Neutrino backgrounds in dark matter detectors

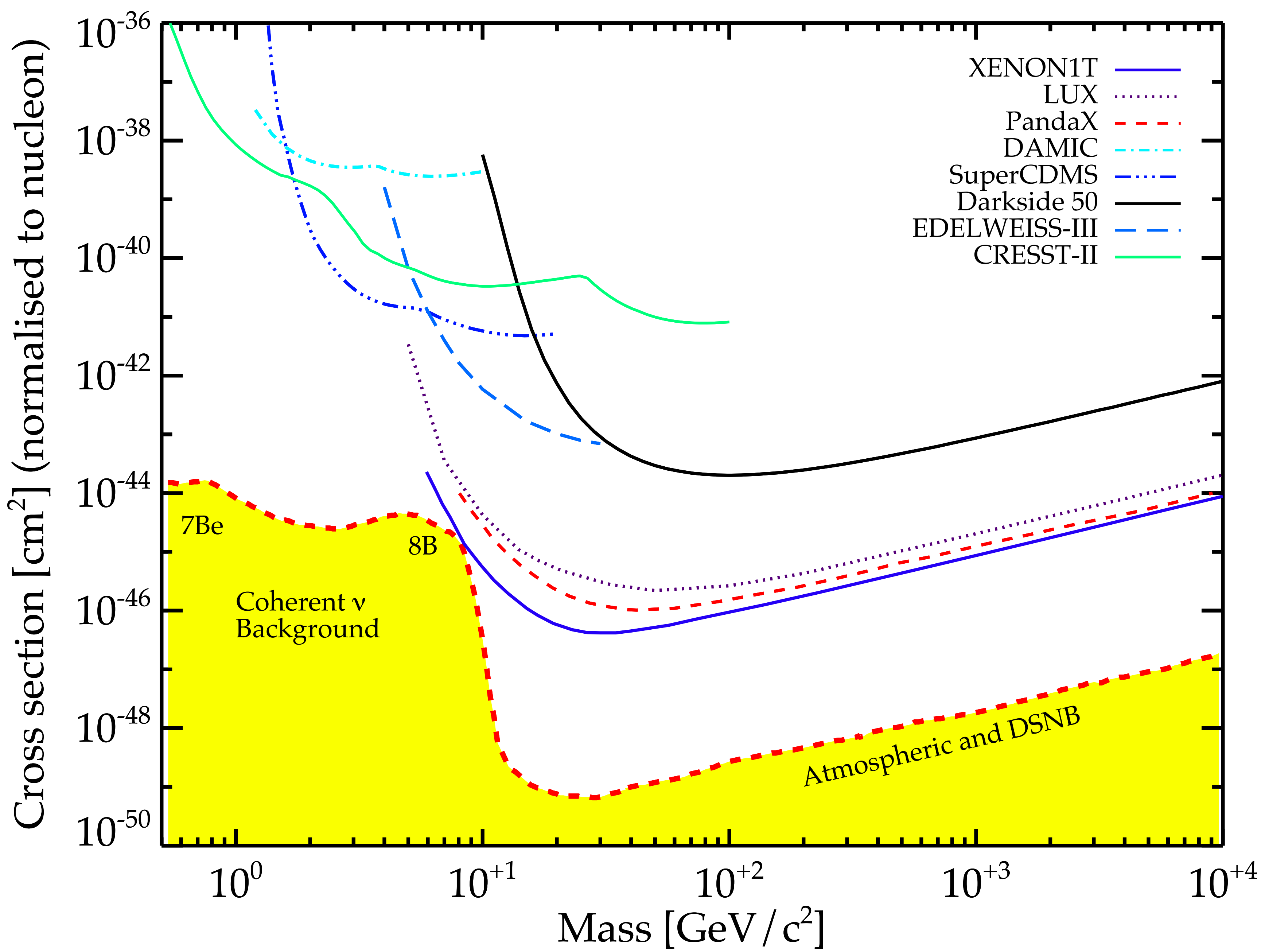
Identification of Dark Matter (IDM 2018)
Brown University—Providence, RI
July 22, 2018

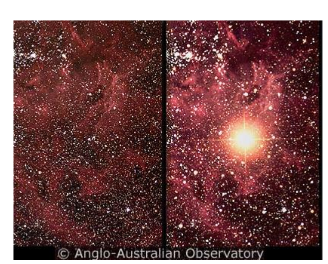
Artwork by Sandbox Studio, Chicago with Ana

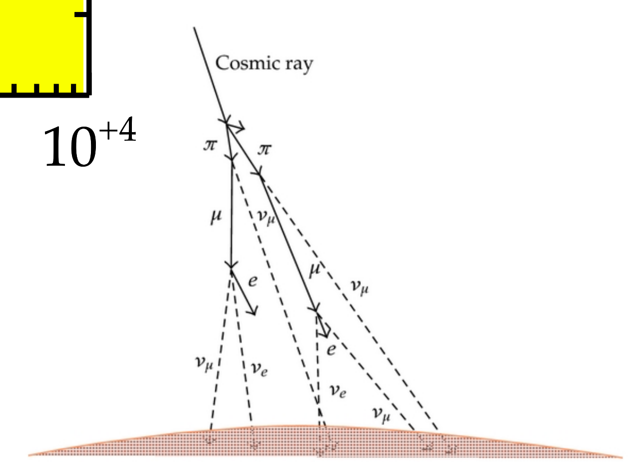
Louis E. Strigari

MITCHELL INSTITUTE
TEXAS A&M UNIVERSITY

Neutrino backgrounds to dark matter detection







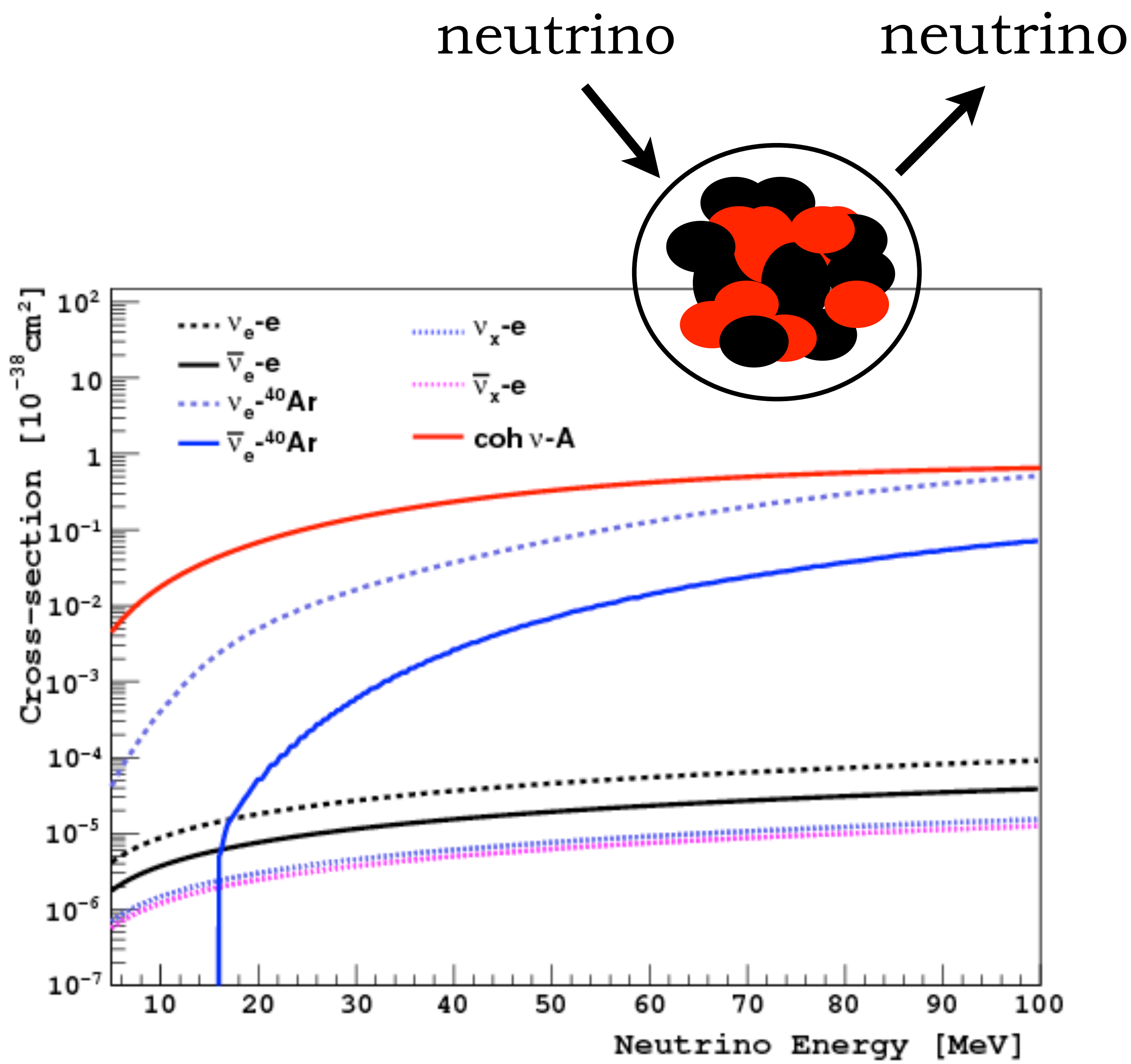
Neutrino-nucleus coherent scattering

Sensitive to BSM physics:

NSI: Scholberg 2005; Barranco et al. 2007
Sterile neutrinos: Dutta et al. 1508.07981, 1511.02834
Z' interactions: Lindner et al 2017; Abdullah et al. 2018

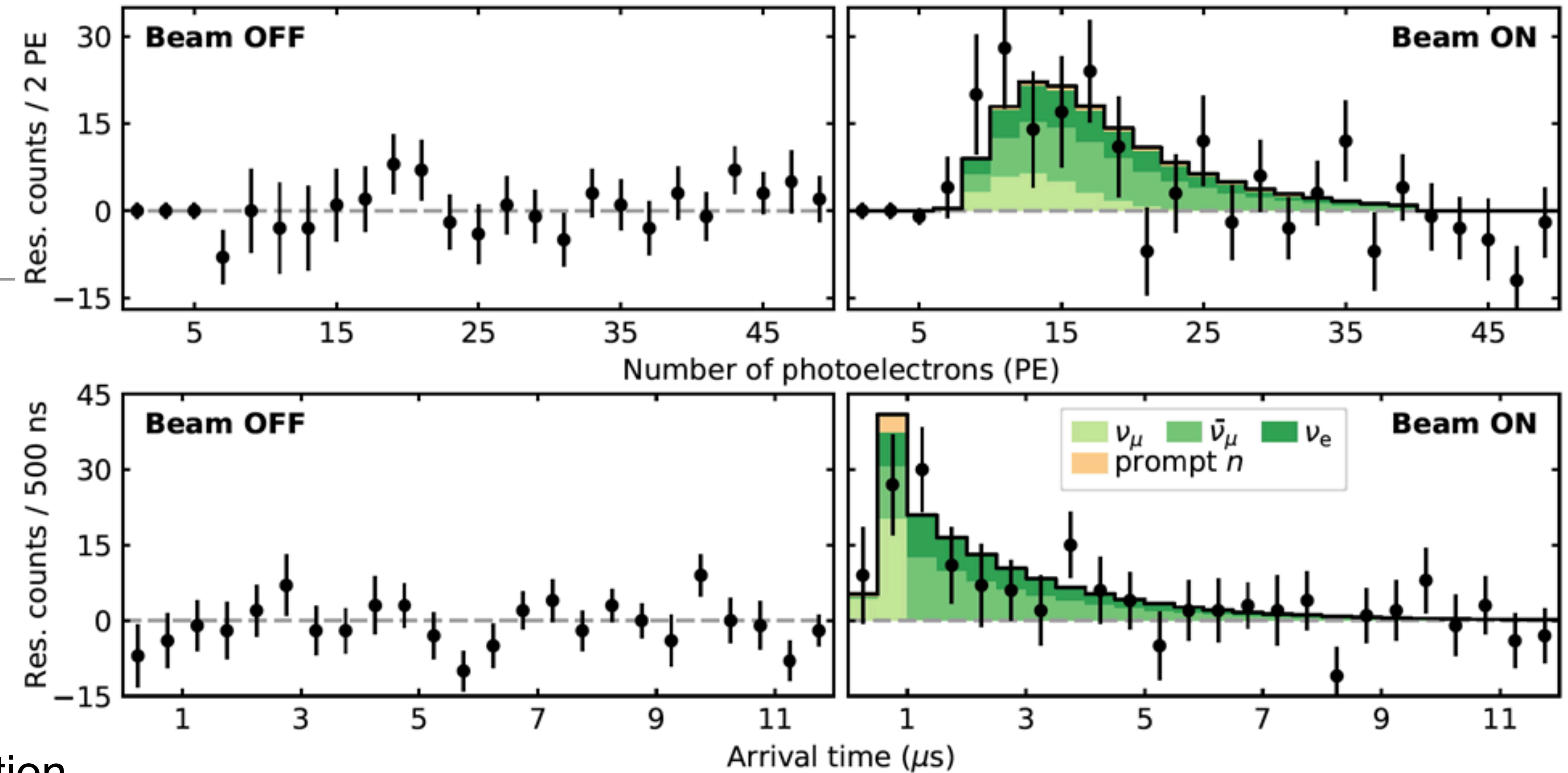
$$\frac{d\sigma_{CNS}(E_\nu, T_R)}{dT_R} = \frac{G_f^2}{4\pi} Q_w^2 m_N \left(1 - \frac{m_N T_R}{2E_\nu^2}\right) F^2(T_R)$$

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

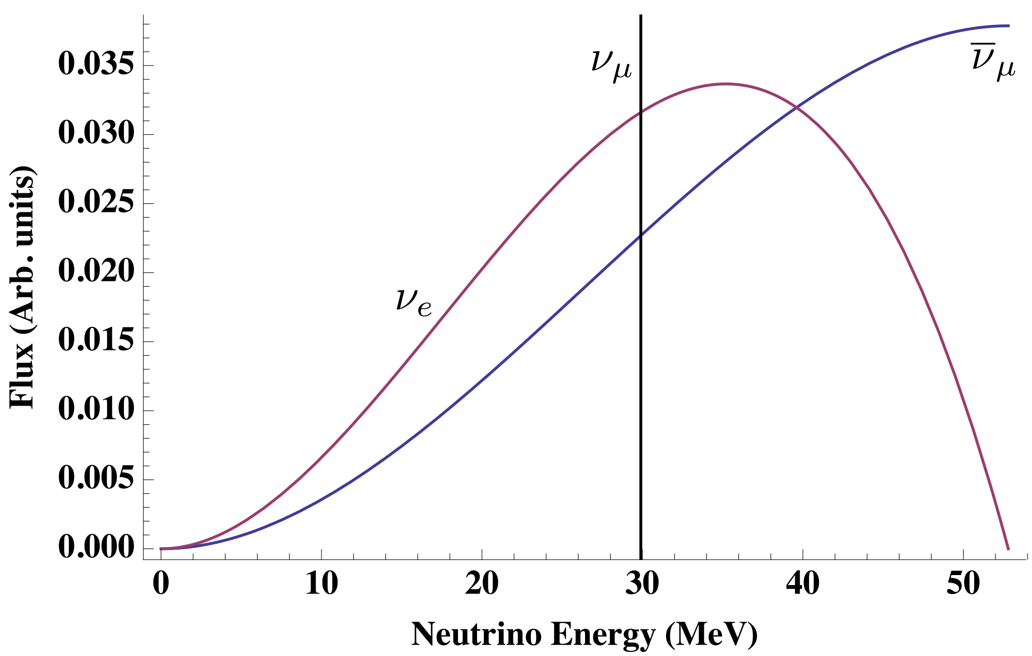


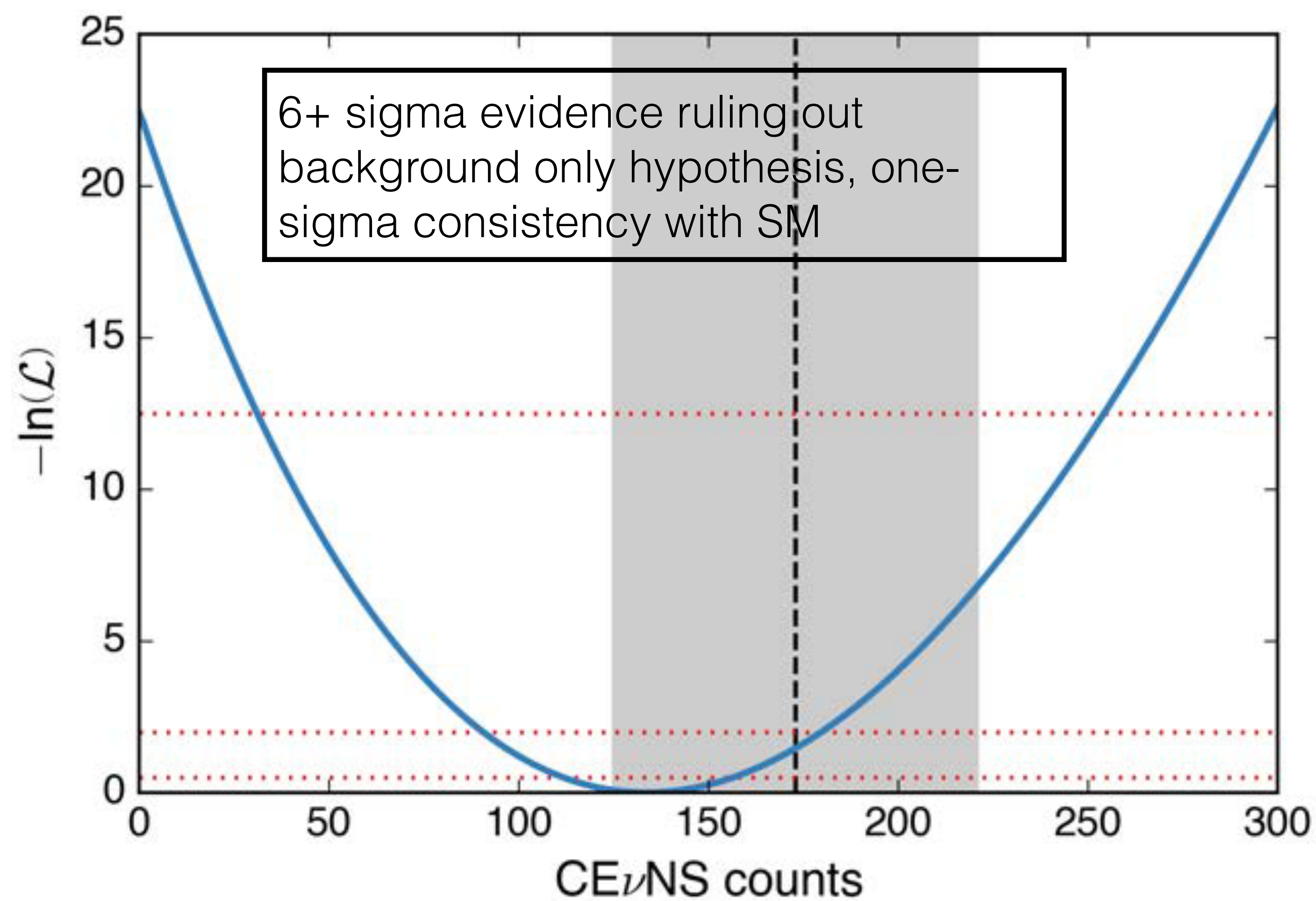
Brice et al, 1311.5958

COHERENT collaboration, Science, 2017



SNS flux (1.4 MW): 430 x 10^5 ν/cm²/s @ 20 m;
~400 ns proton pulses @ 60 Hz ➔~10^{-4} bg rejection





Tolstukhin talk

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]

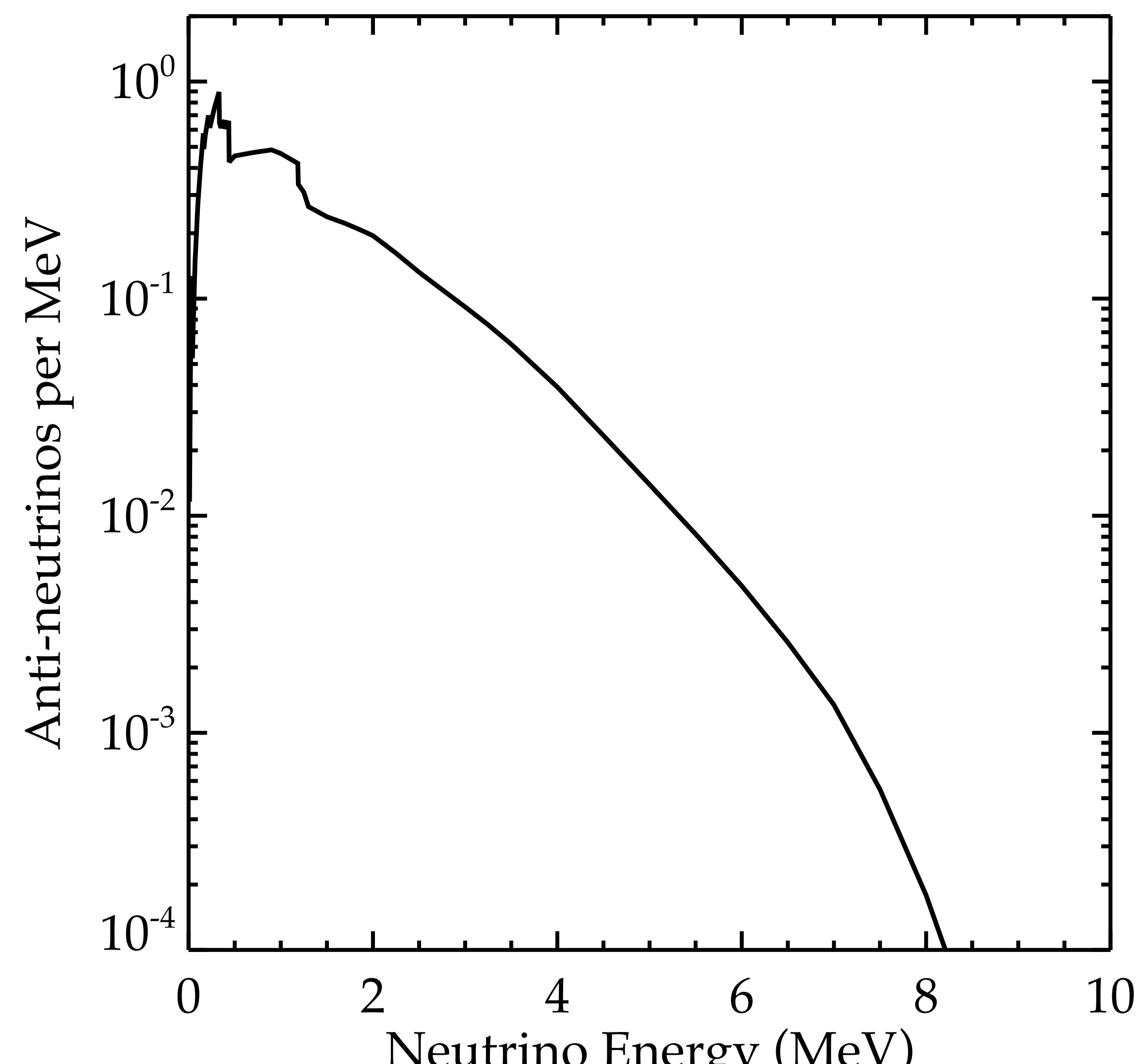
Research program towards observation of neutrino-nucleus coherent scattering

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]

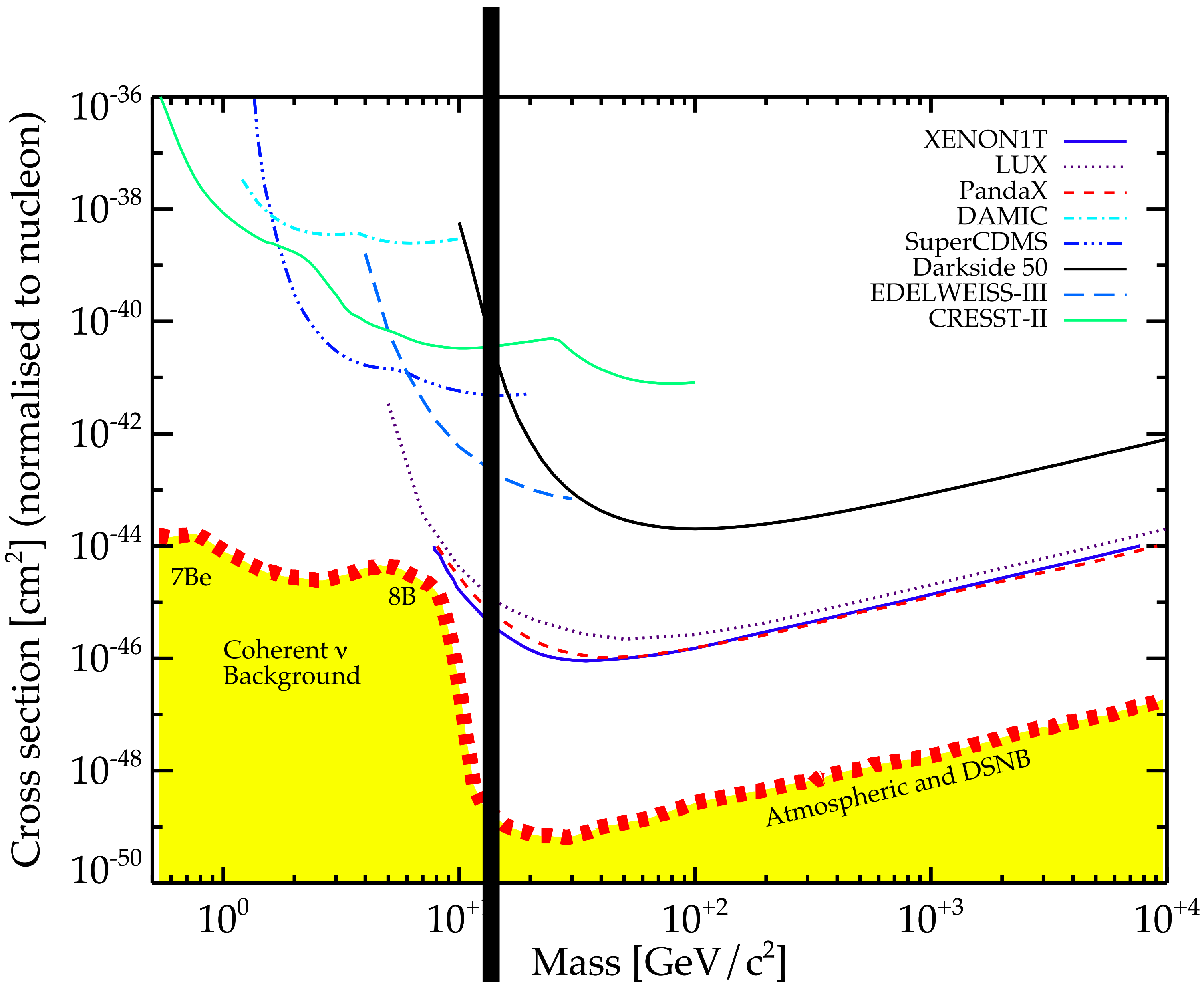
[1] Institute of Physics, Academia Sinica, Taipei 11529, Taiwan.
[2] Department of Engineering Physics, Tsing Hua University, Beijing 100084, China.
[3] Department of Nuclear Physics, Institute of Atomic Energy, Beijing 102413, China.
[4] Department of Physics, Seoul National University, Seoul 151-742,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



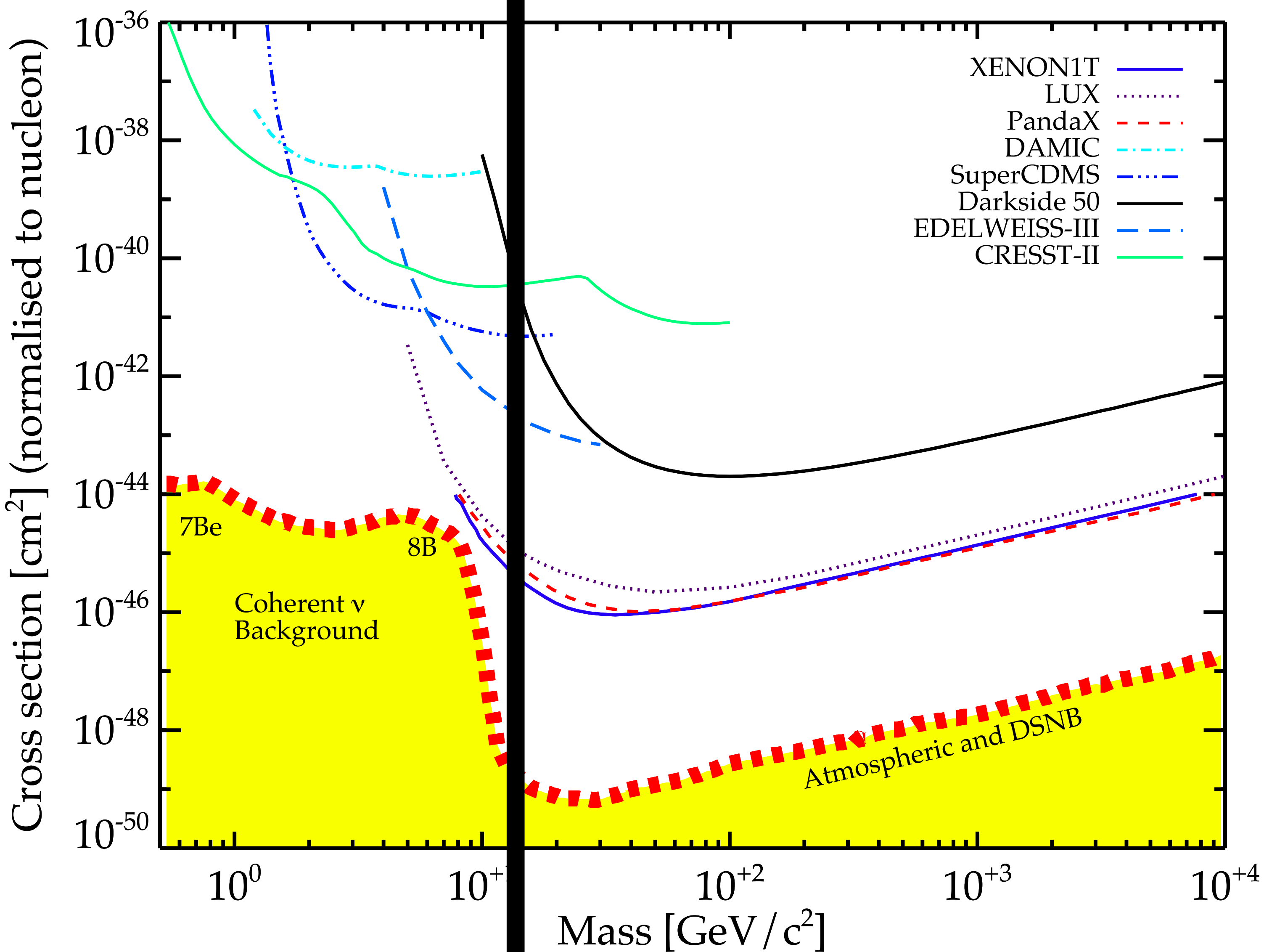
CONUS 2.4 sigma measurement— Neutrino 2018



Reactors

Accelerators

Distinguishing DM from neutrinos:

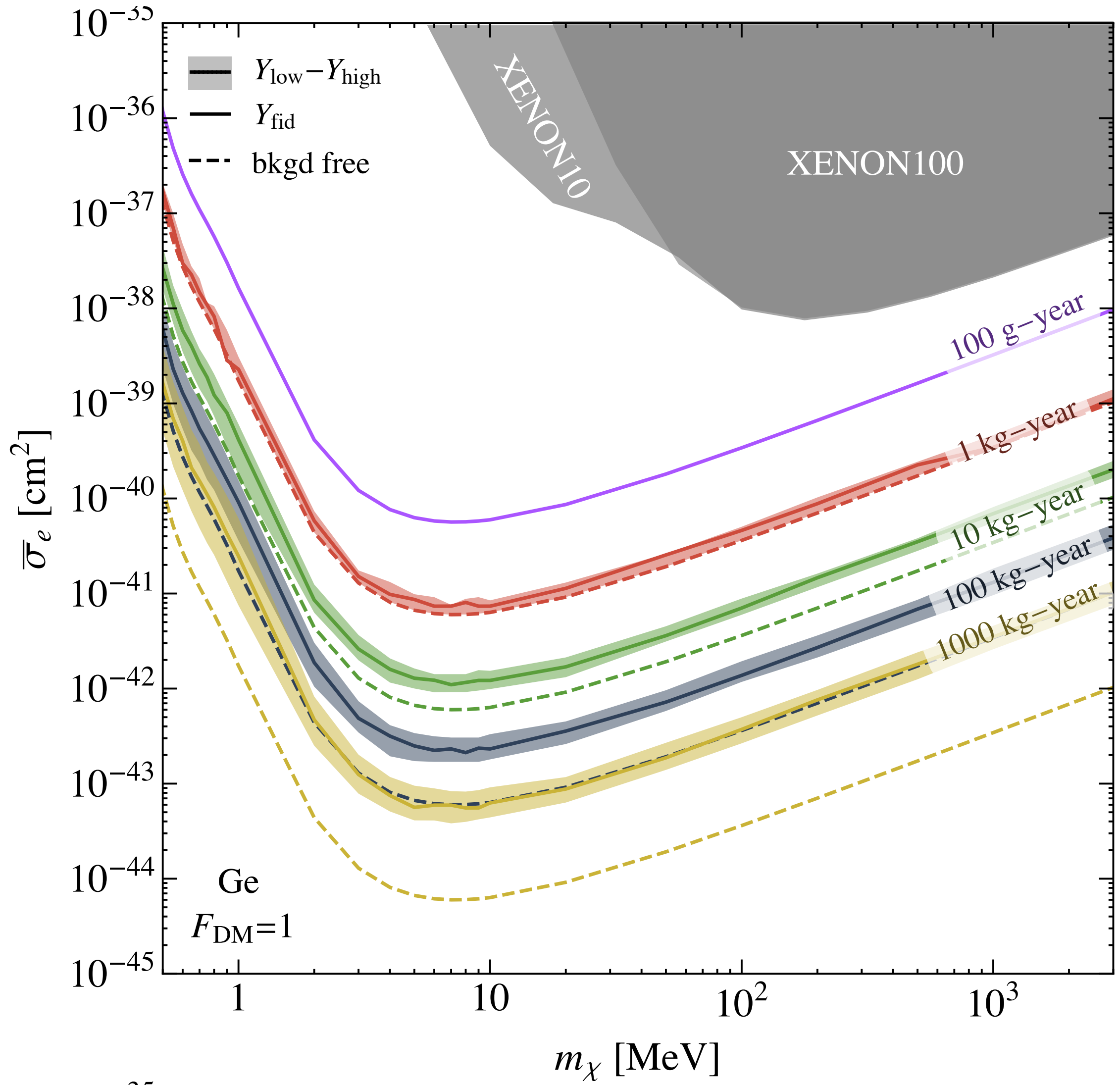


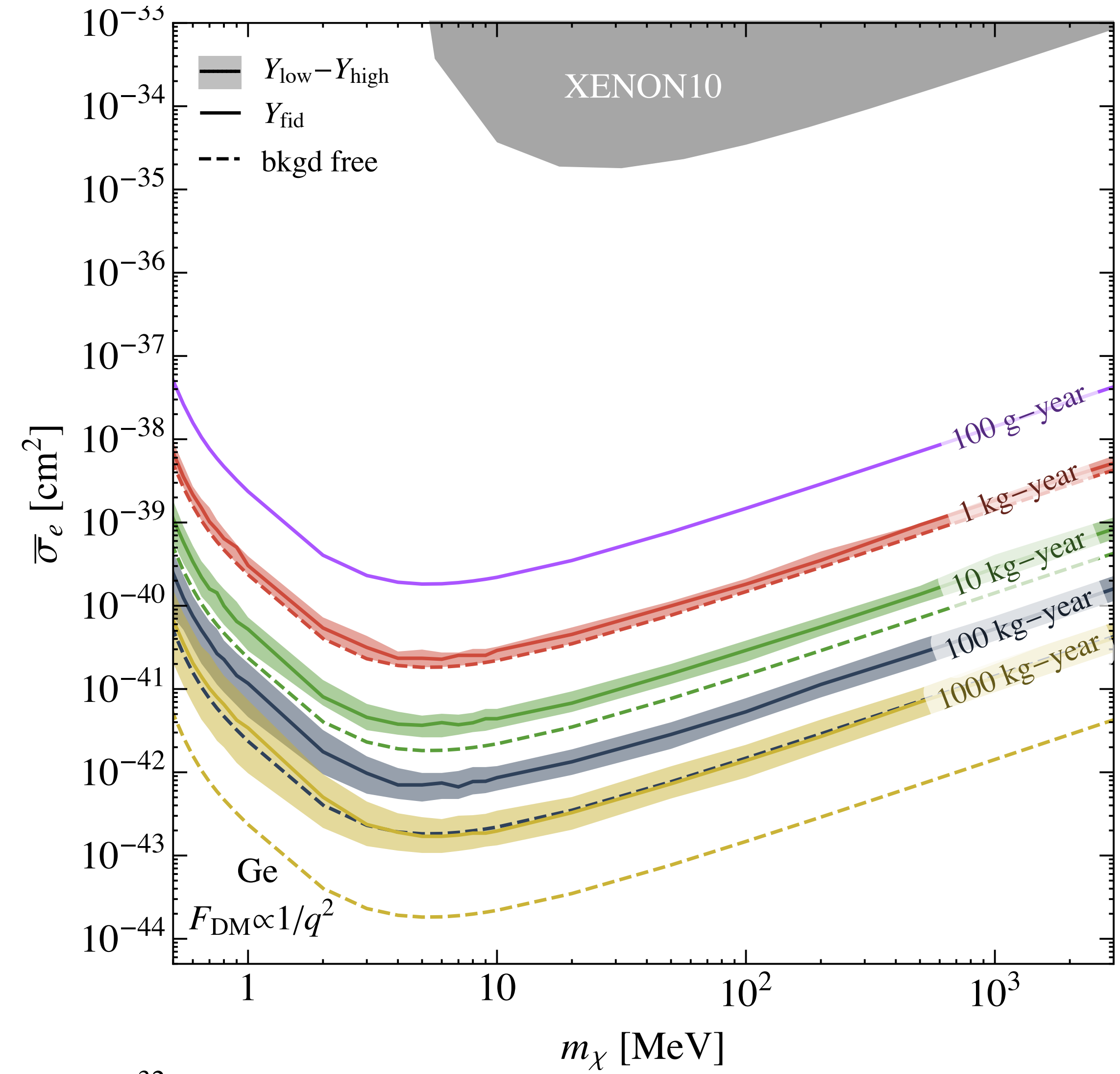
Reactors

Accelerators

- Annual modulation/ directionality: Grothaus, Fairbairn, Monroe 2014; O'Hare et al. 2015, Davis 2015
- SD DM: Ruppin, Billard, Figueroa-Feliciano, Strigari, 2014; Gelmini et al. 2018
- Non-rel EFTs: Dent, Dutta, Strigari, Newstead 2016/2017
- NSI: Dutta, Liao, LS, Walker 2017; Aristizabal Sierra, Rojas, Tytgat 2018; Gonzalez-Garcia et al. 2018

Neutrino floor for light DM

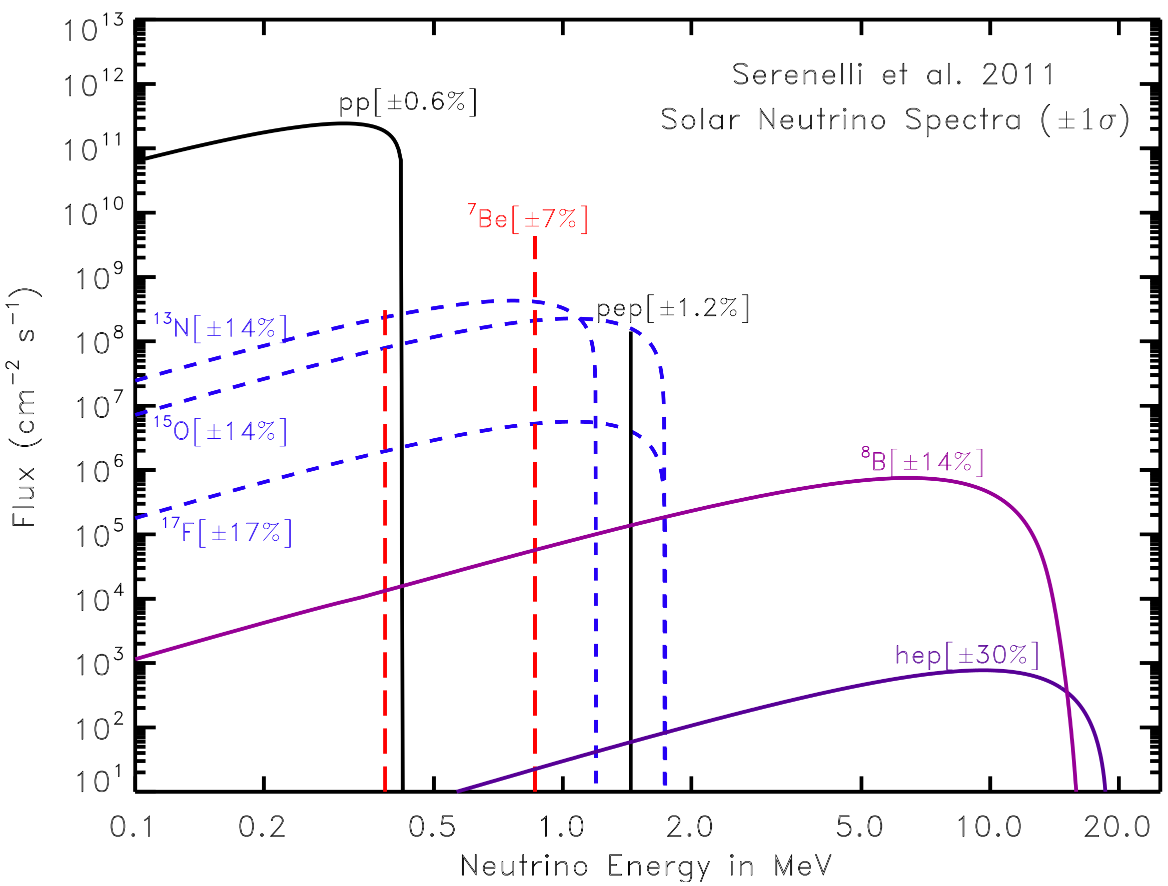


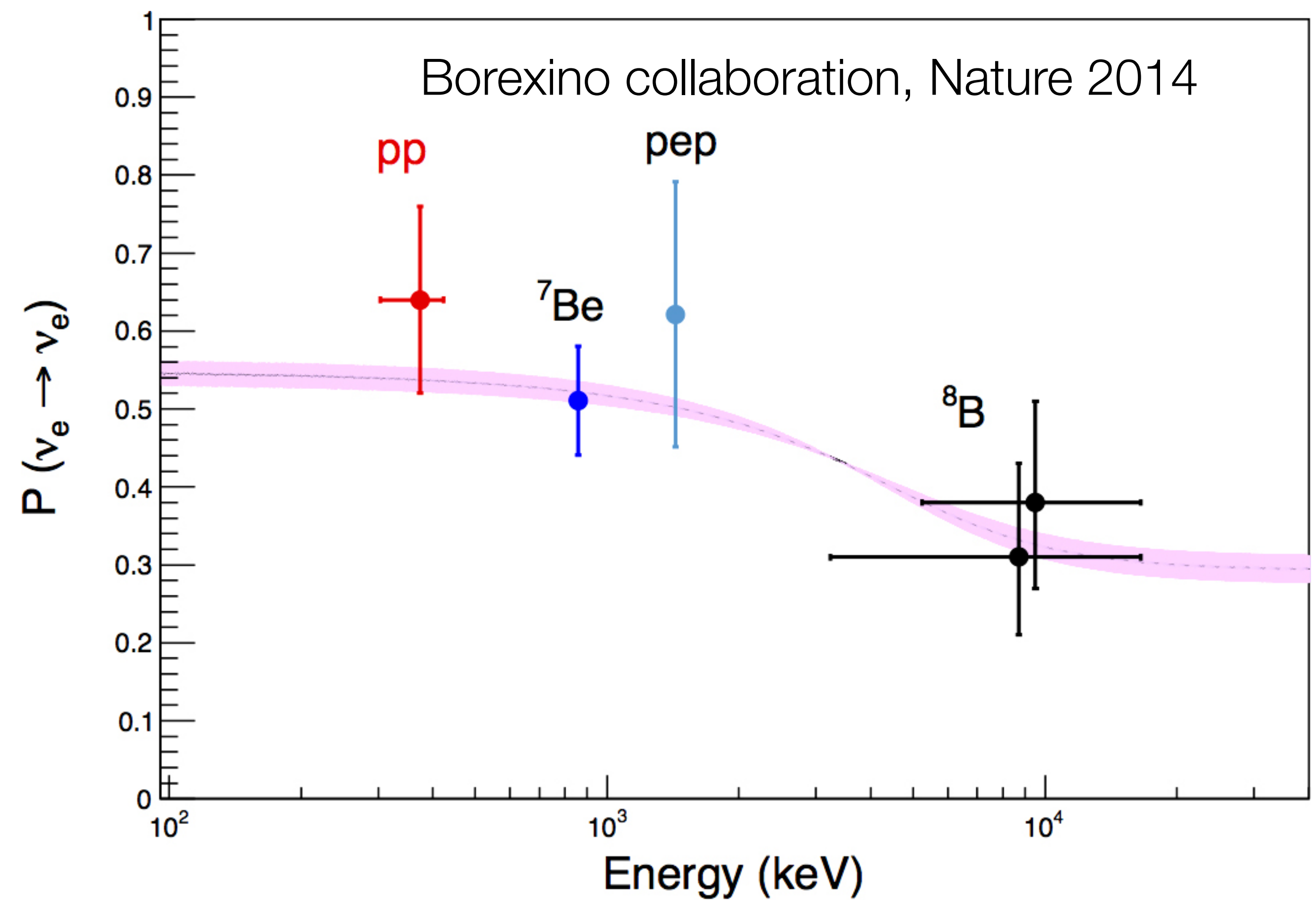


- At low mass, neutrino floor from solar neutrinos
- Particularly important for detectors that lack electron/nuclear discrimination

Essig et al. 2018; Wyenberg and Shoemaker 2018

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

High-Z Low-Z

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%)				
${}^8B\to{}^8Be+e^++\nu$	~ 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

- 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-Z   Low-Z

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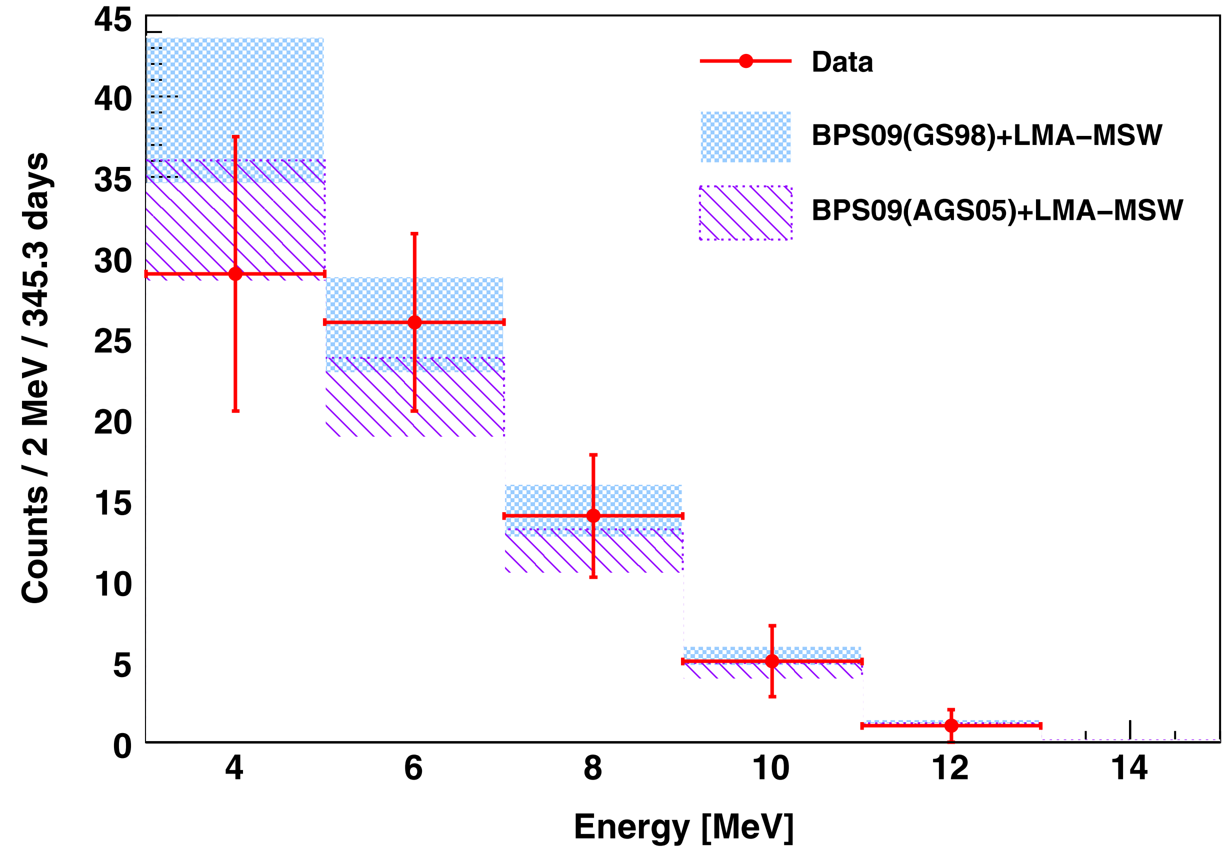
Haxton et al. 2013



Borexino collaboration

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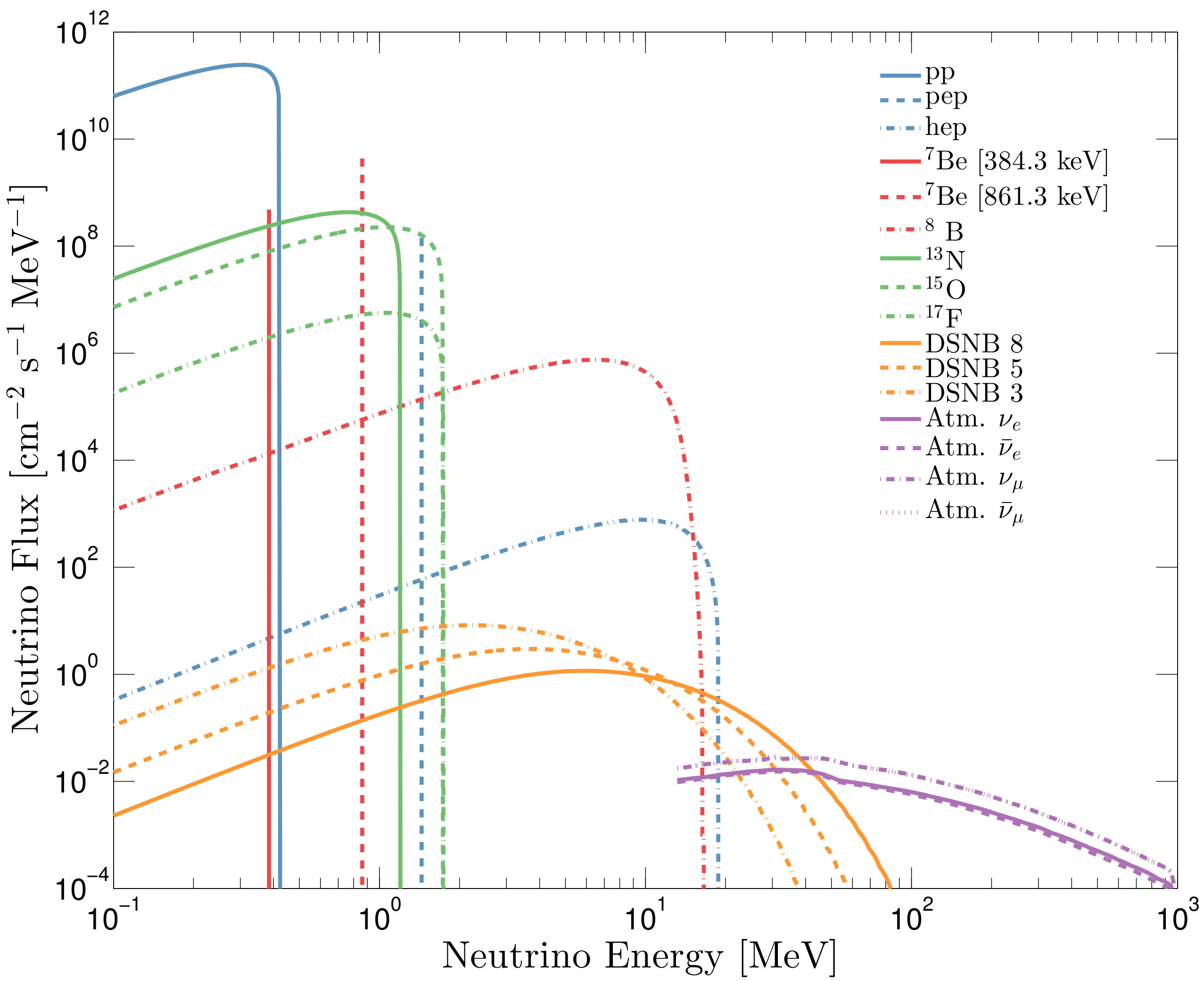
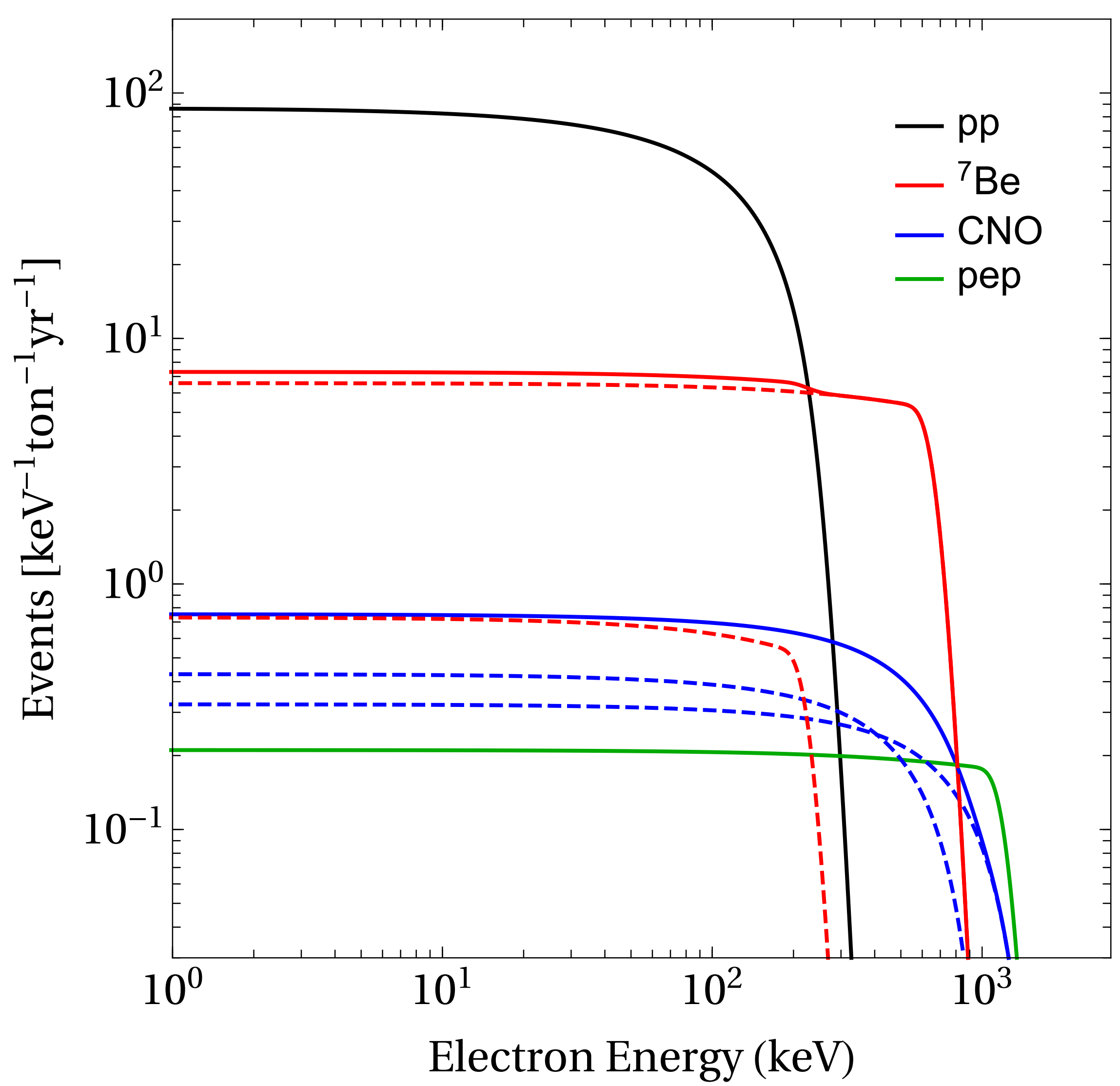
- SNO Neutral Current measurement right in between predictions of low and high metallicity SSMs

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

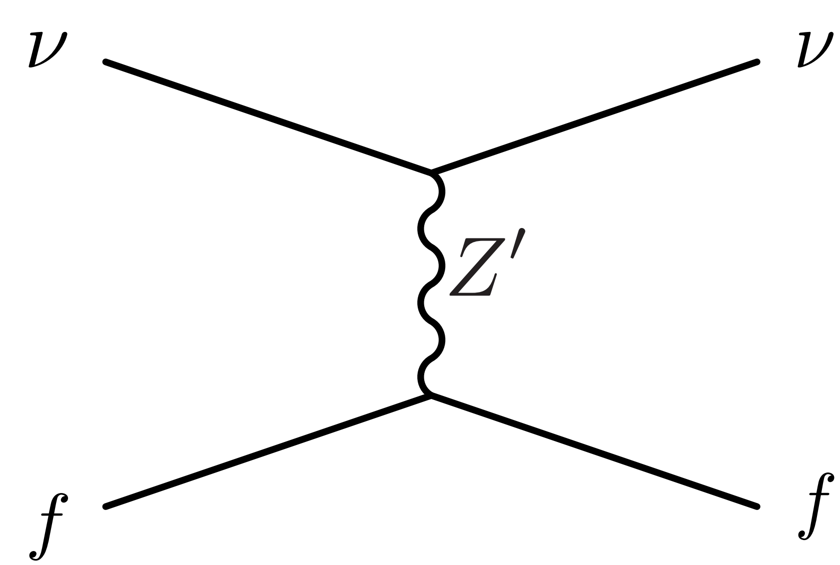
Nuclear and electron recoil spectra





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



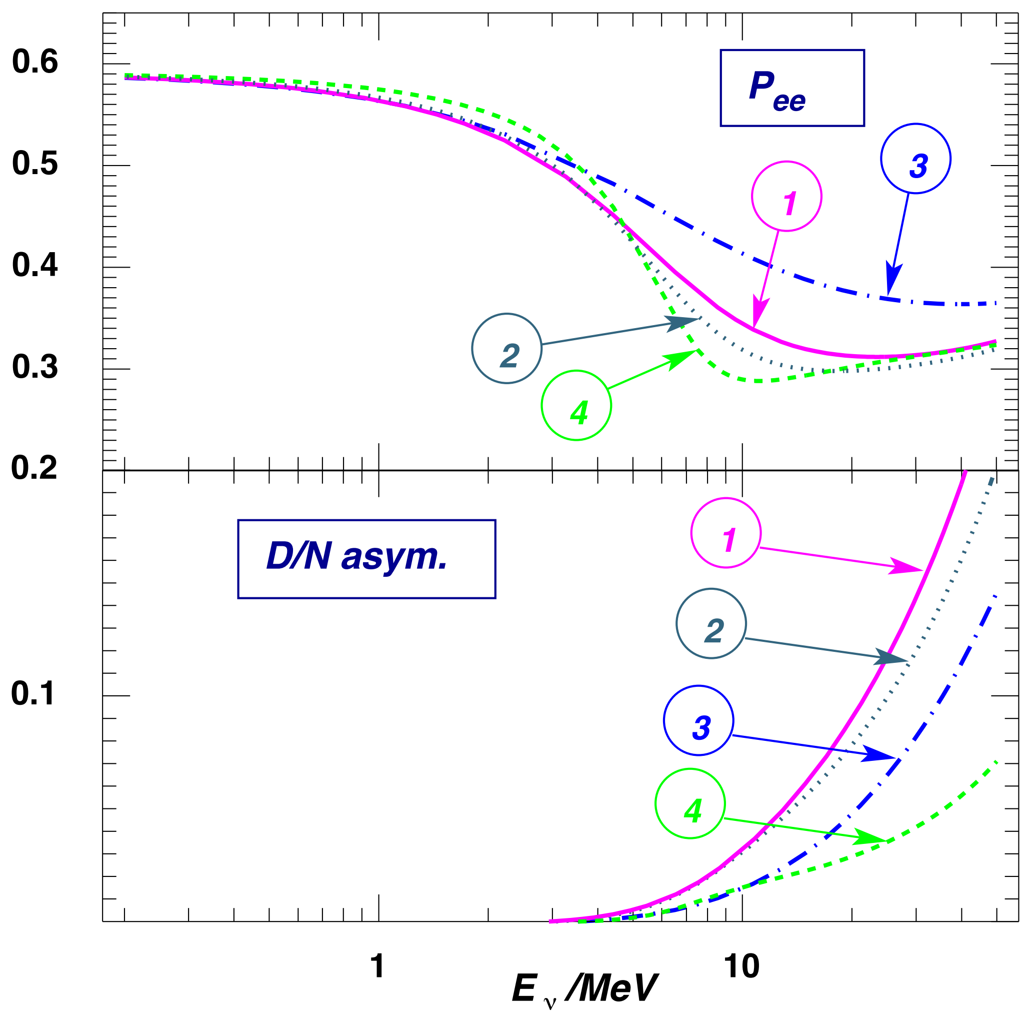
$$\nu_\beta + f \rightarrow \nu_\alpha + f$$

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

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

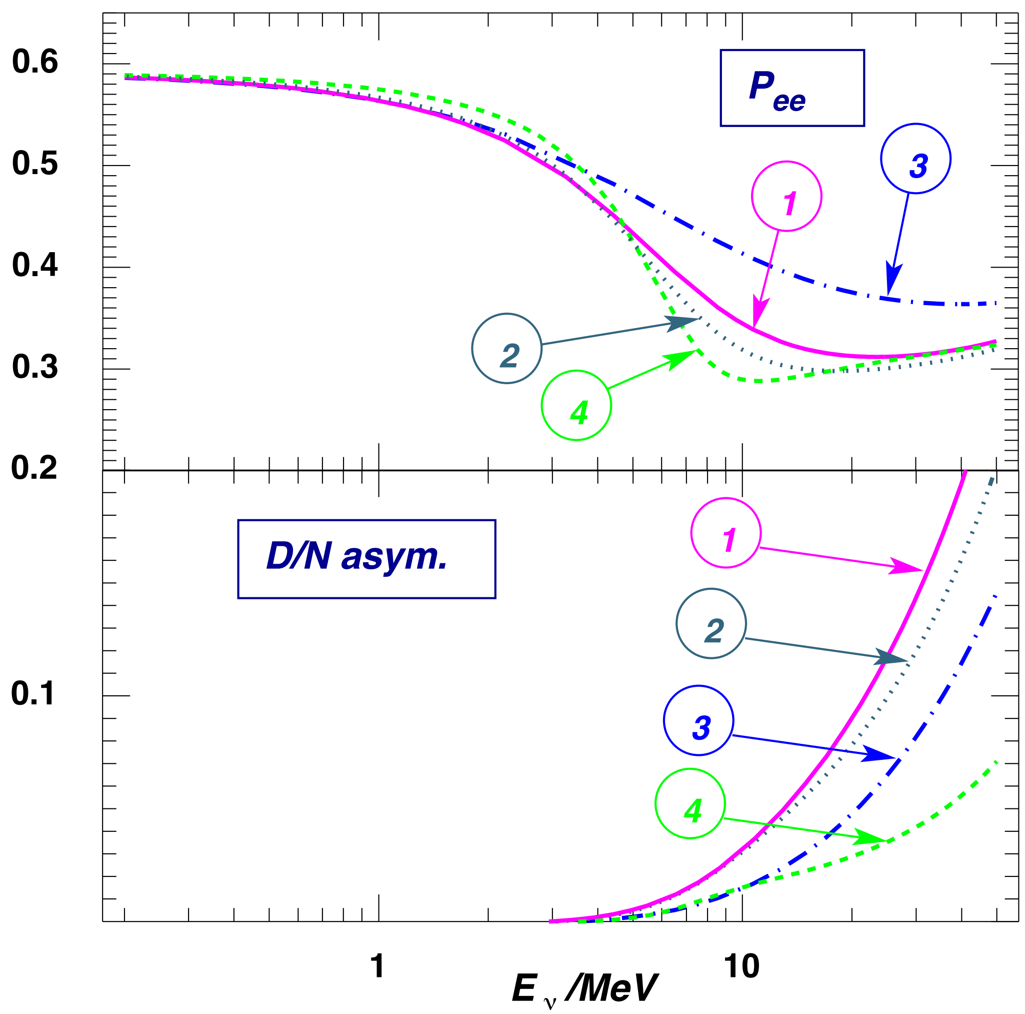
Barranco et al. 2005

Non-standard interactions + MSW + DM detectors



Friedland, Lunardini, Pena-Garay PLB 2004

Non-standard interactions + MSW + DM detectors



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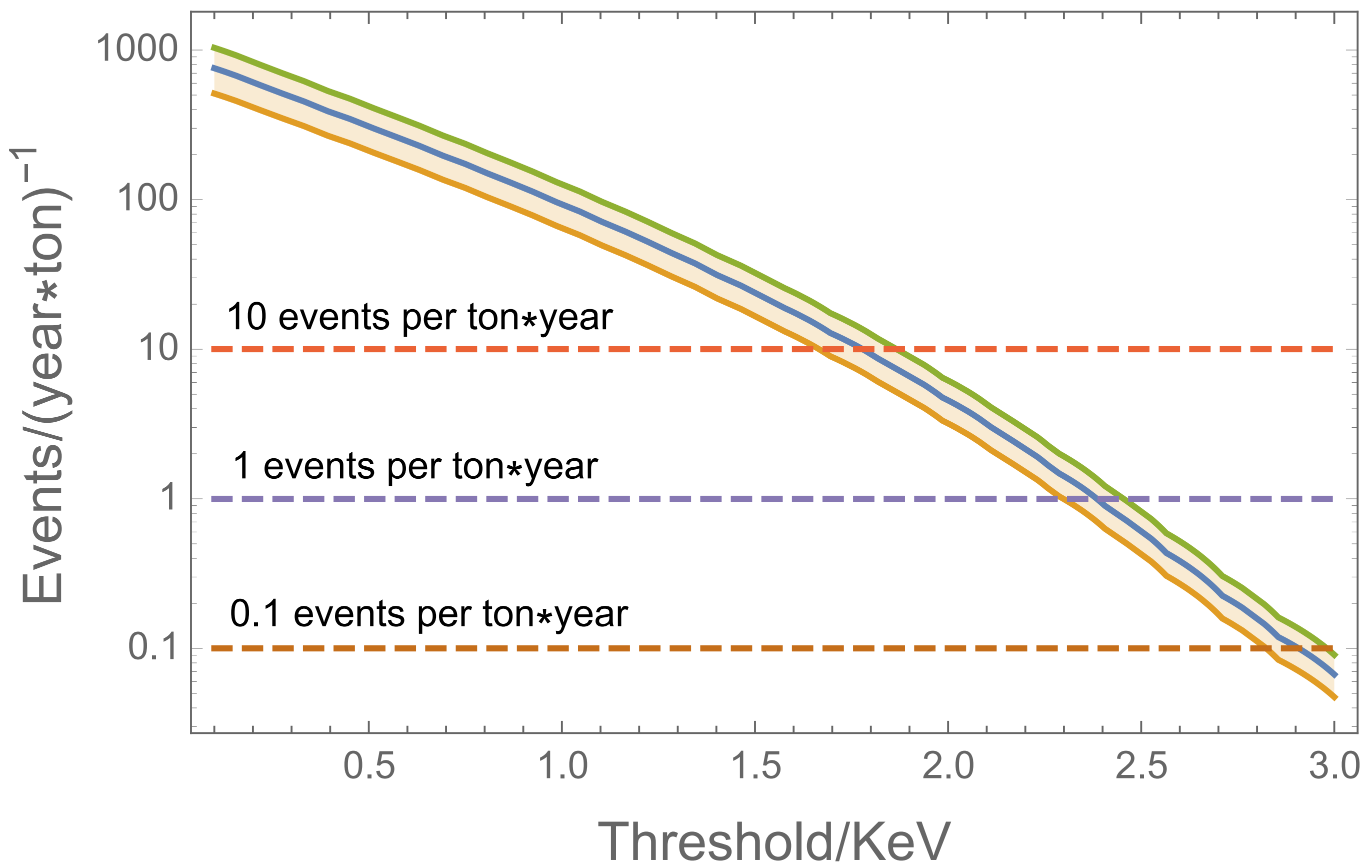
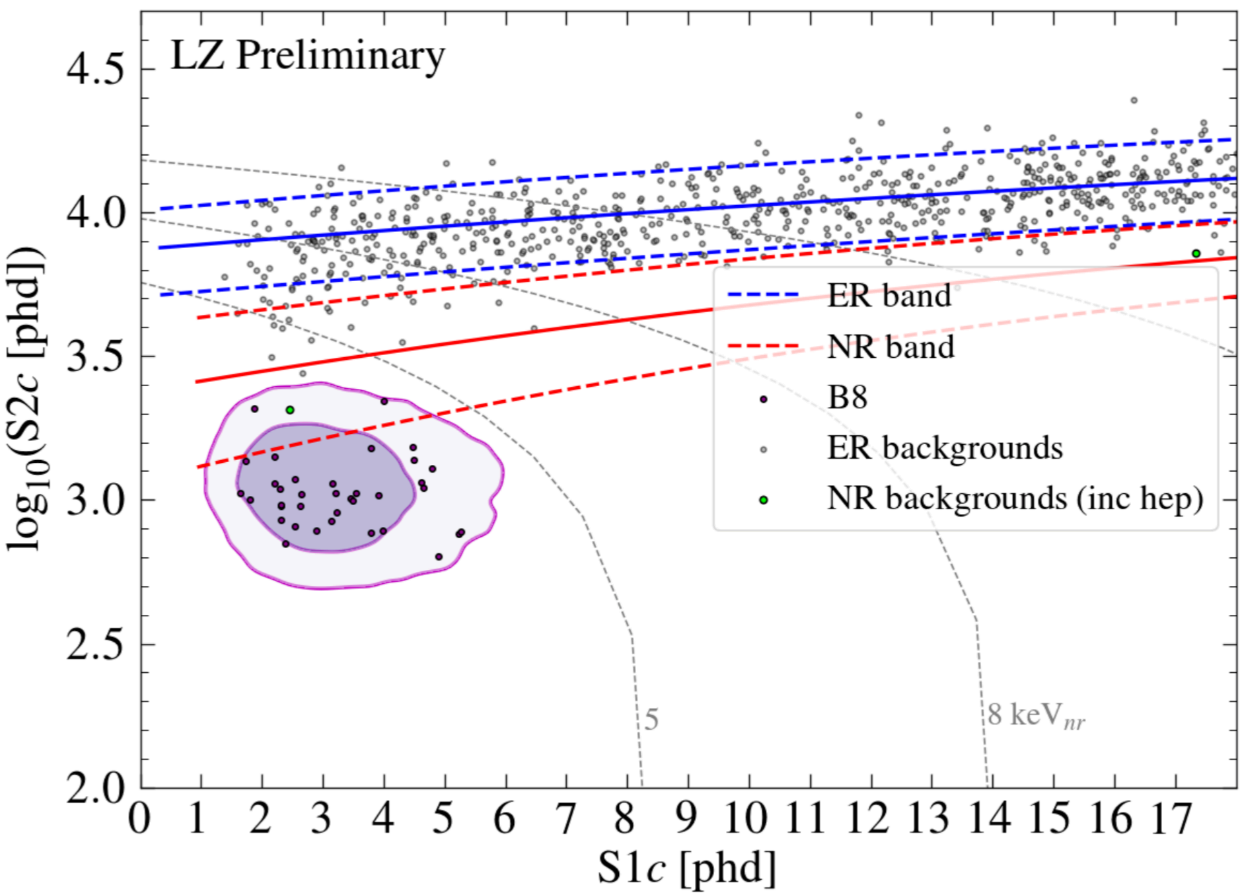
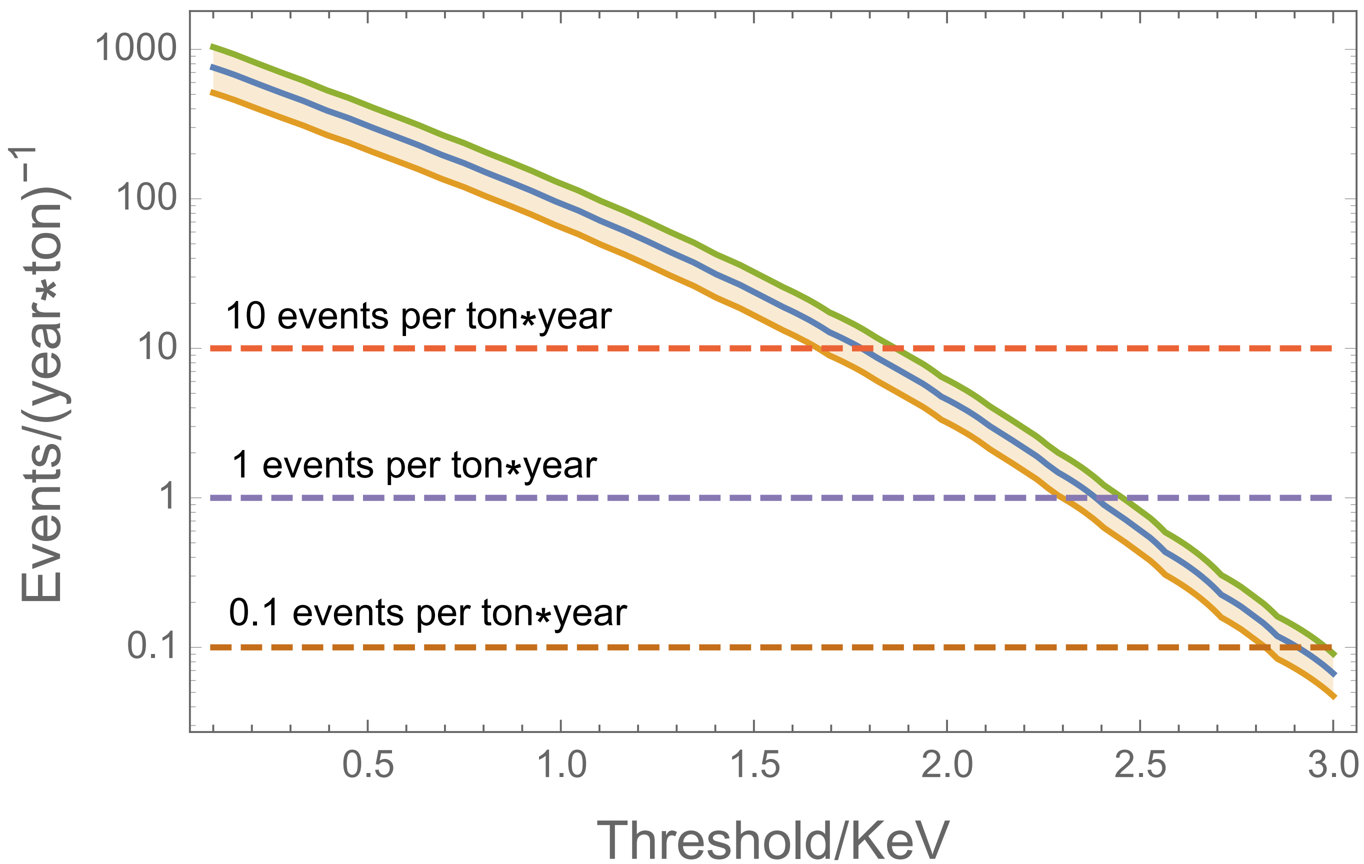


B. Dutta, ***Shu Liao***, L. Strigari, J. Walker, PLB 2017

- NSI may increase or decrease event rate in Xenon
- 1t sensitive to models still consistent with nu oscillations

Non-standard interactions + DM detectors





Carter Hall NDM 2018

B. Dutta, ***Shu Liao***, L. Strigari, J. Walker, PLB 2017

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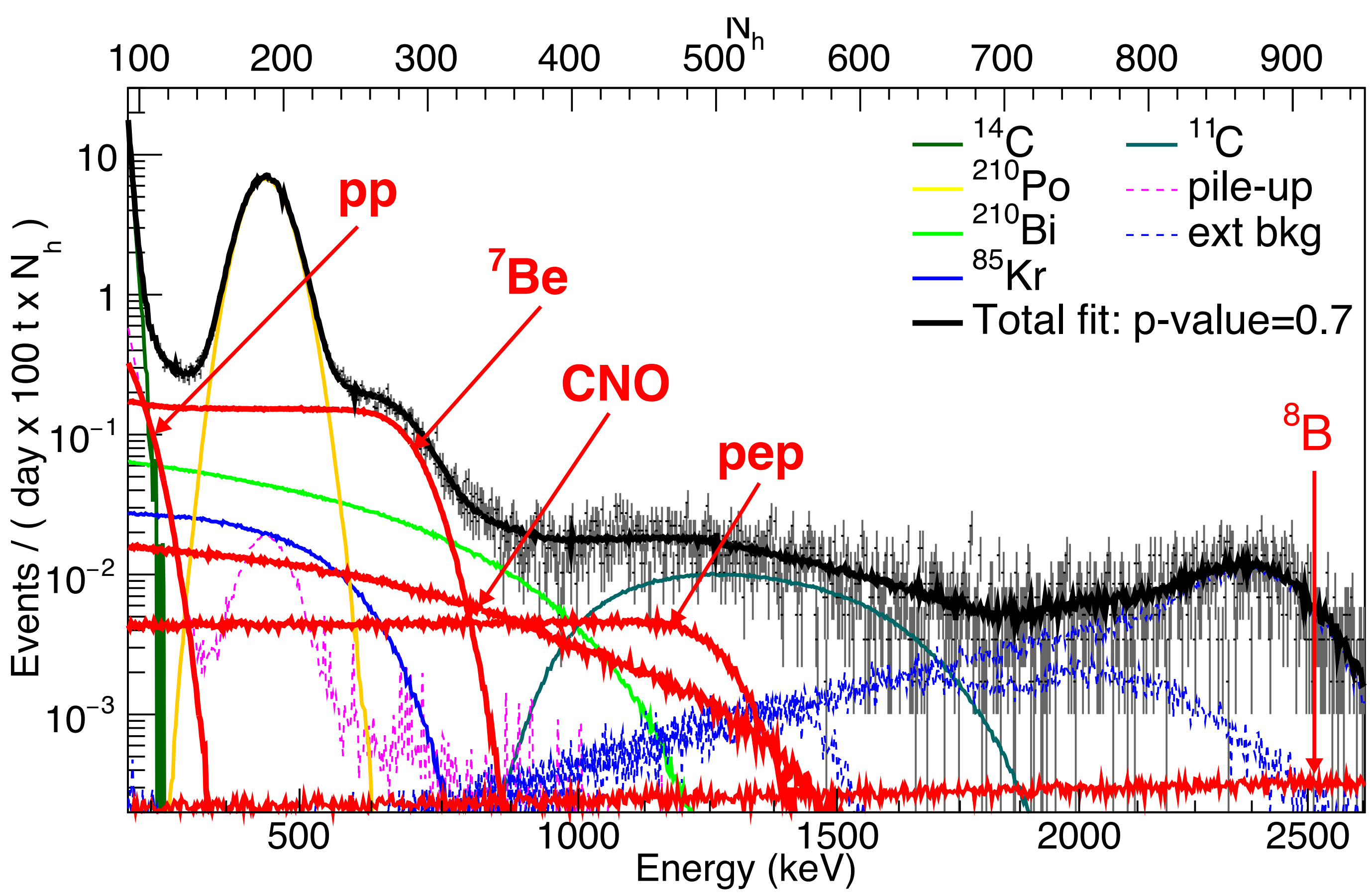
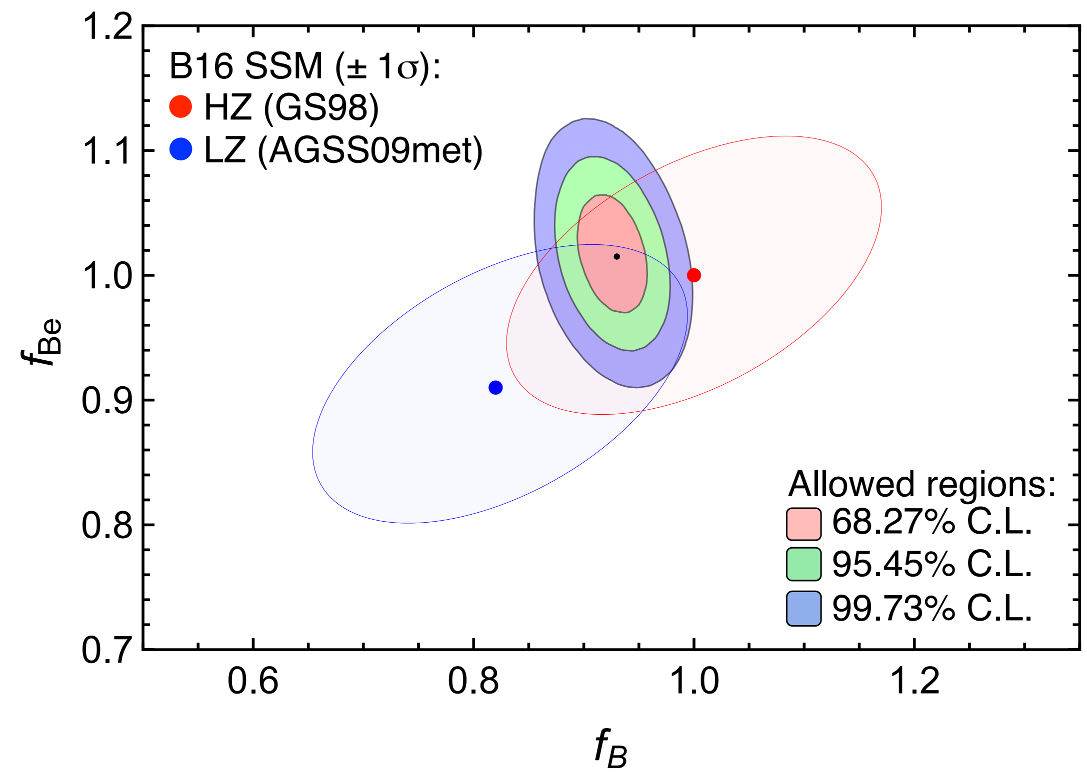
Low energy solar neutrino spectroscopy



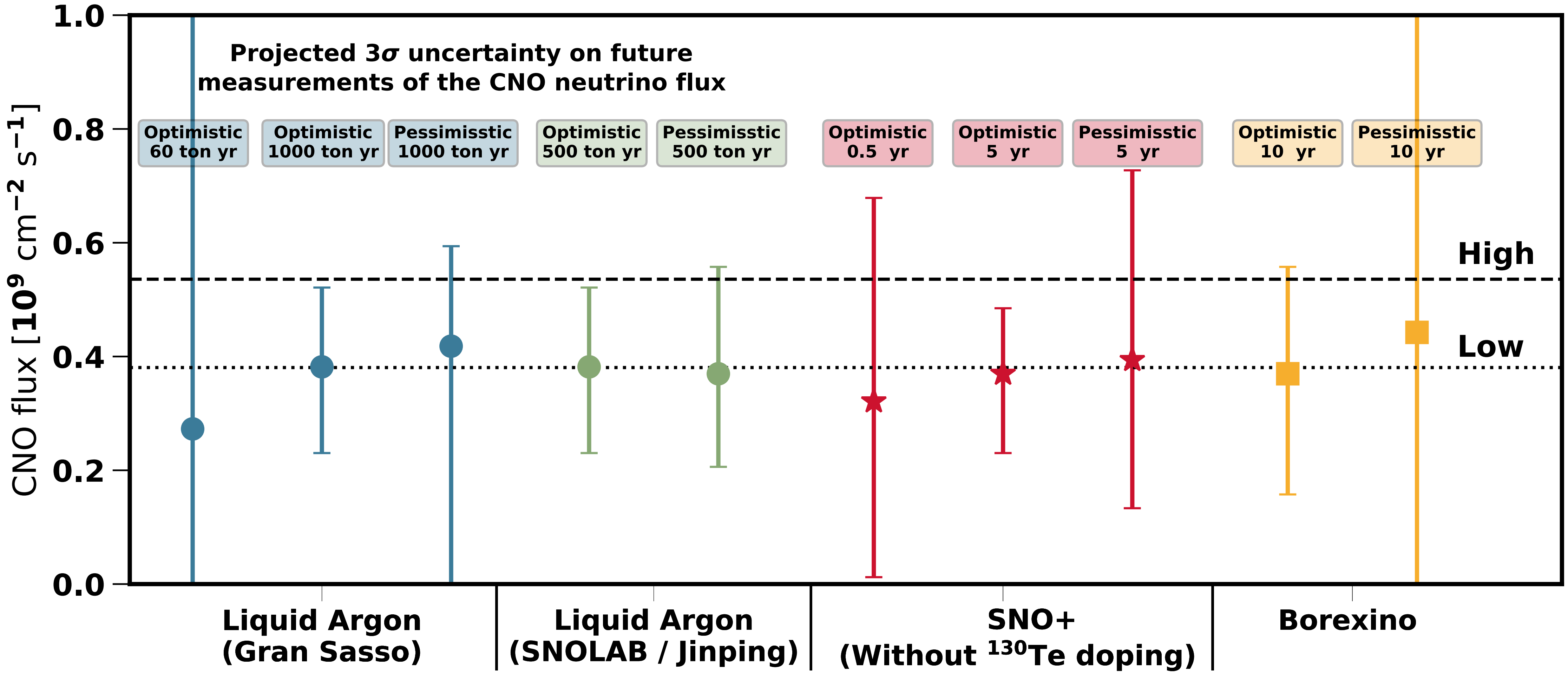


- Multicomponent spectral analysis of low energy solar neutrinos
- 2.7% precision on 7Be
- Strongest upper bound on CNO neutrinos

Borexino collaboration 2017

CNO Solar neutrinos and neutrino luminosity

Future low energy neutrino electron elastic scattering experiments for CNO



Cerdeno, Davis, Fairbairn, Vincent 2018

Low threshold directional detectors: Bonventre & Orebi Gann 2018

CNO Solar neutrinos and neutrino luminosity

- Since nuclear fusion is dominant energy source, linear combination of neutrino fluxes equals the photon luminosity
- Deviation between *neutrino luminosity* and photon luminosity could hint at alternative sources of energy generation

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

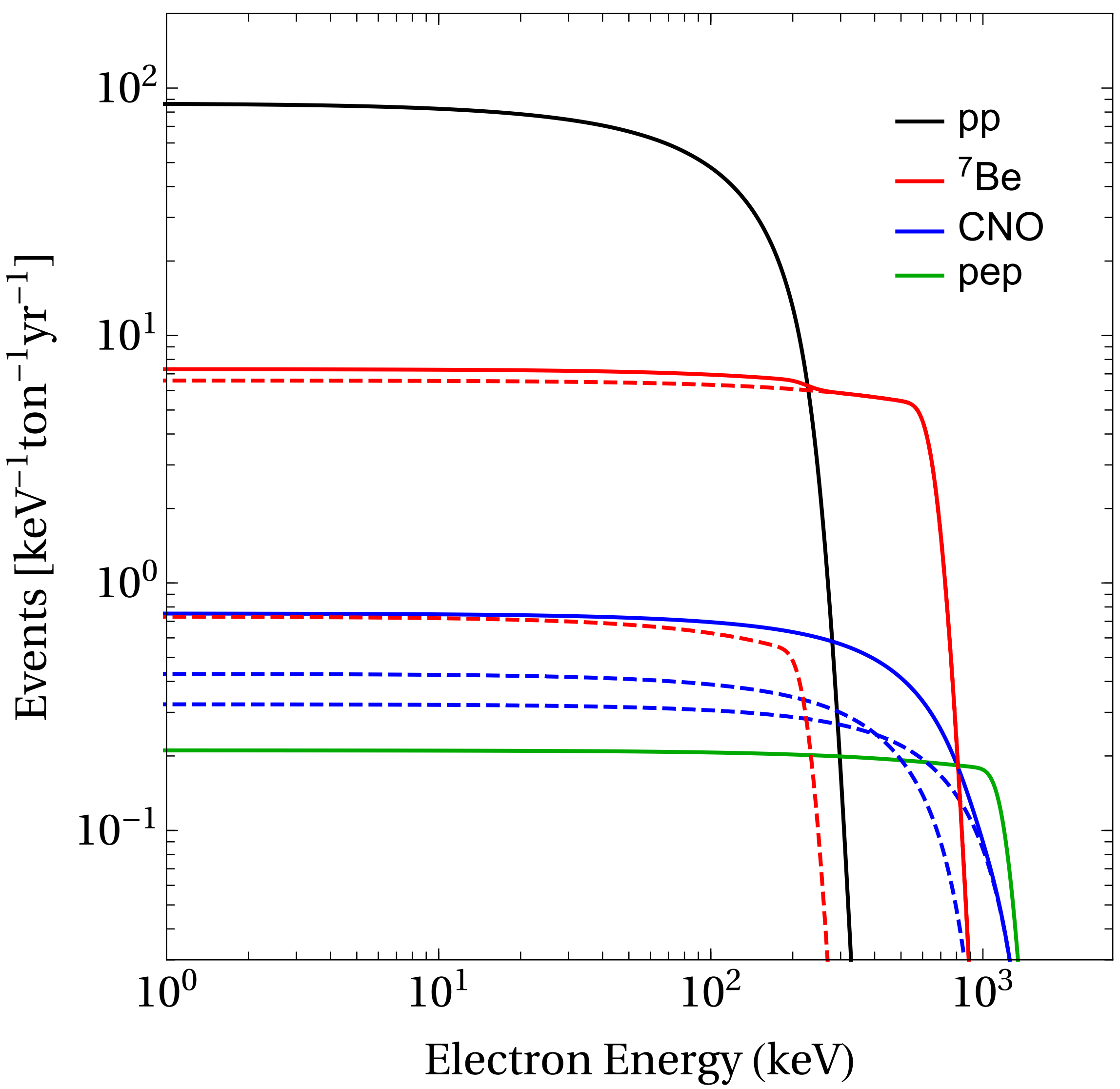
$$\frac{L_\odot(\text{neutrino-inferred})}{L_\odot} = 1.04\left[^{+0.07}_{-0.08}\right]\,\left[^{+0.20}_{-0.18}\right]$$

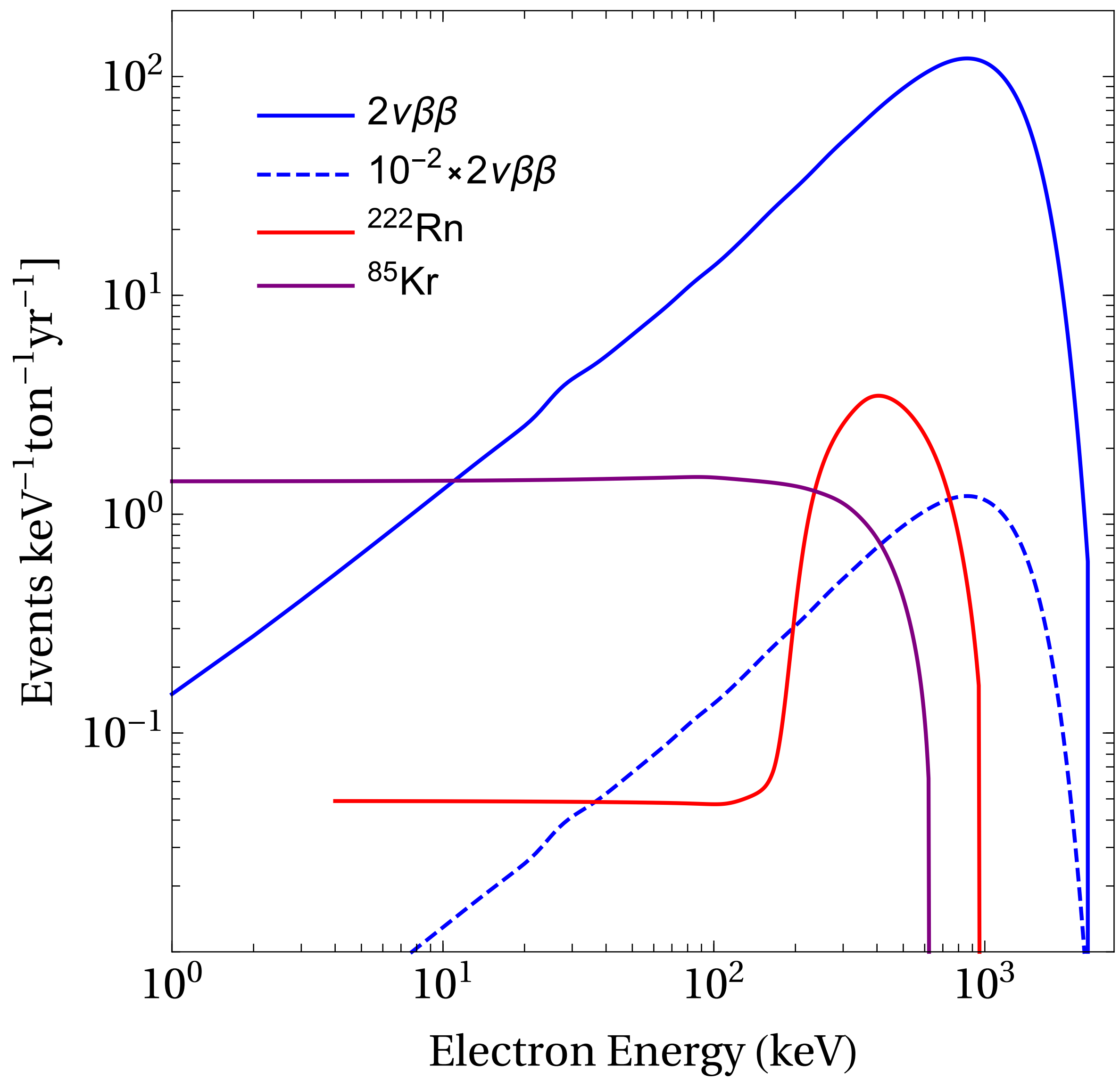
Bergstrom, Gonzalez-Garcia et al.
JHEP 2016

- Since nuclear fusion is dominant energy source, linear combination of neutrino fluxes equals the photon luminosity

Direct pp measurement with Xe at few percent level can improve this constraint

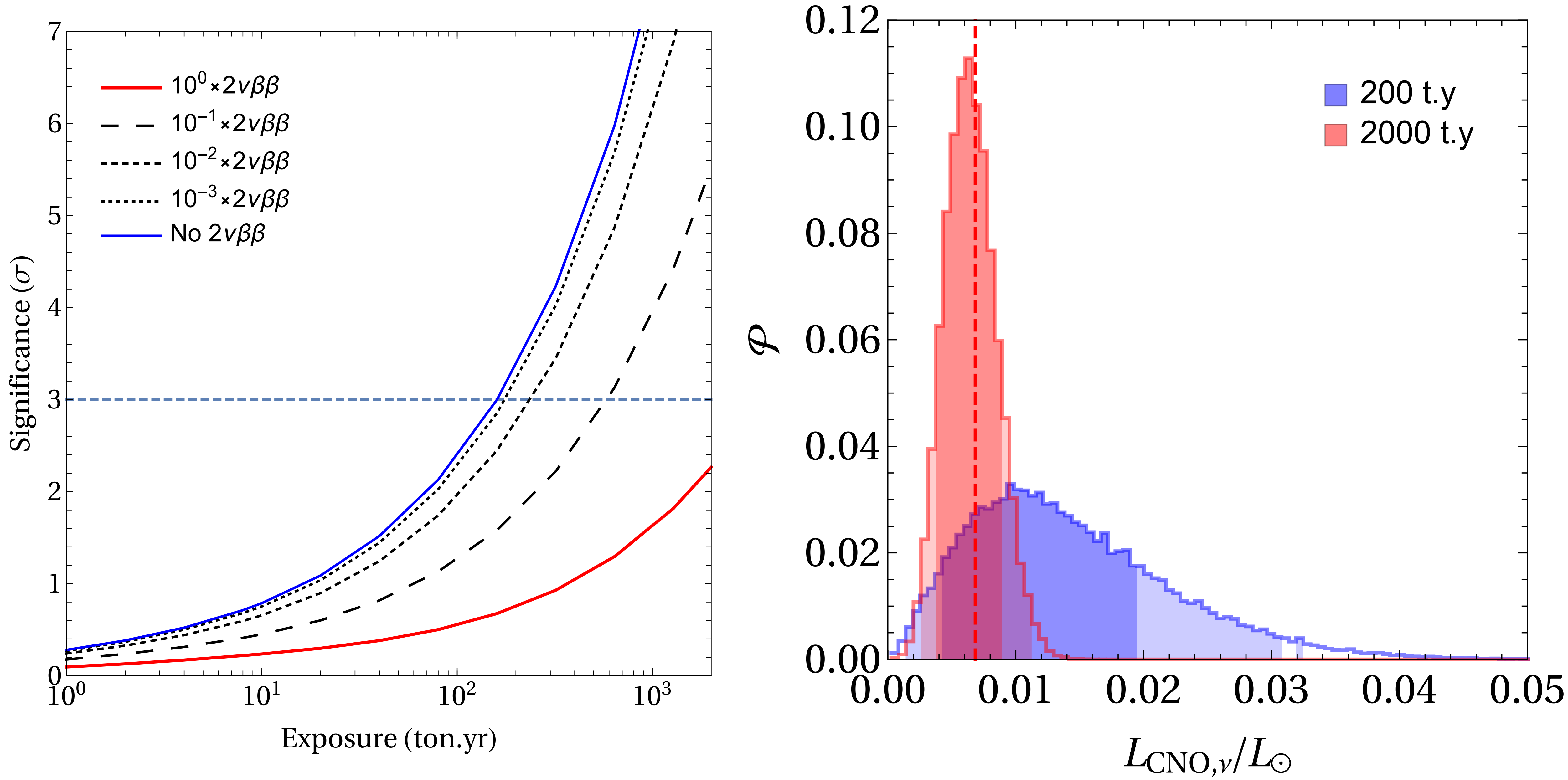
CNO Solar neutrinos and neutrino luminosity





G3 Xe detector may be used for CNO (Newstead, LS, Lang. 2018)
Requires reduction of detector backgrounds

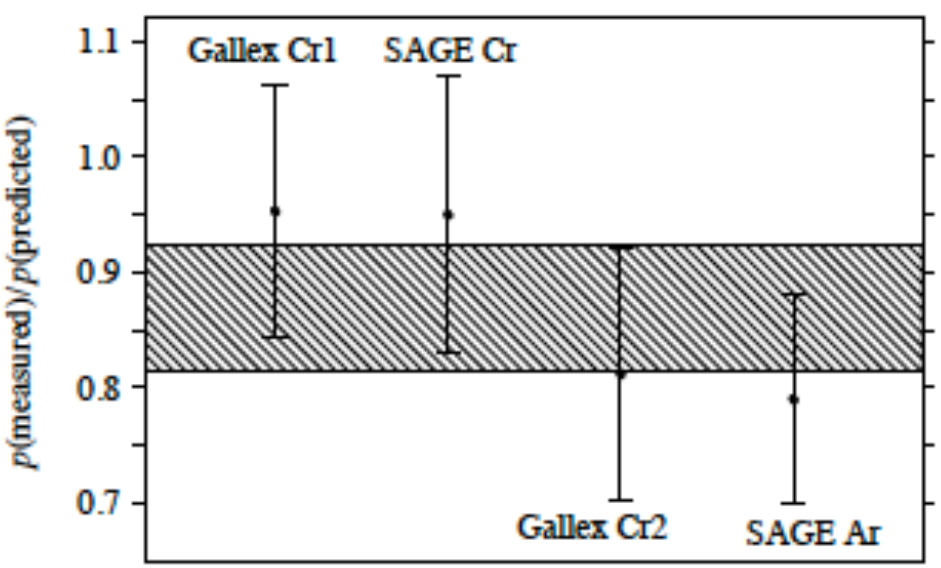
CNO Solar neutrinos and neutrino luminosity

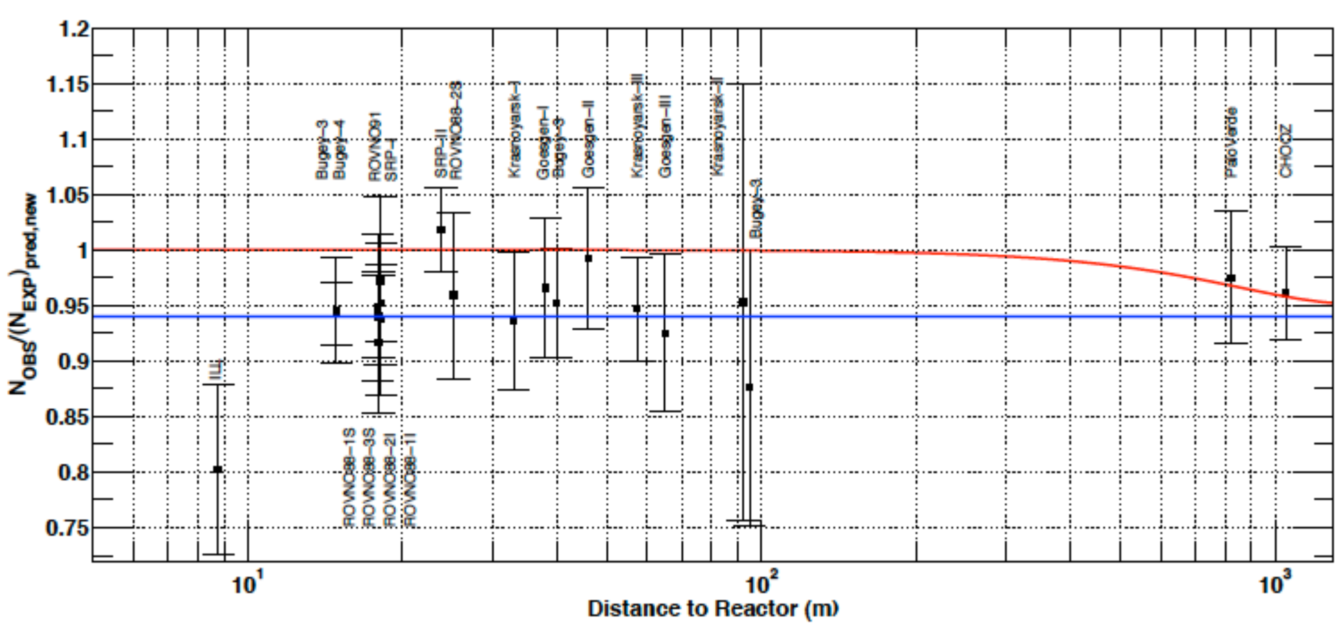


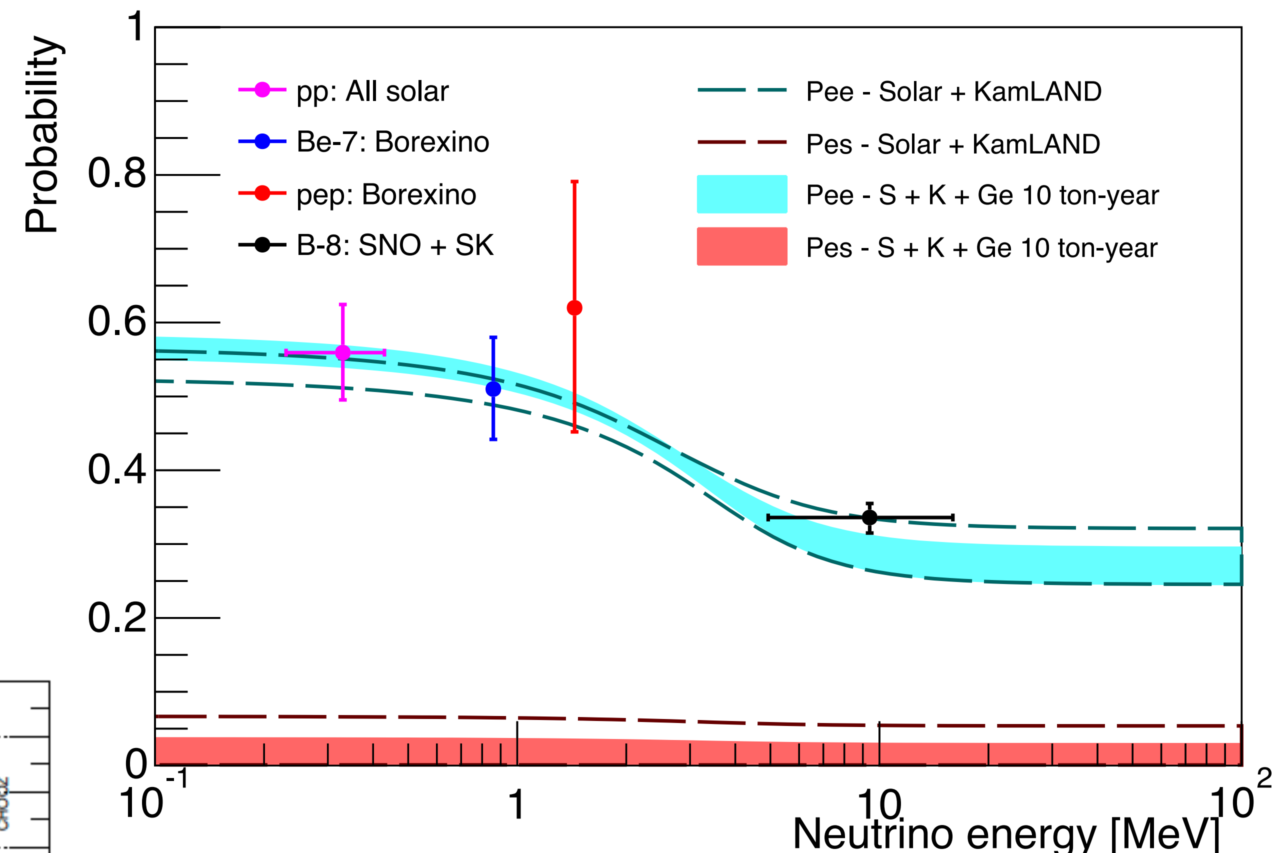
Neutrino luminosity constraints improved by a factor of seven compared to global analysis (Newstead, LS, Lang, 2018)

eV-scale sterile neutrinos

- Combined with 'reactor anomaly', gallium results may hint at new physics, i.e. ~ eV sterile neutrino (Giunti & Laveder 2010; Mention 2011)







G3 detector can provide a test of the reactor/galium anomaly (Billard, LS, Figueroa-Feliciano, PRD 2014, 1409.0050)

Recap: Neutrinos in dark matter experiments

Astrophysics

- 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

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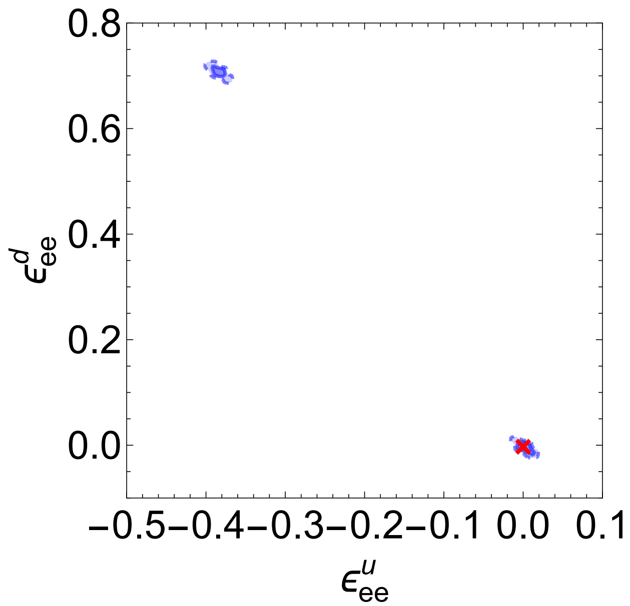
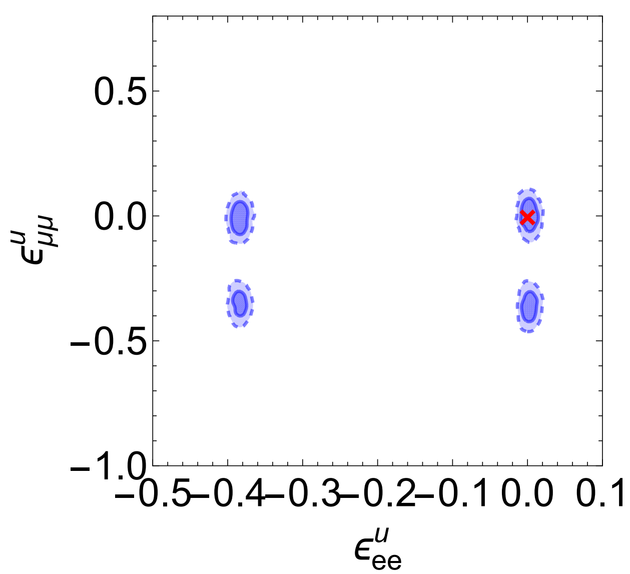
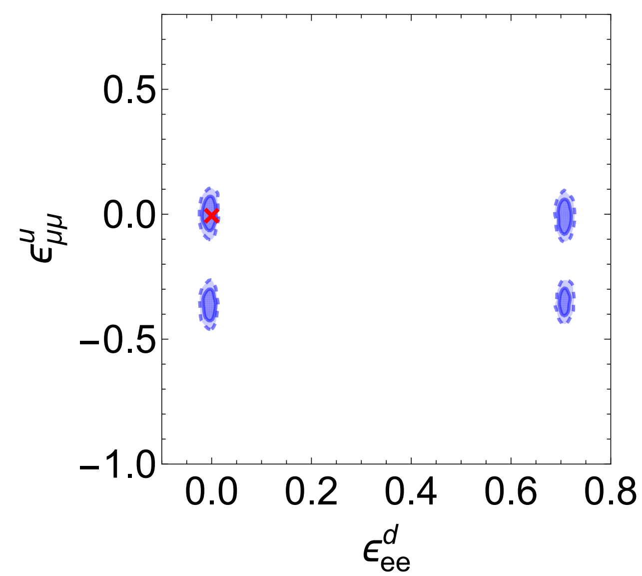
Particle physics

- NSI affects both neutrino-coherent scattering and neutrino-electron elastic scattering channels
- Independent probe of eV-scale sterile neutrinos

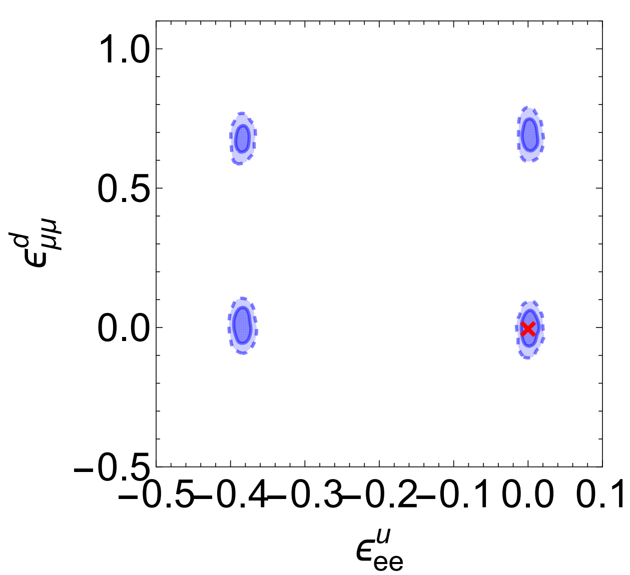


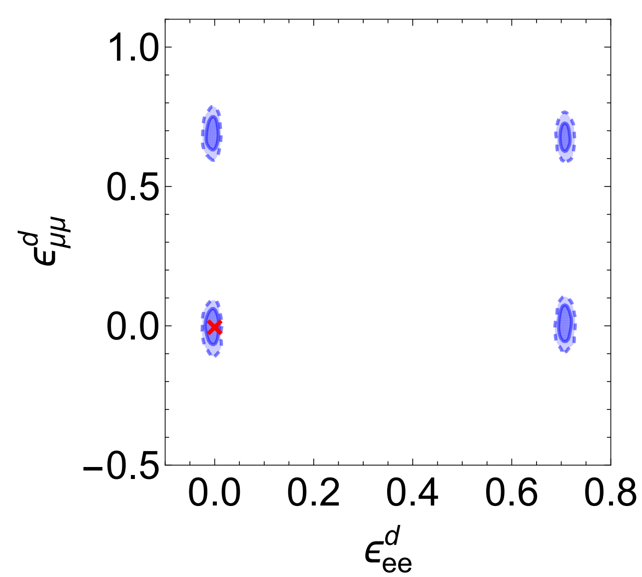
Reactor, accelerator, solar complementarity

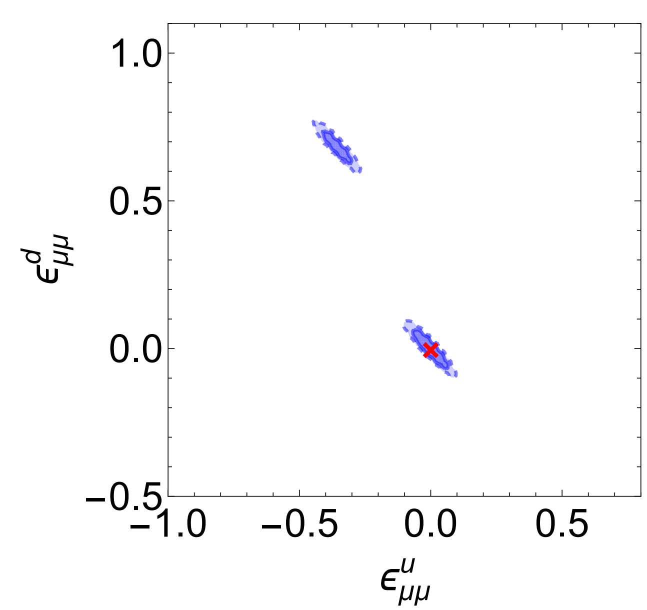




Solar neutrinos add sensitivity to NSI from neutrino propagation

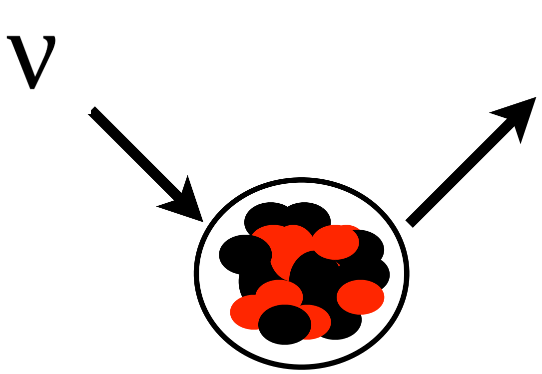


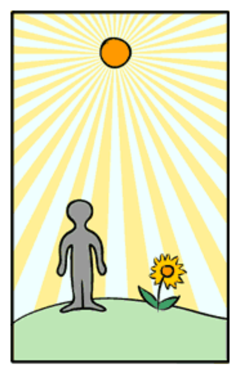




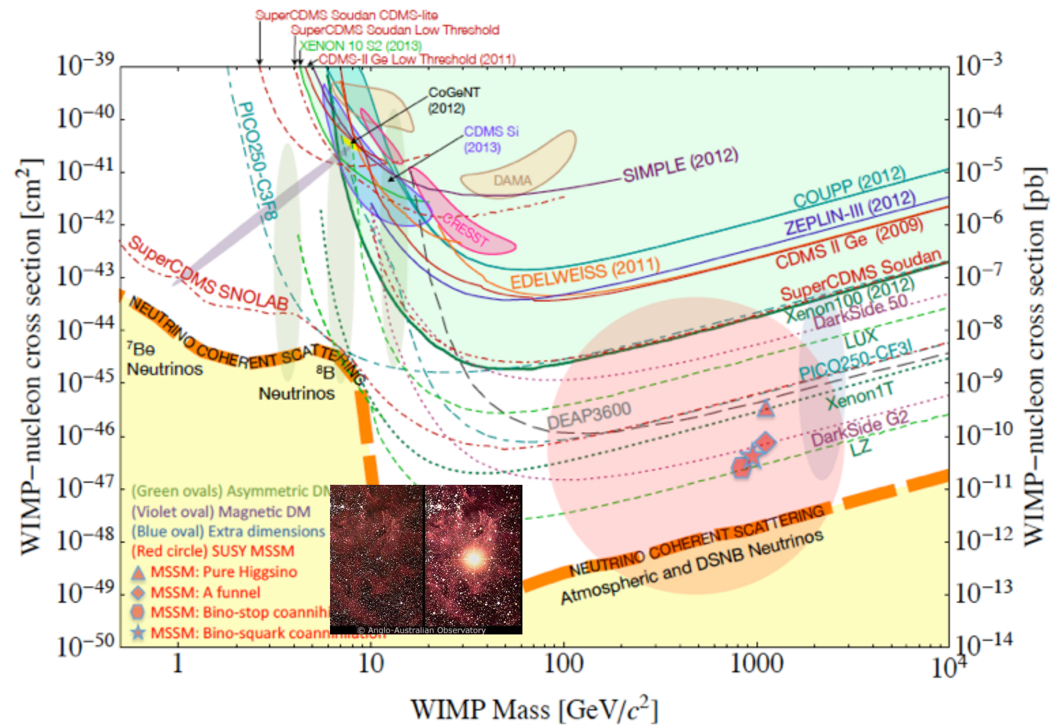
Dent, Dutta, Liao, Newstead, LS, Walker PRD 2018

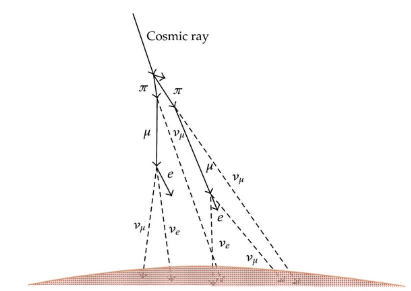
New directions in dark matter and neutrino physics





Astrophysical sources





Reactors

Accelerators