Tracing Out the Neutrino Sky with TAMBO

Will Thompson

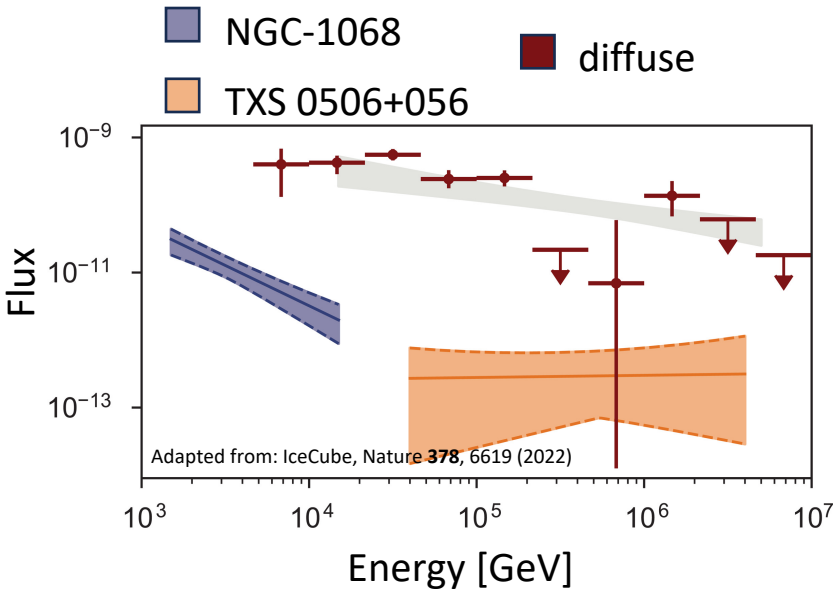
TeVPA 2025

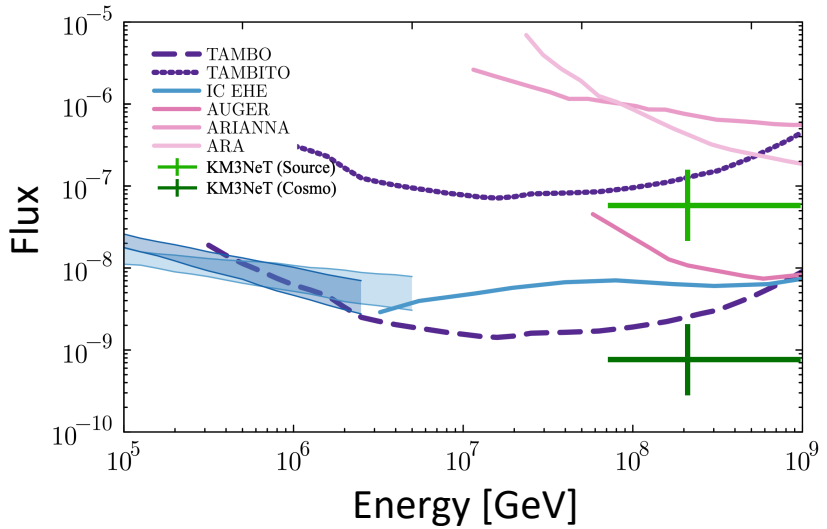
November 5th, 2025

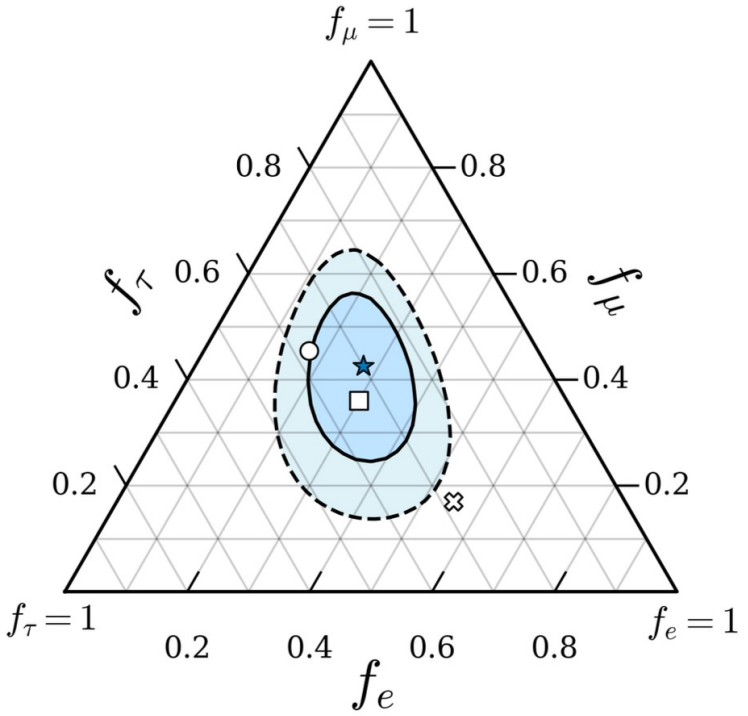
TAMBO

JOHN TEMPLETON FOUNDATION

TAMBO will:





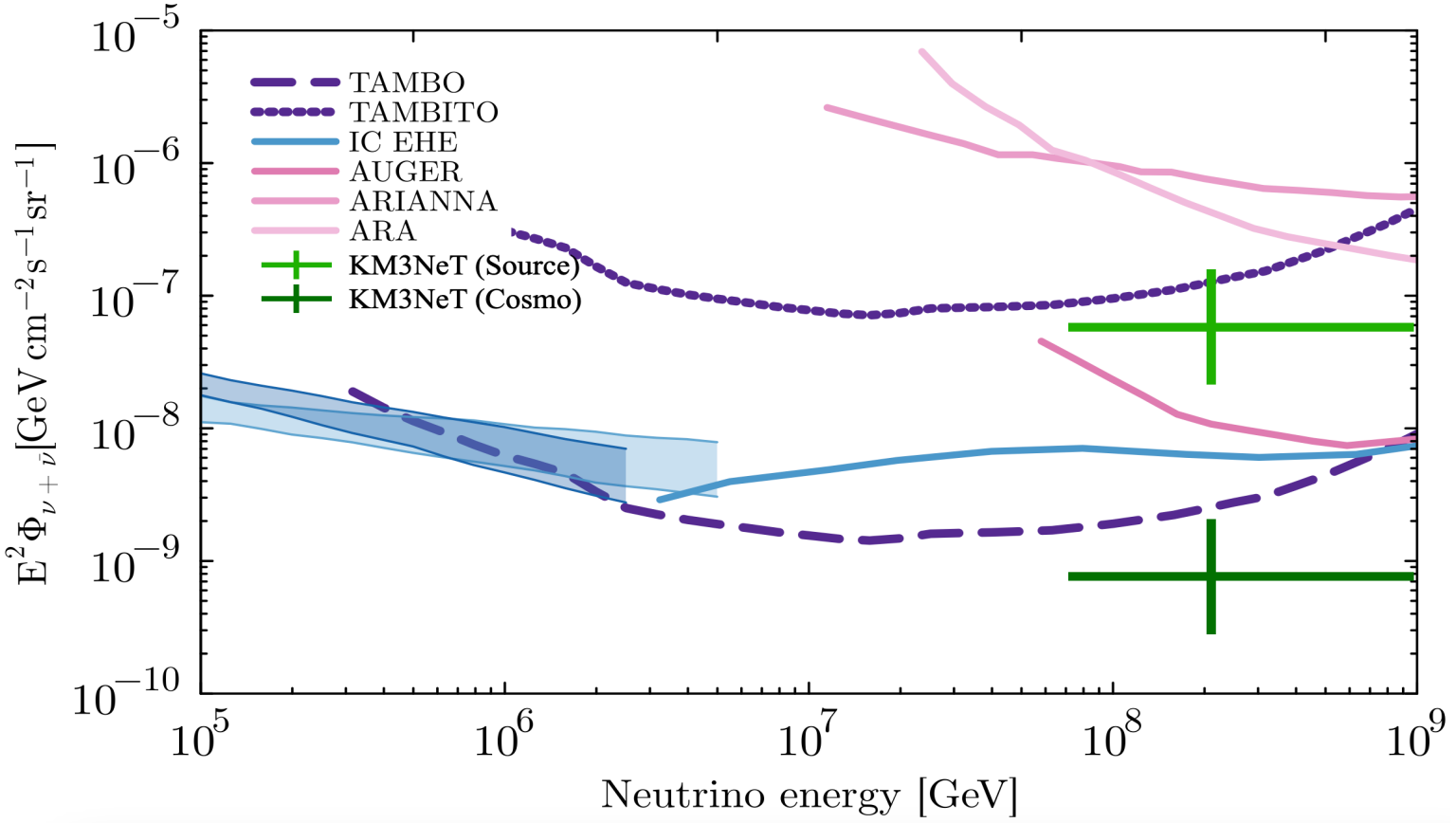


Discover new point sources of neutrinos

Probe nature of diffuse flux from 1-100 PeV

Explore ultra-high energy flavor physics

Bridging the gap between HE & UHE ν observatories



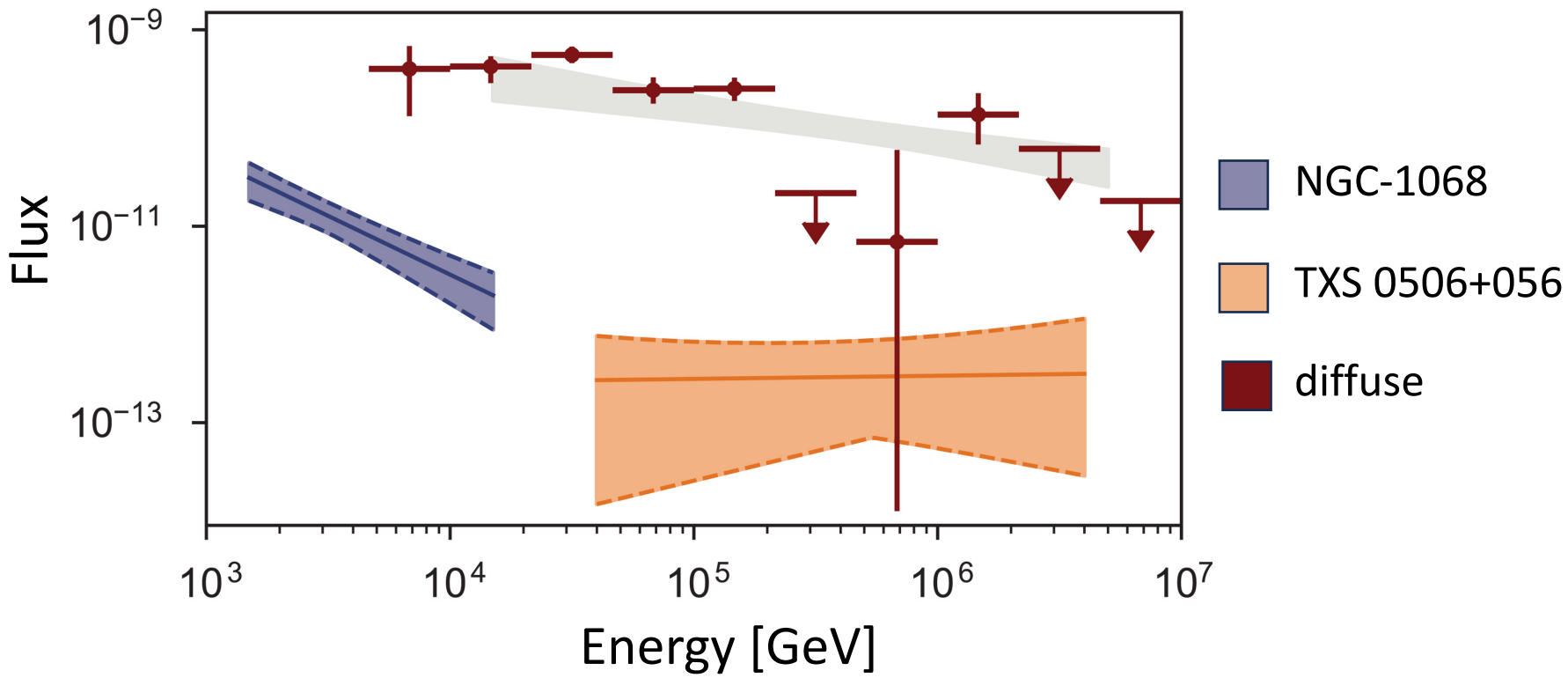
IceCube, KM3NeT, P-ONE, Baikal-GVD & many proposals

GRAND, BEACON, PUEO, RNO-G & more

- Community has heeded call for UHE neutrino observatories
  - But fewer experiments planned for 1-100 PeV
- Explores cosmogenic flux models that peak at PeV energies

Recent result: IceCube 12.6 yr EHE
PRL 135 031001 (2025)

Where are point sources hiding?

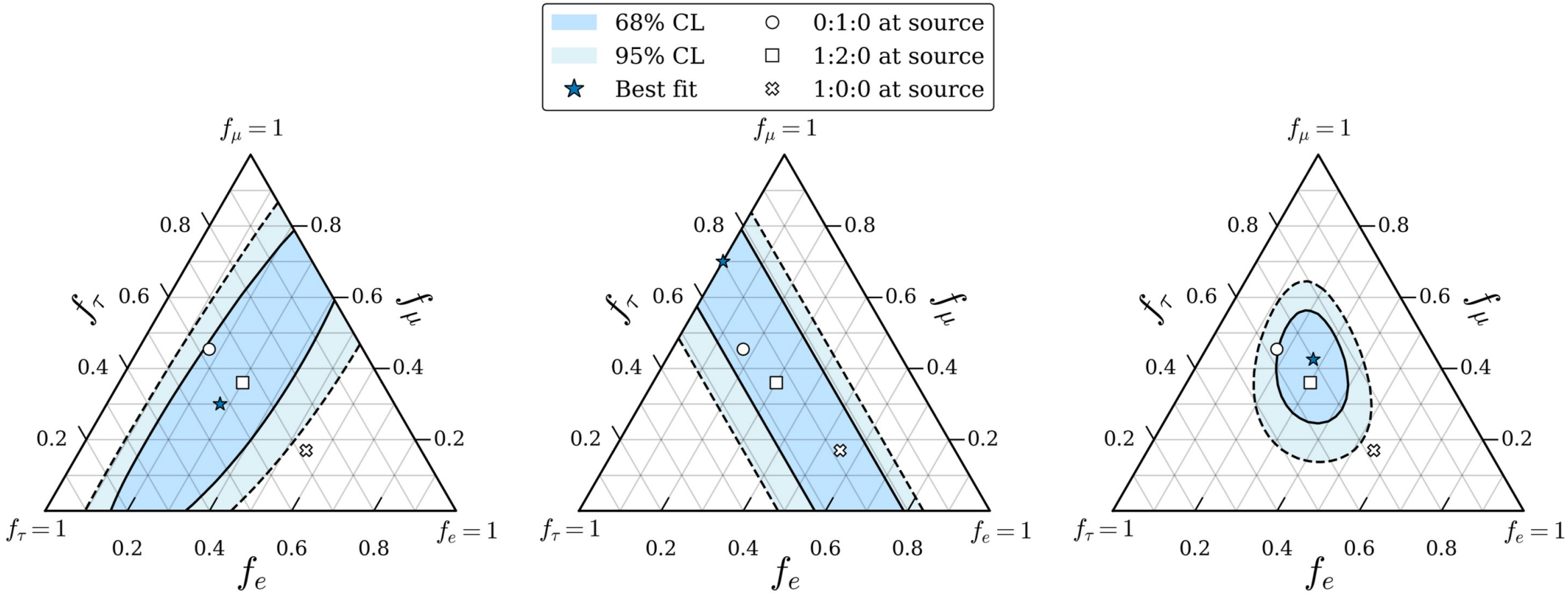


Adapted from: IceCube, Nature **378**, 6619 (2022)

Look-elsewhere effect hampers discovery of neutrino sources

TAMBO will create a neutrino catalog with up to 2 ν_τ per year

What is the flavor of the high-energy Universe?



In-ice radio & radar

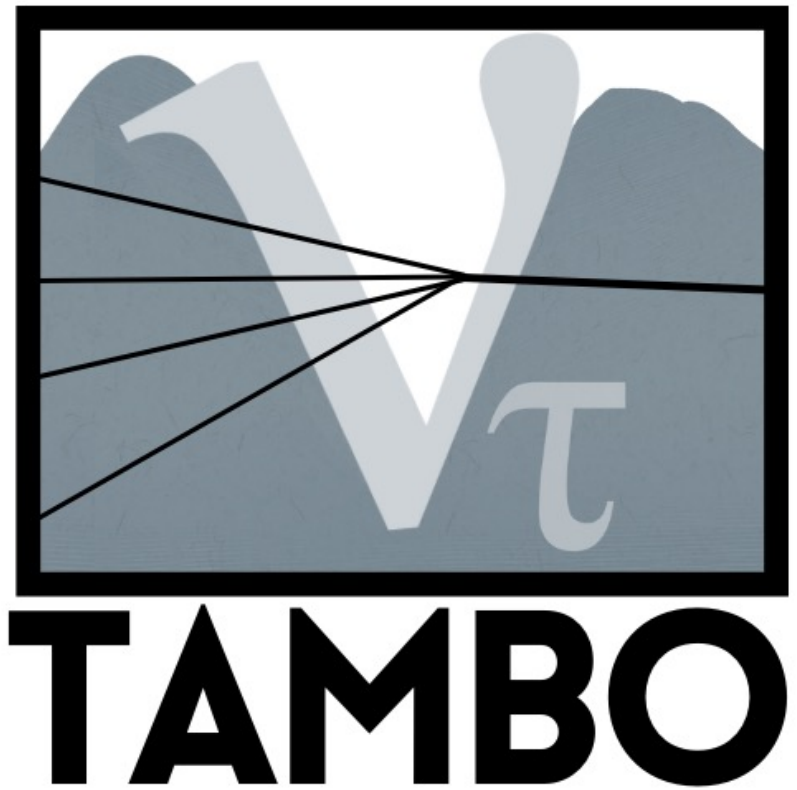
ν_τ-specific observatories

Combined

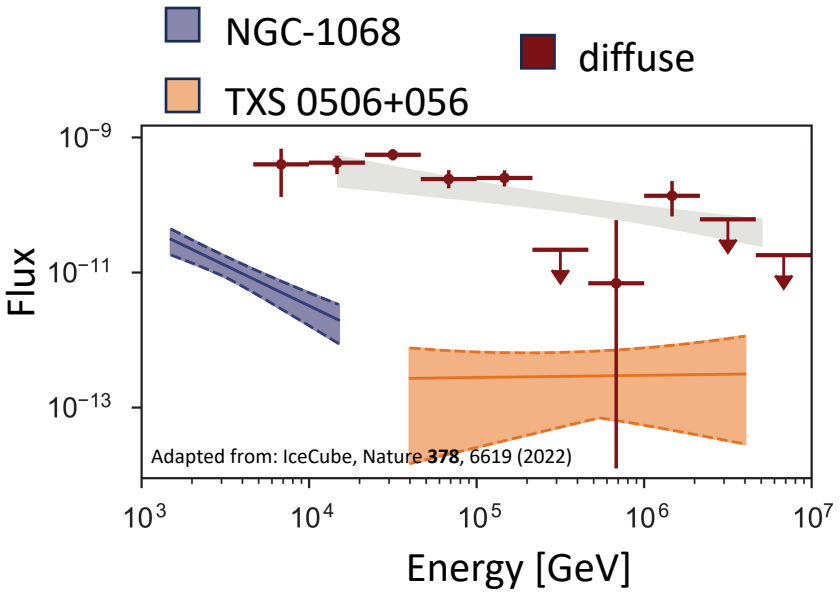
ν_τ-specific observatories are necessary to resolve >100 PeV flavor composition!

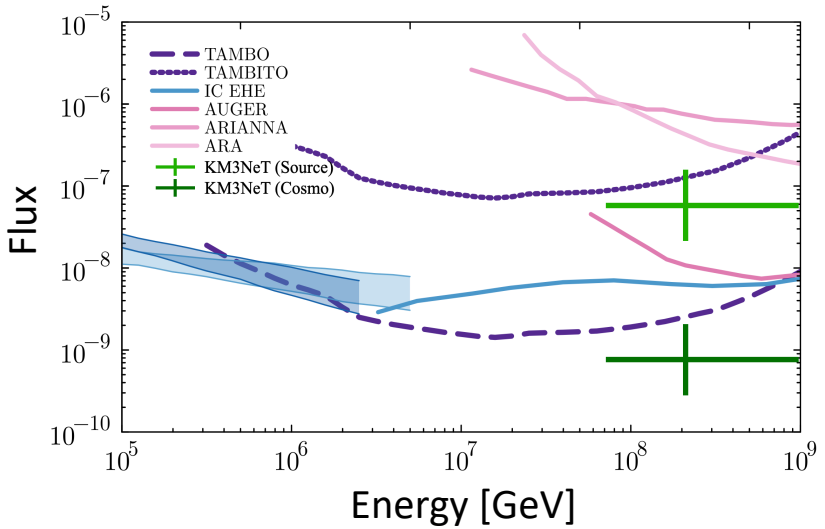
TAMBO: a ν_τ-exclusive neutrino observatory

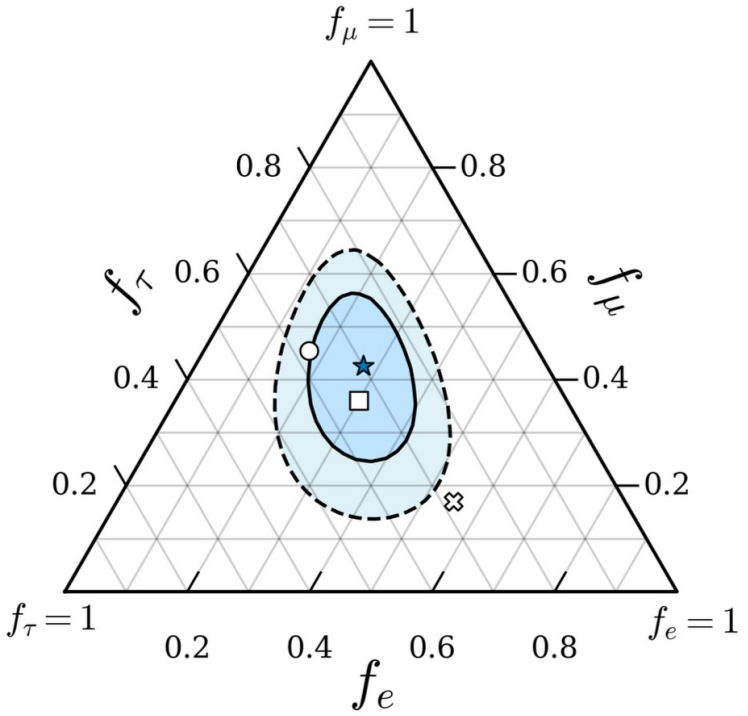
- Detect air shower particles on the side of a canyon
  - High astro purity from ν_τ exclusivity
  - Low cosmic ray backgrounds due to canyon shielding
  - ~1° angular resolution
  - Proven detector technology in air shower arrays
  - Baseline design: 5000 modules, 150m spacing
- Expect to observe ~1-3 ν_τ/yr



1-3 ν_τ will:







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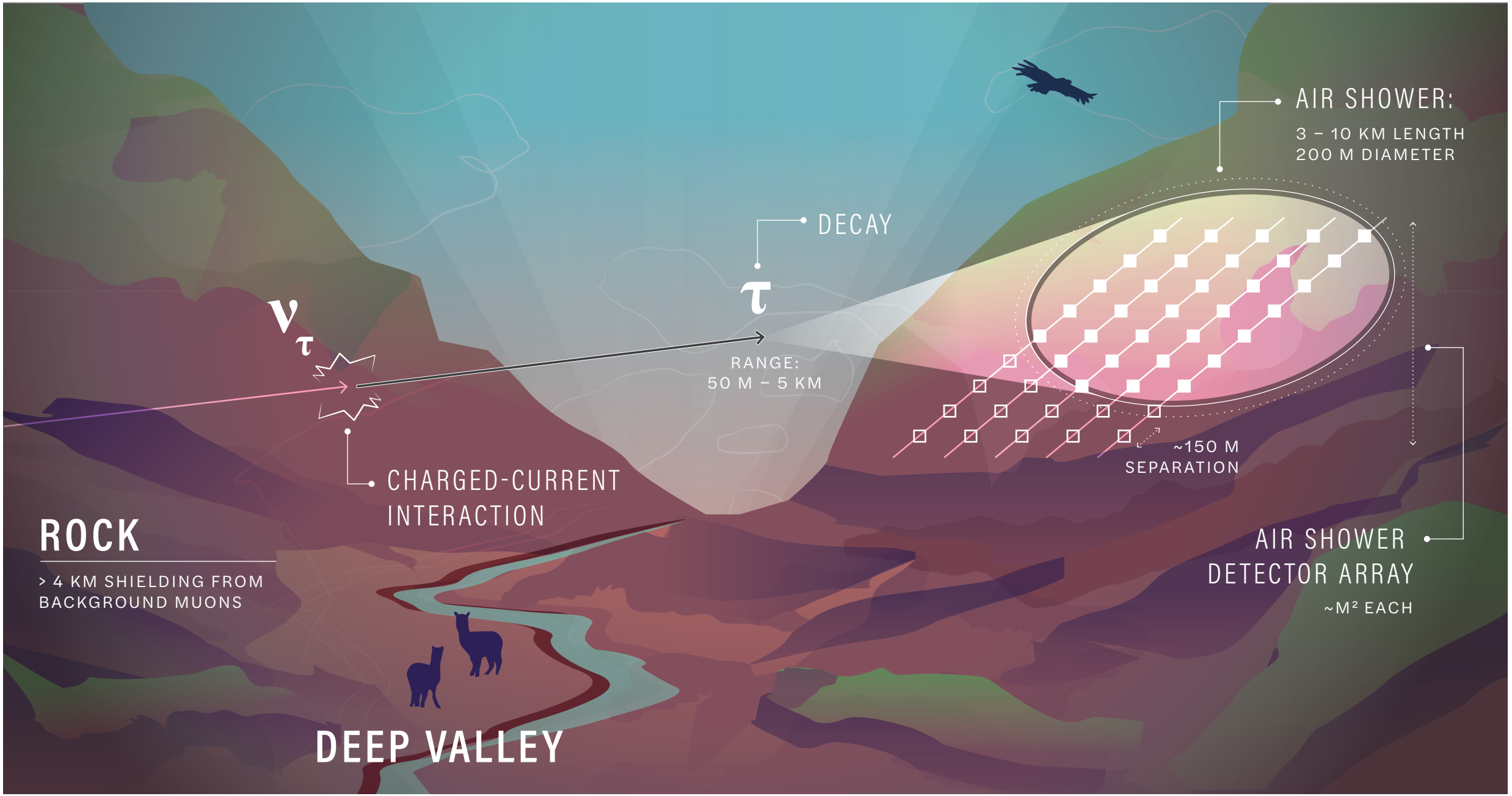
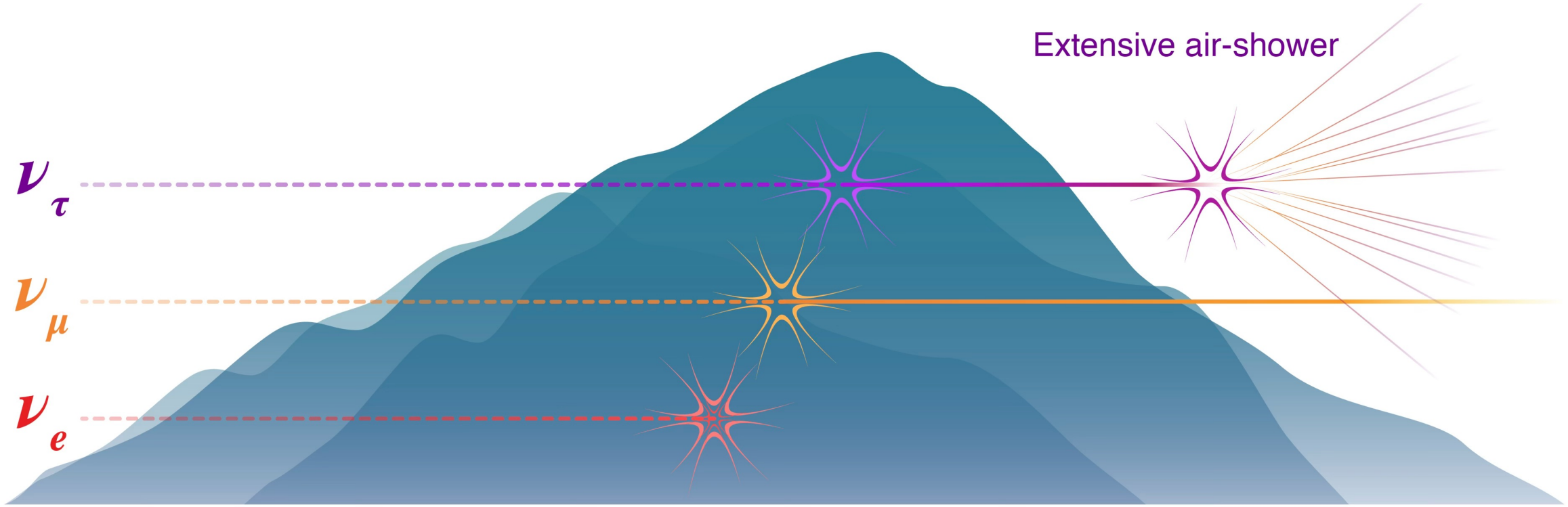


TAU AIR-SHOWER MOUNTAIN-BASED OBSERVATORY (TAMBO)

ν_τ exclusivity → high astro purity



Air showers overwhelmingly come from ν_τ

+ atmospheric flux nearly 0% ν_τ

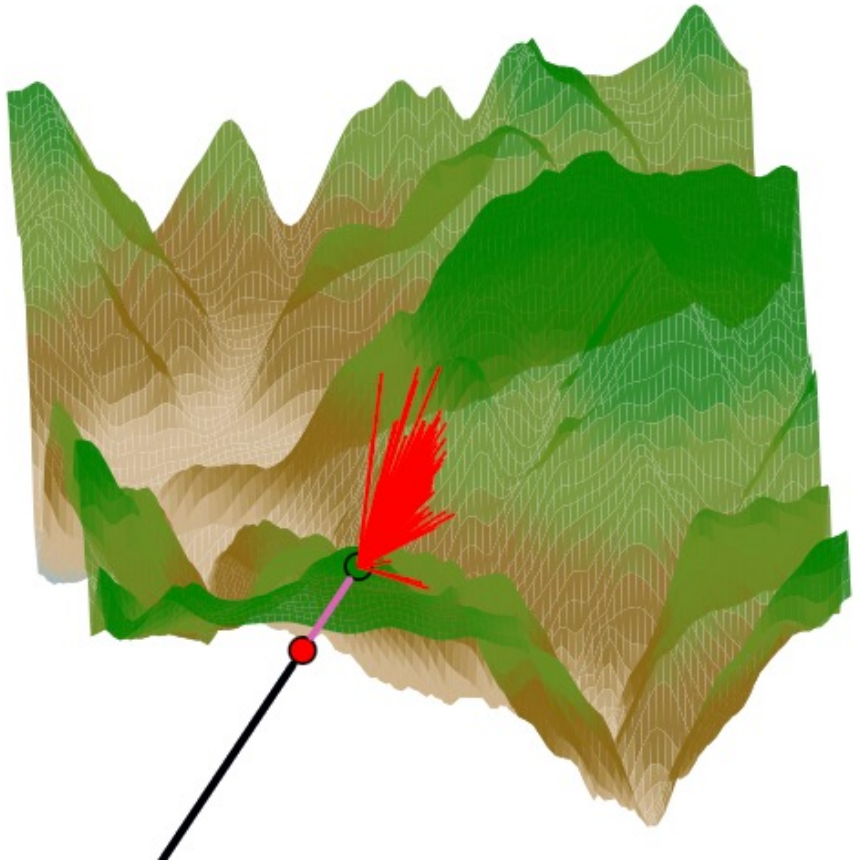
∴ air shower is smoking-gun signal of astrophysical neutrino!

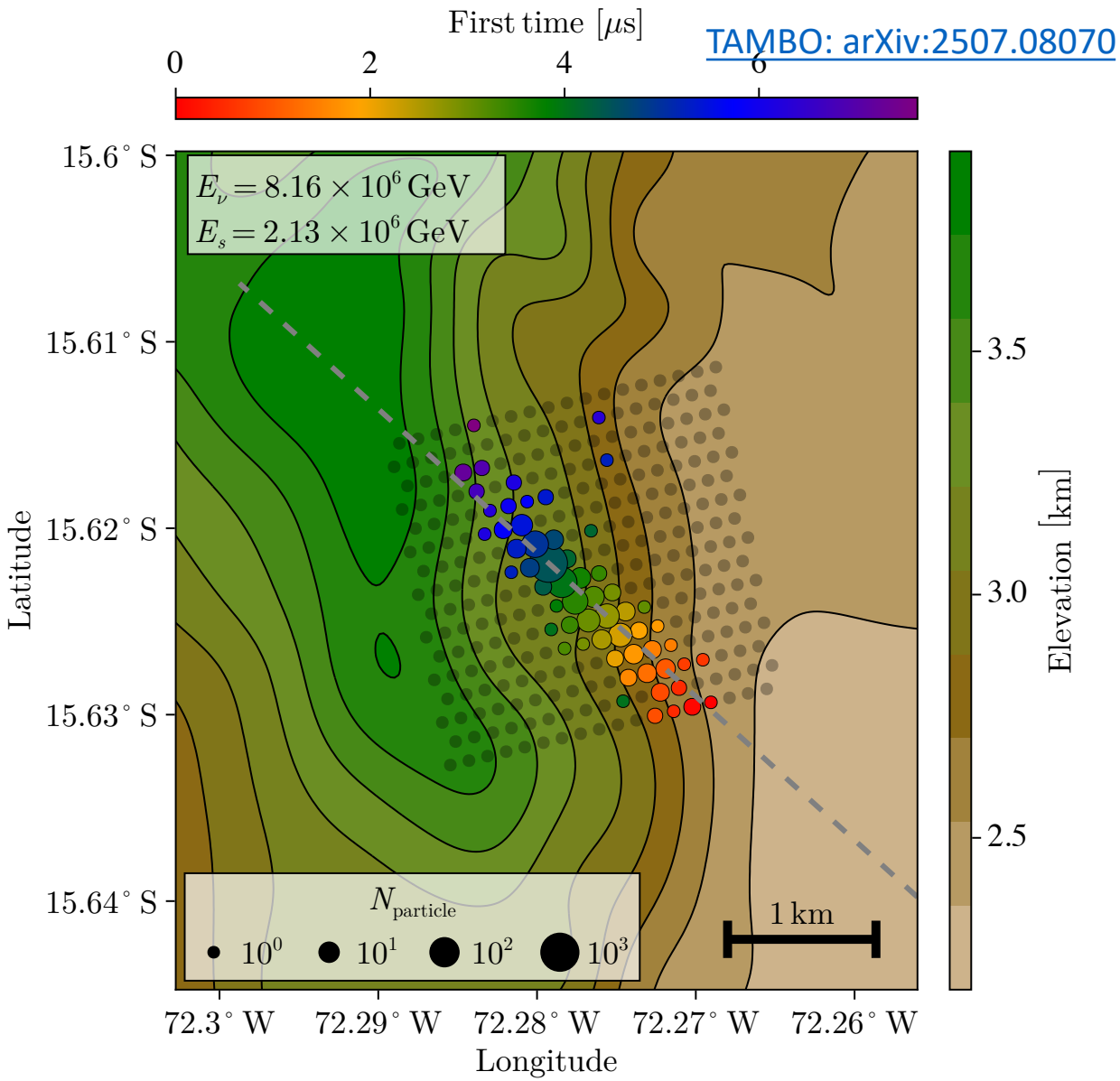
Observatory scale

Benchmark studies include 5000 modules

- 150 meter spacing on triangular grid → ~33 (16.5) km along and 3km up canyon if single- (double-) sided

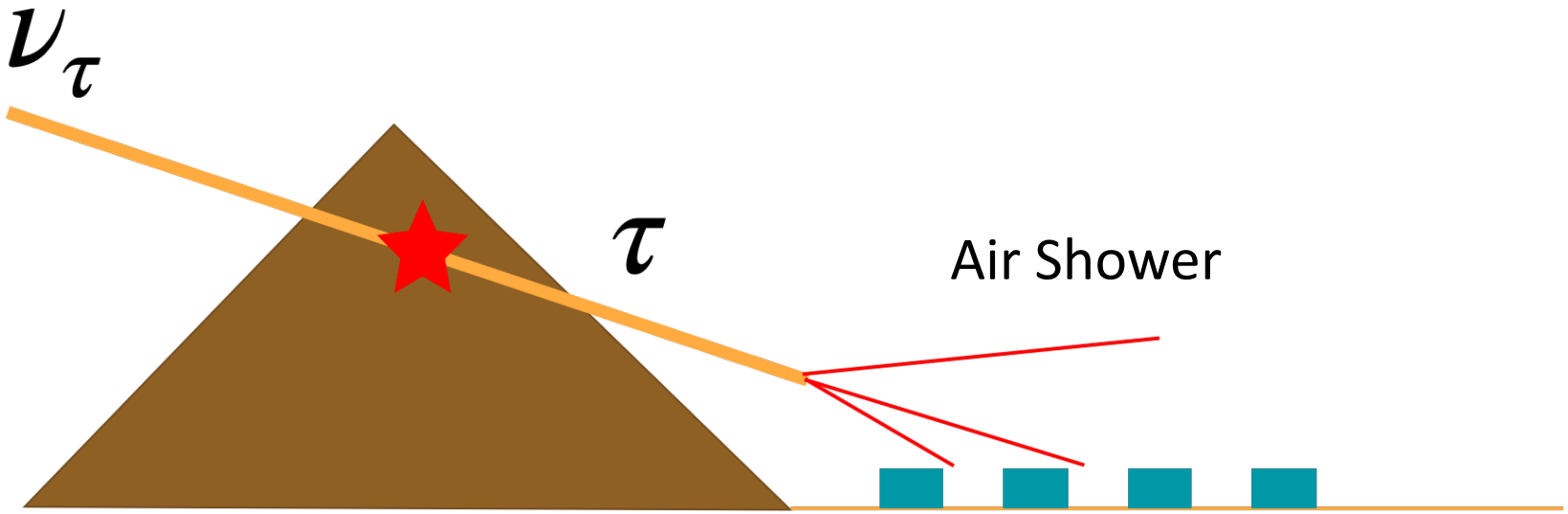
Example ν_τ Event





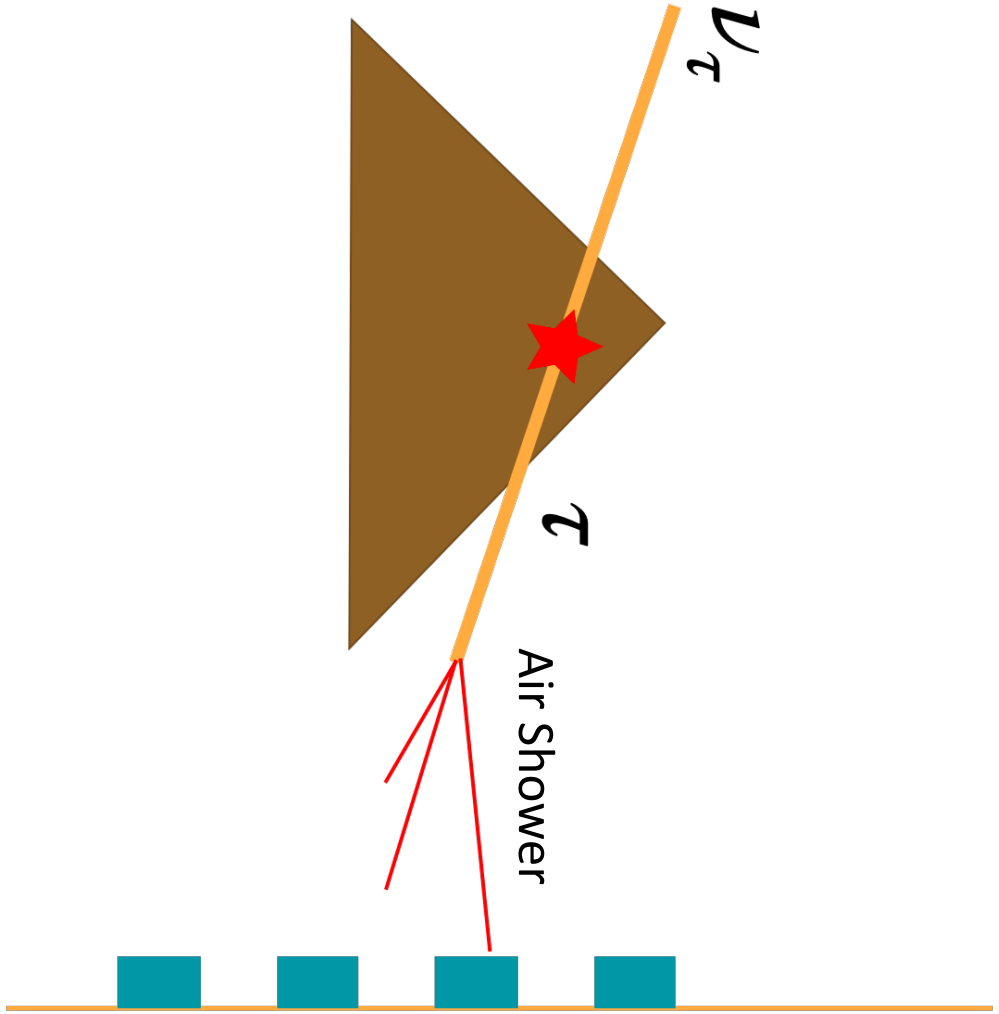
TAMBO: arXiv:2507.08070

Why put a neutrino telescope in a canyon?



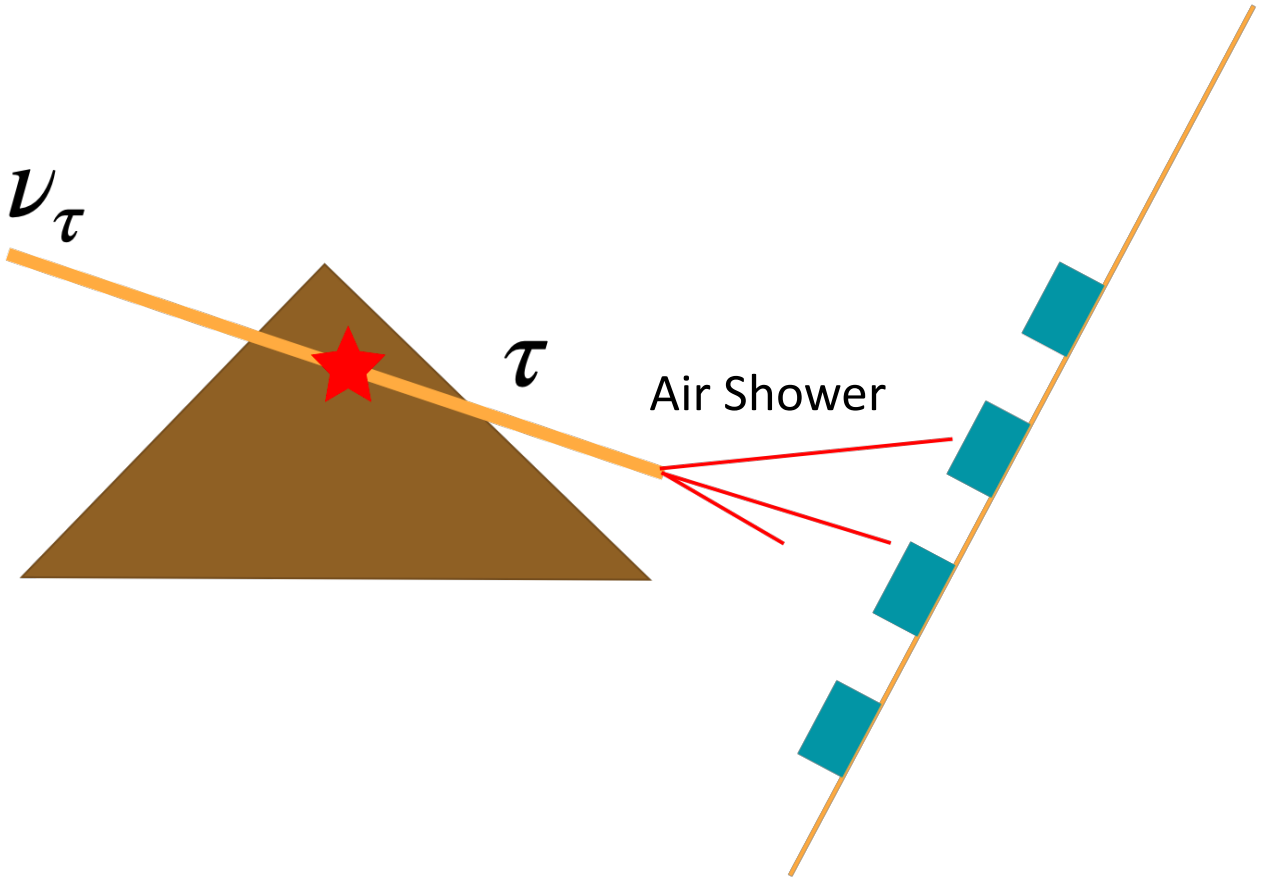
Inherently low geometrical acceptance

Why put a neutrino telescope in a canyon?



Better for physics, but the engineers didn't seem to like it

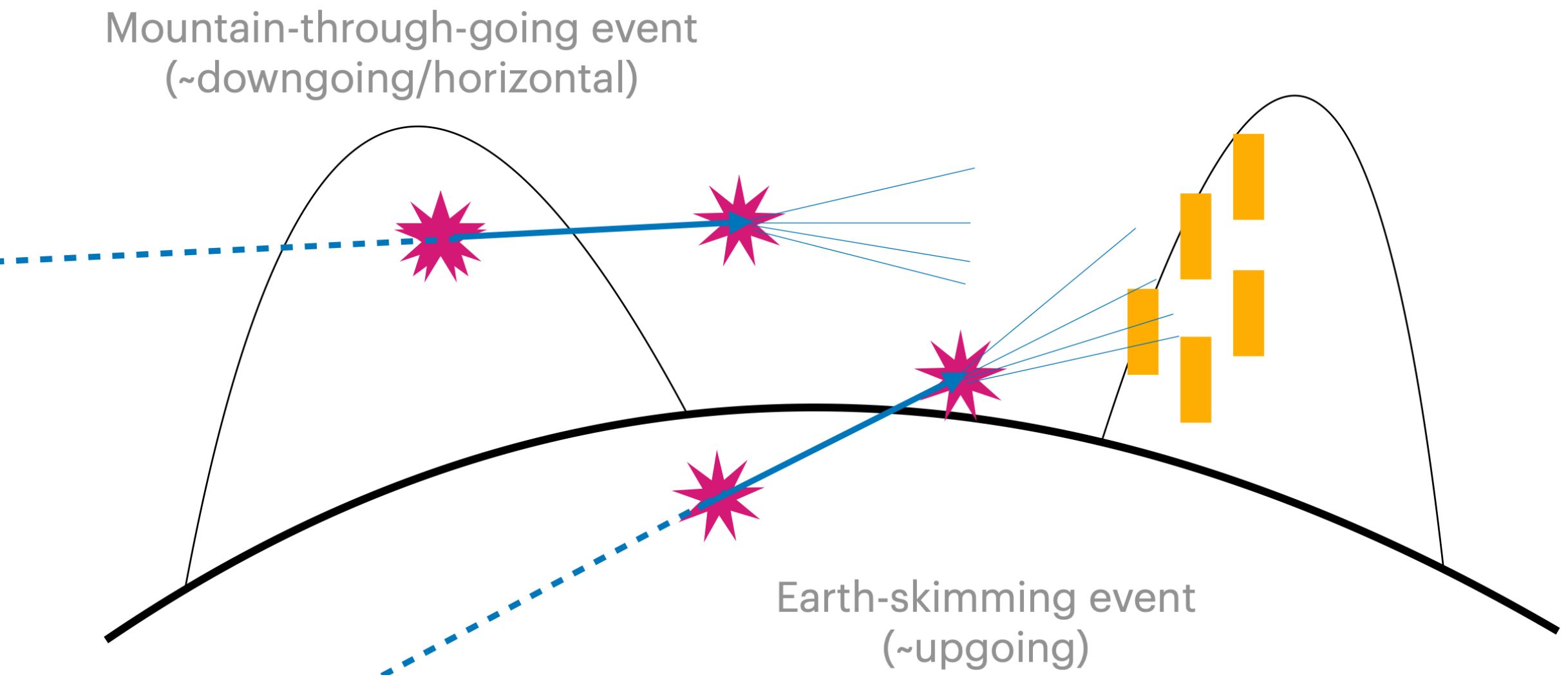
Why put a neutrino telescope in a canyon?



We'll do this instead

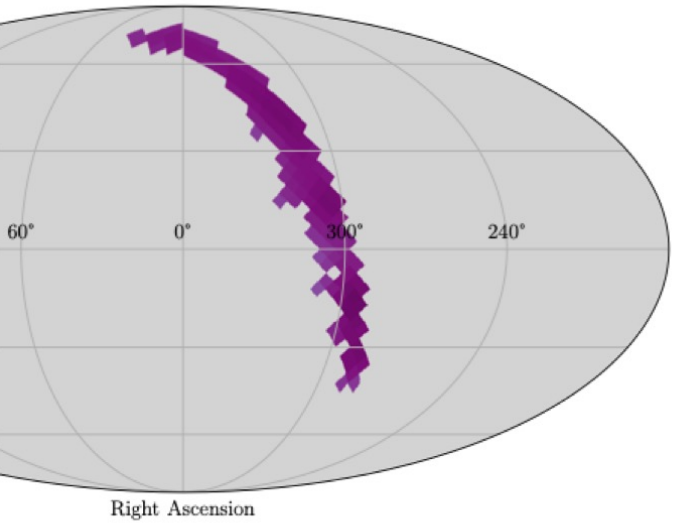
Why put a neutrino telescope in a canyon?

*not to scale

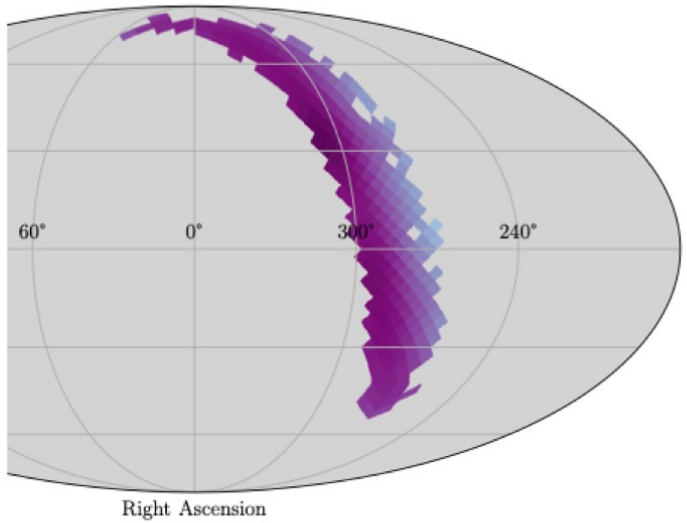


A canyon enhances our sky coverage

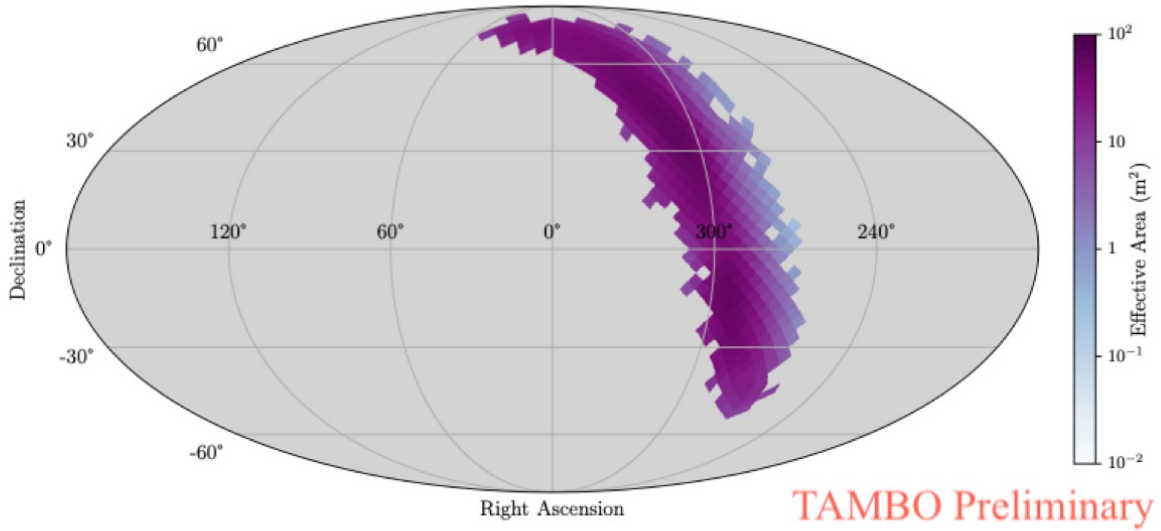
Downgoing



Upgoing



Full acceptance

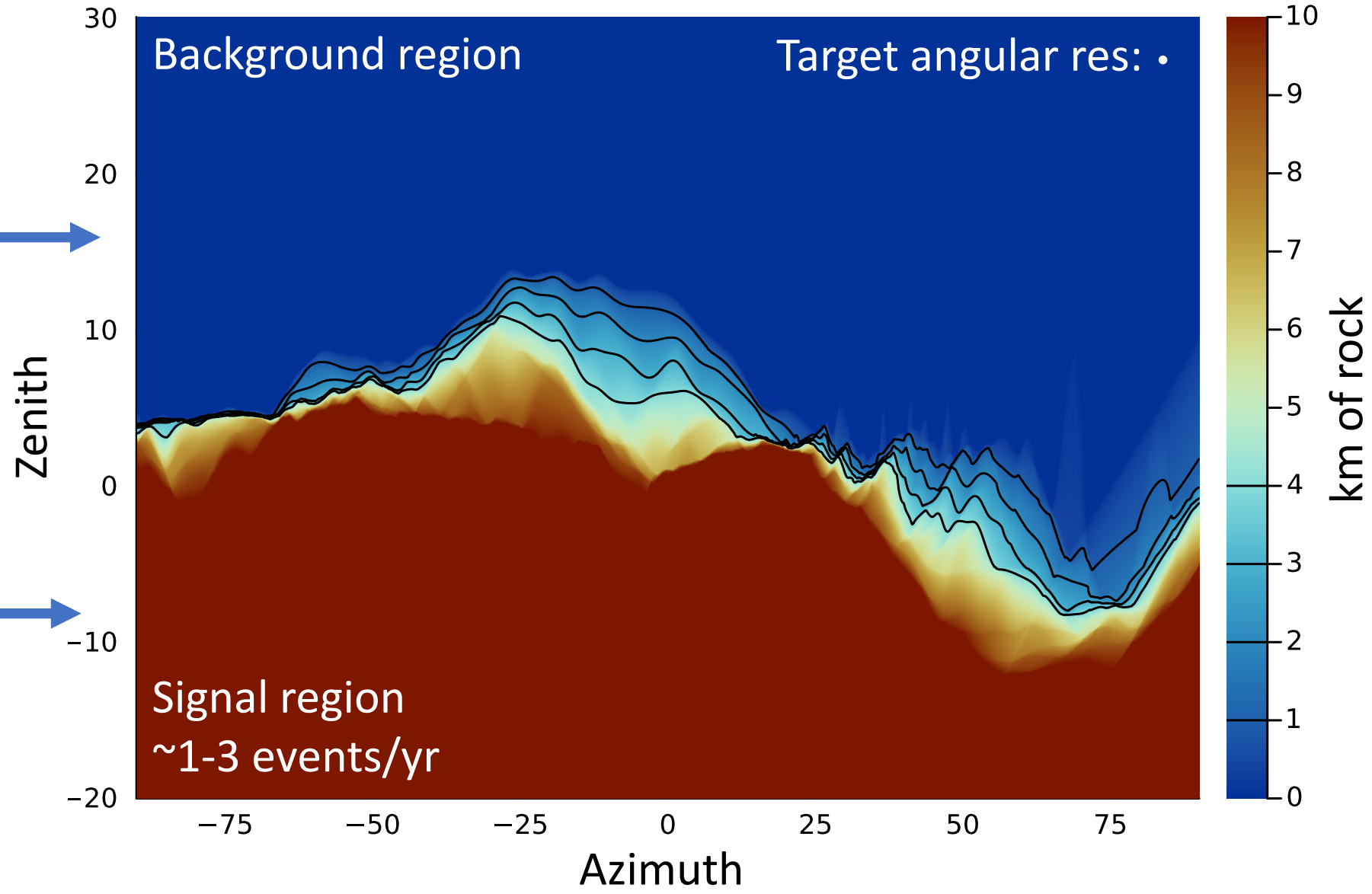


Acceptance increased by ~50% compared with Earth-skimming only

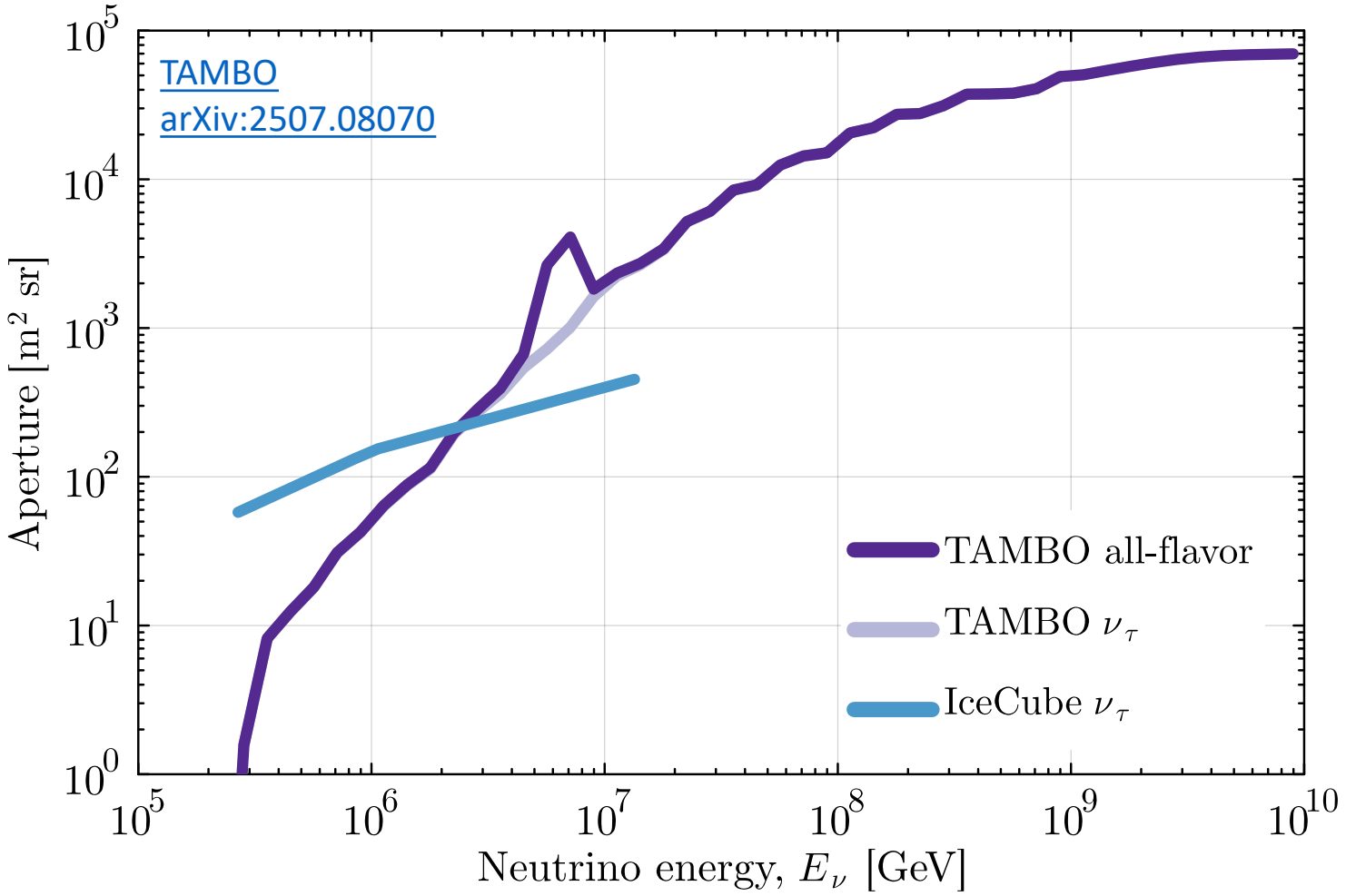
And blocks cosmic-ray backgrounds

Cosmic ray physics

Neutrino physics

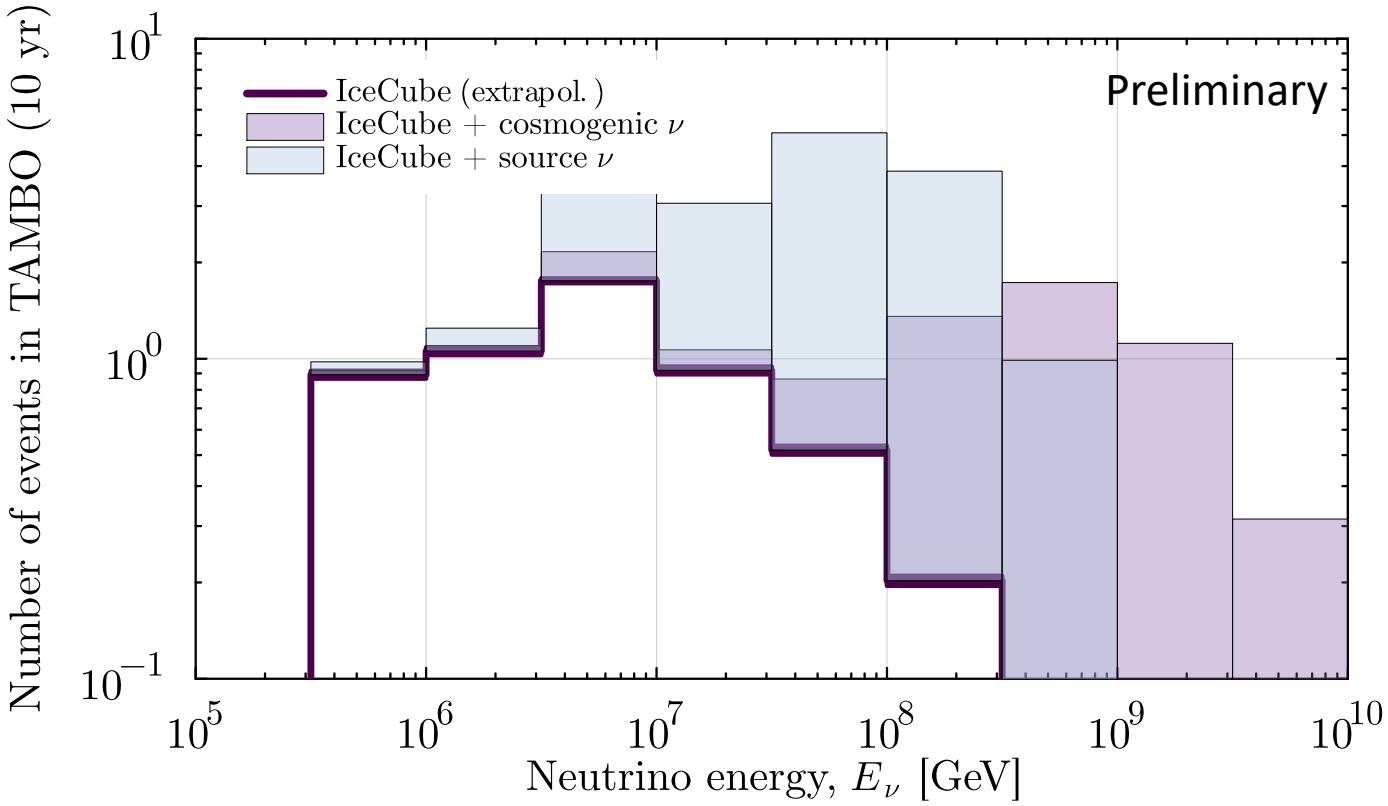


TAMBO's ν_τ sensitivity surpasses large-volume observatories



5x higher ν_τ aperture than IceCube at 10 PeV, before array optimization

Sources of events in TAMBO



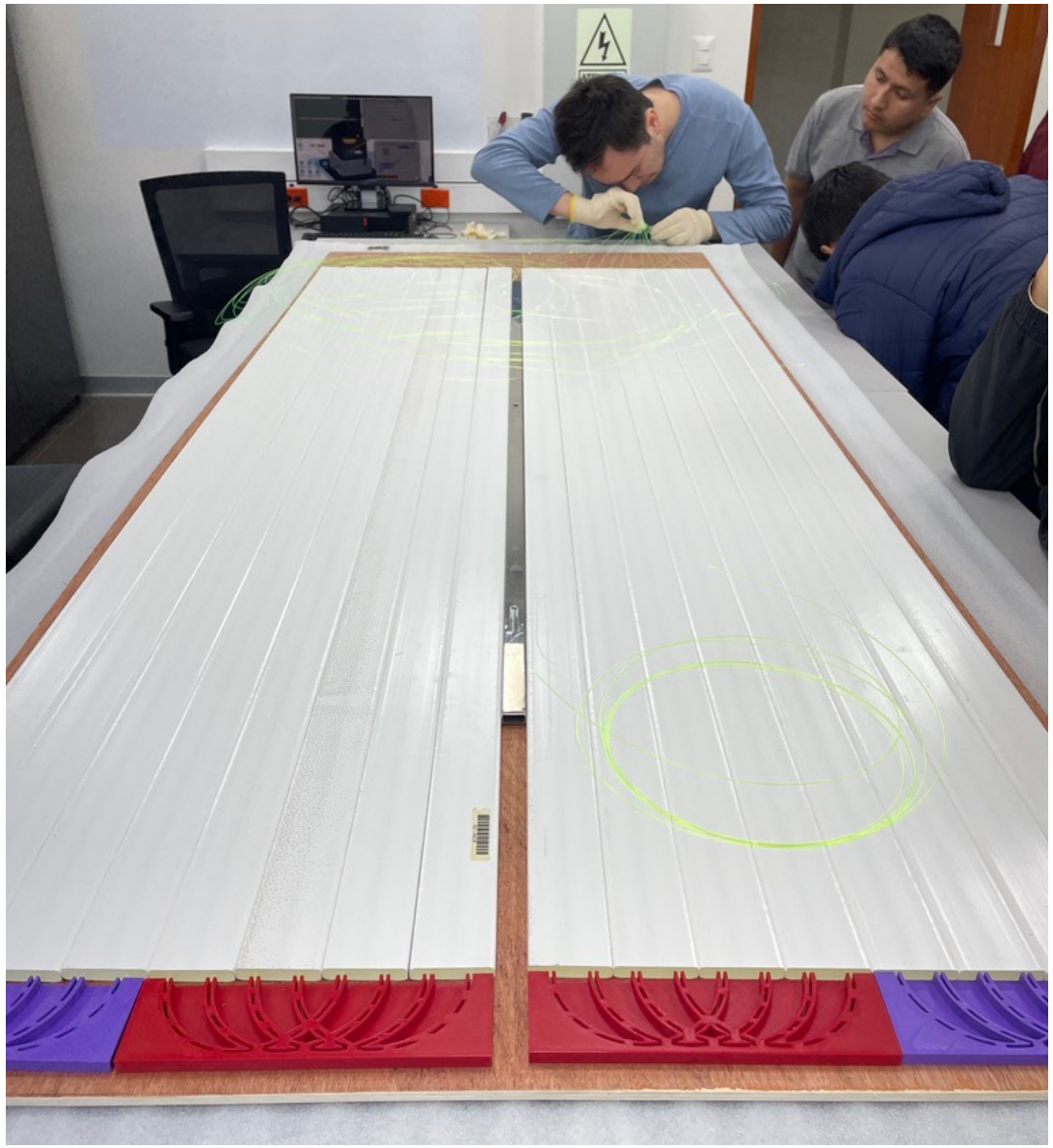
With 5000 modules TAMBO will:

- Observe ~1 neutrino per year assuming just IceCube SPL flux
- Optimistic source[1] & cosmogenic fluxes[2] → ~2 per year, observe cosmogenic flux

[1] Rodrigues *et al.* arXiv:2003.08392
[2] Bergman & van Vliet, arXiv:2004.09841

Enter TAMBITO

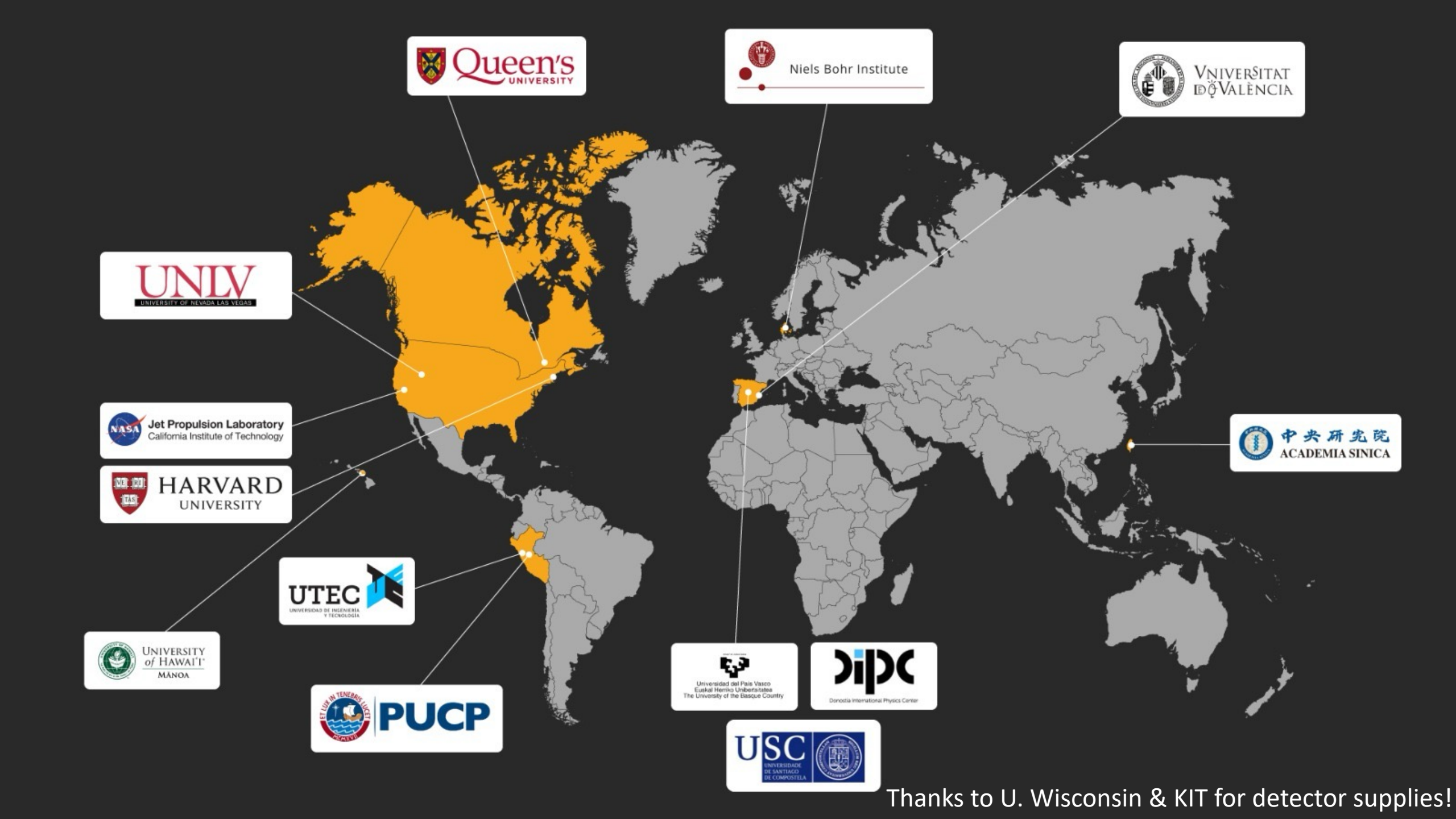
- 100-detector prototype for:
  - Detection unit R&D
  - Deployment tests
  - CR air shower measurements
- Initiate community outreach program
- Fully funded; development began in August!



Core component of TAMBITO: responsible siting

- Want local community to embrace project, not just accept
- First step: workshop in January 2024
- Success story: Pierre Auger

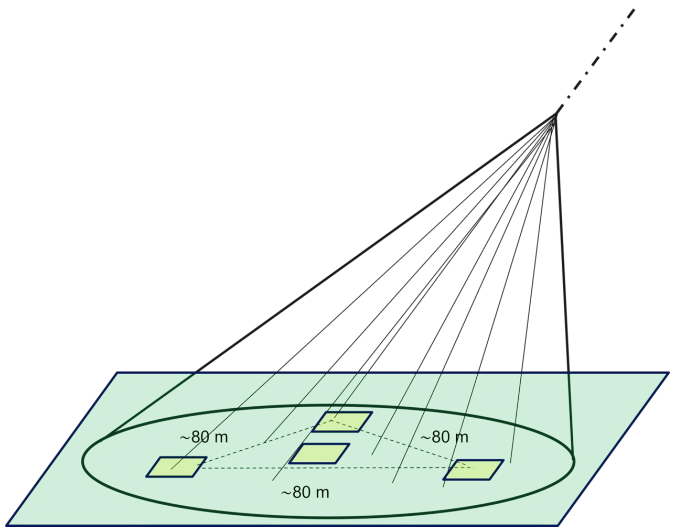
Pierre Auger, ICRC 2025



Thanks to U. Wisconsin & KIT for detector supplies!

TAMBO timeline

Today:
TAMBO-4

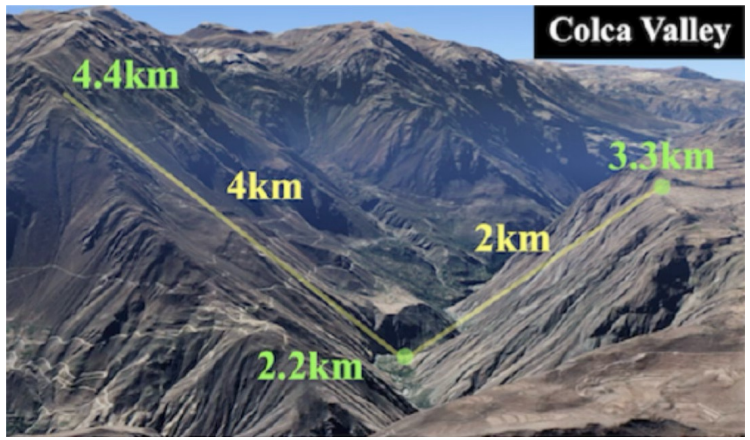


Small test array

Detector & electronics prototypes

2025-2028:
TAMBITO (TAMBO-100)

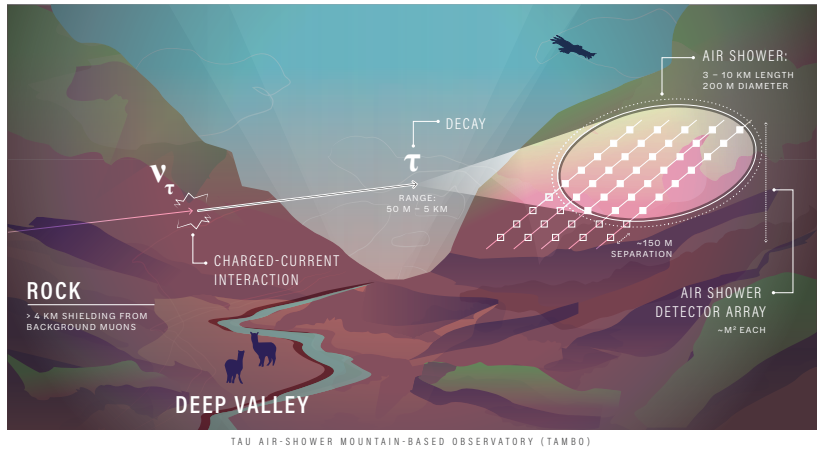
FUNDED!



Pilot array

Deployment techniques, backgrounds, responsible siting

2028-:
TAMBO-5k



Target full size array

¡Gracias por su atención!

Le Verrier, 1846

+

=

TAMBO

+

IceCube

=

Why Neutrino Astronomy?

- Neutrinos are:
  - (Very) weakly interacting
  - Electrically neutral
- They also:
  - Can pass through dense areas of space unimpeded
  - Are not bent by magnetic fields
- But also makes them difficult to detect; enormous detectors

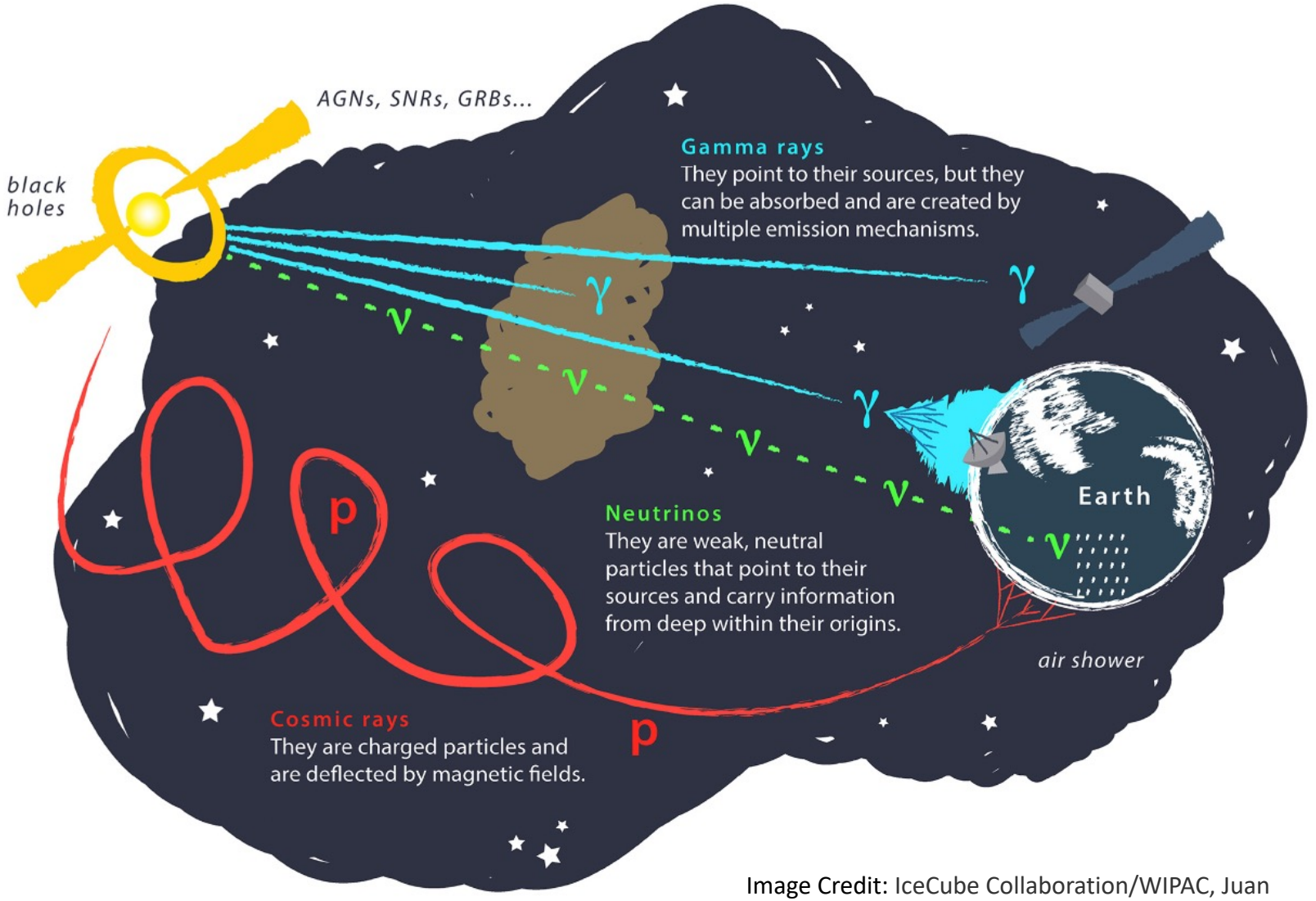
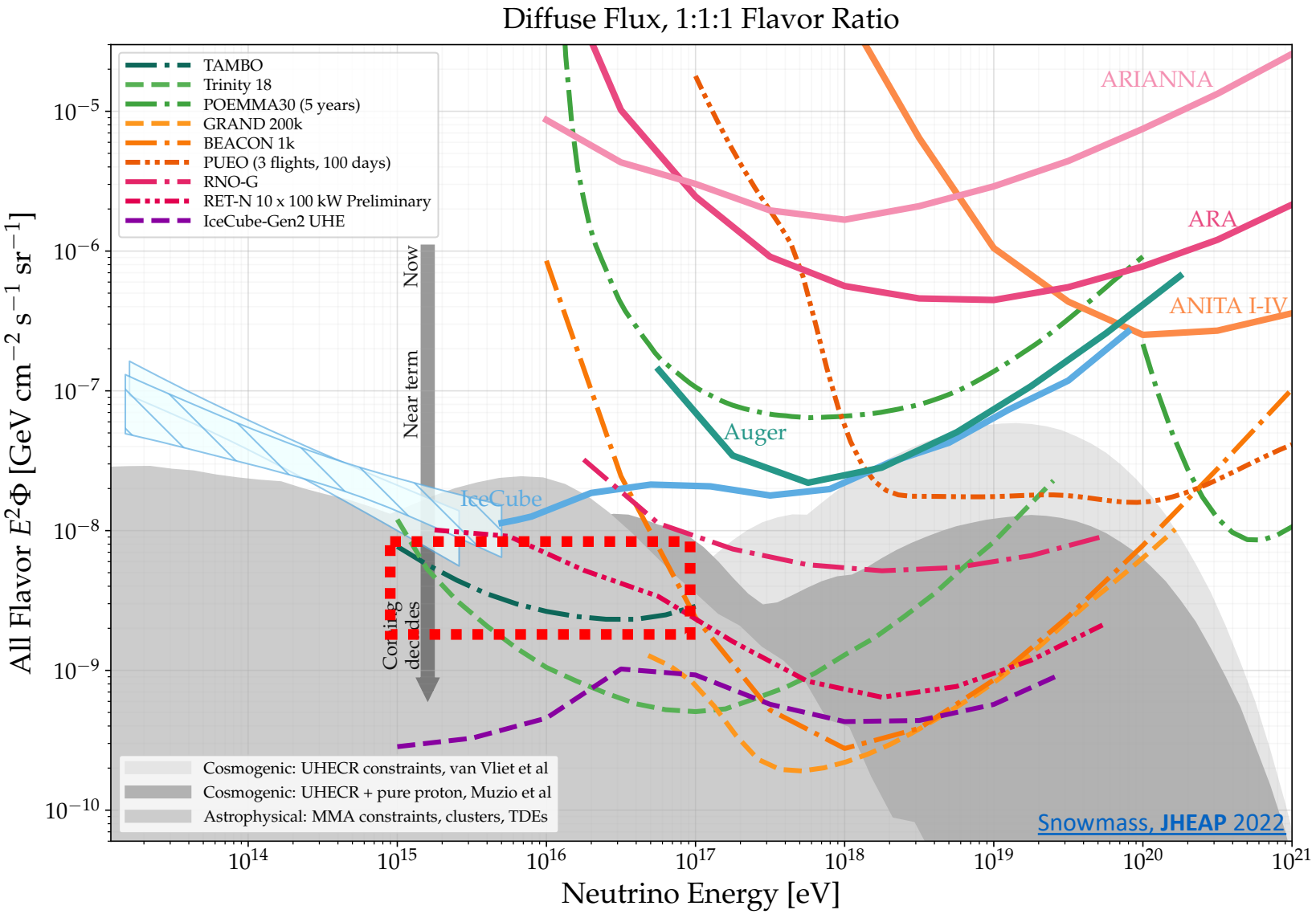
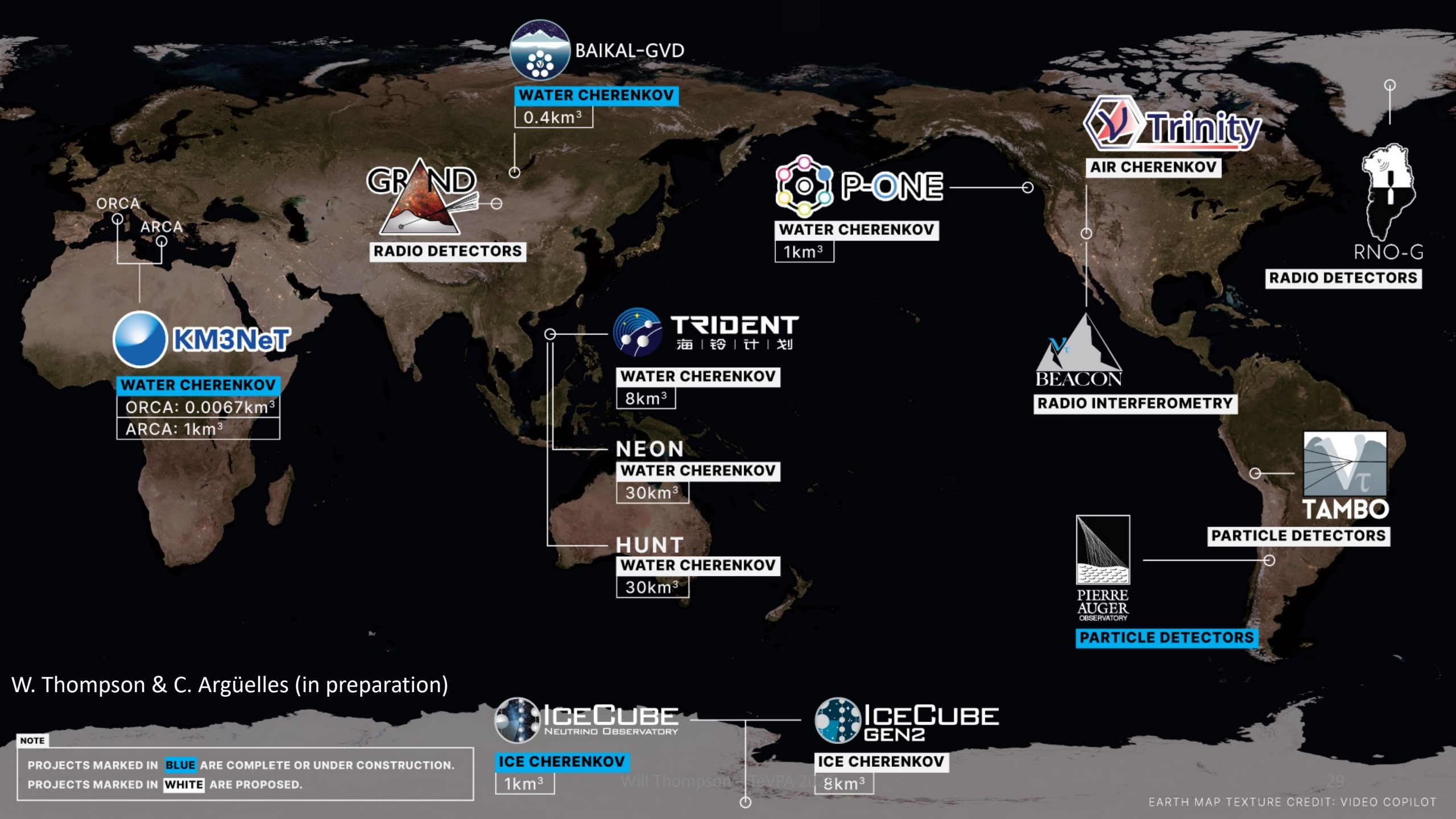


Image Credit: IceCube Collaboration/WIPAC, Juan Antonio Aguilar, and Jamie Yang.

Next-Generation Prospects

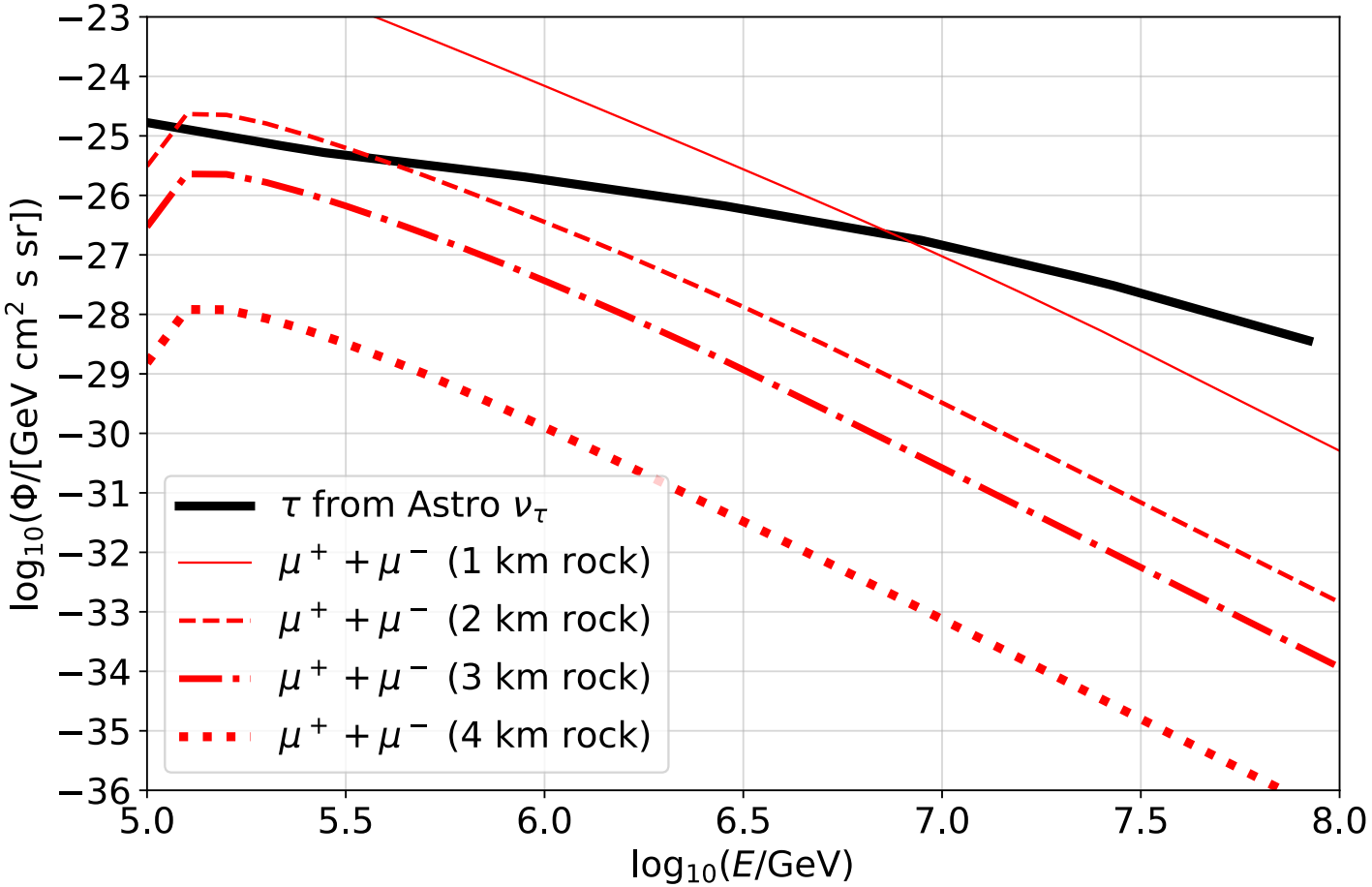


- Community has heeded call for UHE neutrino observatories
  - But fewer experiments planned for 1-100 PeV
- TAMBO bridges the gap between HE & UHE observatories
  - Sensitive from ~300 TeV to ≥ 1 EeV



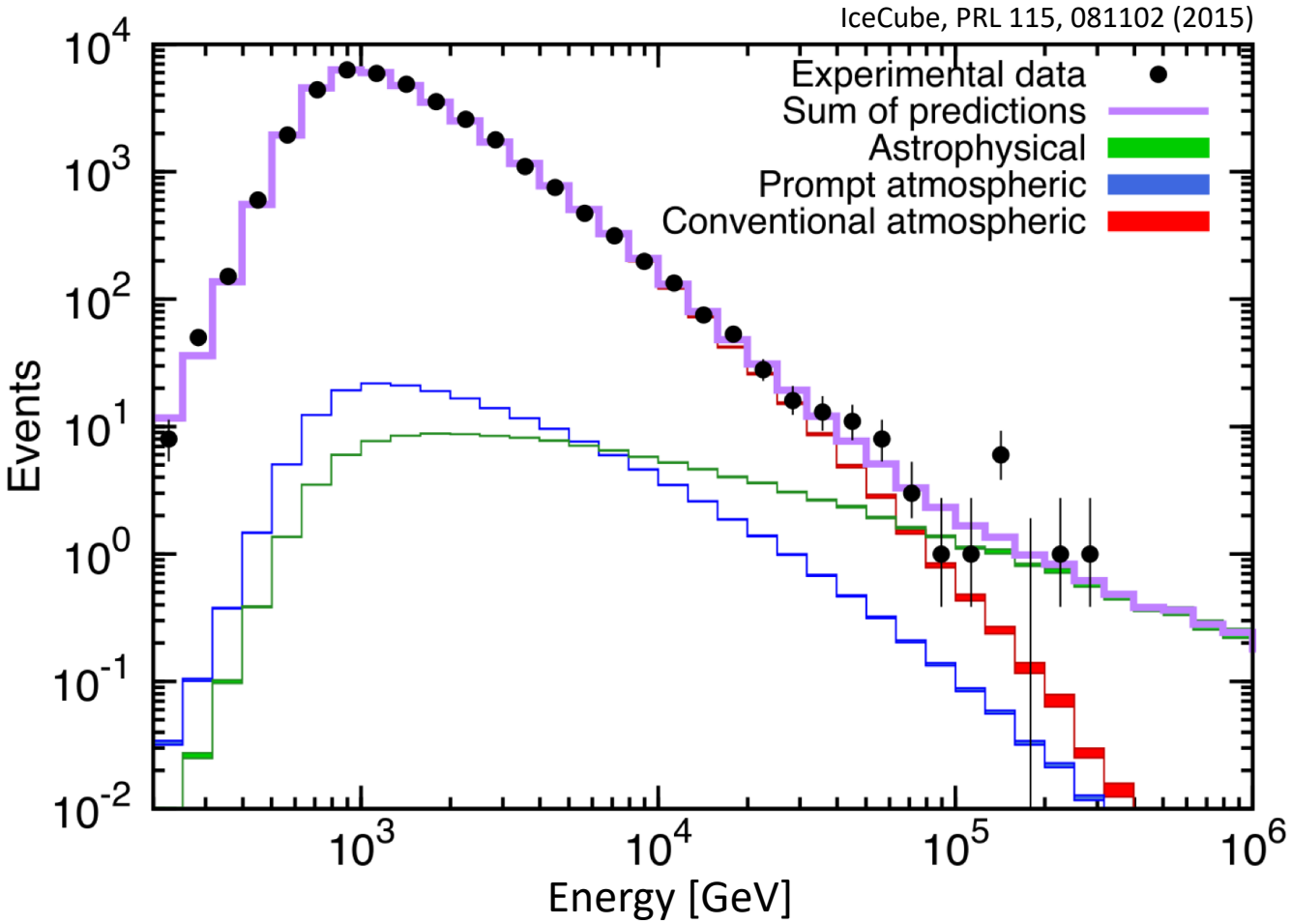
W. Thompson & C. Argüelles (in preparation)

Removing Muon Background Requires Accurate Topography



- Mountain acts as filter for muon backgrounds
- Neutrino purity tunable based on column depth requirement

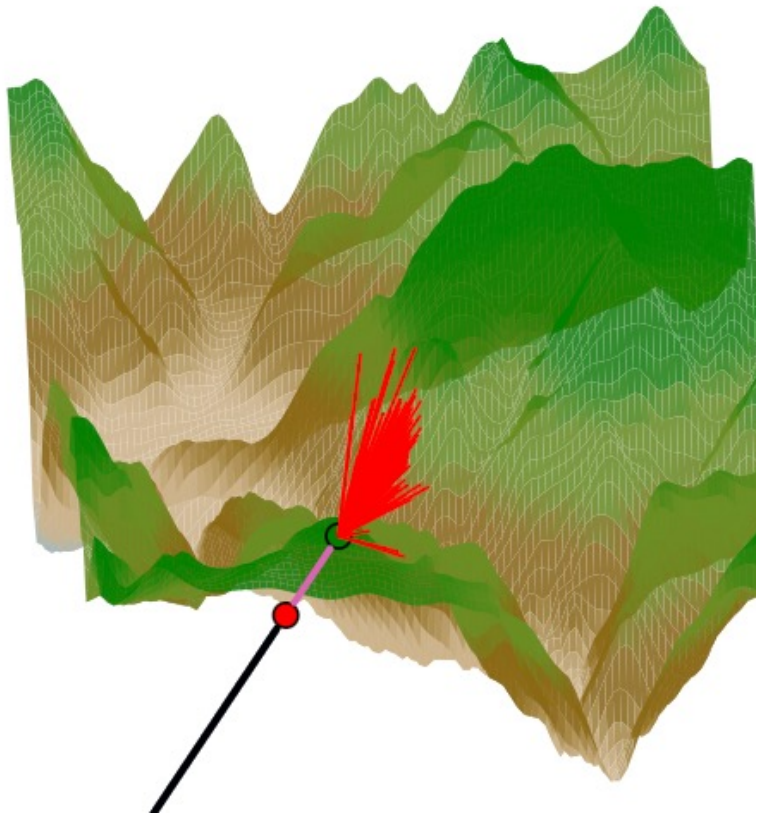
Why ν_τ?

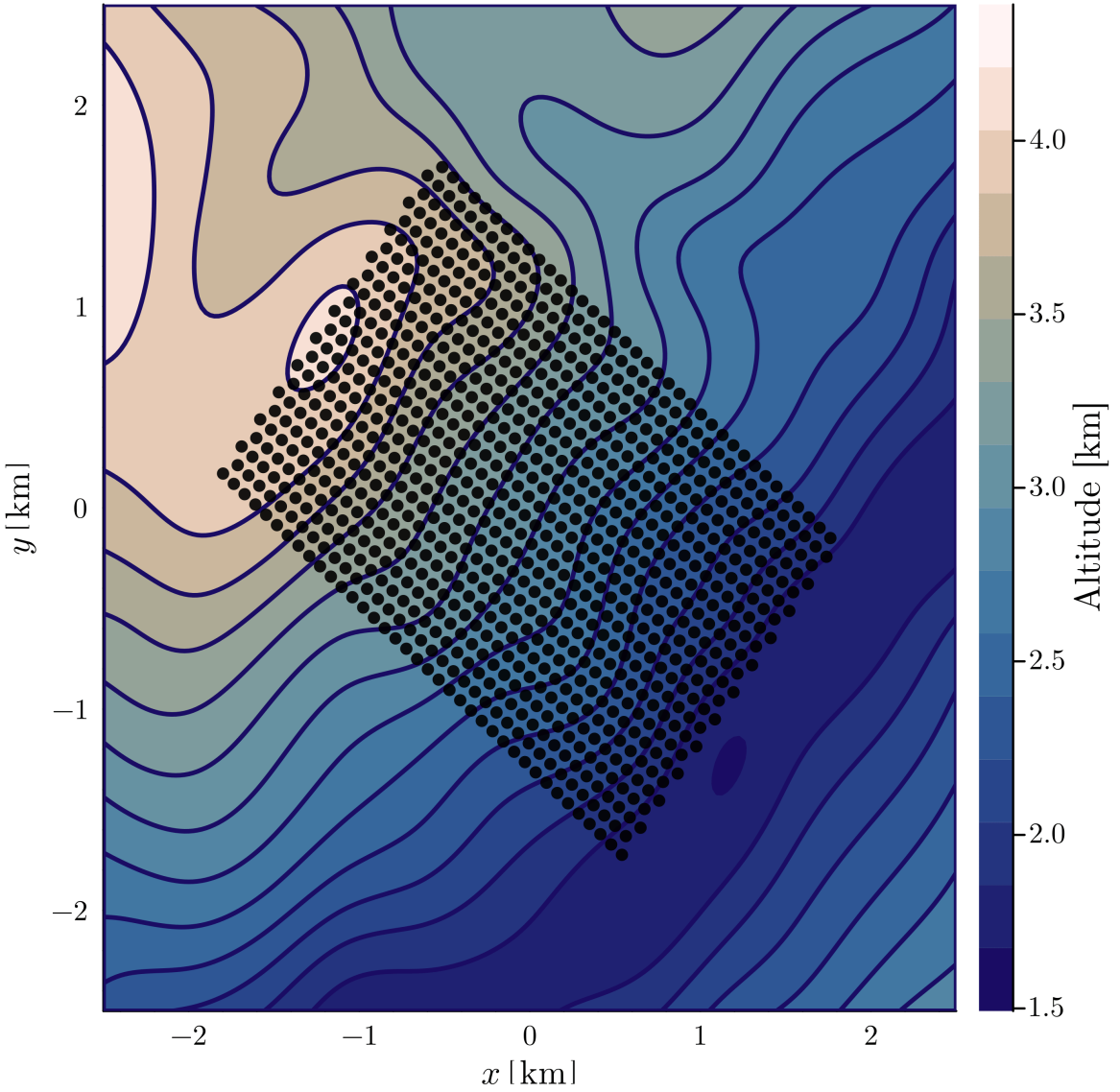


- Complementary flavor measurements with IceCube-style detectors
- High-purity astrophysical neutrino sample
  - Astrophysical flux dominates $\gtrsim$100 TeV
  - Atmospheric flux is τ-poor

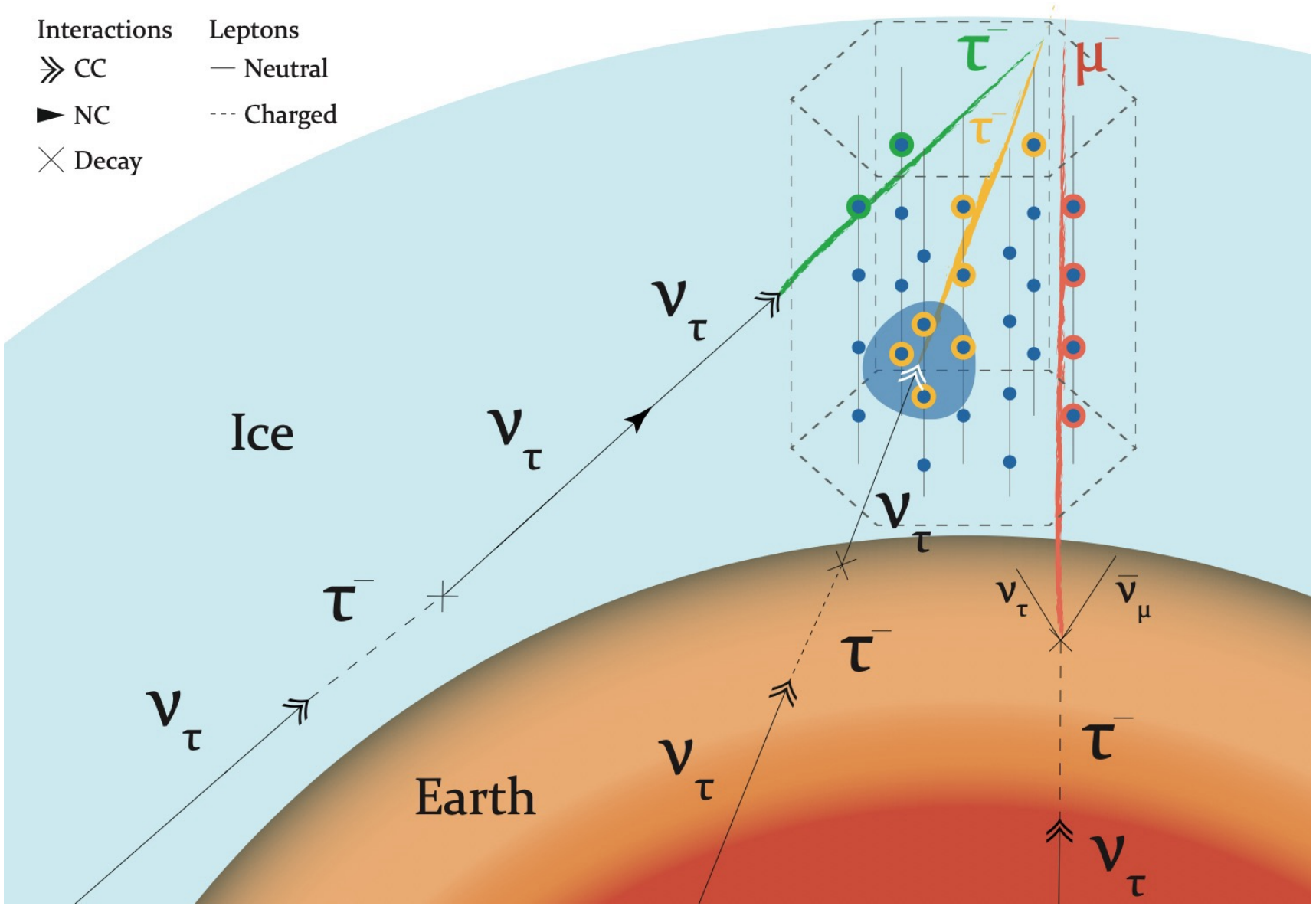
Air-Shower Simulation

- CORSIKA8 tracks individual particle energies & arrival times
- Enables in-depth rate & reconstruction studies





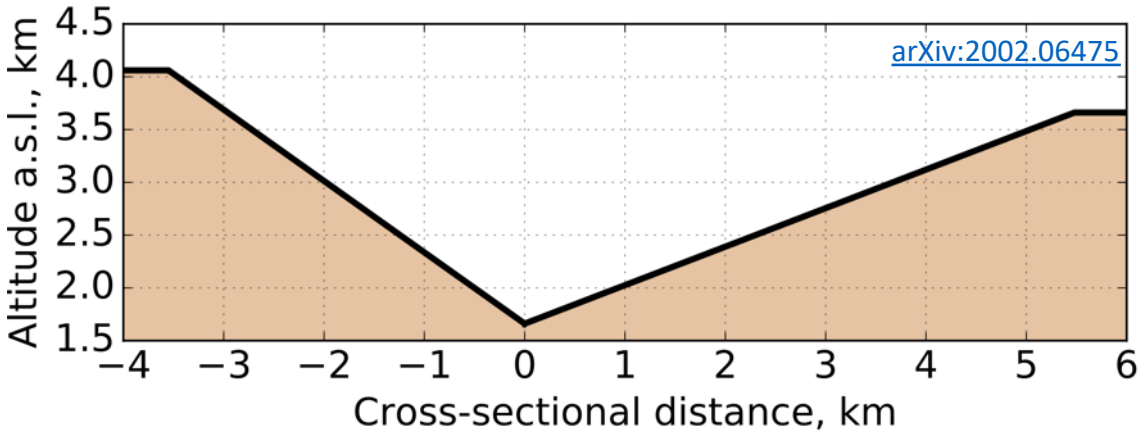
Taking Advantage of Tau Regeneration



Safa *et al.*, JCAP **01** 012 (2020)

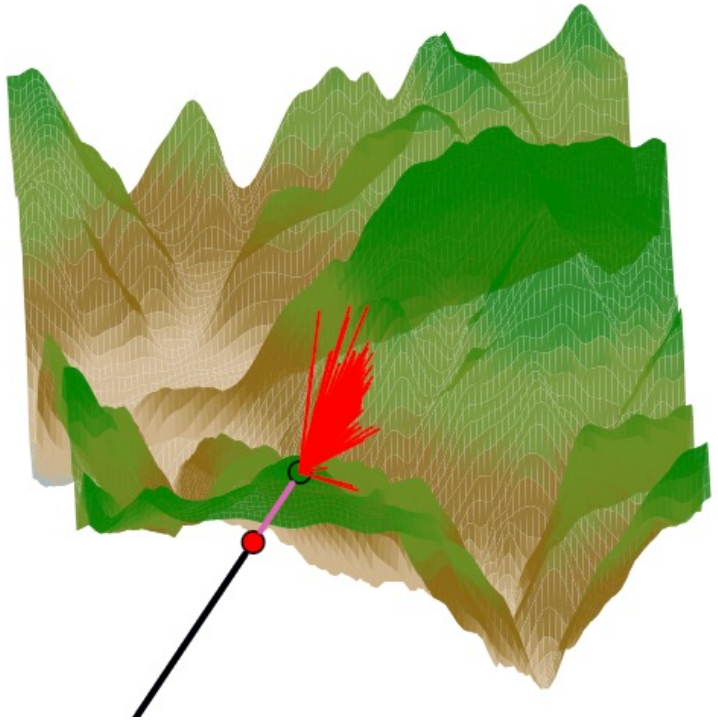
Developing Full Simulation

Preliminary Simulation



- Simplified geometry
- No treatment of τ energy losses
- Approximation of air shower physics

Updated Simulation



- Realistic geometry
- Full treatment of τ energy losses
- Air shower simulation with CORSIKA 8

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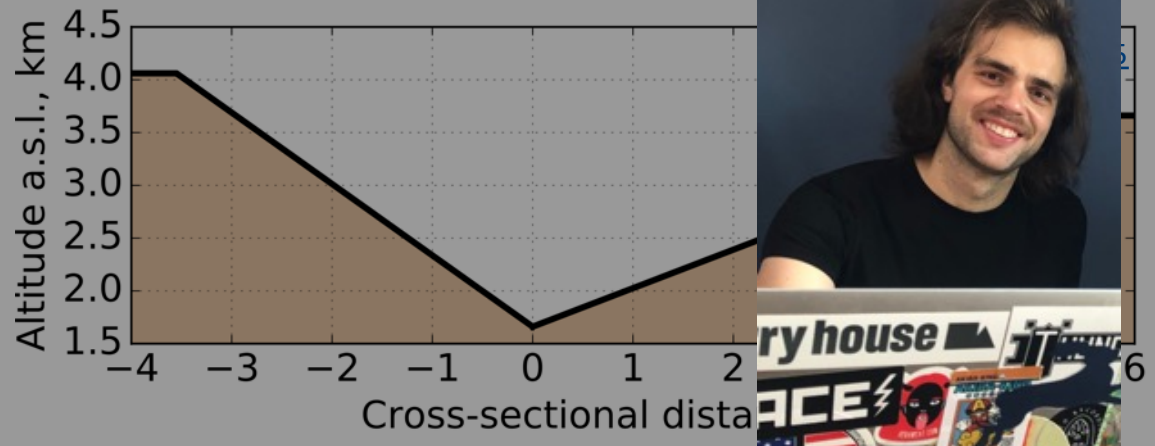

Jeff Lazar

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- No treatment of τ energy losses
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Updated Simulation

Pavel Zhelnin

- Realistic geometry
- Full treatment of τ energy losses
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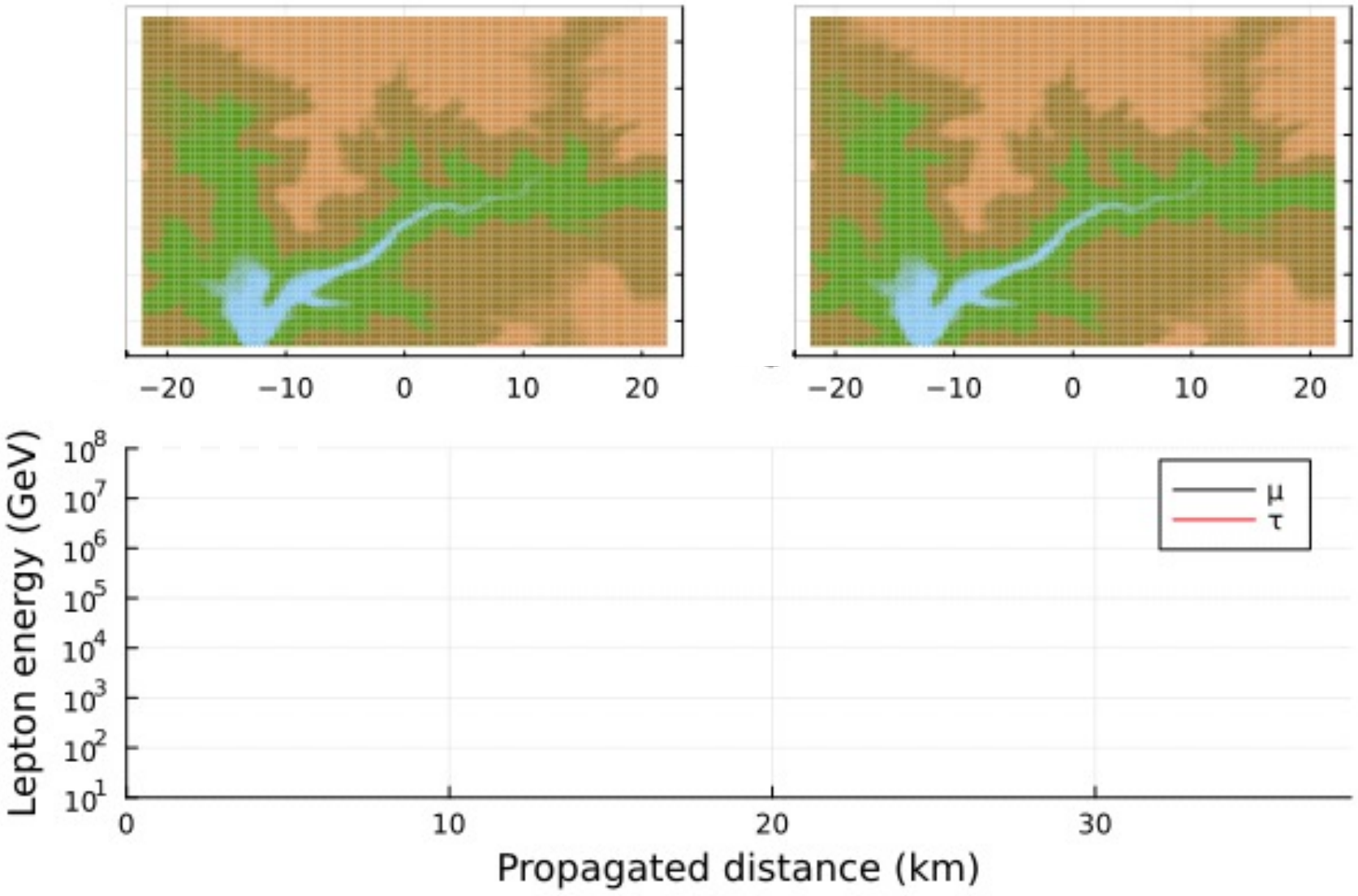
The Canyon is an Astrophysical ν_τ Sieve

- Air-shower is exclusive to ν_τ
- μ^- energy greatly attenuated
- e^- entirely shielded by rock



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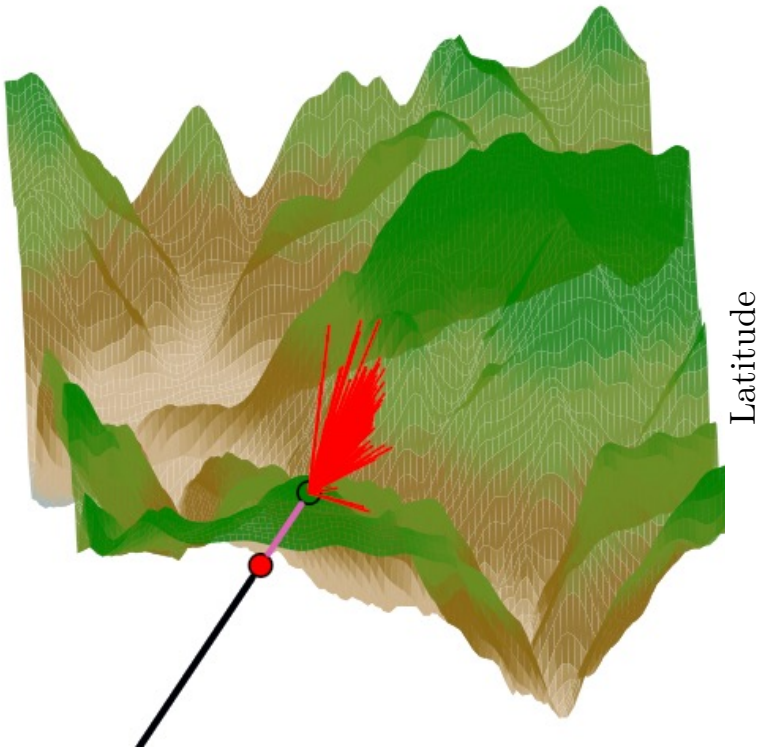
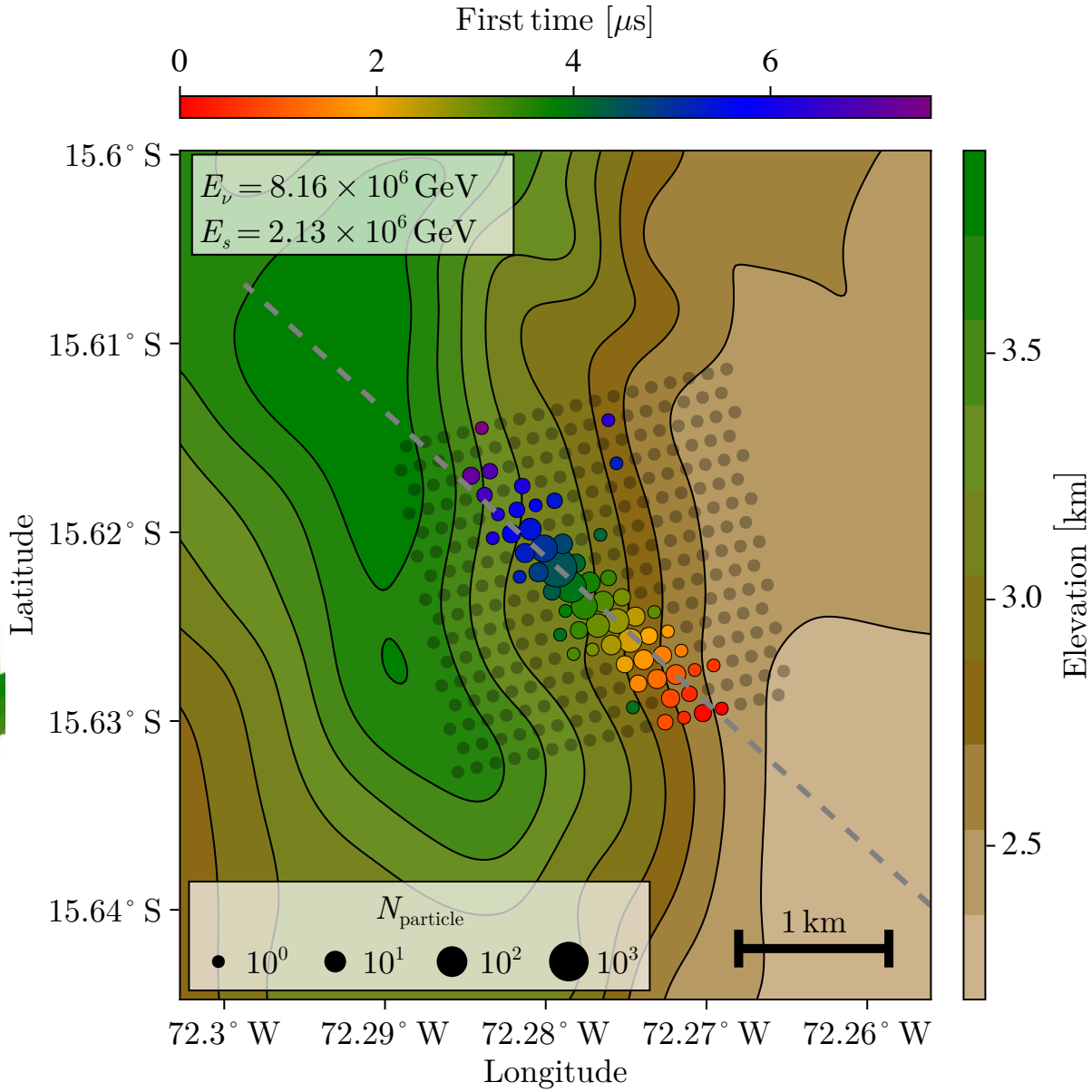
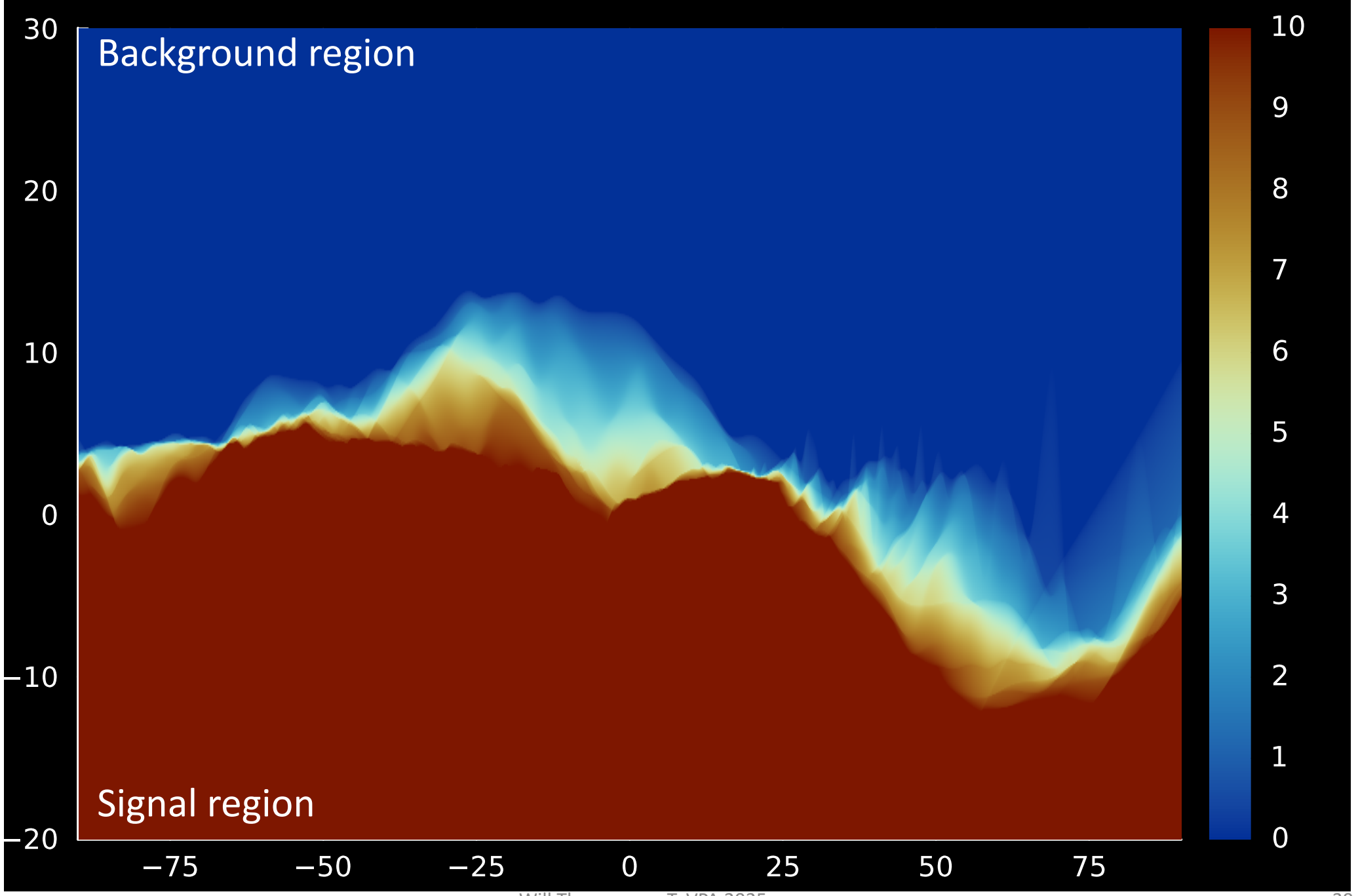





Ccella Ccella
Mismi
Huarancante
Chivay
Tapay
Cabanaconde


Background region
Signal region
30
20
10
0
−10
−20
−75
−50
−25
0
25
50
75
10
9
8
7
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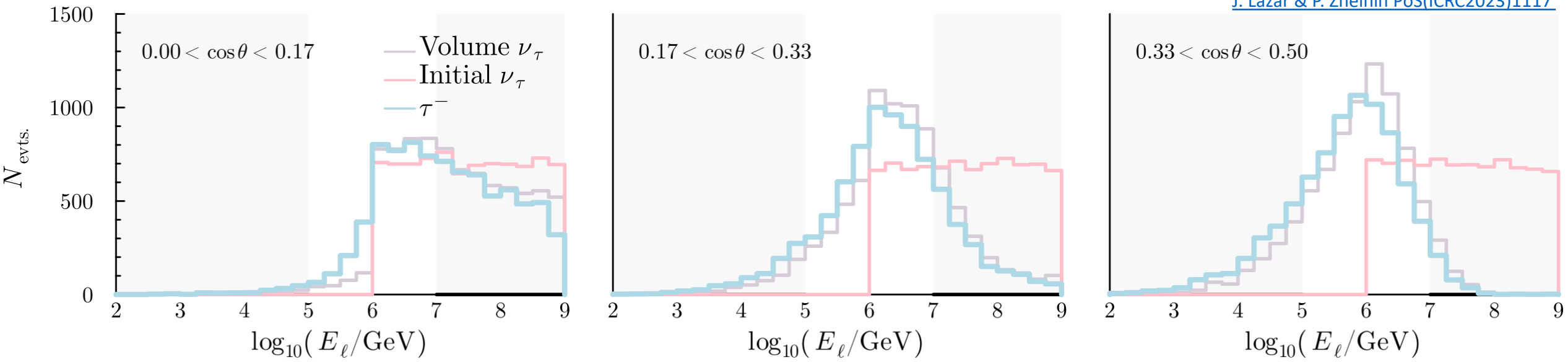
4
3
2
1
0

Taking Advantage of Tau Regeneration

J. Lazar & P. Zhelnin PoS(ICRC2023)1117



- Incoming ν_τ can undergo several $\nu_\tau \leftrightarrow \tau$ conversions in the Earth
- Results in higher rates than predicted by preliminary simulation
- Updated simulation handles tau regeneration via `TauRunner`[1]

[1]Safa *et al.*, CPC **278 108422** (2022)

Peru Outreach Trip

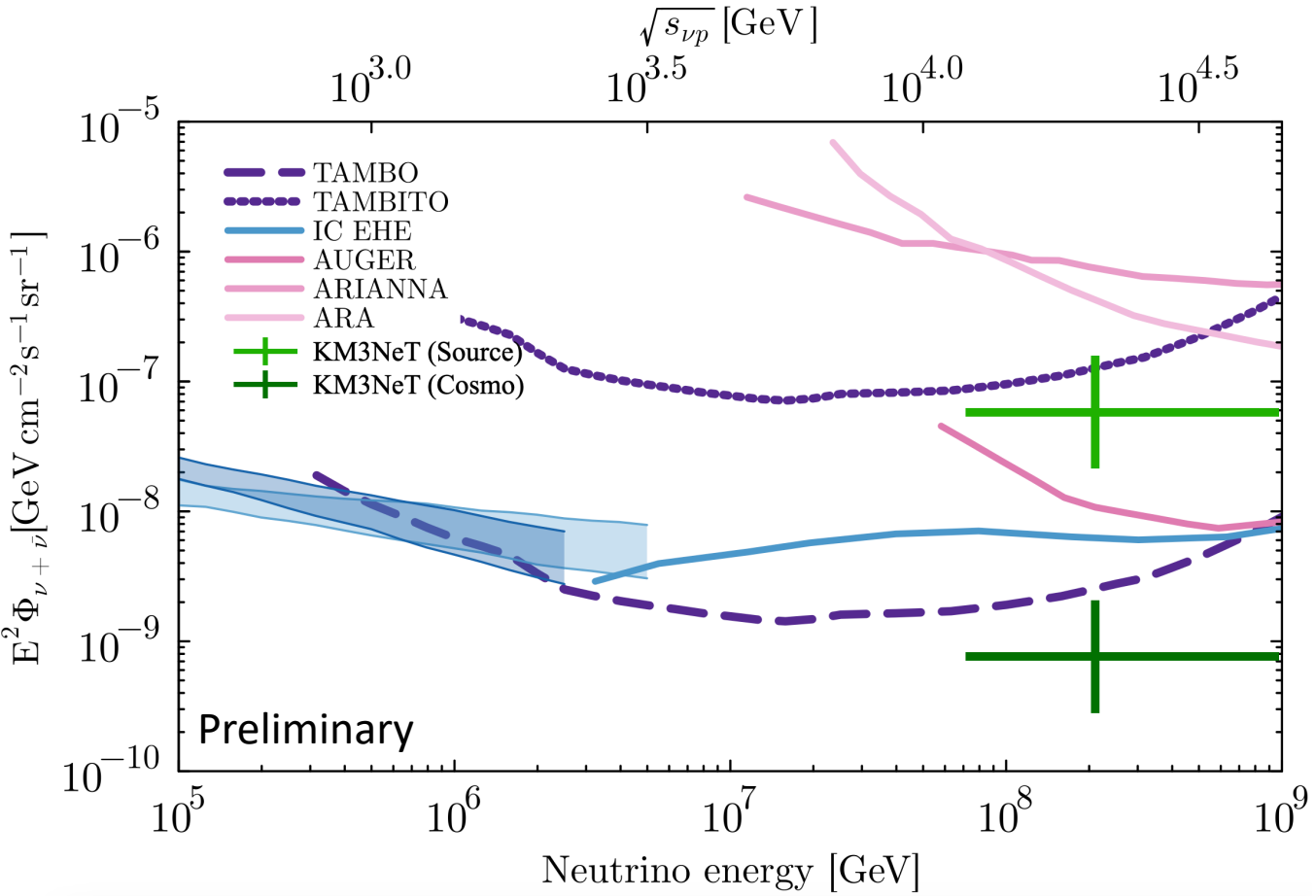
Photo Credit: Universidad Nacional de San Agustin de Arequipa

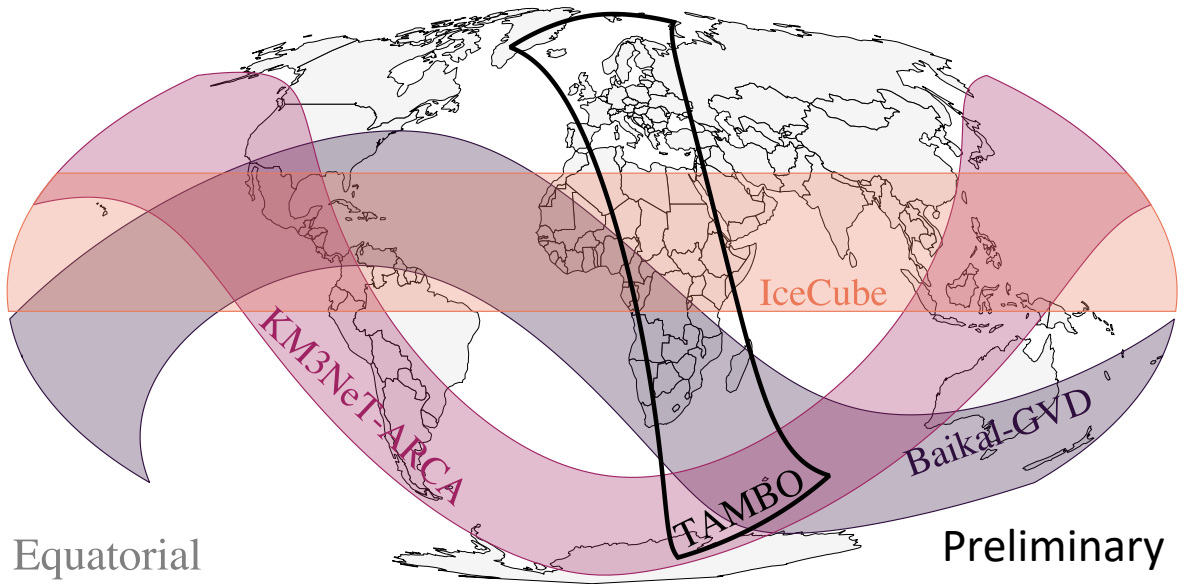
- Traveled to Peru in fall 2022 to meet with officials and visit site

TAMBO & the Canyon

Most promising location quite remote; closer areas for test array

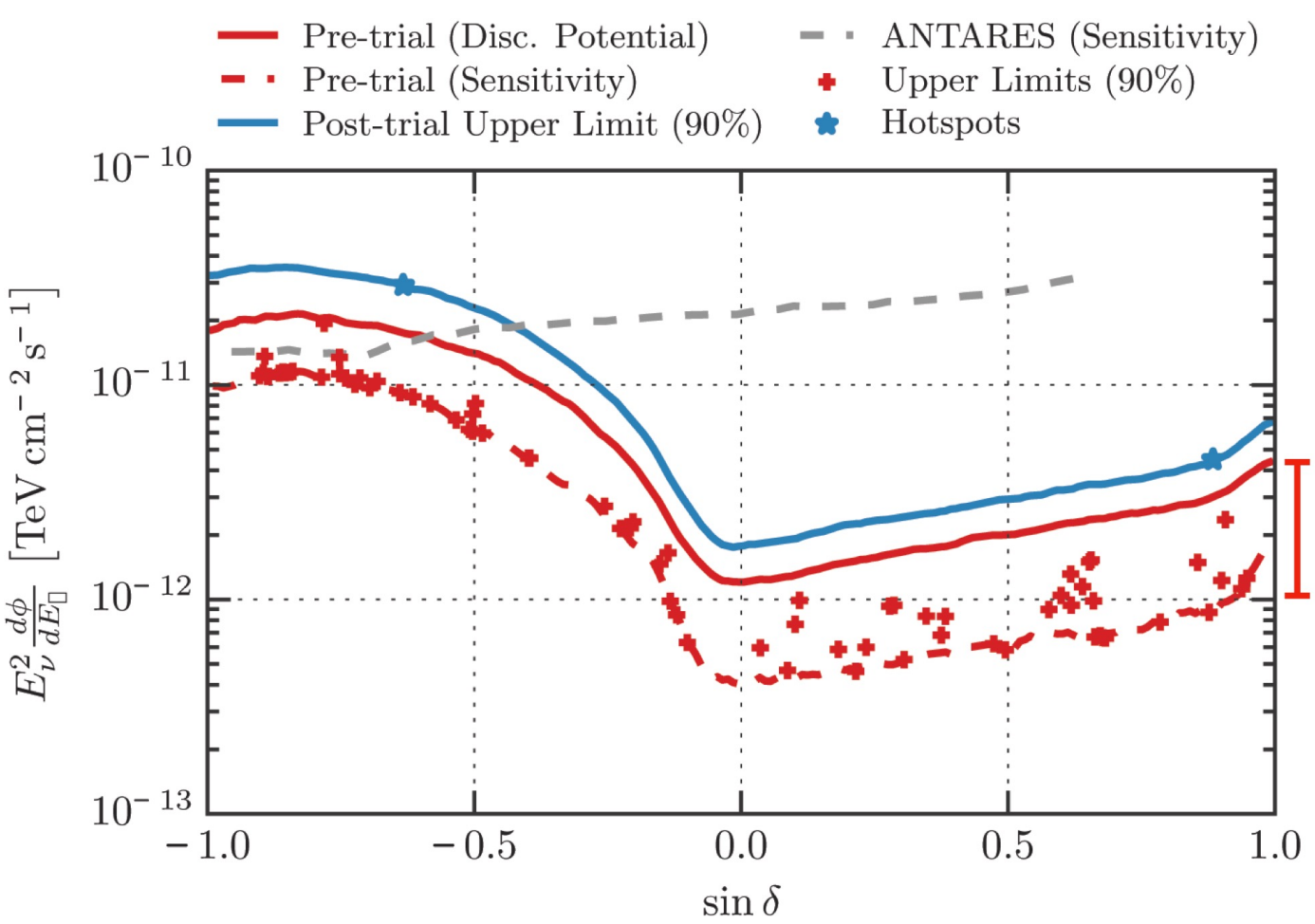
TAMBO Is Complementary to High-Statistics Observatories





- Sensitive to source scenario of KM3NeT flux
- Instantaneous and integrated sky coverage overlaps with Cherenkov telescopes

TAMBO as a Viewfinder: Overcoming the Trials Factor



- All-sky searches penalized by large trials factors:

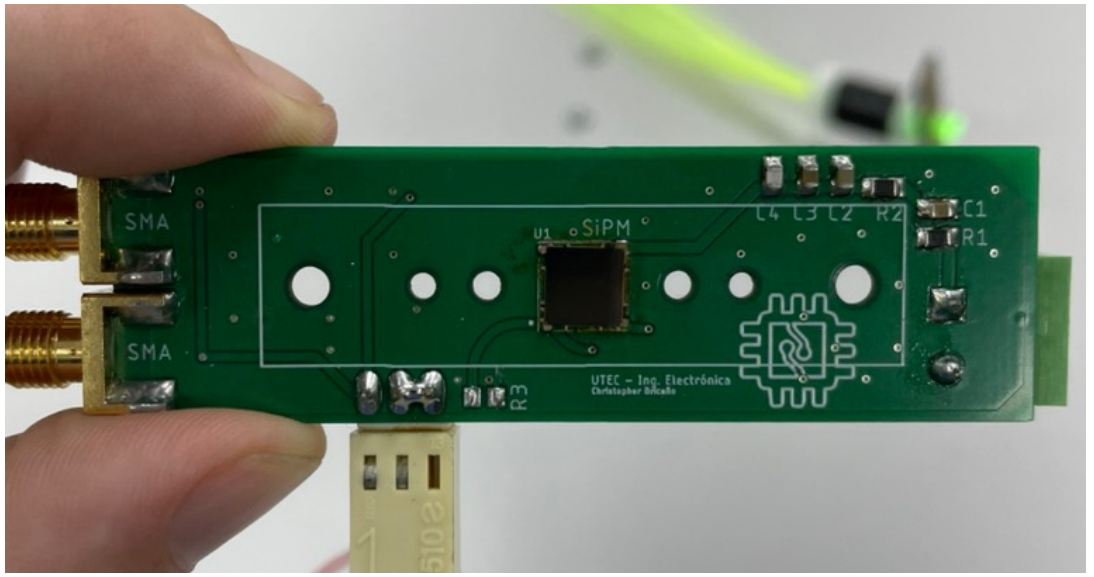
  ~445,000 trials

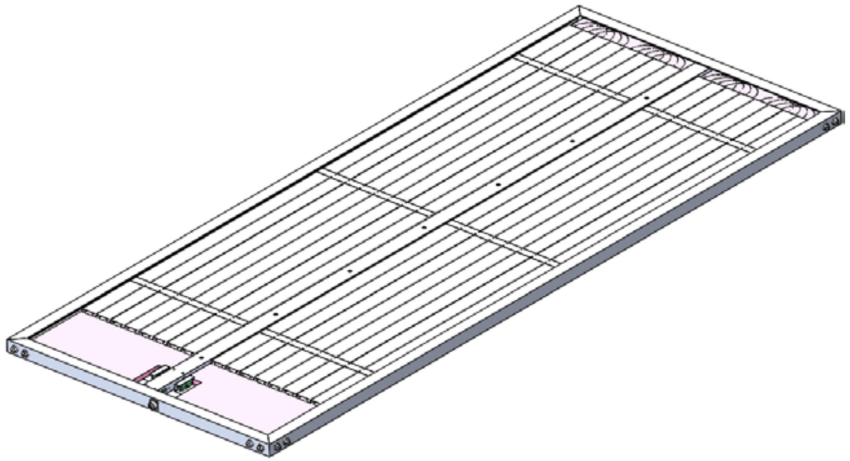
  → 19.8 trials per square degree

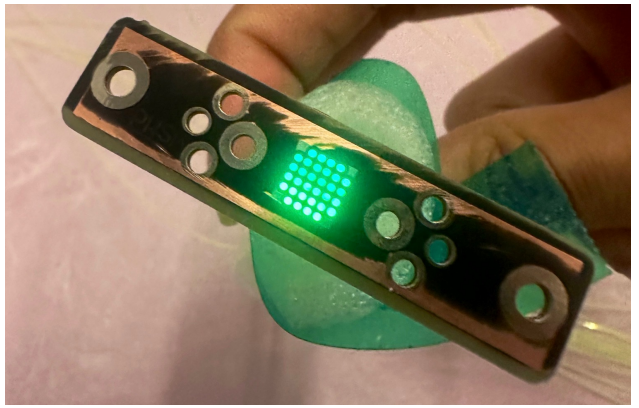
- TAMBO's neutrino catalog with greatly reduce these trials factors

TAMBO Hardware Requirements

- 1° pointing resolution → O(ns) timing
- Ease of deployment on canyon face → water Cherenkov vs plastic scintillator
- Reduce wiring → wireless communication
- Low ecological footprint
- Affordable







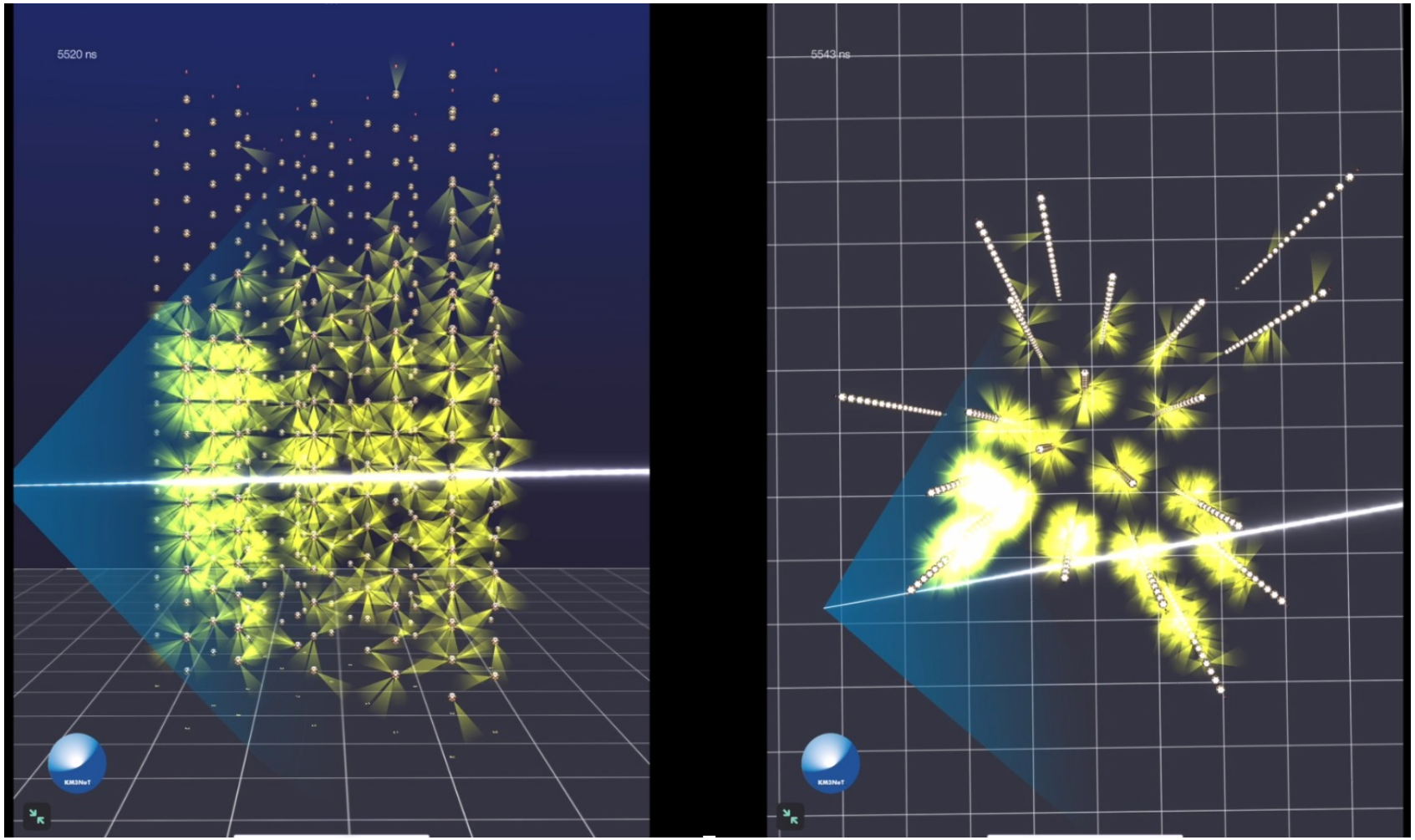
Pierre Auger Observatory: a success story

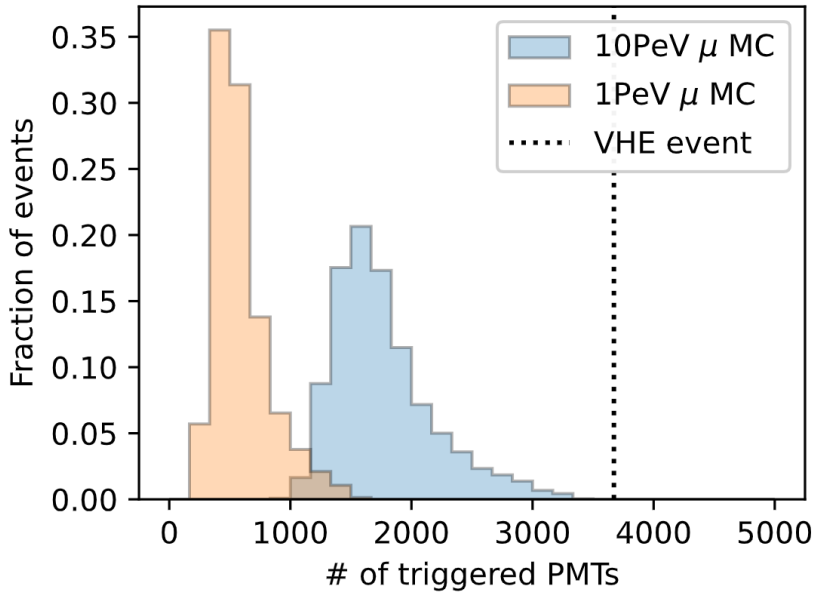
3,000 km^2 observatory in Argentina with:

- Responsible land use agreements with 400+ landowners
- New power lines & internet
- Organized local science fairs
- Competition to name detectors in local schools
- Visitor center open 7 day/week
- Public talks

Pierre Auger Collaboration, ICRC 2017

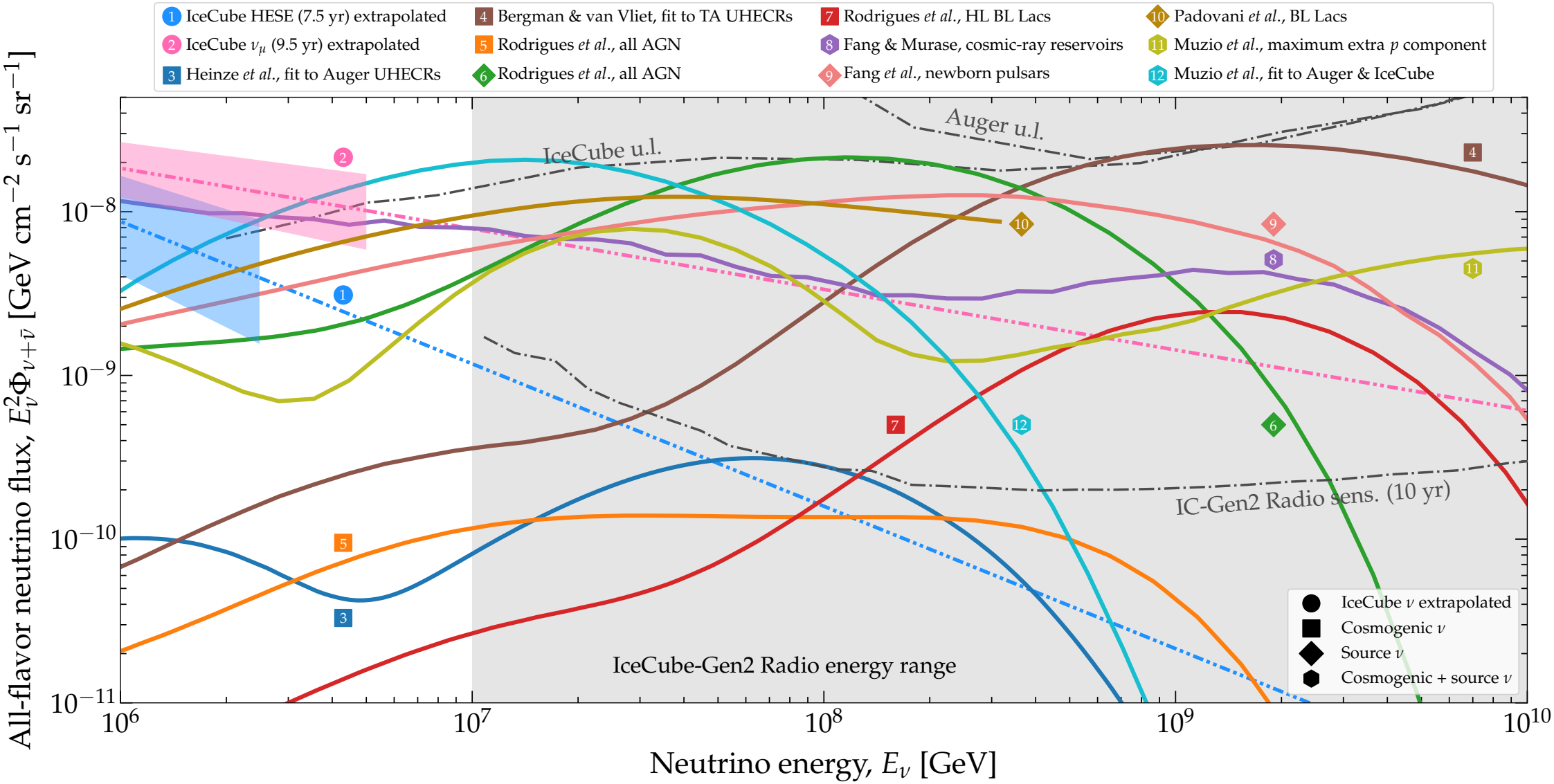
KM3NeT Very High Energy Event





KM3NeT Collaboration, Neutrino 2024

Neutrino Flux Models



Summary

- TAMBO will:
  - Enable the discovery of hidden neutrino sources
  - Bridge gap between HE and UHE neutrino telescopes
- TAMBITO funded; development began in August
- Overview paper available at arXiv:2507.08070
- Interested in joining? Contact (me or Carlos Argüelles) at will_thompson@g.harvard.edu, carguelles@g.harvard.edu