TAMBO: A Deep-Valley Neutrino Observatory

Will Thompson

TAMBO 101

October 20th, 2025

Why neutrino astronomy?

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

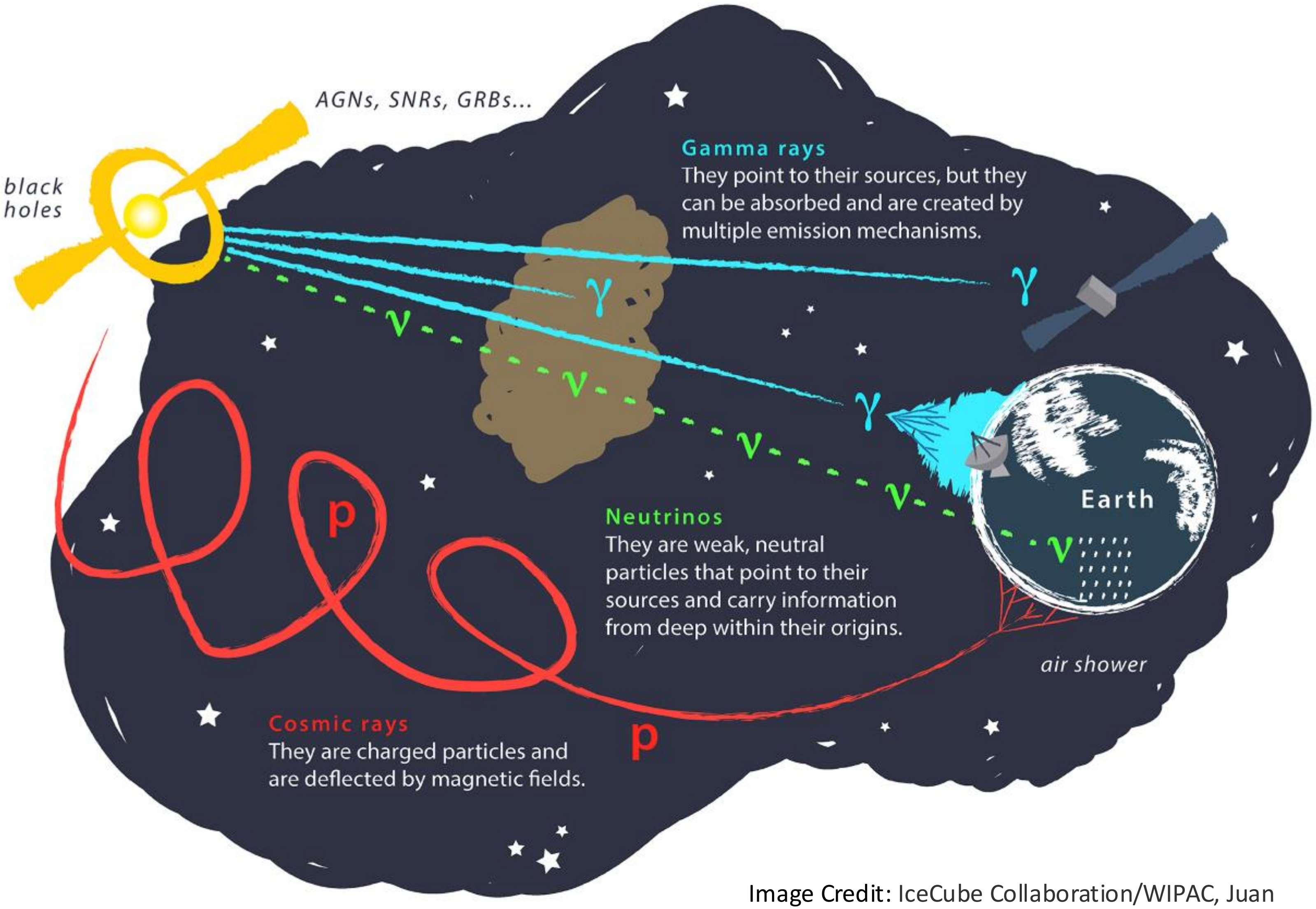
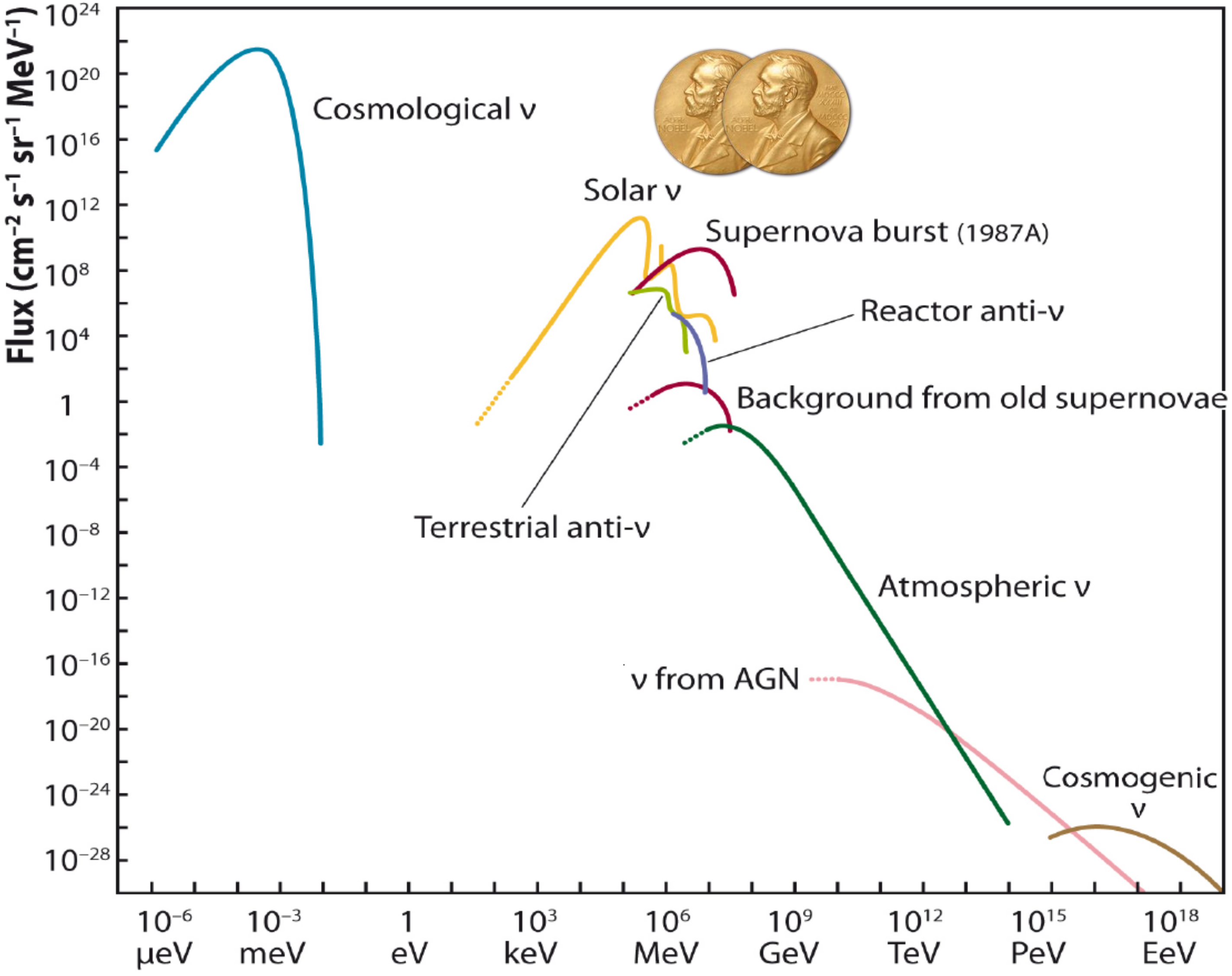


Image Credit: IceCube Collaboration/WIPAC, Juan Antonio Aguilar, and Jamie Yang.

The low flux also doesn't help…



30 orders of magnitude!

U.F. Katz & Ch. Spiering, Prog. Nucl. Part. Phys. **67** 651 (2012)

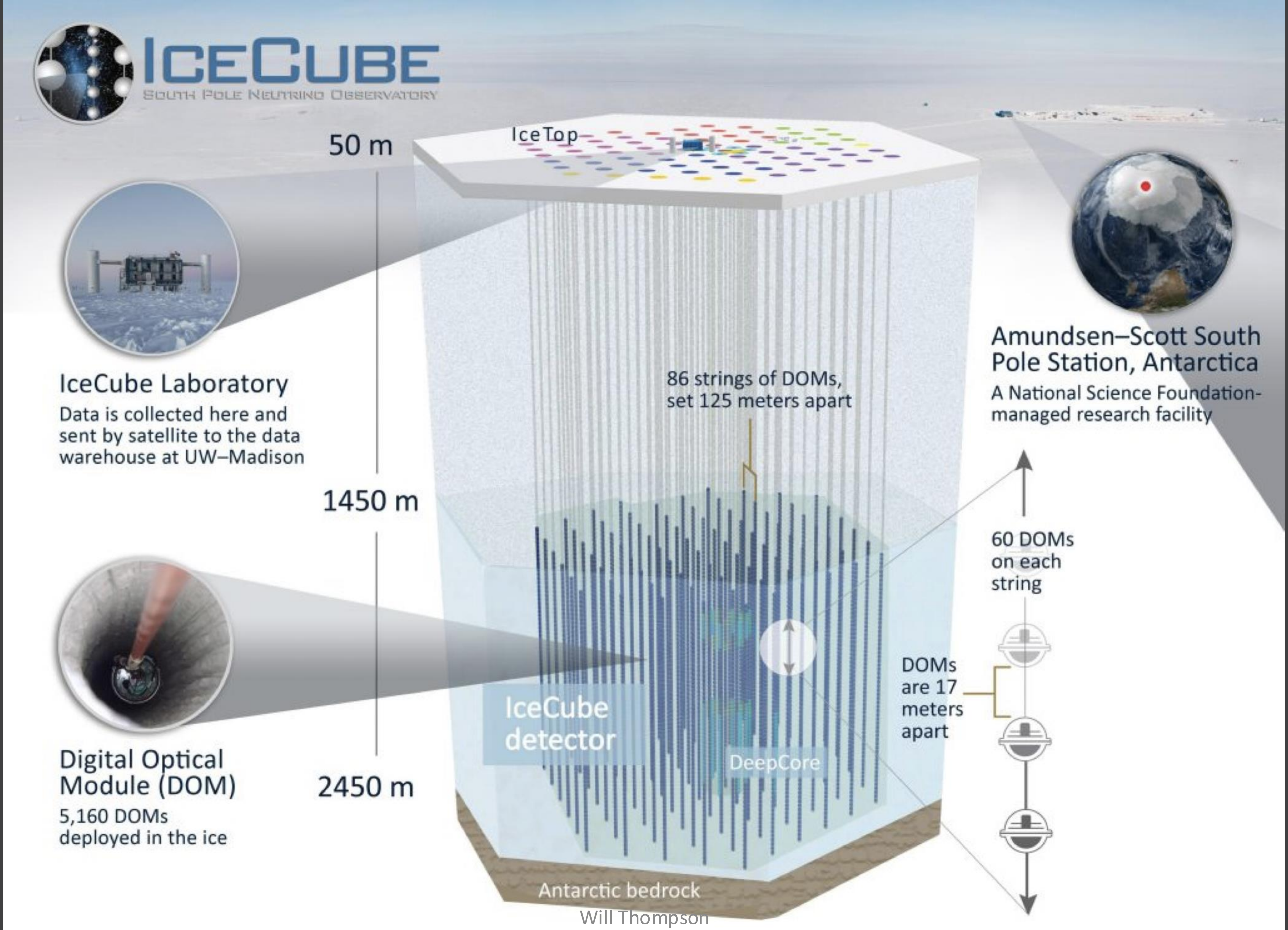
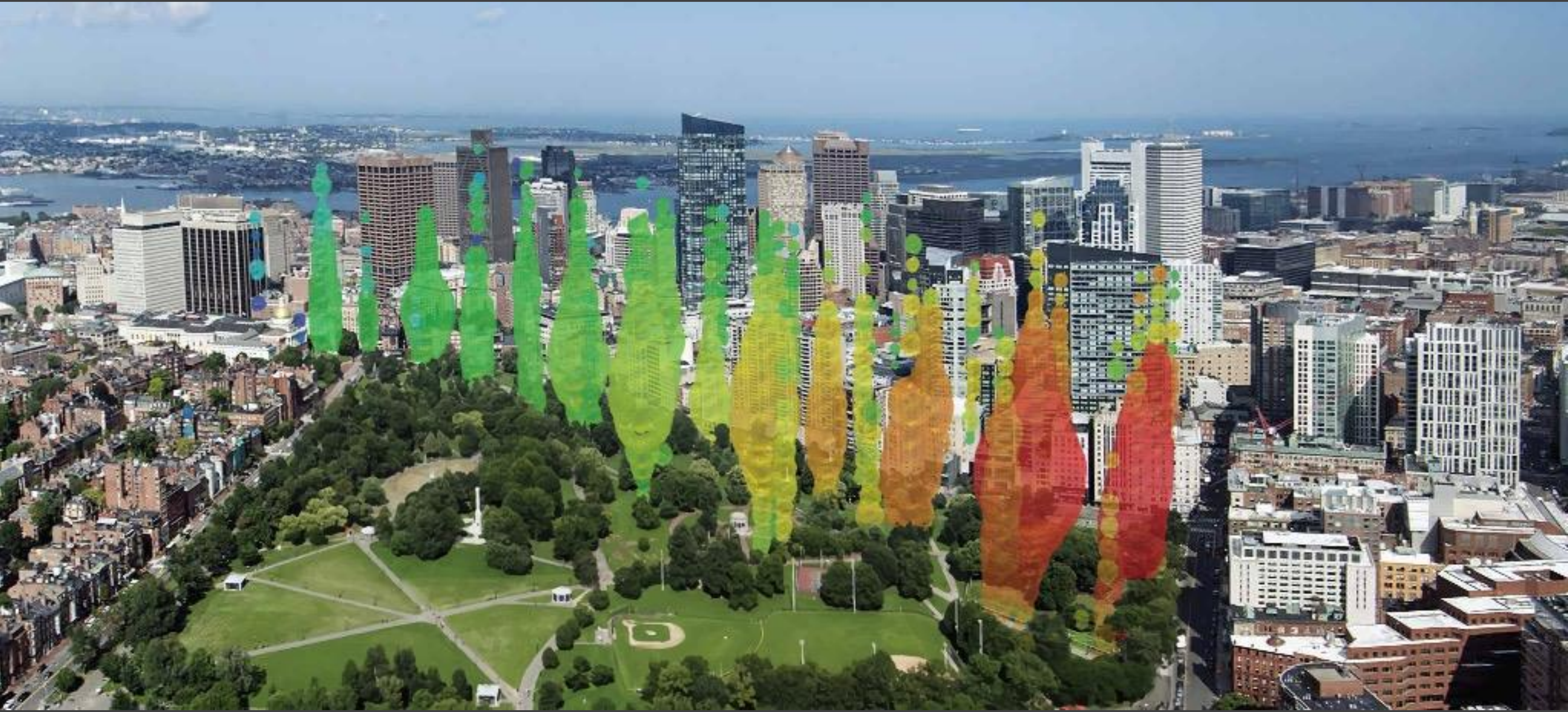
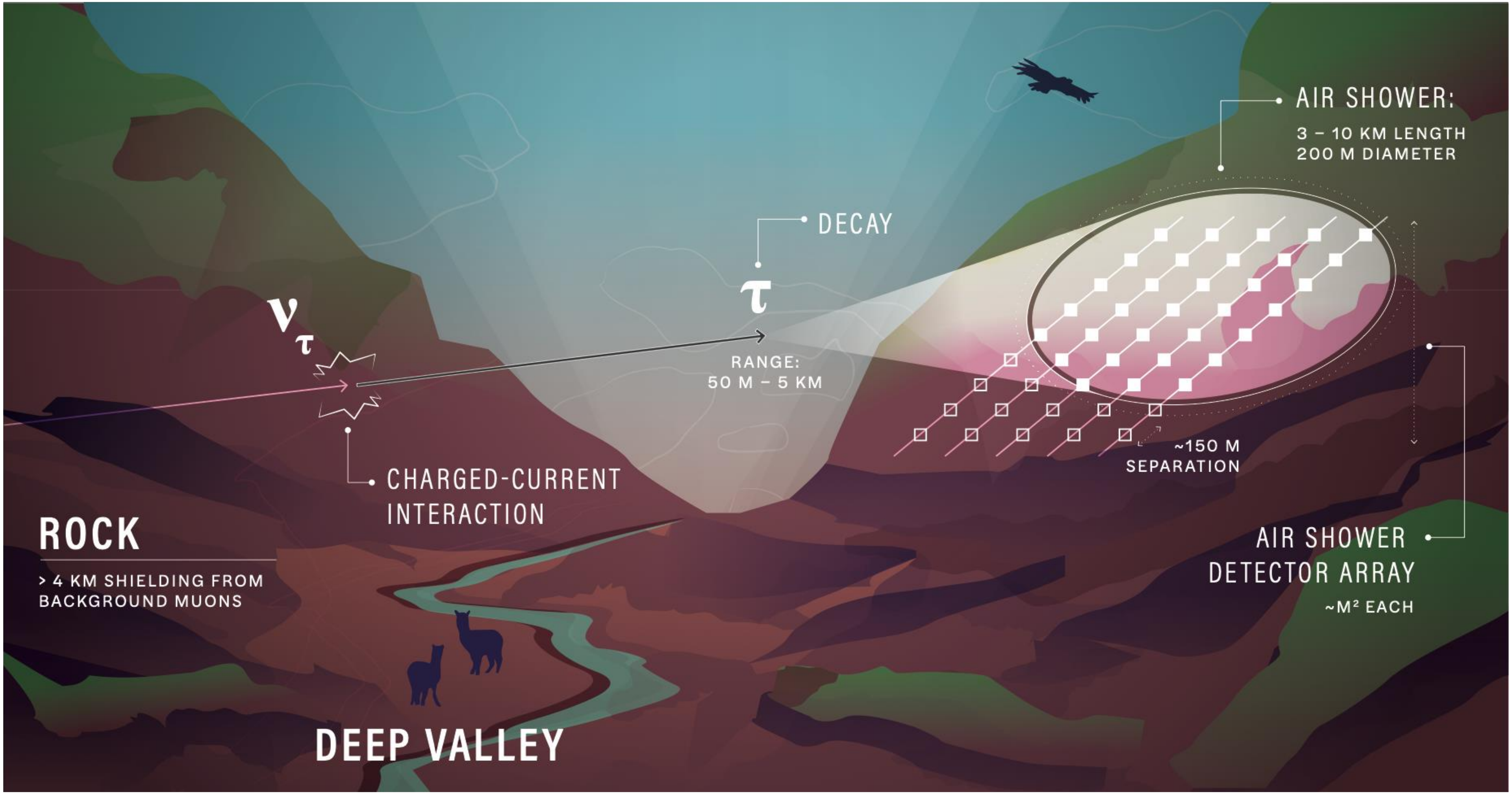
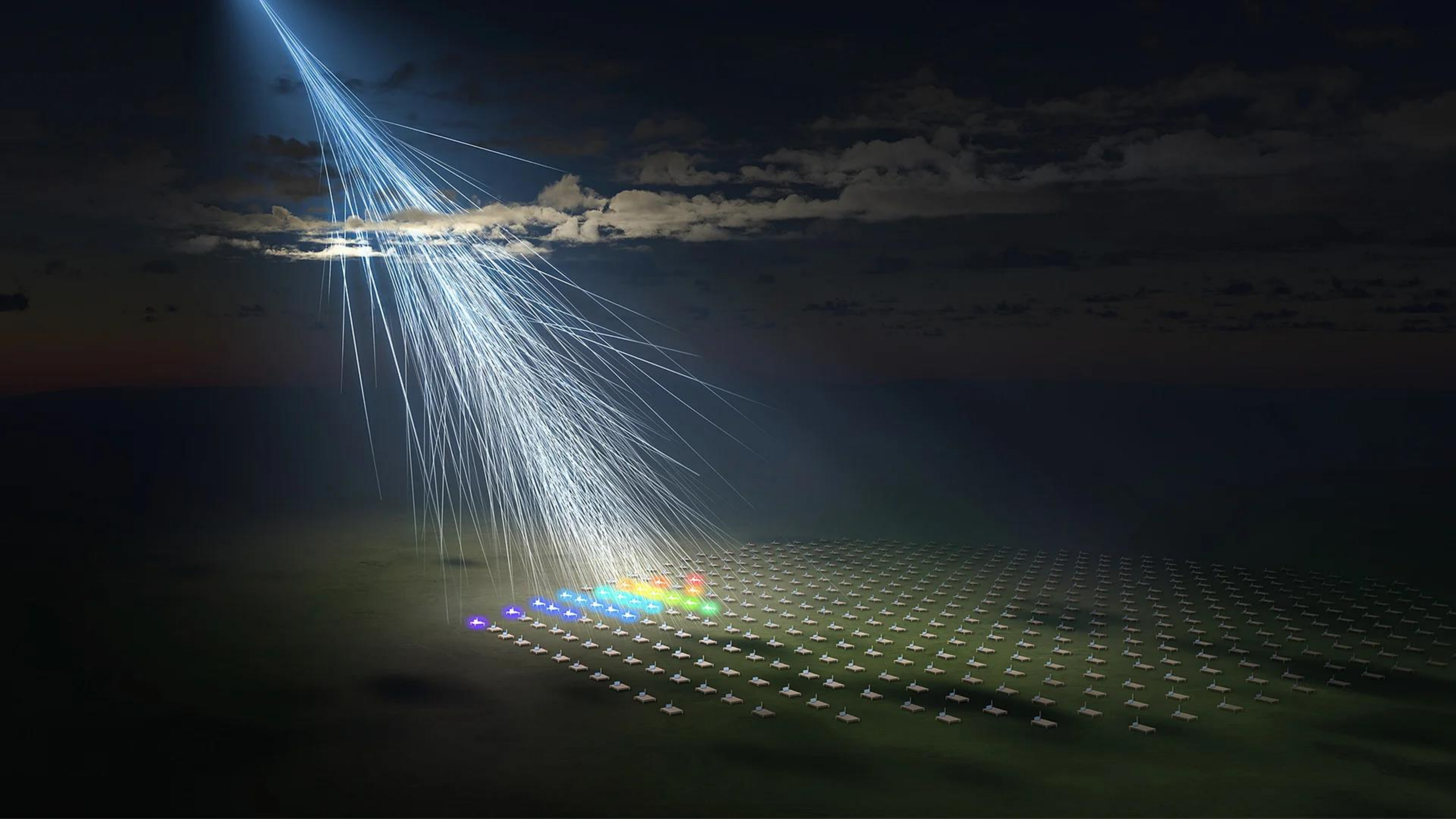


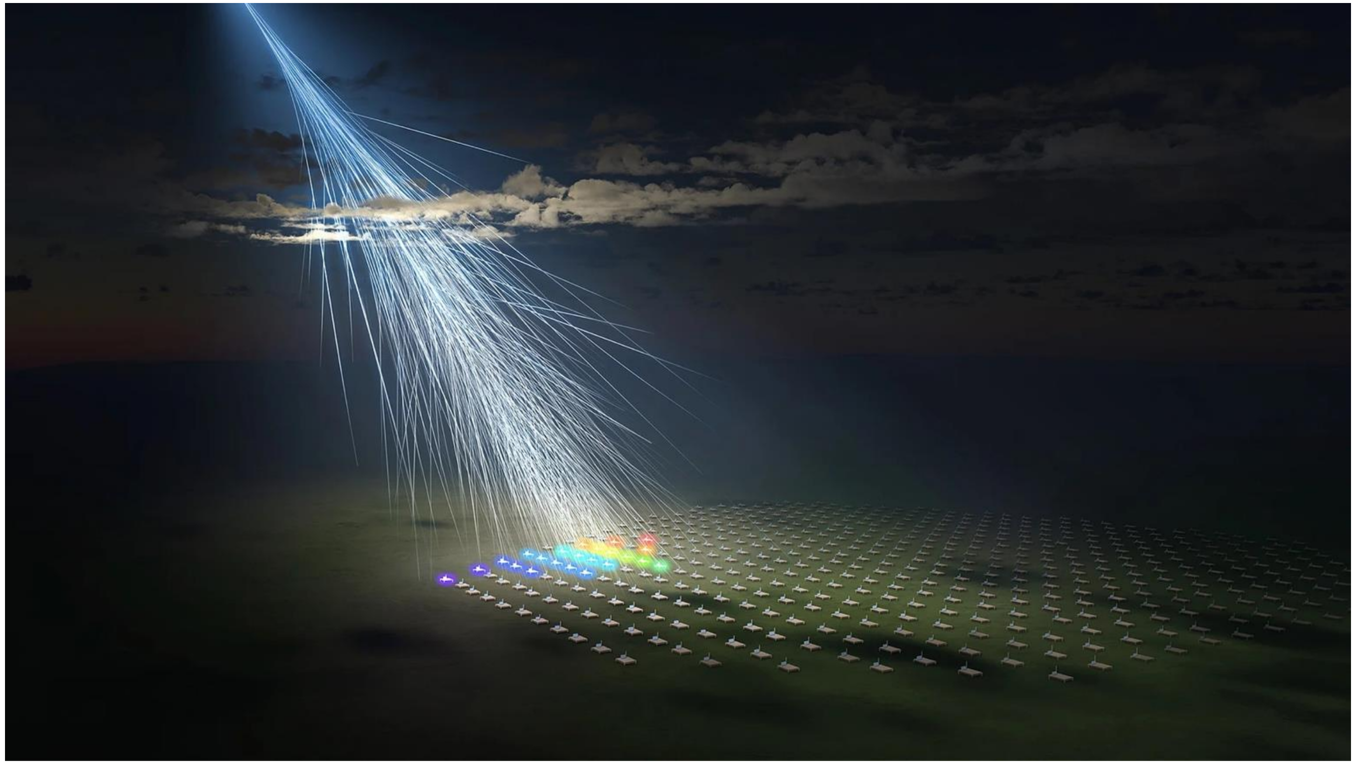
Image Credit: IceCube Collaboration/WIPAC

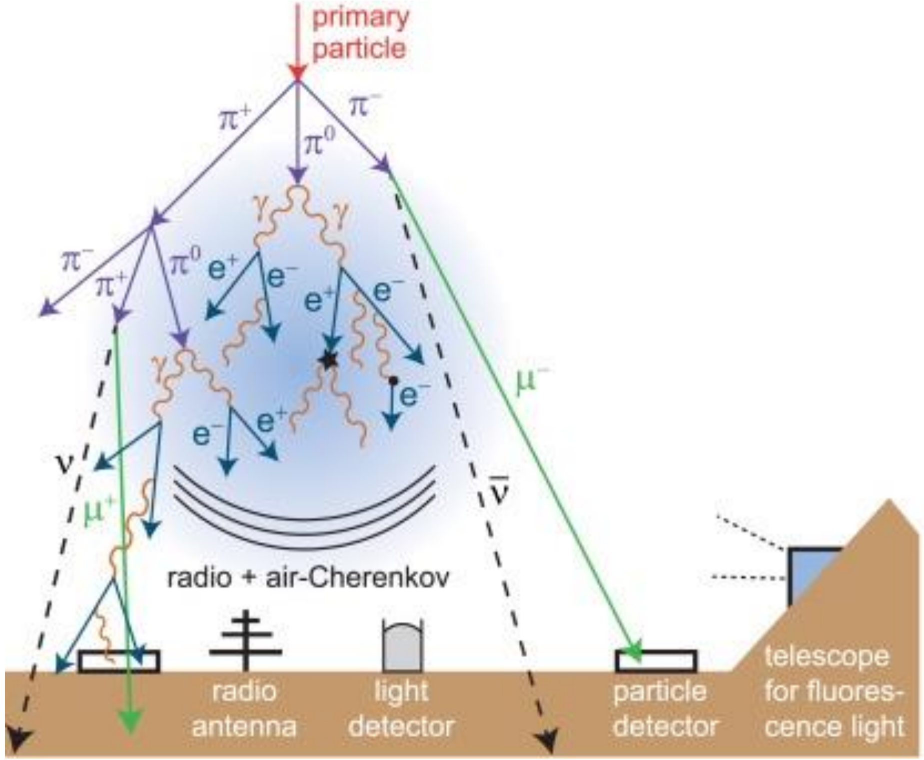



AIR SHOWER:
3 – 10 KM LENGTH
200 M DIAMETER
DECAY
τ
ν_τ
RANGE:
50 M – 5 KM
~150 M
SEPARATION
CHARGED-CURRENT
INTERACTION
ROCK
> 4 KM SHIELDING FROM
BACKGROUND MUONS
AIR SHOWER
DETECTOR ARRAY
~M² EACH
DEEP VALLEY



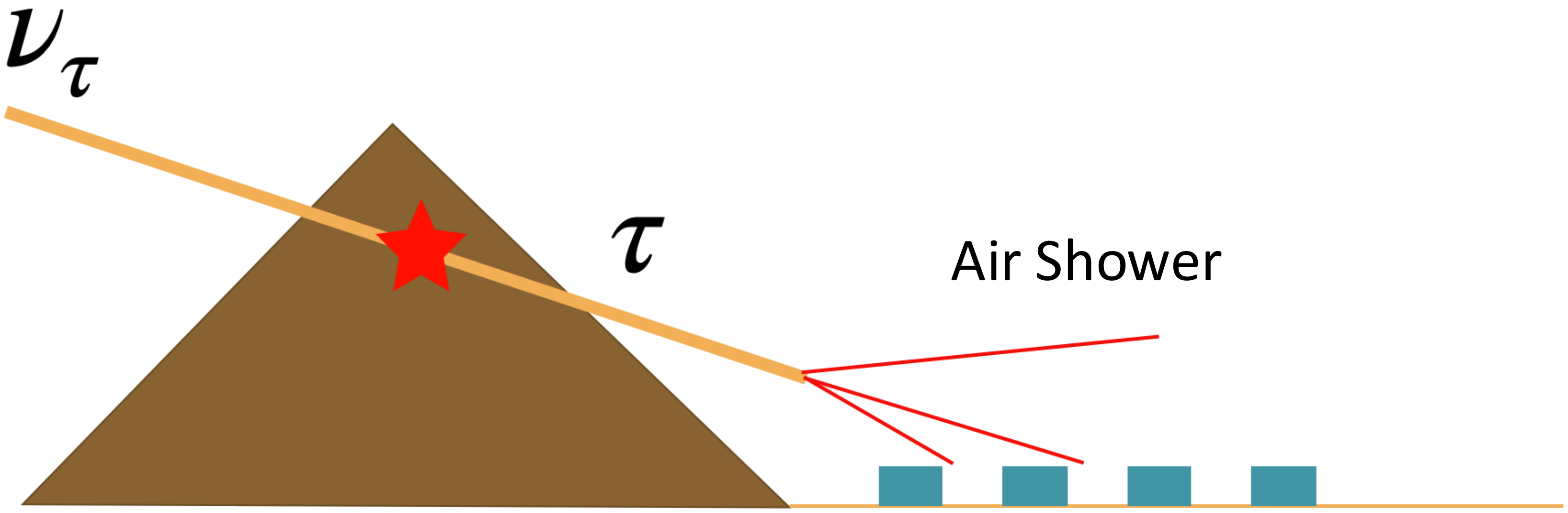
Air Shower Characteristics





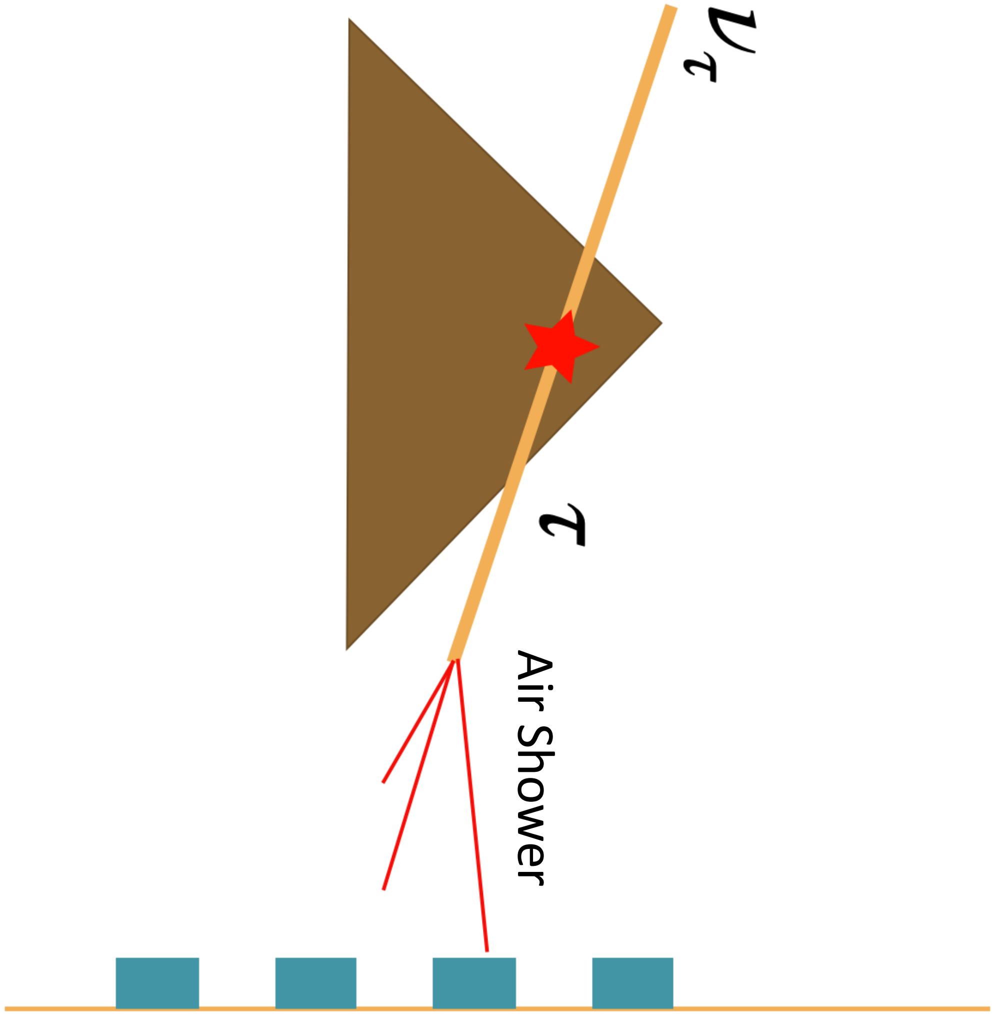
- Air showers have been used as particle physics laboratories for 100+ years
- Many techniques for detecting these showers are well-established

Why Put a Neutrino Telescope in a Canyon?



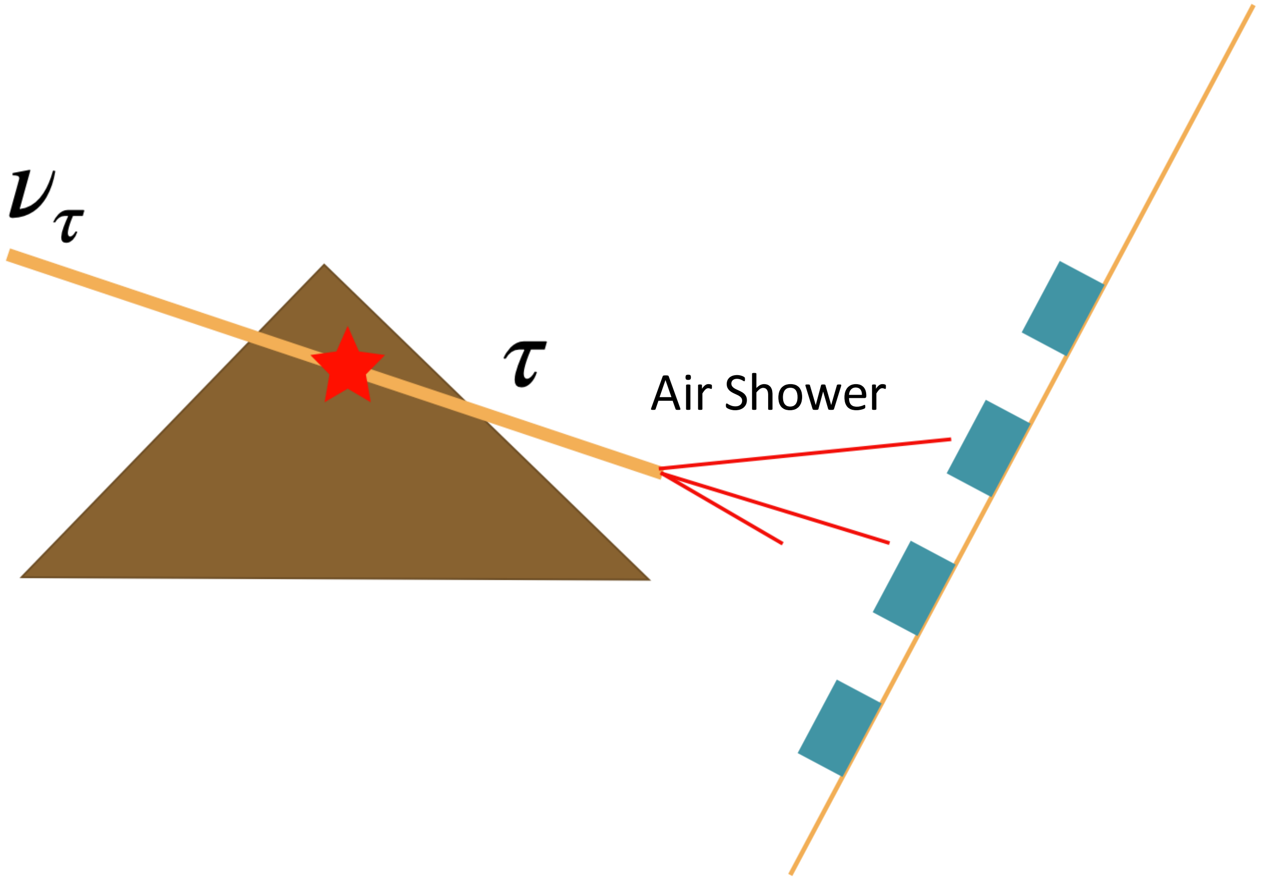
Inherently low geometrical acceptance

Why Put a Neutrino Telescope in a Canyon?



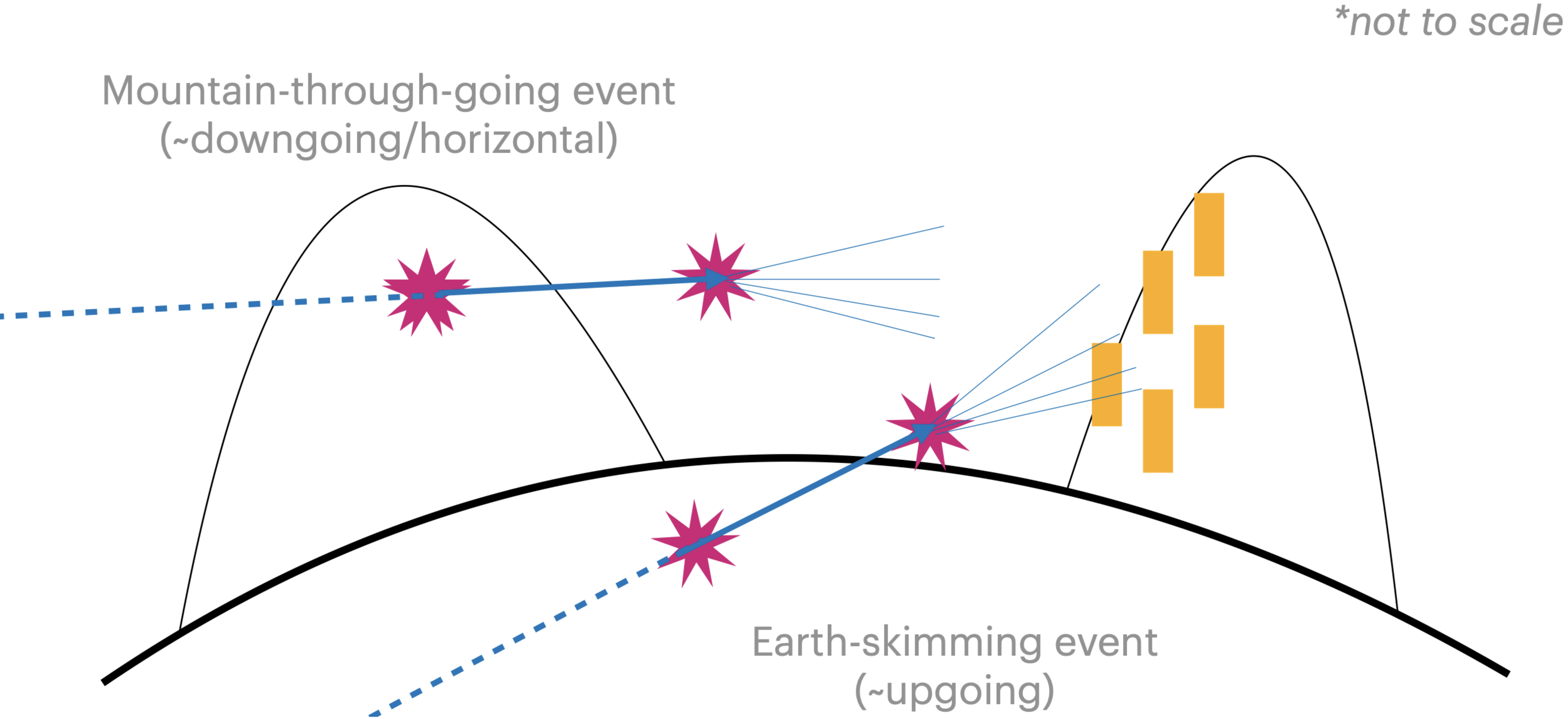
Better for physics, but the engineers didn't seem to like it

Why Put a Neutrino Telescope in a Canyon?

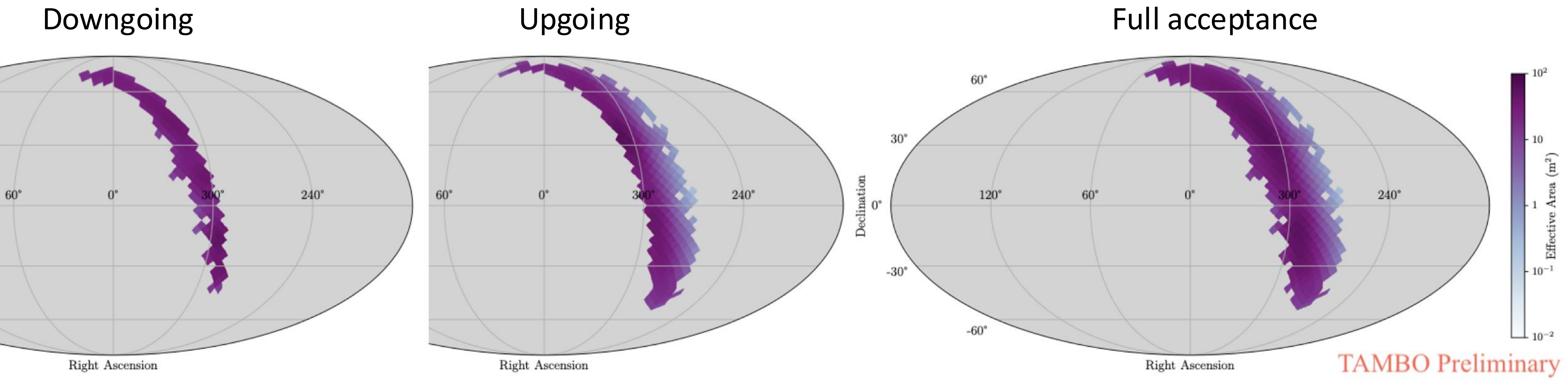


We'll do this instead

Why Put a Neutrino Telescope in a Canyon?



Why Put a Neutrino Telescope in a Canyon?

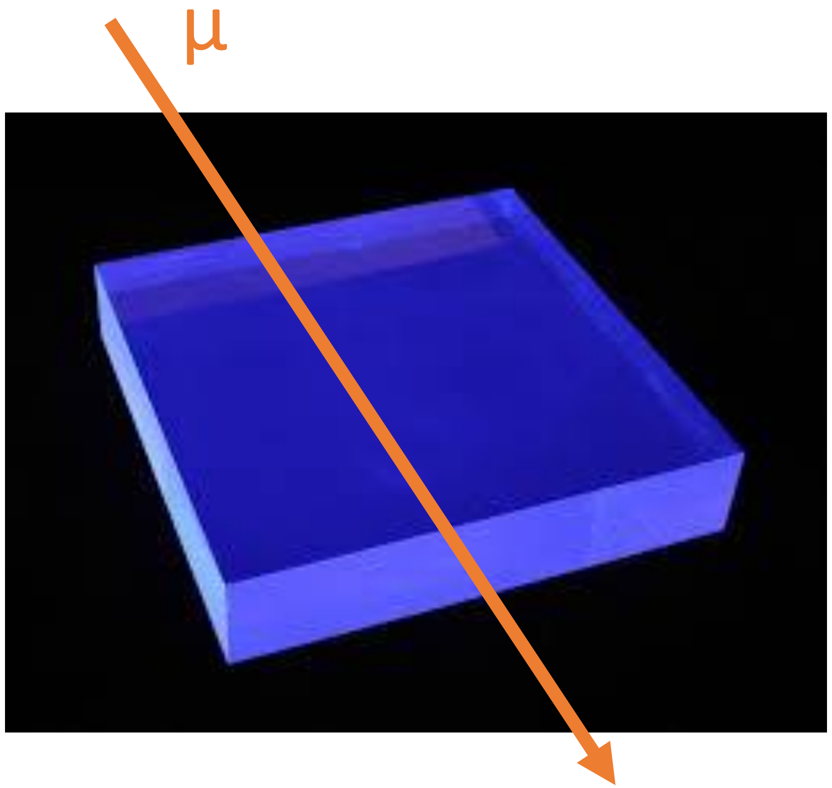


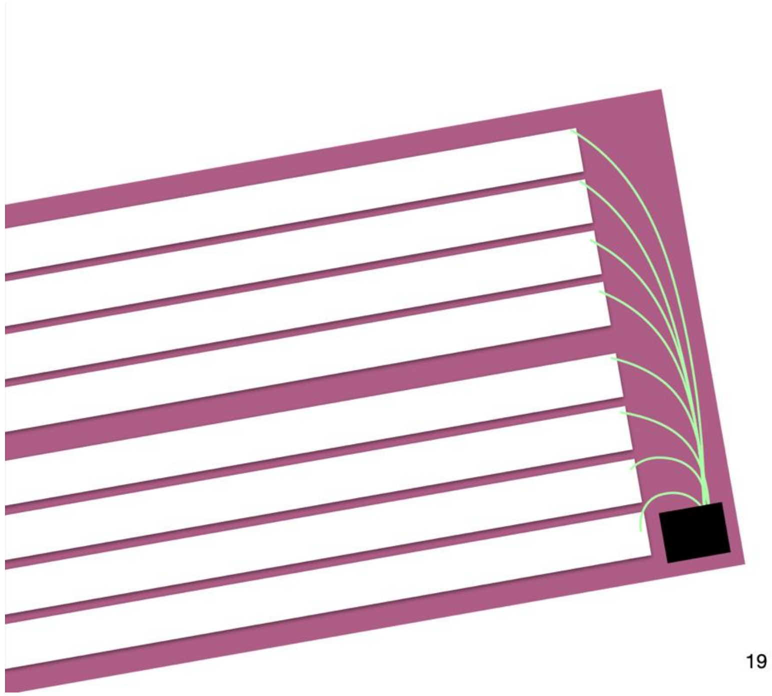
Valley geometry increases acceptance by ~50% compared with Earth-skimming only

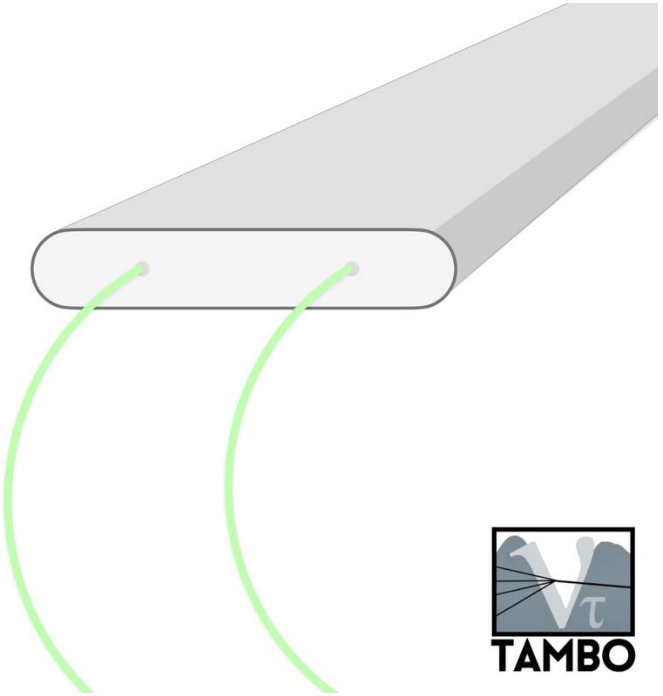
Observatory Scale

- Expect to observe ~3 ν_τ /year with 5000 modules
  - 150 meter spacing on triangular grid → ~33 (16.5) km along and 3km up canyon if single- (double-) sided

Scintillator Detection Principles

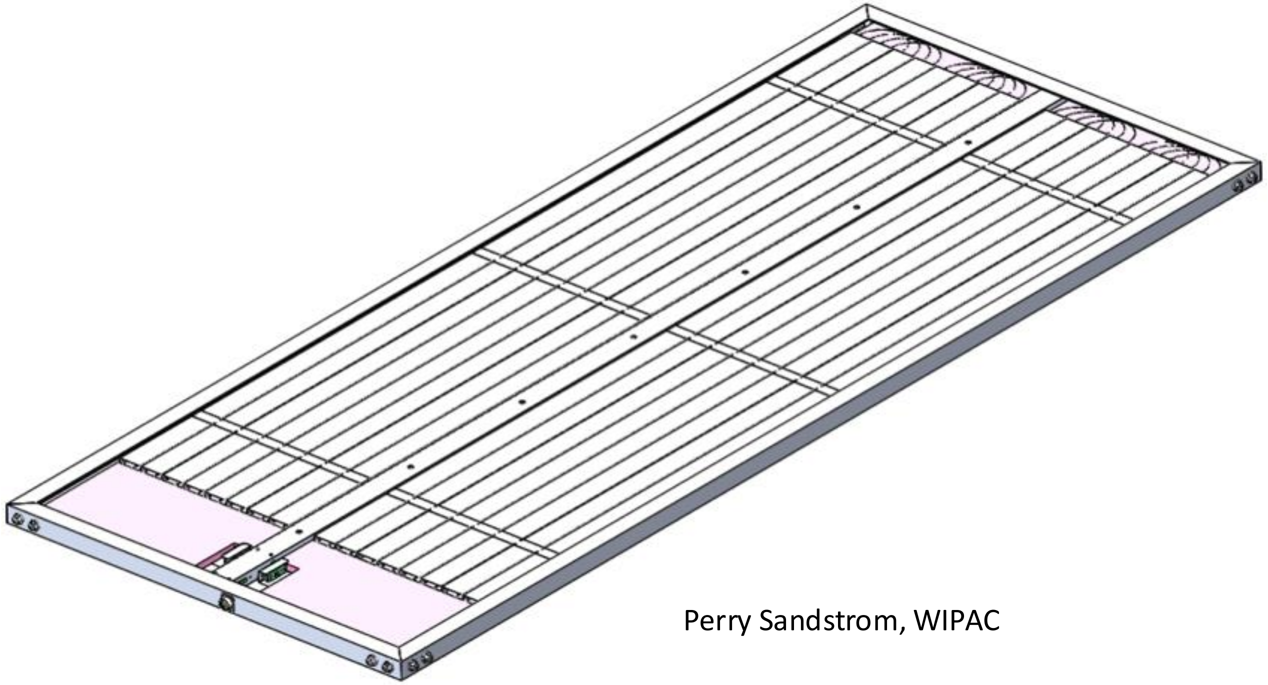




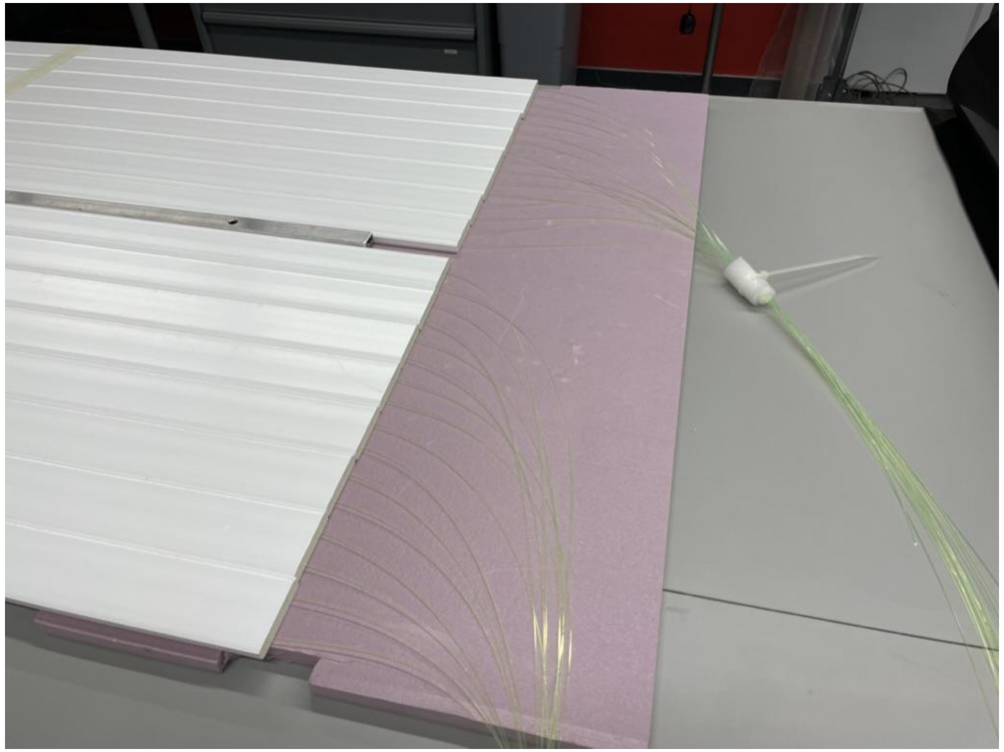


- Energy deposition in scintillator → flash of light
- Challenge is reading out large (2m-long) detector with single SiPM!

Baseline Design Overview



Perry Sandstrom, WIPAC



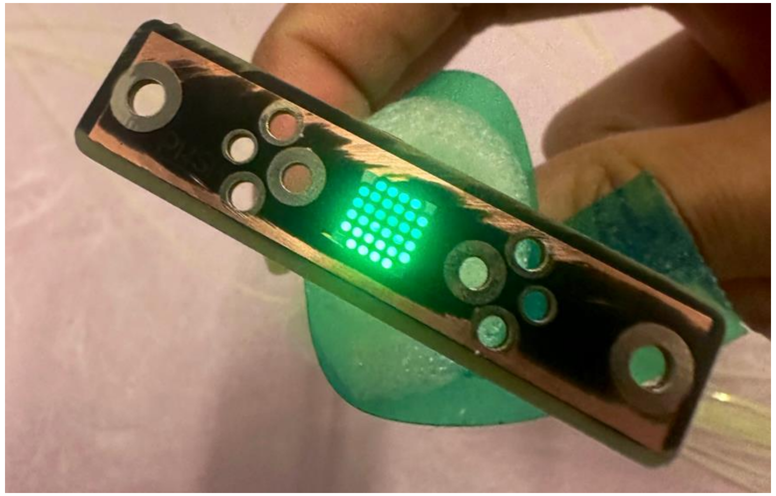
- 16, 1.875m x 5 cm scintillator bars
- Coated with TiO_2 for specular reflection
- Threaded with 0.7 mm diameter wavelength-shifting optical fiber
- Electronics inside module; external device (communications) can just plug in

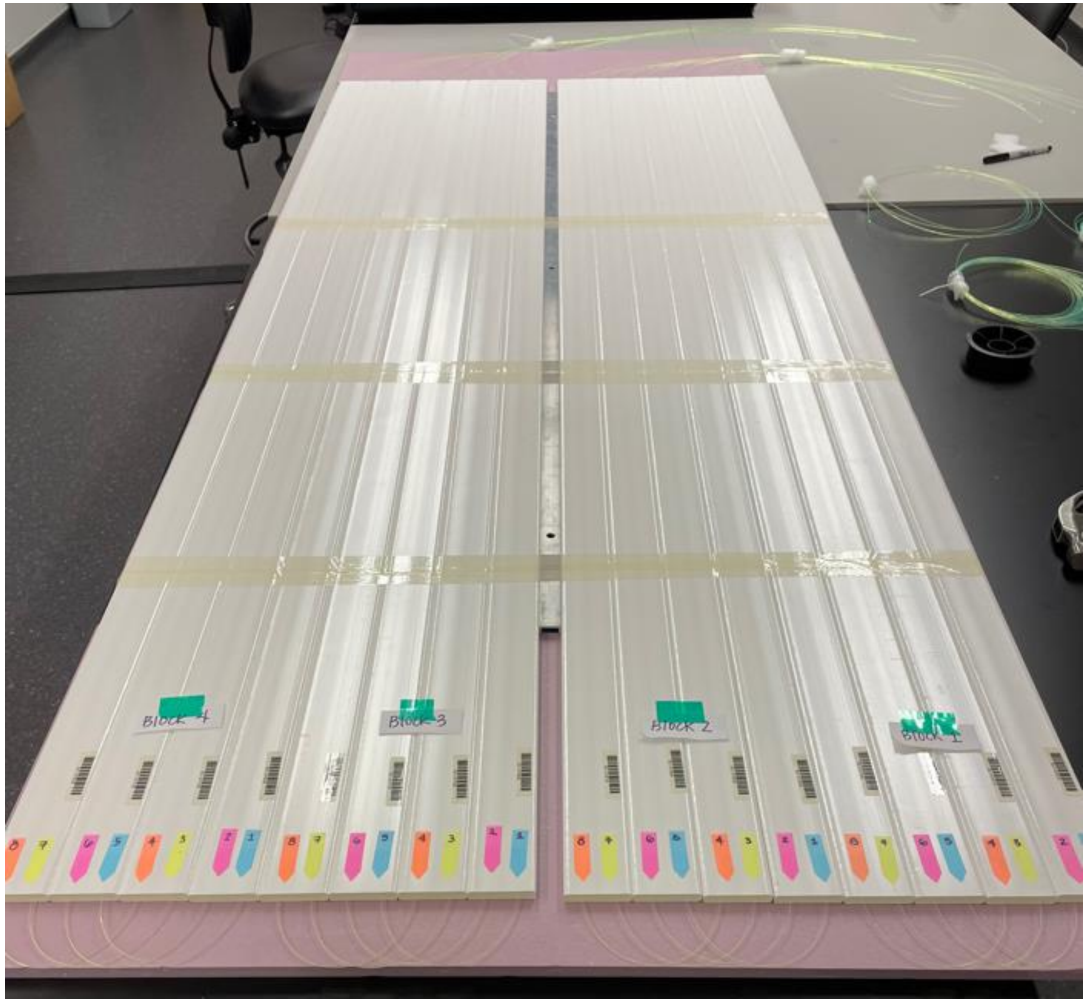
Detector Research & Development

- Detector technology: either water Cherenkov or plastic scintillator
  - Both well-experienced technologies!

- Special considerations for TAMBO:
  - Difficulty of deploying detectors in canyon
  - Cost of producing thousands of detectors

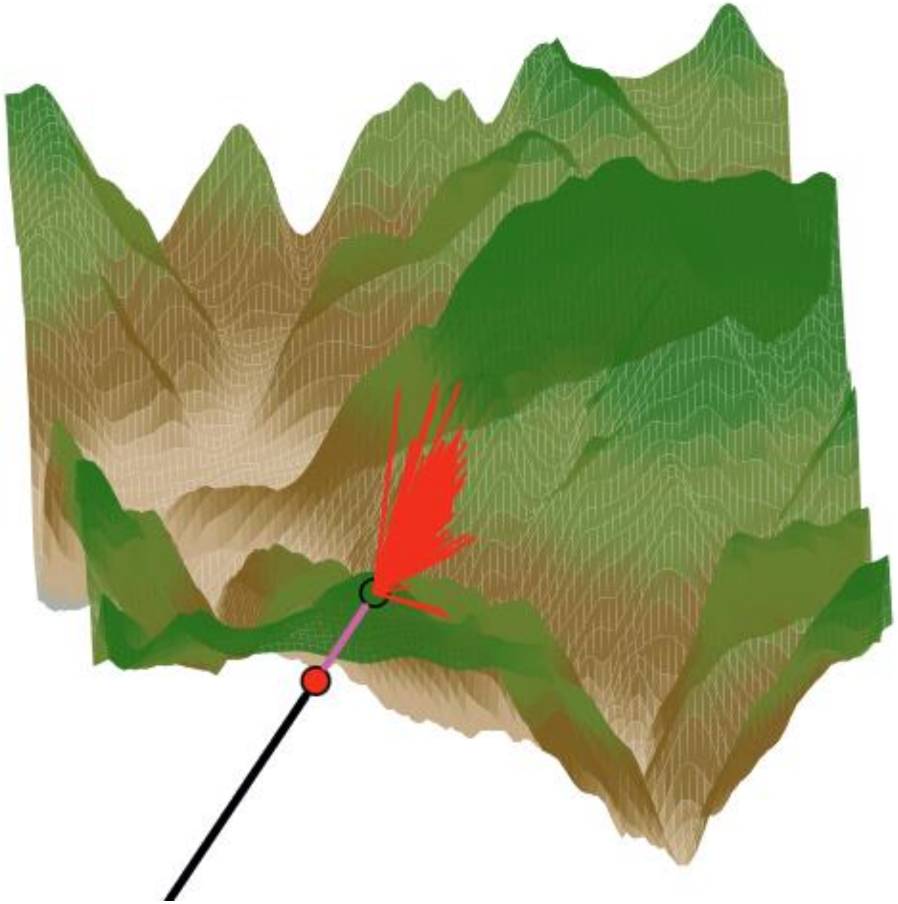
Diyaselis Delgado

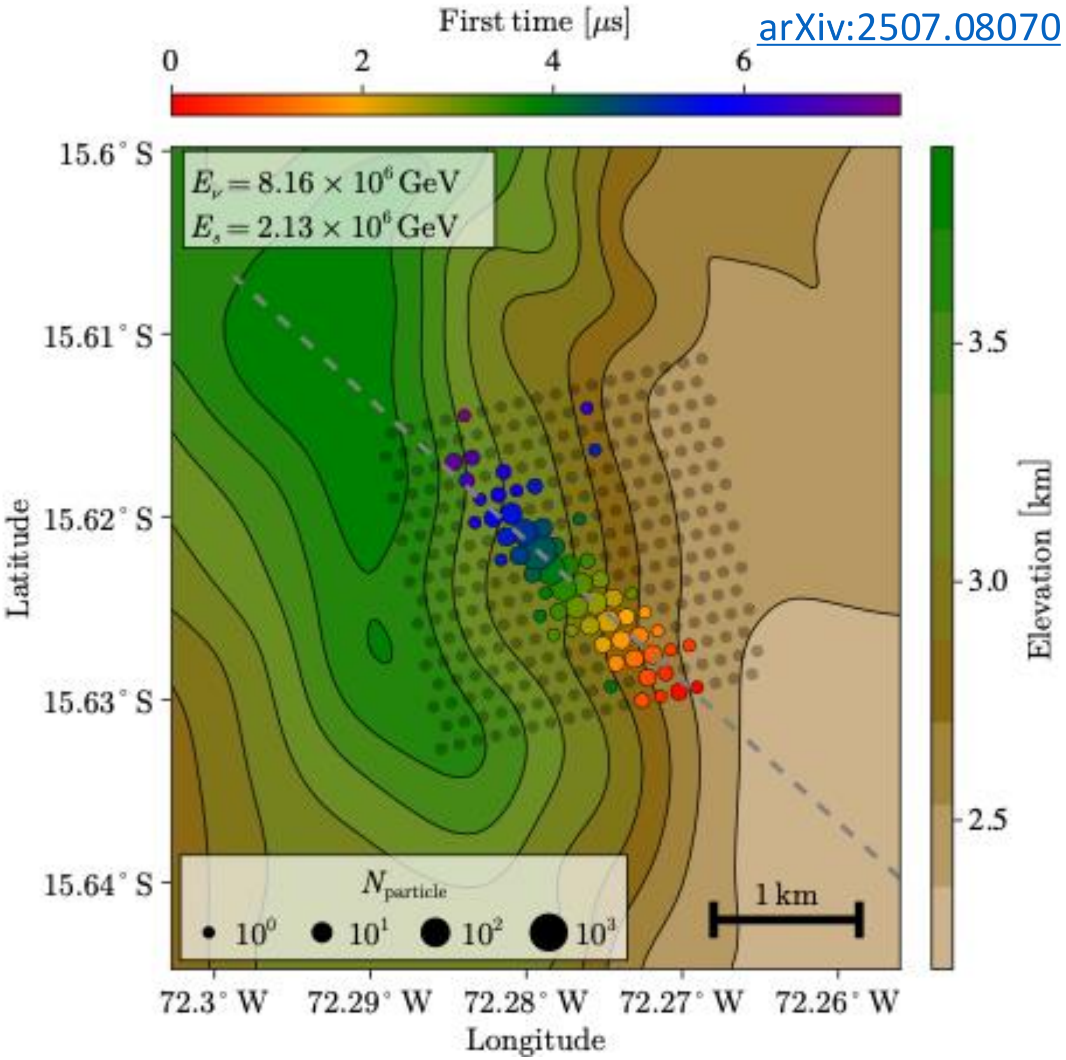




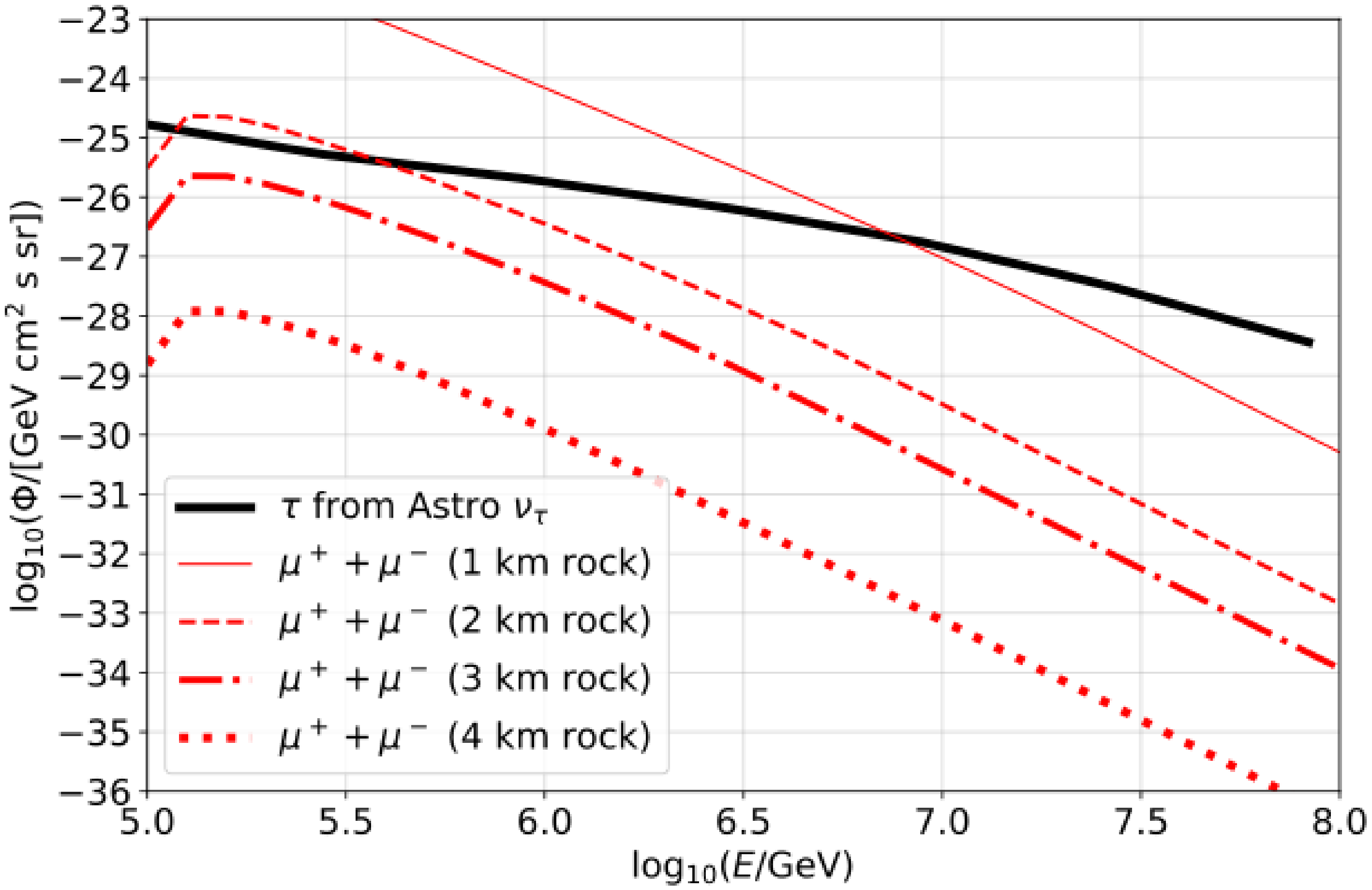
Air Showers in TAMBO

arXiv:2507.08070



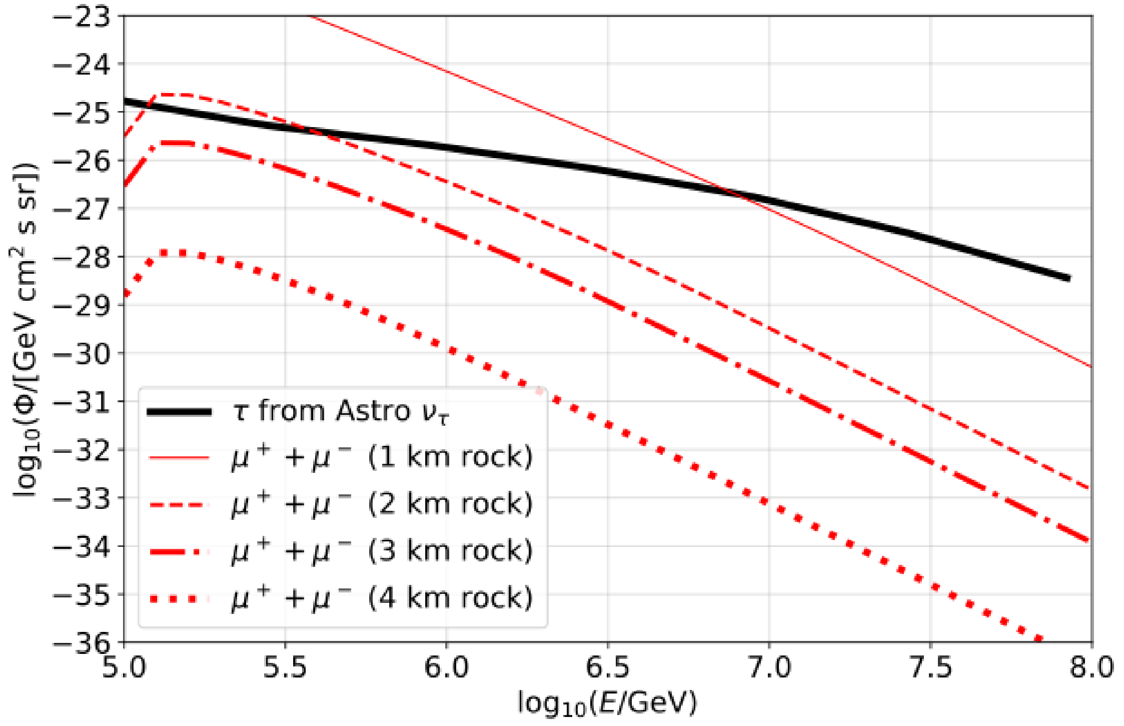


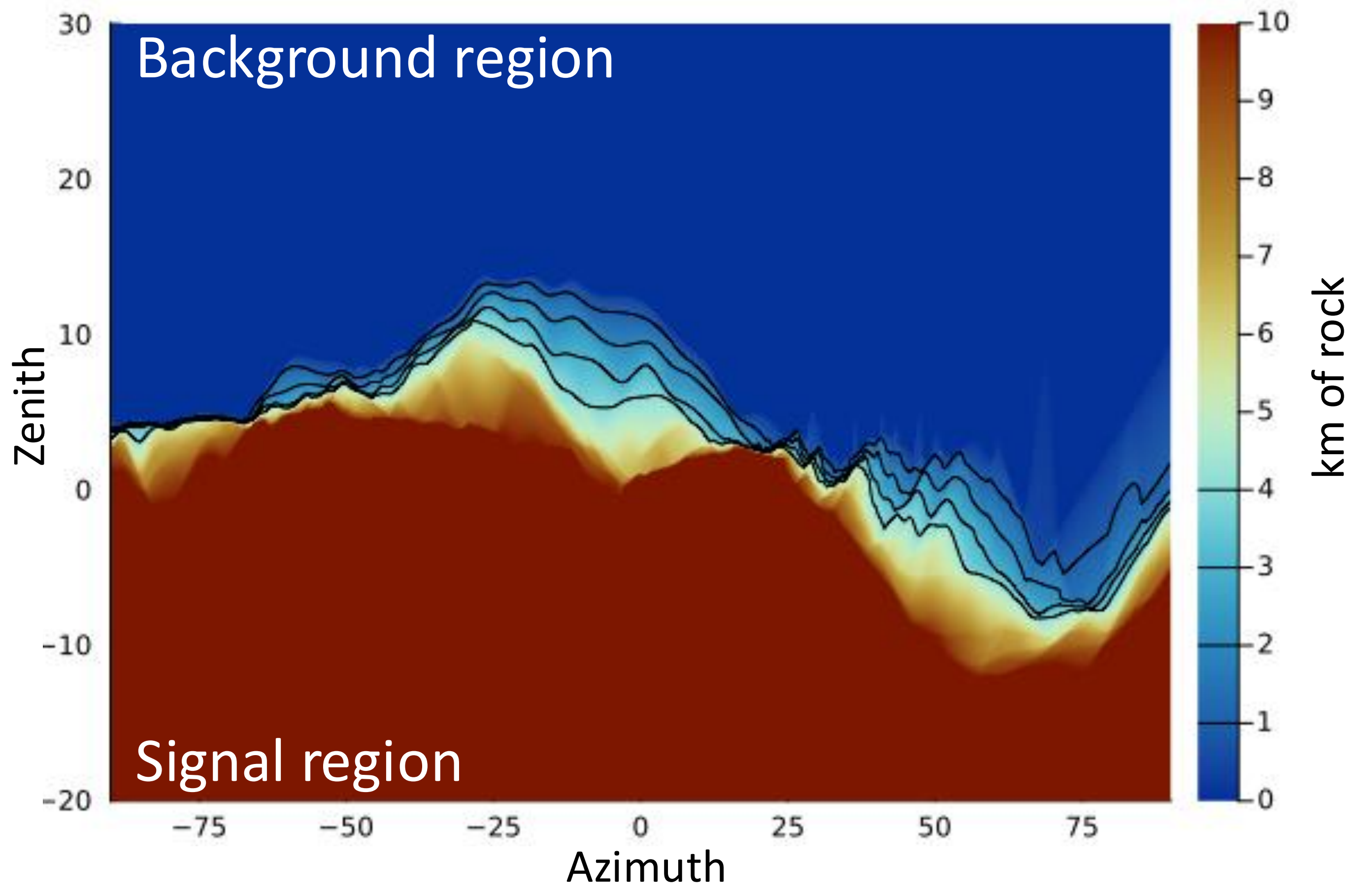
Removing Muon Background Requires Accurate Topography



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

Removing Muon Background Requires Accurate Topography





- Mountain filters muon backgrounds
- Neutrino purity tunable based on column depth requirement

Peru Outreach Trip

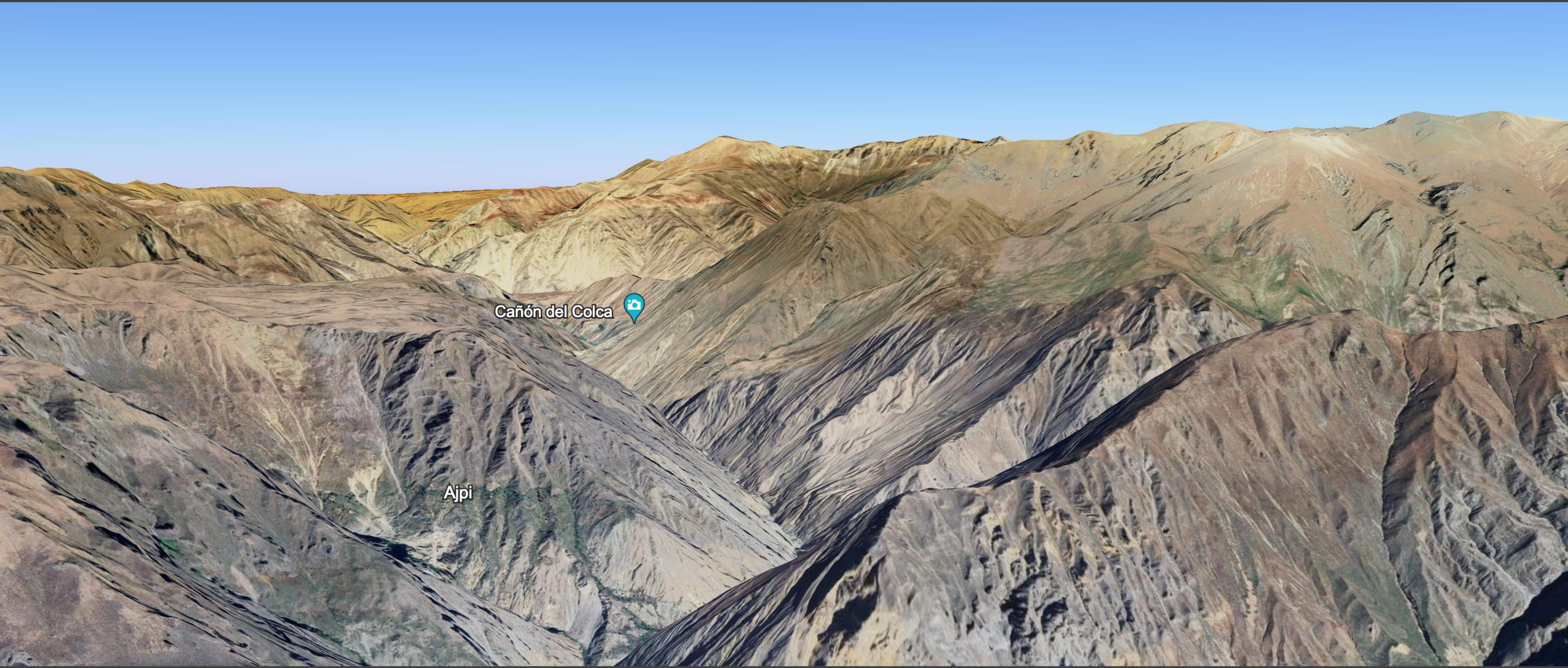
Photo Credit: Universidad Nacional de San Agustin de Arequipa

- 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

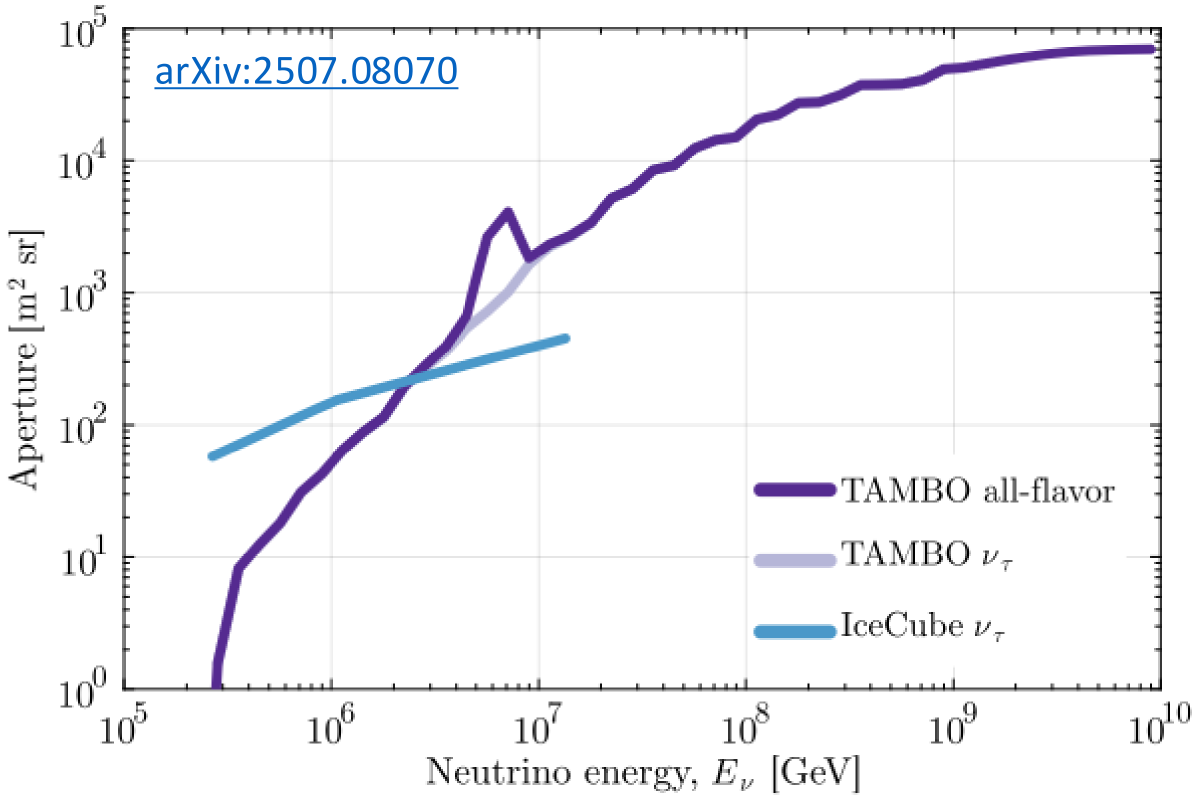

Will Thompson


Cañón del Colca
Ajpi

Societal Impact

- Want local community to embrace project, not just accept
- First steps: workshop with Peruvian social scientists & officials

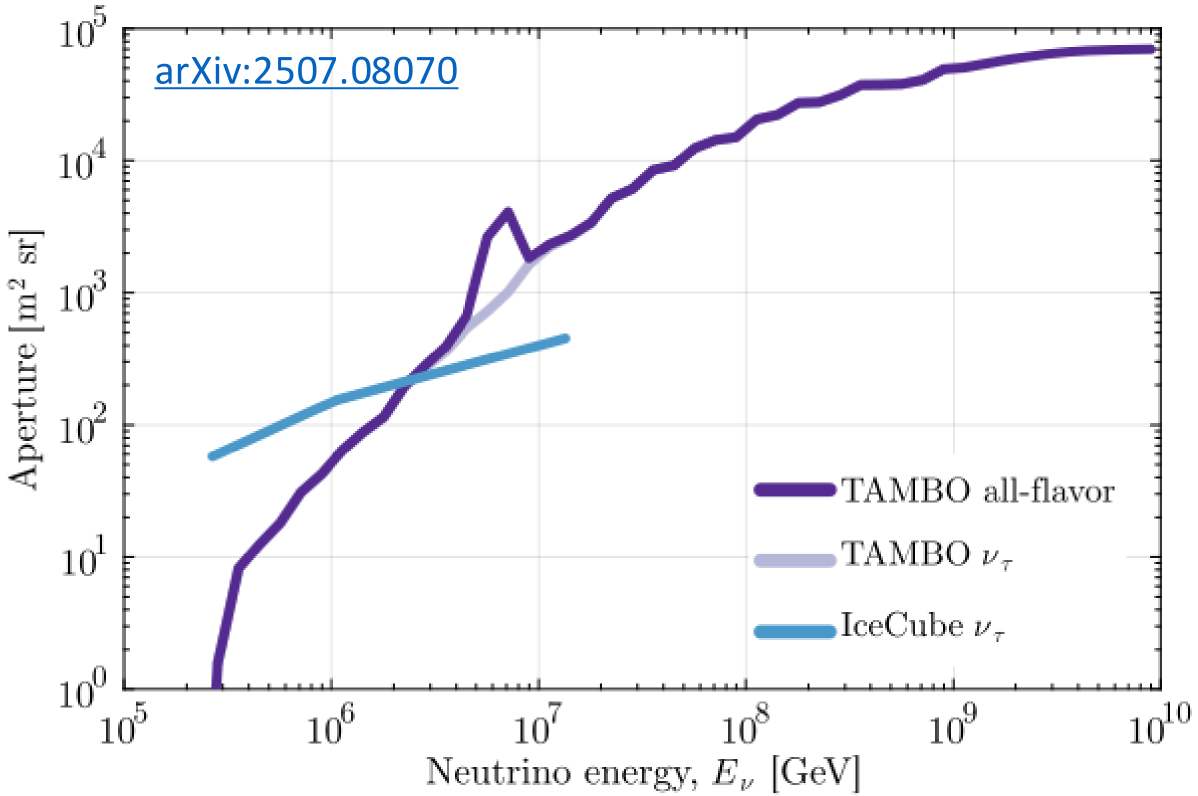
TAMBO's Sensitivity Surpasses All-Flavor Observatories

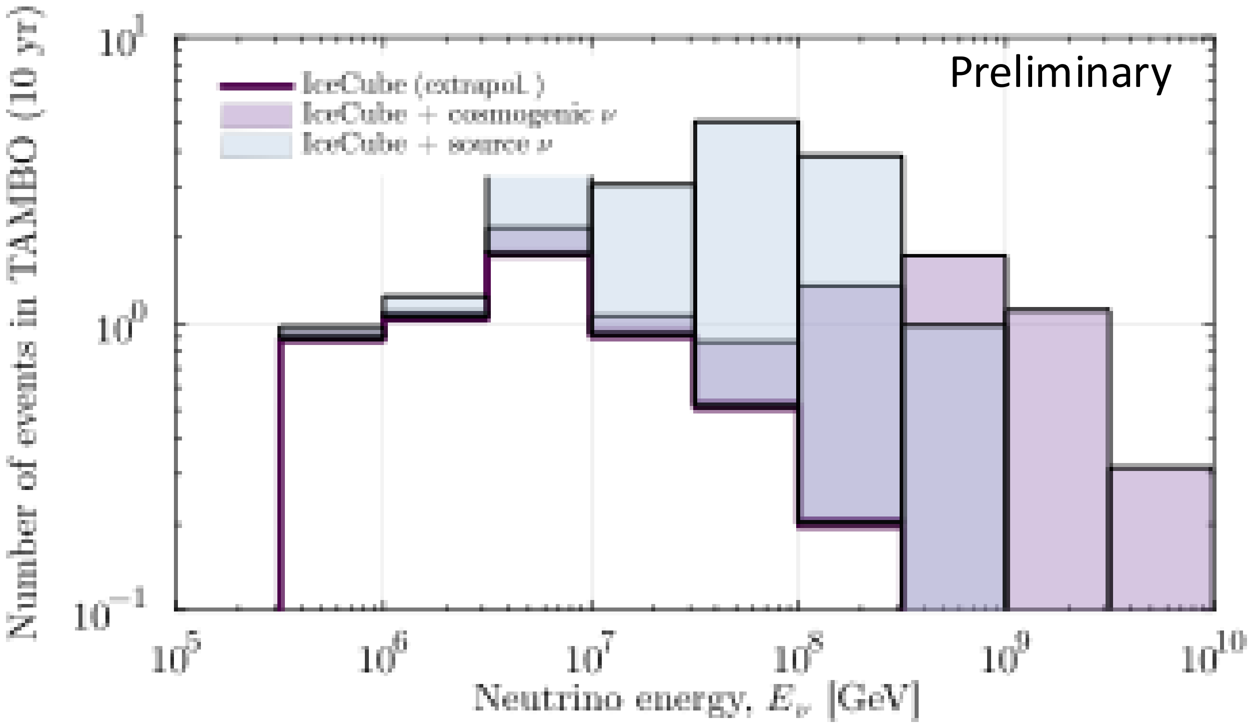


- 5x higher ν_τ aperture than IceCube @ 10 PeV, before array optimization

TAMBO's Sensitivity Surpasses All-Flavor Observatories

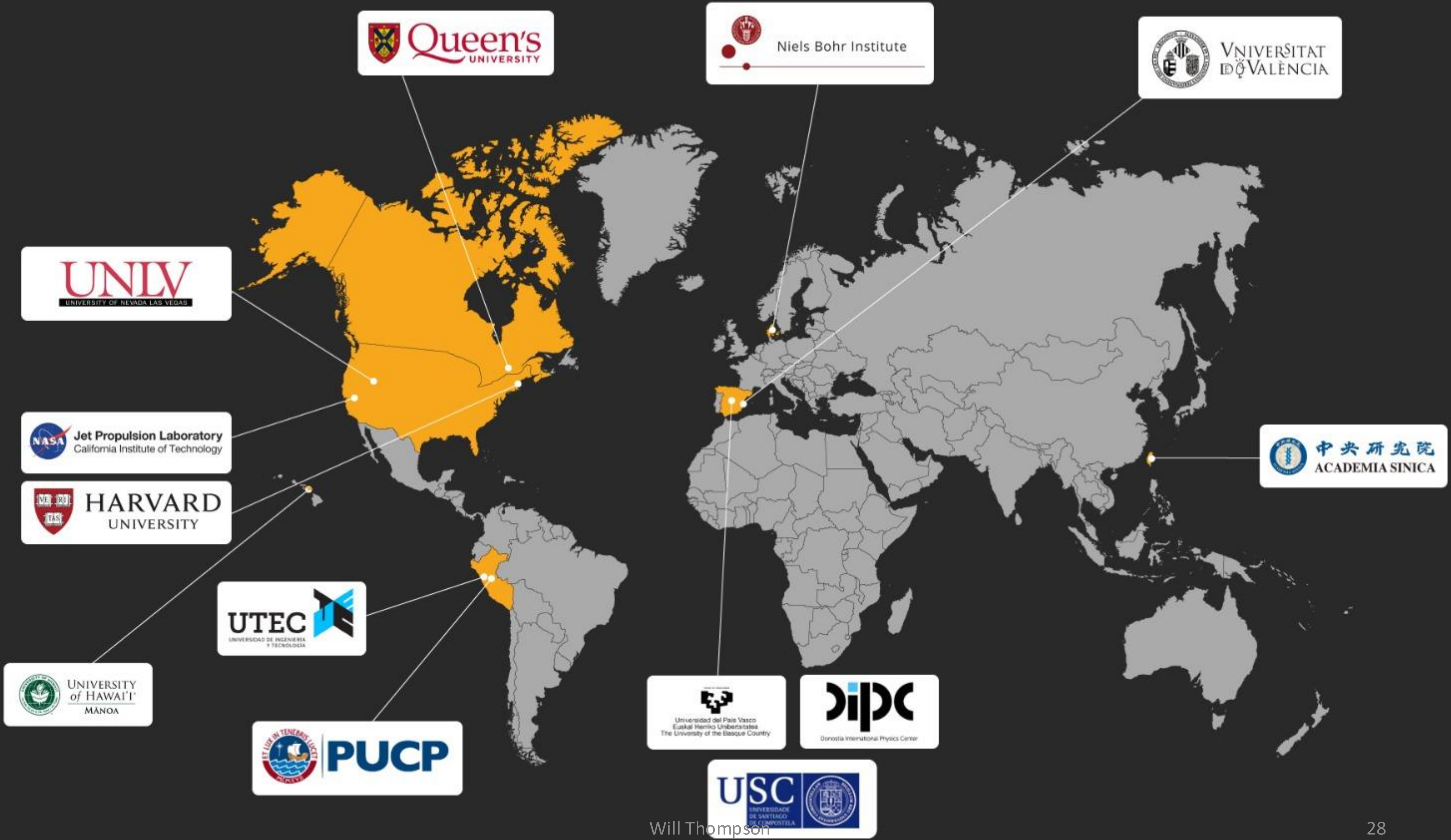
TAMBO





- 5x higher ν_τ aperture than IceCube @ 10 PeV, before array optimization
- With 5000 modules TAMBO will:
  - Observe ~1 neutrino per year from 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



Queen's UNIVERSITY
Niels Bohr Institute
VNIVERSITAT DE VALÈNCIA
UNLV
UNIVERSITY OF NEVADA LAS VEGAS
Jet Propulsion Laboratory
California Institute of Technology
HARVARD UNIVERSITY
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ACADEMIA SINICA
UTEC
UNIVERSIDAD DE INGENIERÍA Y TECNOLOGÍA
UNIVERSITY of HAWAI'I MĀNOA
PUCP
Universidad del País Vasco
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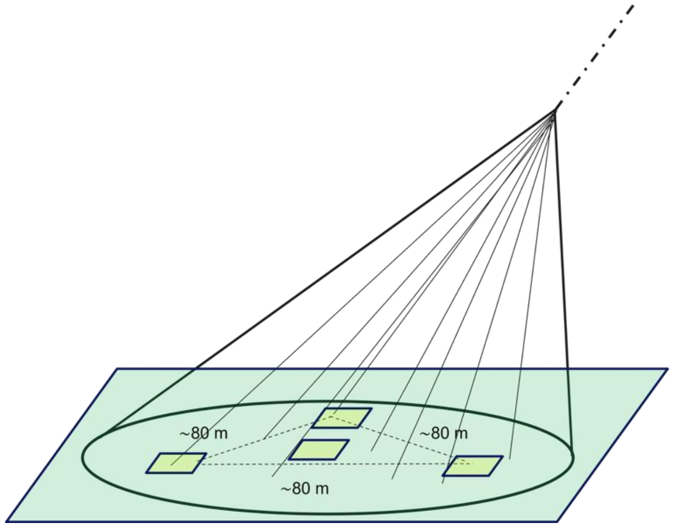
The University of the Basque Country
DIPC
Donostia International Physics Center
USC
UNIVERSIDADE DE SANTIAGO DE COMPOSTELA

TAMBO Timeline

FUNDED!

Today: TAMBO-4	2025-2028: TAMBITO (TAMBO-100)	2028-: TAMBO-5k

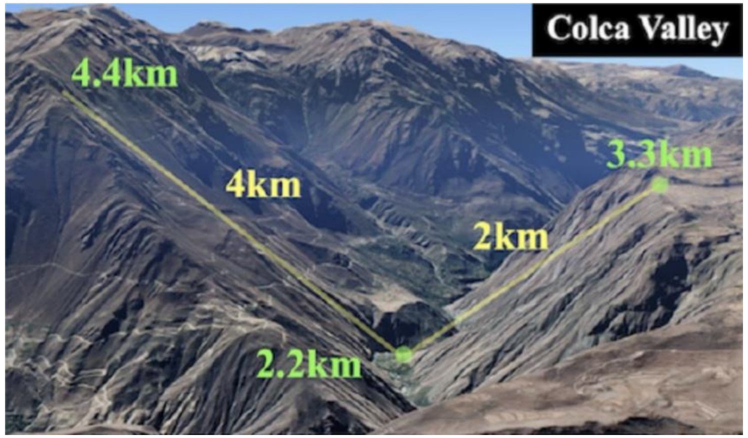
Today:
TAMBO-4



Small test array

Detector & electronics prototypes

2025-2028:
TAMBITO (TAMBO-100)



Pilot array

Deployment techniques, backgrounds, responsible siting

2028-:
TAMBO-5k

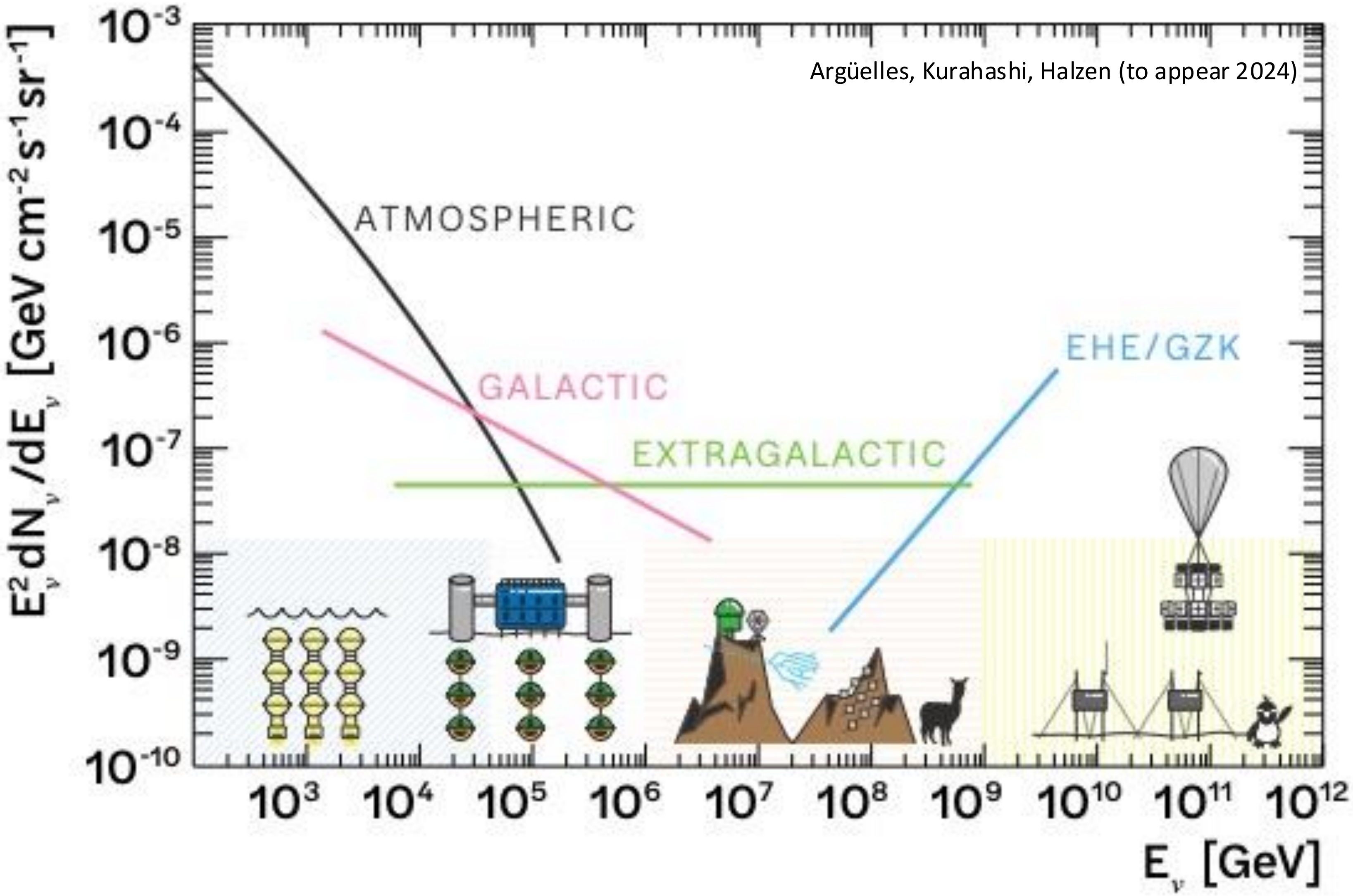
Target full size array

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

Thanks for your attention!

Next-Generation Prospects



ommunity has definitely
eeded call for ultra-
igh-energy
bservatories

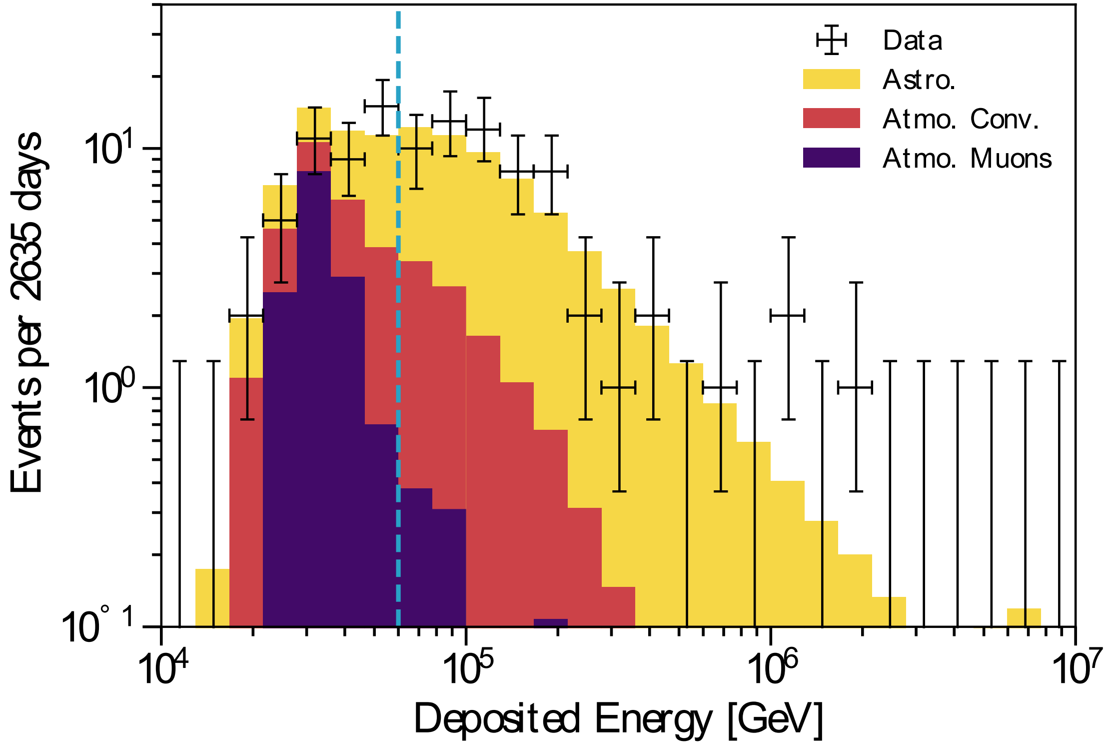
ewer experiments
lanned for 1-100 PeV

TAMBO Objectives

Physics Objective	Observatory Requirement
Determine if ν sources accelerate particles to >10 PeV	>5σ sensitivity to extrapolated IceCube flux from 1-100 PeV
Characterize 1-10 PeV flux by measuring ν_τ component	Efficient τ-flavor discrimination
Constrain multimessenger point source transients' properties	Tau angular resolution of $\lesssim 1°$

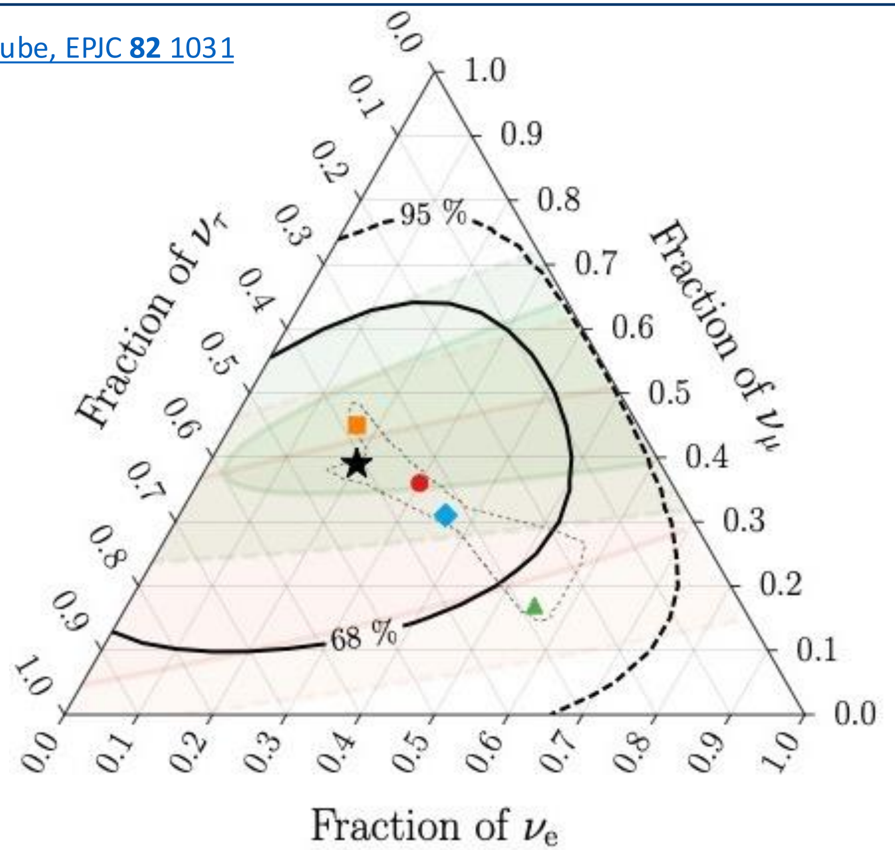
Open Questions in Neutrino Astronomy

IceCube, PRD **104** 022002



- Diffuse astrophysical flux discovered by IceCube
- Is there a high energy cutoff?

IceCube, EPJC **82** 1031

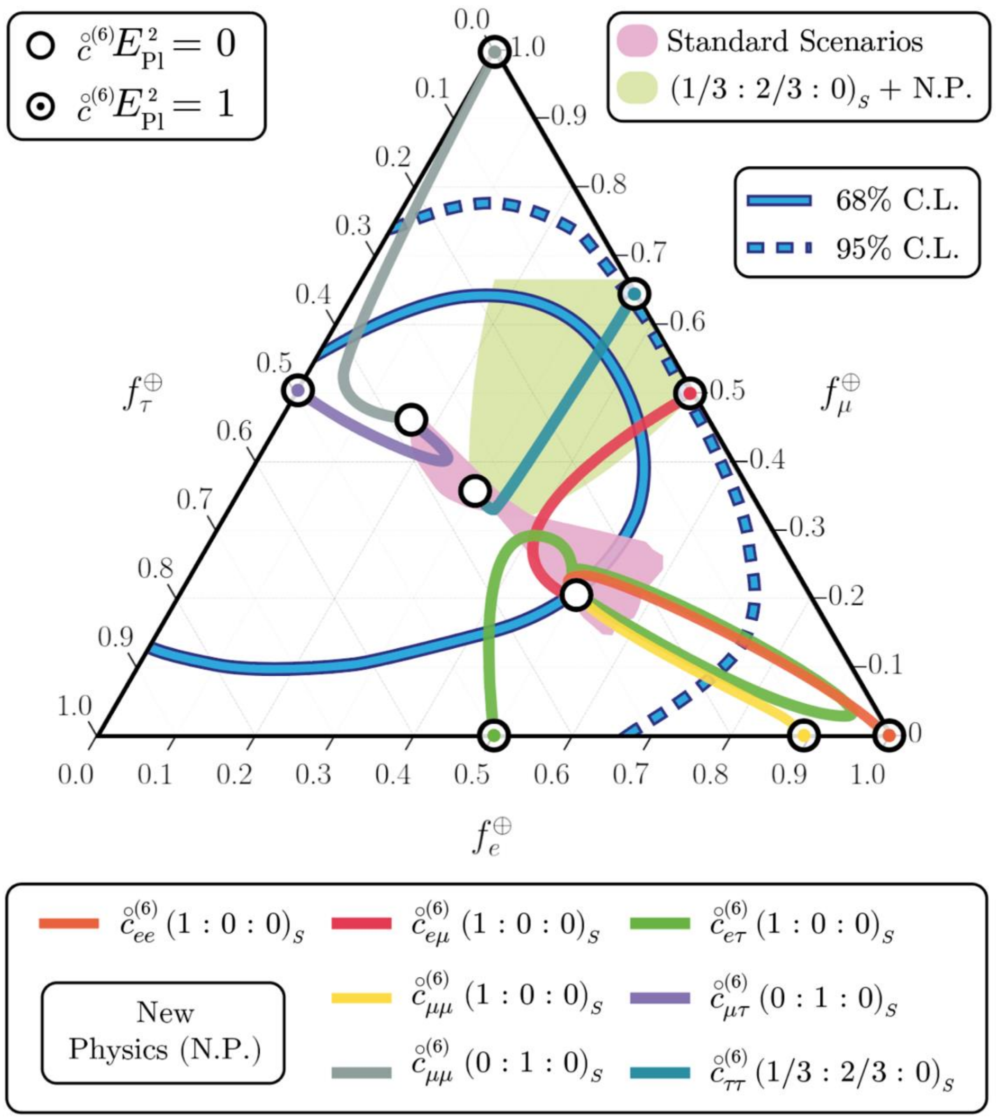


- Astrophysical flavor ratio can probe new physics
- How can we better constrain these measurements?

Astrophysical Flavors

- Flavor ratios characterize physics of sources

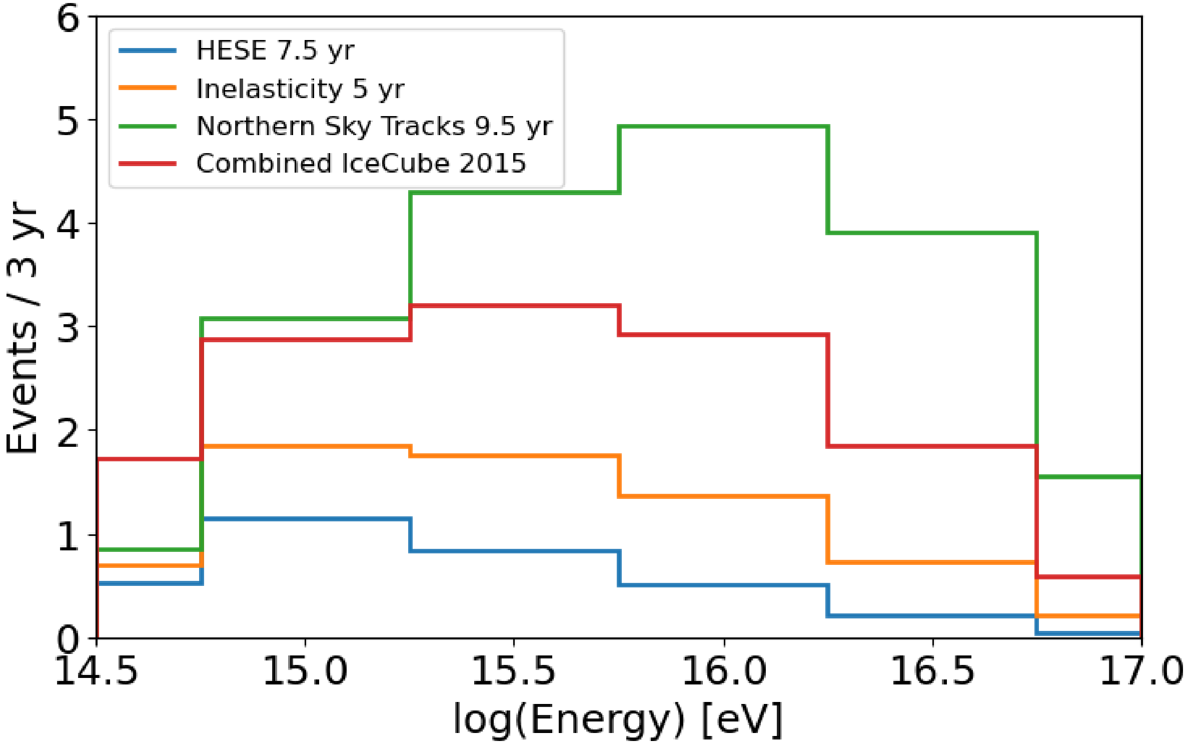
- … and probe BSM physics on "long" baselines

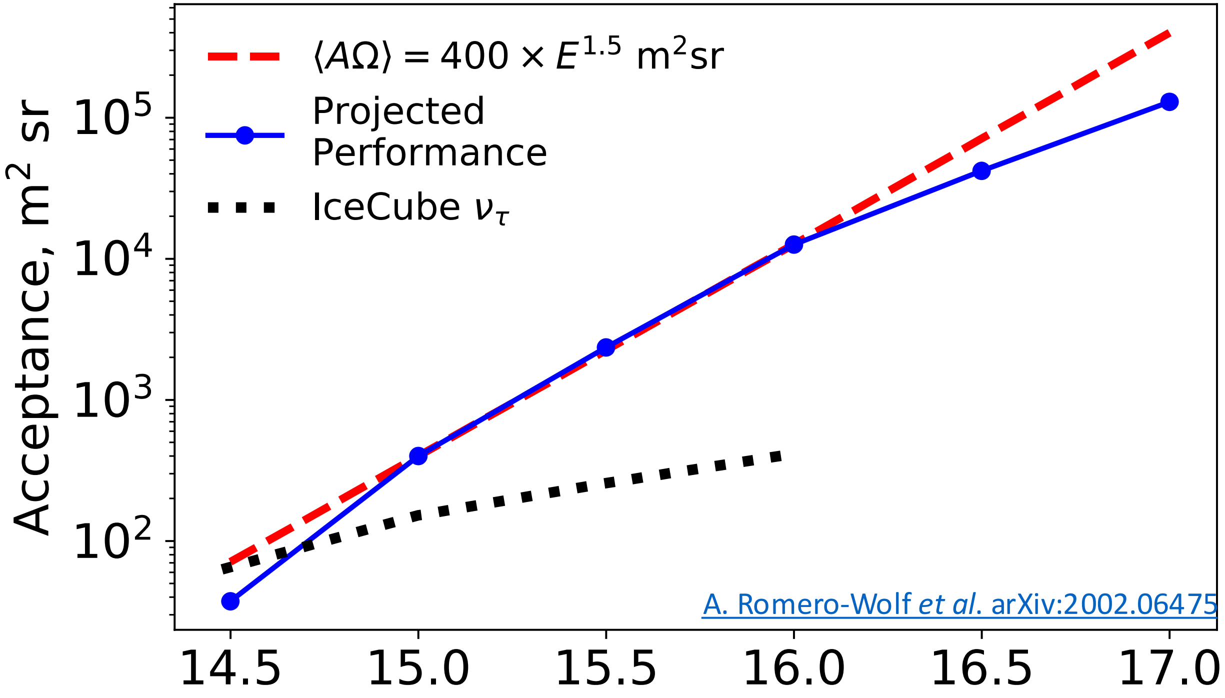


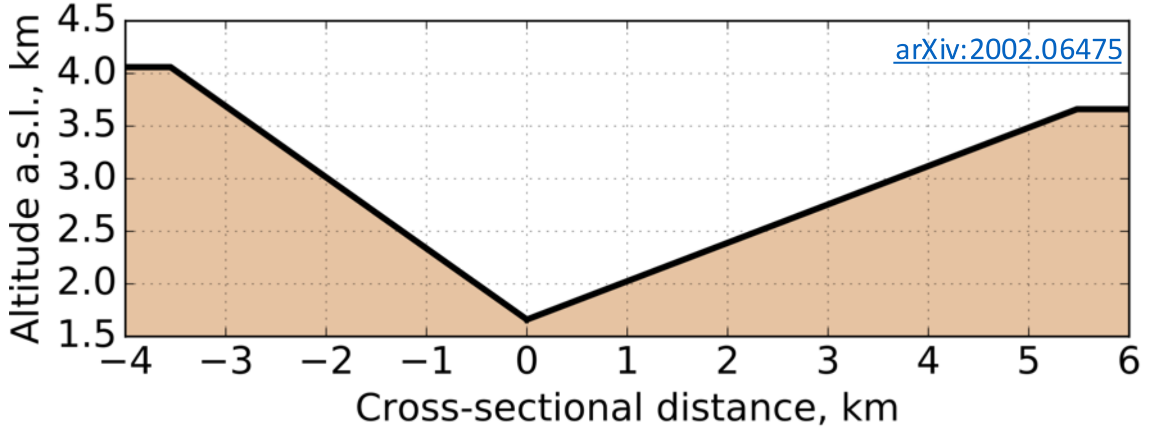
IceCube, Nature Physics (2022)

Is This Insane?

- Original proposal called for ~22,000 detector modules w/ 150m spacing
- This would cover >100 km of canyon

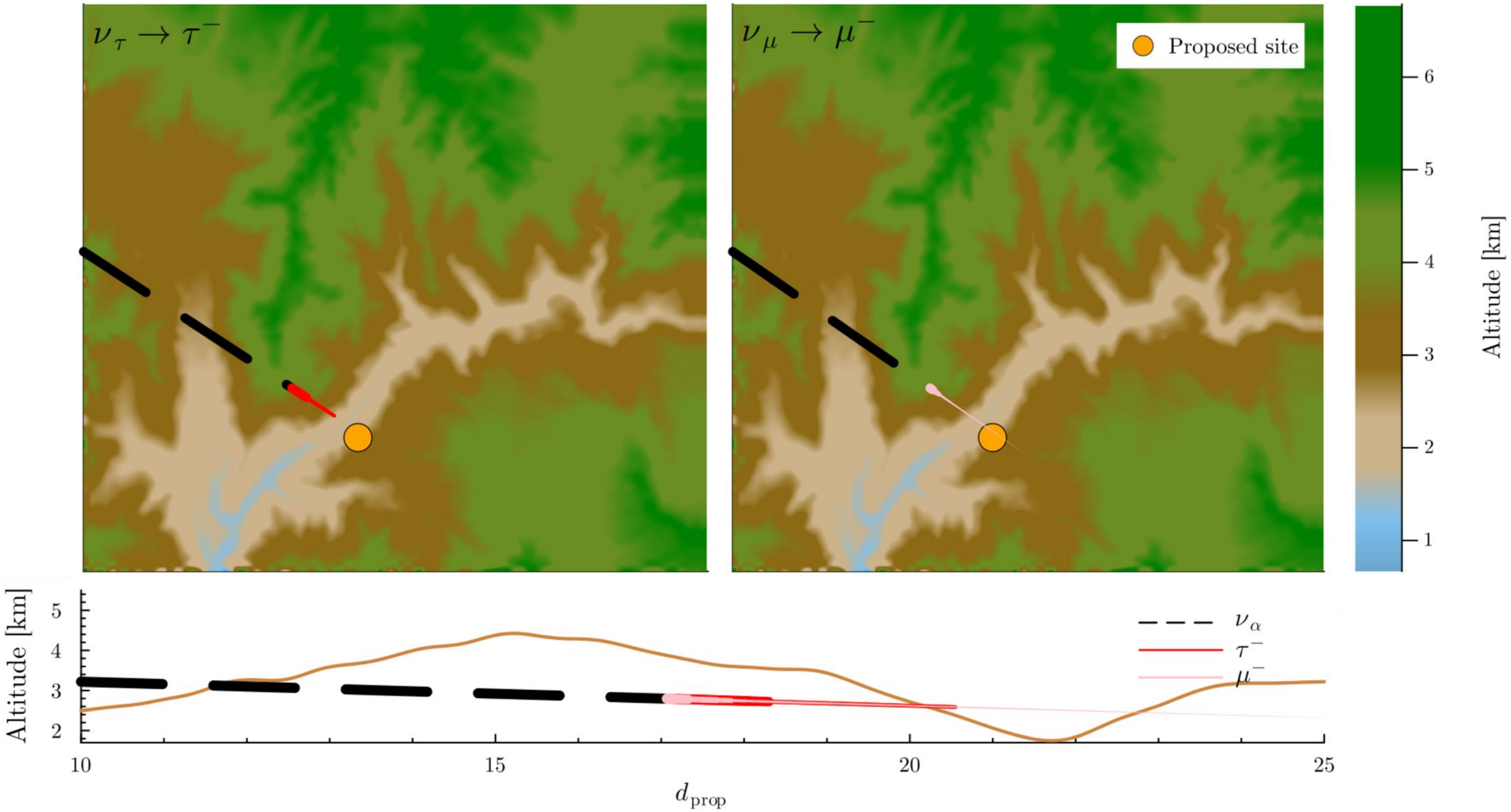






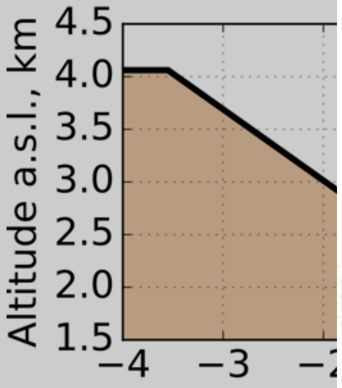
ν_τ Exclusivity

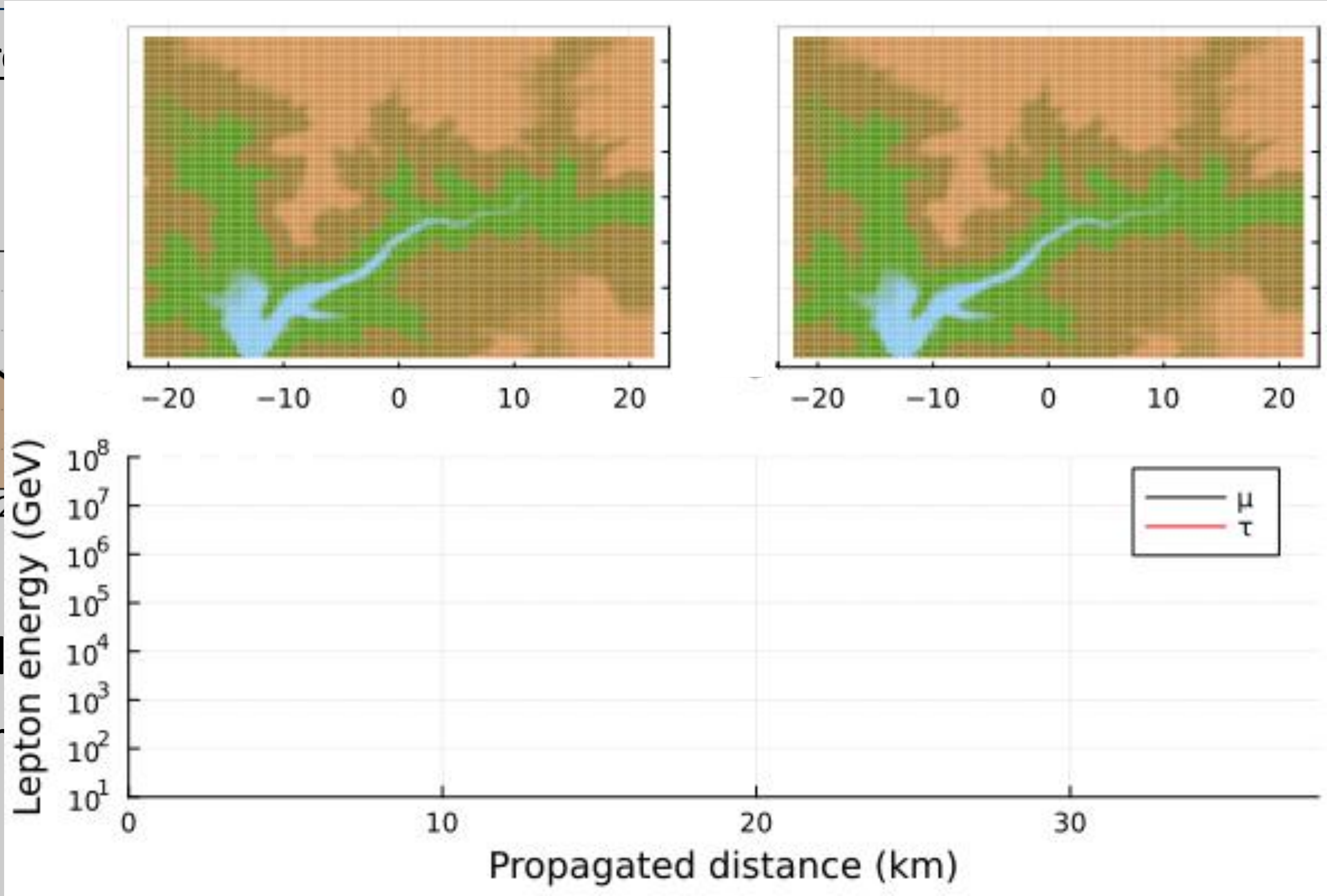
- Air-shower signature isolates ν_τ
- e^- shielded by rock
- μ^- rarely creates extensive air shower

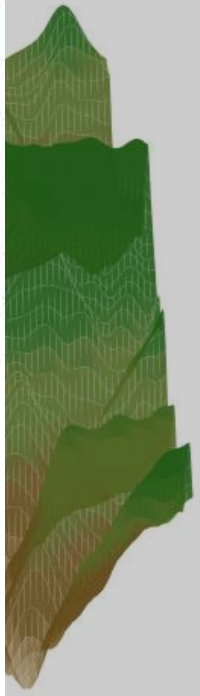


Developing Full Simulation

Pr tion





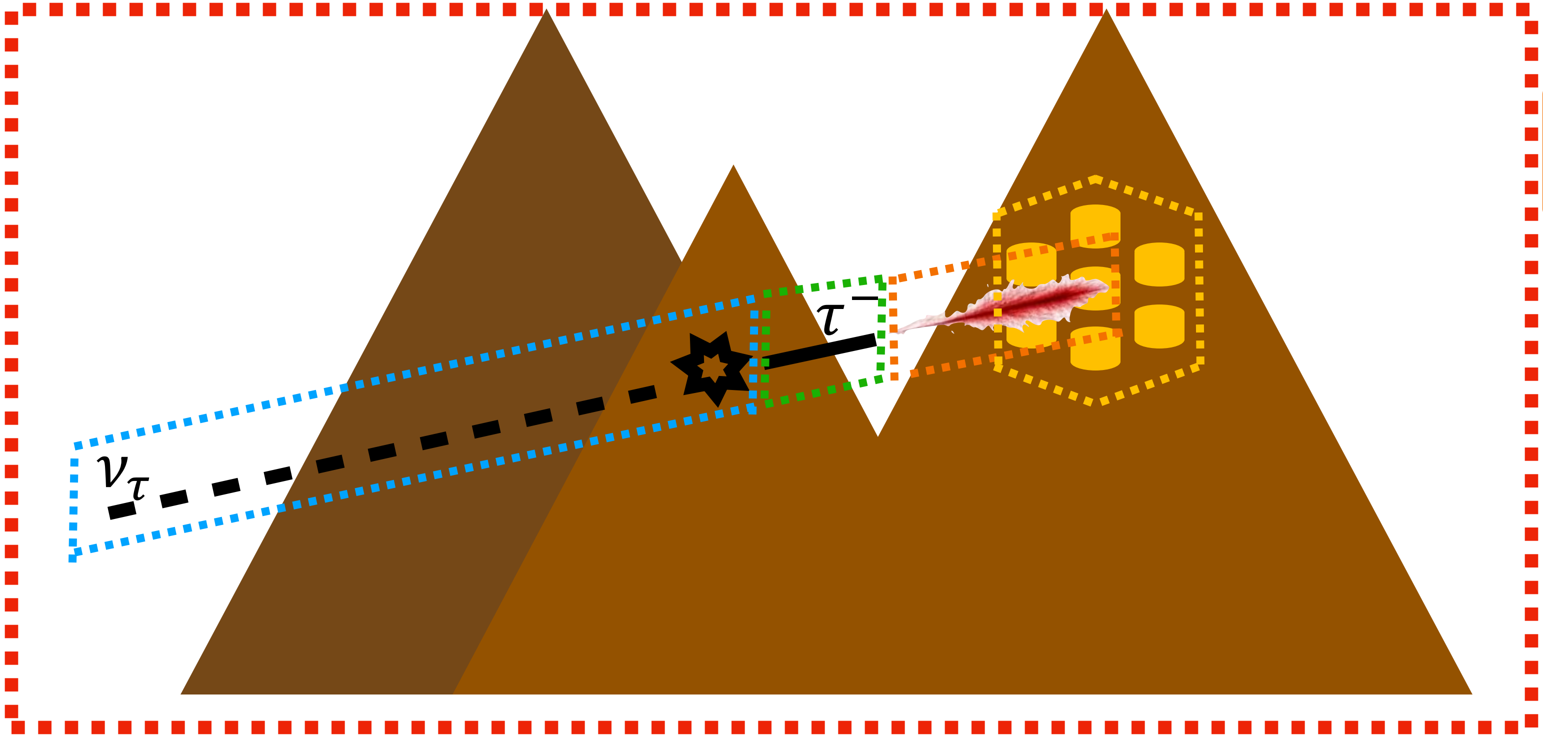


- Simplified
- No treatm losses
- Approxim h CORSIKA 8

Overview of Simulation Framework

Jeff Lazar

Pavel Zhelnin



Initial neutrino injection: Select initial neutrino properties, *i.e.* energy, direction, interaction vertex, *etc.*

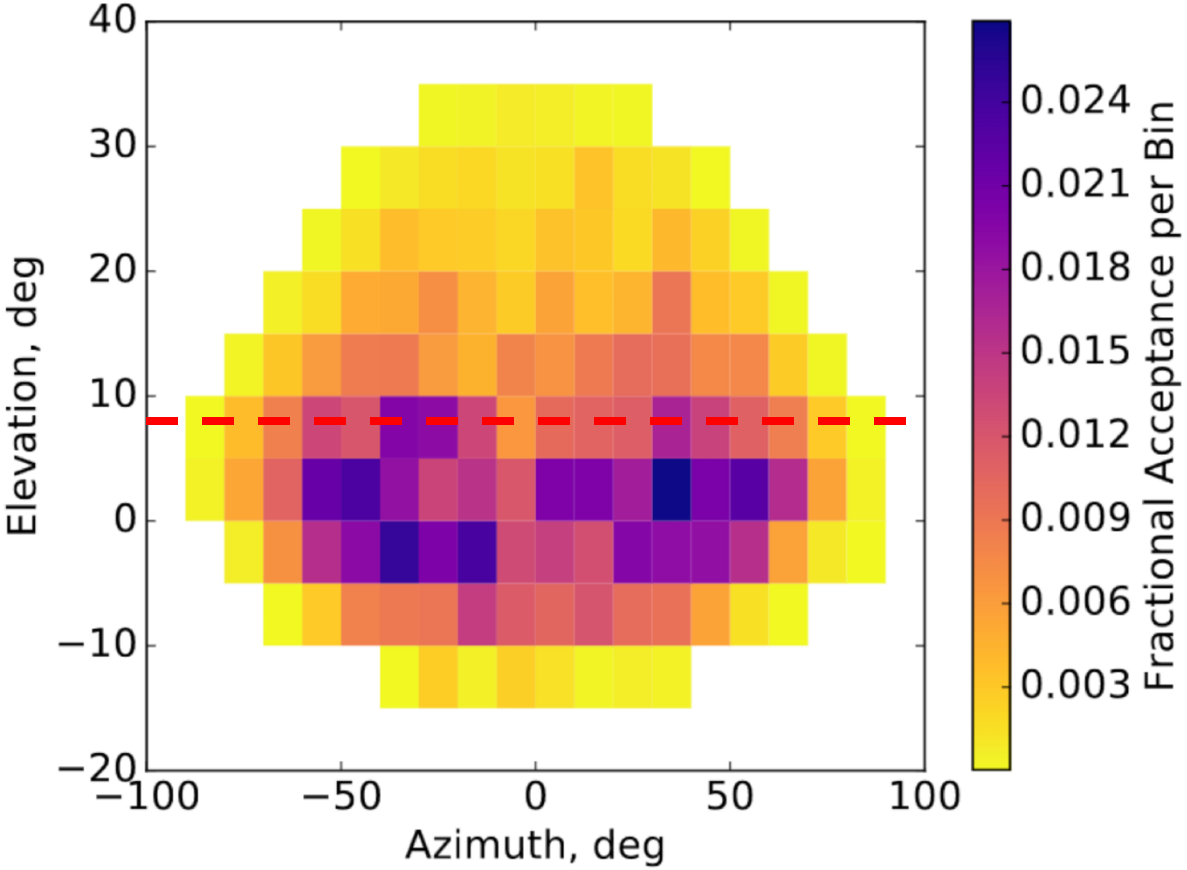
Charged lepton propagation: Propagate outgoing charged lepton, accounting for energy losses and decay, to find decay point

Air-shower simulation: Model shower development from lepton decay

Detector response: Simulate internal hardware to model what we will see

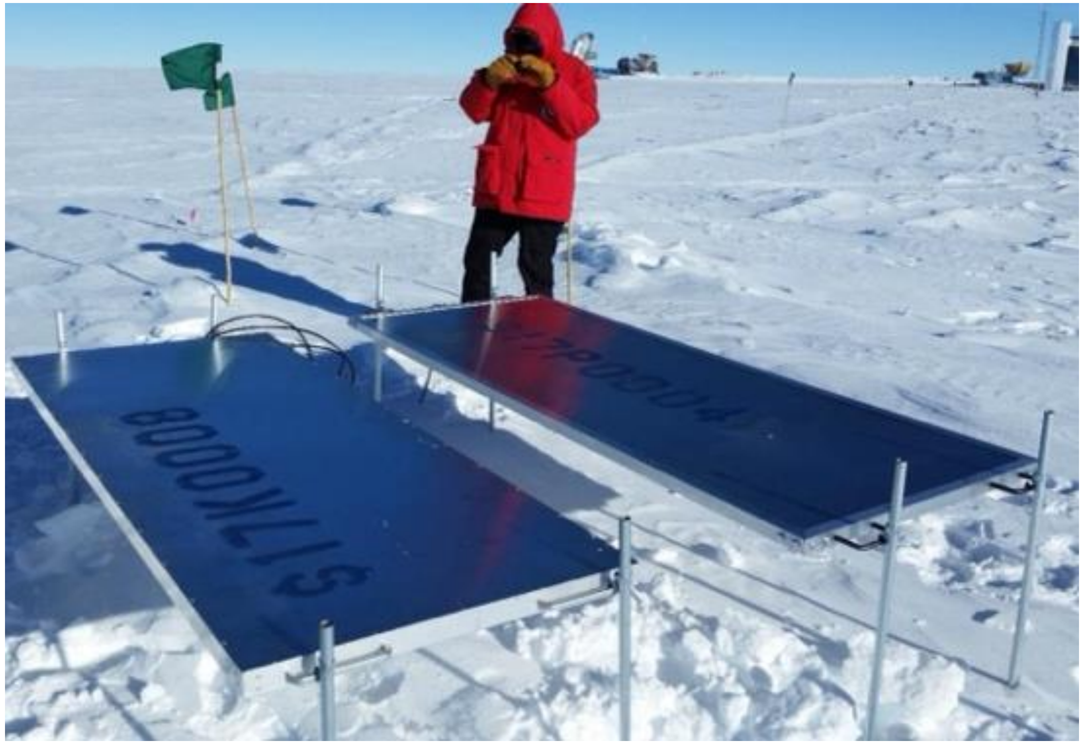
Event weighting: Remove unphysical remnants from selection of initial neutrino properties

What About Backgrounds?

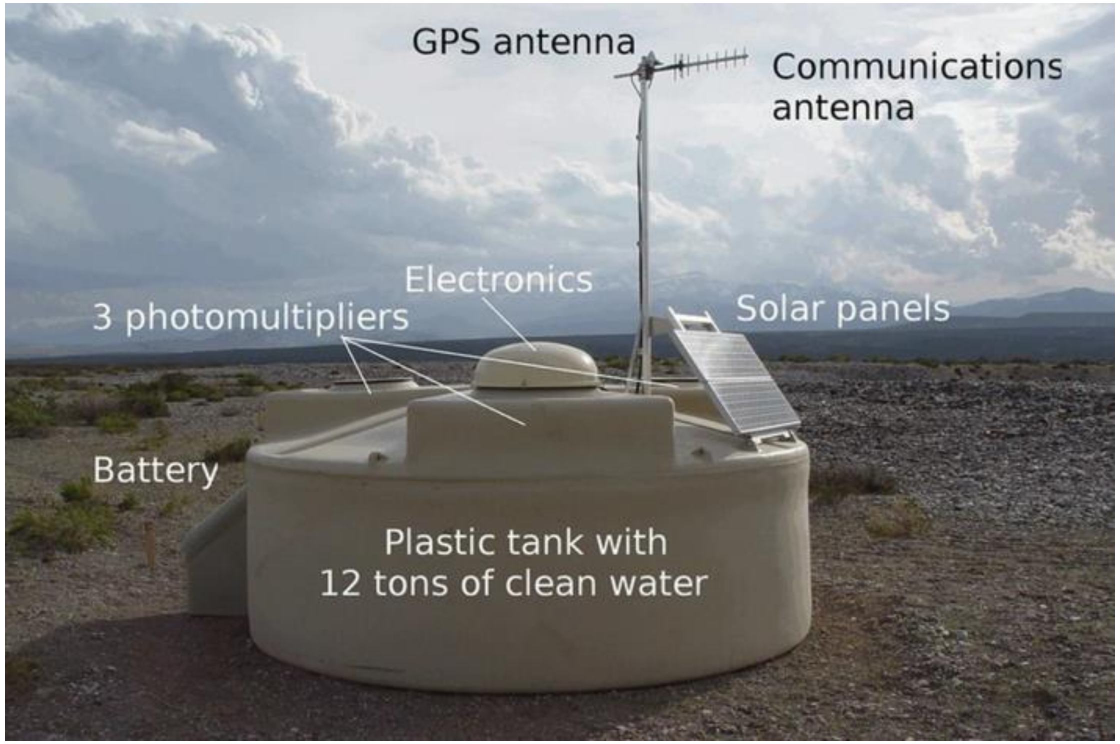


- Cosmic Rays
  - Largely blocked by mountain
  - Random coincidence from pathological low-energy showers
- High-energy muons
  - Create air shower in rare cases
  - >4 km column depth removes atmospherics

TAMBO Air-Shower Detectors



IceCube Collaboration, EPJ Web Conf. **210** (2019)

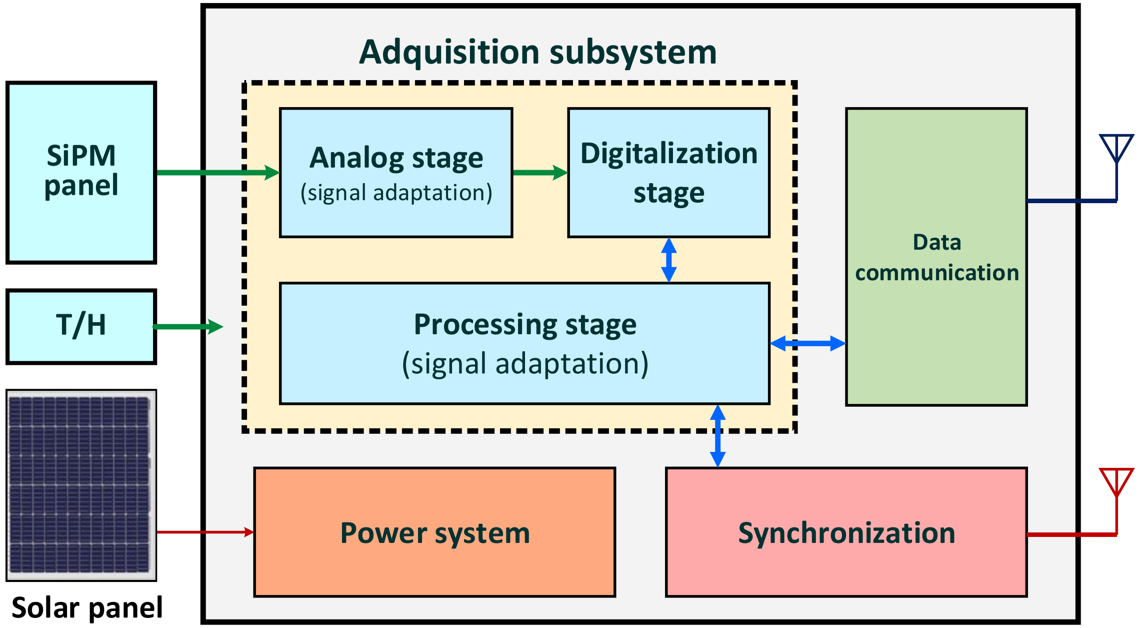


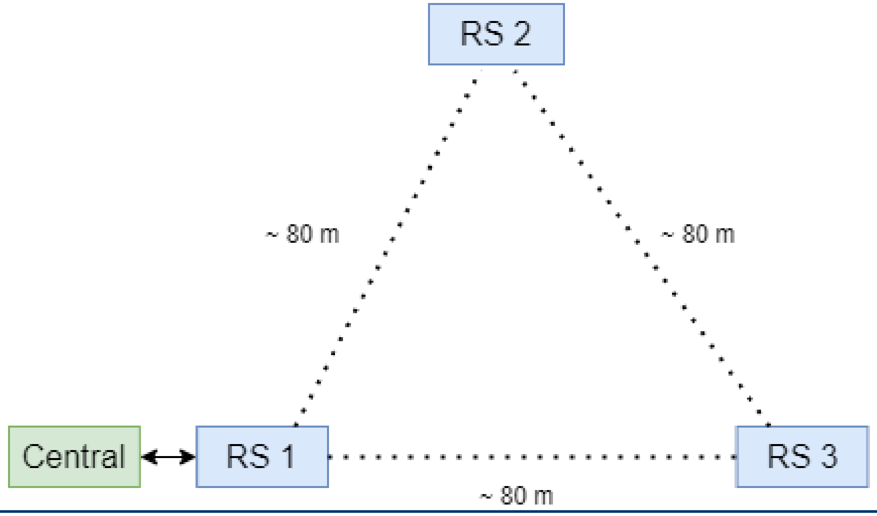
Pierre Auger Collaboration, ICRC(2021)

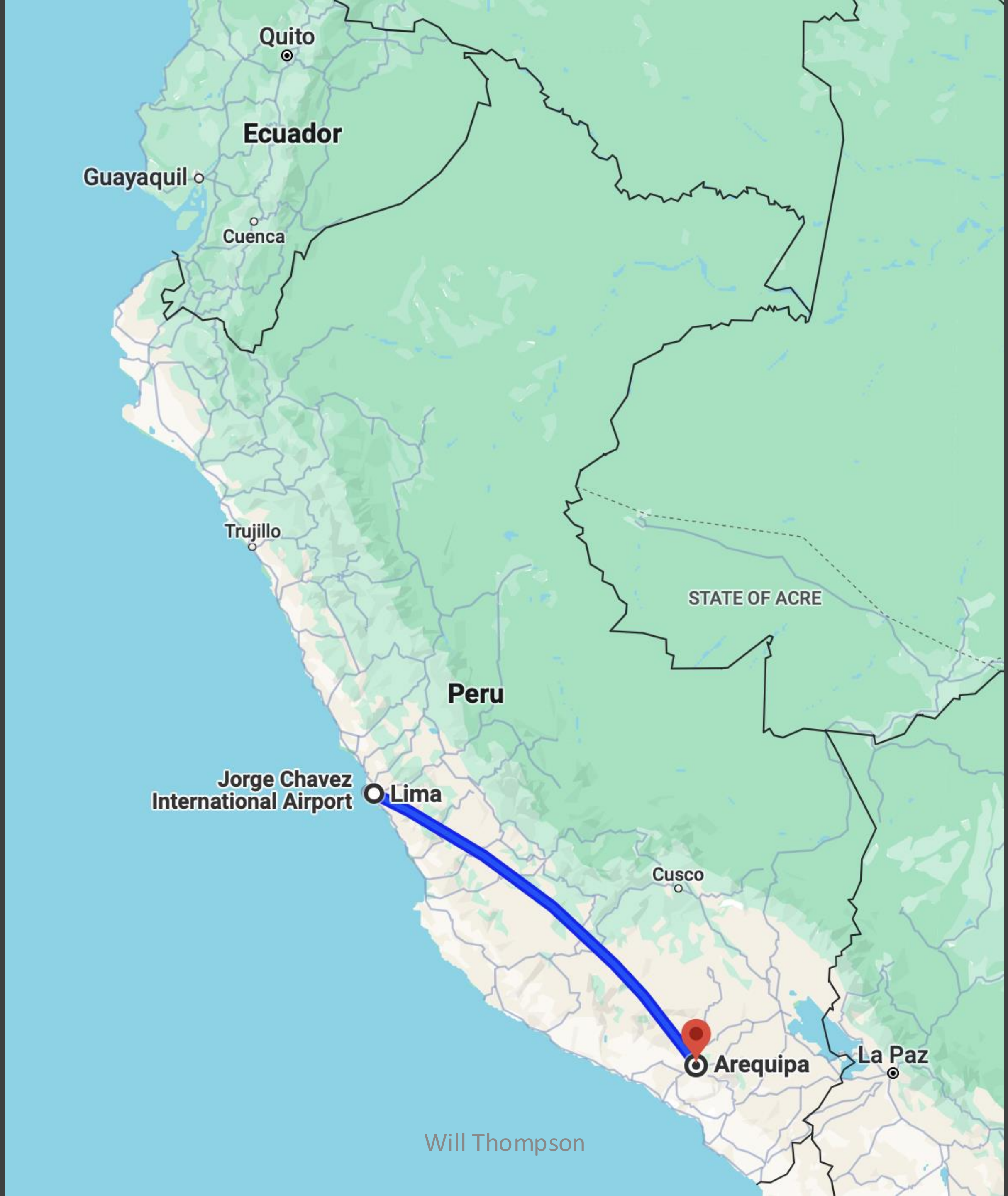
- Observatory is an array of thousands of individual detectors
- Two designs under consideration:
  - Plastic scintillator panels
  - Water Cherenkov tanks

Hardware Development @ UTEC & PUCP

- Timing system is a primary challenge
    - 1° pointing requires $\lesssim$ 10 ns resolution over $\mathcal{O}(\text{km}^2)$
- Wireless timing system under development at UTEC
- Scintillator & timing testbed being built at PUCP






Quito
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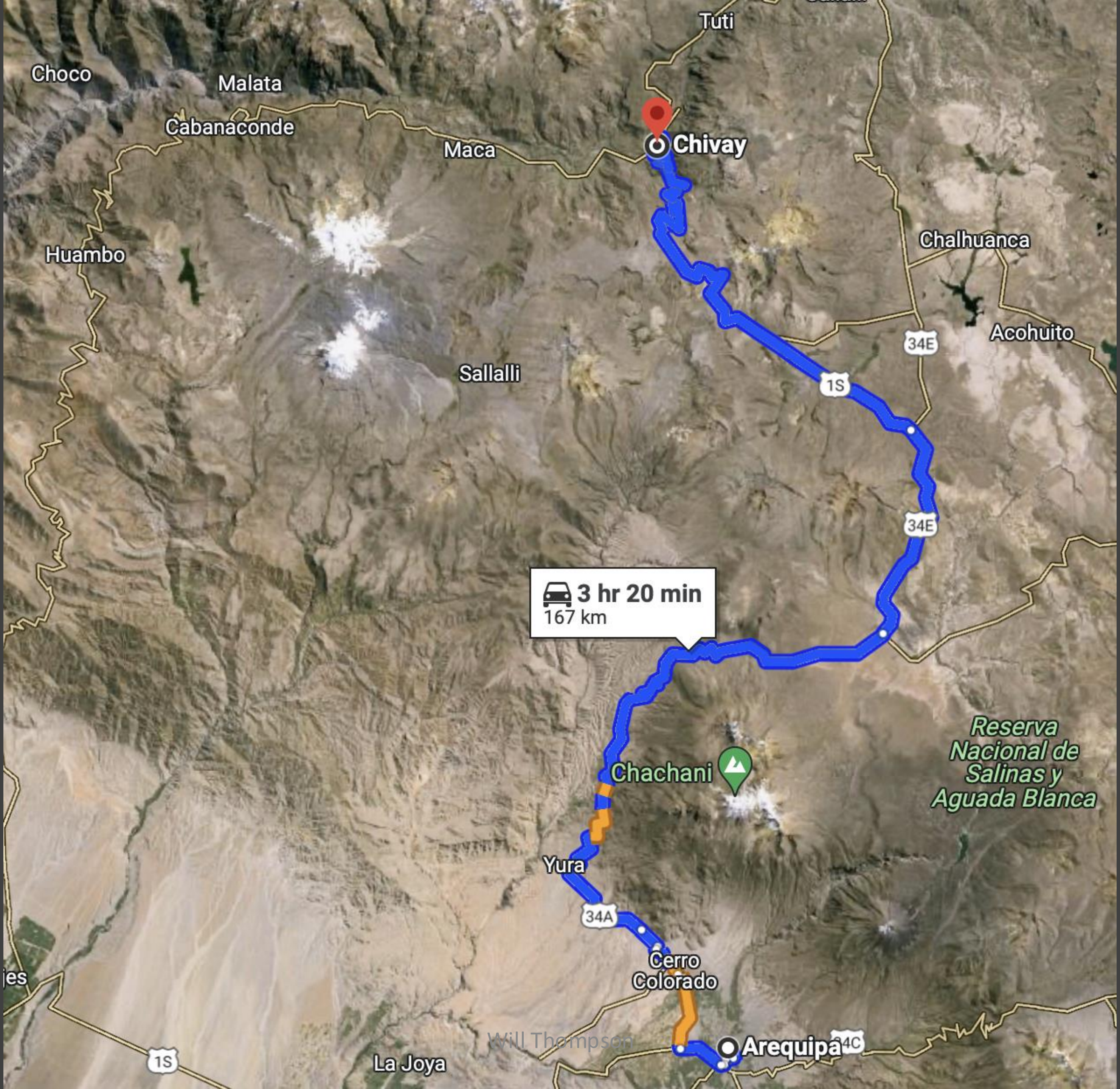
La Paz



Tuti
Choco
Malata
Cabanaconde
Maca
Chivay
Huambo
Chalhuanca
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34E
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3 hr 20 min
167 km
Reserva Nacional de Salinas y Aguada Blanca
Chachani
Yura
34A
Cerro Colorado
Arequipa
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La Joya