



ASKARYAN RADIO ARRAY

First Array-Wide Search for a Diffuse UHE Neutrino Flux with ARA

IceCube Particle Astrophysics Symposium

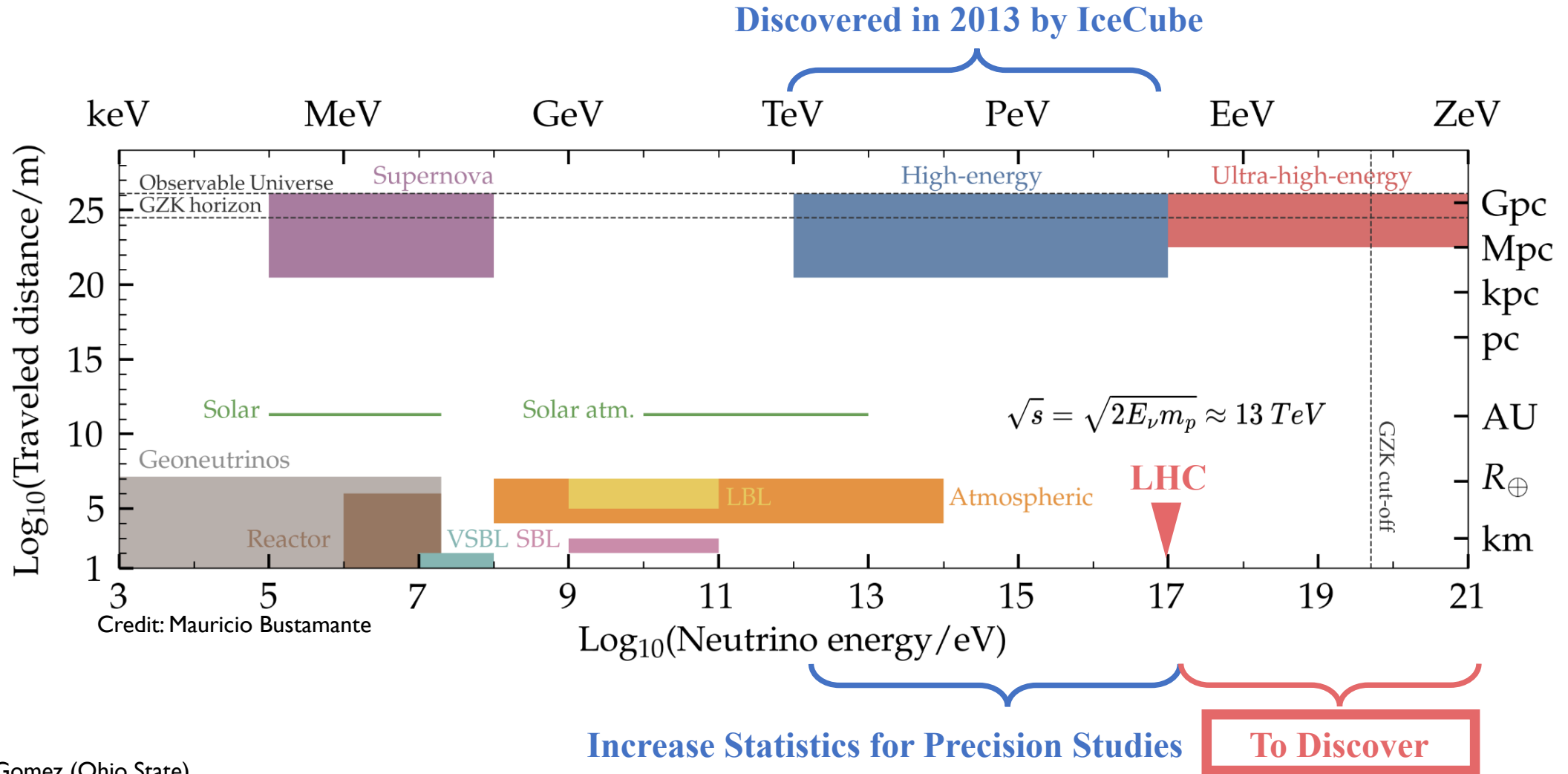
Alan Salcedo Gomez

October 14th, 2026



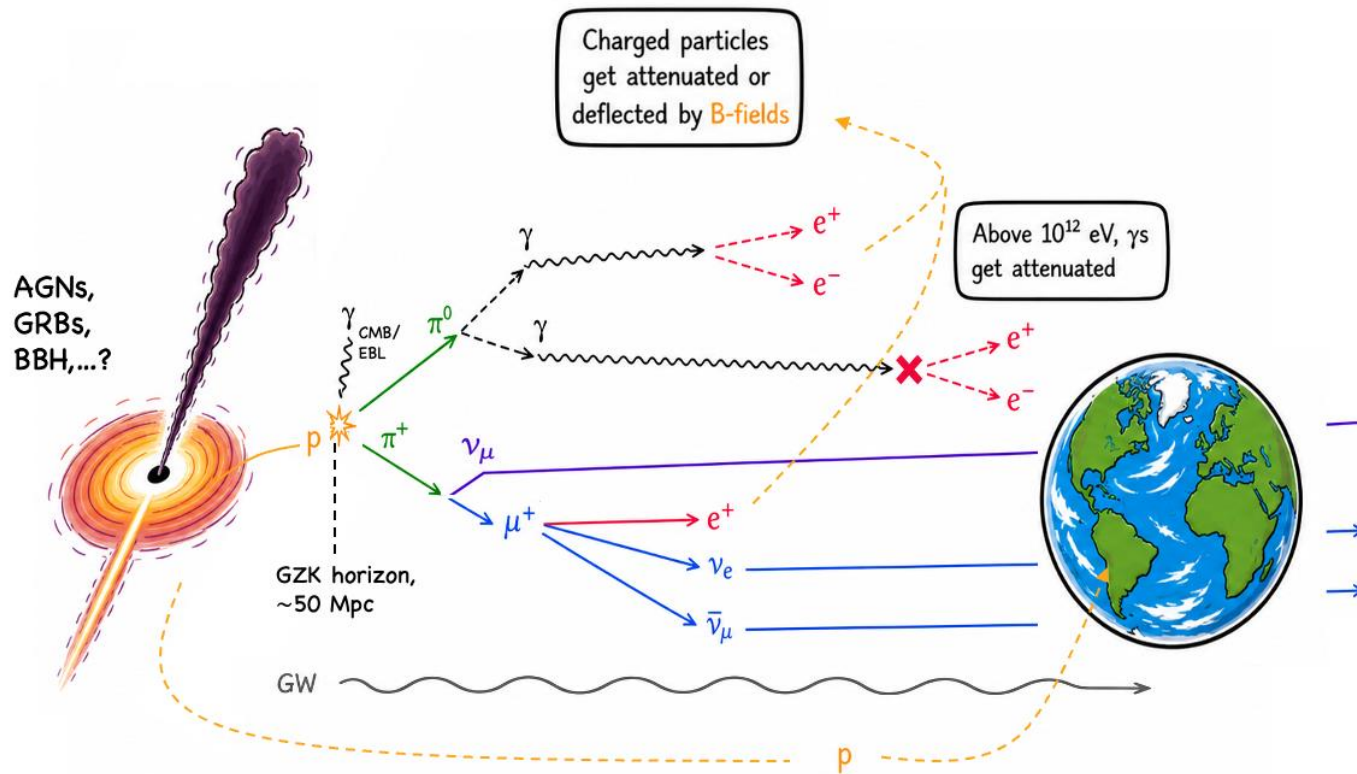
Neutrino Landscape

Neutrino experiments span **long ranges of baselines and energy**



Multi-messenger Astrophysics

What are the sources of ultra-high energy cosmic rays (**UHECR**, $E_p \geq 10^{18}$ eV)?



UHE ν = signature of UHECRs
and point to interaction region

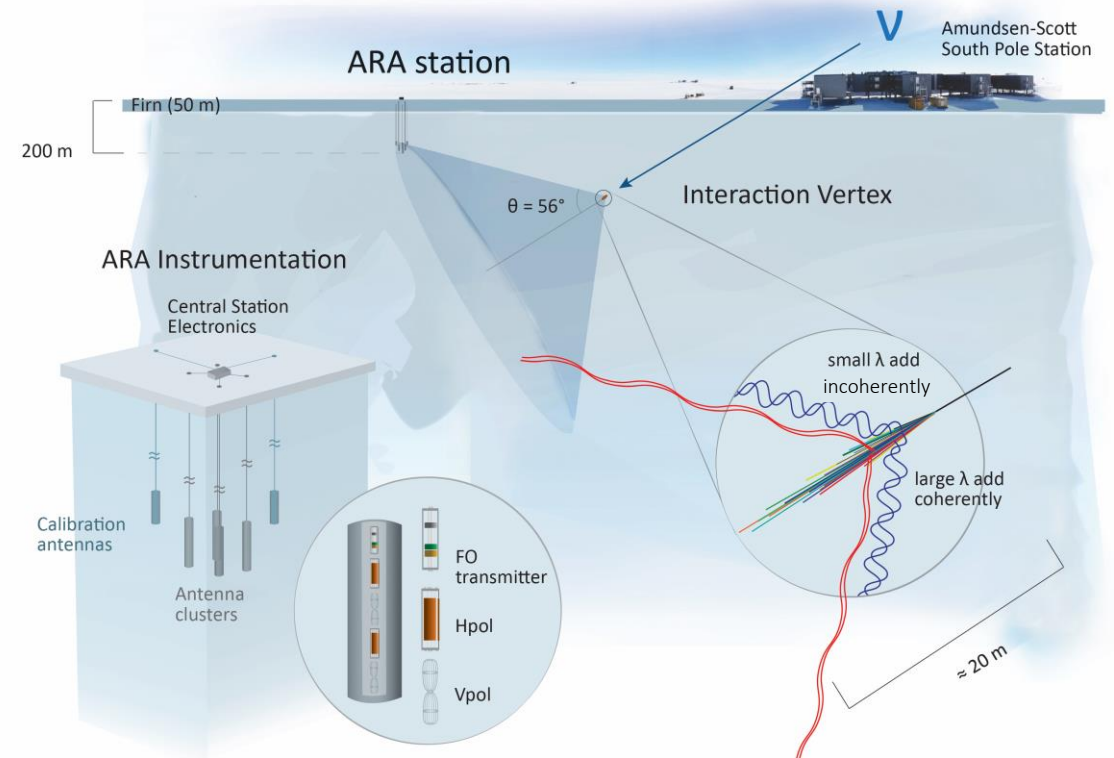
Probe UHECR properties and sources
on cosmological scales

Probe beyond LHC particle
interactions

Askaryan Radiation

Neutrino interactions in dense media initiate particle cascades

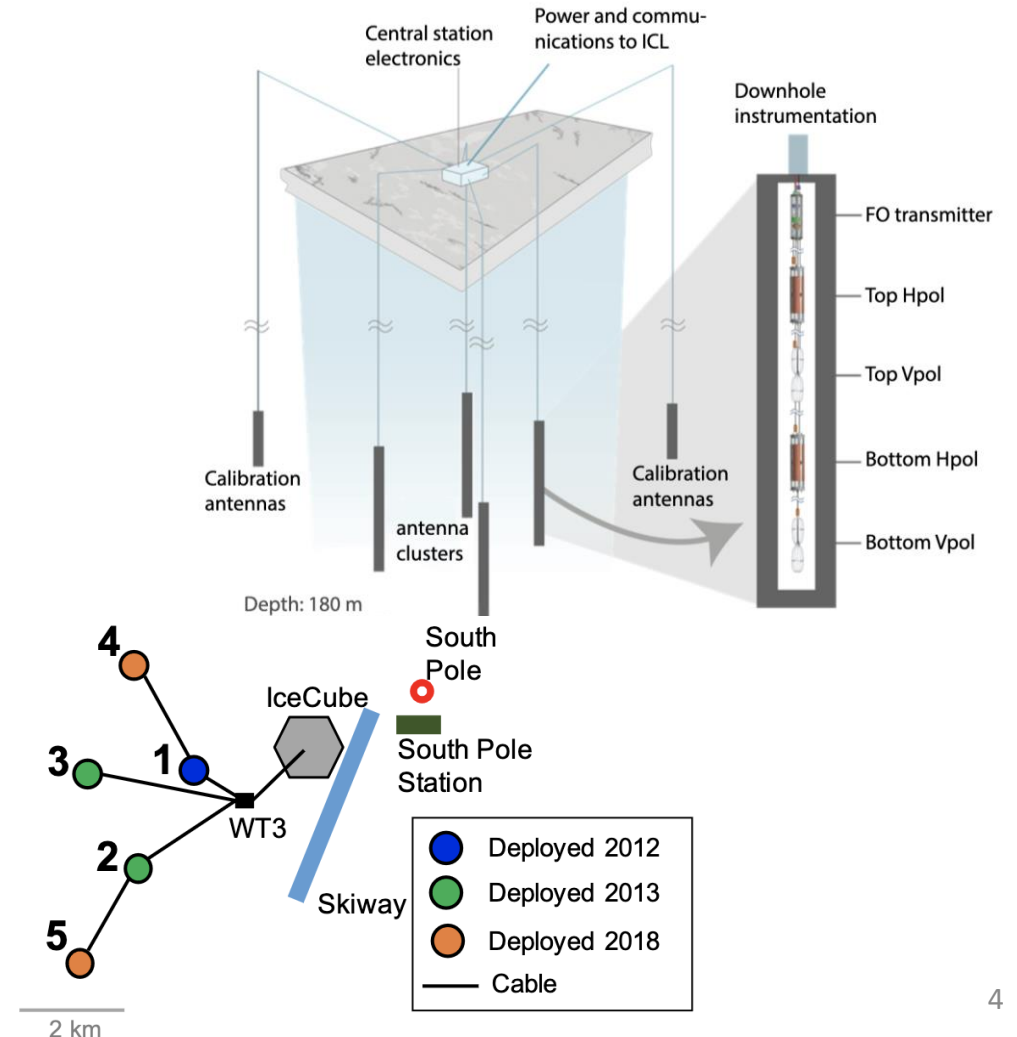
- Particle cascade emits a pulse of coherent radio emission along Cherenkov cone — Askaryan radiation
- Radio has ~ 1 km attenuation length in ice
- **Radio antenna embedded in ice = efficient monitor of enormous volume**



ARA Detector

ARA monitors for Askaryan radiation using antennas

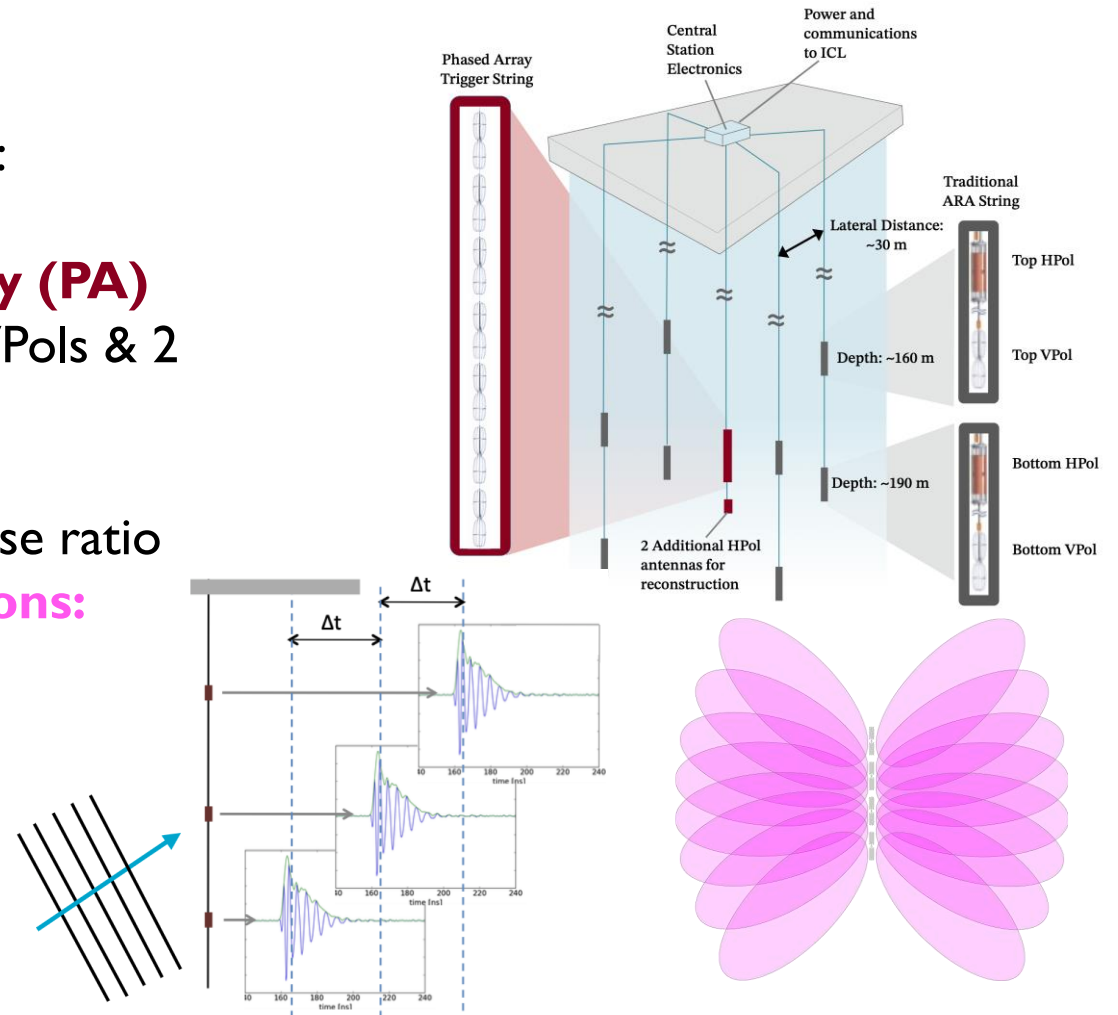
- **5 independent stations (A1-5)** at the South Pole
- Each station has 4 strings embedded in ice
- Each string has 4 radio antennas (2 VPols & 2 HPols) at ~200 m depth
- ~4 Hz physics trigger rate (+1 Hz forced trigger, +1 Hz calibration trigger)



Phased Array Detector

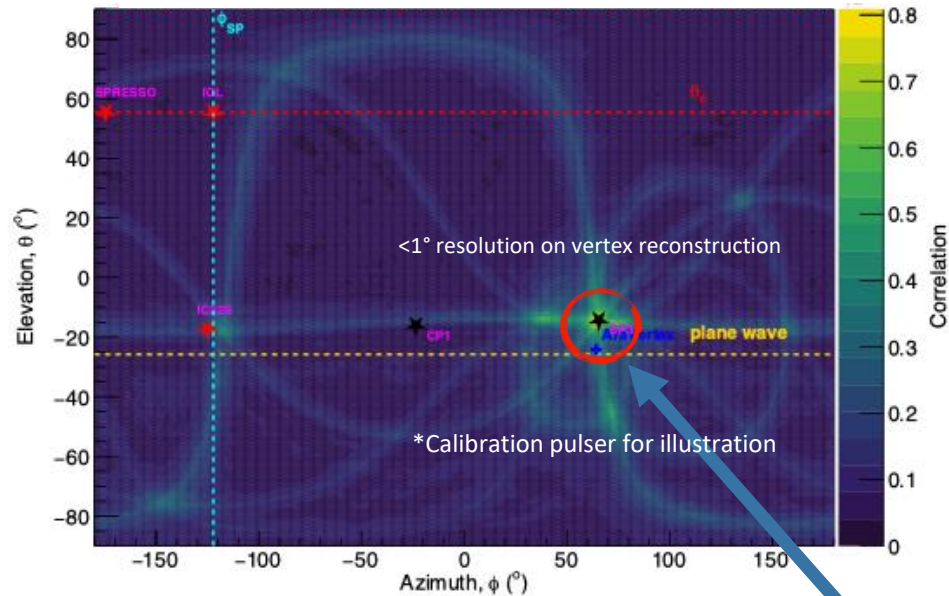
ARA monitors for Askaryan radiation using antennas

- Fifth ARA station (A5) has an extra subdetector:
 - Additional central string: **the Phased Array (PA)**
 - PA string has 9 closely packed antennas (7 VPols & 2 HPols) at ~180 m depth
- **More efficiently triggers** on low signal-to-noise ratio (SNR) signals by adding them in **preset directions**:
 - **Signals add coherently, noise does not**



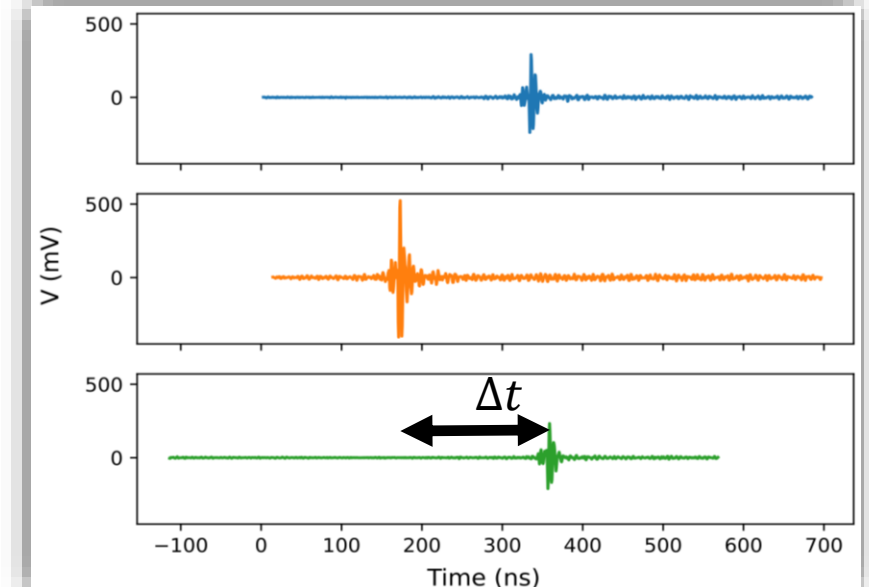
Vertex Reconstruction

ARA's layout enables vertex directional reconstruction



Vertex reconstruction allows for backgrounds to be removed

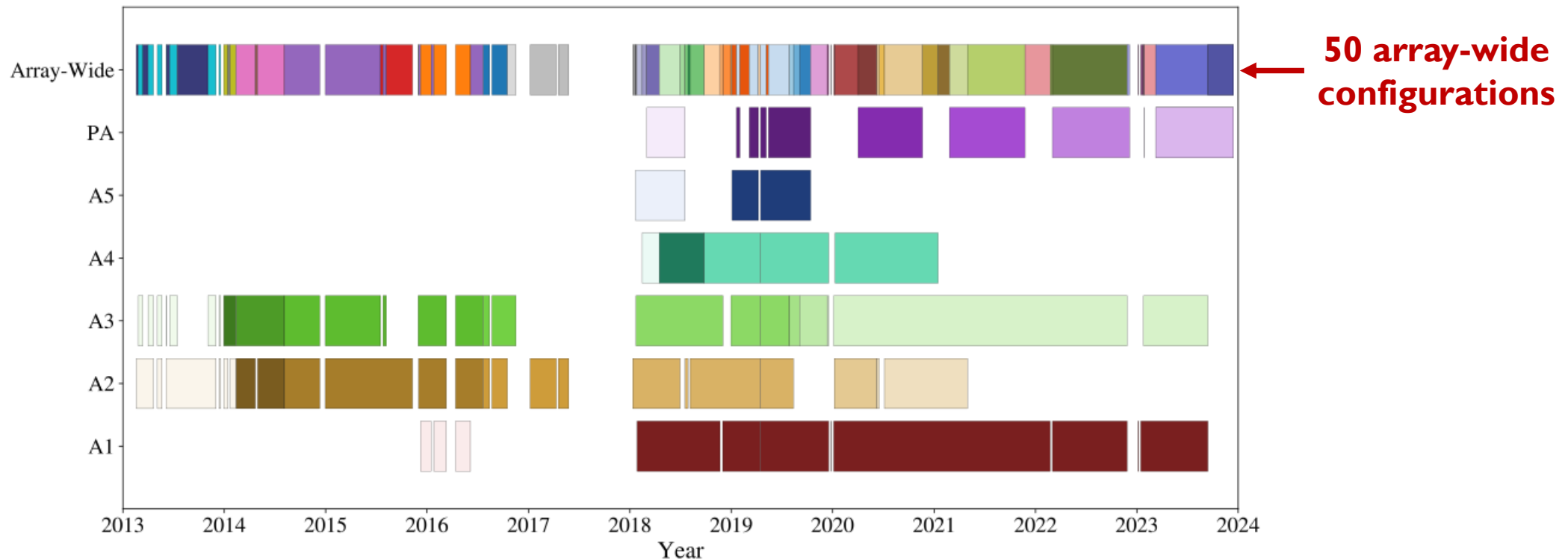
Cross-correlating signals in each antenna allows for interferometric vertex reconstruction



Time Evolution of ARA

Each detector has changed over time into different **configurations**

- Detector configurations = periods with stable hardware, data-recording settings, and noise conditions
- **Each station-configuration requires separate simulation and analysis**

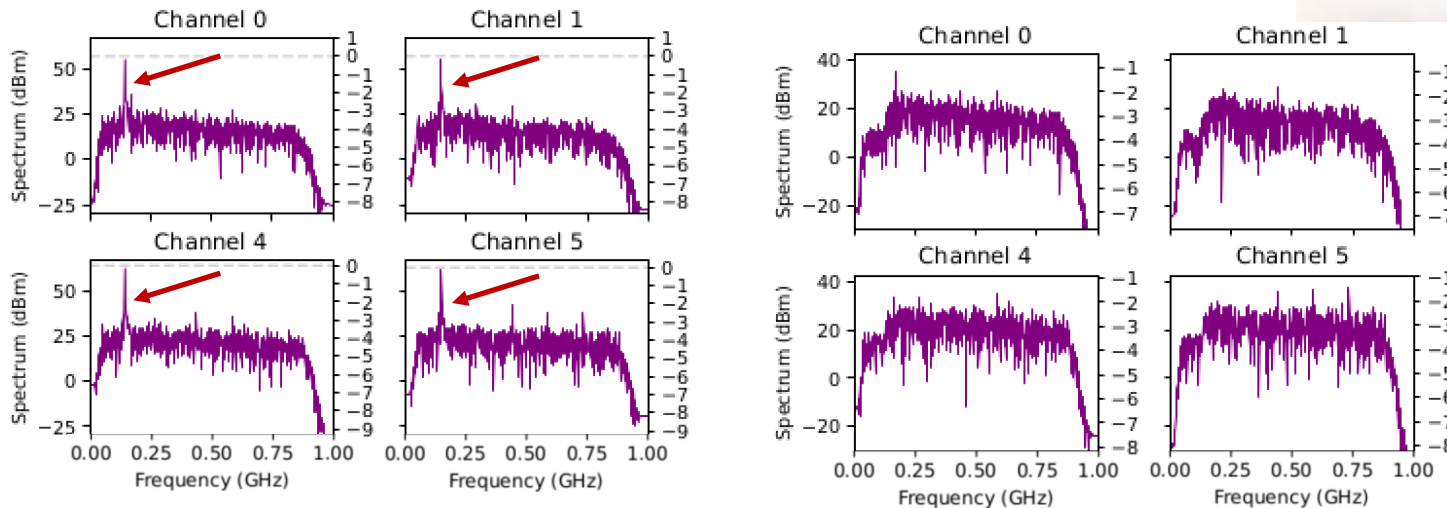


Contamination Removal

Single-frequency **continuous wave (CW)** signals from weather balloons or satellites

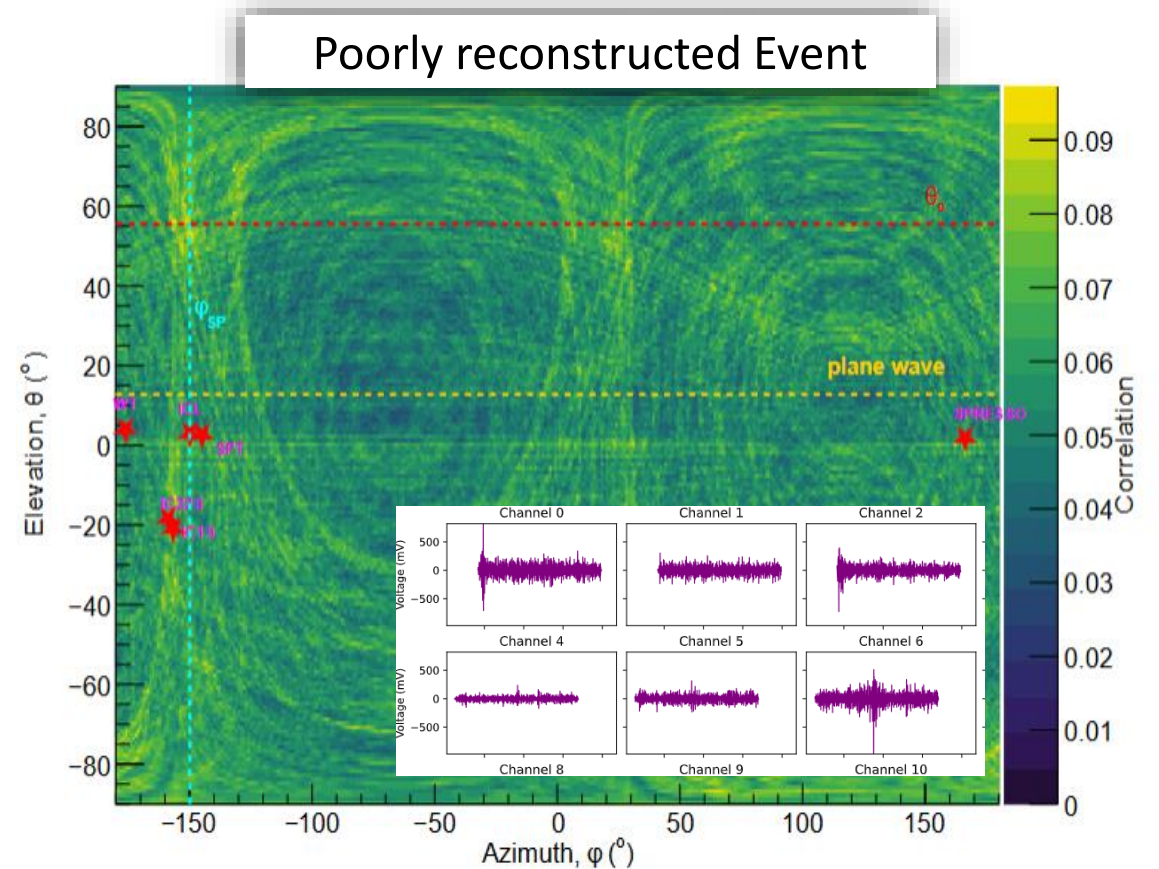
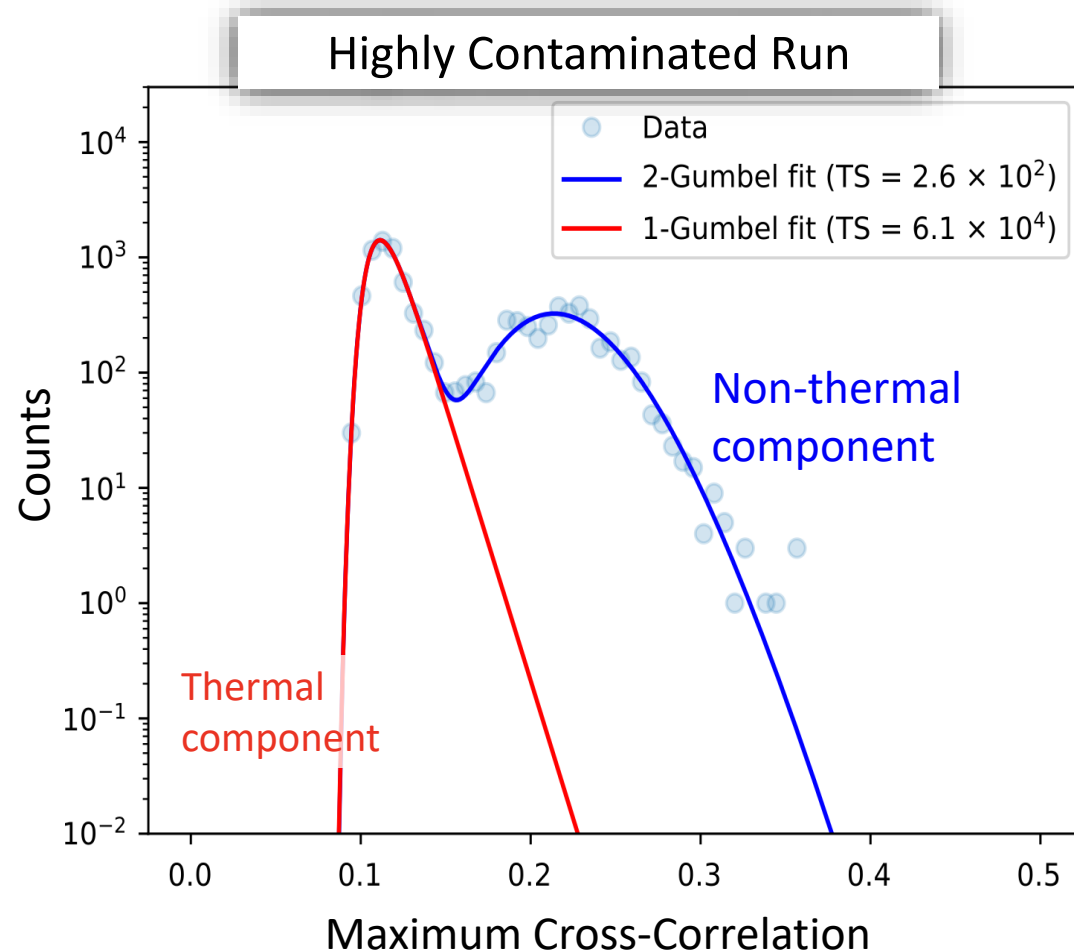
- CW causes artificial increase in correlation
- Removed by fitting a sine wave of a given frequency

CW Removal



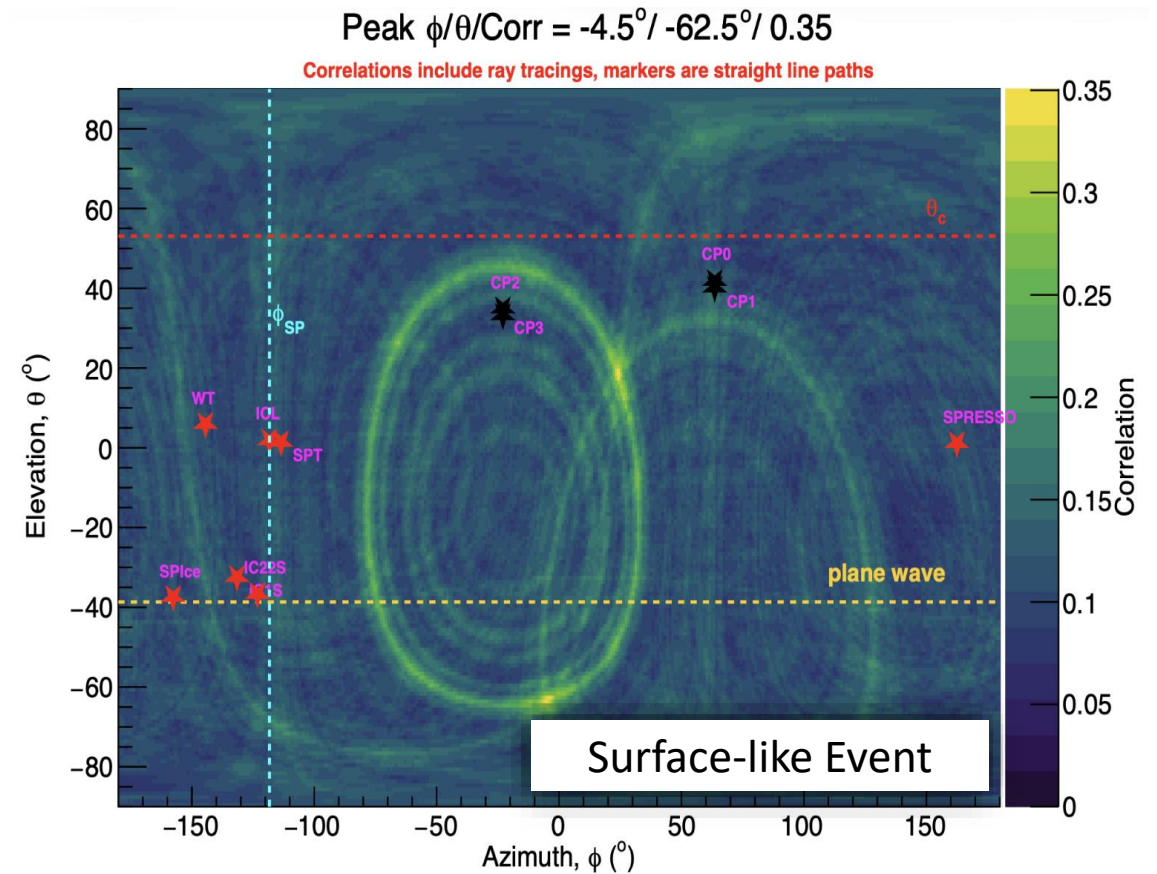
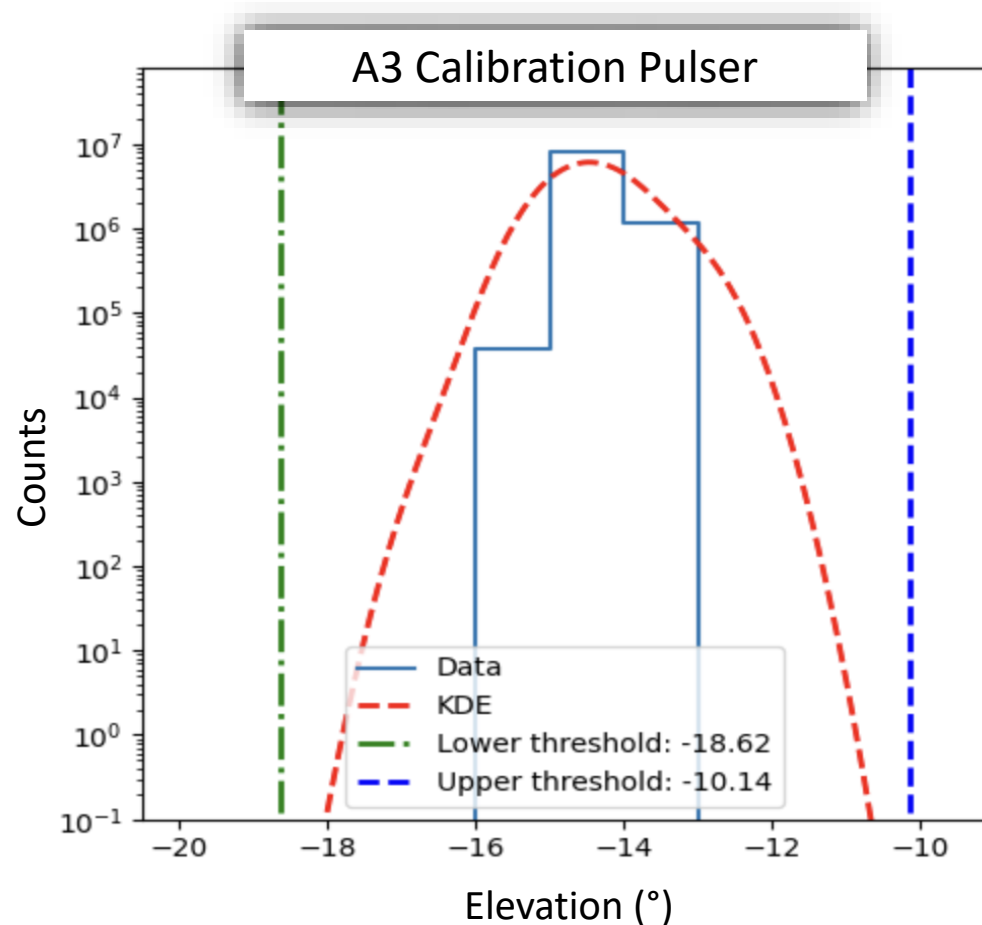
Quality Cuts

High non-thermal activity or unreliable reconstruction, and more



Non-Thermal Backgrounds

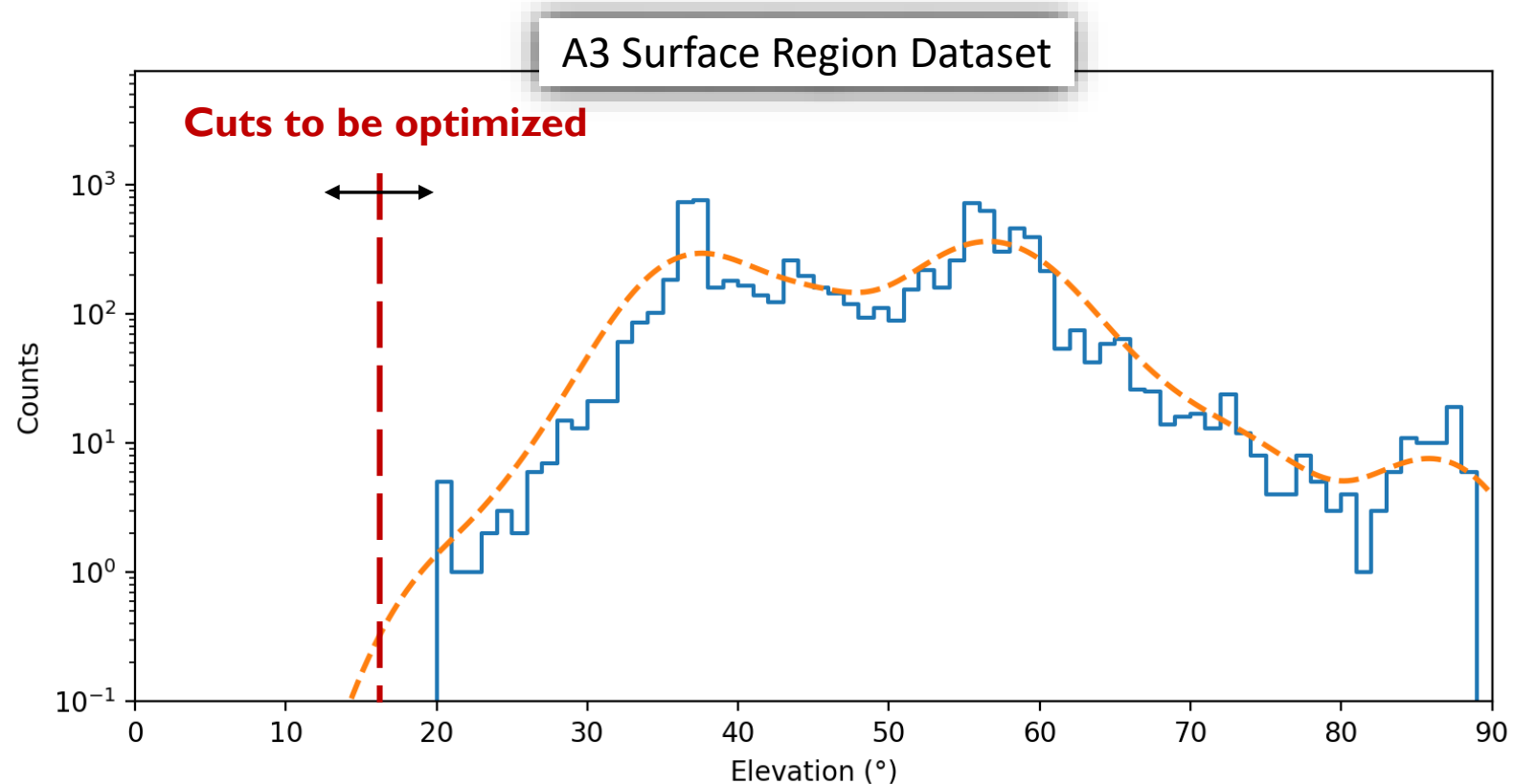
Known source locations, surface-like events, spatiotemporal clusters



Surface-origin Backgrounds

Impulsive events from the surface region: **anthropogenics** and **cosmic rays**

- Model elevation distribution with a **Gaussian Kernel Density Estimator (KDE)**

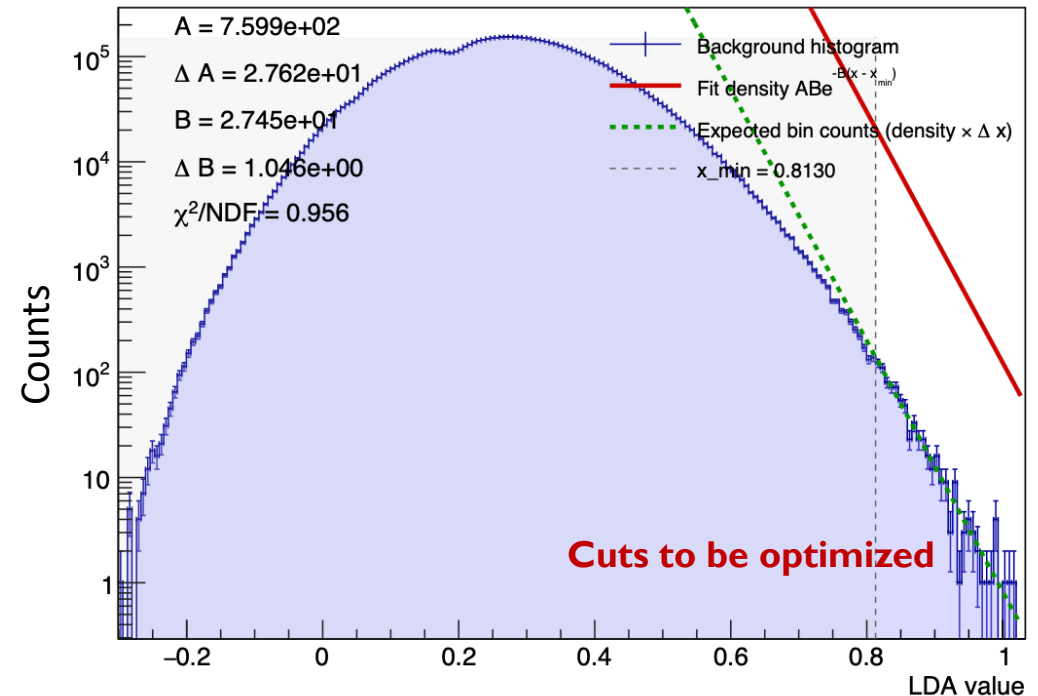
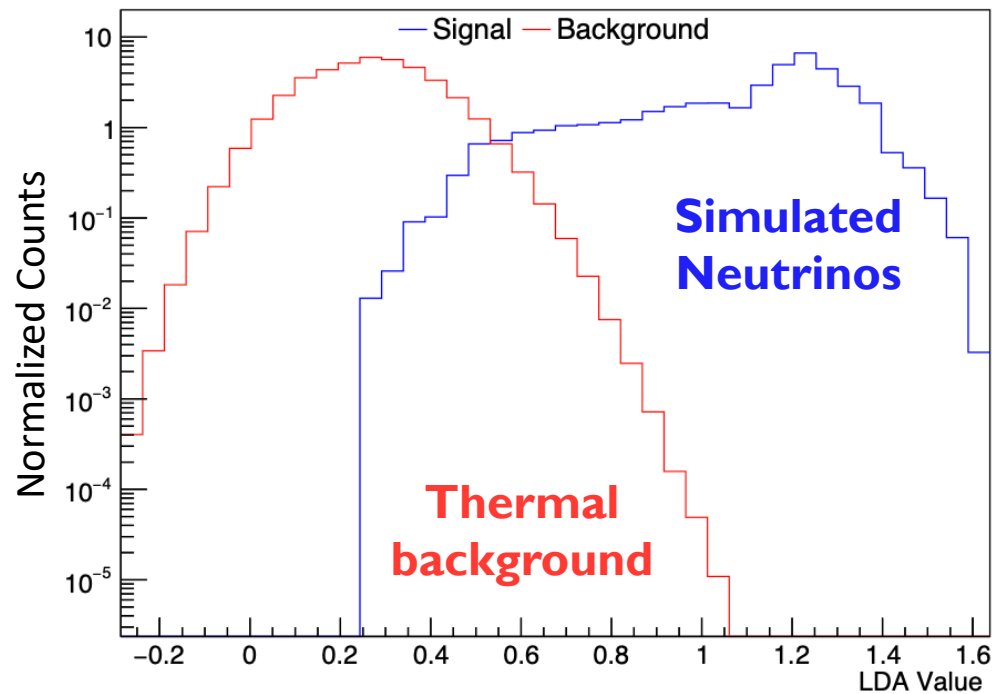


Thermal Backgrounds

Maximize separation of simulated neutrinos from thermal background

- Using a **linear discriminant (LDA)** model background tail

A3 Config. 6



Array-wide Cut Optimization

Optimize cuts $\vec{t}_c = \{t_{c,s}\}^*$ to maximize sensitivity for 5σ discovery potential

ϕ_0^{UL} : flux normalization

$f(E)$: flux shape (global UL)

c : array-wide configuration

s : station

Exposure: $\mathcal{E}(E) = \sum_c T_c [A\Omega]_{\text{eff},c}(E) \epsilon_c(E, \mathbf{t}_c)$

Array-wide Livelimes T_c

Array-wide Acceptances $[A\Omega]_{\text{eff},c}(E)$

Array-wide Efficiencies** $\epsilon_c(E, \mathbf{t}_c)$

Optimize sensitivity:

$$\phi_0^{UL} = \frac{\text{FC}_{1-\alpha}(C^{-1}(1-\beta; B), B)}{\int dE f(E) \mathcal{E}(E)}$$

***Total of 150 cuts to optimize**

FC: Feldman-Cousins interval for the **rate of neutrinos** at α confidence level

β : Significance

Backgrounds: $B = \sum_{c,s} b_{c,s}(t_{c,s})$

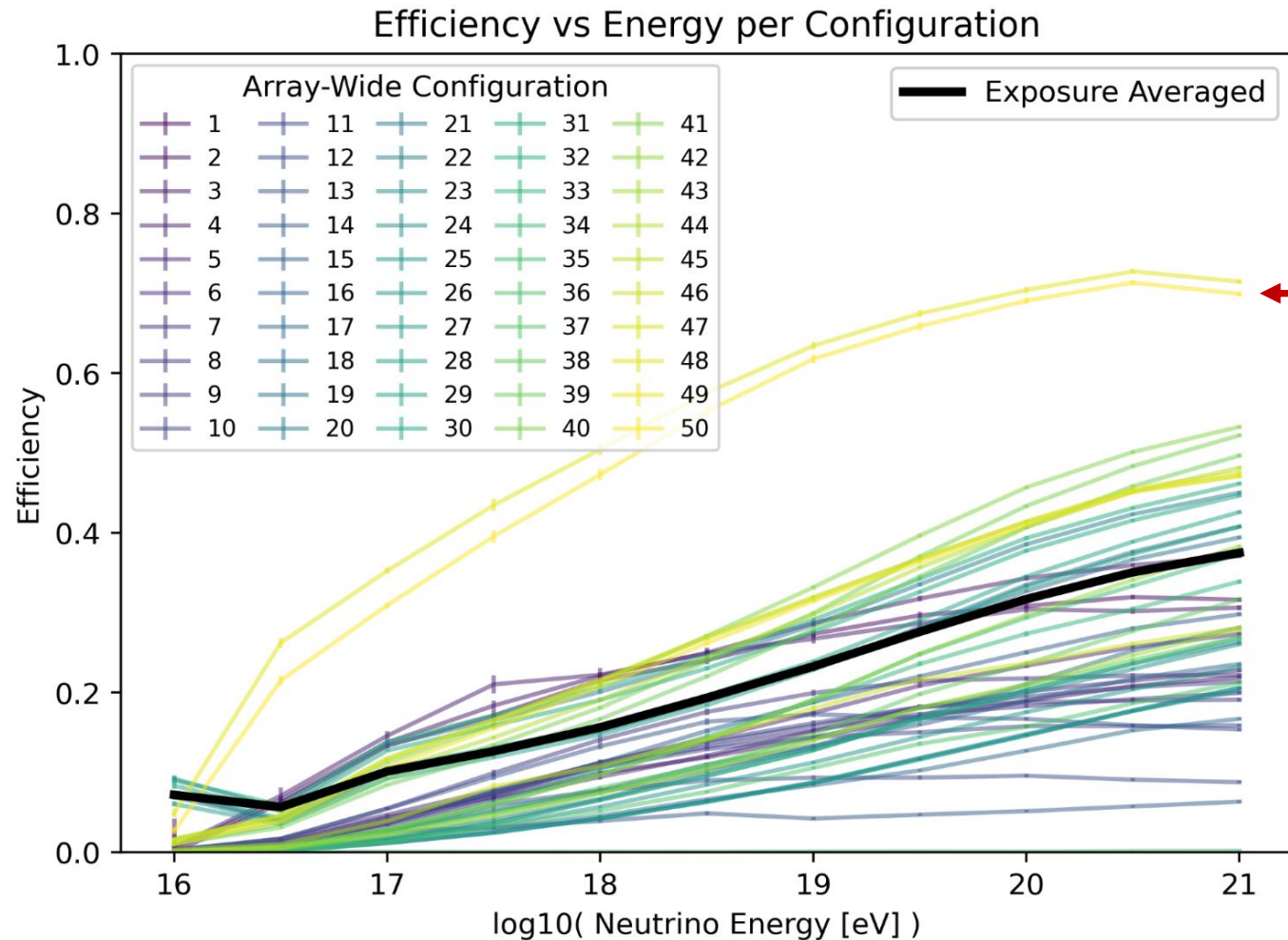
Thermal

Non-thermal

****Weighted fraction of simulated neutrinos passing cuts**

Array-Wide Signal Efficiency

Evaluate weighted fraction of simulated neutrinos surviving cuts, or signal efficiency



**Phased Array-Only
Configurations**

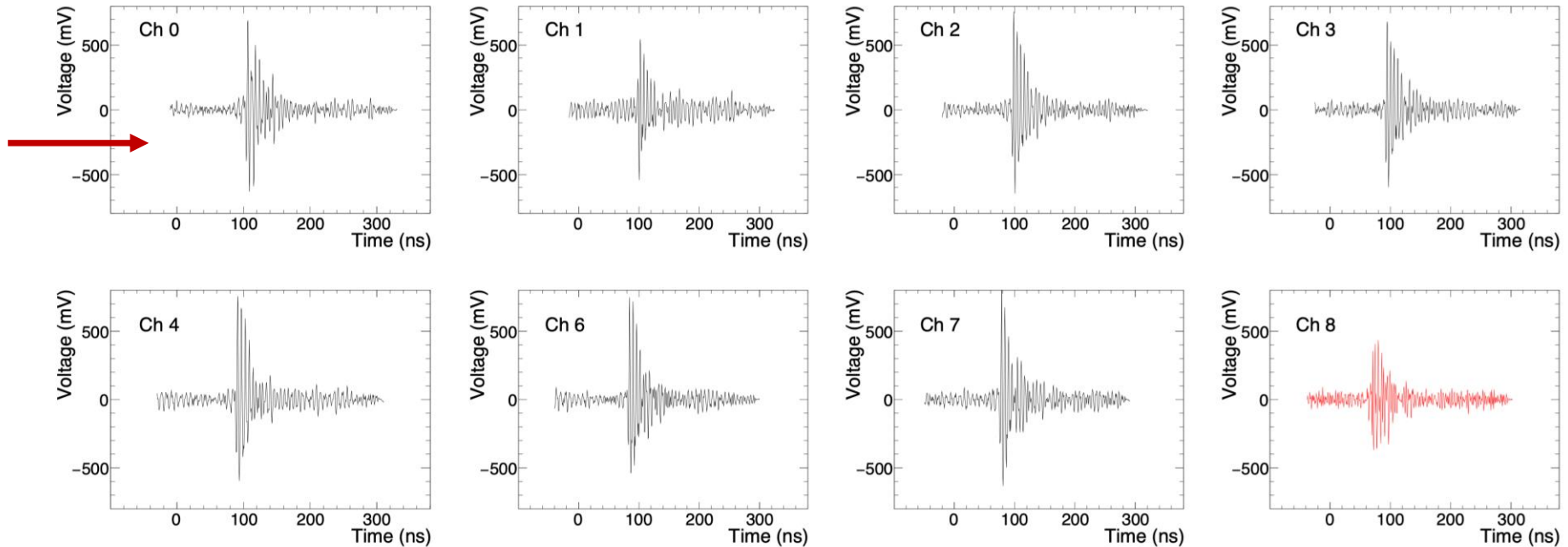
Expected Background:

$$0.13 \pm 0.01 \text{ (stat.) } {}^{+0.05}_{-0.06} \text{ (syst.)}$$

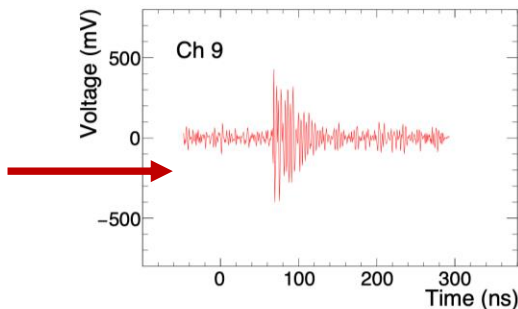
Unblinding Results

In the 100% dataset, 1 event from the Phased Array passed all cuts

Hits top
antenna last



Hits bottom
antenna first

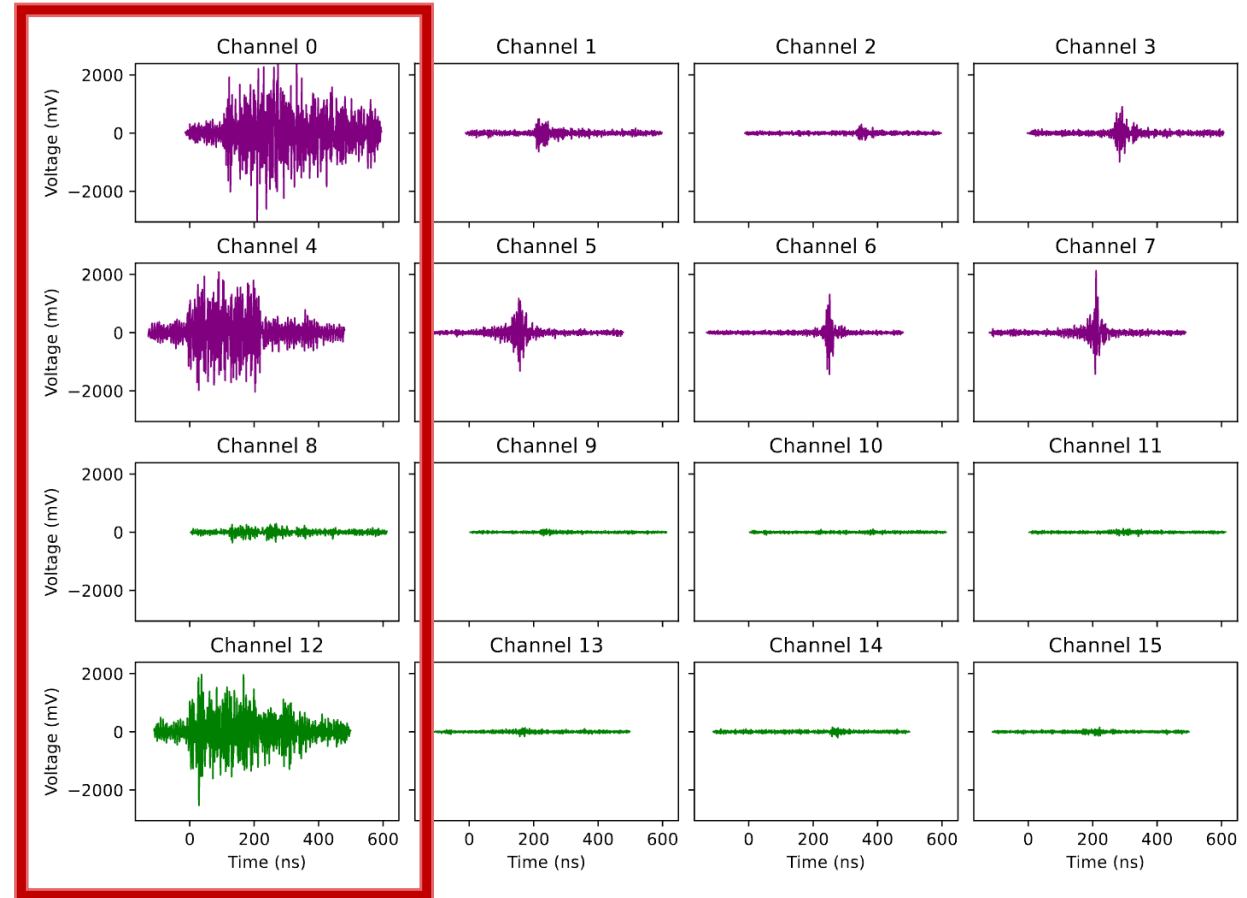


- Recorded on **April 4, 2018**, at 6:01:17am UTC

Follow-up Investigation

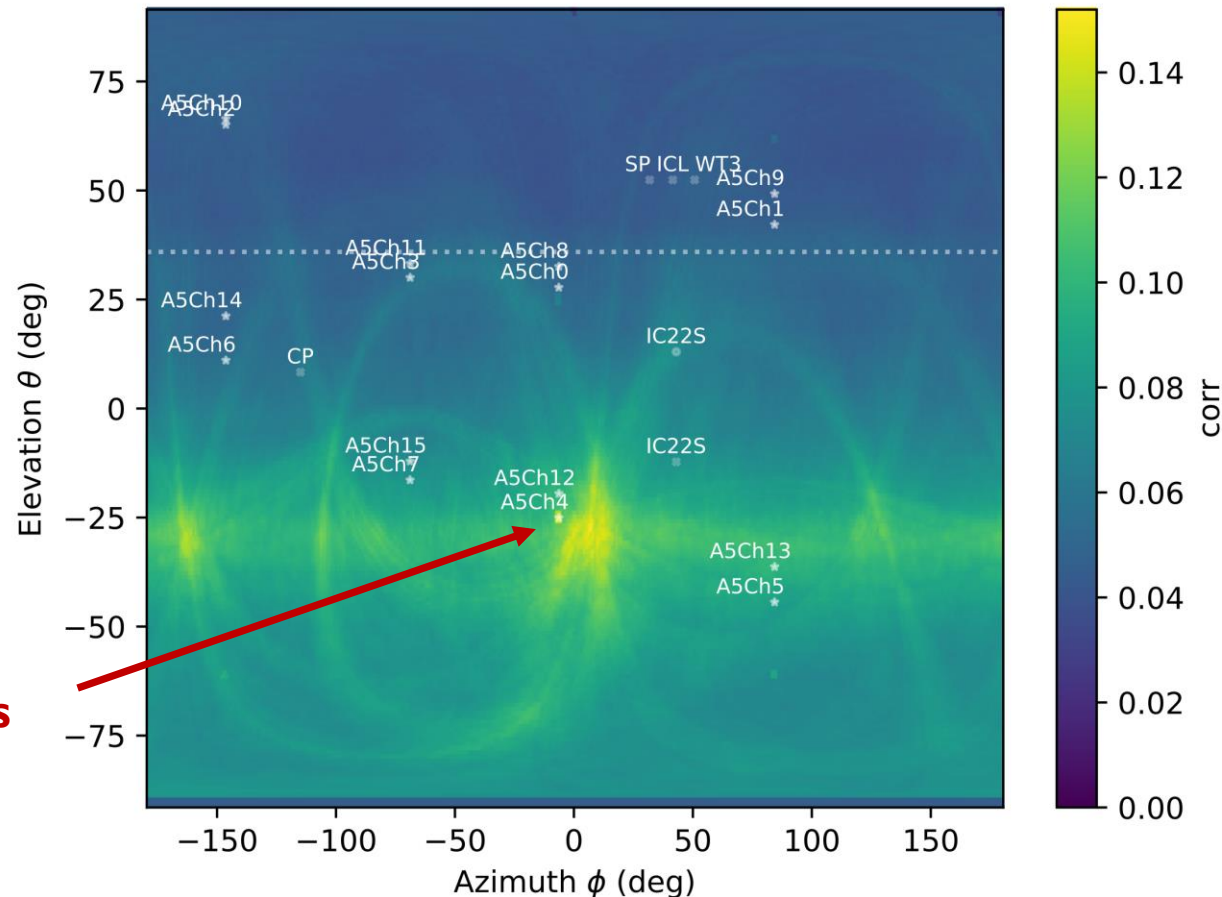
Coincident event observed on A5 (co-located with the phased array)

- **Event removed by a detector quality cut**
- Hypothesized to be a spark-like discharge emitted through the receiver antennas themselves



Follow-up Investigation

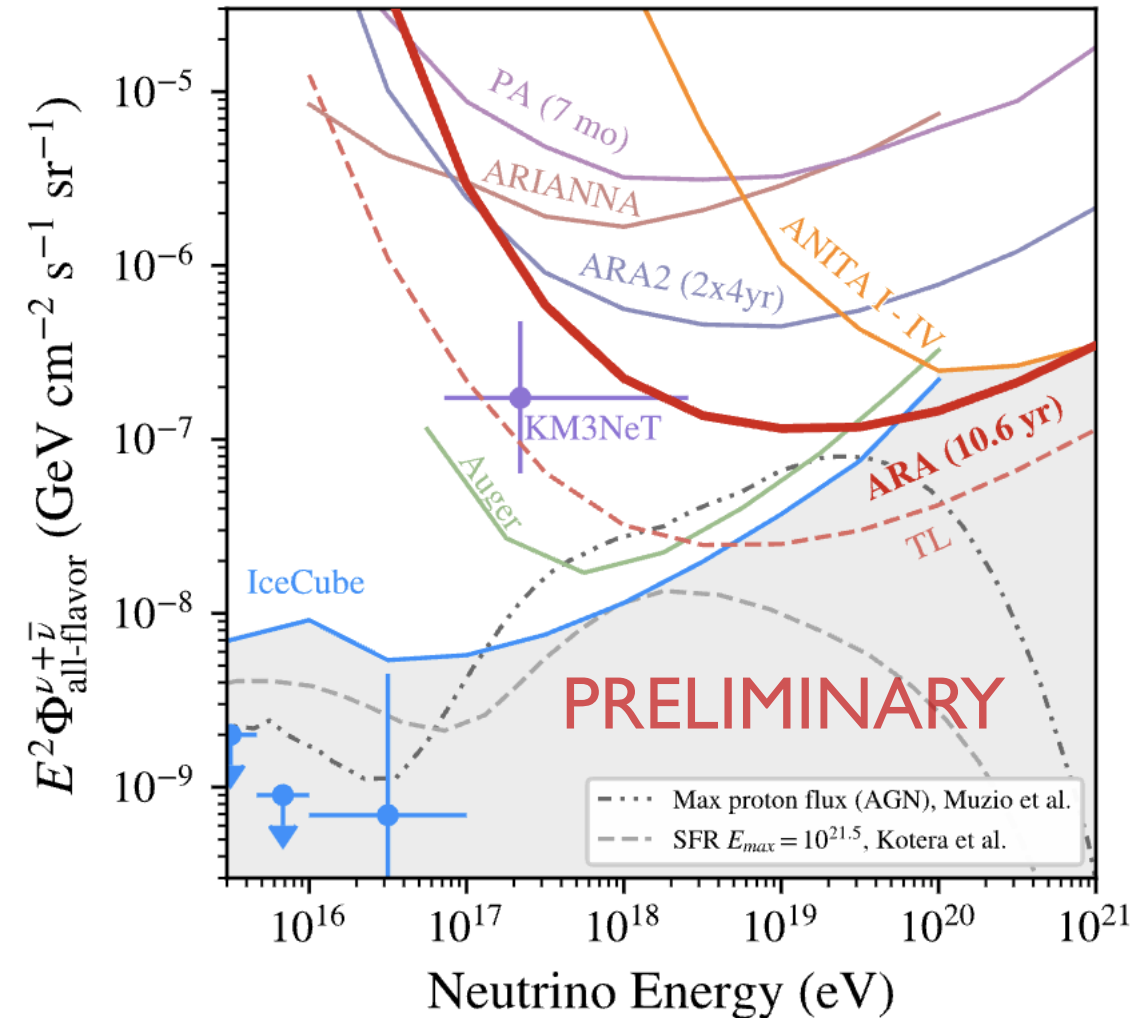
Joint reconstruction of PA passing event and A5 coincident event



- **Decision:** remove PA events within 0.5s of A5 events cut by “anomalous channel” detector quality cut
- This removes 21.9 seconds of data

Results

- Completed First UHE ν diffuse flux search with an ice radio array
- Strongest flux limits above 10^{17} eV from radio-neutrino experiments**
- Most stringent limits globally ~ 50 - 1000 EeV**
- Will inform the analysis strategy for larger radio arrays: RNO-G (under-construction), IceCube-Gen2 Radio (planned)



Team Work

Highly coordinated, first collaboration-wide search across 6 institutions



Fin

Thank you!