Reaching the EeV frontier of neutrino-nucleon cross section

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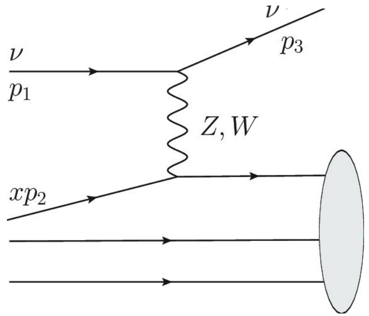
MAIN OBJECTIVES

- **Our main goal** is to prepare the most **detailed prediction** of the measurement capabilities of the **neutrino-nucleon cross section at the ~EeV** scale with the next generation of neutrino telescopes.

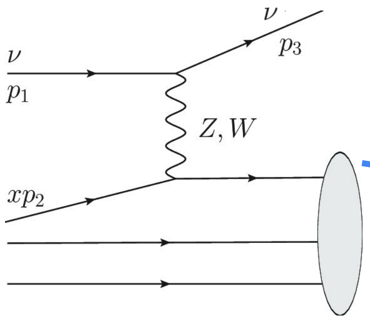
- We assume the flux is known and present our results for 3 benchmark scenarios: cosmogenic, astrophysical source, extrapolation of IceCube flux.



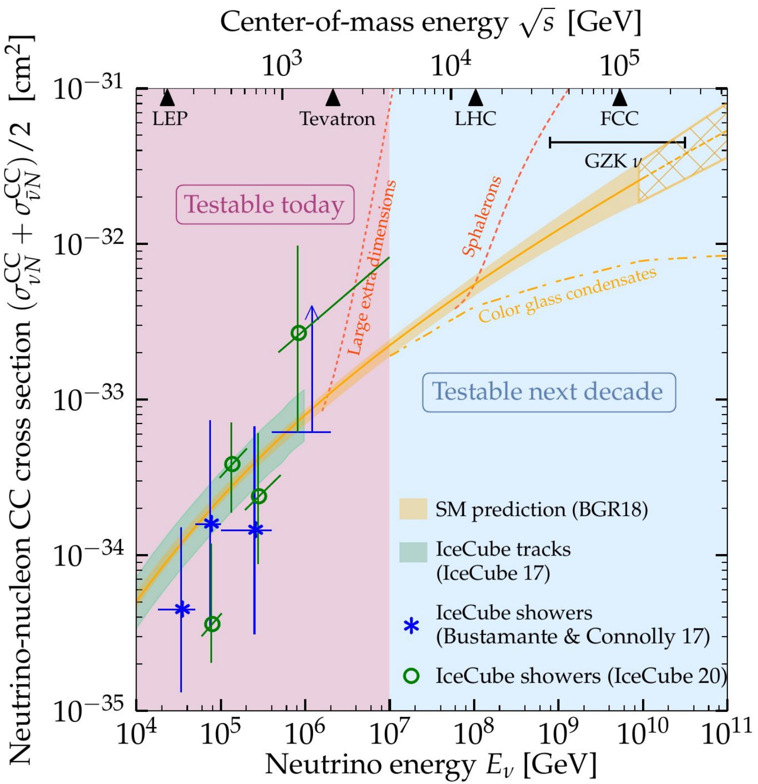
Why should we measure νN cross sections?

- Importance particle/astroparticle physics.
- Precision tests of the SM
- Probes of BSM physics

- $\sigma_{\nu N}$ has been measured up to the PeV scale.
- The next-gen of ν telescopes could go further
- **In preparation for we perform a detailed study of the measurement capabilities in the next decades.**



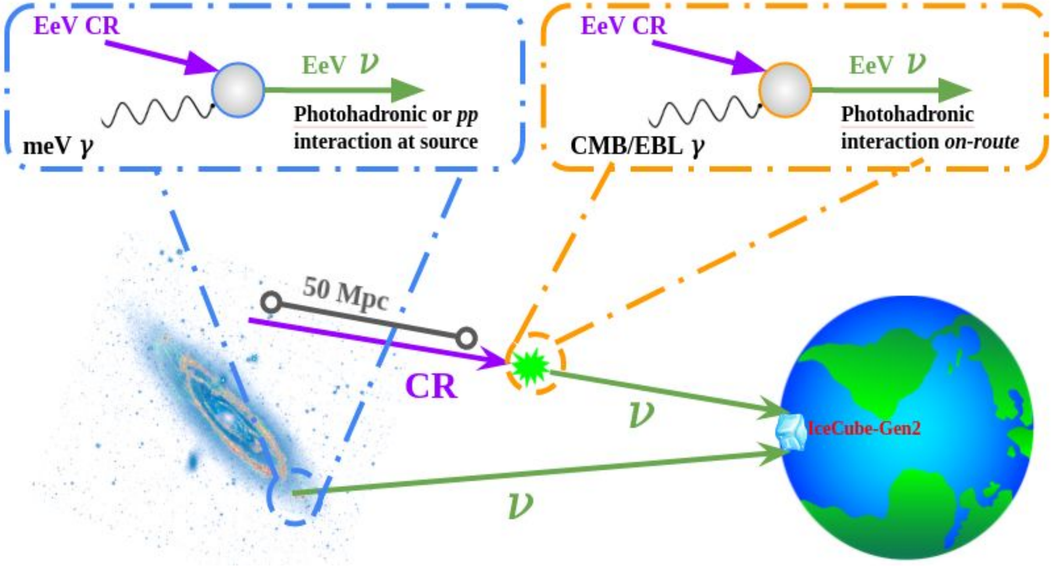
DIS: Deep Inelastic Scattering

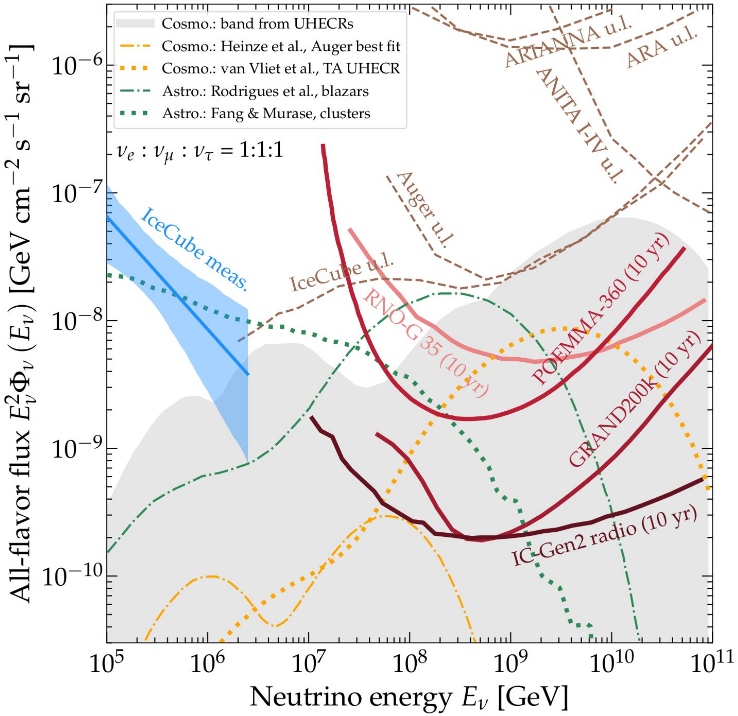


Where do these neutrinos come from?

Astrophysical source flux

Cosmogenic flux

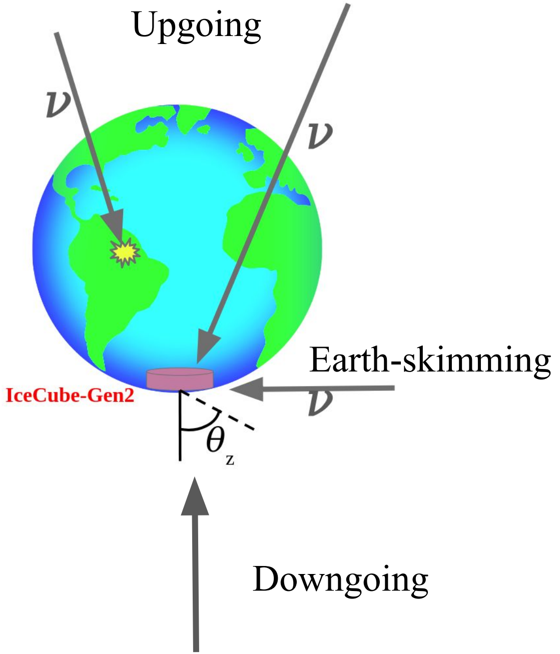


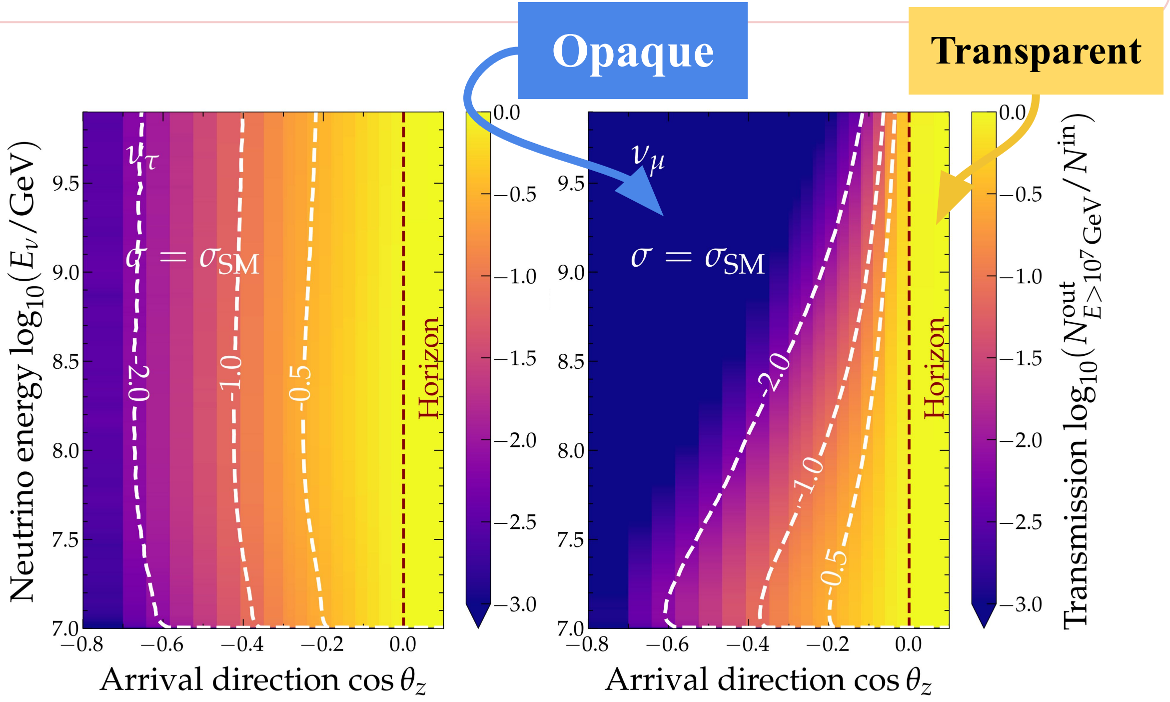


Rodrigues, Heinze, Palladino, van Vliet, Winter, 2003.08392
Heinze, Fedynitch, Boncioli, Winter, *Apj 2019*
Fang & Murase, *Nature Phys. 2018*
POEMMA, 2012.07945
RNO-G, *JINST 2021*
IceCube-Gen2, *J. Phys. G 2021*
GRAND, *Sci. China Phys. Mech. Astron. 2020*

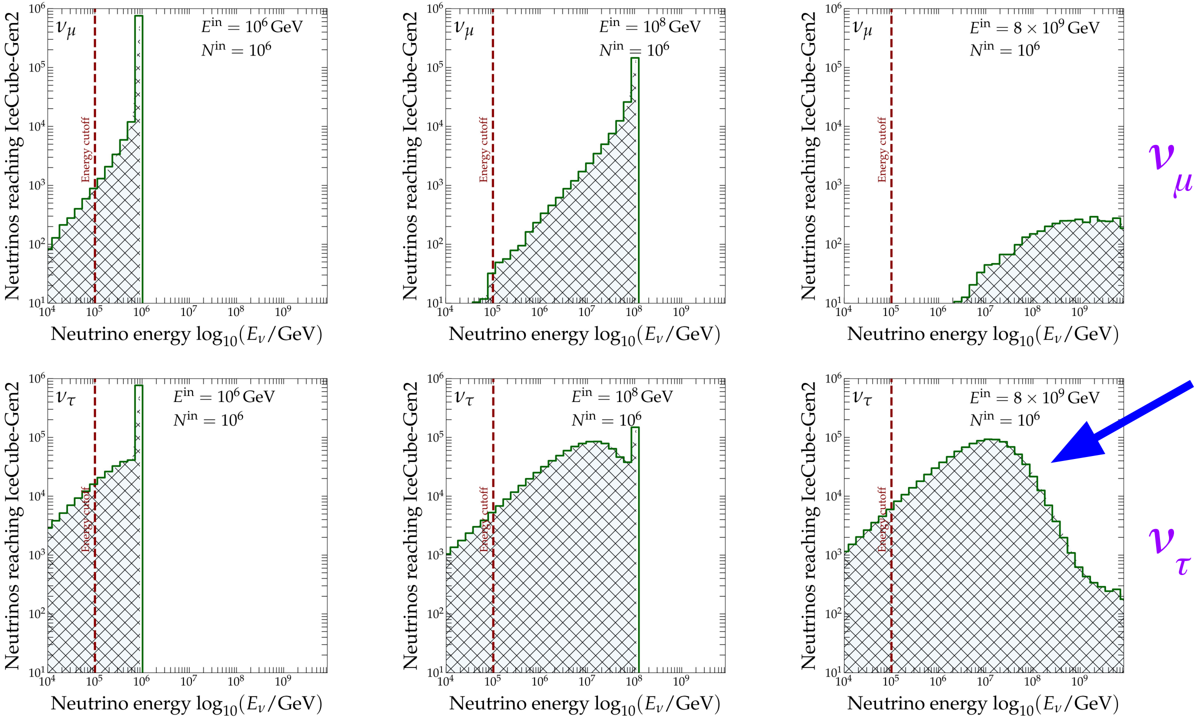
How to extract $\sigma_{\nu N}$ from UHE neutrinos?

At high energies the **Earth is opaque**.
Attenuation factor: $e^{-\tau(E, \theta)} \rightarrow \tau(E, \theta)$ = [Distance traveled in the Earth](θ)/[Interaction length](θ,$\sigma_{\nu N}$)
Event rate: $N \sim \Phi_\nu \sigma_{\nu N} e^{-\tau(E, \theta)}$





- Monte Carlo in-Earth neutrino propagation tool.
- Leading interaction DIS + subleading contributions.
- Most updated $\sigma_{\nu N}$ theoretical predictions.
- Earth density: PREM model.
- Tau neutrino regeneration.

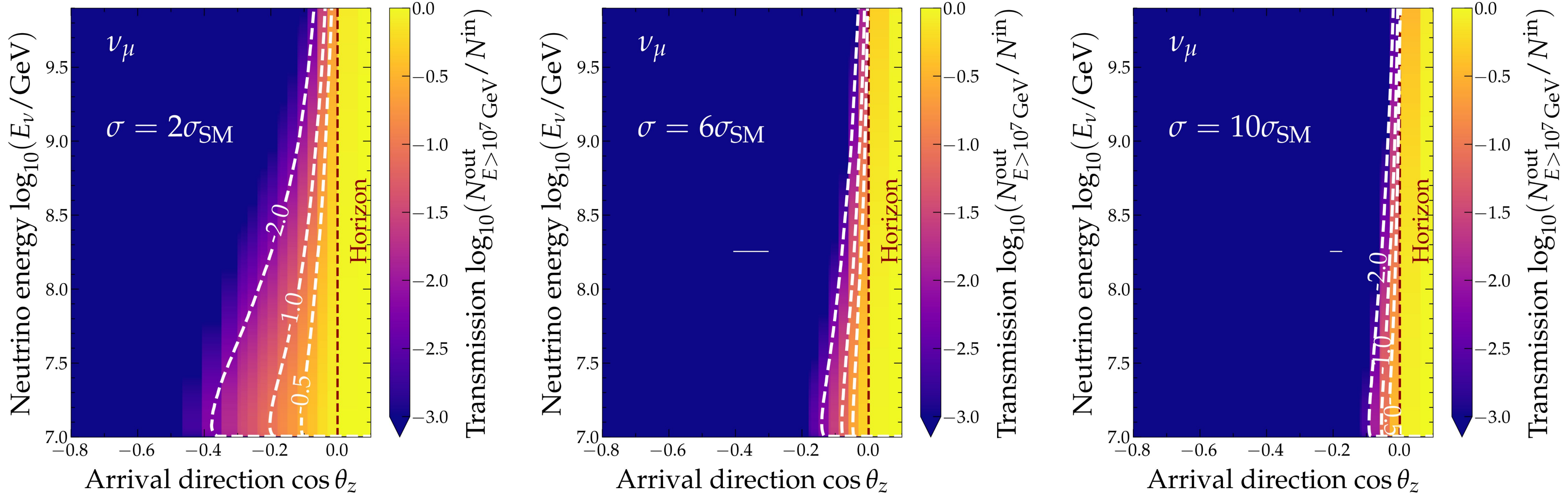


Higher Energy

Garcia et. al., 2020, arXiv: 2004.04756

But, what if $\sigma \neq \sigma^{SM}$?

- BSM physics might manifest as a deviation of the predicted value of the σ^{SM} (*e.g.*, νNSI).
- In that case the attenuation profiles might be modified →signature of BSM physics.



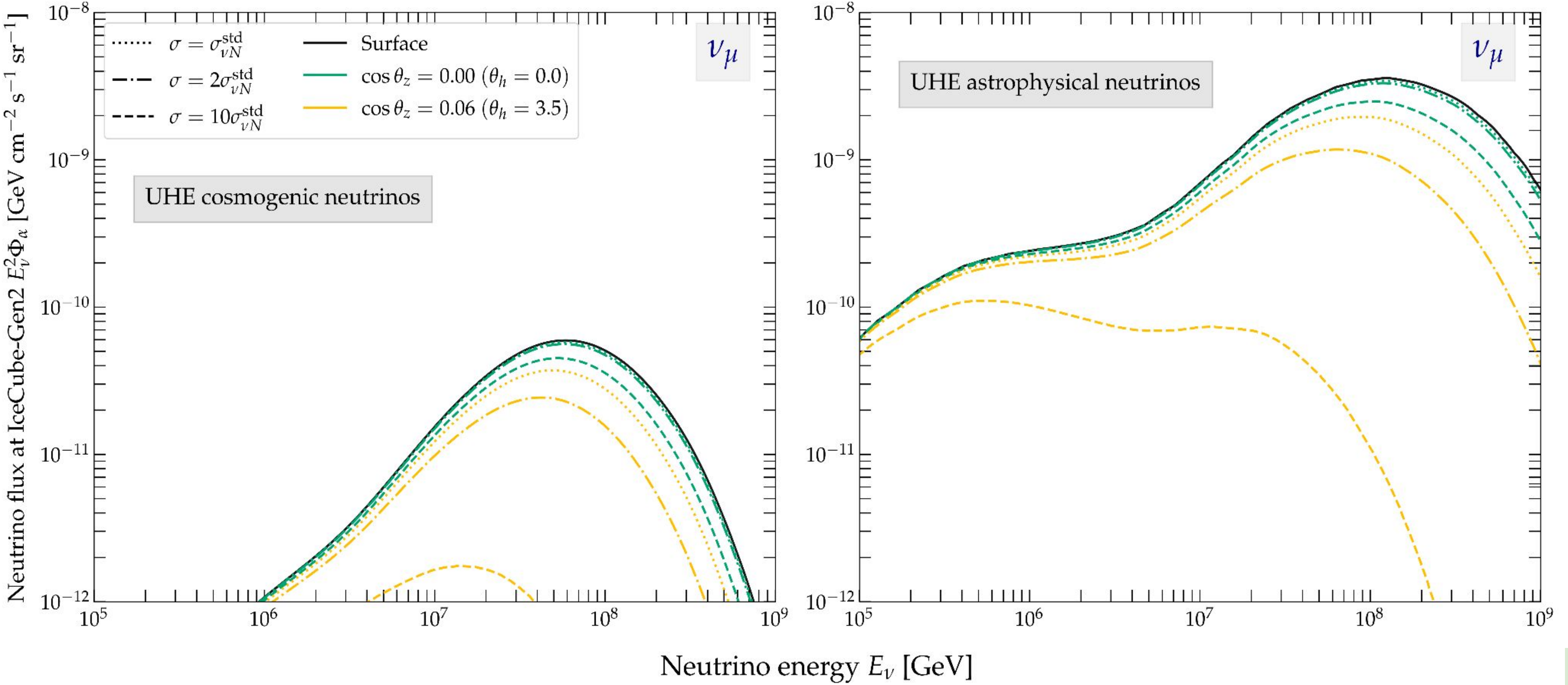
Flux propagation from precomputed tables

The next step:

We sum the transmission histograms for every energy weighted by the

The result:

Propagated neutrino flux for each flavor at different directions.



Predicted event rate at IceCube-Gen2 radio

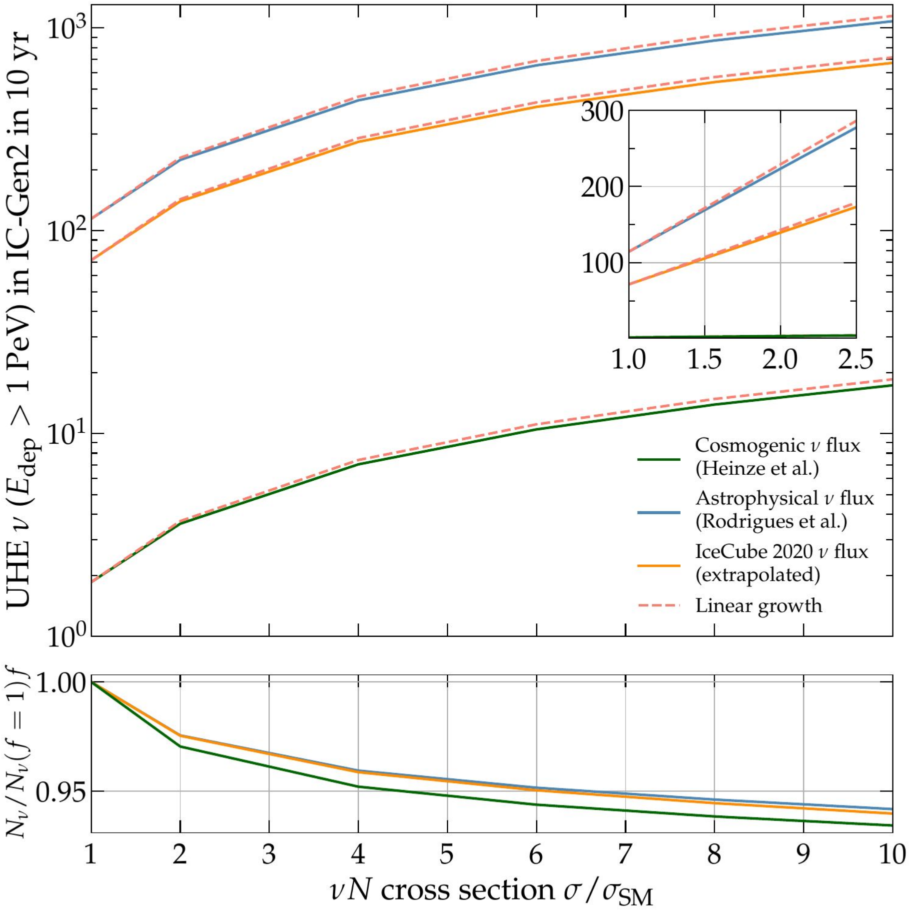
Larger cross section implies a stronger absorption, but increases the probability of detection

$$N \sim \Phi_\nu \sigma_{\nu N} e^{-\tau(E,\theta)}.$$

Increases the probability of a neutrino detection.

Decreases probability of a neutrino transmission

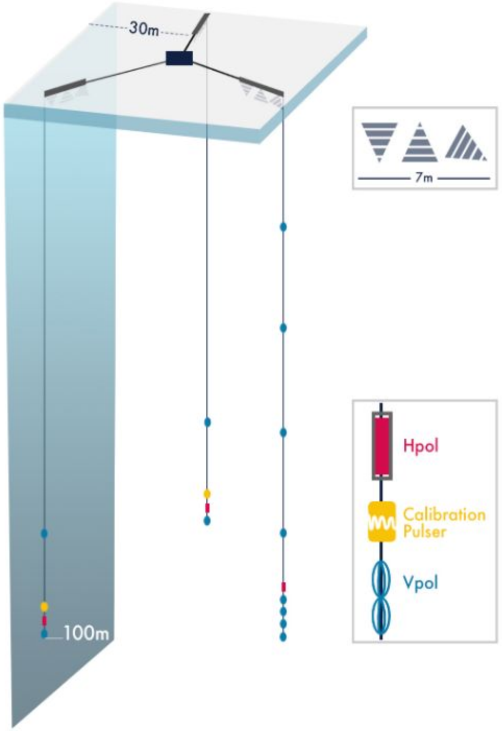
Note: For the actual event rate we account for energy and direction smearing through the resolution functions

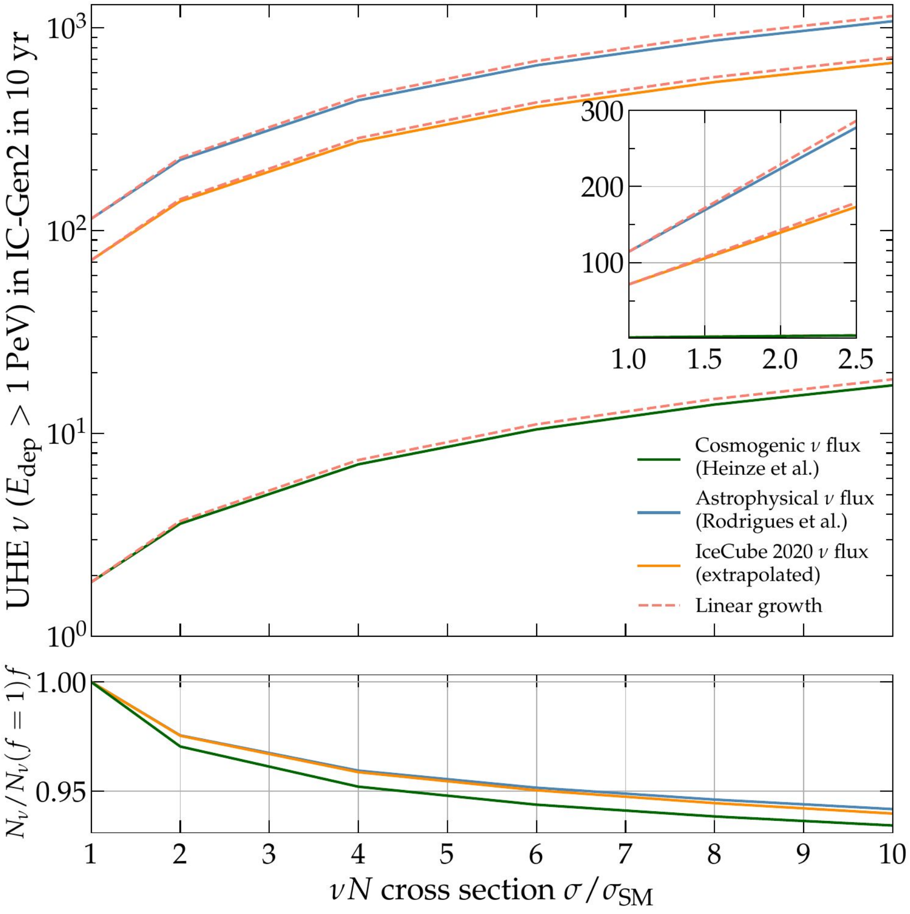


Predicted event rate at IceCube-Gen2 radio

IceCube-Gen2 Radio

M.G. Aartsen et. al. [2008.04323]





How well can we measure $\sigma_{\nu N}$ in the next decade?

- We perform a Bayesian analysis with an unbinned Poissonian likelihood.

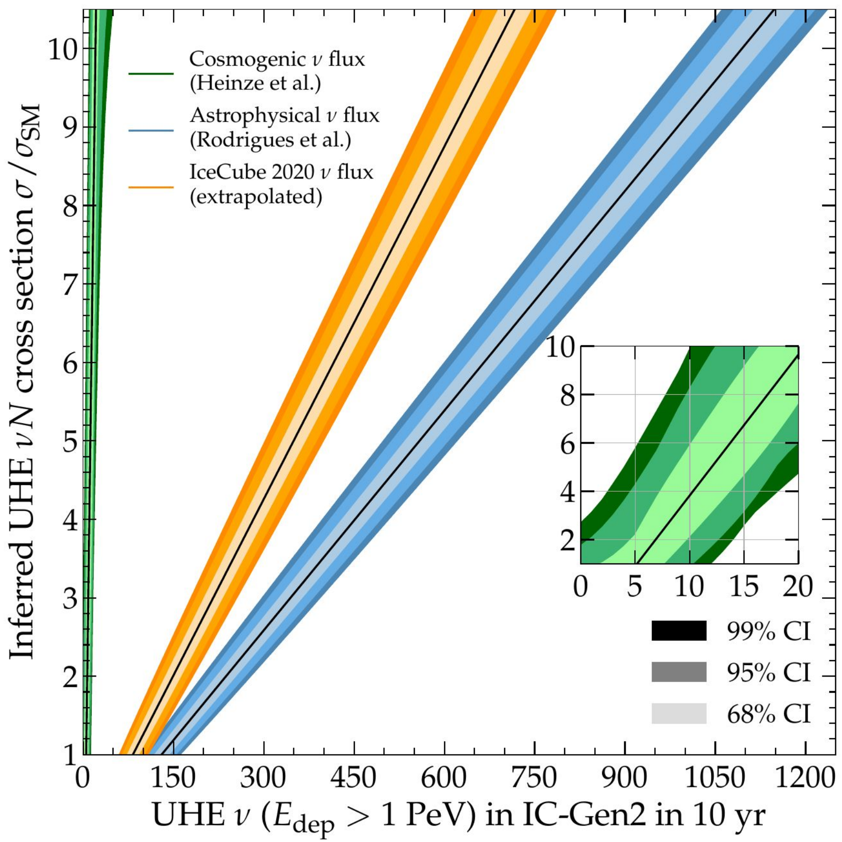
$$\mathcal{L}(f, N_{\rm obs}) = \frac{e^{-[N(f)+N_{\rm bkg}]}[N(f)+N_{\rm bkg}]^{N_{\rm obs}}}{N_{\rm obs}!}$$

- Fix N_{obs} and maximize for $f = \sigma/\sigma_{SM}$
- Credible regions from the posterior assuming flat f prior

N_{obs} = Number of observed events by IC-Gen2

N_{bkg} = Background events **(atm muons)**

$N(f)$ = Predicted number of events



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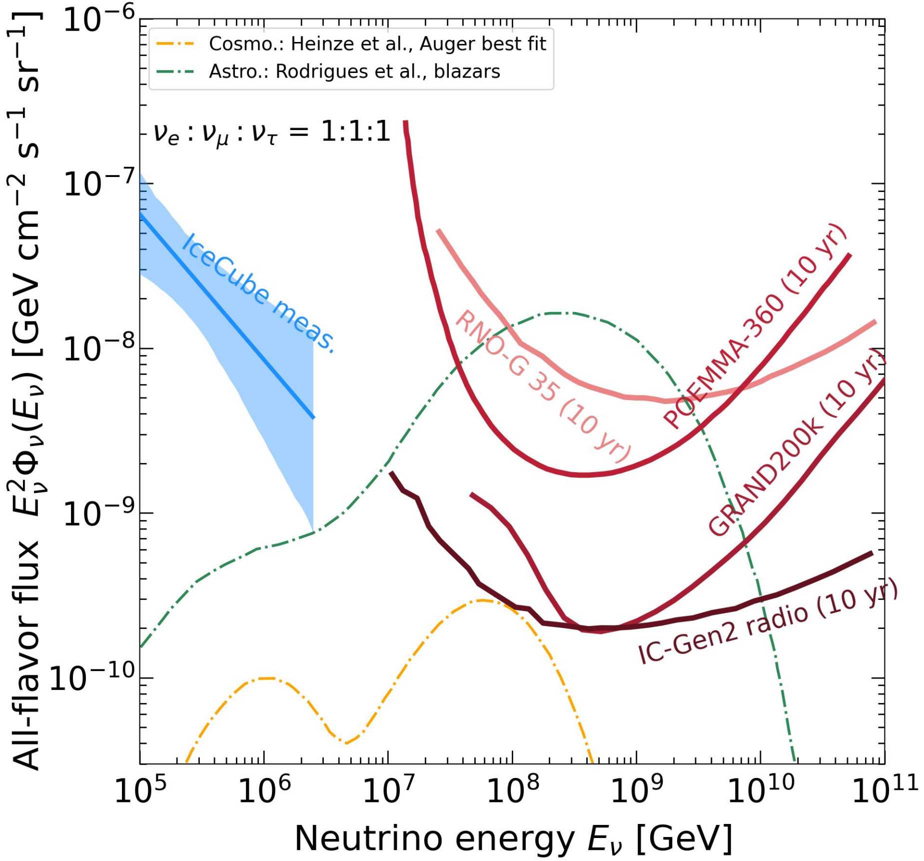

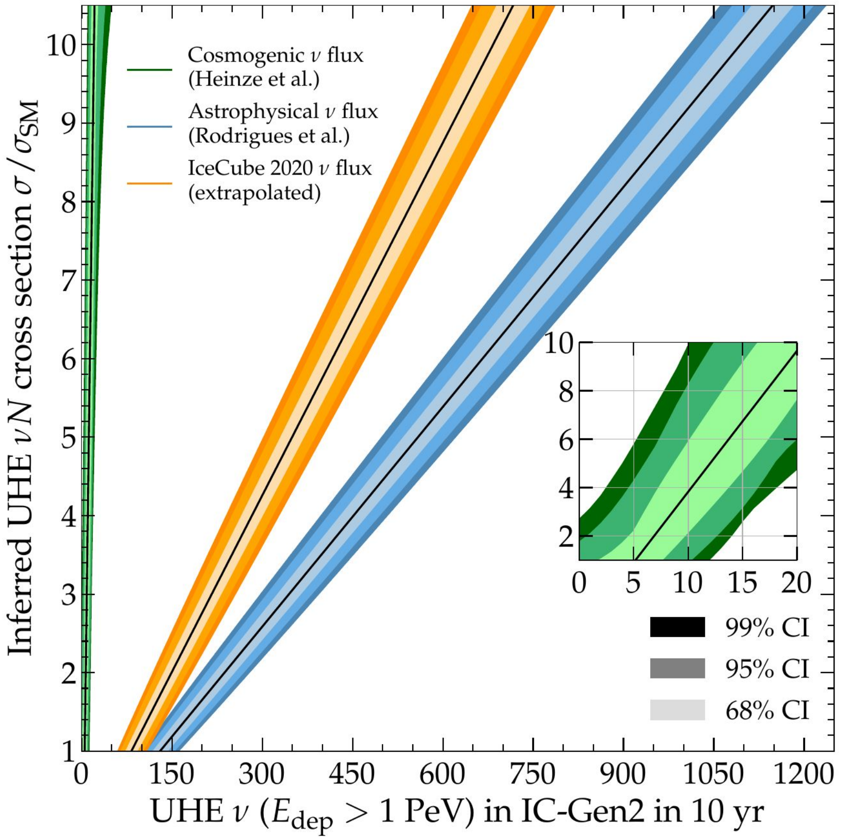

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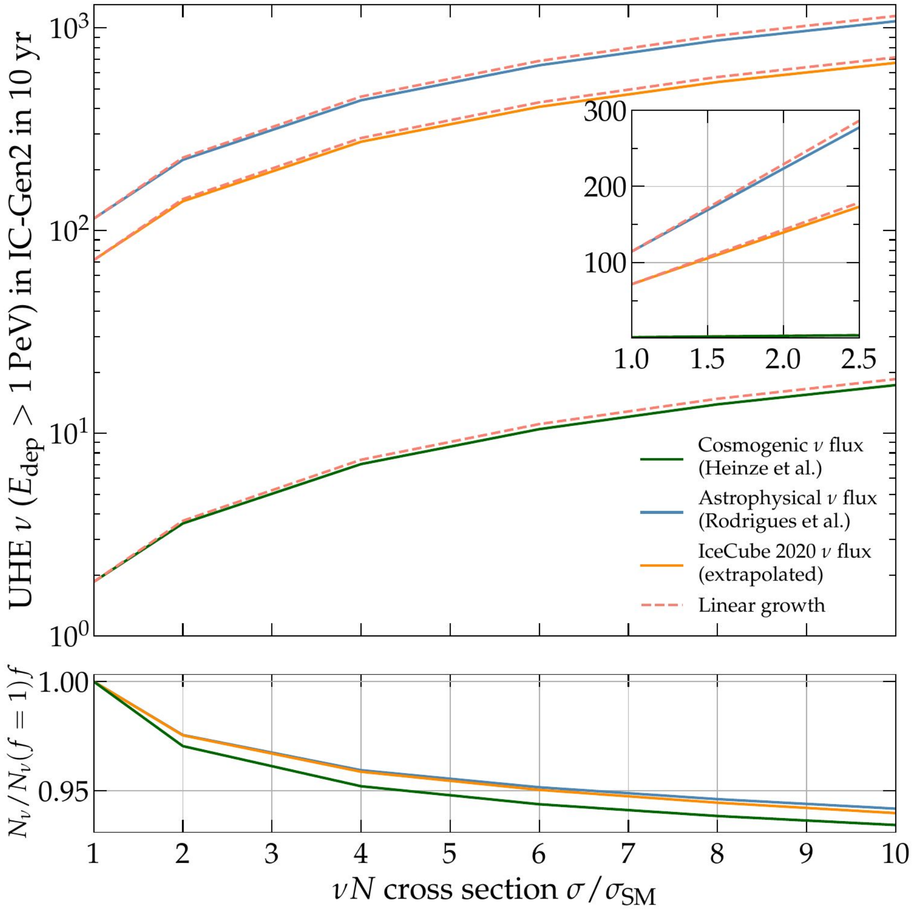

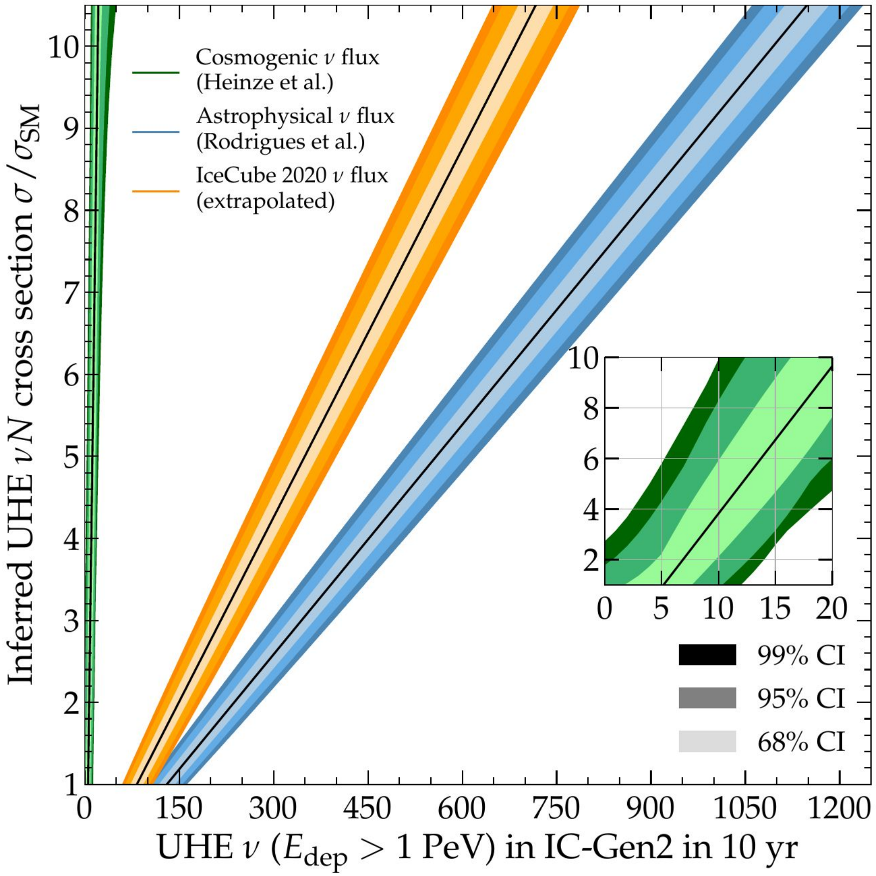

Conclusions & take away message

- The next generation of neutrino telescopes have good chances of finally observing the UHE neutrino flux.
- UHE neutrinos represent an excellent window to explore new physics.
- Measurements of $\sigma_{\nu N}$ are possible at the EeV frontier
- This provides a precise probe of the SM and could unveil new physics.
- The effect of tau regeneration a high energies creates an important lower energy imprint.