ASKARYAN RADIO ARRAY

TeVPA Chicago 2024

A high-efficiency UHE neutrino search with hybrid detector system of the Askaryan Radio Array

Paramita Dasgupta for the ARA Collaboration

28th August, 2024

CCAPP

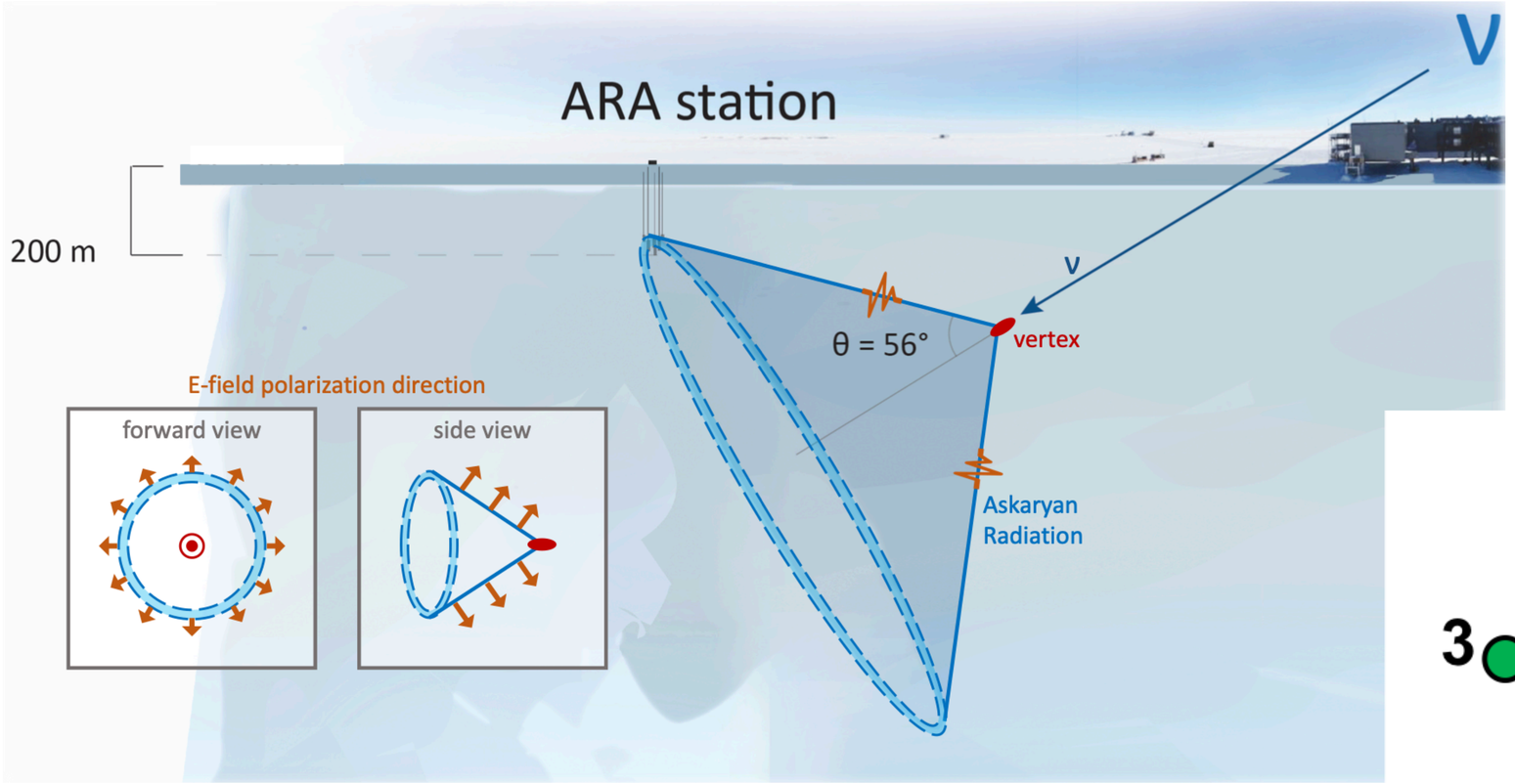
THE OHIO STATE UNIVERSITY

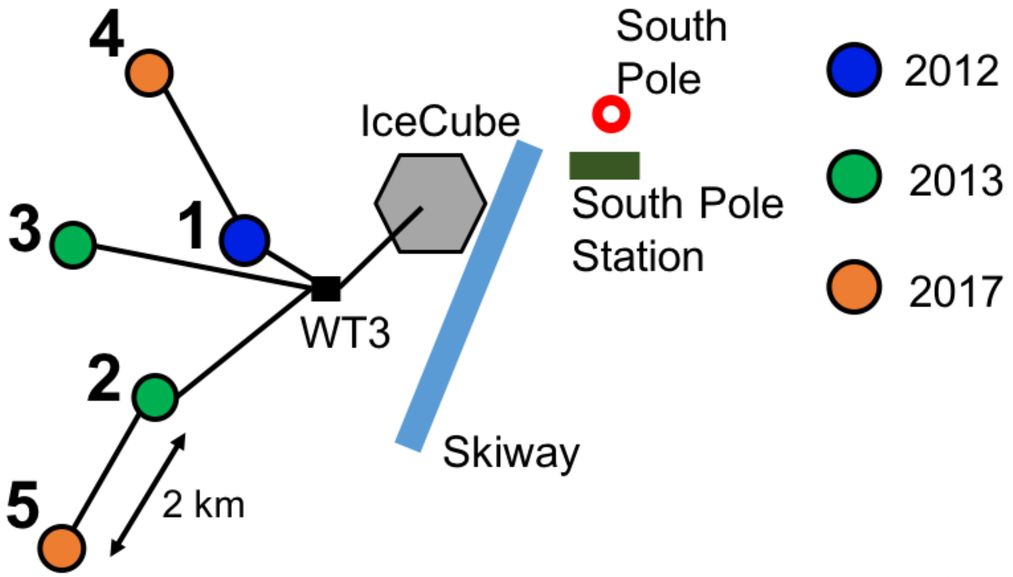
NSF

ARA

Askaryan Radio Array

TeVPA Chicago 2024





ARA's 5th station is special

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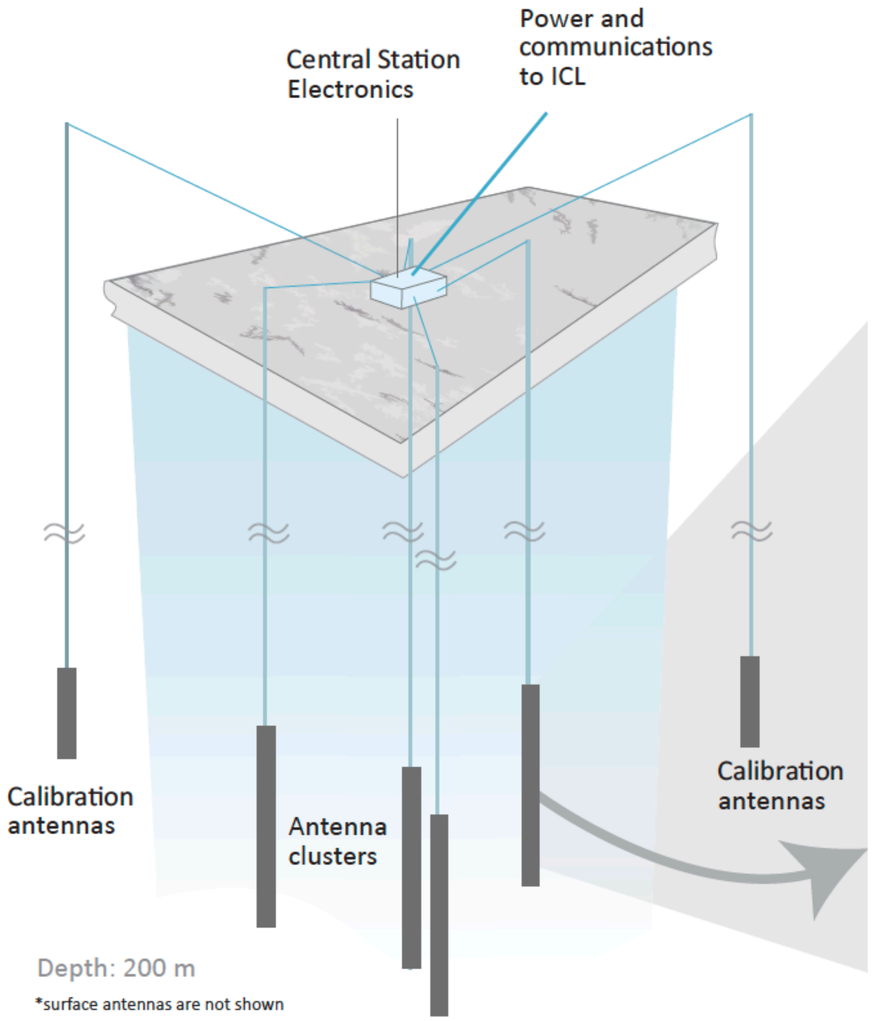
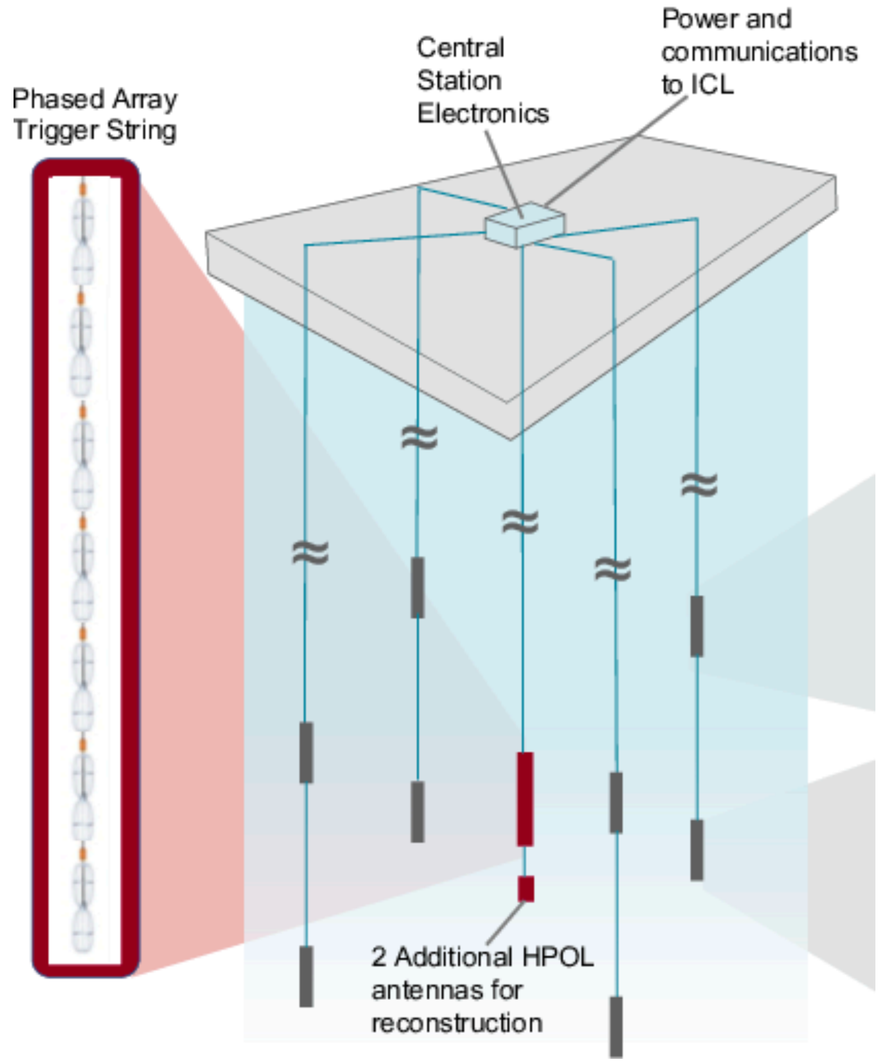
A1 - A4



HPol

VPol

A5 + PA system



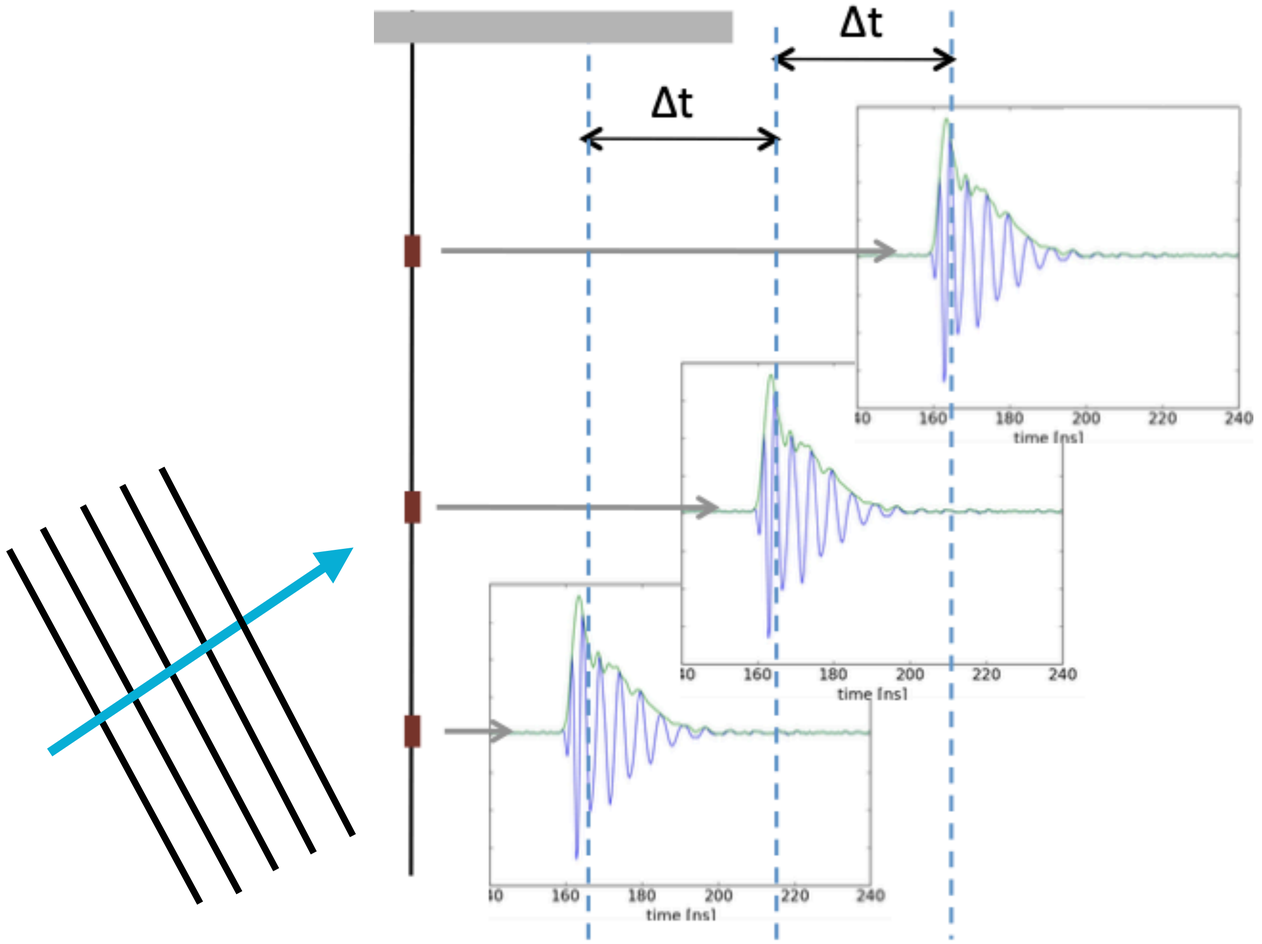
A Phased Array Trigger Design

- **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**

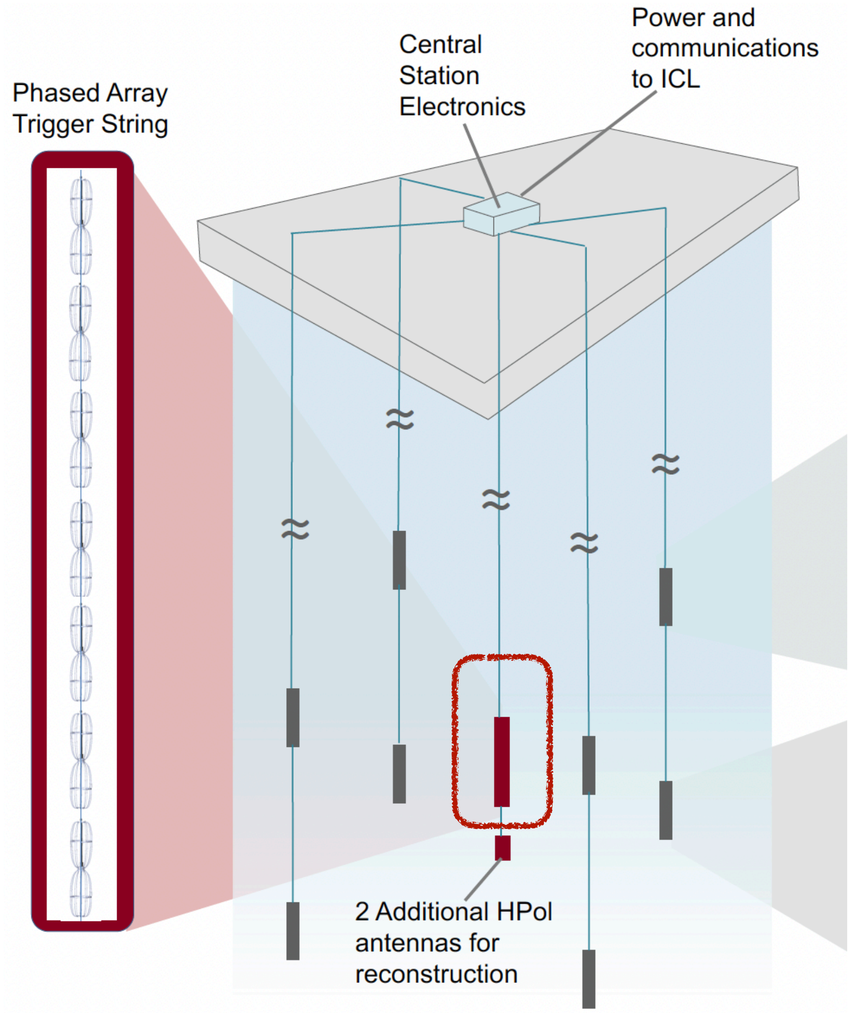


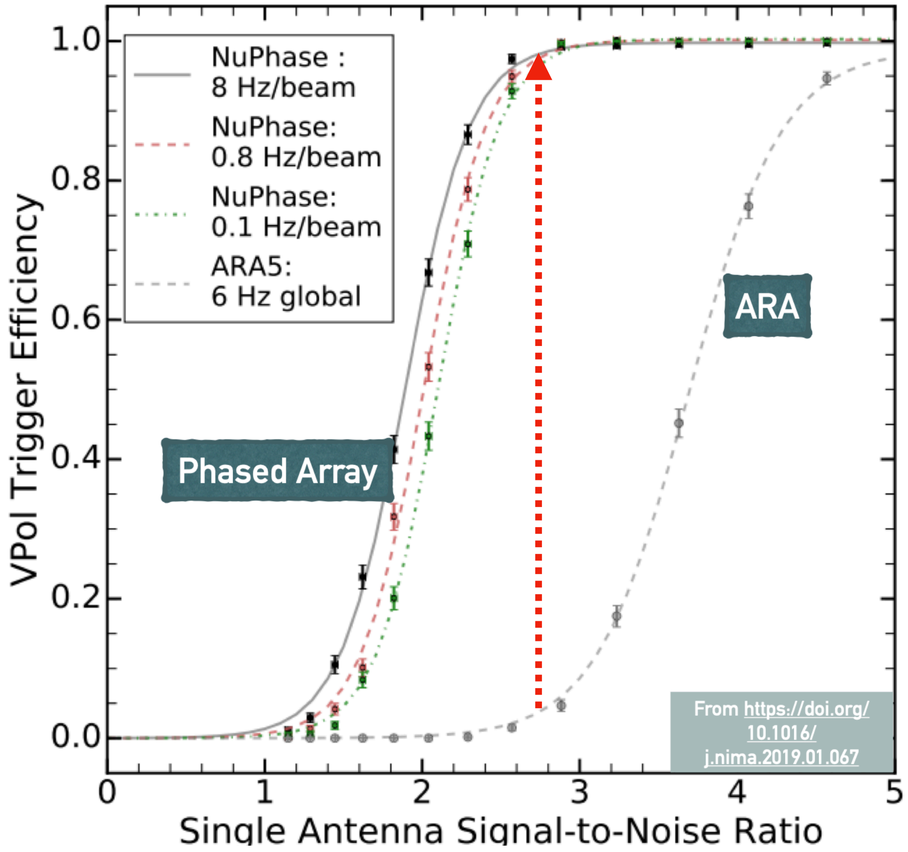
Impulsive plane wave (eg., neutrino signal)

Pic Courtesy: Kaeli Hughes

The phased array detector

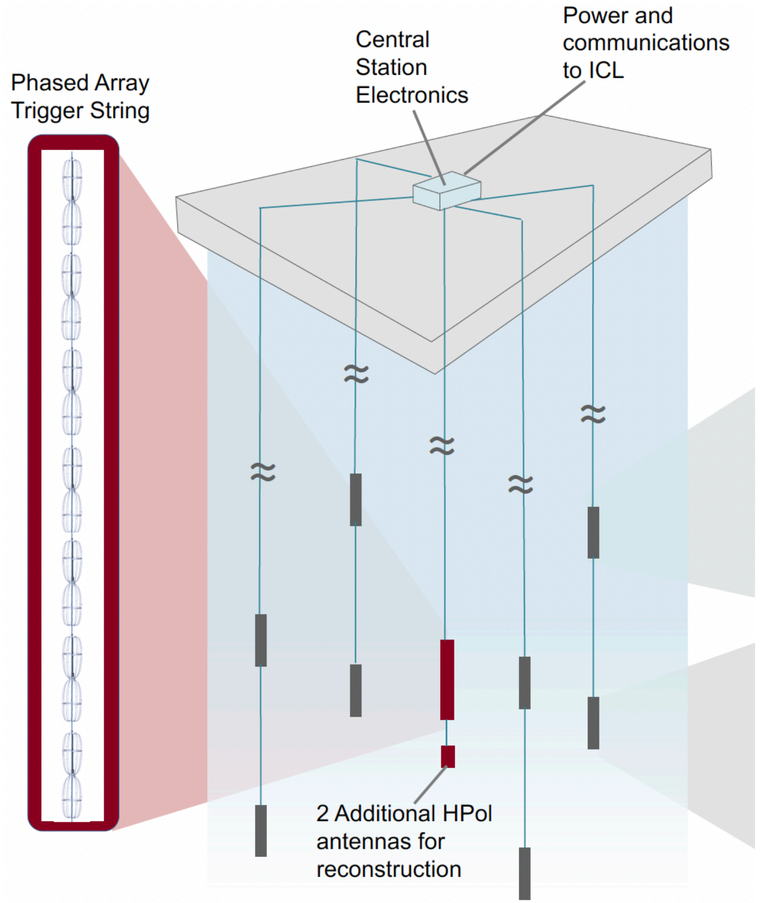
Analysis with *PA antennas alone* significantly improves trigger efficiency



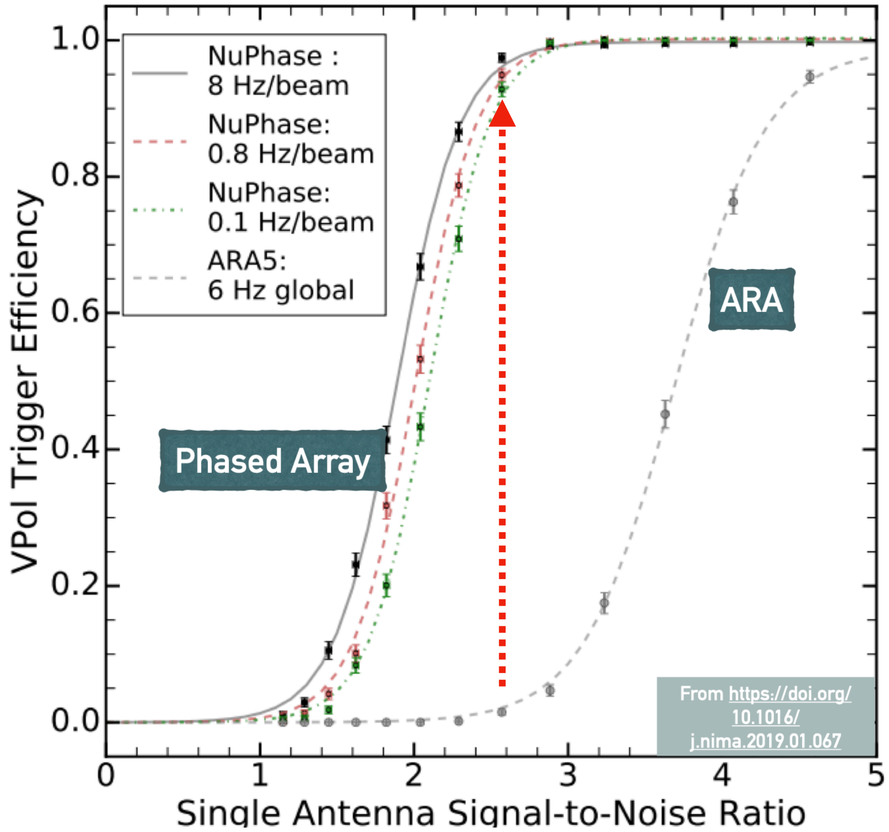


Improved Trigger efficiency

The Phased Array



Improved Trigger efficiency



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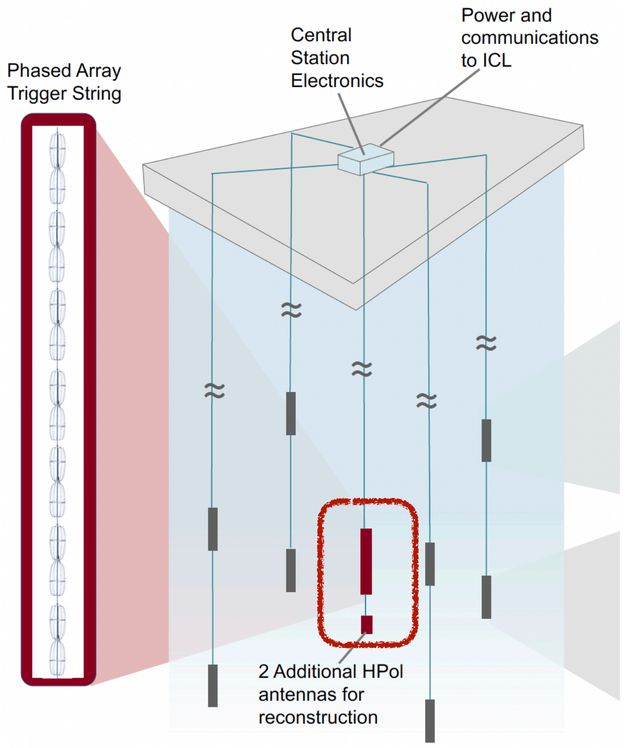
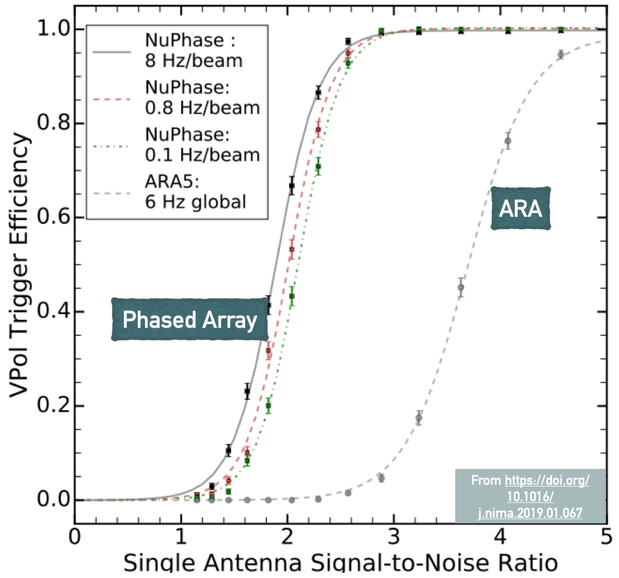
Analysis Efficiency

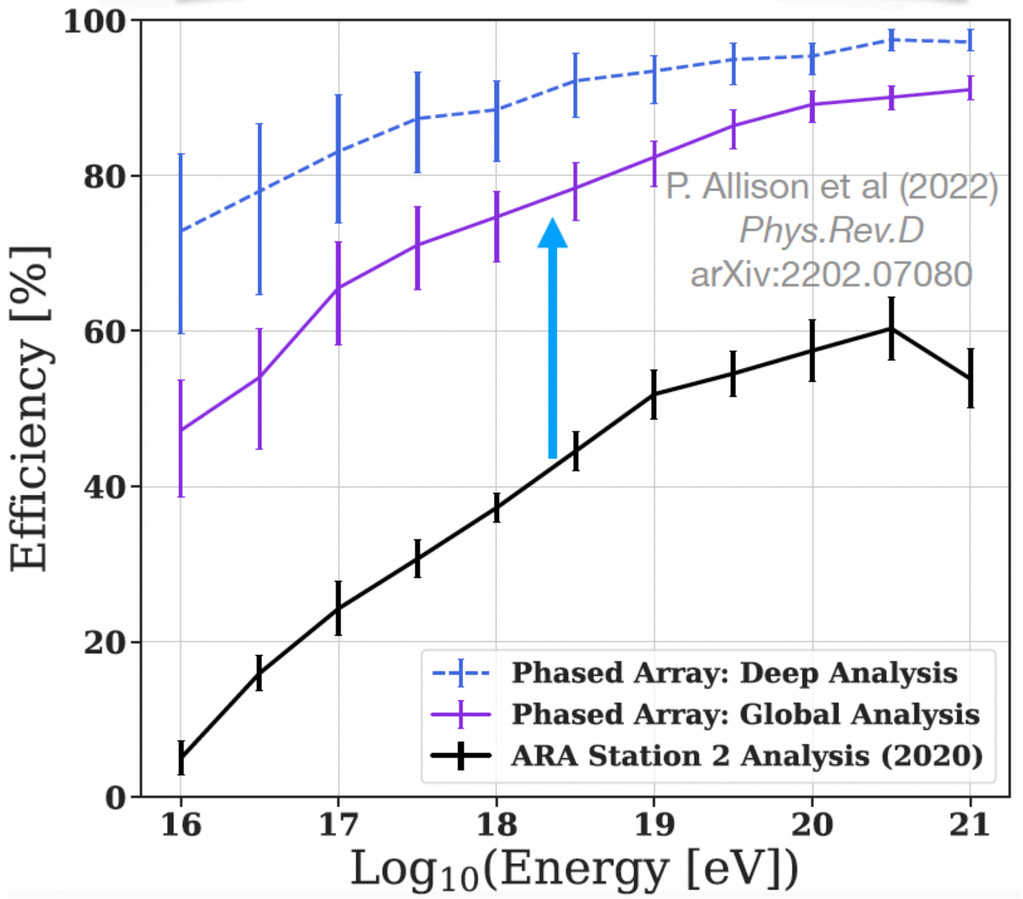
The phased array detector



Improved Trigger efficiency



Improved analysis efficiency



Fraction of triggered ν events in signal region

A Pioneering Hybrid Analysis

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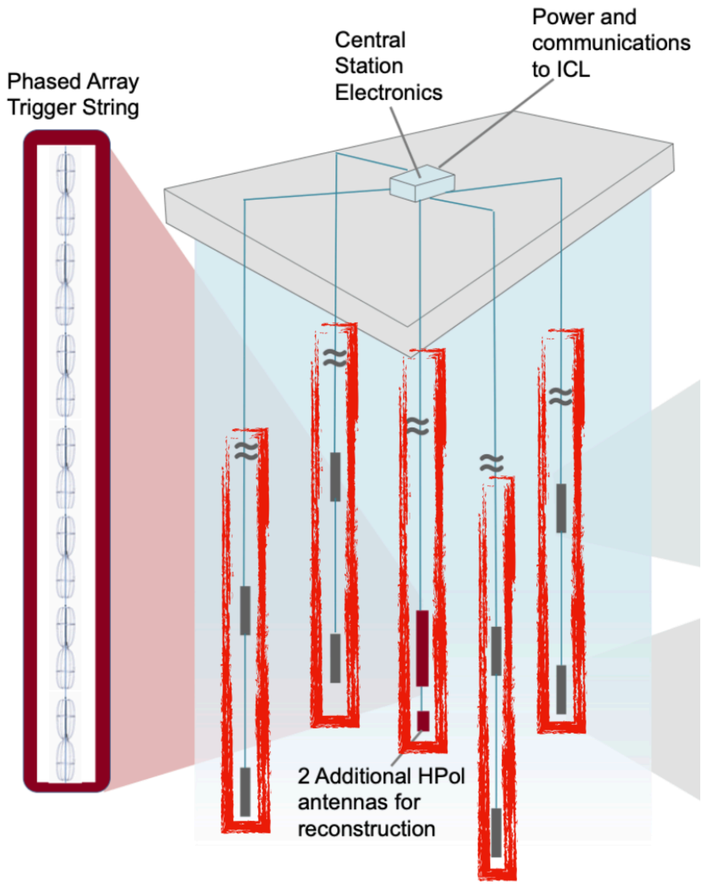
Combine PA & ARA subdetectors to maximize background rejection & analysis efficiency

- **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**
- Optimize cuts for 5σ discovery potential

ARA station 5

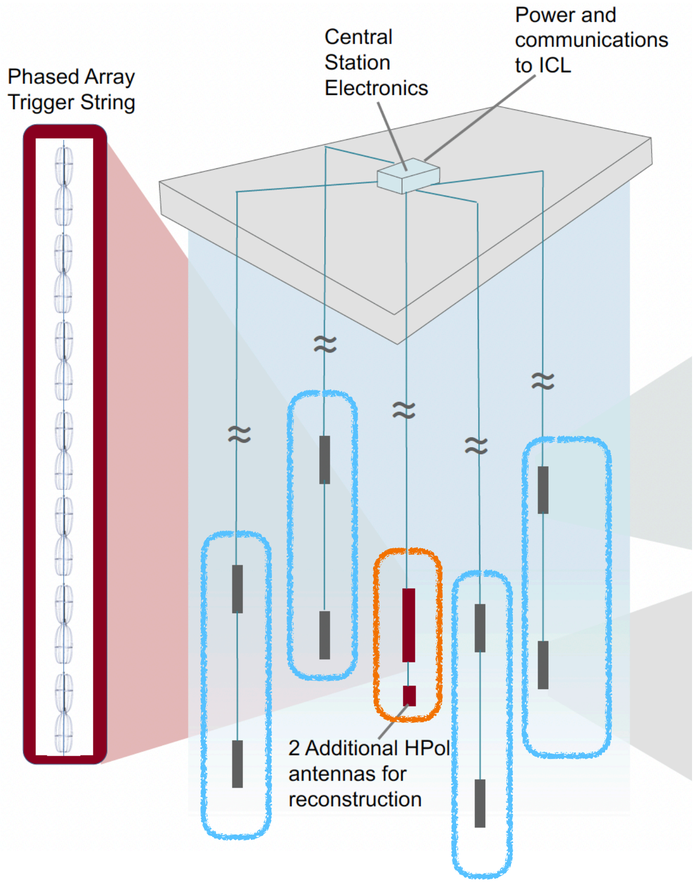


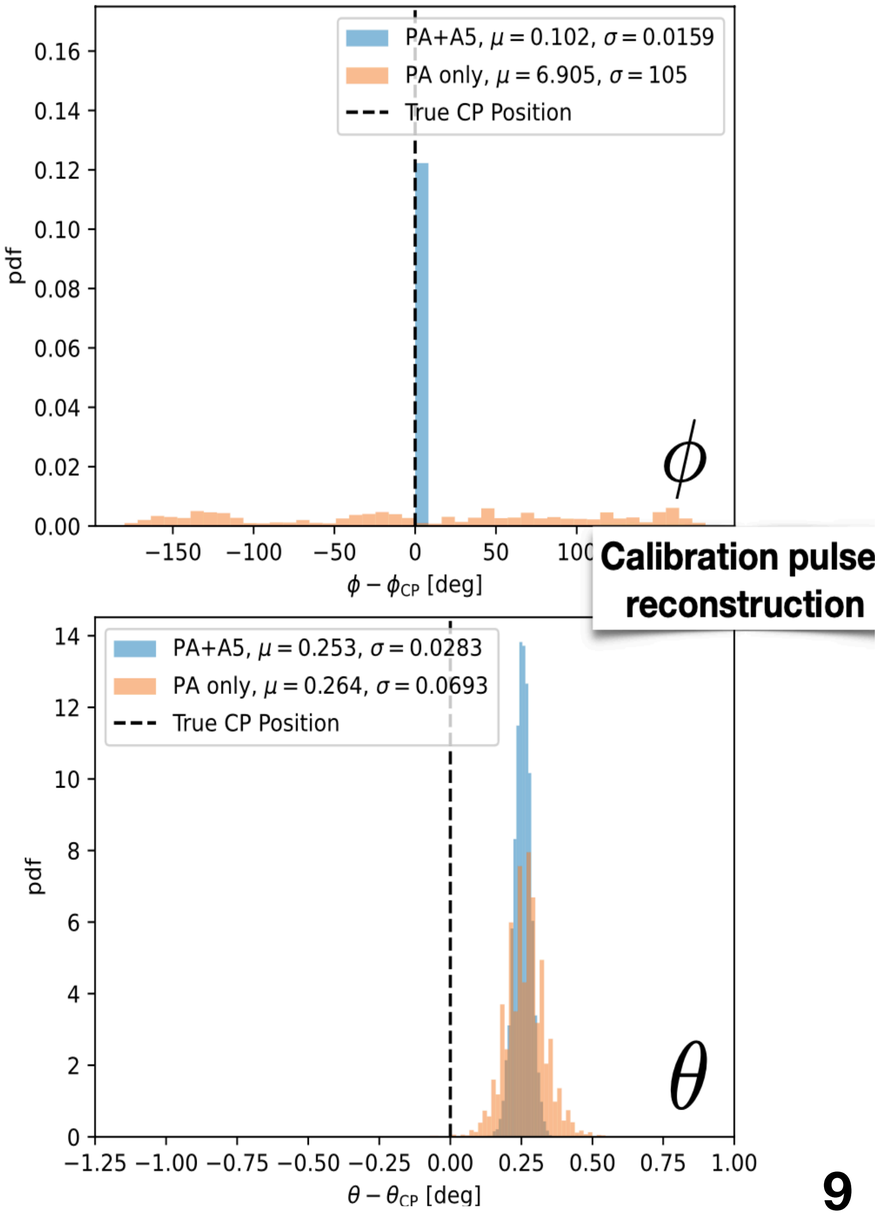
Marco Muzio, Penn State

Paramita Dasgupta, Ohio State

Advantages of a Hybrid detector

- **Excellent amizuth sensitivity with hybrid antennas**
- **~2x zenith sensitivity to vertex position**
- **Precise in-ice reconstruction of events**
- **High background rejection based on direction and timing information**





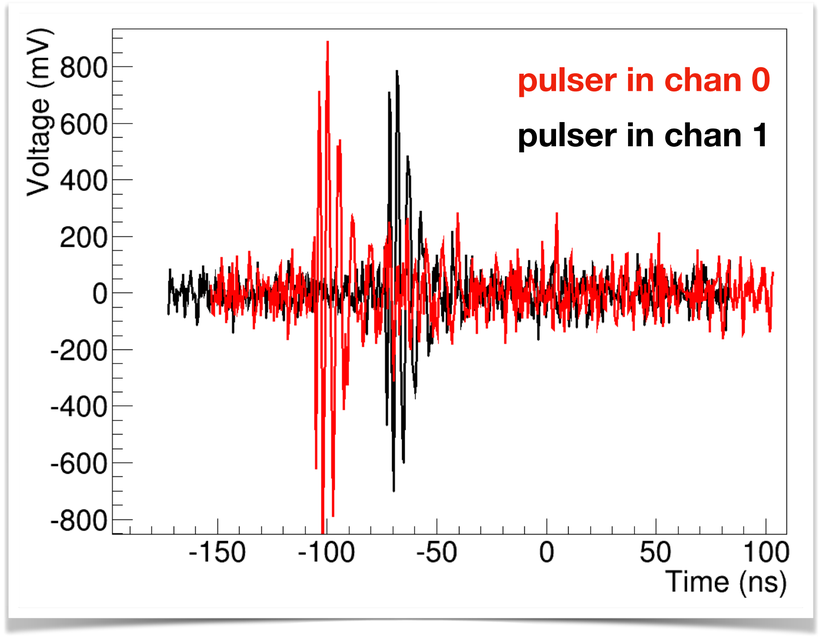
Calibration pulse reconstruction

Reconstruction of Source location with A5-PA hybrid system

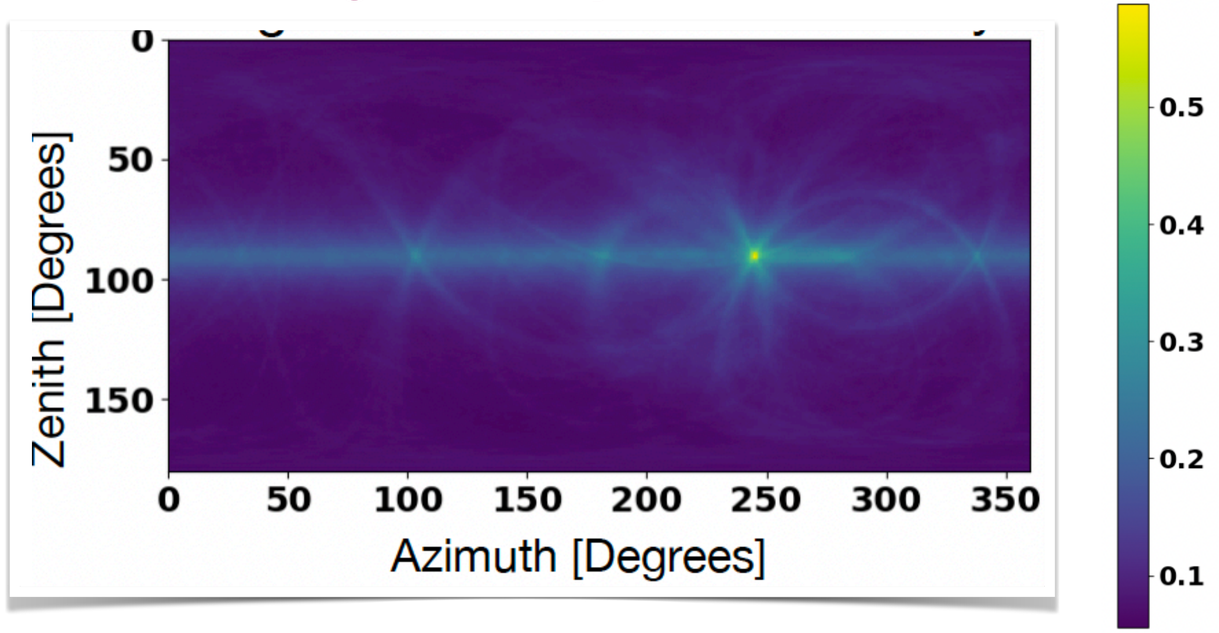
- **Excellent pointing accuracy with A5-PA antennas, improved vertex reconstruction would lead to improved analysis efficiency**

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

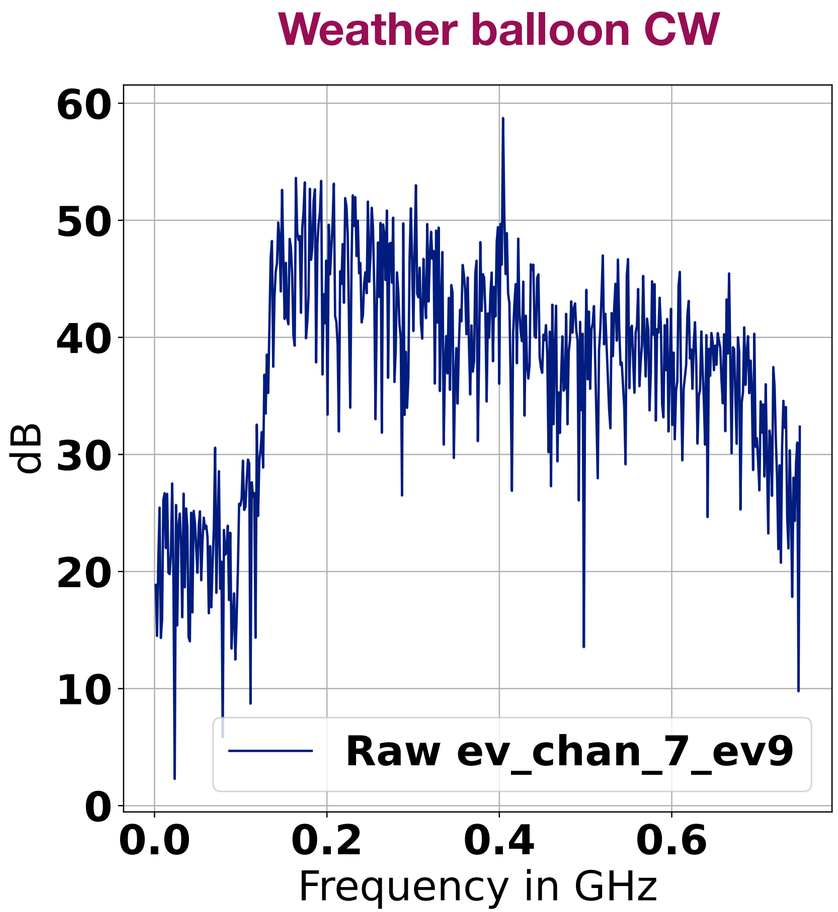
Pulser signal in a pair of channels

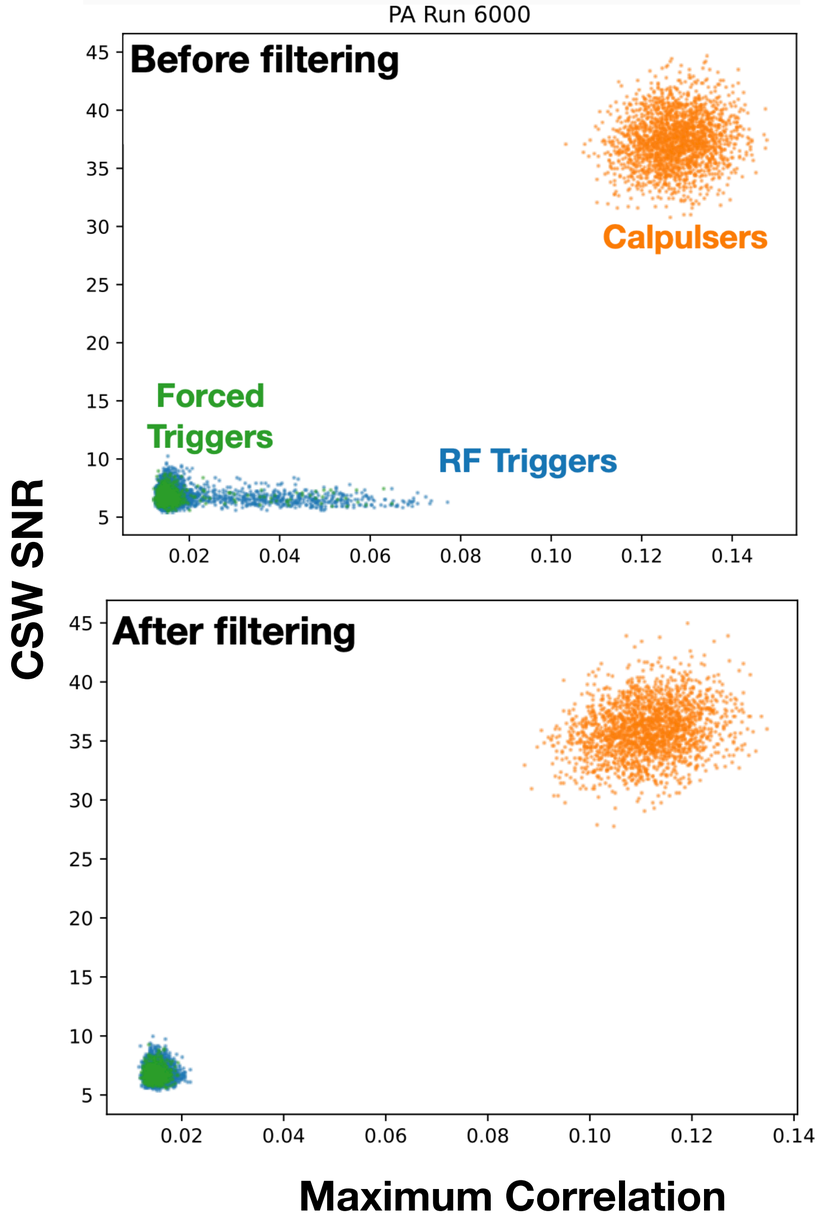


Reconstructed pulser source location using A5-PA hybrid antennas

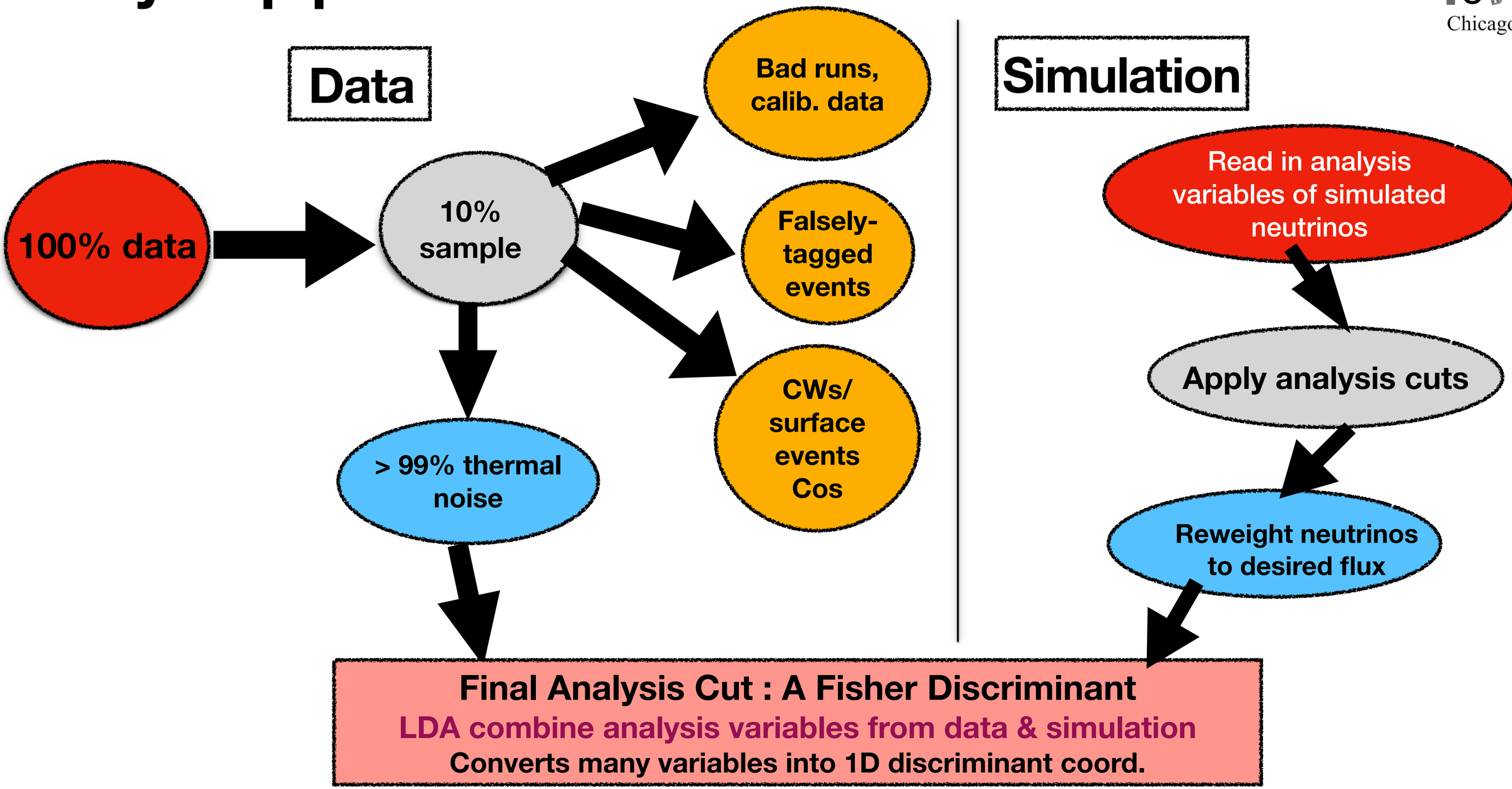


Background removal: Continuous Wave (CW) Signals





Analysis pipeline



Example analysis variables

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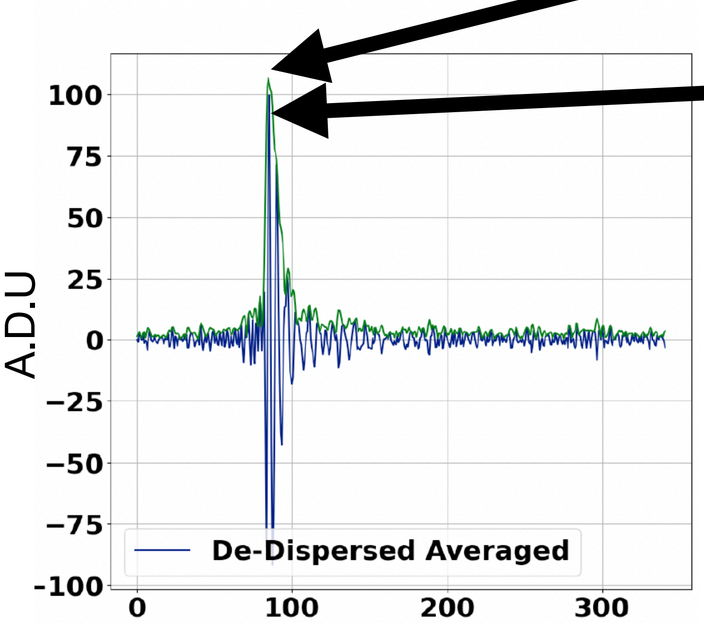
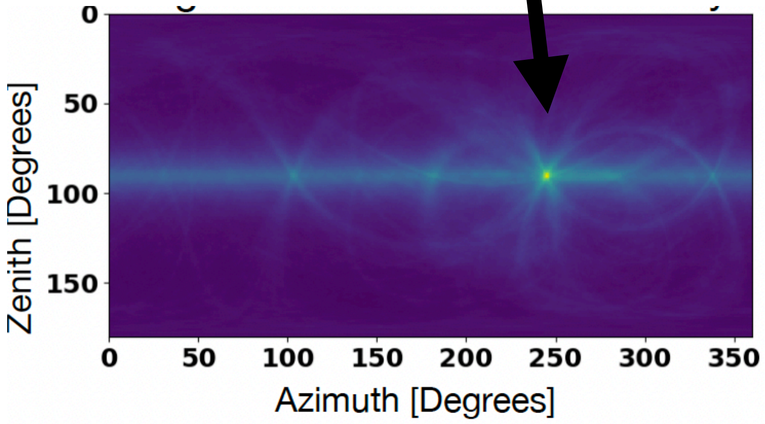
Hilbert Envelope peak power

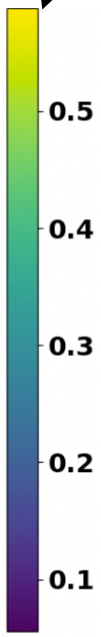
De-dispersed Av. wf peak power



Maximum Corr. Value

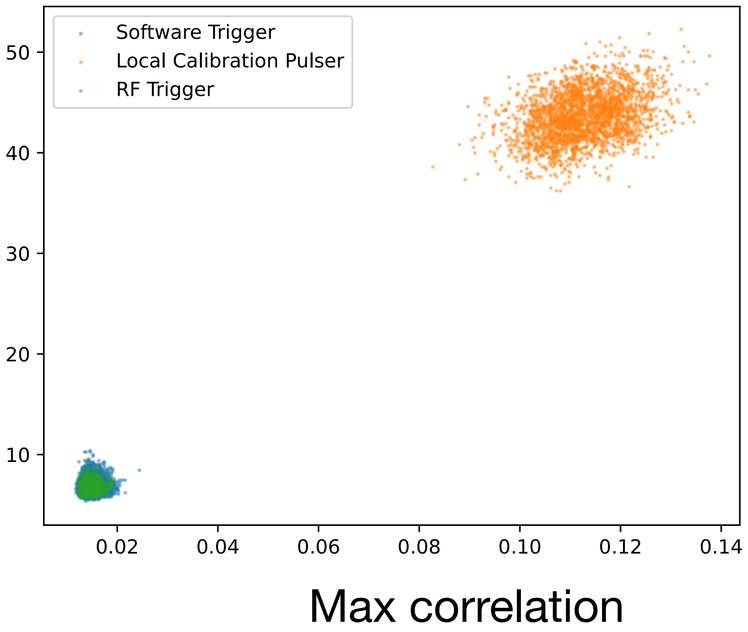
Location of peak Reconstructed (θ, ϕ)





CSW SNR

CSW SNR = SNR of Coherently-Summed Waveform



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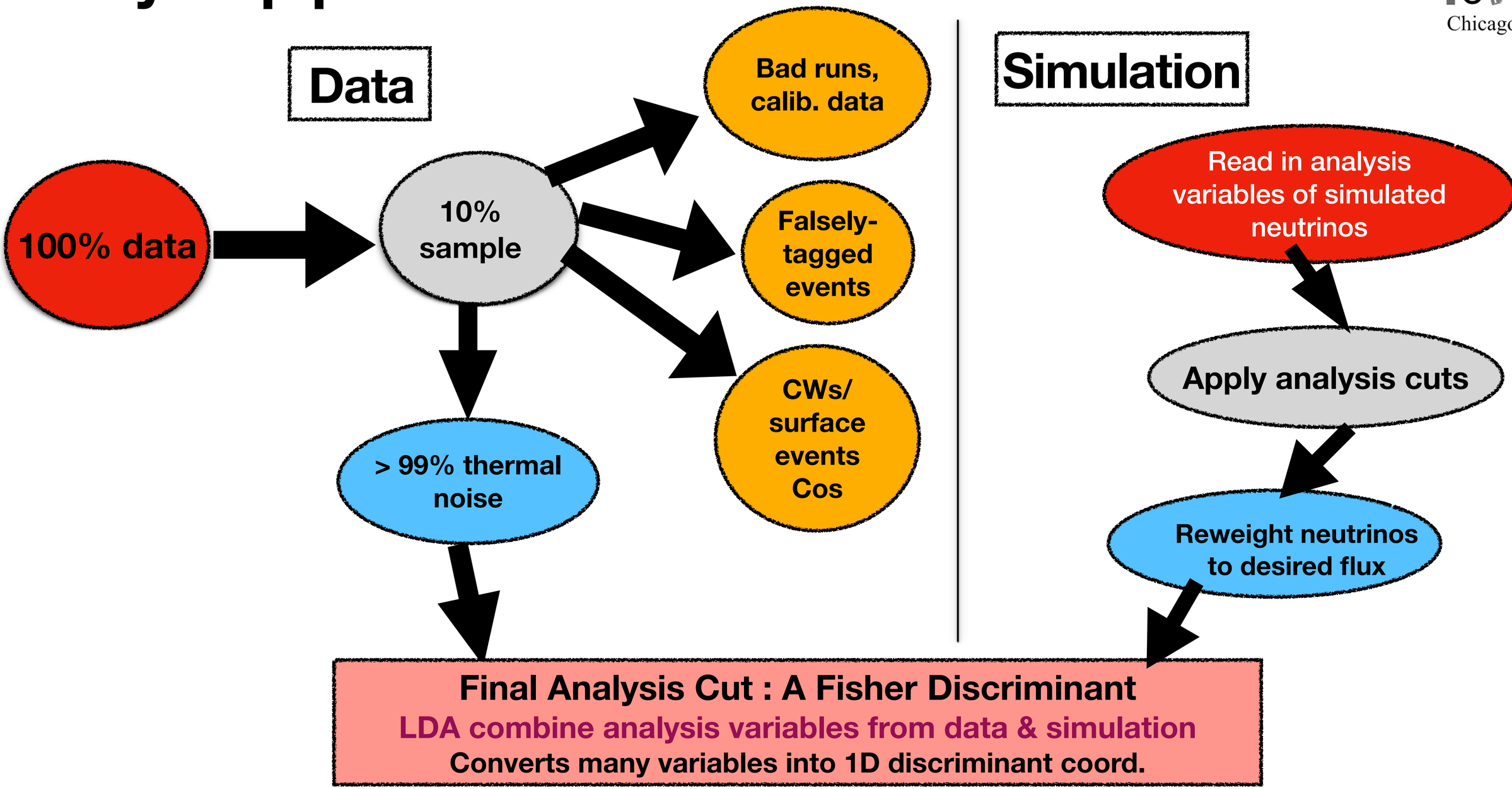
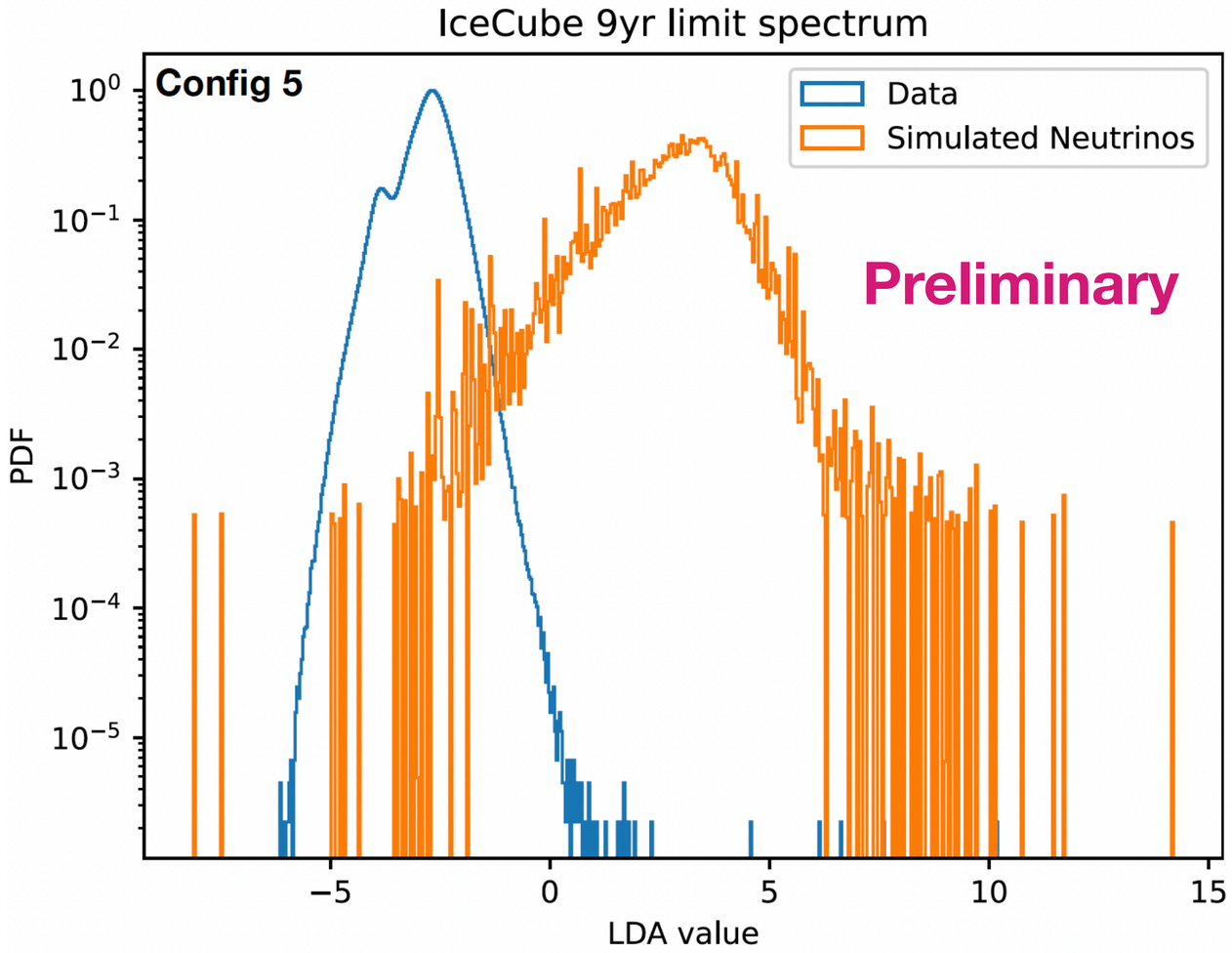


Separating Thermal Noise from Signal: Fisher Discriminant

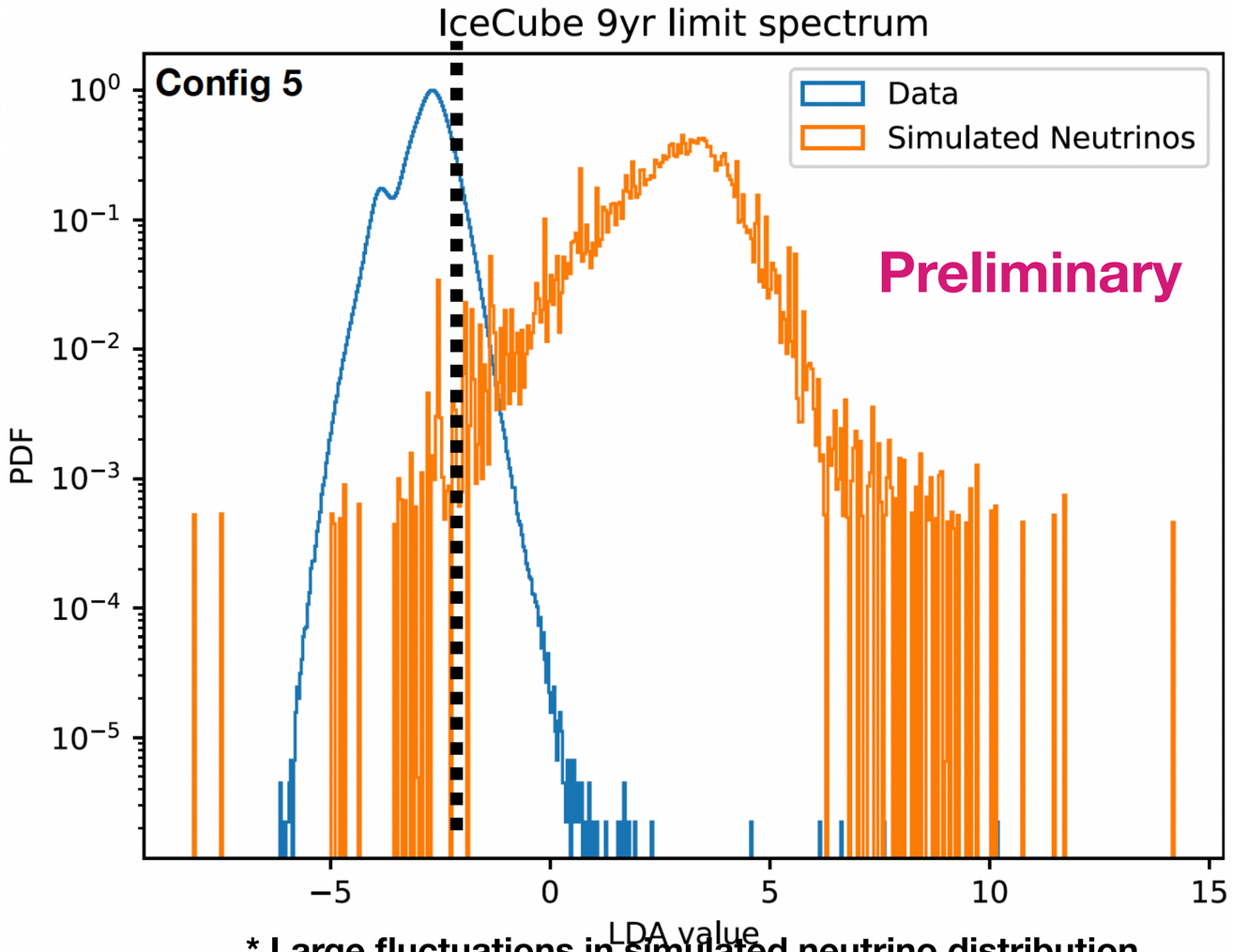
- **We train linear discriminant to maximize separation in our selection variable space.**
- **Final variable = LDA value from data and simulation**
  - **LDA = combination of all analysis variables from data and simulated neutrinos**



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

Separating Thermal Noise from Signal: Fisher Discriminant

- **We train linear discriminant to maximize separation in our selection variable space.**
- **We will set a cut for the best expected sensitivity.**



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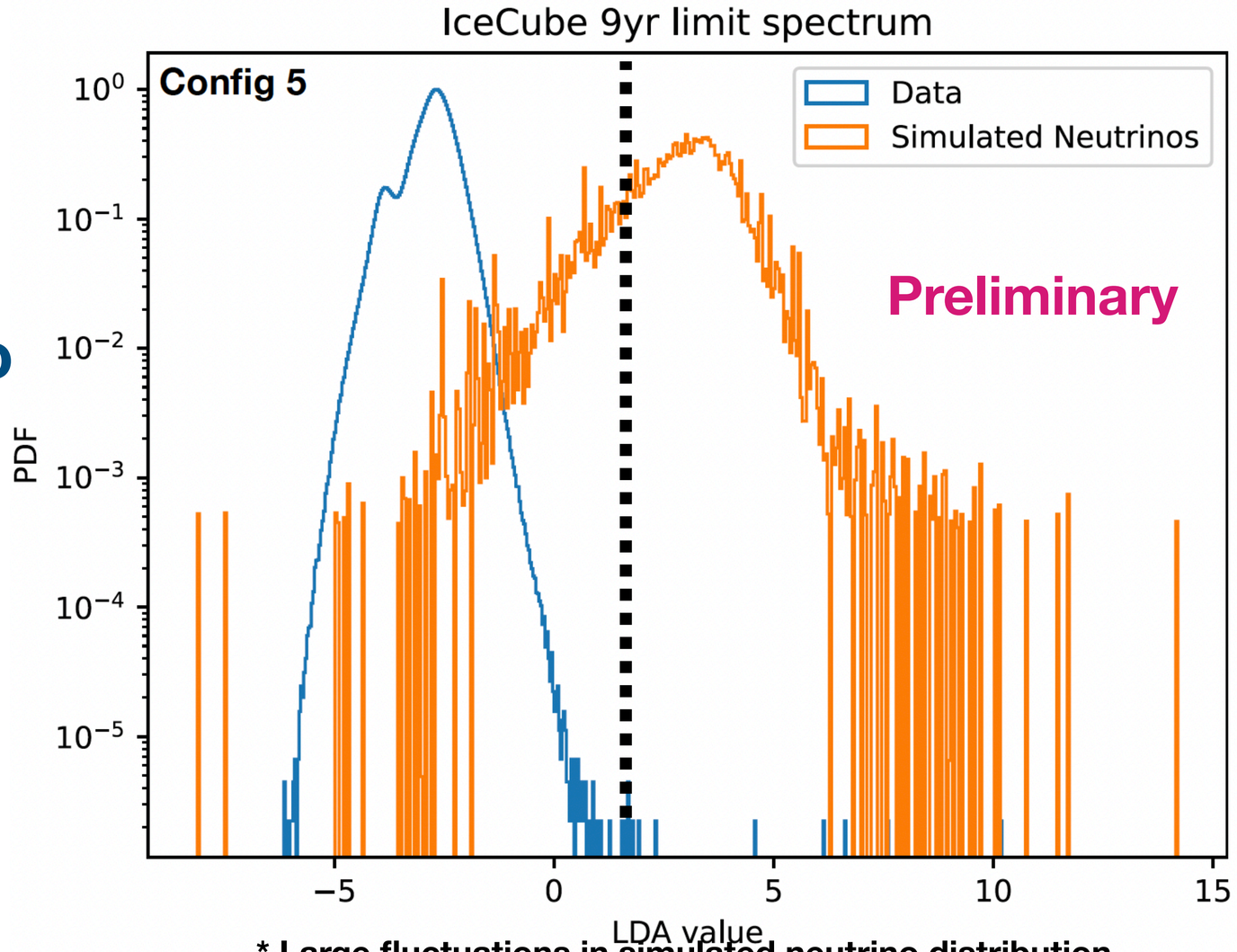

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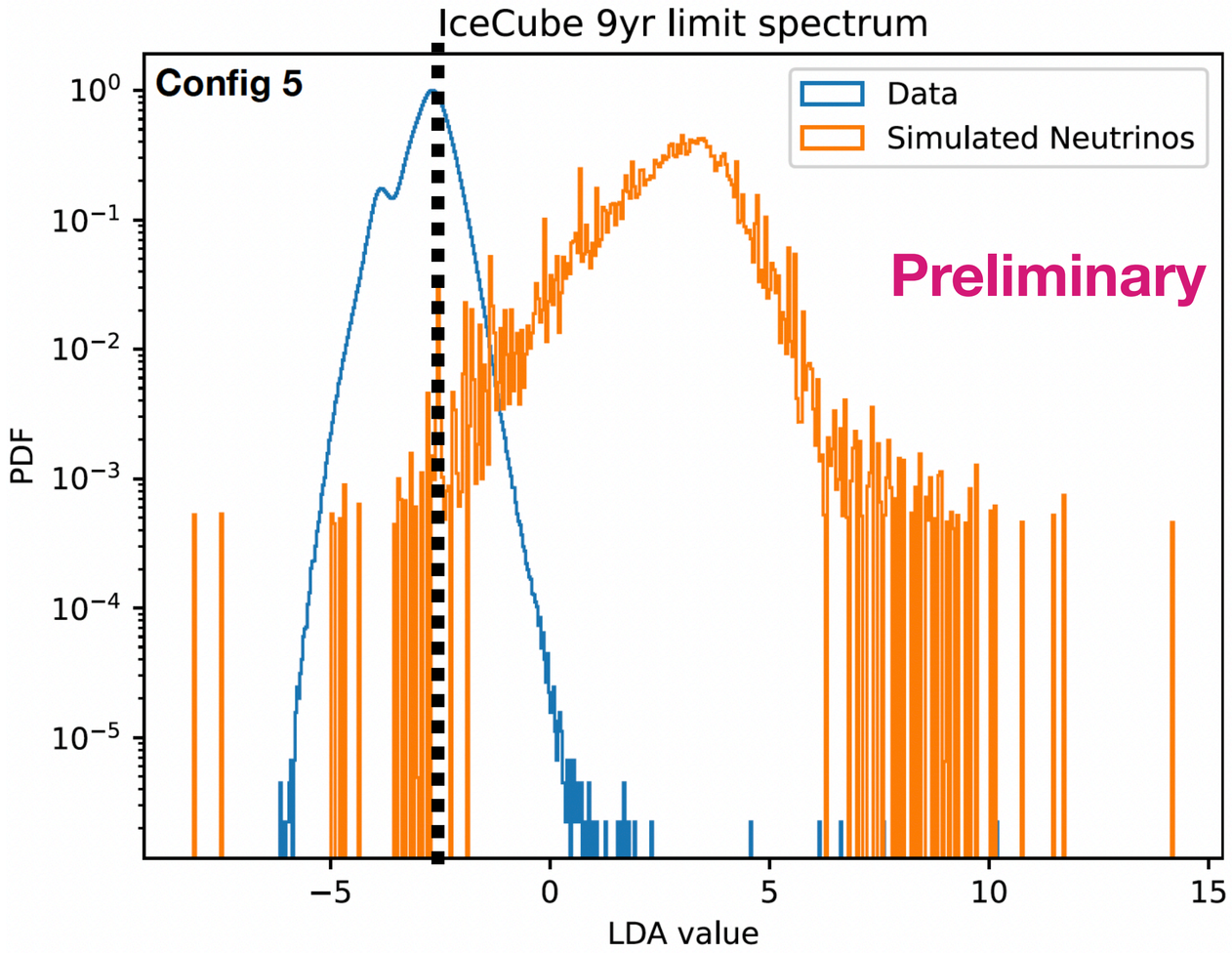
Separating Thermal Noise from Signal: Fisher Discriminant

- **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 & will be optimized for 5σ discovery using IceCube 2018 limit as flux model (https://arxiv.org/abs/1807.01820)**



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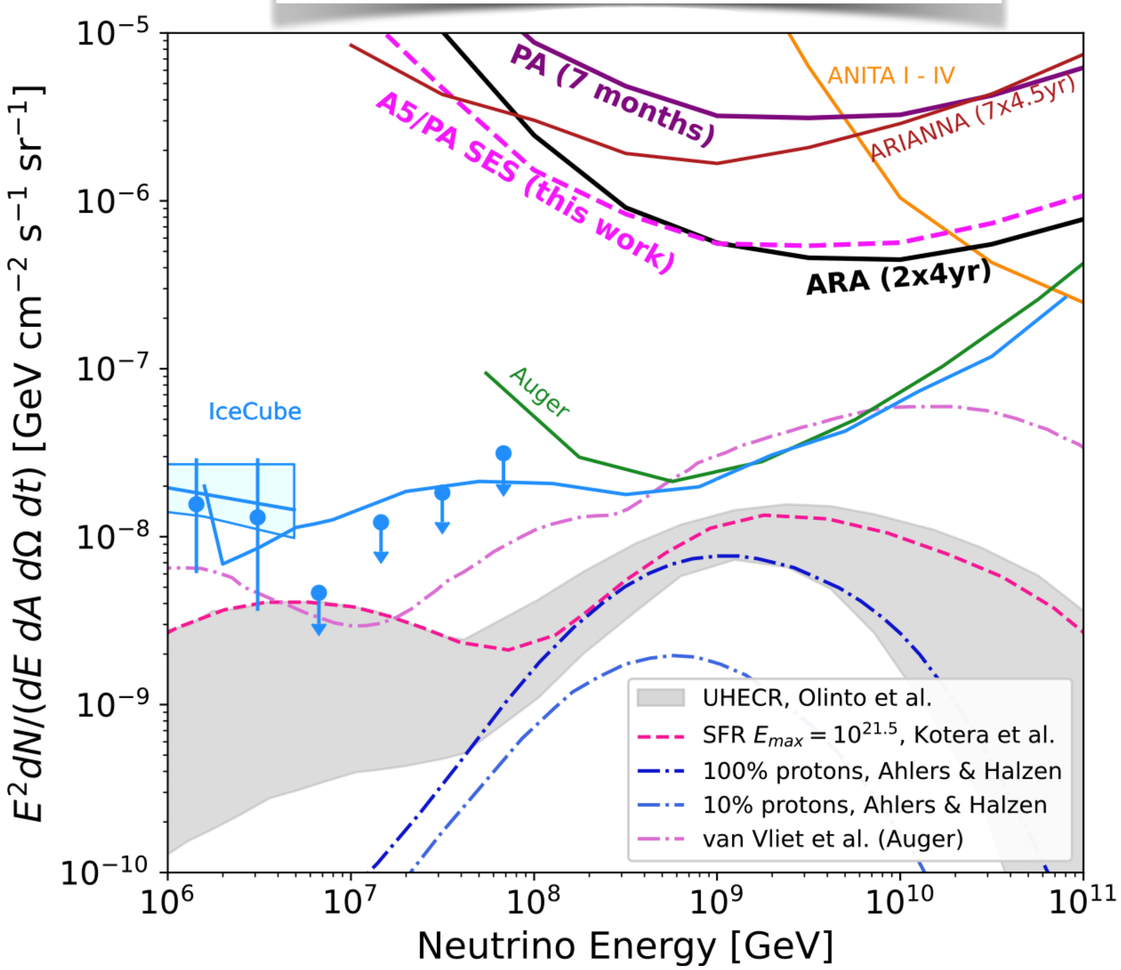
Projected Sensitivity

- **Expected number of events with analyzed livetime of only 1.38 years at trigger level**
  - Kotera et al. flux: ~0.12 events
  - van Vliet et al. (Auger) flux: ~0.61 events
  - IceCube 2018 limit flux: ~0.79 events
- **Demonstration of end-to-end analysis tools**
- **Pioneering analysis with a Phased array-traditional antenna combined system of detectors**
- **Proof of concept for next generation detectors**

  IceCube-Gen2 radio (361 stations) and RNO-G (35 stations)

Sensitivity at analysis level



*Projected assuming same analysis efficiency as 2019 PA analysis

Thank you