李政道研究所

TSUNG-DAO LEE INSTITUTE

TRIDENT

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Probing DM with the TRIDENT

GUTPC 2026

Andrew Cheek, TDLI, SJTU, Shanghai (acheek@sjtu.edu.cn)
Based on arXiv:2601.06817
with TRIDENT collaboration, inc. Yingwei Wang, Xinhui Chu, Iwan Morton-Blake and Xin Xiang.

DM phenomenologist near a Lab

TRIDENT
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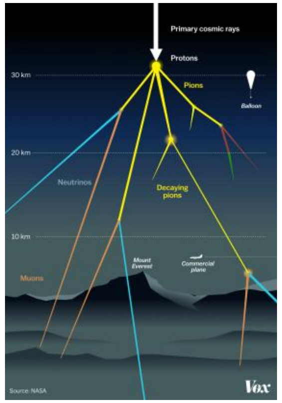
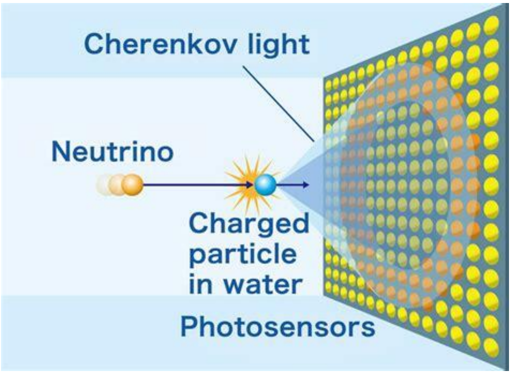
TRIDENT neutrino telescope

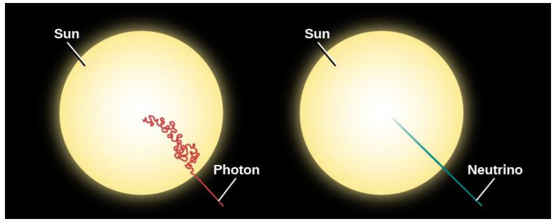
- Cherenkov detector principle gives directionality, and background discrimination.





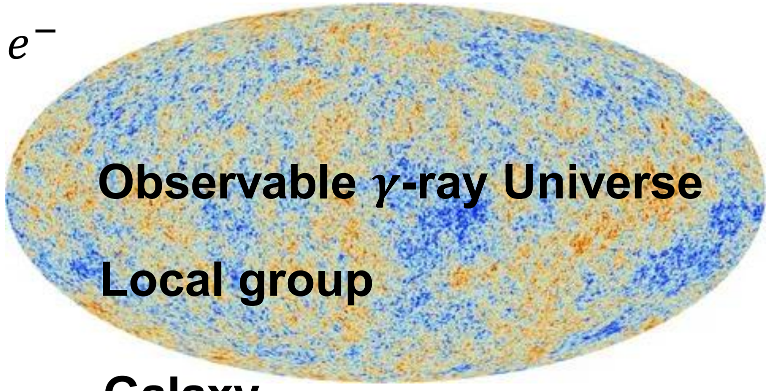
- Neutrinos are weakly interacting, giving us access to processes deep(er) in extreme environments.

$$\gamma + e^- \rightarrow \gamma + e^-$$
$$\gamma + p \rightarrow \gamma + p$$



$$\gamma + \gamma_b \rightarrow e^+ + e^-$$

$E_\gamma \lesssim 100\ \text{GeV}$



$E_\gamma \gtrsim 10\ \text{TeV}$ — **Local group**

$E_\gamma \gtrsim 1\ \text{PeV}$ — **Galaxy**

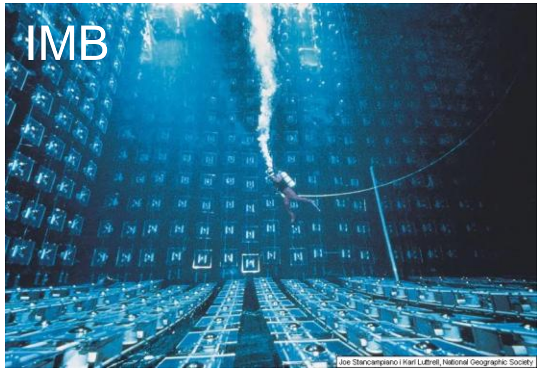
Development over the years

Cowan-Reines

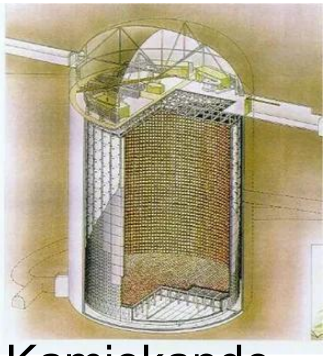
200 kg

IMB

8 kton



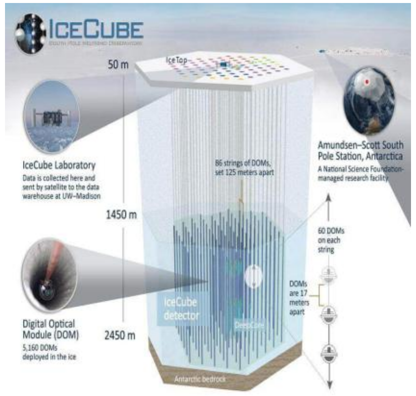
1 kton



Kamiokande

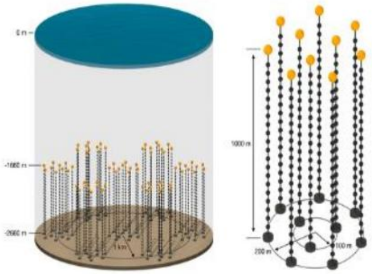
Hyper-K

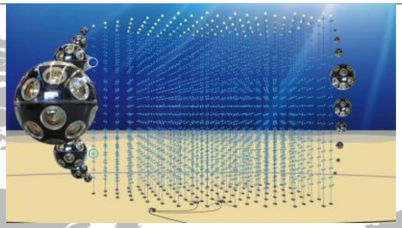
$\sim$188 kton



1 km^3

Landscape of detectors soon(ish)





P-ONE

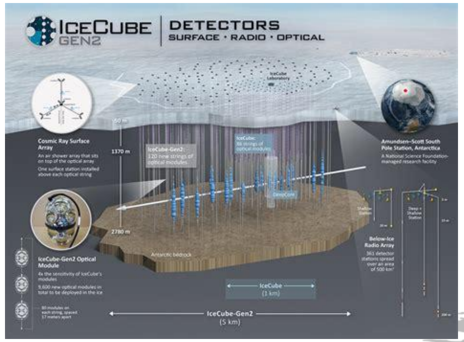
2.6 km deep
$\sim 1\text{km}^3$
70 strings

KM3NeT

3.5 km deep
$\sim 1\text{km}^3$
230 strings

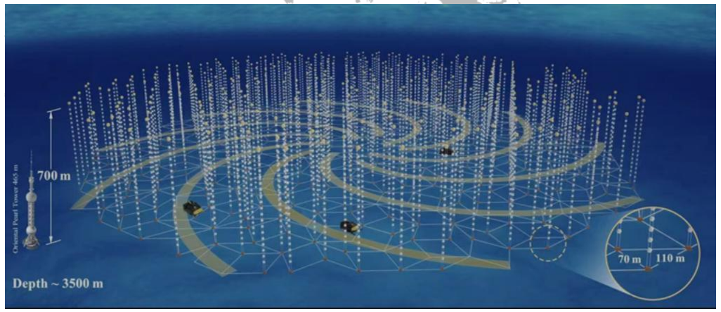
Baikal-GVD

2.6 km deep
$\sim 1\text{km}^3$
70 strings



IceCube Gen 2

2.5 km deep
$\sim 8\ \text{km}^3$
~210 strings

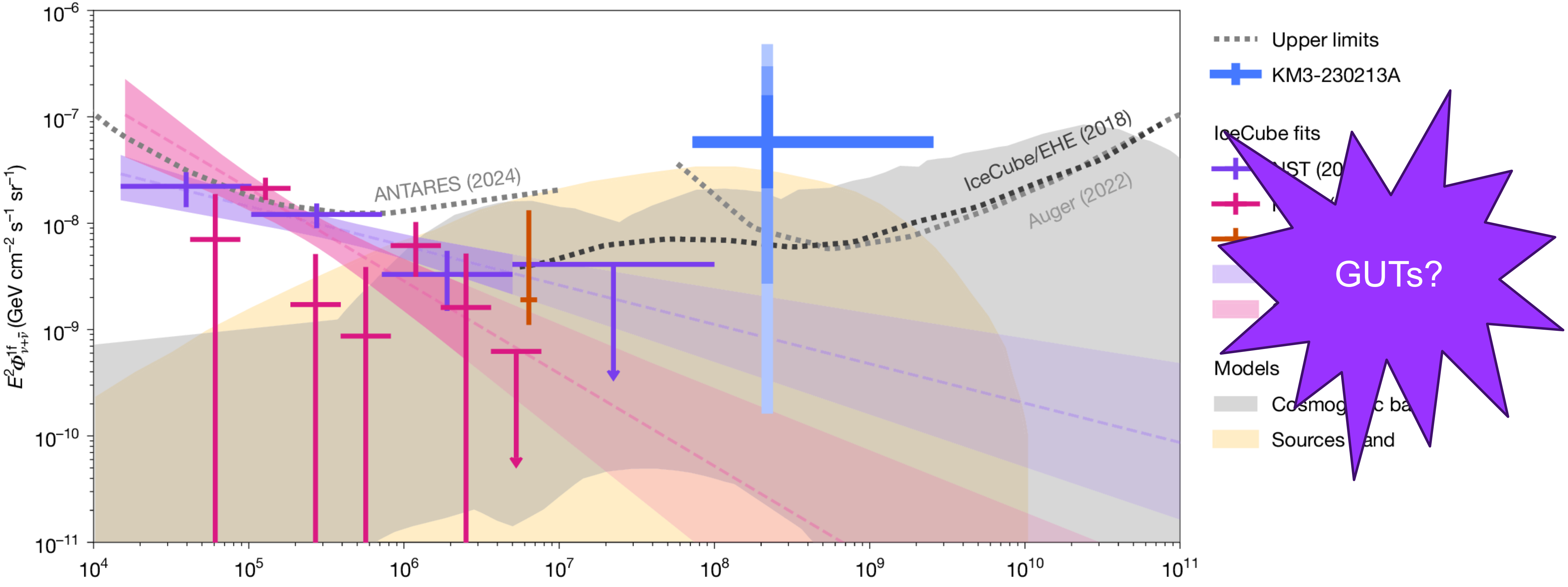


TRIDENT, HUNT

3.5 km deep
$\sim 8\ \text{km}^3$
~1000 strings

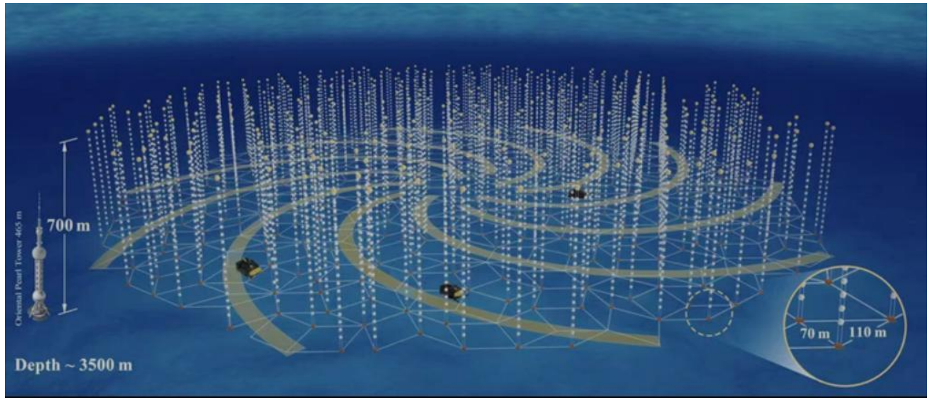
High Energy neutrinos

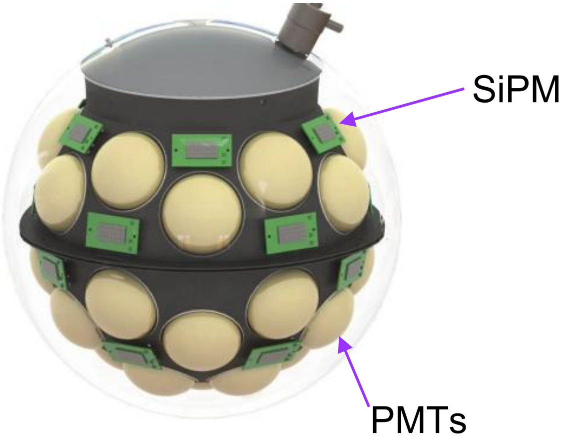
- High energy neutrino events have already been detected, not far off GUT scale



[Nature 638, pages376–382 (2025)]

TRIDENT goals





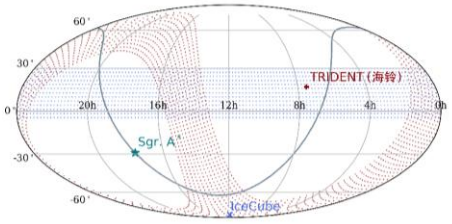
hDOM

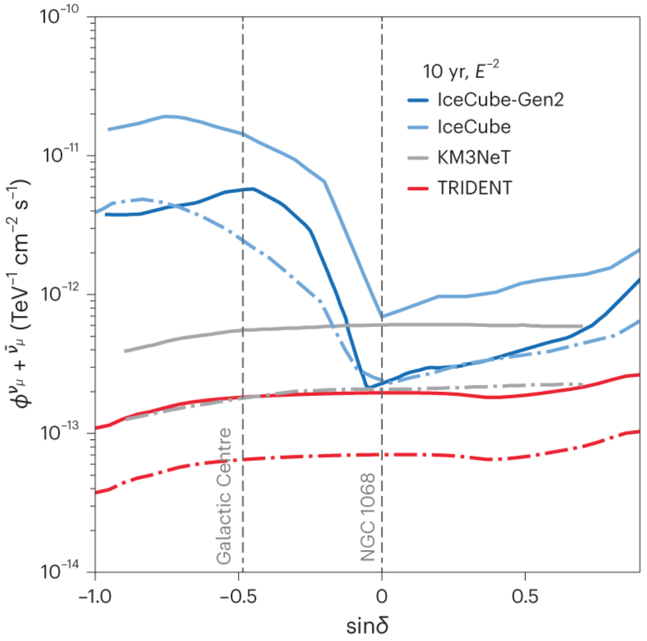
1. Rapidly discover neutrino sources
2. Achieve detector sensitivity to all flavors

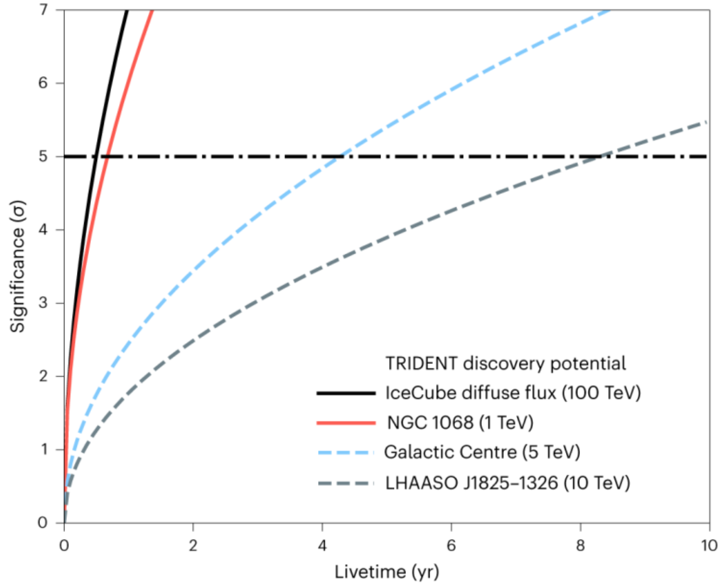
Goal 1:Rapid discovery

- Position, size and technology contribute to impressive discovery potential

3.5 km deep
$\sim 8\ \mathrm{km}^3$
~1000 strings



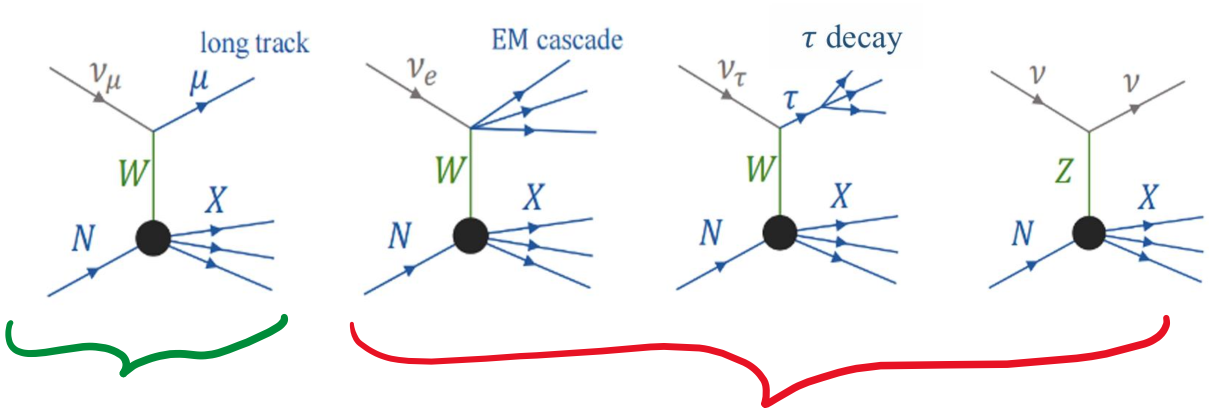




[Nature Astron. 7 (2023) 12, 1497-1505]

Goal 2:Sensitivity to all flavors

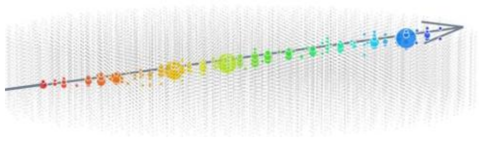
- Experimental challenge to detect and determine the flavor of neutrino



- Sea water detectors have advantages for observing cascades.

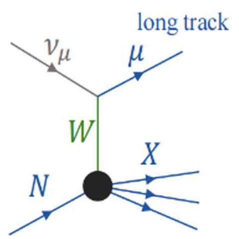
Muon tracks

Cascades

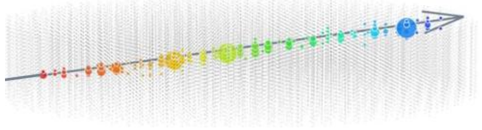


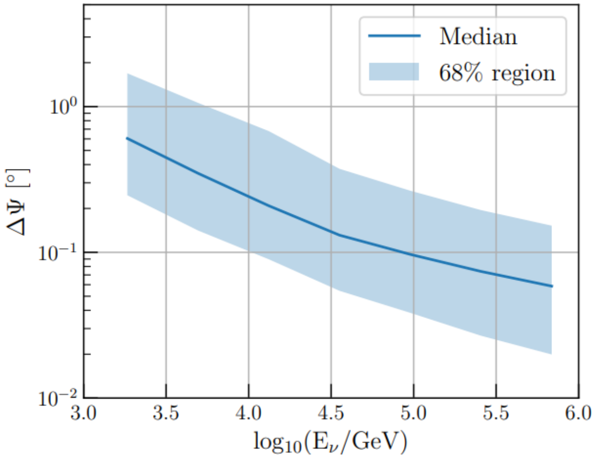
[TRIDENT SIMULATION]

Tracks and Cascades

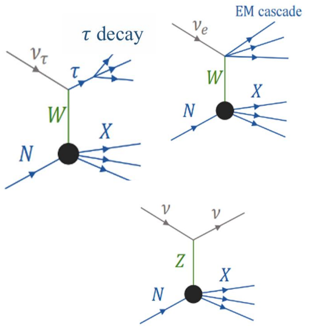


Tracks

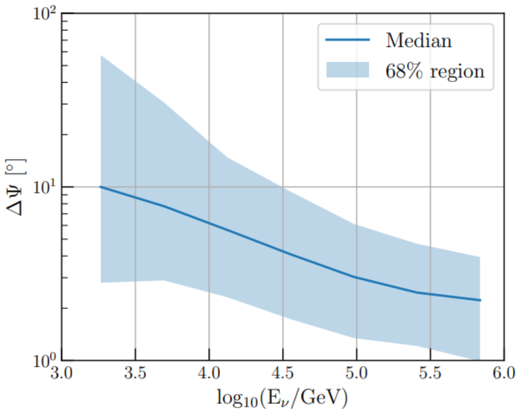




- Good pointing resolution
- Poorer energy resolution



Cascades



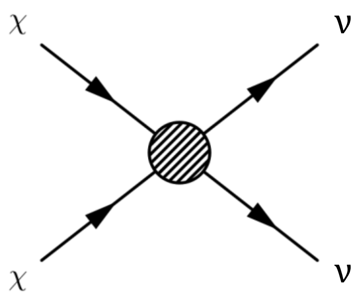
- Okay pointing resolution
- Improved energy resolution

[Phys.Rev.D 113 (2026) 4, 043030]

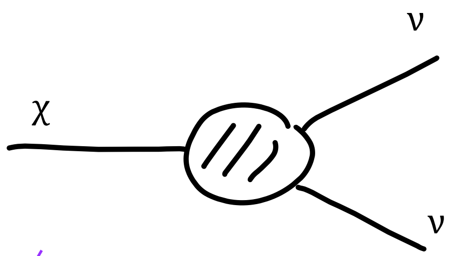
What about dark matter?

- Neutrino Telescopes will probe fundamental physics and astrophysics, but what about dark matter?

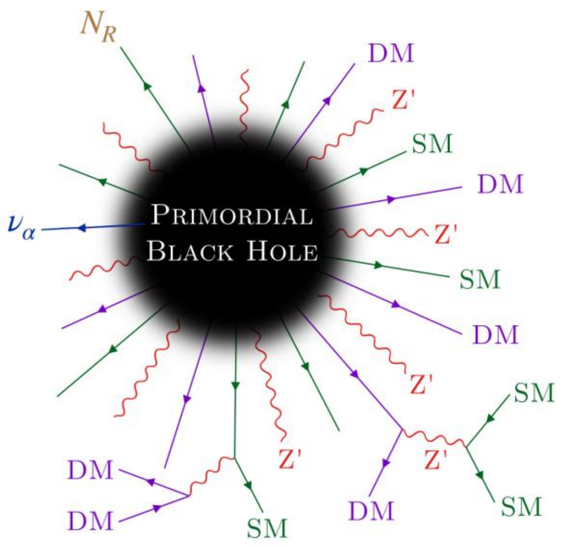
Annihilation

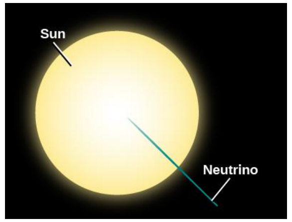


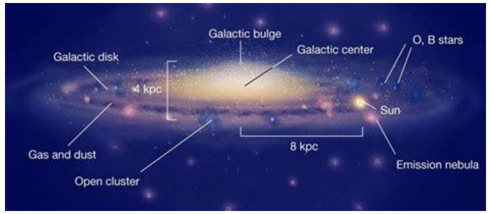
Decay



Something (completely) different







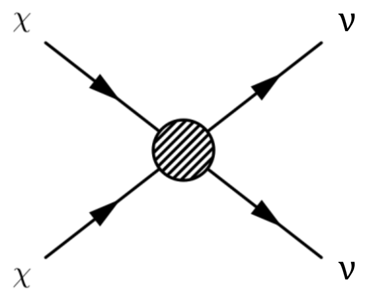
Extragalactic

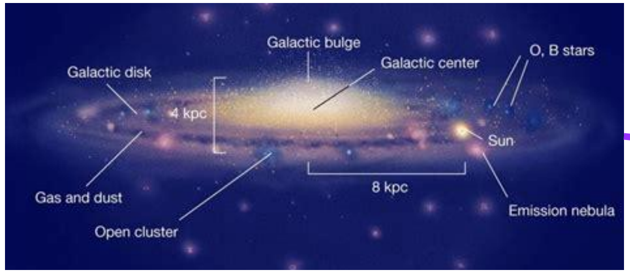
[Image: L. Heurtier & Y. Perez-Gonzalez]

What about dark matter?

- Neutrino Telescopes will probe fundamental physics and astrophysics, but what about dark matter?

Annihilation





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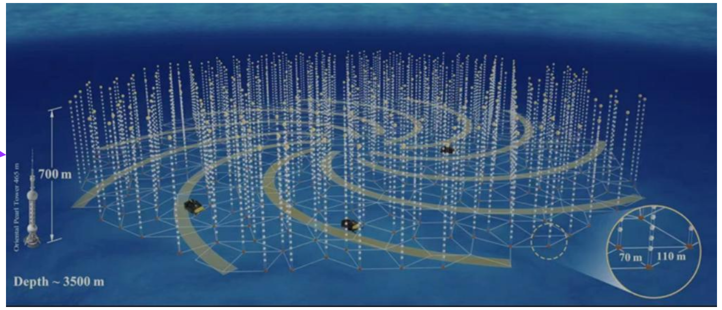
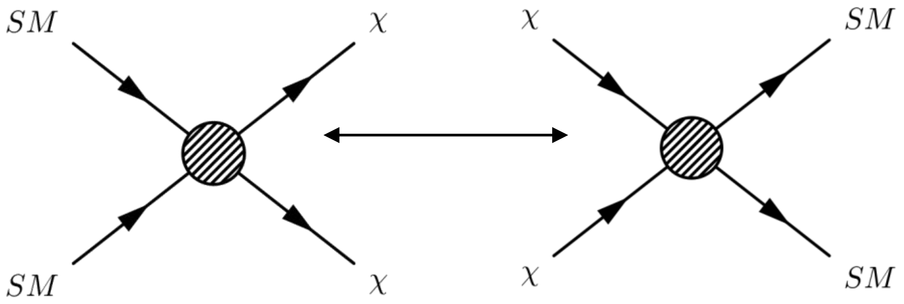
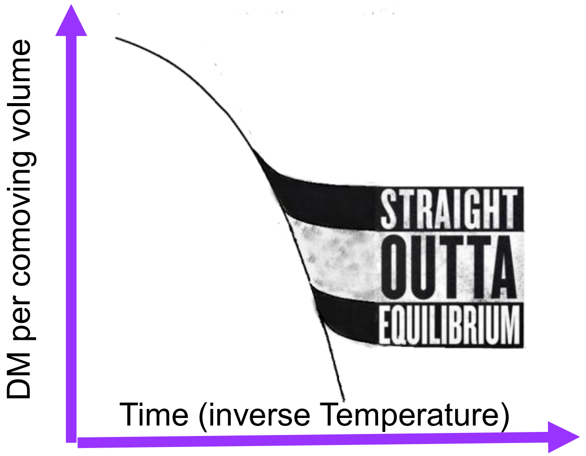


This talk

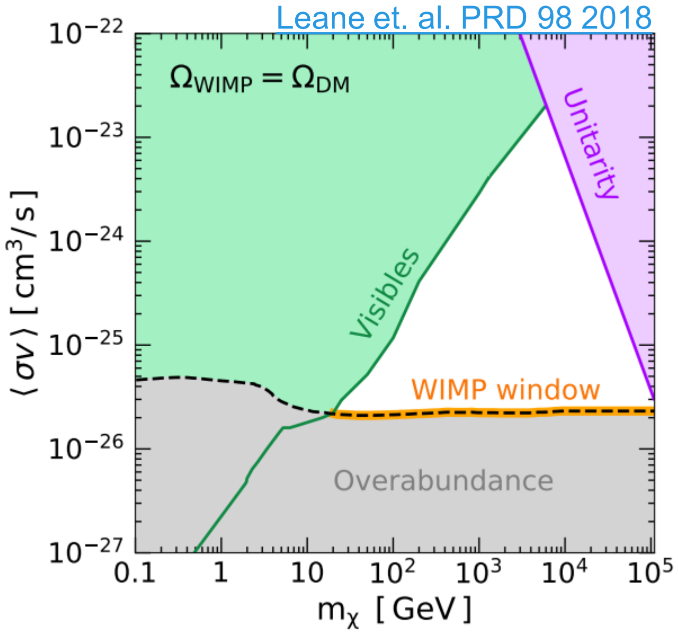
Annihilating dark matter

- Still well motivated but under pressure!





- We should experimentally close this window!



Galactic center annihilation

- Neutrino flux

$$\frac{d\Phi_\nu}{dE_\nu} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{\kappa m_\chi^2}\left(\sum_\alpha \frac{dN^{\rm prod}_{\nu\alpha}}{dE_{\nu\alpha}} P_{\nu\alpha\to\nu\beta}\right) J(\Omega)$$

"hard" process

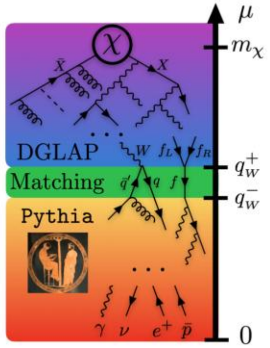
Neutrino energy spectrum per annihilation

Oscillation probs

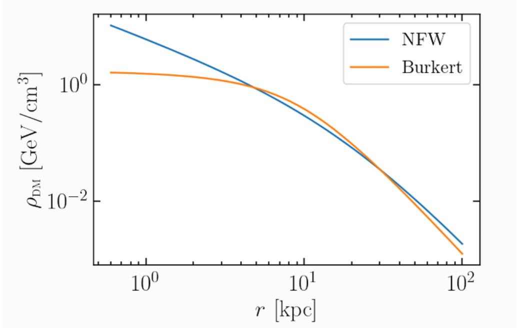
J-factor: 'astrophysics'

- Secondary emission of neutrinos from charged fermions gives signal still

[PPPC4DM, HDMSpectra, CosmiXs]

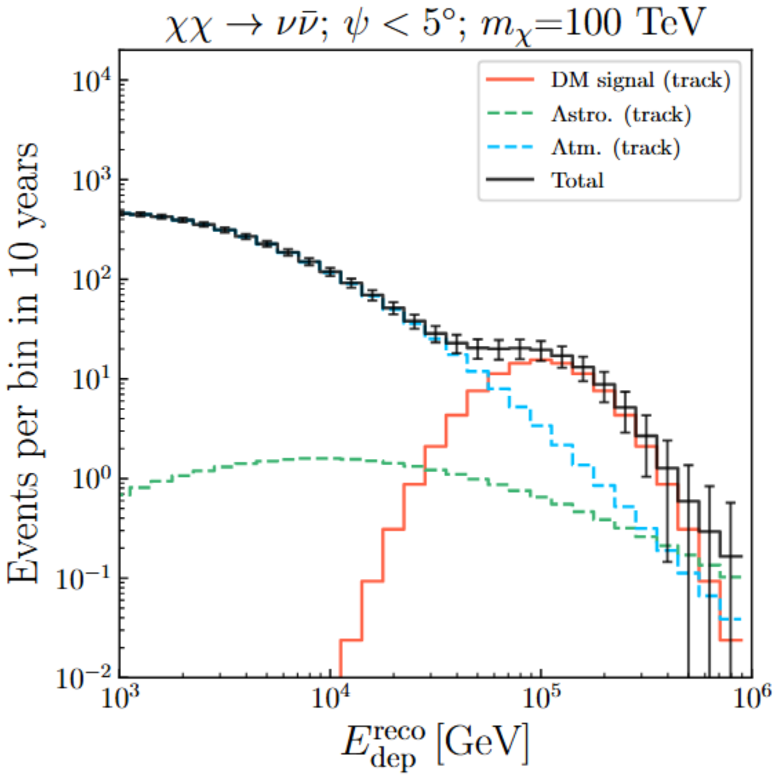


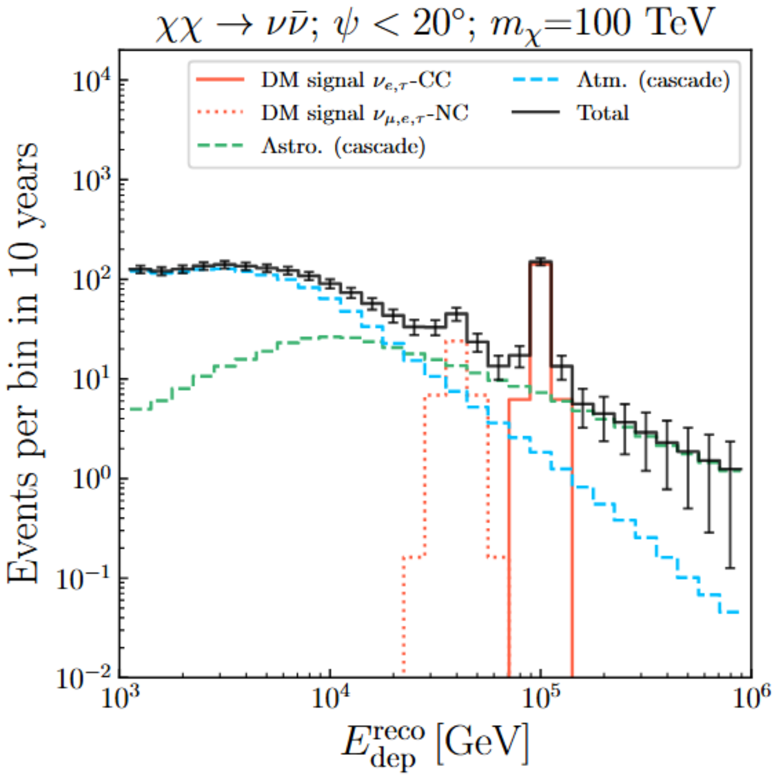
- J-factor: $J \equiv \int d\Omega \int_{\rm l.o.s.} \rho_\chi^2(x)dx$



Most optimistic signals

- Taking as a benchmark the recent KM3NeT exclusion limits, what would a TRIDENT signal be?

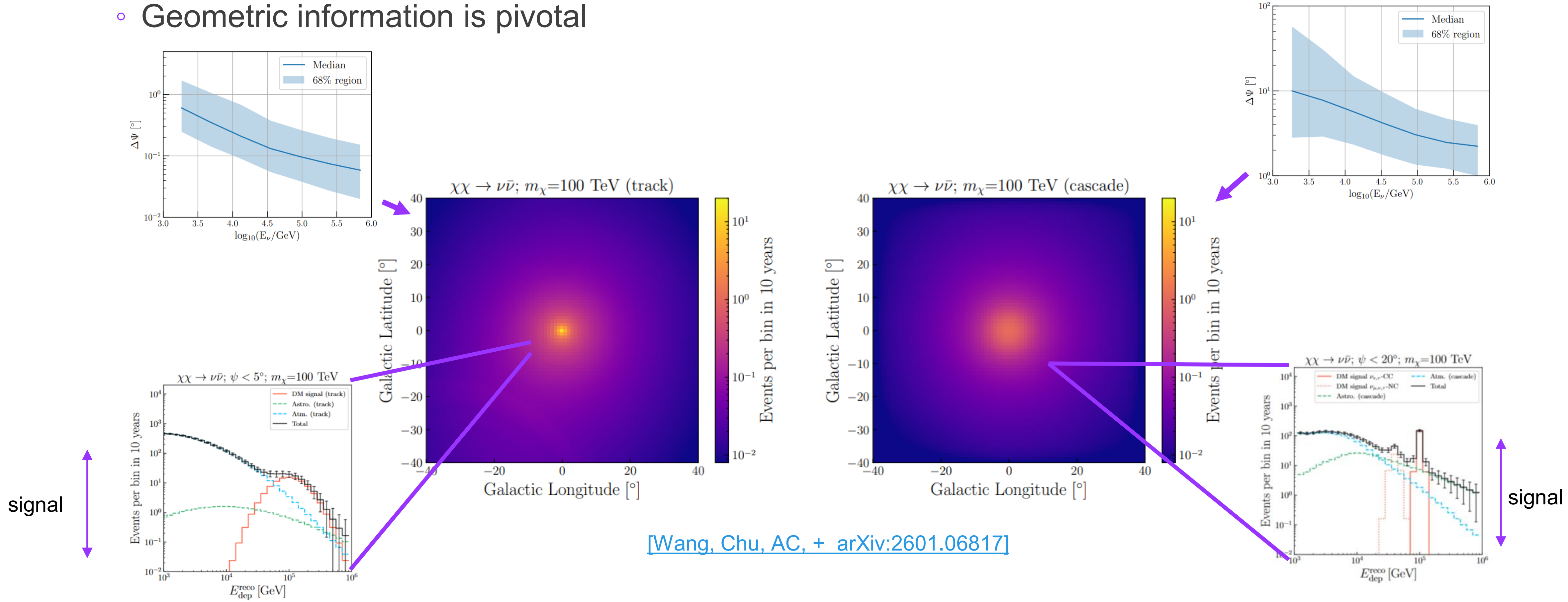




[Wang, Chu, AC, + arXiv:2601.06817]

Sky-map

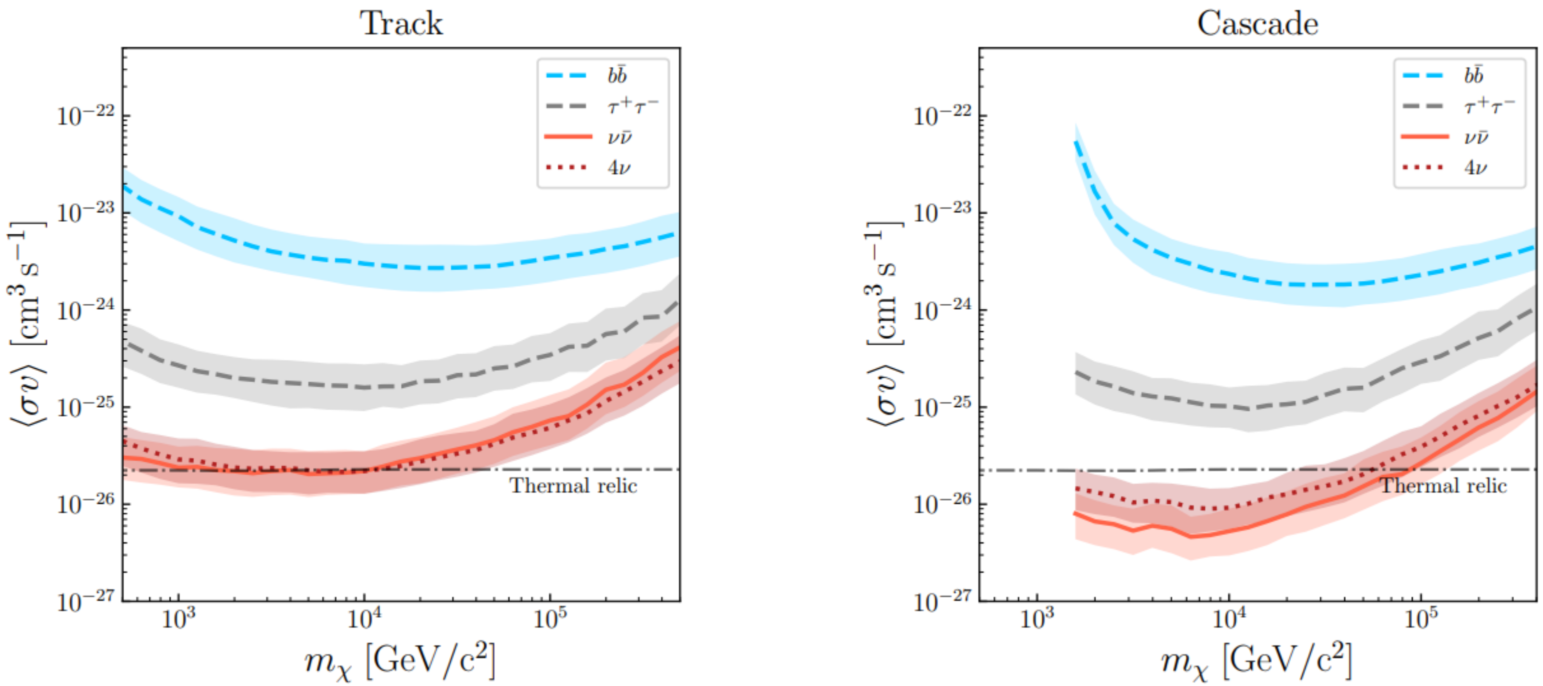
- Geometric information is pivotal



[Wang, Chu, AC, + arXiv:2601.06817]

Model independent results

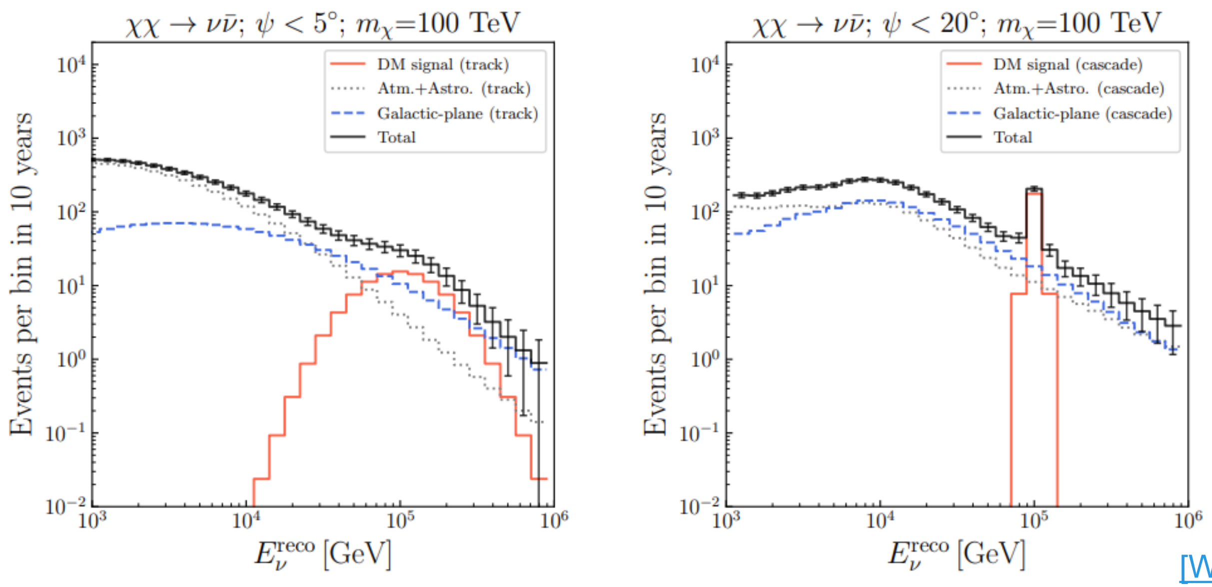
- Our projections for a standard NFW

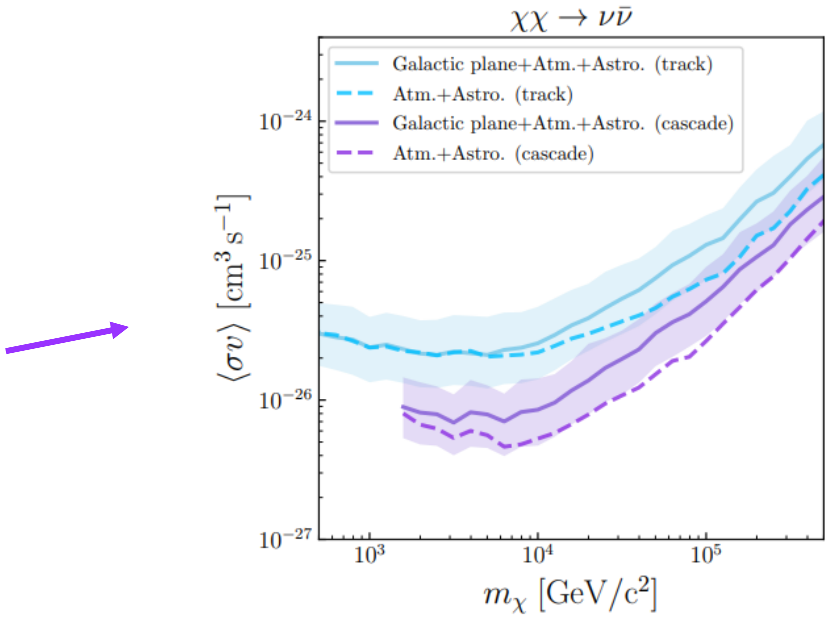


[Wang, Chu, AC, + arXiv:2601.06817]

Additional background

- Typically, people consider atmospheric and diffuse astrophysical neutrinos.
- Additional neutrino background originating from interactions between **cosmic rays** and **interstellar gas**.
- Above about 10 TeV point source injectors become important (see [Kaci and Giacinti JCAP 2025])

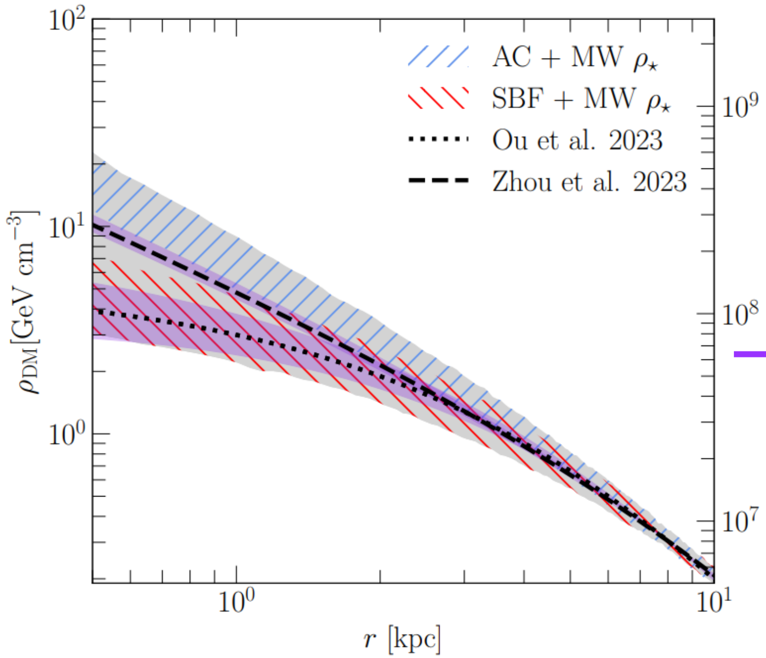




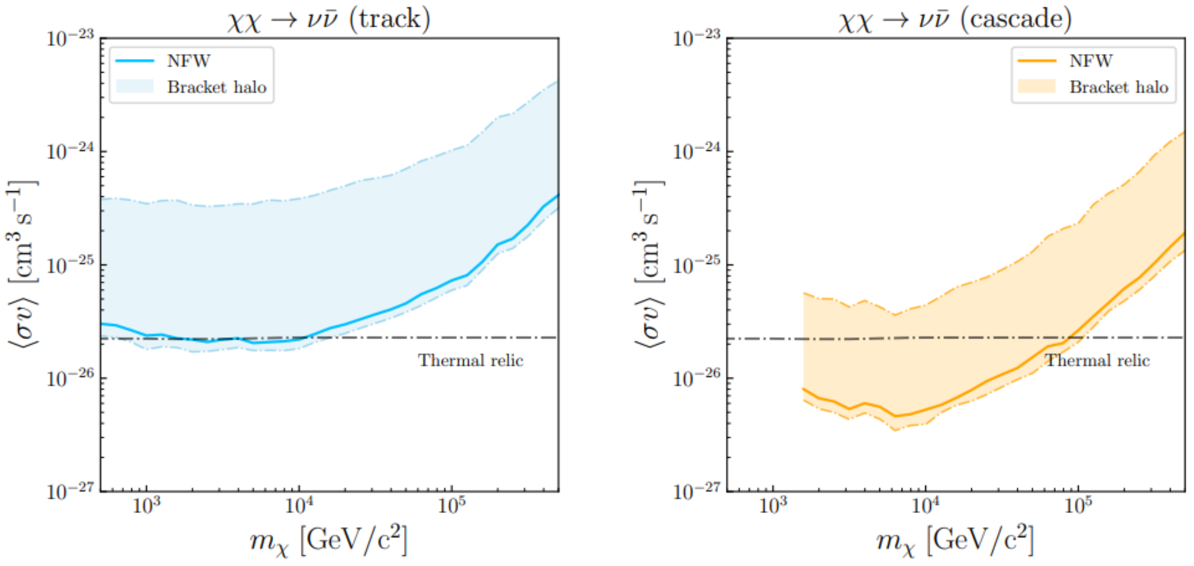
[Wang, Chu, AC, + arXiv:2601.06817]

Effects still not as strong as J-factor

- Uncertainties still dominated by uncertainties in the J-factor



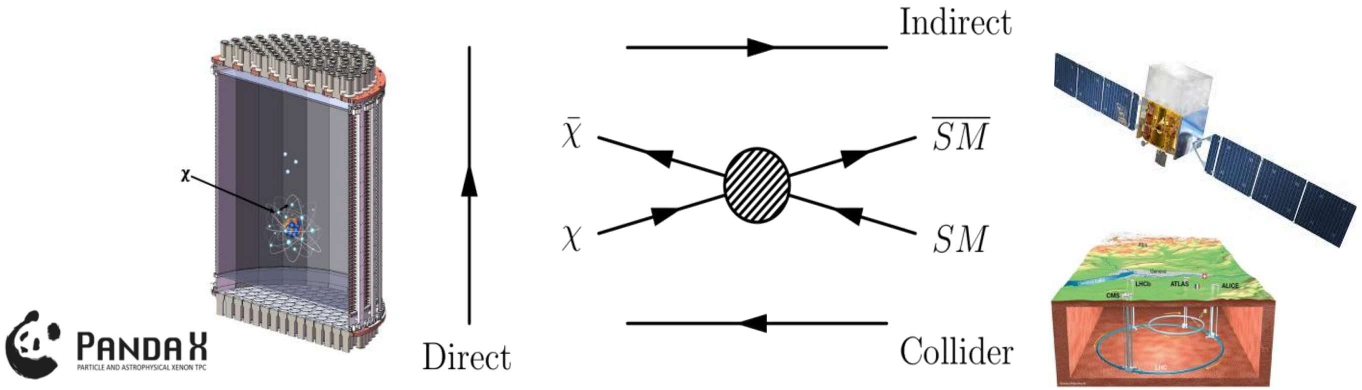
[arXiv:2501.14868]

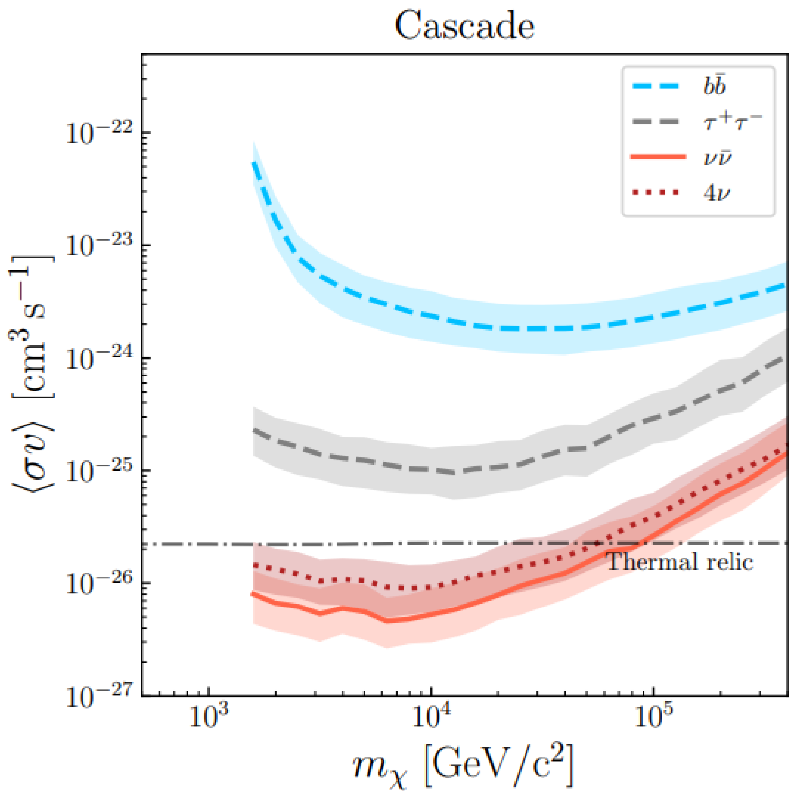


[Wang, Chu, AC, + arXiv:2601.06817]

Making our projections matter

- The projected sensitivities are promising, but are there models that make sense in 2026?
- Thermal dark matter production is mature and has numerous constraints





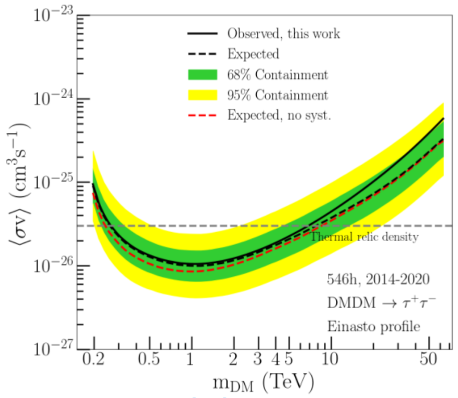
[Wang, Chu, AC, + arXiv:2601.06817]

Phenomenological considerations

- **Collider:** Collider limits are strongest with quark interactions, $m_{\chi,Z',\phi} \gtrsim 5$ TeV. If dark matter is 'leptophilic' situation better, $m_{Z'} \gtrsim 200$ GeV (LEP-II).

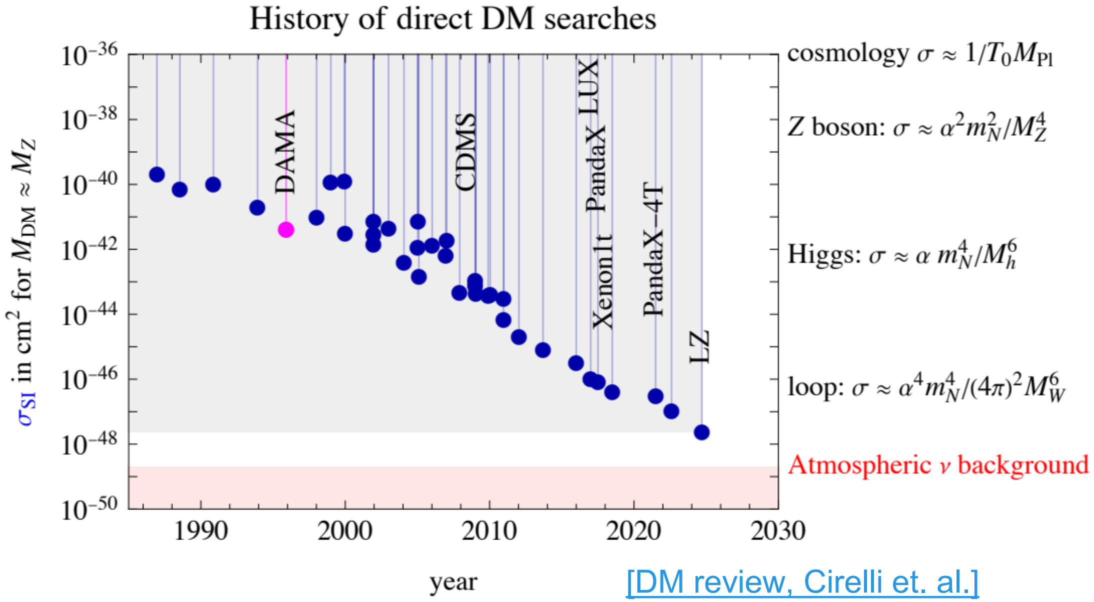
- **Direct detection:** Also have to avoid tree-level couplings to strong sector.

- **Gamma-ray Telescopes:** $L = \begin{pmatrix} \ell_L^- \\ \nu_L \end{pmatrix}$



[H.E.S.S 2022]

HAWC, H.E.S.S, CTA, LHAASO.

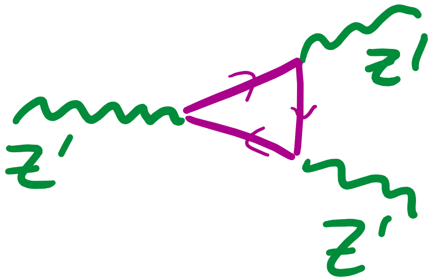


[DM review, Cirelli et. al.]

- **Theoretically motivated?**

Extending SM simply?

- Say you just want to extend the SM with **1 new gauge boson**.
- You have to avoid anomalies
- End up with one **Leptophilic option:** $U(1)_{L_i - L_j}$
- Couplings must be vector-like

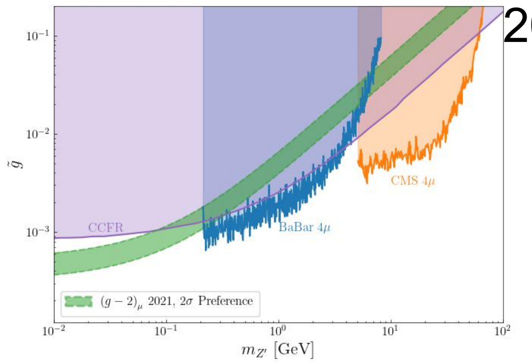


XG He et.al. [Phys.Rev.D (1991)]

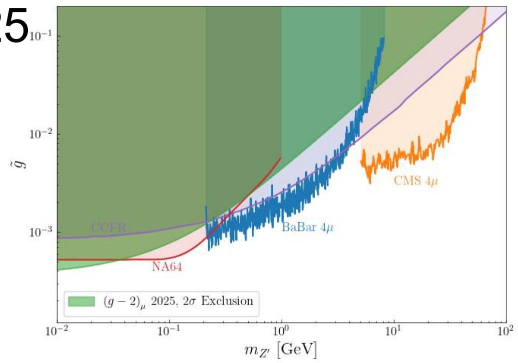
$$j_\alpha^{L_i - L_j} = \bar{L}_i \gamma_\alpha L_i + \bar{\ell}_{i,R} \gamma_\alpha \ell_{i,R} - \bar{L}_j \gamma_\alpha L_j - \bar{\ell}_{j,R} \gamma_\alpha \ell_{j,R} \qquad \text{with } L_i = \begin{pmatrix} \nu_{i,L} \\ \ell_{i,L} \end{pmatrix}$$

- $U(1)_{L_\mu - L_\tau}$ been in (maybe now out) of fashion

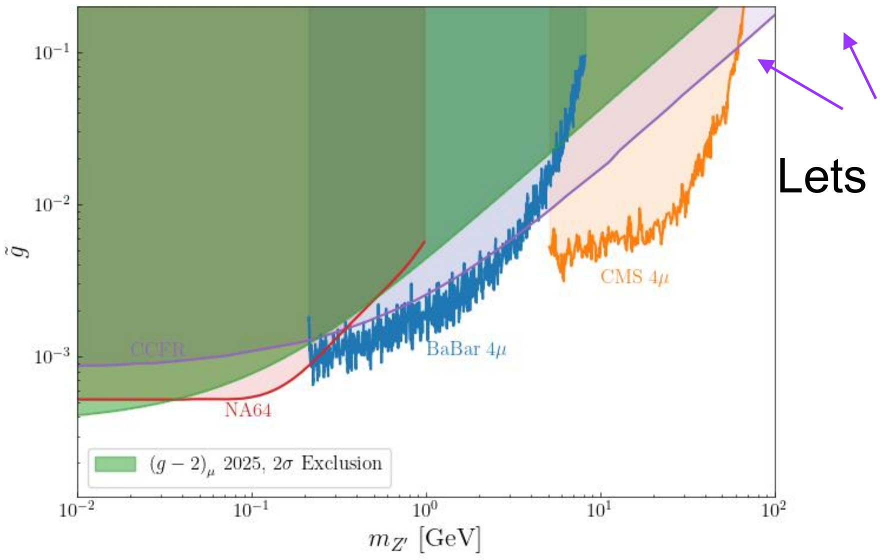
MW Li, XG He, **AC,** X Chu [Phys.Lett.B (2025)]



2021 → 2025



Dark matter and $U(1)_{L_i - L_j}$

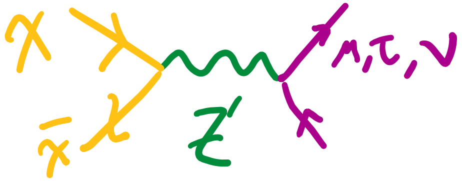


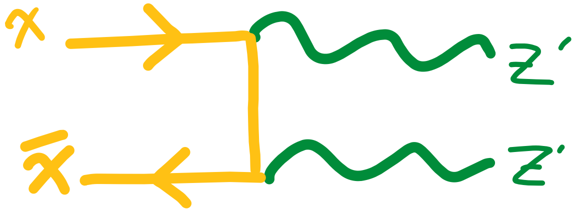
Lets look here

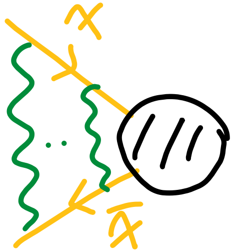
- Can introduce a new fermion to be dark matter, χ.
- Anomaly cancellation requires vector couplings

$$j_\alpha^\chi = \bar{\chi}\gamma_\alpha\chi$$

- Leading to velocity independent annihilation



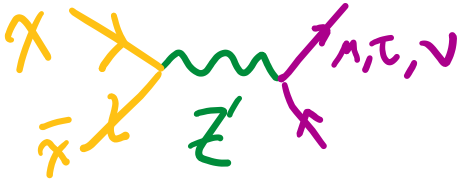




Sommerfeld enhancement

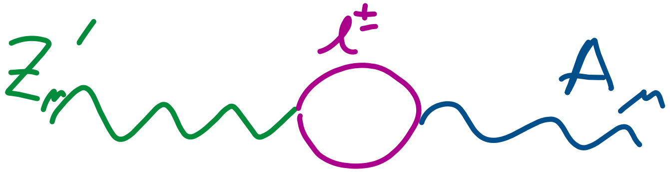
Competing constraints

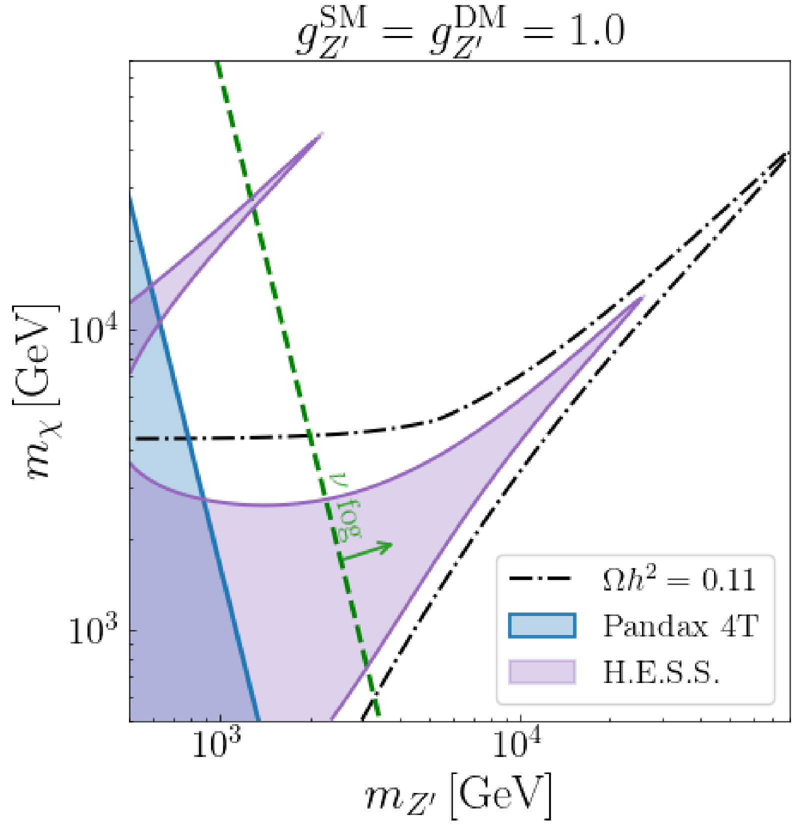
- **Gamma-ray:**



$$\langle \sigma v \rangle_{\chi\chi\to\nu\bar{\nu}} = \frac{1}{2}\langle \sigma v \rangle_{\chi\chi\to\ell^+\ell^-} = \frac{1}{3}\langle \sigma v \rangle_{\rm tot}$$

- **Direct Detection:**

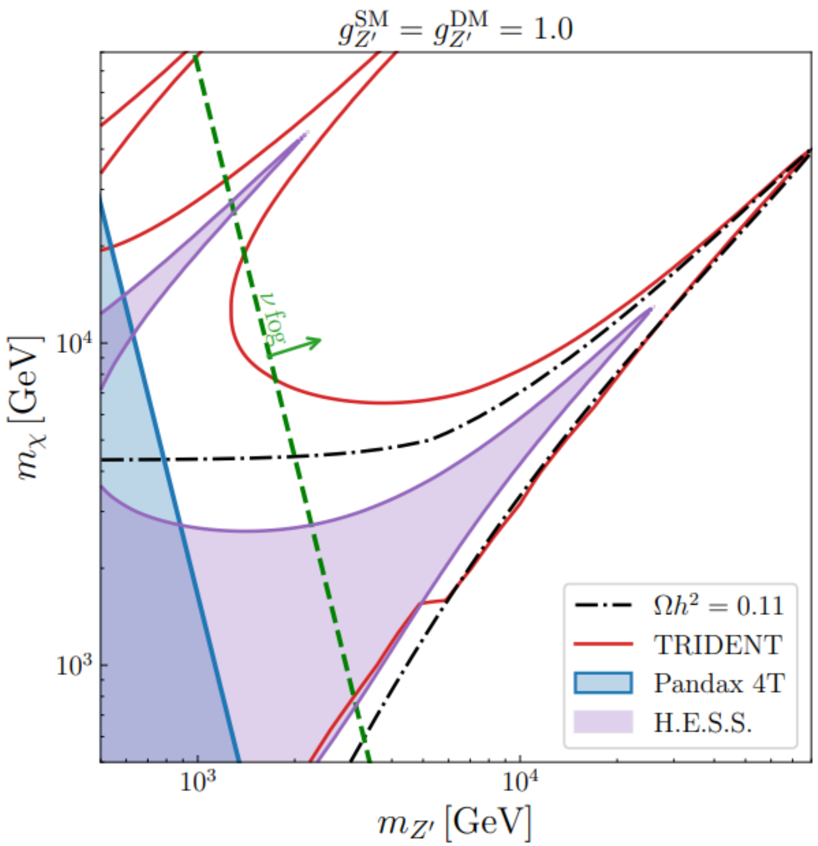




[Wang, Chu, AC, + arXiv:2601.06817]

TRIDENT prospects for $U(1)_{L_i - L_j}$

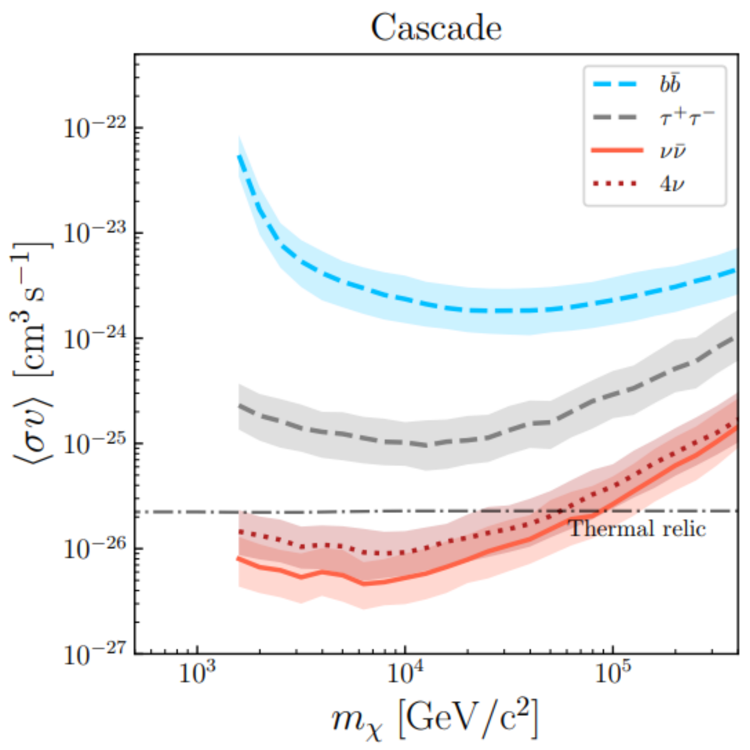
- TRIDENT's prospects are to probe thermal relic.
- Here we are taking the NFW halo as an assumption.
- Resonance regions go deep into ν-fog.
- Sommerfeld enhancement more important for galactic searches ($S \propto 1/v^2$).
- Dwarf spheroidal searches still weaker at these energies (not shown).



[Wang, Chu, AC, + arXiv:2601.06817]

Conclusion and outlook

- The TRIDENT neutrino telescope has a lot of promise.
- Fast neutrino source discovery.
- All flavor sensitivity looks promising with two event topologies, tracks and cascades.
- We performed the first dark matter study for the detector and found it can reach the thermal relic benchmark.
- Introduced a new galactic neutrino background source, first attempt to manage it.
- These sensitivities are meaningful even for a very simple, theoretically consistent dark matter model.
- **More analysis ongoing and open to new ideas: come speak to me!**



Thank you for your attention on this matter