

TAMBO and TAMBITO: Progress Towards a Next-Generation Tau Neutrino Observatory

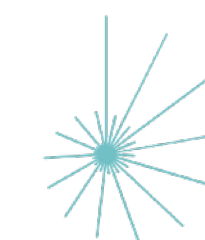
TAMBO means inn in Quechua | TAMBITO means small TAMBO in Spanish

Carlos Argüelles



HARVARD
UNIVERSITY

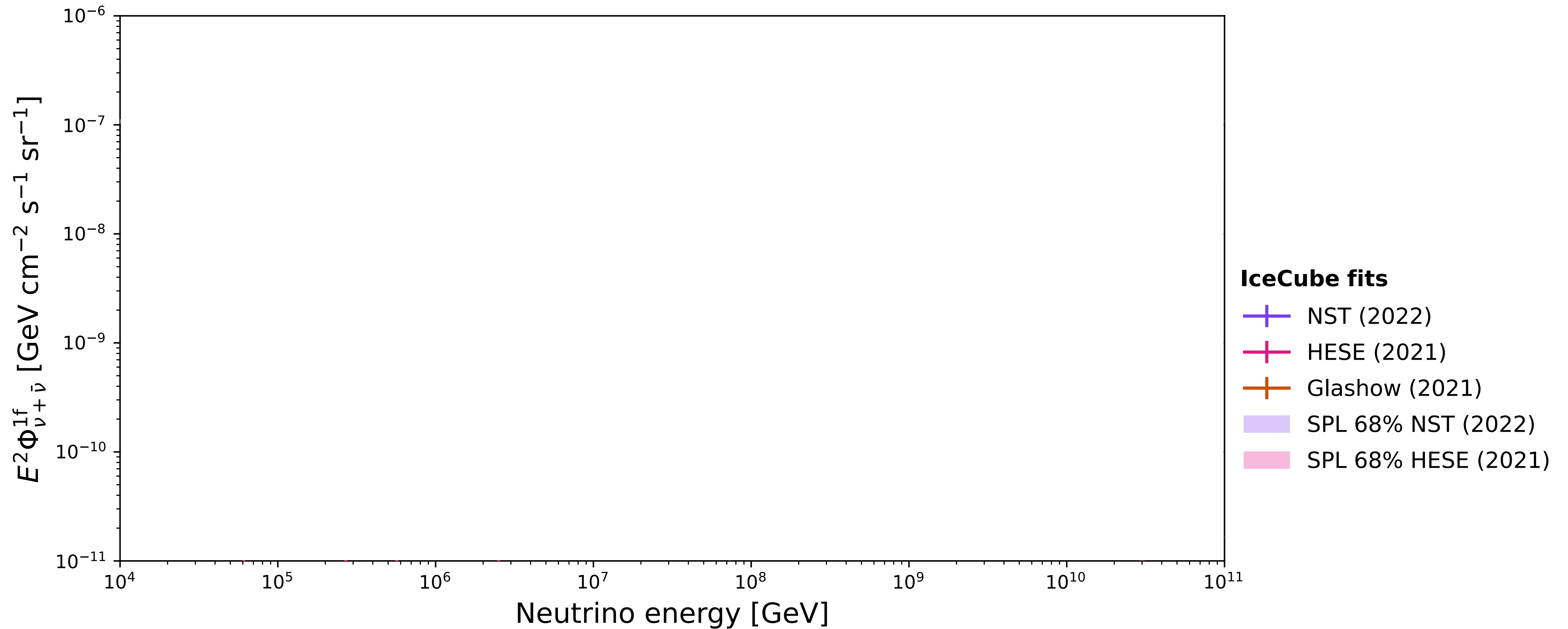
TeVPa2026, Japan, Sept. 2nd, 2026



JOHN
TEMPLETON
FOUNDATION

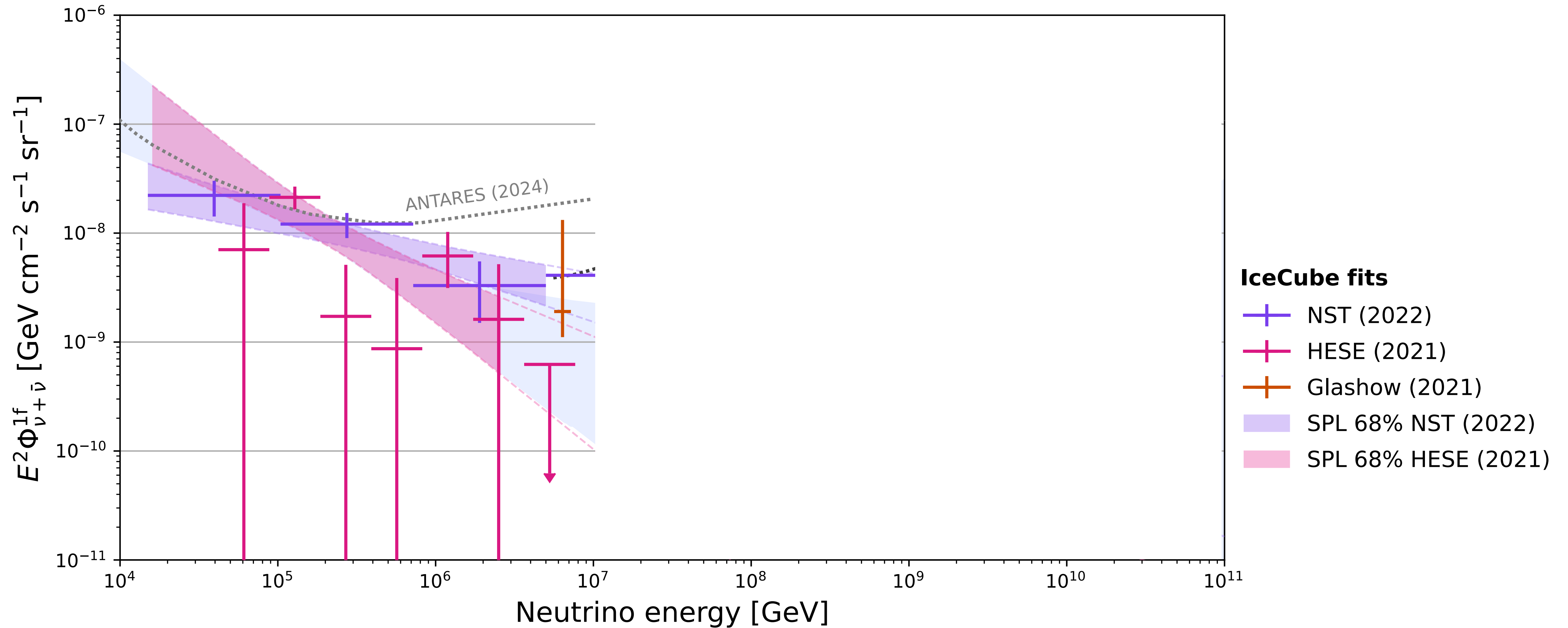
the David
Lucile &
Packard
FOUNDATION

The neutrino sky



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

The neutrino sky



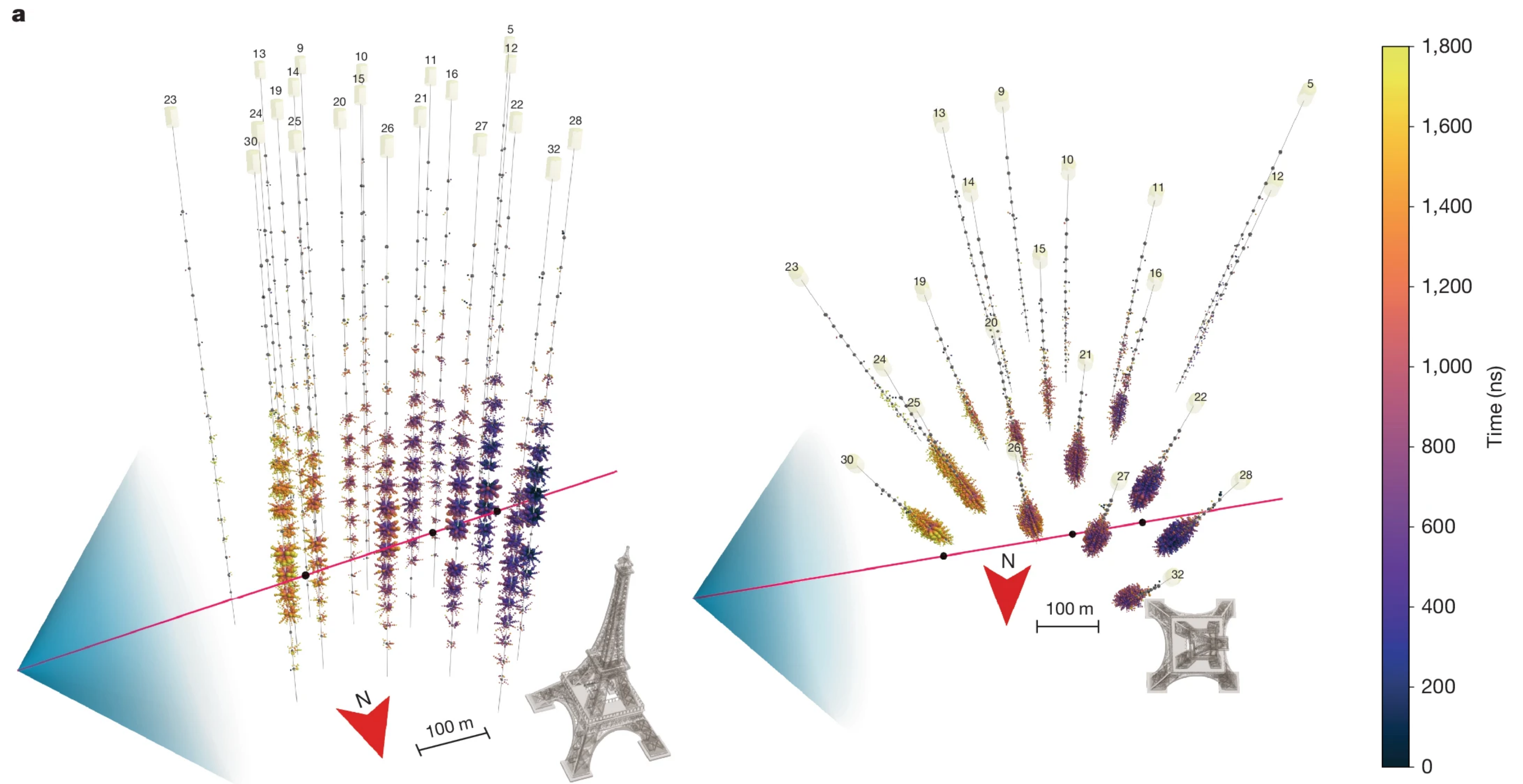
KM3NeT, *Phys. Rev. X* 15, 031016

Observation of KM3-230213A

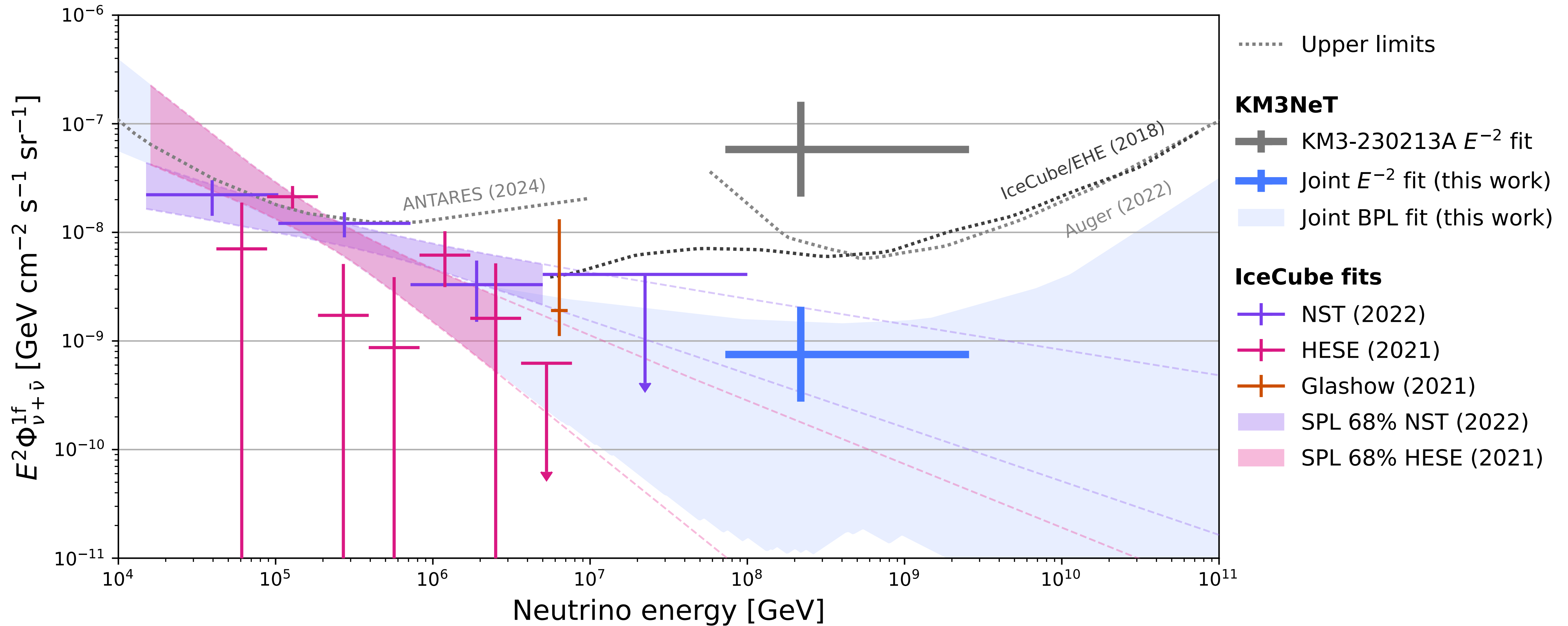
$$E_{\mu} = 120^{+110}_{-60} \text{ PeV} \implies E_{\nu} \gtrsim 100 \text{ PeV!}$$



Nature Volume 638 Issue 8050

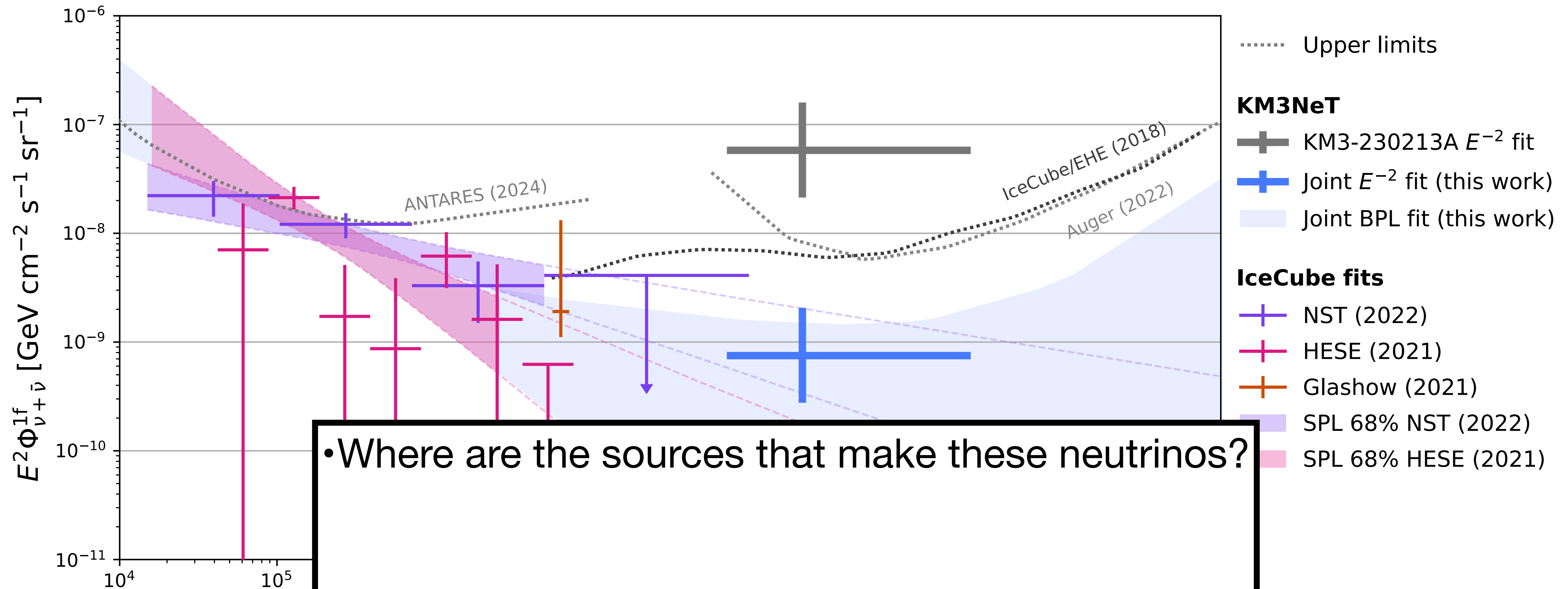


KM3-230213A Within the Global Landscape



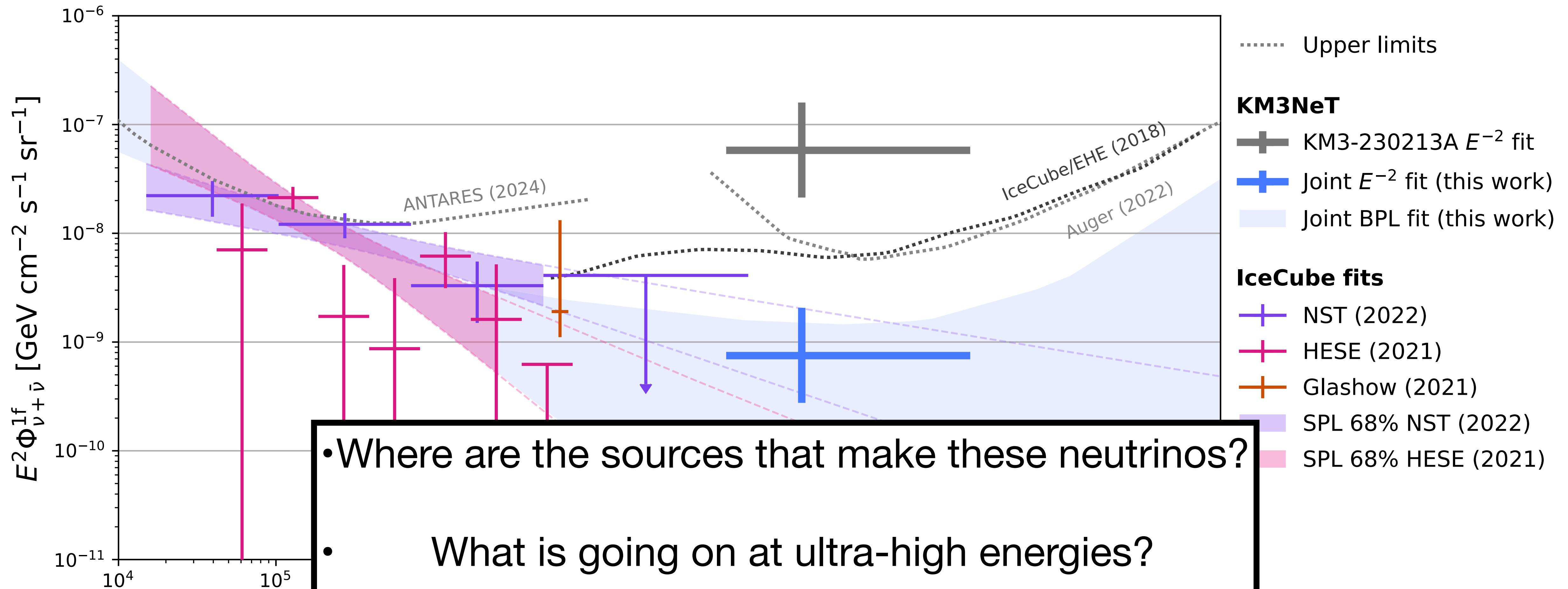
KM3NeT, *Phys. Rev. X* 15, 031016

KM3-230213A Within the Global Landscape



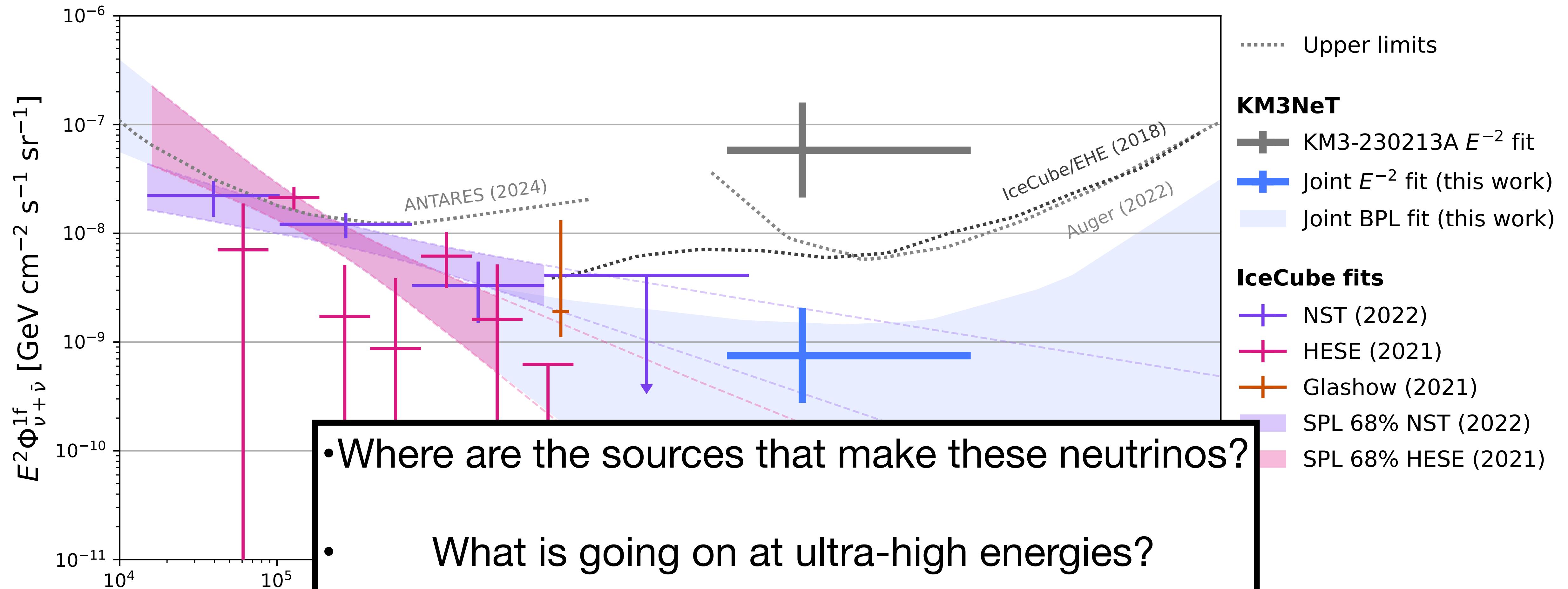
KM3NeT, *Phys. Rev. X* 15, 0

KM3-230213A Within the Global Landscape



KM3NeT, *Phys. Rev. X* 15, 0

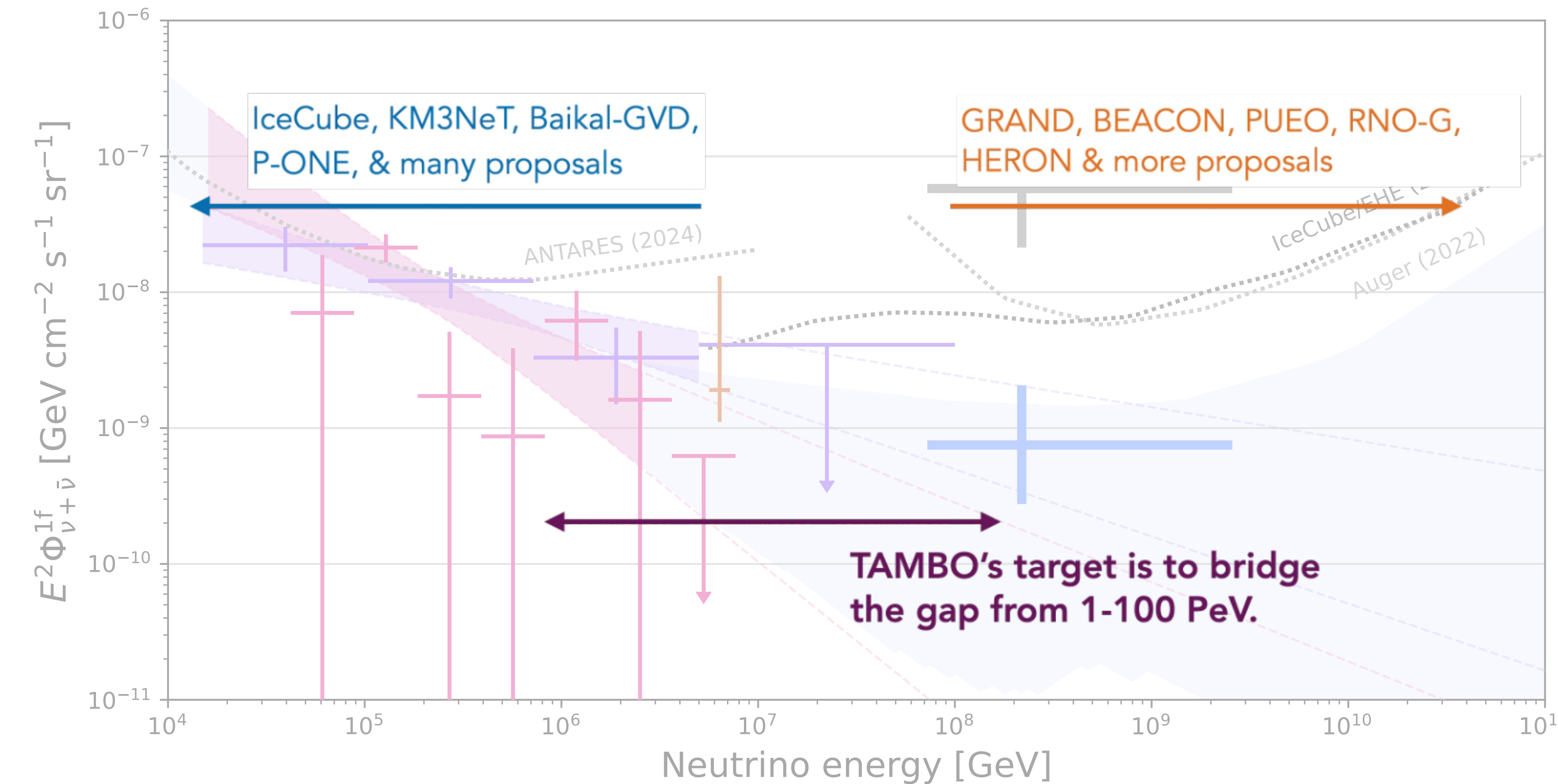
KM3-230213A Within the Global Landscape



- Where are the sources that make these neutrinos?
- What is going on at ultra-high energies?
- Are we seeing any flavor structure?

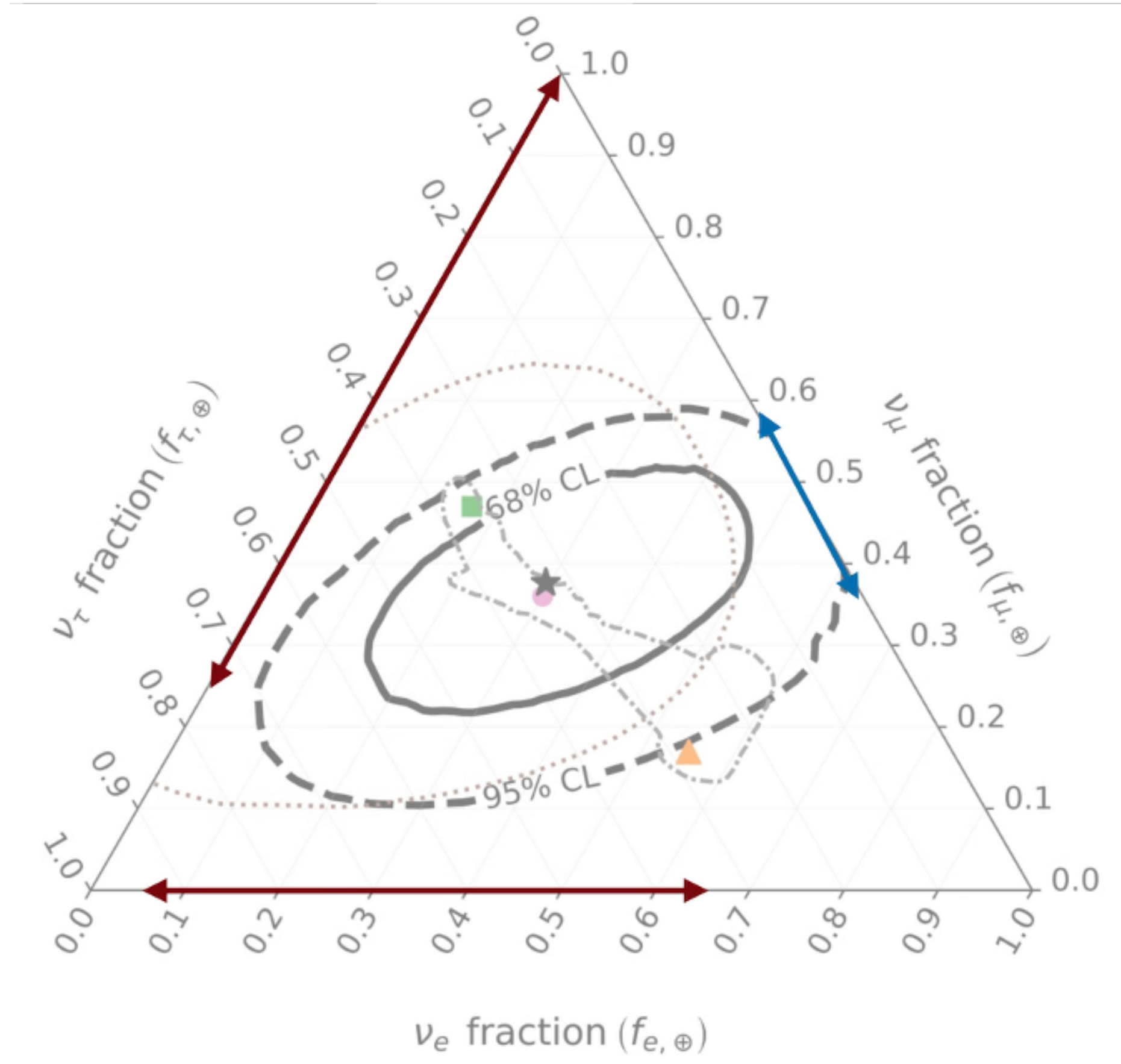
KM3NeT, *Phys. Rev. X* 15, 0

TAMBO will fill in the gap



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

TAMBO will bring unique ways to learn about flavor

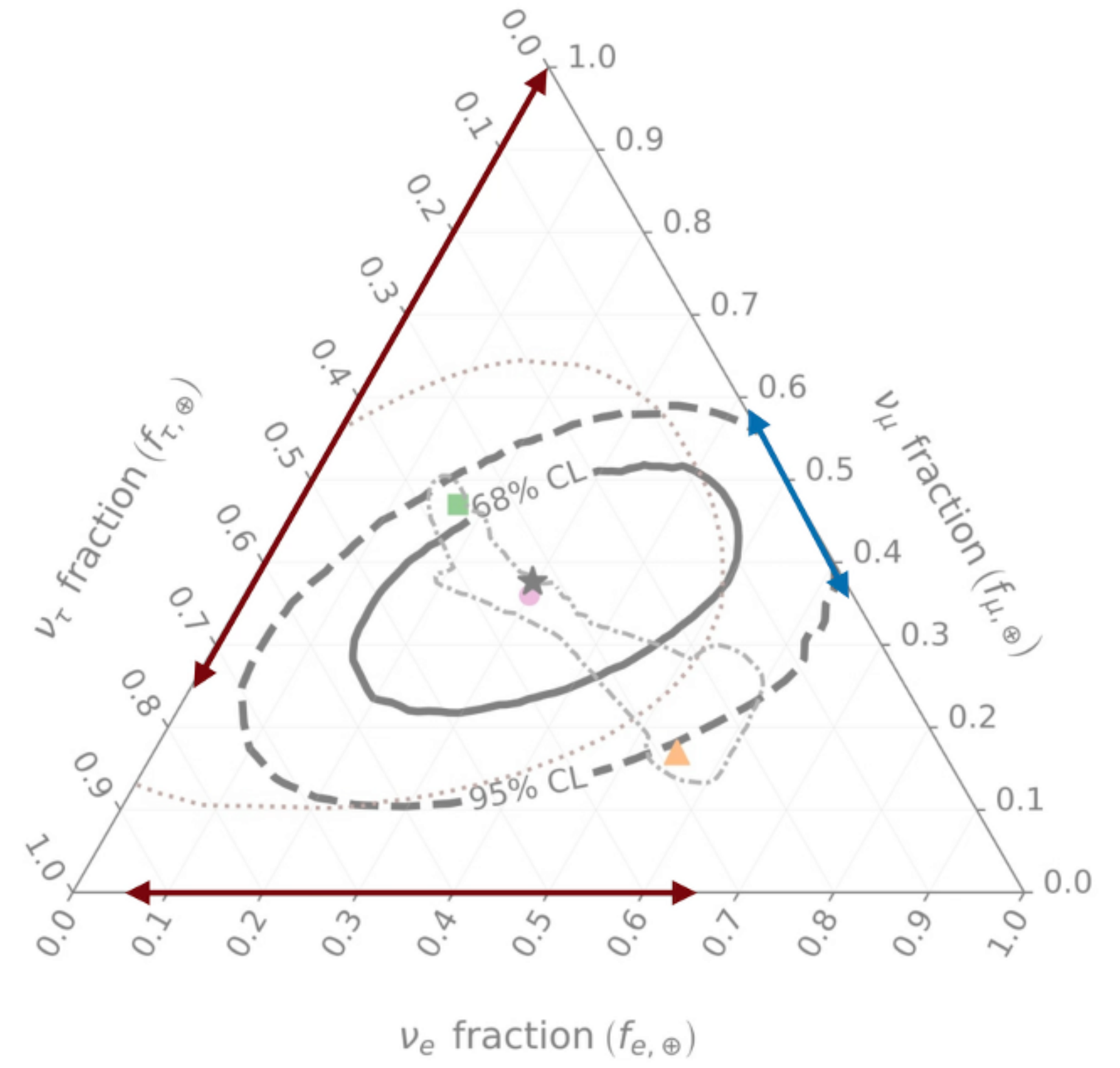


Adapted from
IceCube
arXiv:2510.24957

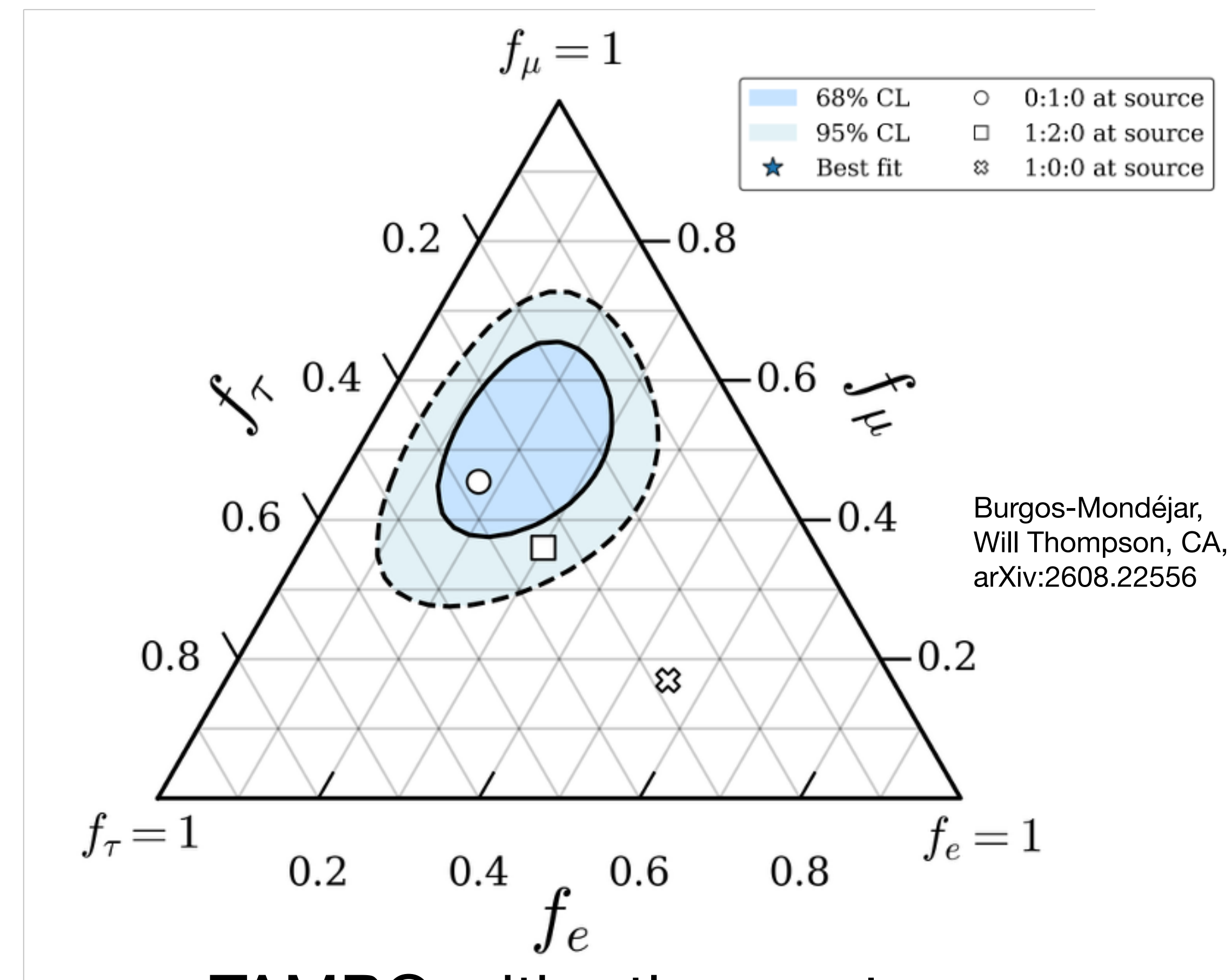
IceCube only, all energies

TAMBO will bring unique ways to learn about flavor

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



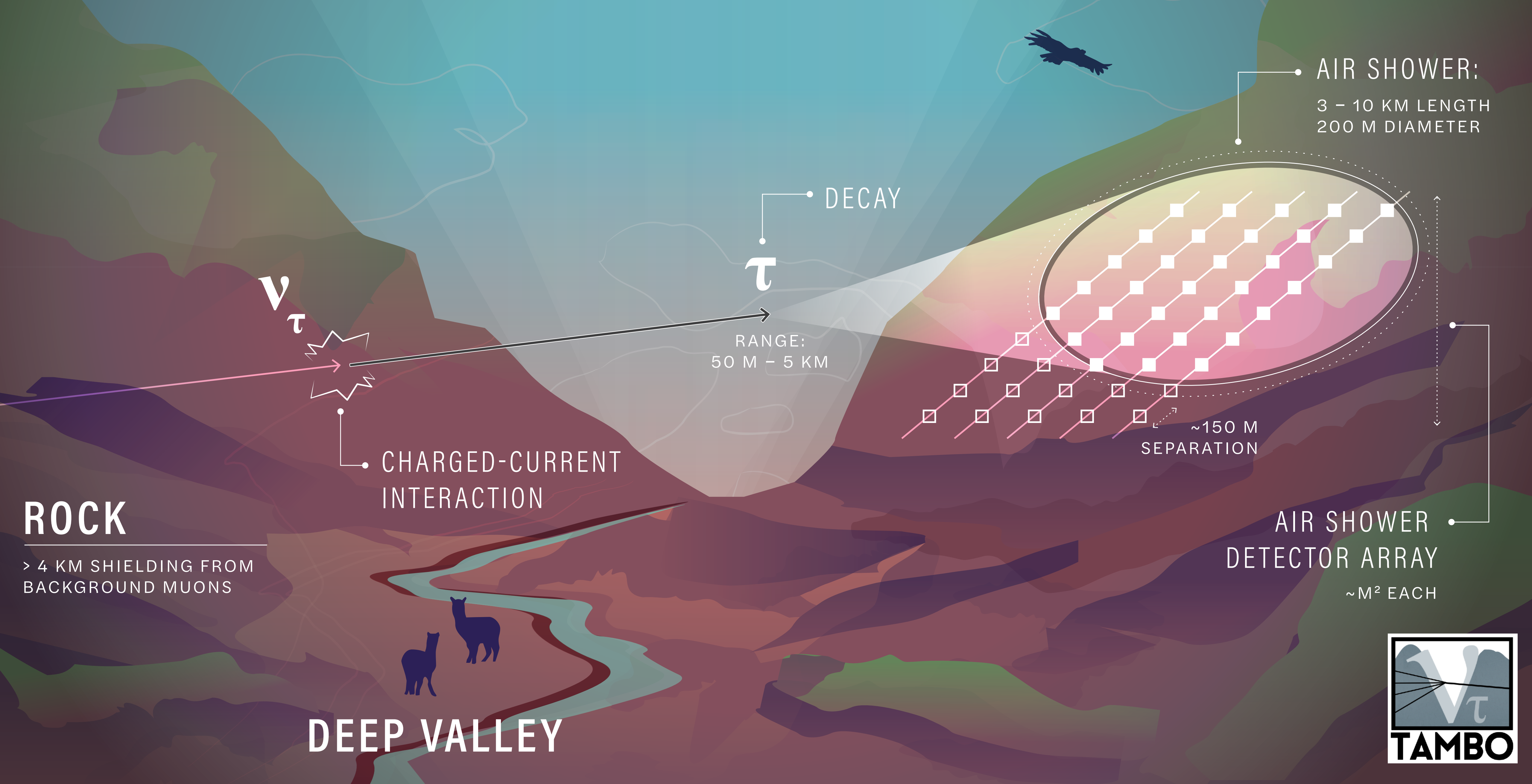
IceCube only, all energies



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

Adapted from
IceCube
arXiv:2510.24957

Burgos-Mondéjar,
Will Thompson, CA,
arXiv:2608.22556



Why are we in a canyon?

DECAY

τ

RANGE:
50 M – 5 KM

ν_τ

CHARGED-CURRENT
INTERACTION

ROCK

> 4 KM SHIELDING FROM
BACKGROUND MUONS

AIR SHOWER:
3 – 10 KM LENGTH
200 M DIAMETER

~150 M
SEPARATION

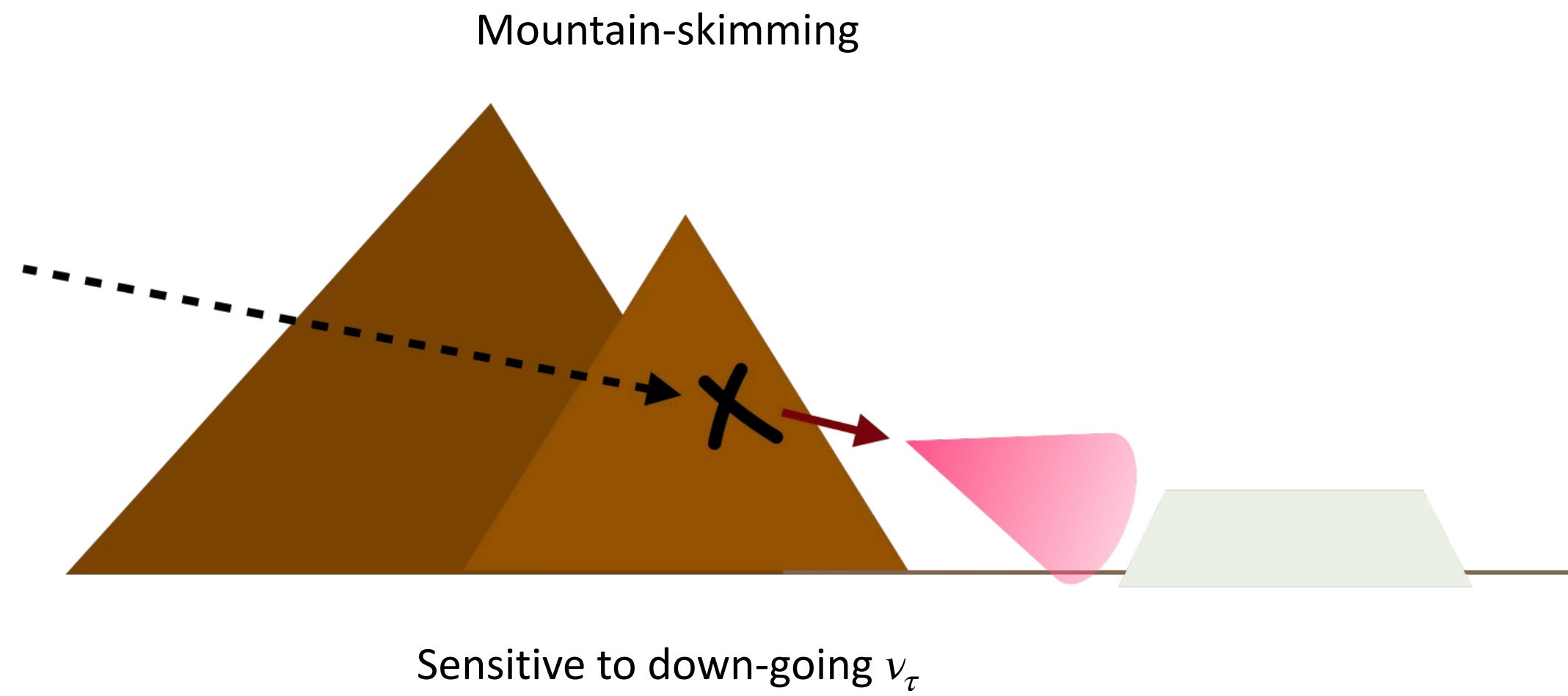
AIR SHOWER
DETECTOR ARRAY
~M² EACH

DEEP VALLEY

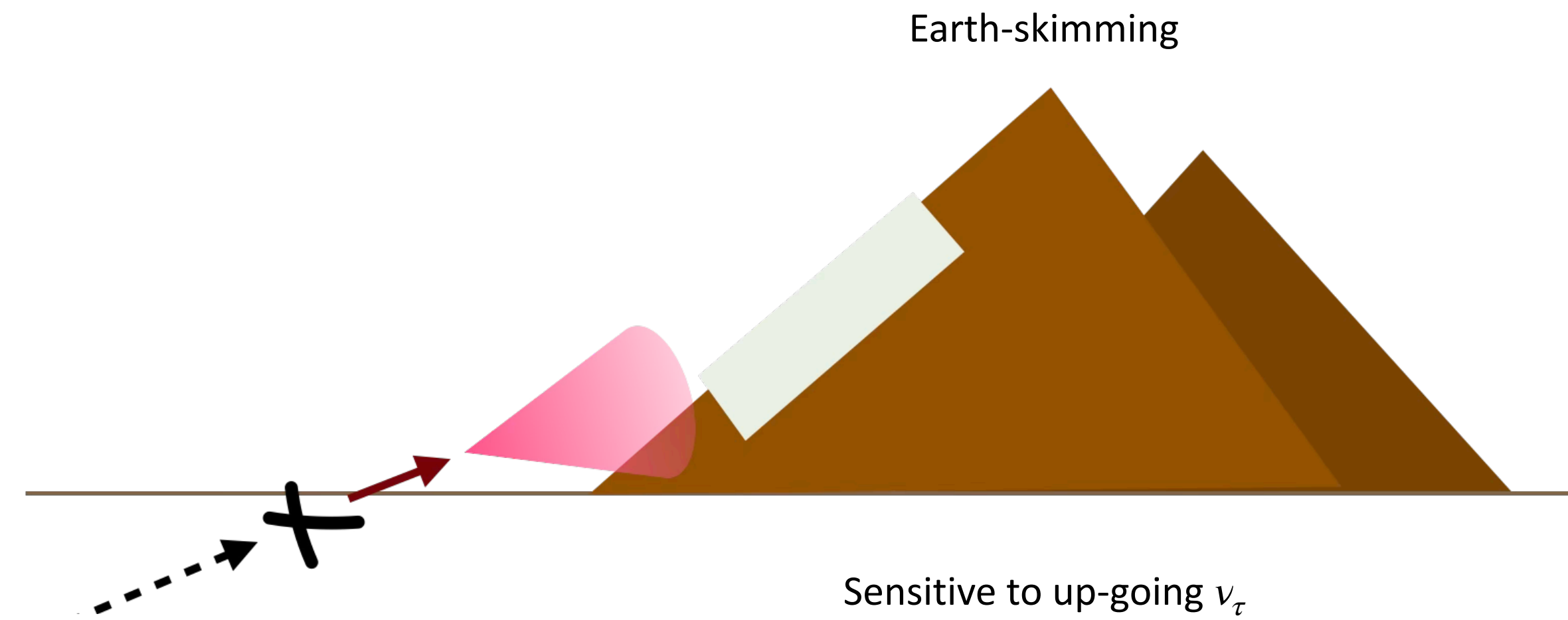
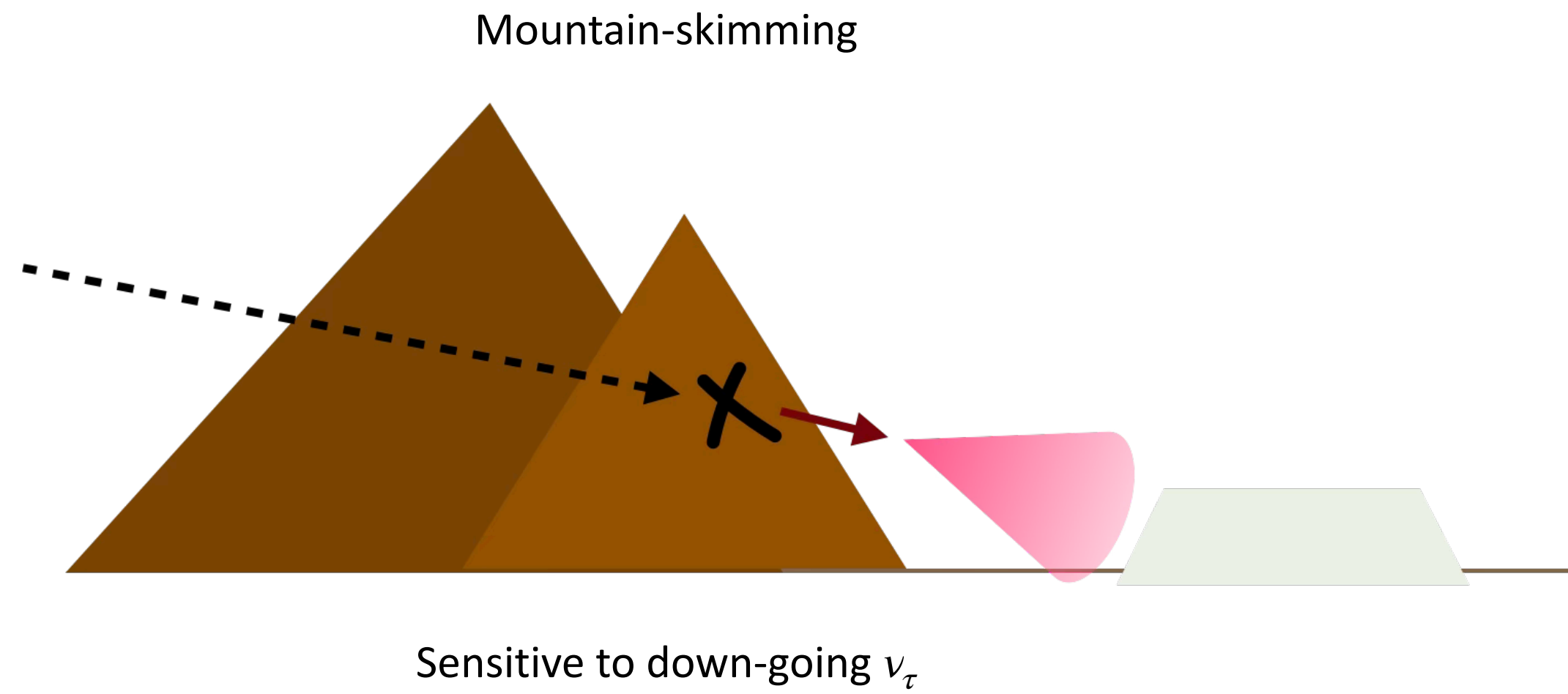


Why are we in a canyon?

Why are we in a canyon?

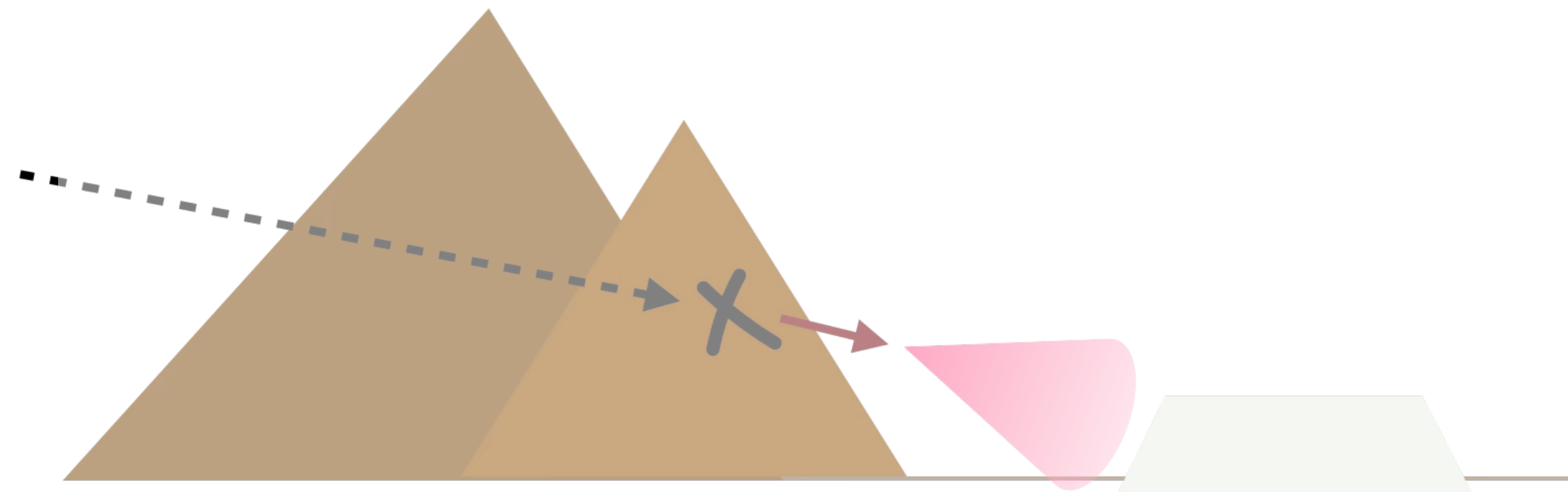


Why are we in a canyon?



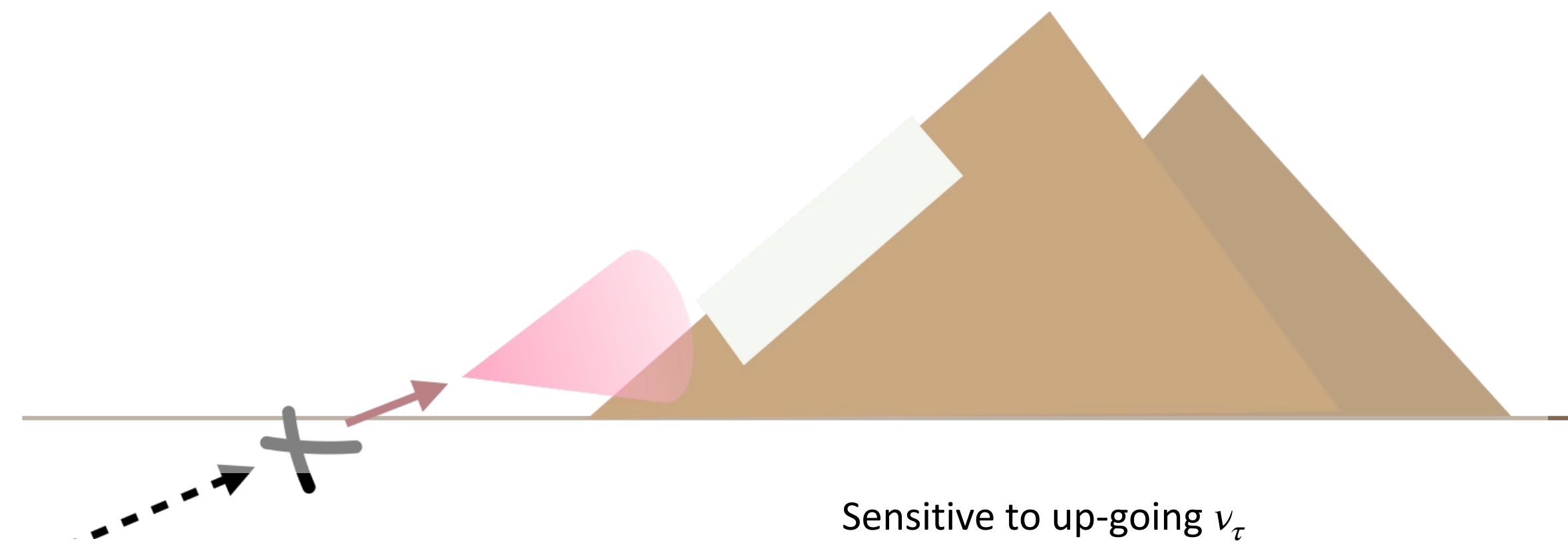
Why are we in a canyon?

Mountain-skimming

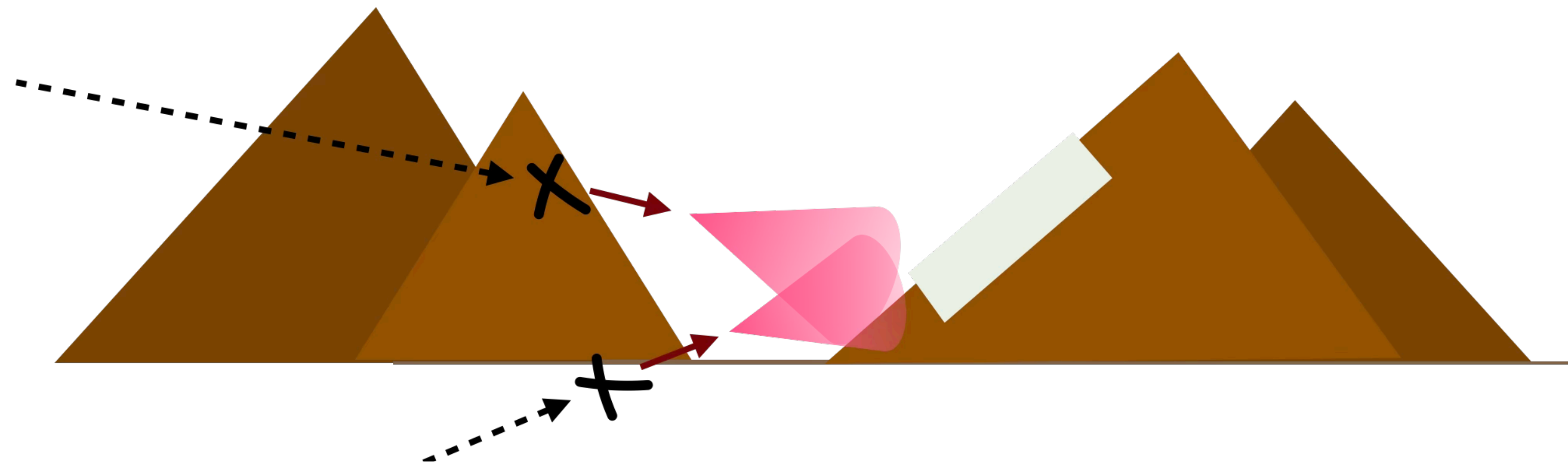


Sensitive to down-going ν_τ

Earth-skimming



Sensitive to up-going ν_τ

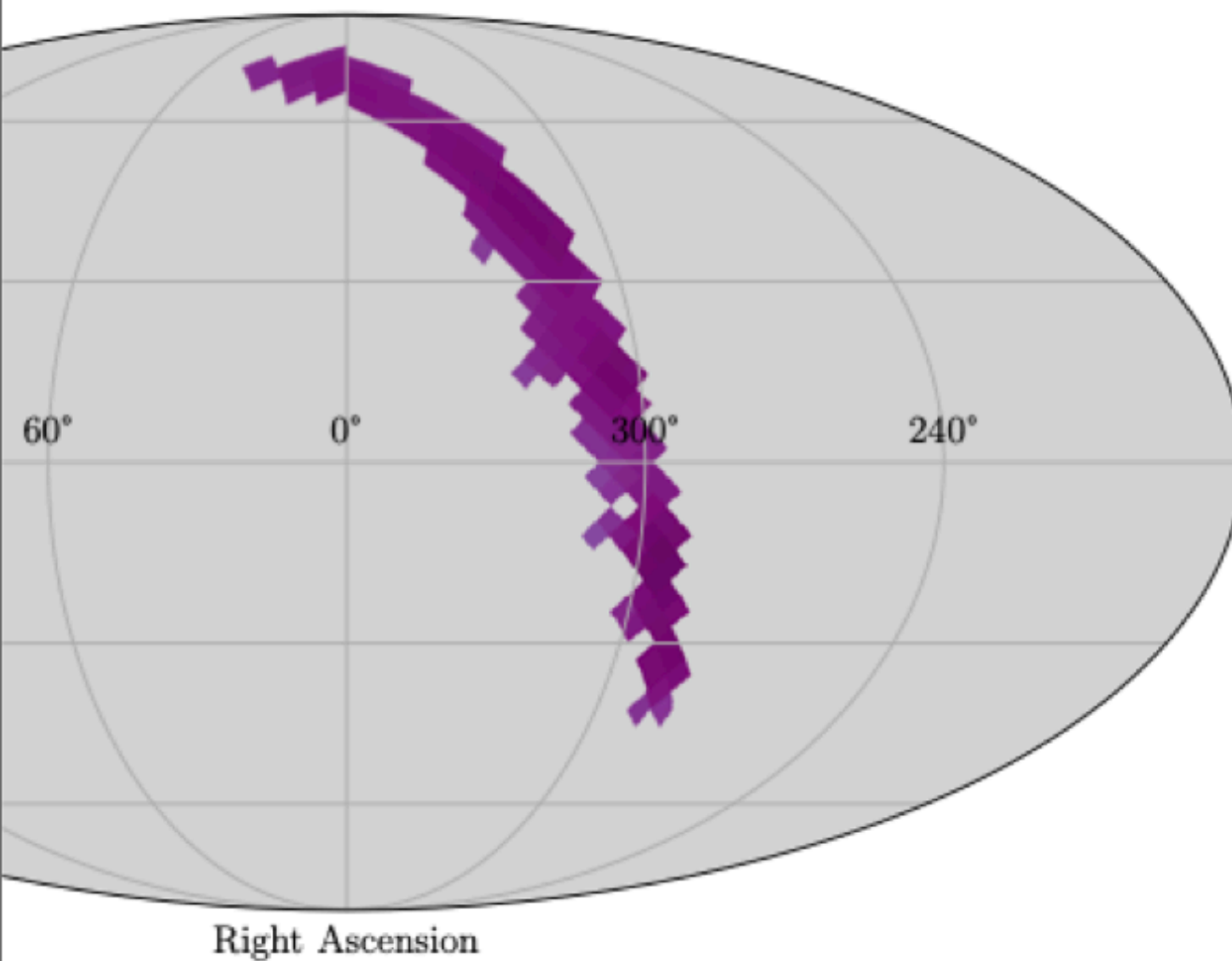


A canyon detector is sensitive to up- and down-going ν_τ

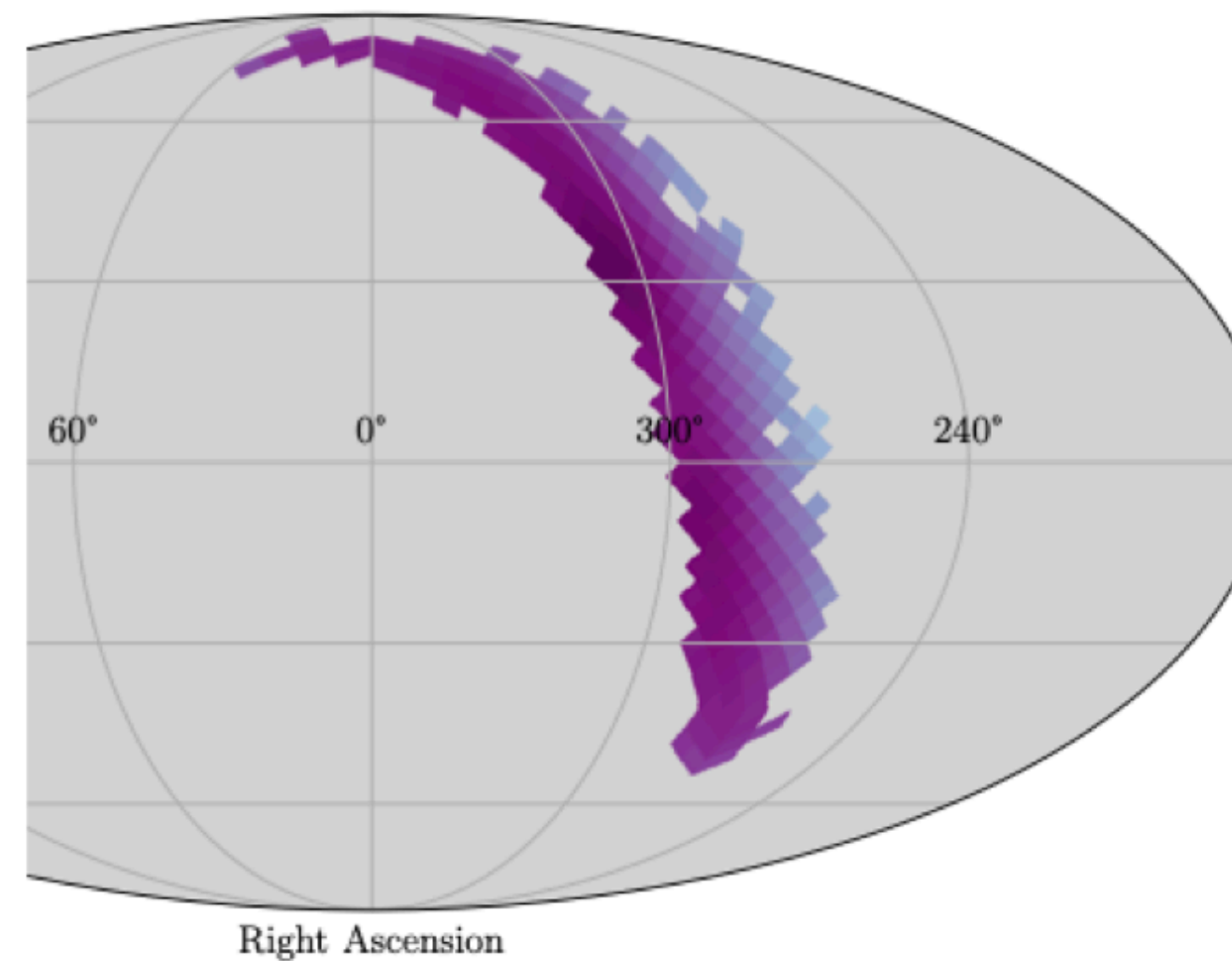
Carlos A. Argüelles — TeVPa, 2026

Why are we in a canyon?

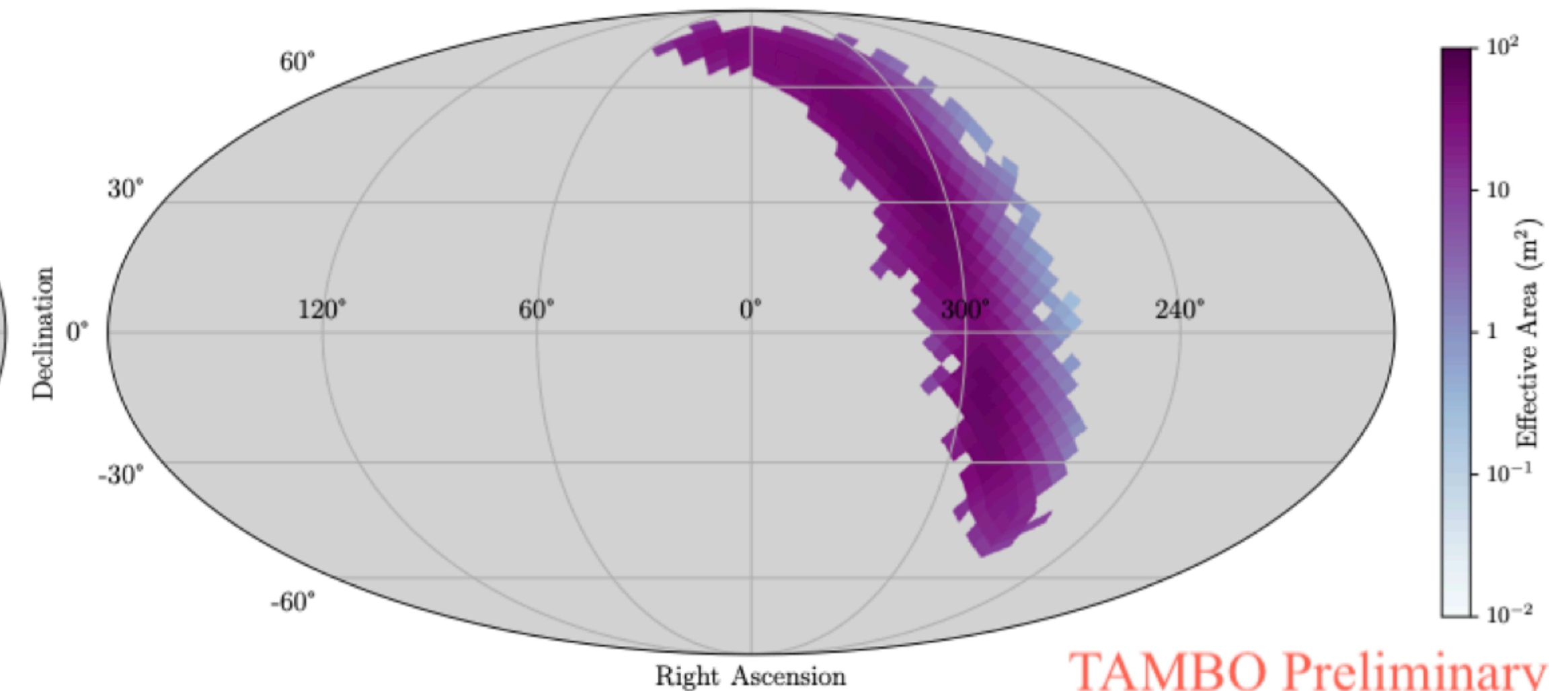
Down-going



Up-going



Full acceptance



TAMBO Preliminary

Mountain-skimming

Earth-skimming

Full TAMBO geometry

Canyon-based arrays maximize sky acceptance

Mountain-skimming contribution is sensitive to Glashow resonance ($\bar{\nu}_e$) T. Ding & Q. Liu ([2607.26128](#))

What about
backgrounds?

DECAY

τ

RANGE:
50 M – 5 KM

ν_τ

CHARGED-CURRENT
INTERACTION

AIR SHOWER:
3 – 10 KM LENGTH
200 M DIAMETER

~150 M
SEPARATION

AIR SHOWER
DETECTOR ARRAY
~M² EACH

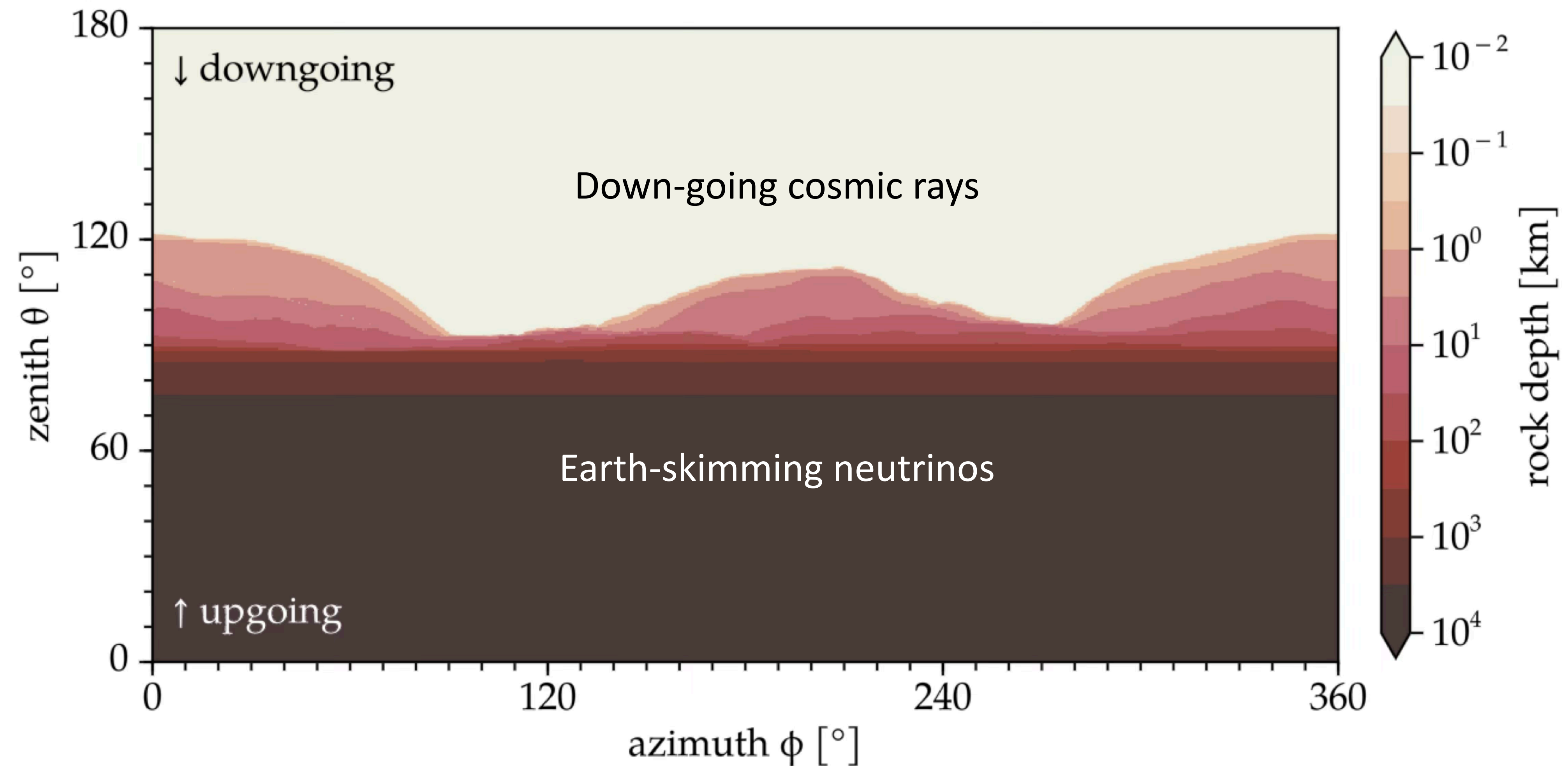
ROCK

> 4 KM SHIELDING FROM
BACKGROUND MUONS

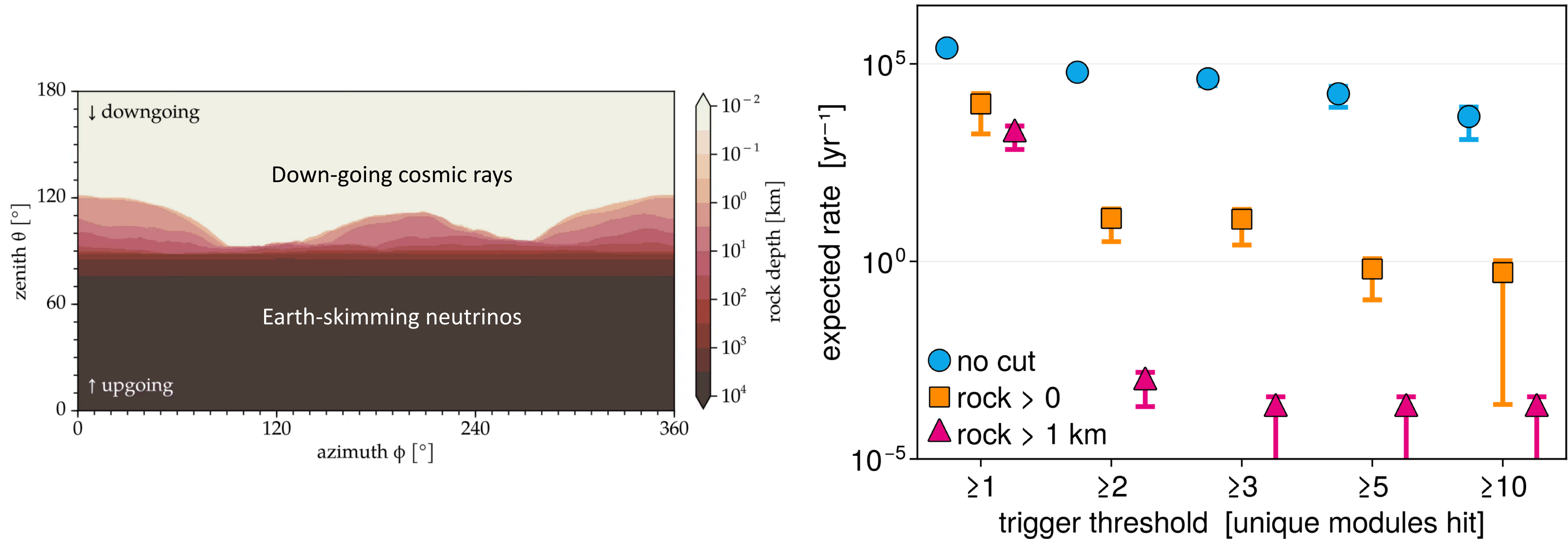
DEEP VALLEY



Canyon shields you from cosmic rays showers



Canyon shields you from cosmic rays showers



Why do we
mainly see ν_τ ?

DECAY

τ

RANGE:
50 M – 5 KM

ν_τ

CHARGED-CURRENT
INTERACTION

AIR SHOWER:
3 – 10 KM LENGTH
200 M DIAMETER

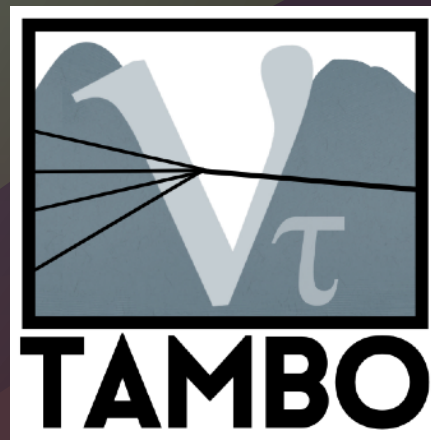
~150 M
SEPARATION

AIR SHOWER
DETECTOR ARRAY
~M² EACH

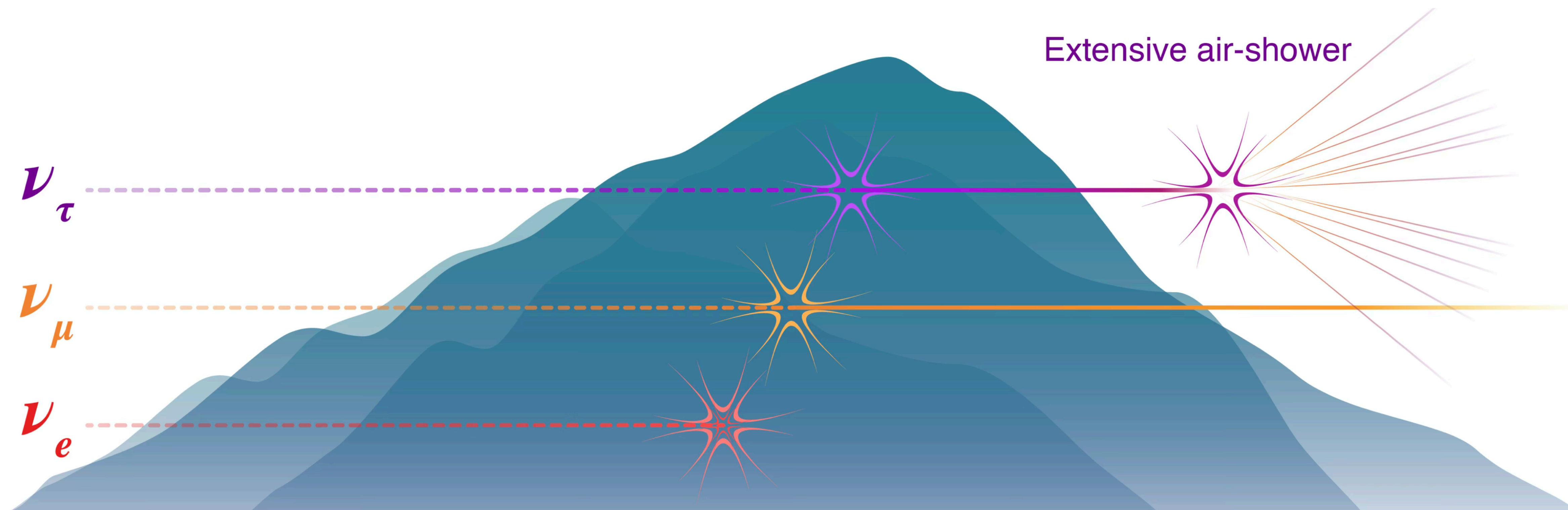
ROCK

> 4 KM SHIELDING FROM
BACKGROUND MUONS

DEEP VALLEY



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

And why did we go from
volumes to a 2D array?

AIR SHOWER:
3 – 10 KM LENGTH
200 M DIAMETER

RANGE:
50 M – 5 KM

~150 M
SEPARATION

CHARGED-CURRENT
INTERACTION

AIR SHOWER
DETECTOR ARRAY
~M² EACH

ROCK

> 4 KM SHIELDING FROM
BACKGROUND MUONS

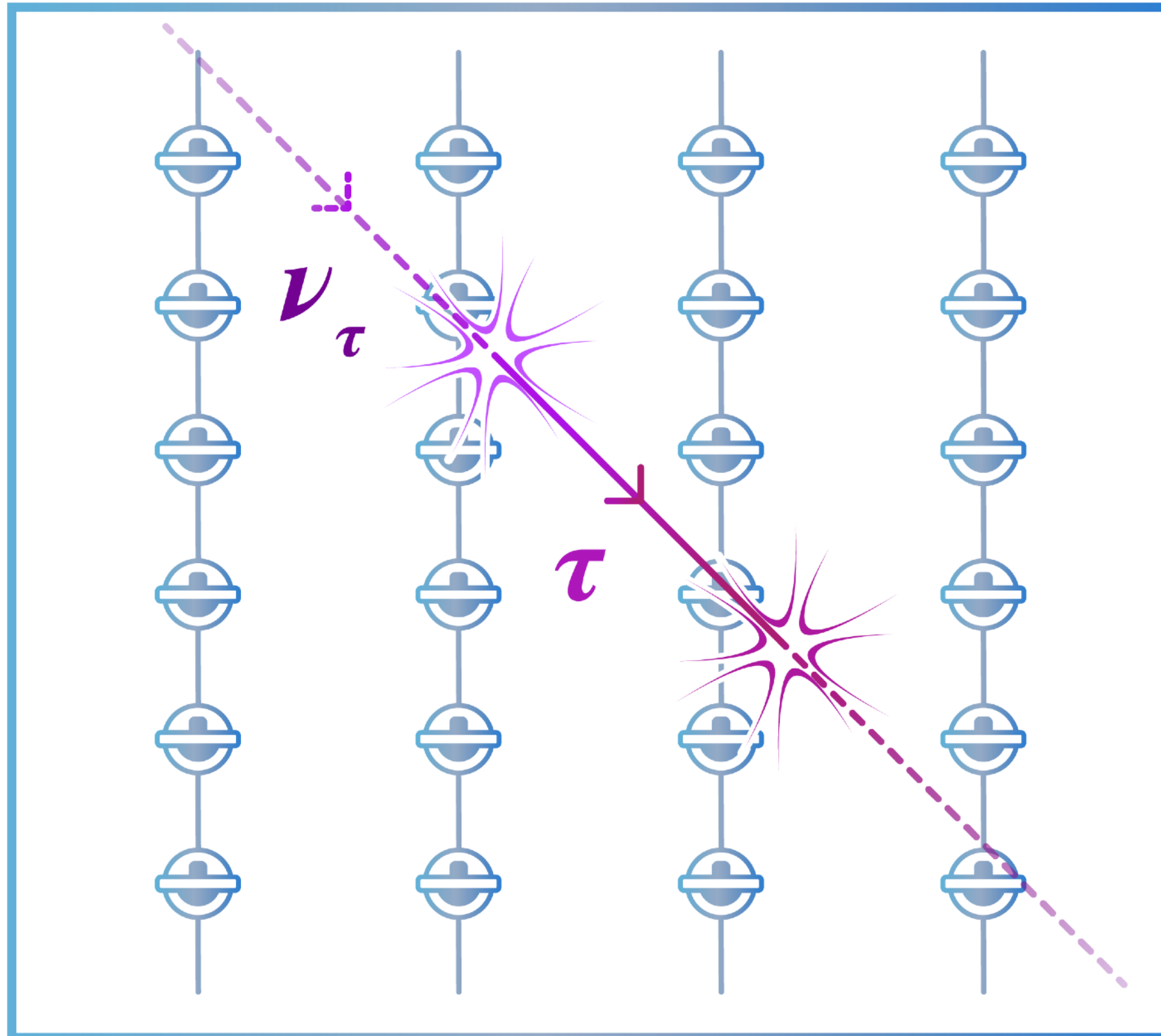
DEEP VALLEY



Advantage over volumetric detectors

Advantage over volumetric detectors

Instrumented volume



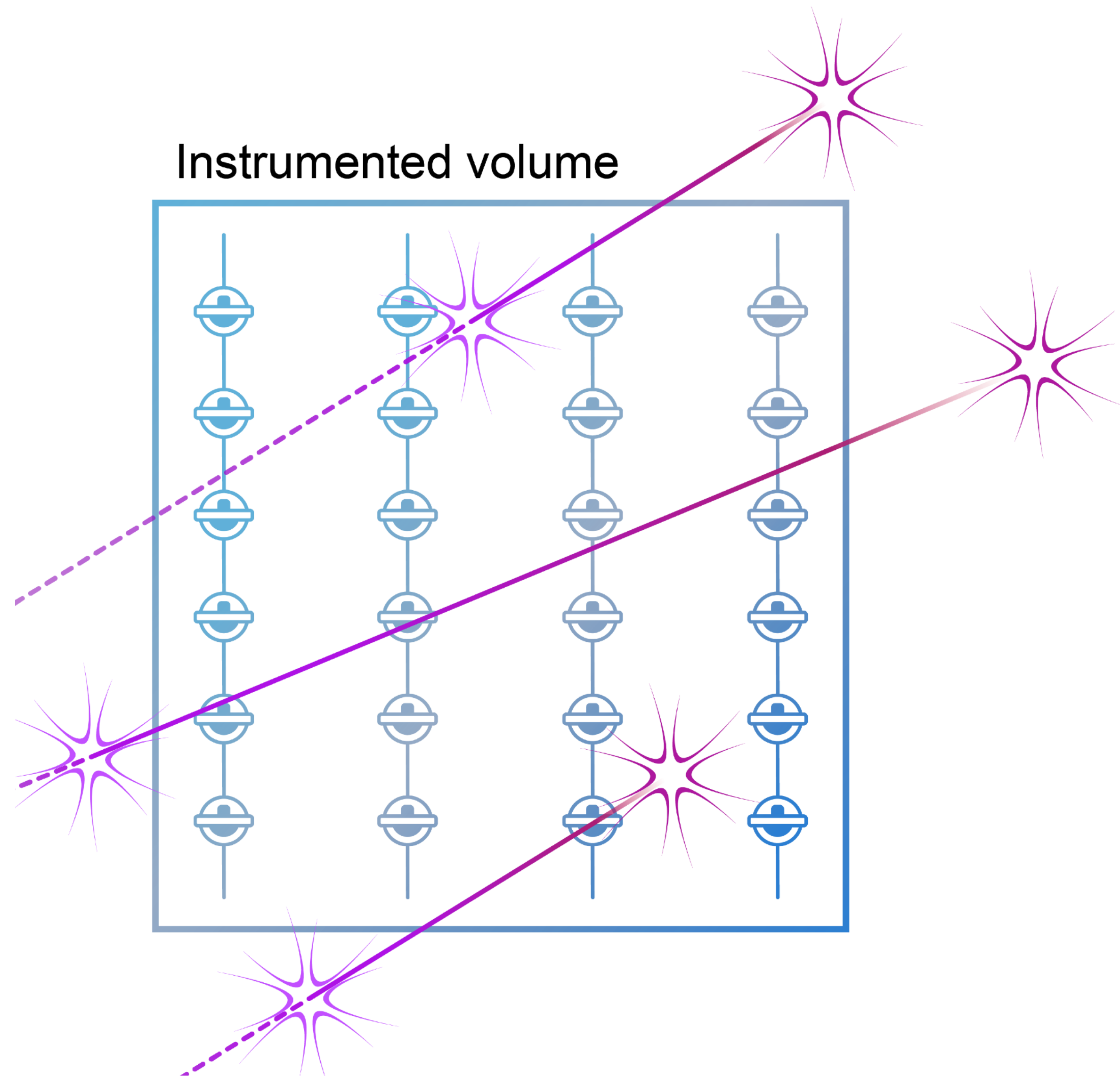
$$N_\tau \sim \sigma_{\nu p} \phi_\nu L_{detector}$$

Identification by separating “bangs”

$$L_\tau \approx 50\text{m} \left(\frac{E}{\text{PeV}} \right)$$

Backgrounds: mis-reco, D-mesons.

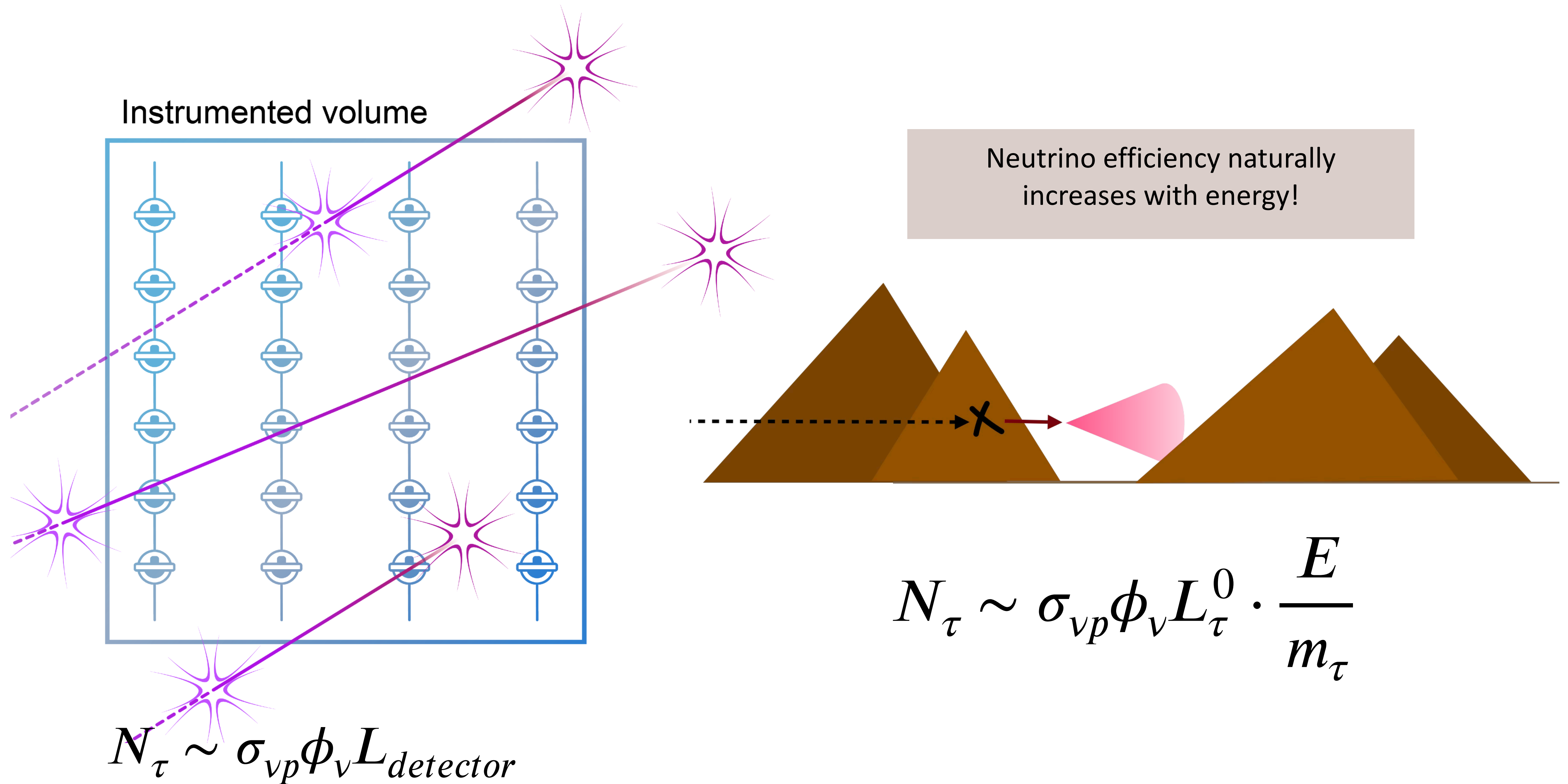
Advantage over volumetric detectors



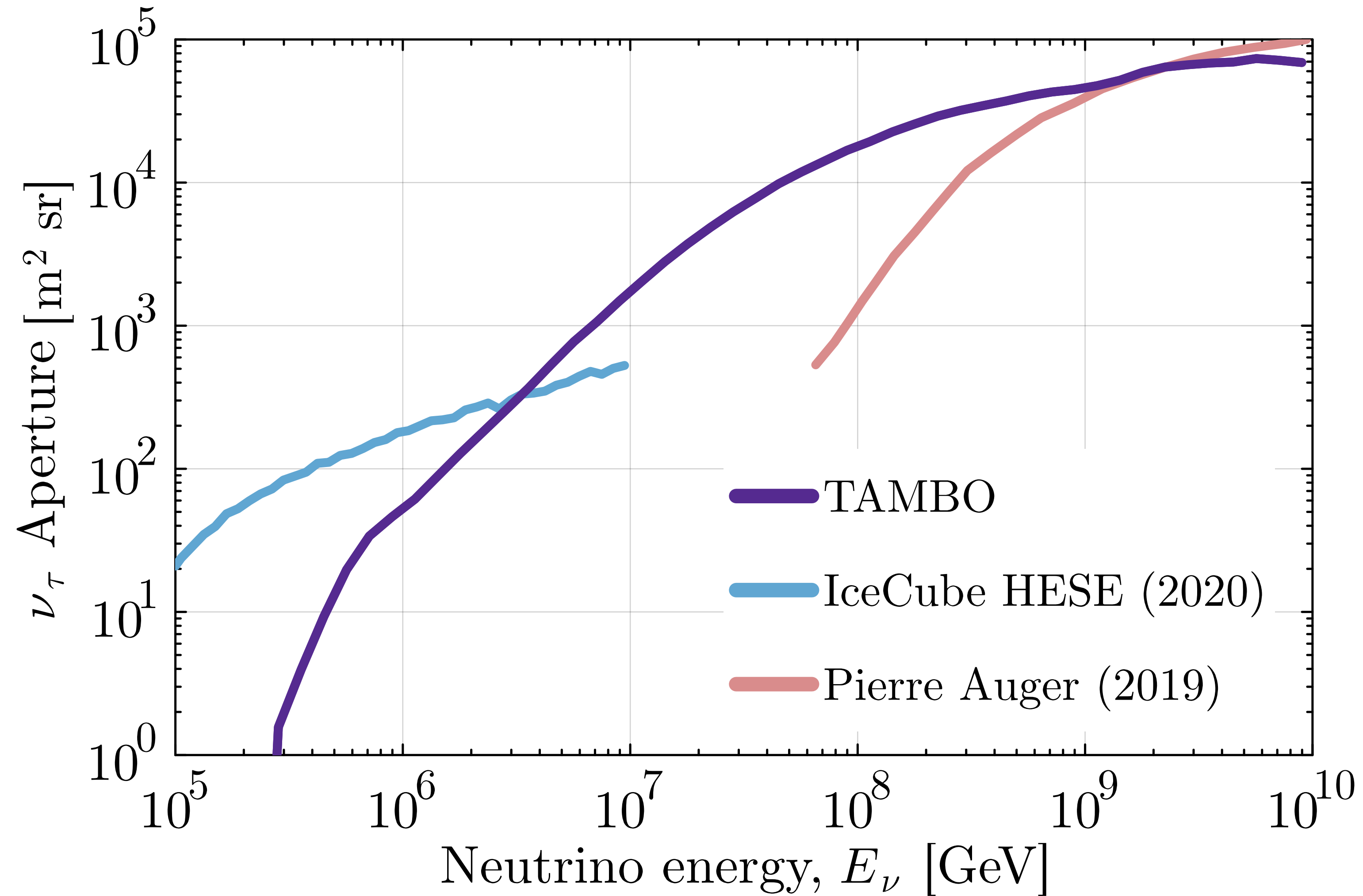
Tau neutrino "double bangs" are increasingly rarer to contain.

Tau neutrino identification in volumetric detector becomes inefficient.

Advantage over volumetric detectors

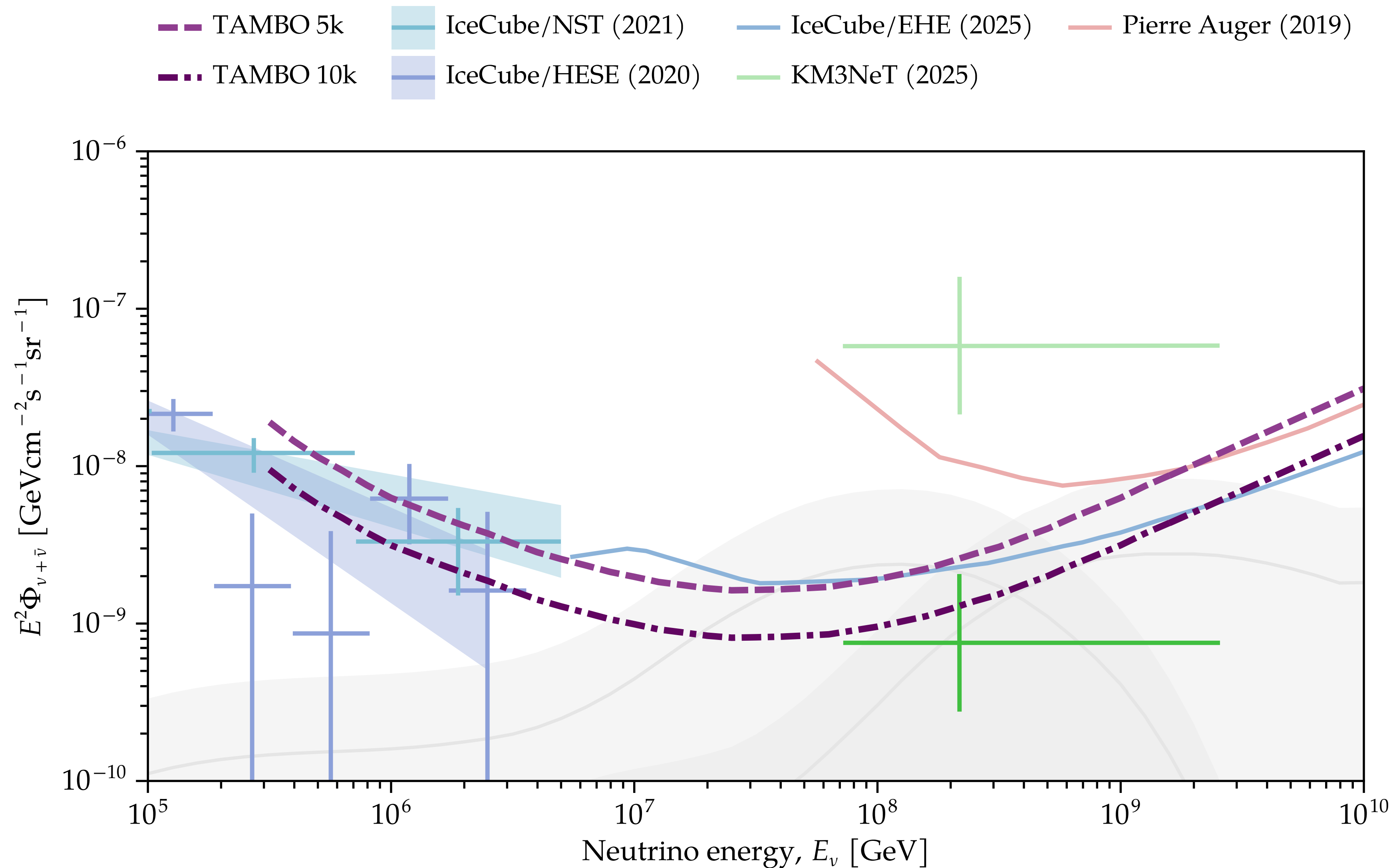


TAMBO's ν_τ sensitivity surpasses volumetric observatories

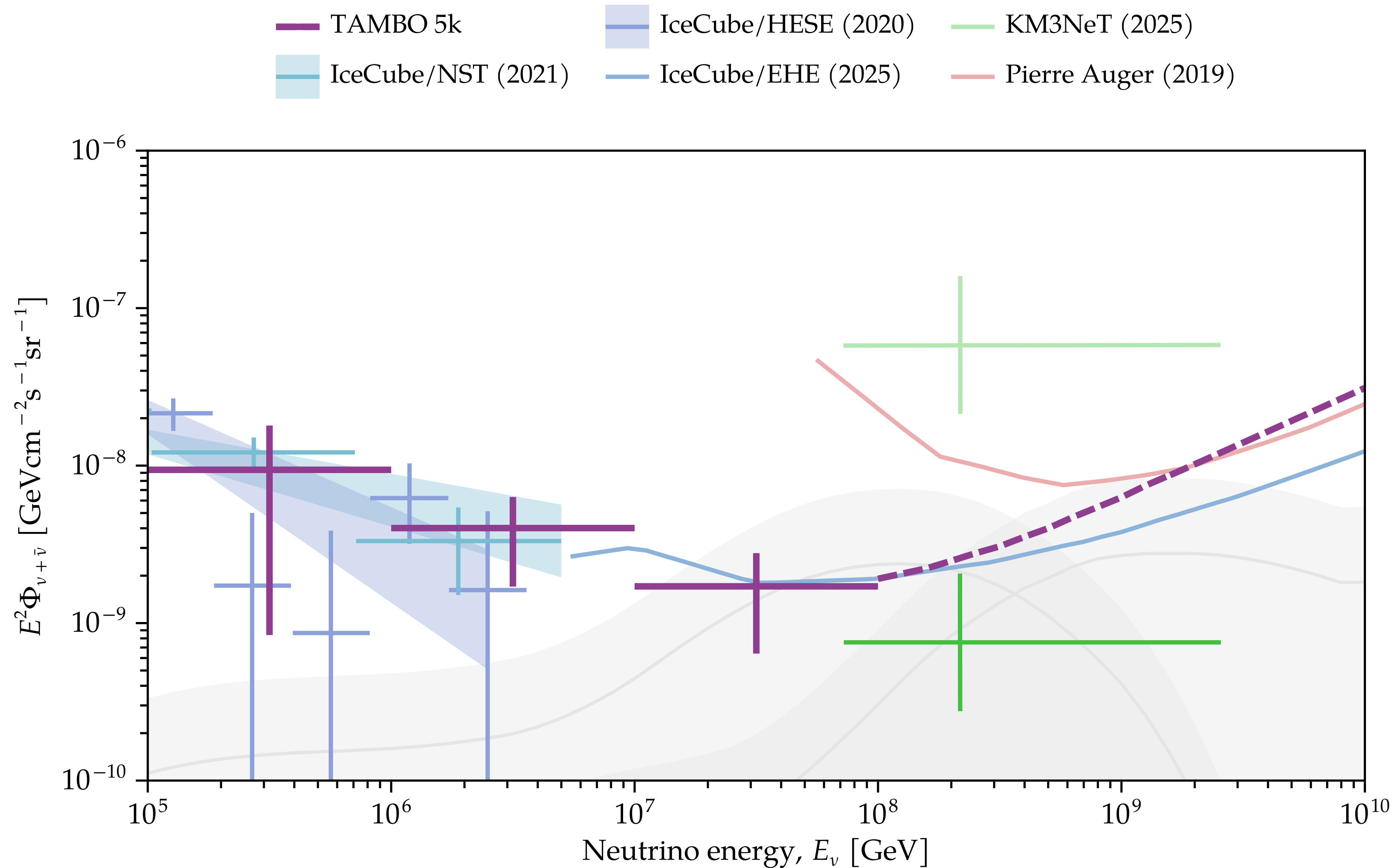


TAMBO's ν_τ sensitivity will dominate over 3 orders of magnitude in energy

TAMBO: An ultra-high-energy neutrino telescope



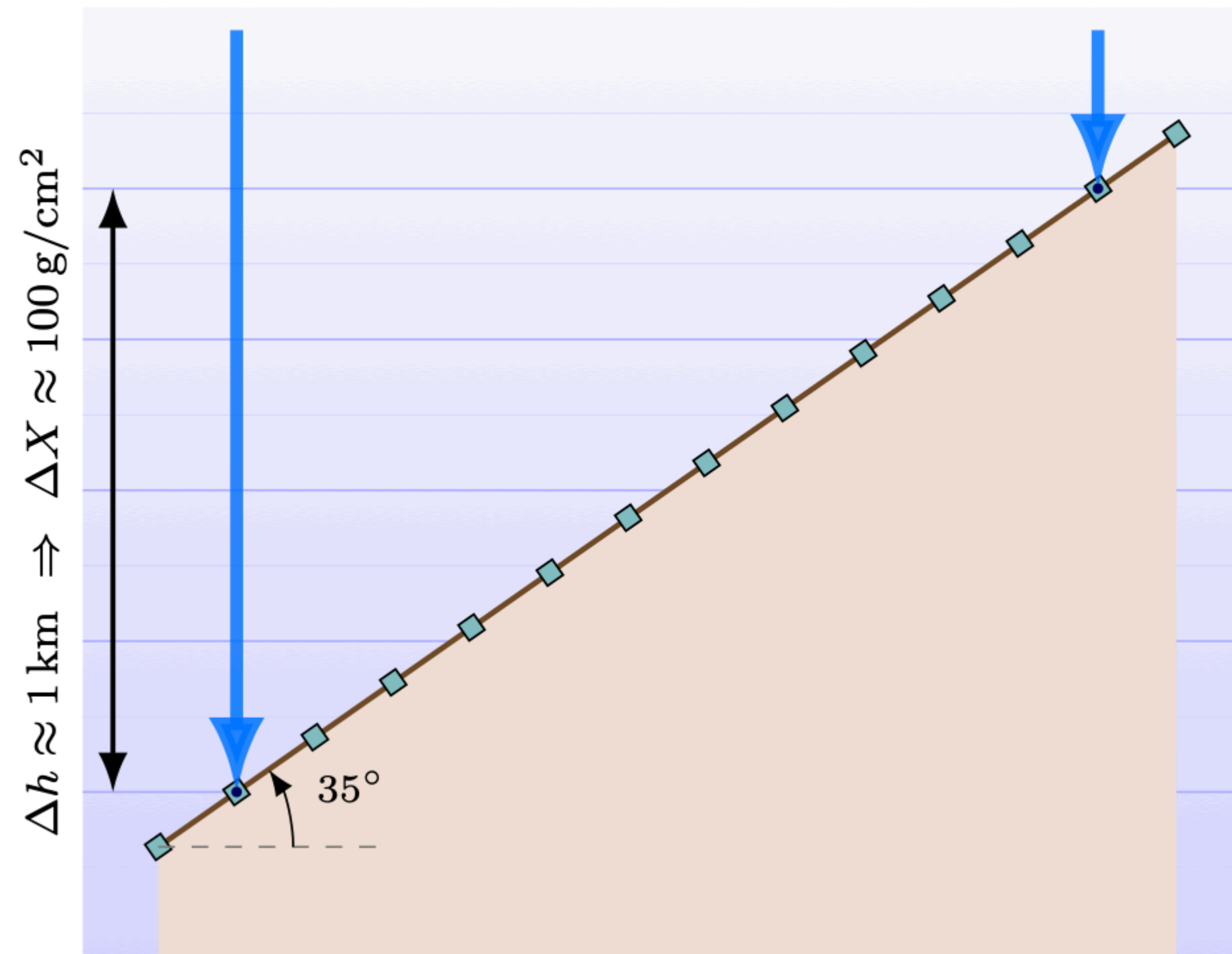
TAMBO: An ultra-high-energy neutrino telescope



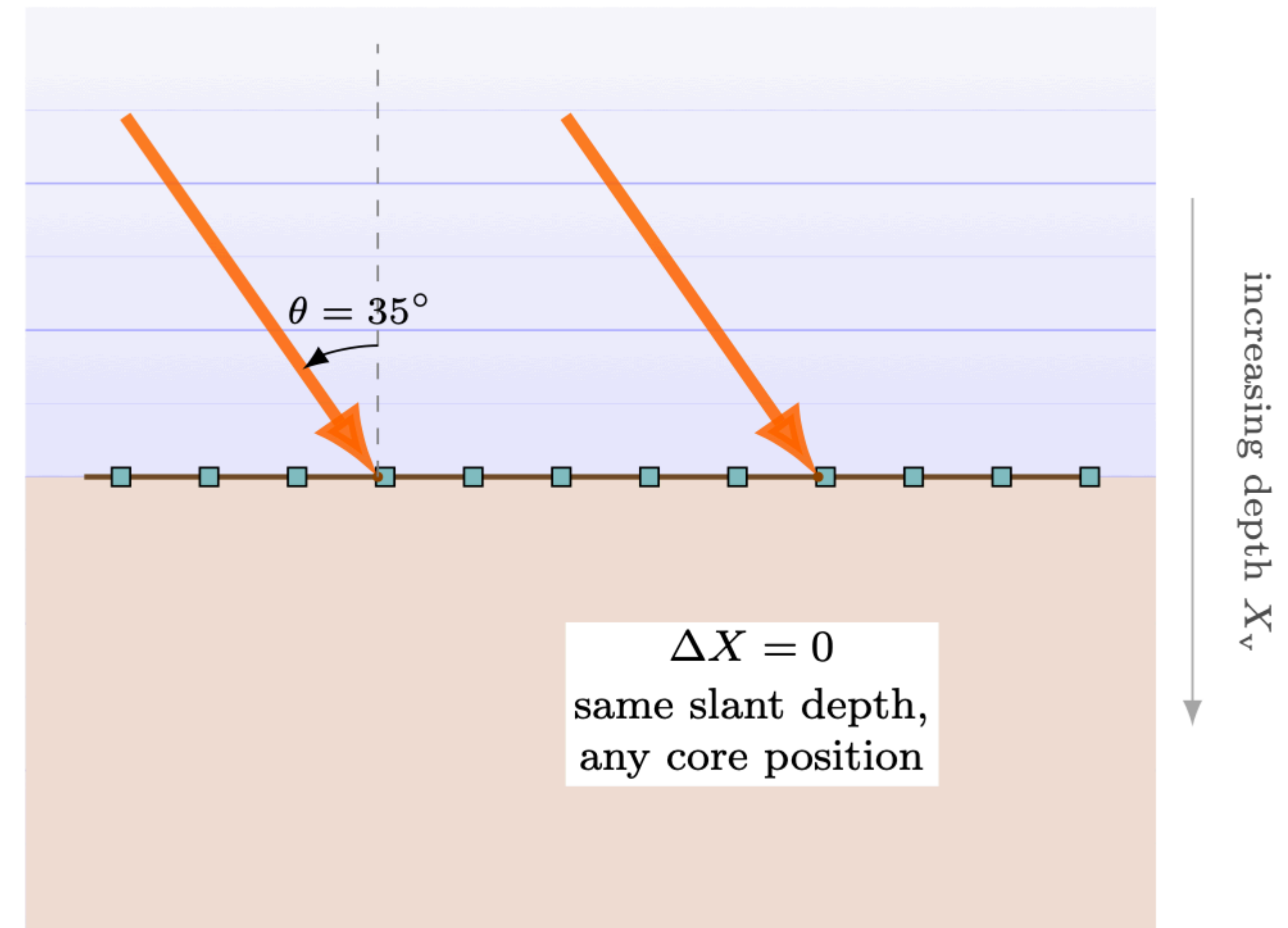
New Opportunities for cosmic-ray physics

Not just a rotation! For flat arrays, the amount of matter traversed is decided by the zenith angle.
For an inclined array, these decouple.

(a) sloped array, vertical showers



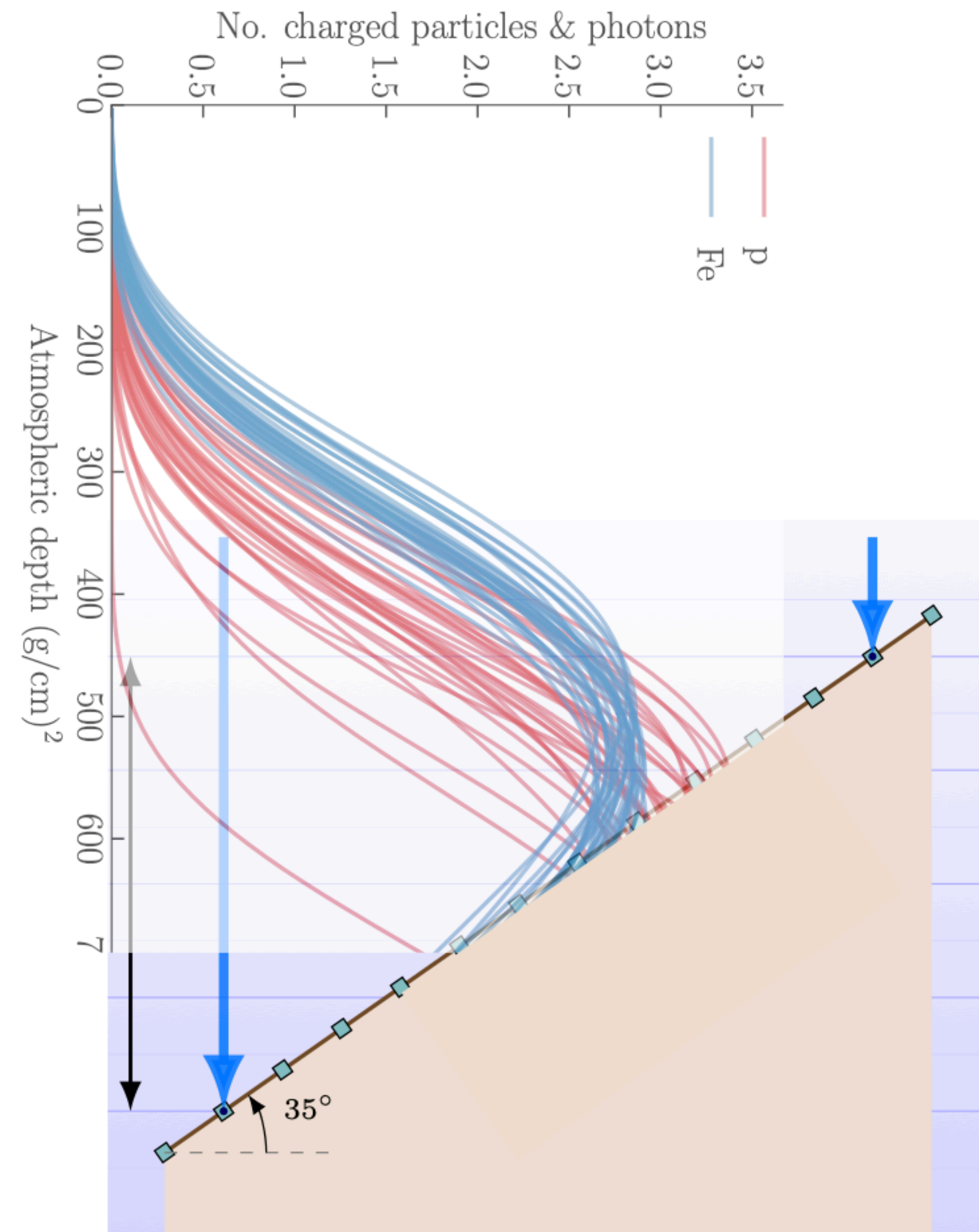
(b) flat array, inclined showers



horizontal lines: iso-depth layers of the stratified atmosphere ($X_v = \text{const}$)

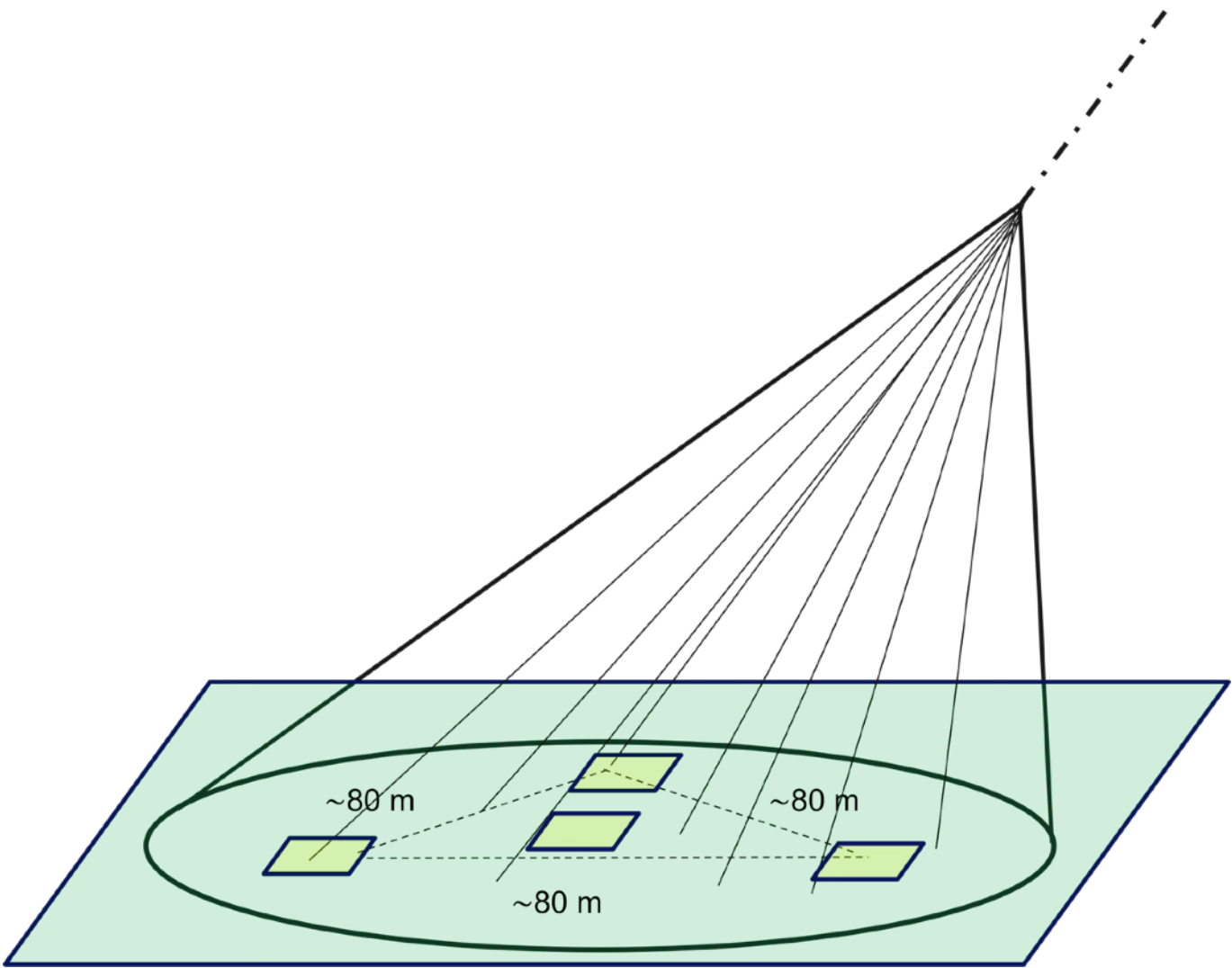
New Opportunities for cosmic-ray physics

- TAMB(IT)O can study the **knee-2nd knee region** of the cosmic ray spectrum
- The inclined array may provide **new ways of testing longitudinal shower development** and probing mass composition
- Studies in progress!



TAMBO timeline & status

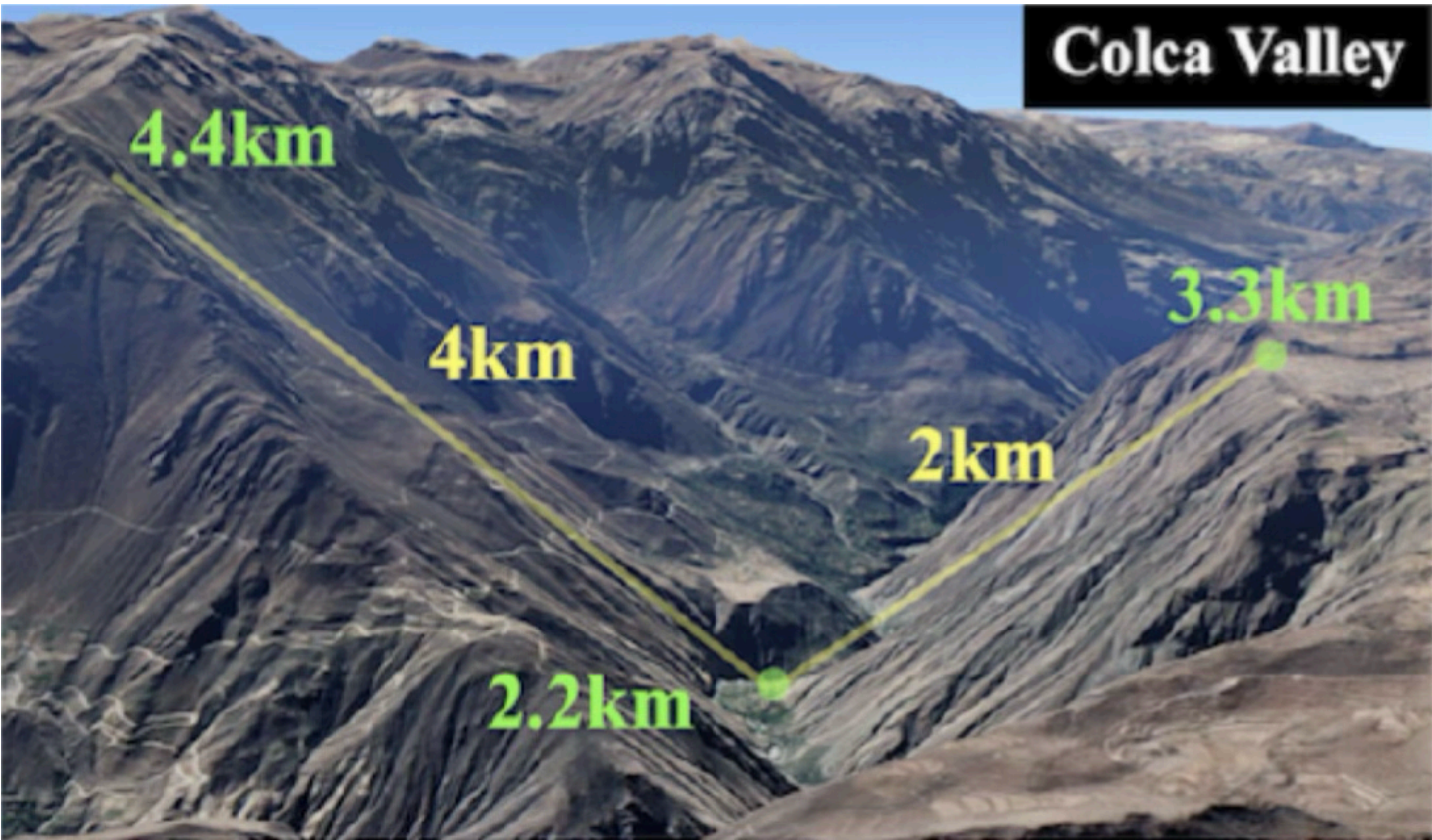
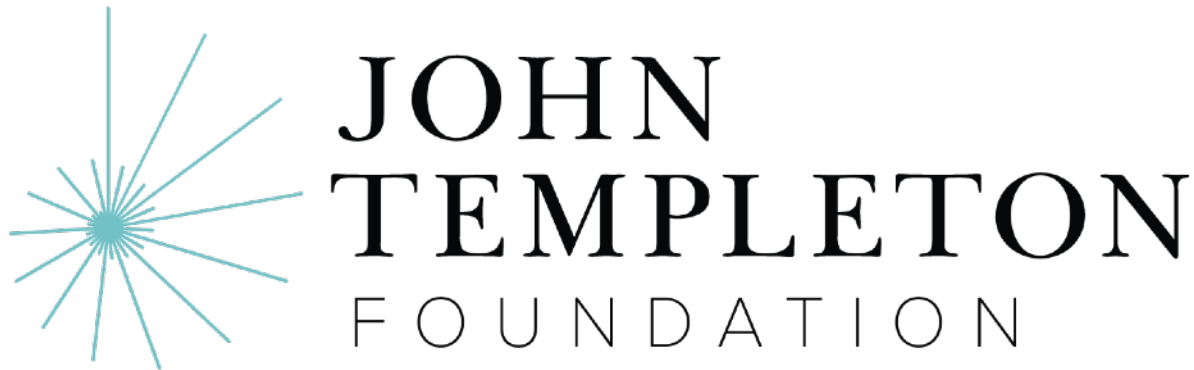
Today:
TAMBO-4



Small test array

Detector & electronics prototypes

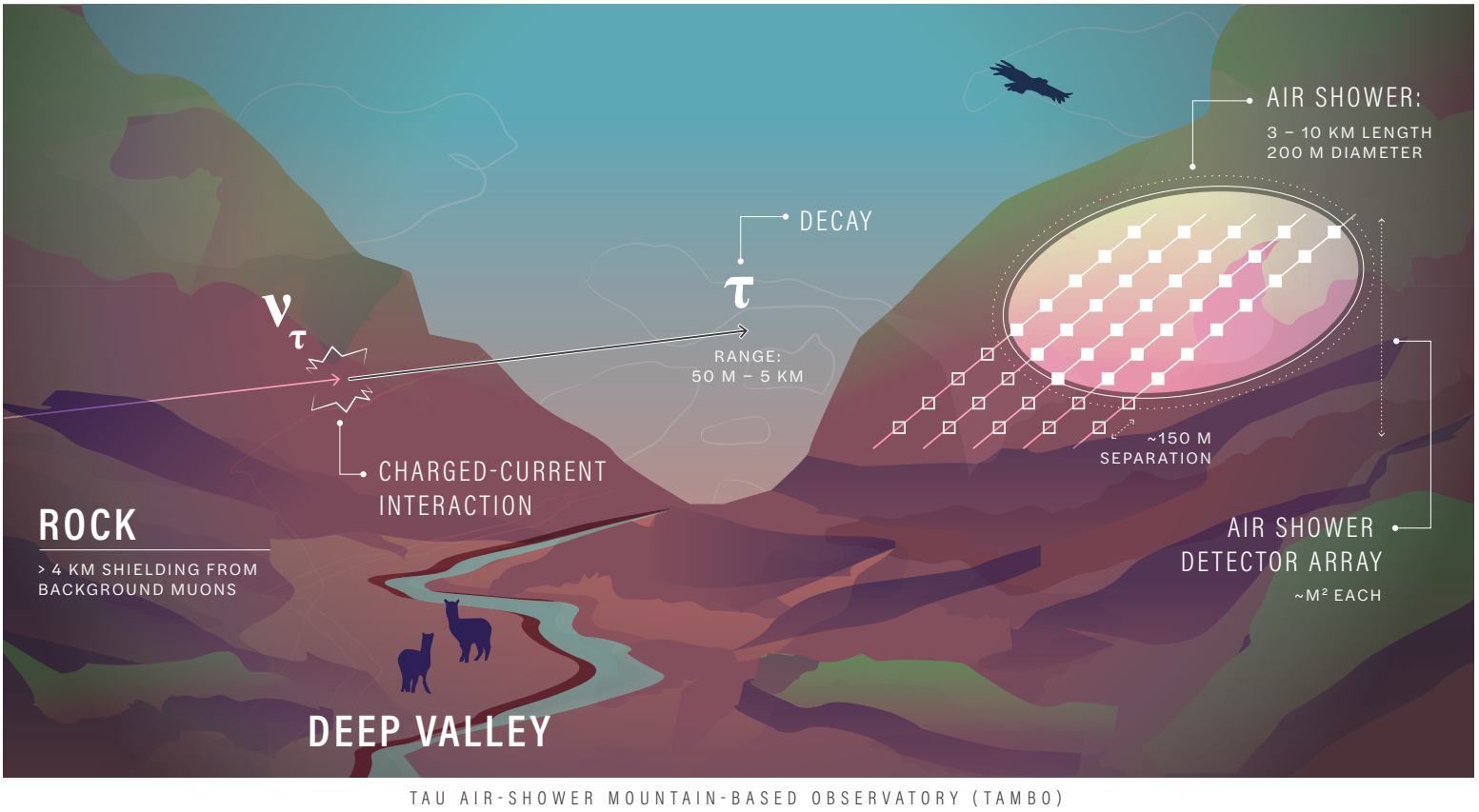
2026-2028:
TAMBITO (TAMBO-100)



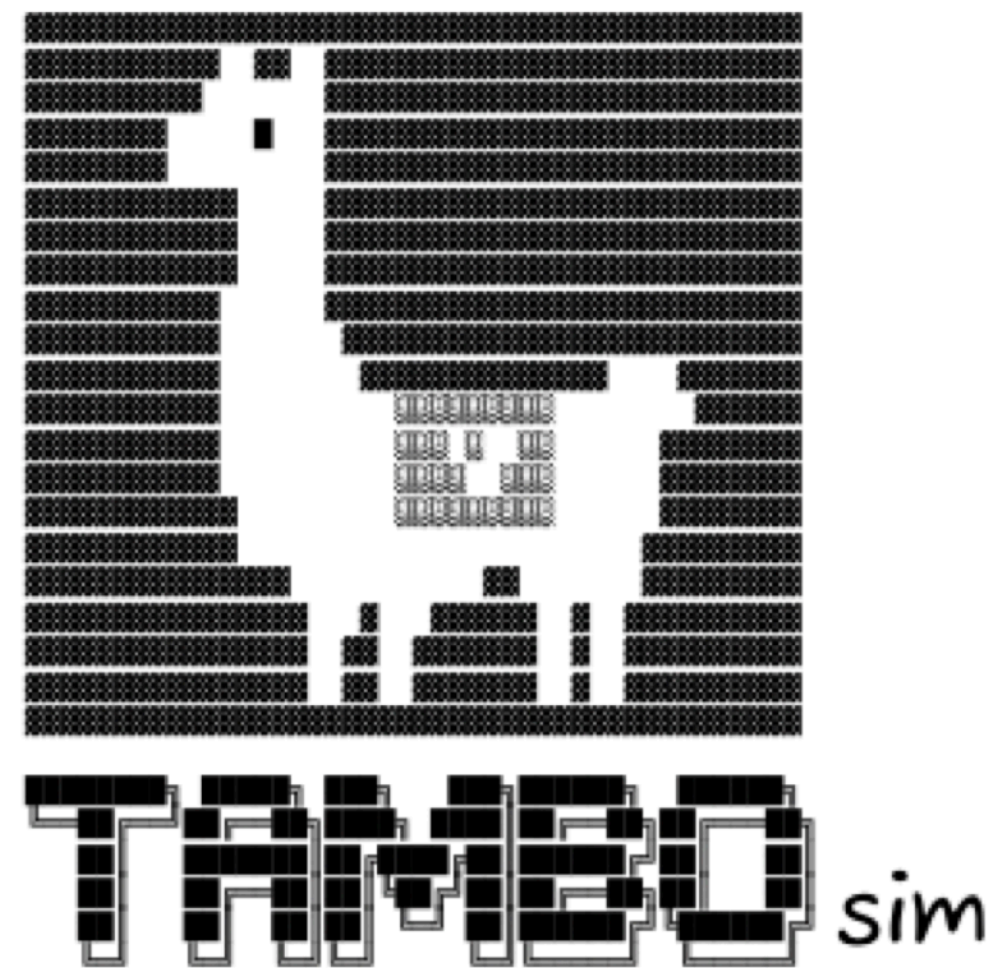
Pilot array in canyon geography

Deployment techniques,
backgrounds, responsible siting

2028-:
TAMBO-5k



Target full size array



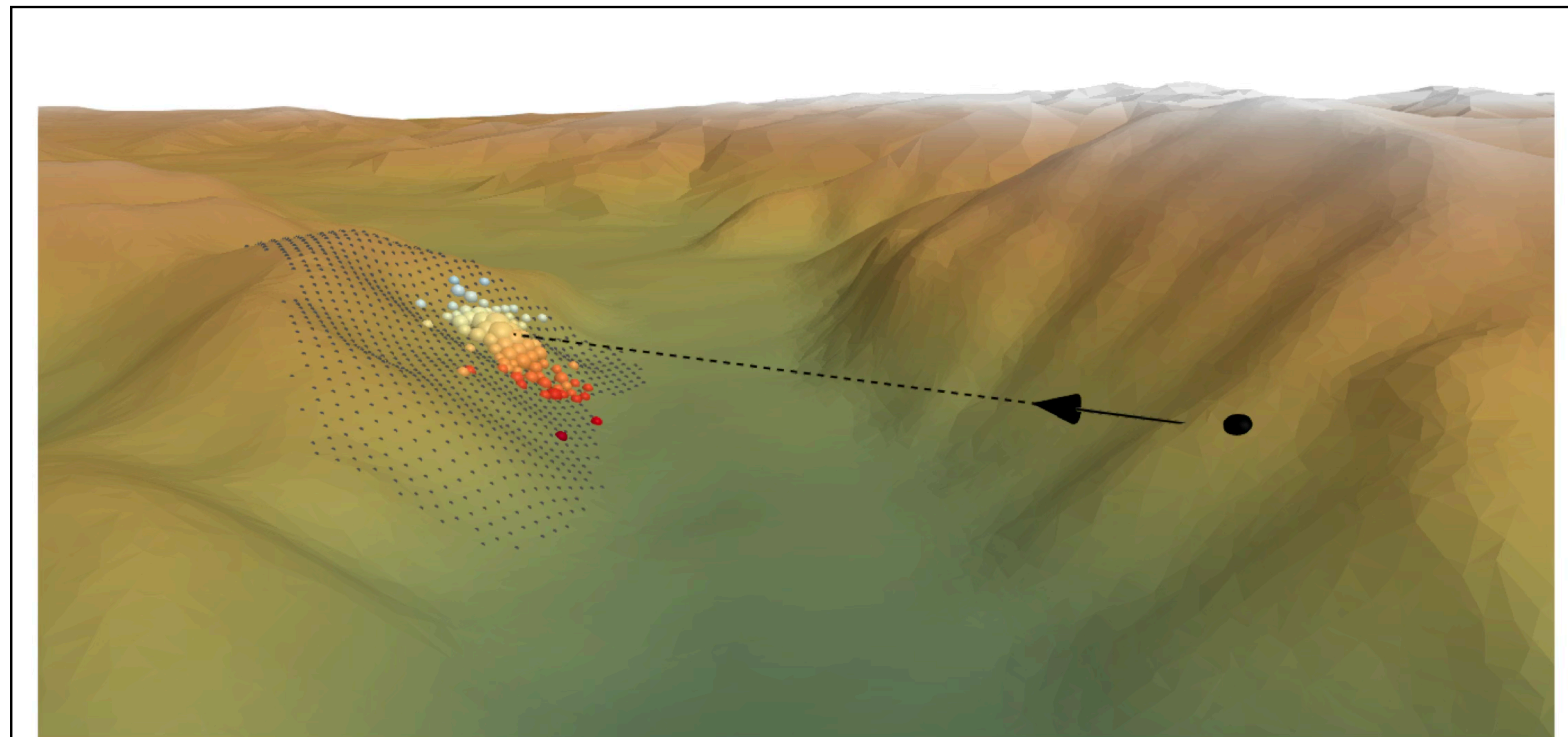
Open-source detection and neutrino simulation: TAMBOSim

Multi-year effort by:

Jeff Lazar (UC Louvain), Pavel Zhelnin
(Harvard), Will Thompson (Harvard), Kiara
Carloni (Harvard)

Supports arbitrary geometries via
triangular meshes.

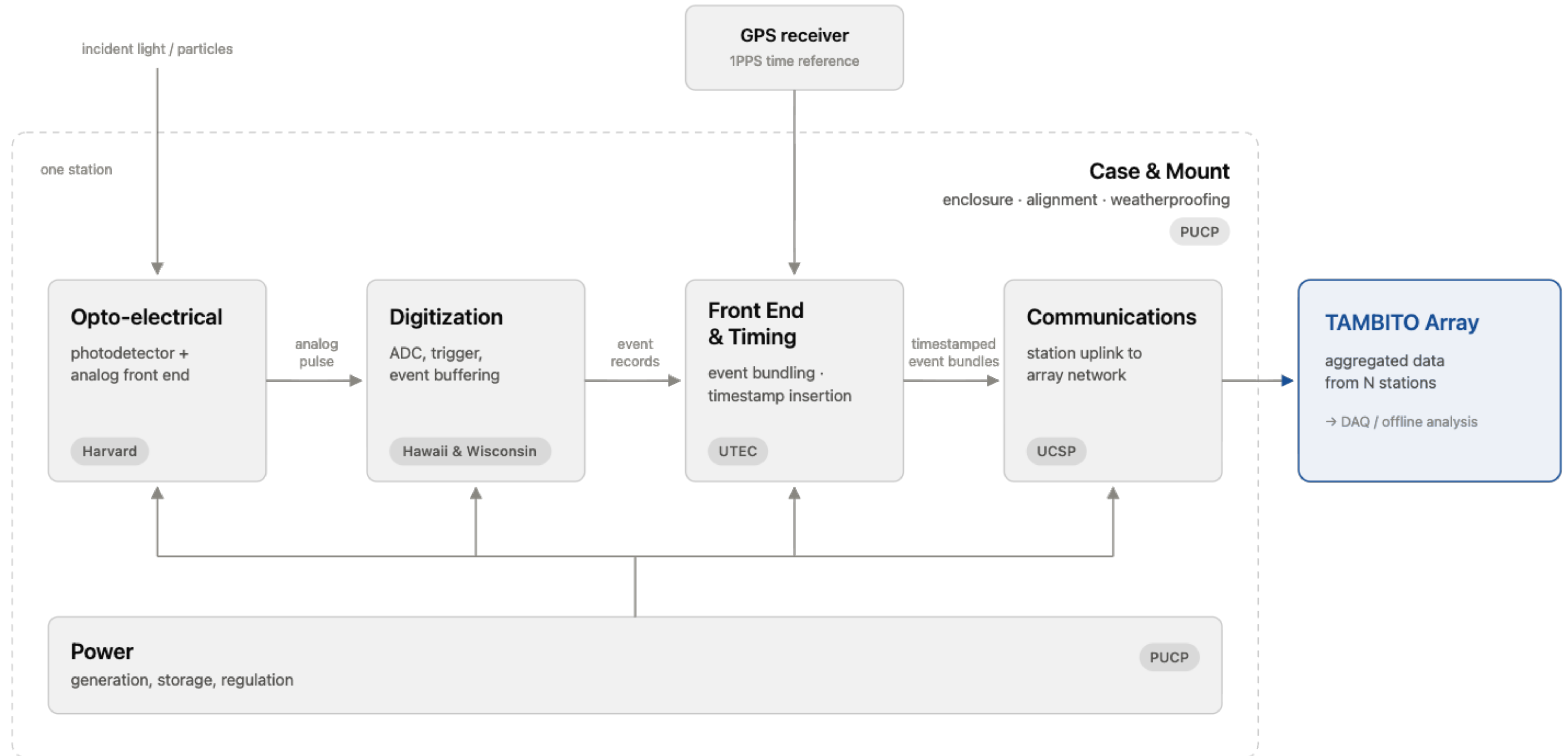
CORSIKA-8 for shower development



Above: 15 PeV τ from 52 PeV ν_τ

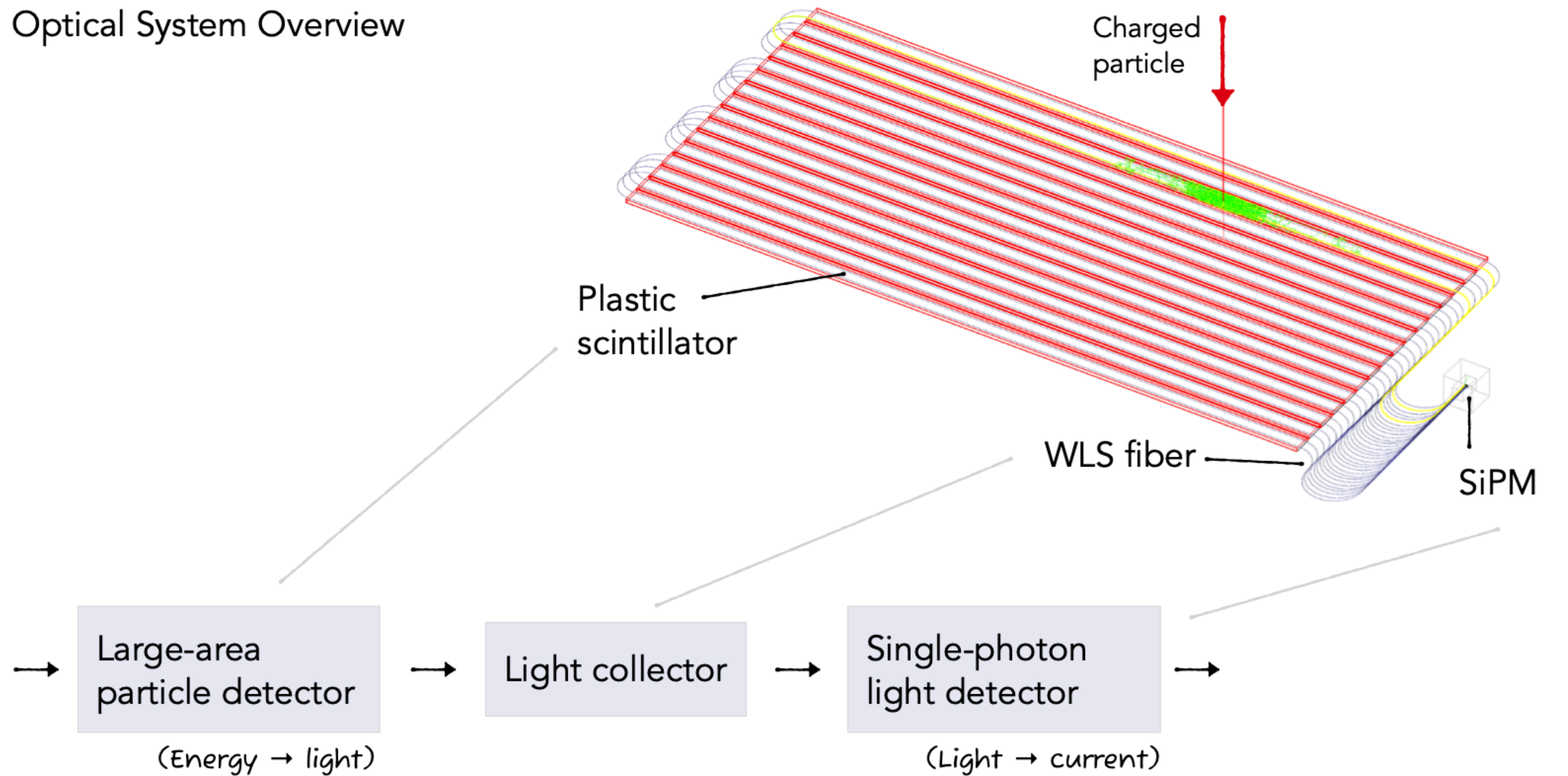
<https://github.com/TAMBO-Observatory/TamboSim>

Module development



Module development

Optical System Overview

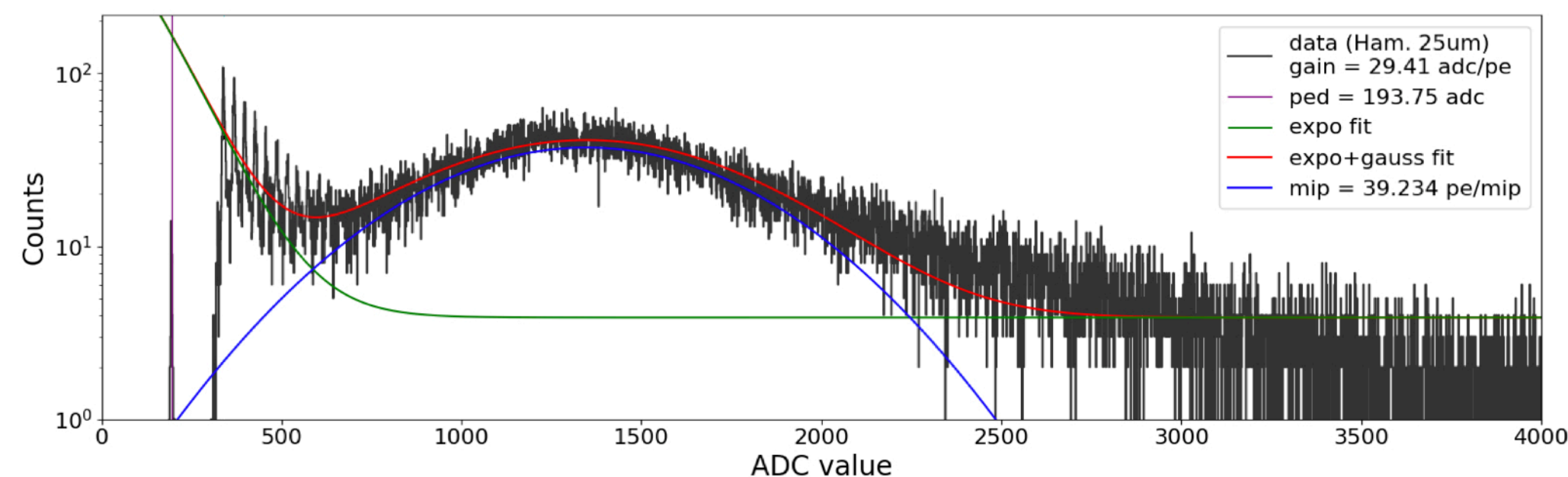


Scintillator calibration

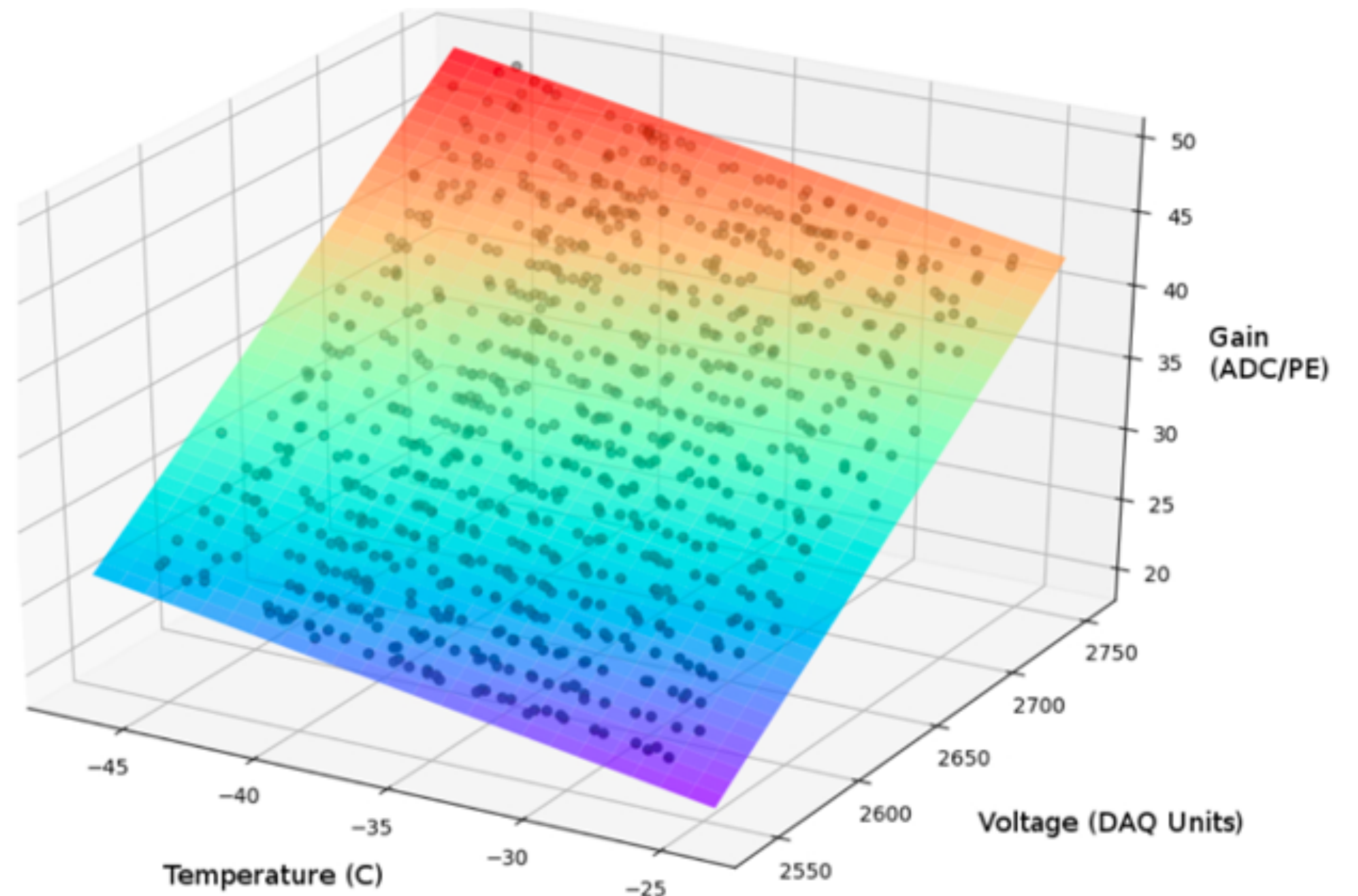
Key requirement: must be able to calibrate detectors *in situ*

Why?

- SiPM gain known to vary with temperature
- Will be corrected in real-time via bias voltage adjustment, but want to verify this correction



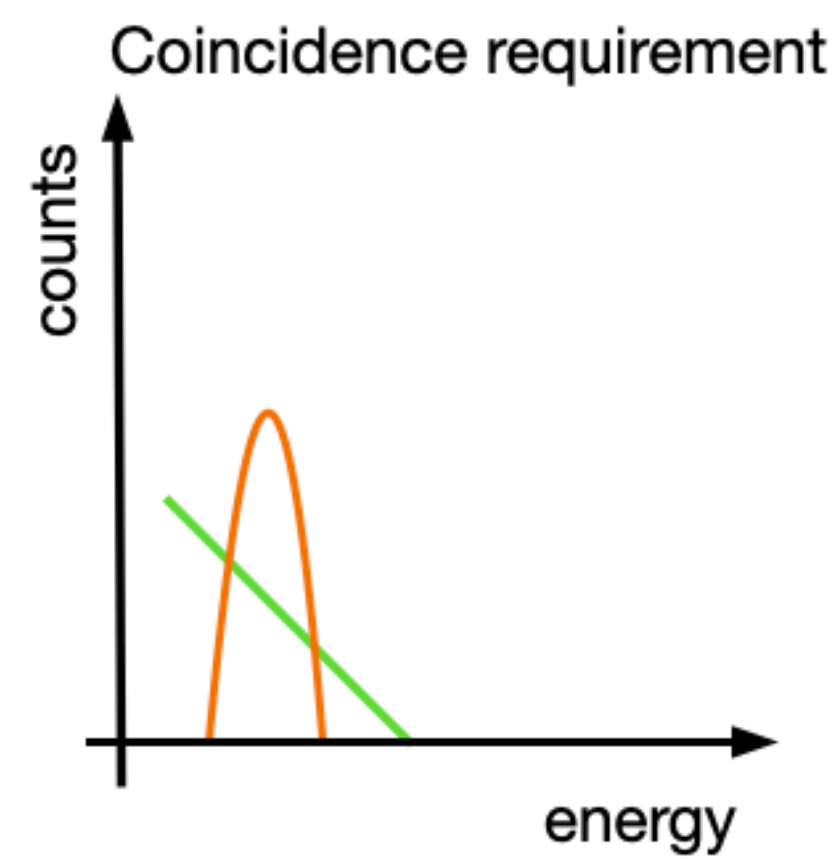
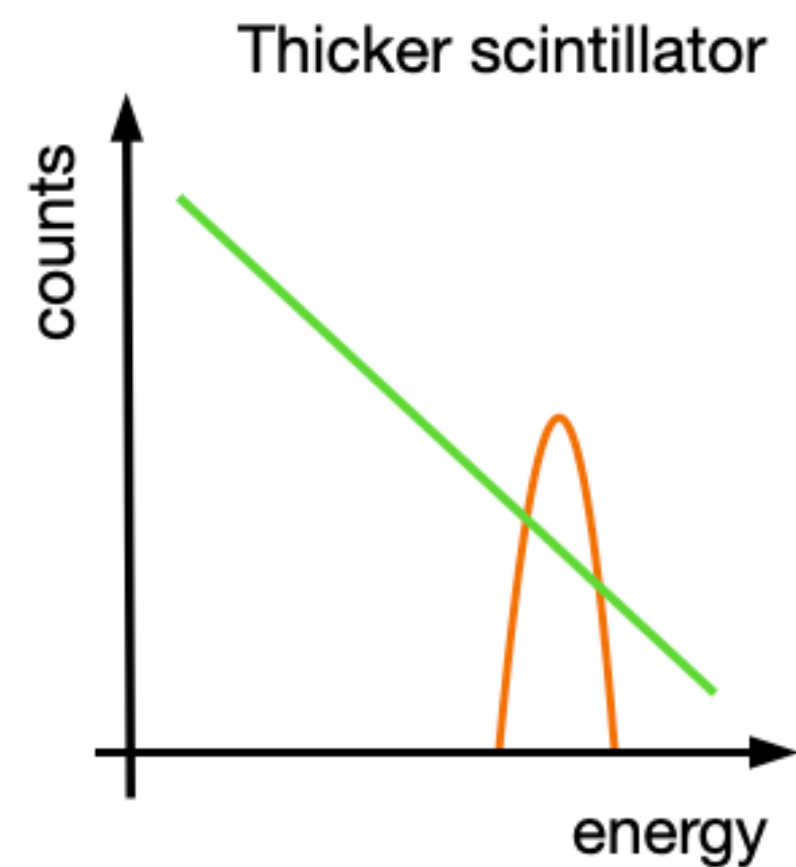
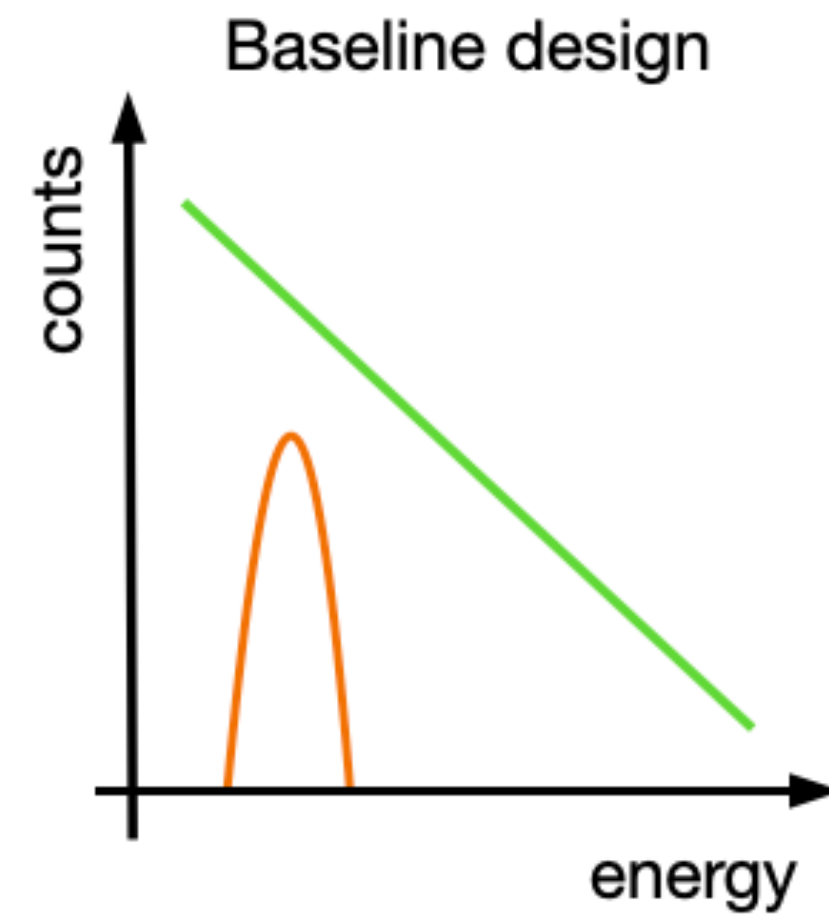
Example muon peak from IceTop panel



IceTop Scintillator Panel
Shefali, 2025, KIT Thesis

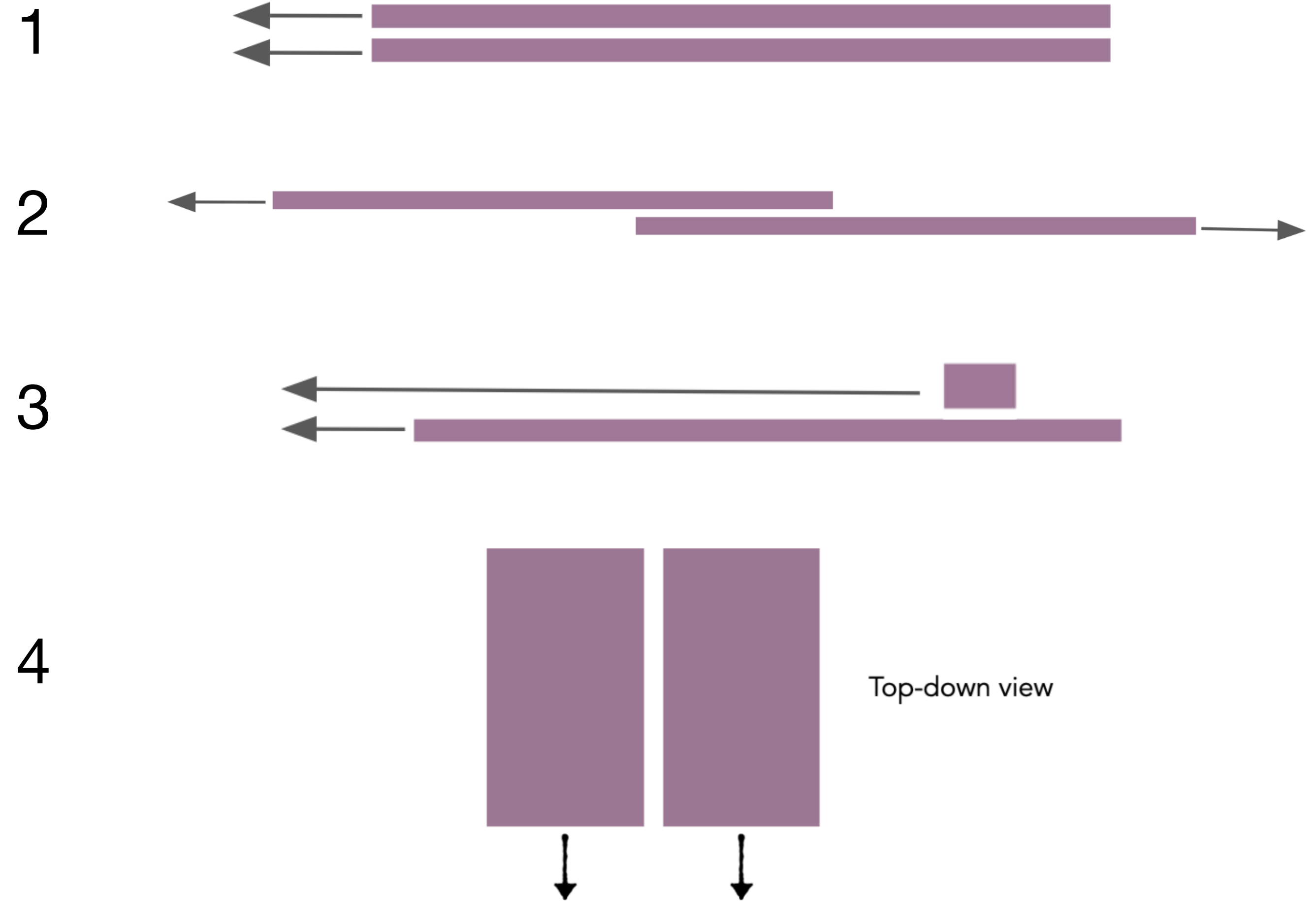
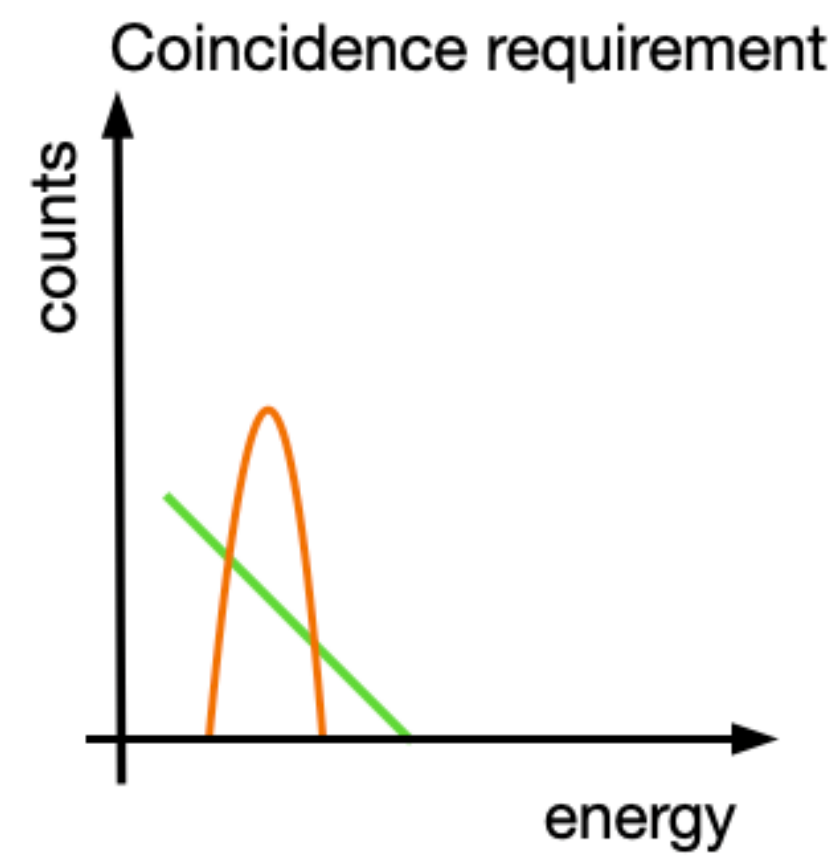
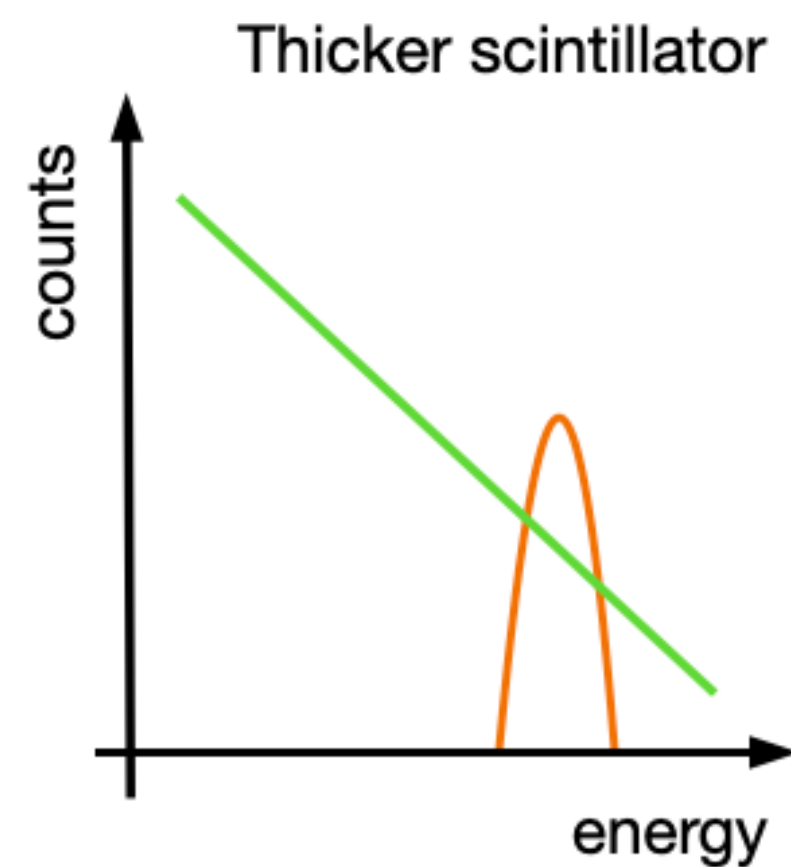
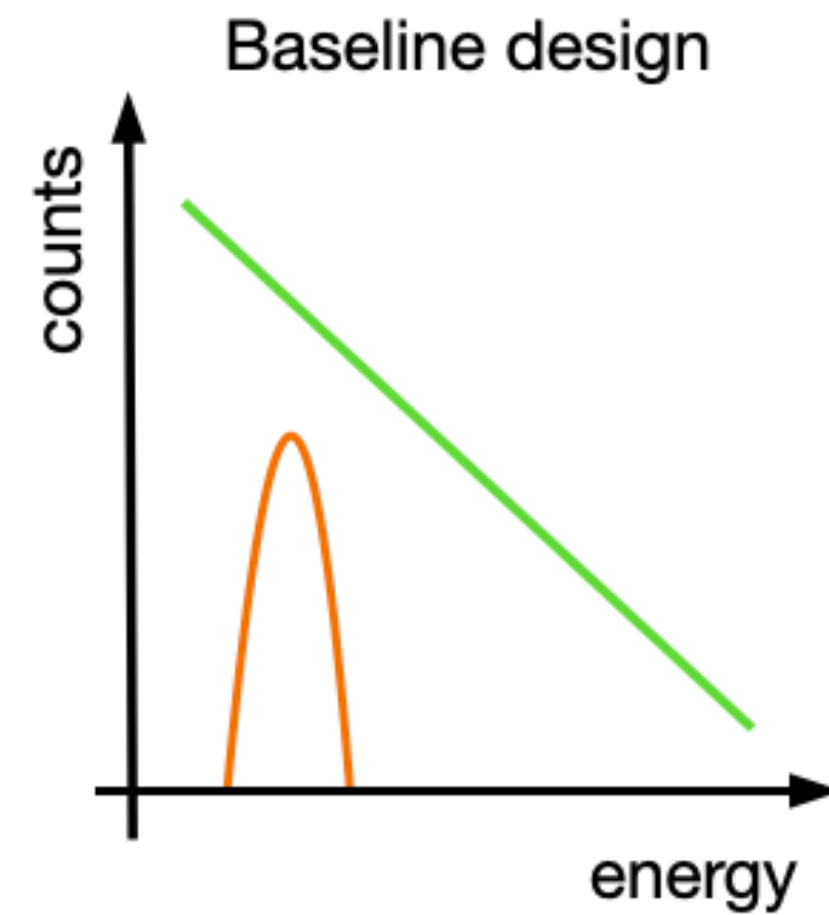
Scintillator detector concepts under study

Since the scintillator is thin, we are exploring various concepts to identify the muon peak.



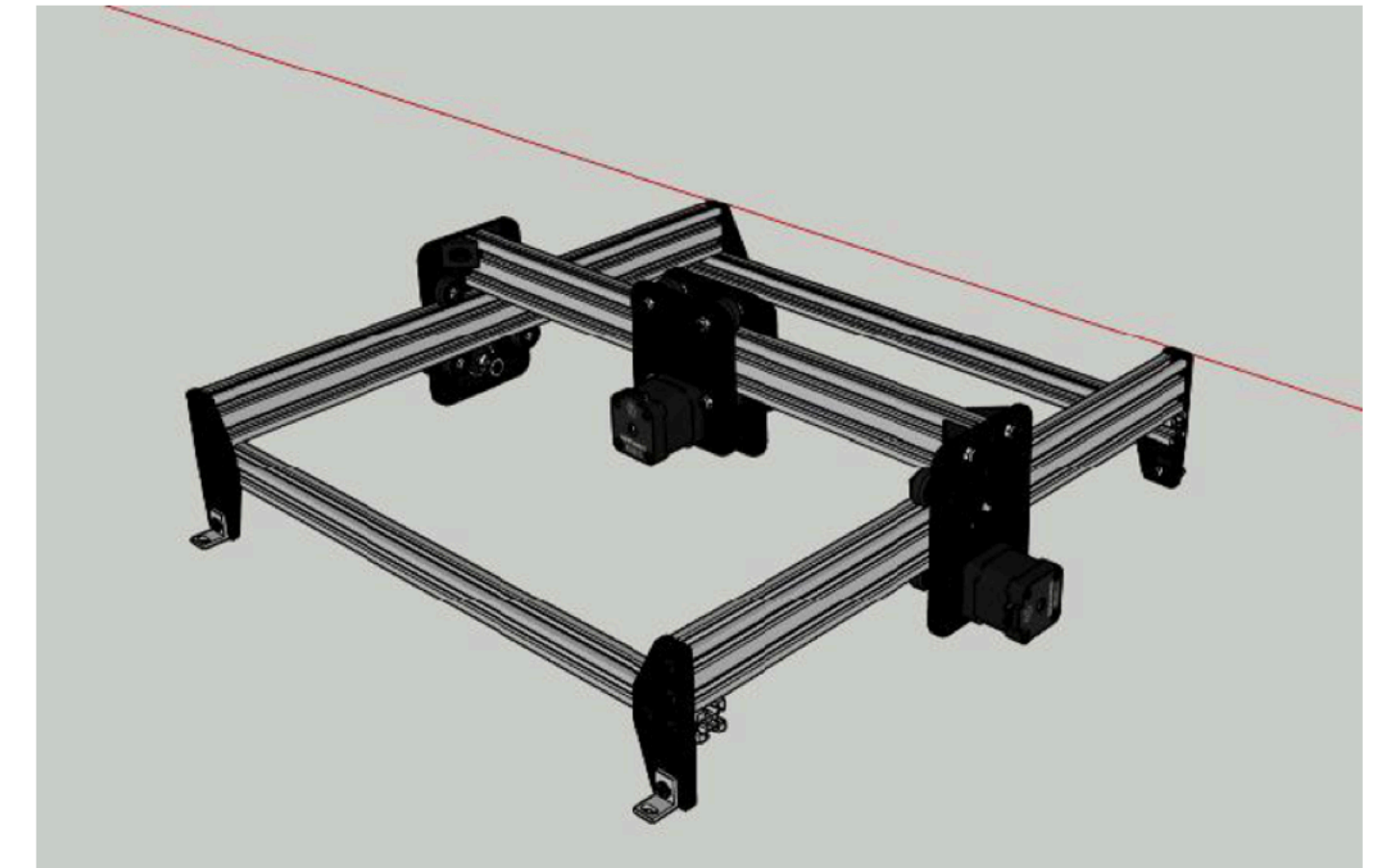
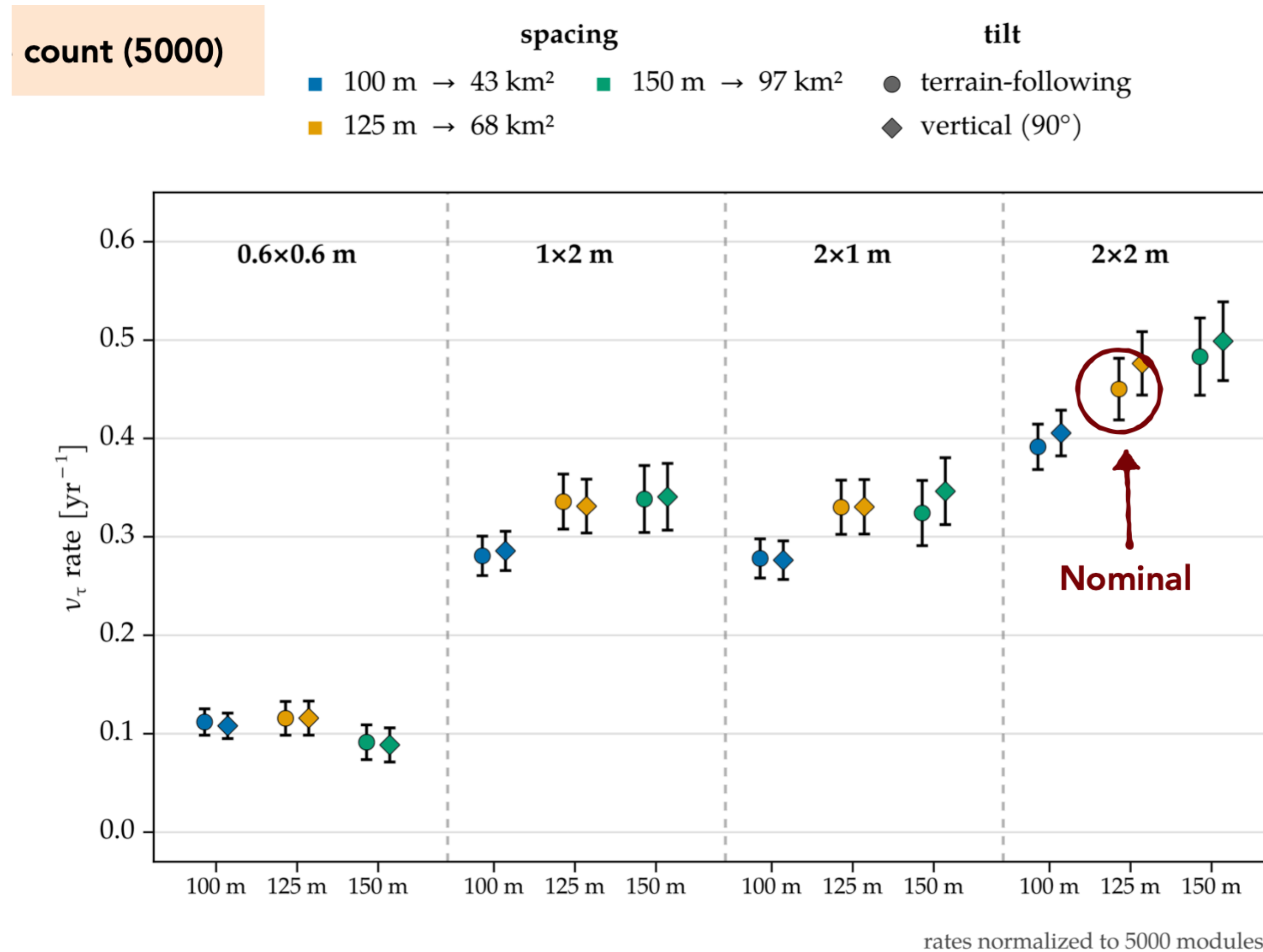
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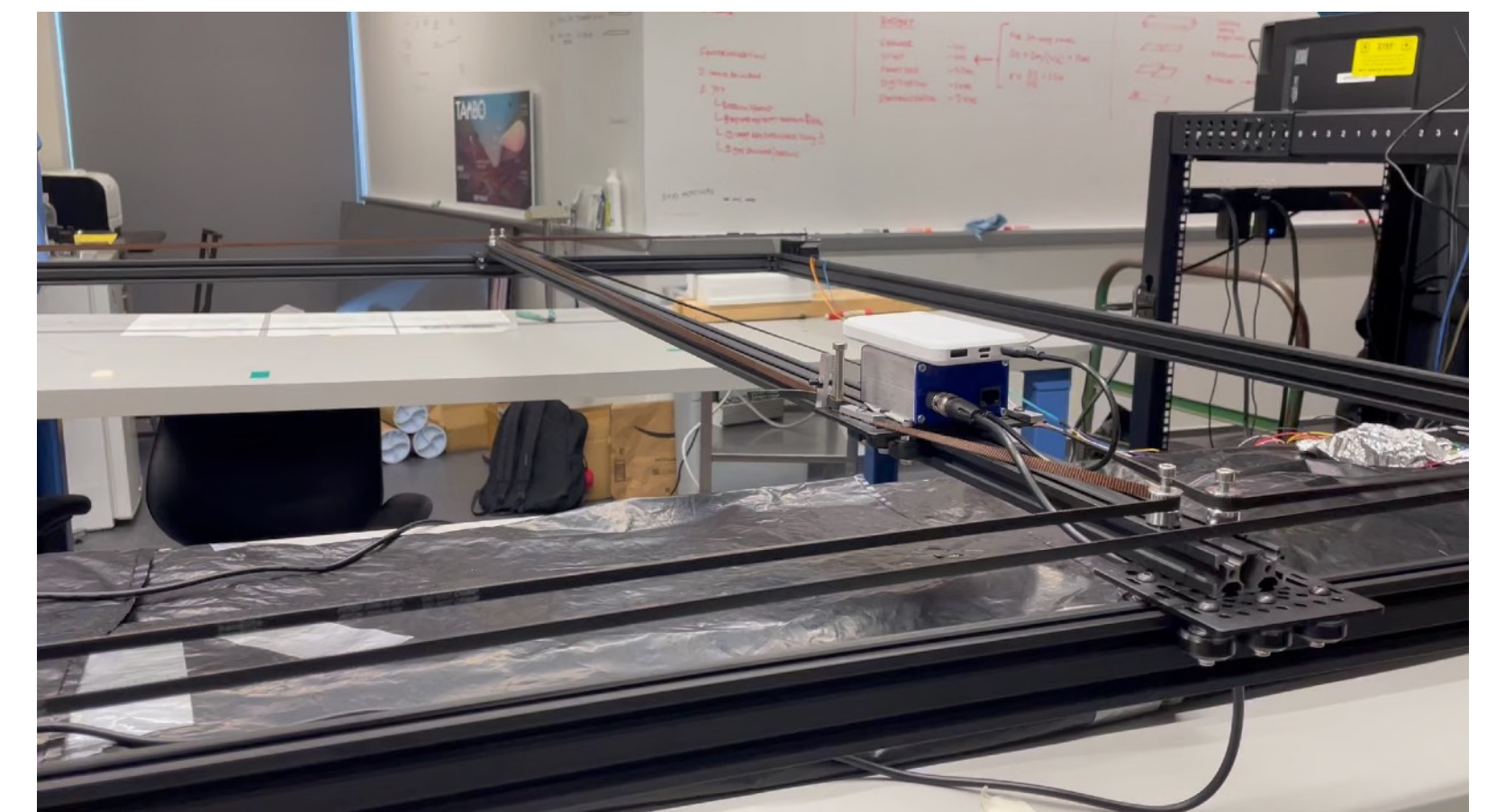


Panel geometry and testing system

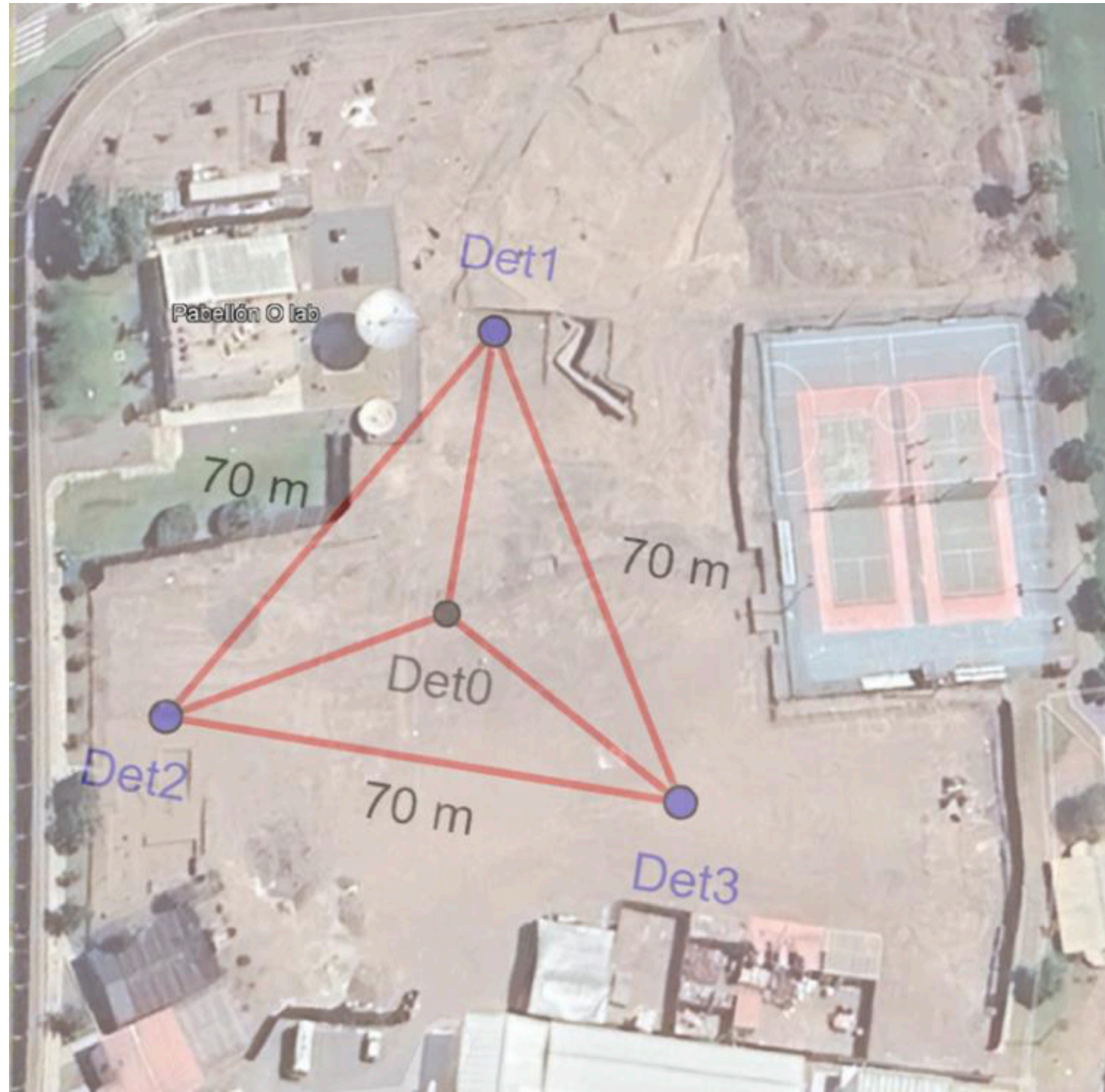
Optimization of panel design and calibration robot at Harvard



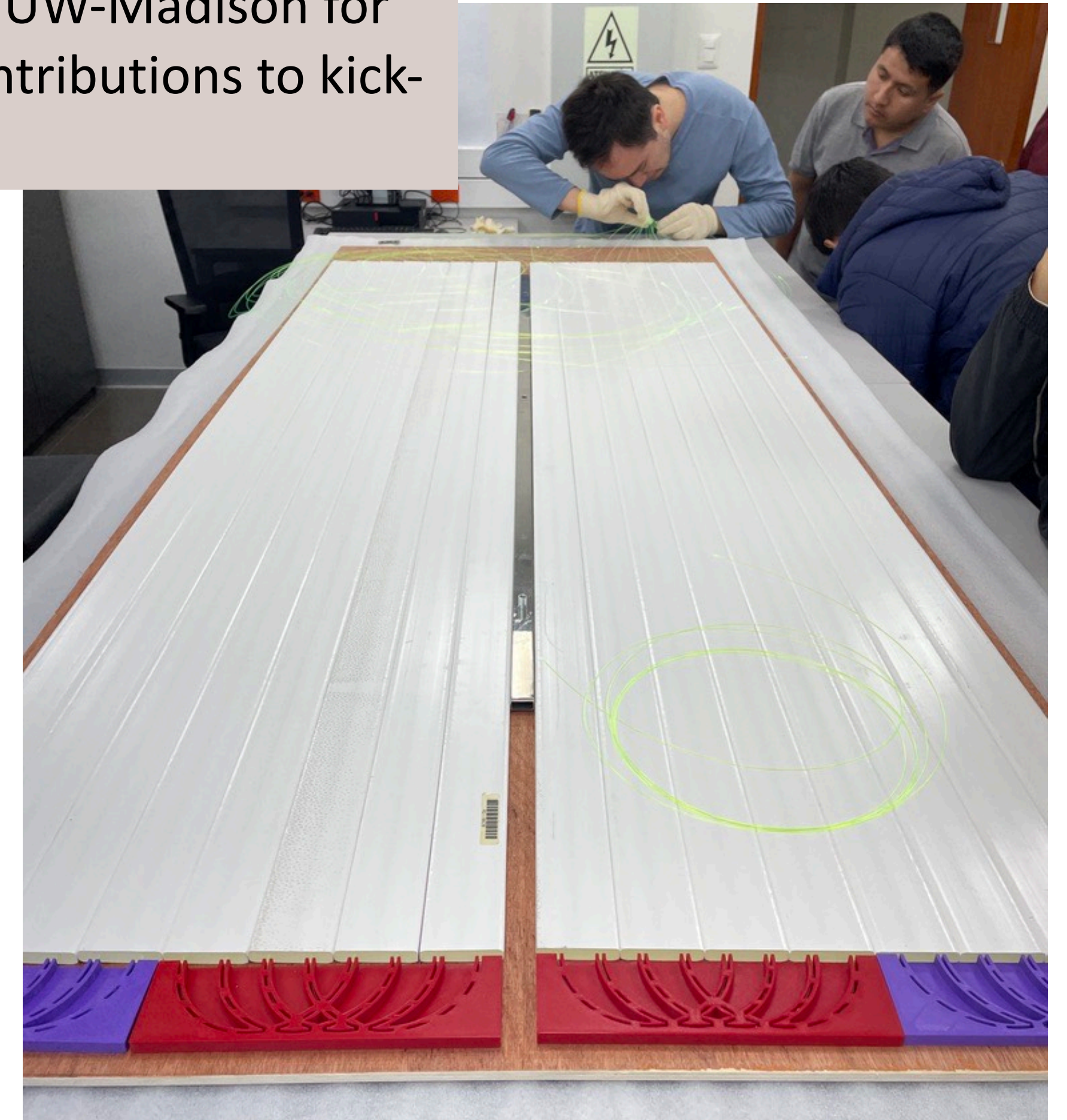
TAMBO panel-scanning robot



First array prototype: TAMBO-4

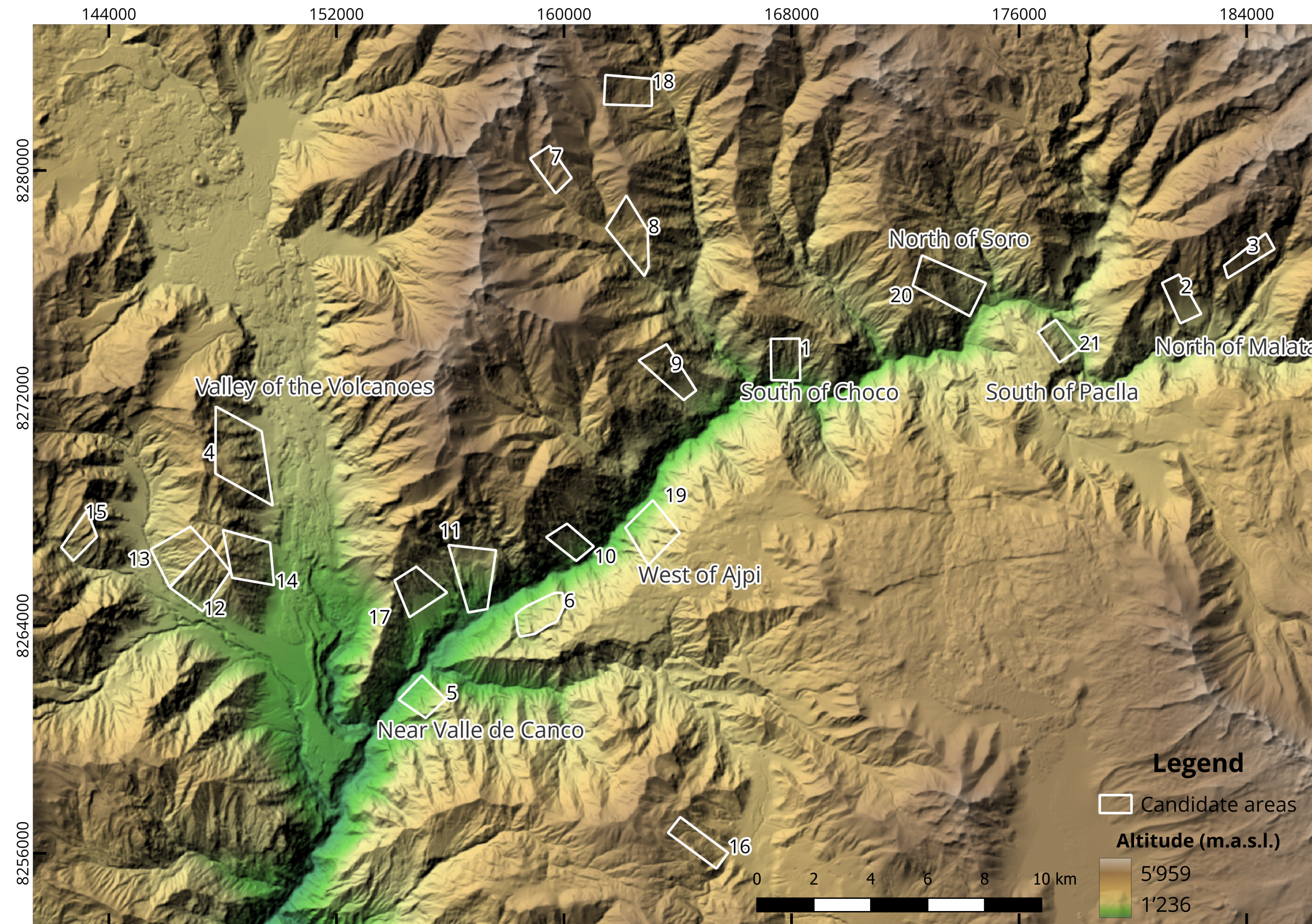


Thanks to KIT and UW-Madison for their generous contributions to kick-start the project!



- Under construction at PUCP in Lima
- First test of our communication system, vet detector & reconstruction performance

Potential locations for TAMBO

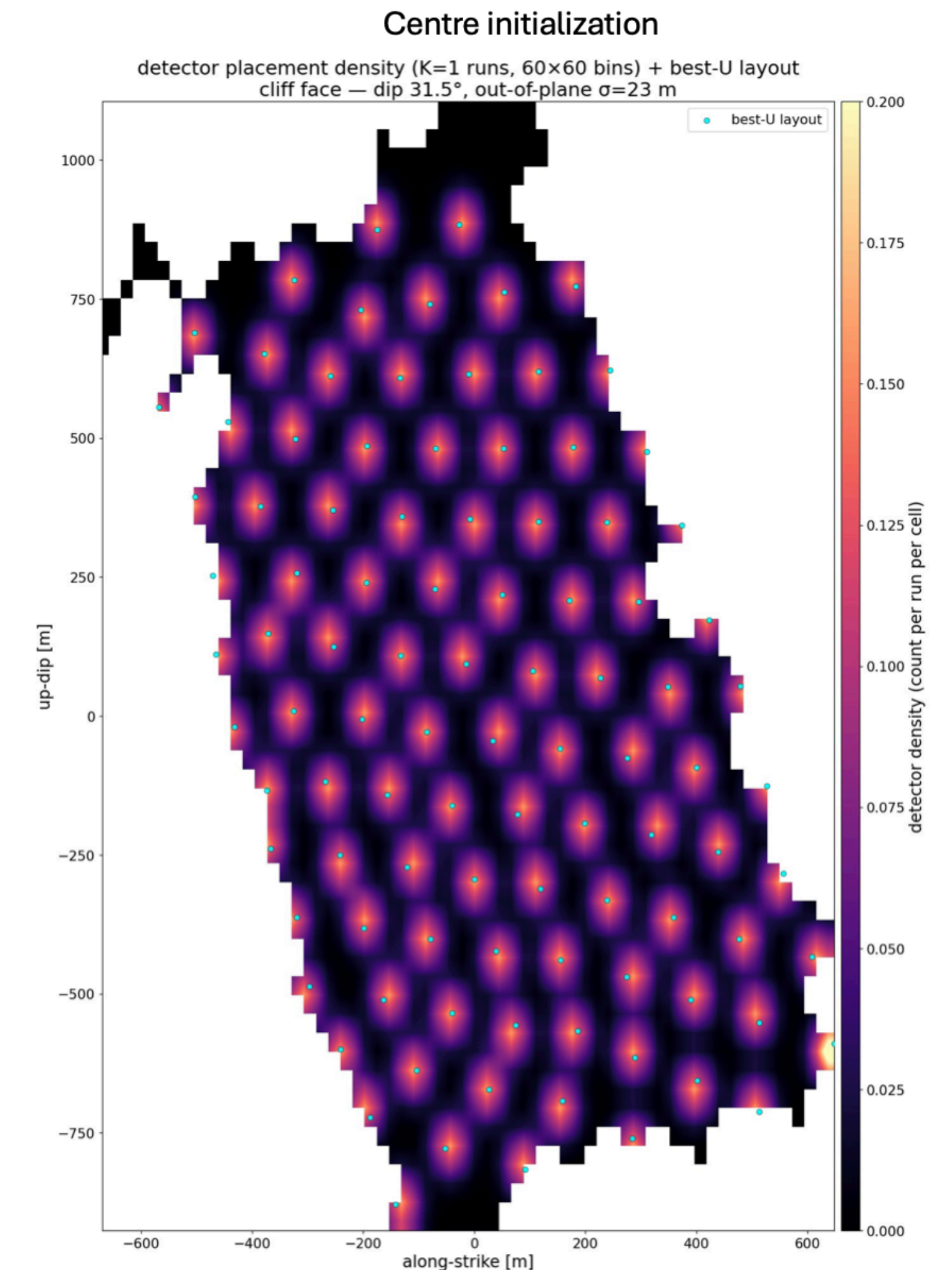
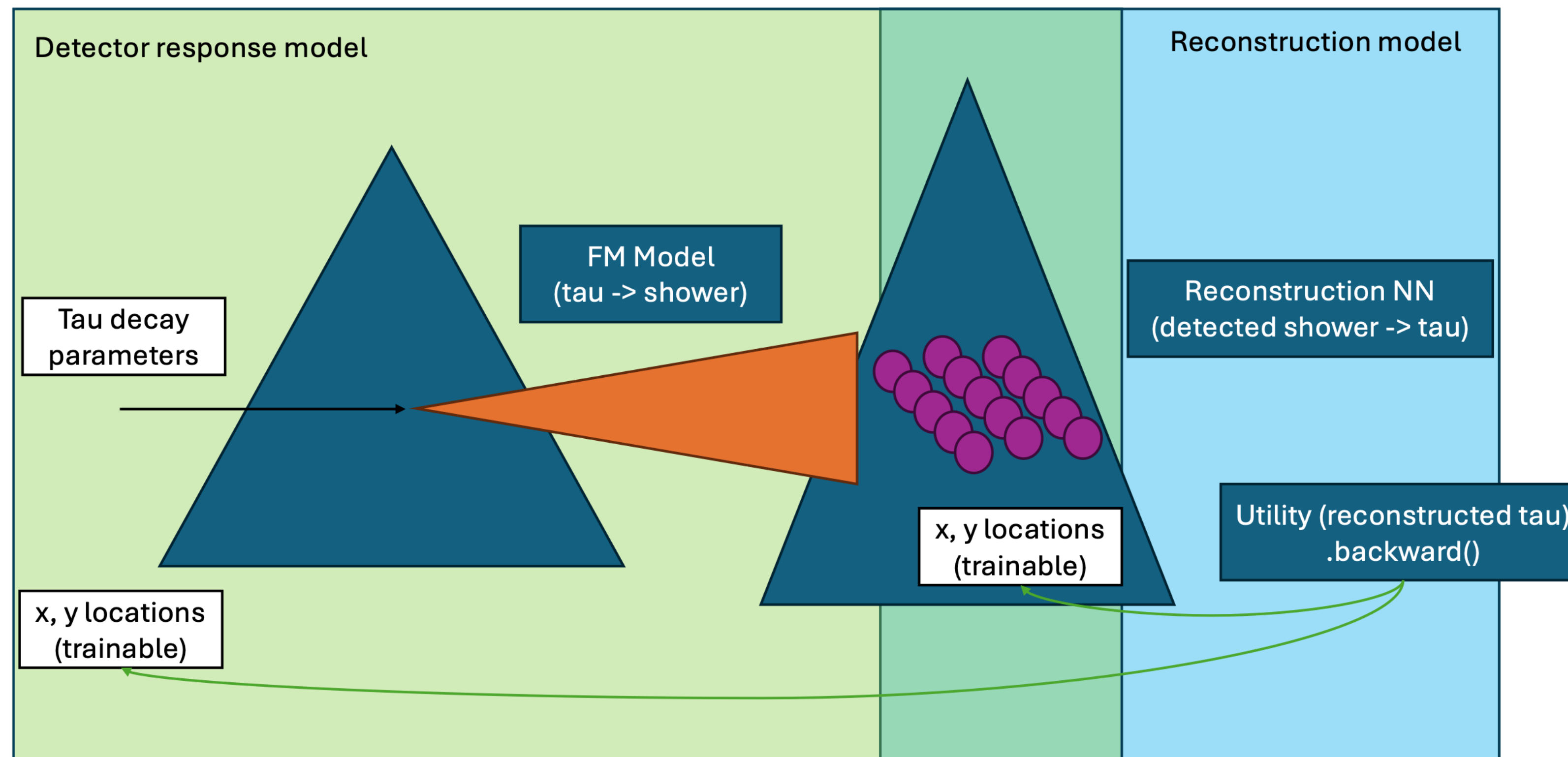


Initial requirements:

- Large enough to fit 100 detectors (125m spacing)
- Max slope 35°
- Opposite face 3-8 km away

100-Station Array Optimization

Array optimization using surrogate shower models in progress.



Zlatan Dimitrov, Hamza Hanif, Jay Agarwal, Izan Flórez García,
Jeffrey Lazar, Pietro Vischia, Tommaso Dorigo, TAMBO Collaboration Geometry Optimization Team

Beyond a Particle Physics experiment: First site visit and community engagement

Key Aims:

- Find ± 1 km², slope of 25° – 35°, valley 3 – 8 km wide in **Colca Canyon**
- **Ethical approach** to site selection and consent
- Mutually beneficial **collaboration with communities**
- Respecting Andean **indigenous practices**

Key Achievements:

- Built **interdisciplinary** ‘responsible site selection’ team
 - sociologist, anthropologist, geographer, and historian
- Outreach **animation video** in Spanish and Quechua
- **Site visit** with Responsible Siting team (August 2026)
 - > 10 stakeholder meetings – governors to farmers
 - Mapped social conditions and governance structure
 - Joined and studied local rituals and festivities
- Down selected from 21 to 5 to **2 main candidate sites**



Joined in local festivity to clean irrigation canals



Learned about representation of stars in local Andean textile designs



Informed about local ecology condor habitat & potential impact



Guided in local ‘offering to the earth’ to respect mountains (Apu)

Beyond a Particle Physics experiment: First site visit and community engagement

Key Aims:

- Fill
- Co
- Et
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- Bu
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- Down selected from 21 to 5 to **2 main candidate sites**

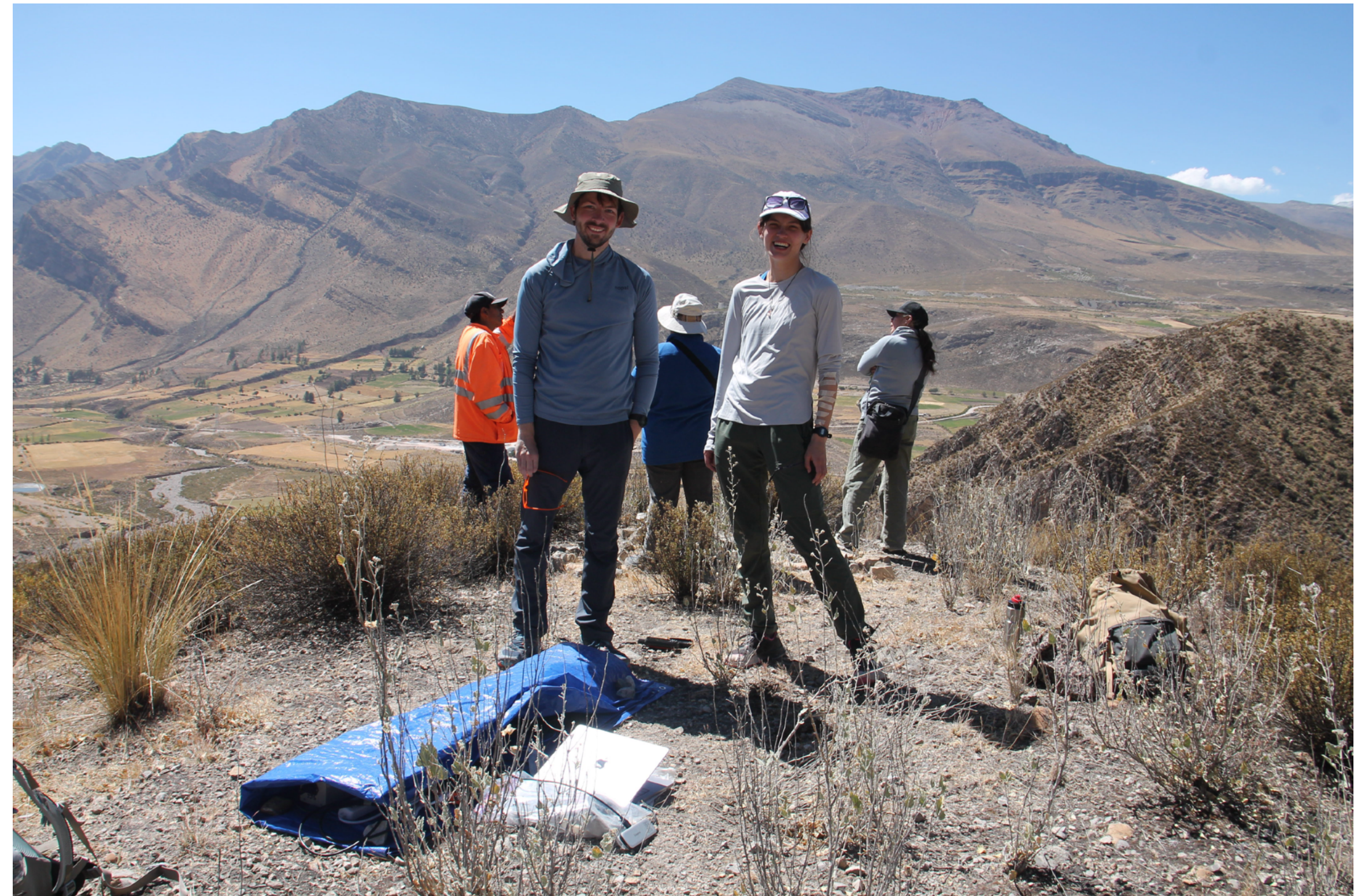
Interdisciplinary Responsible Siting Team



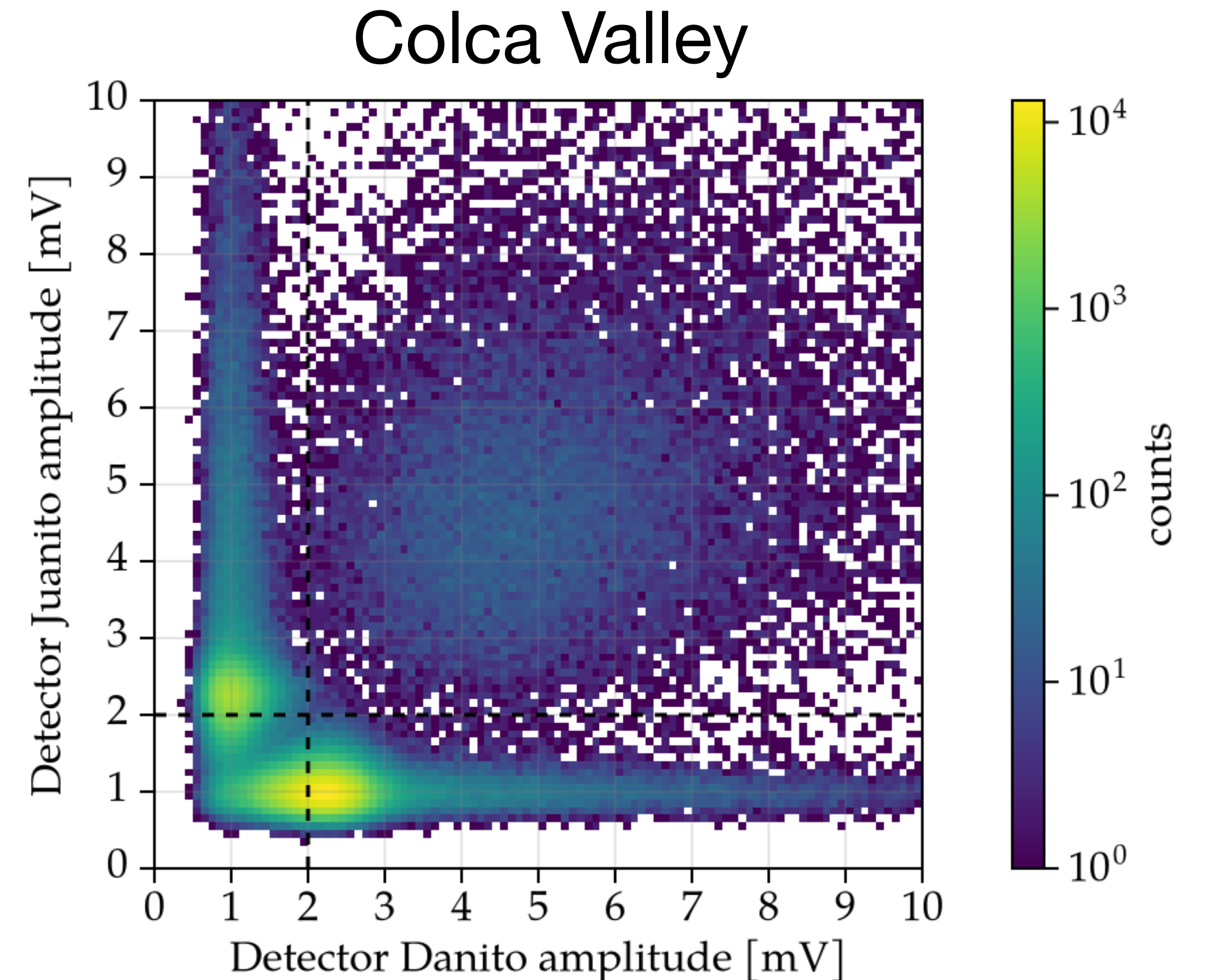
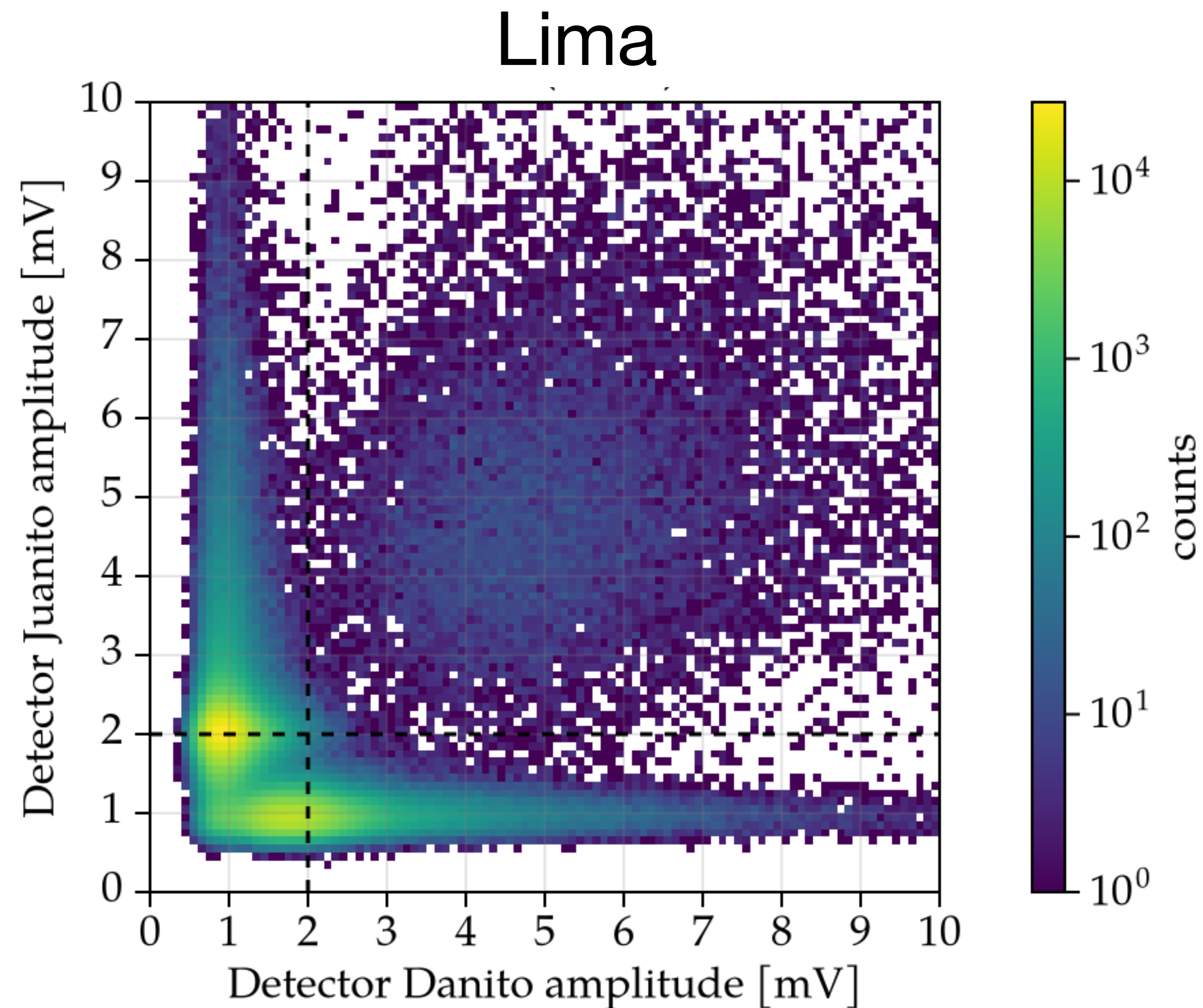
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respect mountains (Apu)

Colca Valley measurements



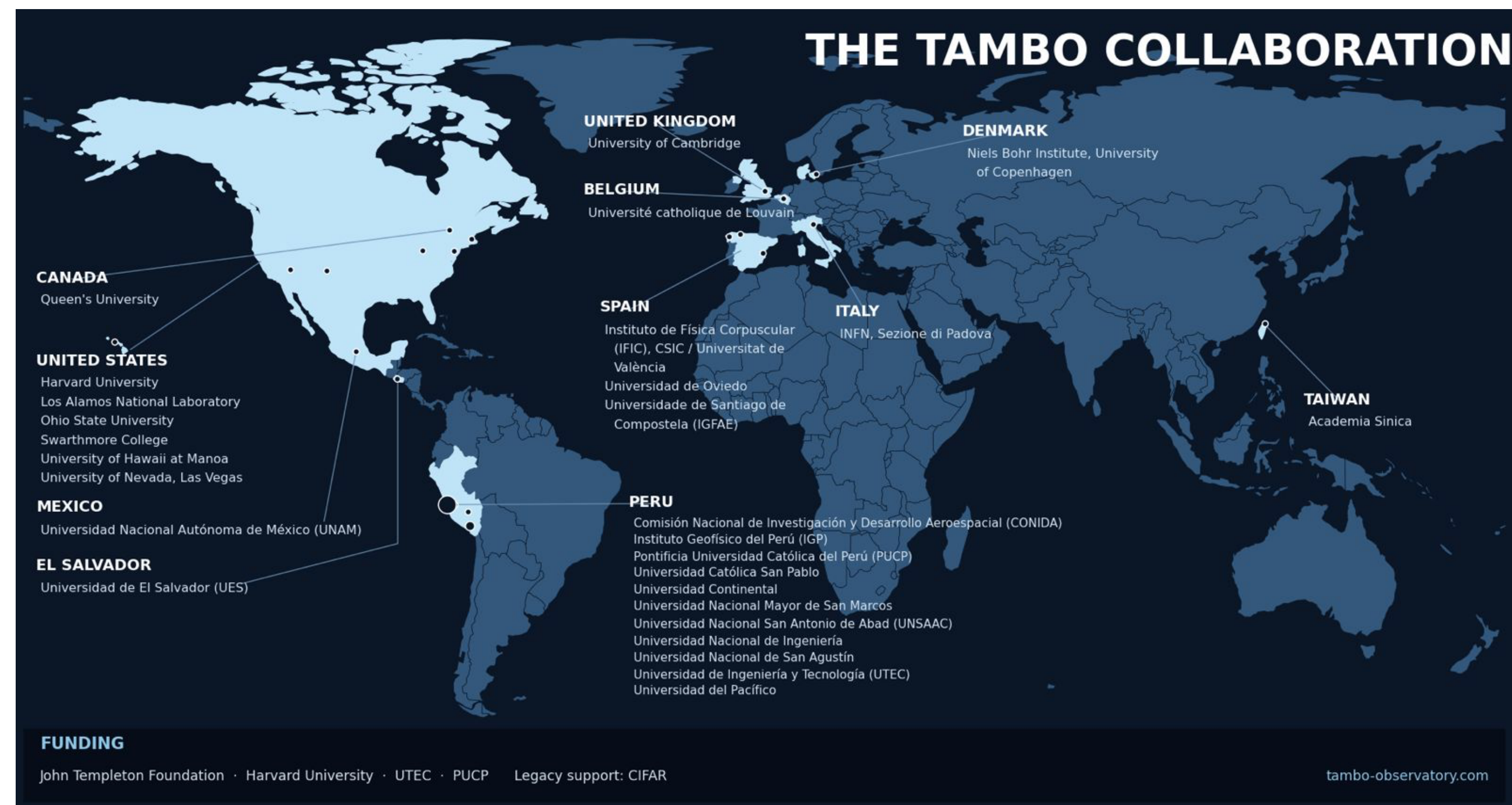
Colca site measurements



Muon peak clearly separated from backgrounds in lab and in field

Take home message

- TAMBO is a new approach to transforming the natural world into a neutrino telescope
- TAMBITO funded; development began in August, 2025.
- Overview paper available at [arXiv:2507.08070](https://arxiv.org/abs/2507.08070)
- Interested in joining? Contact (me or Will Thompson) at will_thompson@g.harvard.edu, carguelles@g.harvard.edu



Thank you on behalf of the TAMBO Collaboration

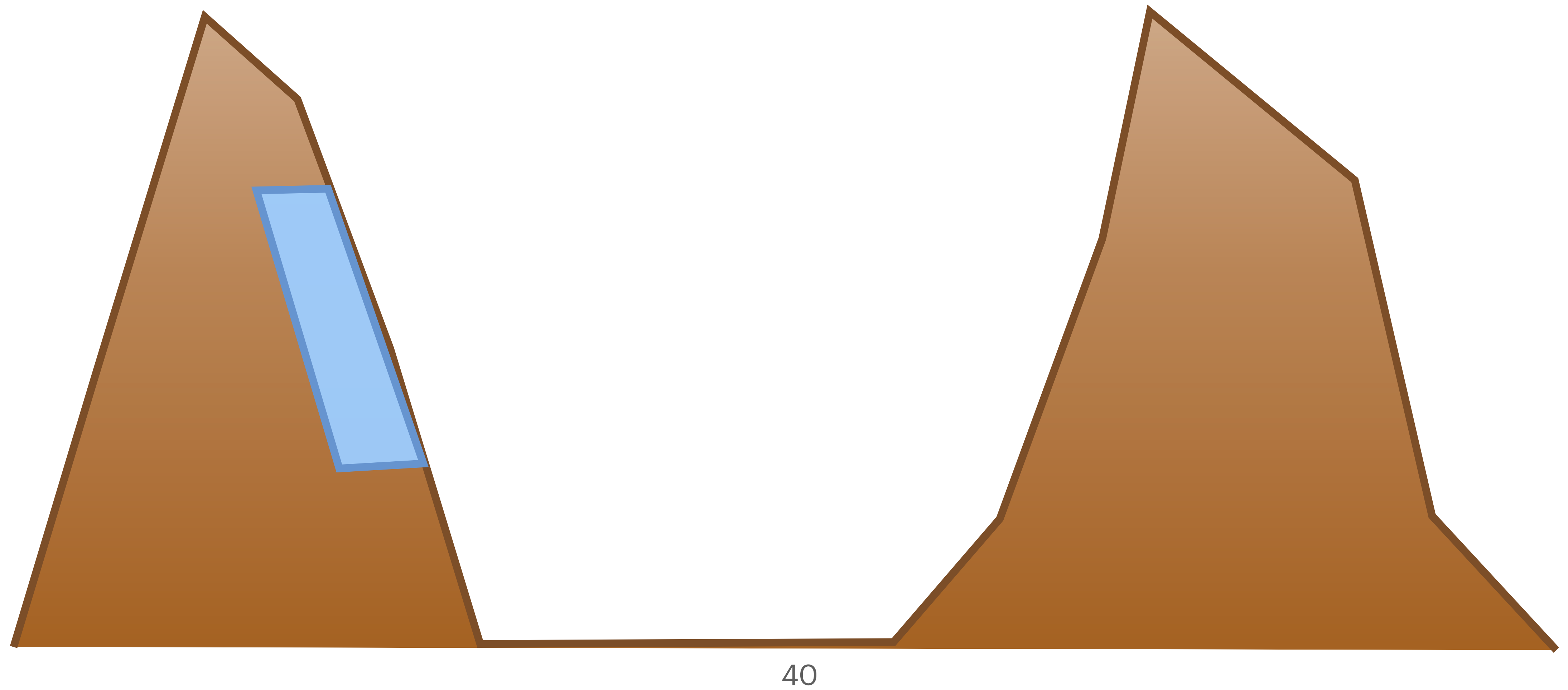


TAMBO Collaboration Meeting, Lima, 2026

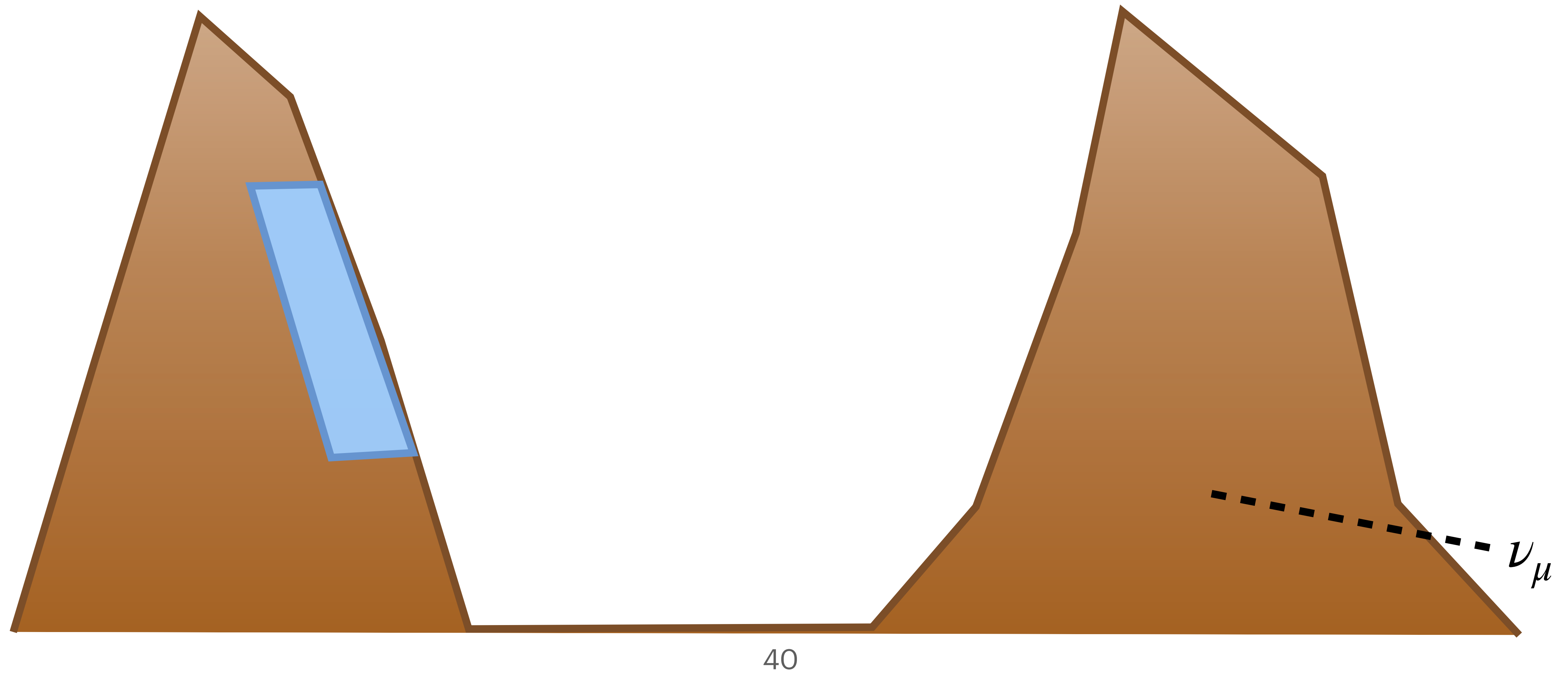
Carlos A. Argüelles — TeVPa, 2026

Bonus

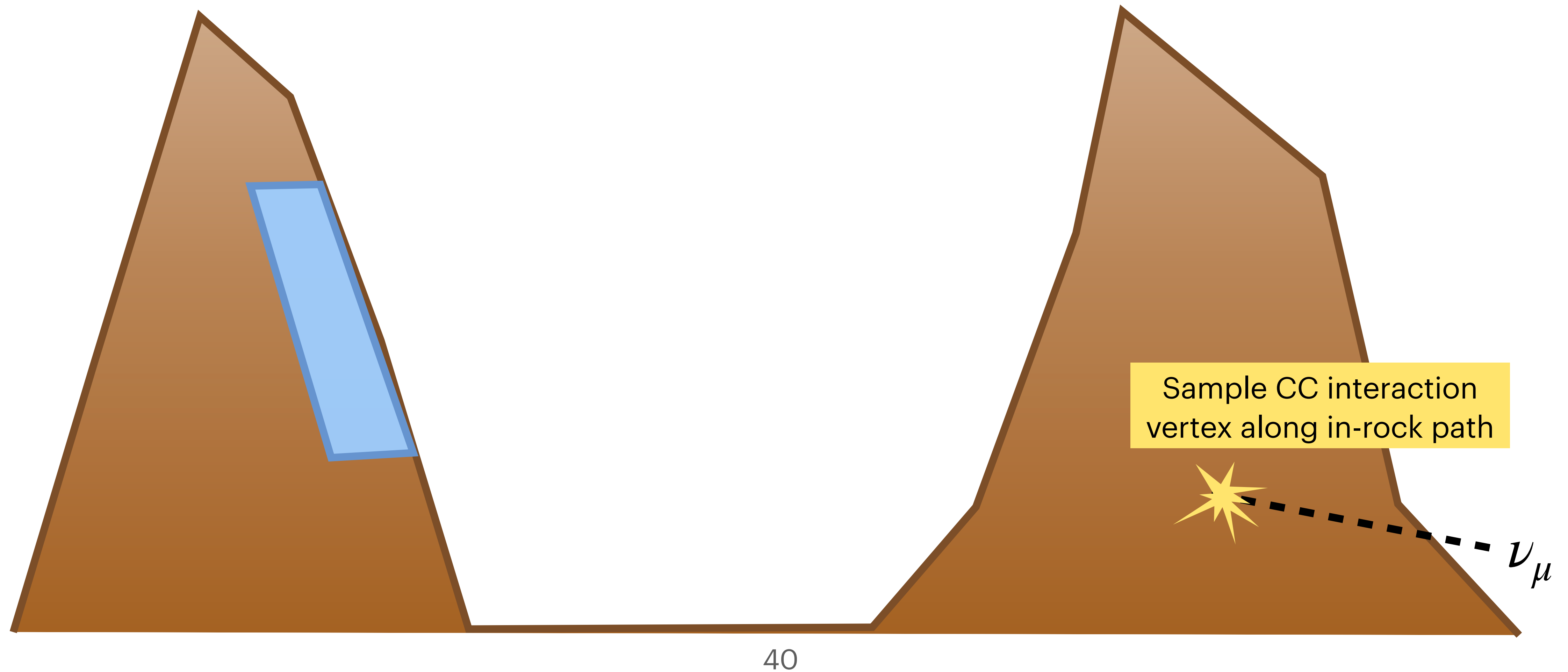
Muon-neutrino induced showers



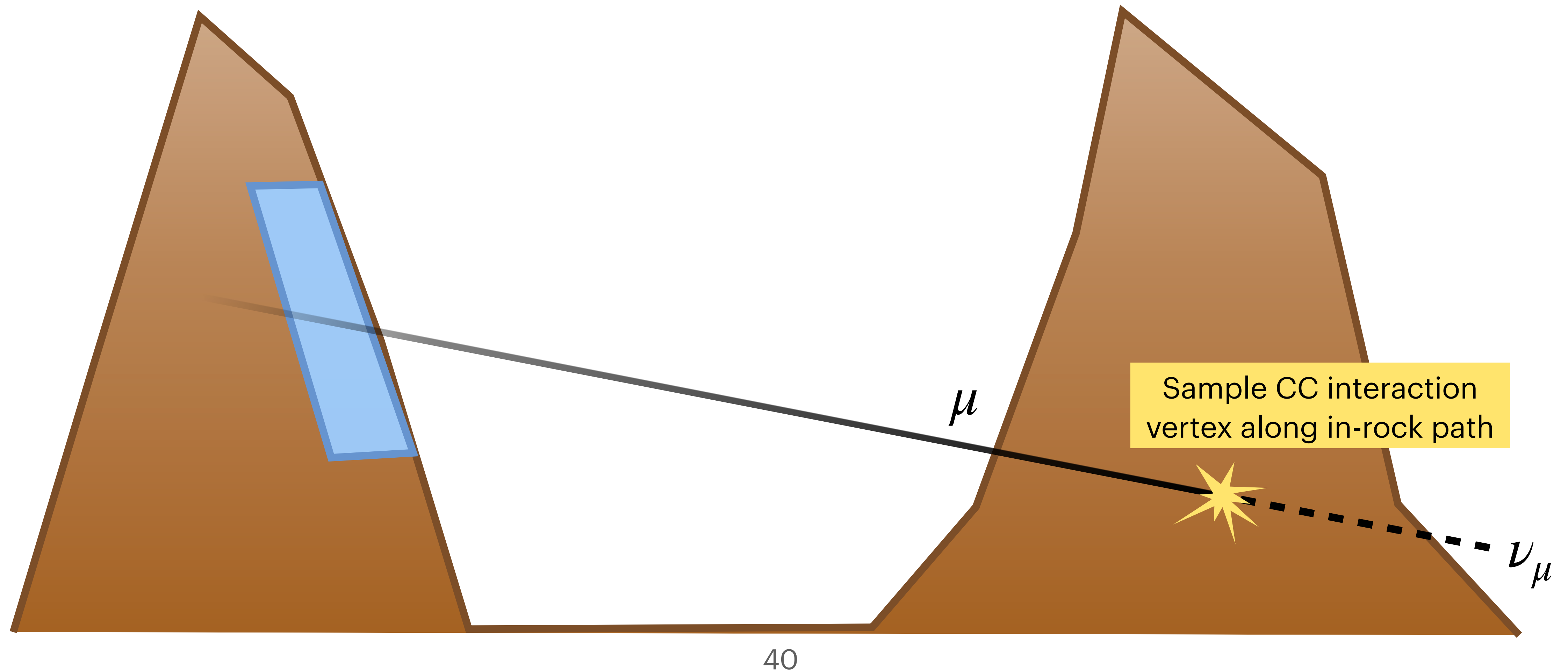
Muon-neutrino induced showers



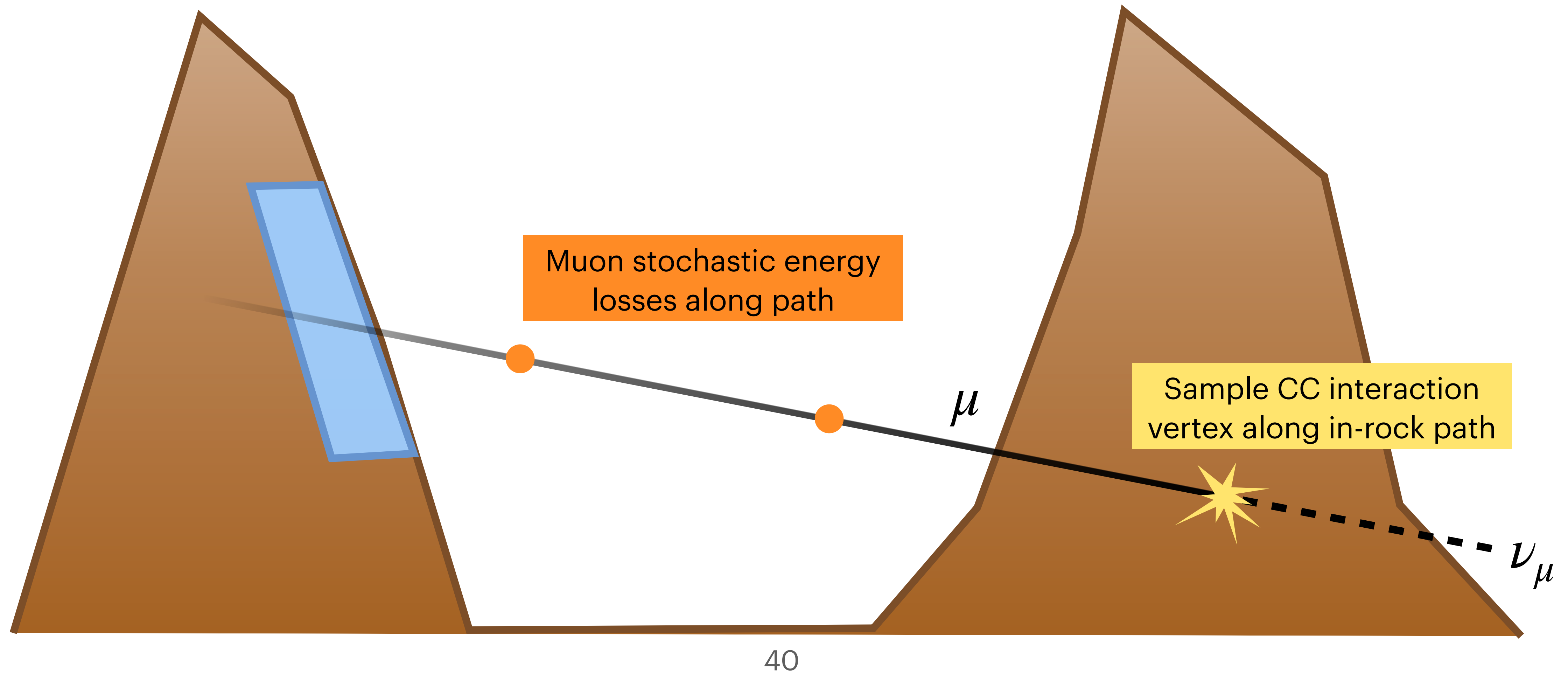
Muon-neutrino induced showers



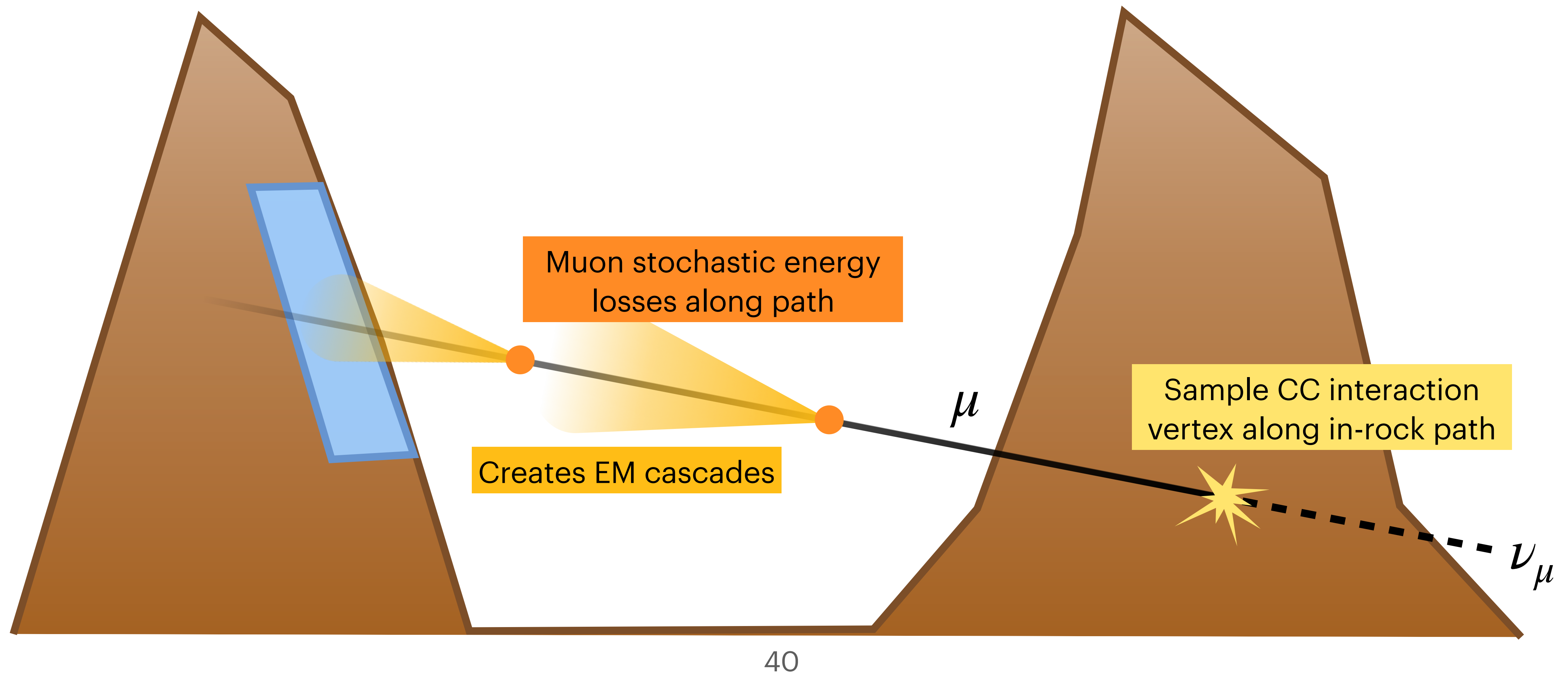
Muon-neutrino induced showers



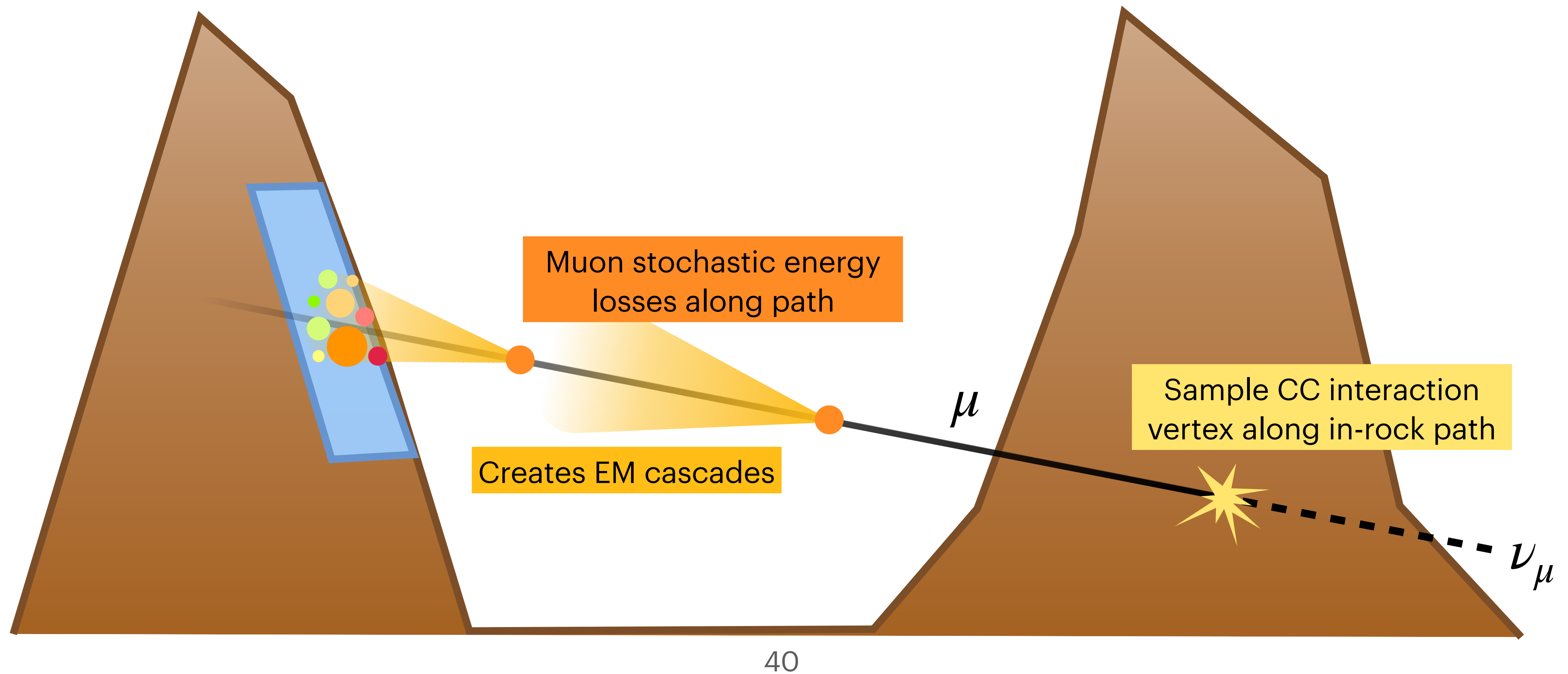
Muon-neutrino induced showers



Muon-neutrino induced showers

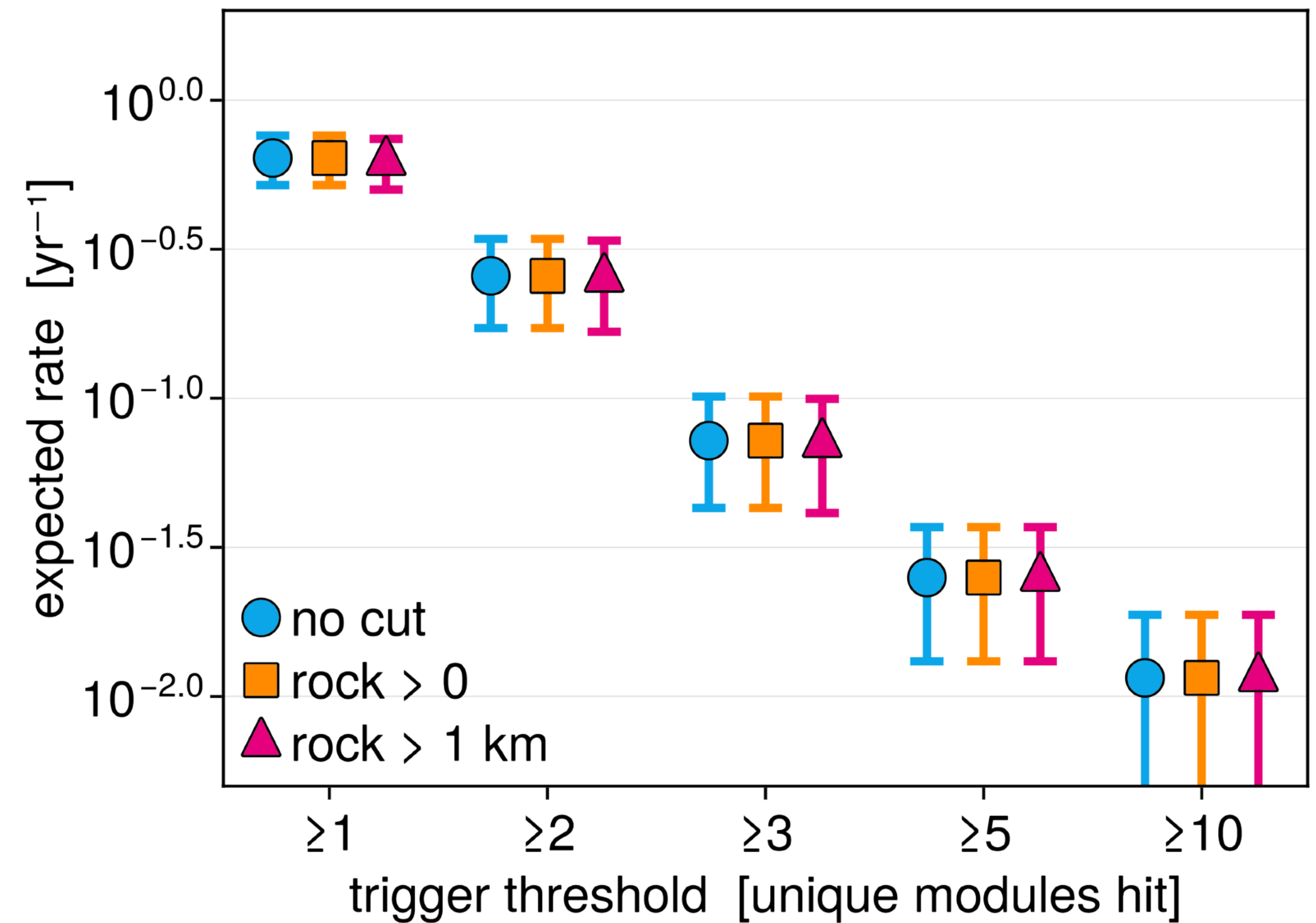


Muon-neutrino induced showers

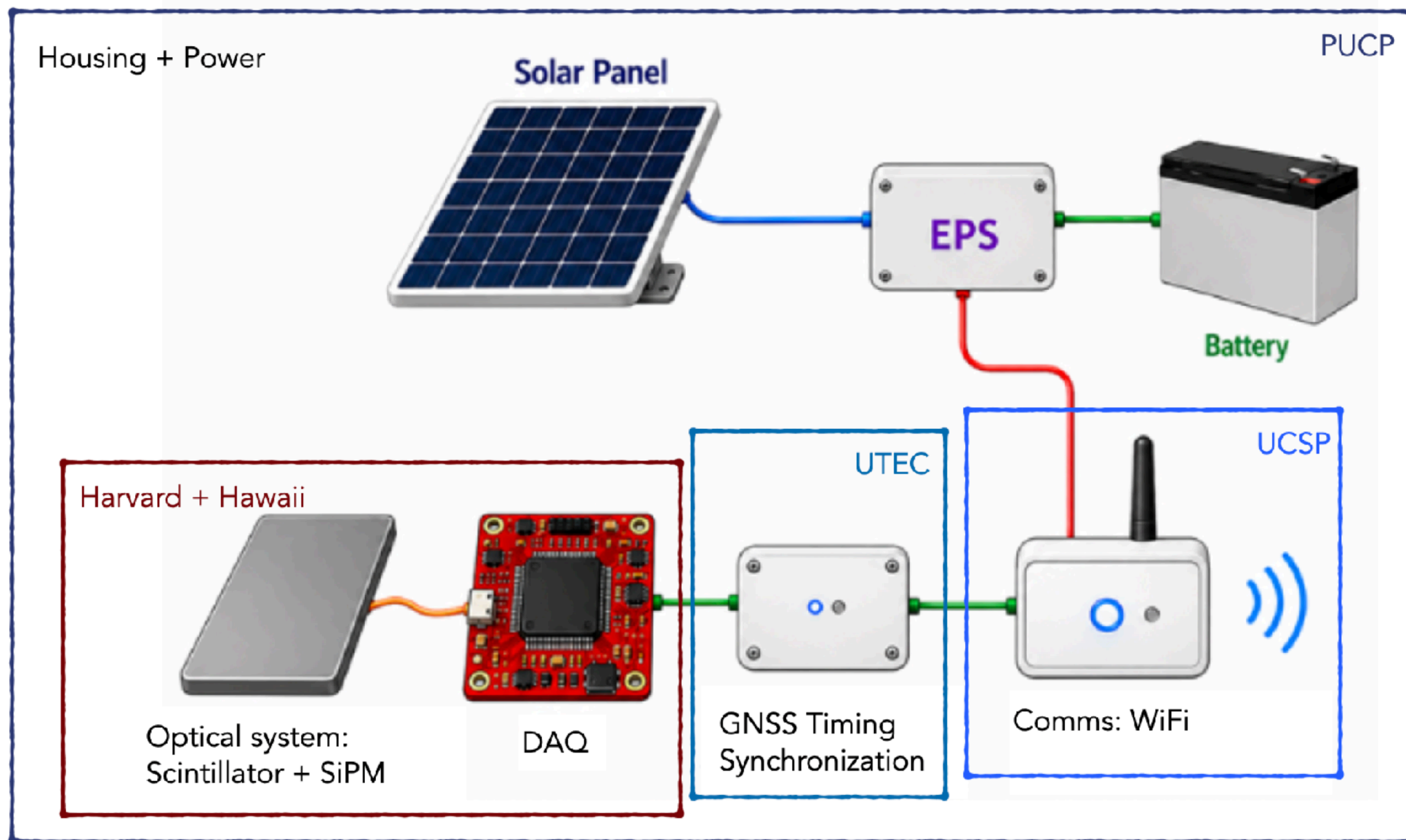


Muon-neutrino induced showers

- For the same flux assumption the >5 modules ν_τ rate is ~ 0.5
- Muon passed straight to CORSIKA to handle stochastic losses
 - Muons don't decay like taus

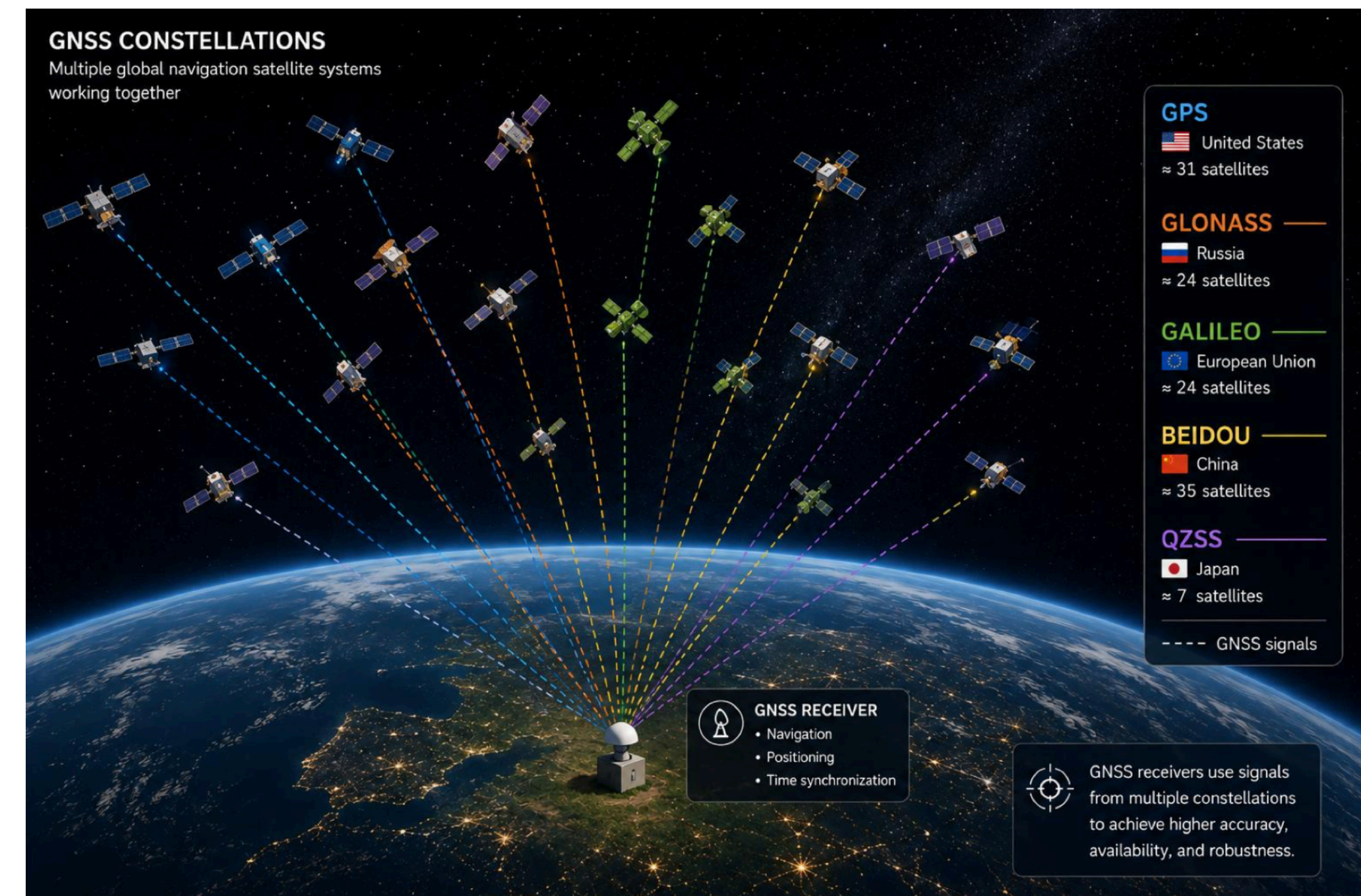
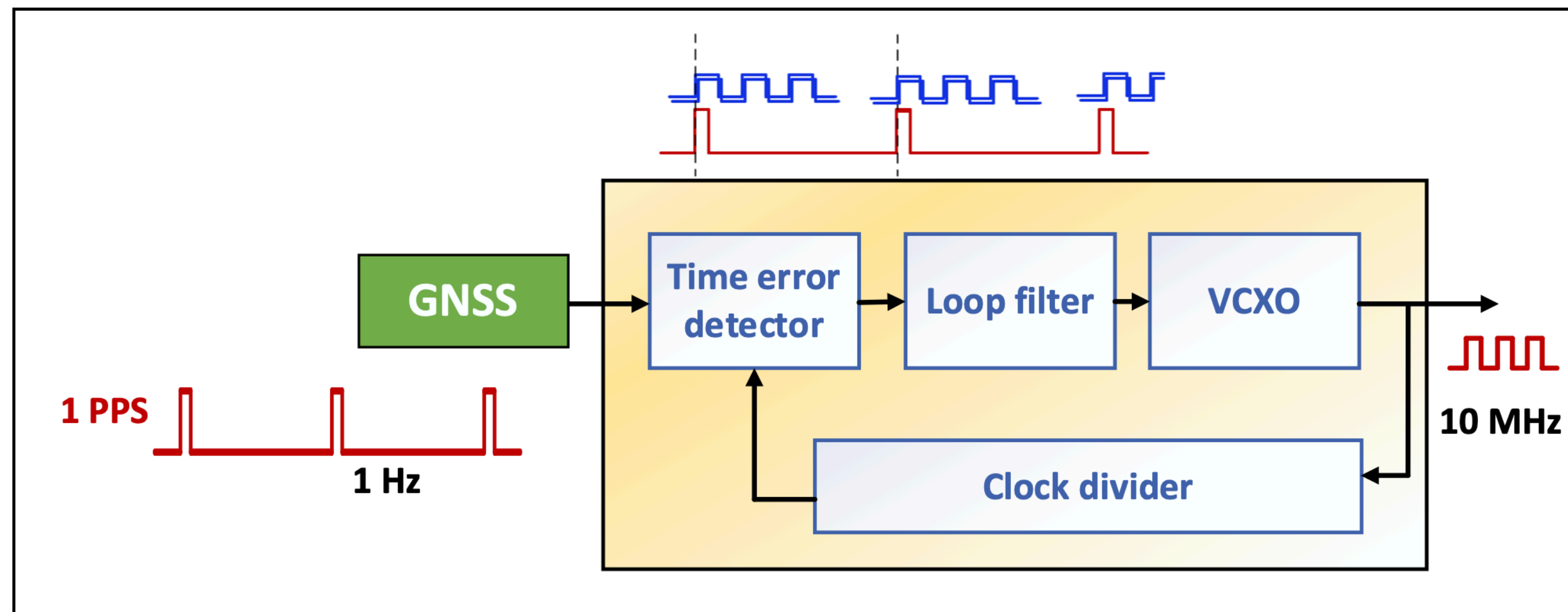


Module development



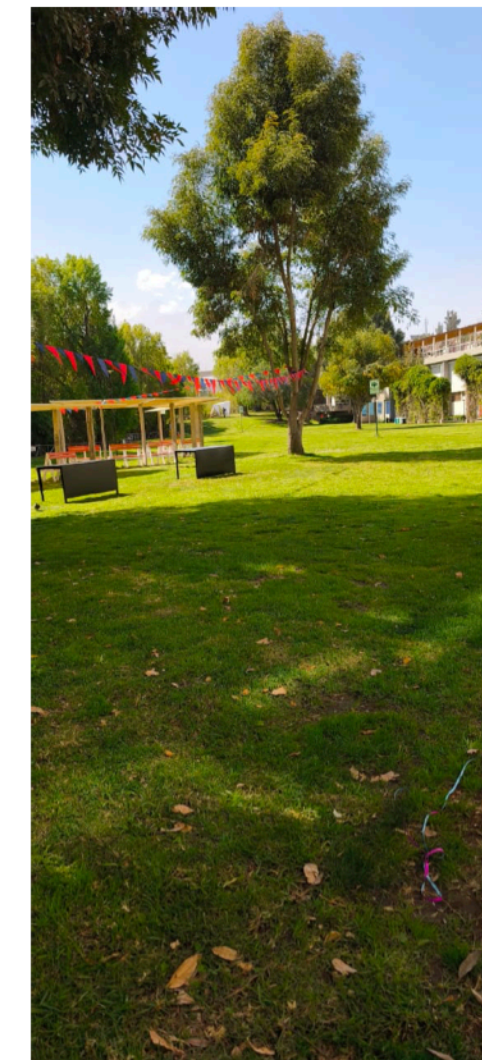
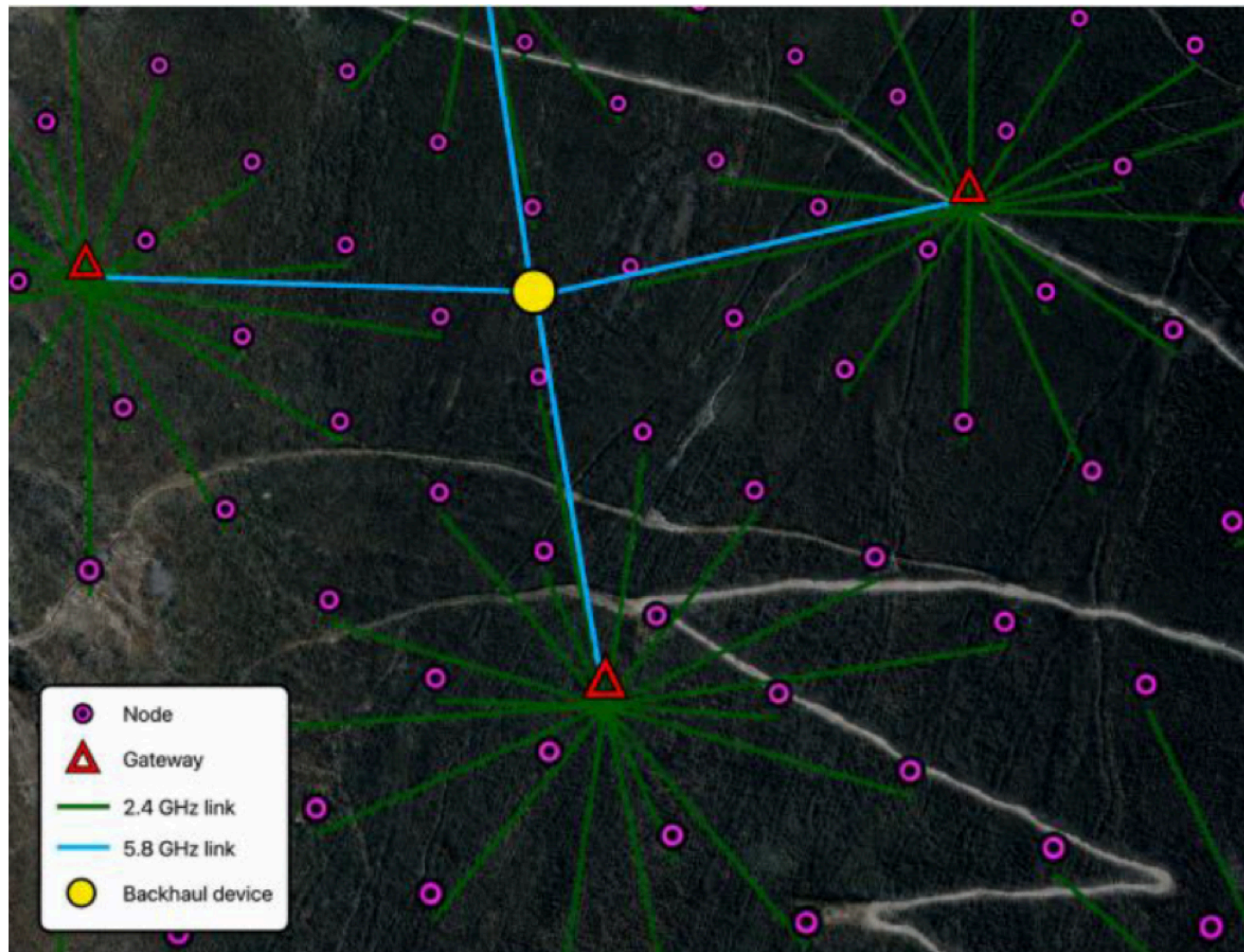
Panel time synchronization system

Timing synchronization system design and DAQ integration at UTEC

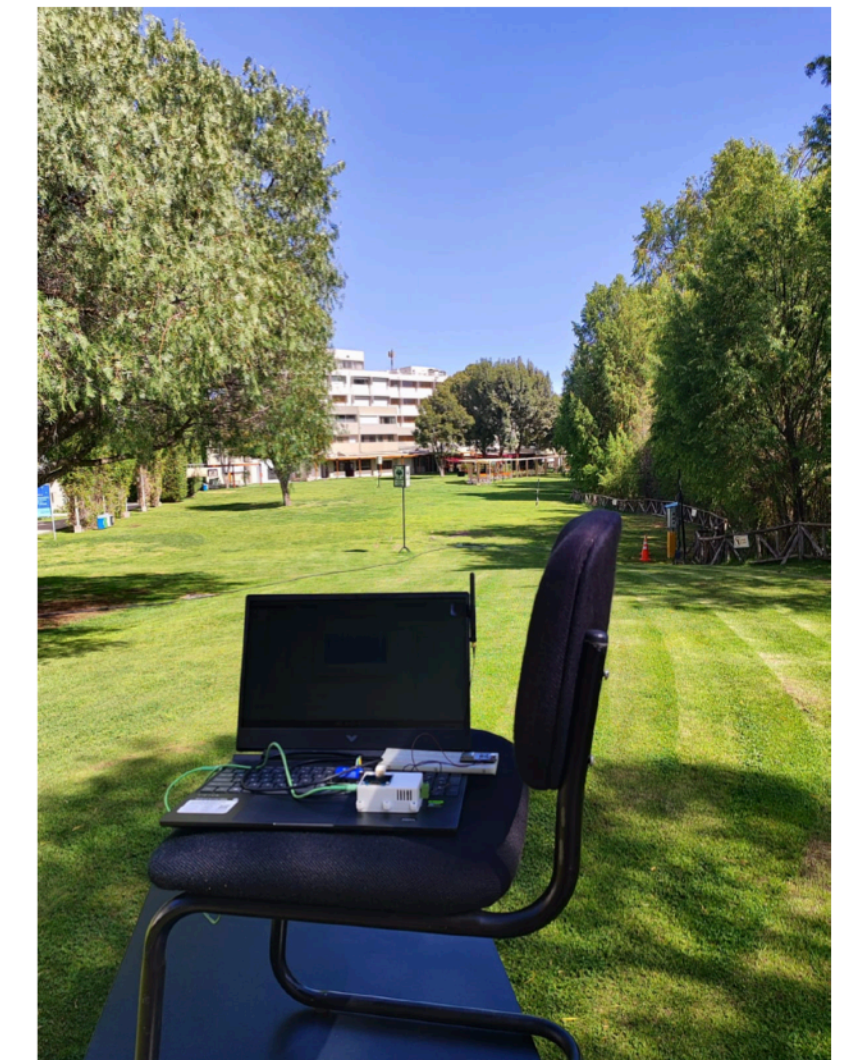


TAMBO Station Communication System

Communication system design by Universidad Catolica San Pablo (Arequipa)

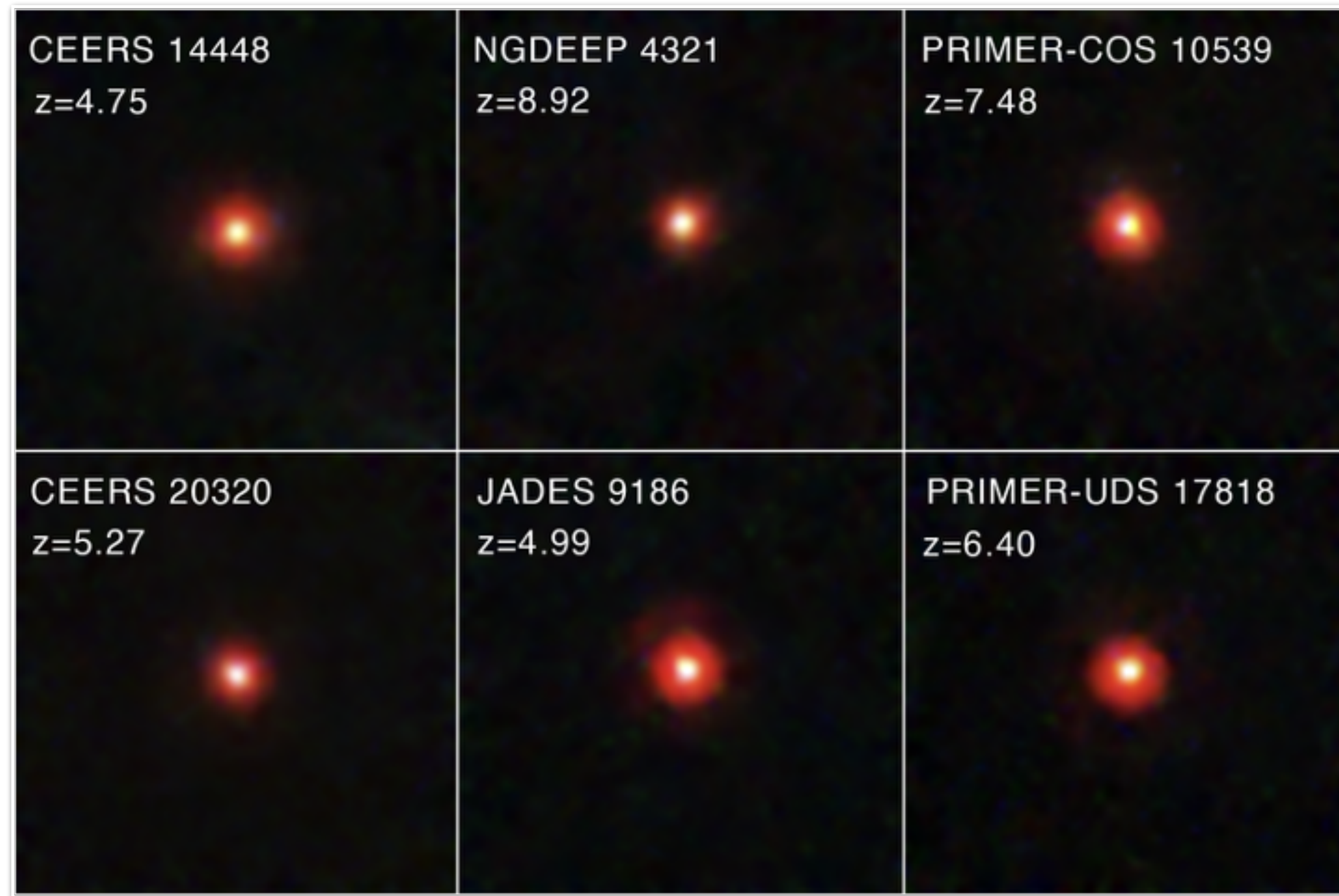


Node viewed from the Gateway

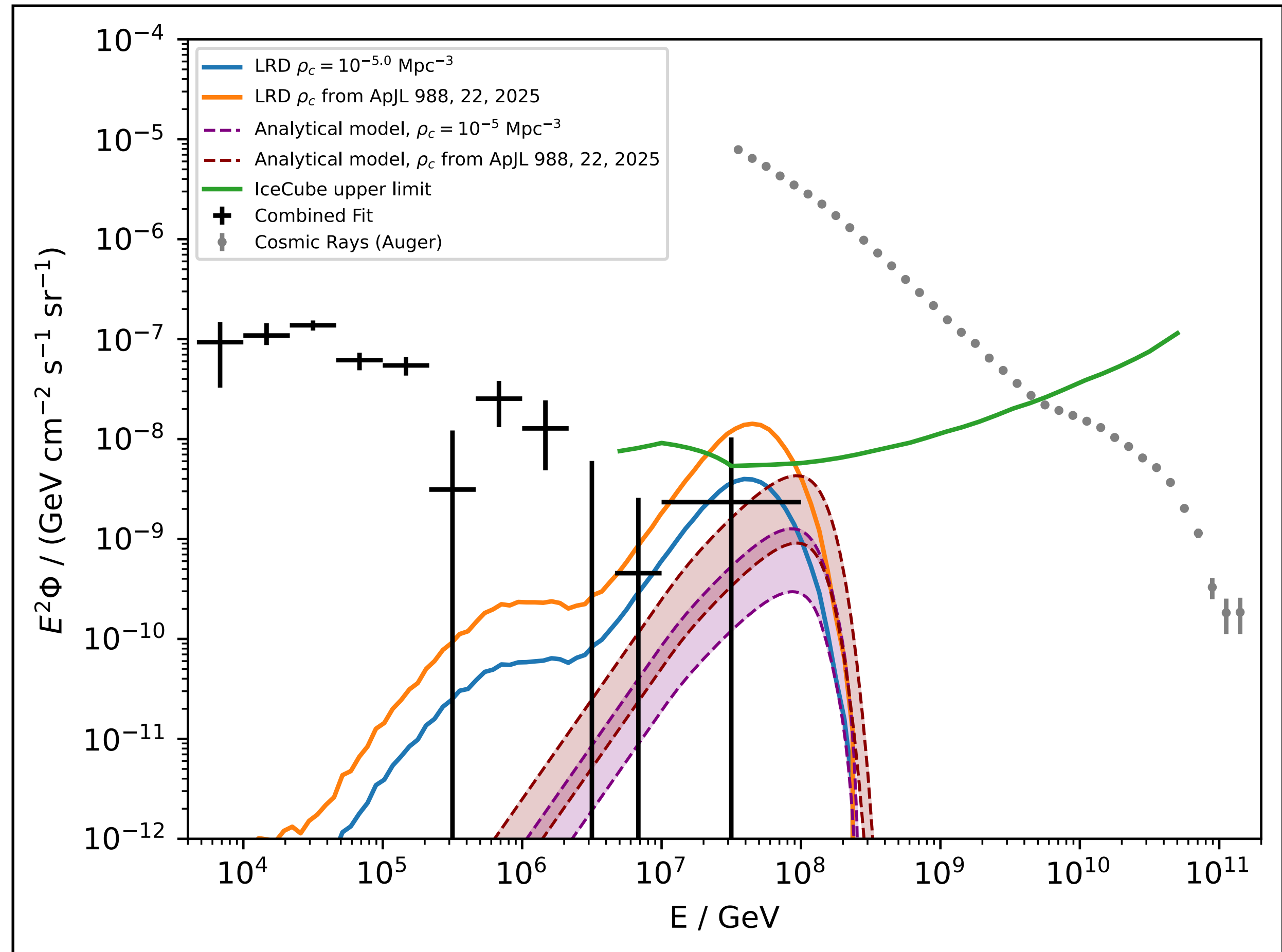


Gateway viewed from the Node

Candidate Sources in the “Gap”



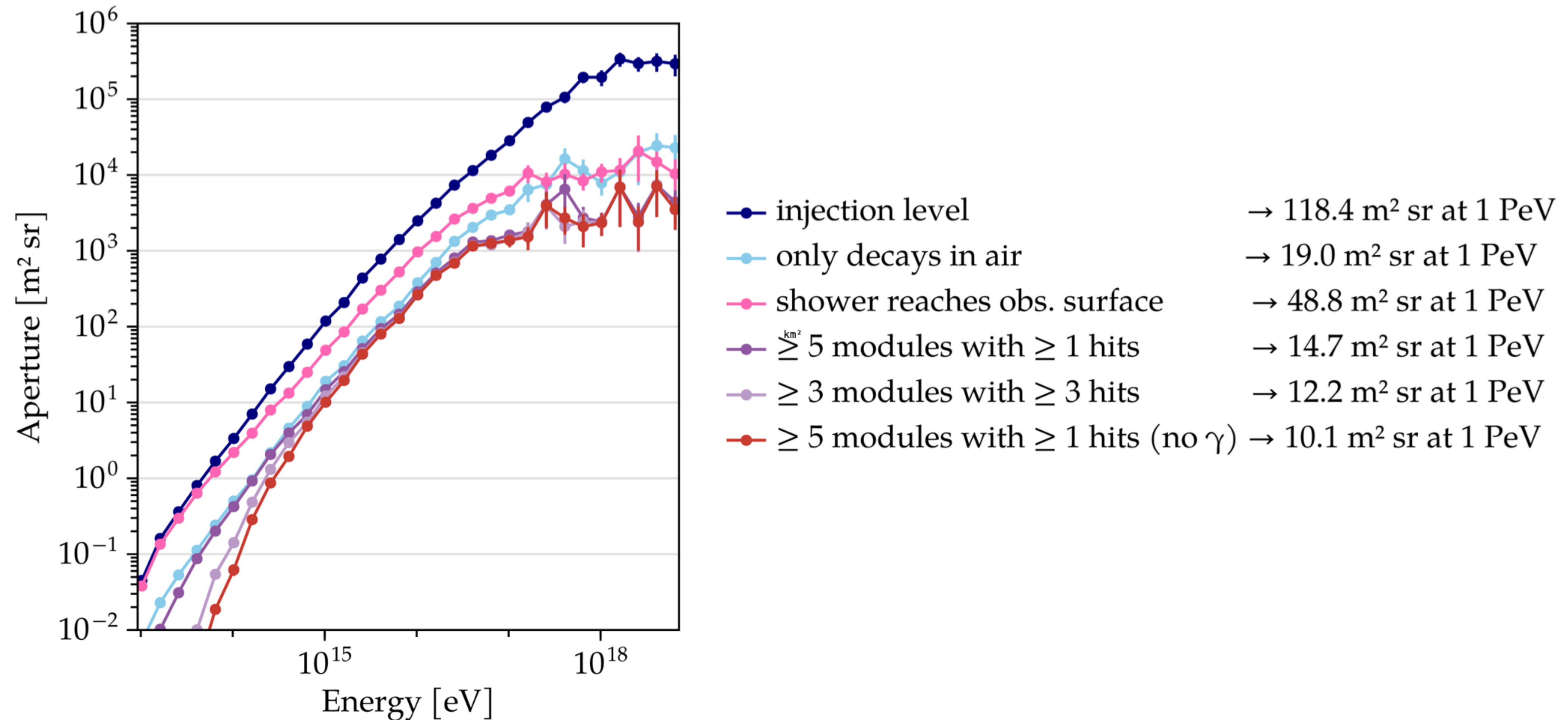
“Little red dots” discovered by JWST in 2024, $5 \lesssim z \lesssim 10$



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

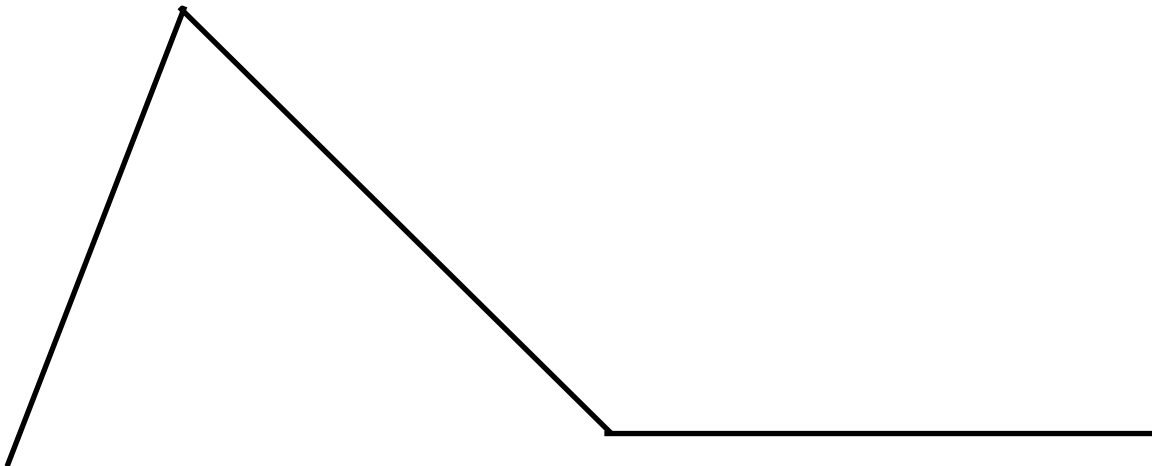
Trigger Studies

Valley of the Volcanoes: 2026 simulation results
(4m² panels, 900 modules / 13km² area — not rescaled)



TAMBO Potential Locations

Canyon	Depth (m)	Width (km)	Location and Notes
Yarlung Tsangpo Canyon	~6000	~5–10	Tibet; extremely deep but very remote.
Cotahuasi Canyon	3535	~3	Peru; deep and accessible.
Colca Canyon	3270	~4–5	Peru; deep and accessible.
Kali Gandaki Gorge	~2500	~5	Nepal; very deep but narrow and remote.
Hells Canyon	~2440	~16	USA (Oregon–Idaho); deepest river gorge in North America with steep walls.
Grand Canyon	~1800	~16	USA (Arizona); massive volume and excellent infrastructure.
Tara River Canyon	~1300	~3	Montenegro/Bosnia; Europe’s deepest.



Location will determine sky coverage, detection efficiency, and background rejection

In what follows I will show results for the Colca Valley Location

The final location of TAMBO is still under consideration and will be decided based on a combination of scientific, logistical, and societal considerations

Humanities can help make physics greener, J de Swart, AC Thresher, CA Argüelles, *Nature Reviews Physics* 6 (7), 404-405

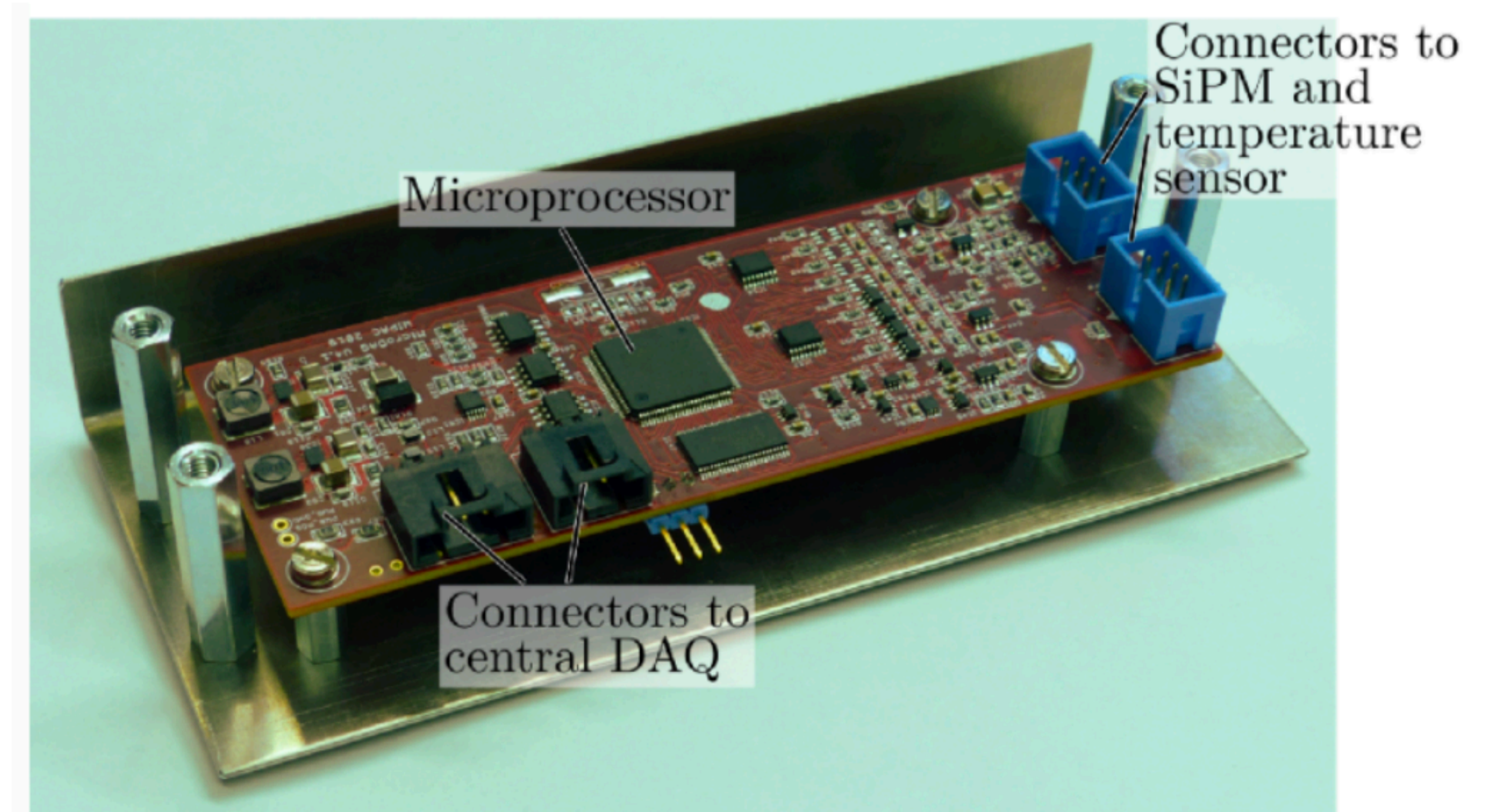
TAMBO Collabotio**n**, arXiv:2507.08070

Carlos A. Argüelles — TeVPa, 2026



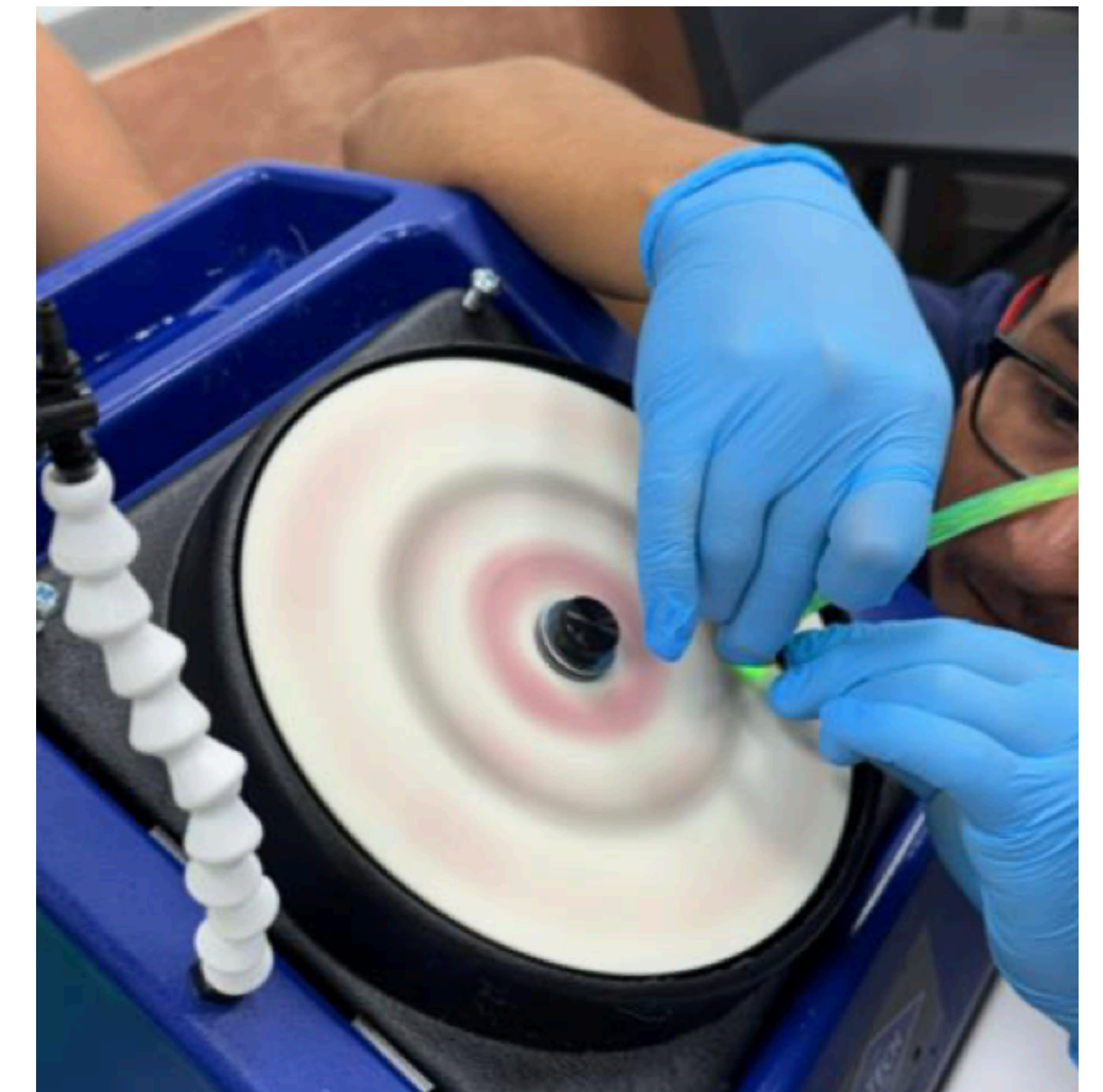
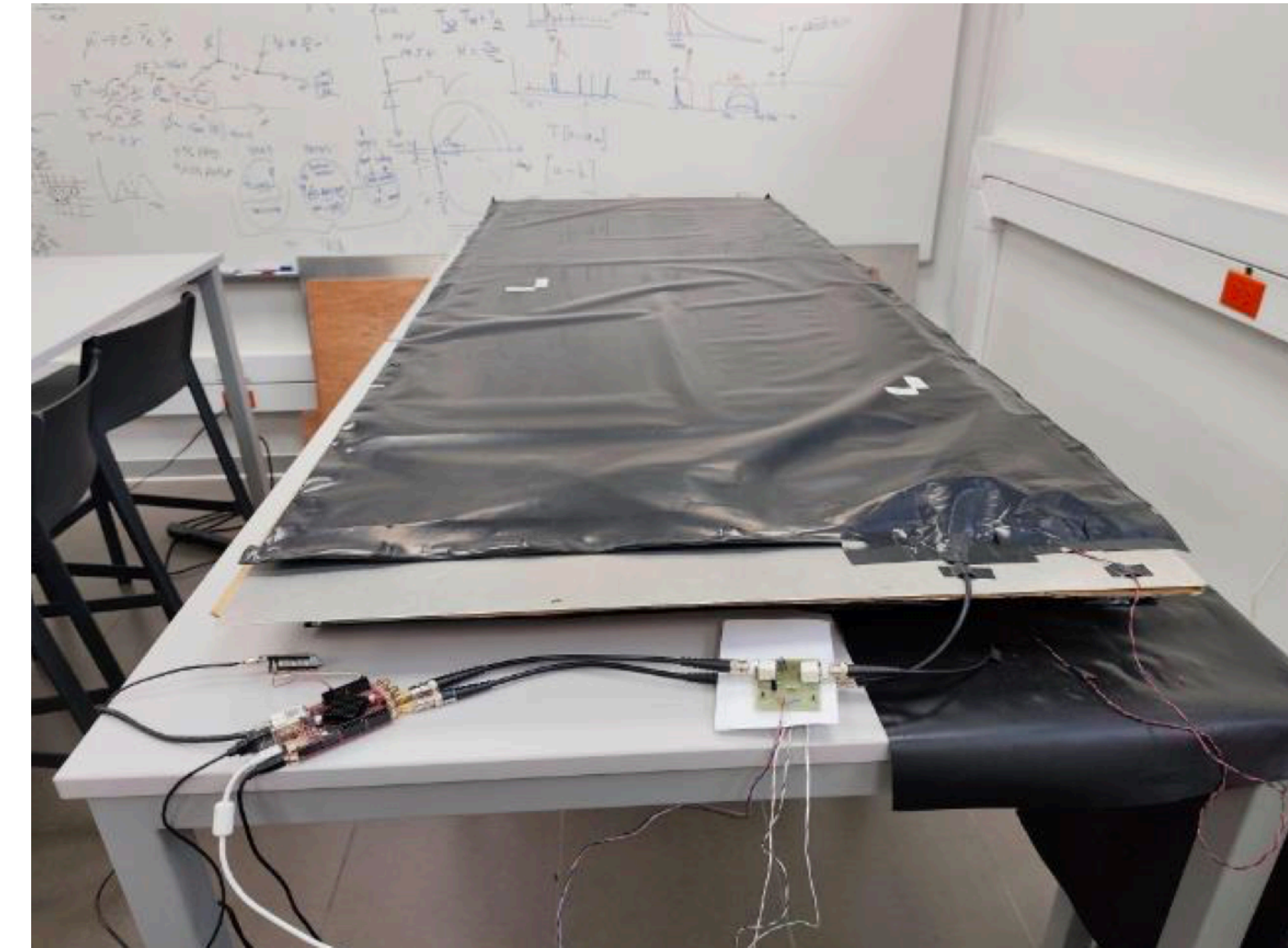
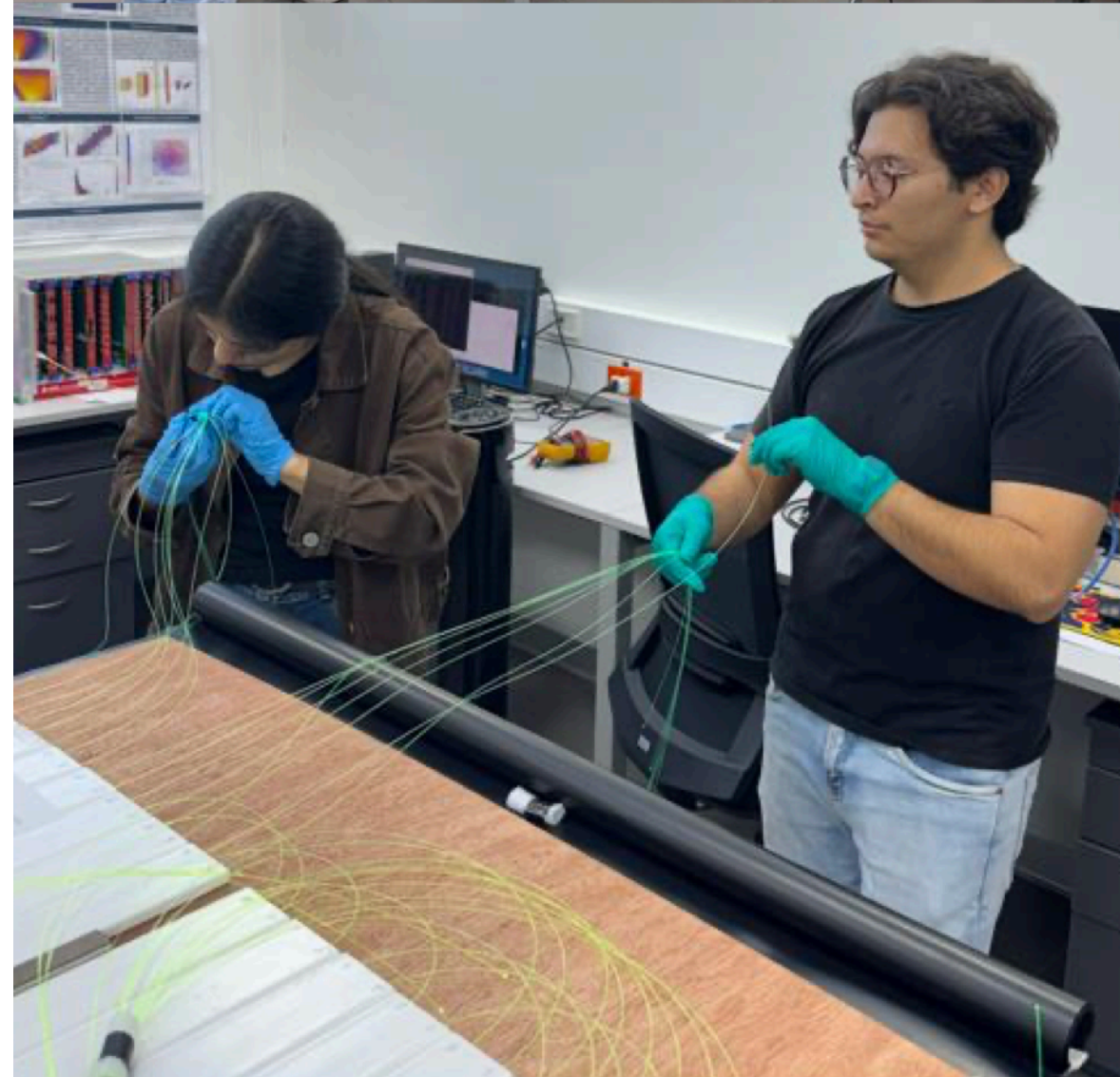
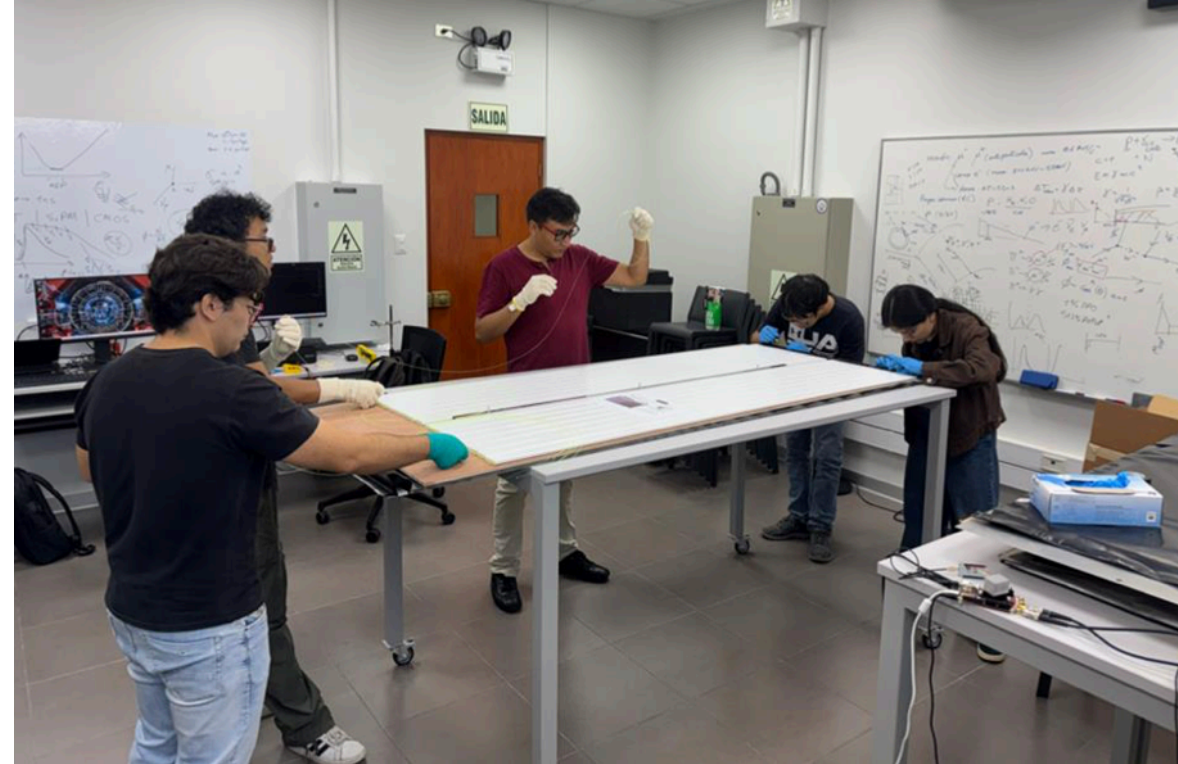
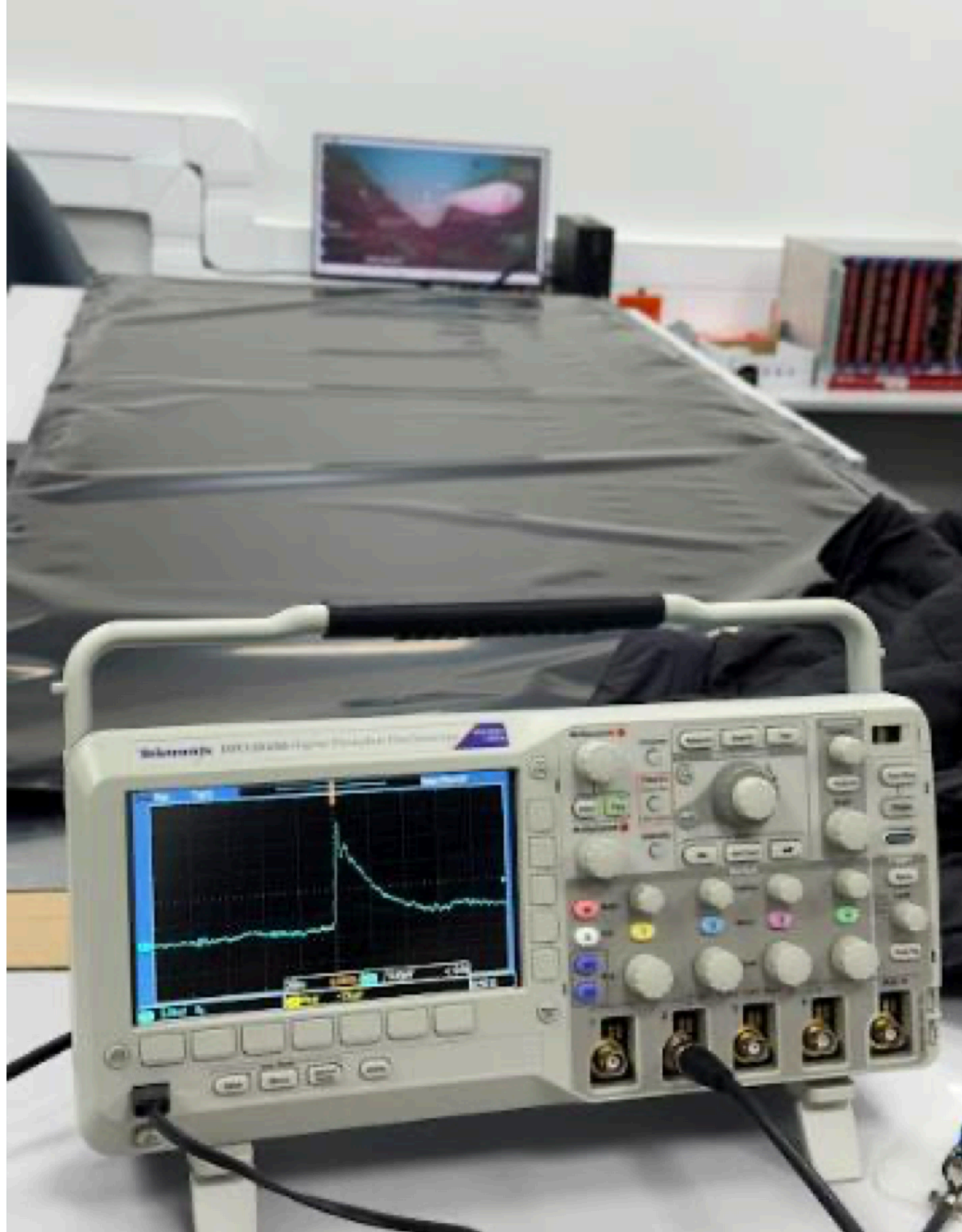
microDAQ Details

- 3 amplification channels with 12-bit amplitude & ~ 1 ns timing precision
- Also supports time-over-threshold measurement
- Supports real-time SiPM gain stabilization based on temperature sensor
- Two data-taking modes:
 - Histogram mode for calibration
 - HitBuffer mode for standard operation

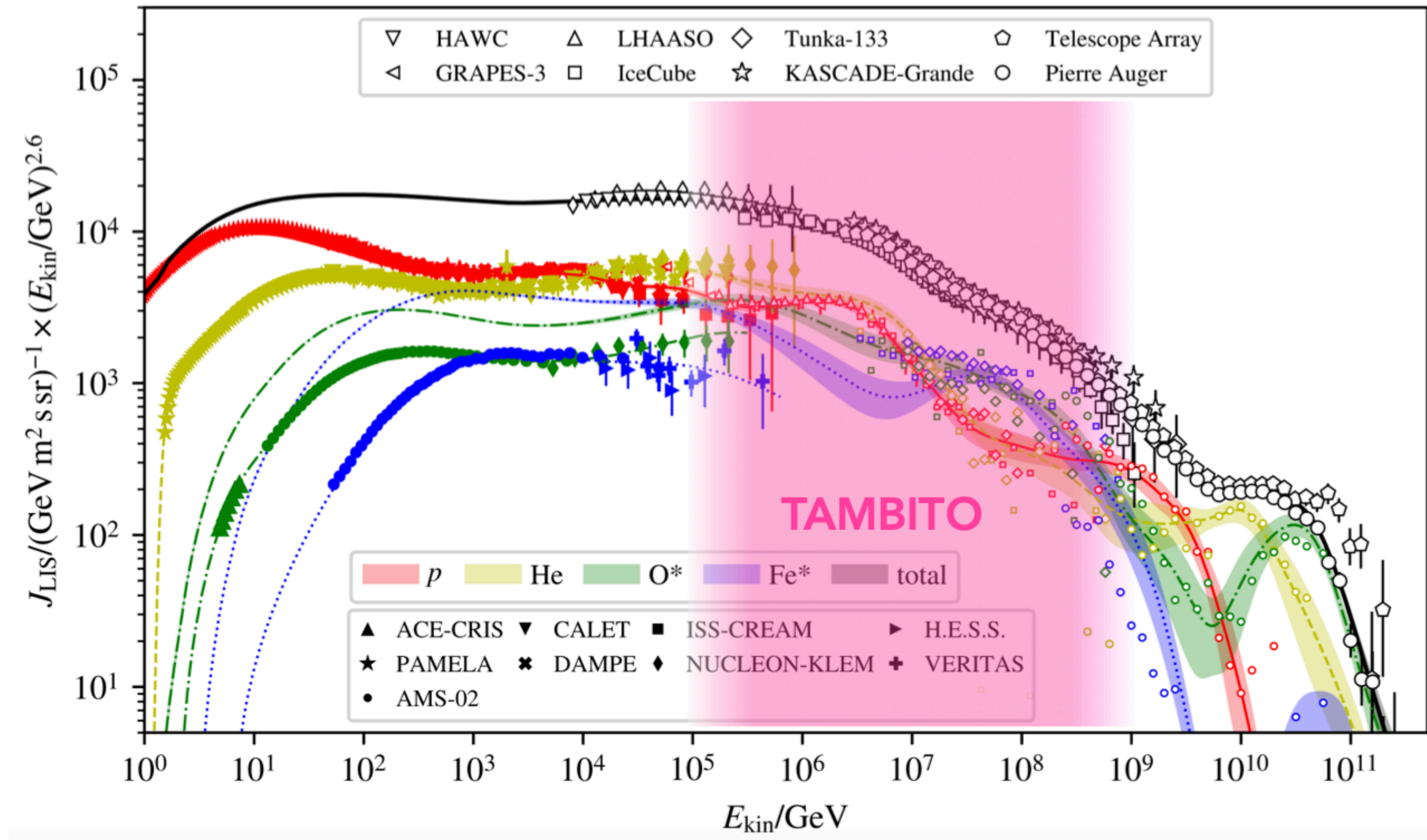


Panel Construction at PUCP

TAMBO-4 Panel Construction On-going at PUCP



Cosmic ray energy range for TAMBITO/TAMBO



[Dembinski et al, PoS(ICRC2025)248]

What about the detector technology?

Two main detector classes used to detect air showers:

Water tanks:

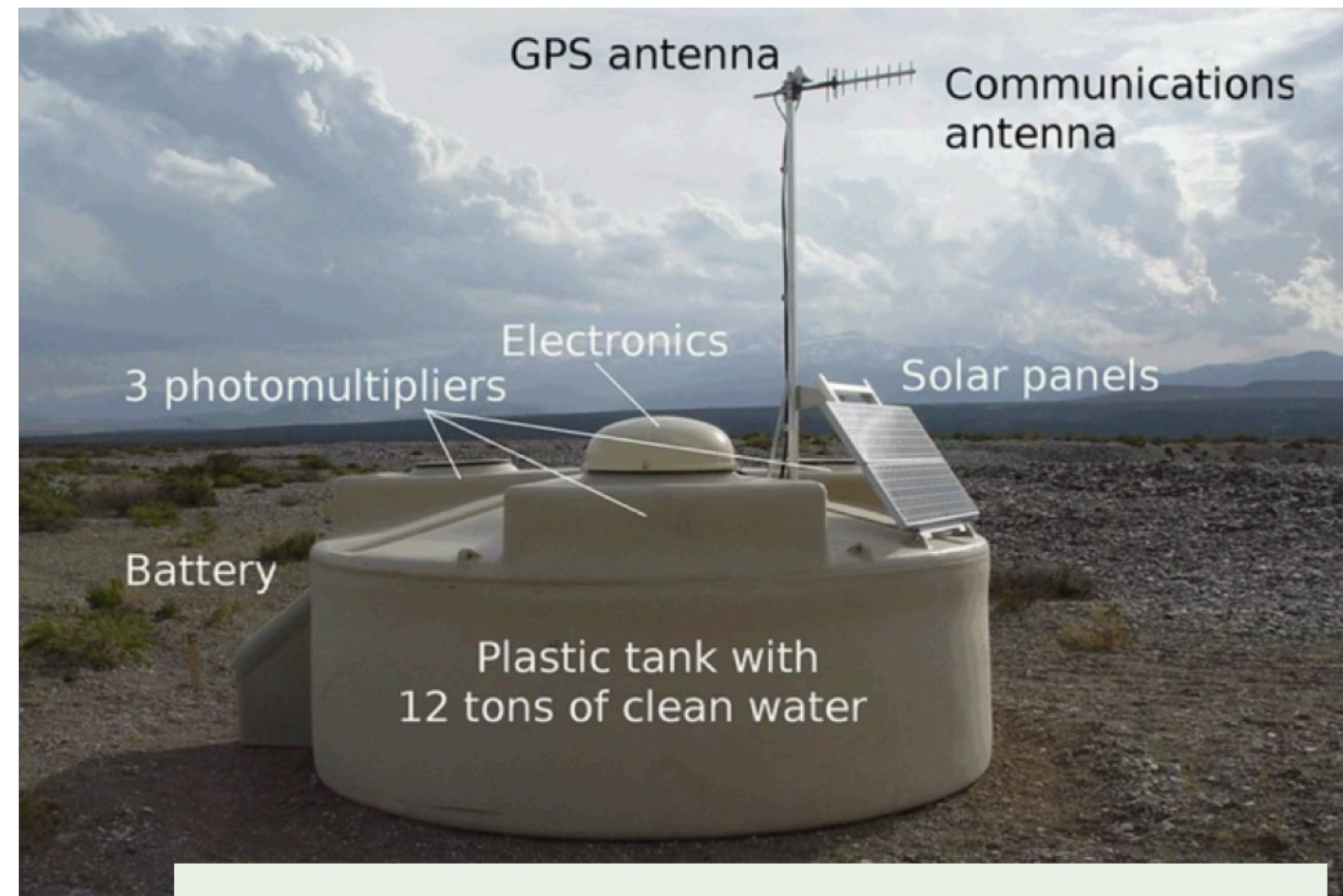


Photo from Pierre Auger Collaboration

Plastic scintillator panels:

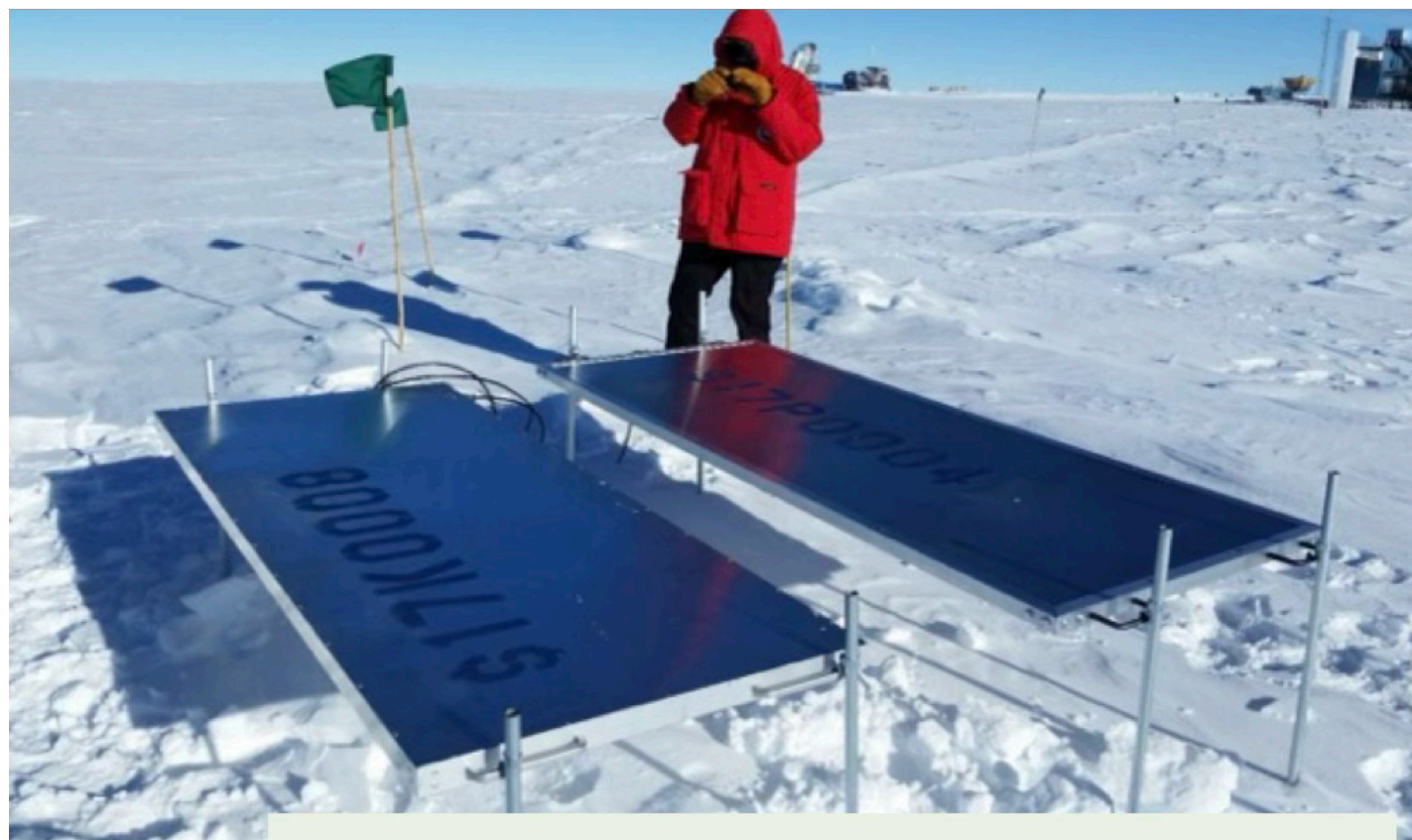
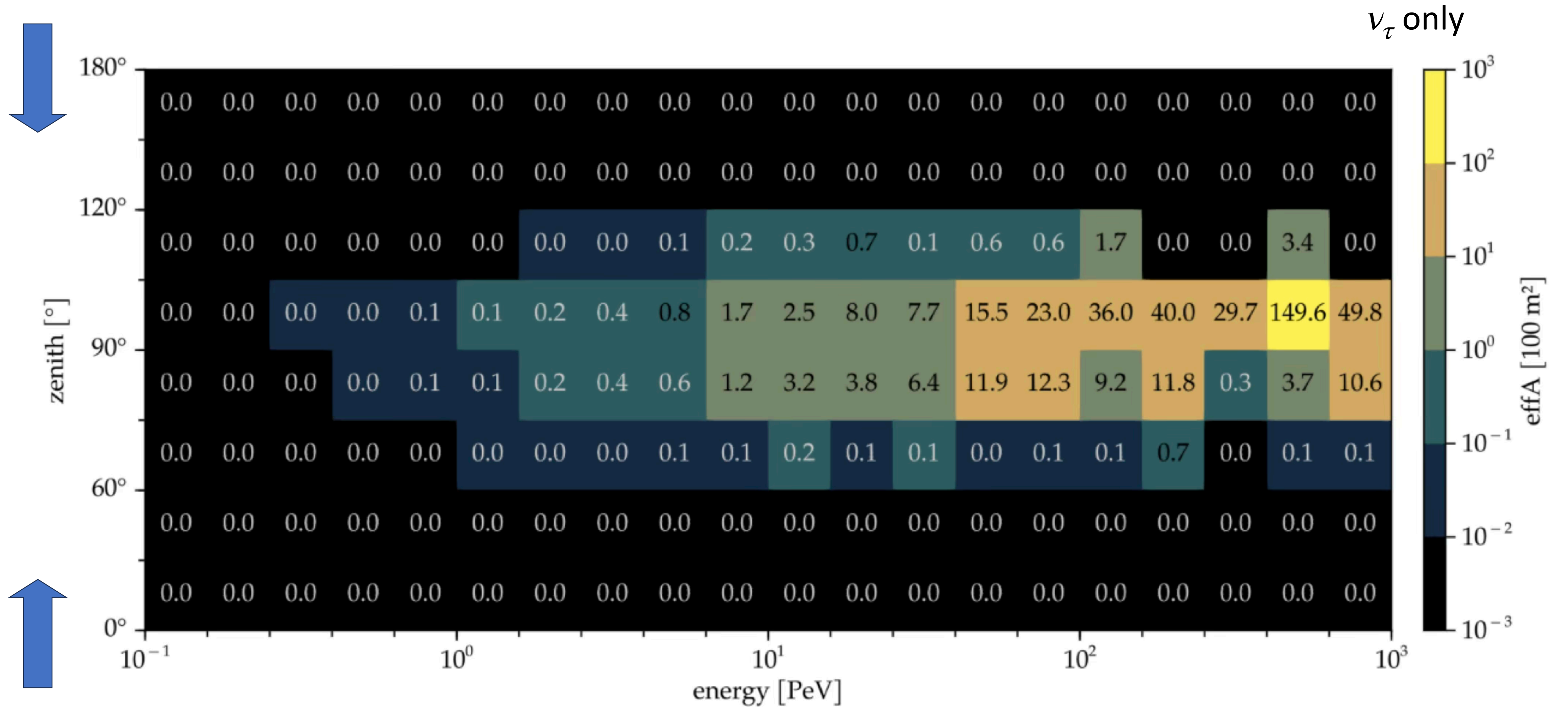
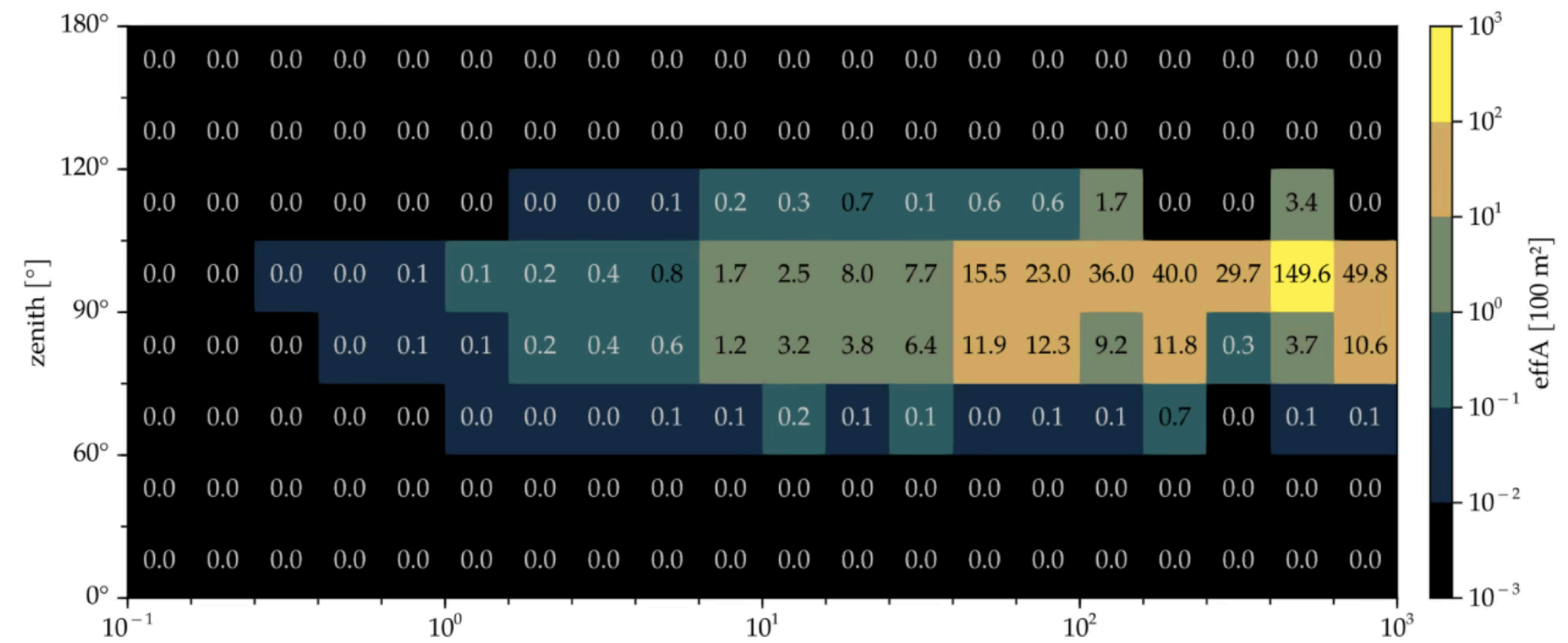


Photo from IceCube Collaboration

- Highly sensitive to gammas (most abundant particle)
 - Expensive to purify and transport water
 - Difficult to deploy in canyon
-
- Sensitive mostly to charged particles
 - Can be built off-site and transported
 - Easier to deploy in canyon

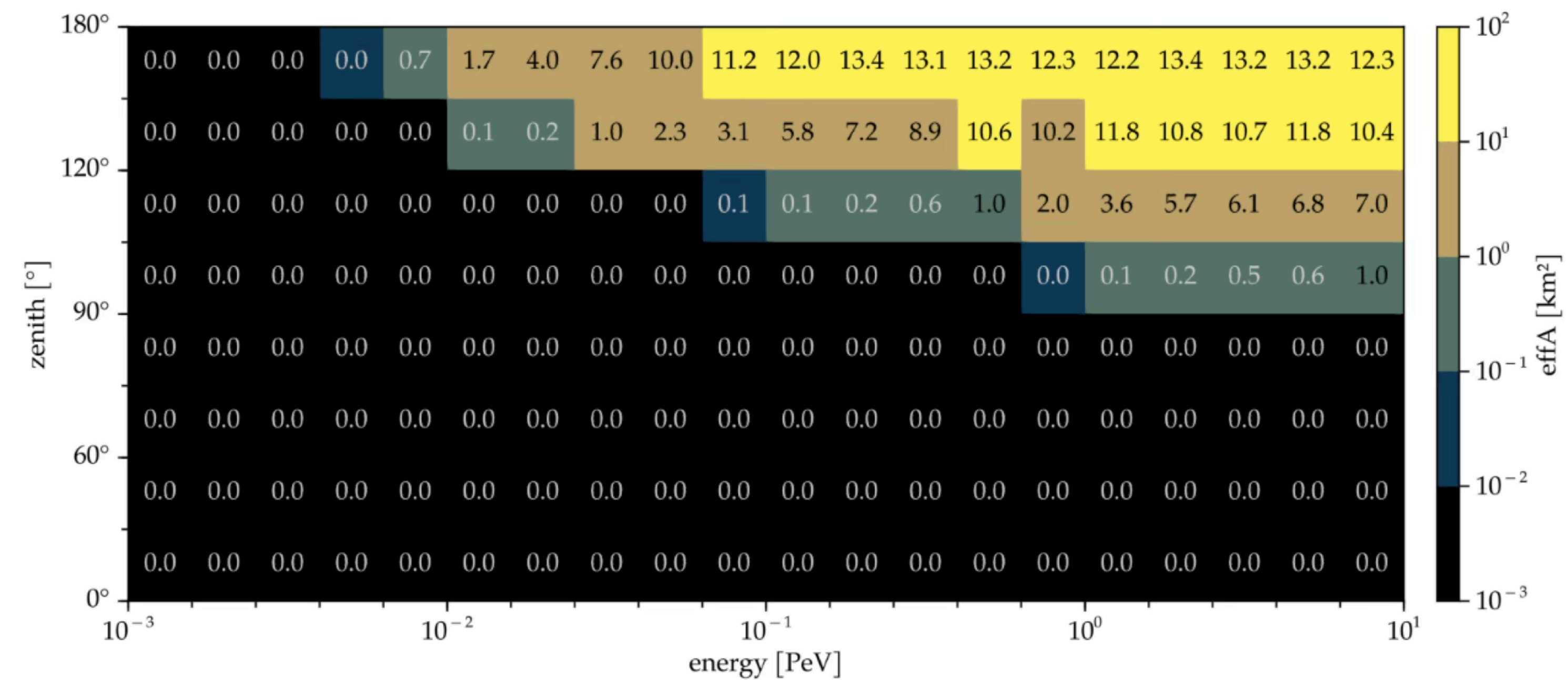
Tau neutrino detection rate



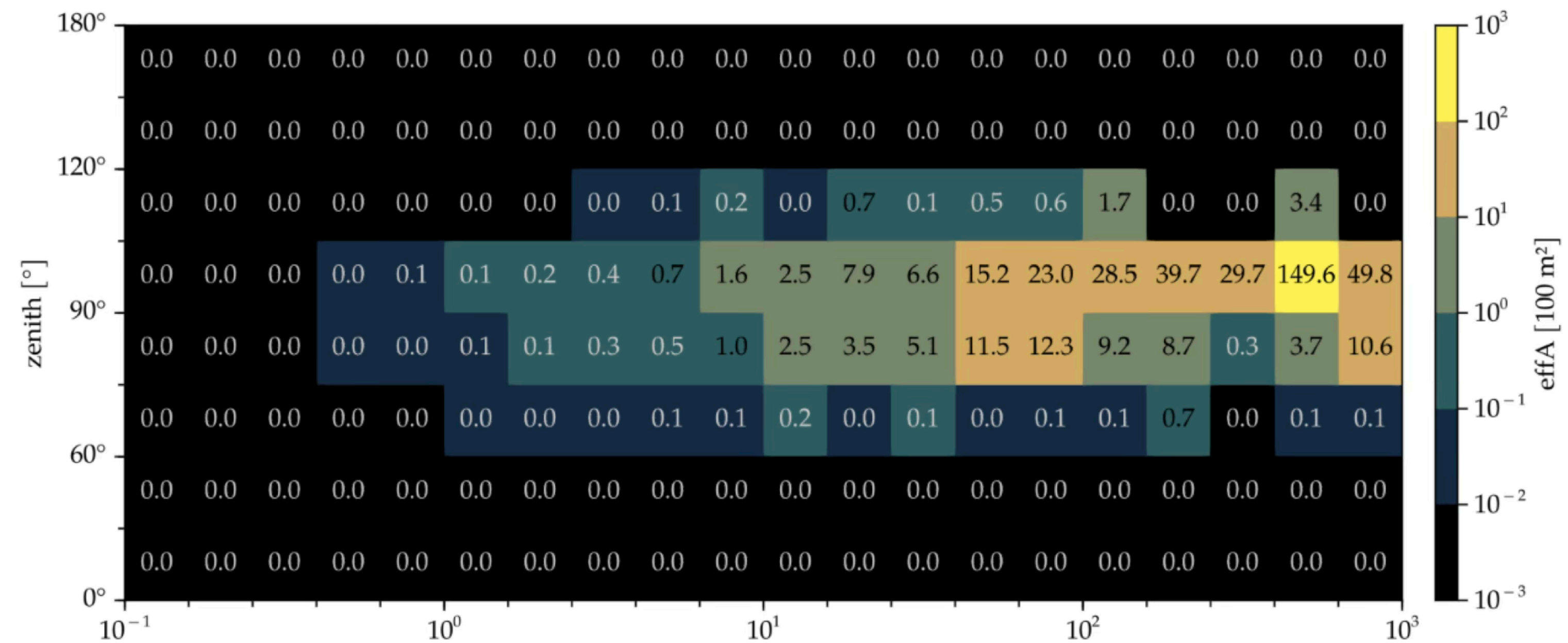


Neutrino rate:
O(1)/ yr

Filter condition:
Water tank-like

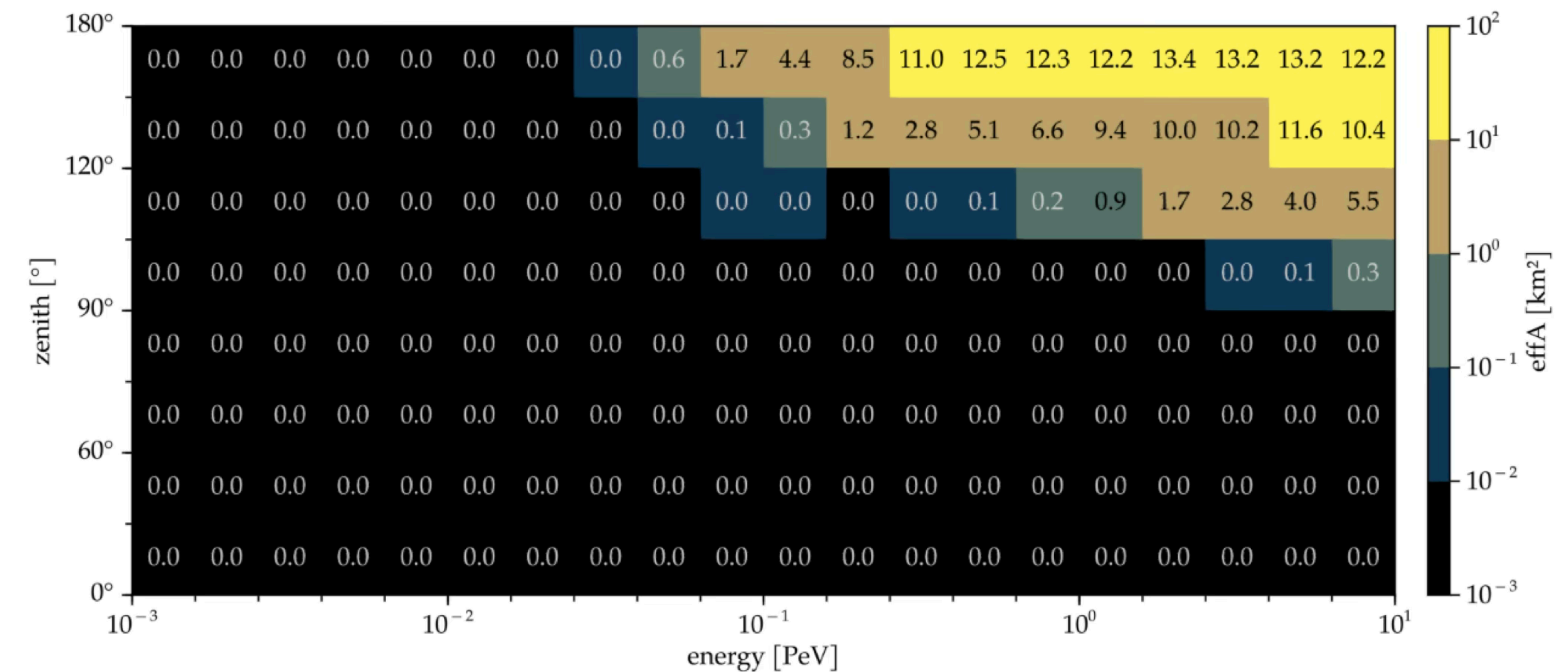


Cosmic ray rate:
30 kHz

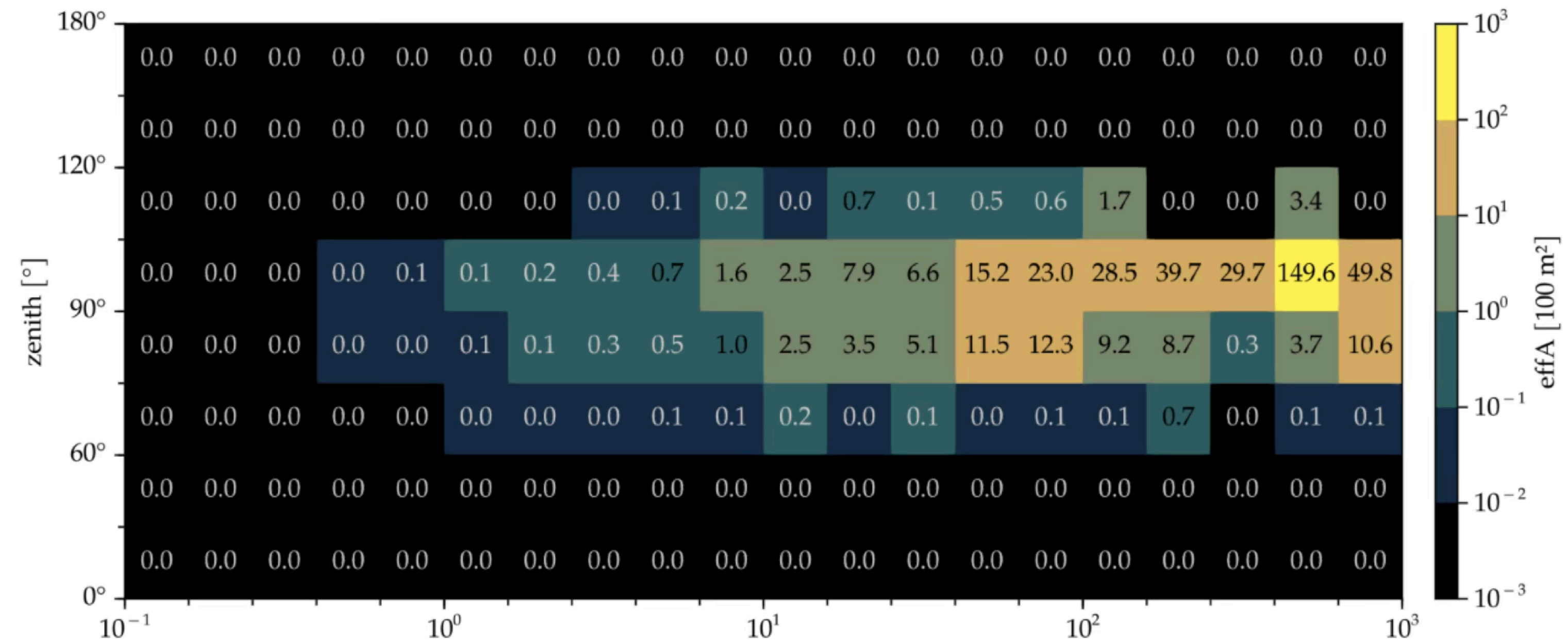


Neutrino rate:
O(1)/ yr

Filter condition:
Scintillator-like

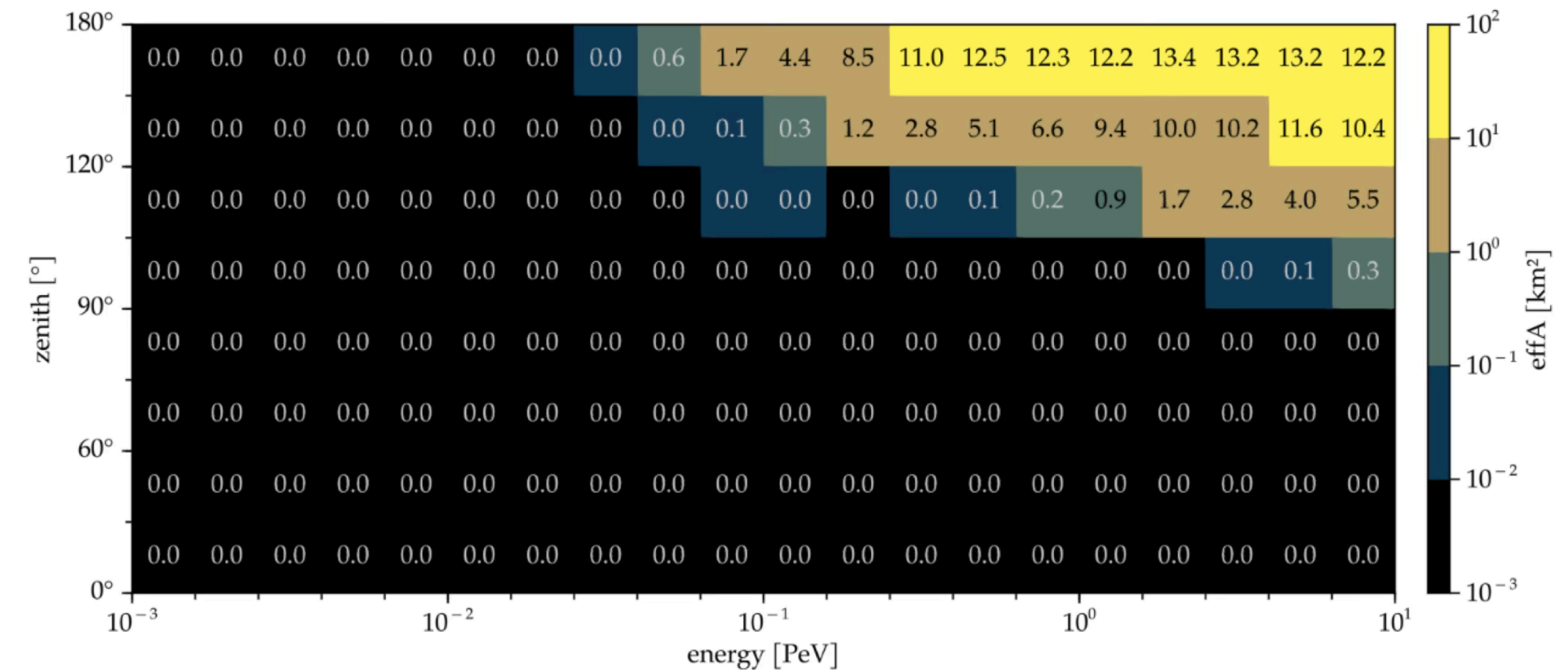


Cosmic ray rate:
1.35 kHz



Neutrino rate:
O(1)/ yr

Filter condition:
Scintillator-like



Cosmic ray rate:
1.35 kHz

Water tanks vs scintillators:
Big impact on CRs, not so
much for neutrinos