Coherent neutrino-nucleus scattering (CEvNS): Overview

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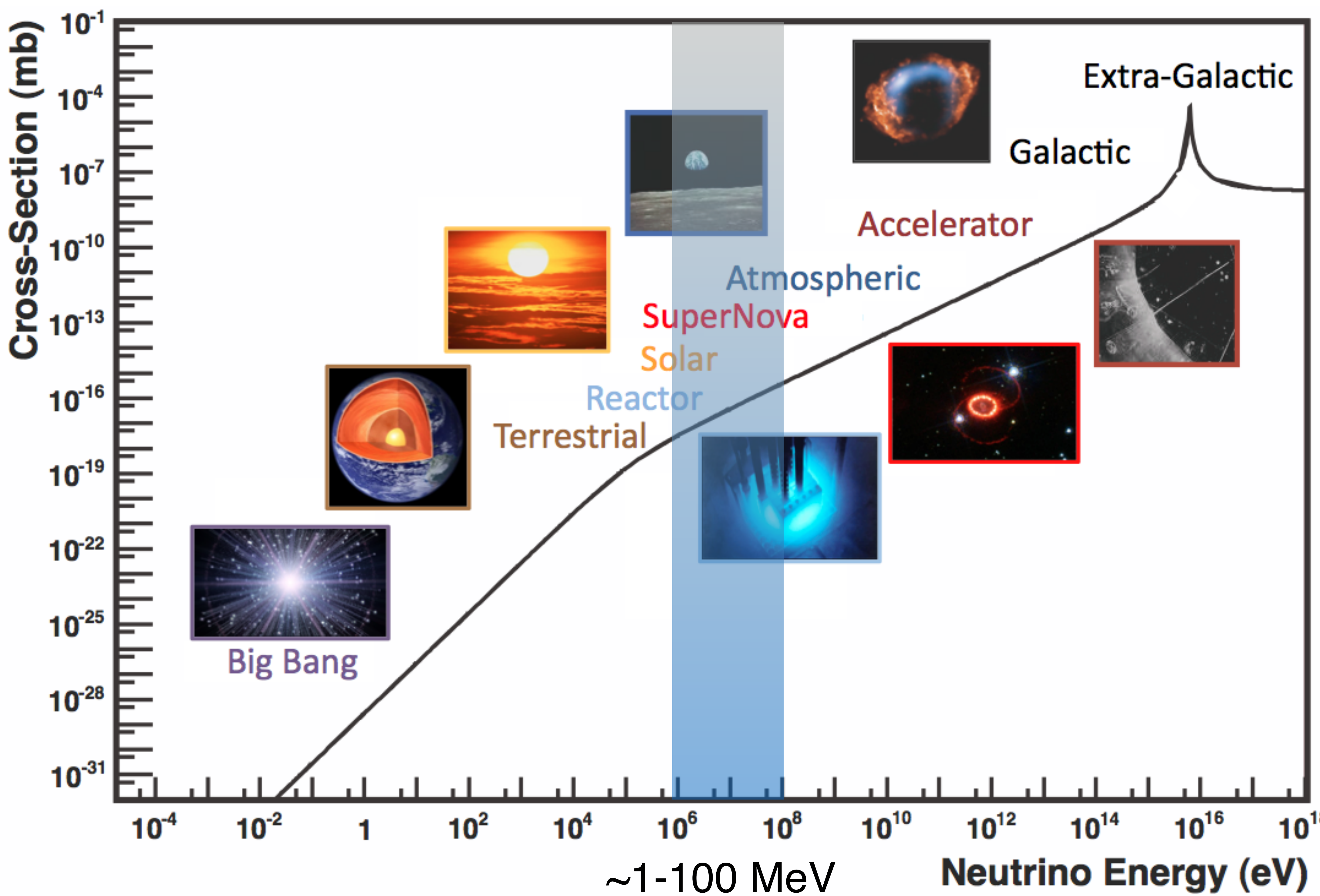
Mitchell Institute for Fundamental Physics and Astronomy

Weak Interactions and Neutrinos 2021
June 8, 2021

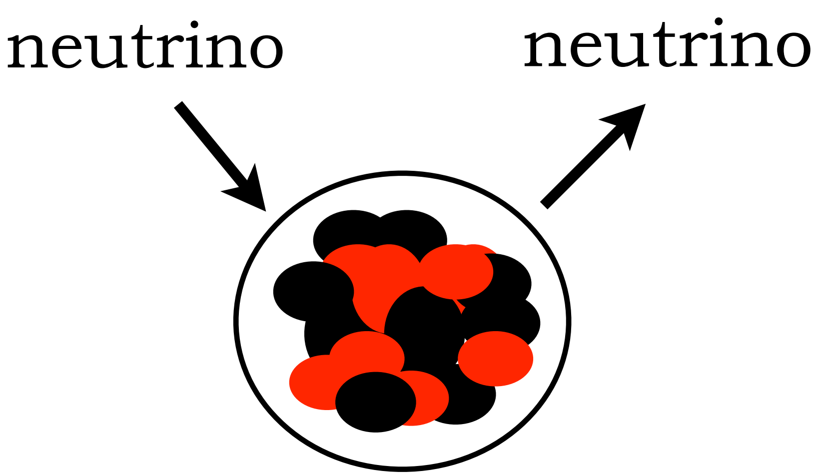
Artwork by Sandbox Studio, Chicago with Ana Kova

Neutrino interactions across all energies



Formaggio & Zeller 2012

Coherent elastic neutrino-nucleus scattering (CEvNS)



Coherent effects of a weak neutral current

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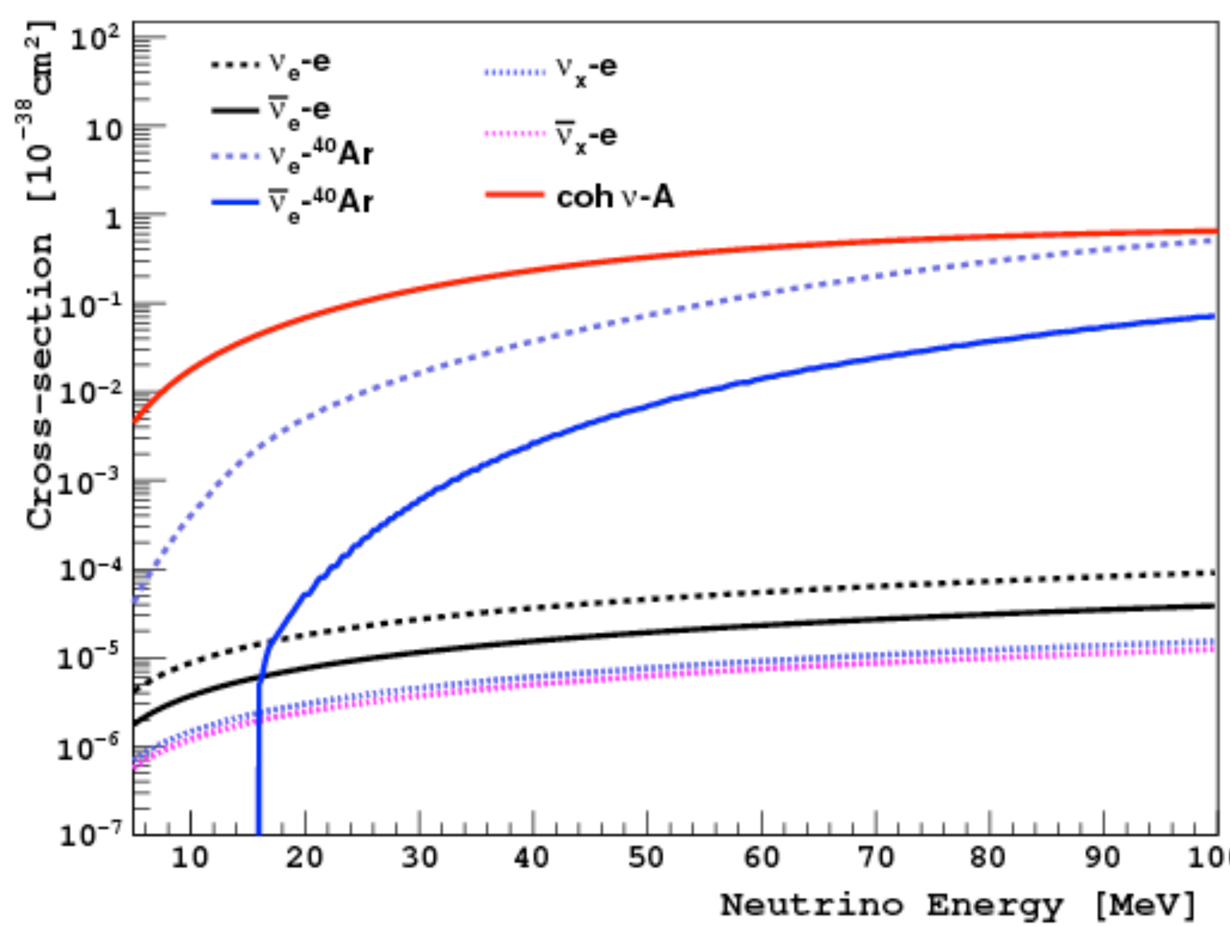
National Accelerator Laboratory, Batavia, Illinois 60510
and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790

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



Neutral current interaction; Due to Standard Model couplings coherent enhancement due to neutrons

Total scattering amplitude sum of that on constituent nucleons

Small momentum transfer relative to target size implies coherent enhancement

Low energy recoil distribution implies difficult to detect

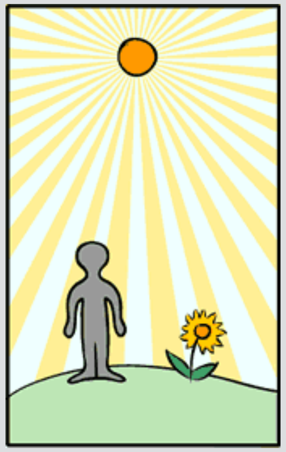
Brice et al, 1311.5958

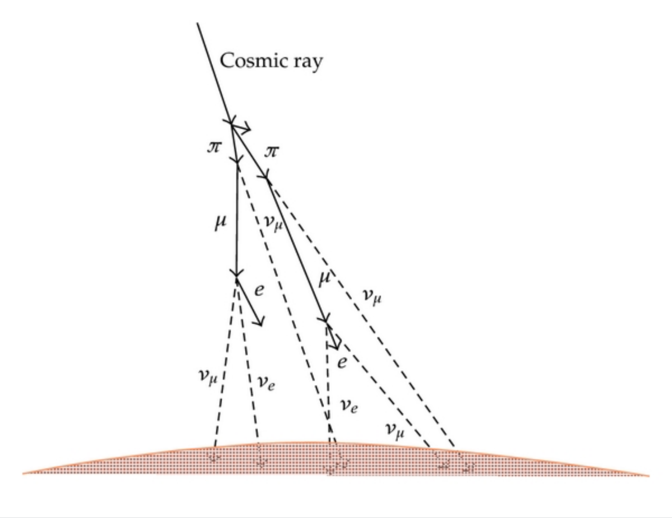
Complementarity in CEvNS

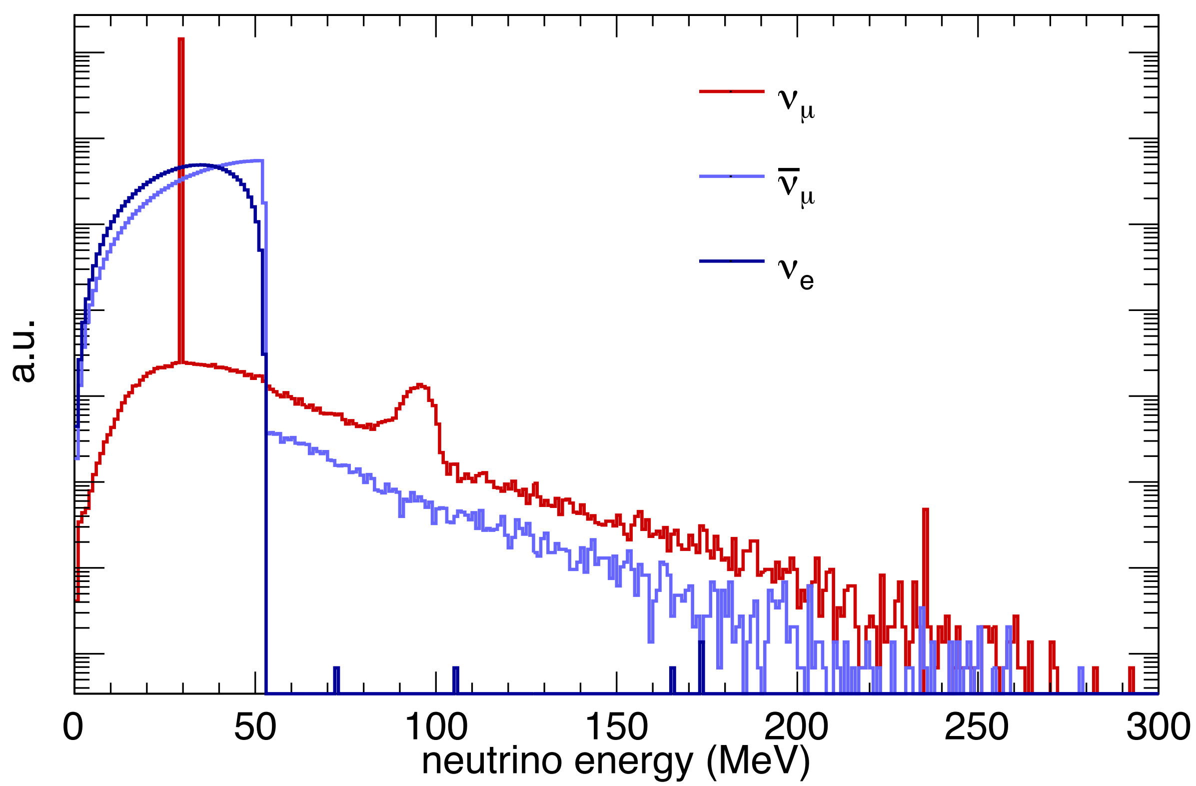
Accelerators (COHERENT)

Reactors

Astrophysical sources







$$\textit{Prompt:} \quad \pi^+ \rightarrow \mu^+ + \nu_\mu$$

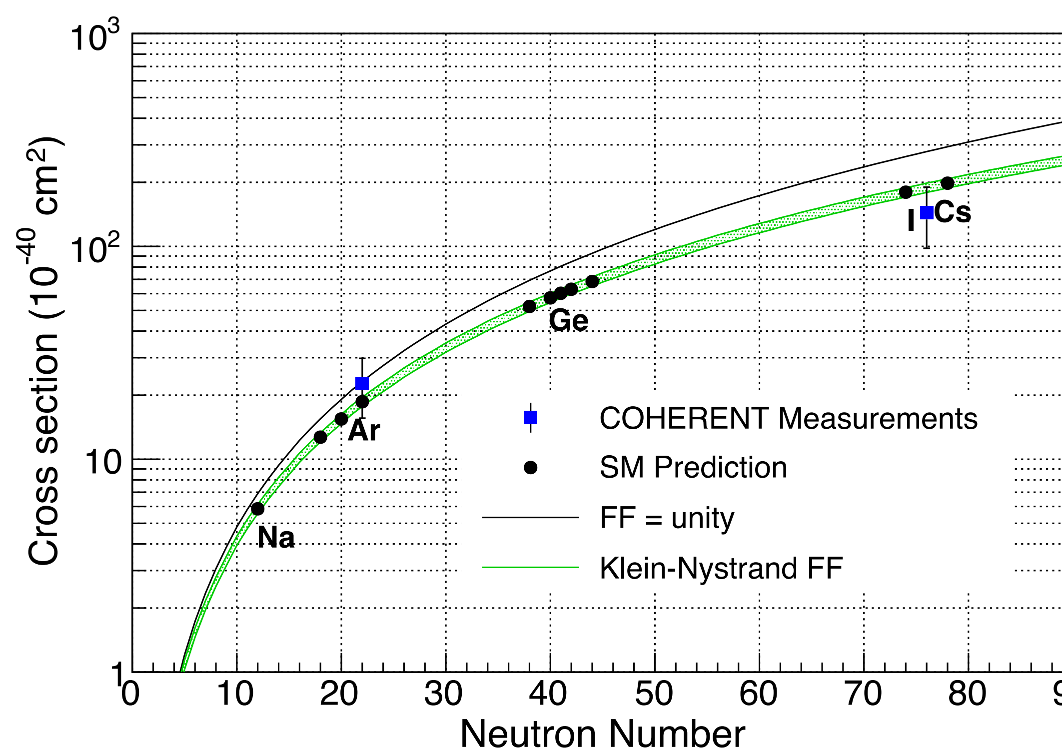
$$\textit{Delayed:} \quad \mu^+ \rightarrow e^+ + \overline{\nu_\mu} + \nu_e$$

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

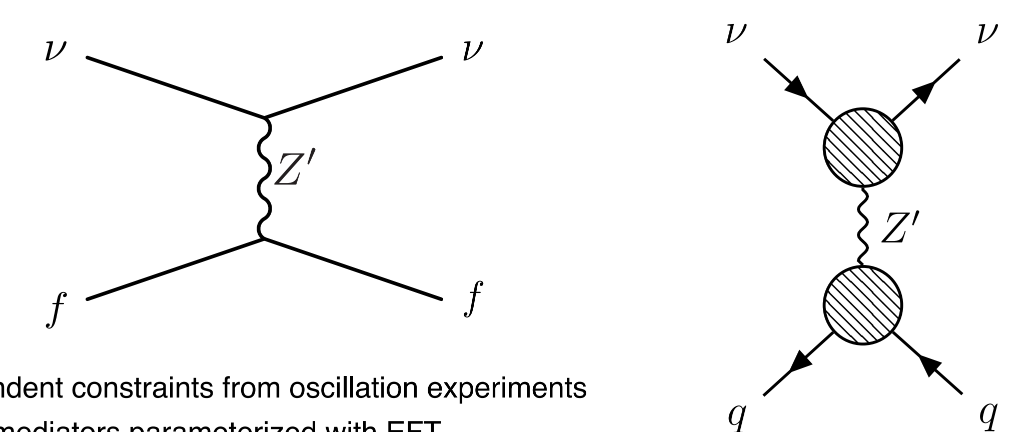
First Detection of Coherent Elastic Neutrino-Nucleus Scattering on Argon

D. Akimov,[1,2] J.B. Albert,[3] P. An,[4,5] C. Awe,[4,5] P.S. Barbeau,[4,5] B. Becker,[6] V. Belov,[1,2] M.A. Blackston,[7] L. Blokland,[6] A. Bolozdynya,[2] B. Cabrera-Palmer,[8] N. Chen,[9] D. Chernyak,[10] E. Conley,[4] R.L. Cooper,[11,12] J. Daughhetee,[6] M. del Valle Coello,[3] J.A. Detwiler,[9] M.R. Durand,[9] Y. Efremenko,[6,7] S.R. Elliott,[12] L. Fabris,[7] M. Febbraro,[7] W. Fox,[3] A. Galindo-Uribarri,[6,7] M.P. Green,[5,7,13] K.S. Hansen,[9] M.R. Heath,[7] S. Hedges,[4,5] M. Hughes,[3] T. Johnson,[4,5] M. Kaemingk,[11] L.J. Kaufman,[3,*] A. Khromov,[2] A. Konovalov,[1,2] E. Kozlova,[1,2] A. Kumpan,[2] L. Li,[4,5] J.T. Librande,[9] J.M. Link,[14] J. Liu,[10] K. Mann,[5,7] D.M. Markoff,[5,15] O. McGoldrick,[9] H. Moreno,[11] P.E. Mueller,[7] J. Newby,[7] D.S. Parno,[16] S. Penttila,[7] D. Pershey,[4] D. Radford,[7] R. Rapp,[16] H. Ray,[17] J. Raybern,[4] O. Razuvaeva,[1,2] D. Reyna,[8] G.C. Rich,[18] D. Rudik,[1,2] J. Runge,[4,5] D.J. Salvat,[3] K. Scholberg,[4] A. Shakirov,[2] G. Simakov,[1,2,19] G. Sinev,[4] W.M. Snow,[3] V. Sosnovtsev,[2] B. Suh,[3] R. Tayloe,[3] K. Tellez-Giron-Flores,[14] R.T. Thornton,[3,12] I. Tolstukhin,[3,†] J. Vanderwerp,[3] R.L. Varner,[7] C.J. Virtue,[20] G. Visser,[3] C. Wiseman,[9] T. Wongjirad,[21] J. Yang,[21] Y.-R. Yen,[16] J. Yoo,[22,23] C.-H. Yu,[7] and J. Zettlemoyer[3]
(COHERENT collaboration)



Scientific impact of COHERENT results

Non-standard interactions (NSI)

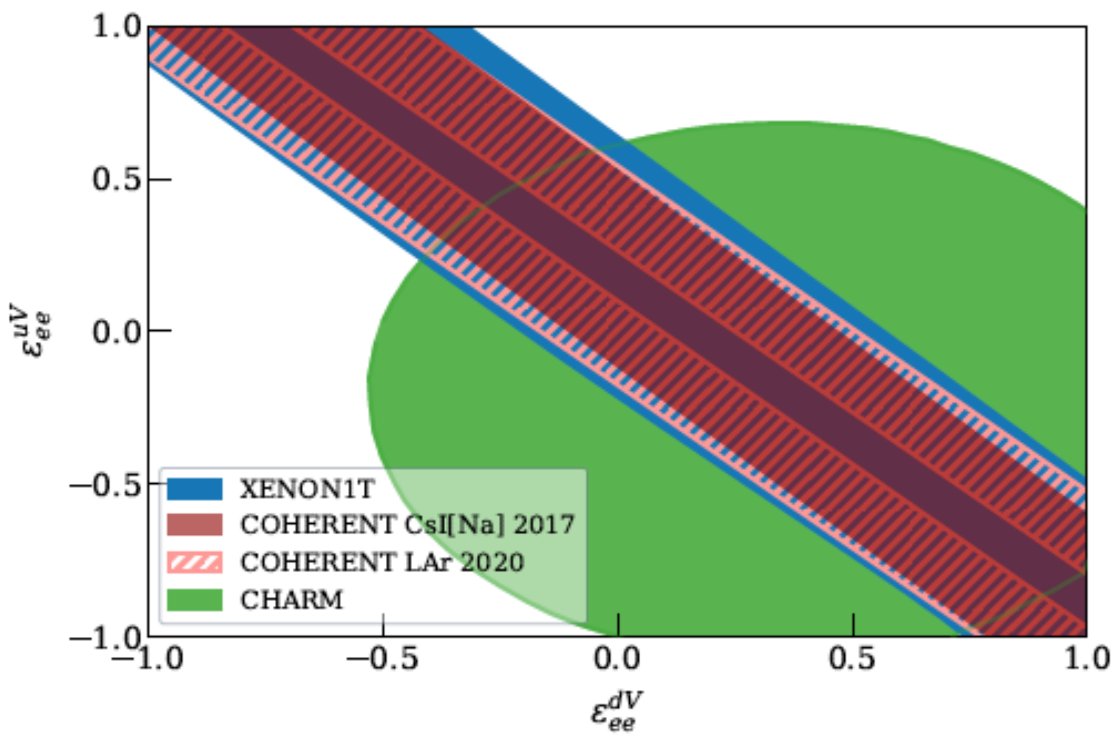


Independent constraints from oscillation experiments

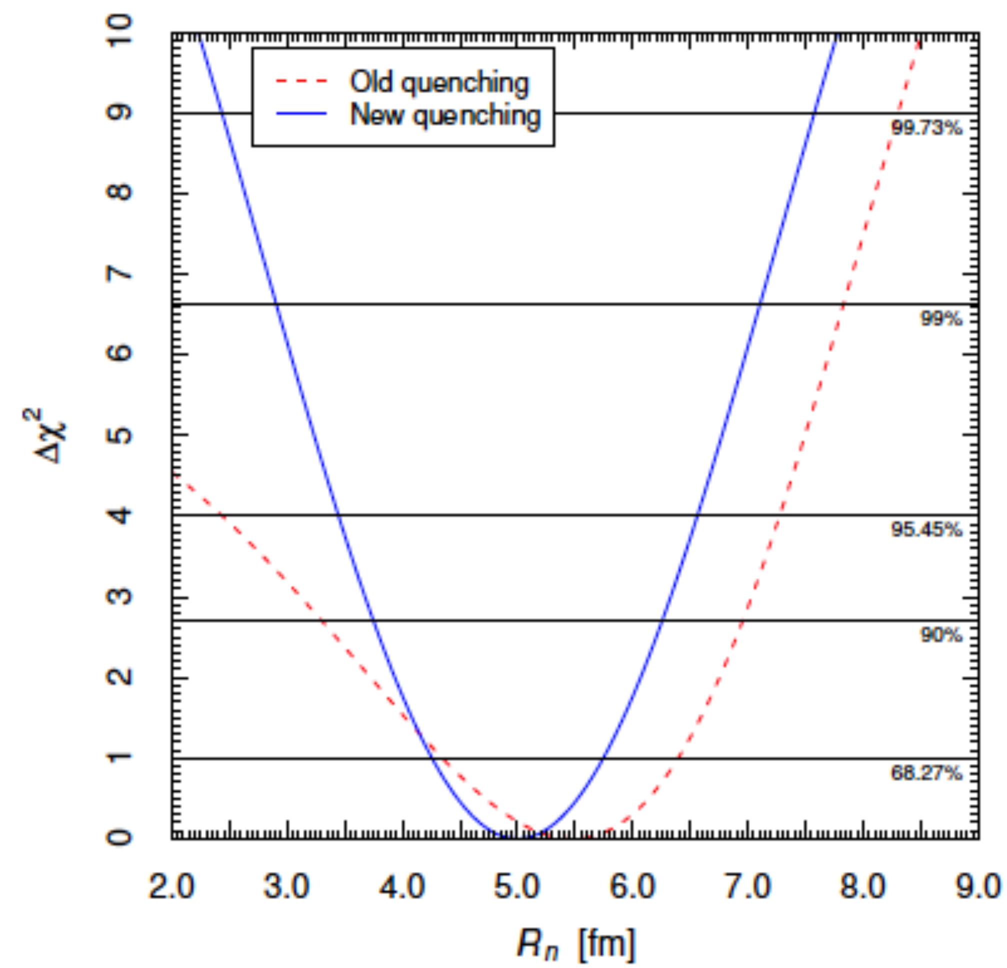
Heavy mediators parameterized with EFT

Dark hypercharge gauge boson; Dark Z boson; Hidden Sector Fermions

Barranco et al. 2005, Scholberg 2005; Liao & Marfatia 2017; Lindner et al. 2017; Farzan et al. 2018; Abdullah et al. 2018, Brdar et al. 2018, Datta et al. 2019



XENON collaboration, PRL 126 (2021) 091301: 2012.02846 [hep-ex]



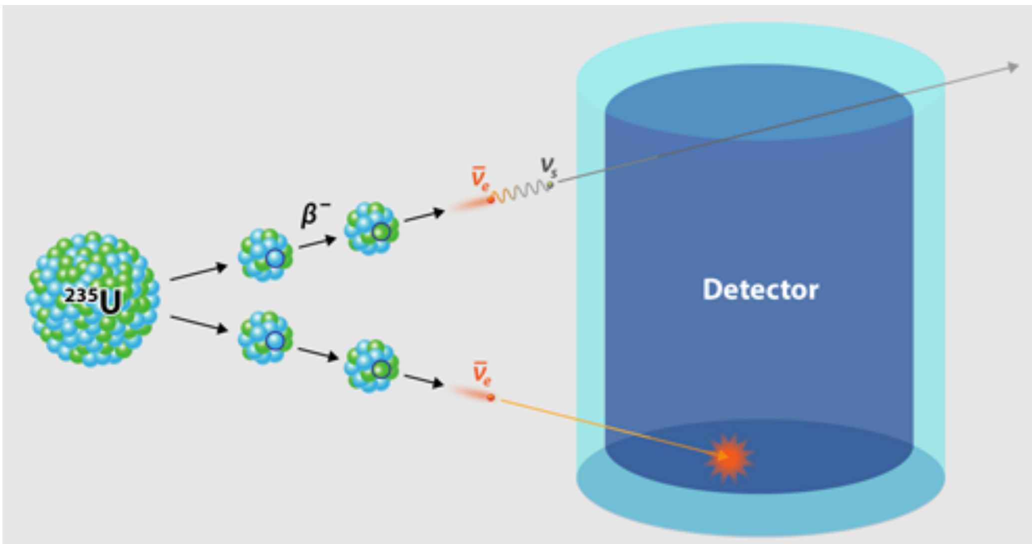
Nuclear structure

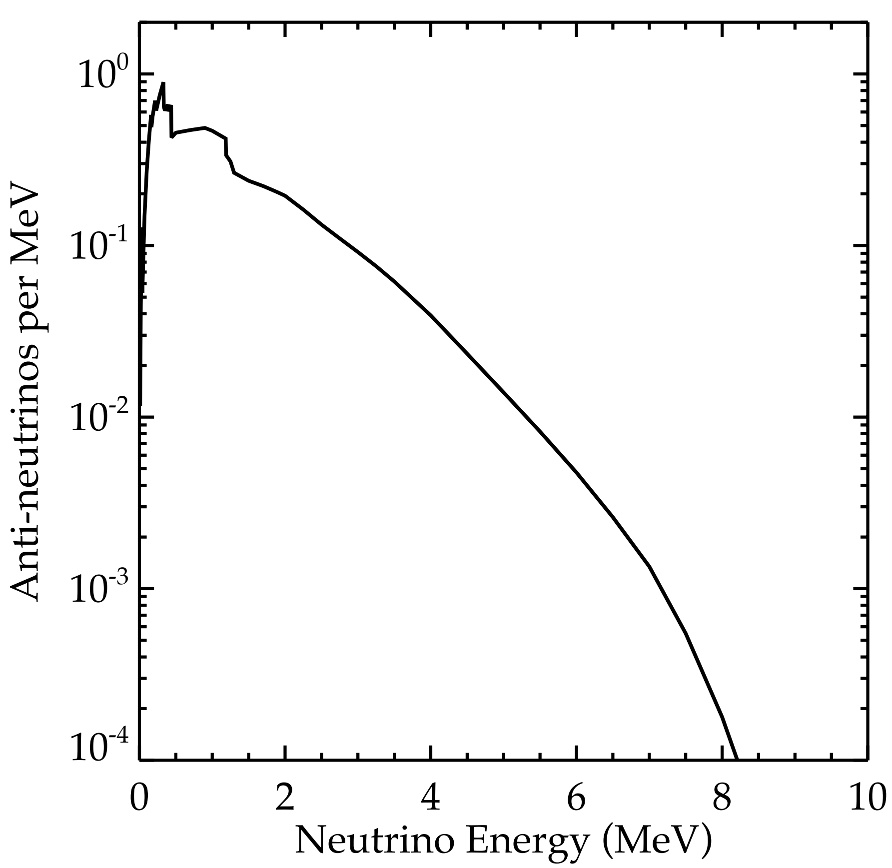
Measurement of the neutron distribution in the nucleus [Cadeddu, Dordei, Giunti, Li, Zhang, 2019; Aristizibal-Sierra, Liao, Marfatia, 2019; Hoferichter, Menendez, Schwenk 2020]

Radiative corrections

Tomalak, Machado, Pandey, Plestid 2021]

CEvNS at nuclear reactors





Exploring CEνNS with NUCLEUS at the Chooz Nuclear Power Plant

G. Angloher[1], F. Ardellier-Desages[2,3], A. Bento[1,4], L. Canonica[1], A. Erhart[5], N. Ferreiro[1], M. Friedl[6], V.M. Ghete[6], D. Hauff[1], H. Kluck[6,7,*], A. Langenkämper[5,*], T. Lasserre[2,3], D. Lhuillier[2], A. Kinast[5], M. Mancuso[1], J. Molina Rubiales[8], E. Mondragon[5], G. Munch[8], C. Nones[2], L. Oberauer[5], A. Onillon[2], T. Ortmann[5], L. Pattavina[5], F. Petricca[1], W. Potzel[5], F. Pröbst[1], F. Reindl[6,7], J. Rothe[1,*], J. Schieck[6,7], S. Schönert[5], C. Schwertner[6,7], L. Scola[2], L. Stodolsky[1], R. Strauss[5], M. Vivier[2], V. Wagner[2,*,†], and A. Zolotarova[2]
(The NUCLEUS Collaboration)

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

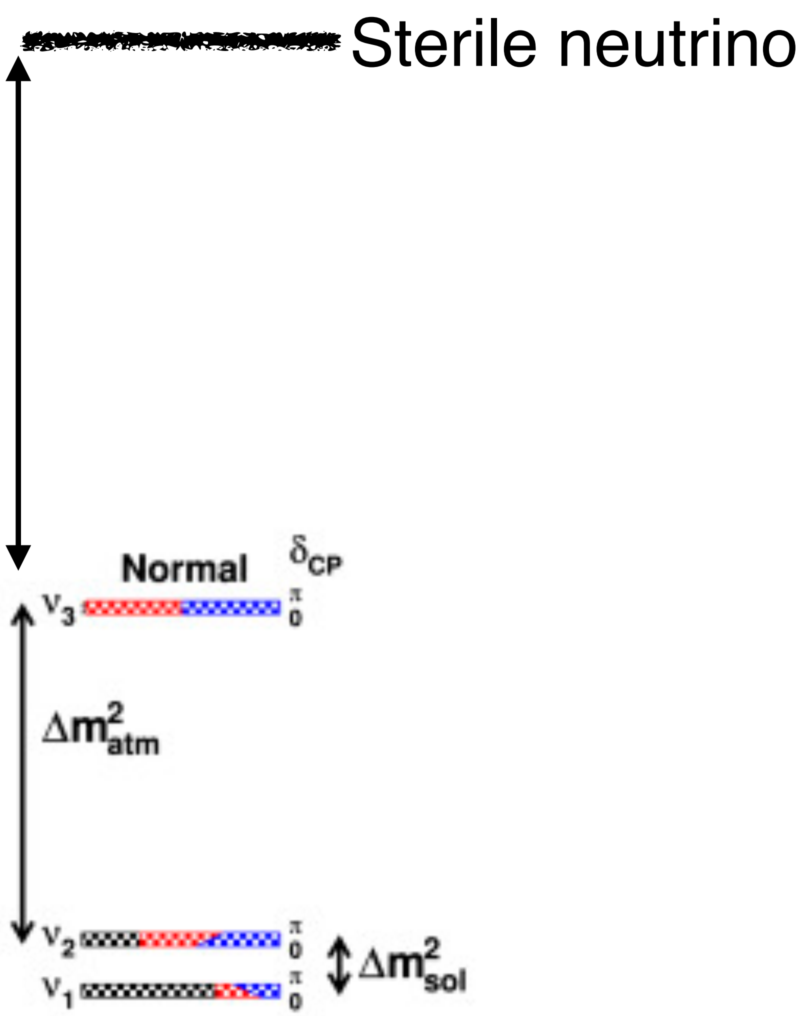
H T Wong[1,*], H B Li[1], S K Lin[1], S T Lin[1], D He[2], J Li[2], X Li[2], Q Yue[2], Z Y Zhou[3] and S K Kim[4]

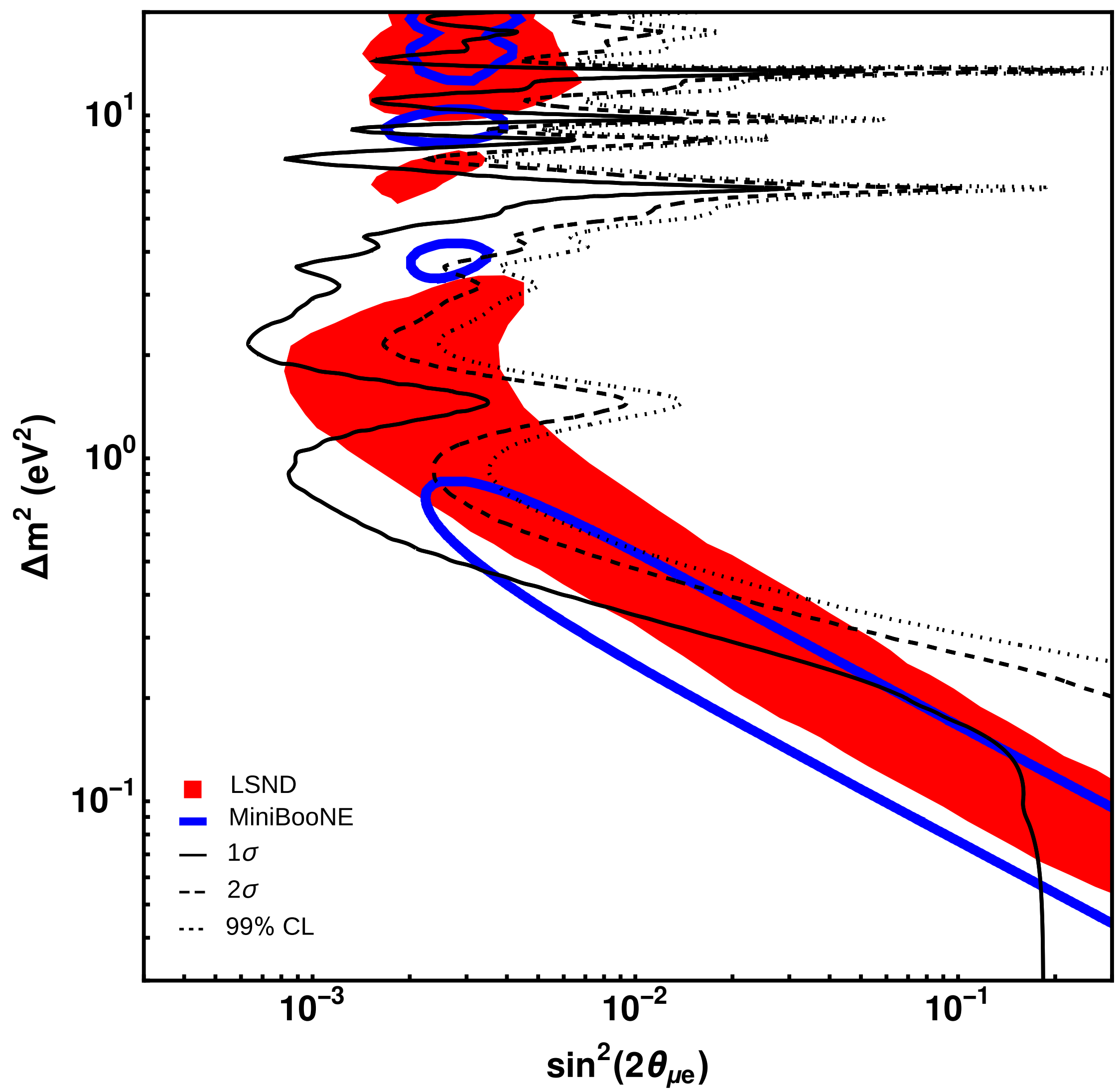
[1] Institute of Physics, Academia Sinica, Taipei 11529, Taiwan.
[2] Department of Engineering Physics, Tsing Hua University, Beijing 100084, China.
[3] Department of Nuclear Physics, Institute of Atomic Energy, Beijing 102413, China.
[4] Department of Physics, Seoul National University, Seoul 151-742,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

New physics searches with reactors and accelerators





LSND, Mini-Boone results may be interpreted as ~ eV sterile neutrinos

Gallium, reactor data also may be interpreted as sterile neutrinos

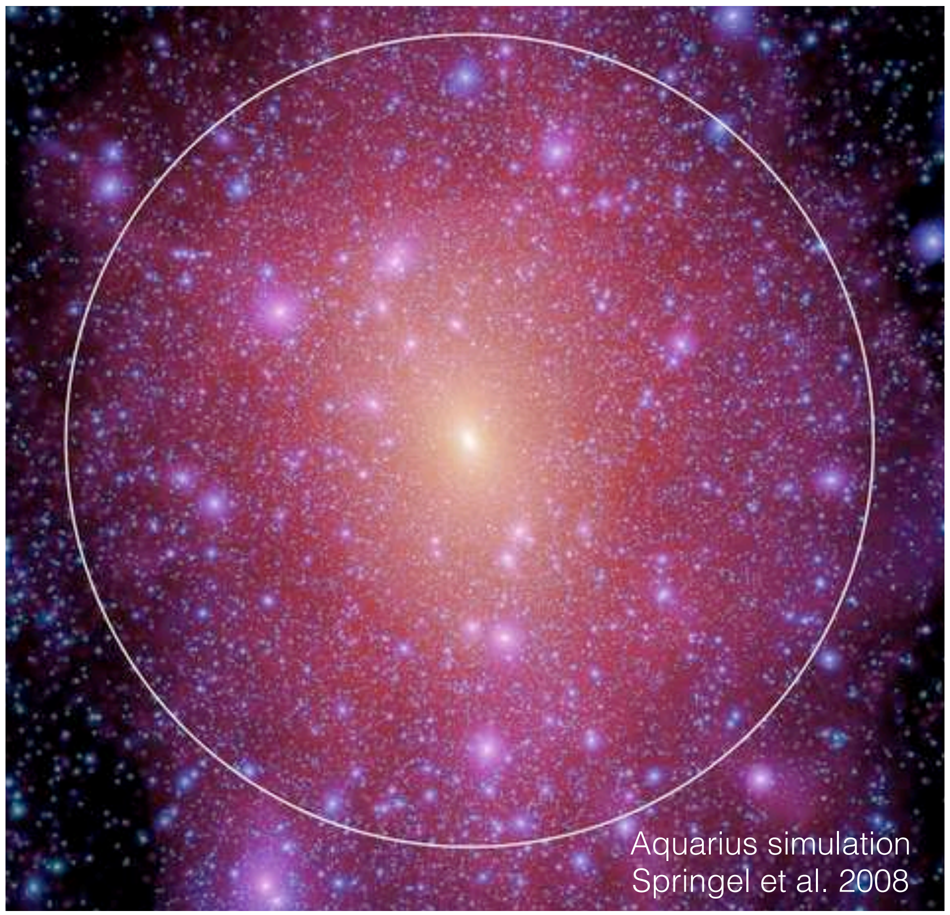
However, some data not consistent with this interpretation (MINOS/IceCube)

COHERENT should be sensitive to sterile neutrinos with several years of data

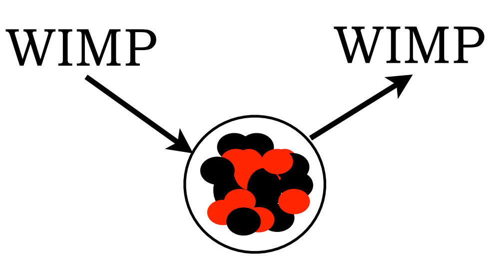
Sterile neutrinos: Anderson et al. 2012; Dutta et al. 2016; Blanco, Machado, Hooper 2019; Miranda et al. 2020

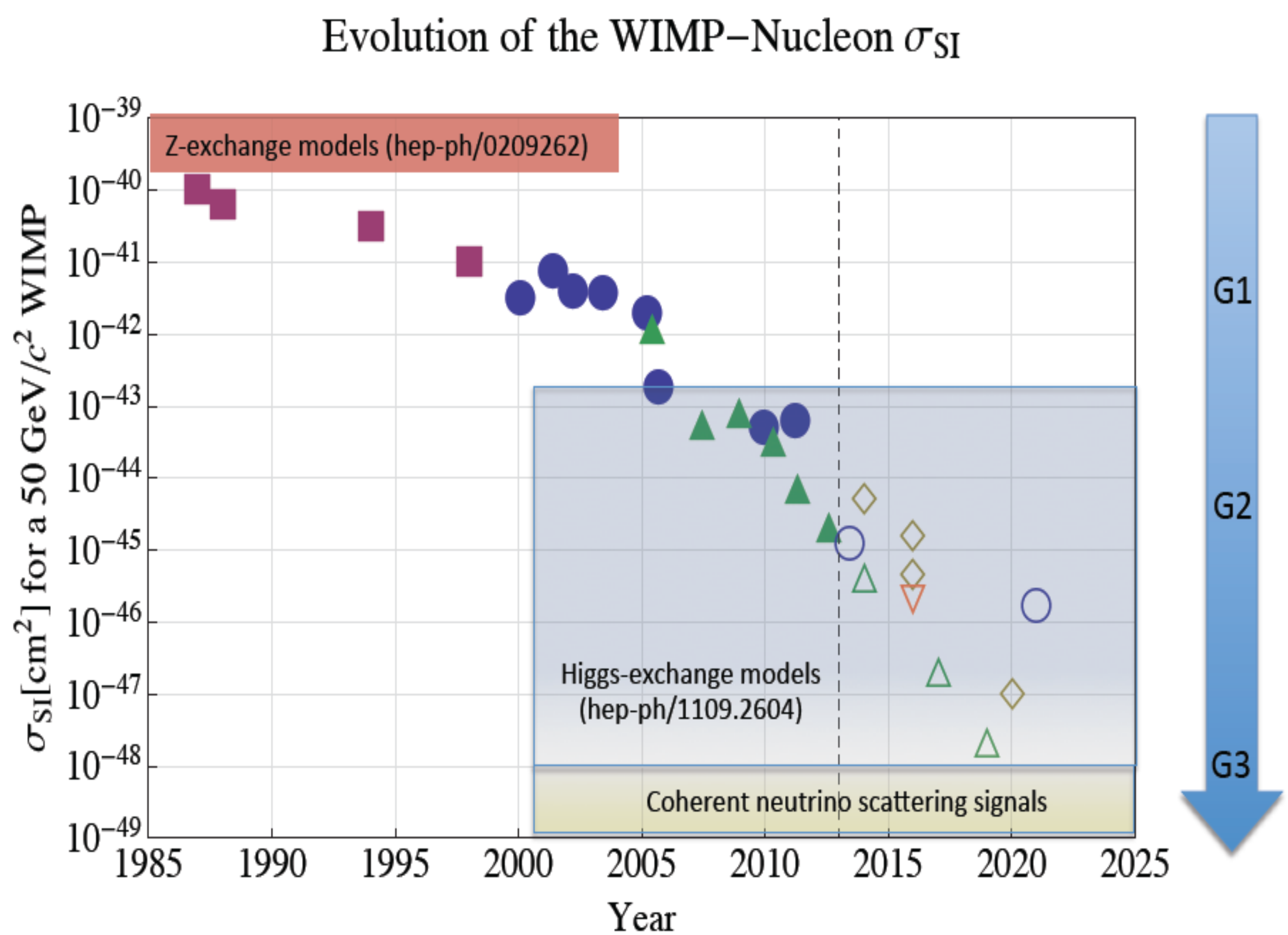
Weak mixing angle: Fernandez-Moroni et al. 2021

Direct detection of weak-scale dark matter



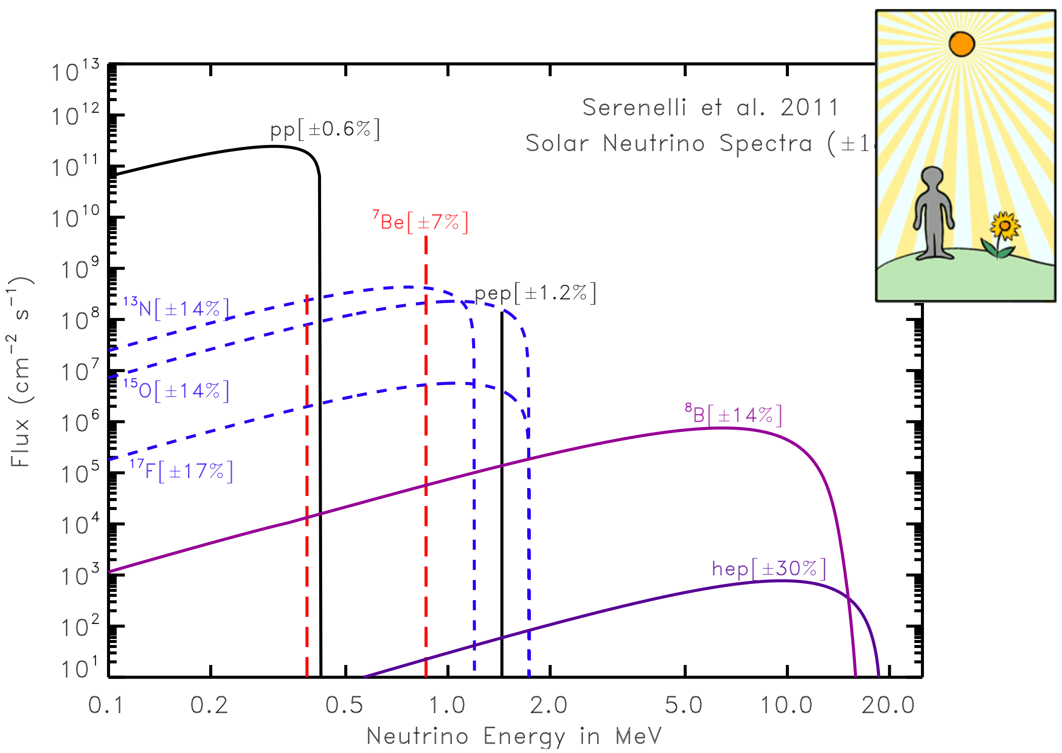
Aquarius simulation
Springel et al. 2008

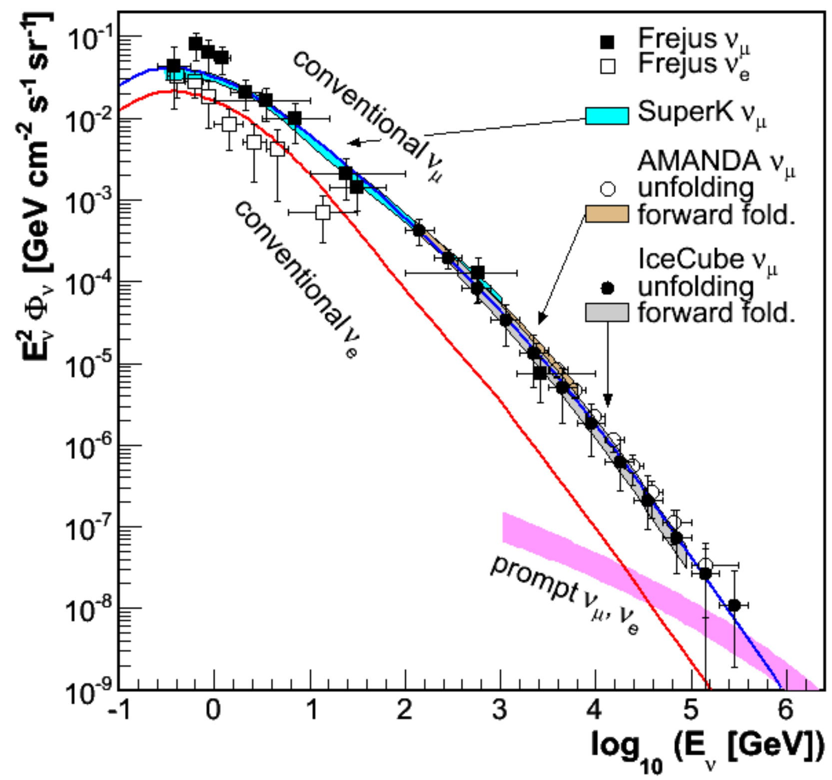


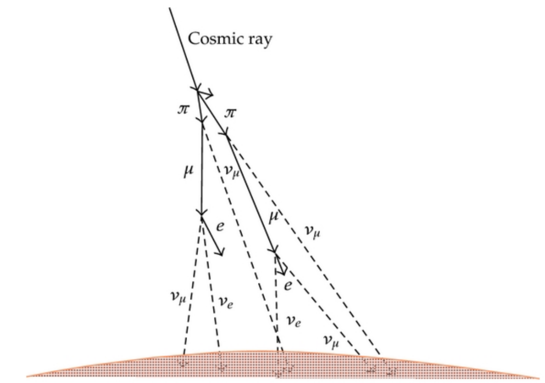


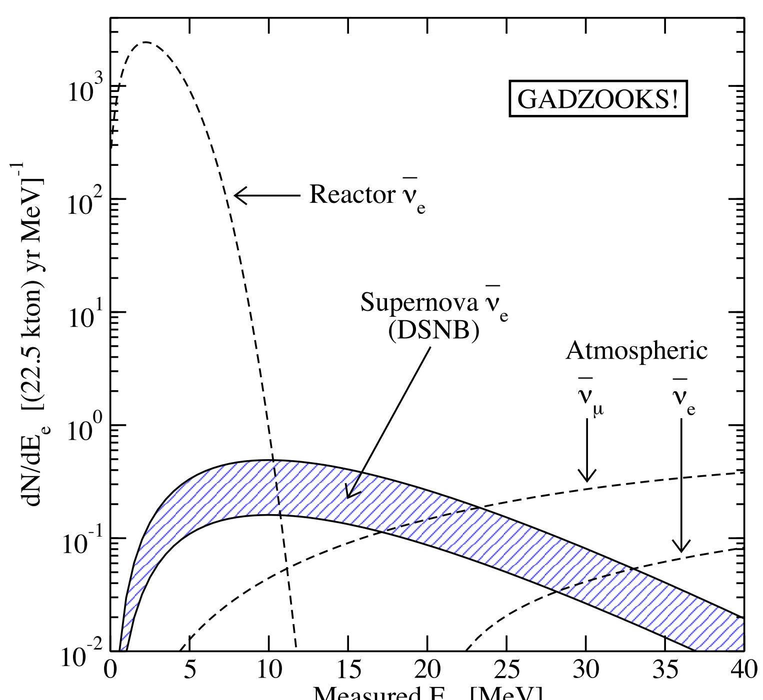
SNOWMASS 2013

Astrophysical neutrinos and dark matter









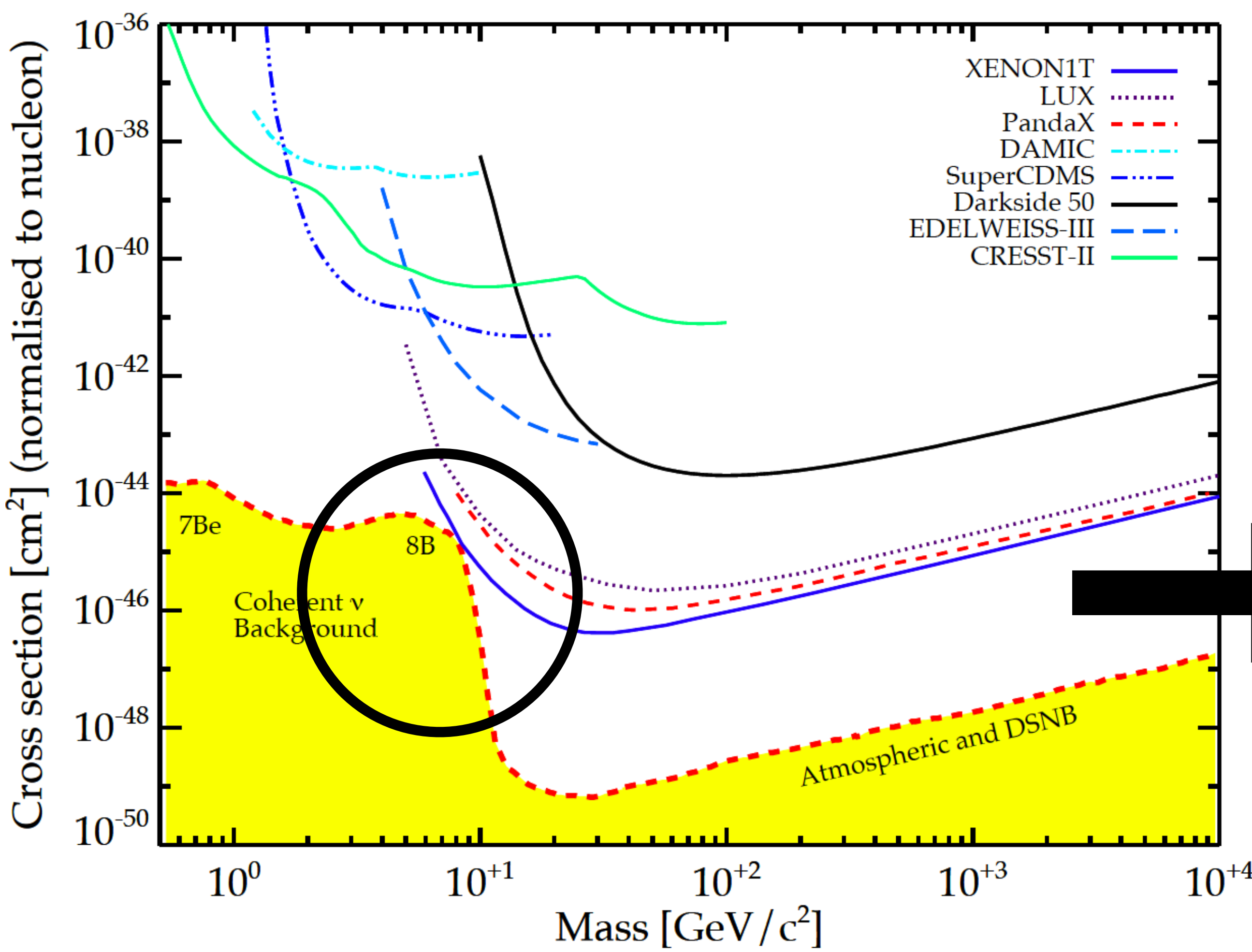
Neutral current sensitivity to all neutrino flavor components

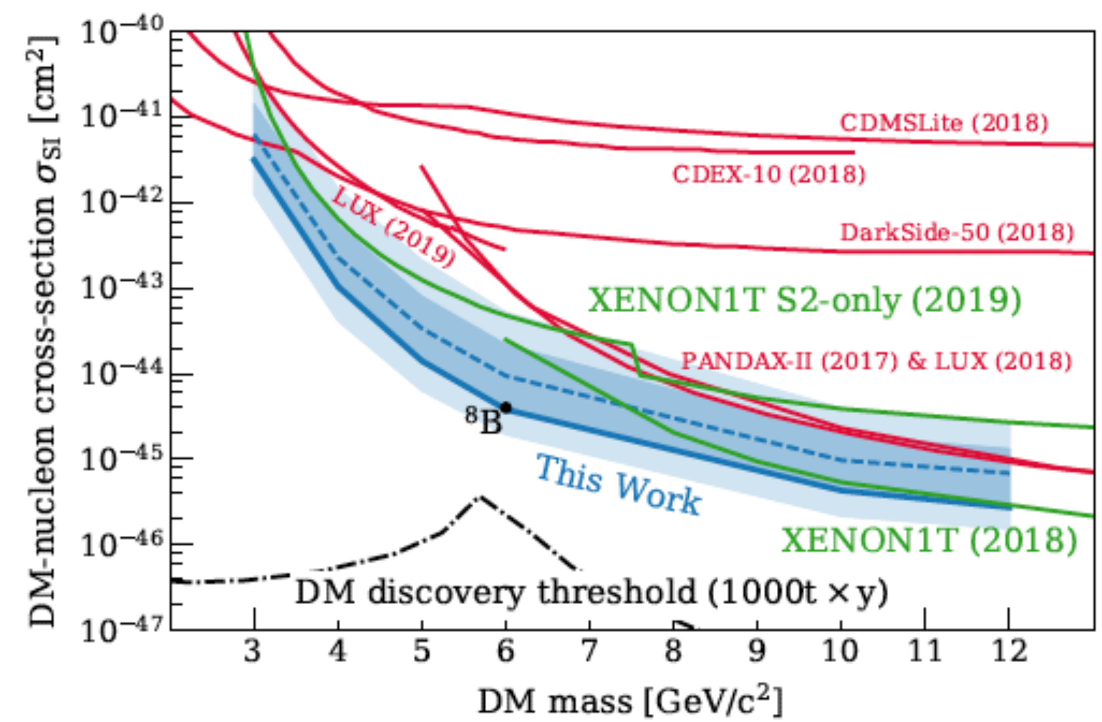
Sensitivity to both Galactic supernova burst [Horiwitz et al. 2003; Lang et al. 2016] and diffuse supernova neutrino background (DSNB) [Strigari 2009]

Galactic SN burst: Lang, McCabe, Richard, Tamborra, Phys.Rev.D 94 (2016) 10, 103009 1606.09243

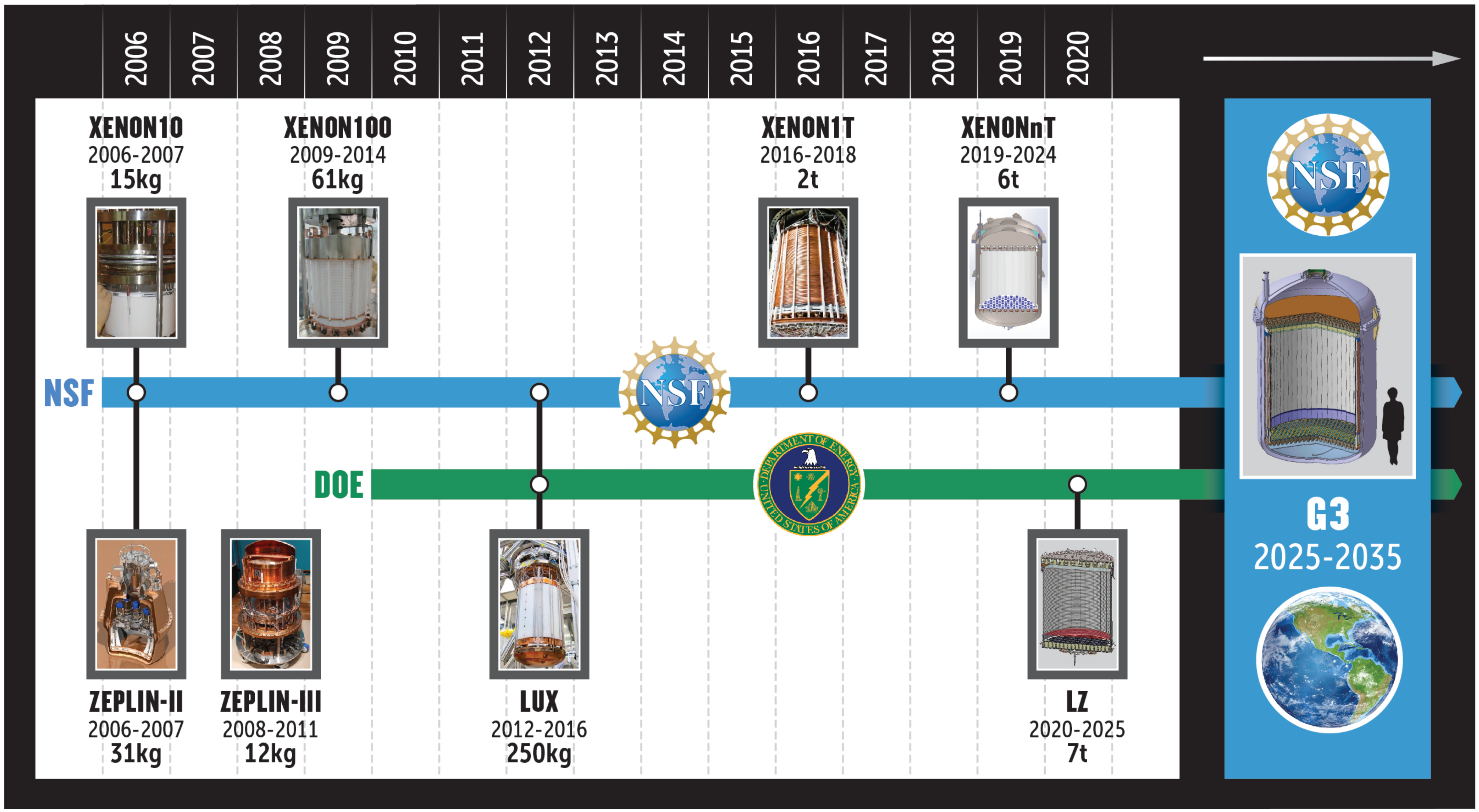
Search for Coherent Elastic Scattering of Solar ^{8}B Neutrinos in the XENON1T Dark Matter Experiment

XENON collaboration, PRL 126 (2021) 091301: 2012.02846 [hep-ex]





Next generation dark matter and neutrino detection



Solar neutrinos

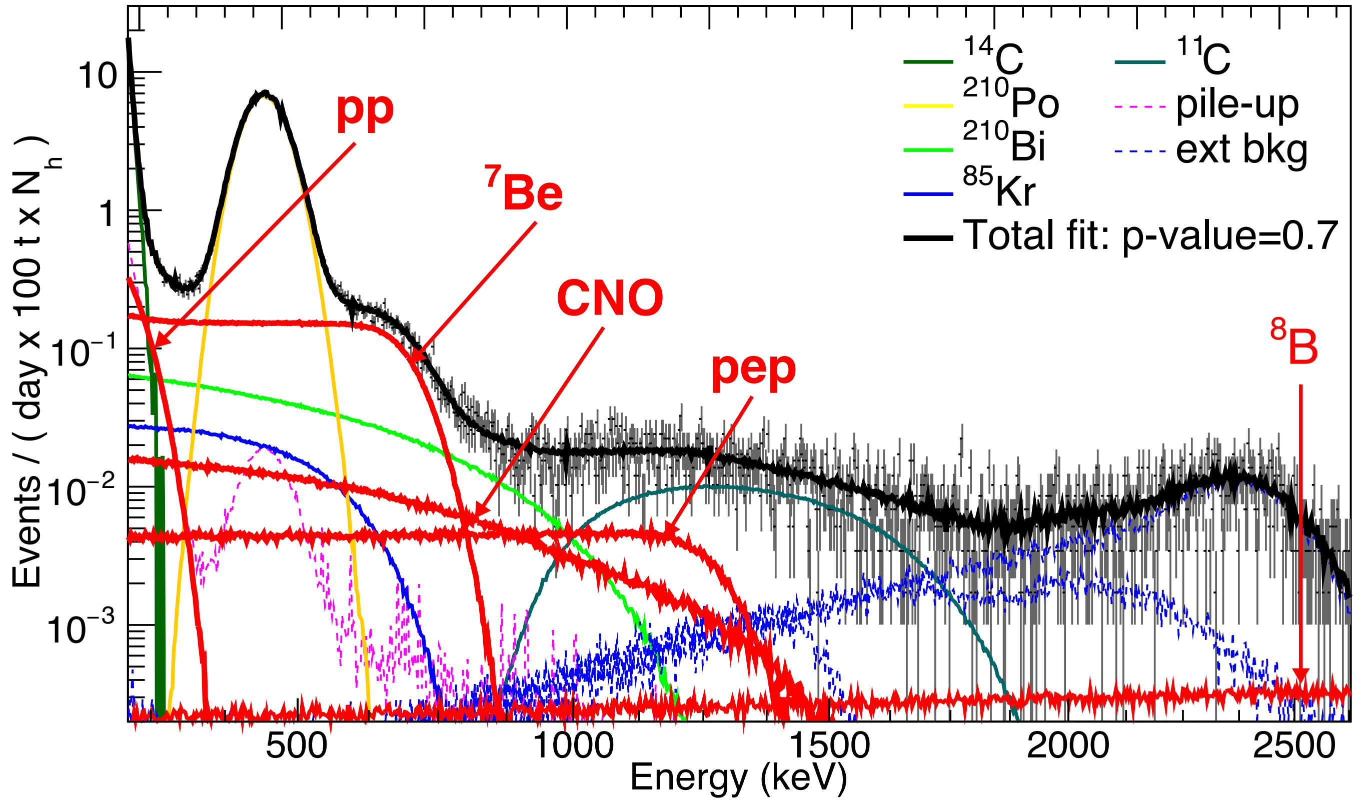
Borexino has performed a multi-component analysis of the Solar neutrino spectrum using neutrino-electron elastic scattering [Borexino Collaboration, Phys.Rev.D 100 (2019) 8, 082004 1707.09279]

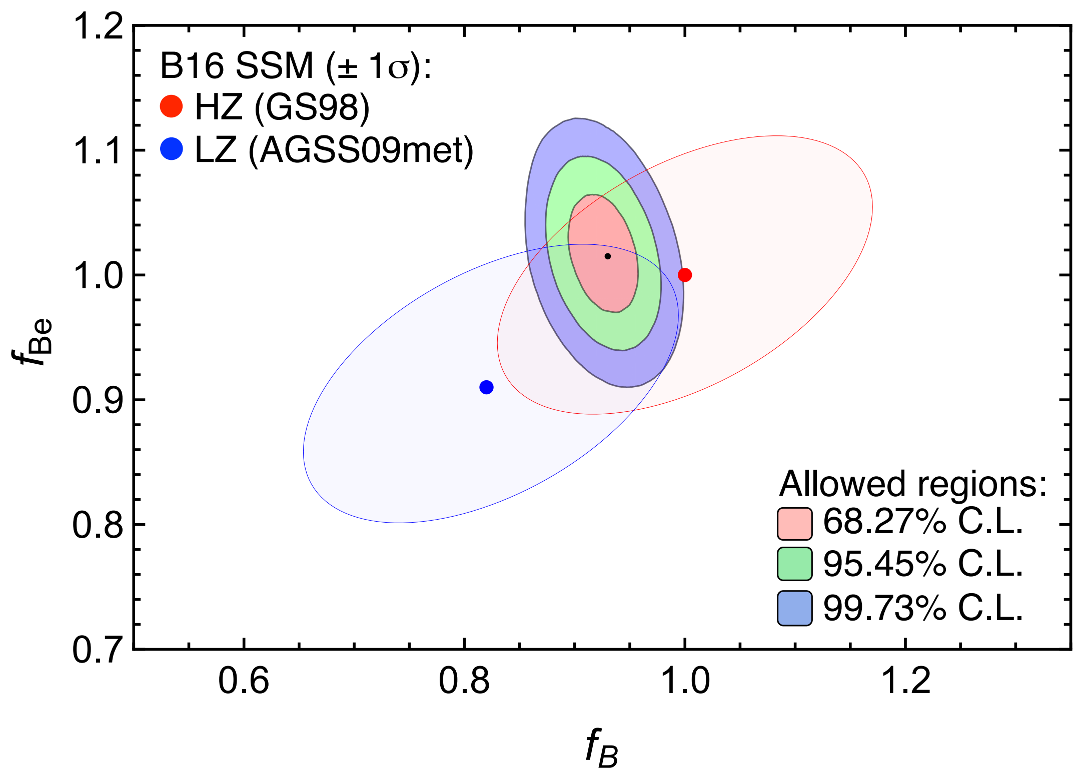
Discovery of the the CNO component of the Solar neutrino flux [Borexino collaboration, Nature 587 (2020) 577-582 2006.15115]

Borexino + solar neutrino data still unable to distinguish between low and high metallicity Solar neutrino models

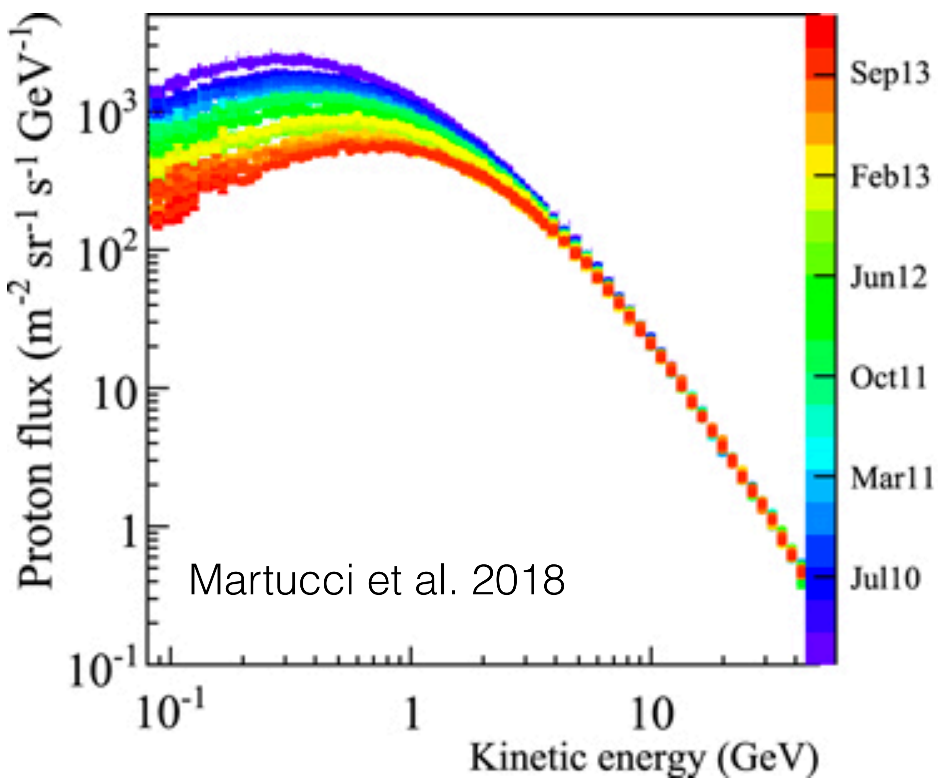
Measurement of neutral current component of the 8B spectrum with CEvNS in a DM detector would directly measure the Solar metallicity

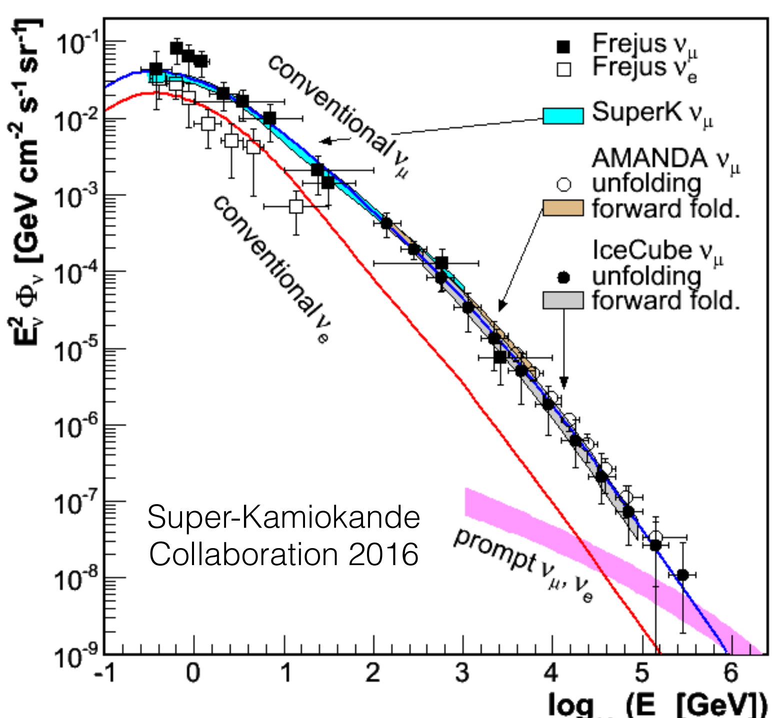
New bound on NSI [Dutta, Liao, Strigari, Walker 2017] and Sterile neutrinos [Billard, LS, Figueroa-Feliciano 2014]

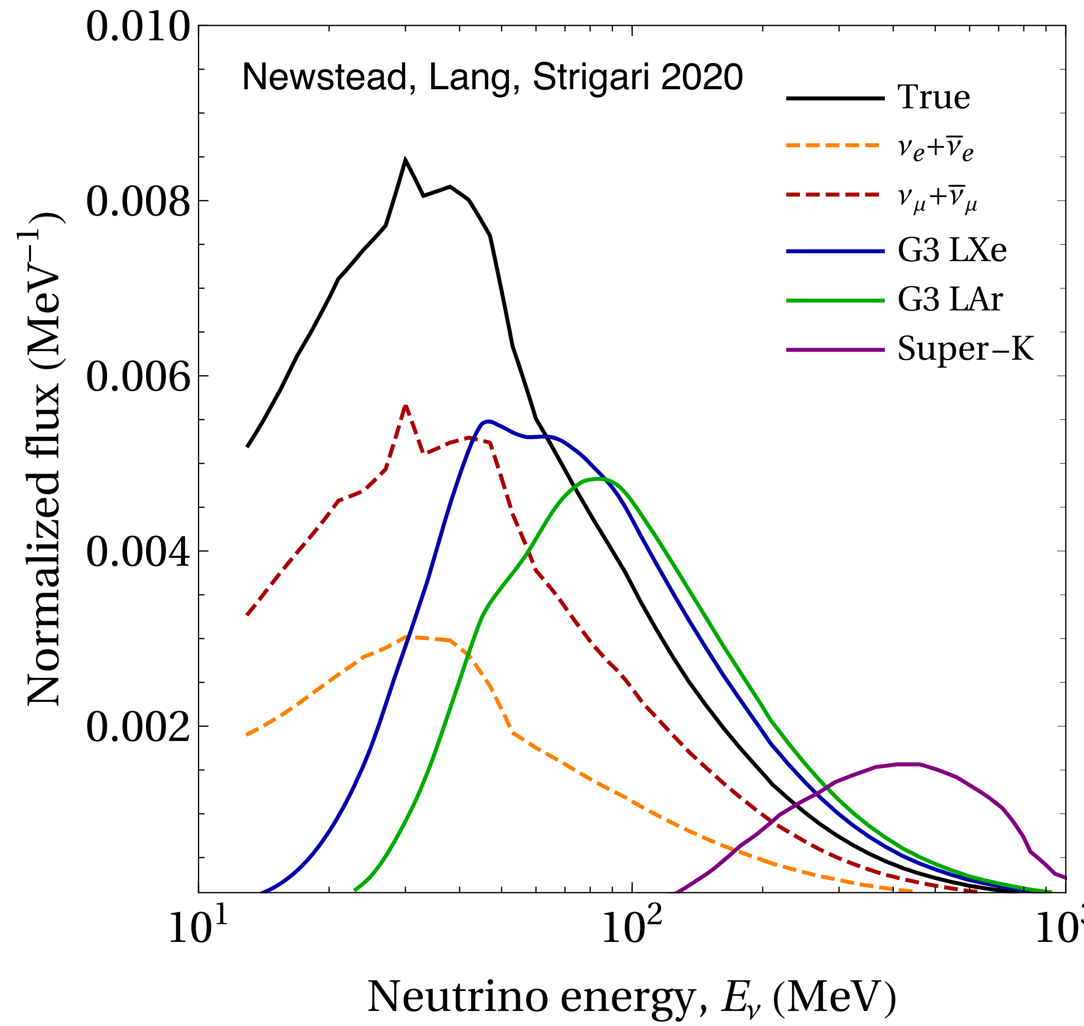




Atmospheric neutrinos





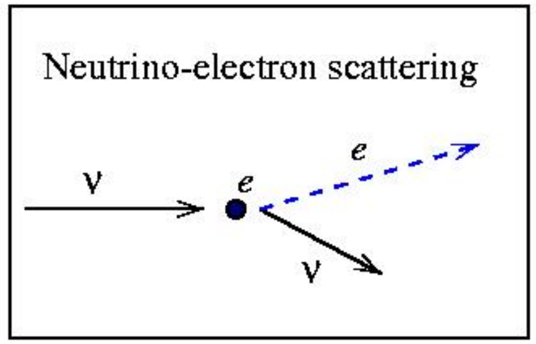


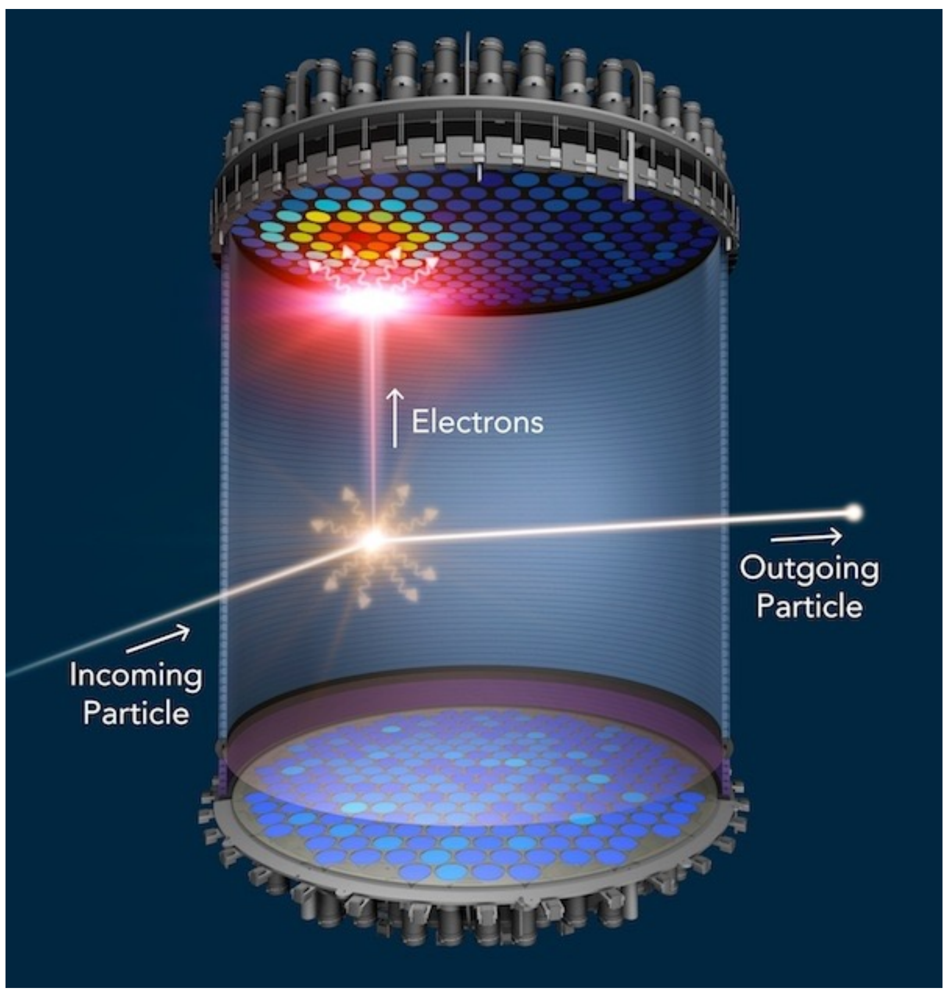
Detection with CEvNS would be the measurement of the lowest energy atmospheric neutrinos

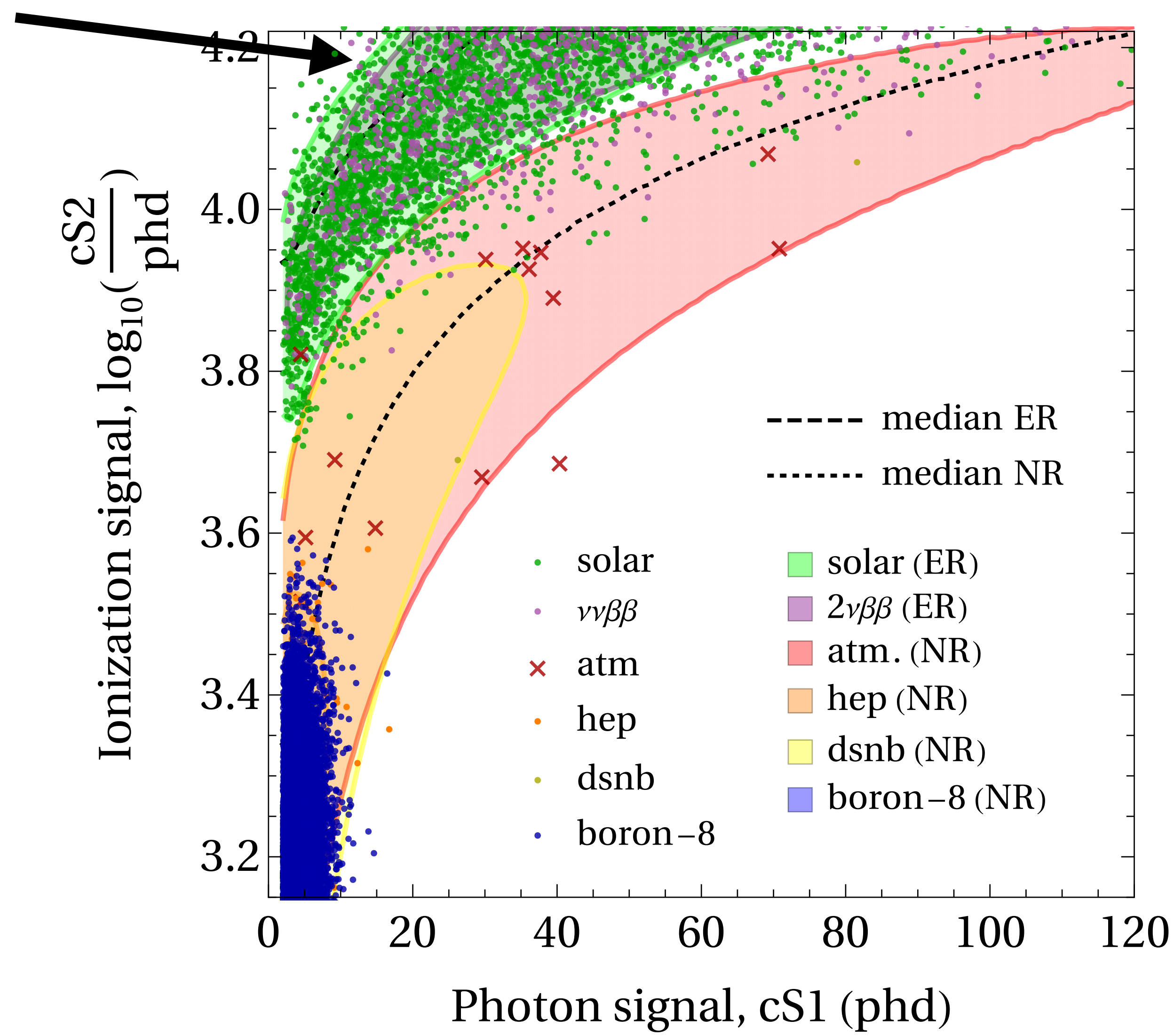
Flux sensitive to Solar modulation, geomagnetic effects

Sensitivity to NSI [Dutta, Lang, Liao, Strigari, Sinha, **Thompson** JCAP 2020]

Next generation dark matter and neutrino detection

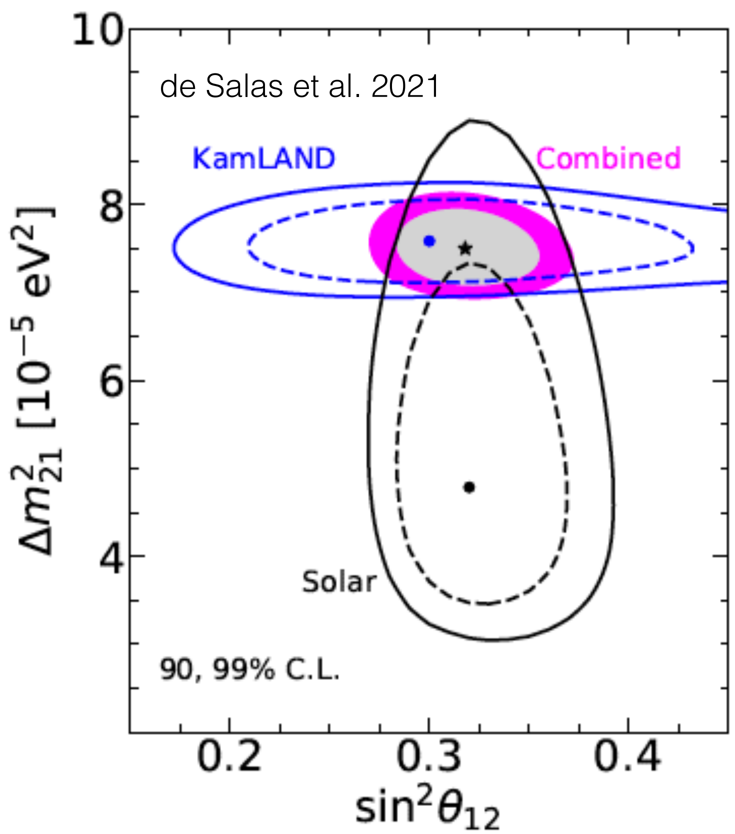


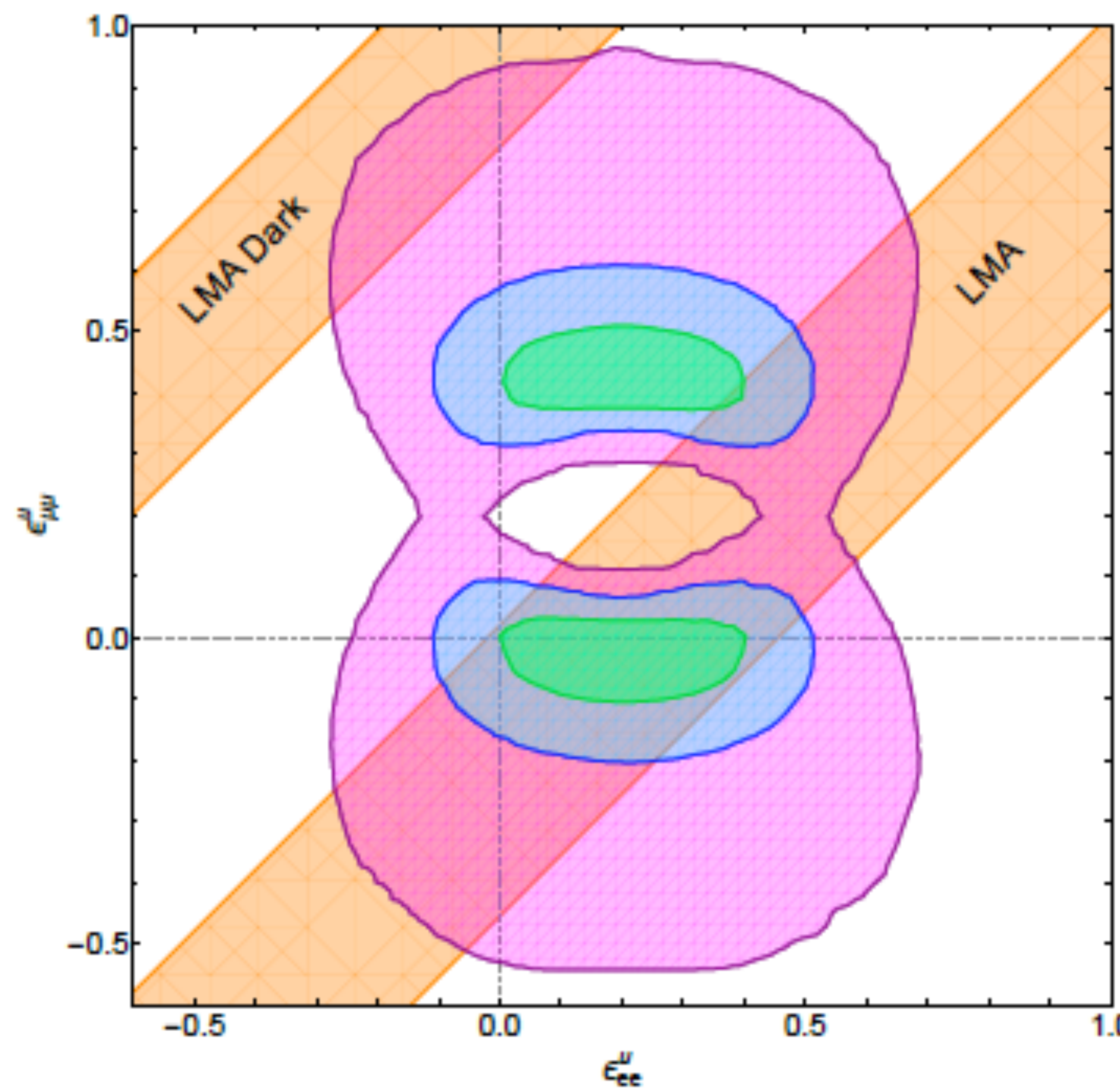




Newstead, Lang, Strigari 2020

Dark side of the Solar neutrino parameter space





Oscillation data still allow for large NSI couplings and MSW LMA *dark side* solution [Miranda, Valle, Tortola, 2006]

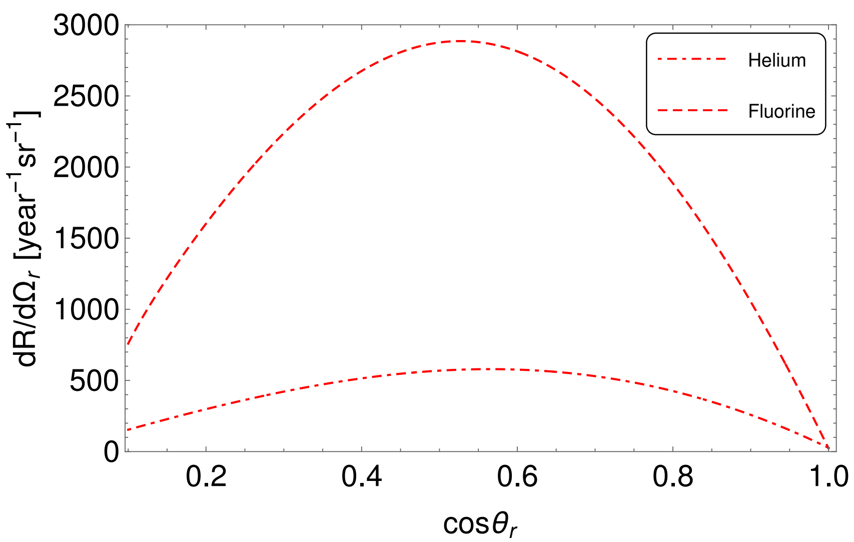
Changes octant of solar angle and sign of mass ordering

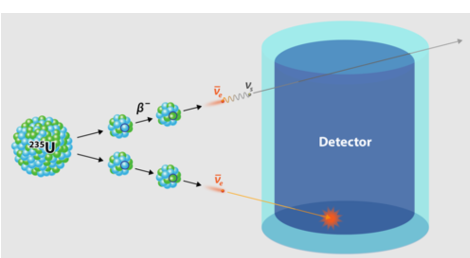
Non-oscillation experiments (e.g. coherent scattering) required to lift existing degeneracy

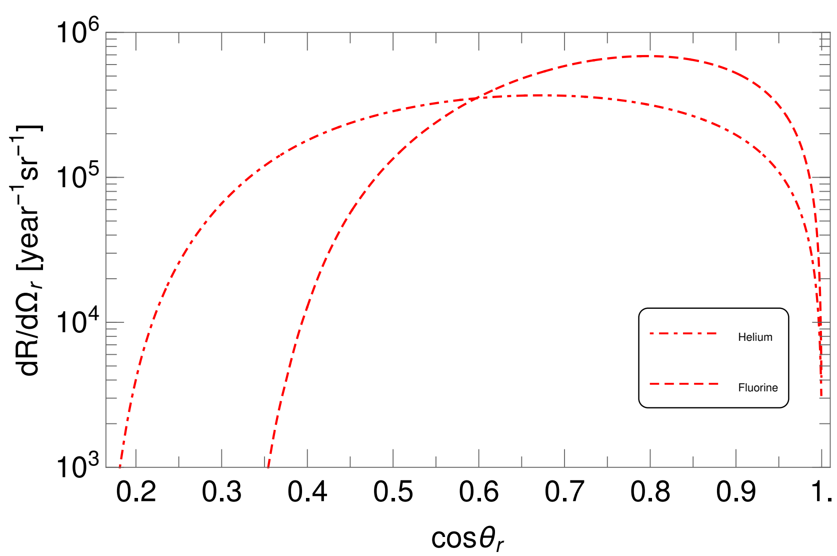
Coloma, Denton, Gonzalez-Garcia, Maltoni 2017; Denton, Farzan, Shoemaker 2018; Denton & Gehrlein 2020

CEvNS with directional detectors

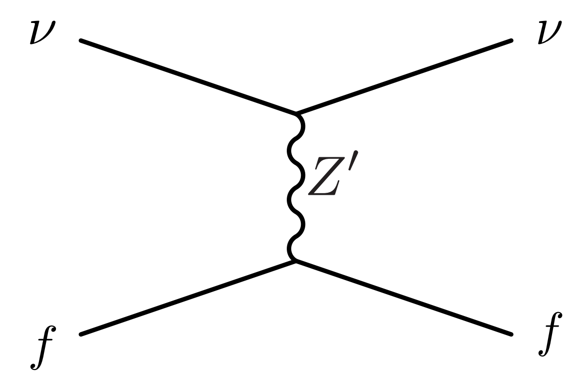
Standard Model

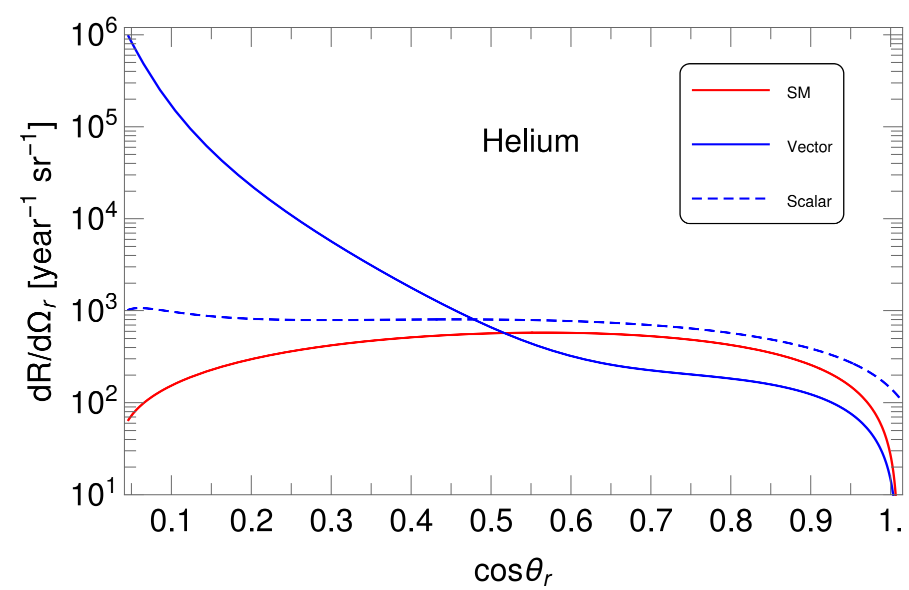






BSM



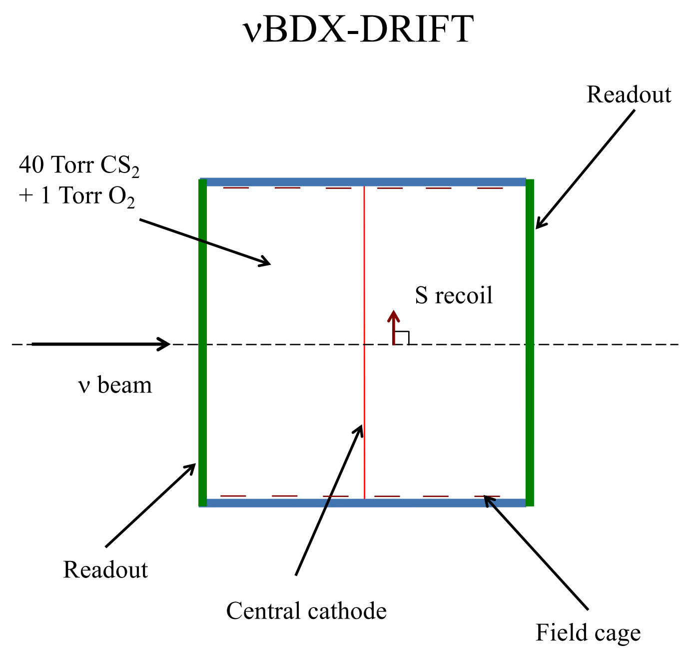


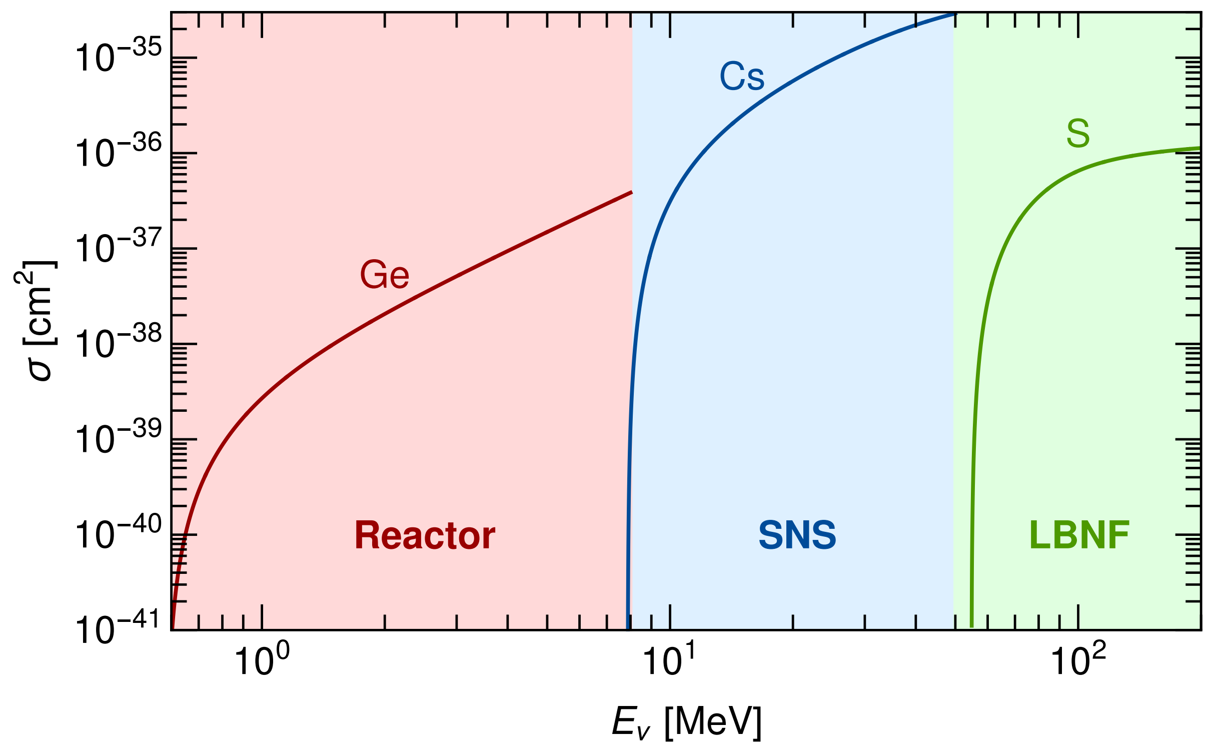
Abdullah, Aristizabal-Sierra, Dutta, Strigari
Phys.Rev.D 102 (2020) 1, 015009 2003.11510

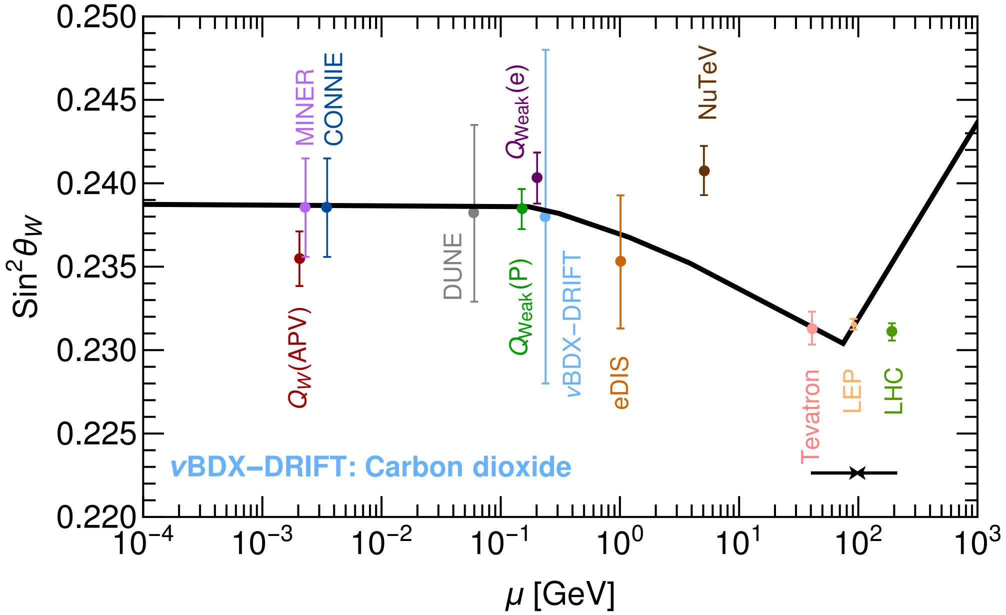
Directional dark matter and neutrino detection:

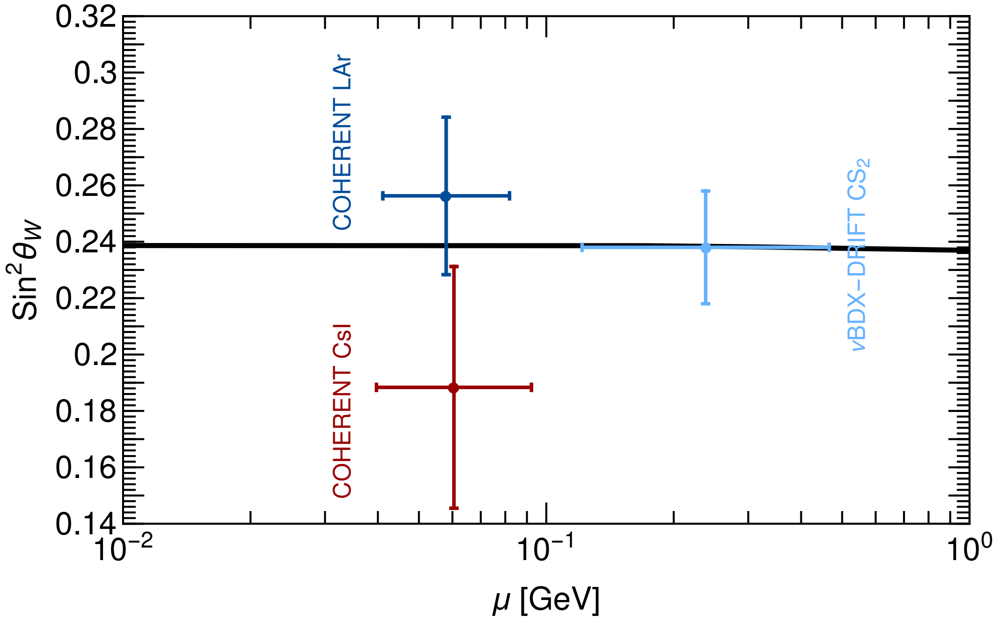
Mayet et al. Phys. Reports 2016 Grothaus, Fairbairn, Monroe, PRD 2014; O'Hare, Billard, Figueroa-Feliciano, Green, Strigari 2015

CEvNS with directional detectors









Aristizabal-Sierra, Dutta, Kim, Snowden-Ifft, Strigari, 2021: 2103.10857

Summary: CEvNS detections and future prospects

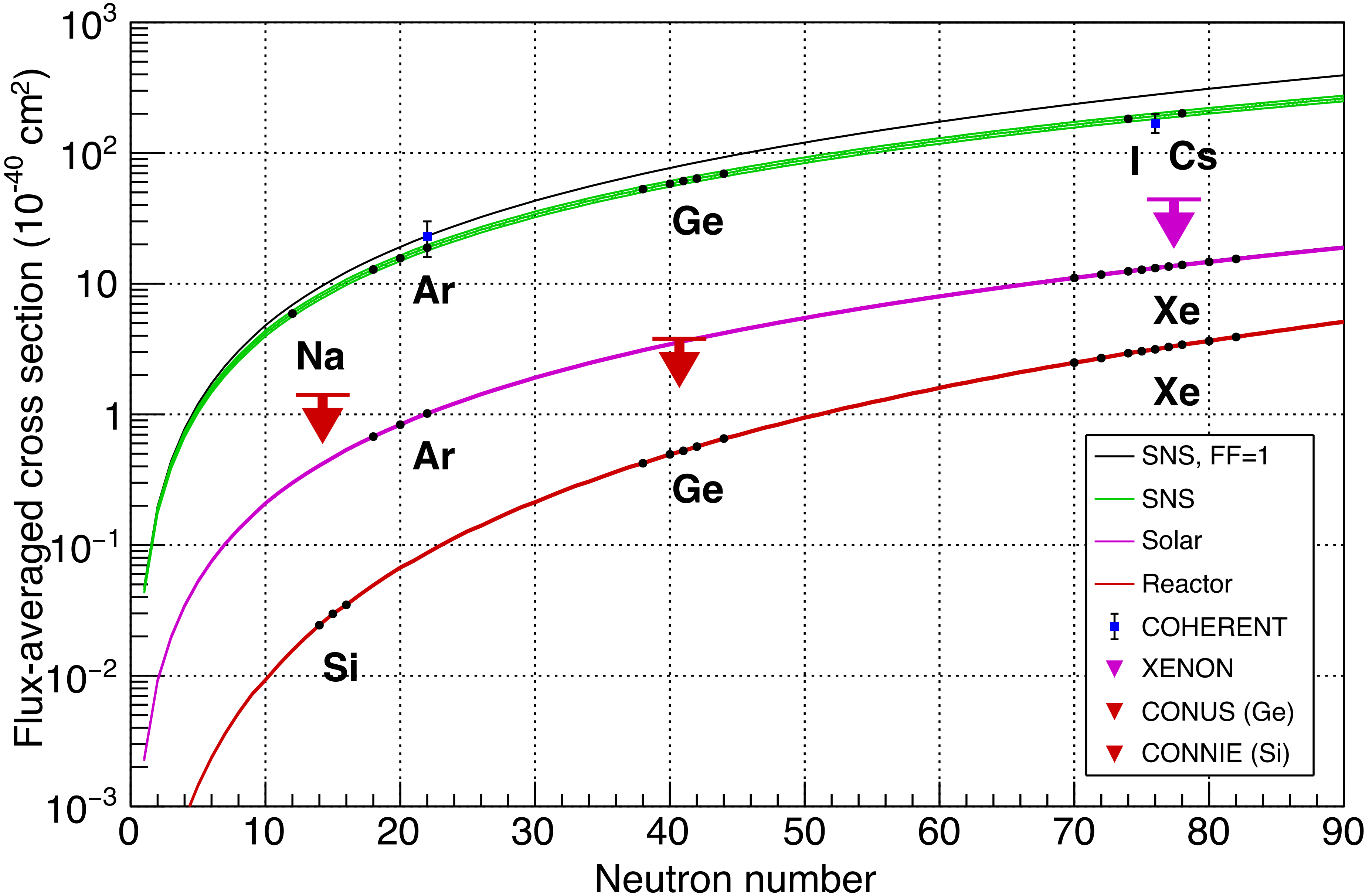


Figure: Kate Scholberg

CEvNS in the coming decade+

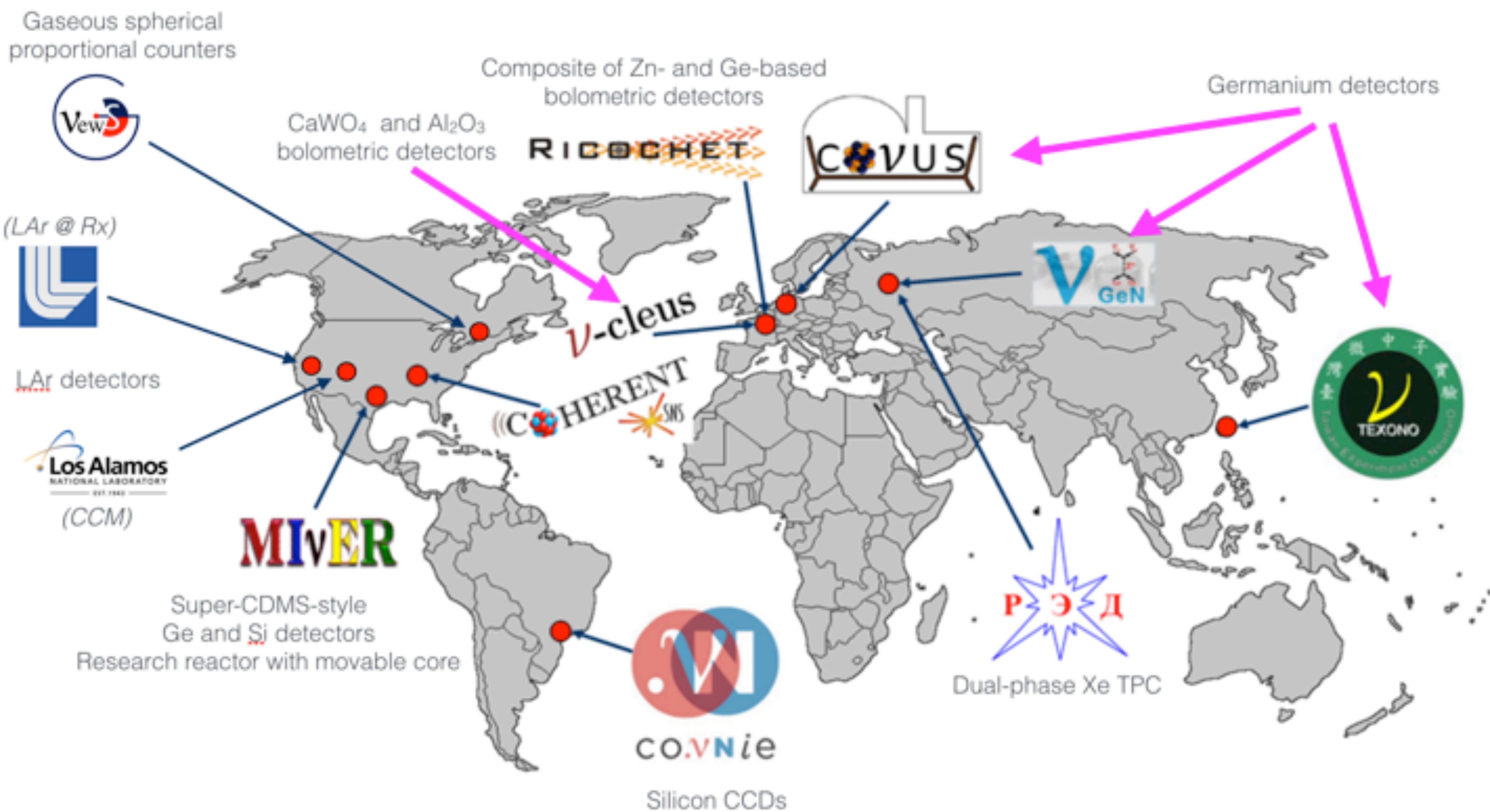


Figure: Phil Barbeau

CEvNS in the coming decade+

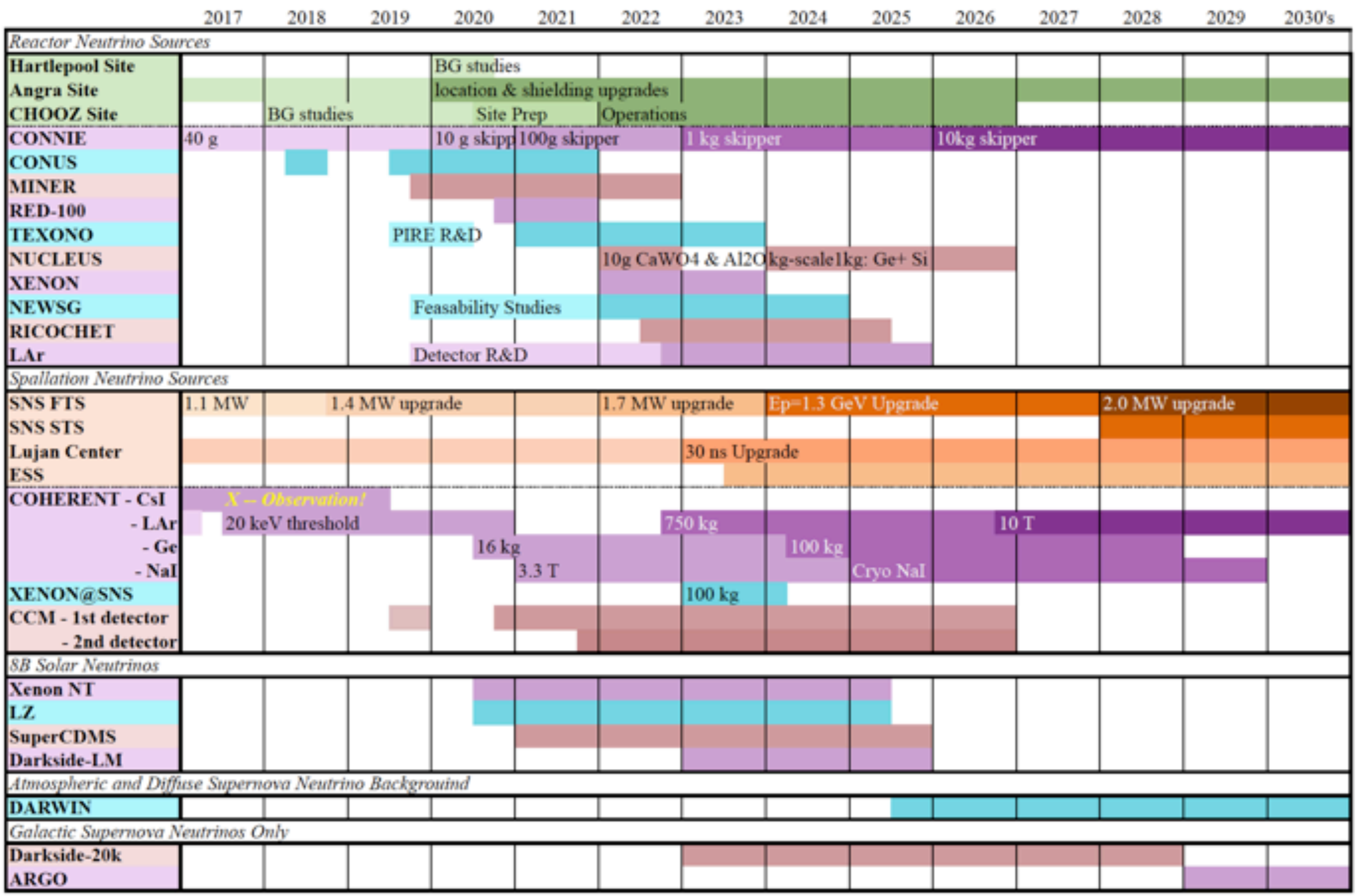


Figure: Phil Barbeau

Two community SNOWMASS white papers: CEvNS Theory + Experiment (Strigari/Barbeau/Strauss); G3 dark matter detection (Rafael Lang et al.)