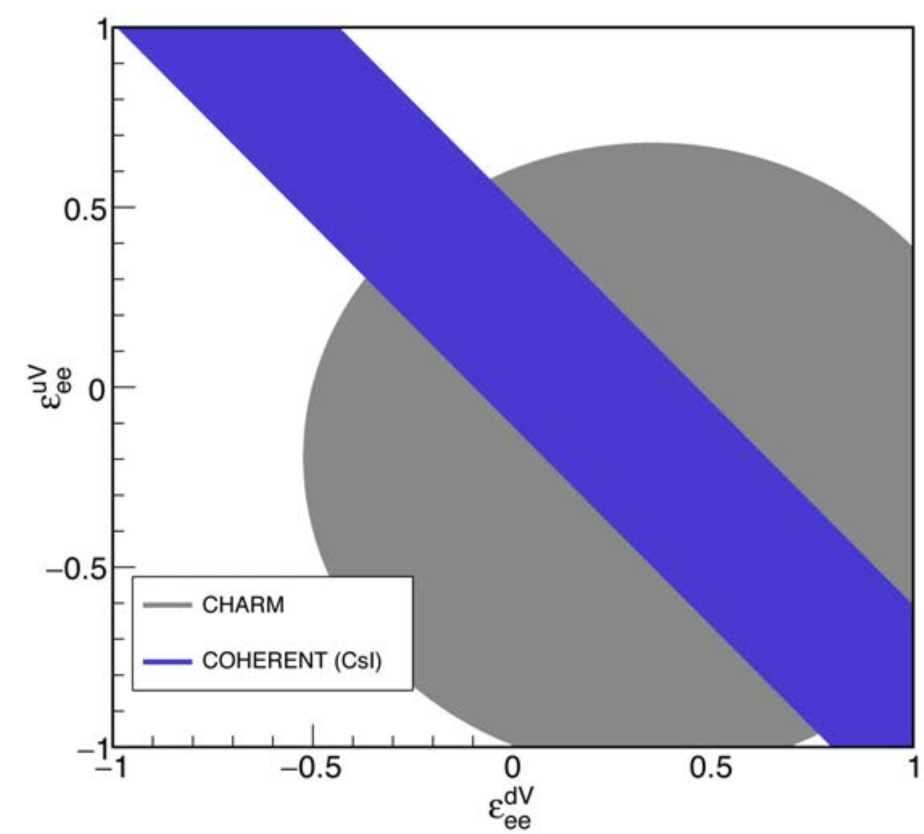
Before a few weeks ago, "…*well known prediction of the Standard Model, but is yet to be detected*…."



Observation of coherent elastic neutrino-nucleus scattering

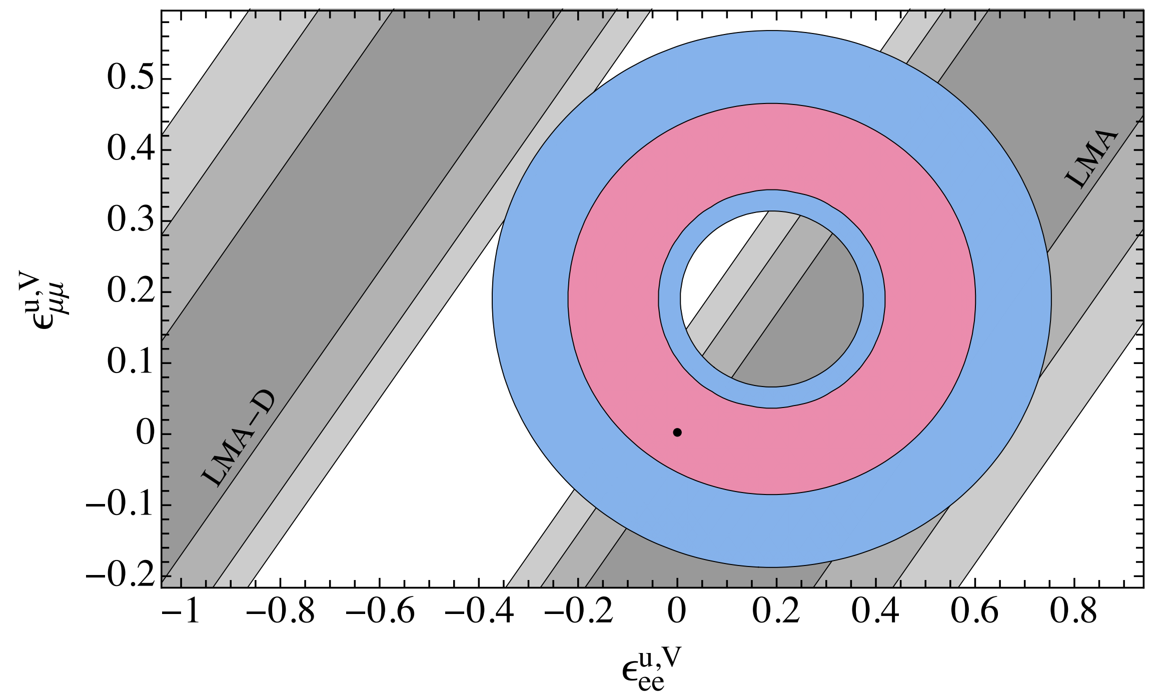
D. Akimov, J. B. Albert, P. An, C. Awe, P. S. Barbeau, B. Becker, V. Belov, A. Brown, A. Bolozdynya, B. Cabrera-Palmer, M. Cervantes, J. I. Collar,* R. J. Cooper, R. L. Cooper, C. Cuesta, D. J. Dean, J. A. Detwiler, A. Eberhardt, Y. Efremenko, S. R. Elliott, E. M. Erkela, L. Fabris, M. Febbraro, N. E. Fields, W. Fox, Z. Fu, A. Galindo-Uribarri, M. P. Green, M. Hai, M. R. Heath, S. Hedges, D. Hornback, T. W. Hossbach, E. B. Iverson, L. J. Kaufman, S. Ki, S. R. Klein, A. Khromov, A. Konovalov, M. Kremer, A. Kumpan, C. Leadbetter, L. Li, W. Lu, K. Mann, D. M. Markoff, K. Miller, H. Moreno, P. E. Mueller, J. Newby, J. L. Orrell, C. T. Overman, D. S. Parno, S. Penttila, G. Perumpilly, H. Ray, J. Raybern, D. Reyna, G. C. Rich, D. Rimal, D. Rudik, K. Scholberg, B. J. Scholz, G. Sinev, W. M. Snow, V. Sosnovtsev, A. Shakirov, S. Suchyta, B. Suh, R. Tayloe, R. T. Thornton, I. Tolstukhin, J. Vanderwerp, R. L. Varner, C. J. Virtue, Z. Wan, J. Yoo, C.-H. Yu, A. Zawada, J. Zettlemoyer, A. M. Zderic, COHERENT Collaboration





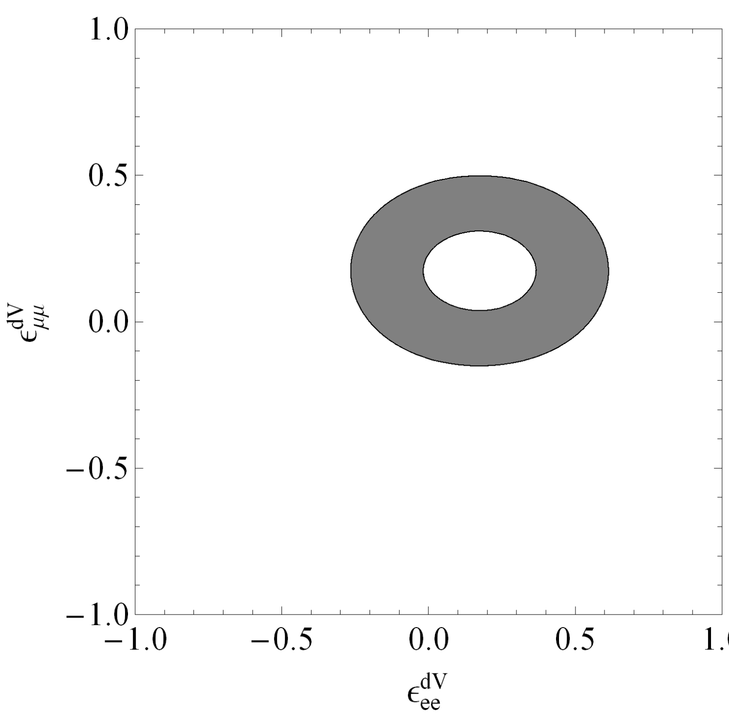
A COHERENT enlightenment of the neutrino Dark Side

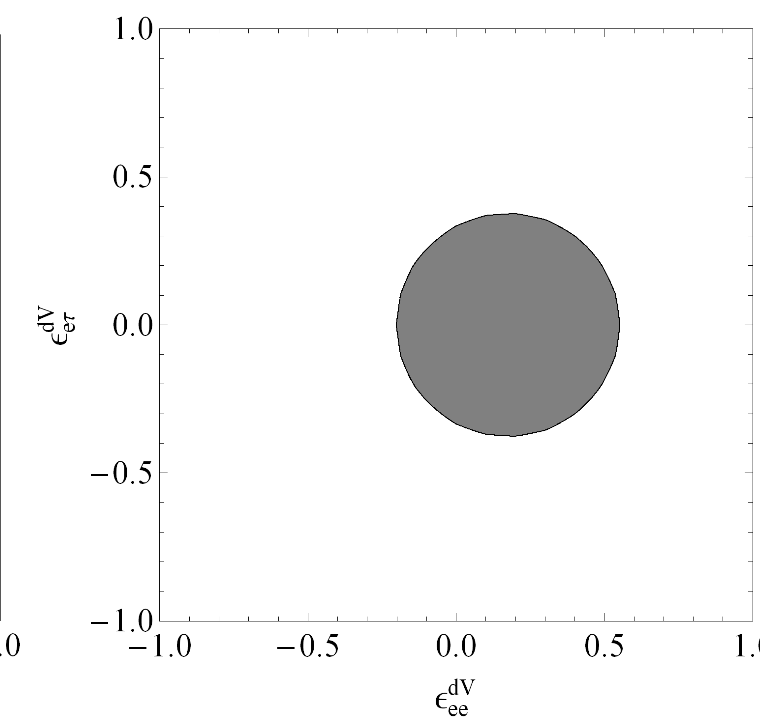
Pilar Coloma,[1,*] M. C. Gonzalez-Garcia,,[2,3,4,†] Michele Maltoni,,[5,‡] and Thomas Schwetz[6,§]



COHERENT constraints on nonstandard neutrino interactions

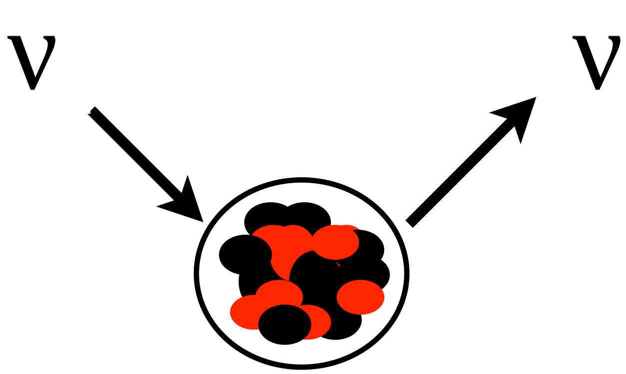
Jiajun Liao and Danny Marfatia

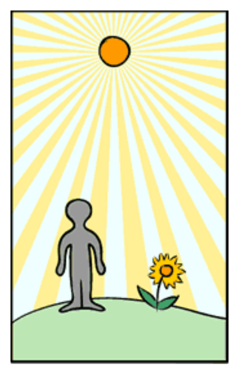




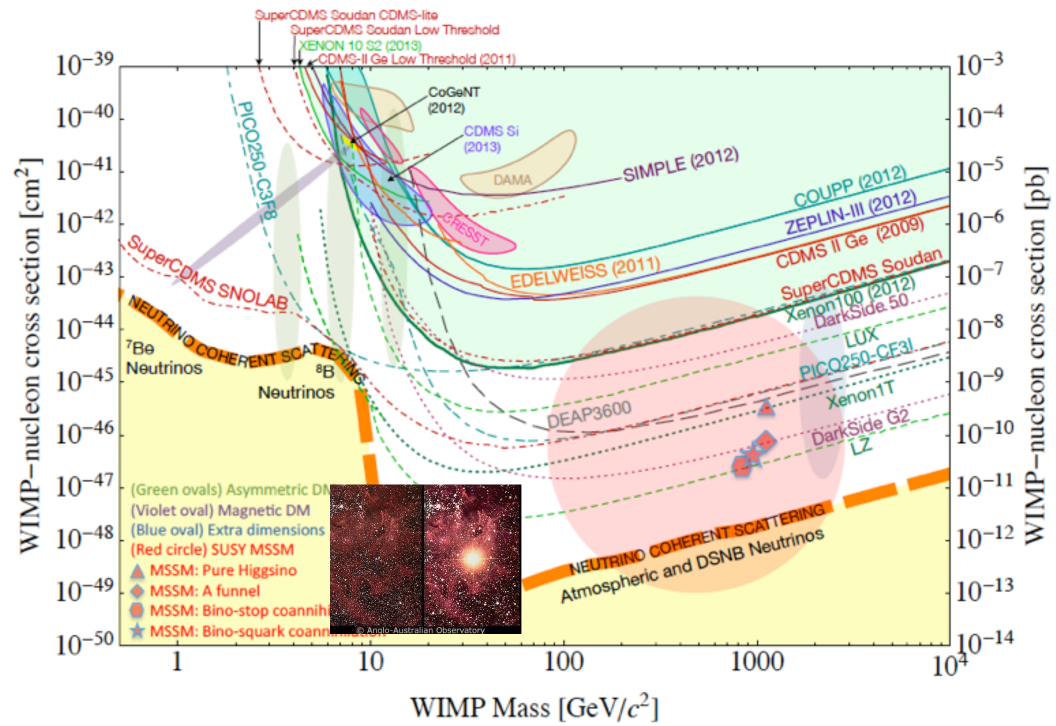
J. Dent, S. Liao talks

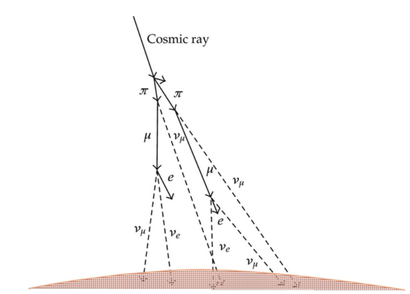
Coherent Neutrino Scattering: Complementarity





Astrophysical sources



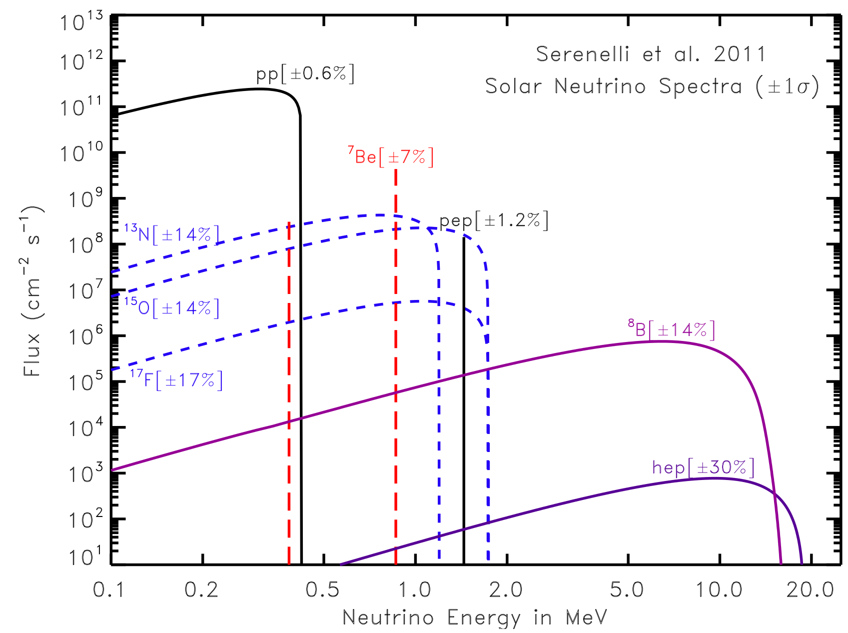


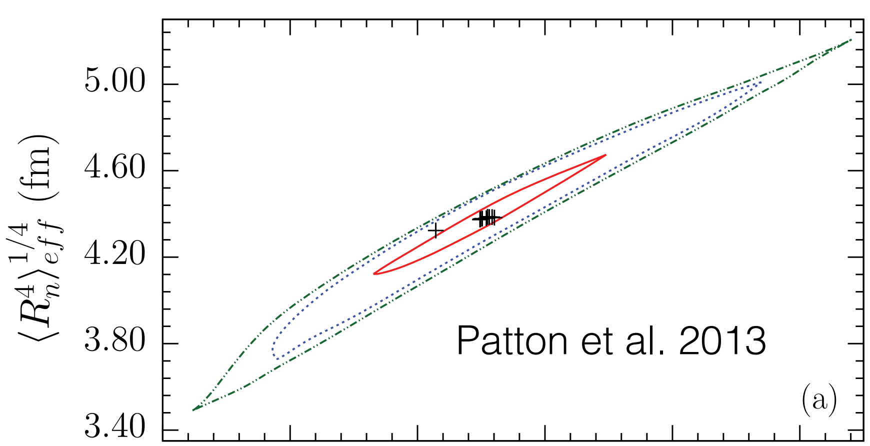
Reactors

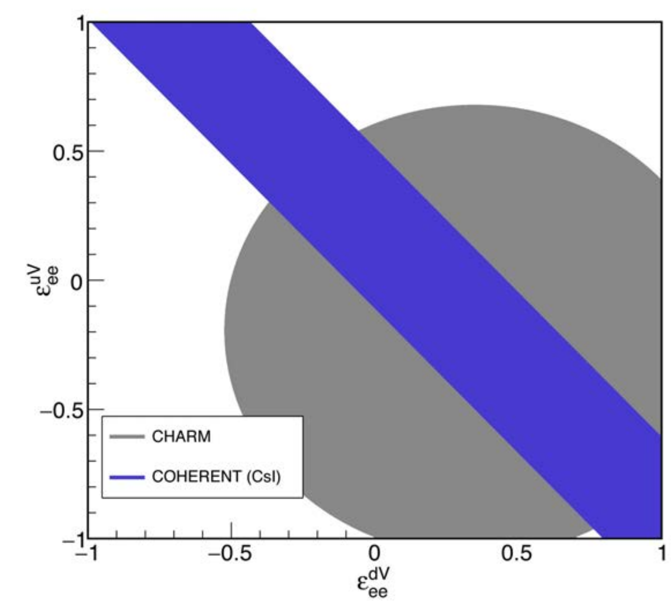
Accelerators

Coherent Neutrino Scattering: Complementarity

Astrophysics





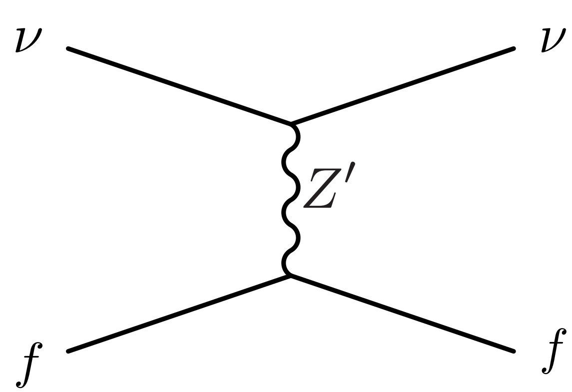


Nuclear Physics

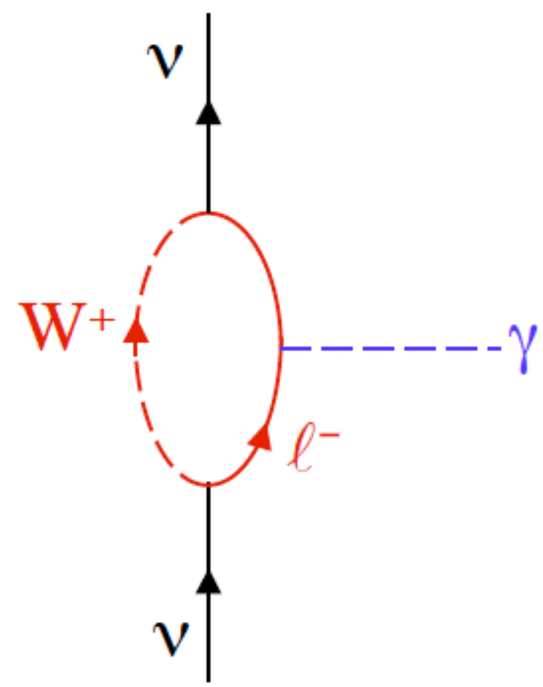
High-energy Physics

Searches for new physics

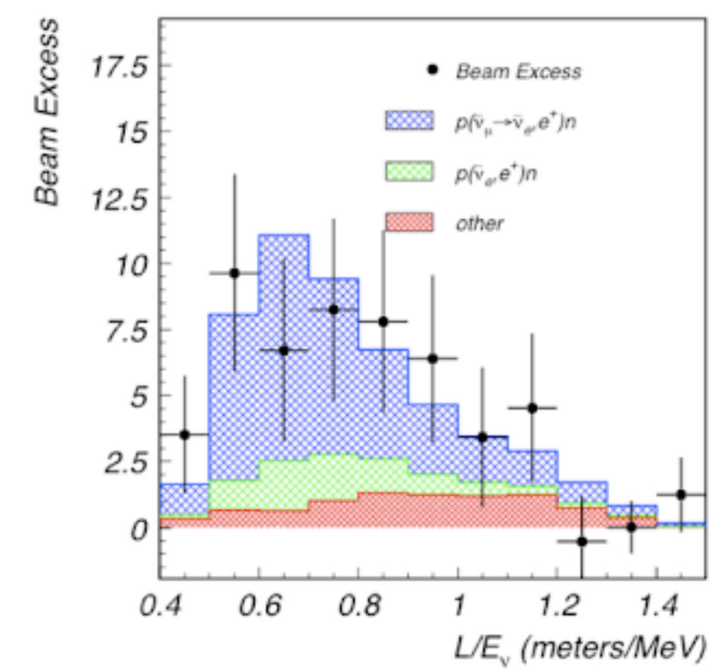
NSI



Magnetic moment



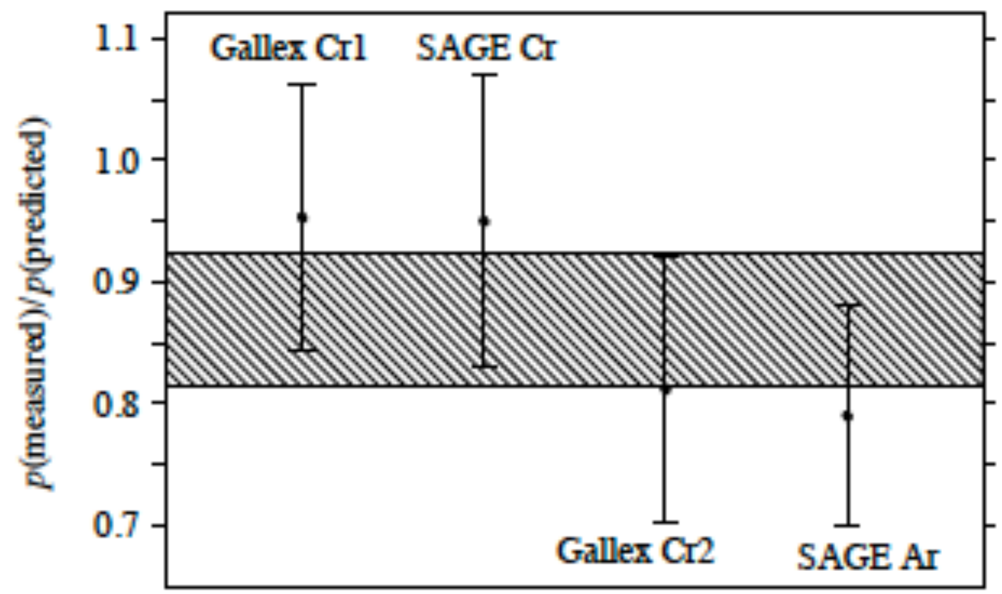
Sterile neutrinos



Gallium/Reactor anomaly

- Gallium calibration experiments check the capture cross section for two excited states not constrained by ^{71}Ge lifetime

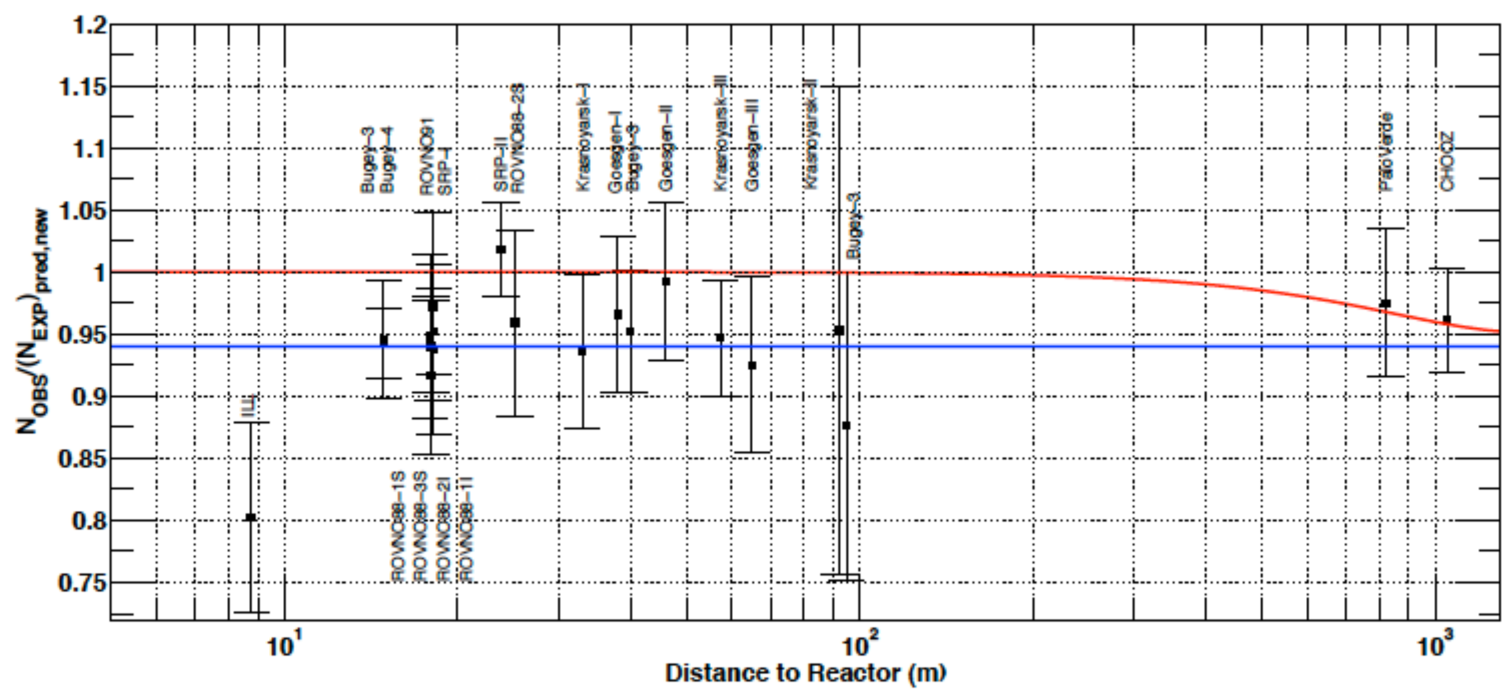
- Ratio of measured ^{71}Ge relative to that expected from source strength indicates ~ 2sigma discrepancy



SAGE collaboration, 2009

- Discrepancy may be larger when accounting for uncertainty in cross section (Giunti & Laveder 2010)

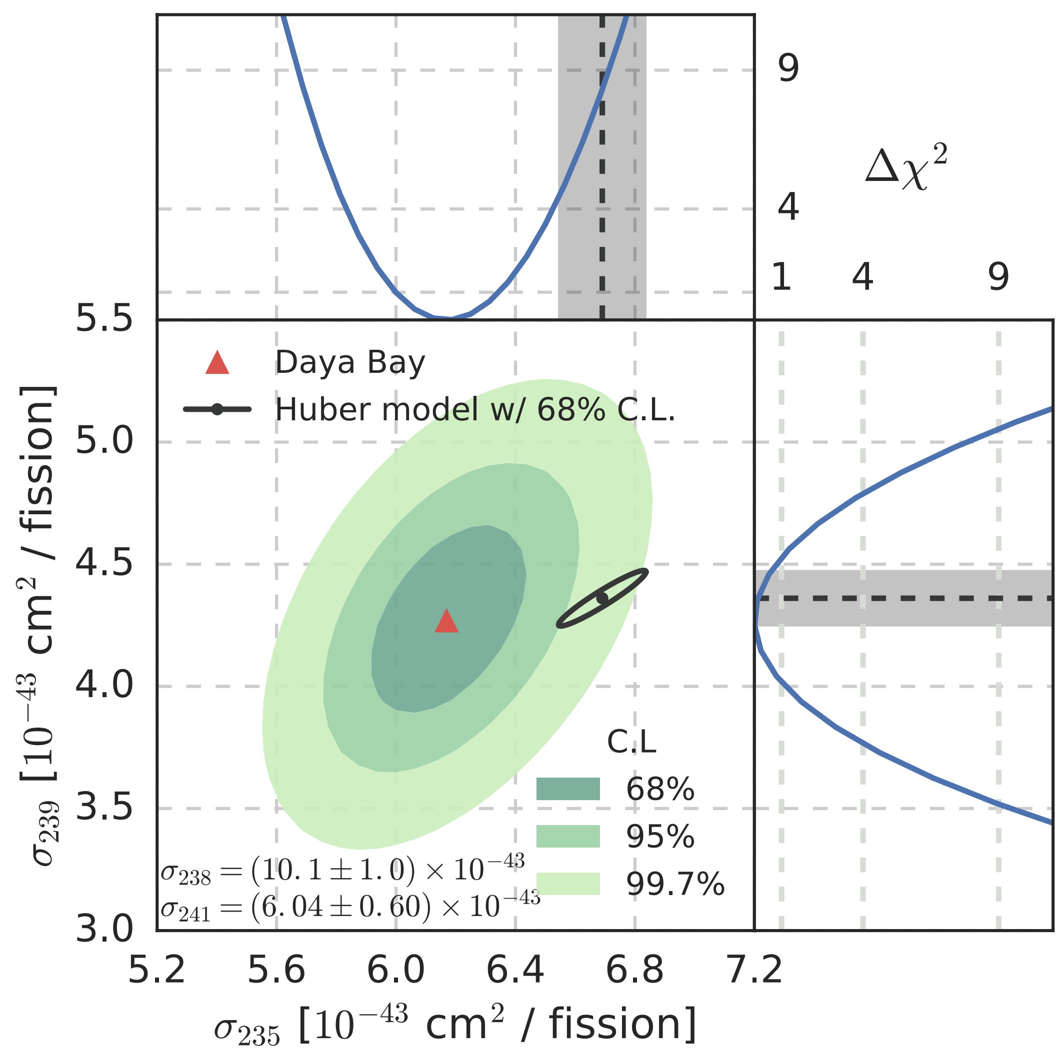
- Combined with ‘reactor anomaly’, gallium results may hint at new physics, i.e. ~ eV sterile neutrino



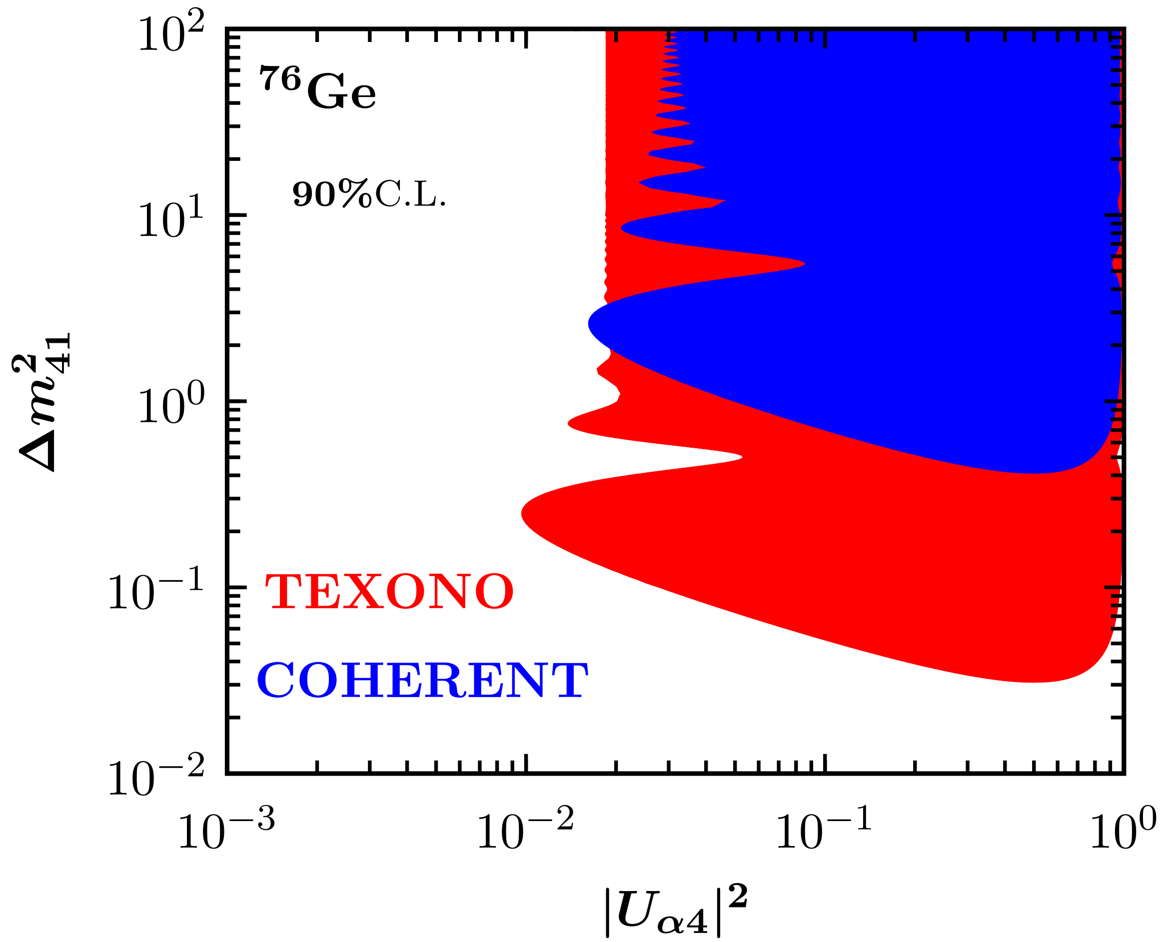
Mention et al. 2011

Recent Daya Bay results

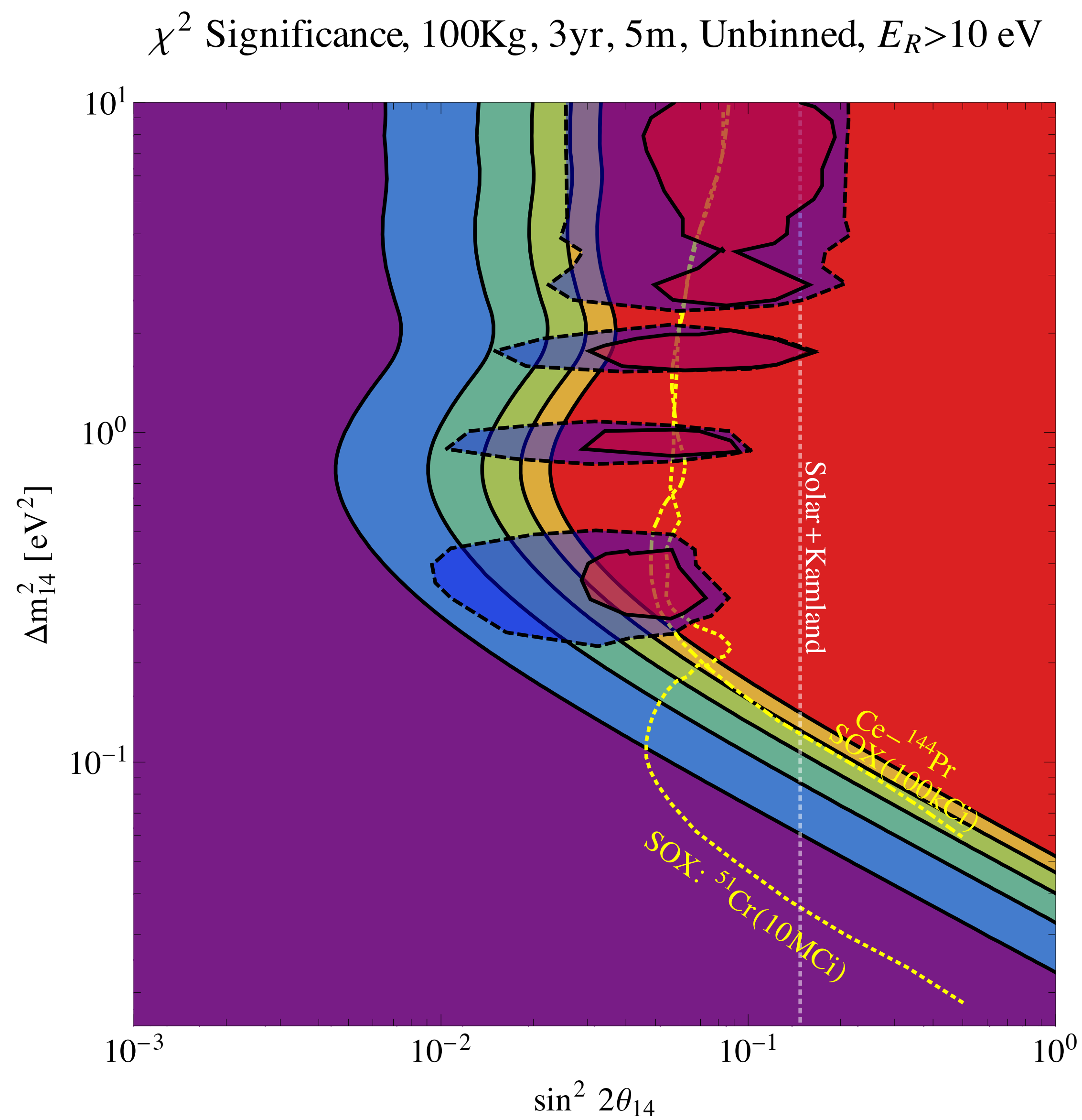
- Recent Daya Bay results show changes in the antineutrino flux and spectrum with the burn-up of the reactor fuel
- Theoretical systematics in antineutrino spectrum to consider (Hayes et al., 2017, Giunti et al. 2017)
- Future measurements of flux from reactors with different fuel compositions will help



Reactor/COHERENT sterile searches



Kosmas et al. 2017



Dutta et al. 1511.02834

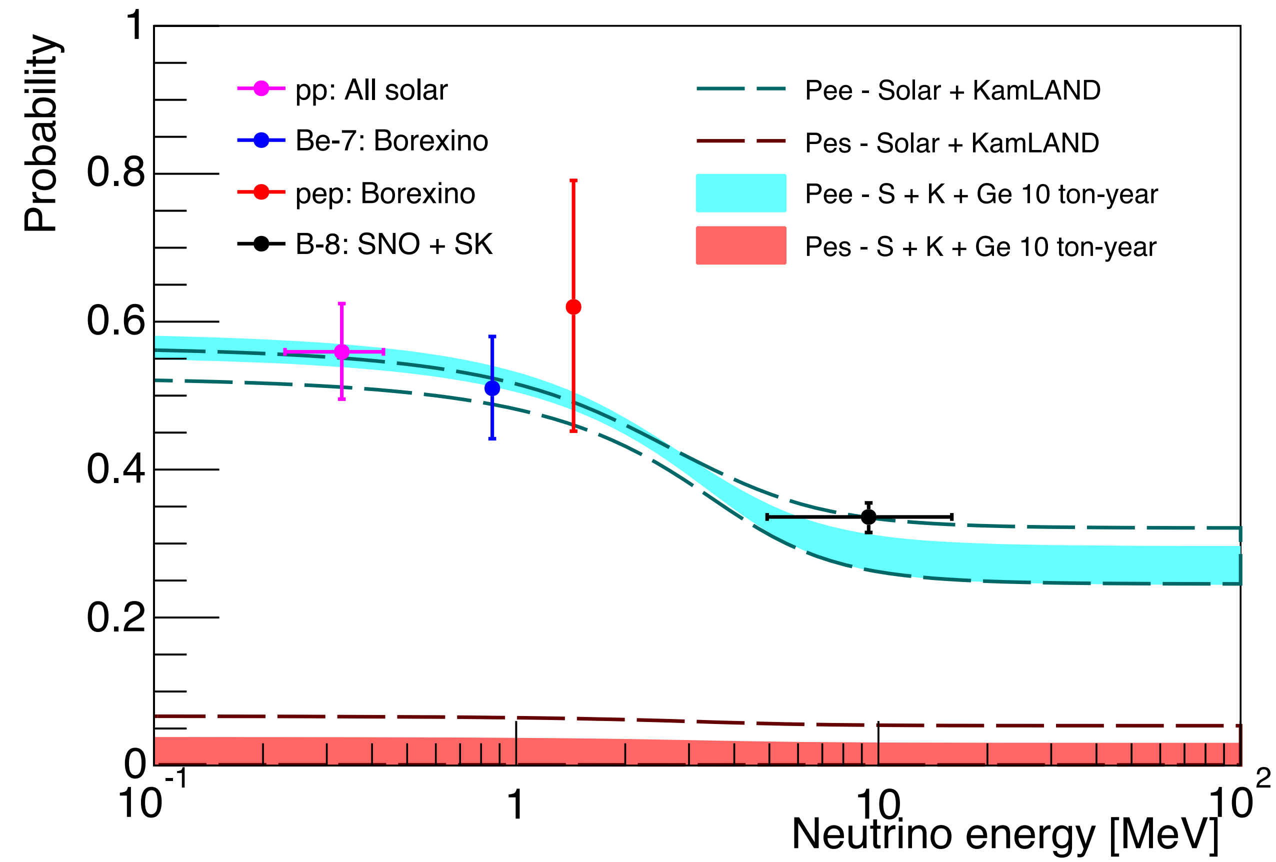
$$P(\nu_\alpha \to \nu_{\not\alpha}) = 4|U_{\alpha 4}|^2(1-|U_{\alpha 4}|^2)\sin^2(1.27\Delta m^2_{41} L/E)$$

Sterile neutrinos from Sun

Super-K, SNO CC, and Borexino may not be seeing the upturn in the MSW survival probability at intermediate energy

- DM experiments provide first measurement of the energy dependence of the survival probability
- Sensitive to oscillation to 4th generation sterile neutrino

Palazzo 2012

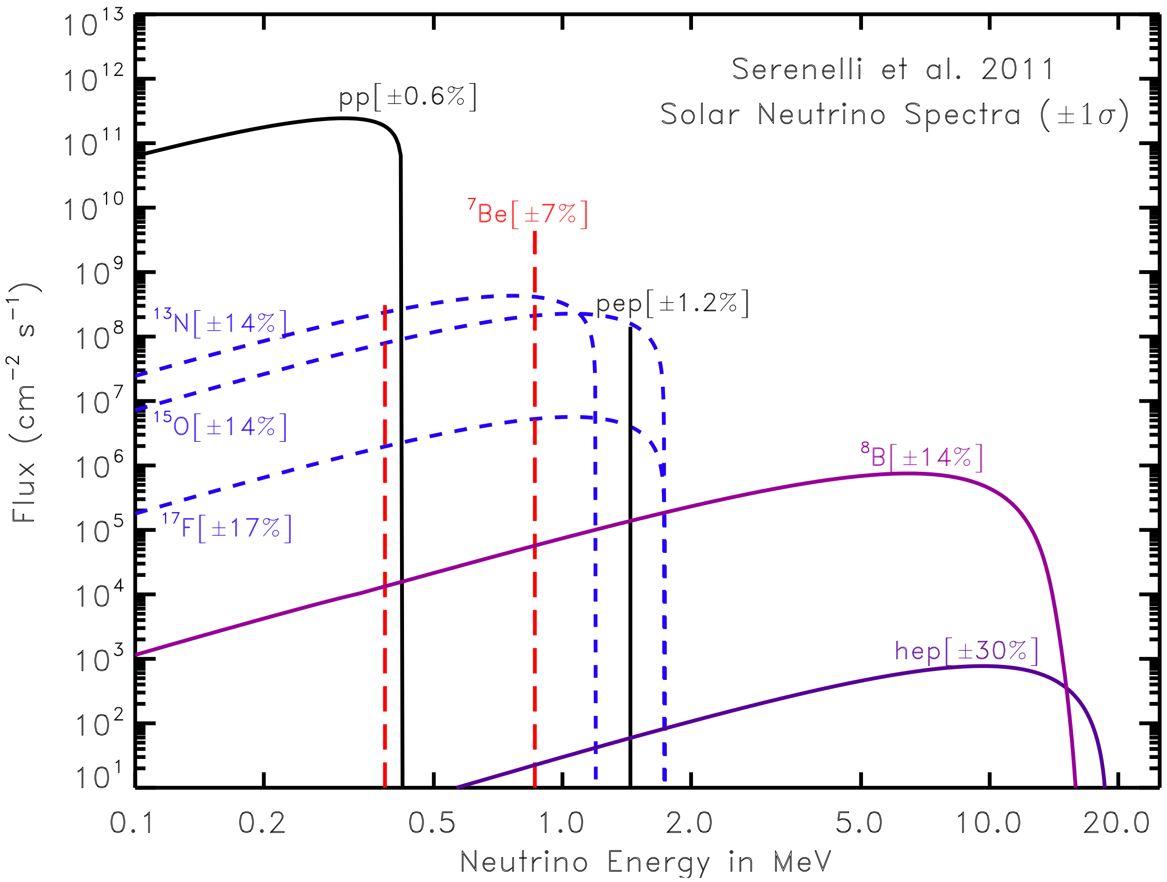


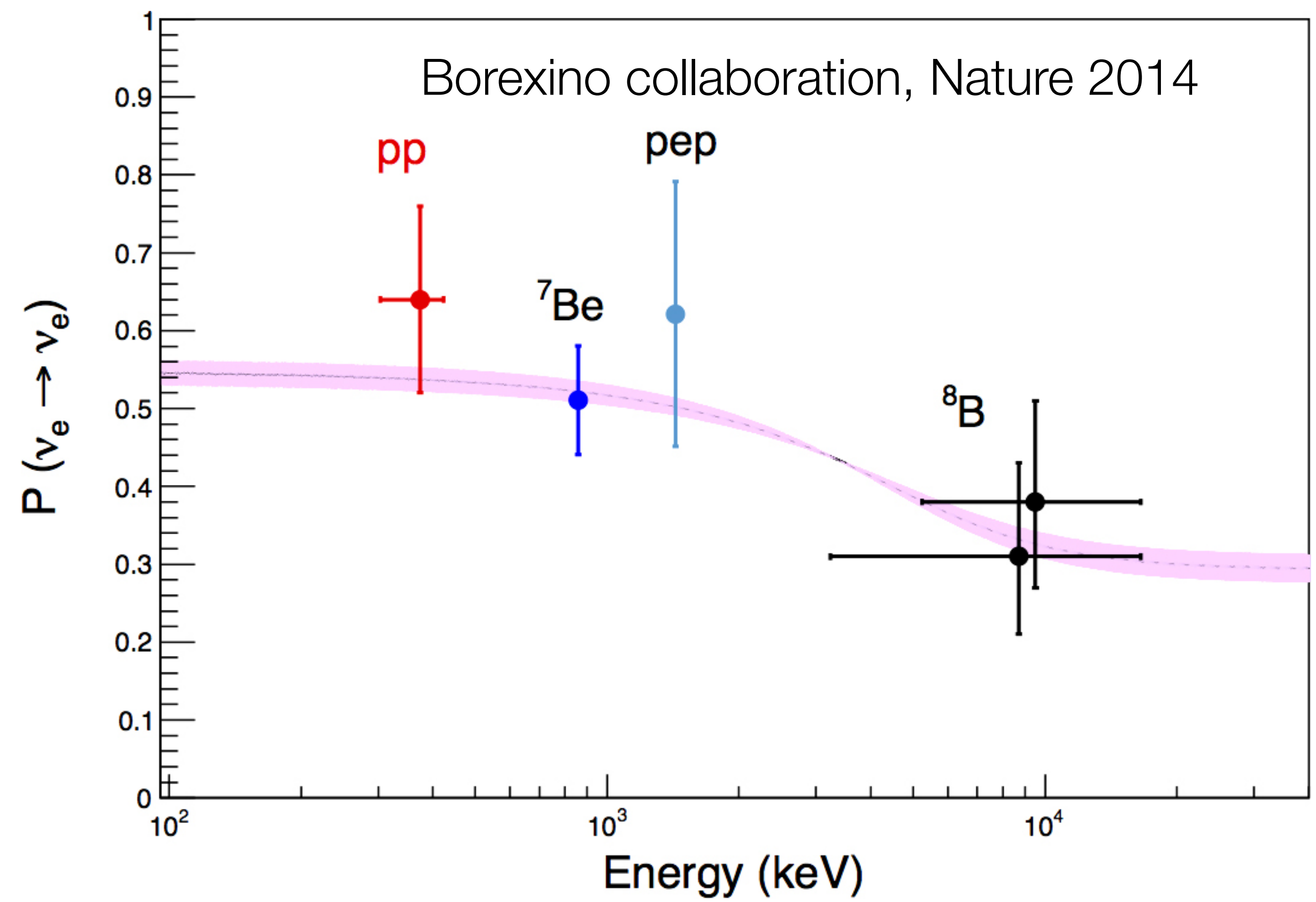
Billard, Strigari, Figueroa-Feliciano, PRD 1409.0050

Solar neutrino signals:
Astrophysical goals for dark matter experiments

- First measurement of the 8B neutral current energy spectrum
- First direct measurement of the survival probably for low energy solar neutrinos
- Direct measurement of the CNO flux
- PP flux measurement to ~ few percent will provide most stringent measurement of the ``neutrino luminosity” of the Sun

Solar neutrinos: Status





Solar Neutrinos:
Status and Prospects

W.C. Haxton,[1] R.G. Hamish Robertson,[2] and Aldo M. Serenelli[3]

The program of solar neutrino studies envisioned by Davis and Bahcall has been only partially completed. Borexino has extended precision measurements to low-energy solar neutrinos, determining the flux of ^{7}Be neutrinos to 5%, and thereby confirming the expected increase in the ν_e survival probability for neutrino energies in the vacuum-dominated region. First results on the pep neutrino

Solar neutrinos: Outstanding issue I

- Solar metallicity
  - 3D rotational hydrodynamical simulations suggest lower metallicity in Solar core (Asplund et al. 2009)
  - Low metallicity in conflict with heliosiesmology data
  - SNO Neutral Current measurement right in between predictions of low and high metallicity SSMs

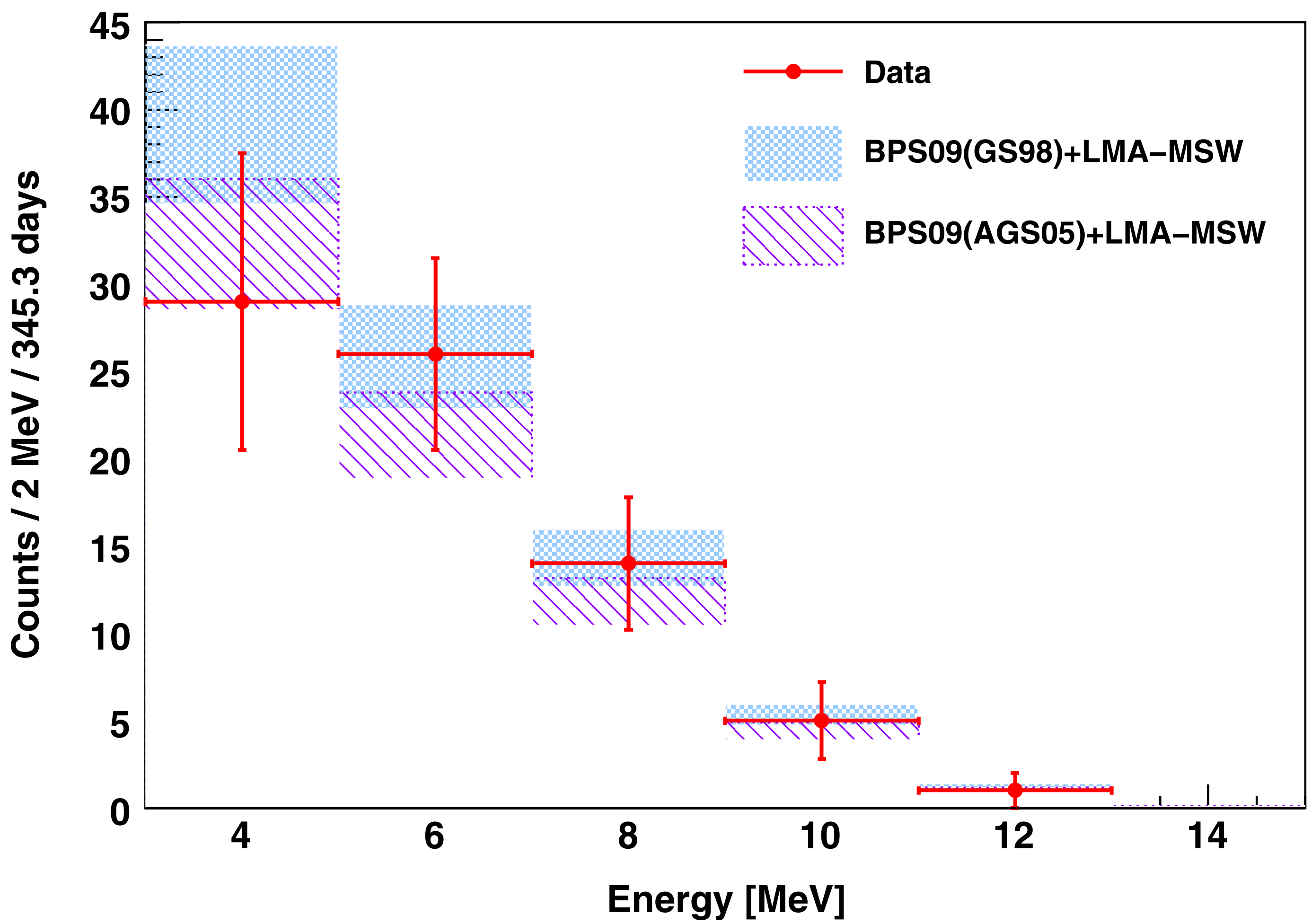
High metallicity | Low metallicity

ν flux	$E_\nu^{\max}$ (MeV)	GS98-SFII	AGSS09-SFII	Solar	units
$p{+}p{\to}^2H{+}e^+{+}\nu$	0.42	$5.98(1 \pm 0.006)$	$6.03(1 \pm 0.006)$	$6.05(1^{+0.003}_{-0.011})$	$10^{10}/cm^2s$
$p{+}e^-{+}p{\to}^2H{+}\nu$	1.44	$1.44(1 \pm 0.012)$	$1.47(1 \pm 0.012)$	$1.46(1^{+0.010}_{-0.014})$	$10^{8}/cm^2s$
$^7Be{+}e^-{\to}^7Li{+}\nu$	0.86 (90%)	$5.00(1 \pm 0.07)$	$4.56(1 \pm 0.07)$	$4.82(1^{+0.05}_{-0.04})$	$10^{9}/cm^2s$
	0.38 (10%)				
$^8B{\to}^8Be{+}e^+{+}\nu$	~ 15	$5.58(1 \pm 0.14)$	$4.59(1 \pm 0.14)$	$5.00(1 \pm 0.03)$	$10^{6}/cm^2s$
$^3He{+}p{\to}^4He{+}e^+{+}\nu$	18.77	$8.04(1 \pm 0.30)$	$8.31(1 \pm 0.30)$	—	$10^{3}/cm^2s$
$^{13}N{\to}^{13}C{+}e^+{+}\nu$	1.20	$2.96(1 \pm 0.14)$	$2.17(1 \pm 0.14)$	≤ 6.7	$10^{8}/cm^2s$
$^{15}O{\to}^{15}N{+}e^+{+}\nu$	1.73	$2.23(1 \pm 0.15)$	$1.56(1 \pm 0.15)$	≤ 3.2	$10^{8}/cm^2s$
$^{17}F{\to}^{17}0{+}e^+{+}\nu$	1.74	$5.52(1 \pm 0.17)$	$3.40(1 \pm 0.16)$	$\leq 59.$	$10^{6}/cm^2s$
χ^2/P^{agr}		3.5/90%	3.4/90%		

Haxton et al. 2013

Solar neutrinos: Outstanding issue II

- Borexino, SNO, SK indicate the low energy ES data lower than MSW predicts
- More generally, upturn in MSW survival probability not been measure
- May indicate new physics (e.g. Holanda & Smirnov 2011)



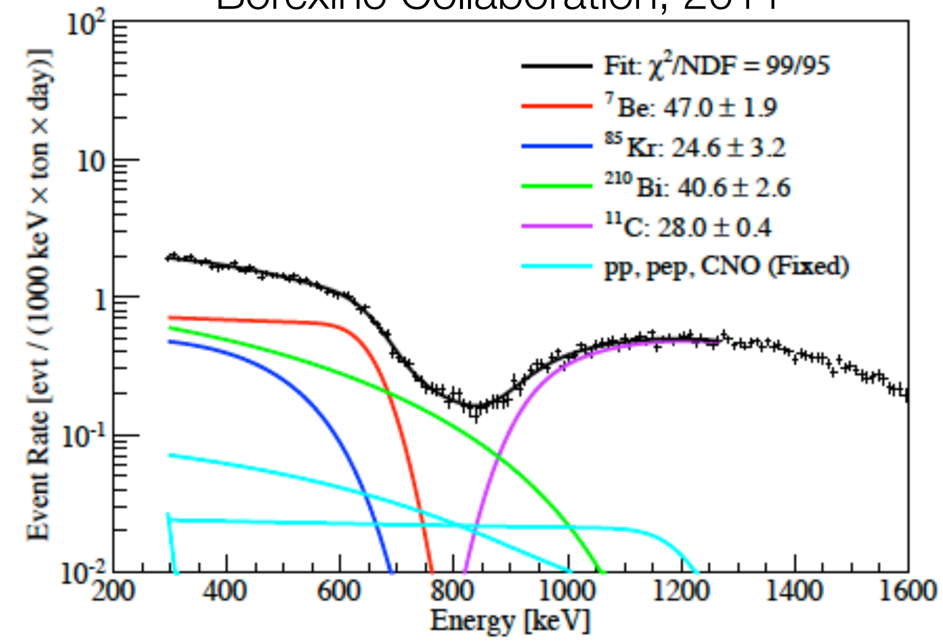
Borexino Collaboration, 2010

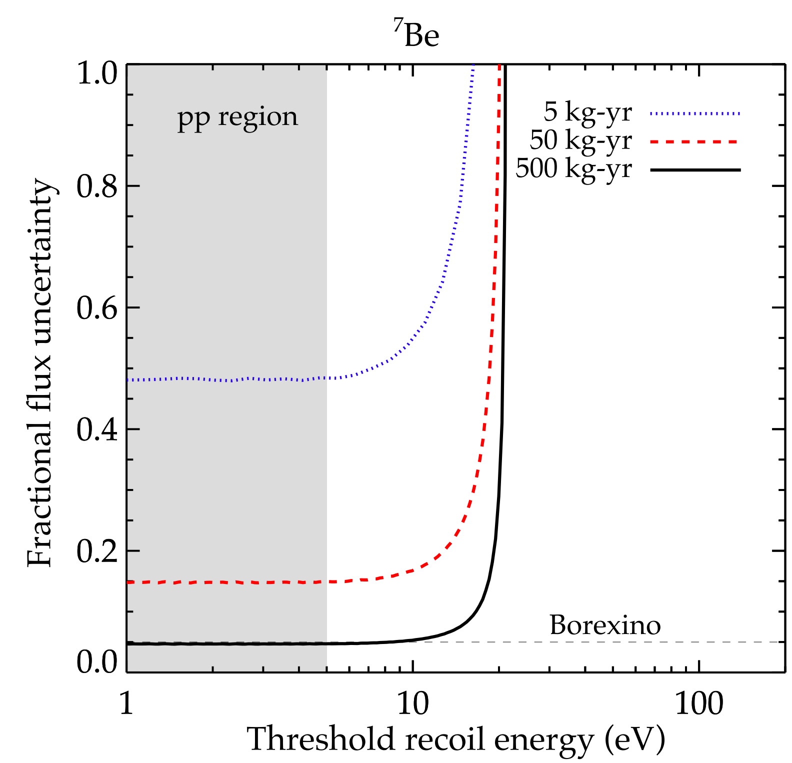
Low energy solar neutrino survival probability

- Assume the MSW solution and deduce the SSM 7Be flux, or
- Assume the SSM 7Be flux, and deduce the survival probability
- Good consistency with the high-Z SSM
- Ultra-low threshold (< 100 eV) detectors will make first neutral current measurement of low energy Solar neutrino fluxes

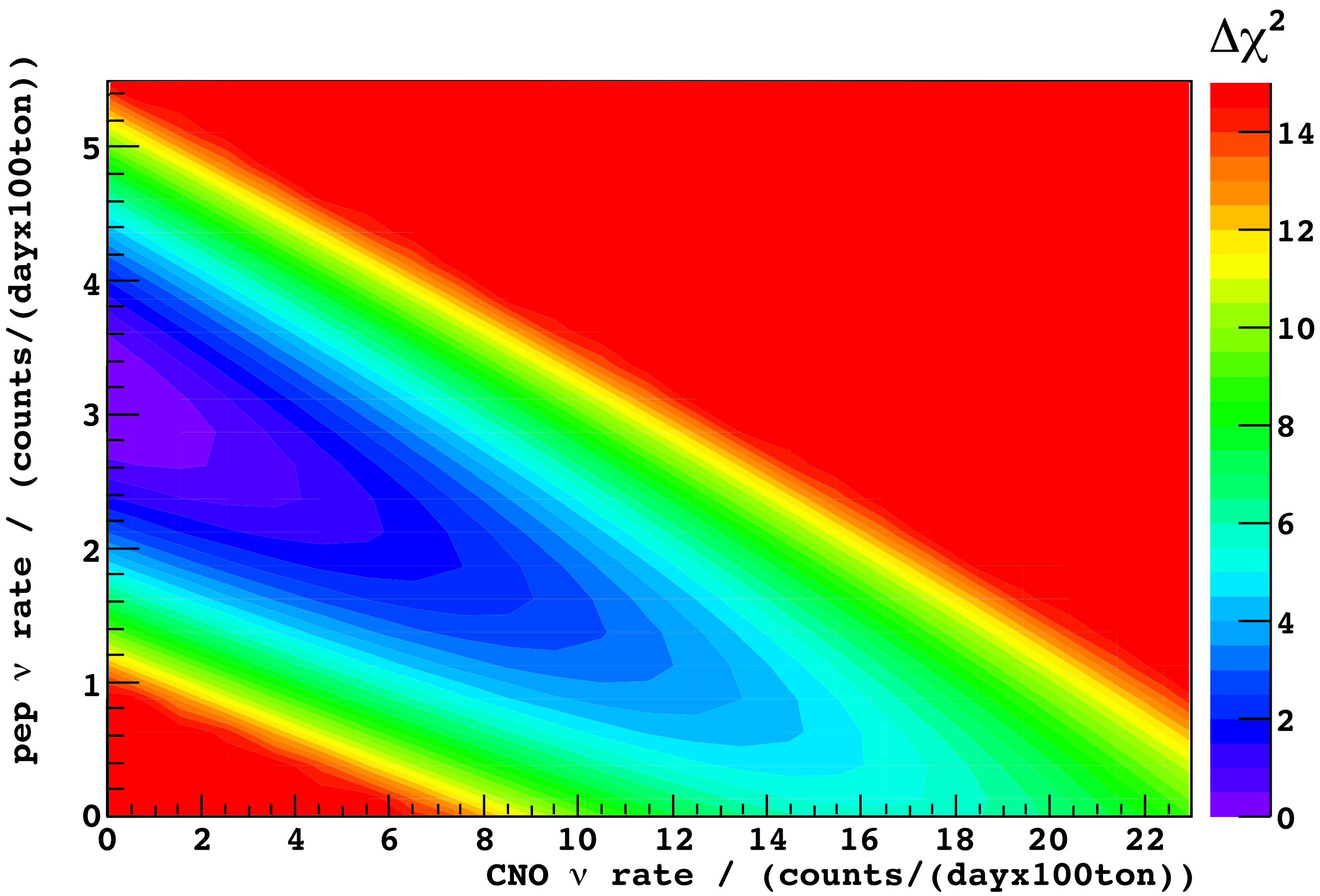
New Borexino results from global analysis (1707.09279)

Borexino Collaboration, 2011



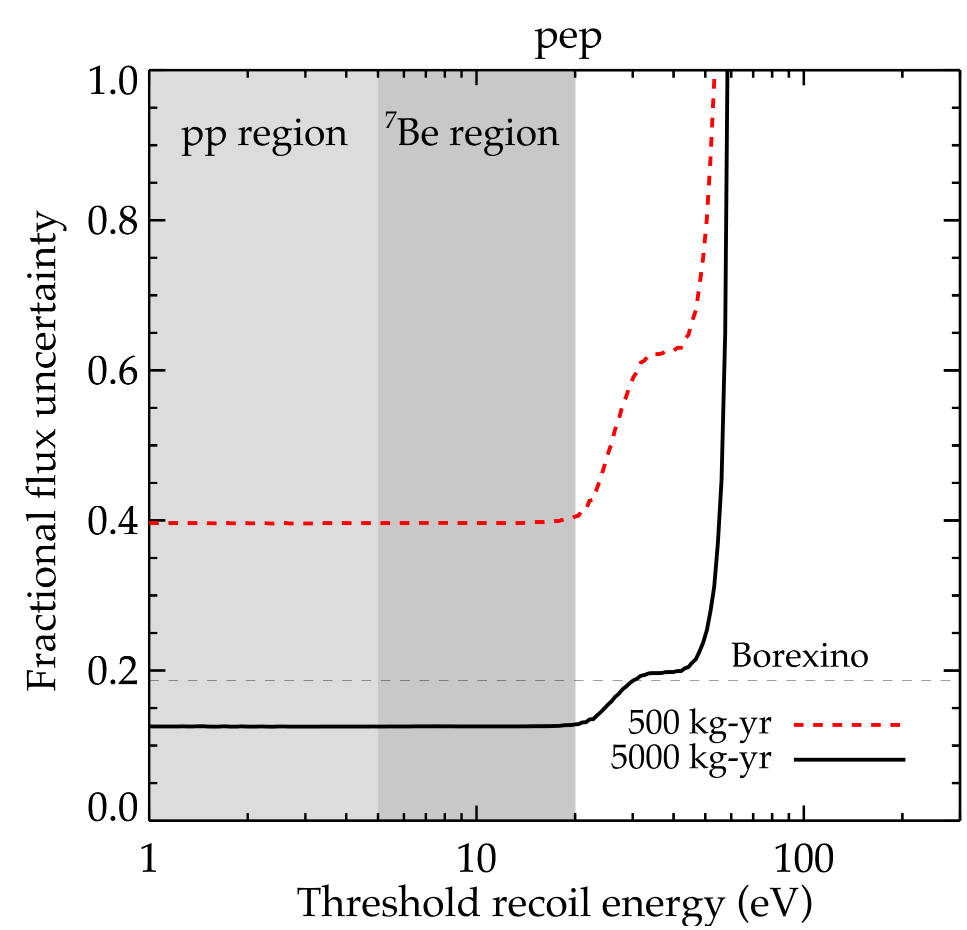


Neutrino Astrophysics: ultra-low thresholds



First evidence of *pep* solar neutrinos by direct detection in Borexino

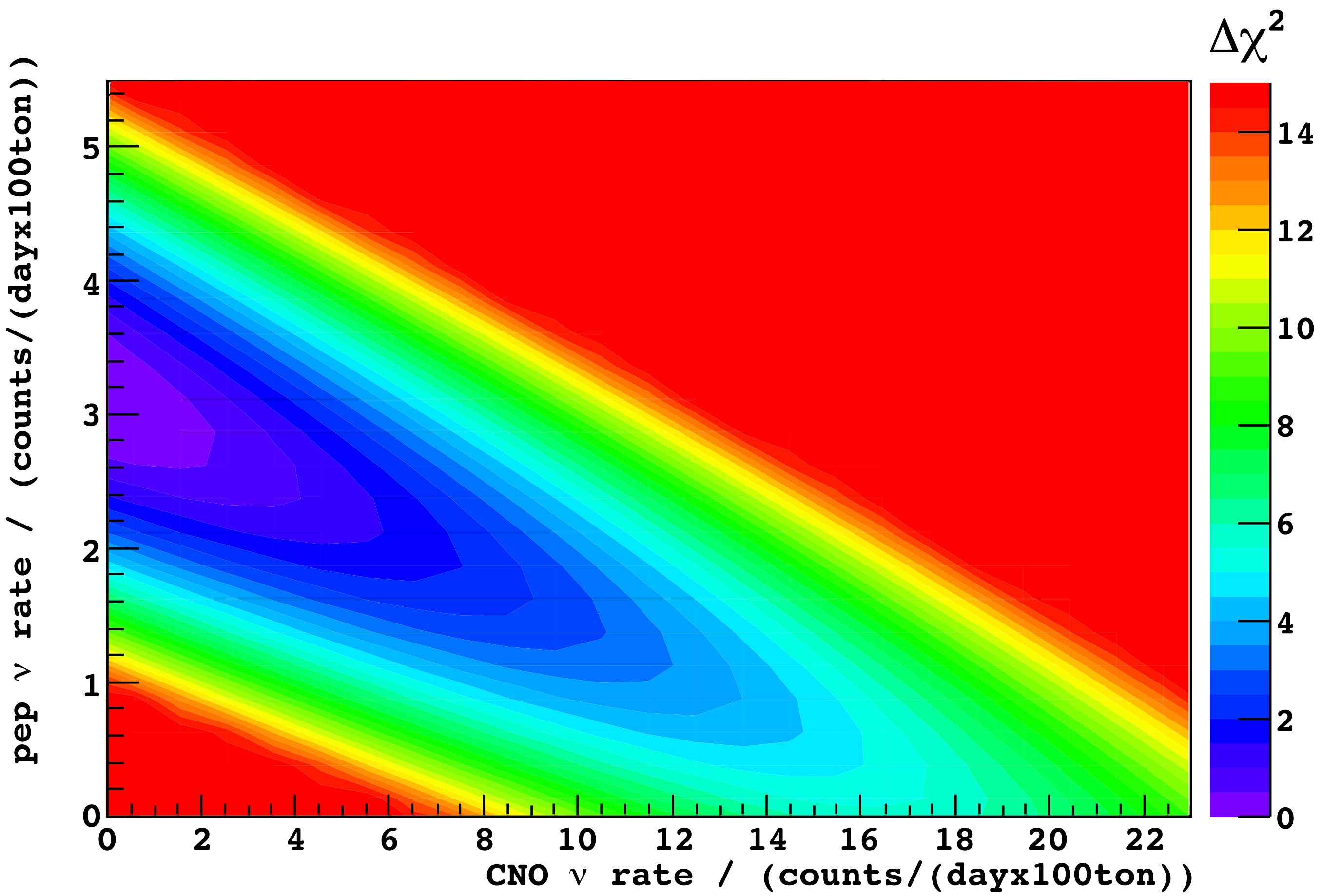
1110.3230



LS, PRD 2016

G3 experiments at low threshold (~ 20 eV) would improve
the sensitivity to the pep spectrum

Neutrino Astrophysics: ultra-low thresholds



First evidence of *pep* solar neutrinos by direct detection in Borexino

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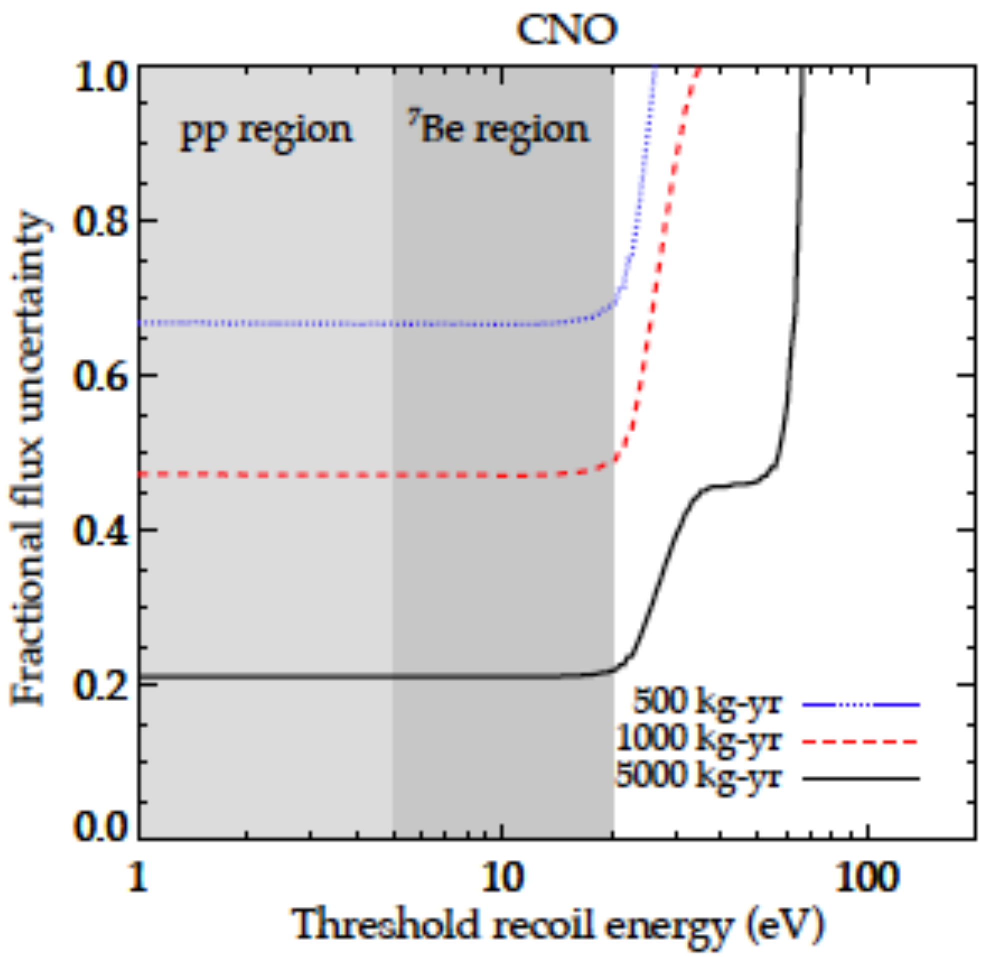

LS, PRD 2016

G3 experiments at low threshold may be able to study the CNO Solar neutrino flux

Neutrino luminosity of the Sun

- Neutrinos can test the idea that the Sun shines because of nuclear fusion
    - Compare the neutrino-inferred luminosity to the Solar luminosity
- Imposing the luminosity constraint gives the share of energy production between PP chain and CNO cycle,

$$\frac{L_{\text{pp-chain}}}{L_\odot} = 0.991^{+0.005}_{-0.004}\,\left[^{+0.008}_{-0.013}\right] \iff \frac{L_{\text{CNO}}}{L_\odot} = 0.009^{+0.004}_{-0.005}\,\left[^{+0.013}_{-0.008}\right]$$

- Without the luminosity constraint,

$$\frac{L_\odot(\text{neutrino-inferred})}{L_\odot} = 1.04\left[^{+0.07}_{-0.08}\right]\,\left[^{+0.20}_{-0.18}\right]$$

Bergstrom, Gonzalez-Garcia et al. JHEP 2016

- Direct pp measurement (e.g. Xenon) at few percent level can improve this constraint

New direction in neutrino physics?