Queen's UNIVERSITY

Centre Canadien de Recherche en Physique des Astroparticules
Arthur B. McDonald
Canadian Astroparticle Physics Research Institute

Dark matter vs high-energy neutrinos

Aaron Vincent

Dark Interactions | SFU | Vancouver | October 17 2024

Featuring

Carlos Argüelles
Harvard

Ali Kheirandish
UNV Las Vegas

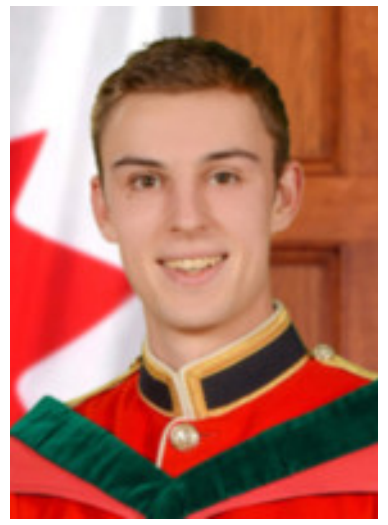
Henry White
Queen's

Qinrui Liu
Queen's

Ibrahim Safa
UW Madison

Andrés Olivares-del-Campo
IPPP Durham

Ningqiang Song
CN Yang ITP



Adam
McMullen
Queen's

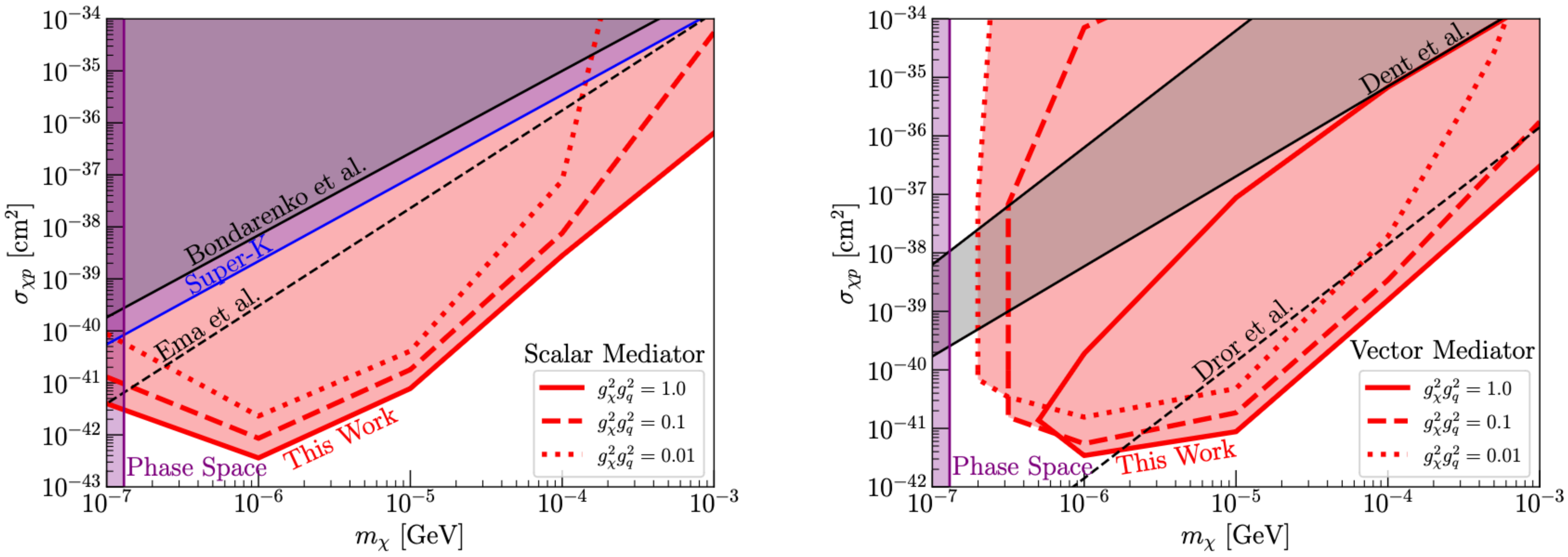
Alejandro Diaz
MIT

Diyaselis
Delgado
Harvard

I won’t talk about

Detecting dark matter at neutrino telescopes

- Cosmic Ray-Boosted Dark Matter at IceCube

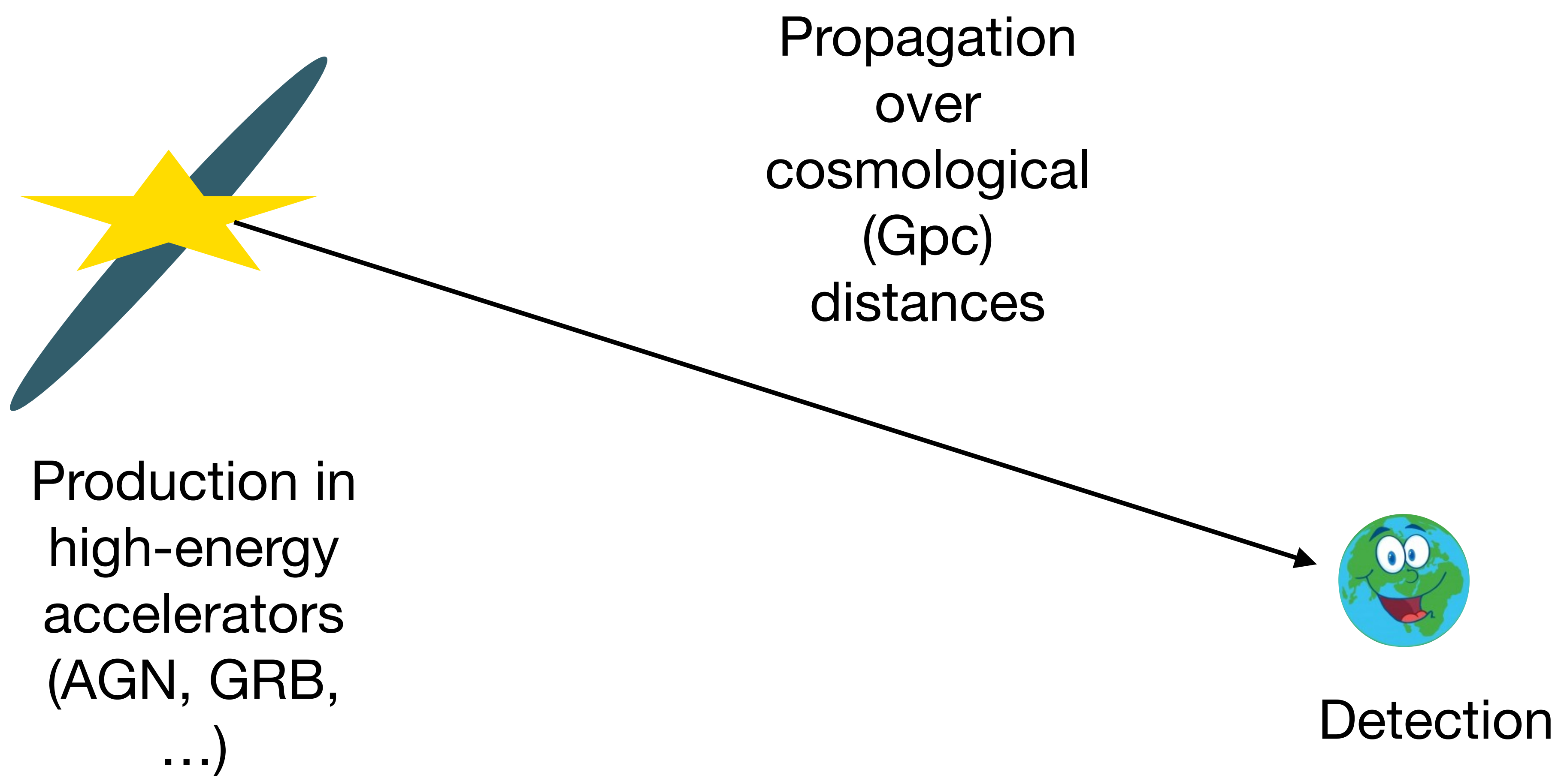


Cappiello Liu Mohlabeng ACV 2405.00086

I will talk about

Dark matter-neutrino interactions: how do you see the most invisible particle?

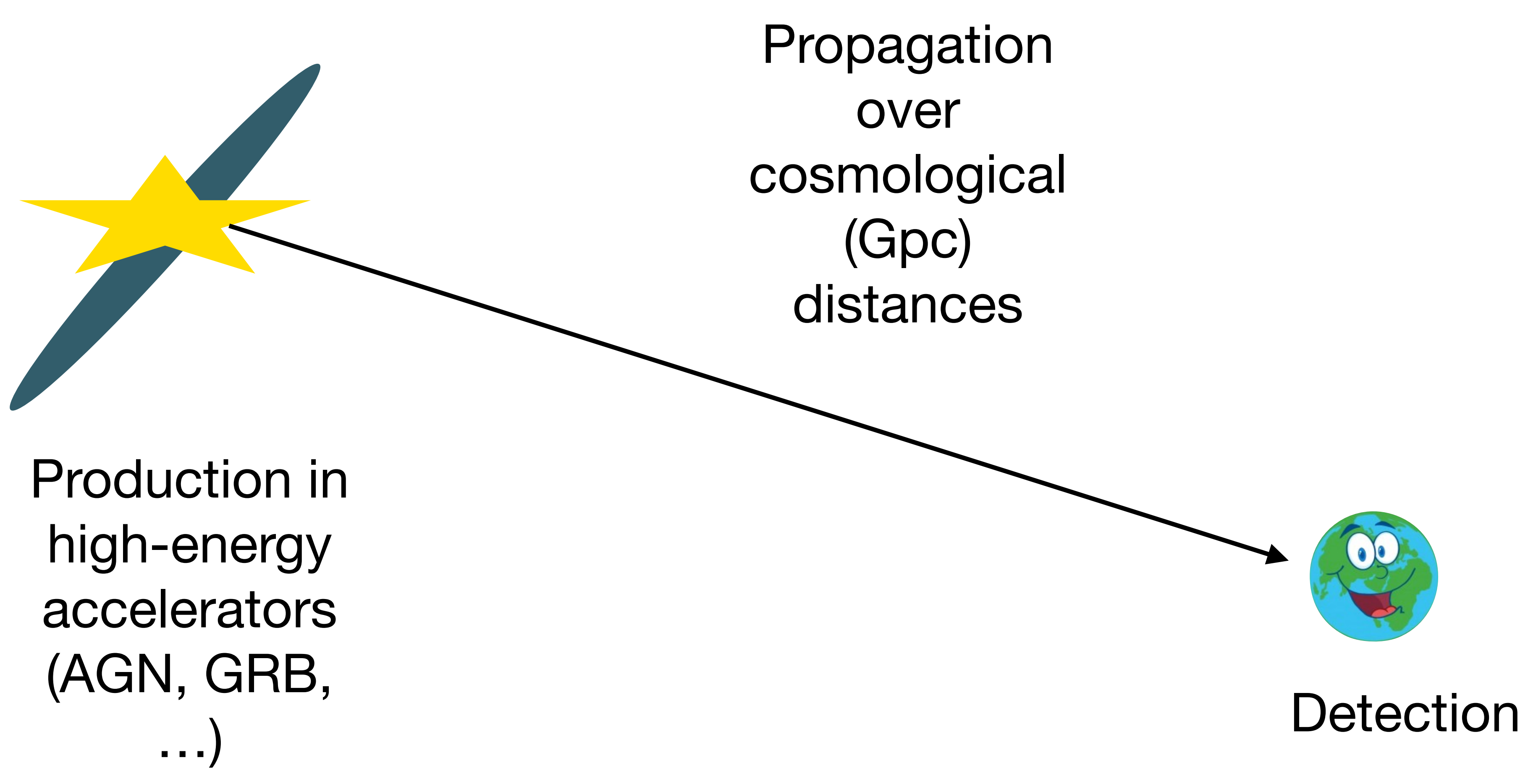
High-energy neutrinos

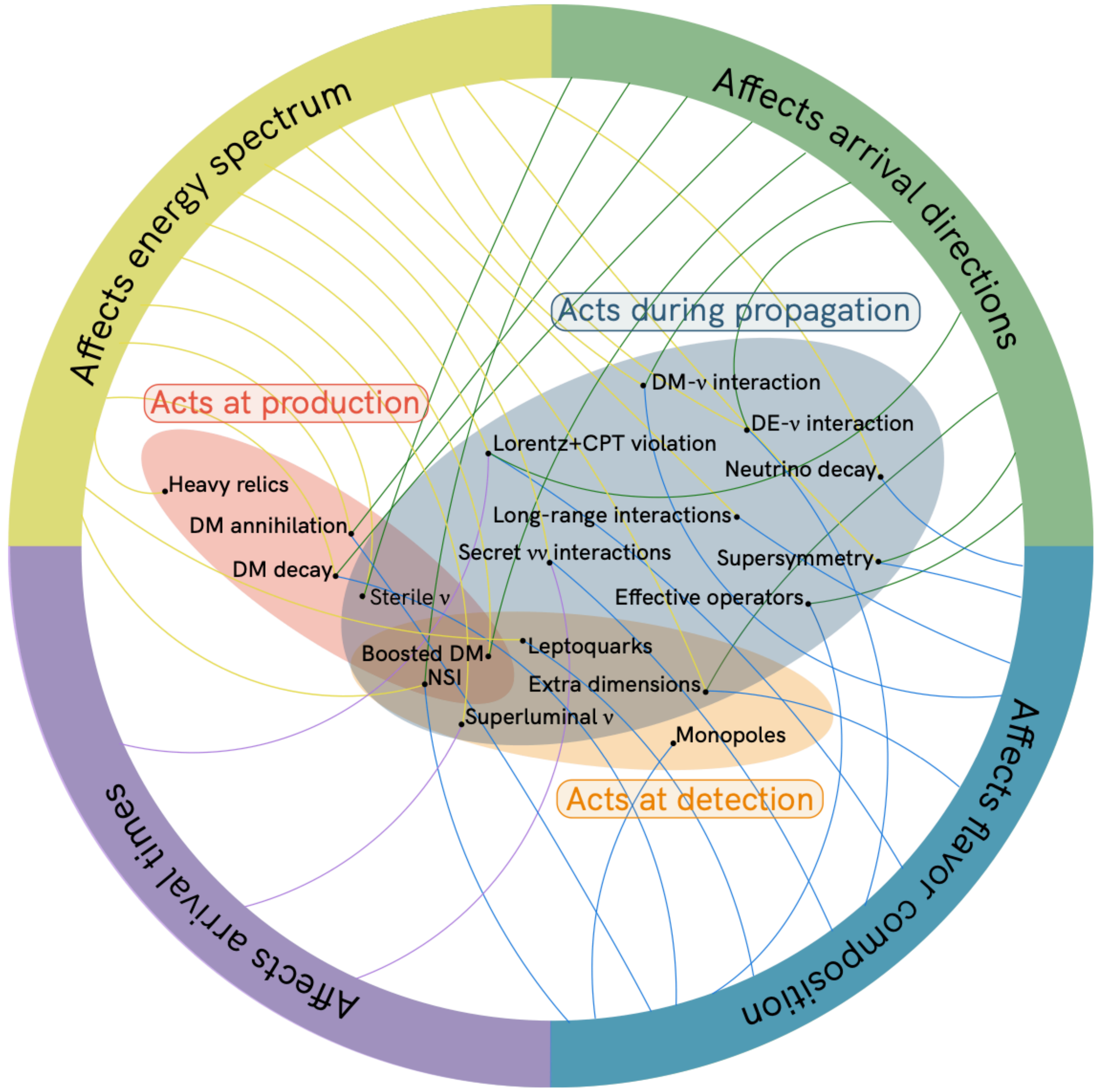


Neutrinos can tell us about "standard model" physics:

- Nature of these accelerators
- Oscillation, interaction with intergalactic medium
- Detection: high-energy neutrino-nucleus cross sections

High-energy neutrinos





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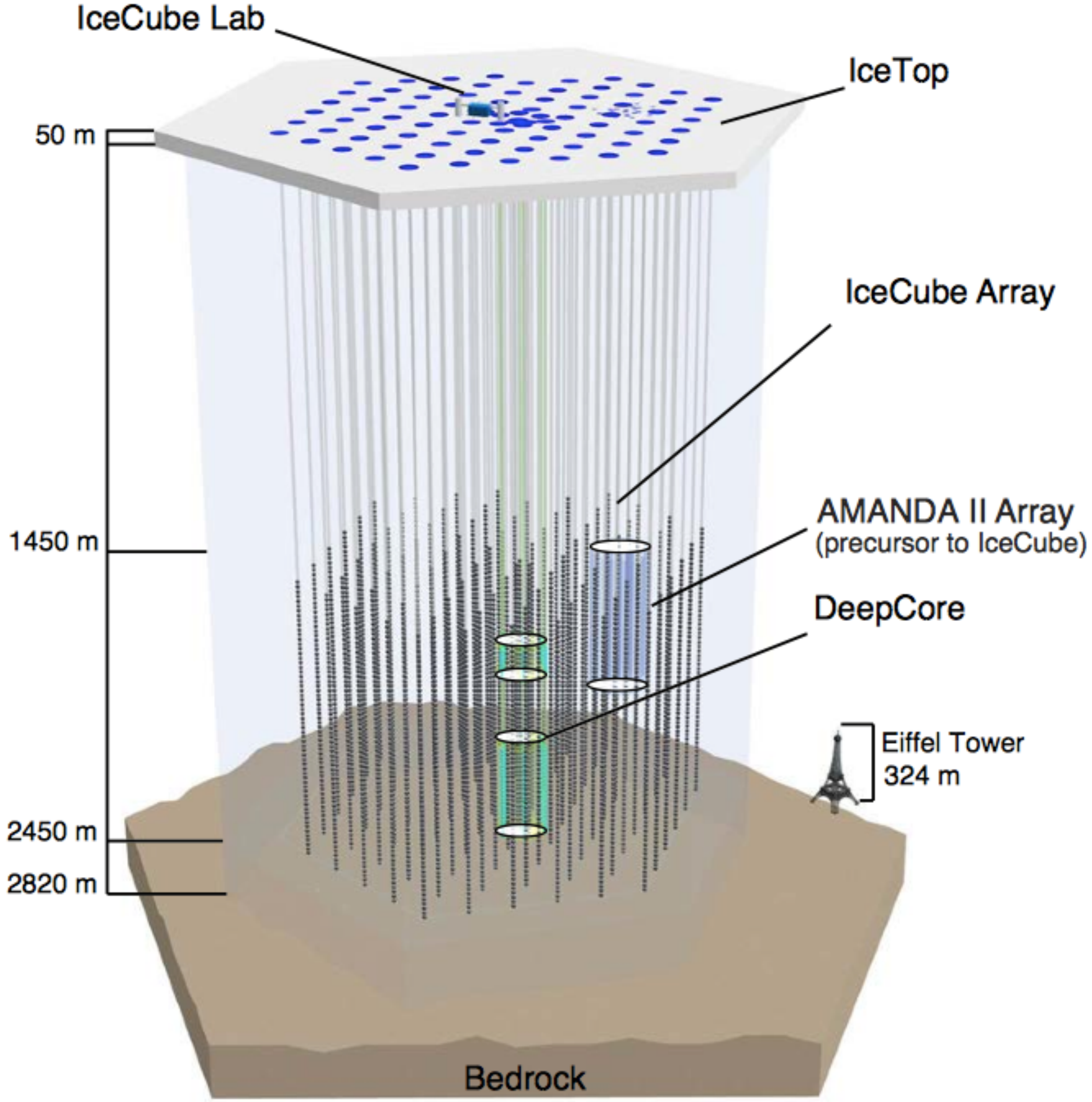
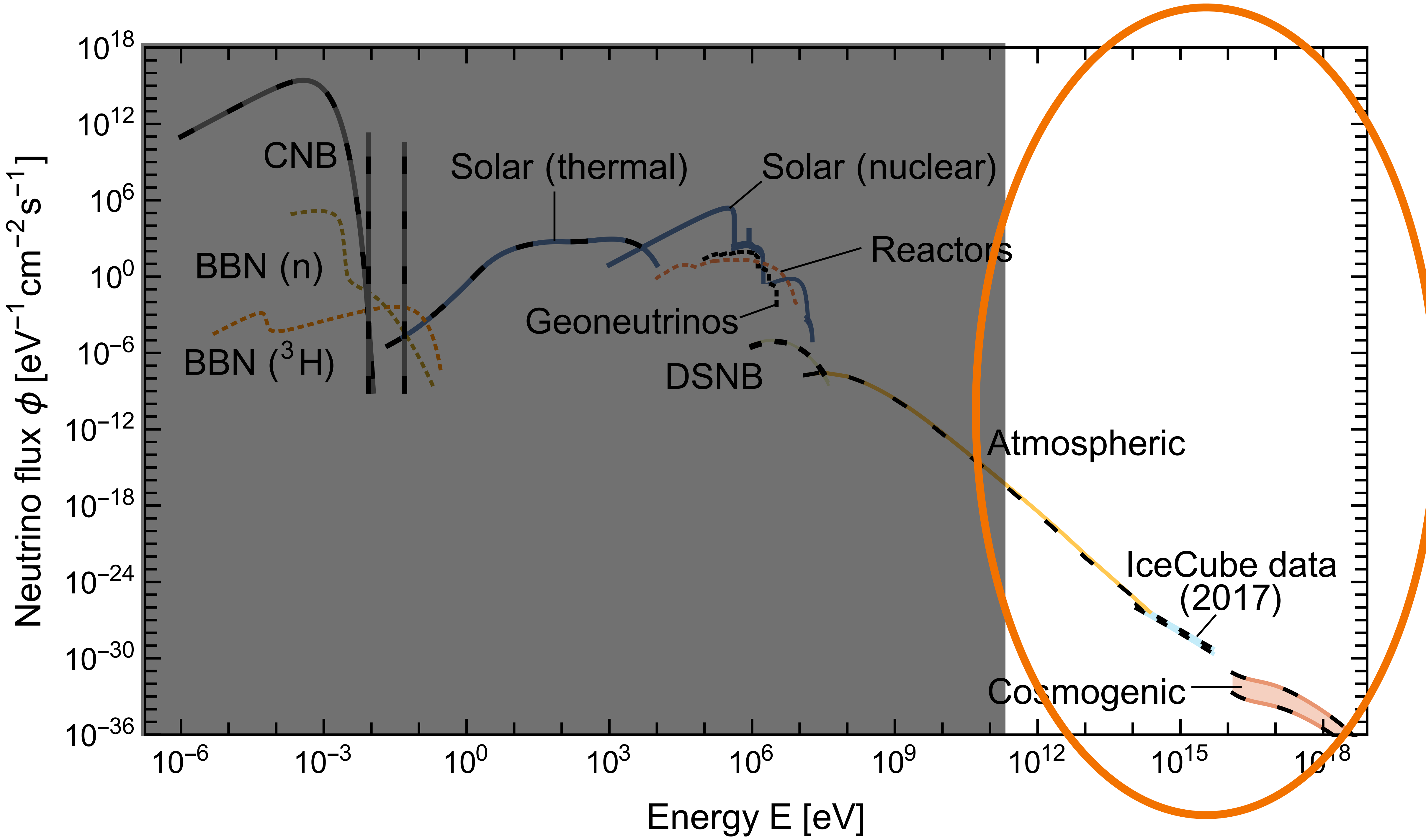
New Physics?

1907.08690 Argüelles,Bustamante,Kheirandish,Palomares-Ruiz,Salvado, ACV

Current observations: IceCube (south pole)

Effective volume $\sim 1\,\mathrm{km}^3$





large exposures necessary
due to low fluxes

Current observations: IceCube (south pole)

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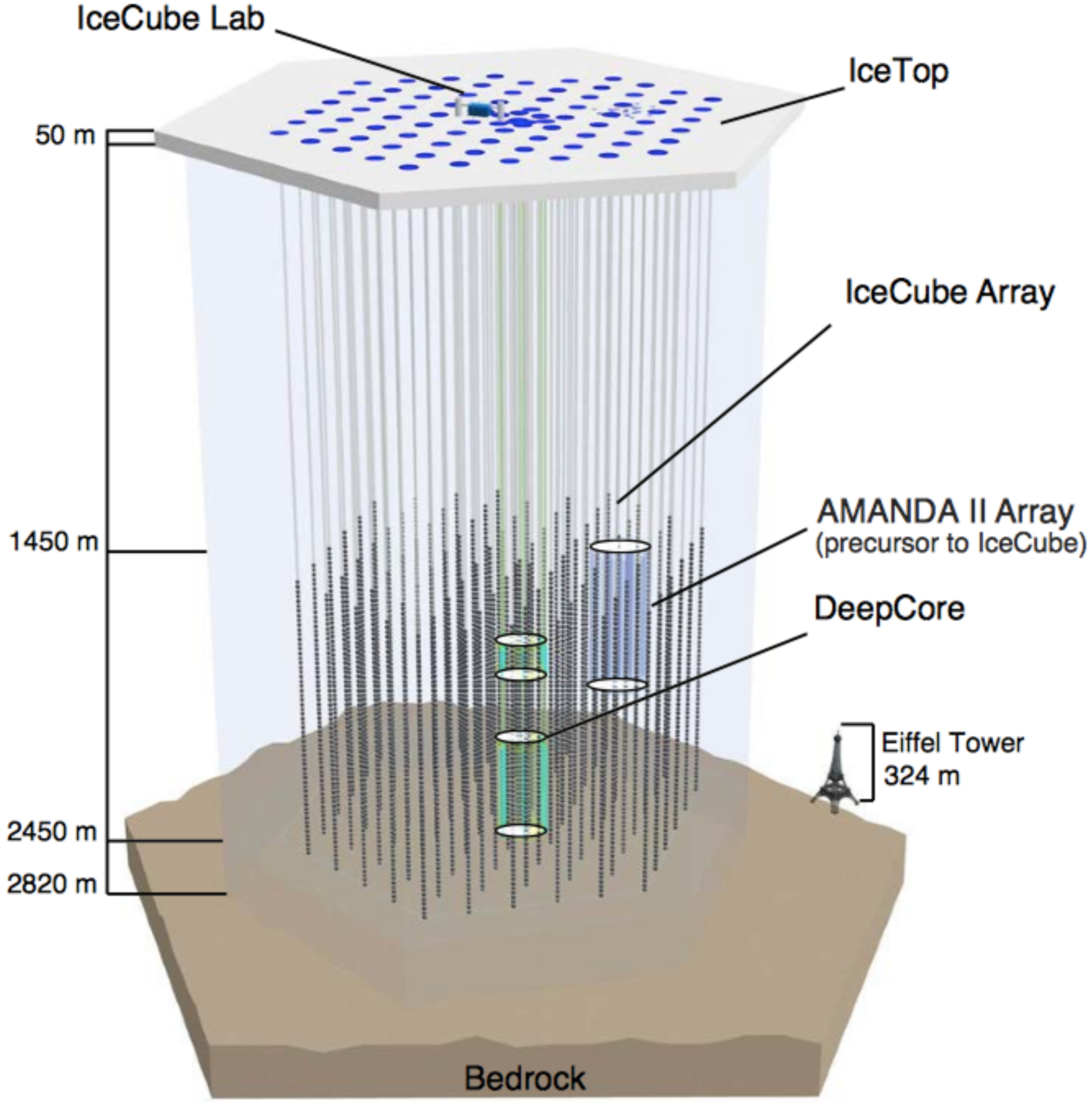

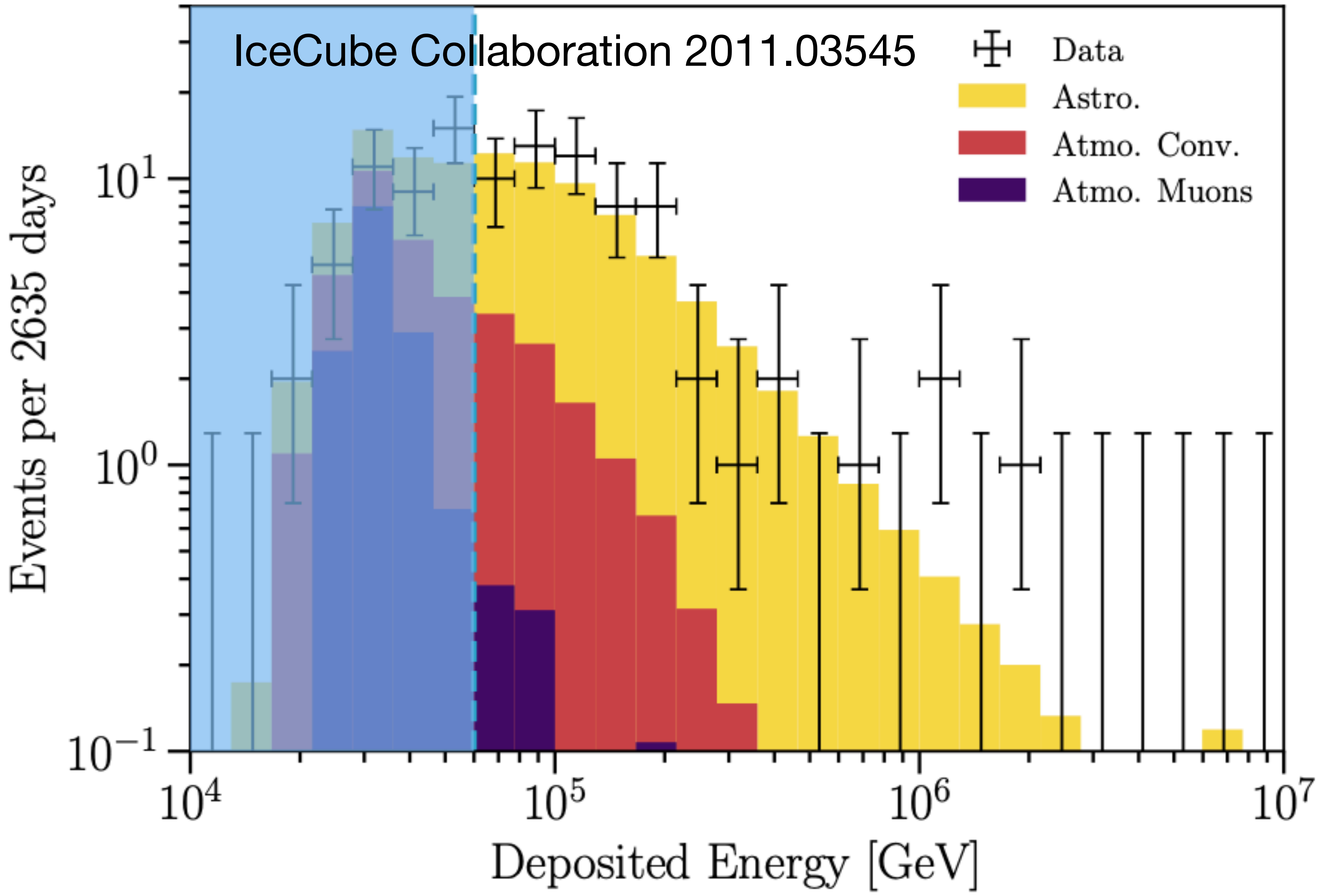

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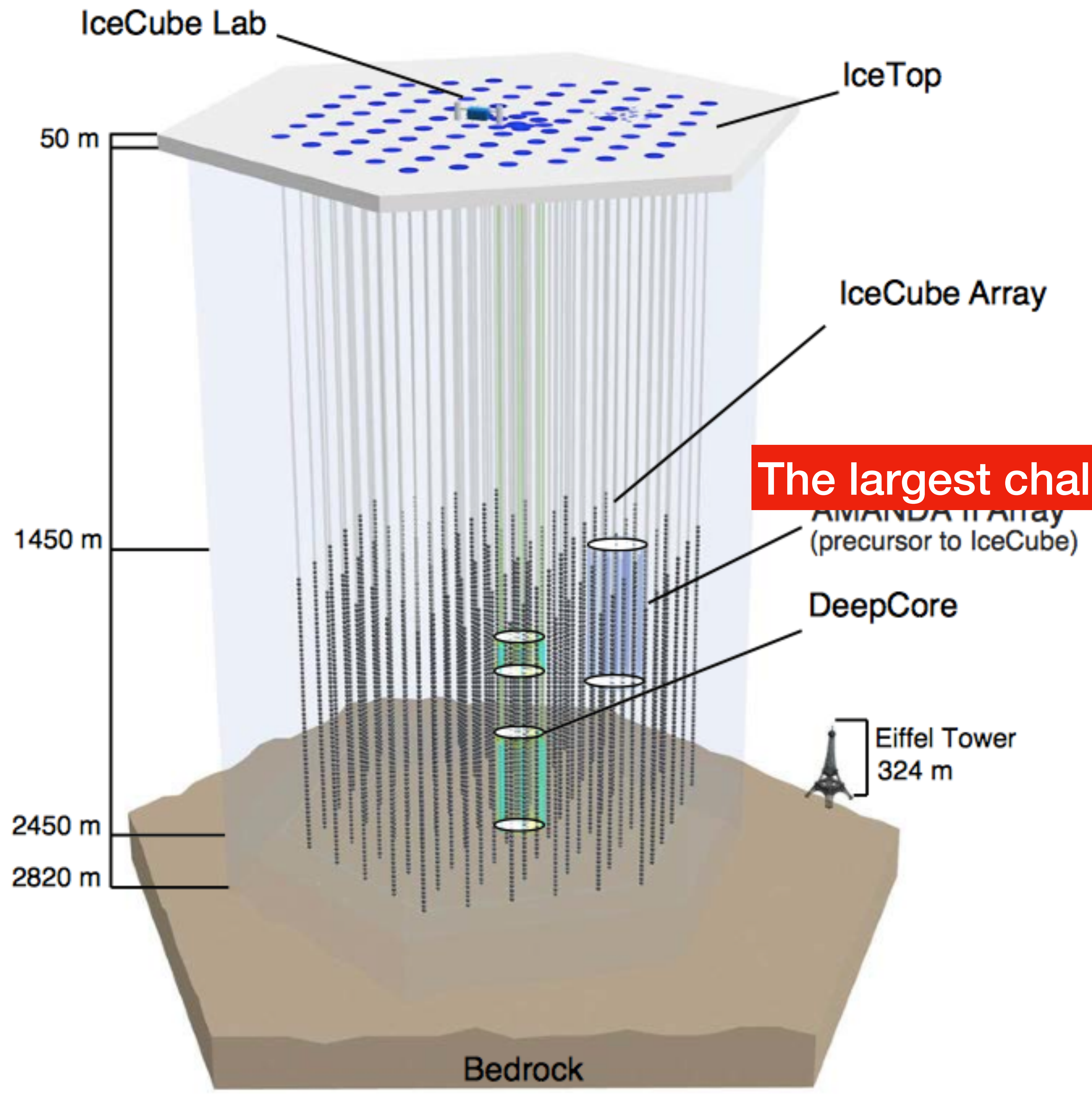
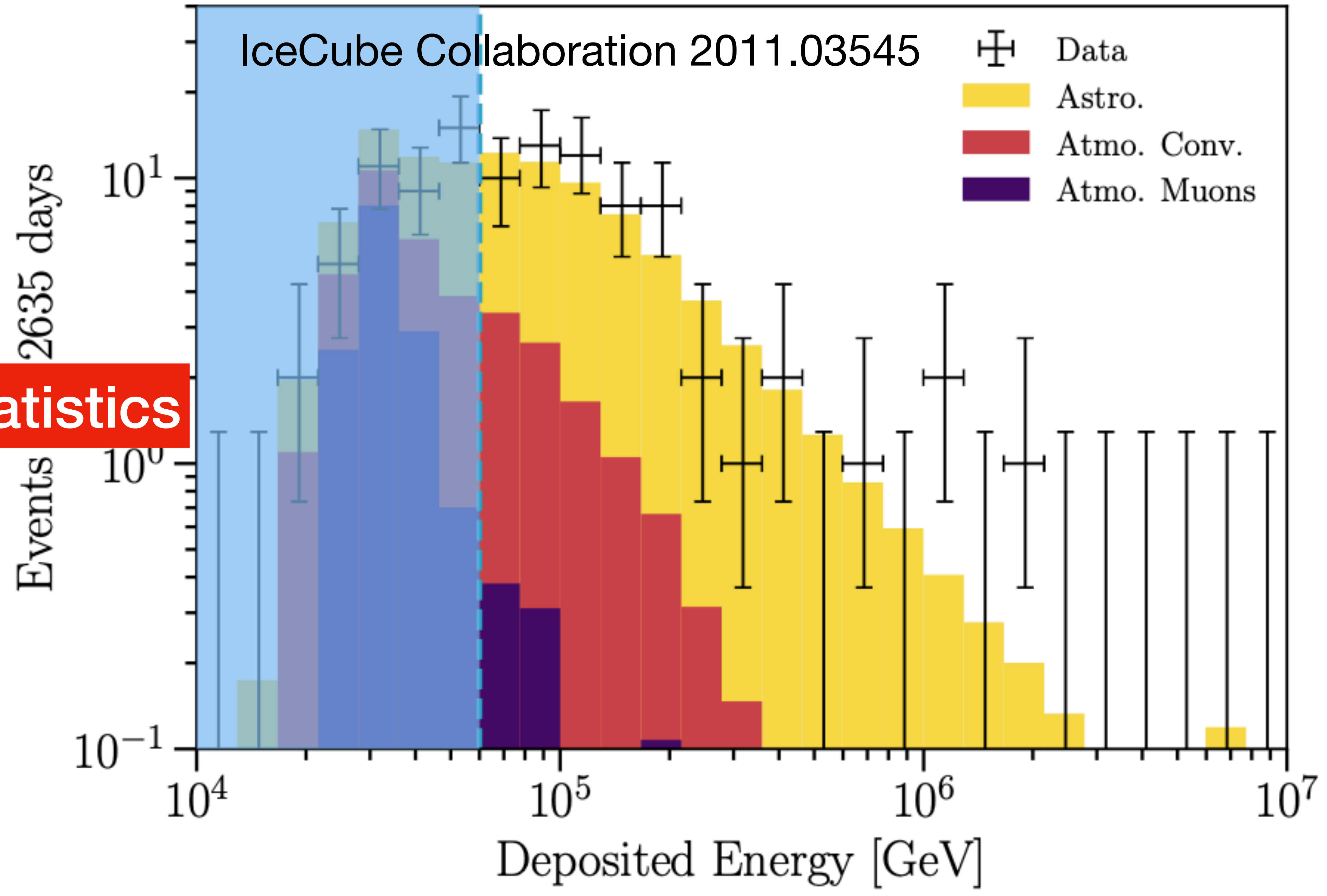
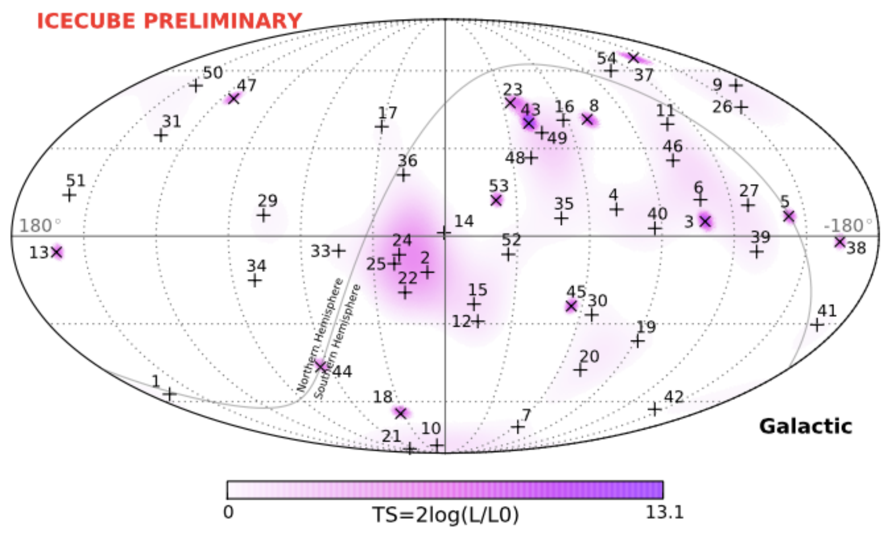


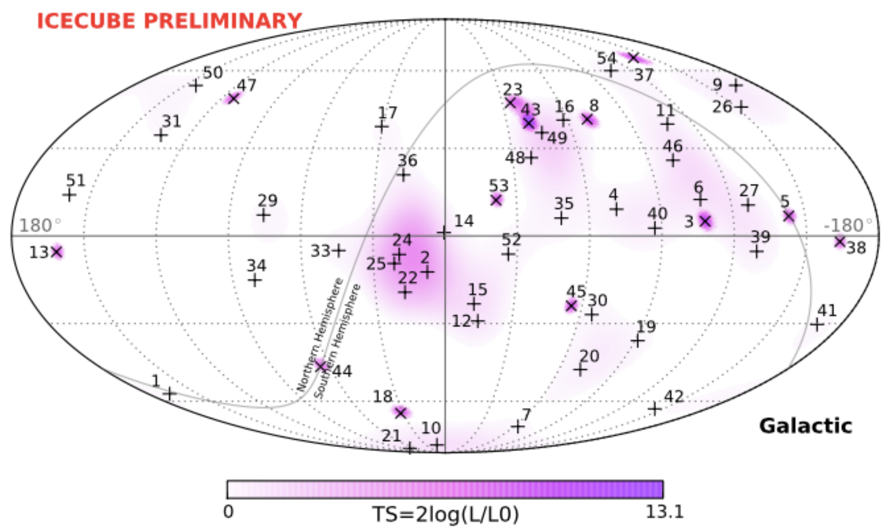
The largest challenge is low statistics



Arrival direction

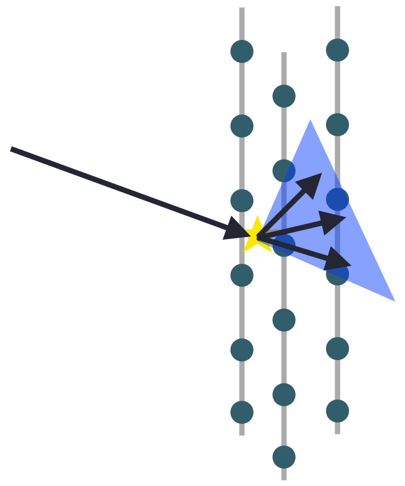


Arrival direction

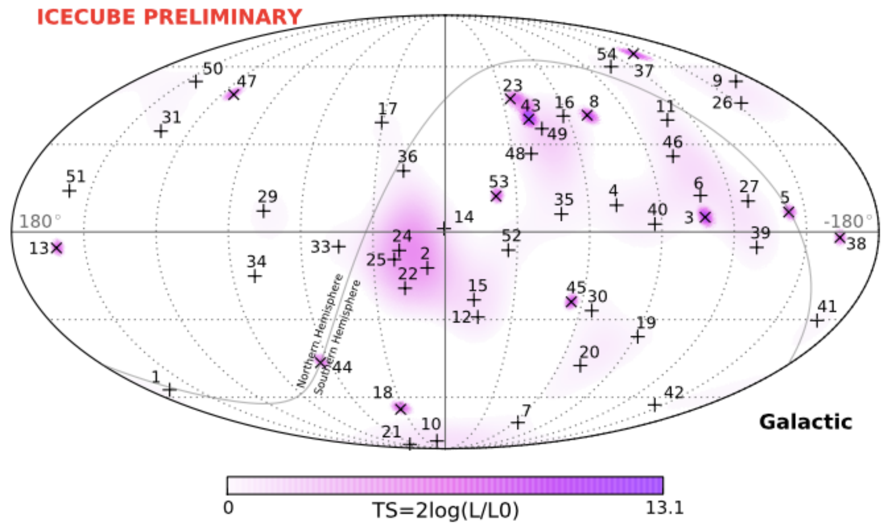


Energy

Deposited EM-equivalent



Arrival direction



Energy

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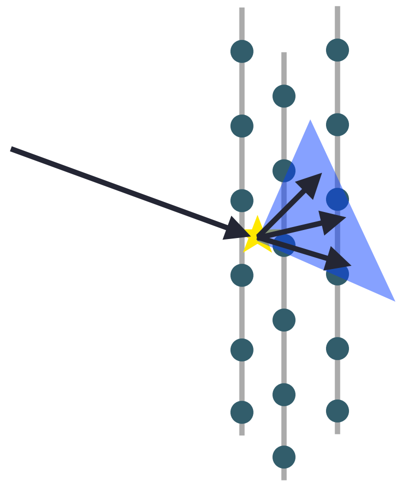
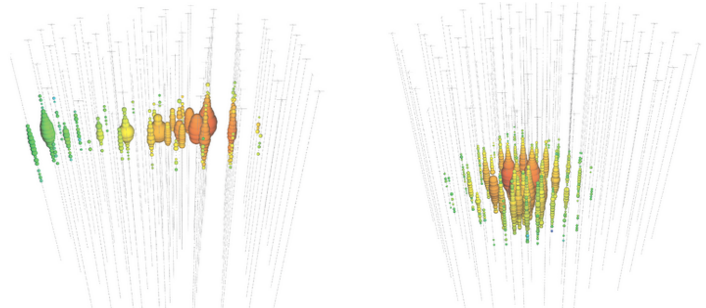


Flavour (e, μ, τ)

Morphology

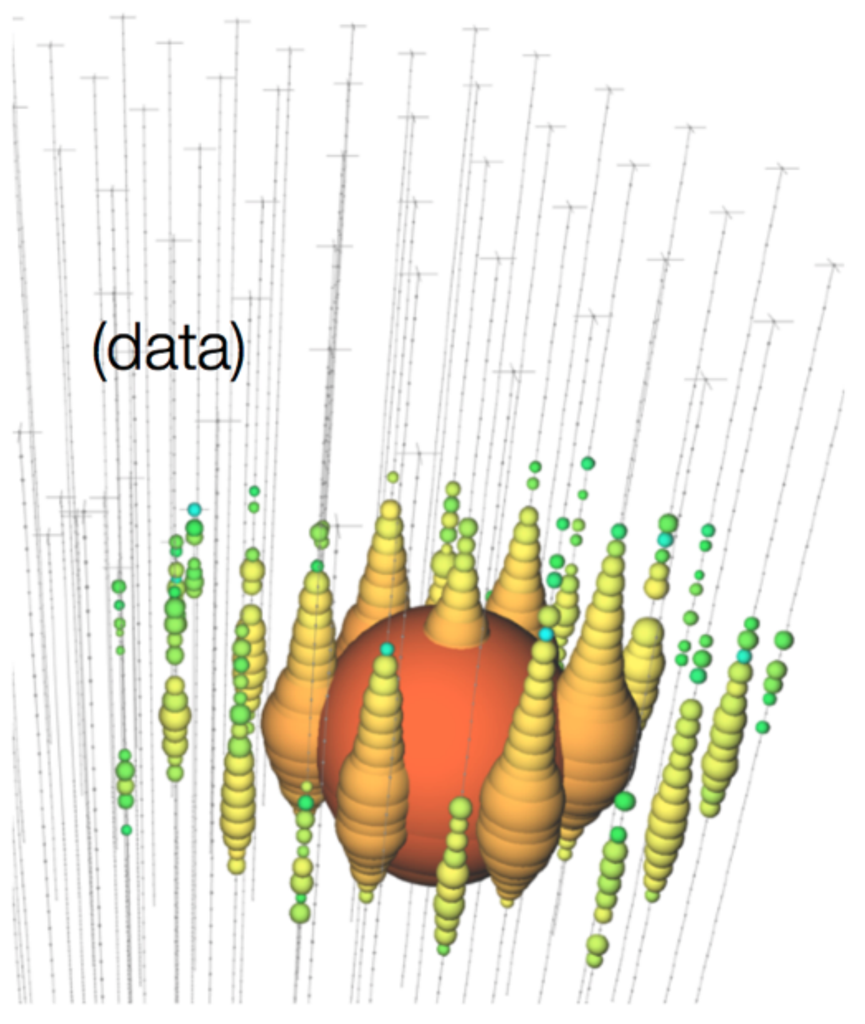


muon track

shower

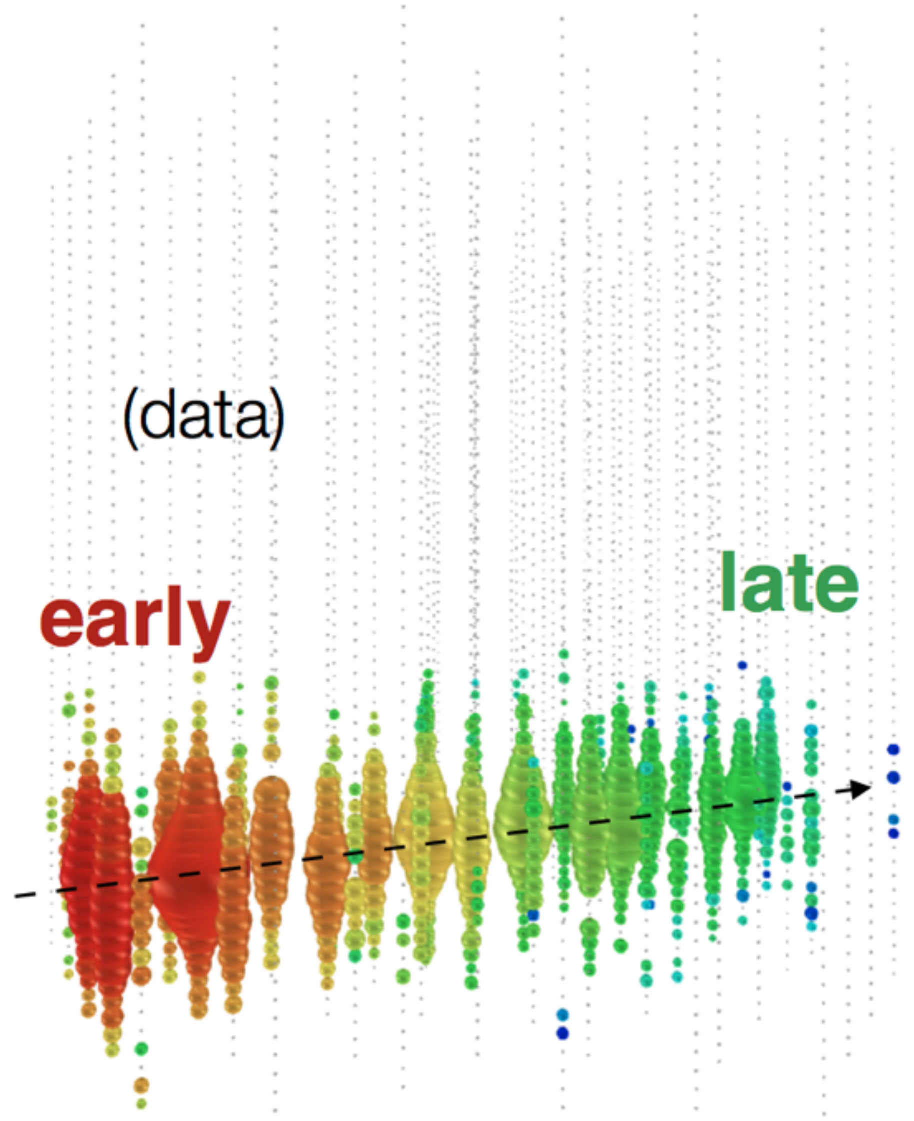
Flavour: event morphology

Neutral-current / ν_e



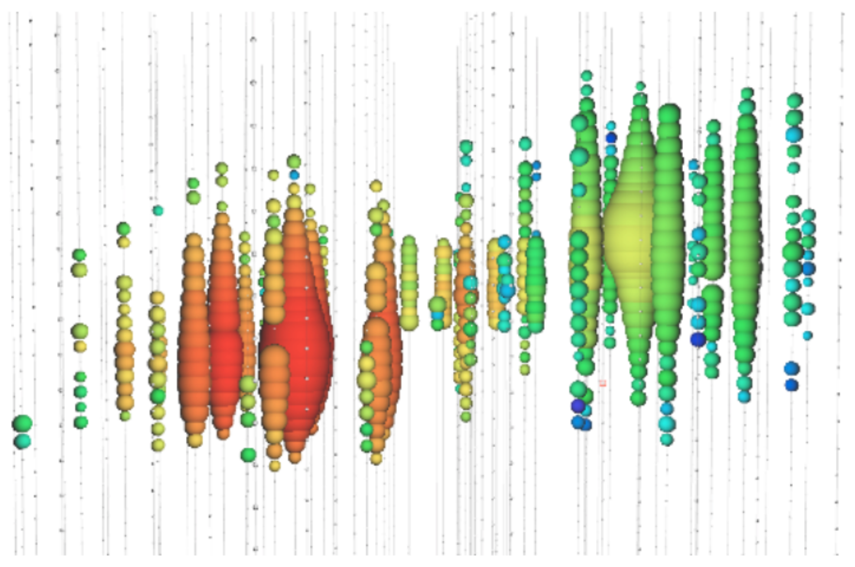
Isolated energy deposition (cascade) with no track

Charged-current ν_μ



Up-going track

Charged-current ν_τ



Double cascade

Angular resolution: crap ok depends

Images: icecube.wisc.edu

Flavour composition in astrophysical sources

(GRBs, AGNs, blazars, pulsars…)

$(\alpha_e : \alpha_\mu : \alpha_\tau)$

Pion sources

(c.c. for π^-)

$\pi^+ \to \mu^+ + \nu_\mu$

$\mu^+ \to e^+ + \nu_\mu + \bar{\nu}_e$

(1 : 2 : 0)

“muon-damped”

(c.c. for π^-)

$\pi^+ \to \cancel{\mu^+} + \nu_\mu$

(0 : 1 : 0)

“muon source”

(c.c. for π^-)

$\pi^+ \to \mu^+ + \cancel{\nu_\mu}$

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(1 : 1 : 0)

Neutron source $n \to p + e^- + \bar{\nu}_e$

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Different scenarios: different production environments

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Neutron source

$n \to p + e^- + \bar{\nu}_e$

(1 : 0 : 0)

Different scenarios: different production environments

Flavour can be distinguished **statistically** in neutrino detectors: different charged-current interactions lead to different event **morphologies** (there is some degeneracy)

Flavour composition in astrophysical sources

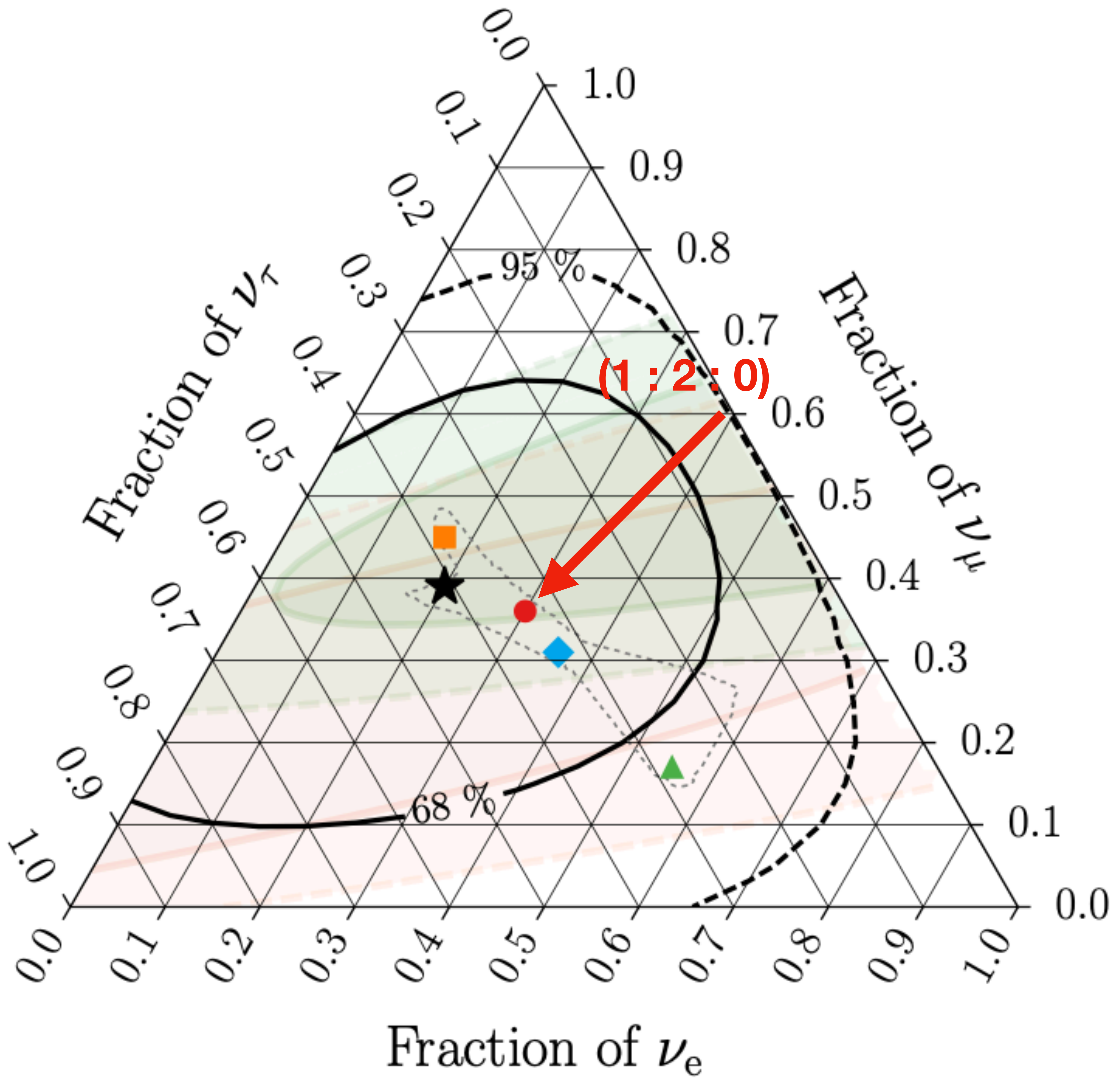
(GRBs, AGNs, blazars, pulsars…)

Source	Process	$(\alpha_e : \alpha_\mu : \alpha_\tau)$
Pion sources (c.c. for π^-)	$\pi^+ \to \mu^+ + \nu_\mu$, $\mu^+ \to e^+ + \nu_\mu + \bar{\nu}_e$	**(1 : 2 : 0)**
“muon-damped” (c.c. for π^-)	$\pi^+ \to \cancel{\mu^+} + \nu_\mu$	**(0 : 1 : 0)**
“muon source” (c.c. for π^-)	$\pi^+ \to \mu^+ + \cancel{\nu_\mu}$, $\mu^+ \to e^+ + \nu_\mu + \bar{\nu}_e$	**(1 : 1 : 0)**
Neutron source	$n \to p + e^- + \bar{\nu}_e$	**(1 : 0 : 0)**

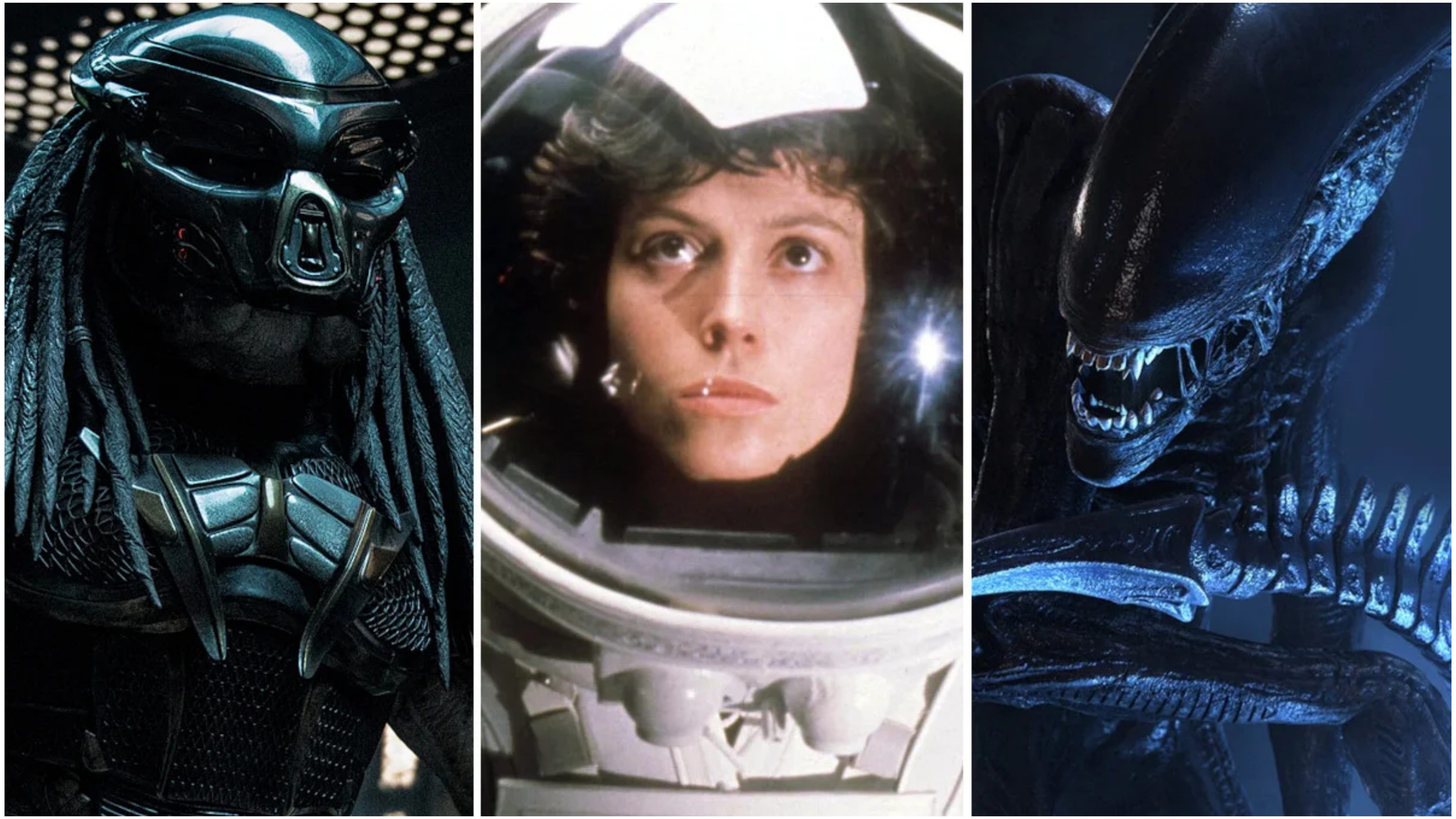
Different scenarios: different production environments

Flavour can be distinguished **statistically** in neutrino detectors: different charged-current interactions lead to different event **morphologies** (there is some degeneracy)

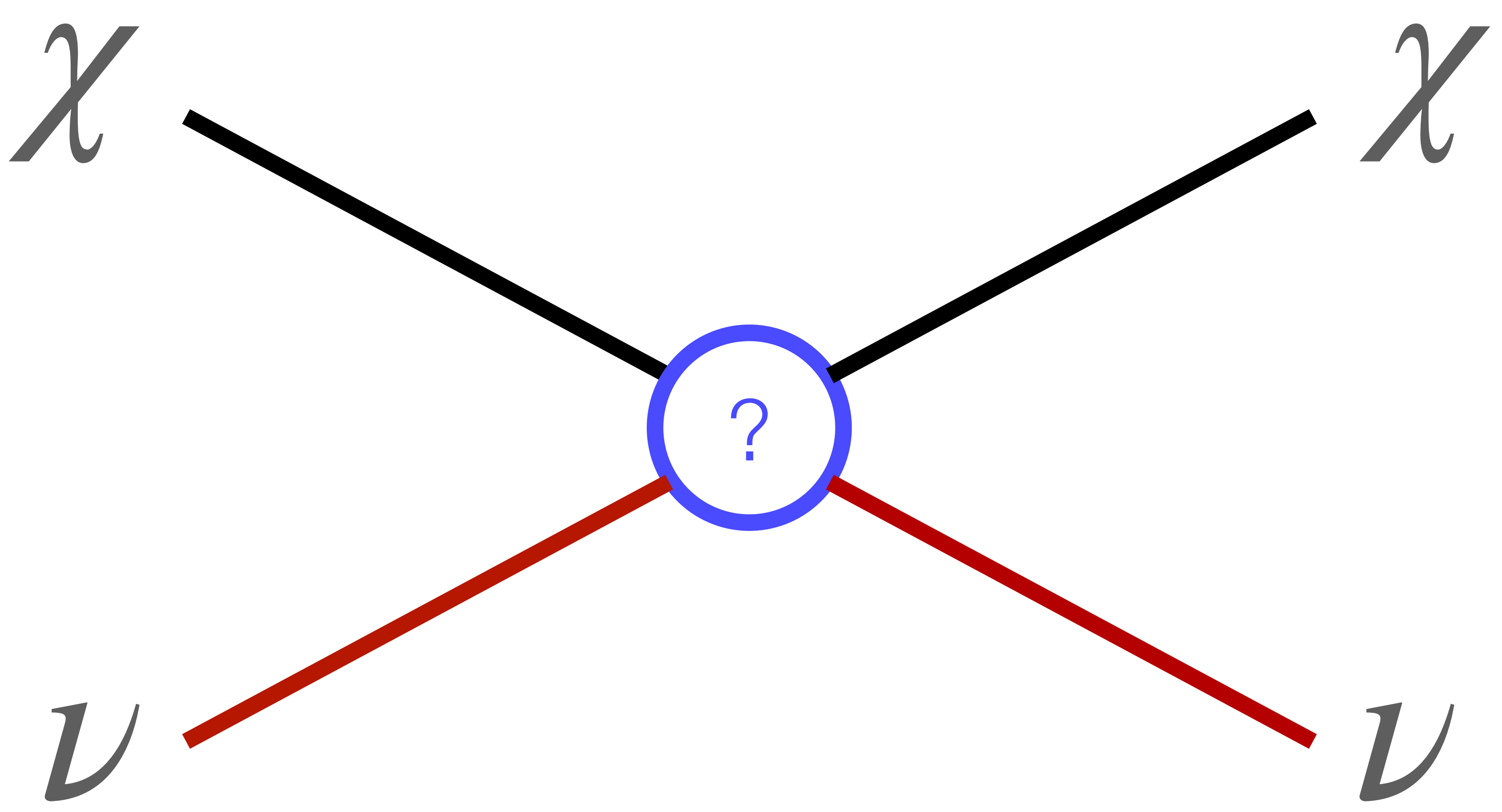
Everything oscillates to ~ 1:1:1



Dark Matter?



Elastic scattering



Elastic scattering

We've just heard about limits on dark matter-neutrinos scattering at low (~recombination) energies.

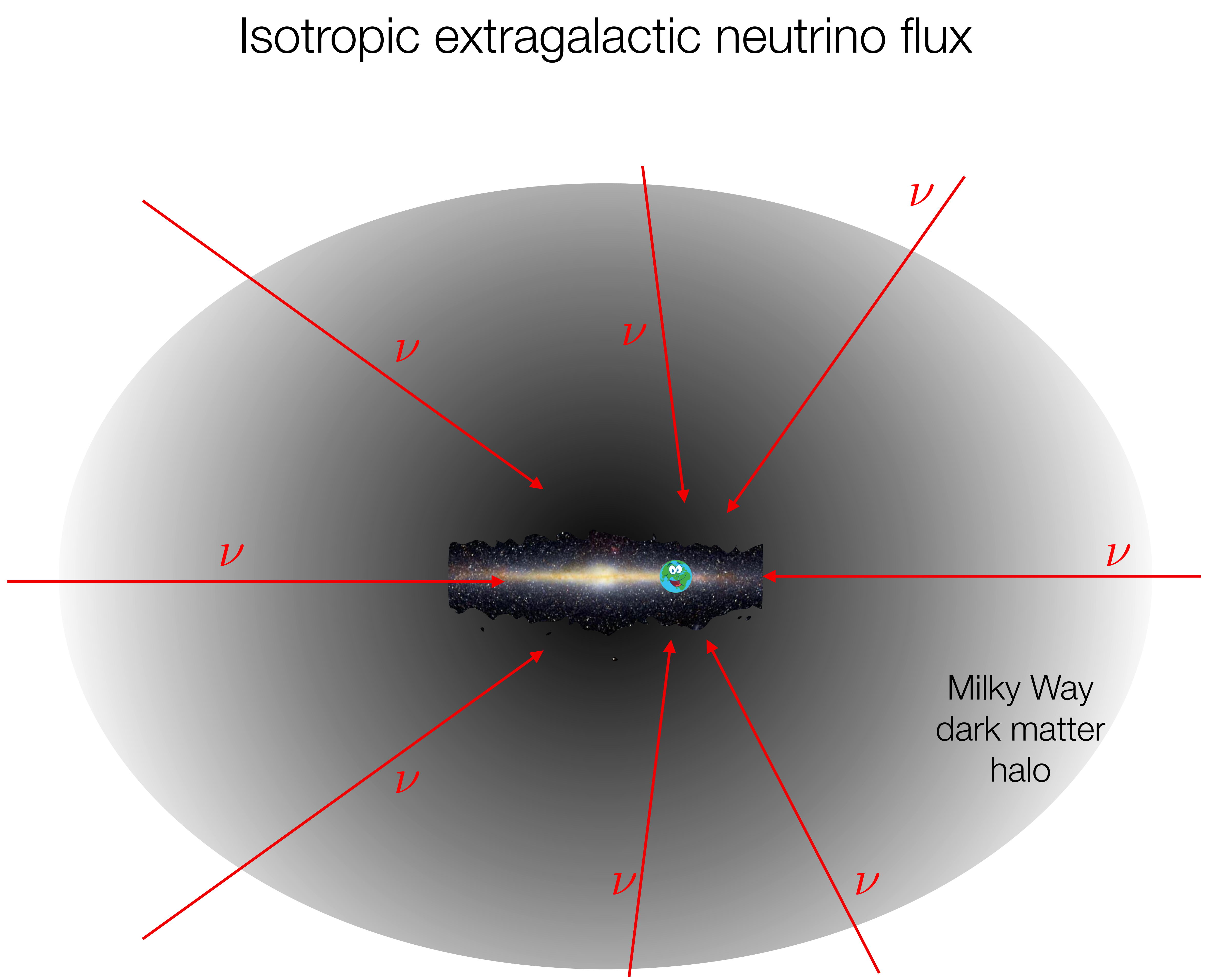
Generically, cross sections grow as $s = E_{CM}^2$

$$\sigma_{DM-\nu} \propto E_\nu^2$$

IceCube has seen events above a PeV….

$$\left(\frac{\mathrm{PeV}}{T_{\nu,recomb.}}\right)^2 \sim 10^{30}$$

Let's look there!



b, l: galactic latitude, longitude

column density: $\tau(b,l) = \int_{l.o.s} n_\chi(x;b,l)\;dx.$

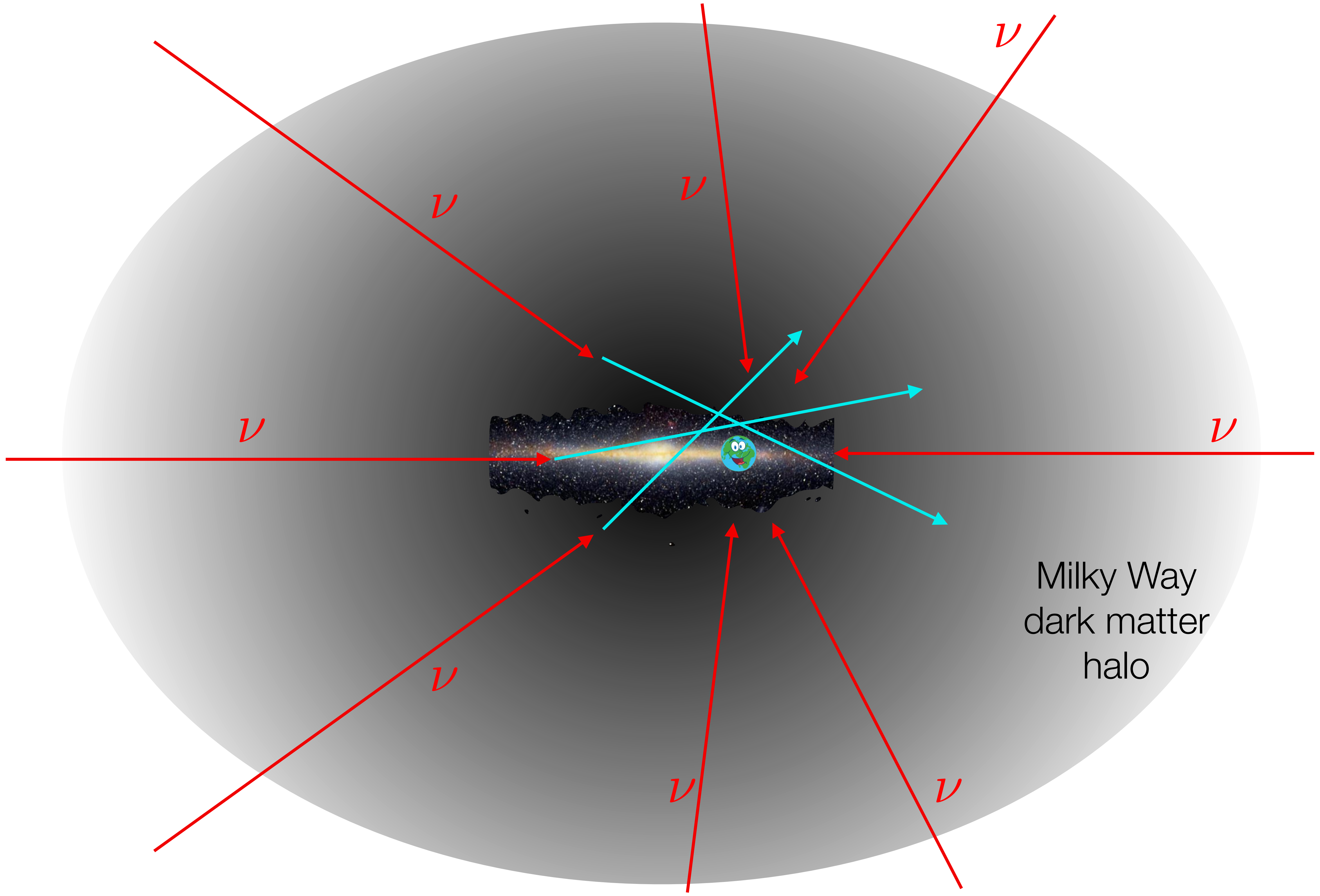
$$\frac{d\Phi(E,\tau)}{d\tau} = -\sigma(E)\Phi(E,\tau) + \int_E^\infty d\tilde{E}\,\frac{d\sigma(\tilde{E},E)}{dE}\Phi(\tilde{E},\tau)$$

scattering **from** *E* to any energy

scattering **to** *E* from any energy $\tilde{E}$

Solve to find flux at earth at energy E and direction (b,l)

Isotropic extragalactic neutrino flux



Anisotropic deflection/energy loss

b, l: galactic latitude, longitude

column density: $\tau(b,l) = \int_{l.o.s} n_\chi(x;b,l)\ dx.$

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scattering **from** *E* to any energy

scattering **to** *E* from any energy $\tilde{E}$

Solve to find flux at earth at energy E and direction (b,l)

Solve by being clever

$$\frac{d\Phi(E,\tau)}{d\tau} = -\sigma(E)\Phi(E,\tau) + \int_E^\infty d\tilde{E}\frac{d\sigma(\tilde{E},E)}{dE}\Phi(\tilde{E},\tau)$$

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$$\frac{d\Phi(E,\tau)}{d\tau} = -\sigma(E)\Phi(E,\tau) + \int_E^\infty d\tilde{E}\frac{d\sigma(\tilde{E},E)}{dE}\Phi(\tilde{E},\tau)$$

$$E \to \vec{E} \qquad \Phi \to \vec{\Phi} \qquad C_{ij} = d\tilde{E}_i\frac{d\sigma}{dE}(\tilde{E}_i, E_j)$$

Solve by being clever

$$\frac{d\Phi(E,\tau)}{d\tau} = -\sigma(E)\Phi(E,\tau) + \int_E^\infty d\tilde{E}\frac{d\sigma(\tilde{E},E)}{dE}\Phi(\tilde{E},\tau)$$

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$$\vec{\Phi}'(\tau) = -(\mathrm{diag}(\vec{\sigma}) + C)\vec{\Phi}(\tau)$$

λ_i eigenvalues

$\hat{\phi}_i$ eigenvectors

$$\vec{\Phi} = \sum c_i \hat{\phi}_i e^{\lambda_i \tau}$$

Solve by being clever

$$\frac{d\Phi(E,\tau)}{d\tau} = -\sigma(E)\Phi(E,\tau) + \int_E^\infty d\tilde{E}\frac{d\sigma(\tilde{E},E)}{dE}\Phi(\tilde{E},\tau)$$

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λ_i eigenvalues
$\hat{\phi}_i$ eigenvectors

$$\vec{\Phi} = \sum c_i \hat{\phi}_i e^{\lambda_i \tau}$$

c_i*'s* determined by initial condition of isotropic power law flux

$$\sigma_{DM-\nu} \propto E_\nu^2 \quad \xrightarrow[??]{} \left(\frac{\text{PeV}}{T_{\nu,recomb.}}\right)^2 \sim 10^{30}$$

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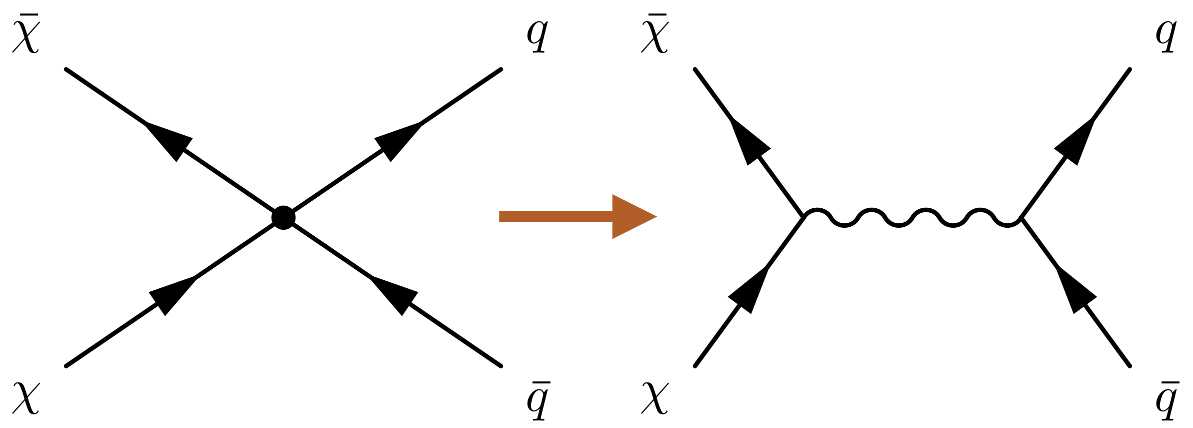
No!

$$\sigma_{DM-\nu} \propto E_\nu^2 \xrightarrow[??]{} \left(\frac{\text{PeV}}{T_{\nu,recomb.}}\right)^2 \sim 10^{30}$$ No!

$$E \to \Lambda_{New\,physics}$$



The low energy approximation does not work at a PeV!!

Begin to resolve microphysics: **need more concrete model**

$$\sigma_{DM-\nu} \propto E_\nu^2 \xrightarrow[??]{} \left(\frac{\mathrm{PeV}}{T_{\nu,recomb.}}\right)^2 \sim 10^{30}$$

No!

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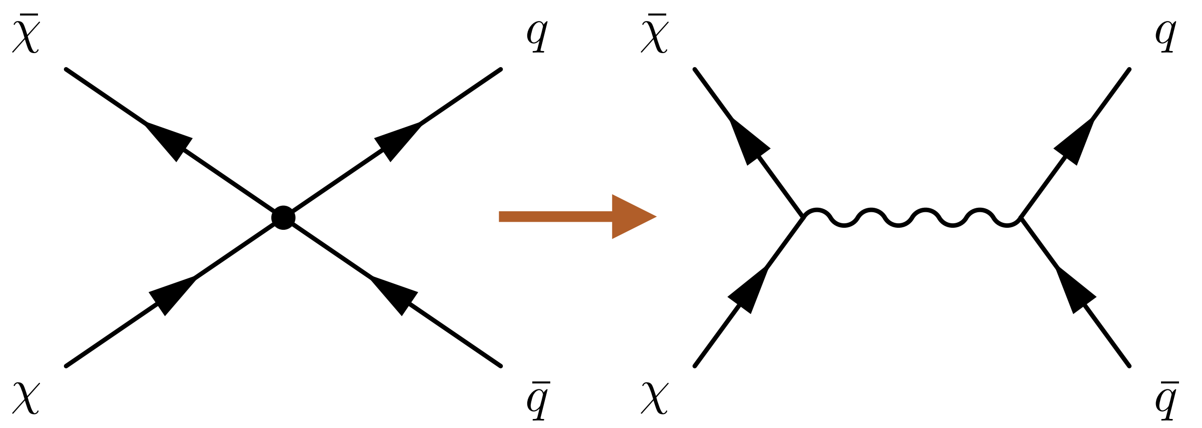

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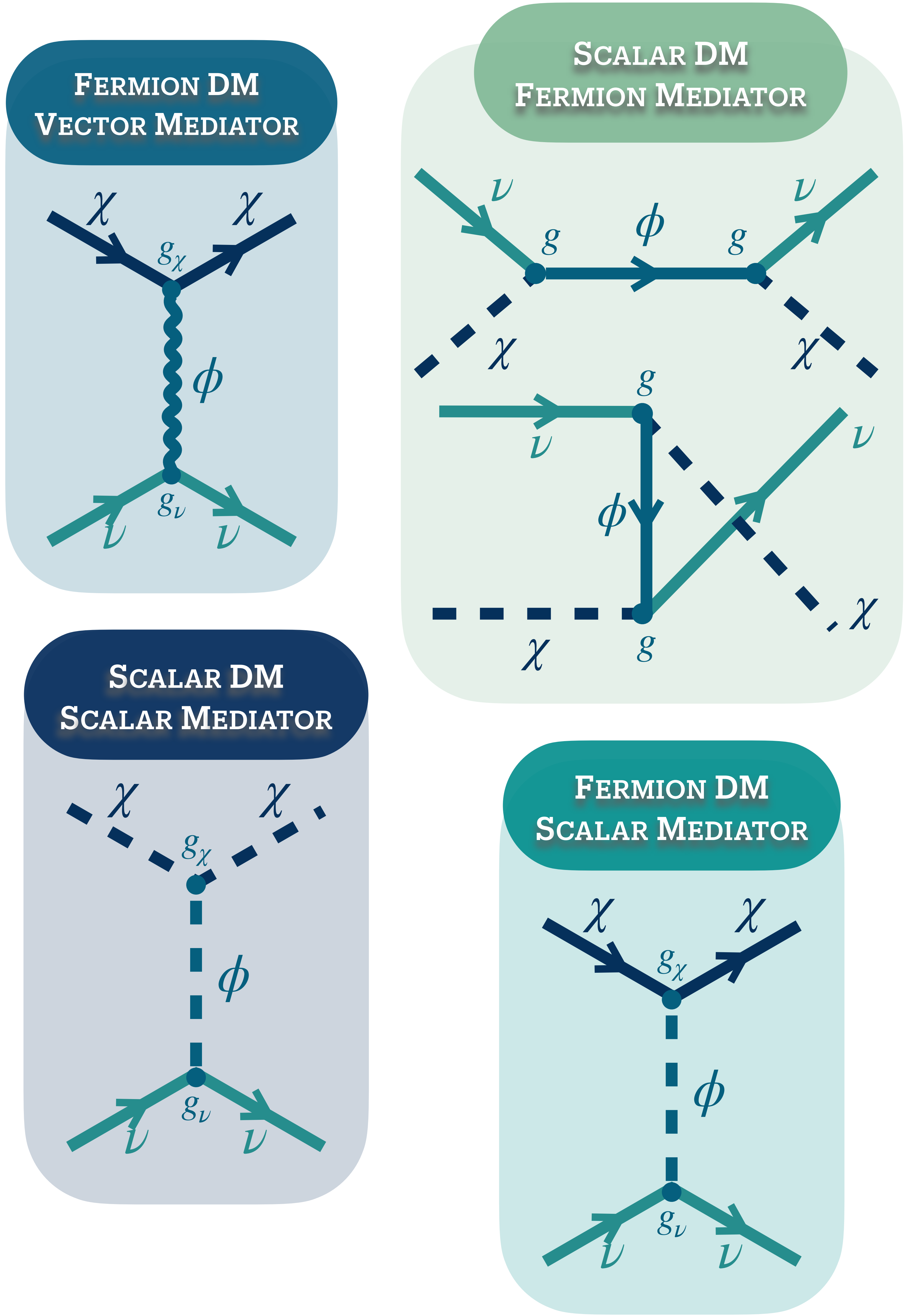
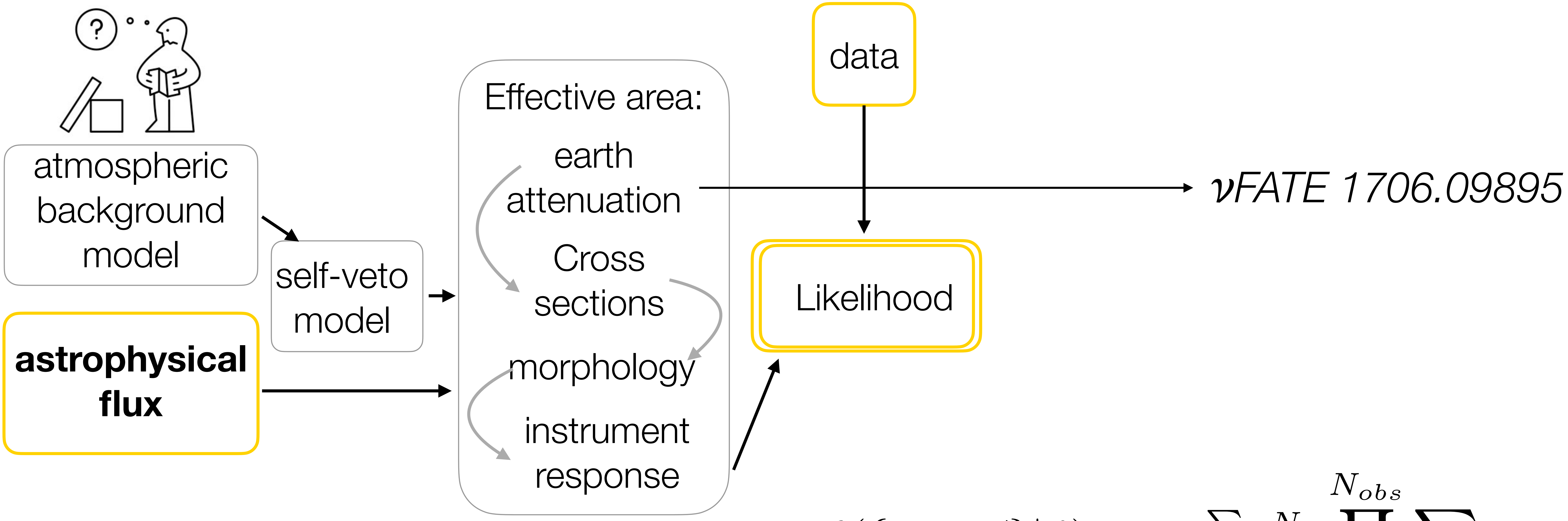


Some simplified models: specify
- Dark matter spin
- Mediator spin

Diyaselis Delgado



Classical recipe: 1502.02649

$$\mathcal{L}(\{t, E, \vec{x}\}|\vartheta) = e^{-\sum_a N_a} \prod_{i=1}^{N_{obs}} \sum_a N_a P_a(t_i, E_i, \vec{x}_i|\vartheta),$$

i: observed (or simulated) event

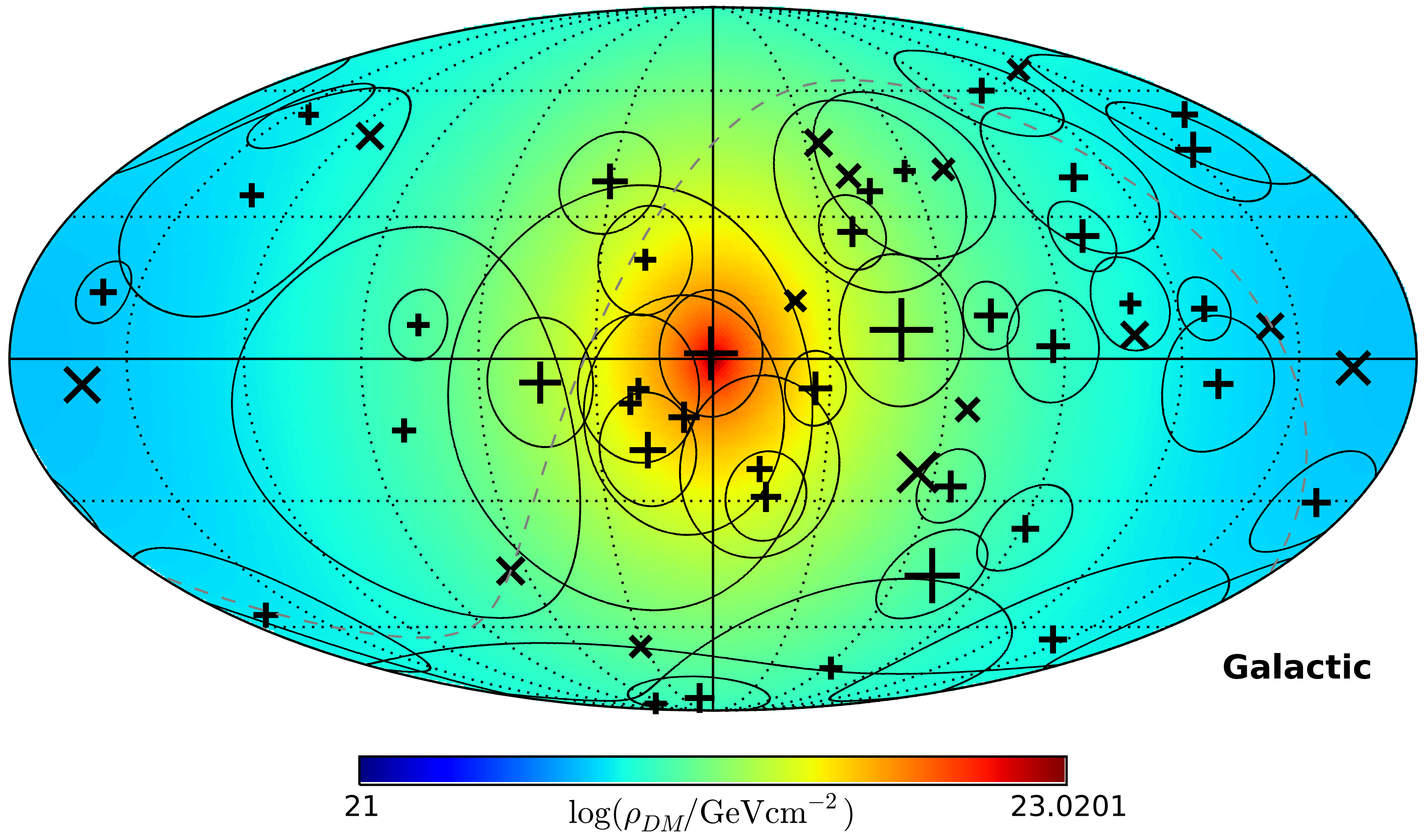
a: source (atmospheric muon, atm. neutrino, astro. neutrino)

t: morphology (track, shower)

E, x: Energy, arrival direction

$P_a(t_i, E_i, \vec{x}_i|\vartheta)$ Probability of given event properties, given model parameters ϑ

Dark matter column density seen from Earth



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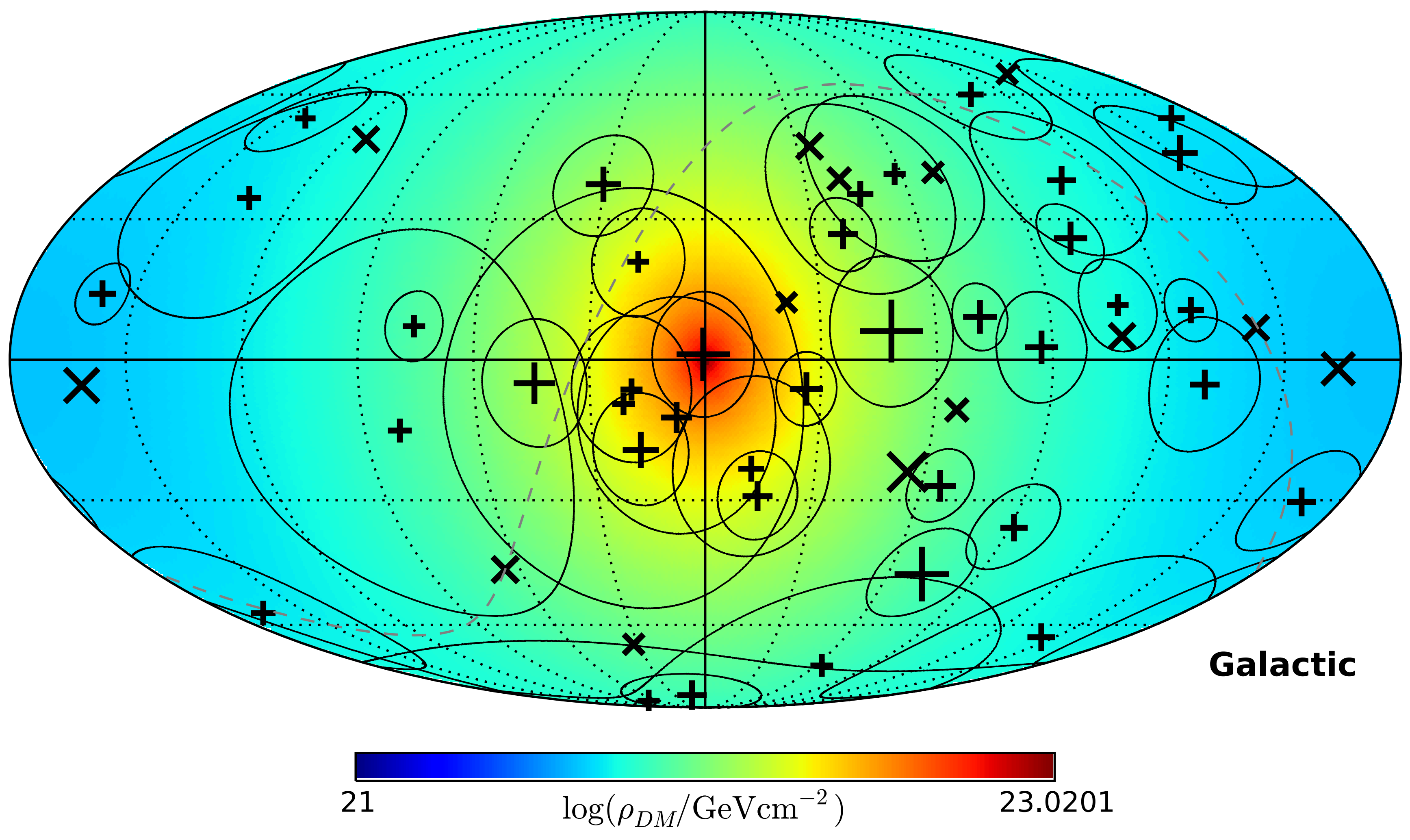
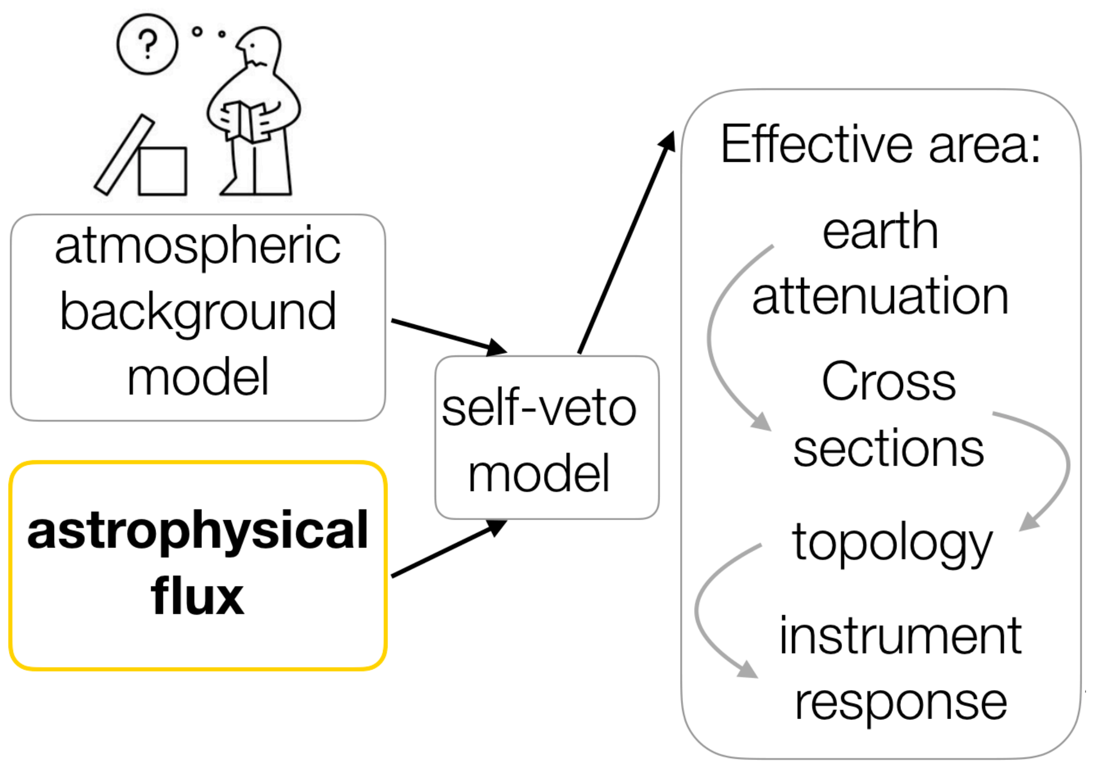
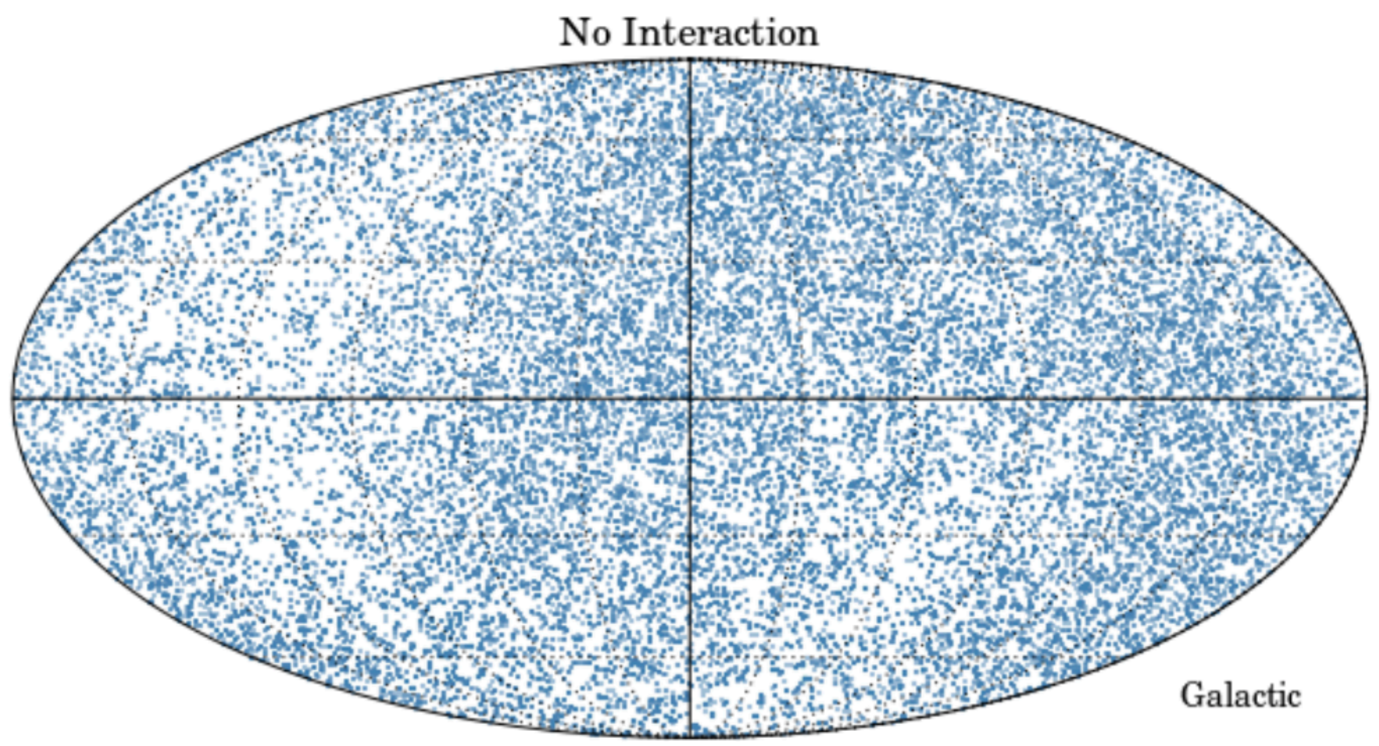


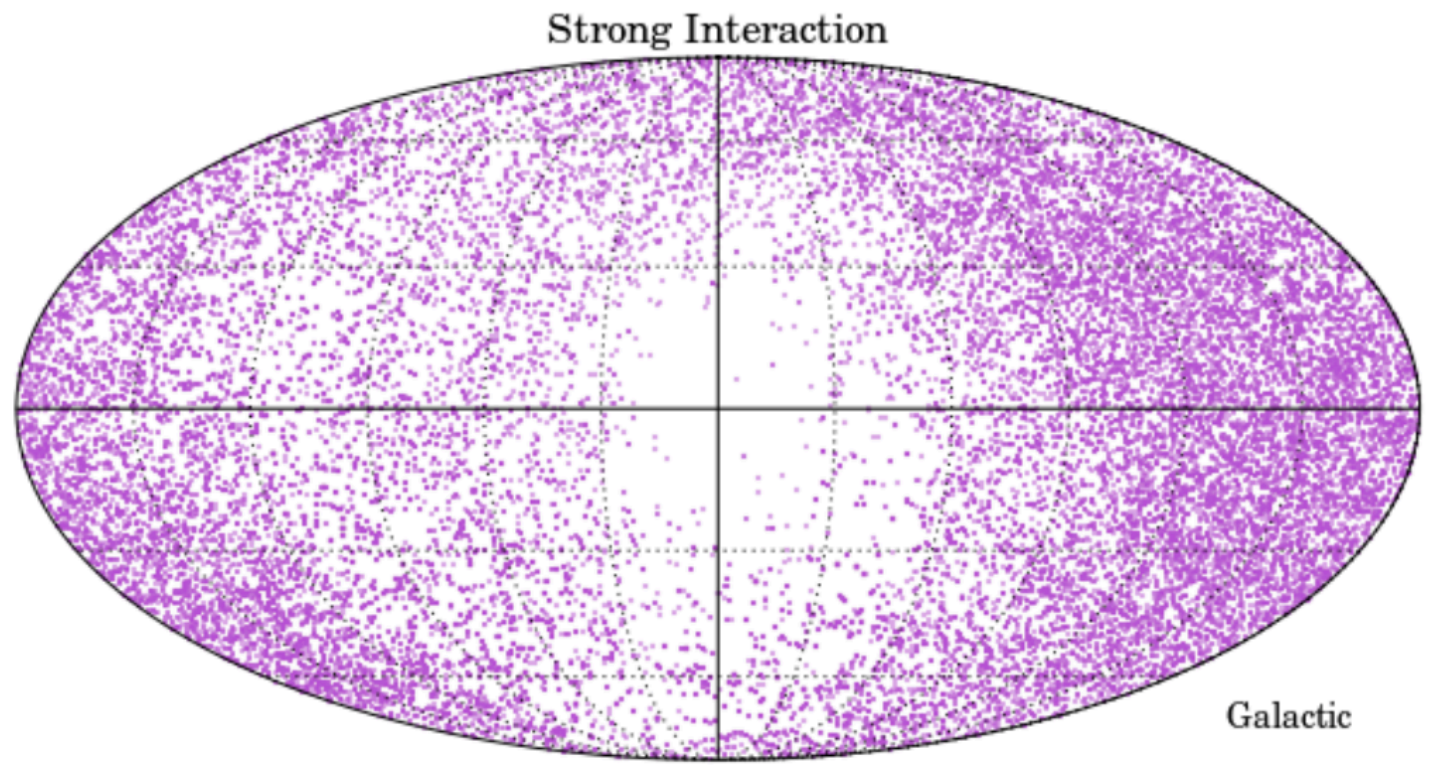
Simulation including effects of detector, Earth



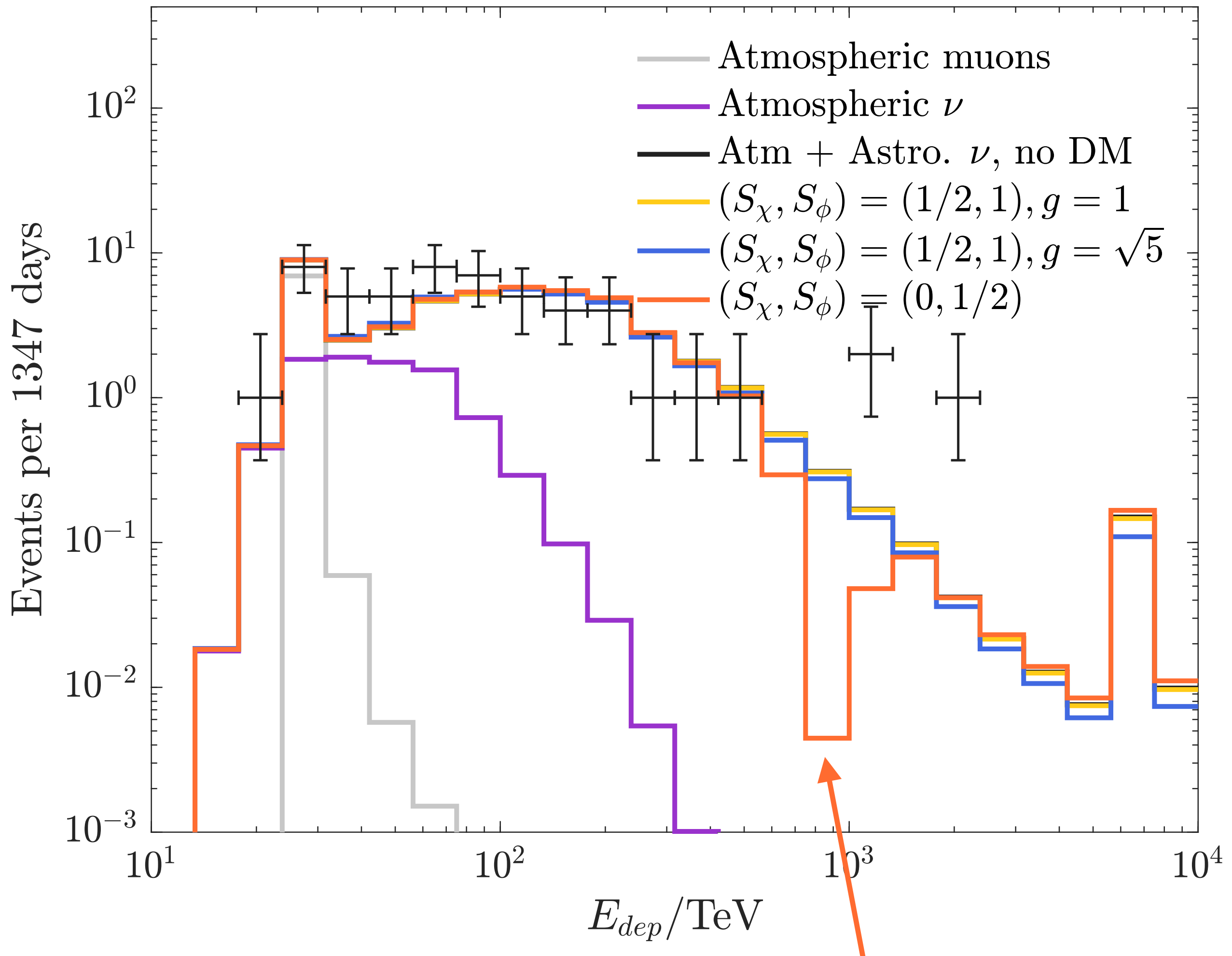
no interaction



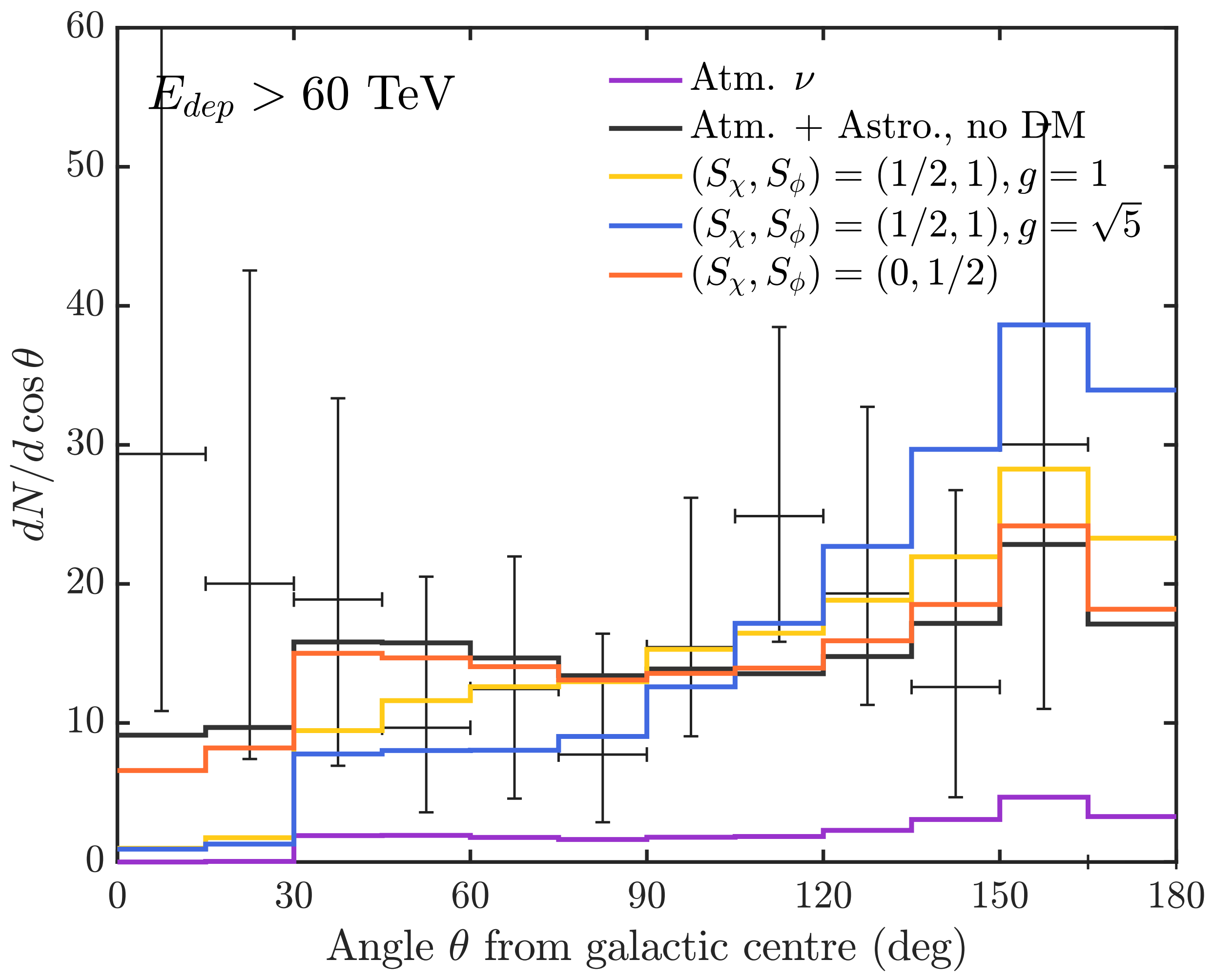
strong interaction



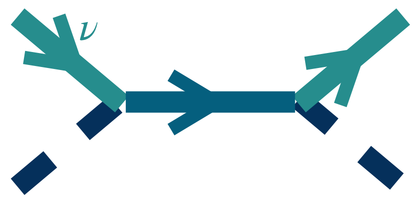
Energy



Angle from galactic centre



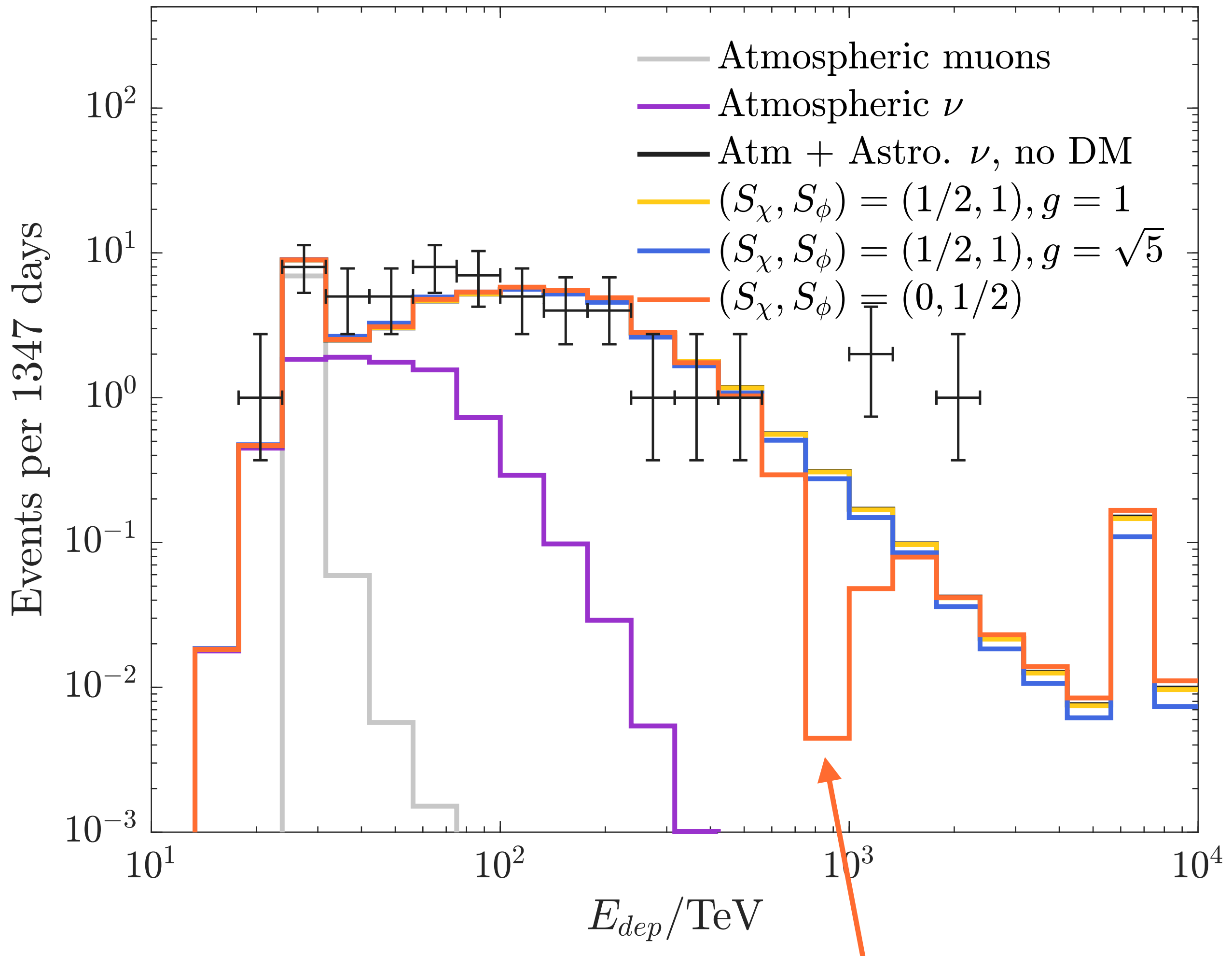
Resonance @ 810 TeV



IceCube HESE events

Argüelles, Kheirandish, ACV 1703.00451/PRL

Energy



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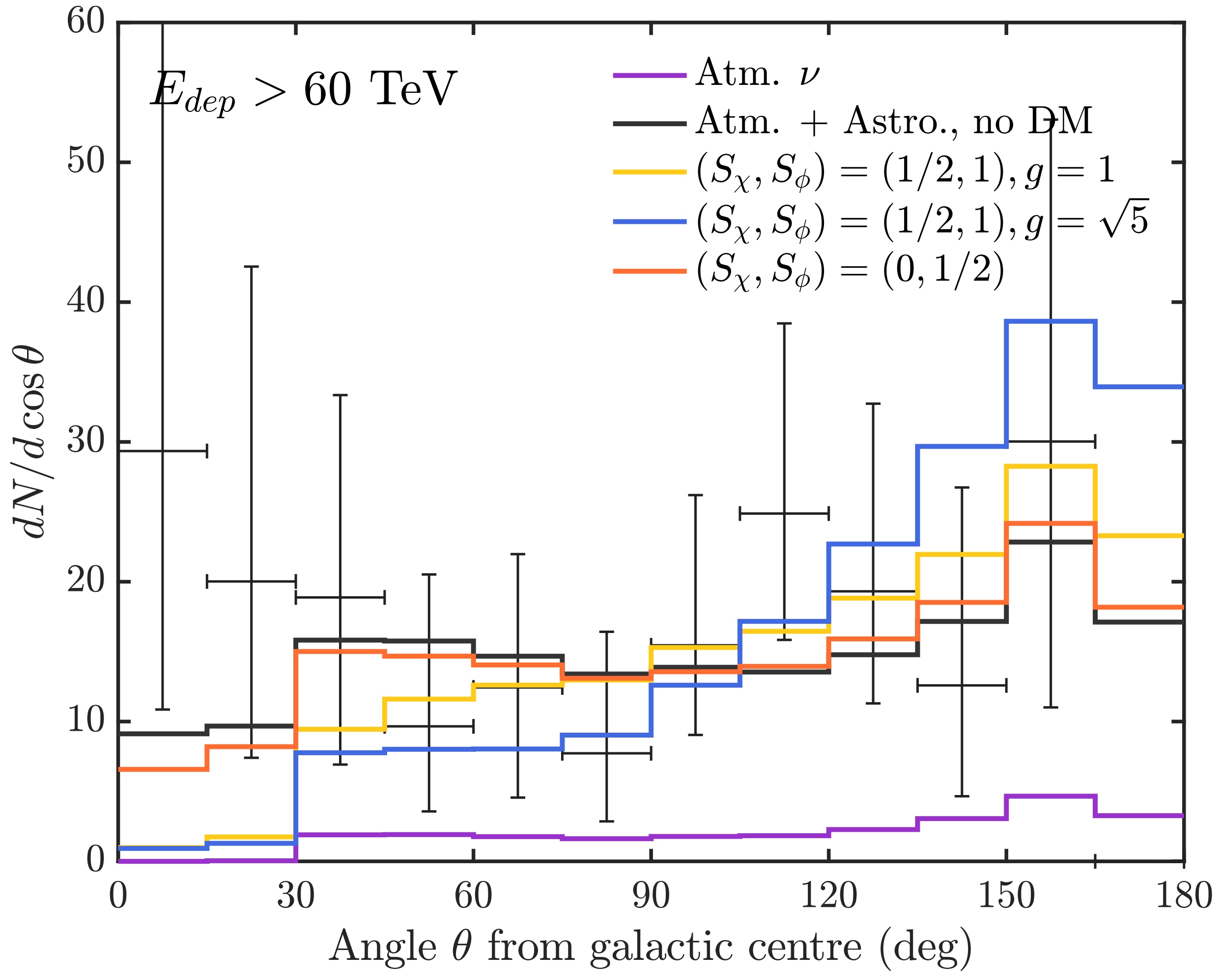

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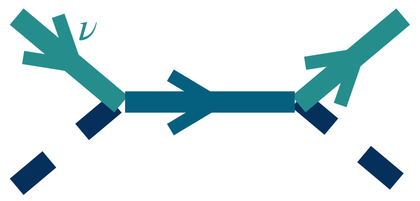

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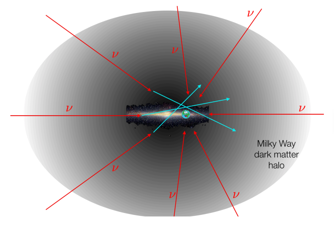
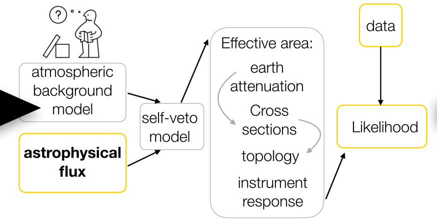


model

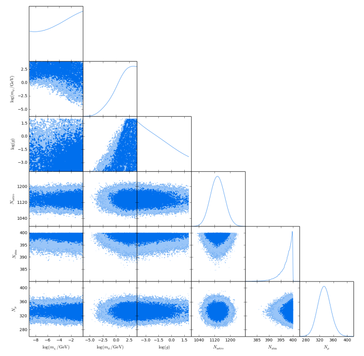


likelihood

IceCube data

emcee
The MCMC Hammer

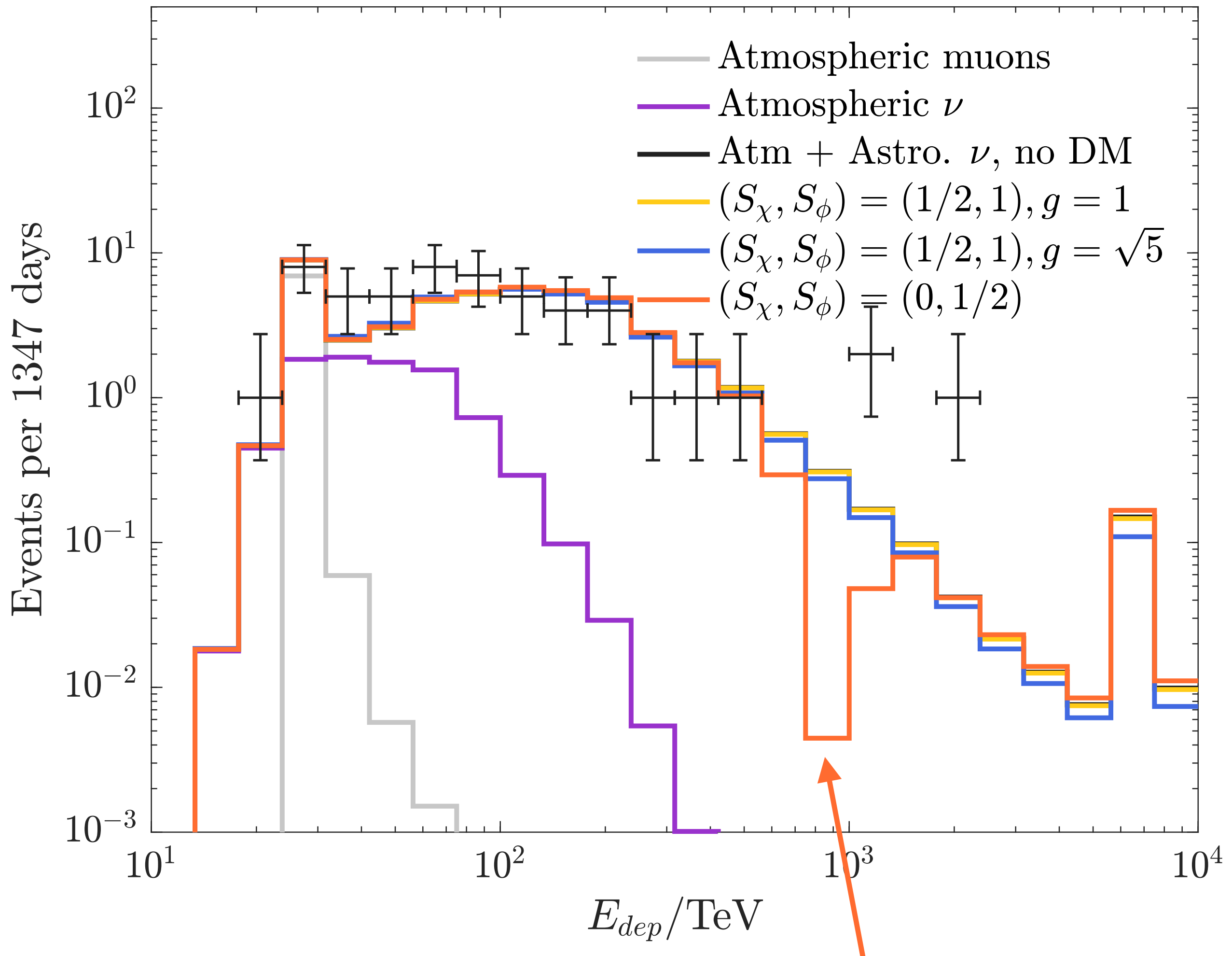
MCMC



posterior

Argüelles, Kheirandish, ACV 1703.00451/PRL

Energy



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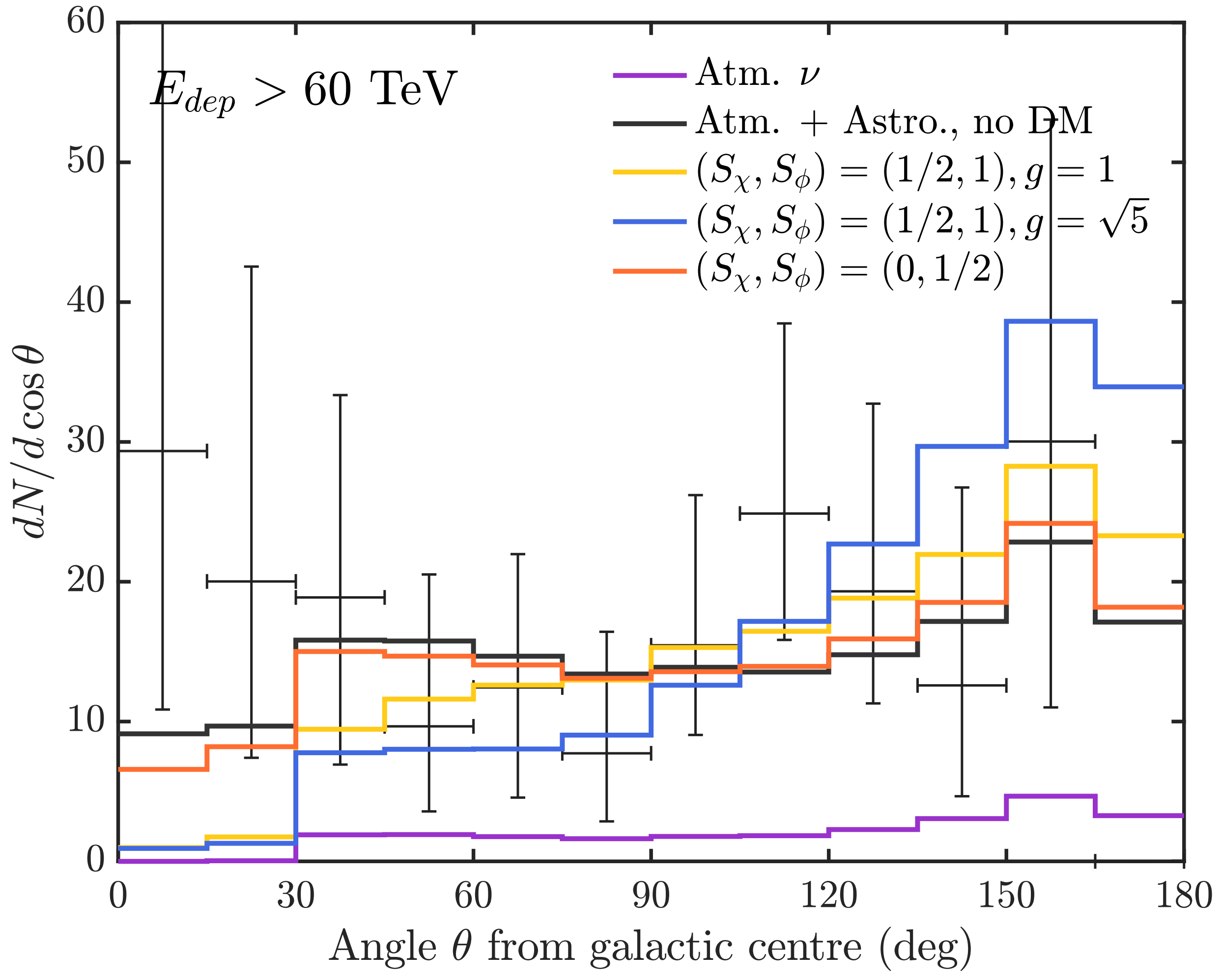
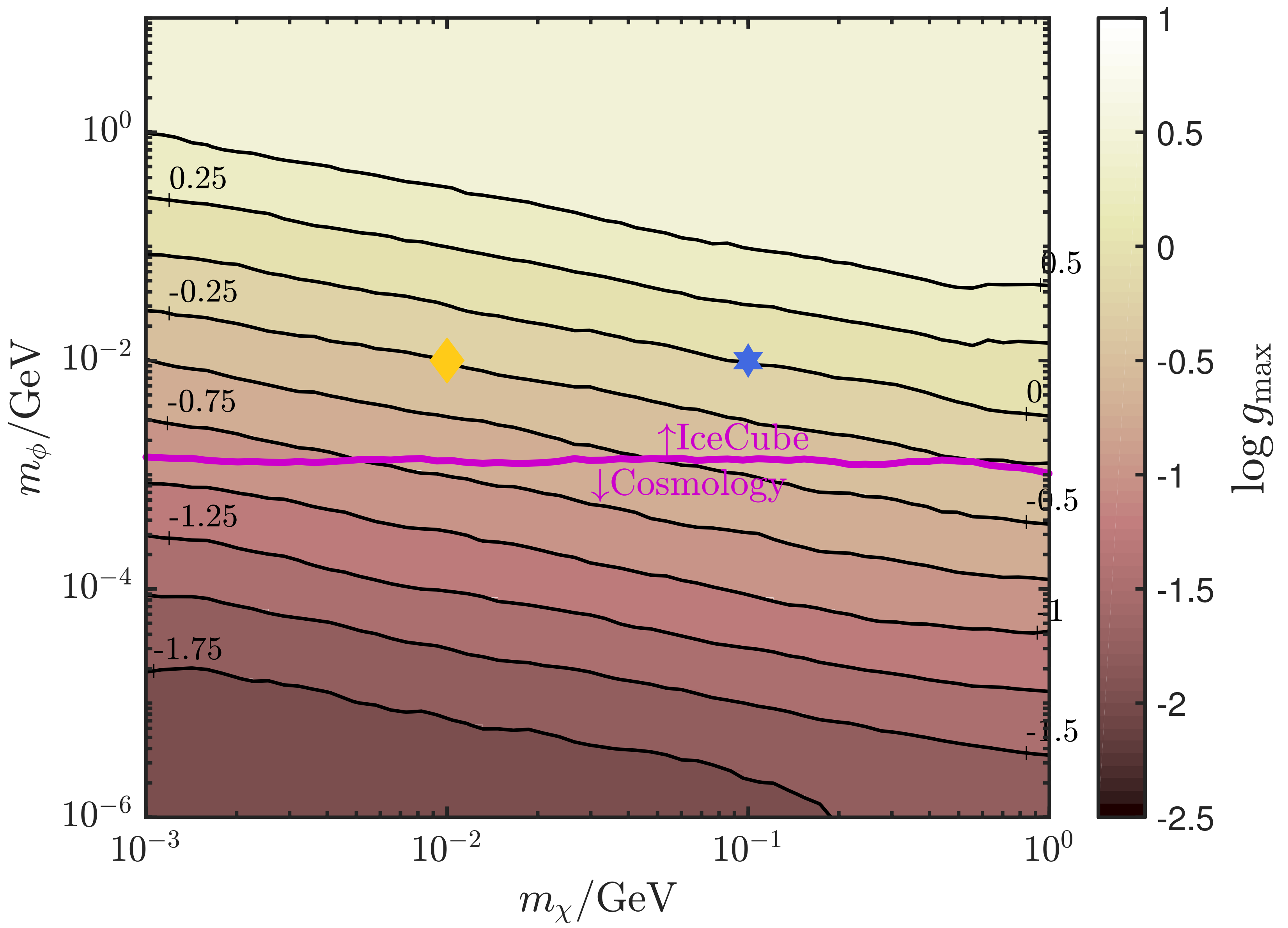
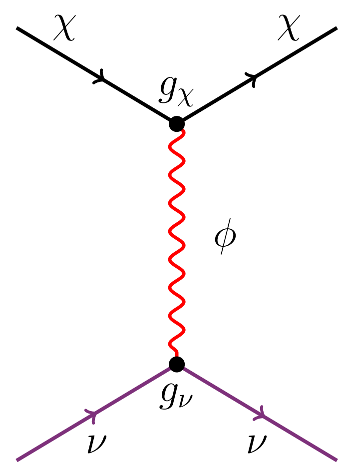
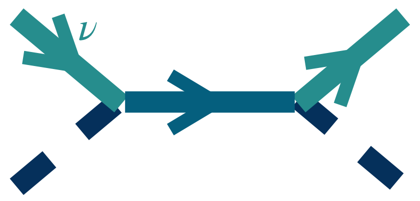


MeV GeV

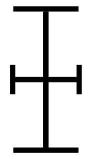


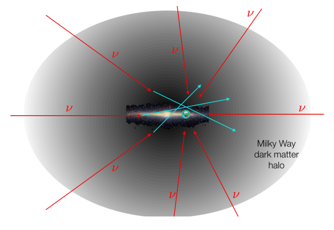


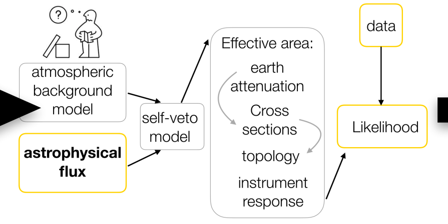
Resonance @ 810 TeV



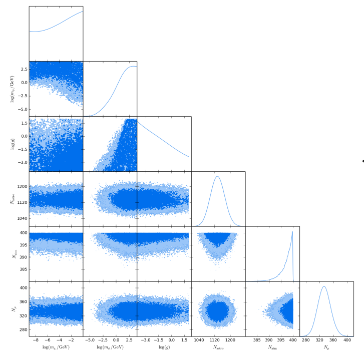
IceCube HESE events



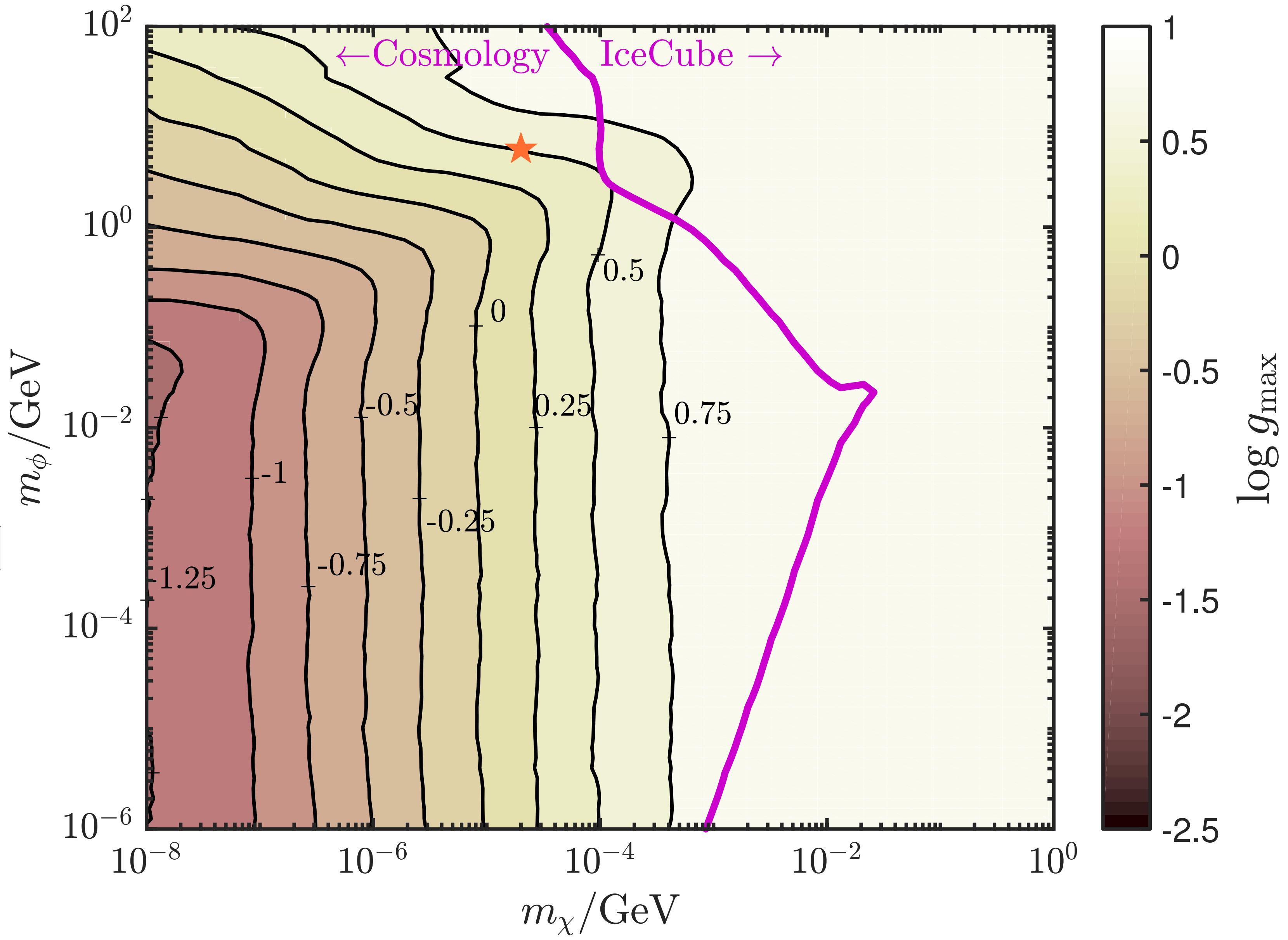




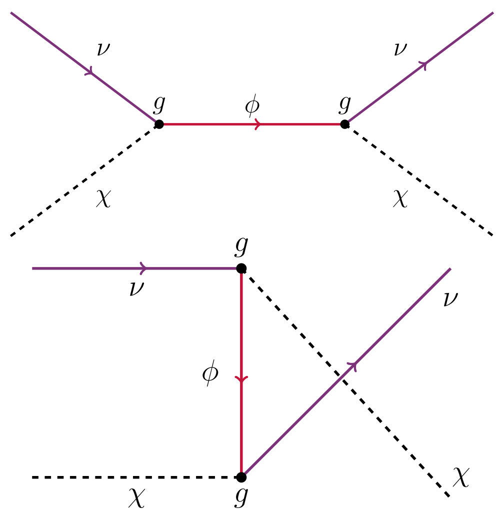
emcee
The MCMC Hammer



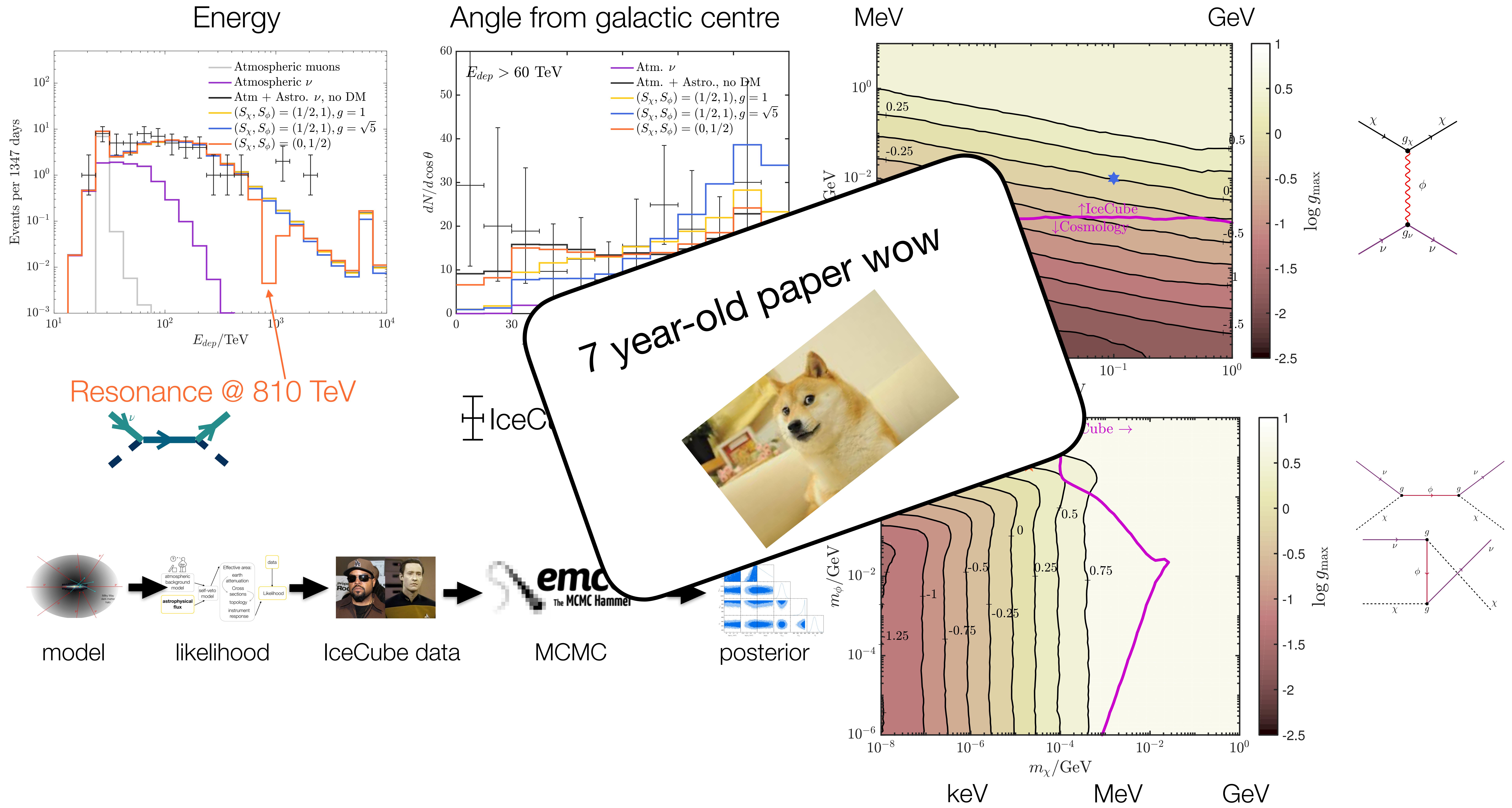
model likelihood IceCube data MCMC posterior



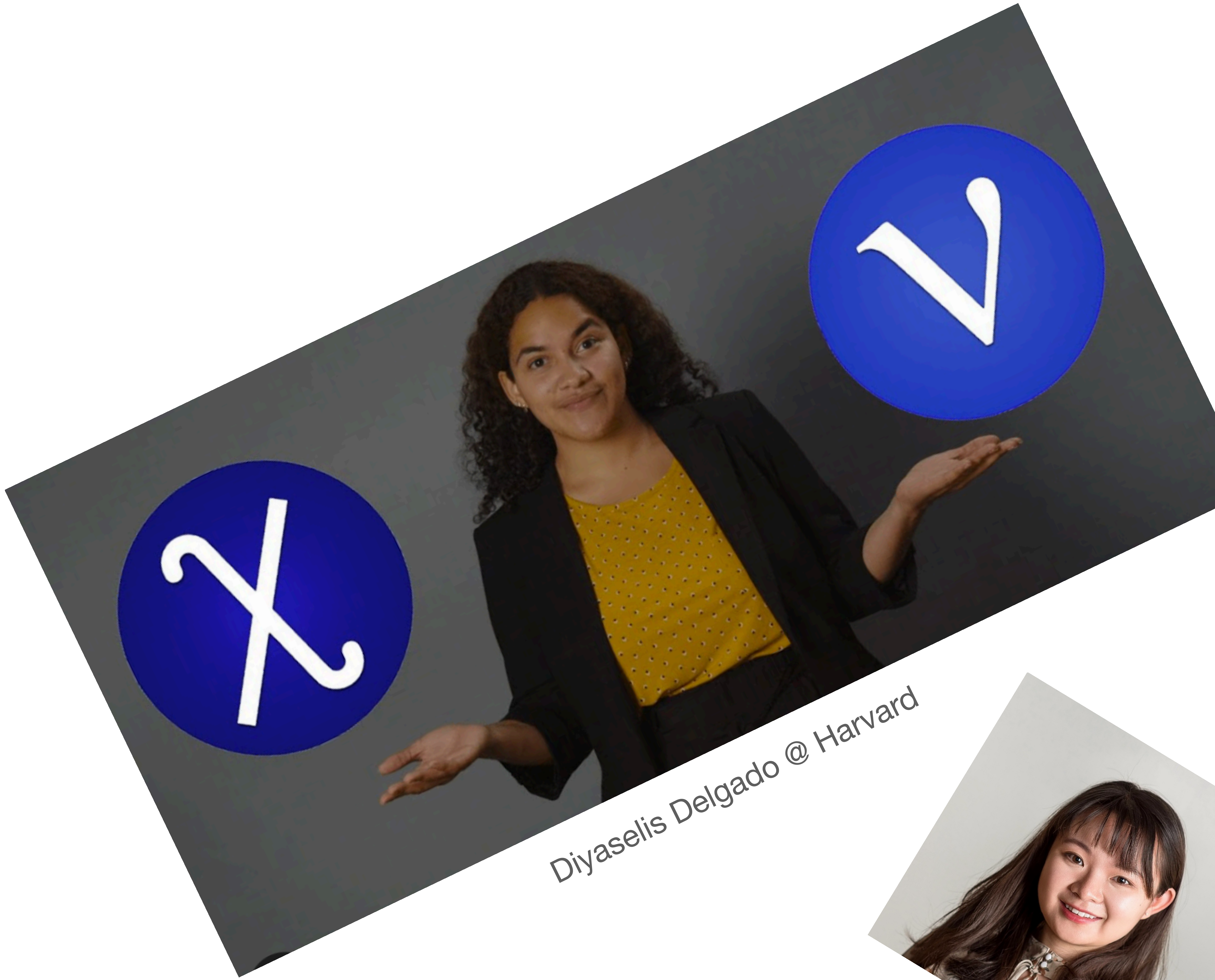
keV MeV GeV



Argüelles, Kheirandish, ACV 1703.00451/PRL



Argüelles, Kheirandish, ACV 1703.00451/PRL



Diyaselis Delgado @ Harvard

also Qinrui

Profile Binned Likelihood: Signal Subtraction Approach

$$\mathscr{L} = \sum_{i}^{\text{bins}} \log \text{Pois}(\vec{x_i}, \mu_i(\vec{\theta}))$$

$$\text{TS} = -2\Delta\text{LLH}$$

$$\vec{x} = \langle E, \text{RA}, \text{dec} \rangle \qquad \vec{\theta} = \langle g, m_\phi, m_\chi \rangle$$

$$\mu(\vec{\theta}) = \mu^{\text{signal}}_{\text{astro}_\nu}(\vec{\theta}) + \mu^{\text{bkg}}$$

EXTRAGALACTIC ASTROPHYSICAL NEUTRINOS

Follows a power law spectrum

$$\phi(\vec{x}, \vec{\theta}) = E^{-\gamma} \cdot \mathscr{P}_{\text{surv}} \quad \propto \sum c_i \hat{\phi}_i e^{\lambda_i \tau}$$

BACKGROUND: ATMOSPHERIC NEUTRINOS AND MUONS

$$\mu^{\text{bkg}} = \mu_{\text{atm}_\nu} + \mu_{\text{muon}}$$

Scrambling over RA

$$\mu^{\text{bkg}} = \tilde{\mu}_{\text{data}} - \tilde{\mu}^{\text{signal}}_{\text{astro}_\nu}(\vec{\theta})$$

Profile Binned Likelihood: Signal Subtraction Approach

$$\mathscr{L} = \sum_{i}^{\text{bins}} \log \text{Pois}(\vec{x}_i, \mu_i(\vec{\theta}))$$

$$\text{TS} = -2\Delta\text{LLH}$$

$$\vec{x} = \langle E, \text{RA}, \text{dec} \rangle \qquad \vec{\theta} = \langle g, m_\phi, m_\chi \rangle$$

$$\mu(\vec{\theta}) = \mu^{\text{ex-gc}}_{\text{astro}_\nu}(\vec{\theta}) + \mu^{\text{gc}}_{\text{astro}_\nu}(\vec{\theta}) + \mu^{\text{bkg}}$$

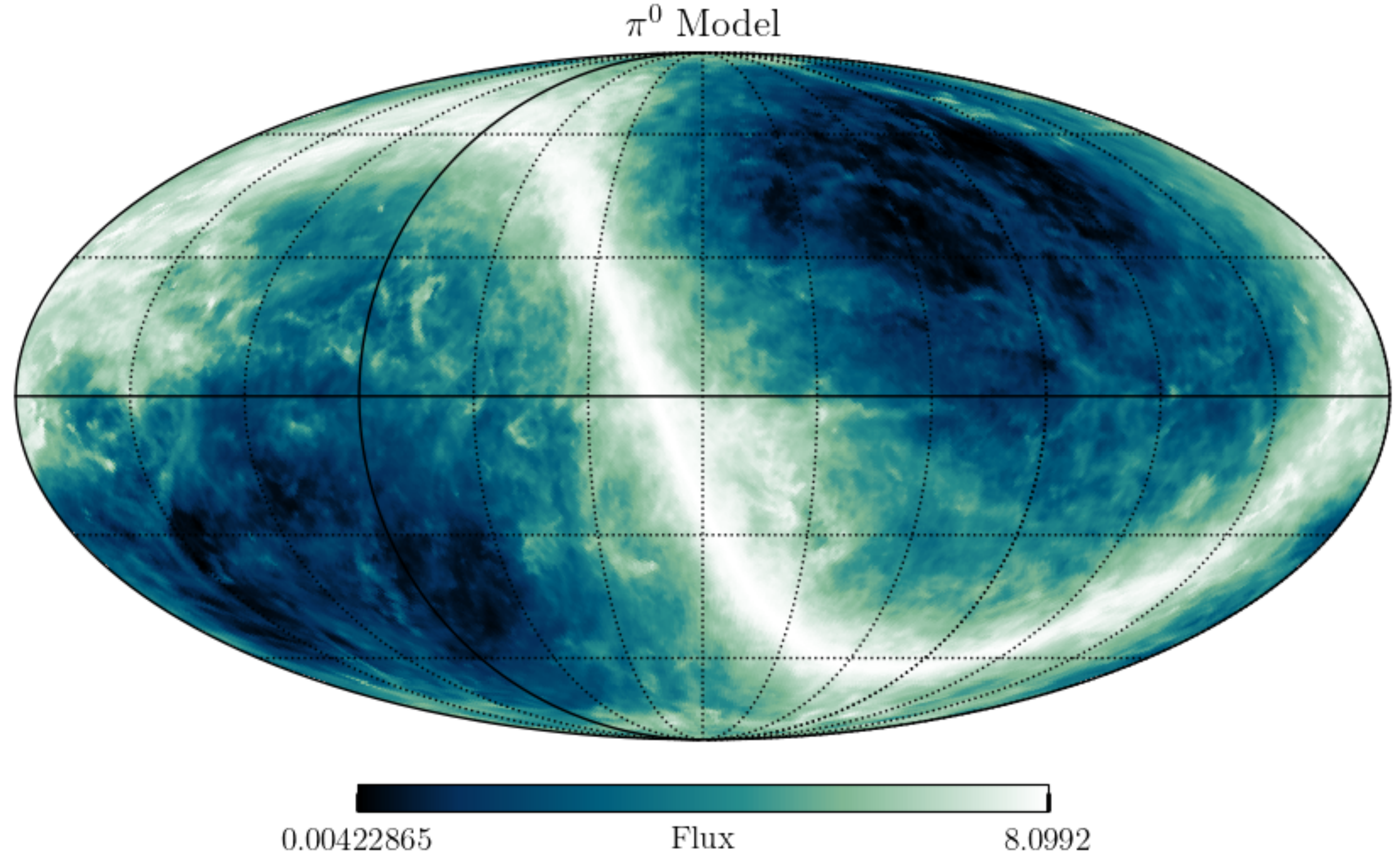
Galactic Astrophysical Neutrinos

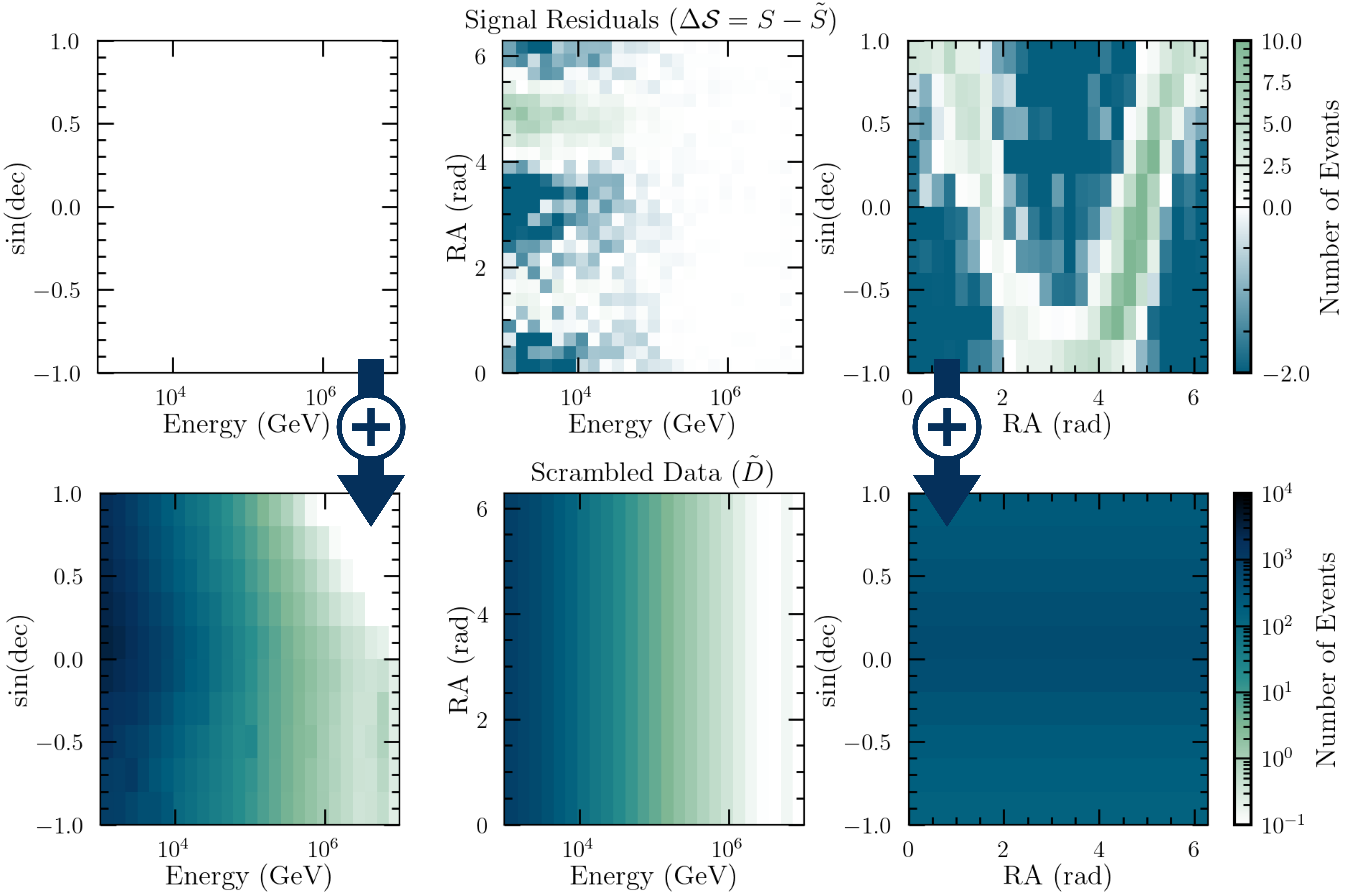
From model template of GC ν emission

$$\phi(\vec{x}, \theta) = \int_{l.o.s.} ds\, n_\nu(s(\vec{x}))\, \phi(\vec{x}, \vec{\theta}; s(\vec{x}))$$

n_ν Spatial Distribution

ϕ Energy Distribution





Scalar χ - Fermion ϕ

$g = 1$

$m_\phi = 1$ GeV

$m_\chi =$ 1e-06 GeV

$N_{\mathrm{astro}} = 1.66$

$\gamma_{\mathrm{astro}} = 2.53$

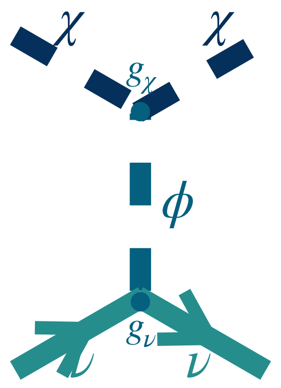
$N_{\mathrm{galactic}} = 21.8$

Event Distribution =

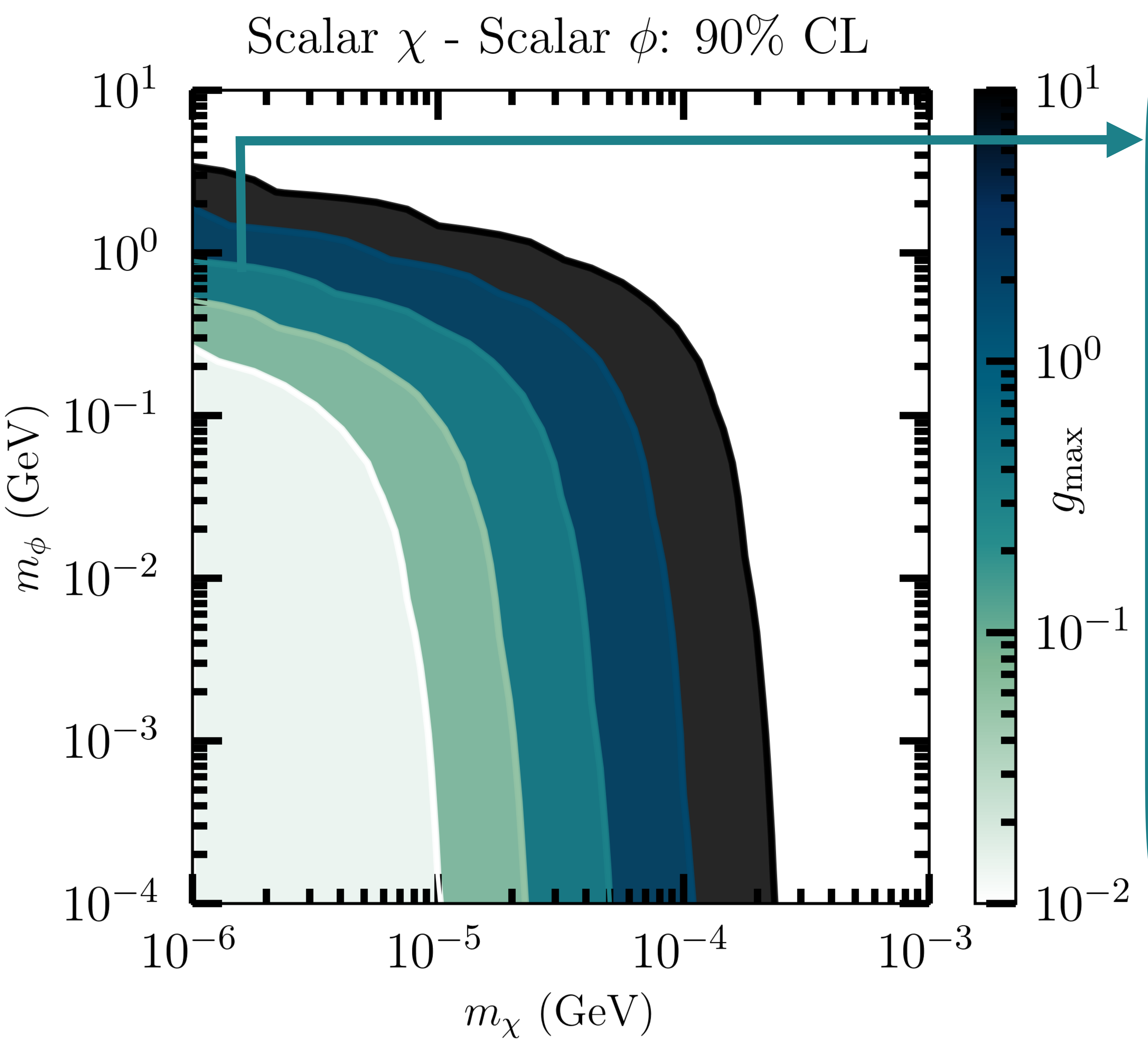
Signal (S) -

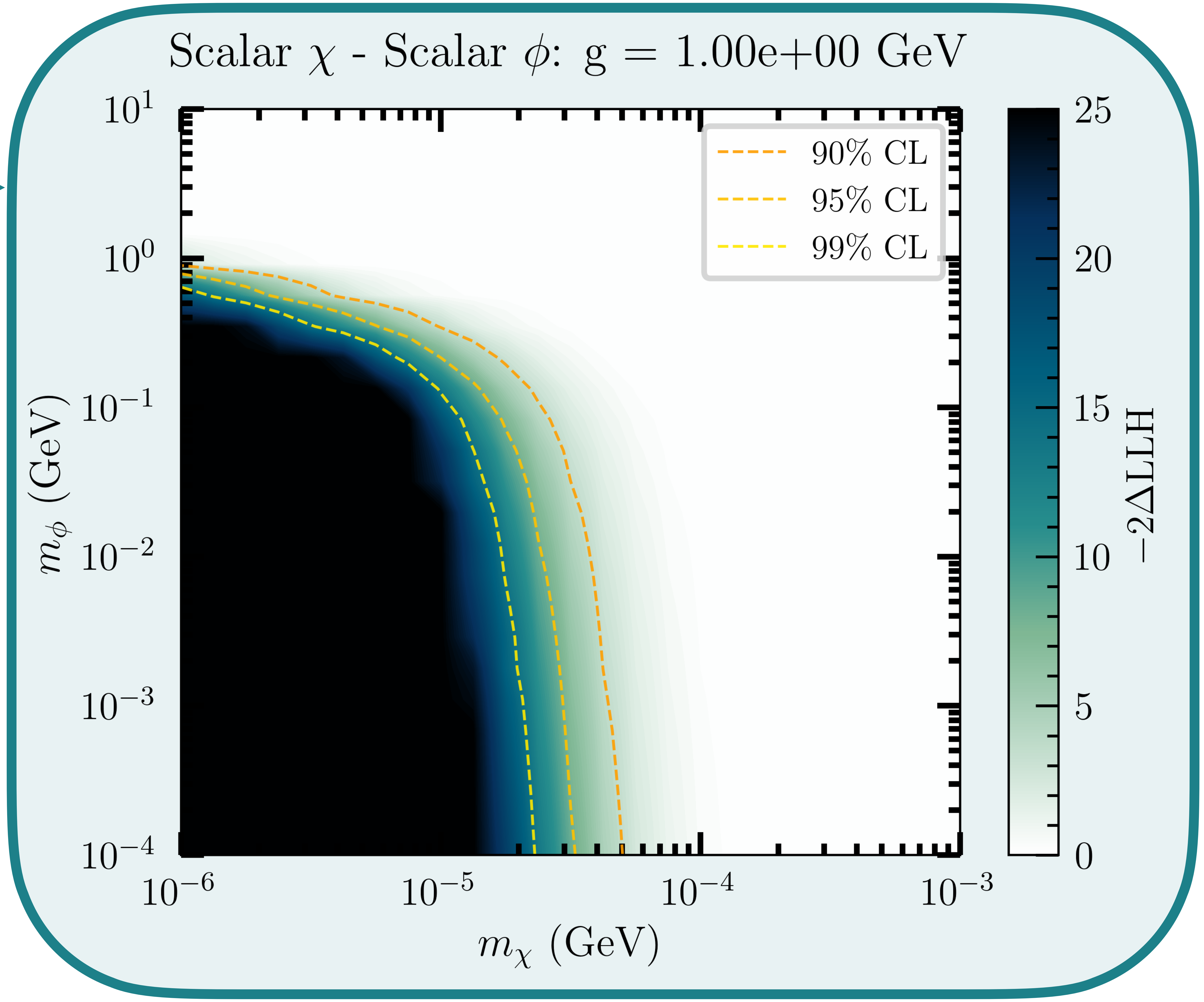
Scrambled Signal ($\tilde{S}$) +

Scrambled Data ($\tilde{D}$)



Asimov Sensitivities (One Example)

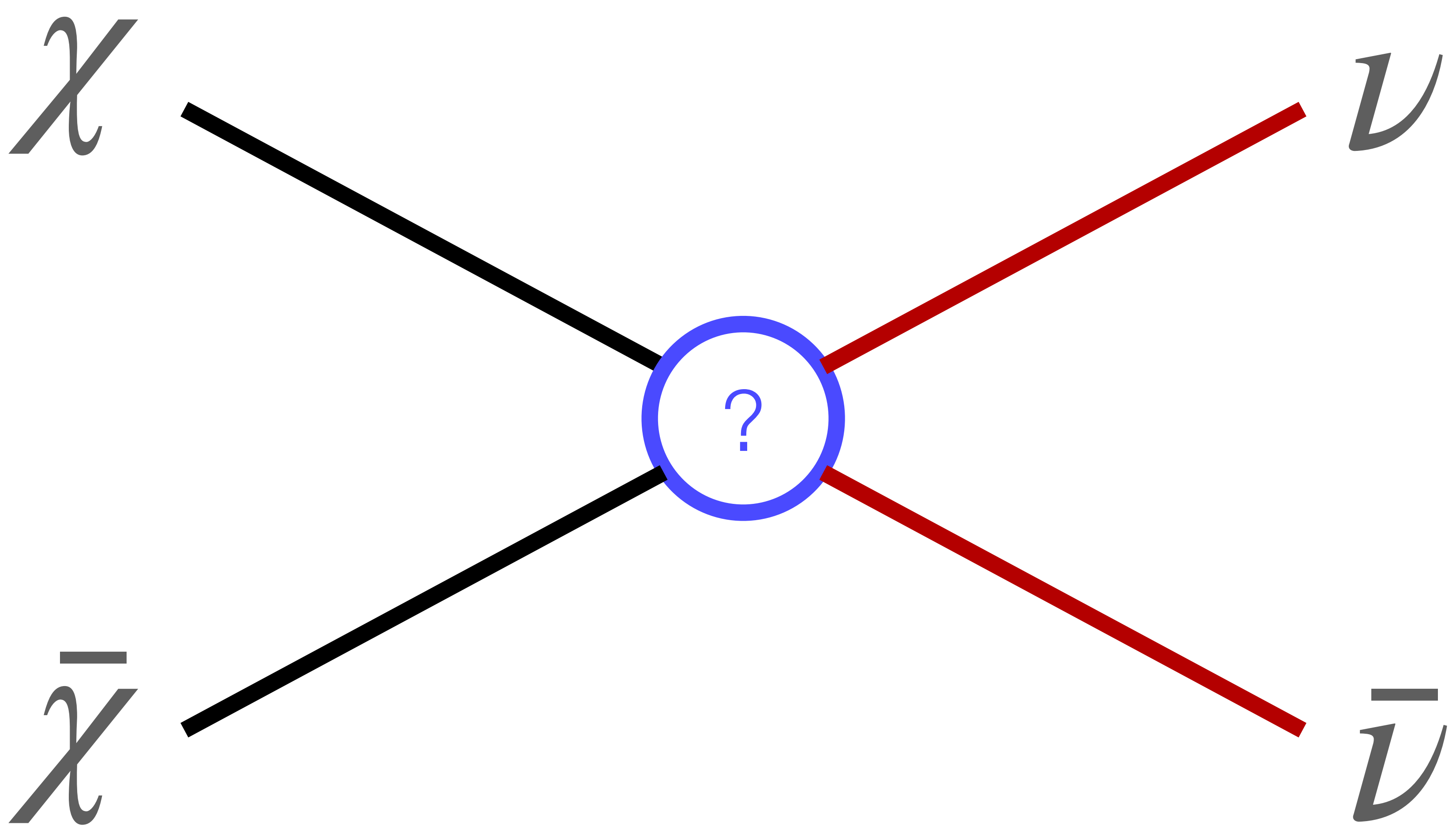




Unblinding This Week!

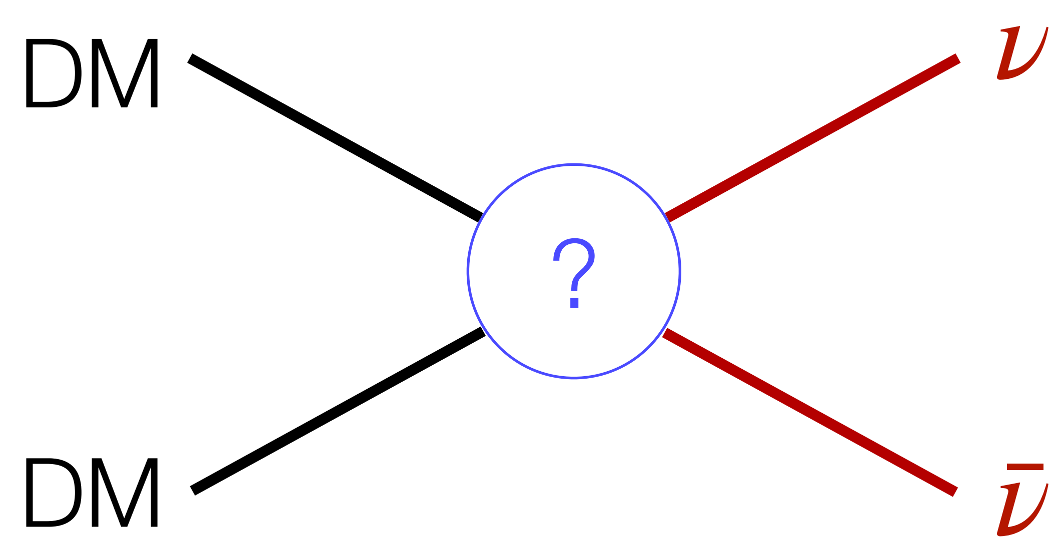
Diyaselis Delgado

Annihilation



Annihilation

Indirect searches $\chi\chi \rightarrow SM, SM$: gammas dominate, *except* if neutrinos are the only product

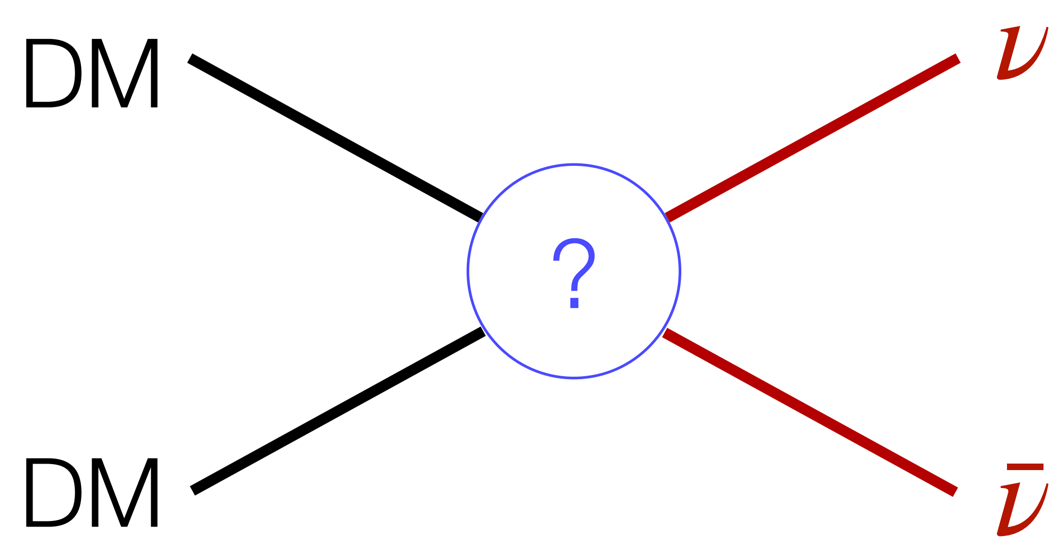


Annihilation

Indirect searches $\chi\chi \to SM, SM$: gammas dominate, *except* if neutrinos are the only product

$$\frac{d\Phi_{\nu+\bar{\nu}}}{dE_\nu} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{\kappa m_\chi^2}\frac{1}{3}\frac{dN_\nu}{dE_\nu}J(\Omega)$$

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



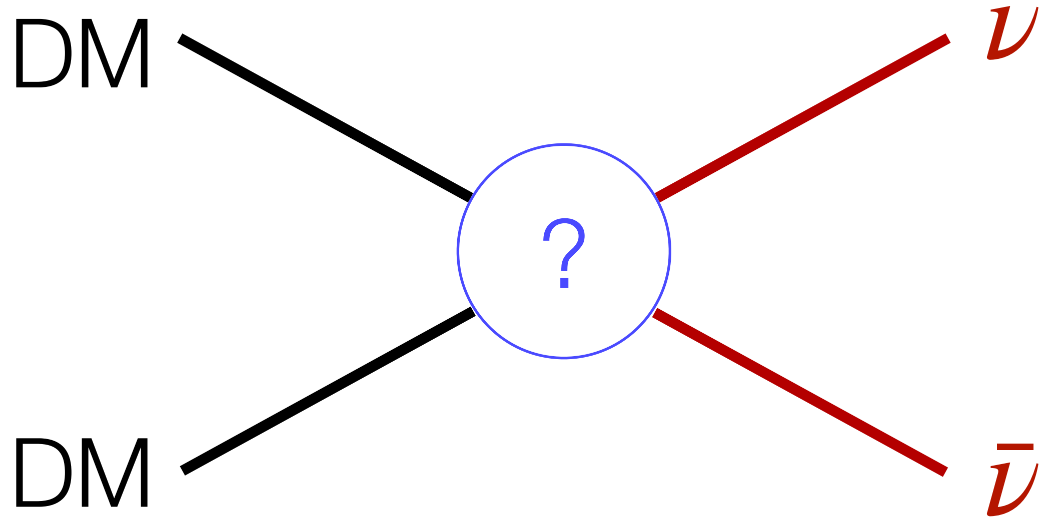
$$\frac{dN_\nu}{dE_\nu} = 2\delta(1 - E/m_\chi)m_\chi/E^2\,.$$

Annihilation

Indirect searches $\chi\chi \to SM, SM$: gammas dominate, *except* if neutrinos are the only product

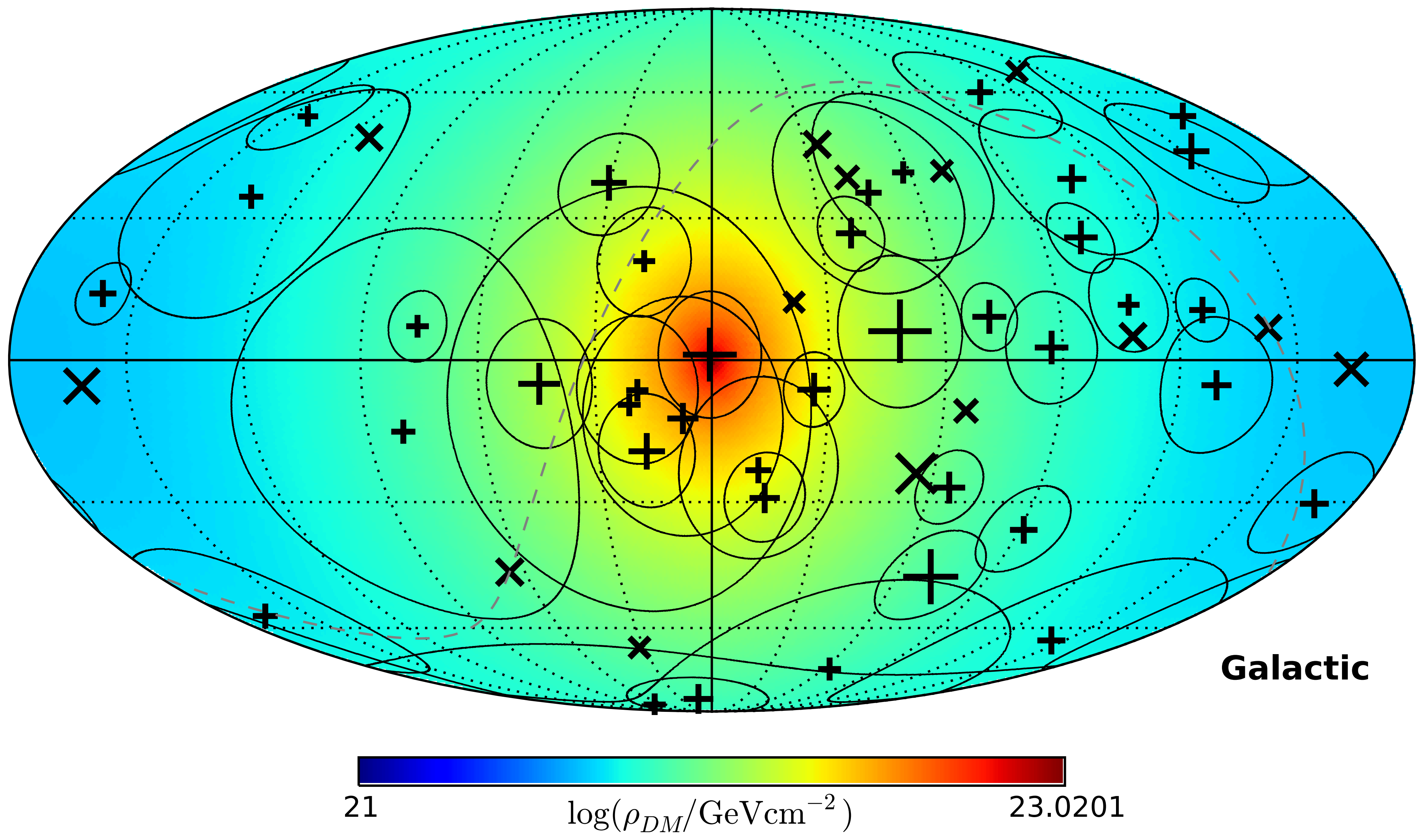
$$\frac{d\Phi_{\nu+\bar{\nu}}}{dE_\nu} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{\kappa m_\chi^2}\frac{1}{3}\frac{dN_\nu}{dE_\nu}J(\Omega)$$

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



$$\frac{dN_\nu}{dE_\nu} = 2\delta(1 - E/m_\chi)m_\chi/E^2\,.$$

Dark matter column density

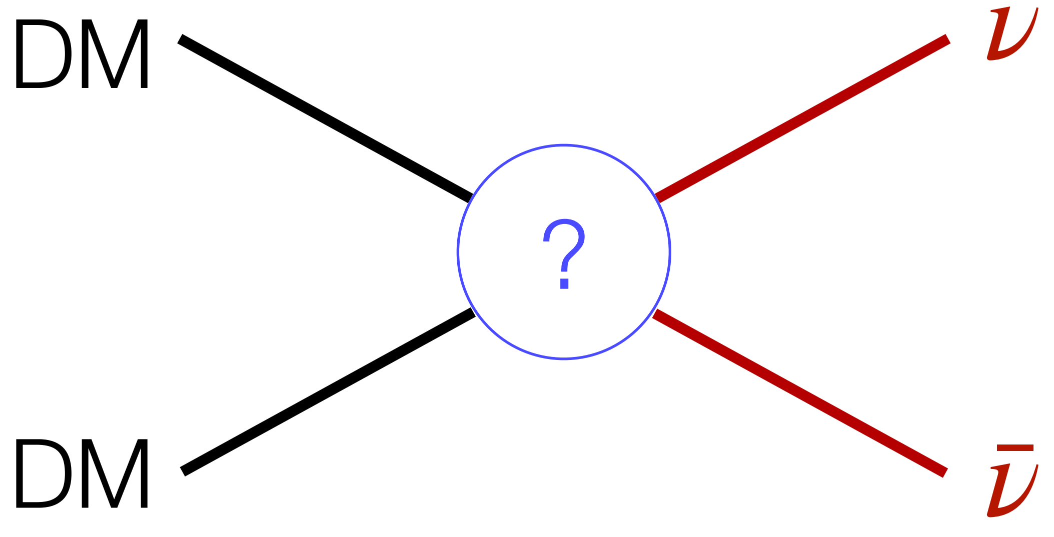


Annihilation

Indirect searches $\chi\chi \rightarrow SM, SM$: gammas dominate, *except* if neutrinos are the only product

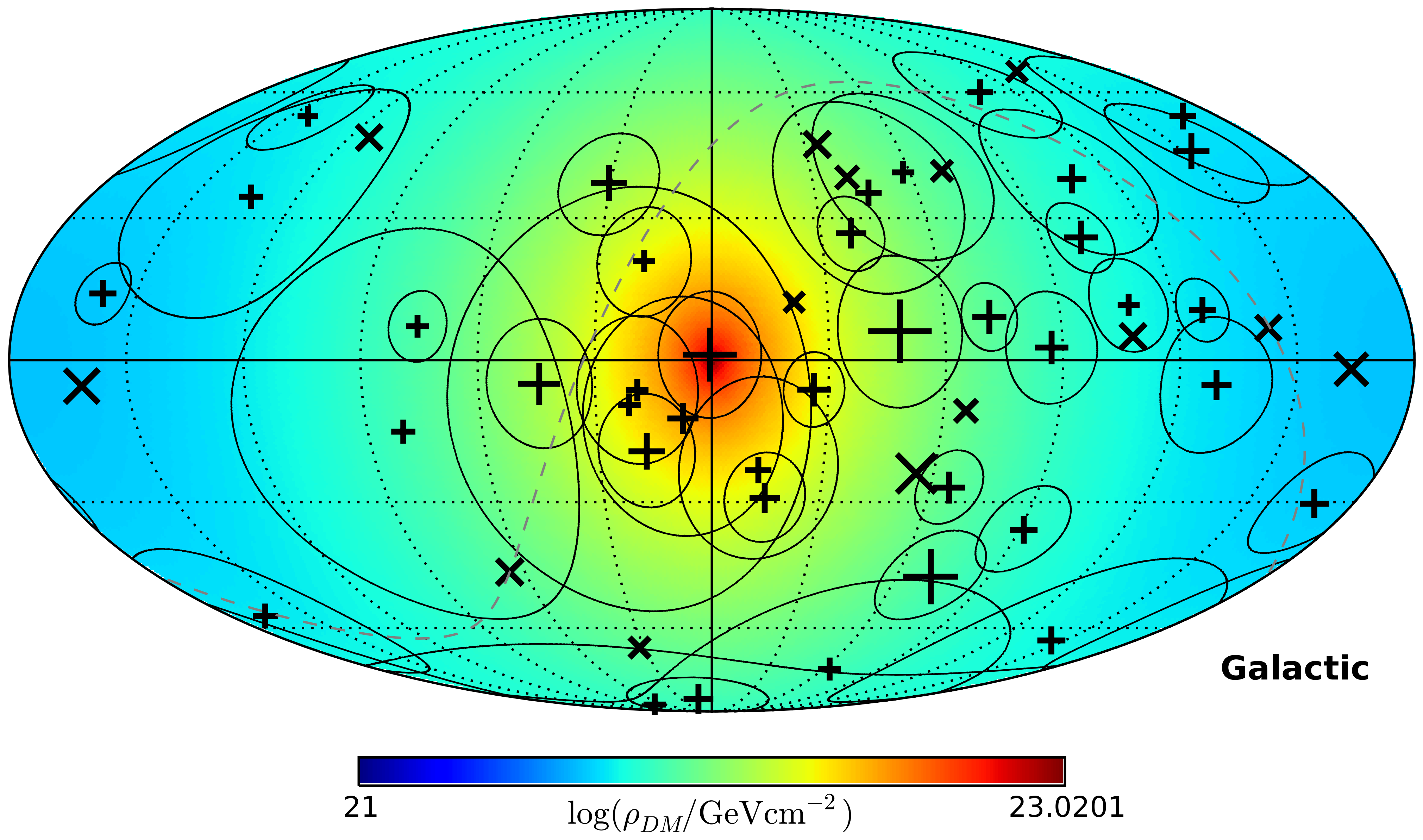
$$\frac{d\Phi_{\nu+\bar{\nu}}}{dE_\nu} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{\kappa m_\chi^2}\frac{1}{3}\frac{dN_\nu}{dE_\nu}J(\Omega)$$

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



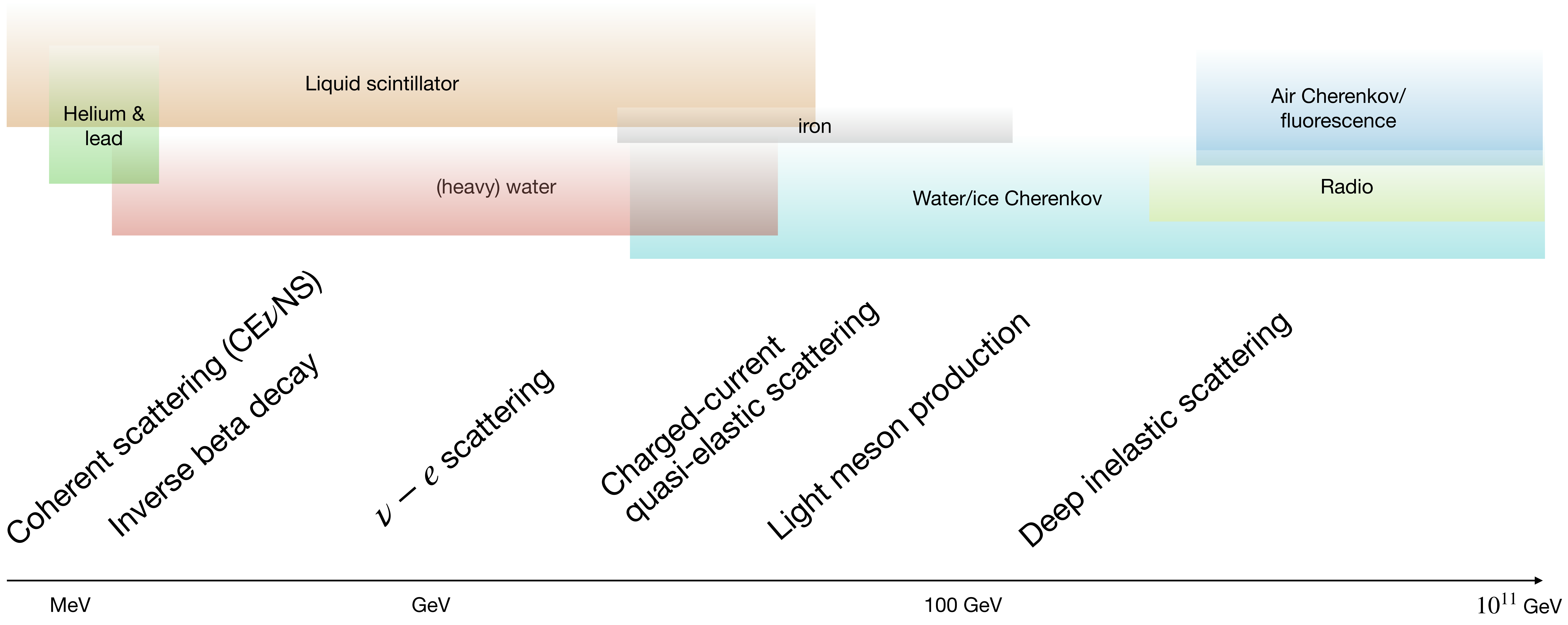
$$\frac{dN_\nu}{dE_\nu} = 2\delta(1 - E/m_\chi)m_\chi/E^2\,.$$

Dark matter column density

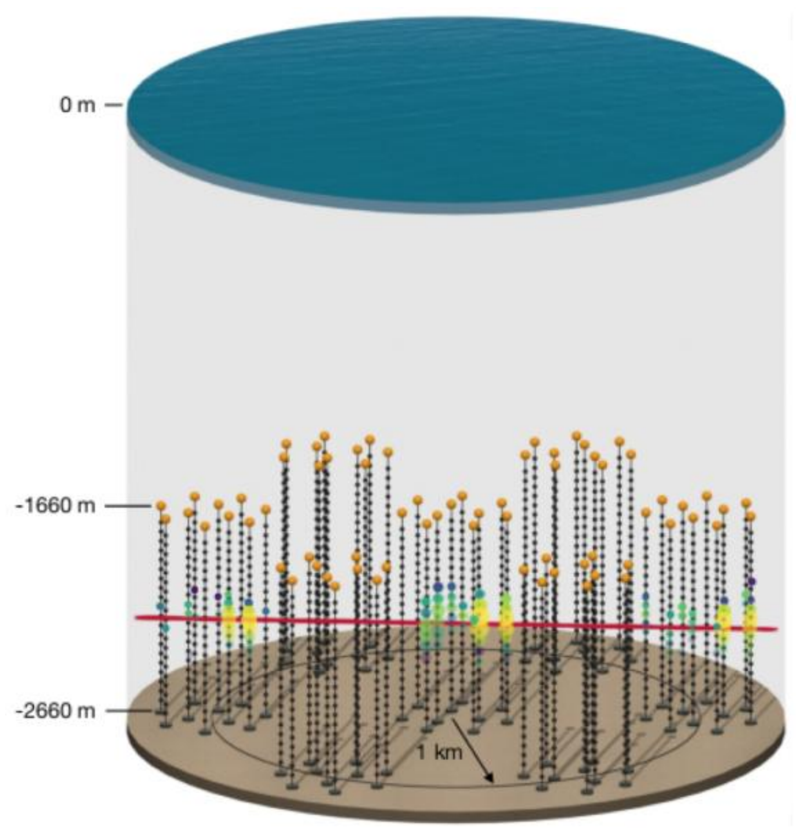


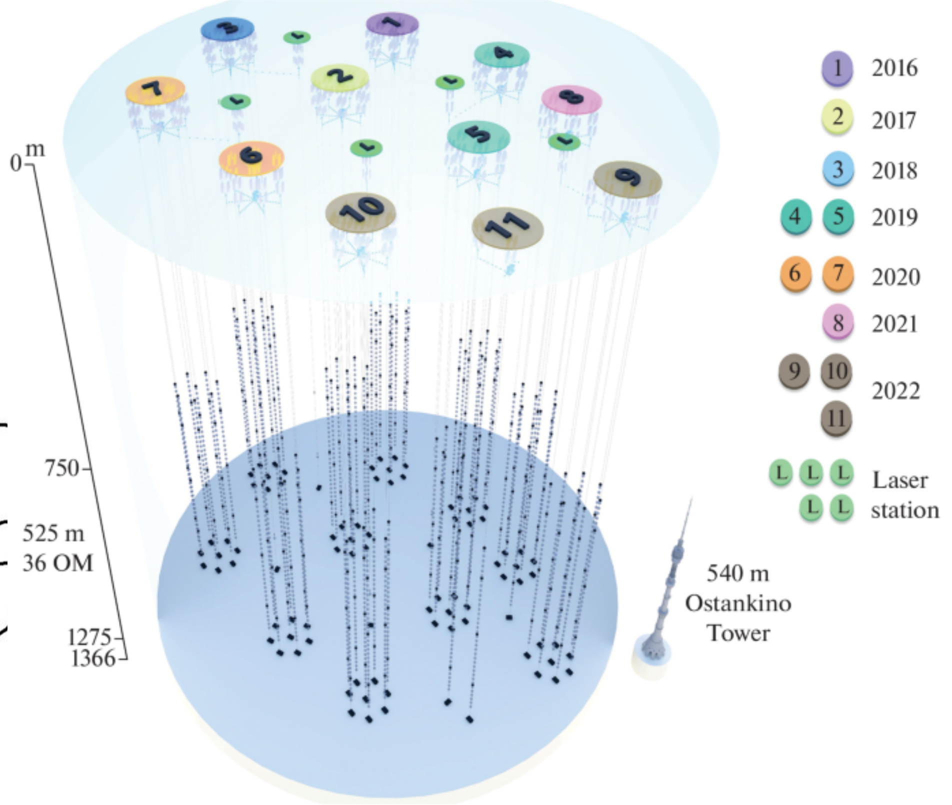
*We also spent a long time calculating extragalactic constraints. They are subdominant though

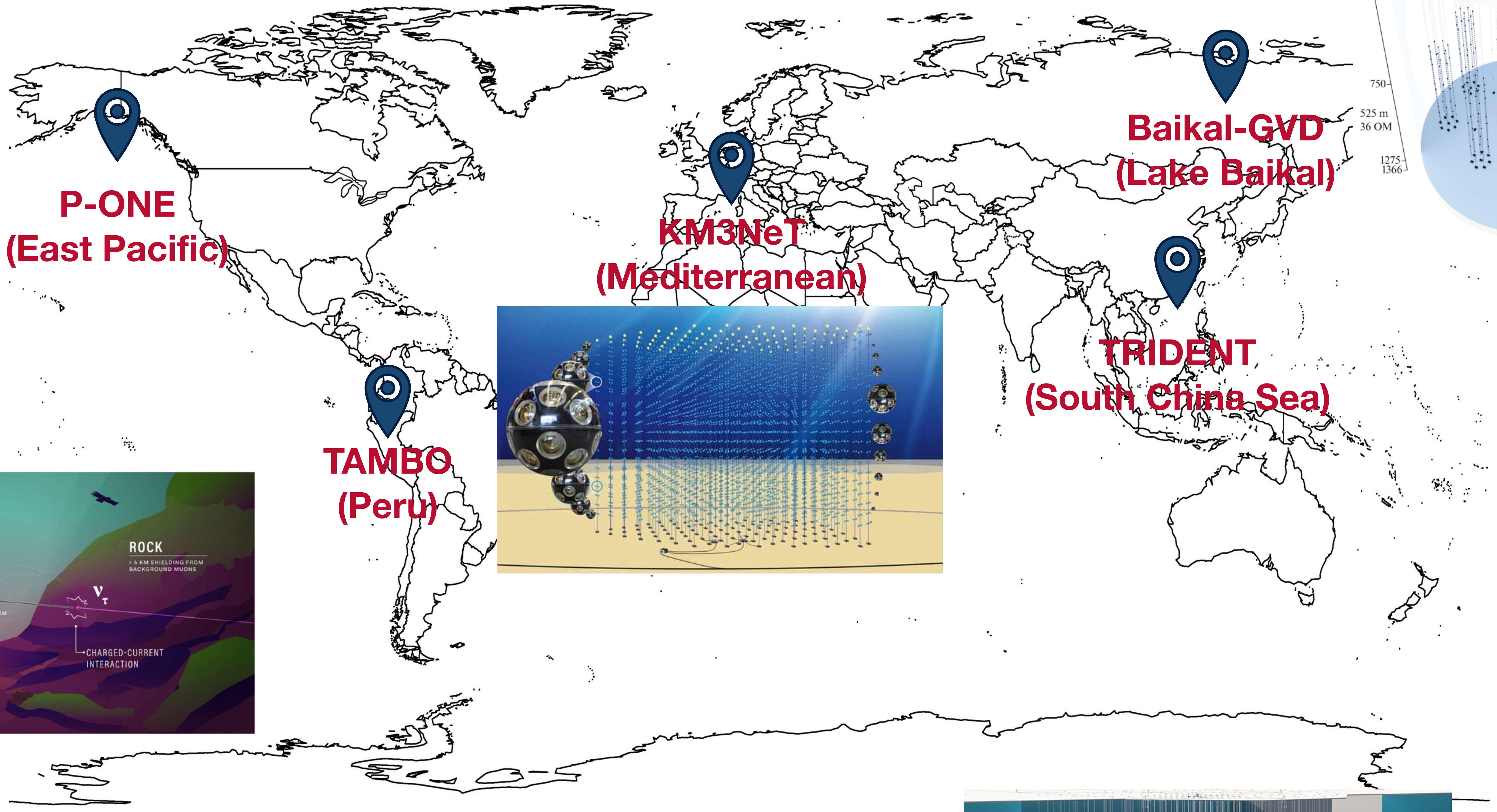
What if we looked at *every neutrino telescope in the world?*

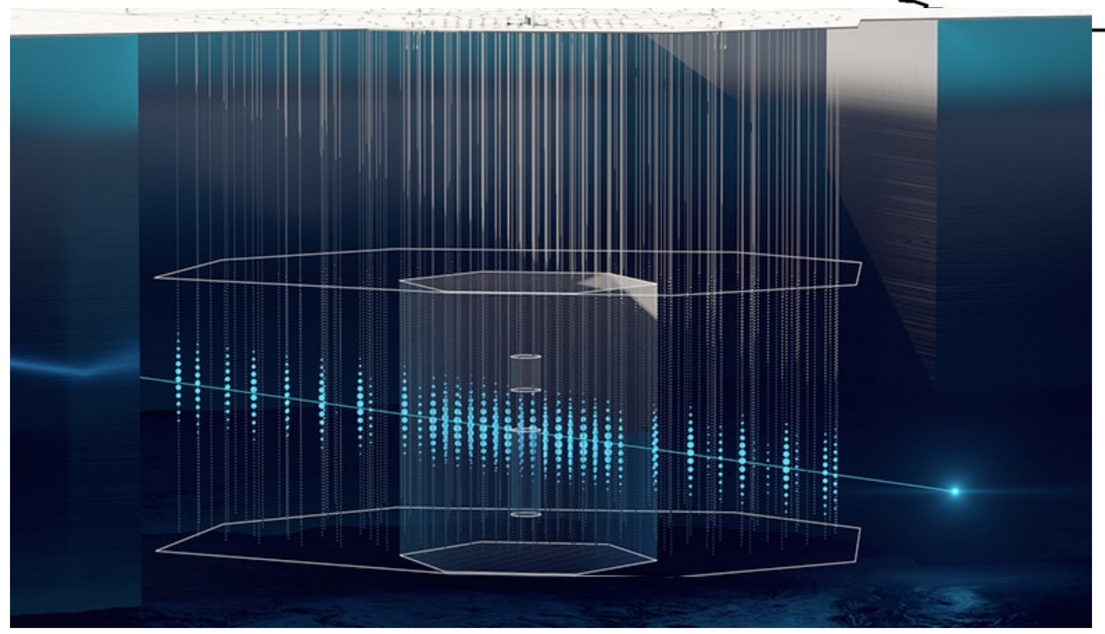


Next-Generation High-Energy Neutrino Telescopes

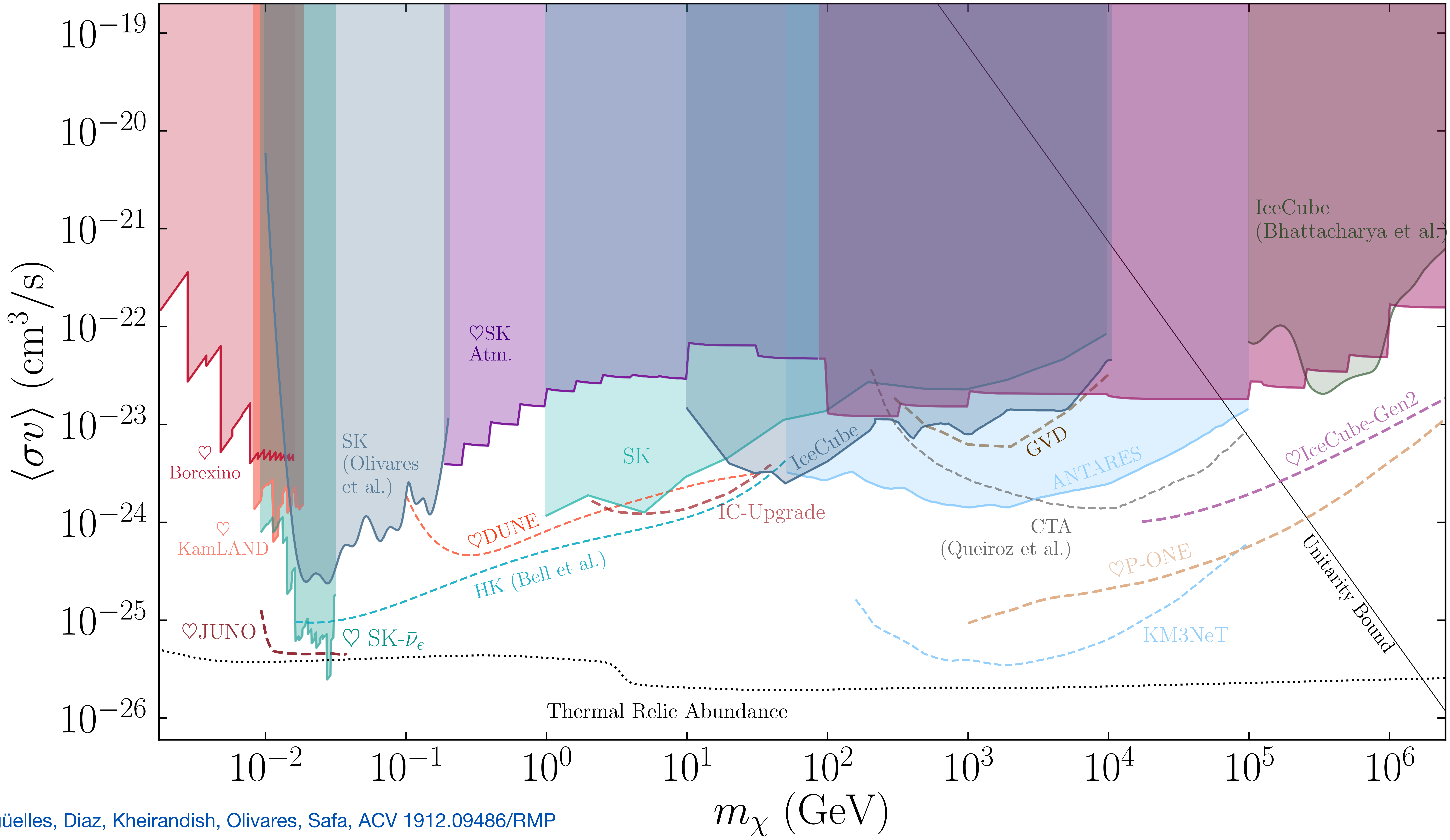




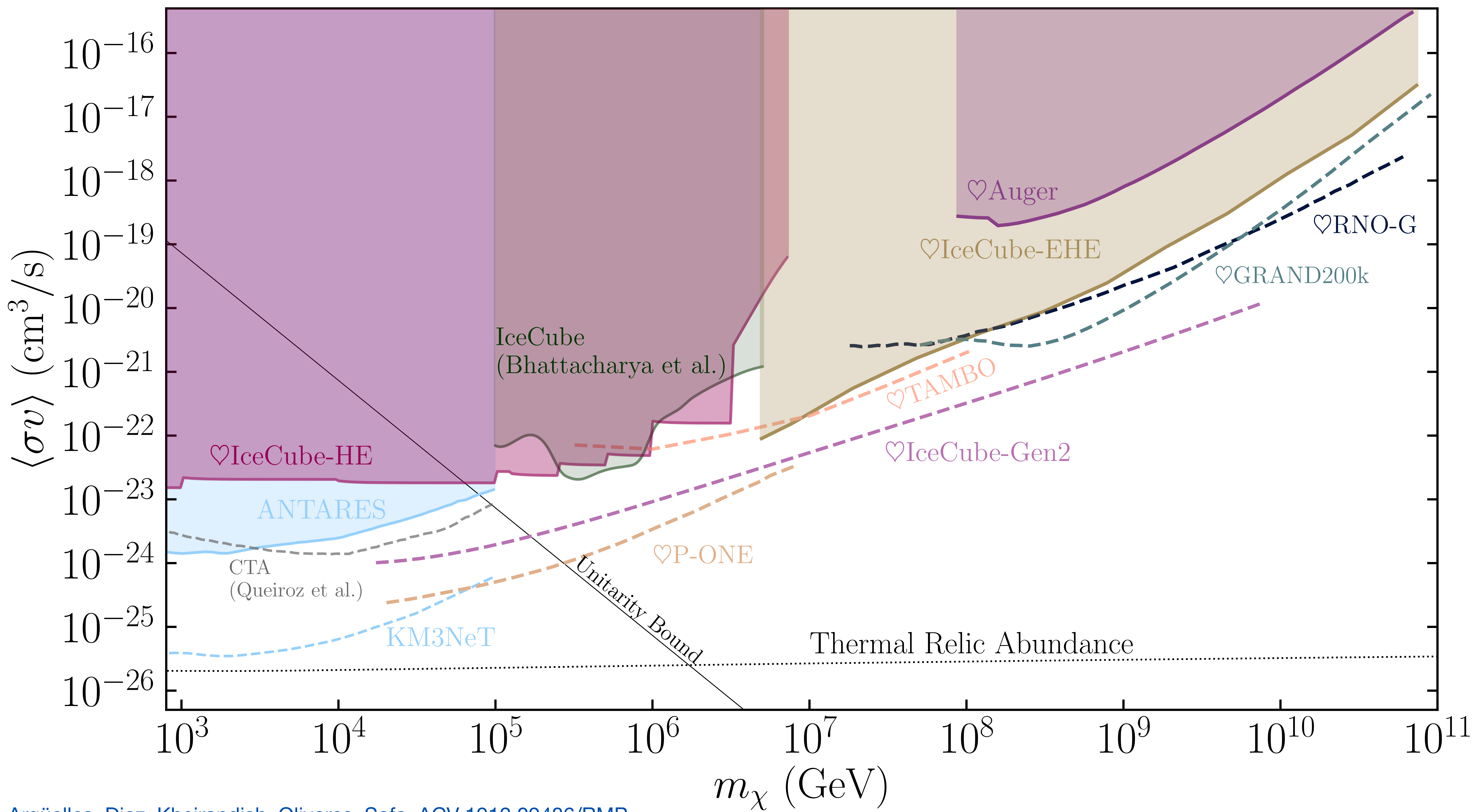




More telescopes with larger exposure!

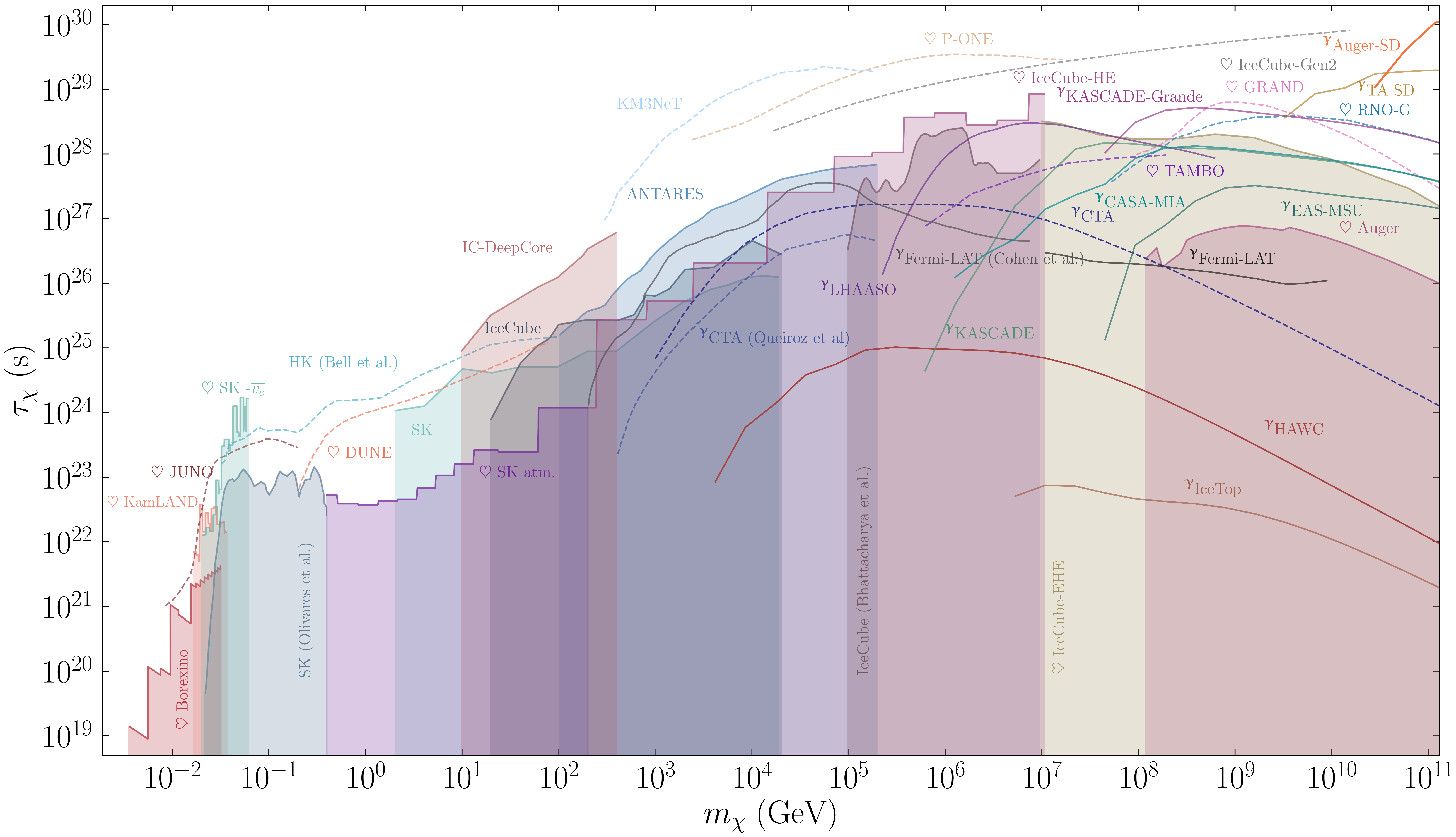


Argüelles, Diaz, Kheirandish, Olivares, Safa, ACV 1912.09486/RMP



Argüelles, Diaz, Kheirandish, Olivares, Safa, ACV 1912.09486/RMP

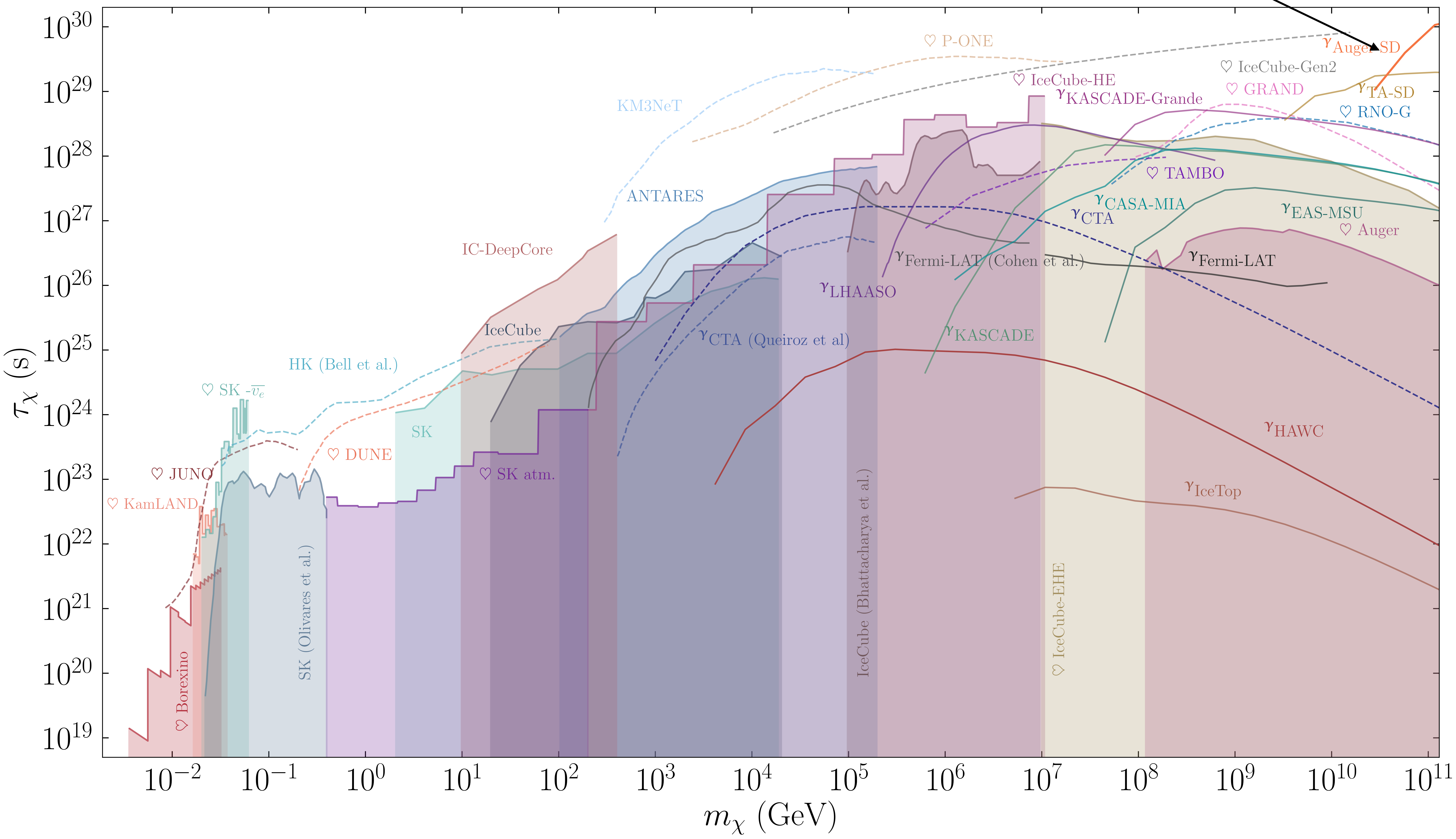
Decay to $\chi \rightarrow \bar{\nu}\nu$



Arguelles, Friedlander, Kheirandish, Safa, ACV, White 2210.01303

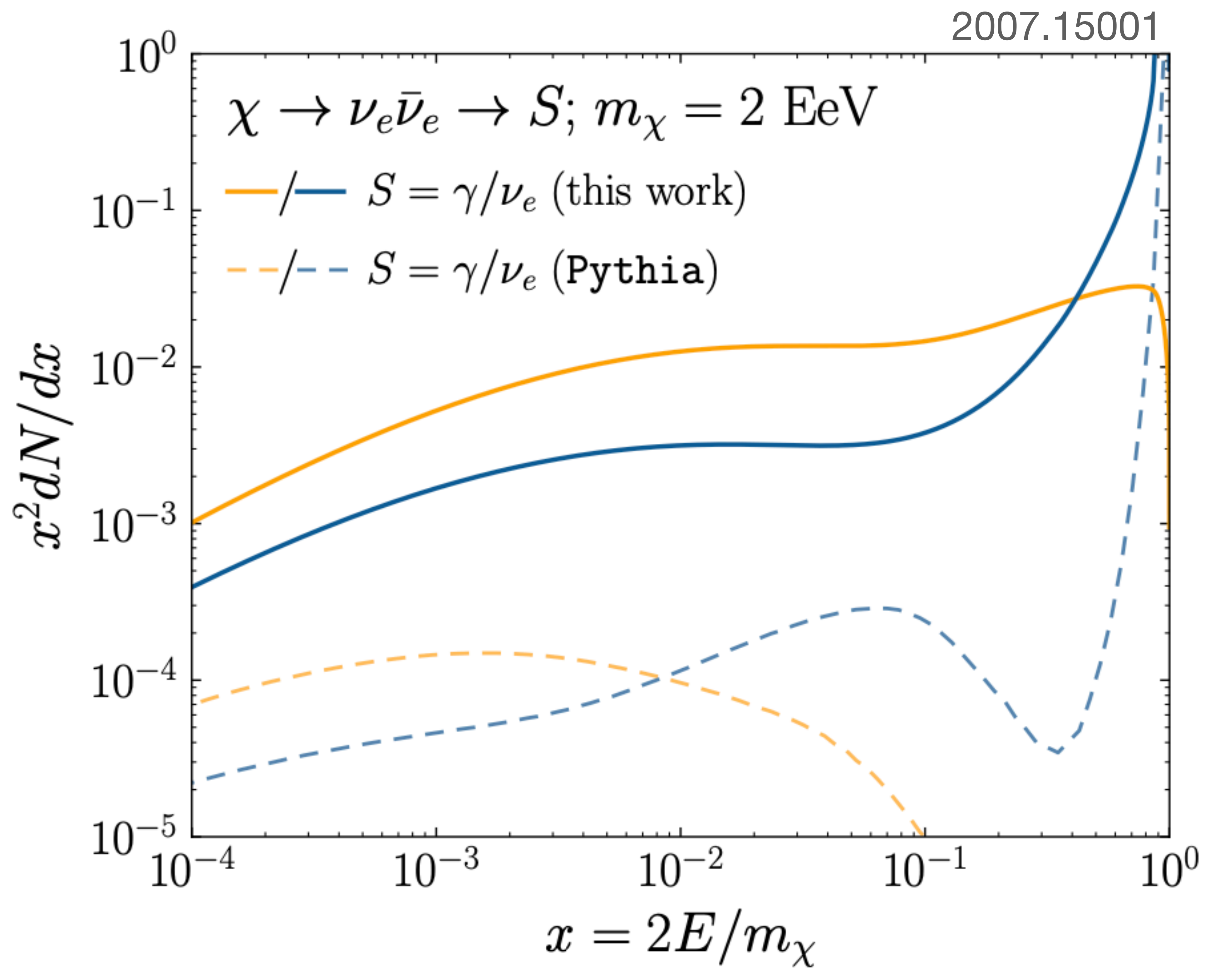
Decay to $\chi \to \bar{\nu}\nu$

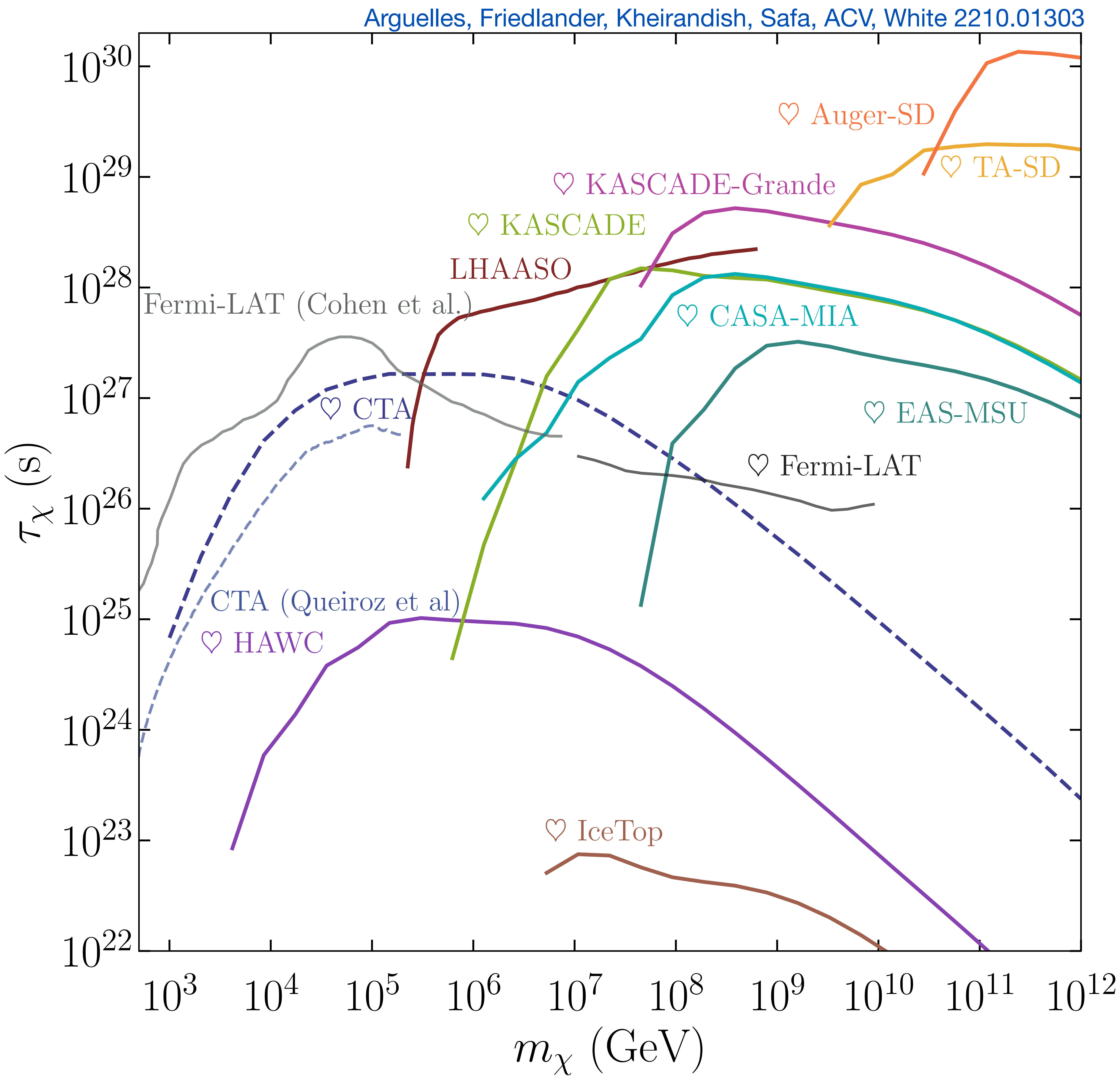
these are gamma-ray telescopes



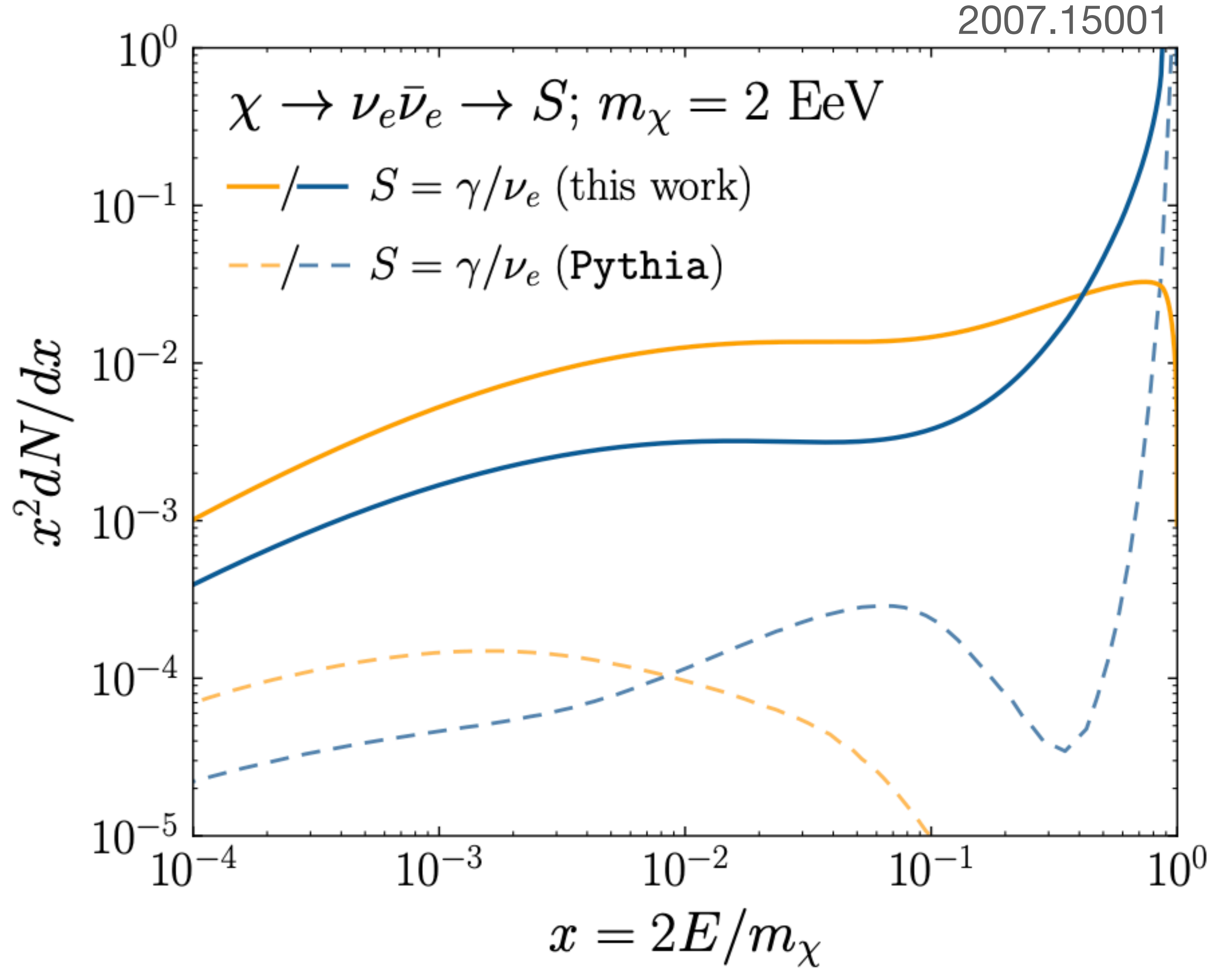
Arguelles, Friedlander, Kheirandish, Safa, ACV, White 2210.01303

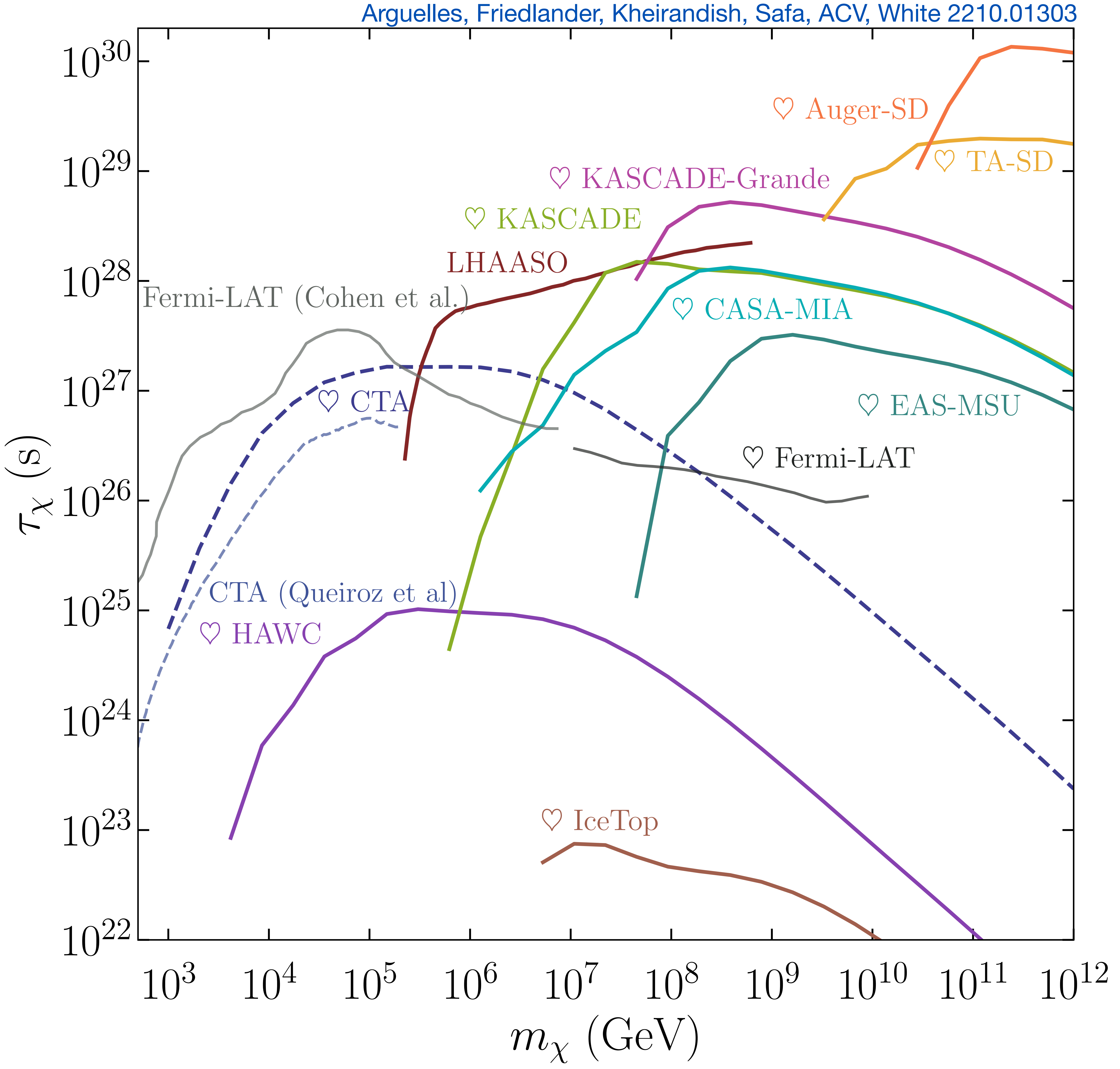
Electroweak corrections





Electroweak corrections

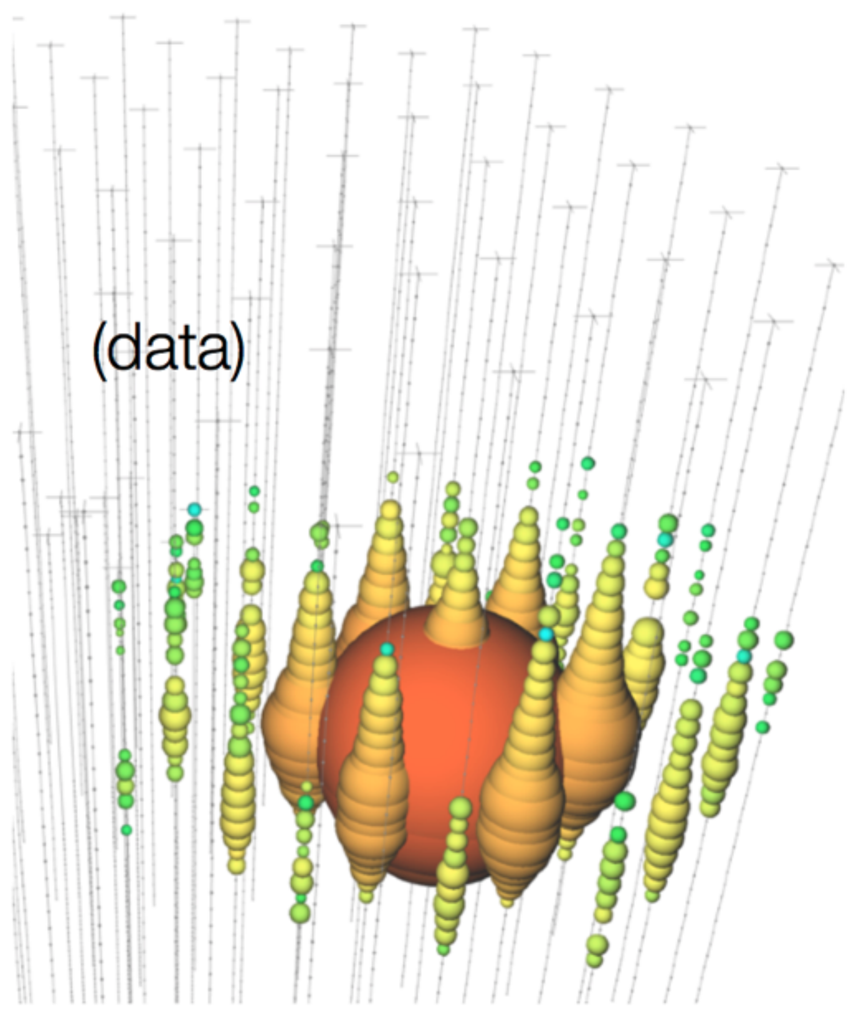




Looks like the gamma rays do better than neutrinos… but not quite the end of the story!

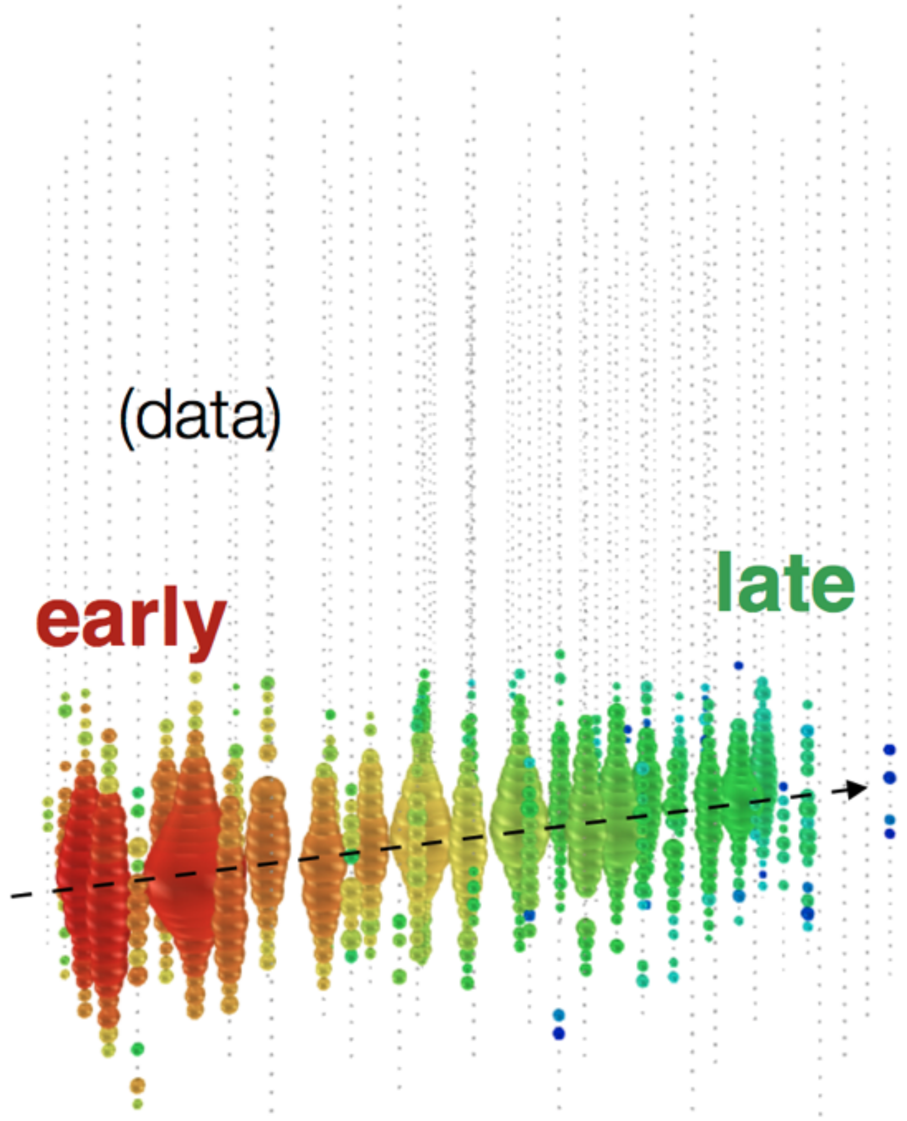
Flavour again

Neutral-current / ν_e



Isolated energy deposition (cascade) with no track

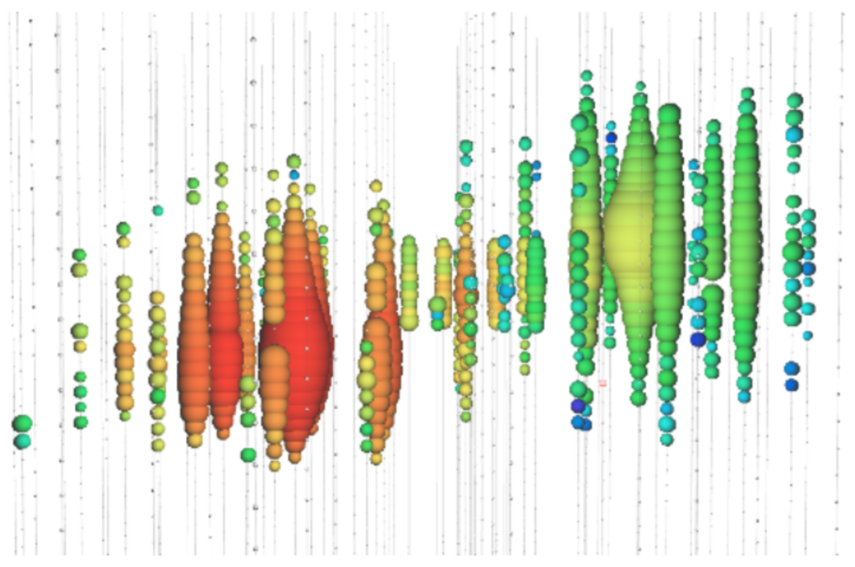
Charged-current ν_μ



Up-going track

Charged-current ν_τ

(simulation)



Double cascade

both ν and $\bar{\nu}$ look the same

Images: icecube.wisc.edu

What does ν vs $\bar{\nu}$ do for you?

Are neutrinos coming from pp or $p\gamma$ collisions? These give different π^+/π^- ratios

$$\{\nu_e, \bar{\nu}_e\} : \{\nu_\mu, \bar{\nu}_\mu\} : \{\nu_\tau, \bar{\nu}_\tau\}$$

$$p + p \to n_\pi \left[\pi^0 + \pi^+ + \pi^-\right] \qquad p + \gamma \to \Delta^+ \to \pi^+ + n$$

Production	Source flavor ratio	Earth flavor ratio $\nu + \bar{\nu}$	Earth flavor ratio	$f_{\bar{\nu}_e}$
pp	$\{1,1\} : \{2,2\} : \{0,0\}$	$0.33 : 0.34 : 0.33$	$\{0.17, 0.17\} : \{0.17, 0.17\} : \{0.16, 0.16\}$	0.17
$p\gamma$	$\{1,0\} : \{1,1\} : \{0,0\}$	$0.33 : 0.34 : 0.33$	$\{0.26, 0.08\} : \{0.21, 0.13\} : \{0.20, 0.13\}$	0.08

Standard model stuff: Liu, Song, ACV 2304.06068/PRD

What does ν vs $\bar{\nu}$ do for you?

Are neutrinos coming from pp or $p\gamma$ collisions? These give different π^+/π^- ratios

$$\{\nu_e, \bar{\nu}_e\} : \{\nu_\mu, \bar{\nu}_\mu\} : \{\nu_\tau, \bar{\nu}_\tau\}$$

$$p + p \rightarrow n_\pi \left[\pi^0 + \pi^+ + \pi^-\right] \qquad p + \gamma \rightarrow \Delta^+ \rightarrow \pi^+ + n$$

Production	Source flavor ratio	Earth flavor ratio $\nu + \bar{\nu}$	Earth flavor ratio	$f_{\bar{\nu}_e}$
pp	$\{1,1\} : \{2,2\} : \{0,0\}$	$0.33 : 0.34 : 0.33$	$\{0.17, 0.17\} : \{0.17, 0.17\} : \{0.16, 0.16\}$	0.17
$p\gamma$	$\{1,0\} : \{1,1\} : \{0,0\}$	$0.33 : 0.34 : 0.33$	$\{0.26, 0.08\} : \{0.21, 0.13\} : \{0.20, 0.13\}$	0.08
$pp\,\mu$ damped	$\{0,0\} : \{1,1\} : \{0,0\}$	$0.23 : 0.39 : 0.38$	$\{0.11, 0.11\} : \{0.20, 0.20\} : \{0.19, 0.19\}$	0.11
$p\gamma\,\mu$ damped	$\{0,0\} : \{1,0\} : \{0,0\}$	$0.23 : 0.39 : 0.38$	$\{0.23, 0.00\} : \{0.39, 0.00\} : \{0.38, 0.00\}$	0

Standard model stuff: Liu, Song, ACV 2304.06068/PRD

New physics?

ν vs $\bar{\nu}$

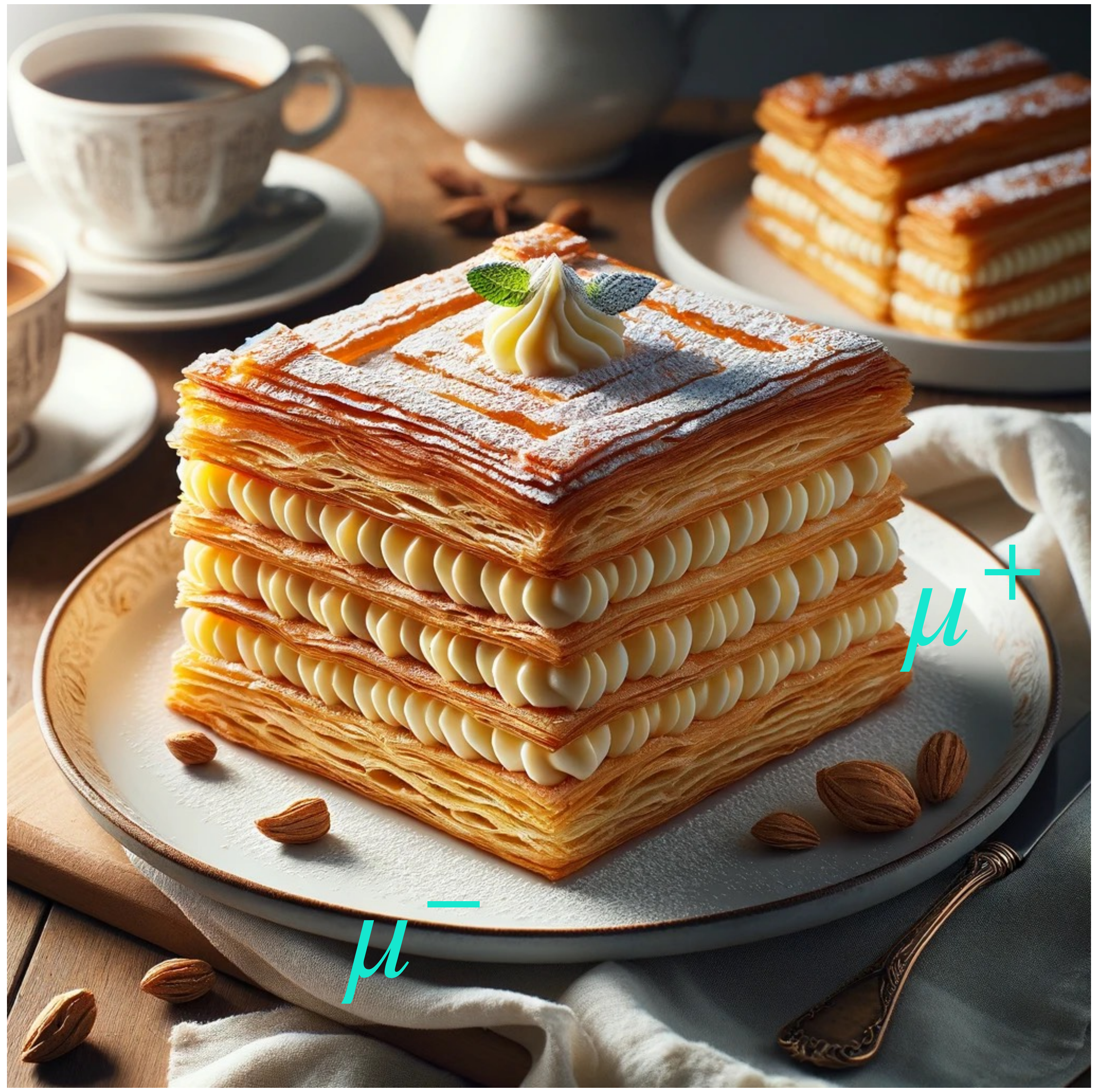
- Symmetric dark matter annihilation/decay: equal parts neutrino/antineutrino
- Asymmetric dark matter

$$\mathcal{O}_{\rm ADM} = \frac{\mathcal{O}_X \mathcal{O}_{\rm SM}}{\Lambda^{m+n-4}}$$

Benchmark	B1 (scalar X)	B2 (scalar X)	B3 (fermion X)	B4 (fermion X)
$\mathcal{O}_{X\to\nu}$	$\frac{1}{\Lambda} X\psi L\Phi$	$\frac{1}{\Lambda^2} X(L\Phi)^2$	$\frac{1}{\Lambda^2} XL\psi^2$	$\frac{1}{\Lambda^2} XLL\nu^c$
Decay	$X \to \bar{\nu}\psi/\nu\psi$	$X \to \bar{\nu}\bar{\nu}/\nu\nu$	$X \to \bar{\nu}\psi\bar{\psi}/\nu\psi\bar{\psi}$	$X \to \bar{\nu}\nu\bar{\nu}/\nu\nu\bar{\nu}$

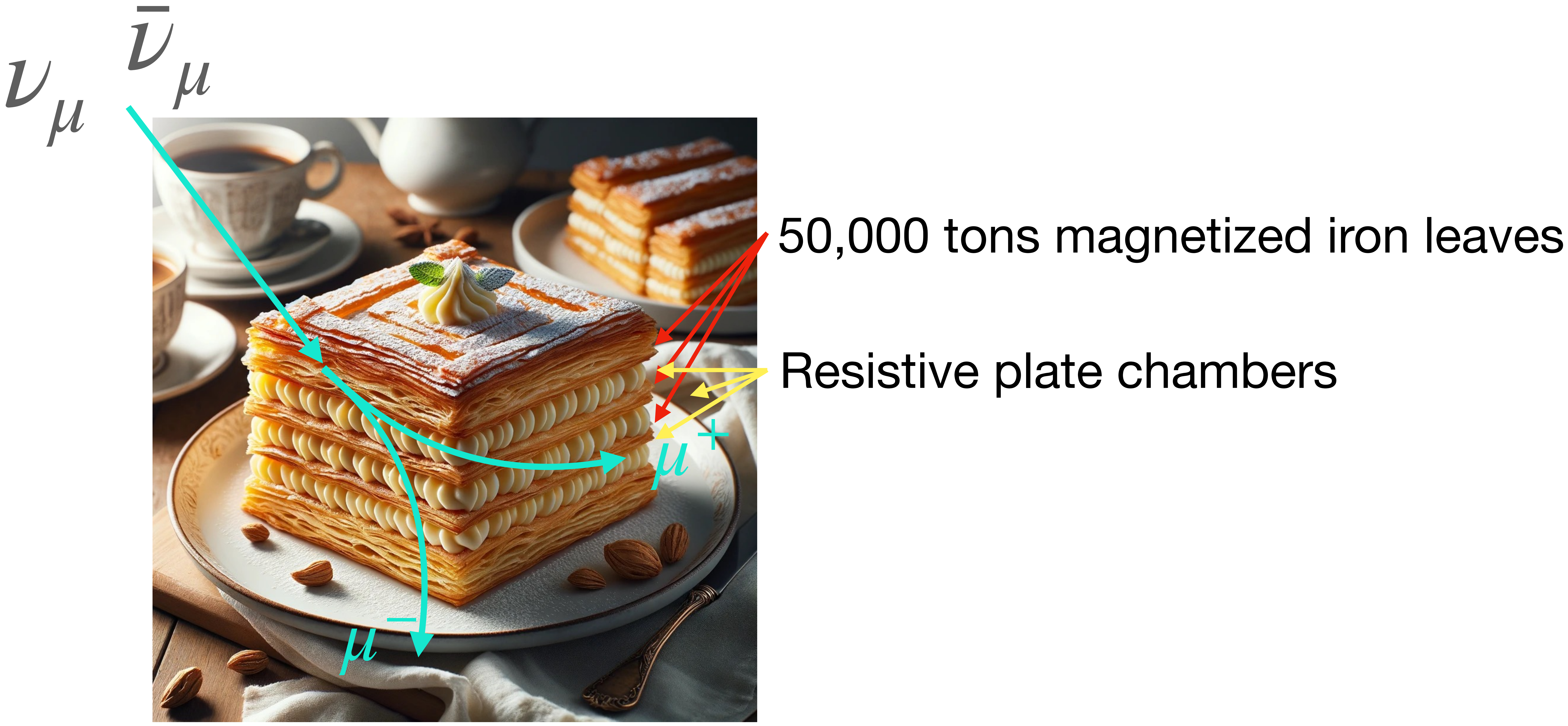
Liu, Song, ACV, 2304.06068

(Aside: India-based Neutrino Observatory proposal)

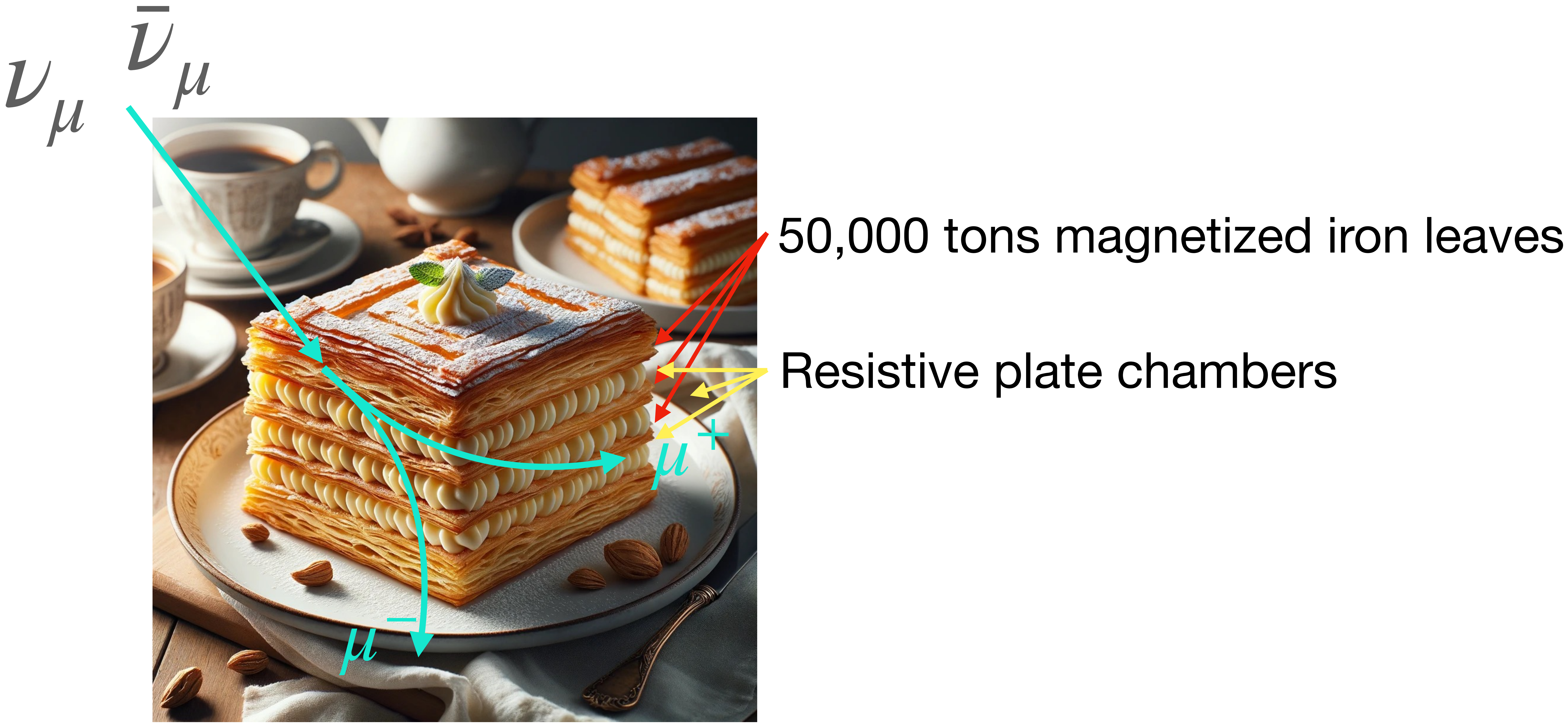


(Aside: India-based Neutrino Observatory proposal)

(Aside: India-based Neutrino Observatory proposal)



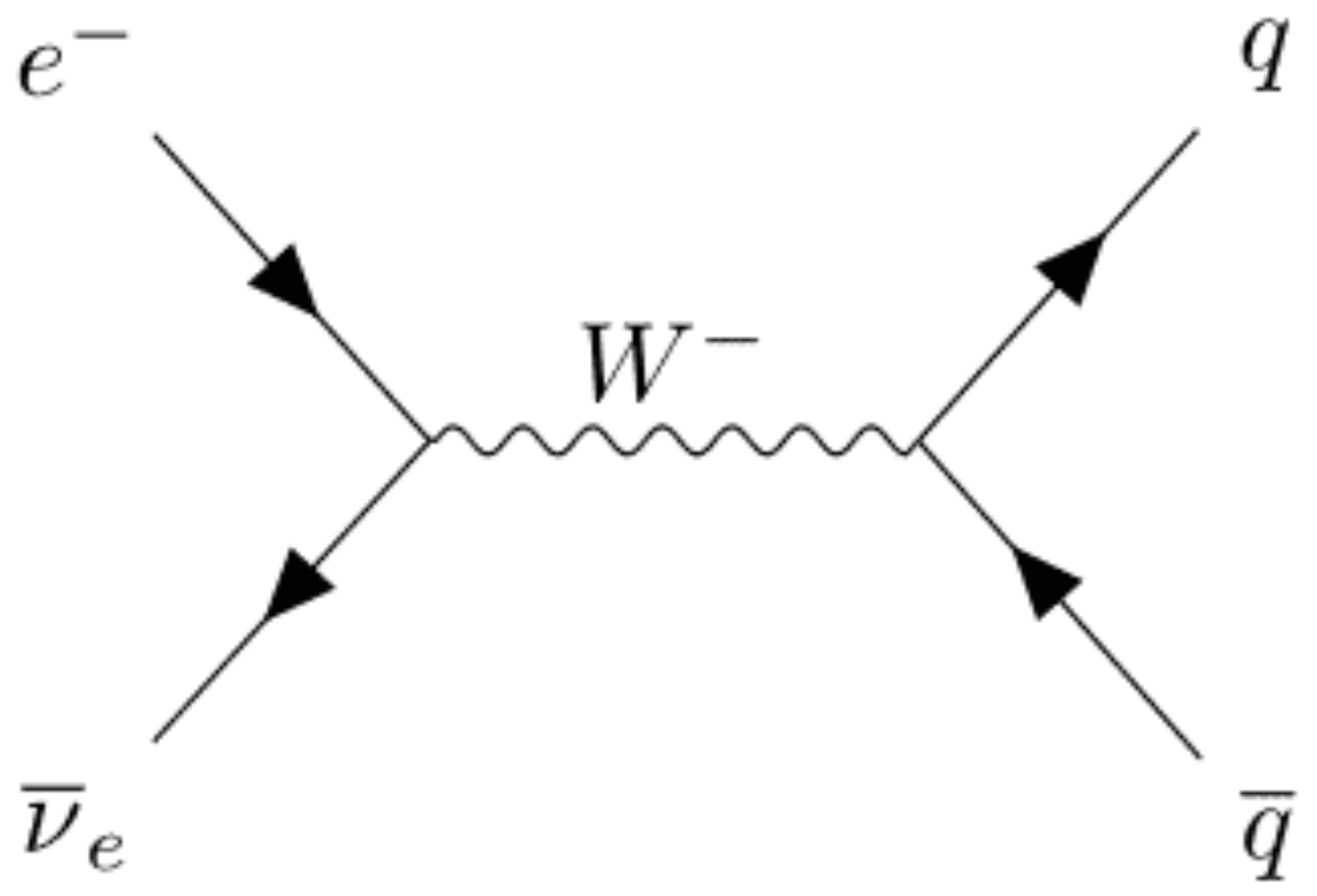
(Aside: India-based Neutrino Observatory proposal)

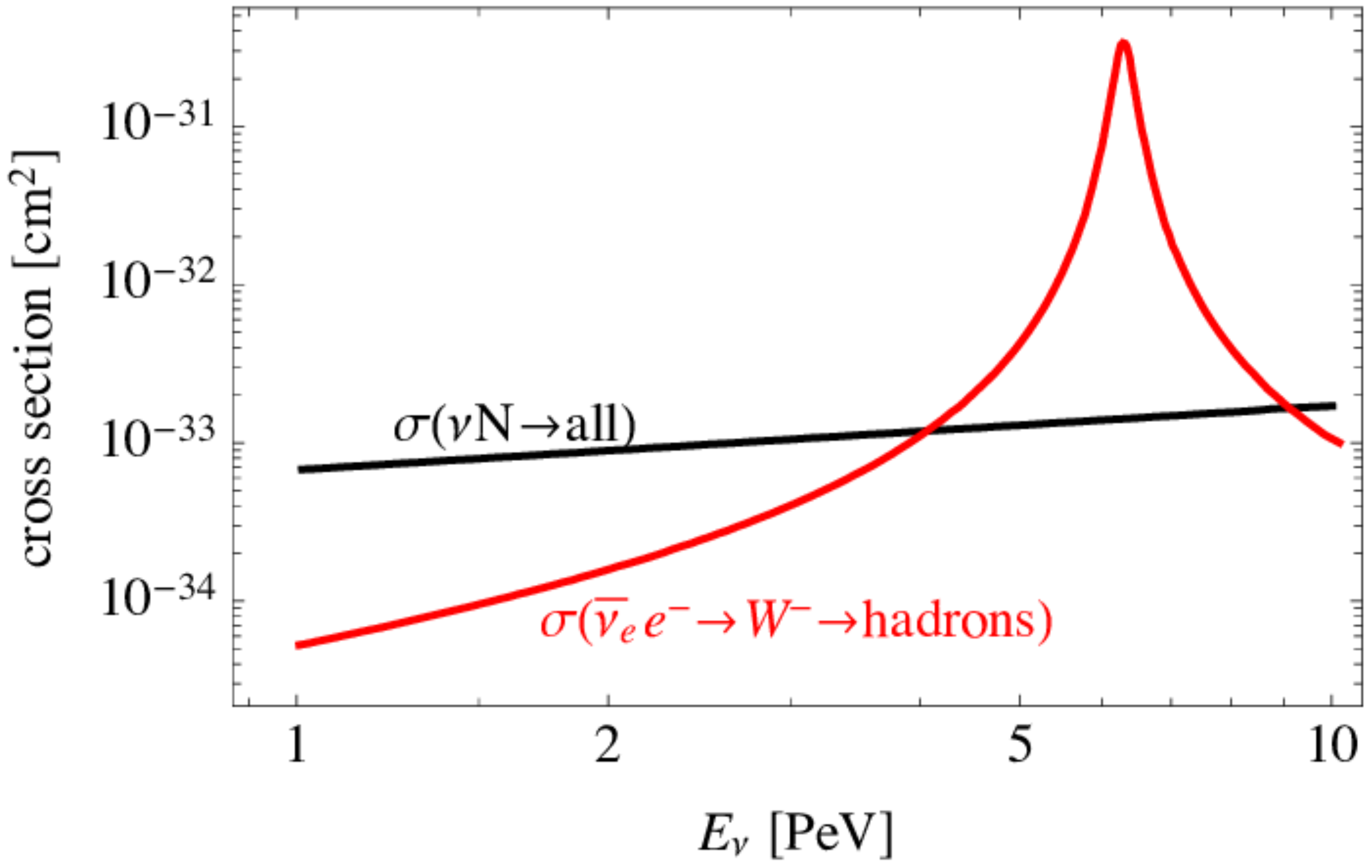


Currently stalled due to ecological concerns (blasting, excavation, …)

Distinguishing ν vs $\bar{\nu}$?

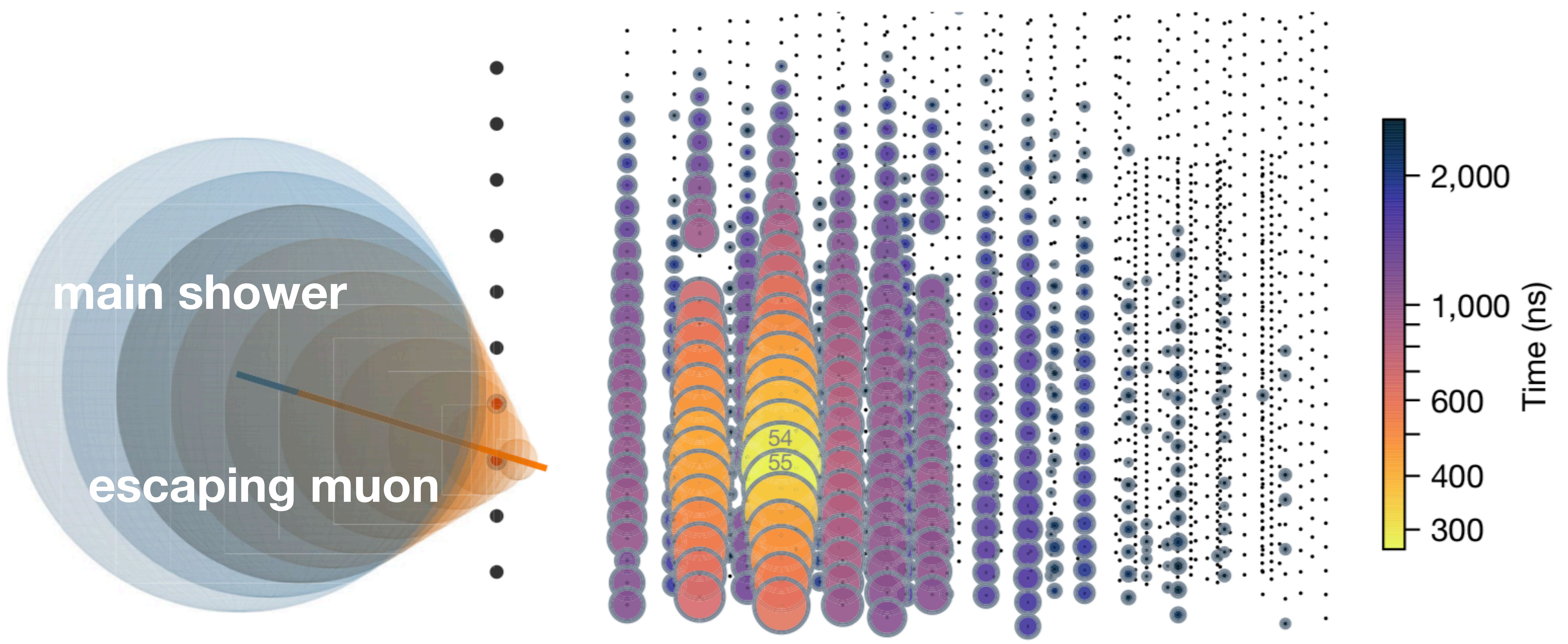
- At high energies, neutrino/antineutrino separation is almost impossible
- Exception: the Glashow resonance.
  At $E_{CM} = M_W$, or $E_\nu = 6.3$ PeV, can produce on-shell W for $\bar{\nu}_e$ only.

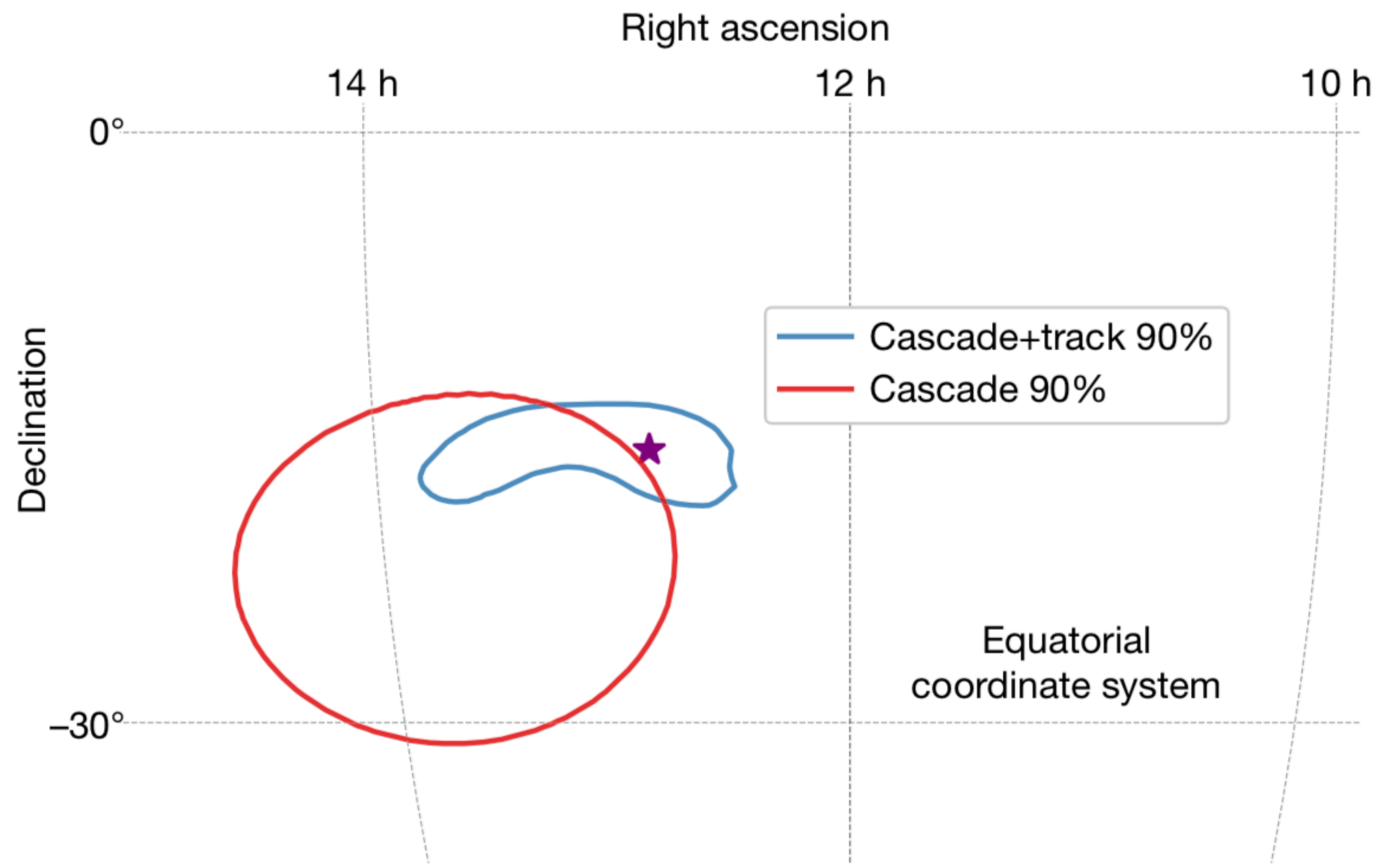




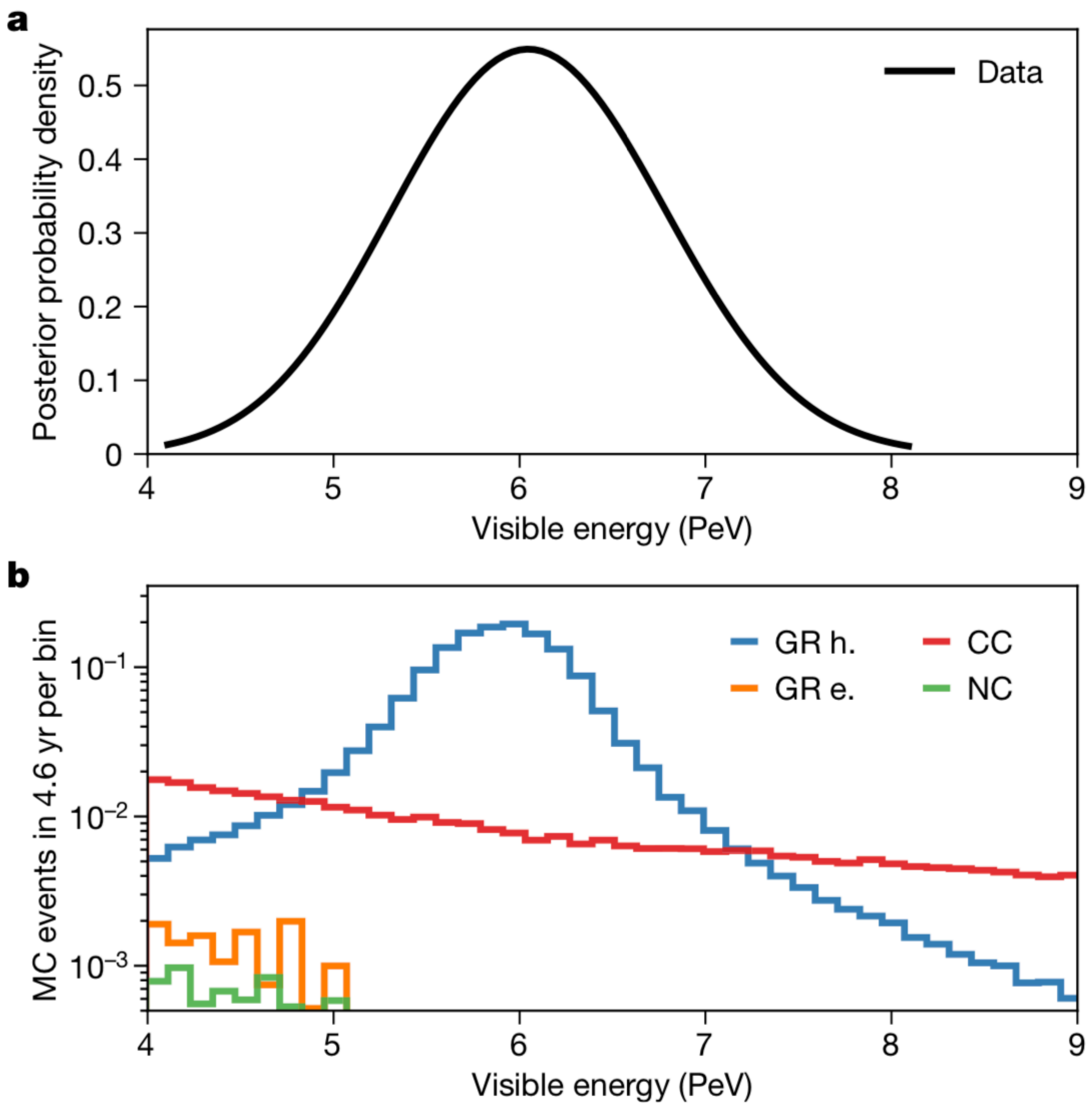
Liu, Song, ACV, 2304.06068

First Detection of Glashow Resonance





PeV energy partially-contained event selection



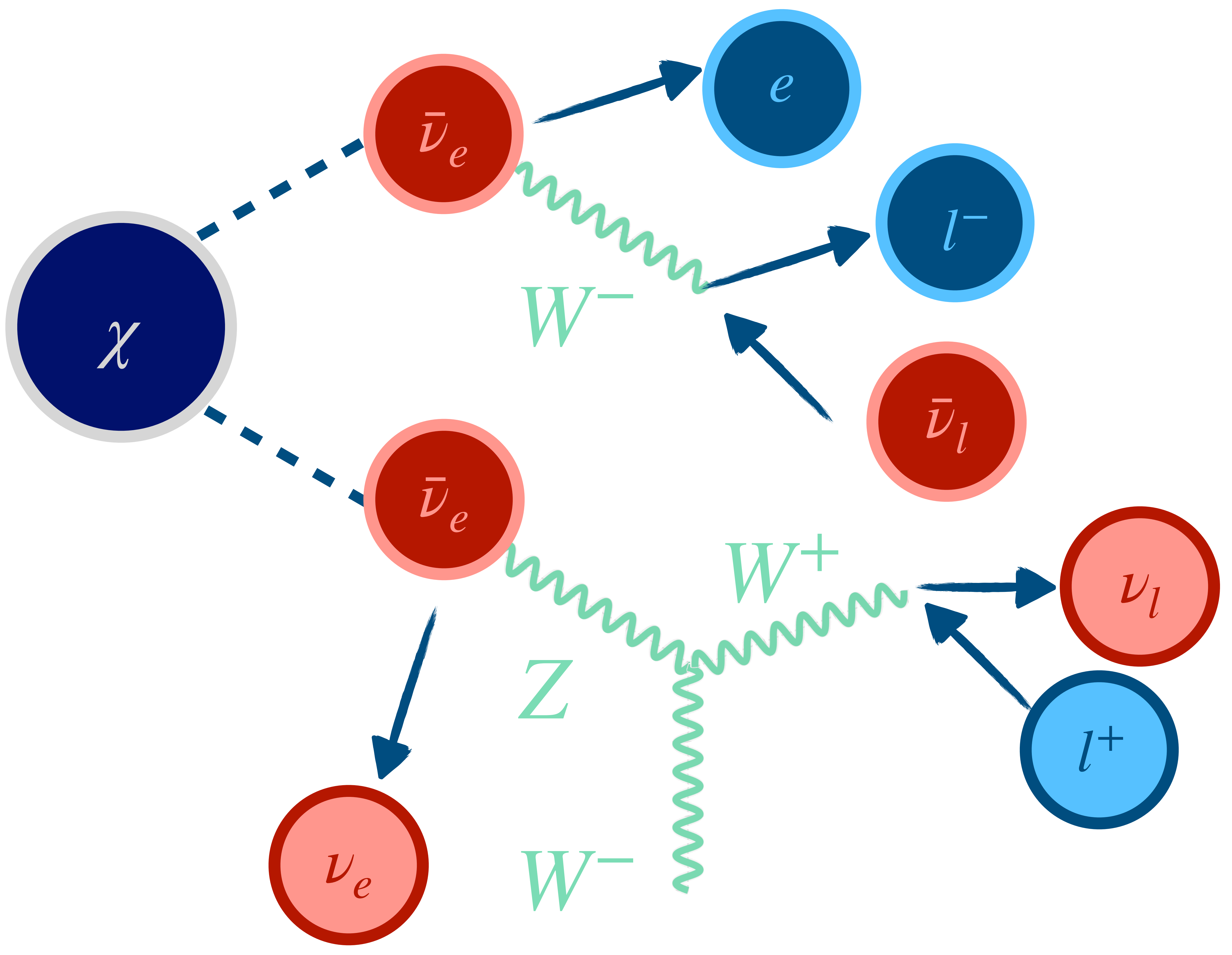
- Reconstructed energy of 6.05 ± 0.72 PeV.
- The detectable escaping muon suggests it's a hadronic shower.

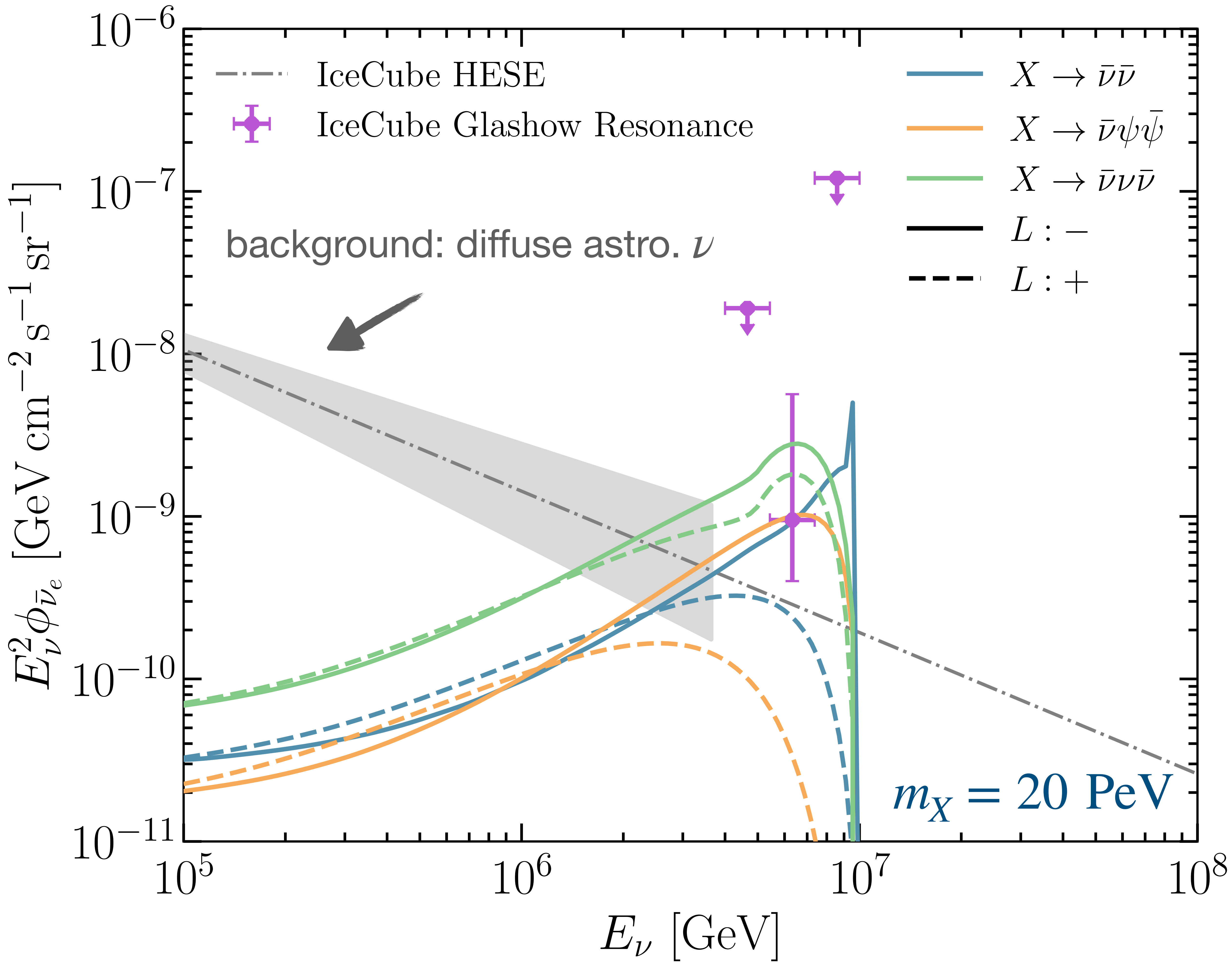
IceCube Nature 2021

Electroweak Showering

Liu, Song, ACV, 2304.06068

- Both ν and $\bar{\nu}$ can be produced no matter whether the lepton number is positive or negative.
- The spectrum $dN^{\rm ch}_{\bar{\nu}_i}/dE_\nu$ becomes softer.

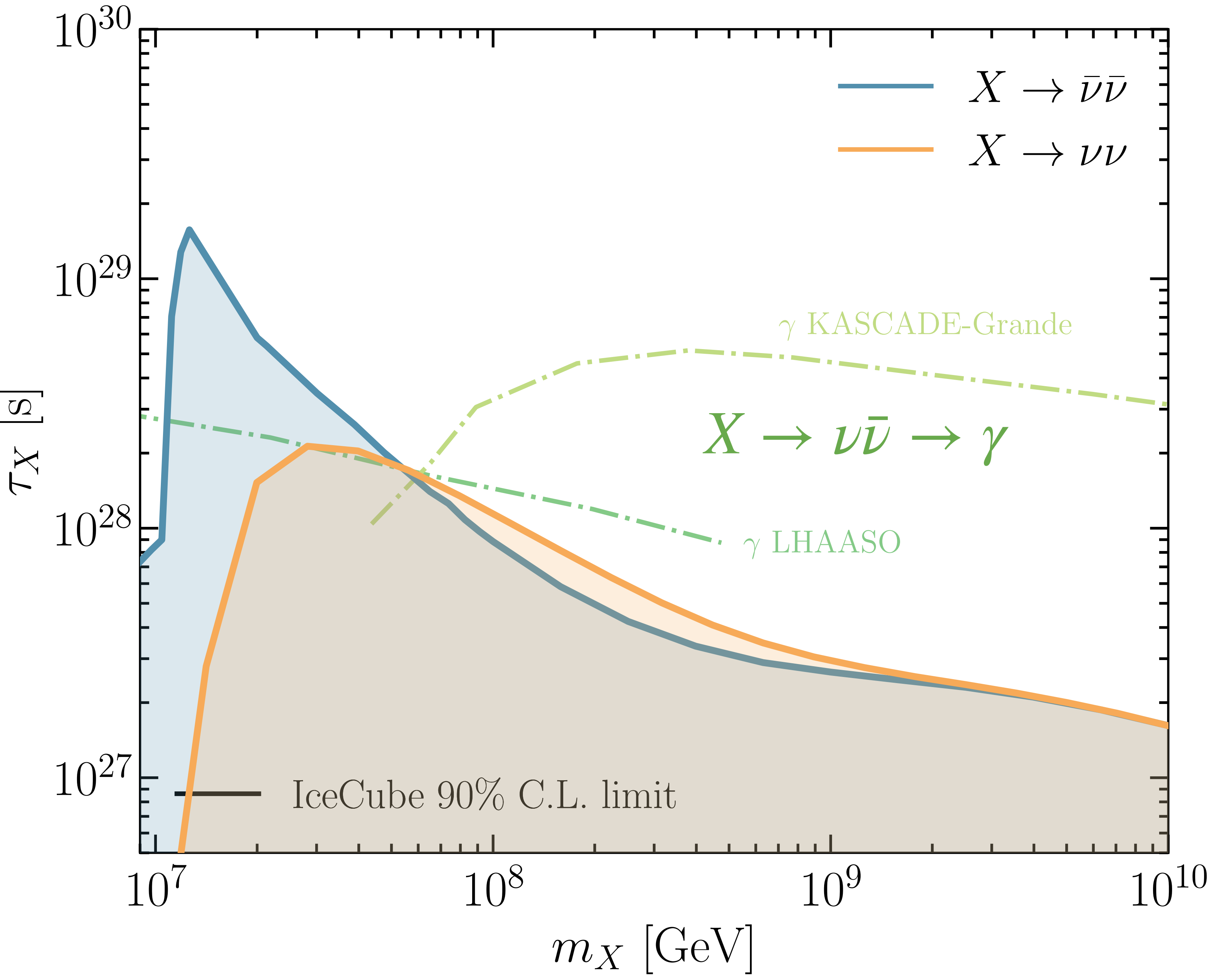


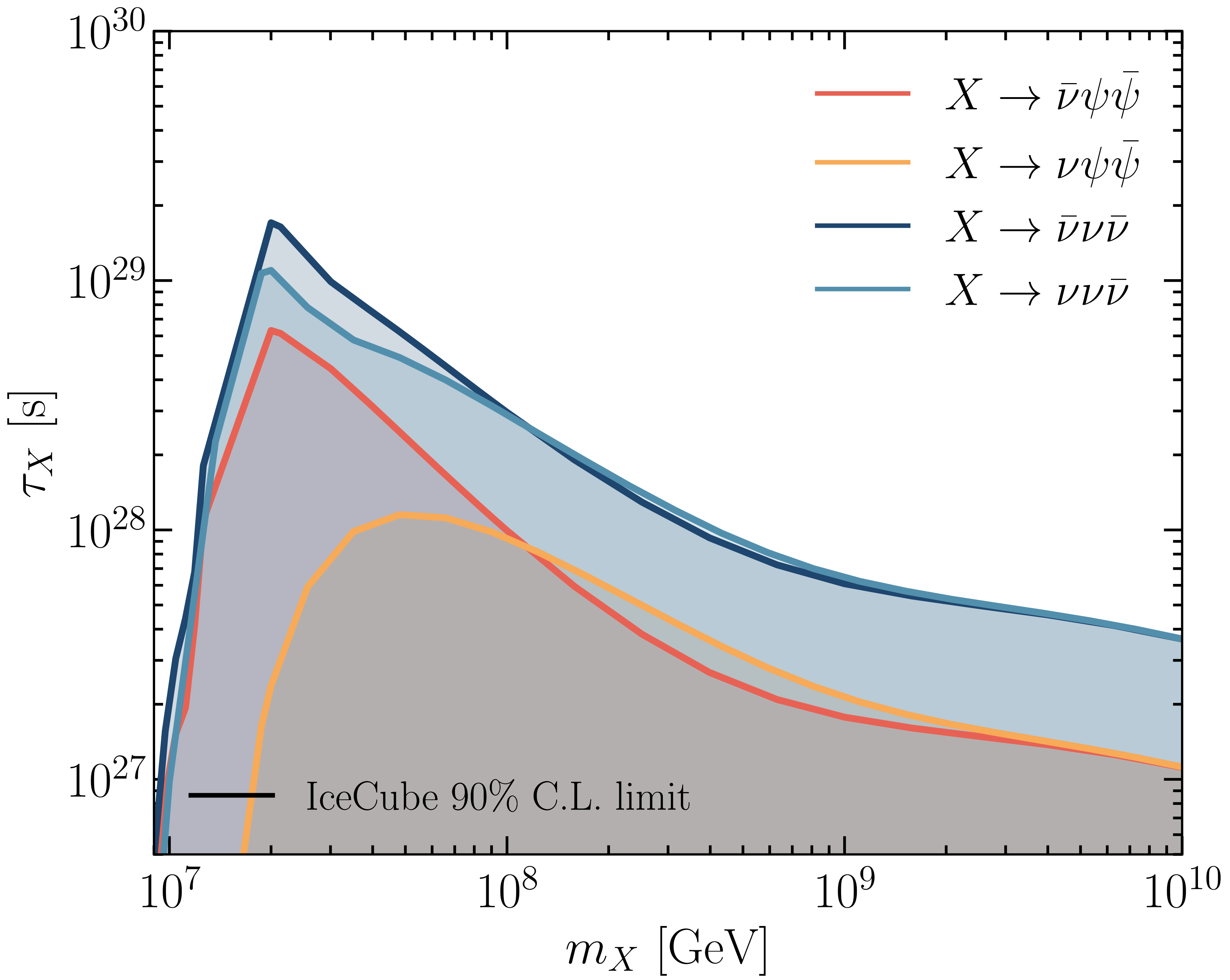


fragmentation functions from HDMSpectra

Bauer, Rodd, Webber 2007.15001

Constraints with Current Observation





- **Scenarios with positive/negative lepton numbers can be constrained respectively for m_X ~ PeV - EeV.**
- **The sensitivity of Glashow Resonance weakens when the number of decay products increases as $\nu : \bar{\nu} \to 1 : 1$.**

Liu, Song, ACV, 2304.06068

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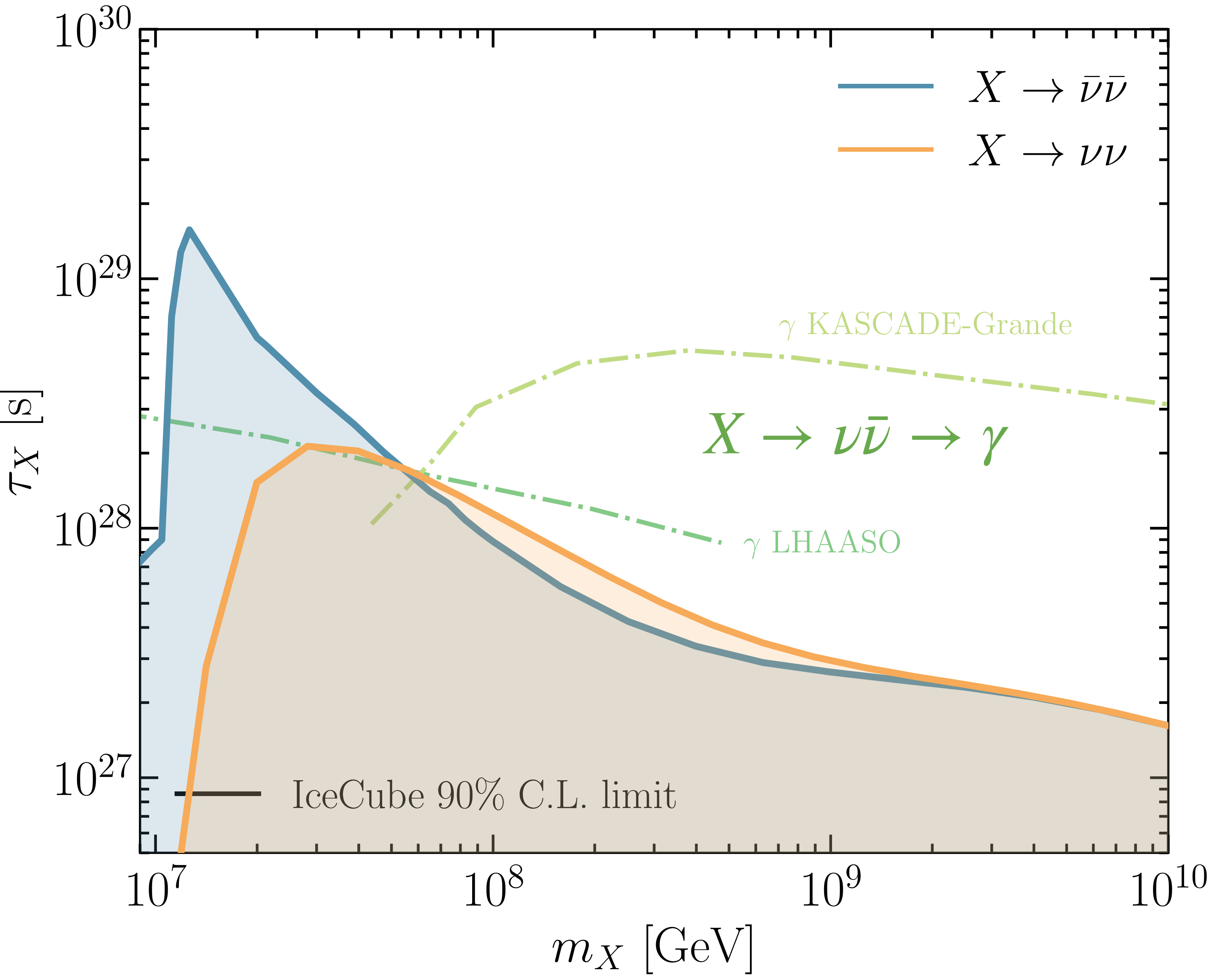

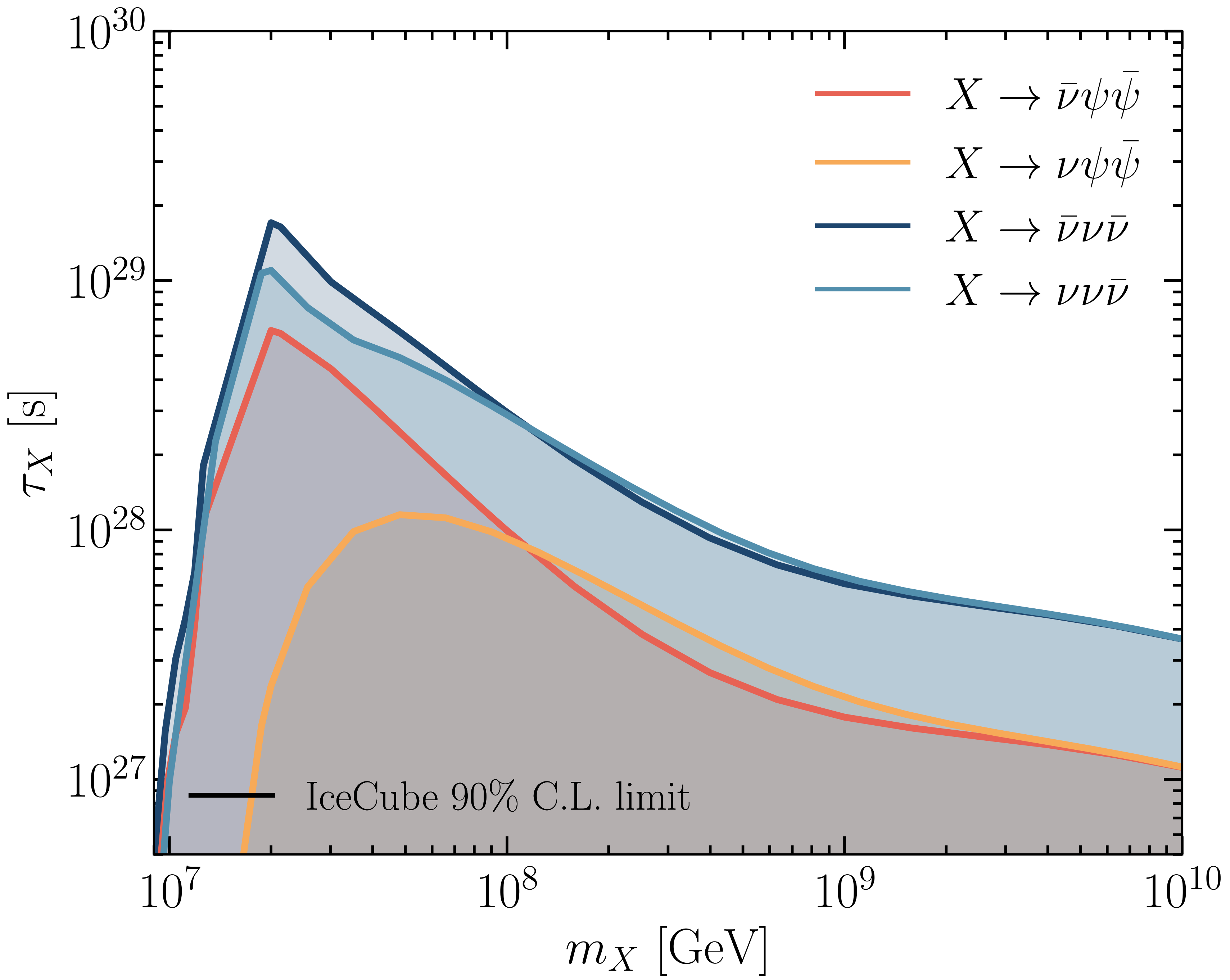

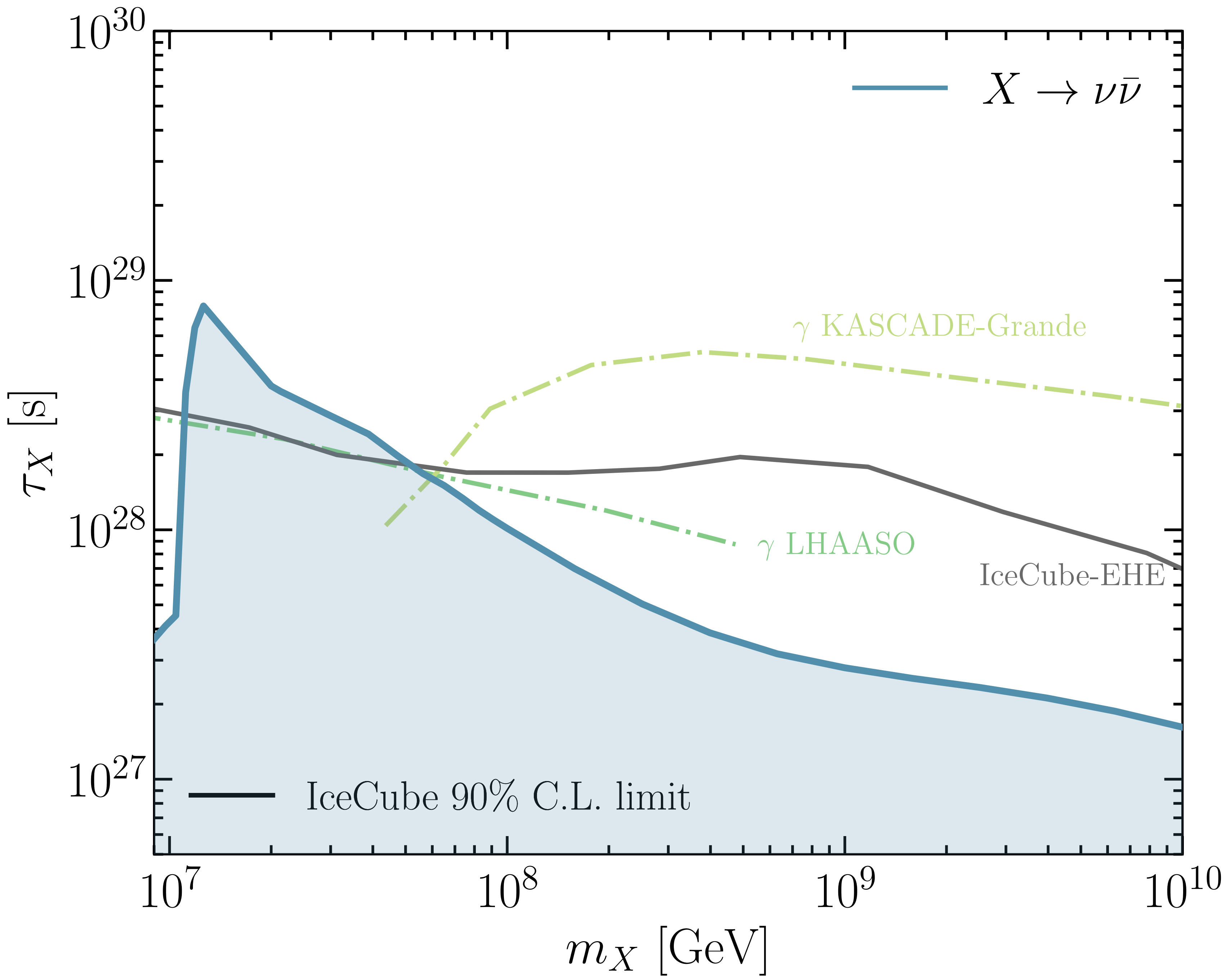

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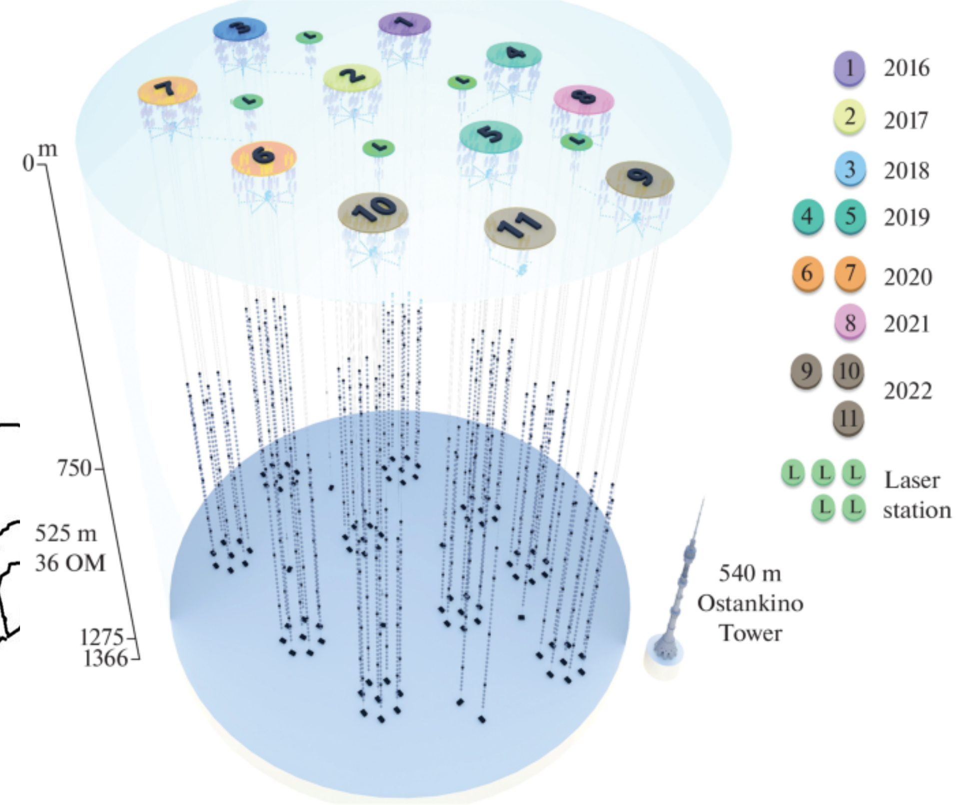
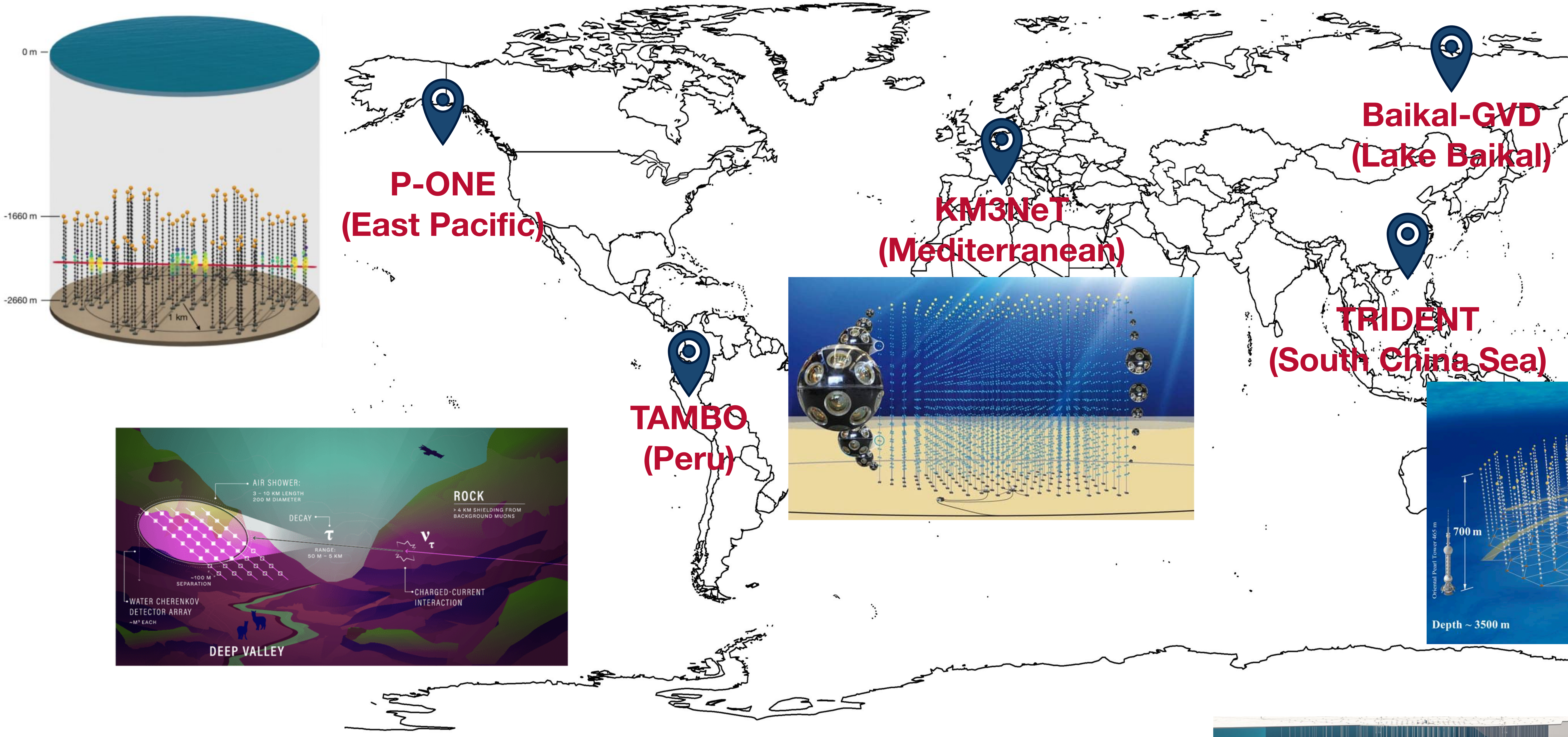
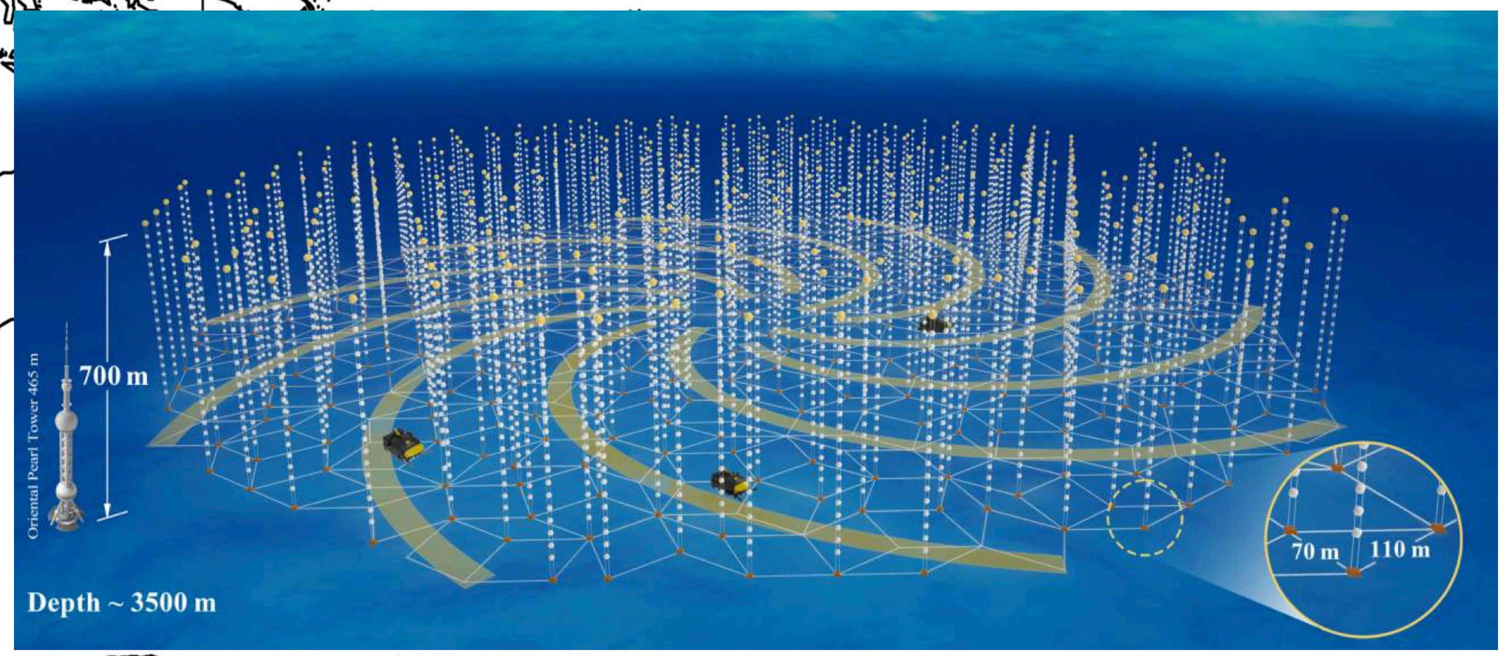
Better constraints on neutrino portal of symmetric DM decay for m_X ~ 10 - 100 PeV

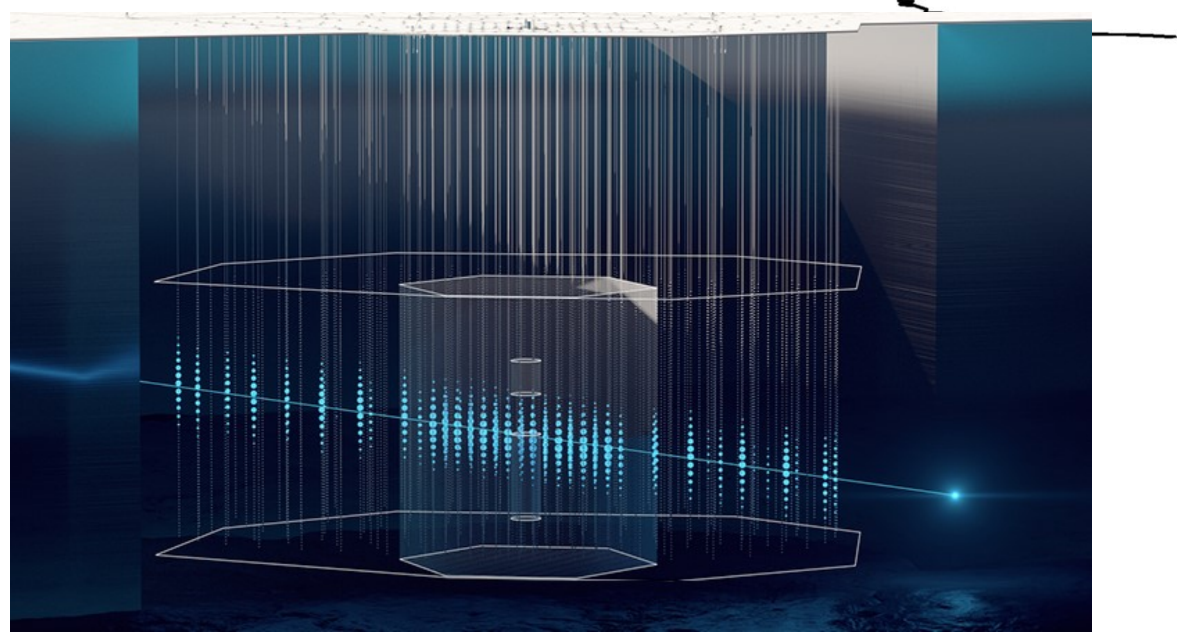
Liu, Song, ACV, 2304.06068

Next-Generation High-Energy Neutrino Telescopes









IceCube-Gen2
(South Pole)

More telescopes with larger exposure!

Glashow Resonance Signal

Glashow resonant events can be identified on an event-wise basis in the [4,10] PeV deposited energy window.

★ $W^- \to \text{hadrons}$ **BR ~67 %**

✔ escaping muons, the only irreducible background is from neutral-current events

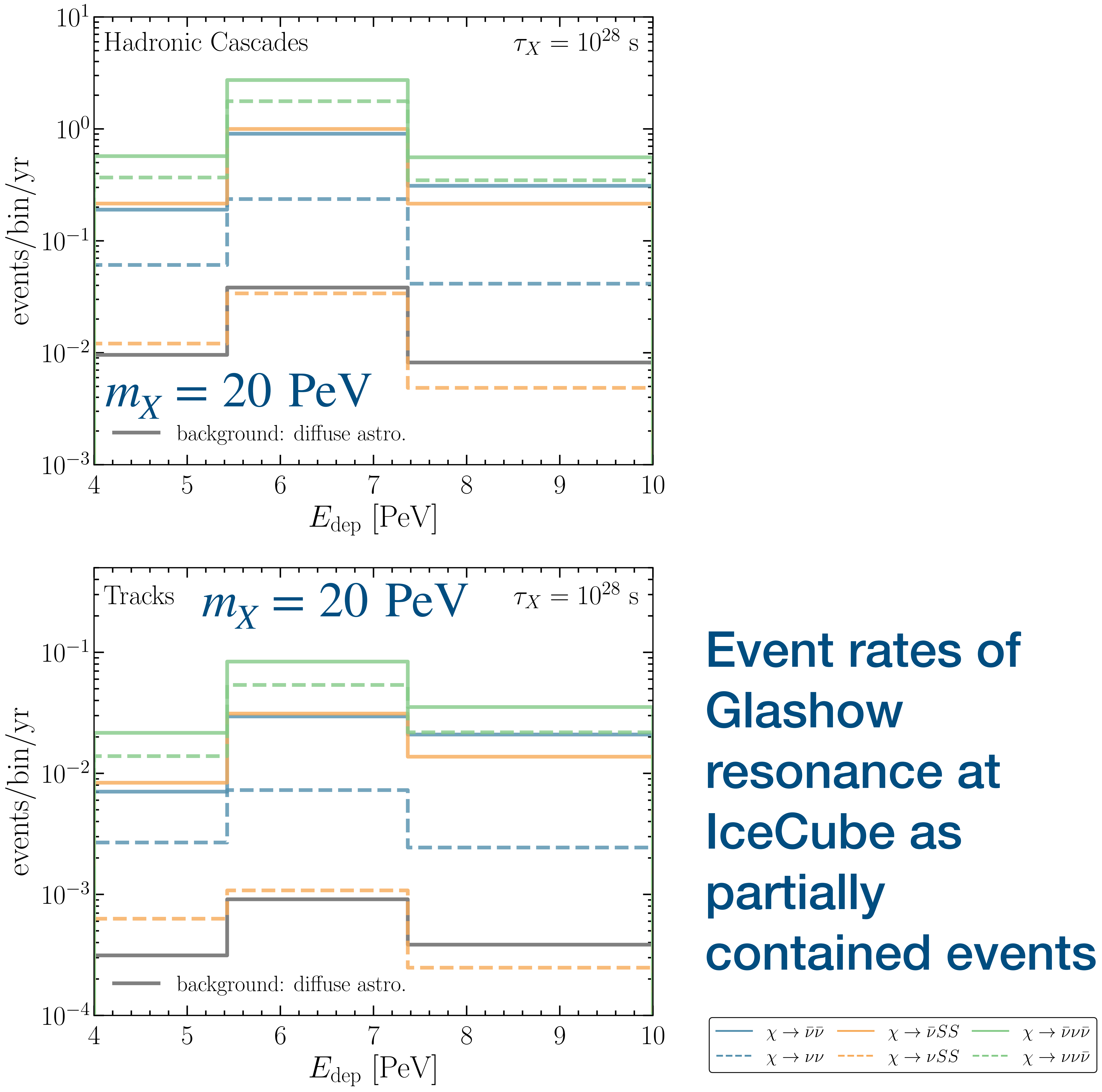
★ $W^- \to e^-\bar{\nu}_e/\tau^-\bar{\nu}_\tau$ **BR ~11 %**

✖ Indistinguishable from a deep-inelastic-scattering cascade

★ $W^- \to \mu^-\bar{\nu}_\mu$ **BR ~11 %**

✔ track without the initial cascade compared to ν_μ charged-current events

Liu, Song, ACV, 2304.06068



Event rates of Glashow resonance at IceCube as partially contained events

Projected Sensitivities in the Future

- **90% C.L. sensitivities are estimated.**
- **Projected 10yr IceCube-Gen2 (8 × IceCube) sensitivities have lifetimes ~5 of current constraints.**

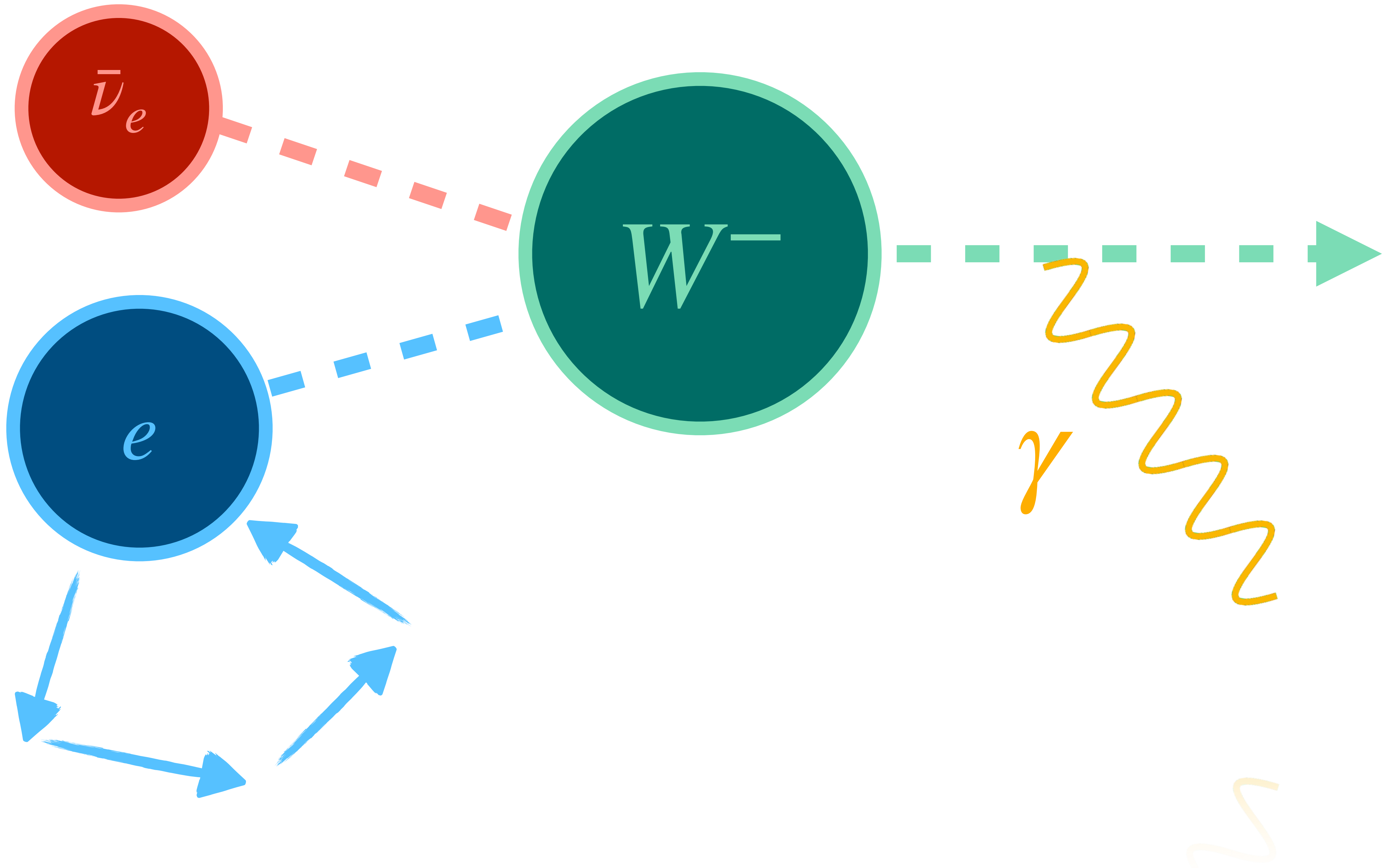
Liu, Song, ACV, [2304.06068]

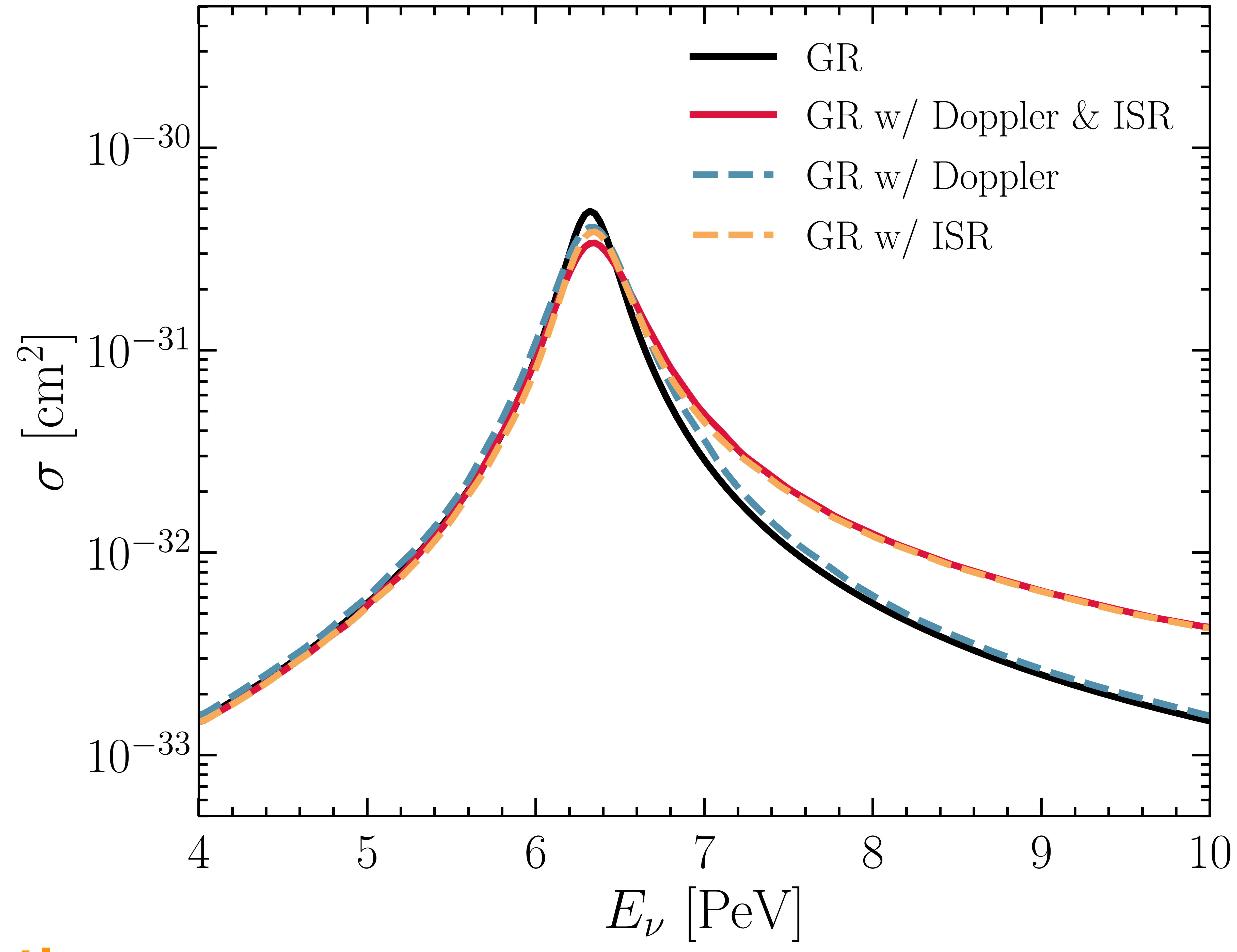
(not really a) Summary

- Even though neutrinos are the most invisible channel, neutrino telescopes cover at least **14 orders of magnitude in energy** & can say all sorts of things about the dark sector & new physics.
- Electroweak cross section rises with energy, but events become rarer (big detectors)
- Electroweak corrections means that even if the dark matter tries to cloak itself with the neutrino… it cannot hide forever.

Corrected Cross Section

subleading effects that affect the cross section





Atomic e motion:
Doppler Broadening

Initial State Radiation