Recent progress towards a 5-station neutrino search with ARA

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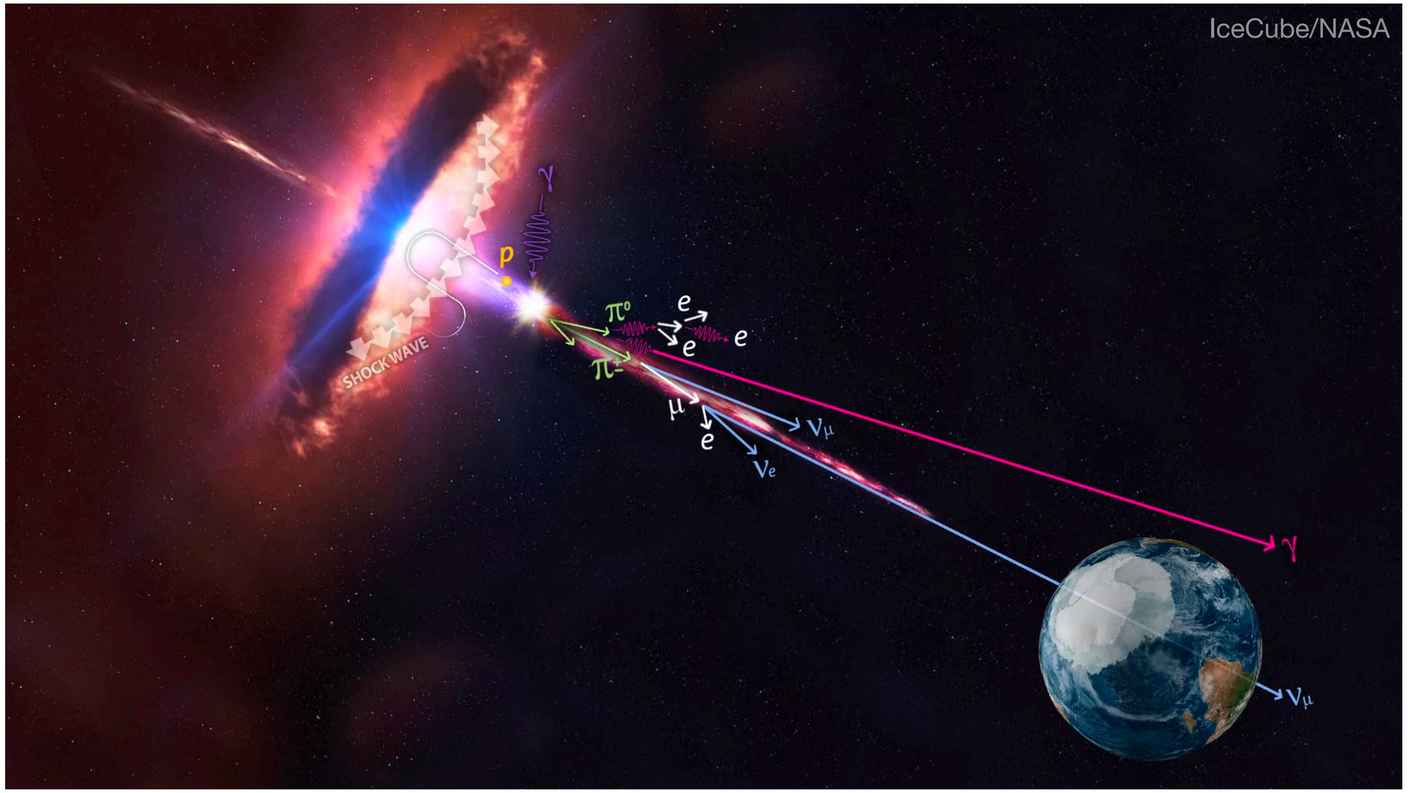
on behalf of the ARA Collaboration

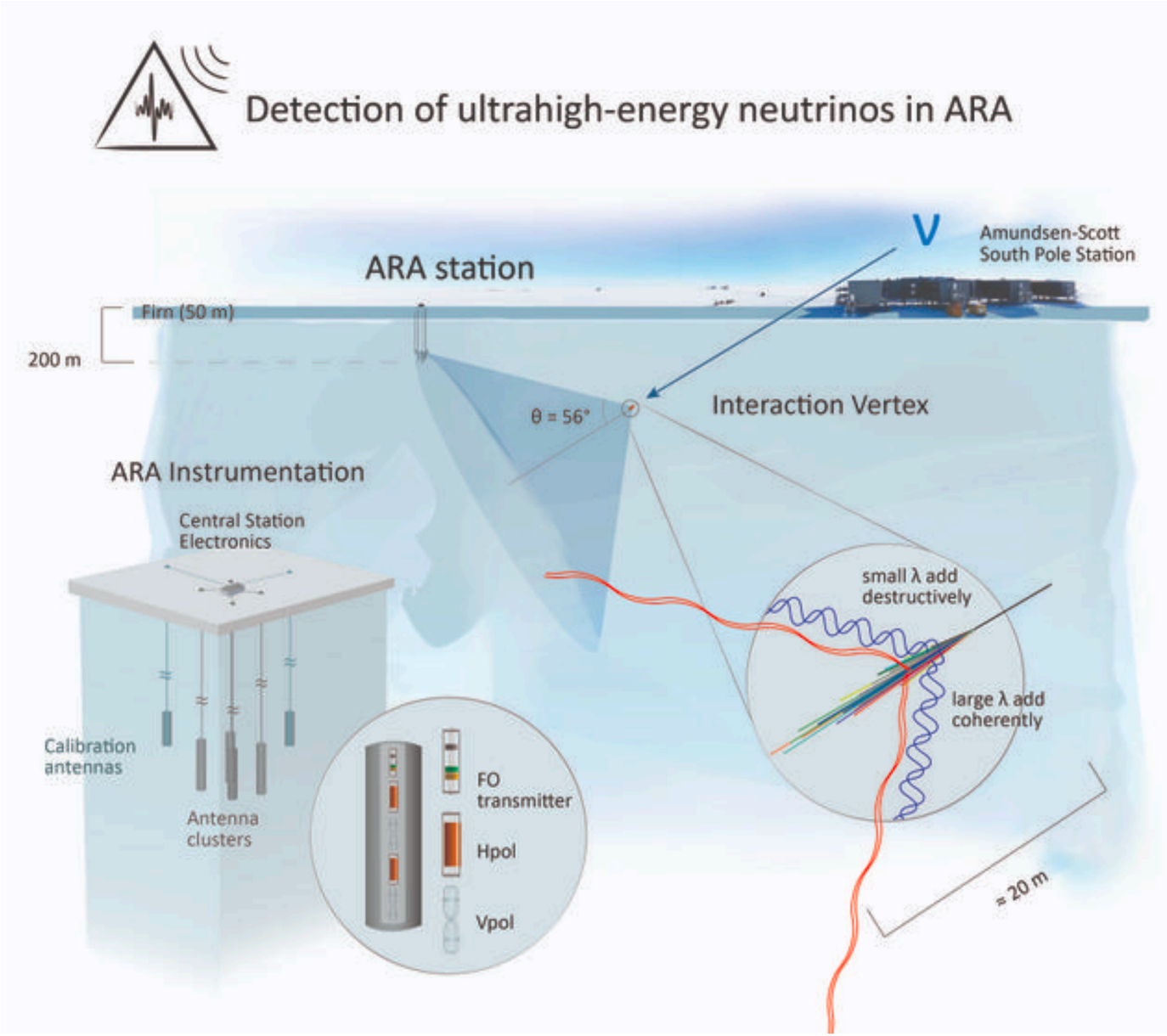
Motivation

- UHE (≳EeV) neutrinos are expected to be produced by UHECRs
- Ideal messenger
  - Propagate cosmological distances (minimal attenuation)
  - Undeflected by magnetic fields
  - Carry information about their production channel
- Unique probe of:
  - Extreme environments across all redshifts
  - Particle physics at post-LHC energies



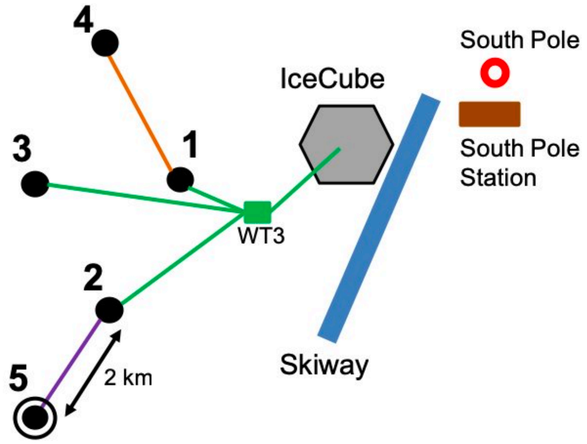
Askaryan Radiation & ARA

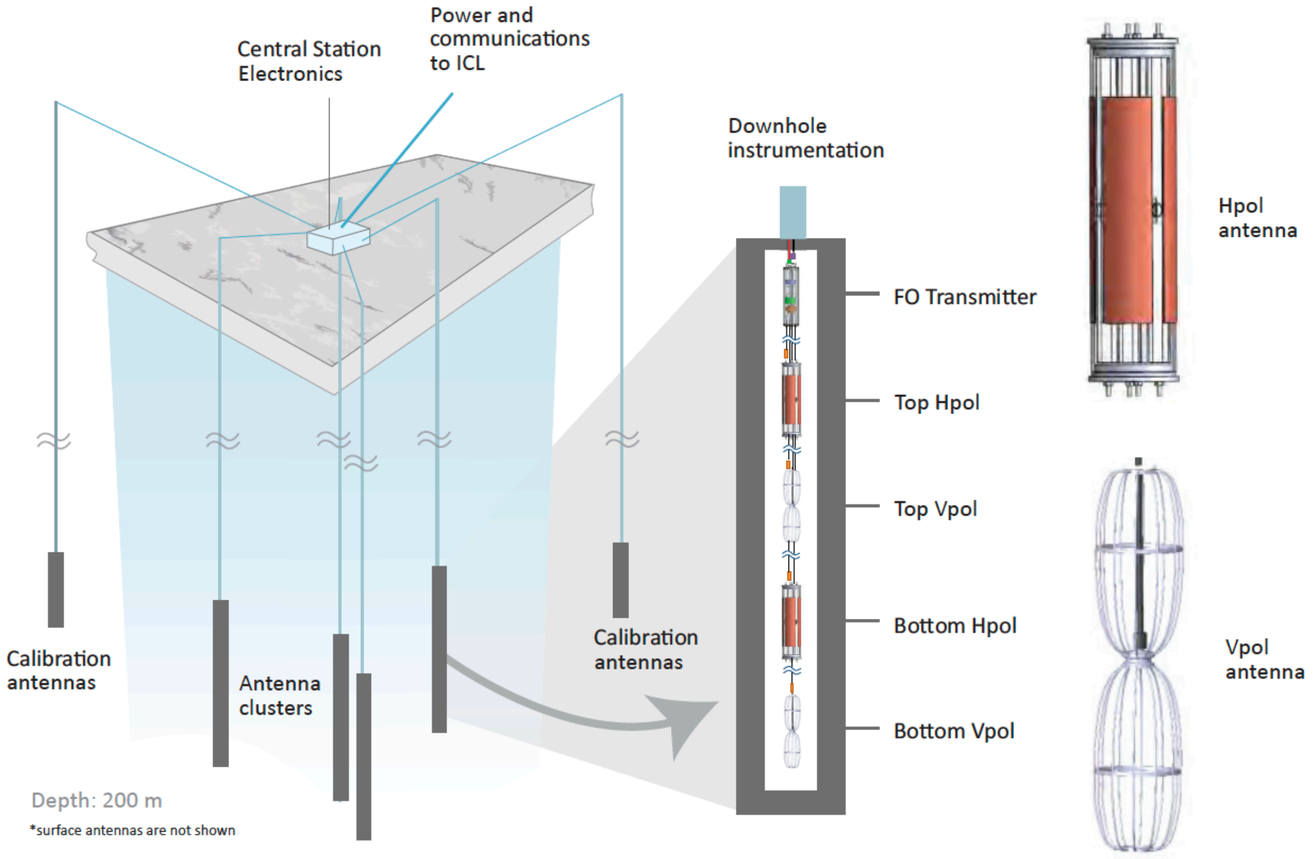
- UHE neutrino initiates particle shower in ice
- Short wavelengths (relative to shower size) are incoherent
- Large wavelengths add coherently
  - Radio Cherenkov emission
  - Impulsive plane wave
- Askaryan Radio Array (ARA) designed to detect UHE neutrinos via Askaryan radiation



ARA Detector

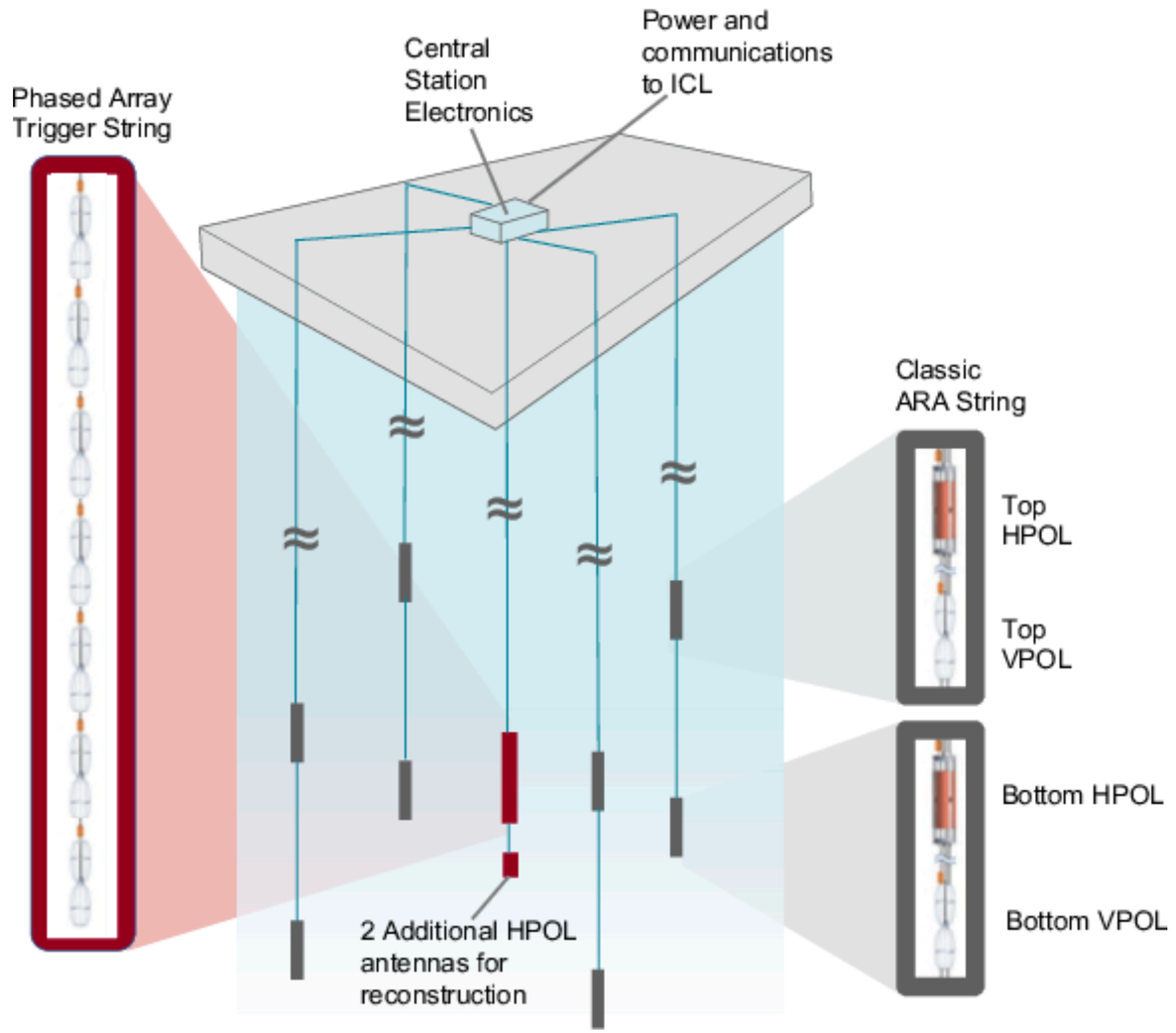
- Consists of 5 stations
  - First station deployed in 2011, 5th deployed in 2018
- Each station has 16 radio antennas across 4 strings
  - 8 detect horizontal polarization (Hpol) & 8 detect vertical polarization (Vpol)
- Triggers when 3+ antennas' power is >5x noise in a 25 ns window





Phased Array Detector

- 5th ARA station has an additional detector system: the Phased Array (PA)
- Consists of 1 string with 7 Vpol & 2 Hpol antennas
- More efficiently triggers on low signal-to-noise ratio (SNR) signals by adding signals in preset directions (beams)
  - Signals add coherently, noise does not
- Triggers when a beam has excess power in 10 ns window
  - PA trigger also triggers the ARA station
- Analysis efficiency is also increased



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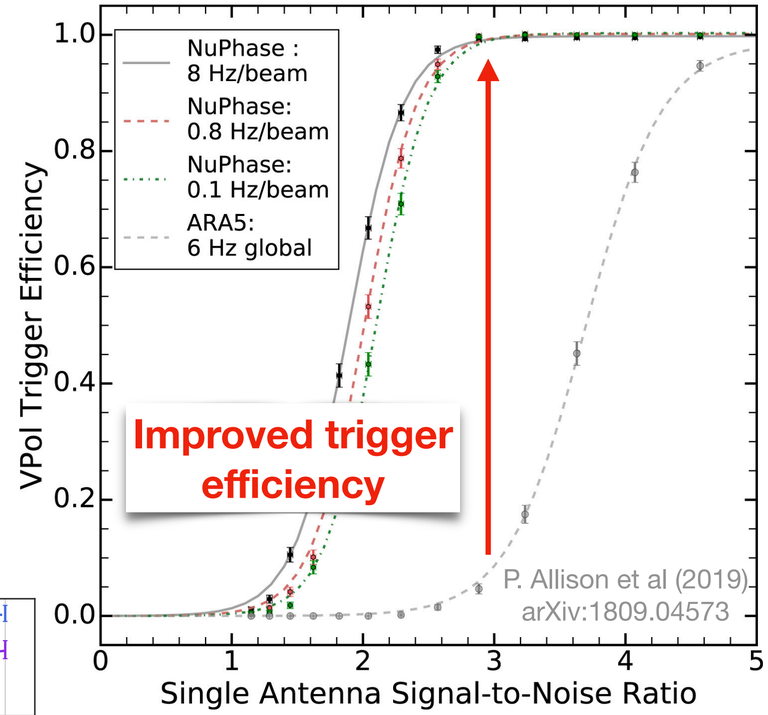
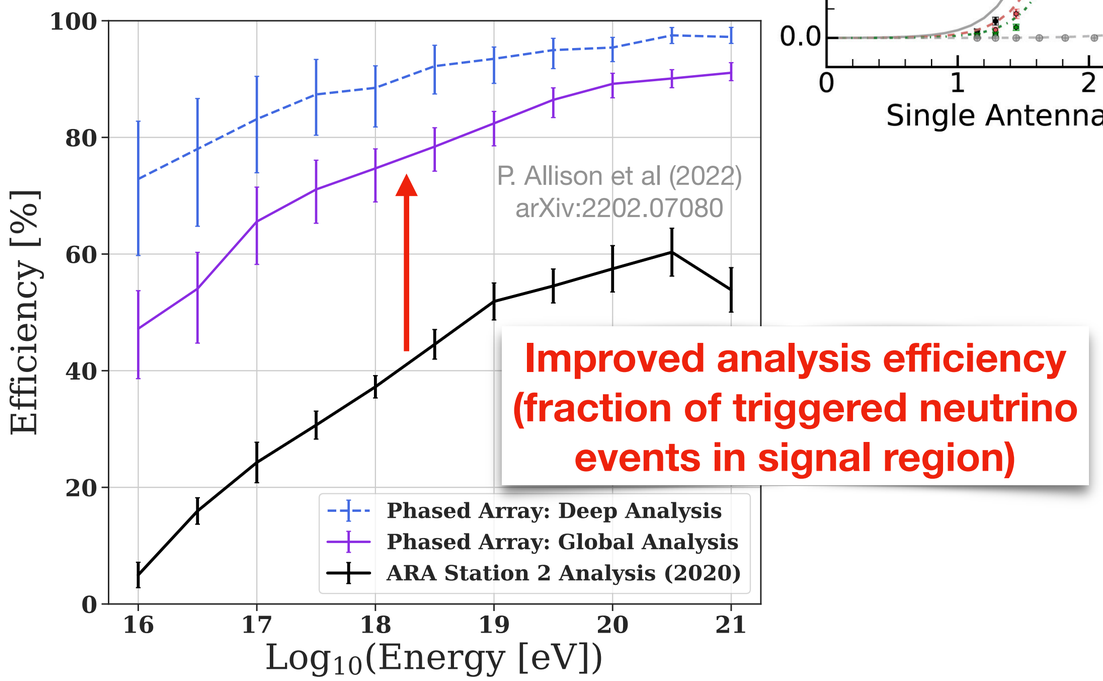
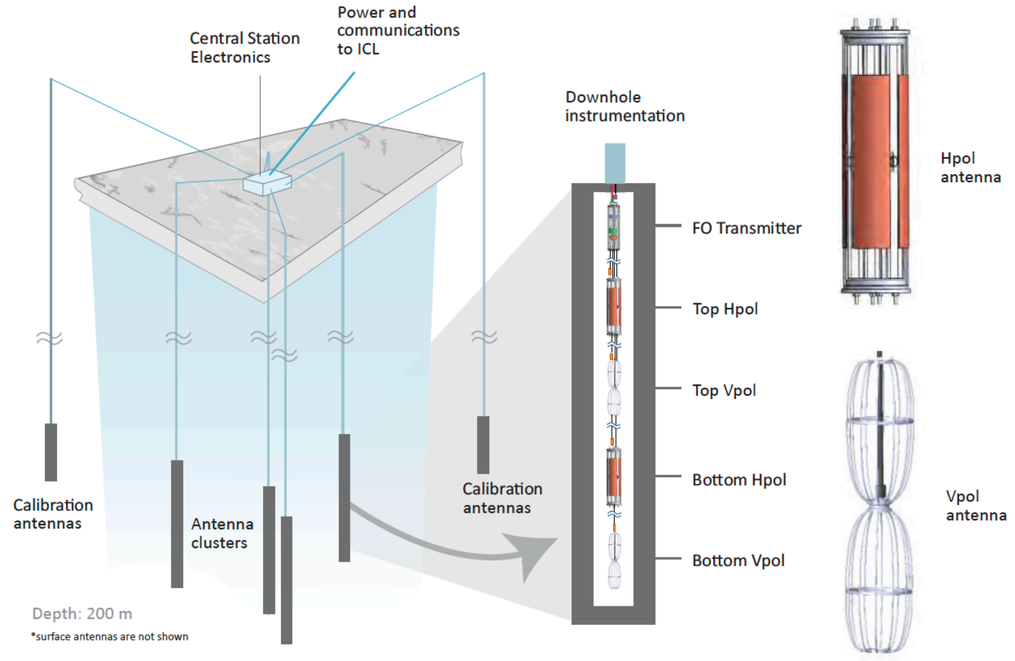
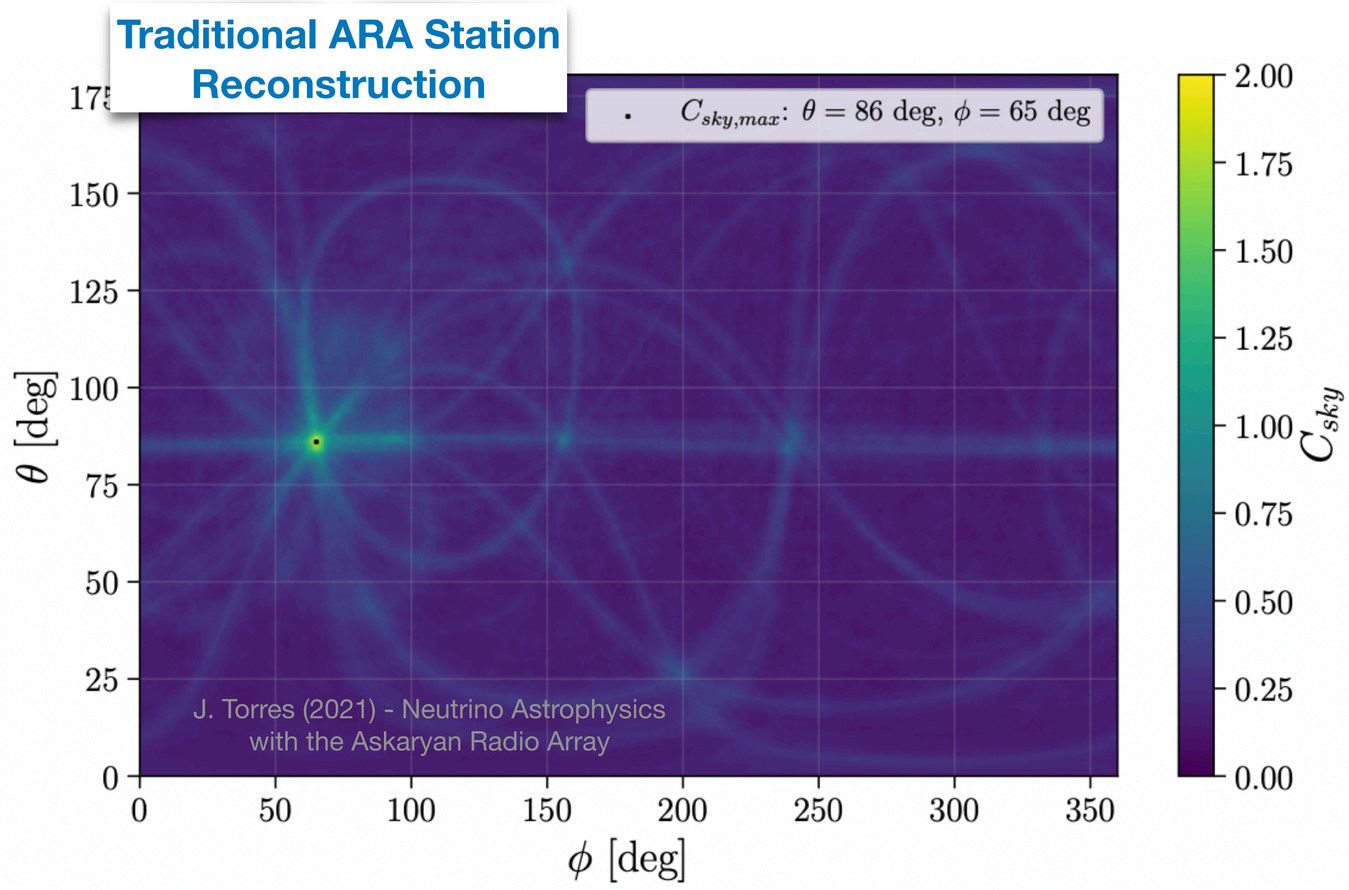




Vertex Reconstruction - ARA

- Cross-correlating signal in each antenna allows for interaction vertex reconstruction
- Vertex reconstruction allows for background CR and anthropogenic signals to be discarded





<1° resolution on vertex reconstruction

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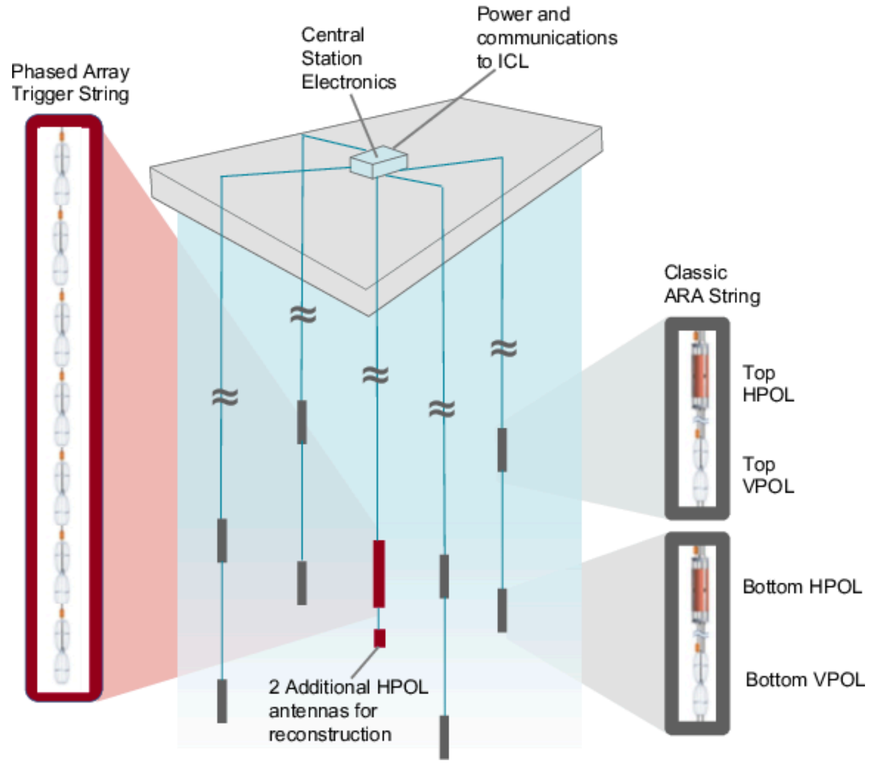
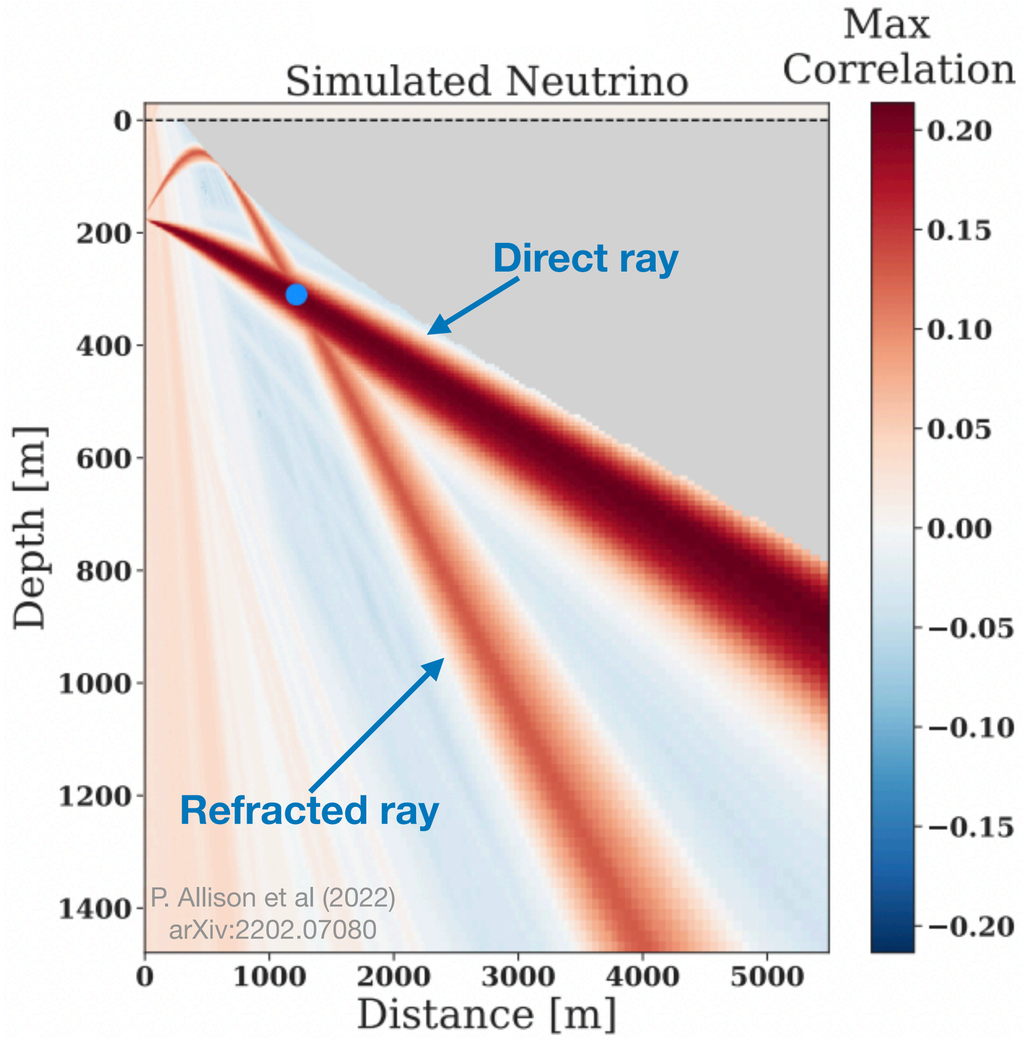
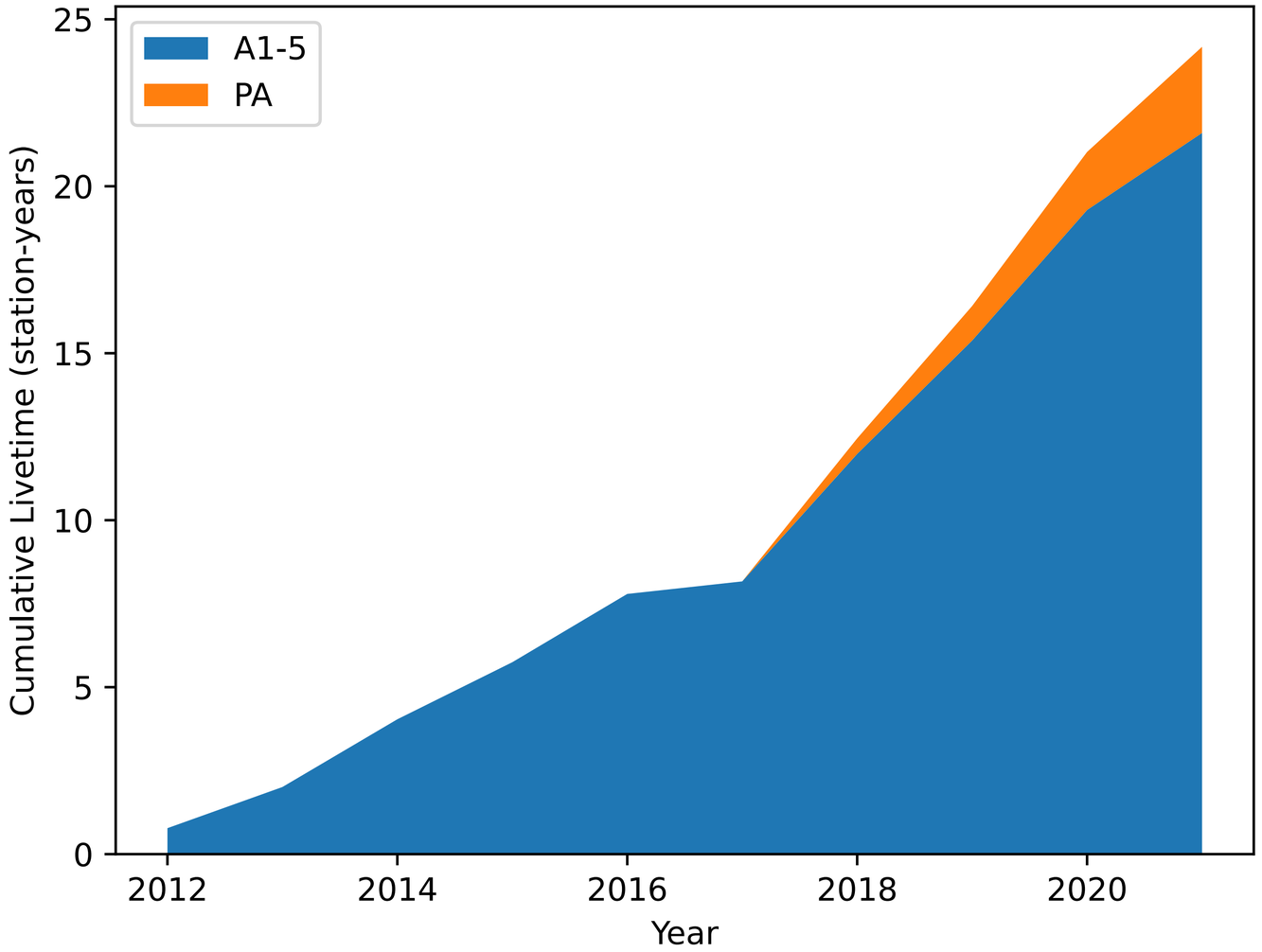




Overview of Five-Station Analysis

- Diffuse neutrino search in full livetime of all 5 ARA stations & the PA
  - **Almost 25 station-years of livetime**



Overview of Five-Station Analysis

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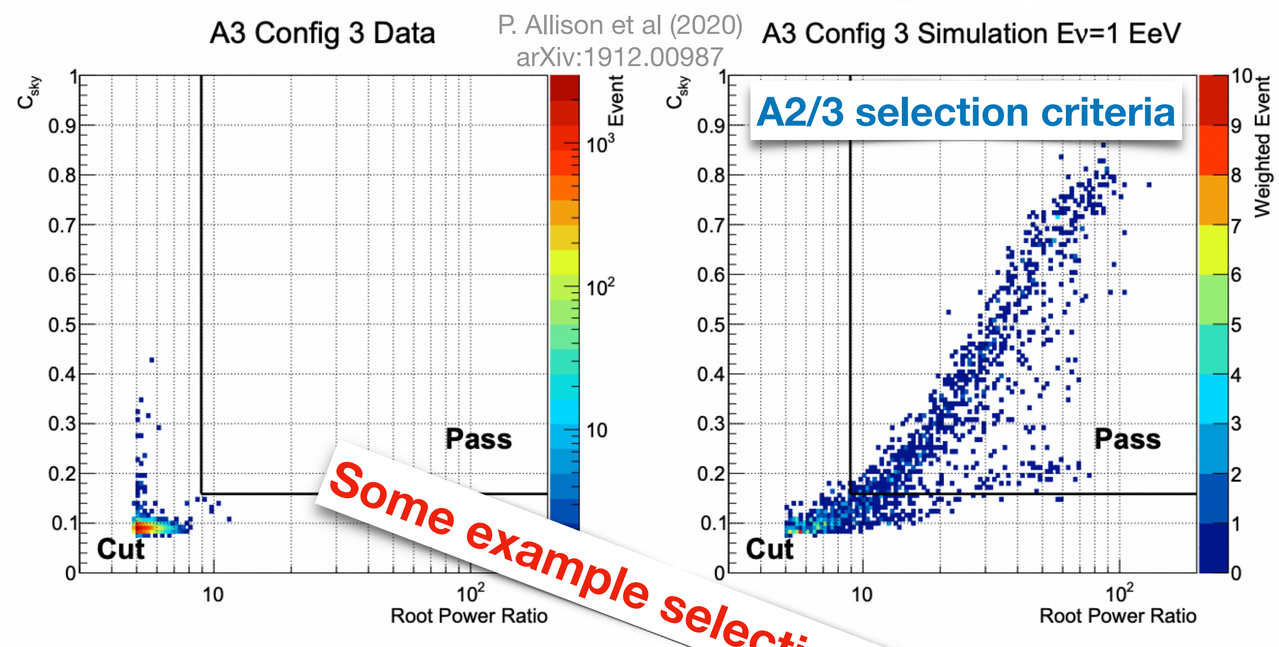
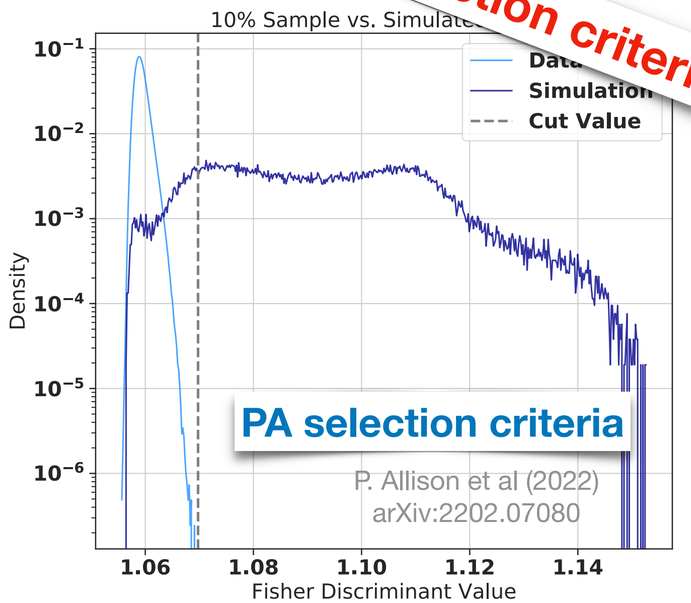
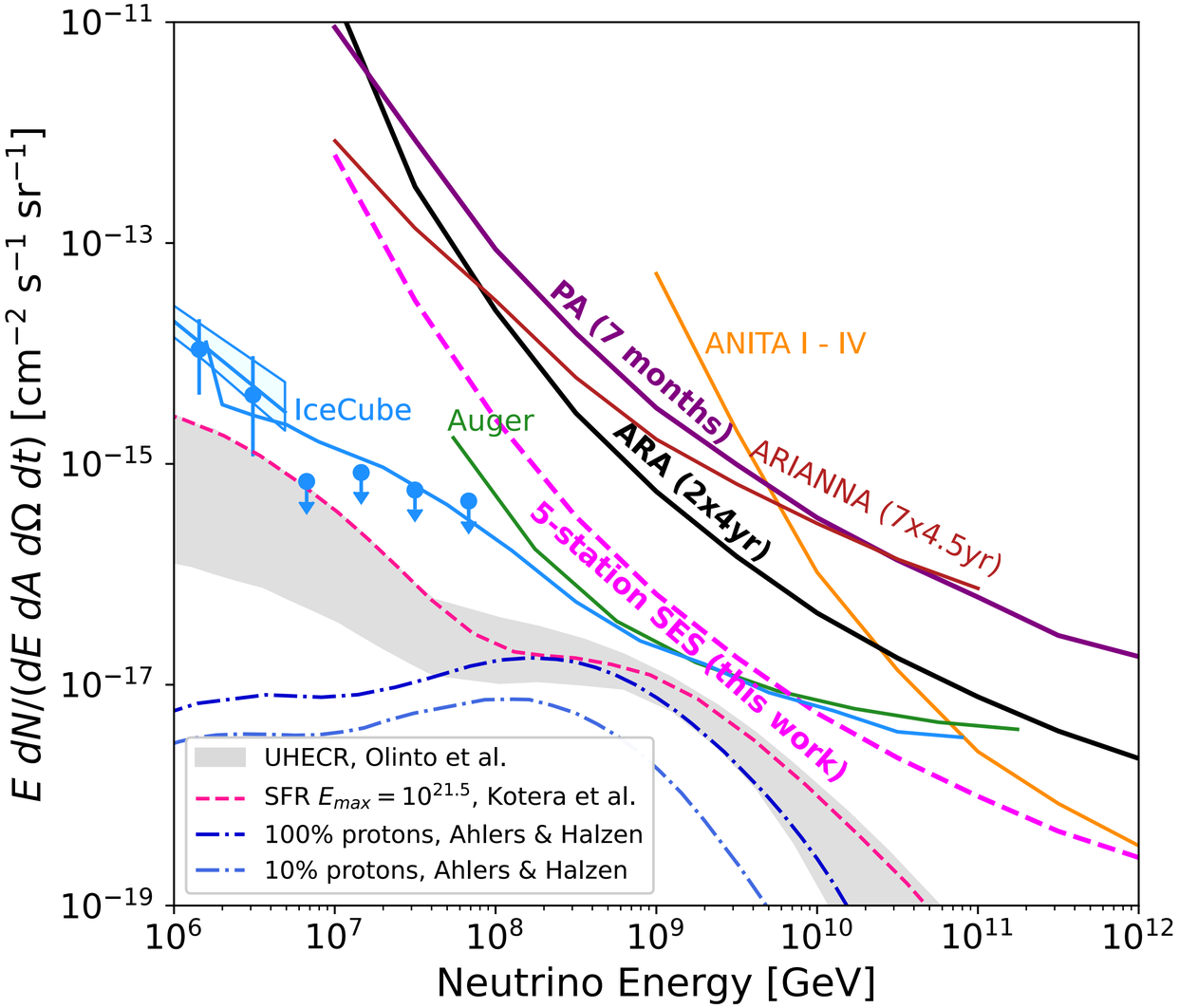
- Each station will be analyzed independently to determine best selection criteria
  - Different stations may be best analyzed with different parameters
- Selection criteria from each station will be jointly optimized to maximize discovery potential





Comparison to Previous Work

- Strongest limits previously set by analysis of:
  - A2/3 data: 8 station-years
  - PA data: 0.6 station-years
- This work: 24 station-years
  - ARA: 22 station-years
  - PA: 2 station-years
- **Will represent strongest limits by radio on 1-100 EeV neutrinos to date!**



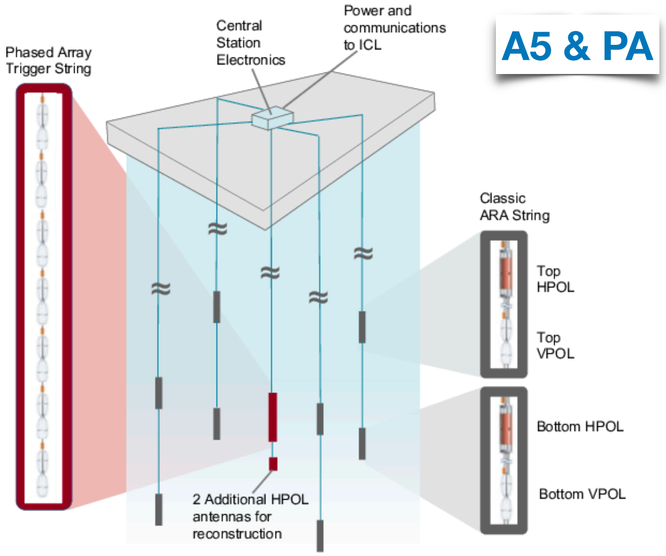
*assuming analysis efficiency of A2/3 & PA analyses

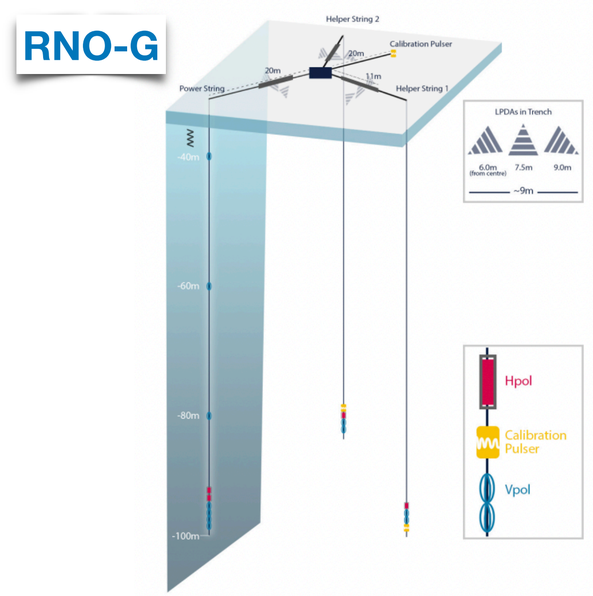
First Steps Towards an Analysis

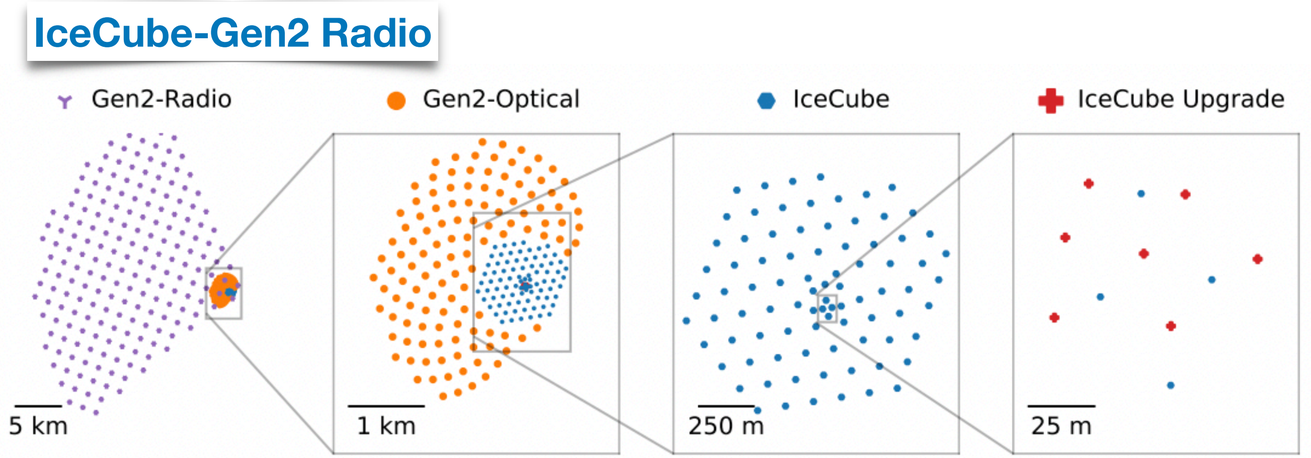
- Preparing A5/PA data for blinding
  - Data must be synchronized & categorized before blinding
- Building a data-driven model of detector noise

PA & A5 Dataset

- **PA-A5 dataset is paradigmatically representative of upcoming detectors**
  - Combines low threshold phased array trigger w/ info from traditional antennas (providing azimuthal information)
  - Similar to Radio Neutrino Observatory in Greenland (RNO-G, currently deploying) & IceCube-Gen2 Radio (planning stage)
- Analysis of this dataset will be a proof of concept and inform the next generation of analyses as to the challenges & how to overcome them

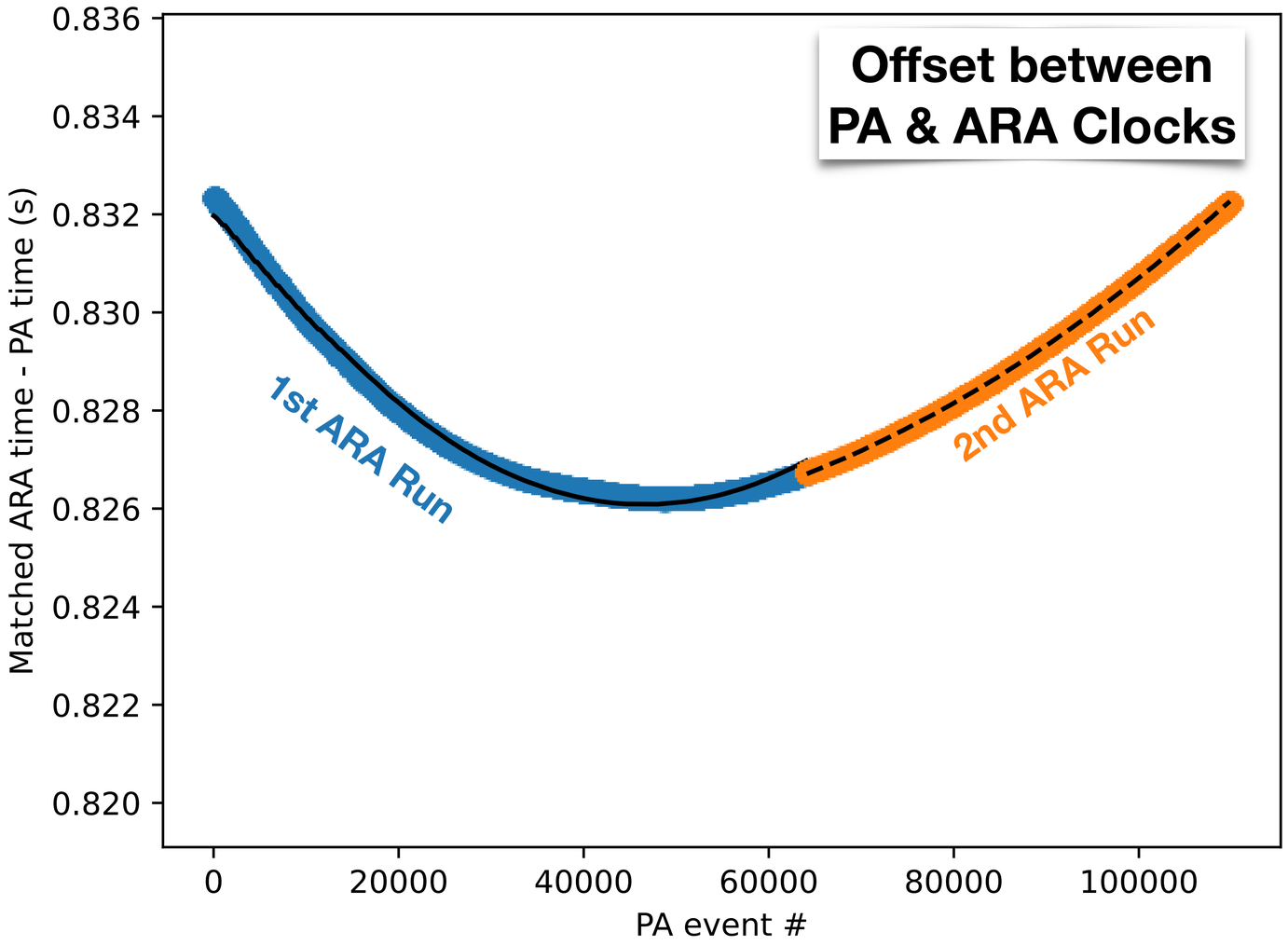




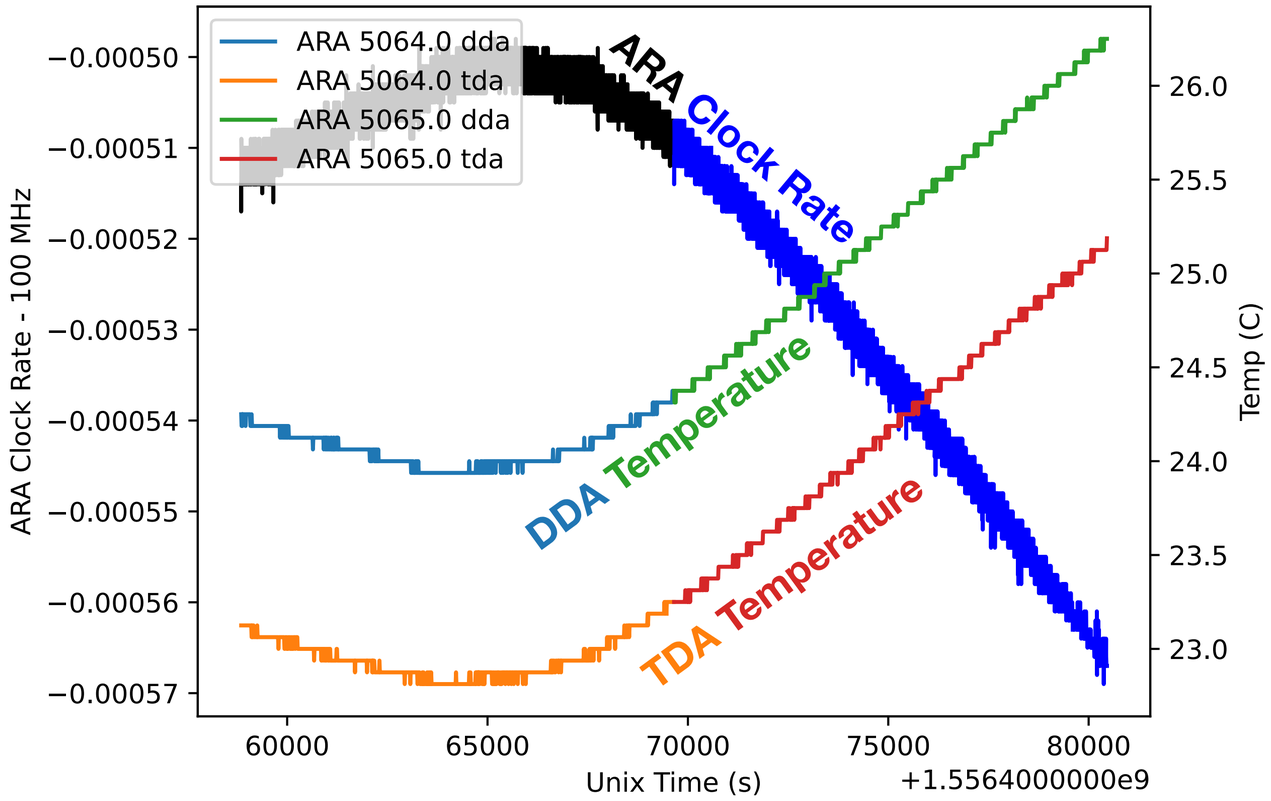


Synchronizing PA & A5 Events

- Four event types for PA/A5 system:
  - PA-only events
  - A5-only events
  - Joint events, PA-triggered
  - Joint events, separately triggered
- Event types matched via a combination of timestamps & other event information
  - (Variable) clock offset needs to be accounted for



Correcting for Variable Clock Rate



Clock rates inversely related to system temperature

$\tau =$ uncorrected time

$t =$ corrected time

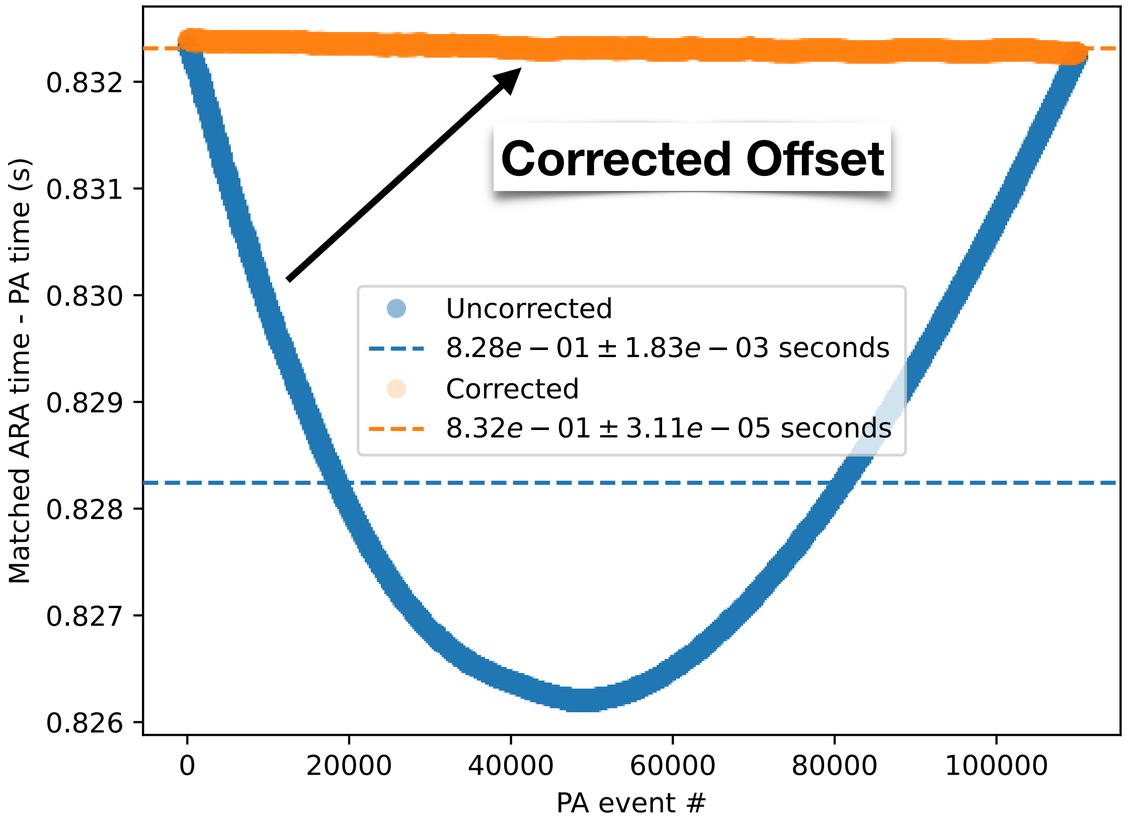
$\nu =$ nominal const. clock rate

$f_i =$ true clock rate at cycle i

$$t_i = t_{i-1} + \frac{\nu}{f_i}(\tau_i - \tau_{i-1}),$$

$$t_0 = \tau_0$$

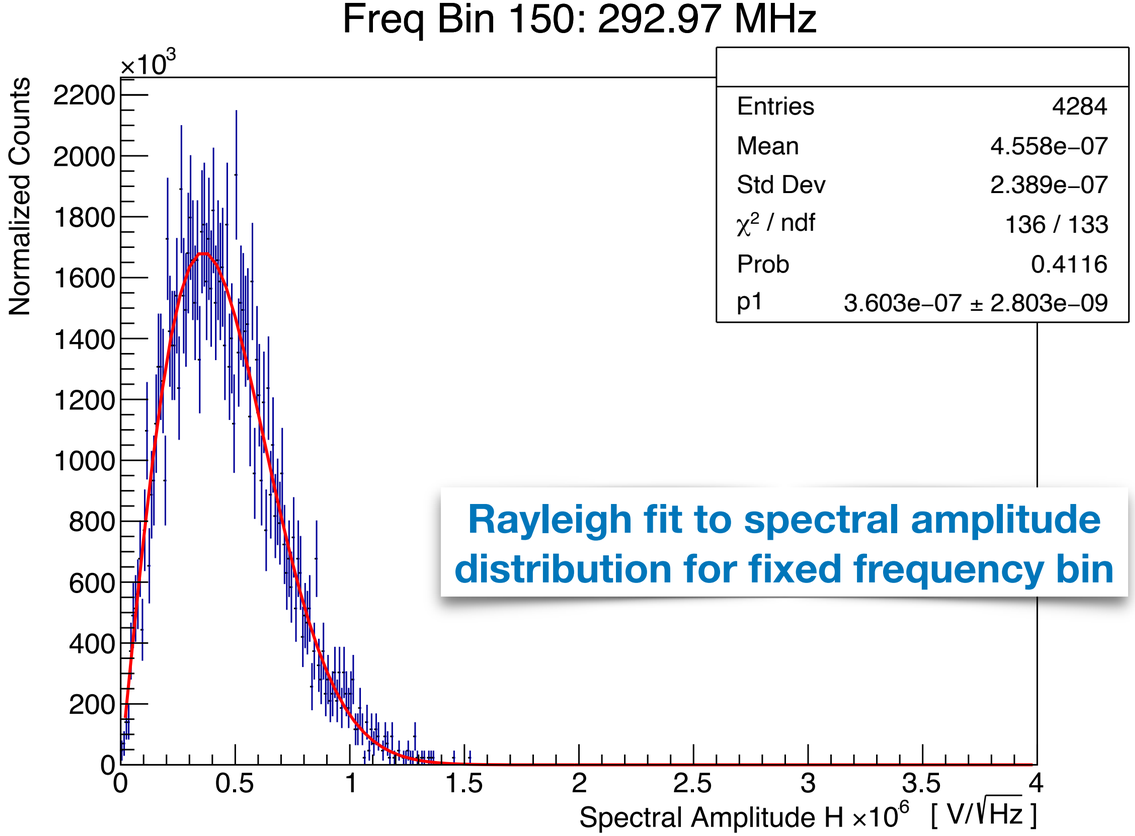
Time correction for variable clock rate



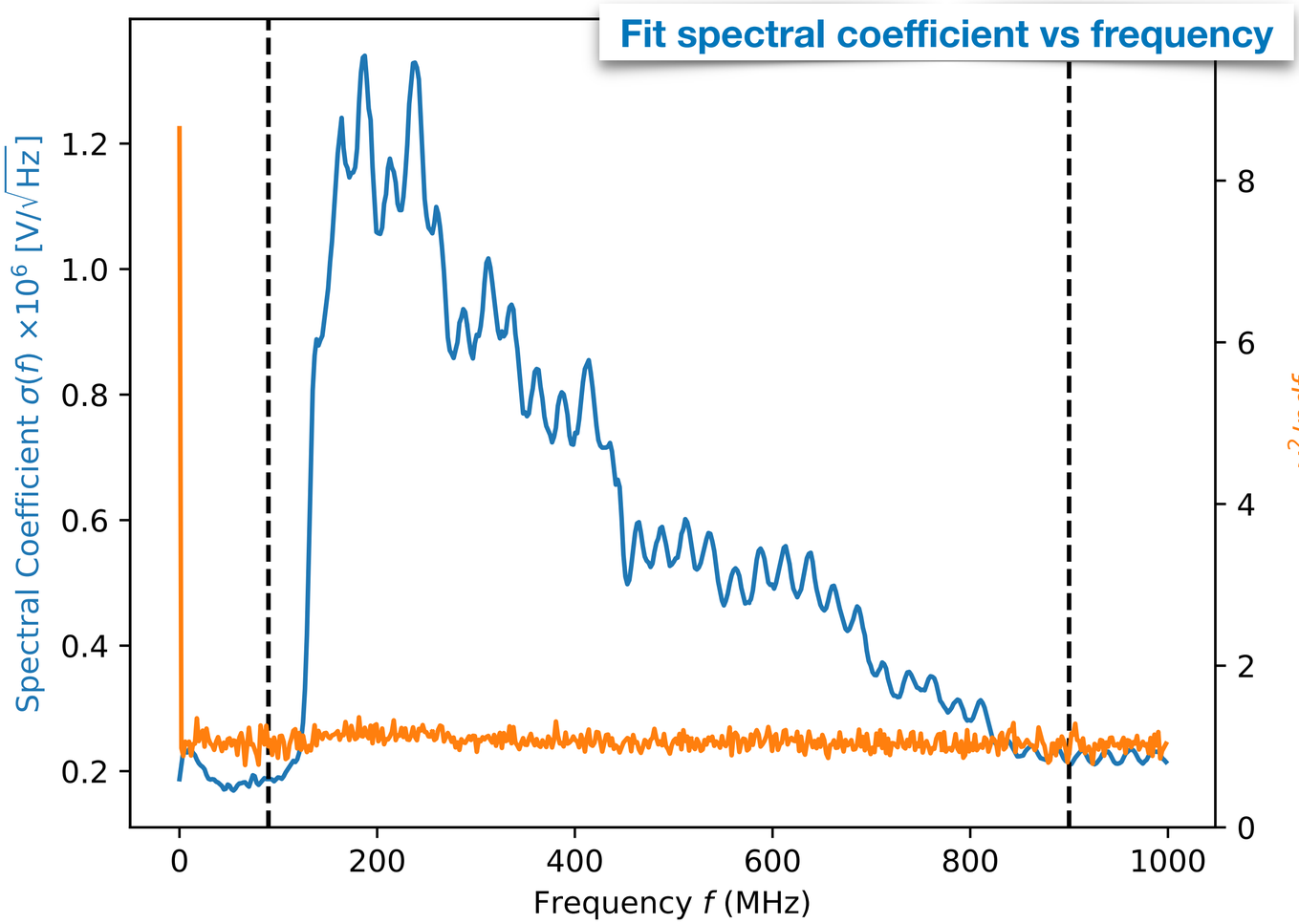
Noise Modeling

- Expect thermal noise to follow a Rayleigh distribution in the frequency domain

$$F(f;\sigma) = \frac{f}{\sigma^2} e^{-f^2/2\sigma^2}$$



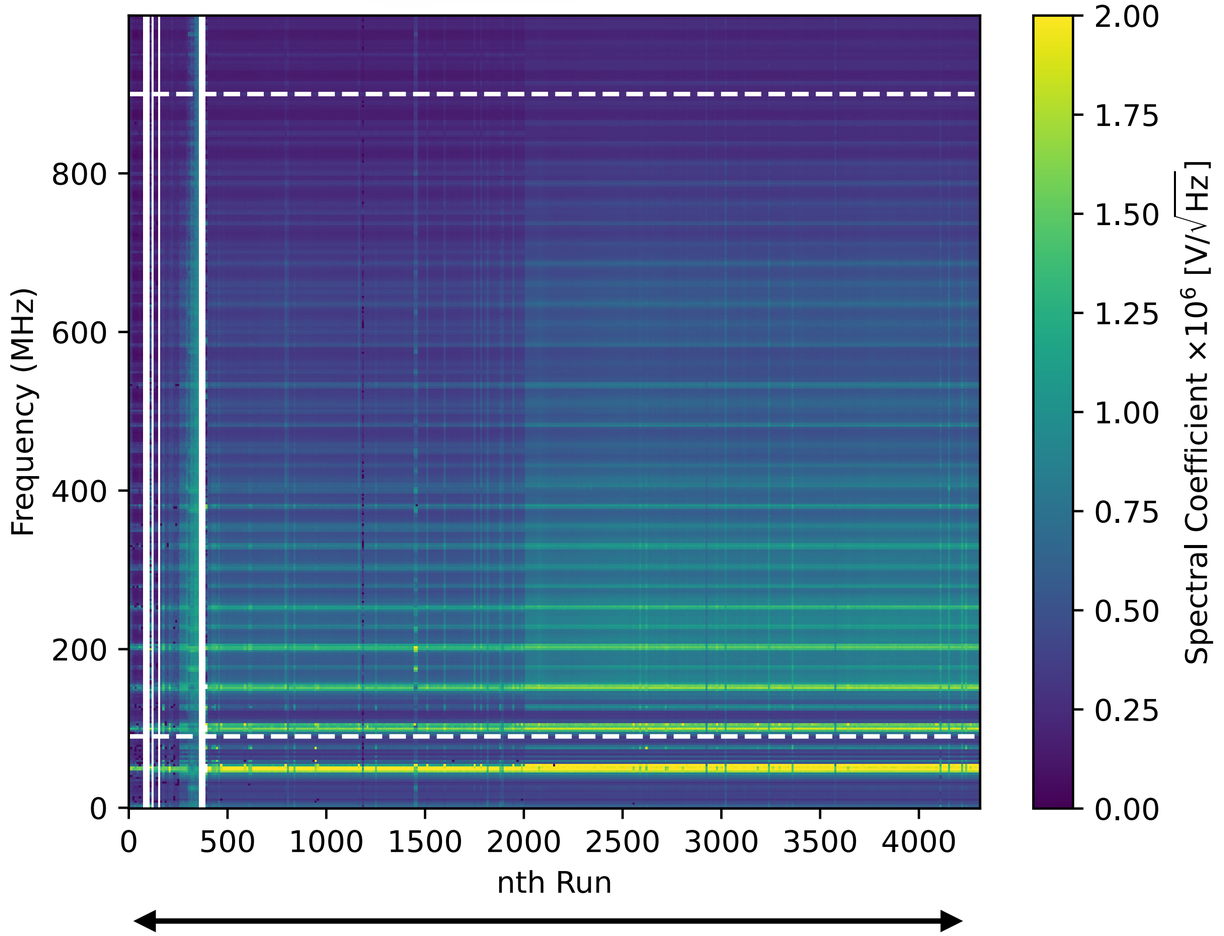
Rayleigh fit to spectral amplitude distribution for fixed frequency bin



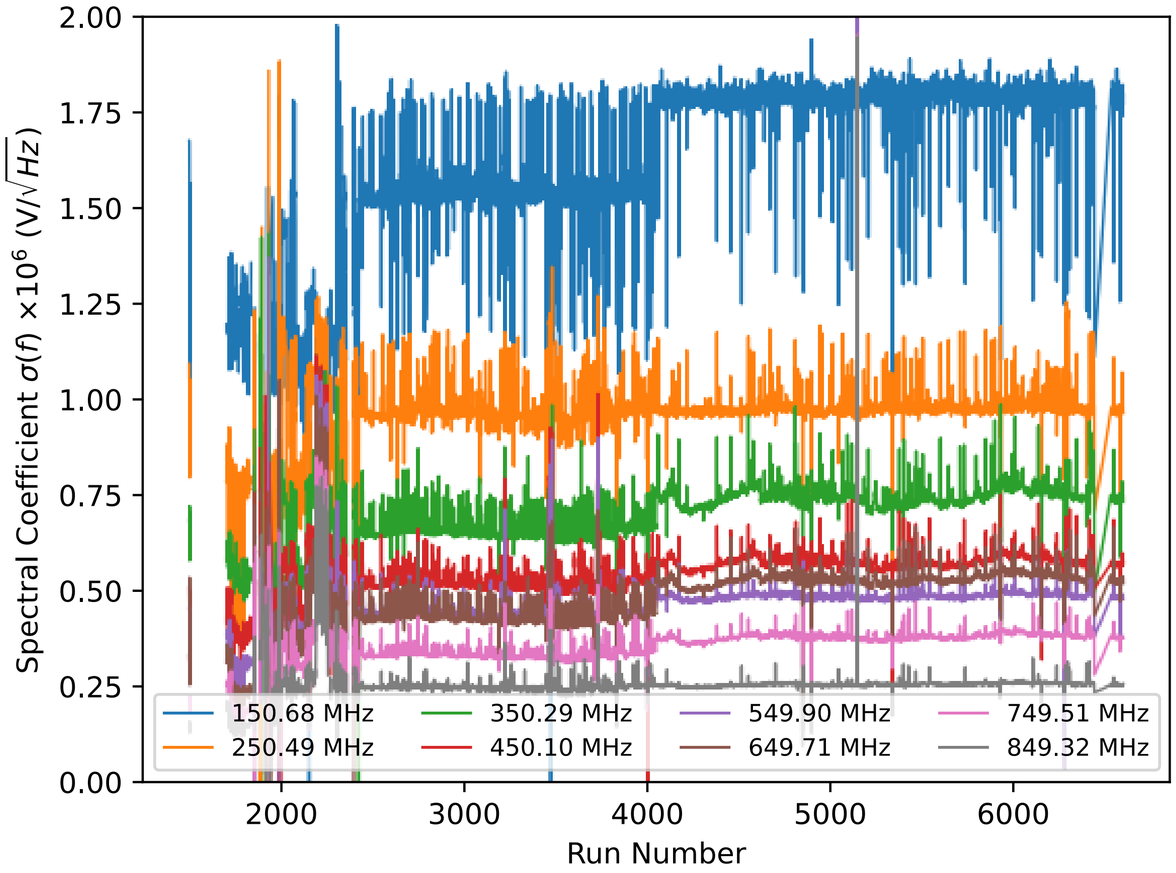
Fit spectral coefficient vs frequency

Noise Modeling

Spectral coefficient over time shows the detector is stable for long periods, & can also help identify when changes in detector configuration occur



2 year period

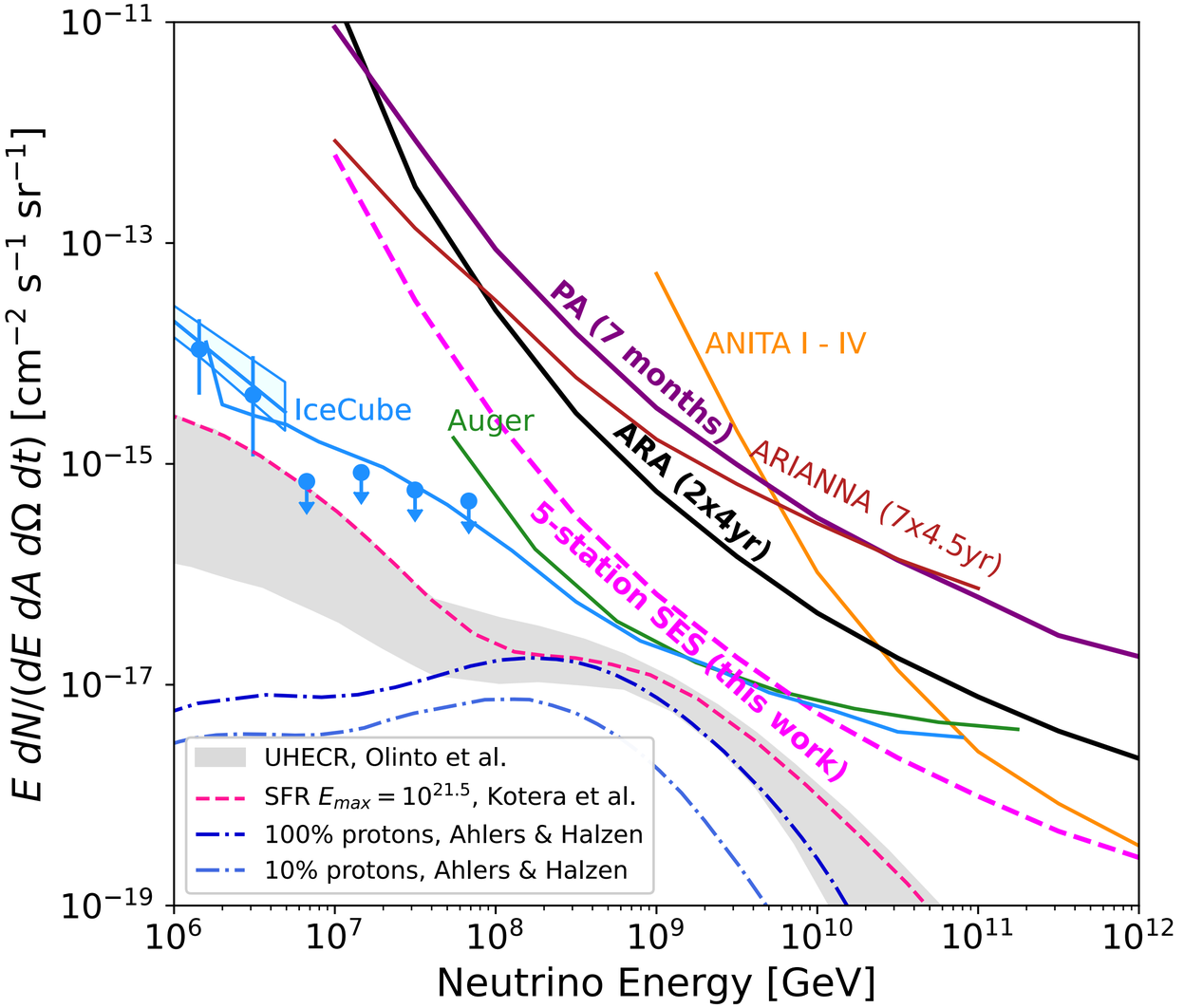


2 year period

Summary

- Efforts are well underway to perform a diffuse neutrino search in the full ARA dataset
- **Projected limit will be ARA's most sensitive and the strongest radio limit in the 1-100 EeV range to date**
- Next steps:
  - Complete data-driven detector gain model
  - Blind data & start analyzing!

Thank you!



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