

An UHE event at KM₃NeT

and how to leverage it for BSM

Toni Bertólez-Martínez

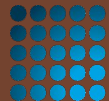
Based on 2603.28941, 2506.08993

IPA Symposium 2026

μ



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UNIVERSITY OF WISCONSIN-MADISON



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WISCONSIN ICECUBE
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A *neutrino* with the *highest energy* ever measured

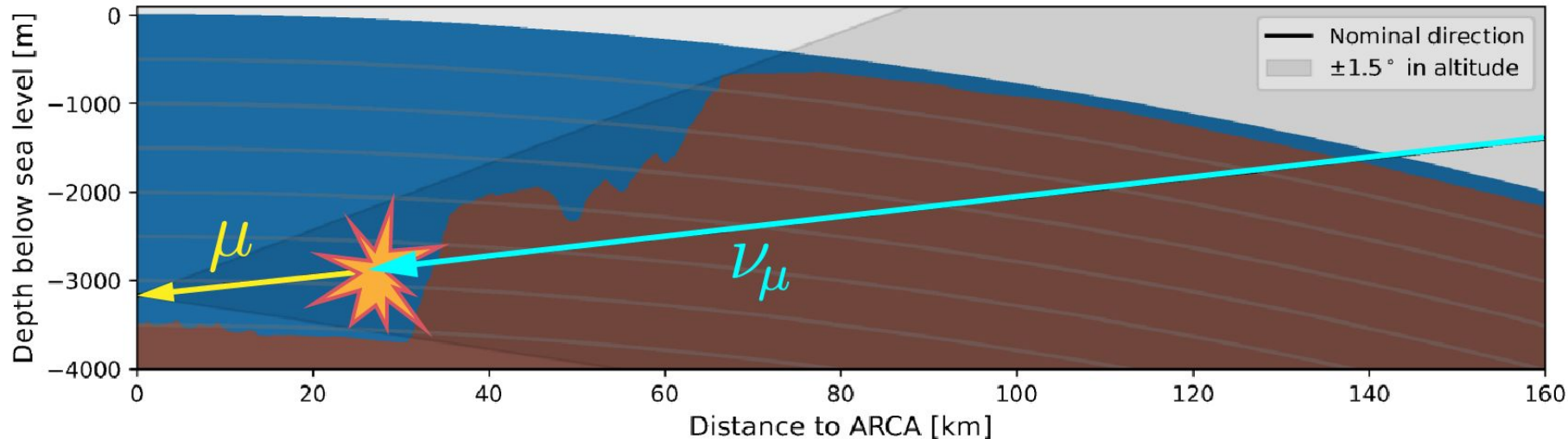
They measured a muon with energy

a muon neutrino with energy

$$E_{\mu} = 120_{-60}^{+110} \text{ PeV} \xrightarrow{\text{interpretable as}} E_{\nu} = 110 - 790 \text{ PeV}_{(68\%)}$$

KM3NeT Collaboration, Nature 638 (2025) 8050, 376-382

The Earth-skimming direction is consistent with it.



KM₃NeT has surpassed the LHC energy threshold

The collision of a neutrino with energy

$$E_\nu = 110 - 790 \text{ PeV}$$

with a proton at rest, implies a center-of-momentum energy

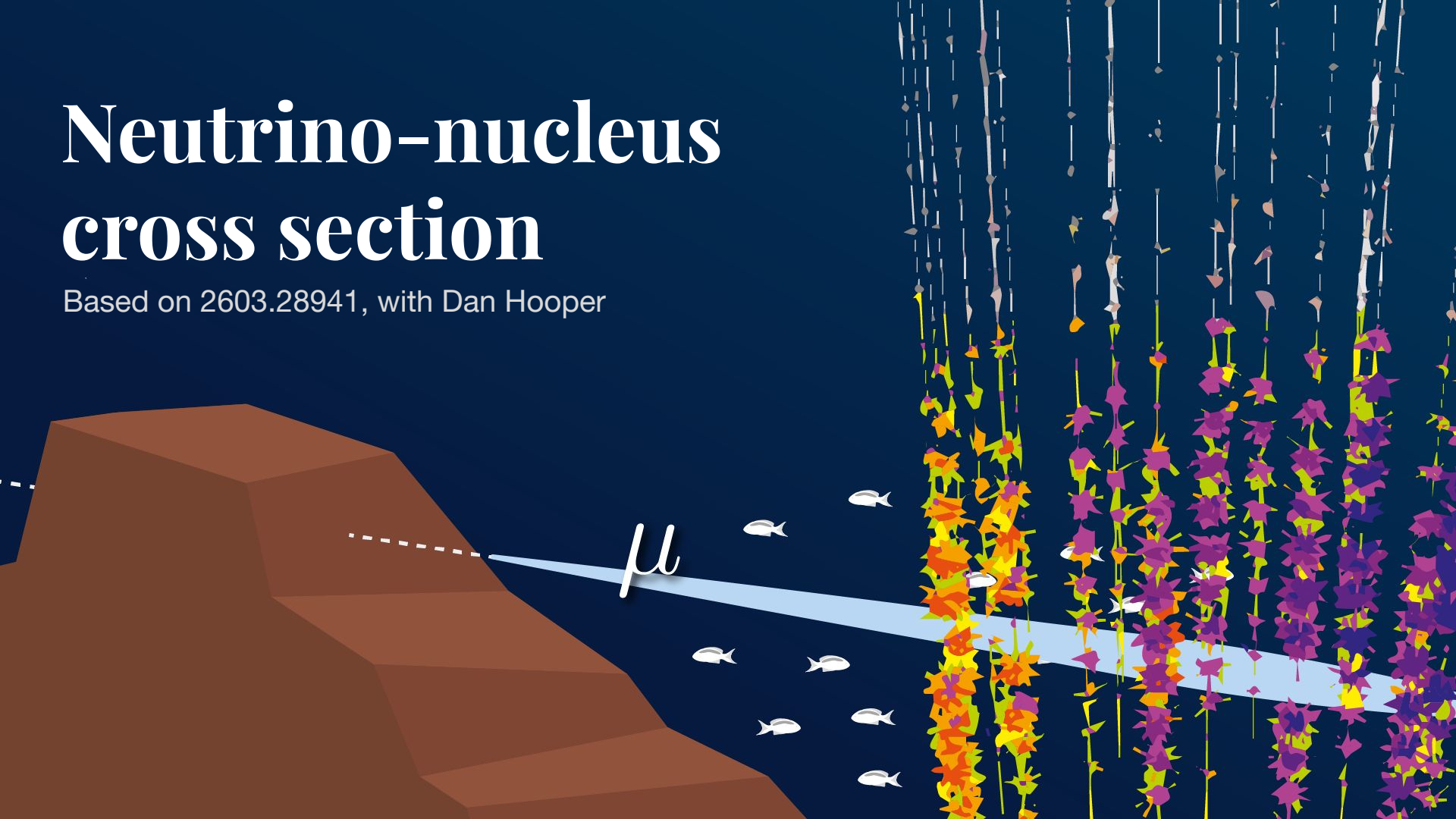
$$E_{\text{c.o.m.}} = \sqrt{2E_\nu m_p} = 14 - 39 \text{ TeV}$$

We're entering an exciting frontier!

If this neutrino belonged to the cosmogenic diffuse flux,
we could be close to more and more events!

Neutrino-nucleus cross section

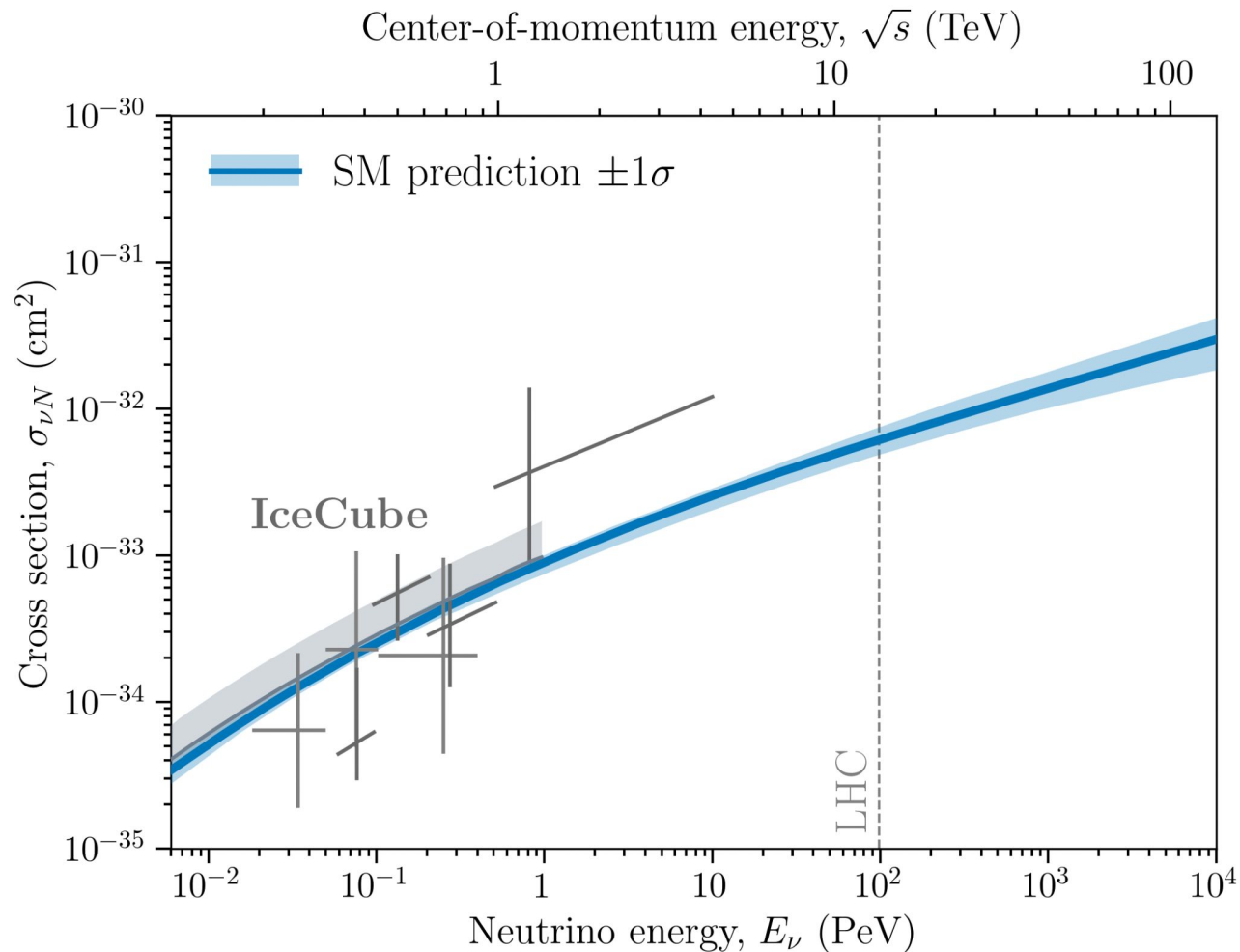
Based on 2603.28941, with Dan Hooper



Cross section measurements

Assuming standard perturbative QCD, we can predict the energy dependence of the neutrino-nucleus cross section.

However, above 10 PeV, no measurements exist.



SM prediction: Bertone, Gauld, Rojo; 1808.02034

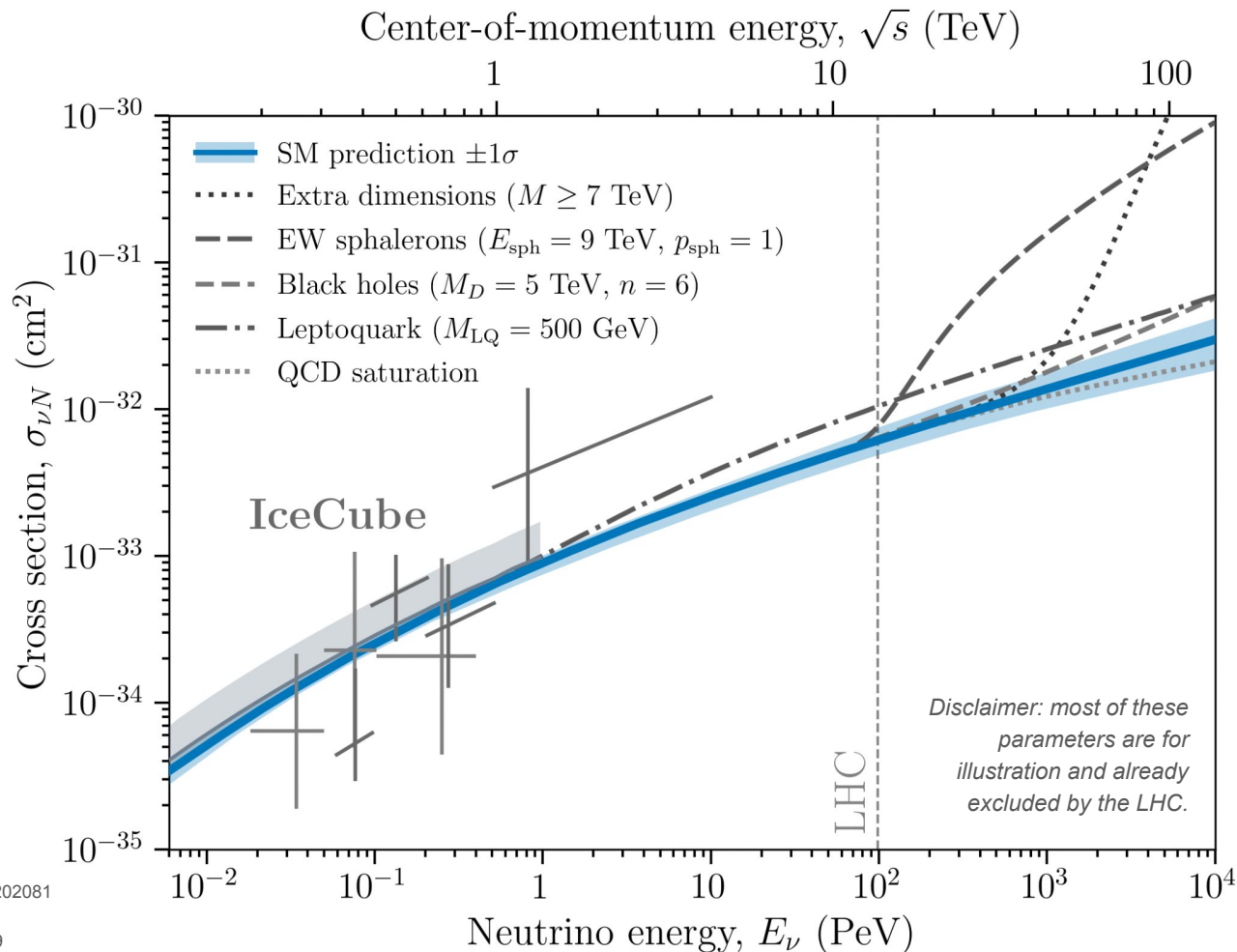
Data: IceCube; 2011.03560

IceCube; 1711.08119

Bustamante, Connolly; 1711.11043

BSM deviations

Many BSM extensions predict deviations from $\sigma_{\nu N}^{\text{SM}}$ at high energies, where the complementarity with the LHC becomes interesting.



Extra dimensions: Jain, McKay, Panda, Ralston; hep-ph/0001031

Sphalerons: Ellis, Sakurai, Spannowsky; 1603.06573

Black holes: Álvarez-Muñiz, Fen, Halsen, Han, Hooper; hep-ph/0202081

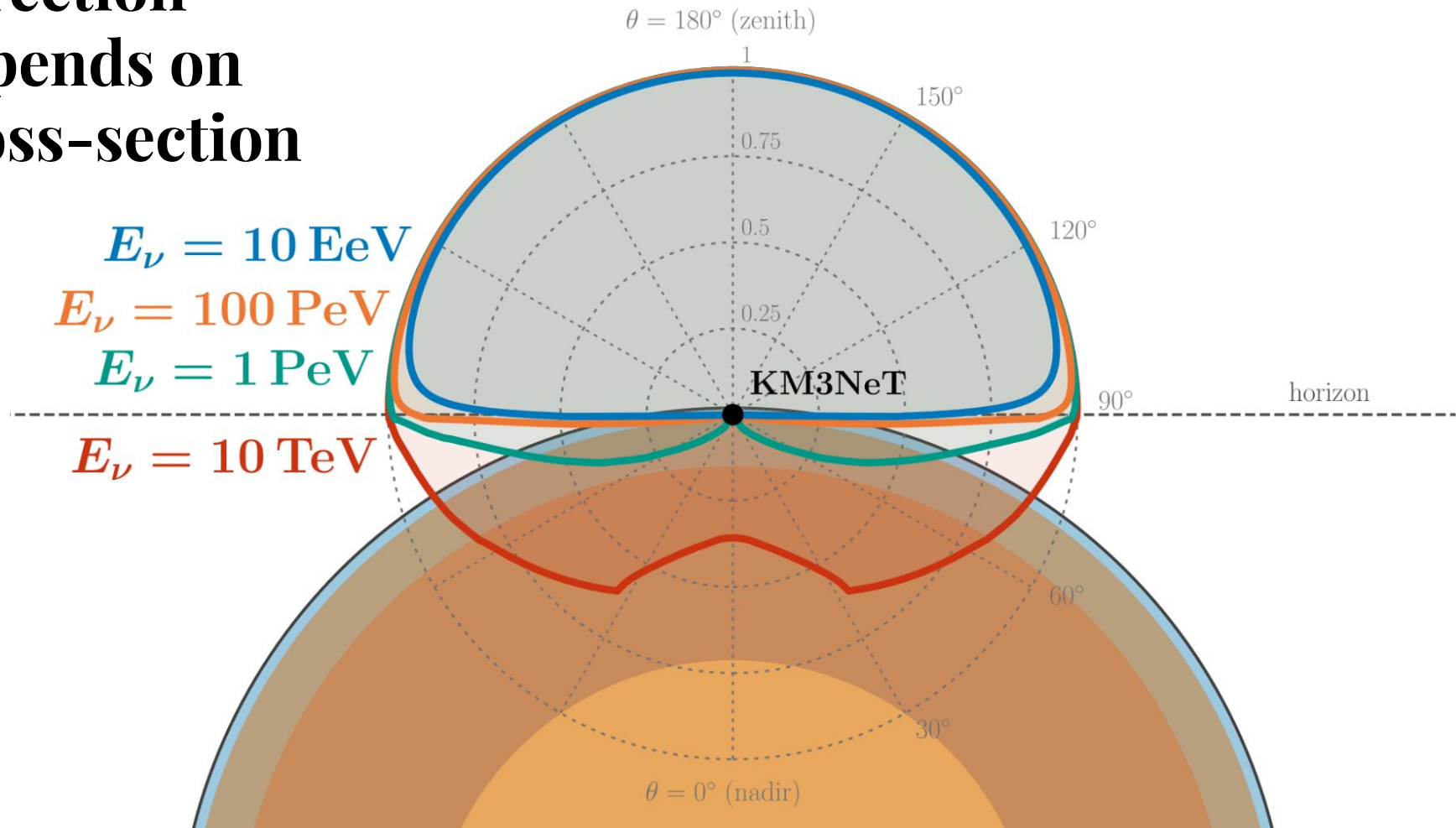
Leptoquarks: Bečirević, Panes, Sumensari, Funchal; 1803.10112

QCD saturation: Argüelles, Halzen, Wille, Kroll, Reno; 1504.06639

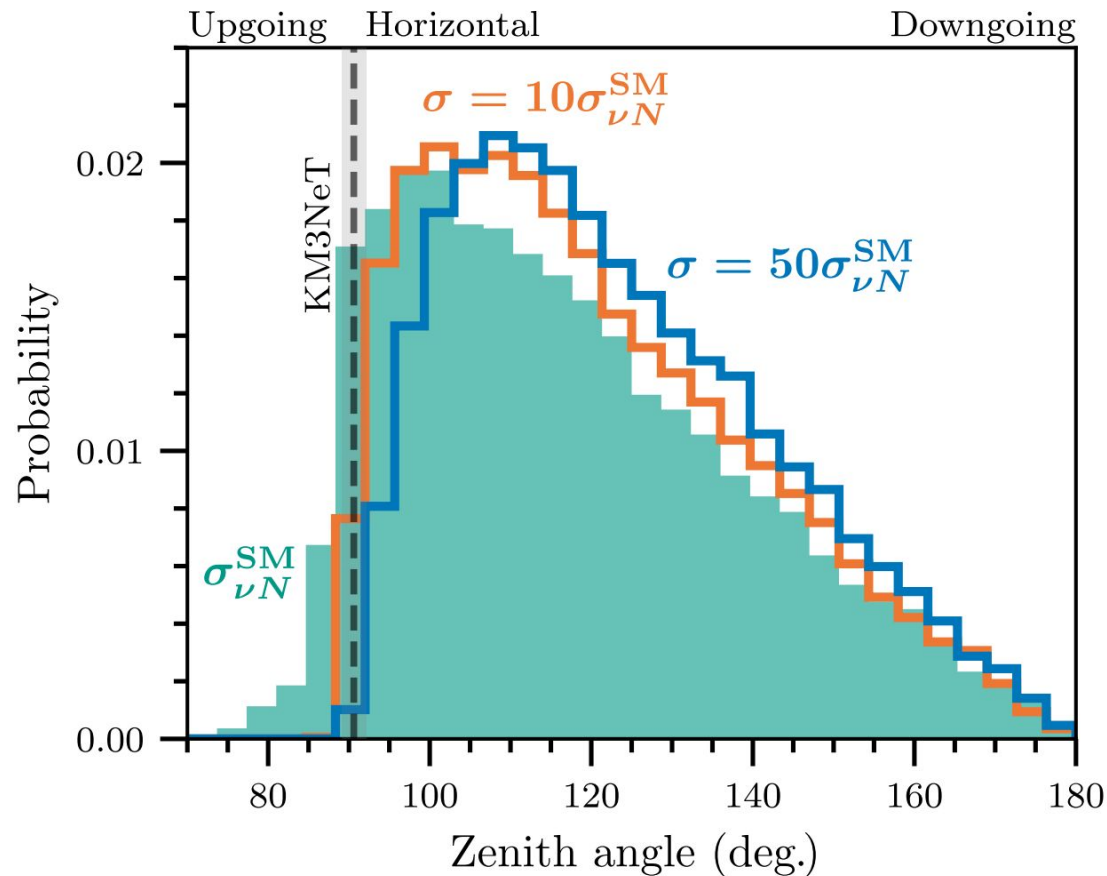
Figure inspired in Esteban, Prohera, Beacom; 2205.09763

Direction depends on cross-section

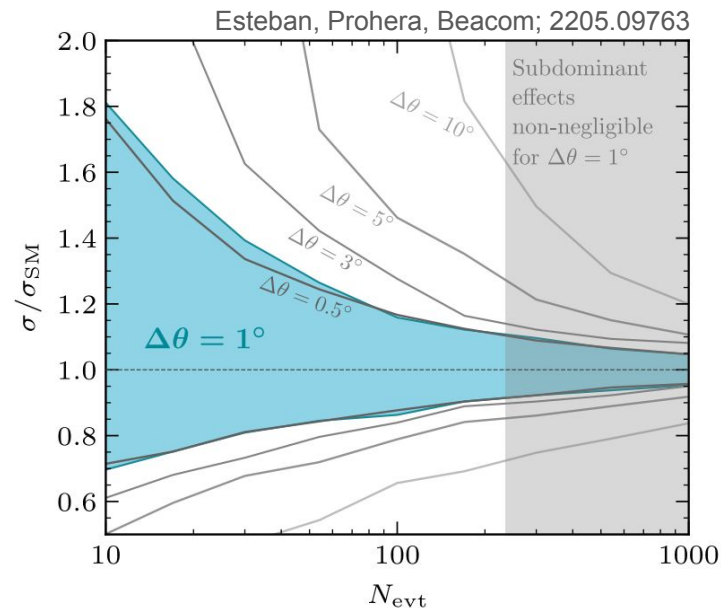
Probability to reach KM3NeT, $e^{-n\sigma_{\nu N}^{\text{SM}}(E_\nu)L(\theta)}$



Better angular resolution, better $\sigma_{\nu N}$ constraint



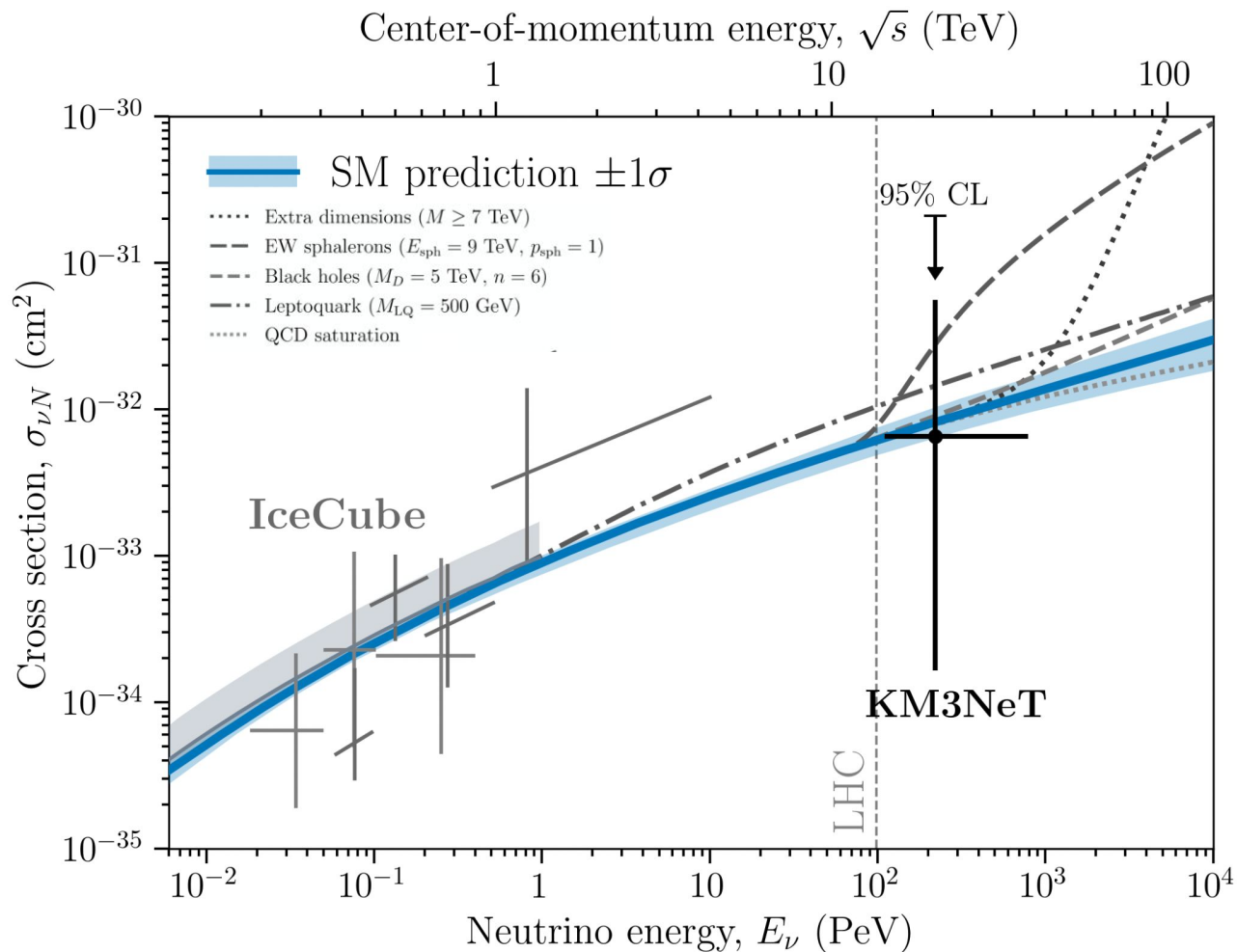
Angular resolution is essential to measure the column depth.
Sub-degree resolution is needed to reach 10% precision w/100 events.



KM₃NeT measurement

While constraining power is weak, a *single measurement* has enough for a 1σ measurement.

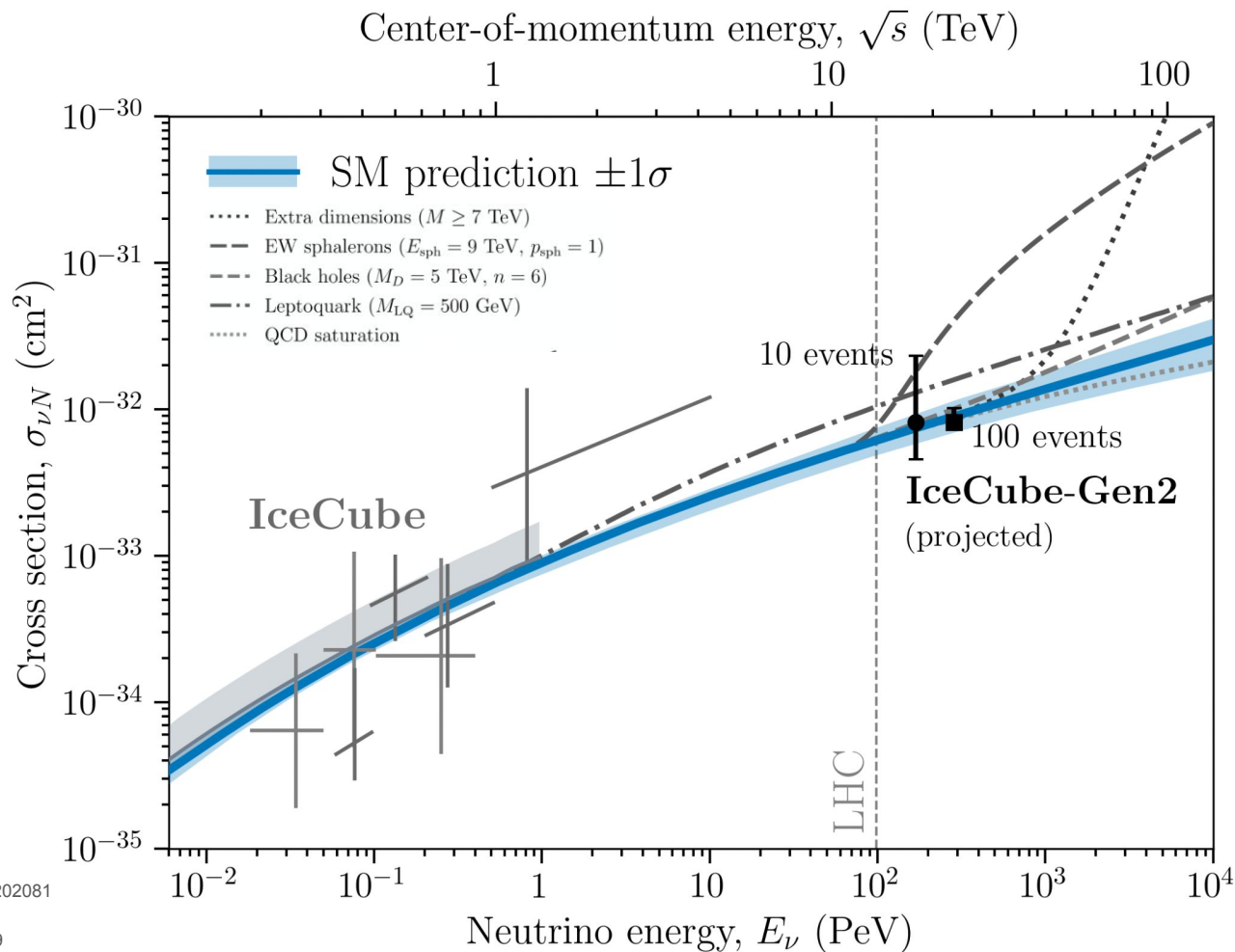
KM₃NeT alone is not competitive at all with LHC bounds.



The future: IceCube-Gen2

Assuming the cosmogenic flux is close to the current bound, we expect at least O(10) UHE events in Gen2.

These measurements would come for free.



Extra dimensions: Jain, McKay, Panda, Ralston; hep-ph/0001031

Sphalerons: Ellis, Sakurai, Spannowsky; 1603.06573

Black holes: Álvarez-Muñiz, Fen, Halsen, Han, Hooper; hep-ph/0202081

Leptoquarks: Bečirević, Panes, Sumensari, Funchal; 1803.10112

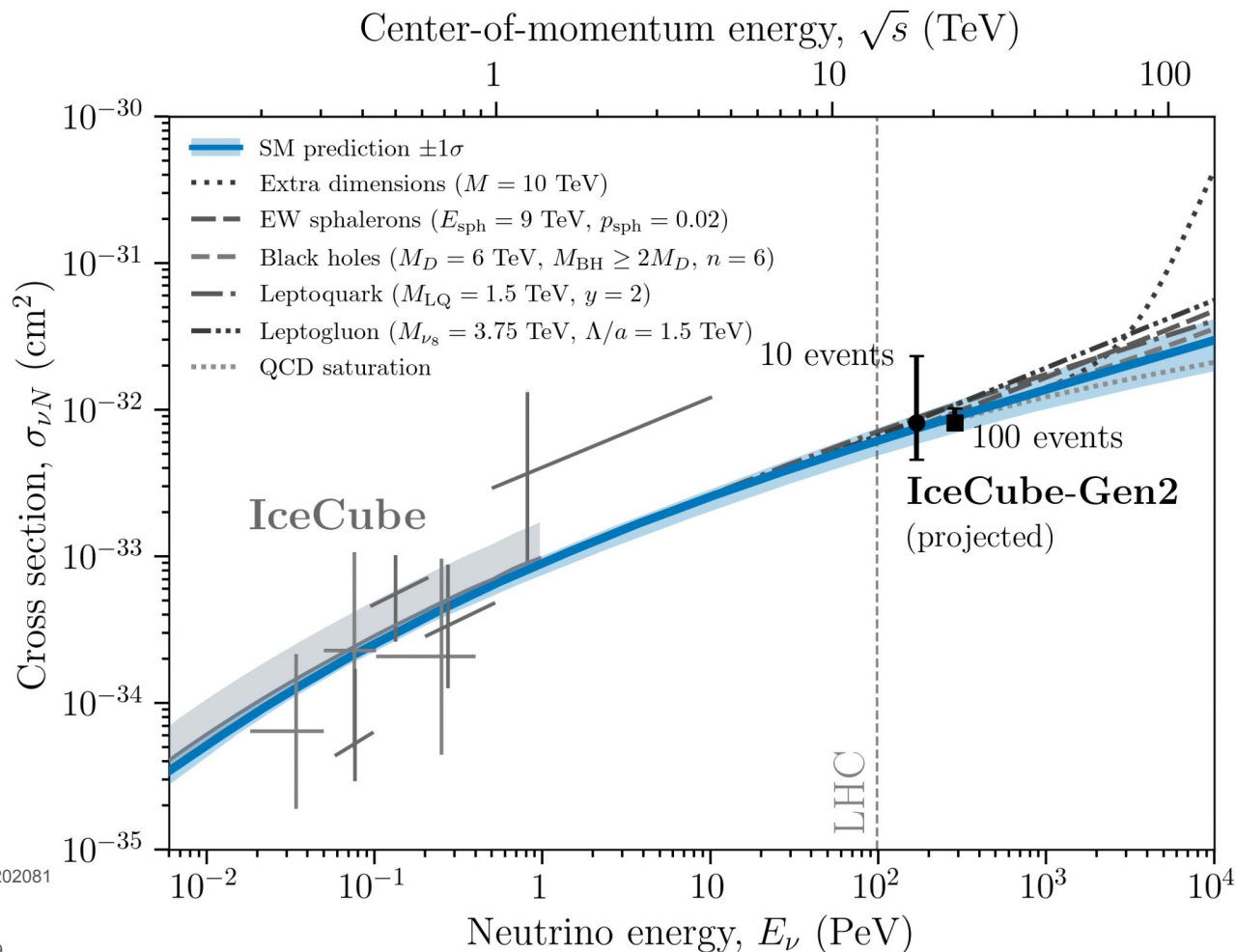
QCD saturation: Argüelles, Halzen, Wille, Kroll, Reno; 1504.06639

Figure inspired in Esteban, Prohera, Beacom; 2205.09763

The future: IceCube-Gen2

However, for the measurement to be competitive with the LHC, O(100) events are needed.

Still, a competitive measurement before the FCC is possible.



Extra dimensions: Jain, McKay, Panda, Ralston; hep-ph/0001031

Sphalerons: Ellis, Sakurai, Spannowsky; 1603.06573

Black holes: Álvarez-Muñiz, Fen, Halsen, Han, Hooper; hep-ph/0202081

Leptoquarks: Bečirević, Panes, Sumensari, Funchal; 1803.10112

Leptogluons: Bai, Xie, Zhou; 2510.13948

QCD saturation: Argüelles, Halzen, Wille, Kroll, Reno; 1504.06639

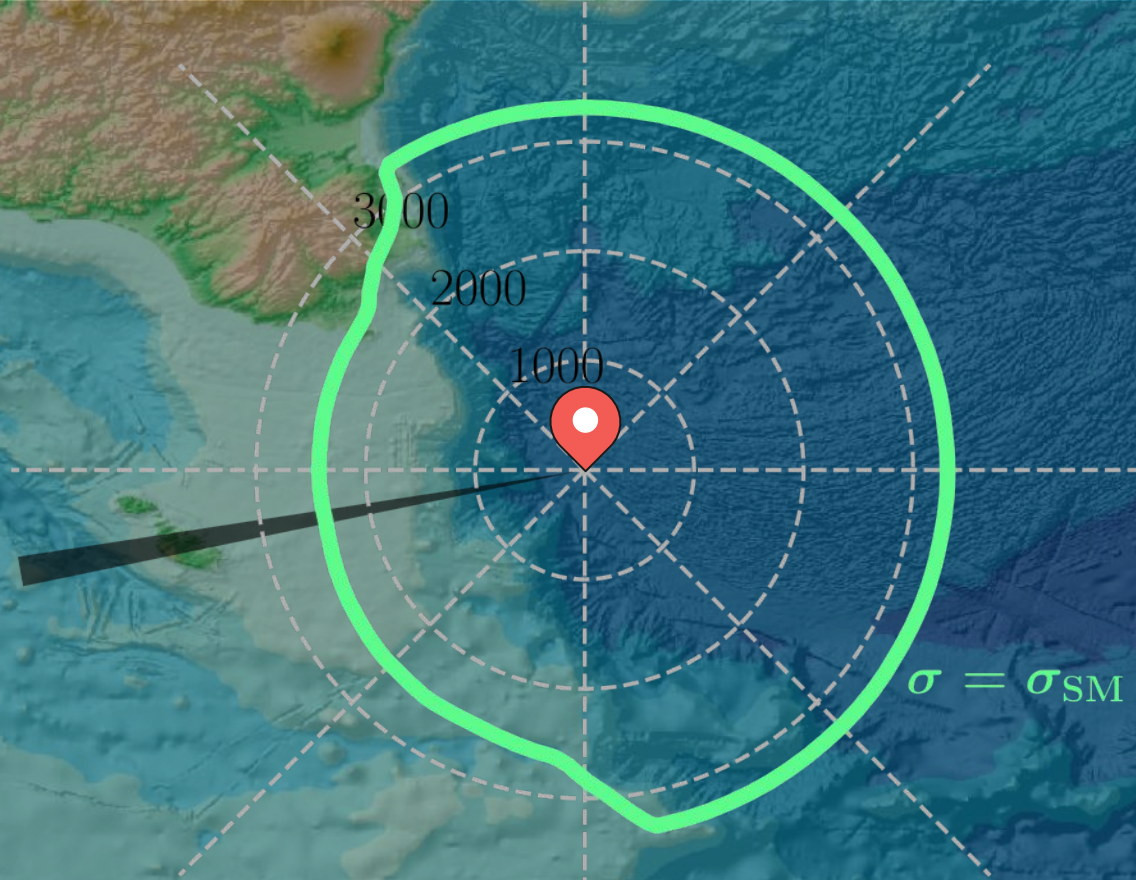
Figure inspired in Esteban, Prohera, Beacom; 2205.09763

A topographic map of the Mediterranean Sea and surrounding landmasses. The land is shown in shades of green and brown, indicating elevation. The sea is depicted in various shades of blue, representing depth. A red location pin is placed in the central part of the sea, near the coast of North Africa. The text "Is more info available?" is written in a white, italicized serif font in the upper right corner.

Is more info available?

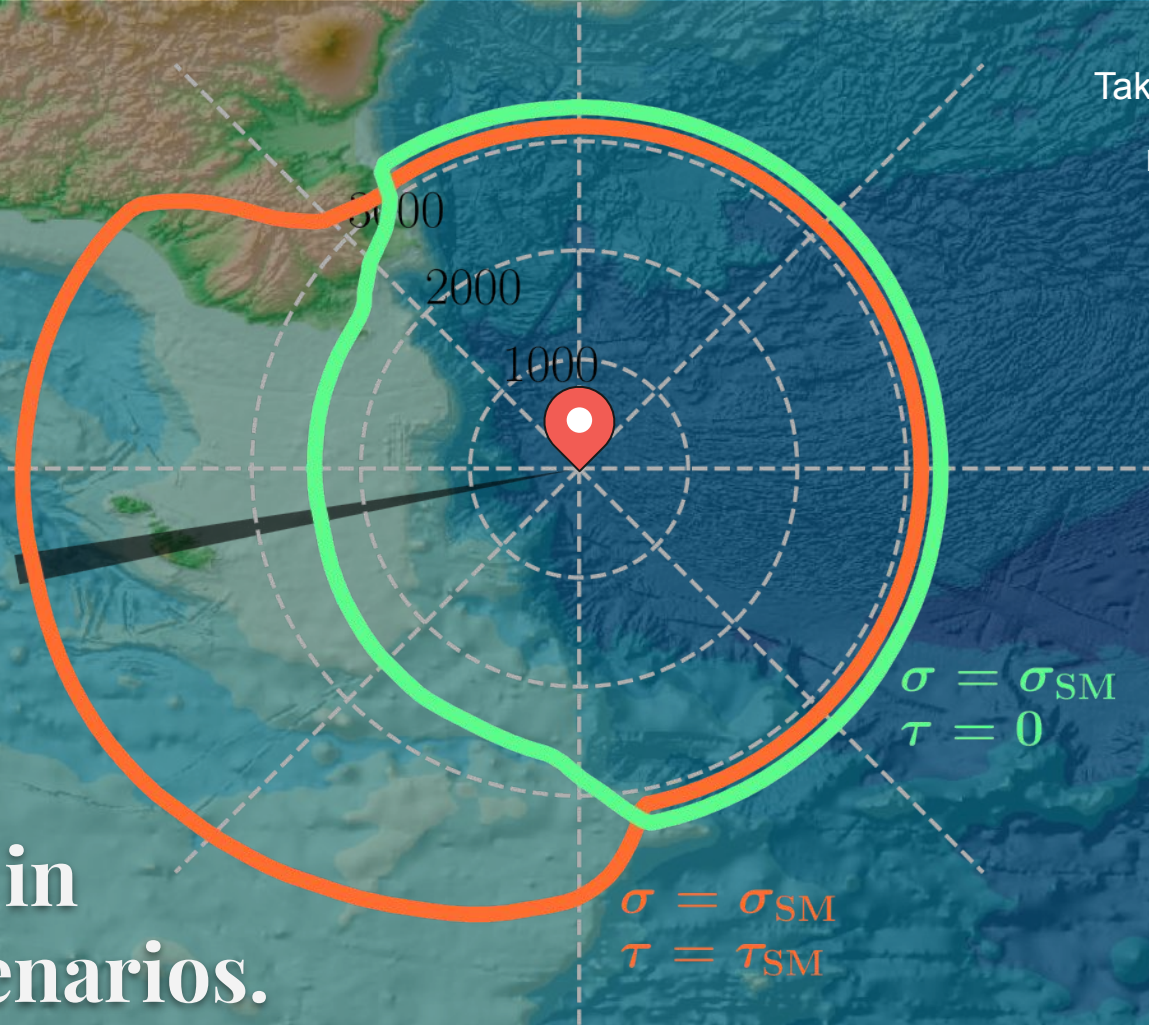


ARCA, KM_3Net



Azimuthal information is not extremely useful.

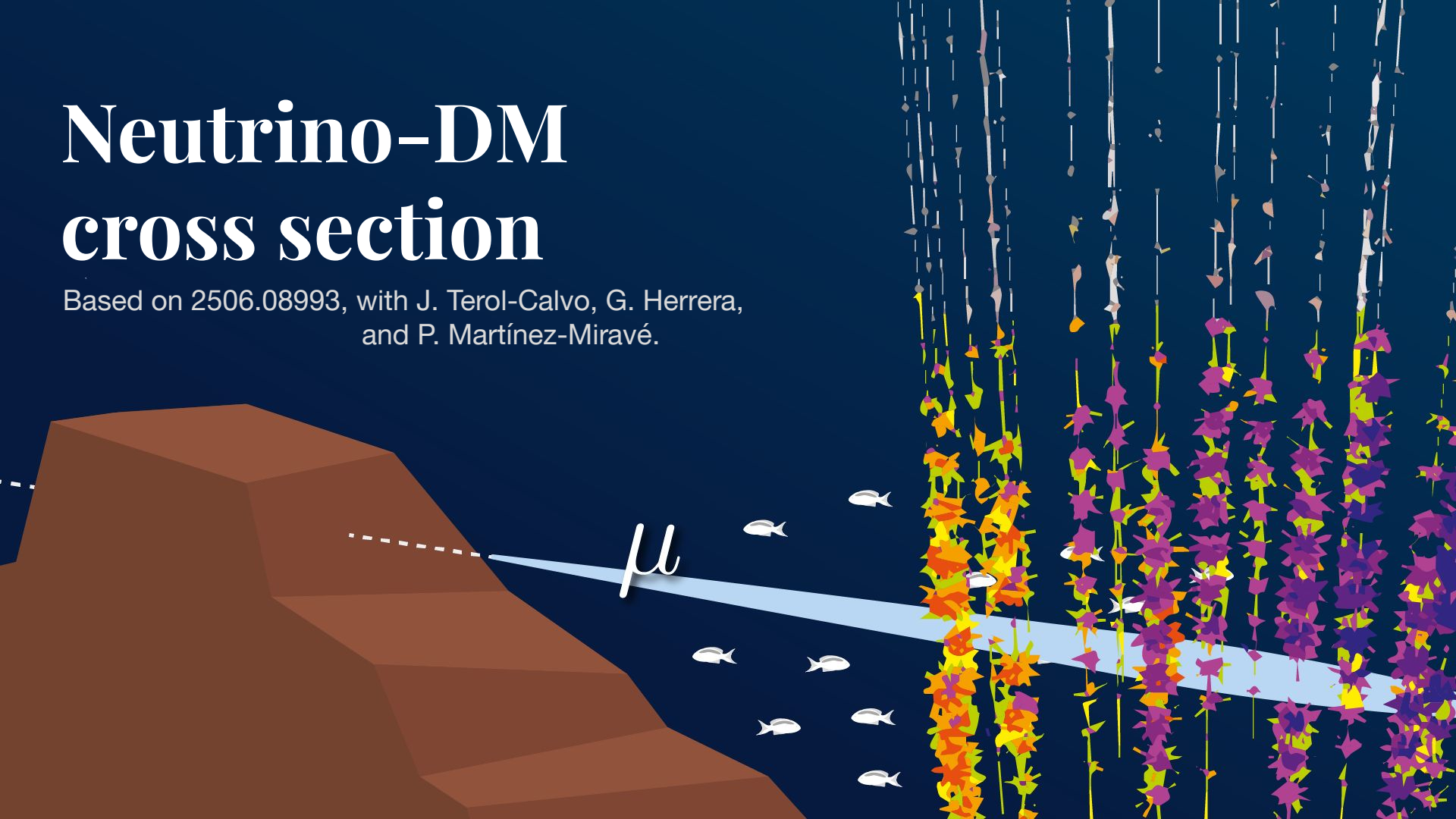
Want to learn more?
Take a look at 2510.21929;
Argüelles, **TBM**, Burgos,
Burns, López-Pavón, Salvadó.



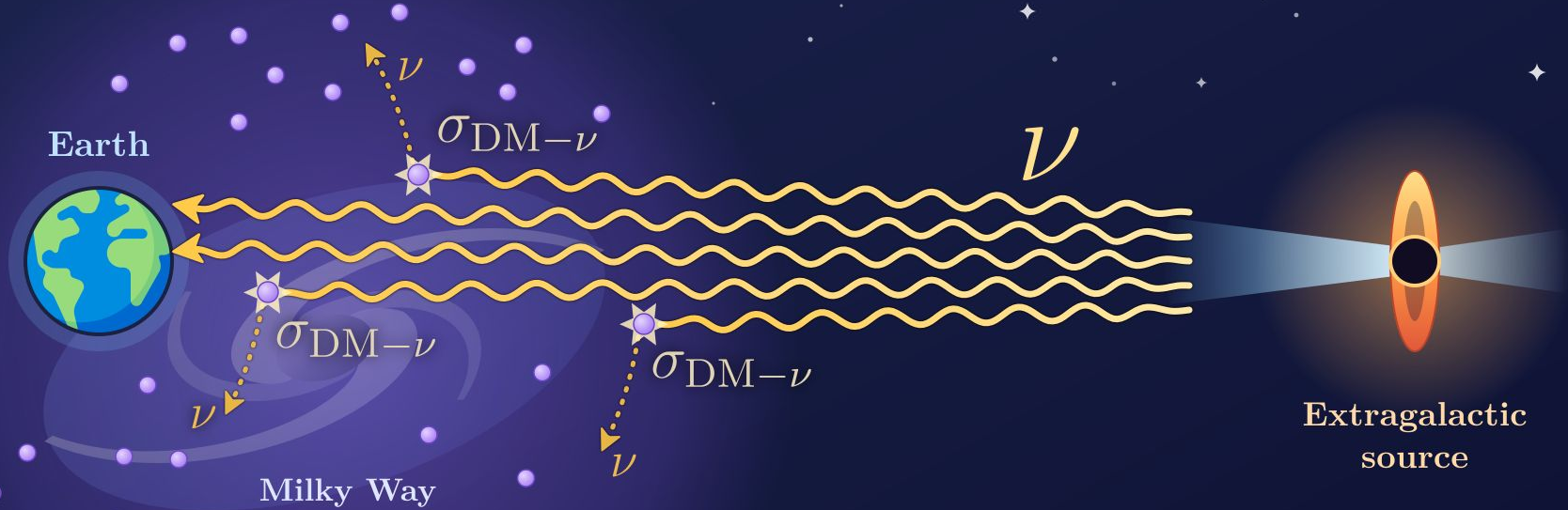
But it is in
BSM scenarios.

Neutrino-DM cross section

Based on 2506.08993, with J. Terol-Calvo, G. Herrera,
and P. Martínez-Miravé.



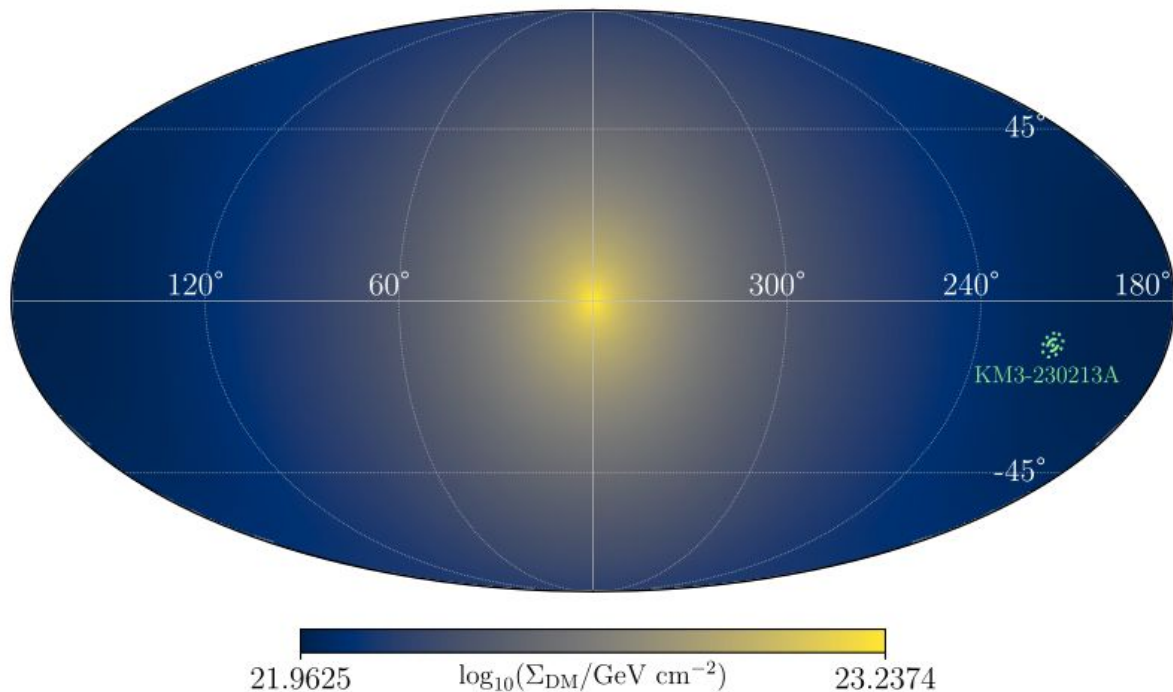
Dark Matter halo



If neutrinos scatter-off DM, they will get **exponentially attenuated**. However, at least **one neutrino** has reached KM3NeT.

Known direction, known DM column density

The neutrino has crossed the MW halo, of which we know its column density.



The flux is exponentially attenuated

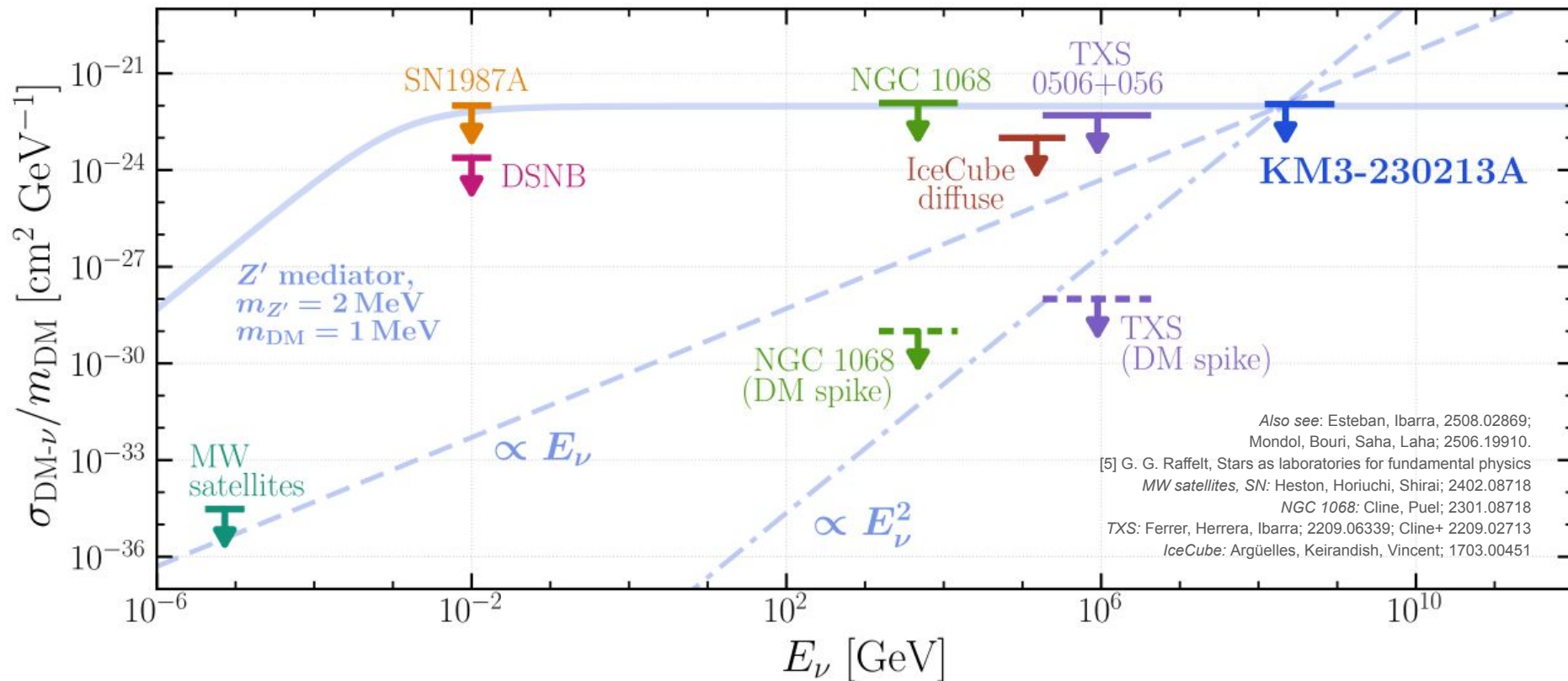
$$\frac{\Phi_{\nu}^{\text{obs}}}{\Phi_{\nu}^{\text{em}}} = e^{-\sigma \cdot \frac{\Sigma_{\text{DM}}}{m_{\text{DM}}}}$$

Asking for less than 90% of attenuation,

$$\sigma_{\text{DM}-\nu} \lesssim \frac{2.3 m_{\text{DM}}}{\Sigma_{\text{DM}}}$$

KM₃NeT measurement

It is the measurement of the cross section at the highest energy.
Whether it is the most competitive is a model-dependent question.



- Cosmogenic neutrinos are a guaranteed source of UHE collisions.
- Bounds *mostly* independent of the flux normalization are possible.
- 1 event gives a constraint on the neutrino-nucleus cross section, you need $O(100)$ to get a competitive measurement.
- 1 event already constrains neutrino portals to the dark sector, at energies otherwise unreachable.

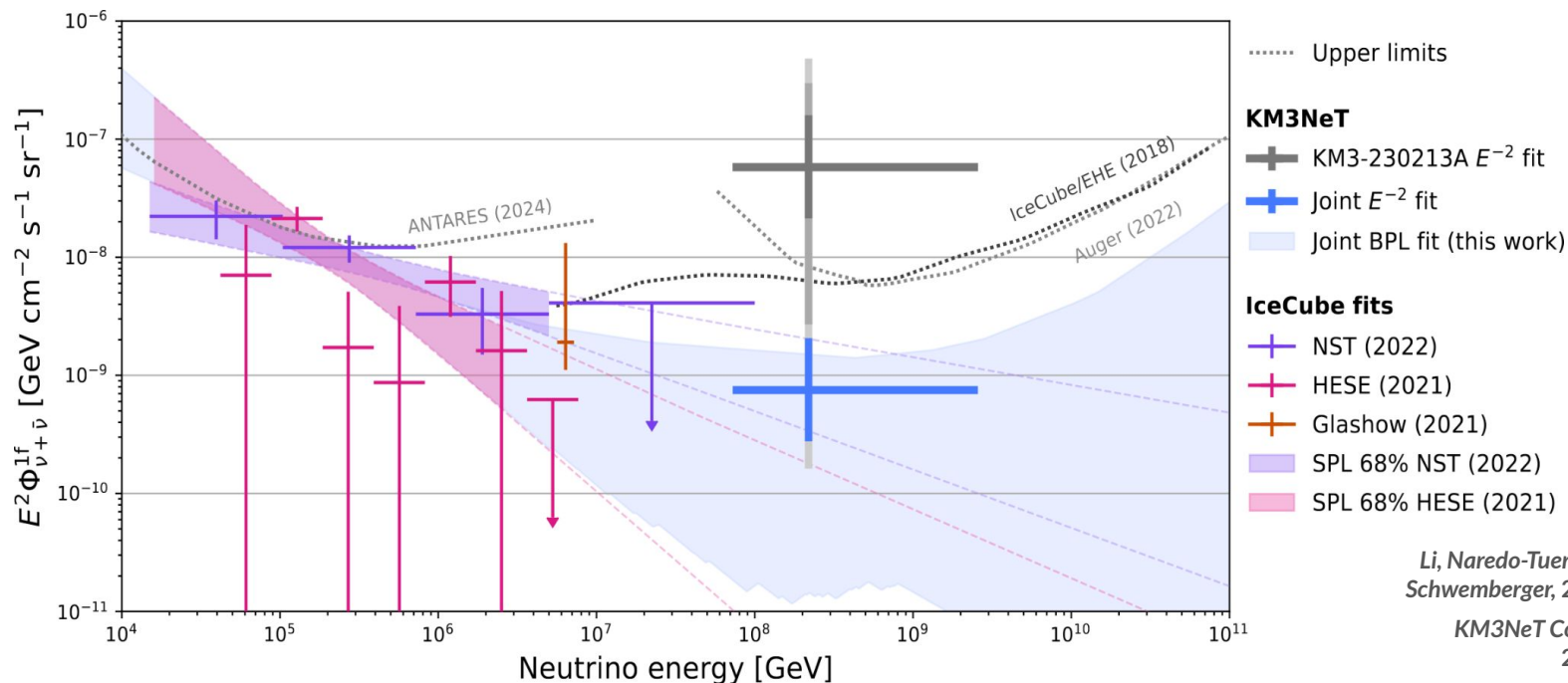
Thanks!



Backup slides



KM3NeT is in tension with IceCube

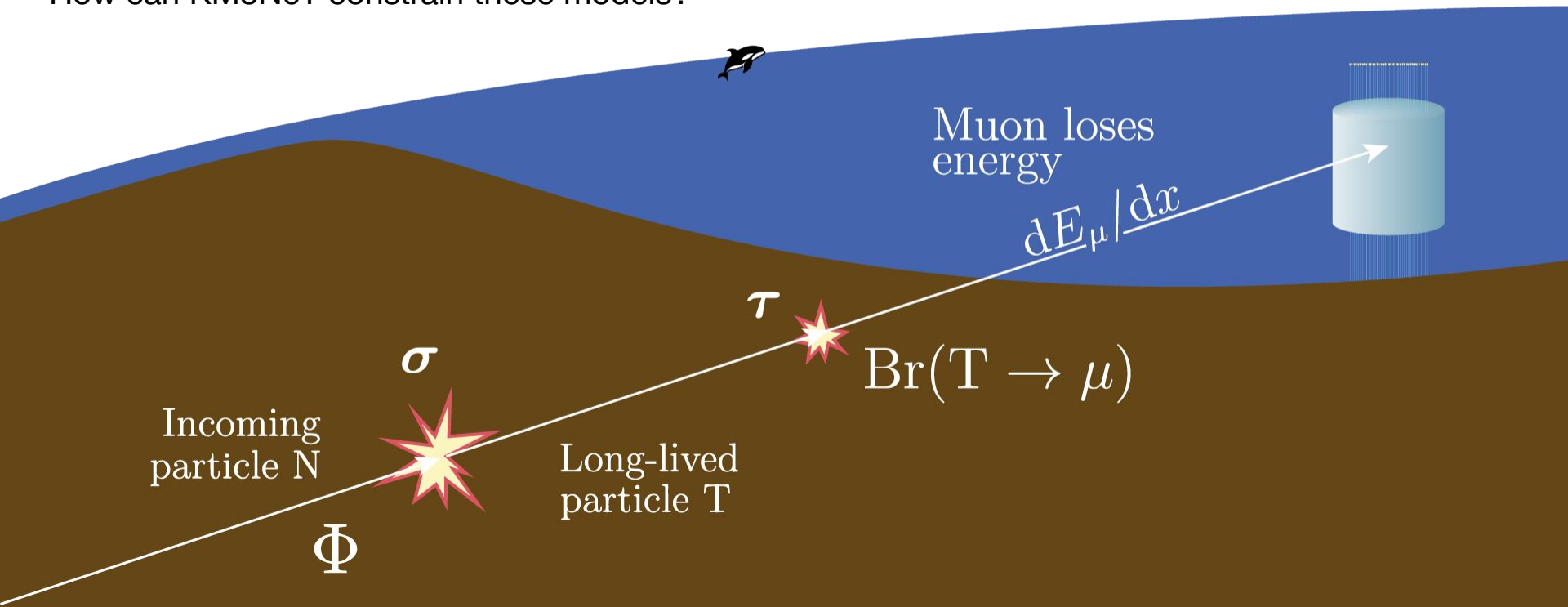


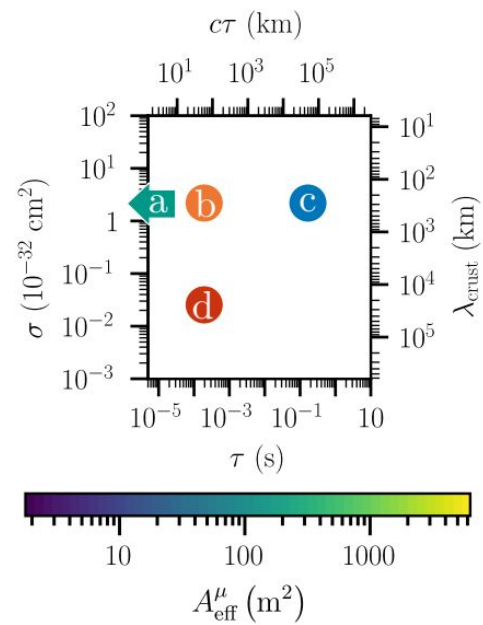
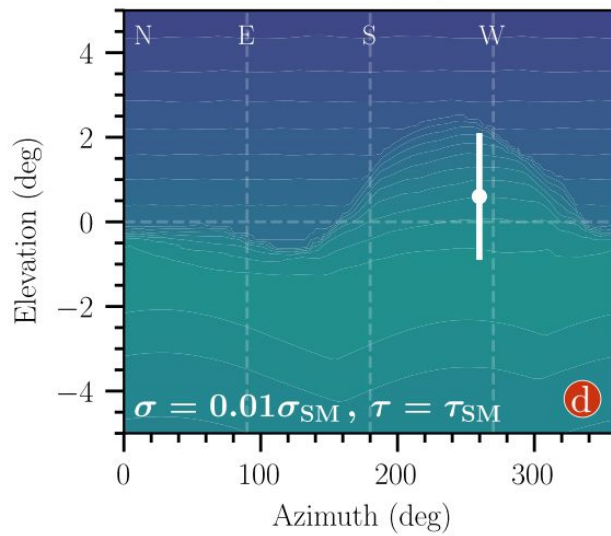
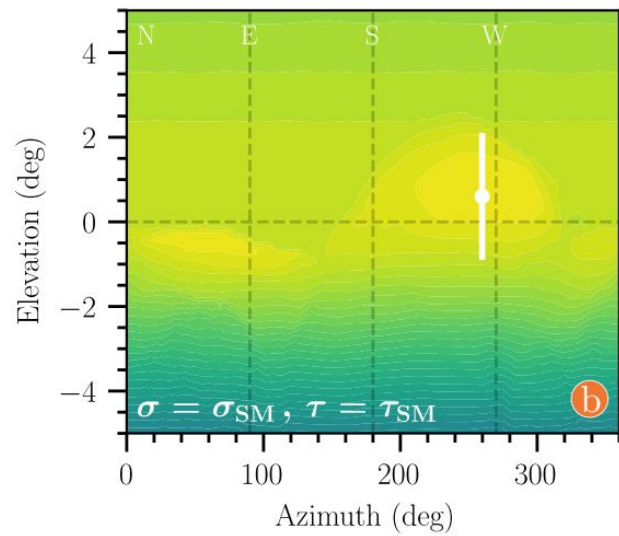
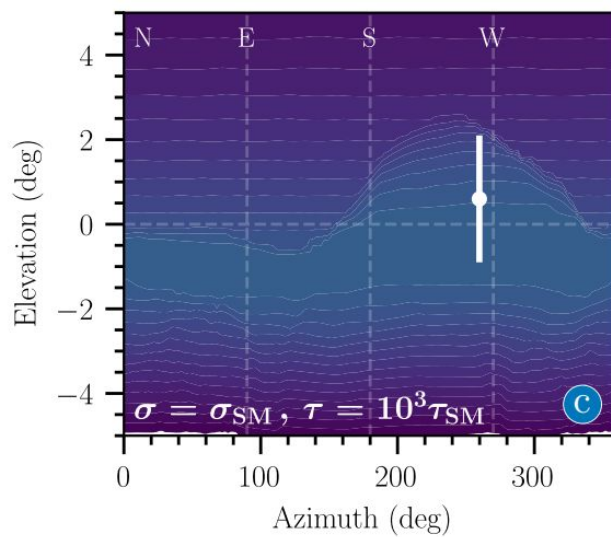
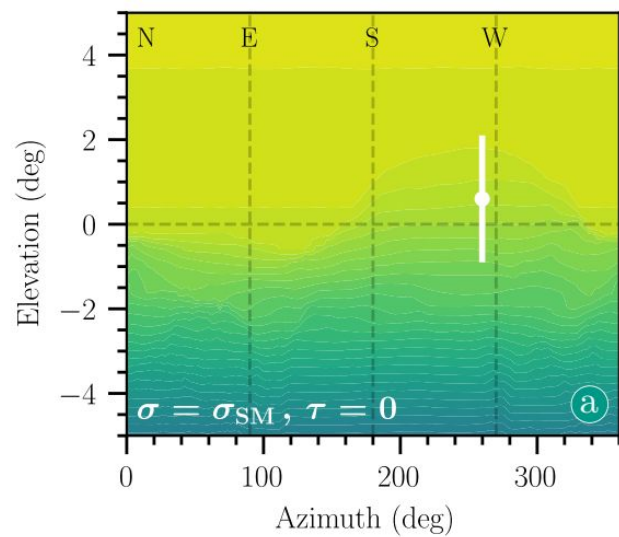
The necessary (constant and isotropic) flux to explain the KM3NeT event is in a 2.5σ to 3.8σ tension with the non-observation of IceCube.

Constraining BSM particles at KM3NeT

Adding a branching ratio to the decay of the secondary particle is a natural extension of our model-independent BSM.

How can KM3NeT constrain these models?

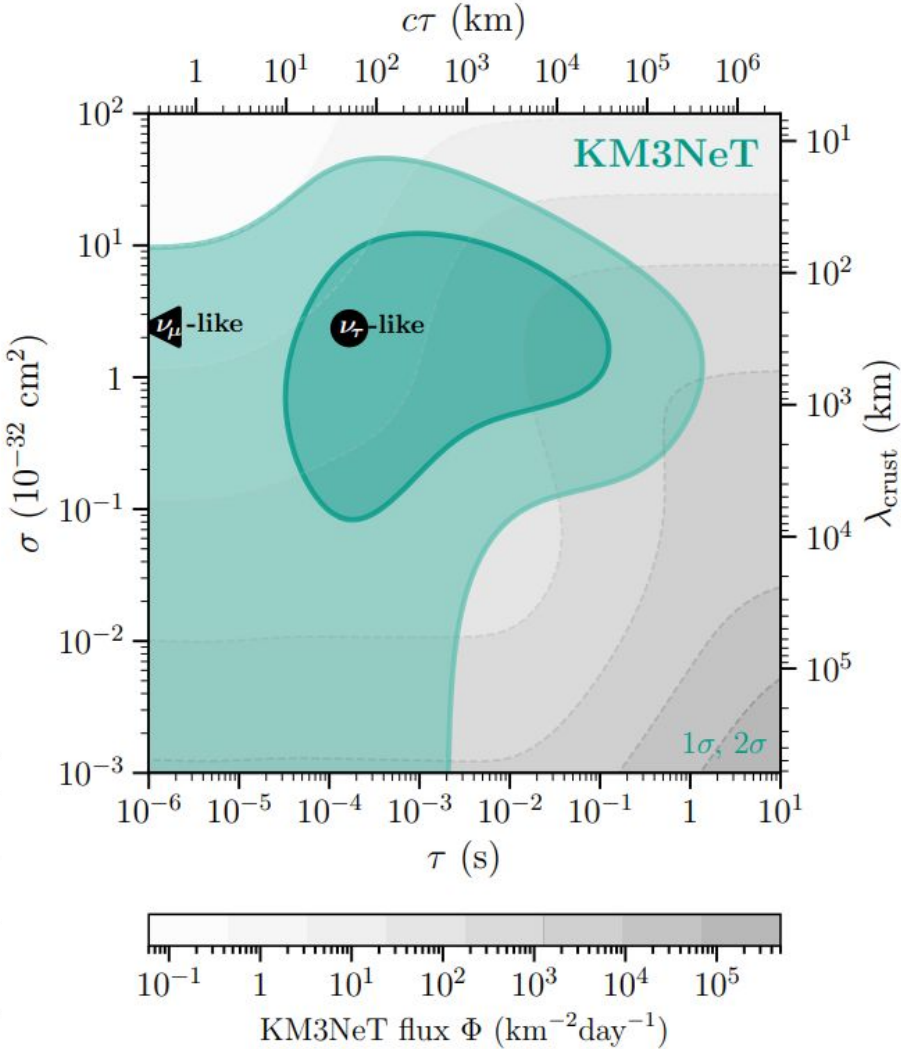




Preferred region in a BSM scenario for the KM3NeT event

Tension still remains

Joint fit	Framework	Tension
ANITA-IV + IceCube	SM, diffuse flux [42]	$\gg 3\sigma$
	BSM, diffuse flux [26]	$\sim 0.1\sigma$
KM3NeT + IceCube	SM, diffuse flux [1, 9–11]	$2.5\text{--}3.5\sigma$
	BSM, this work	2.2σ
ANITA-IV + KM3NeT + IceCube	SM, diffuse flux	$\gg 3\sigma$
	BSM, this work	2.7σ
	BSM, this work, relaxed assumptions (App. B)	$2.3\text{--}3.3\sigma$



The ingredients

$$\phi$$

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

Extremely massive
Dark Matter

$$\chi_1$$

$$\chi_2$$

$$m_1 < m_2$$

Two heavy
neutral fermions

$$X_\mu$$

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

Mongillo *et al.* - 2302.05414

Abdullahi *et al.* - 2302.05410

Kolb, Long - 1708.04293

... and many more!

