IceCube and the origin of the ANITA-IV events

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arXiV 2305.03746

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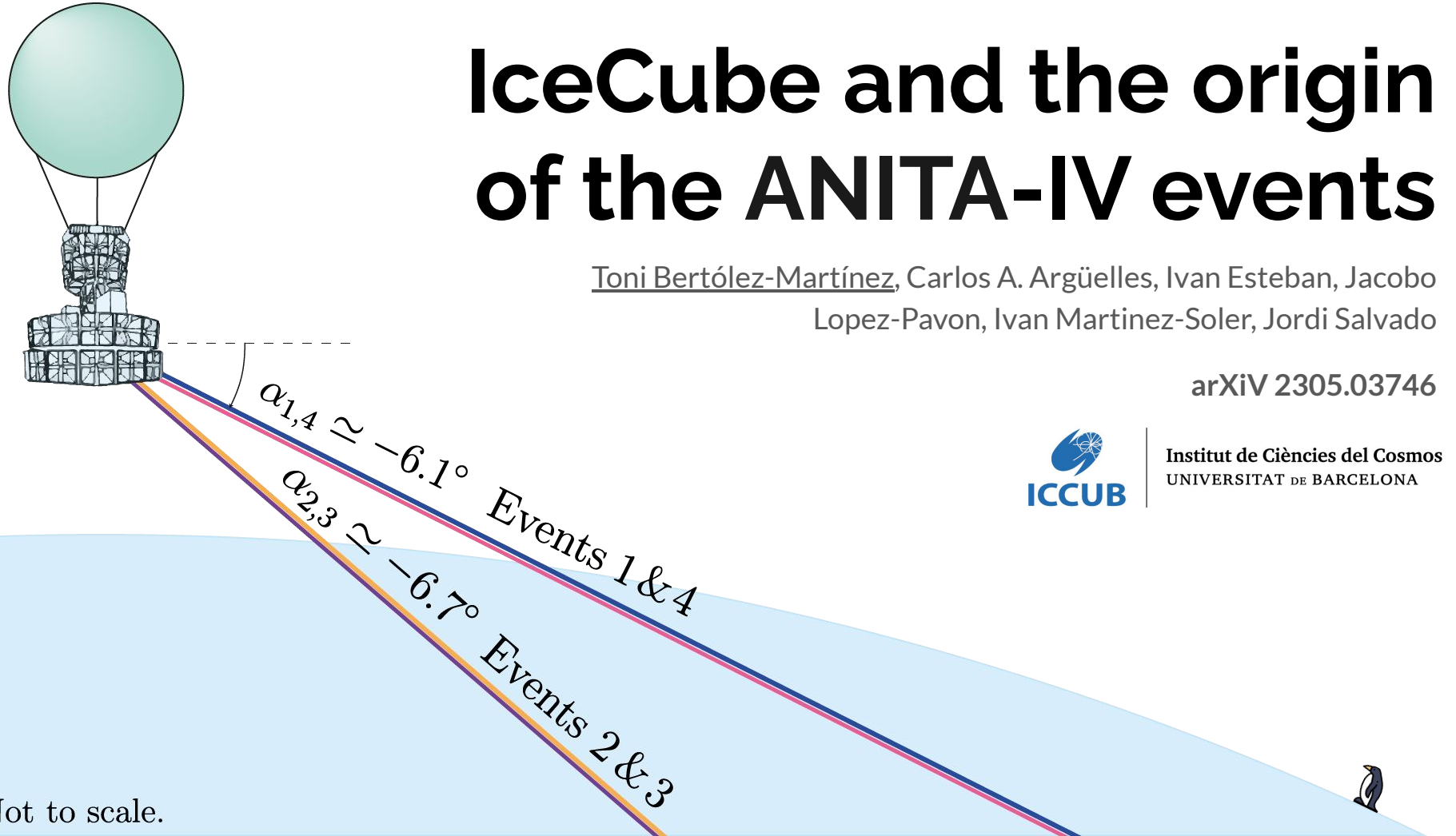

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…del Cosmos
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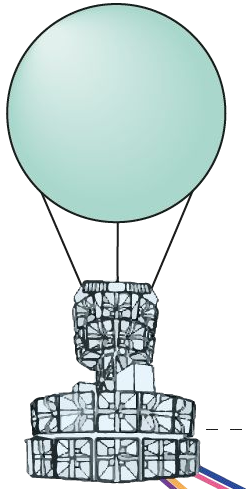


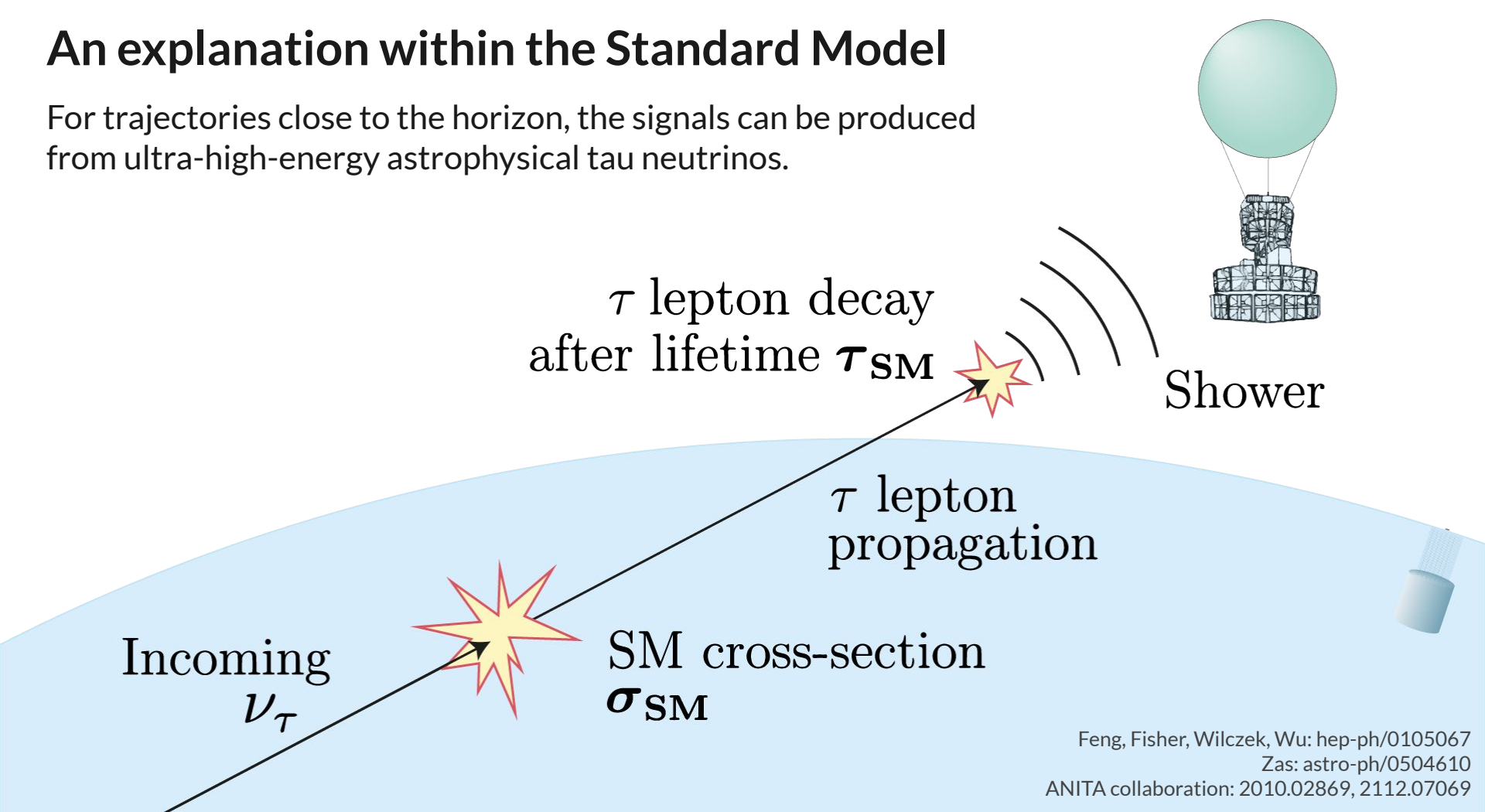
$\alpha_{1,4} \simeq -6.1°$ Events 1 & 4

$\alpha_{2,3} \simeq -6.7°$ Events 2 & 3

Not to scale.

An explanation within the Standard Model

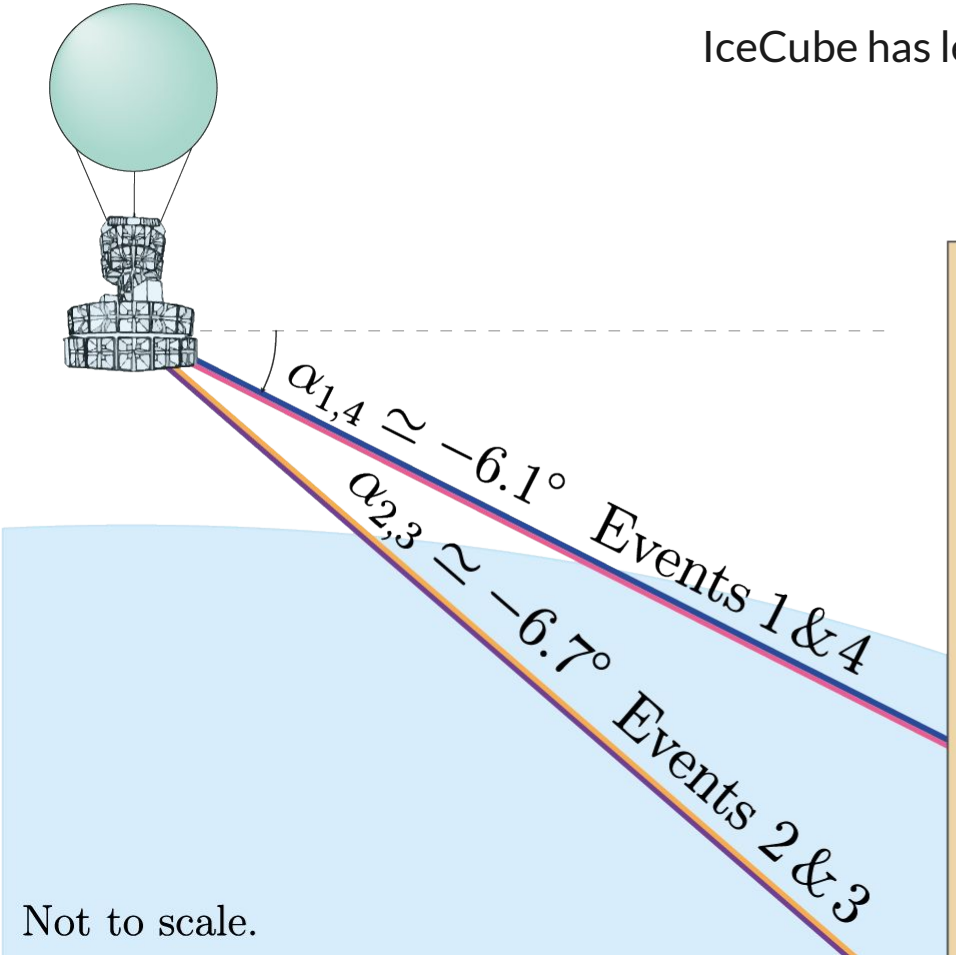
For trajectories close to the horizon, the signals can be produced from ultra-high-energy astrophysical tau neutrinos.

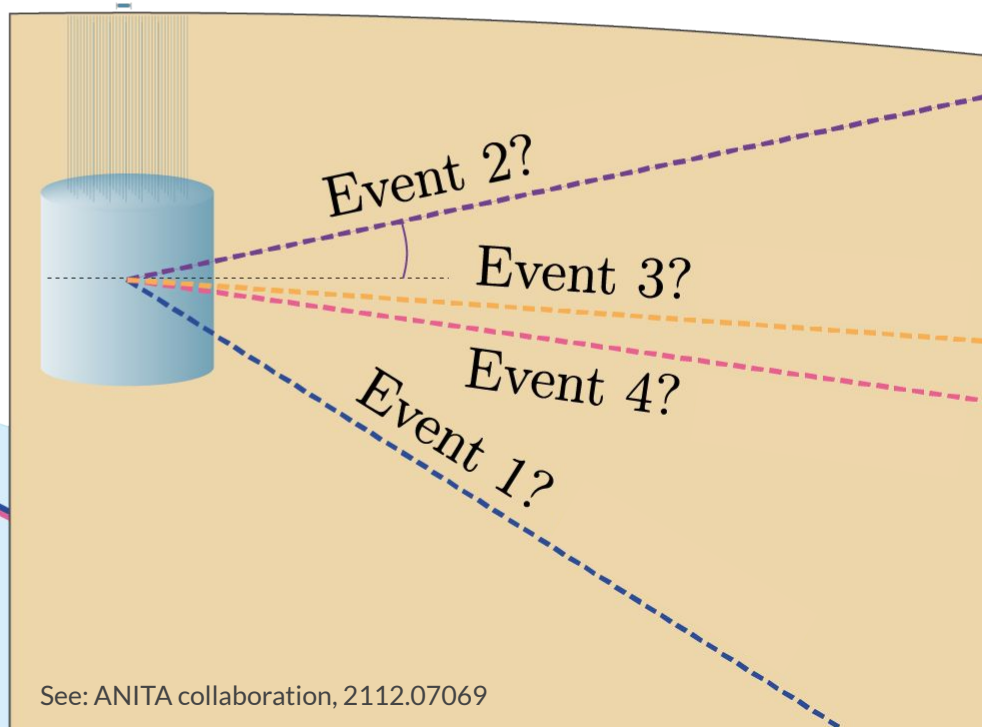


Feng, Fisher, Wilczek, Wu: hep-ph/0105067
Zas: astro-ph/0504610
ANITA collaboration: 2010.02869, 2112.07069

ANITA has seen 4 events, IceCube has seen none: tension!

IceCube has less effective area, but much more exposure time, angular aperture and control of the systematics.

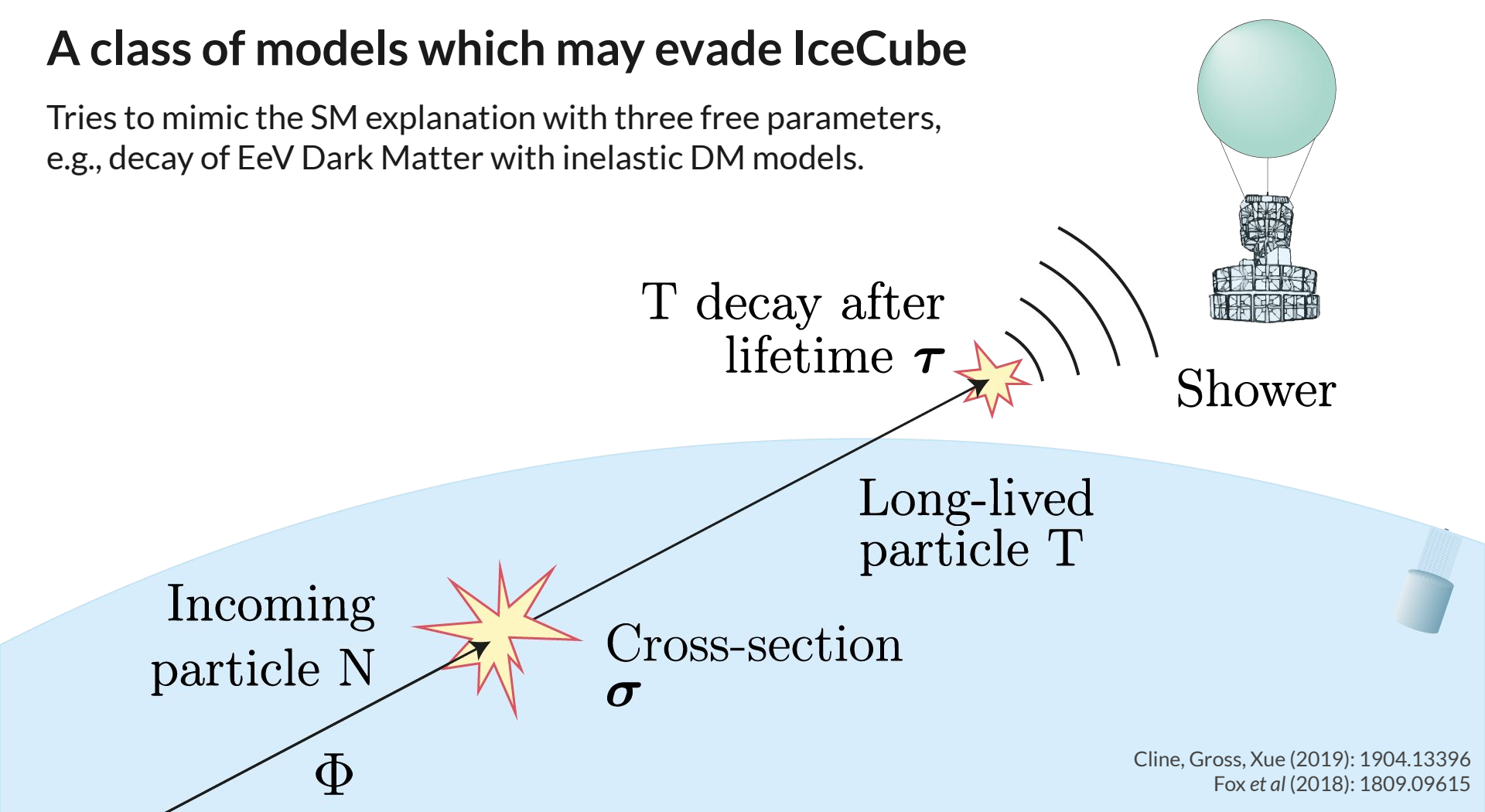




See: ANITA collaboration, 2112.07069

A class of models which may evade IceCube

Tries to mimic the SM explanation with three free parameters,
e.g., decay of EeV Dark Matter with inelastic DM models.



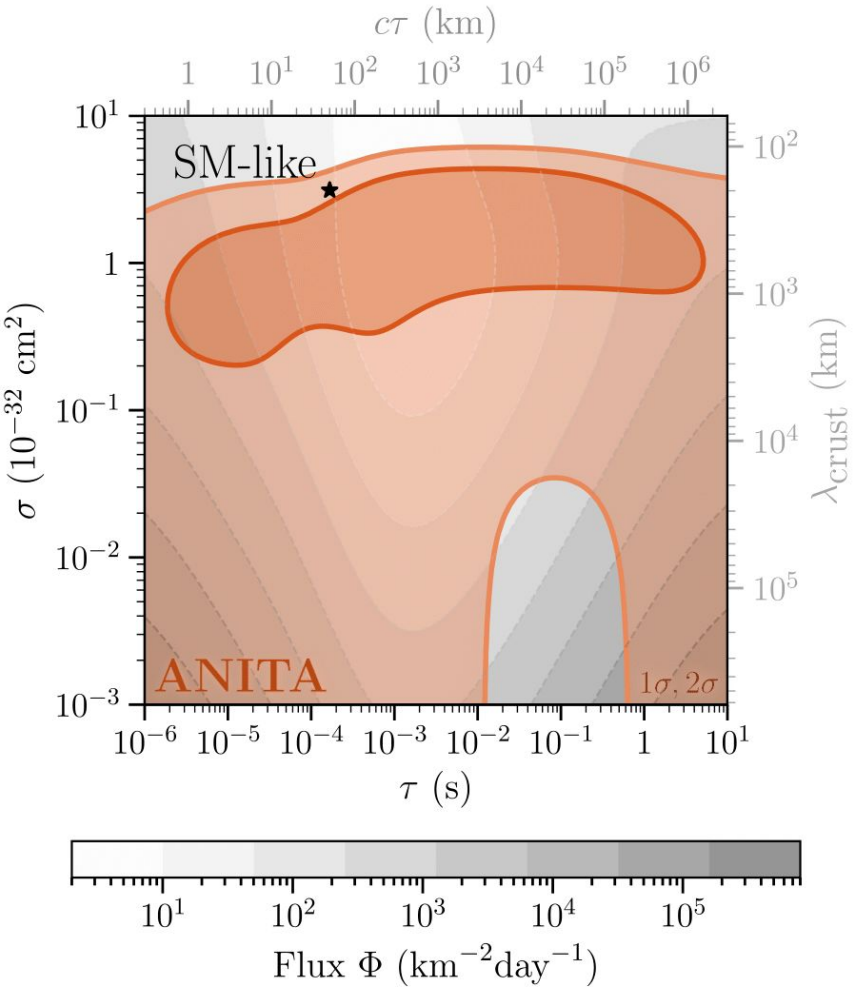
Cline, Gross, Xue (2019): 1904.13396
Fox *et al* (2018): 1809.09615

Constraints from the ANITA angular event distribution

Why are events coming from where they come?

A closed region to 1 sigma!

- σ Best-fit slightly smaller than SM.
- τ Poorly constrained, degenerate with flux normalisation.



Constraints from ANITA events and IceCube's absence of events

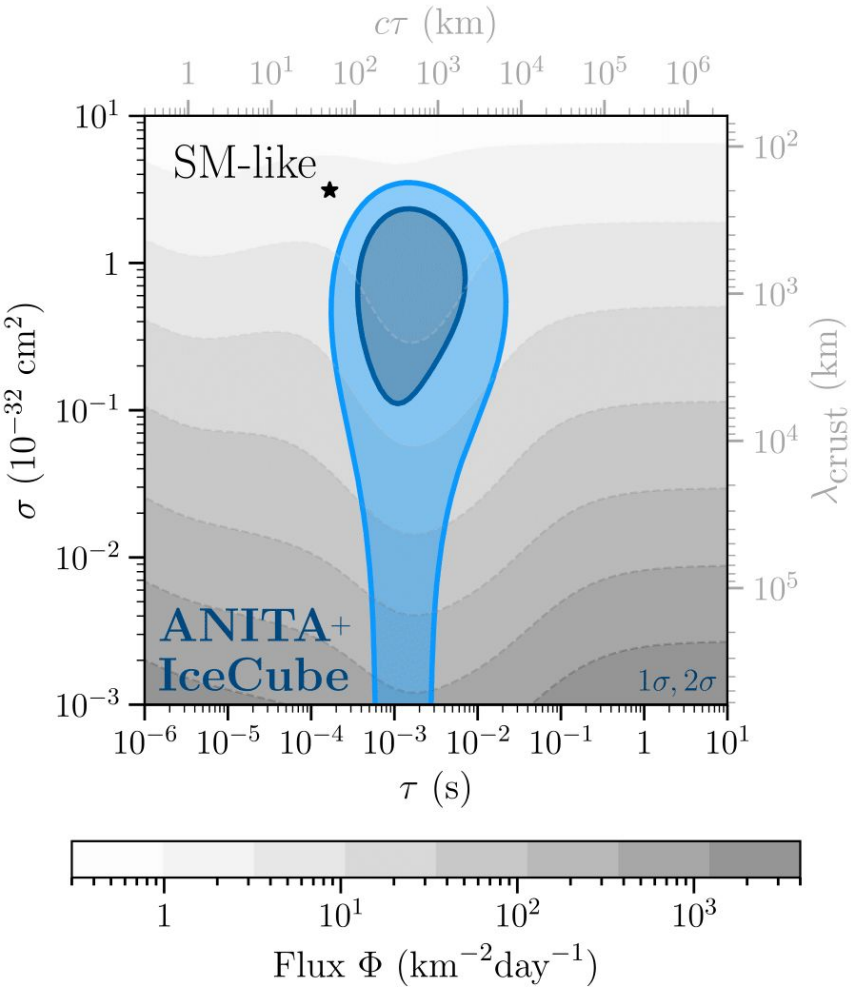
Which parameters explain *both* experiments simultaneously?

BSM relaxes the tension: best-fit predicts O(1) events for the 9 years of IceCube.

Signals would be observable in IceCube-Gen2!

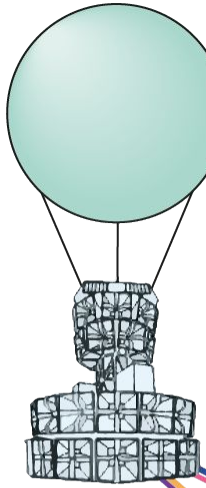
$\mathcal{T}$ Degeneracy is broken, best-fit ~1 ms.

Φ Similar to CR fluxes in this energy range.



Take home messages

- Ultra-high-energy experiments can restrict the BSM parameter space even with small statistics,
- But we must take profit of the interplay between experiments to make the most out of them!
- All eyes are set on future experiments: PUEO, IceCube-Gen2... Either we find a signal of BSM, or we must revise systematics.

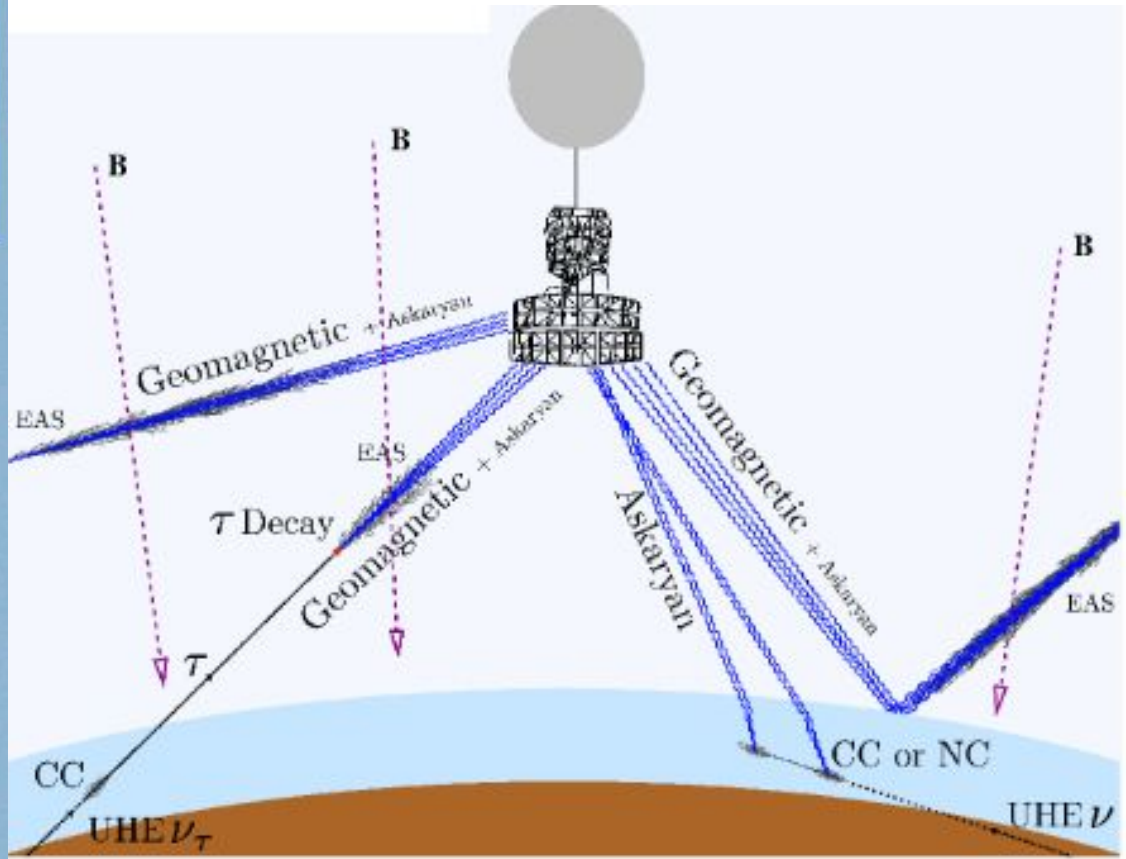


Thanks!

Find me around,
in the poster or in the arXiV: 2305.03746

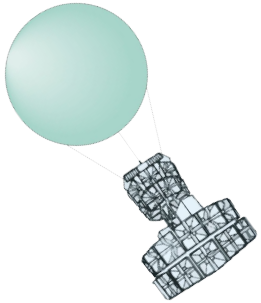
Backup slides

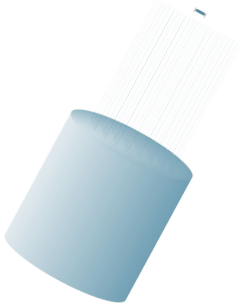
Left: ANITA-II, 1003.2961
Right: ANITA-IV, 2008.05690



ANITA vs IceCube: who wins?

Despite having smaller effective area, IceCube has larger exposure time and visibility of the full 4π solid angle.



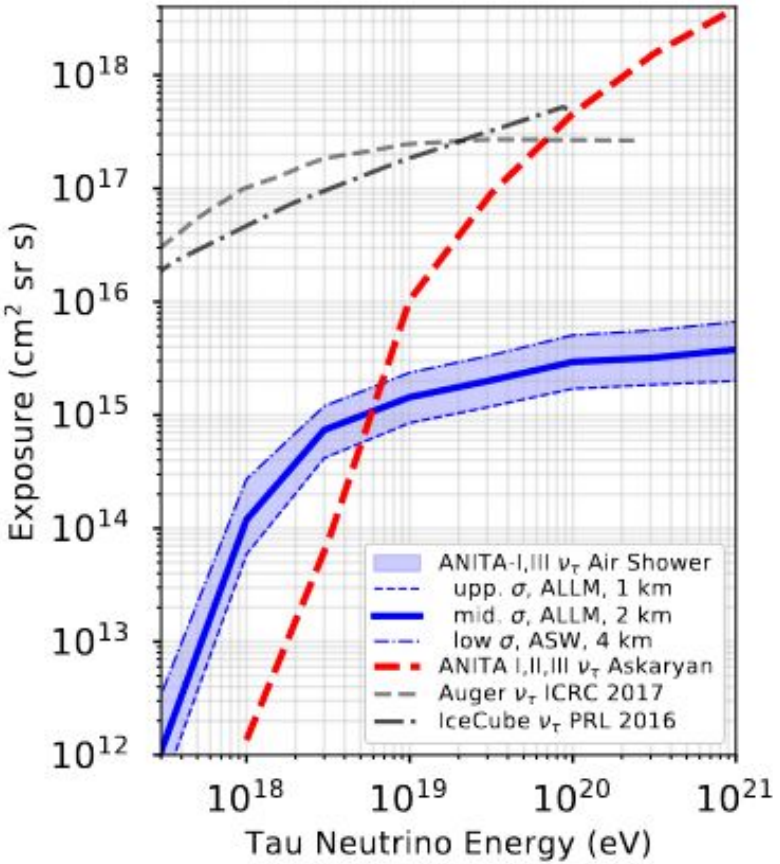


Effective area	~200 km^2	1 km^2
Angular aperture	Narrow (< 40°)	Full 4π solid angle
Exposure time	26.4 days	>9 years
Systematics & background	Harder to control	Good control w/atmospheric nus

A tau neutrino diffuse flux origin is in strong tension with IceCube and Auger

Despite a four-transients hypothesis is not.

IceCube (and Auger) exposure is ~2 orders of magnitude larger than ANITA's for a tau neutrino diffuse flux.

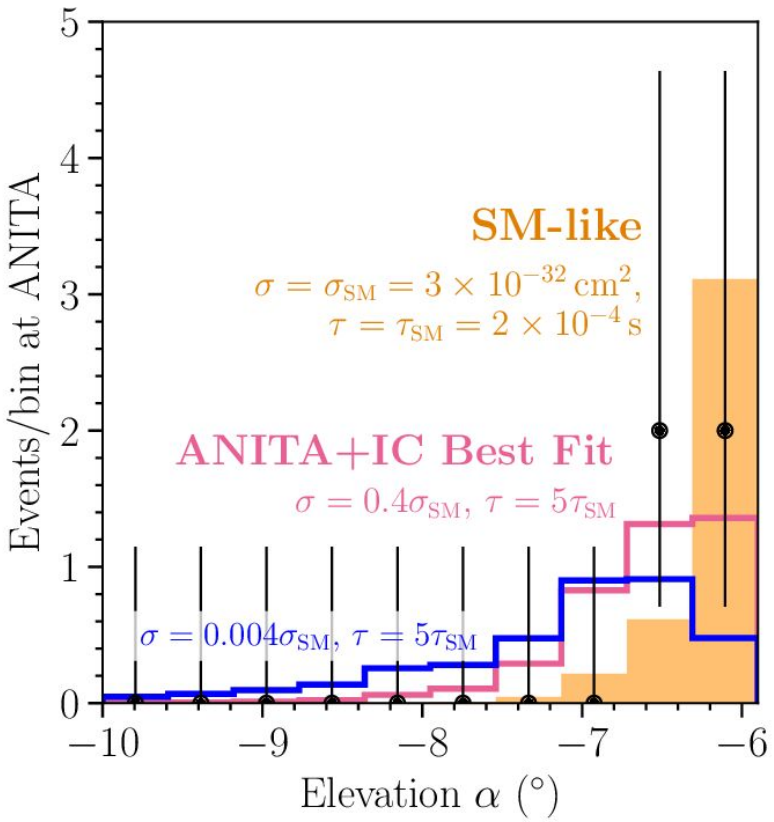


A. Romero-Wolf *et al.*, 1811.07261

Constraints from the ANITA angular event distribution

The 4 ANITA events occur near the horizon, and not anywhere else.

Even with a free flux normalization, some parameters are discarded by data!



In ANITA, σ mostly controls where the events peak, and τ mostly controls the normalization.

Constraints from the absence of events in IceCube

If ANITA has seen four events, how many events should have seen IceCube?

SM-like

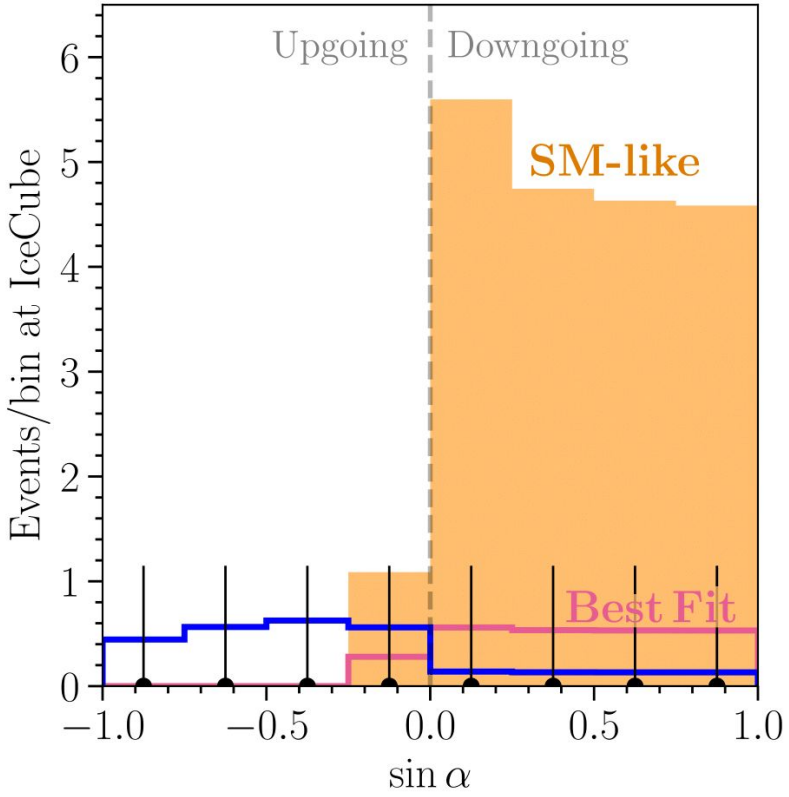
$\sigma = \sigma_{\rm SM} = 3 \times 10^{-32}\,{\rm cm}^2,$
$\tau = \tau_{\rm SM} = 2 \times 10^{-4}\,{\rm s}$

ANITA+IC Best Fit

$\sigma = 0.4\sigma_{\rm SM},\ \tau = 5\tau_{\rm SM}$

$\sigma = 0.004\sigma_{\rm SM},\ \tau = 5\tau_{\rm SM}$

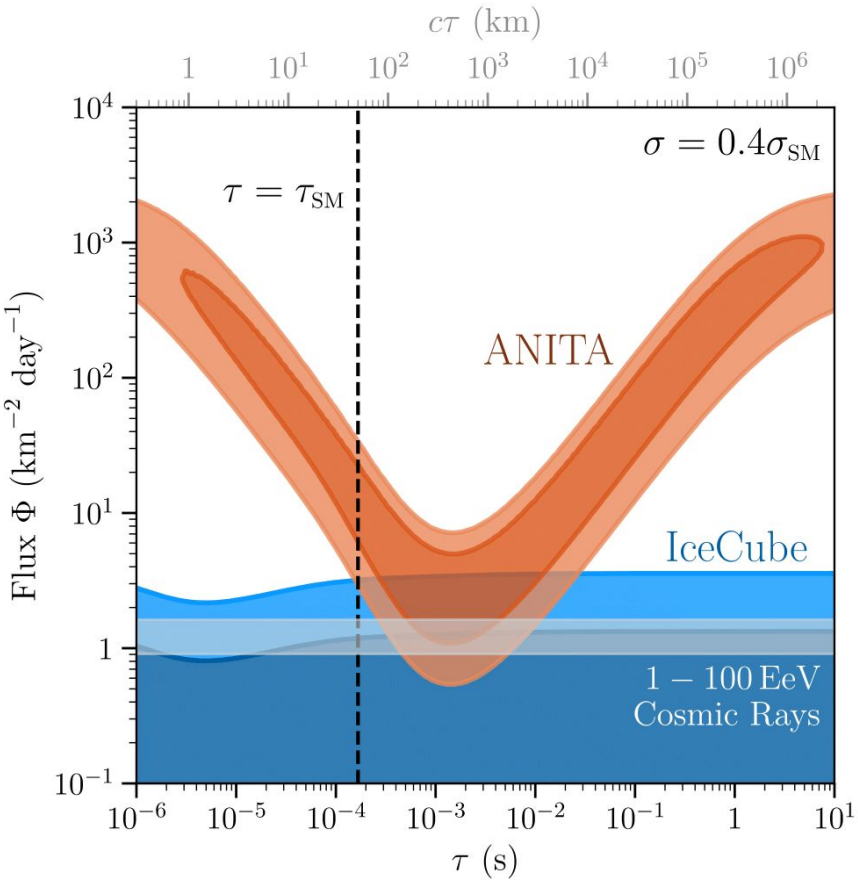
In IceCube, the flux normalization plays the most significant role.



Visualizing the tension between ANITA and IceCube

ANITA is mostly sensitive to secondary (T) particles. T particles need to decay *after* exiting the Earth but *before* reaching the antenna. Therefore, τ and Φ are strongly correlated.

IceCube is mostly sensitive to primary (N) particles, not very sensitive to τ.



The flux normalization is similar (or larger) than cosmic rays fluxes in the 1-100 EeV range.

The ingredients

ϕ

$m_\phi \sim \mathrm{EeV}$

Extremely massive Dark Matter

$\begin{pmatrix} \chi_1 \\ \chi_2 \end{pmatrix}$

$m_1 < m_2$

Doublet of heavy neutral fermions

X_μ

Dark boson w/kinetic mixing to the photon

$\lambda \phi \bar{\chi_1} \chi_1$

$g \bar{\chi_2} \gamma^\mu \chi_1 X_\mu$

Only a Yukawa coupling and a portal to the SM

The recipe

$\phi \xrightarrow[\lambda \phi \bar{\chi_1} \chi_1]{\text{Decay}} \chi_1 \xrightarrow[g \bar{\chi_2} \gamma^\mu \chi_1 X_\mu]{\text{Interaction with a nucleus}} \chi_2 \xrightarrow[g \bar{\chi_2} \gamma^\mu \chi_1 X_\mu \quad m_1 < m_2]{\text{Semi-visible decay}} \chi_1$ **+ shower**

Details of the statistical analysis

Since the number of events is small, we introduce an unbinned log likelihood, this helps not to introduce any bias by the binning choice.

$$\mathcal{TS}(\Phi, \sigma, \tau) = 2 \int \mathrm{d}\varphi \, \mathrm{d}\theta \sin\theta \, \mu(\theta, \varphi; \Phi, \sigma, \tau) - 2 \sum_{i=1}^{N} \log \tilde{\mu}(\theta_i^{\mathrm{rec}}; \Phi, \sigma, \tau)$$

Here, μ is the number of events in the experiment, and $\tilde{\mu}$ is a Gaussian-averaged number of events around a given angle, accounting for angular uncertainty.

Accounting for secondary absorption