ASKARYAN RADIO ARRAY

THE OHIO STATE UNIVERSITY

CCAPP

Latest Updates in the Search for Ultra-High Energy Neutrinos with the Askaryan Radio Array

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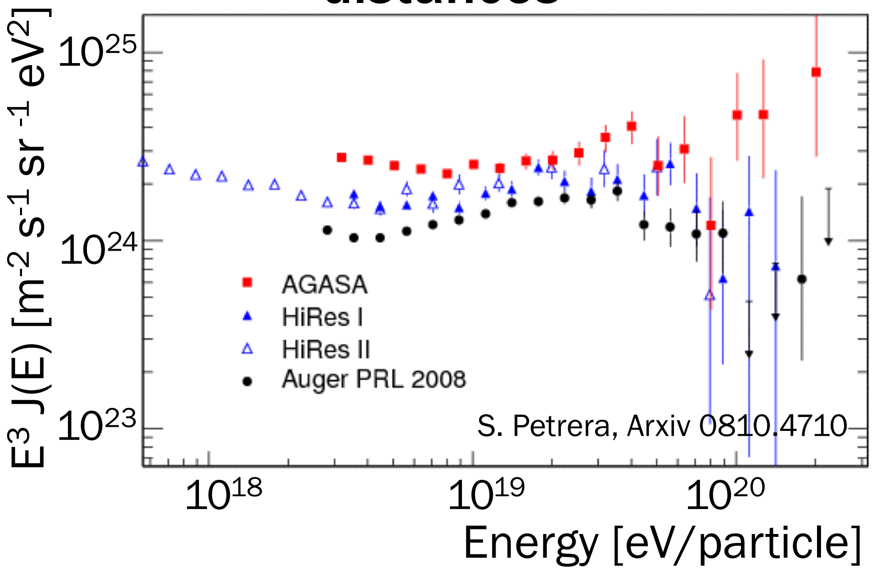
Why Study EeV Neutrinos?

Astrophysics

Probe highest energies at cosmic distances



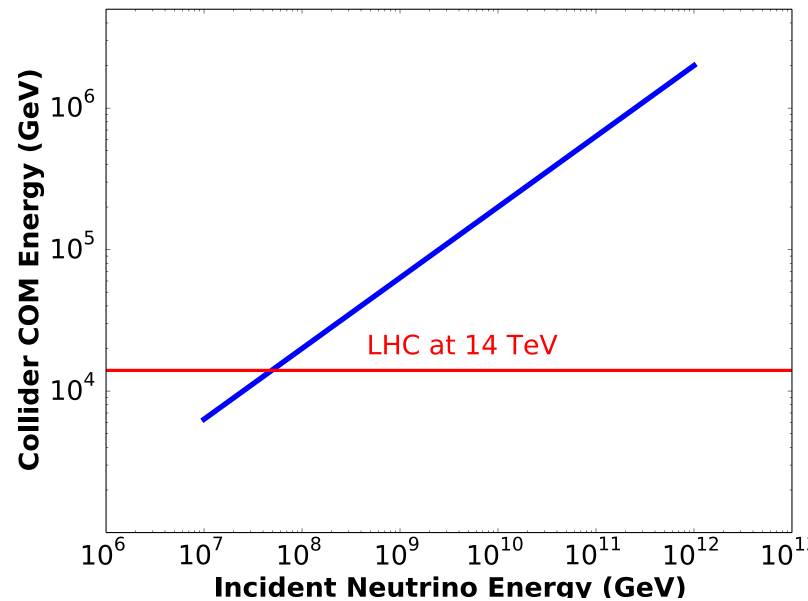
Cosmic rays >$10^{19.5}$ eV attenuated, e.g.:

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

Gamma rays pair-annihilate (with EBL) above ~1 TeV

Particle Physics

Measure cross sections at >LHC energies



10^{18} eV neutrino interacting in ice has COM energy of ~60 TeV

$$E_{COM} = \sqrt{4\, E_{\nu}\, m_{n}}$$

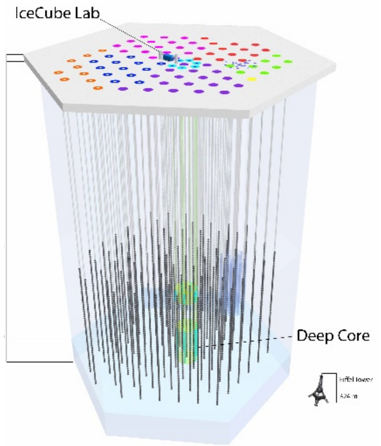
Detecting an UHE Neutrino

Rare Signal

- Low fluxes (~10/km^3/yr) and low cross-sections (interaction length ~300km in rock)
- Need ~100 km^3 of target volume to enable detection (e.g., few per year)
- Several Options:
  - Balloon experiments: radio
  - *In-Situ* experiments: optical, radio
  - Ground based arrays: air shower, radio

ANITA-III (radio)

IceCube (optical)



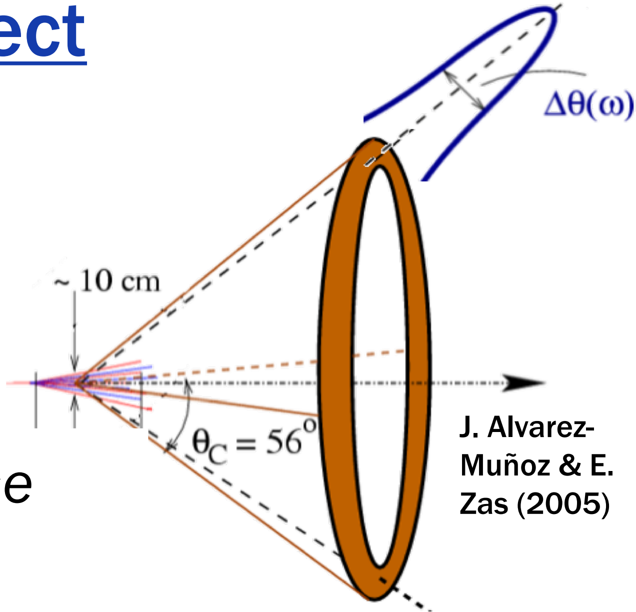
LUNASKA (radio)

Auger (air shower)

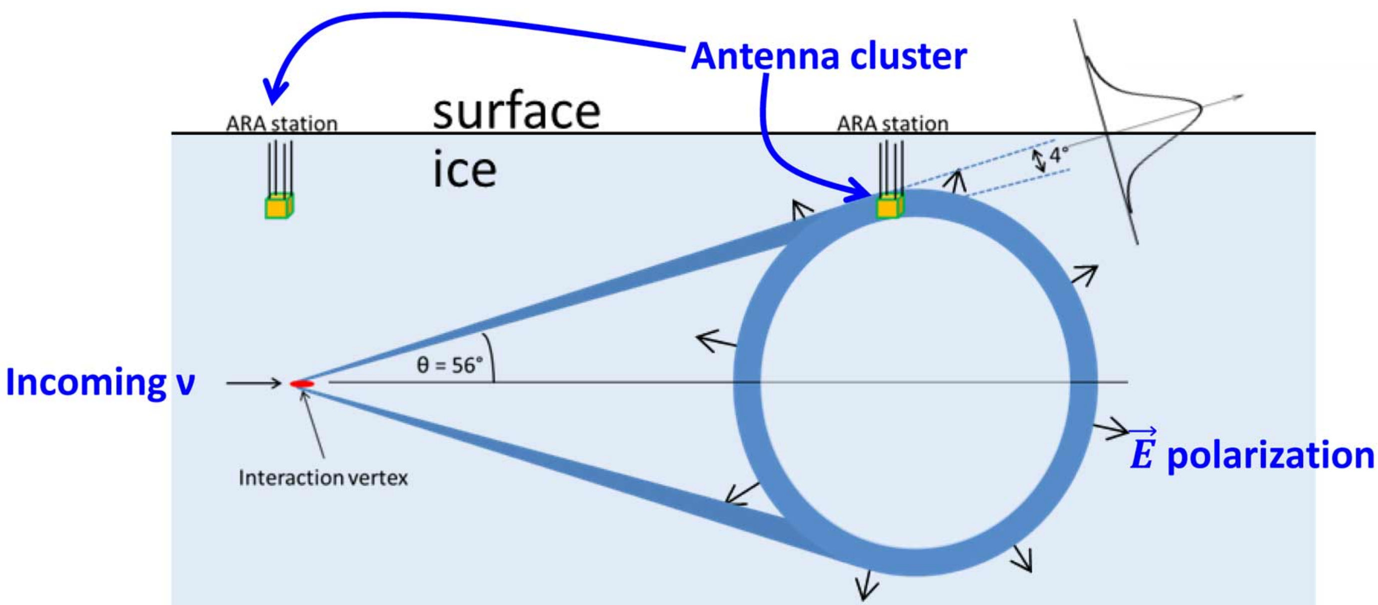
Radio Cherenkov Effect

How ARA will measure neutrinos

- Neutrino-induced particle showers develop negative charge excesses
- Wavelengths the size of the bunch (~10cm) add *coherently*
- Get Broadband (200 MHz → 1.2GHz) radio *pulse*
- Conical emission (57 ° in ice); strongest on cone

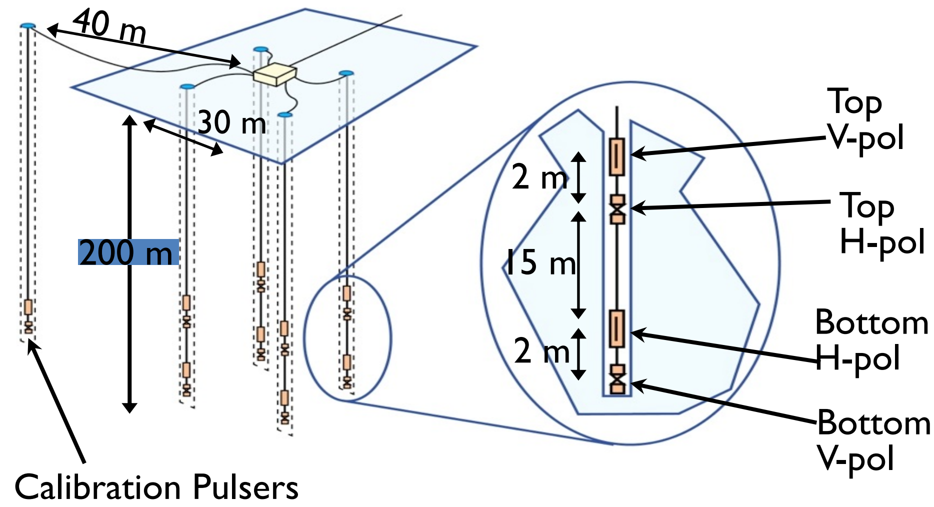


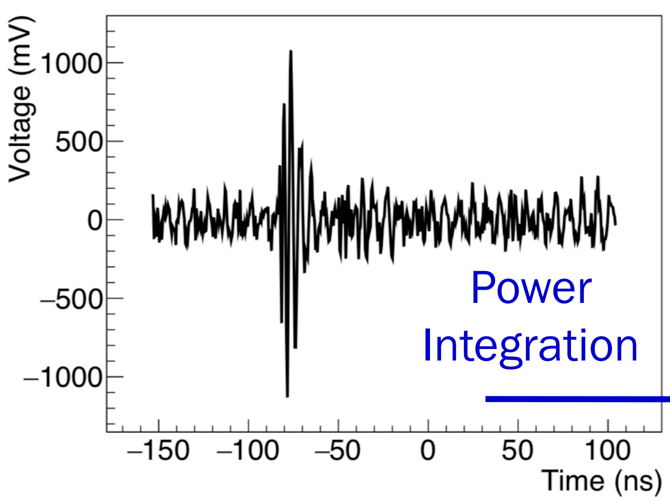
J. Alvarez-Muñoz & E. Zas (2005)

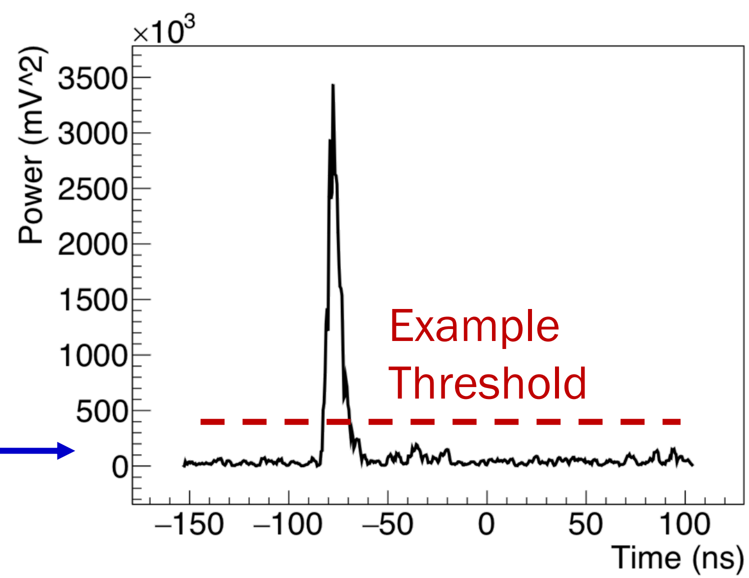


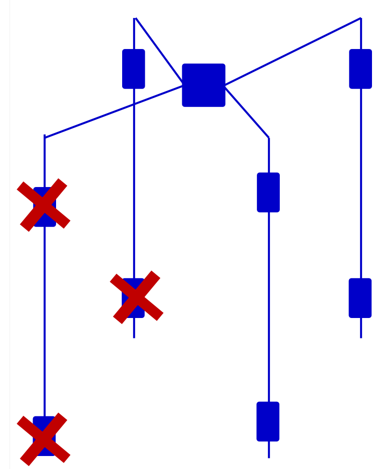
Askaryan Radio Array (ARA)

- 16 antennas (8 V-pol, 8 H-pol, 200-850 MHz bandwidth)
- Cubical lattice at 200m depth
- Energy range: $10^{16} \rightarrow 10^{19}$ eV
- Trigger when 3/8 antennas see something impulsive
- 5 Hz of triggers → 1.6×10^{8} events/year/station!



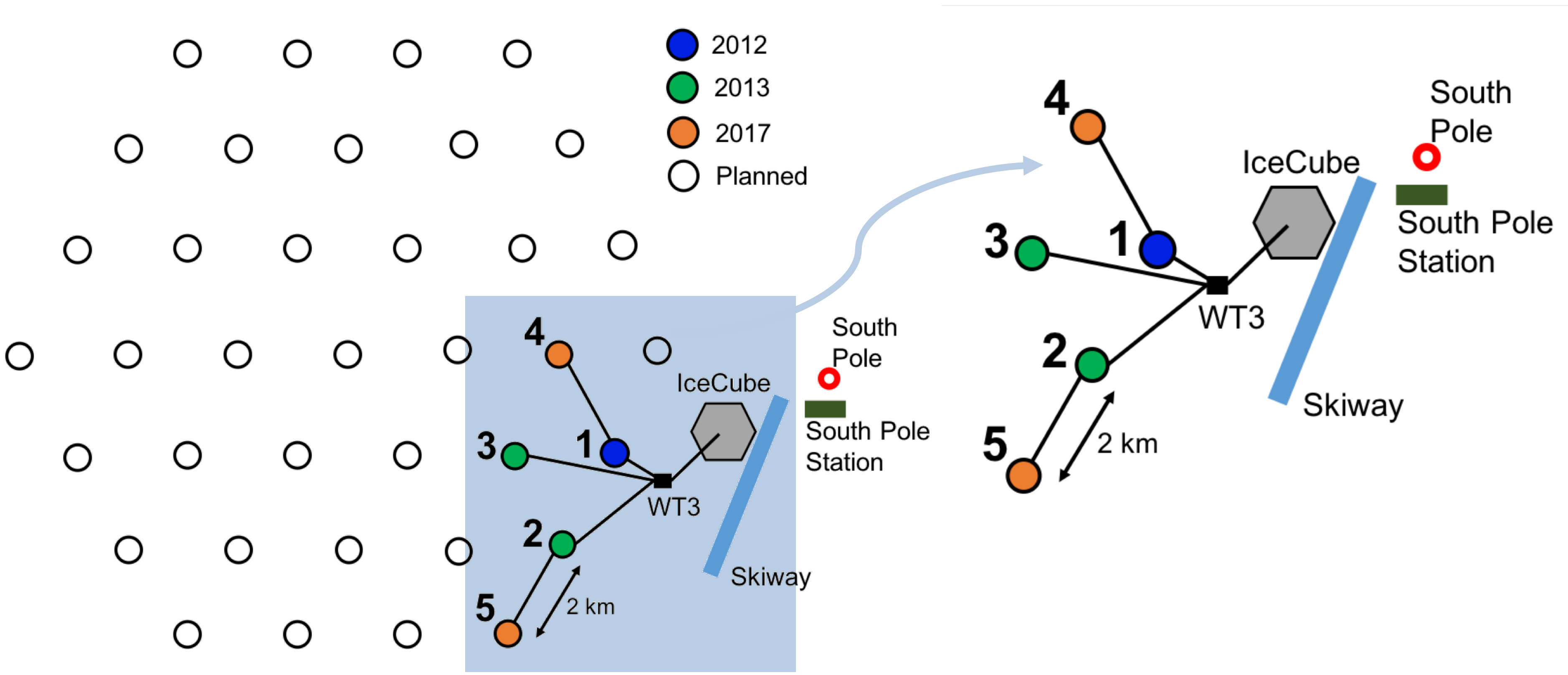






Current Status of the Instrument

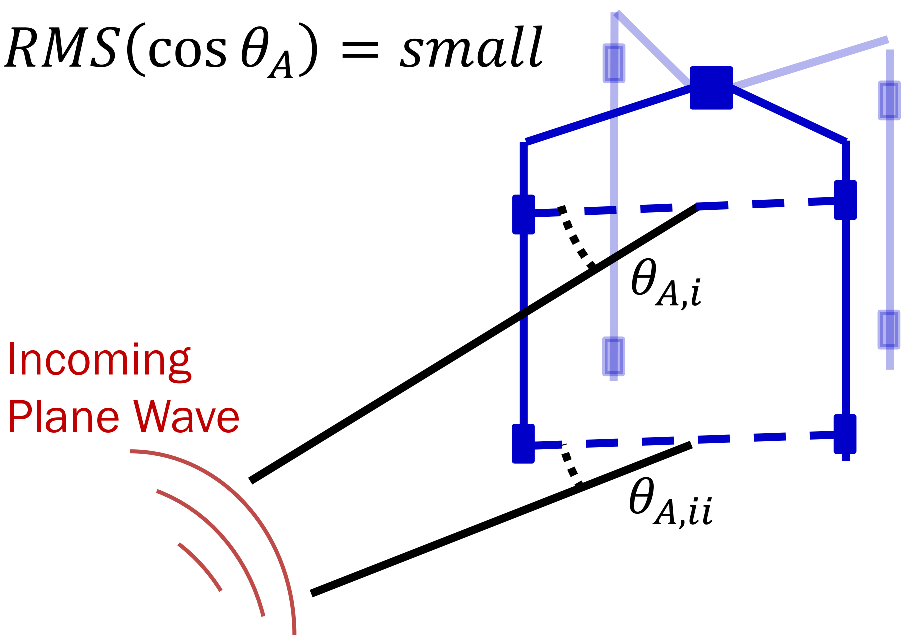
- Under phased construction in the ice near South Pole
- Phase 1 goal is ~37 stations, spaced 2km apart, covering ~100 km^2 of ice
- Prototype ("Testbed") + 5 (!) stations deployed so far

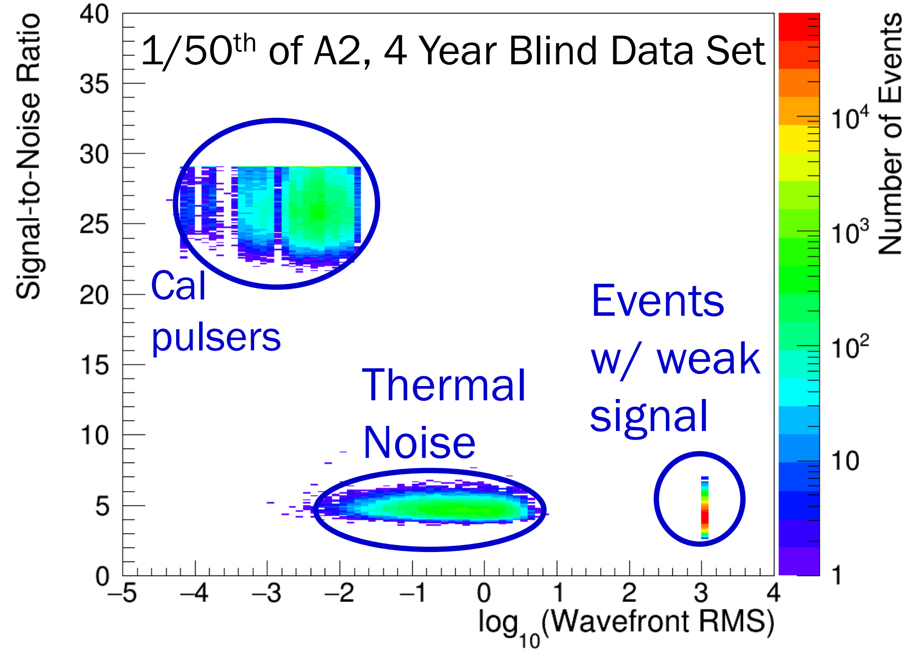


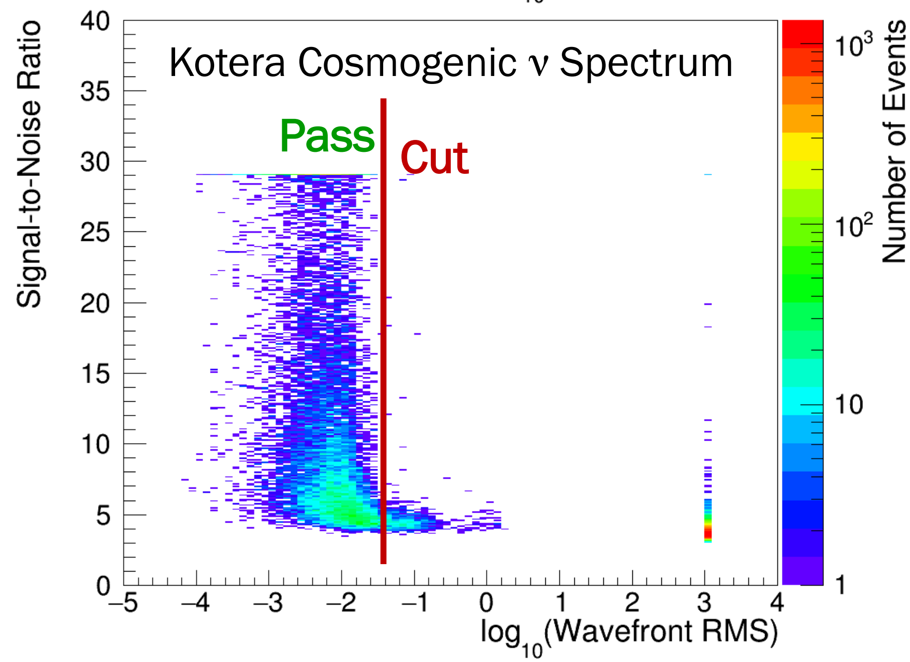
Data Analysis: Event Filter

- Use regular ARA station geometry to remove events without plane-wave properties
- Large variation in signal arrival directions between cube faces → cut event

$$RMS(\cos\theta_A) = small$$

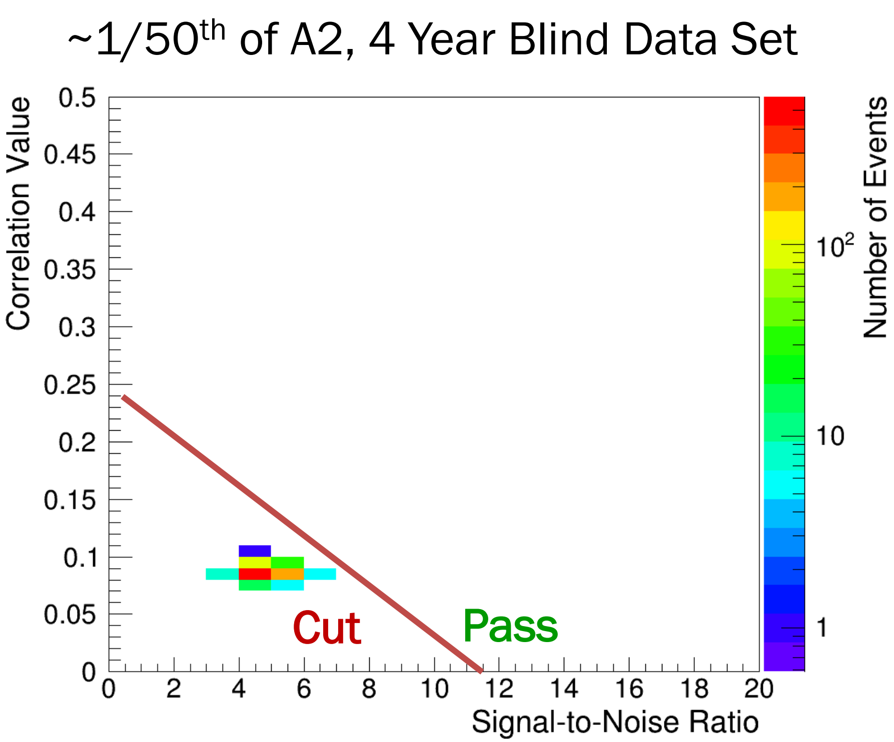


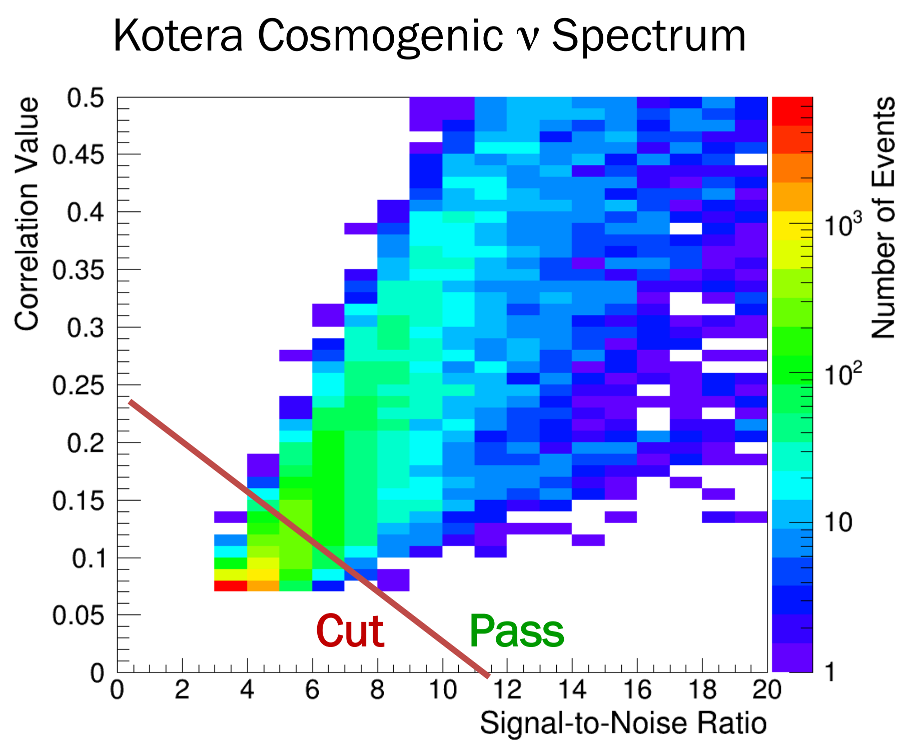




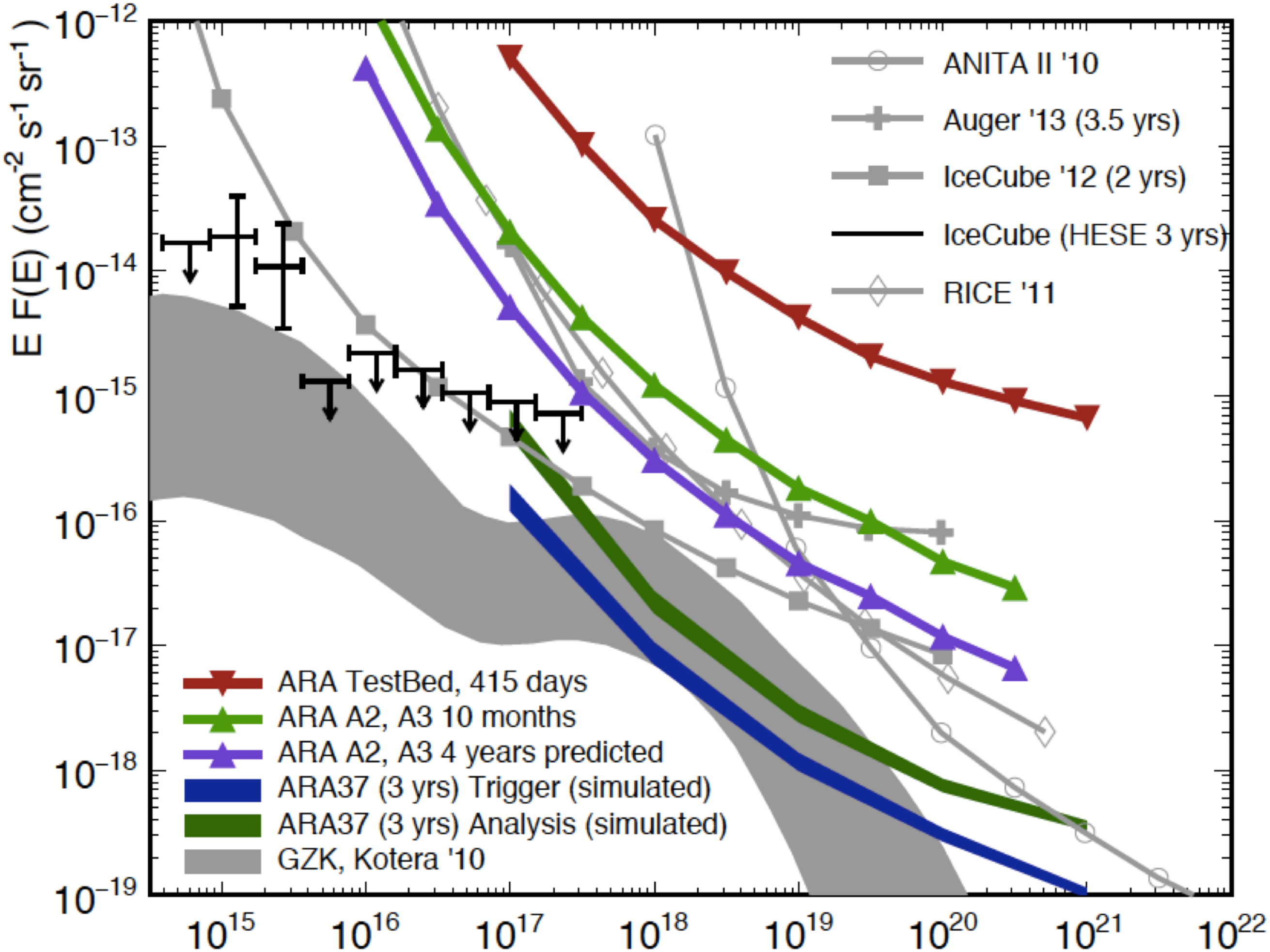
Data Analysis: Final Cut

- Calibration sources and human contaminated events are removed
- Final cut: line in the plane of signal-to-noise ratio vs waveform cross-correlation → chosen to set the strongest possible limit





Estimate of Diffuse Analysis Sensitivity



C. Pfender, APS April U17.00006

ARA becomes competitive with Auger/IceCube at high energies.

Phase 1 array should probe even pessimistic cosmogenic models.

Summary

- Neutrinos are key windows to fundamental physics
- The ARA two station limit will begin to be competitive with existing experiments
- Projections for ARA-Phase1 will dig deeply into neutrino models

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- The OSU Center for Cosmology and Astroparticle Physics
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Back-up Slides

Astrophysical Messengers

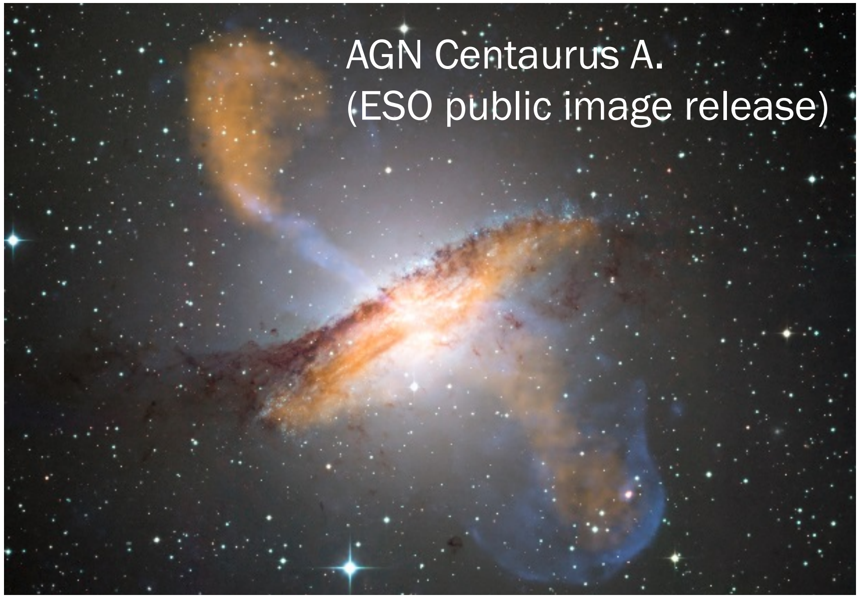
Two Sources of Neutrinos

- *Predicted* "BZ Flux": pions from GZK process decay into neutrinos
- "Source Flux": Neutrinos from the CR accelerators
  - Gamma Ray Bursts (GRB)
  - Active Galactic Nuclei (AGN)

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$
$$\rightarrow e^+ + \nu_e + \bar{\nu}_\mu + \nu_\mu$$

Neutrinos have attractive properties

- Weakly interacting: travel cosmic distances unattenuated
- Chargeless: not deflected by (inter) galactic magnetic field → point back to source!



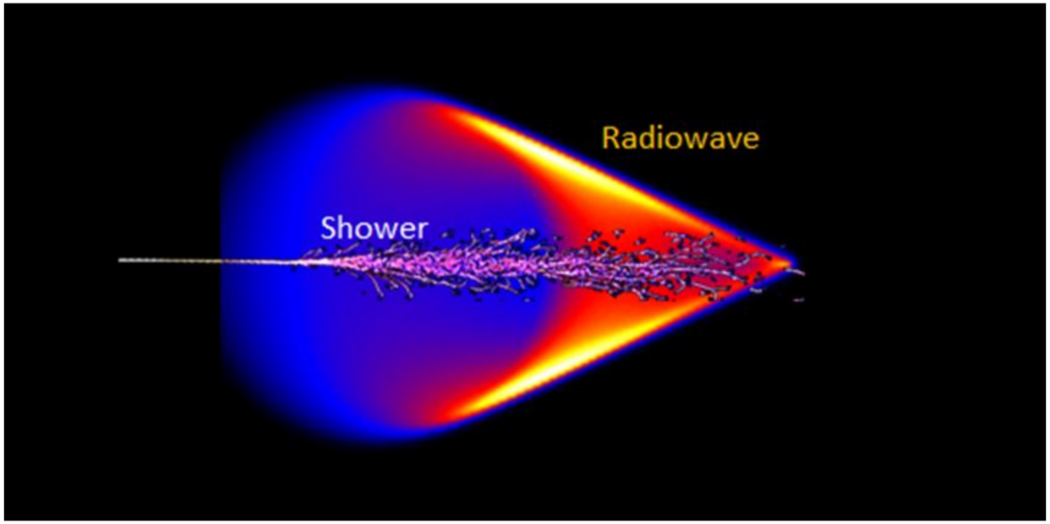
Neutrino Interactions

- Two varieties of interactions: Charged current (CC) and Neutral Current (NC)

CC: $\nu_\ell + N \rightarrow \ell + X$
$\ell \rightarrow EM\ Shower$

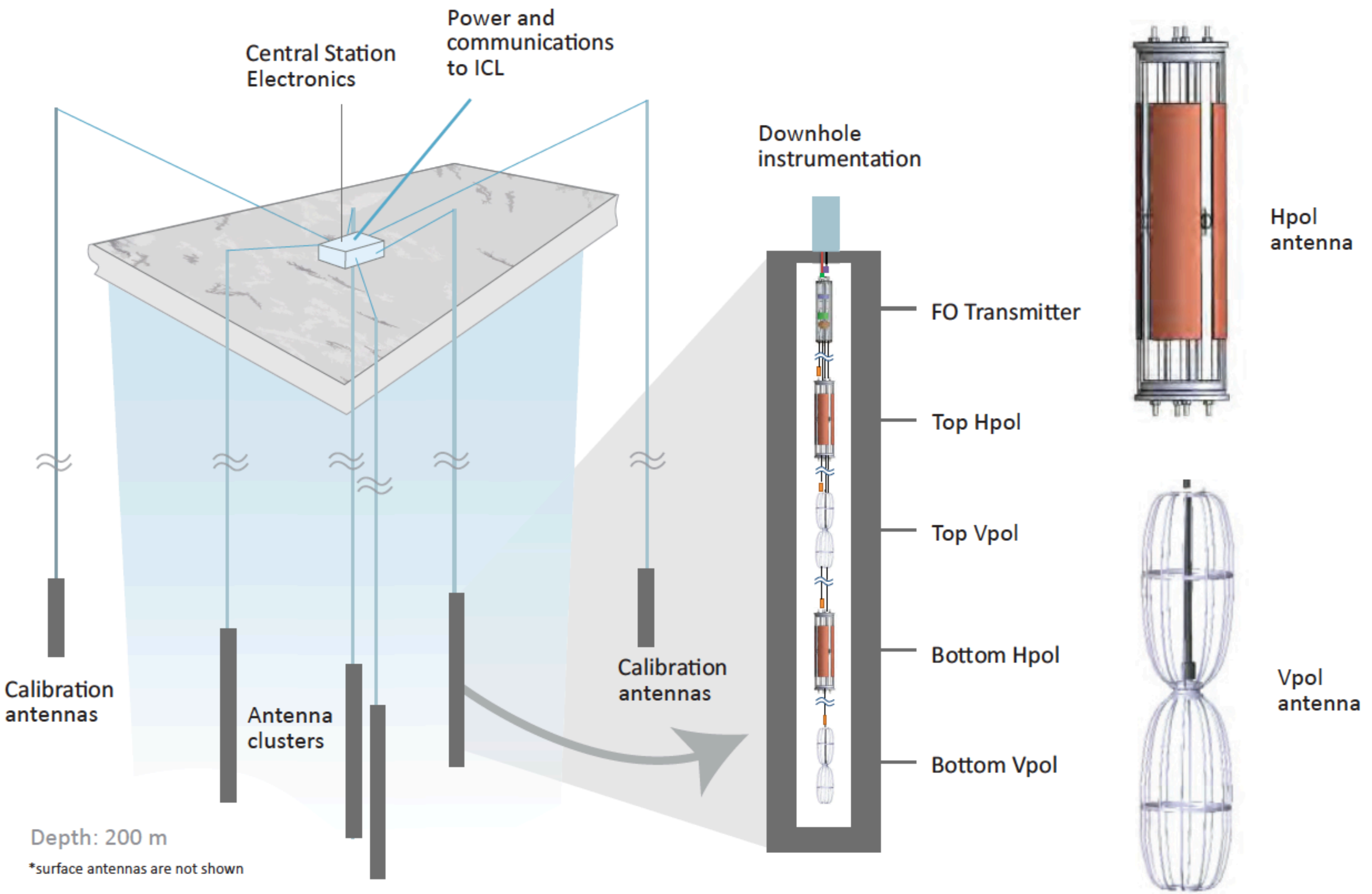
NC: $\nu + N \rightarrow \nu + X$
$X \rightarrow Hadronic\ Shower$

- Showers are ultra-relativistic ($\beta \approx 1$) $\longrightarrow$ emit Cherenkov radiation in dense dielectric media (i.e., water, ice)
- Intensity is greatest at Cherenkov angle θ_C
- Two varieties of interest: optical (IceCube) and radio (ARA/ANITA)



$$\cos\theta_C = \frac{1}{n\beta}$$

Alternate Station Schematic



USA:

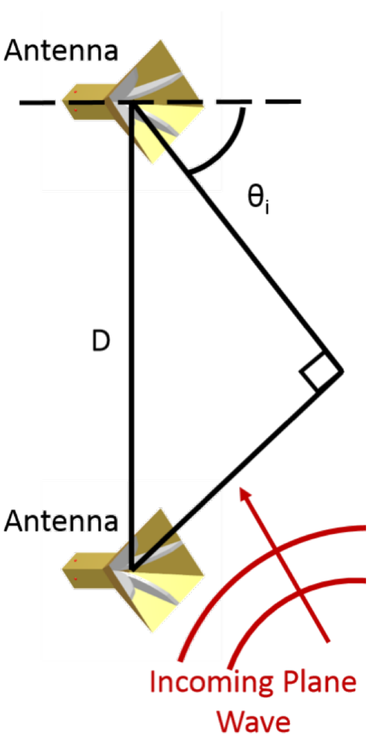
- Ohio State University
- Cal Poly
- University of Chicago
- University of Delaware
- University of Kansas
- University of Maryland
- University of Nebraska
- University of Wisconsin – Madison

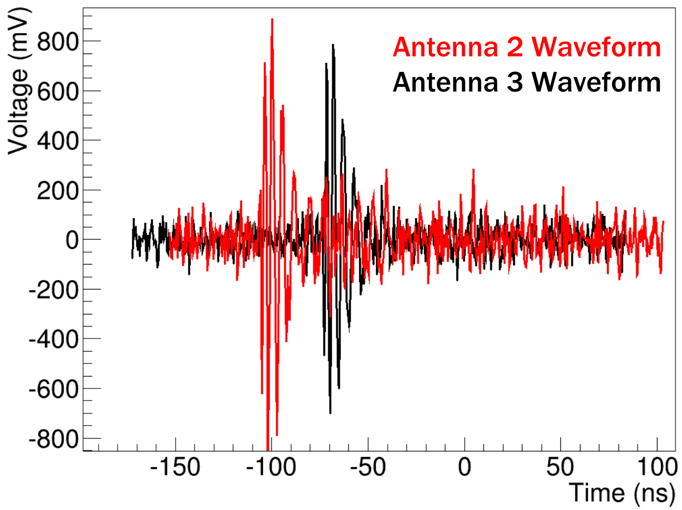
ARA is an International Collaboration

UK:	University College London
Belgium:	Université Libre de Bruxelles
Japan:	Chiba University
Taiwan:	National Taiwan University
Israel:	Weizmann Institute of Science

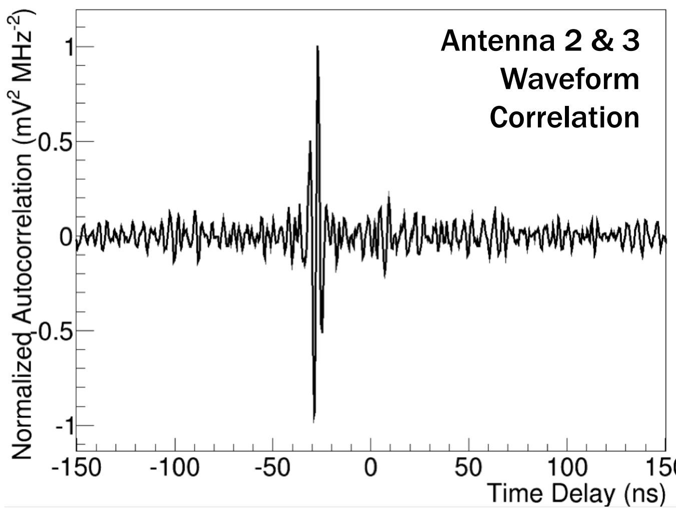
Interferometric Maps

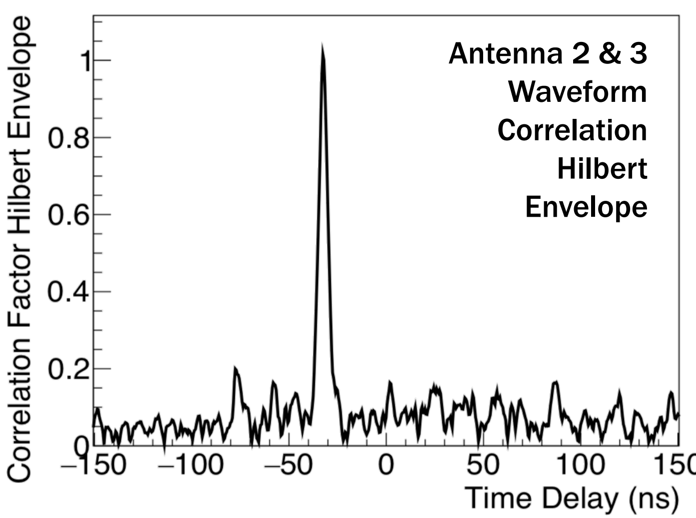
- Timing information → geometry information
- Punitive source angle → Time Delay → Correlation Value for that delay
- Take Hilbert envelope to interpret as *power*





$$\theta_i = \arcsin\left(\frac{c\,\Delta t}{D}\right)$$

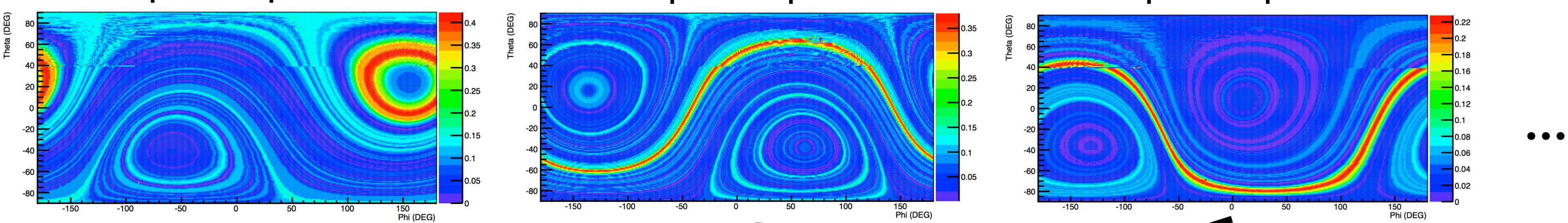




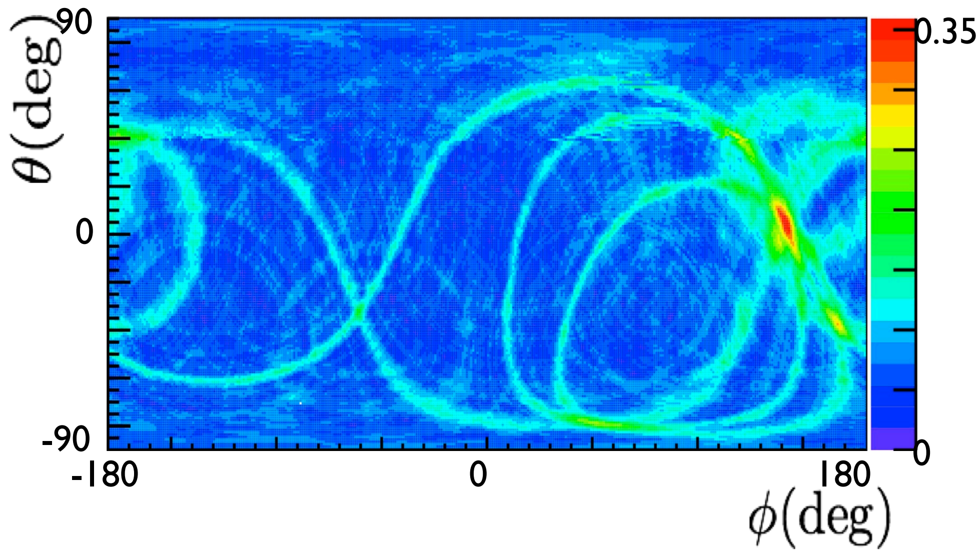
Interferometric Maps

- Punitive source angle → Time Delay → Correlation Value for that delay
- Plot that correlation value for all points on the sky, for all pairs of antennas

Map from pair 1 | Map from pair 2 | Map from pair 3



Figures by E. Hong



Peak in final map gives source direction