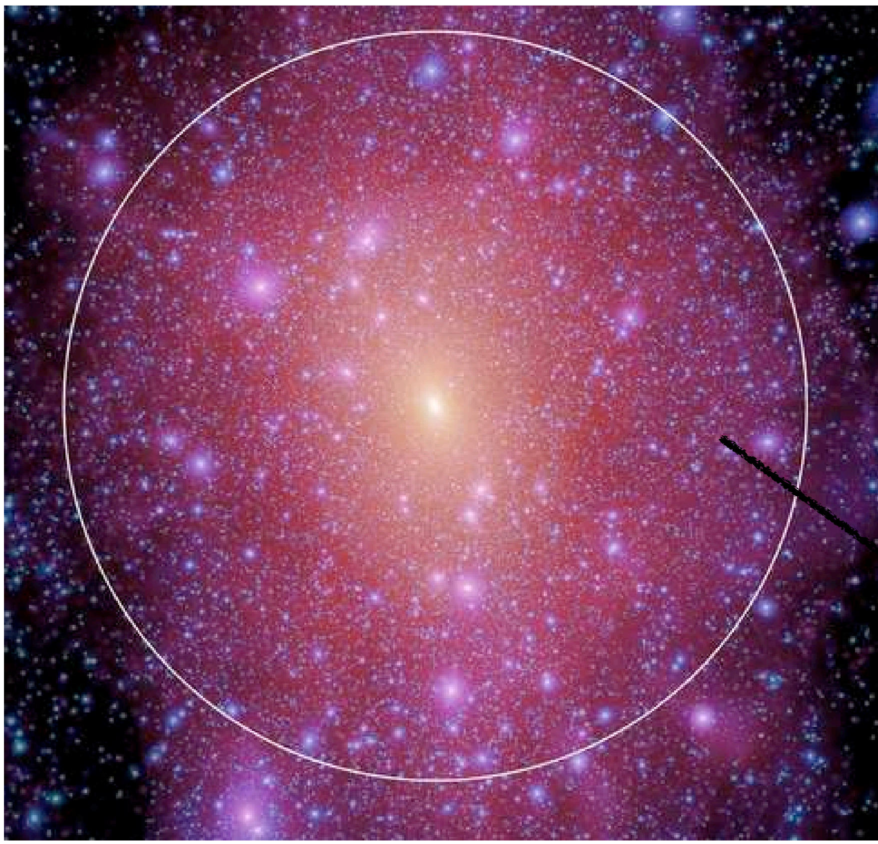
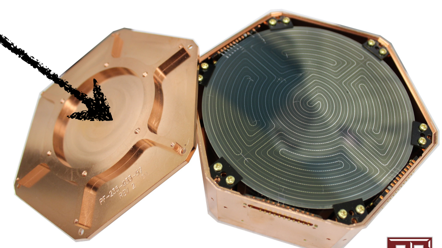
Neutrinos in dark matter detectors

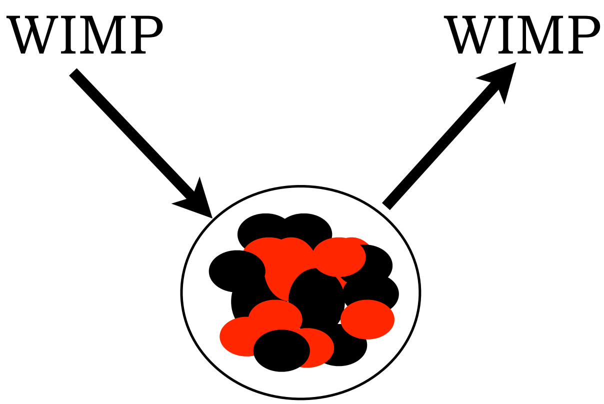


Louis E. Strigari
TAMU/Mitchell Institute
NC State CNS workshop
January 11, 2015

Based on work with:
Julien Billard
Enectali Figueroa-Feliciano



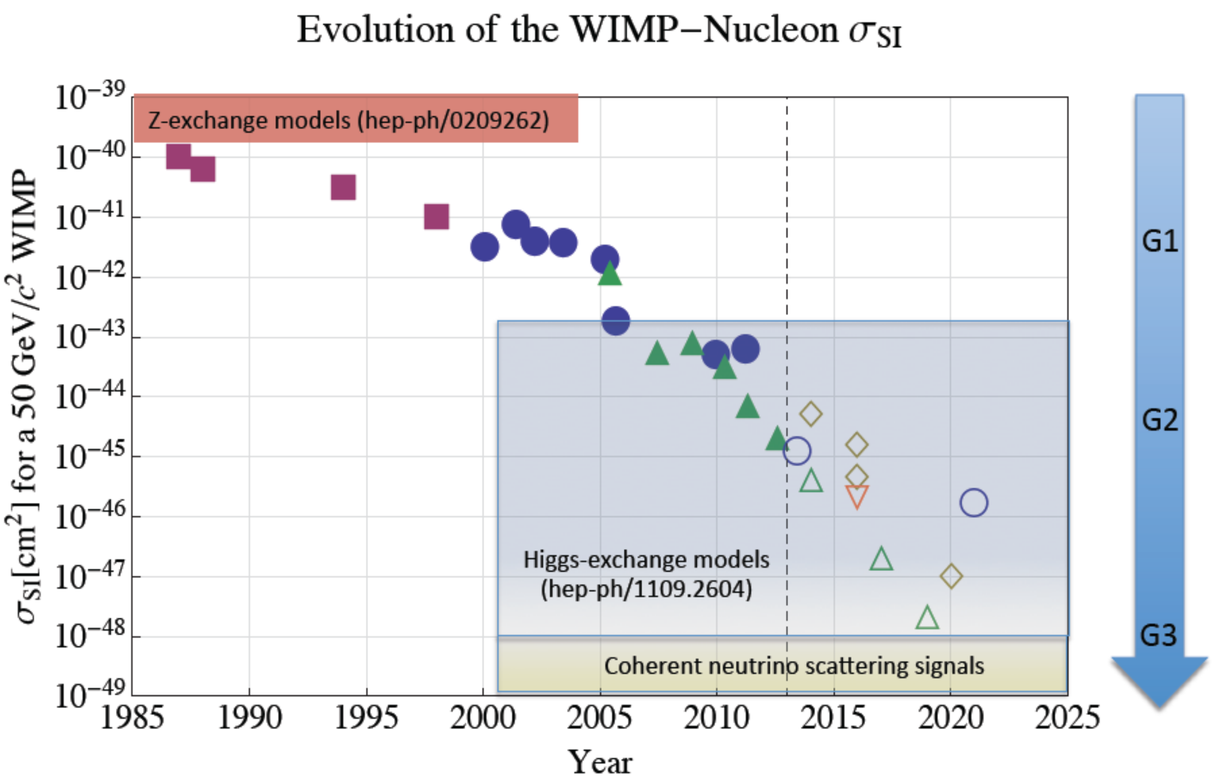
Direct dark matter searches: Basics



✦ *Spin-Independent:* Cross section scales as the mass number of nucleus.

✦ *Spin-dependent:* Cross section depends on angular momentum

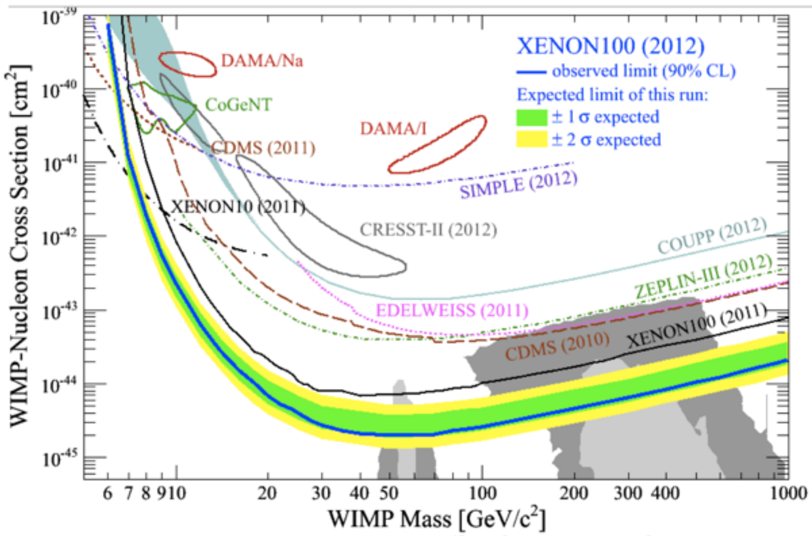
Goodman & Witten 1984, Ellis & Flores 1988, Engel 1991



Adapted from SNOWMASS

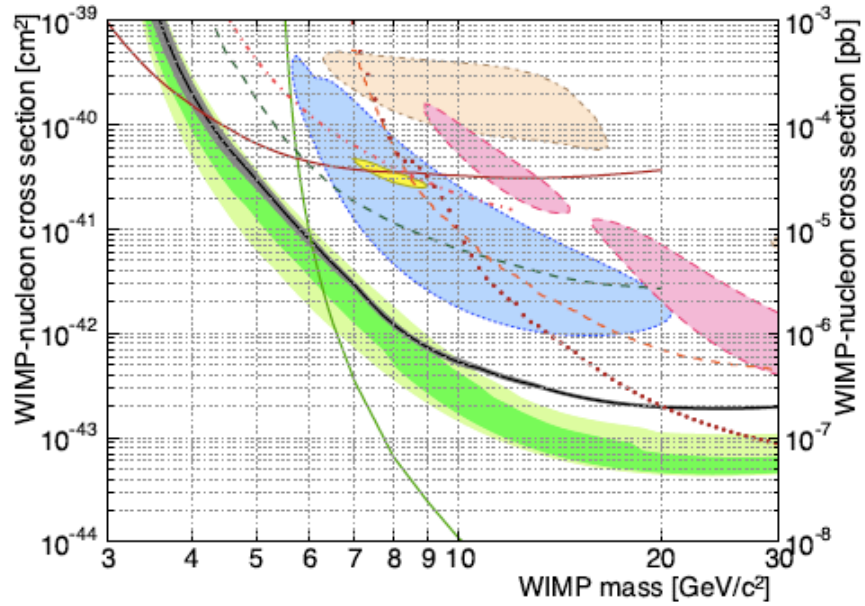
Plethora of experimental results

XENON100: New Spin-Independent Results



Upper Limit (90% C.L.) is 2 x 10^{-45} cm² for 55 GeV/c² WIMP

SuperCDMS

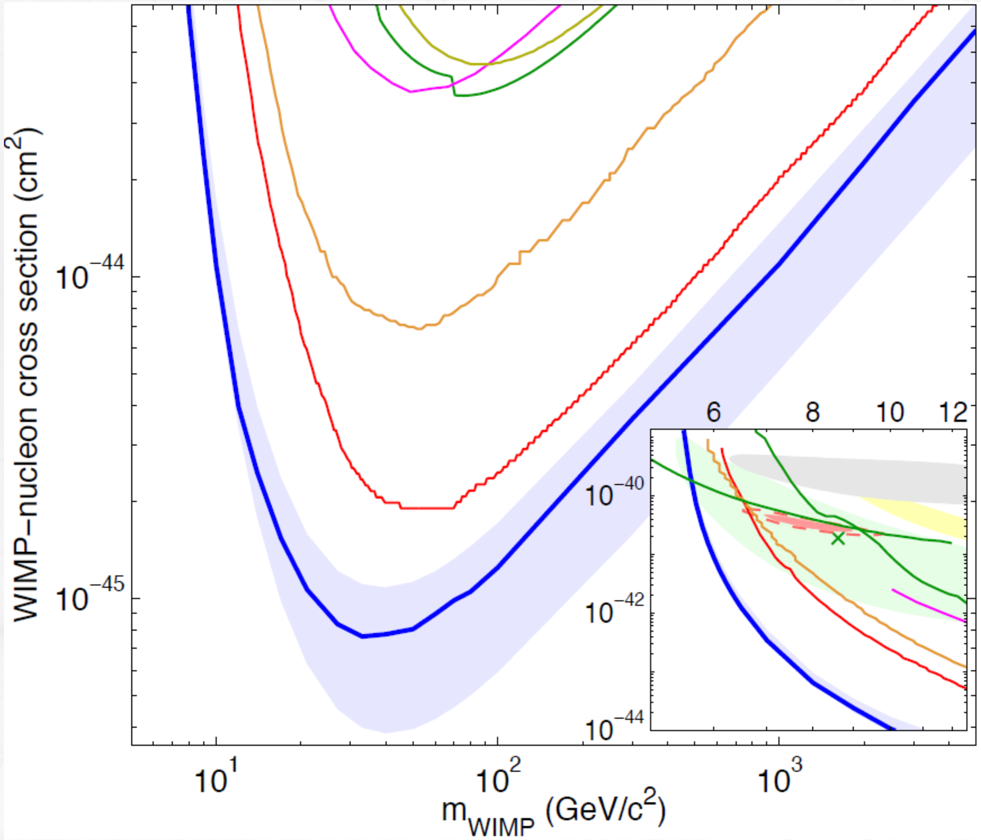


- Possible ways to make results consistent:
  1) Experimental issues
  2) Particle model (e.g. Isospin-violating DM, e.g. Feng & Kumar 2008)
  3) Galactic halo model

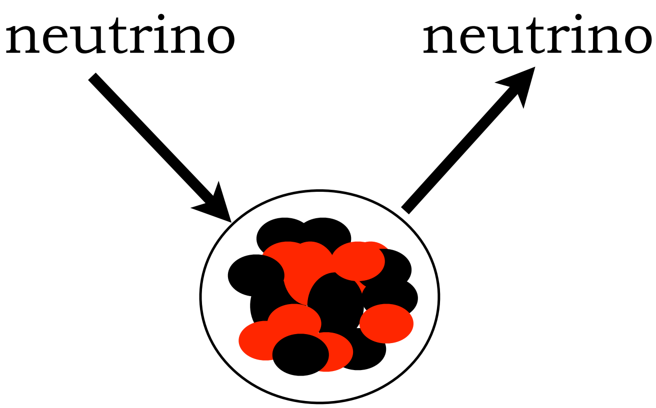
LUX results

- LUX results compatible with background only
  - –Appears to be no ``non-standard" particle or astrophysics

- As cross section limits improve, will become more difficult to disentangle particle physics from astrophysics.



Coherent neutrino scattering channel



- Proportional to the number of neutrons^2 due to vector current coupling

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

✦ *Coherent neutrino scattering will produce a signal similar to a WIMP*

Friedman 1974; Tubbs & Schramm 1977

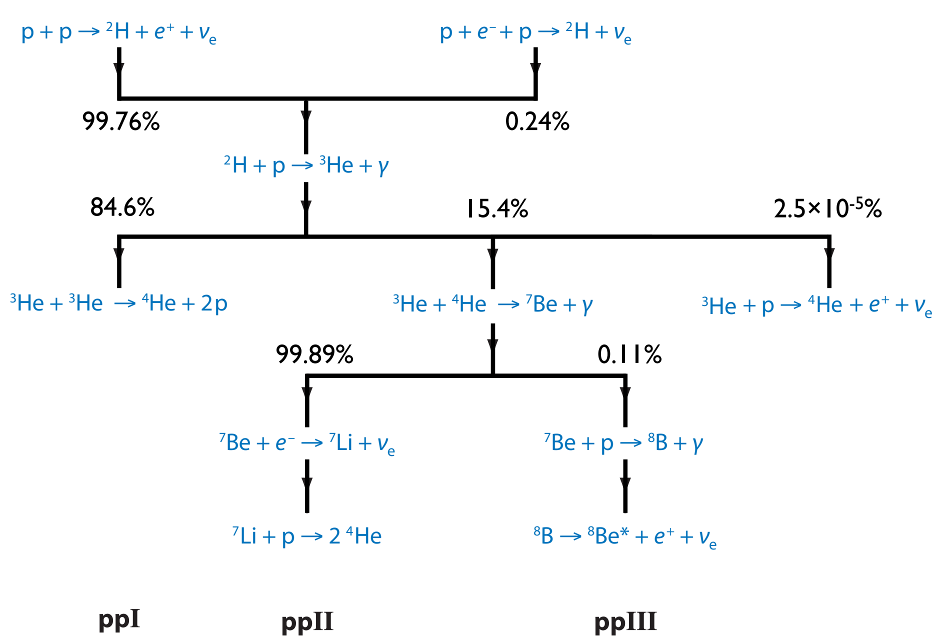
- Compare to spin-independent WIMP-nucleus cross section which is proportional to A^2

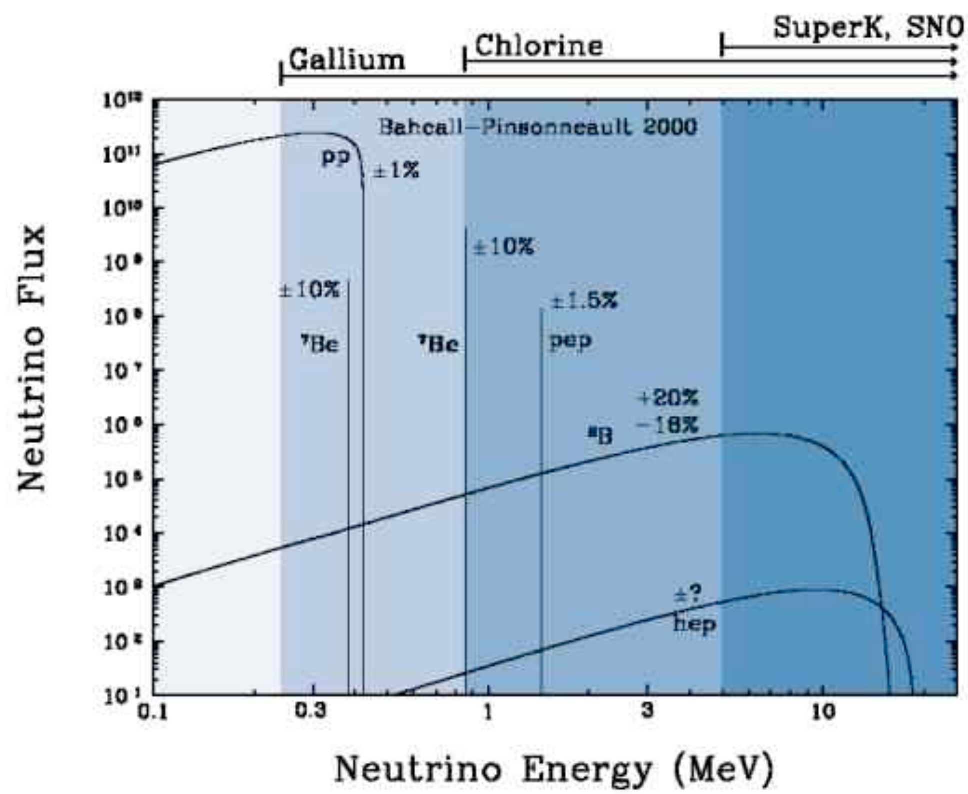
- Straightforward prediction of Standard Model. Though not yet detected.

pp chain and Solar neutrinos

Stars powered by fusion of light nuclei $4p \rightarrow {}^4\mathrm{He} + 2e^+ + 2\nu_e$

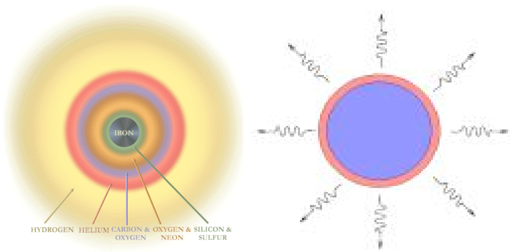
Beginning of the cycle: $p + p \rightarrow {}^2\mathrm{H} + e^+ + \nu_e$





Atmospheric and supernova neutrinos

SN
Neutrinos

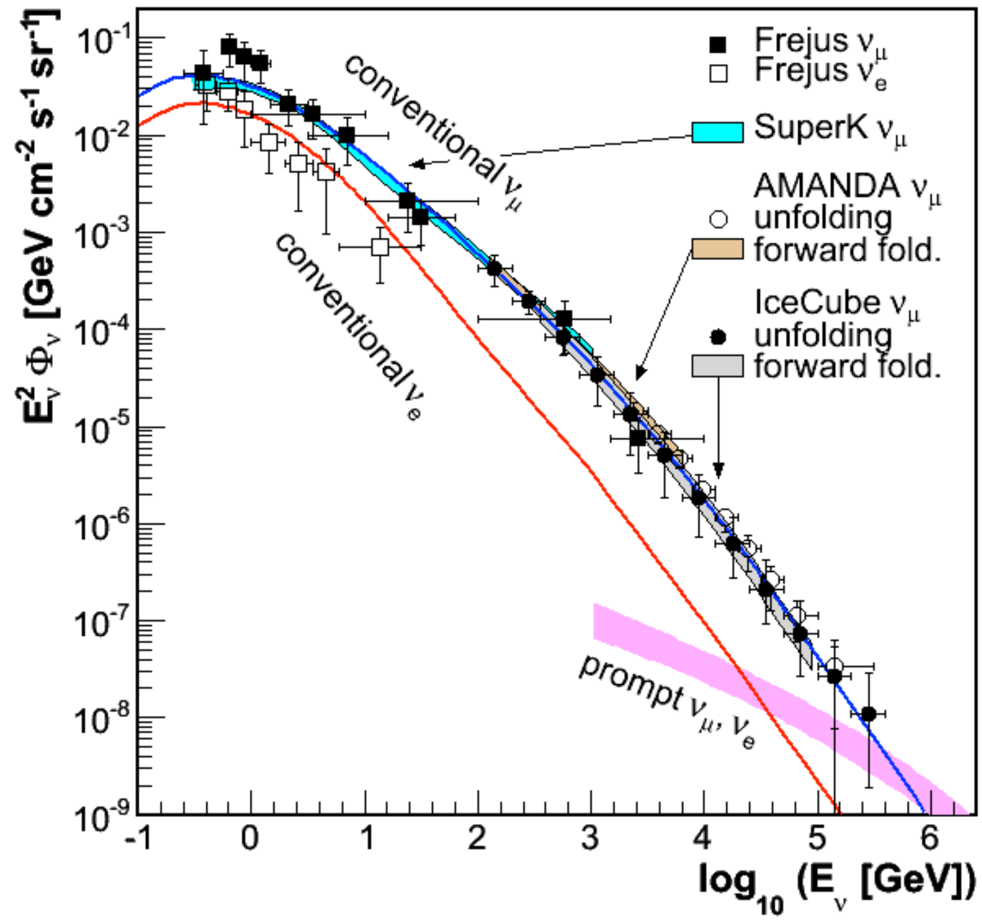


$$\pi^{\pm} \rightarrow \quad \mu^{\pm} \quad + \nu_{\mu}(\overline{\nu}_{\mu})$$

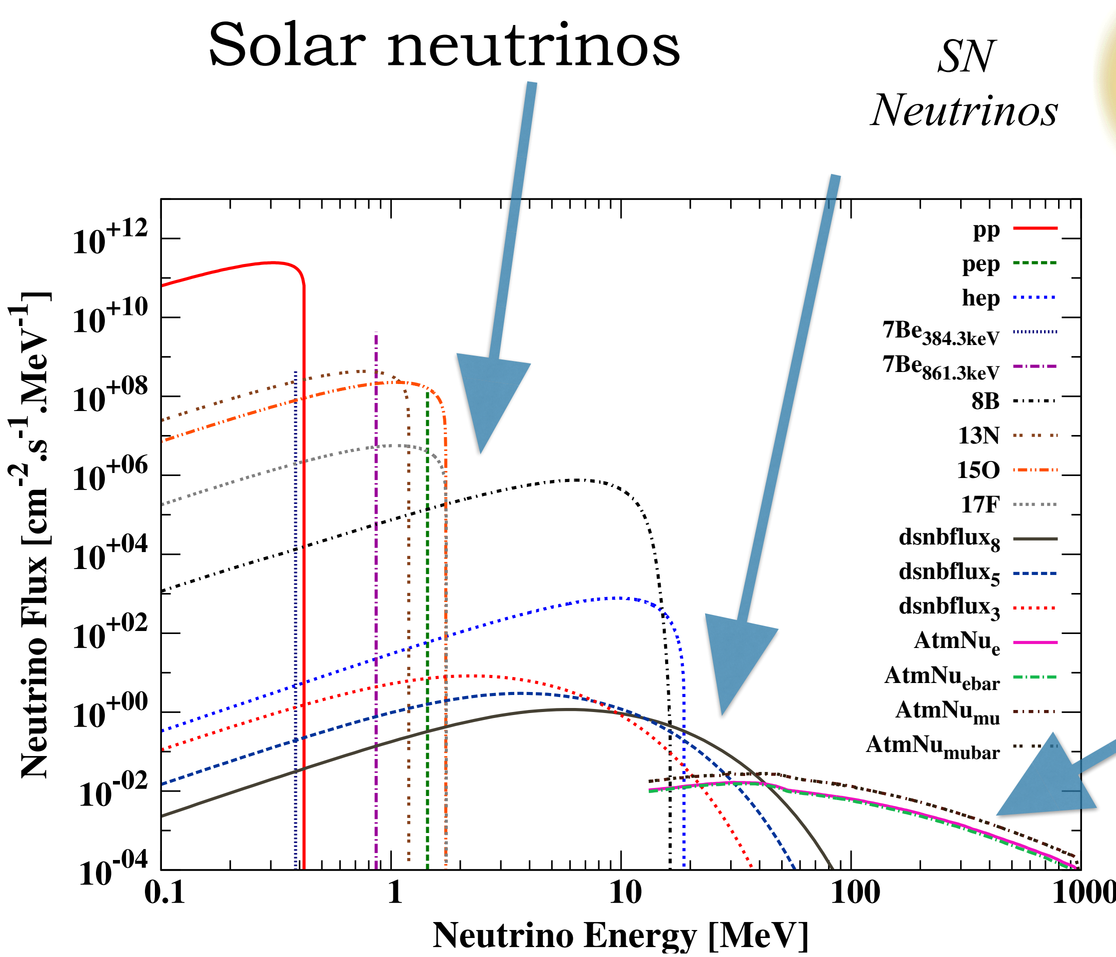
$$\searrow$$

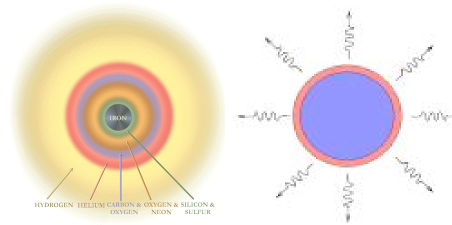
ATM
Neutrinos

$$e^{\pm} + \nu_e(\overline{\nu}_e) + \overline{\nu}_{\mu}(\nu_{\mu})$$



Solar, atmospheric, supernova neutrinos



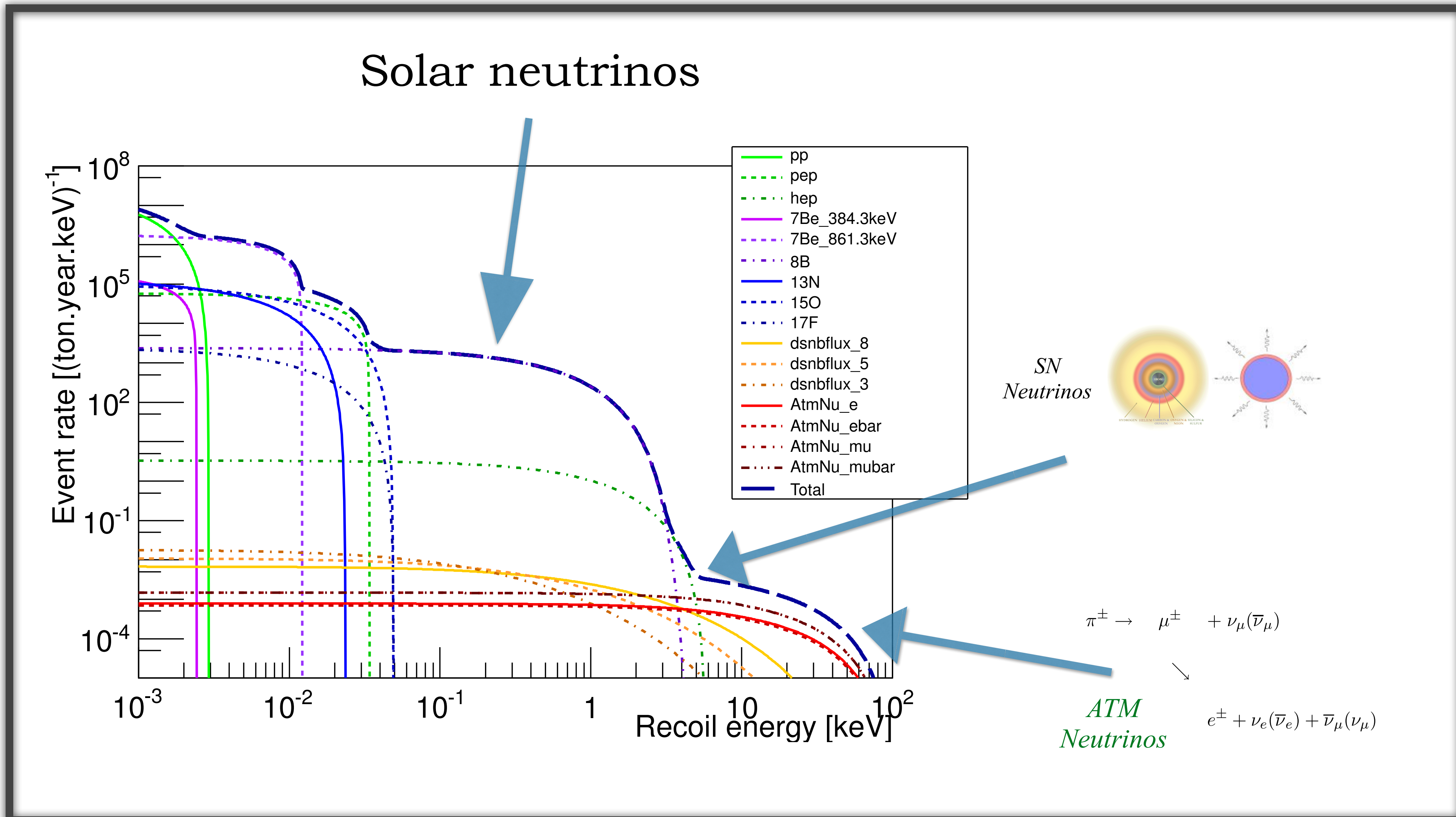


$$\pi^{\pm} \rightarrow \mu^{\pm} + \nu_\mu(\overline{\nu}_\mu)$$

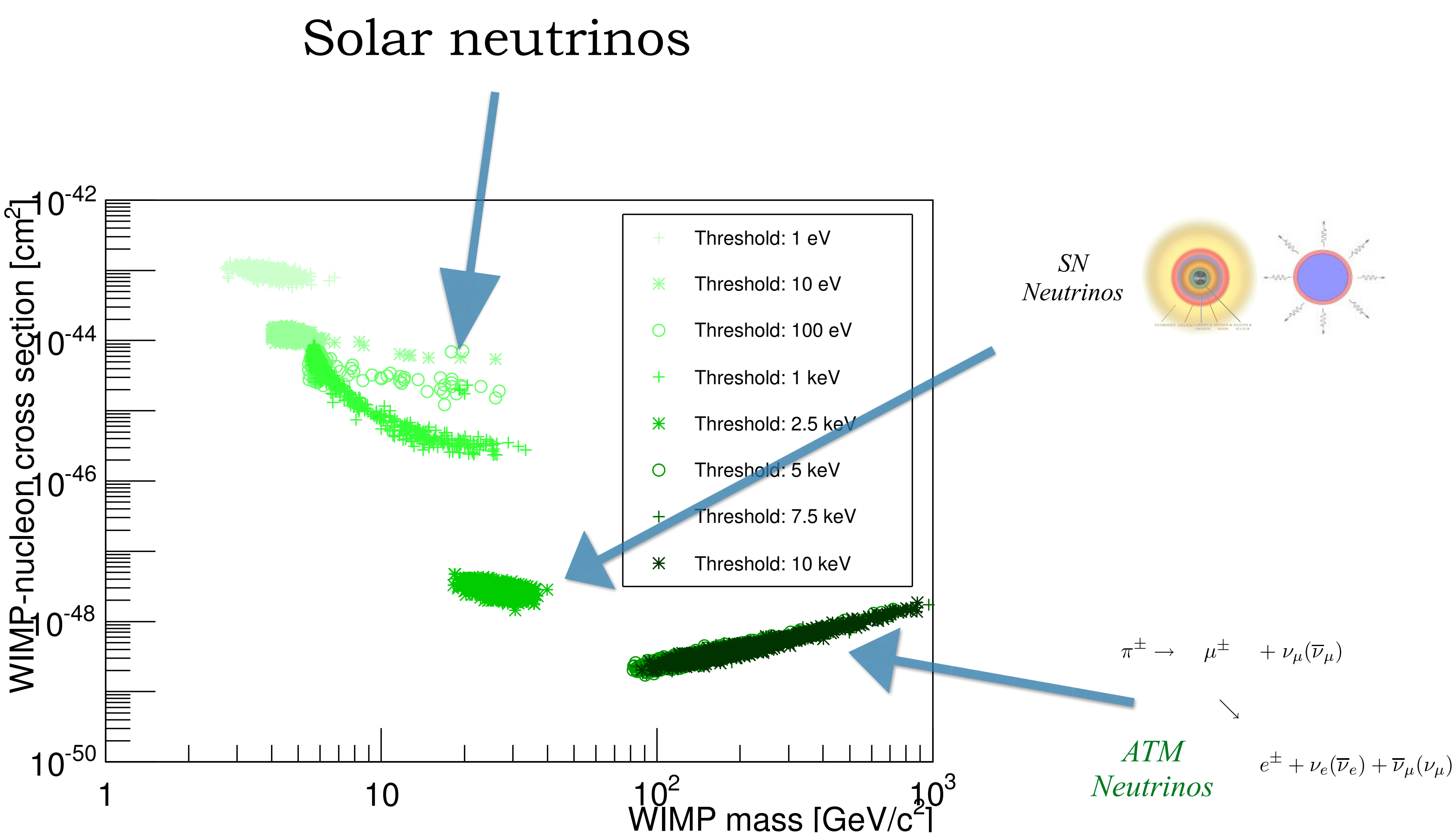
$$\searrow$$

$$e^{\pm} + \nu_e(\overline{\nu}_e) + \overline{\nu}_\mu(\nu_\mu)$$

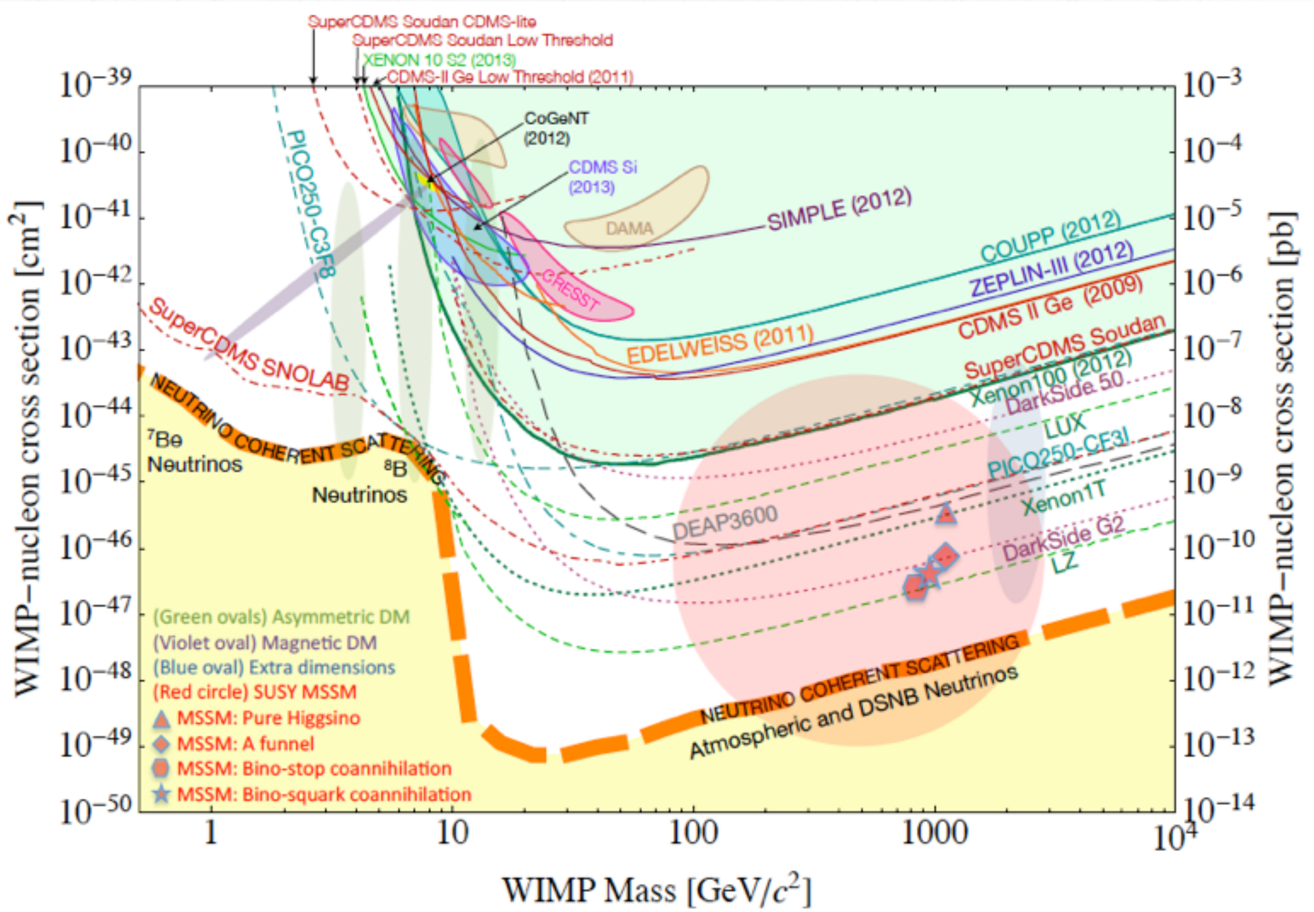
Predicted event rates in dark matter detectors



Can neutrinos mimic the WIMP signal?



End of (non directional) direct detection?



Billard, Strigari, Figueroa-Feliciano PRD 2014

Reducing solar neutrino background

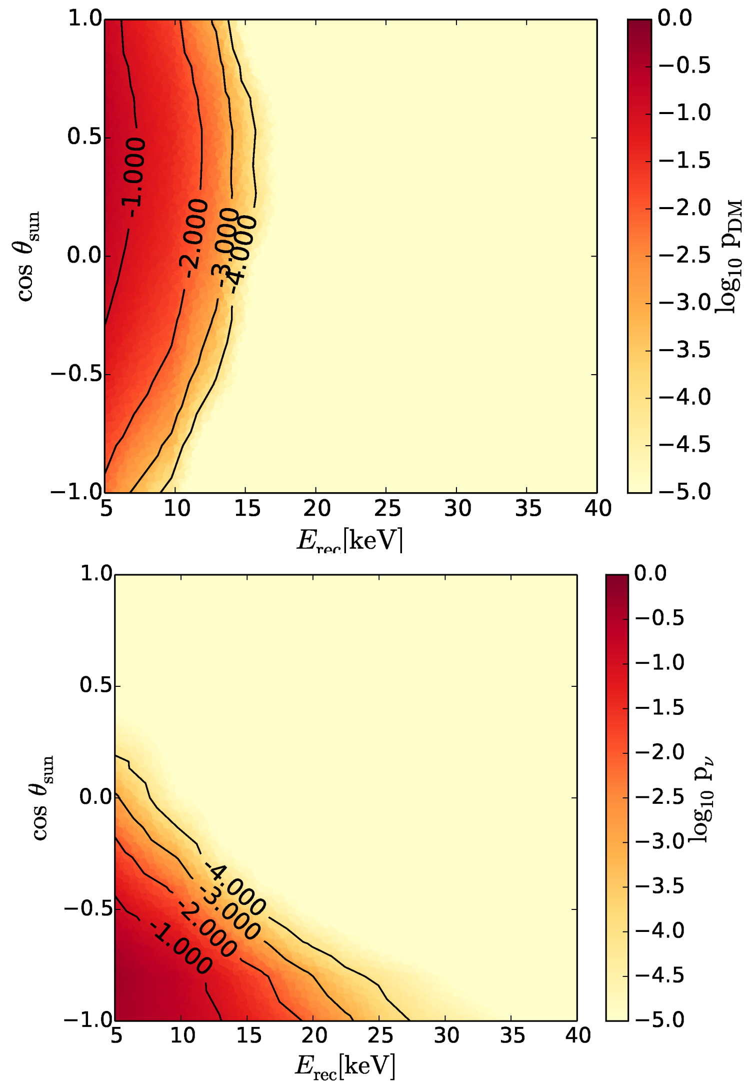
WIMP-nucleus scattering is isotropic in cos (theta)

The angular dependence of the neutrino coherence cross section is:

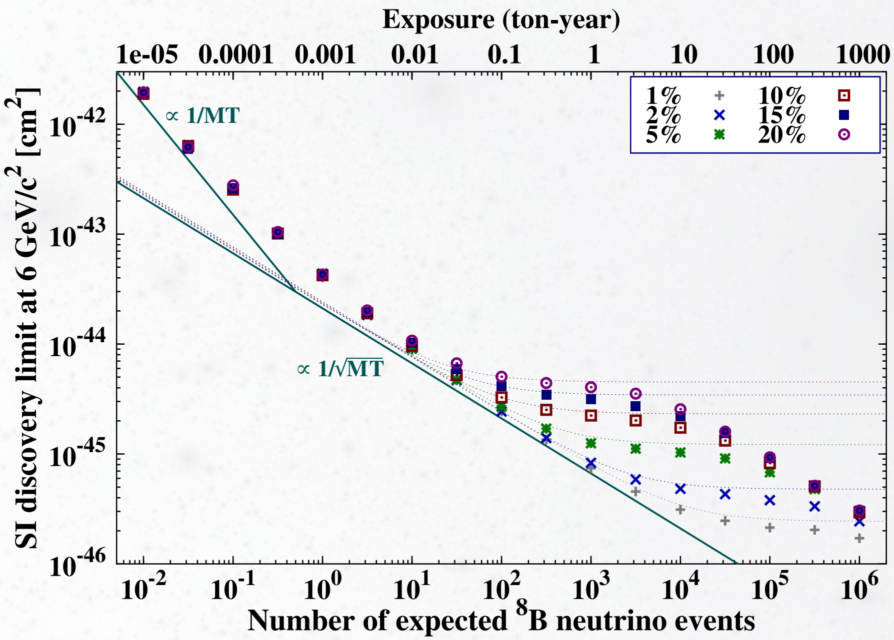
$$\frac{d\sigma}{d(\cos\theta)} = \frac{G_F^2}{8\pi} Q_W^2 \; E_\nu^2 \; (1 + \cos\theta) \; F(Q^2)^2$$

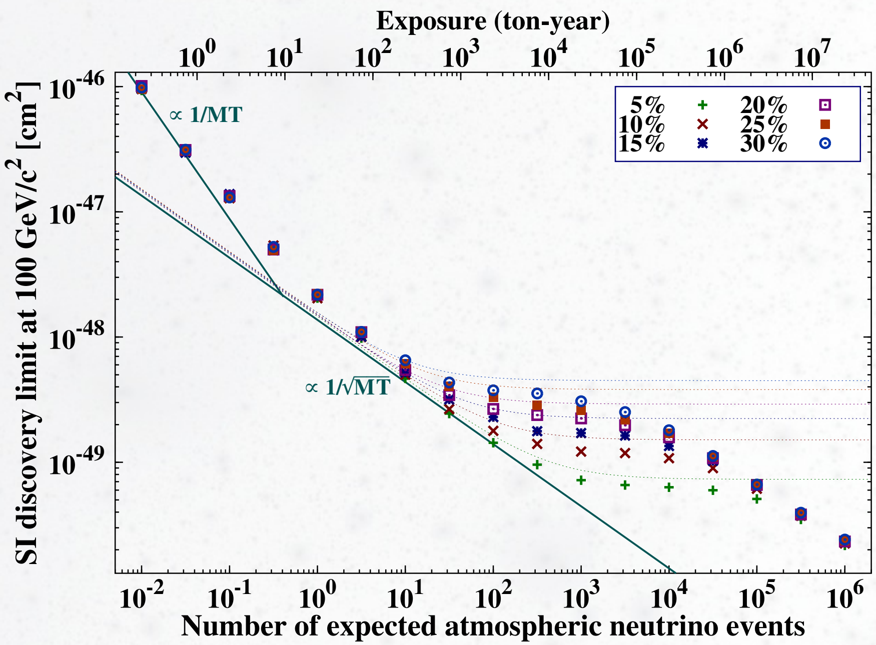
Solar neutrino events point back to the Sun

Grothaus et al. 2014



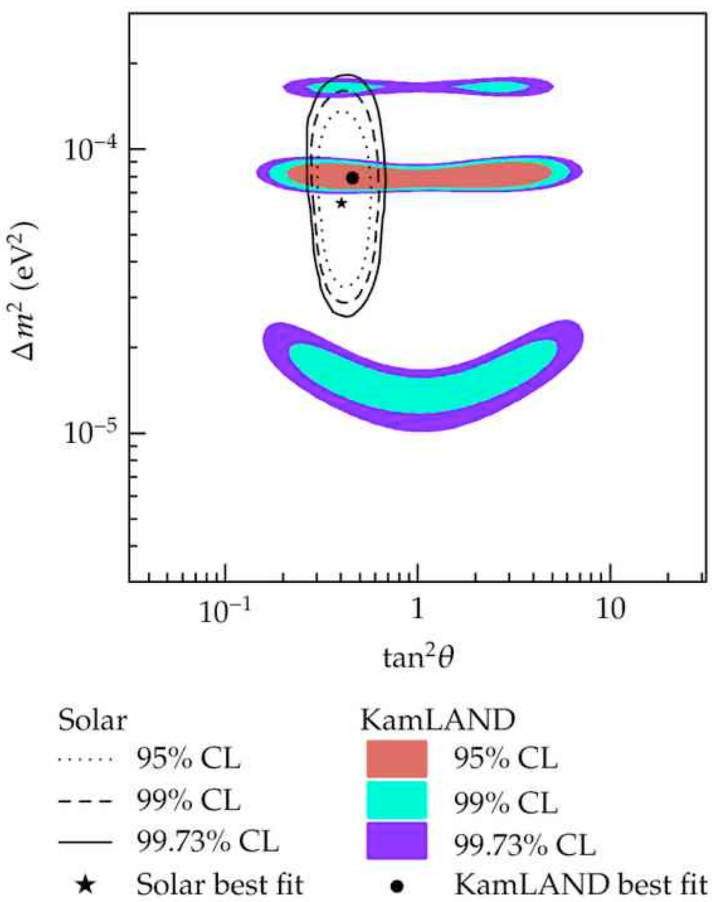
Reducing neutrino backgrounds



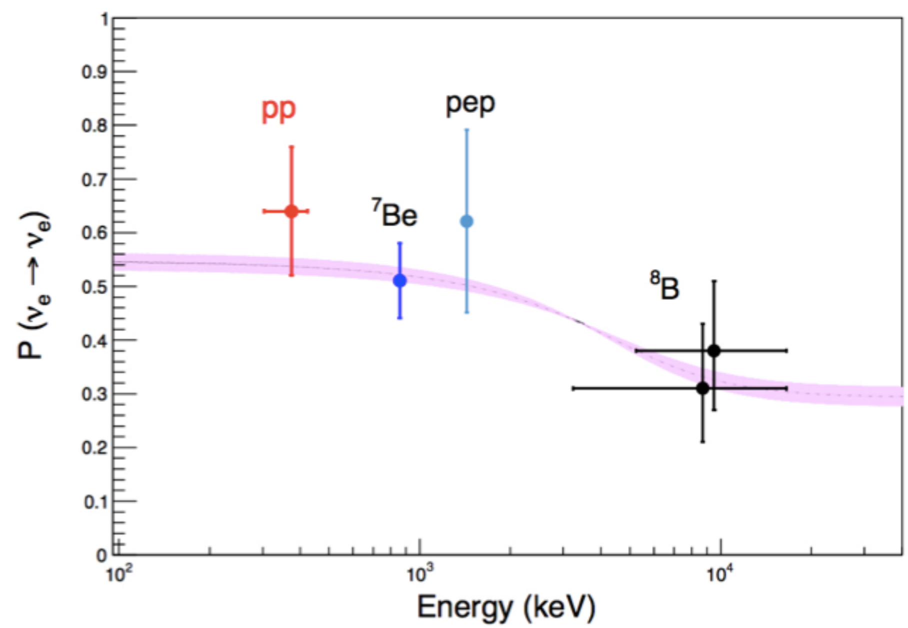


Ruppin, Billard, Figueroa-Feliciano, Strigari PRD 2014

LMA-MSW solution provides neutrino parameters



Electron neutrino survival probability



Borexino collaboration, Nature 2014

Solar neutrinos: Outstanding issues

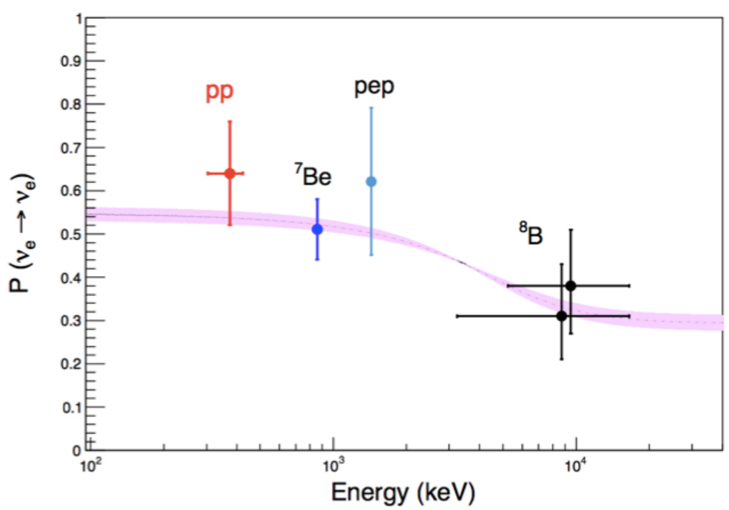
1. Solar Metallicity problem

New 3D rotational hydrodynamical simulations suggest lower metallicity in Solar core [Asplund et al. 2009]

However the low metallicity appears in conflict with helioseismology data

2. Intermediate energy survival probability

SK, Borexino, SNO CC data seem to not indicate an 'upturn' in the electron neutrino survival probability



Standard Solar Model predictions

		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%)				
${}^8B \to {}^8Be + e^+ + \nu$	~ 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 Solar neutrino review, 2013

SNO NC measurement (5.25 x 10^6) right in between predictions of low and high metallicity SSMs

Solar neutrino signals in dark matter detectors

- Nuclear recoil from neutrino-nucleus coherent scattering of primarily 8B neutrinos

  - 8B flux normalization

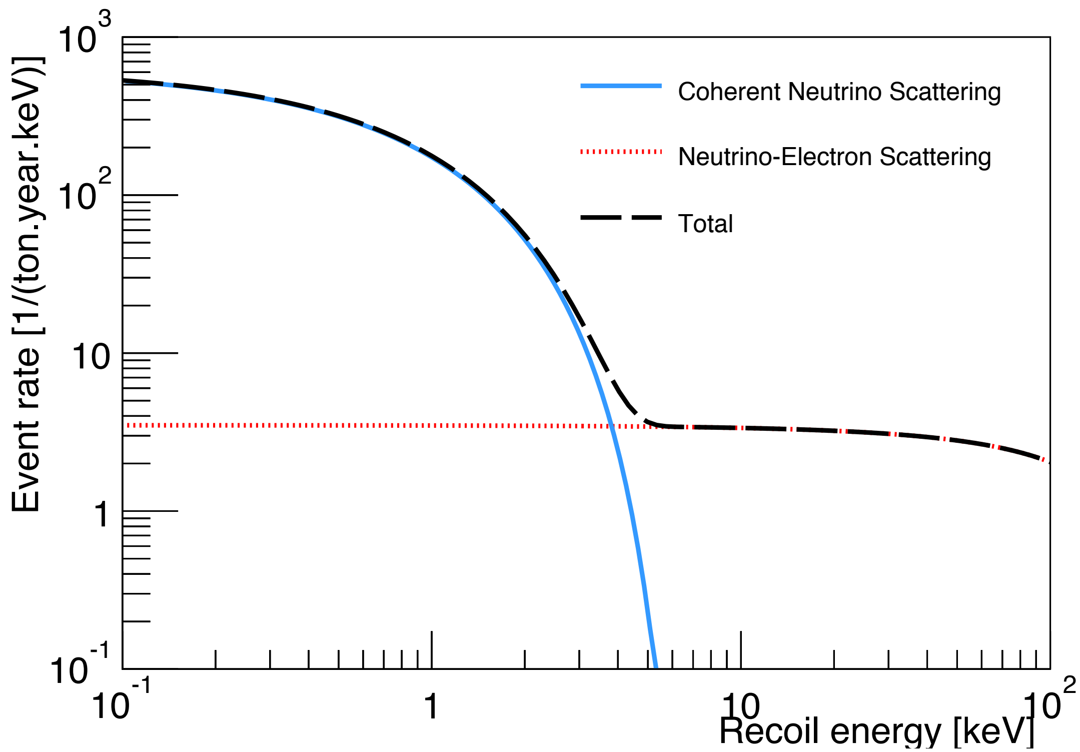
  - Energy dependence of survival probability

- Electron recoil from elastic scattering of primarily pp neutrinos

  - Lower average energy than Borexino

  - Sensitive to flavors

  - Weakly dependent on detector type



Complication: sterile neutrinos

If sterile neutrinos exist, how can one determine the total solar neutrino fluxes?

John N. Bahcall,[1,*] M. C. Gonzalez-Garcia,[2,3,4,†] and C. Peña-Garay[3,‡]
[1]*School of Natural Sciences, Institute for Advanced Study, Princeton, New Jersey 08540*
[2] *Theory Division, CERN, CH-1211 Geneva 23, Switzerland*
[3]*Instituto de Física Corpuscular, Universitat de València–CSIC, Edificio Institutos de Paterna, Apt 22085, 46071 València, Spain*
[4]*C. N. Yang Institute for Theoretical Physics, State University of New York at Stony Brook, Stony Brook, New York 11794-3840*
(Received 9 May 2002; published 19 September 2002)

- Main SNO CC and NC results do not account for sterile neutrinos

- To get constraints on sterile neutrinos from the Sun, combine with KamLAND data and assume LMA-MSW solution

Evidence for a ~ 1 eV sterile neutrino?

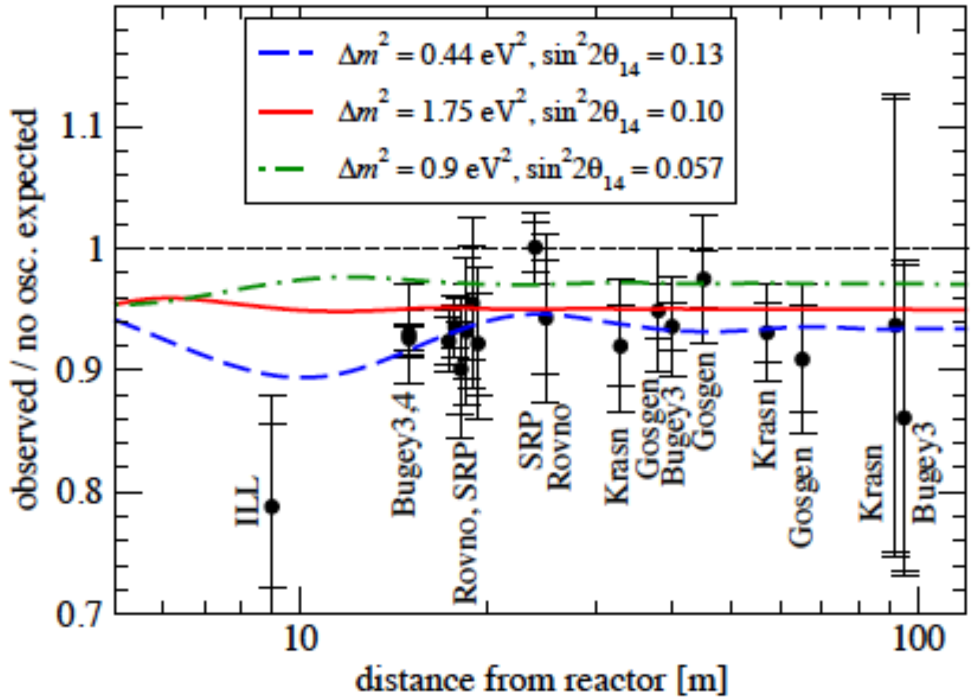
Hints for sterile neutrinos from:

- *electron neutrino disappearance* experiments: Gallium, reactor anomaly (Giunti & Lavedar 2006; Mention et al. 2011)

- *muon to electron neutrino appearance* experiments (LSND, MiniBooNE)

No hints for sterile neutrino from:

- *muon neutrino disappearance* experiments (Super-K, MiniBooNE, MINOS)



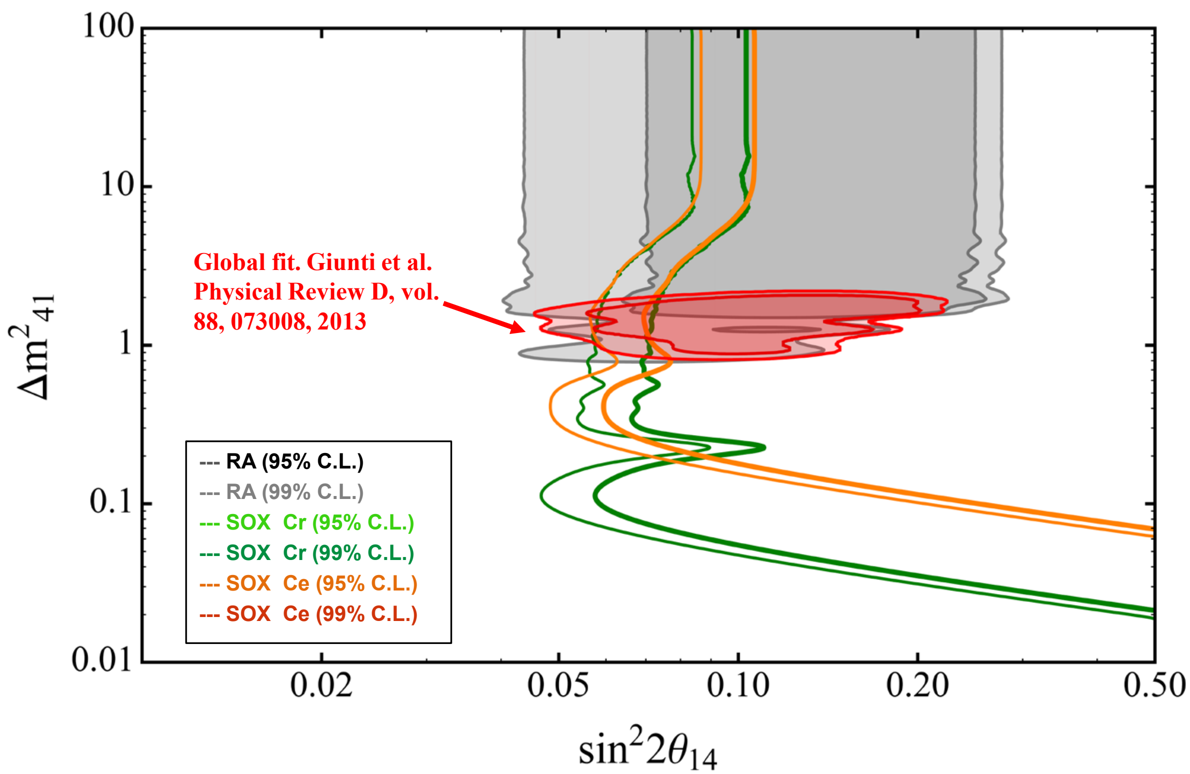
Kopp et al., sterile neutrino review 2013

Evidence for a ~ 1 eV sterile neutrino?

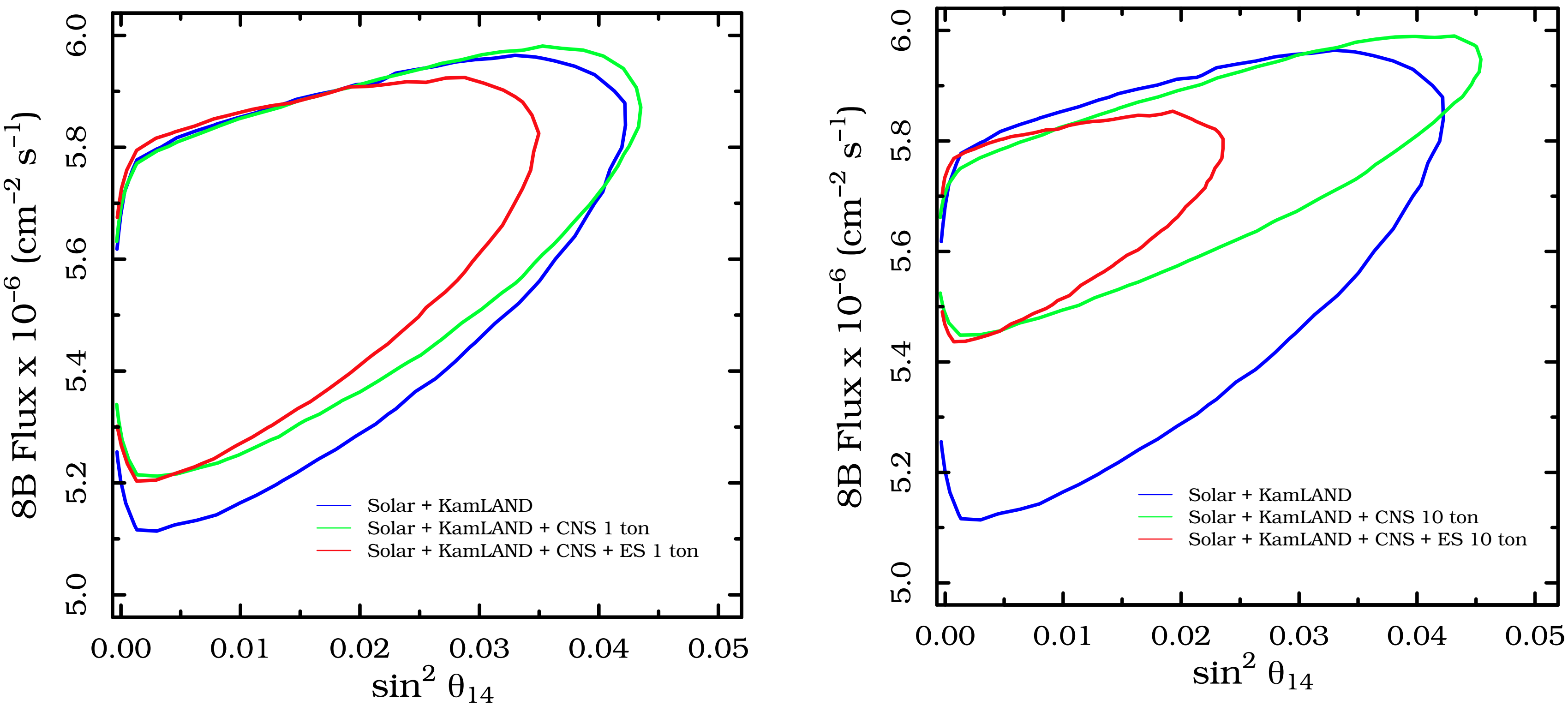
- Also, possible evidence from cosmology (Giusarma et al.; Dvorkin et al.; Zhang et al. 2014)

- Most generally constraints on sterile neutrinos are model-dependent (3+1,3+2, etc).

- We considered a 3+1 sterile neutrino model (Giunti & Li 2009; Palazzo 2011, Giunti et al. 2013). Electron neutrino mixes with 4th mass eigenstate



Constraints on neutrino parameters including DM detectors

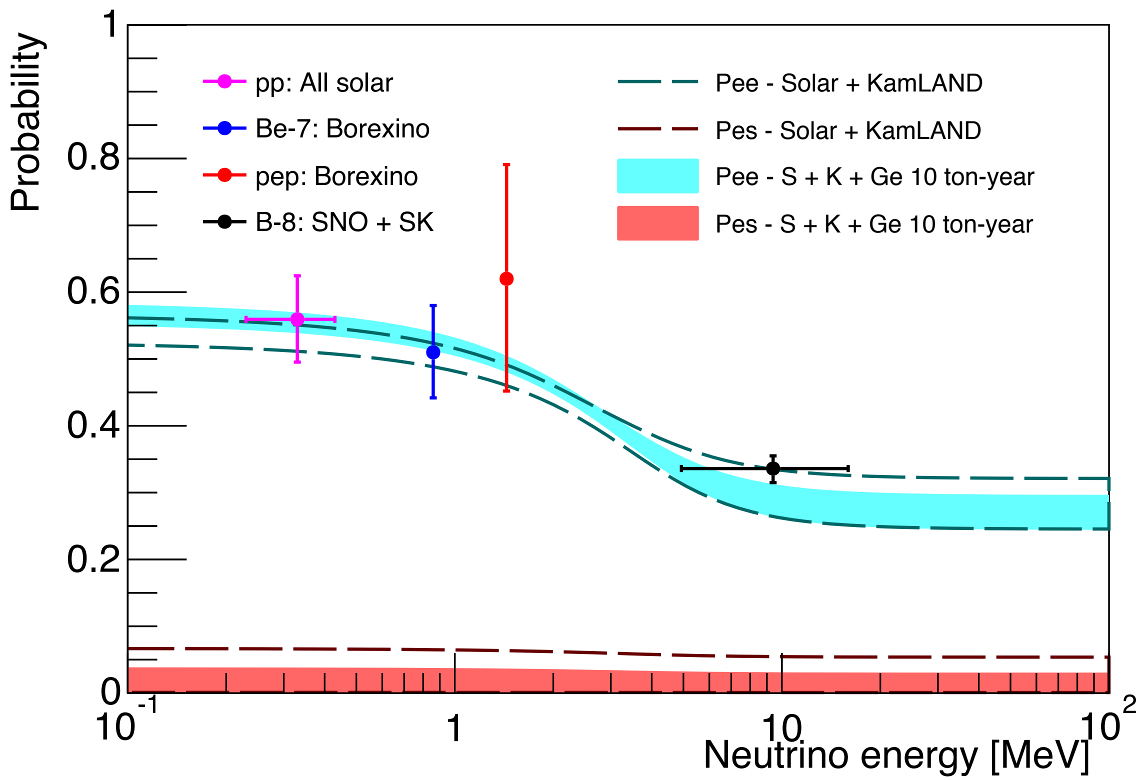


Threshold 100 eV assumed

Billard, Strigari, Figueroa-Feliciano, arXiv:1409.0050

Measurement of survival probability

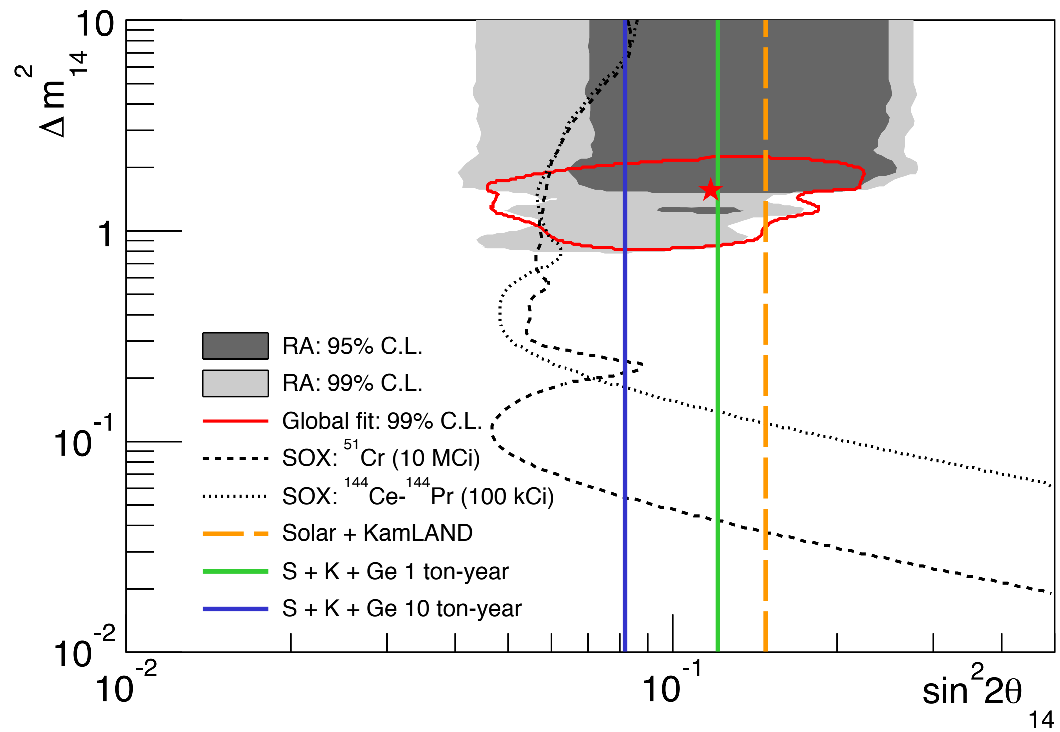
- DM detectors measure both the low and high energy survival probability
- Reduction of uncertainty on energy dependence of electron neutrino survival probability
- Reduction of uncertainty on probability to oscillate into a sterile neutrino



Billard, Strigari, Figueroa-Feliciano, arXiv:1409.0050

Sterile neutrinos with low threshold DM detectors

- Sterile neutrino sensitivity of DM detectors complementary to terrestrial searches for eV scale sterile neutrinos



Billard, Strigari, Figueroa-Feliciano, arXiv:1409.0050

Additional issues and discussion

- Have assumed that cross section is predicted by the Standard Model
- Some new physics ideas (e.g. Pospelov 2011 Baryonic sterile neutrino)
- Will CNS cross section be measured before DM experiments hit neutrino floor?
- Solar neutrino program with DM detectors?
- Electron/nucleus discrimination at low threshold?