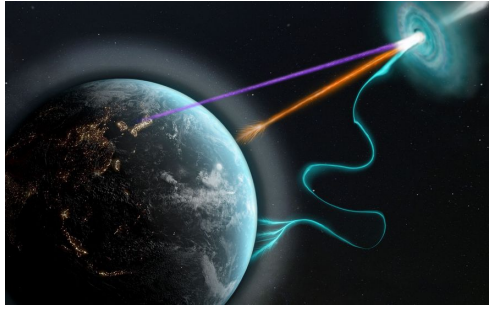
Neutrino properties at Ultra-High energies

CCAPP 20th Anniversary



Ivan Esteban
CCAPP Fellow 2020–2023

12th June, 2026

EHU Quantum Center

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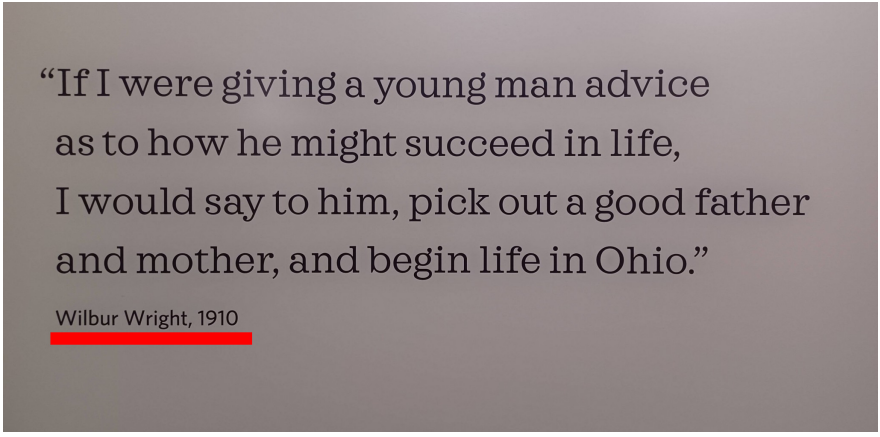
Before and after



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Before and after

THE OHIO STATE UNIVERSITY

CENTER FOR COSMOLOGY AND ASTROPARTICLE PHYSICS

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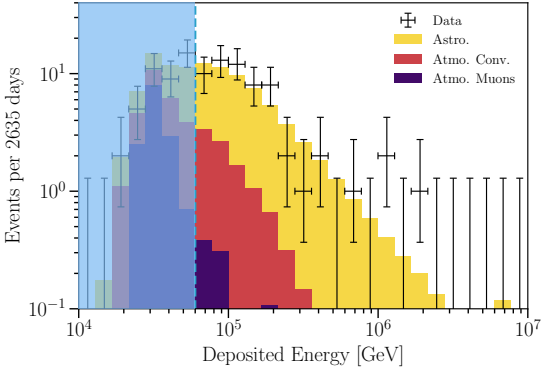
High-Energy neutrinos

More than a decade of success at IceCube.



What lies beyond?

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How to get them

Can we go further? Do we expect a flux?
The idea is simple:
Ultra-high energy proton flux $\Rightarrow$ **Ultra-High Energy neutrino flux**

$$p + \gamma_{\rm bkg} \Rightarrow \Delta^+ \Rightarrow \begin{cases} n + \pi^+ \\ \quad \hookrightarrow \mu^+ + \nu_\mu \\ \qquad \hookrightarrow \bar{\nu}_\mu + e^+ + \nu_e \end{cases} \qquad n \hookrightarrow p + e^- + \bar{\nu}_e$$

Greisen–Zatsepin–Kuzmin, 1966

For $E_p \gtrsim 10^9\,\mathrm{GeV}$, we **expect** this flux at $E_\nu \sim 10^7$–$10^{10}\,\mathrm{GeV}$
$\phi_\nu \sim 1$–$100\,\nu/\mathrm{km}^2/\mathrm{year}$

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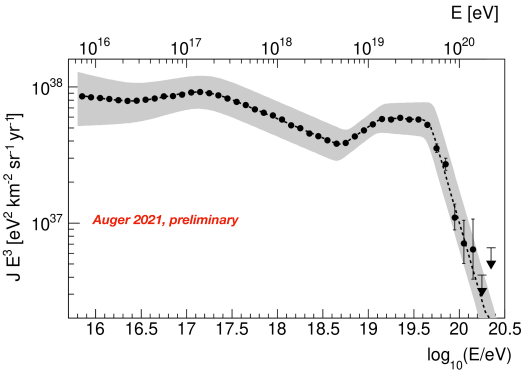
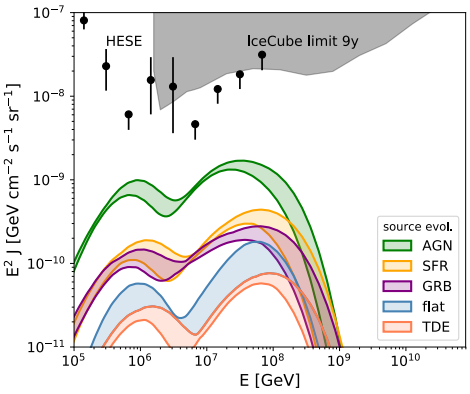
How to get them

Ultra-high energy proton flux $\Rightarrow$ **Ultra-High Energy neutrino flux**



Auger, ICRC2021



Heinze et al, 1901.03338

(Of course, sources could also directly produce neutrinos)

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Why do we want to detect them?

Astrophysics

- Multimessenger
- UHE cosmic ray sources
- UHE cosmic ray composition
- High redshift ($z \sim 2$–4)

Particle physics

Not strongly explored, but

- Largest energies
- Largest distances

Let's look for this!

$$N_{\rm evt} \sim \phi \times \sigma \times N_{\rm targets} \sim 6 \times 10^{-4} \, \frac{\rm evts}{\rm yr} \, \frac{\rm M}{\rm M_{IceCube}}$$

New ideas are needed.

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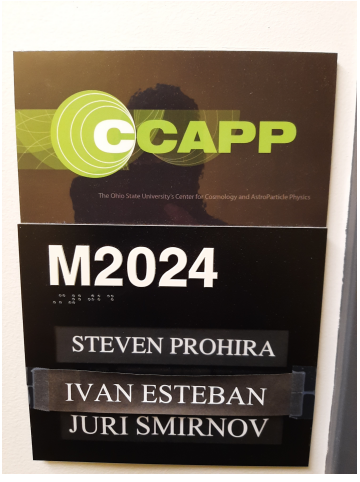
The relevance of CCAPP



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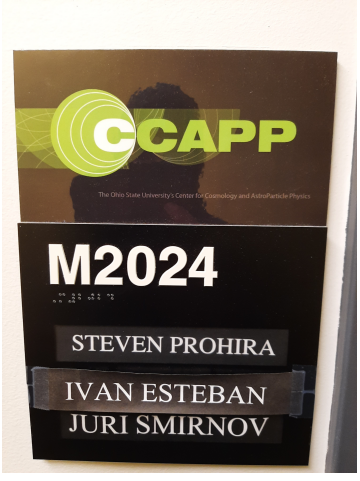

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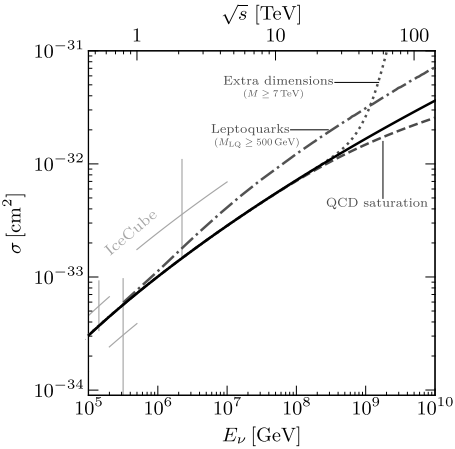
Physics opportunities: cross section



When UHE neutrinos hit a nucleon in our detector, $E_{\rm com} \sim 5$–$100\,\mathrm{TeV}$, beyond collider reach!

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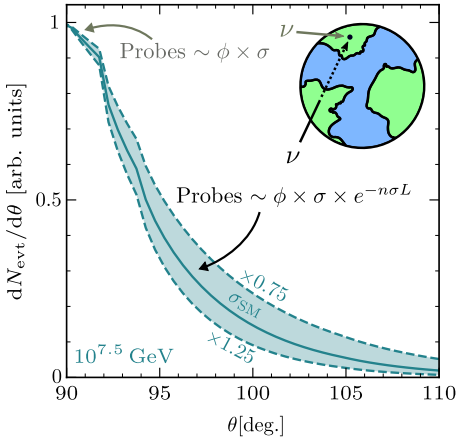
Physics opportunities: cross section

- $\sigma \sim 10^{-32}\,\mathrm{cm}^2$;
  $\lambda \sim \frac{1}{n\sigma} \sim 1000\,\mathrm{km}$!

- Neutrinos get **exponentially** attenuated by Earth with a **characteristic scale set by σ**.

Kusenko & Weiler, 2002; Anchordoqui et al, 2002; Jain et al, 2002; Hooper, 2002 ...



Esteban, Prohira, Beacom, 2205.09763

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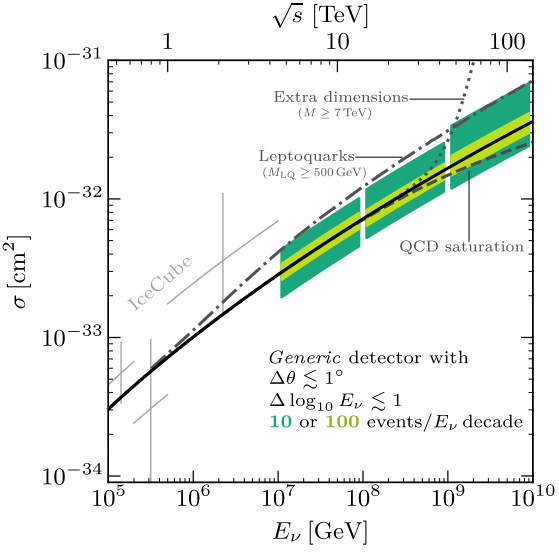

Esteban, Prohira, Beacom, 2205.09763

- Measurement **within reach** with modest statistics and resolution.
- The critical parameters are
  1. **Angular resolution**
  2. **Statistics**

  and nothing else matters. We can combine data!

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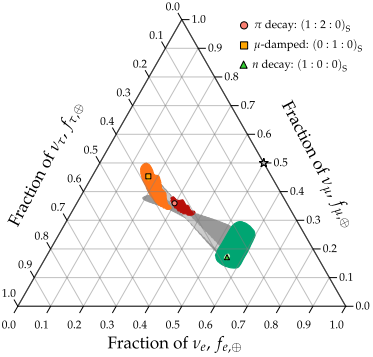
Physics opportunities: flavor

Neutrino flavor (ν_e vs ν_μ vs ν_τ)

- Has information on the production process
- The possibilities can be cleanly predicted within the Standard Model



Song et al, 2012.12893

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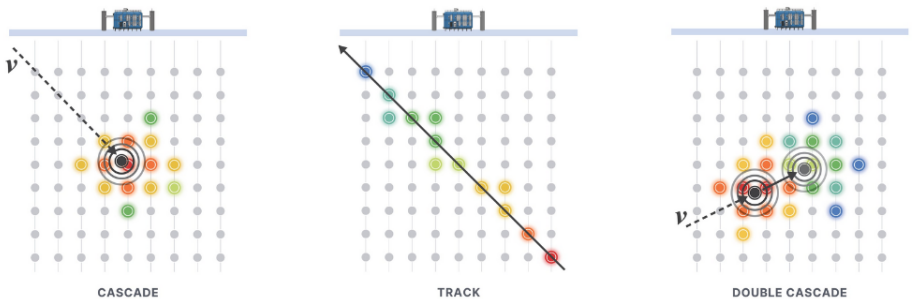

Flavor at UHE detectors is hard: high threshold, directional, low stats...

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Physics opportunities: flavor

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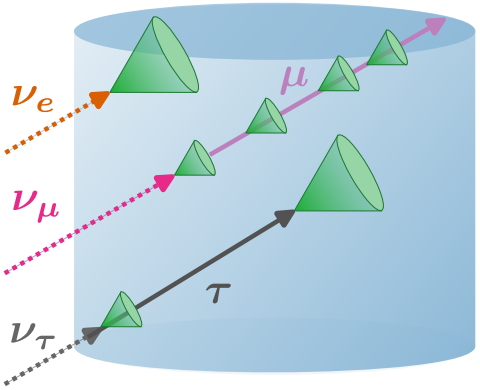
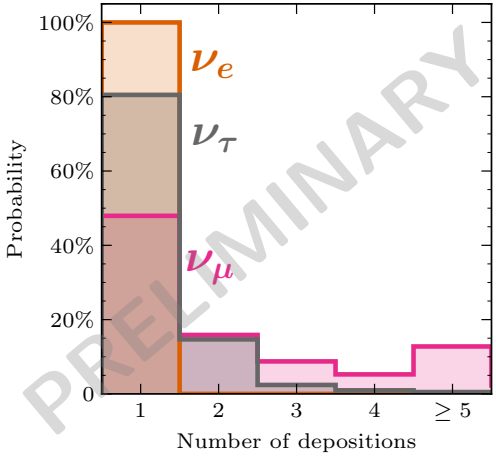
Radar may have a chance





Last words

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- Ultra-High-Energy neutrino astronomy may be within reach.
- It's the largest energies and distances, but also
  - Diverse detectors
  - Unique morphologies

  Experiments are being planned and deployed: **opportunities**!
- In my opinion, progress in frontiers requires
  - Hard work
  - Friendly environment
  - Not being afraid of collaborating
- CCAPP is a **unique** environment for this.
  I look forward to the 30th/40th anniversary CCAPP Conference, hopefully in the era of UHE neutrino astronomy!

Thank you for being home 6500 km away from home!