

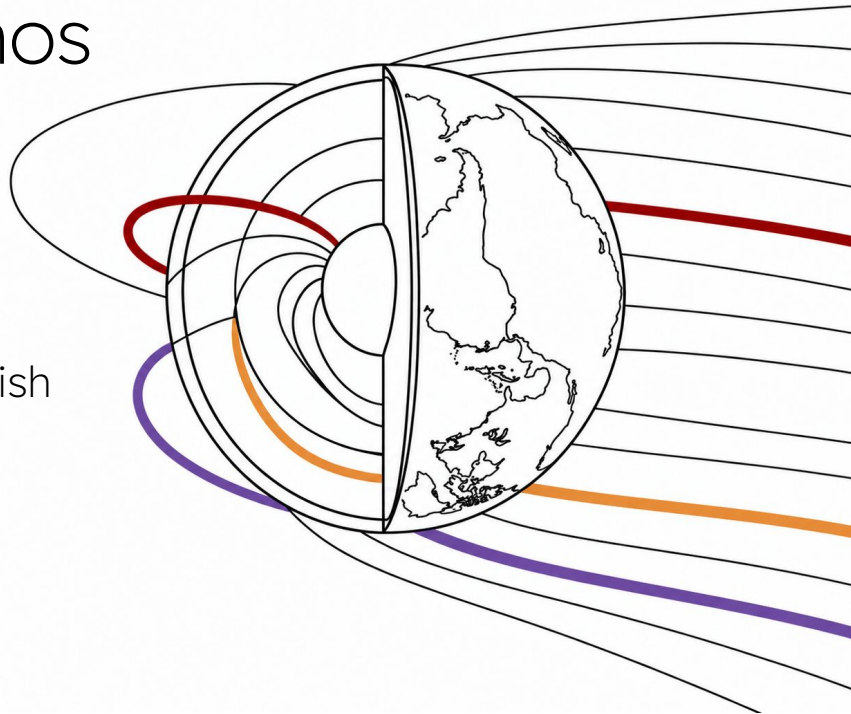
Illuminating Very Heavy Dark Matter in the Earth with Tau Neutrinos

JCAP 04 (2026) 001

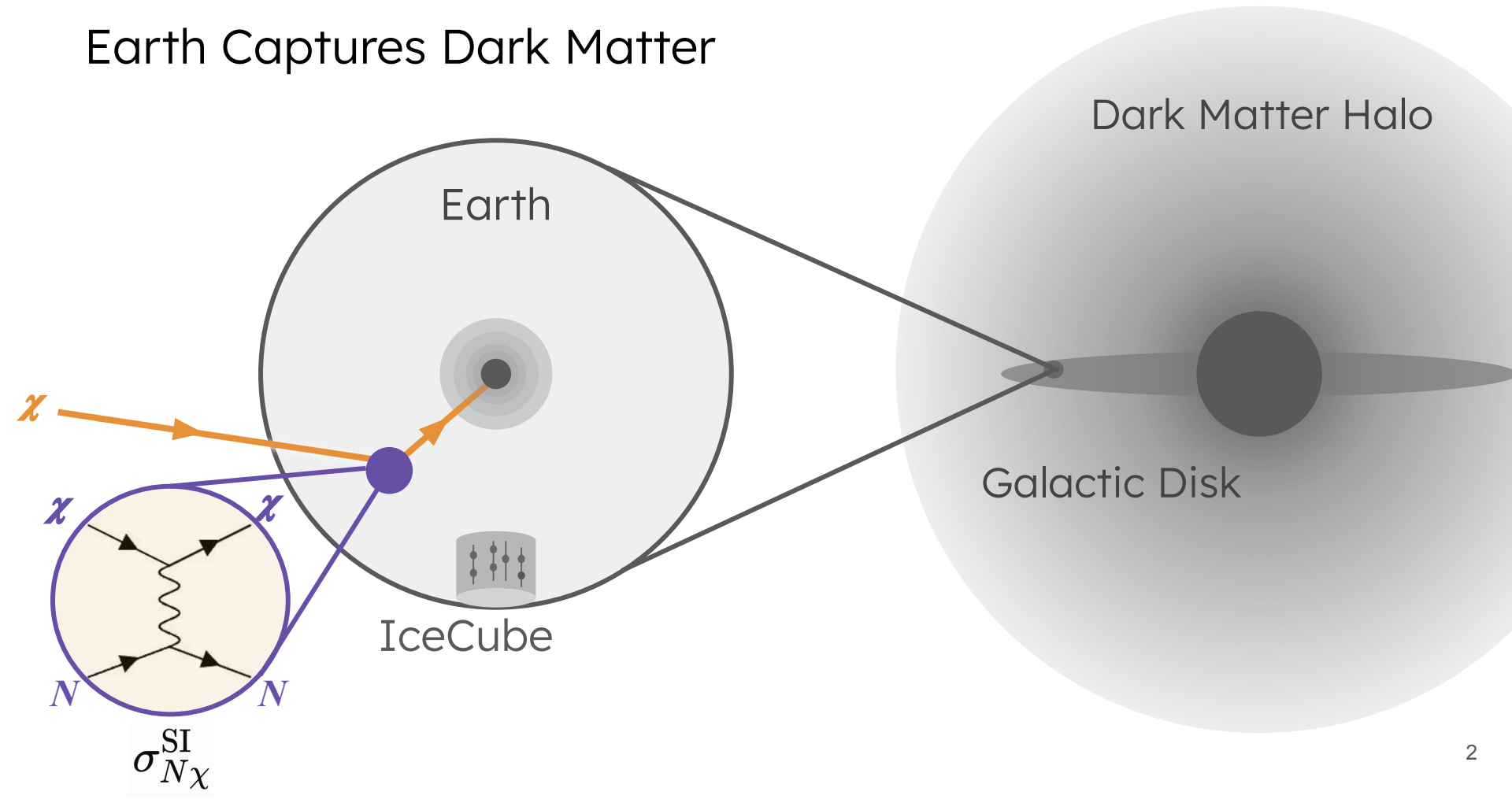
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University of Nevada, Las Vegas

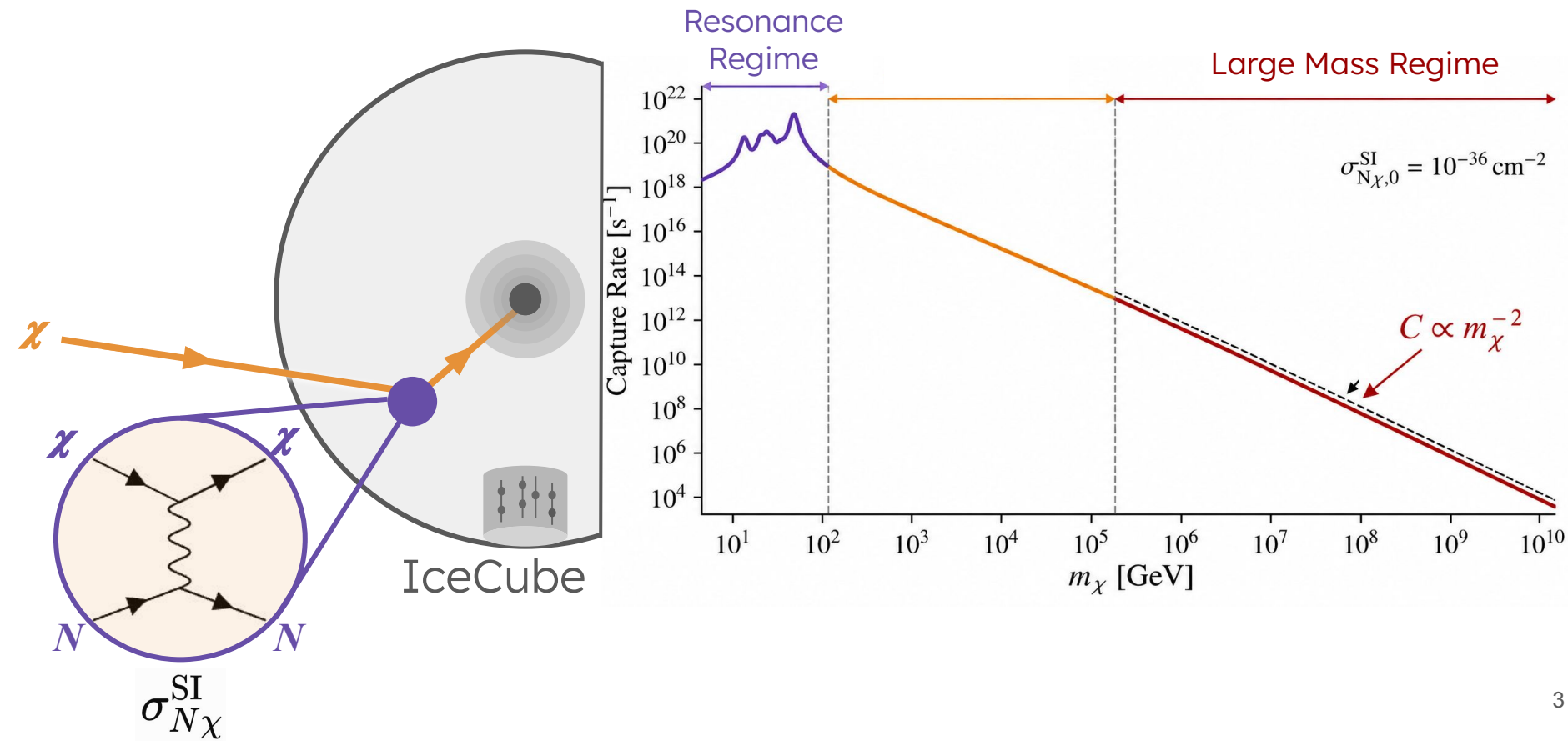
IPA Symposium 2026



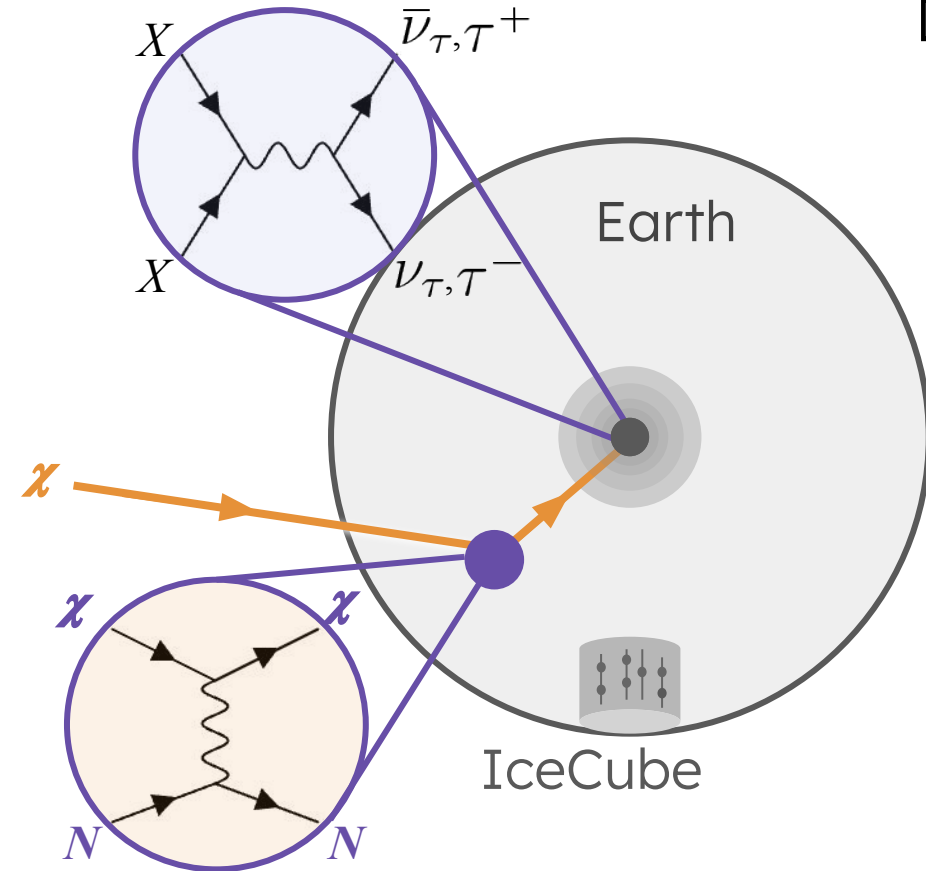
Earth Captures Dark Matter



Earth Captures Dark Matter

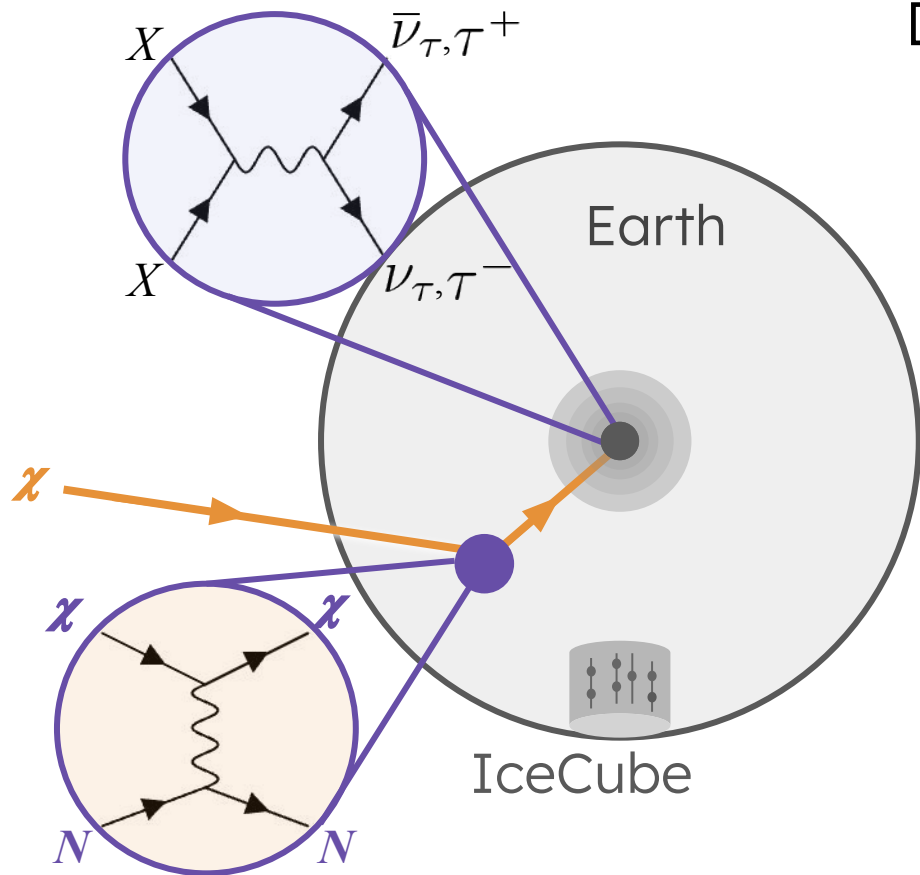


Dark Matter Annihilation



$$\frac{dN(t)}{dt} = C - AN(t)^2$$

Dark Matter Annihilation

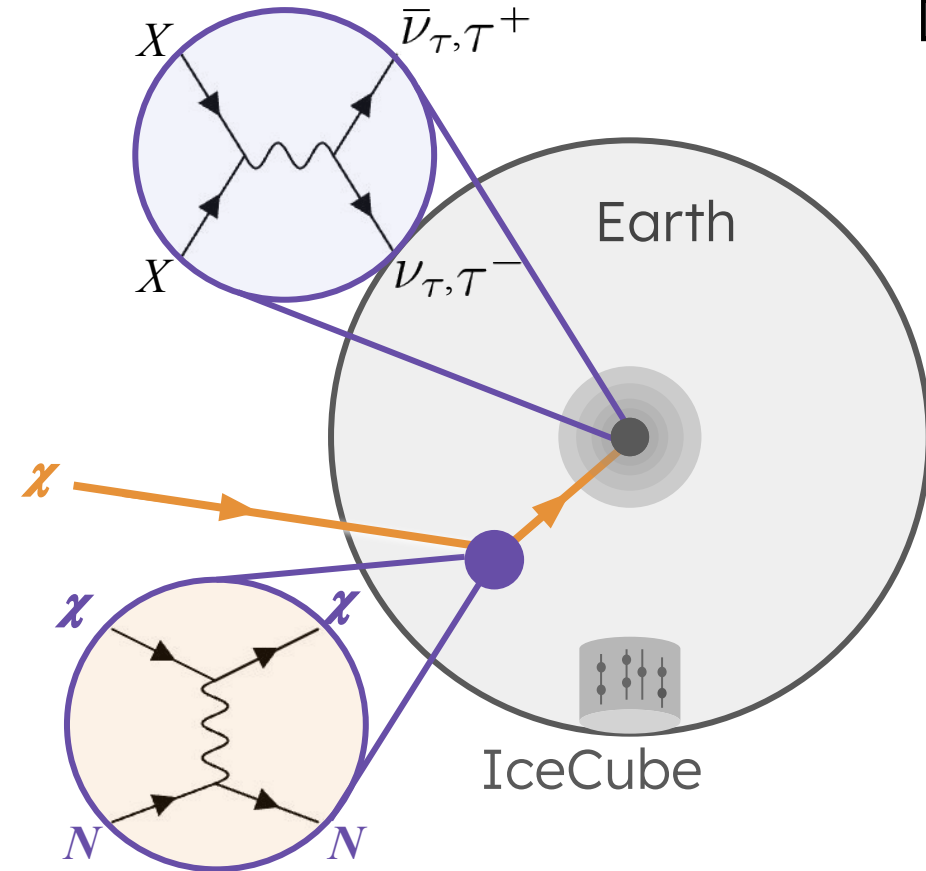


Capture rate $\propto \sigma_{N\chi}^{\text{SI}} m_\chi^{-2}$

$$\frac{dN(t)}{dt} = C - AN(t)^2$$

Annihilation
factor

Dark Matter Annihilation



$$\frac{dN(t)}{dt} = C - AN(t)^2$$

Capture rate $\propto \sigma_{N\chi}^{\text{SI}} m_\chi^{-2}$

Annihilation factor $\frac{\langle \sigma v \rangle}{V_0} \left(\frac{m_\chi}{20 \text{ GeV}} \right)^{\frac{3}{2}}$

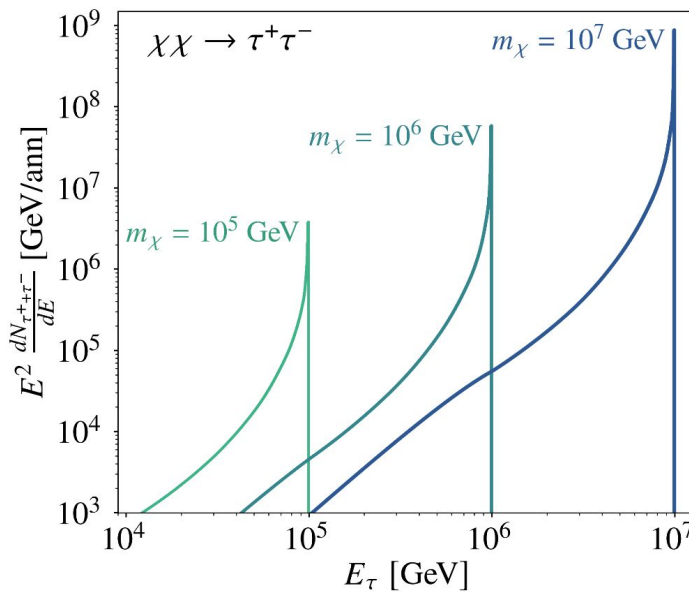
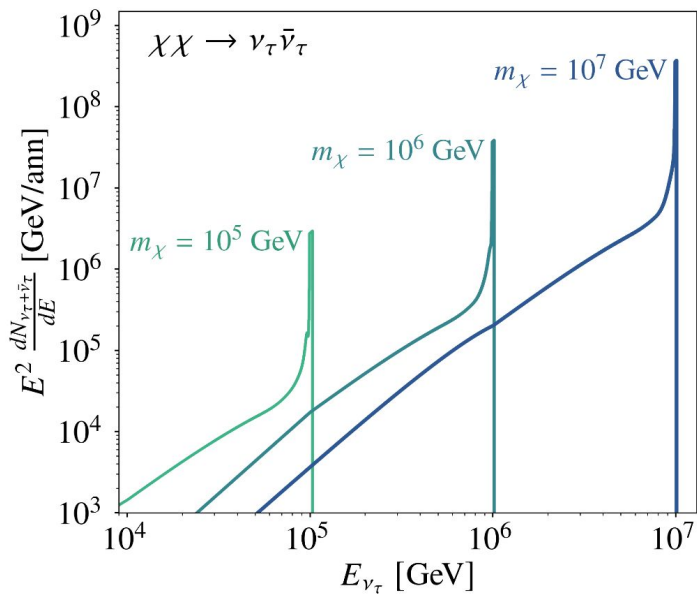
$3 \times 10^{-26} \text{ cm}^3/\text{s}$

Earth's effective volume

Dark Matter Annihilation

Annihilation rate: $\Gamma_a = \frac{1}{2} A N(t)^2 = \frac{C}{2} \tanh^2\left(\frac{t}{\sqrt{CA}}\right)$

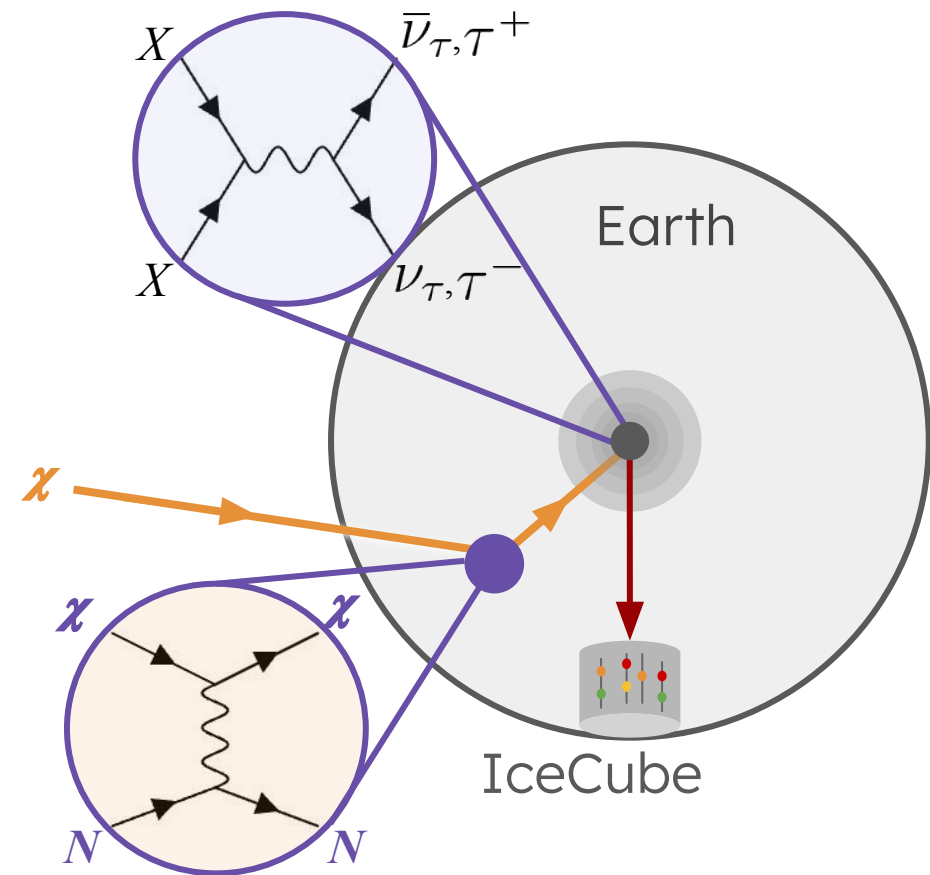
Age of Earth



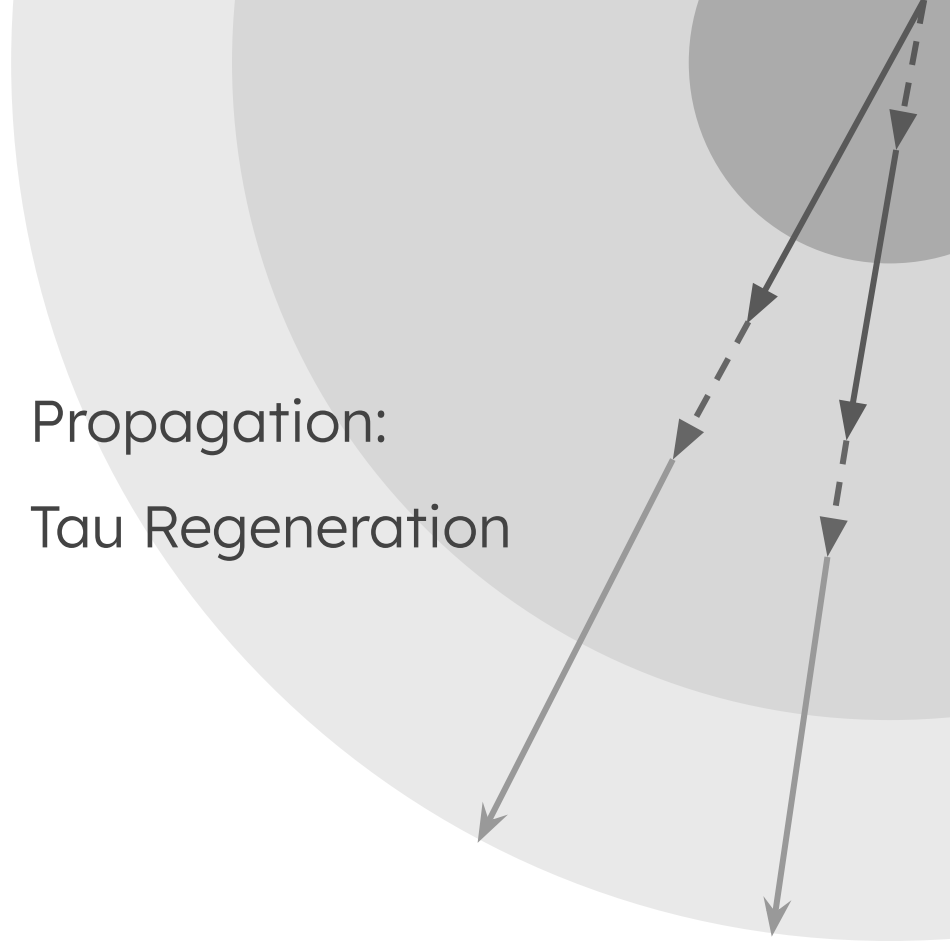
Calculated expected flux from dark matter by



Liu et al., 2020



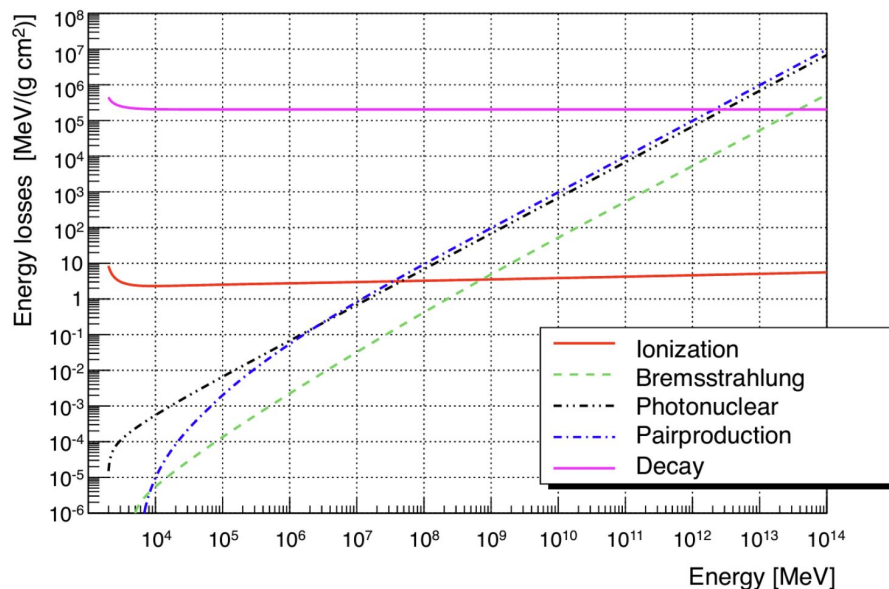
Propagation:
Tau Regeneration



Propagation: Tau Regeneration



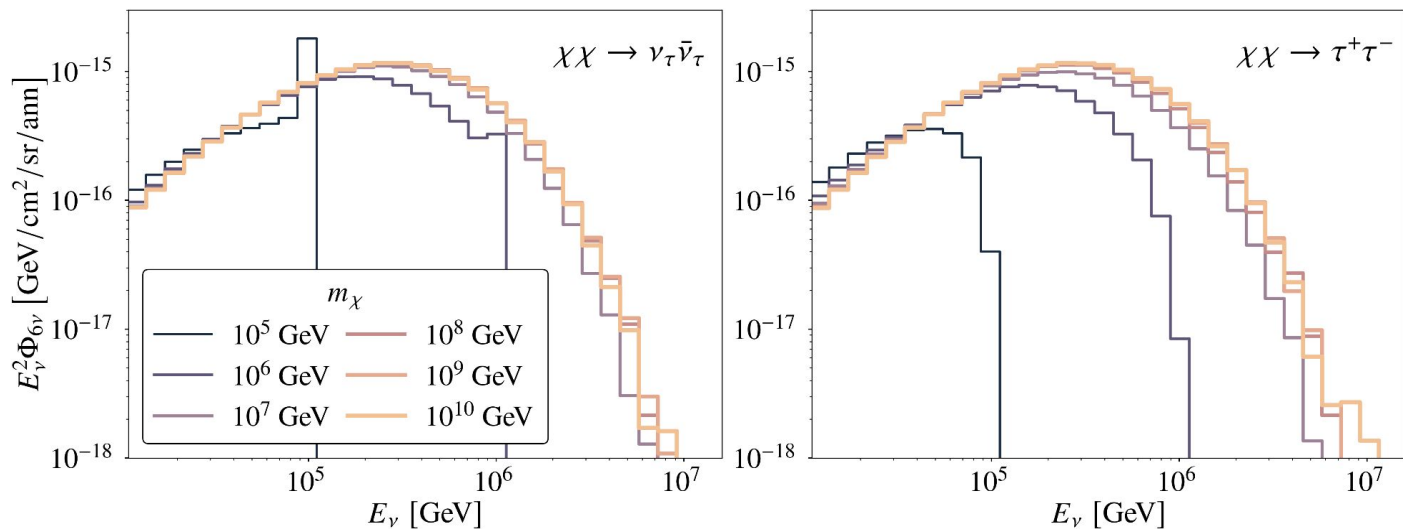
Rapidly decays back into a tau neutrino



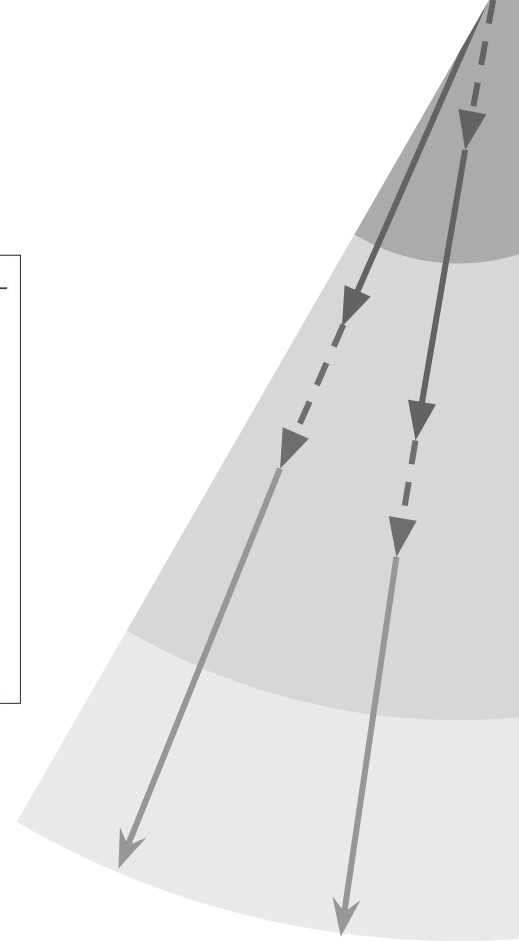
Below 100 PeV, tau decay dominates over other energy-loss processes during propagation through the Earth.

Flux at Earth surface

Flux at Earth surface of all flavors



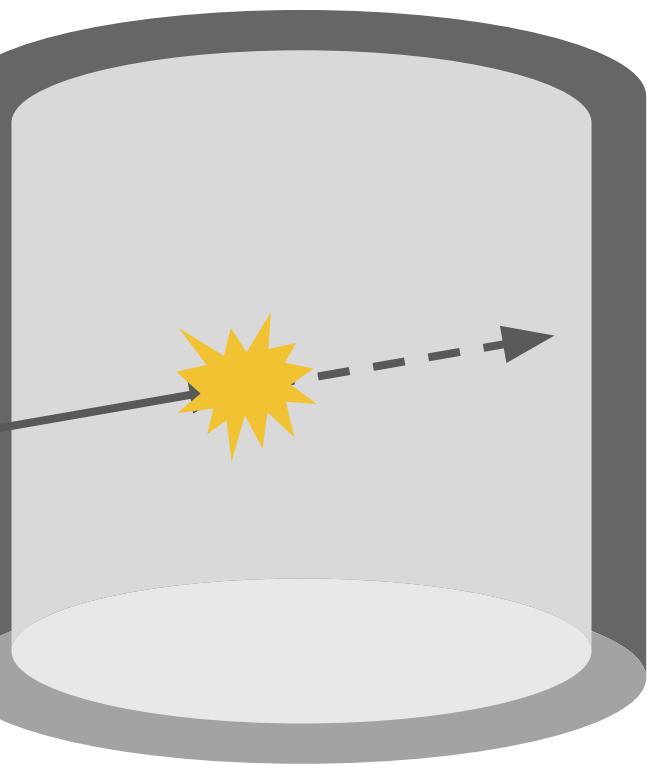
τ has larger chance to undergo photonuclear interactions in Earth's dense core, which causes stronger attenuation.



IceCube HESE 7.5 years

IceCube Collaboration,
Phys. Rev. D 104, 022002 (2021)

High-Energy Starting Events: Interaction vertices inside the detector volume



Direction of
Earth

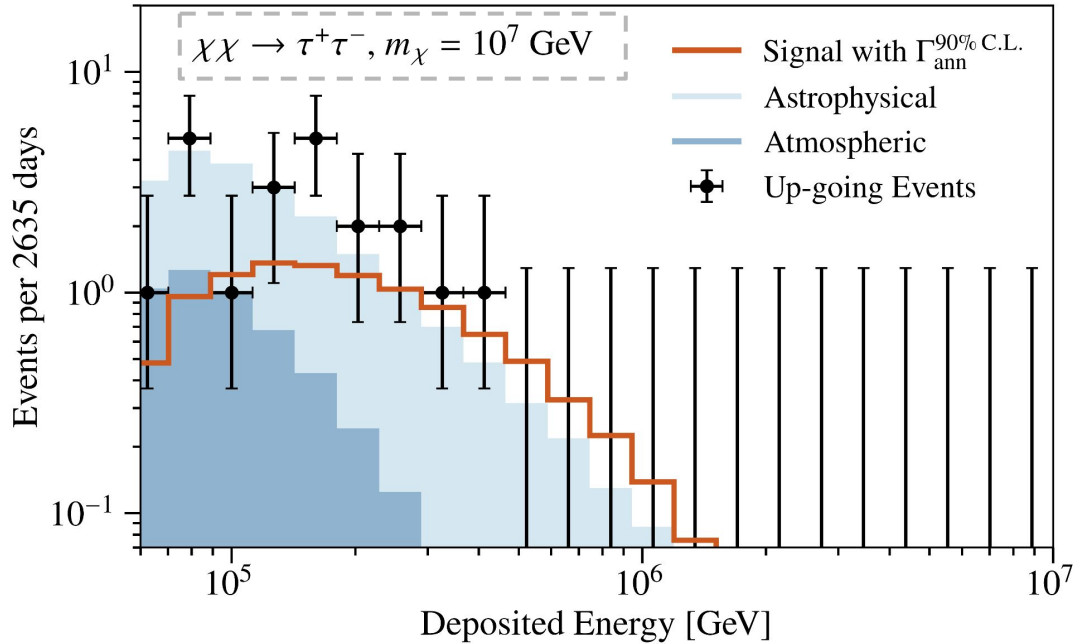
Category	$E < 60 \text{ TeV}$	$E > 60 \text{ TeV}$	Total
Total Events	42	60	102
Up	19	21	40
Down	23	39	62
Cascade	30	41	71
Track	10	17	27
Double Cascade	2	2	4

Southern Sky(Down-going)

Not from the direction of Earth!

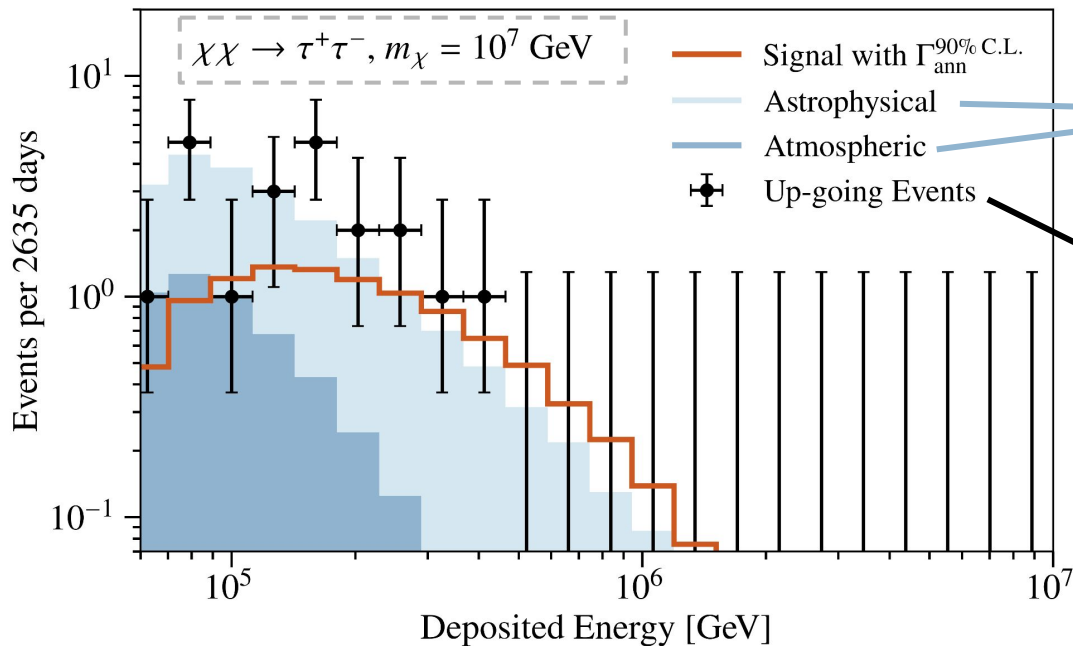
Draw the Limits

Binned Events Likelihood Analysis



Draw the Limits

Binned Events Likelihood Analysis

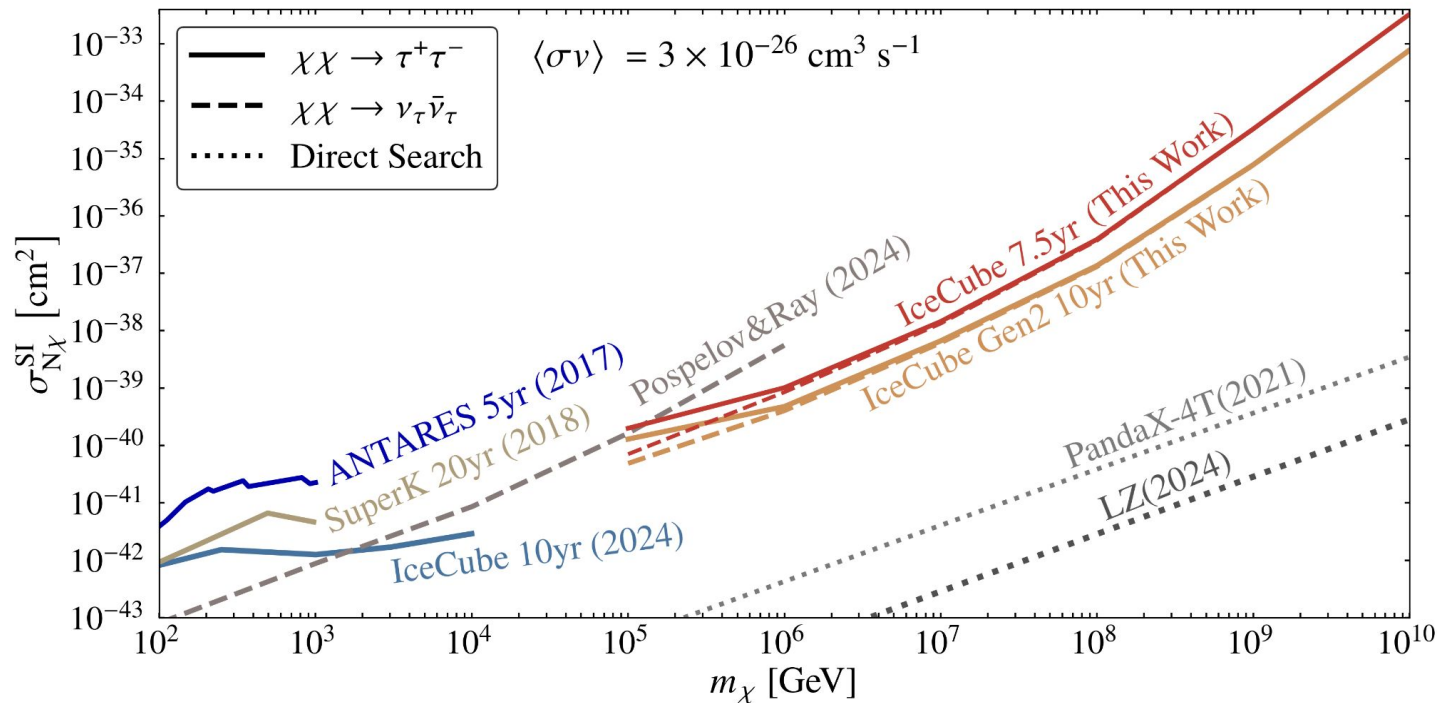


Based on spectrums with
best-fit parameter in HESE
7.5yr analysis

Cascade+Double-cascade

Compared to using other
morphologies, it provides
strongest upper limit on
annihilation rate.

Constraints on DM-nucleon Interaction



We establish 90% C.L. upper limits on the spin-independent DM-nucleon cross section for very heavy DM.

For $m_\chi \gtrsim 10^7 \text{ GeV}$, the constraints from both channels become identical.

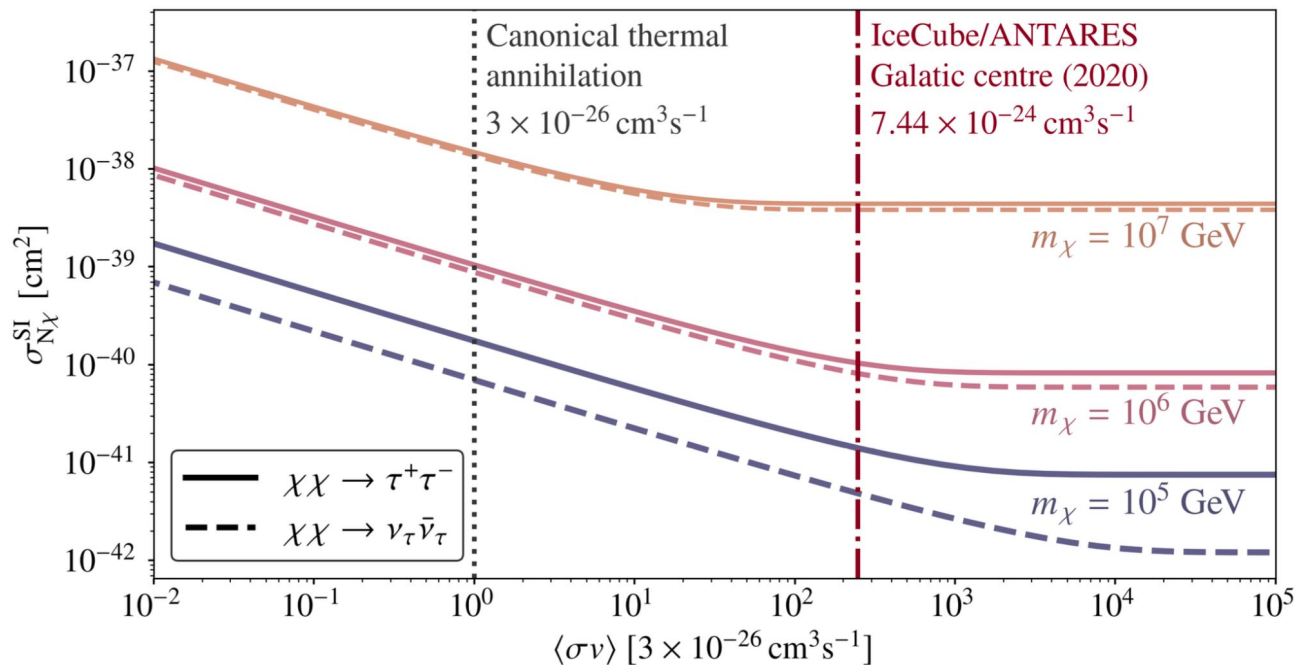
Gen2 improve the limits by about a factor of three

Constraints on DM-nucleon Interaction

Larger $\langle\sigma v\rangle$ gives stronger constraints because more efficient annihilation produces a larger neutrino flux for a given capture rate.

The constraints eventually saturate:

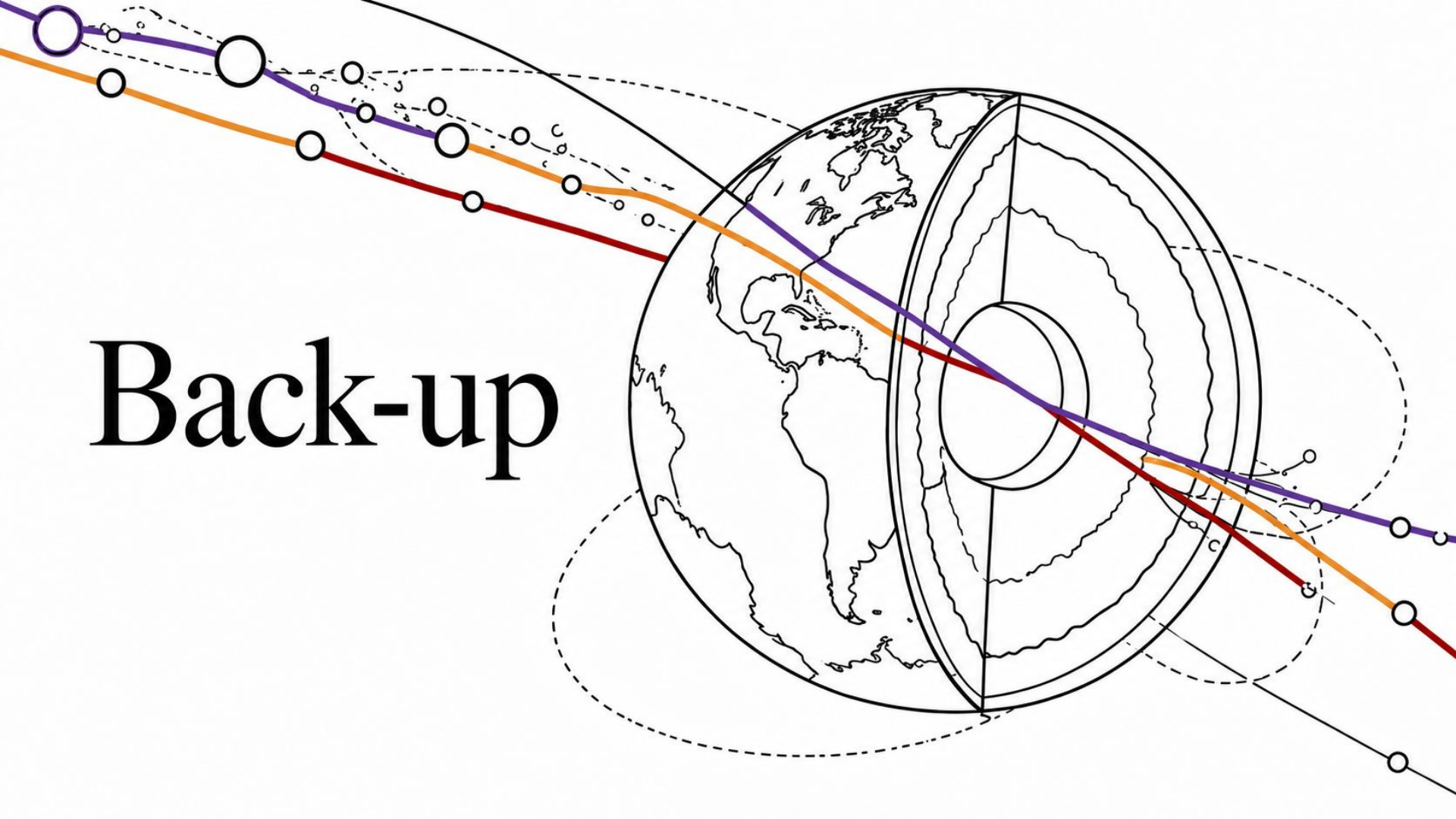
$$\Gamma_a = \frac{C}{2} \tanh^2(t\sqrt{CA}) \longrightarrow \frac{C}{2}$$



Conclusion

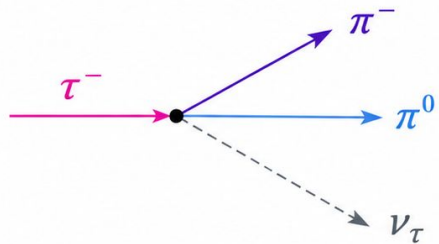
- We present a new search for very heavy dark matter annihilation in the Earth's core using tau neutrino signals.
- Neutrino propagation is simulated with electroweak showering and tau regeneration using TauRunner.
- Using IceCube's 7.5-year HESE data, we set upper limits on the spin-independent DM-nucleon cross section, focusing on cascade and double-cascade events in the northern sky.
- Our results extend constraints at PeV–EeV scales, and future detectors like IceCube-Gen2 can improve sensitivity further.

Back-up



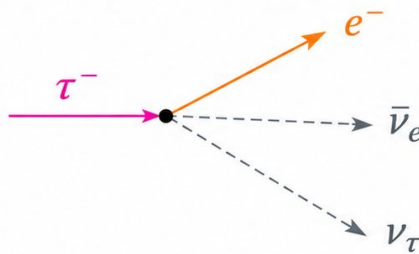
Hadronic decays 64.8%

e.g. $\tau^- \rightarrow \pi^- \nu_\tau$, $\tau^- \rightarrow \pi^- \pi^0 \nu_\tau, \dots$



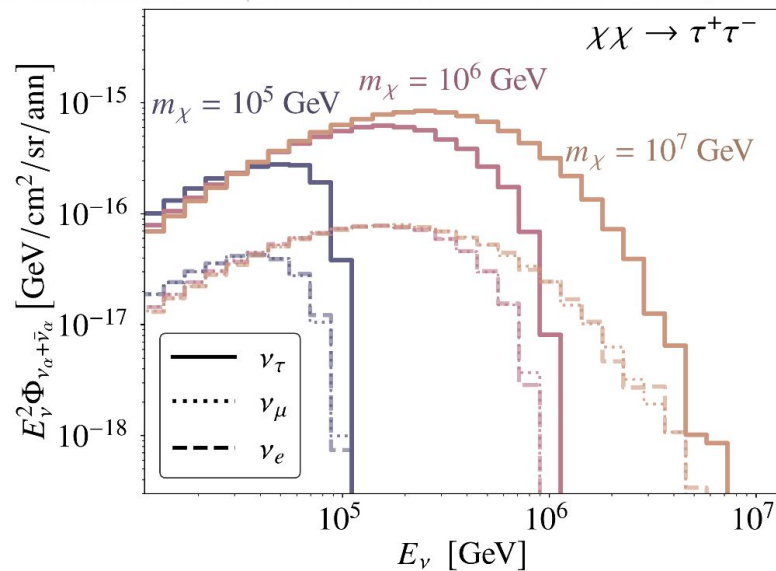
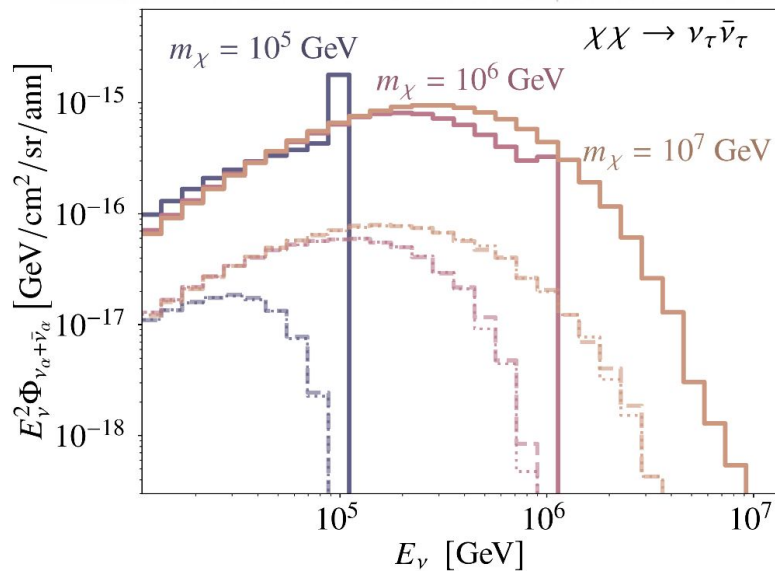
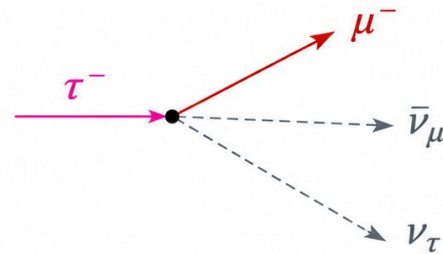
Electronic decays 17.8%

$\tau^- \rightarrow e^- \bar{\nu}_e \nu_\tau$



Muonic decays 17.4%

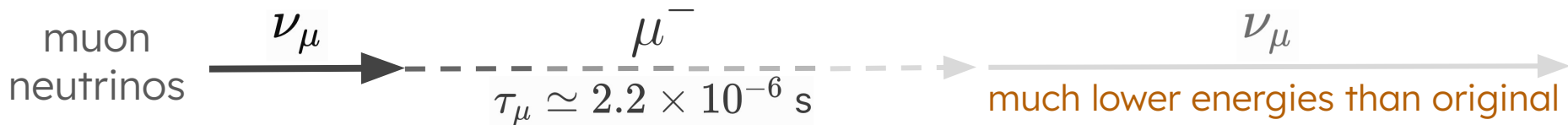
$\tau^- \rightarrow \mu^- \bar{\nu}_\mu \nu_\tau$



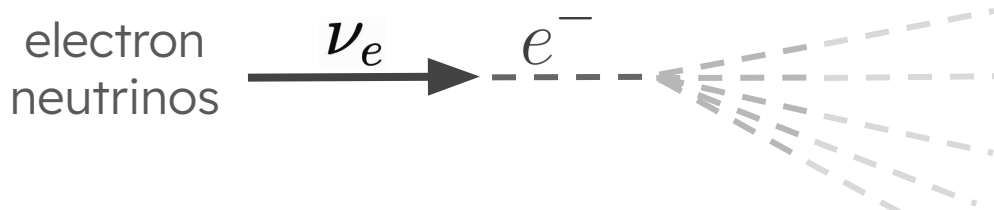
Propagation: Tau Regeneration



Rapidly decays back into a tau neutrino



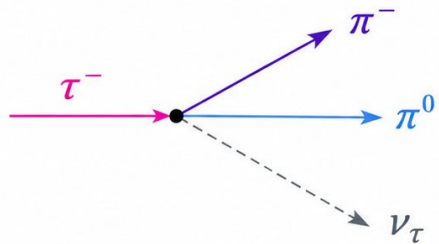
loses energy through *ionization, pair production, bremsstrahlung, and photonuclear interactions*



electron is stable
and it rapidly loses energy through
electromagnetic shower

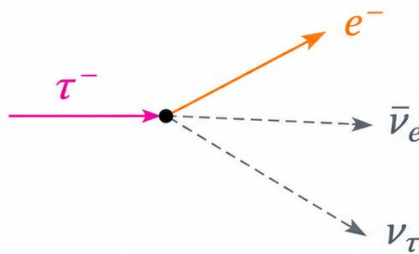
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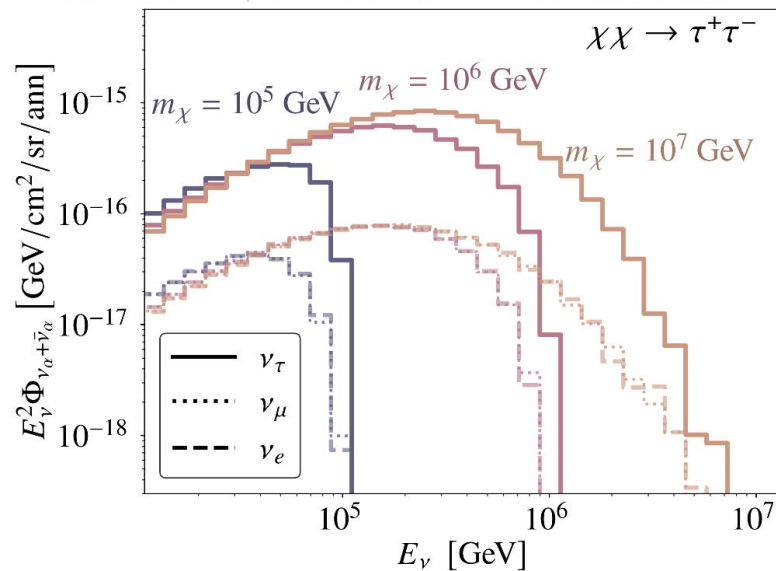
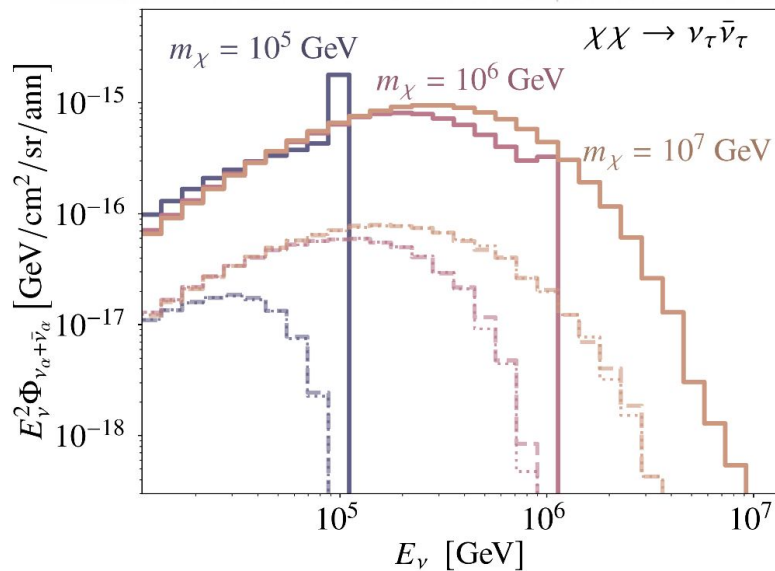
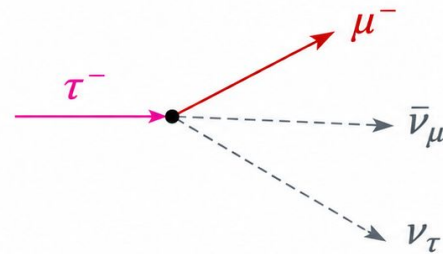
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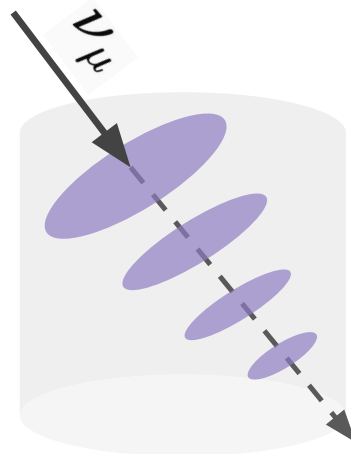
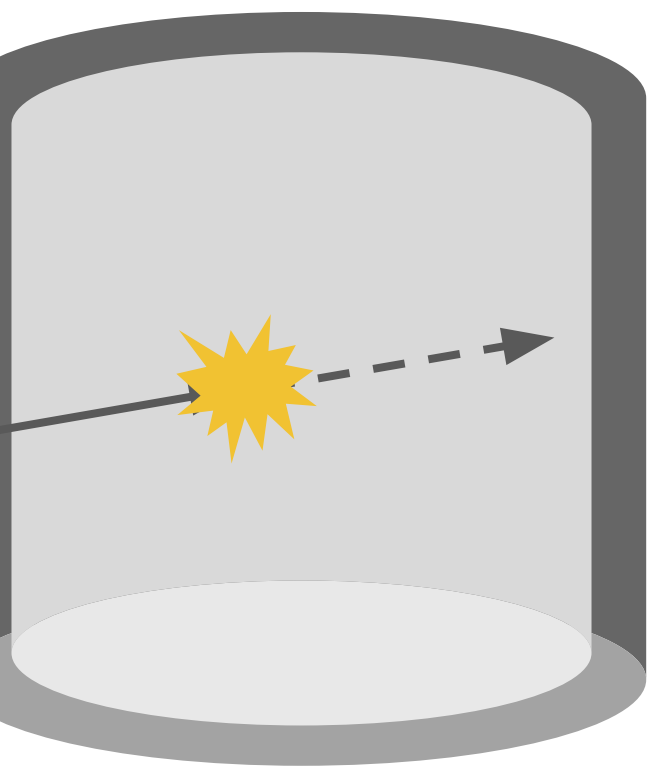
$\tau^- \rightarrow \mu^- \bar{\nu}_\mu \nu_\tau$



IceCube HESE 7.5 years

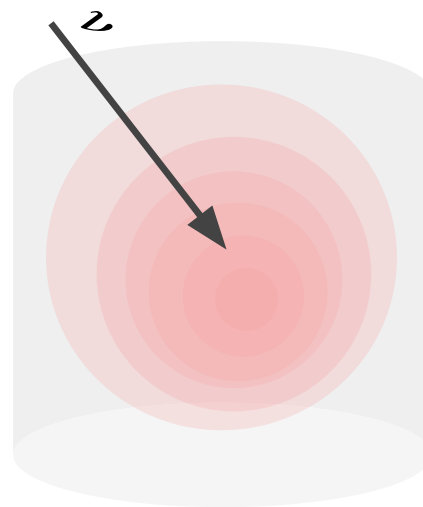
IceCube Collaboration,
Phys. Rev. D 104, 022002 (2021)

High-Energy Starting Events: Interaction vertices inside the detector volume



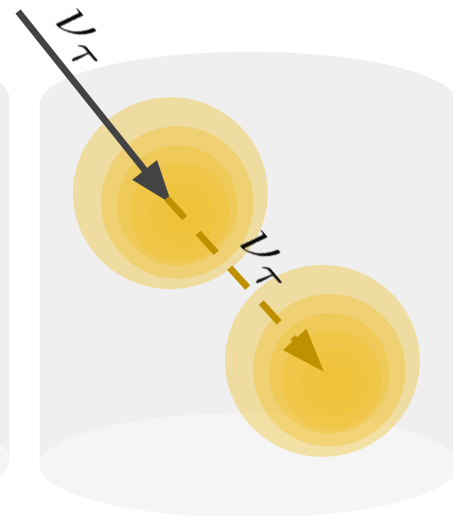
Tracks

muon neutrino
only



Cascades

All flavors



Double Cascades

tau neutrino
only

Why spin-independent?

- Interact with the **entire nucleus coherently**, not just the spin;
- Most of Earth's nuclei have **even numbers of protons and neutrons**, so they have **low or zero spin** → very weak spin-dependent interaction rates.

Element	Main Isotope	Protons	Neutrons	Nuclear Spin
Oxygen	^{16}O	8	8	0 (even-even)
Silicon	^{28}Si	14	14	0 (even-even)
Magnesium	^{24}Mg	12	12	0 (even-even)
Iron	^{56}Fe	26	30	0 (even-even)
Nickel	^{58}Ni	28	30	0 (even-even)
Sulfur	^{32}S	16	16	0 (even-even)
Calcium	^{40}Ca	20	20	0 (even-even)

Upper-limits with different Morphologies

