RESHAPING THE NEUTRINO FOG: EVALUATING WIMP-XENON SCATTERING VIA SHELL-MODEL RESPONSE FUNCTIONS

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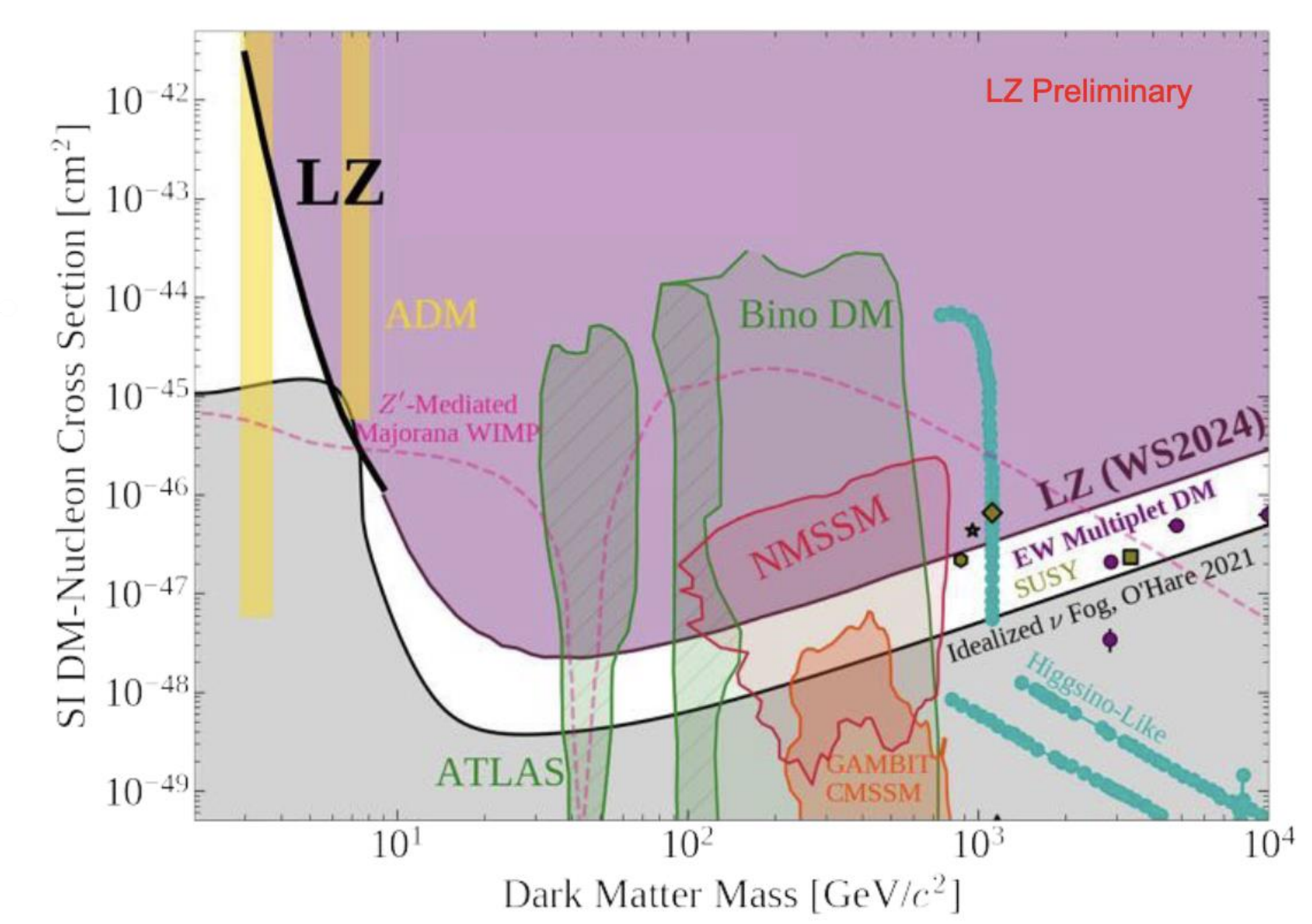
DARK MATTER DIRECT DETECTION

LUX-ZEPLIN is a 7-tonne liquid xenon detector and it is the world's most sensitive direct detection experiment



[LZ Collaboration presentation December 2025]

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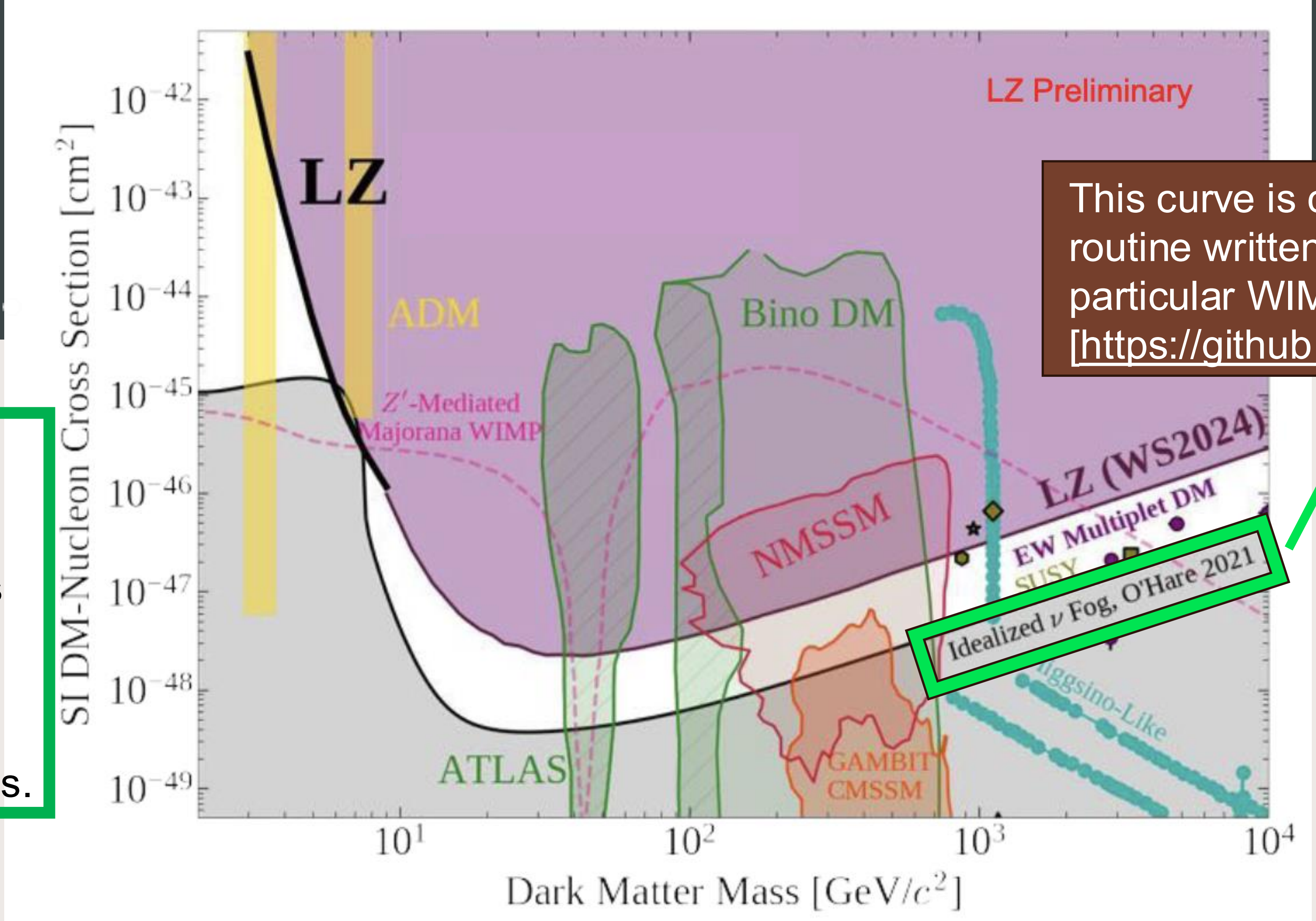


This curve is calculated using a routine written by O'Hare for a particular WIMP interaction [https://github.com/cajohare]

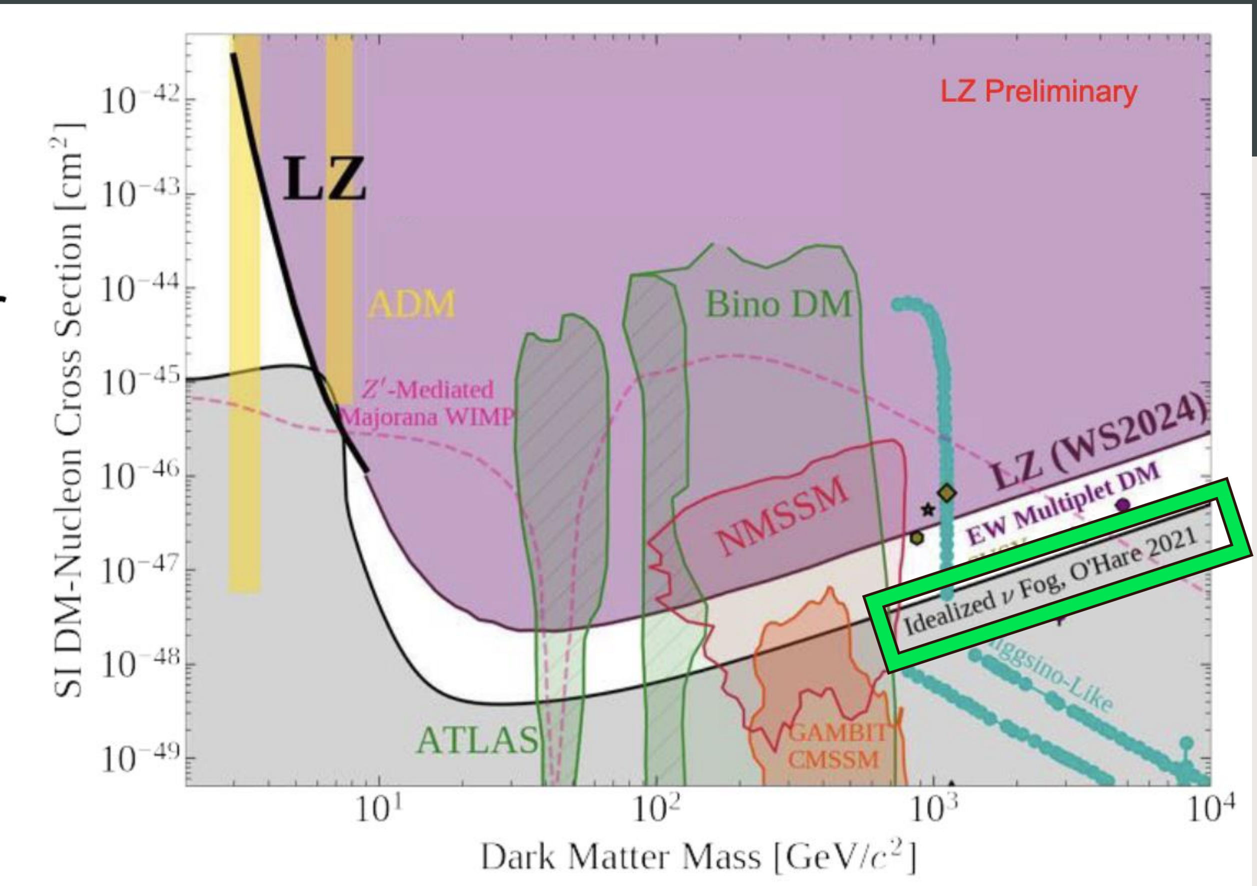
The neutrino fog acts as a soft sensitivity boundary where WIMP discovery scaling shifts from being statistically limited to being dominated by systematic uncertainties.

[LZ Collaboration presentation December 2025]

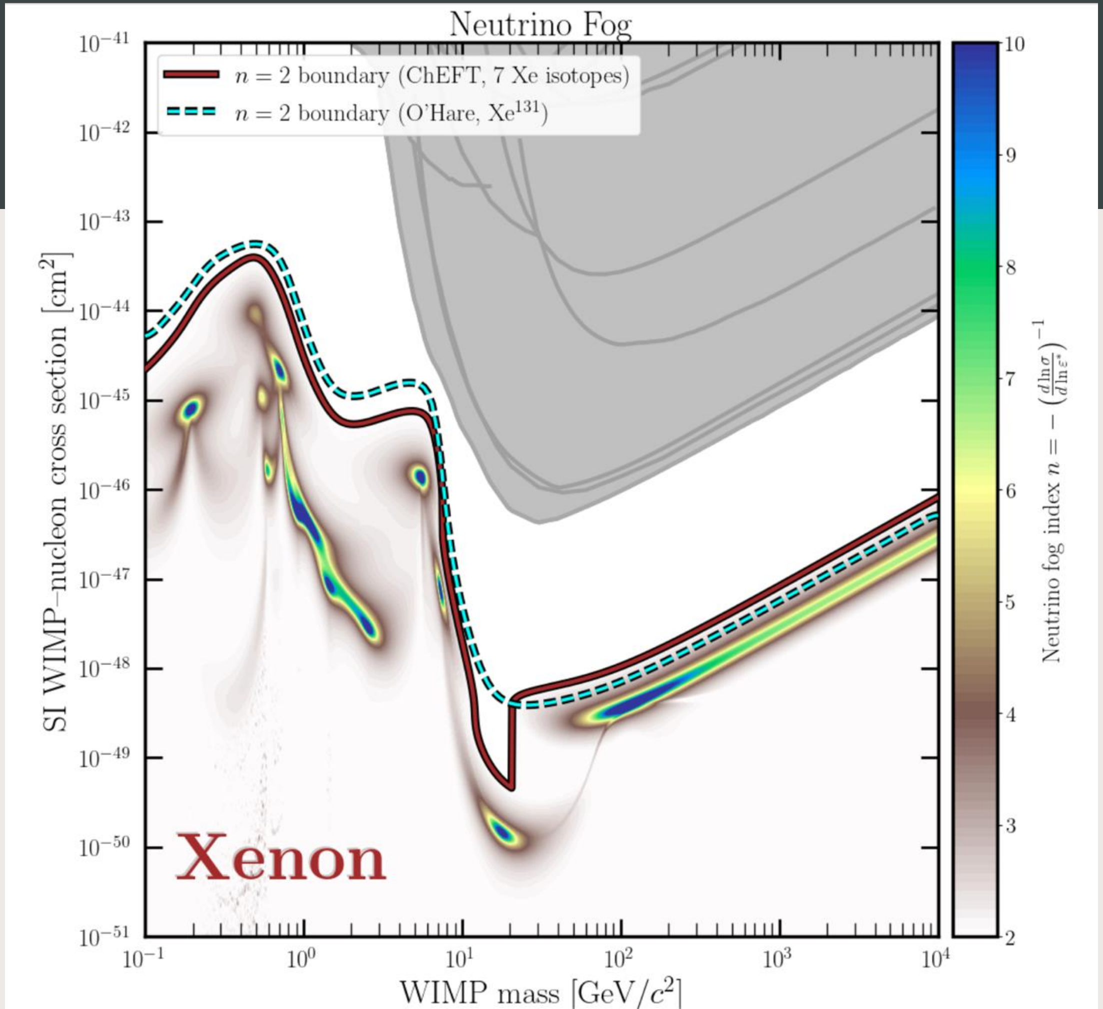
OUR GOAL: WE WANT TO AUTOMATIZE THIS CALCULATION FOR ANY INTERACTION A WIMP CAN HAVE

We use the DirectDM Mathematica package to pick an operator in the Chiral EFT and compute the neutrino fog. [DirectDM]

For the vector-vector operator $Q_{1,q}^{(6)} = (\bar{q}\gamma_\mu q)(\bar{\chi}\gamma^\mu \chi)$ we obtain the following neutrino fog



[LZ Collaboration presentation December 2025]



WHAT IS THE NEUTRINO FOG?

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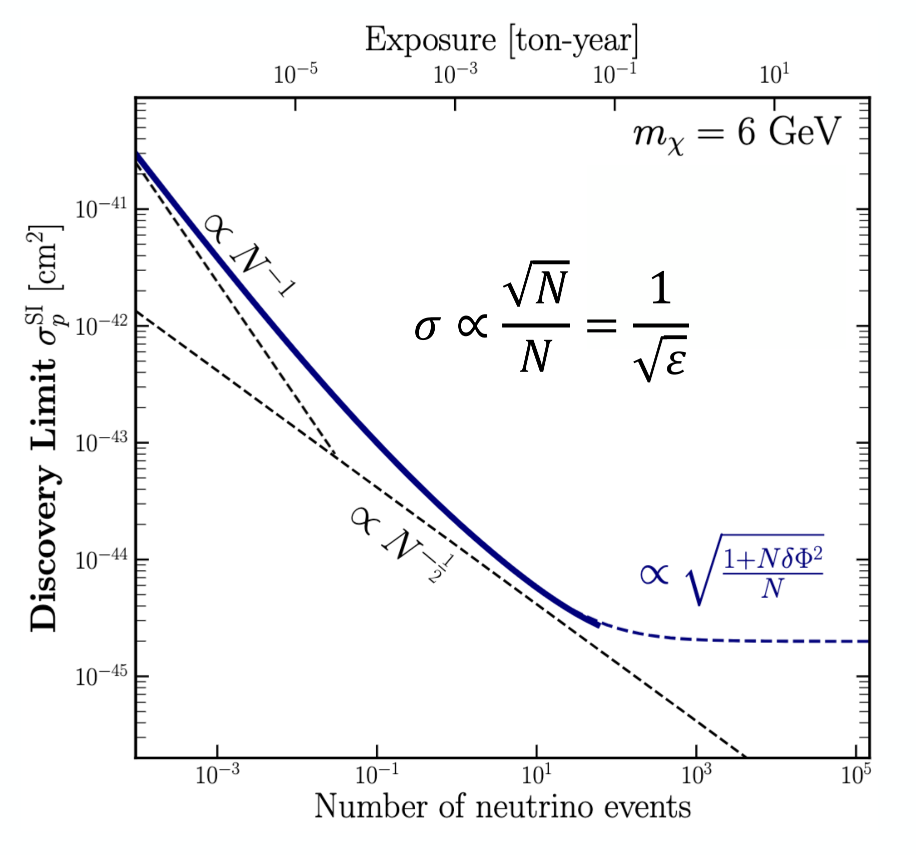
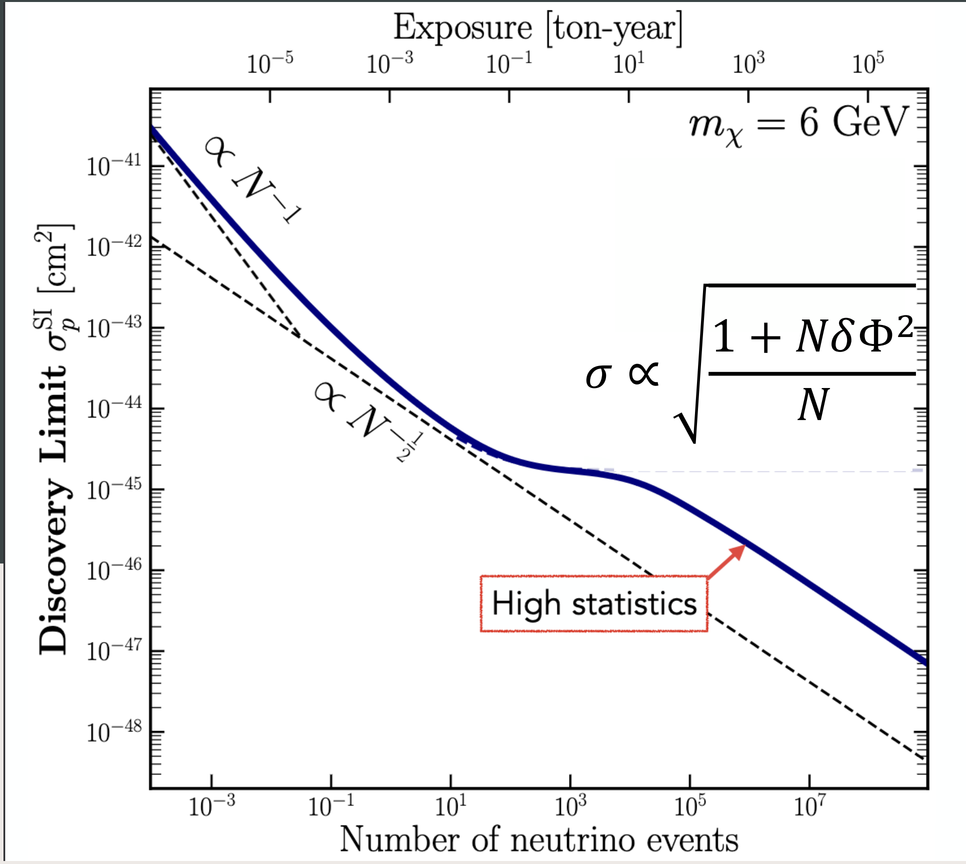
[O'Hare talk 2024]





The **neutrino fog** index n is

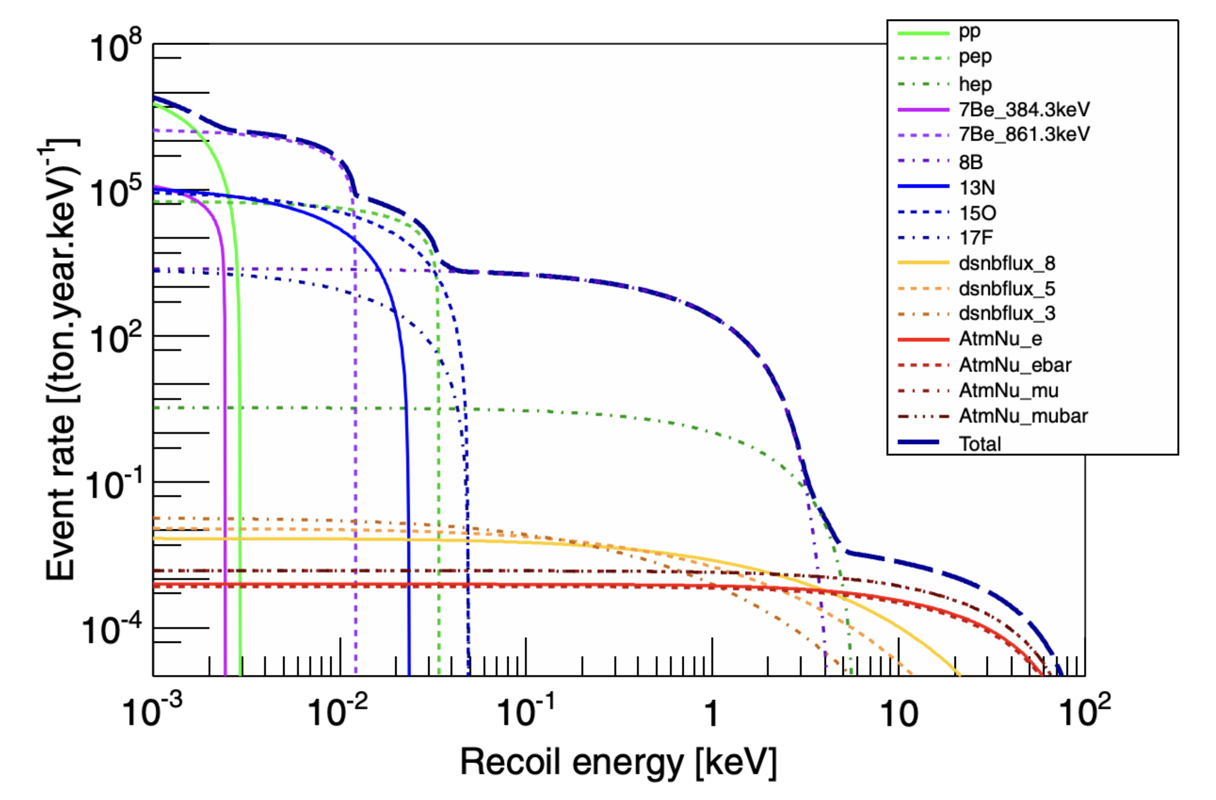
$$n = -\left(\frac{d\ln\sigma}{d\ln\varepsilon^*}\right)^{-1}$$

The exposure for which one claims 3σ discovery

$n(m_\chi, \sigma)$ defines a region in parameter space where $n \geq 2$, indicating that sensitivity scales worse than Poissonian background subtraction

NEUTRINO BACKGROUND AND ITS UNCERTAINTIES

The total neutrino background event rate is $\frac{dR_\nu}{dE_r} = \frac{1}{m_N} \sum_\alpha \Phi_\alpha \int \frac{d\sigma}{dE_r}(E_\nu, E_r)\, \phi_\alpha(E_\nu)\, dE_\nu$



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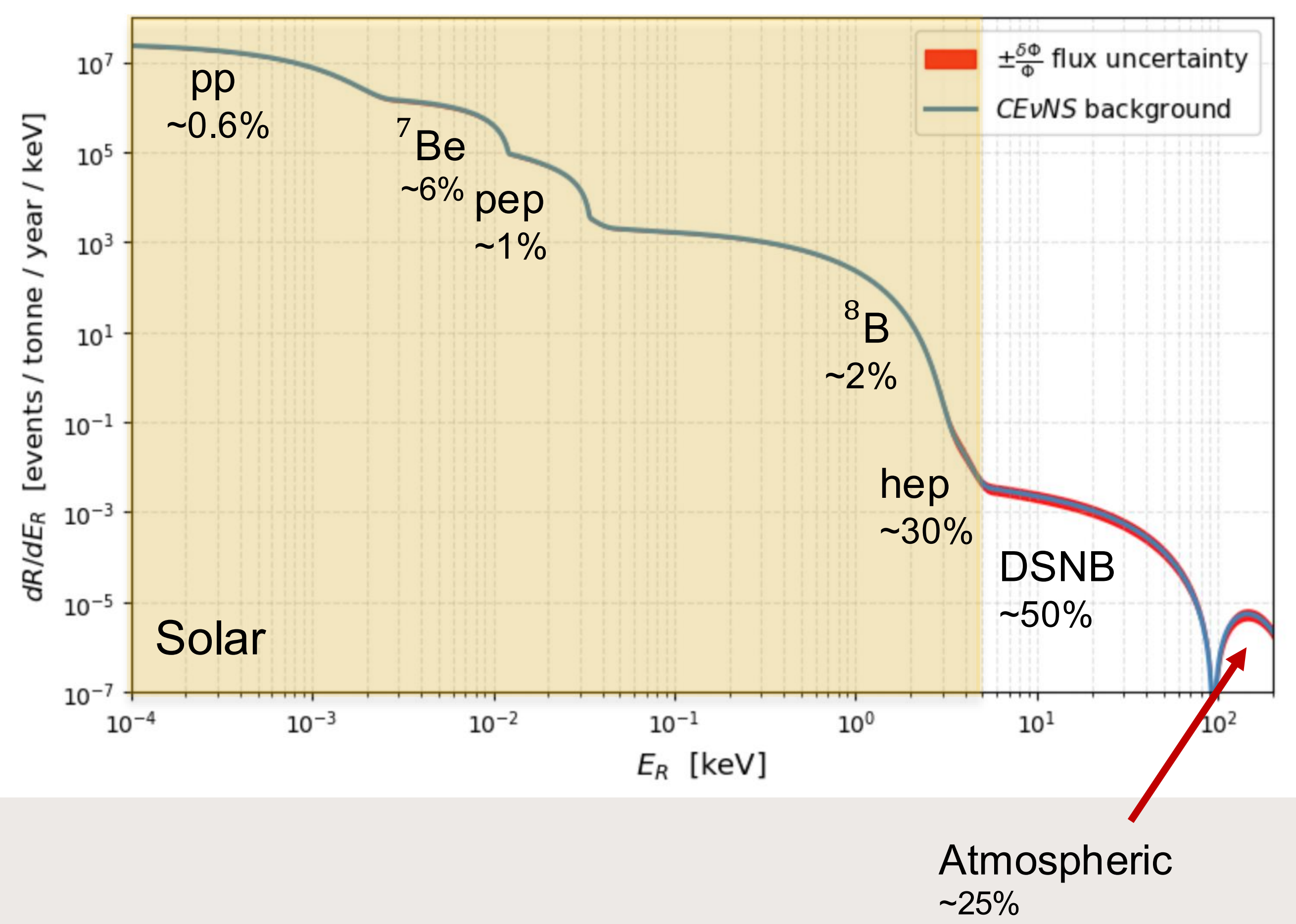
But there are uncertainties associated with the flux normalizations for each source



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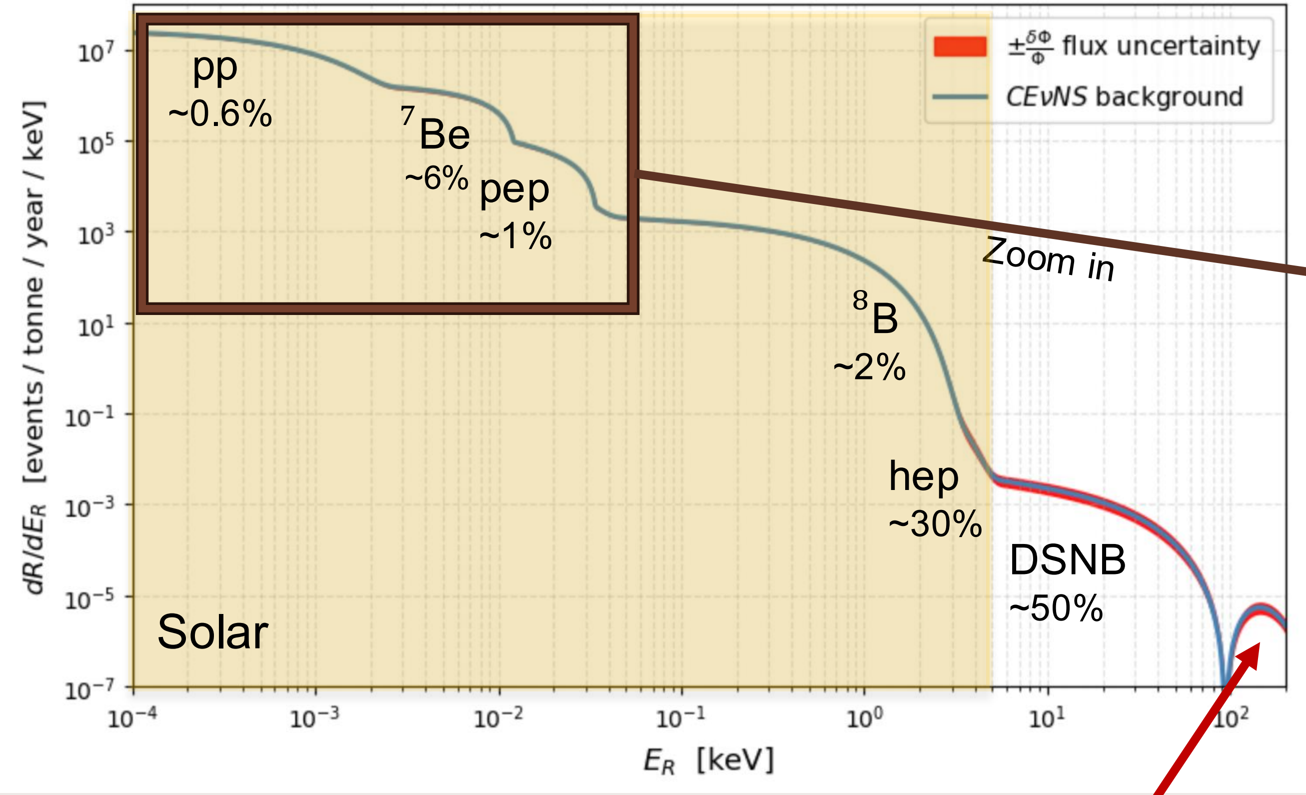
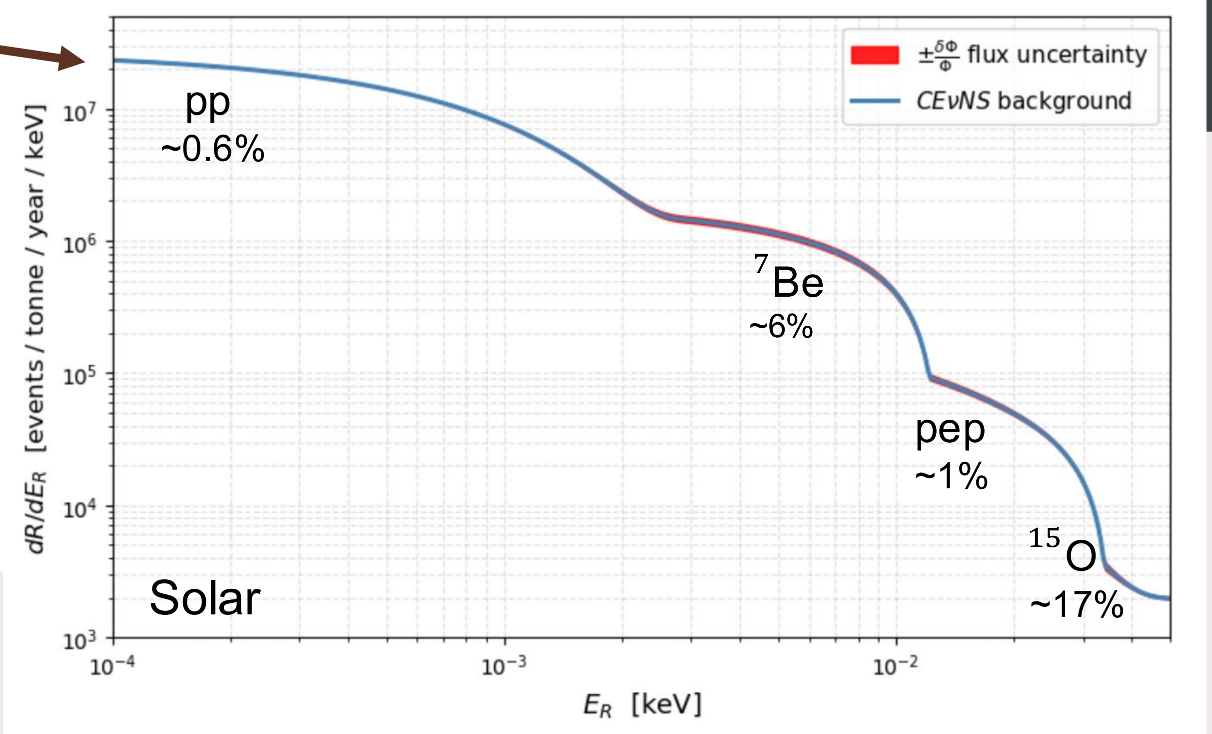
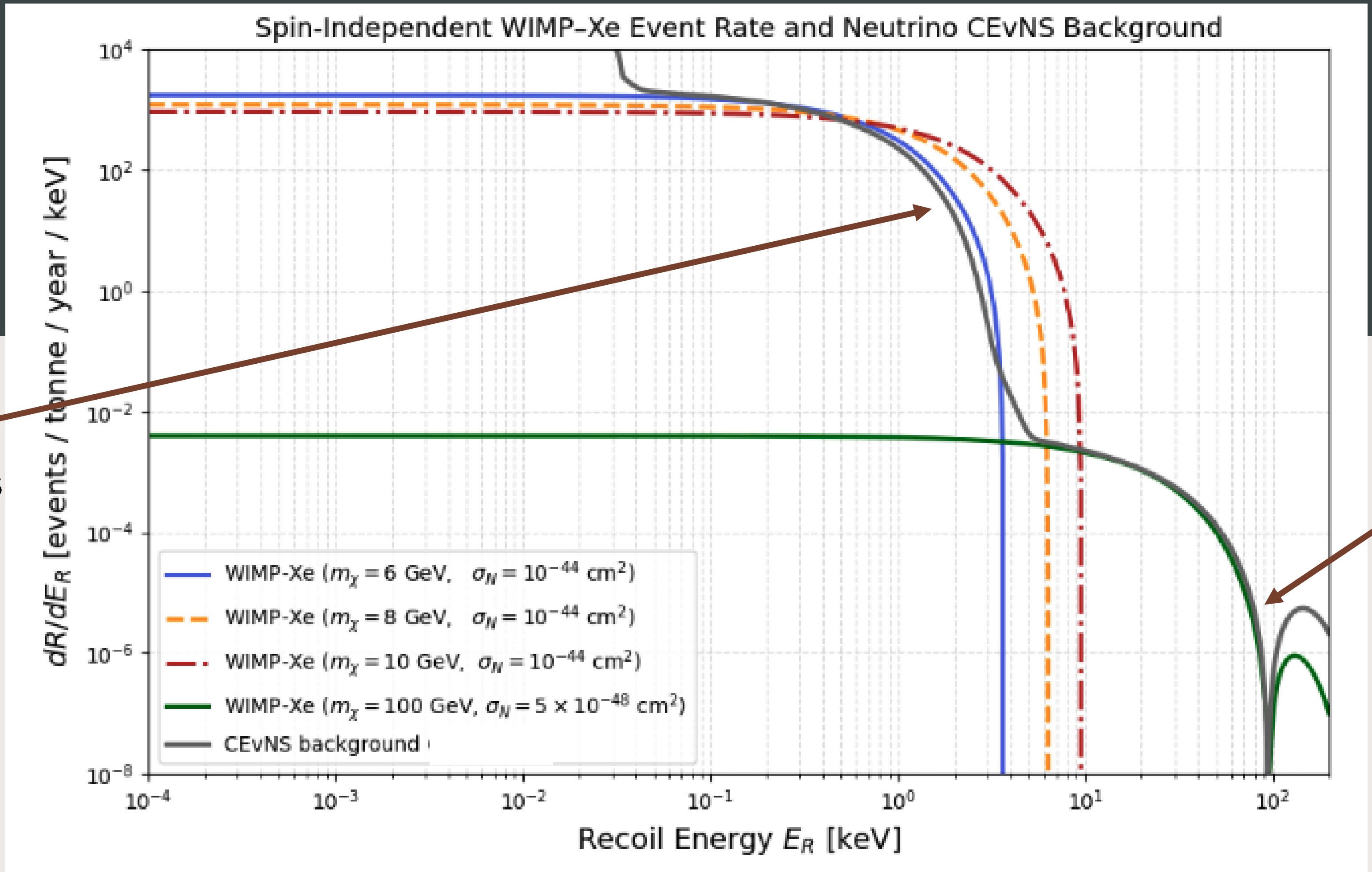




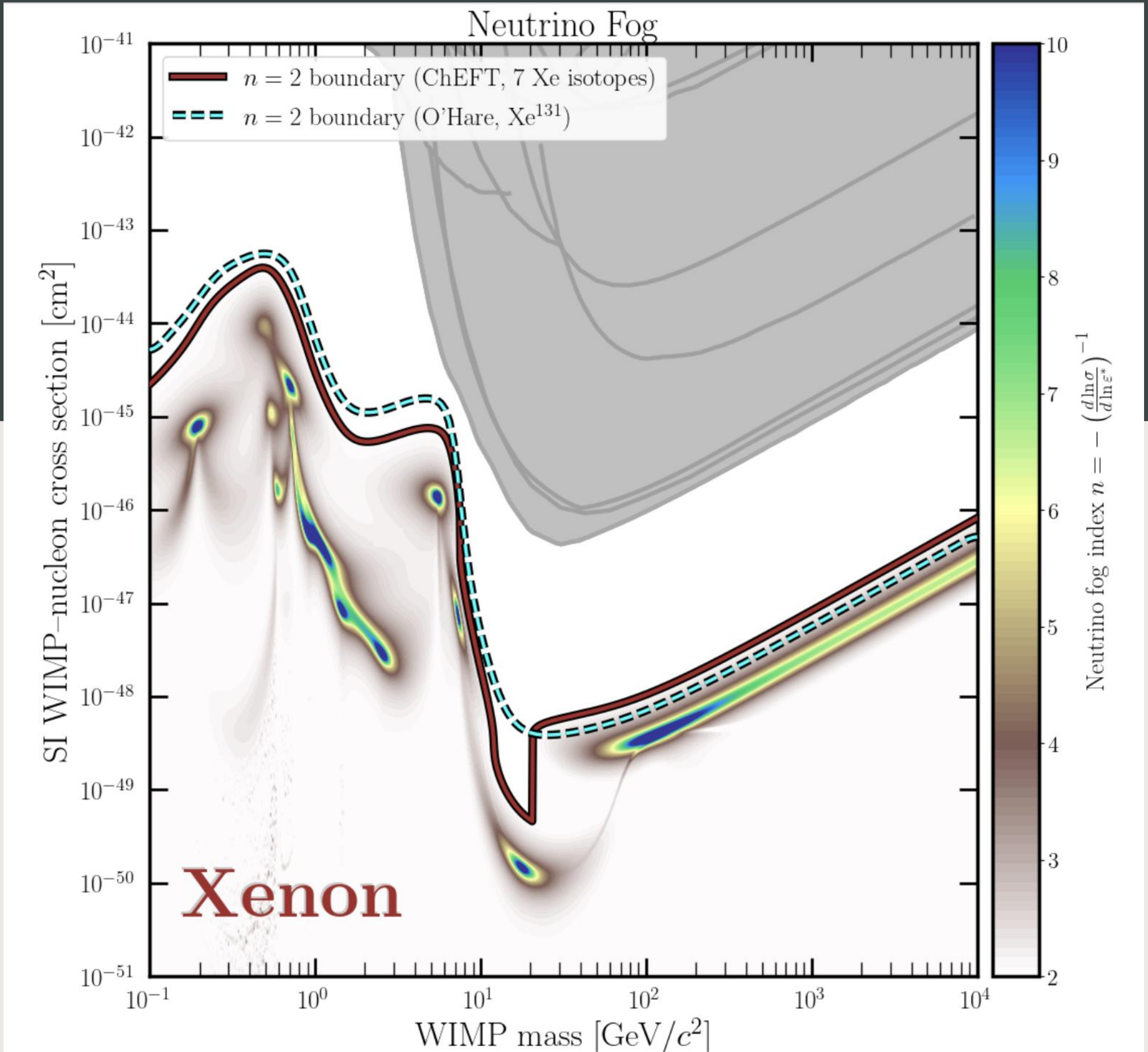
WIMP-XENON EVENT RATE AND NEUTRINO BACKGROUND



^{8}B solar neutrinos

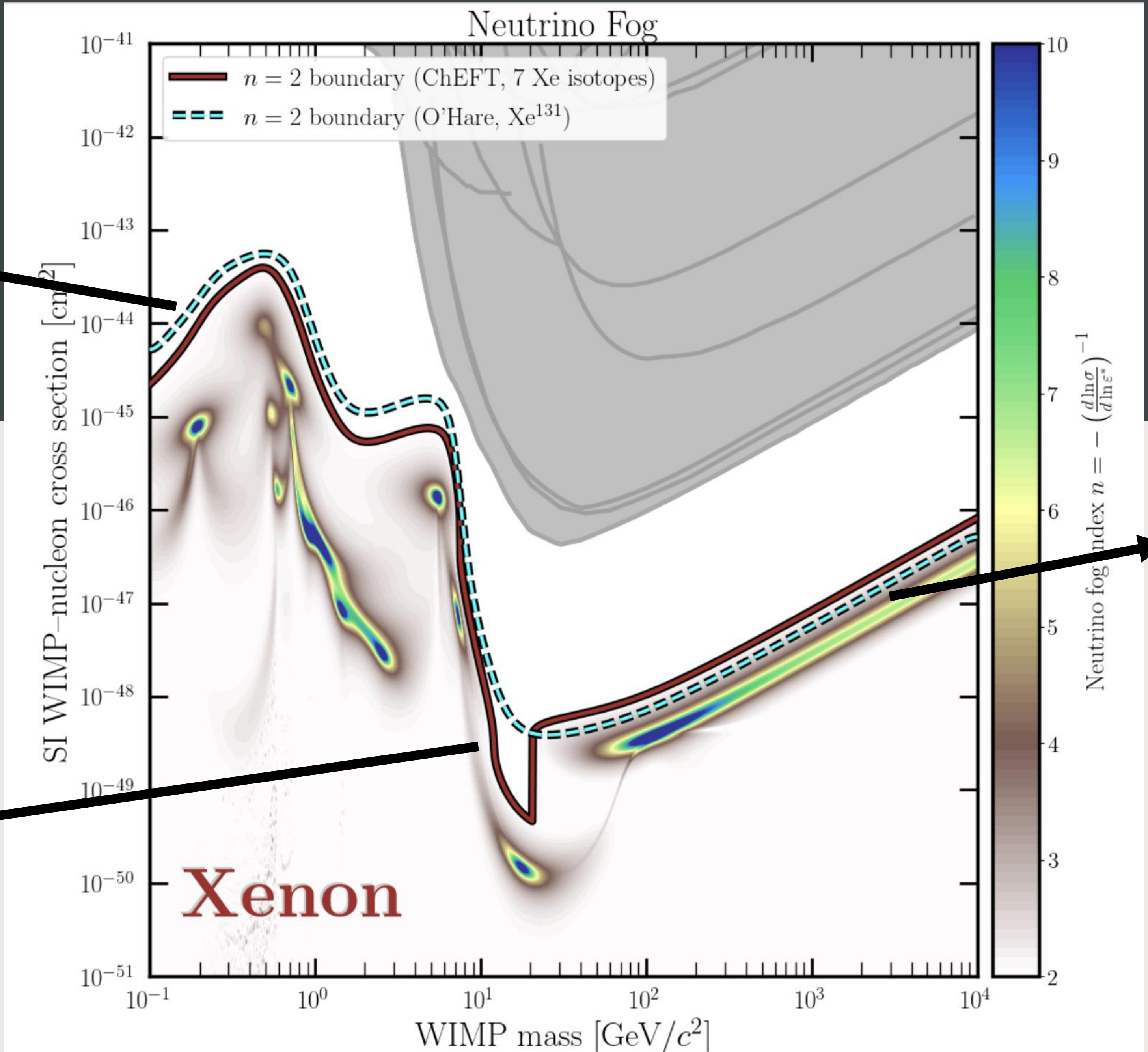
Atmospheric neutrinos

BACK TO OUR RESULT: SPIN-INDEPENDENT FOG RESULT



BACK TO OUR RESULT: SPIN-INDEPENDENT FOG RESULT

Why is our fog lower than O'Hare's?



Why is our fog higher than O'Hare's?

Why is there a vertical line?

MAIN DIFFERENCES BETWEEN O'HARE'S CALCULATION AND OURS

O'Hare

WIMP event rate: proportional to Helm form factor (Assumes uniform spherical density spin-0 nucleus)

Neutrino background: Also proportional to Helm form factor. No axial-vector contributions

Target: ^{131}Xe isotope

ChEFT (our code)

WIMP event rate: Shell model response functions that come from **matching** the EFT relativistic operator onto the non-relativistic basis of operators. [Anand, Fitzpatrick, Haxton (2014)] $(W_M, W_{\Sigma''}, W_{\Sigma}, W_{\Phi''}, W_{\Phi'}$ and $W_{\Delta})$

$$Q^{(6)}_{1,q} = (\bar{\chi}\gamma^{\mu}\chi)(\bar{q}\gamma_{\mu}q) \rightarrow \mathcal{O}^{\mathcal{NR}}_1 = 1_{\chi}1_{\mathcal{N}} \rightarrow W_M(E_r)$$

Neutrino background: Match the axial-vector Standard model operator to the NR basis

$$\mathcal{L} \supseteq -\frac{G_F}{\sqrt{2}}[\bar{\nu}\gamma^{\mu}(1-\gamma^5)\nu][\bar{q}\gamma_{\mu}(g_V^q - g_A^q\gamma^5)q]$$

$$\rightarrow \mathcal{O}^{\mathcal{NR}}_1 = 1_{\nu}1_{\mathcal{N}} \text{ and } \mathcal{O}^{\mathcal{NR}}_{10} = -1_{\nu}\left(\overrightarrow{S_N}.\frac{i\vec{q}}{m_N}\right) \rightarrow W_M \text{ and } W_{\Sigma'}$$

Target: 7 isotopes of Xe using natural abundance

SPIN-INDEPENDENT FOG RESULT

Why is our fog lower than O'Hare's for $m_\chi < 10$ GeV?

For the ChEFT fog, $\frac{dR_\chi}{dE_r} \propto W_M(E_r)$ and $\frac{dR_\nu}{dE_r}$ depends on $W_M(E_r)$ spin-independent response functions

and **<u>also</u>** the spin-dependent part $W_{\Sigma'}(E_r)$

For O'Hare's fog, both $\frac{dR_\chi}{dE_r}$ and $\frac{dR_\nu}{dE_r}$ are proportional to the Helm form factor $F_{Helm}(E_r)$

⇒ **our signal is more distinct from our background than O'Hare's signal from their background**

SPIN-INDEPENDENT FOG RESULT

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For the ChEFT fog, $\frac{dR_\chi}{dE_r} \propto W_M(E_r)$ and $\frac{dR_\nu}{dE_r}$ depends on $W_M(E_r)$ spin-independent response functions and **also** the spin-dependent part $W_{\Sigma'}(E_r)$

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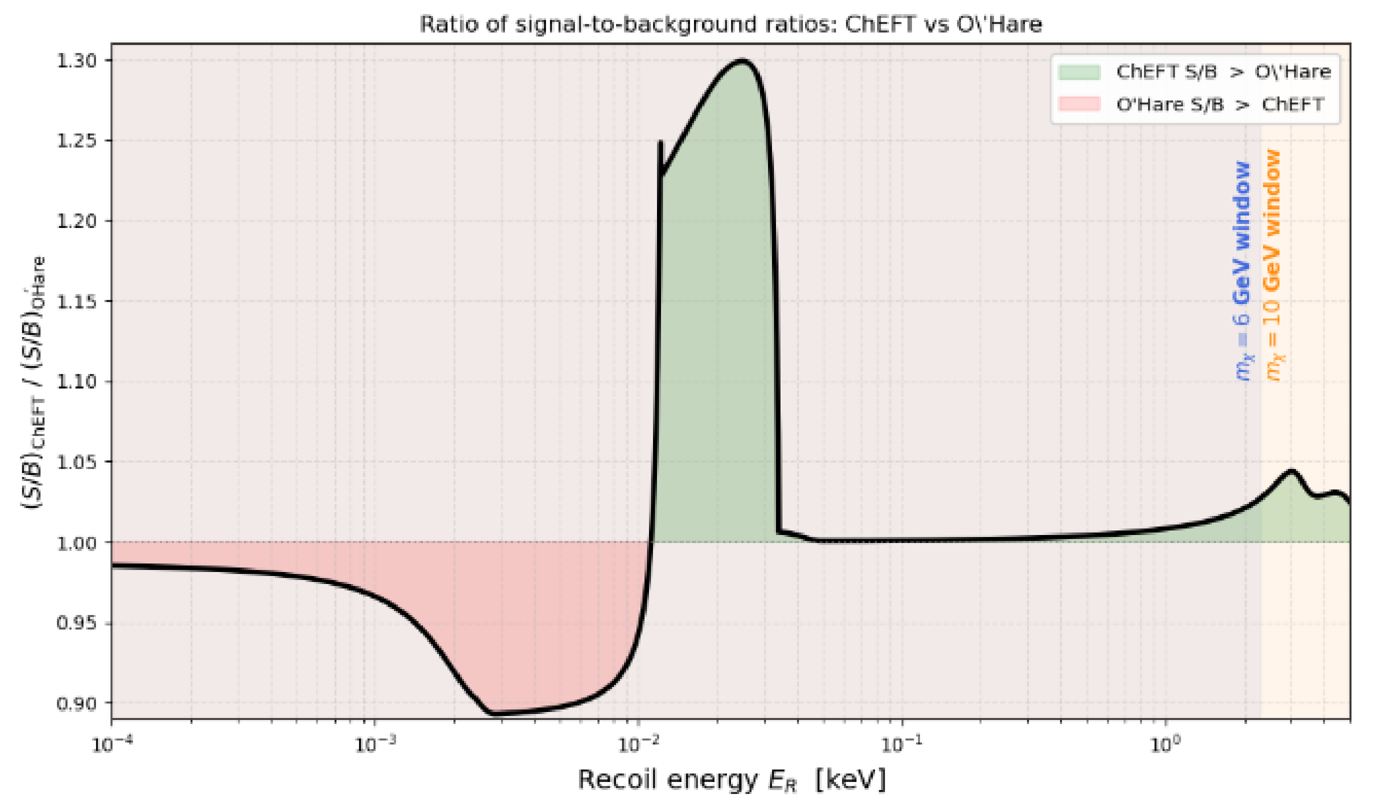
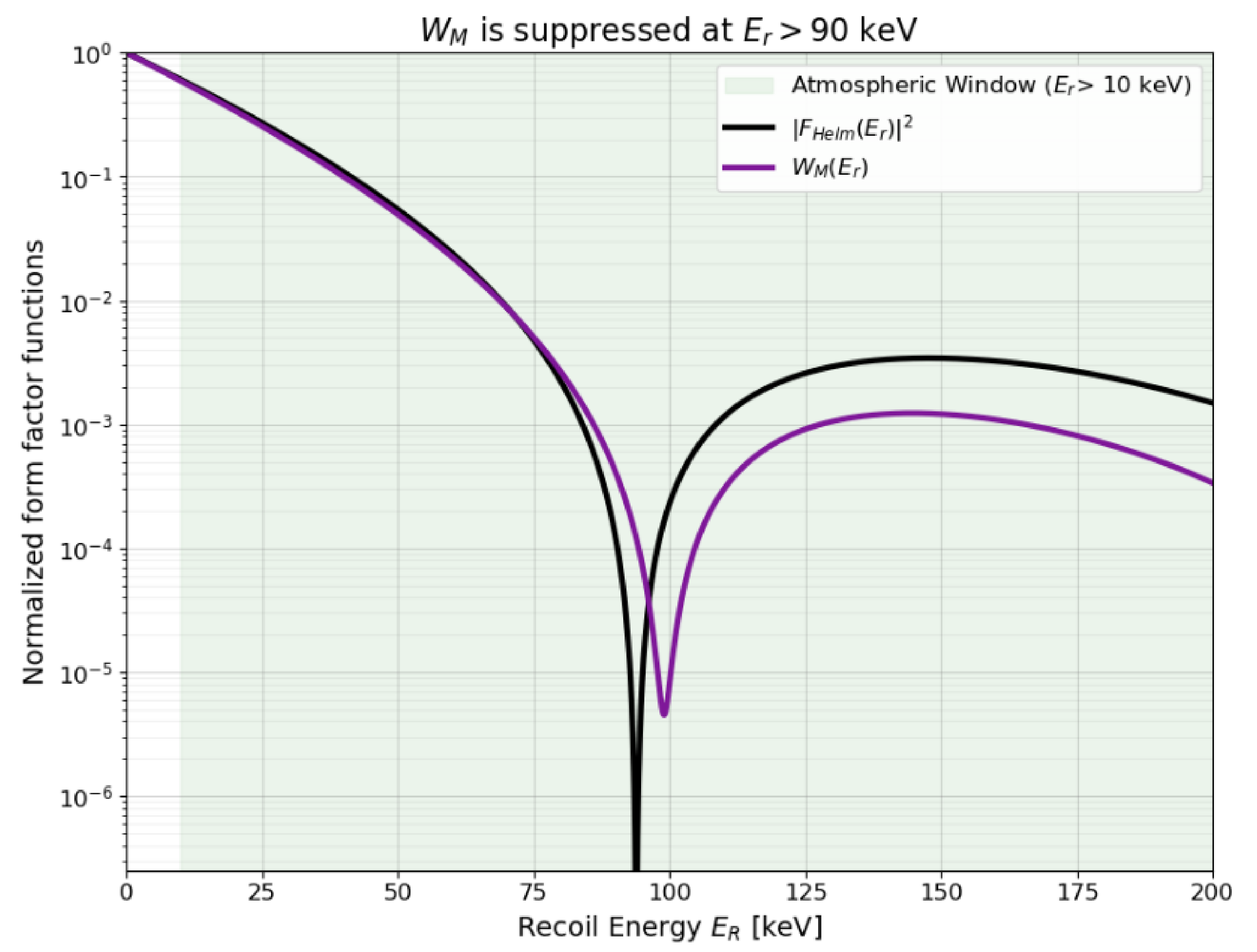


⇒ our fog is less strict in σ
Smaller required σ to claim discovery

SPIN-INDEPENDENT FOG RESULT

- **Why is our fog higher than O'Hare's for $m_\chi > 40$ GeV?** → $E_r^{max}(m_\chi = 40 \text{ GeV}) \simeq 100$ keV
- The response functions are further suppressed for $E_r > 80$ keV compared to the Helm form factor. All bins have events, but our model has less events.

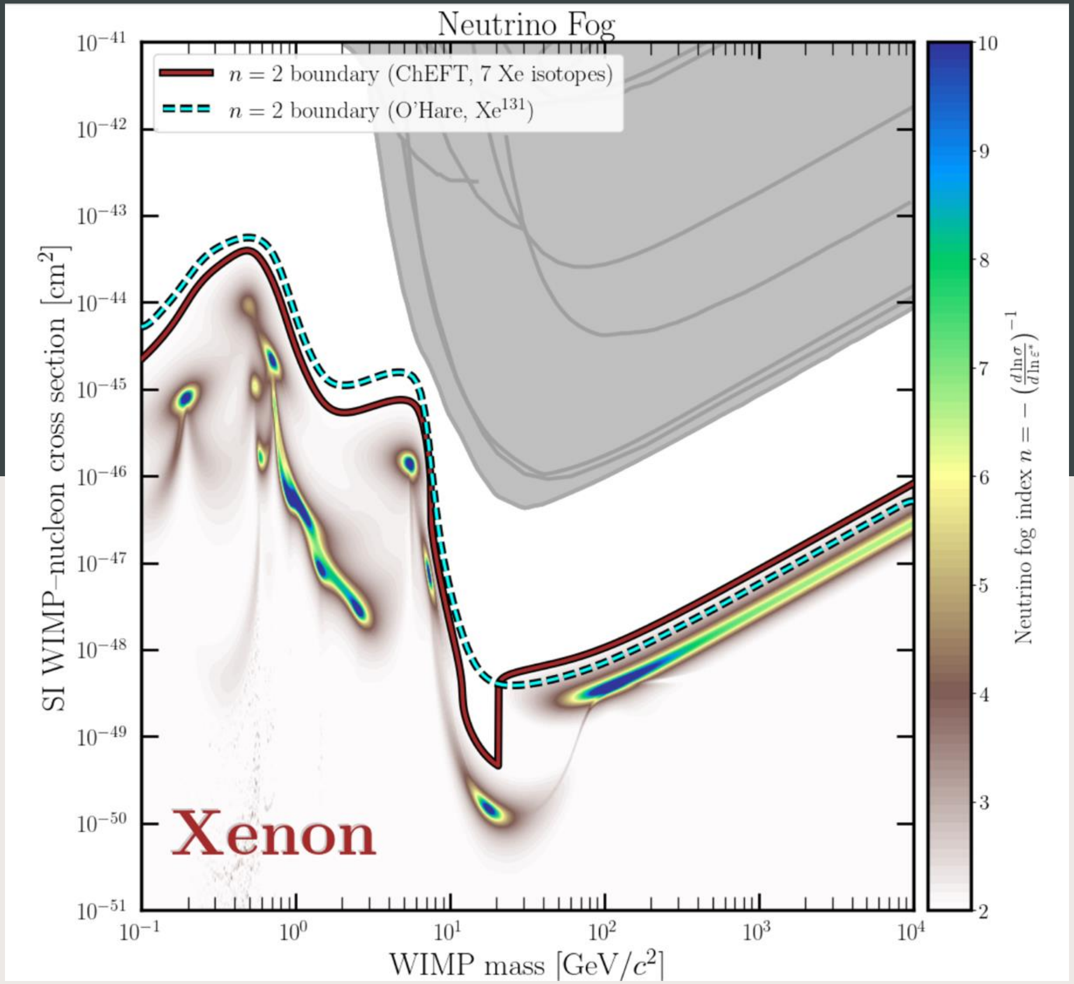


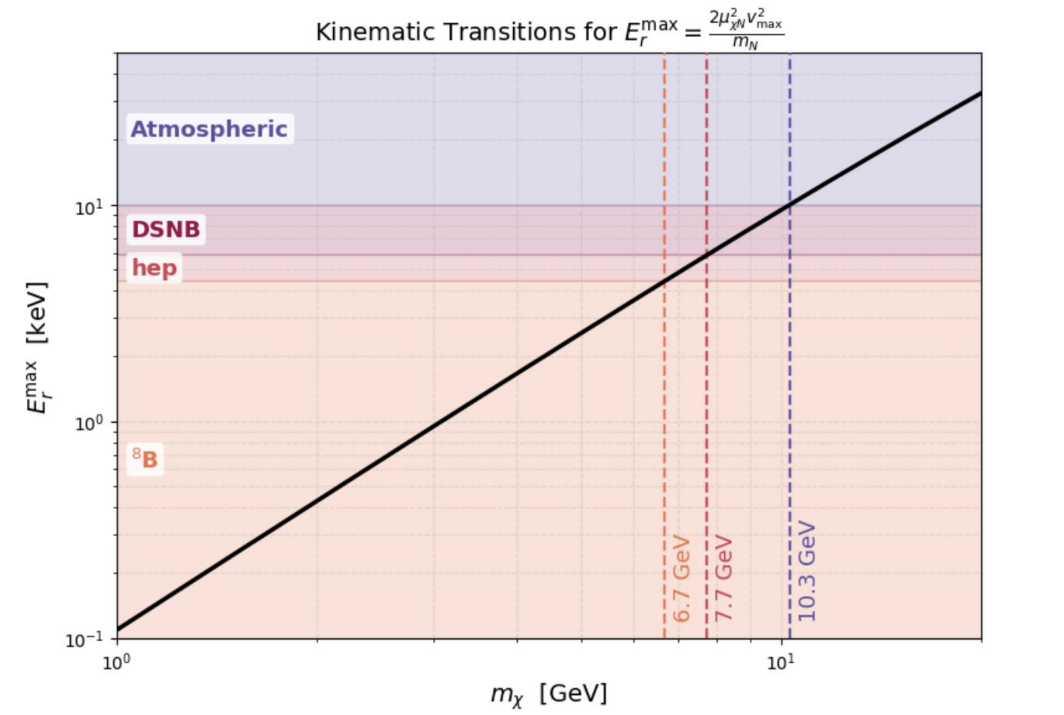
⇒ our fog is more strict in σ

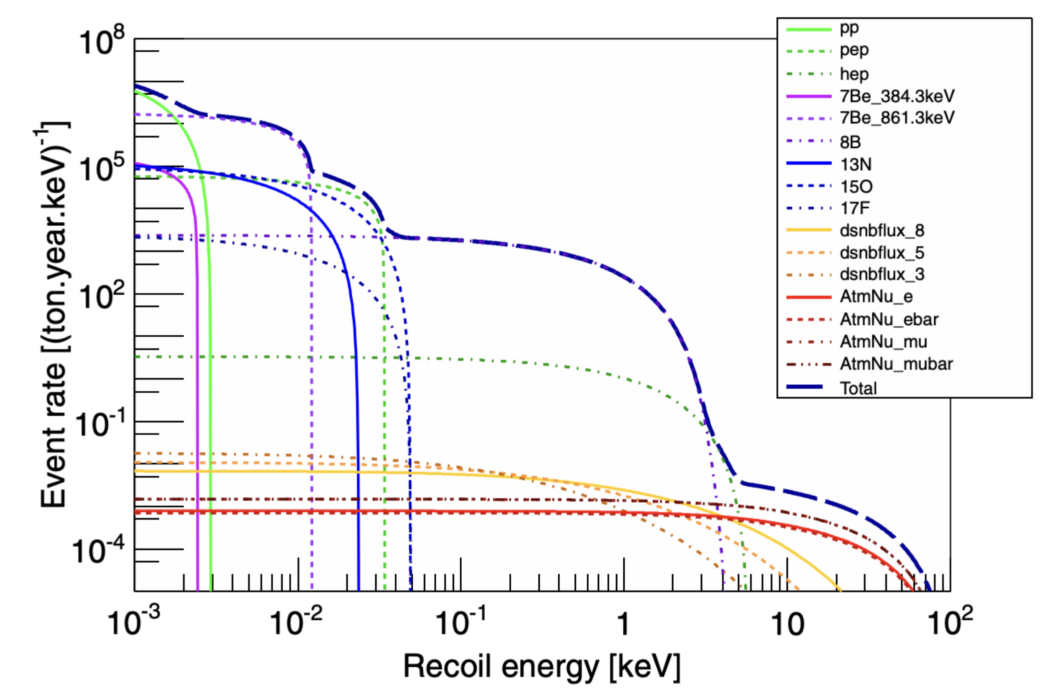
Larger required σ to claim discovery

SPIN-INDEPENDENT FOG RESULT

Why is there a vertical line in our fog?



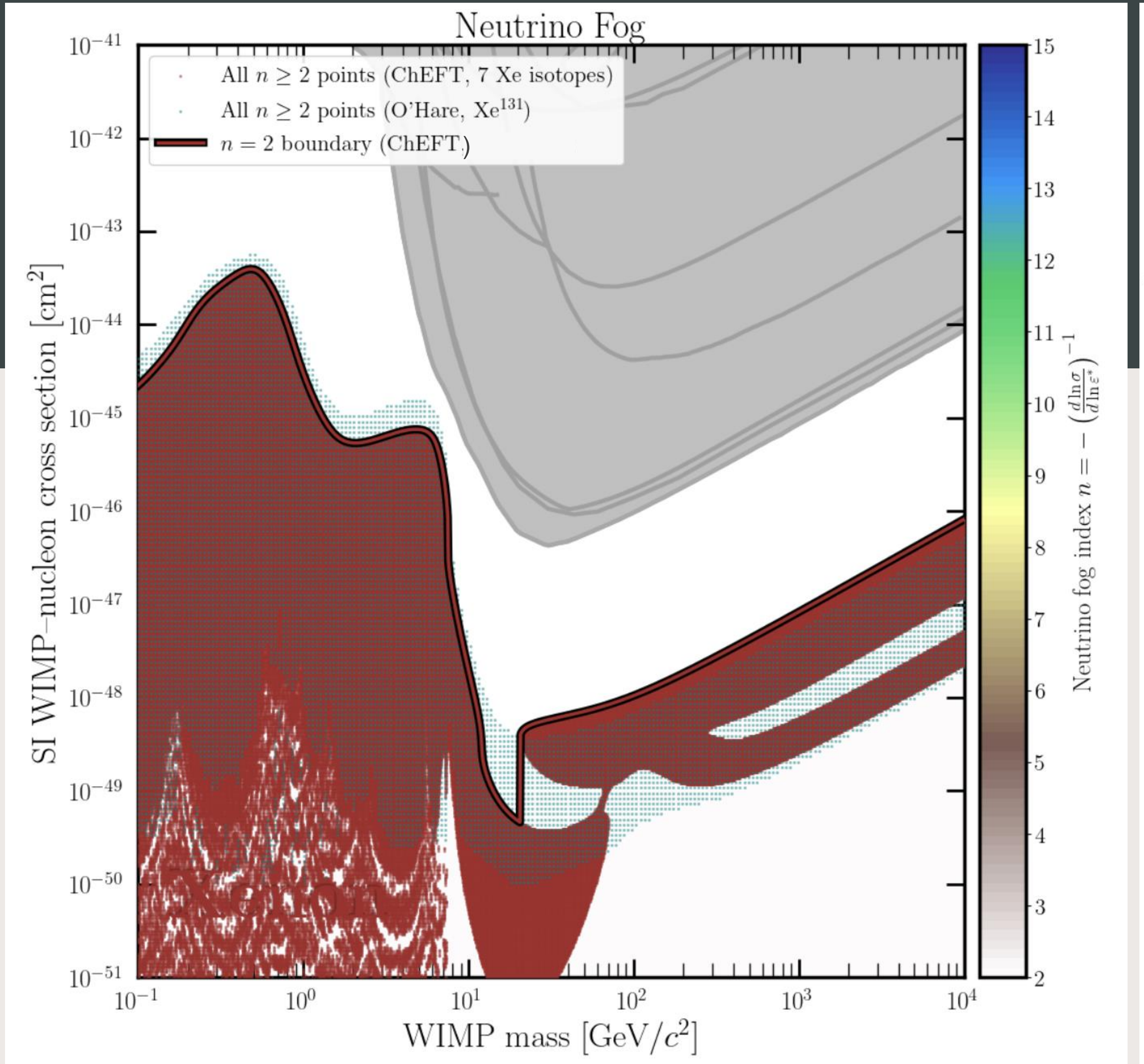


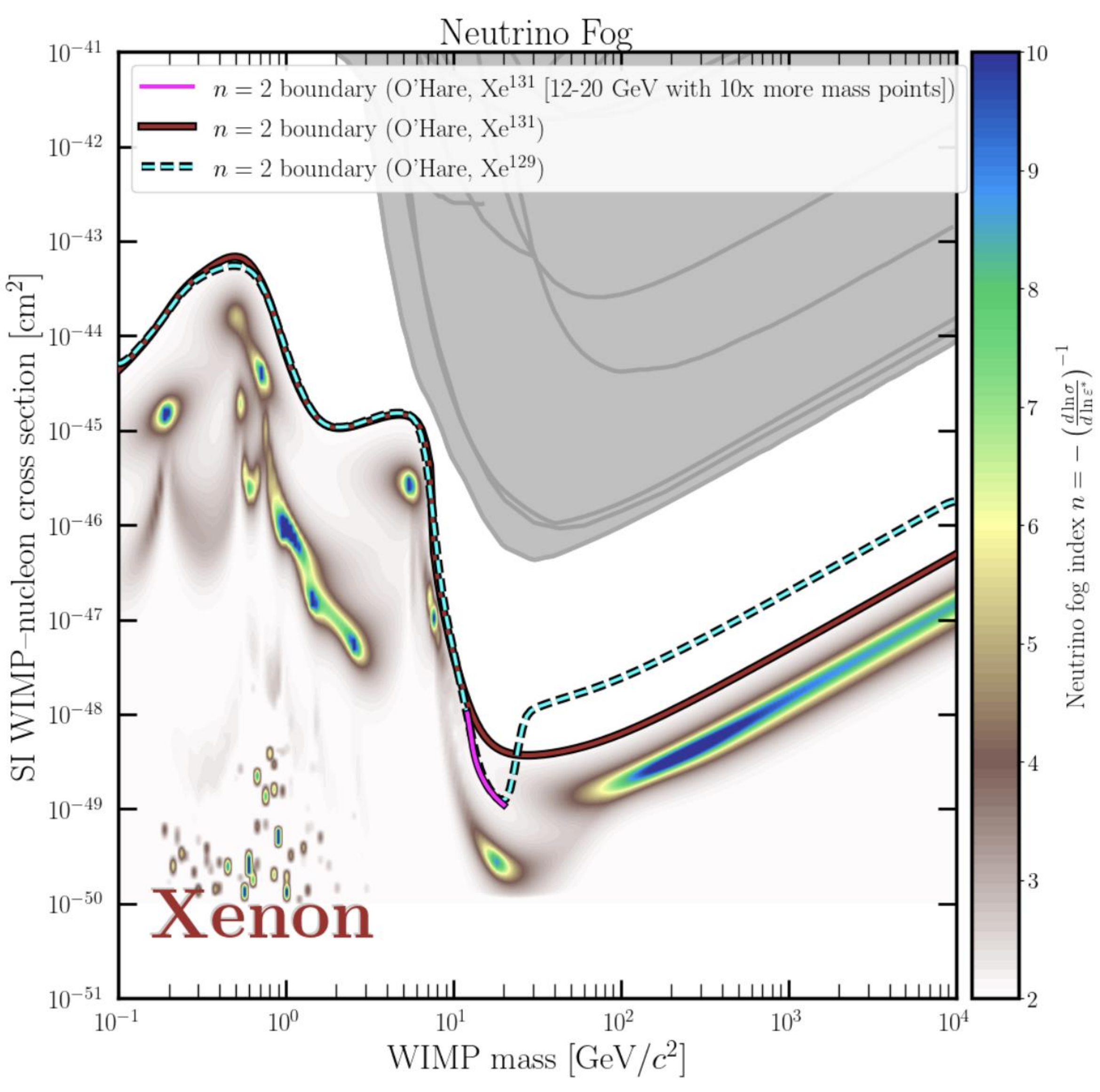


For $m_\chi > 10.3$ GeV the solar neutrino background is kinematically excluded and the atmospheric neutrinos start to dominate

SPIN-INDEPENDENT FOG RESULT

Why does not O'Hare see the vertical drop? → Mass points resolution





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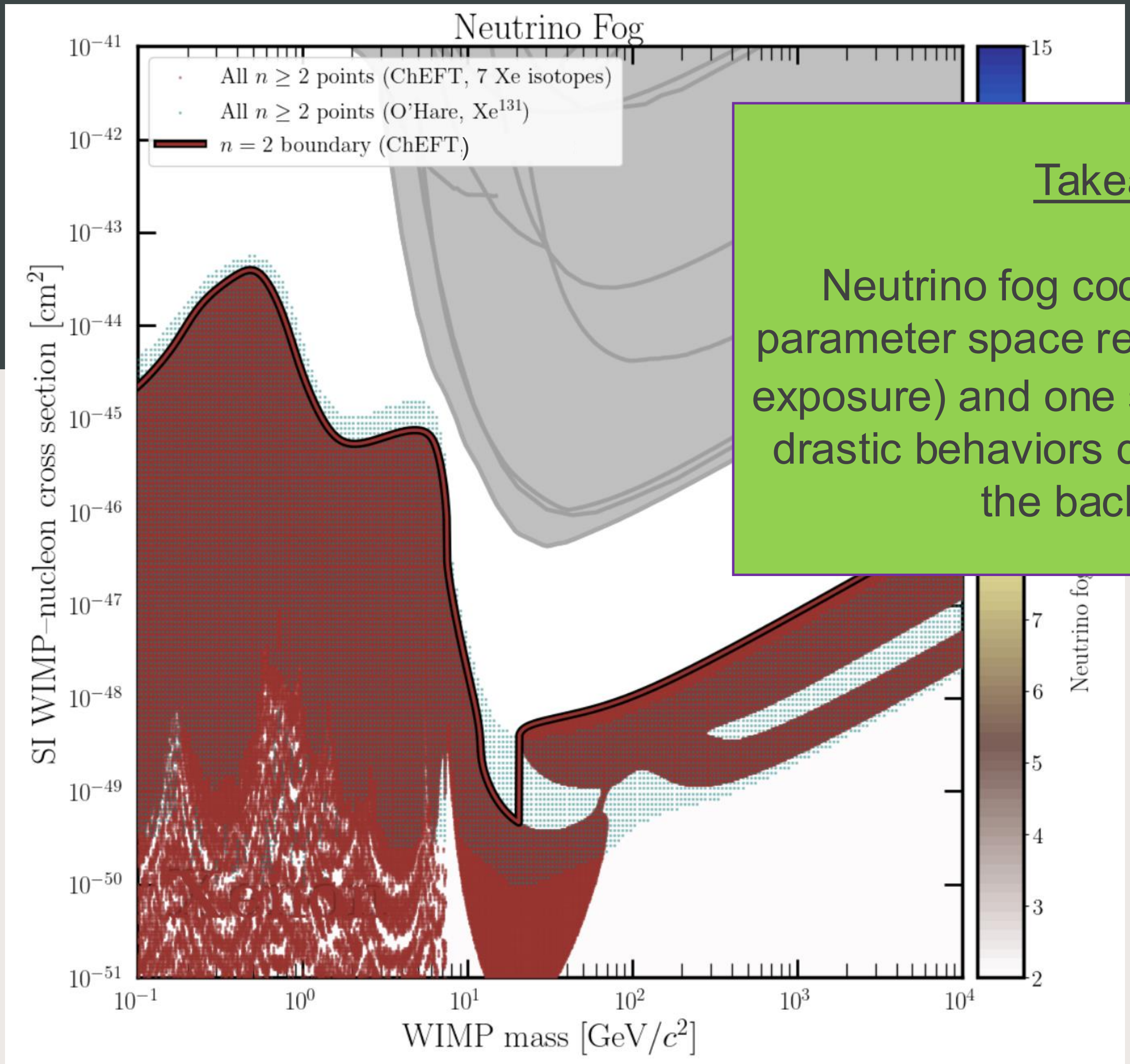
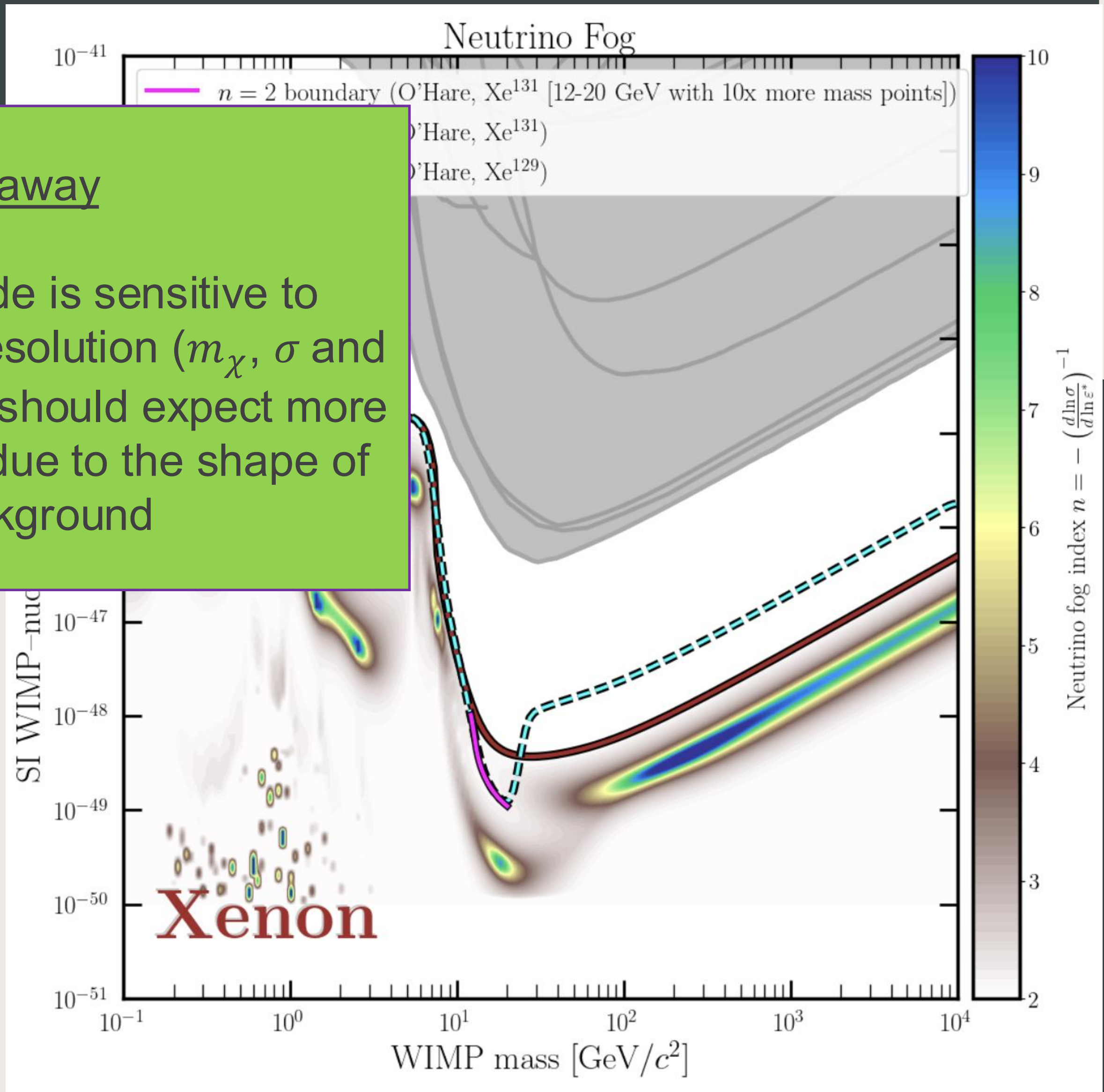




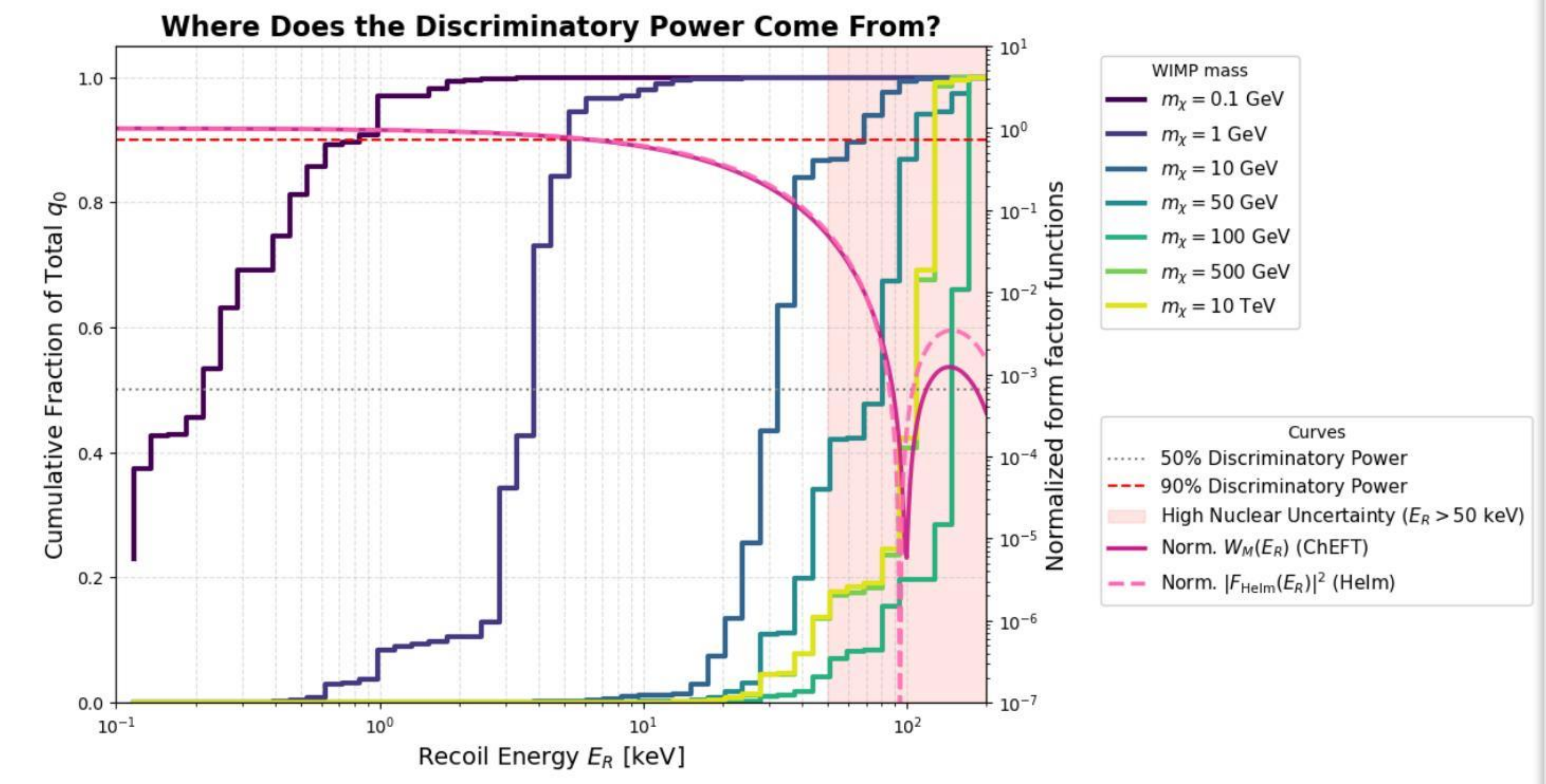
Takeaway

Neutrino fog code is sensitive to parameter space resolution (m_χ, σ and exposure) and one should expect more drastic behaviors due to the shape of the background

HOW CAN WE IMPROVE OUR RESULT?

Response functions have more uncertainties for higher E_r and we are seeing a large fractional contribution to the test statistic from the higher E_r bins for higher masses.

We will include a nuisance parameter associated with the shape of the response functions for larger E_r



CONCLUSION

- We have computed the neutrino fog for an operator in the ChEFT by computing both the WIMP event rate and the neutrino background event rate after matching them with the shell model response functions
- The idealized fog code is sensitive to the parameter space resolution
- Vertical lines in the fog signal the need for more sophisticated uncertainty treatment

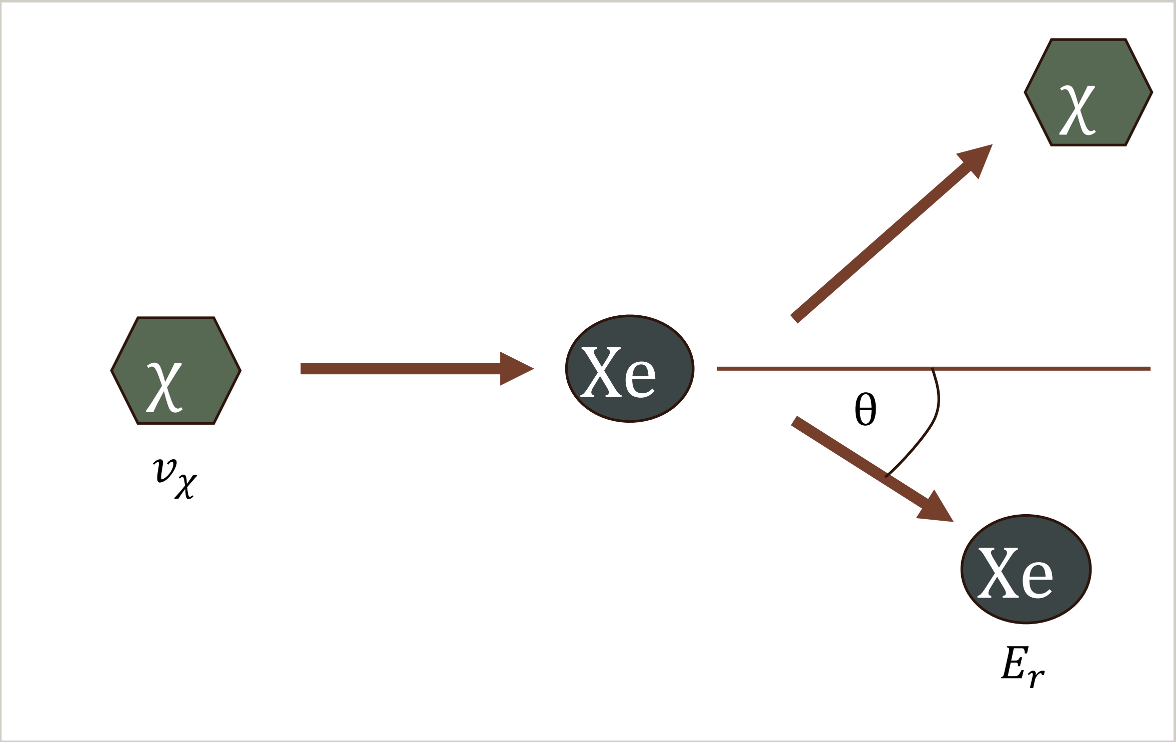
FUTURE

- Nuisance parameter addition to the background shape for some of the sources
- Add a nuisance parameter for the latter bins for the signal (response function is less accurate for higher Er)
- Repeat this process for all the operators in the EFT and compare with SDp and SDn
- Implement this fog code to other targets (Iodine, Fluorine, Argon)

THANK YOU

BACKUP SLIDES

DARK MATTER DIRECT DETECTION



In the rest frame of the Xenon target, we can describe the interaction with only one observable E_r

$$E_r = \frac{\mu_{\chi,Xe}^2 v_\chi^2}{m_{Xe}}(1 - \cos\theta)$$

Or in terms of the momentum transfer q

$$q = \sqrt{2m_{Xe}E_r}$$

The WIMP must have a certain minimum velocity in order to produce E_r

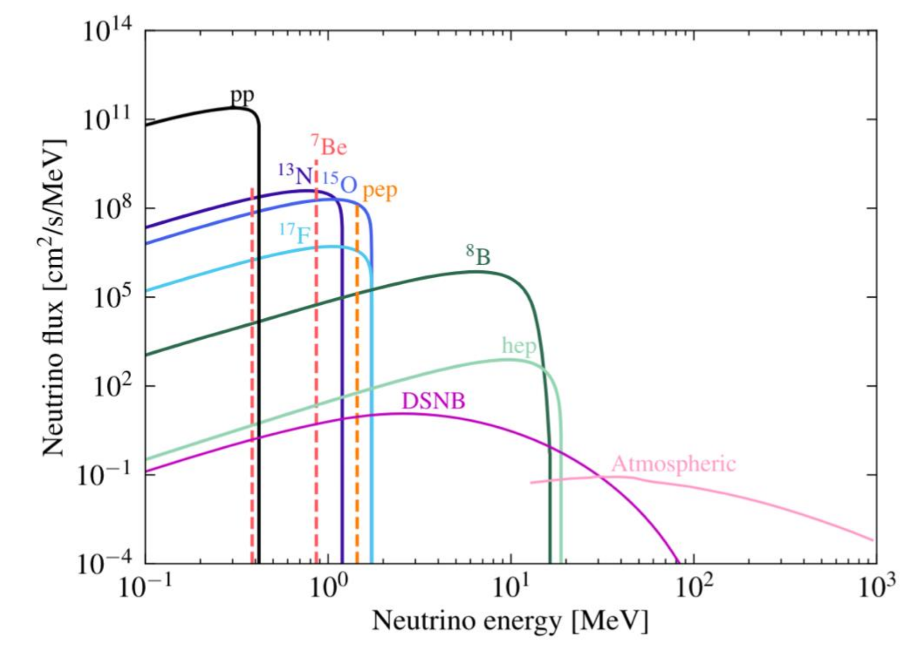
$$v_{\chi,min} = \sqrt{\frac{m_{Xe}E_r}{2\mu_{\chi,Xe}^2}}$$

NEUTRINO-NUCLEUS EVENT RATE

Neutrino fluxes

$$\frac{dR_\nu}{dE_r} = \frac{1}{m_N} \sum_\alpha \Phi_\alpha \int \frac{d\sigma}{dE_r}(E_\nu, E_r)\, \phi_\alpha(E_\nu)\, dE_\nu$$

$$\frac{d\sigma}{dE_r} = \frac{G_F^2 m_N}{4\pi} Q_W^2 \left(1 - \frac{E_r}{E_\nu} - \frac{m_N E_r}{2E_\nu^2}\right) F^2(E_r) \quad \text{with} \quad Q_W = N - (1 - 4\sin^2\theta_W) Z$$



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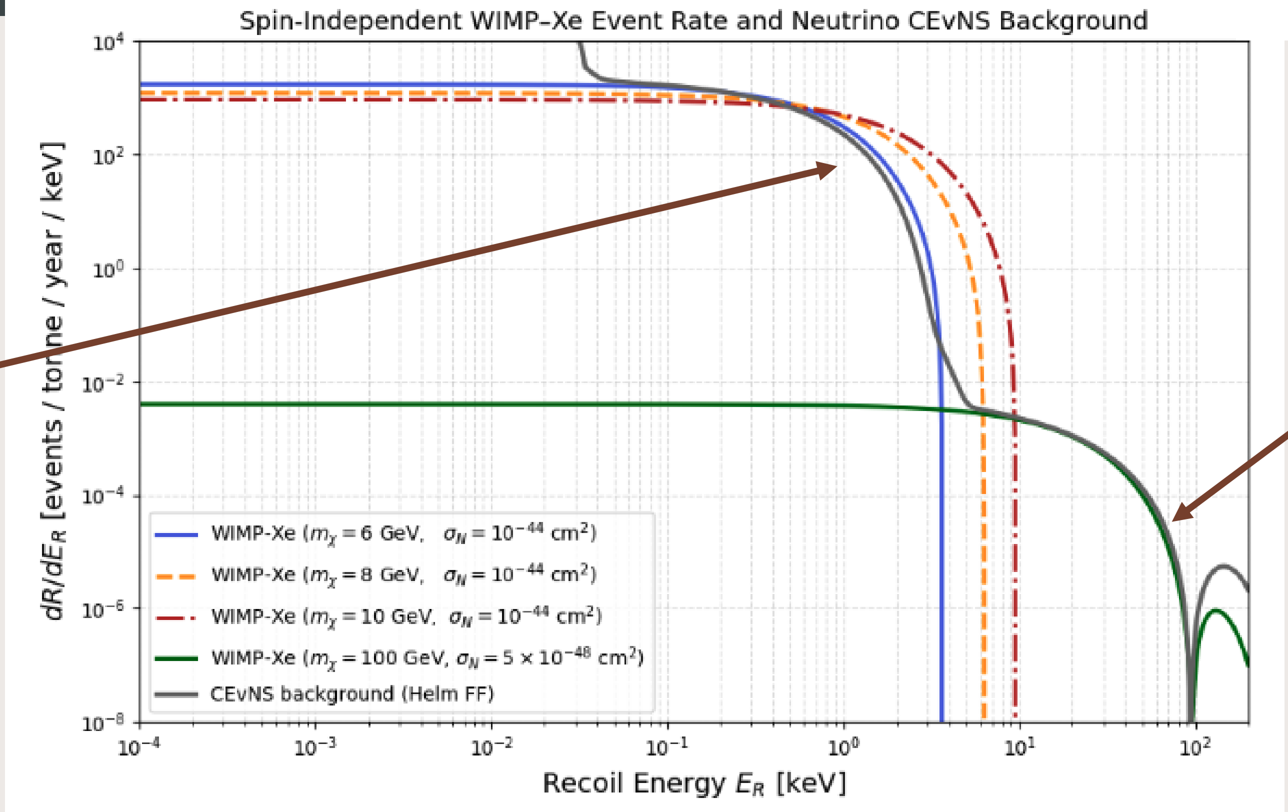
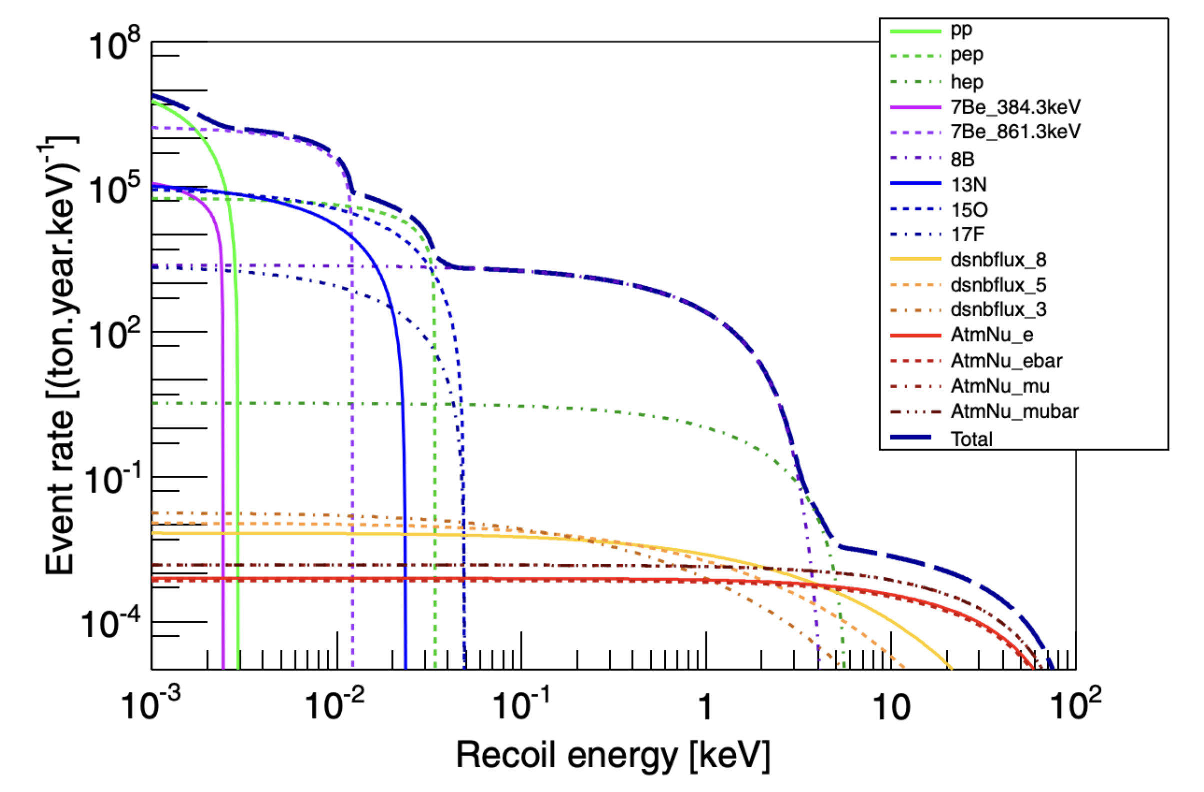


^{8}B solar neutrino

Atmospheric neutrinos

NEUTRINO BACKGROUND AND ITS UNCERTAINTIES

The total neutrino background event rate is



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But there are uncertainties associated with the flux normalizations for each source

ν type		$E_\nu^{\rm rms}$ [MeV]	$E_{\rm Xe}^{\rm med}$ [keV]	$E_{\rm Ar}^{\rm med}$ [keV]	$E_{\rm Xe}^{\rm max}$ [keV]	$E_{\rm Ar}^{\rm max}$ [keV]	$\Phi(1 \pm \delta\Phi/\Phi)$ [$\rm cm^{-2}\,s^{-1}$]	$\times 10^n$	Ref.
Solar	*pp*	0.280	0.001	0.002	0.003	0.010	$5.98\,(1 \pm 0.006)$	10^{10}	[61]
	pep	1.440	0.011	0.034	0.035	0.114	$1.44\,(1 \pm 0.01)$	10^8	[61]
	hep	10.29	0.604	2.030	5.859	19.367	$7.98\,(1 \pm 0.30)$	10^3	[61]
	^{7}Be	0.384	0.001	0.003	0.002	0.008	$4.93\,(1 \pm 0.06)$	10^8	[61]
	^{7}Be	0.861	0.004	0.013	0.012	0.041	$4.50\,(1 \pm 0.06)$	10^9	[61]
	^{8}B	7.259	0.314	1.046	4.443	14.687	$5.16\,(1 \pm 0.02)$	10^6	[62]
	^{13}N	0.749	0.004	0.017	0.024	0.078	$2.78\,(1 \pm 0.15)$	10^8	[61]
	^{15}O	1.058	0.008	0.023	0.050	0.164	$2.05\,(1 \pm 0.17)$	10^8	[61]
	^{17}F	0.801	0.005	0.014	0.050	0.166	$5.29\,(1 \pm 0.20)$	10^6	[61]
Geo.	U	1.051	0.011	0.032	0.343	1.135	$4.34(1 \pm 0.20)$	10^6	[63]
	Th	0.933	0.010	0.030	0.090	0.299	$4.23(1 \pm 0.25)$	10^6	
	K	0.801	0.005	0.014	0.031	0.101	$2.05(1 \pm 0.17)$	10^7	
Reactor		0.817	0.035	0.107	2.170	7.173	$3.06(1 \pm 0.08)$	10^6	[64]
DSNB		8.781	0.788	2.844	138.240	455.660	$8.57(1 \pm 0.50)$	10^1	[65]
Atmospheric		477.9	10.27	63.60	> 1000	> 1000	$1.07(1 \pm 0.25)$	10^1	[66]

arXiv: 2002.07499

THE NEUTRINO FOG

For each WIMP mass $m_\chi$and WIMP-nucleon cross section σ, one can find the exposure ε^* for which one can have 3σ discovery limit $Z = \sqrt{q_0} = 3 \Rightarrow q_0(\varepsilon^*) = 9$

Zero systematic uncertainty:. The background variance is purely statistical (N). To claim discovery, the signal must exceed Poissonian fluctuations $S \propto \sqrt{N}$, meaning that the cross sections scales as $\sigma \propto \frac{\sqrt{N}}{N}$

Fractional systematic uncertainty: The total background variance becomes $N + (N\delta\Phi)^2$.
The cross sections scales as $\sigma \propto \frac{\sqrt{1+N\delta\Phi^2}}{N}$

As $N \to \infty$, this creates a theoretical ”floor”. However, because WIMP and neutrino shapes are not identical, large enough exposure eventually breaks the degeneracy.

The neutrino fog index n is defined

$$n = -\left(\frac{d\ln\sigma}{d\ln\varepsilon^*}\right)^{-1}$$

$n(m_\chi, \sigma)$ defines a region in parameter space where $n > 2$, indicating that sensitivity scales worse than Poissonian background substraction

WIMP-NUCLEUS EVENT RATE

The WIMP-nucleus cross section is

$$\frac{d\sigma_A}{dE_r} = \frac{m_A}{{v_\chi}^2}\frac{2}{\pi}\left[Z\, f_p + (A-Z)\, f_n\right]^2 F^2(E_r)$$

Helm Form factor → $F(q) = \frac{3\, j_1(q r_n)}{q r_n}\, e^{-q^2 s^2/2}$ with $r_n = \sqrt{r_0^2\, A^{2/3} - 5 s^2}\,,\ r_0 \simeq 1.2 \text{ fm and s} \simeq 0.9 \text{ fm}$

The event rate in unit events per $\text{ton}^{-1}\ \text{yr}^{-1}\ \text{keV}^{-1}$ is:

$$\frac{dR}{dE_r} = \frac{\rho_0\, \sigma_p}{2\, m_\chi\, \mu_{\chi p}^2}\, A^2\, \frac{\mu_{\chi A}^2}{\mu_{\chi p}^2}\, F^2(E_r)\, g(v_{\min}, t)$$

with

$$g(v_{\min}, t) = \int_{v_{min}}^{v_{esc}+v_{lab}} \frac{f(\mathbf{v}, t)}{|\mathbf{v}|}\, d^3\mathbf{v}$$

Maxwell-Boltzmann distribution function normalized with a cutoff at v_{esc}

- Say why this method is not accurate, what assumptions does it use?

NEUTRINO-XE EVENT RATE MATCHING CALCULATION

The effective Hamiltonian for the neutrino-quark is

$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}} \int d^3\mathbf{x}\, [\bar{\nu}\gamma^{\mu}(1-\gamma^5)\nu](\mathbf{x}) \left[\bar{q}\gamma_{\mu}\frac{1}{2}\left(g_V^q - g_A^q\gamma^5\right)q\right](\mathbf{x})$$

The vector and axial couplings are determined by weak isospin T_3 and charge Q

$g_V^q = T_3^q - 2Q^q \, sin^2\,\theta_W$ and $g_A^q = T_3^q$.

$$\frac{d\sigma}{dE_R} = \frac{G_F^2 m_N}{\pi}\left[\left(1 - \frac{E_R}{E_\nu} - \frac{m_N E_R}{2E_\nu^2}\right)\sum_{\tau,\tau'} c_V^{\tau} c_V^{\tau'} W_M^{\tau\tau'}(q) + \left(1 - \frac{E_R}{E_\nu} + \frac{m_N E_R}{2E_\nu^2}\right)\sum_{\tau,\tau'} c_A^{\tau} c_A^{\tau'} W_{\Sigma'}^{\tau\tau'}(q)\right]$$

$c_i^{0(1)} = \frac{1}{2}\left(c_i^p \pm c_i^n\right)$ $\quad c_A^{p(n)} = \pm\frac{1}{2} g_A$ $\quad c_V^p = \frac{1}{2} - 2\sin^2\theta_W$ $\quad c_V^n = -\frac{1}{2}$

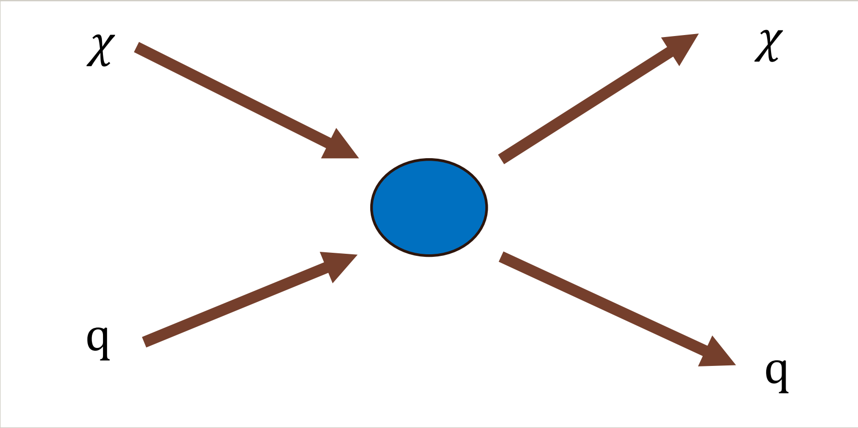
MATCHING PROCESS

We use an EFT to calculate the interaction between WIMPs and quarks

$$\mathcal{L}_\chi = \sum_{a,\mathrm{d}} \frac{c_a^{(d)}}{\Lambda^{d-4}} Q_a^{(d)}$$

We study the spin-independent interaction using a vector-vector operator

$$Q_{1,q}^{(6)} = (\bar{q}\gamma_\mu q)(\bar{\chi}\gamma^\mu \chi) \longrightarrow \mathcal{M}_{\chi\mathcal{N}} = \sum_{q=u,d} c_{1,q} \langle \mathrm{N'}|(\bar{q}\gamma_\mu q)|\mathrm{N}\rangle \langle \chi'|(\bar{\chi}\,\gamma^\mu\,\chi)|\chi\rangle$$



The nucleon-level matrix amplitude is written in terms of form factors

$$\langle N'|(\bar{q}\gamma_\mu q)|N\rangle = \bar{u}'_N \left[F_1^{q/N}(E_r)\gamma_\mu + \frac{i}{2m_N} F_2^{q/N}(E_r)\sigma_{\mu\nu}\mathrm{q}^\nu \right] u_N$$

In the non-relativistic limit

$$\bar{u}'_N\gamma_0 u_N \simeq 1_\mathcal{N} \quad \text{and} \quad \bar{u}'_N\gamma_\mathrm{i} u_N \simeq \frac{p_i}{m_N}$$

Leading order in $\mathrm{v/c}$

Suppressed $v/c \sim 10^{-3}$

Match onto non-relativistic operator basis

$$(\bar{u}'_\chi\gamma_\mu u_\chi)\,(\bar{u}'_N\gamma^\mu u_N) \simeq (\bar{u}'_\chi\gamma_0 u_\chi)\,(\bar{u}'_N\gamma^0 u_N) = \mathcal{O}_1^{\mathcal{NR}} = 1_\chi 1_\mathcal{N}$$

[Fitzpatrick, Haxton, Katz, Lubbers, Xu (2012)]

Rewrite the Wilson coefficient in terms of the Xe-nucleon cross section

$$\sigma_\mathrm{p} = \frac{\mu_{\chi p}^2}{\pi}|2c_u + c_d|^2 = \frac{\mu_{\chi\mathrm{p}}^2}{\pi}\left|c_1^p\right|^2$$

FORMULATING THE DISCOVERY TEST STATISTIC

The binned likelihood for a WIMP signal N_χ and the sum of all neutrino backgrounds N_ν^i is

$$\mathcal{L}(\sigma, \boldsymbol{\Phi}) = \prod_{i=1}^{N_{bins}} \mathcal{P}\left[N_{\mathrm{obs}}^i \middle| N_X^i(\sigma) + \sum_{j=1}^{n_\nu} N_\nu^i(\Phi^j)\right] \prod_{j=1}^{n_\nu} \mathbf{N}\left(\boldsymbol{\Phi}^{\mathrm{j}} | \boldsymbol{\Phi}_{\mathbf{0}}^{\mathrm{j}}, \delta \boldsymbol{\Phi}^{\mathrm{j}}\right)$$

with the nuisance parameters associated with the neutrino fluxes uncertainties $\boldsymbol{\Phi}$

The Profile Likelihood ratio tests the background-only hypothesis ($\sigma = 0$) against the best-fit hypothesis ($\hat{\sigma}$)

$$q_0 = \begin{cases} -2 \ln\left[\frac{\mathcal{L}(0, \Phi | \mathcal{M}_{\hat{\sigma}=0})}{\mathcal{L}(\hat{\sigma}, \hat{\Phi} | \mathcal{M}_{\hat{\sigma}=0})}\right] & \hat{\sigma} > 0 \\ 0 & \hat{\sigma} \leq 0 \end{cases} \Rightarrow \quad q_0 = \sum_{E_r \; bins} q_0^{bin}$$

We study the events per recoil energy bin

$$q_0^{bin} = 2\left[N_{obs}^i \ln\left(\frac{N_{obs}^i}{B_i}\right) - N_{obs}^i + B_i\right] + \sum_{j=1}^{n_\nu}\left(\frac{\Phi_j - \Phi_{0,j}}{\delta \Phi_j}\right)^2 \quad \text{with} \quad N_{obs}^i = \sigma \varepsilon R_\chi^i$$

RELATIVISTIC OPERATOR BASIS & THE EFT PIPELINE

Electroweak scale
Degrees of freedom: WIMPs, quarks and Gluons

$$\mathcal{L}_{\mathcal{EFT}} = \sum_{d,i} \frac{c_i^{(d)}}{\Lambda^{d-4}} Q_i^{(d)}$$

→ RGE to QCD scale →

Nuclear scale (Chiral EFT)
Match quark currents onto nucleon and pion currents

$$(\bar{q}\gamma_\mu q) \rightarrow J_\mu^N$$

→ NR limit →

Galilean invariant basis

$$\mathcal{O}_1^{\mathcal{NR}} = 1_\chi 1_N$$

→

Nuclear response functions

$$\langle N|\mathcal{O}_1^{\mathcal{NR}}|\mathrm{N}\rangle \rightarrow W_M(E_r)$$

Nuclear Shell model

Set of relativistic operators

5-dimensional

$$Q_1^{(5)} = \frac{e}{8\pi^2}(\bar{\chi}\sigma^{\mu\nu}\chi)F_{\mu\nu}$$

$$Q_2^{(5)} = \frac{e}{8\pi^2}(\bar{\chi}\sigma^{\mu\nu}i\gamma_5\chi)F_{\mu\nu}$$

6-dimensional

$$Q_{1,q}^{(6)} = (\bar{\chi}\gamma^\mu\chi)(\bar{q}\gamma_\mu q)$$

$$Q_{2,q}^{(6)} = (\bar{\chi}\gamma^\mu\gamma_5\chi)(\bar{q}\gamma_\mu q)$$

$$Q_{3,q}^{(6)} = (\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu\gamma_5 q)$$

$$Q_{4,q}^{(6)} = (\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{q}\gamma^\mu\gamma_5 q)$$

7-dimensional

$$Q_1^{(7)} = \frac{\alpha_s}{12\pi}(\bar{\chi}\chi)G^{a,\mu\nu}G_{\mu\nu}^a$$

$$Q_2^{(7)} = \frac{\alpha_s}{12\pi}(\bar{\chi}i\gamma_5\chi)G^{a,\mu\nu}G_{\mu\nu}^a$$

$$Q_3^{(7)} = \frac{\alpha_s}{8\pi}(\bar{\chi}\chi)G^{a,\mu\nu}\widetilde{G}_{\mu\nu}^a$$

$$Q_4^{(7)} = \frac{\alpha_s}{8\pi}(\bar{\chi}i\gamma_5\chi)G^{a,\mu\nu}\widetilde{G}_{\mu\nu}^a$$

$$Q_{5,q}^{(7)} = m_q(\bar{\chi}\chi)(\bar{q}q)$$

$$Q_{6,q}^{(7)} = m_q(\bar{\chi}i\gamma_5\chi)(\bar{q}q)$$

$$Q_{7,q}^{(7)} = m_q(\bar{\chi}\chi)(\bar{q}i\gamma_5 q)$$

$$Q_{8,q}^{(7)} = m_q(\bar{\chi}i\gamma_5\chi)(\bar{q}i\gamma_5 q)$$

$$Q_{9,q}^{(7)} = m_q(\bar{\chi}\sigma^{\mu\nu}\chi)(\bar{q}\sigma_{\mu\nu}q)$$

$$Q_{10,q}^{(7)} = m_q(\bar{\chi}i\sigma^{\mu\nu}\gamma_5\chi)(\bar{q}\sigma_{\mu\nu}q)$$

NON-RELATIVISTIC OPERATOR BASIS

$$\frac{|q|}{m_N} \sim 10^{-3}$$

$$|\overrightarrow{v_\perp}| \sim 10^{-3}$$

$$\mathcal{O}_1^{\mathcal{N}} = 1_\chi 1_N$$

$$\mathcal{O}_2^{\mathcal{N}} = (v_\perp)^2 1_\chi 1_N$$

$$\mathcal{O}_3^{\mathcal{N}} = 1_\chi \overrightarrow{S_N}.\left(\overrightarrow{v_\perp} \times \frac{i\vec{q}}{m_N}\right)$$

$$\mathcal{O}_4^{\mathcal{N}} = \overrightarrow{S_\chi} \times \overrightarrow{S_N}$$

$$\mathcal{O}_5^{\mathcal{N}} = \overrightarrow{S_\chi}.\left(\overrightarrow{v_\perp} \times \frac{i\vec{q}}{m_N}\right)$$

$$\mathcal{O}_6^{\mathcal{N}} = \left(\overrightarrow{S_\chi}.\frac{\vec{q}}{m_N}\right)\left(\overrightarrow{S_N}.\frac{\vec{q}}{m_N}\right)$$

$$\mathcal{O}_7^{\mathcal{N}} = 1_\chi(\overrightarrow{S_N}.\overrightarrow{v_\perp})$$

$$\mathcal{O}_8^{\mathcal{N}} = (\overrightarrow{S_\chi}.\overrightarrow{v_\perp})1_N$$

$$\mathcal{O}_9^{\mathcal{N}} = \overrightarrow{S_\chi}.\left(\frac{i\vec{q}}{m_N} \times \overrightarrow{S_N}\right)$$

$$\mathcal{O}_{10}^{\mathcal{N}} = -1_\chi\left(\overrightarrow{S_N}.\frac{i\vec{q}}{m_N}\right)$$

$$\mathcal{O}_{11}^{\mathcal{N}} = -\left(\overrightarrow{S_\chi}.\frac{i\vec{q}}{m_N}\right)1$$

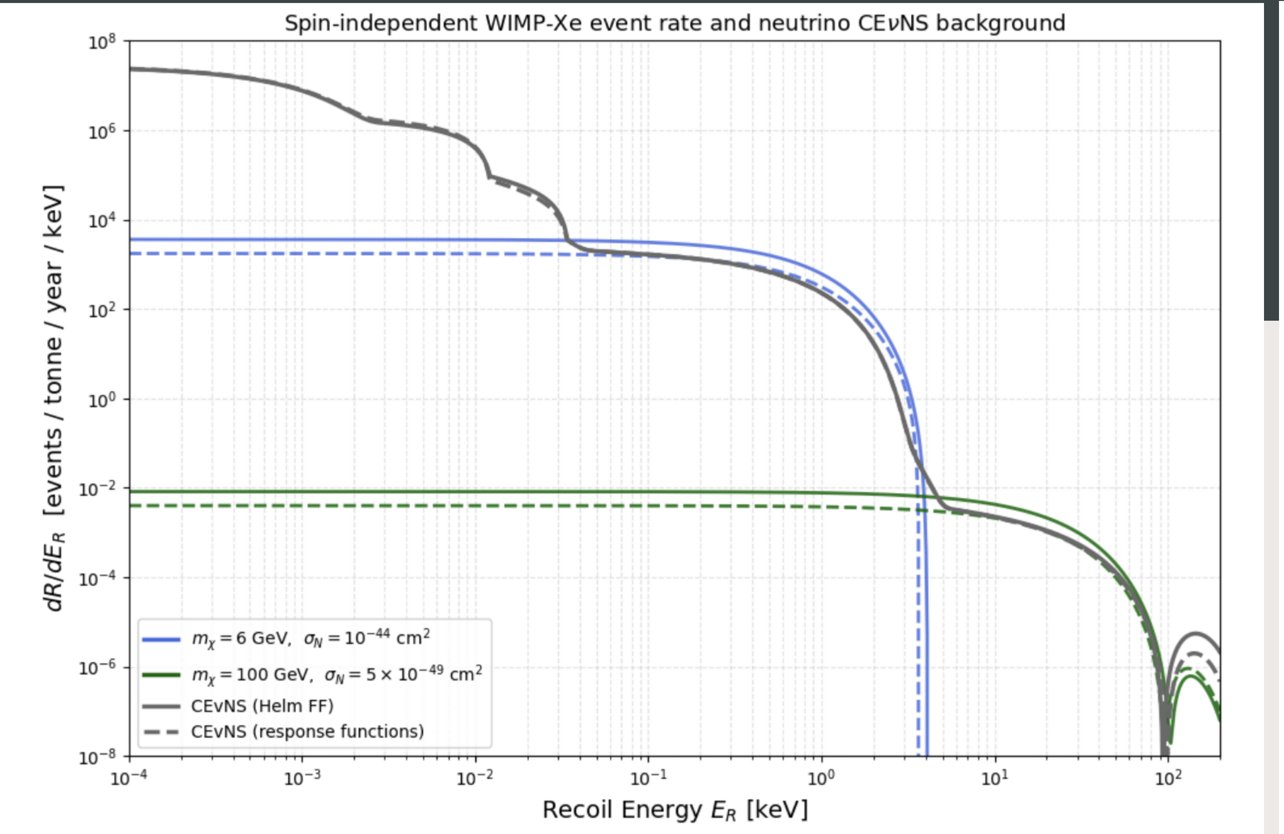
$$\mathcal{O}_{12}^{\mathcal{N}} = \overrightarrow{S_\chi}.(\overrightarrow{S_N} \times \overrightarrow{v_\perp})$$

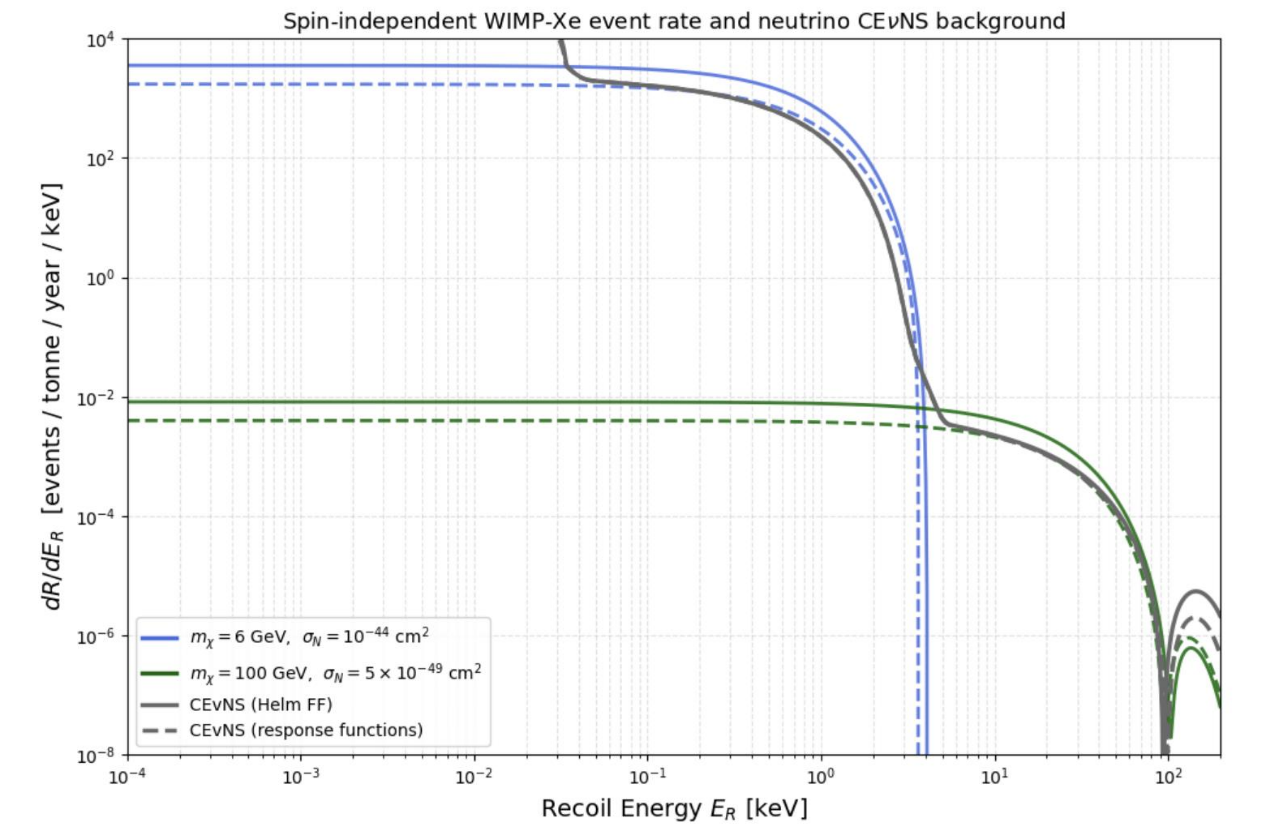
$$\mathcal{O}_{13}^{\mathcal{N}} = -(\overrightarrow{S_\chi}.\overrightarrow{v_\perp})\left(\overrightarrow{S_N}.\frac{i\vec{q}}{m_N}\right)$$

$$\mathcal{O}_{14}^{\mathcal{N}} = -\left(\overrightarrow{S_\chi}.\frac{i\vec{q}}{m_N}\right)(\overrightarrow{S_N}.\overrightarrow{v_\perp})$$

where $v_\perp = v_{rel} - \frac{q}{2\mu_{\chi n}}$

RESULTS FROM WIMP- AND NEUTRINO-NUCLEUS EVENT RATE





CONCLUSION

- We have computed the neutrino fog for an operator in the ChEFT by computing both the WIMP event rate and the neutrino background event rate after matching them with the shell model response functions
- The idealized fog code is sensitive to the parameter space resolution
- Vertical lines in the fog signal the need for more sophisticated uncertainty treatment

FUTURE

- Nuisance parameter addition:

  (i) 8B slope is uncertain due to decaying into 7Be [1][2]

  (ii) Atmospheric neutrinos are described using a power law for the different Enu range with a 5-10% uncertainty on that parameter. [3][4].

  (iii) DSNB also has shape uncertainties ~15%. DSNB is an average of historical supernovi [5][6]

[1]Bahcall et al. (1996)
[2]Winter et al. (2006).
[3]*Atmospheric neutrino flux calculation using the NRLMSISE-00 atmospheric model* (2015)
[4]*Atmospheric neutrinos as a background in dark matter searches (2020)*
[5]Annual Review of Nuclear and Particle Science (2010)
[6]Diffuse supernova neutrino background from extensive core-collapse simulations of 8–100 M⊙ progenitors