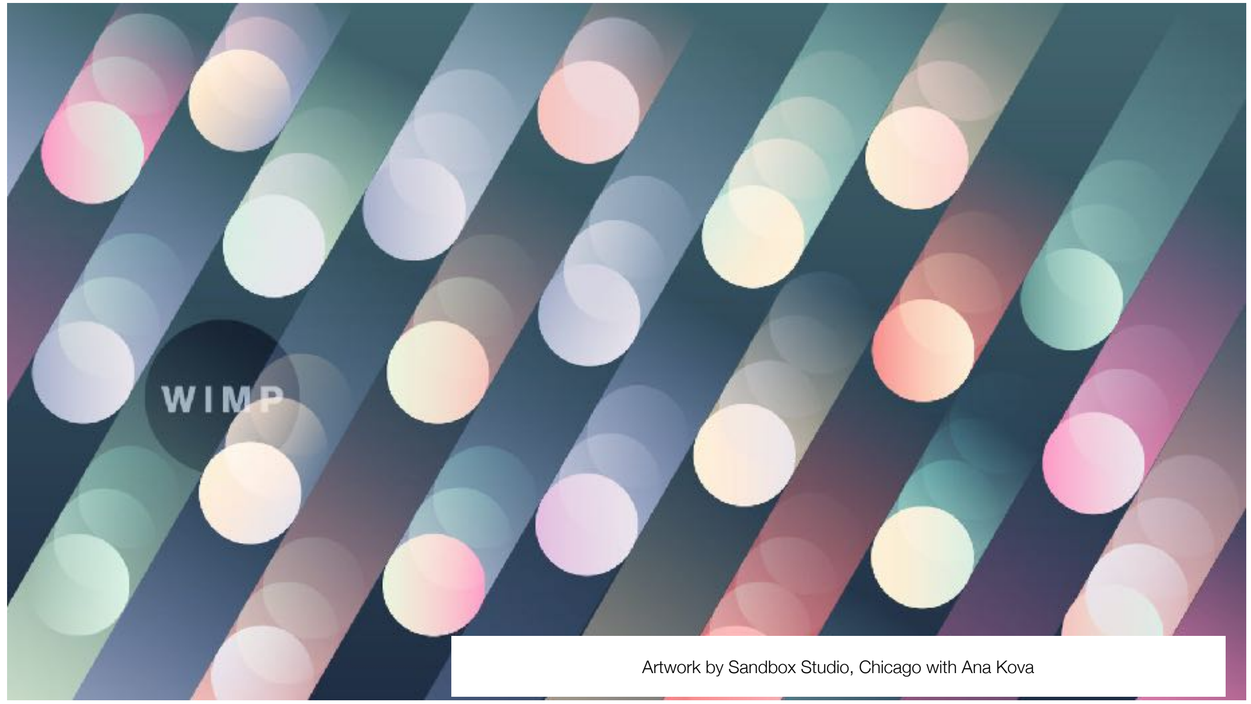
Solar neutrinos with coherent scattering

Snowmass: Neutrinos from natural sources
December 7, 2020

Louis Strigari
Texas A&M University



Artwork by Sandbox Studio, Chicago with Ana Kova

Coherent elastic neutrino-nucleus scattering & solar neutrinos

Coherent effects of a weak neutral current

Daniel Z. Freedman†
National Accelerator Laboratory, Batavia, Illinois 60510
and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790
(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

Principles and applications of a neutral-current detector for neutrino physics and astronomy

A. Drukier and L. Stodolsky
Max-Planck-Institut für Physik und Astrophysik, Werner-Heisenberg-Institut für Physik, Munich, Federal Republic of Germany
(Received 21 November 1983)

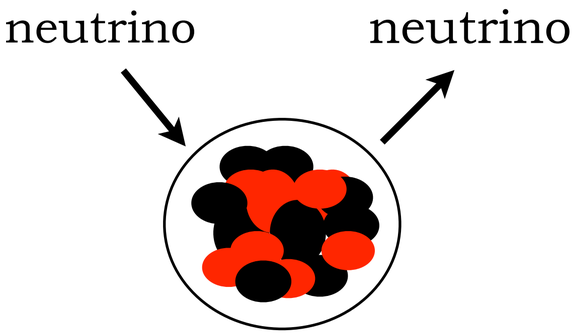
We study detection of MeV-range neutrinos through elastic scattering on nuclei and identification of the recoil energy. The very large value of the neutral-current cross section due to coherence indicates a detector would be relatively light and suggests the possibility of a true "neutrino observatory." The recoil energy which must be detected is very small (10–10^3 eV), however. We examine a realization in terms of the superconducting-grain idea, which appears, in principle, to be feasible through extension and extrapolation of currently known techniques. Such a detector could permit

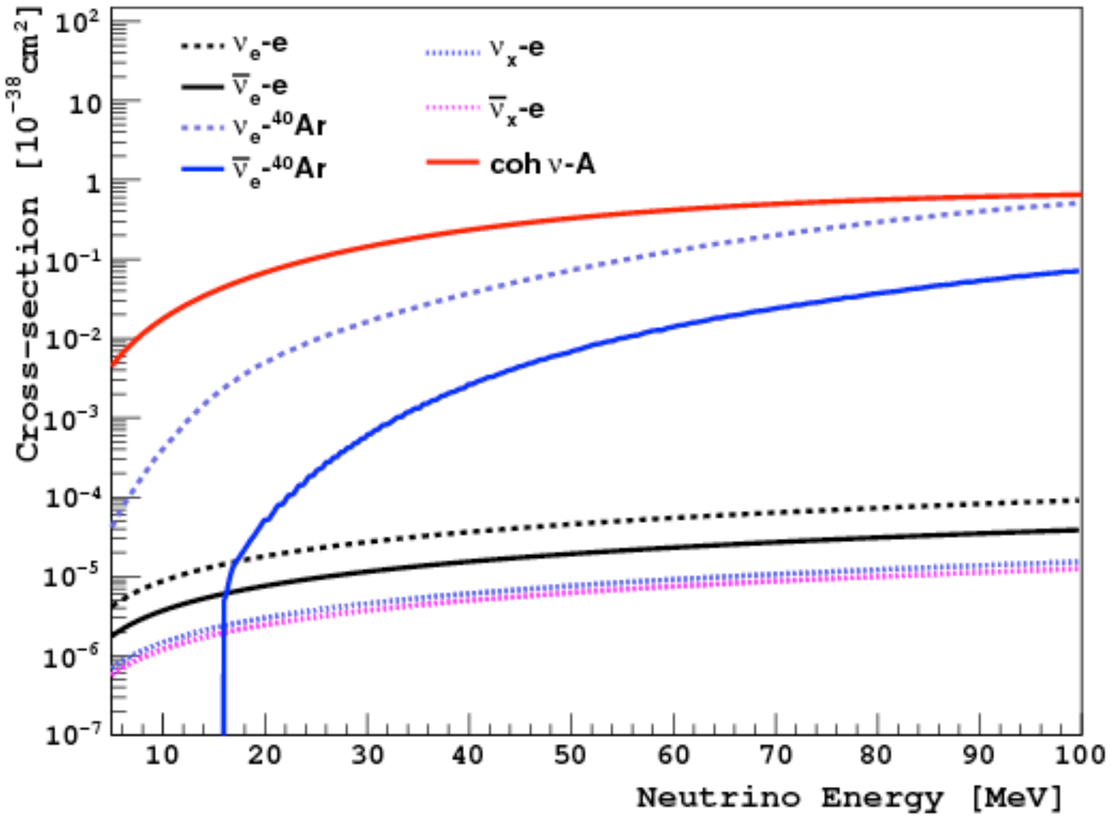
Bolometric Detection of Neutrinos

Blas Cabrera, Lawrence M. Krauss, and Frank Wilczek
Department of Physics, Stanford University, Stanford, California 94305
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 01238
Institute for Theoretical Physics, University of California, Santa Barbara, California 93106
(Received 14 December 1984)

Elastic neutrino scattering off electrons in crystalline silicon at 1–10 mK results in measurable temperature changes in macroscopic amounts of material, even for low-energy (< 0.41MeV) *pp* ν's from the sun. We propose new detectors for bolometric measurement of low-energy ν interactions, including coherent nuclear elastic scattering. A new and more sensitive search for oscil-

Coherent elastic neutrino-nucleus scattering (CEvNS)

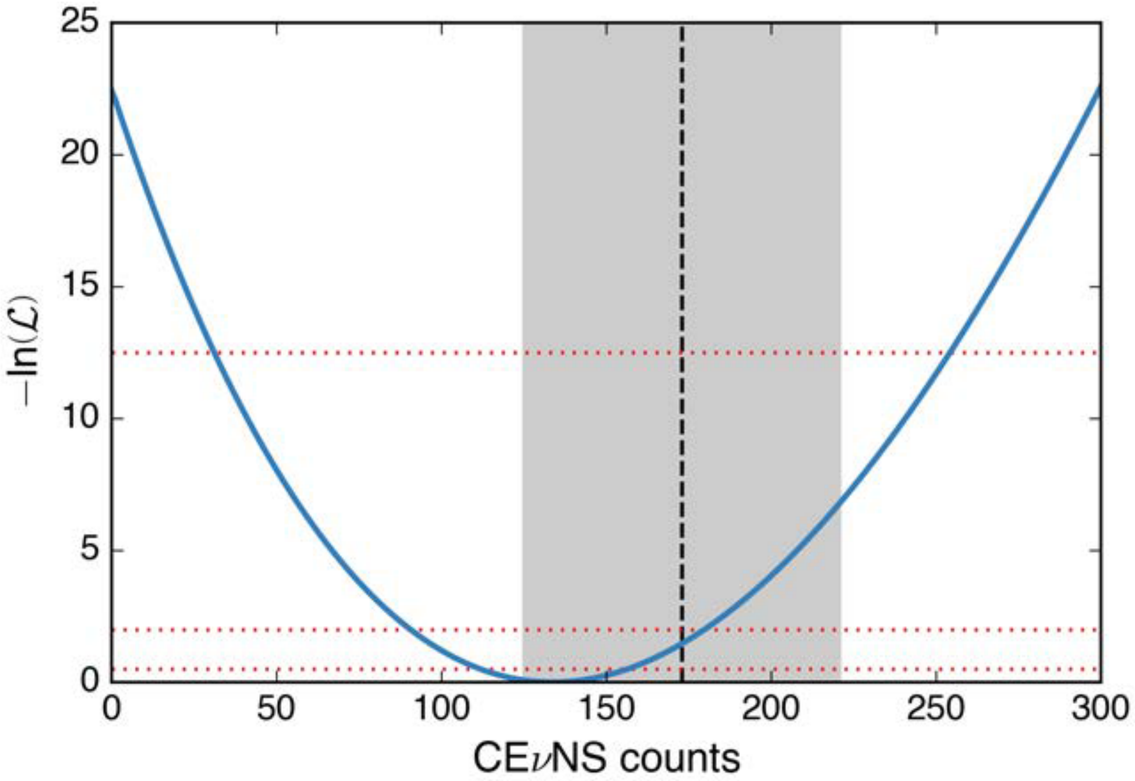




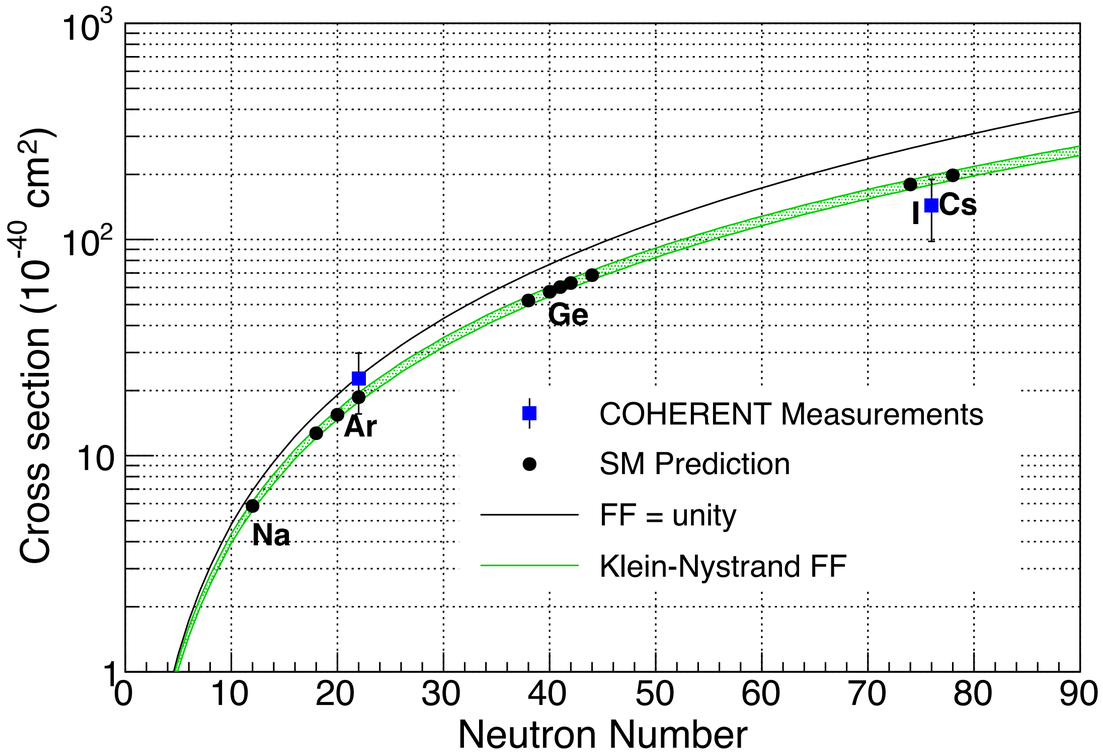
- Neutral current interaction; Total scattering amplitude sum of that on constituent nucleons
- Small momentum transfer wrt to the target size implies coherent enhancement
- Due to Standard Model couplings coherent enhancement due to neutrons
- Low energy recoil distribution implies difficult to detect

Brice et al, 1311.5958

First detections of CEvNS

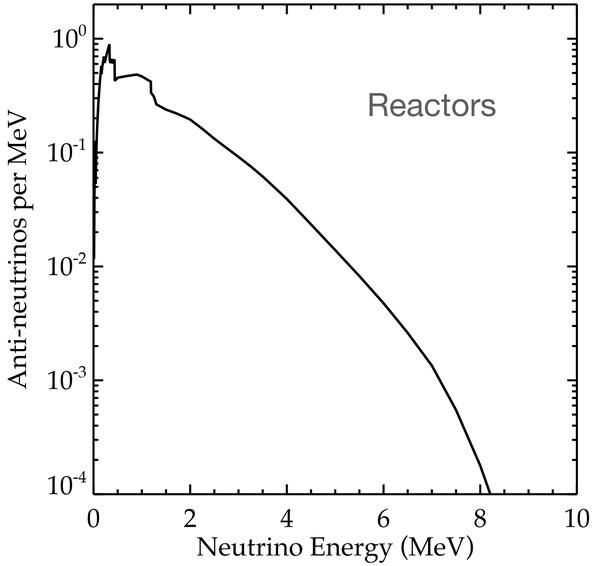


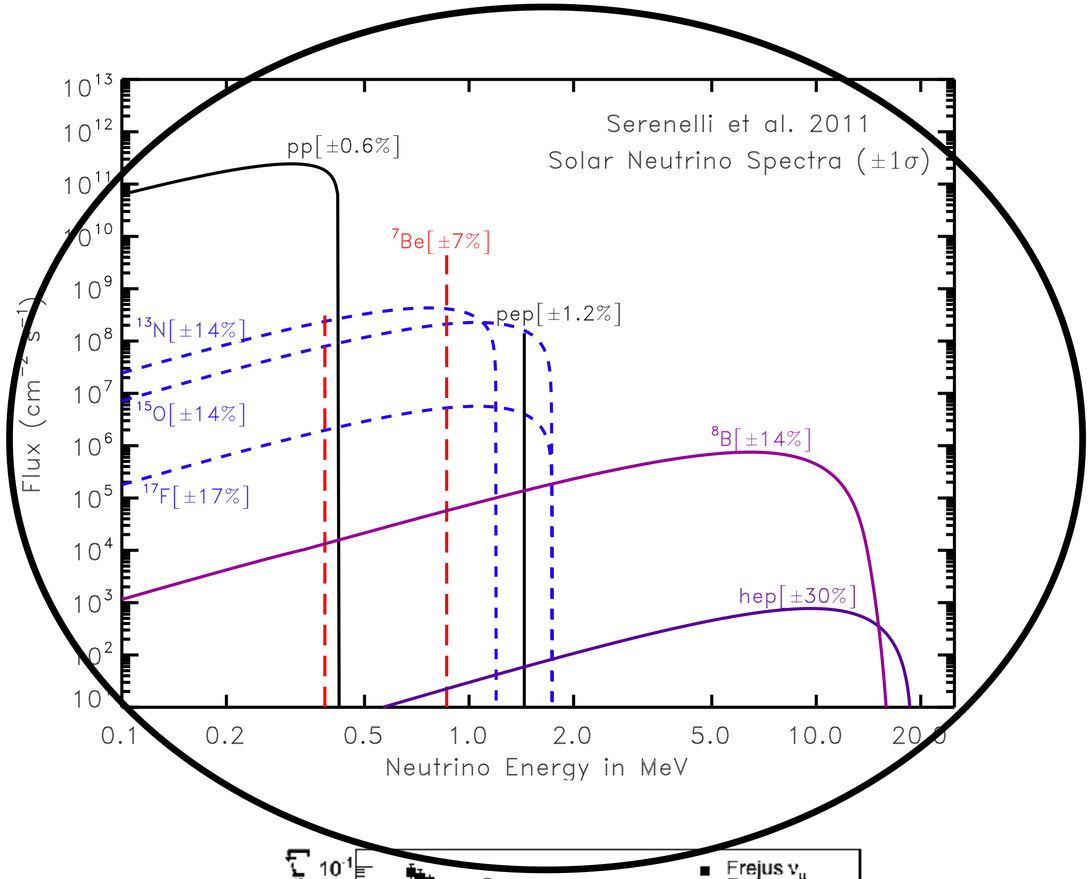
COHERENT collaboration 2017

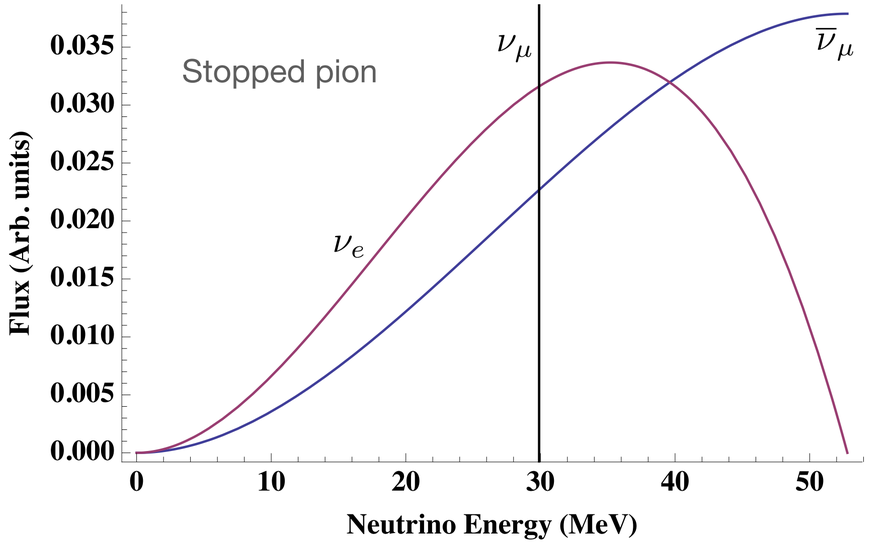


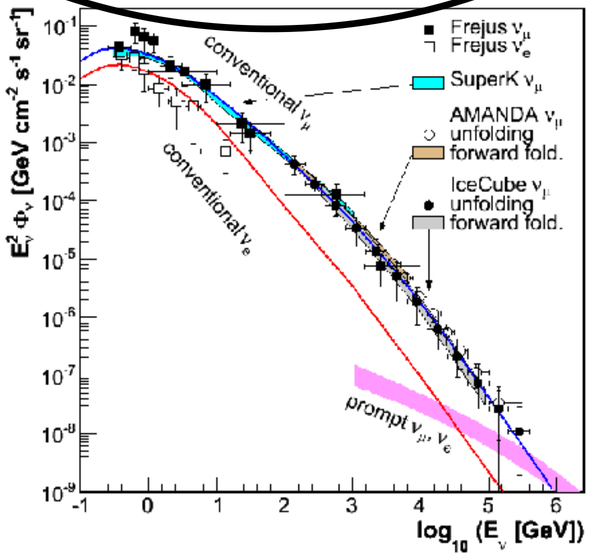
COHERENT collaboration 2020

Energy scales for CEvNS

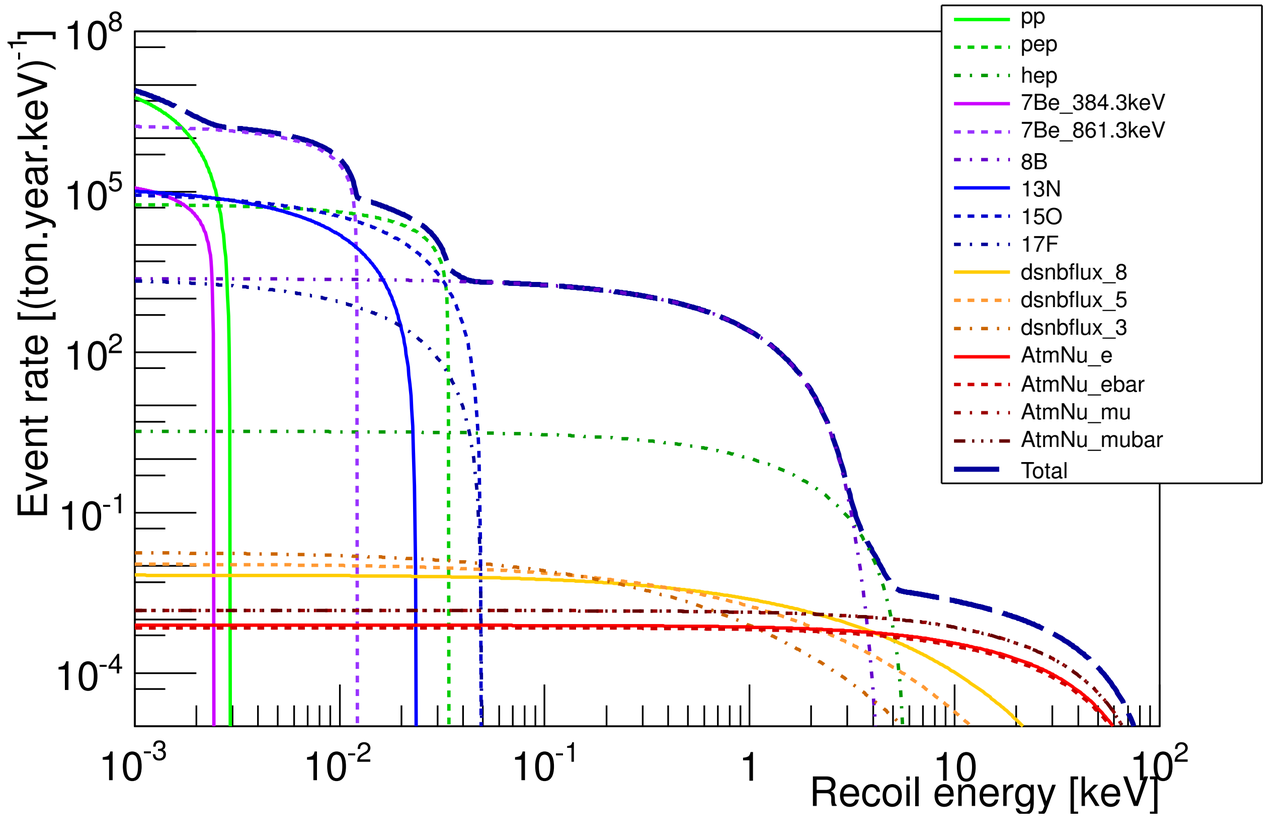


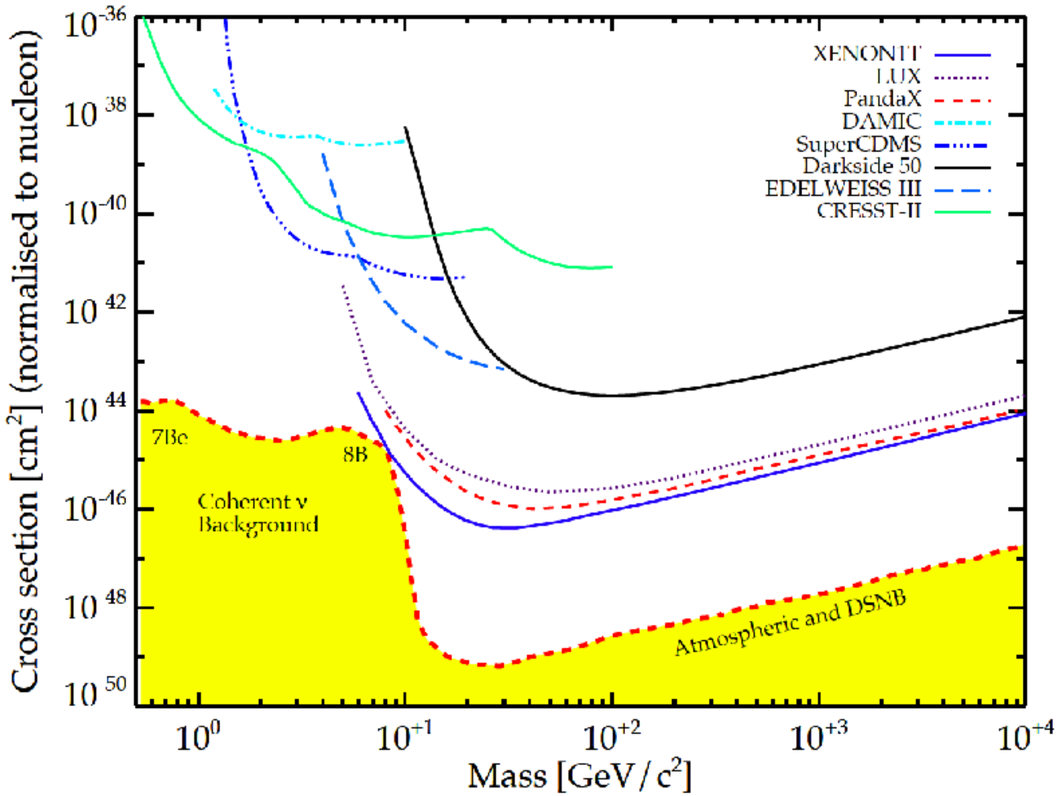




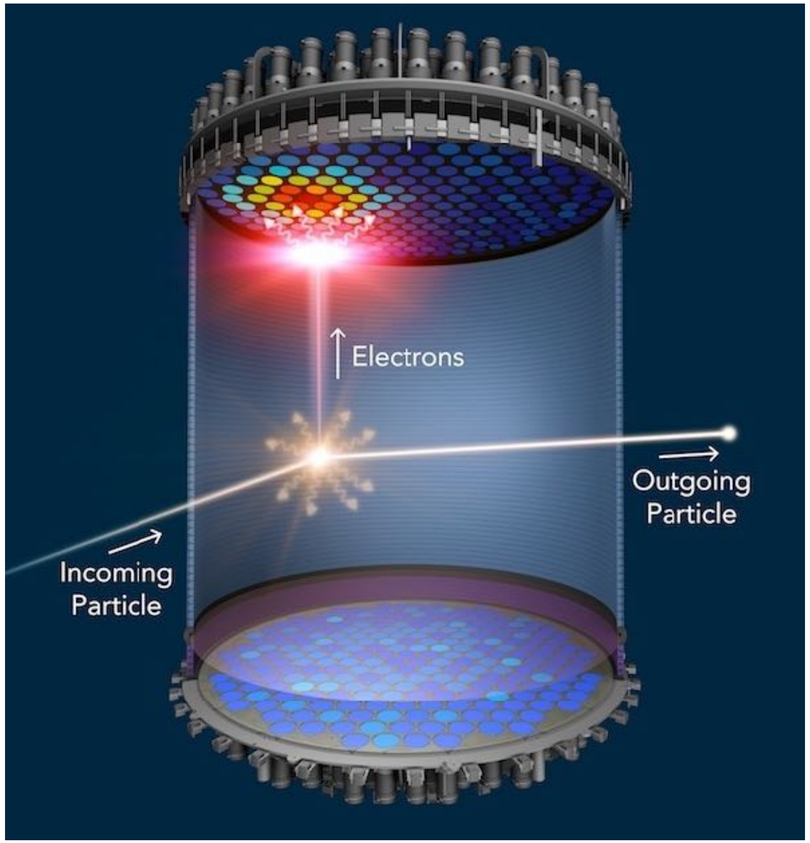


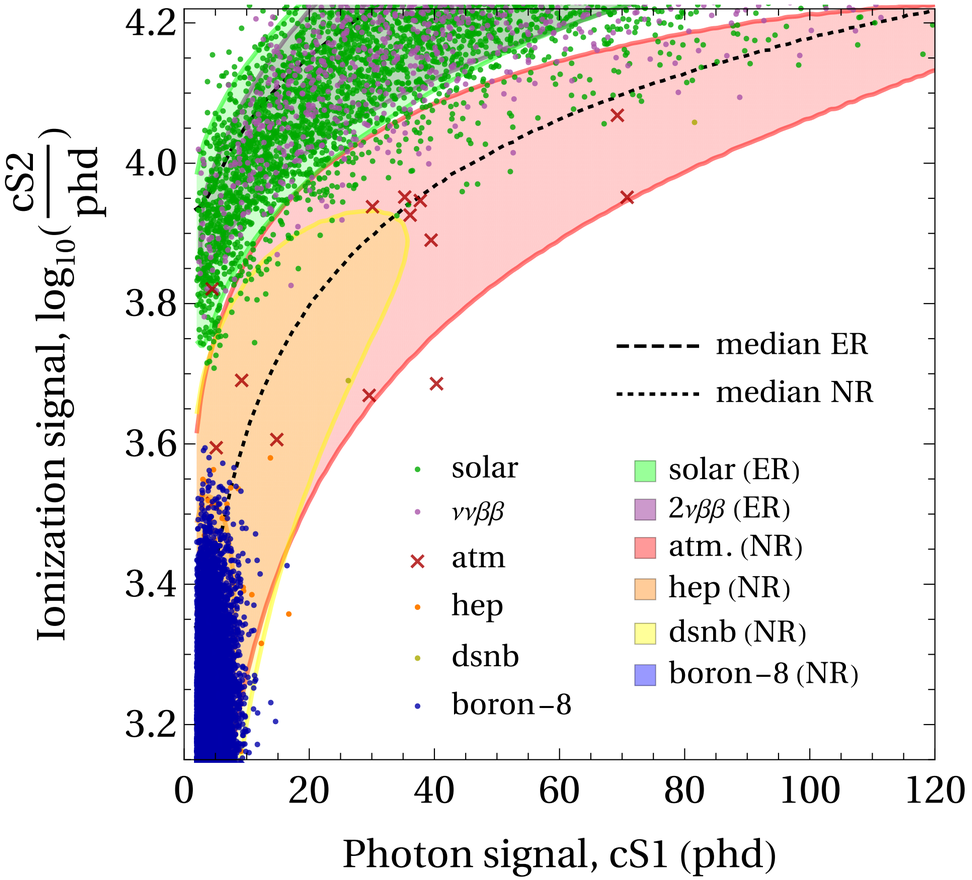
Solar neutrino spectrum in Xenon



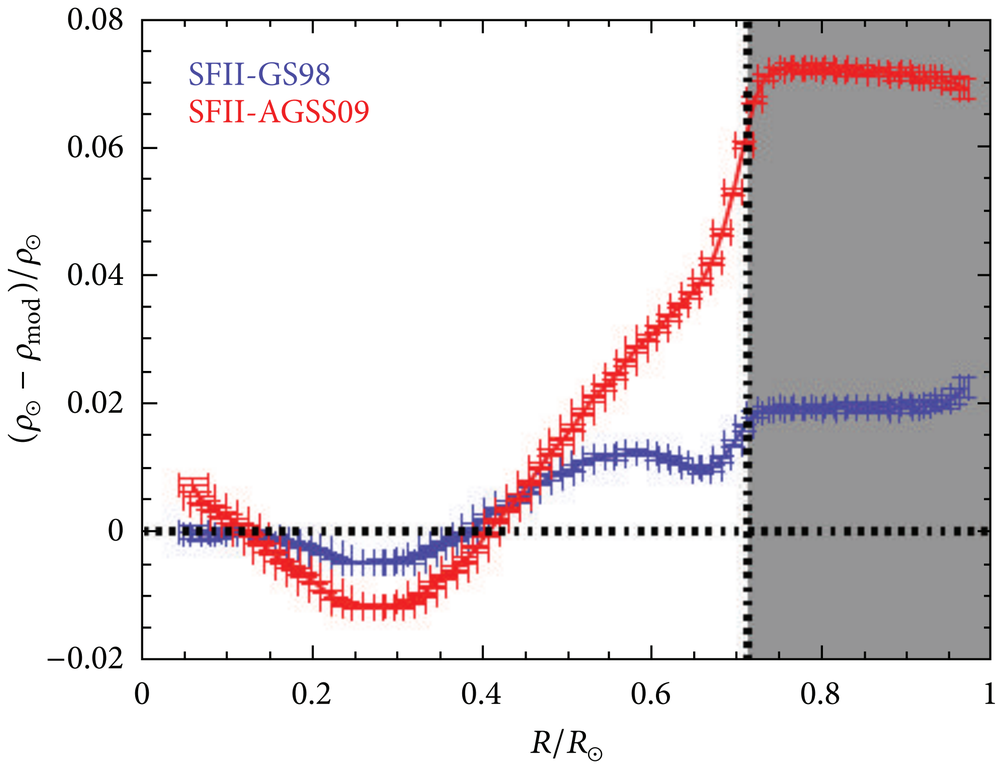


Dark matter and neutrino detection





Solar metallicity question



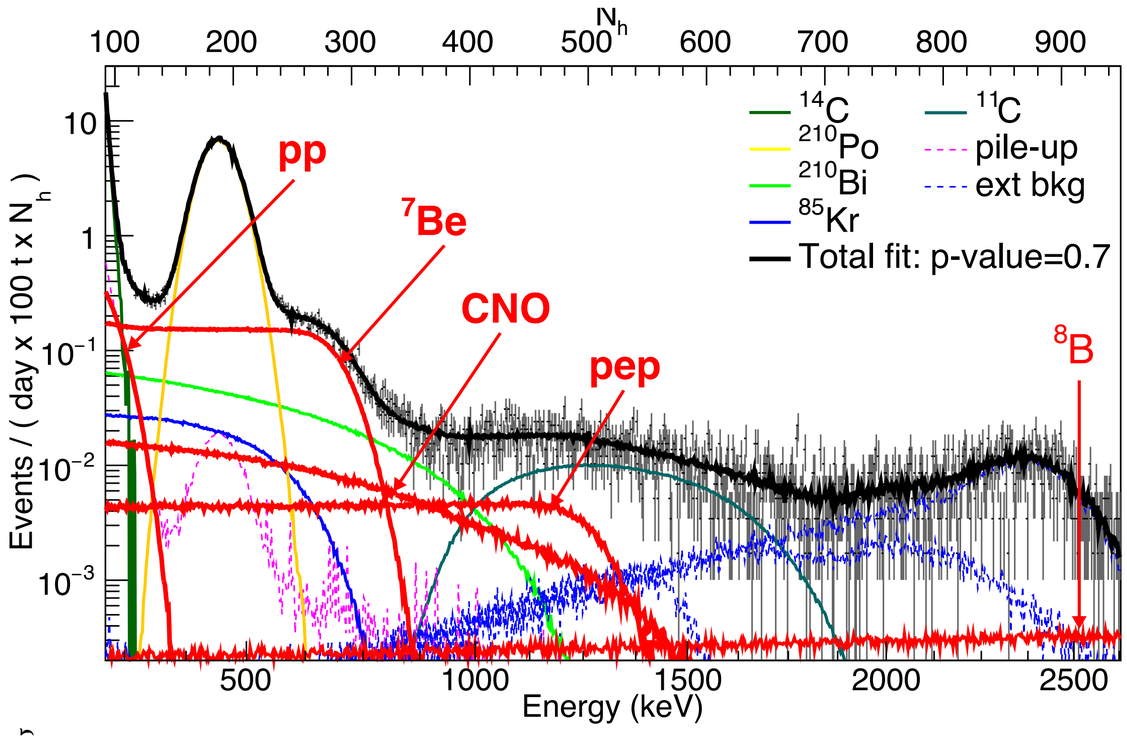
Antonelli et al. 2013

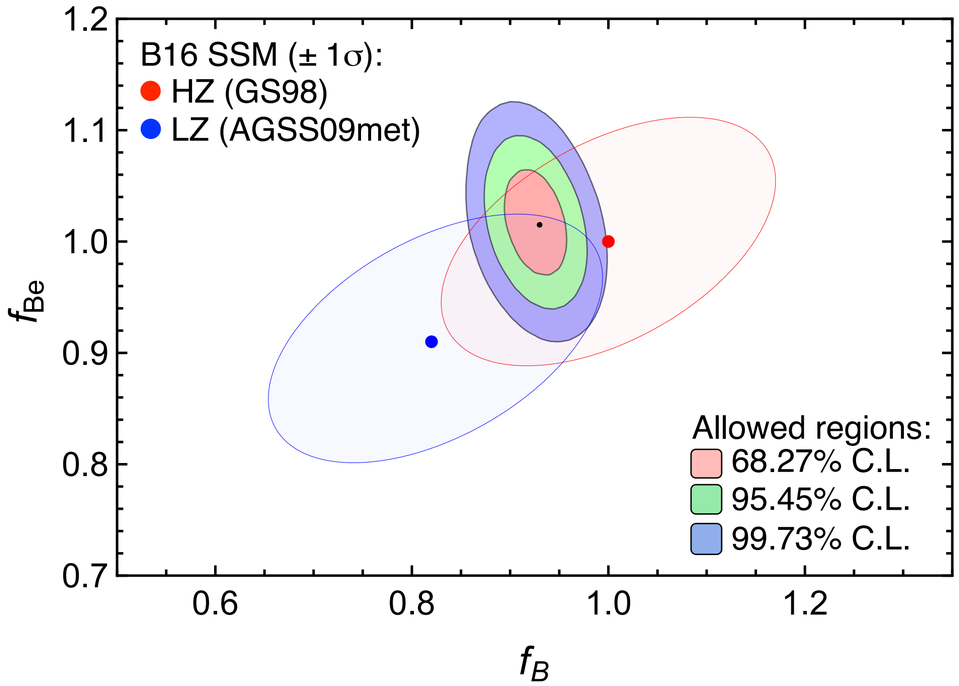
High-Z Low-Z

ν flux	$E_\nu^{\rm max}$ (MeV)	GS98-SFII	AGSS09-SFII	Solar	units
$p+p\to{}^2H+e^++\nu$	0.42	$5.98(1\pm0.006)$	$6.03(1\pm0.006)$	$6.05(1^{+0.003}_{-0.011})$	$10^{10}/cm^2s$
$p+e^-+p\to{}^2H+\nu$	1.44	$1.44(1\pm0.012)$	$1.47(1\pm0.012)$	$1.46(1^{+0.010}_{-0.014})$	$10^8/cm^2s$
${}^7Be+e^-\to{}^7Li+\nu$	0.86 (90%)	$5.00(1\pm0.07)$	$4.56(1\pm0.07)$	$4.82(1^{+0.05}_{-0.04})$	$10^9/cm^2s$
	0.38 (10%)				
${}^8B\to{}^8Be+e^++\nu$	~ 15	$5.58(1\pm0.14)$	$4.59(1\pm0.14)$	$5.00(1\pm0.03)$	$10^6/cm^2s$
${}^3He+p\to{}^4He+e^++\nu$	18.77	$8.04(1\pm0.30)$	$8.31(1\pm0.30)$	—	$10^3/cm^2s$
${}^{13}N\to{}^{13}C+e^++\nu$	1.20	$2.96(1\pm0.14)$	$2.17(1\pm0.14)$	≤ 6.7	$10^8/cm^2s$
${}^{15}O\to{}^{15}N+e^++\nu$	1.73	$2.23(1\pm0.15)$	$1.56(1\pm0.15)$	≤ 3.2	$10^8/cm^2s$
${}^{17}F\to{}^{17}0+e^++\nu$	1.74	$5.52(1\pm0.17)$	$3.40(1\pm0.16)$	$\leq 59.$	$10^6/cm^2s$
$\chi^2/P^{\rm agr}$		3.5/90%	3.4/90%		

Haxton et al. 2013

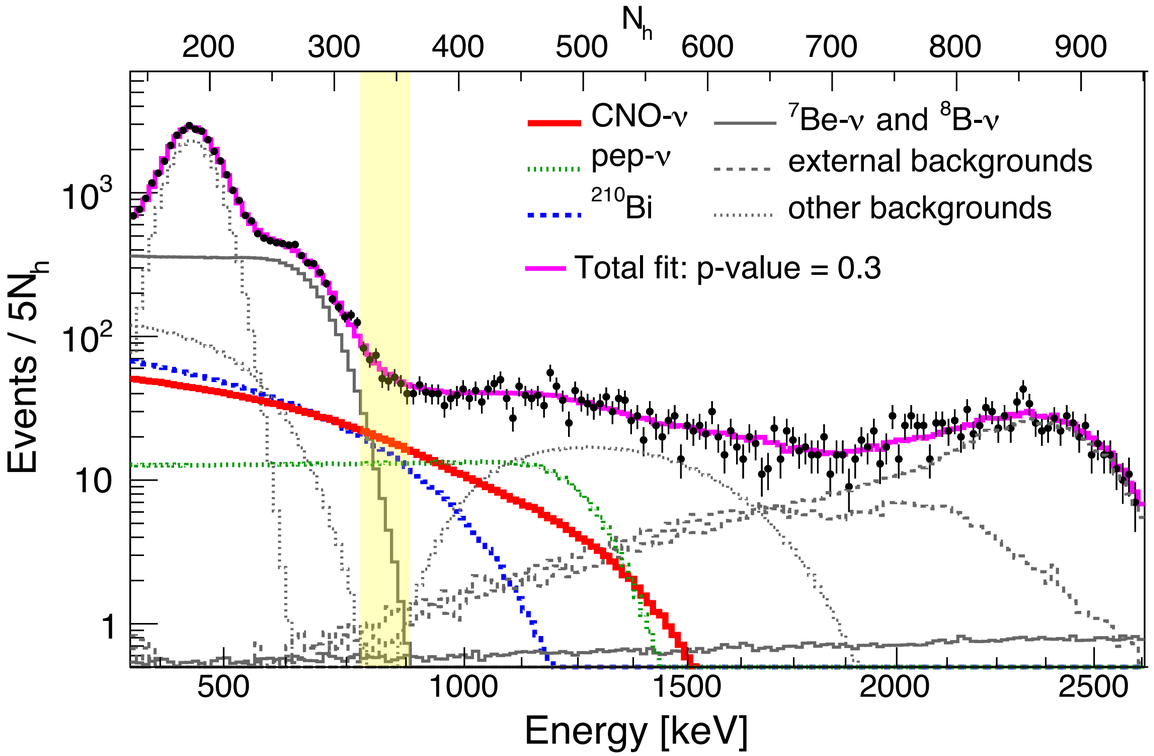
Solar metallicity with Borexino

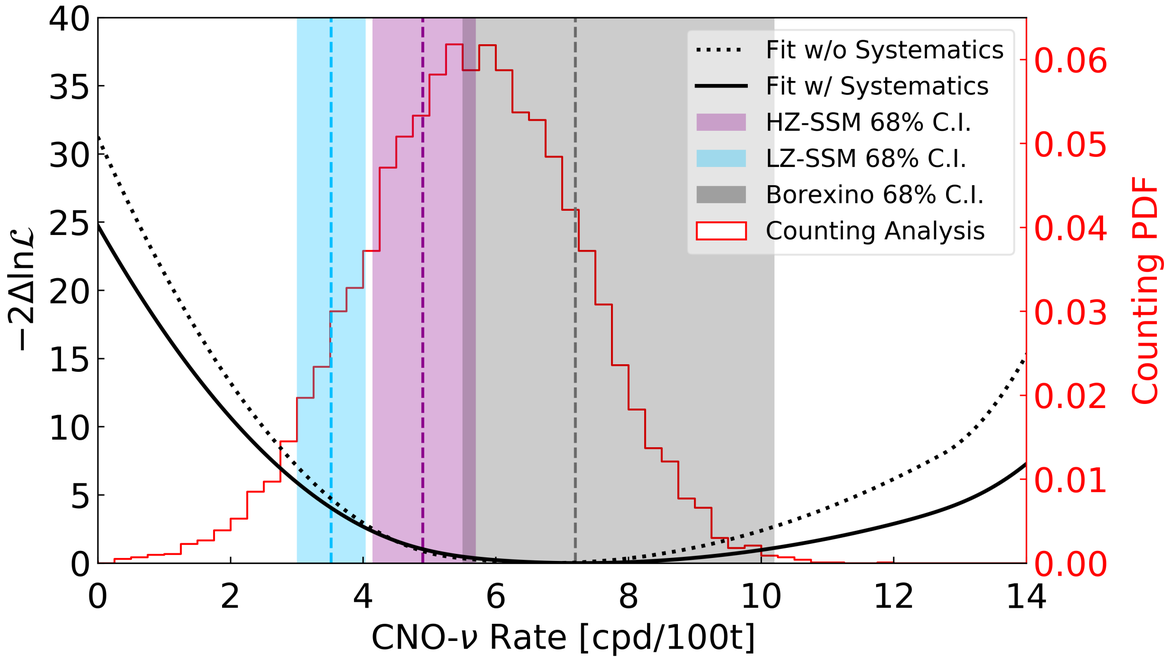




Borexino collaboration 2017

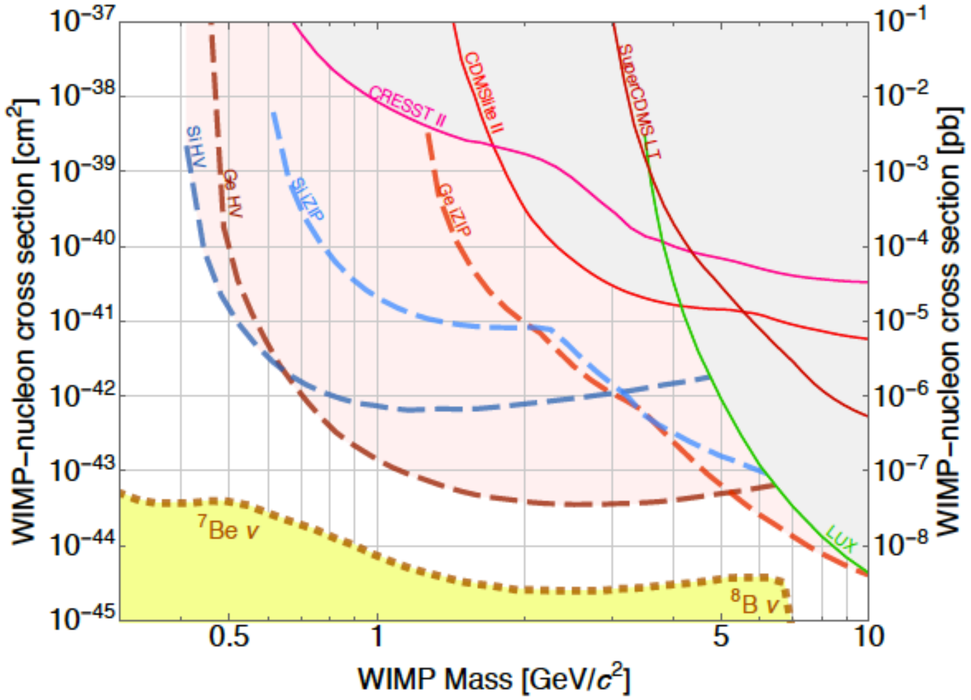
Solar metallicity with Borexino





Borexino collaboration 2020

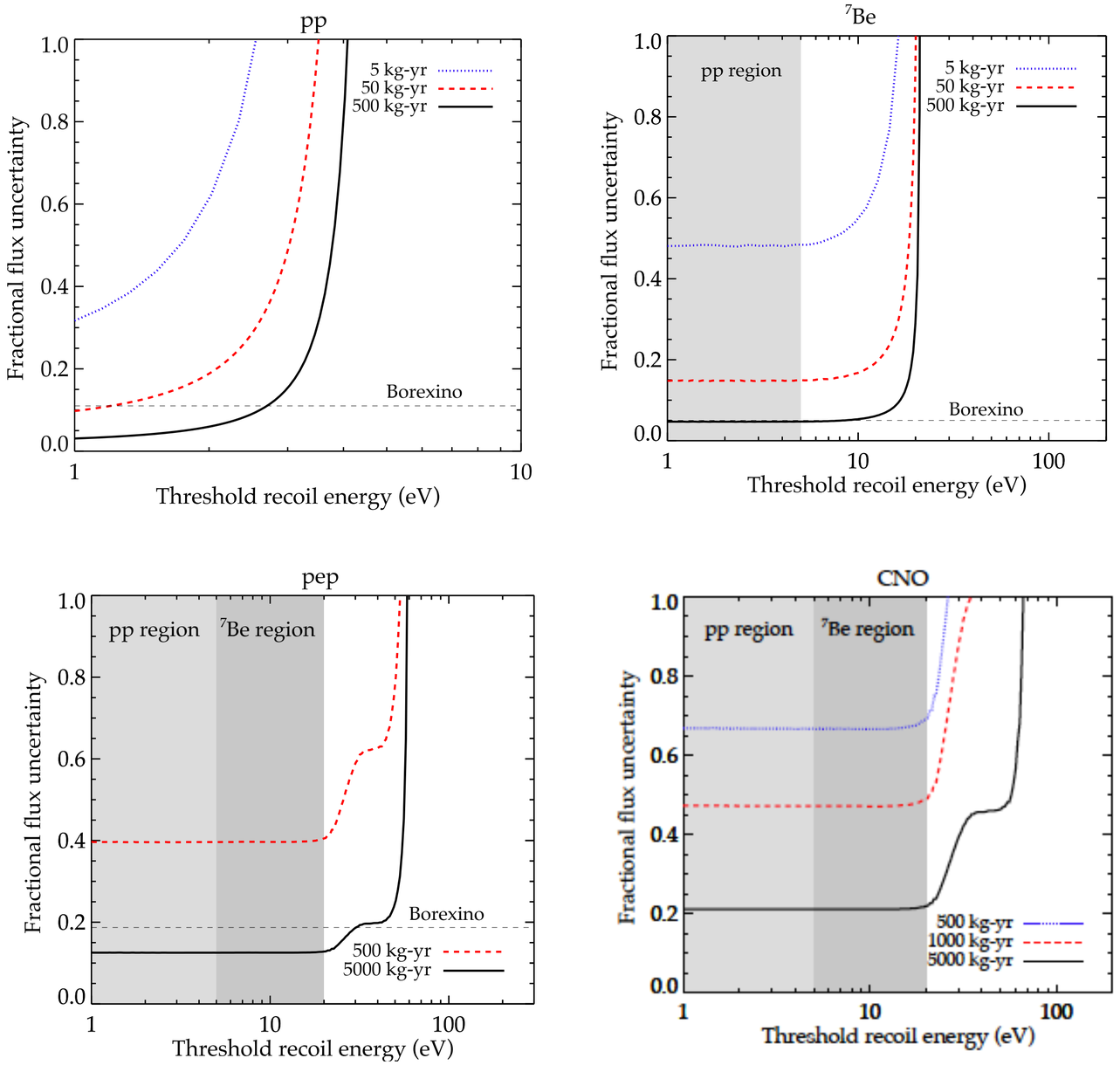
Ultra-low thresholds



SuperCDMS SNOLAB projections [1610.00006]

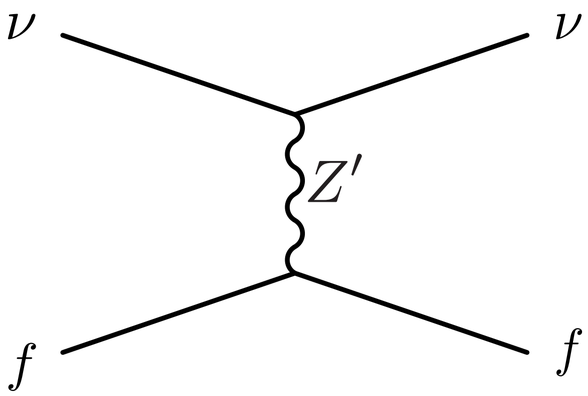
Nu-cleus experiment [1704.04320]

Translated into constraints on Solar model parameters [Cerdeno et al, 1604.01025]

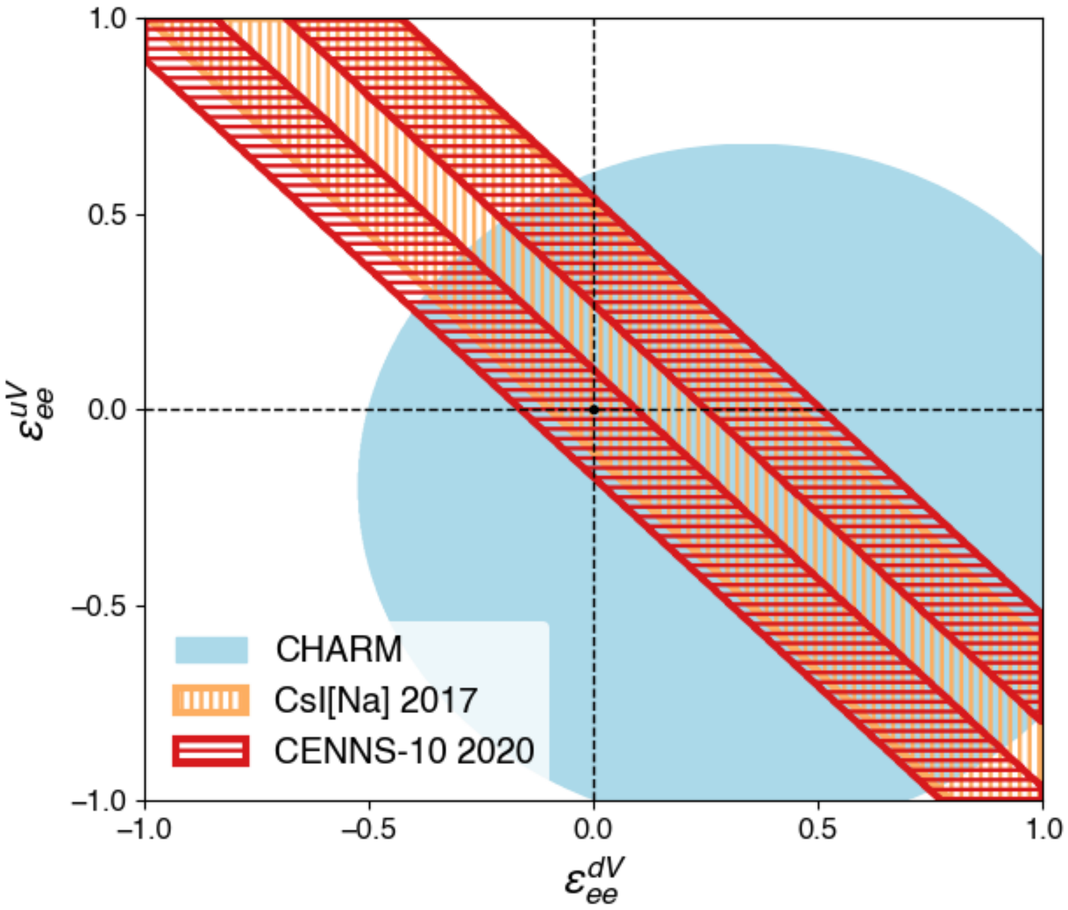


L. Strigari PRD 2016

Non-Standard Neutrino Interactions

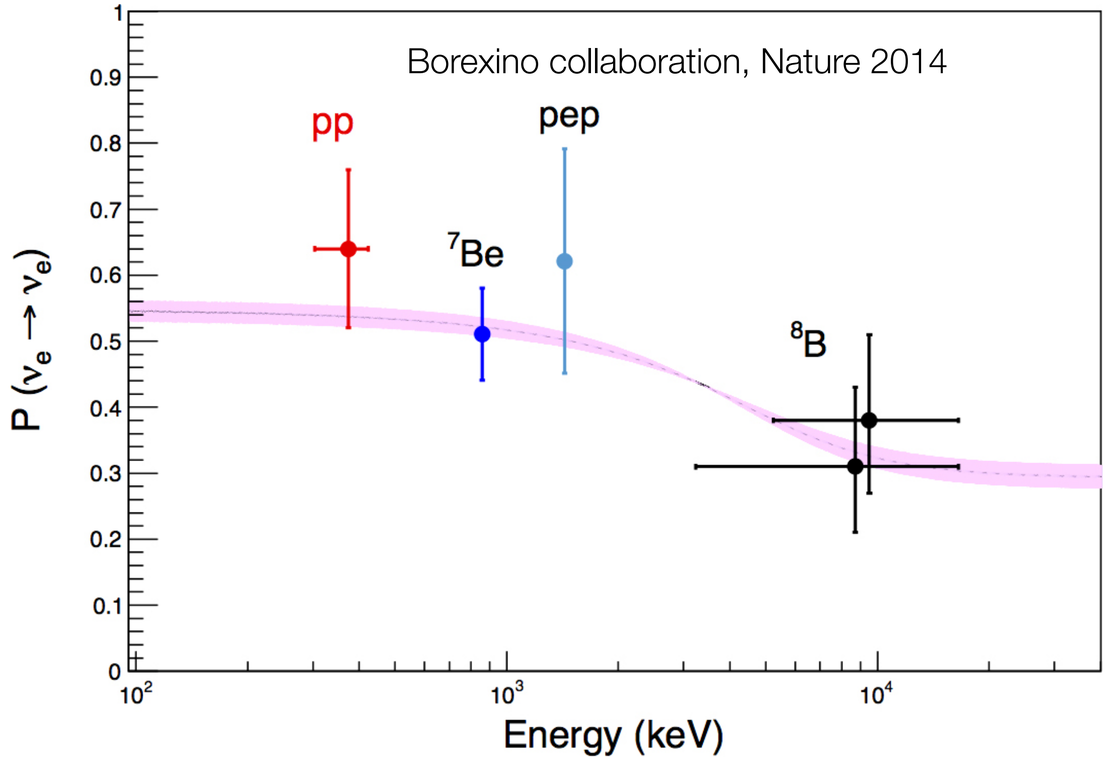


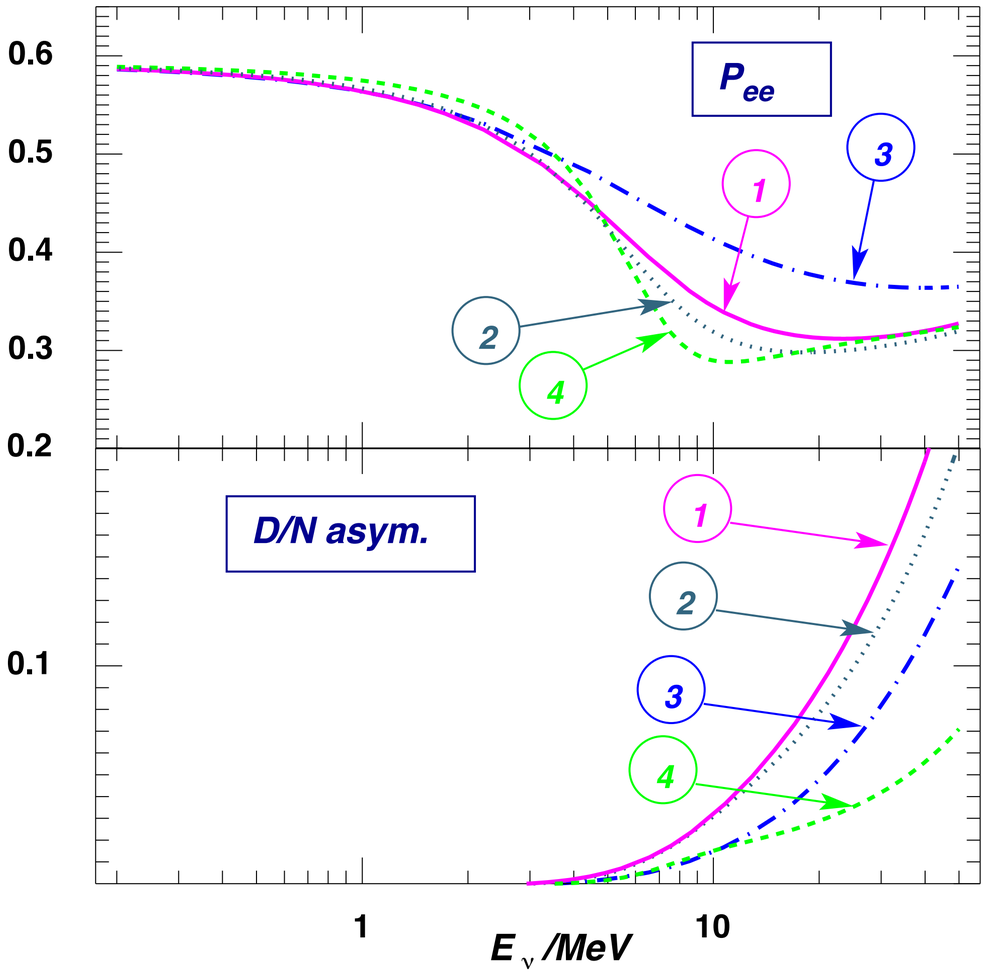
$$\mathcal{L}_{int} = 2\sqrt{2}G_F\bar{\nu}_{\alpha L}\gamma^\mu\nu_{\beta L}\left(\epsilon^{fL}_{\alpha\beta}\bar{f}_L\gamma_\mu f_L + \epsilon^{fR}_{\alpha\beta}\bar{f}_R\gamma_\mu f_R\right)$$



$$\frac{d\sigma}{dT}(E_\nu, T) = \frac{G_F^2 M}{\pi}\left(1 - \frac{MT}{2E_\nu^2}\right) \times \left\{\left[Z(g_V^p + 2\varepsilon_{ee}^{uV} + \varepsilon_{ee}^{dV}) + N(g_V^n + \varepsilon_{ee}^{uV} + 2\varepsilon_{ee}^{dV})\right]^2 + \sum_{\alpha=\mu,\tau}\left[Z(2\varepsilon_{\alpha e}^{uV} + \varepsilon_{\alpha e}^{dV}) + N(\varepsilon_{\alpha e}^{uV} + 2\varepsilon_{\alpha e}^{dV})\right]^2\right\}$$

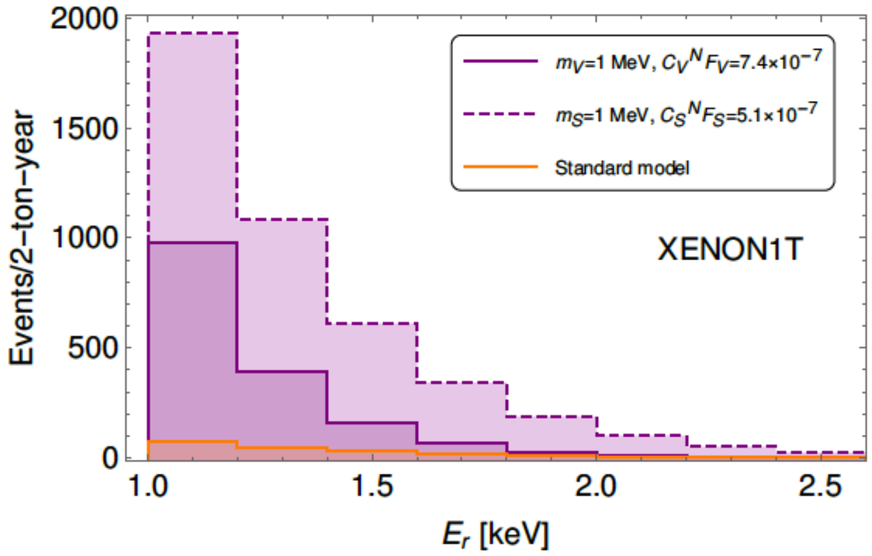
Survival probability with Non-Standard Neutrino Interactions

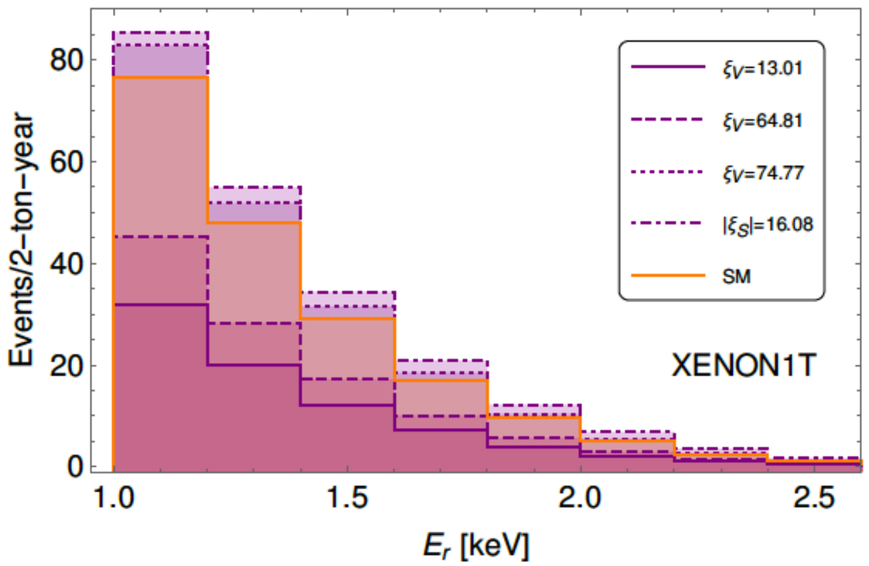




Friedland, Lunardini, Pena-Garay PLB 2004

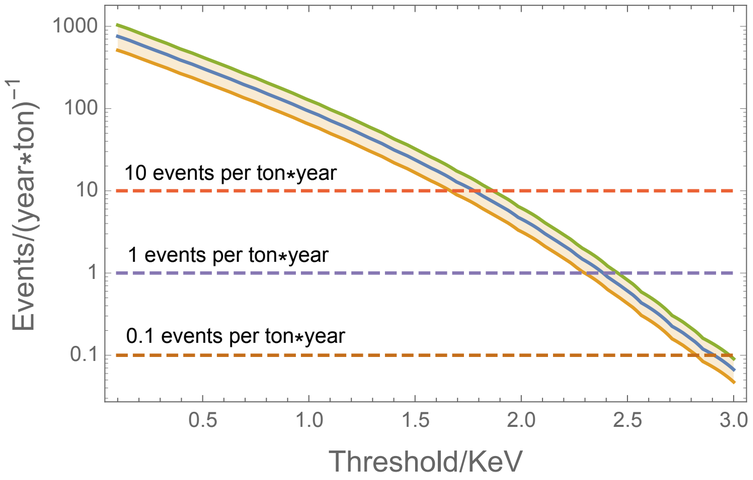
Solar neutrinos and Non-Standard Interactions





In the effective or in the light mediator limit, NSI may increase or decrease the predicted rate in low-threshold detectors [D. Aristizabal-Sierra, B. Dutta, S. Liao, L. Strigari 2019]

Matter potential introduces new phenomenology
[B. Dutta, S. Liao, L. Strigari, J. Walker, PLB 2017 (1705.00661)]

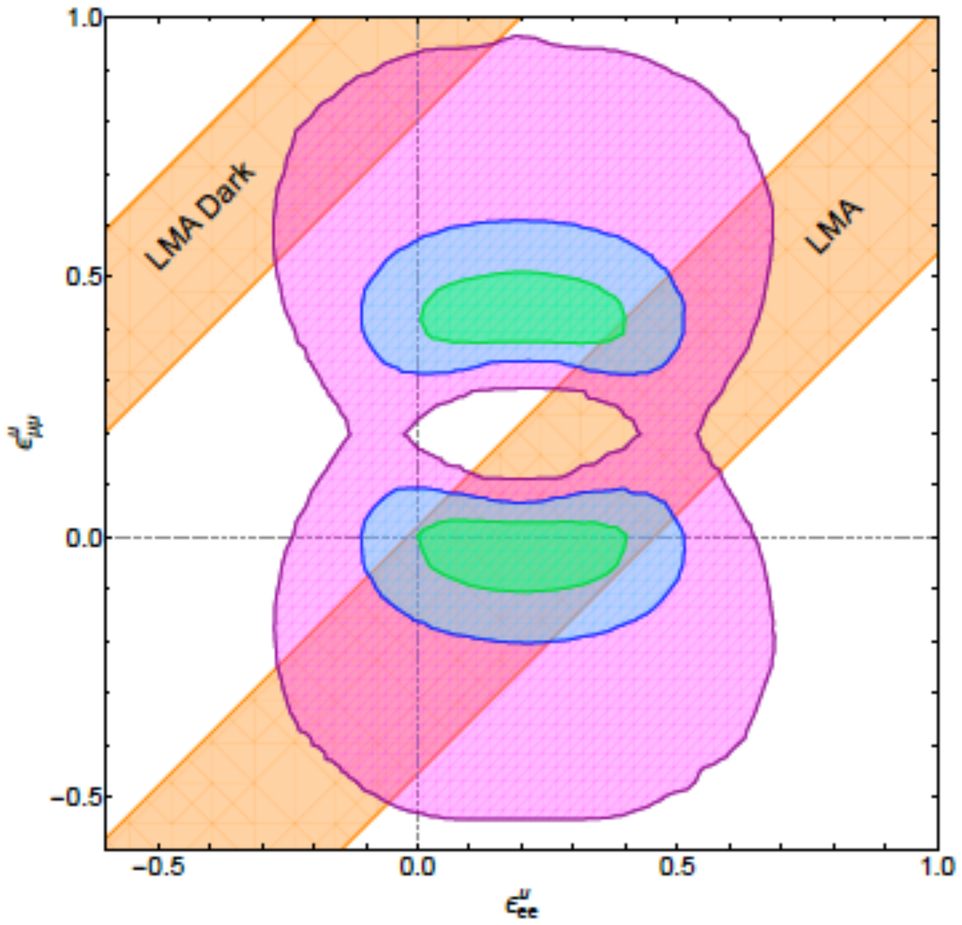


Constraints on ***dark side*** solutions

- Measurements of oscillation parameters are degenerate with NSI parameters. Oscillation data still allow for large NSI couplings and MSW LMA Dark side solution [Miranda, Valle, Tortola, 2006]

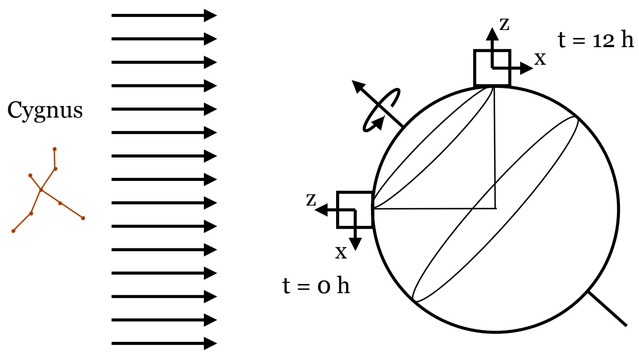
- Changes octant of solar angle and sign of mass ordering

- Non-oscillation experiments (e.g. coherent scattering) required to lift this degeneracy

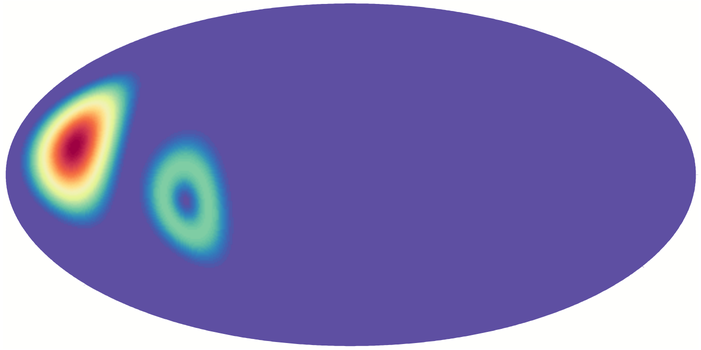


Coloma, Gonzalez-Garcia, Maltoni, Schwetz PRD 2017; Coloma, Denton, Gonzalez-Garcia, Maltoni 2017; Denton, Farzan, Shoemaker 2018; Denton & Gehrlein 2020

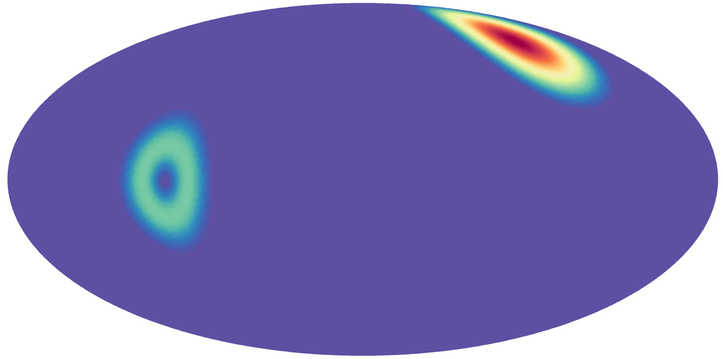
Directional detectors

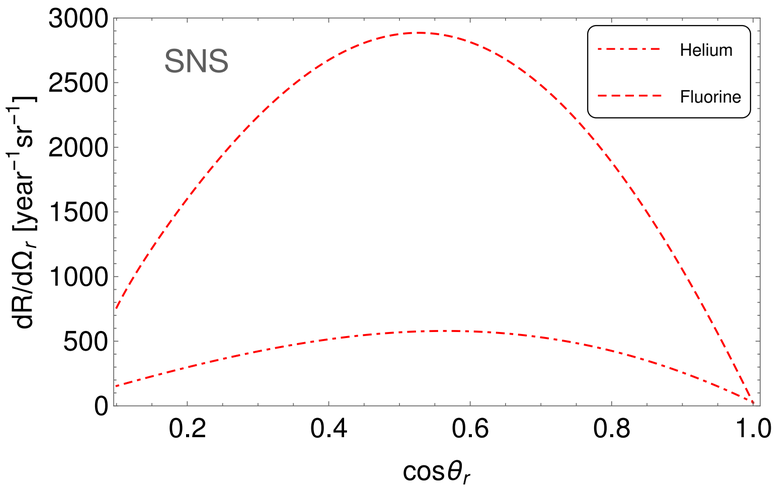


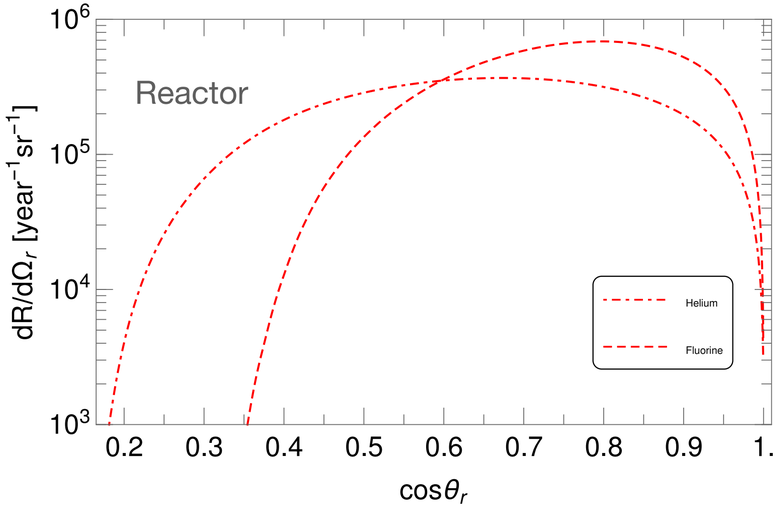
Feb. 26



Sept. 6

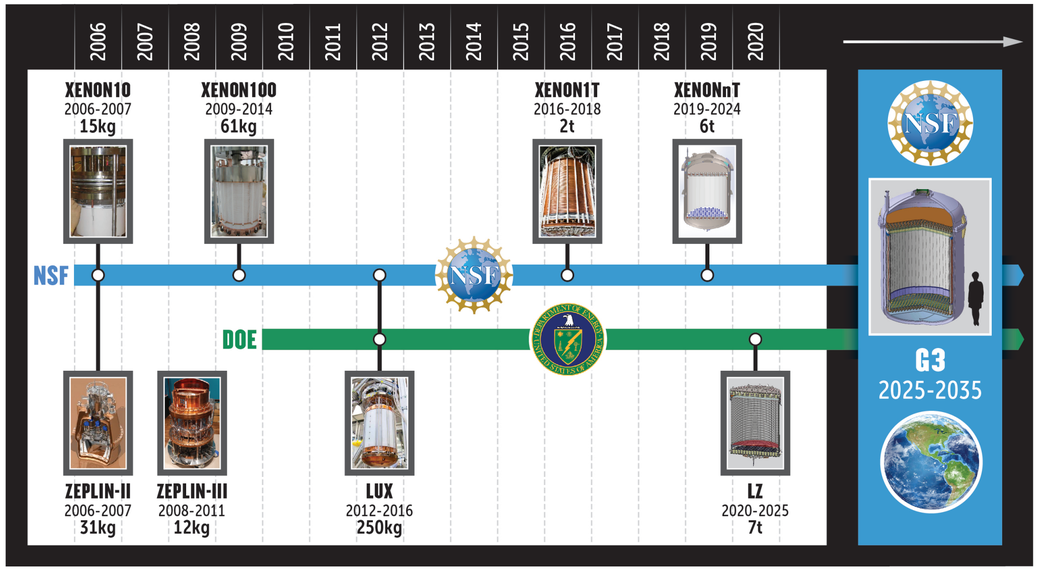






Dark matter detectors with directional sensitivity can eliminate the neutrino background [O' Hare et al. PRD 2015]

Abdullah, Aristizibal-Sierra, Dutta, Strigari PRD 2020

CEvNS in the next decade

- Dark matter/neutrino observatories will gain new sensitivities to solar, supernovae, and atmospheric neutrinos
- CEvNS detections from astrophysics and terrestrial sources