Searching for the Highest Energy Neutrinos with the Askaryan Radio Array

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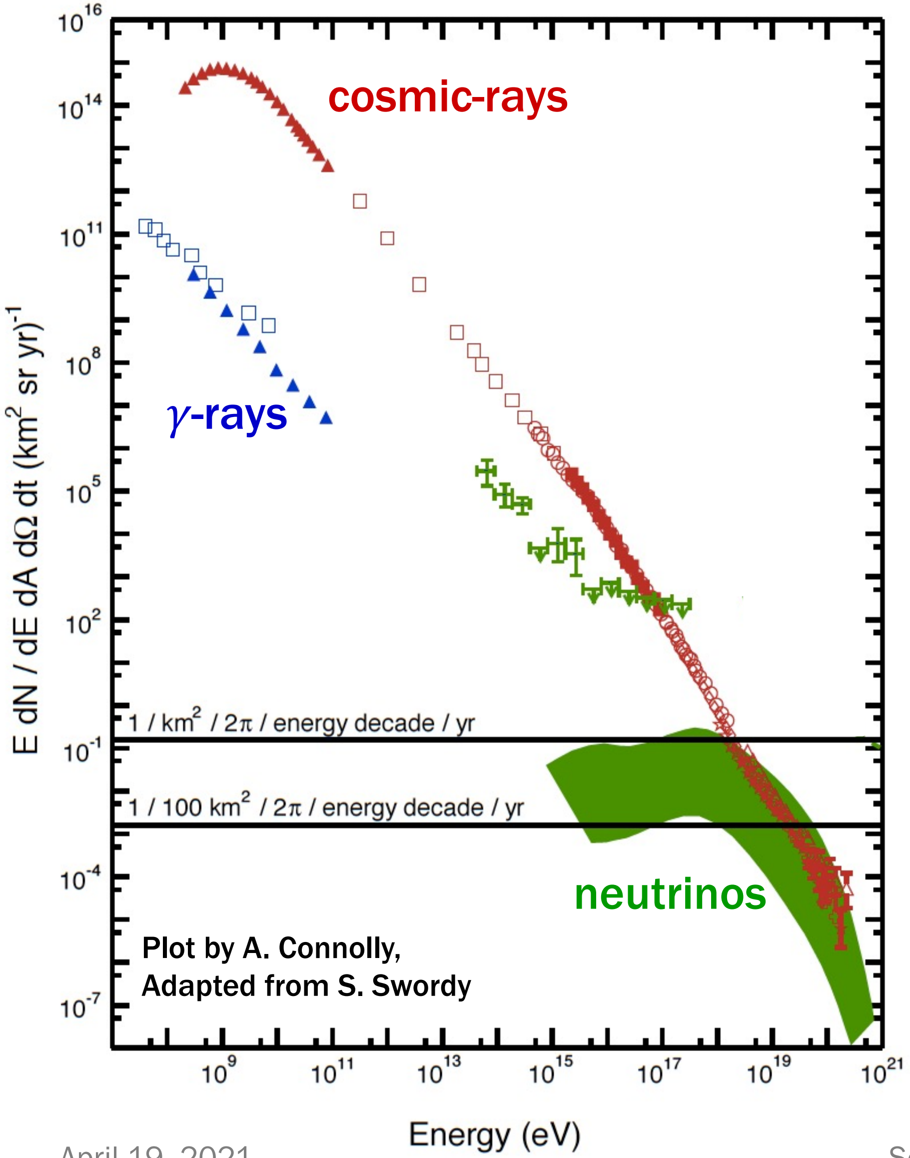
APS April Meeting

Why Study Neutrinos?



Unique Messengers to distant (>100Mpc) universe

- Cosmic rays $>10^{19.5}$ eV attenuated, e.g. the GZK process

$$p + \gamma \rightarrow \Delta^{+} \rightarrow p(n) + \pi^{0}(\pi^{+})$$

→ Screens extragalactic (>100 MPc) sources
→ Makes neutrinos and gamma rays

- γ-rays annihilate w/ CMB @ ~1 TeV

Observational Advantages

- Chargeless = point back to source
- Weakly interacting = no observation horizon

About Askaryan Radio Array

- Designed to detect radio impulses from UHE neutrino-ice interactions
- 8 VPol & 8 HPol antennas deployed in 200m "boreholes"

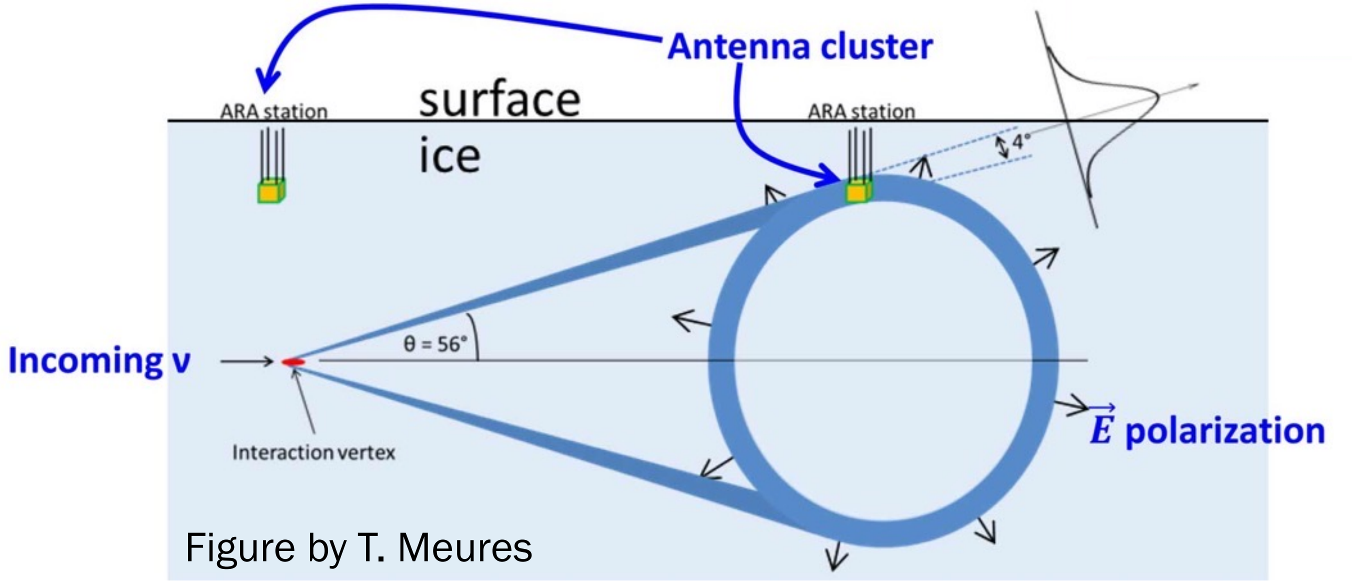
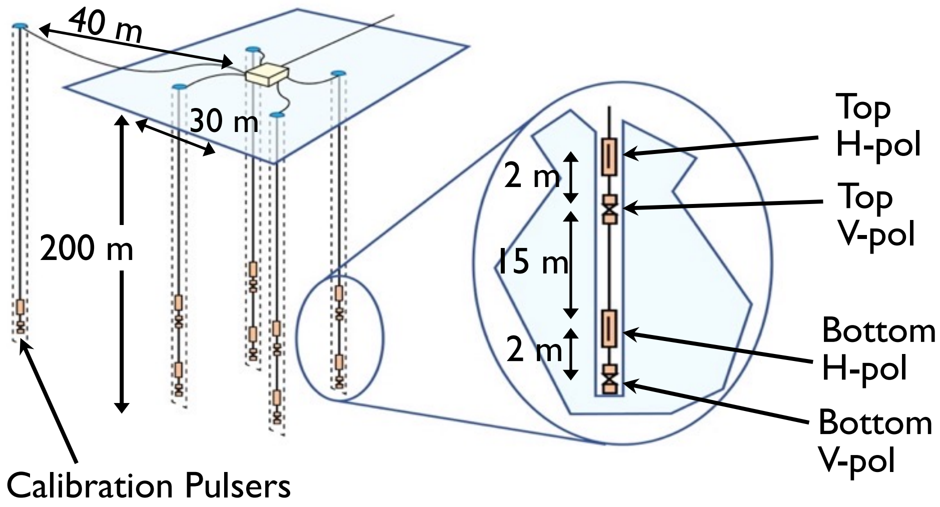


Figure by T. Meures



The ARA Collaboration

USA

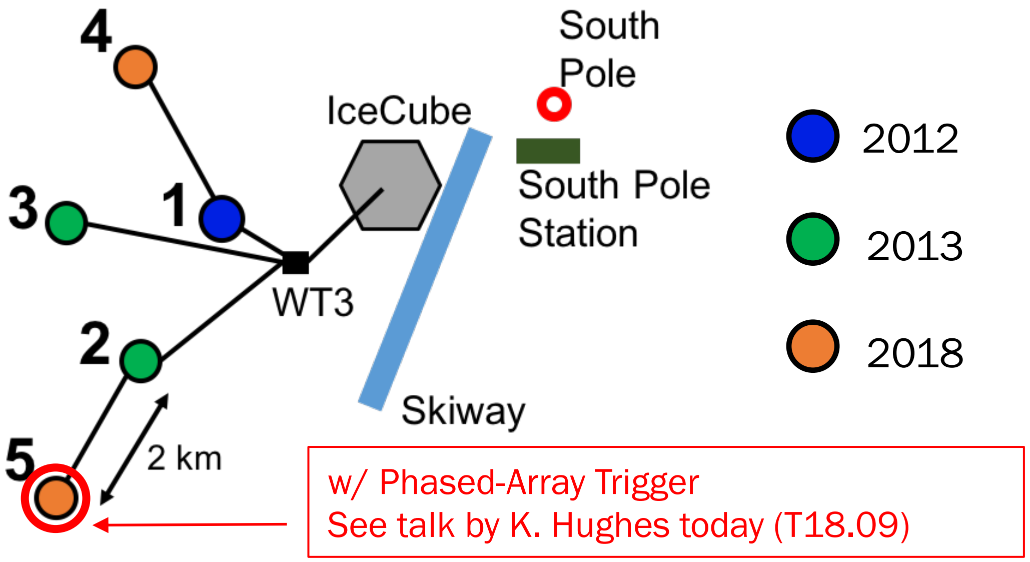
Denison University
Michigan State University
The Ohio State University
Penn State University
University of Chicago
University of Delaware
University of Kansas
University of Maryland
University of Nebraska
University of Wisconsin-Madison
Whittier College

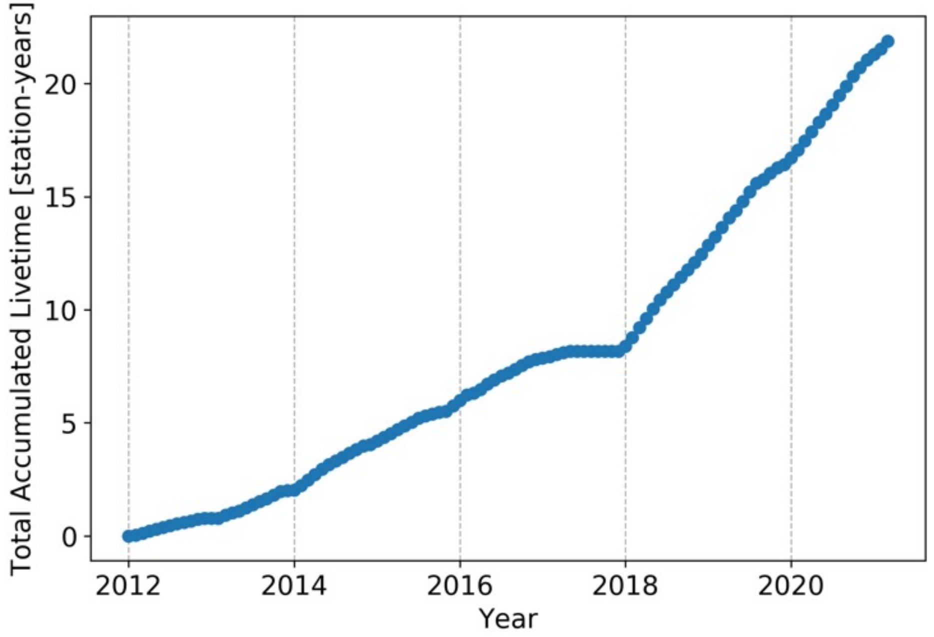
International Collaborators

Chiba University
Moscow Engineering Physics Institute
National Taiwan University
University College London
Vrije Universiteit Brussel
Université Libre de Bruxelles
Weizmann Institute of Science

Status of ARA

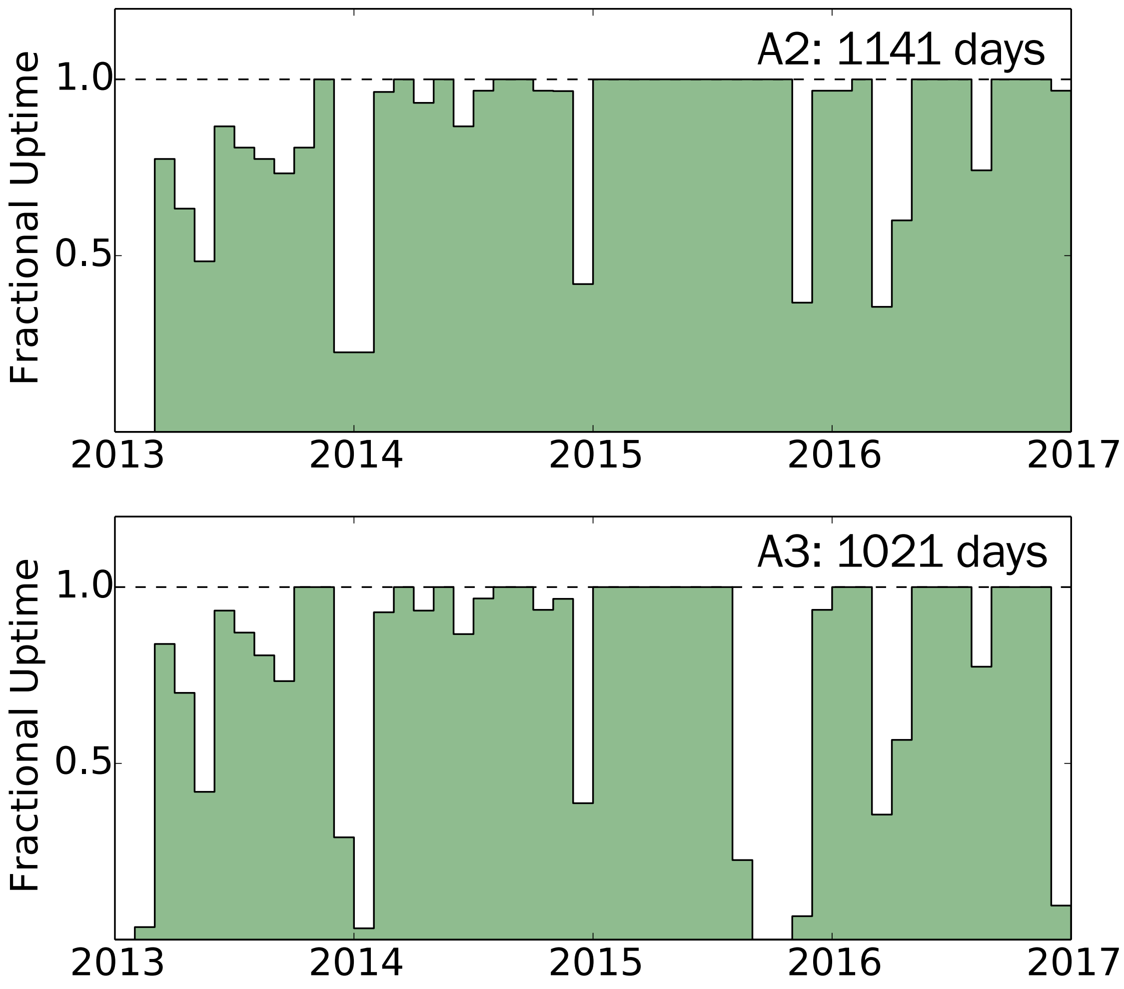
- 5 Stations deployed
  - A1 in 2012
  - A2 & A3 in 2013
  - A4 & A5 in 2018
- Stations have been taking data and continue to accumulate livetime





Diffuse Neutrino Search

- A2 and A3 collecting data since Feb 2013—10 months of data published previously
  [P. Allison *et. al.* 2016 PRD 93, 082003 (2016)]
- Published expansion to the 2013-2016 data set in August 2020 (PRD 102, 043021)-- 5x as much data!
- Analysis is done "blind"—tune cuts on 10% of data, remaining 90% sets the limit
- Data is cleaned before analysis begins
  - Remove digitizer & system readout errors (~1/10^5 events)
  - Exclude calibration runs (~2 weeks/yr)

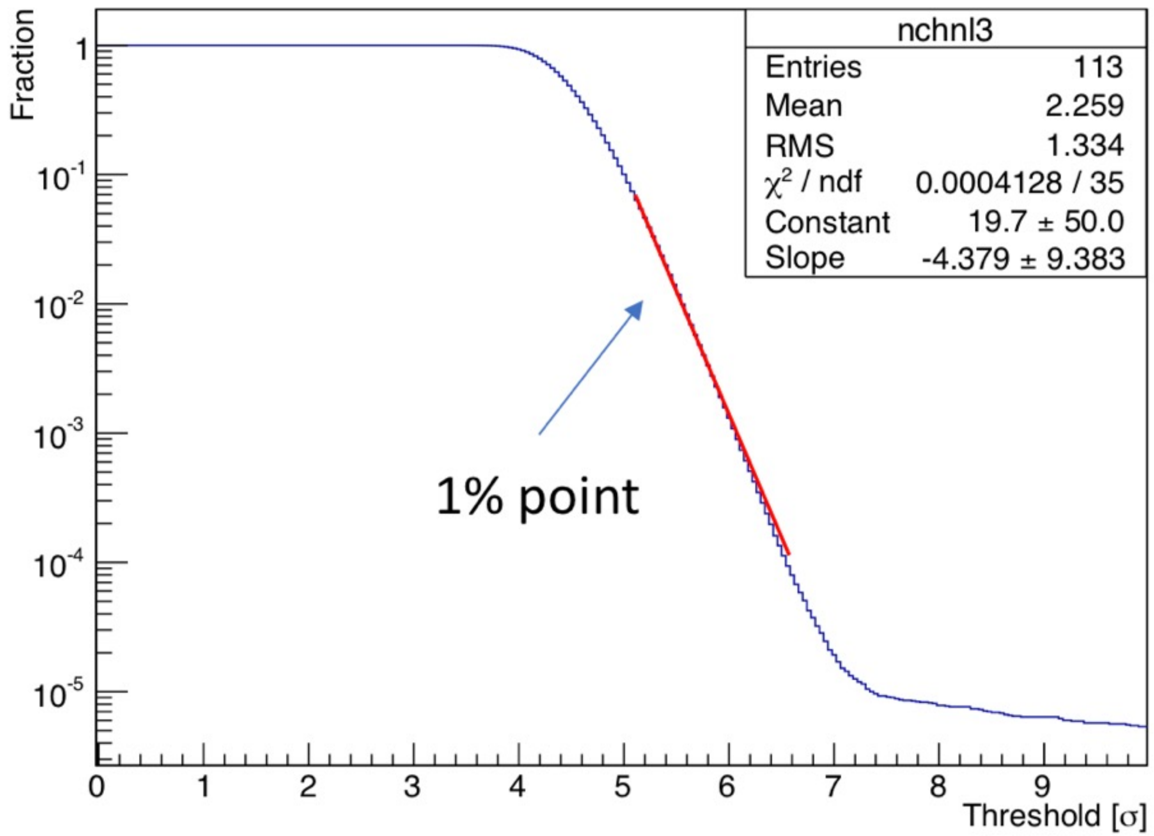


Diffuse Neutrino Search: Filtering

- ~5 Hz trigger rate →10^8 events/year, which are >99.9999% thermal noise
- Apply a fast event filter to reduce data set to before attempting computationally intensive reconstructions
- Filter requires 3 VPol channels have a signal-to-noise (SNR) ratio above a threshold N_{thresh}
- N_{thresh} chosen to achieve 1% thermal noise passing rate

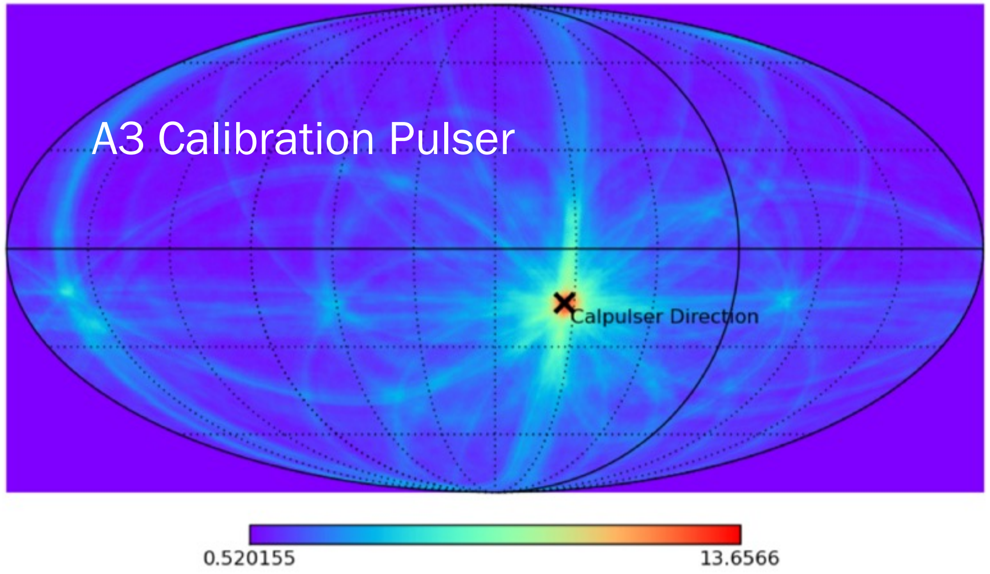
$$\frac{V_{peak}}{\sigma_{noise}} \geq N_{thresh}$$

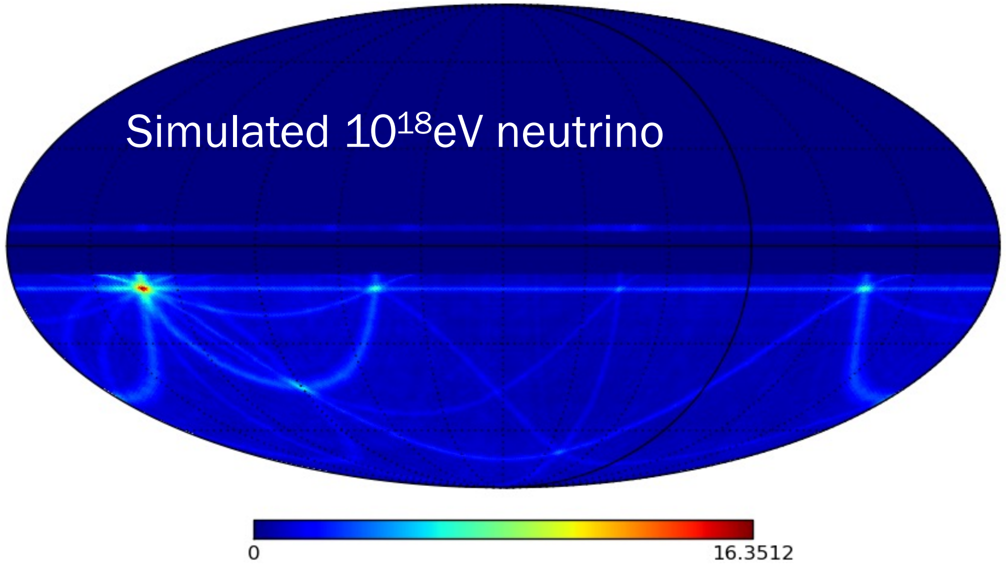
Plot by Ming-Yuan Lu (UW)



Diffuse Neutrino Search: Reconstruction

- For events surviving the filter, we perform interferometric reconstructions
  - Accounts for n(z)
  - Direct and refracted ray solutions
- Peak in the map is interpreted as the RF source direction
- Make geometric cuts to remove:
  - Events at and above the surface
  - Events in the direction of the local calibration pulser



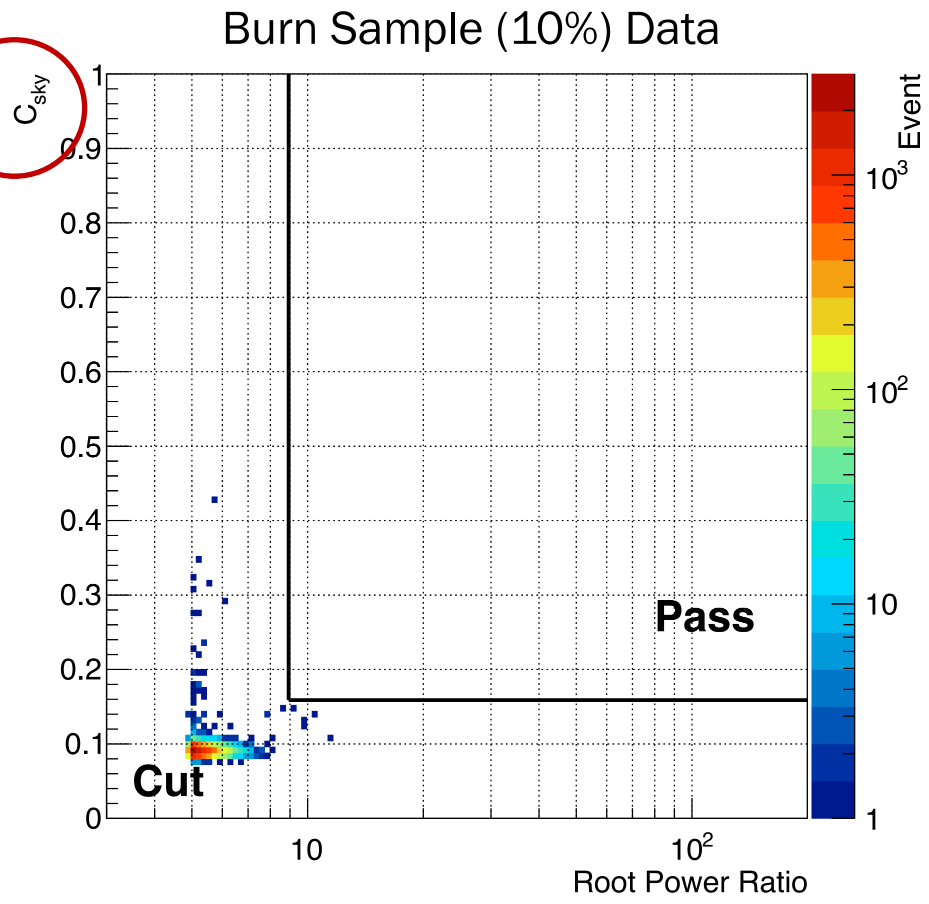


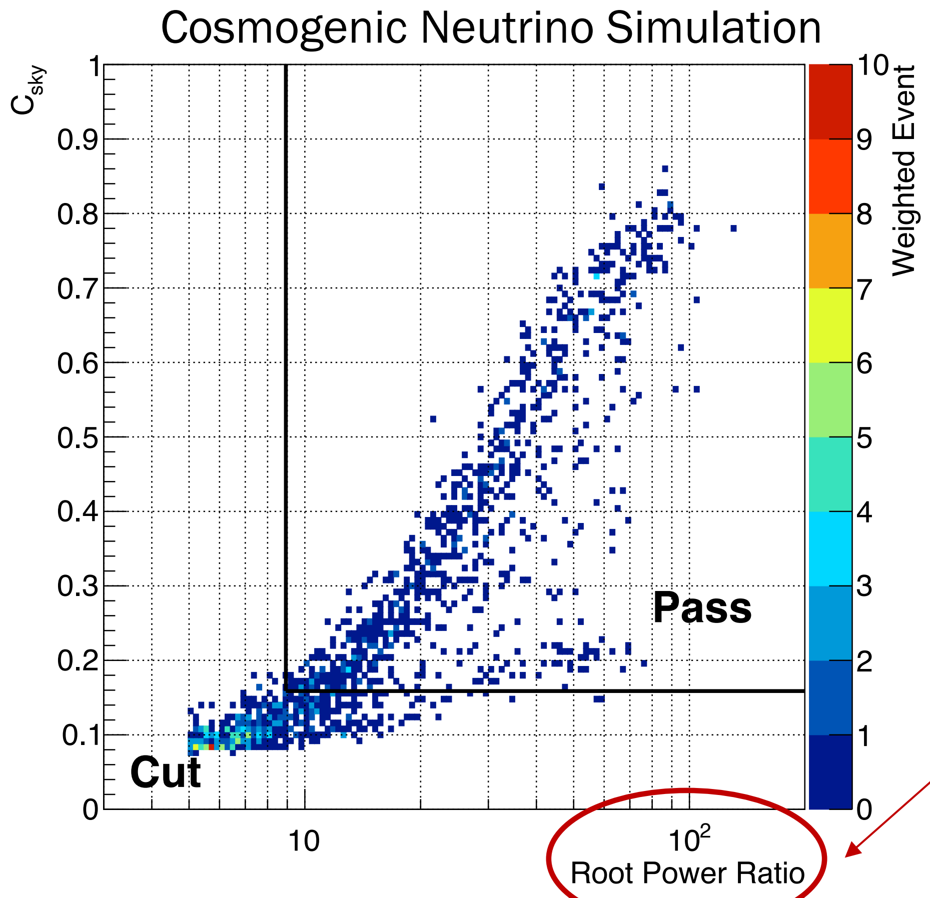
Unnormalized Summed cross-correlation (coherence)

Separating Signal and Background

- Linear discriminant separates backgrounds from neutrinos
- Optimize cut for best limit (~0.1 passing events/year)

“Reconstruction quality” parameter

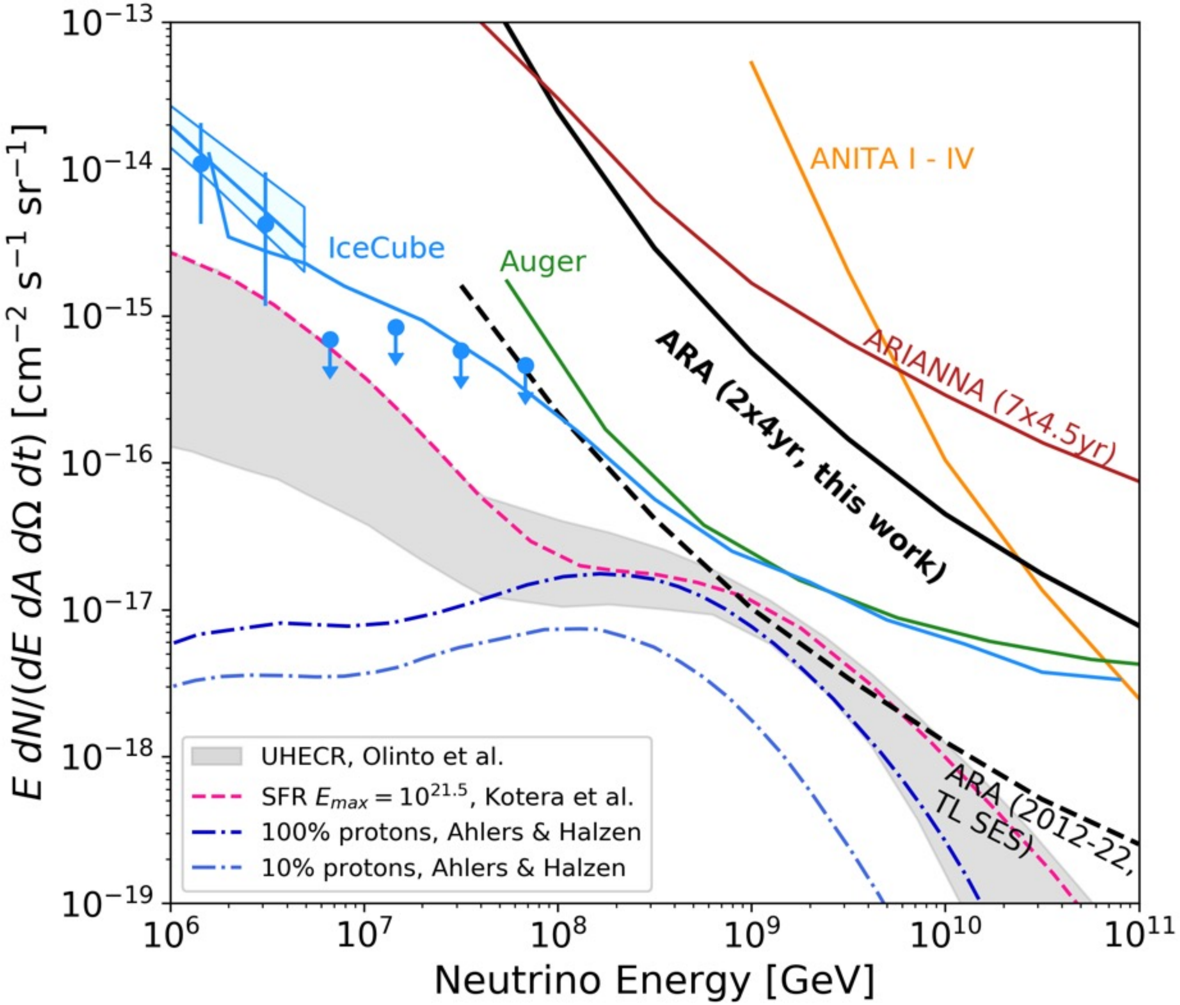




”SNR-like” measure

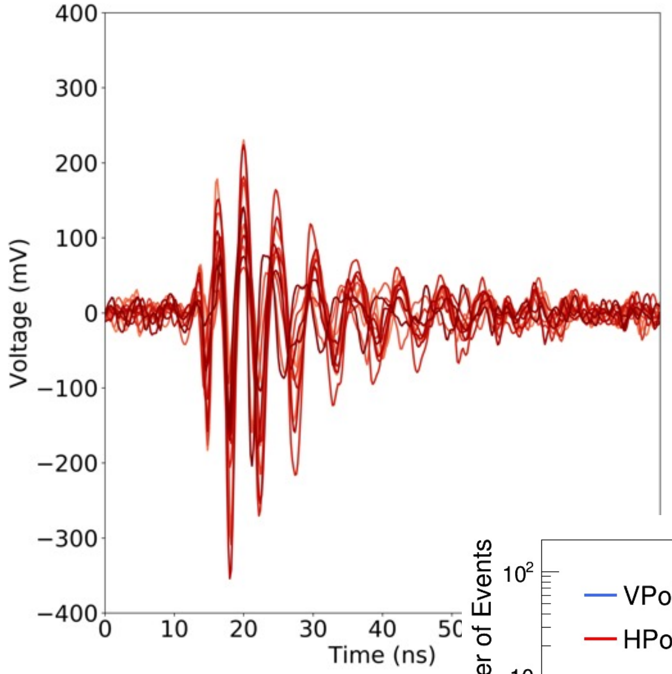
Analysis: Results

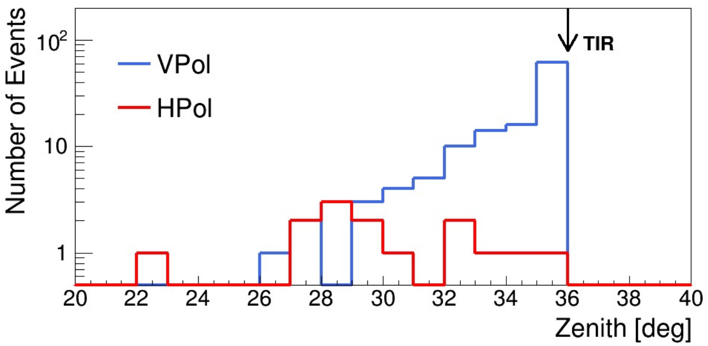
- Observe no statistically significant excess on background of 10^{-2}
- Result is best limit set by in-ice radio neutrino detector, and uses *only half the data on archive already*
- By 2022, ARA will have world-leading sensitivity and carve out exciting new parameter space
- A source search using the same data is underway—see talk by J. Torres in this same session



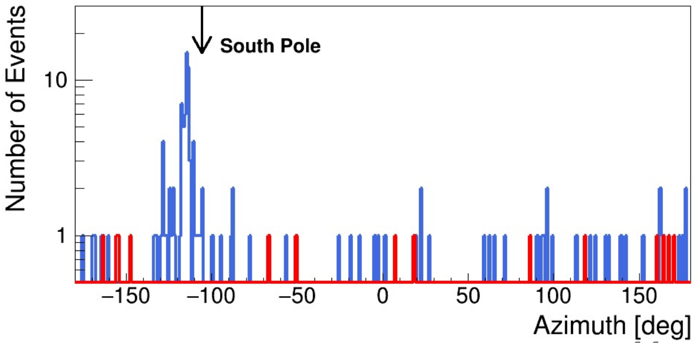
Cosmic Ray Candidates

- Radio emission from CR air showers is seen in other experiments, e.g. ANITA and ARIANNA
- In the A2&3 search, some events pass the neutrino search criteria, *except* reconstruct *outside* the ice
  - 23 isolated events in HPol
  - 200 isolated events in VPol (expected to be mostly background)
- Dedicated search and study is ongoing

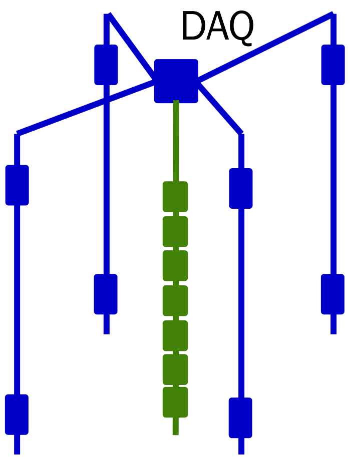




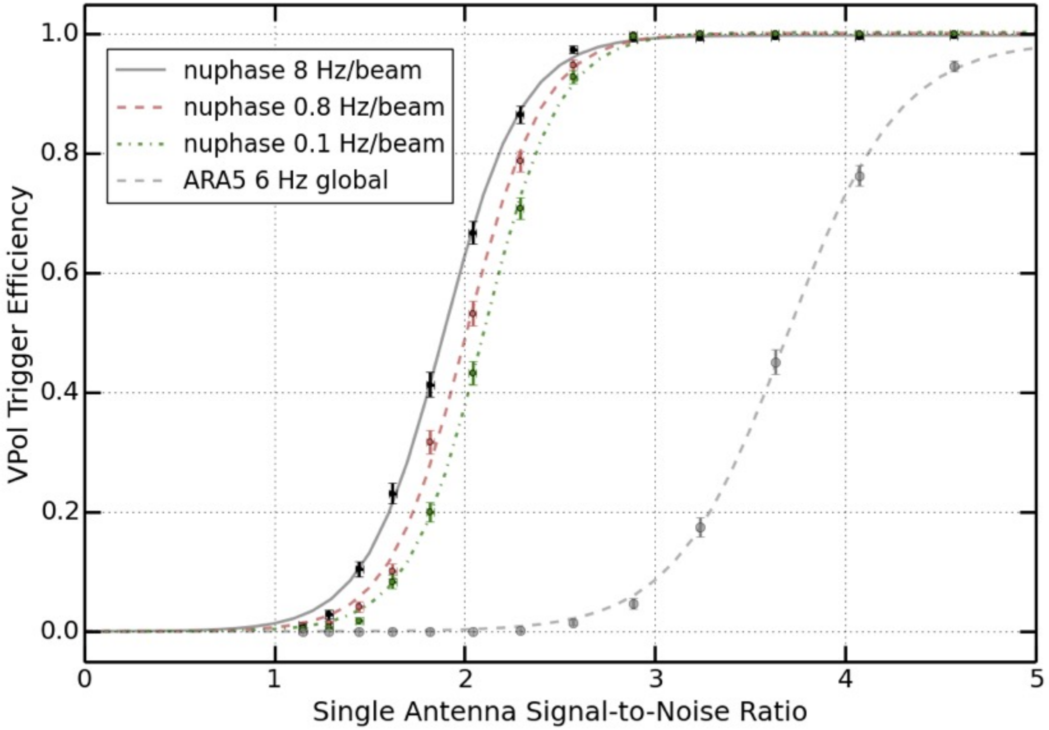
Spatial Distribution of A2 isolated HPol events relative to isolated VPol events

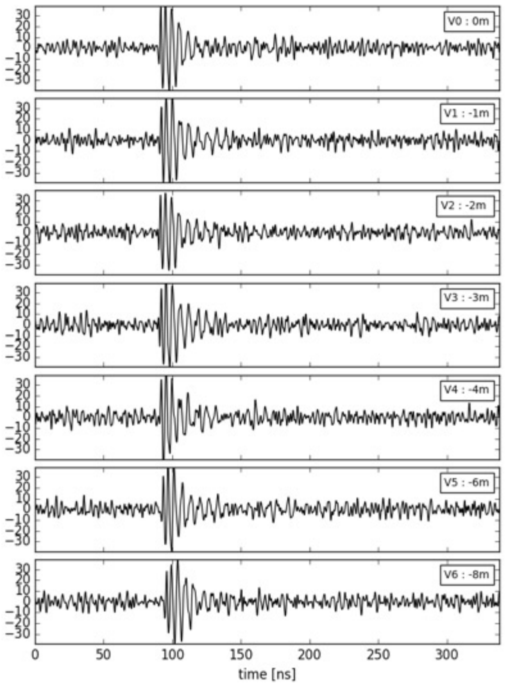


Improving Trigger and Analysis Efficiencies



- ARA5 is equipped with a *phased array* trigger
- Beamform *before* triggering → ~2x lower triggering threshold
- Analysis efforts underway to lower *analysis* thresholds (see talk by K. Hughes in this session)





See 10.1016/j.nima.2019.01.067

Summary

1. Neutrinos are important and complimentary messengers to the cosmos

2. ARA 2x4yr analysis is best limit by in-ice radio detector, and will be world-leading by 2022.

3. Efforts are accelerating to improve analysis efficiencies, quantify reconstruction performance, etc.

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