

Interferometry in UHE particle astrophysics

Andres Romero-Wolf
Jet Propulsion Laboratory,
California Institute of Technology
April 22, 2012



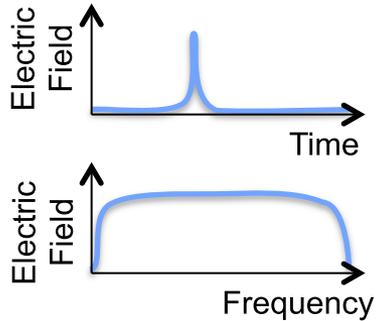
Motivation



- First detection of ultra-high energy neutrinos are expected to lie close to the detector threshold.
- Increased demands for higher sensitivity techniques to reduce the detection threshold.
- Interferometric techniques have been applied for decades to improve sensitivity to weak signals.



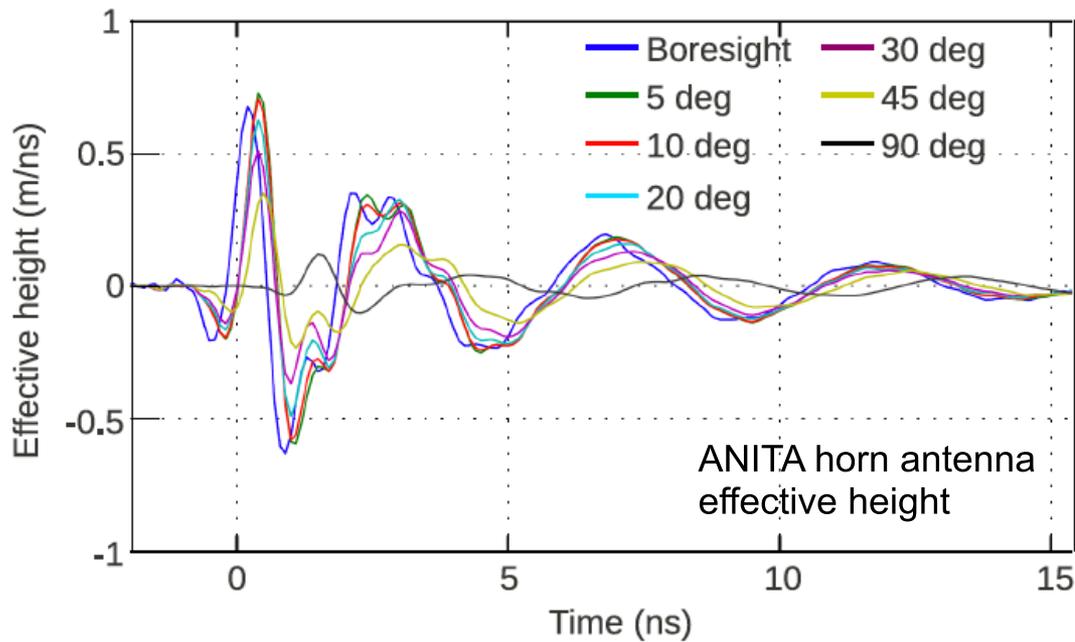
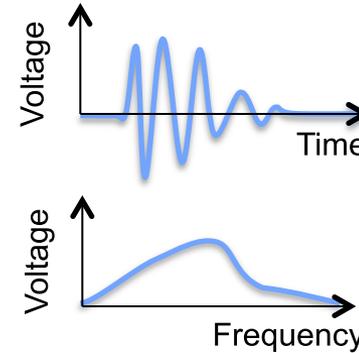
Impulse Response



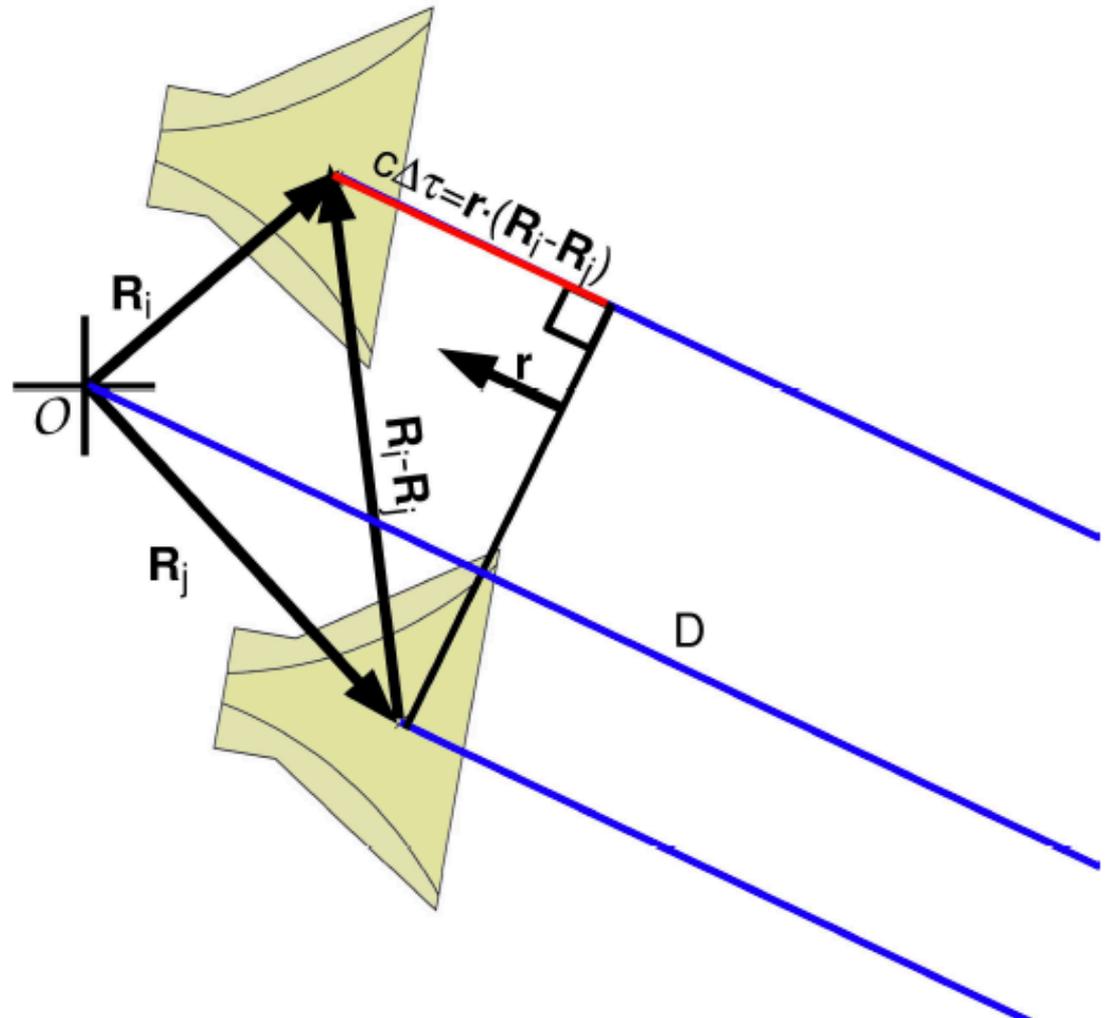
Impulse response
Or Effective Height

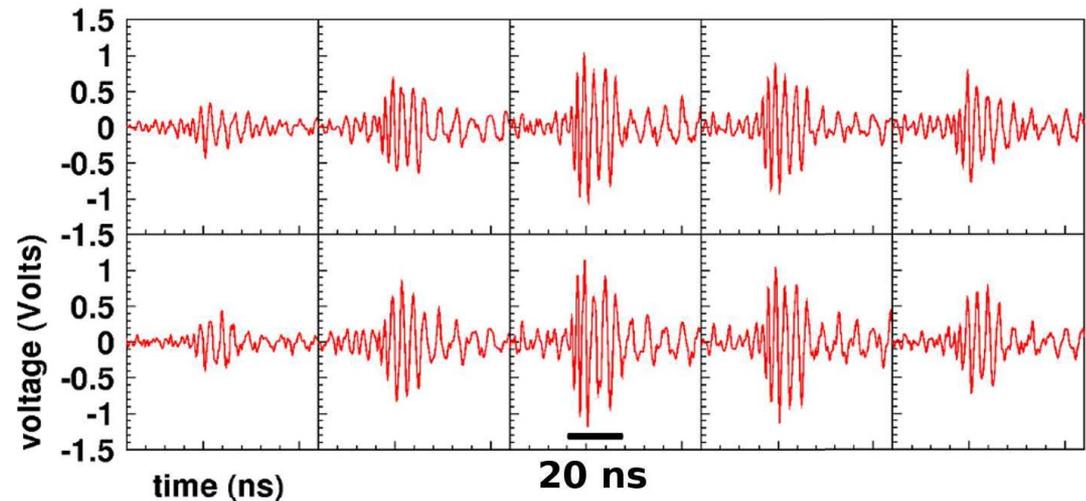
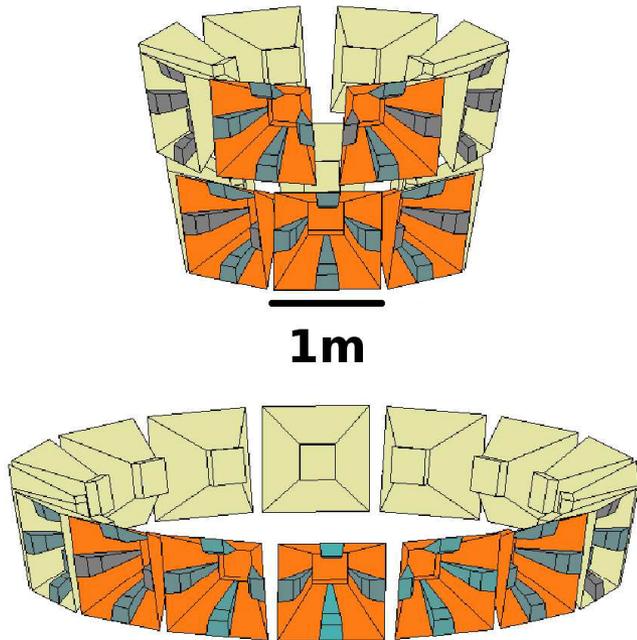


$$v = E \star h$$

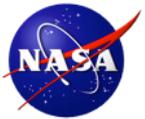


- Beam forming combines the signals from multiple antennas.
- The geometric delay is the basic quantity that connects multiple observations of the same signal.





- ANITA antenna array observes the same impulse with multiple channels.
- The array is unusual in that the antennas are not all pointed in the same direction.
- The arrangement is designed for full azimuthal coverage.

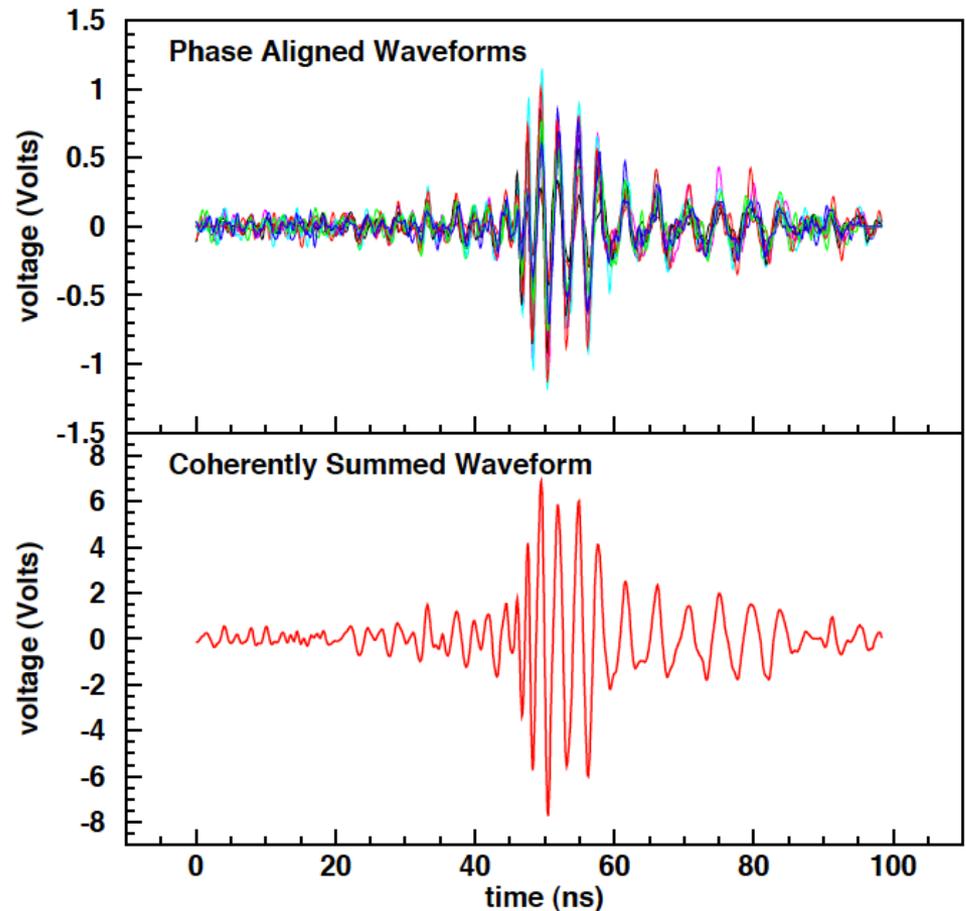


Beam-forming



The signals from the previous slide are aligned in time according to the true geometric delay of the signal.

The directional response of the antennas does not affect the phase of the signal and it can be added coherently.





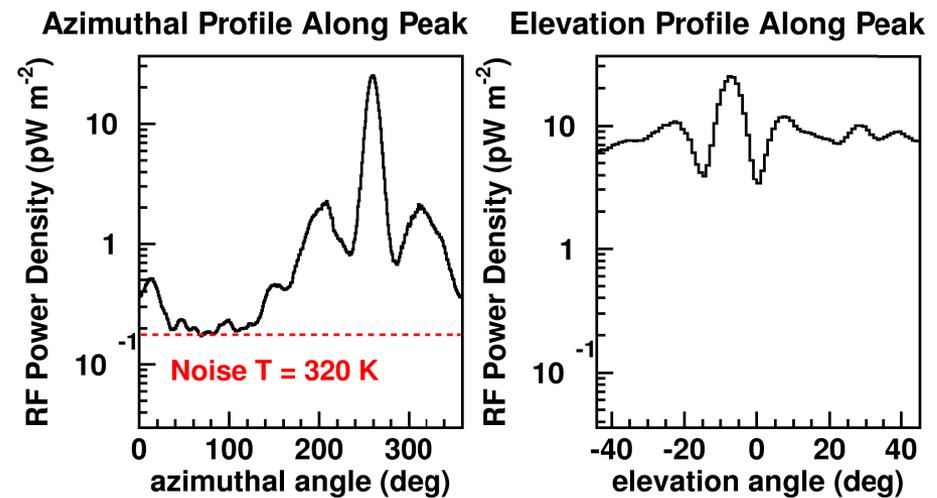
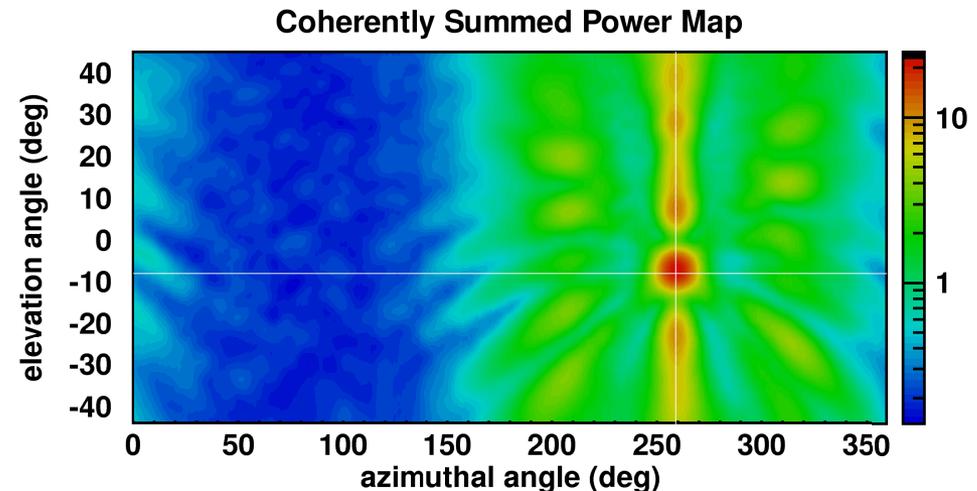
Coherently Summed Waveform Power



Global image of the coherently summed power for each assumed direction of the incident radiation.

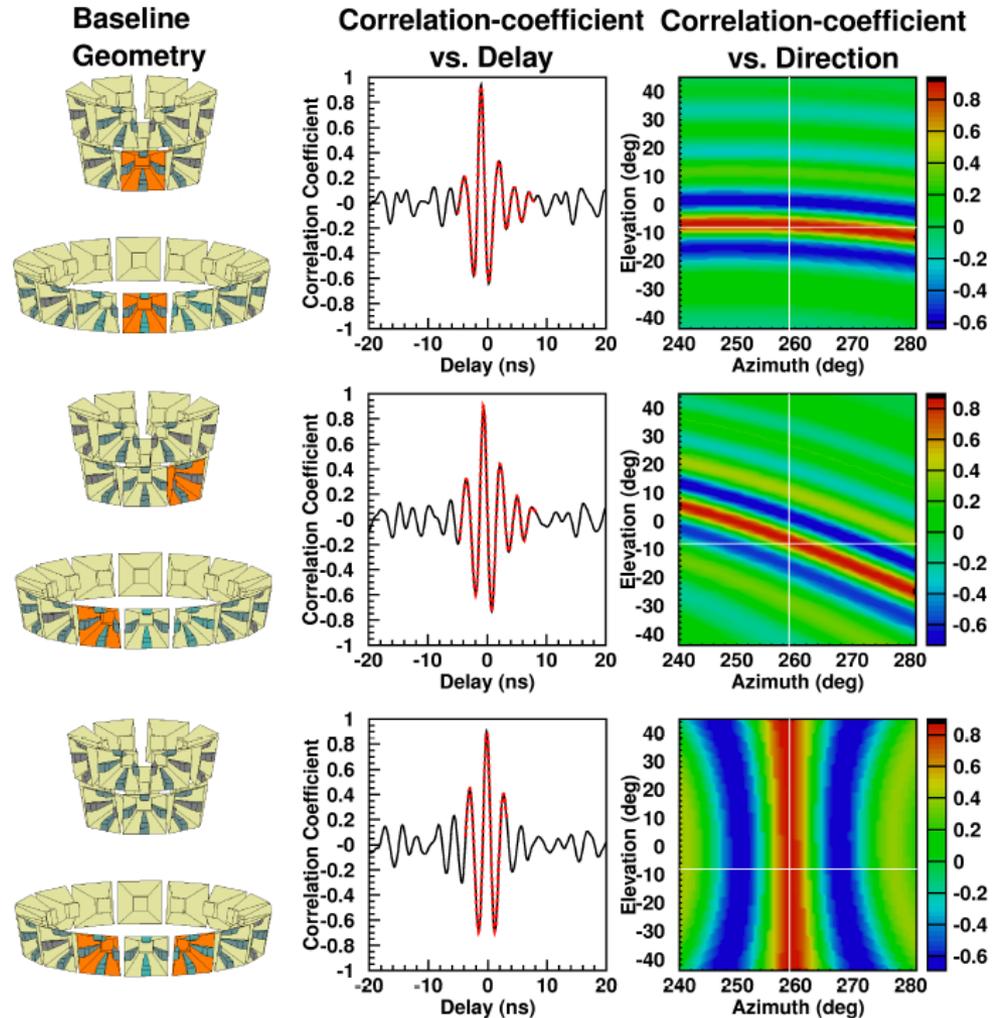
The direction of true incidence presents itself as a sharp peak.

The diametrically opposed direction sees the thermal noise background.



Cross-correlations of an impulsive signal event.

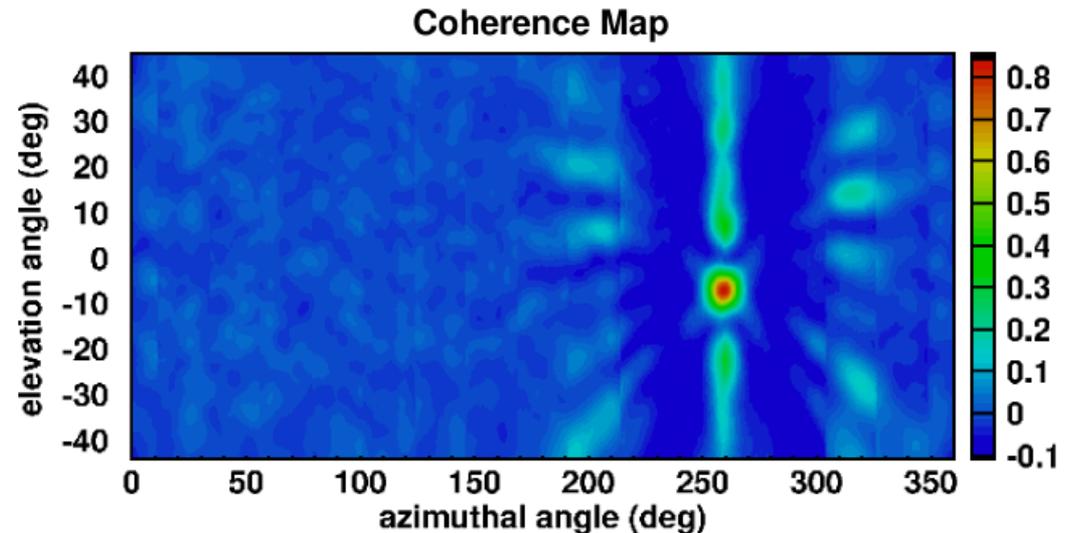
The time-domain cross-correlation is mapped to incident direction via the geometric delay relation.



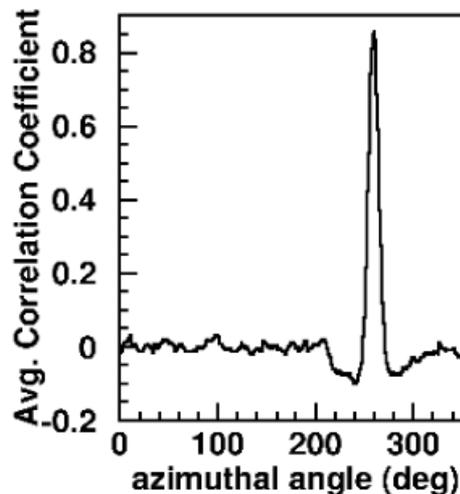
Example of a global coherence map derived from the sum of cross-correlations.

The true direction of the signal presents itself as a sharp peak.

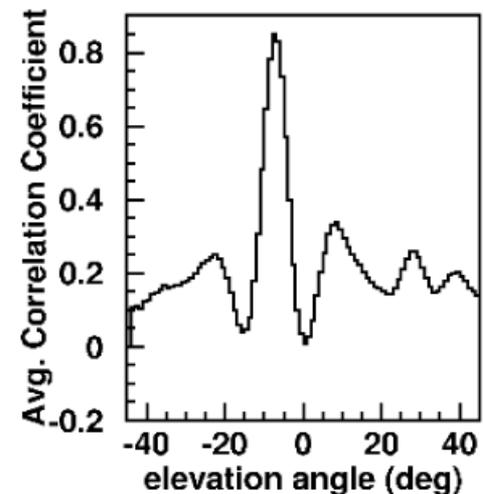
The map is analogous to the dirty map of radio interferometry.

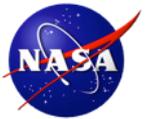


Azimuthal Profile Along Peak



Elevation Profile Along Peak

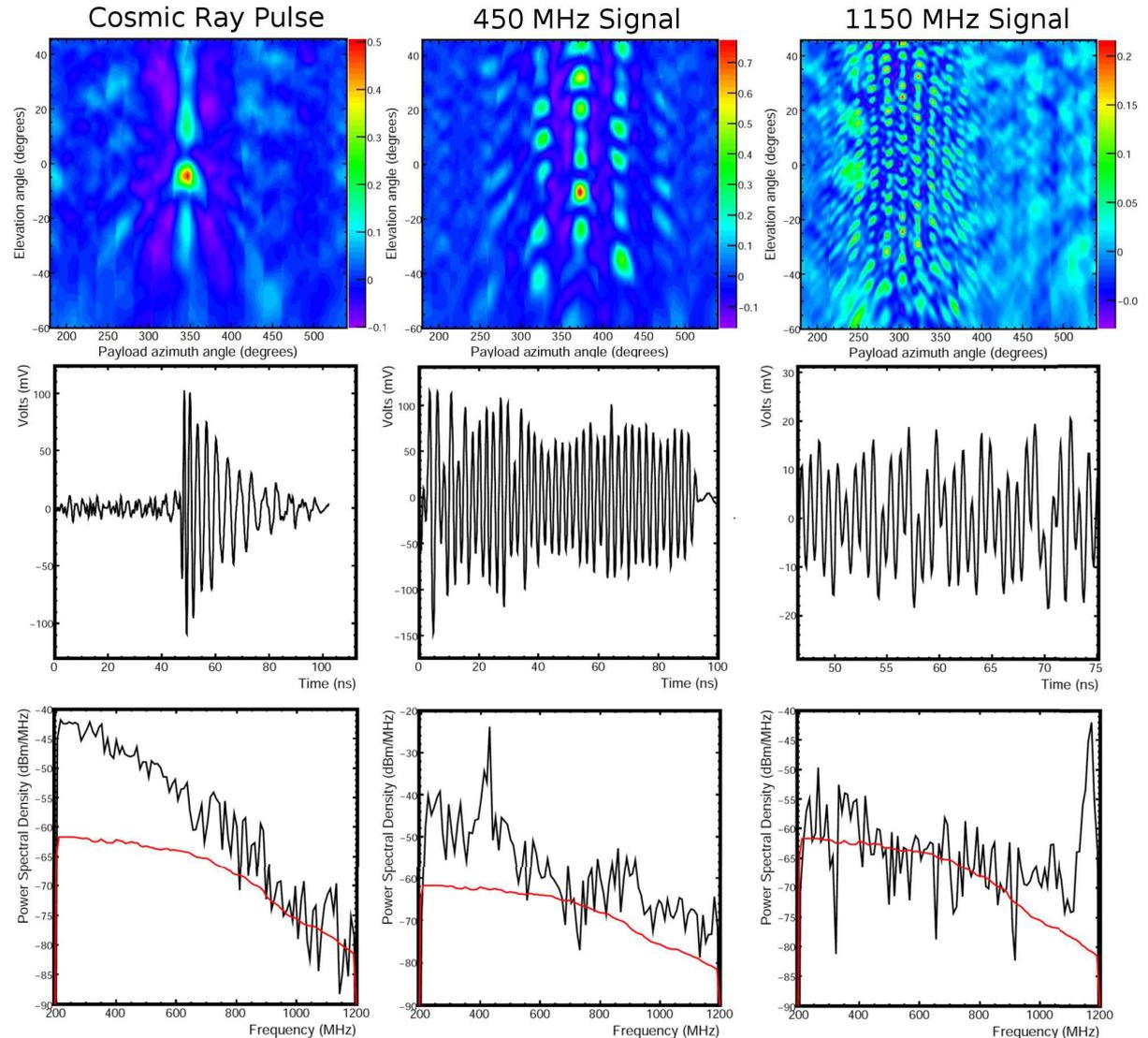


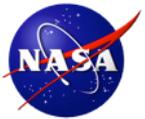


Beam-forming with Cross-correlations



Examples of signals and background s detected with ANITA.



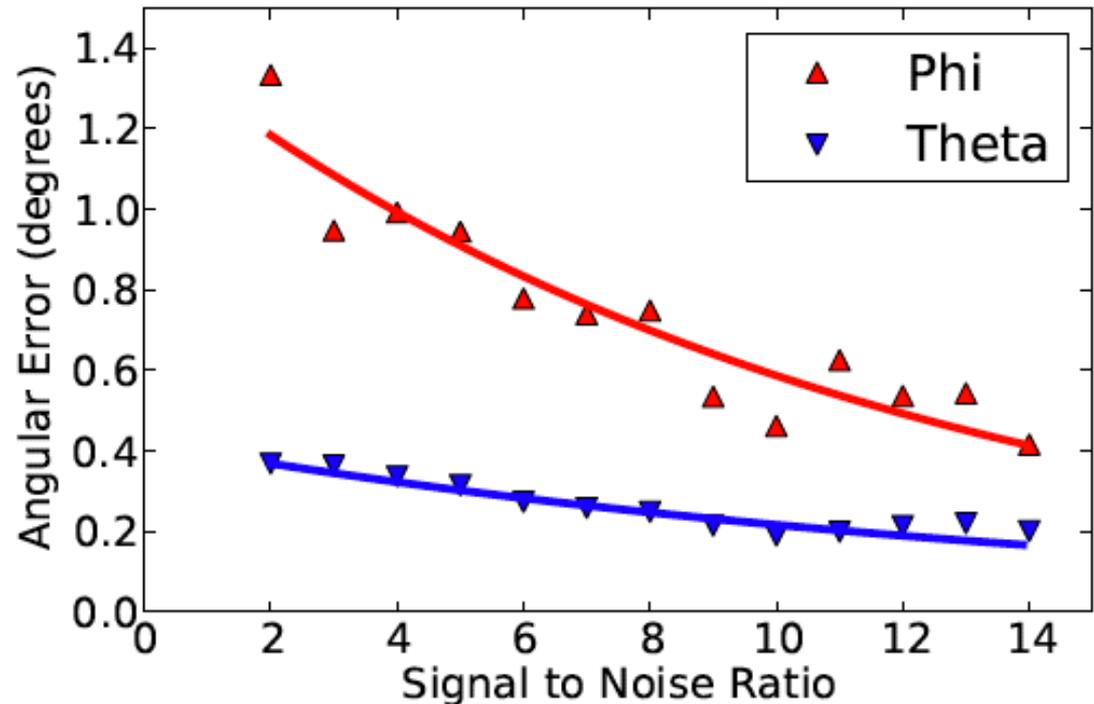


Angular Error

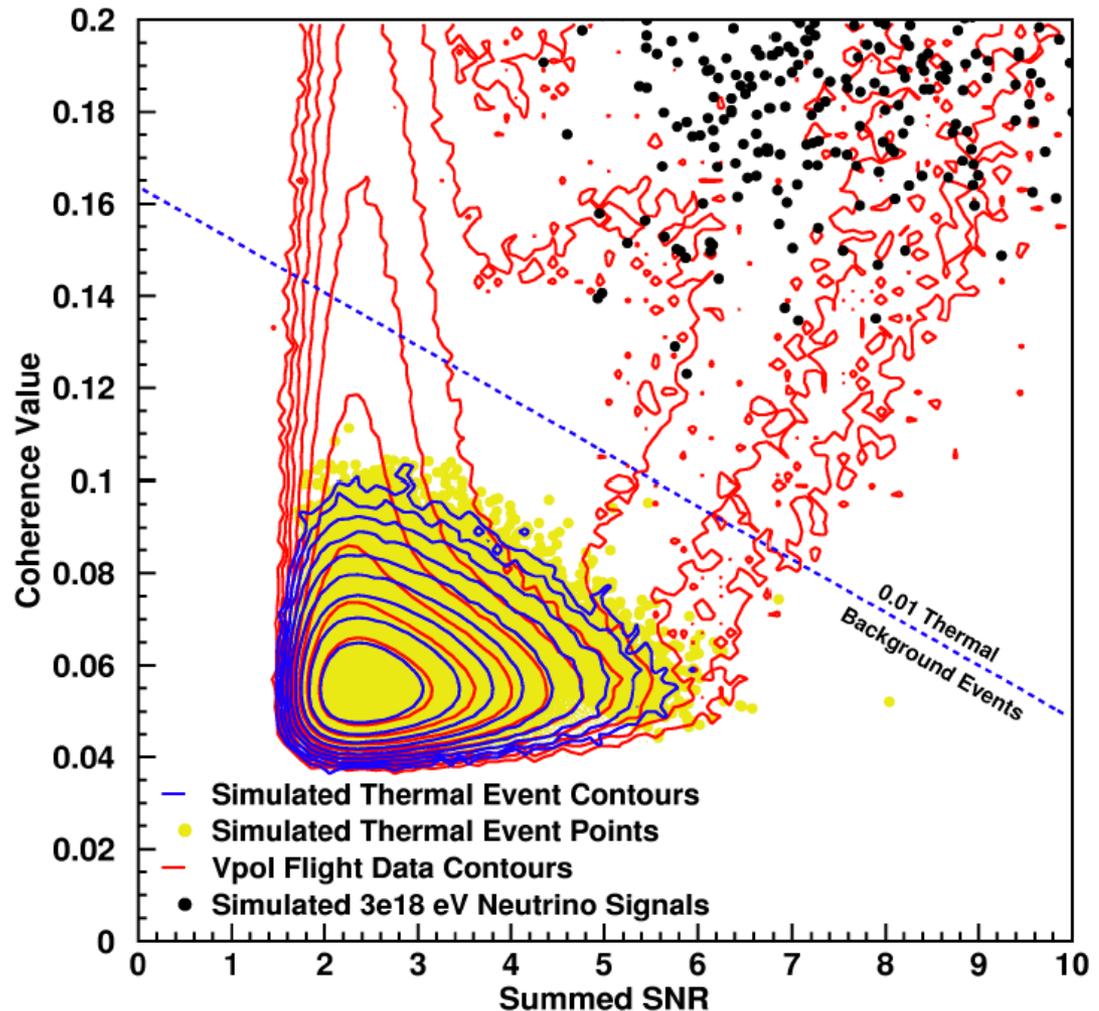


The ANITA array has < 1 -degree angular errors.

This is due to the ultra-wideband signals used in the correlation.



The relation between the summed waveform signal to noise ratio and cross-correlation coefficient reveals features that are specific to each kind of signal and background.

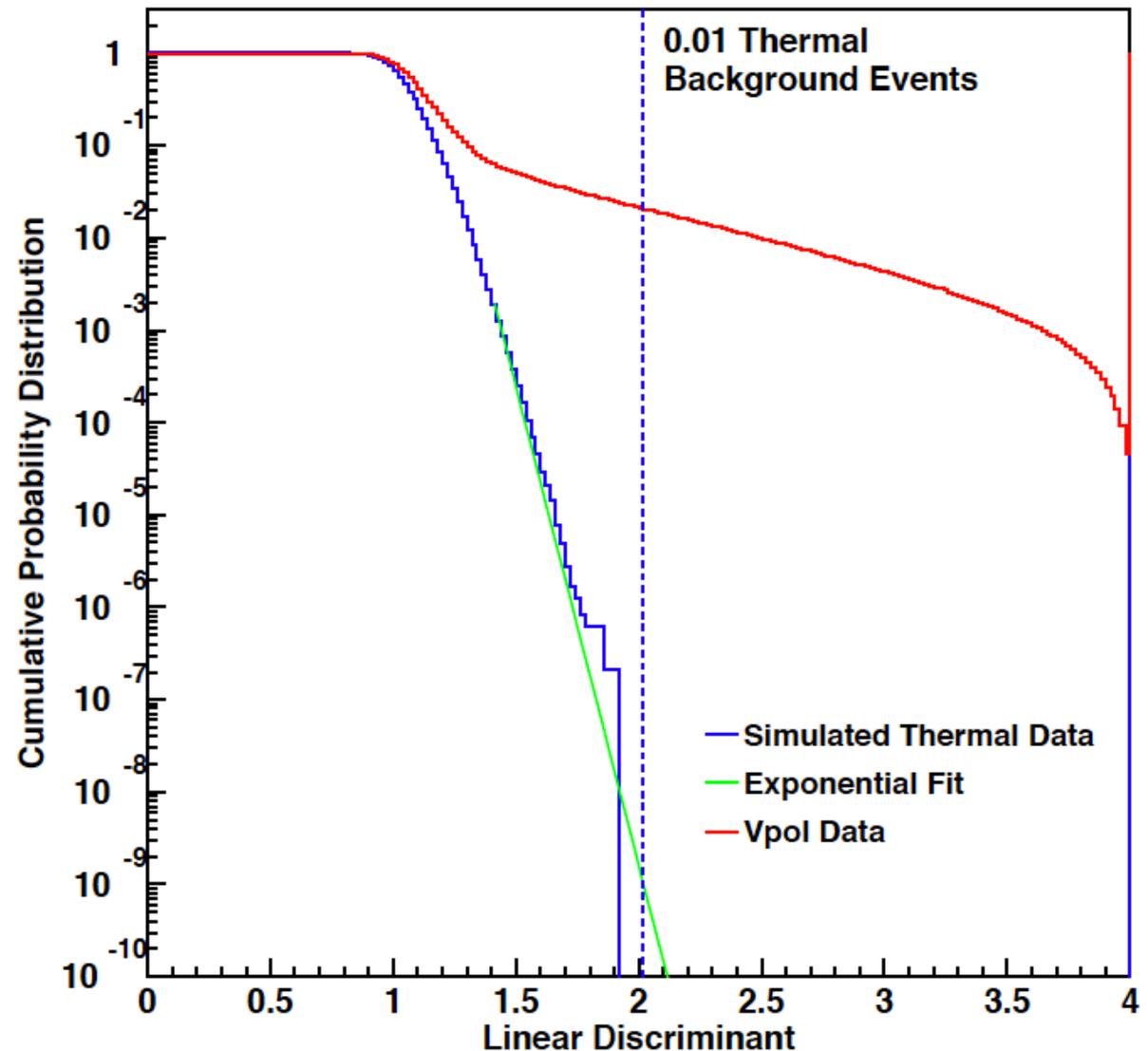




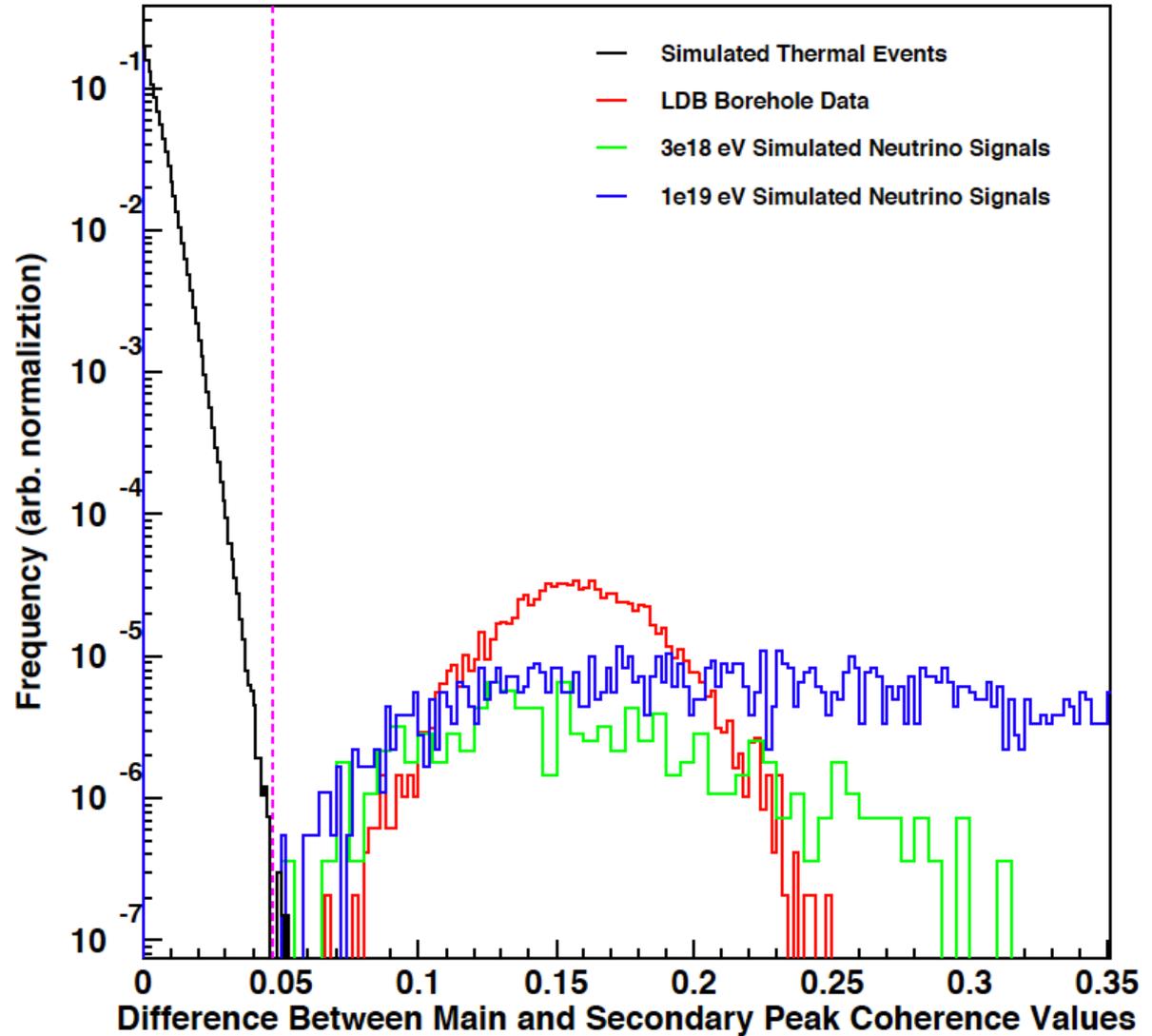
Thermal Noise Rejection



A discriminant formed by the linear combination of the cross correlation coefficient and the peak of the summed waveform provides a highly efficient filter.



Thermal noise and carrier wave signal backgrounds both have comparable peak and secondary lobes.

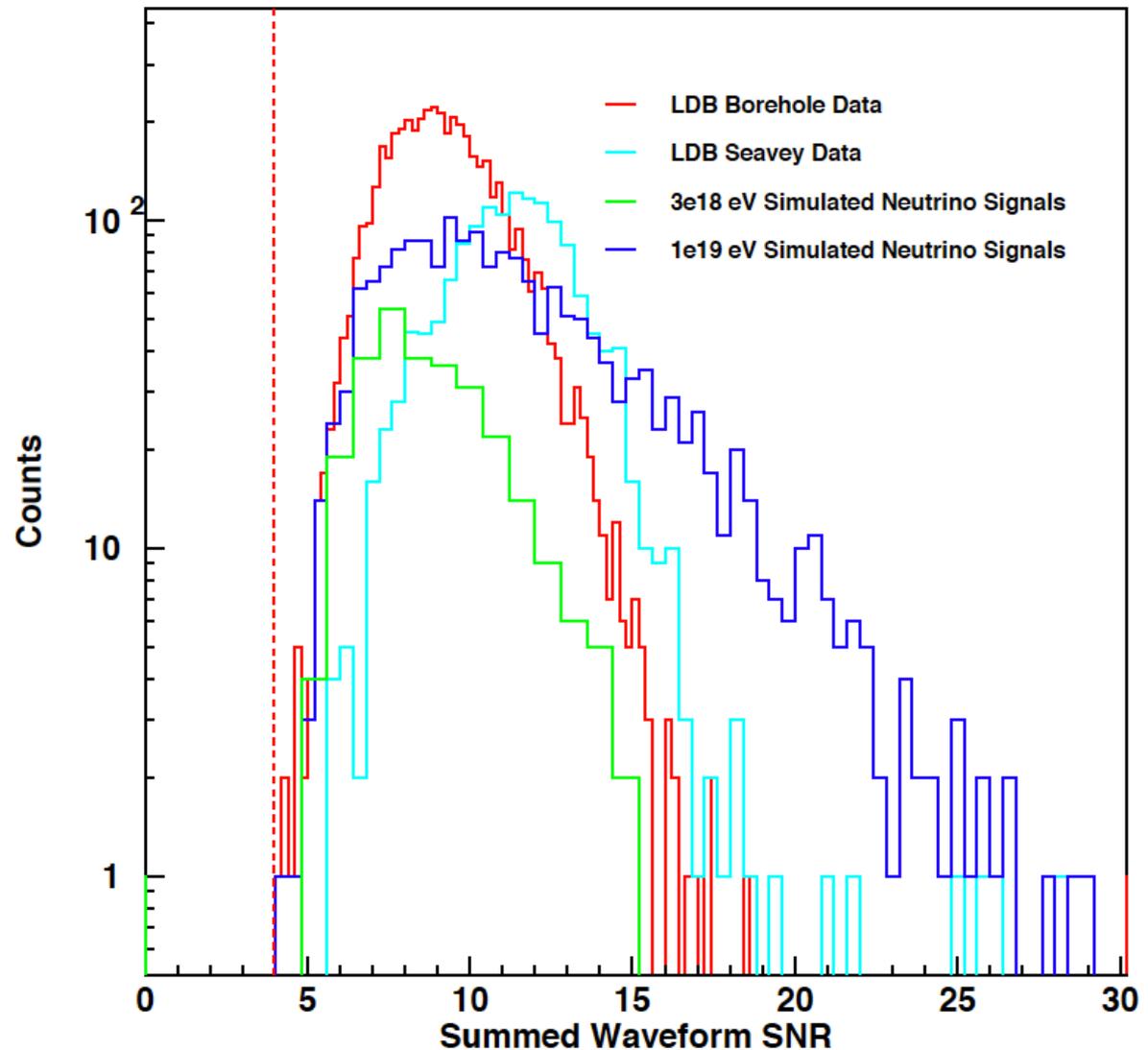




Signal Strength



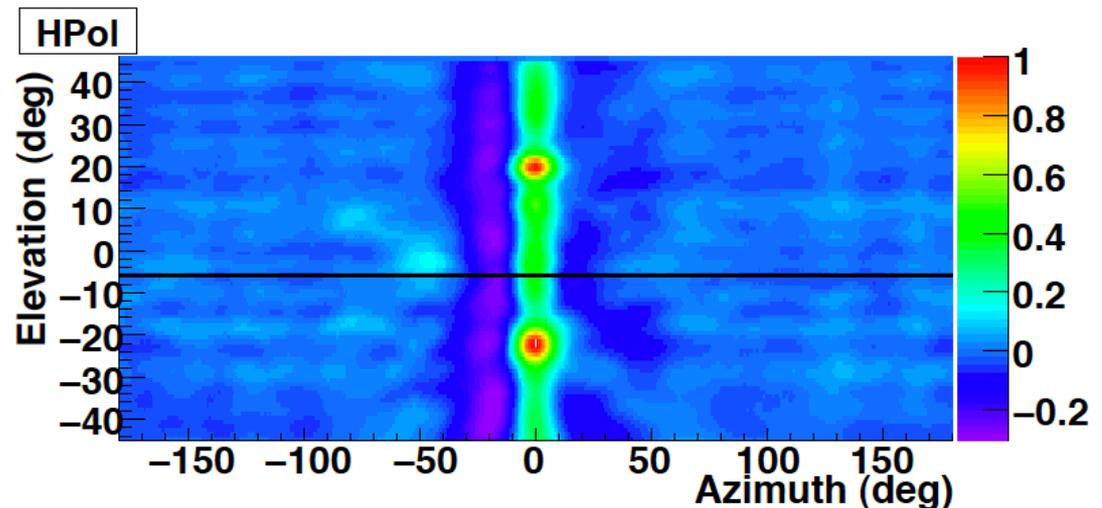
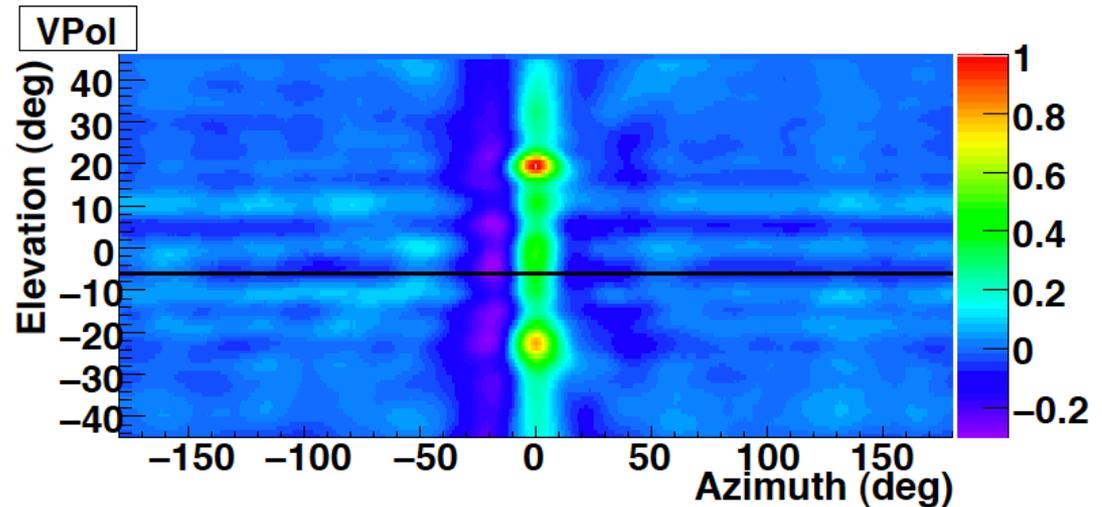
The peak of the coherent waveform sum provides additional efficient discrimination between signals of interest and thermal noise.

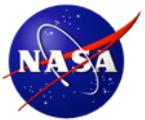


Averaging events in a sun-centered coordinate system reveals a radio image of the sun along with its reflection on the ice.

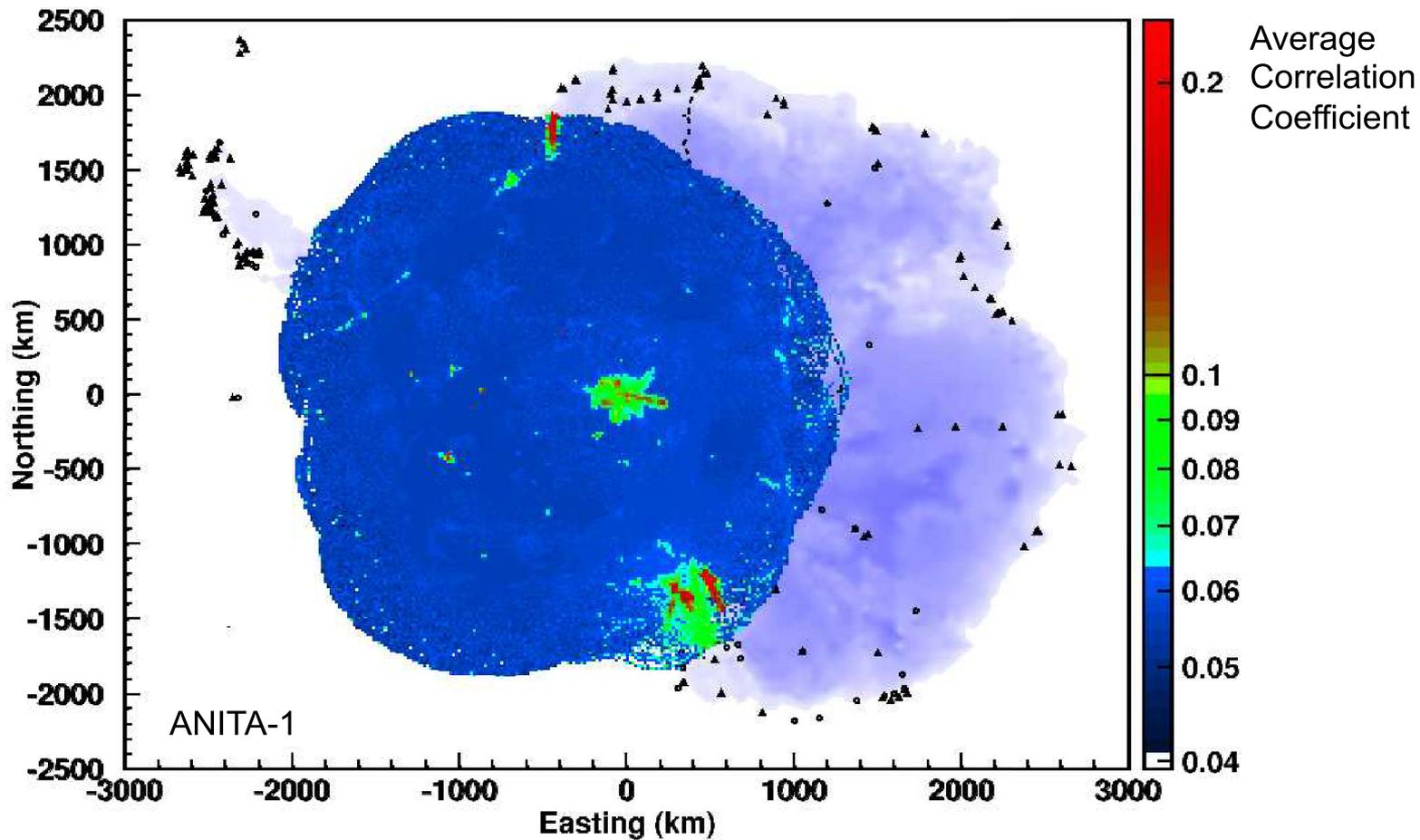
These images can be used to measure the surface roughness of the ice.

See talk by J. Stockham.



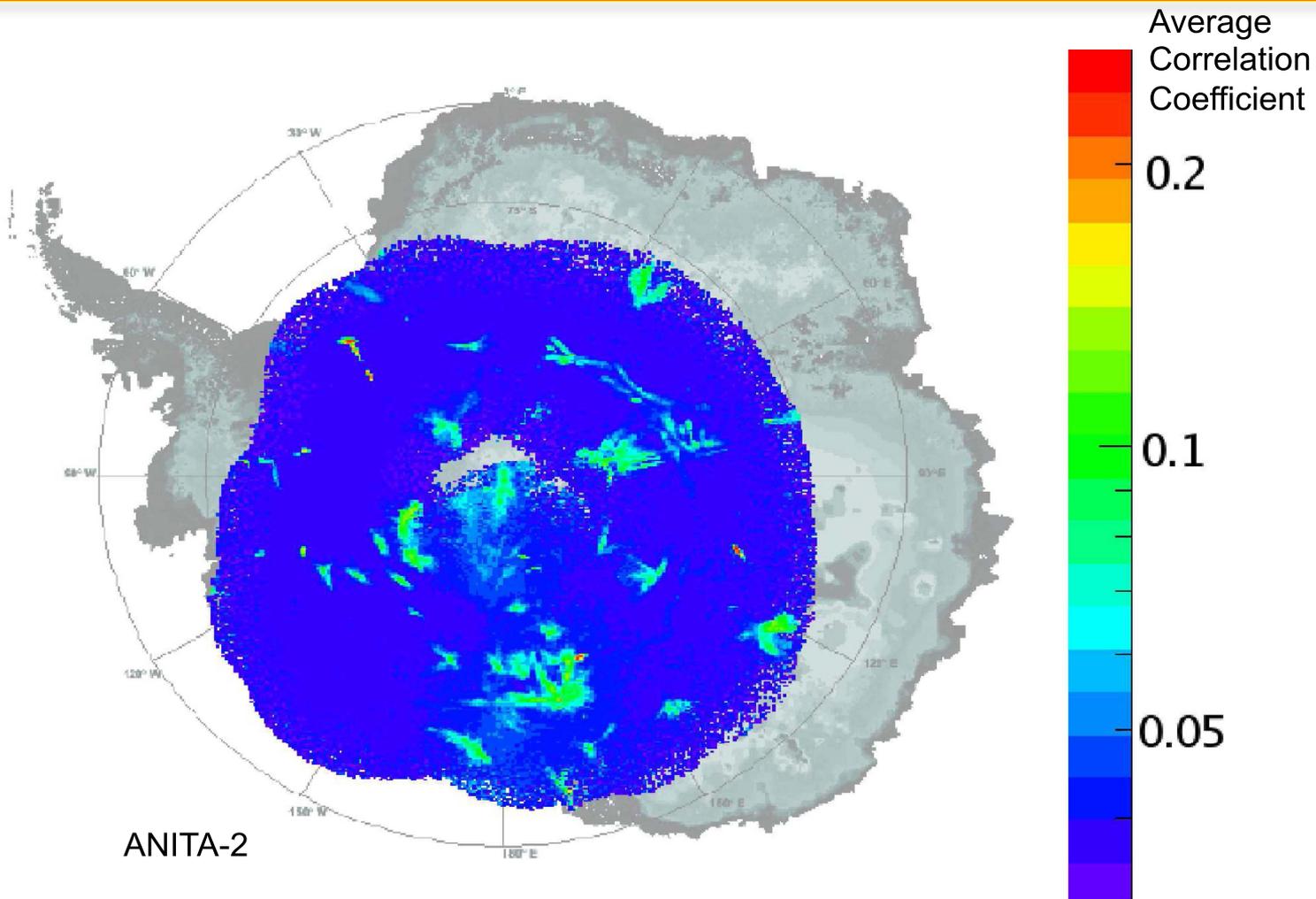


Imaging Anthropogenic Backgrounds





Imaging Anthropogenic Backgrounds





Conclusions



Pulse-phase interferometry offers highly sensitive techniques for analysis of ultra-high energy particle transients.

Implementation of this technique into a real-time digitization and triggering scheme can yield improvements in detection sensitivity.