Observing EeV neutrinos at PeV energies

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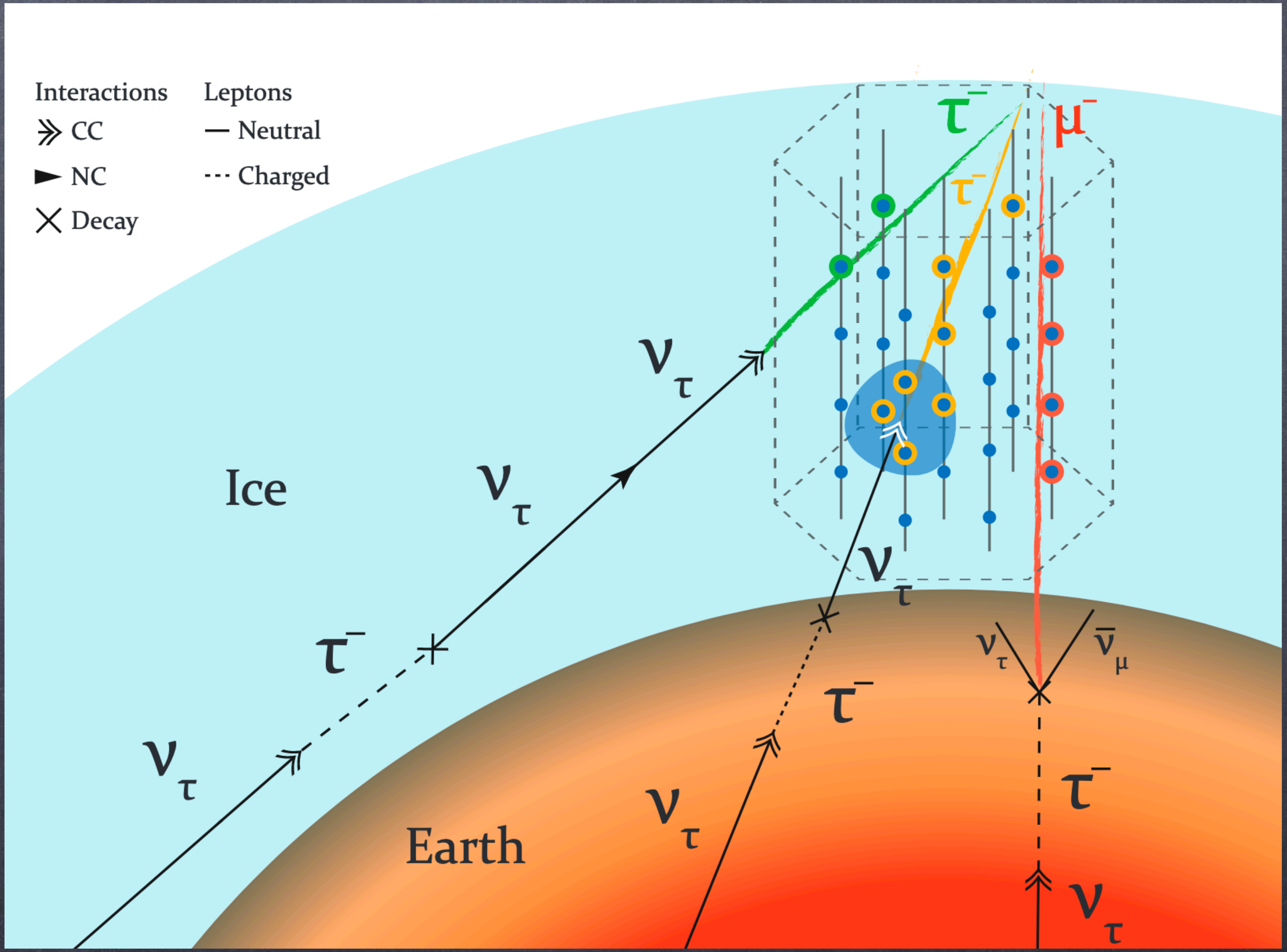
Based on JCAP01(2020)012
Safa, Pizzuto, Argüelles, Halzen, Kheirandish, Vandenbroucke



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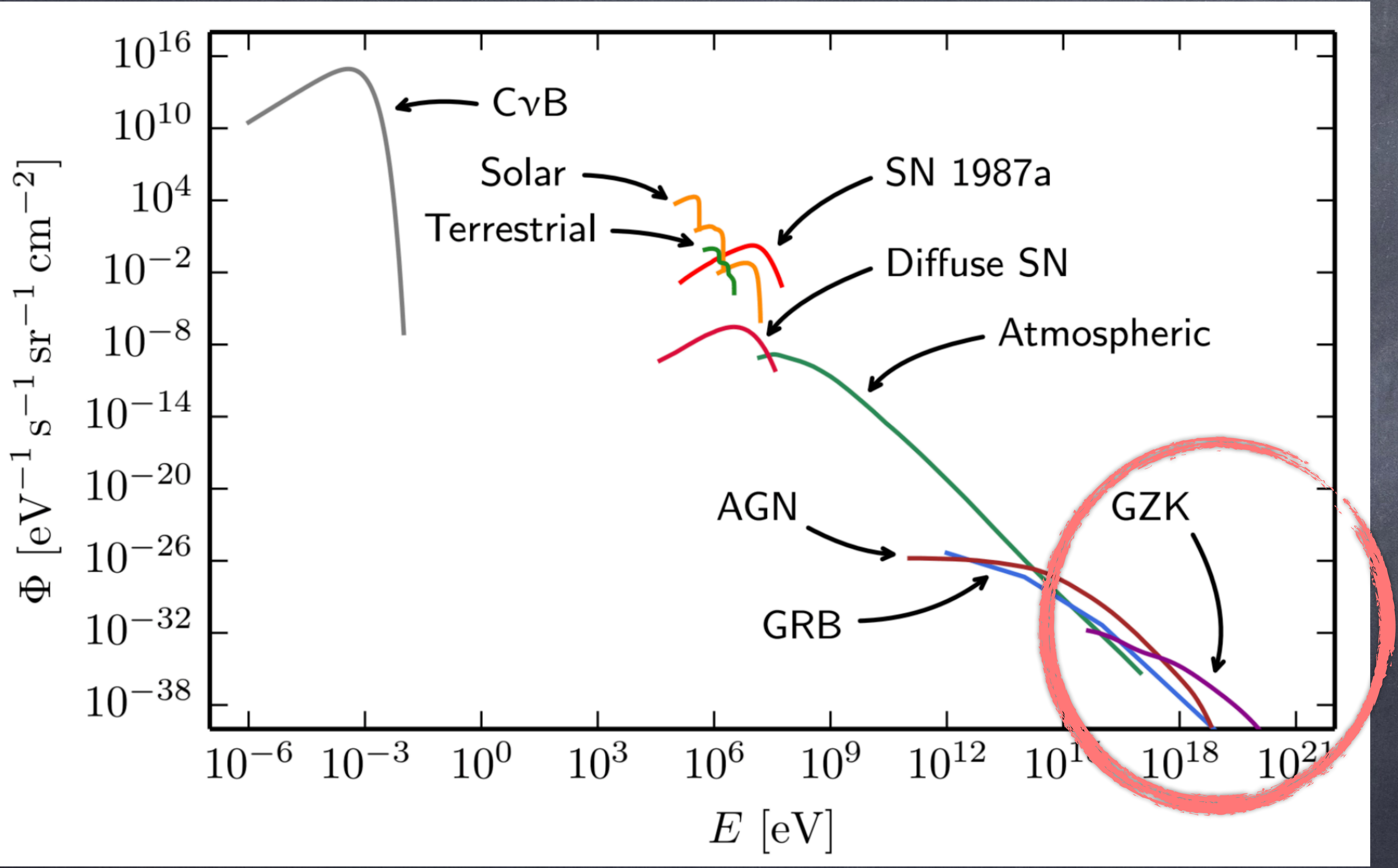
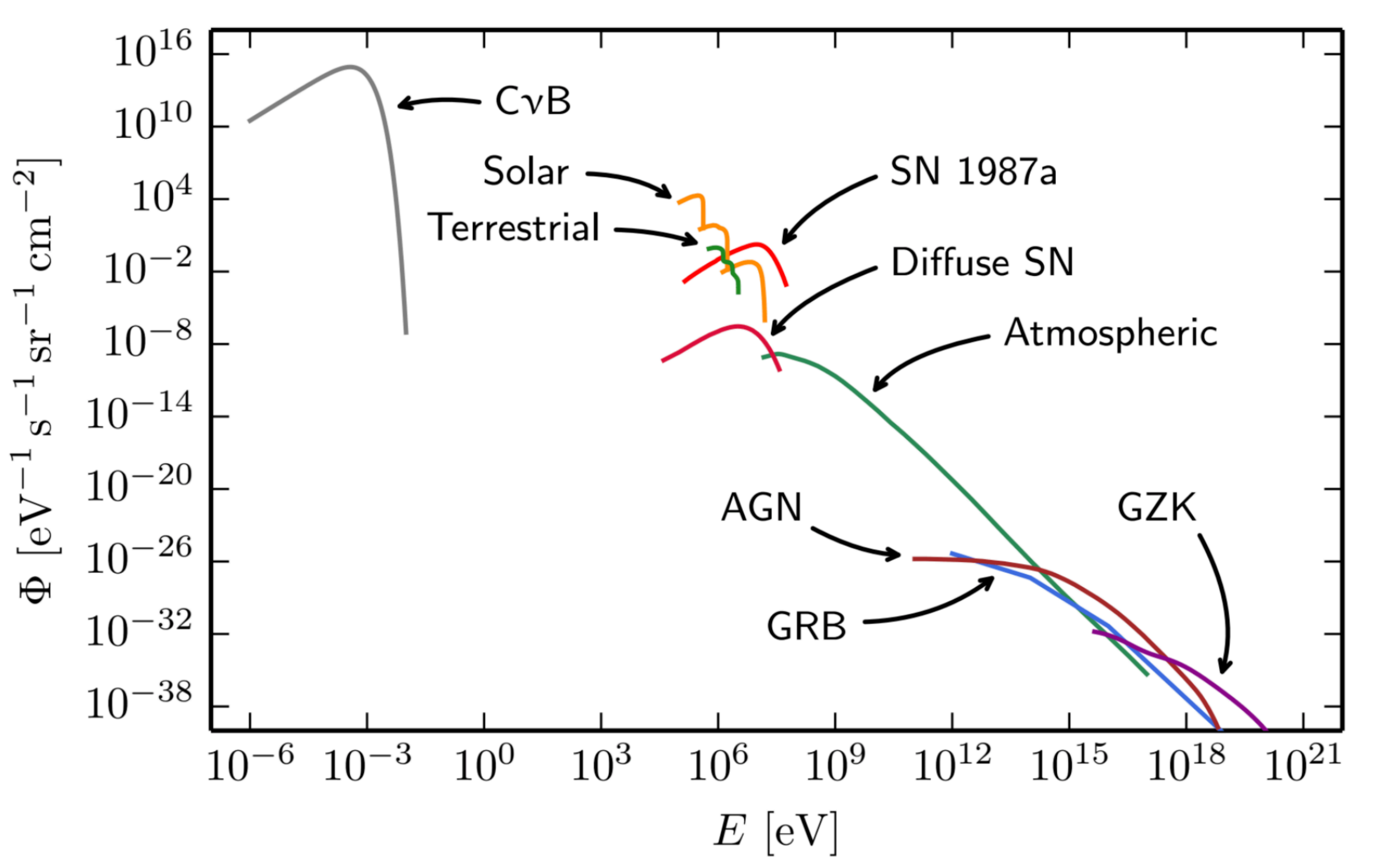
Cosmic rays with energies >10^{19} eV interact with CMB photons to produce a neutrino flux





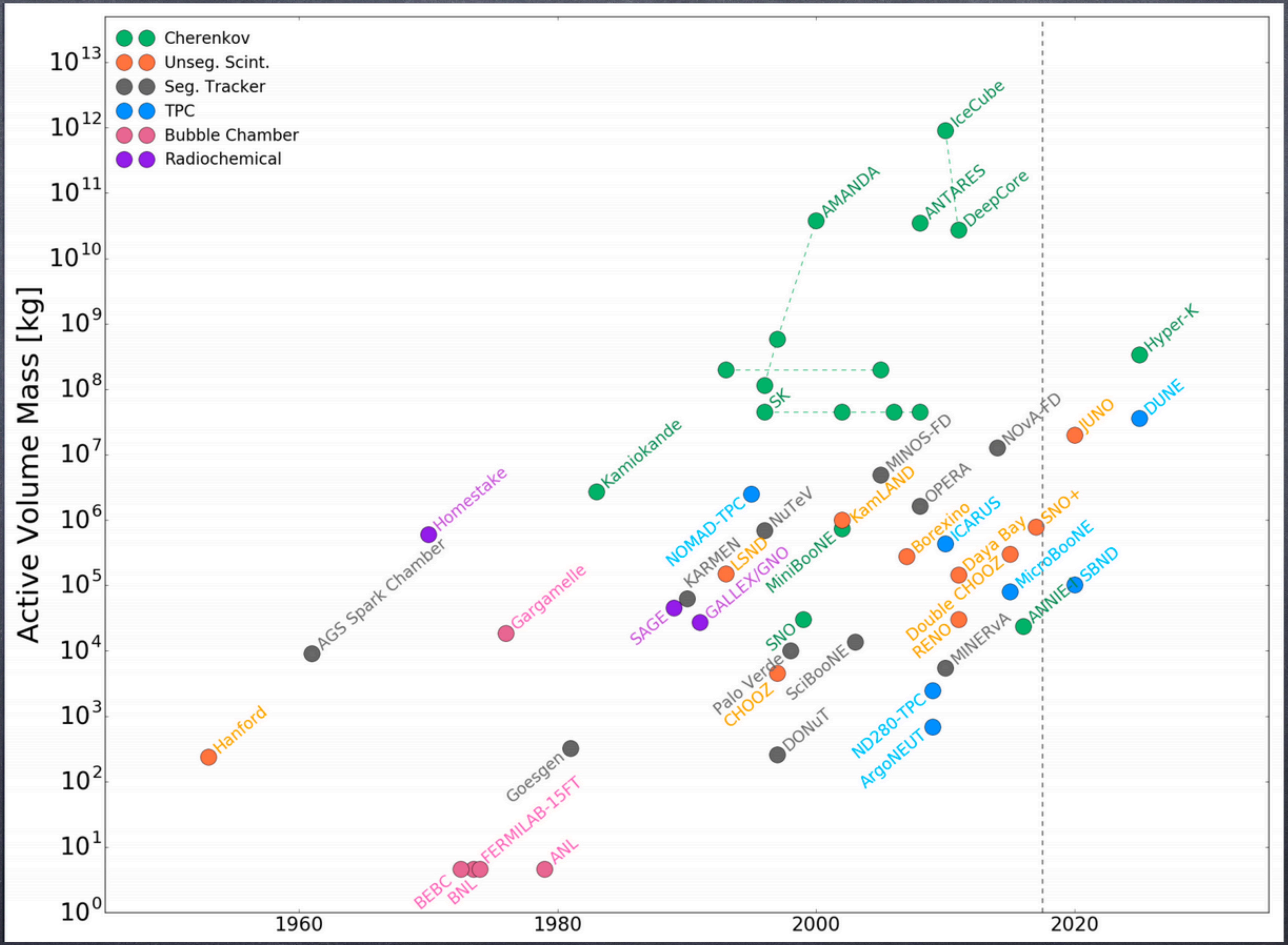
We're gonna need a bigger detector.

Major advances in neutrino detection over the last two decades:

Cherenkov detection technology enabled the utilization of natural bodies of water/ice to build Mton - Gton detectors

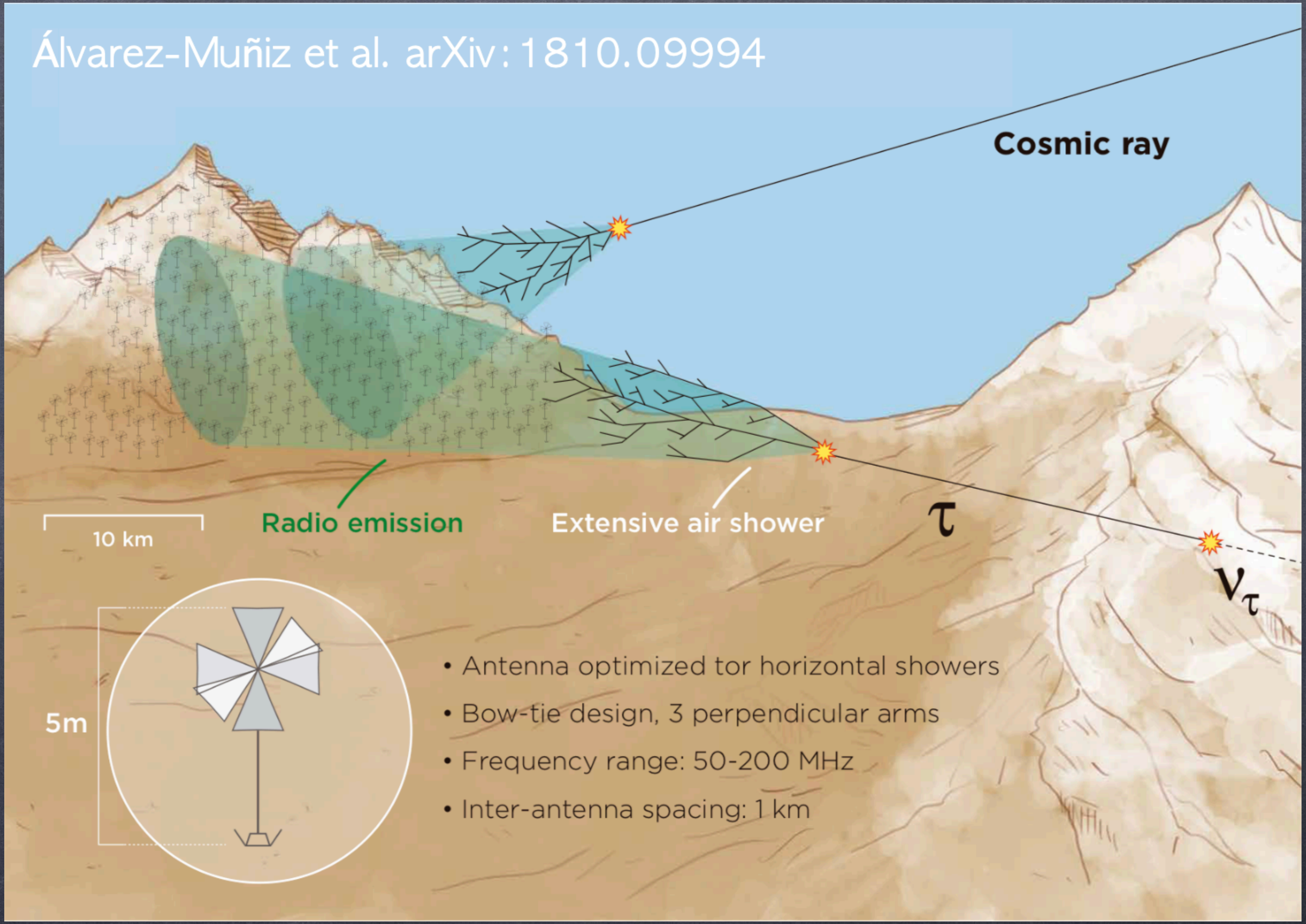
Naive scaling suggests active mass needs to increase by another factor of 10-100 to detect GZK neutrinos.

New detection technologies/ techniques are needed

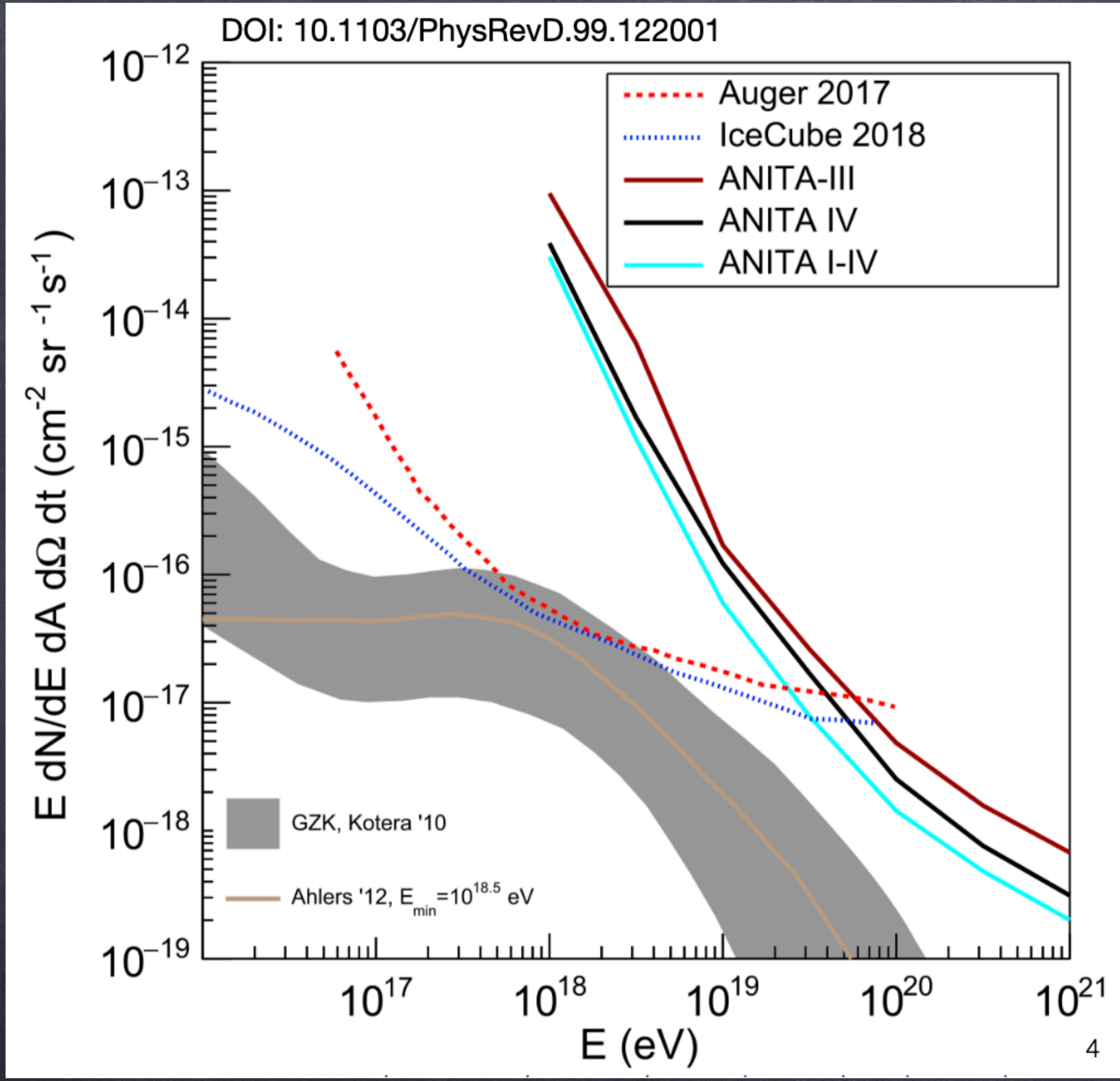


Direct detection

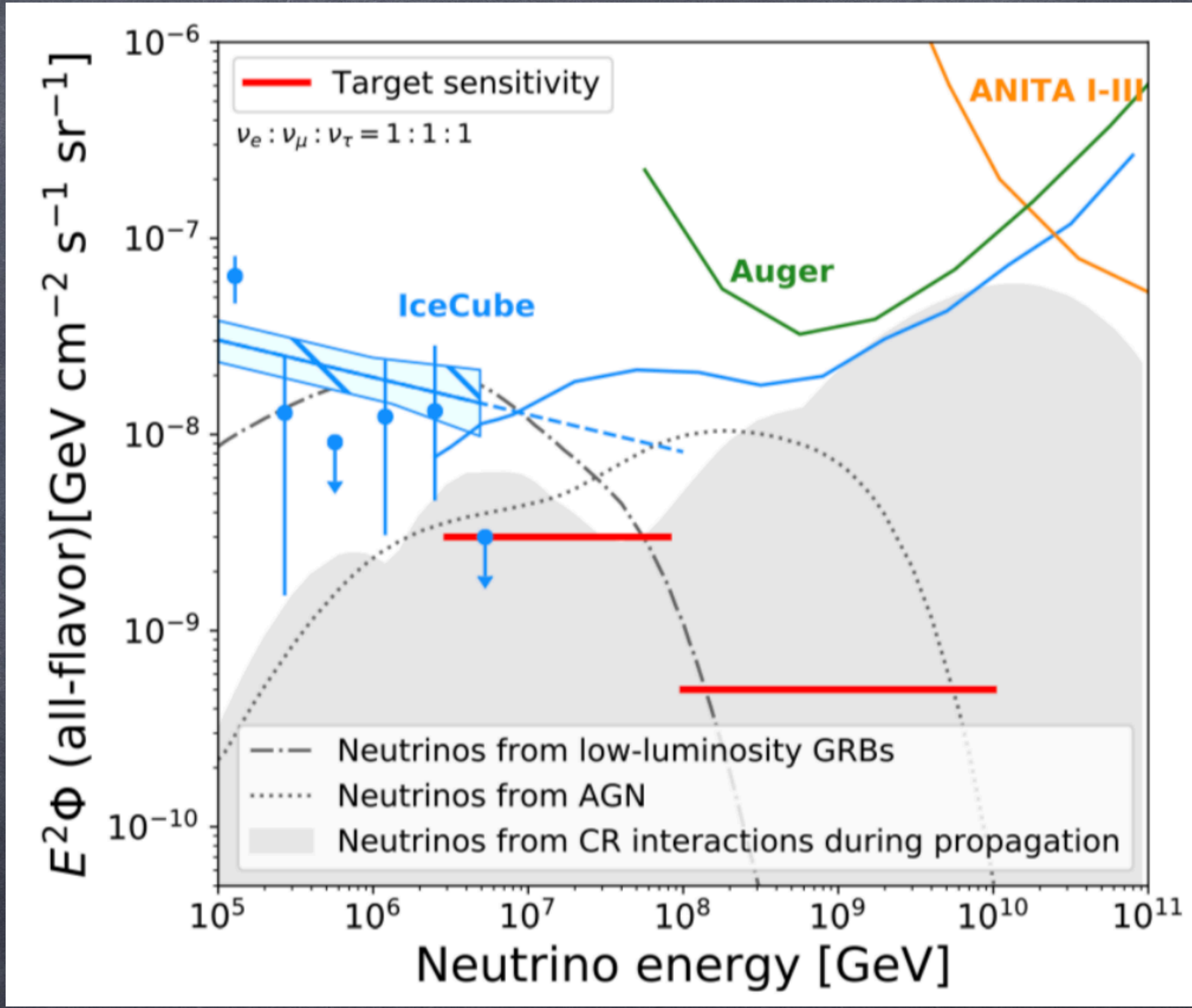
- Use atmosphere, mountains, volcanoes, and a sliver of the Earth as target.
- Detect radio emission from tau decay showers in the ice/atmosphere. (ANITA/GRAND/RNO/POEMMA)
- Cherenkov light from taus also detectable (POEMMA)
- Fluorescent light detection possible with precision optical detectors (ASHRA/NTA)



Current limits

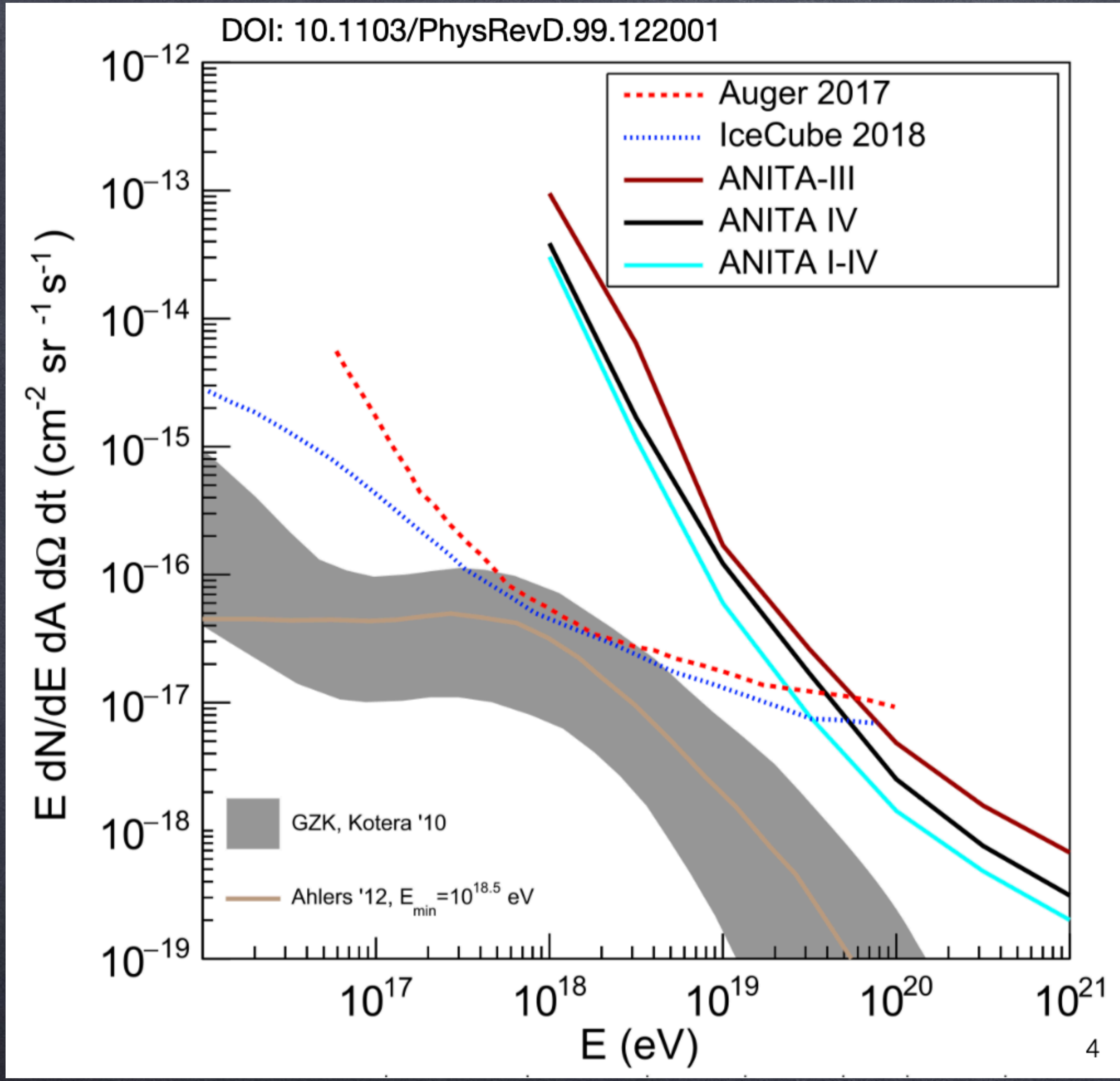


Projections

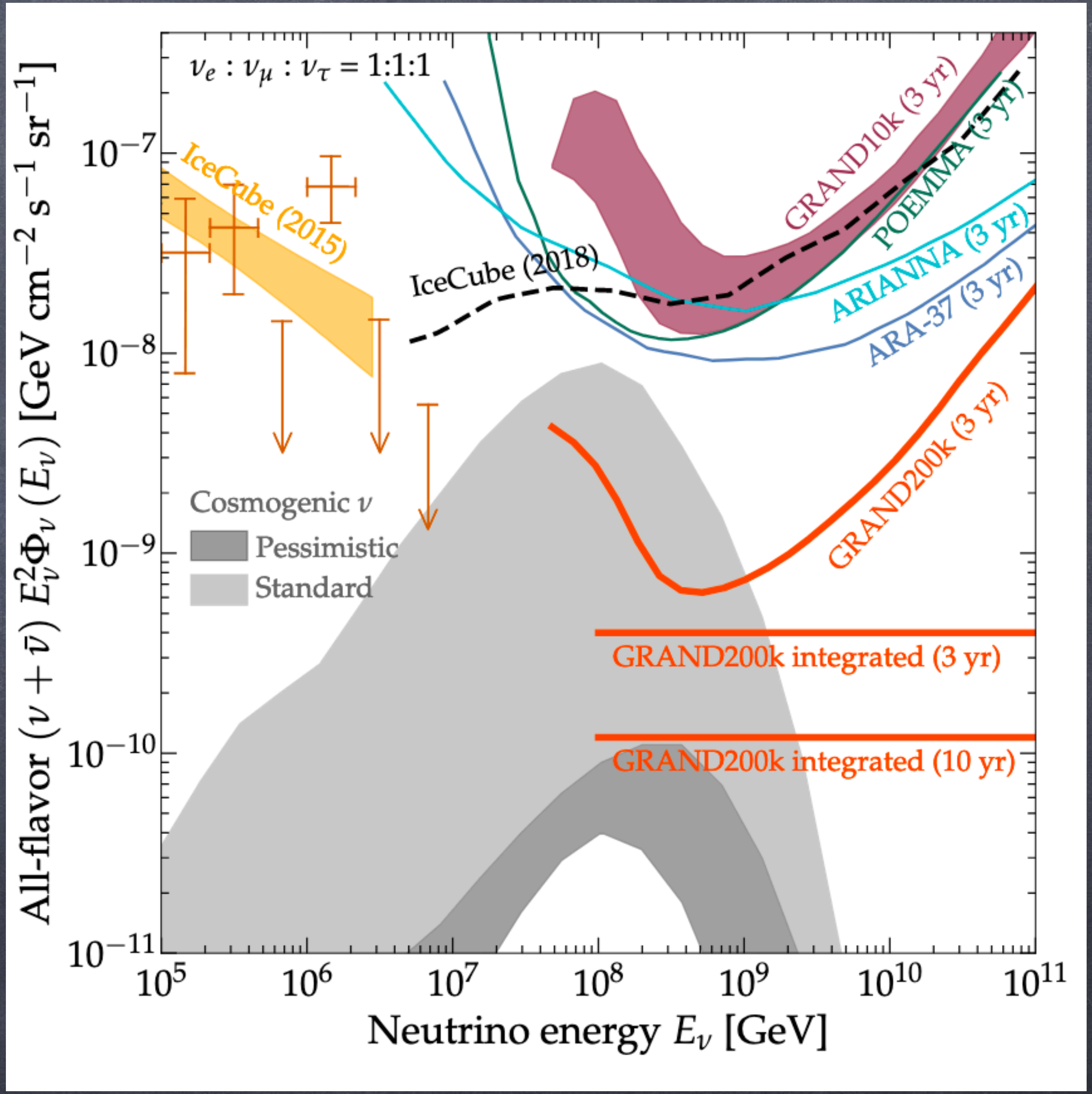


arXiv:1903.04334

Current limits

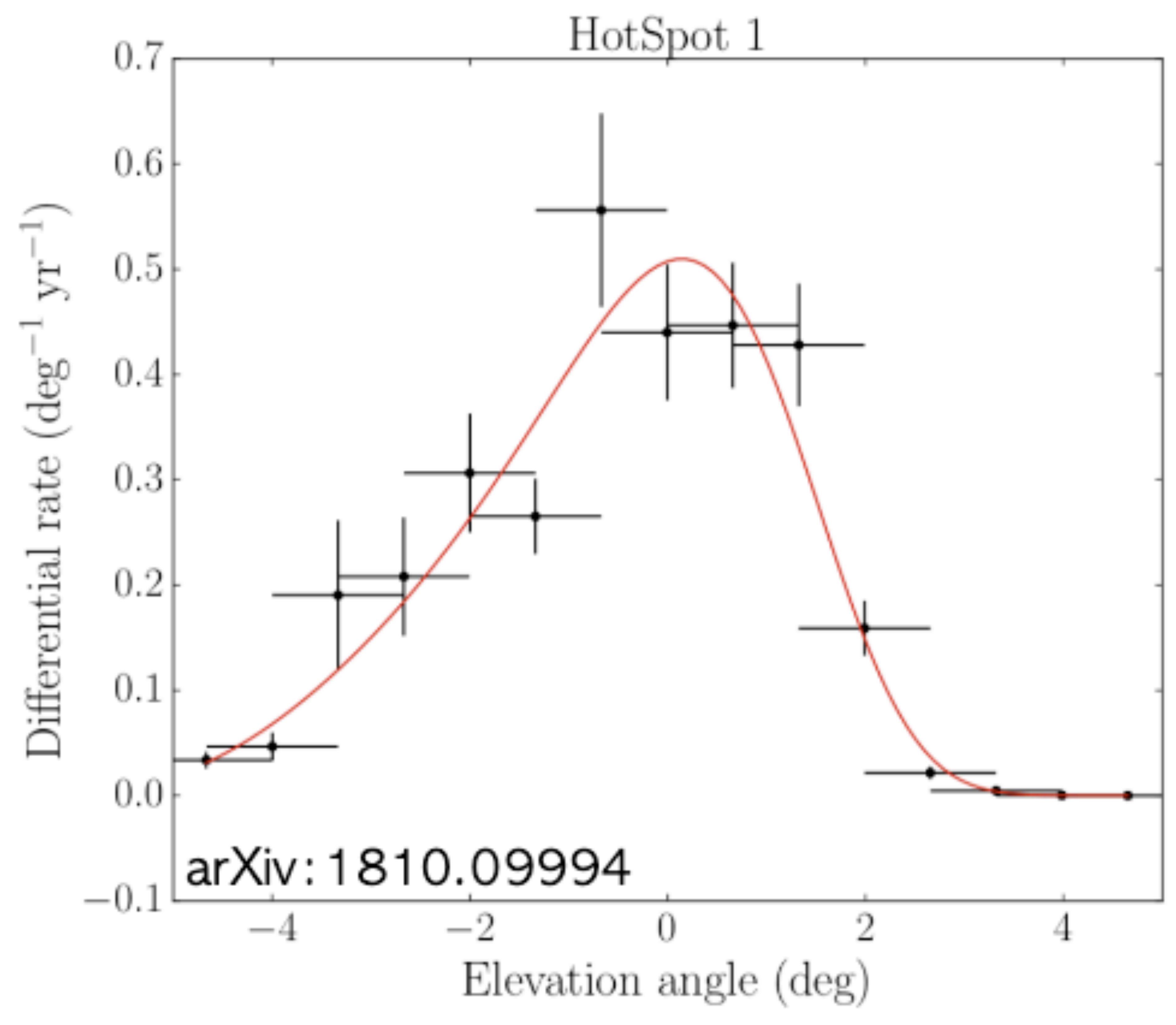


Projections



Limitations of direct detection techniques

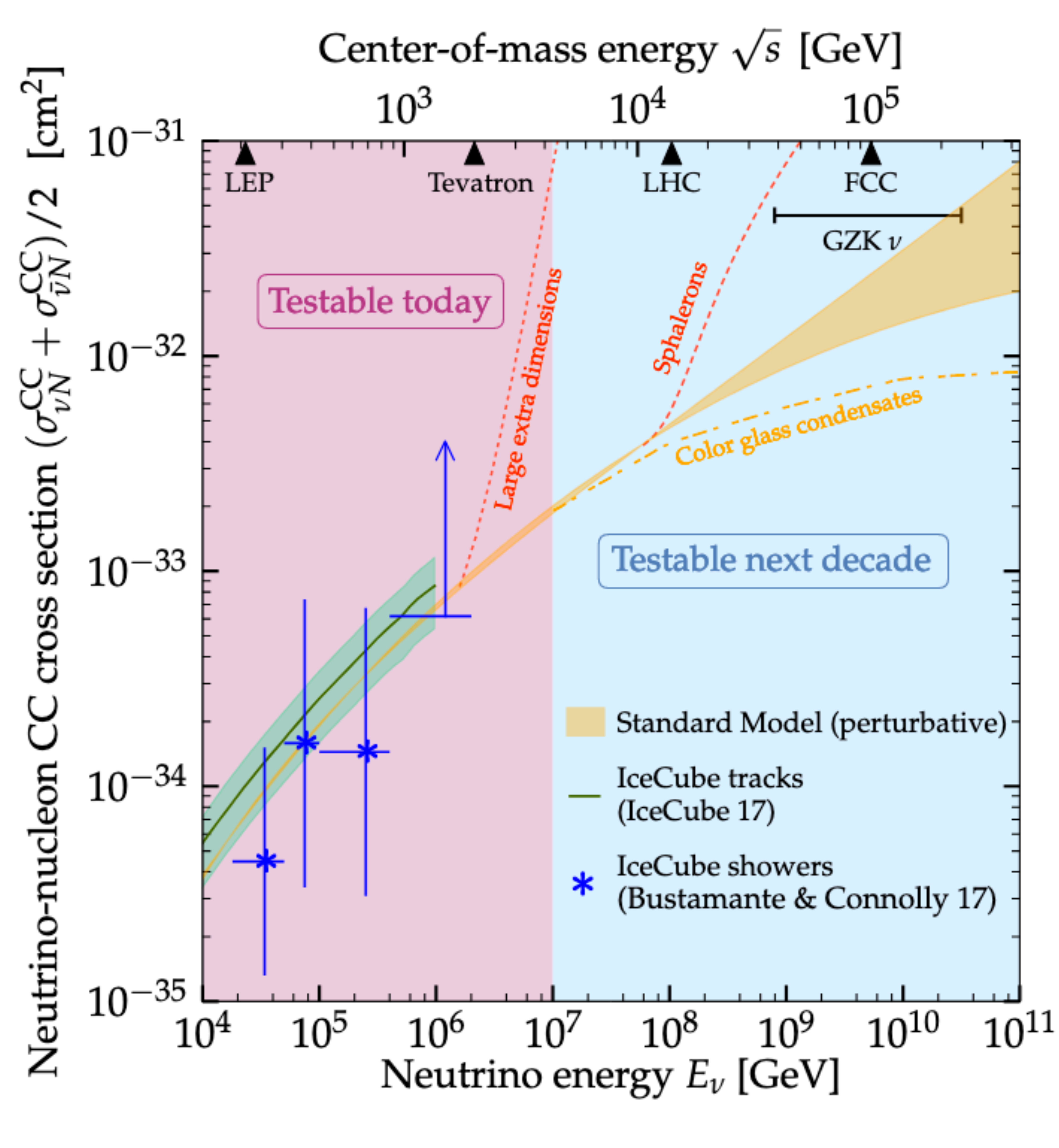
- Searches are limited to a small fraction of the sky.



Predicted GRAND rates as a function of elevation angle.

Limitations of direct detection techniques

- Searches are limited to a small fraction of the sky.
- The neutrino-nucleon cross section is not well predicted above at EeV energies. Uncertainties can exceed an order of magnitude.



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Tau neutrino regeneration

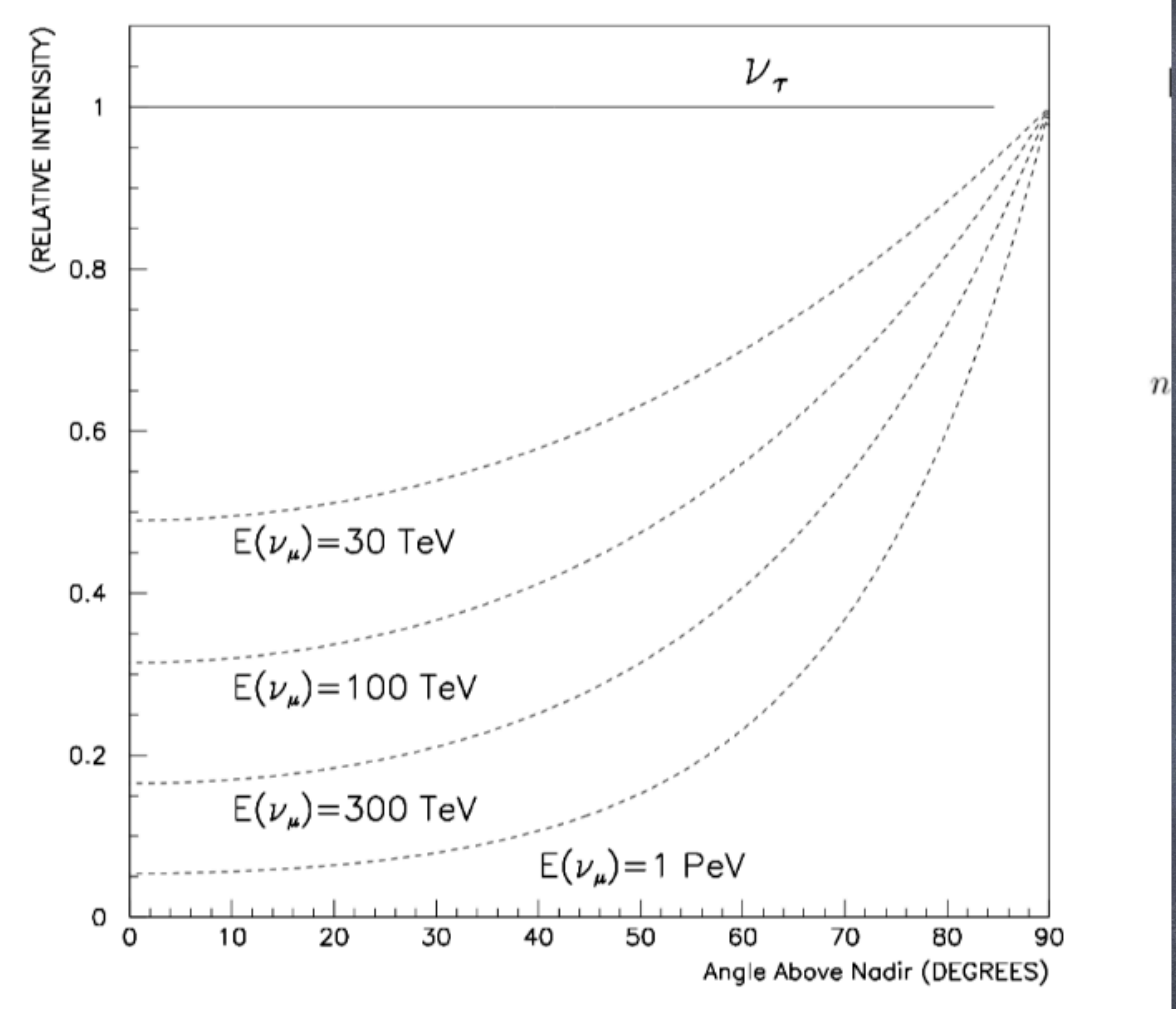
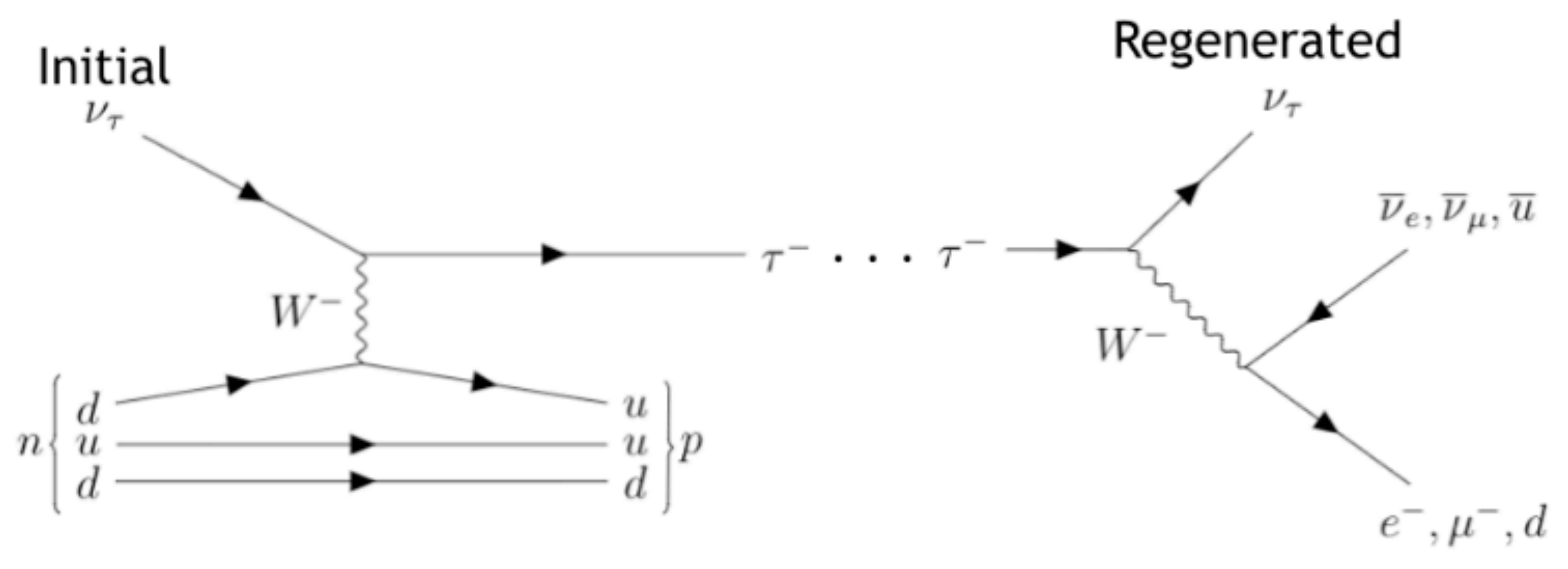


FIG. 2. Plot of the transmission of ν_μ and ν_τ through the Earth's. The transmission of ν_τ is essentially independent of their energy, as described in the text. The event rates are normalized to the maximum.

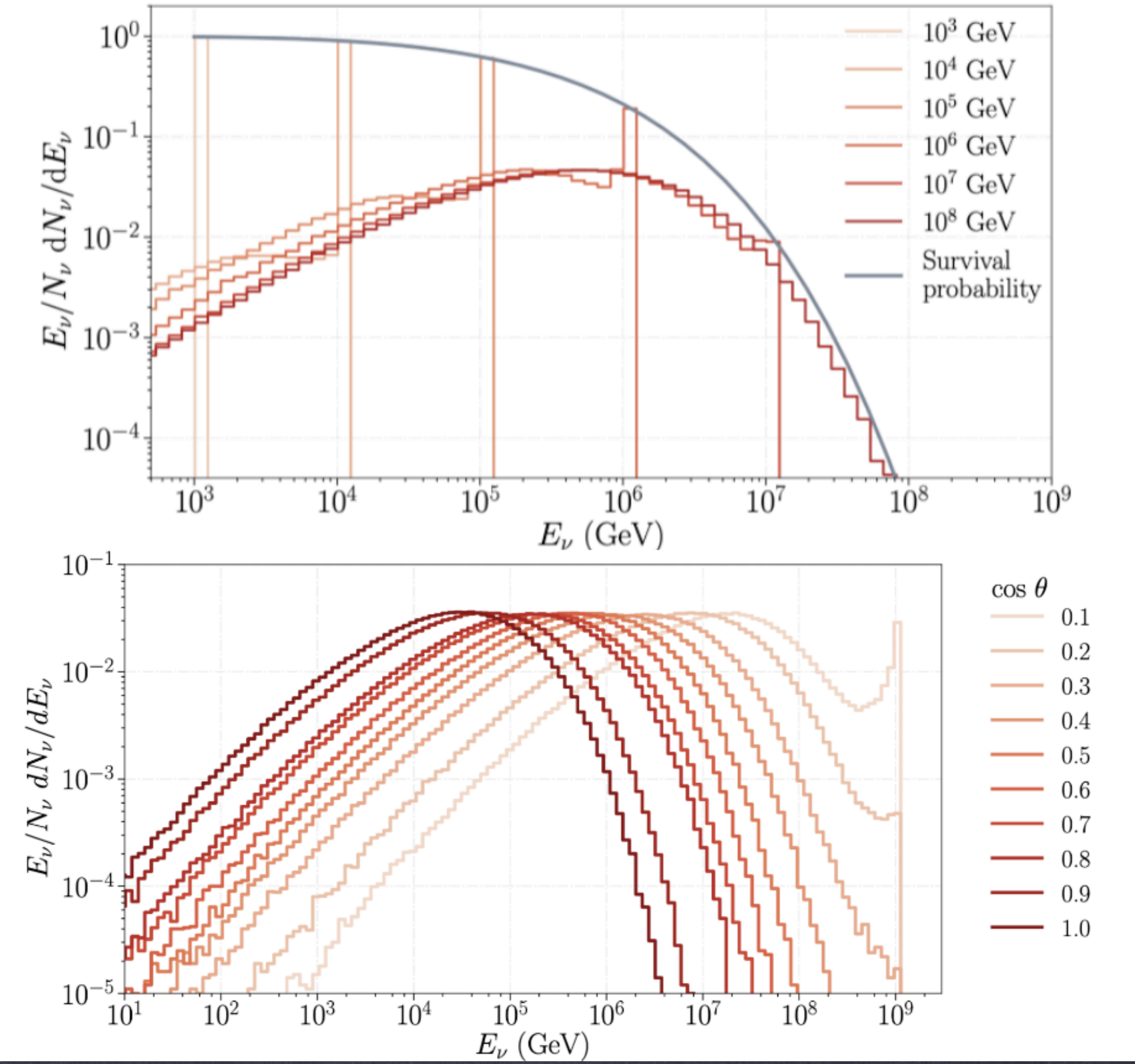
10.1103/PhysRevLett.81.4305



- Tau lifetime is roughly 10^7 times shorter than the muon's.
- The neutrino produced from the subsequent tau decay will have a significant fraction of the primary neutrino energy.

TauRunner MC

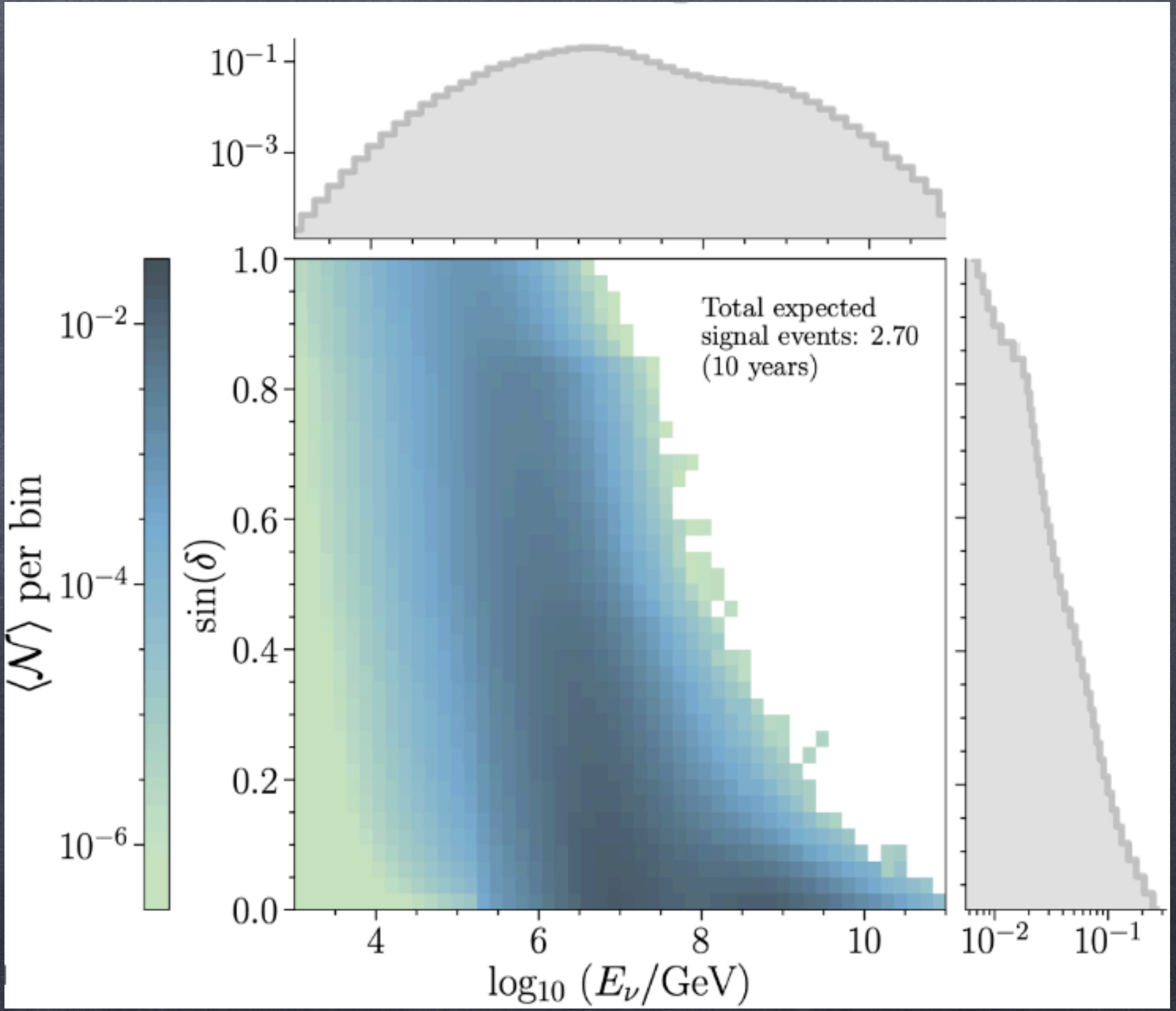
- We developed a python package to propagate EHE neutrinos and taus through the Earth. (available publicly https://github.com/IceCubeOpenSource/TauRunner).
- We found that tau neutrinos traversing the Earth undergo 2-3 CC interactions, on average.
- They emerge at O(0.1-10) PeV energies for most column depths, where existing ice cherenkov detector, IceCube, is sensitive.



Event Expectation

$$\mathcal{N}_\nu^{\rm GZK} = \int dE' d\Omega\ \Phi_\nu(E'_\nu)\Delta T \left[\sigma_{\nu N}^{CC}(E'_\nu)\cdot \frac{\Gamma_{\tau\to\mu}}{\Gamma_{total}}\cdot N_N^{CC}(E'_\nu) + \sigma_{\nu N}^{NC}(E'_\nu)\cdot N_N^{NC}\right],$$

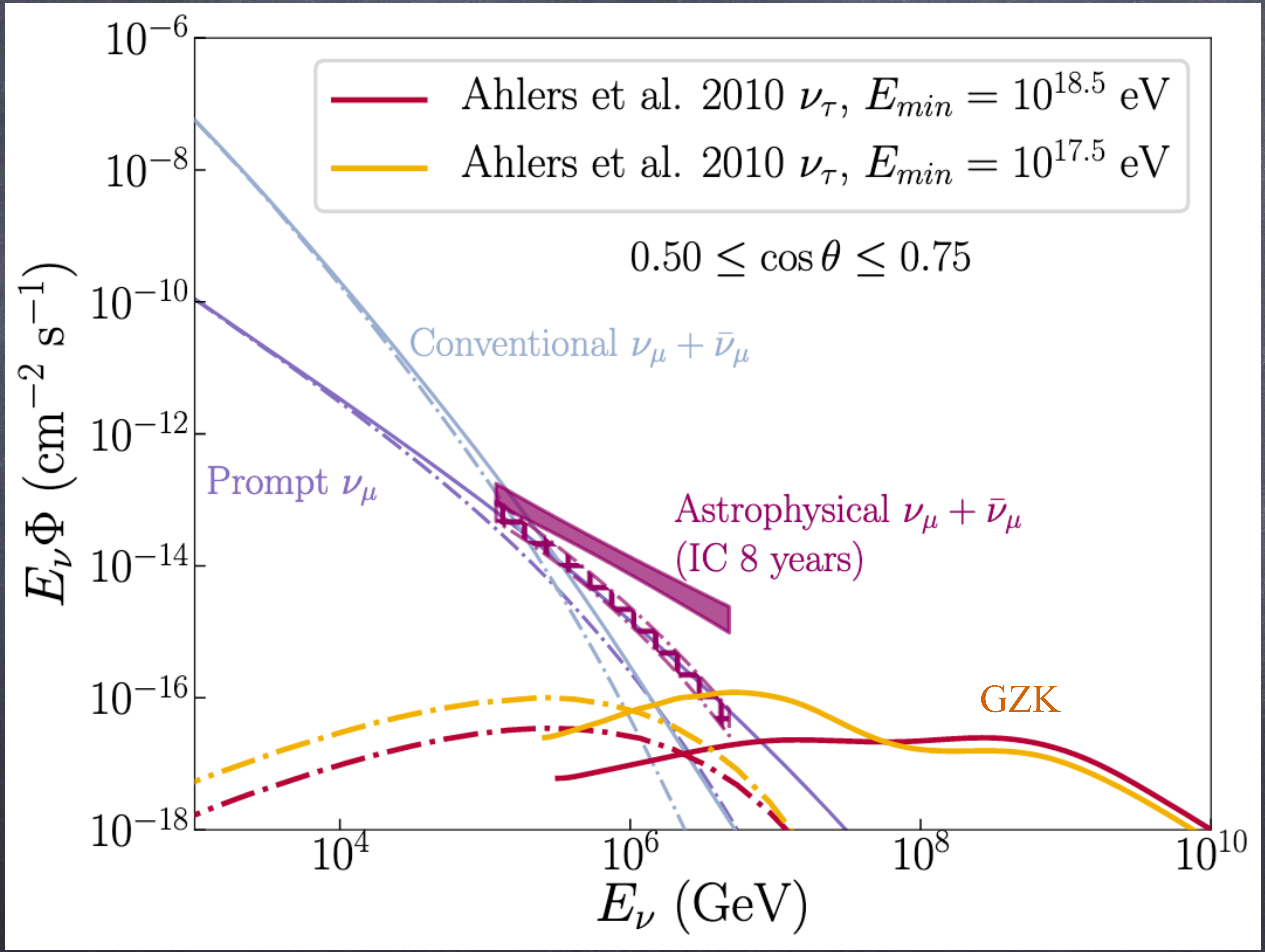
- Isotropic cosmogenic neutrino flux[1] propagated to IceCube.
- Event expectation calculated for 10 years of data (available now).
- Pileup at a few PeV.
- Earth-skimming events are only one-third the total rate.



[1] arXiv:1005.2620

Event Expectation

Solid: flux arriving at Earth
dashed: flux at IceCube



Conclusions

- It is possible to detect EeV neutrinos at PeV energies.
- This opens up the possibility to indirectly detect GZK fluxes.
- Will require a good understanding of the astrophysical neutrino flux.
- But, neutrino cross section at PeVs is well-predicted. At EeV still unknown.
- Direct searches at EeV energies with radio detectors are complementary. Both are crucial for the understanding and characterization of the GZK flux.