Title: New physics searches with neutrino-coherent scattering

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Abstract:

New physics and astrophysics with coherent neutrino scattering

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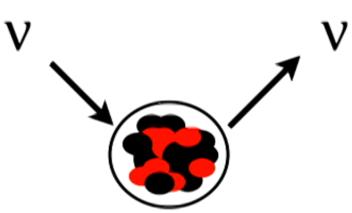
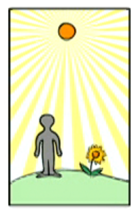
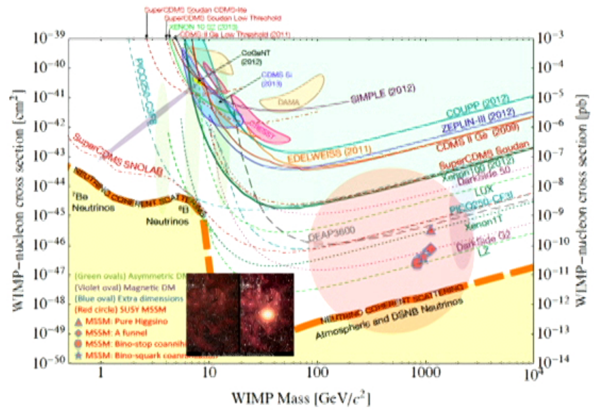
Texas A&M University
Mitchell Institute for Fundamental Physics and Astronomy
New directions in dark matter and neutrino physics, Perimeter Institute
July 21, 2017

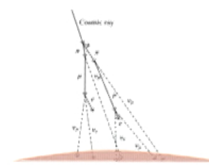
Detecting Coherent Neutrino Scattering



Astrophysical sources



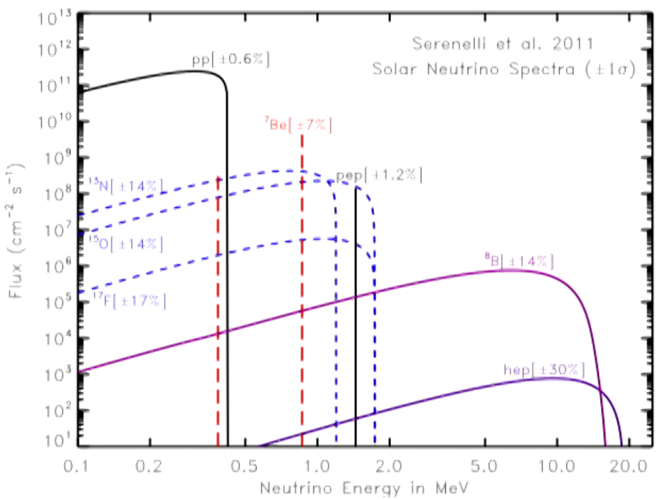


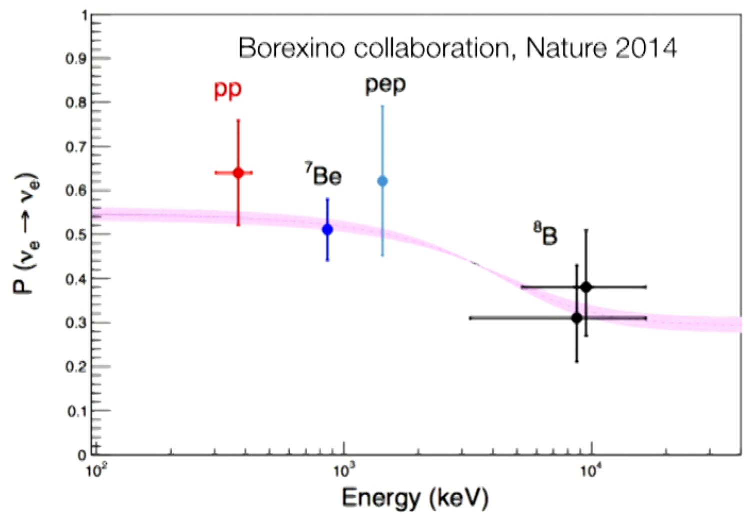


Reactors

Accelerators

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

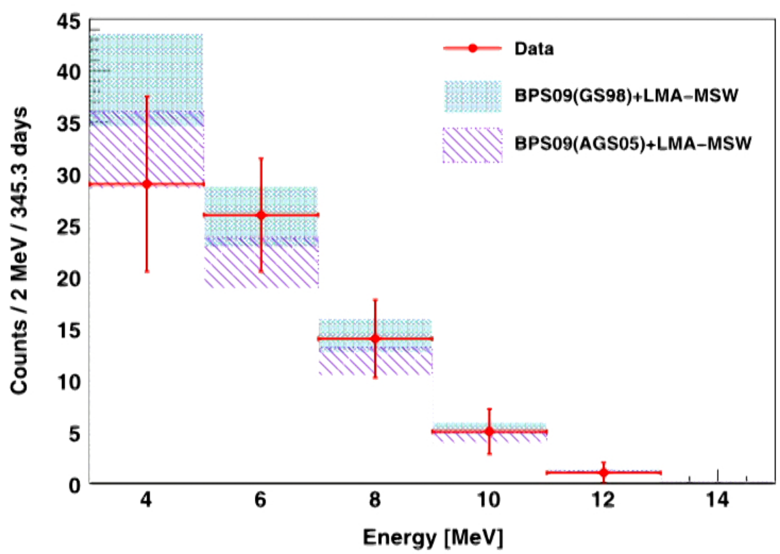
High metallicity | Low metallicity

ν flux	E_ν^{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%)				
${}^8B\to{}^8Be+e^++\nu$	[illegible]15	$5.58(1 \pm 0.14)$	$4.59(1 \pm 0.14)$	$5.00(1 \pm 0.03)$	$10^6/cm^2s$
${}^3He+p\to{}^4He+e^++\nu$	[illegible]	$8.04(1 \pm 0.30)$	$8.31(1 \pm 0.30)$	—	$10^3/cm^2s$
${}^{13}N\to{}^{13}C+e^++\nu$	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	$10^8/cm^2s$
${}^{17}F\to{}^{17}O+e^++\nu$	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

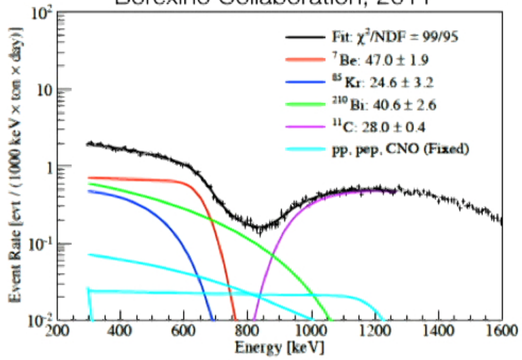
Solar neutrino signals:
Astrophysical goals for dark matter experiments

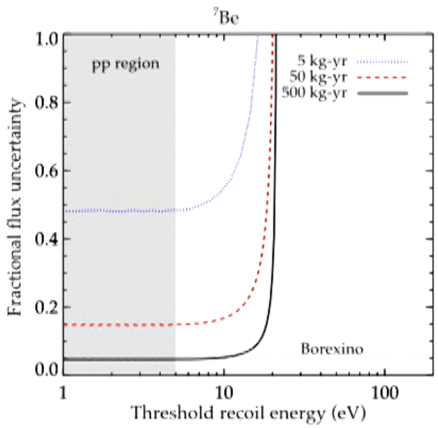
- First measurement of the 8B neutral current energy spectrum
- First direct measurement of the survival probably for low energy solar neutrinos
- Direct measurement of the CNO flux
- PP flux measurement to ~ few percent will provide most stringent measurement of the ``neutrino luminosity" of the Sun

Low energy solar neutrino survival probability

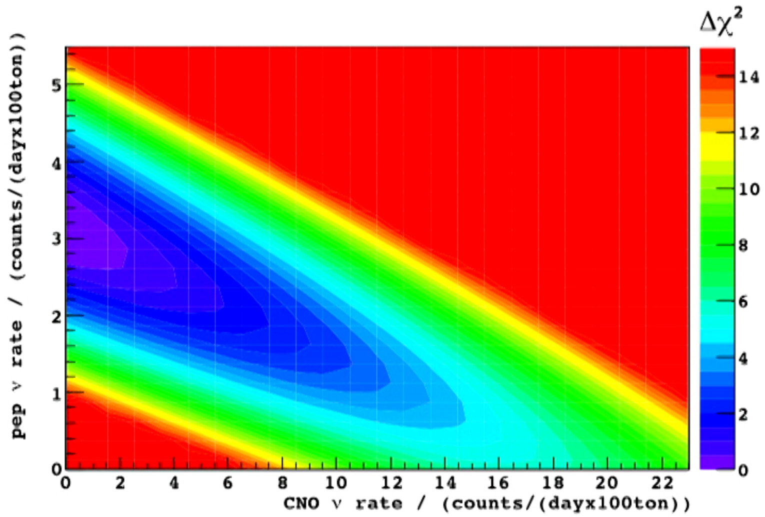
- Assume the MSW solution and deduce the SSM 7Be flux, or
- Assume the SSM 7Be flux, and deduce the survival probability
- Good consistency with the high-Z SSM
- Ultra-low threshold (< 100 eV) detectors will make first neutral current measurement of low energy Solar neutrino fluxes

Borexino Collaboration, 2011



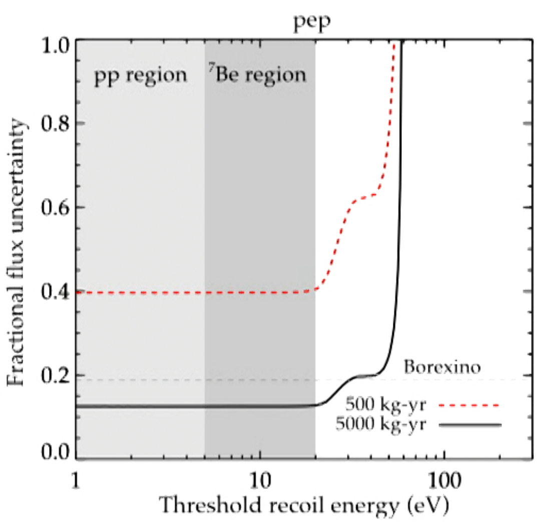


Neutrino Astrophysics: ultra-low thresholds



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

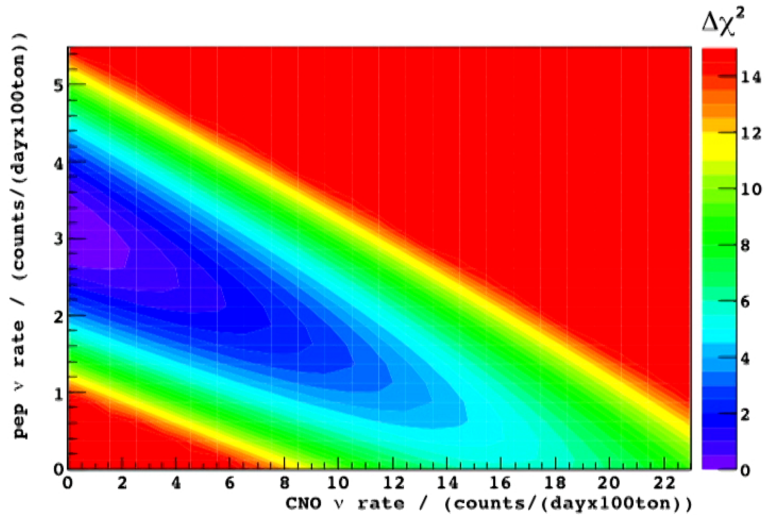
1110.3230



LS, PRD 2016

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

Neutrino Astrophysics: ultra-low thresholds



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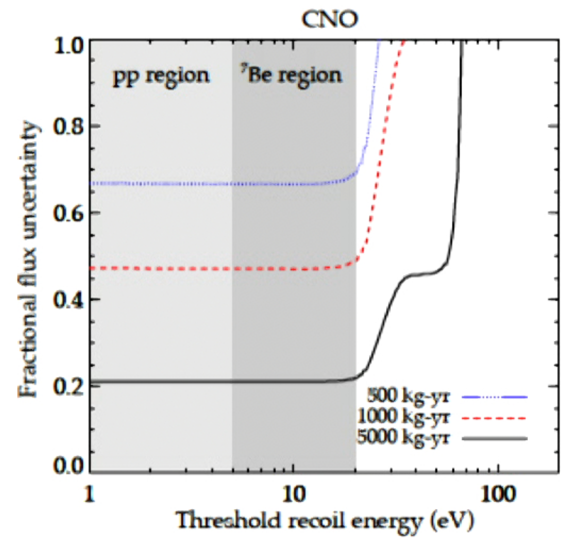


LS, PRD 2016

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,

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

- Without the luminosity constraint,

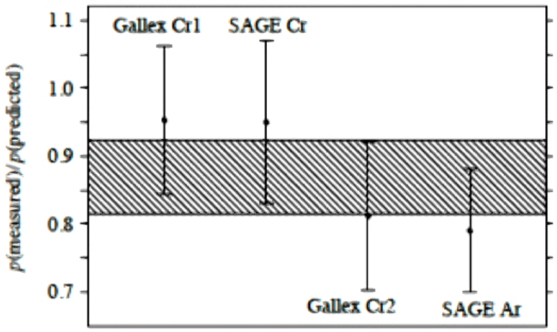
$$\frac{L_\odot(\text{neutrino-inferred})}{L_\odot} = 1.04\left[^{+0.07}_{-0.08}\right]\left[^{+0.20}_{-0.18}\right]$$

Bergstrom, Gonzalez-Garcia et al. JHEP 2016

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

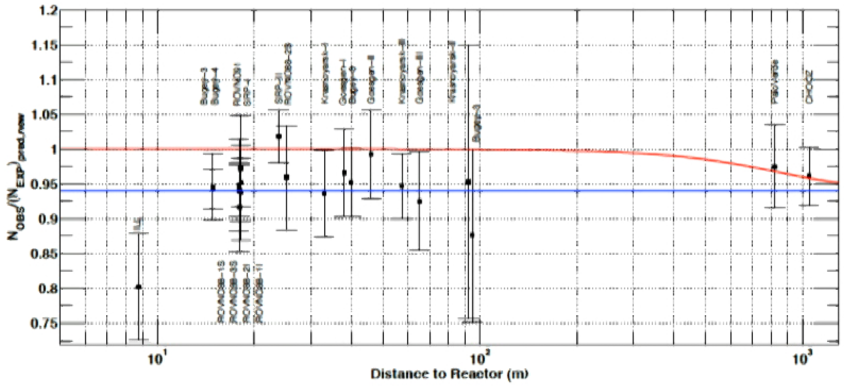
Outstanding issues III: New physics?

- 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

Coherent neutrino scattering at reactors

The CONNIE experiment

A. Aguilar-Arevalo[1], X. Bertou[2], C. Bonifazi[3], M. Butner[4],
G. Cancelo[4], A. Castaneda Vazquez[1], B. Cervantes Vergara[1],
C.R. Chavez[5], H. Da Motta[6], J.C. D'Olivo[1], J. Dos Anjos[6],
J. Estrada[4], G. Fernandez Moroni[7,8], R. Ford[4], A. Foguel[3,6],
K.P. Hernandez Torres[1], F. Izraelevitch[4], A. Kavner[9],
B. Kilminster[10], K. Kuk[4], H.P. Lima Jr.[6], M. Makler[6], J. Molina[5],
G. Moreno-Granados[1], J.M. Moro[11], E.E. Paolini[7,12], M. Sofo Haro[2],
J. Tiffenberg[4], F. Trillaud[1], and S. Wagner[6,13]

Coherent Neutrino Scattering with Low Temperature Bolometers at Chooz Reactor Complex

J. Billard[1], R. Carr[2], J. Dawson[3], E. Figueroa-Feliciano[4], J. A. Formaggio[2], J. Gascon[1], M. De Jesus[1], J. Johnston[2], T. Lasserre[5,6], A. Leder[2], K. J. Palladino[7], S. H. Trowbridge[2], M. Vivier[5], and L. Winslow[2]

Research program towards observation of neutrino-nucleus coherent scattering

H T Wong[1,*], H B Li[1], S K Lin[1], S T Lin[1], D He[2], J Li[2], X Li[2], Q Yue[2], Z Y Zhou[3] and S K Kim[4]

[1] Institute of Physics, Academia Sinica, Taipei 11529, Taiwan.
[2] Department of Engineering Physics, Tsing Hua University, Beijing 100084, China.
[3] Department of Nuclear Physics, Institute of Atomic Energy, Beijing 102413, China.
[4] Department of Physics, Seoul National University, Seoul 151-742, Korea.

Background Studies for the MINER Coherent Neutrino Scattering Reactor Experiment

G. Agnolet[a], W. Baker[a], D. Barker[b], R. Beck[a], T.J. Carroll[c], J. Cesar[c], P. Cushman[b], J.B. Dent[d],
S. De Rijck[c], B. Dutta[a], W. Flanagan[c], M. Fritts[b], Y. Gao[a,e], H.R. Harris[a], C.C. Hays[a], V. Iyer[f],
A. Jastram[a], F. Kadribasic[a], A. Kennedy[b], A. Kubik[a], I. Ogawa[g], K. Lang[c], R. Mahapatra[a], V. Mandic[b],
R.D. Martin[h], N. Mast[b], S. McDeavitt[i], N. Mirabolfathi[a], B. Mohanty[f], K. Nakajima[g], J. Newhouse[i],
J.L. Newstead[j], D. Phan[c], M. Proga[c], A. Roberts[k], G. Rogachev[l], R. Salazar[c], J. Sander[k], K. Senapati[f],
M. Shimada[g], L. Strigari[a], Y. Tamagawa[g], W. Teizer[a], J.I.C. Vermaak[i], A.N. Villano[b], J. Walker[m],
B. Webb[a], Z. Wetzel[a], S.A. Yadavalli[c]

Mitchell Institute Neutrino Experiment at Reactor

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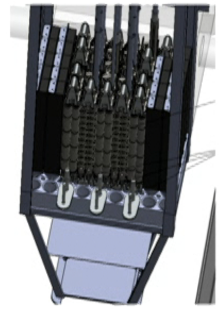
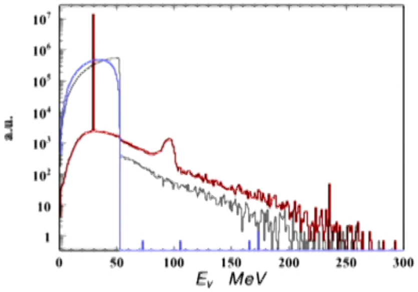
 

Mirabolfathi et al. 1510.00999

- Reactor-based proposal developed with Nuclear Science Center at Texas A&M University
- Detector technology based on scalable ultra-low threshold Germanium and Silicon arrays
- Close proximity of ~ 1m to MW reactor core
- Equivalent rate to larger detectors at larger distance from core (e.g. TEXONO)
- MW reactor ON/OFF
- Moveable core: Important for sterile neutrino searches

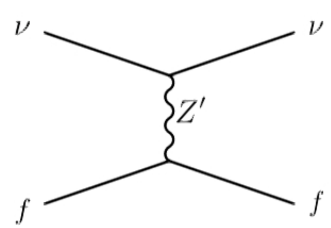
The primary goal of COHERENT is detection of CEvNS using the extremely clean, pulsed stopped-pion flux at SNS



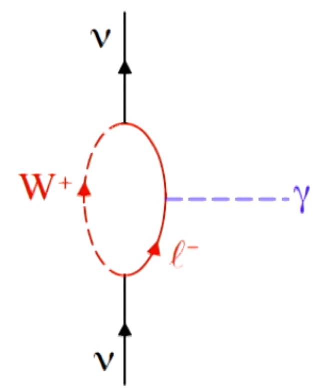
SNS flux (1.4 MW): 430 x 10^5 $\nu/cm^2/s$ @ 20 m;
~400 ns proton pulses @ 60 Hz → ~10^{-4} bg rejection

Searches for new physics

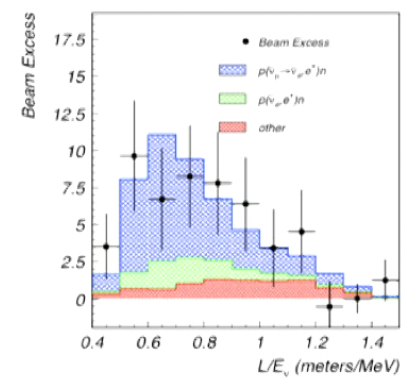
NSI



Magnetic moment

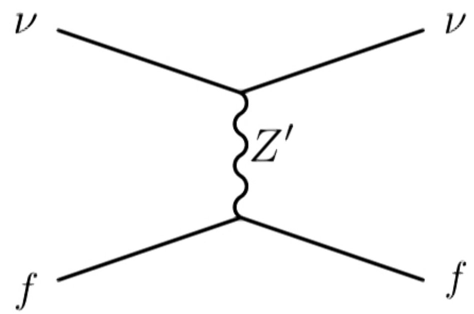


Sterile neutrinos



Non-Standard Neutrino Interactions

- NSI describe new physics at high energy in form of heavy scalars, gauge bosons
- Best sensitivity to flavor-conserving Neutral Current NSI models
- NSI identified in CNS detection



$$\nu_\beta + f \to \nu_\alpha + f$$

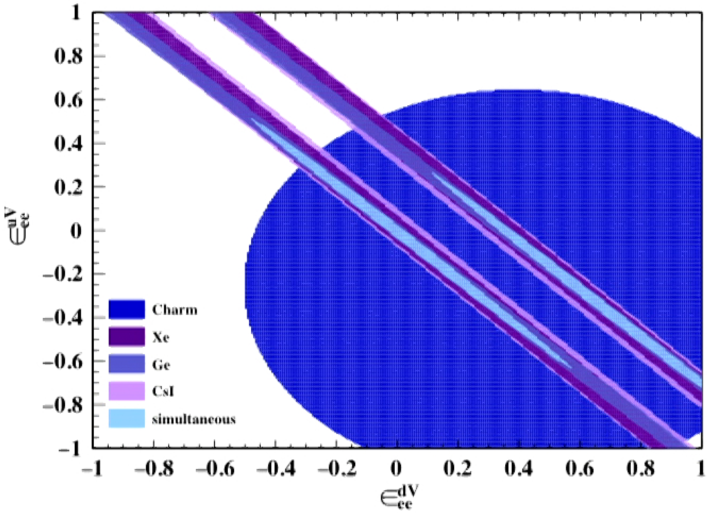
$$\mathcal{L}_{int} = 2\sqrt{2} G_F \bar{\nu}_{\alpha L} \gamma^\mu \nu_{\beta L} \left(\epsilon_{\alpha\beta}^{fL} \bar{f}_L \gamma_\mu f_L + \epsilon_{\alpha\beta}^{fR} \bar{f}_R \gamma_\mu f_R \right)$$

$$\frac{\mathrm{d}\sigma}{\mathrm{d}E_r} = \frac{2}{\pi} G_F^2 m_f \left[\left|\epsilon_{\alpha\beta}^{fL}\right|^2 + \left|\epsilon_{\alpha\beta}^{fR}\right|^2 \left(1 - \frac{E_r}{E_\nu}\right)^2 - \frac{1}{2} \left(\epsilon_{\alpha\beta}^{fL*} \epsilon_{\alpha\beta}^{fR} + \epsilon_{\alpha\beta}^{fL} \epsilon_{\alpha\beta}^{fR*} \right) \frac{m_f E_r}{E_\nu^2} \right]$$

Barranco et al. 2005

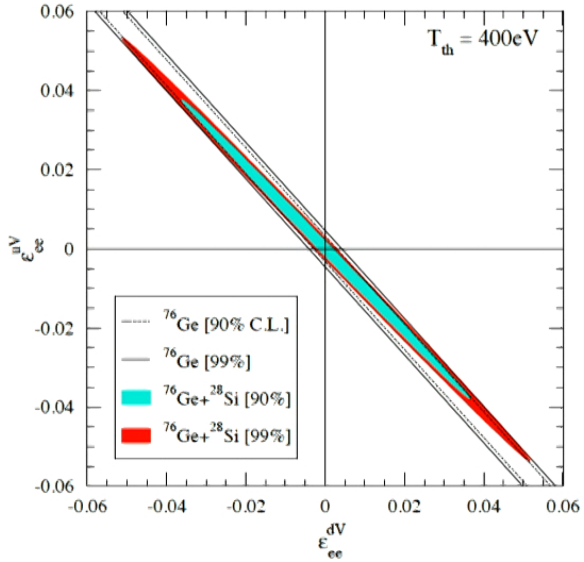
Non-standard interactions

Accelerators



COHERENT collaboration, 2015

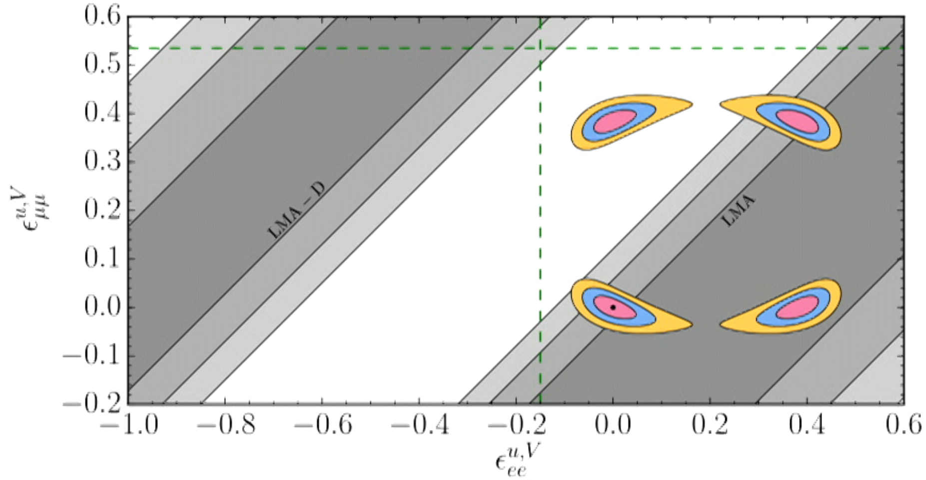
Reactors



Barranco et al. 2005

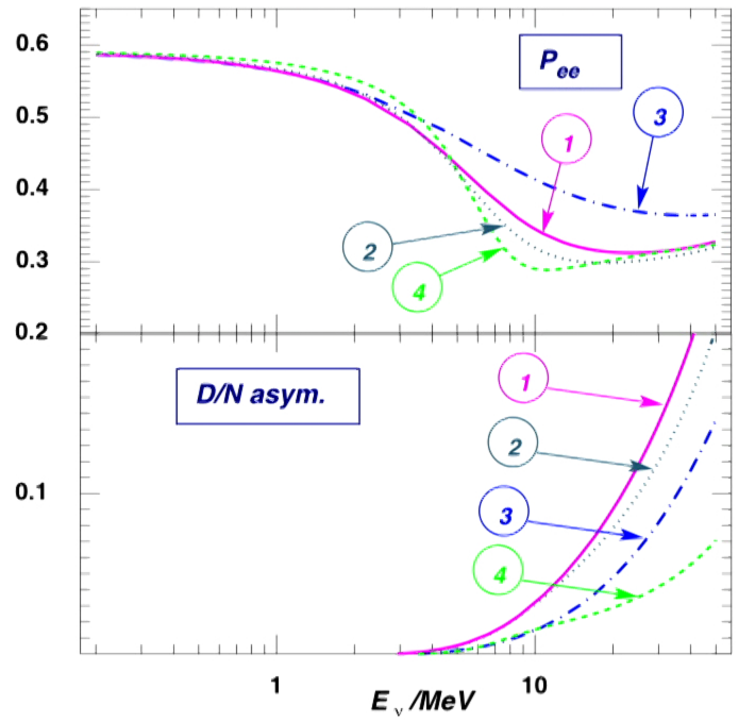
Non-standard interactions: MSW LMA Dark Side

- Oscillation data still allow for large NSI couplings and MSW LMA Dark side solution [Miranda, Valle, Tortola, 2006]
- Changes octant of solar angle and sign of mass ordering
- Non-oscillation experiments (e.g. coherent scattering) required to lift this degeneracy



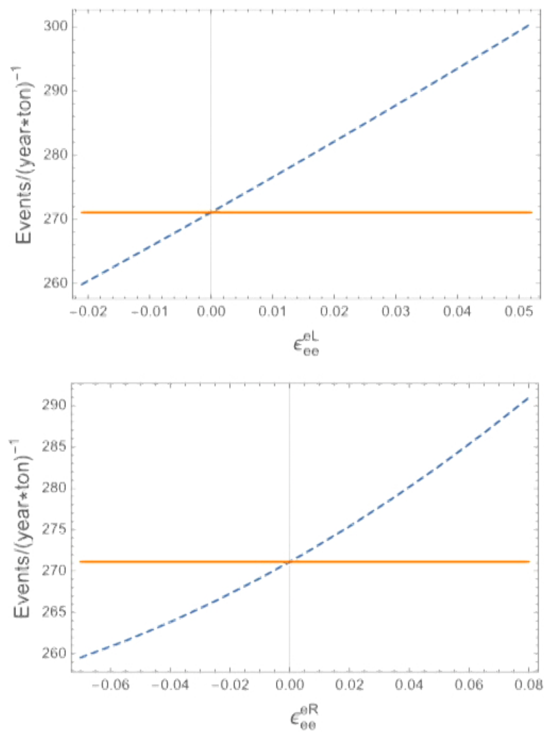
Coloma et al. 2017

Solar neutrinos, MSW, and NSI



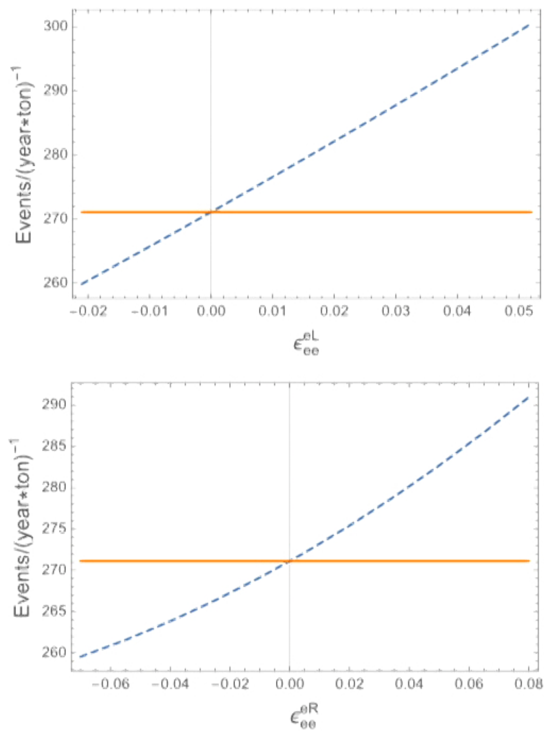
Friedland, Lunardini, Pena-Garay PLB 2004

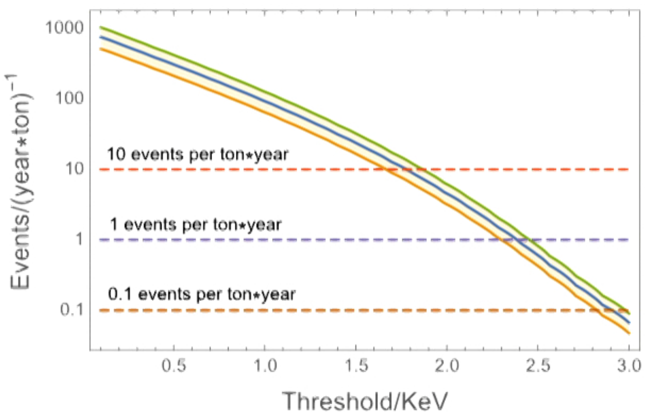
Non-standard interactions + MSW + DM detectors



J. Dutta, ***Shu Liao***, LS, J. Walker, 2017

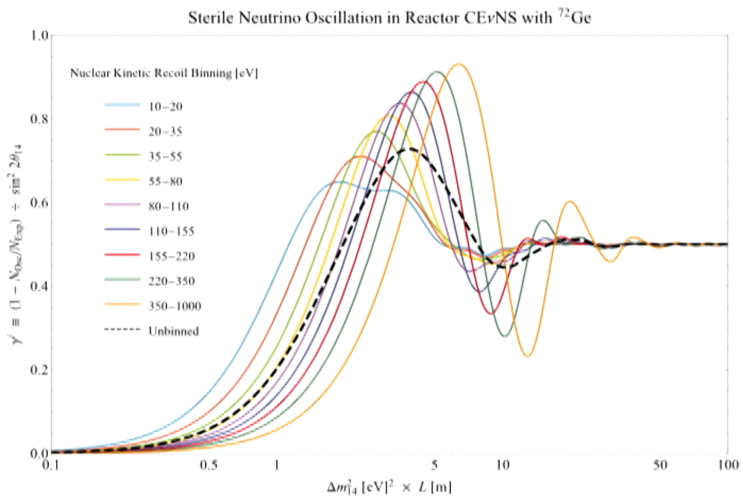
Non-standard interactions + MSW + DM detectors

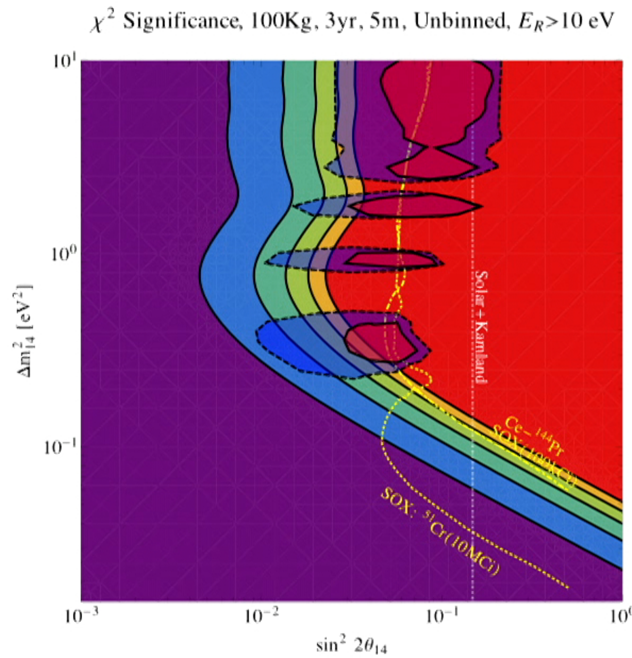




J. Dutta, ***Shu Liao***, LS, J. Walker, 2017

Sterile neutrino search at reactors





Dutta et al. 1511.02834

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

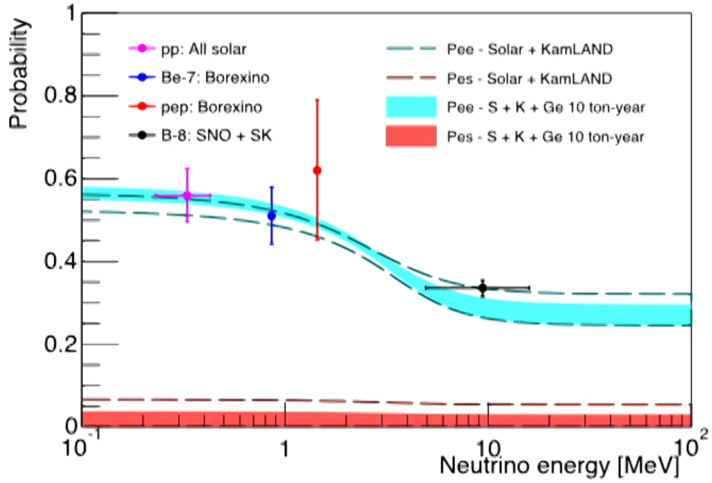
Neutrino properties: Sterile neutrinos

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

Kosmas et al. 2017 for COHERENT sterile analysis



Billard, Strigari, Figueroa-Feliciano, PRD 1409.0050

Summary: Important physics reach of coherent neutrino-nucleus scattering