Simulation for the Tau Air-Shower Mountain-Based Observatory

Jeff Lazar on behalf of TAMBO

01 Oct., 2024

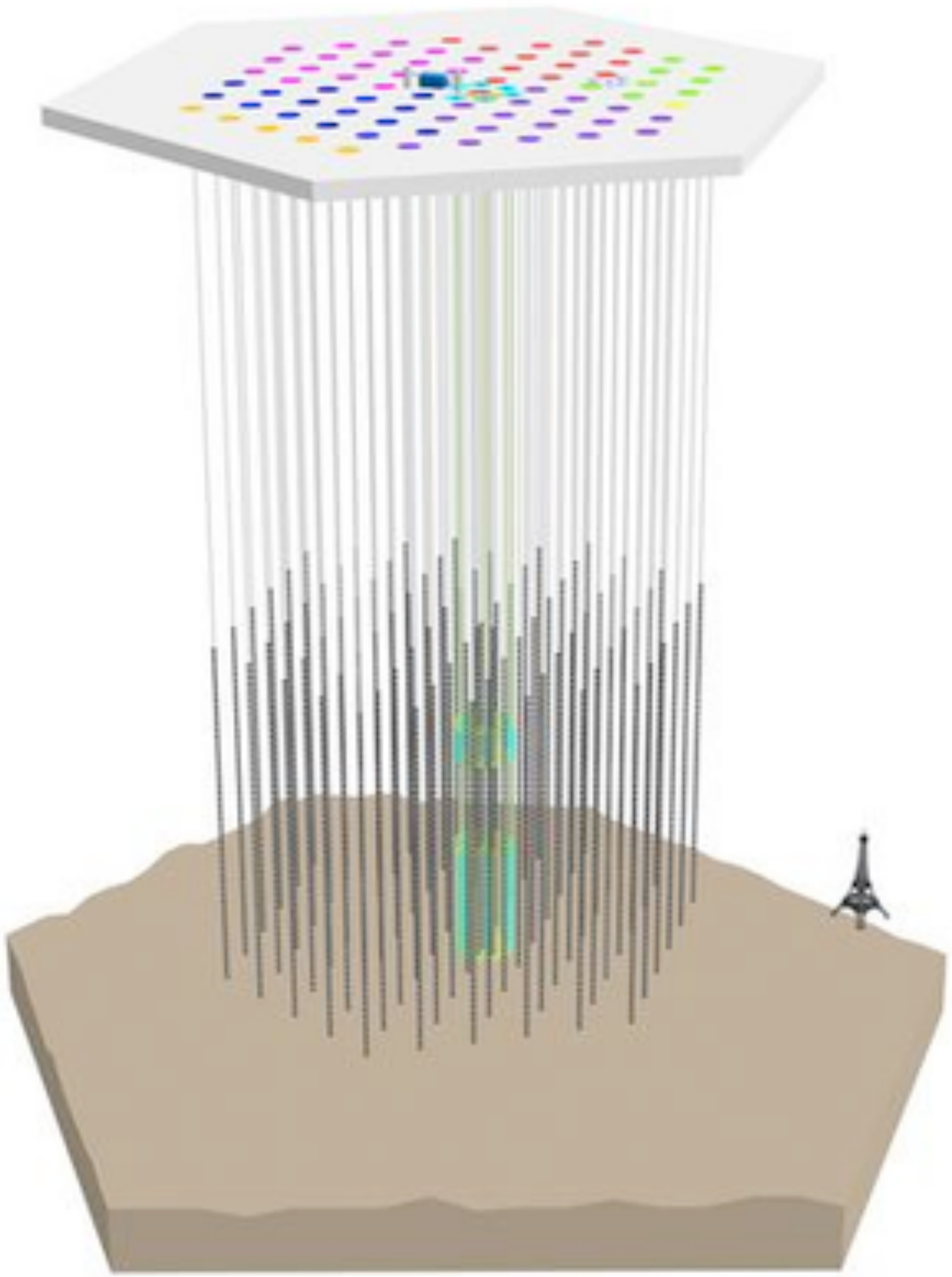
JuliaHEP 2024

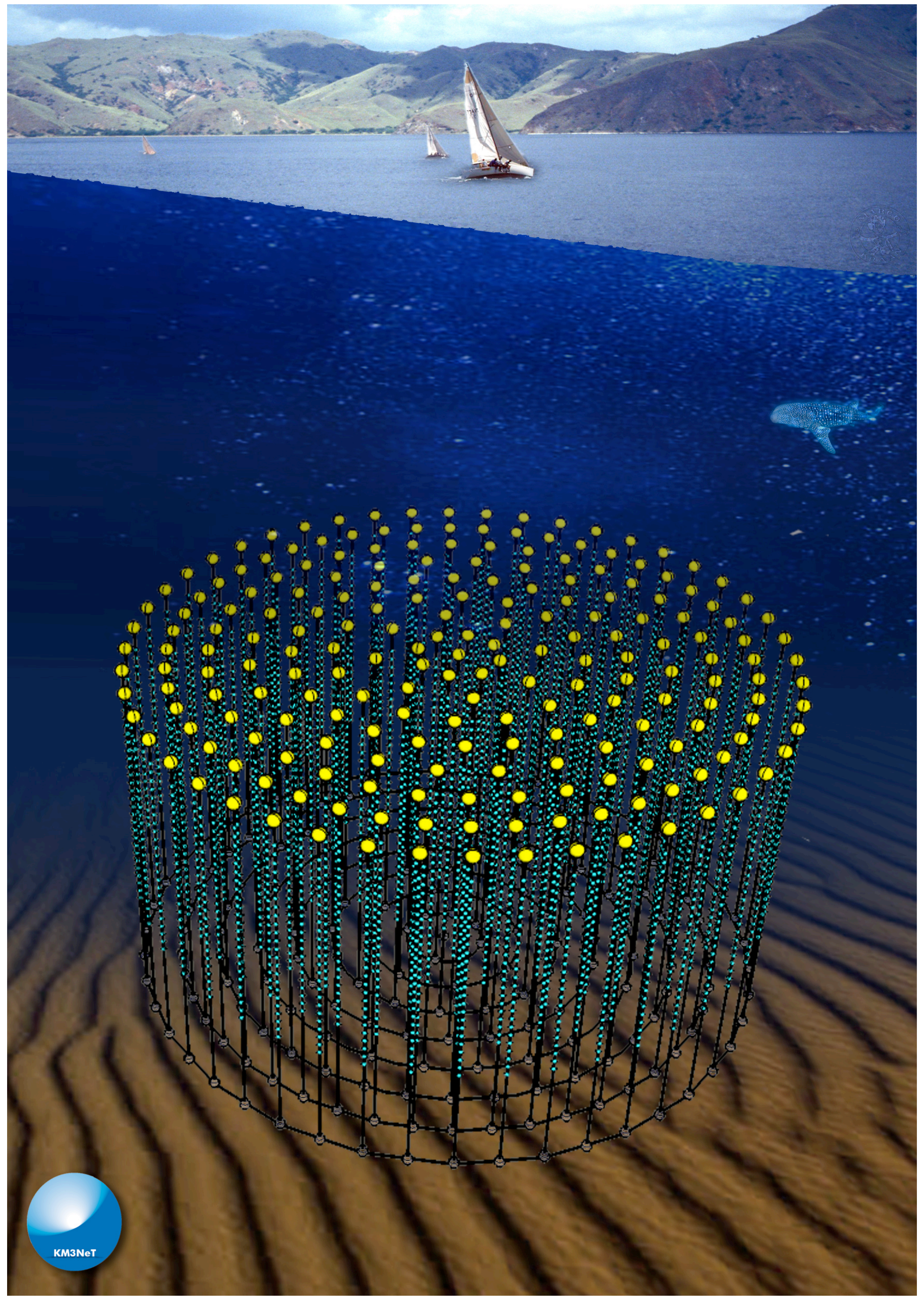
Geneva, Switzerland

Outline

- Introduction to neutrino astronomy
- Introduction to the Tau Air-Shower Mountain-Based Observatory (TAMBO)
- The TAMBO simulation stack
- TAMBO status and prospects
- Final comments about Julia in neutrino astronomy

Goals of Neutrino Astro

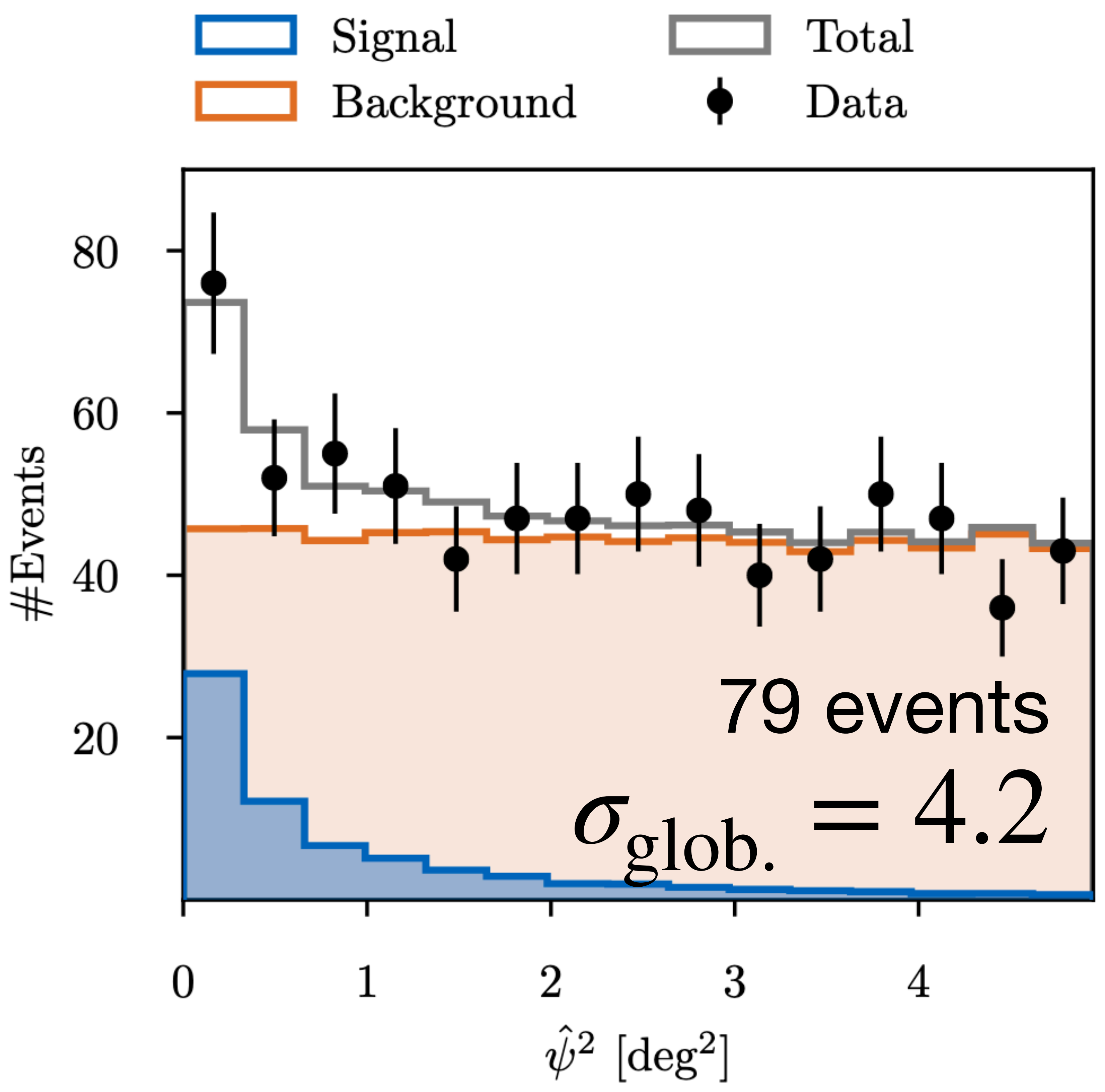




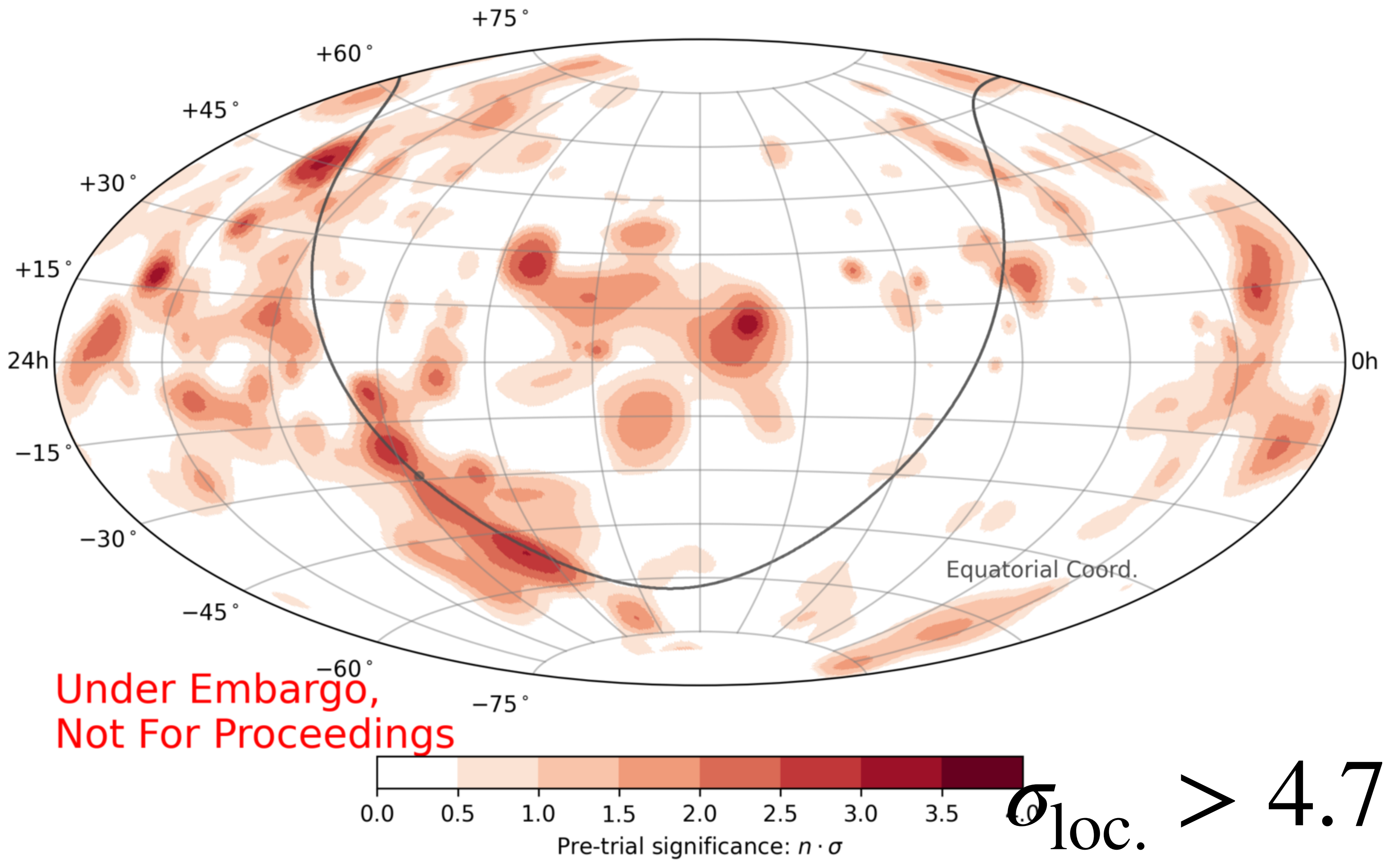
- Cherenkov neutrino observatories use optical modules to detect charged by-products of neutrino interaction
- Goal of detecting and **characterizing diffuse astrophysical flux** and **finding neutrino point sources**

A Decade on, We're Delivering

A Decade on, We're Delivering

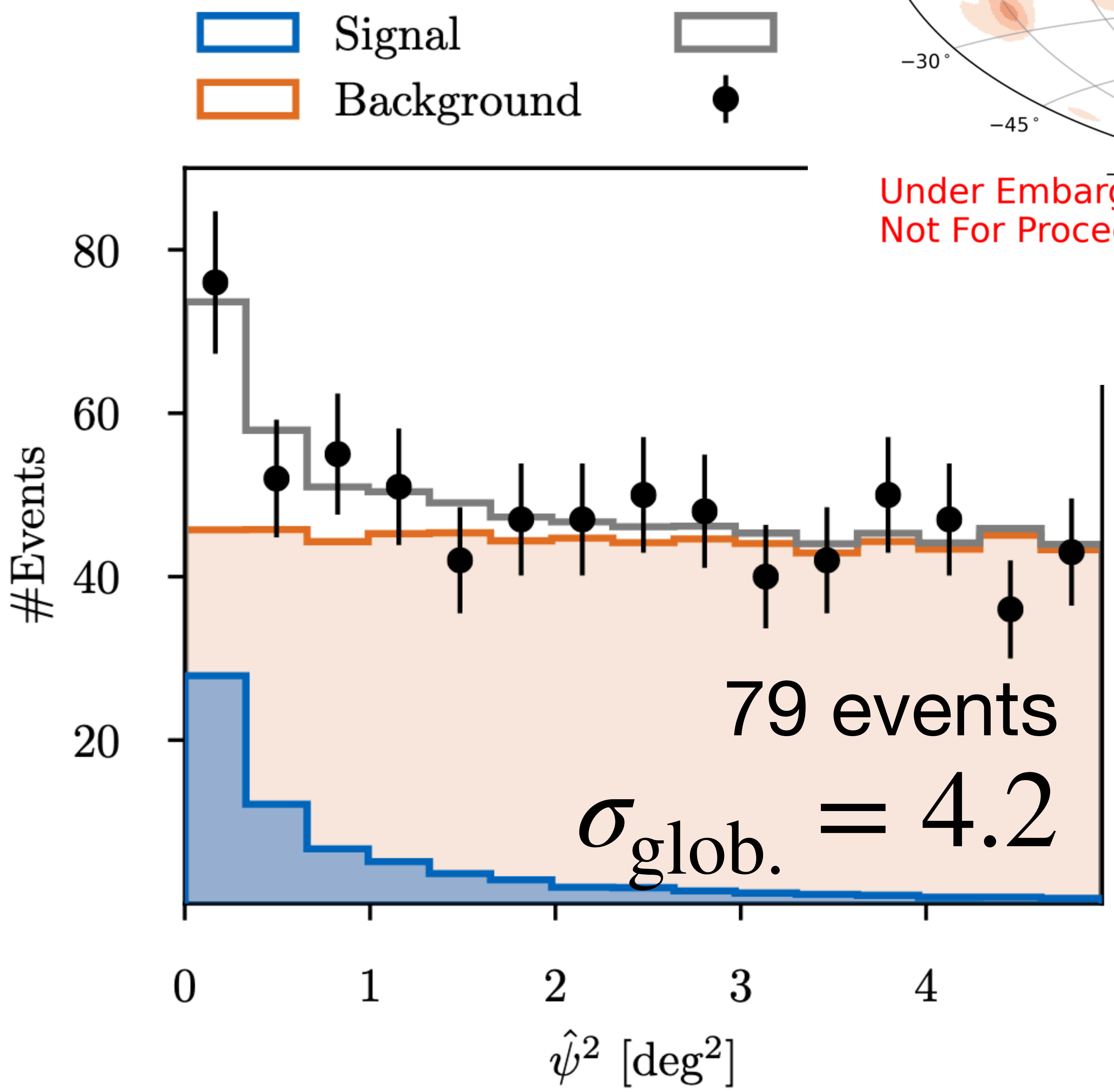


A Decade on, We’re Delivering



Under Embargo,
Not For Proceedings

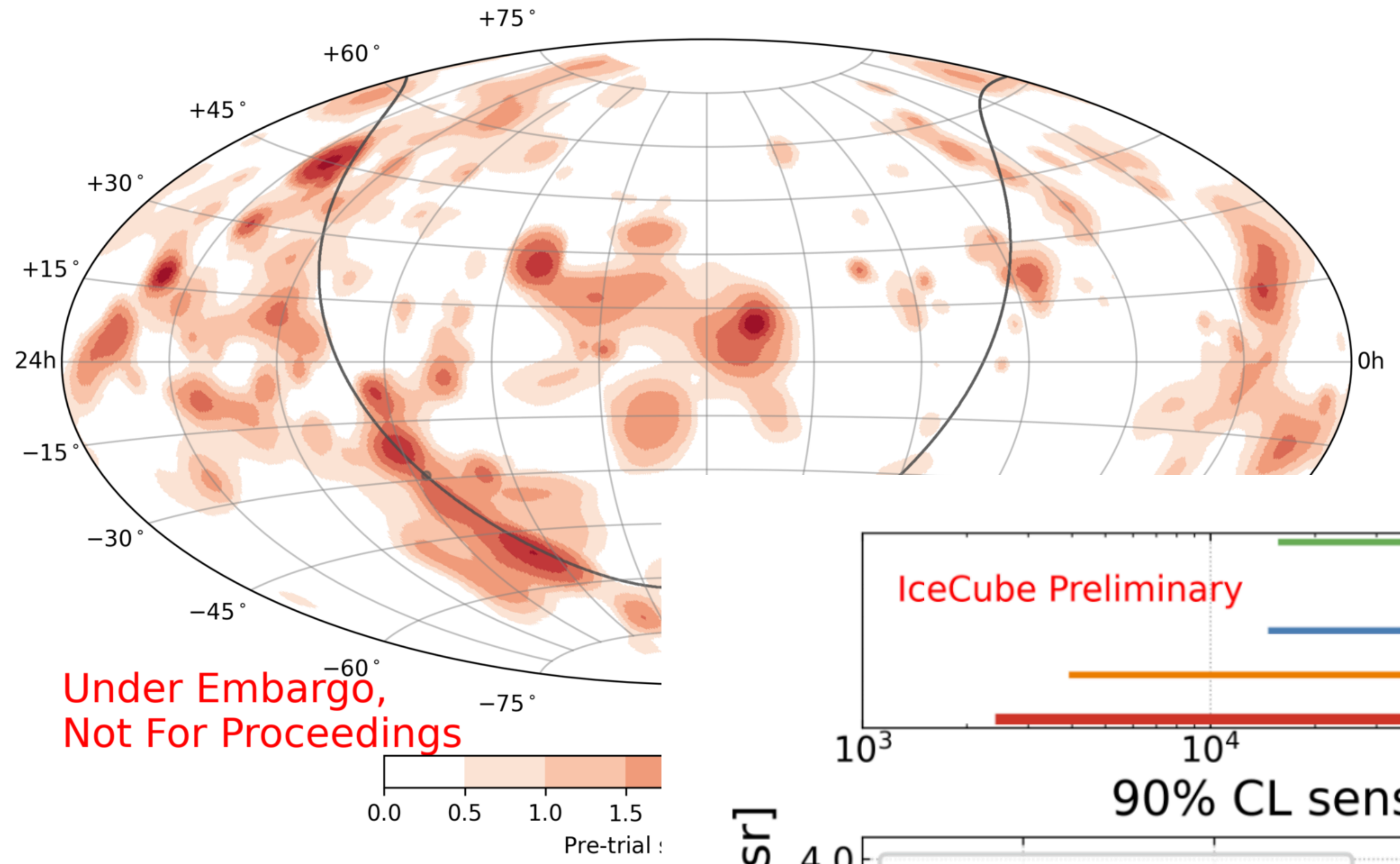
$\sigma_{\mathrm{loc.}} > 4.7$

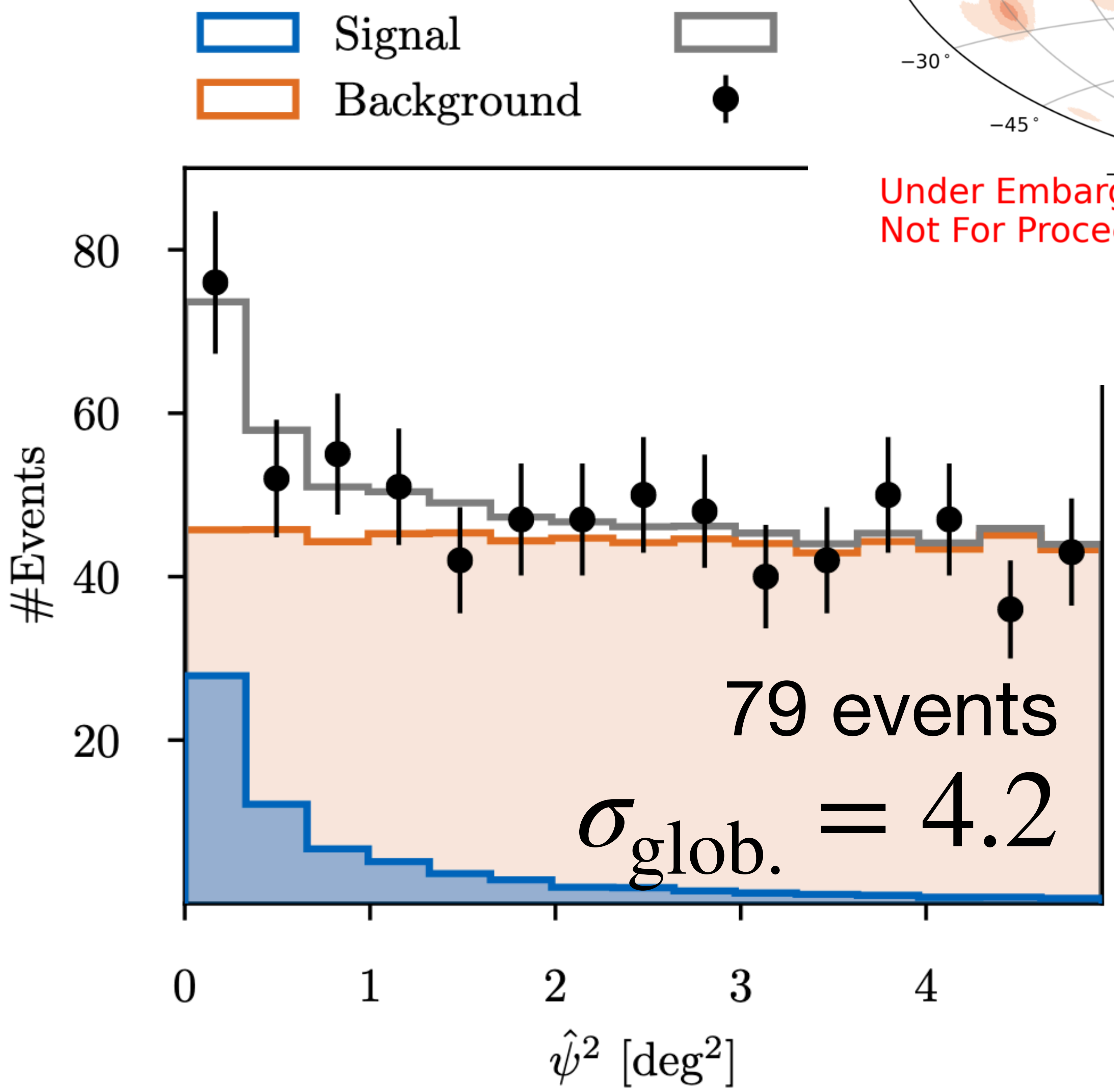


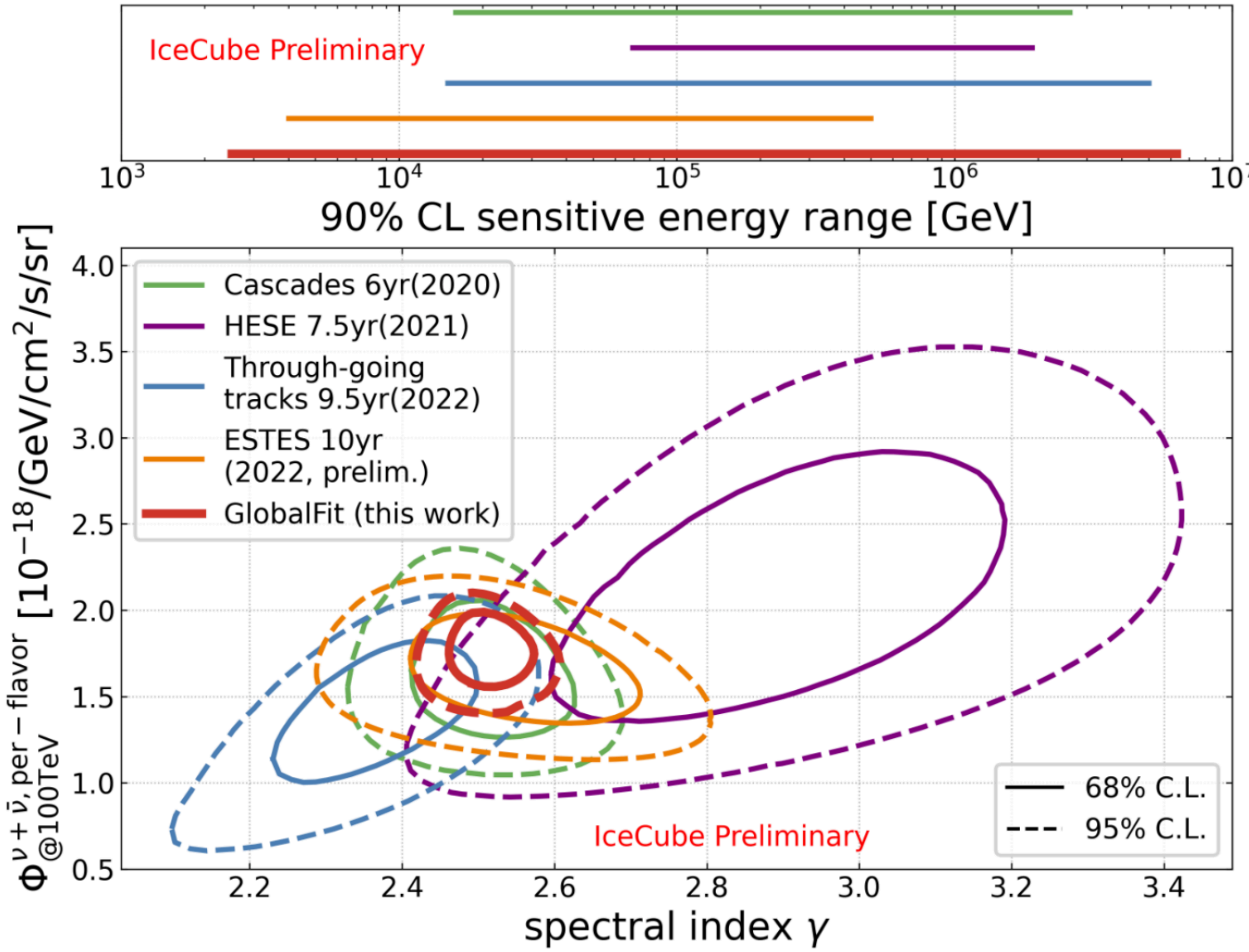
79 events

$\sigma_{\mathrm{glob.}} = 4.2$

A Decade on, We're Delivering

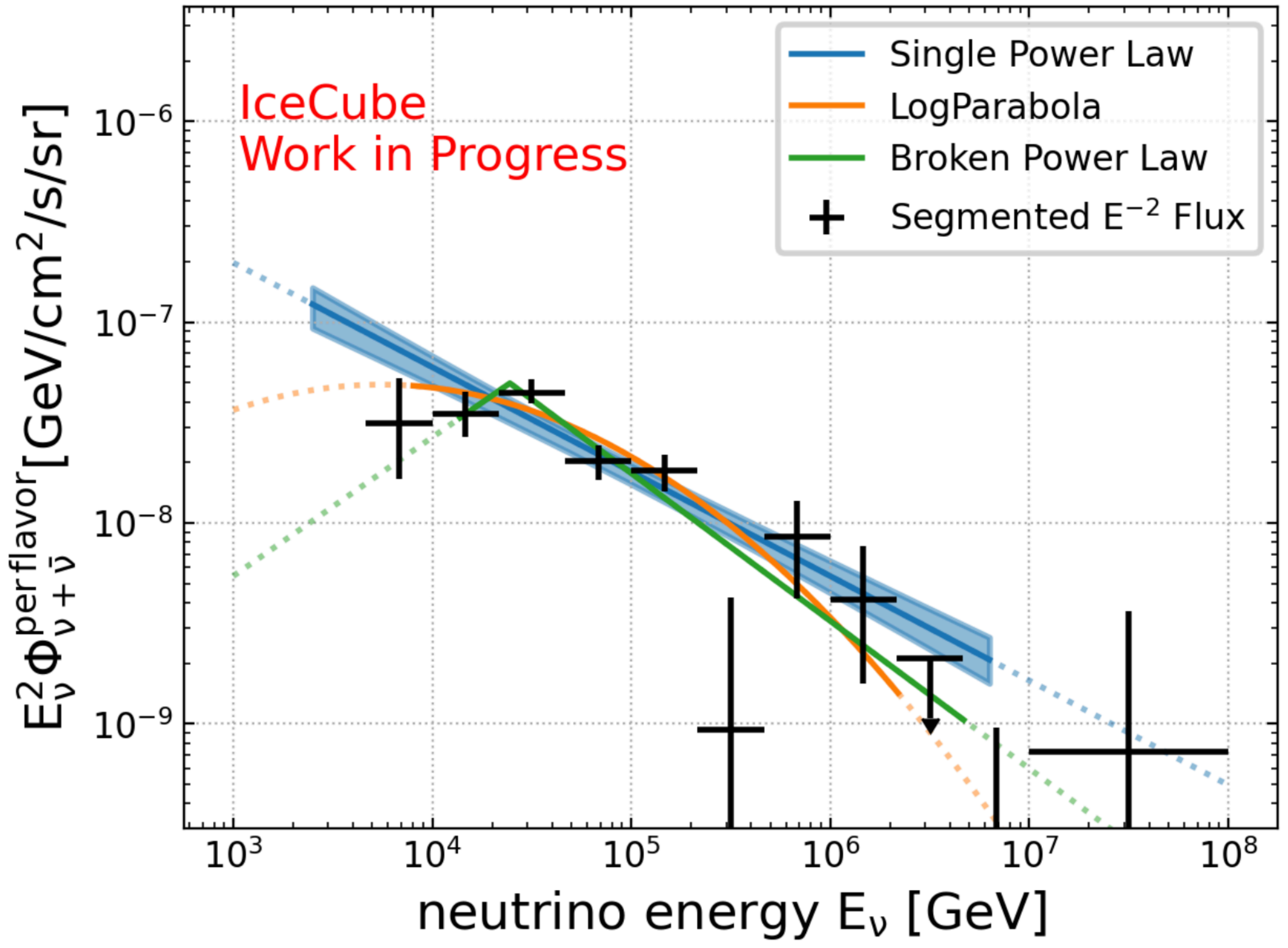


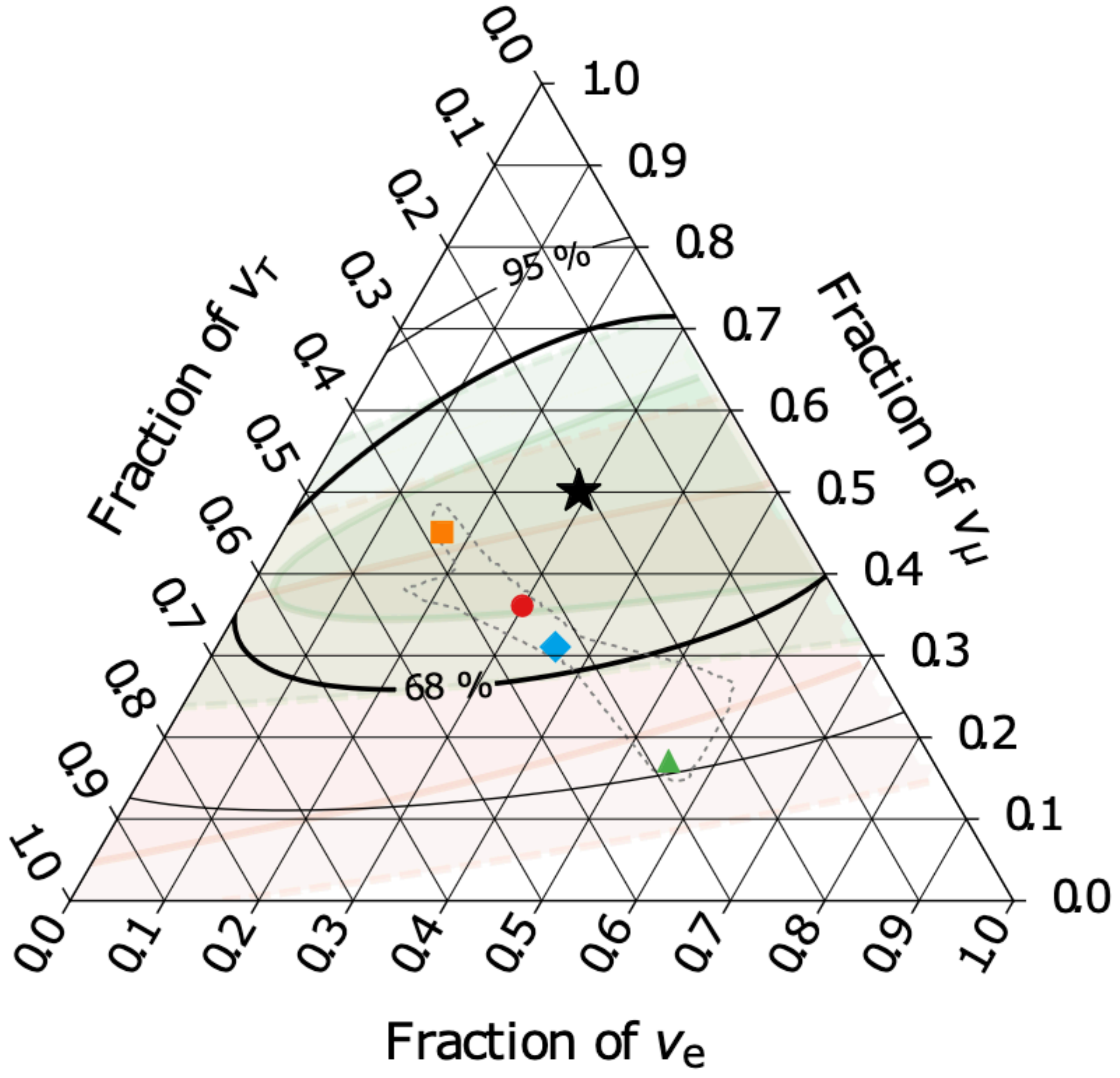


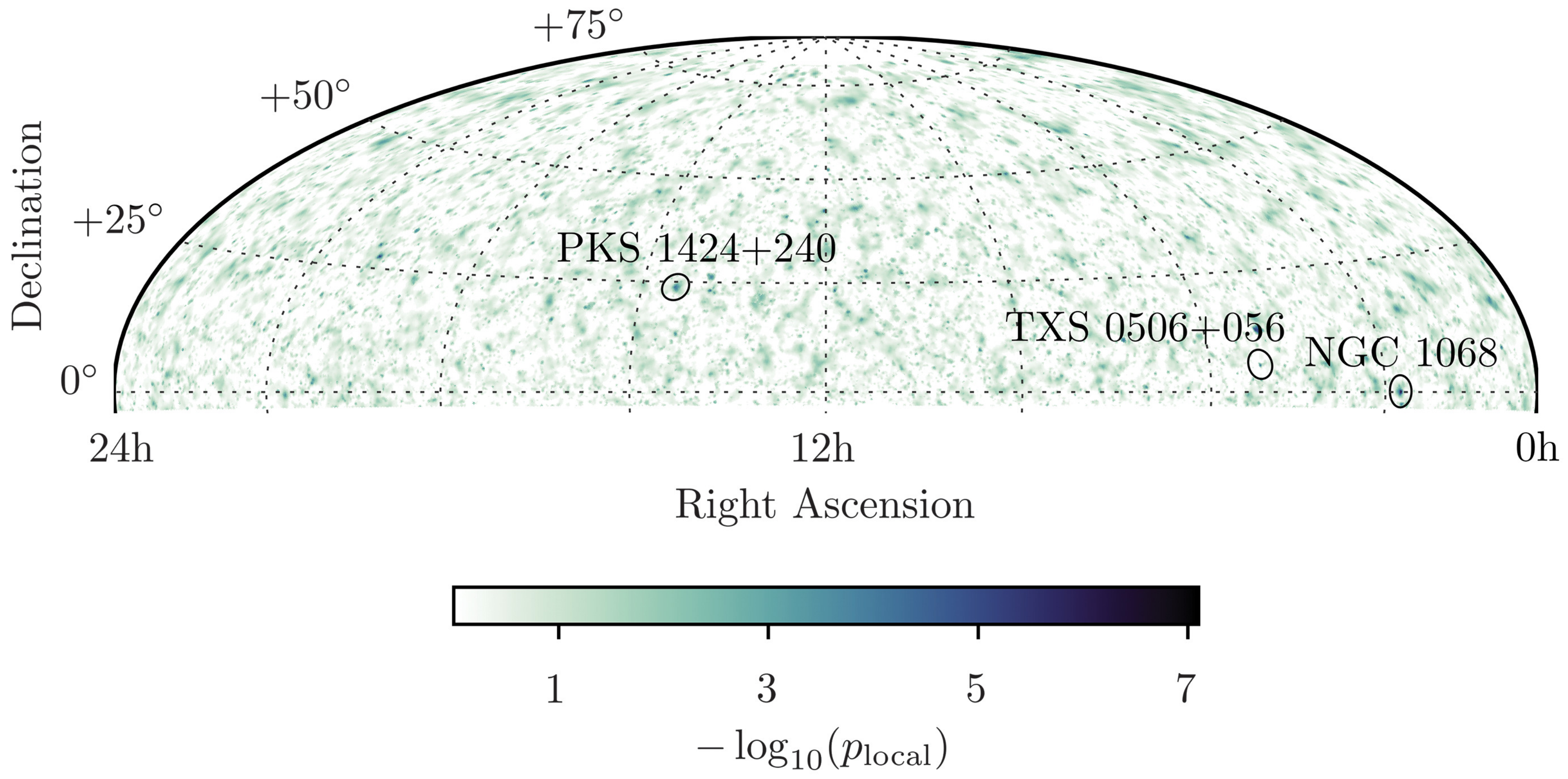


A Decade on, We're Delivering

Roadmap Towards Future Discovery







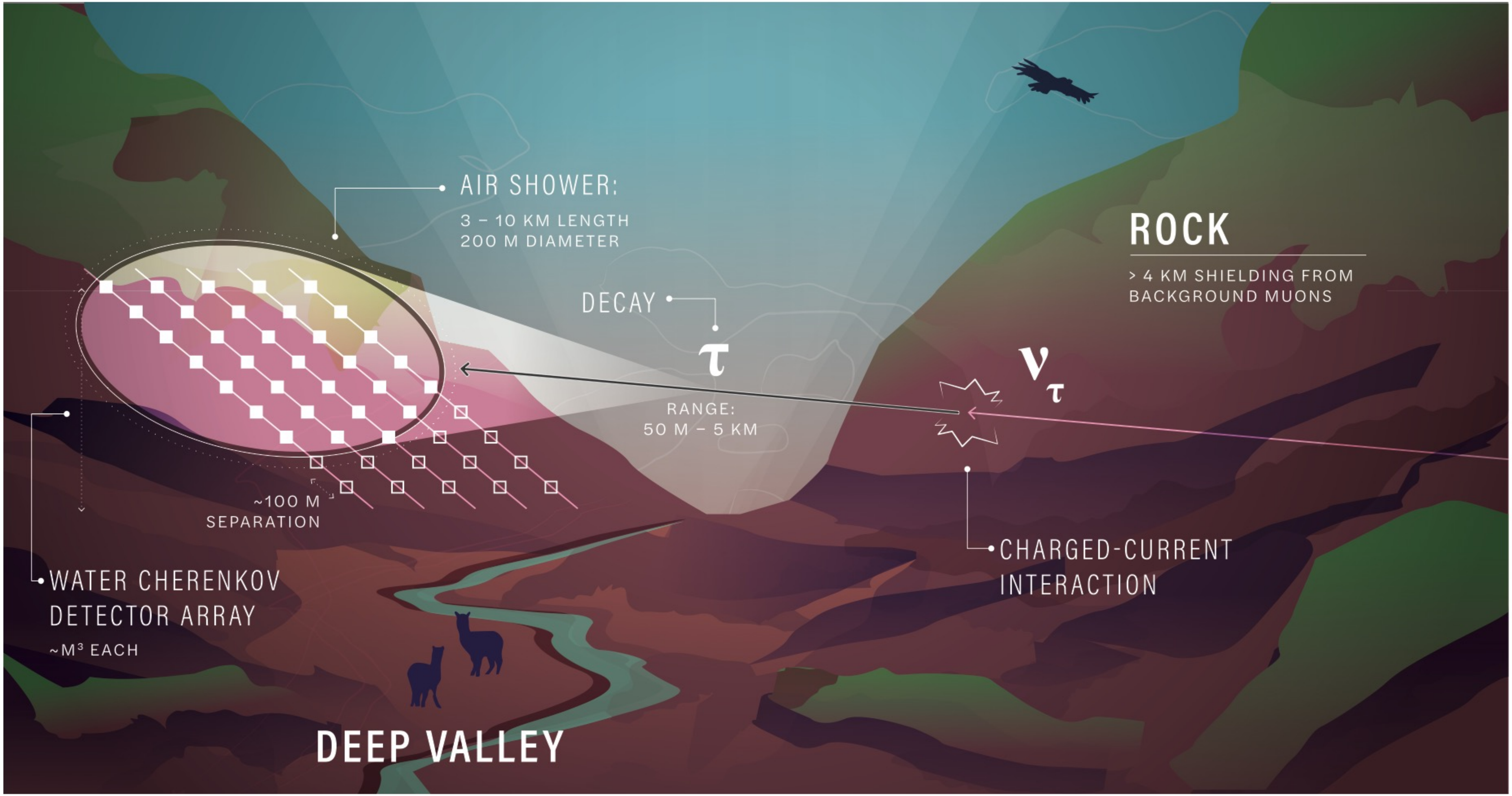
- Beginning to see features in spectrum
- ***Challenge***: Hard to go beyond current energy range due to large backgrounds and low stats

- Flavor degeneracy along ν_e / ν_τ axes
- ***Challenge***: Difficult to distinguish $\tau^\pm$ at relevant energies

- Current point make up <1% of diffuse flux
- ***Challenge***: Current search strategies lead to huge trials factors

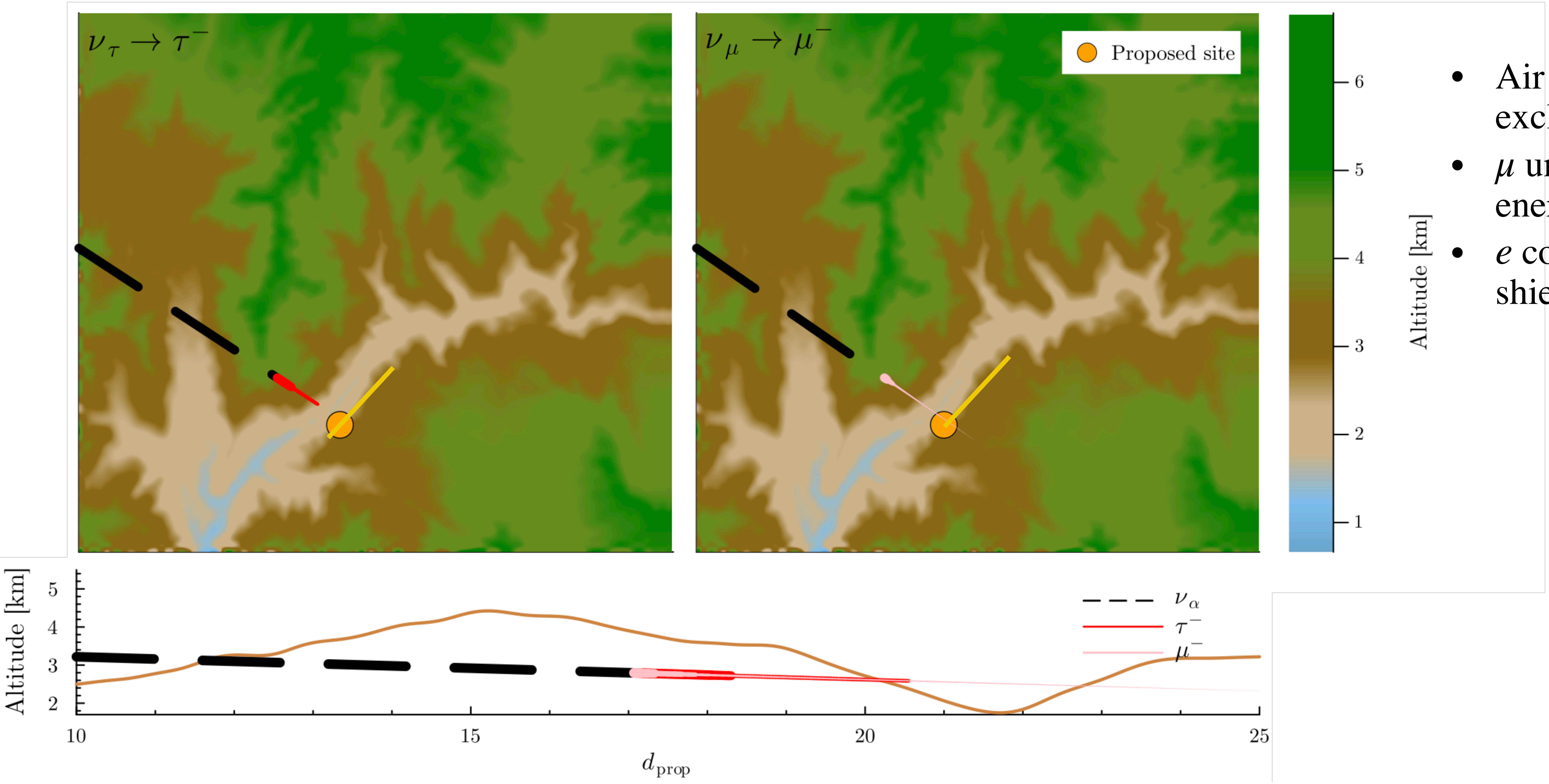
Outline

- Introduction to neutrino astronomy
- Introduction to the Tau Air-Shower Mountain-Based Observatory (TAMBO)
- The TAMBO simulation stack
- TAMBO status and prospects
- Final comments about Julia in neutrino astronomy



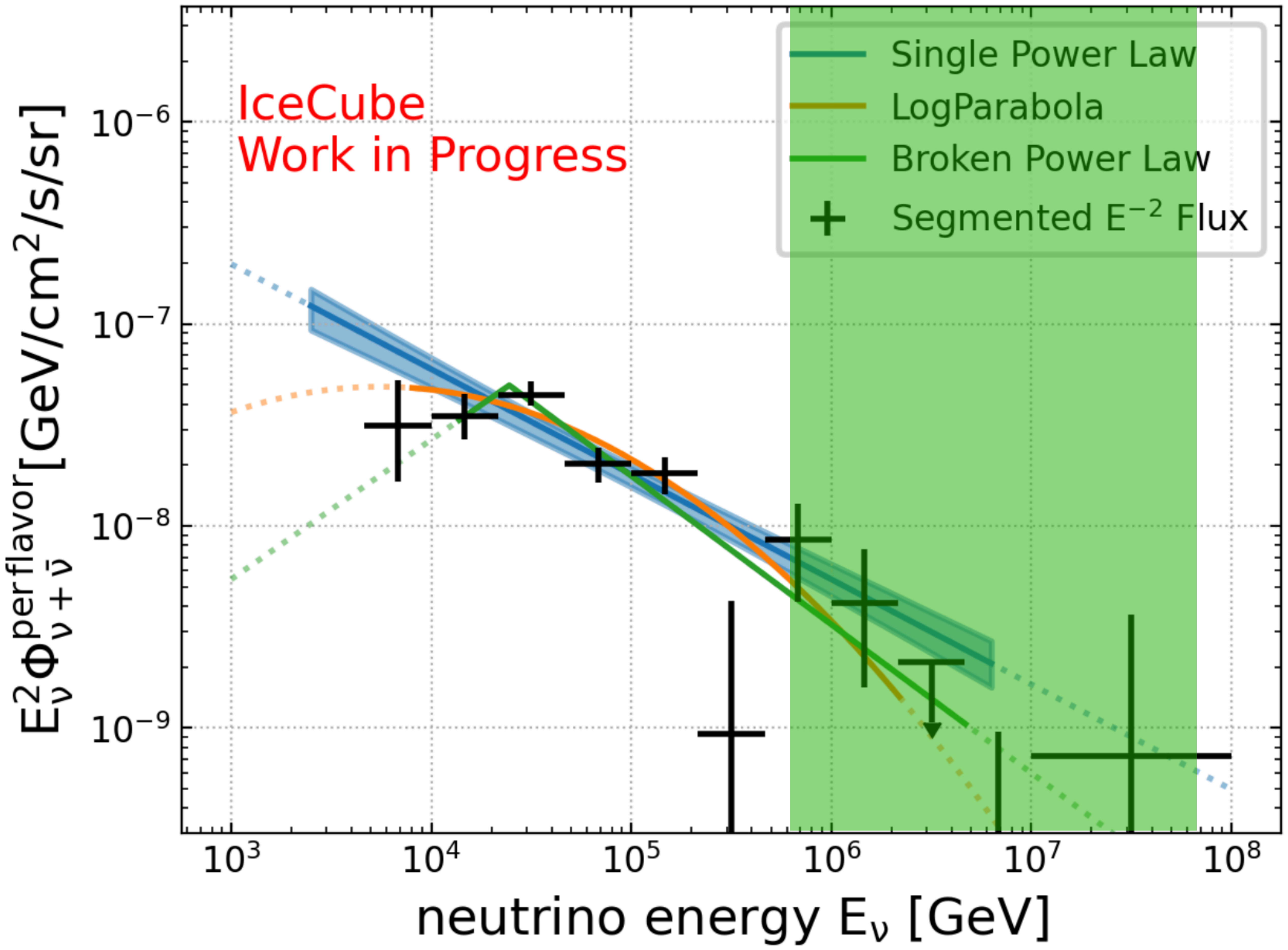
TAU AIR-SHOWER MOUNTAIN-BASED OBSERVATORY (TAMBO) · COLCA VALLEY, PERU

A ν_τ Sieve

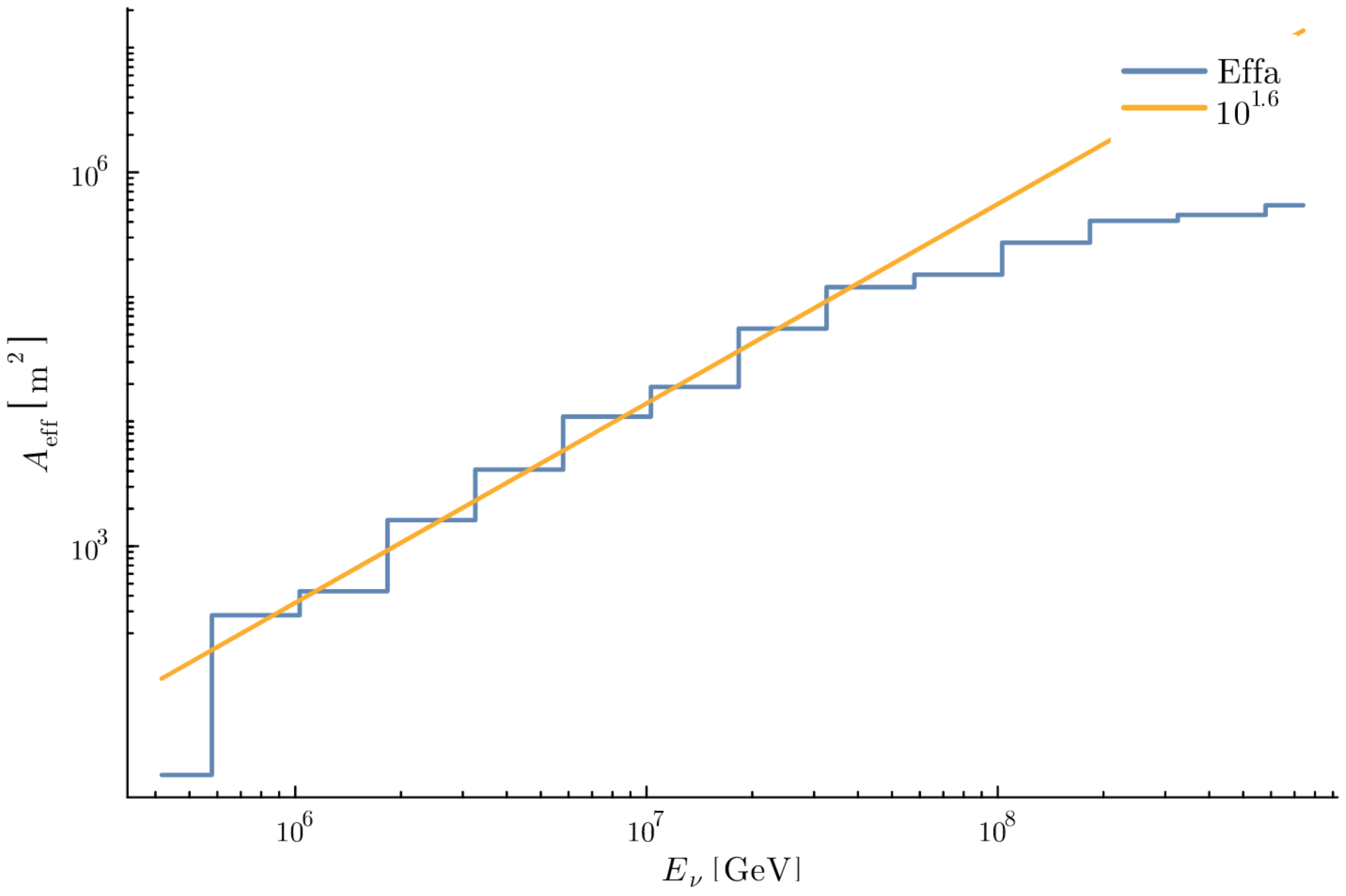


- Air shower ie exclusive to ν_τ
- μ undergoes rapid energy loss
- e completely shielded

Passing the Energy Baton



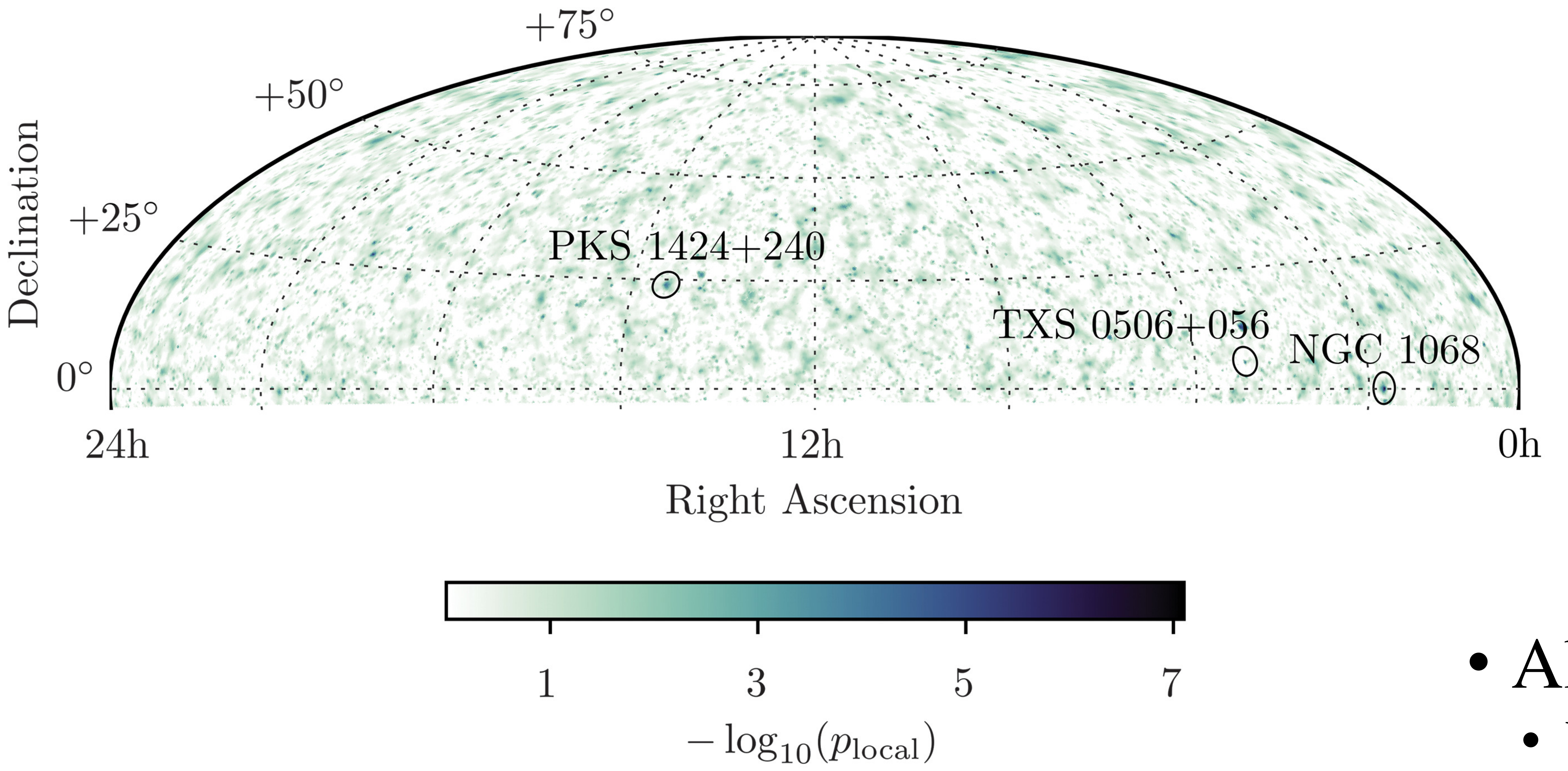
TAMBO regime

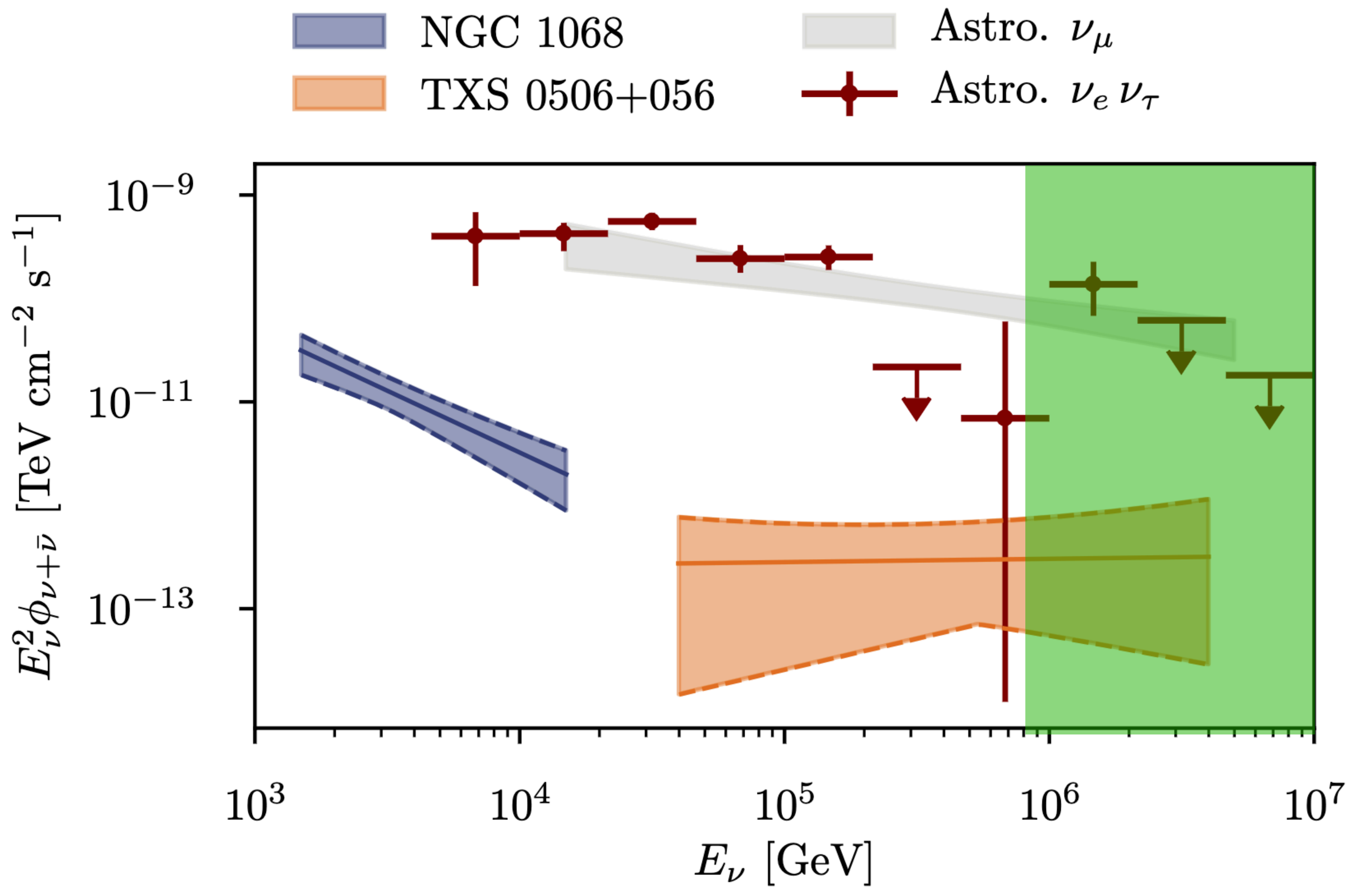


TAMBO becomes sensitive right towards the end of IceCube's sensitivity

Reducing IceCube's Trials Factor

Test type	Pre-trial p-value (p_{local})	Post-trial p-value (p_{global})
Northern Hemisphere scan	5.0×10^{-8} ($5.3\,\sigma$)	2.2×10^{-2} ($2.0\,\sigma$)





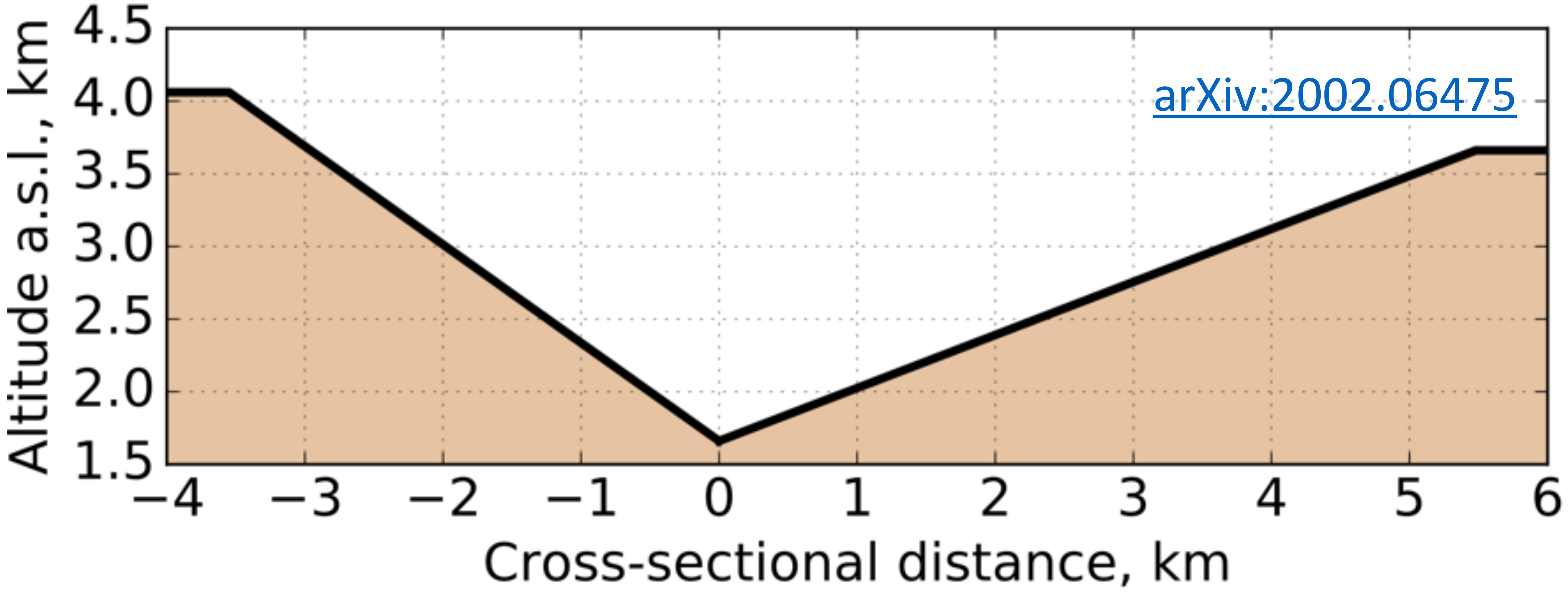
- All-sky search limits IceCube sensitivities
  - What if we knew exactly where to point?
- Low-background, astrophysical ν_τ from TAMBO remove trial factor from IceCube

Outline

- Introduction to neutrino astronomy
- Introduction to the Tau Air-Shower Mountain-Based Observatory (TAMBO)
- The TAMBO simulation stack
- TAMBO status and prospects
- Final comments about Julia in neutrino astronomy

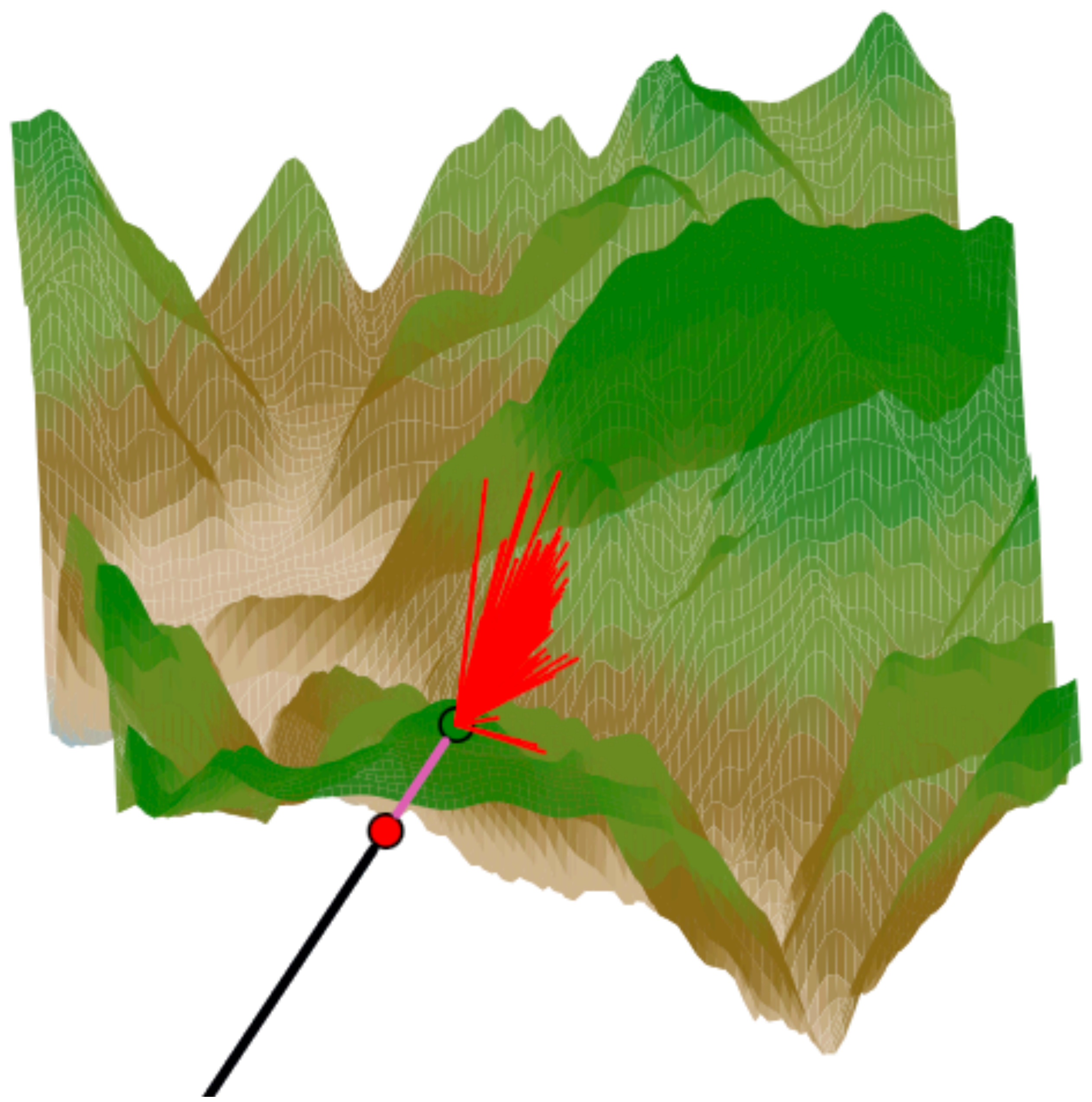
An Initial Estimation

Initial Calculation



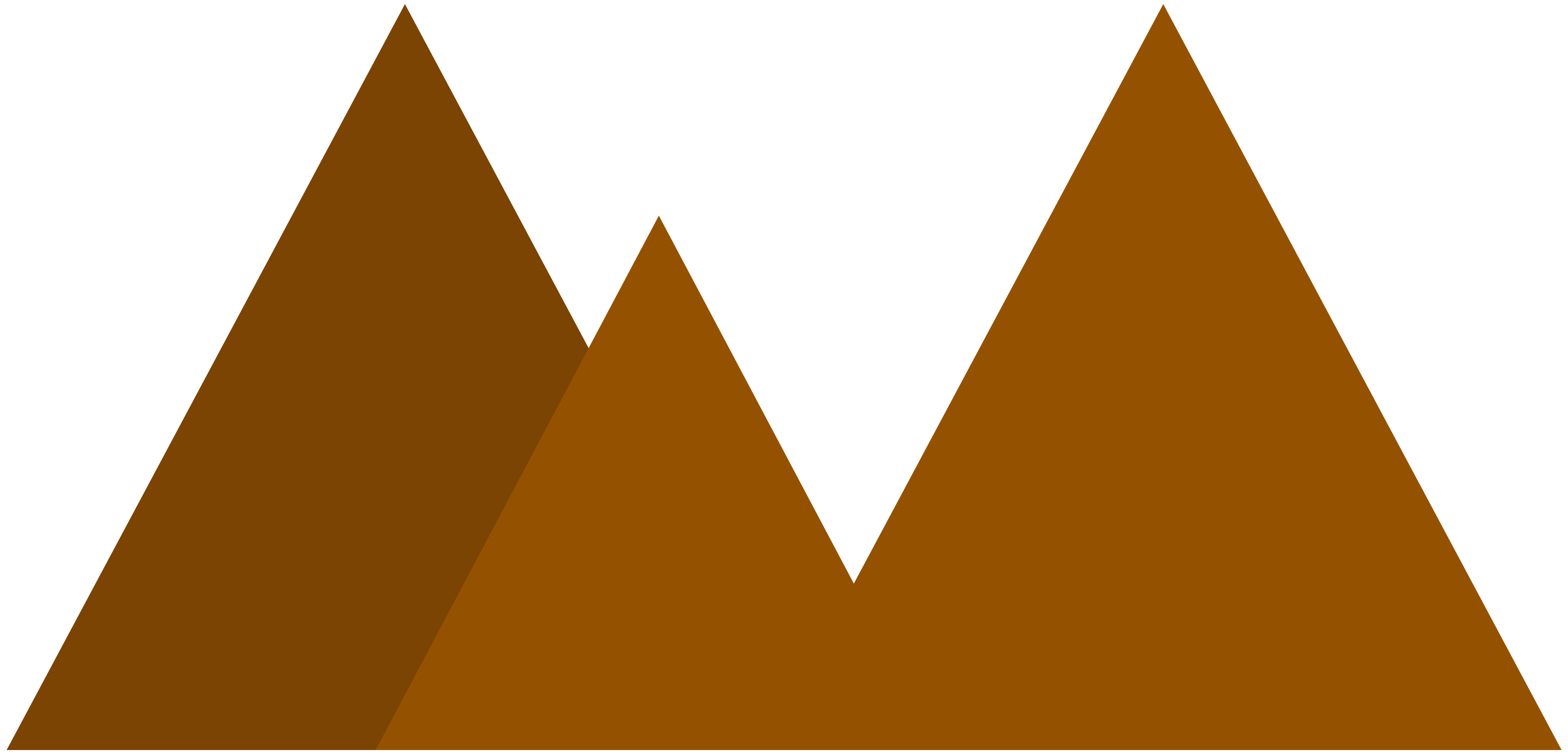
- Simplified geometry
- No treatment of $\tau^{\pm}$ energy losses
- Approximation of air-shower physics

Updated Simulation

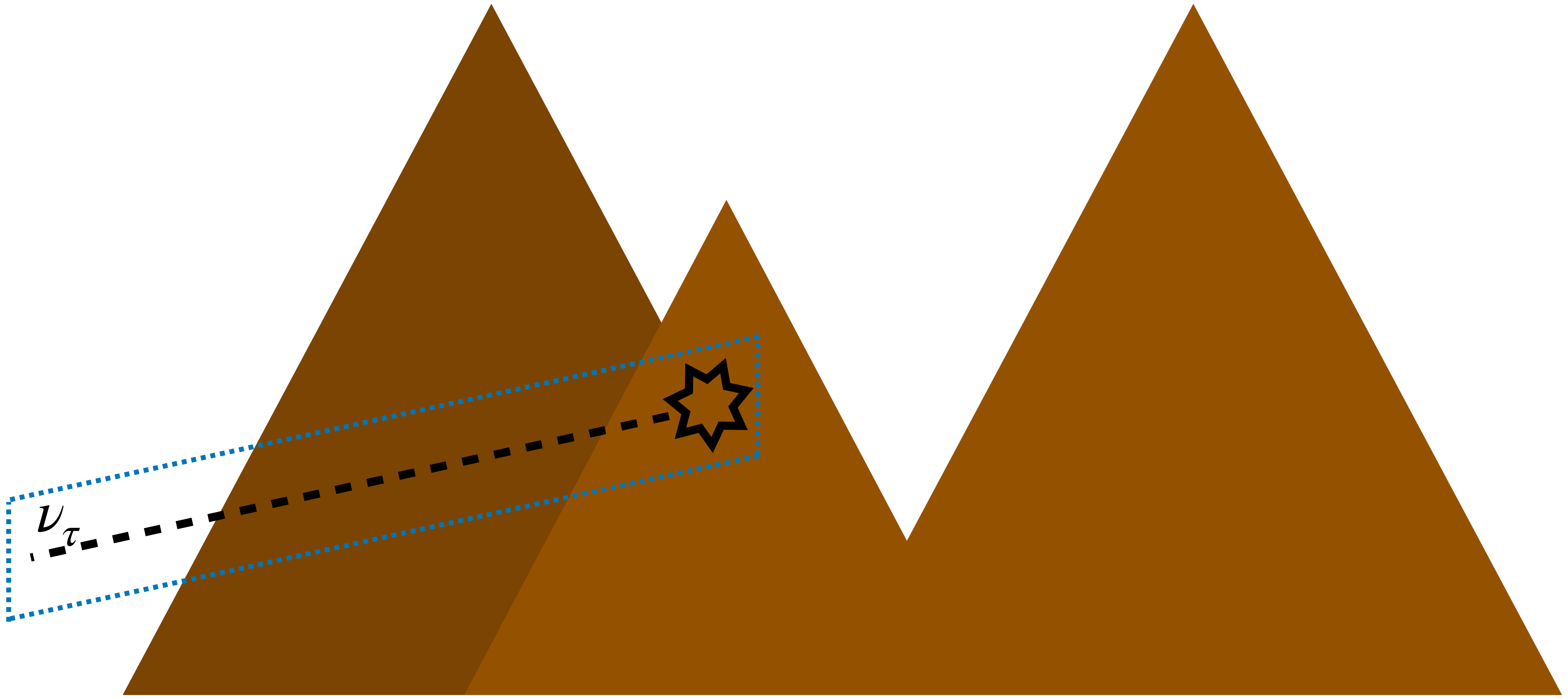


- Realistic geometry
- Full treatment of $\tau^{\pm}$ energy losses
- Air-shower simulation with CORSIKA 8

Simulation Overview

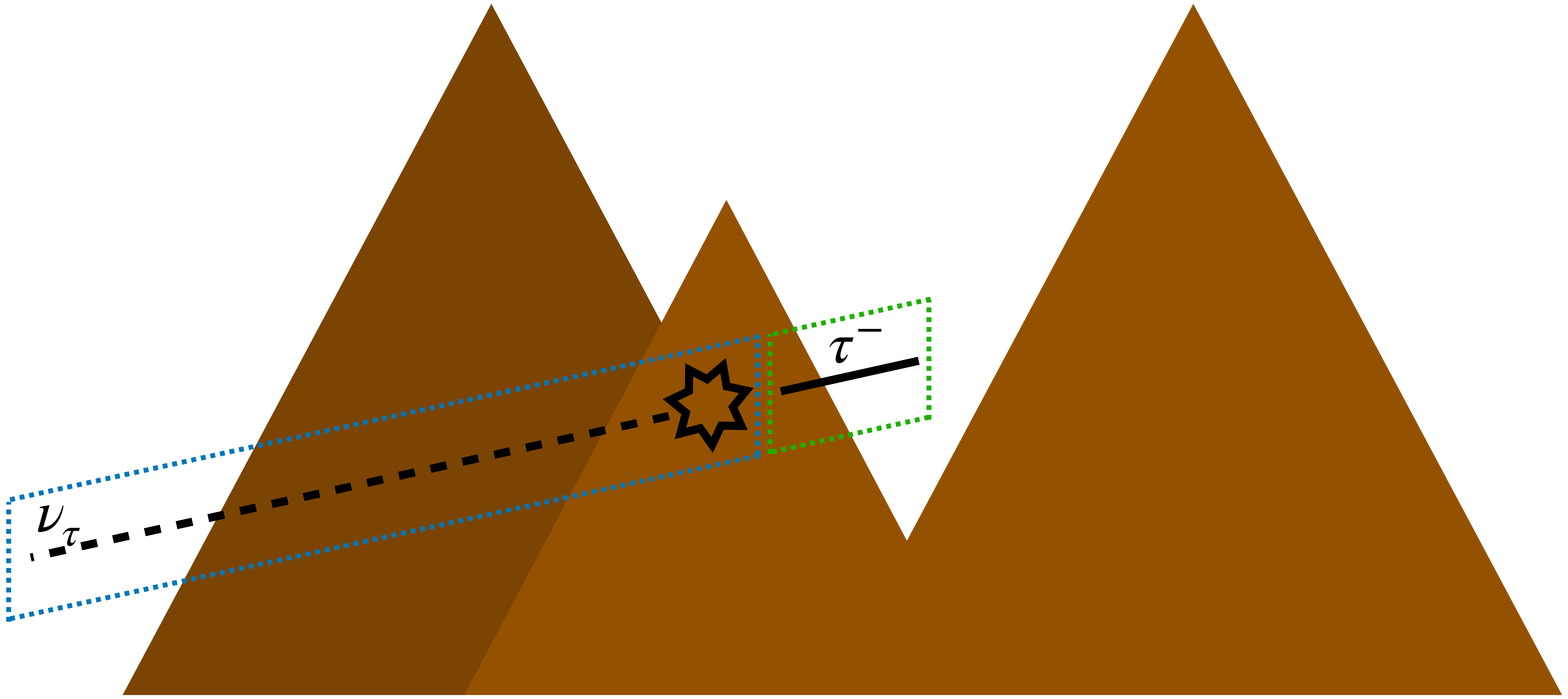


Simulation Overview



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

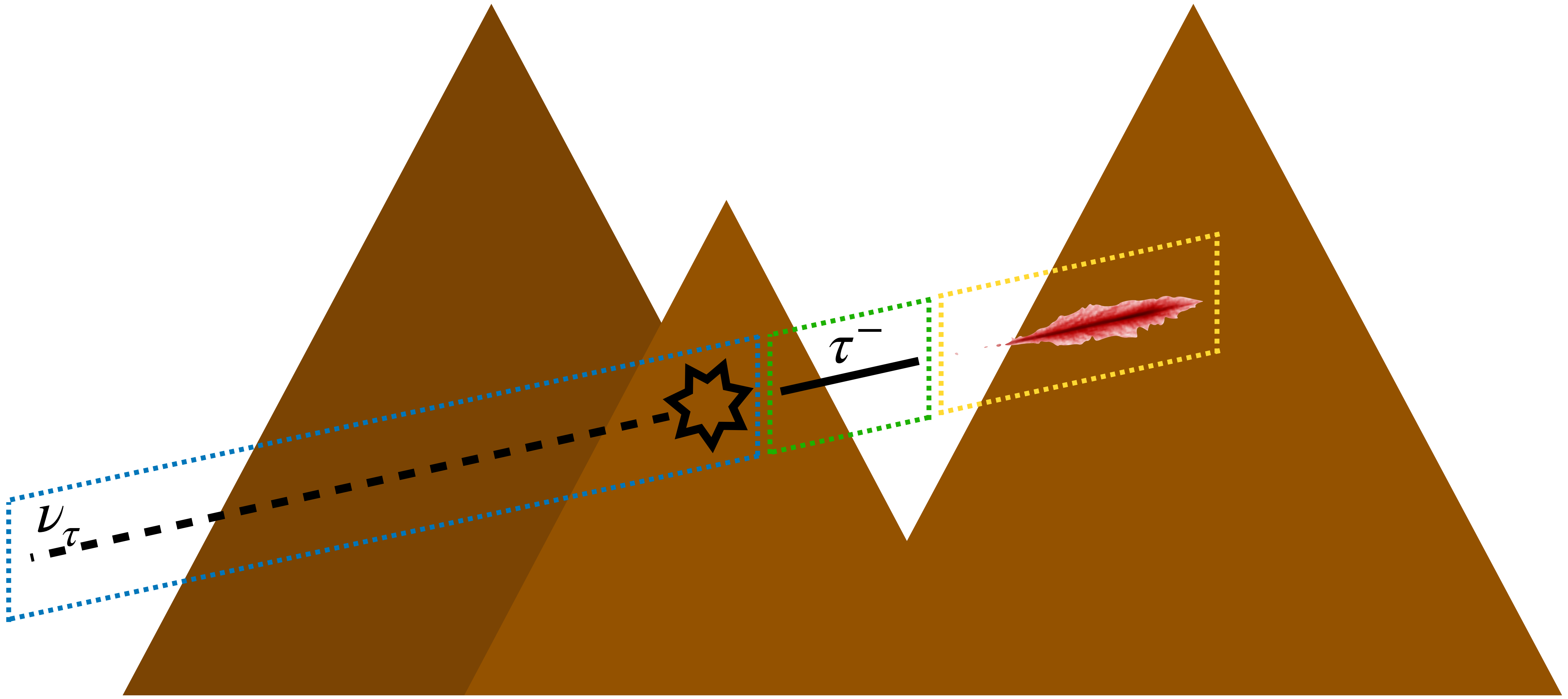
Simulation Overview



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

Simulation Overview

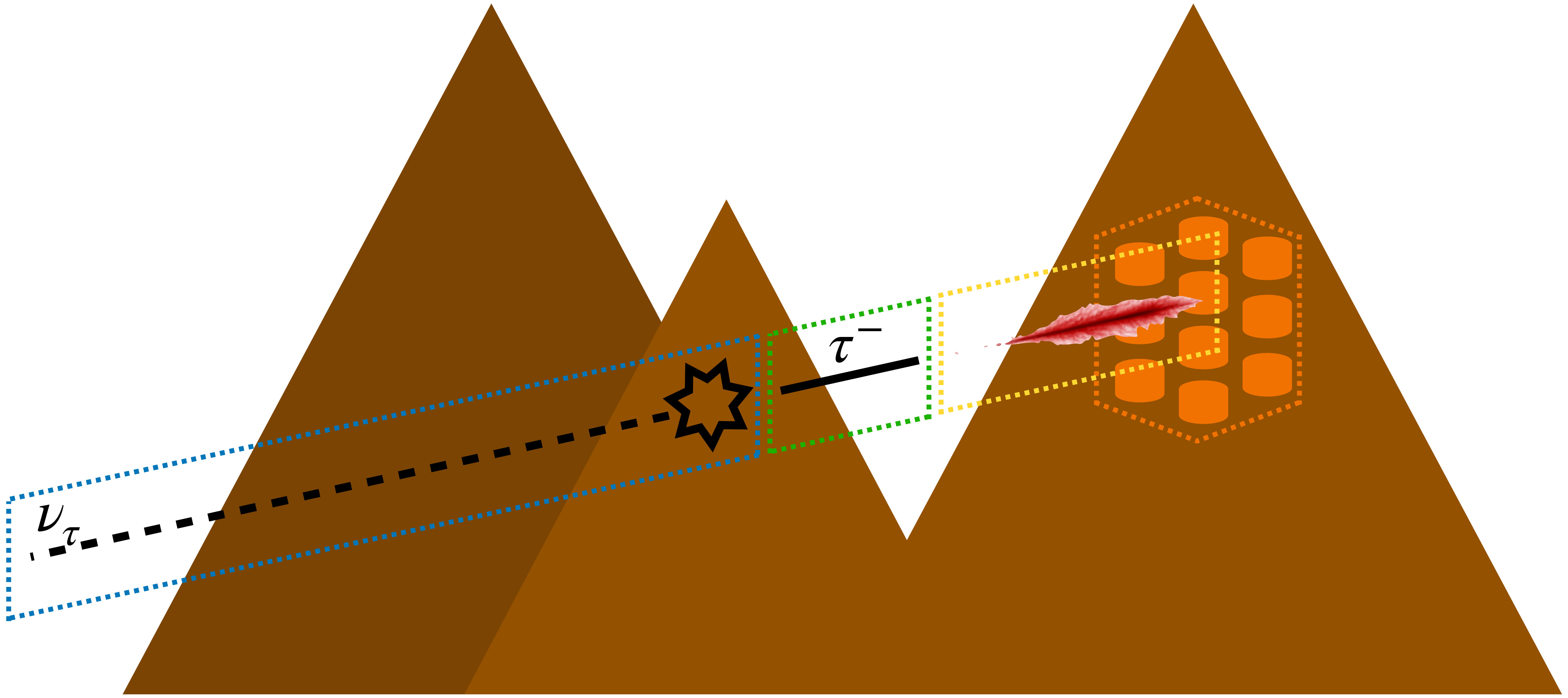


Initial neutrino injection: Select initial neutrino properties, *i.e.* energy, direction, interaction vertex, *etc*.

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

Simulation Overview



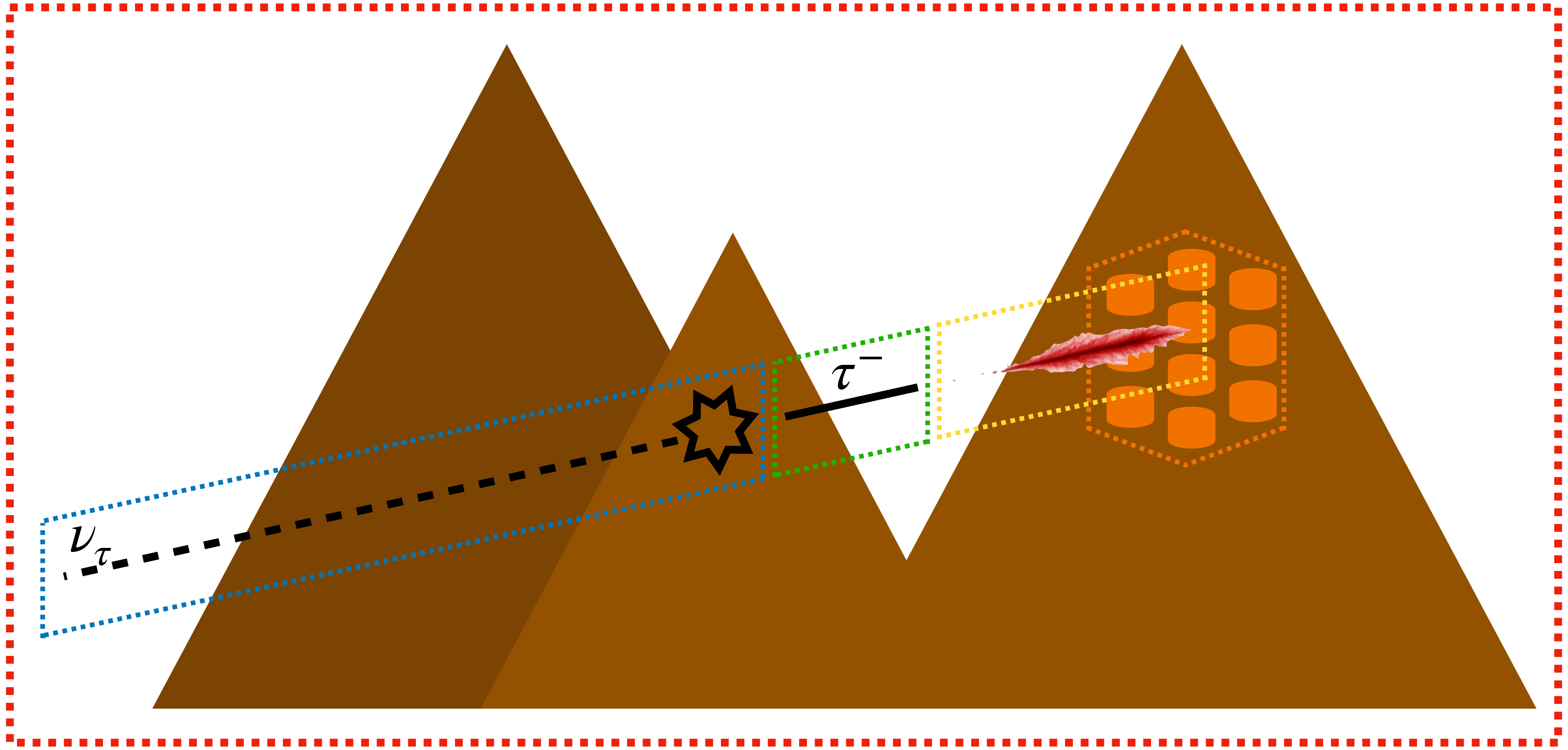
Initial neutrino injection: Select initial neutrino properties, *i.e.* energy, direction, interaction vertex, *etc*.

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

Simulation Overview



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

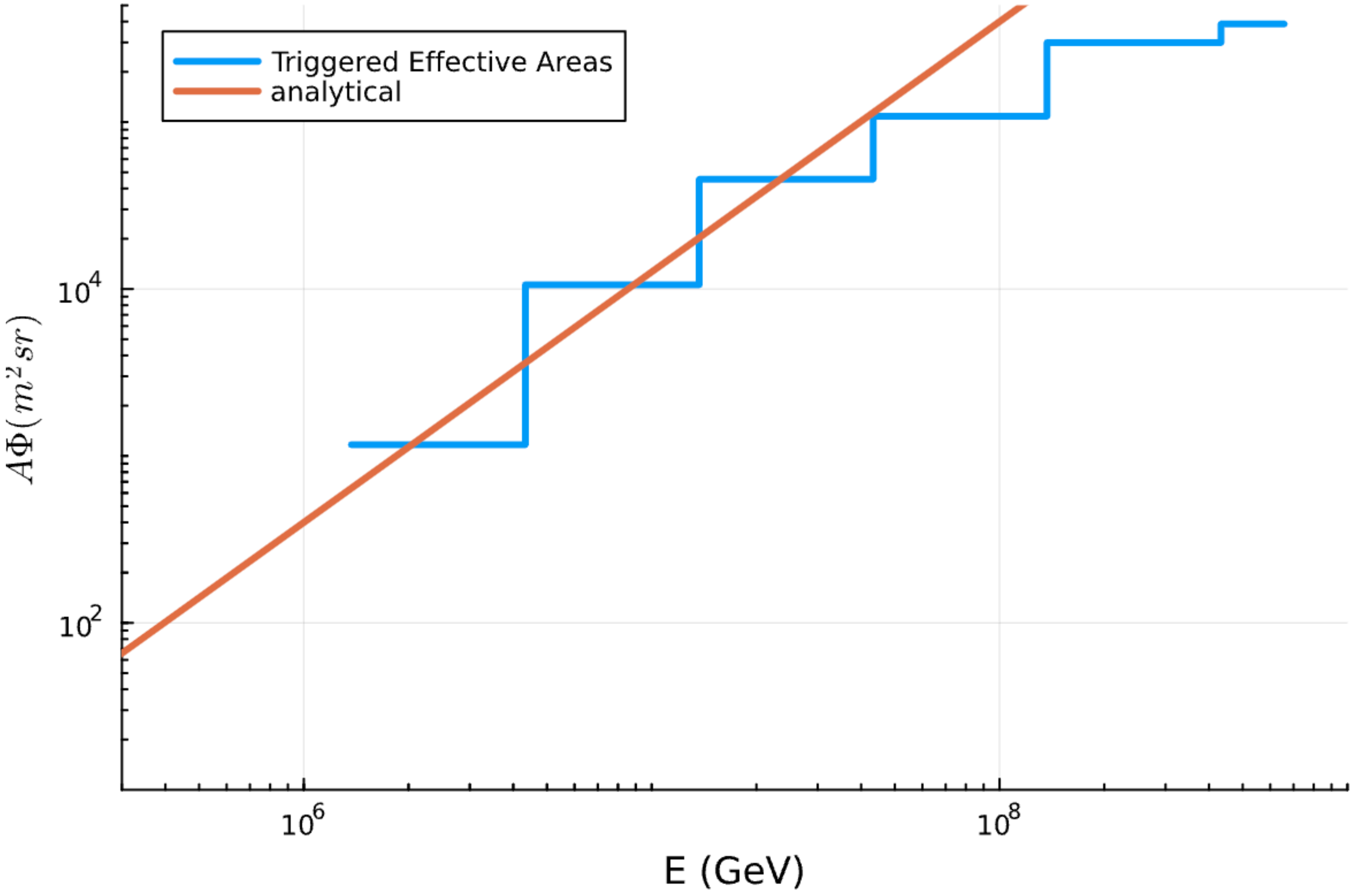
Charged lepton propagation: Propagate outgoing charged lepton, accounting for energy losses and decay, to find decay point

Air-shower simulation: Model shower development from lepton decay

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

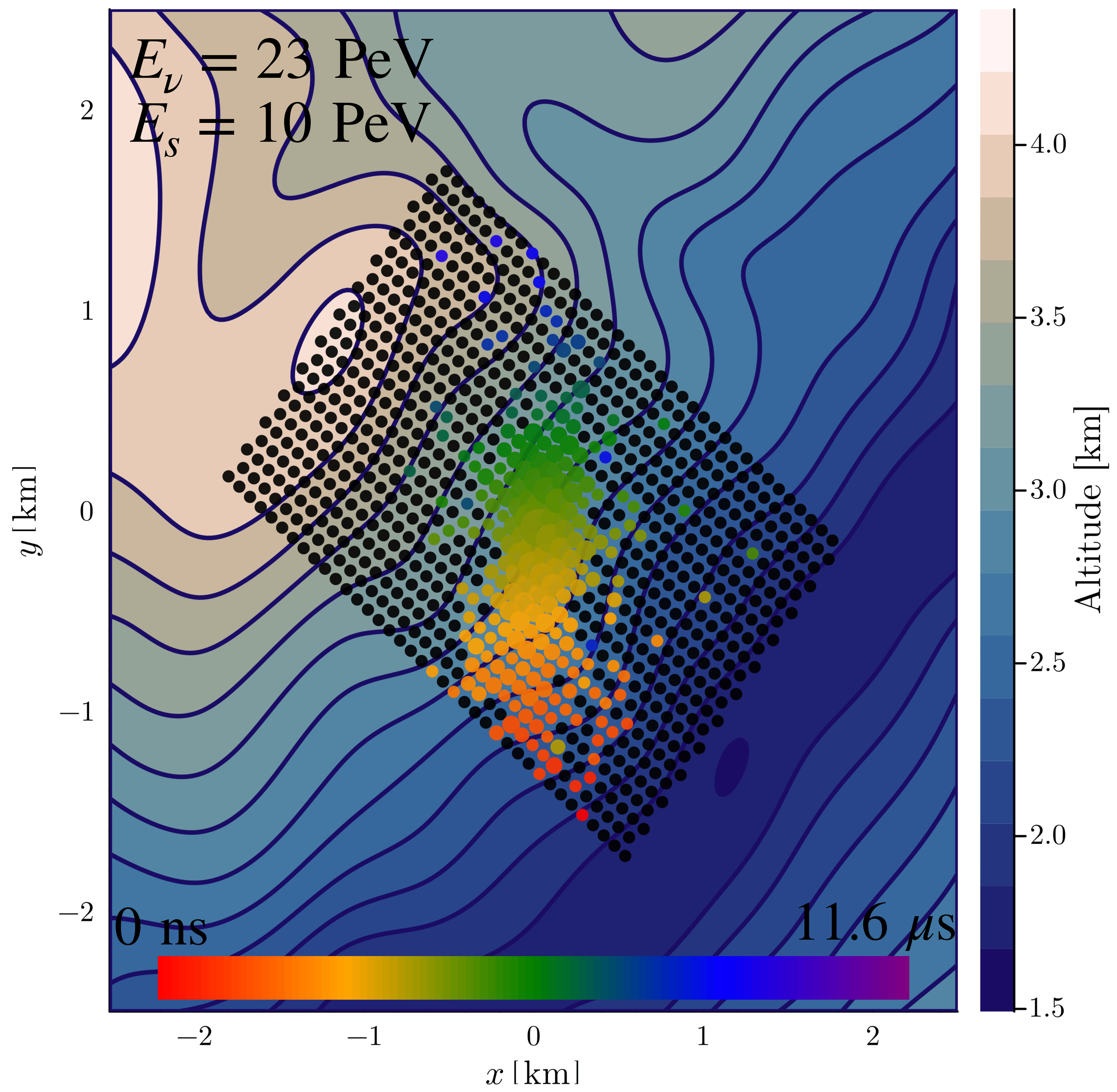
Event weighting: Remove unphysical remnants from selection of initial neutrino properties

Effective Area Comparison



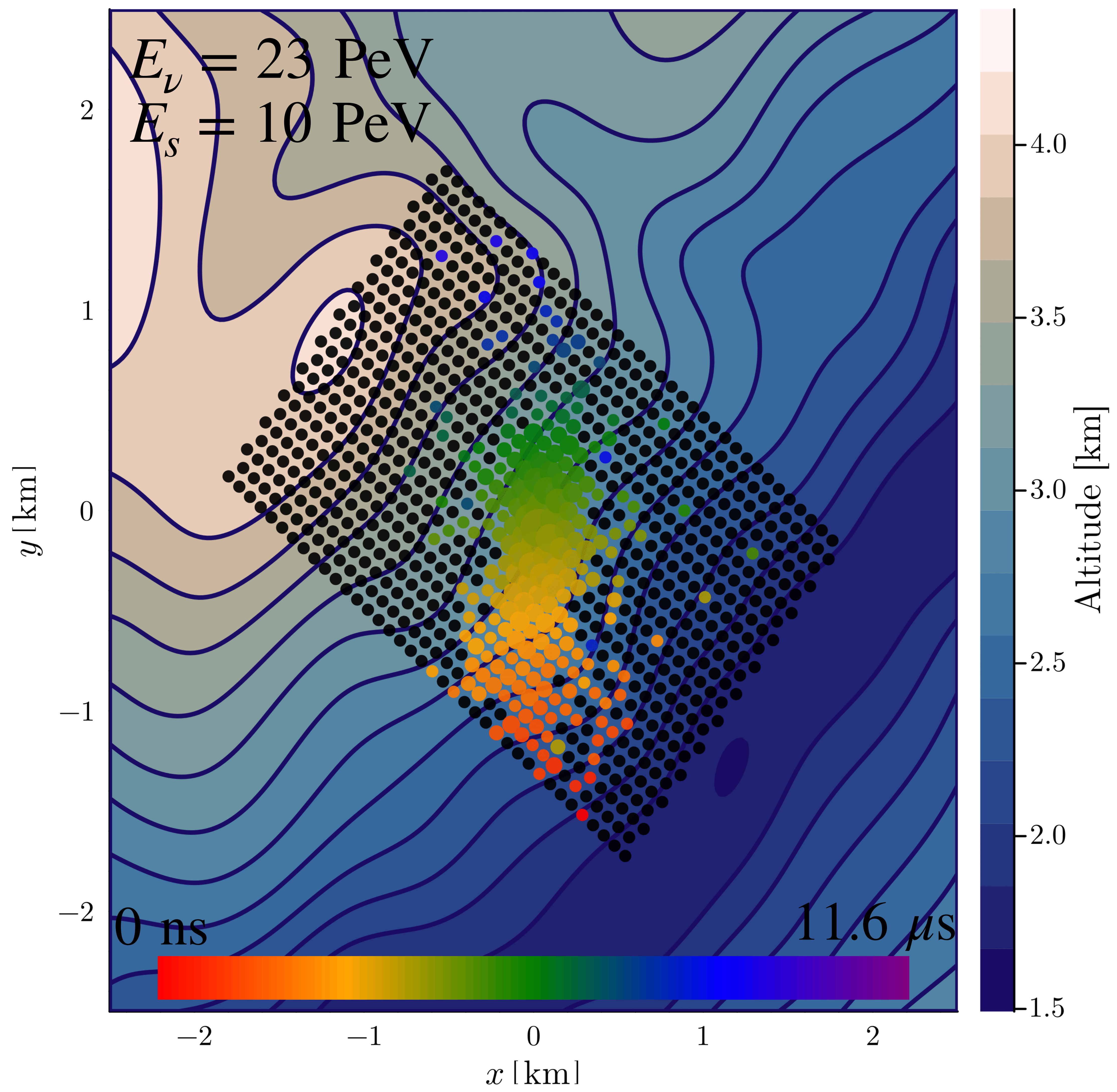
- Effective area computed with current simulation is in good agreement with that from analytic calculation

Full Timing Information



- Full simulation chain gives full timing information, enabling:
  - Pretty event displays
  - Reconstruction

Full Timing Information



- Full simulation chain gives full timing information, enabling:
  - Pretty event displays
  - Reconstruction

Julia-Based* Simulation Chain

- Cherenkov neutrino observatories use optical modules to detect charged by-products of neutrino interaction
- Goal of detecting and **characterizing diffuse astrophysical flux** and **finding neutrino point sources**

Julia-Based* Simulation Chain

- Event sampling
- Tau neutrino transport with TauRunner

- Charged lepton transport with PROPOSAL
- Tau decay with PROPOSAL or TAUOLA

- Air-shower simulation with CORSIKA8

- PE conversion
- Module triggering
- Detector triggering

- Oneweight and rate calculations
- Effective area calculations

Julia-Based* Simulation Chain

Initial neutrino injection

- Event sampling
- Tau neutrino transport with TauRunner

Charged lepton propagation

- Charged lepton transport with PROPOSAL
- Tau decay with PROPOSAL or TAUOLA

Air-shower simulation

- Air-shower simulation with CORSIKA8

Detector response

- PE conversion
- Module triggering
- Detector triggering

Event Weighting

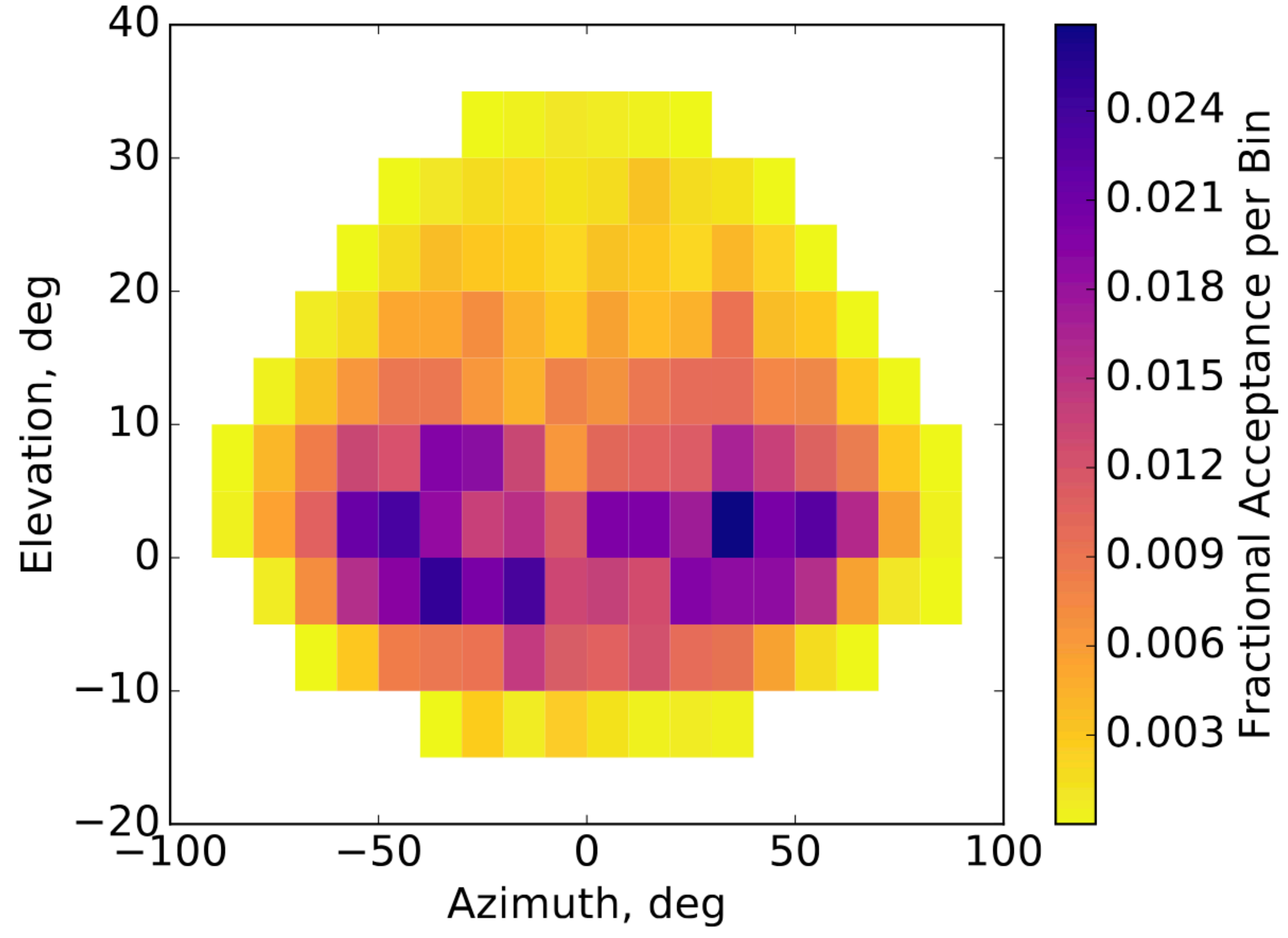
- Oneweight and rate calculations
- Effective area calculations

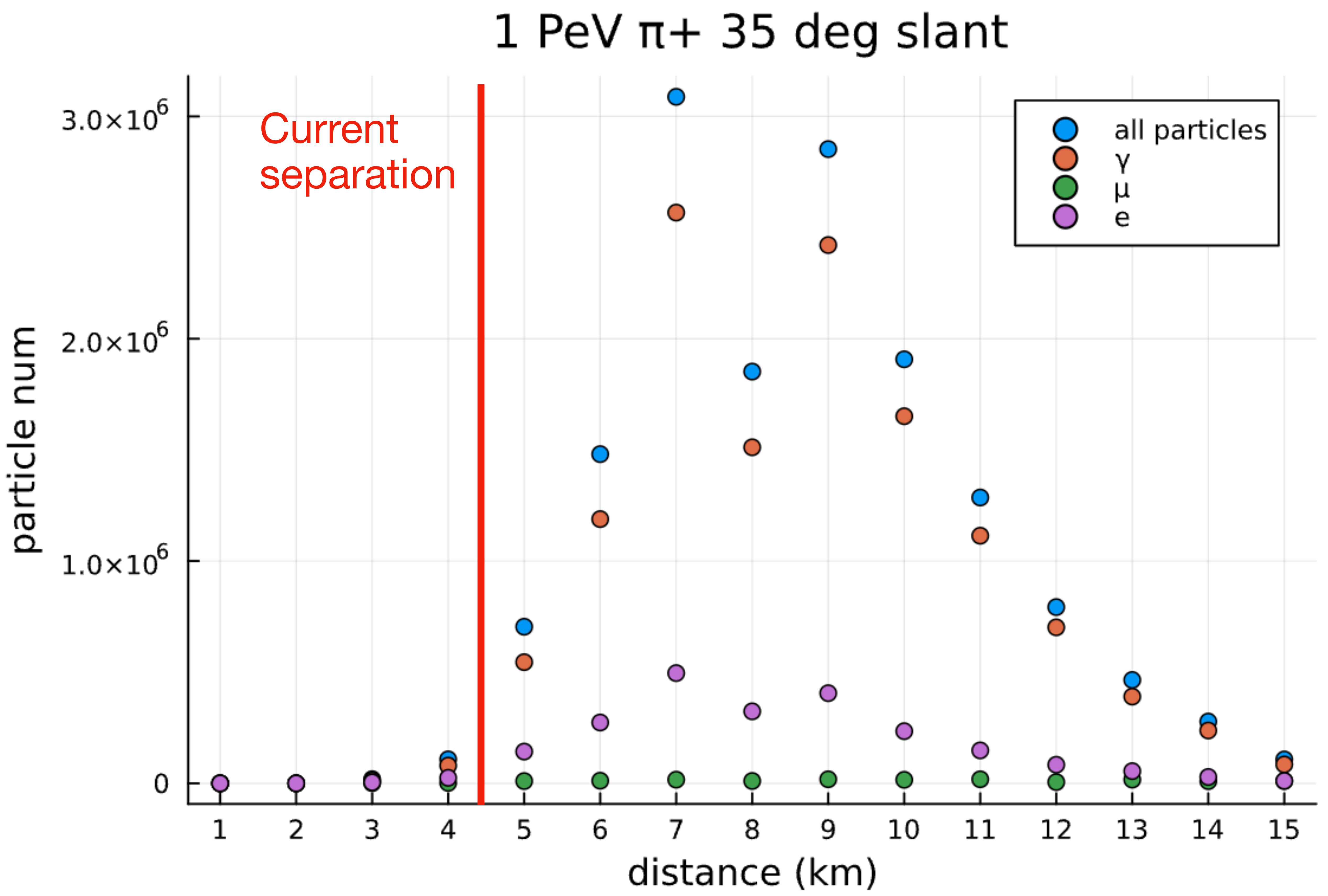
Outline

- Introduction to neutrino astronomy
- Introduction to the Tau Air-Shower Mountain-Based Observatory (TAMBO)
- The TAMBO simulation stack
- TAMBO status and prospects
- Final comments about Julia in neutrino astronomy

Site Optimization

- Peak particle count occurs between 7 and 9 km after shower initiated
- Nominal TAMBO location has separation of ~4.5 km



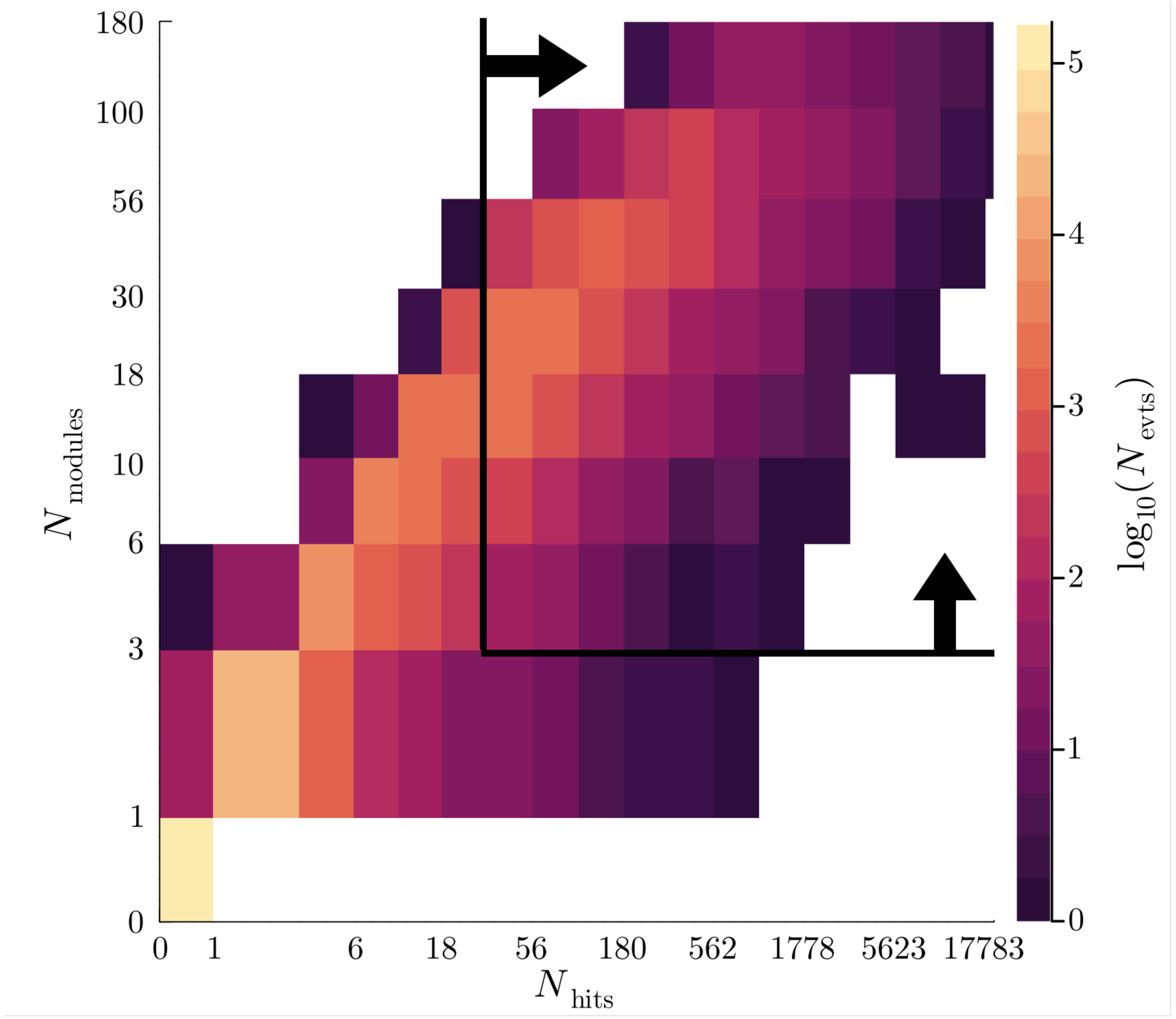


Site Optimization

- Currently trawling the canyon for the widest points
- Not clear whether maximizing distance is the imperative
- We need to test this in several configurations

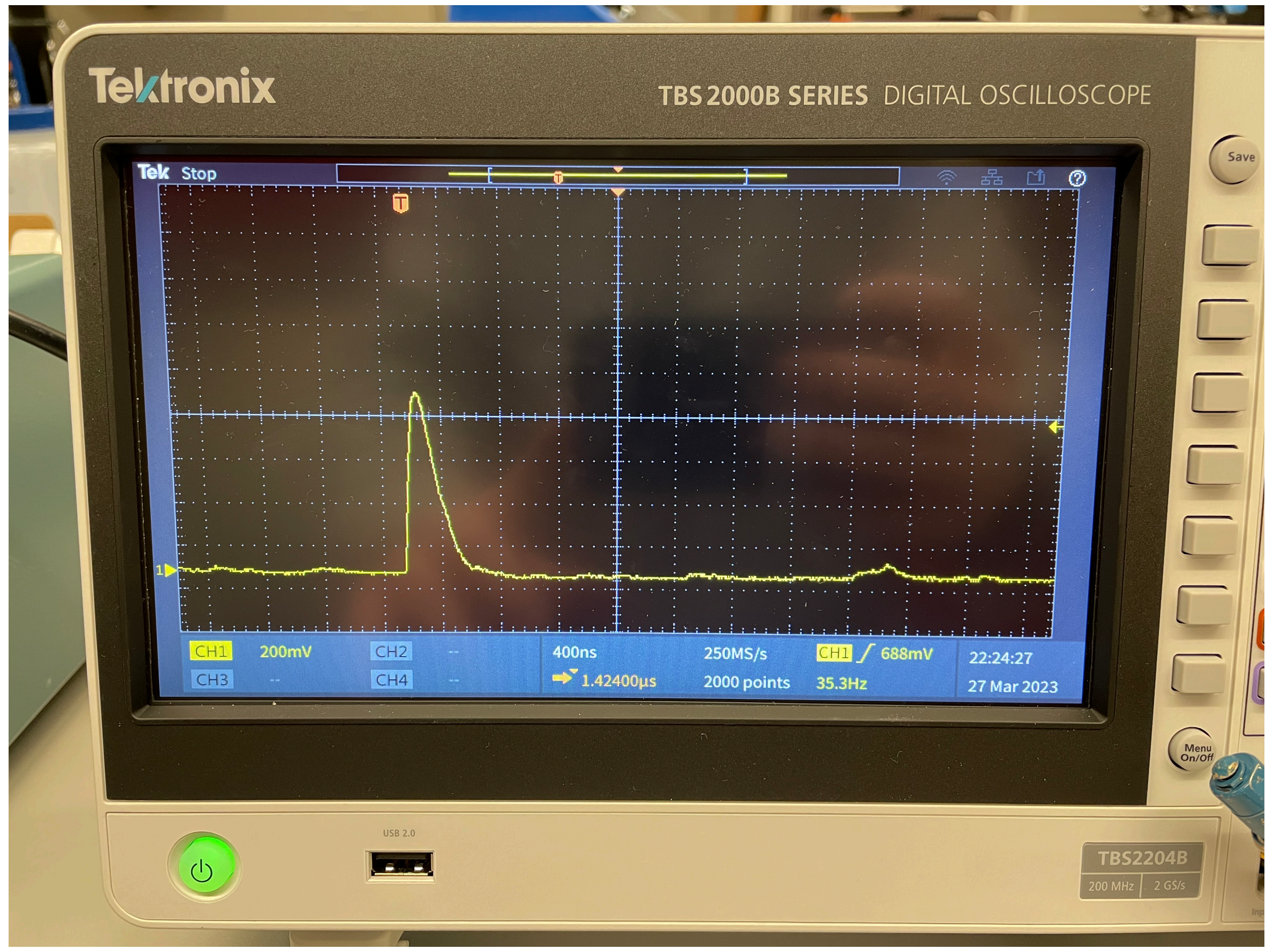
Trigger Optimization

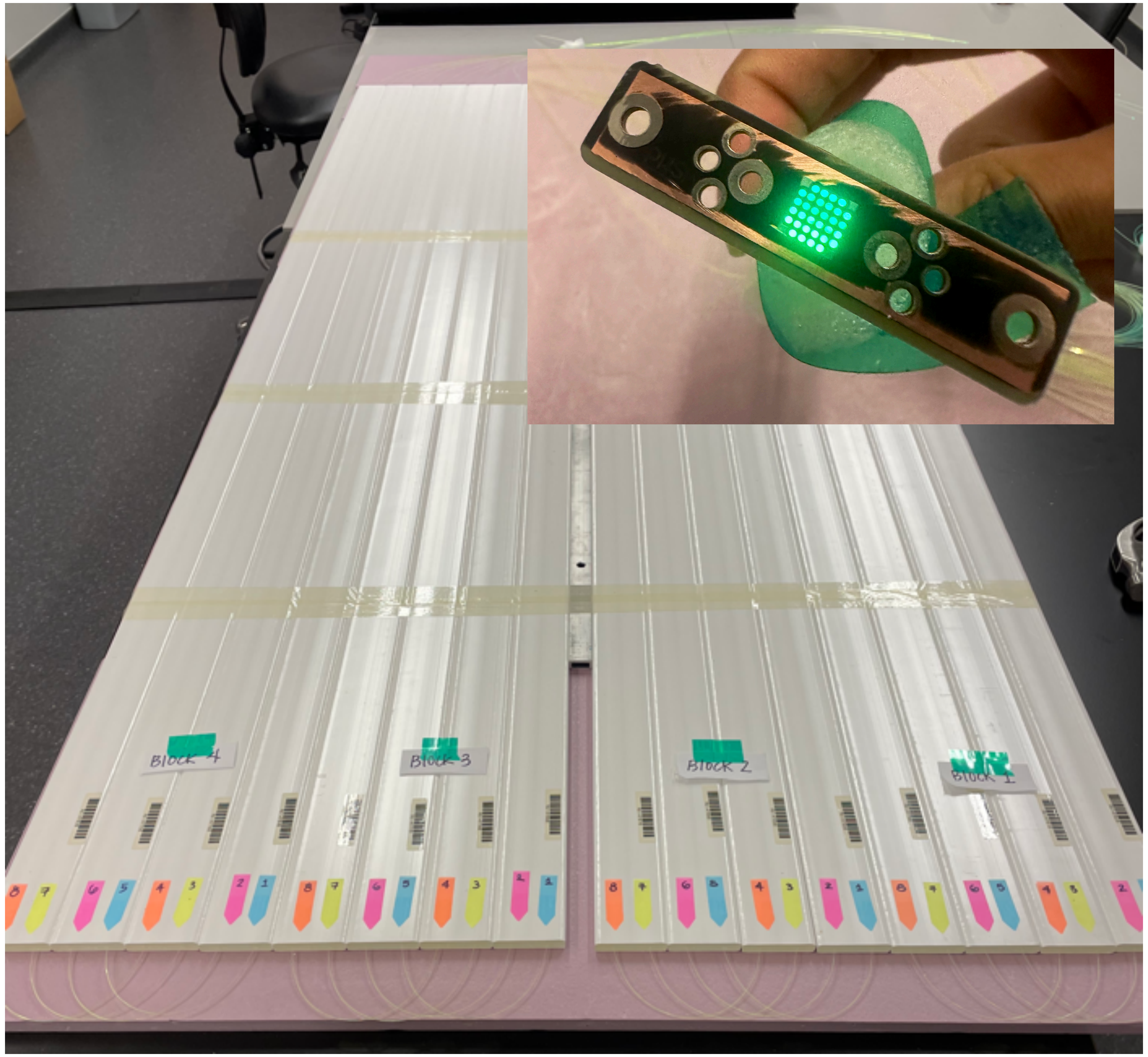
- When using the trigger definition from the previous study, we are particle starved
- Relaxing this trigger could



Panel Construction and Array Development

- Scintillator panels under construction via the Harvard group
  - 4 constructed and material to make 10 procured
- Array communications and readout being developed at PUCP





Outline

- Introduction to neutrino astronomy
- Introduction to the Tau Air-Shower Mountain-Based Observatory (TAMBO)
- The TAMBO simulation stack
- TAMBO status and prospects
- Final comments about Julia in neutrino astronomy

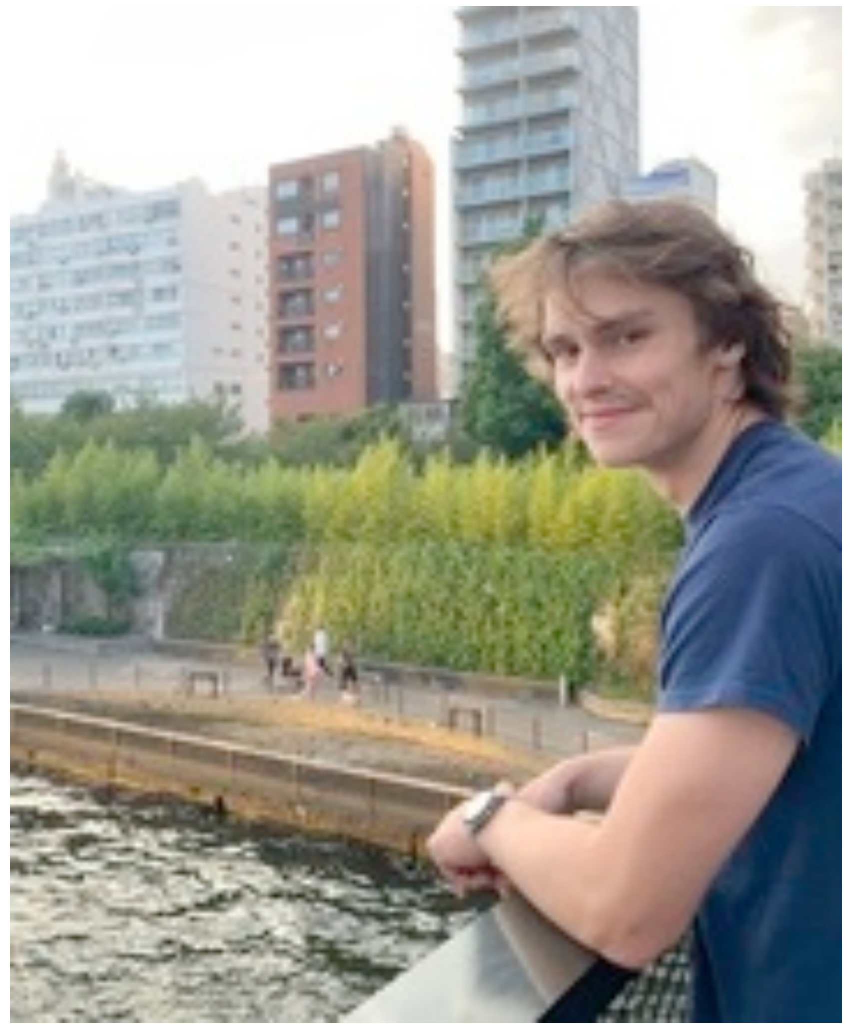
Opportunities to Julia-ify Simulation Stack

- TAMBO is relatively committed to using Julia
- A new generation of neutrino telescopes is coming online. This is a good chance to act
- There are three main points where we use non-Julia workarounds:
  - Extending injection framework to be more flexible: Medium
  - Transporting ν_τ through the Earth: Easy
  - Propagating final-state leptons: Relatively hard
  - Decaying final-state leptons: Medium
  - Propagating air-showers: Very hard
- These last three are definitely multi-person efforts, which I would be happy to contribute to if there is broader interest

Questions I have !

- Is there a Makie-based event display package, and if so, how flexible is it ?
- Is there a conventional way to schedule jobs via a Julia interface. Everything except air-shower simulation is fast and so we would like a wa to run only that part distributedly.

TAMBO Team



Thank you :-)