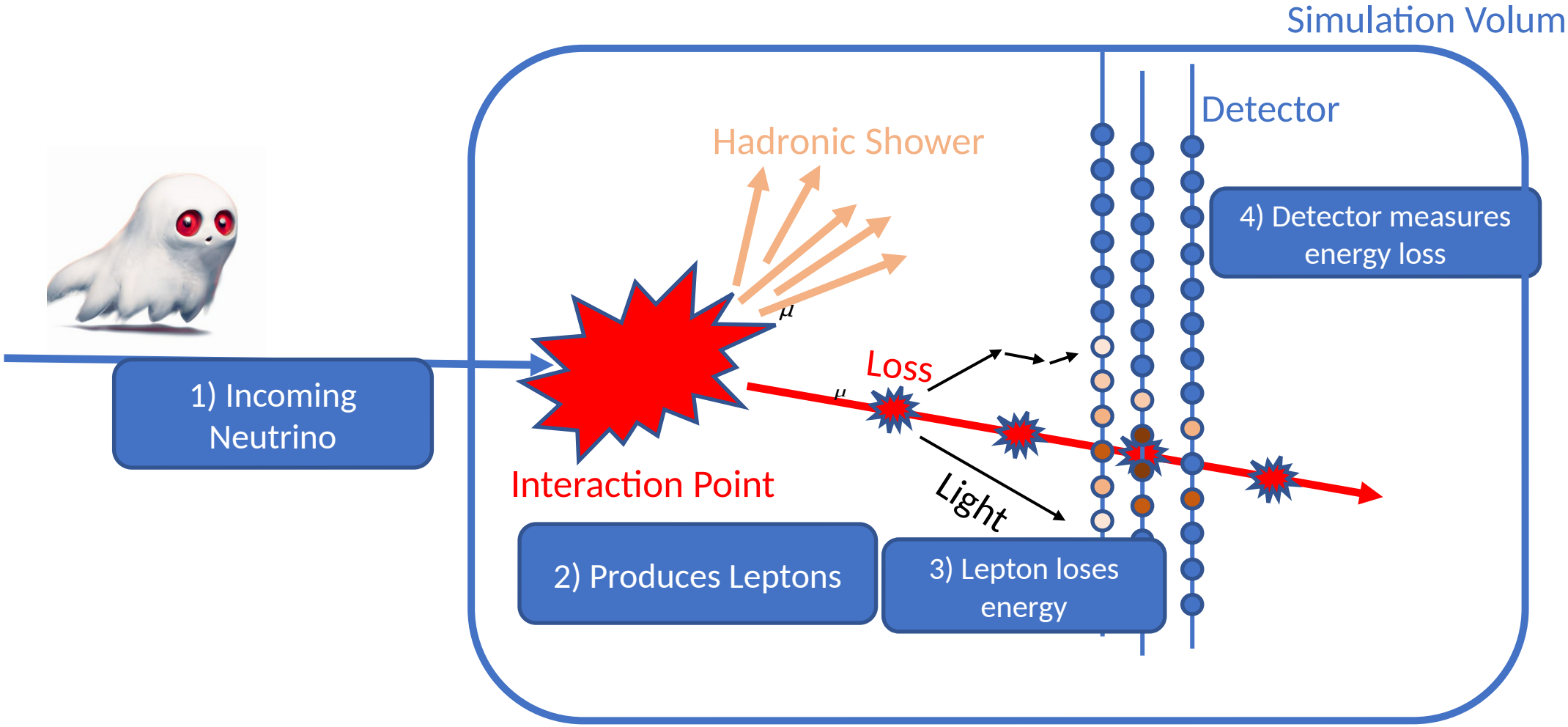
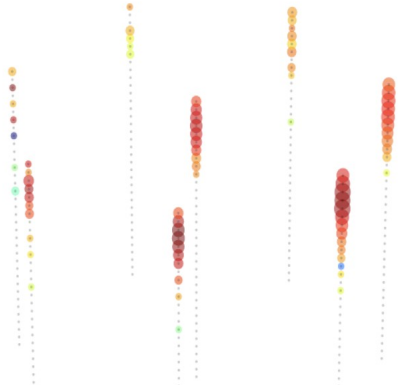
Searching for Dark Matter Annihilation with IceCube and P-ONE

Kruteesh Desai, Ruohan Li, and Stephan Meighen-Berger

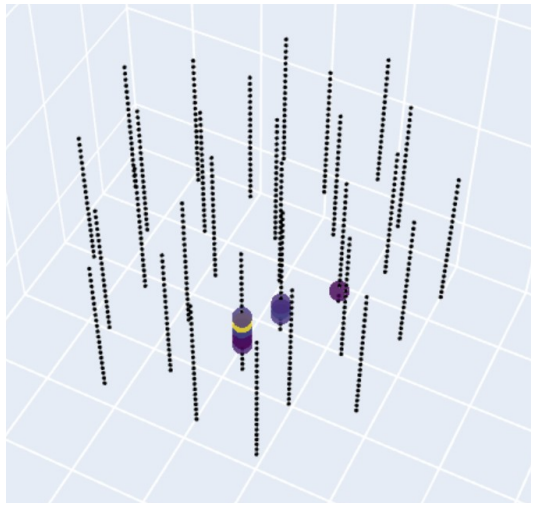
Detection Principle



Multiple Detectors Exist/Planned



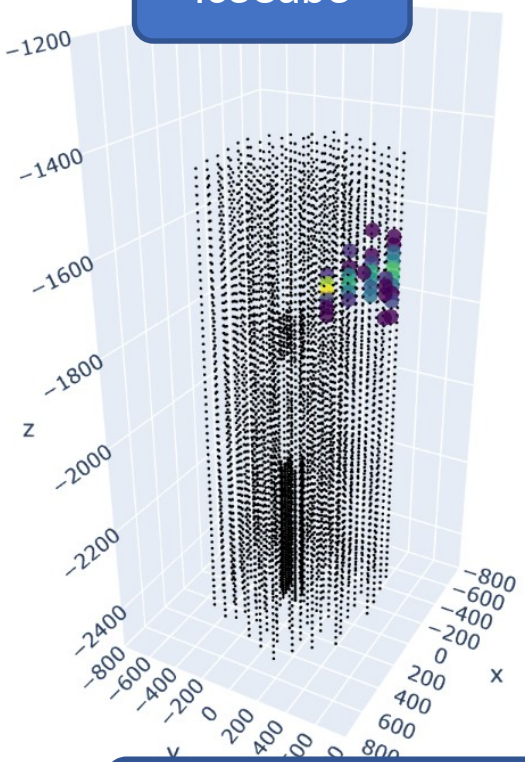
GVD



KM3NeT

For a KM3NeT discussion see
https://arxiv.org/pdf/2211.12235.pdf

IceCube

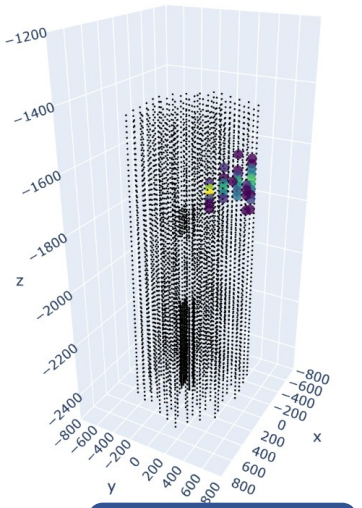


P-ONE

Here we will focus on IceCube and P-ONE

What are the Differences?

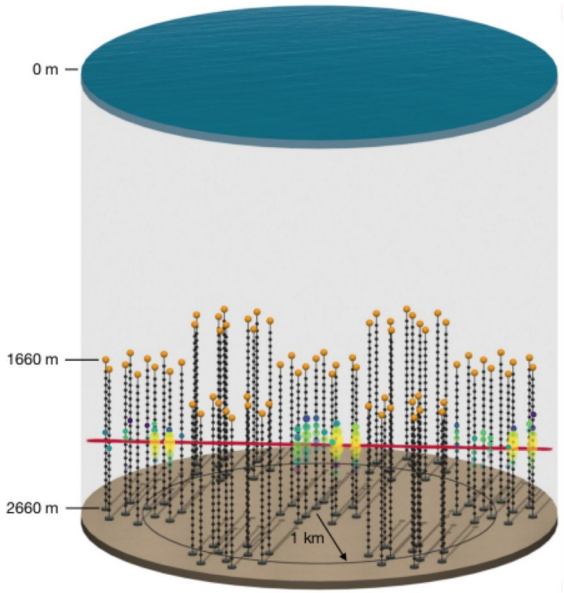
IceCube

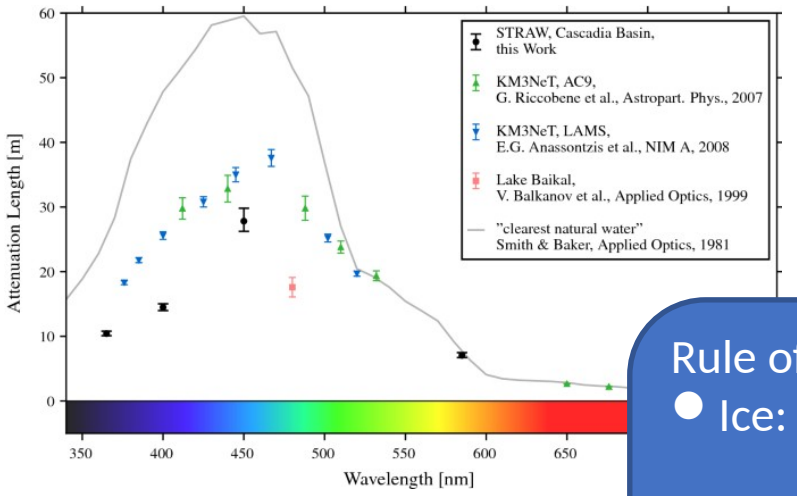


Geometry

P-ONE

arXiv:2005.09493





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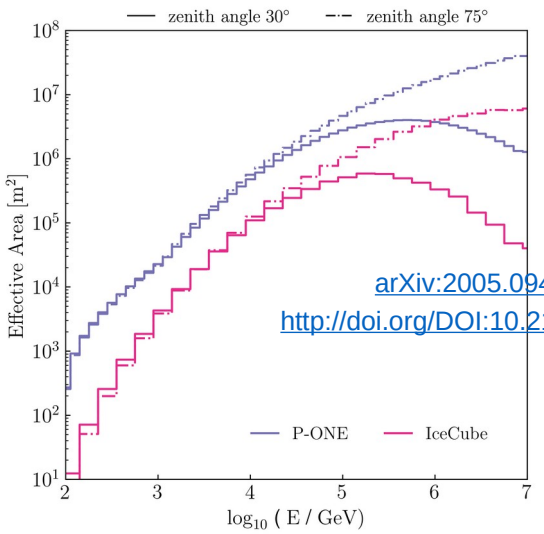
Optical Properties

Rule of Thumb:

- Ice:
  - Attenuation: 150 m
  - Scattering: 30 m
- Water:
  - Attenuation: 30 m
  - Scattering: 150 m



All if this is usually combined into an effective area

arXiv:2005.09493

http://doi.org/DOI:10.21234/sxvs-mt83

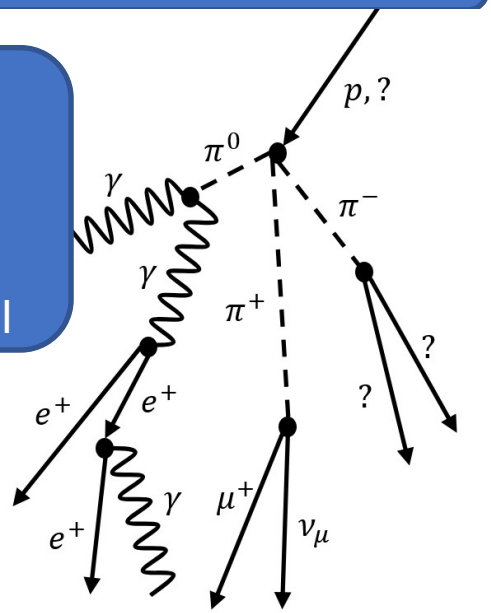
$$N = \int A \frac{\mathrm{d}\phi}{\mathrm{d}E} \mathrm{d}E$$

One Last Thing…

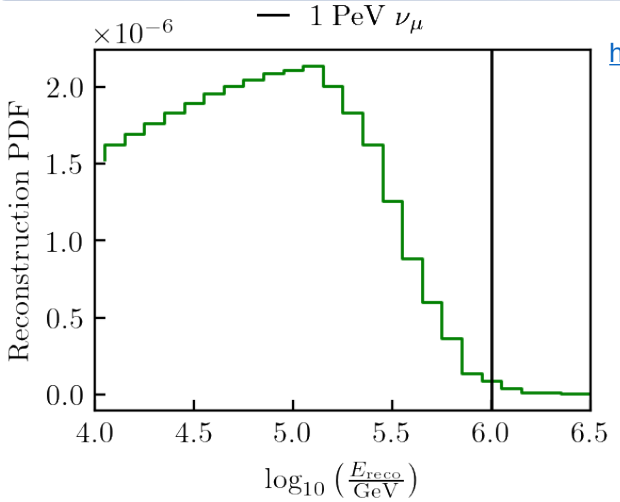
Everyone's favorite topic: Backgrounds

Let's ignore some uncertainties:

- Interaction Model
- Primary Model
- Atmospheric Model

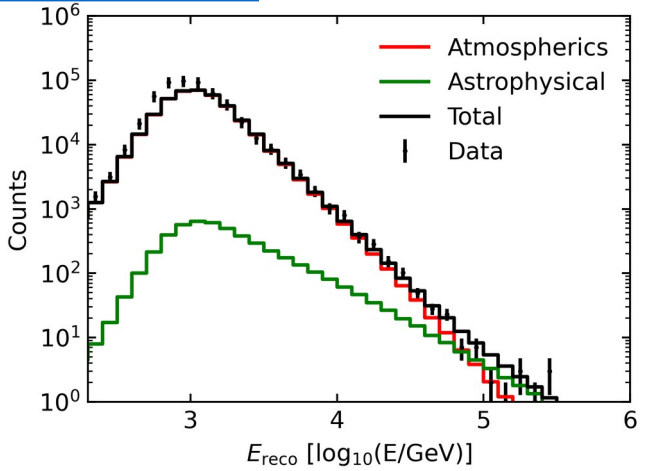


The reconstruction isn't perfect either

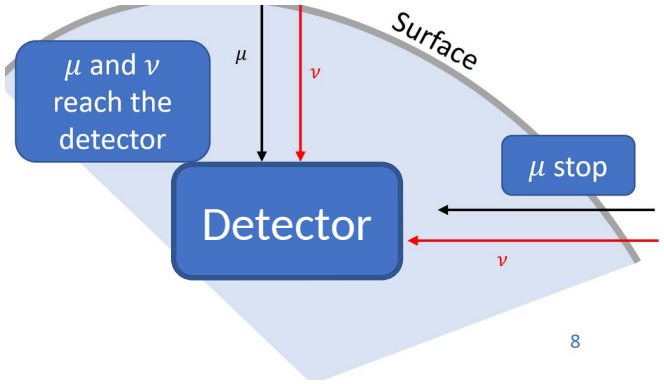


arXiv:2109.07885

http://doi.org/DOI:10.21234/sxvs-mt83



https://github.com/MeighenBergerS/fledgeling

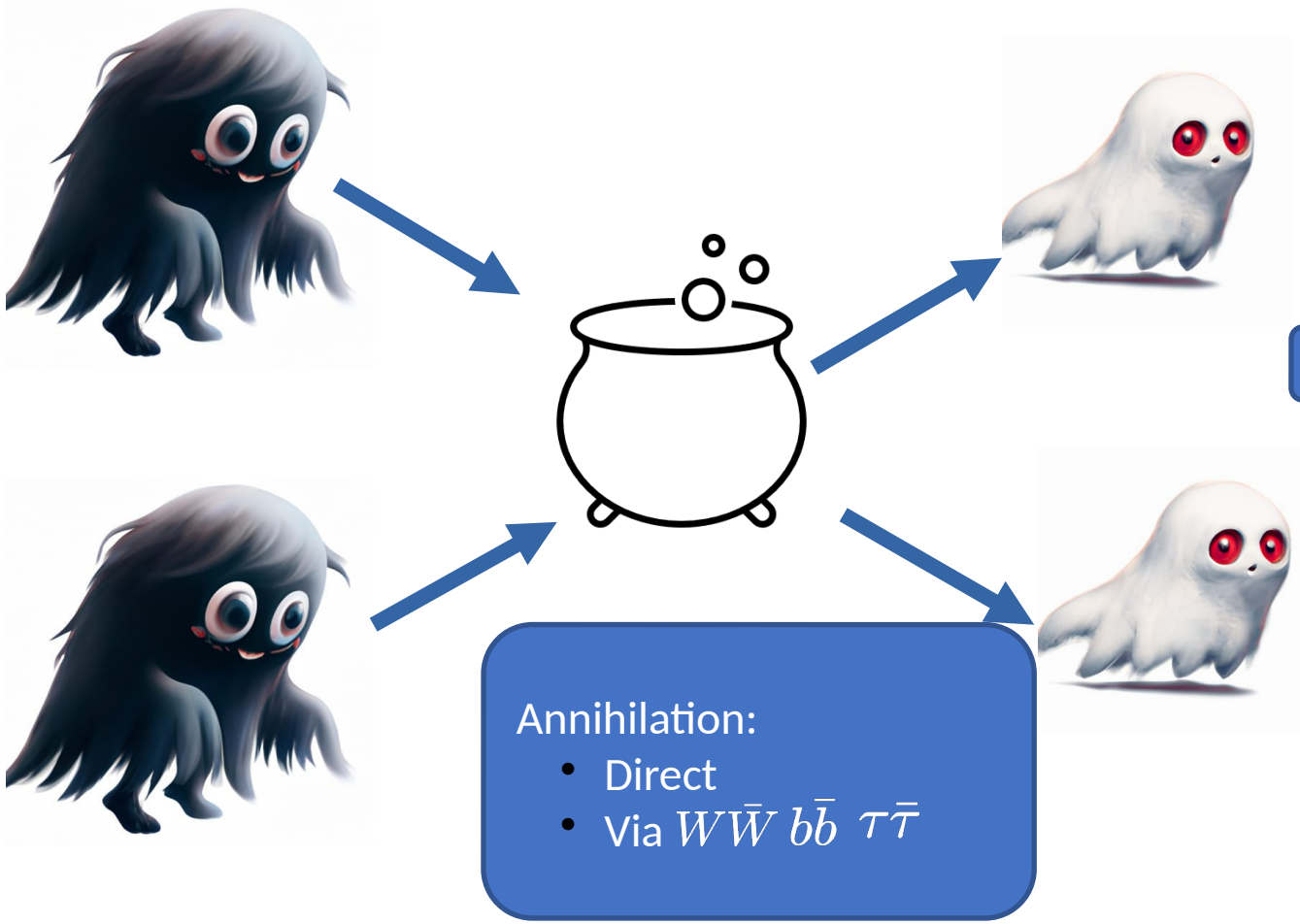


Even the astrophysical diffuse flux is a background!

You found me!

… Took you long enough

Let's go with the simplest case I



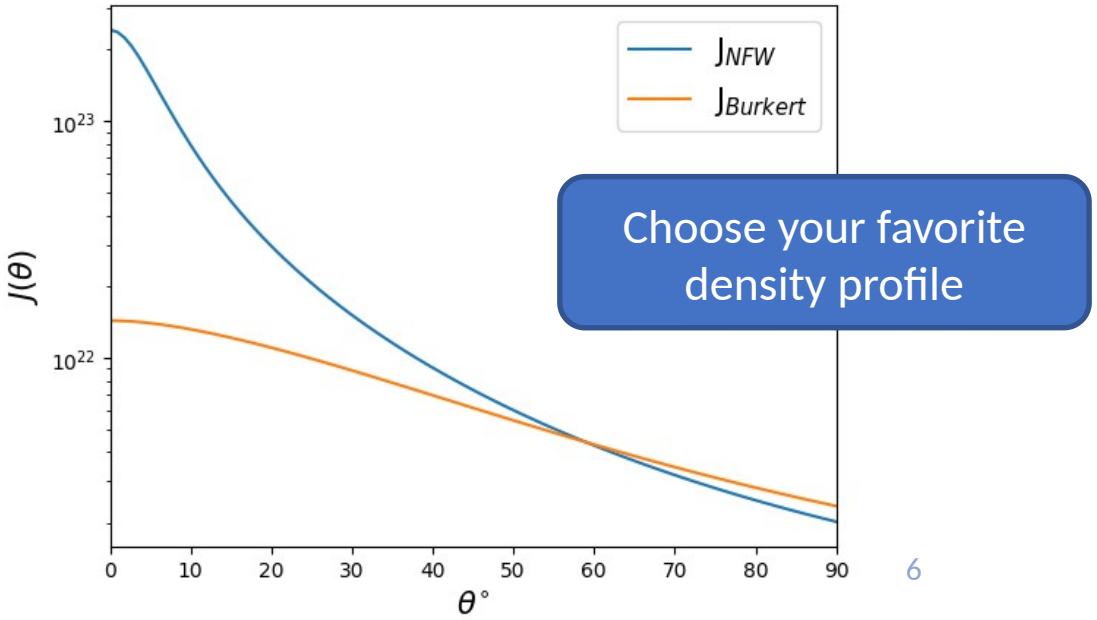
Annihilation:
- Direct
- Via $W\bar{W}$ $b\bar{b}$ $\tau\bar{\tau}$

Galactic

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

Direct

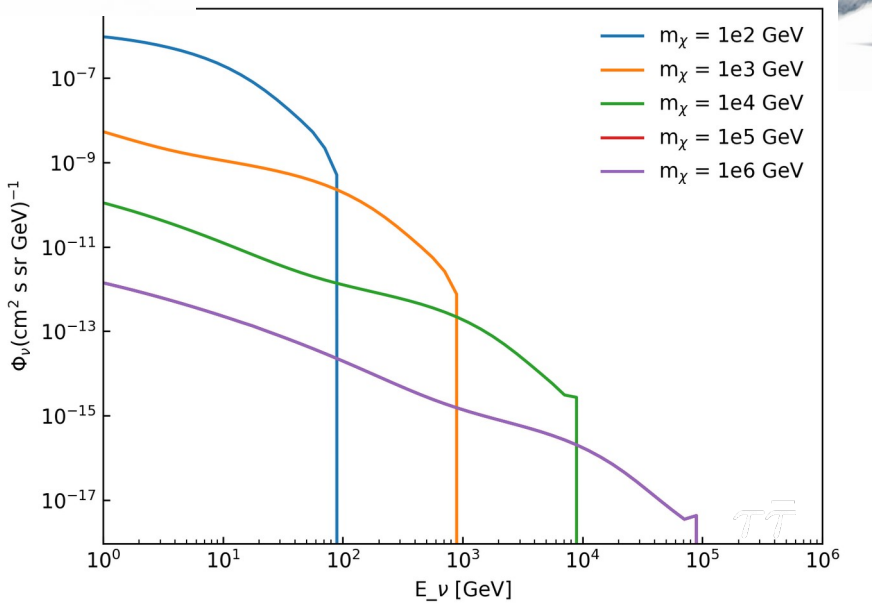
$$\frac{dN_\nu}{dE_\nu} = 2\delta\left(1-\frac{E}{m_\chi}\right)\frac{m_\chi}{E^2}$$



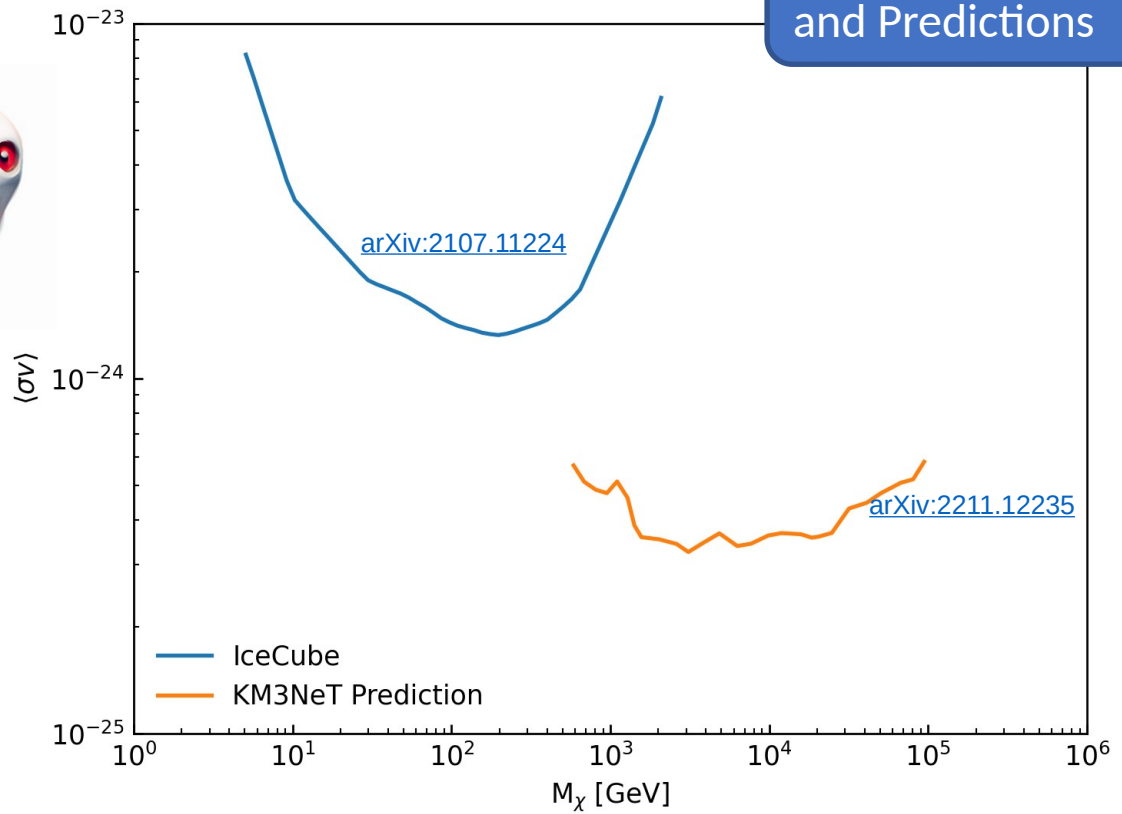
Choose your favorite density profile

Let's go with the simplest case II

Galactic via $\tau\bar{\tau}$



Current Limits and Predictions



Let's see what this means for IceCube and P-ONE with 10 years

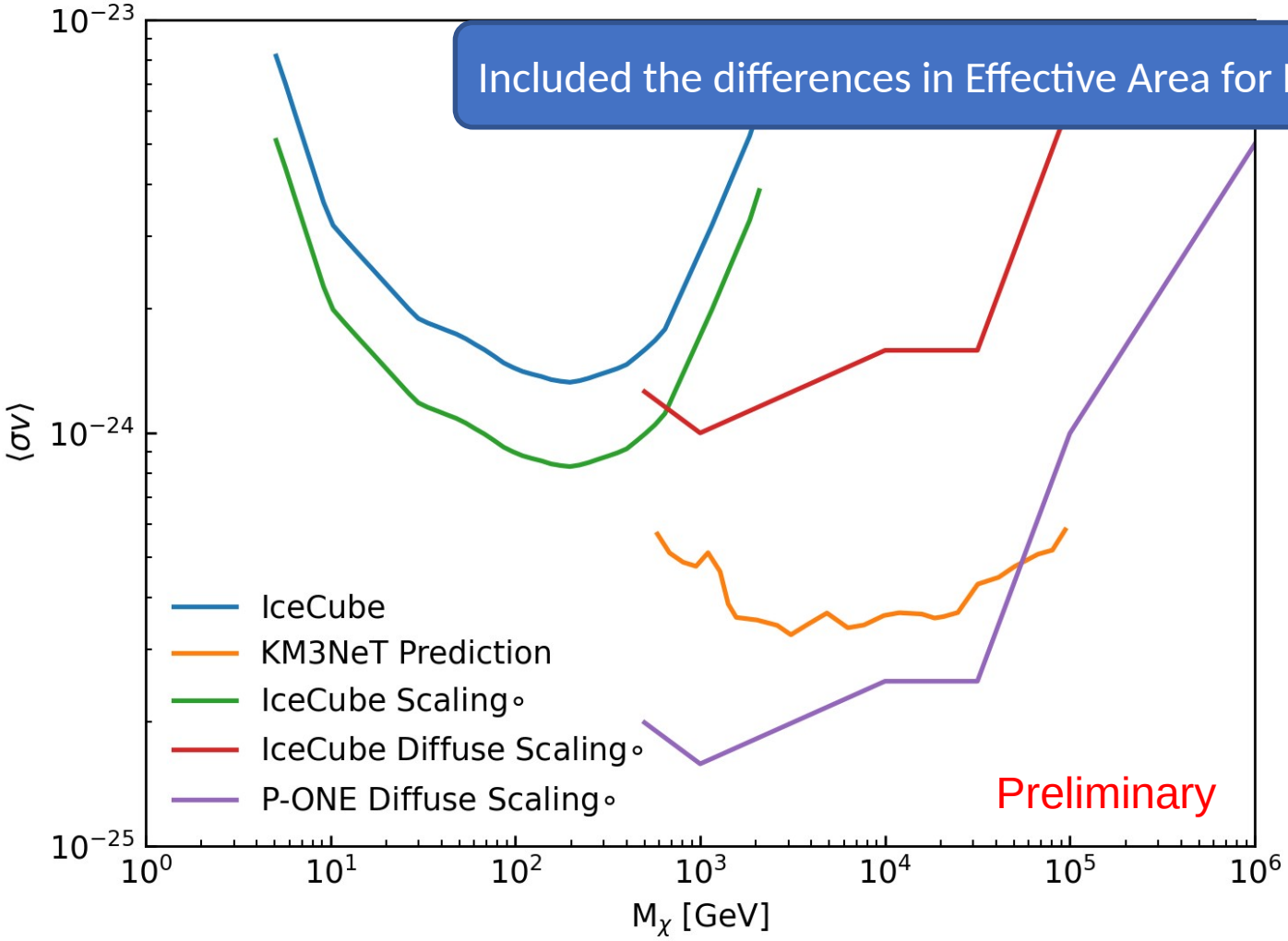
Using simple scaling for now

Precise analysis incoming

Previously IceCube used five years of data. Ten years are now publicly available.
Since IceCube is in the South, it is “blind” to the GC → x20 penalty to sensitivity

arXiv:1910.08488

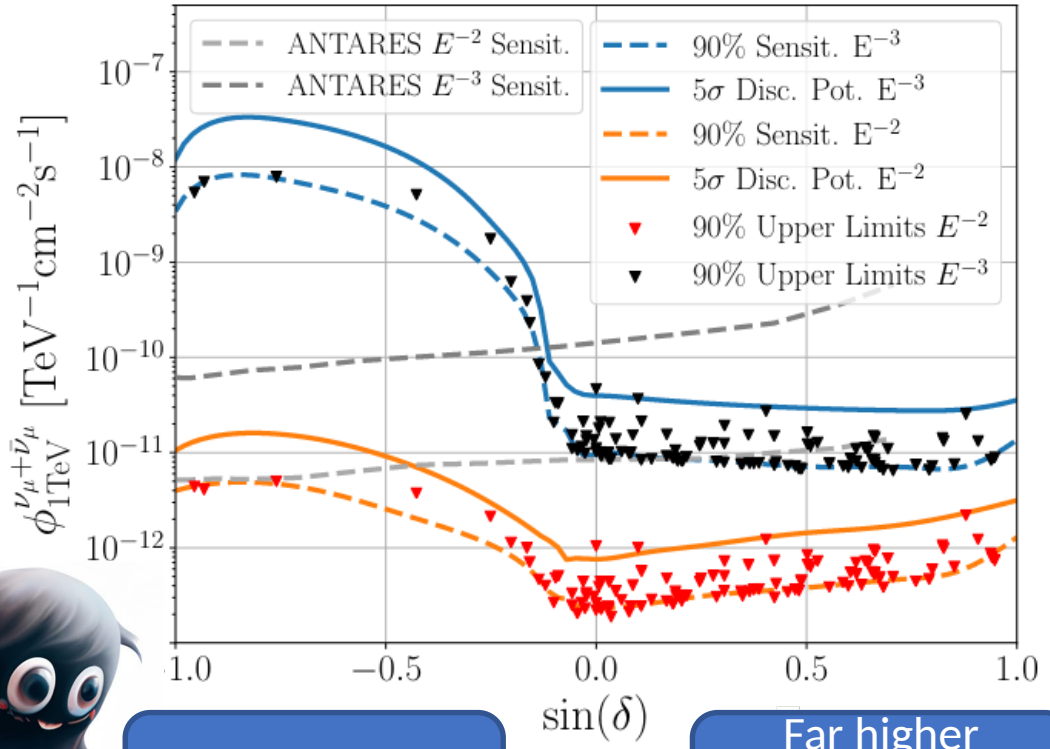
Included the differences in Effective Area for P-ONE

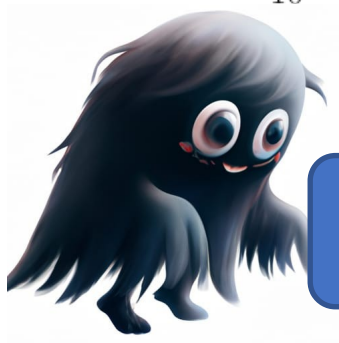


For direct annihilation the limits are ~x10 better!

Until we have Northern Data

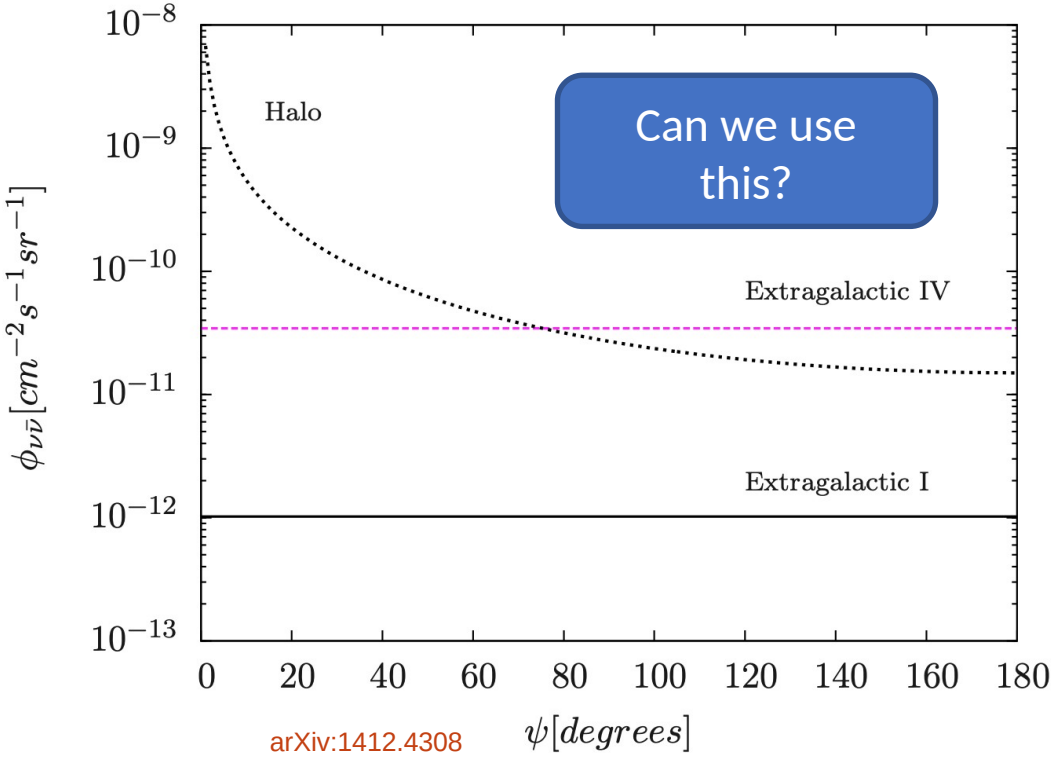
Can we use the extra-galactic flux to improve the IceCube limits?





GC is over here

Far higher sensitiviy to "up-going"



Can we use this?

arXiv:1412.4308

Let's talk about the Models I

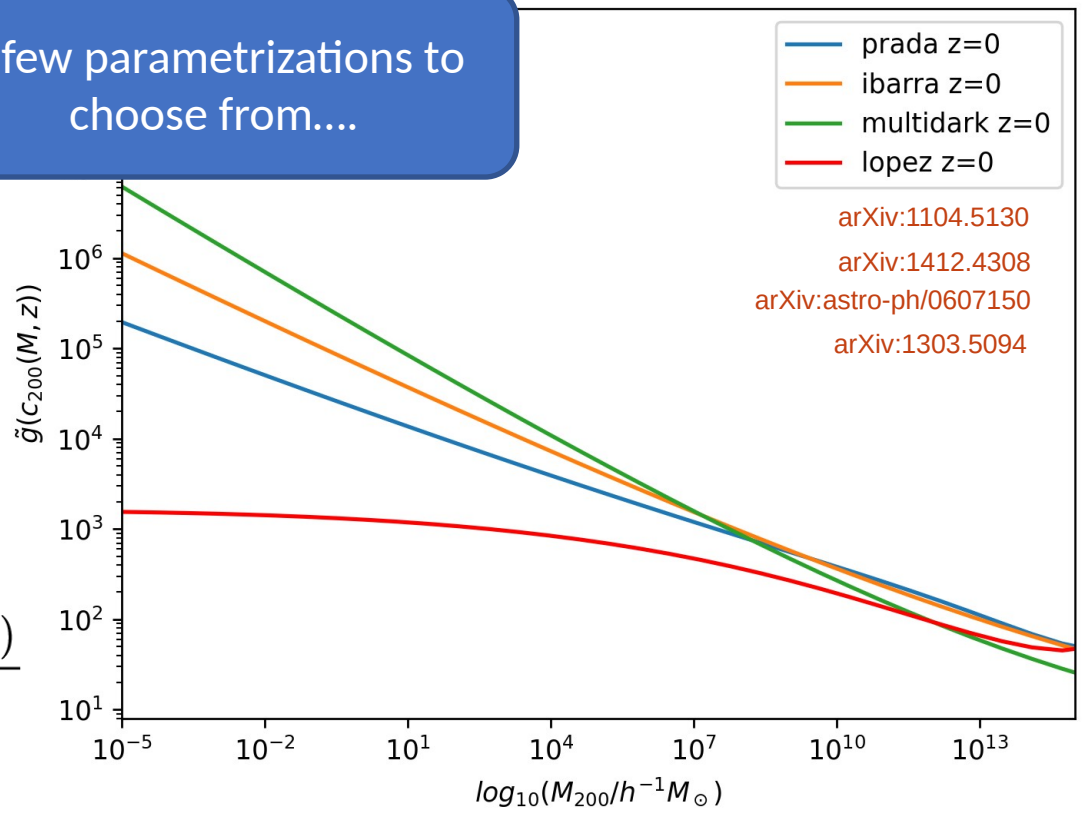
$$\frac{d\Phi_{extra}}{dE_\nu} = \frac{1}{4\pi}\frac{\Omega_{DM}^2\rho_c^2\langle\sigma\nu\rangle}{\kappa m_\chi^2}\frac{1}{3}$$

$$\times\int_0^{z_{up}} dz \frac{[1+G(z)](1+z)^3}{H(z)}\frac{dN_\nu}{dE_\nu}$$

$$G(z) = \frac{1}{\Omega_{DM,0}^2\rho_c^2(1+z)^6}\times\int dM\frac{dn(M,z)}{dM}\int dr 4\pi r^2\rho_\chi^2(r)$$

Quite a few sources of uncertainty

A few parametrizations to choose from....



$$\int_0^{r_\Delta} \mathrm{d}r 4\pi r^2\rho_{halo}^2(r) = \tilde{g}(c_\Delta)\frac{M\Delta\rho_c(z)}{3}$$

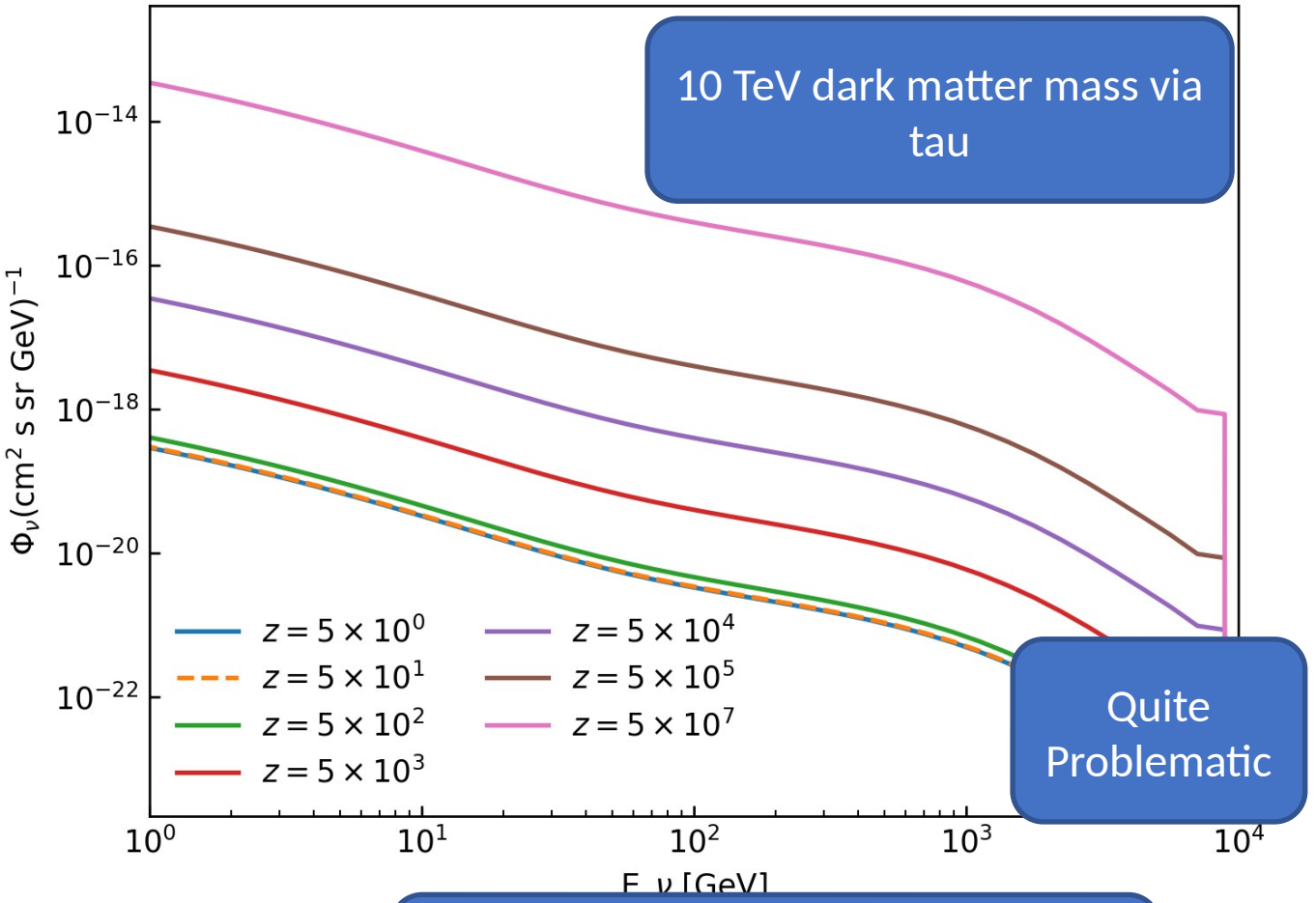
Let's talk about the Models II

$$\frac{d\Phi_{extra}}{dE_\nu} = \frac{1}{4\pi}\frac{\Omega_{DM}^2\rho_c^2\langle\sigma\nu\rangle}{\kappa m_\chi^2}\frac{1}{3}$$

$$\times \int_0^{z_{up}} dz \frac{[1+G(z)](1+z)^3}{H(z)}\frac{dN_\nu}{dE_\nu}$$

Also… What red-shift to choose?

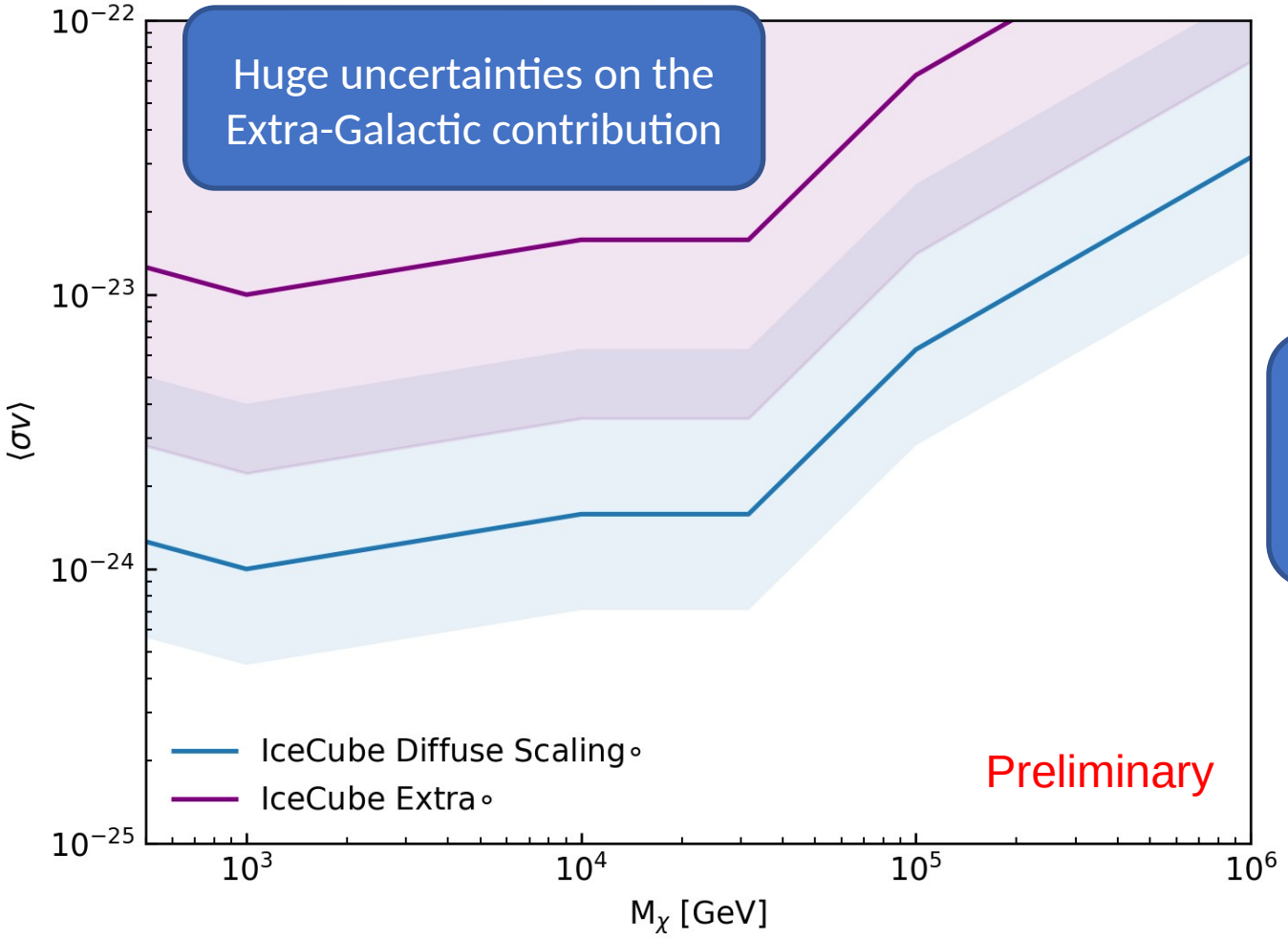
Neutrino Decoupling? (z~10e10)

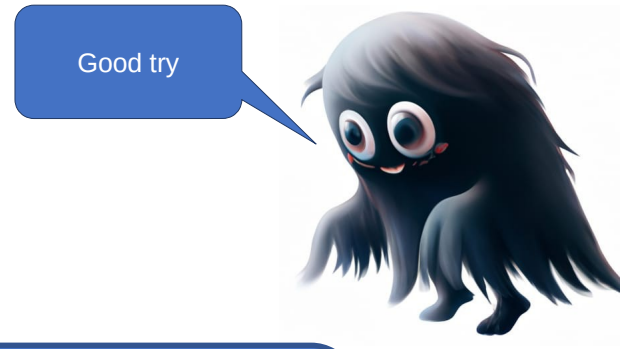


This is (in part) limited by numerical N body simulation and how to extrapolate to high z!

arXiv:1912.09486

What does this mean?





Small overlap region between the contribution when accounting for uncertainties in the DM halo

Take home messages

Future detectors will be a fantastic probe for heavy dark matter

Using extra-galactic (diffuse) DM still proves elusive

Driven by theory and experimental uncertainties

Questions?

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