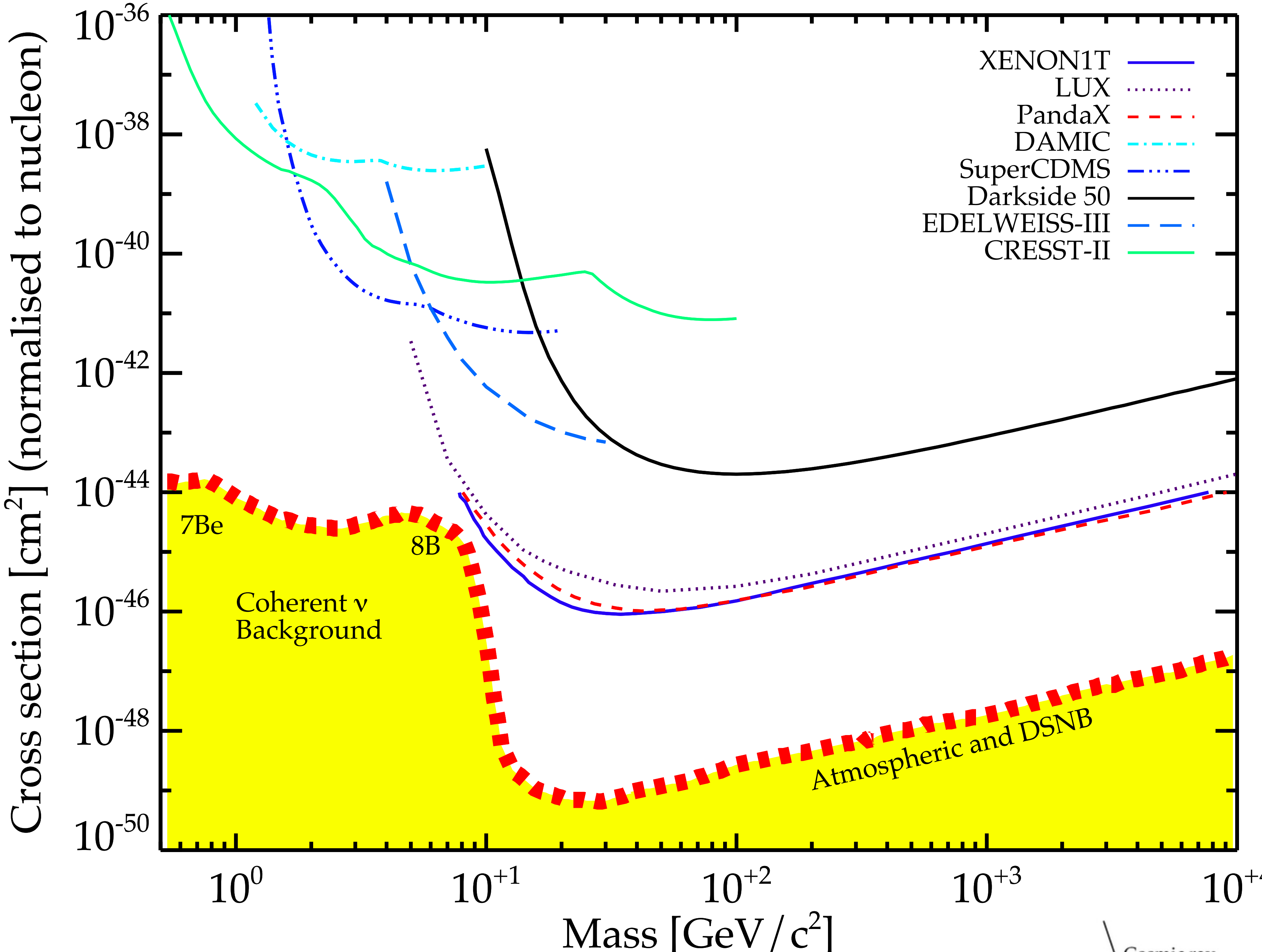
Astrophysical uncertainties on direct dark matter searches, and new directions in neutrino physics

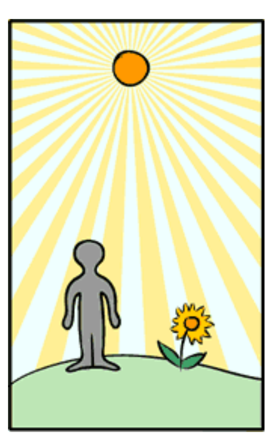
Dark matter at the dawn of discovery?
Heidelberg University
April 9-11, 2018

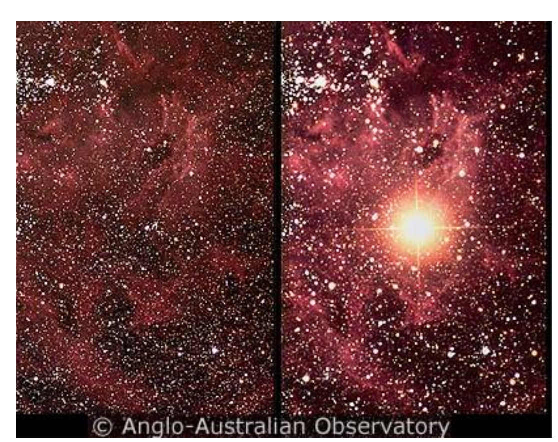
Louis E. Strigari

MITCHELL INSTITUTE
TEXAS A&M UNIVERSITY



Cross section [cm2] (normalised to nucleon)
Mass [GeV/c2]
10-36
10-38
10-40
10-42
10-44
10-46
10-48
10-50
100
10+1
10+2
10+3
10+4
XENON1T
LUX
PandaX
DAMIC
SuperCDMS
Darkside 50
EDELWEISS-III
CRESST-II
7Be
8B
Coherent ν
Background
Atmospheric and DSNB





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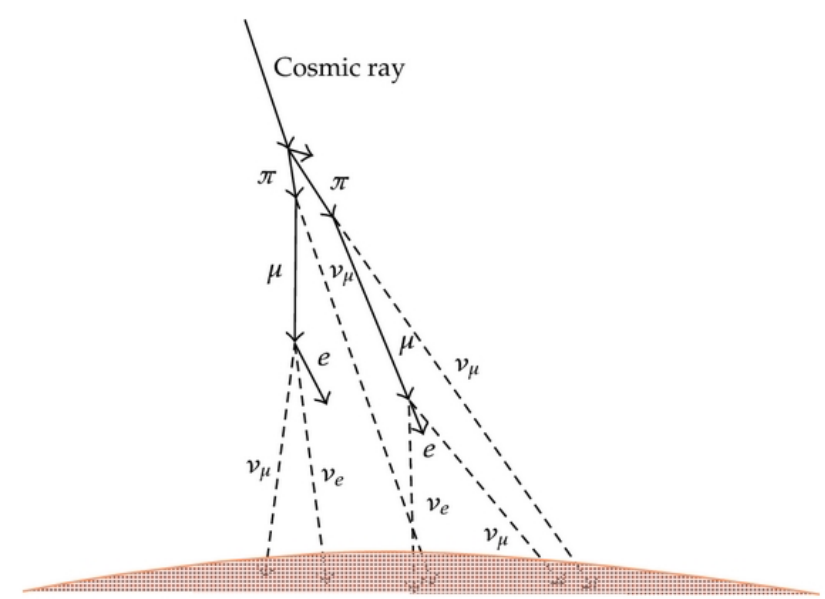
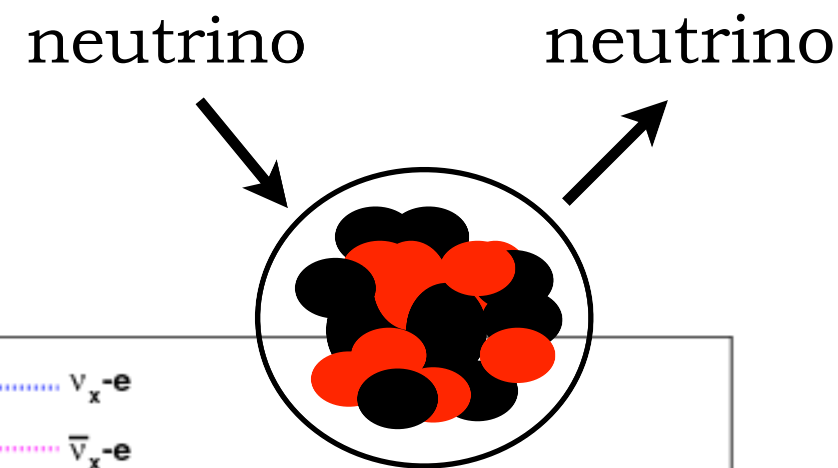


Cosmic ray
π
π
μ
νμ
μ
νμ
e
e
νμ
νe
νe
νμ

Neutrino-nucleus coherent scattering

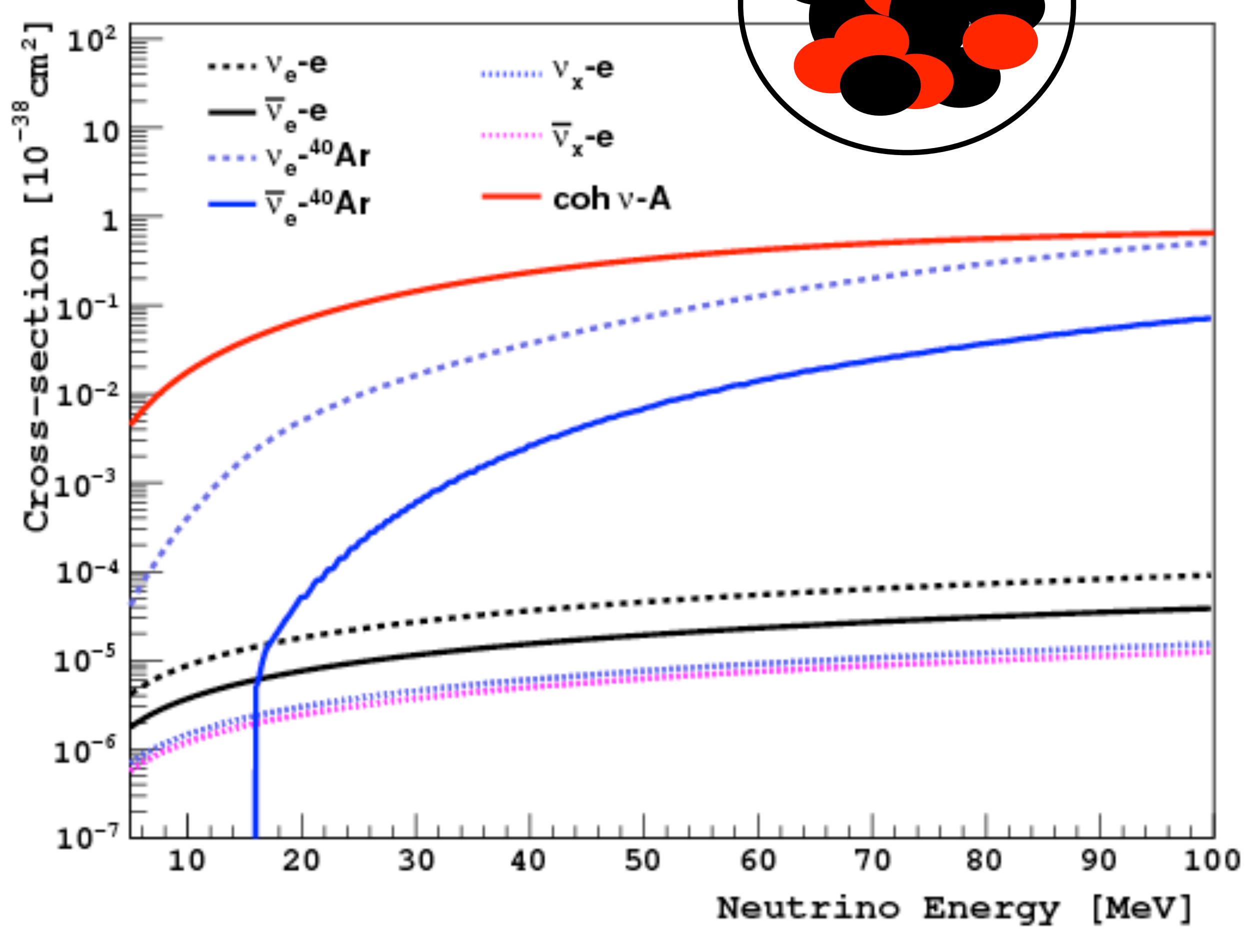


Sensitive to BSM physics:

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

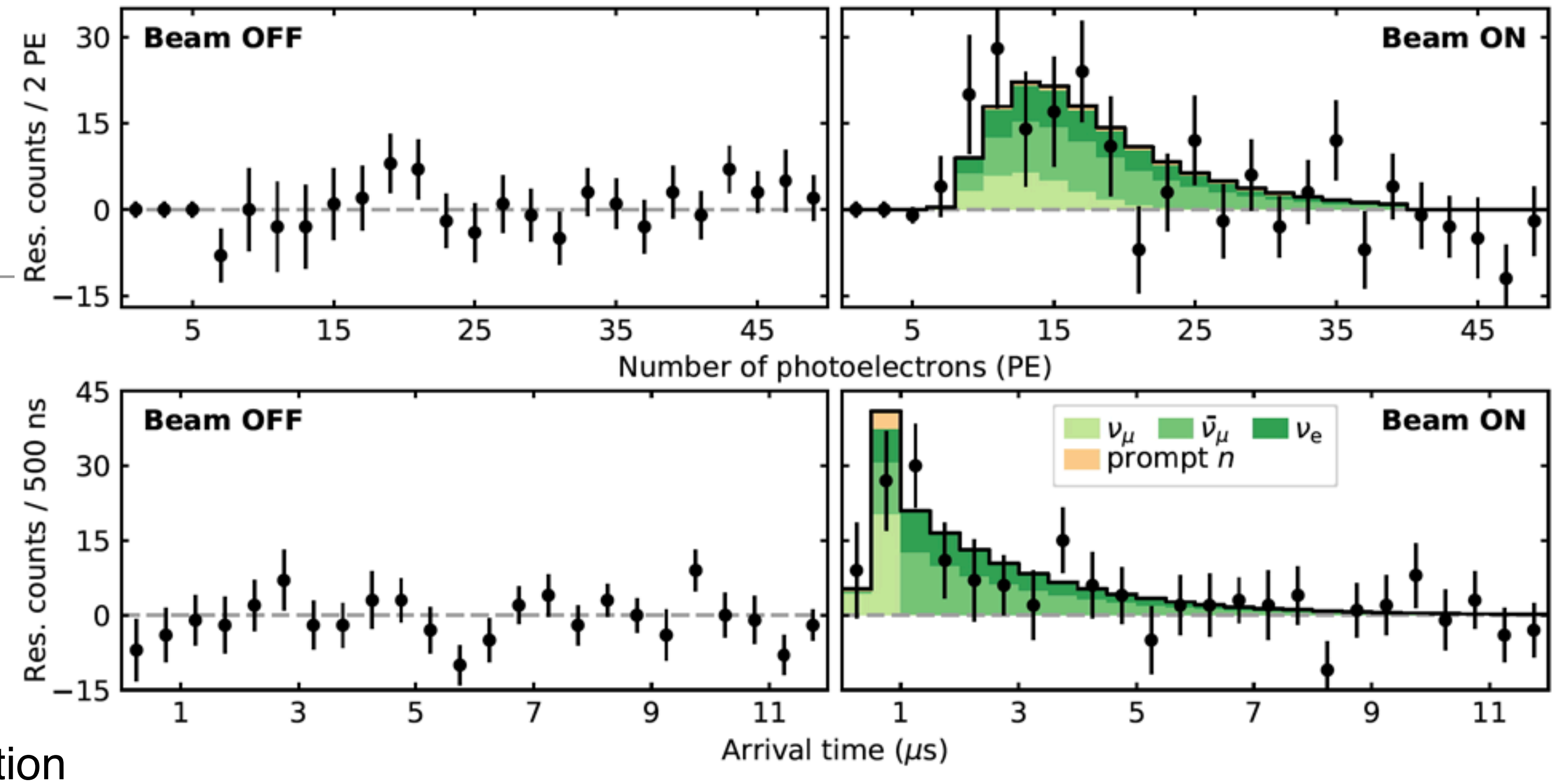
$$\frac{d\sigma_{CNS}(E_\nu, T_R)}{dT_R} = \frac{G_f^2}{4\pi} Q_w^2 m_N \left(1 - \frac{m_N T_R}{2E_\nu^2}\right) F^2(T_R)$$

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

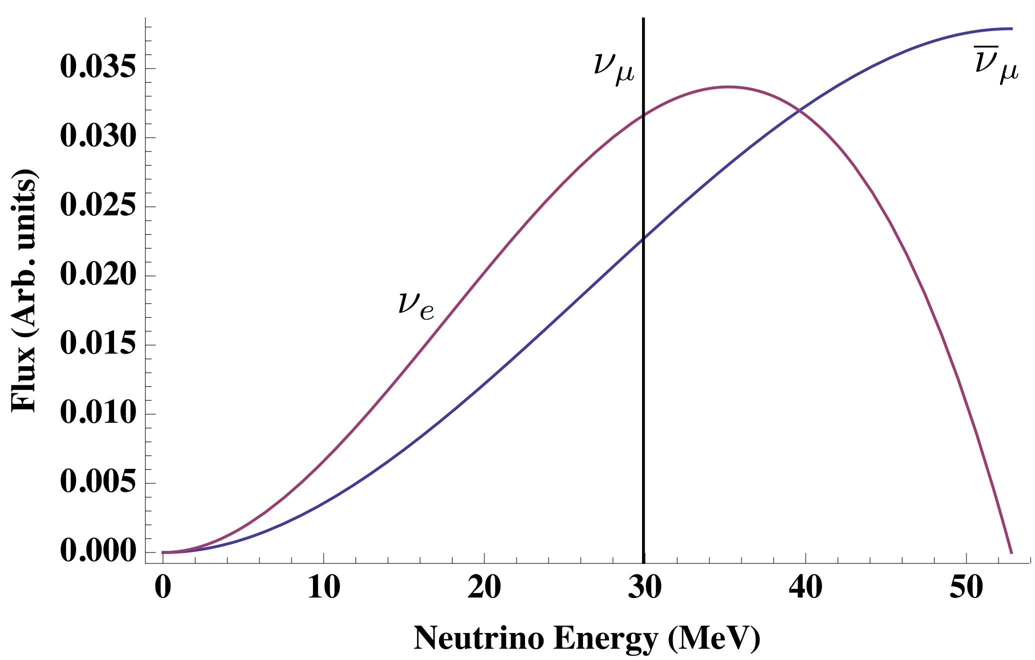


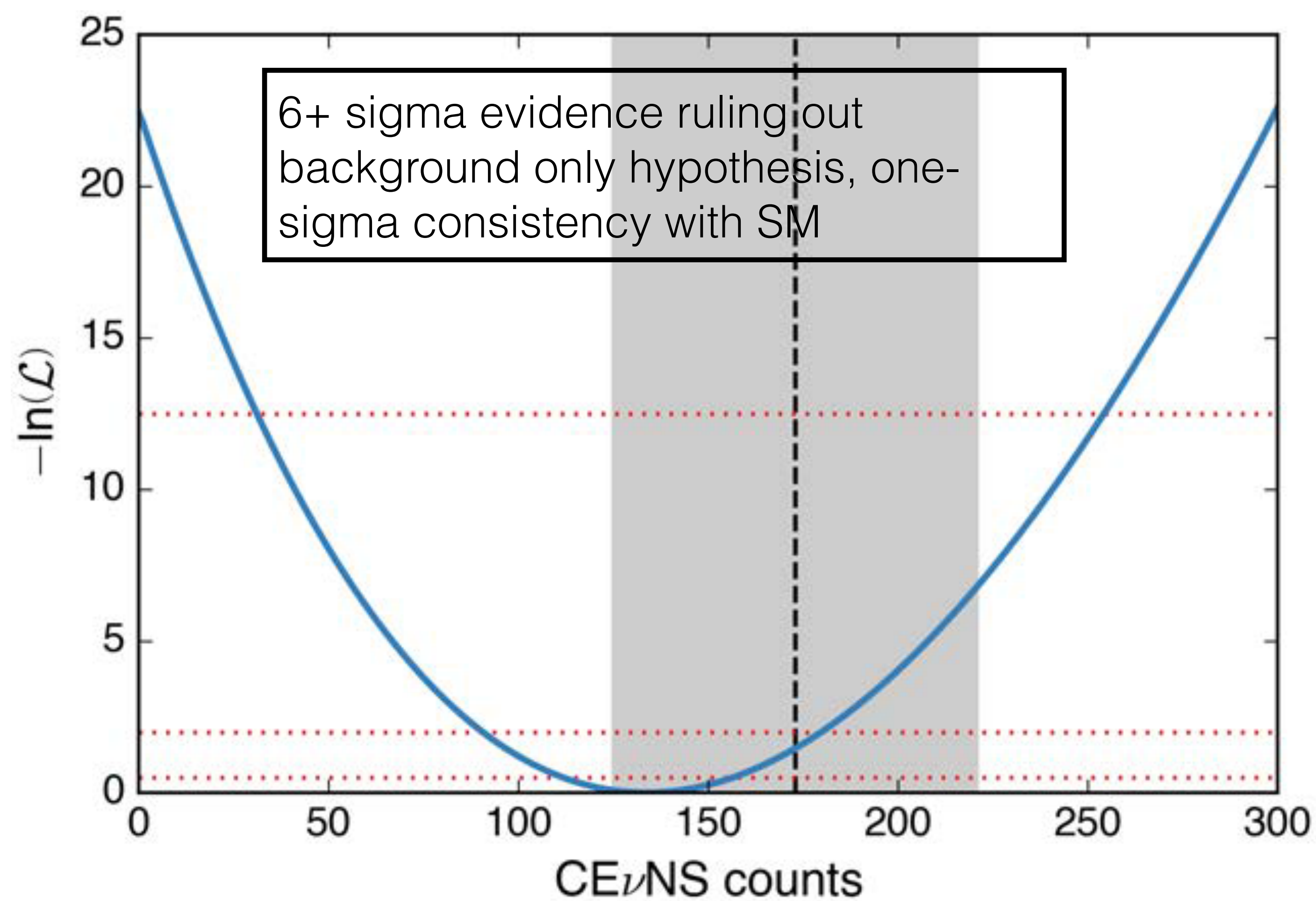
Brice et al, 1311.5958

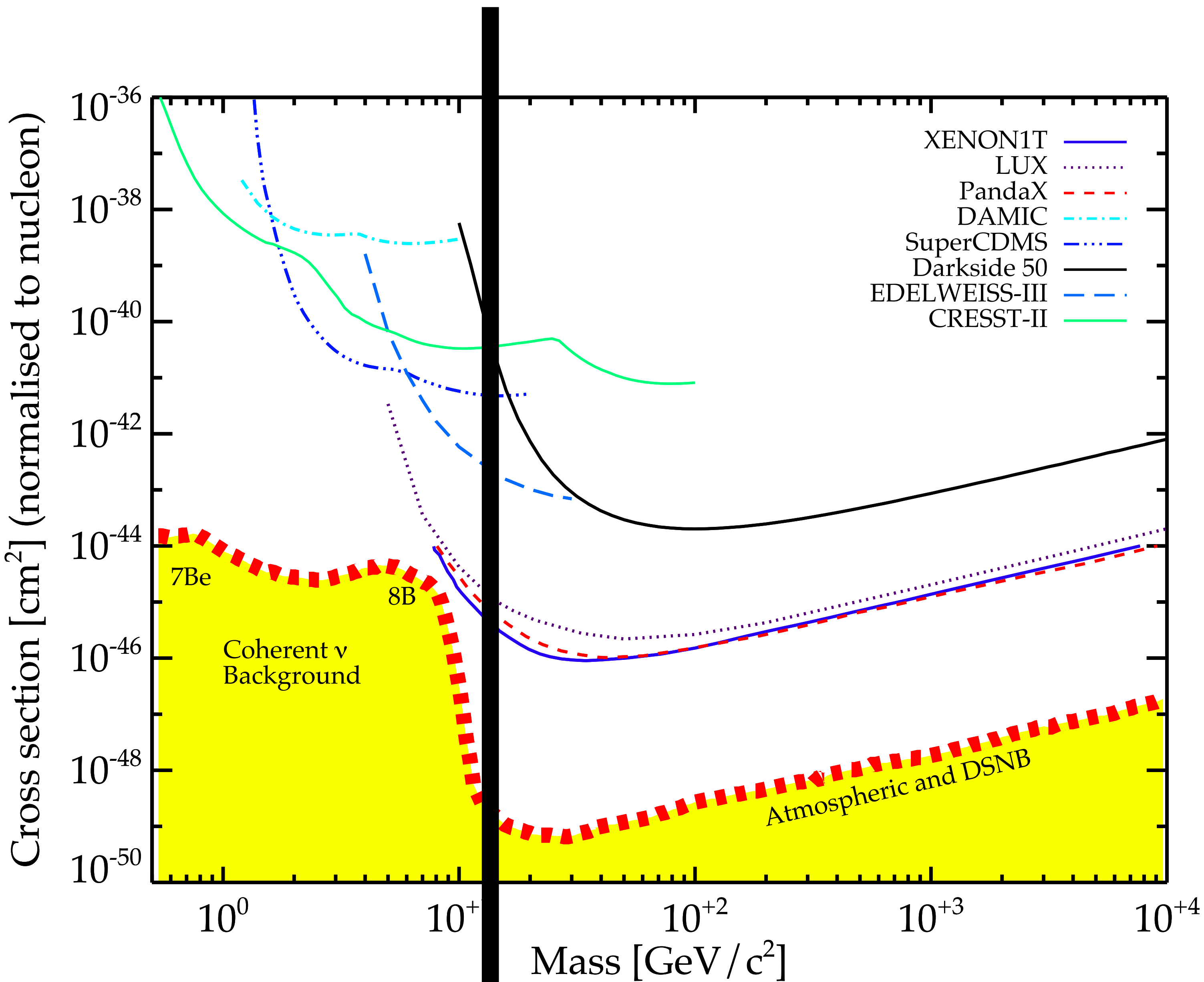
COHERENT collaboration, Science, 2017



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

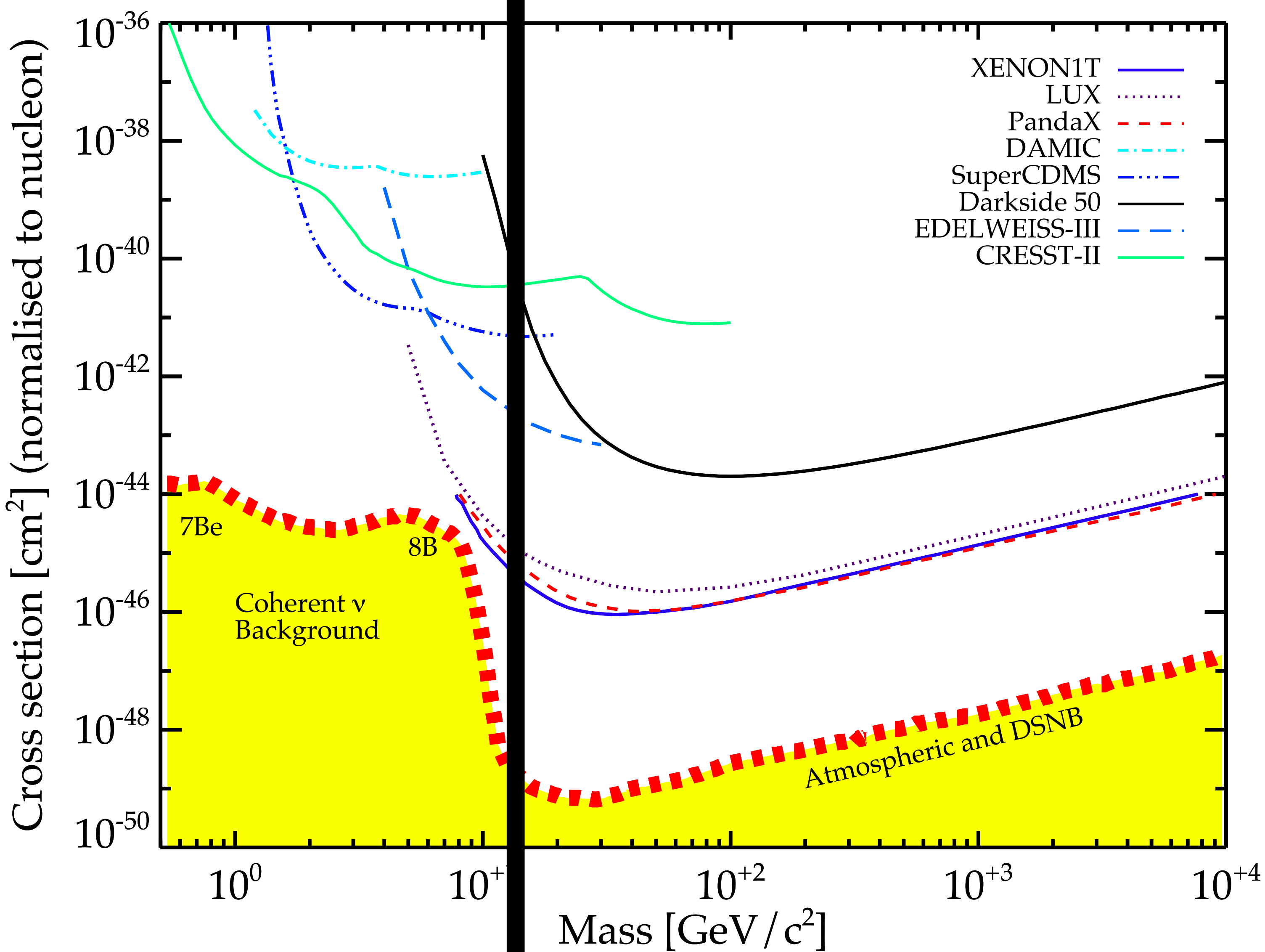






Reactors

Accelerators



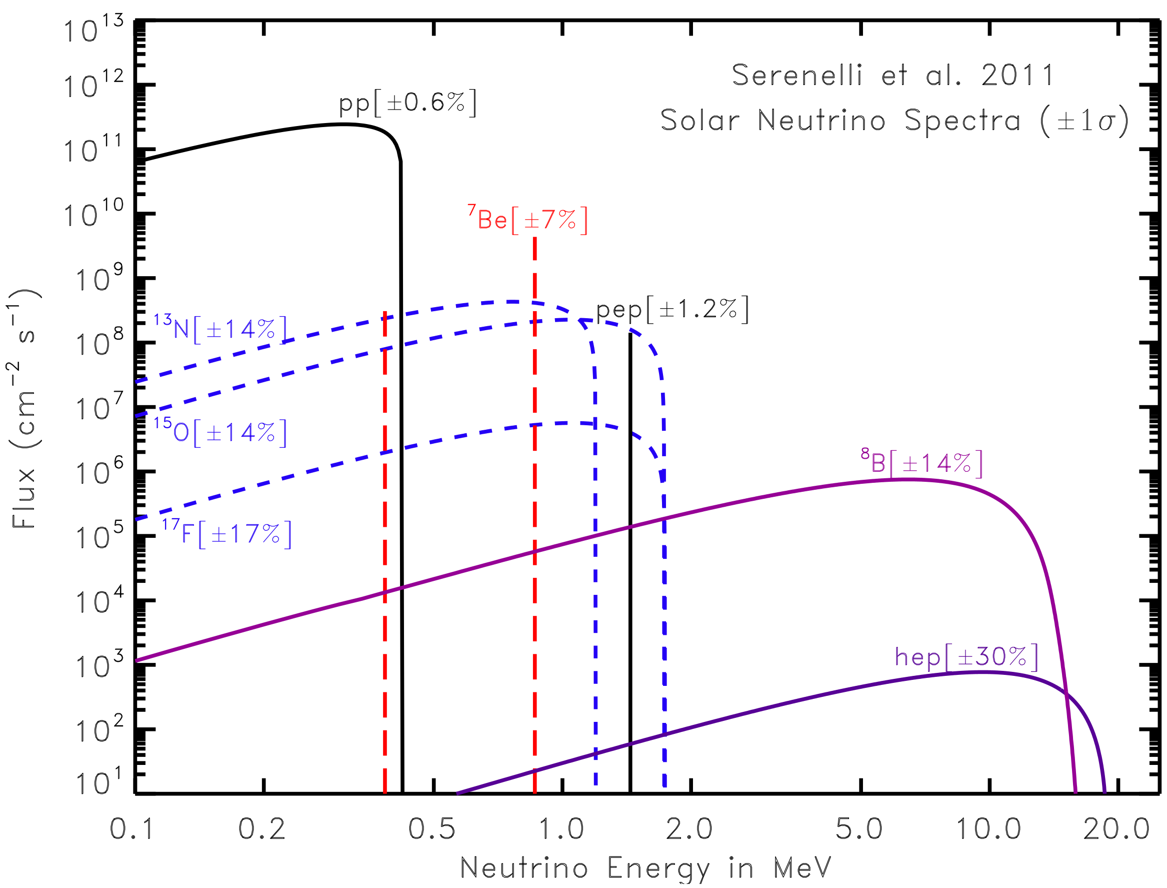
Reactors

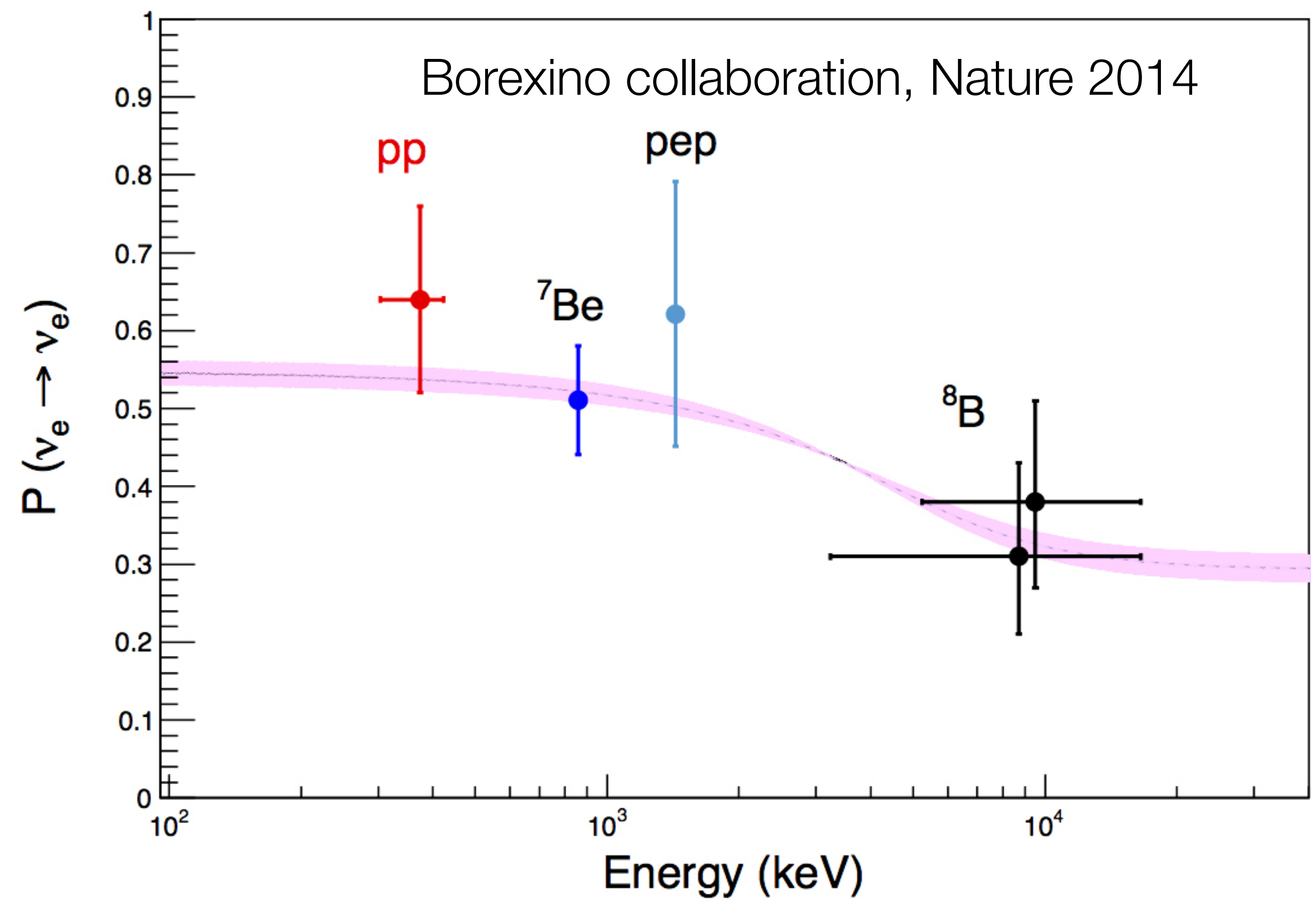
Accelerators

Distinguishing DM from neutrinos:

- **Annual modulation/ directionality:** Grothaus, Fairbairn, Monroe 2014; O'Hare et al. 2015, Davis 2015
- **SD DM:** Ruppin, Billard, Figueroa-Feliciano, Strigari, 2014
- **Non-rel EFTs:** Dent, Dutta, Strigari, Newstead 2016/2017
- **NSI:** Sierra, Rojas, Tytgat 2018; Gonzalez-Garcia et al. 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
$p+p \rightarrow {}^2H+e^+ +\nu$	0.42	$5.98(1 \pm 0.006)$	$6.03(1 \pm 0.006)$	$6.05(1^{+0.003}_{-0.011})$	$10^{10}/cm^2s$
$p+e^- +p \rightarrow {}^2H+\nu$	1.44	$1.44(1 \pm 0.012)$	$1.47(1 \pm 0.012)$	$1.46(1^{+0.010}_{-0.014})$	$10^8/cm^2s$
${}^7Be+e^- \rightarrow {}^7Li+\nu$	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%)				
${}^8B \rightarrow {}^8Be+e^+ +\nu$	~ 15	$5.58(1 \pm 0.14)$	$4.59(1 \pm 0.14)$	$5.00(1 \pm 0.03)$	$10^6/cm^2s$
${}^3He+p \rightarrow {}^4He+e^+ +\nu$	18.77	$8.04(1 \pm 0.30)$	$8.31(1 \pm 0.30)$	—	$10^3/cm^2s$
${}^{13}N \rightarrow {}^{13}C+e^+ +\nu$	1.20	$2.96(1 \pm 0.14)$	$2.17(1 \pm 0.14)$	≤ 6.7	$10^8/cm^2s$
${}^{15}O \rightarrow {}^{15}N+e^+ +\nu$	1.73	$2.23(1 \pm 0.15)$	$1.56(1 \pm 0.15)$	≤ 3.2	$10^8/cm^2s$
${}^{17}F \rightarrow {}^{17}0+e^+ +\nu$	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

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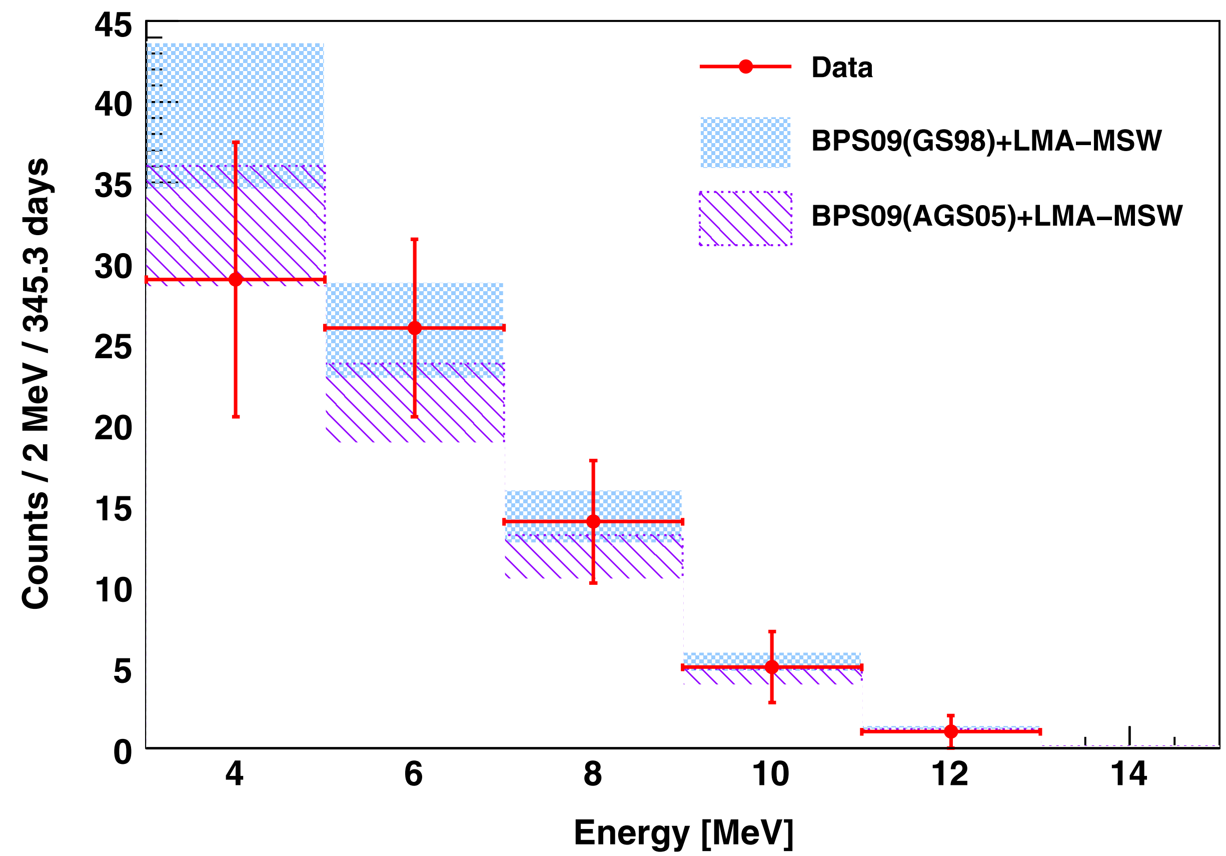

Borexino collaboration

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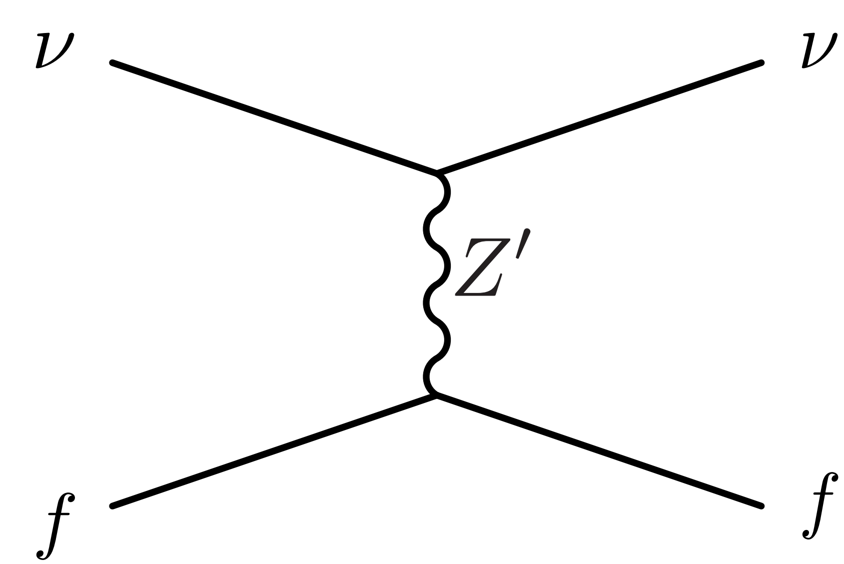
- Borexino, SNO, SK indicate the low energy ES data lower than MSW predicts
- Upturn in MSW survival probability not been measured
- May indicate new physics (e.g. Holanda & Smirnov 2011)

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



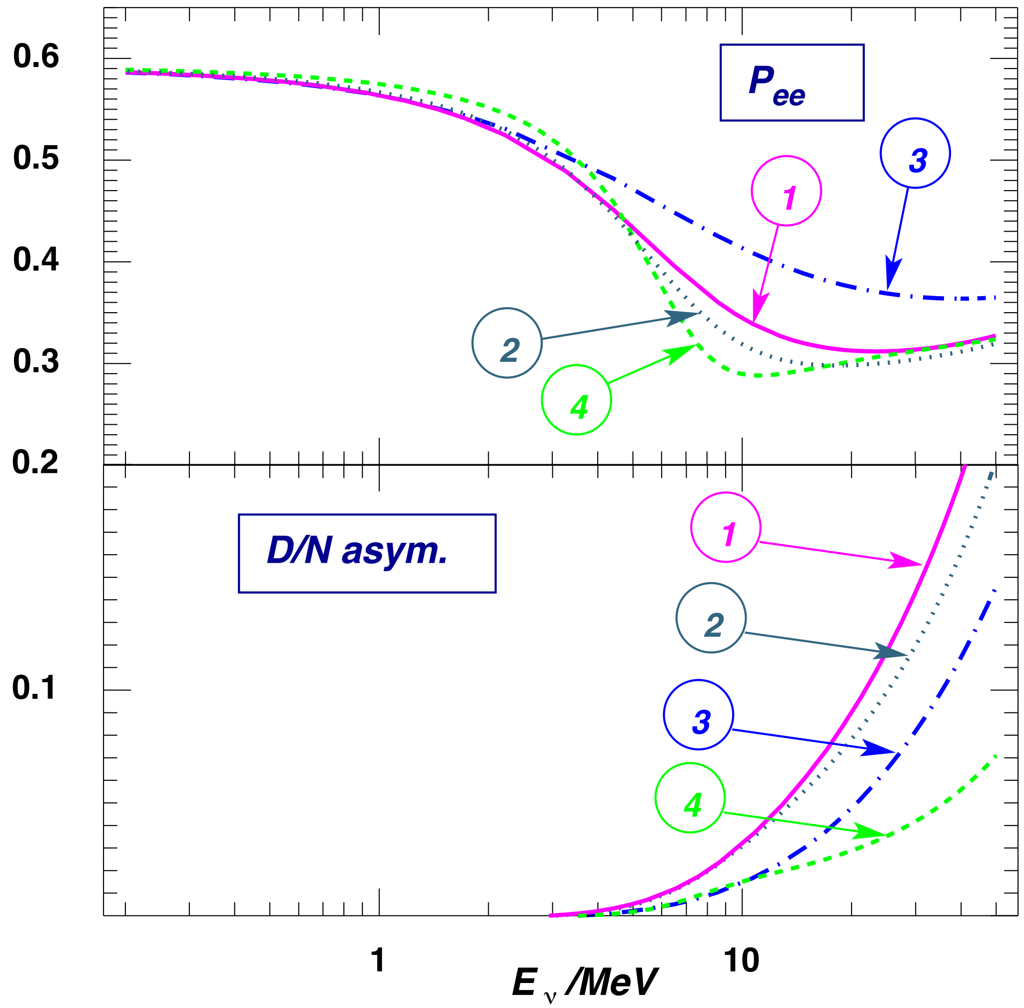
$$\nu_\beta + f \to \nu_\alpha + f$$

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

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

Barranco et al. 2005

Non-standard interactions + MSW + DM detectors



Friedland, Lunardini, Pena-Garay PLB 2004

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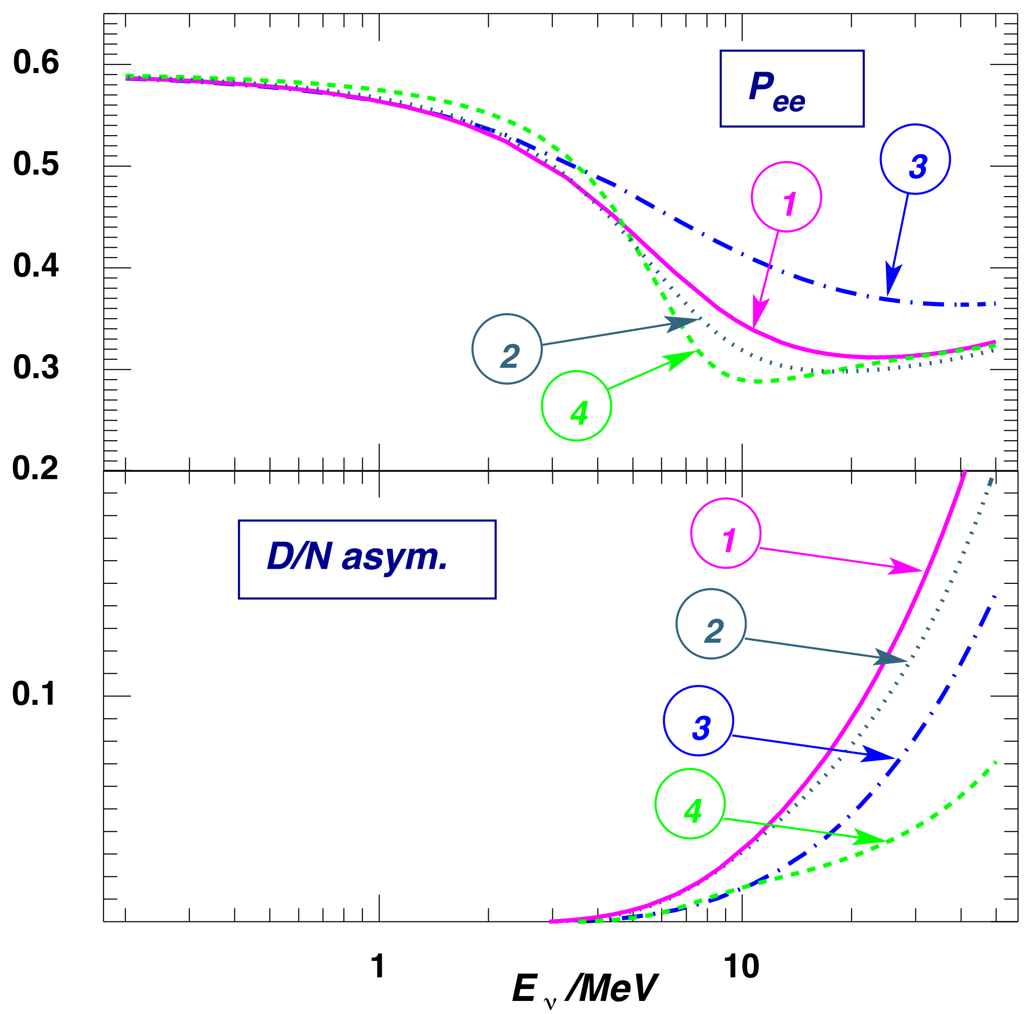

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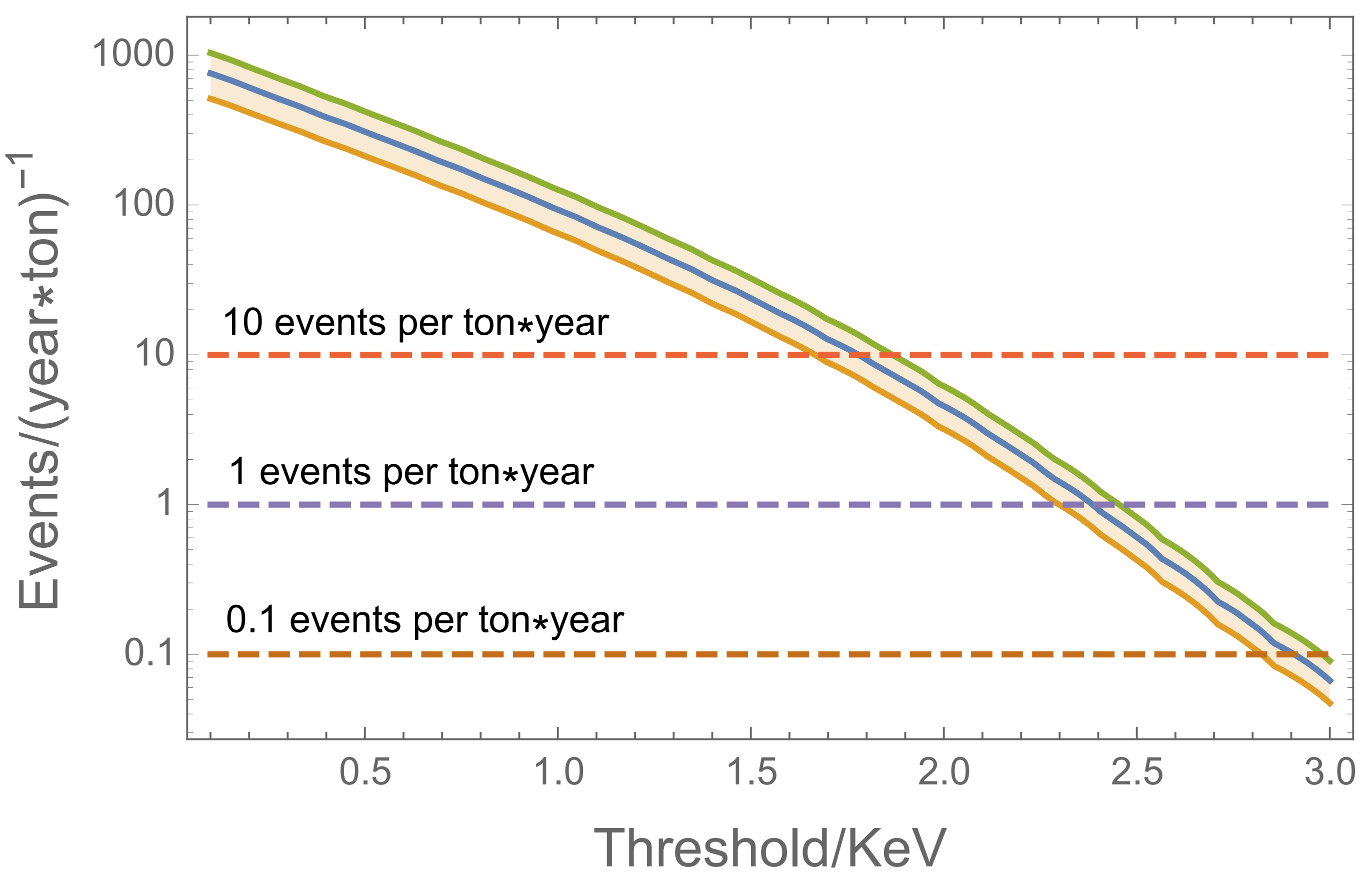
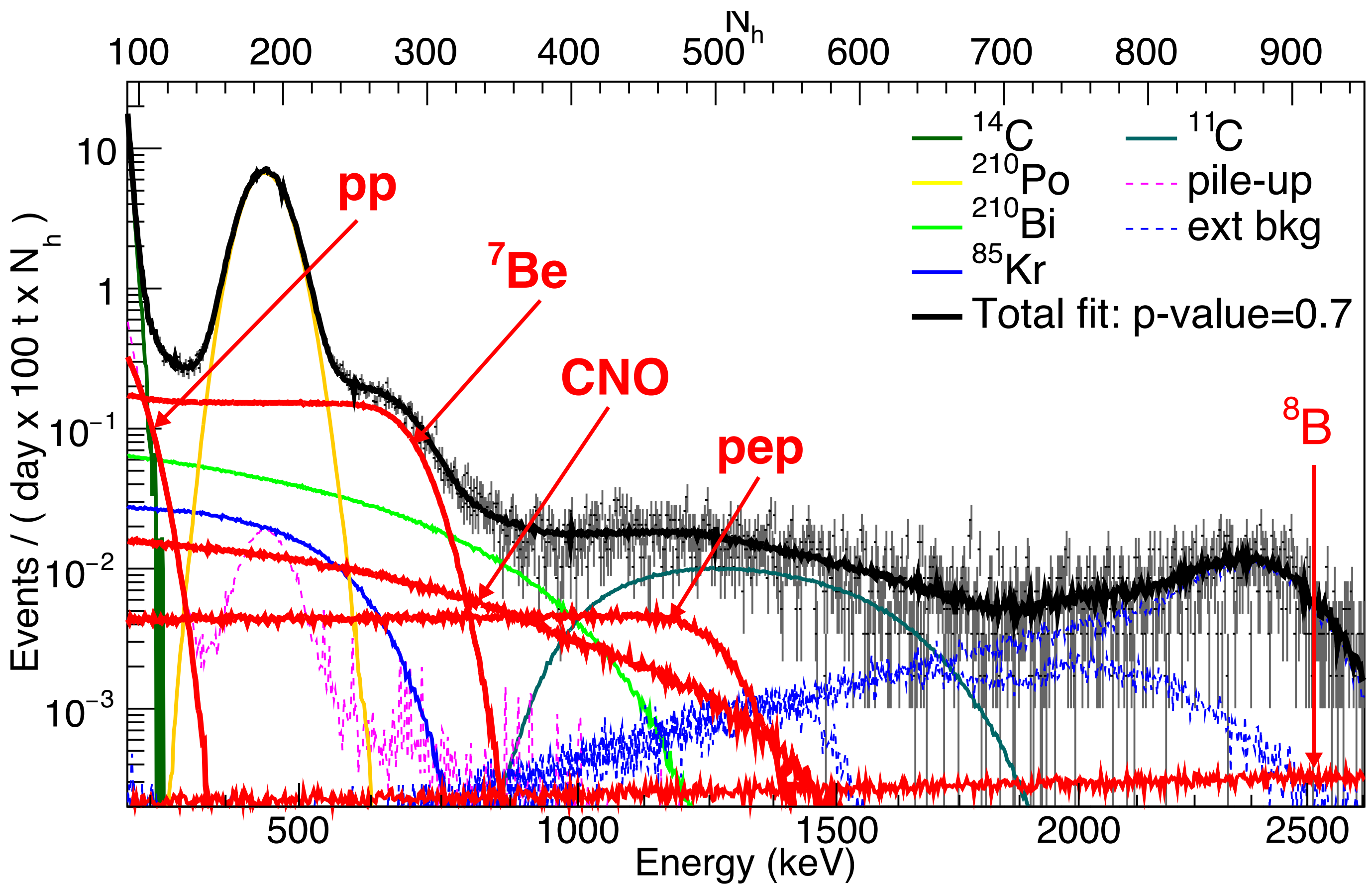
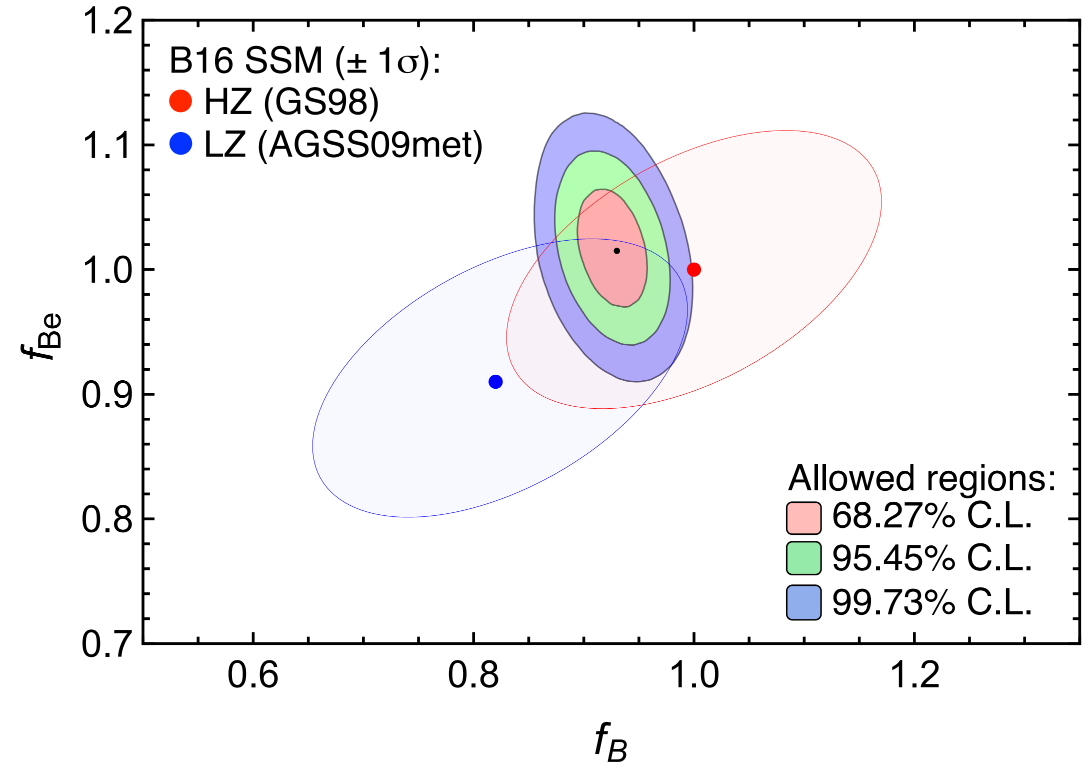


B. Dutta, ***Shu Liao***, L. Strigari, J. Walker, PLB 2017

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

Low energy solar neutrino spectroscopy



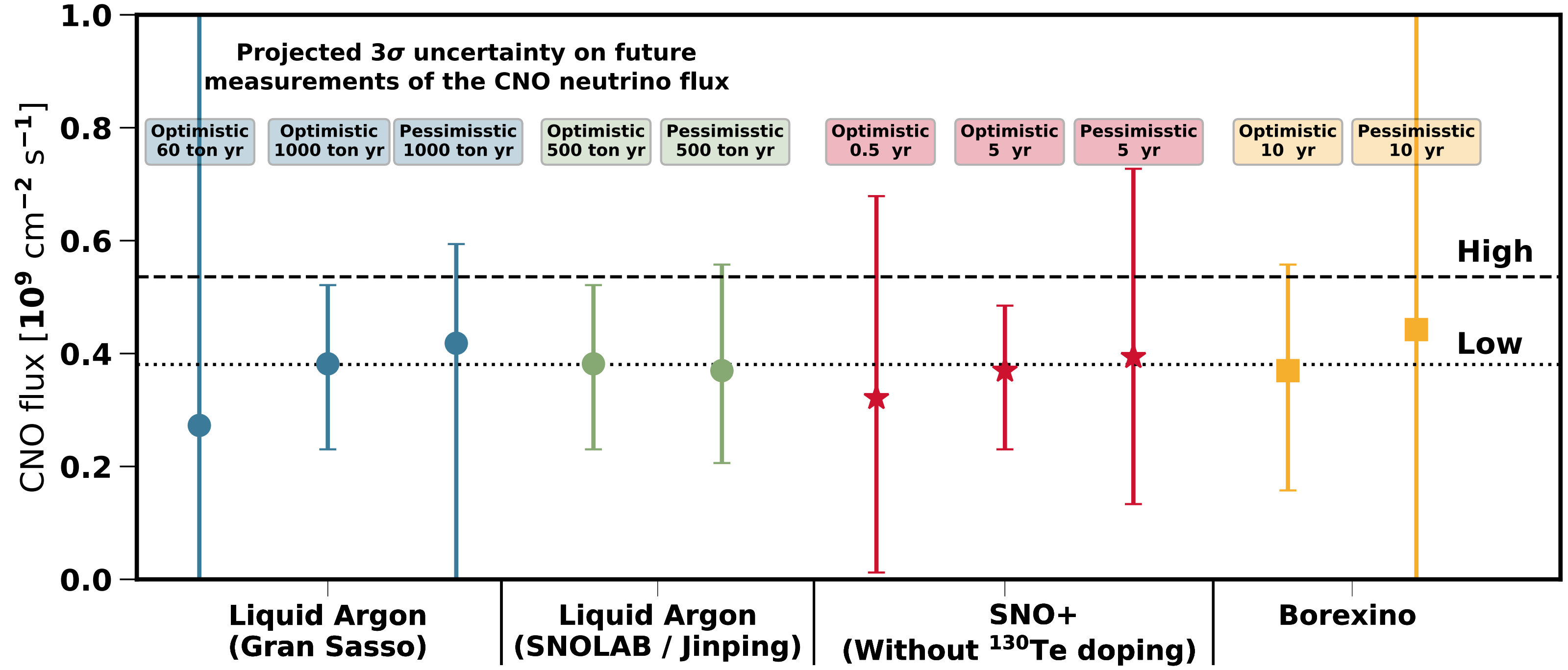


- Multicomponent spectral analysis of low energy solar neutrinos
- 2.7% precision on 7Be
- Strongest upper bound on CNO neutrinos

Borexino collaboration 2017

CNO Solar neutrinos and neutrino luminosity

Future low energy neutrino electron elastic scattering experiments for CNO



Cerdeno, Davis, Fairbairn, Vincent 2018

CNO Solar neutrinos and neutrino luminosity

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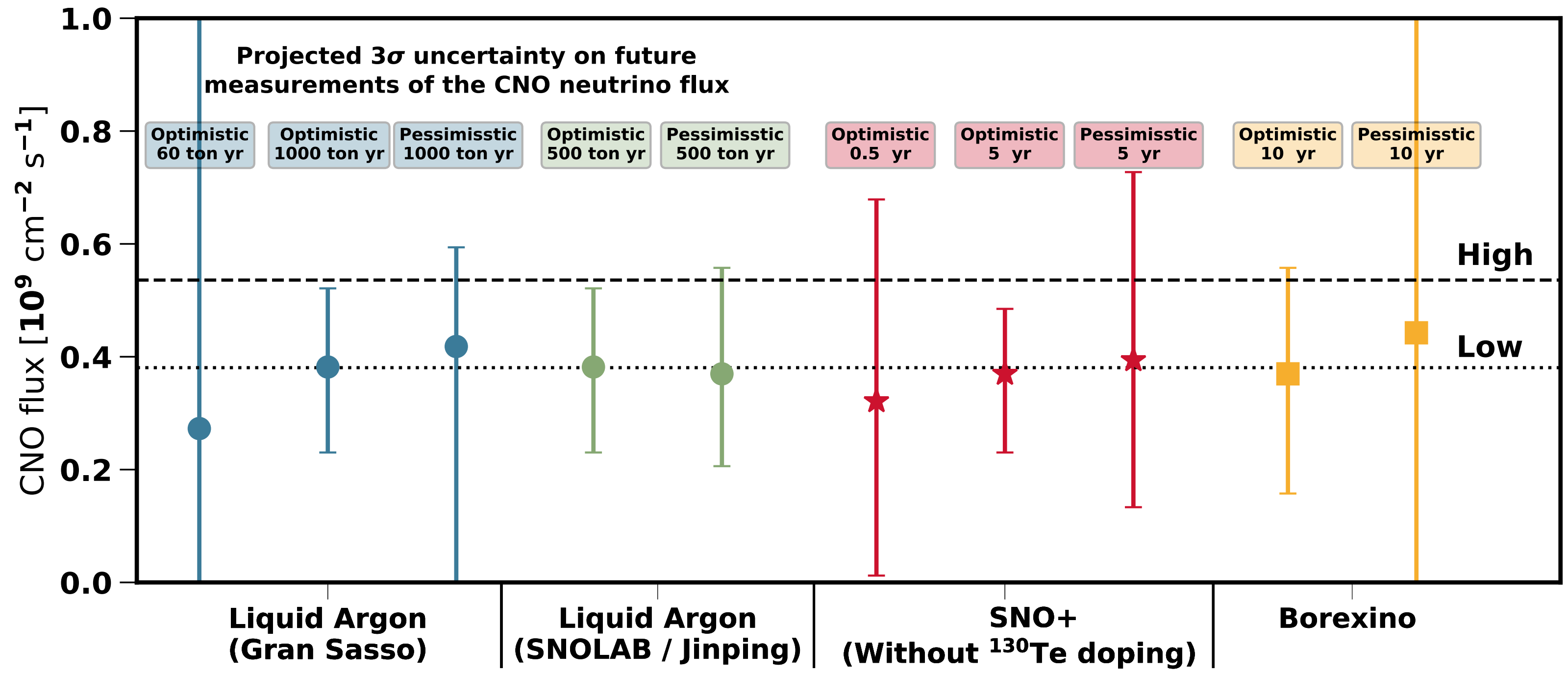


Cerdeno, Davis, Fairbairn, Vincent 2018

Future low energy neutrino electron elastic scattering experiments for pp

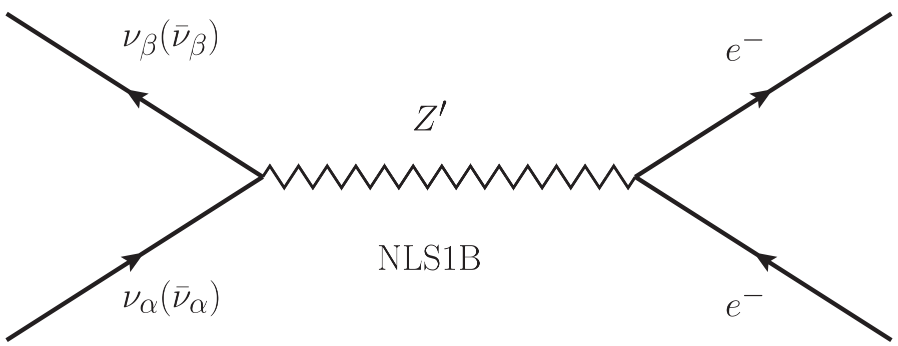
$$\frac{L_{\text{pp-chain}}}{L_\odot} = 0.991^{+0.005}_{-0.004}\,\left[^{+0.008}_{-0.013}\right] \iff \frac{L_{\text{CNO}}}{L_\odot} = 0.009^{+0.004}_{-0.005}\,\left[^{+0.013}_{-0.008}\right]$$

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

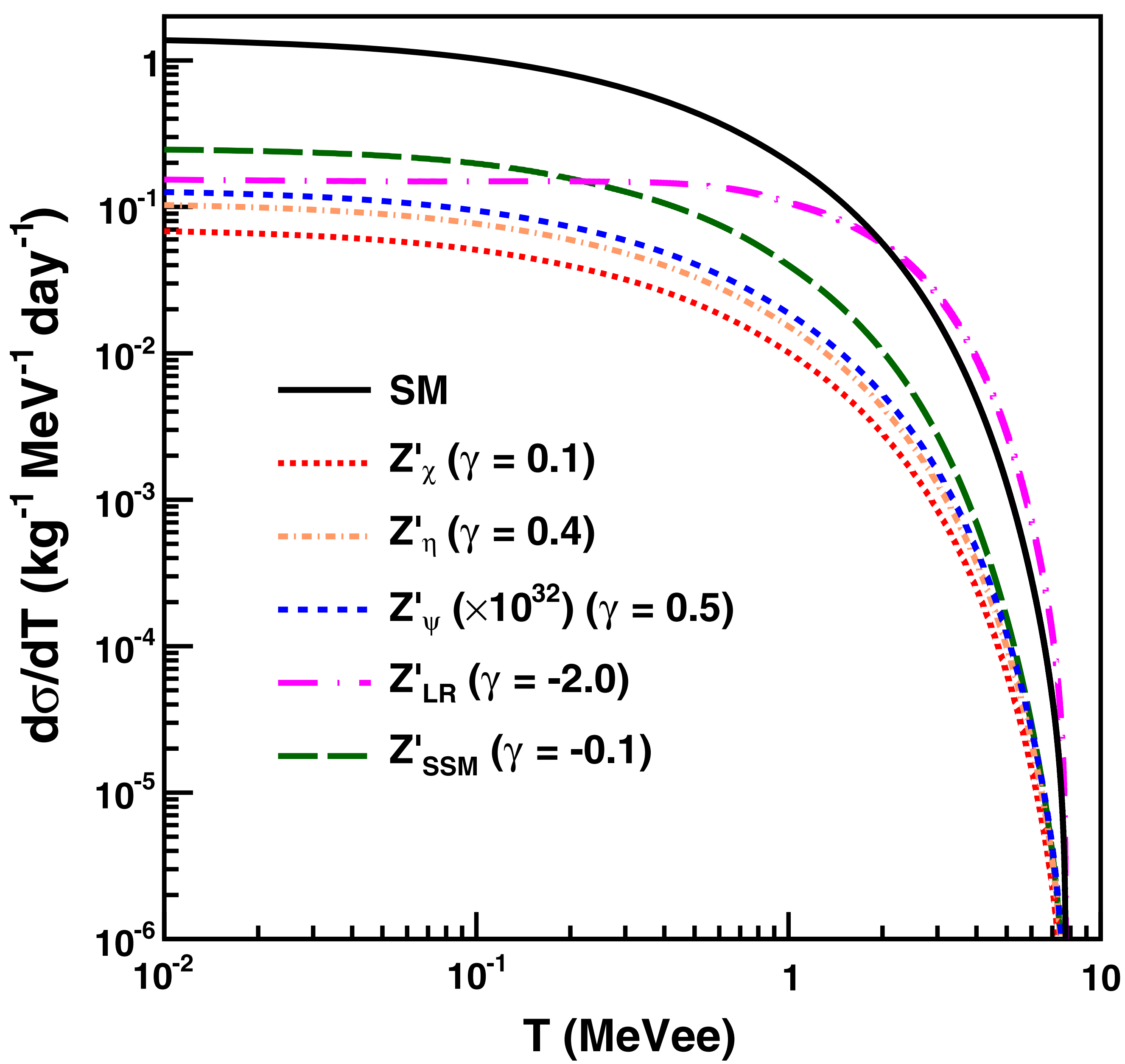
Bergstrom, Gonzalez-Garcia et al. JHEP 2016

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

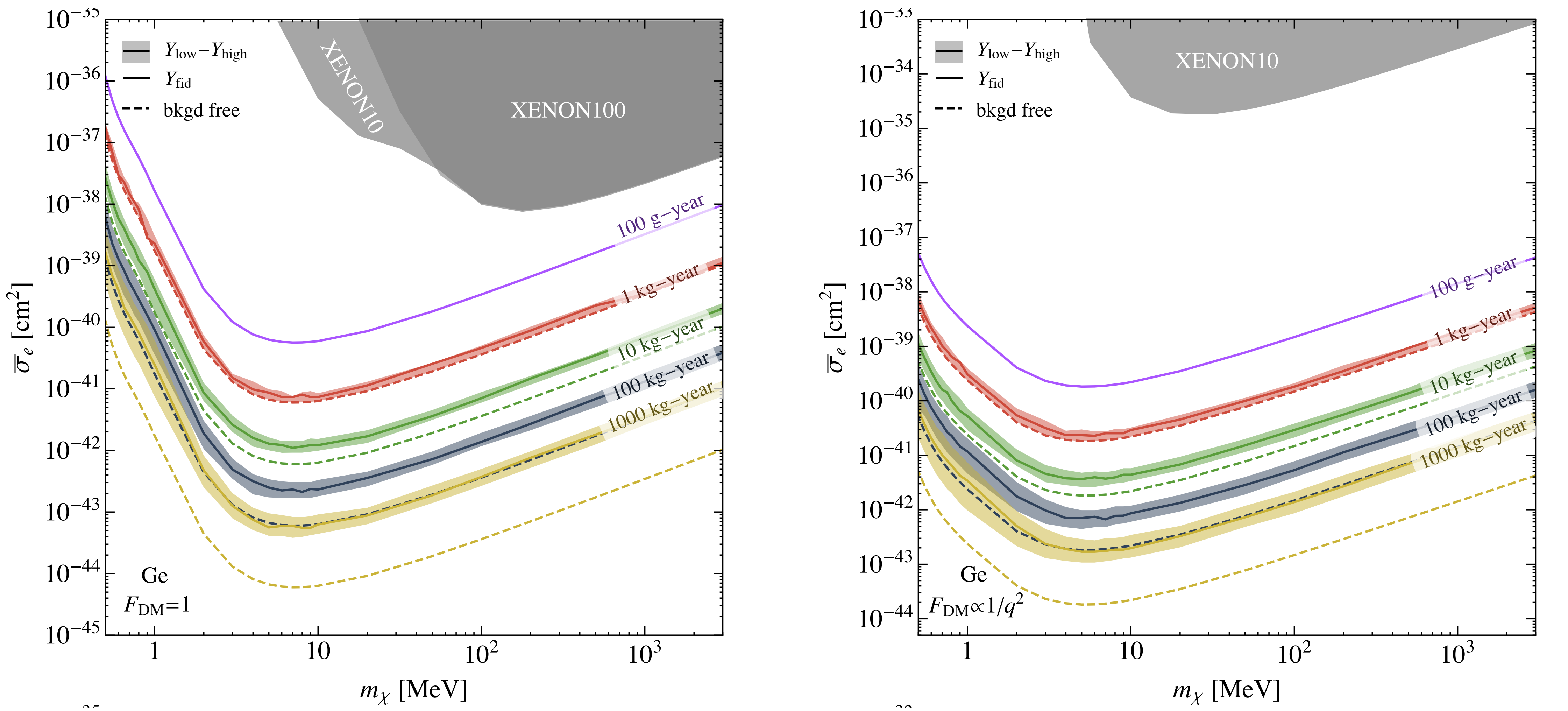
NSI in neutrino-electron scattering



Bolanos et al. 2009; Sevda et al. 2017; Lindner et al. 2018



Neutrino floor for light DM



Essig et al. 2018; Wyenberg and Shoemaker 2018

- 8B energy spectrum at low threshold used to probe NSI, sterile neutrinos (Billard, LS, Figueroa-Feliciano 2014)
- Also possible to go for CNO with low thresholds (Strigari PRD 2016)

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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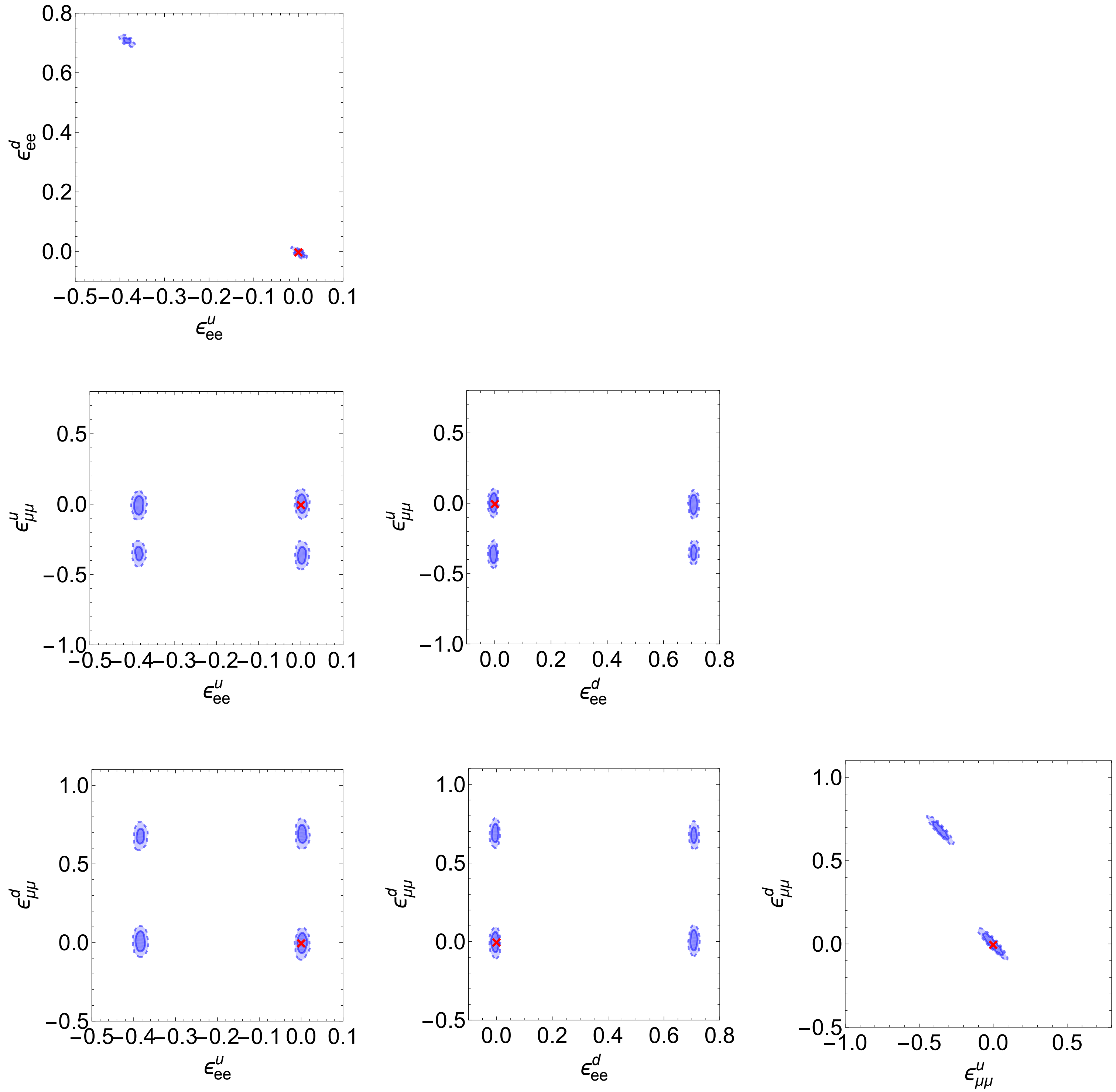
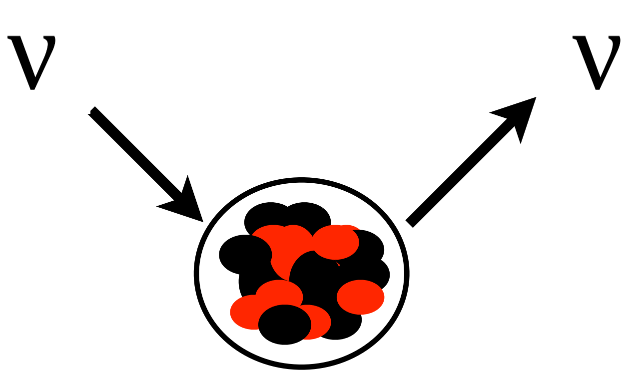
Particle physics

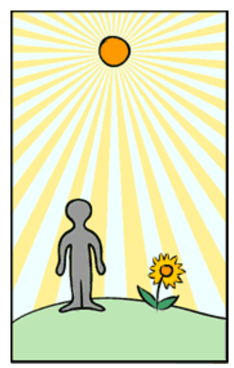
- NSI affects both neutrino-coherent scattering and neutrino-electron elastic scattering channels
- Probe of low mass mediators via neutrino-electron elastic scattering

Reactor and accelerator complementarity

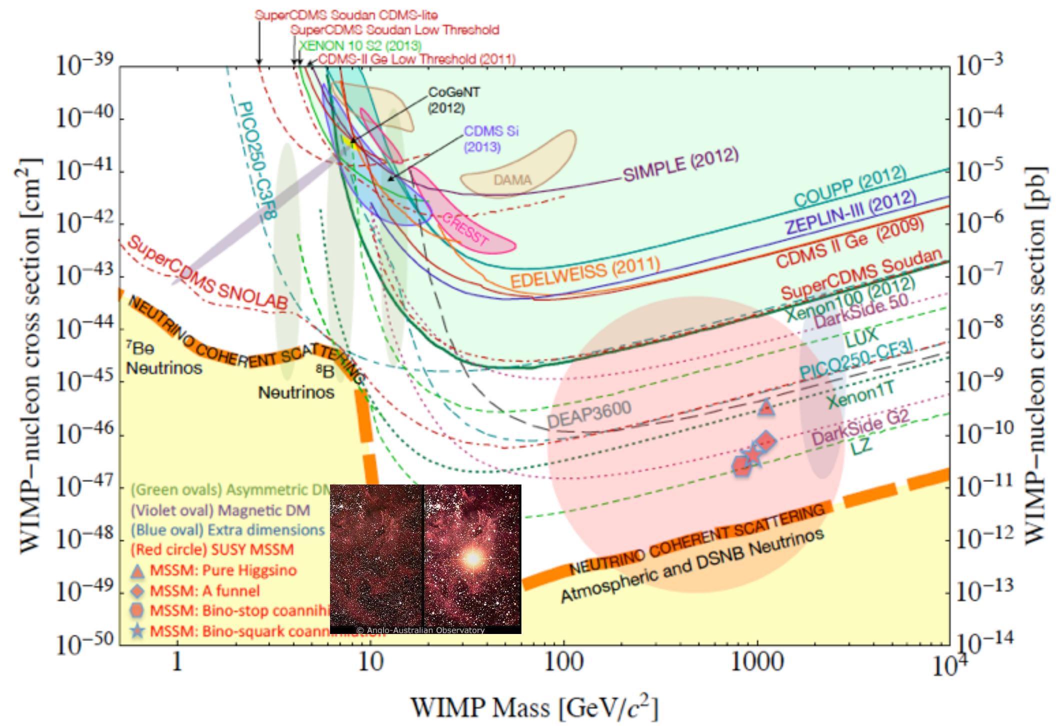


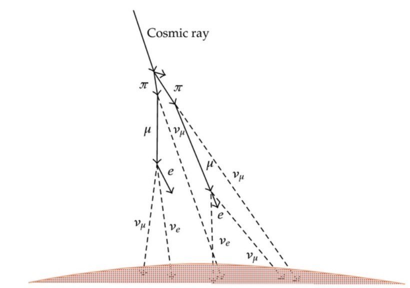
Dark matter and neutrino complementarity





Astrophysical sources



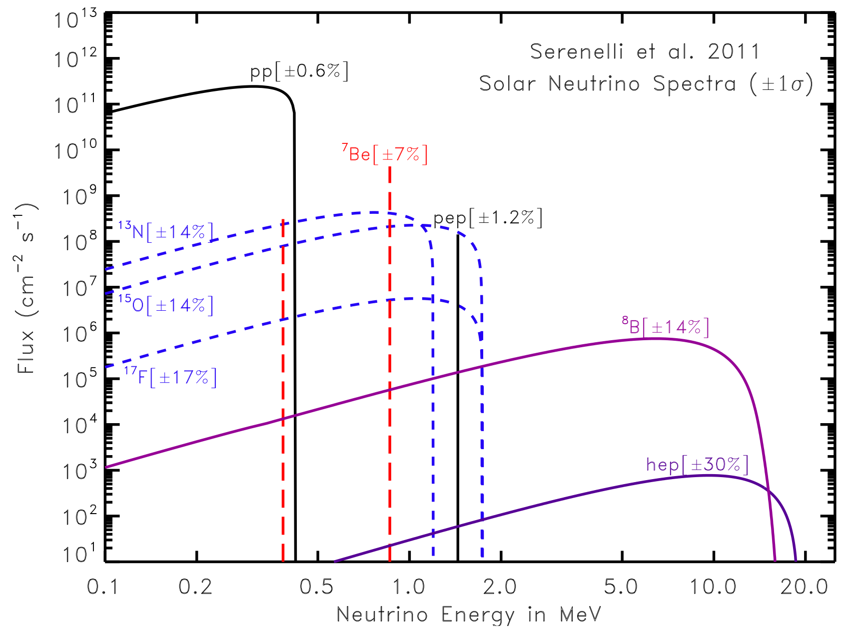


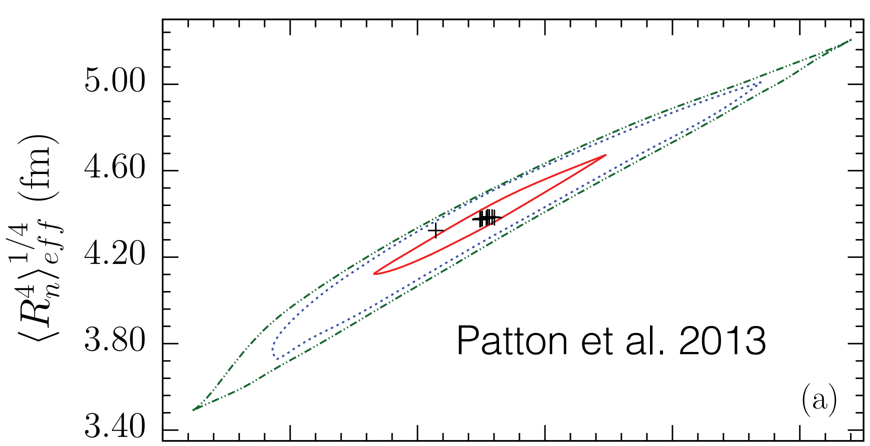
Reactors

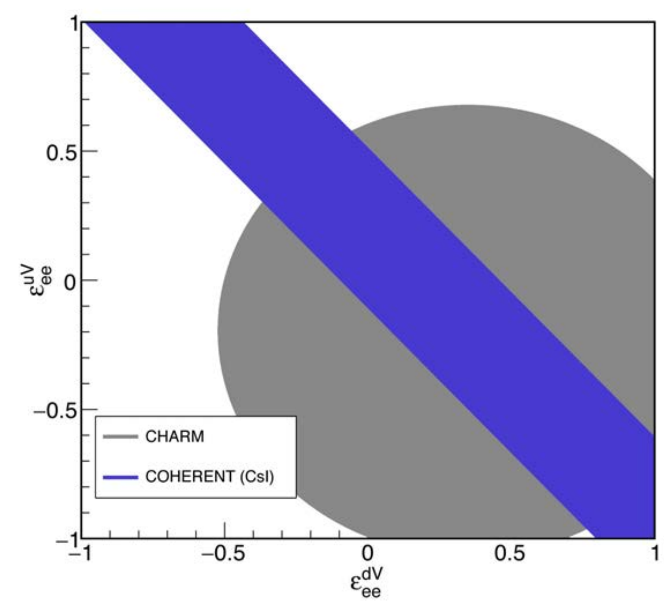
Accelerators

Dark matter and neutrino complementarity

Astrophysics







Nuclear Physics

High-energy Physics