Neutrino Line Searches with IceCube

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on behalf of IceCube

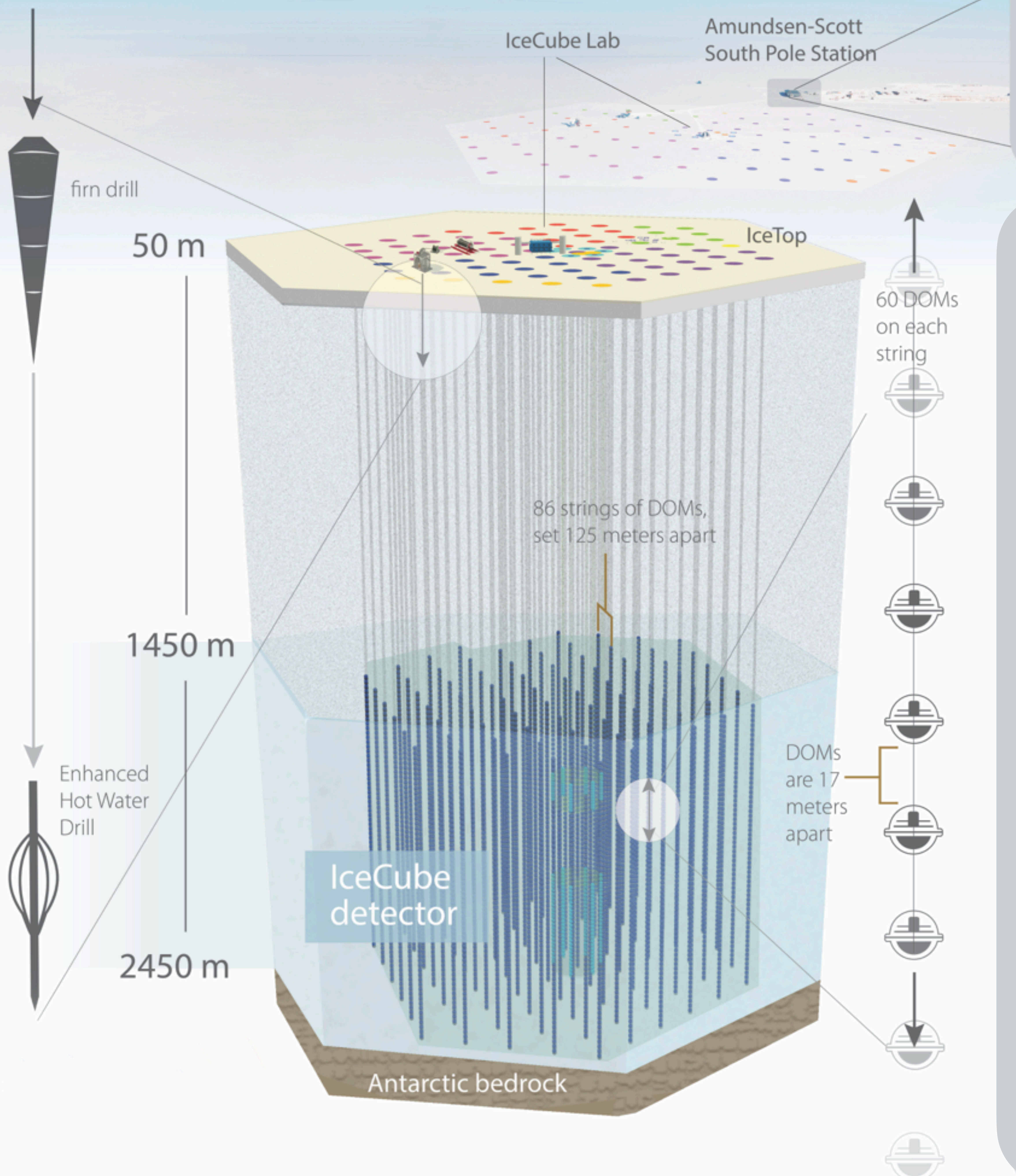
Photo: Ian Reese

ULB

Dark Ghosts 2022

iihe

IceCube Neutrino Observatory



5,160 Digital Optical Modules (DOMs)

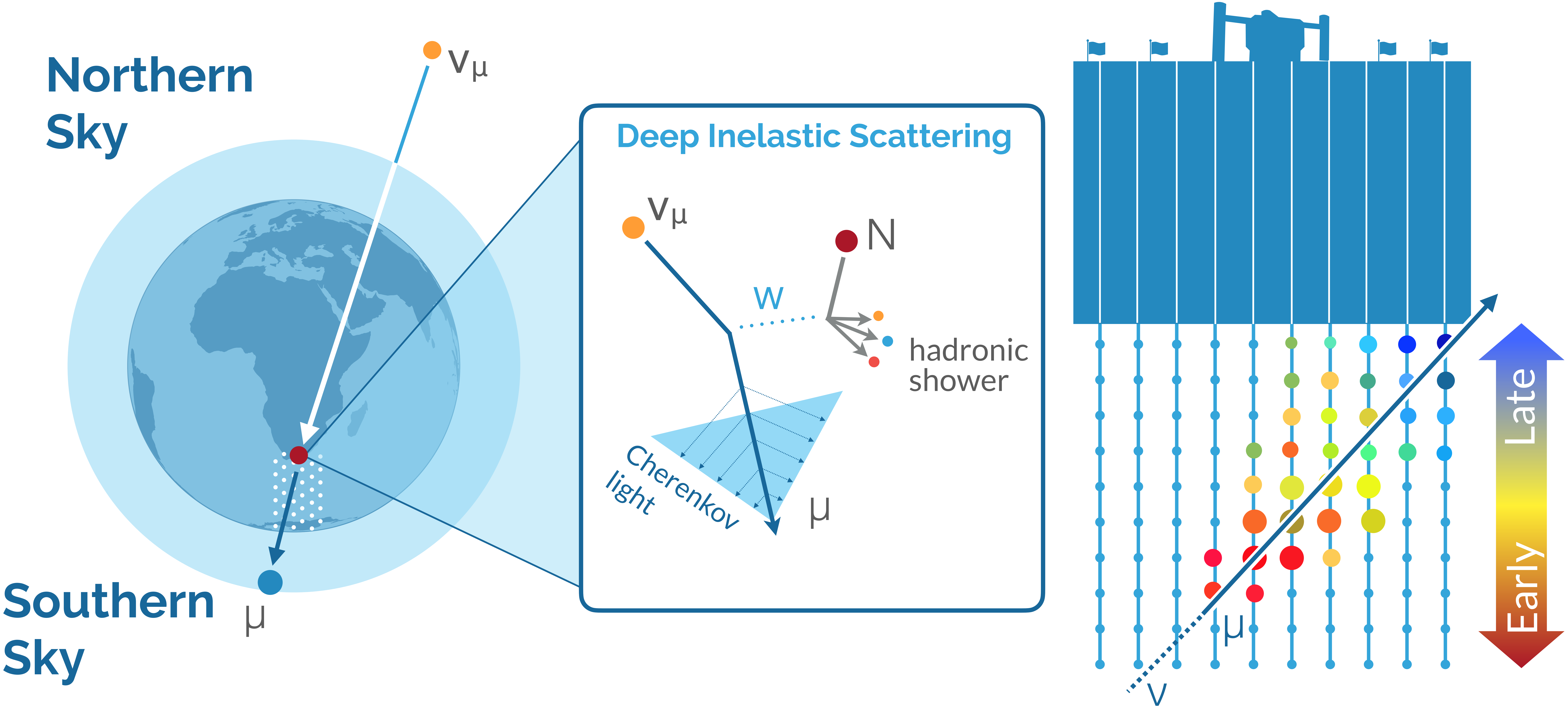
86 string with 60 DOMs each

6 denser strings called **DeepCore**

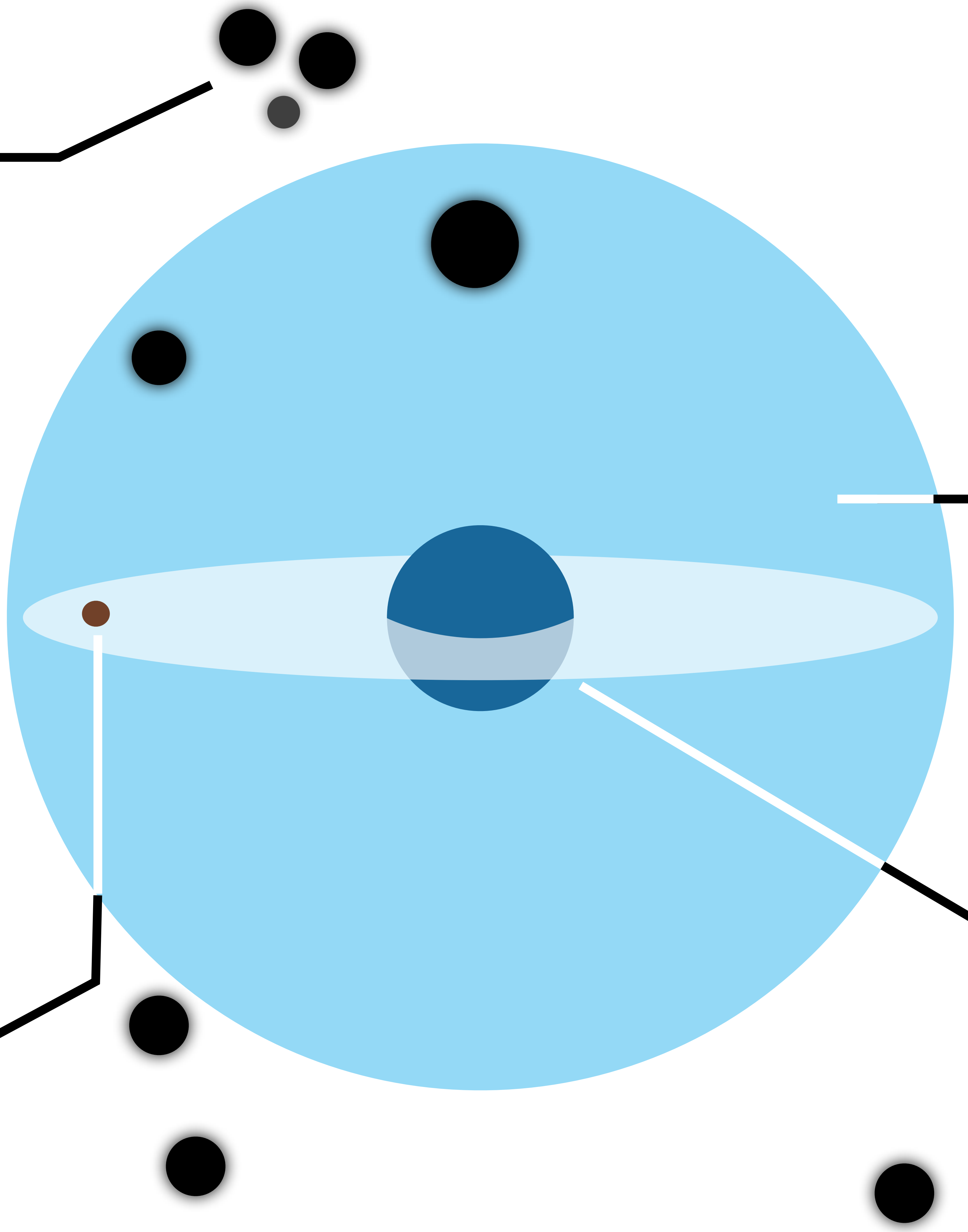
1 km² surface array with 324 DOMs: **IceTop**

Completion in December 2010

Detection Principle How Do We Detect Neutrinos?



Dark Matter Searches with Neutrinos Where to Look?



Dwarf spheroidal Galaxies
Cluster of Galaxies

Probe velocity-averaged DM annihilation cross section $\langle v\sigma_A \rangle$

Galactic Halo

Probe velocity-averaged DM annihilation cross section $\langle v\sigma_A \rangle$

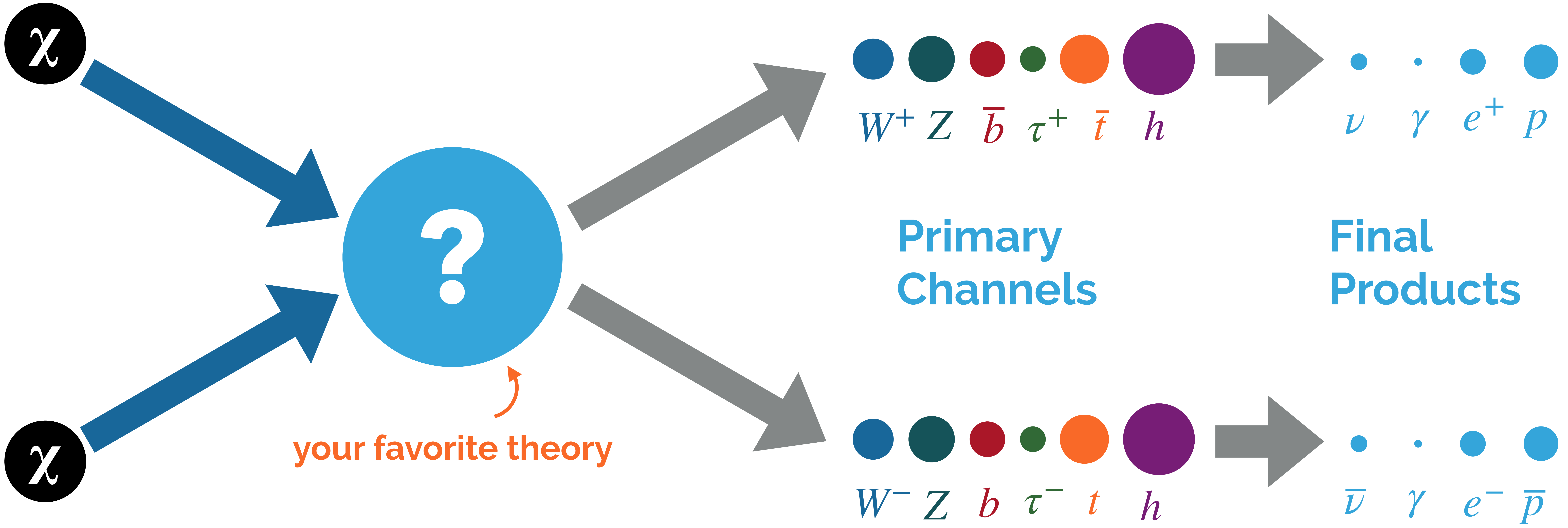
Galactic Center

Probe velocity-averaged DM annihilation cross section $\langle v\sigma_A \rangle$

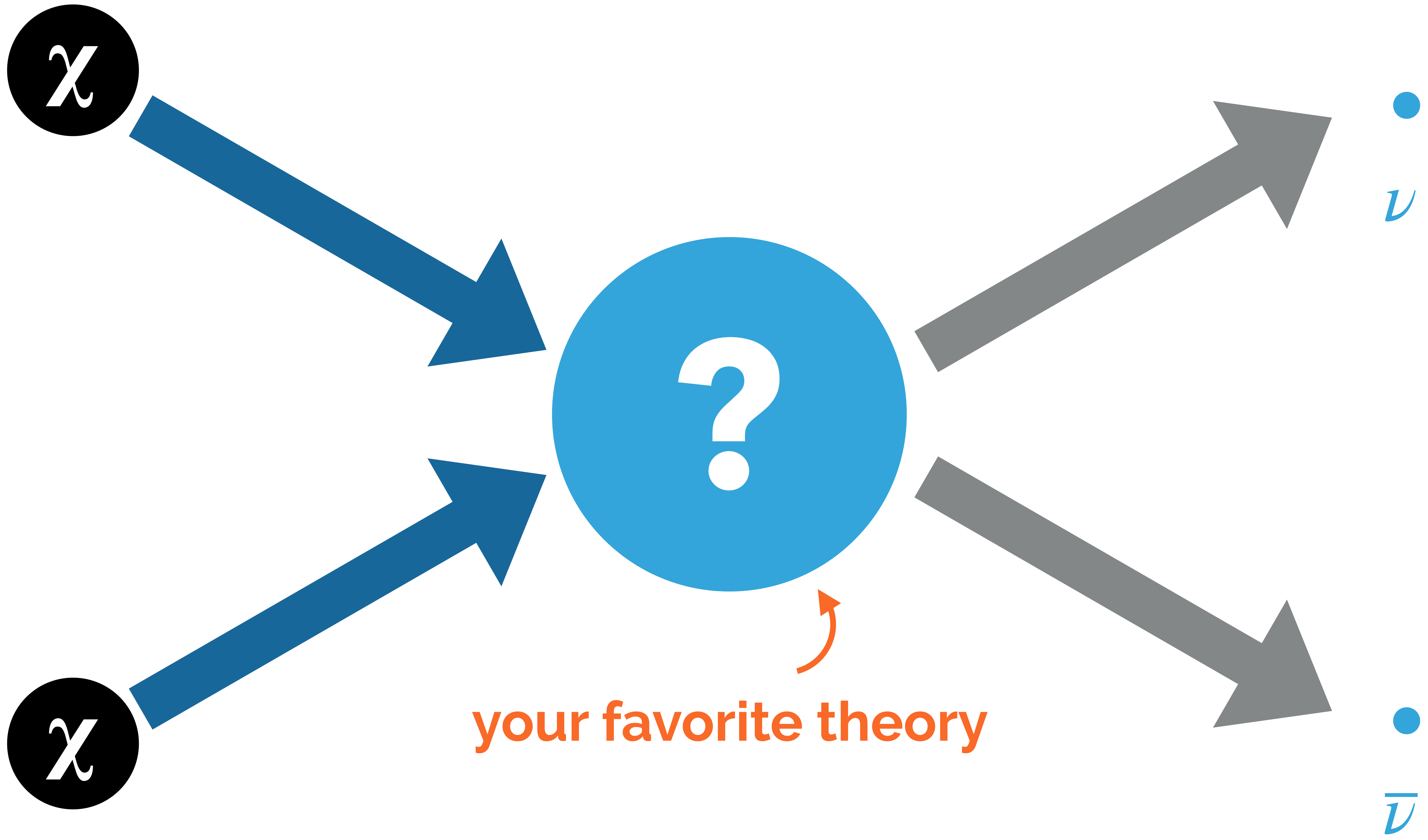
Local Sources (Sun, Earth)

Only accessible with neutrinos
Under equilibrium they can probe σ_{SI} and σ_{SD}

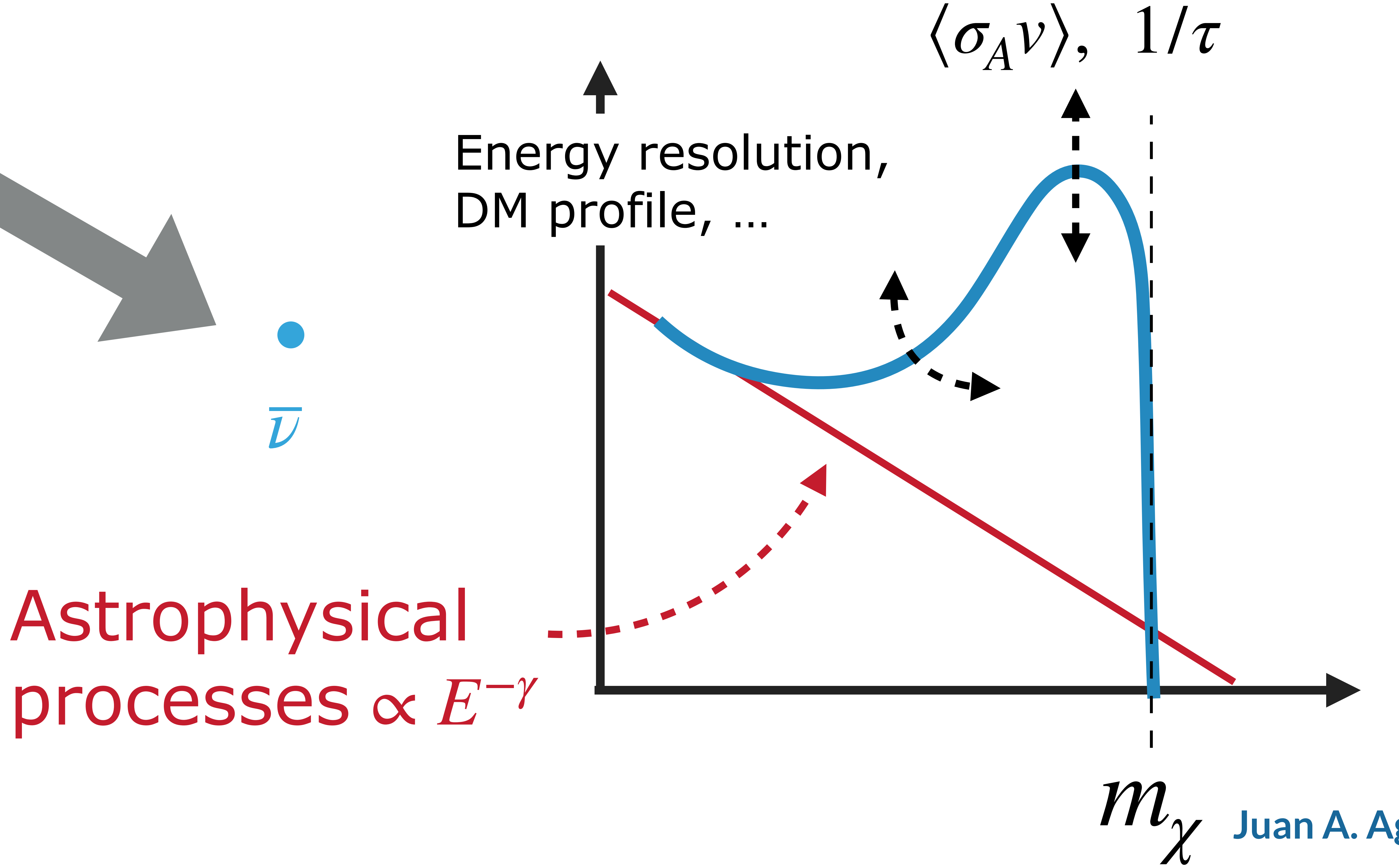
Indirect Detection of Dark Matter



Indirect Detection of Dark Matter: Neutrino Lines



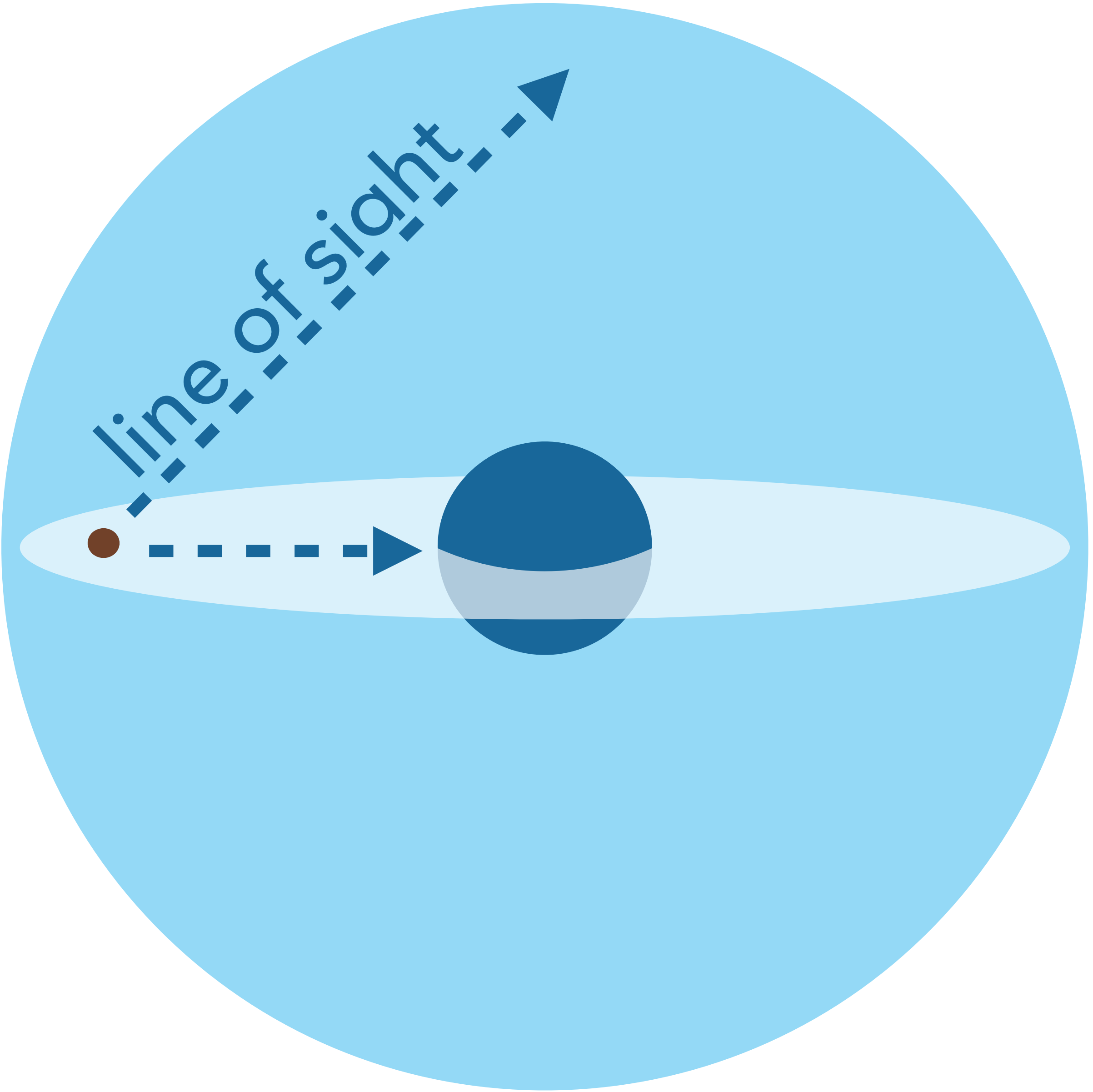
- Focusing on direct annihilation/ decay to neutrinos.
- No astrophysical background, **smoking gun** signature of dark matter.



The Galactic Center The Astrophysical Input

Annihilation

$$\frac{d\Phi_\nu}{dE_\nu} = \frac{1}{4\pi}\frac{\langle\sigma_A v\rangle}{2m_\chi^2}\frac{dN_\nu}{dE_\nu} \int_0^{\Delta\Omega} d\Omega \int_{l.o.s} \rho_\chi^2(r(s,\Psi,\theta))ds$$



Particle physics

Astrophysics

Decay

$$\frac{d\Phi_\nu}{dE_\nu} = \frac{1}{4\pi}\frac{1}{m_\chi\tau_\chi}\frac{dN_\nu}{dE_\nu} \int_0^{\Delta\Omega} d\Omega \int_{l.o.s} \rho_\chi(r(s,\Psi,\theta))ds$$

The Astrophysical Input: J-factors, D-factors

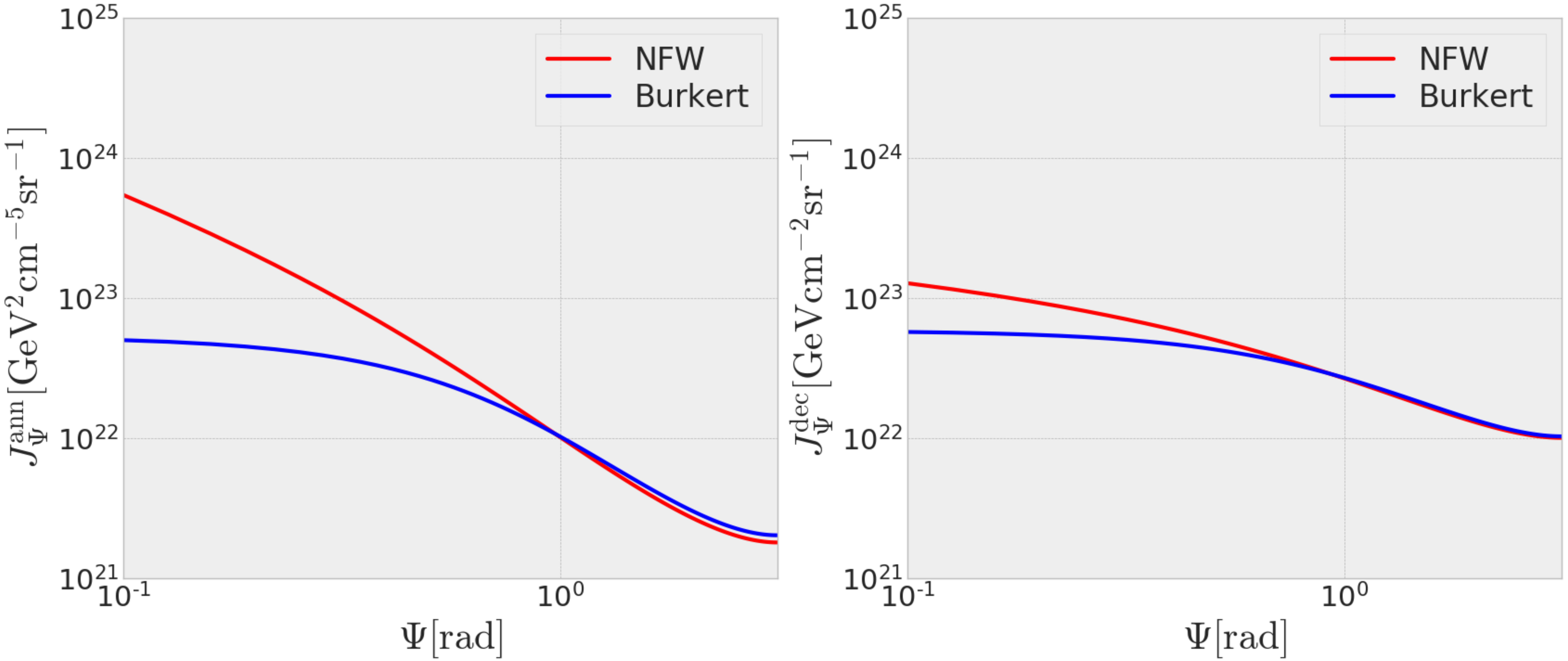
- Two archetypical density profile tested: NFW and Burkert

$$\rho_{Burkert}(r) = \frac{\rho_s}{(1 + r/r_s)(1 + (r/r_s)^2)}$$

$$\rho_{NFW}(r) = \rho_s \frac{r_s}{r}\left(1 + \frac{1}{r_s}\right)$$

Parameter	Units	Navarro-Frenk-White (NFW)	Burkert
ρ_0	$10^7 M_\odot/kpc^3$	$1.40^{+2.9}_{-0.93}$	$4.13^{+6.2}_{-1.6}$
r_s	kpc	$16.1^{+17}_{-7.8}$	$9.26^{+5.6}_{-4.2}$

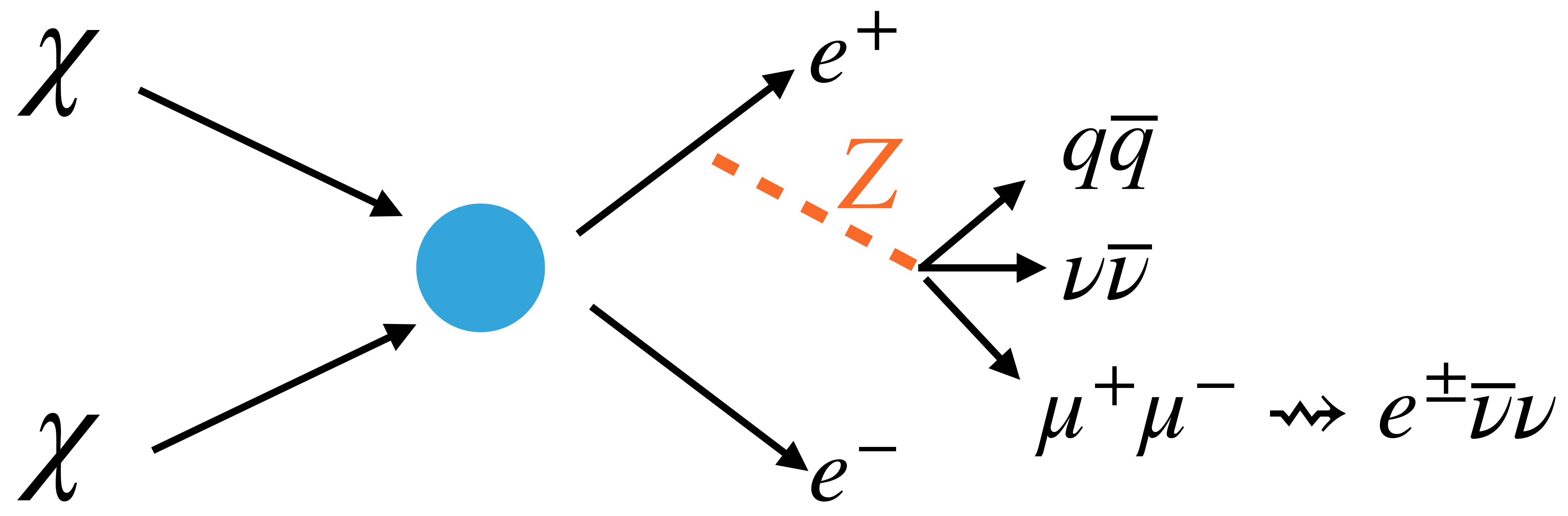
*values taken from arxiv:1304.5127



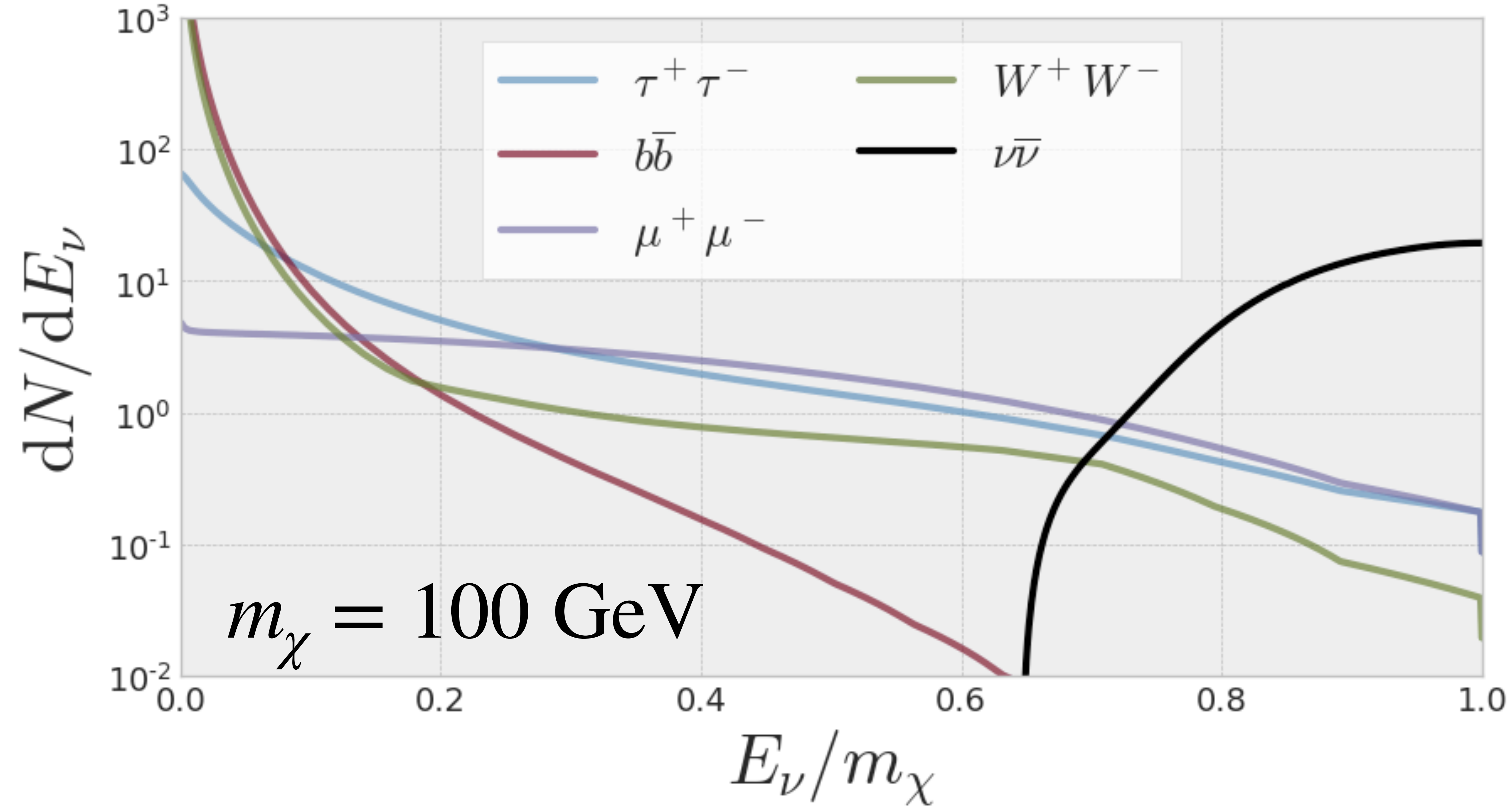
Local clumps not considered

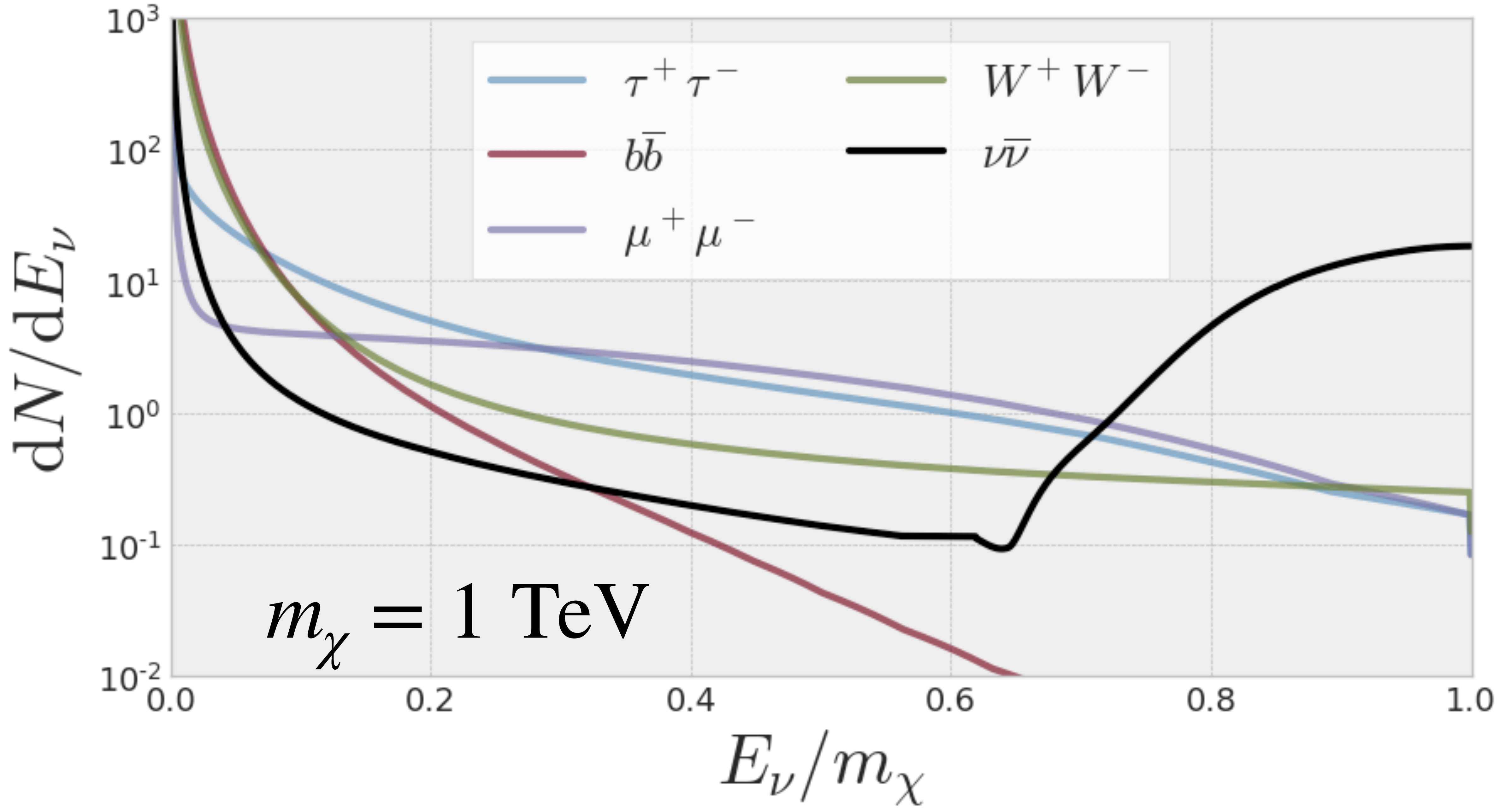
The Galactic Center The Particle Physics Input

- Neutrino Spectra from primary (neutrino lines) and secondary production $(W^+W^-, \tau^+\tau^-, \ldots)$
- Spectra from PPPC4* with electroweak radiation (important for high masses)



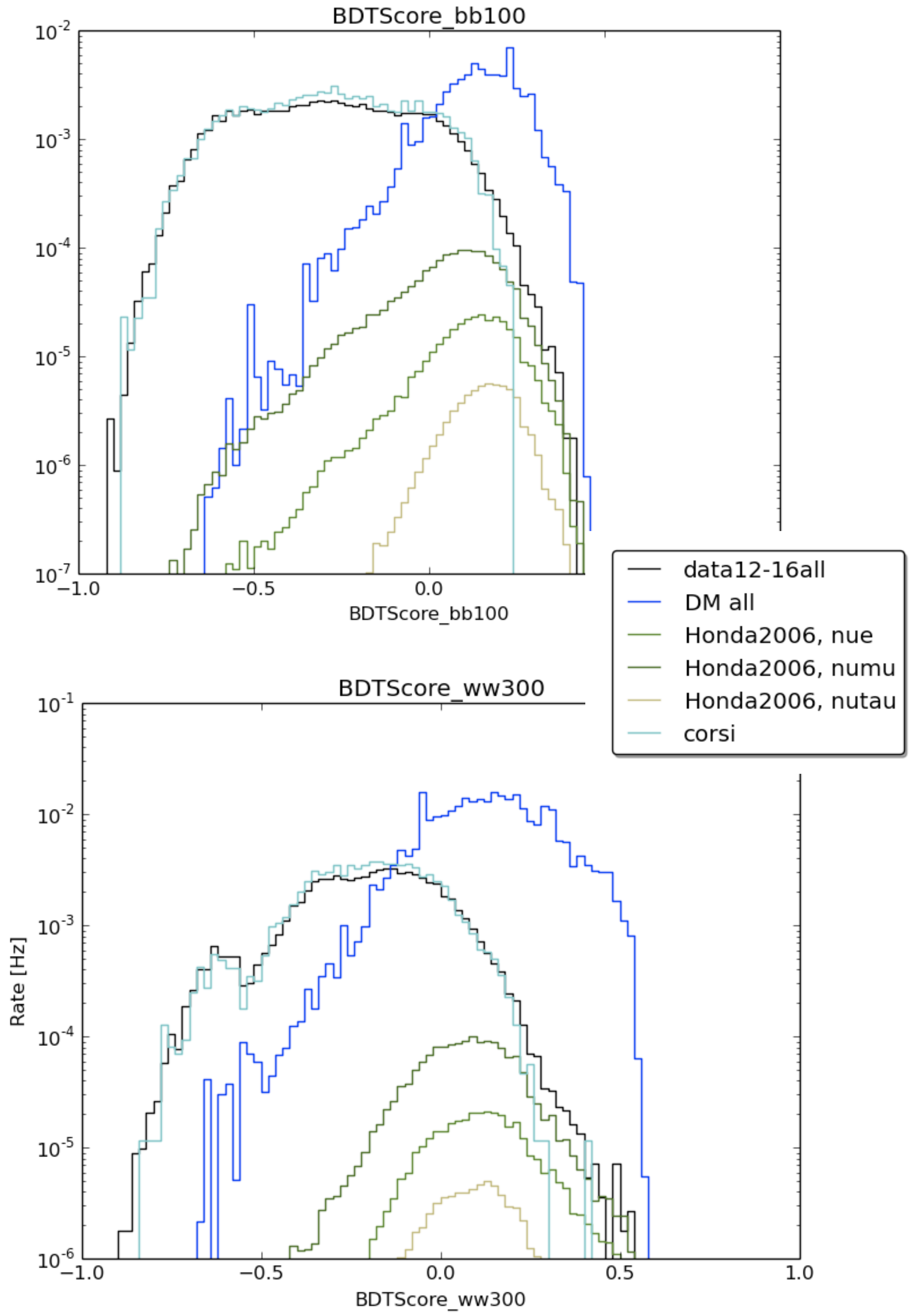
*https://arxiv.org/abs/1012.4515



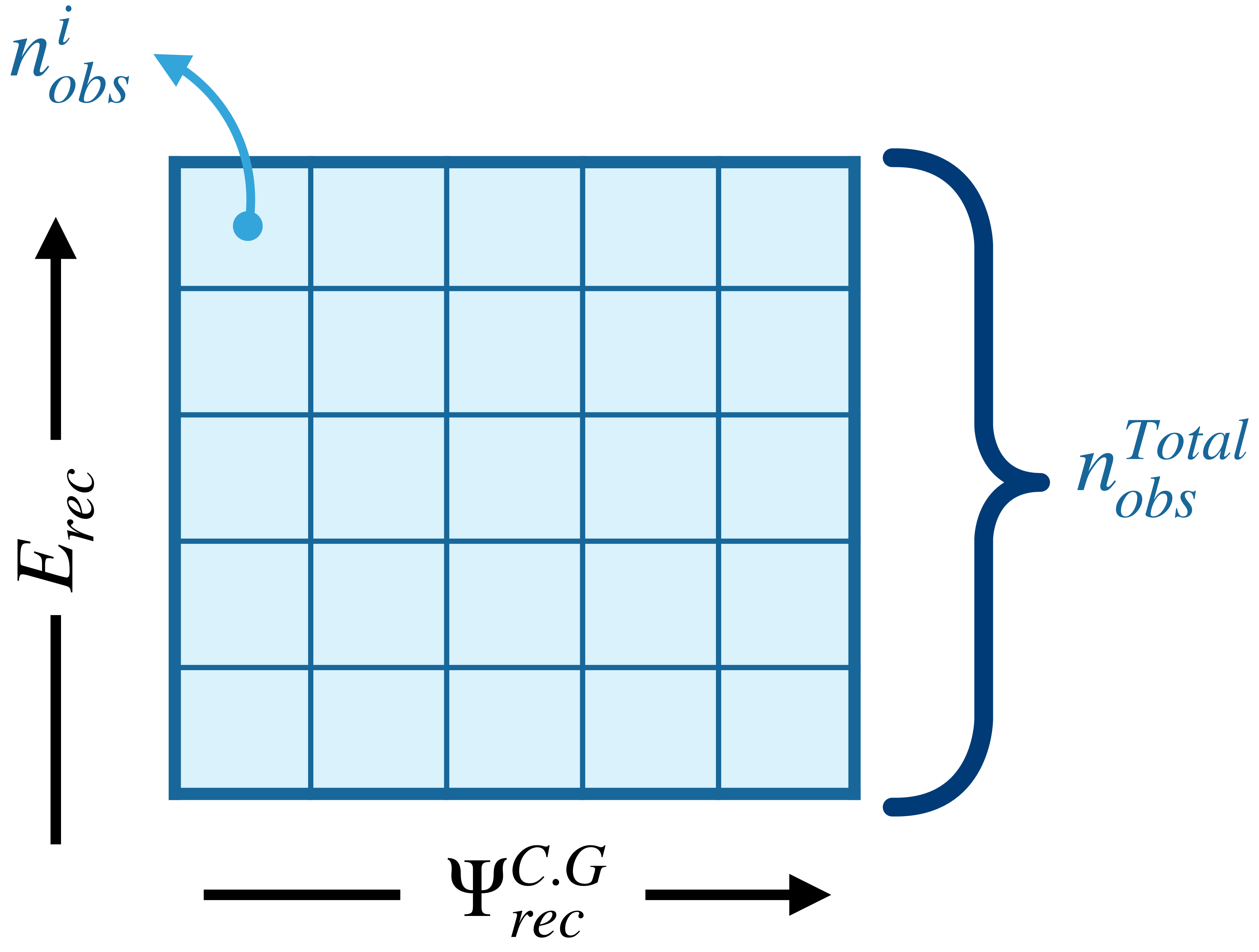


Data Selection

- 5 years of IceCube data: 2012 to 2016
- DeepCore data focusing on cascade events (better energy resolution)
- Selection optimized with 2 generic BDTs:
  - $100\ \mathrm{GeV},\ \chi\chi \to b\bar{b}$ as a proxy for low energies > LE sample
  - $300\ \mathrm{GeV},\ \chi\chi \to W^{+}W^{-}$ as a proxy for high energies > HE sample



Analysis: Binned Likelihood Method



$$\mathcal{L}(\mu) = \prod^{N_{bins}} \text{Poisson}(n_{obs}^{i}; n_{obs}^{Total} f(i;\mu))$$

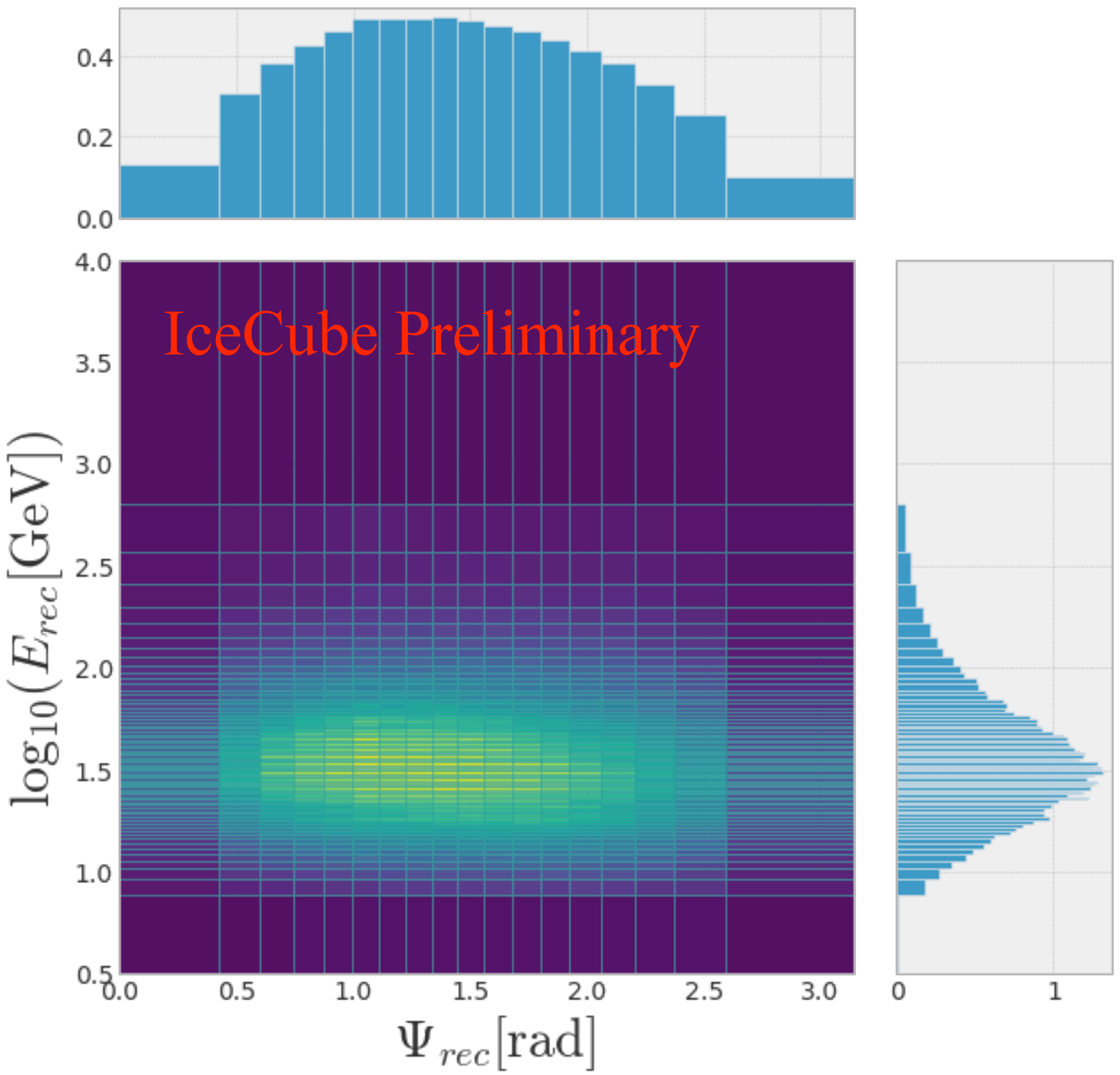
$$f(i;\mu) = \mu \mathcal{S}_i + (1-\mu)\mathcal{B}_i$$

$$\mathcal{B}_i = \frac{1}{(1-\mu)}[\mathcal{B}_i^{scambled} - \mu \mathcal{S}_i^{scambled}]$$

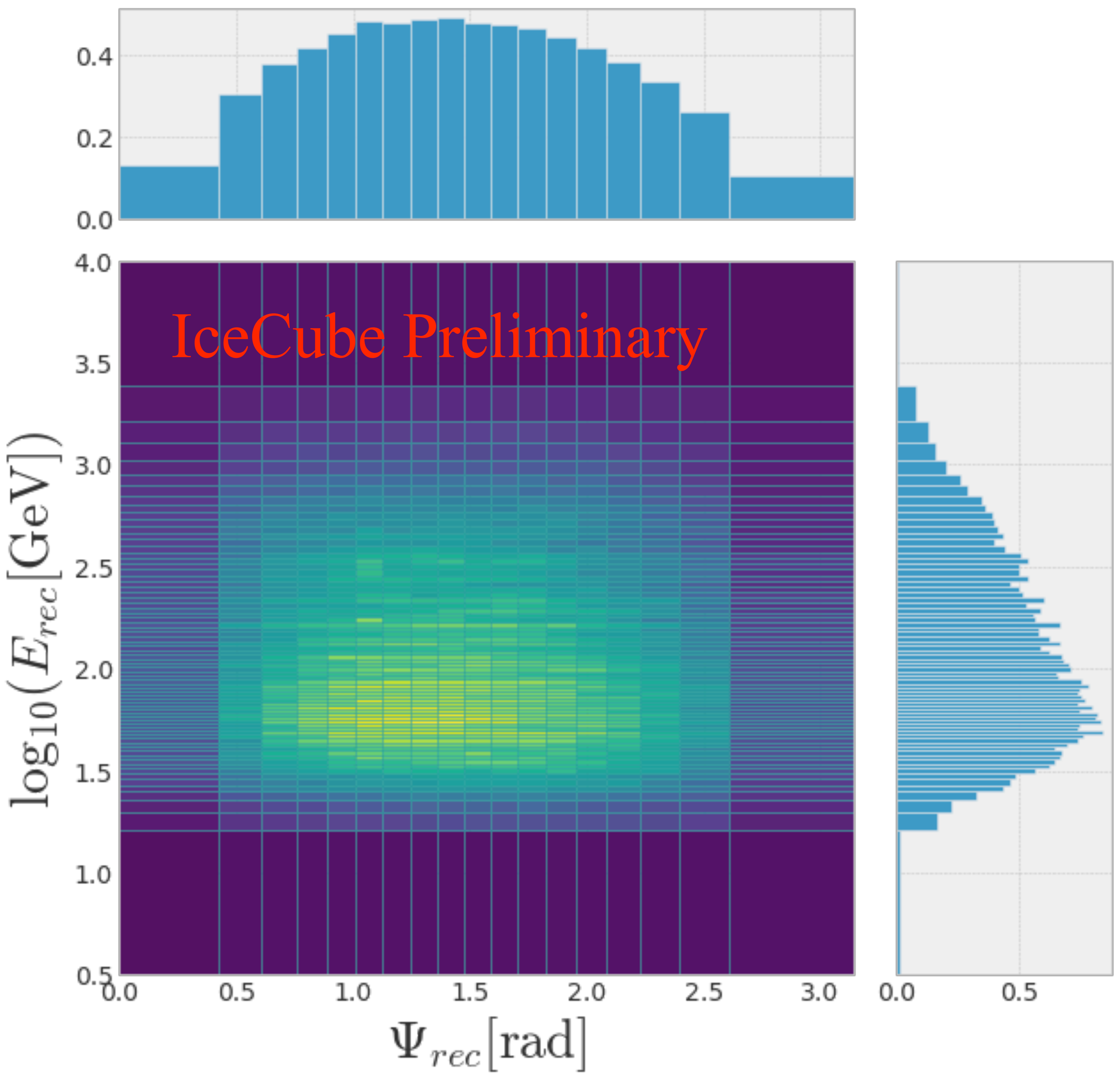
- Two observables considered: E_{rec}, $\Psi_{rec}^{G.C.}$
- Background pdf is obtained from scrambled (in RA) data.
- Signal Subtraction Likelihood: To correct for "signal contamination" in the background pdf

Analysis: Background PDFs

LE Sample



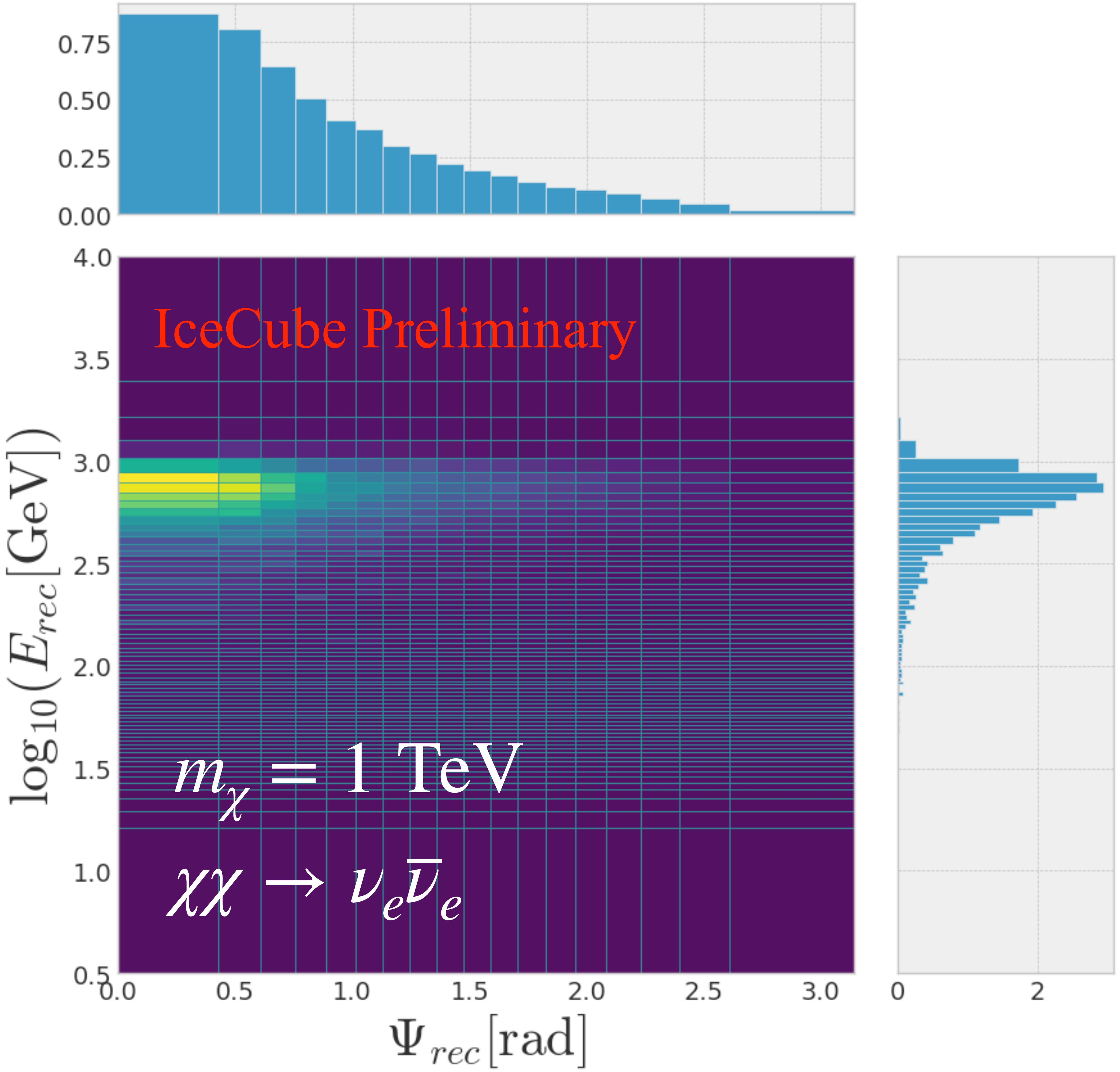
HE Sample



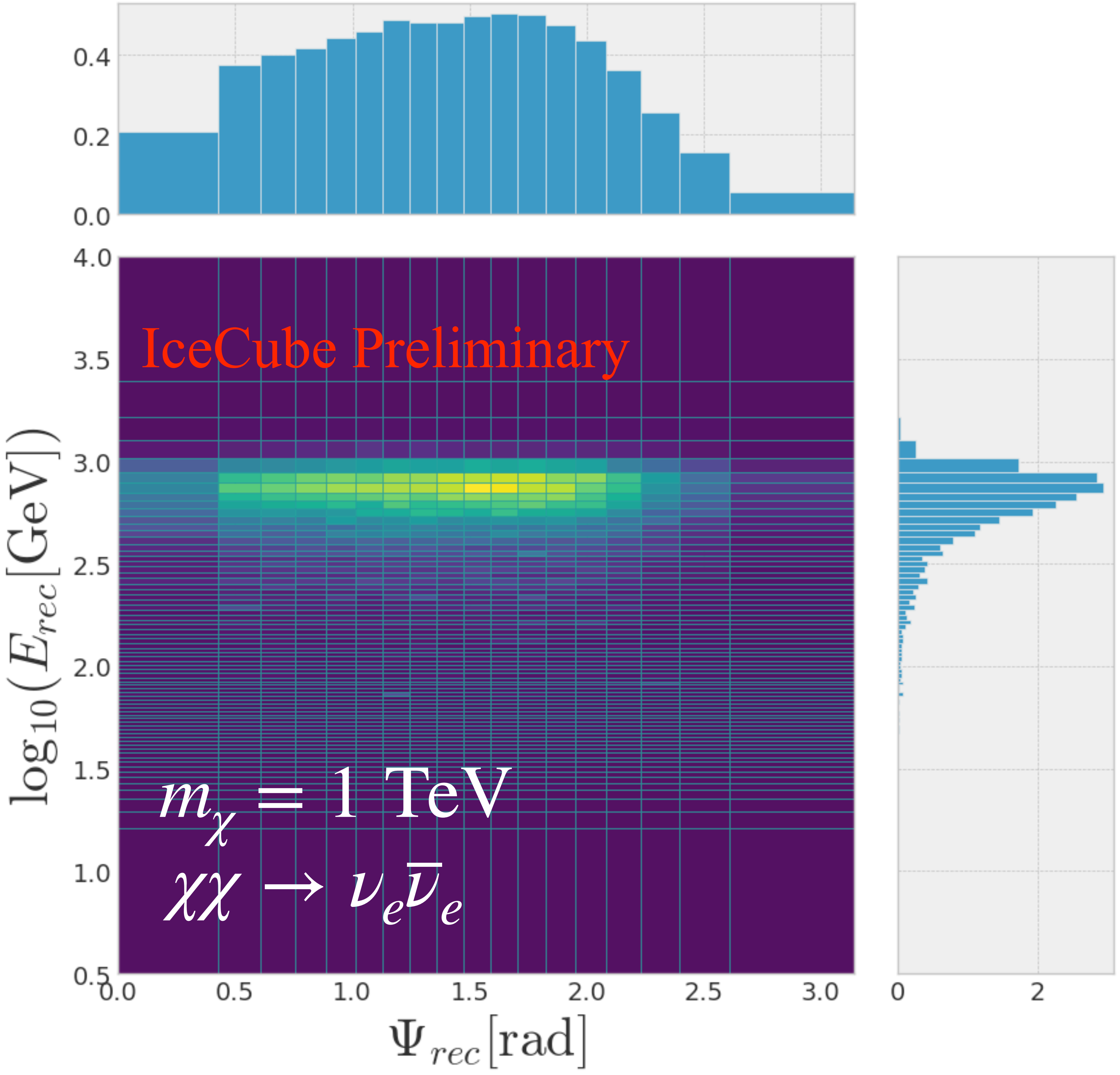
- Background built from scrambled data in RA.
- Irregular (quantile) binning (https://github.com/janpipek/physt)

Analysis: Signal PDFs

Signal (HE sample)

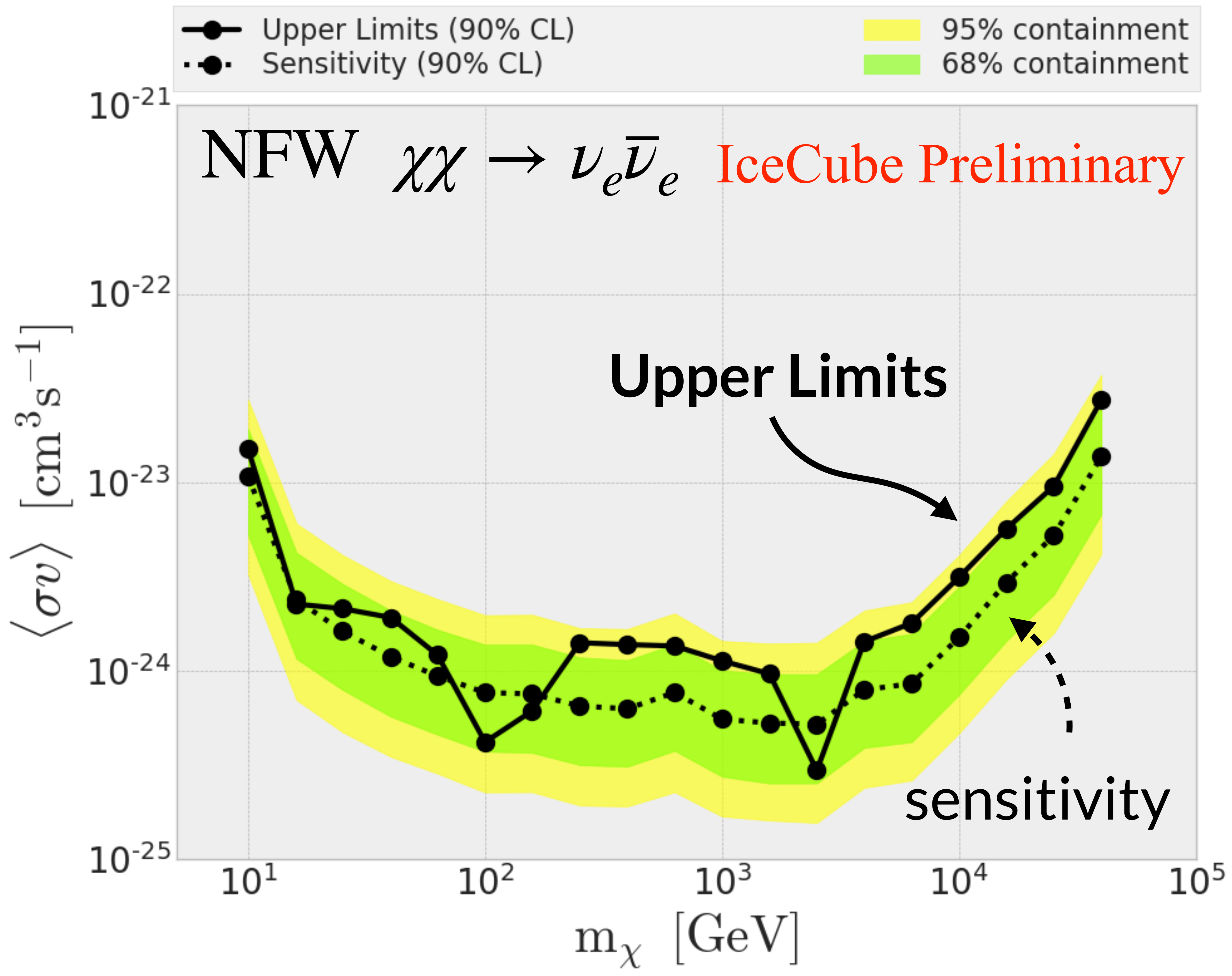


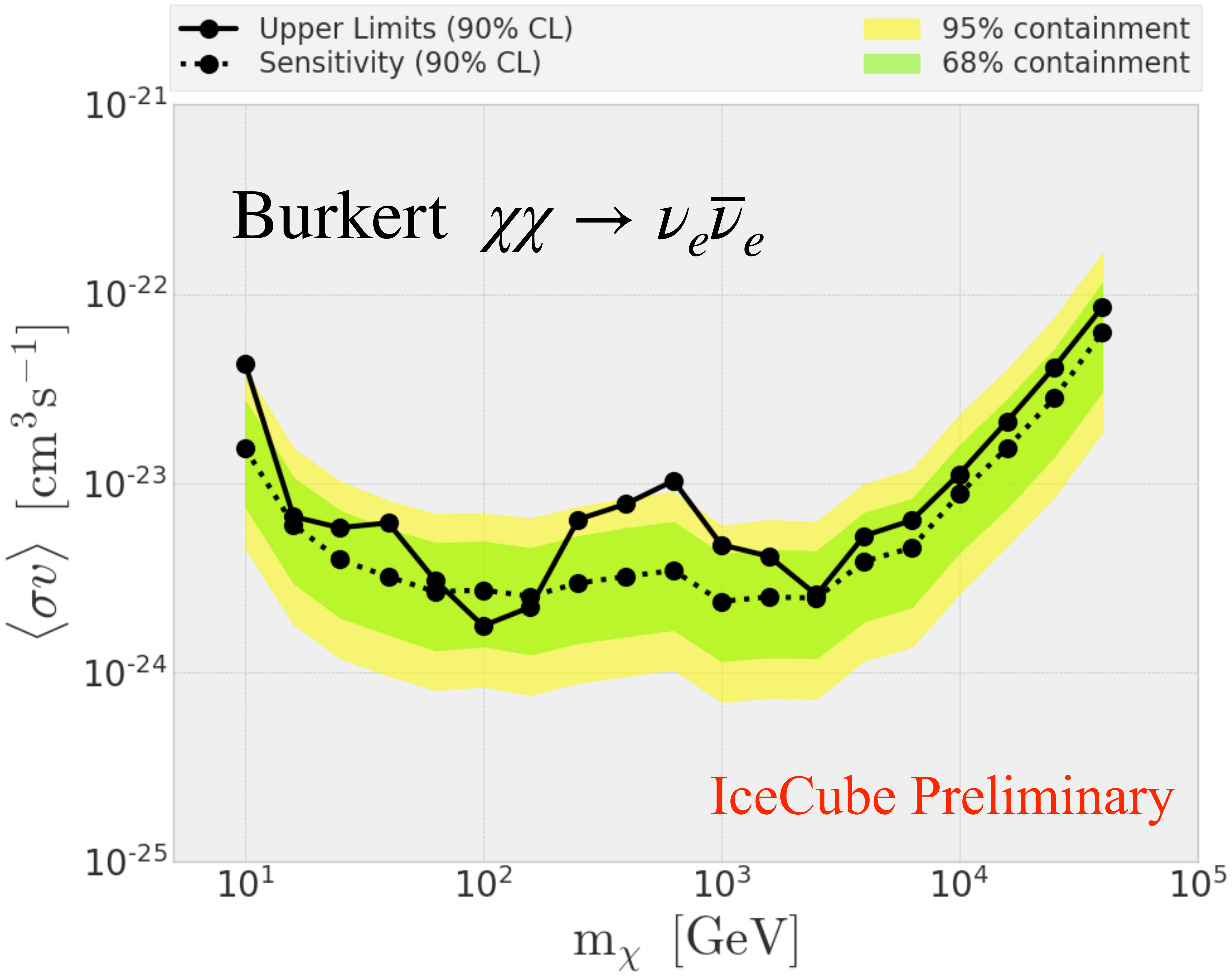
Scrambled Signal (HE sample)



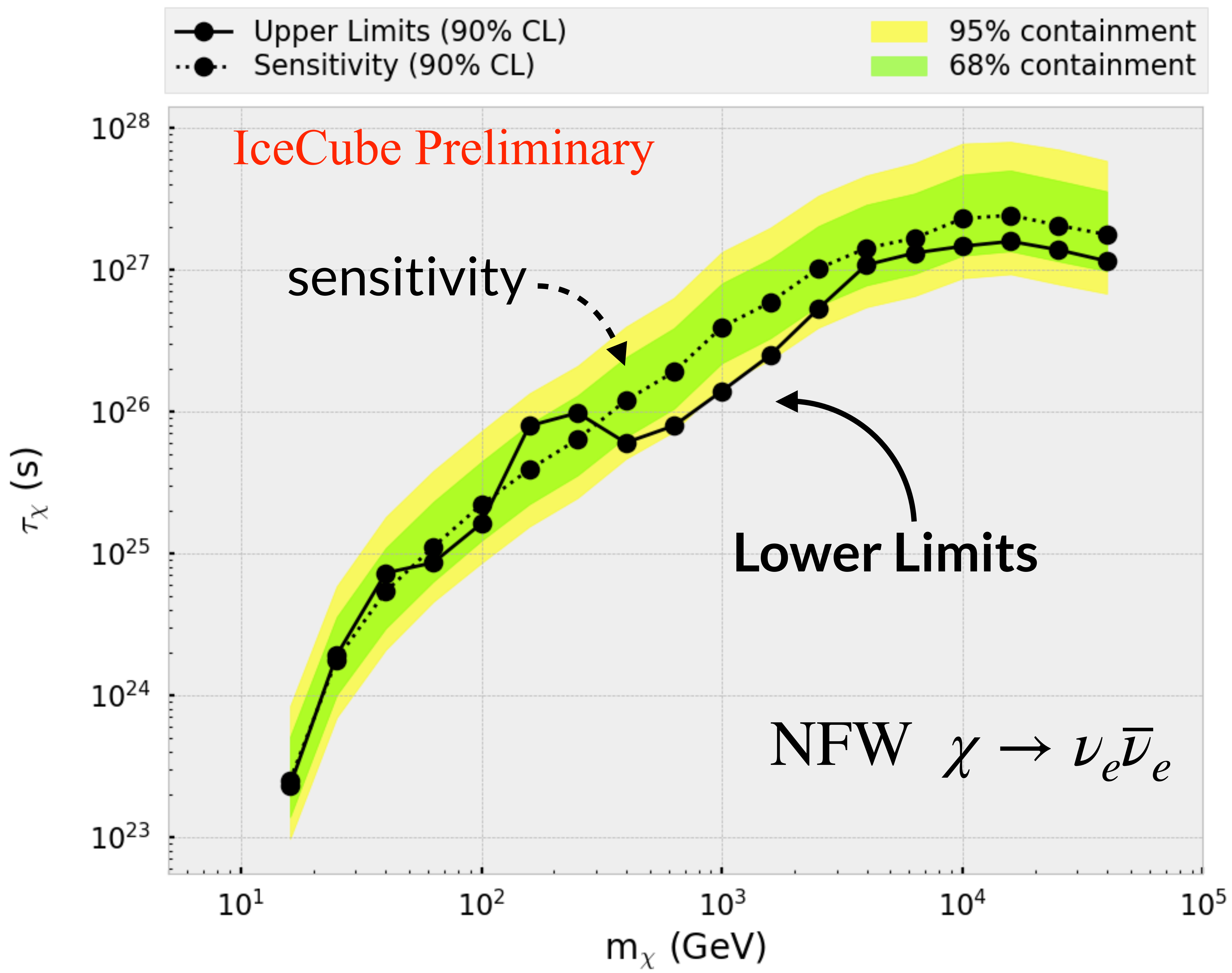
- Binning follows the same binning as the background PDF.

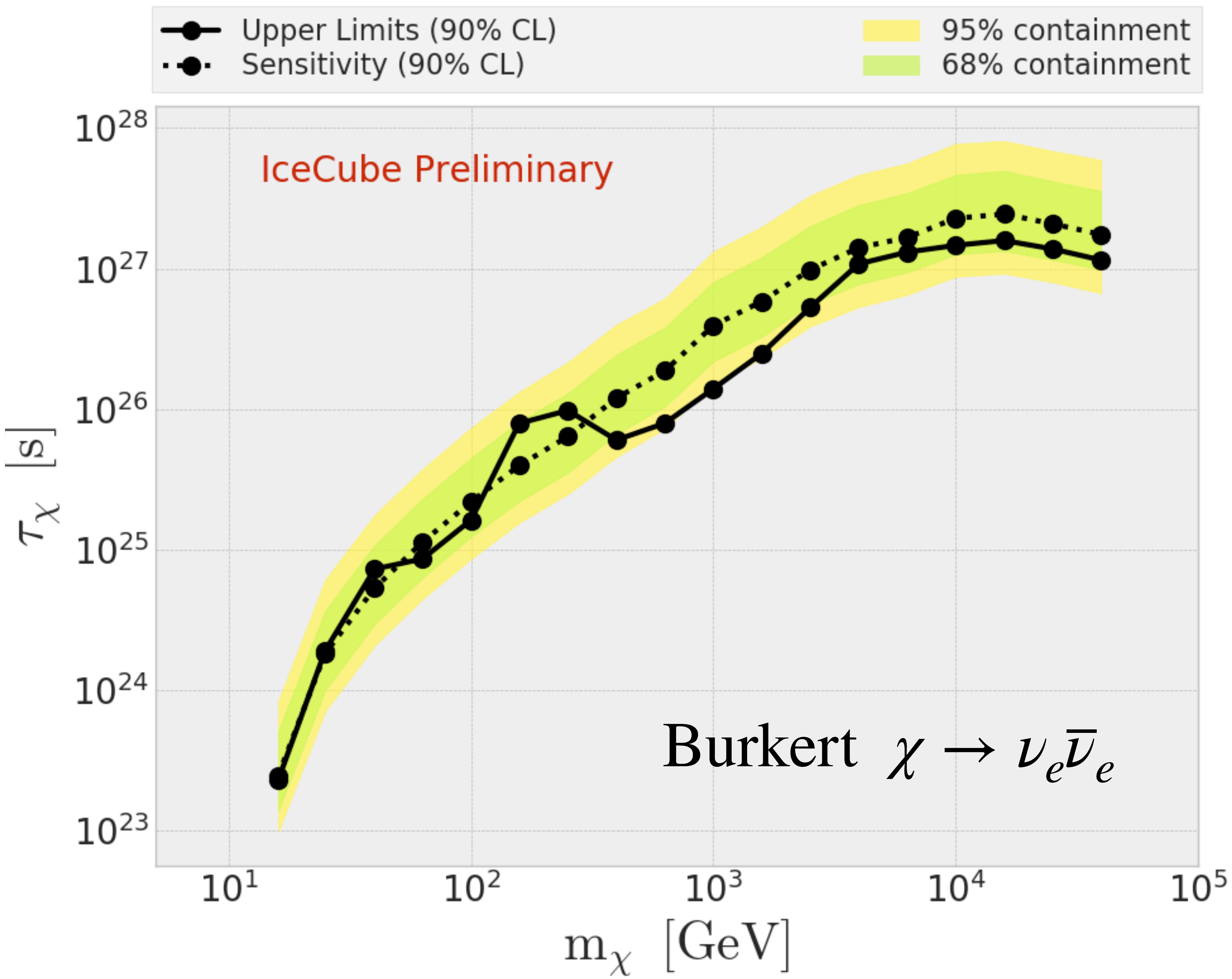
Analysis: Results Annihilation $\nu_e \bar{\nu}_e$



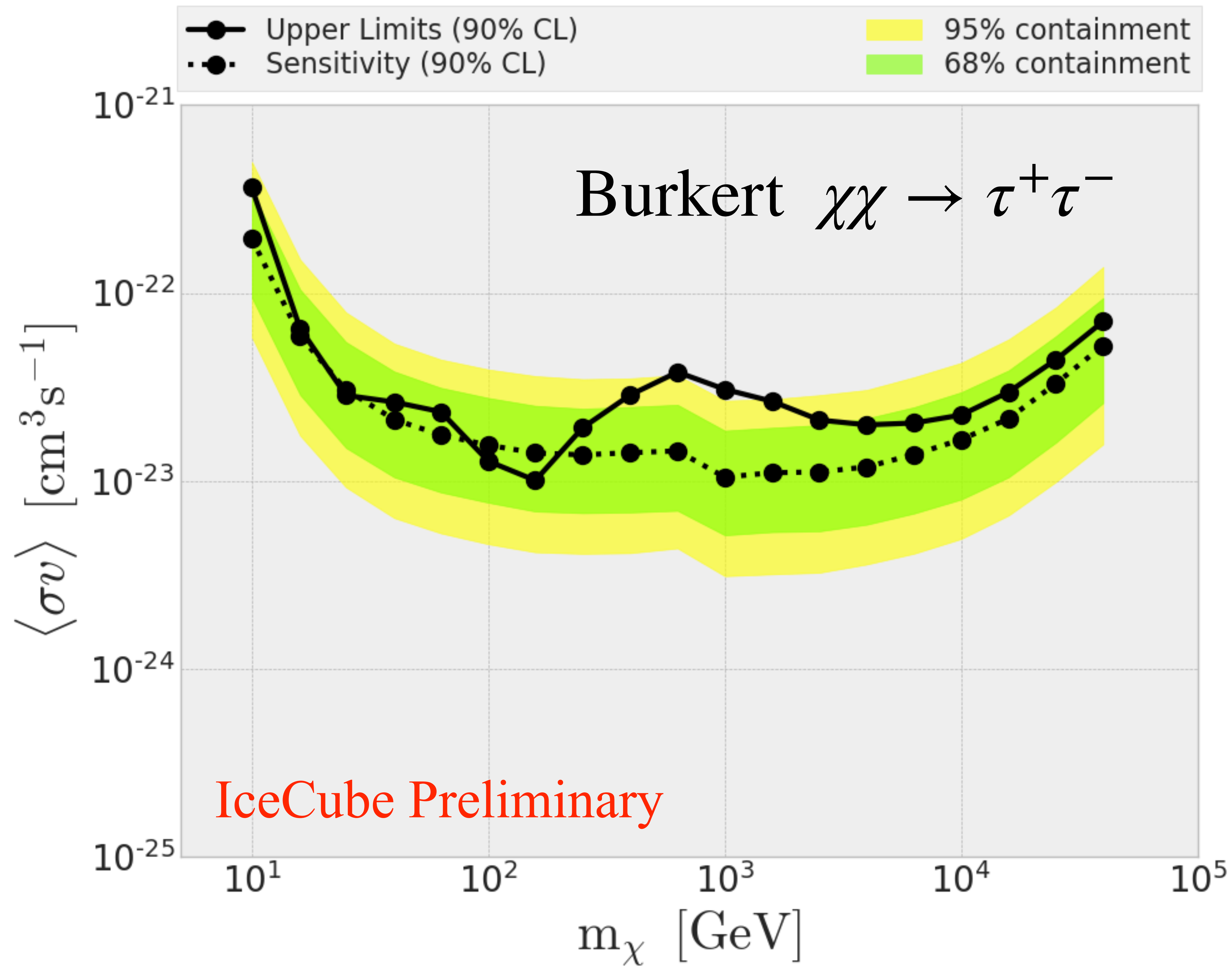


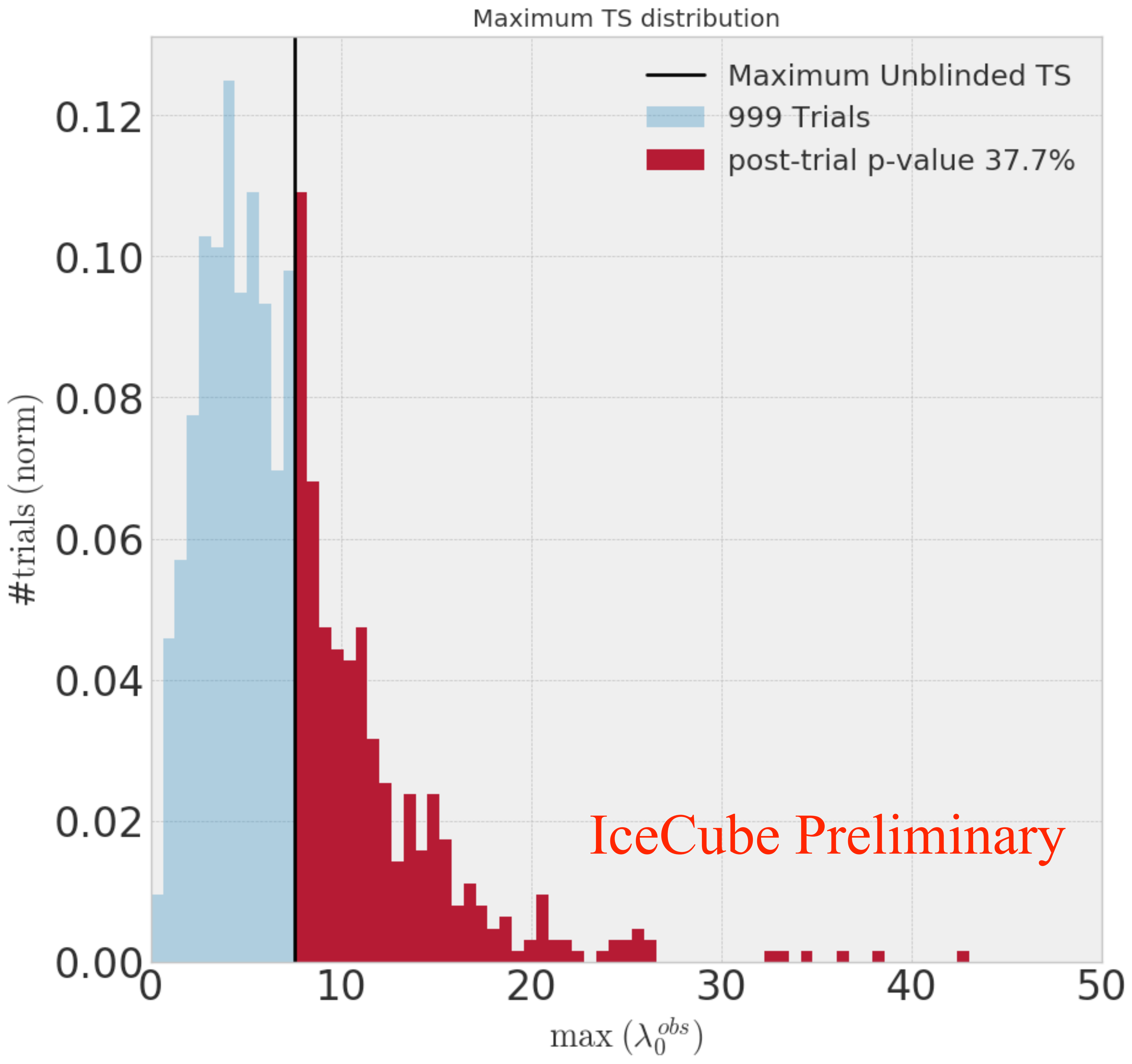
Analysis: Results Decay $\nu_e\bar{\nu}_e$





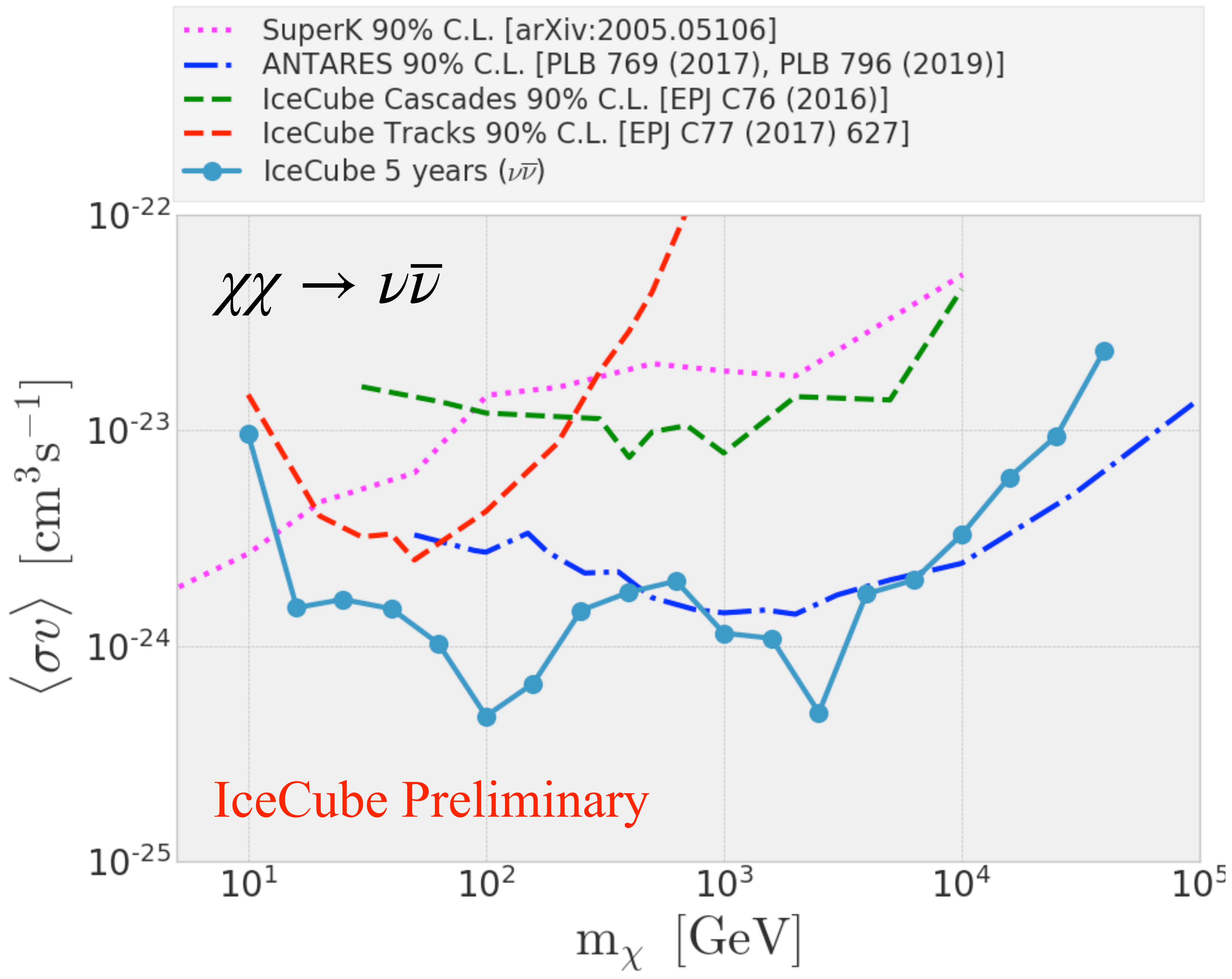
Analysis: Most Significant Result

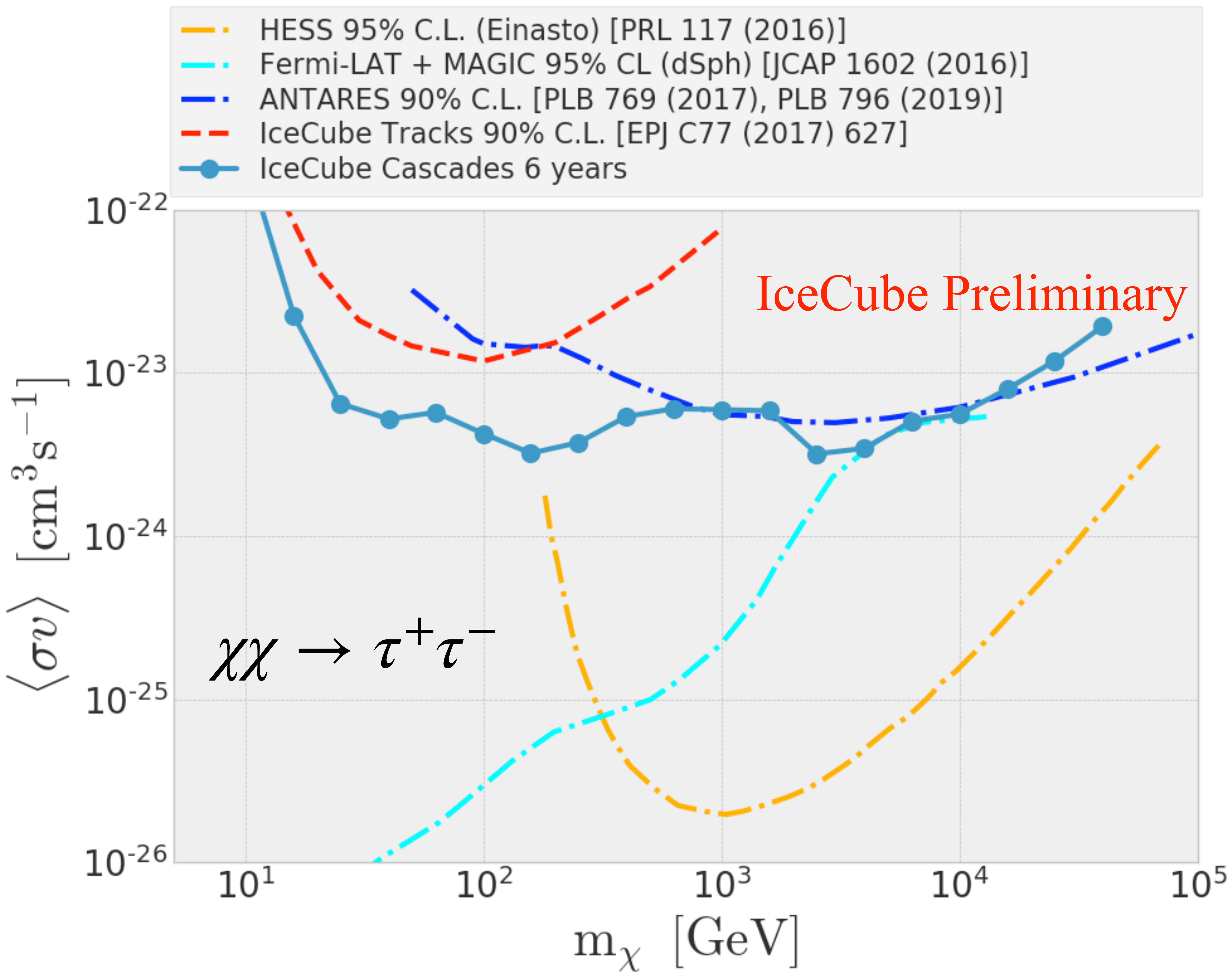




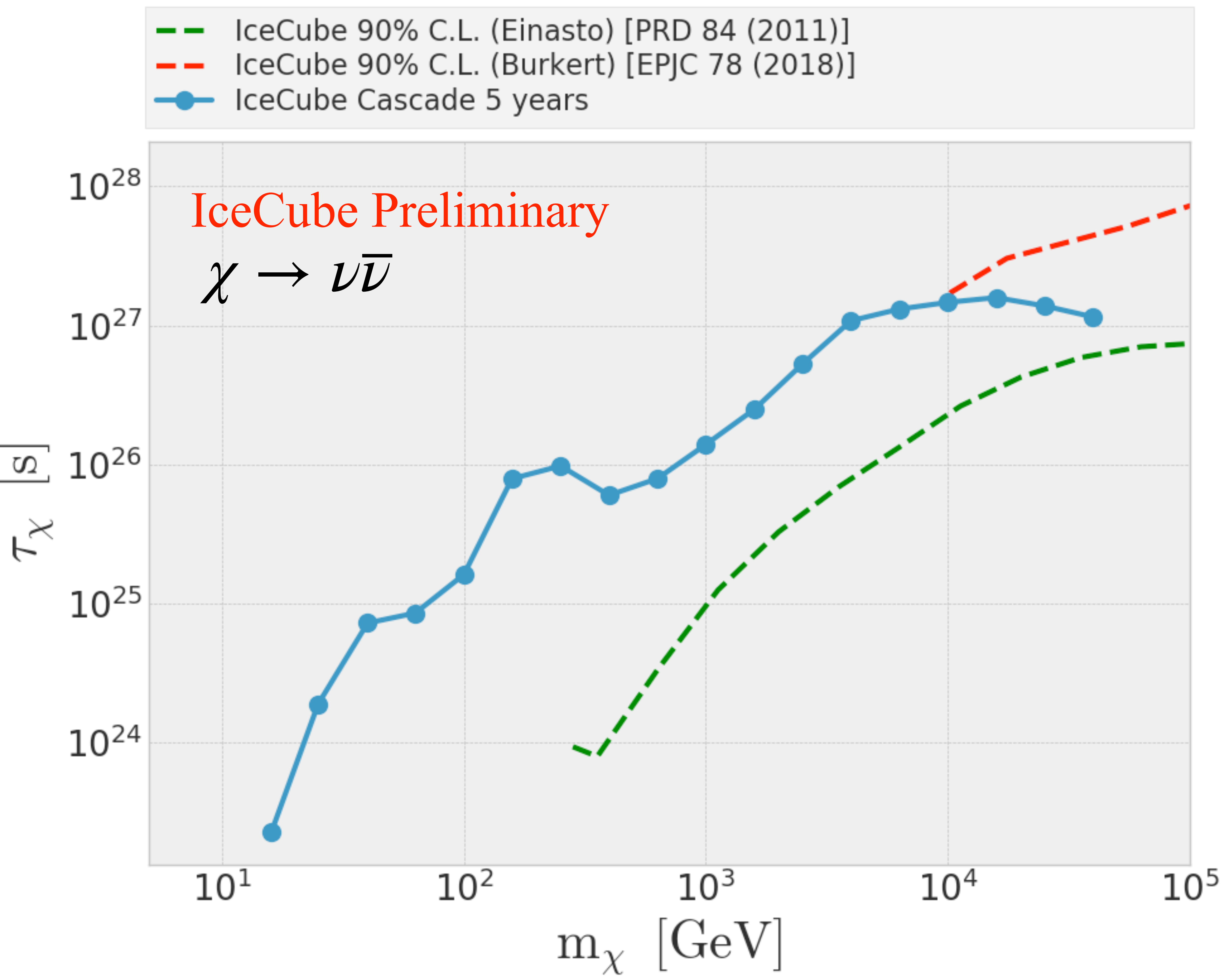
- Most significant results is $m_\chi = 1$ TeV with pre(post)-trial p-value 0.3% (~38%)

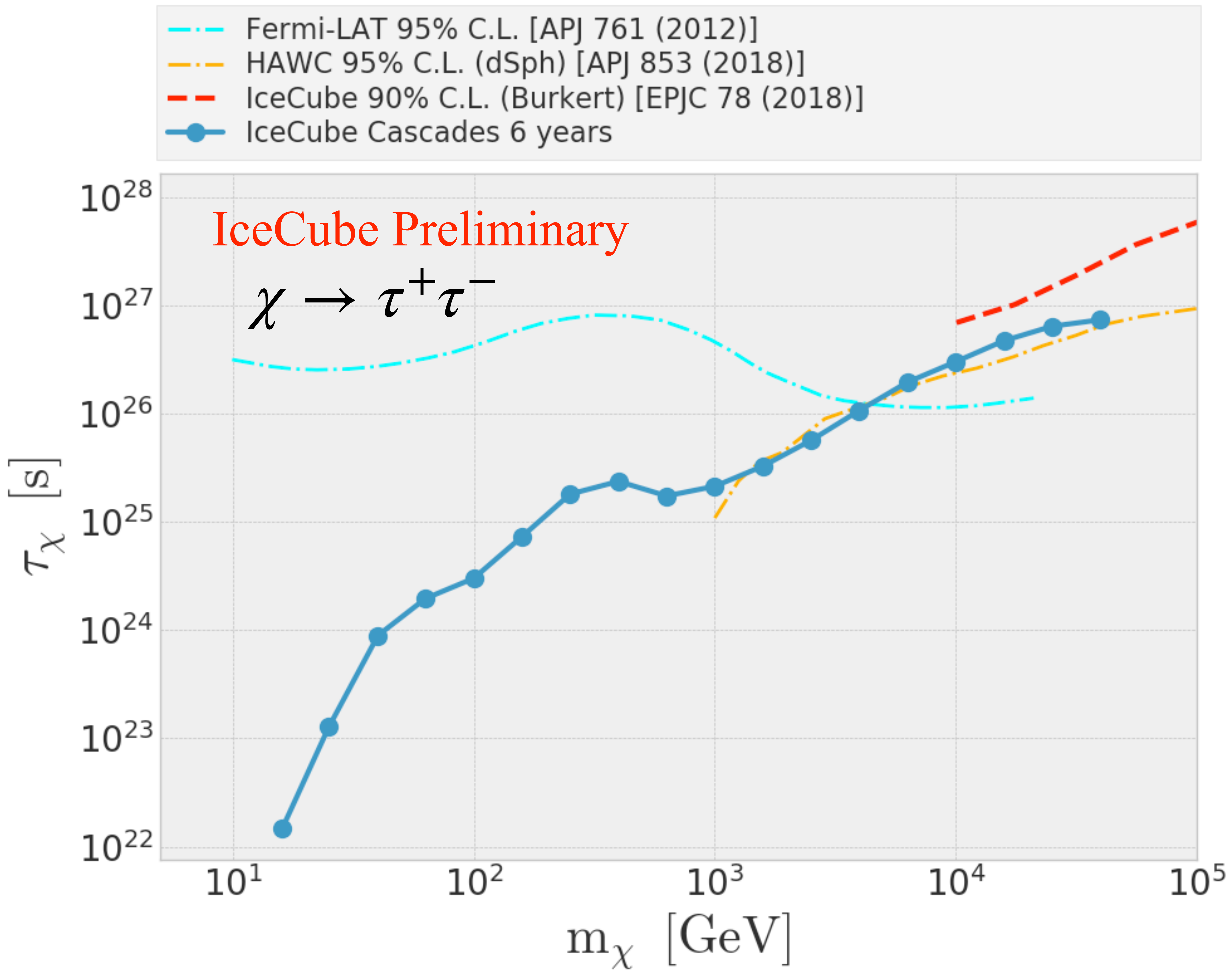
Comparison with Other Experiments: Annihilation





Comparison with Other Experiments: Decay





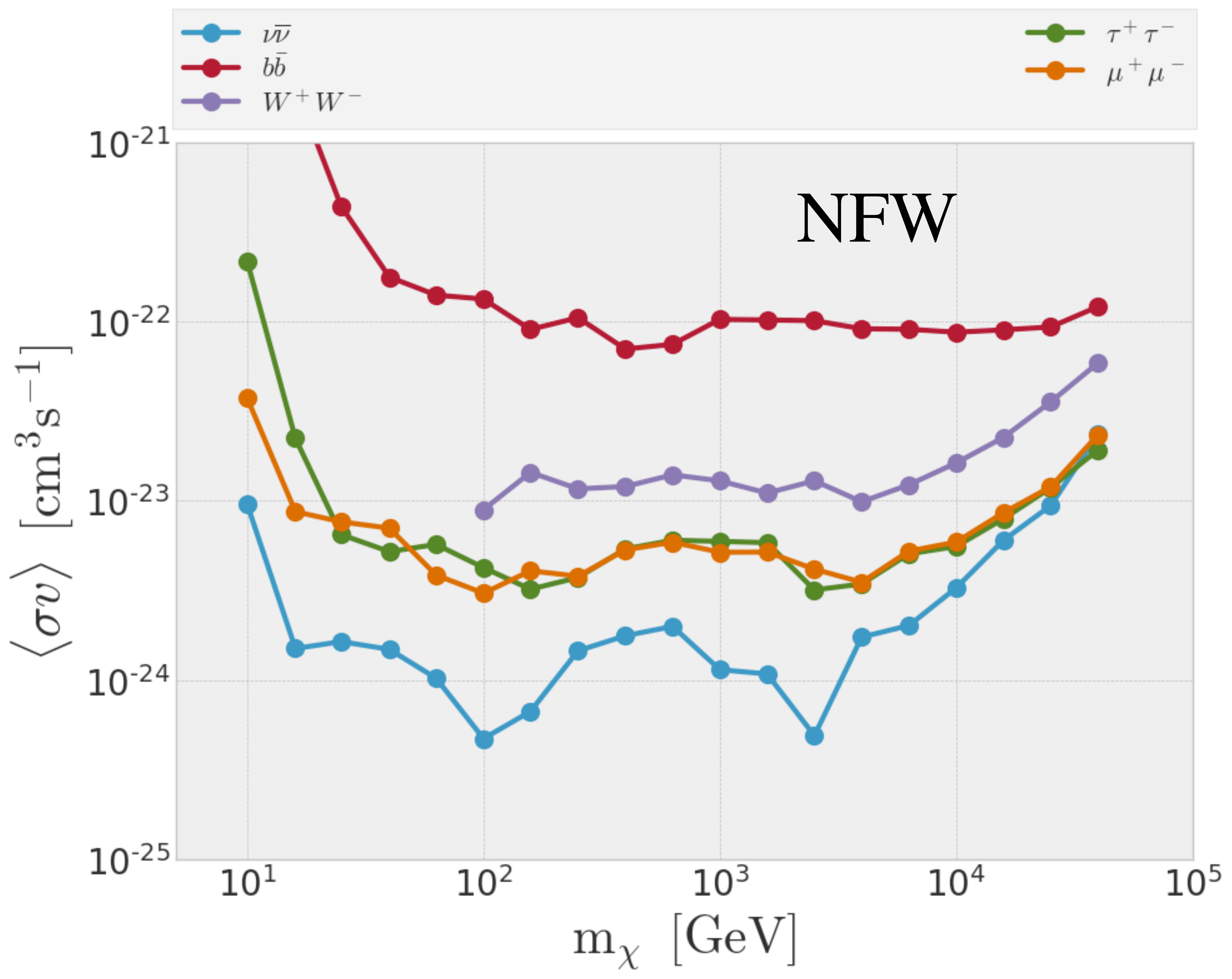
Conclusions

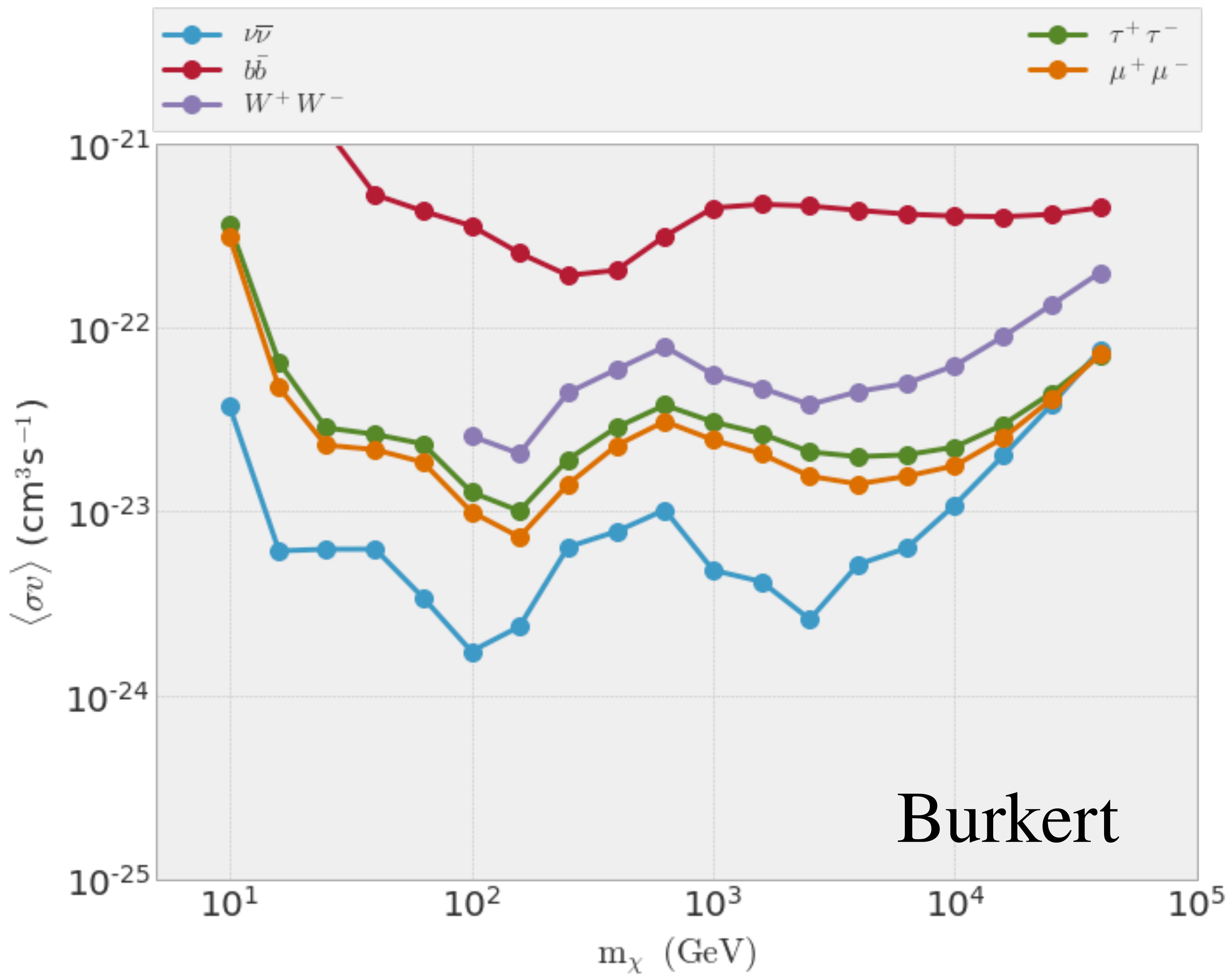
IceCube is a **multipurpose experiment** with a **rich program on BSM and Dark Matter** searches.

- Indirect detection of Dark Matter with neutrino telescopes provides **complementarity to other techniques** due to different backgrounds and systematics.
- Direct annihilation/decay to neutrinos can provide a smoking gun signature (no astrophysical background)
- Results on 5 years of dark matter search from the Galactic Center found no evidence of dark matter (best post-trial 38%)
  - IceCube has the best limits in the neutrino channel for masses < TeV and best lower limits in the decay lifetime.

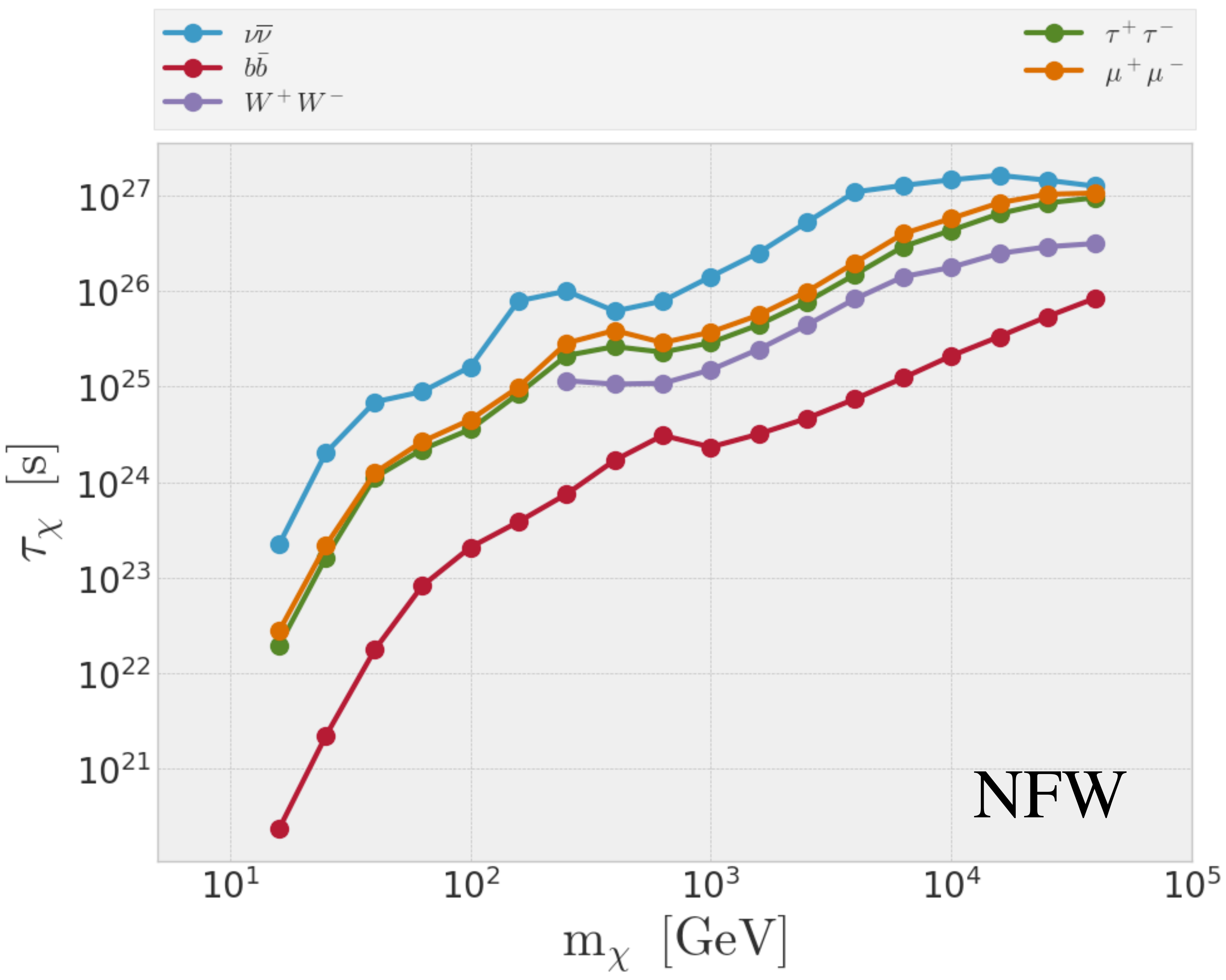
backups

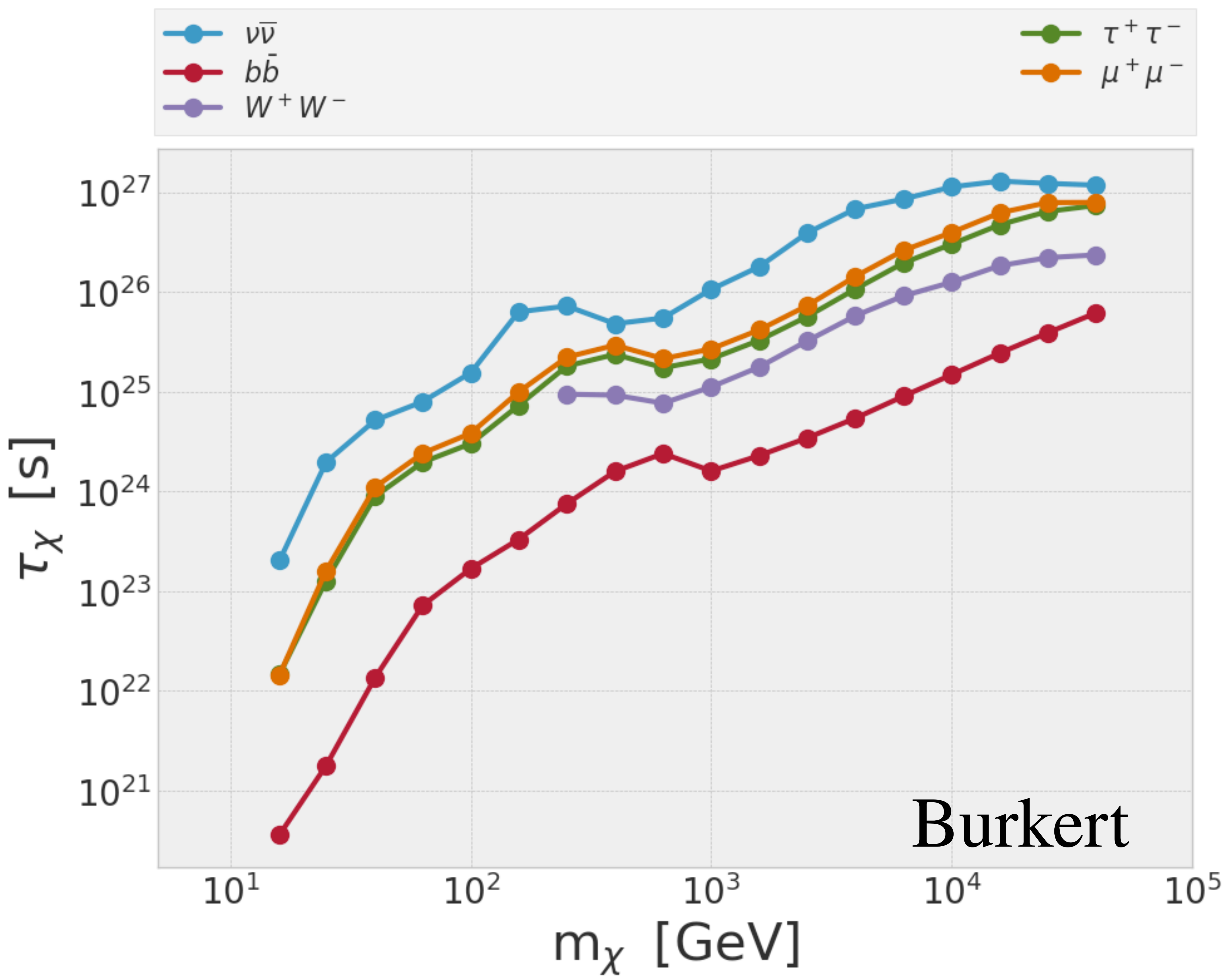
All Annihilation Channels





All Decay Channels





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