TRIDENT 海铃计划

暗物质物理全国重点实验室 State Key Laboratory of Dark Matter Physics

Searching for Dark Matter with TRIDENT

Projected sensitivity to WIMP annihilation in the Galactic Centre

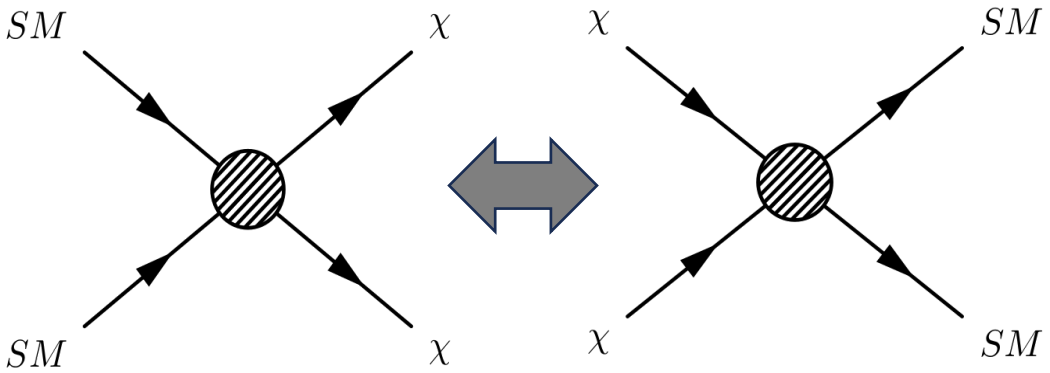
Xin Xiang Tsung-Dao Lee Institute & Shanghai Jiao Tong University

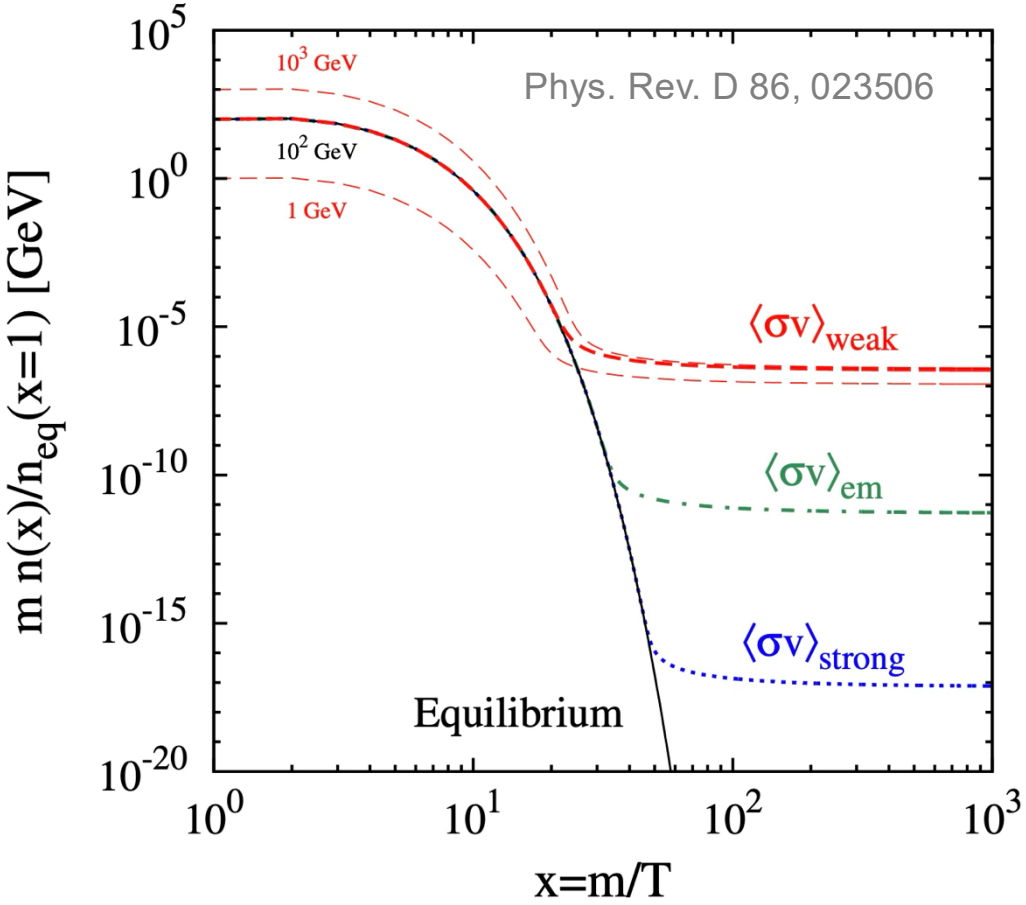
Based on **arXiv:2601.06817** · with A. Cheek, Y. Wang, and the TRIDENT Collaboration

中国物理学会高能物理分会第十二届全国会员代表大会暨学术年会 · Guangzhou, July 2026

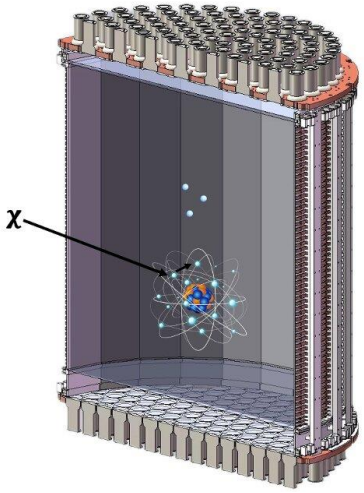
WIMPs

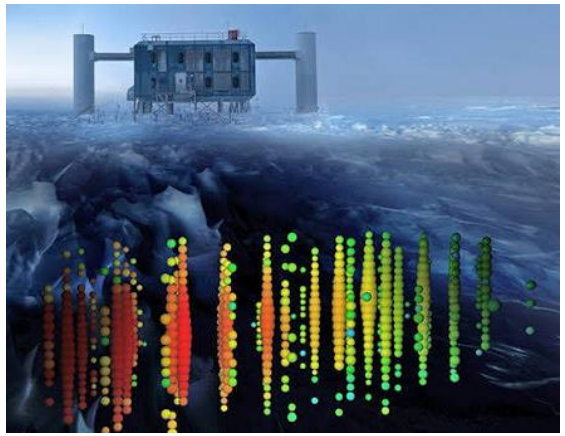
- "A WIMP Miracle": A weak-scale thermal relic naturally gives the observed abundance
- $\langle \sigma v \rangle_{\text{thermal}} \sim 3 \times 10^{-26}\ \text{cm}^3\ \text{s}^{-1}$

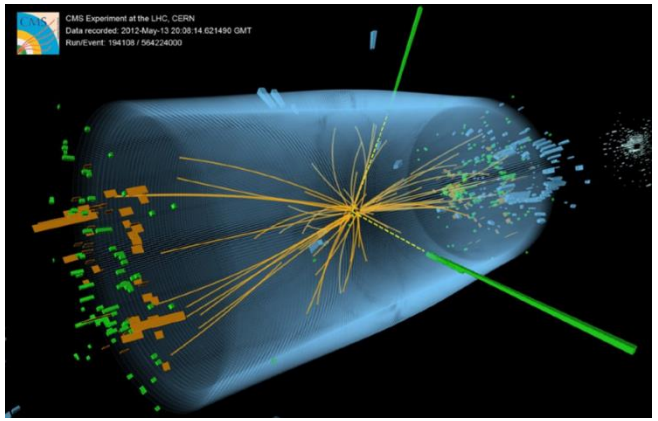


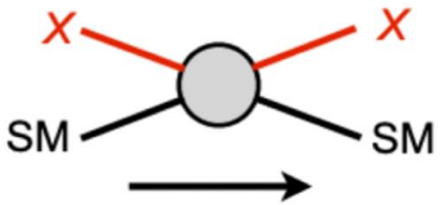


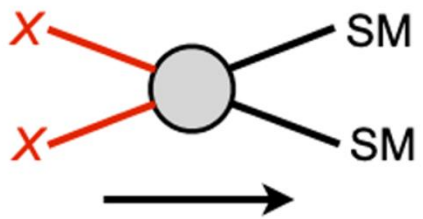
World-wide hunt for WIMPs since 1987

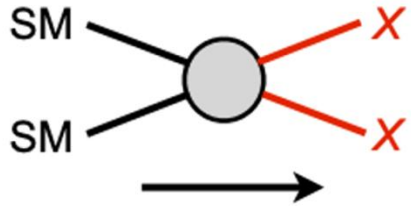










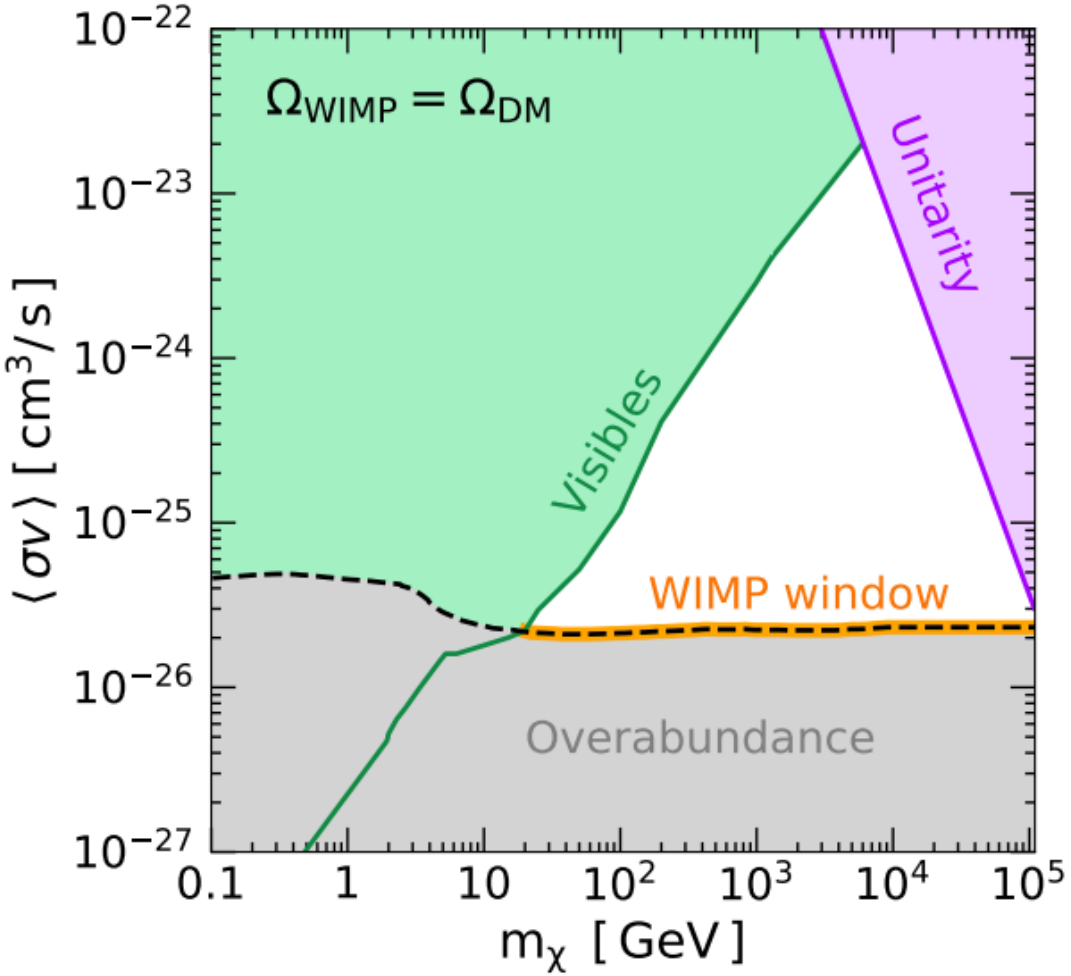


- Indirect detection probes the very process behind thermal freeze-out: $\chi\chi$ annihilation

The WIMP miracle — still open

- Low-mass WIMPs (<1 TeV) are now tightly constrained
- The **multi-TeV thermal window** remains largely untested — where we look.
- We should experimentally close this window!

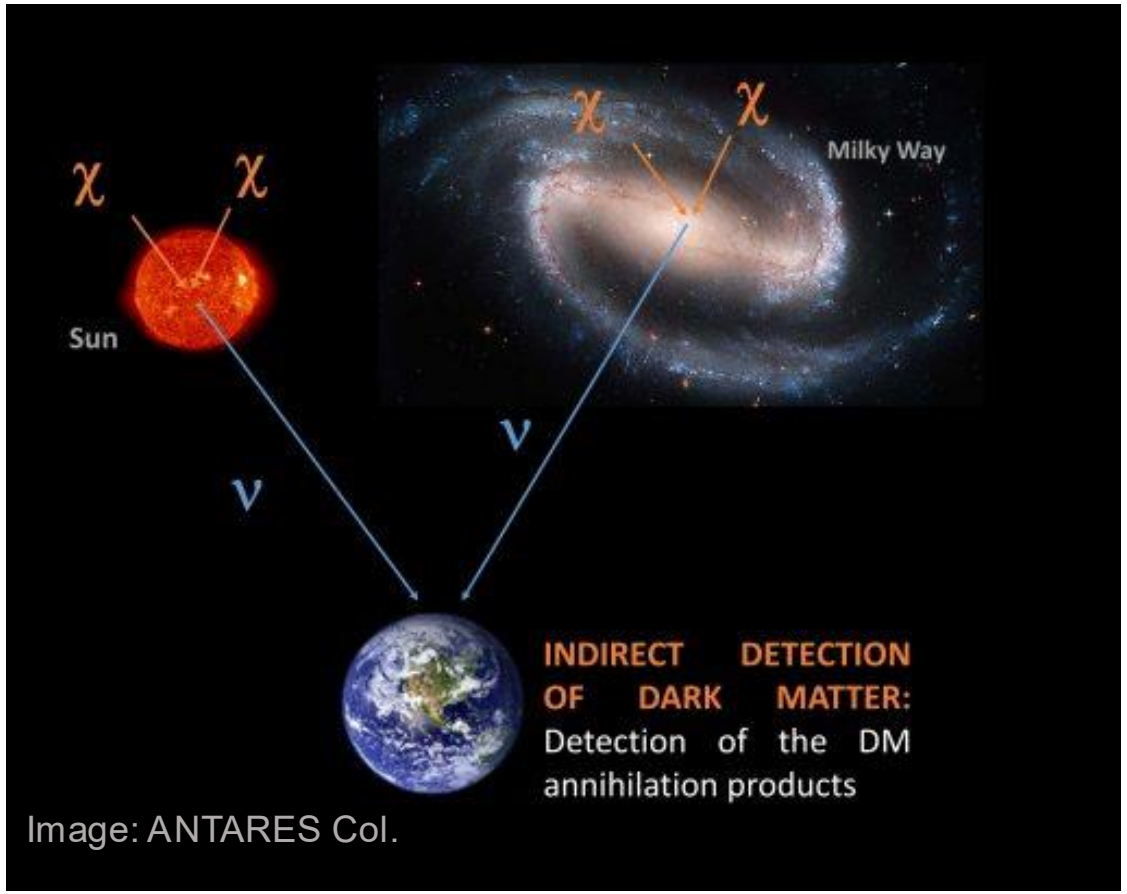
Indirect Detection Landscape



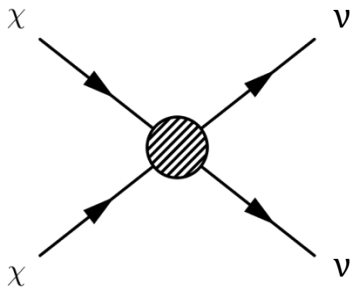
Leane et al., PRD 98 (2018)

Indirect Search with Neutrino Telescope

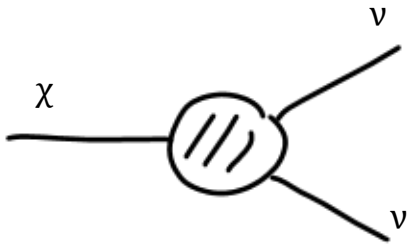
How does a neutrino telescope search for DM?



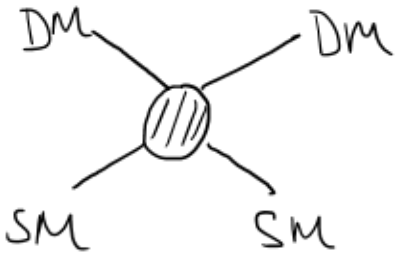
1) Annihilation



2) Decay



3) Solar capture



$$\Gamma_{\mathrm{cap}} = 2\Gamma_{ann}$$

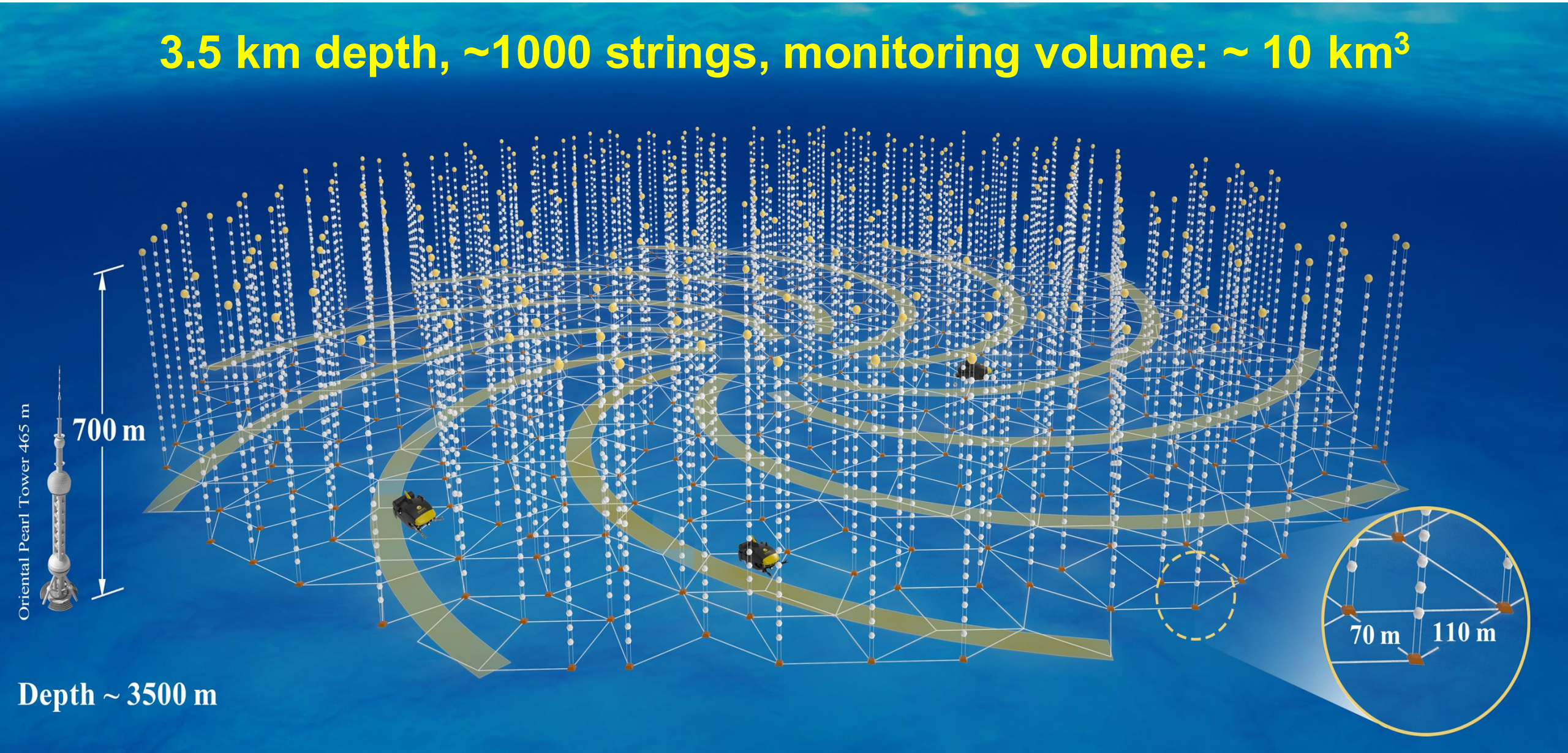
Outline

1. Instrument: TRIDENT

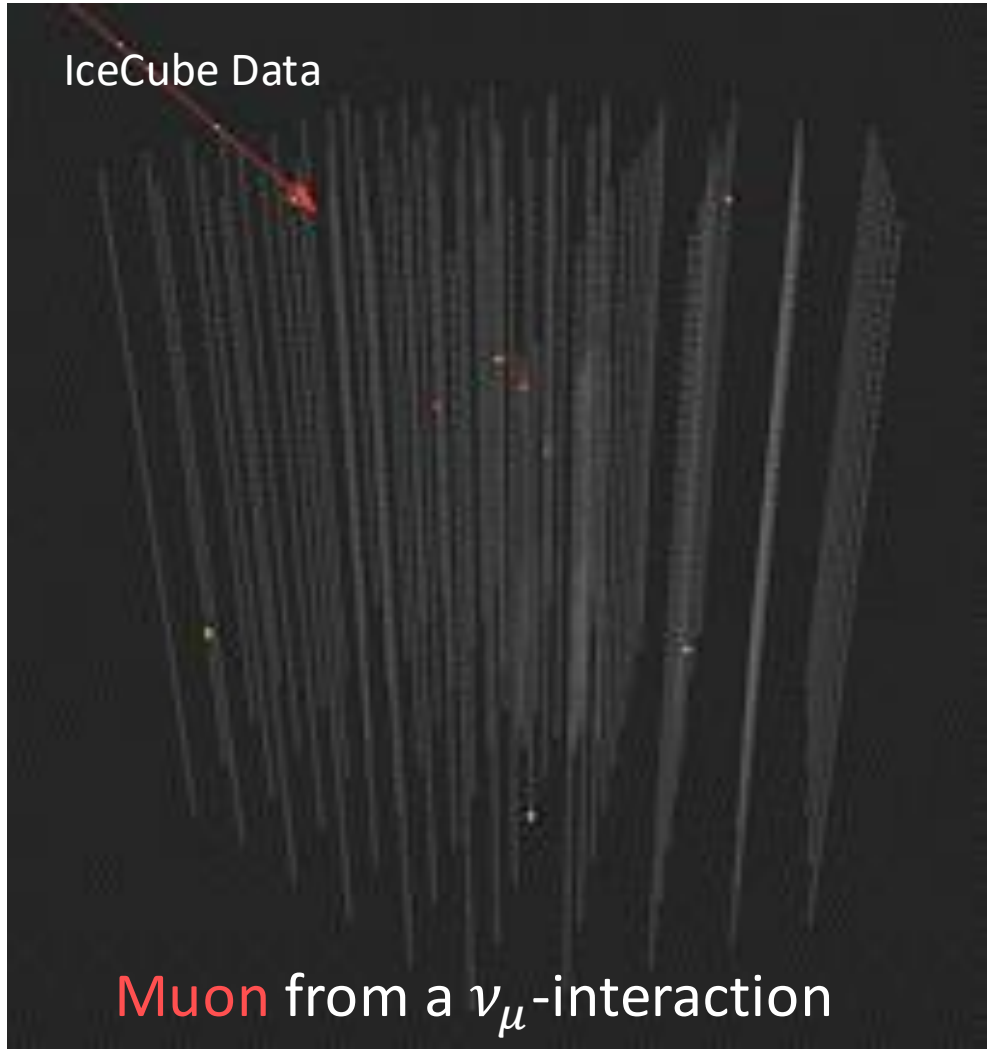
2. Simulation Pipeline

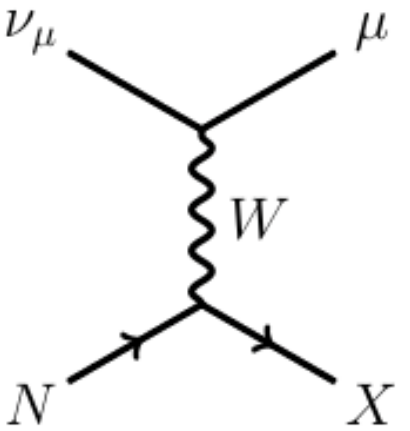
3. Results and Implication

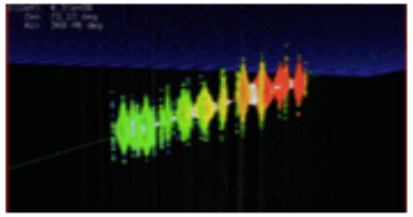
TRopical DEep-sea Neutrino Telescope (TRIDENT)



Large Water-Cherenkov Detector

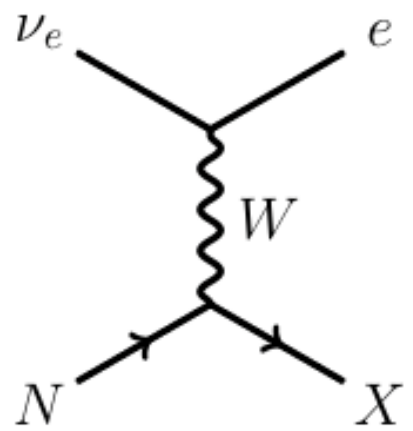


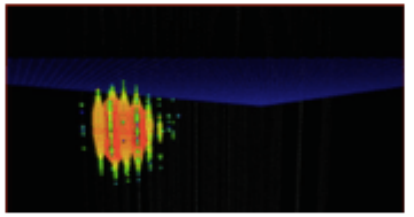




Track
~ 0.1°

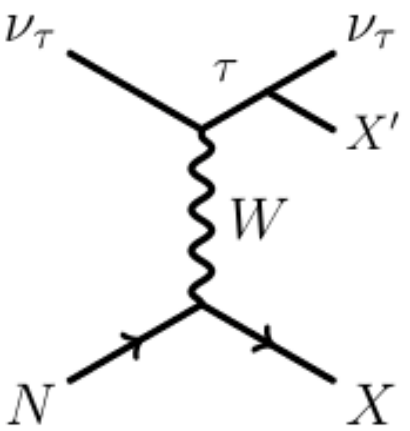
υ_μ

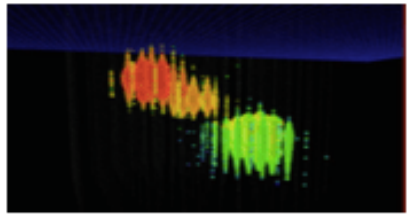




Cascade
~ 2°

υ_e



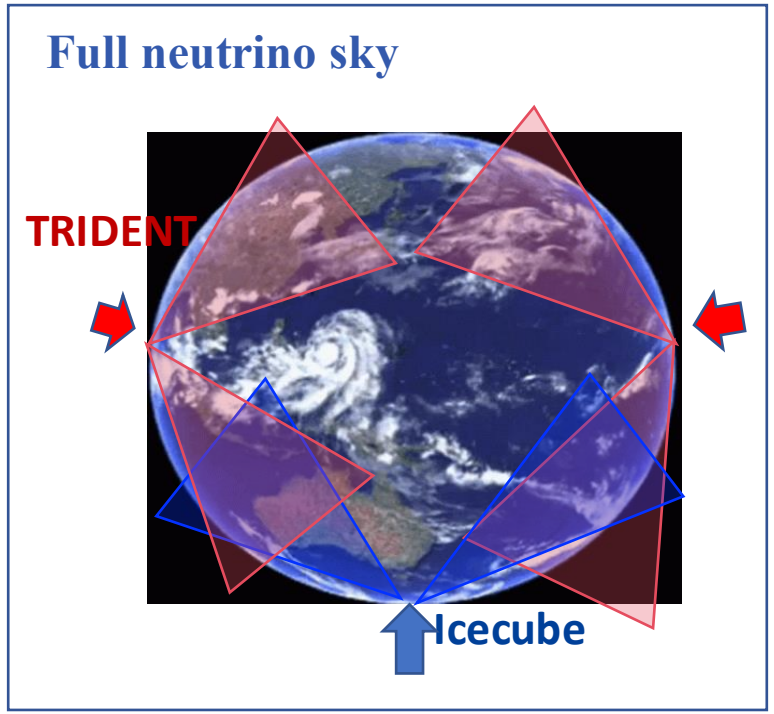


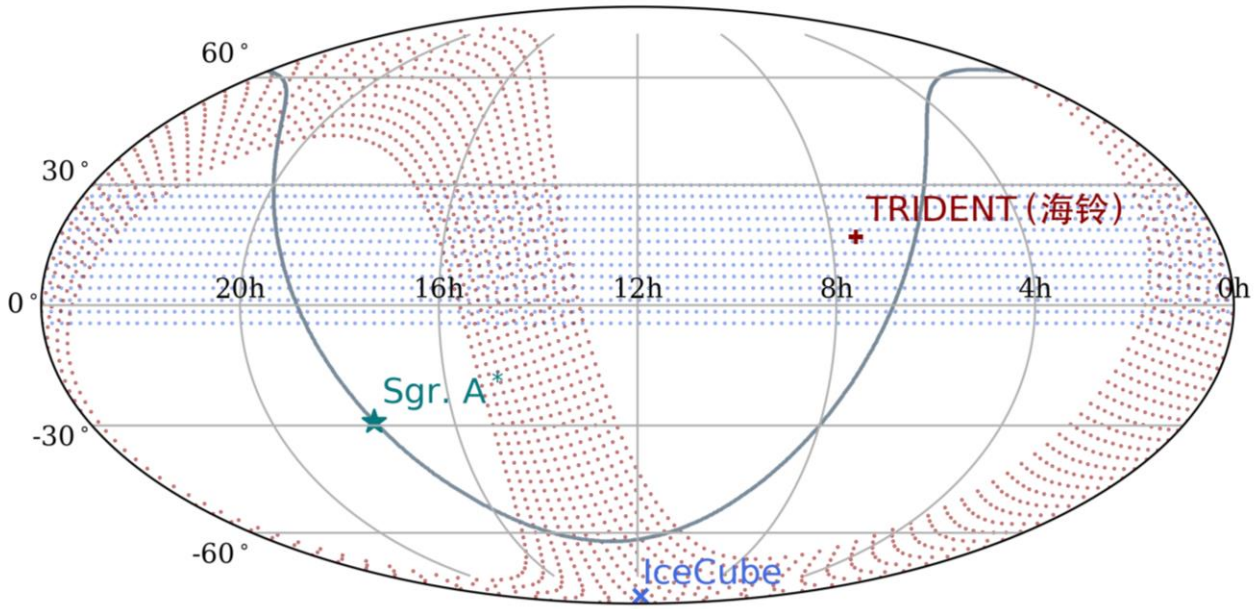
Double Cascade

υ_τ

Advantage I: Near equator location

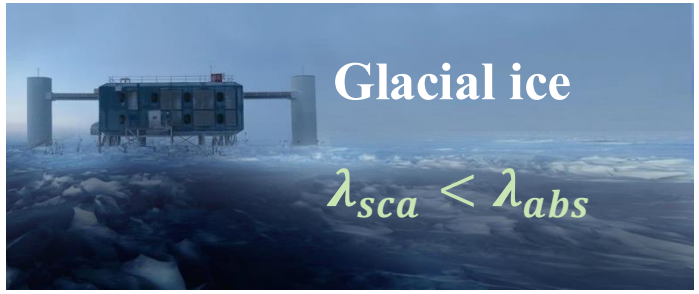
- Full sky coverage & good visibility at the galactic center (GC)
- **Less atm background looking toward GC**

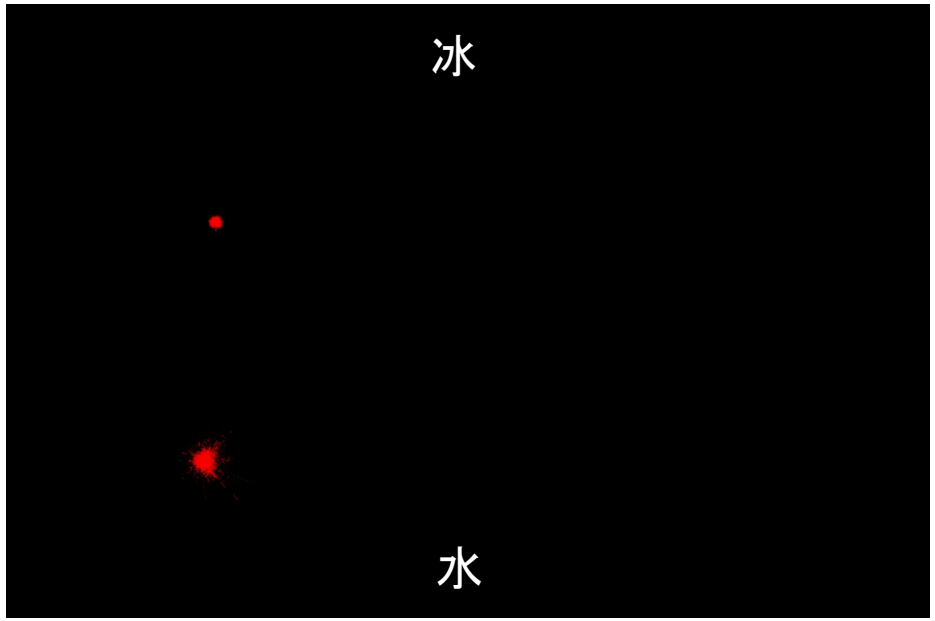




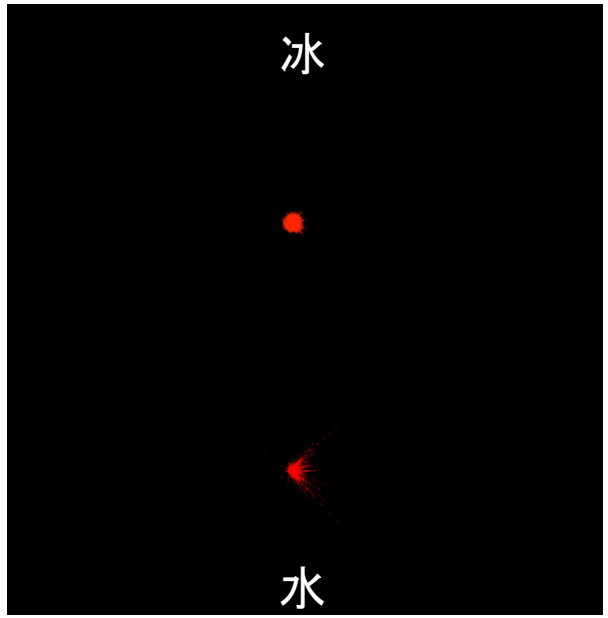
Advantage II: Excellent Pointing Resolution

- Deepsea water scattering length is much smaller than glacial ice
- **Directionality is better preserved.**





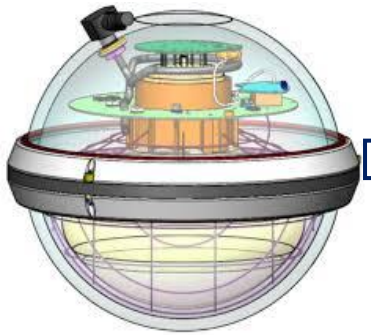
Simulated ν_μ event



Simulated ν_e event

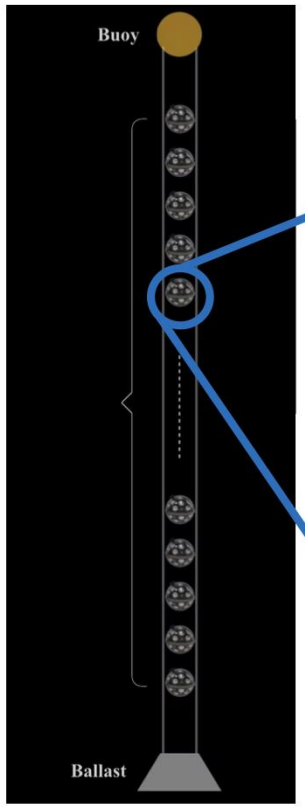
The hybrid Digital Optical Module (hDOM)

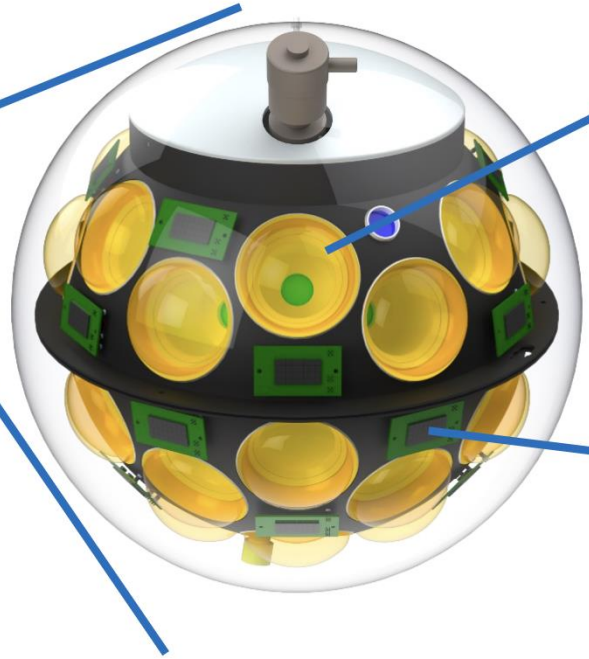
IceCube DOM

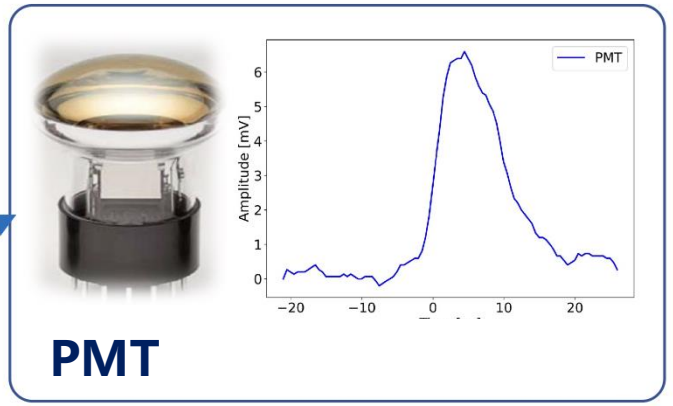


IceCube Upgrade D-Egg

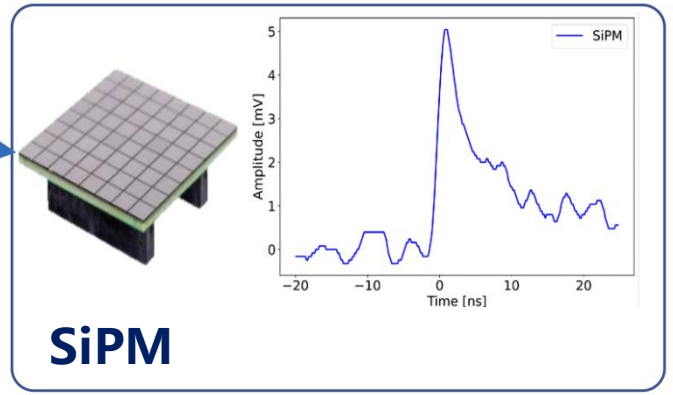
IceCube Gen-2 mDOM







PMT



SiPM

High coverage PMT with waveform readout + SiPM Time stamp

→ Angular resolution < 0.1° @ 100TeV

Outline

1. Instrument: TRIDENT
2. **Simulation Pipeline**
3. Results and Implication

Overview

1 Initial flux

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

with PPPC4DM, HDMSpectra, (PYTHIA8.2)

- 4 SM channels : $\nu\bar{\nu}, b\bar{b}$, $\tau^+\tau^-, 4\nu$ $(100\%\ \mathrm{BR})$
- Electroweak radiation included (>500GeV)

2 Detector Response

Optimizing underwater neutrino telescopes for all-flavor point source sensitivity

PDF

Share

Iwan Morton-Blake[1], Fuyudi Zhang[1], Qichao Chang[1], Shuhua Hao[1], Weilun Huang[1], Hualin Mei[1,2,3], Wei Tian[1], Yingwei Wang[1], Xin Xiang[1,2,3] *et al.*

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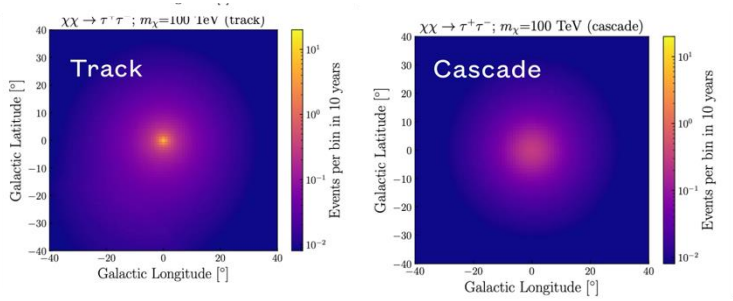
- Full-chain TRIDENTSim (trigger-level) → A_{eff} , angular & energy resolution
- Real seawater optics @ at Hai-Ling Basin

3 Likelihood



- **The maximum-likelihood method**

$$\mathcal{L}(\langle\sigma v\rangle) = \prod_{ij} \frac{(s_{ij}+b_{ij})^{n_{ij}}}{n_{ij}!} e^{-(s_{ij}+b_{ij})}$$

- **The test statistics (TS)**

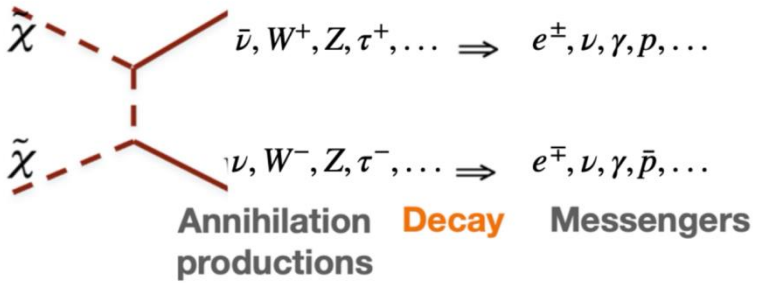
$$\mathrm{TS} = -2\ln\left(\frac{\mathcal{L}(\hat{s})}{\mathcal{L}(s=0)}\right)$$

- Binned MLE (sky × energy)
- TS → 90% C.L. upper limit on ⟨σv⟩ (Asimov)

The Signal

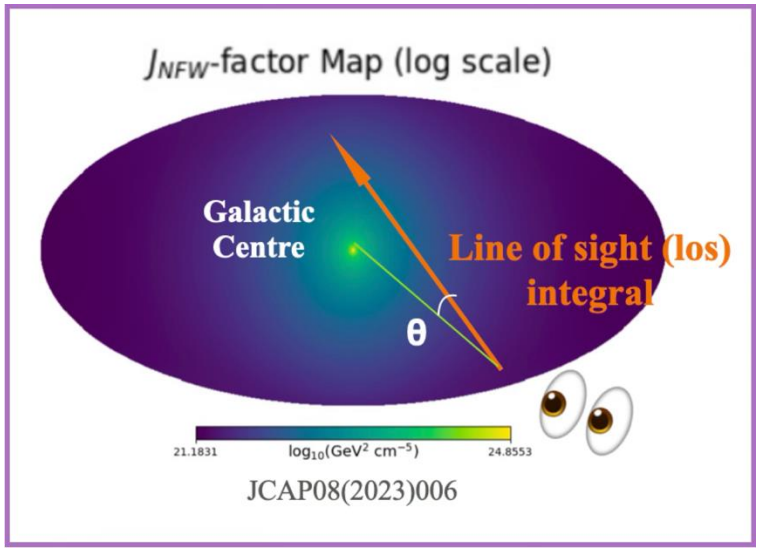
❖ Excess neutrino flux are expected from **Galactic Centre**, where DM is thought to accumulate

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



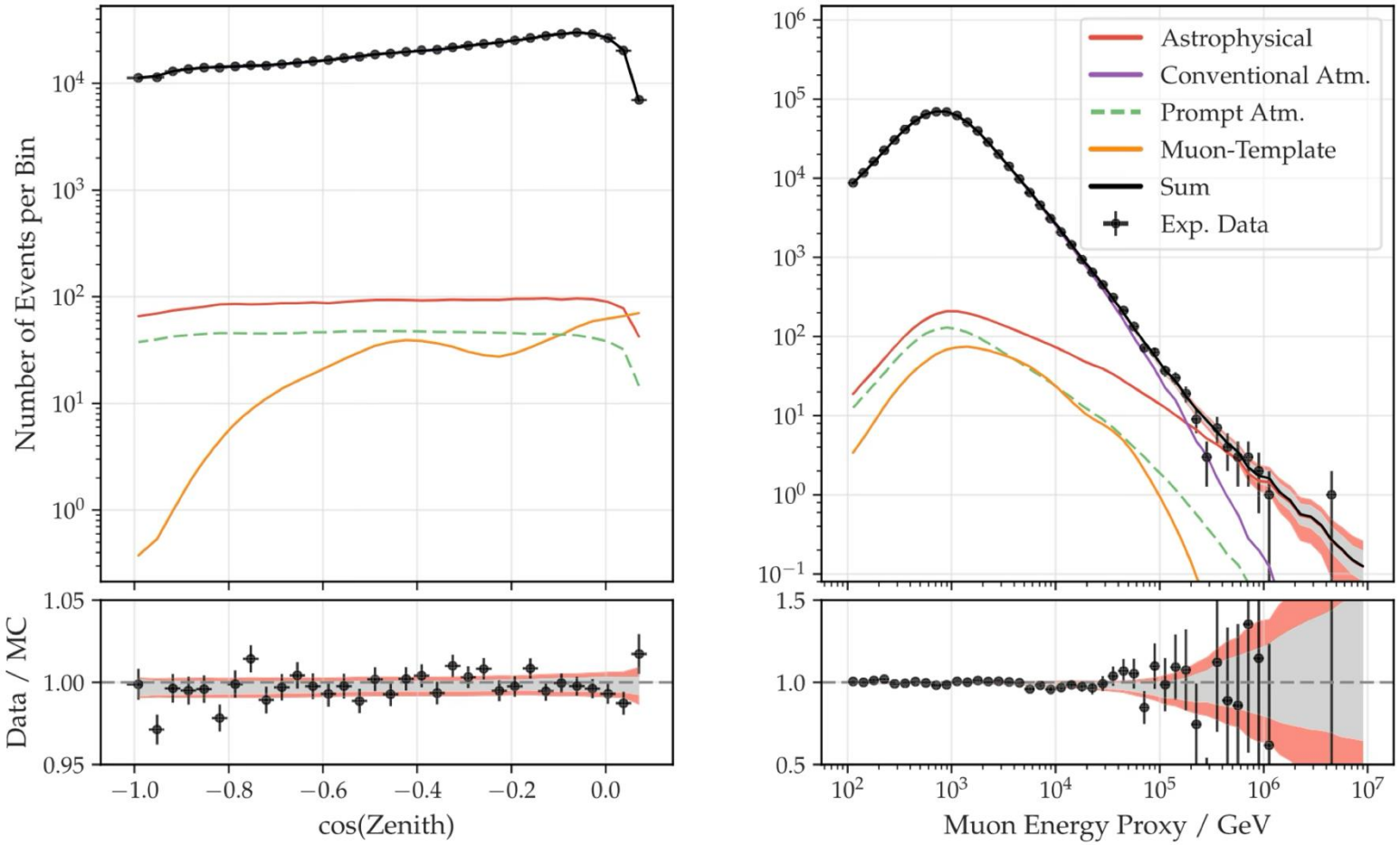
- Annihilation probability, $\kappa = 2$ if $\chi = \bar{\chi}$
- Neutrino energy spectrum per annihilation
- DM distribution

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



Main Backgrounds

- **Atmospheric muons**
  - Remove via upward-going cut
- **Atmospheric neutrinos**
  - DaemonFlux (conv.+prompt)
- **Diffuse astrophysical neutrinos**
  - an isotropic flux following IceCube's best-fit power law
- **Galactic plane neutrinos (new)**
  - stochastic point source fitted with IceCube observation

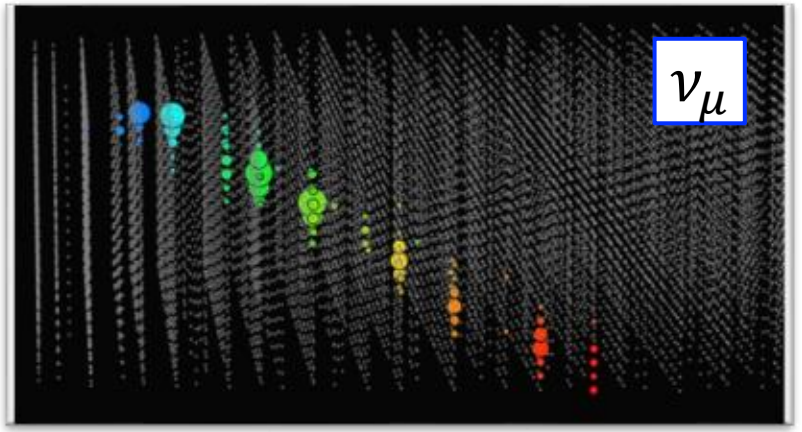


IceCube *Astrophys. J.*, 928(1):50, 2022

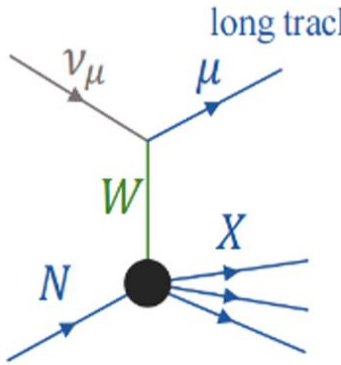
Track and Cascade

➢ **Novelty 1**: this work includes both **track** and **cascade** topologies

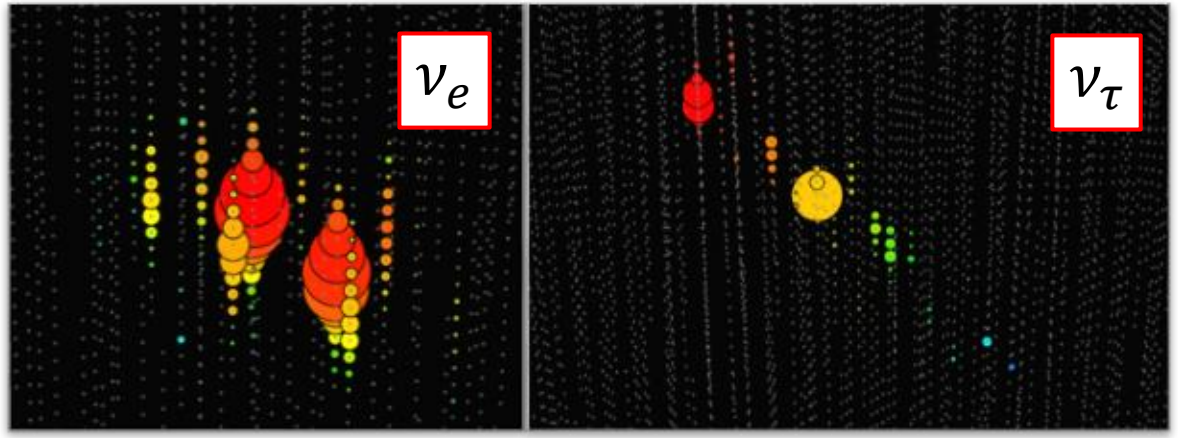
Track



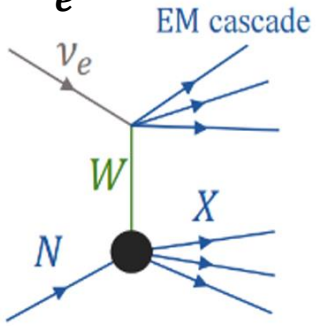
ν_μ CC



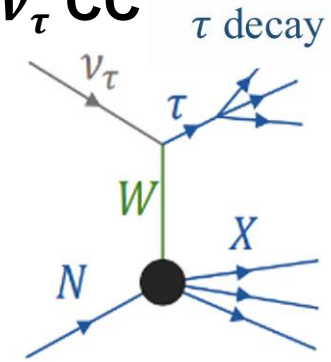
Cascade



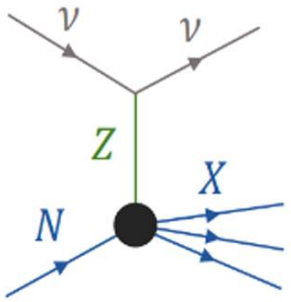
ν_e CC



ν_τ CC



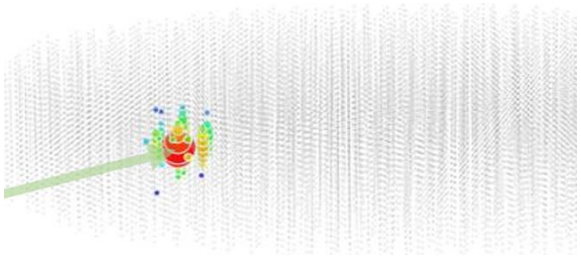
NC



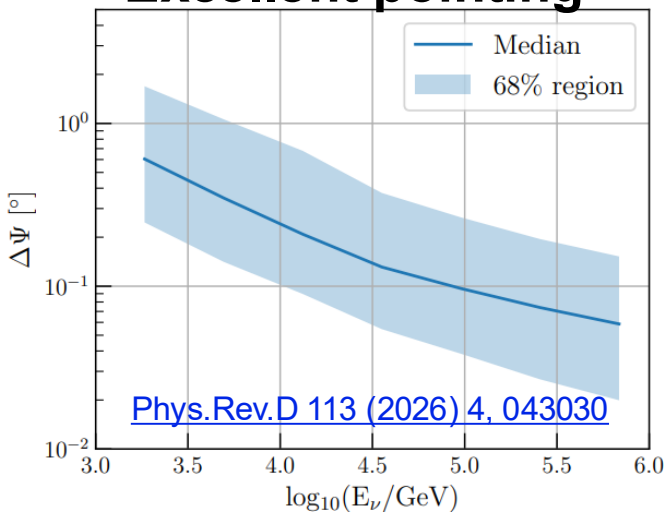
Detector Response: Angular Resolution

Track

Cascade



Excellent pointing



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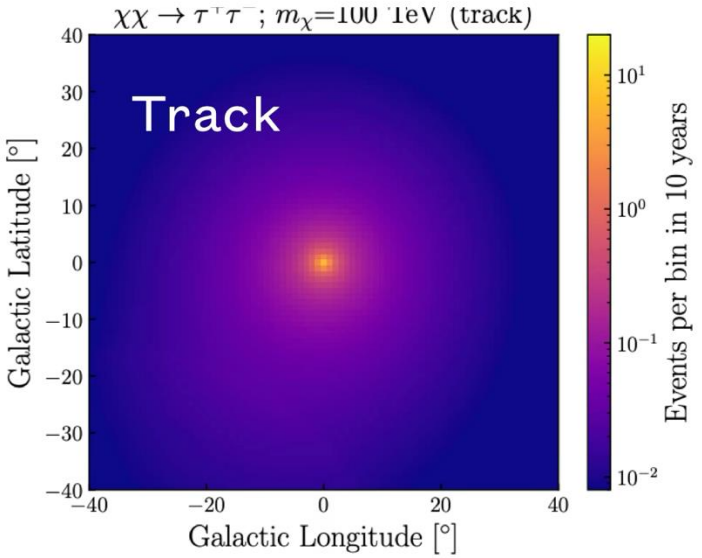
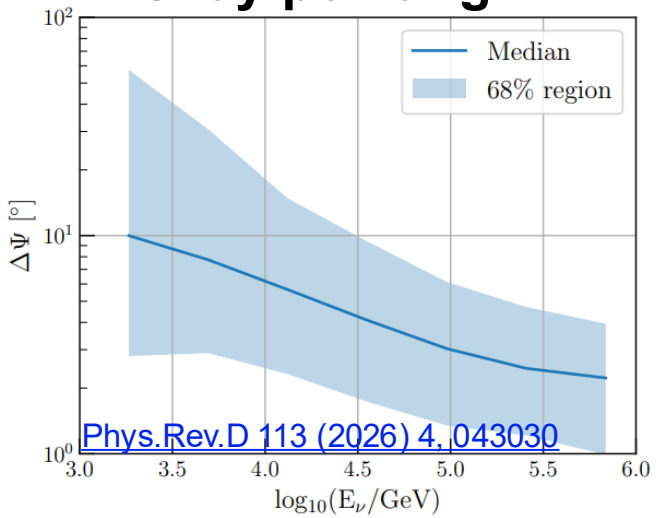


Okay pointing



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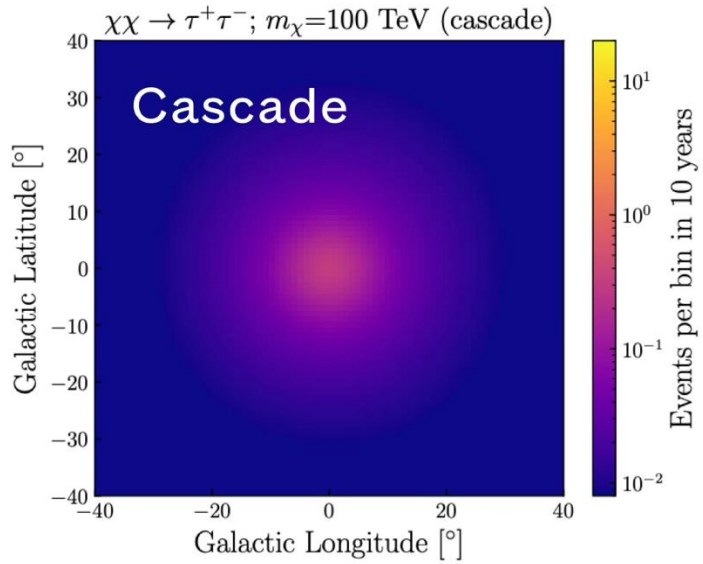
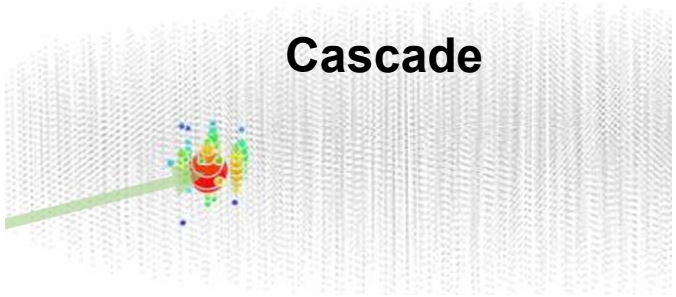
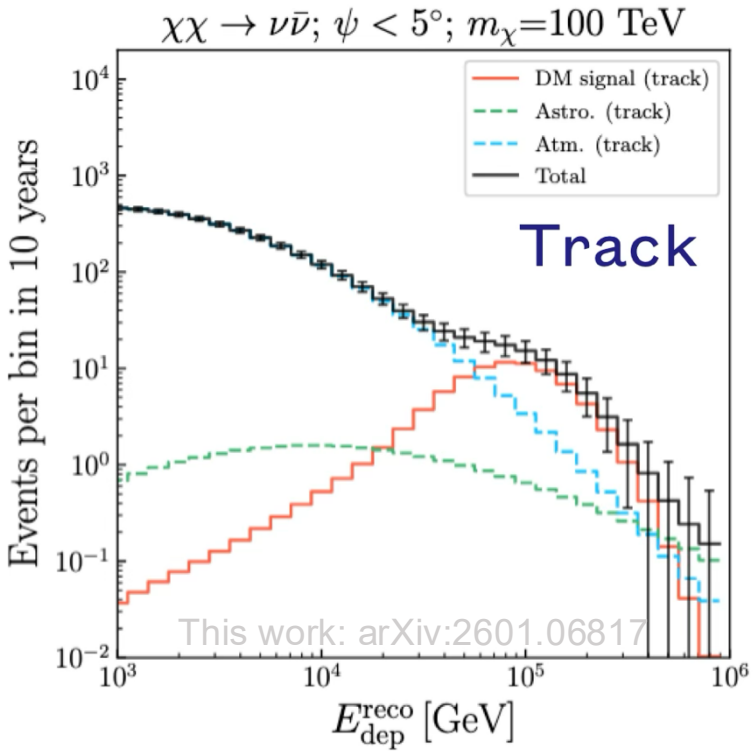
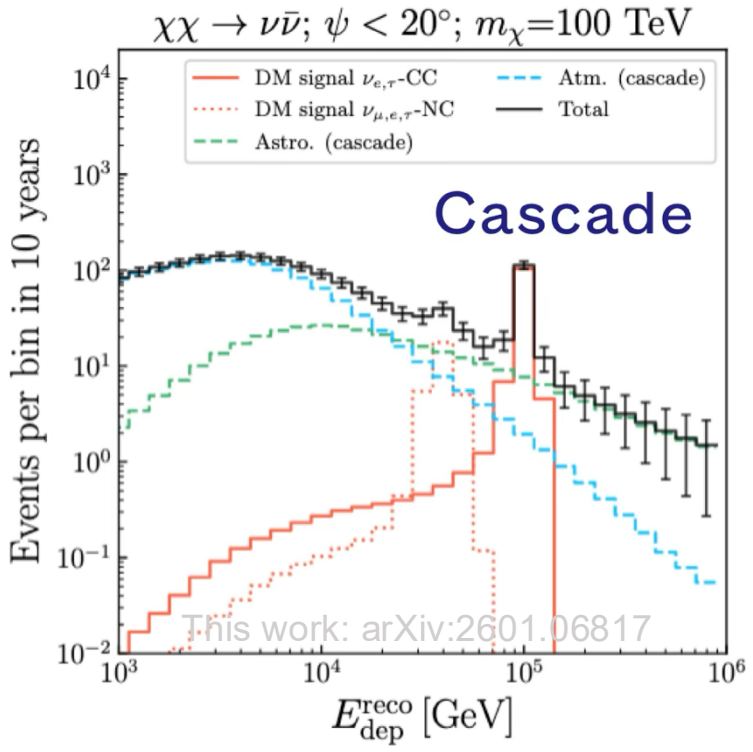


This work: arXiv:2601.06817

Detector Response: Energy Resolution







- Resolution: $\sigma_E \approx 10\ \%$ (cascade) vs 80 % (track)

- Cascade is critical:
  1) $\chi\chi \to \nu\bar{\nu}$ produce a line spectrum at m_χ; **a line over smooth power-law bkg is a "smoking gun" signature**.
  2) cascade can resolve it

Outline

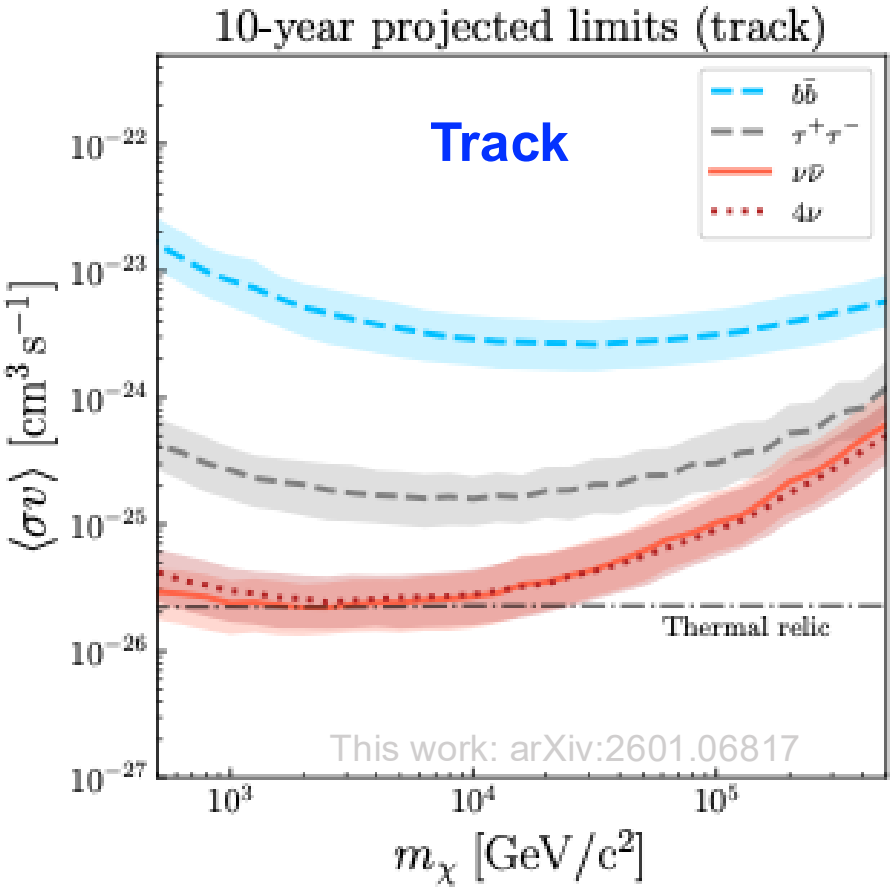
1. Instrument: TRIDENT

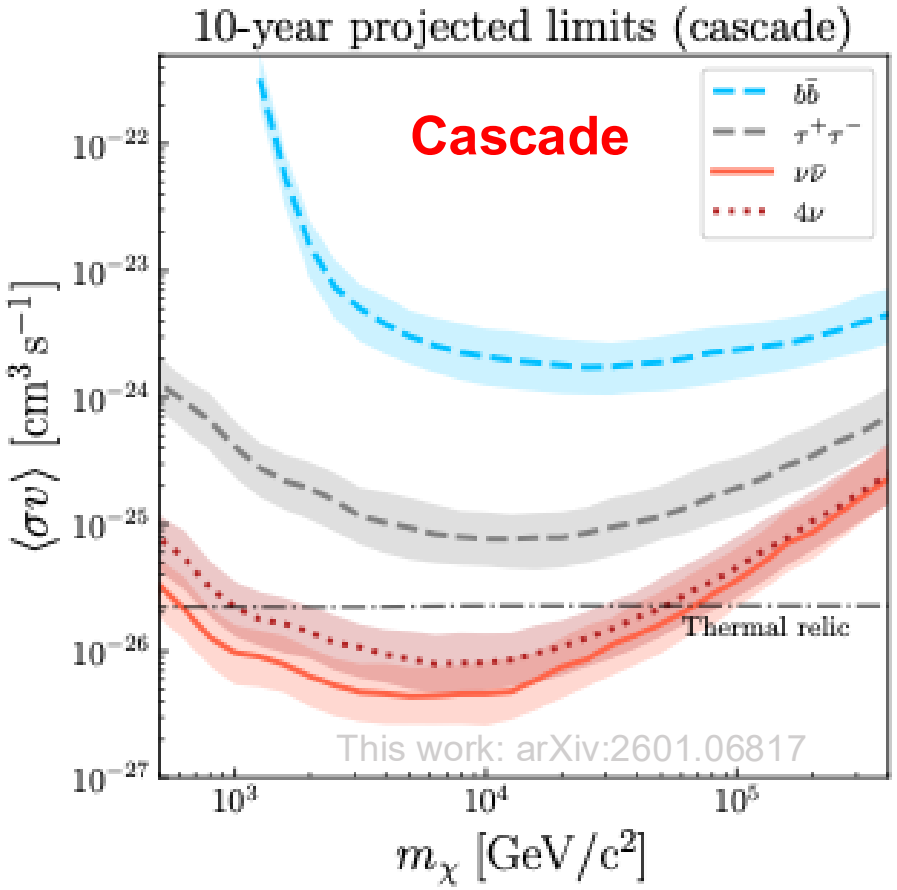
2. Simulation Pipeline

3. Results and Implication

Limits reach the thermal relic

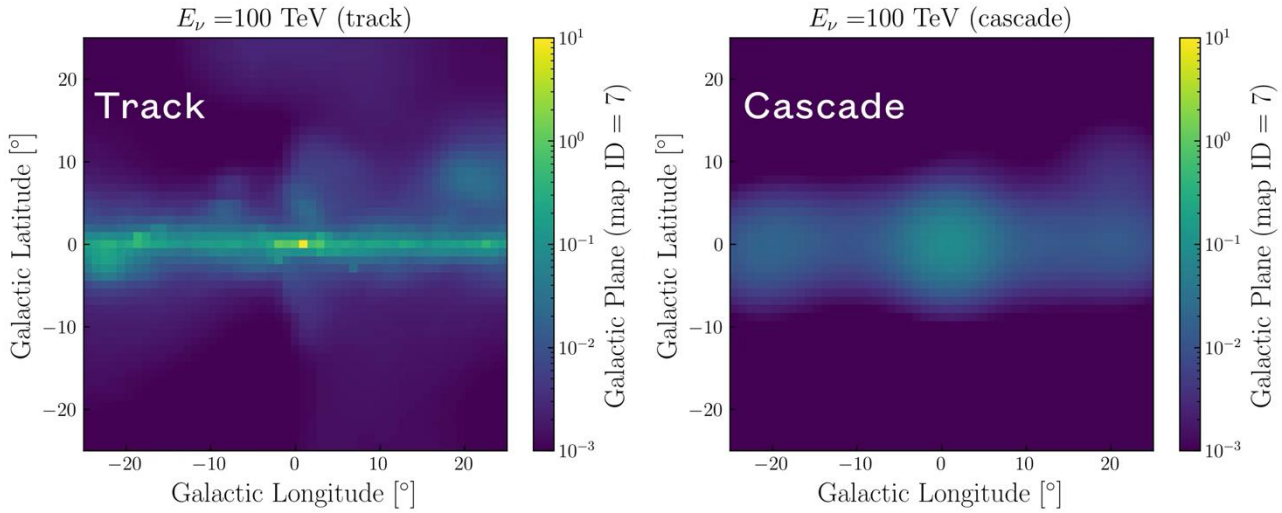
- TRIDENT's 10-year sensitivity to Galactic DM, reaches as low as $5 \times 10^{-27}\ \mathrm{cm^3\ s^{-1}}$ for 10 TeV DM for both track and cascade.



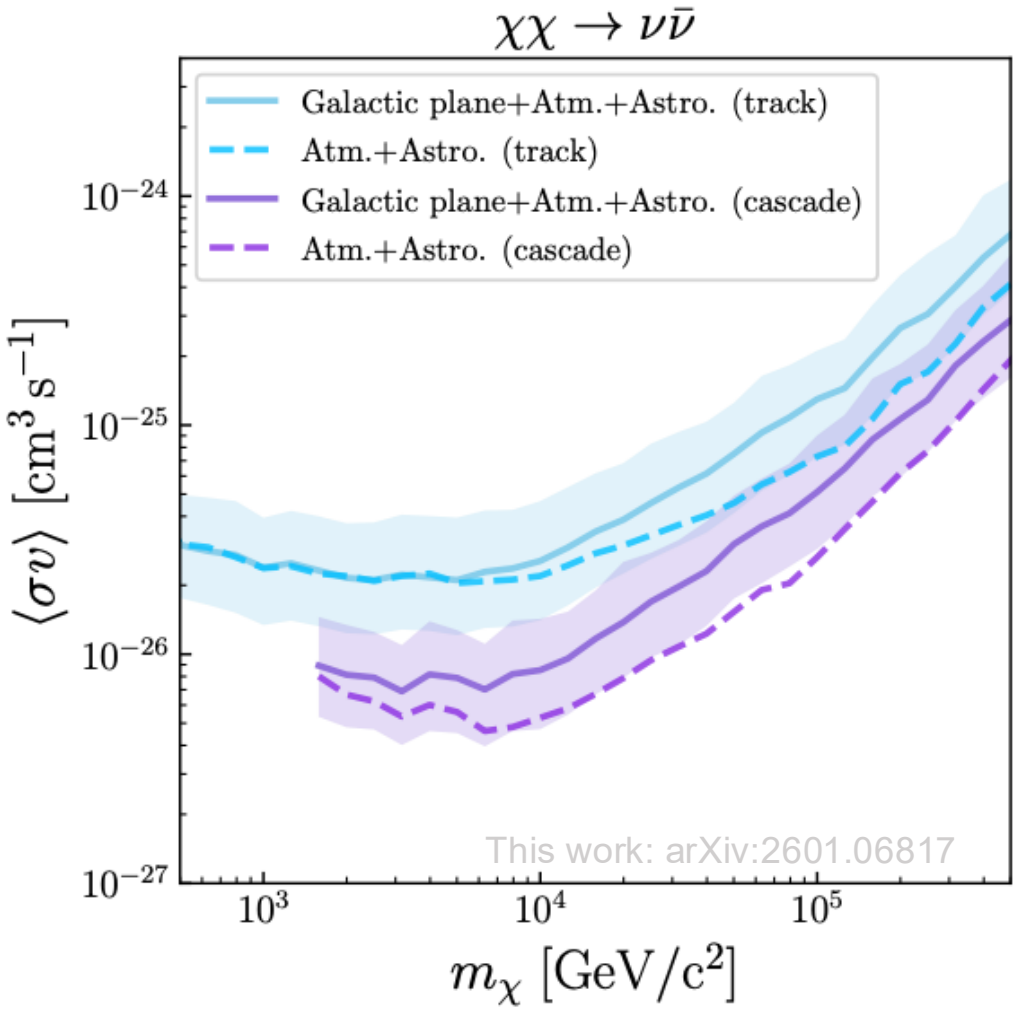


A New Bkg: Galactic-plane Neutrinos

- **Novelty 2**: First-time assessed the impact of **galactic plane neutrinos** as a DM background.
- The cascade events are more affected due to the limited angular resolution



Template used in this work (by Samy Kaci @ TDLI)

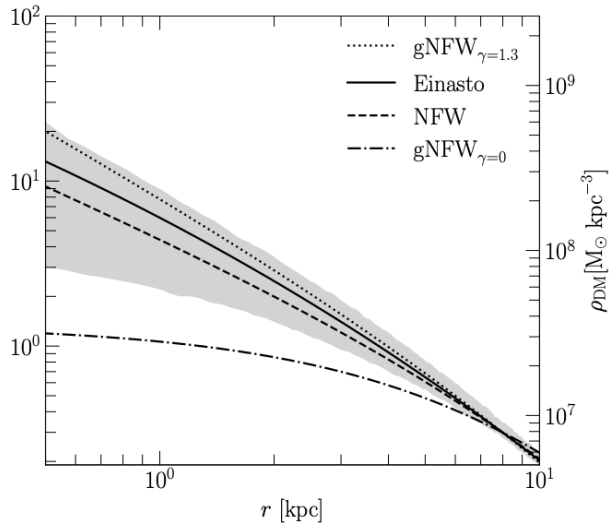


Robust against halo uncertainty

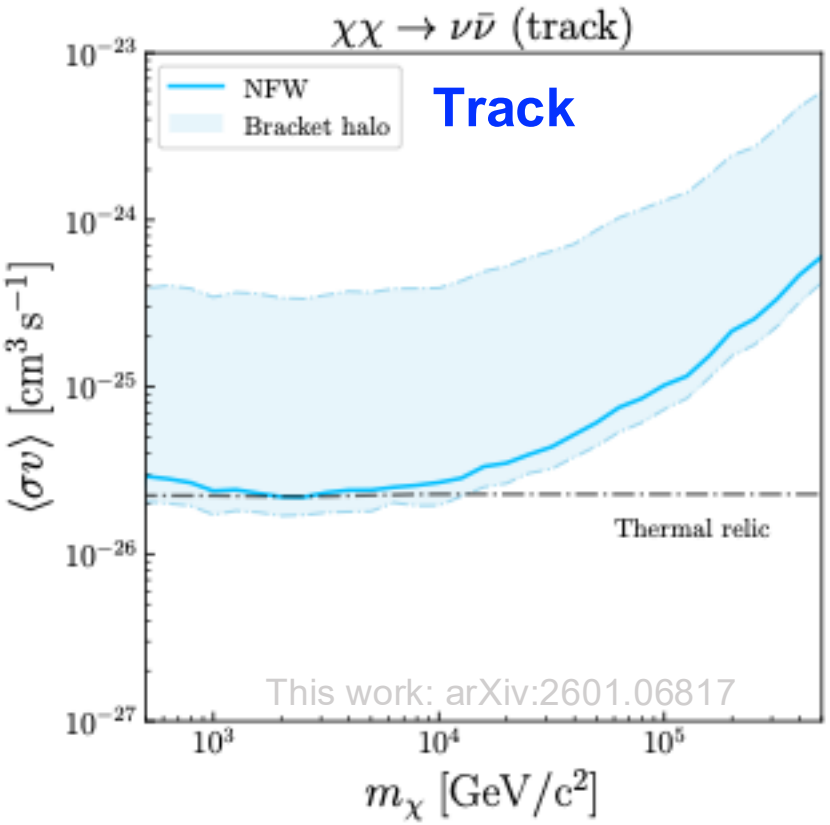
- Assessed the impact of various DM halo assumptions; **even on the pessimistic edge, the cascade limit reaches the thermal relic**

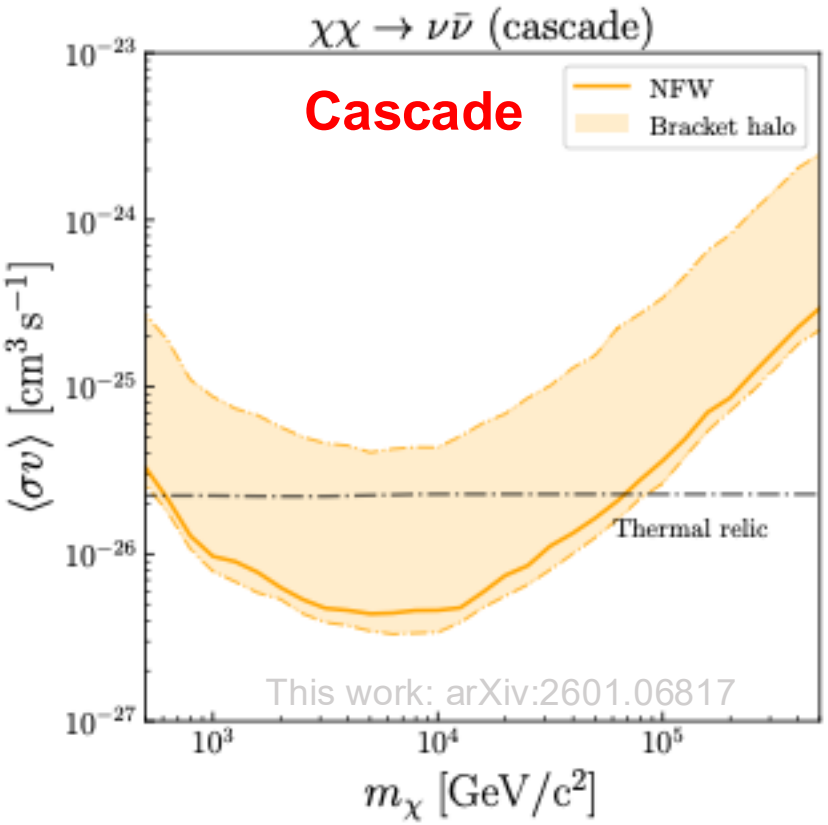
The bracket profile

N-body sim + Gaia astrometry (by Samy Kaci @ TDLI)



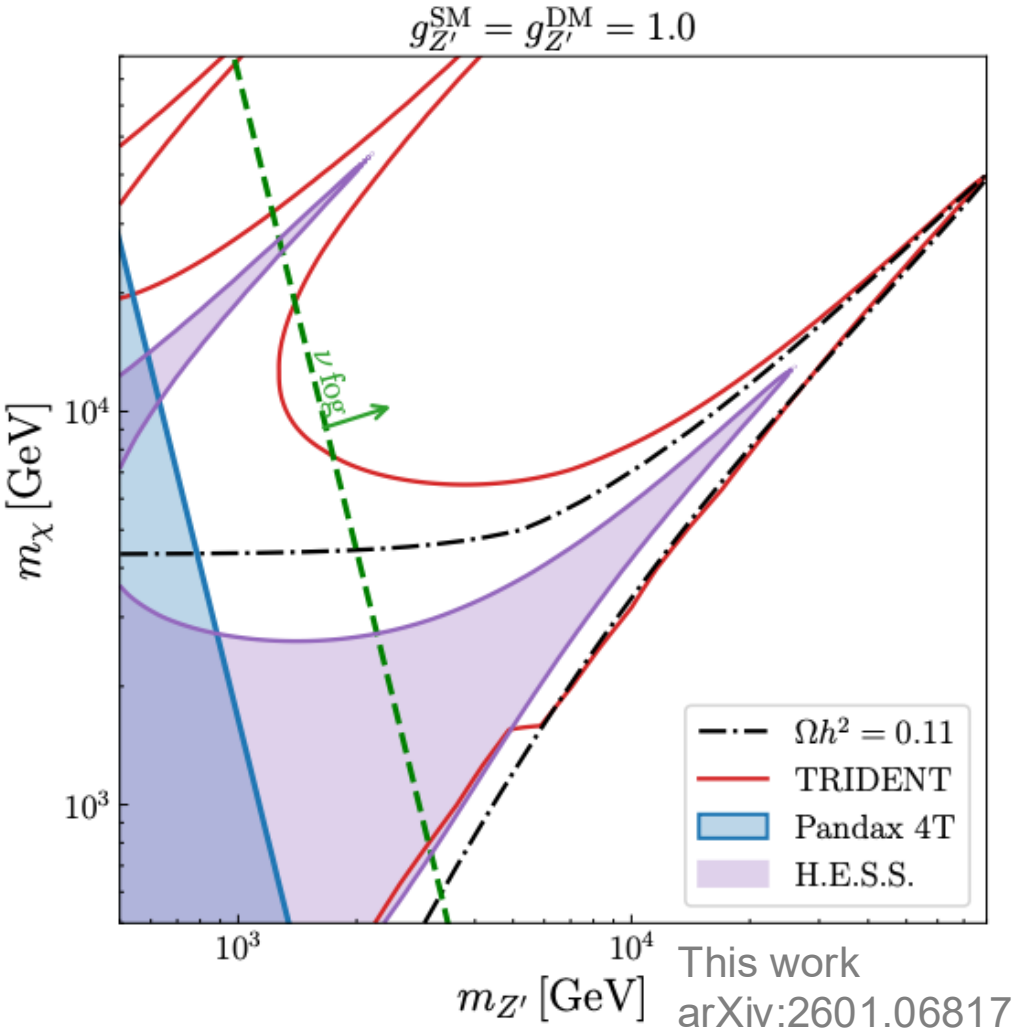
Arxiv: 2501.14868





Complementary to γ-rays & direct detection

- Studied a specific model $U(1)_{L_i - L_j}$ to exhibit **TRIDENT's complementarity with γ-ray telescopes and direct DM detection**.
  - 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)

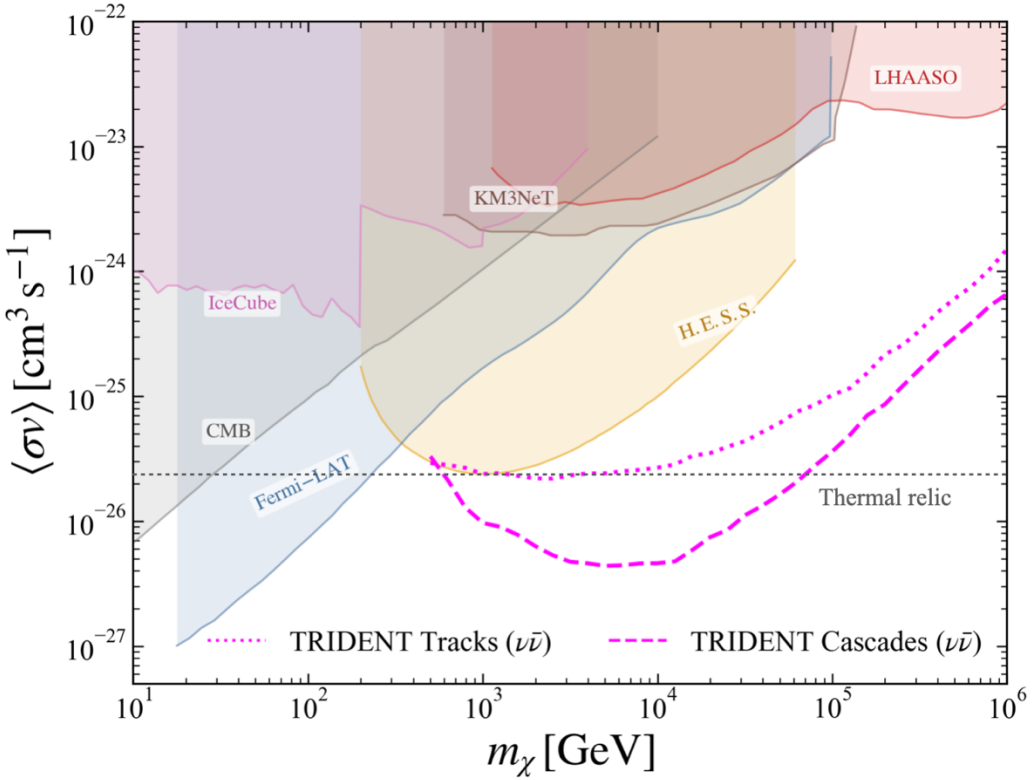


This work
arXiv:2601.06817

Collaboration with A. Cheek @ TDLI

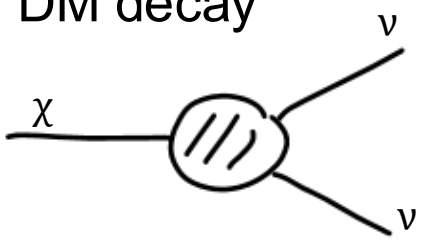
Summary

- **First DM-annihilation forecast for TRIDENT — and it reaches the thermal relic.**
- **Cascades beat tracks** — touching the relic even for a pessimistic halo
- A new background — Galactic-plane neutrinos — that can mimic a signal.
- Above 1 TeV, γ-rays & direct detection fade — **neutrinos open a complementary window.**

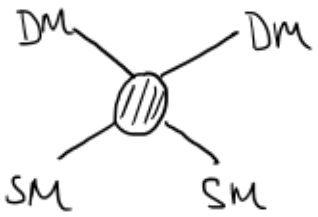


Next Up:

DM decay



Solar capture



Probing Dark Matter annihilation in the Galactic Centre with TRIDENT

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TRIDENT
海 | 铃 | 计 | 划

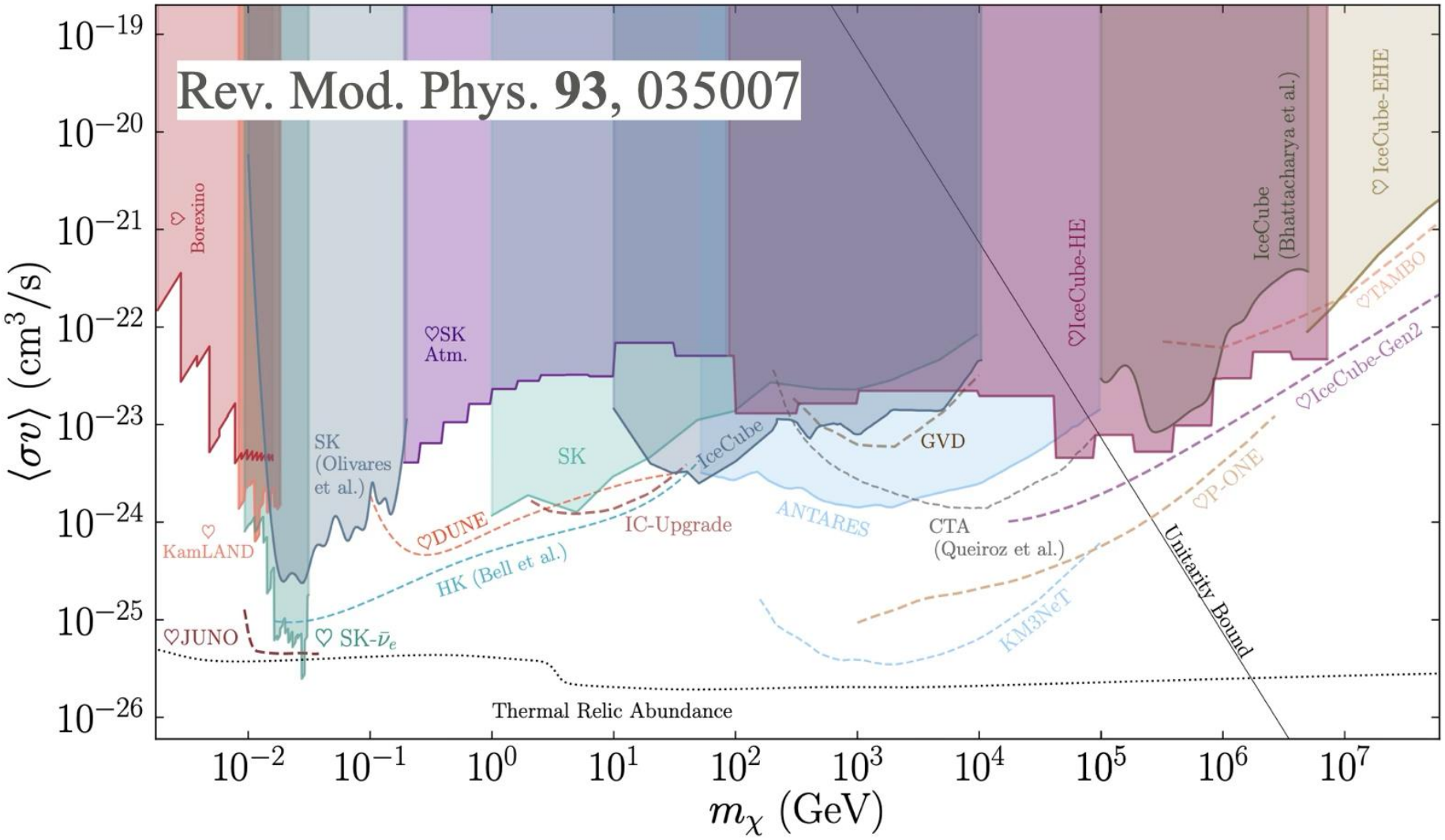
Thank you

Neutrinos give an orthogonal constraint on the DM parameter space.

arXiv:2601.06817

DM Landscape using Neutrino

No neutrino telescope reach the thermal relic yet



The Unknown

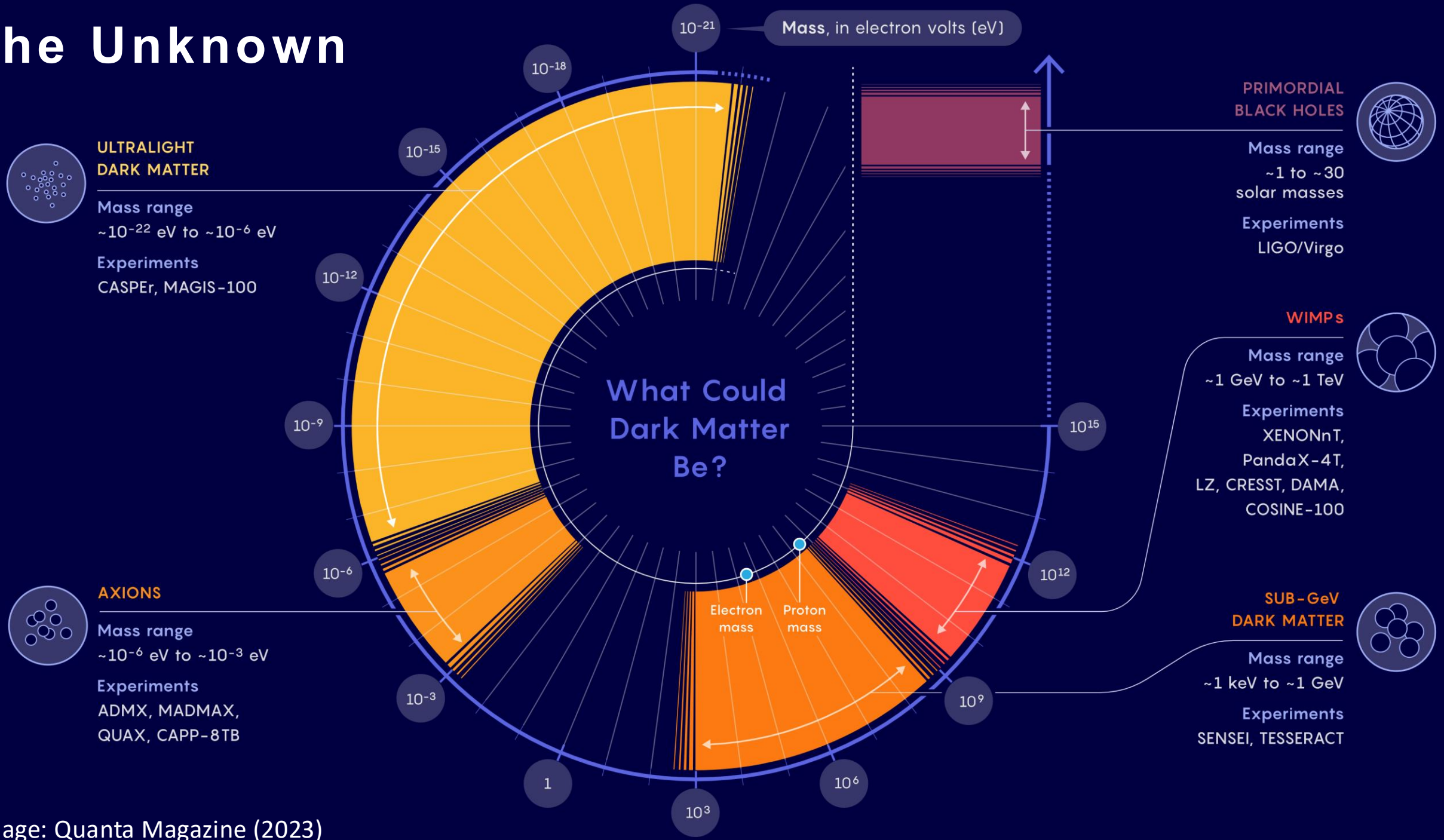


Image: Quanta Magazine (2023)

Example of Signal & Bkg Spectrum