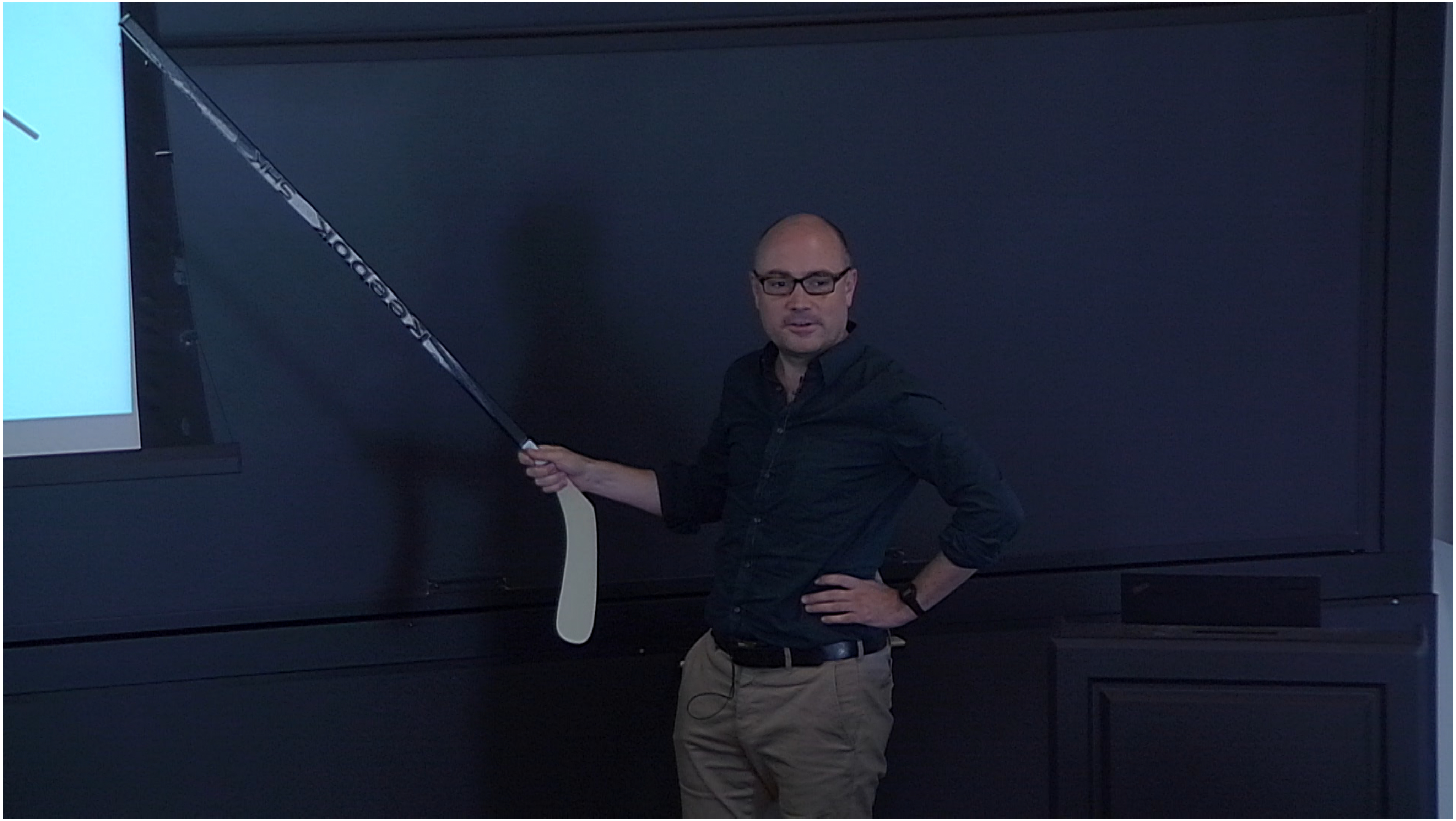
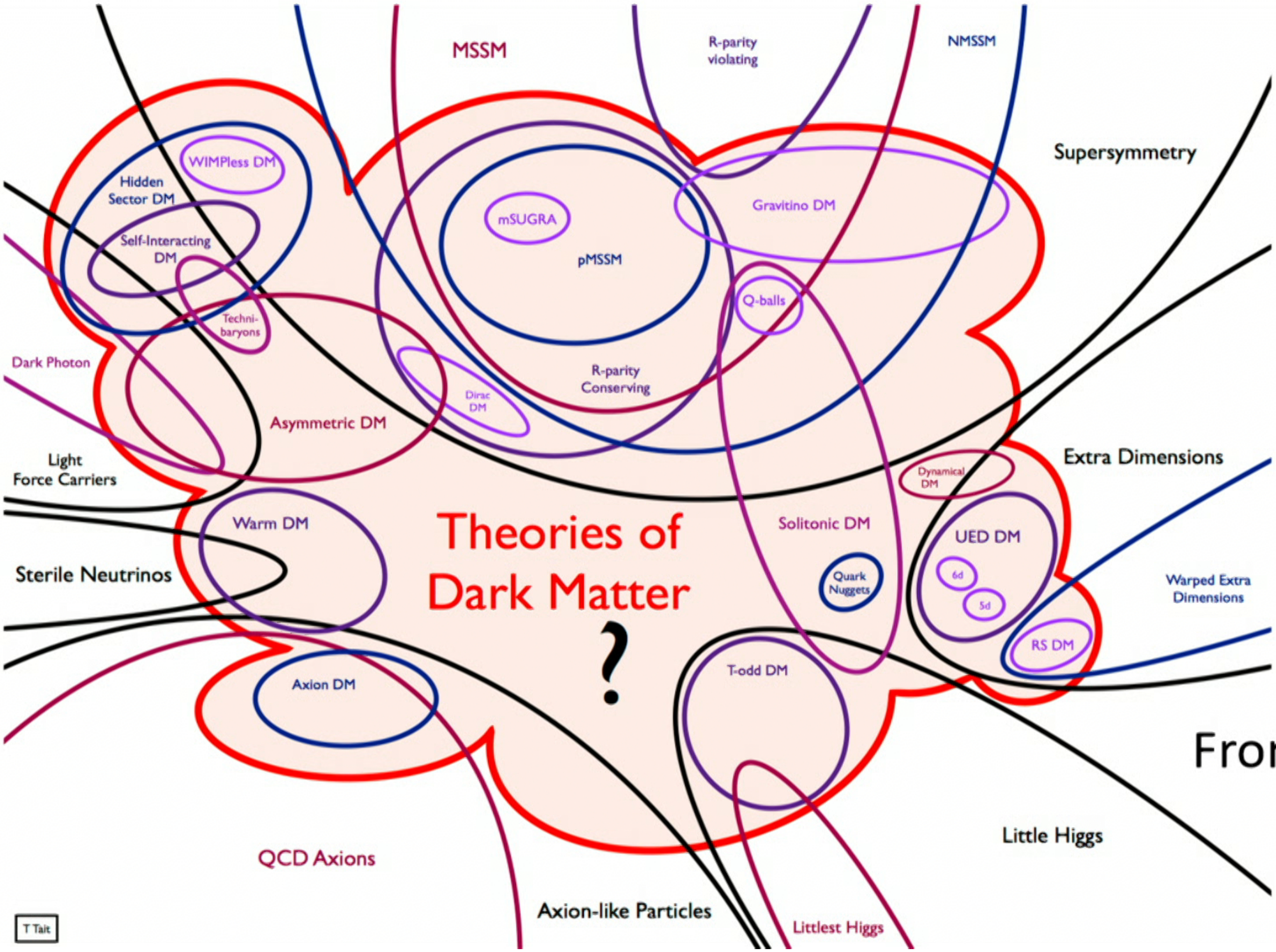
Title: Neutrinos as Signal and Background - detecting and avoiding neutrinos at dark matter detectors

Date: Jul 21, 2017 09:50 AM

URL: http://pirsa.org/17070017

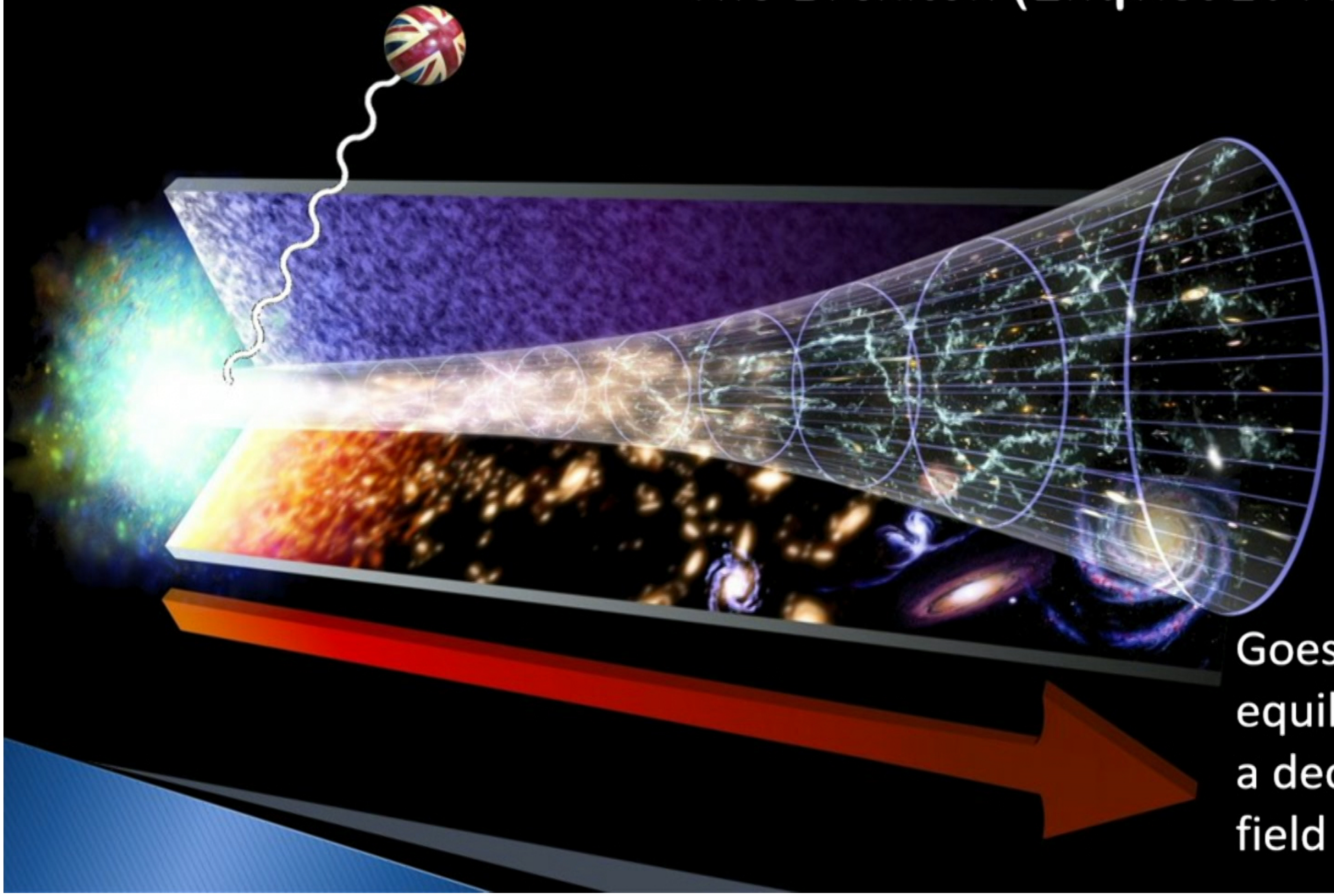
Abstract:





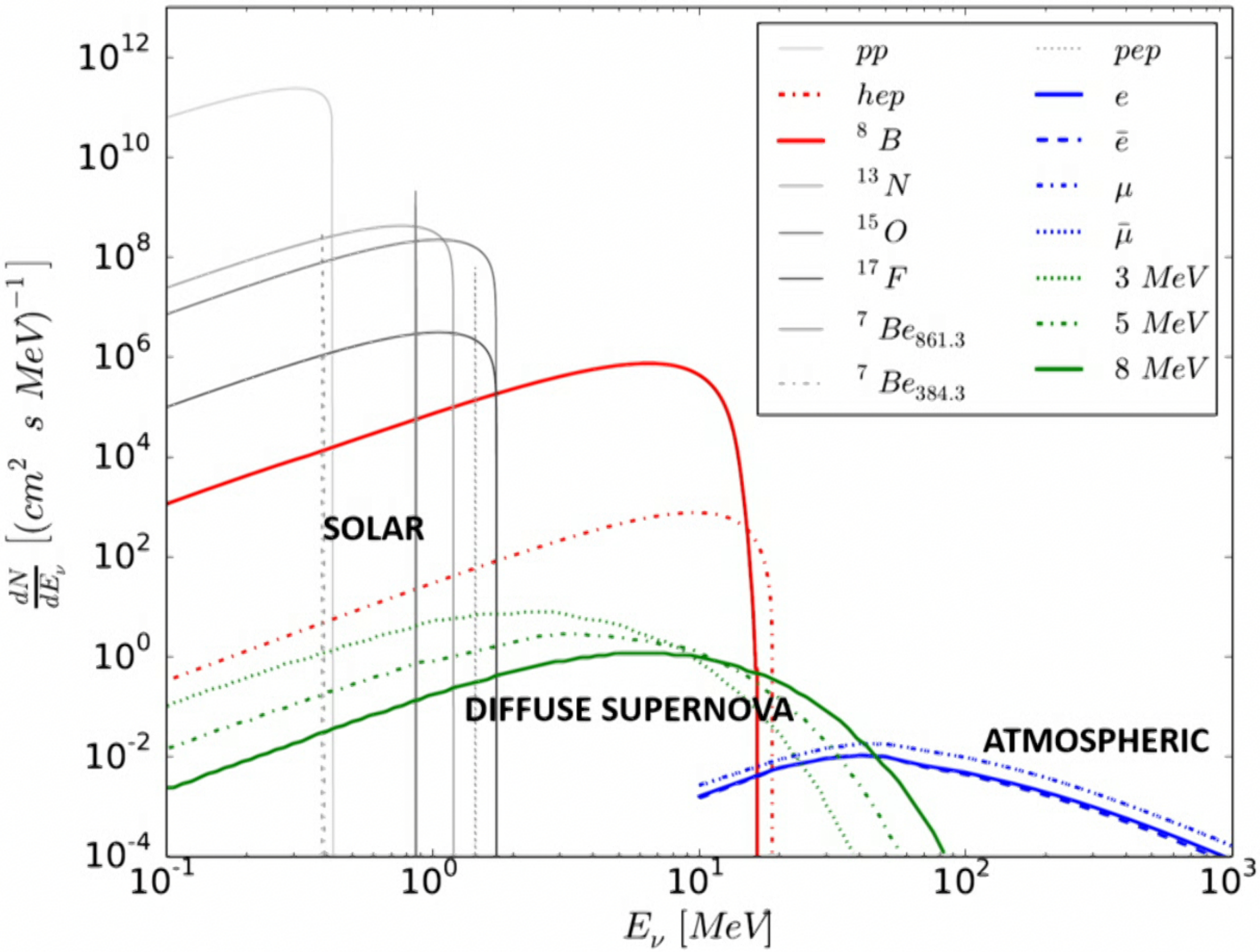
From Tim Tait

The Brexiton (Enqvist 2017, Rajantie 2017)



Goes out of thermal equilibrium then acts as a decoupled spectator field while it decays

Neutrino Background



Coherent Neutrino-Nucleon Interactions

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

- Enhanced by factor N^2:

$$Q_W = N - (1 - 4\sin^2\theta_W)Z \approx N - 0.08 \times Z \approx N$$

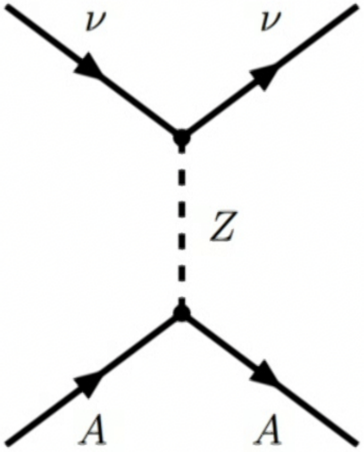
- $\cos\theta$: angle between in- and outgoing neutrino direction
- $2m_T E_r = q^2 = 2E_\nu^2(1-\cos\theta)$

$$\Rightarrow \frac{d\sigma}{dE_\mathrm{r}} = \frac{G_F^2}{4\pi} Q_W^2 m_T \left(1 - \frac{m_T E_\mathrm{r}}{2E_\nu^2}\right) F(Q^2)^2.$$

$$\frac{dR_\nu}{dE_r} = n_T \int_{t_0}^{t_1} \int_{E_\nu^\mathrm{min}}^{\infty} \frac{dN(t)}{dE_\nu} \frac{d\sigma(E_\nu, E_\mathrm{r})}{dE_\mathrm{r}} dE_\nu \, dt$$

$$R_\nu = \int_{E_\mathrm{thr}}^{E_\mathrm{up}} \frac{dR_\nu}{dE_r} dE_r$$

$qR \ll 1$



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- $\cos\theta$: angle between in-

- $2m_T E_r = q^2 = 2E_\nu^2(1 -$ $\ll 1$

STILL NOT OBSERVED IN STANDARD MODEL

$$\Rightarrow \frac{d\sigma}{dE_\mathrm{r}} = \frac{G_F^2}{4\pi} Q_W^2 \, m_T \, (1 - \frac{m_T E_\mathrm{r}}{2E_\nu^2}) \, F(Q^2)^2.$$

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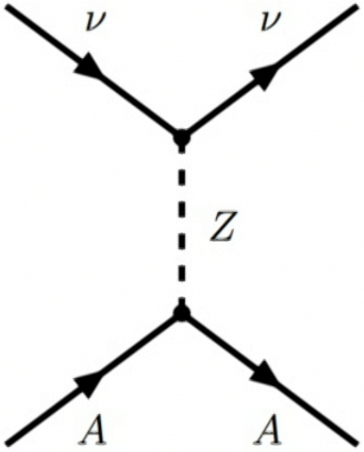
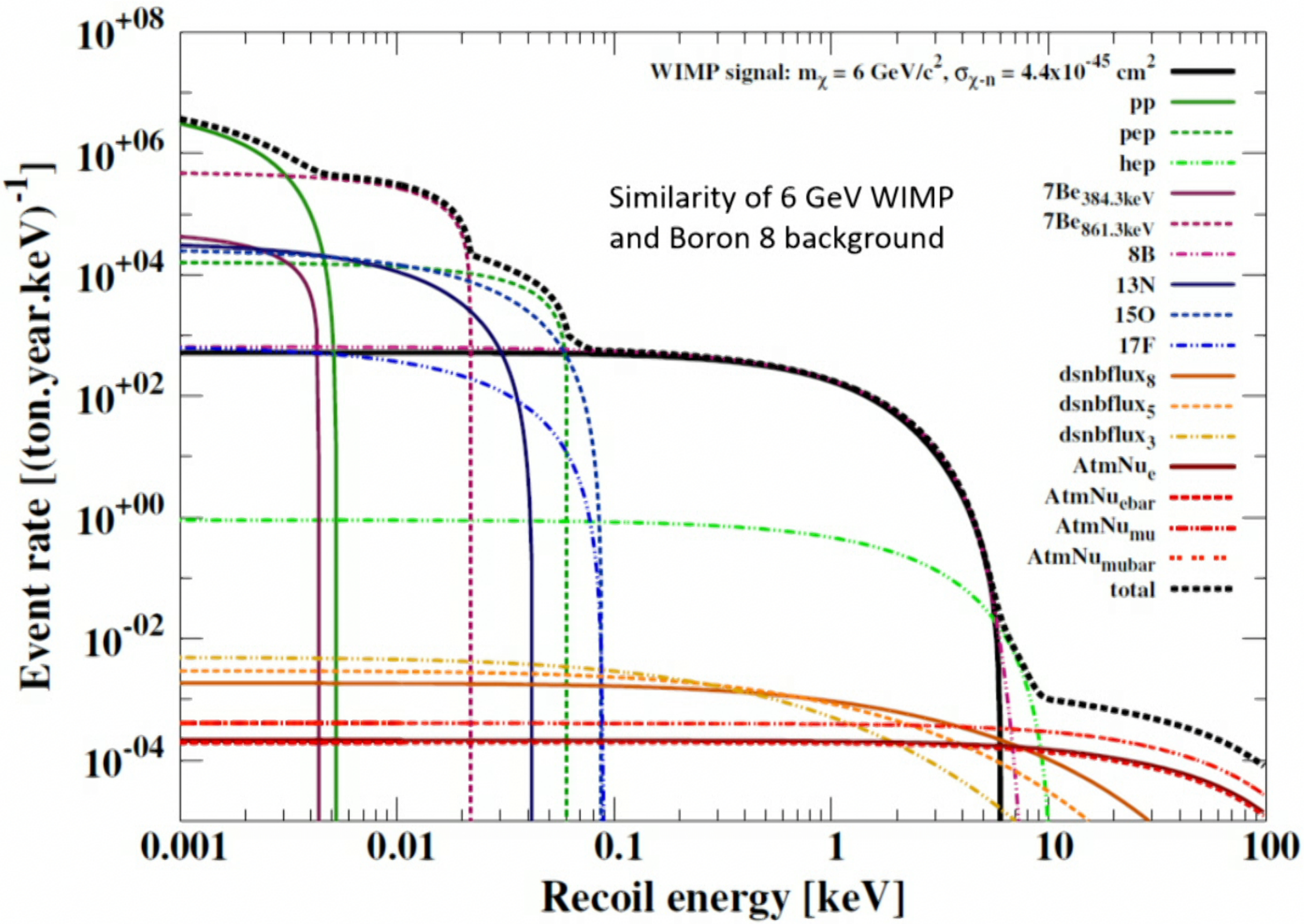




Similarity of 6 GeV WIMP and Boron 8 background

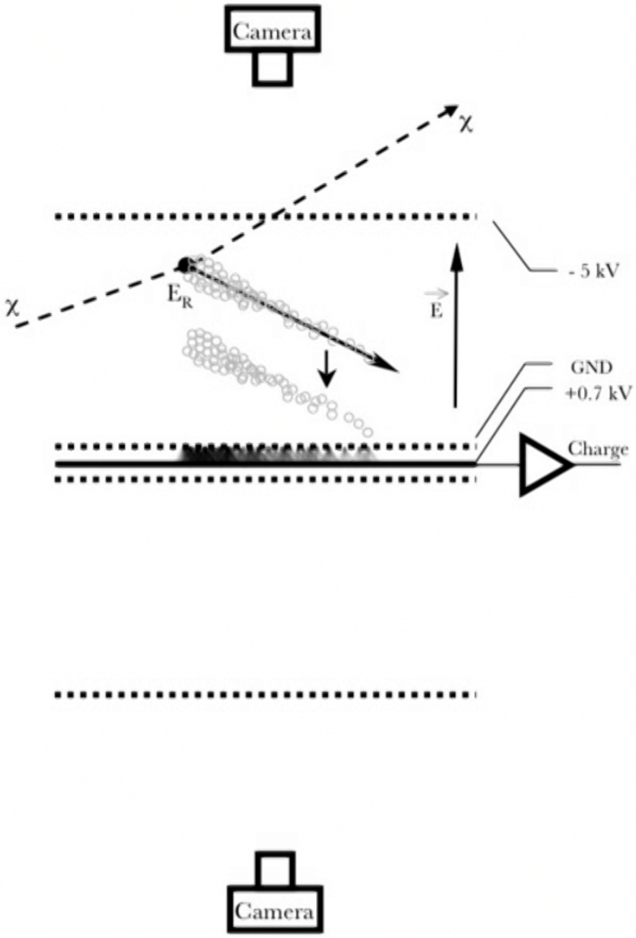
Ruppin et al 1408.3581

What if we can Tell which direction the dark matter is coming from?

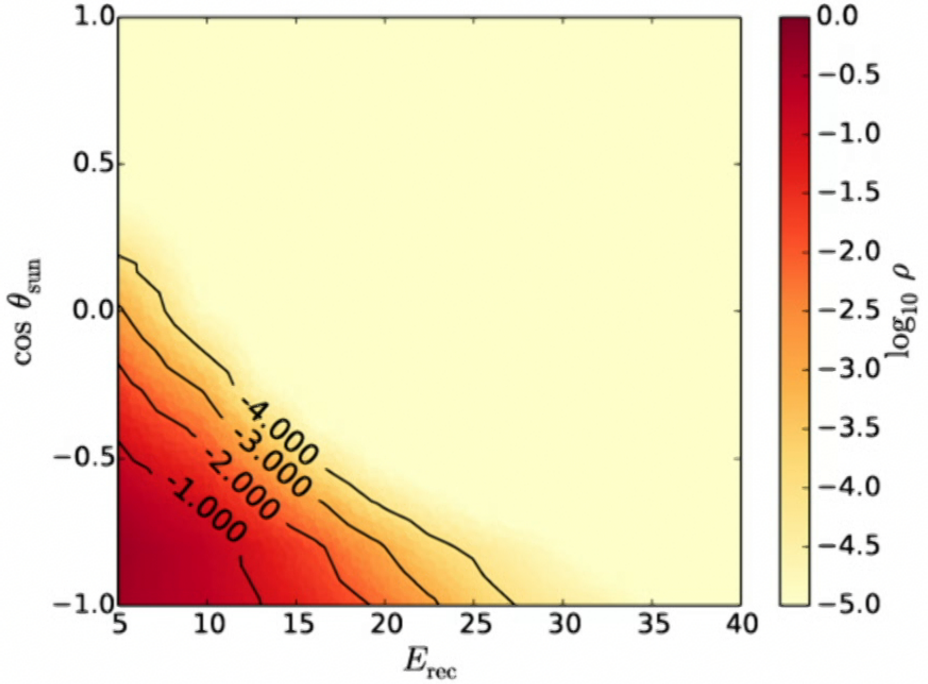
DIRECTIONAL DARK MATTER DETECTION

e.g. DMTPC

Faces major technical challenges to scale up but lets carry on regardless…



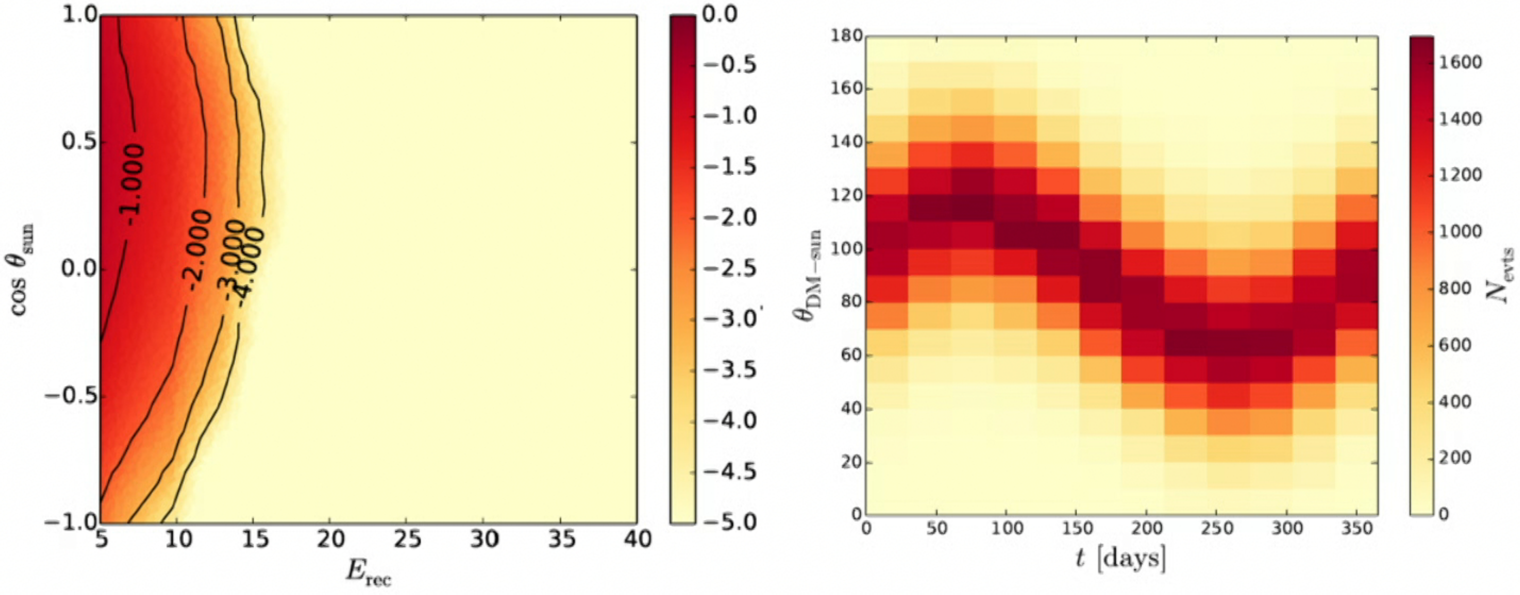
angle between recoil from Solar neutrino and sun



$$\cos\theta' = \frac{E_\nu + m_T}{E_\nu}\sqrt{\frac{E_{\rm r}}{2m_T}}$$

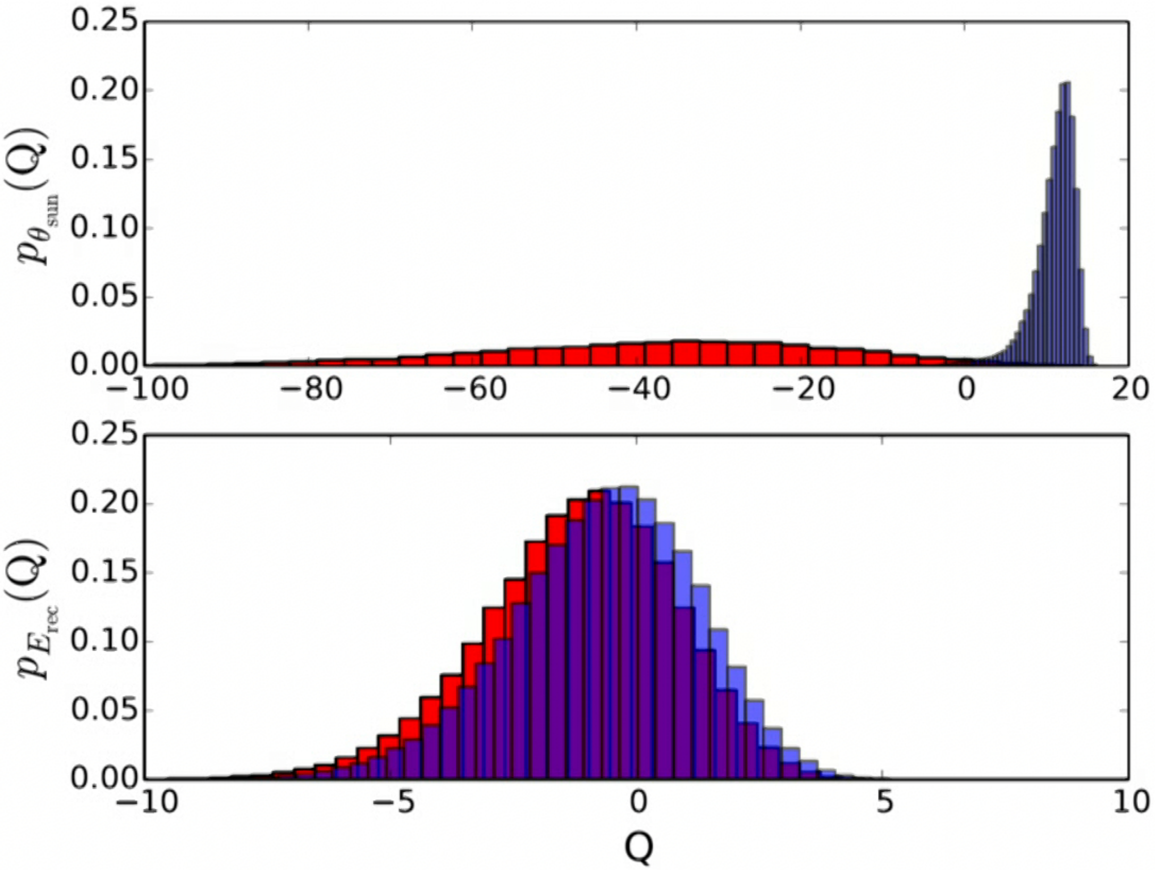
arXiv:1406.5047

angle between recoil from Dark Matter and sun



- Preferred arrival direction roughly from Cygnus A
- This changes during the year
- Lighter (heavier) dark matter more (less) directional above a given threshold

arXiv:1406.5047



The normalised background only distribution $p_B(Q_B)$ (blue) and signal plus background distribution $p_{SB}(Q_{SB})$ (red) including angular information (top) and excluding angular information (bottom) for s=10 and b=500 for a 6 GeV dark matter particle in a CF_4 detector.

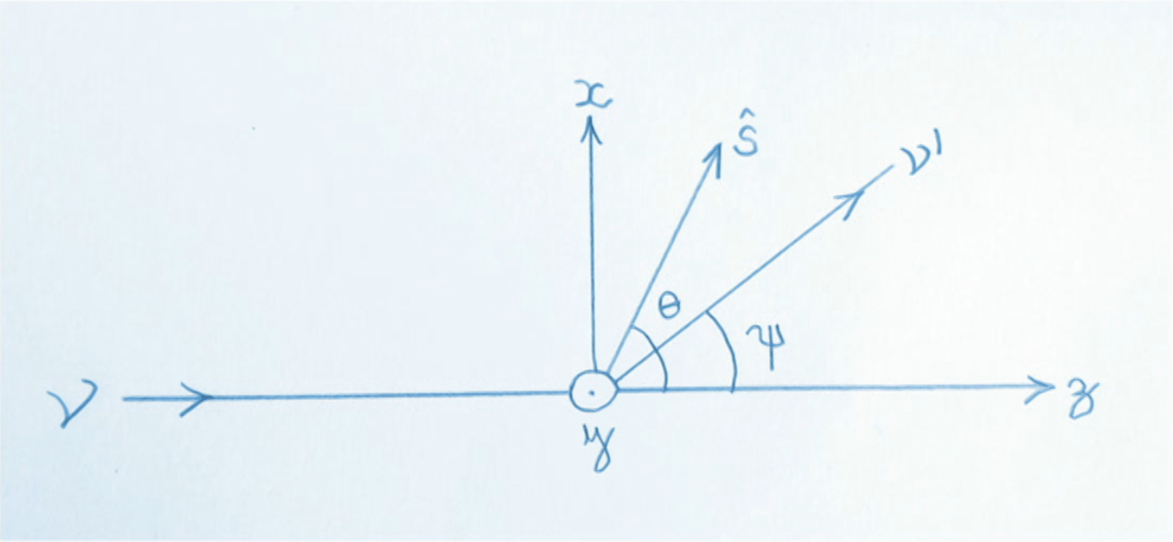
arXiv:1406.5047

Interesting Possibility – Polarised targets

- Polarised targets not very directional for dark matter
  (effect is supressed when no preferred helicity)
- Polarised targets with unpaired neutrons ARE directional to axial coupling of neutrinos
- Effect usually dwarfed by vector coupling due to coherent enhancement
- Notable exception is Helium-3

arXiv:1605.08727

see also
"Dark Matter Detection with Polarized Detectors"
Chiang, Kamionkowski & Krnjaic, arXiv:1202.1807



if N=1 and c_A due to unpaired neutron

cancellation between V and A for particular orientations of the spin and the arrival direction of the neutrino

$$\frac{d\sigma}{d\Omega} = \frac{G_F^2 E_\nu^2}{16\pi^2}\{\underbrace{c_V^2 - 3c_A^2 + (c_V^2 - c_A^2)\cos\psi}_{\textbf{SI}} + \underbrace{2c_A[(c_V - c_A)\hat{v}.\hat{s} + (c_V + c_A)\hat{v}'.\hat{s}]}_{\textbf{SD}}\}$$

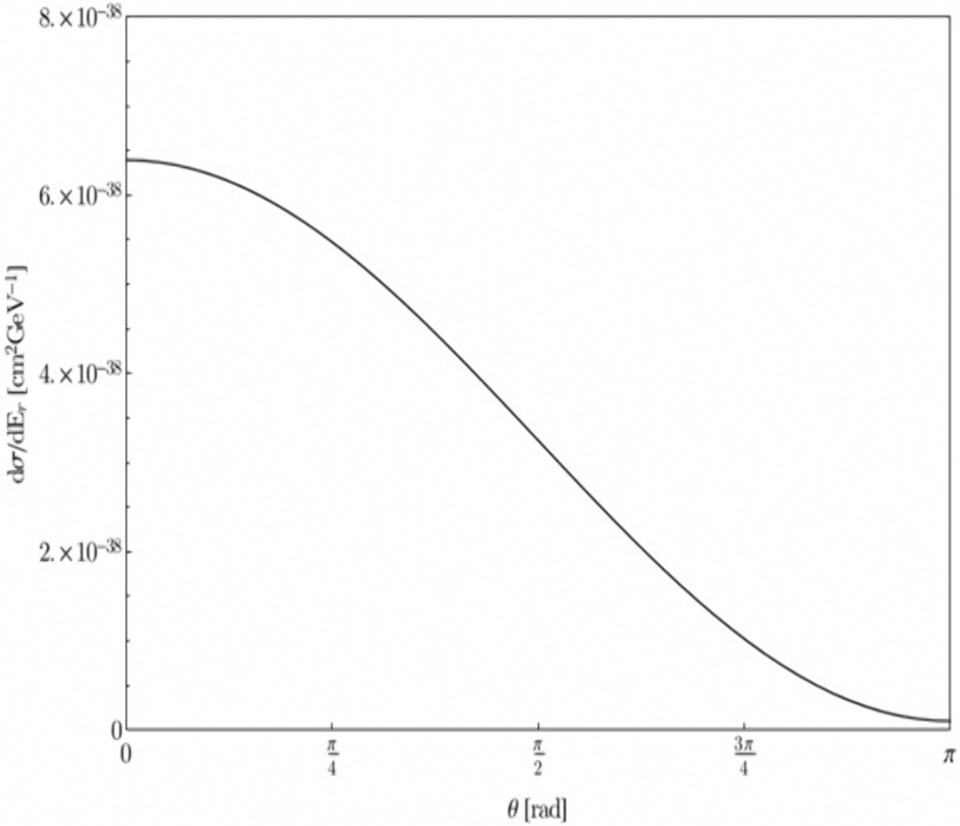
$$c_V^{\text{nucleus}} = Zc_V^p + Nc_V^n$$

$$c_A^{\text{nucleus}} = c_A^{\text{unpaired nucleon}}$$

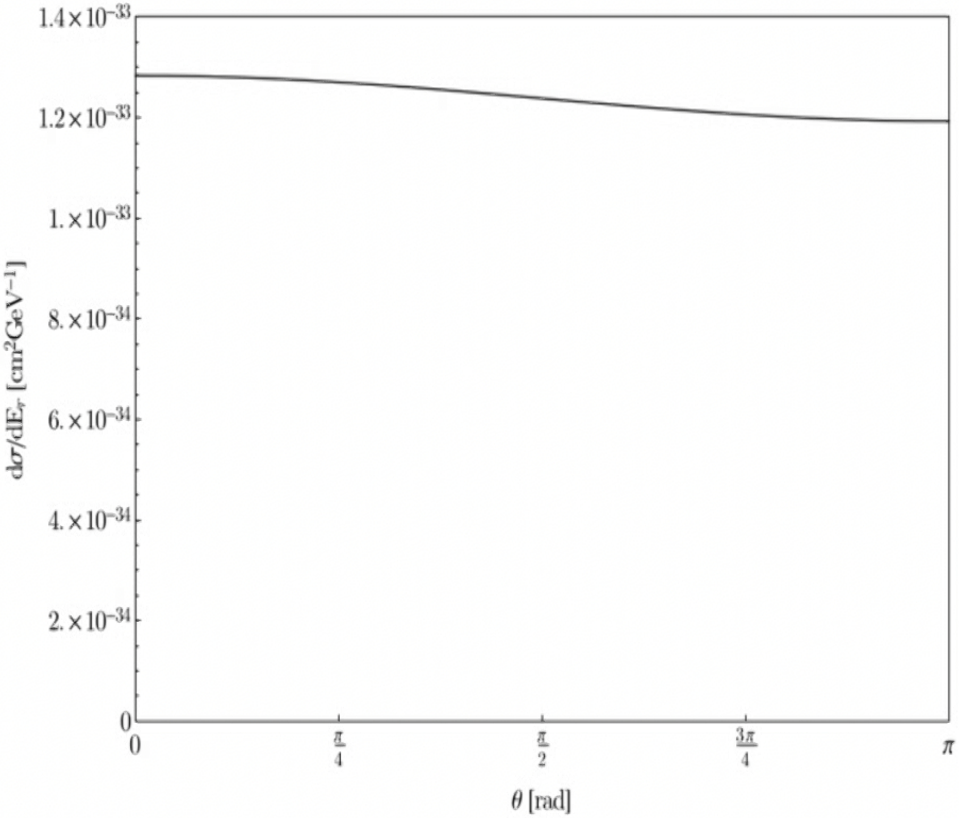
	c_V	c_A
Proton	$1 - 4\sin^2\theta_W$	1.26
Neutron	-1	-1.26

6.4 MeV Neutrino-nucleon cross section as function of angle

For Xenon there is a small effect while for Helium-3 there is almost a complete cancellation.



^{3}He



^{129}Xe

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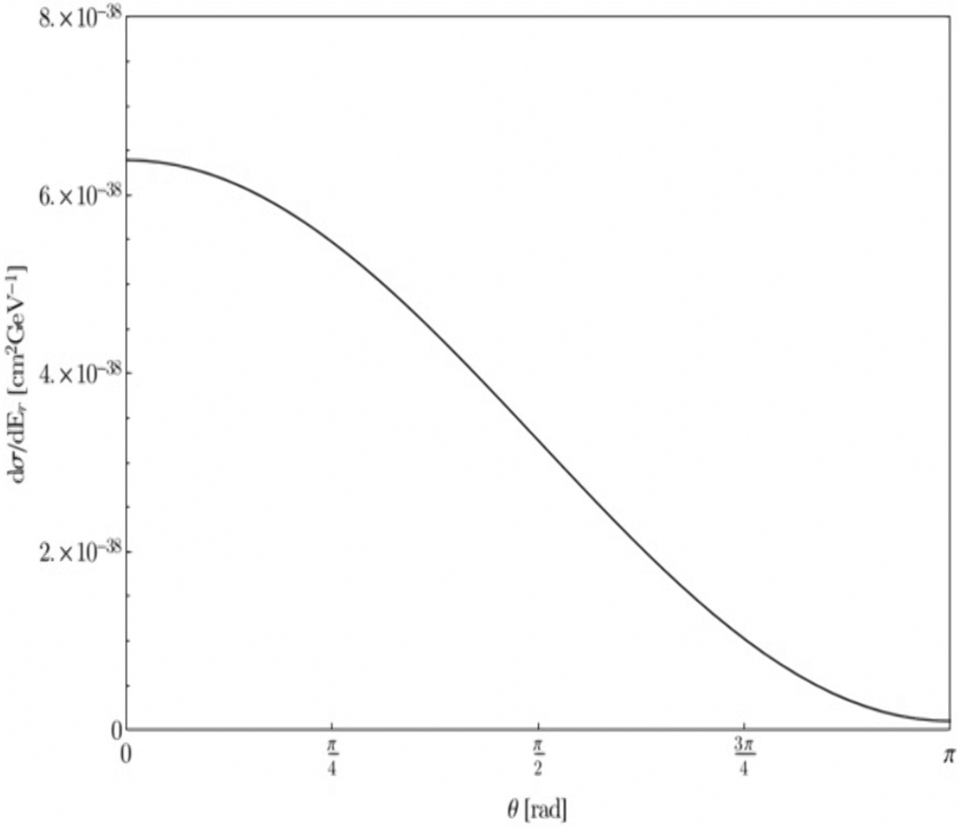

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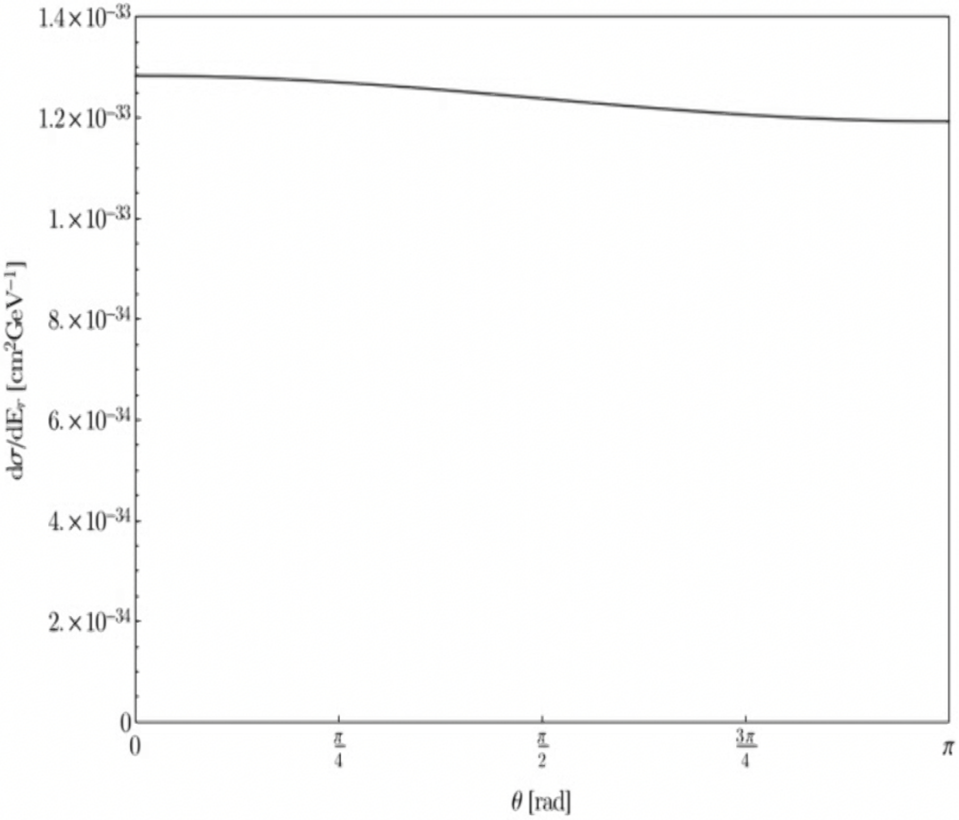


^{129}Xe

arXiv:1605.08727

Some obvious problems with Helium-3

- Tritium contamination would be a major background

- Simplest Polarisation scheme for He-3 for NMR uses potassium and/or rubidium, both of which are potential contaminants

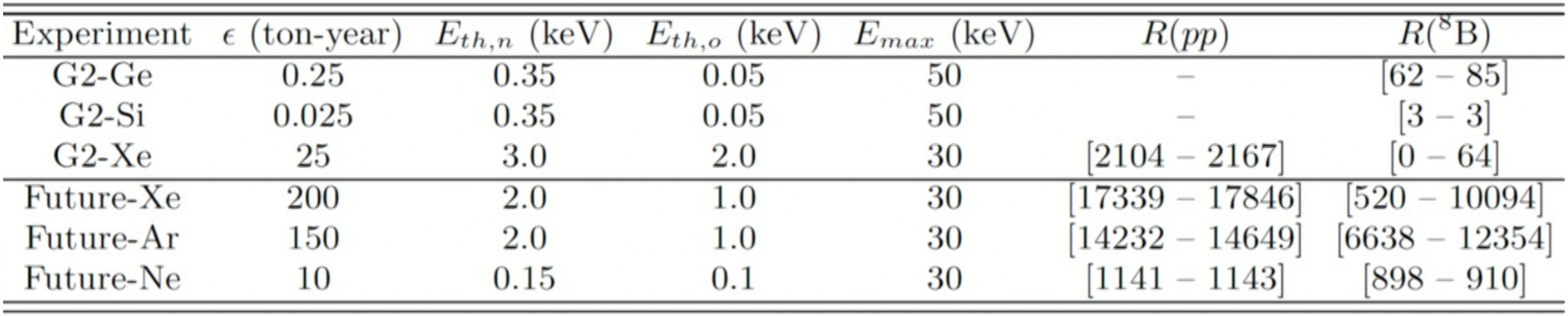
- Helium-3 makes Xenon look as cheap as water

$$\alpha = \frac{1}{2}\left|\frac{\frac{d\sigma}{dE_r}(0) - \frac{d\sigma}{dE_r}(\pi)}{\frac{d\sigma}{dE_r}(\pi/2)}\right|$$

arXiv:1605.08727

	α
$^{3}\mathrm{He}$	0.97
$^{13}\mathrm{C}$	0.41
$^{15}\mathrm{N}$	0.36
$^{19}\mathrm{F}$	0.22
$^{129}\mathrm{Xe}$	0.04

We expect to detect Neutrinos. What could we do with this information?



Experiment	ϵ (ton-year)	$E_{th,n}$ (keV)	$E_{th,o}$ (keV)	E_{max} (keV)	$R(pp)$	$R(^8\mathrm{B})$
G2-Ge	0.25	0.35	0.05	50	–	[62 – 85]
G2-Si	0.025	0.35	0.05	50	–	[3 – 3]
G2-Xe	25	3.0	2.0	30	[2104 – 2167]	[0 – 64]
Future-Xe	200	2.0	1.0	30	[17339 – 17846]	[520 – 10094]
Future-Ar	150	2.0	1.0	30	[14232 – 14649]	[6638 – 12354]
Future-Ne	10	0.15	0.1	30	[1141 – 1143]	[898 – 910]

arXiv:1604.01025

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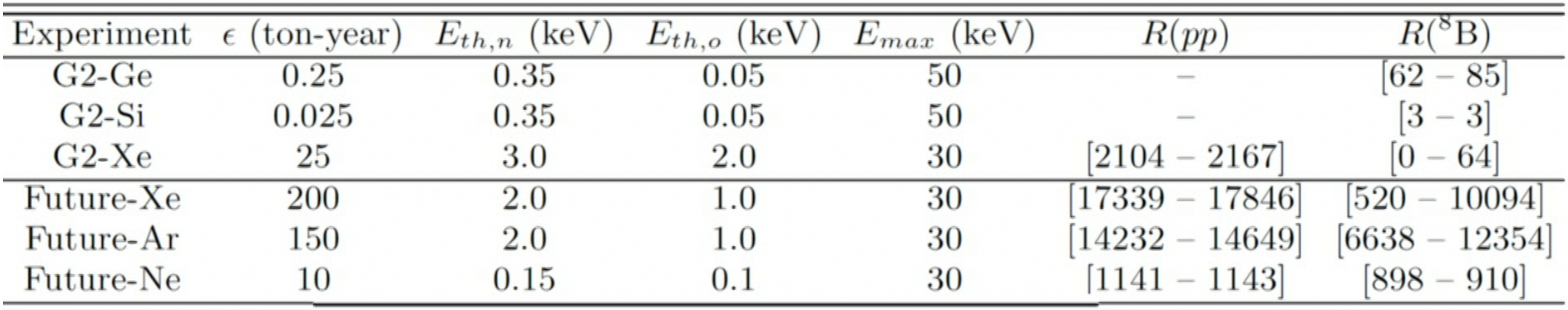

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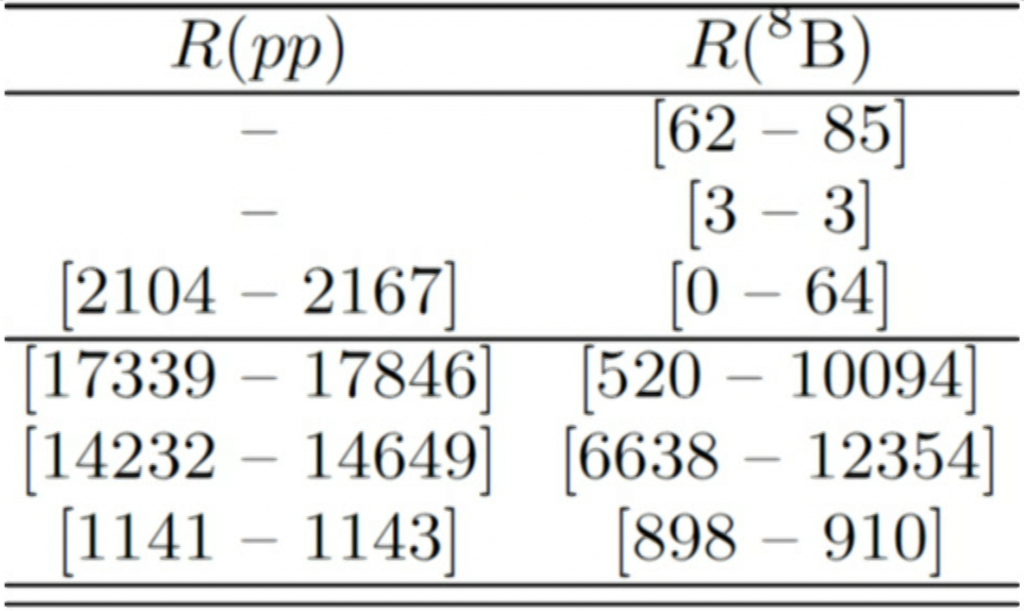

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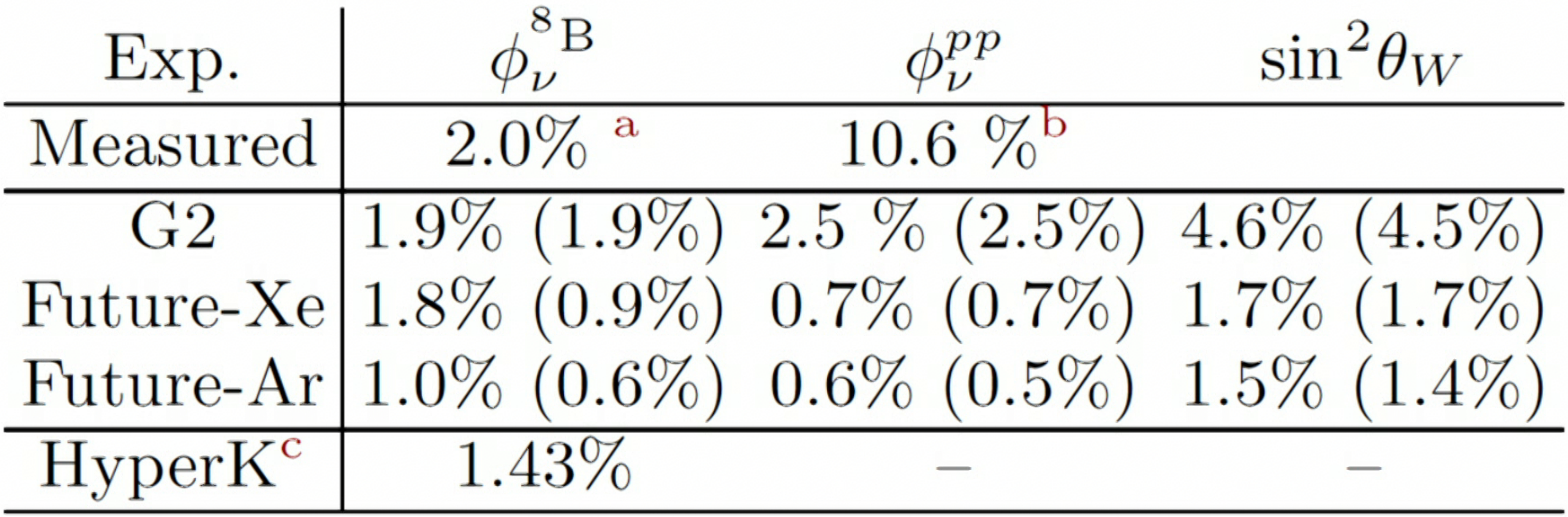
We expect to detect Neutrinos. What could we do with this information?

Measure Boron-8 flux using nuclear recoils and pp flux using electron recoils

Can measure the Weinberg angle at very low energies



Exp.	$\phi_\nu^{^8\mathrm{B}}$	ϕ_ν^{pp}	$\sin^2\theta_W$
Measured	2.0% [a]	10.6 % [b]	
G2	1.9% (1.9%)	2.5 % (2.5%)	4.6% (4.5%)
Future-Xe	1.8% (0.9%)	0.7% (0.7%)	1.7% (1.7%)
Future-Ar	1.0% (0.6%)	0.6% (0.5%)	1.5% (1.4%)
HyperK [c]	1.43%	–	–

arXiv:1604.01025

We expect to detect Neutrinos. What could we do with this information?

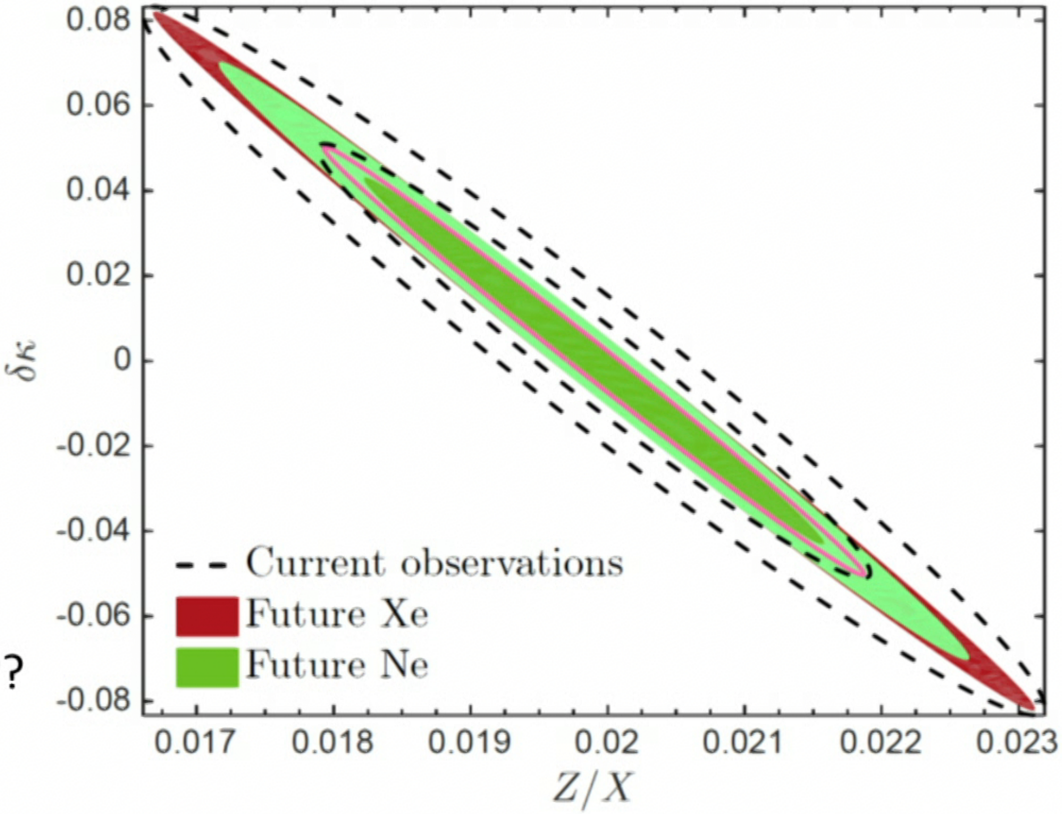
Limits average opacity vs. metallicity

Narrows line but still huge degeneracy

Needs to be broken by observation of CNO neutrinos –

SNO+ ???

Future direct detection experiments ???



arXiv:1604.01025

Tests of BSM Physics

Momentum exchanged for pp-neutrino electron events is around 10 keV

Momentum exchanged for neutrino-nucleon events is about MeV scale

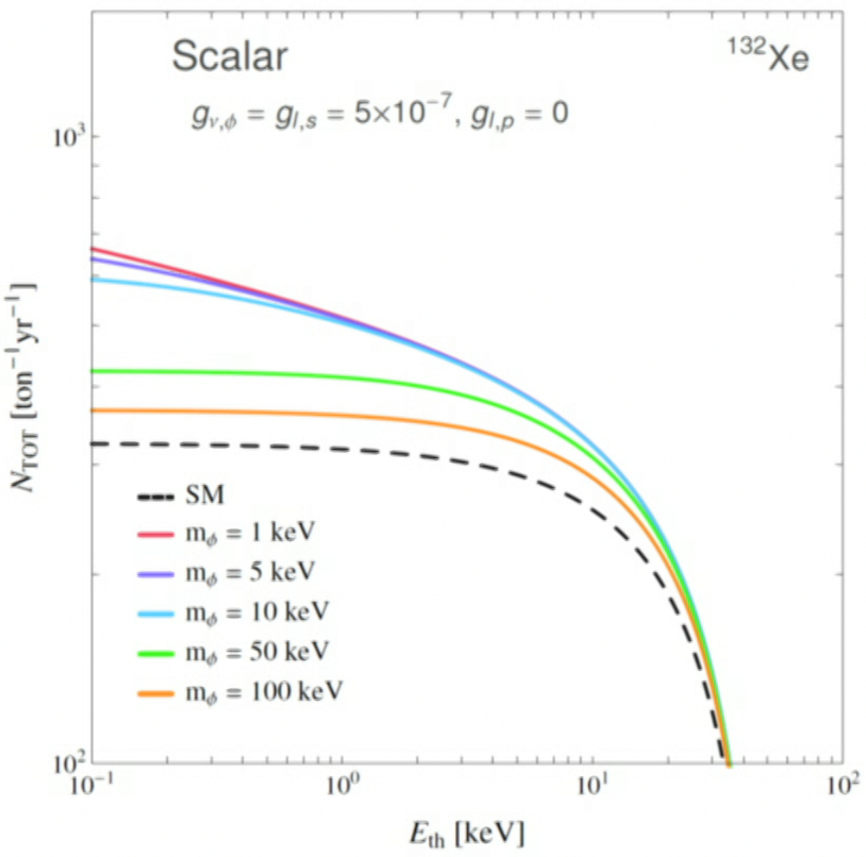
Both Q^2 unstudied in those settings, can probe new interactions.

arXiv:1604.01025

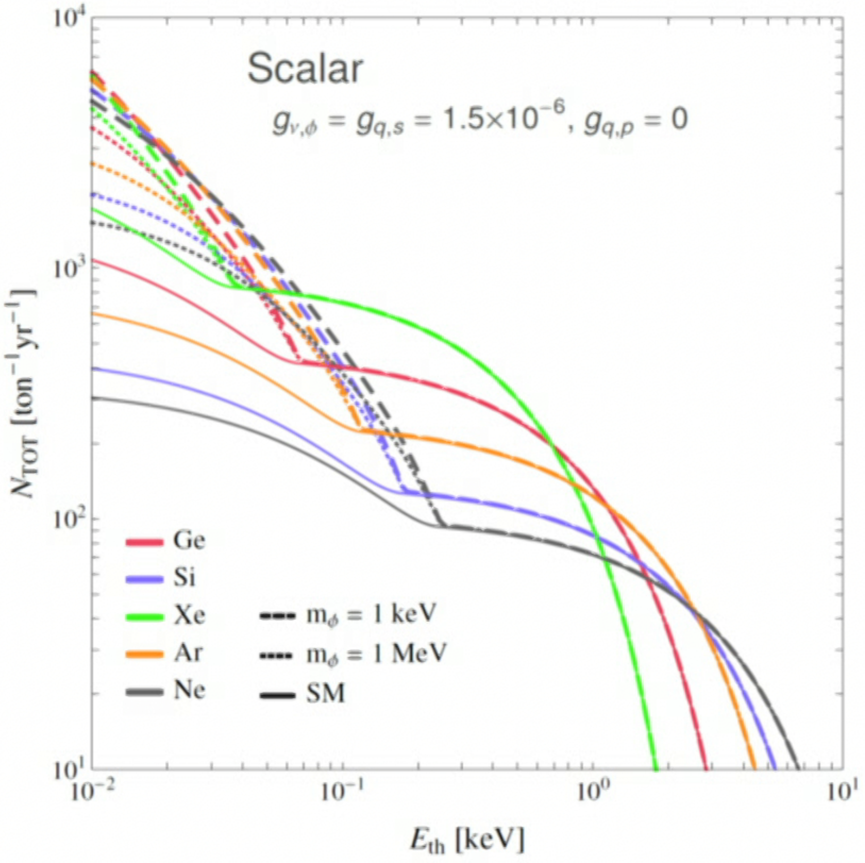
Tests of BSM Physics

arXiv:1604.01025

$$(g_{\nu,\phi}\,\phi\bar{\nu}_R\nu_L + h.c.)$$
$$+\,\phi\bar{\ell}g_{\ell,s}\ell + \phi\bar{q}g_{q,s}q$$



electron recoils



nuclear recoils

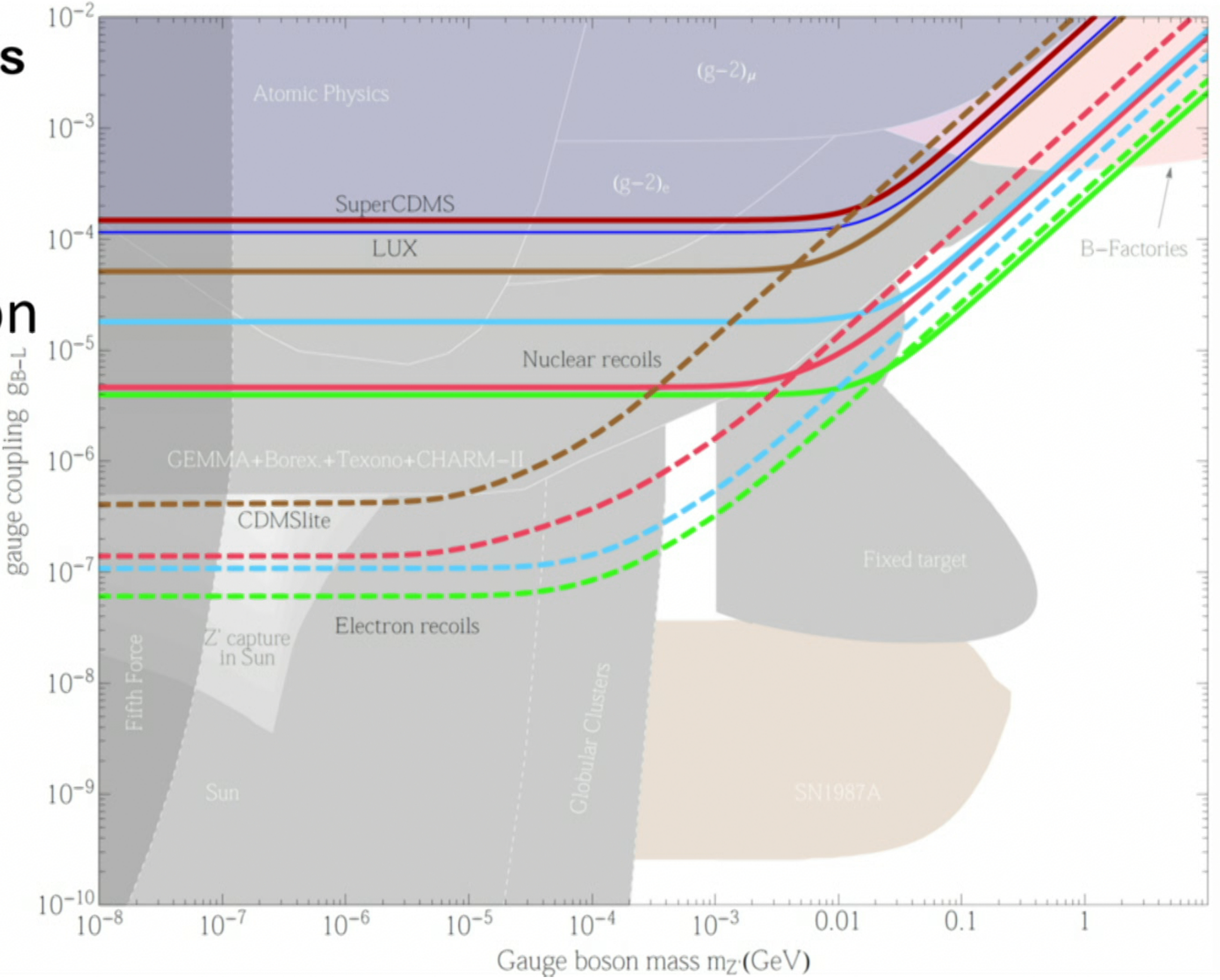
Tests of BSM Physics

arXiv:1604.01025

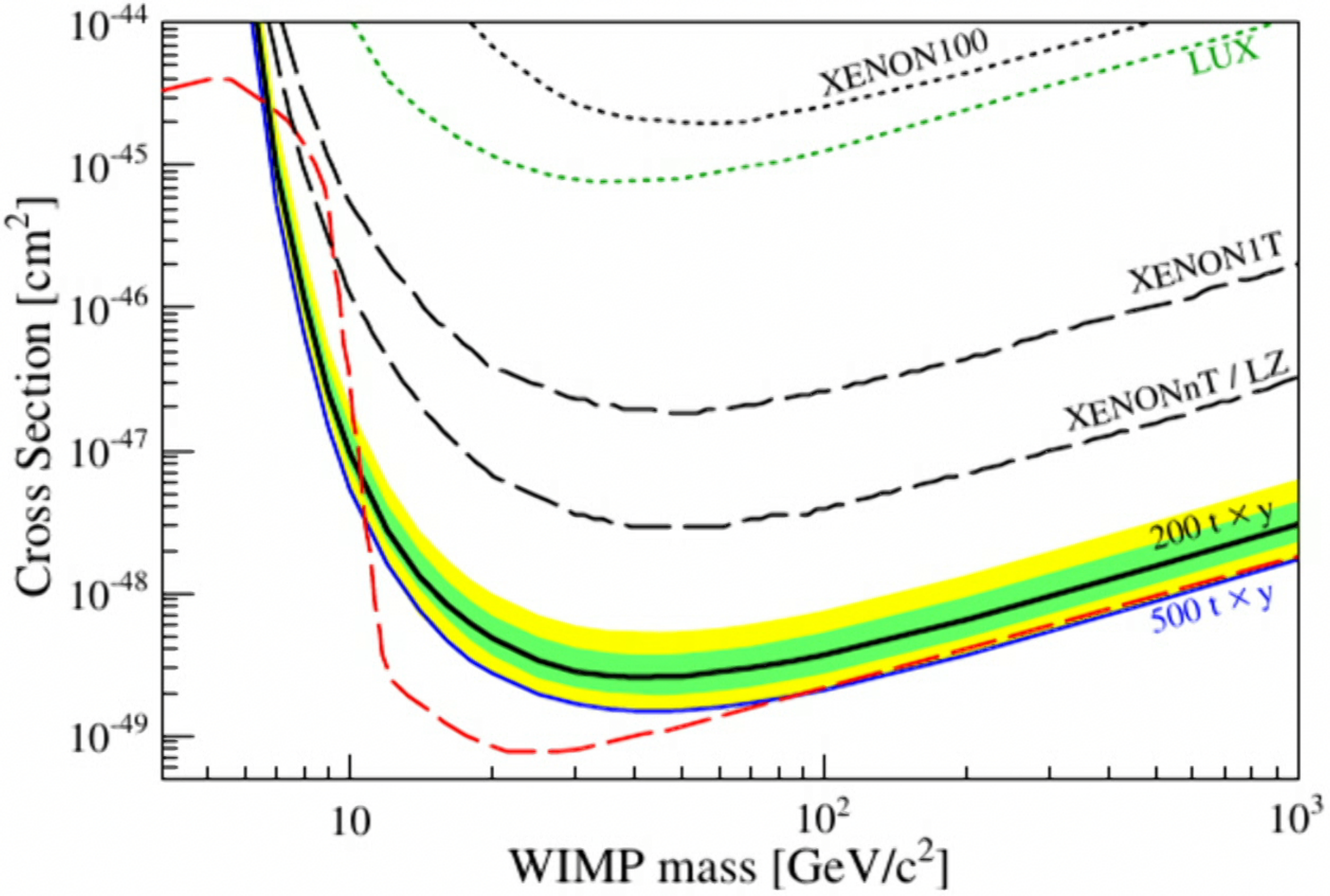
U(1)$_{B-L}$ gauge boson couples to B-L charge of SM particles

Dashed electron, solid nucleon.

Green future xenon
Blue G2 xenon
Red G2 germanium



Doesn’t seem possible to measure Diffuse Supernova Neutrino Background even with Darwin



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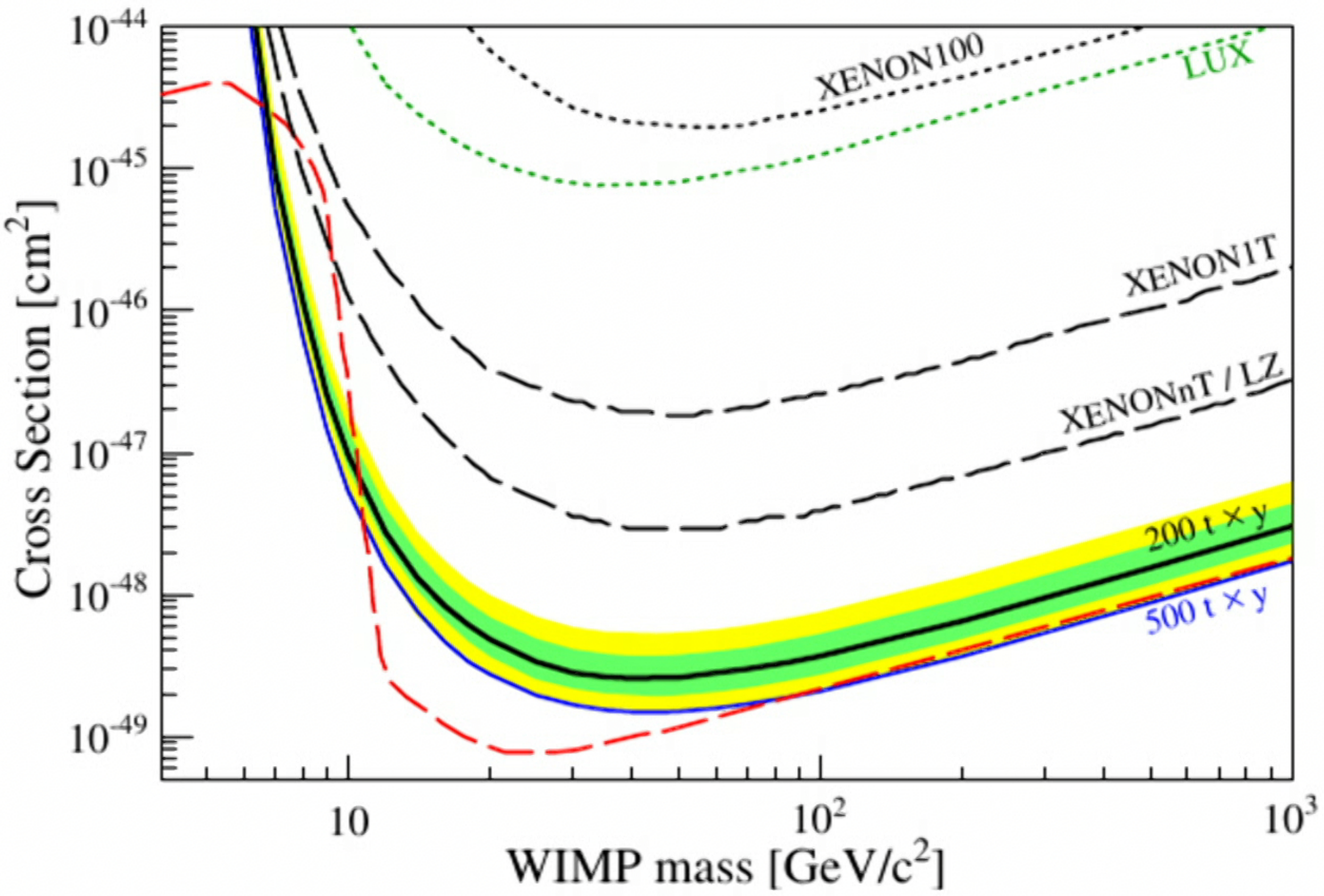

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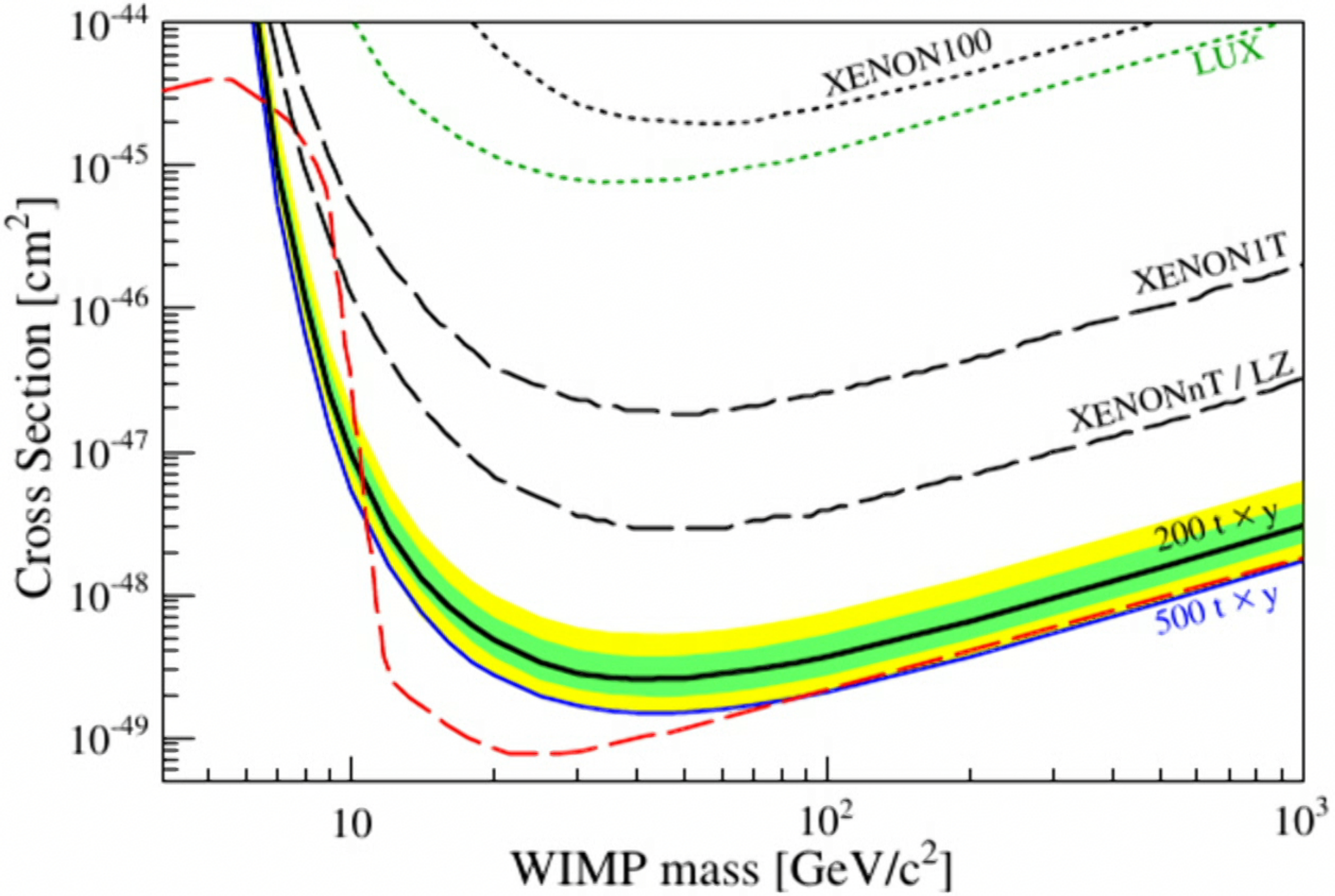

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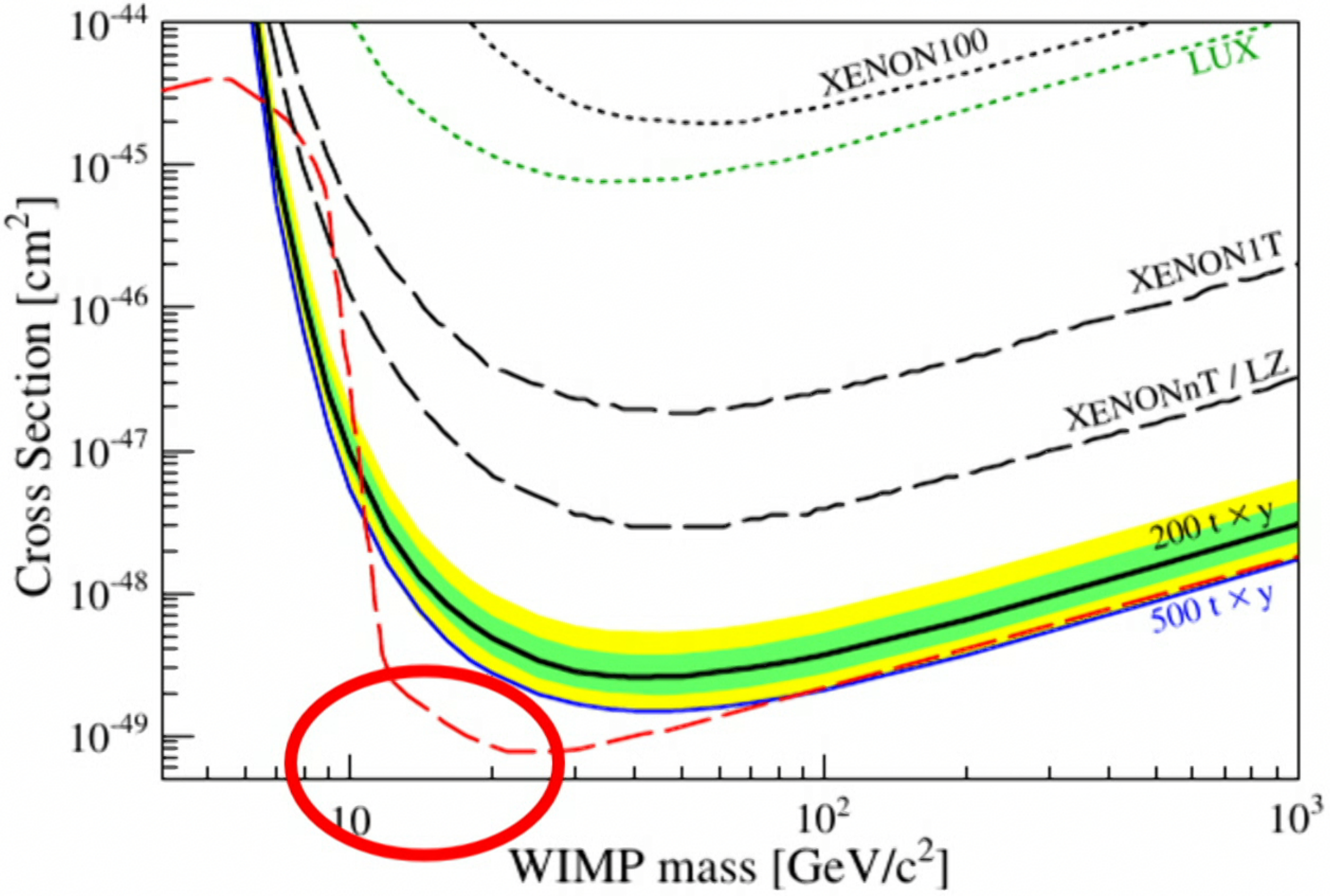
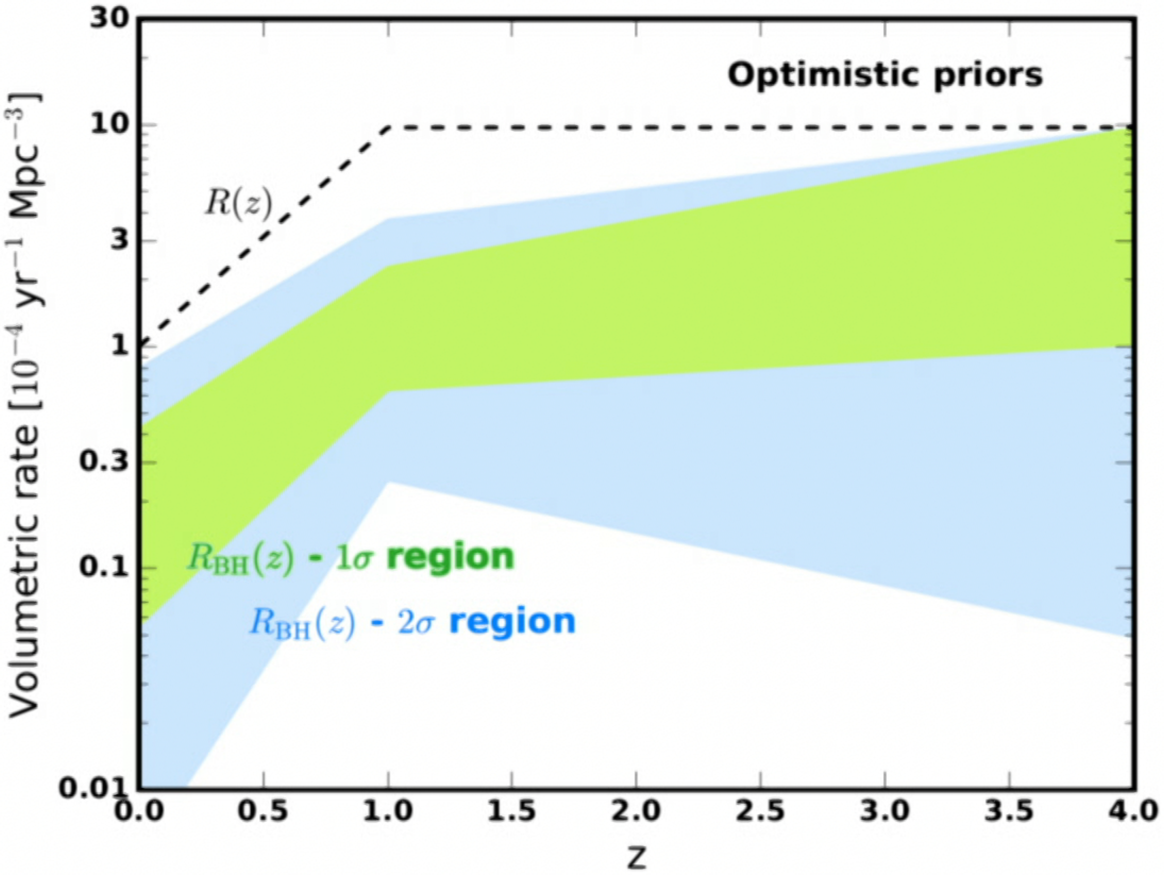


Diffuse Supernova Neutrino Background

Can hopefully be seen with Super-K (gadzooks) and Hyper-K and probably DUNE.

Difficult with Darwin Xenon or Darkside because neutrinos too low energy.

BH Formation Rate from **DNSB** at **HyperK** Davis and Fairbairn 1704.05073

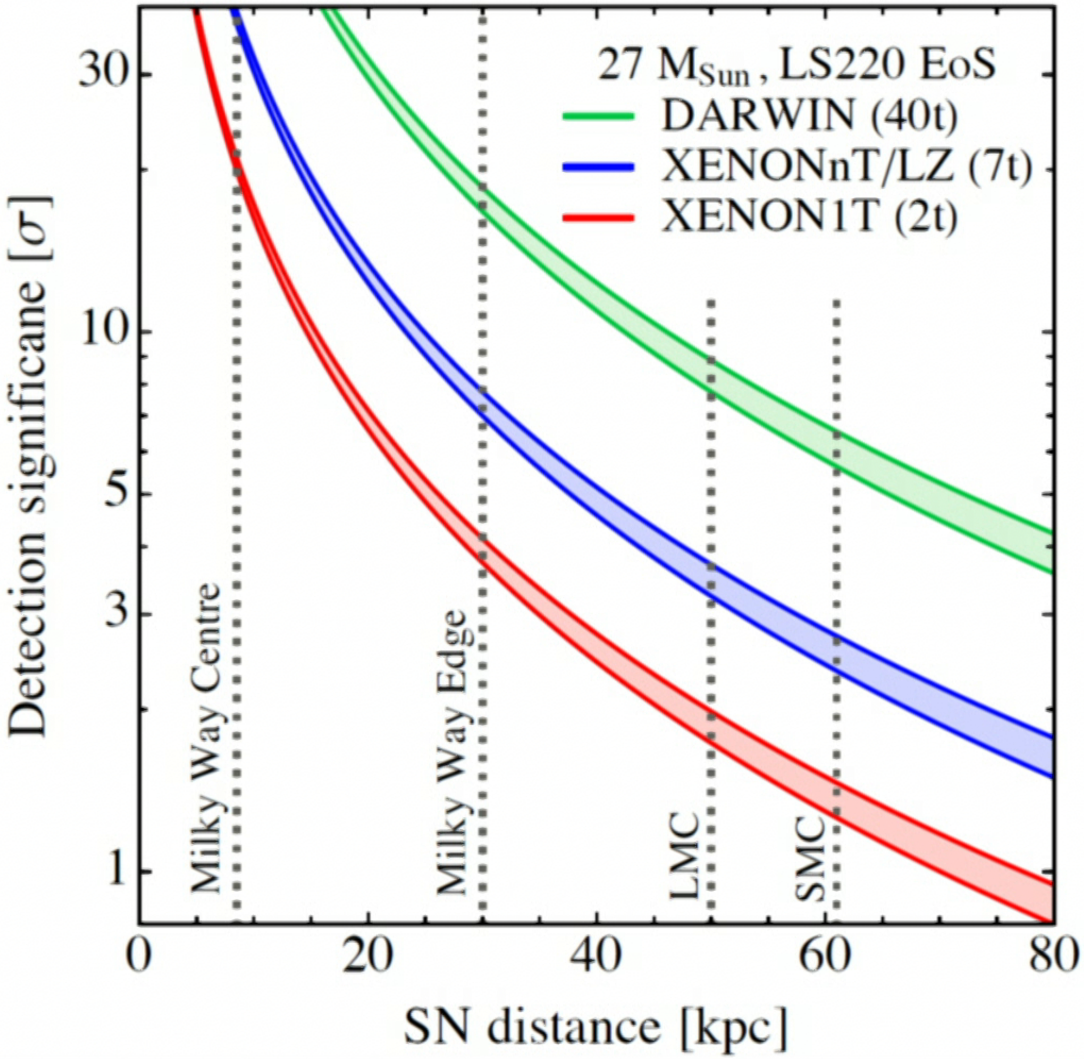


$$\Phi(E) = \frac{c}{H_0}\int_0^{z_{\rm max}} \frac{{\rm d}z}{\sqrt{\Omega_m(1+z)^3+\Omega_\Lambda}}\left[R_{\rm NS}(z)F_{\rm NS}(E(1+z);\bar{E}_{e{\rm NS}},\bar{E}_{x{\rm NS}},L_{e{\rm NS}},L_{x{\rm NS}})\right.$$
$$\left.+R_{\rm BH}(z)F_{\rm BH}(E(1+z);\bar{E}_{e{\rm BH}},\bar{E}_{x{\rm BH}},L_{e{\rm BH}},L_{x{\rm BH}})\right]$$

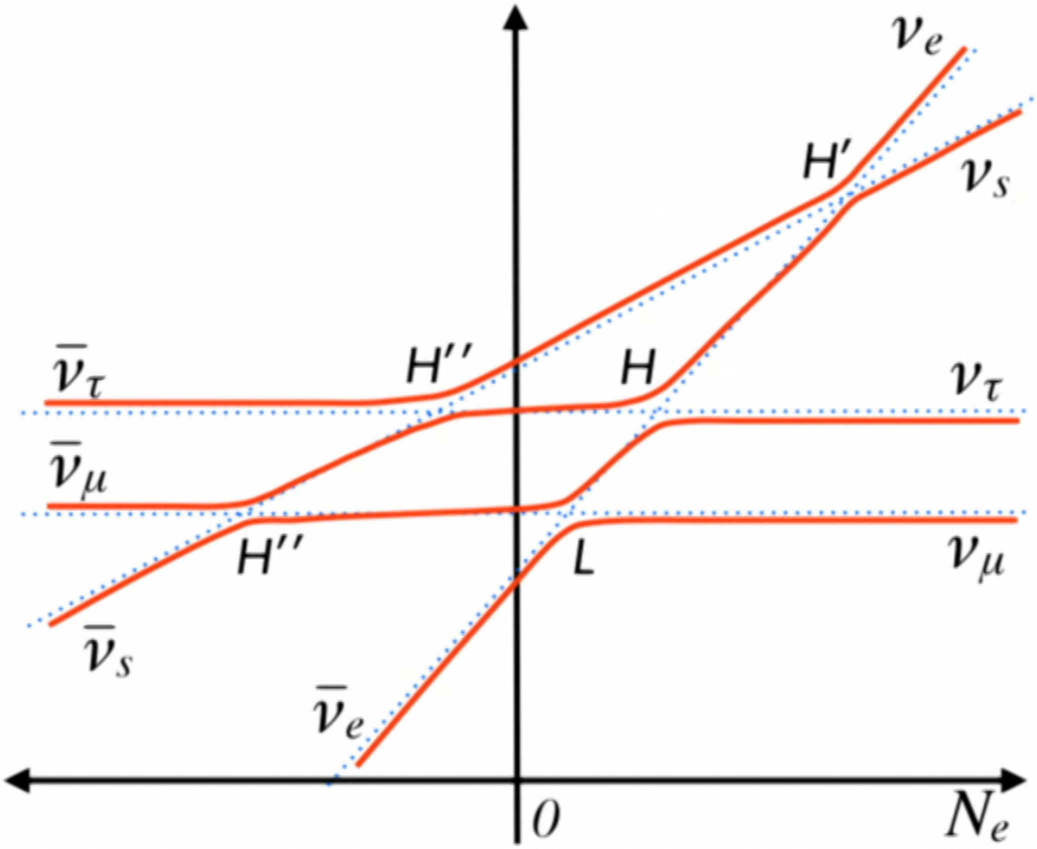
Observing a supernova with DM detectors

Should be easily possible
 (see e.g. Lang, McCabe et al 1606.09243)

Question is, can we do new fundamental physics with such observations?



Mixing with Sterile Neutrino during Supernova Explosion



Normal hierarchy

At the first resonance:

$$\begin{pmatrix} F'_1 \\ F'_2 \\ F'_3 \\ F'_4 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1-p_{H'} & p_{H'} \\ 0 & 0 & p_{H'} & 1-p_{H'} \end{pmatrix} \begin{pmatrix} F^0_{\bar{\nu}_\mu} \\ F^0_{\bar{\nu}_\tau} \\ F^0_{\bar{\nu}_s} \\ F^0_{\bar{\nu}_e} \end{pmatrix}$$

Then:

$$\begin{pmatrix} F''_1 \\ F''_2 \\ F''_3 \\ F''_4 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1-p_H & p_H & 0 \\ 0 & p_H & 1-p_H & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} F'_1 \\ F'_2 \\ F'_3 \\ F'_4 \end{pmatrix}$$

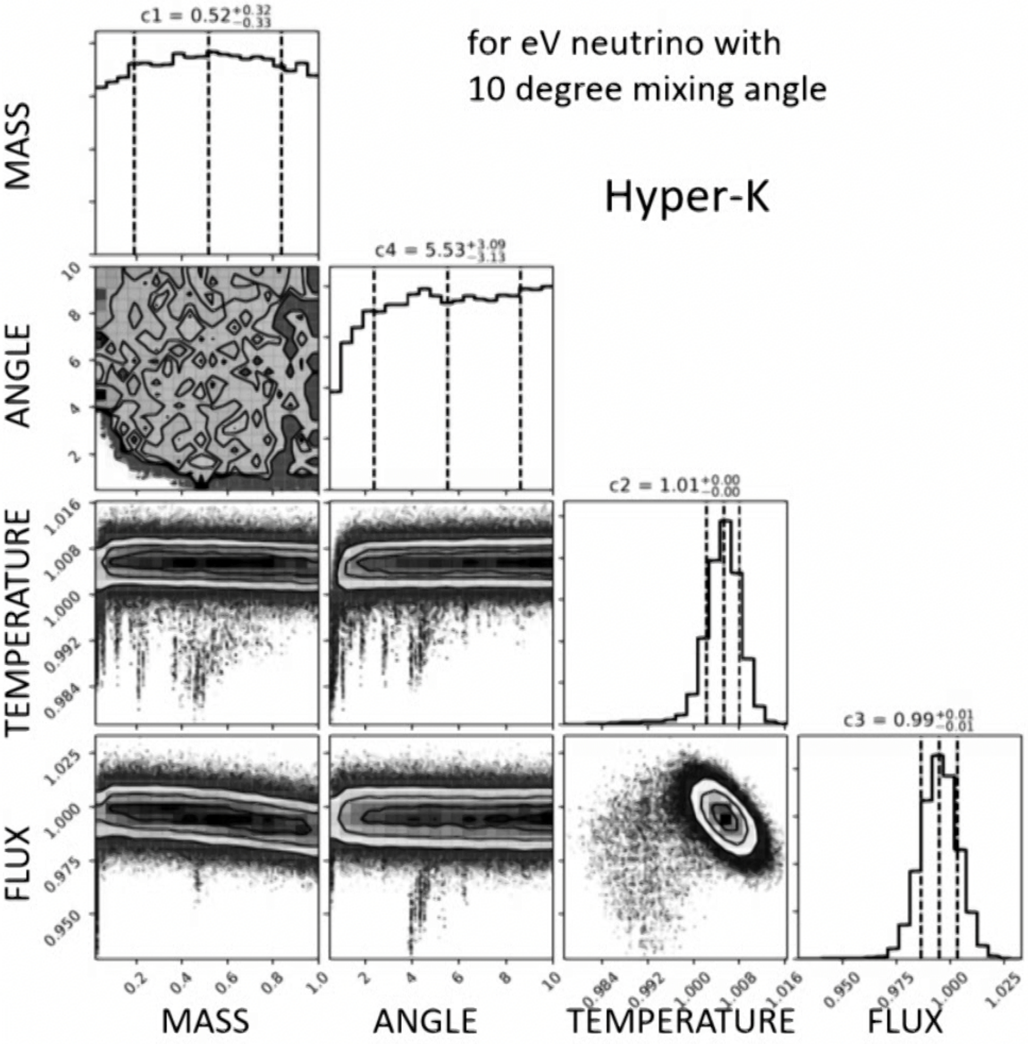
Finally:

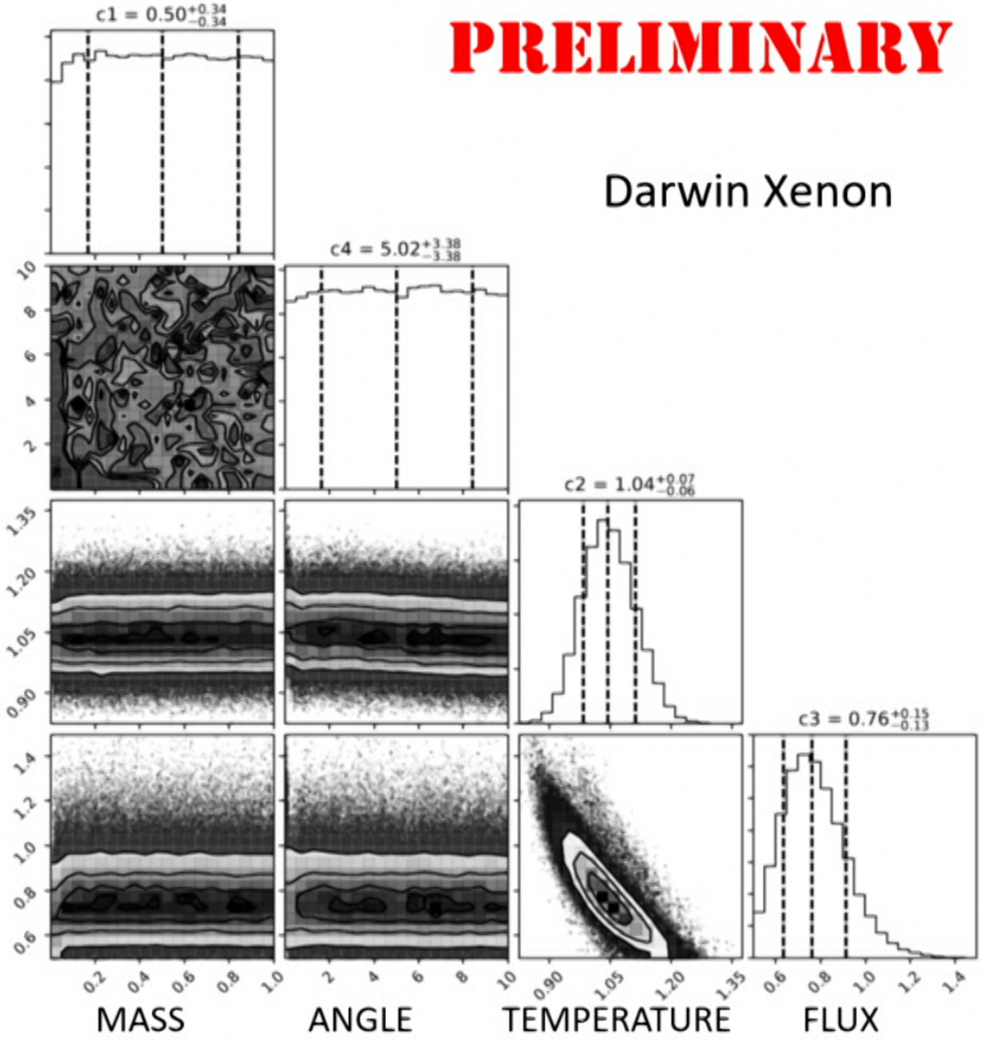
$$\begin{pmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \end{pmatrix} = \begin{pmatrix} 1-p_L & p_L & 0 & 0 \\ p_L & 1-p_L & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} F''_1 \\ F''_2 \\ F''_3 \\ F''_4 \end{pmatrix}$$

Sensitivity of Hyper-K and Darwin to Sterile mixing from Supernova at 10 kpc

for eV neutrino with
10 degree mixing angle

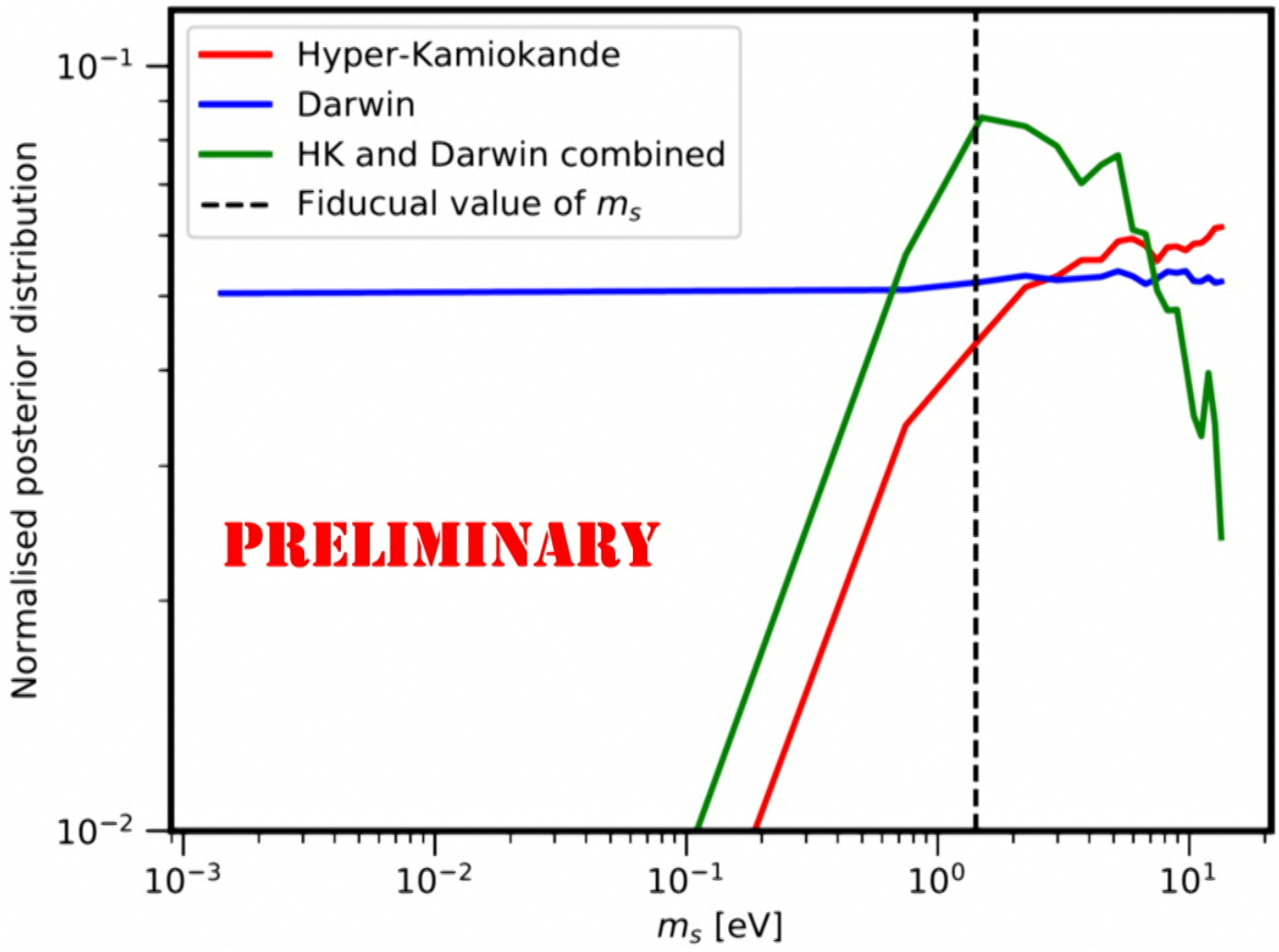
PRELIMINARY





Combined power of Hyper-K and Darwin Xenon

Added power of nuclear recoils very clear



King's College London, most central London University

Currently looking for strong fellowship candidates for five year royal society and STFC fellowships some of which are suitable for flexible working conditions

In addition, recruiting one or two regular postdocs in the Autumn

Dark Matter detectors are about to detect neutrinos

This is very exciting, and will lead to new tests of solar physics and BSM physics.

This new subject area will continue to grow in the next years.

Science & Technology Facilities Council

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