How high is the neutrino floor?

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Based on:
Boehm, Cerdeño, Machado, Olivares-Del Campo and Reid; JCAP 01 (2019) 043 (1809.06385)

IP3
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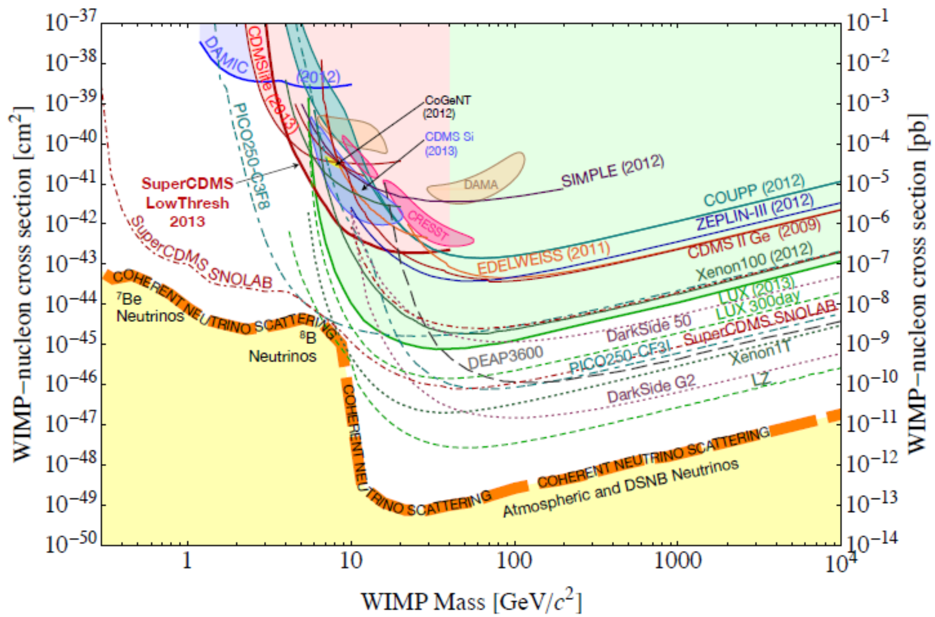
Introduction: Dark Matter Direct Detection

- Dark matter direct detection experiments aim to detect the scattering of WIMPs with atomic nuclei

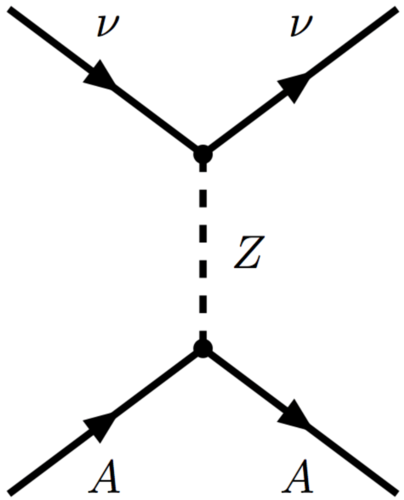
- As sensitivities improve, we approach the so-called neutrino floor

- Here, further WIMP discoveries are limited by an "irreducible" background due to CNS



Neutrino Scattering in the SM

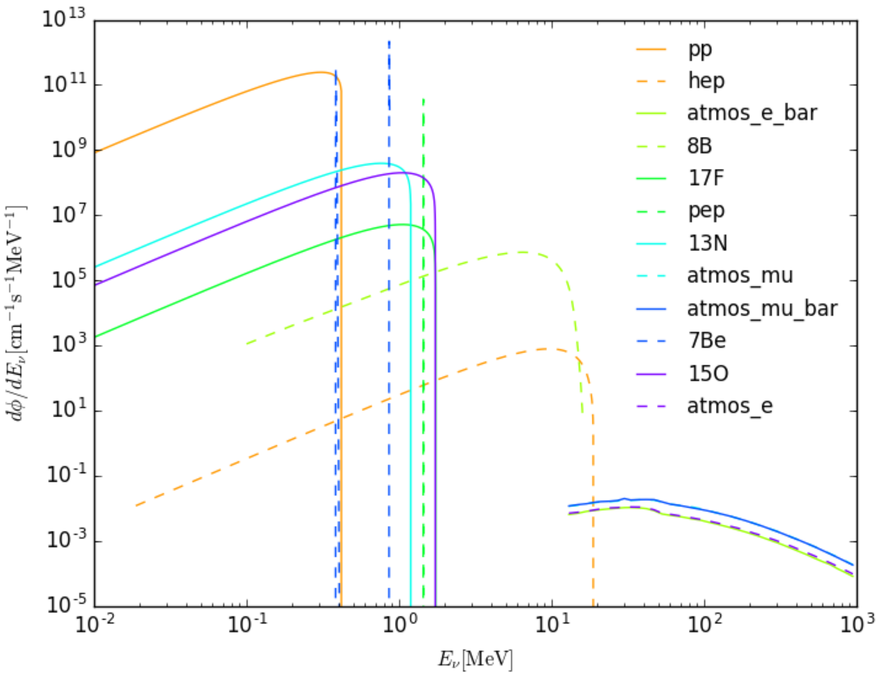
- Neutrinos can scatter with nuclei or electrons in a detector
- Nuclear scattering is very difficult to distinguish from a WIMP signal
- Coherent Neutrino Scattering (CNS) proceeds via exchange of a Z boson in the SM
- Gains an O(1000) enhancement to the cross section due to coherence



Coherent Neutrino Scattering: Neutrino Fluxes

$$N^k_{CE\nu NS} = \frac{\epsilon}{m_N} \int_{E_k}^{E_{k+1}} dE_R\, \varepsilon(E_R) \int_{E_\nu^{\min}} dE_\nu \frac{d\phi}{dE_\nu} \frac{d\sigma_{\nu N}}{dE_R}$$

- Solar neutrinos dominate at low energies
- For CNS, Boron-8 neutrinos are important
- Atmospheric neutrinos reach higher energies, but with much lower flux



The Coherent Neutrino Scattering Rate

$$\frac{d\sigma_{\nu N}}{dE_R} = \frac{G_f^2}{4\pi} Q_w^2 m_N \left(1 - \frac{m_N E_R}{2E_v^2}\right) F^2(E_R)$$

$$\mathrm{Q}_w = N - (1 - 4\sin^2\theta_w)Z$$

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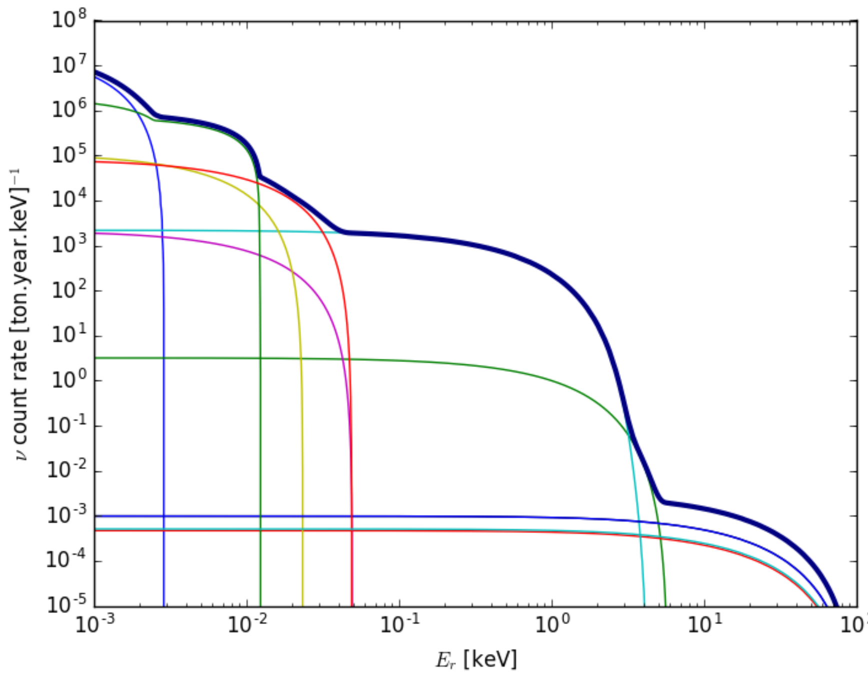
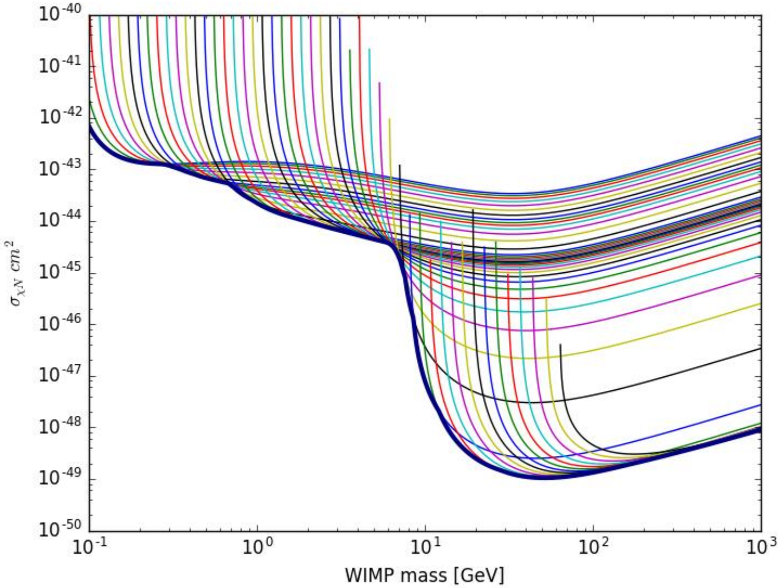


Computing the Neutrino Floor

- Choose a threshold energy for the experiment and integrate the count rate above it
- Set the exposure to give 1 ν count
- For each WIMP mass, calculate the cross section at which a 90% CL could be drawn
- Now, vary the threshold and take a lower envelope

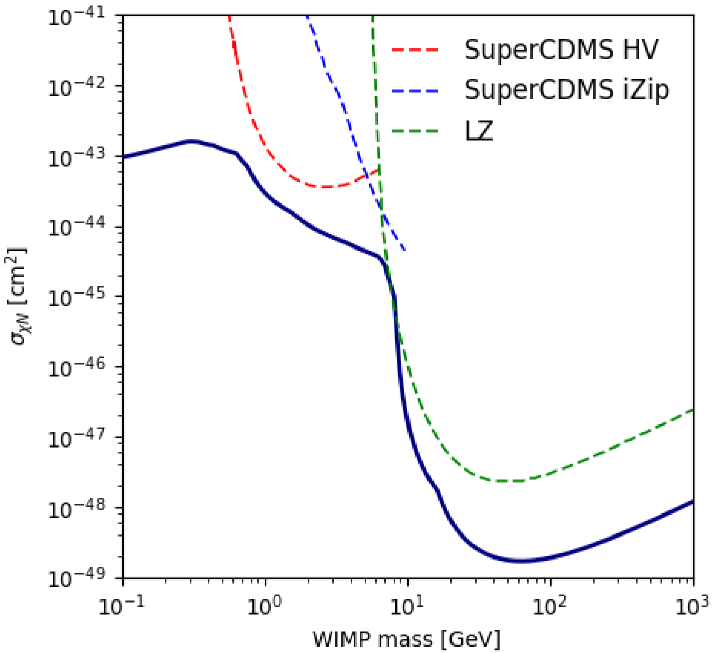


What Does the Neutrino Floor Represent?

- If the projected sensitivity curve for a DM experiment crosses this line, we expect to see >1 counts of CNS

- Some plots show a “discovery limit”

- This is the minimum WIMP cross section below which no further discovery could be made, given current uncertainties on the neutrino flux



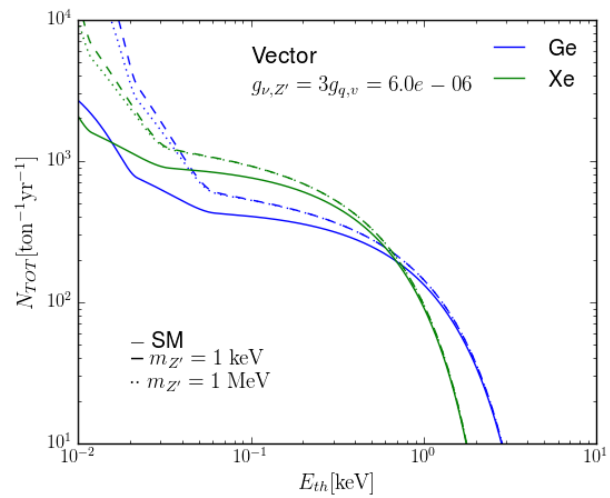
New Physics in the Neutrino Sector

- Until 2017, CNS had never been observed
- The COHERENT experiment utilised a spallation source of neutrinos with energies around 15-50 MeV
- Although it is a SM process, new physics could affect the rate of coherent scattering
- We consider two models which introduce a new light mediator: one vector, one scalar

Vector Mediator: The B-L Model

$$\mathcal{L} = -g'_v Q'_\nu \bar{\nu_L} Z' \gamma^\mu \nu_L - g'_v Q'_q \bar{q} Z' \gamma^\mu q - g'_v Q'_\ell \bar{\ell} Z' \gamma^\mu \ell$$

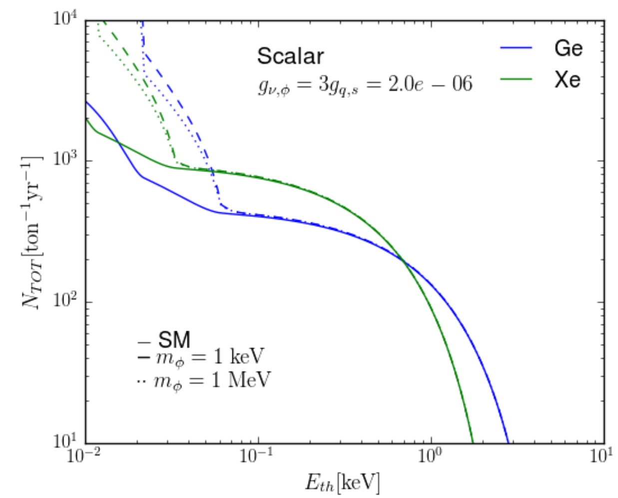
- We consider a model which introduces a new $U(1)_{B-L}$ symmetry
- This is spontaneously broken to give a new Z' mediator which couples to all Standard Model particles
- Leptons are charged under this new symmetry with $Q'_{l,\nu} = -1$; quarks have $Q'_q = \frac{1}{3}$
- Smaller mediator masses produce a greater enhancement to the spectrum at low energies



Scalar Mediator

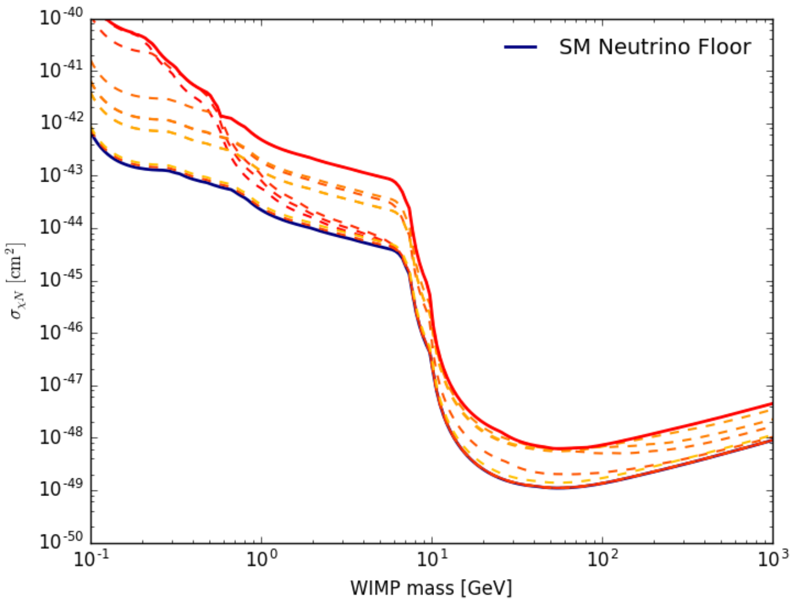
$$\mathcal{L} = -yQ'_\nu \bar{\nu}_L^c \phi \nu_L - yQ'_q \bar{q} \phi q - yQ'_\ell \bar{\ell} \phi \ell$$

- Similarly, we consider a model which introduces a new scalar, φ, which couples to SM fields
- Leptons have charge $Q'_l = 1$; quarks have charge $Q'_q = \frac{1}{3}$
- Again, the greatest enhancement to the cross section is at low energies
- This model is less well motivated than the B-L, but the parameter space is less constrained



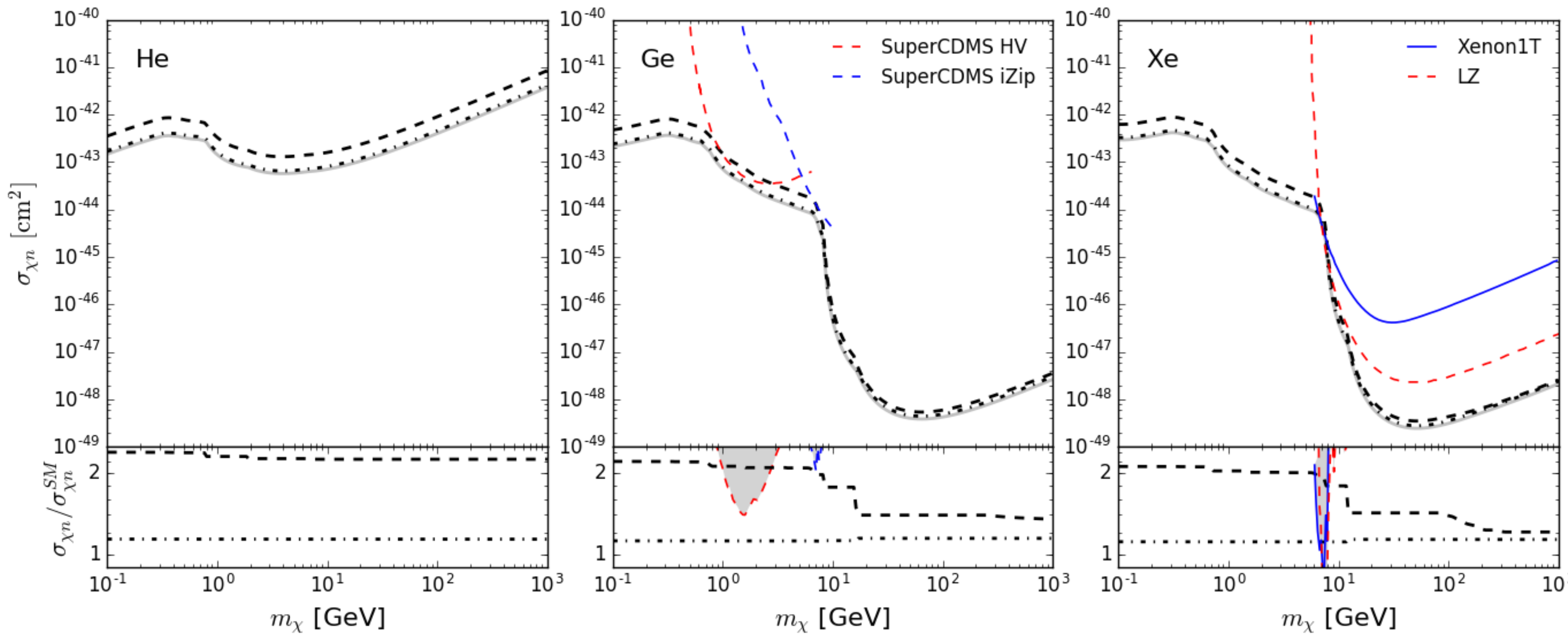
Raising the Neutrino Floor

- Take an array of mediators allowed by the existing constraints
- With each of these mediators, recalculate the neutrino floor
- We take an upper envelope, giving the maximum possible increase to the neutrino floor



The New Neutrino Floor: Vector Mediator

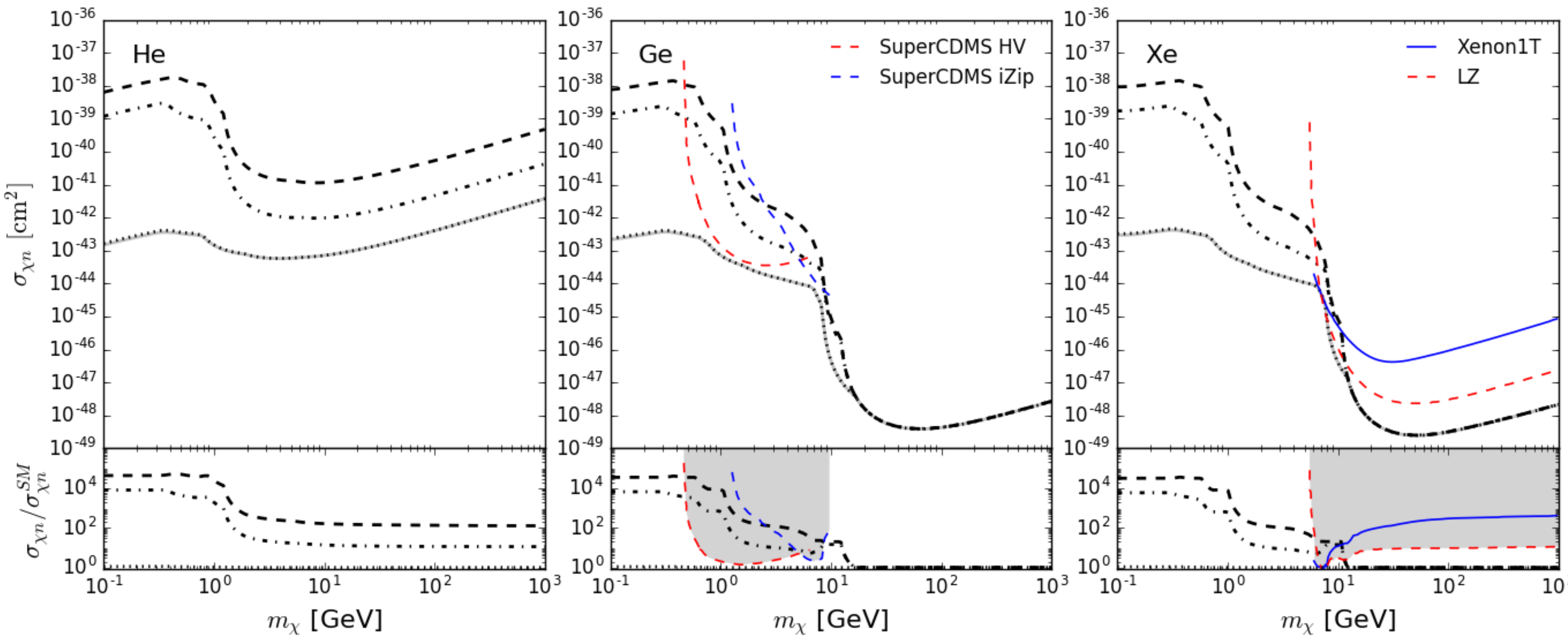
- The B-L model can give up to a factor two increase at low energies
- The neutrino floor for Helium has a significantly different shape due to the different kinematics



The New Neutrino Floor: Scalar Mediator

- When supernova constraints are relaxed we can get an increase of several OOM at low energies

- Future DD experiments could put competitive constraints on new physics

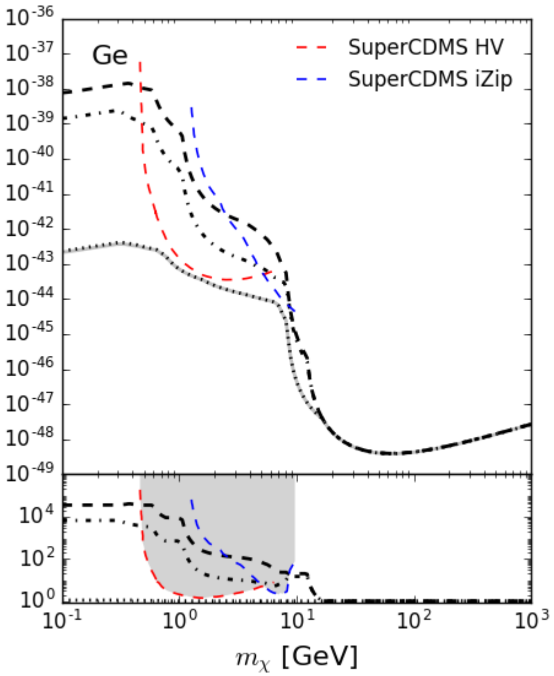


Consequences of a Raised Neutrino Floor

- We may start to see neutrinos sooner than expected

- An apparent WIMP signal above the SM neutrino floor could be caused by new physics in the neutrino sector

- However, if no signal is seen, we can put constraints on these models directly



Conclusions

- As direct detection experiments improve, they will soon reach the neutrino floor and be sensitive to coherent neutrino scattering

- New physics interacting in the neutrino sector could affect the level of the neutrino floor

- An increase in the neutrino cross section due to a new vector or scalar mediator could be mistaken for a dark matter signal

- However, this also means that direct detection experiments have the potential to set competitive constraints on neutrino physics

Current Work

- Working directly with direct detection experiments (SuperCDMS) to place direct limits on new neutrino physics

- Made projections for the sensitivity of future detectors (DAMIC)

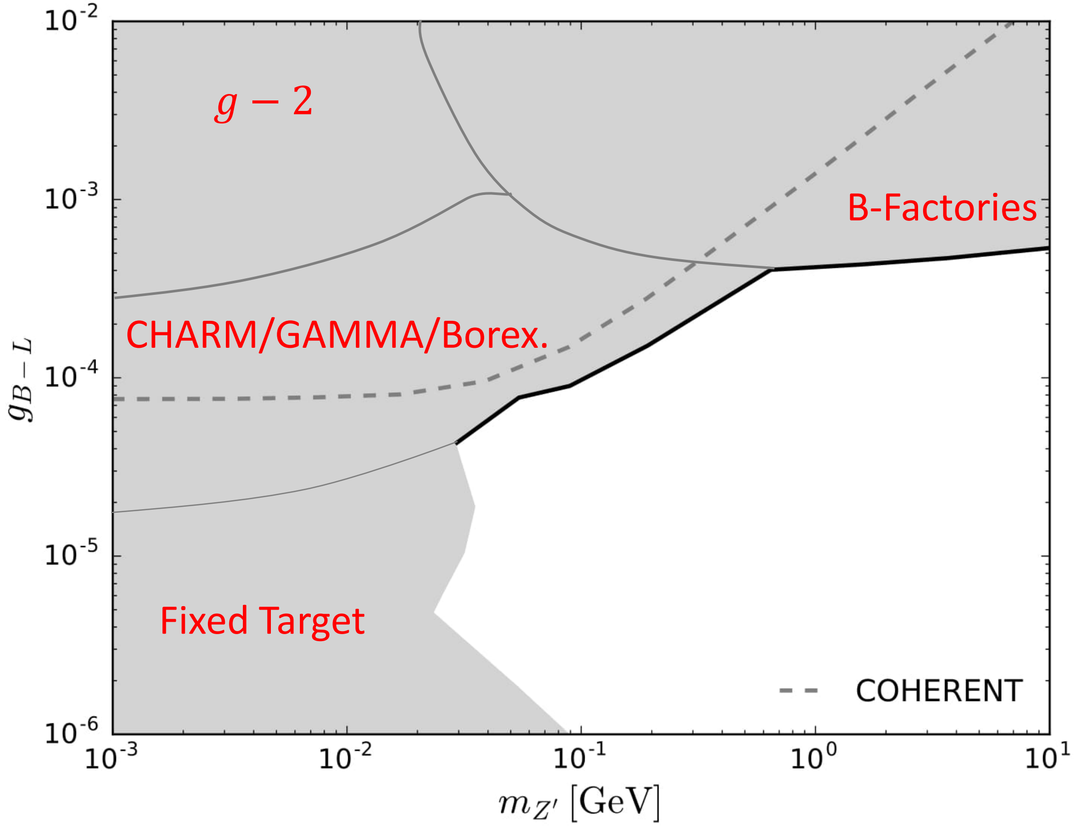
- Working with CYGNO we are investigating how directional detection could break the degeneracy between neutrinos and WIMPs

- Re-evaluating existing constraints on our simplified models from e.g. supernovae

Thank You

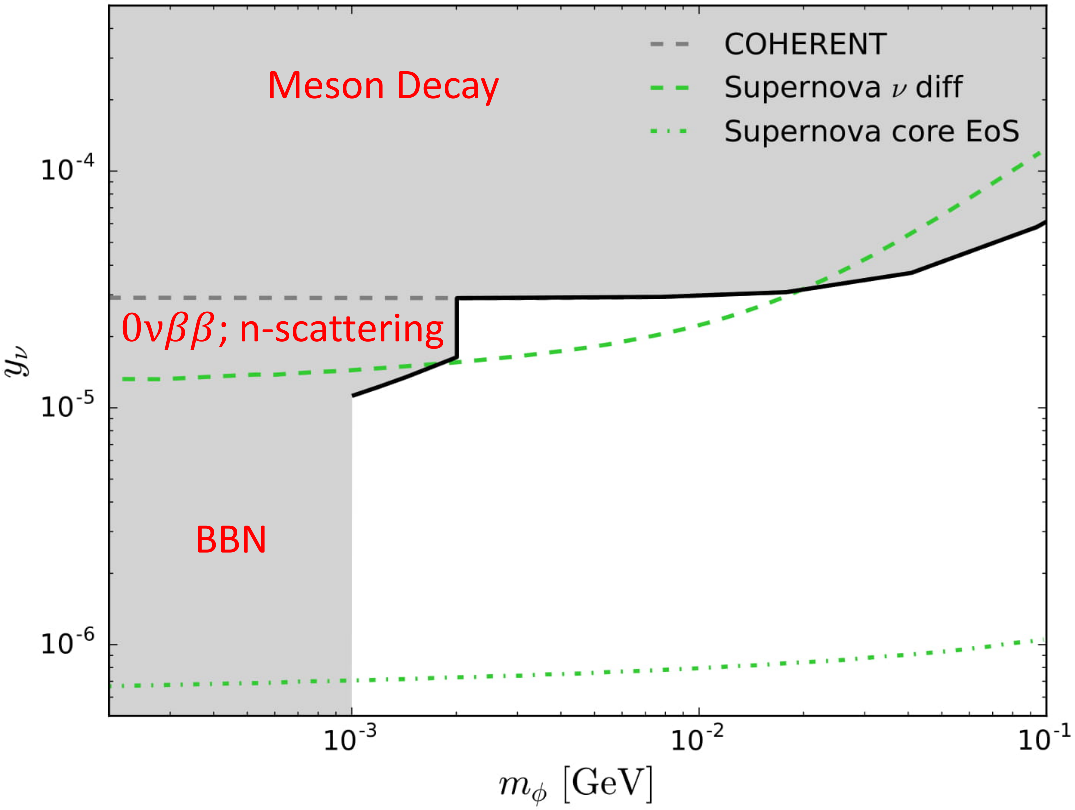
“Raising the neutrino floor”

Extra Slides: Vector Mediator Constraints



arXiv:1604.01025

Extra Slides: Scalar Mediator Constraints



arXiv:1802.05171

D. G. Cerdeño, M. Cermeño Gavilán, M. Á. Pérez García, E. Reid (ongoing)

Likelihood Test

$$\mathcal{L}(N_{det}|m_{Z'}, g'_v, b) = \frac{(b+\mu)^{N_{det}} e^{-(b+\mu)}}{N_{det}!}$$

$$\mathcal{L}(\boldsymbol{\sigma}|m_{Z'}, g'_v, b) = \prod_{k=1}^{n} \mathcal{L}(N_k|m_{Z'}, g'_v, b)$$

$$\lambda(\boldsymbol{\sigma}|m_{Z'}, g'_v) = \frac{\mathcal{L}(\boldsymbol{\sigma}|m_{Z'}, g'_v, \hat{b})}{\mathcal{L}(\boldsymbol{\sigma}|\hat{m}_{Z'}, \hat{g}'_v, \hat{b})}$$

- To calculate the 90% confidence limit we use a binned profile likelihood test, treating each bin independently
- For a point in the m, g parameter space, the test statistic λ is the ratio of the maximum likelihood found by optimising the background amplitudes to the maximum likelihood at any point in the parameter space
- The quantity $-2\log\lambda$ follows a χ^2 distribution, so the 90% C.L. lies where $-2\log\lambda = 2.706$.