

Neutrinos, astrophysics, and TAMBO

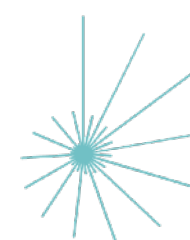
Carlos Argüelles



HARVARD
UNIVERSITY



The NSF Institute for
Artificial Intelligence and
Fundamental Interactions



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the David
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PUCP, Lima, Aug. 17th, 2026

One slide about me

“Professional” neutrino physicist.

Science fiction fan, specially Star Wars, Star Trek.

Undergraduate/Master PUCP

PhD: UW-Madison

Postdoc: MIT

Allergic to peanuts and shrimp

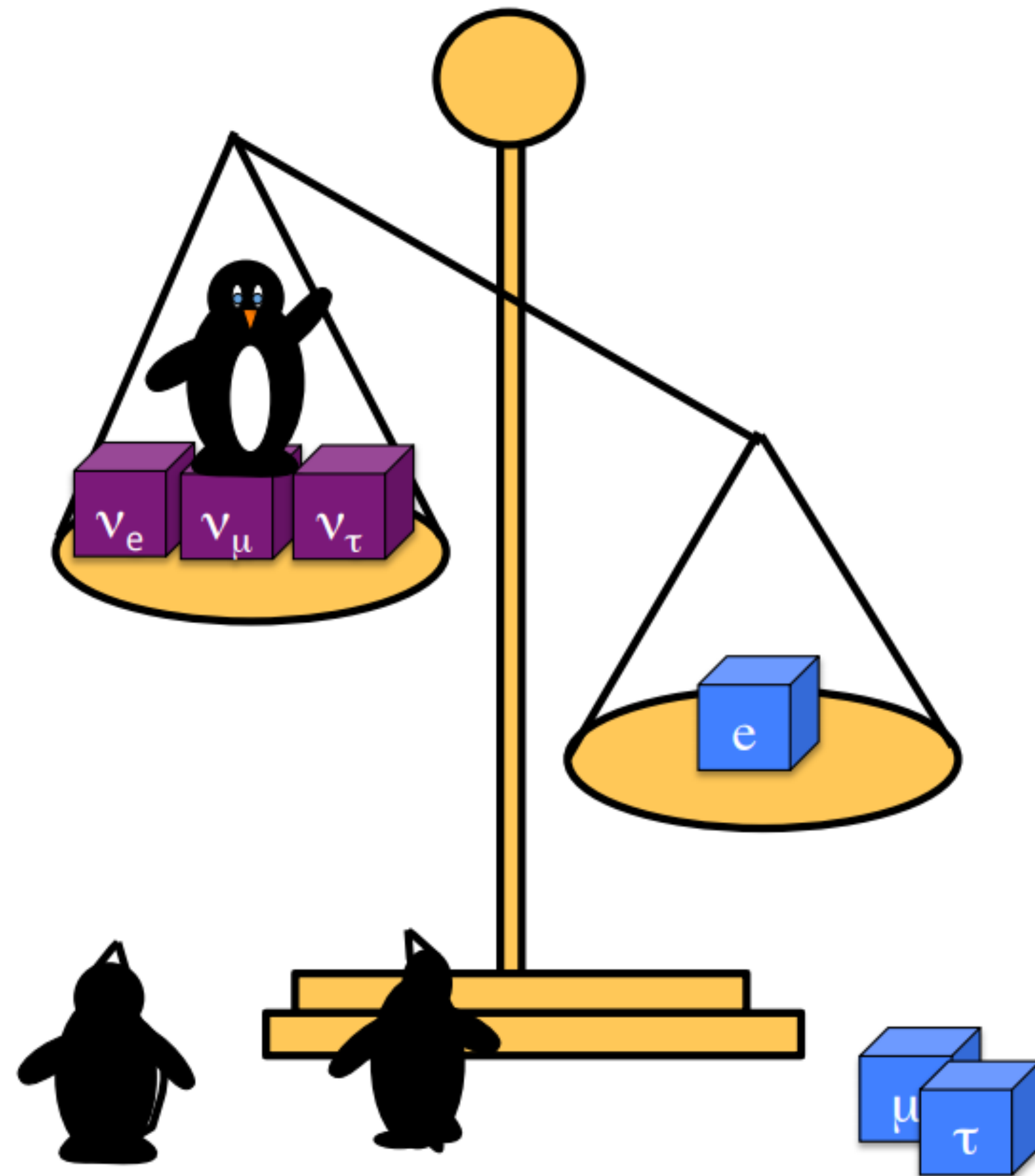
Like food and wine



Three flavorful neutrinos

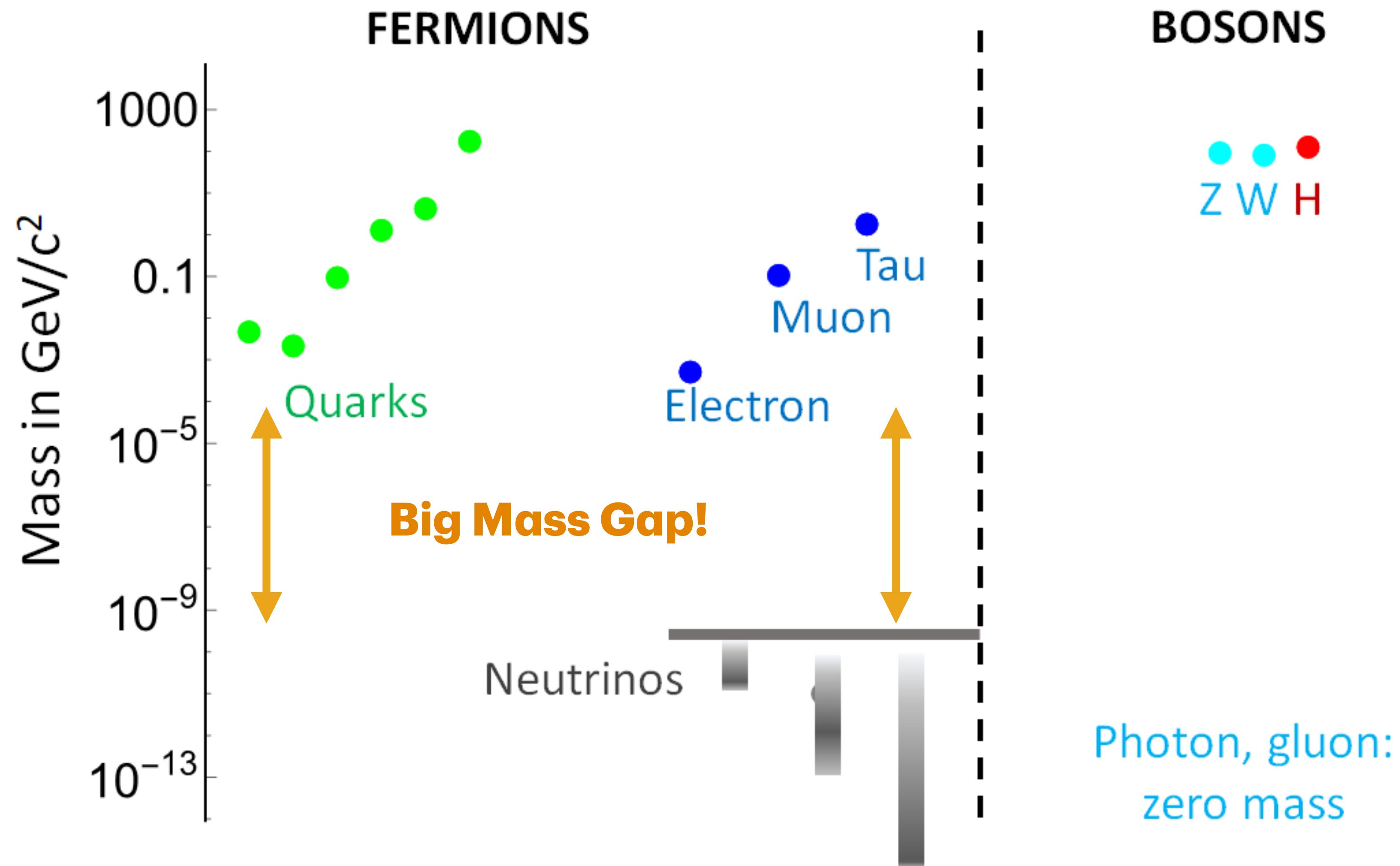


Neutrinos are light, neutral, fundamental particles

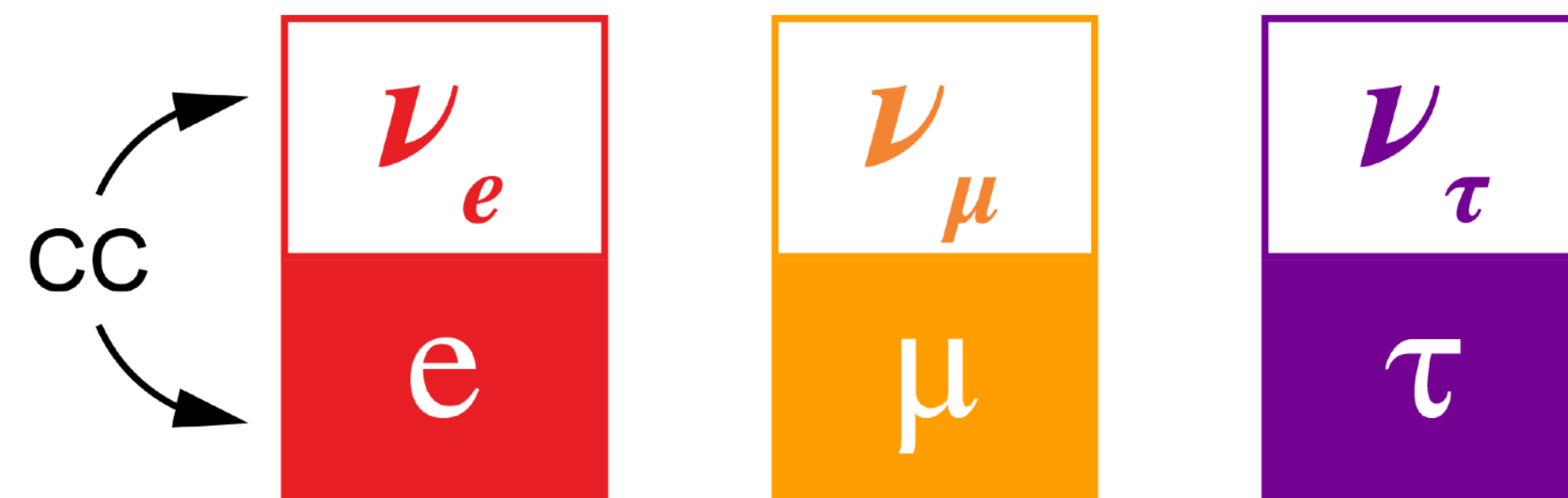
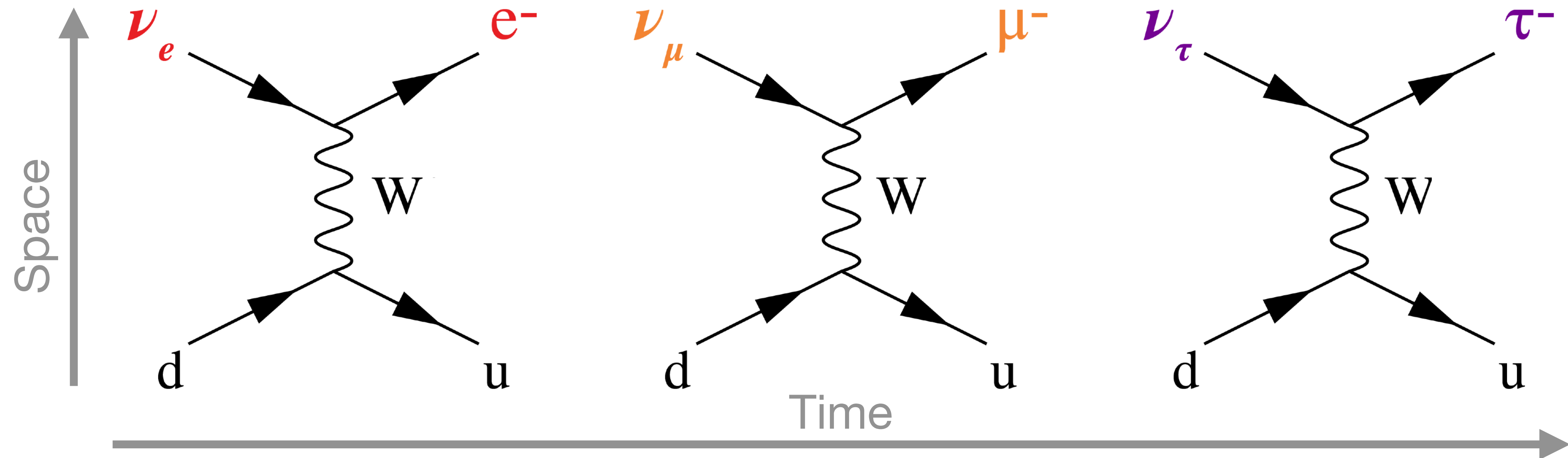


1. Neutrinos are fundamental particles.
2. There are three types of neutrinos.
3. Neutrinos have no electric charge.
4. Neutrinos interact very rarely.
5. Second most abundant particle in the Universe.
6. Have a tiny mass.

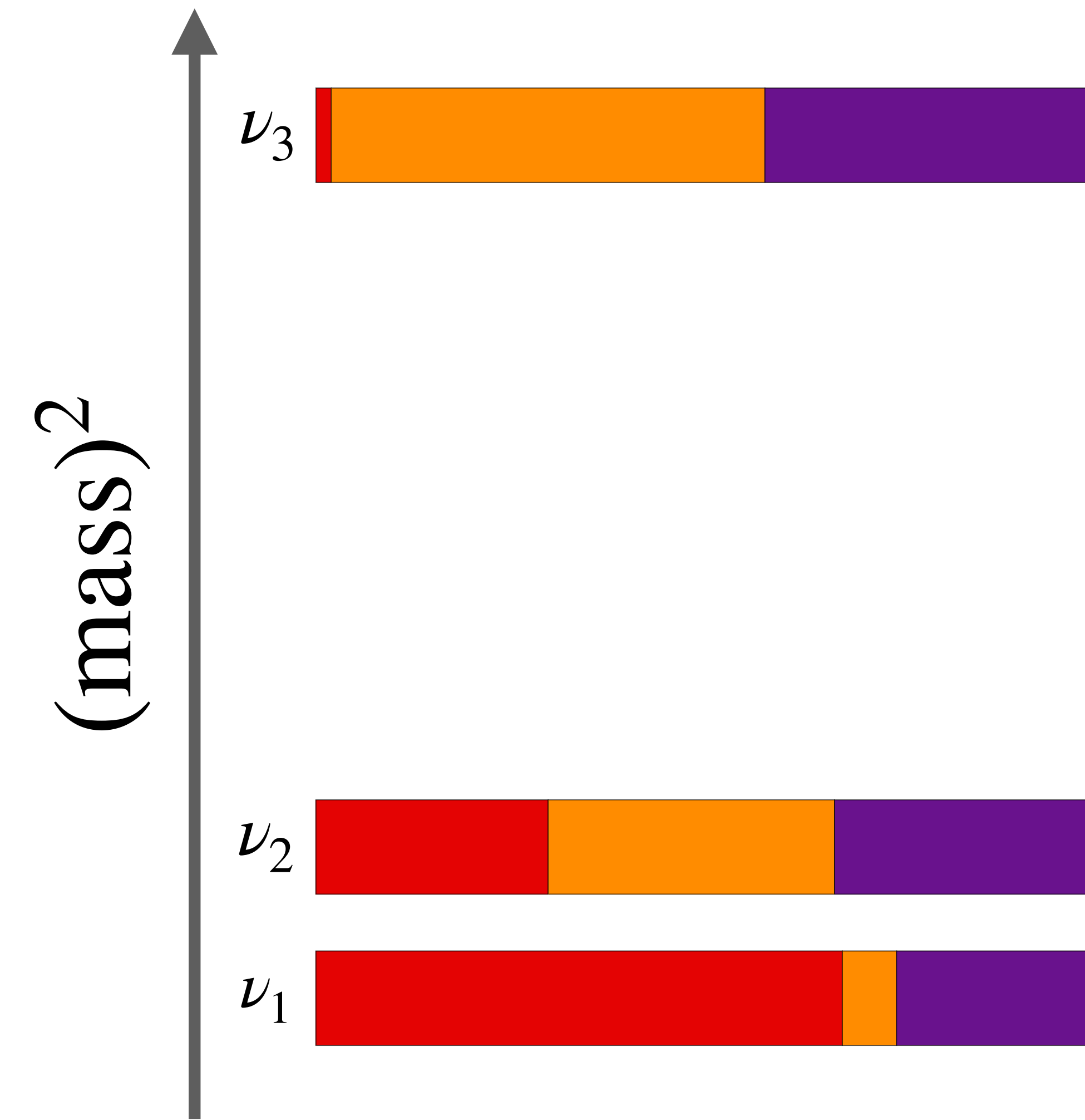
Neutrinos are the lightest known massive particles



We use the outgoing particle to classify the neutrino.
We term this neutrino “flavor.”



Each flavor is a superposition of mass states



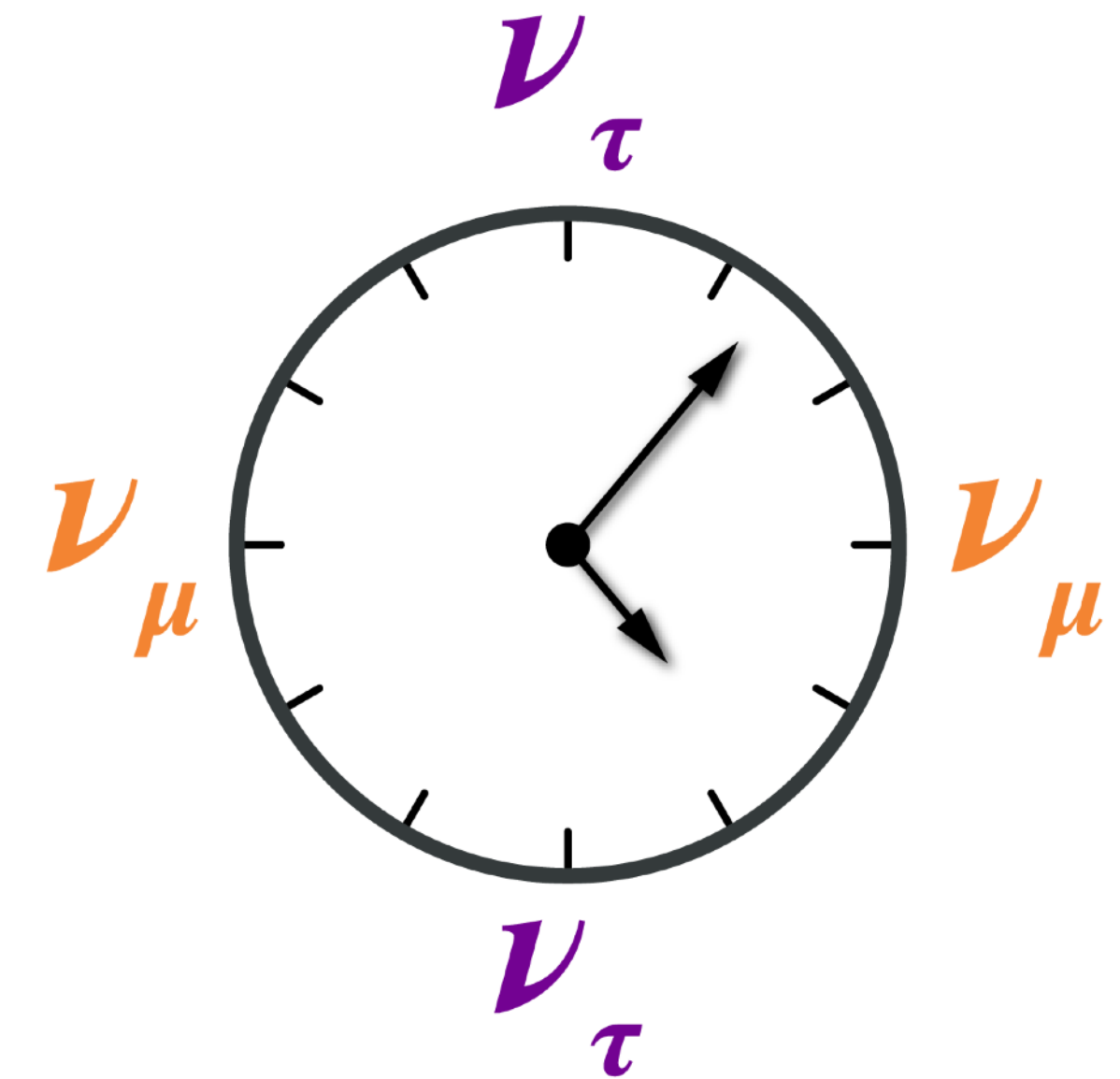
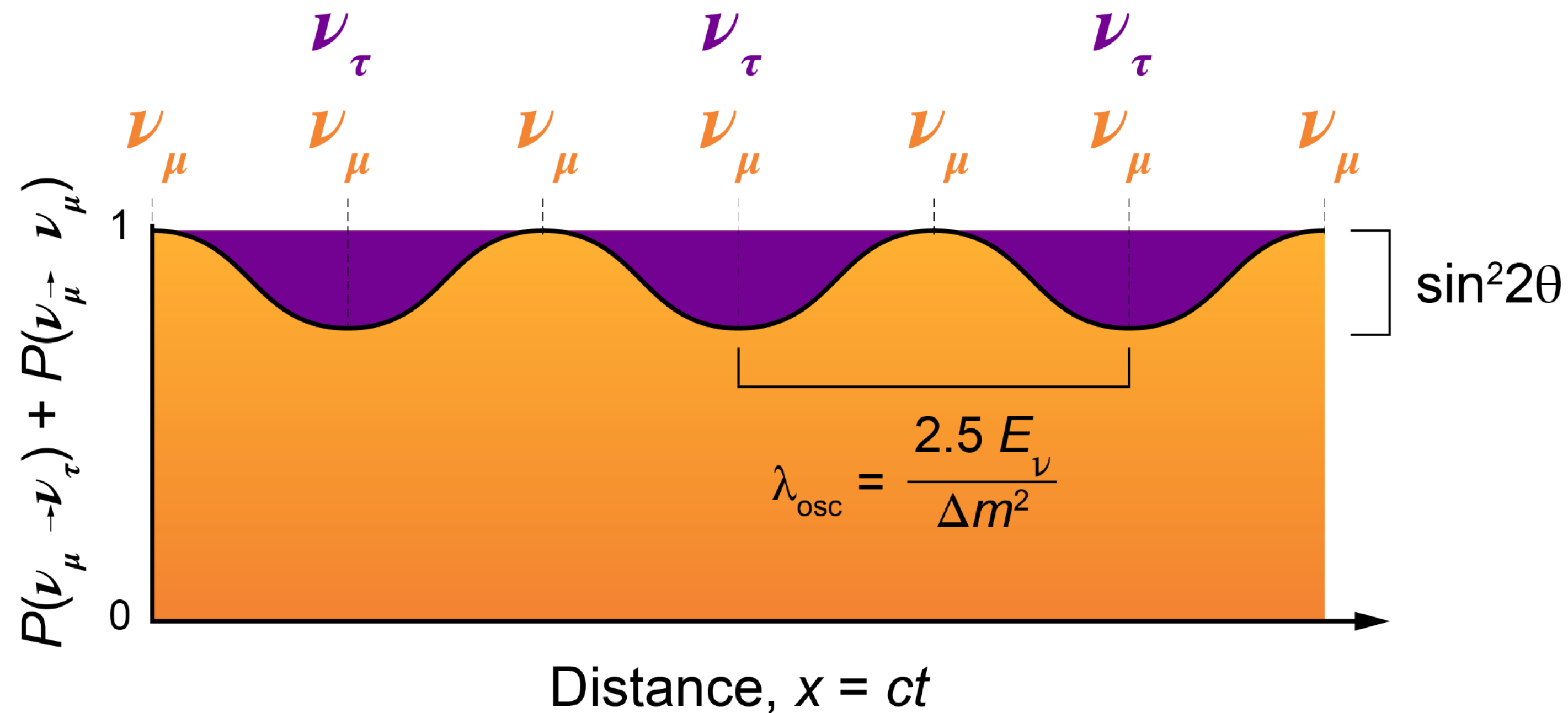
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu1} & U_{\mu2} & U_{\mu3} \\ U_{\tau1} & U_{\tau2} & U_{\tau3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}.$$

$$\nu_e [U_{ei}^2] \quad \nu_\mu [U_{\mu i}^2] \quad \nu_\tau [U_{\tau i}^2]$$

Neutrino Oscillation Observables

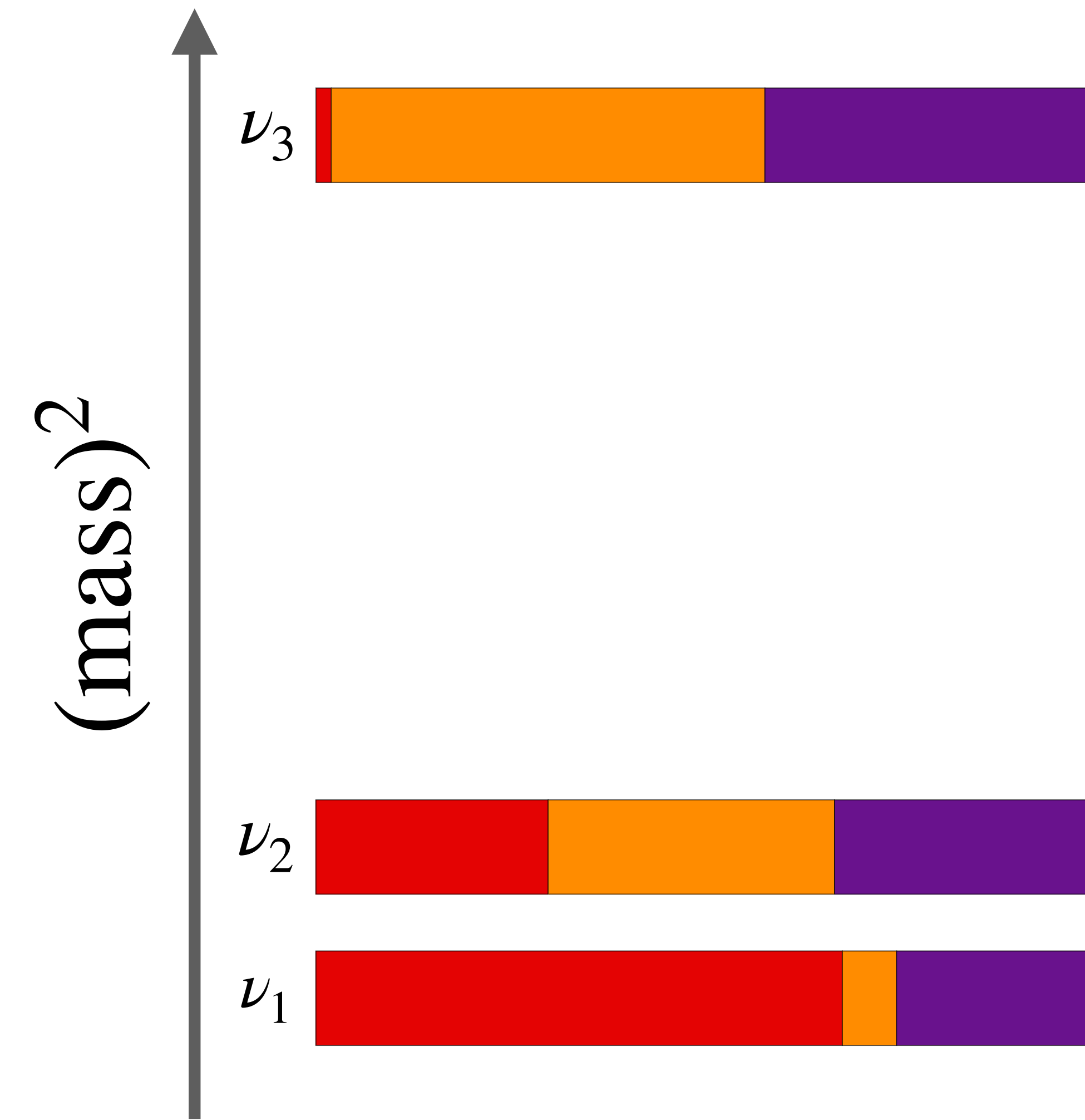
In two generations, the neutrino survival oscillation probability is given by:

$$P(\nu_\alpha \rightarrow \nu_\alpha) = 1 - \sin^2(2\theta) \sin^2\left(\frac{1.27 \Delta m^2 L}{E}\right)$$



Probability that ν_μ has become ν_τ
 Probability that ν_μ is still ν_μ

What we know about Neutrino Mixing



$$\Delta m_{21}^2 \approx 7.5 \times 10^{-5} \text{eV}^2$$

$$|\Delta m_{31}^2| \approx 2.4 \times 10^{-3} \text{eV}^2$$

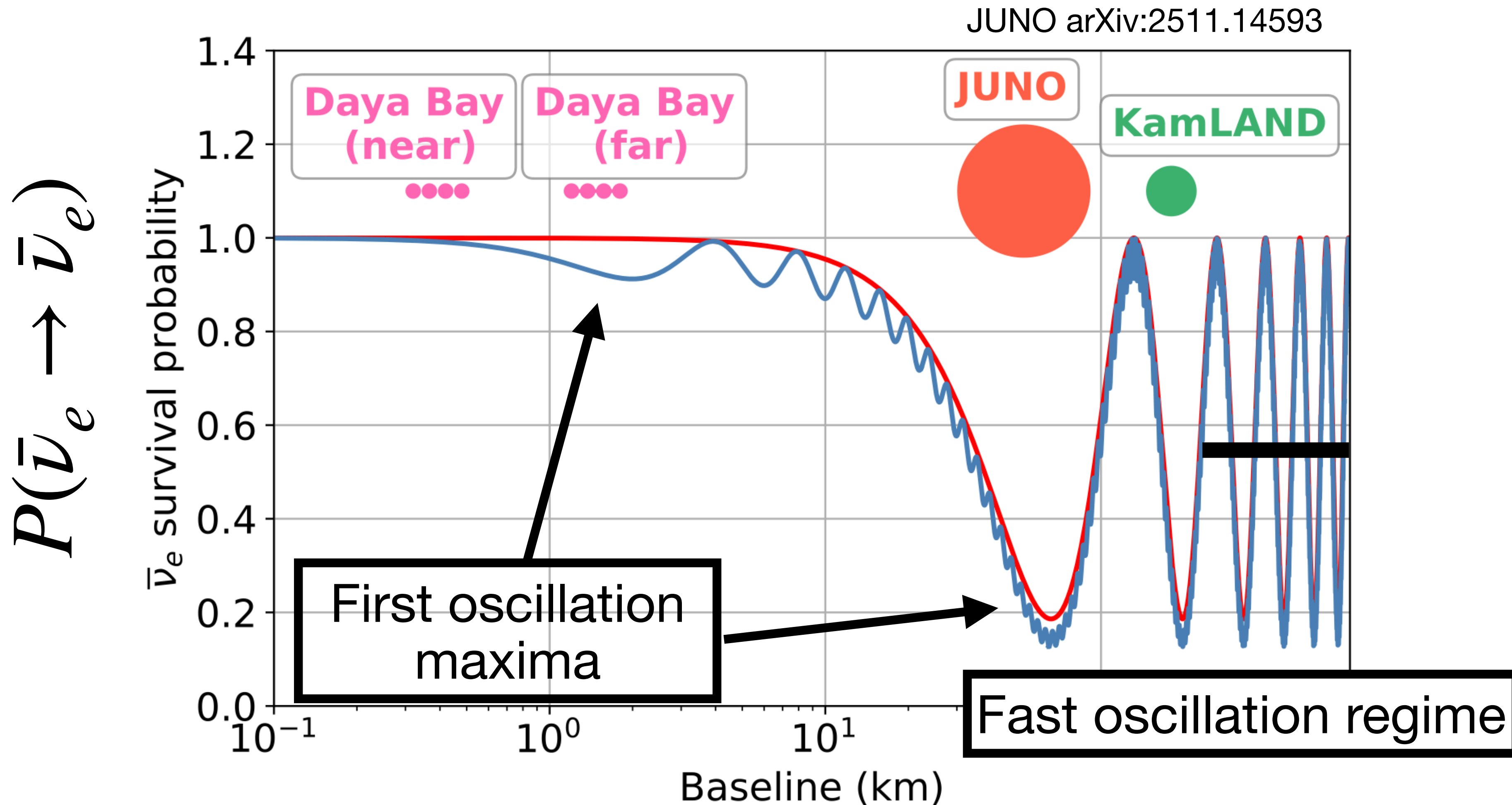
$$U \simeq \begin{pmatrix} 0.8 & 0.5 & 0.1 \\ -0.5 & 0.5 & 0.7 \\ 0.3 & -0.7 & 0.6 \end{pmatrix}$$

$$\nu_e [U_{ei}^2] \quad \nu_\mu [U_{\mu i}^2] \quad \nu_\tau [U_{\tau i}^2]$$

Except for the CP-phase, we have measured these quantities to the few-percent level

Oscillation Regimes

Parameters measured in many experiments. Neutrino oscillations is in a precision era. Latest measurement: JUNO.



Observation of solar ν



Oscillation of ν

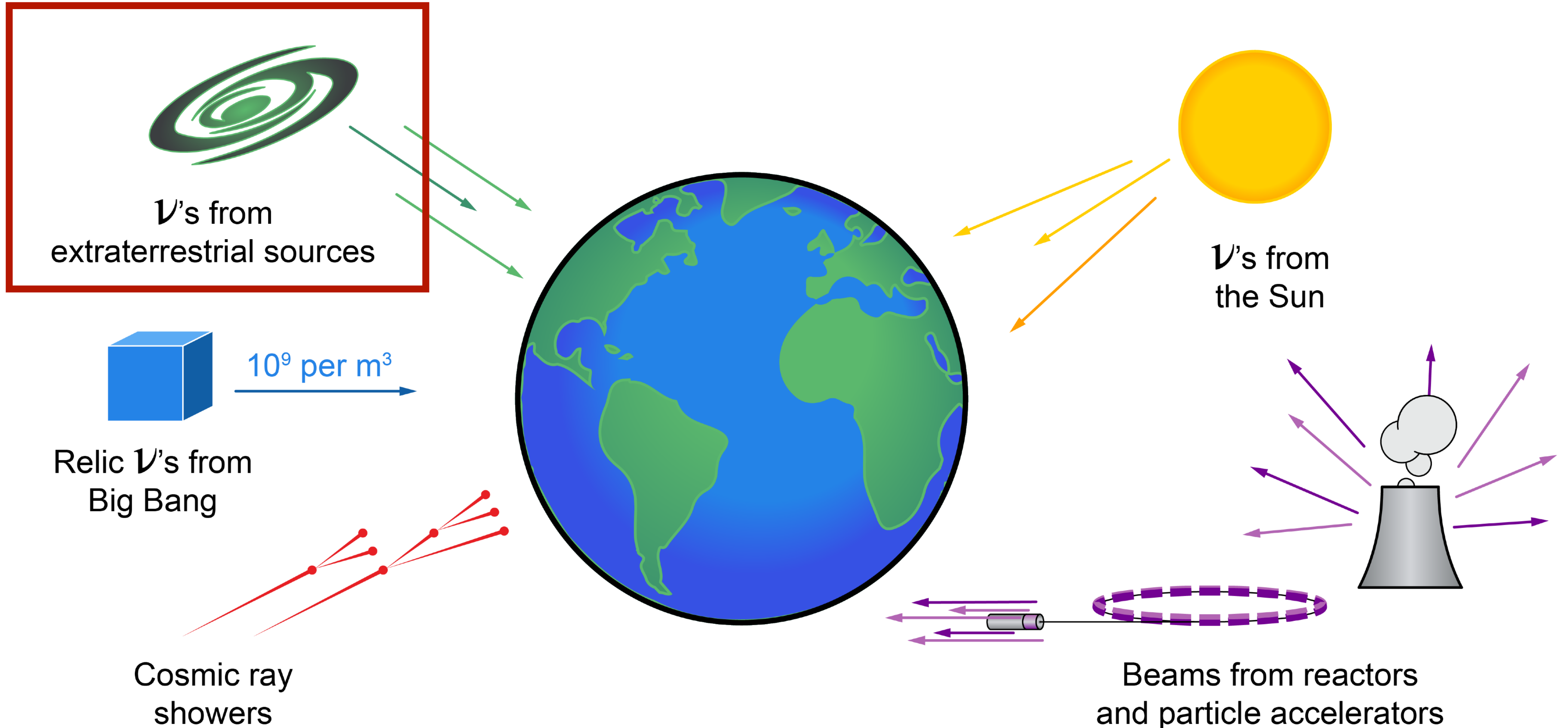
Open questions in neutrino physics

- What is the origin of neutrino mass?
- Are neutrinos connected to dark sectors (dark matter)?
- What is the origin of the neutrino flavor structure?
- What does the mass spectrum of neutrinos look like?
- Are neutrinos their own antiparticle?
- Do neutrinos behave the same as antineutrinos?

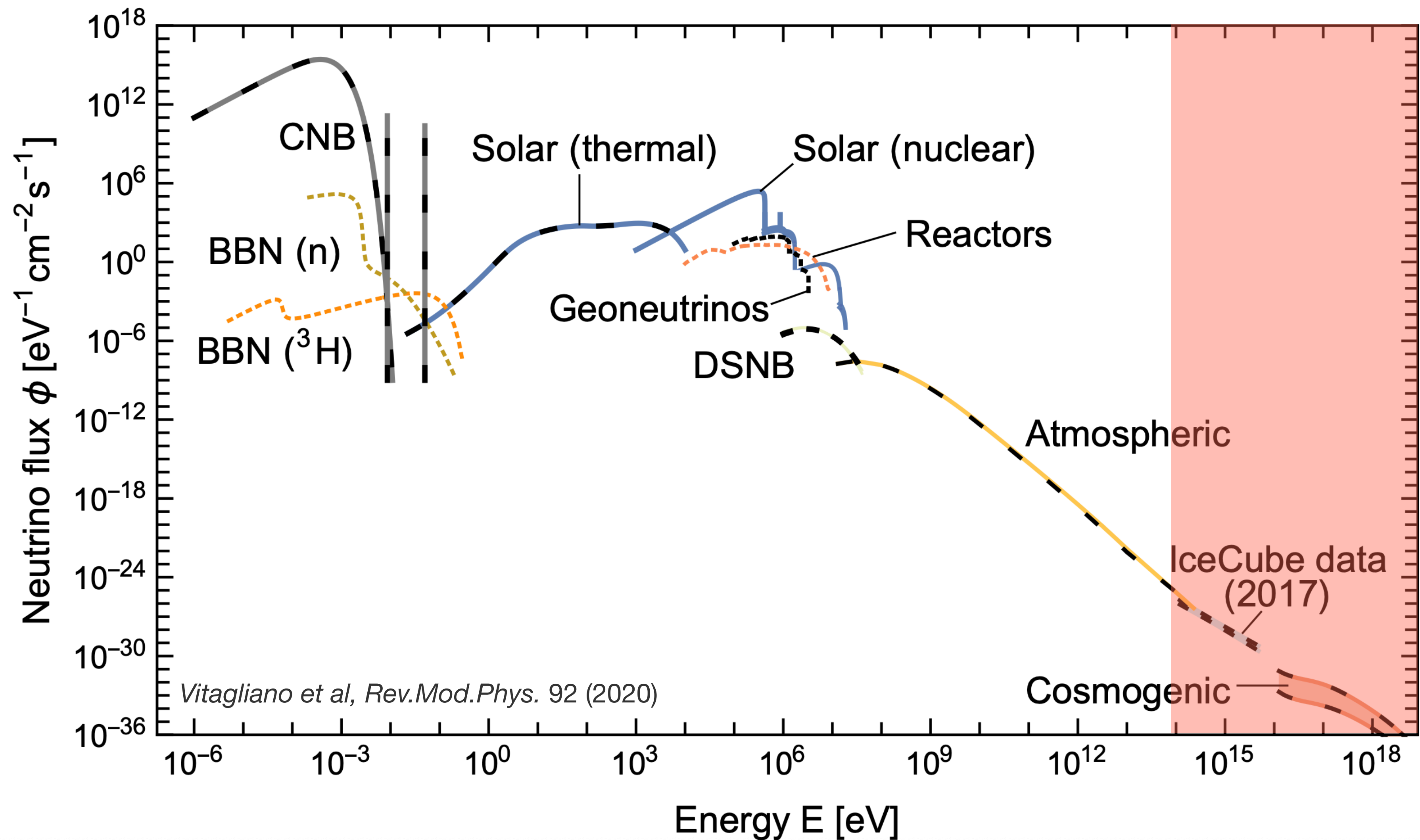


Detecting neutrinos and their sources

Oscillations in different neutrino sources



We are after the highest energy neutrinos

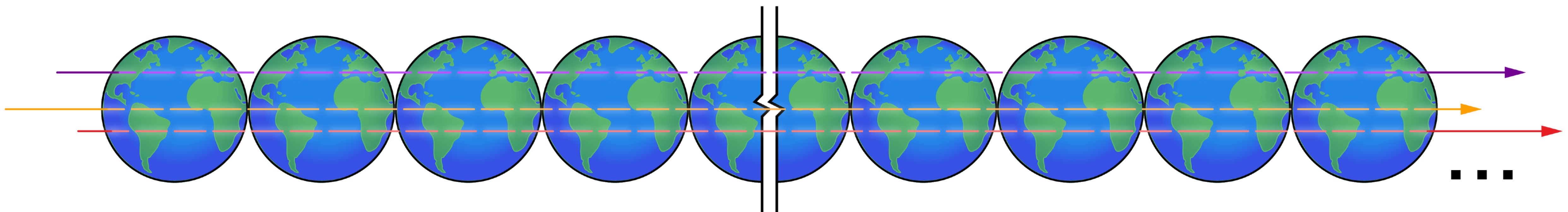


Astrophysical
neutrinos

Neutrino intensity **steeply falls** with energy

To see neutrinos you need an enormous detector

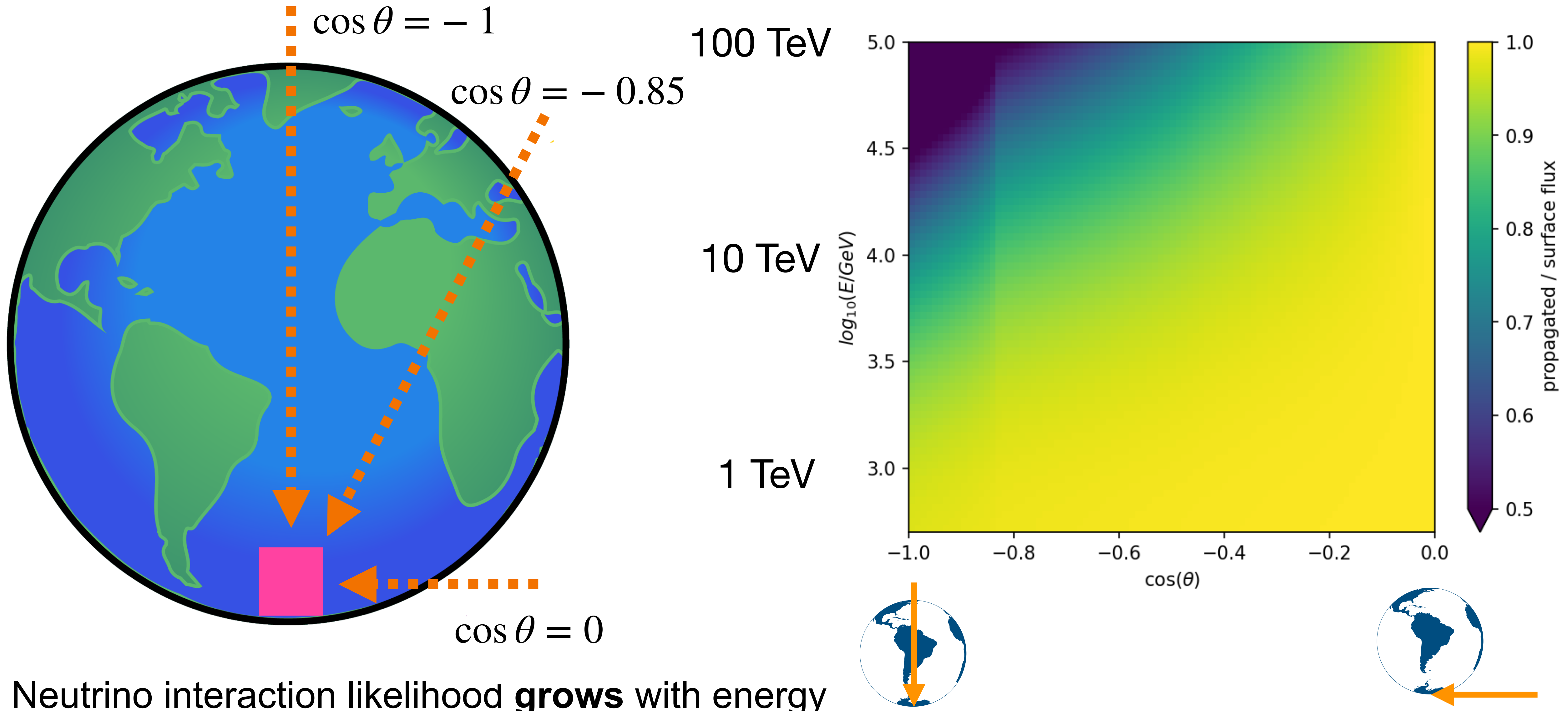
Neutrino interactions are **weak** for example a solar neutrino



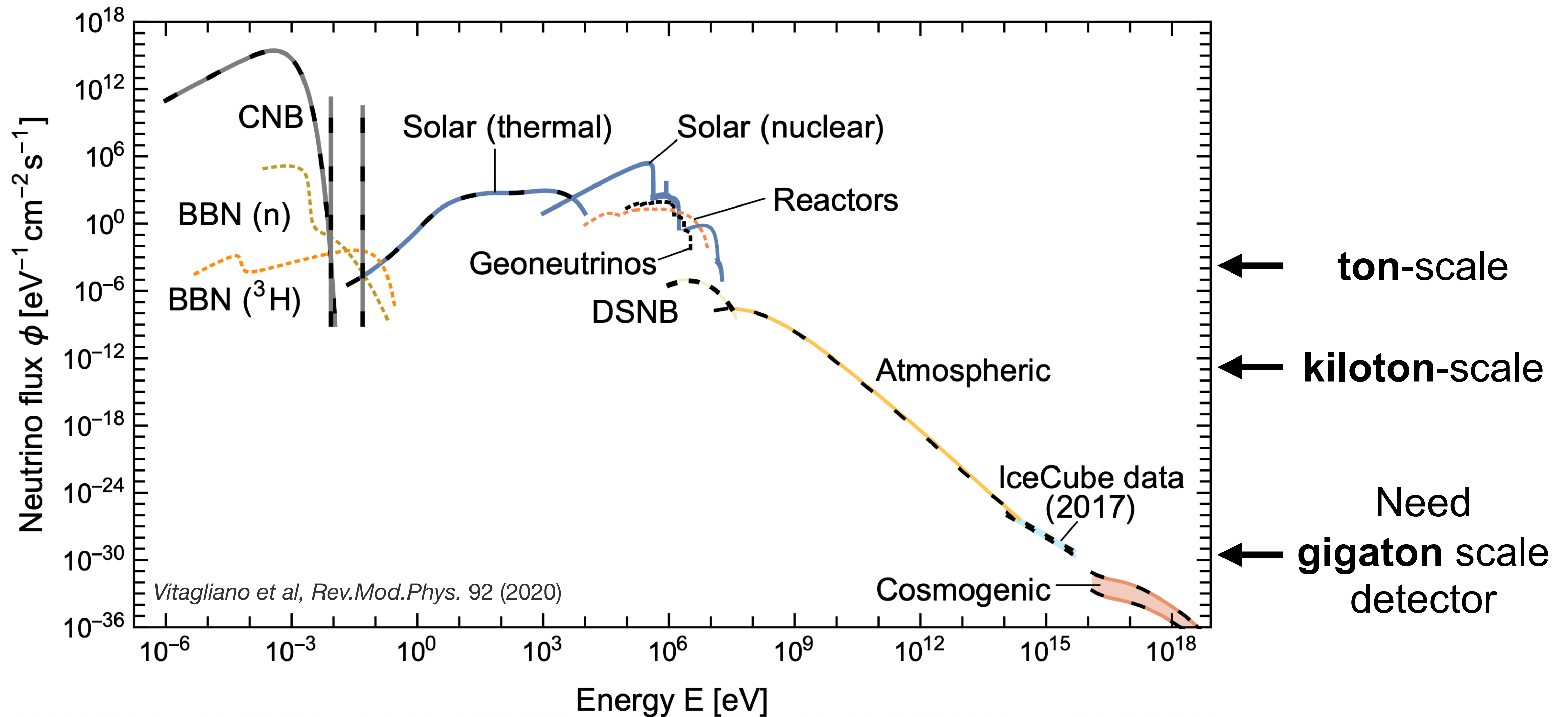
~ 20 billion Earths

Much weaker than strong and electromagnetic forces

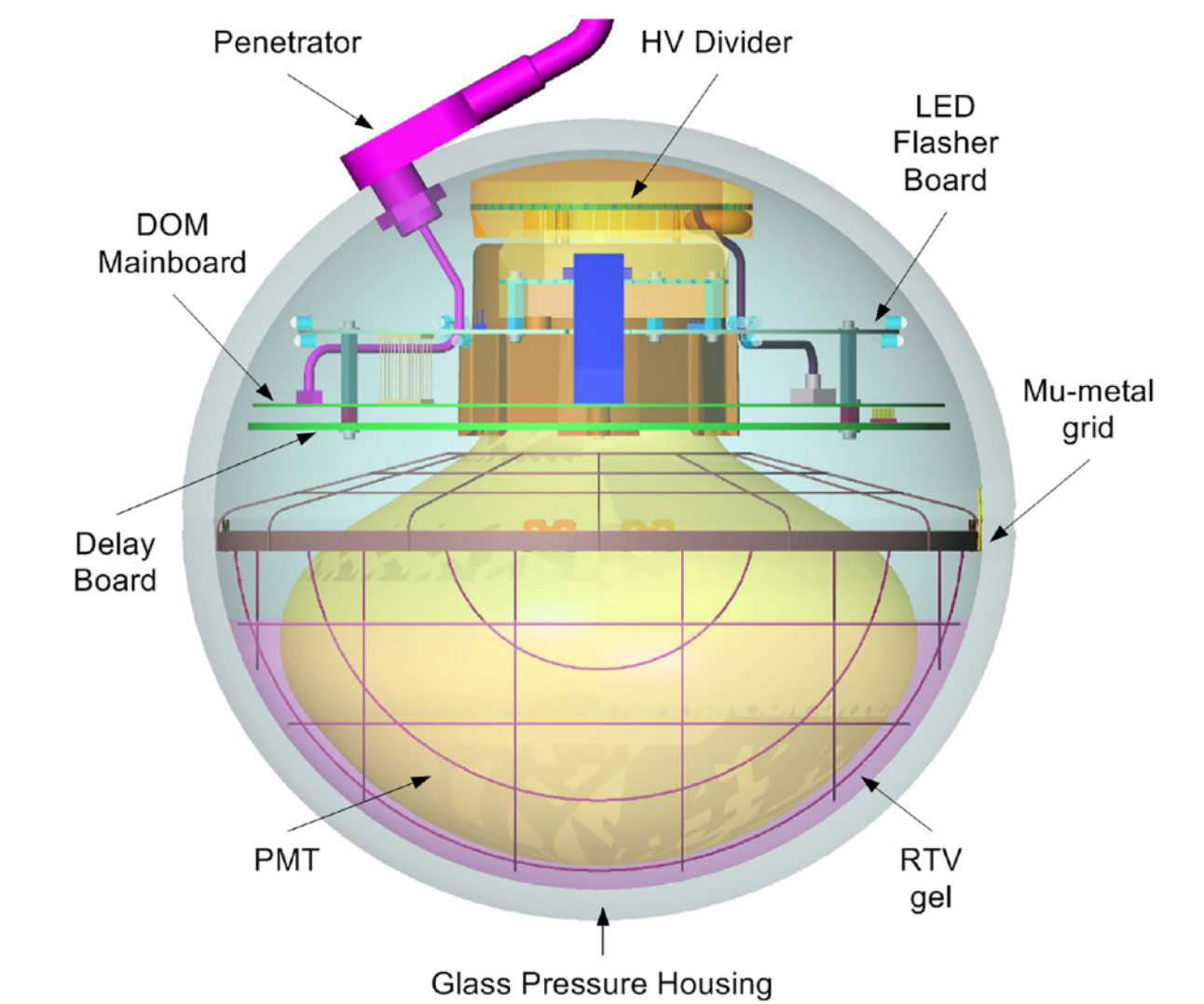
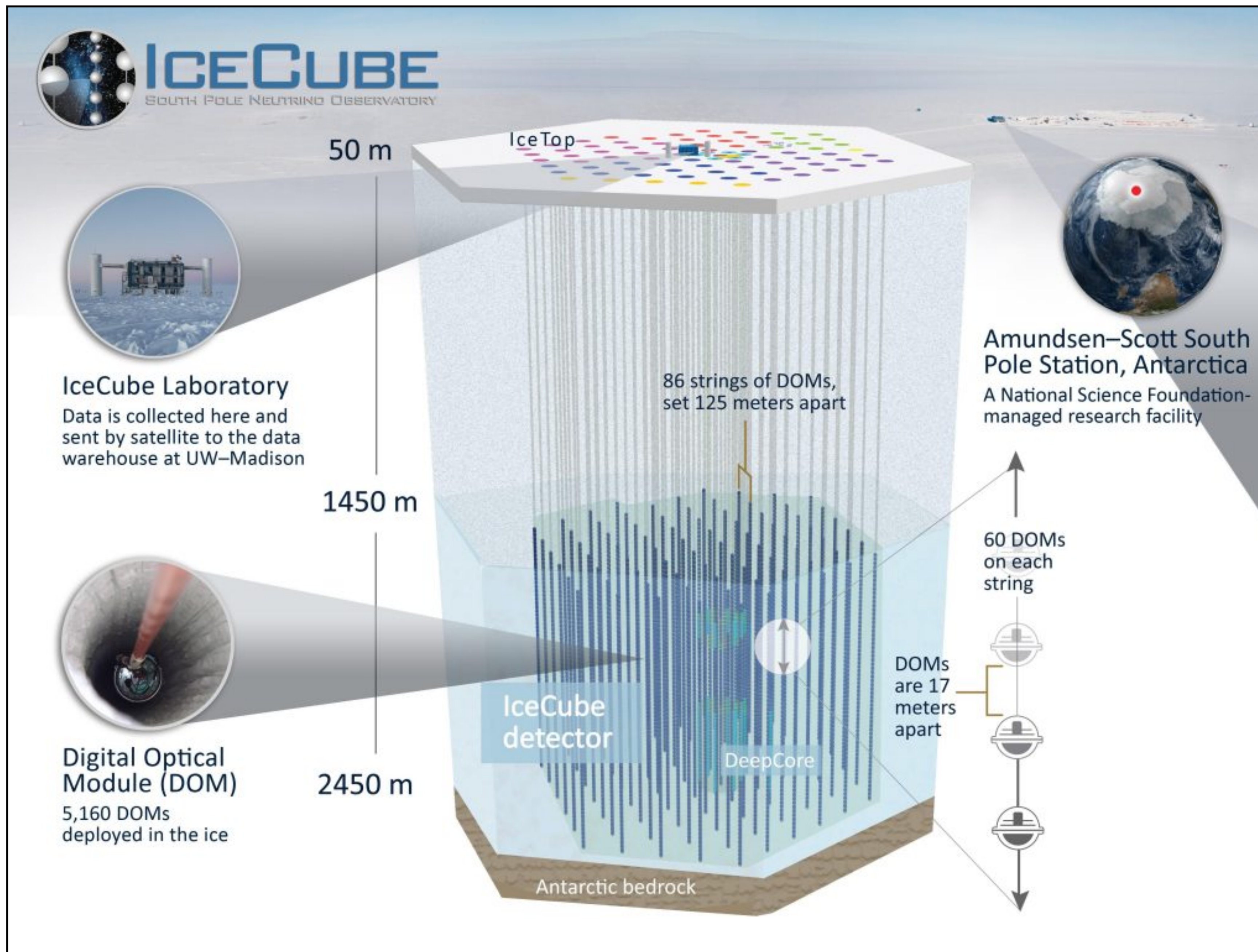
However, the cross section rises with energy



We need a gigaton-scale detector



Neutrino intensity **steeply falls** with energy



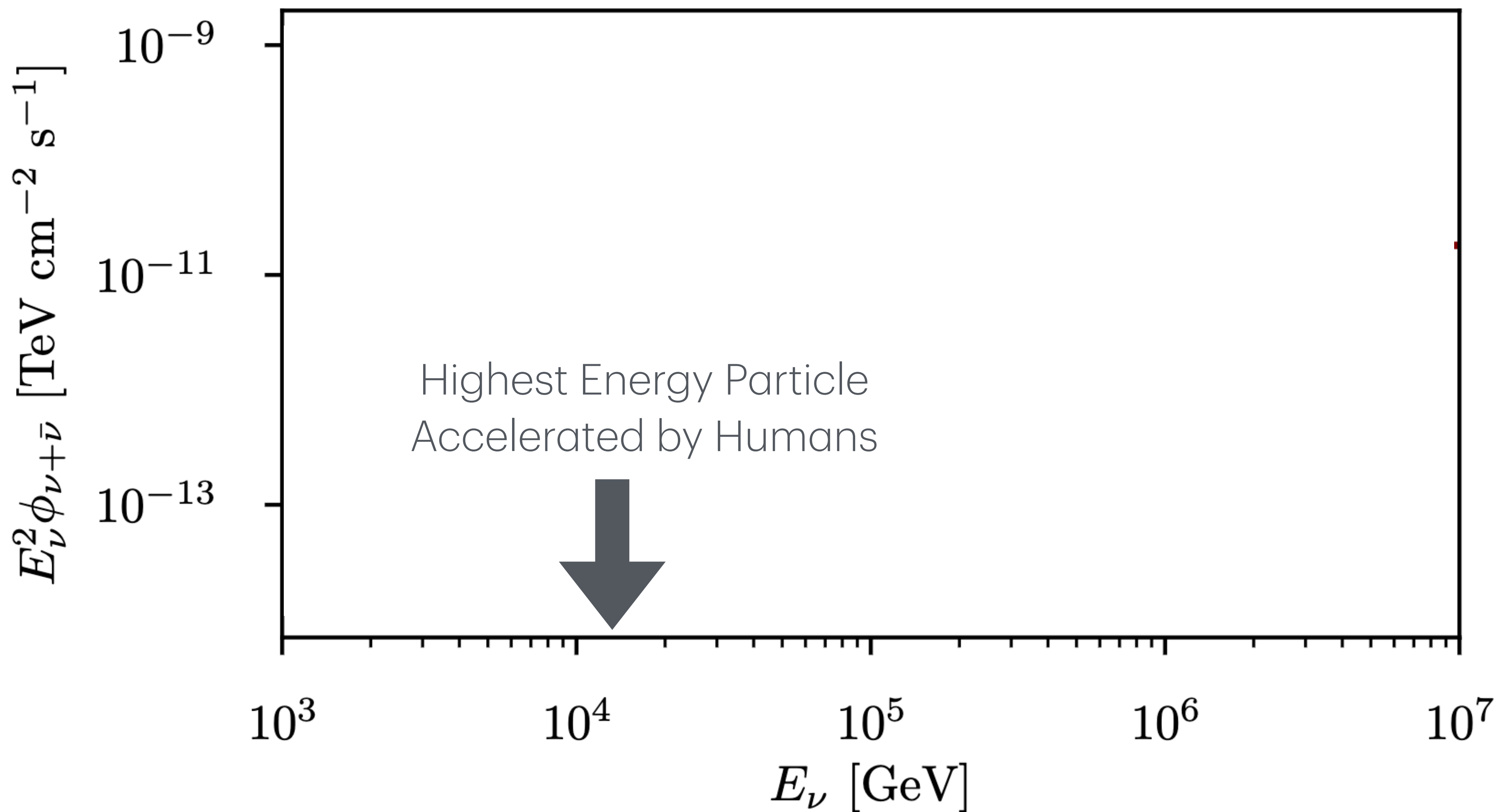
A cubic-kilometer of clear ice instrumented with photo sensors.

~1 Gigaton target mass for neutrinos to interact.

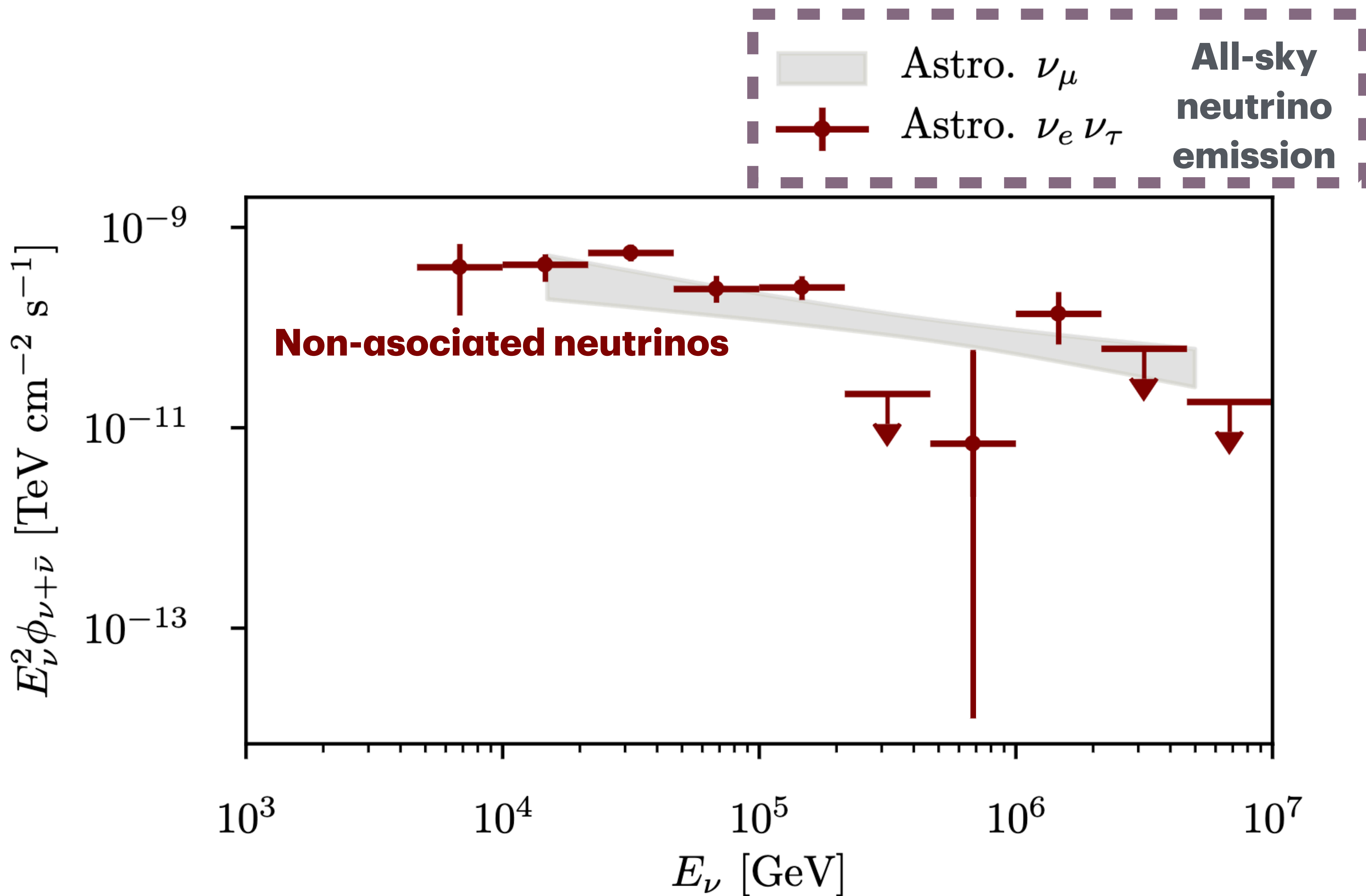
Most significant observations in high-energy neutrino astrophysics

Astrophysical neutrino emission

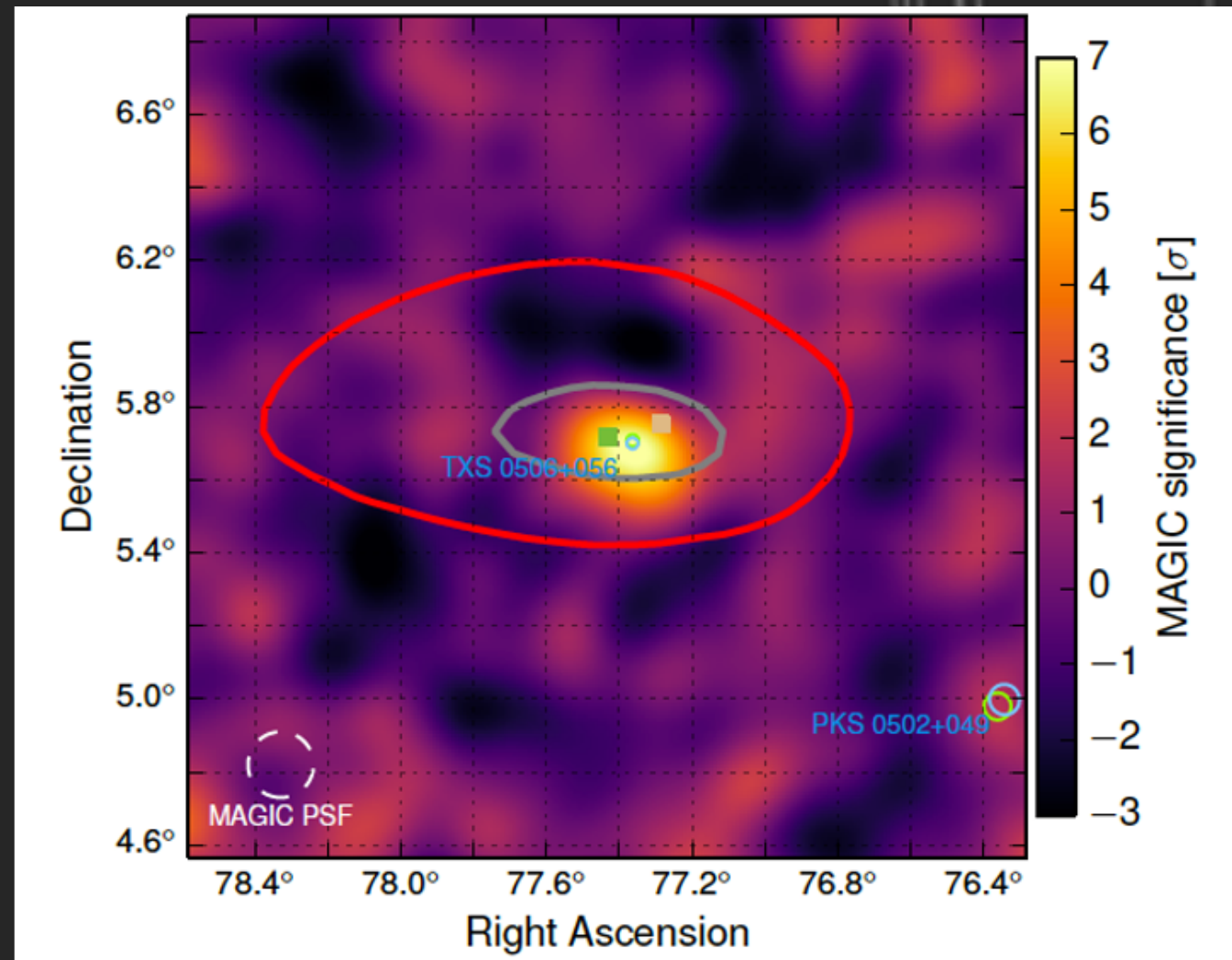
**Intensity of
Neutrino
Emission**



Intensity of Neutrino Emission

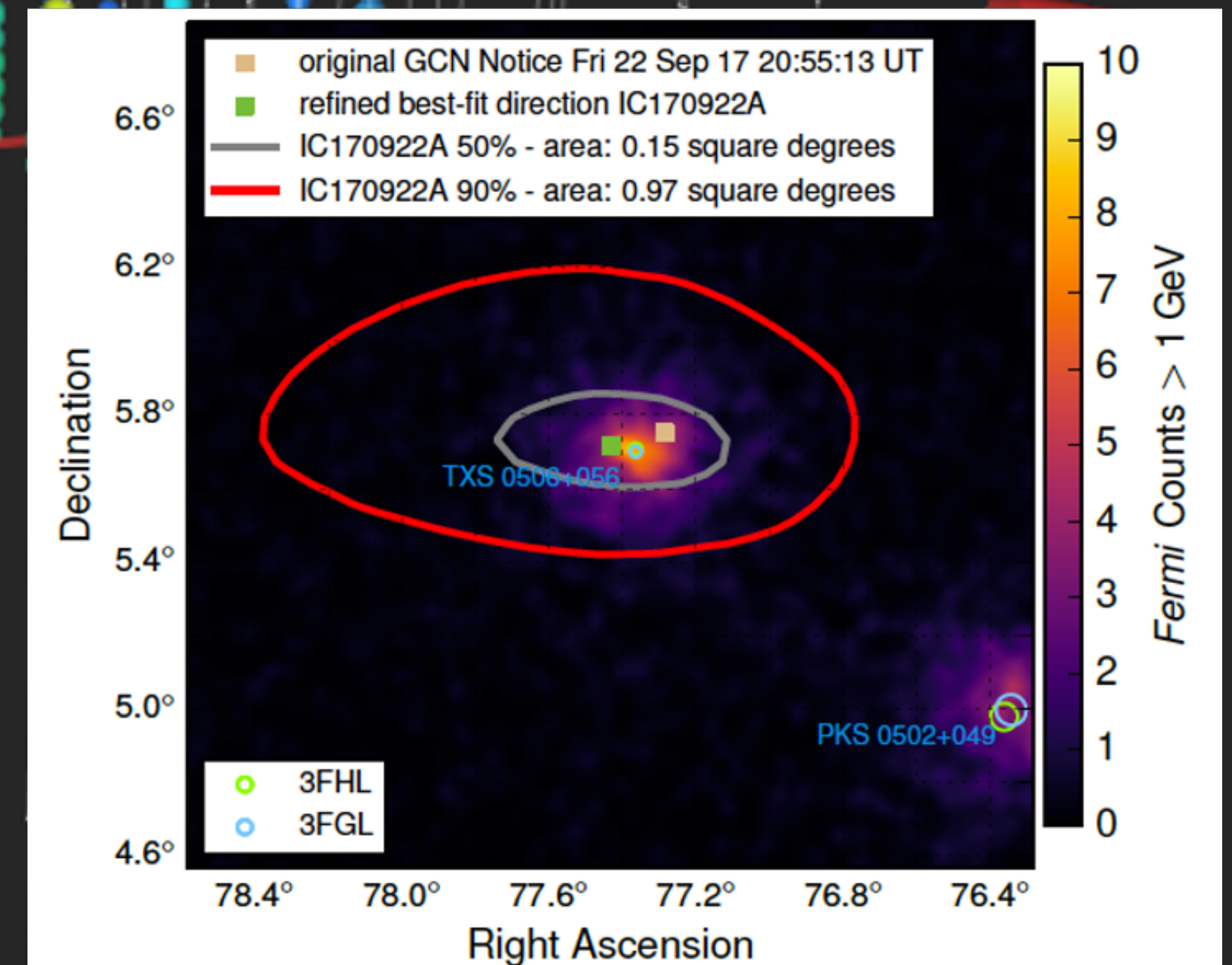


IceCube 170922

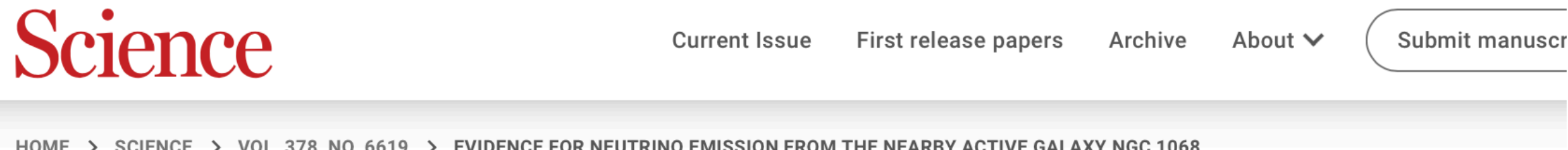


MAGIC
detects emission of
> 100 GeV gammas

Fermi
detects a flaring
blazar within 0.1°

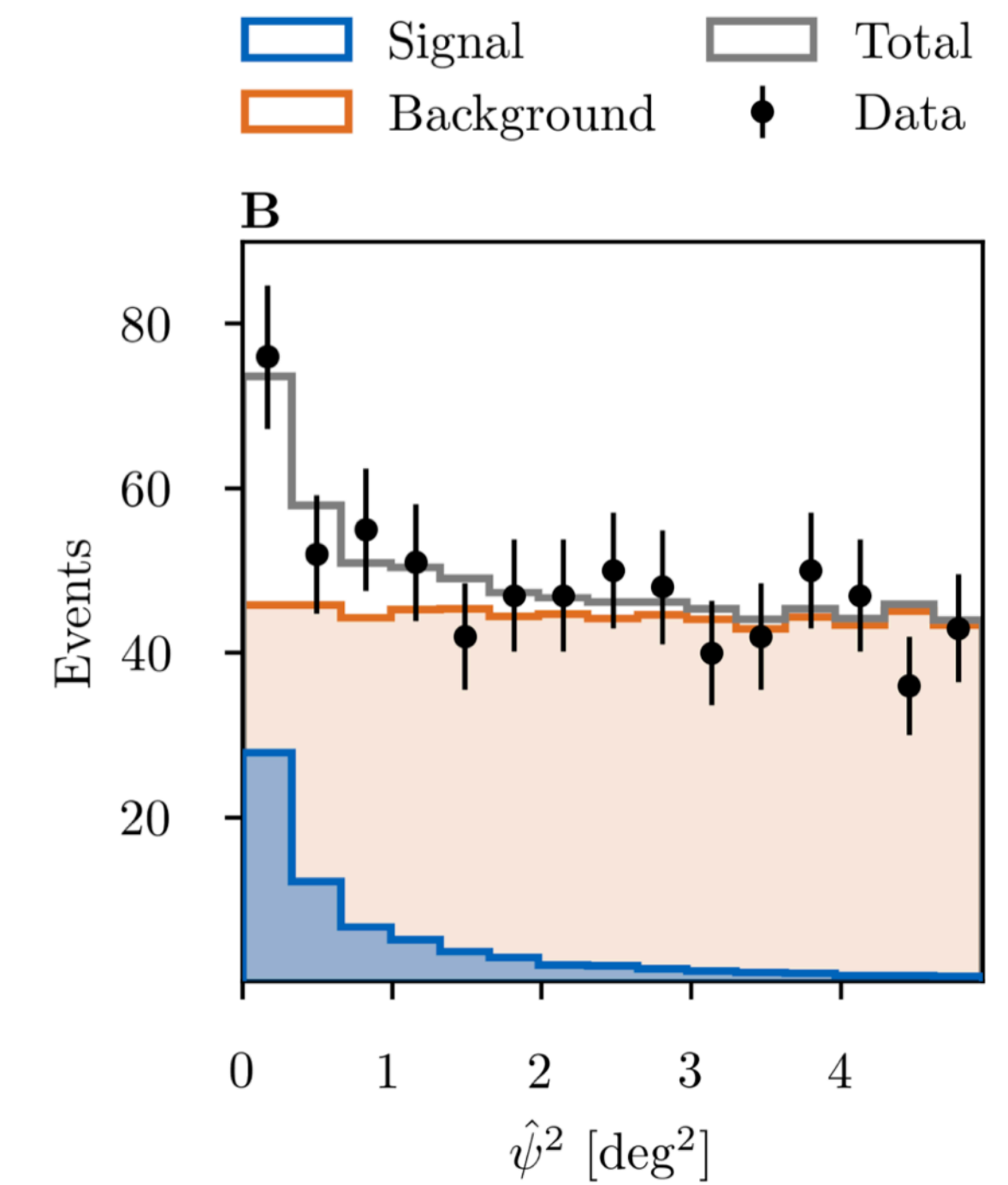
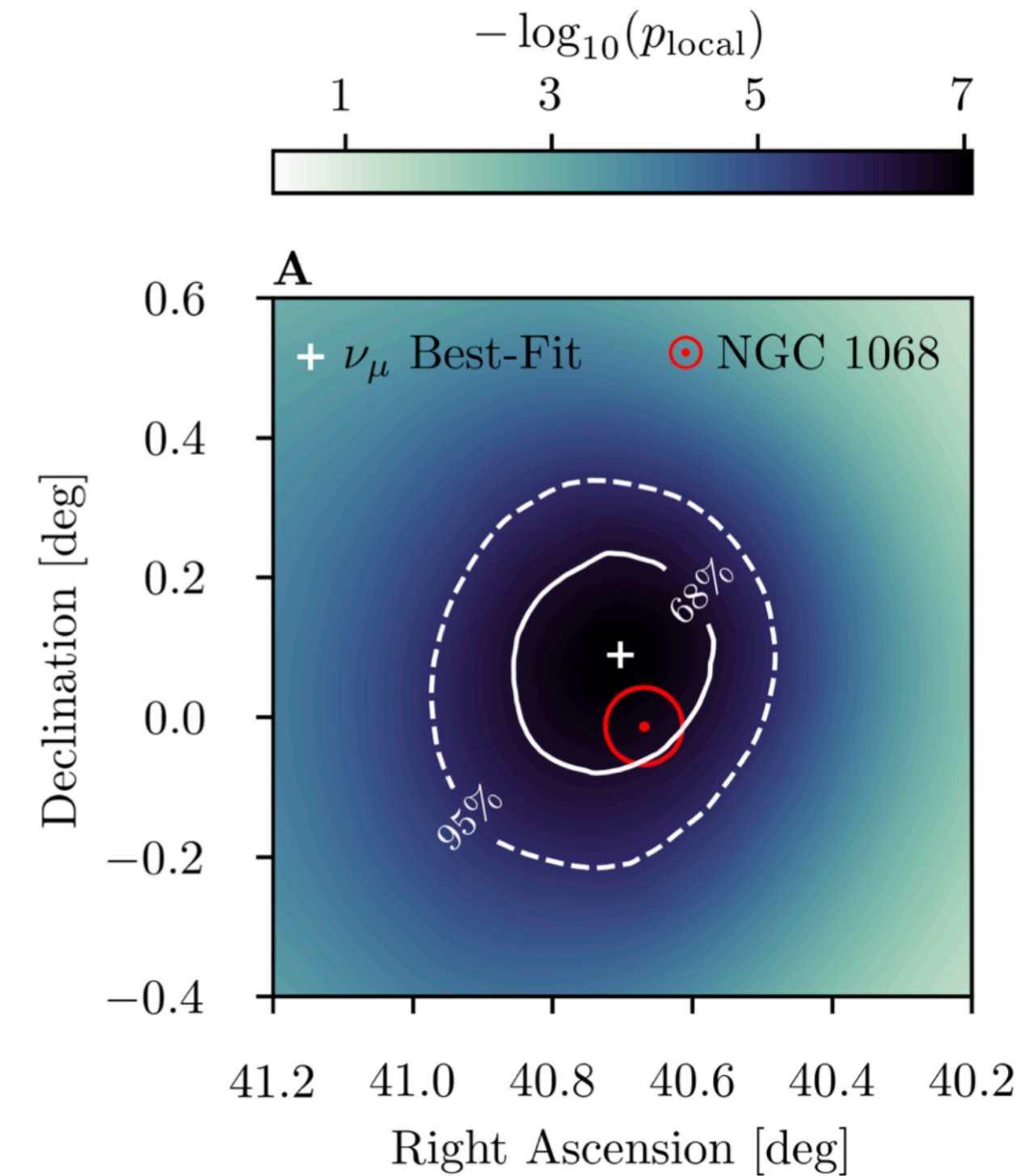
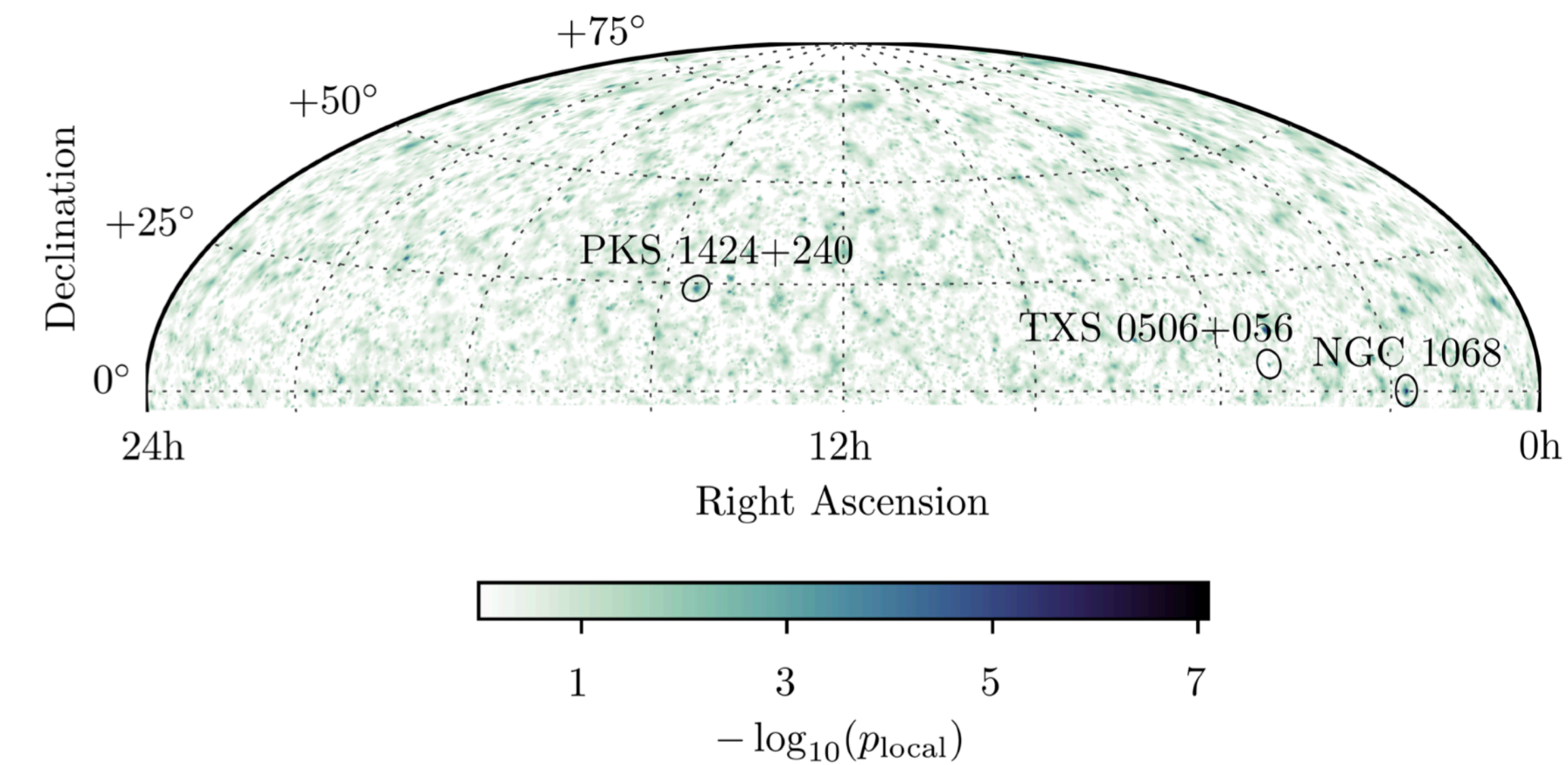


NGC 1068: The brightest Steady Neutrino Emittor In the Nothern Hemisphere

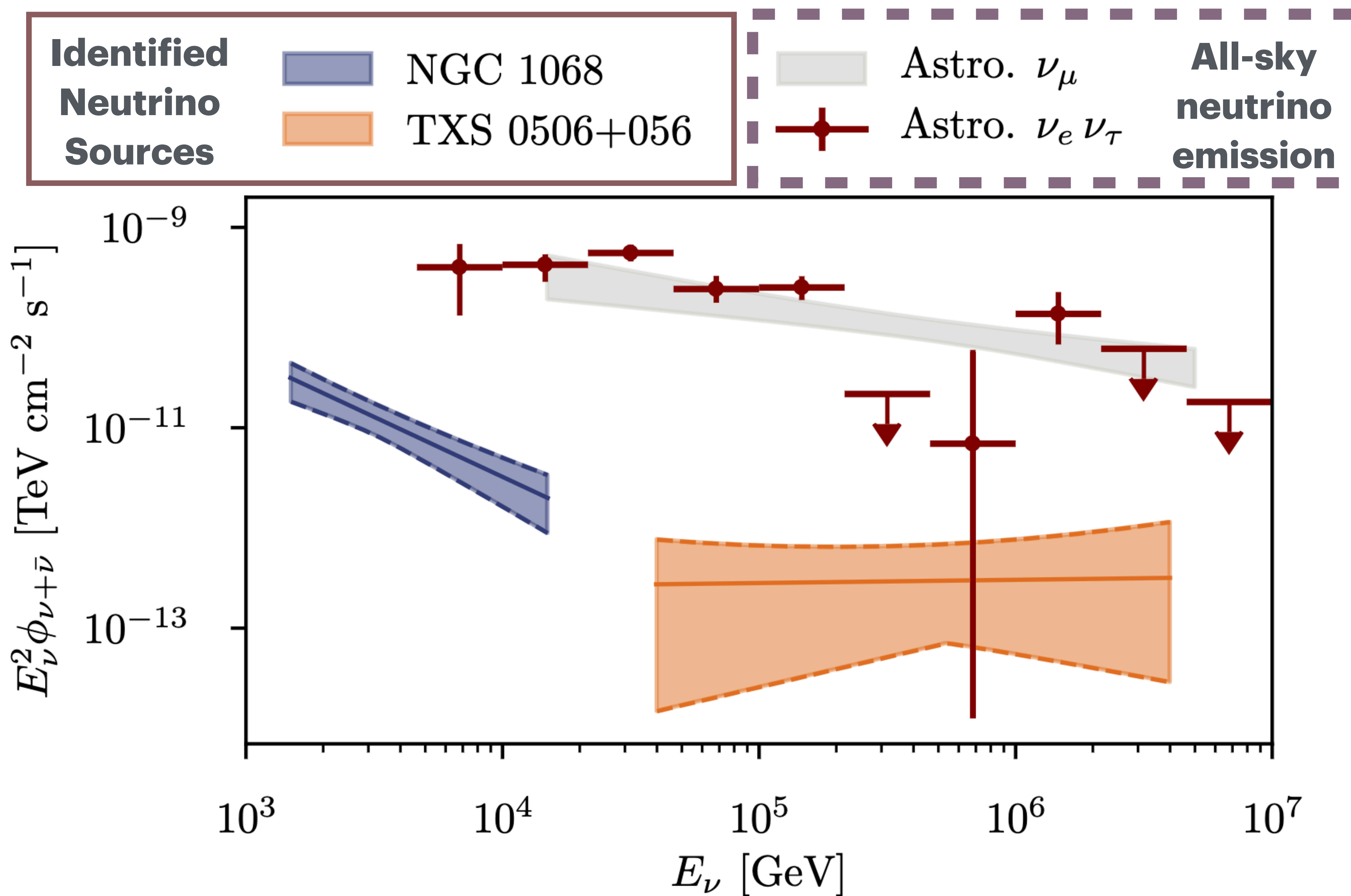


RESEARCH ARTICLE | NEUTRINO ASTROPHYSICS

Evidence for neutrino emission from the nearby active galaxy NGC 1068

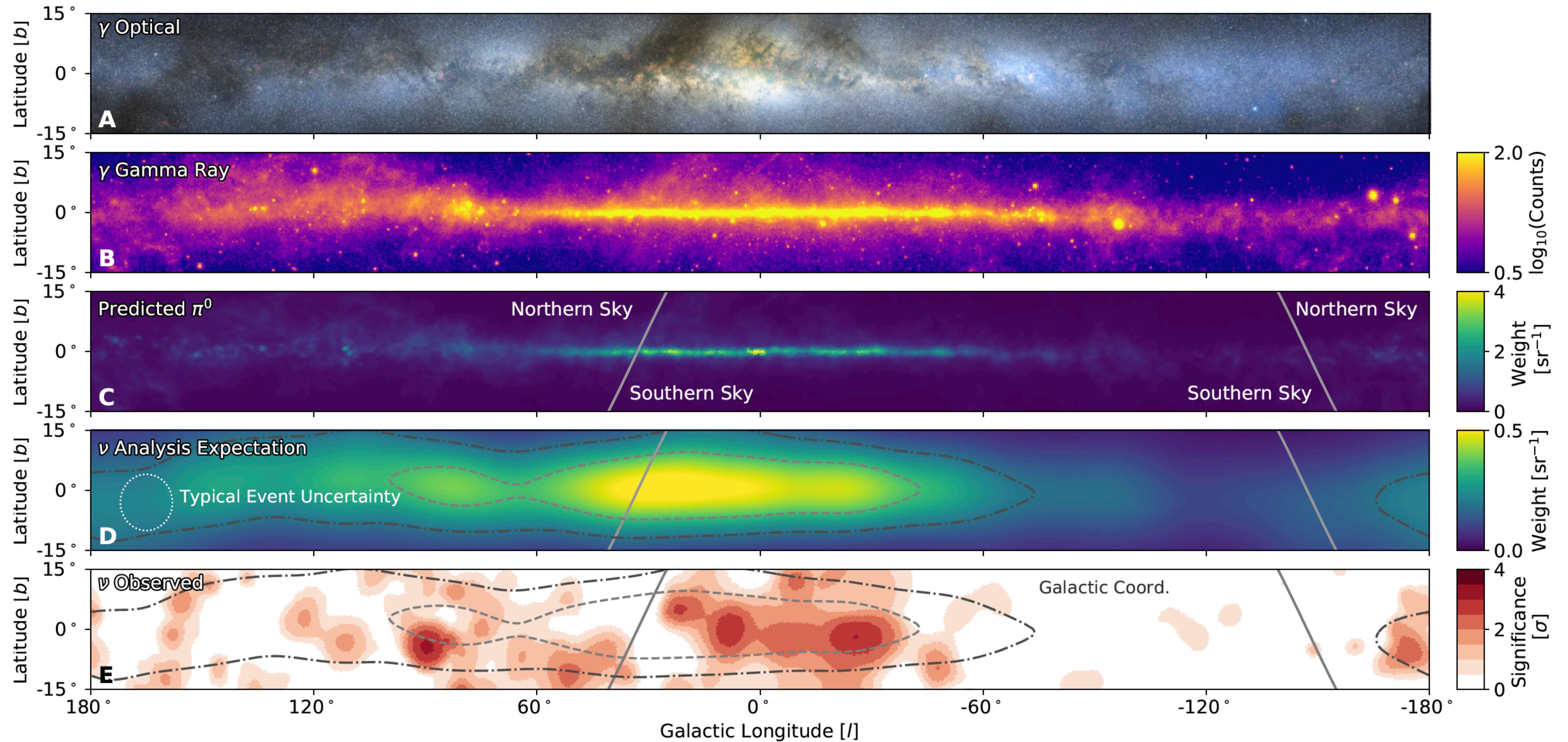


Intensity of Neutrino Emission



Neutrinos from Our Galaxy

IceCube Collaboration, Science, 2023



Identified Neutrino Sources



Galactic
Neutrinos



NGC 1068



TXS 0506+056

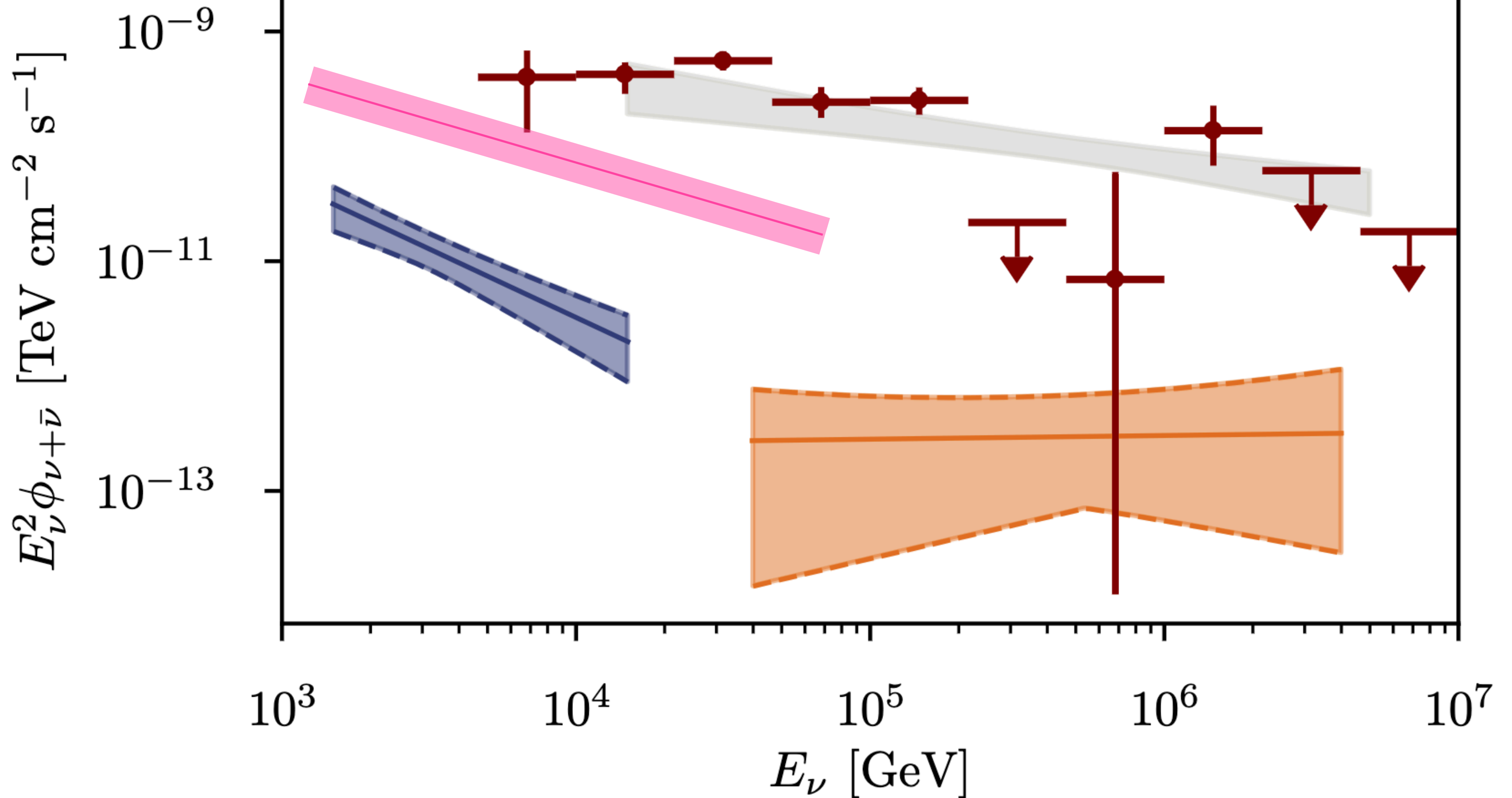


Astro. ν_μ



Astro. $\nu_e \nu_\tau$

Intensity of Neutrino Emission

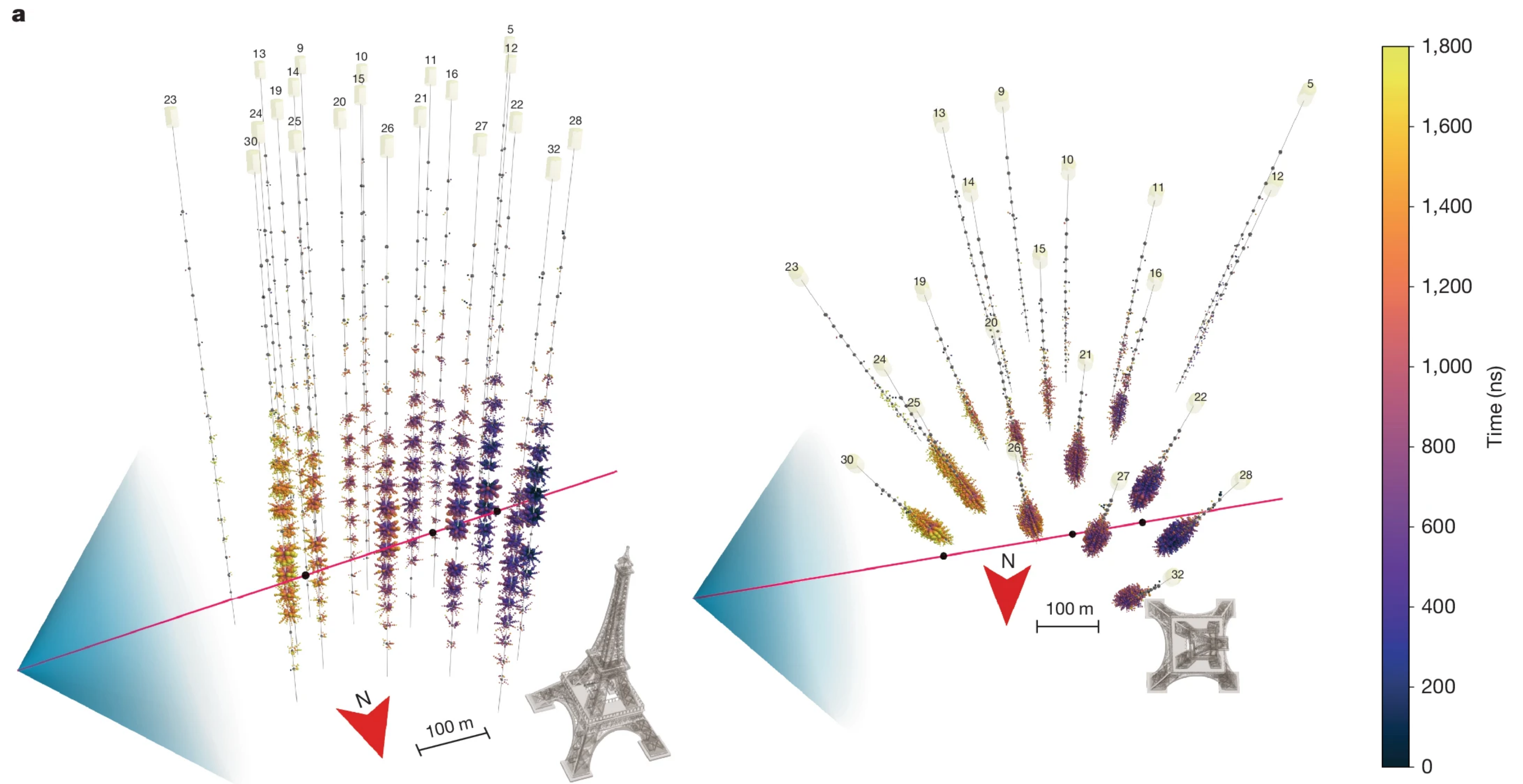


Observation of KM3-230213A

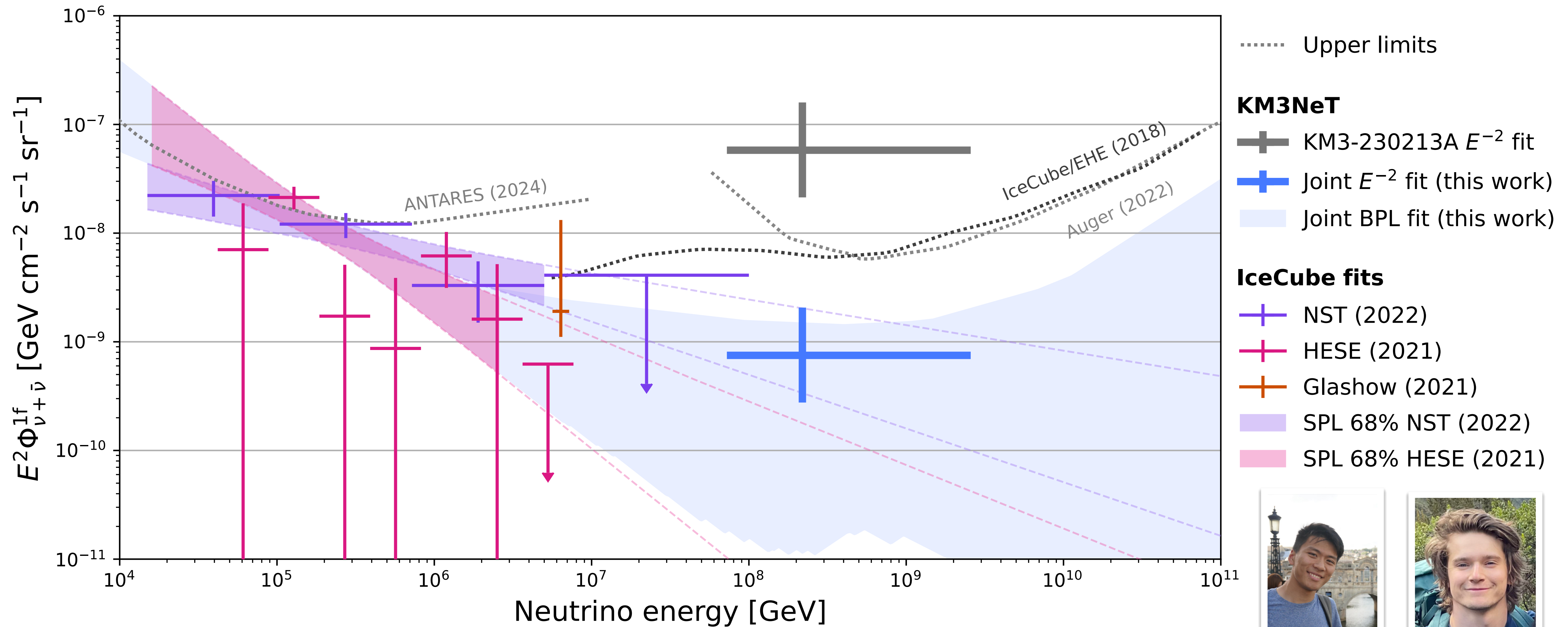
$$E_{\mu} = 120^{+110}_{-60} \text{ PeV} \implies E_{\nu} \gtrsim 100 \text{ PeV!}$$



Nature Volume 638 Issue 8050



KM3-230213A Within the Global Landscape



KM3NeT, *Phys. Rev. X* 15, 031016



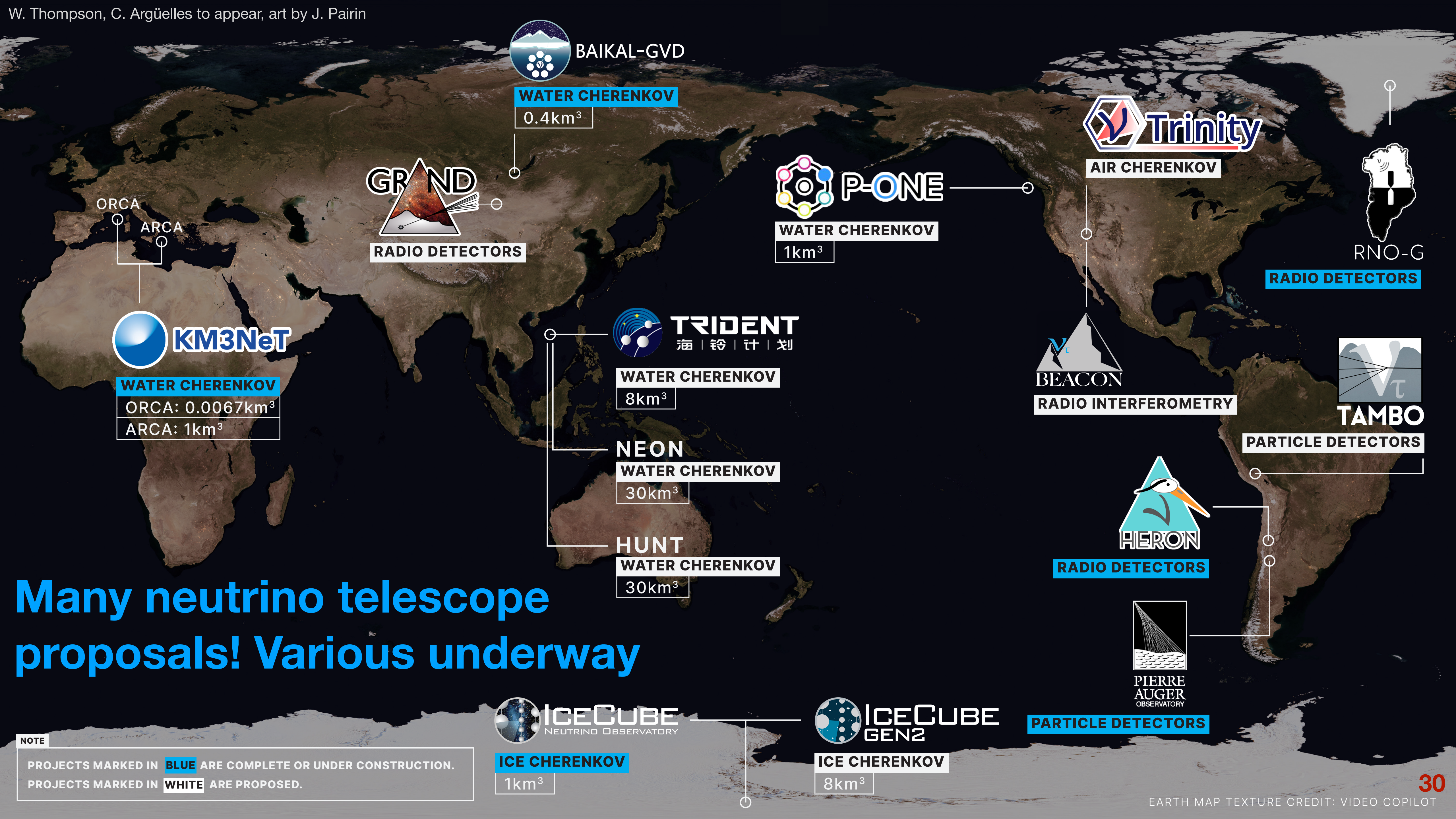
Alex Wen



Nick Kamp

Open questions in high-energy neutrino astrophysics

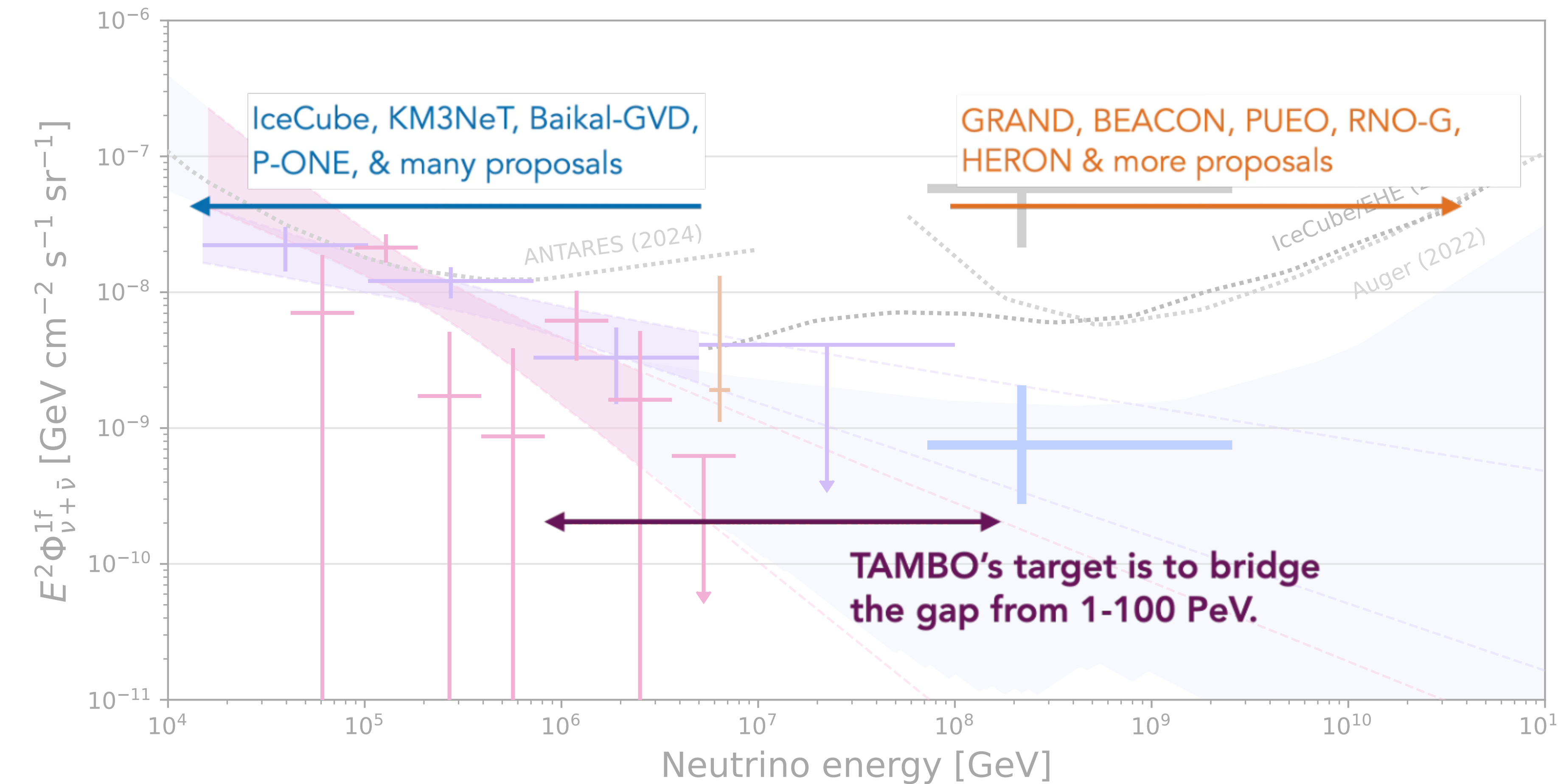
- What are the dominant sources of the IceCube-observed neutrino flux?
- What is the connection between the neutrino and light observations?
- What is going on at ultra-high energies? Are we seeing “cosmogenic neutrinos”?
- What is the flavor composition of neutrinos at different energies?
- Are there sources in the galactic neutrino emission?



Many neutrino telescope proposals! Various underway

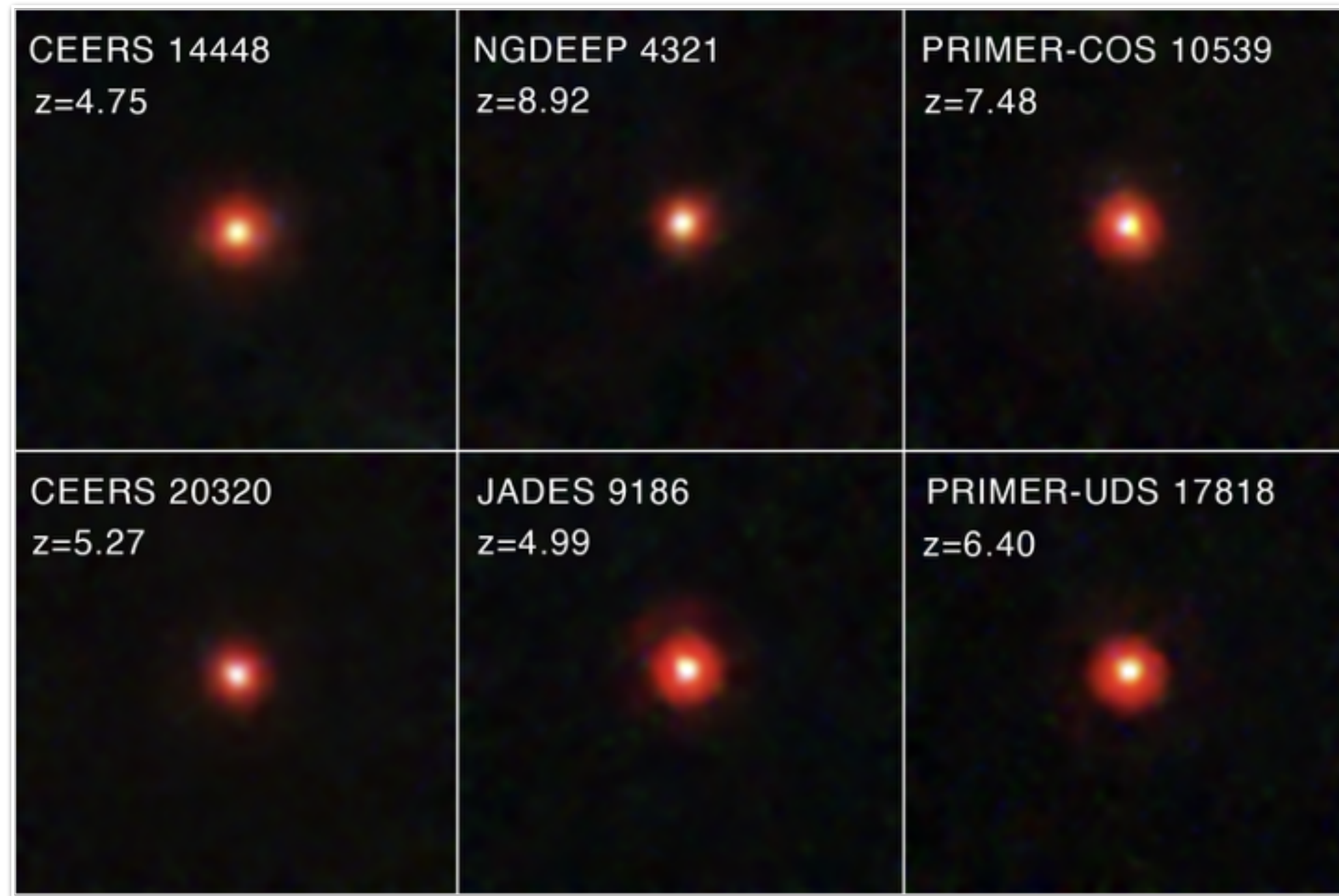
NOTE
PROJECTS MARKED IN **BLUE** ARE COMPLETE OR UNDER CONSTRUCTION.
PROJECTS MARKED IN **WHITE** ARE PROPOSED.

TAMBO in context

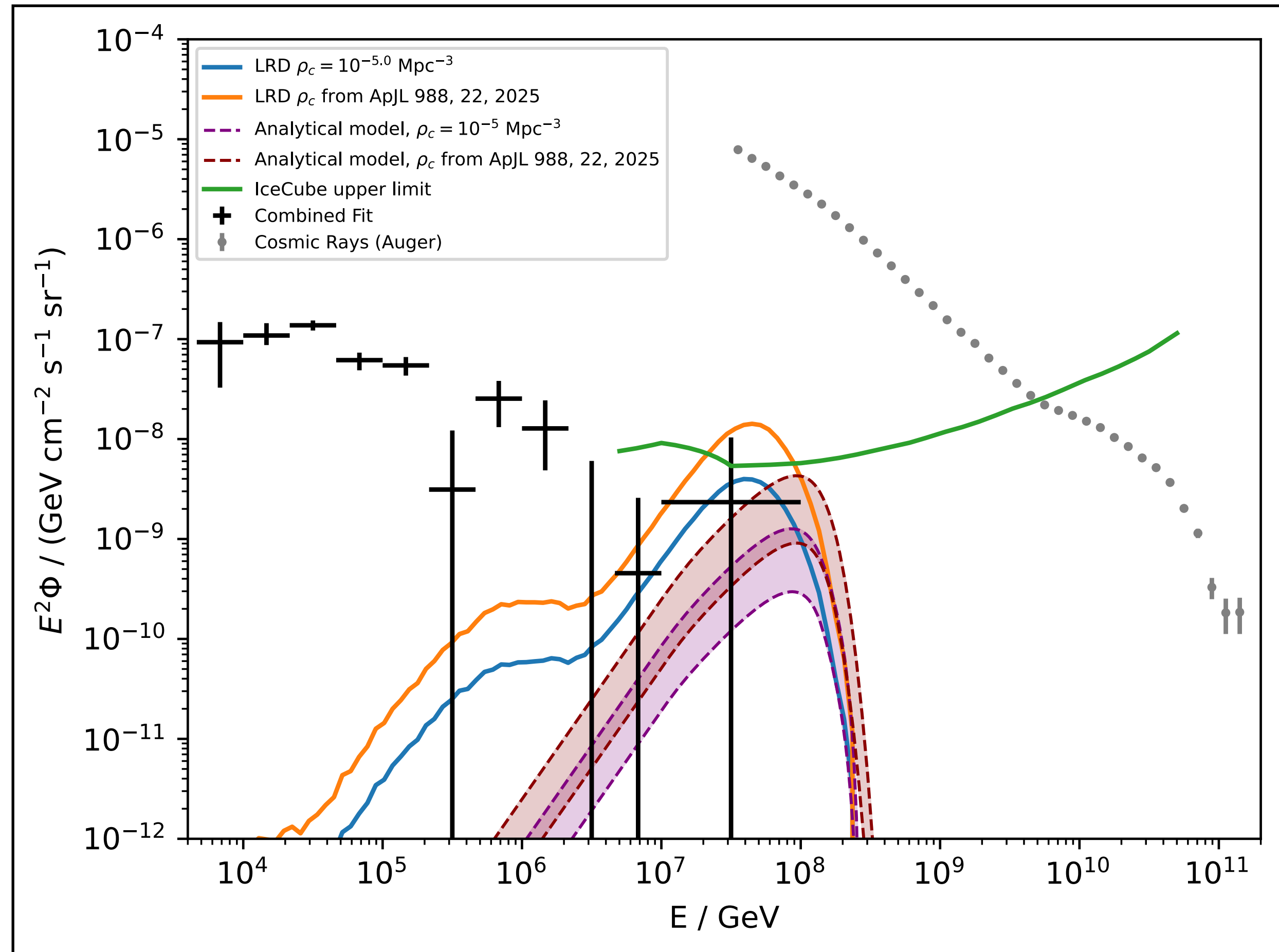


- Traditional neutrino telescopes target ≈ 1 PeV
- Radio-based telescopes planned at ≈ 100 PeV
- Fewer in 1-100 PeV range

Potential sources for TAMBO

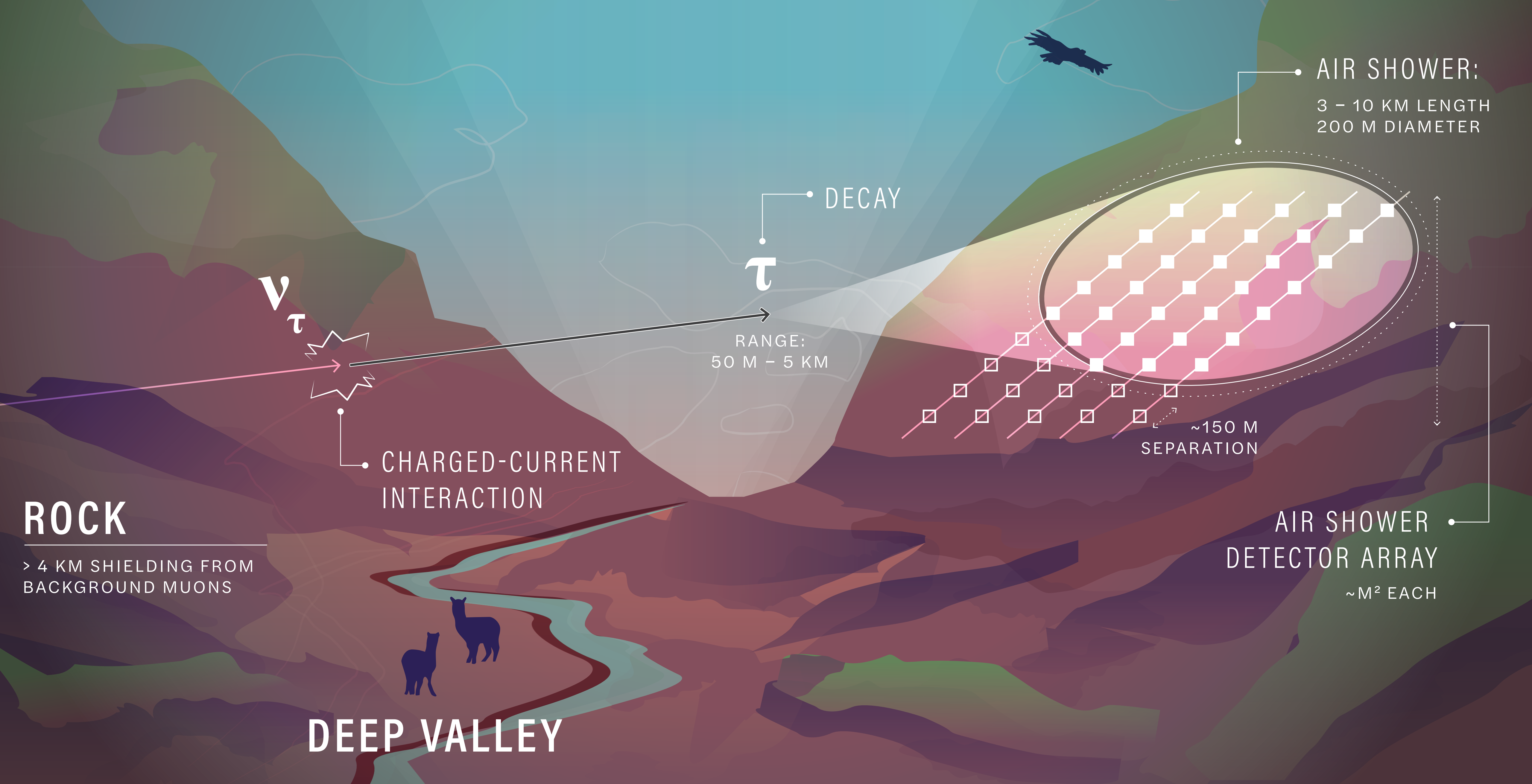


“Little red dots” discovered by JWST in 2024, $5 \lesssim z \lesssim 10$

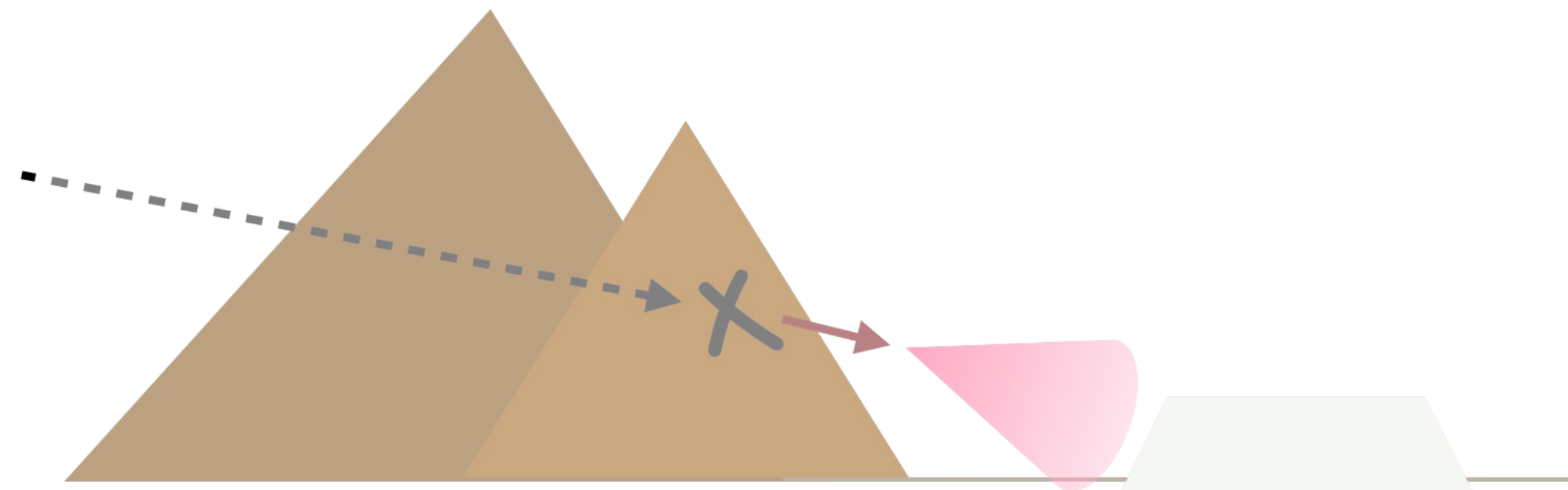


Kuze et al. *Phys.Rev.D* 113 (2026) 083048

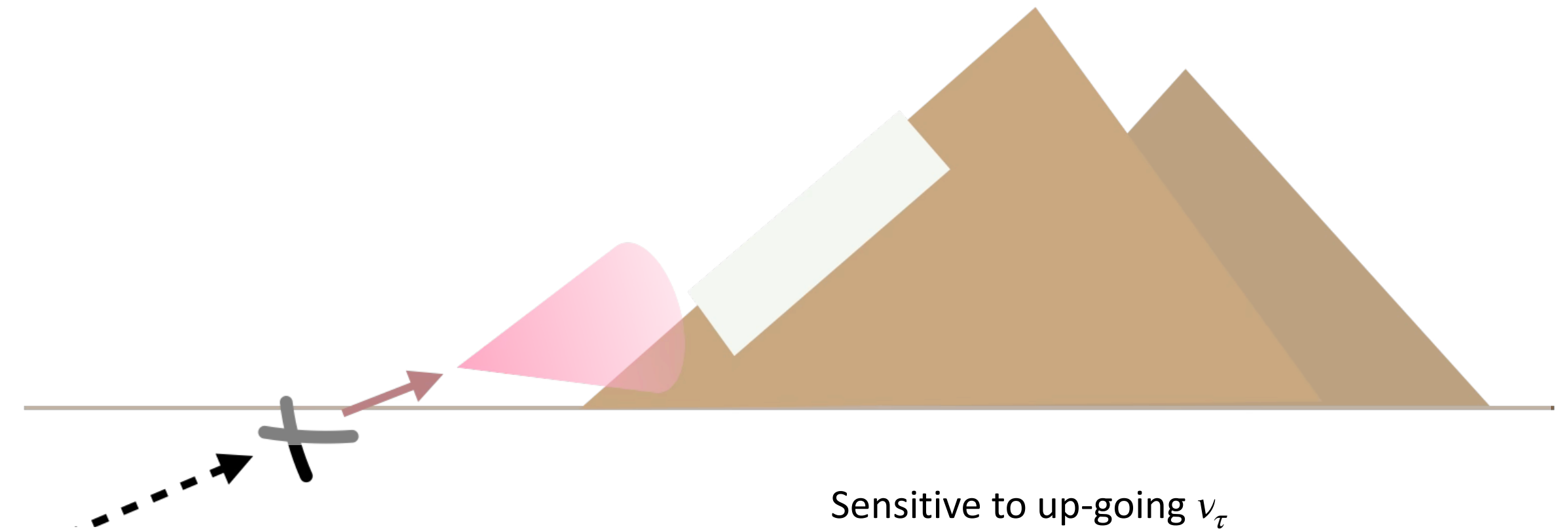
Carlos A. Argüelles — Harvard University, 2026



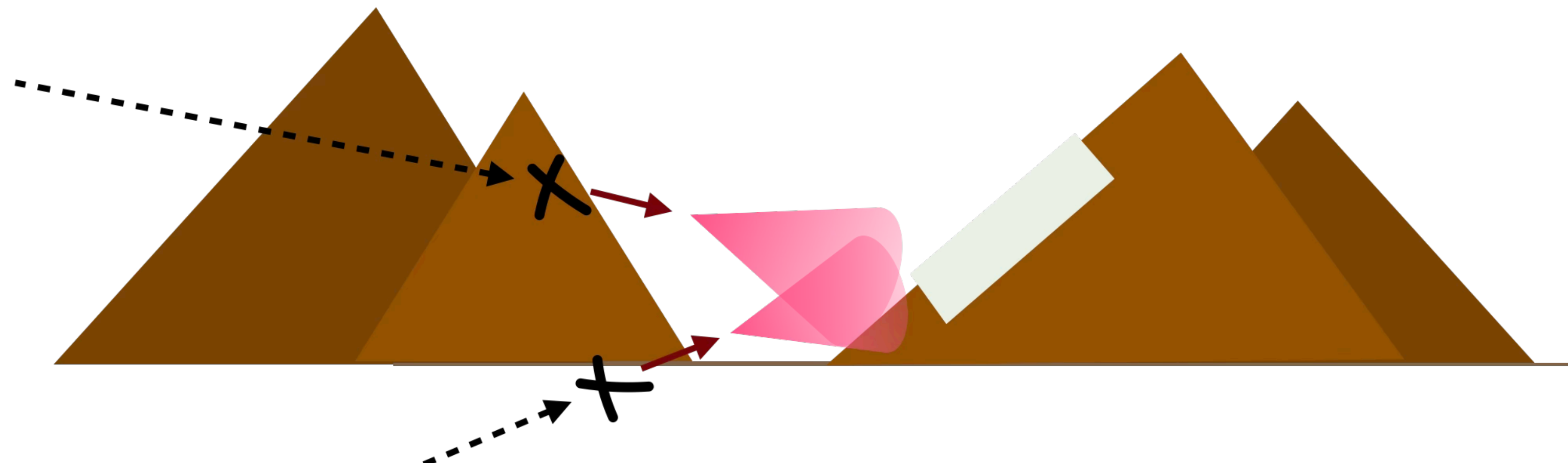
Why are we in a canyon?



Sensitive to down-going ν_τ



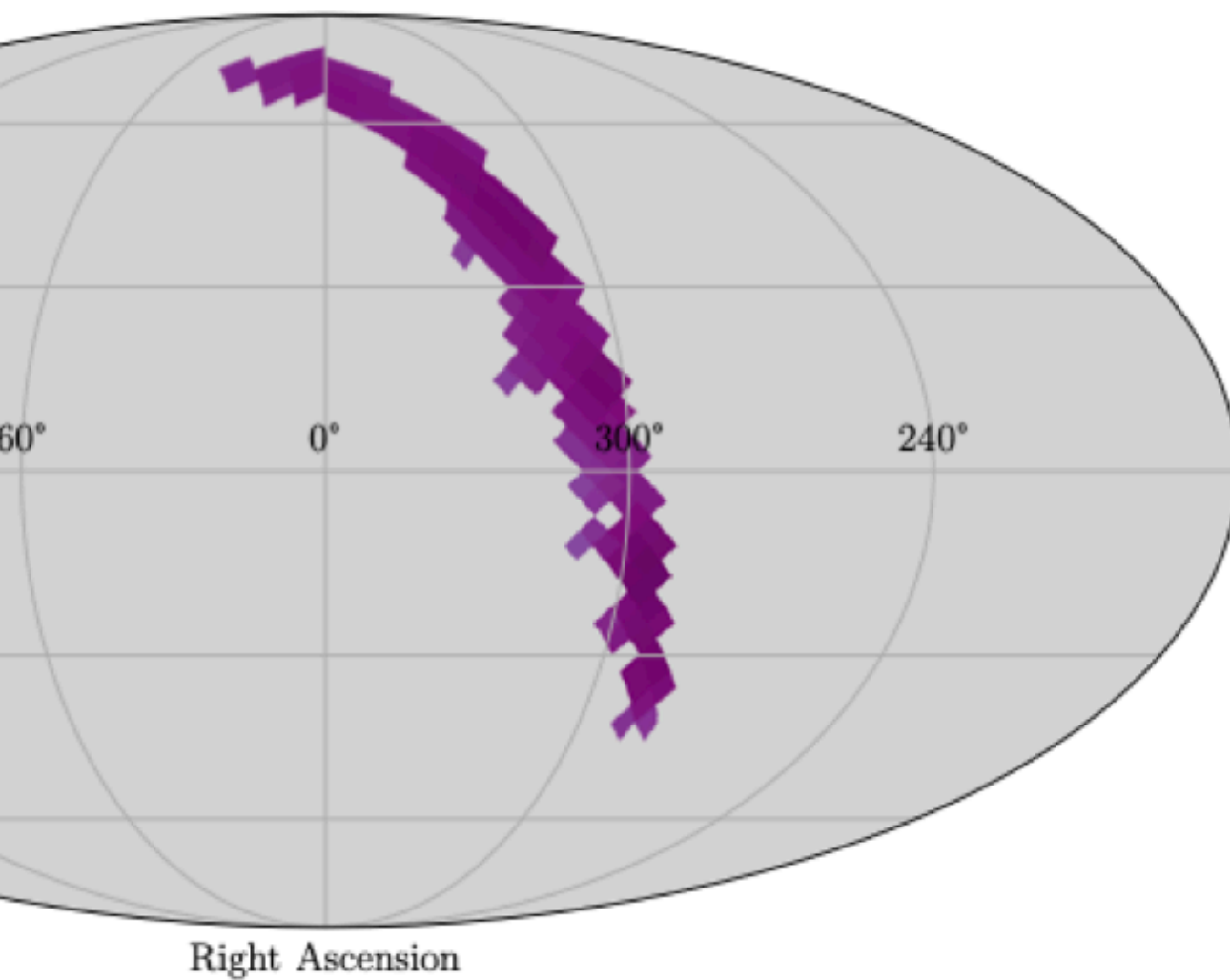
Sensitive to up-going ν_τ



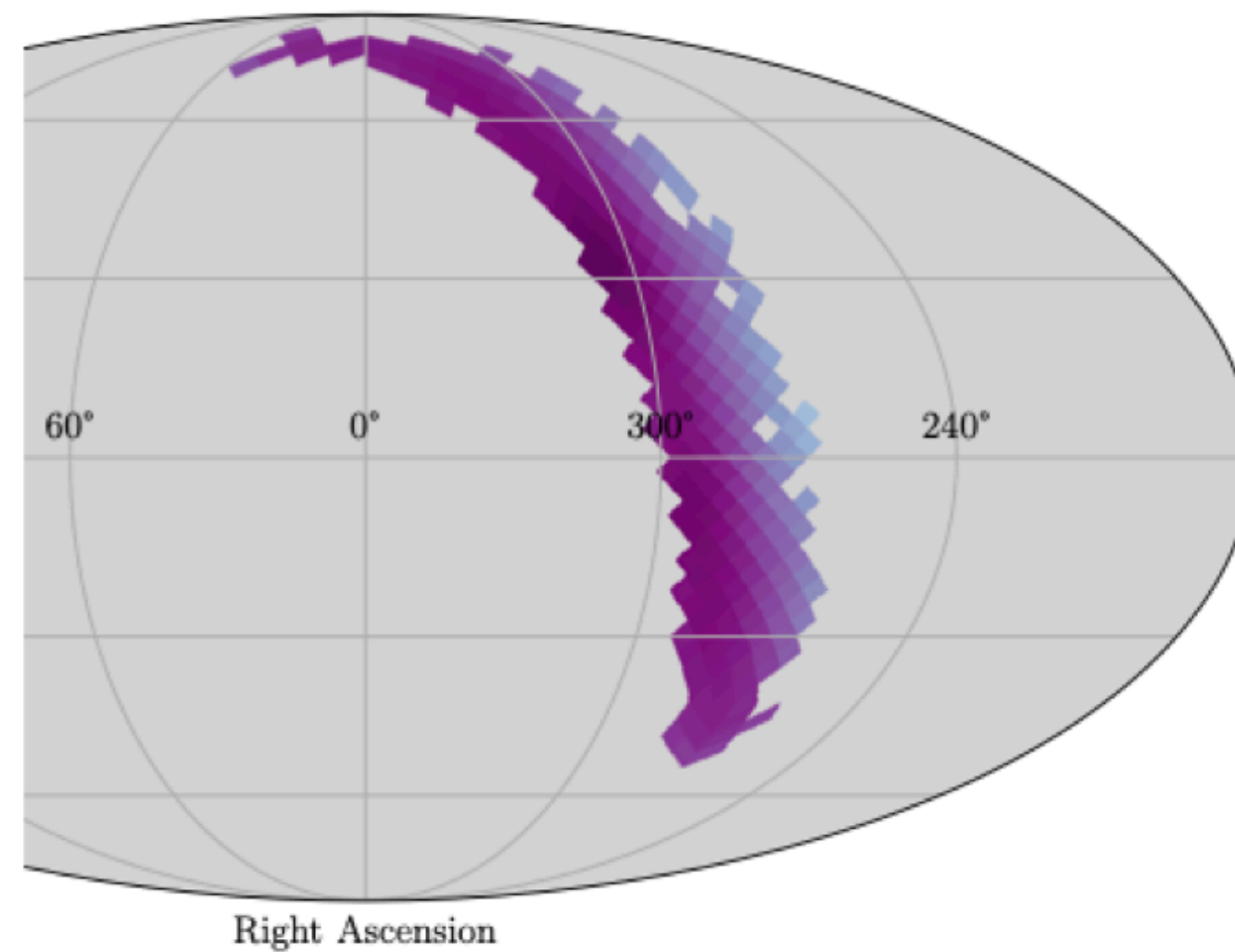
A canyon detector is sensitive to up- and down-going ν_τ

Why are we in a canyon?

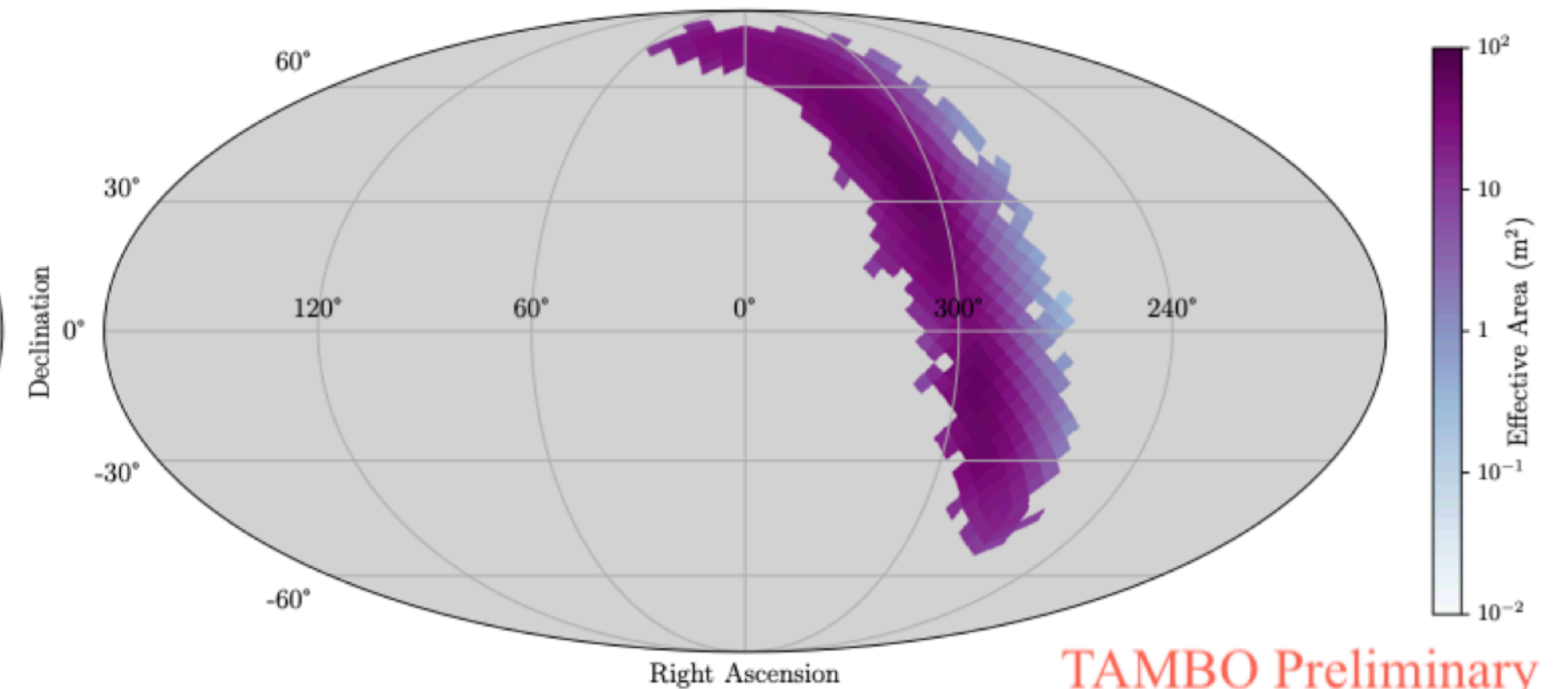
Down-going



Up-going



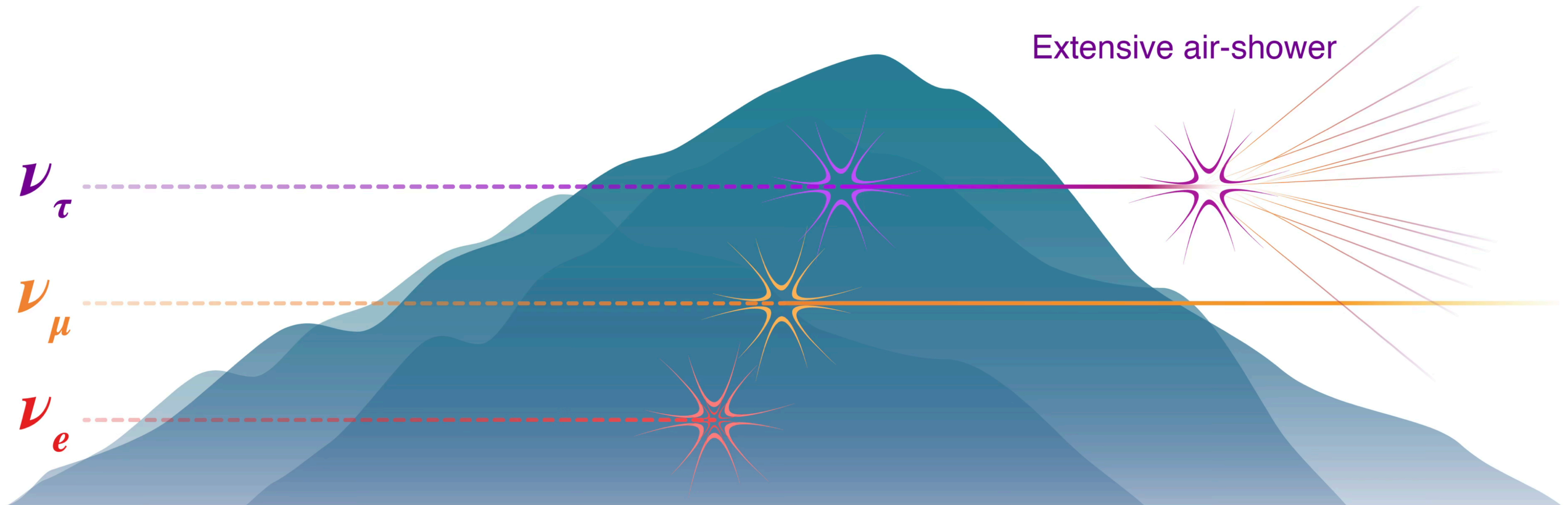
Full acceptance



TAMBO Preliminary

Canyon-based arrays maximize sky acceptance

Why are we predominantly a tau-neutrino experiment?



All flavors have same interaction probability, but:

- Electrons shielded by canyon
- Muons are very good at retaining energy
- Only τ efficient at creating shower

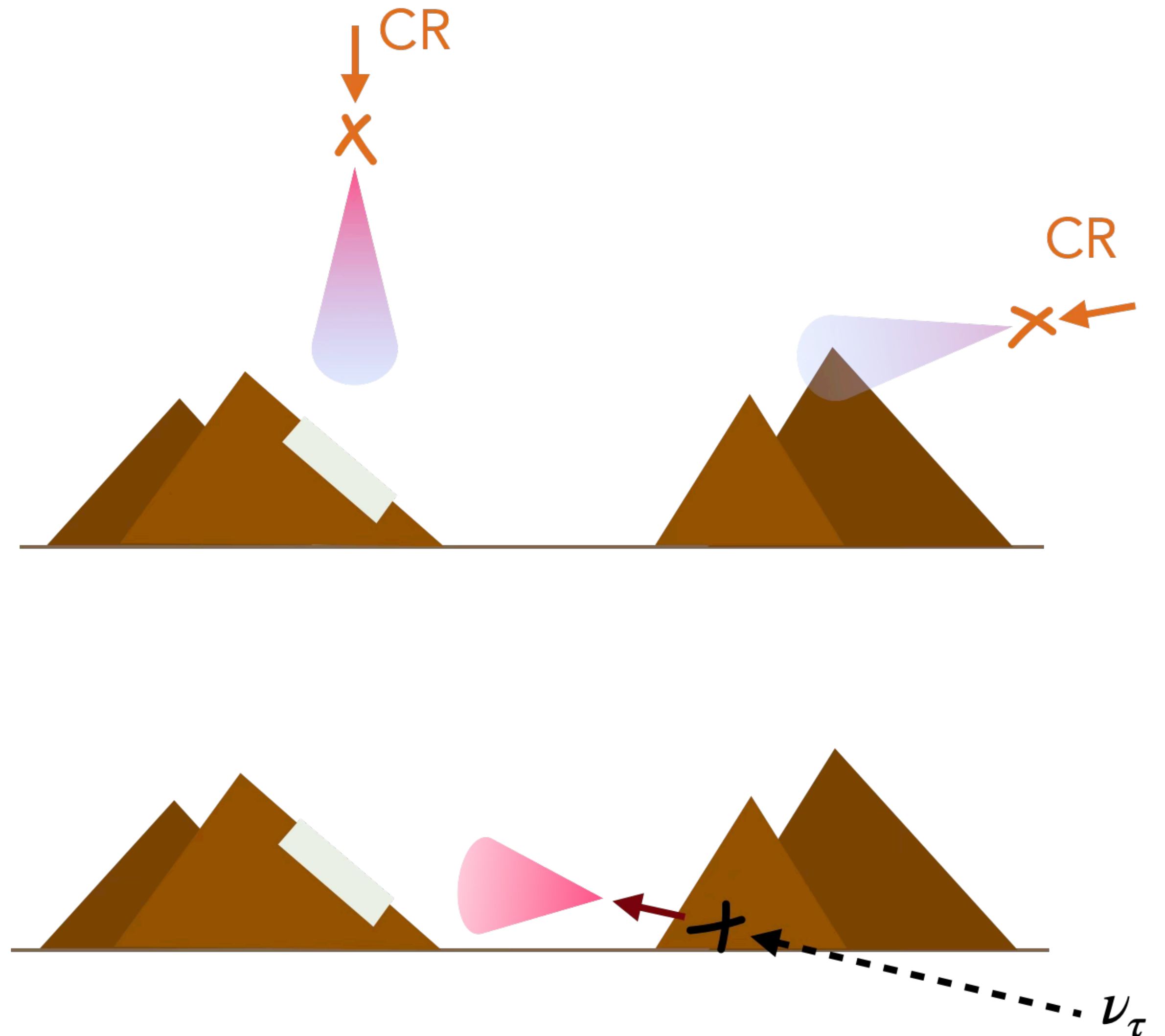
Canyon shields you from cosmic rays showers

Backgrounds dominate neutrino telescopes:

- $1:10^9$ signal to cosmic ray background in IceCube

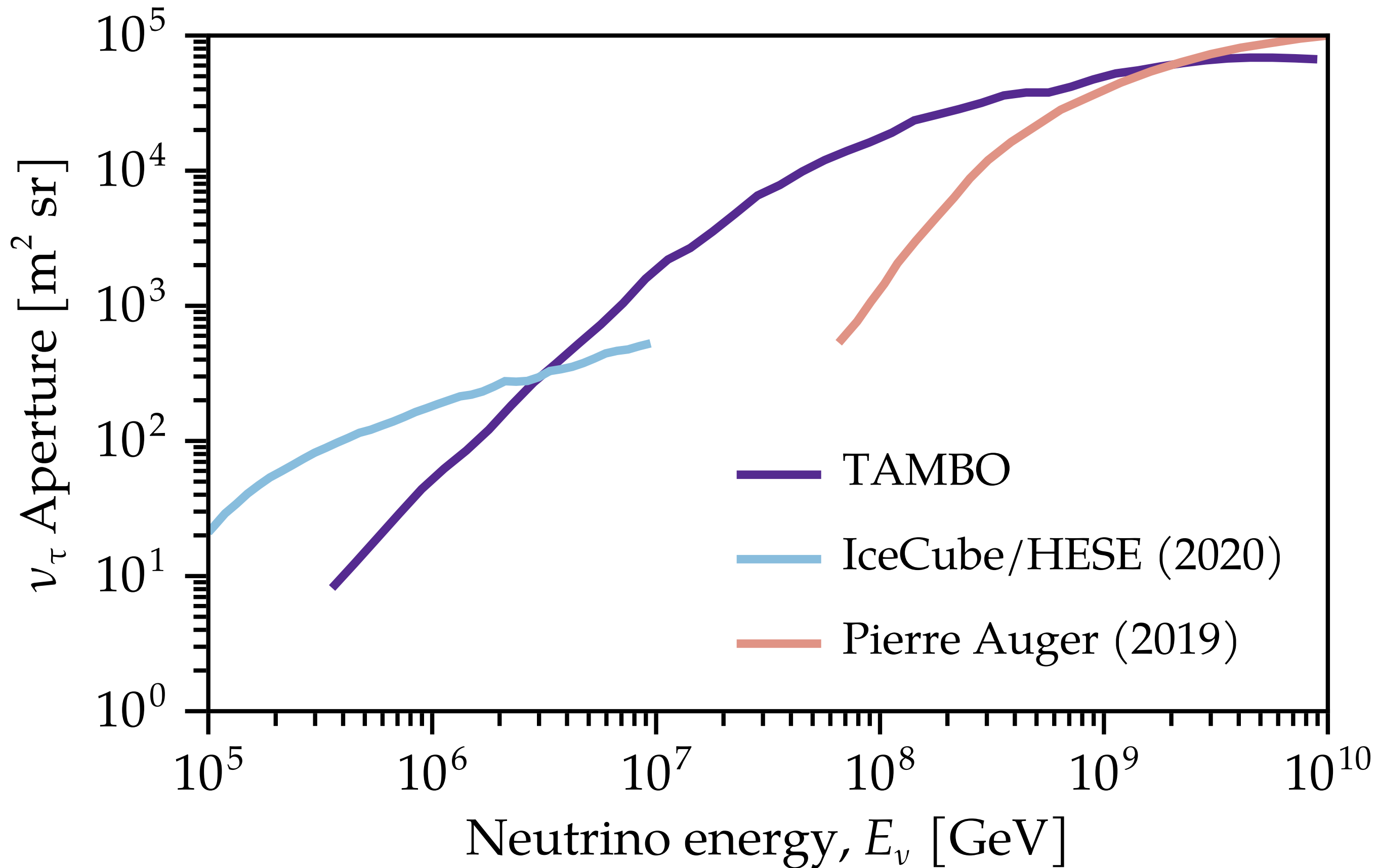
Cosmic ray background shielded by canyon

But what about muon backgrounds?

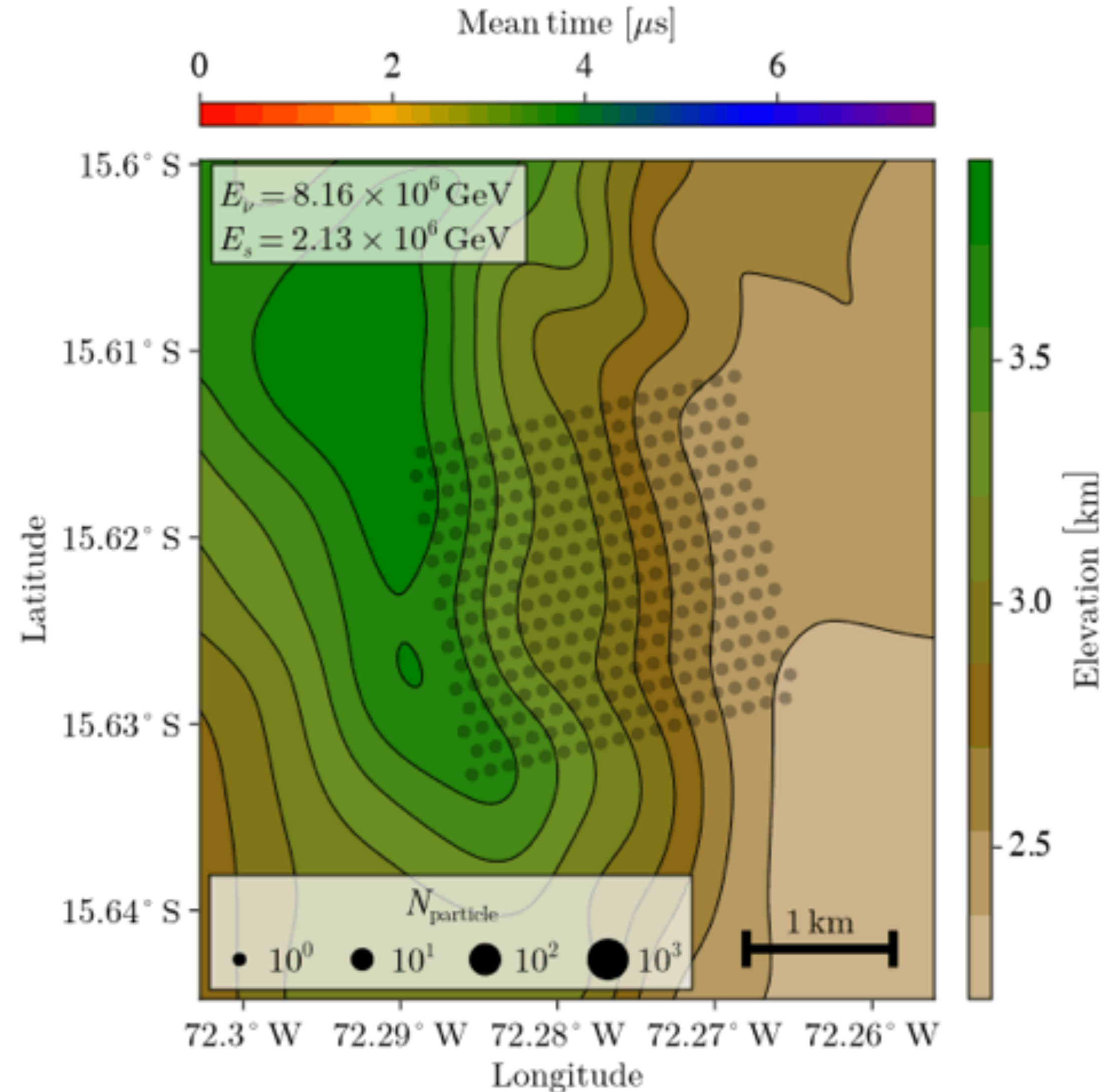


TAMBO: An ultra-high-energy neutrino telescope

Design goal: Aim to go as low as possible in energy: 1 PeV to 100 PeV range

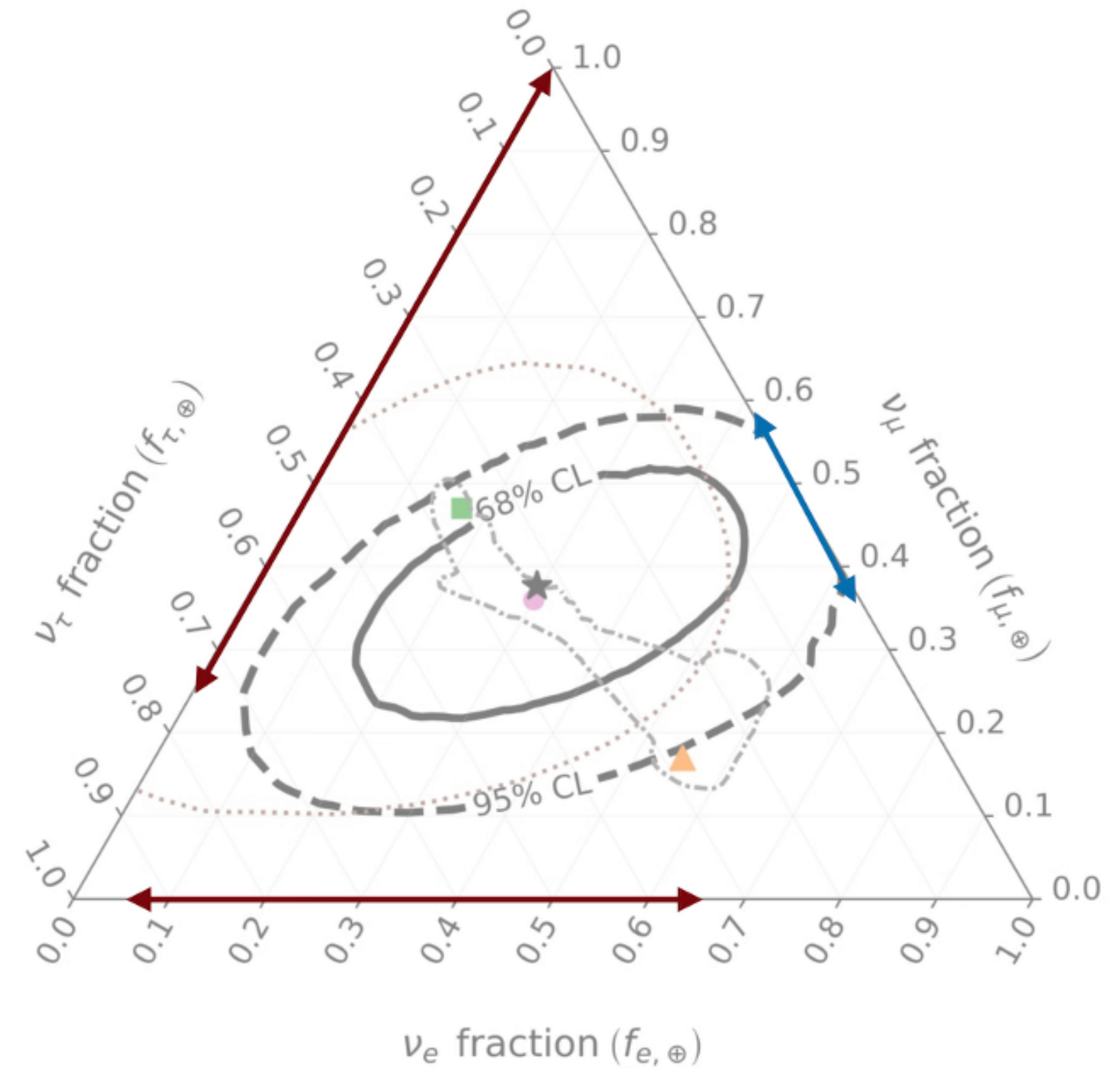


With ~ 5000 modules we have comparable or greater effective areas for identified taus

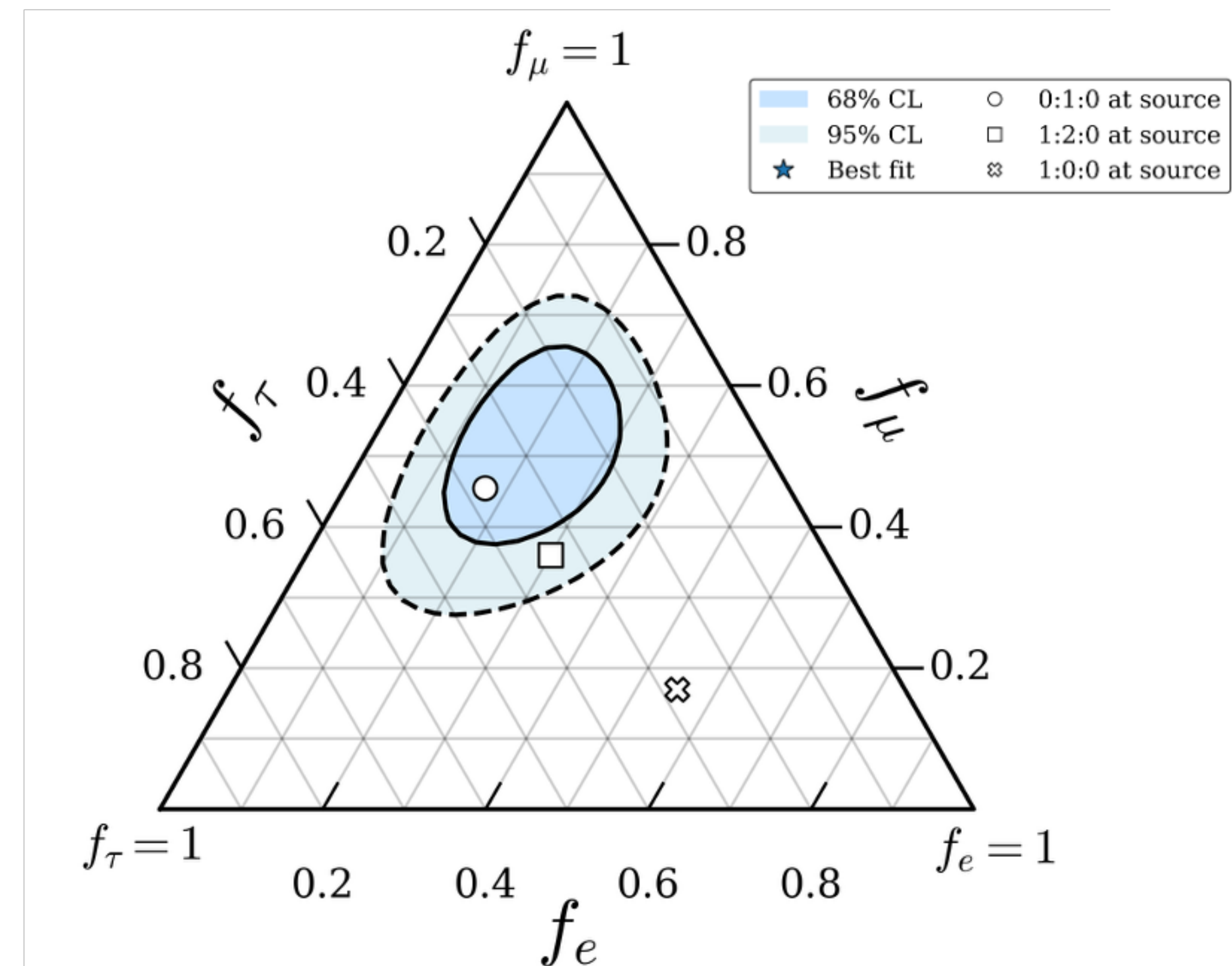


TAMBO will bring unique ways to learn about flavor

TAMBO's detection principle breaks the ν_τ/ν_e flavor degeneracy



IceCube only, all energies



TAMBO with other next-gen telescopes, 1-100 PeV

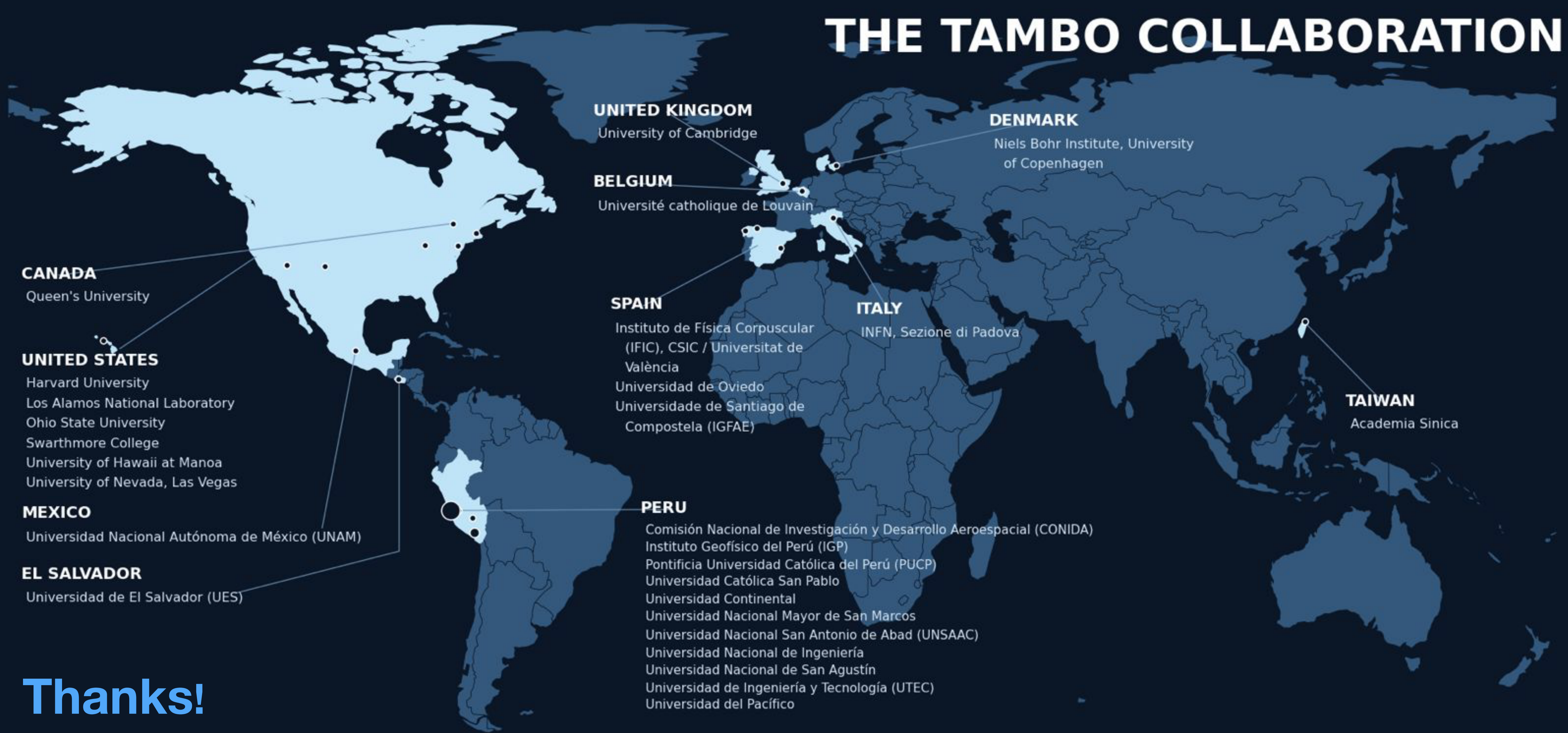
Adapted from
IceCube
arXiv:2510.24957



**Welcome to the first in-person
TAMBO Collaboration Meeting!**

I look forward to many more

THE TAMBO COLLABORATION



Thanks!

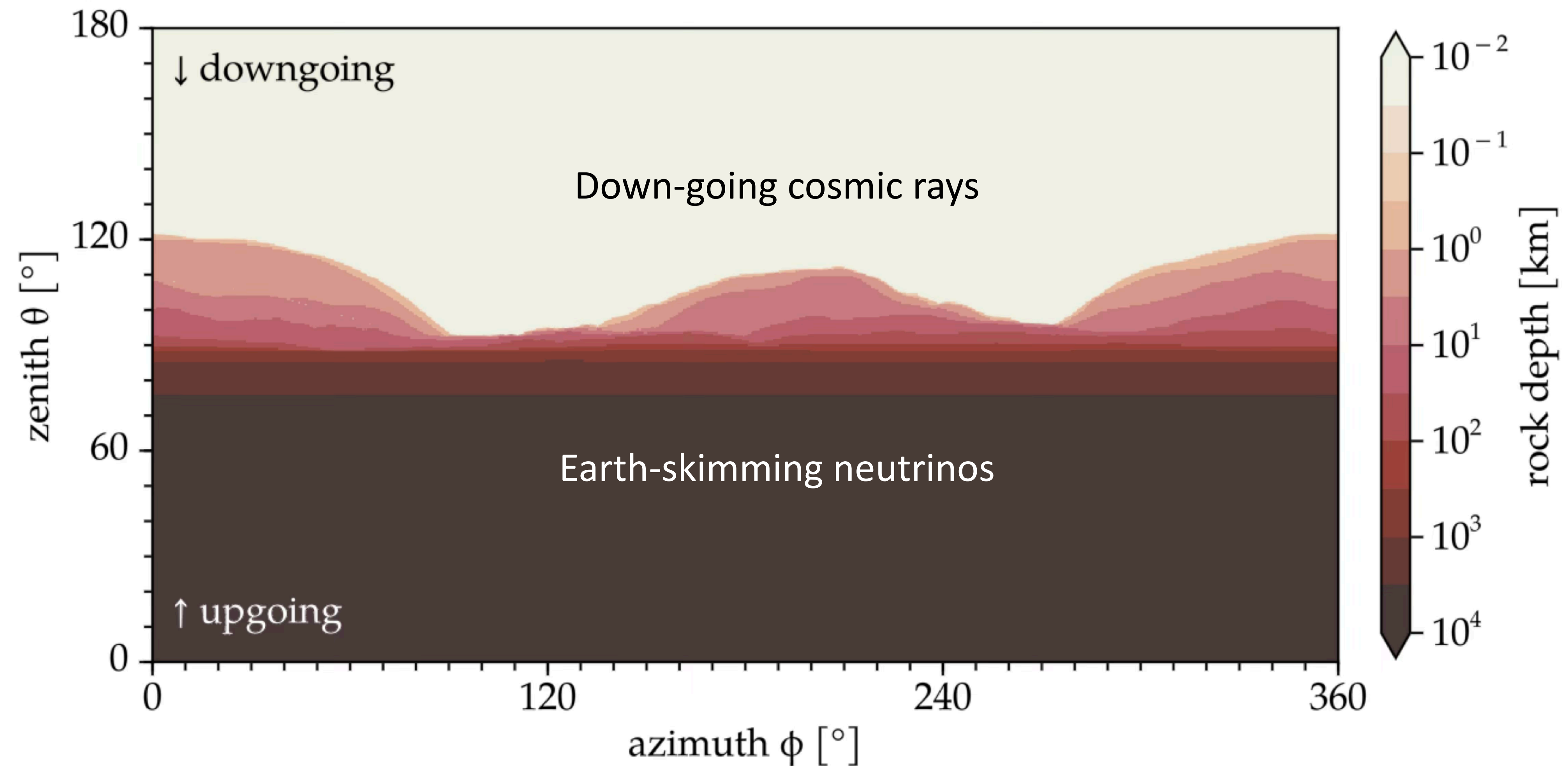
FUNDING

John Templeton Foundation · Harvard University · UTEC · PUCP Legacy support: CIFAR

tambo-observatory.com



Canyon shields you from cosmic rays showers



Canyon shields you from cosmic rays showers

