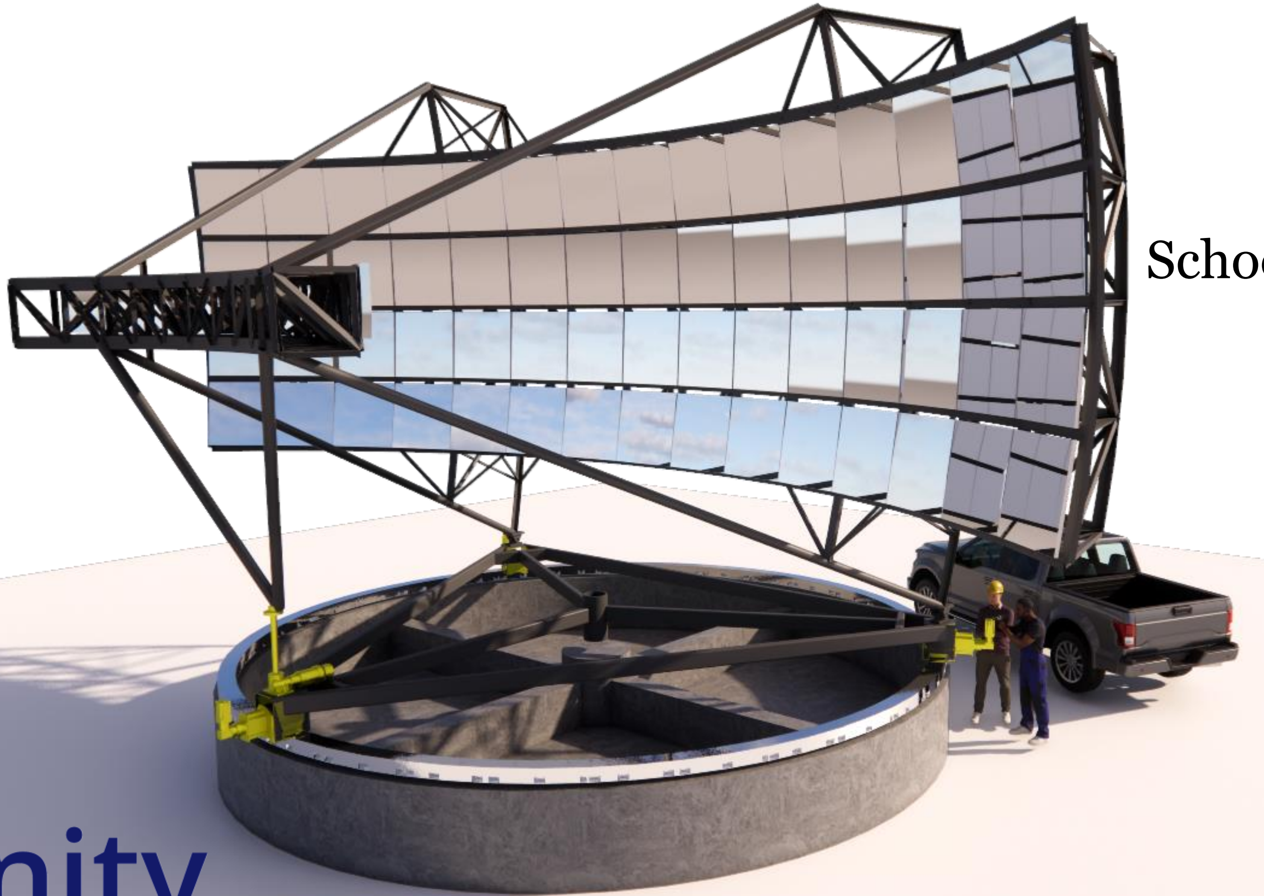
The Trinity Neutrino Observatory: Probing the PeV-EeV Neutrino Sky

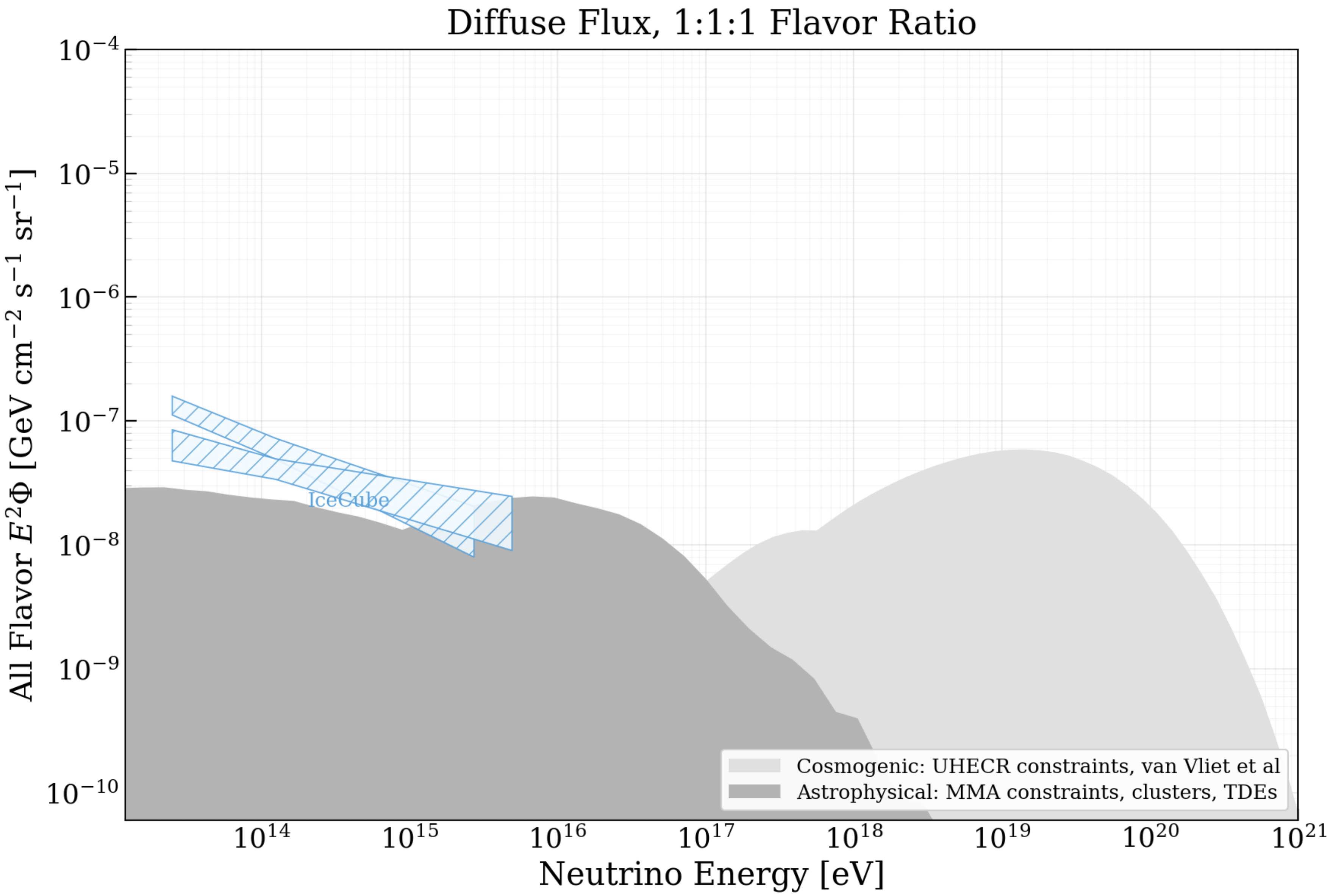


David A. Raudales
on behalf of the ***Trinity Collaboration***

School of Physics and Center for Relativistic Astrophysics, **Georgia** Institute of **Tech**nology

trinity-observatory.org

Neutrino Astronomy has made great progress over the last decade…



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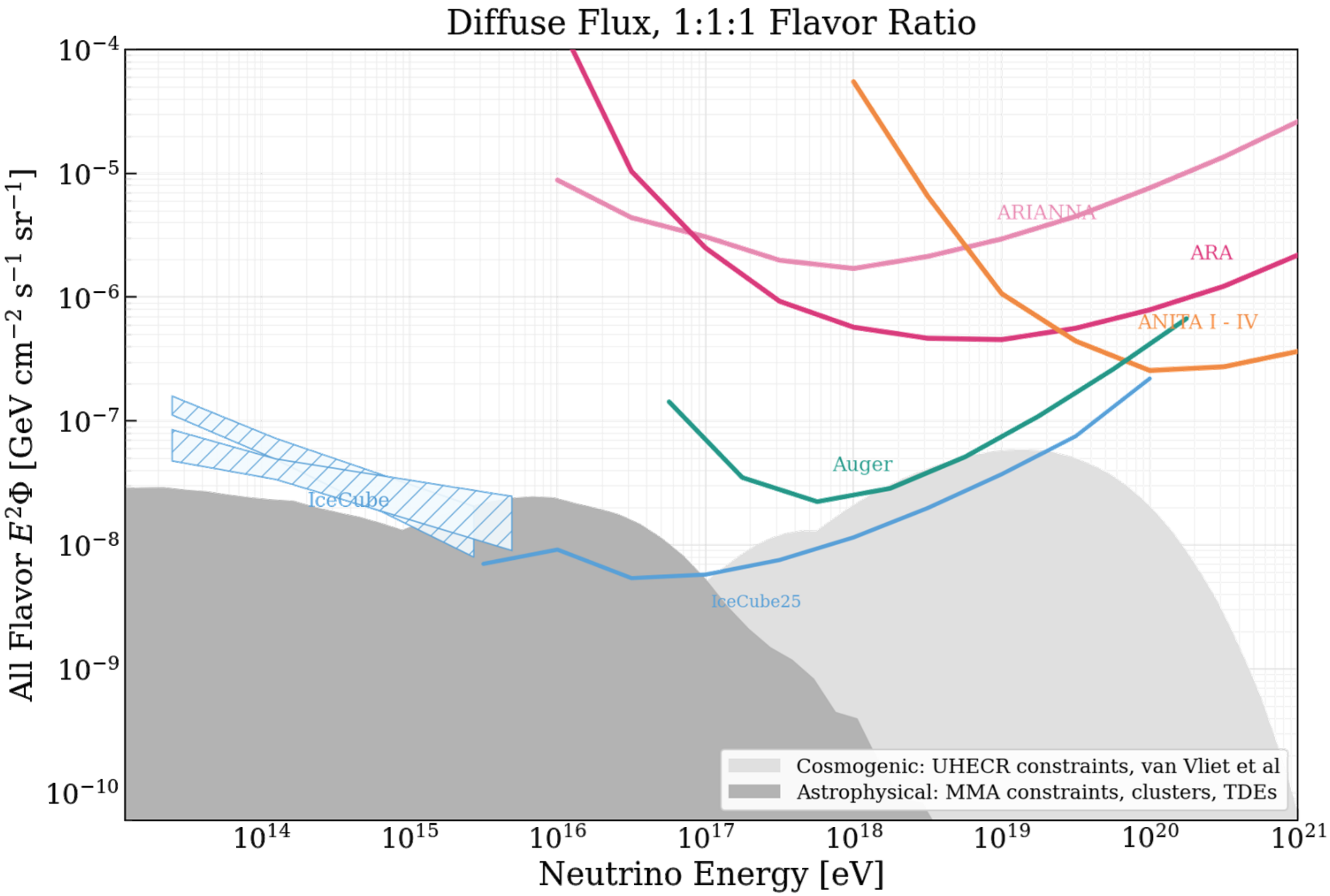

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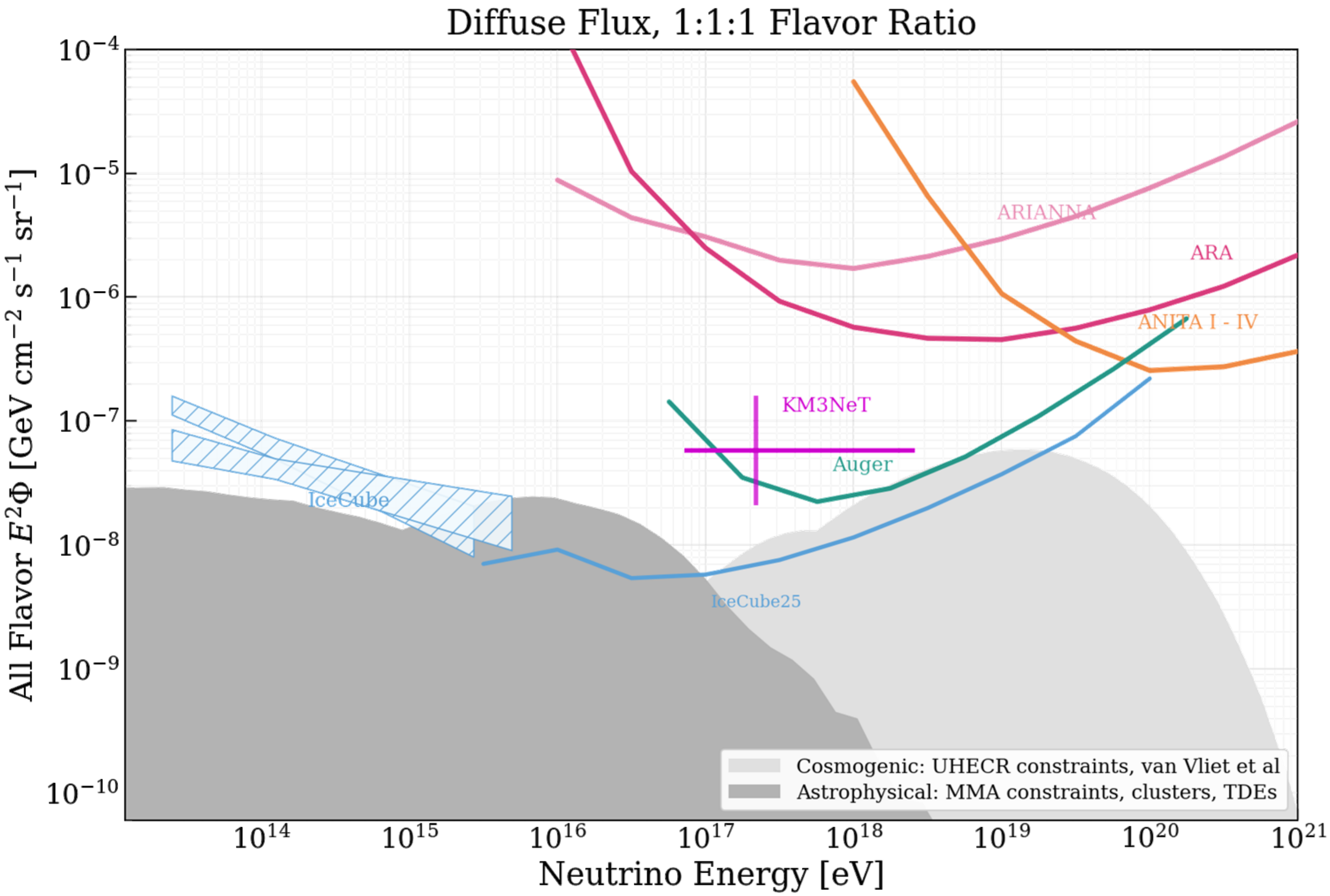

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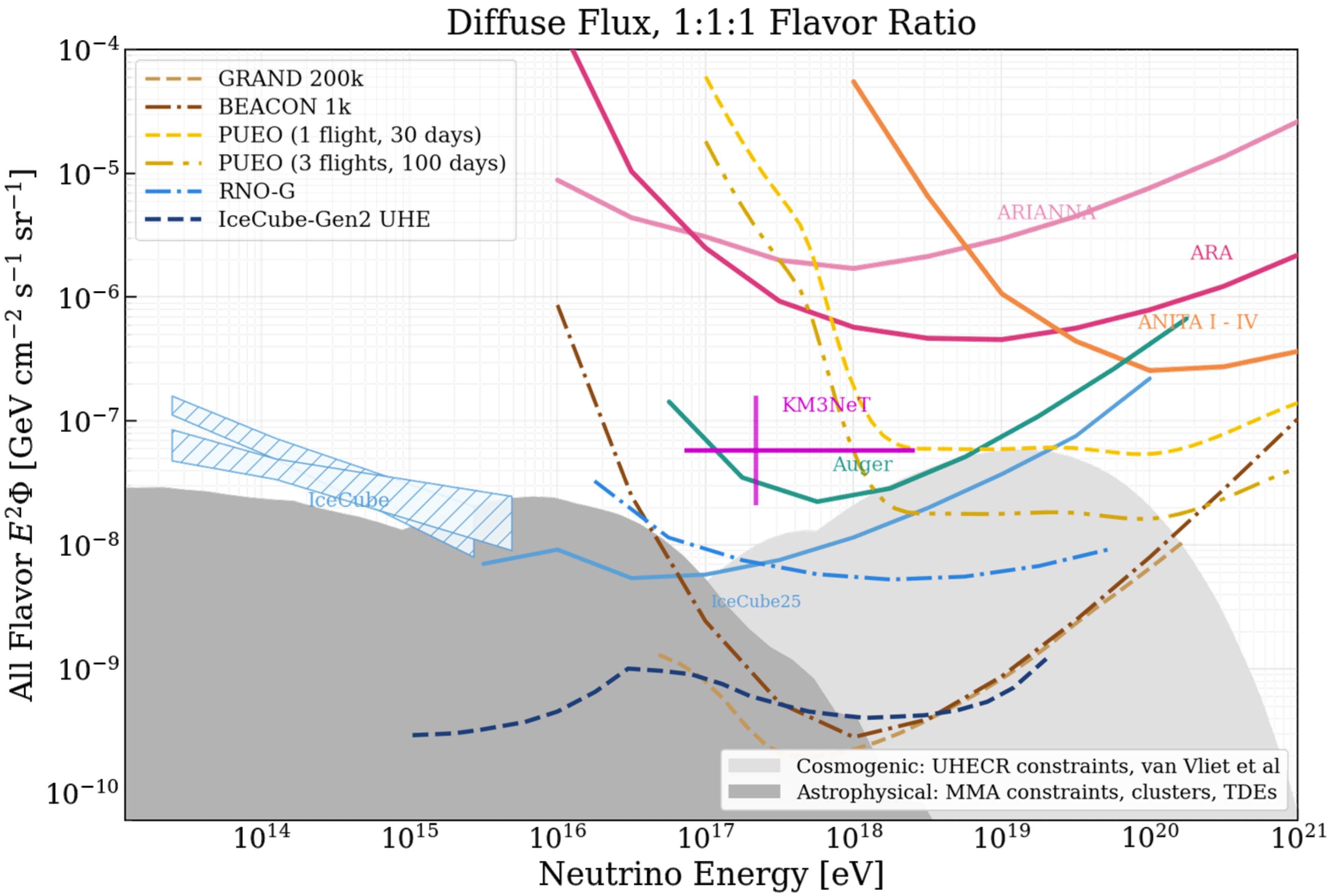
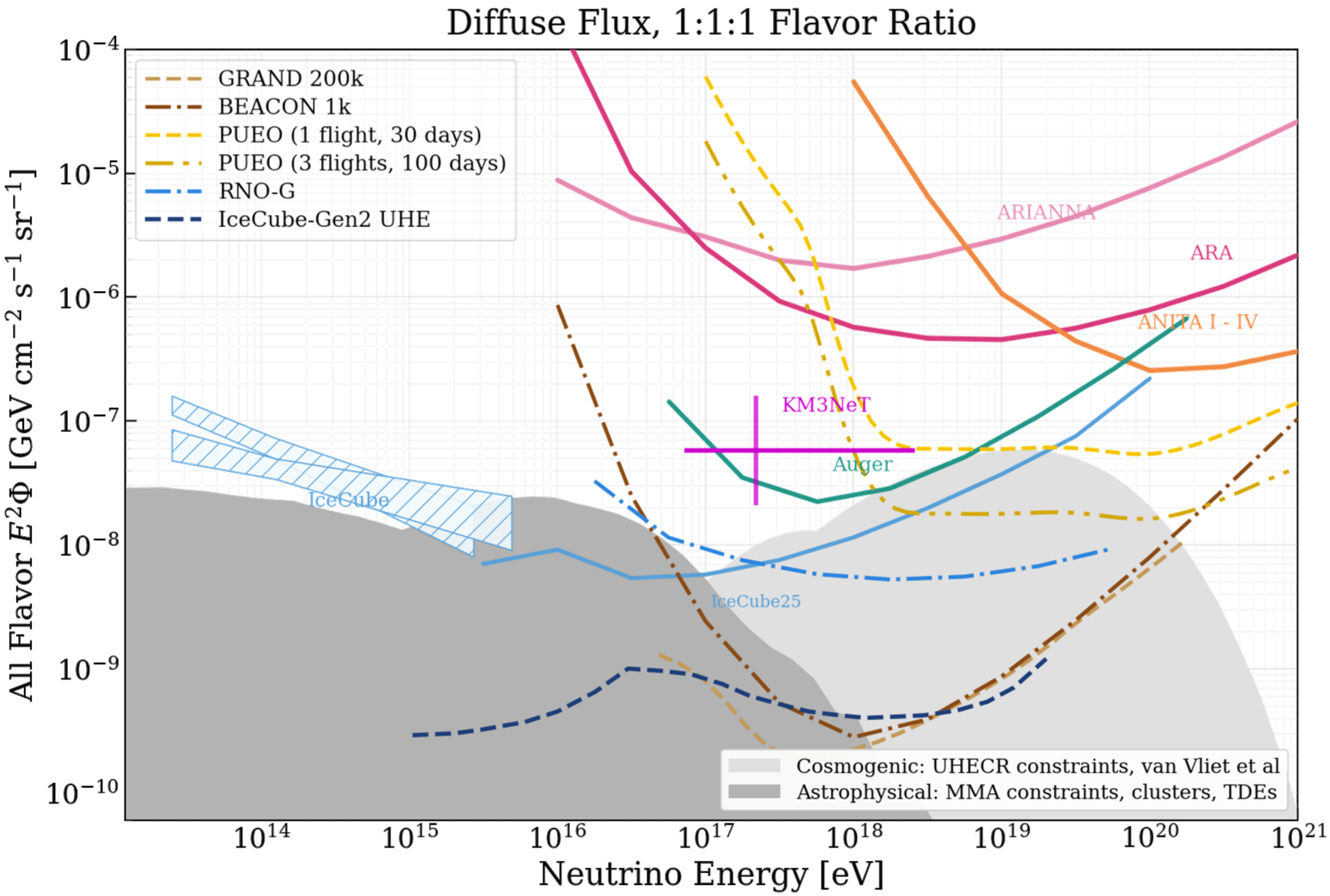


… but there are still gaps to be filled



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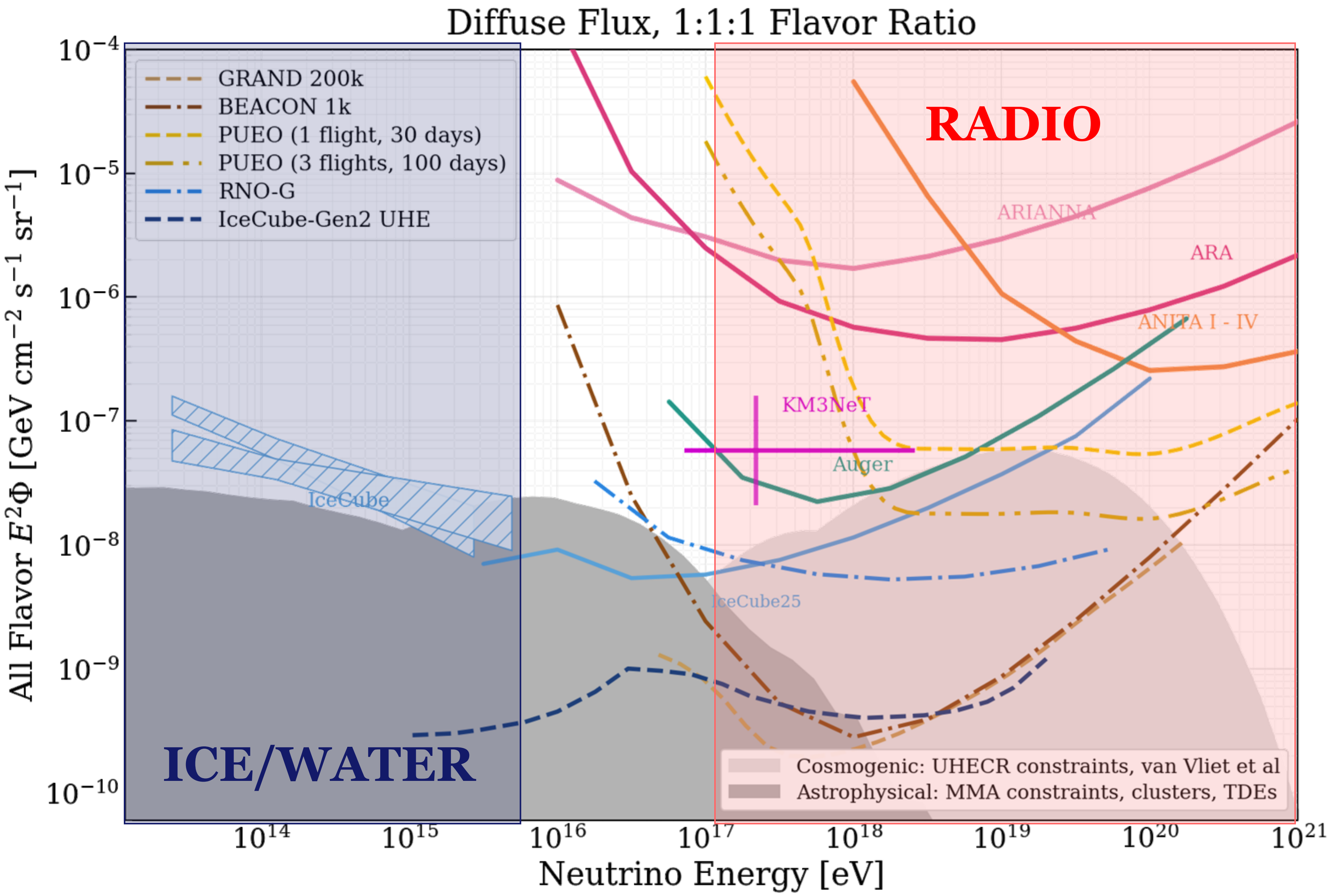

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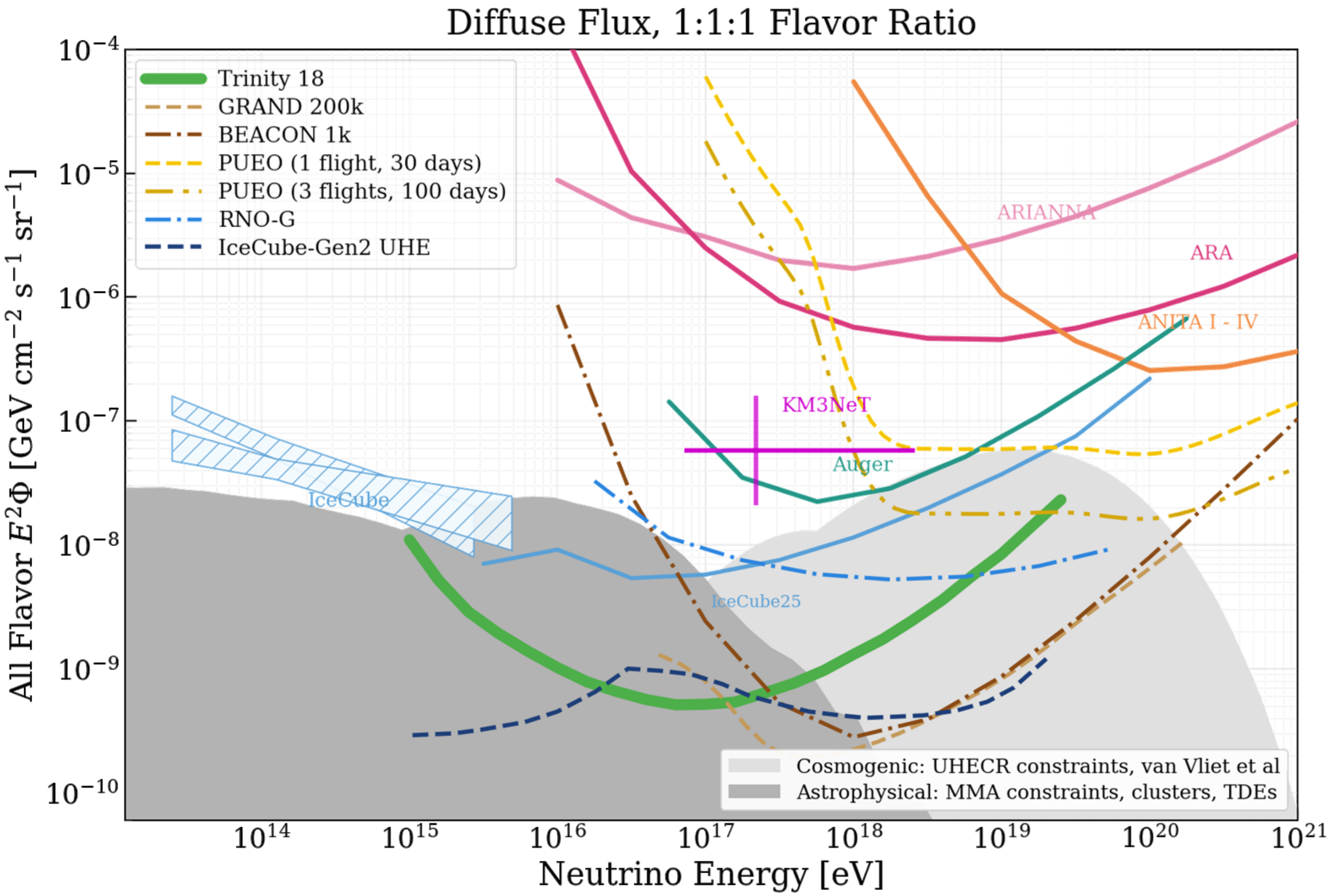
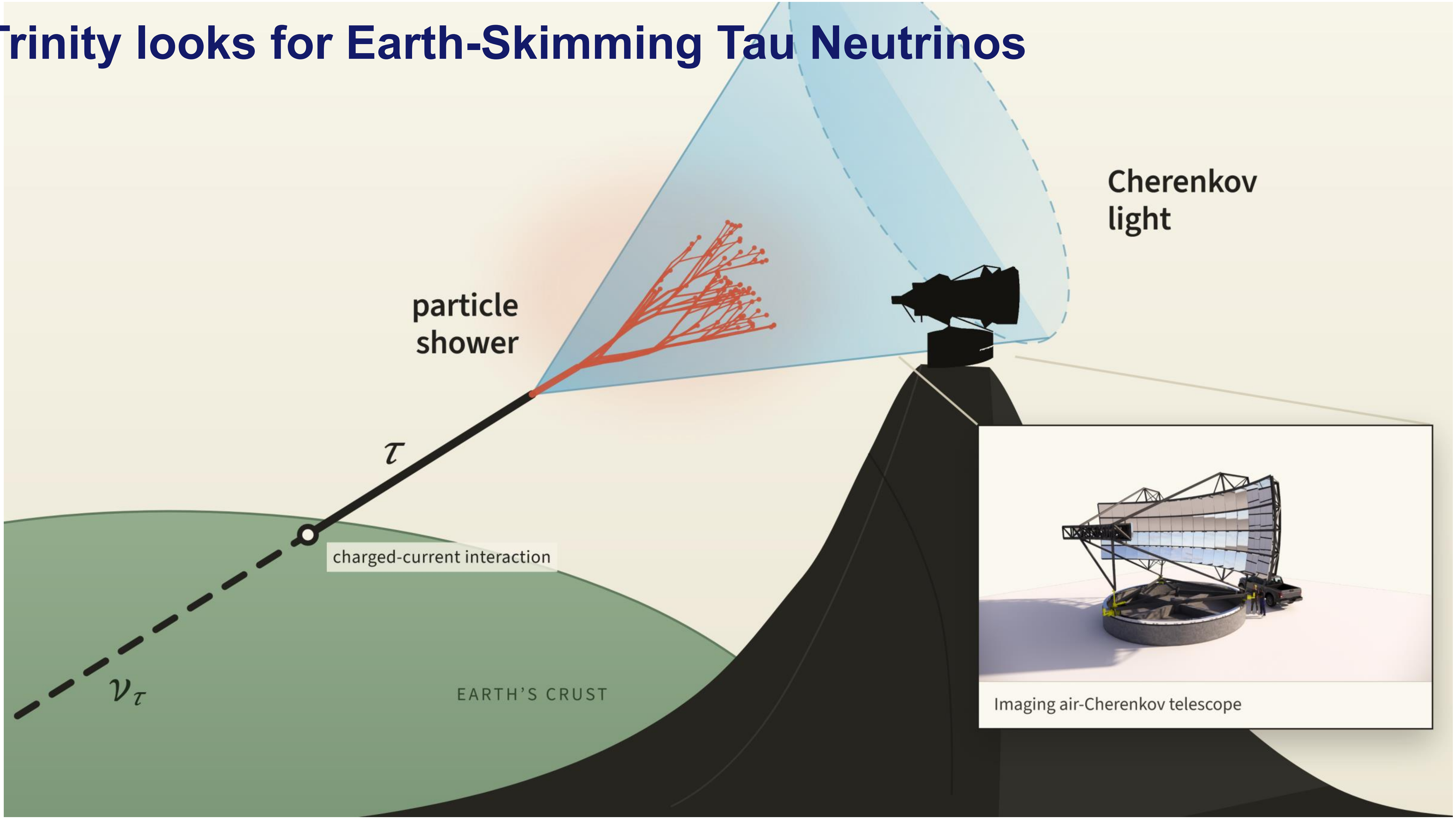
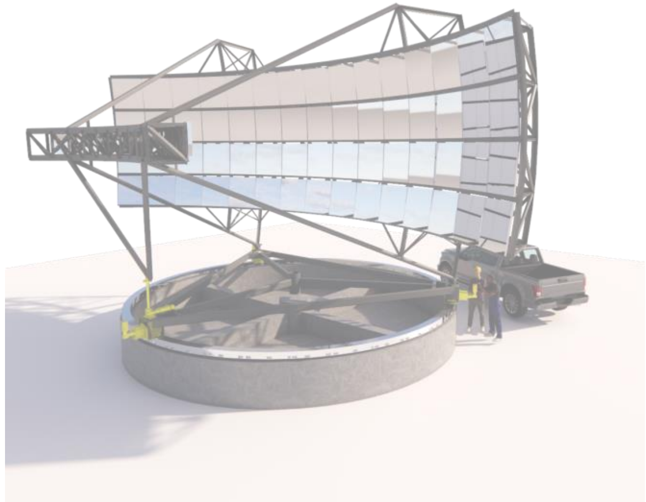
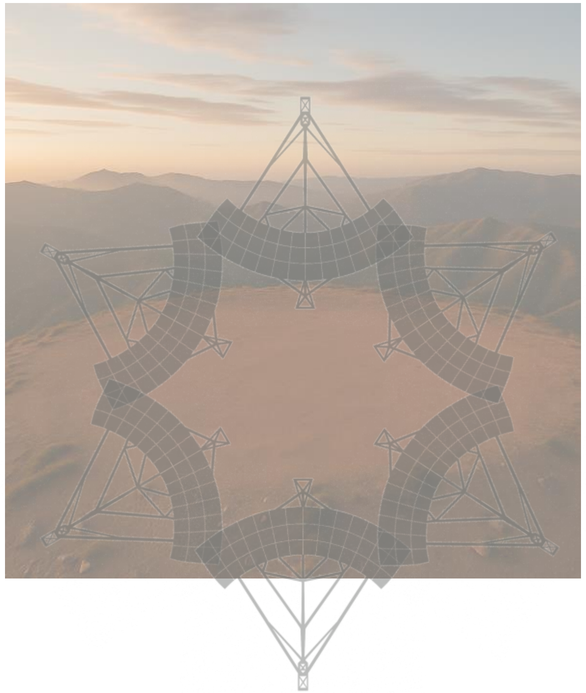


Trinity looks for Earth-Skimming Tau Neutrinos



The path towards the Trinity Observatory is ready





- Area -> 1 sq meter
- Field of View -> 3.87°x3.87°
- Resolution -> 0.24 °
- Commissioning Started October 2023

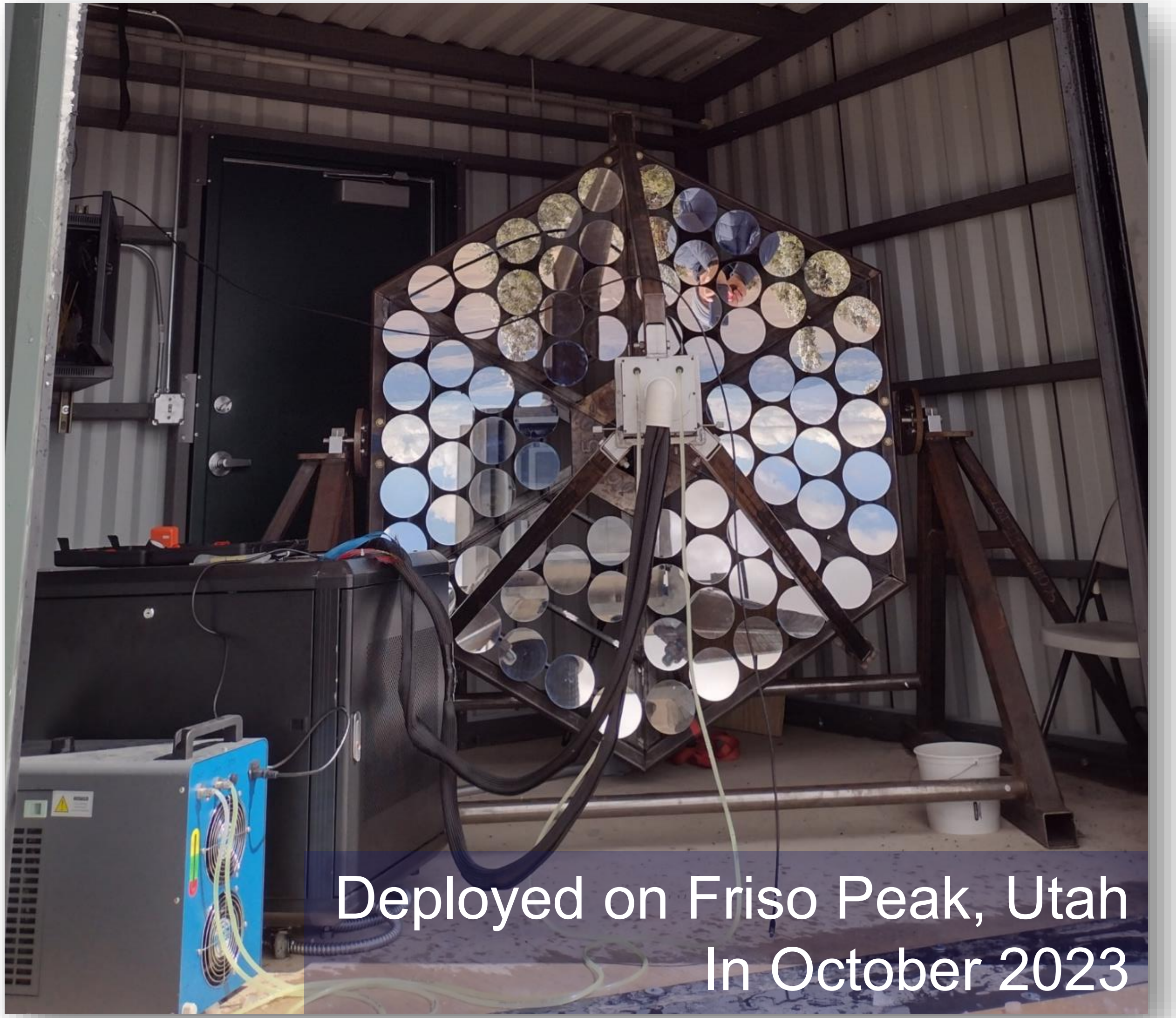
Demonstrator

The Demonstrator is a Success!!

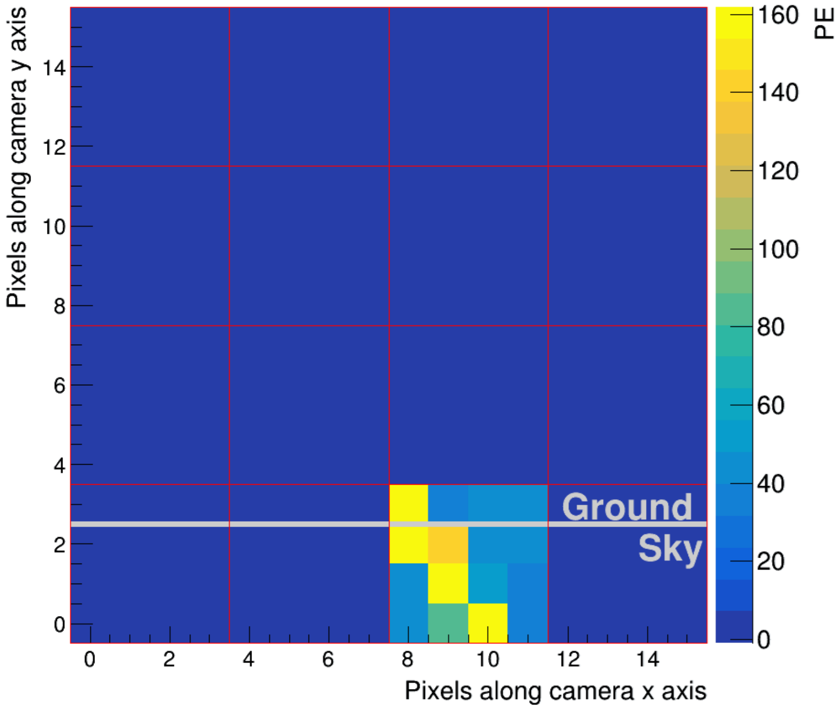
Purpose:
Validate detection concept
Characterize background

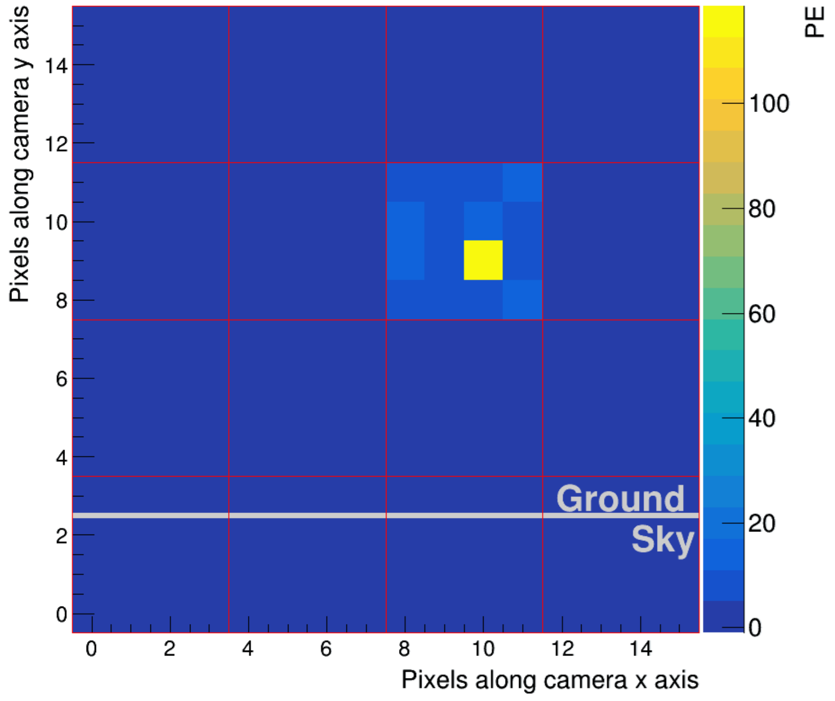
Data Taking Period	October 2024-Dec 2025
Hours Analyzed	554 Hours Door Open 238 Hours Door Closed
Triggered Events	1.2 Million Door Open 0.6 Million Door Closed

Camera paper: [arXiv:2406.08274]
Commissioning paper: [arXiv:2503.11864]



Event Processing Significantly Reduces Noise





1.2 Million Events

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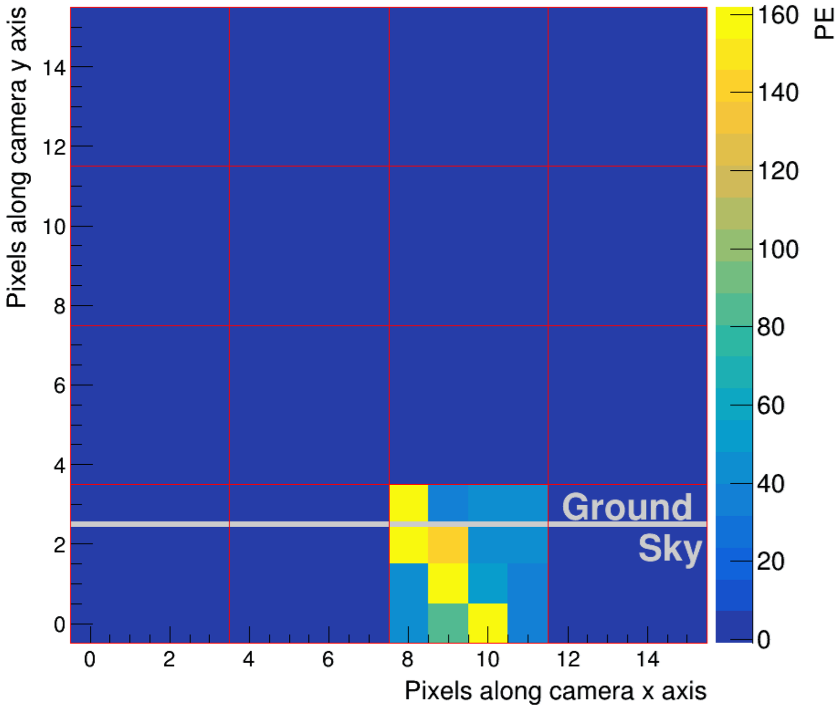
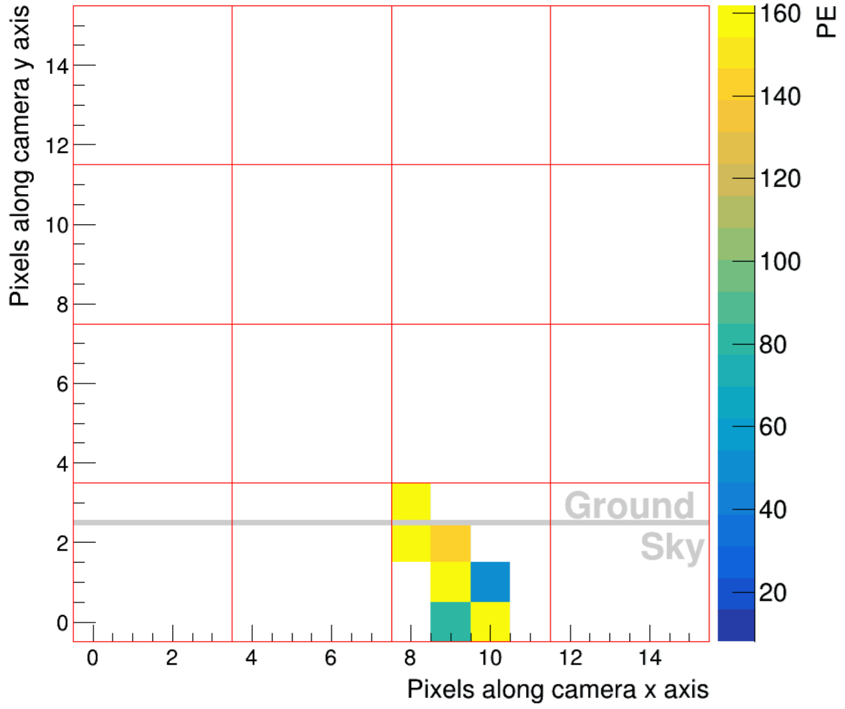


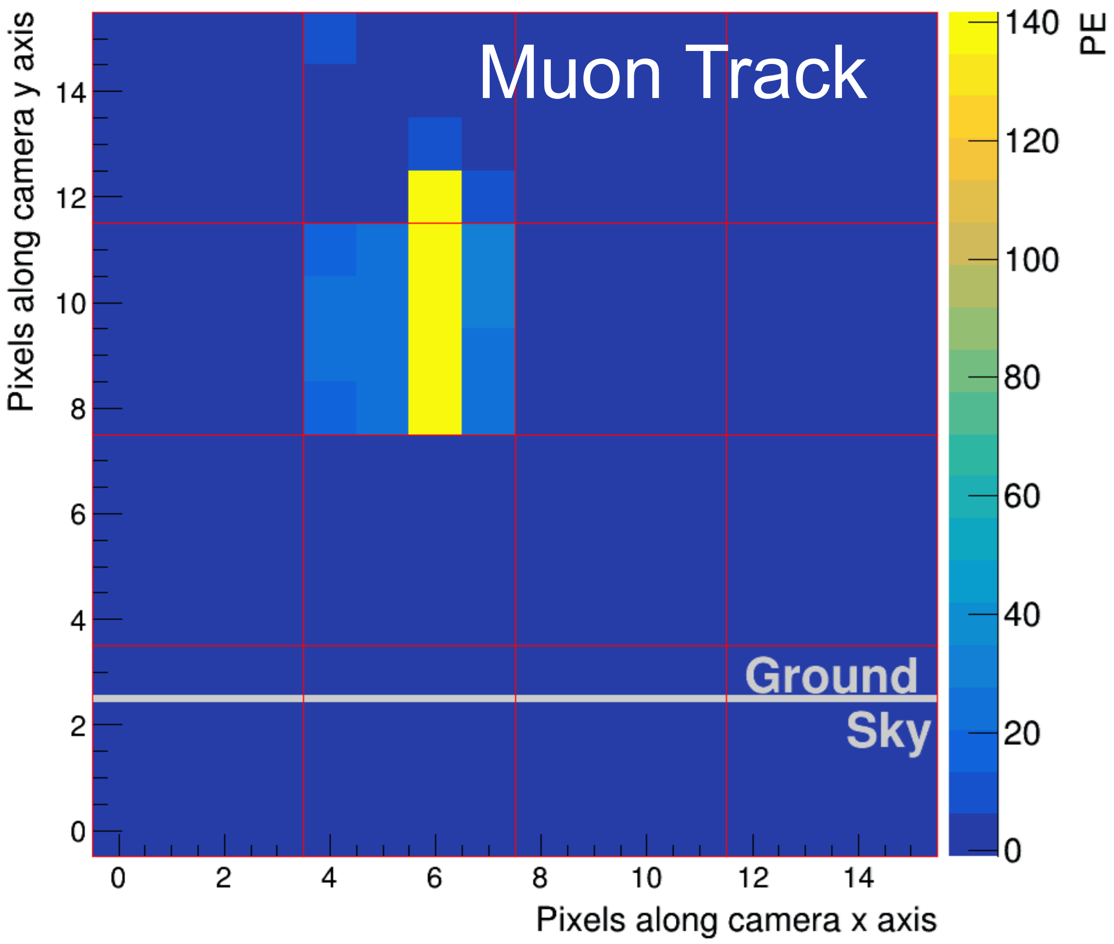
1.2 Million Events

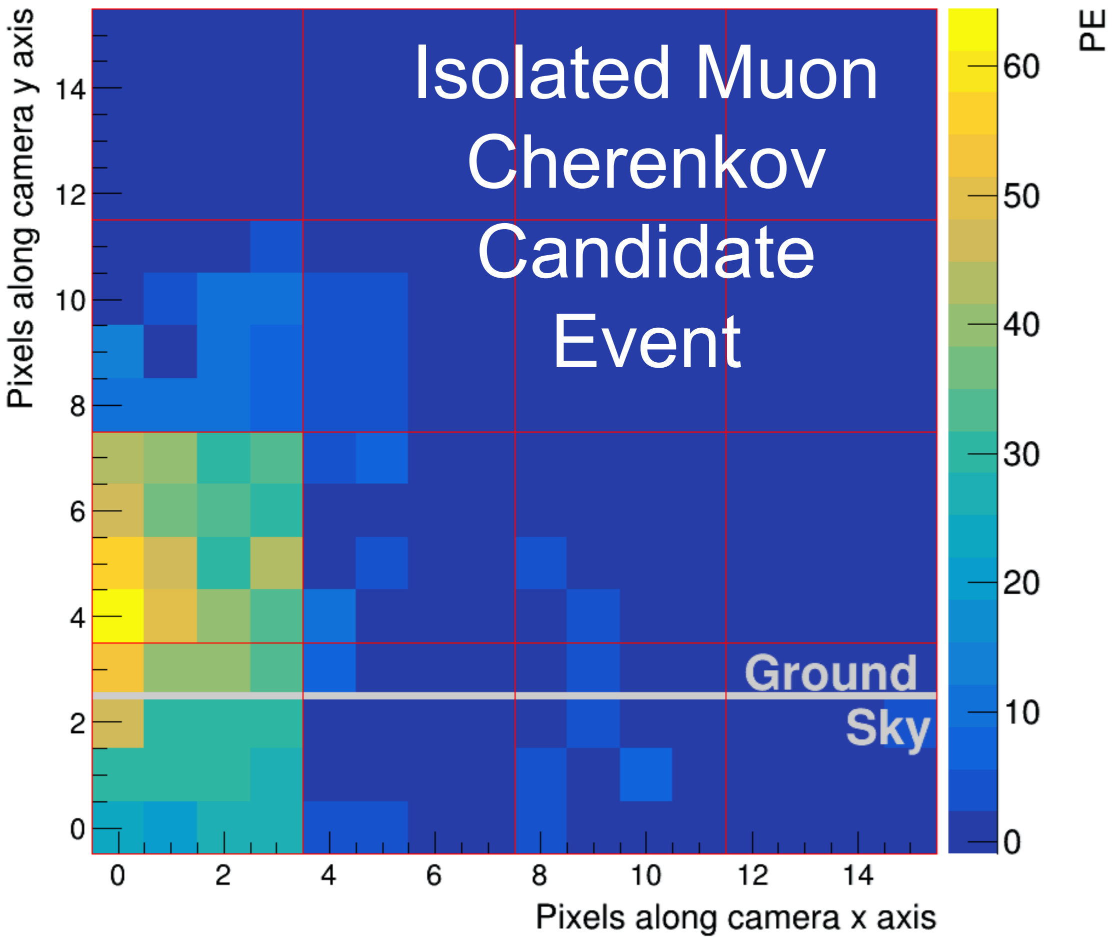
3 Surviving pixels
2 Core pixels
Same time bin



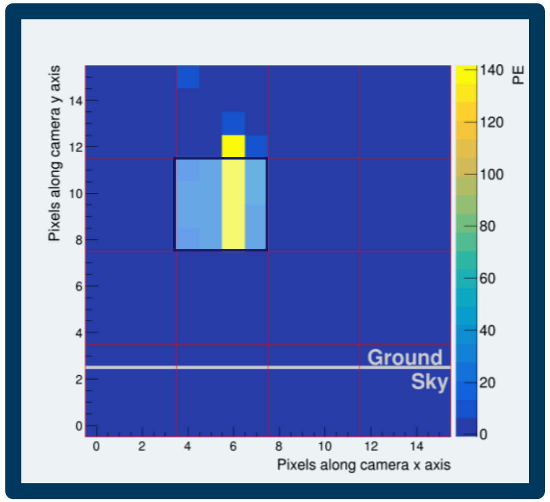
2193 Events

All Surviving Events are Muon Events





Muon Tracks Arise when Muons Cross the Camera



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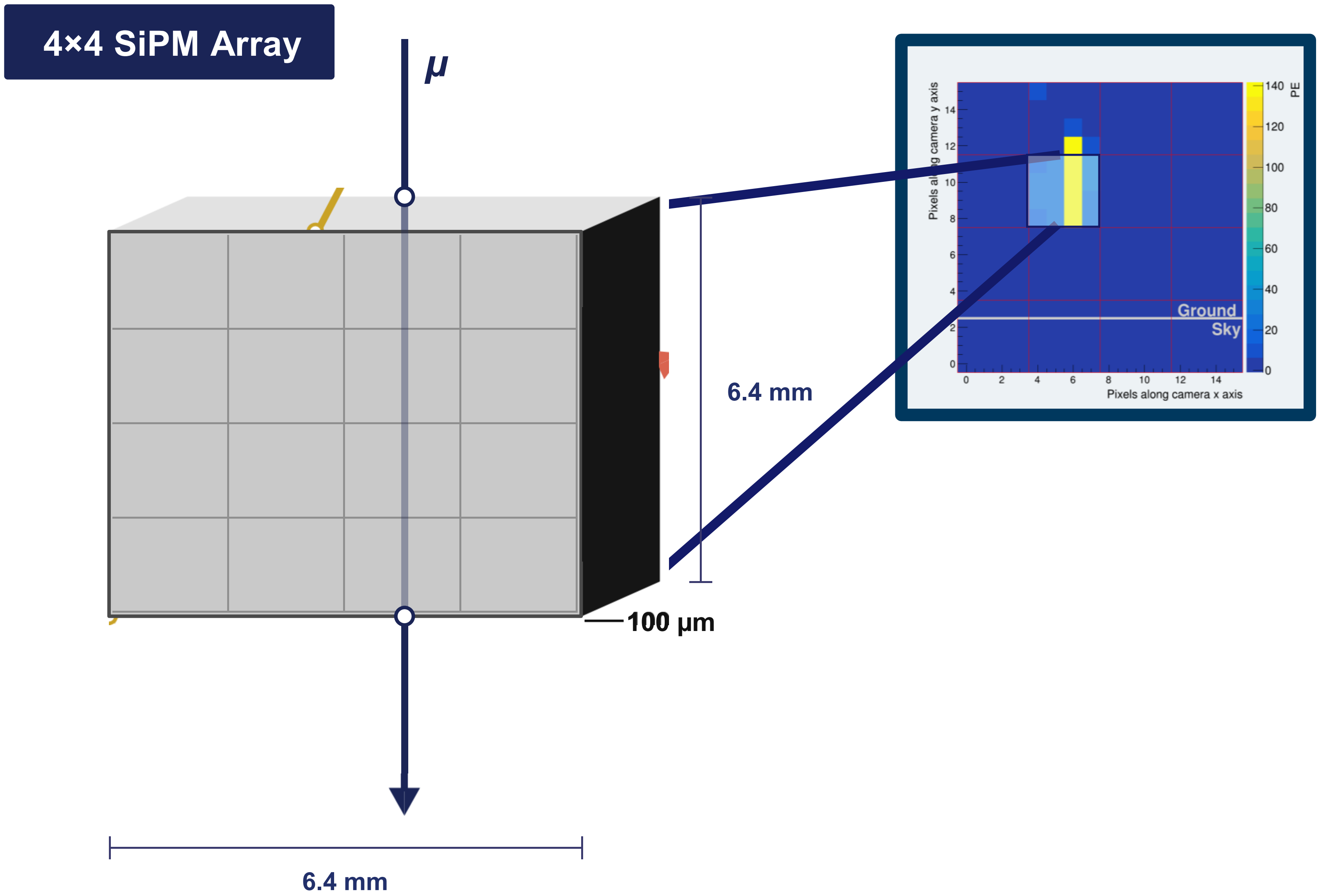

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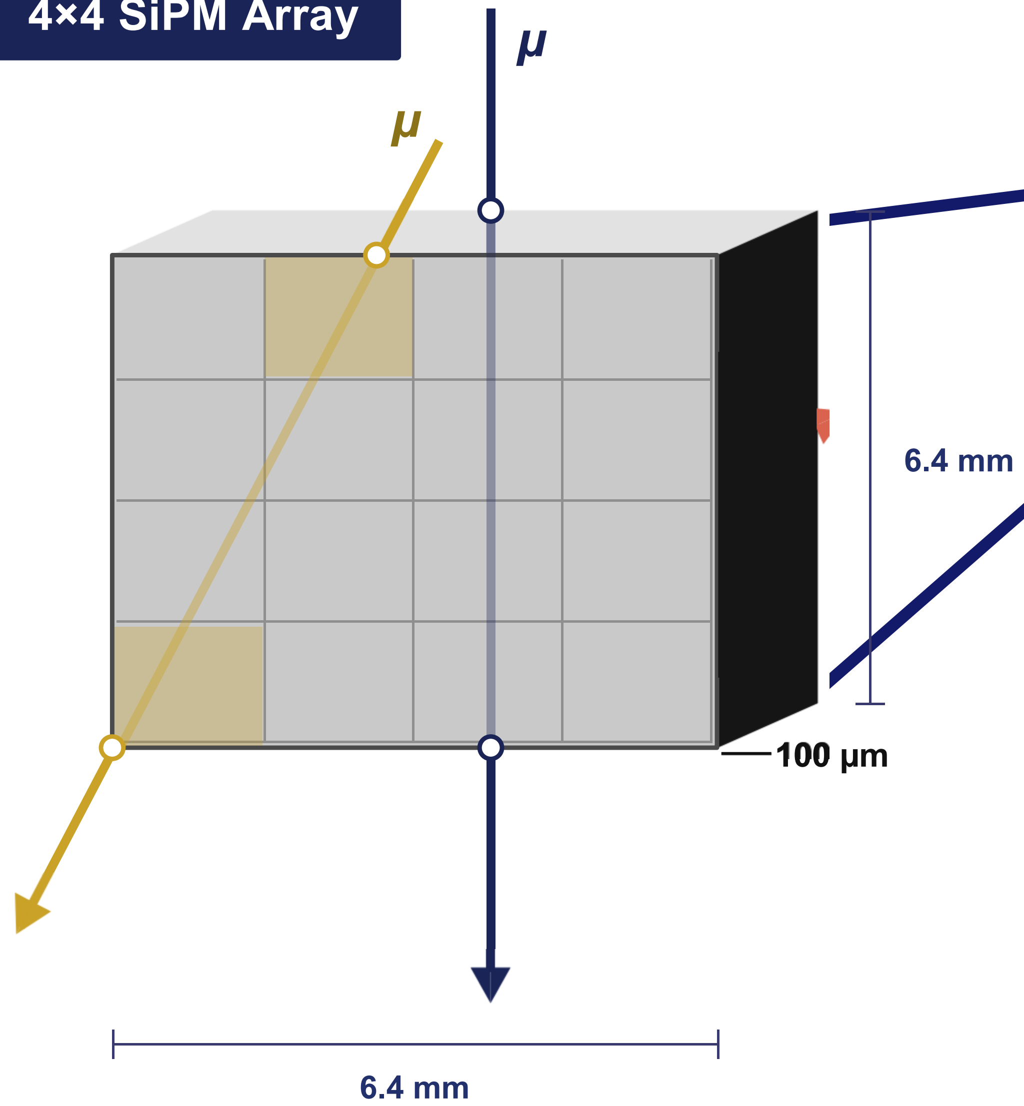

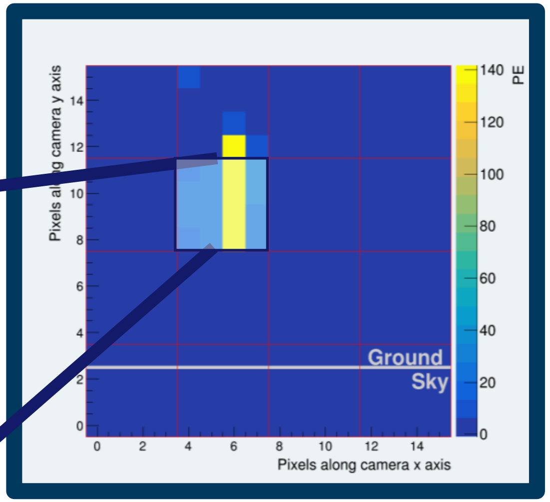

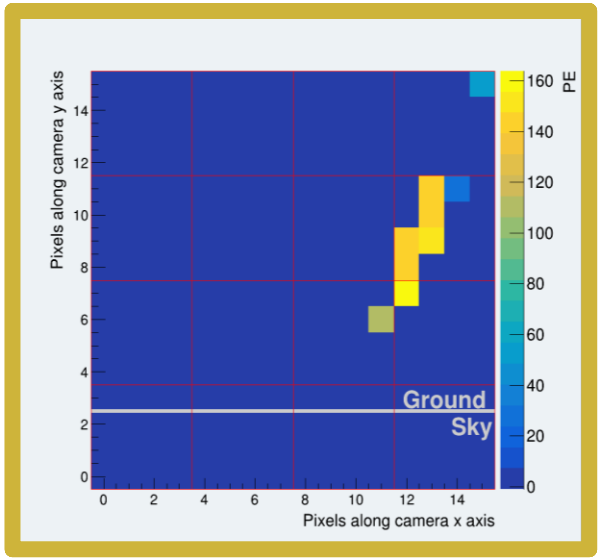

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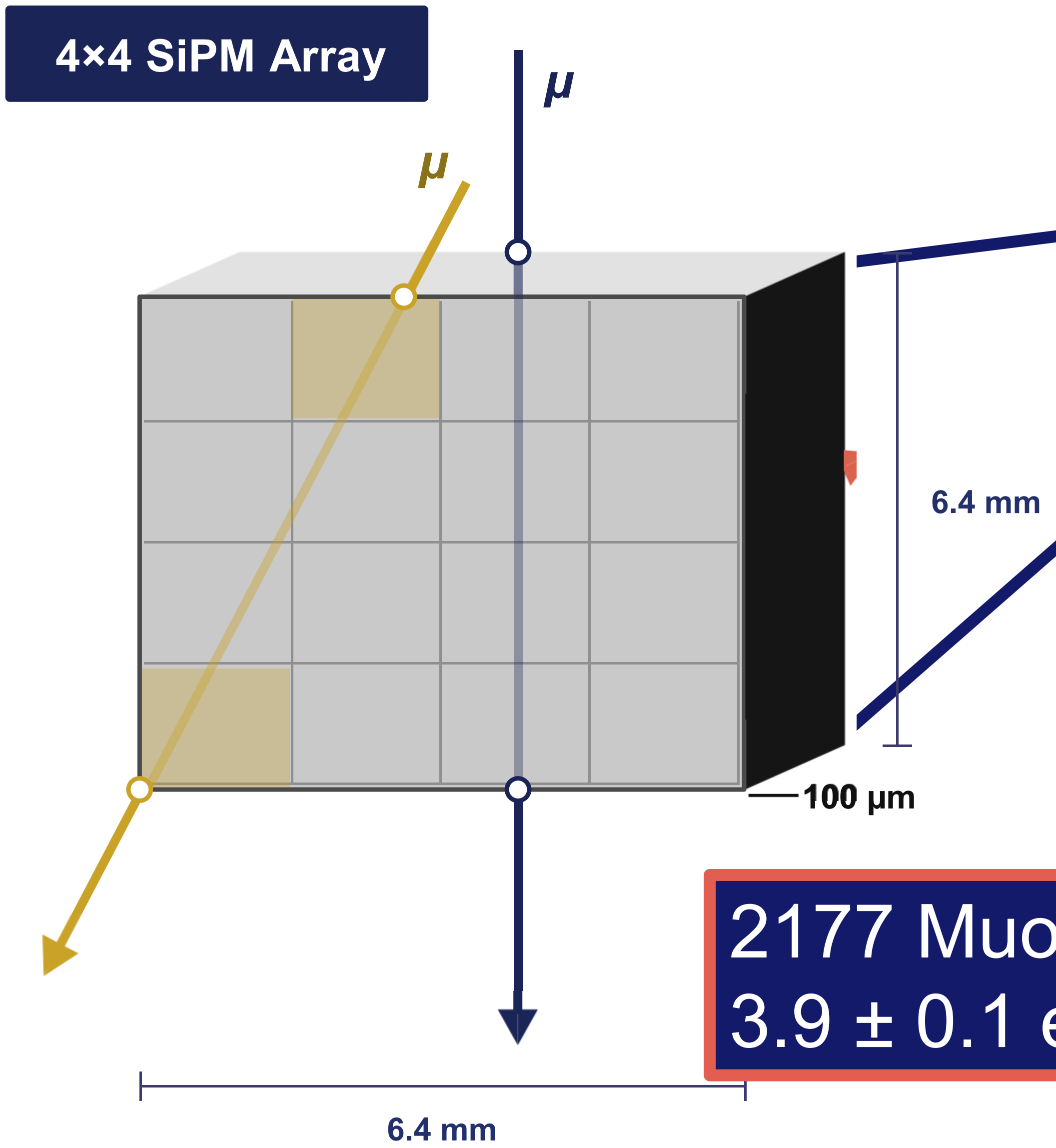
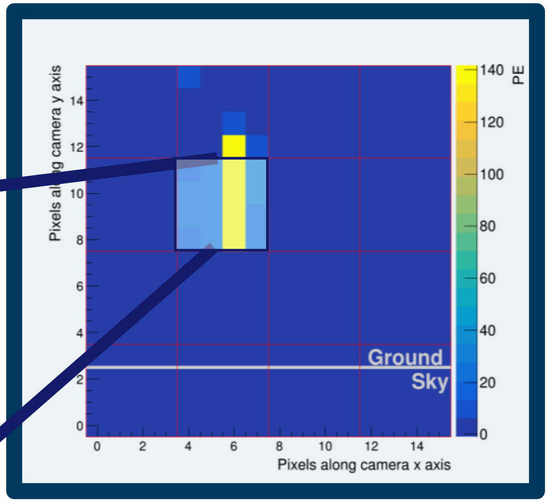
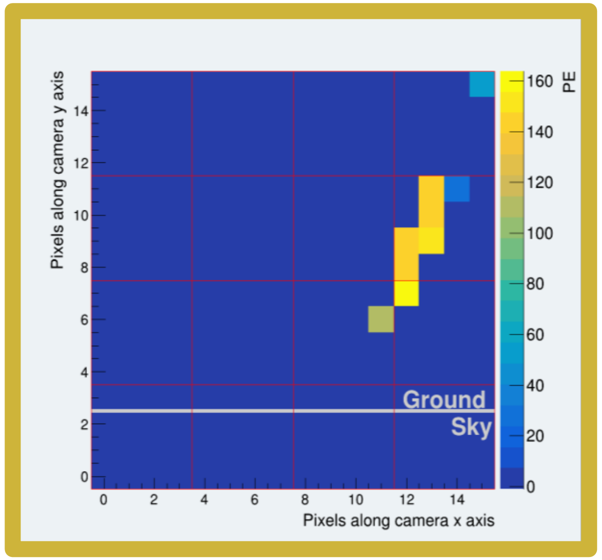
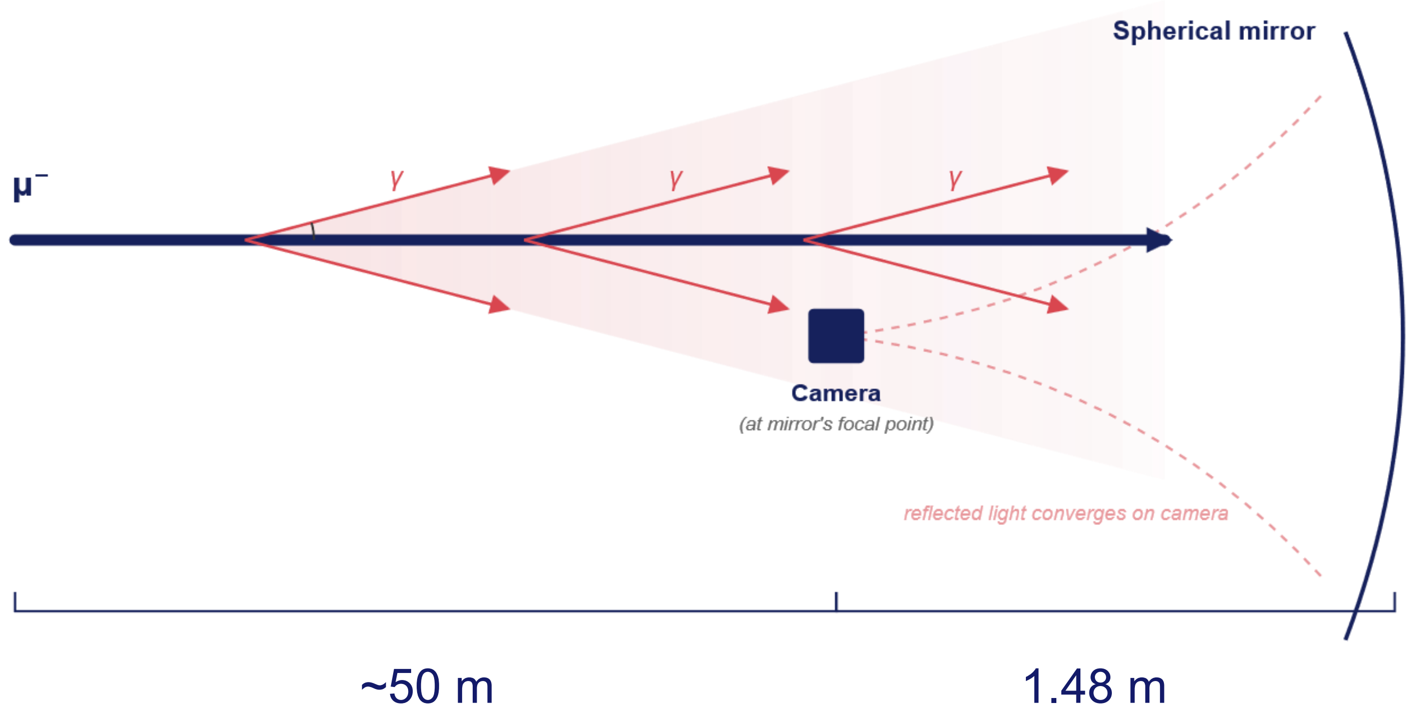






2177 Muon Tracks Events
3.9 ± 0.1 event per hour

Cherenkov Light from Muons Also Survives



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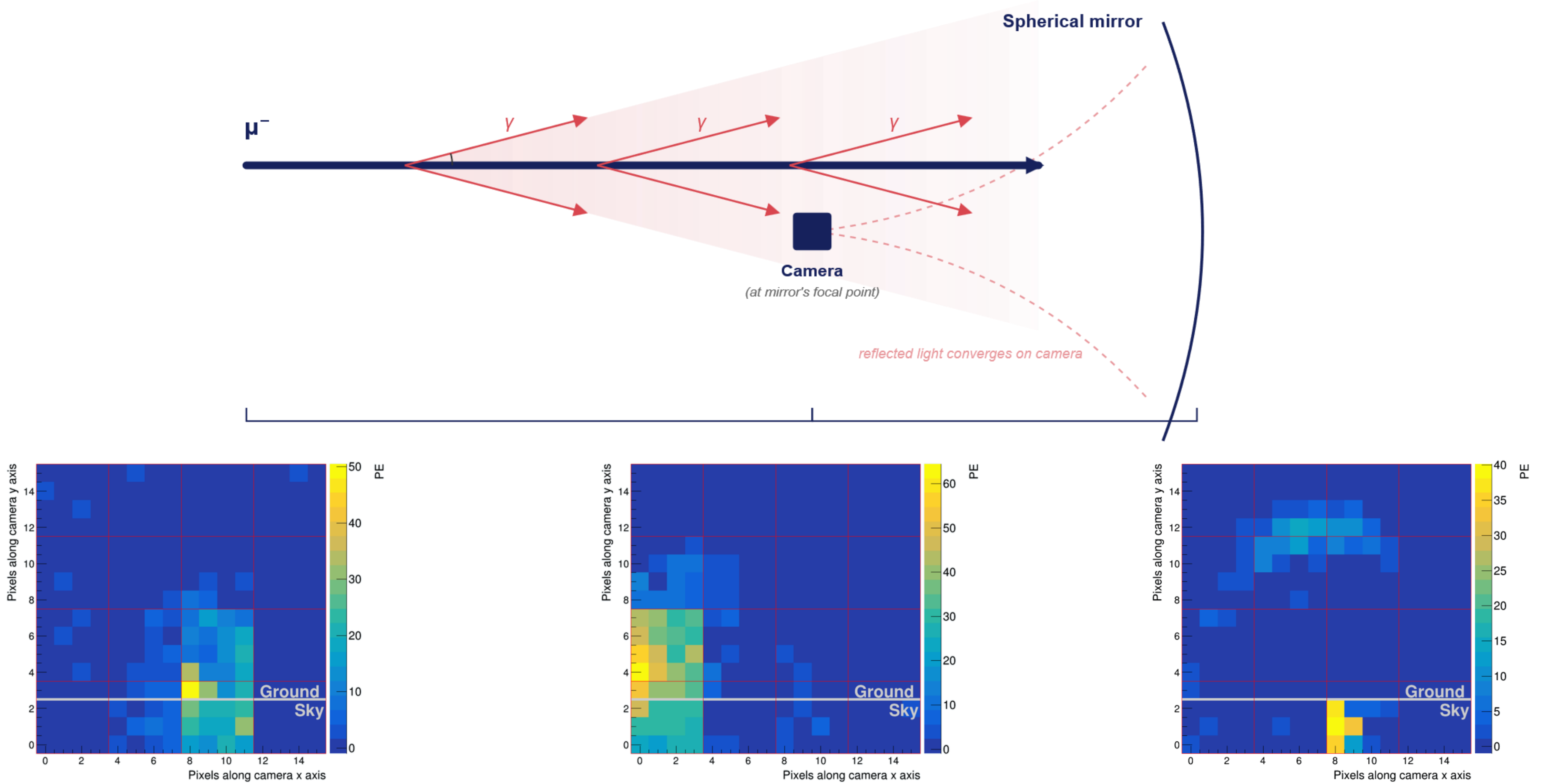
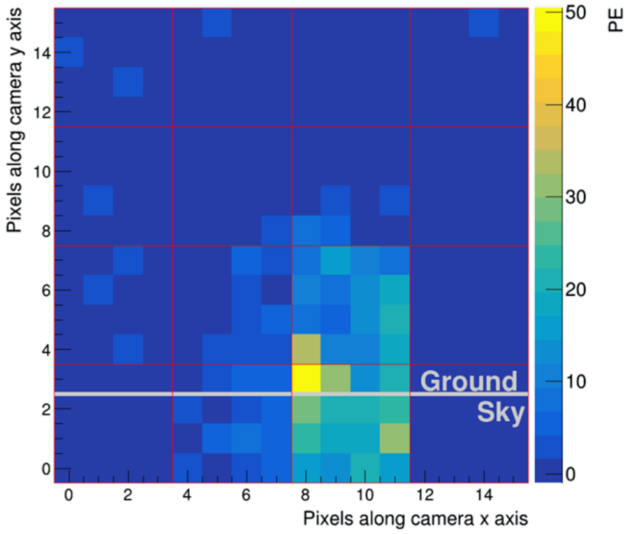
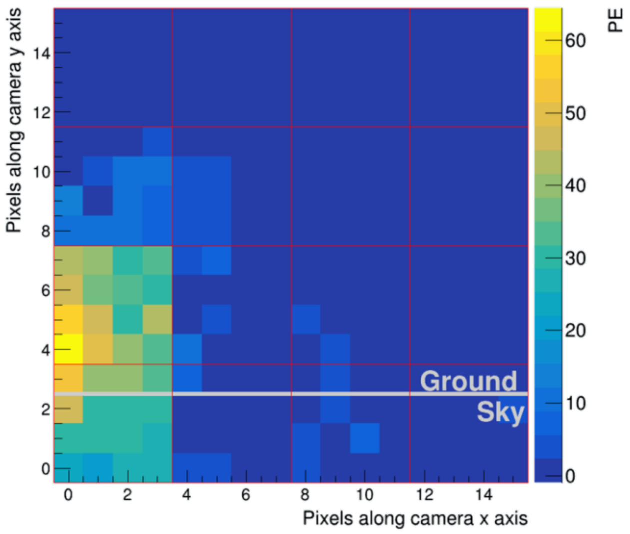
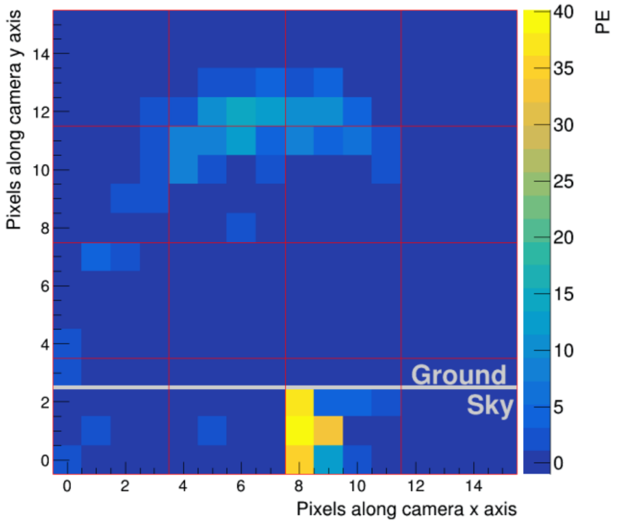


Cherenkov Light from Muons Also Survives

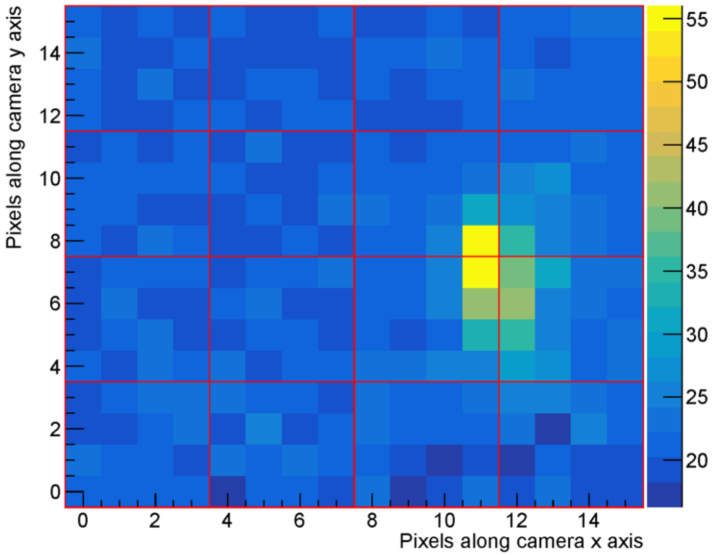
16 Isolated Muon Cherenkov Candidate Events
1.0 ± 0.1 event per 34 hours

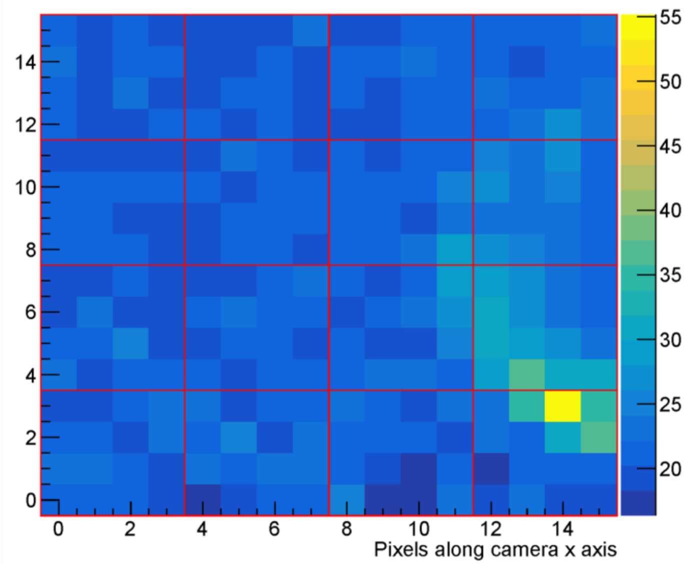






Muon Cherenkov Events are Consistent with Simulations





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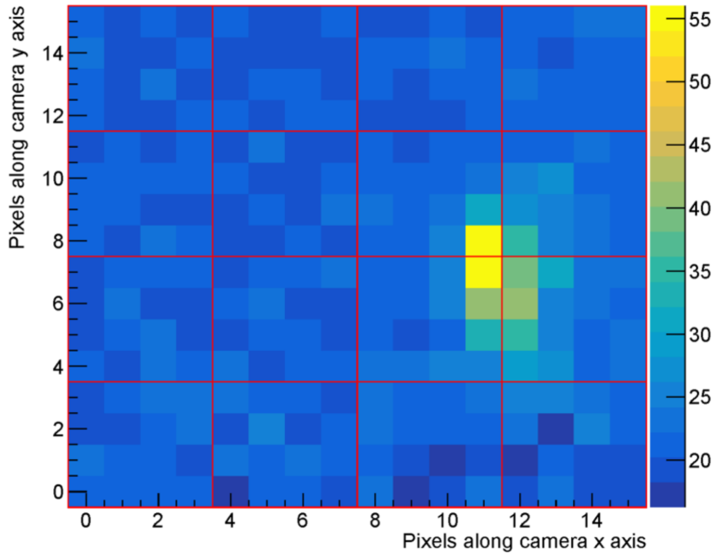
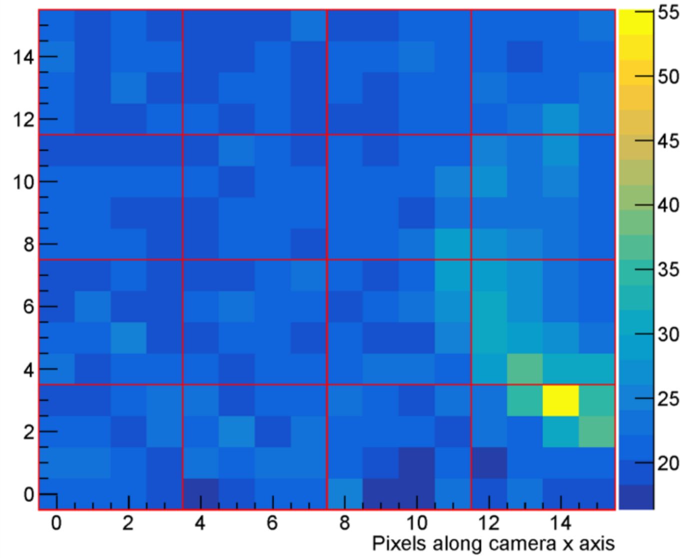
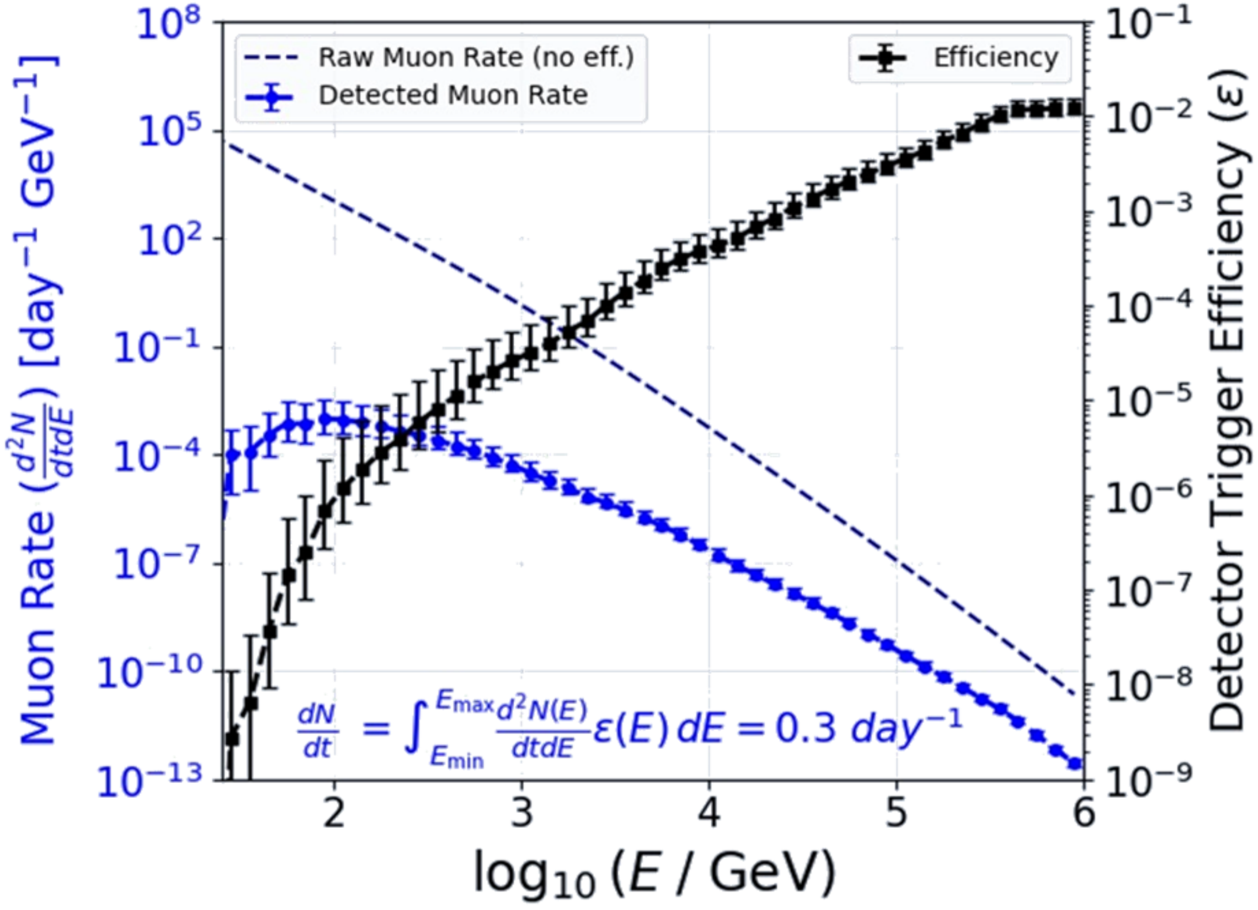
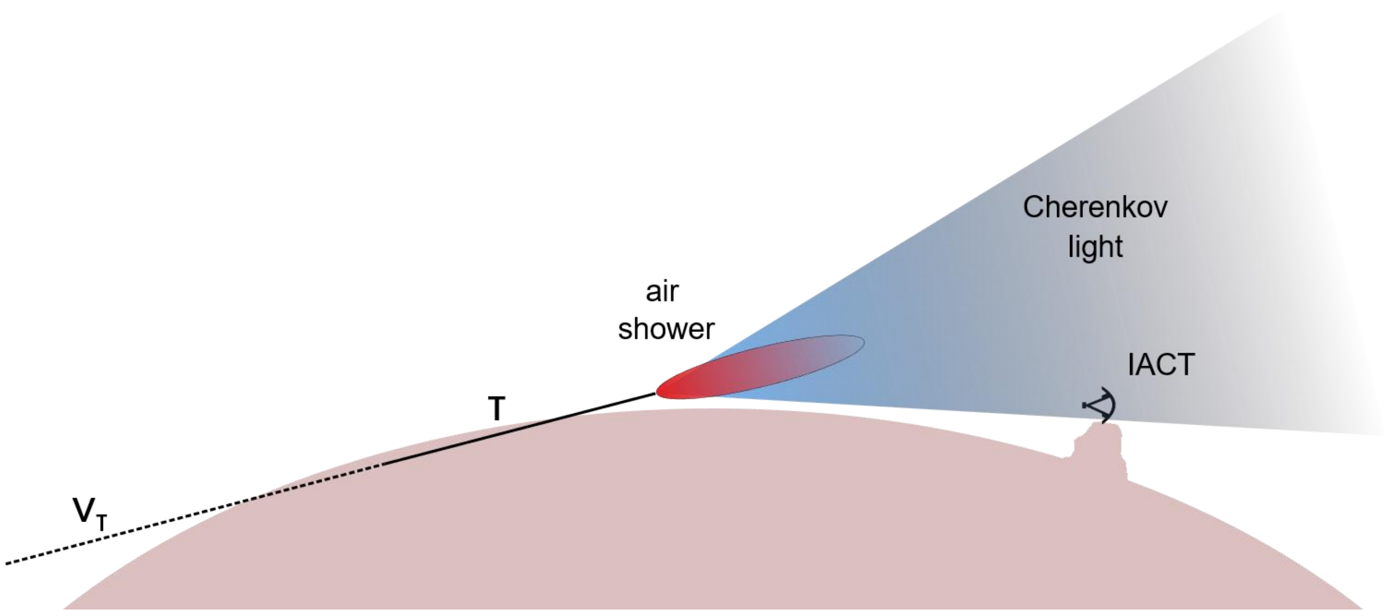




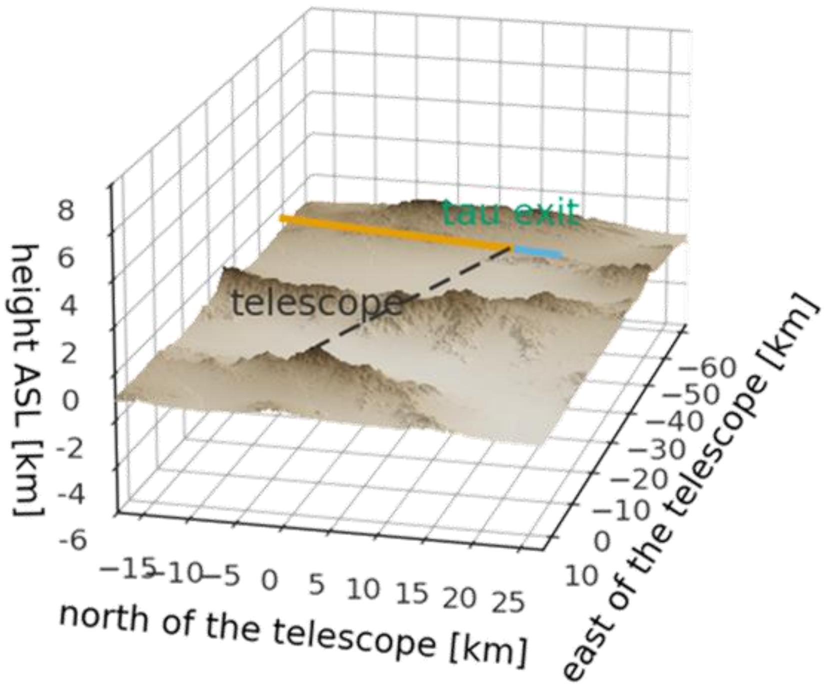


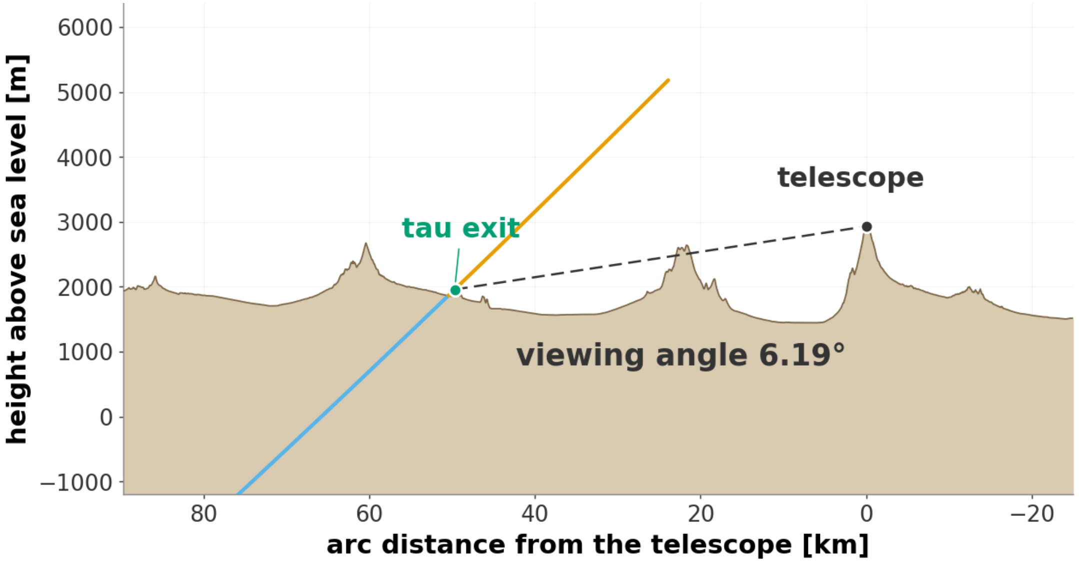
Simulated observed muon rate is $\mathbf{0.01}_{-0.003}^{+0.02}$ event/hour

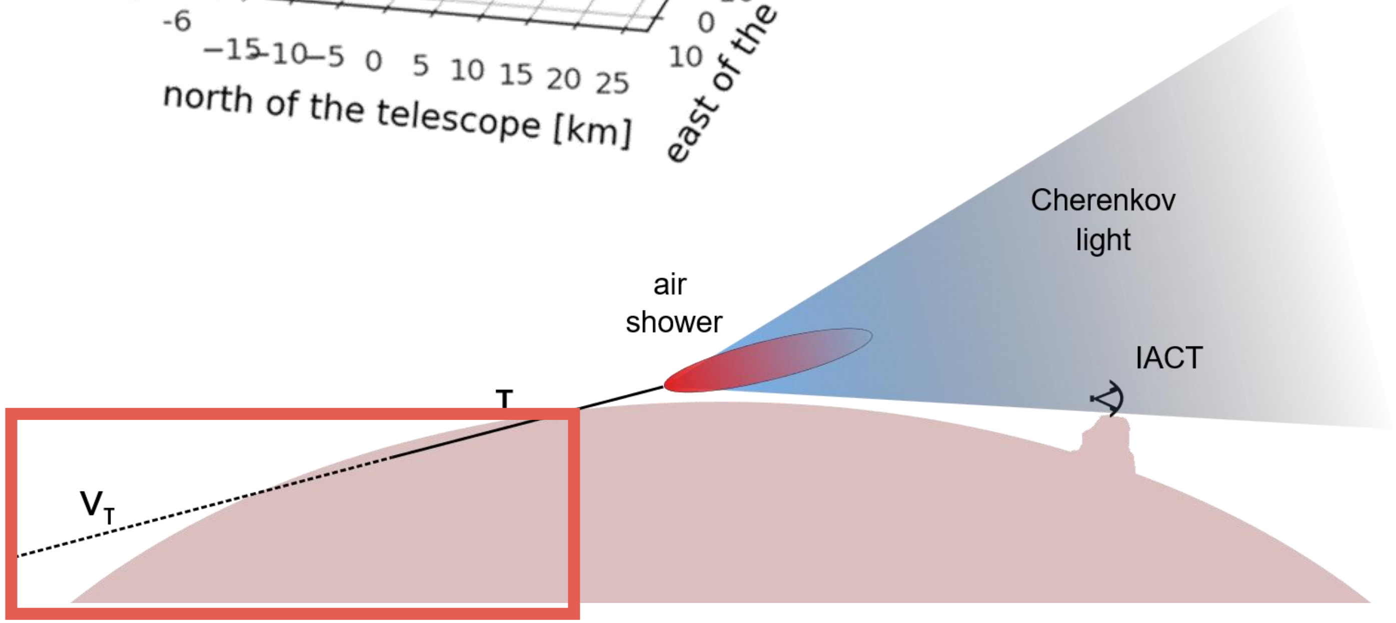
Tau Neutrino Simulation Chain

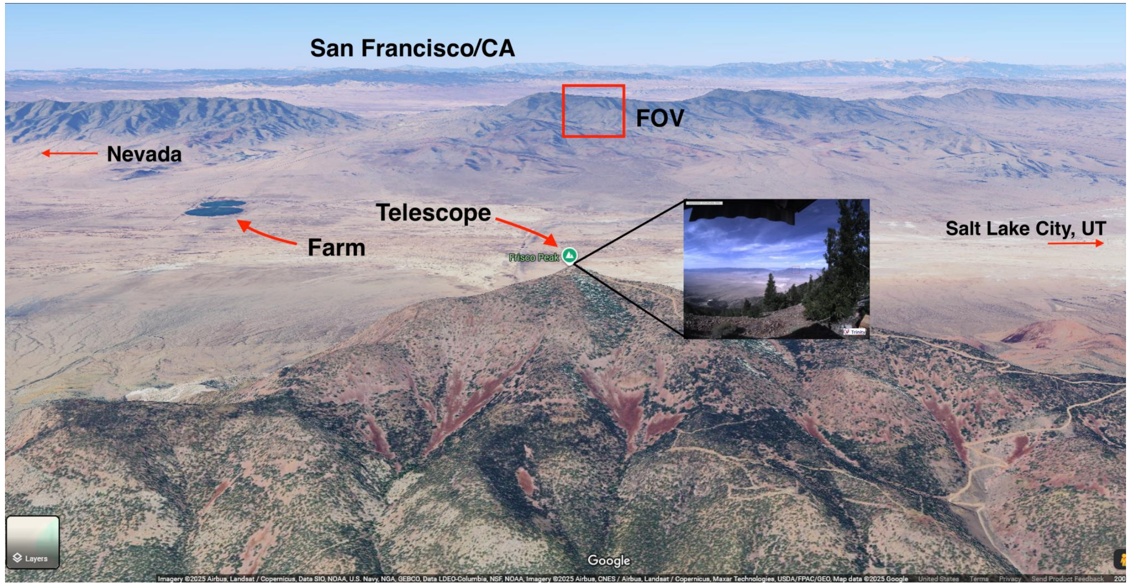


Tau Neutrino Simulation Chain: ISOG

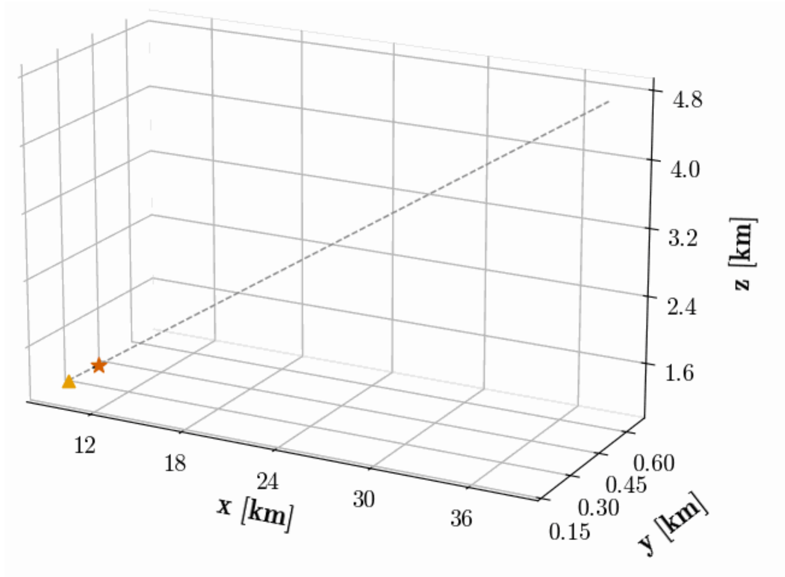


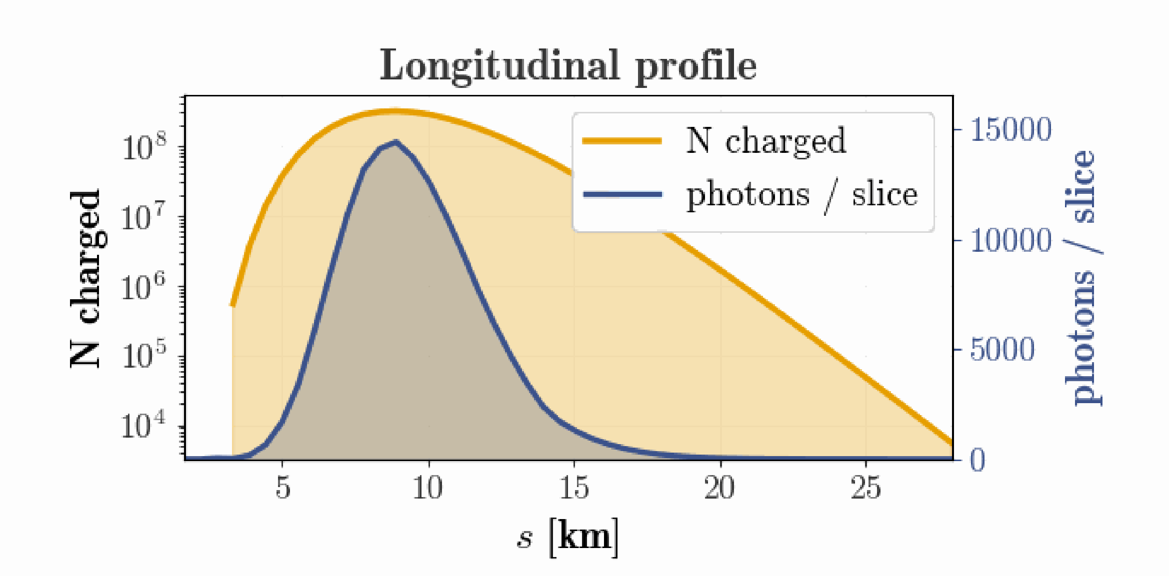




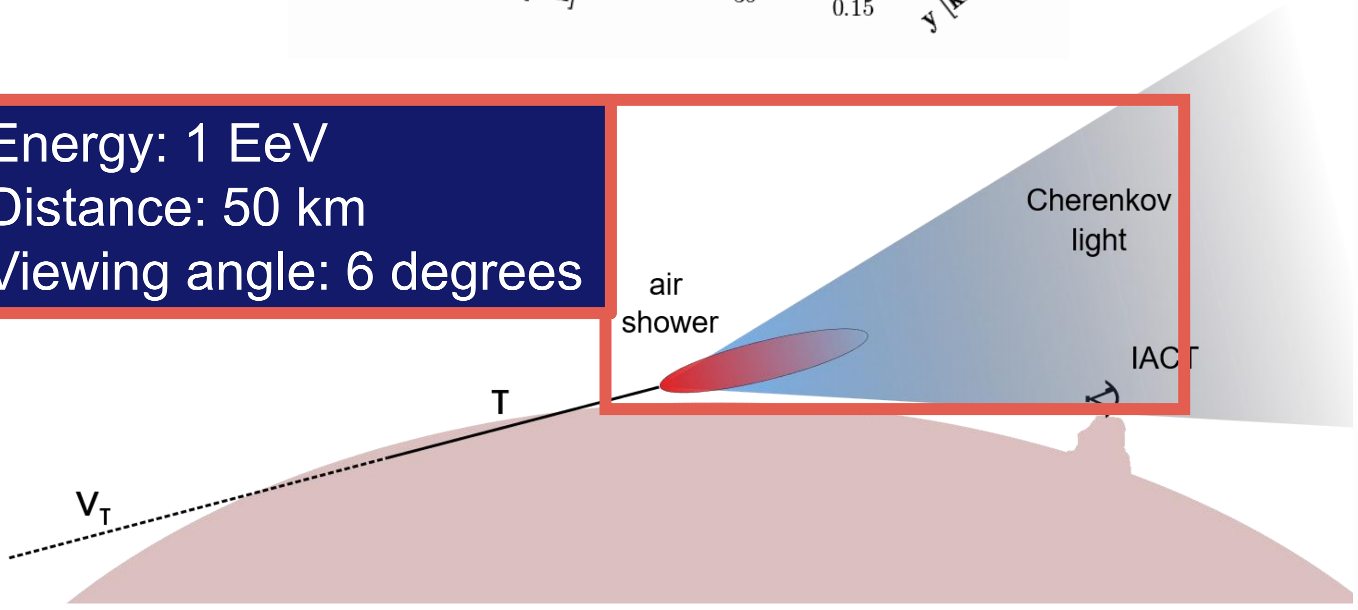


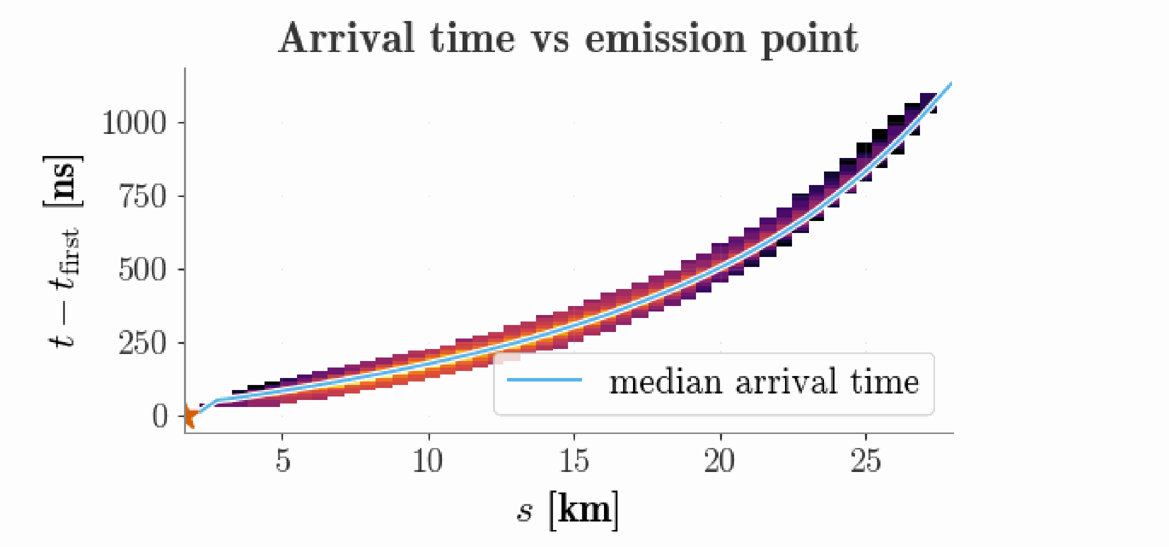
Tau Neutrino Simulation Chain: CHASM



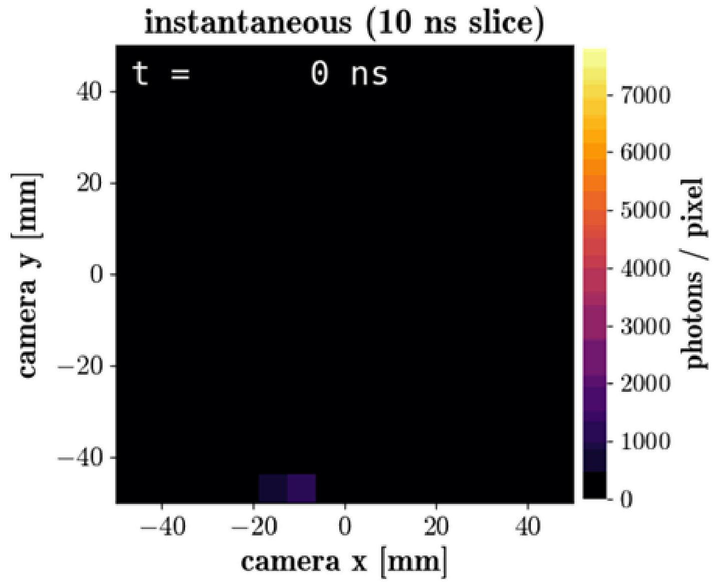


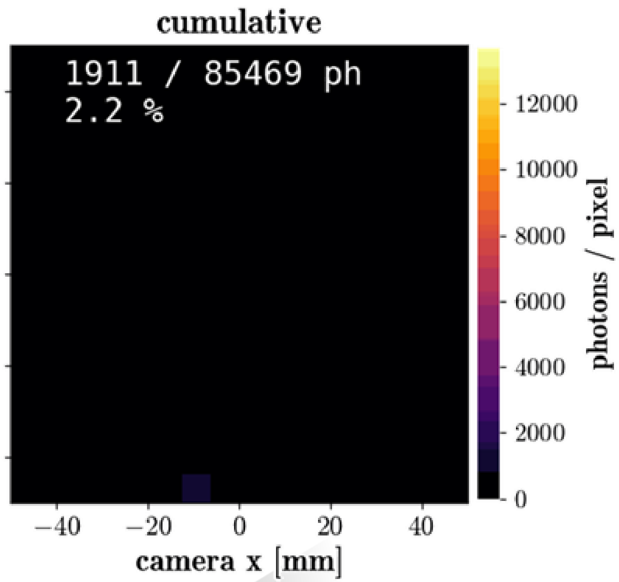
Energy: 1 EeV
Distance: 50 km
Viewing angle: 6 degrees

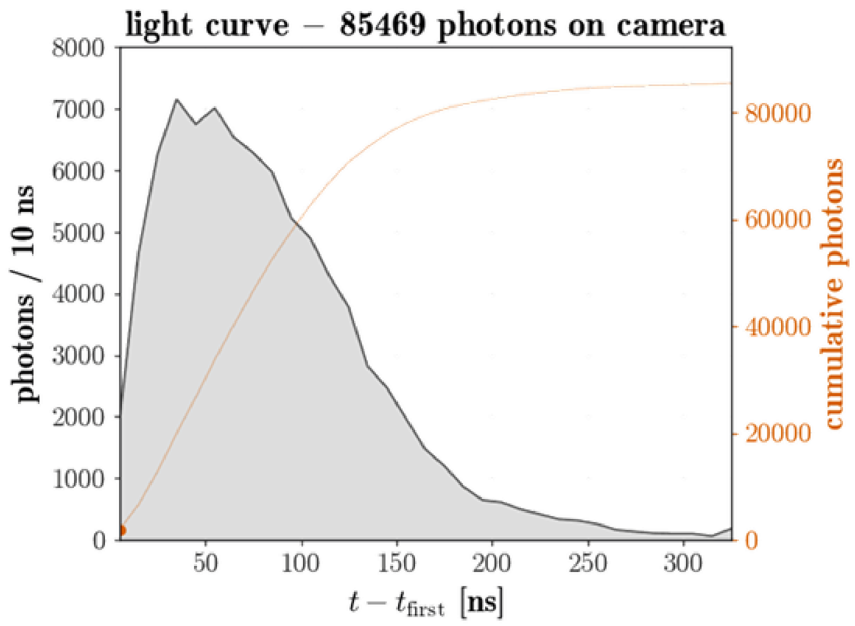




Tau Neutrino Simulation Chain: GrOptics







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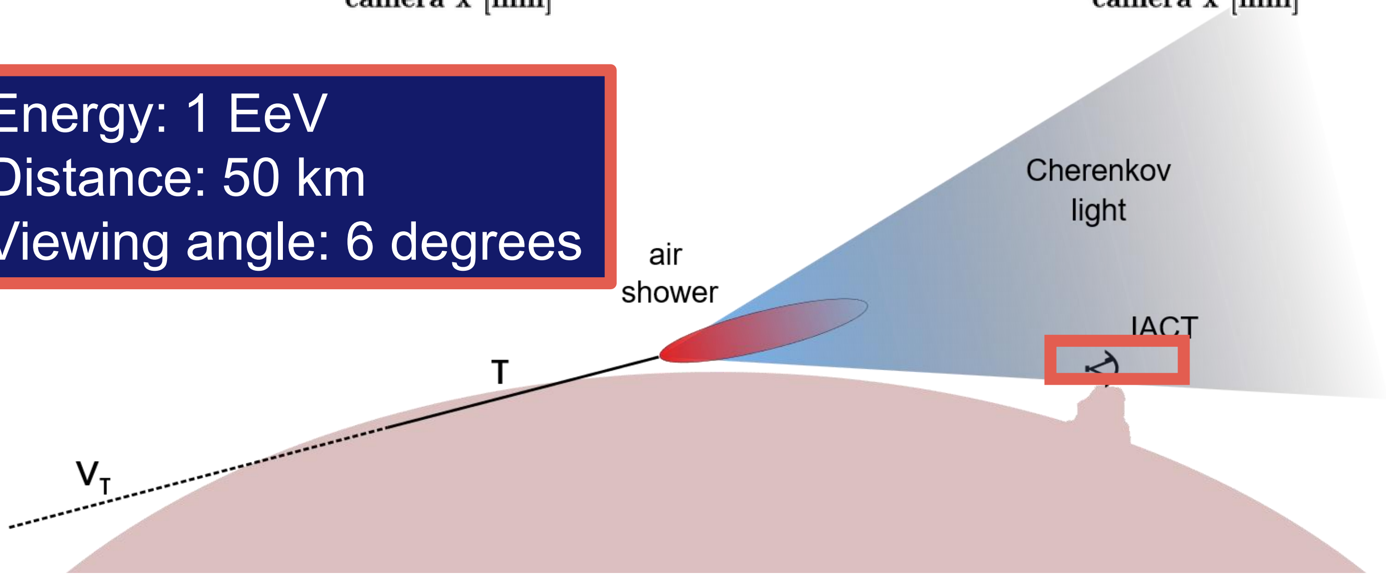
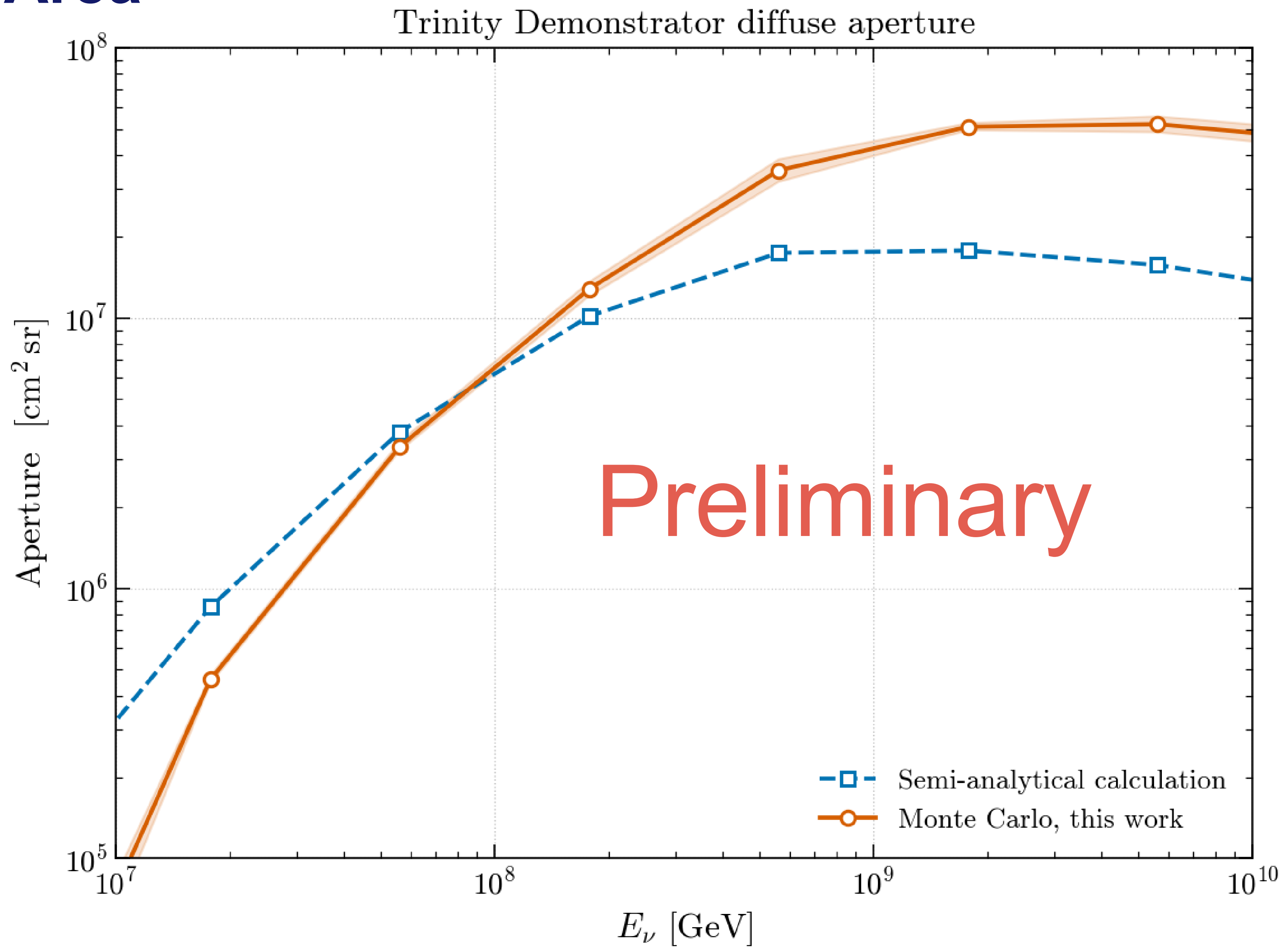


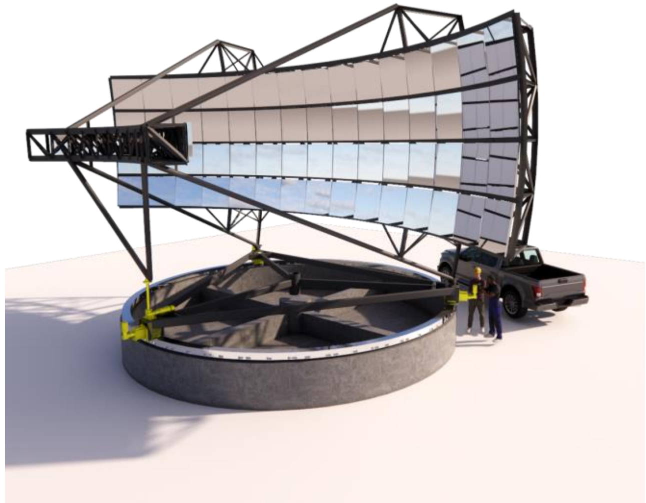
Effective Area

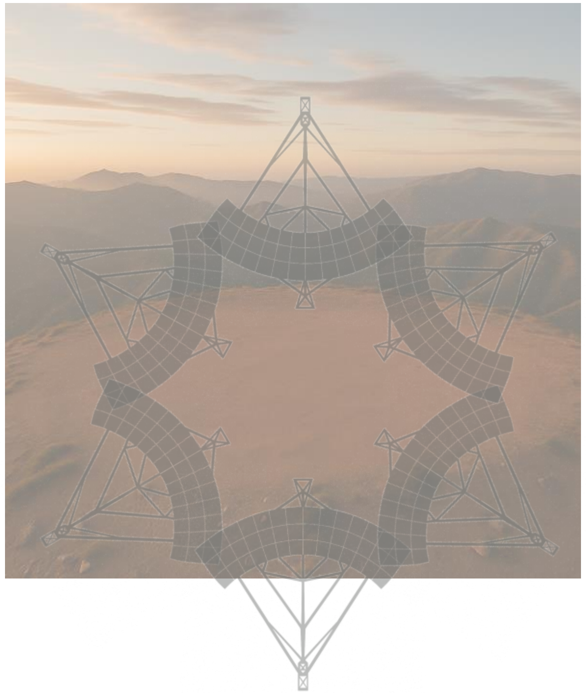


Pointing:
90 degree zenith

Maximum Distance:
~150 km (horizon)

The path towards the Trinity Observatory is ready



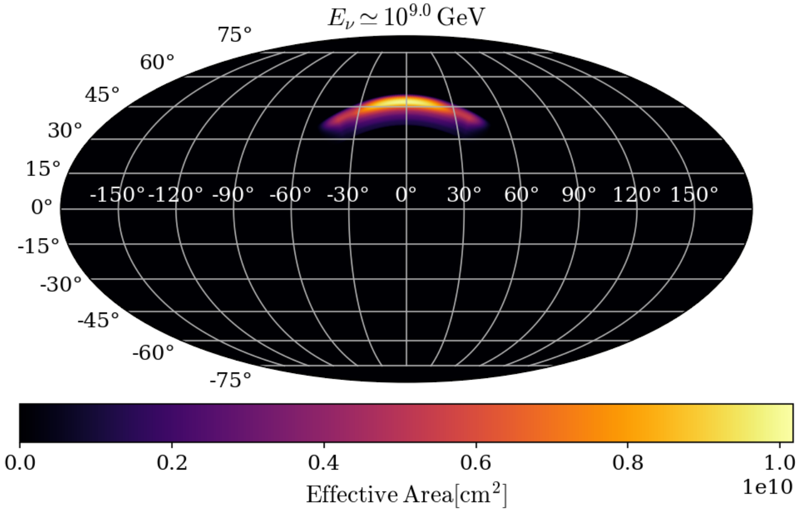


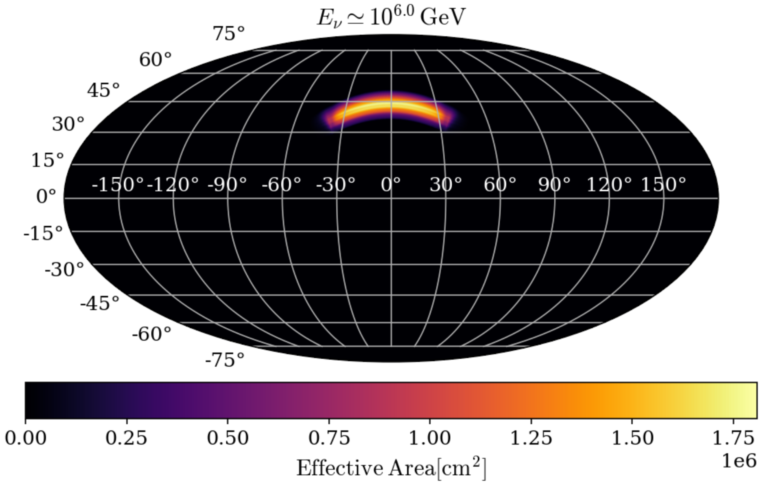
- Area -> 1 sq meter
- Field of View -> 3.87°x3.87°
- Resolution -> 0.24 °
- Taking data since October 2023

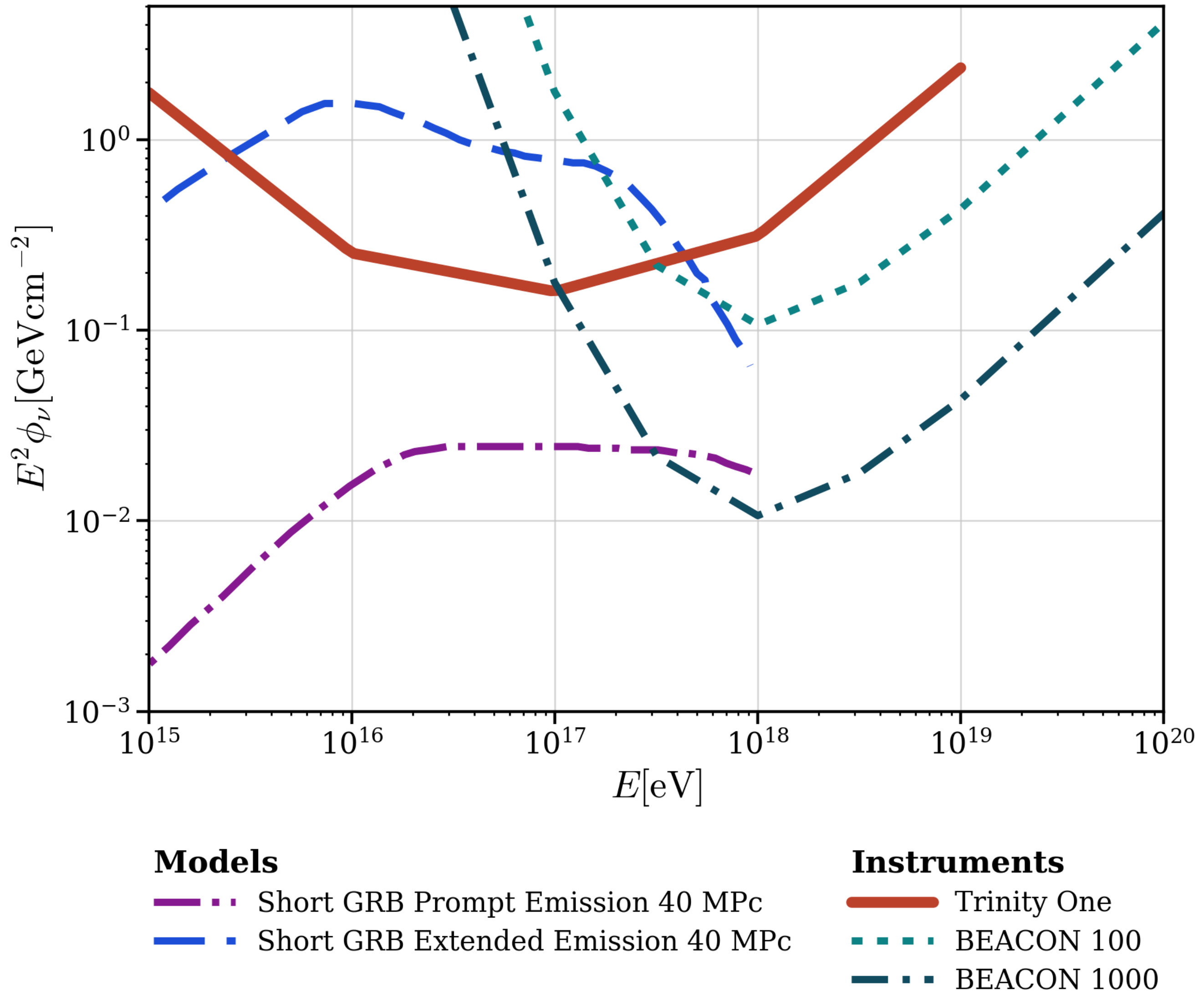
- Area -> 60 sq meter
- Field of View -> 60°x5°
- Resolution -> 0.3 °
- Construction starting next year. (?)

Demonstrator | Trinity One

Trinity-One will have very deep point source sensitivity







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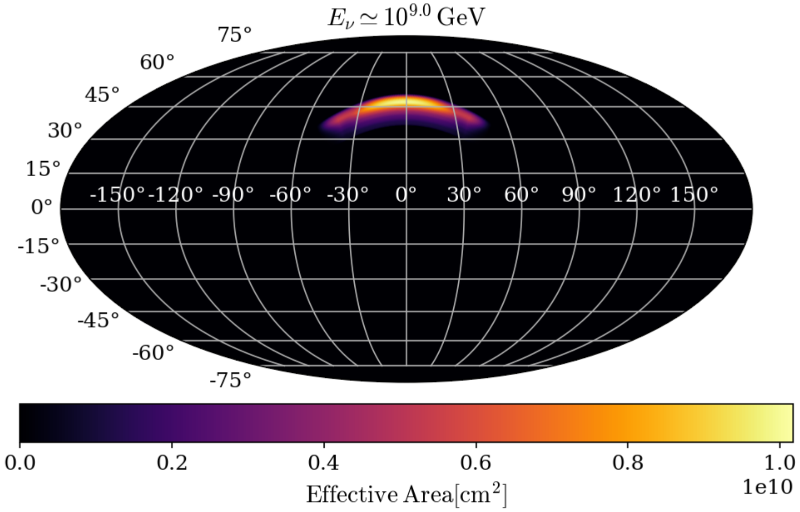
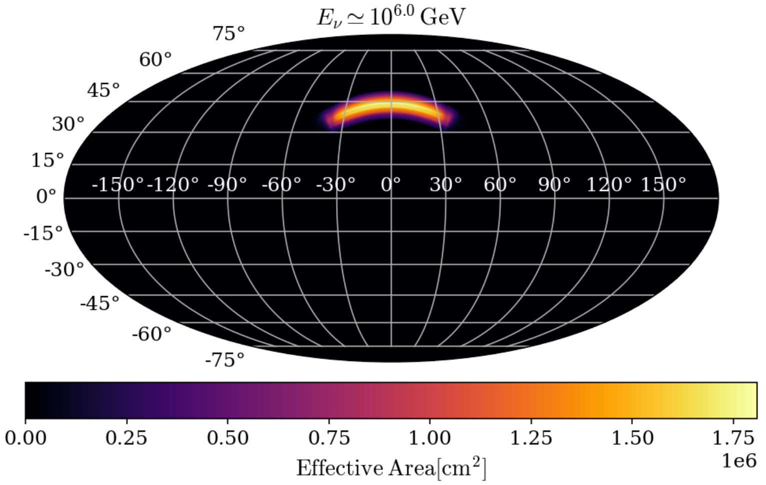
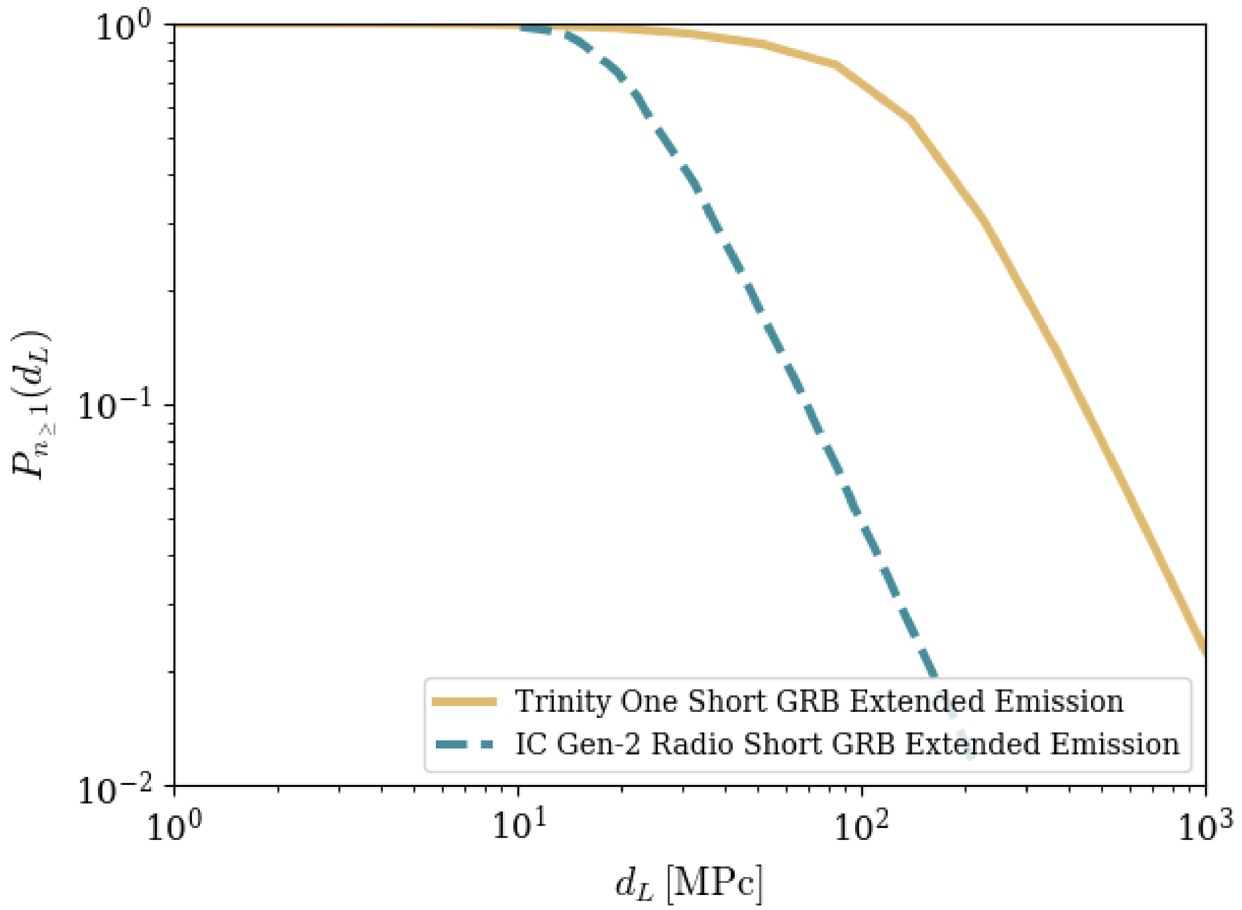
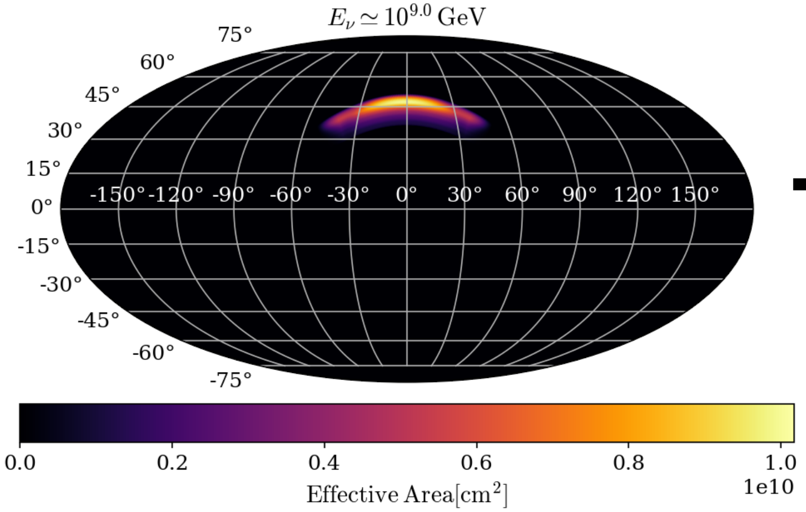
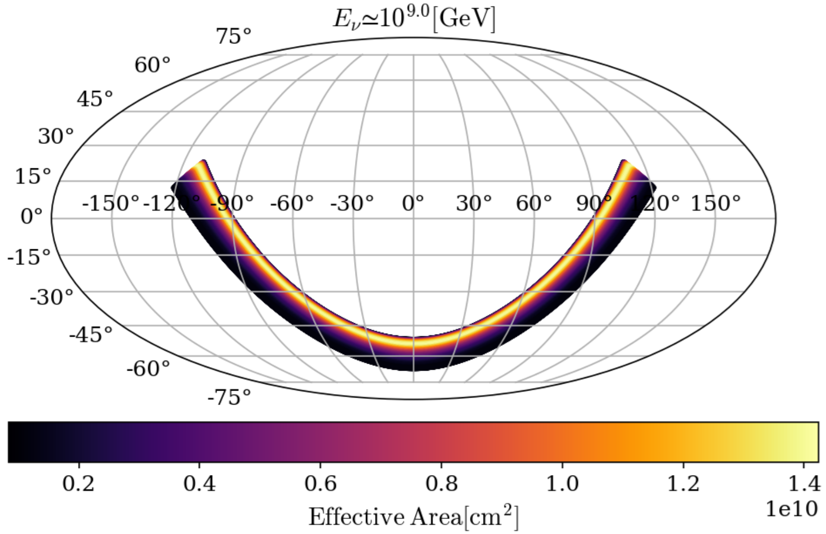




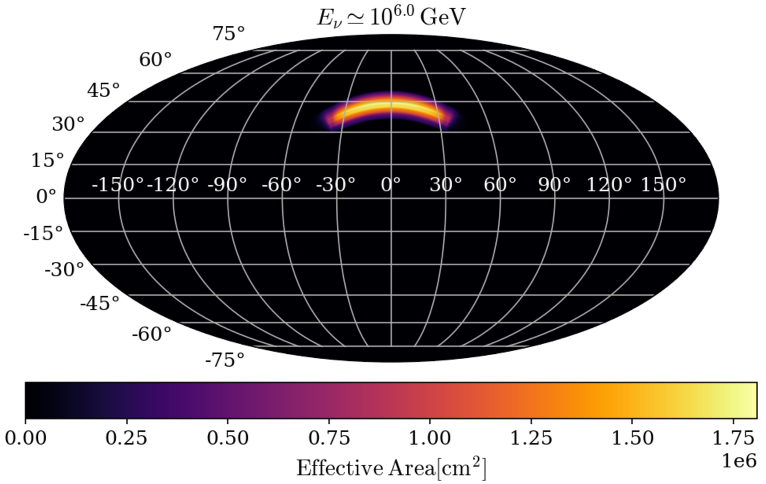


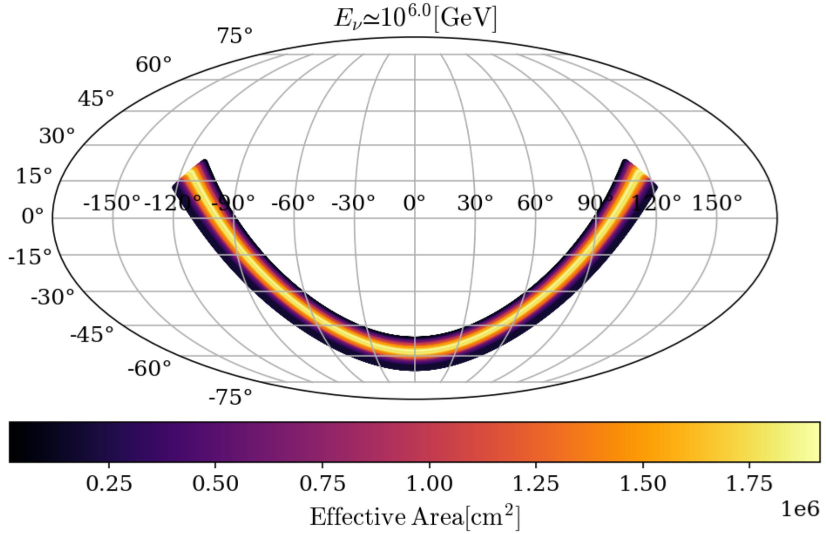
Azimuth rotation will enable source follow-ups



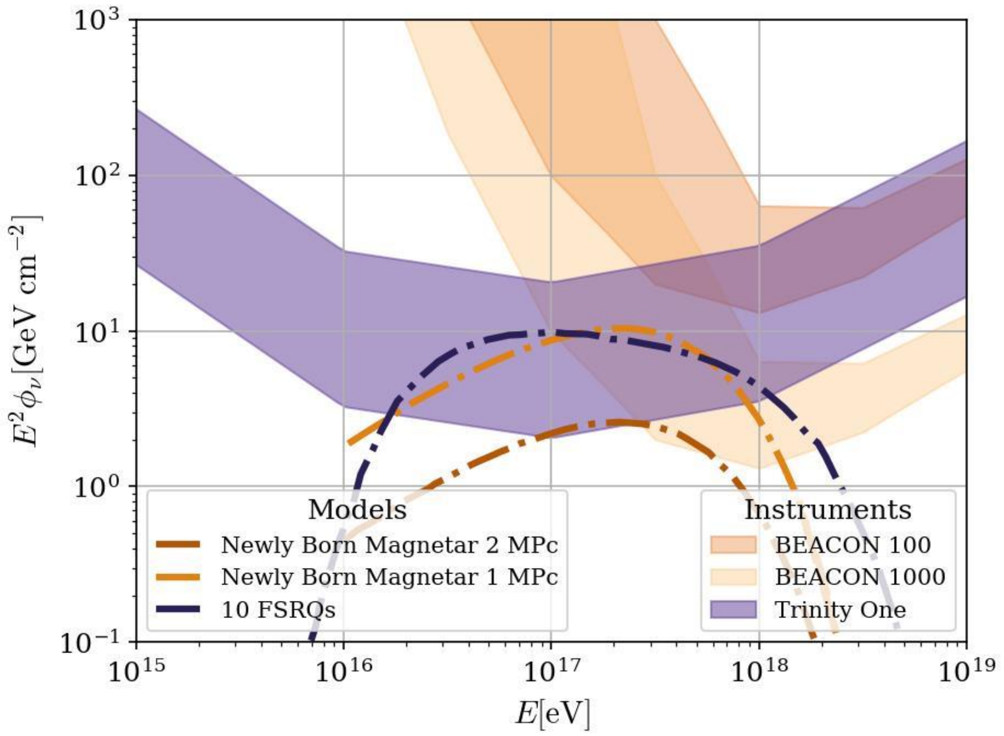


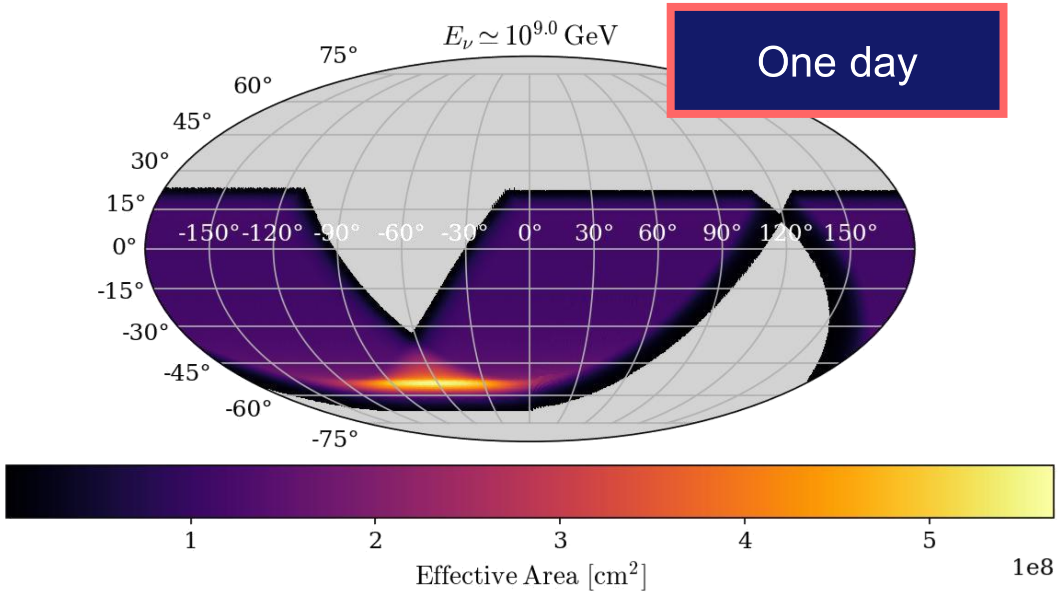
Accessible sky with repointing





Azimuth rotation also enhances long duration burst sensitivity





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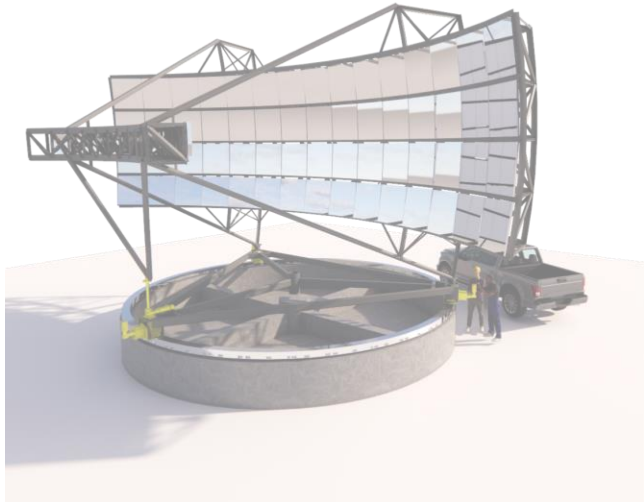


- Area -> 60 sq meter
- Field of View -> 60°x5°
- Resolution -> 0.3 °
- Construction starting next year. (?)

- 3 sites
- 6 telescopes per site
- Linear increase in diffuse flux sensitivity with number of telescopes

Demonstrator | Trinity One | Trinity Observatory

Summary and Outlook

- Current Data Analysis Run Points to a Background Free Experiment.
- Event discrimination and selection based on end-to-end Monte Carlo on the way!
- Pretty good transient source sensitivity and follow up potential with repointing.
- Limit on diffuse neutrino flux and some point sources soon!

Thank you!!

Trinity **Graduate Students**

Phenomenology and Science

Tau Simulations and Performance

David Raudales (me)

Nathan Rauch

Muon Simulations

Kiet Tran

Sameeksha Saini

Analysis and Operations

Sofia Stepanoff

Atmospheric Calibration

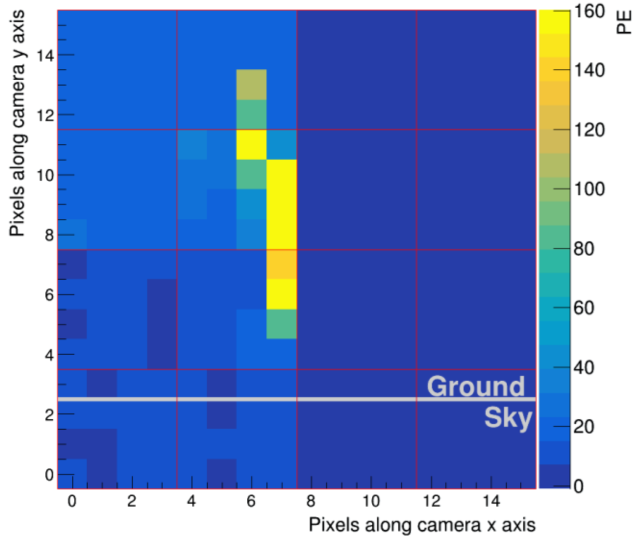
Jake McMillan

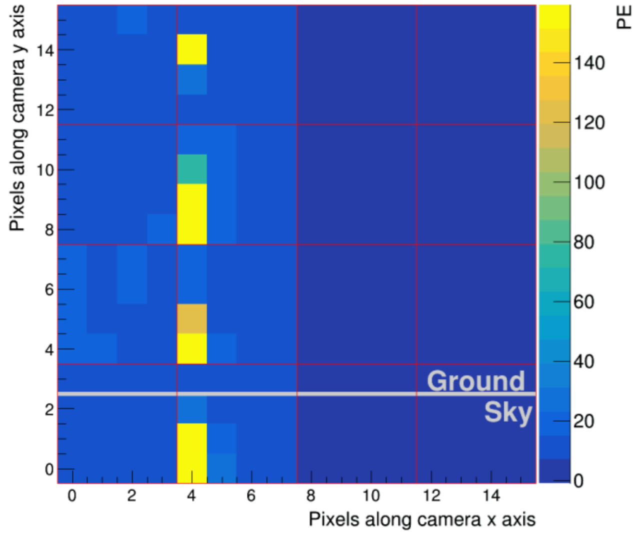
Backups

Images consistent with scintillator trigger

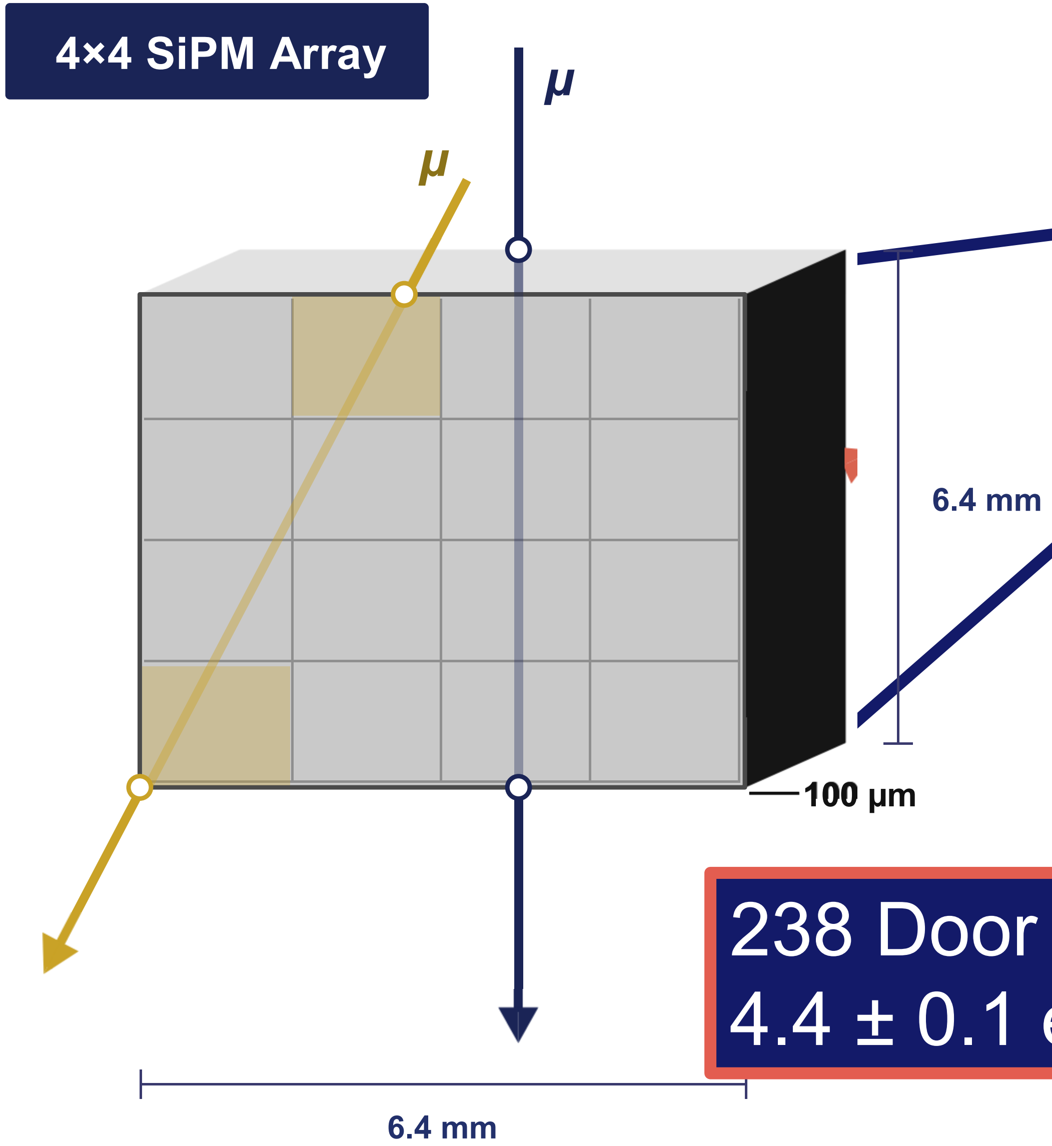
Door Closed

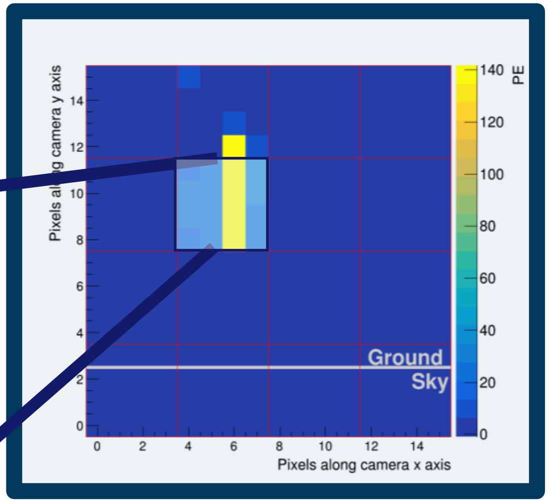
Plastic Scintillator Detectors

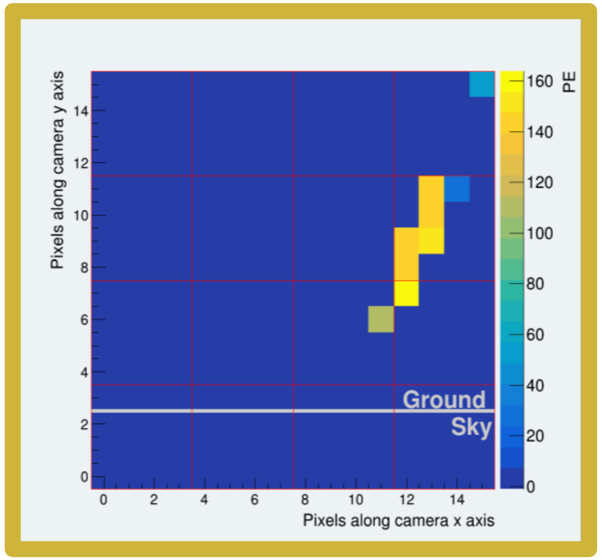




Muon Tracks Arise when Muons Cross the Camera

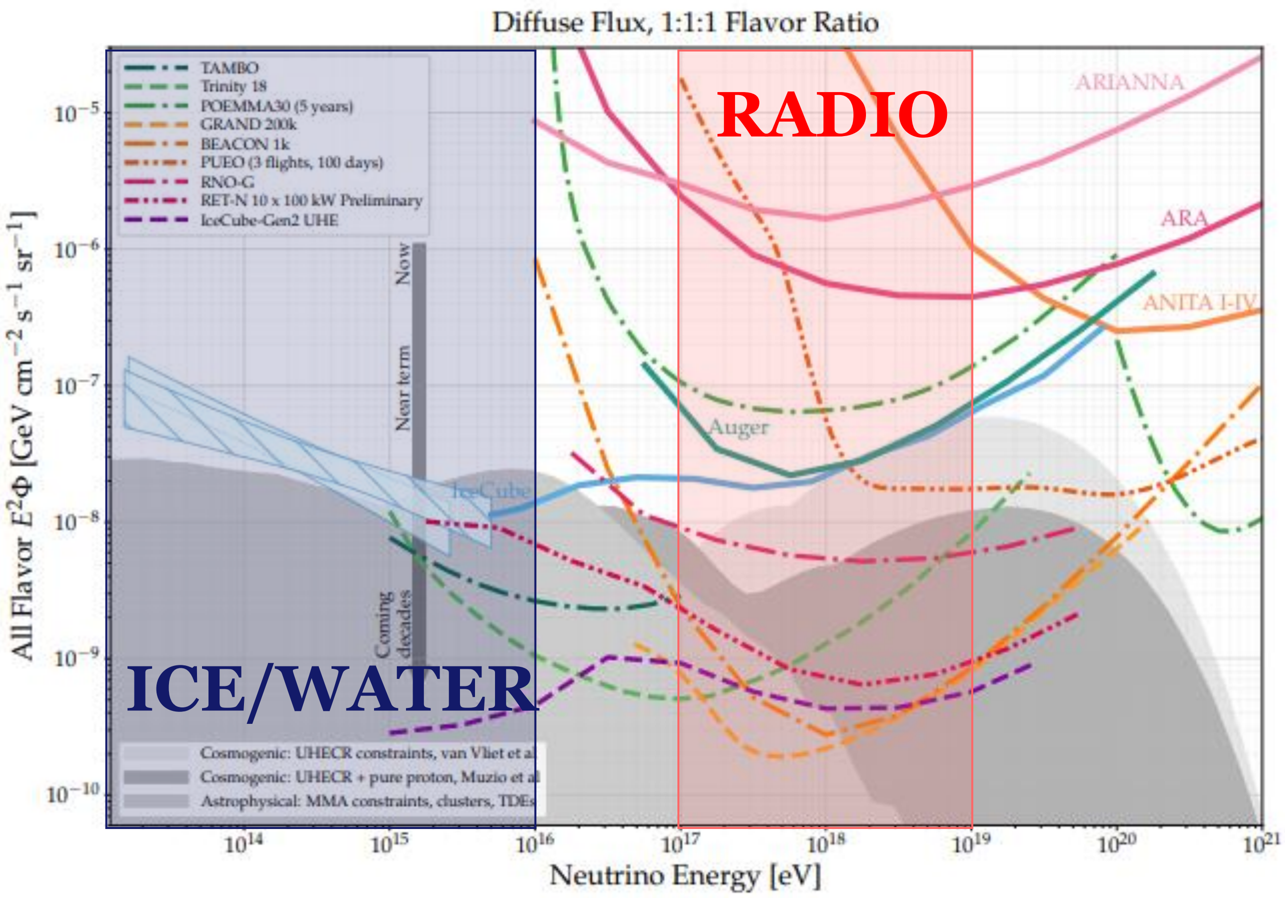




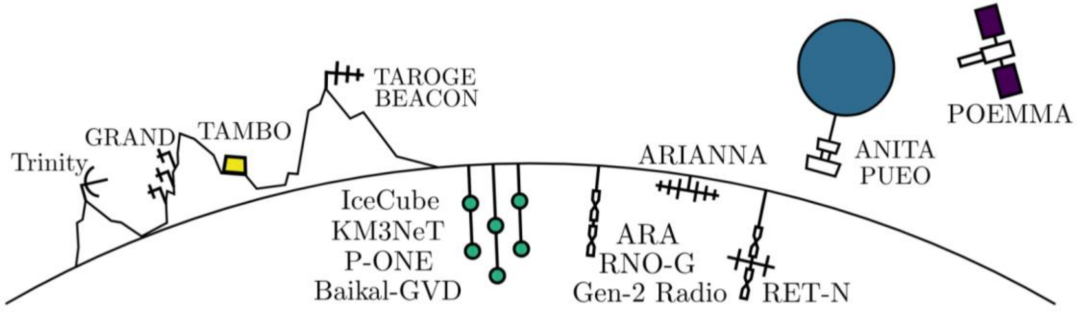


238 Door Closed Hours
4.4 ± 0.1 event per hour

Neutrino Telescopes Landscape

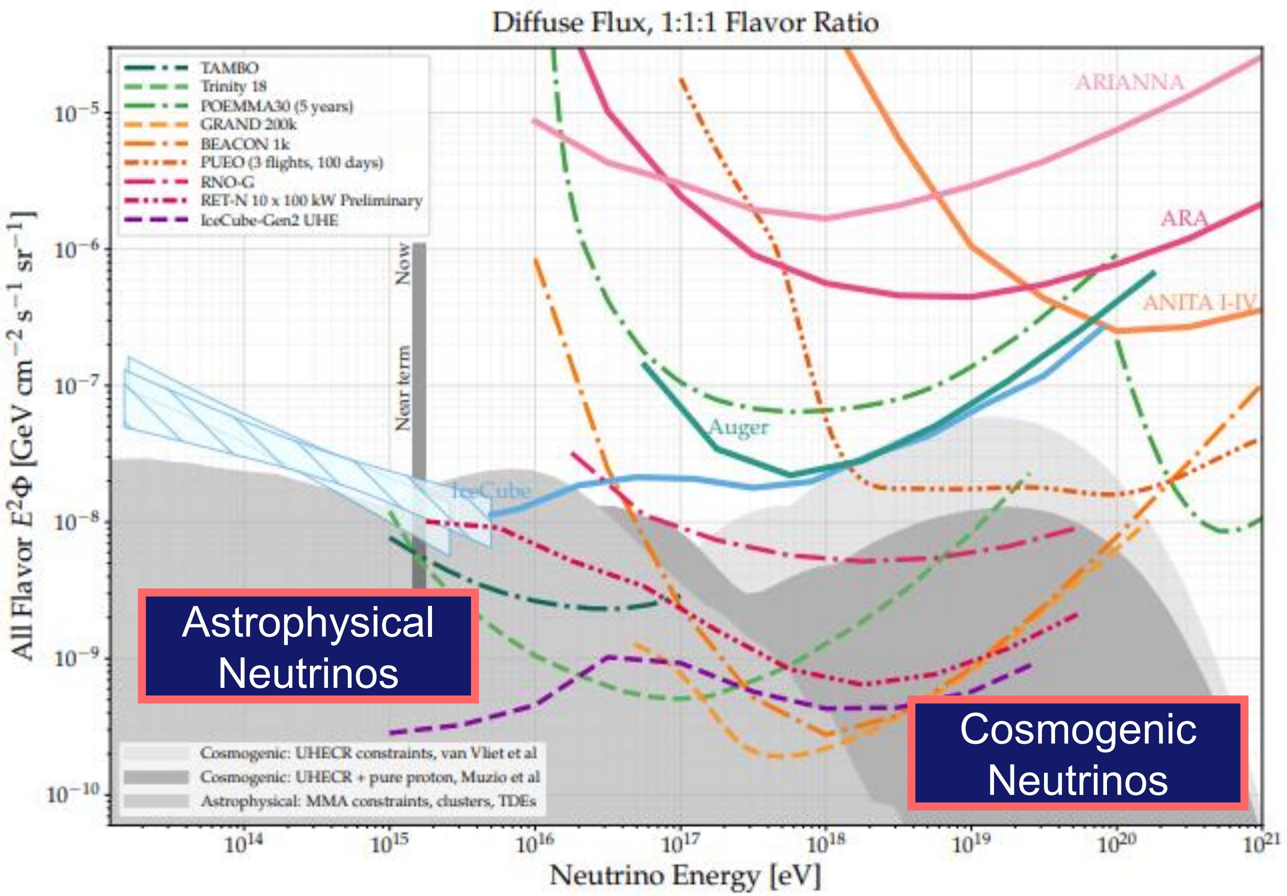


Ackermann, M. *et al.*, Snowmass, **JHEAp** 36 (2022) 55–110



Esteban, Prohira, Beacom, Phys. Rev. D 106, 023021

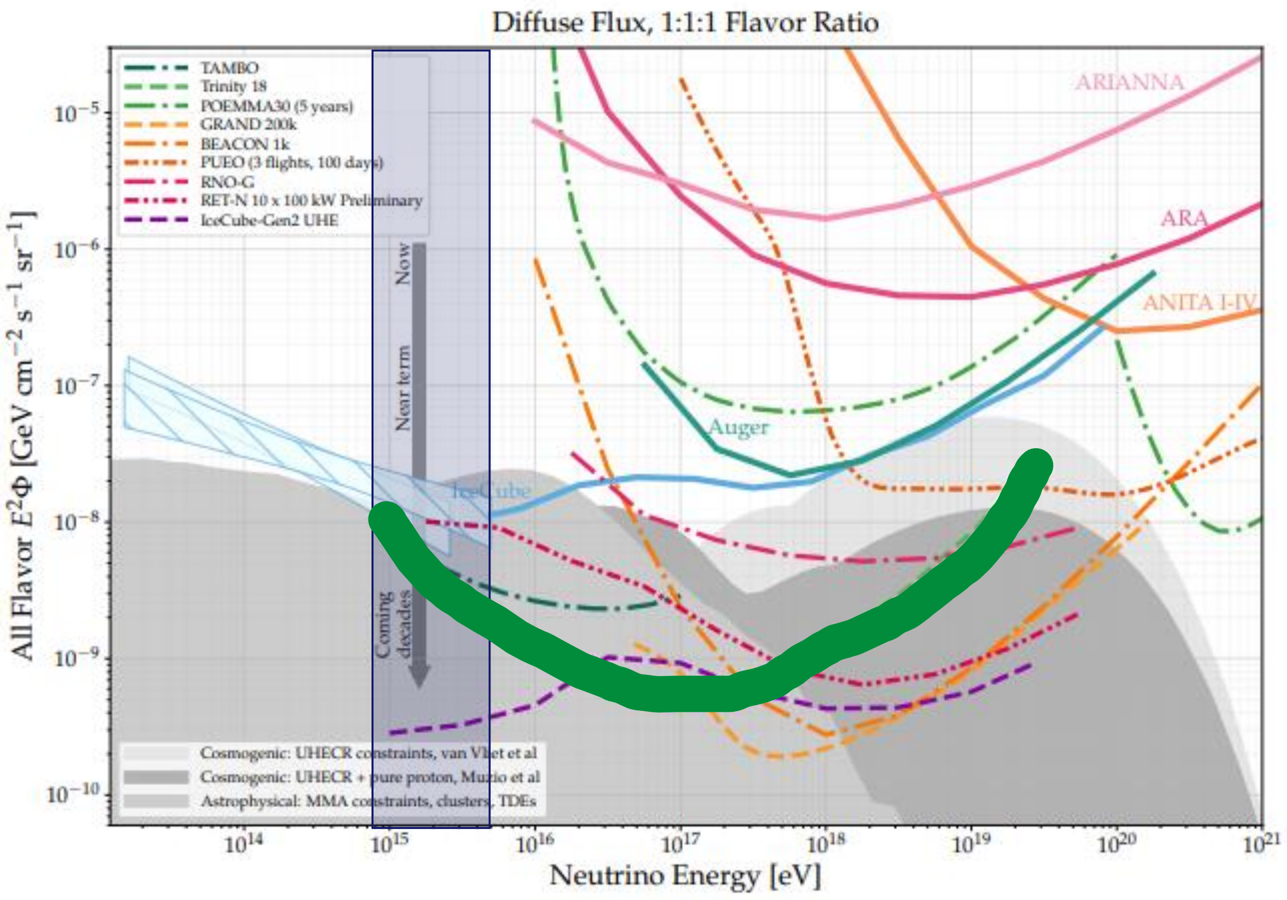
Neutrino Telescopes Landscape



Ackermann, M. *et al.*, Snowmass, **JHEAp** 36 (2022) 55–110

- Closes the gap between ice/water Cherenkov telescopes and radio detectors

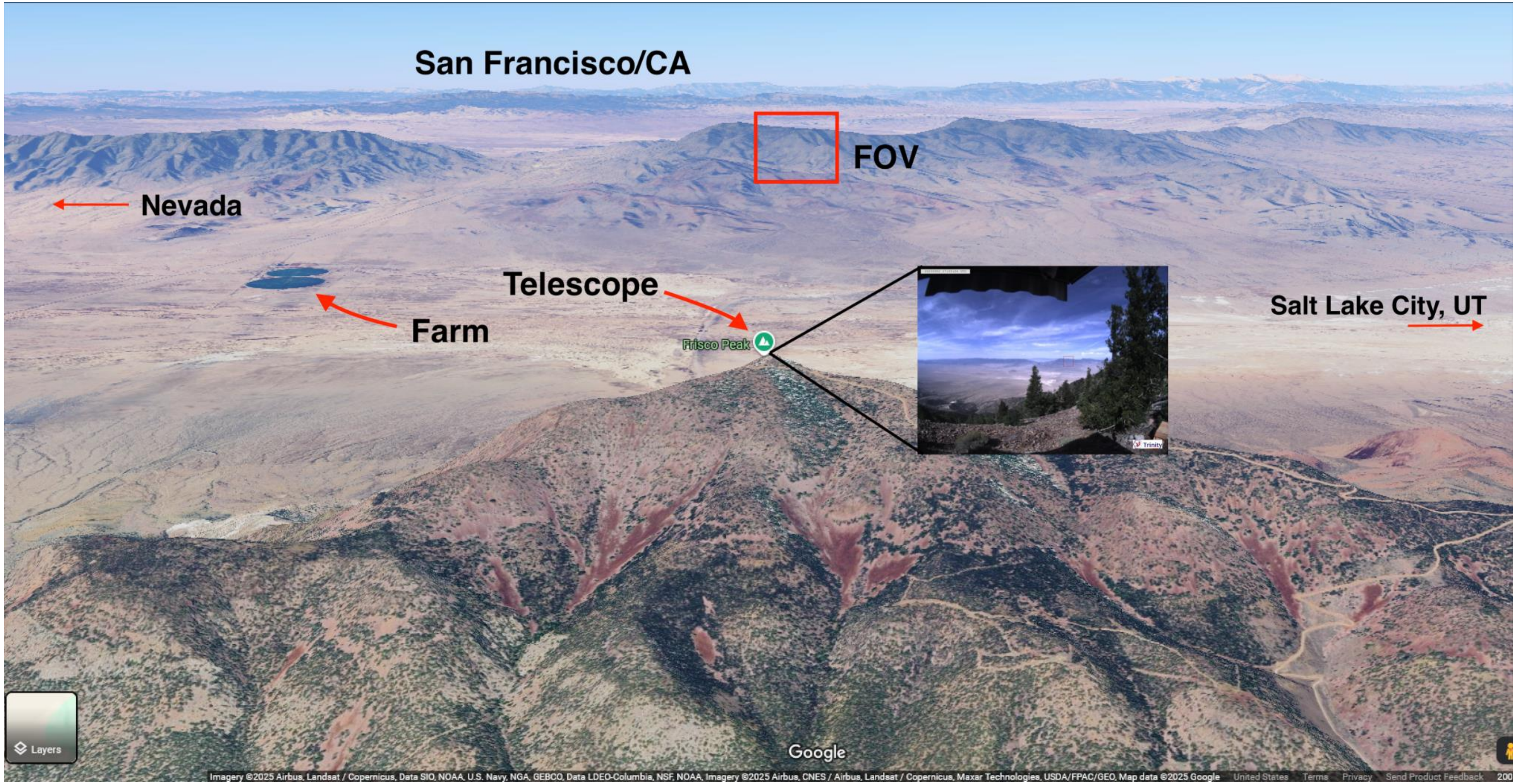
Neutrino Telescopes Landscape



Ackermann, M. *et al.*, Snowmass, **JHEAp** 36 (2022) 55–110

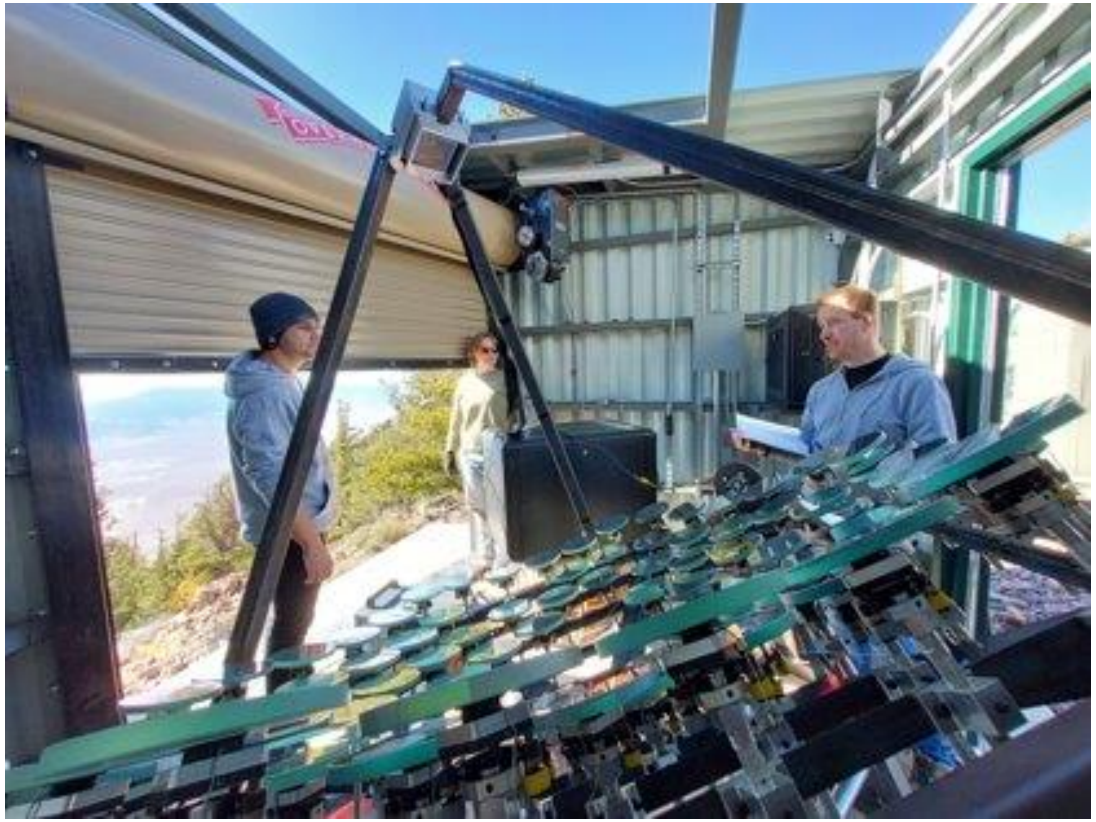
- Closes the gap between ice/water Cherenkov telescopes and radio detectors
- Overlap with IceCube ensures neutrino detection

What is the past, present and future of Trinity?



Commissioning

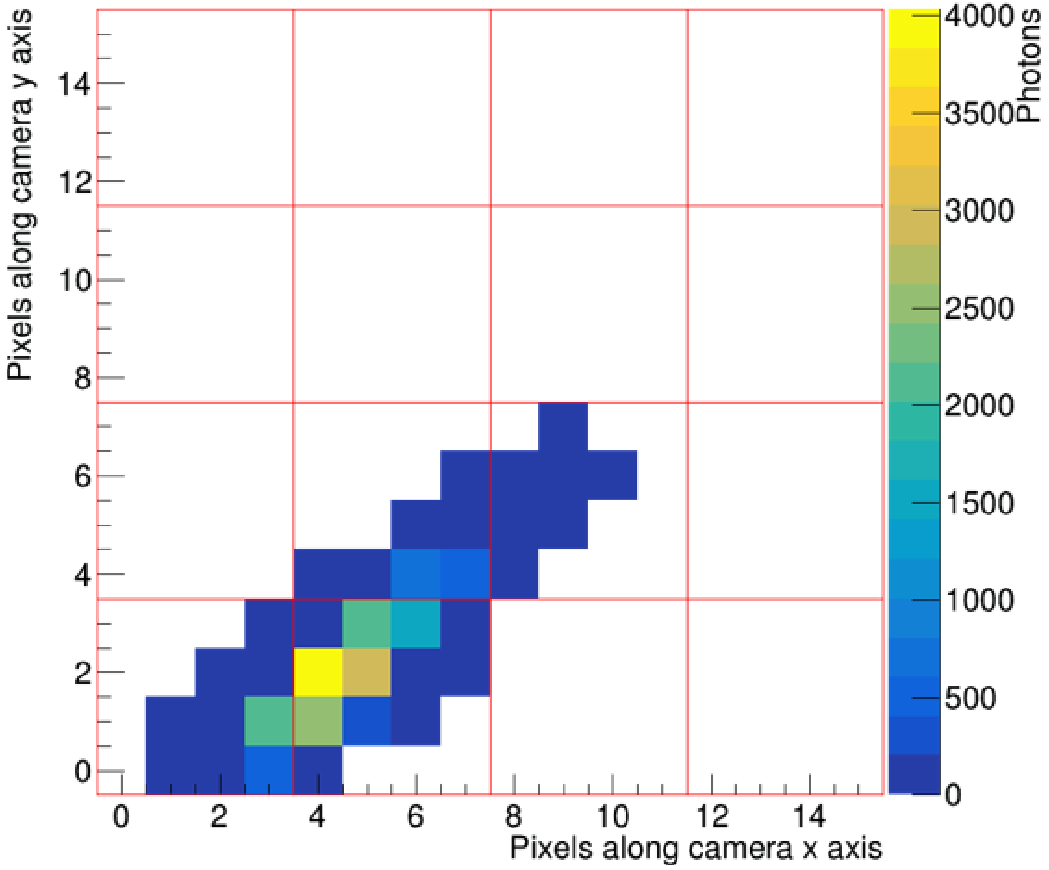
- Aligning optics
- Signal calibration
- Trigger calibration
- Remote operation



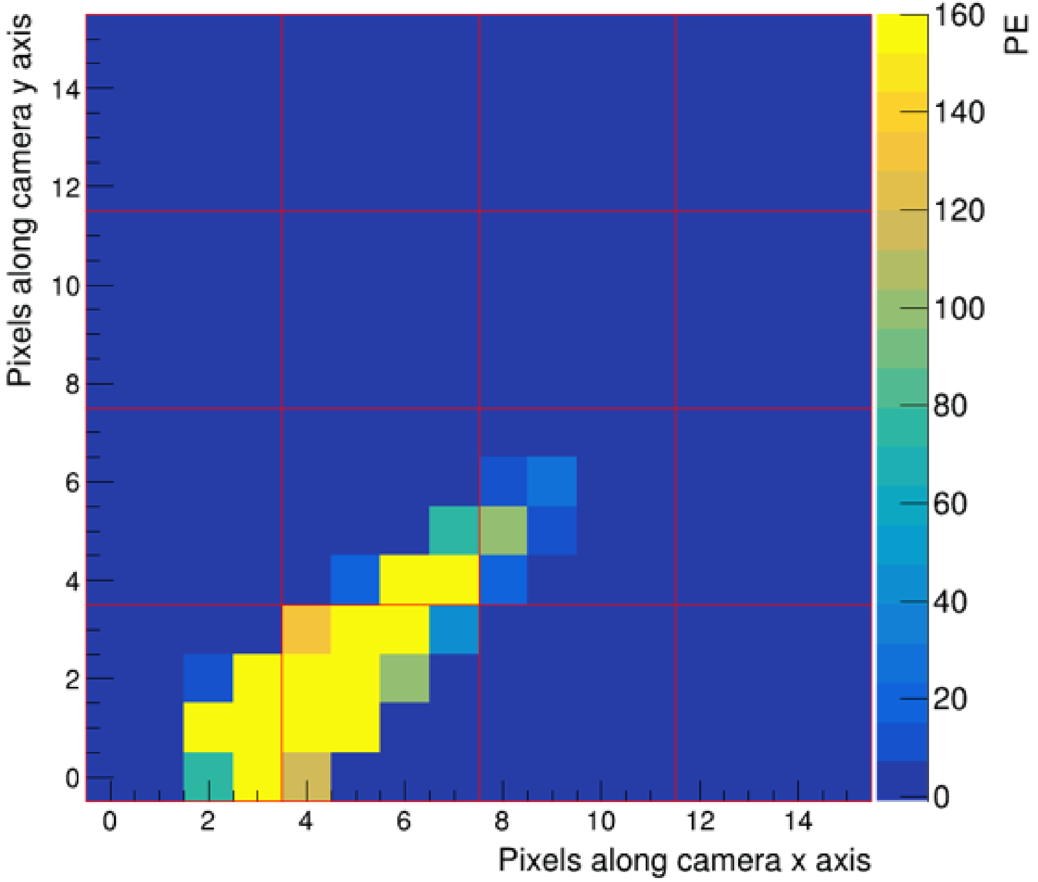
Commissioning paper:
Bagheri et al., Nucl. Instrum. Meth. A 1080, 170769 (2025)

Event Cleaning

Simulated Gold-Plated Event
Energy: 414 PeV, Distance: 170 km, Emergence Angle: 1.75°

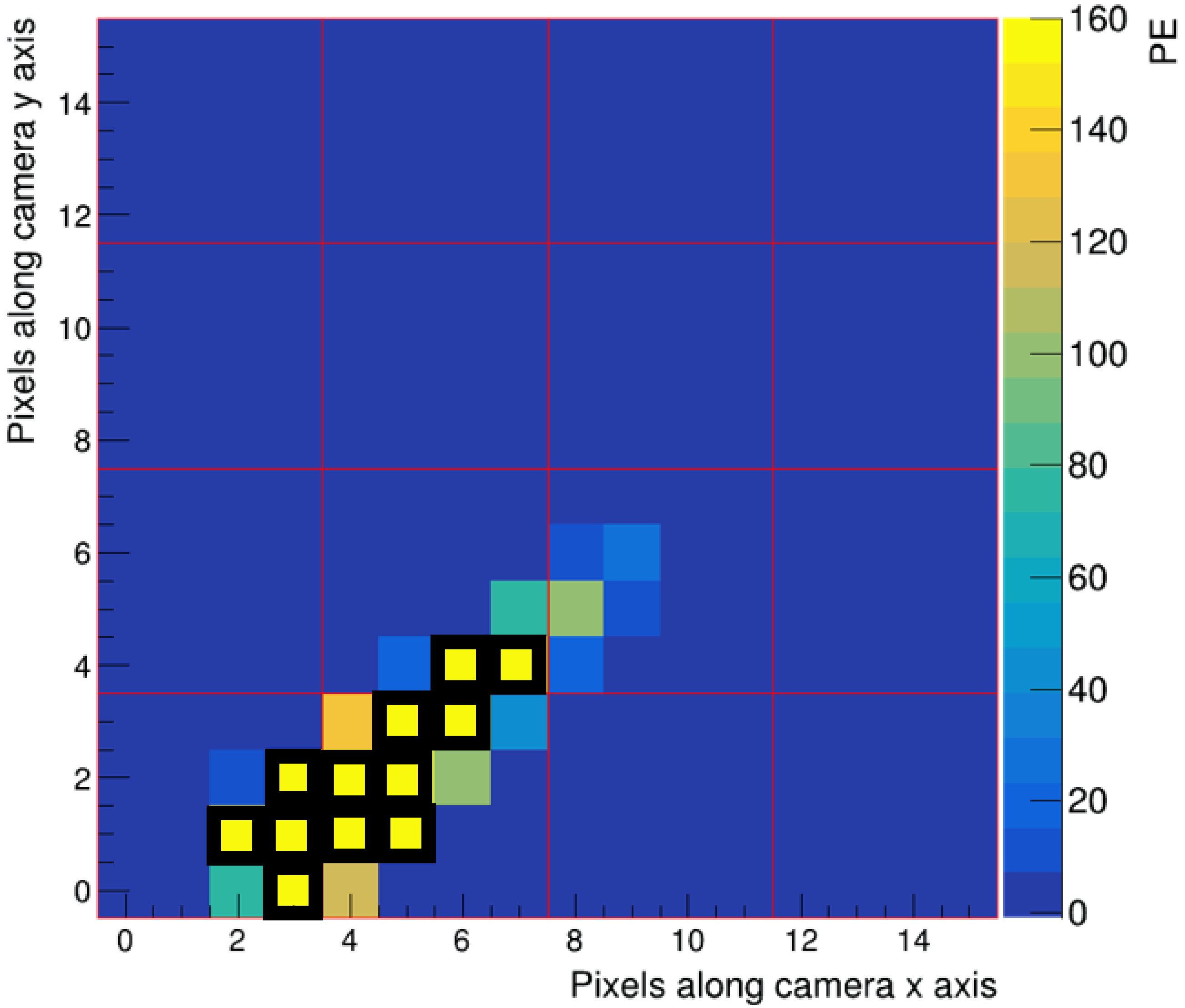


Expected Camera Response



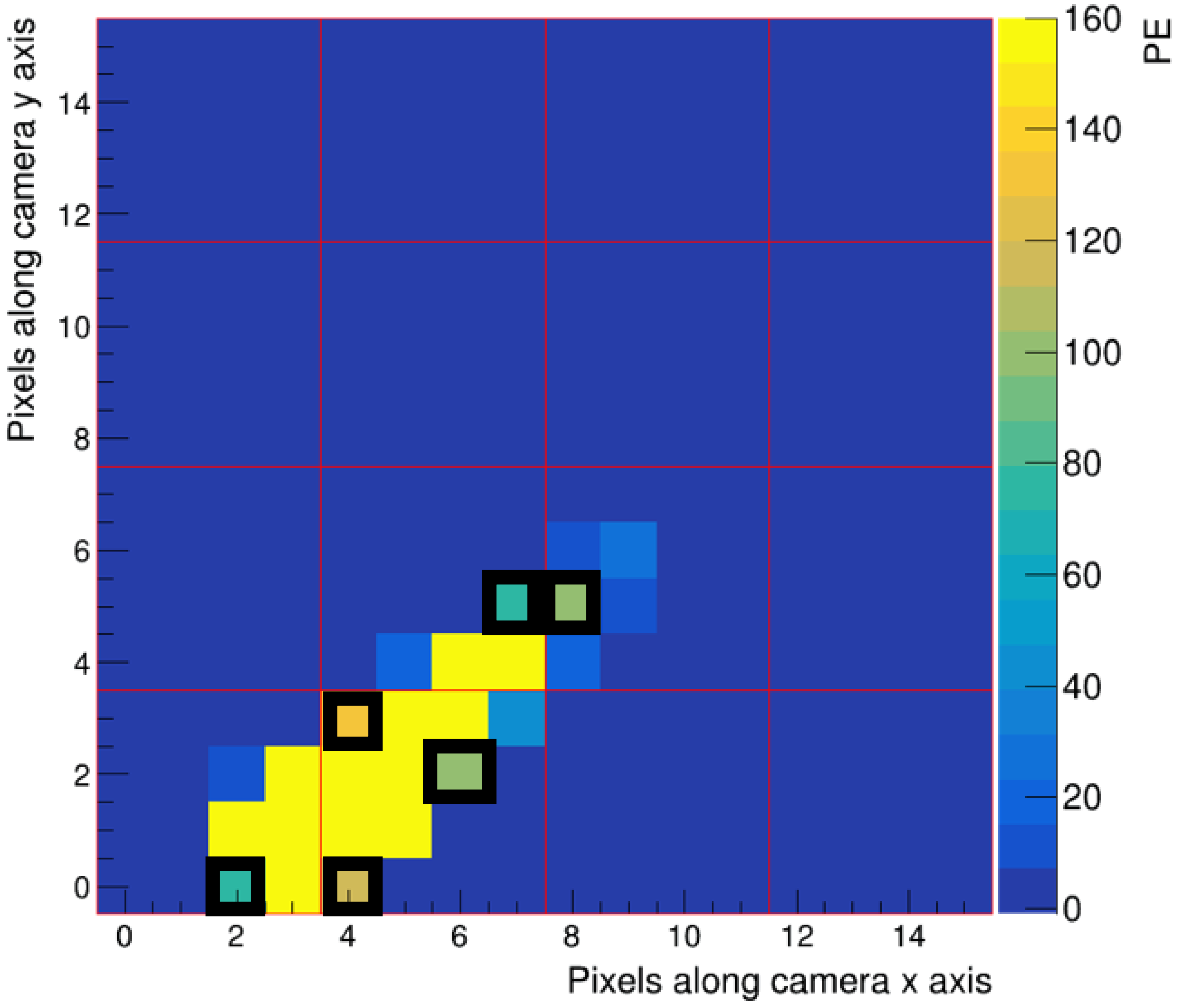
Event Cleaning

Core Pixel Selection



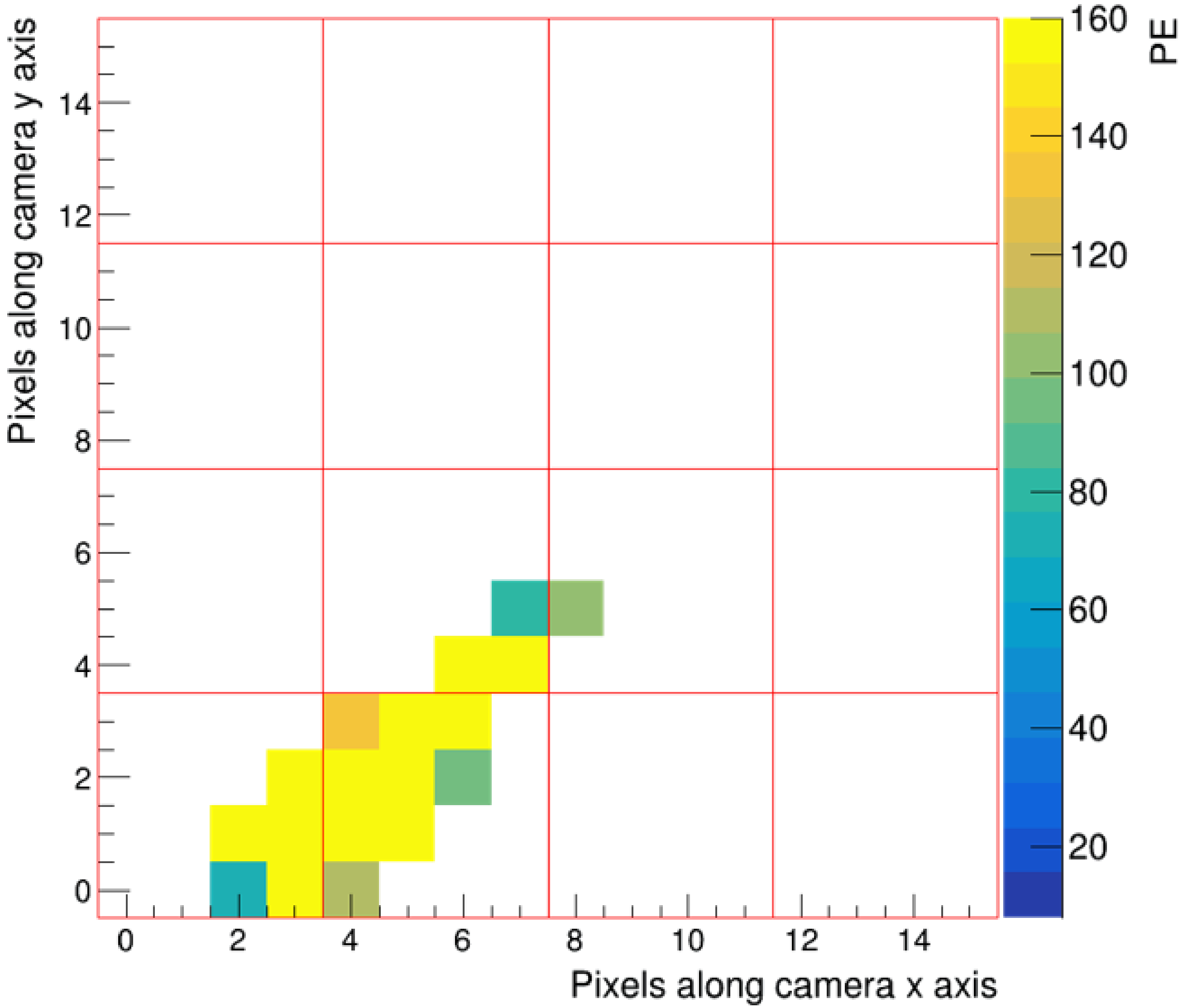
Event Cleaning

Boundary Pixel Selection



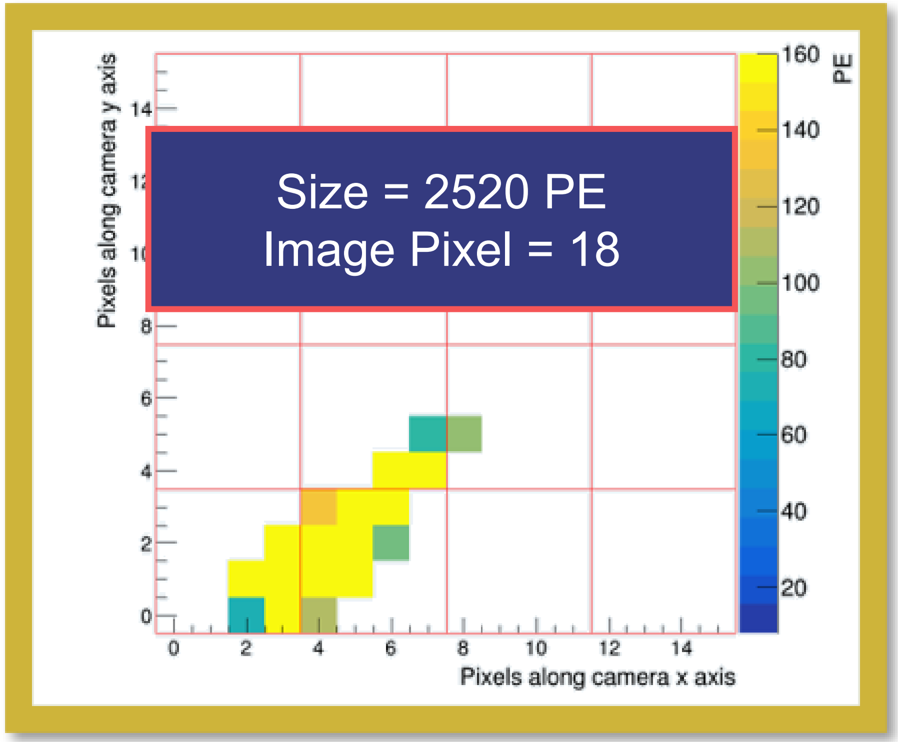
Event Cleaning

Cleaned Event



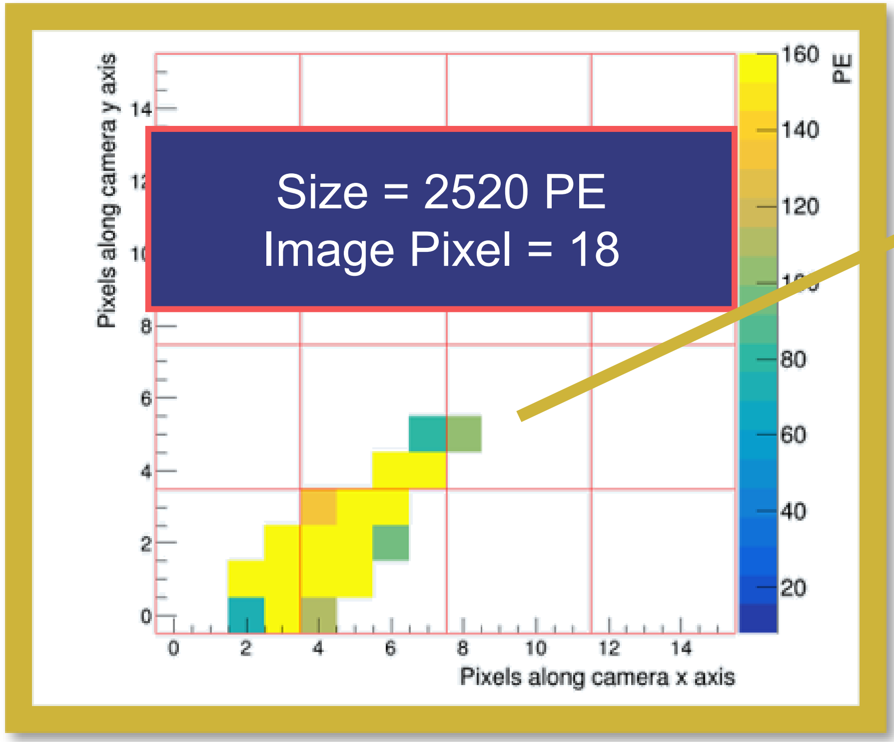
Distribution of Cleaned Events

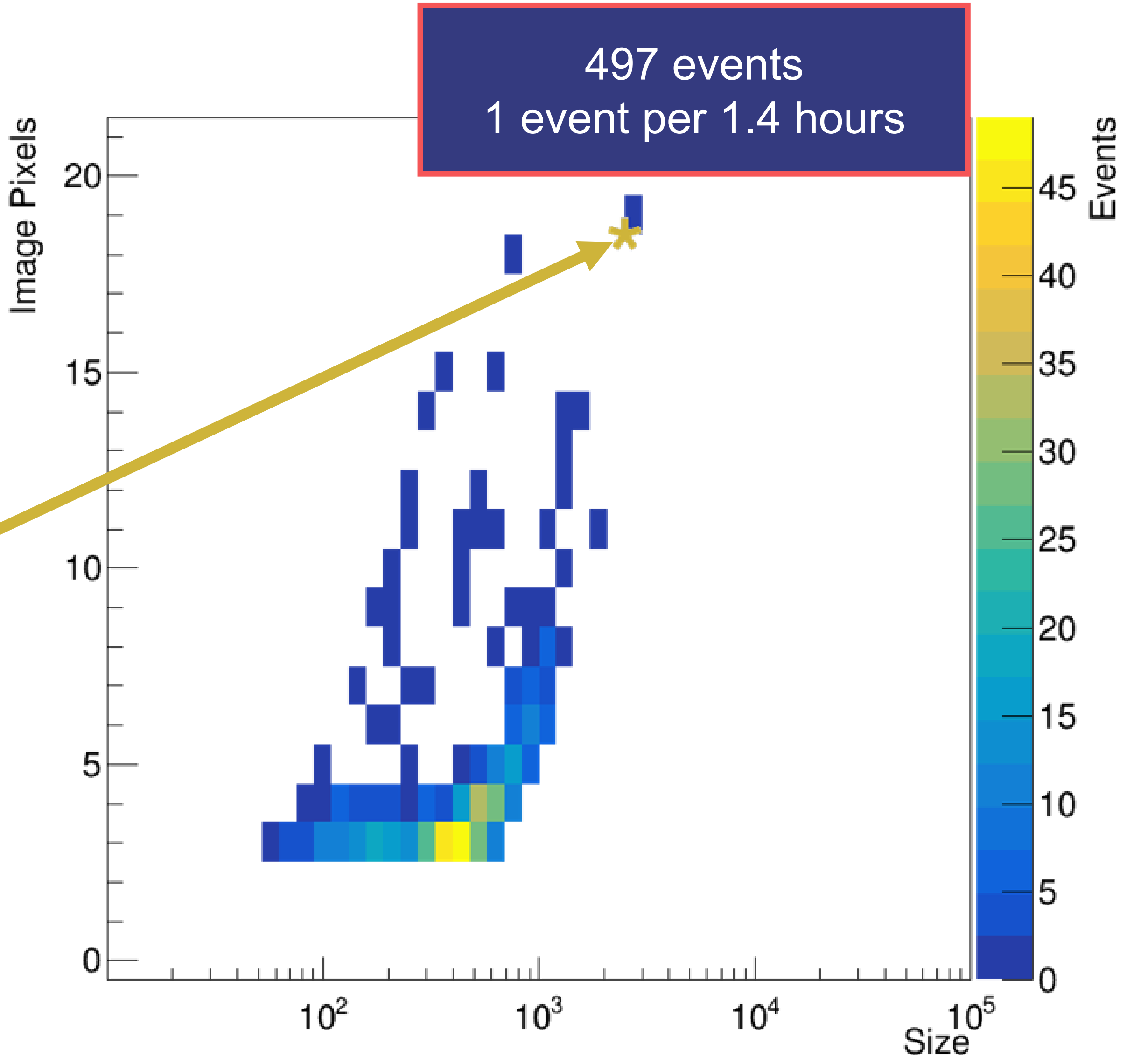
Image Pixels: Pixels in the cleaned image	Size: Sum signal of all pixels in the cleaned image



Distribution of Cleaned Events

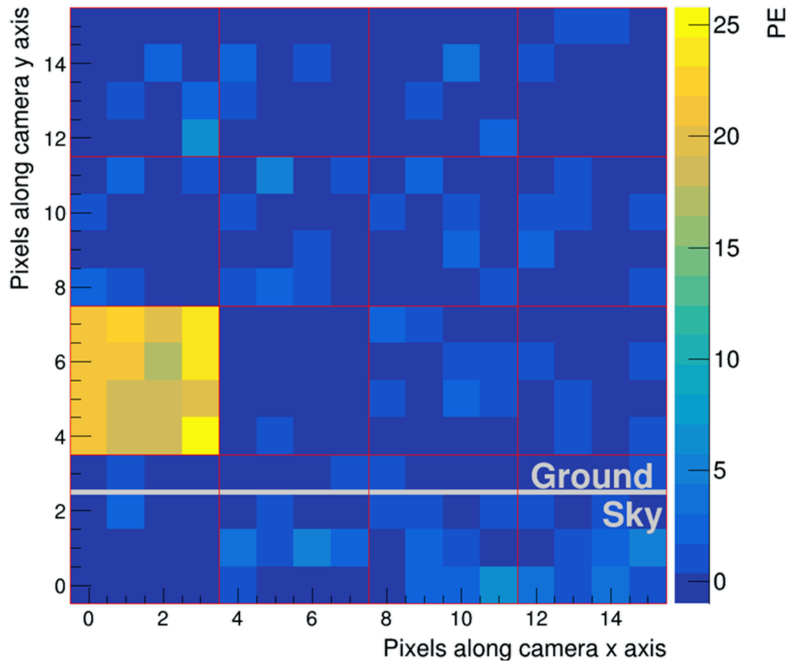
Image Pixels: Pixels in the cleaned image	Size: Sum signal of all pixels in the cleaned image

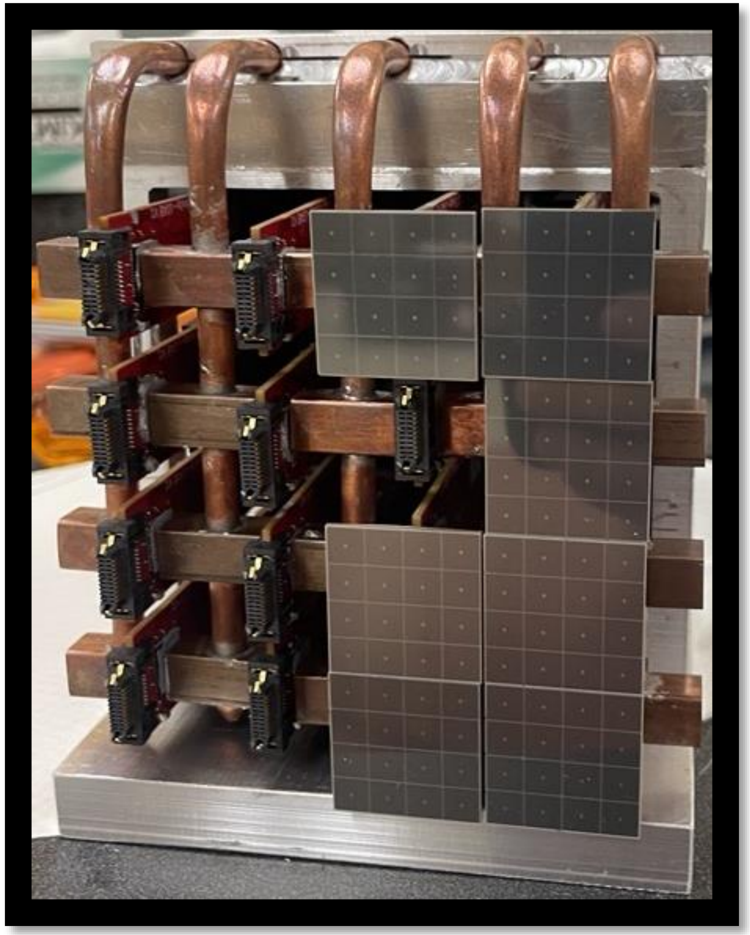




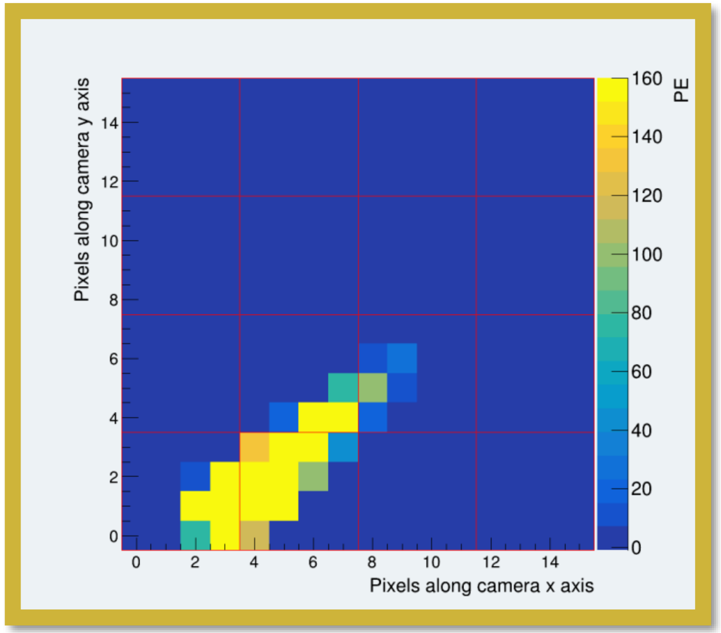
Event Taxonomy

19 events in one glitching camera module

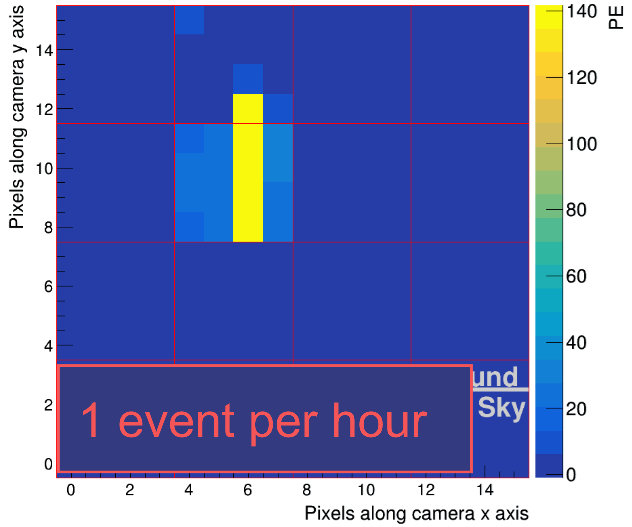




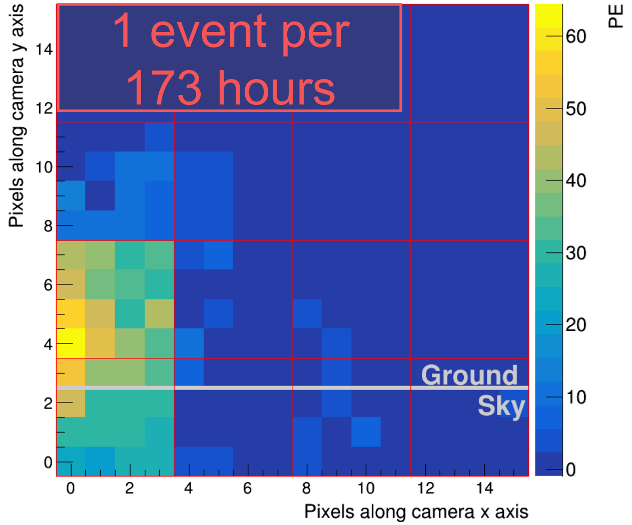
Trinity Is Effectively Background Free!

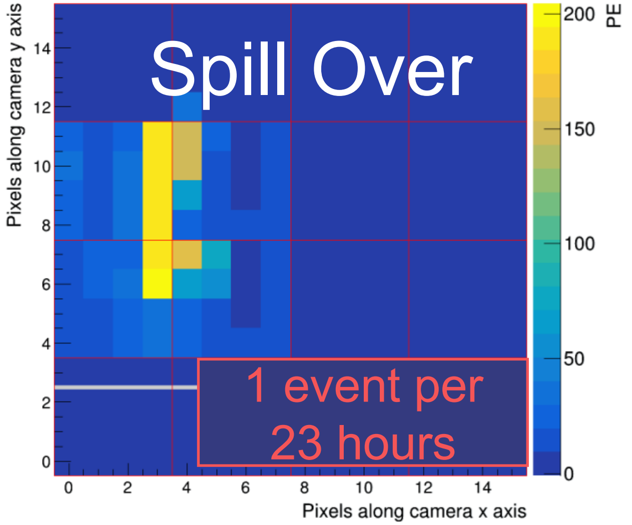


Gold Plated Simulation Event

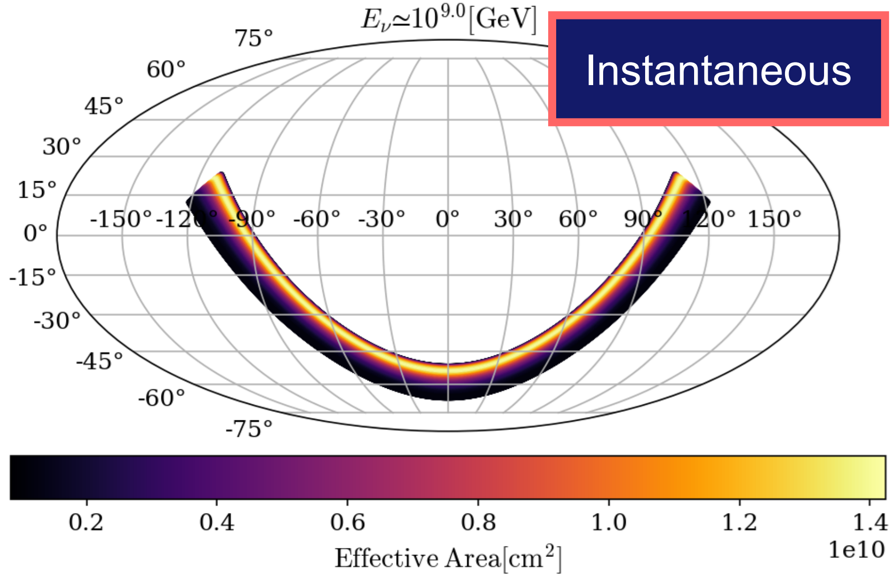


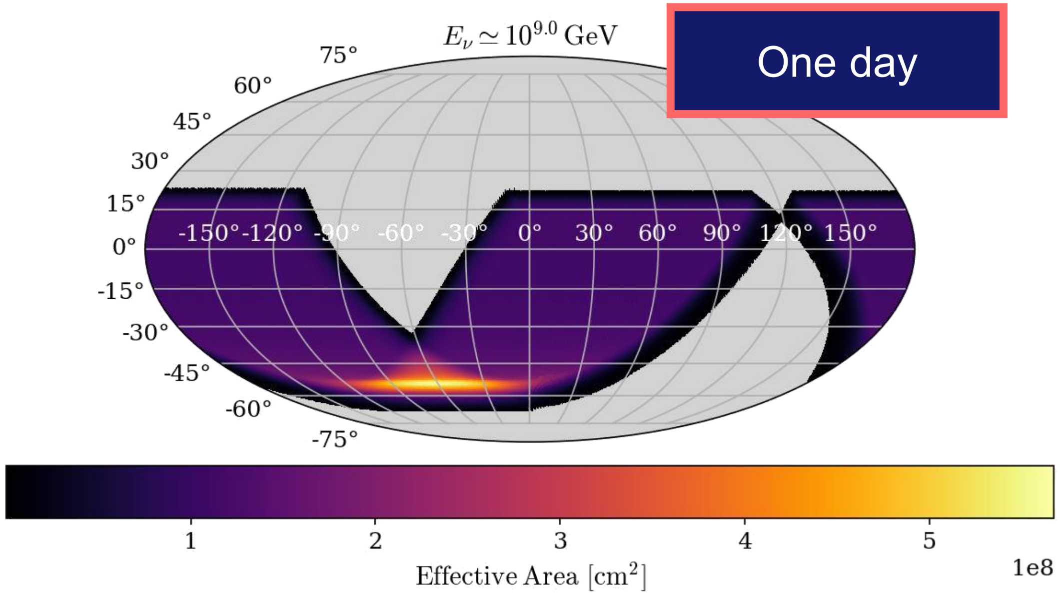
Background events are caused by muons hitting the camera.





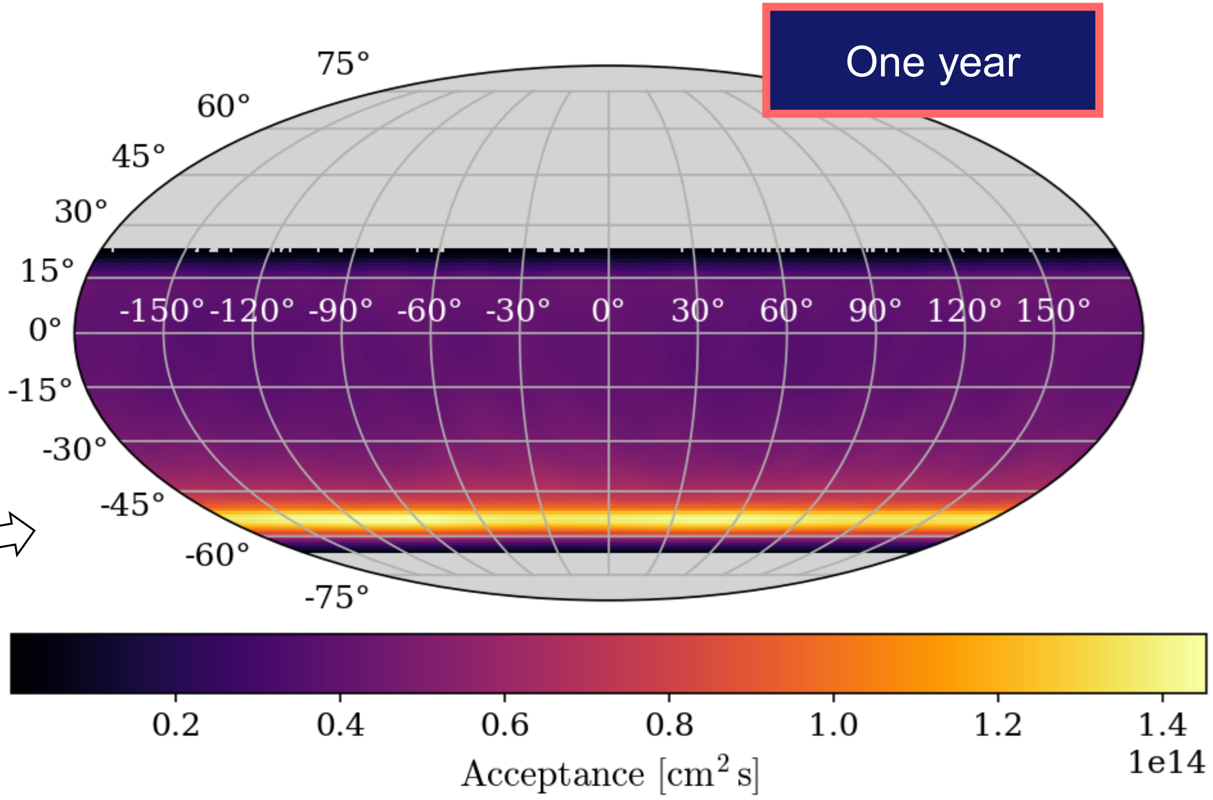
Daily Effective Area





$$\langle A_{eff}(\phi, \theta, E_\nu) \rangle = \frac{1}{T} \int dt \, A_{eff}(\phi, \theta, E_\nu)$$

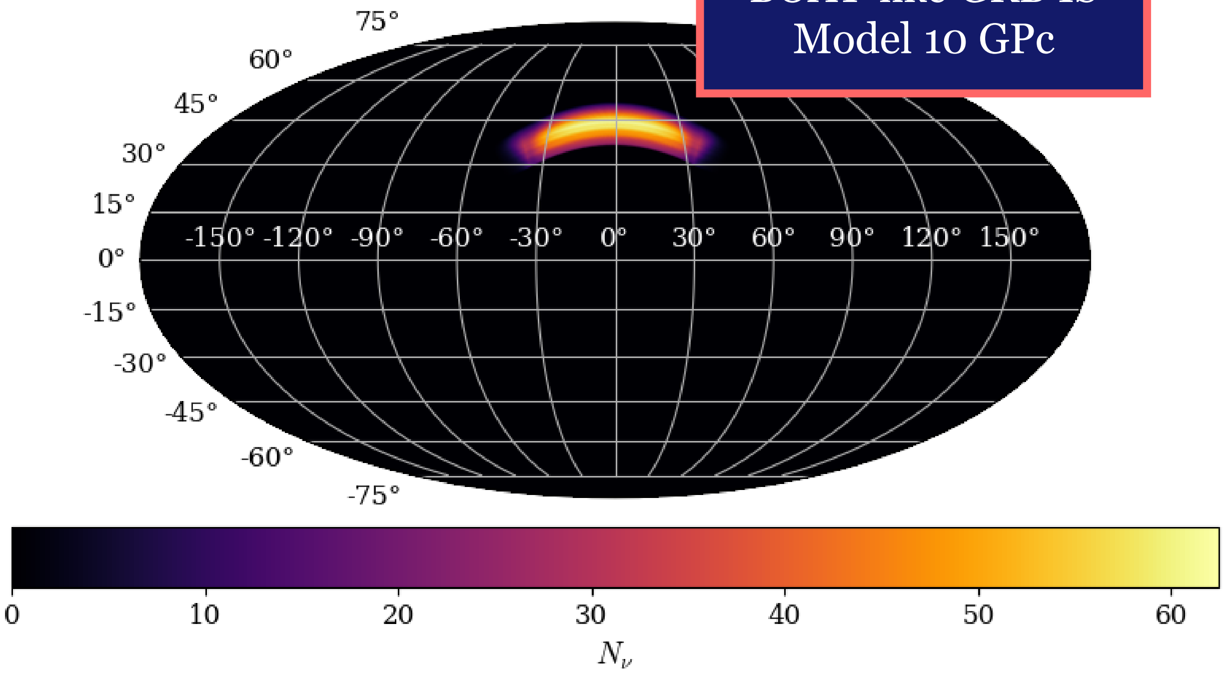
Acceptance

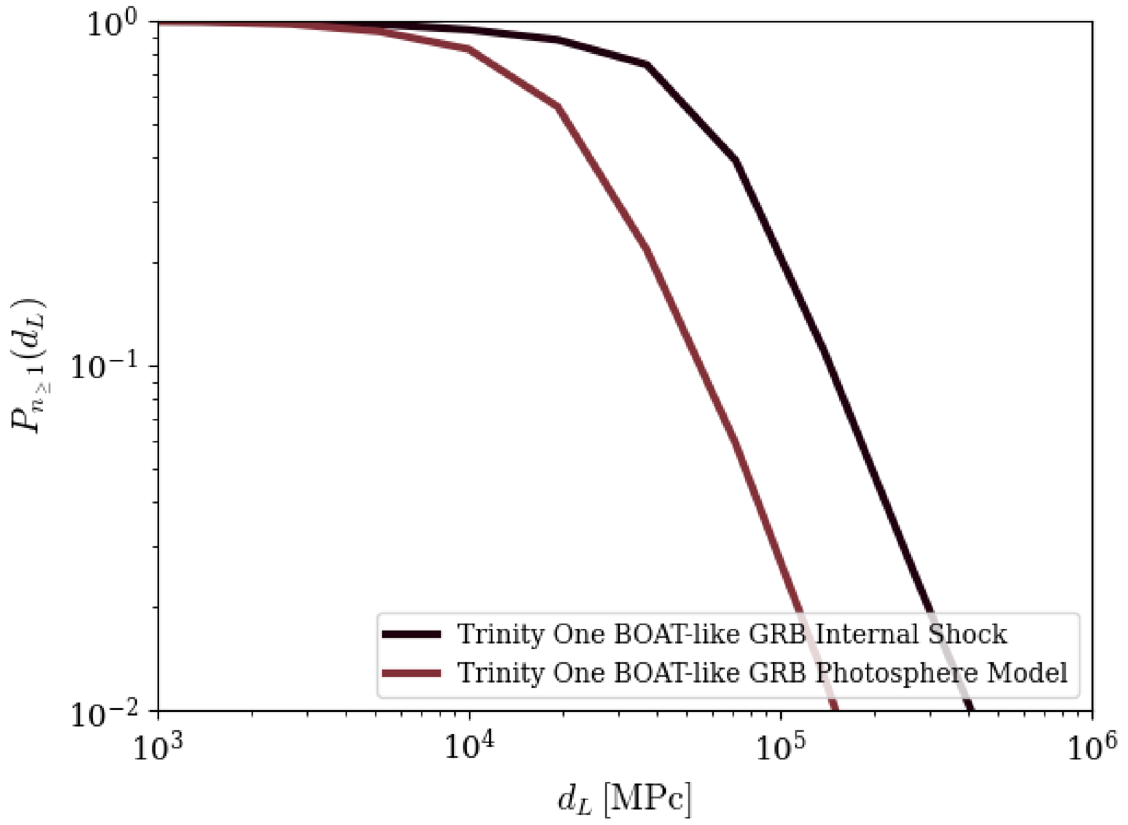


20% duty cycle

What Can We Expect from Transient Sources?

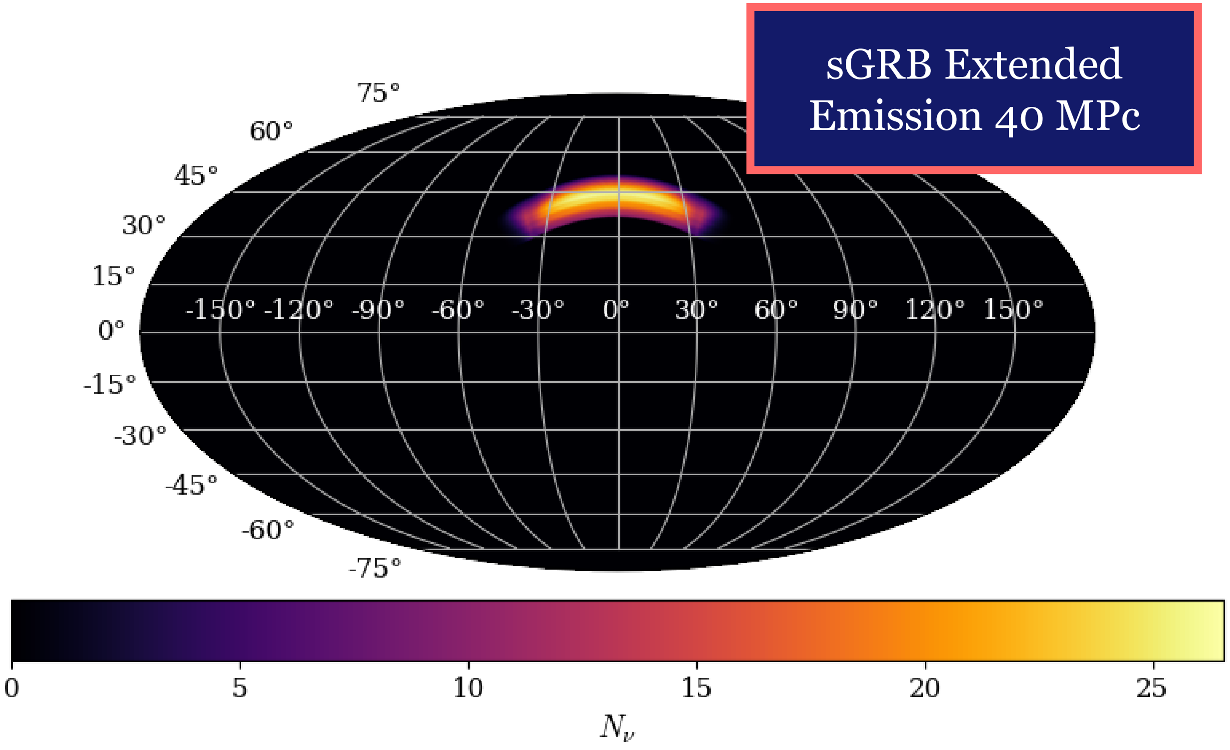
BOAT-like GRB IS Model 10 GPc

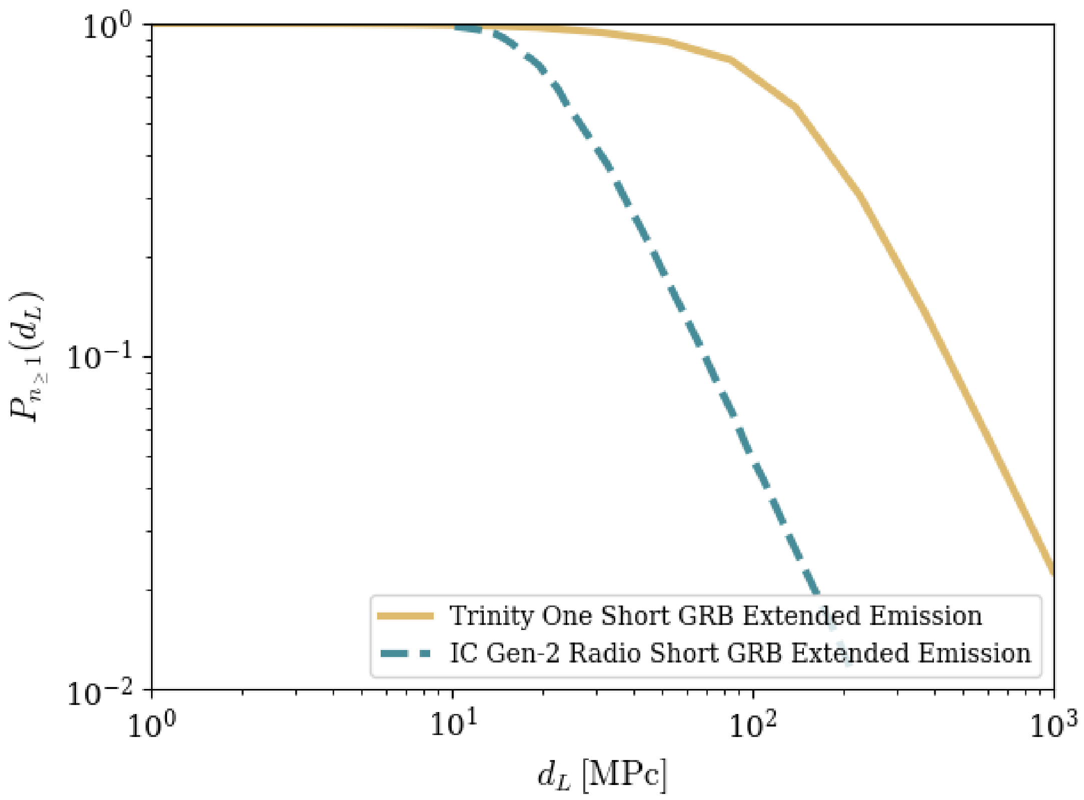




$$P_{n\geq 1}(d_L) = \frac{1}{\Omega_{\text{norm}}}\int_\Omega d\Omega\, p_{n\geq 1}(\phi,\theta,d_L) \Longrightarrow p_{n\geq 1}(\phi,\theta,d_L) = 1 - \exp\left(-N_\nu(\phi,\theta,d_L)\right)$$

What Can We Expect from Transient Sources?





$$P_{n\geq 1}(d_L) = \frac{1}{\Omega_{\text{norm}}} \int_{\Omega} d\Omega p_{n\geq 1}(\phi, \theta, d_L) \Longrightarrow p_{n\geq 1}(\phi, \theta, d_L) = 1 - \exp\left(-N_\nu(\phi, \theta, d_L)\right)$$