Latest Analysis Updates from the Askaryan Radio Array

Brian Clark for the ARA Collaboration

The Ohio State University
Department of Physics and
the Center for Cosmology and Astroparticle Physics (CCAPP)

April 15, 2019
APS April Meeting—Denver, CO
About Askaryan Radio Array

Designed to detect radio impulses from UHE neutrino-ice interactions

- 8 VPol & 8 HPol antennas deployed in 200m “boreholes”
- 5 stations deployed, the latest (A5) with enhanced phased array trigger

Figure by T. Meures

Neutrinos, Cosmic Rays, and Ice with ARA

15 April 2019
The ARA Collaboration

USA
- Cal Poly
- The Ohio State University
- Otterbein University
- University of Chicago
- University of Delaware
- University of Kansas
- University of Maryland
- University of Nebraska
- University of Wisconsin-Madison

International Collaborators
- Chiba University
- National Taiwan University
- University College London
- Vrije Universiteit Brussel
- Weizmann Institute of Science
• A2 and A3 collecting data since Feb 2013—10 months of data published previously [P. Allison et. al. 2016 PRD 93, 082003 (2016)]

• Expansion to the 2013-2016 data set underway in two parallel analyses

• 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

\[
\frac{V_{peak}}{\sigma_{noise}} \geq N_{thresh}
\]
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
Diffuse Neutrino Search: Separating Signal and Background

• A linear discriminant in the SNR-vs-correlation plane separates backgrounds from neutrinos

• Examples:
  – Box in the plane
  – Line in the plane

• Choose line or box to achieve necessary background rejection (~0.1 passing events/year)
Diffuse Neutrino Search: Projected Limits

- Limits include analysis efficiencies, which are ~40% at an EeV

- Projections for ARA5 have exciting physics reach—world leading above 10EeV
What’s next: Source Searches

• ARA continuously monitors 35% of the southern sky
  – Useful multimessenger instrument
  – For both flaring and steady state sources

• Cen A is in the field-of-view
  – Auger sees a spatial correlation with a handful of UHECRs [Auger 2007, Science Vol. 318, Issue 5852]
  – UHE neutrino emission is expected [e.g. Cuoco ’08, Kachelriess ’09]
Antarctic Ice Properties: Attenuation Length

- Pulsers deployed on IceCube strings 1 and 22 illuminate the entire array.

- Pulse amplitude at A4 vs A5 is the longest horizontal-baseline measurement of $L_\alpha$

\[
\frac{SNR_{A5}}{SNR_{A4}} = \frac{r_4}{r_5} e^{\frac{r_4-r_5}{L_\alpha}}
\]

New measurement:

$\langle L_\alpha \rangle_{z<1500} = 1660^{+255}_{-120}$ m

$\langle L_\alpha \rangle_{z<2550} = 820^{+120}_{-65}$ m

Adapted from [P. Allison et. al.]. astropartphys.2011.11.010
Antarctic Ice Properties: Constraining $n(z)$

- In Austral season ‘18 and ‘19, we deployed pulser down the South Pole IceCore (SPIce) hole

- The depth dependent index of refraction produces two solutions: direct and reflected/refracted

- Time-difference between pulses is sensitive to $n(z)$
Search for Cosmic Rays

- Cosmic rays are useful “test beam”
- Use CoREAS to generate templates
- Emission is dominant in HPol, as expected from geomagnetic emission at South Pole
Summary

1. New neutrino search with 4x the livetime is nearly complete—ARA is closing in on world leading limits

2. Measurements of the Antarctic ice will improve our detector modelling and reconstruction capabilities

3. A template-based search for CR’s is underway, and will serve as important “calibration beam” for ARA

The OSU ARA Team is generously supported by:
- NSF GRFP Award DGE-1343012
- NSF Awards 1255557, 1806923, 1404212
Back-up Slides
Reconstruction Details

- Interferometry based reconstruction:
  - Putative source angle → Time Delay between antennas → Correlation Value
  - Take Hilbert envelope to interpret as power
Interferometry (cont.)

- For pair of antennas, compute time delays and correlation values for all points on the sky
  - Propose a source distance, $\theta$, and $\phi$
  - Trace ray from source to array center

- Sum up correlation value for many pairs of antennas

- Interpret peak in map as source direction

Interferograms by E. Hong

1. P. Allison et. al. j.astropartphys.2015.04.006
2. P. Allison et. al. j.astropartphys.2016.12.003
Choosing a Box Cut

- Thermal cut: fit coherence distribution with GEV, determine the $10^{-8}$ background rejection cut value
- SNR Cut: Fit Weibull distribution, extrapolate to same background rate ($\sim 0.1/\text{yr}$)
Choosing a Slanted Cut

• Optimize the slope and intercept to achieve best limit on a Kotera flux of neutrinos

• Background estimate comes from exponential fit to the data when projected onto the SNR axis
Search for Cosmic Rays

- Cosmic rays are useful “test beam” (flux and the physics of geomagnetic emission is well understood, e.g., ANITA, AERA, Tunka-Rex)

- CoREAS provides emission at the ice surface, which is propagated to the antennas, and folded with the detector response
Search for Cosmic Rays: Templates

• Example CoREAS template
  – EeV shower at 60° inclination
  – Hadronic modelling with QGSJETII.04 UrQMD 1.3

• CoREAS provides emission at the ice surface, which is propagated to the antennas, and folded with the detector response

• Emission is dominant in HPol channels, as expected from geomagnetic emission at South Pole
“Zenith angle distribution of detected neutrino arrival directions for a range of neutrino energies. Events are detected over a range from $\sim 45^\circ$ above the horizon to $\sim 5^\circ$ below it.”