ASKARYAN RADIO ARRAY

ARENA CHICAGO 2024

A search for the ultra high energy neutrinos with the low threshold phased array trigger system of the Askaryan Radio Array

Paramita Dasgupta for the ARA Collaboration

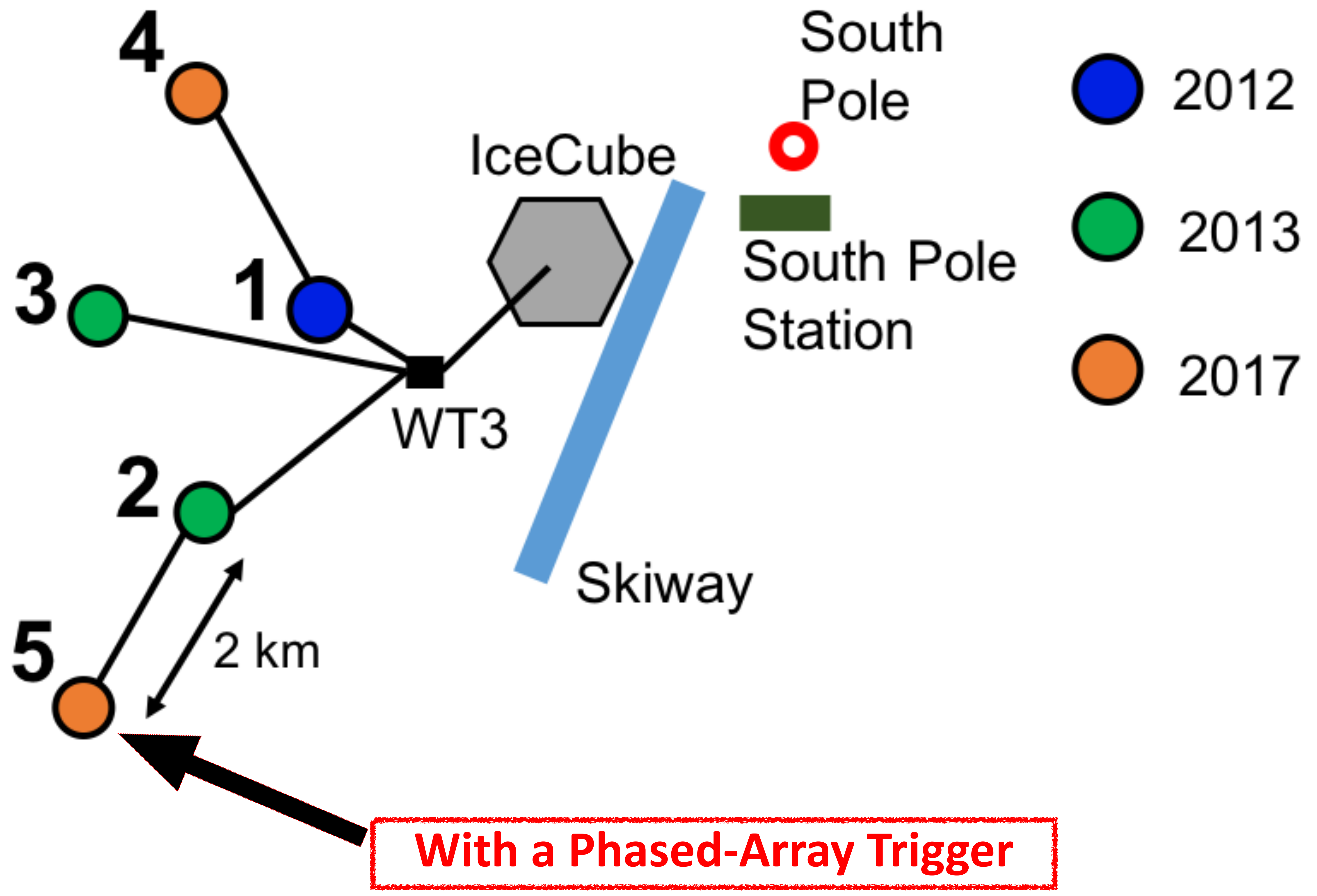
11th June, 2024

CCAPP

THE OHIO STATE UNIVERSITY

NSF

ARA Detector Overview



ARA's 5th station compared to other ARA stations

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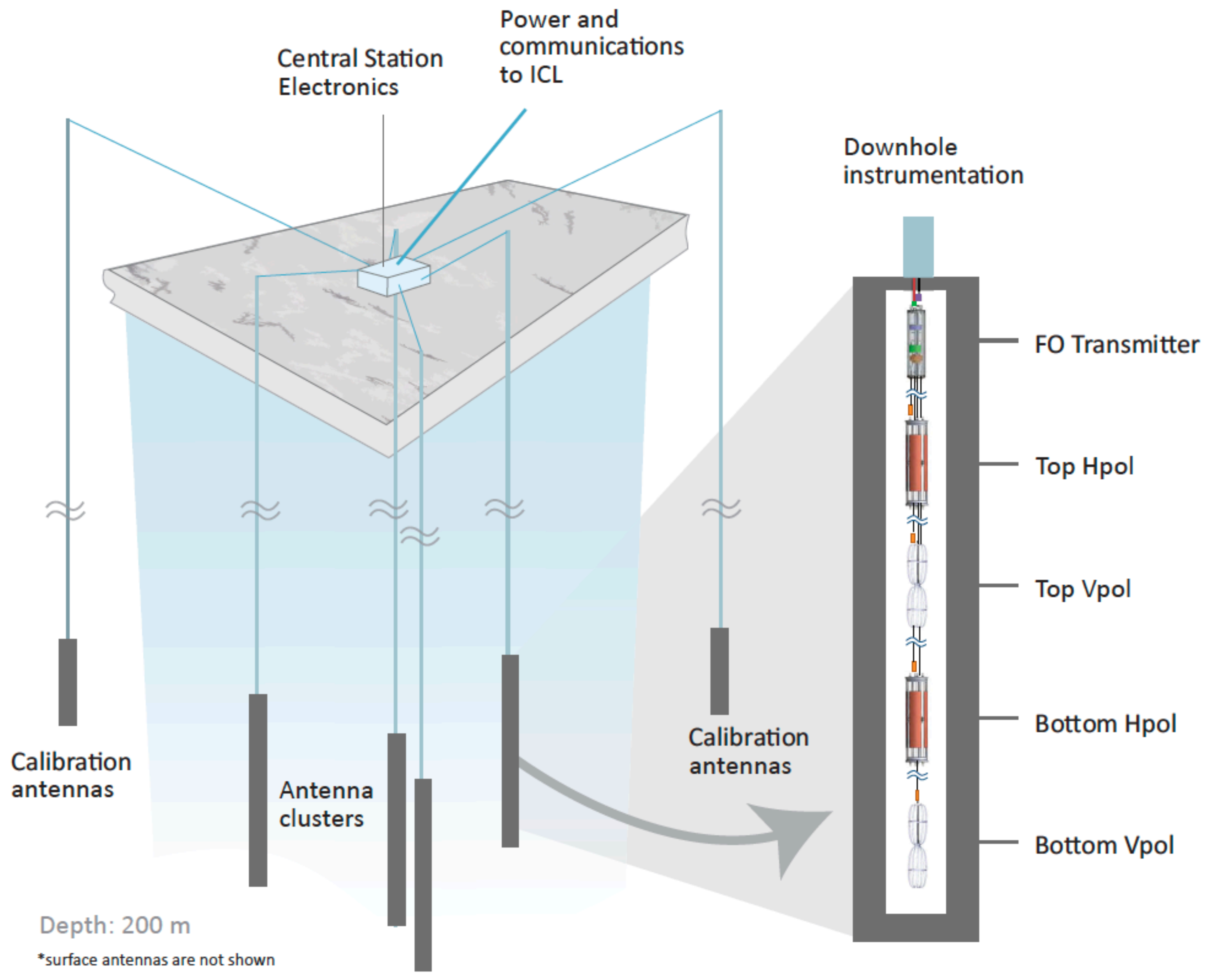
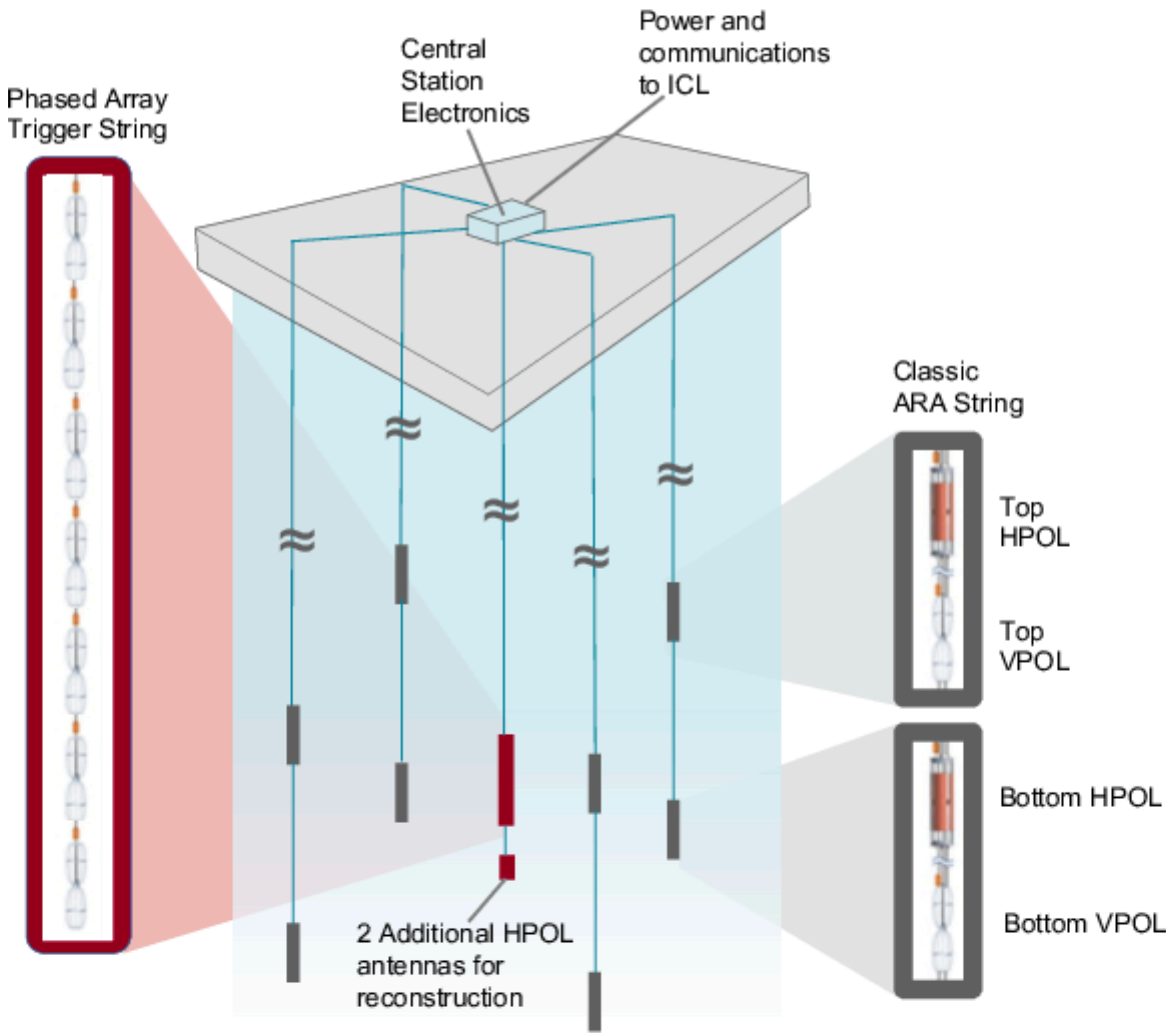
A1 - A4



A5 + PA system



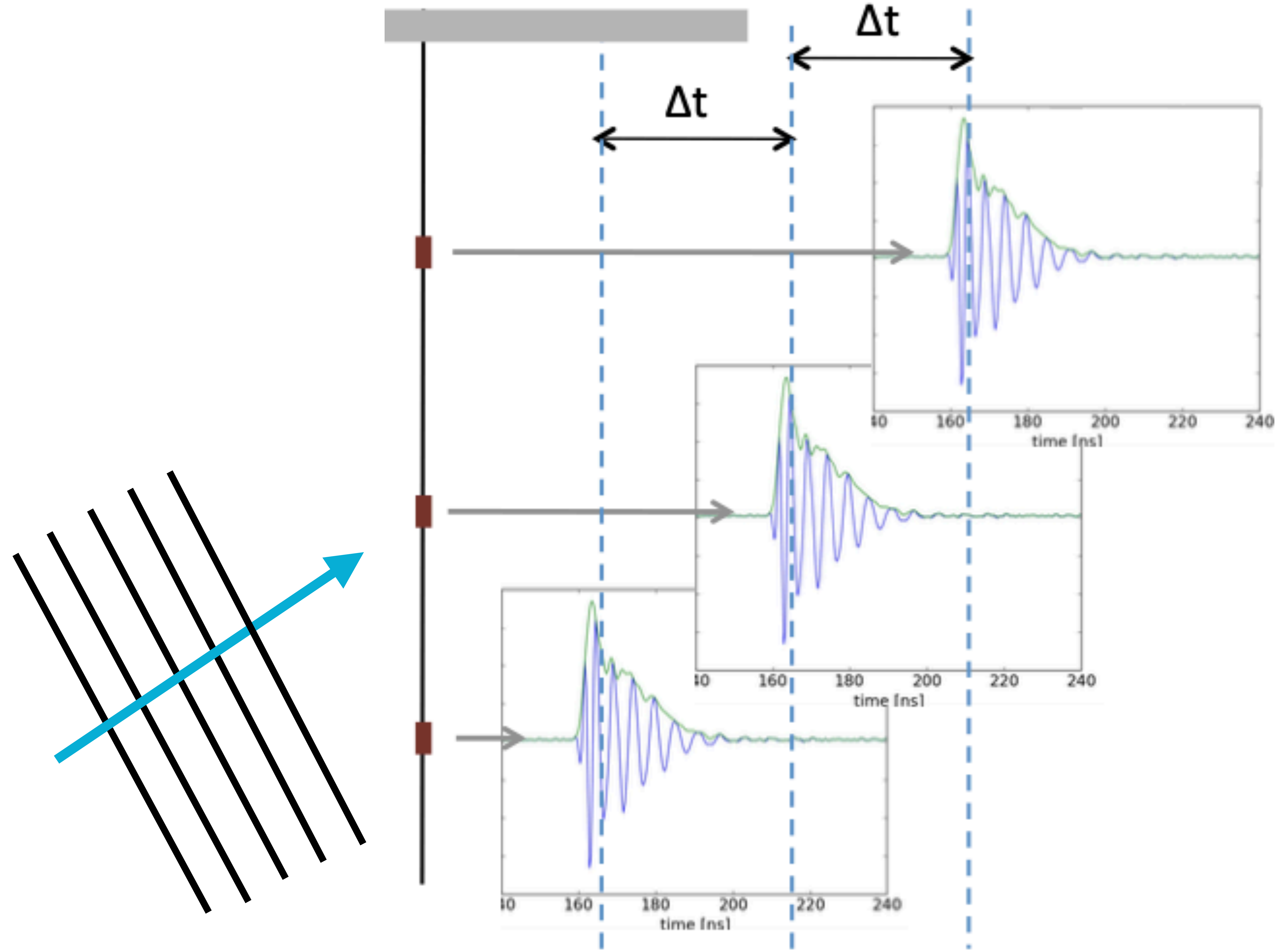
A Phased Array Trigger Design

- **Phased Array demonstrated capabilities of triggering on low SNR signals which are otherwise buried in noise**

- **Phased Array improves signal strength by combining multiple signals together before the signals are fed into the trigger system**

- **Adds signals together in predetermined directions (“beams”) through delay-and-sum method.**

- **Plane wave signals add coherently, noise likely does not. This effectively lowers trigger threshold**



Impulsive plane wave (eg., neutrino signal)

Pic Courtesy: Kaeli Hughes

The phased array detector

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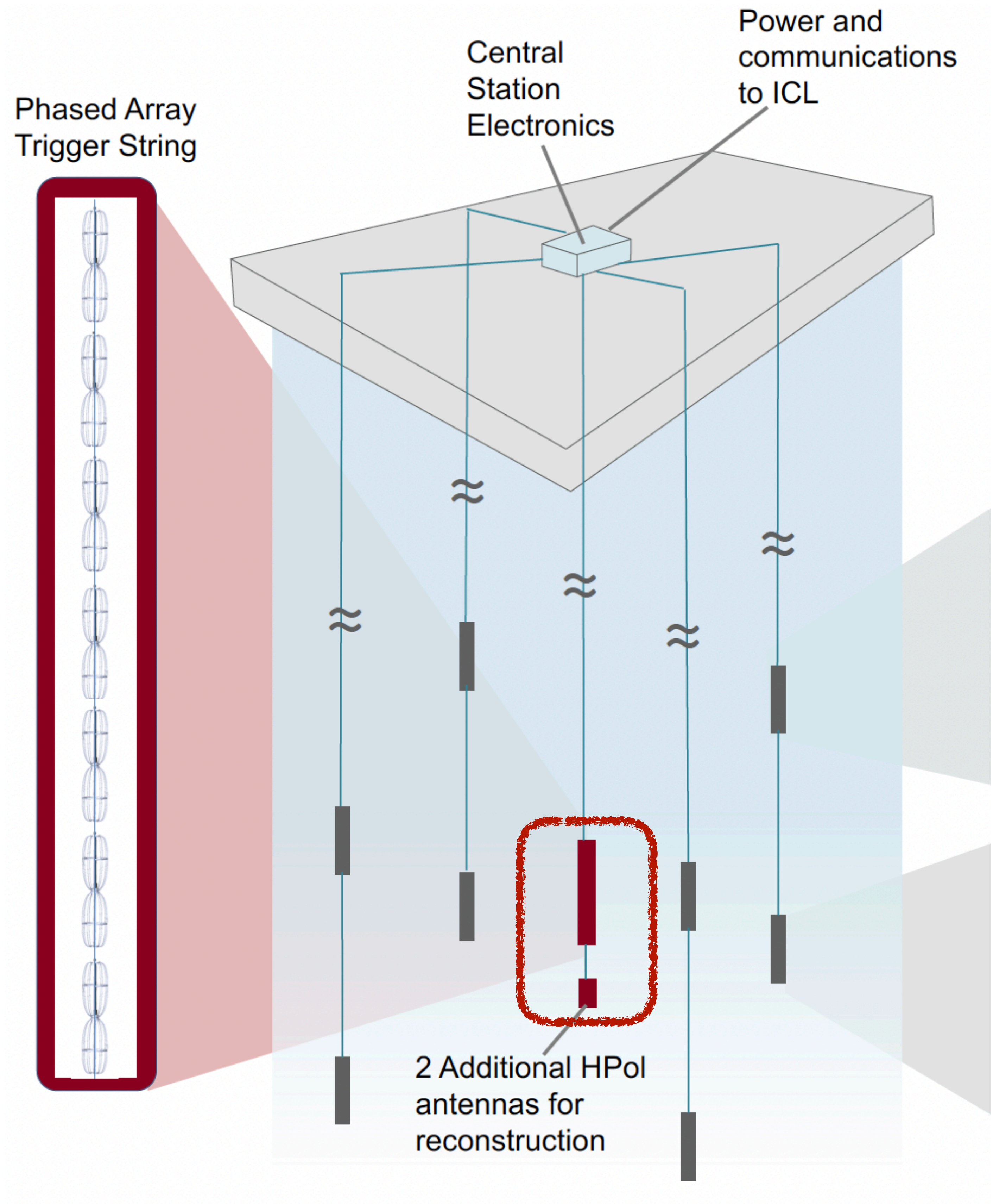
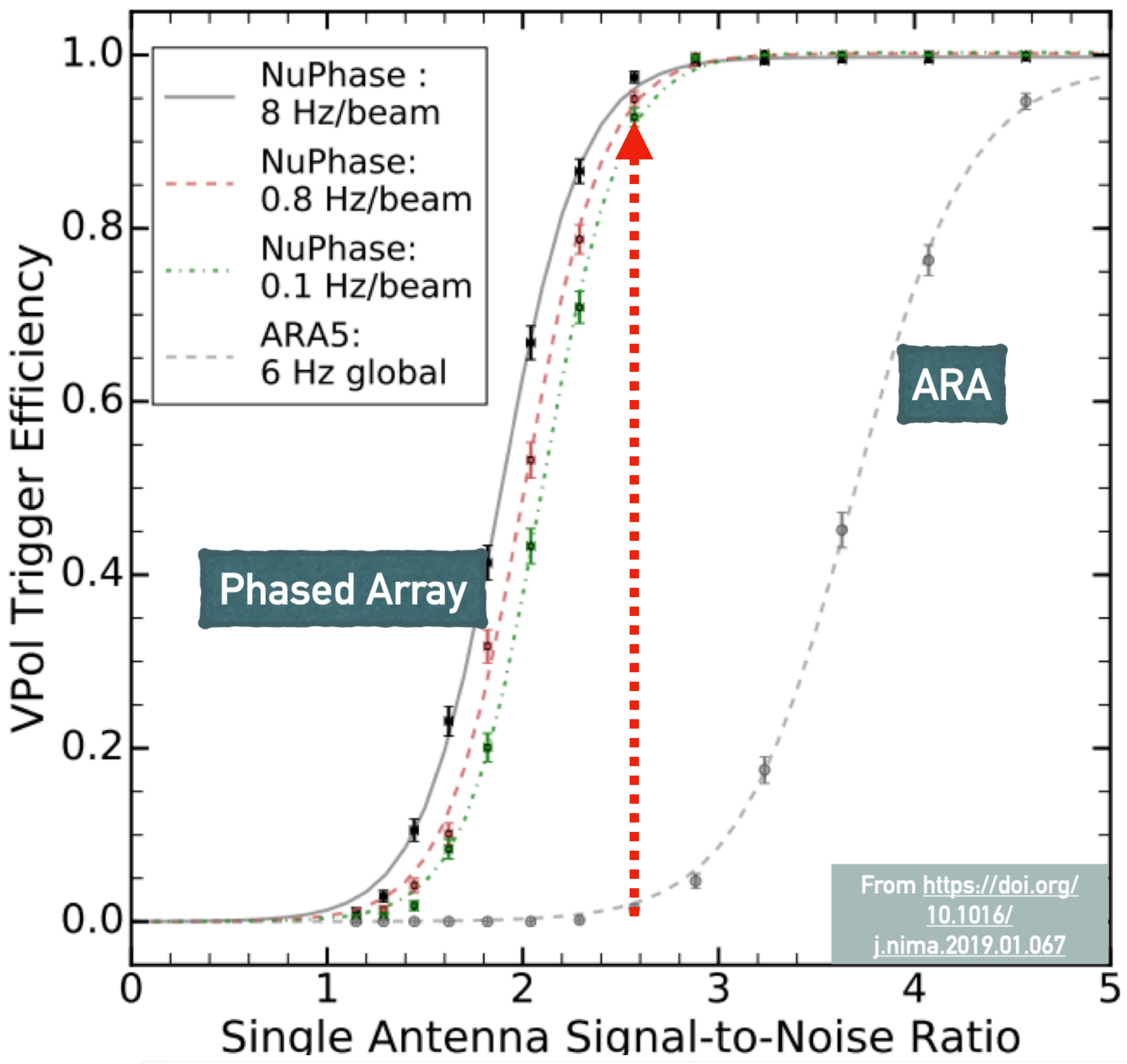
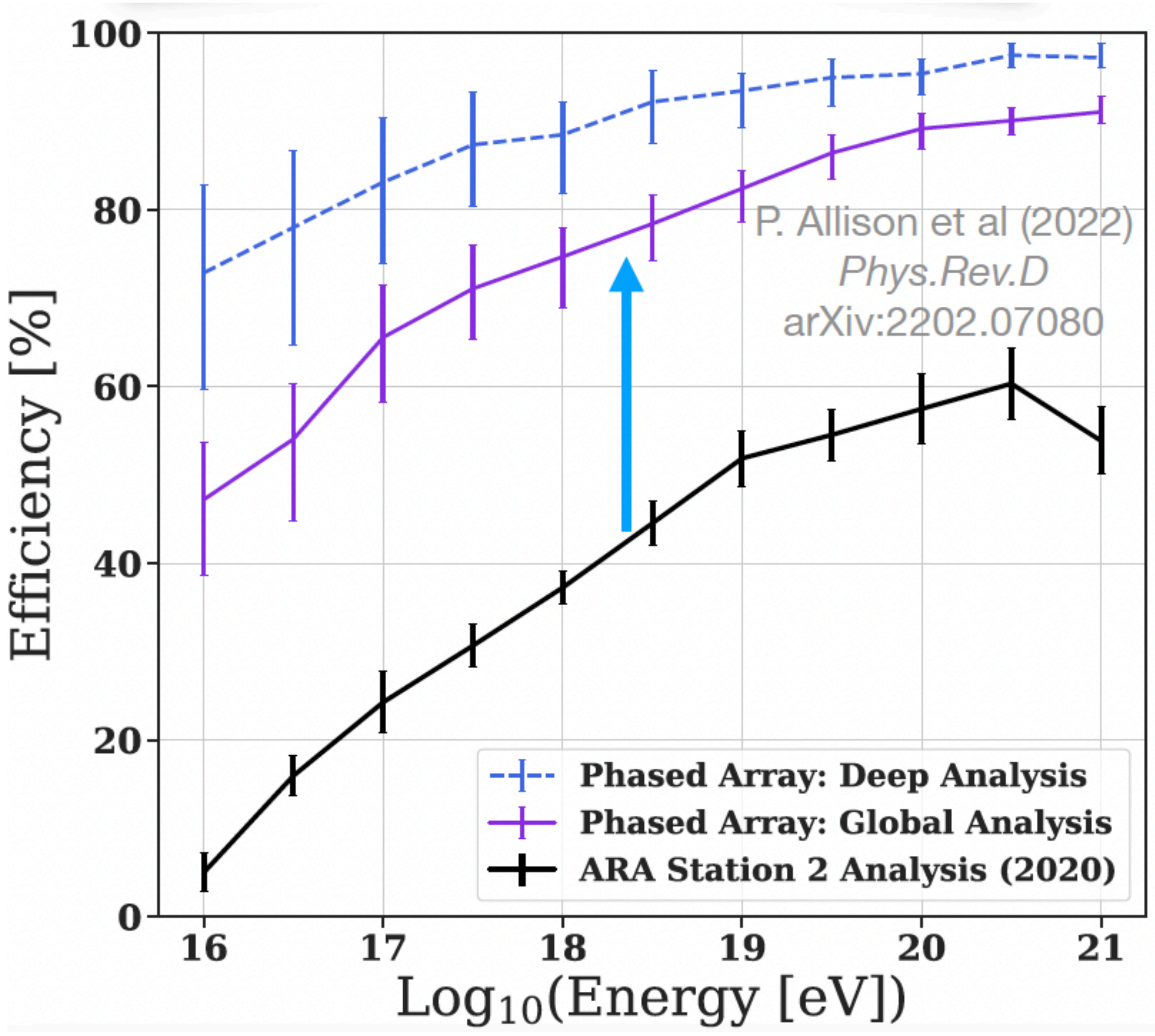
Analysis with *PA alone* significantly improves trigger efficiency and analysis efficiency





Improved Trigger efficiency



Improved analysis efficiency

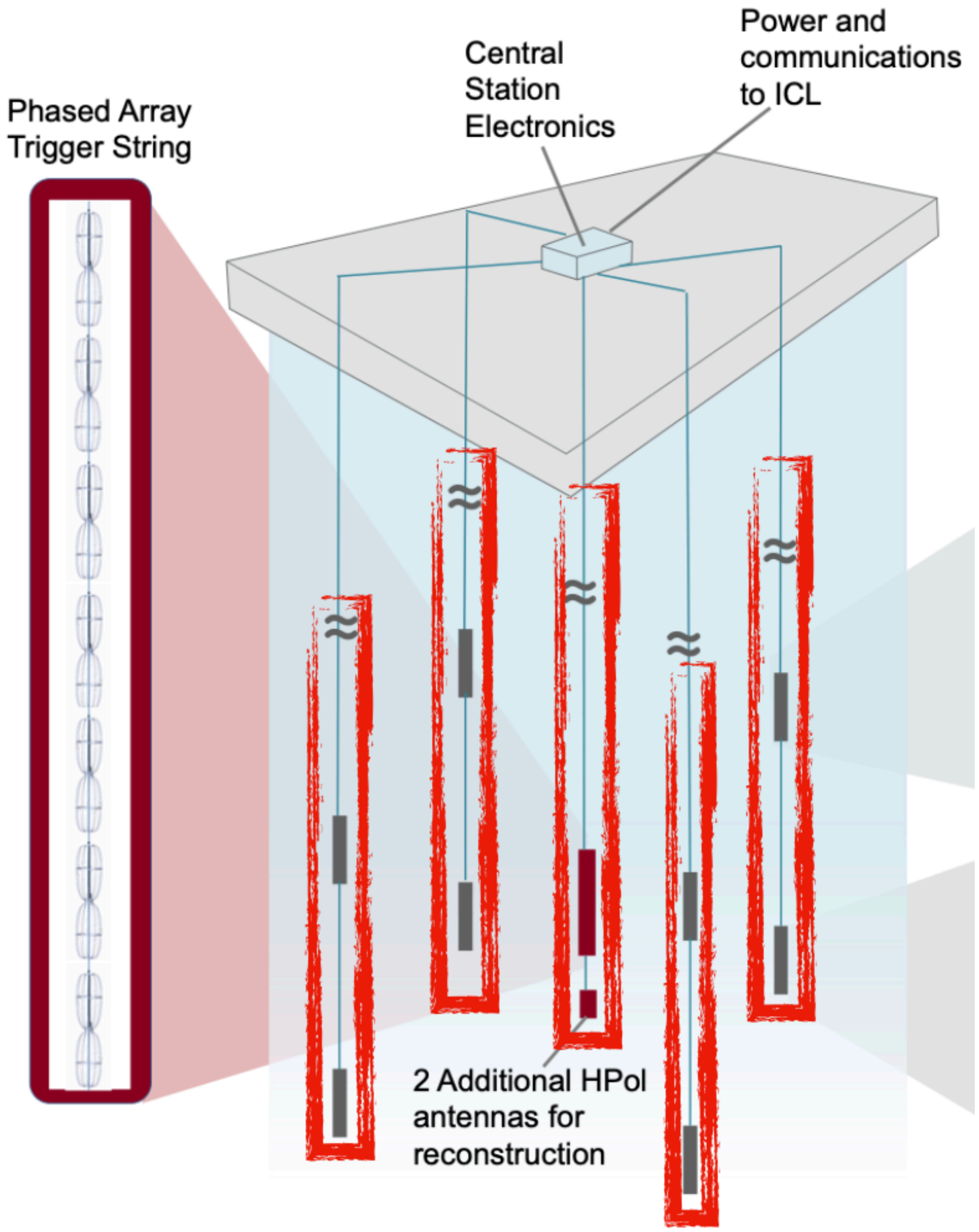
Fraction of triggered ν events in signal region

A Pioneering Hybrid Analysis

Combine PA & ARA subdetectors to maximize background rejection & analysis efficiency

- **Hybrid design = Phased array + 7 A5 Vpols** readout through the Phased Array DAQ
- **Unique detector, representative of next generation of detectors like RNO-G & IceCube-Gen2**
- **Livetime : 2020 + 2021 data from hybrid system**
- **Blinded analysis using "burn sample" randomly selecting 1 in every 10 events**
- Optimize cuts for 5σ discovery potential

ARA station 5

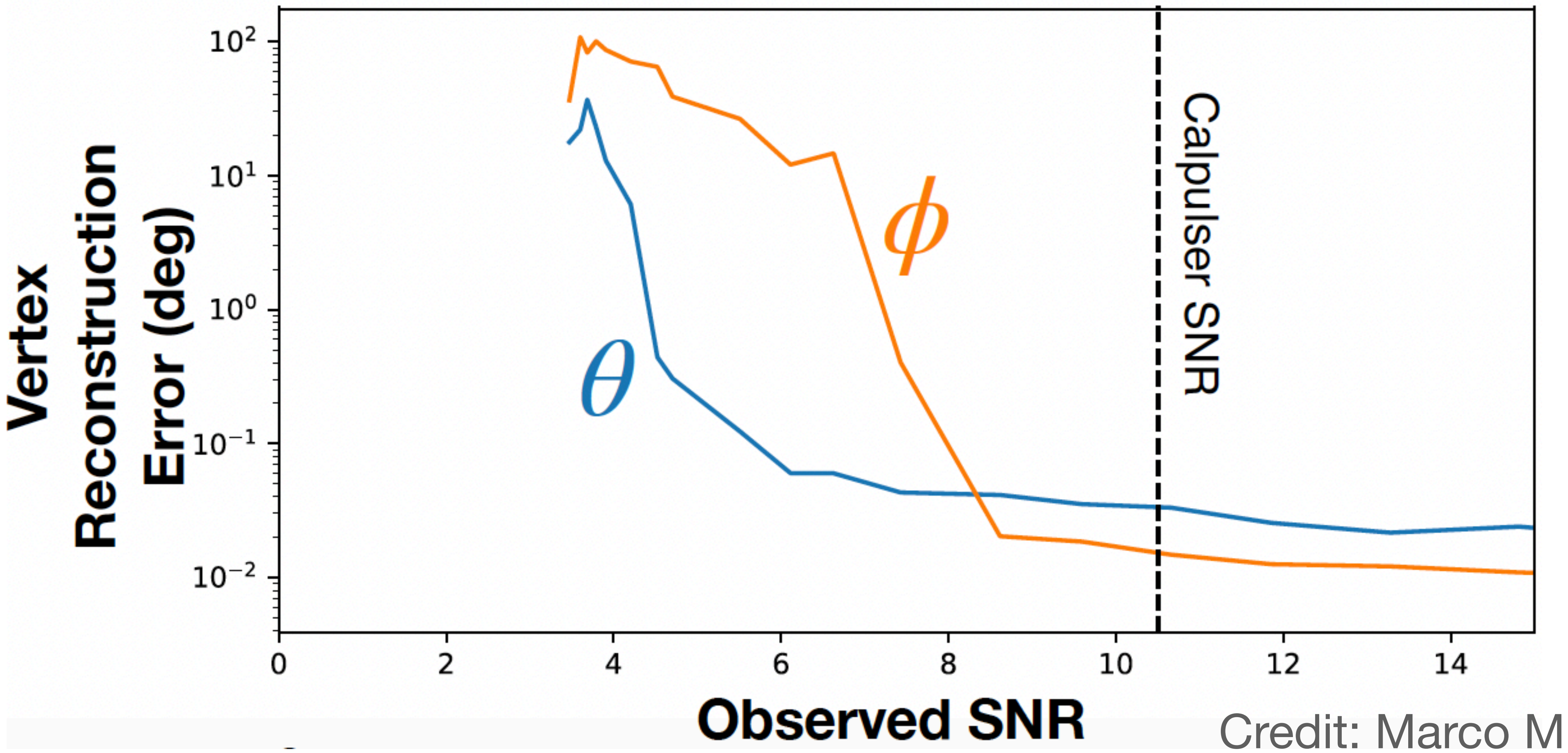


Marco Muzio, Penn State

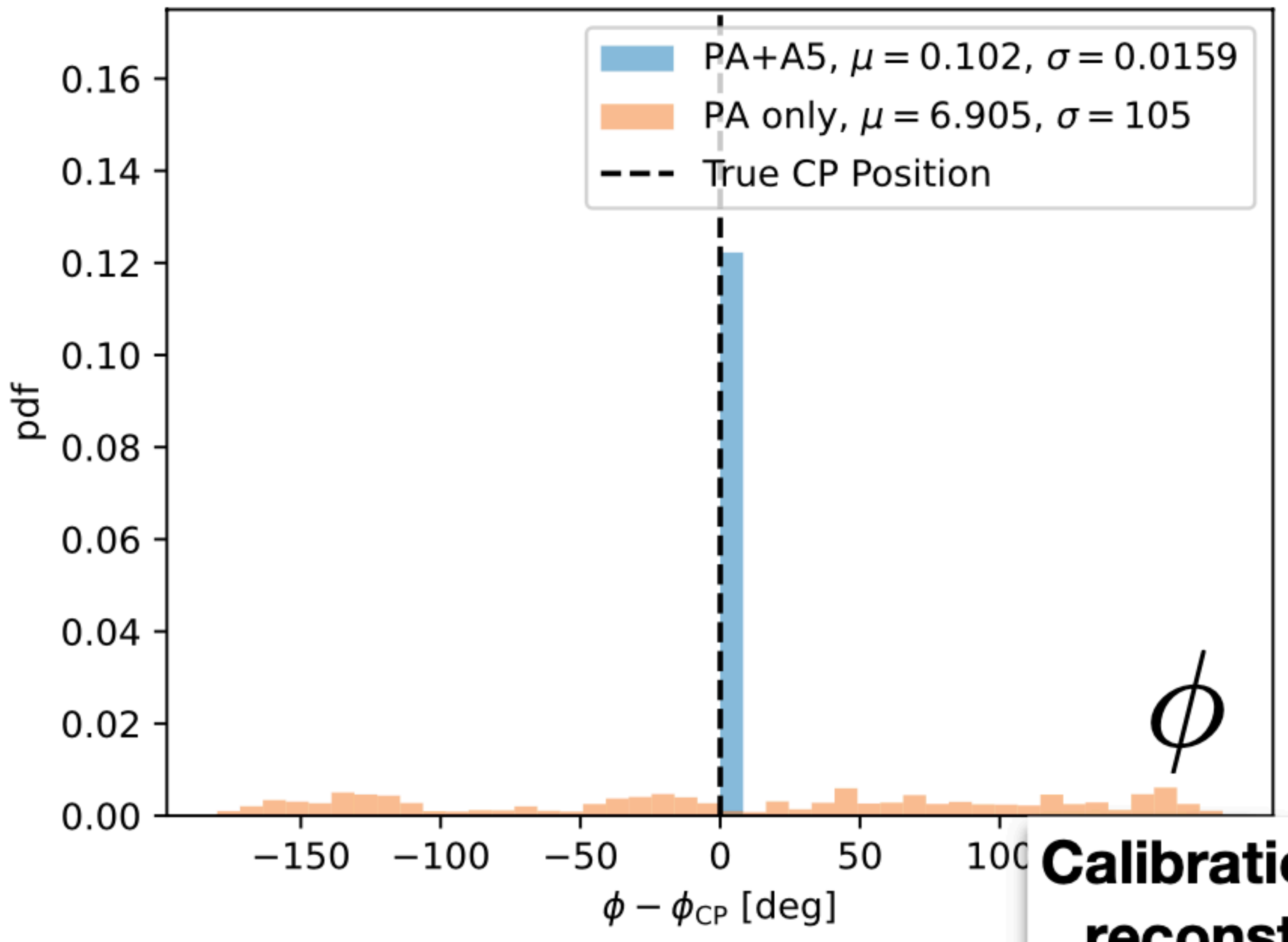
Paramita Dasgupta, Ohio State

Advantages of a Hybrid detector

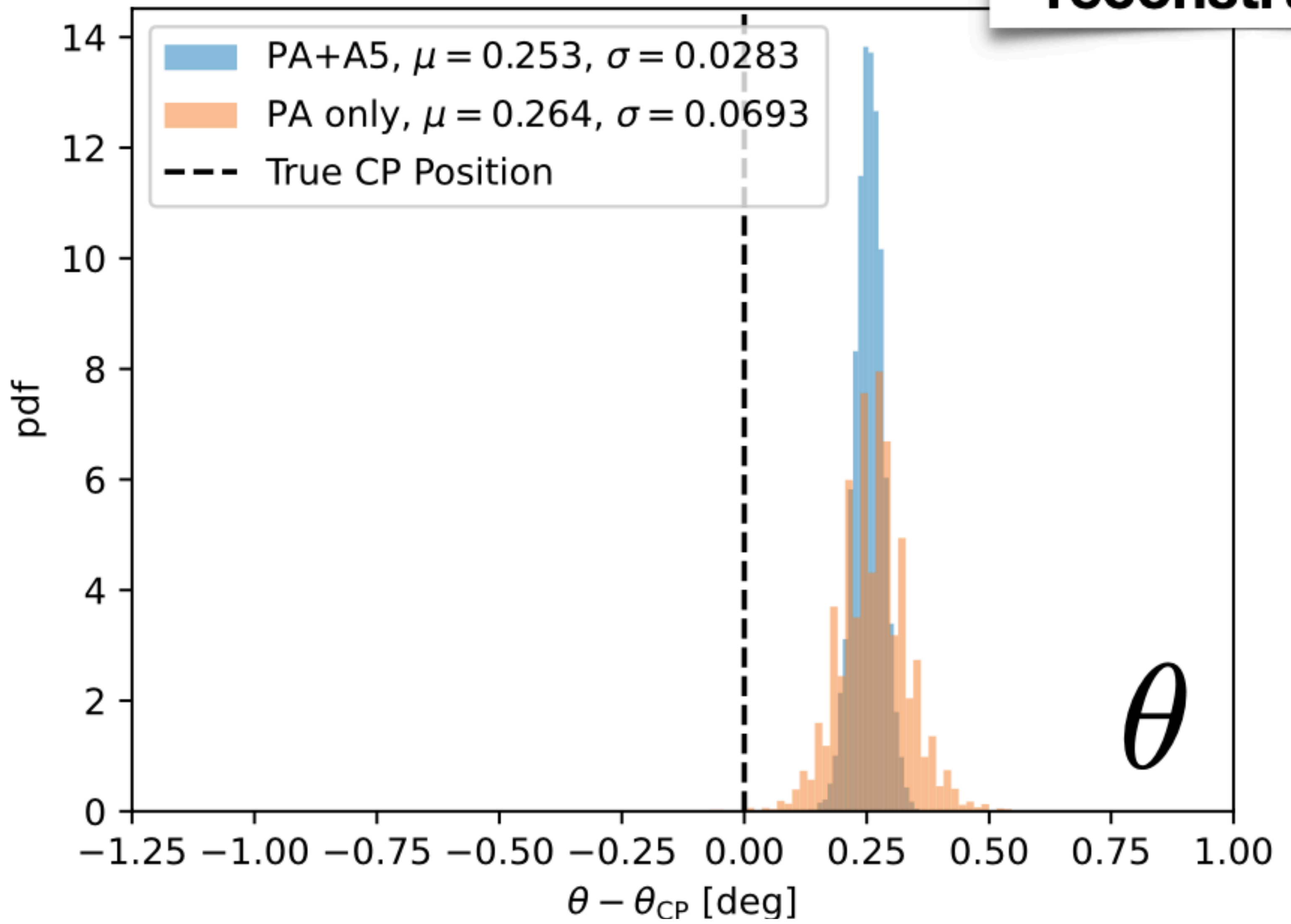
- **Improved Pointing accuracy**
  - **PA string alone has no azimuthal sensitivity to vertex position**
  - **Hybrid system has azimuthal sensitivity *and* ~2x improved zenith sensitivity to vertex position**
- **Enables high-efficiency background rejection based on direction and timing information**



Credit: Marco Muzio



Calibration pulser reconstruction



Classification of ARA data

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1. Calibration Pulser Events

Recoded every second for in-situ calibration

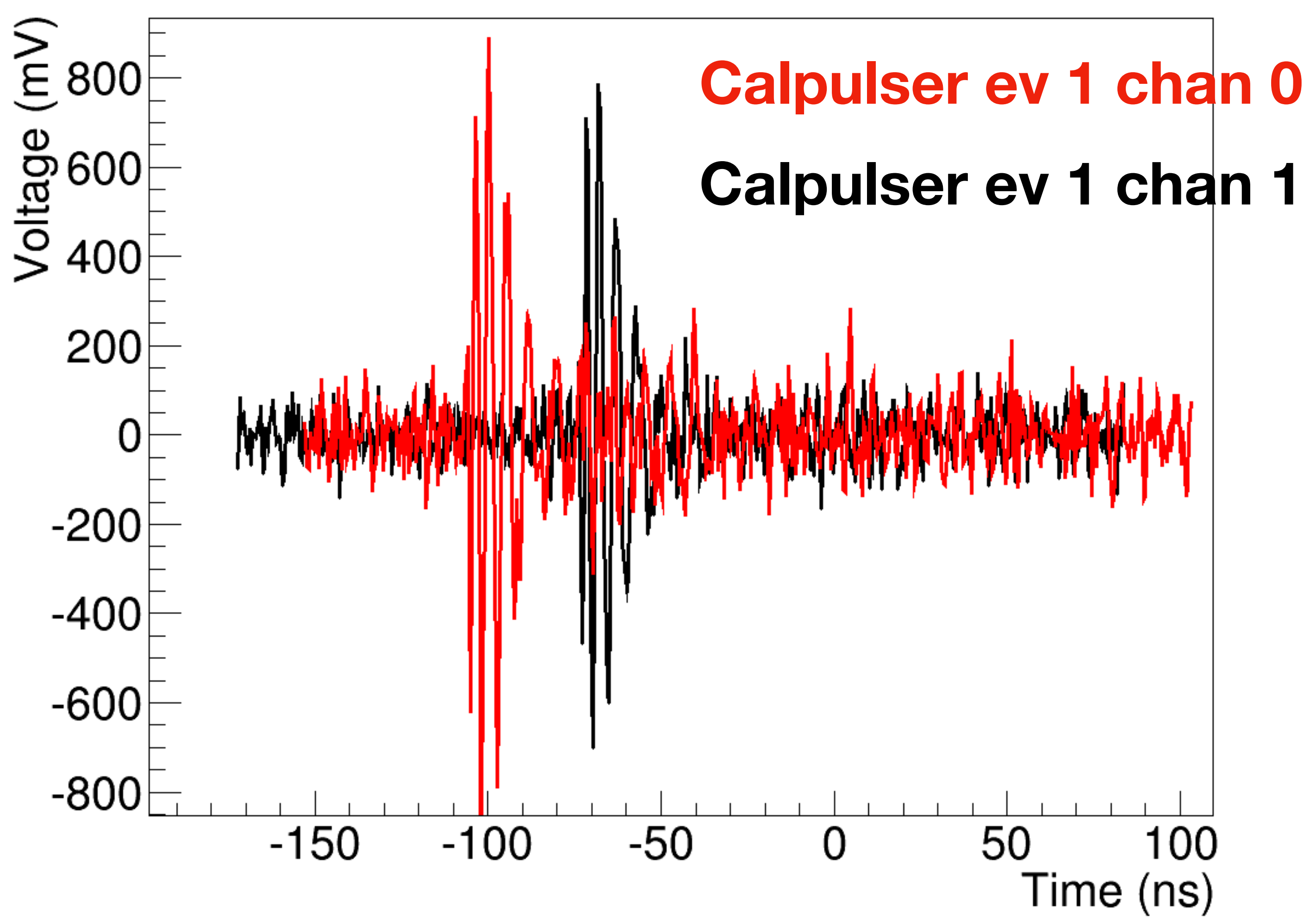
2. Software Trigger Events (Forced Triggers)

Recorded every second to monitor the detector performance, sample the noise environment

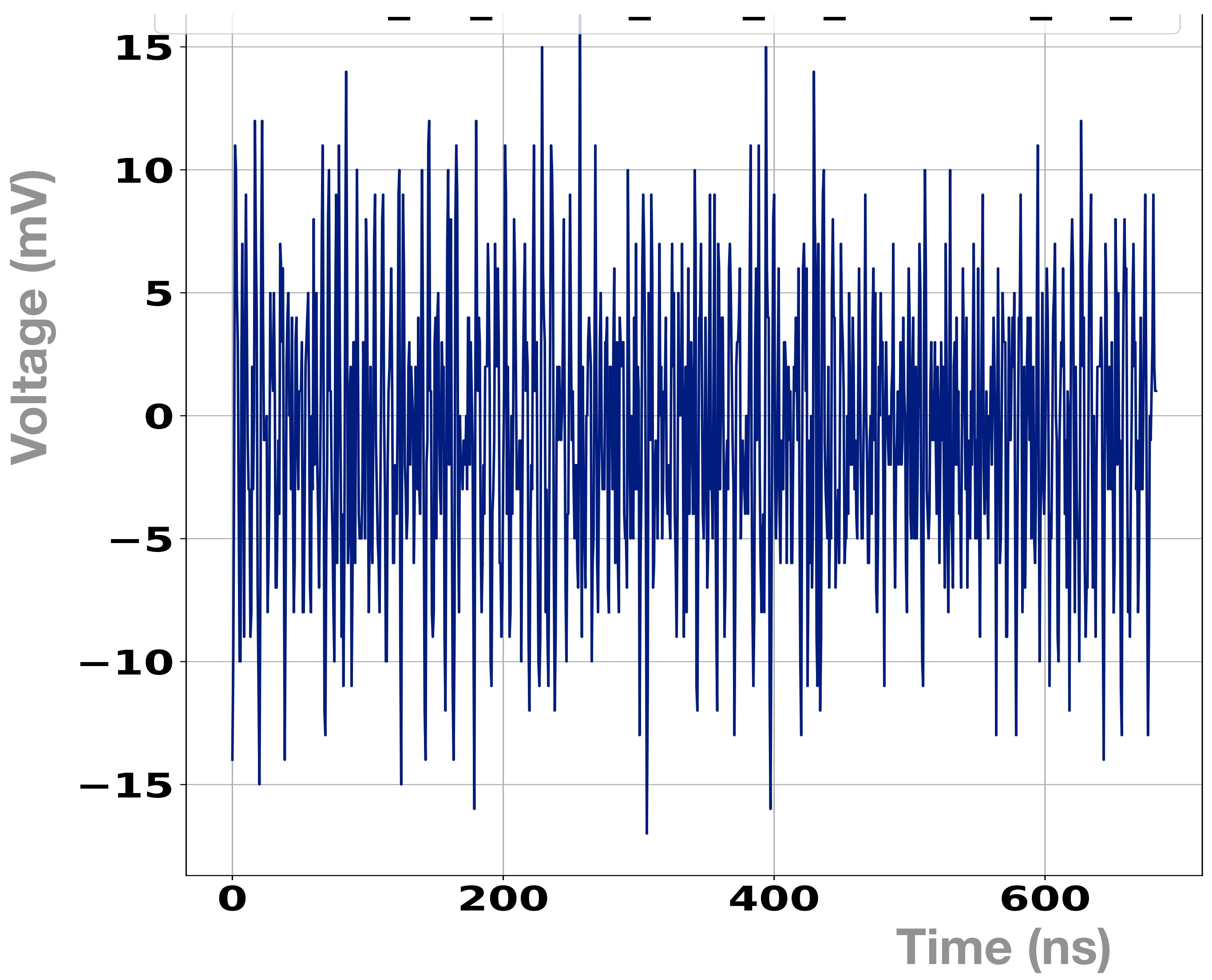
3. RF Trigger Events

Mostly thermal events + non-thermal background (eg, CR, CW, anthropogenic events, ….) + non-thermal ν-induced signal events

Calibration pulser event



Thermal noise event

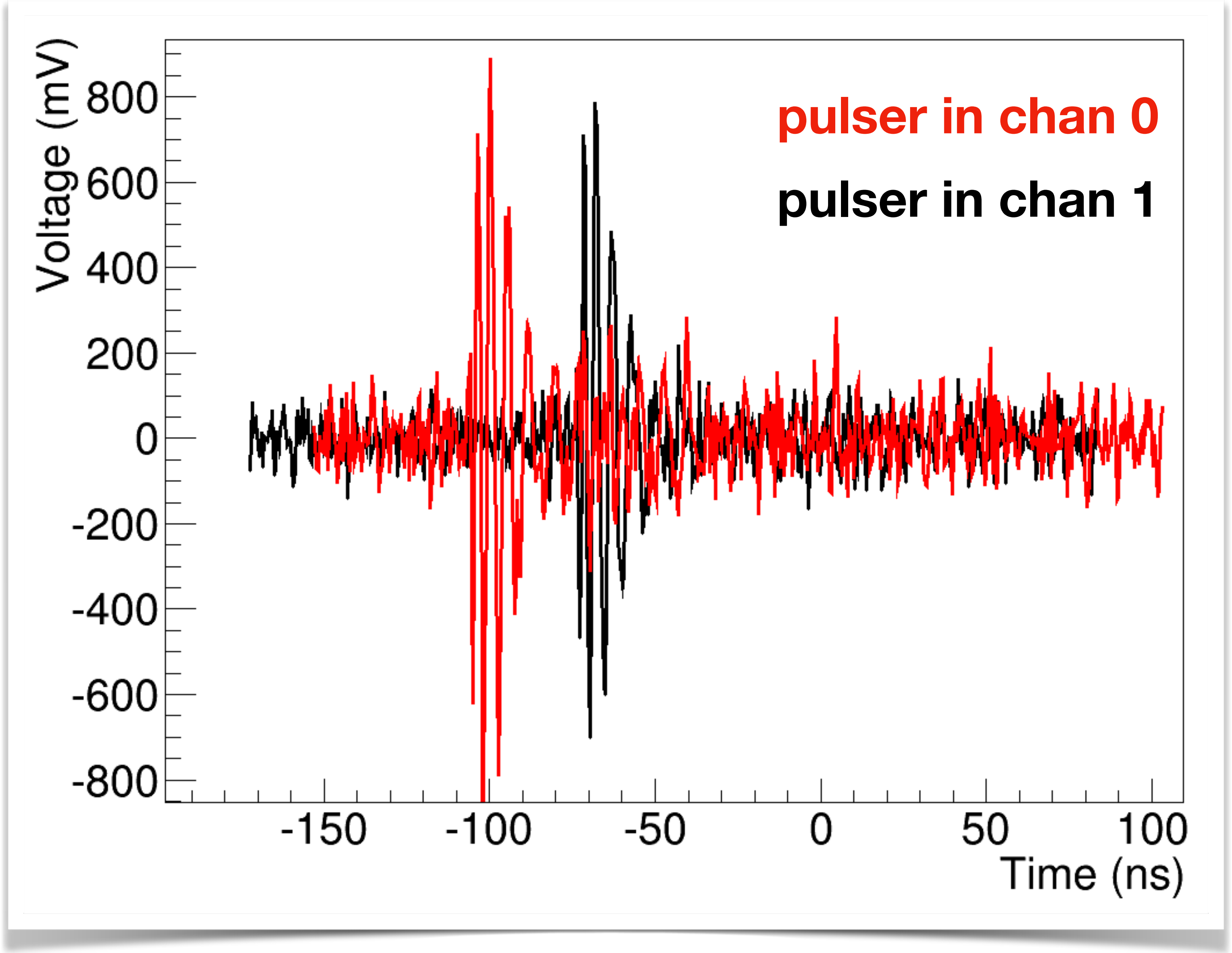


Reconstruction of Source location with A5-PA hybrid system

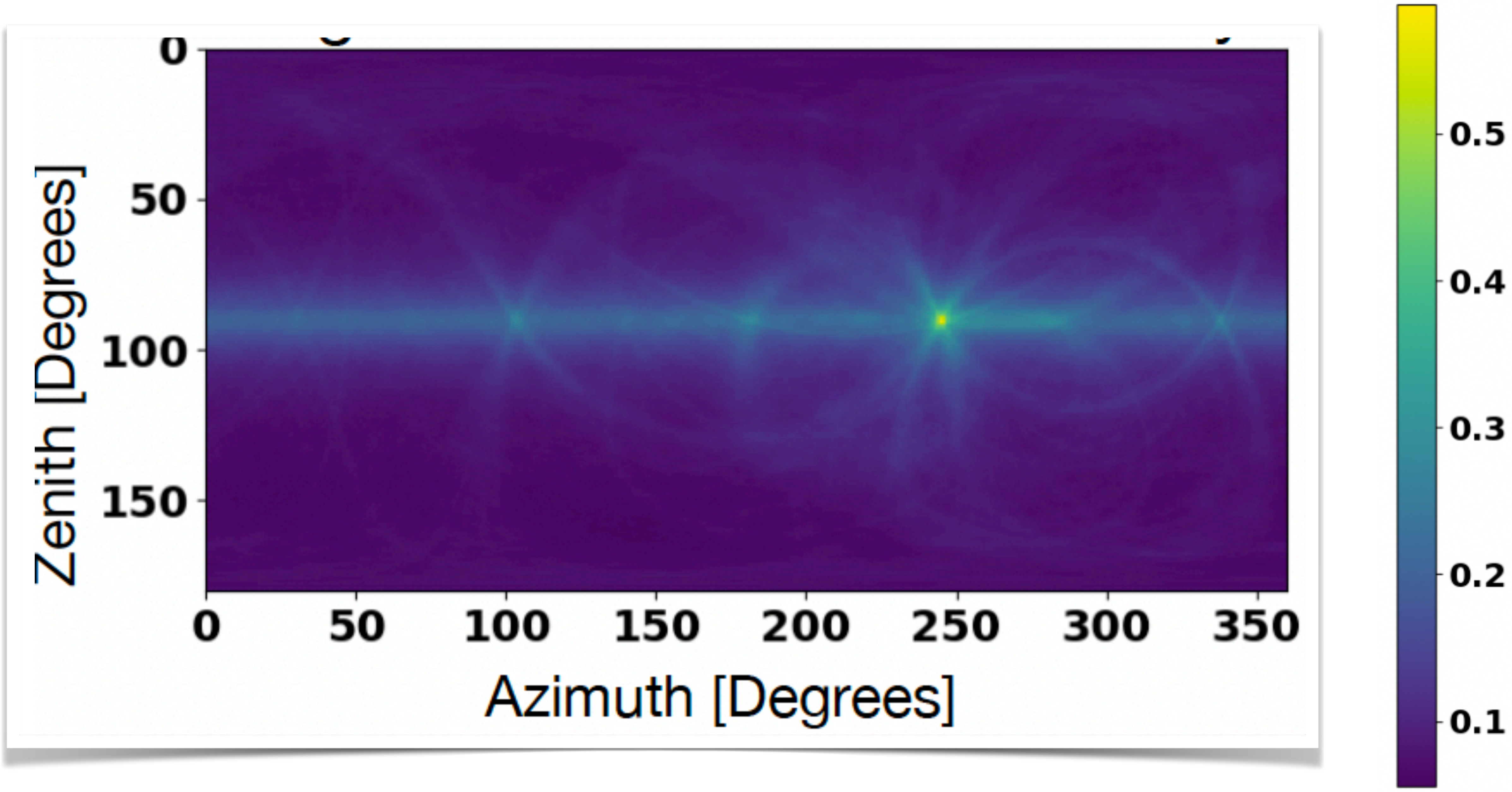
- **Excellent pointing accuracy with A5-PA antennas, improved vertex reconstruction would lead to improved analysis efficiency**

- **Improved surface background removal using correlation map**

Pulser signal in a pair of channels

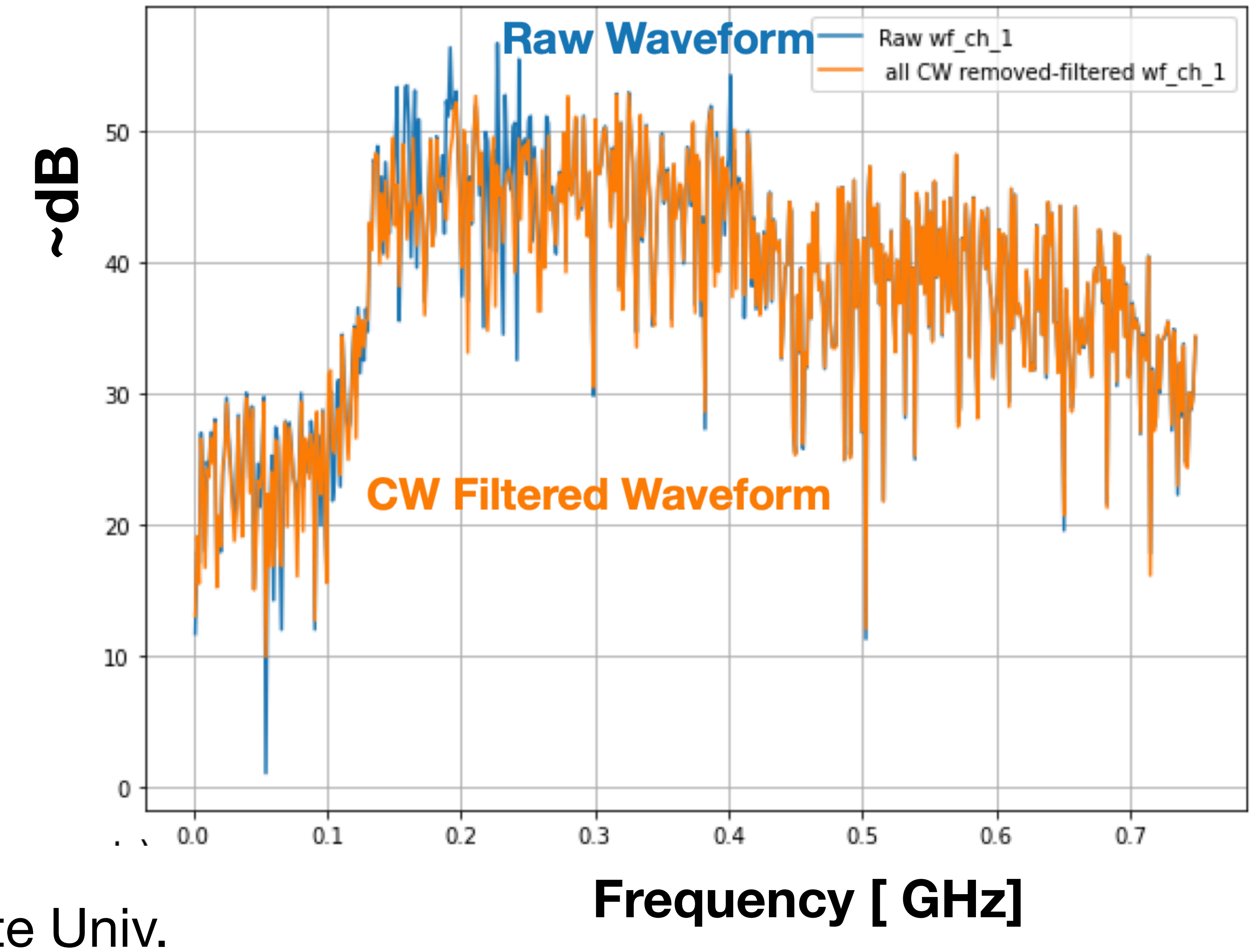


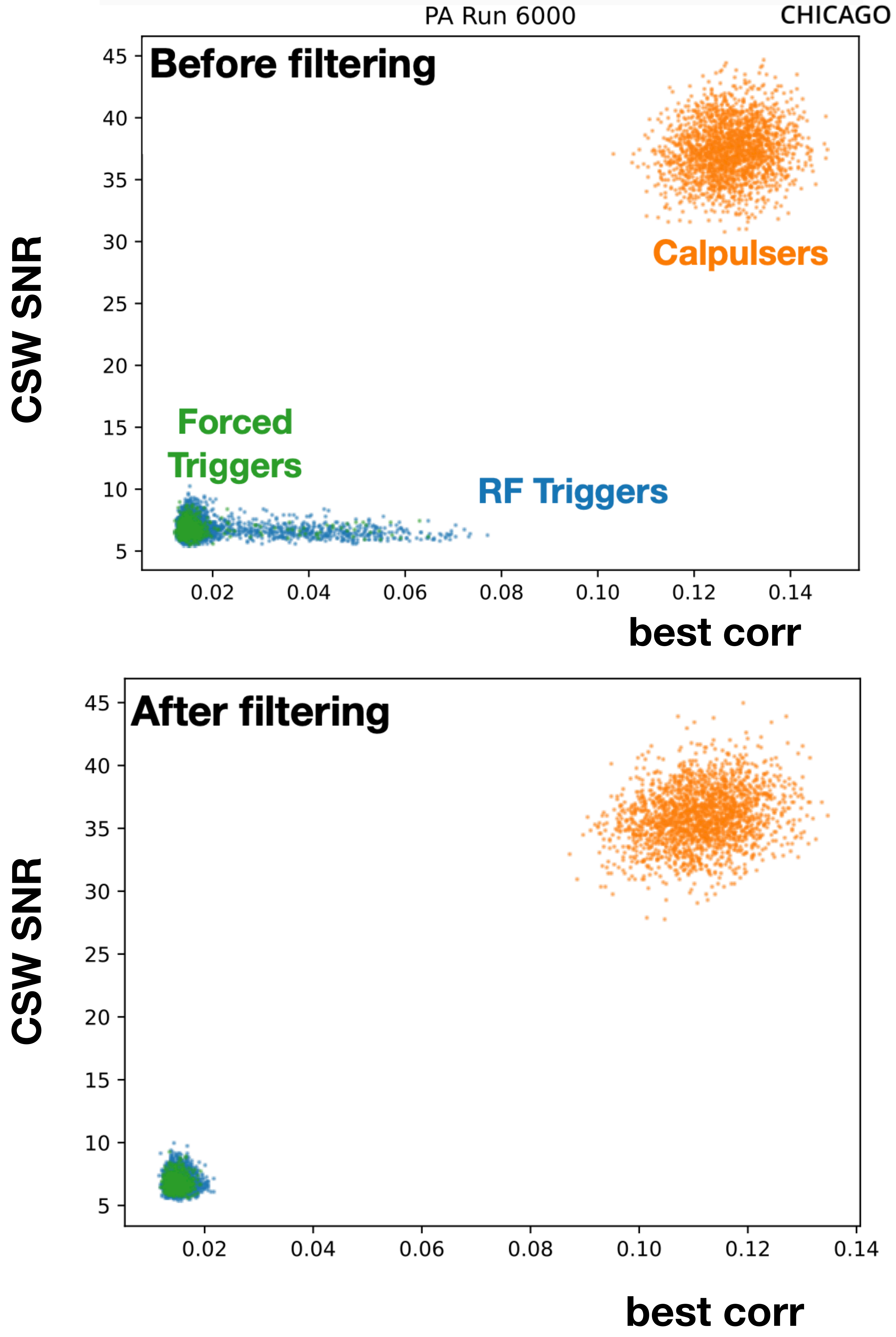
Reconstructed pulser source location using A5-PA hybrid antennas



Background removal: Continuous Wave (CW) Signals

- CW occurs at a specific frequency intermittently depending on time of the day, time of the year
- **CW signals identified in frequency domain**
- **We use the Sine Subtraction method developed for the ANITA experiment [Gorham et. al Phys. Rev. D, 98:022001]**
- Filter allows event contaminated with CW signal to be cleaned so they can remain in the burn sample





Analysis pipeline

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Example analysis variables

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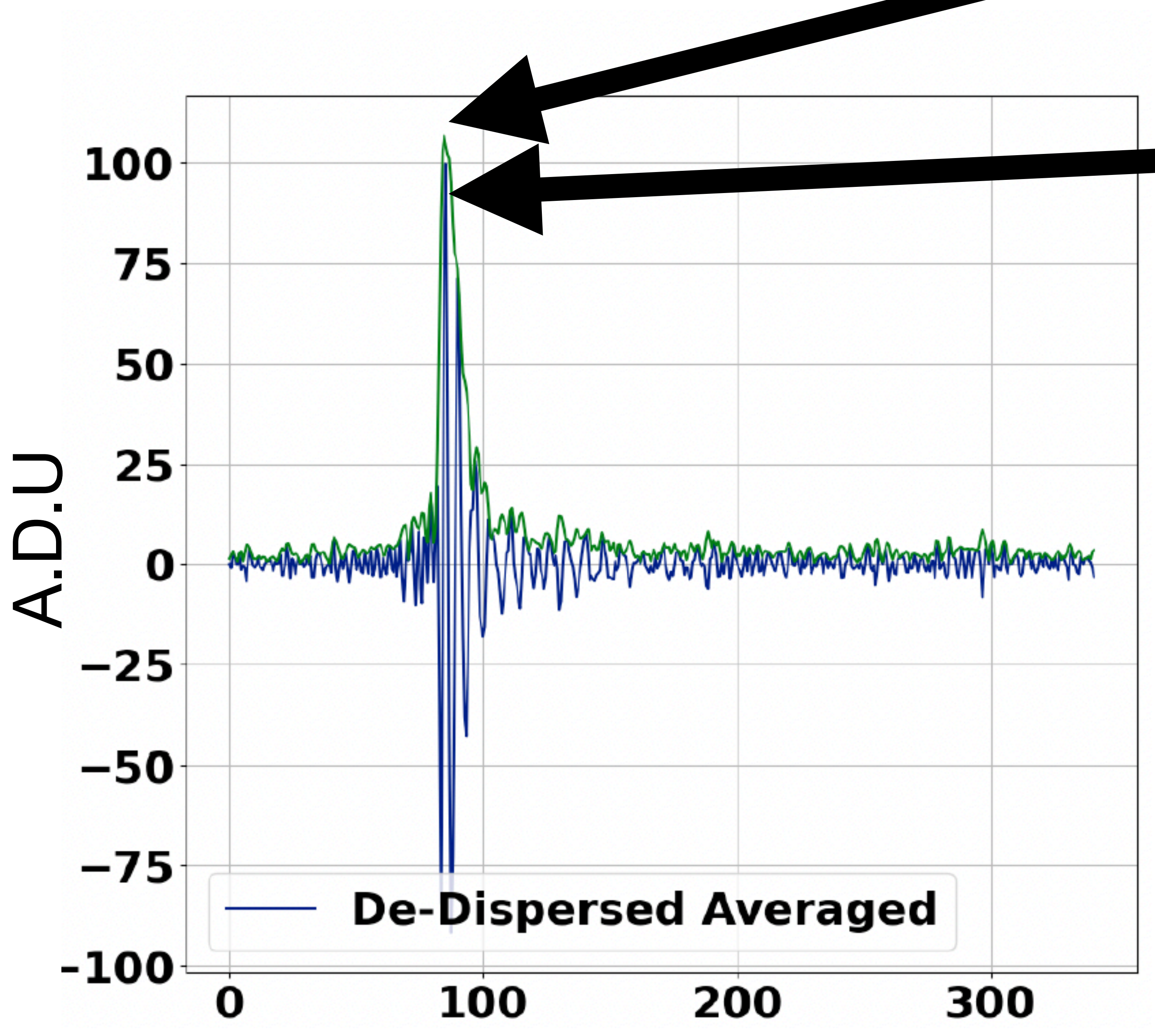
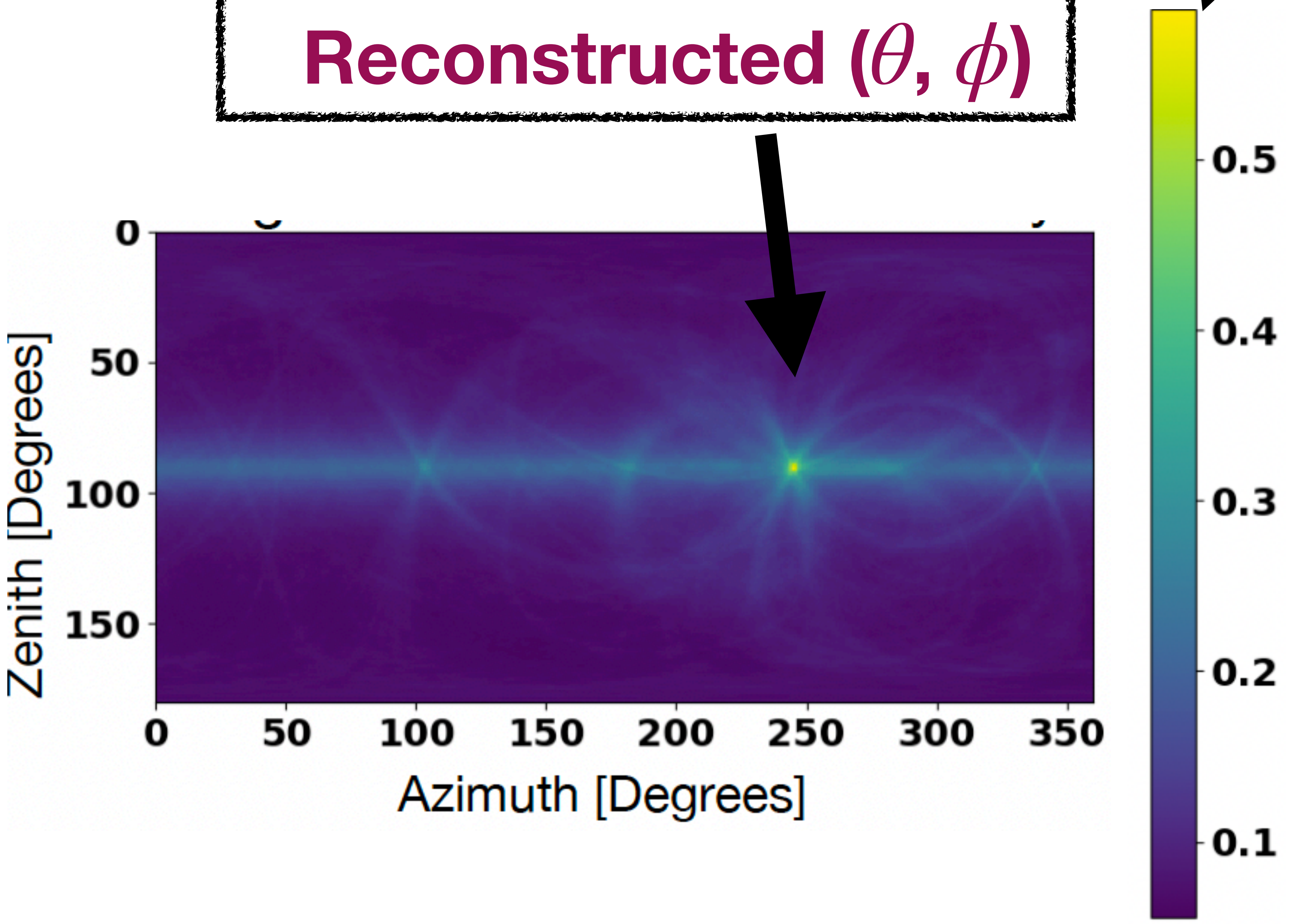
Hilbert Envelope peak power

De-dispersed
Av. wf peak power



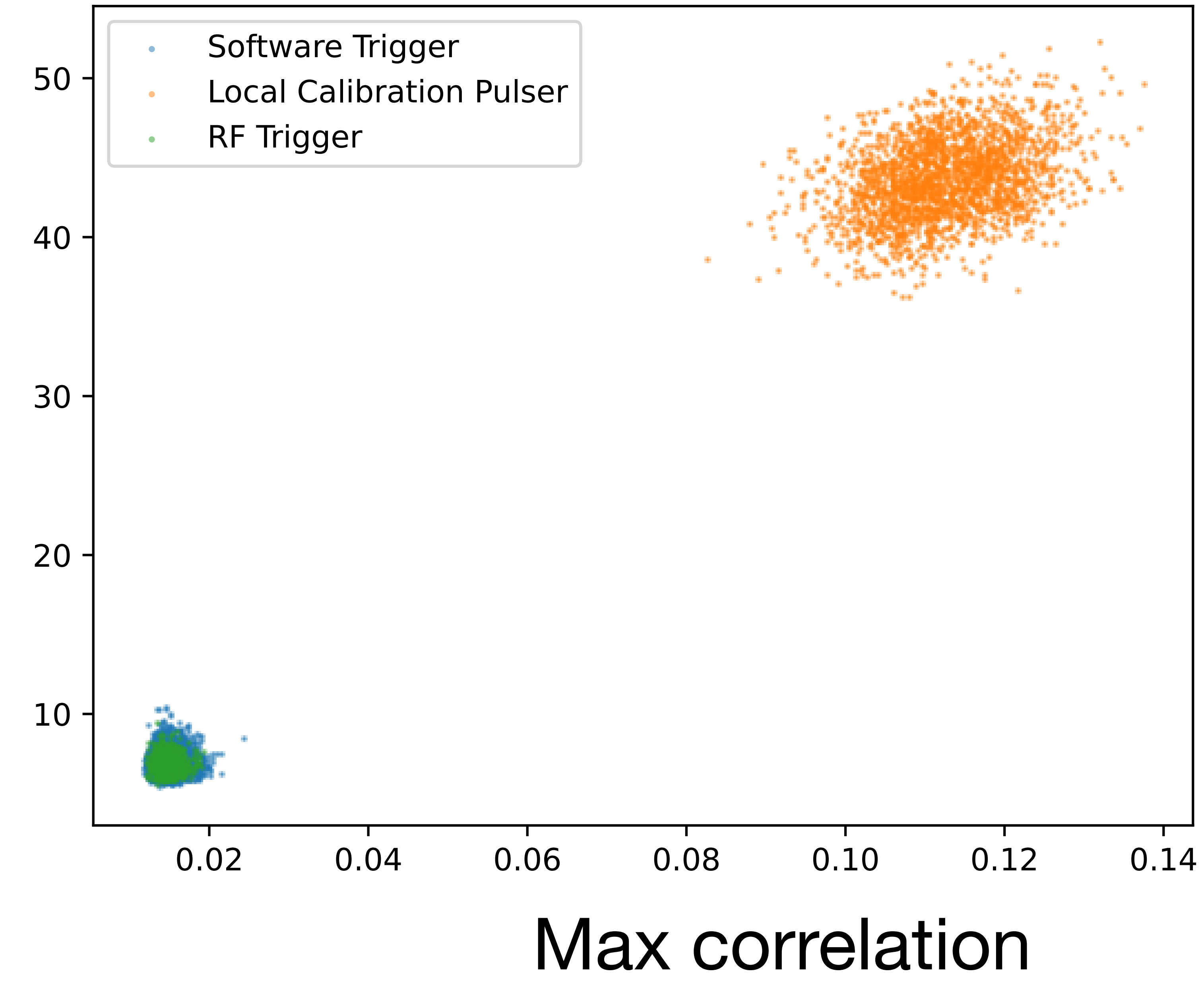
Maximum Corr.
Value

Location of peak
Reconstructed (θ, ϕ)



CSW SNR = SNR of
Coherently-Summed
Waveform

CSW SNR



Separating Thermal Noise from Signal: Fisher Discriminant

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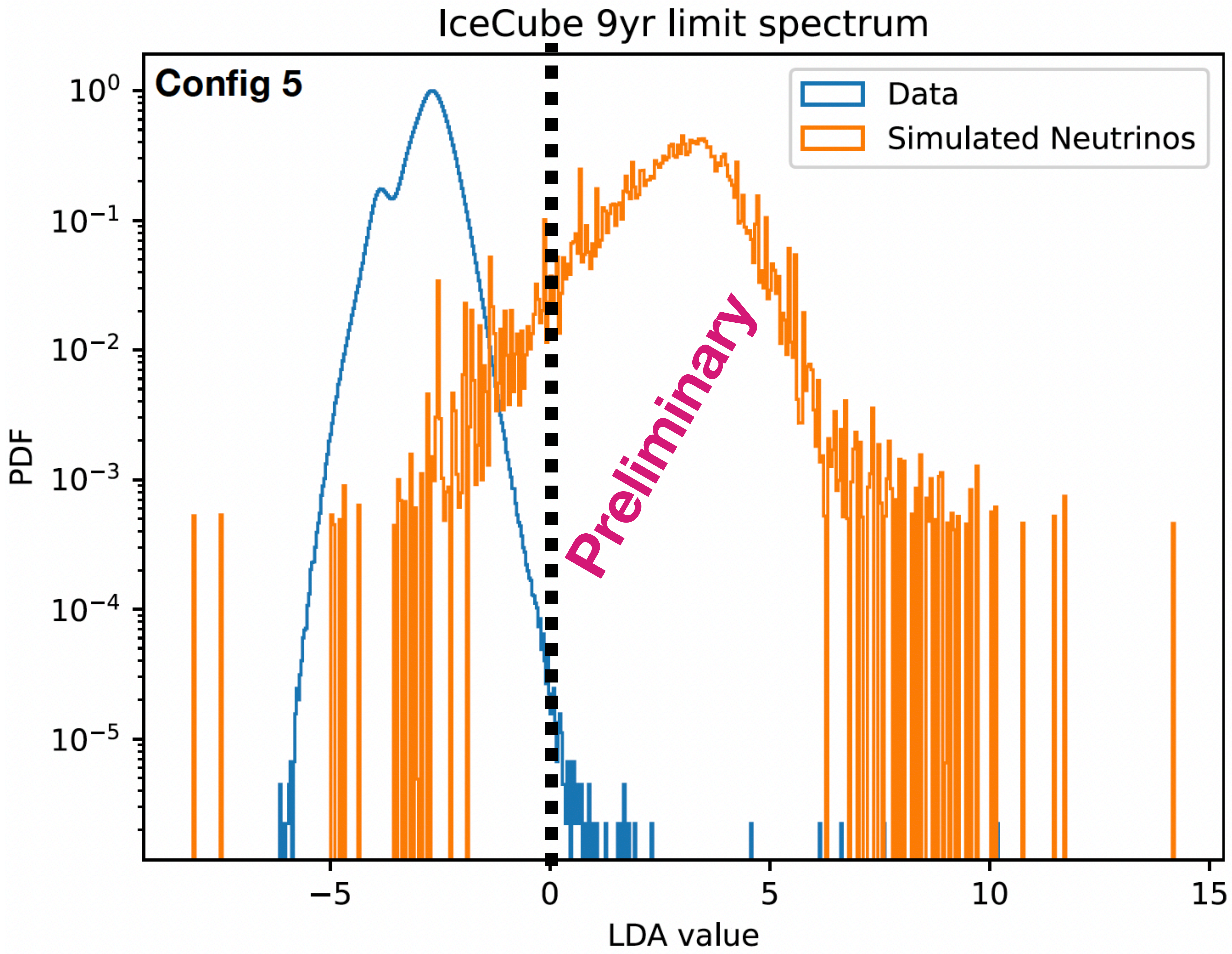
- We train linear discriminant to maximize separation in our selection variable space.
- **We will set a cut for the best expected sensitivity.**
- Final cut will be on LDA value & optimized for 5σ discovery assuming **IceCube 2018 limit as flux model** (https://arxiv.org/abs/1807.01820)



* Large fluctuations in simulated neutrino distribution due to limited statistics at low energies
additional simulations underway

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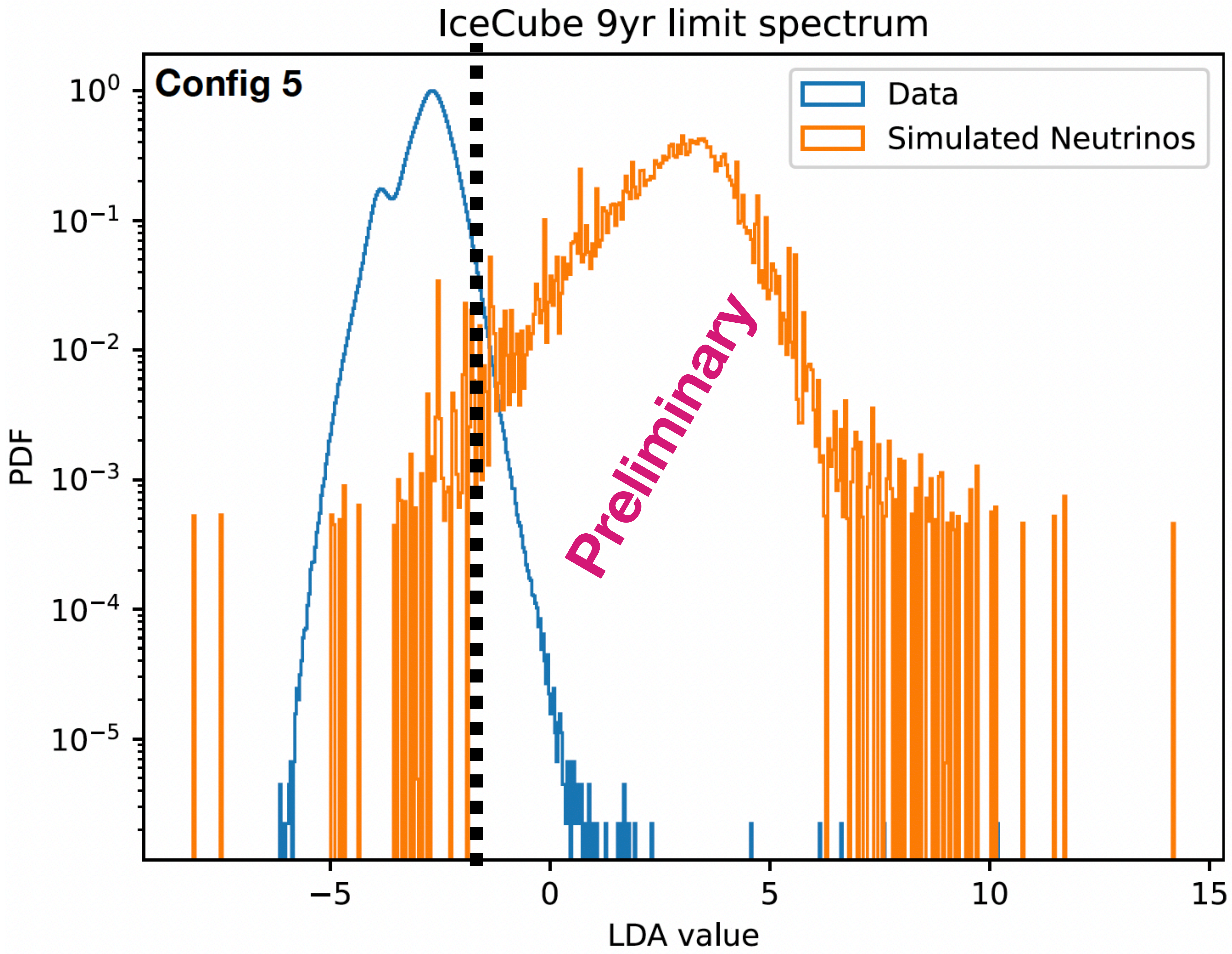

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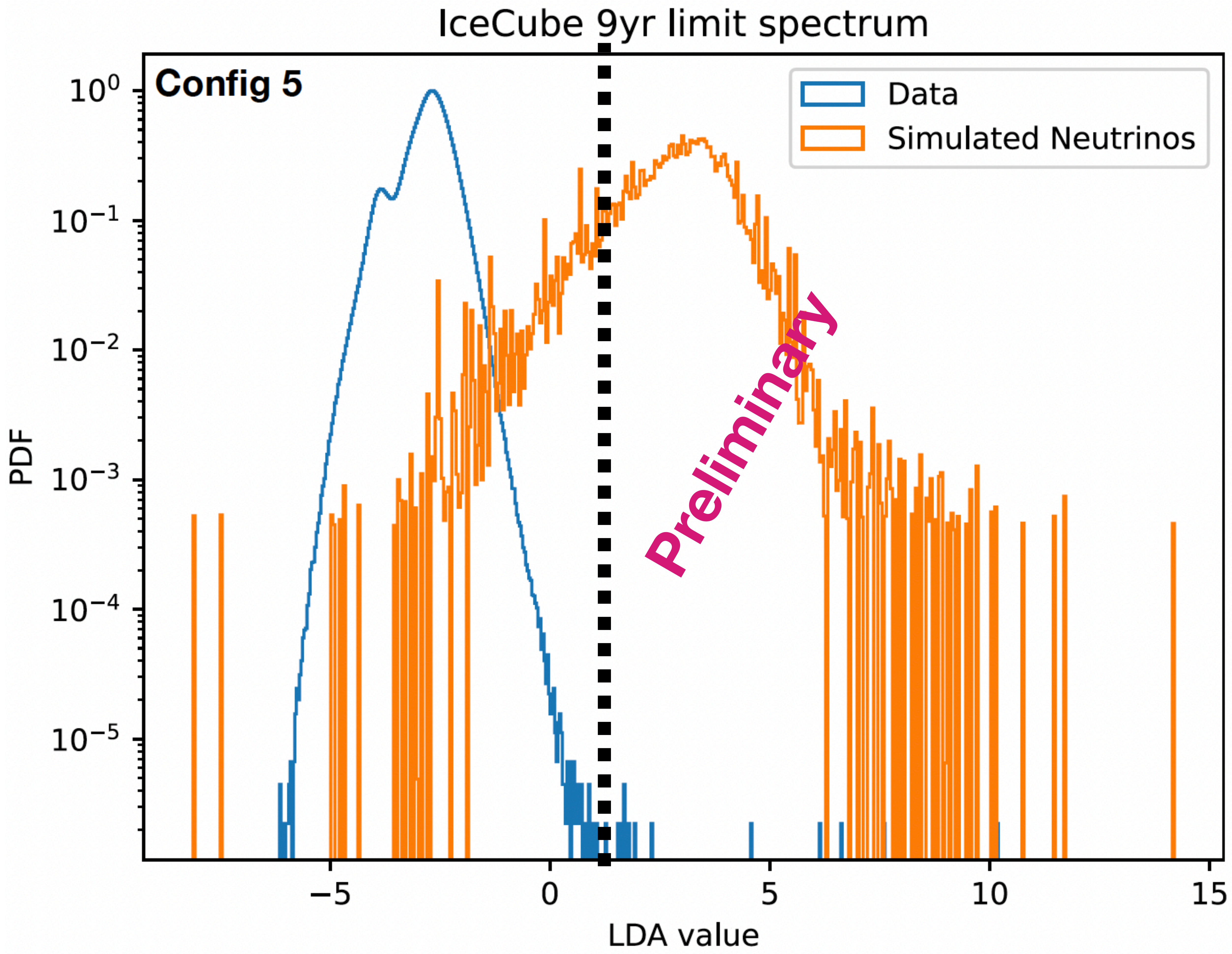

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Projected Sensitivity

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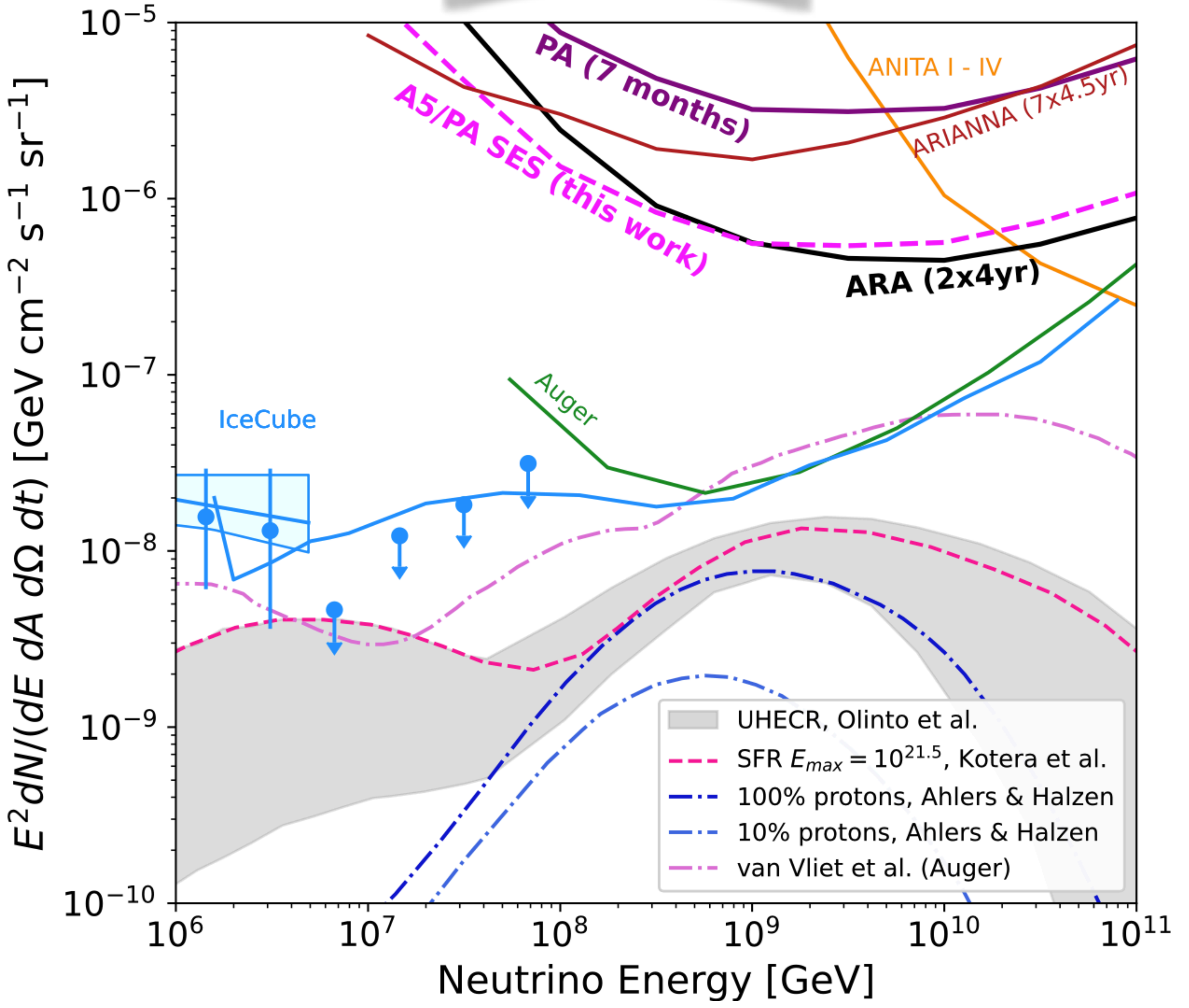
- **Expected number of events with analyzed livetime of only 1.38 years**
  - Kotera et al. flux: ~0.12 events
  - van Vliet et al. (Auger) flux: ~0.61 events
  - IceCube 2018 limit flux: ~0.79 events

Sensitivity



***Projected assuming same analysis efficiency as 2019 PA analysis**

Summary

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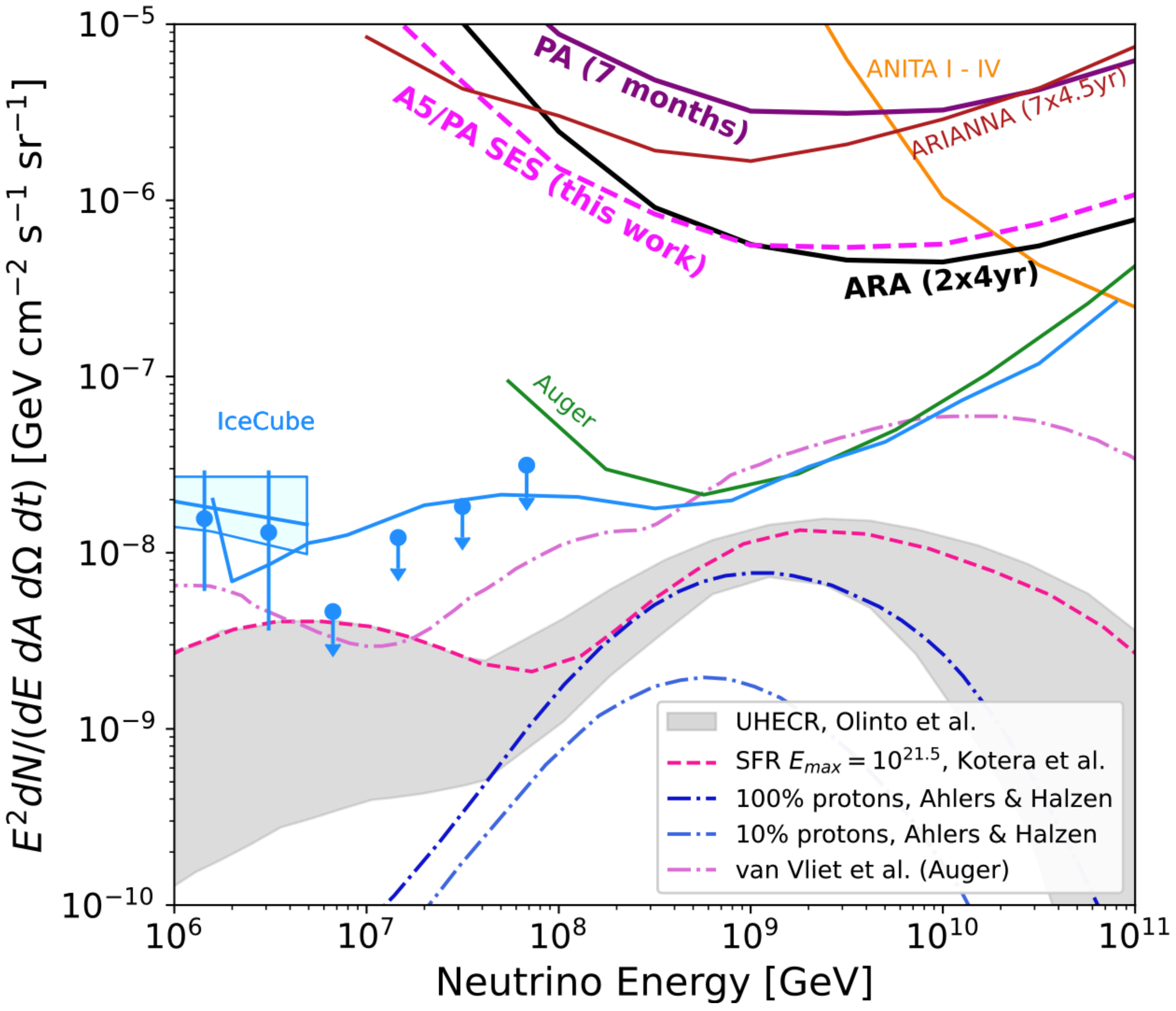
- **Pioneering diffuse neutrino search combining phased array trigger with traditional deep antennas**

- **Representative of next generation of in-ice radio neutrino experiments like RNO-G, IceCube-Gen2 Radio (same hybrid design as A5-PA)**

- **Effects of Biaxial Birefringence on Polarization Reconstruction (talk from Alan Salcedo Gomez)**

- **New DAQ and trigger architecture (talk from Pawan Giri)**



Thank you