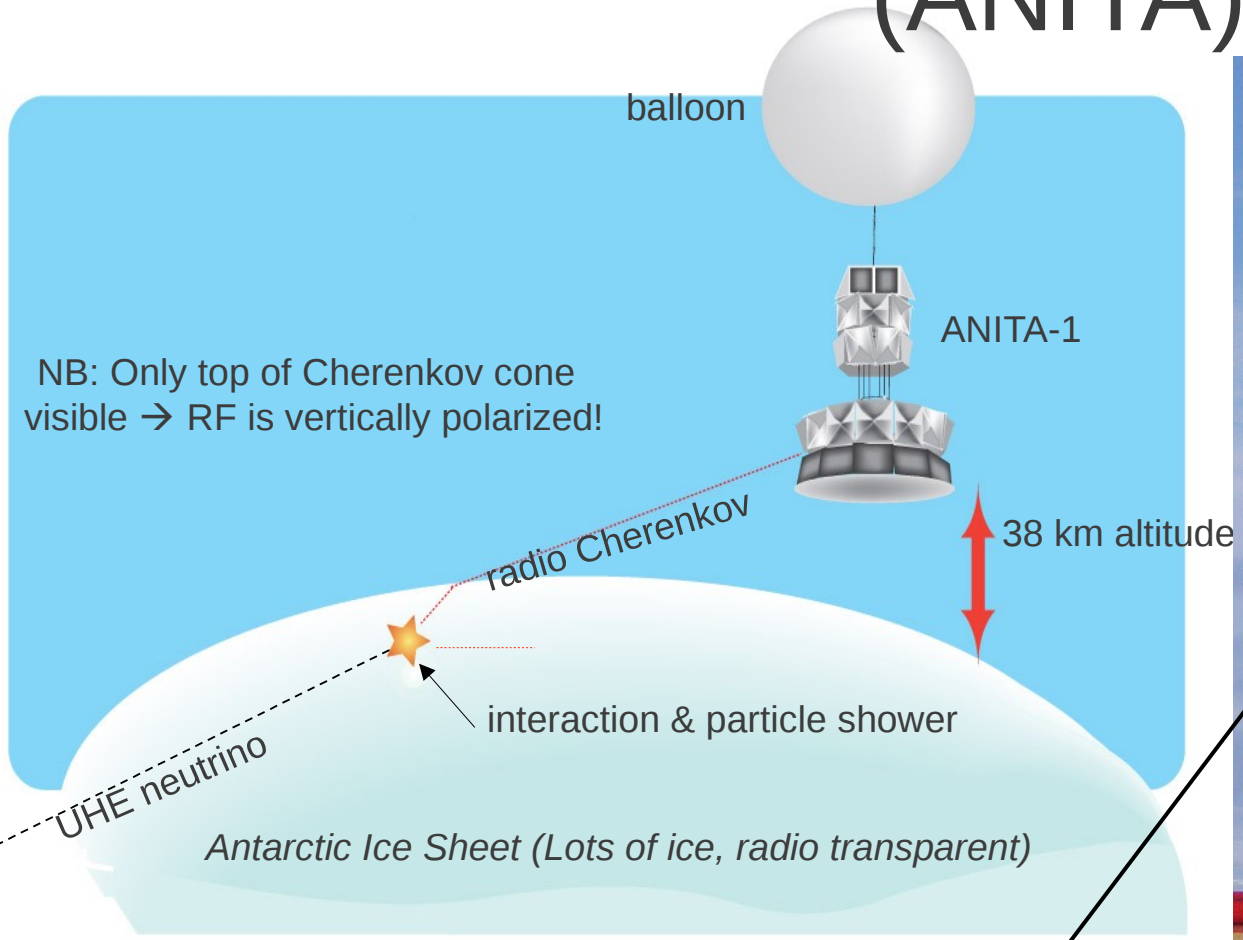
When a Continent Is Your Detector

Finding Cosmic rays above Antarctica

Stephen Hoover
APS DPF Annual Meeting
13 August 2011

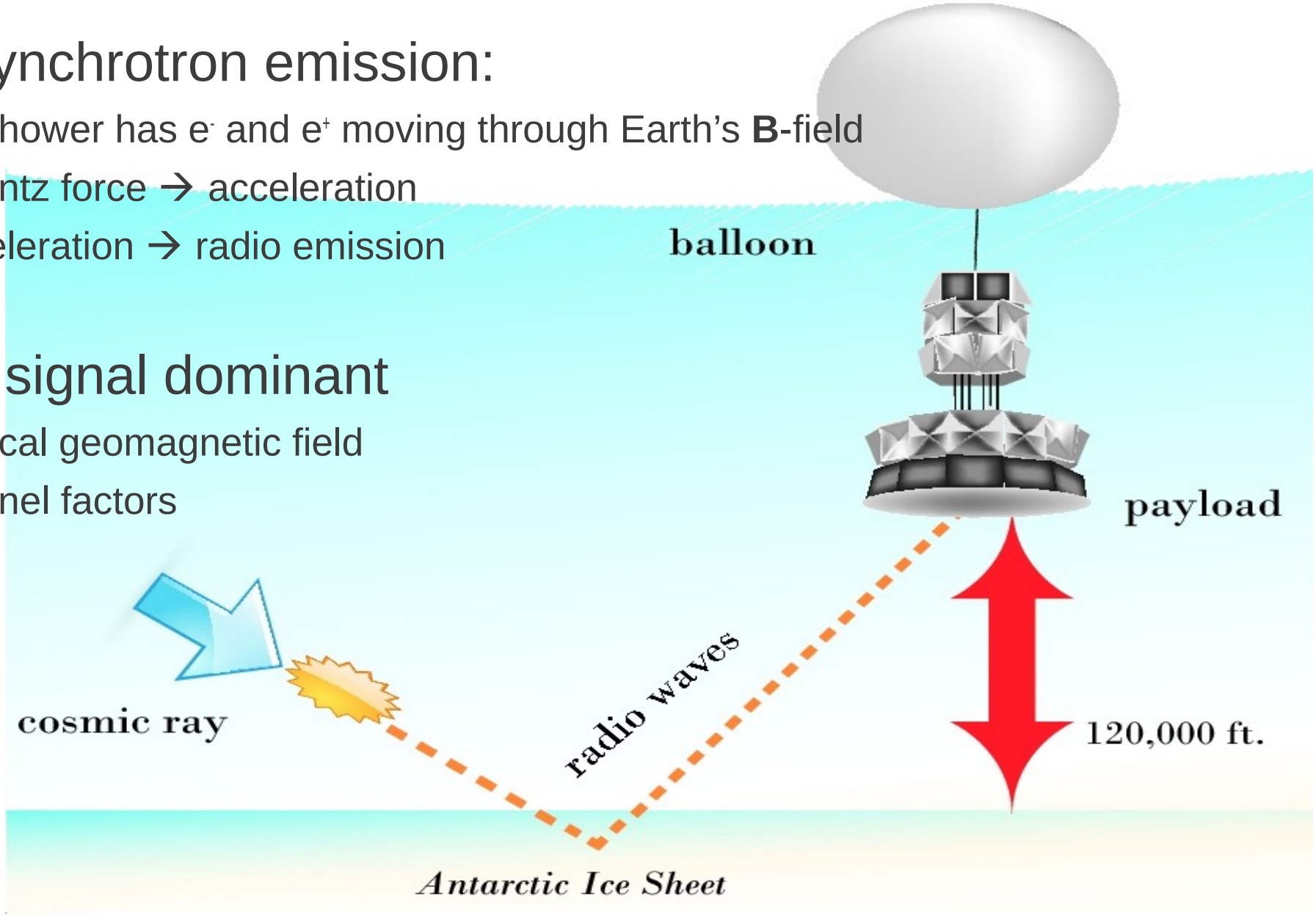
The ANtarctic Impulsive Transient Antenna (ANITA)



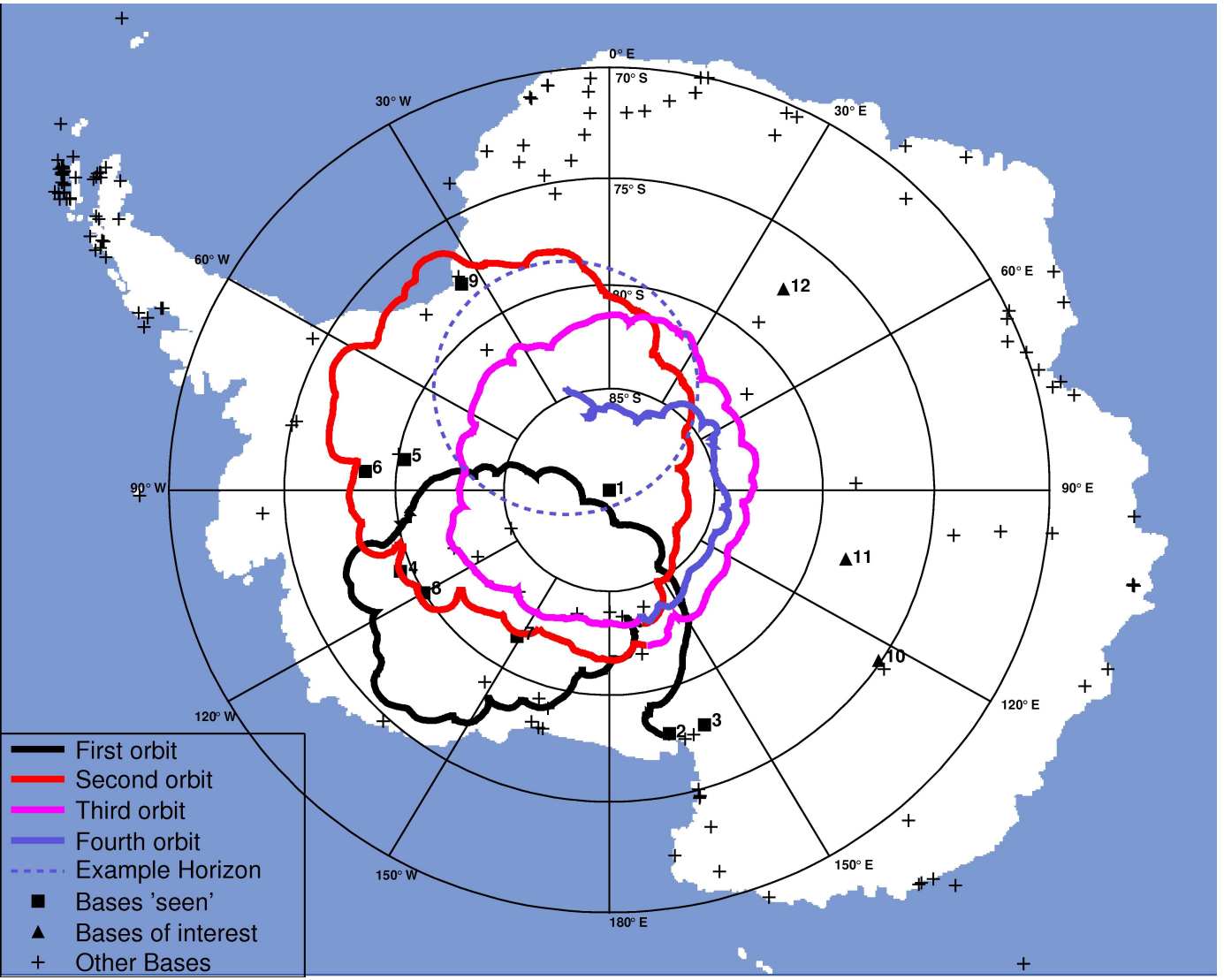
32 dual-polarization radio antennas (200-1200 MHz)

Radio Cosmic Ray Detection

- Geosynchrotron emission:
  - Air shower has e^- and e^+ moving through Earth's **B**-field
  - Lorentz force → acceleration
  - Acceleration → radio emission
- H-pol signal dominant
  - Vertical geomagnetic field
  - Fresnel factors

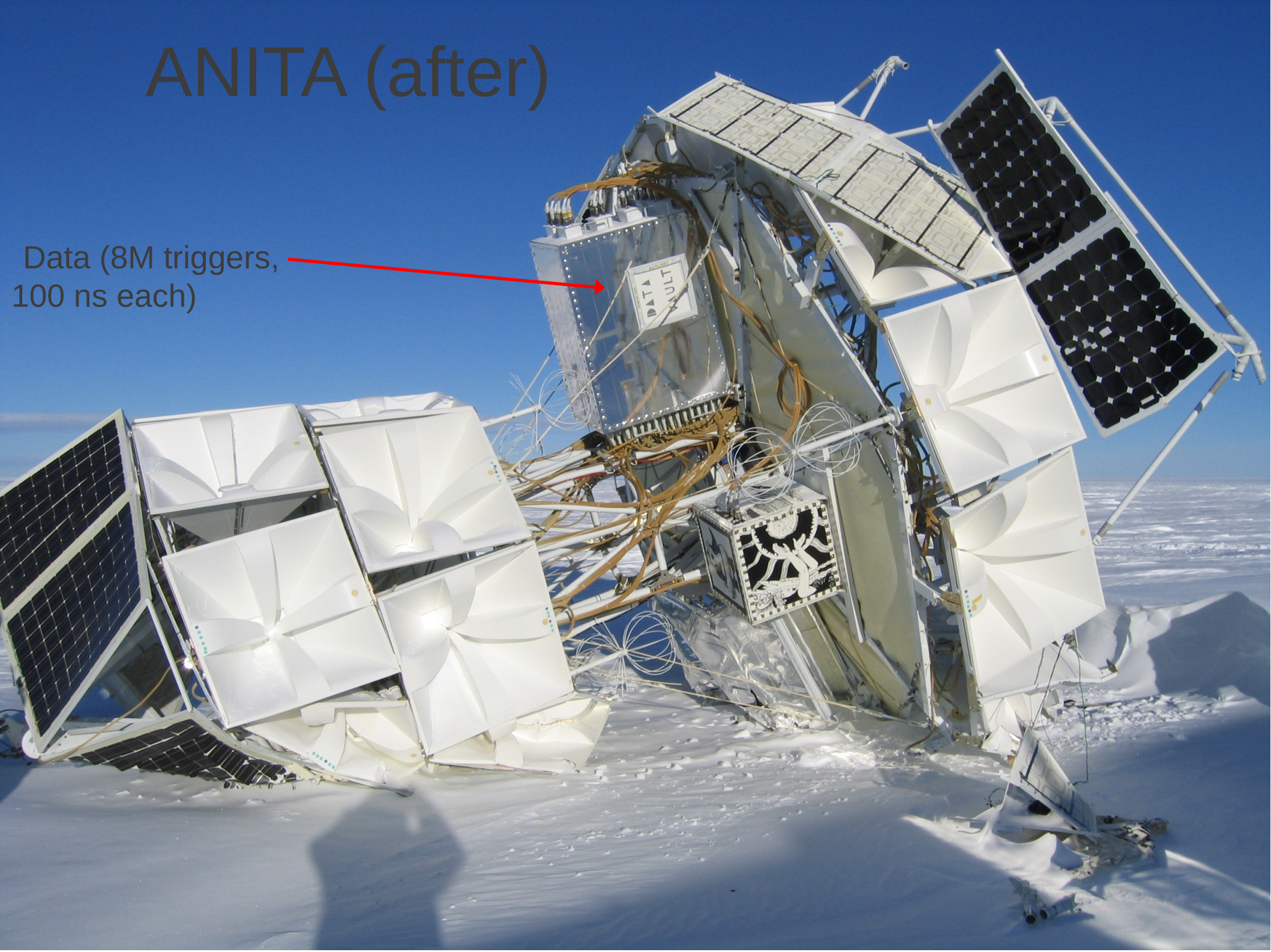


The First Flight



- Launched:
  15 December 2006
- Landed :
  19 January 2007
  - 35 day flight
- Full recovery
  - Thank you NSF and CSBF!

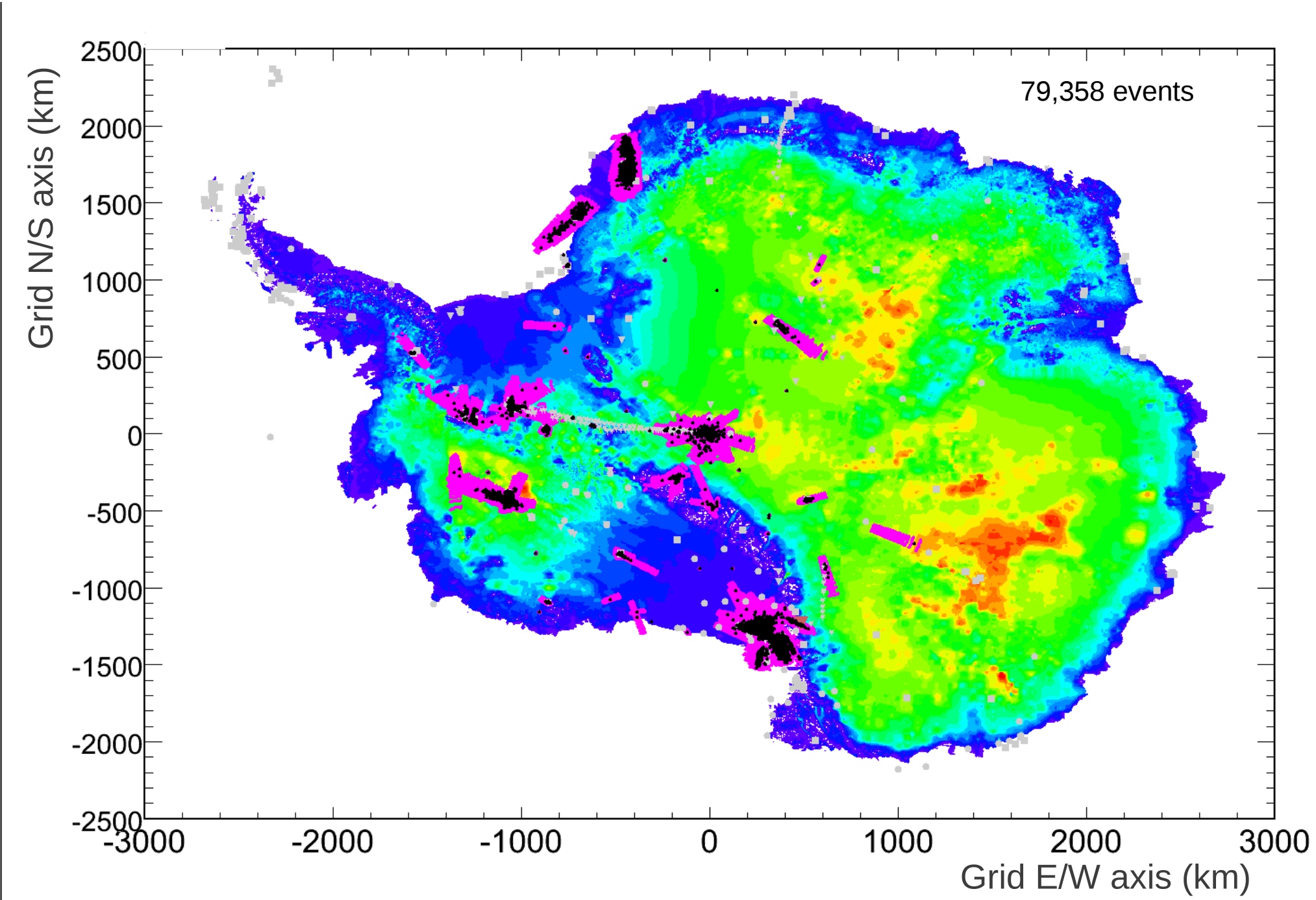
ANITA (after)



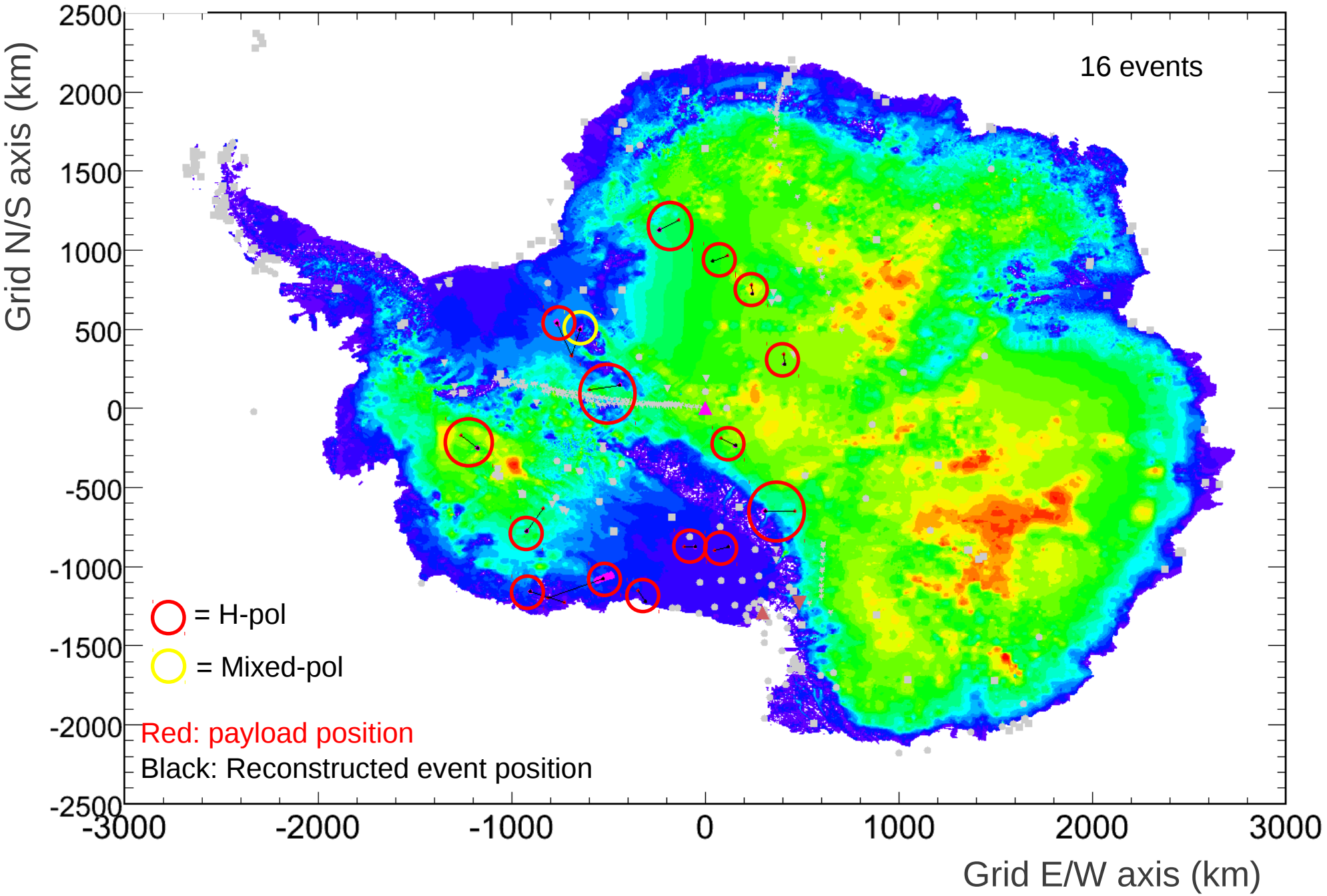
Data Analysis

- Must separate
  - Thermal noise (black-body radiation)
  - Man-made signals
  - Physics!
- Use waveform cross-correlations
  - Shape & size
  - Pointing

Reconstructed Events



Remove Base & Clustered Events



Summary of Results

Vertical/Mixed Polarization (neutrino search)

Expected Background	Observed Events
1	1

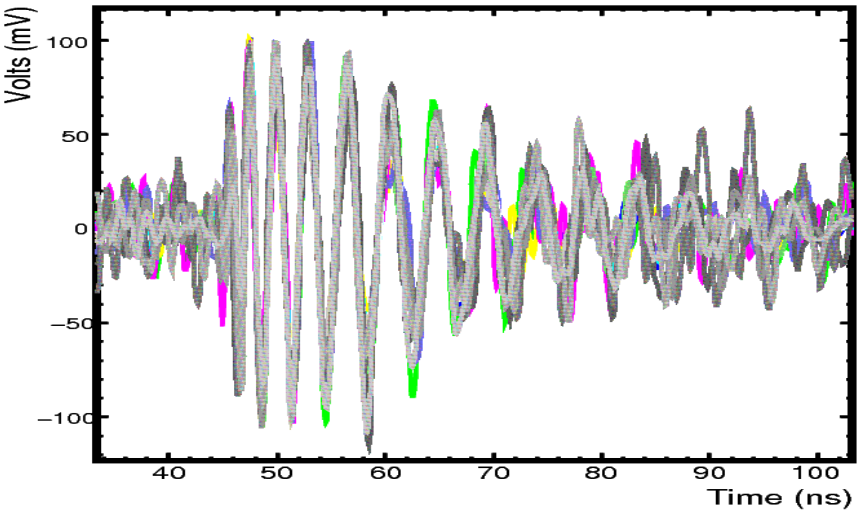
Horizontal/Mixed Polarization (cosmic rays)

Expected Background	Observed Events
2	16

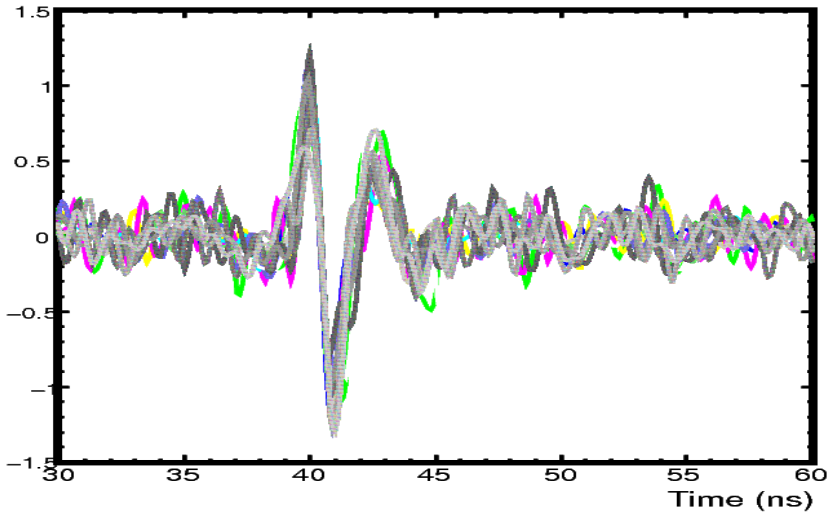
H-pol Events

- 13 of 16 h-pol events have similar waveforms
  - Impulsive
  - Steeply falling spectrum
- Same polarity

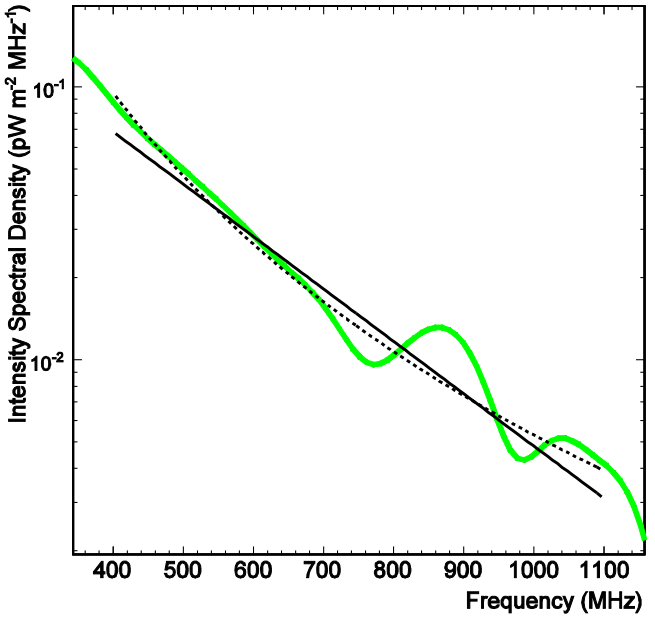
Superimposed Waveforms (scaled)



Instrument Response Removed (scaled)



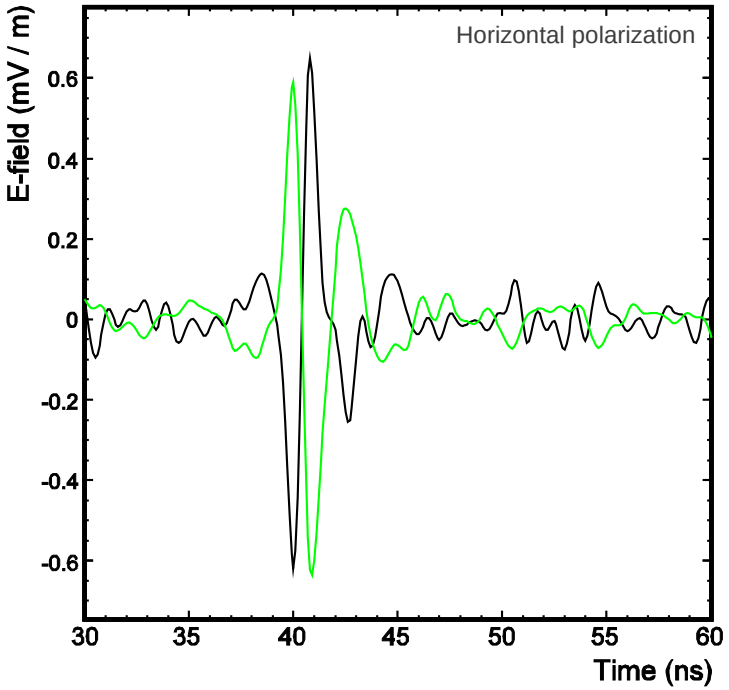
Average spectrum



Expanded Search

- 6° between horizon and horizontal
- *2 above horizon* events!
  - Exactly like others in pulse shape and spectrum, except…

Event #1

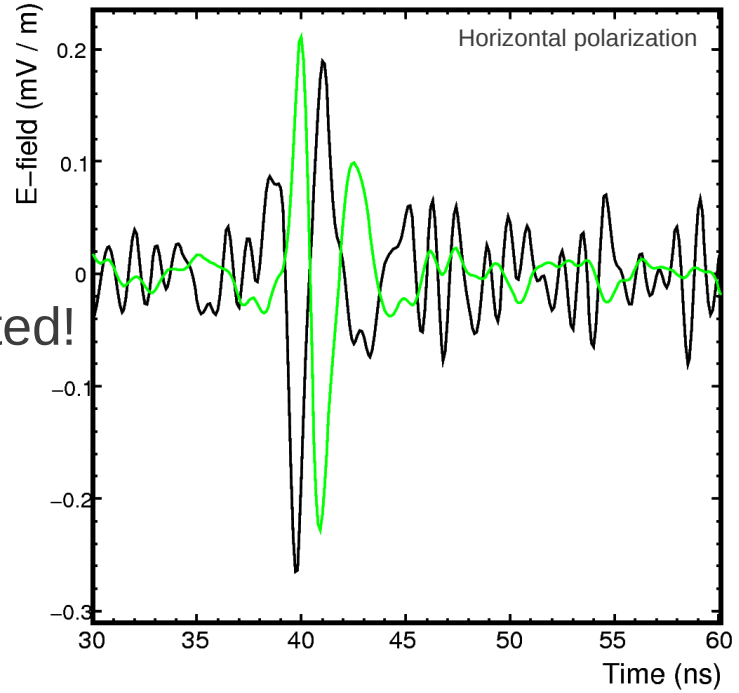


Inverted polarity!

NB…reflections are inverted!

Black line: Event waveform
Green line: Average of 14 similar events

Event #2

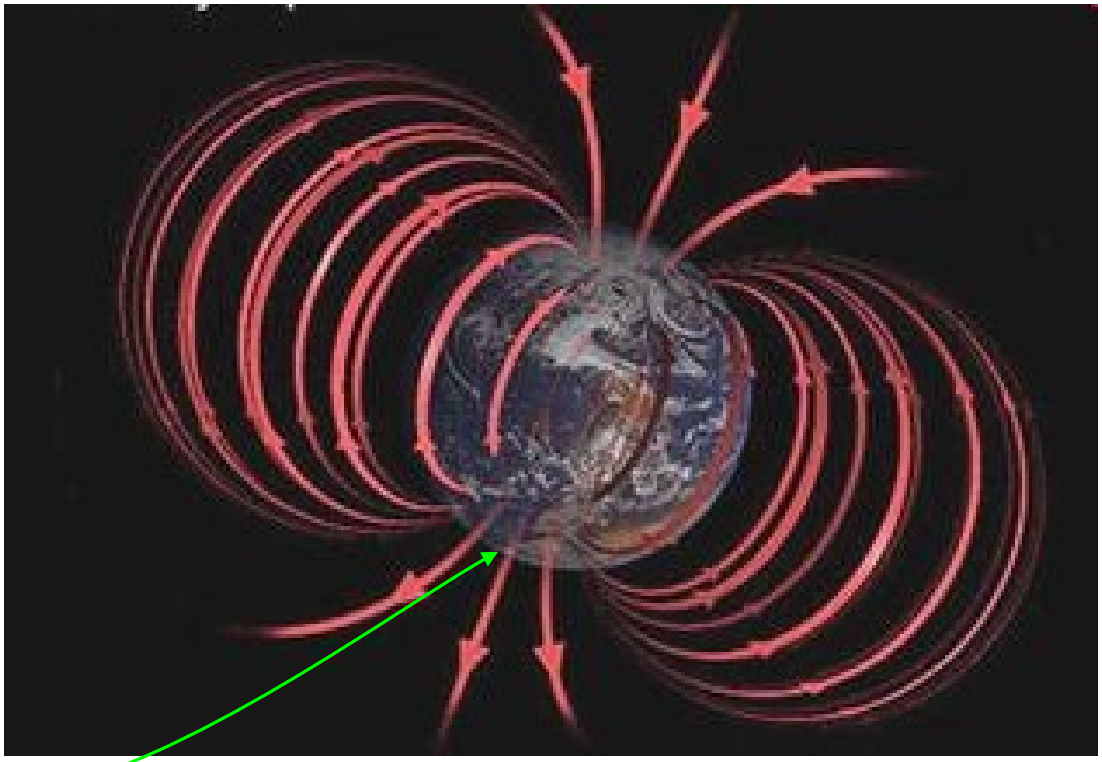


Antarctic Geomagnetic Field

- Vicinity of magnetic pole, so vertical component dominates and points everywhere up

- $B_{vertical}$: 30 – 60 μT

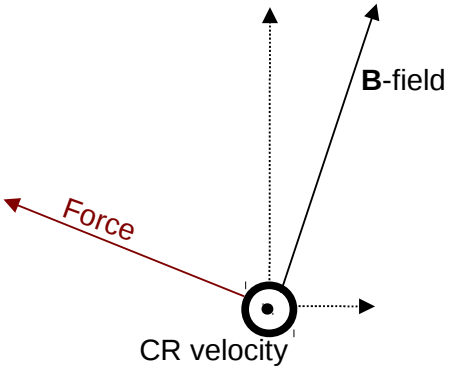
- $B_{horizontal}$: 0 – 20 μT



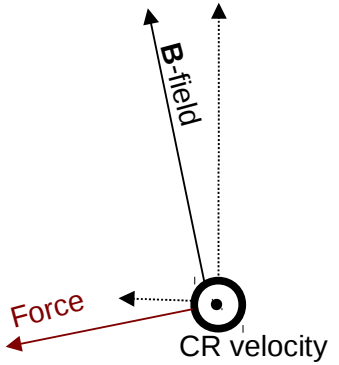
Polarity of Geosynchrotron Emission

- If ANITA h-pol impulses are CRs, what should the polarity be?

- Viewed from the payload
  - Every CR is moving *towards* us
  - The vertical component of the Earth's magnetic field is always pointing *up*
  - The horizontal component can point in any direction

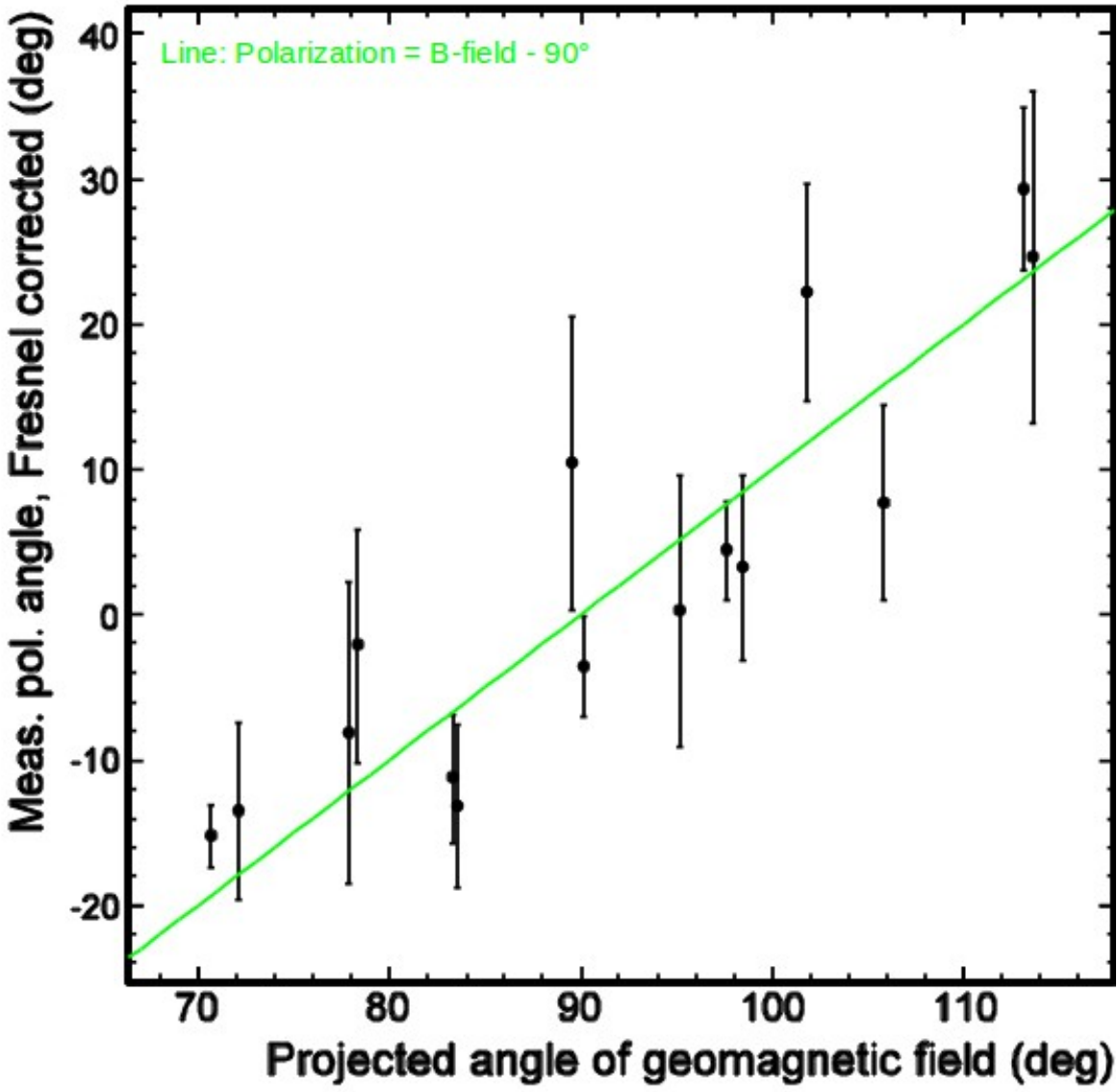


- **F** = e**v** x **B**
  - e^- *always* move right, e^+ *always* move left!
    - Creates h-pol emission – always same polarity!
  - Horizontal component of B-field arbitrary, so v-pol radiation has arbitrary polarity



Polarization Angle

- Compare measured polarization angle (including polarity) to B-field angle
- 90 degree offset = Lorentz force direction!

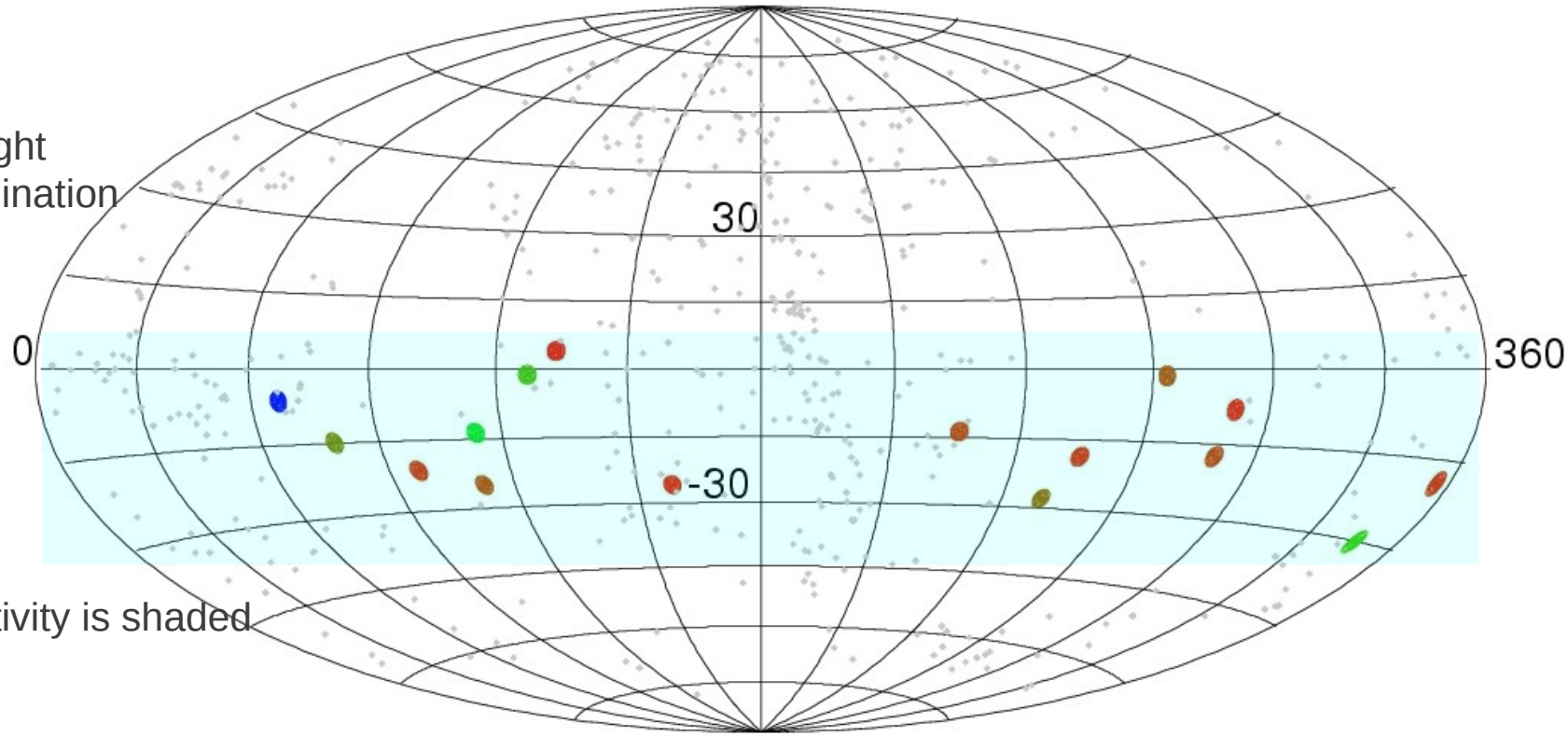


Cosmic Ray Origins

No clustering of reconstructed cosmic ray directions

Errors are a combination of ANITA's pointing resolution (0.75° x 0.3°) and the unknown shower view angle (degree scale)

Coordinates are right ascension and declination



ANITA's CR sensitivity is shaded pale blue (roughly)

ANITA, Present & Future

- ANITA-1 (2006-2007)
  - UHE neutrino flux limits
  - Observation of UHE cosmic rays
- ANITA-2 (2008-2009)
  - Better neutrino limits
  - Worse CR sensitivity (neutrino-optimized)
  - Monopole limits
  - Limits on neutrino flux from GRBs
- ANITA-3 (2013, in prep)
  - Dual-purpose UHE neutrino & UHE CR detector

Additional Slides

The ANITA-1 Collaboration

University of California, Irvine
Irvine, California

Ohio State University
Columbus, Ohio

University of Kansas
Lawrence, Kansas

Washington University in St. Louis
St. Louis, Missouri

University of Delaware
Newark, Delaware

University of California, Los Angeles
Los Angeles, California

University of Hawaii at Manoa
Honolulu, Hawaii

National Taiwan University
Taipei, Taiwan

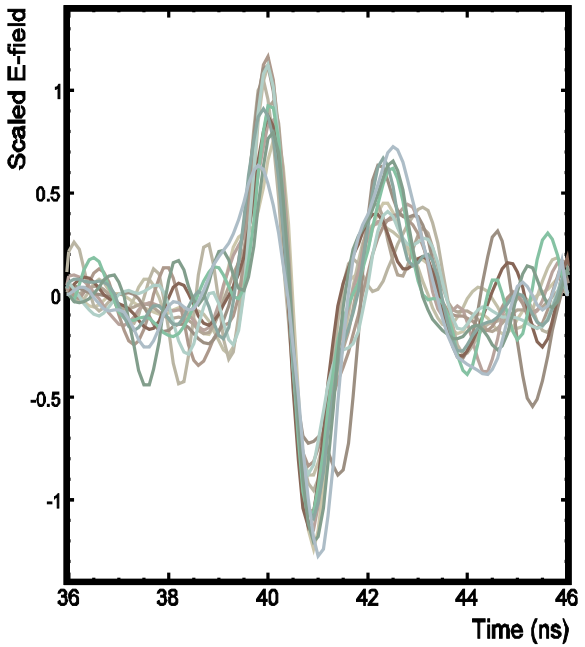
University College London
London, England

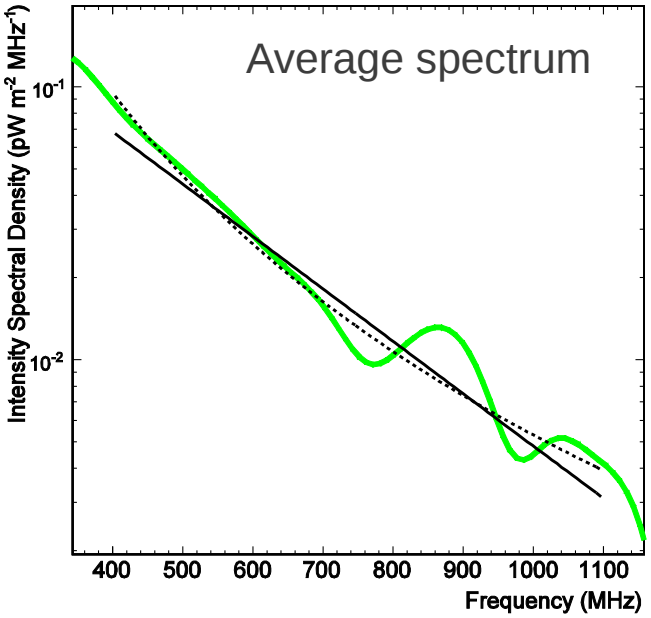
Jet Propulsion Laboratory
Pasadena, California

Stanford Linear Accelerator Center
Menlo Park, CA

Ultrahigh-Energy Cosmic Rays

Scaled overlap of UHECR events





13 of 16 h-pol events in ν search are UHECRs

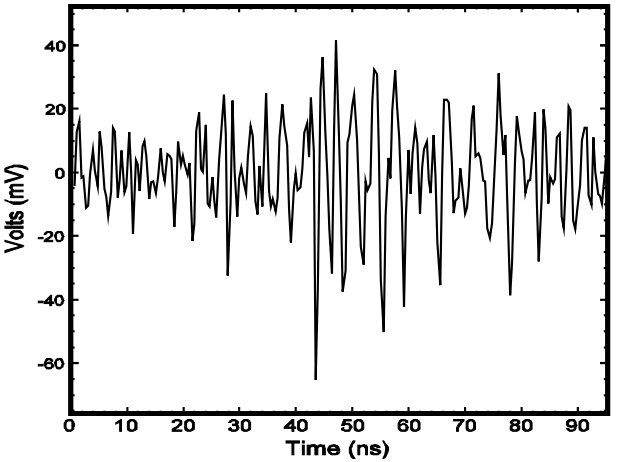
CR search finds 3 more

- 1 low elevation
- 2 above horizon (inverted)

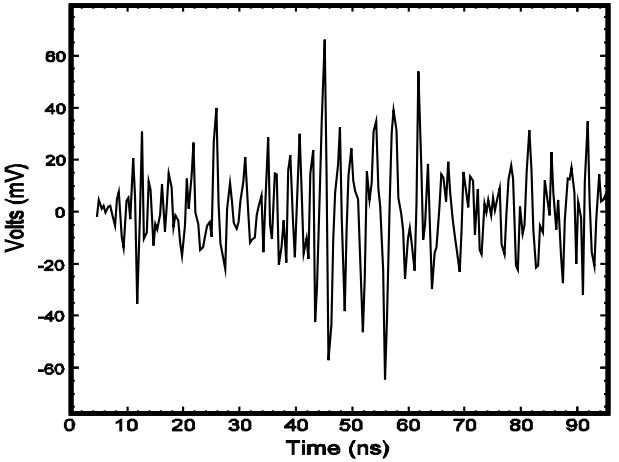
All have same h-pol polarity (after reflection effects), as expected

Interferometry Example

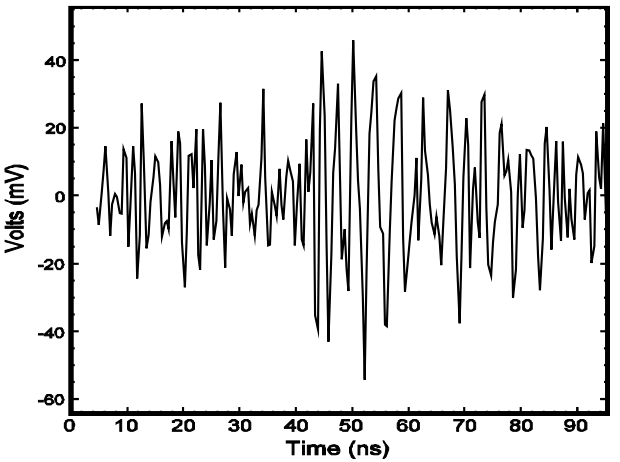
Event# 4338830: Antenna 10H



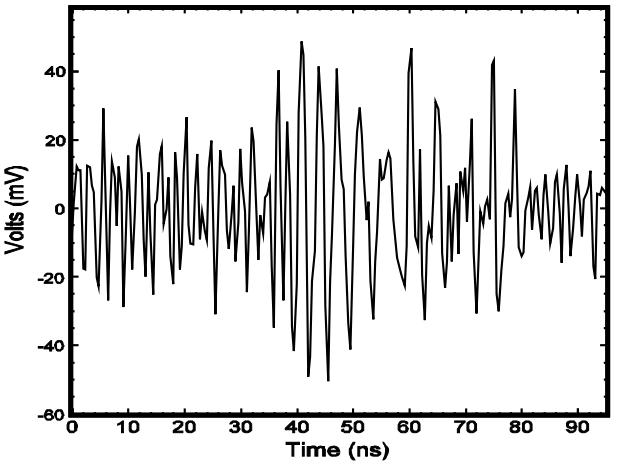
Event# 4338830: Antenna 2H



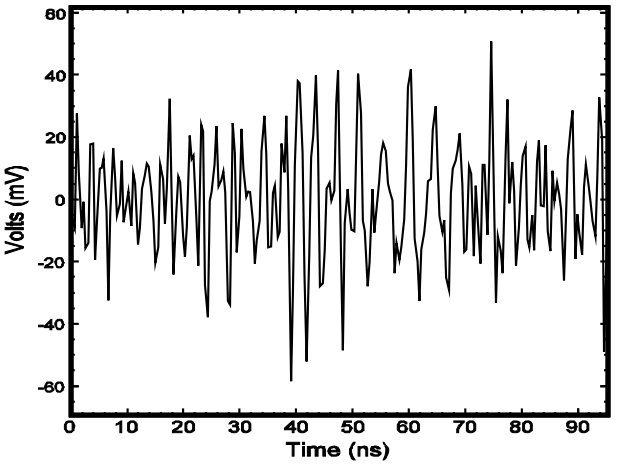
Event# 4338830: Antenna 11H



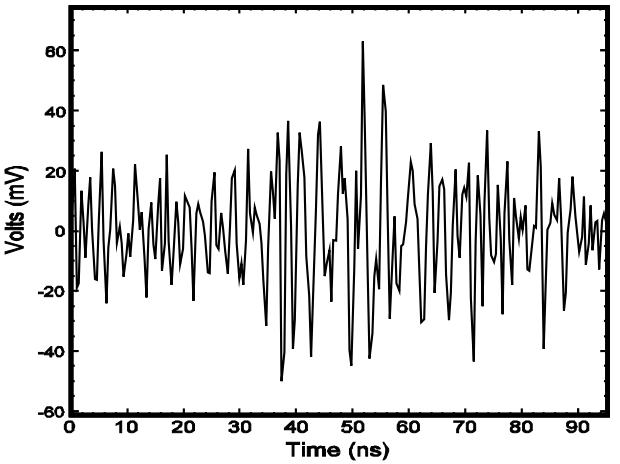
Event# 4338830: Antenna 19H



Event# 4338830: Antenna 20H

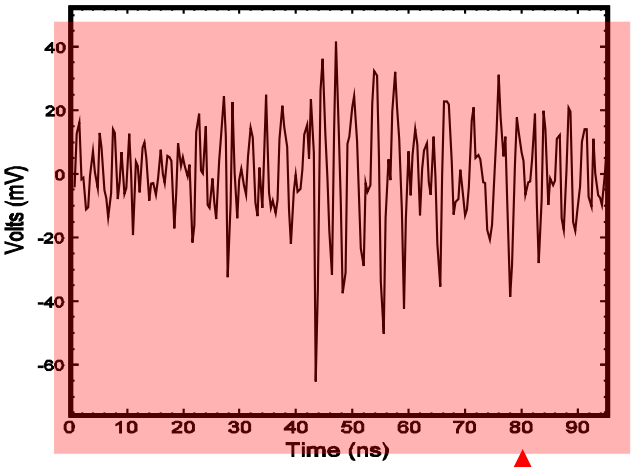


Event# 4338830: Antenna 21H

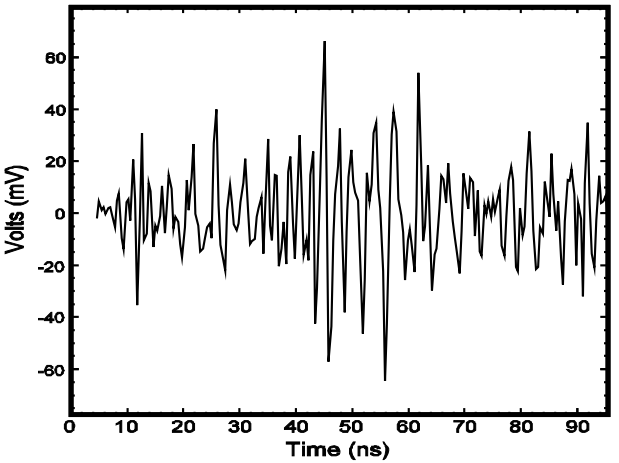


Interferometry Example

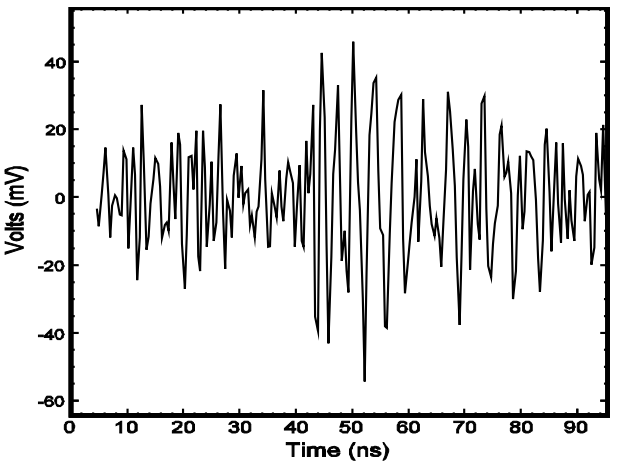
Event# 4338830: Antenna 10H



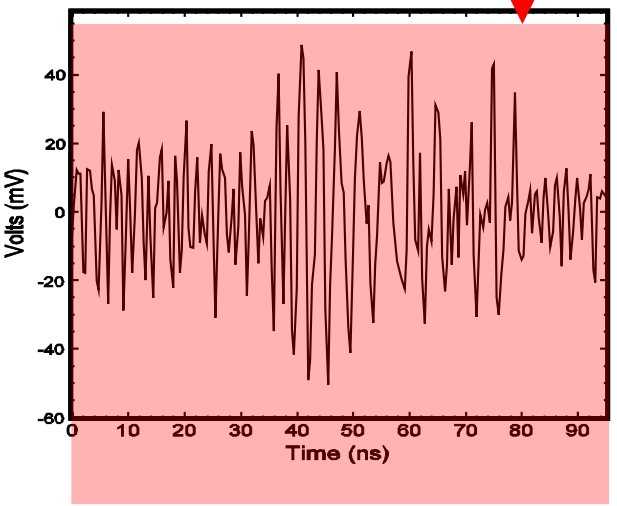
Event# 4338830: Antenna 2H



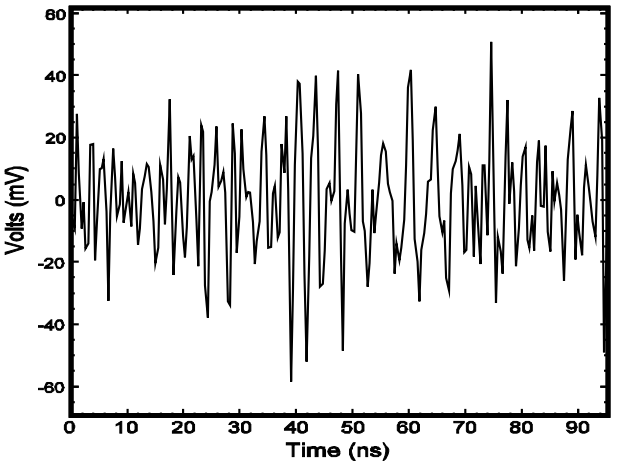
Event# 4338830: Antenna 11H



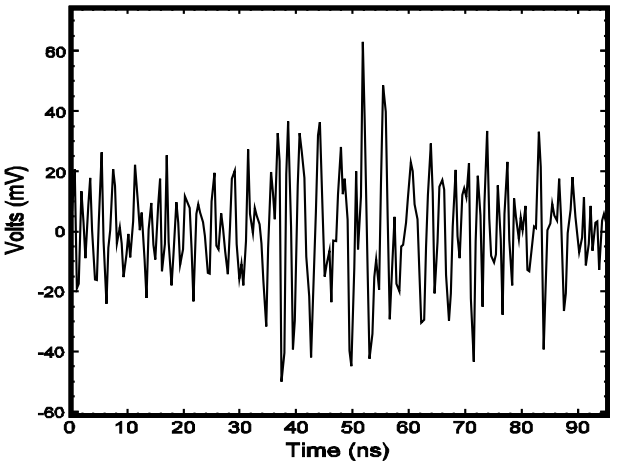
Event# 4338830: Antenna 19H



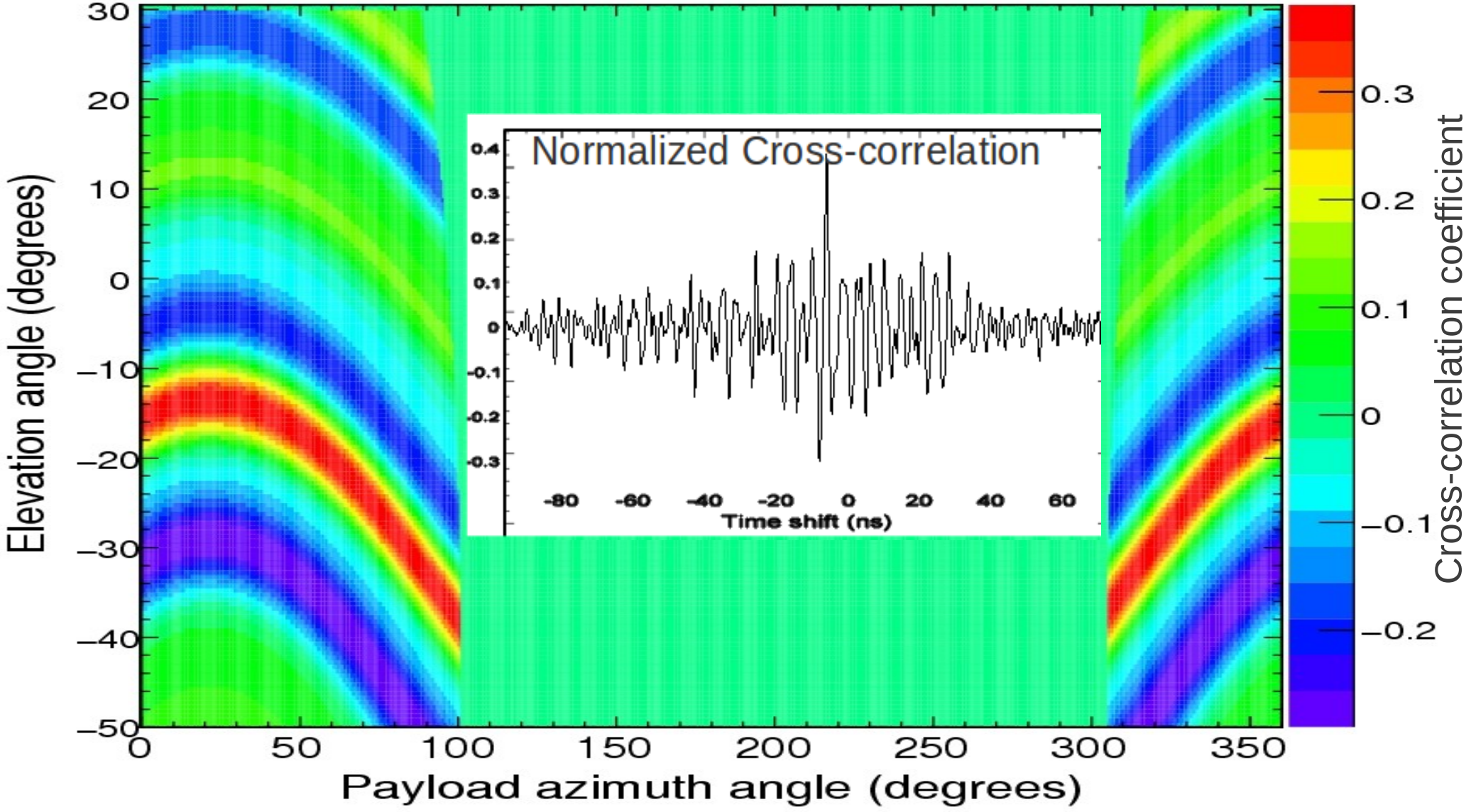
Event# 4338830: Antenna 20H



Event# 4338830: Antenna 21H

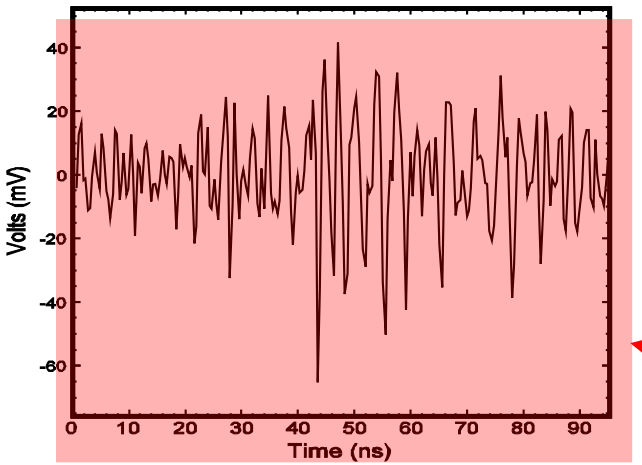


2-Antenna Interferometric Image

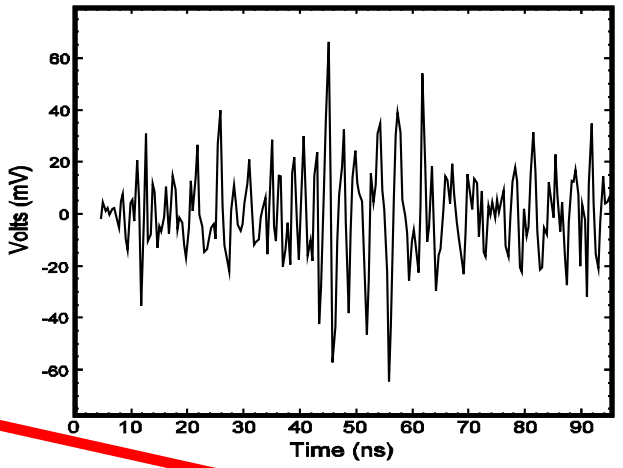


Another Antenna Pair

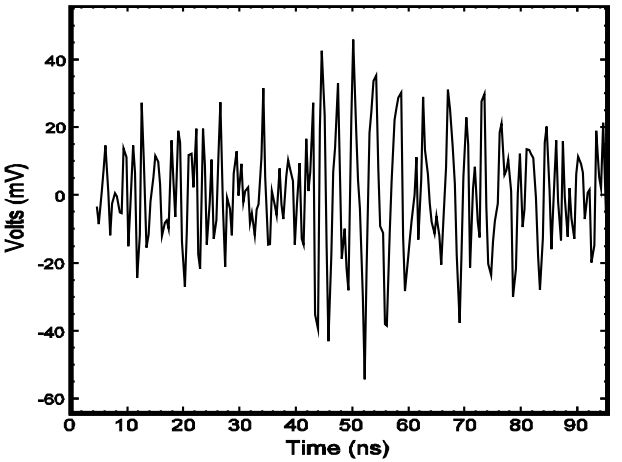
Event# 4338830: Antenna 10H



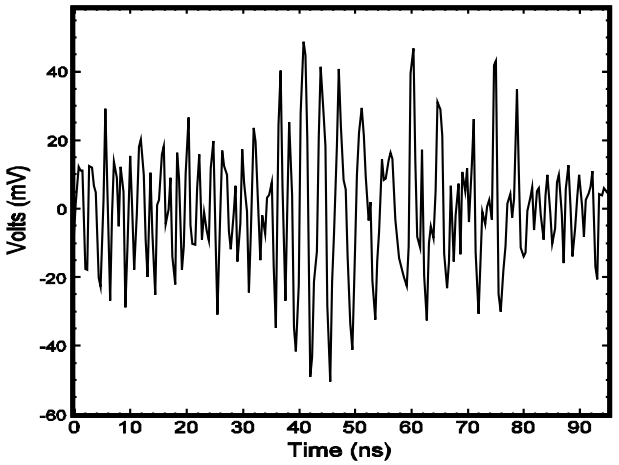
Event# 4338830: Antenna 2H



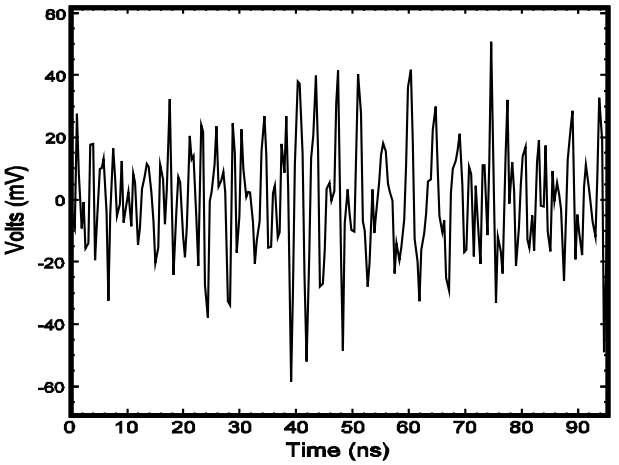
Event# 4338830: Antenna 11H



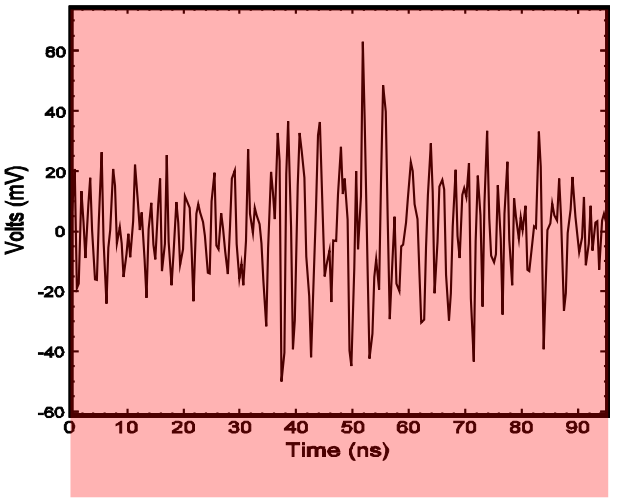
Event# 4338830: Antenna 19H



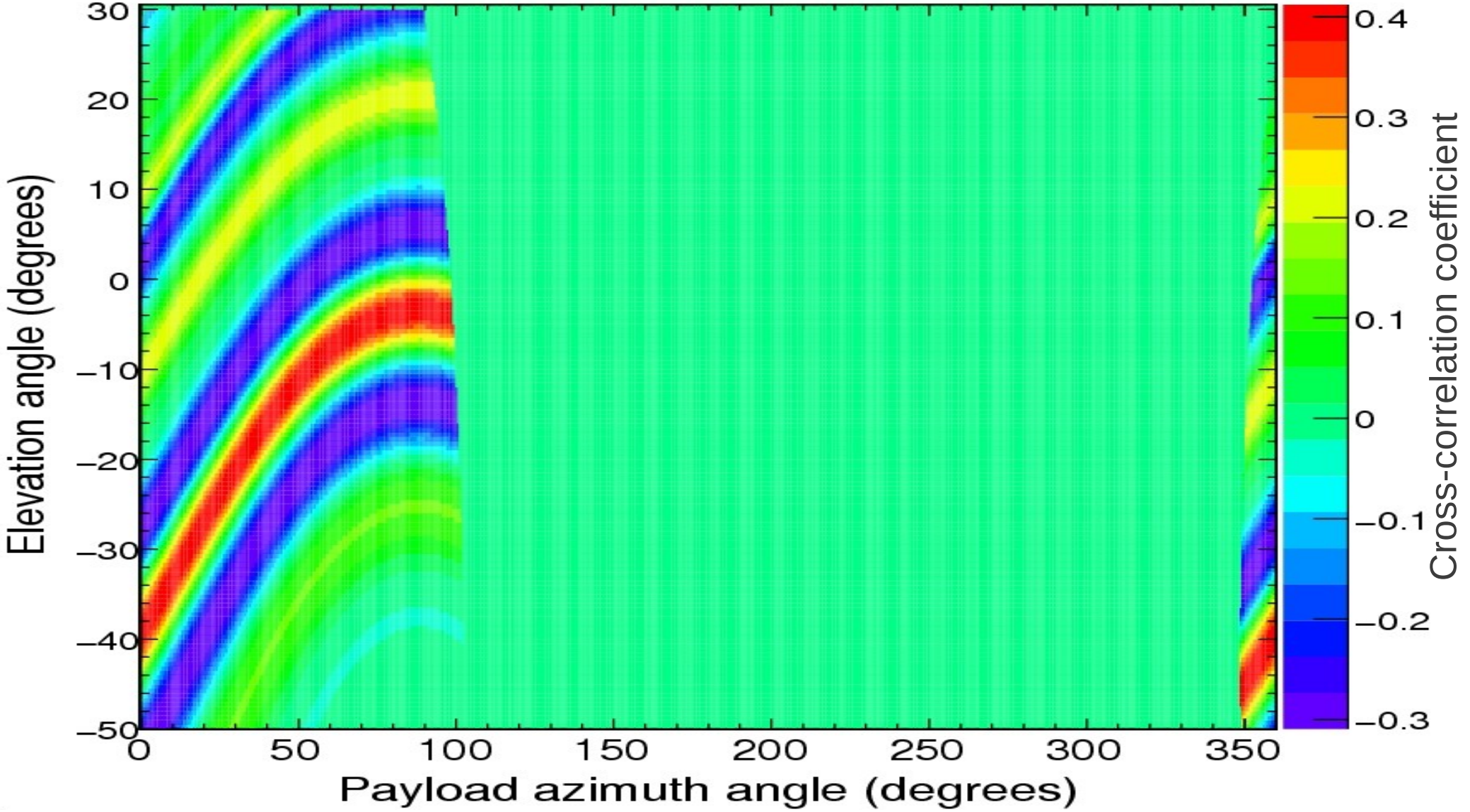
Event# 4338830: Antenna 20H



Event# 4338830: Antenna 21H

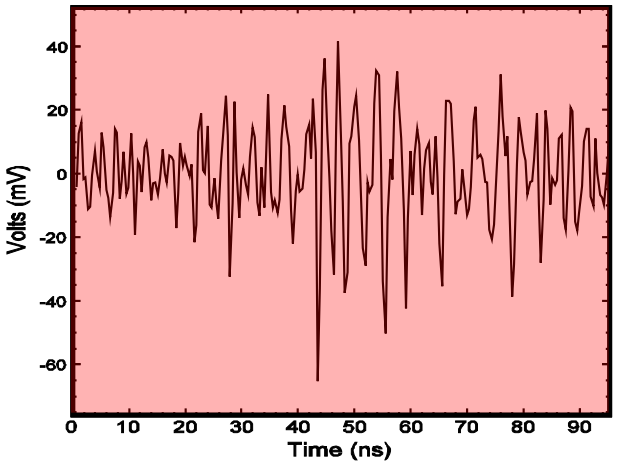


2-Antenna Interferometric Image

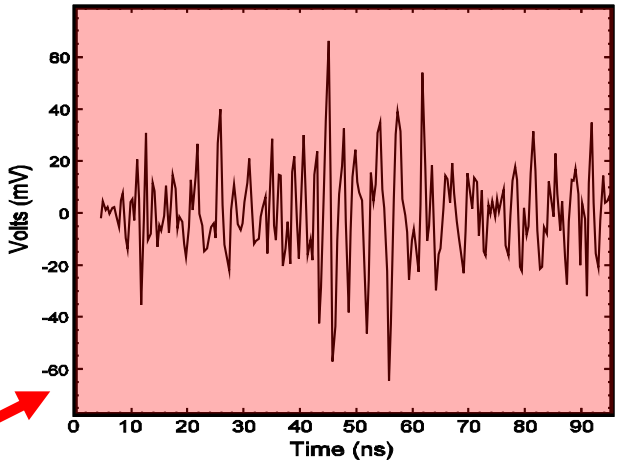


Yet Another Pair…

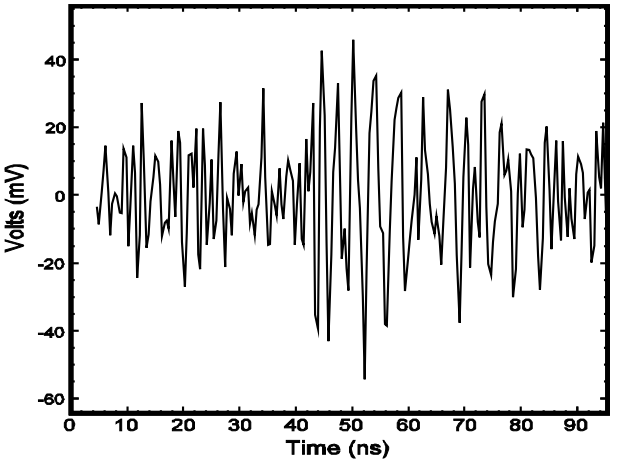
Event# 4338830: Antenna 10H



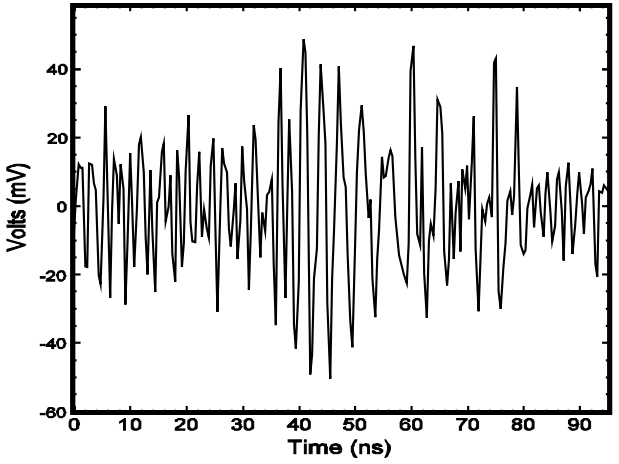
Event# 4338830: Antenna 2H



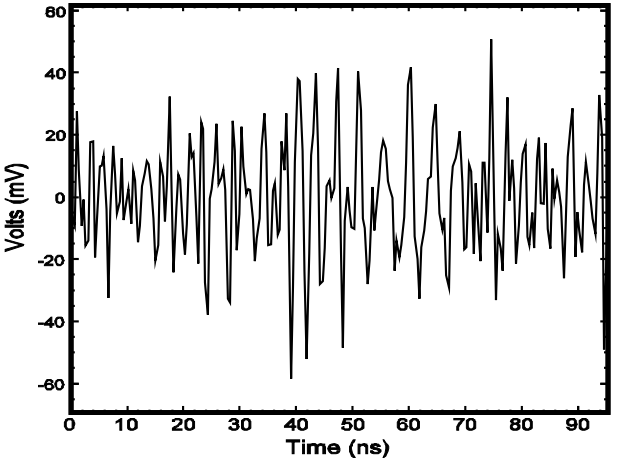
Event# 4338830: Antenna 11H



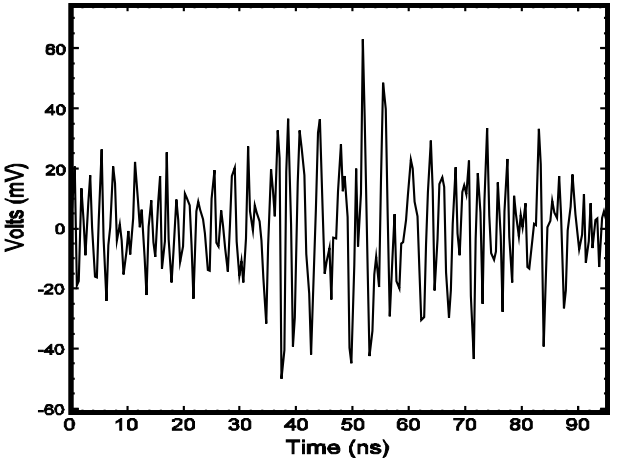
Event# 4338830: Antenna 19H



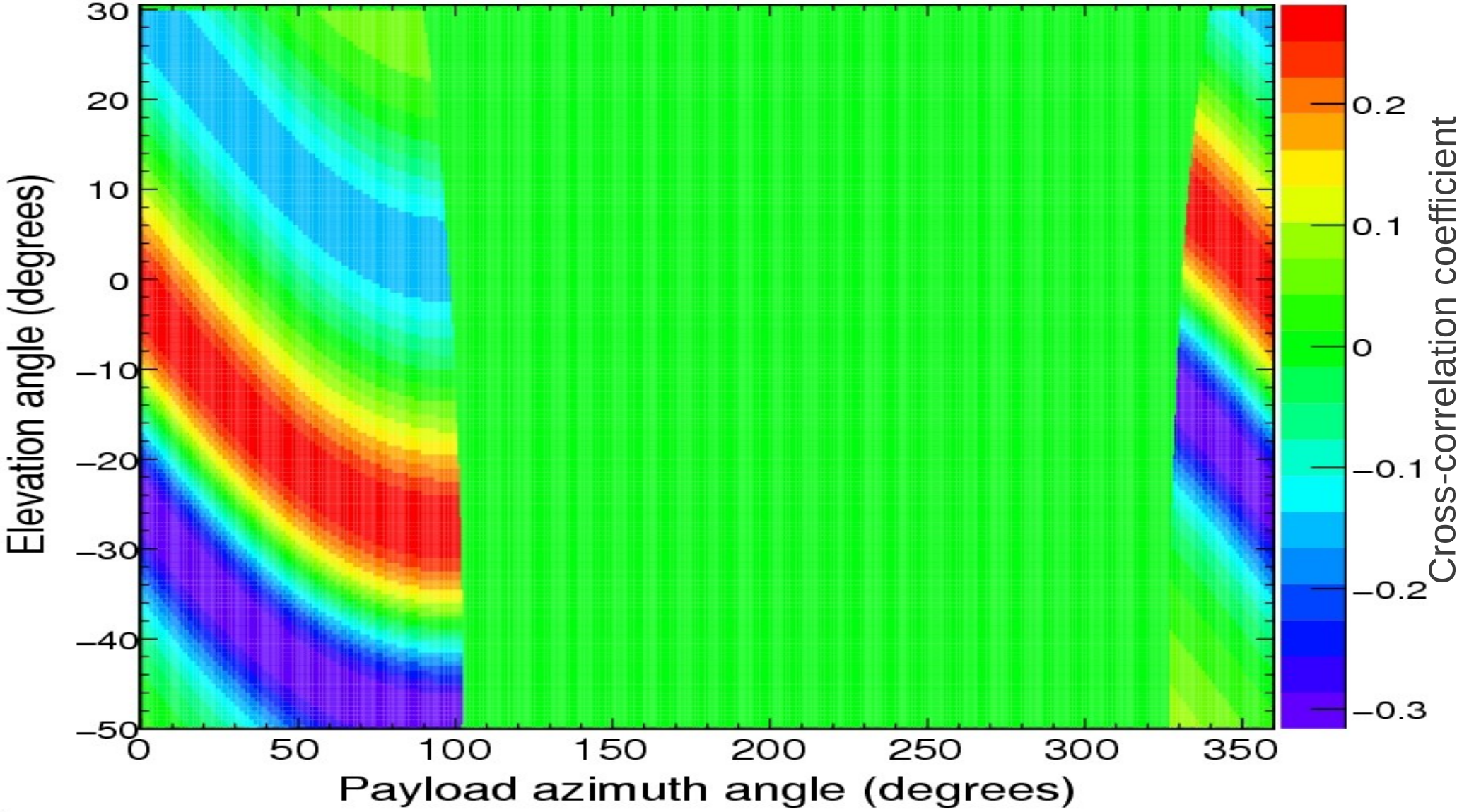
Event# 4338830: Antenna 20H



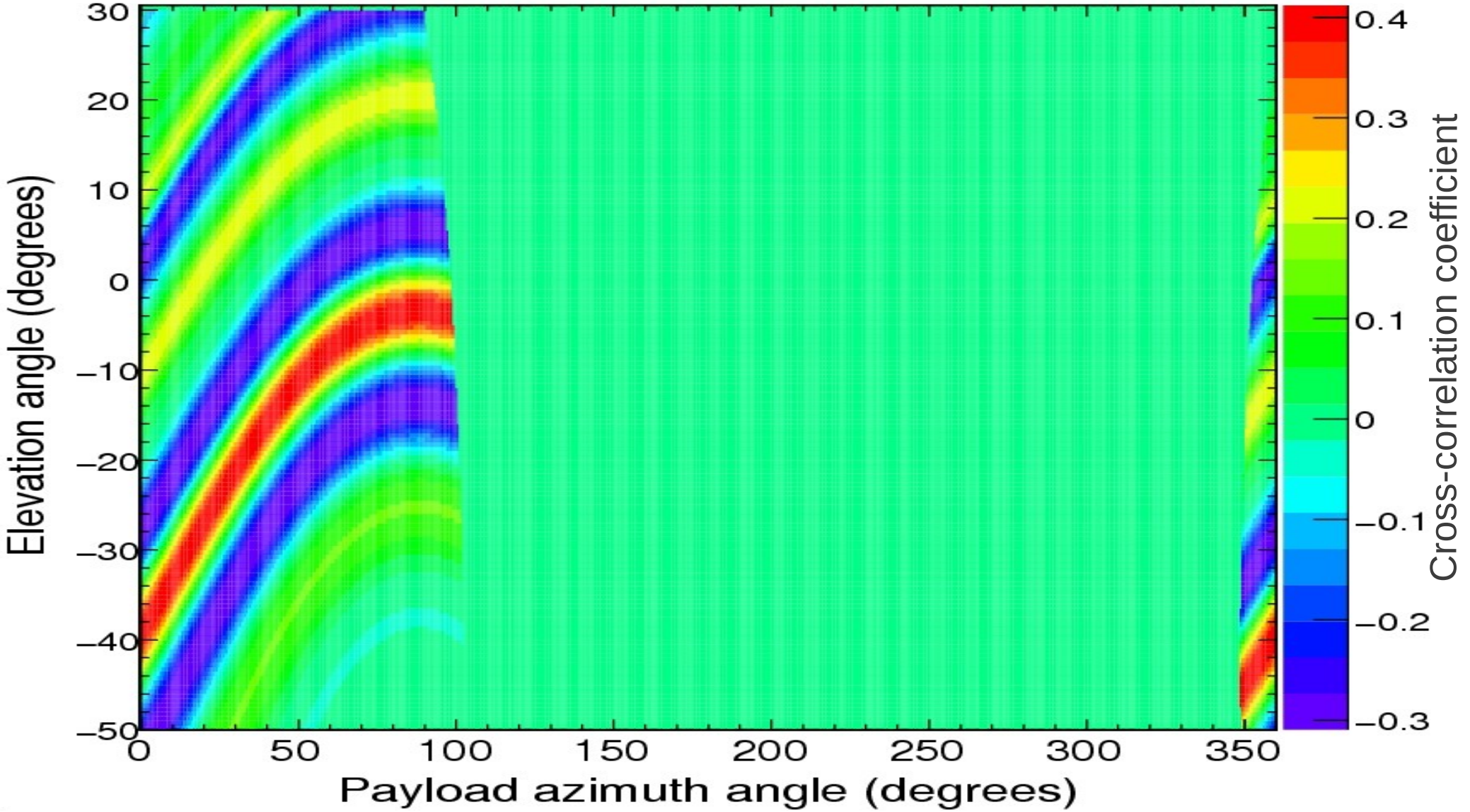
Event# 4338830: Antenna 21H



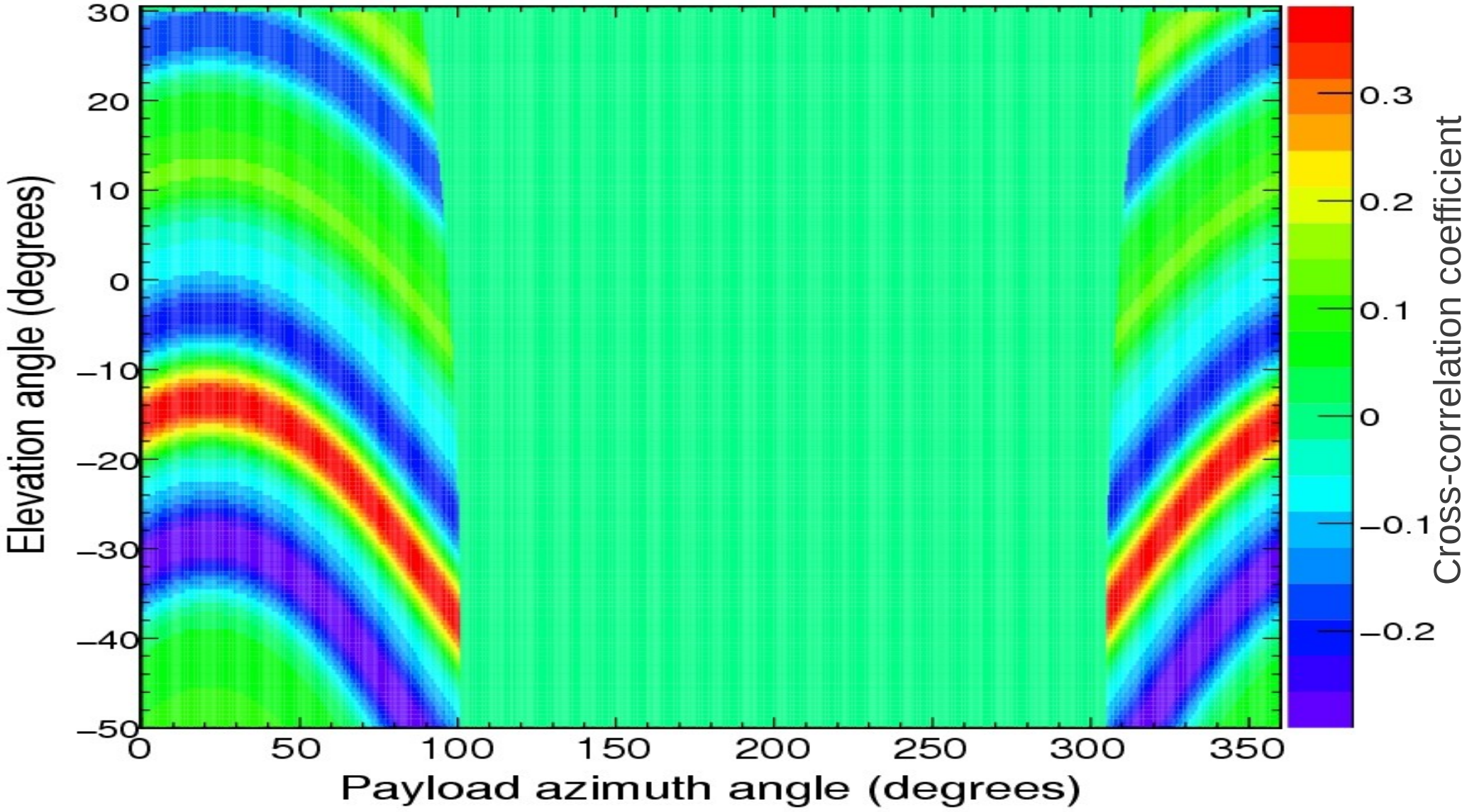
2-Antenna Interferometric Image



2-Antenna Interferometric Image

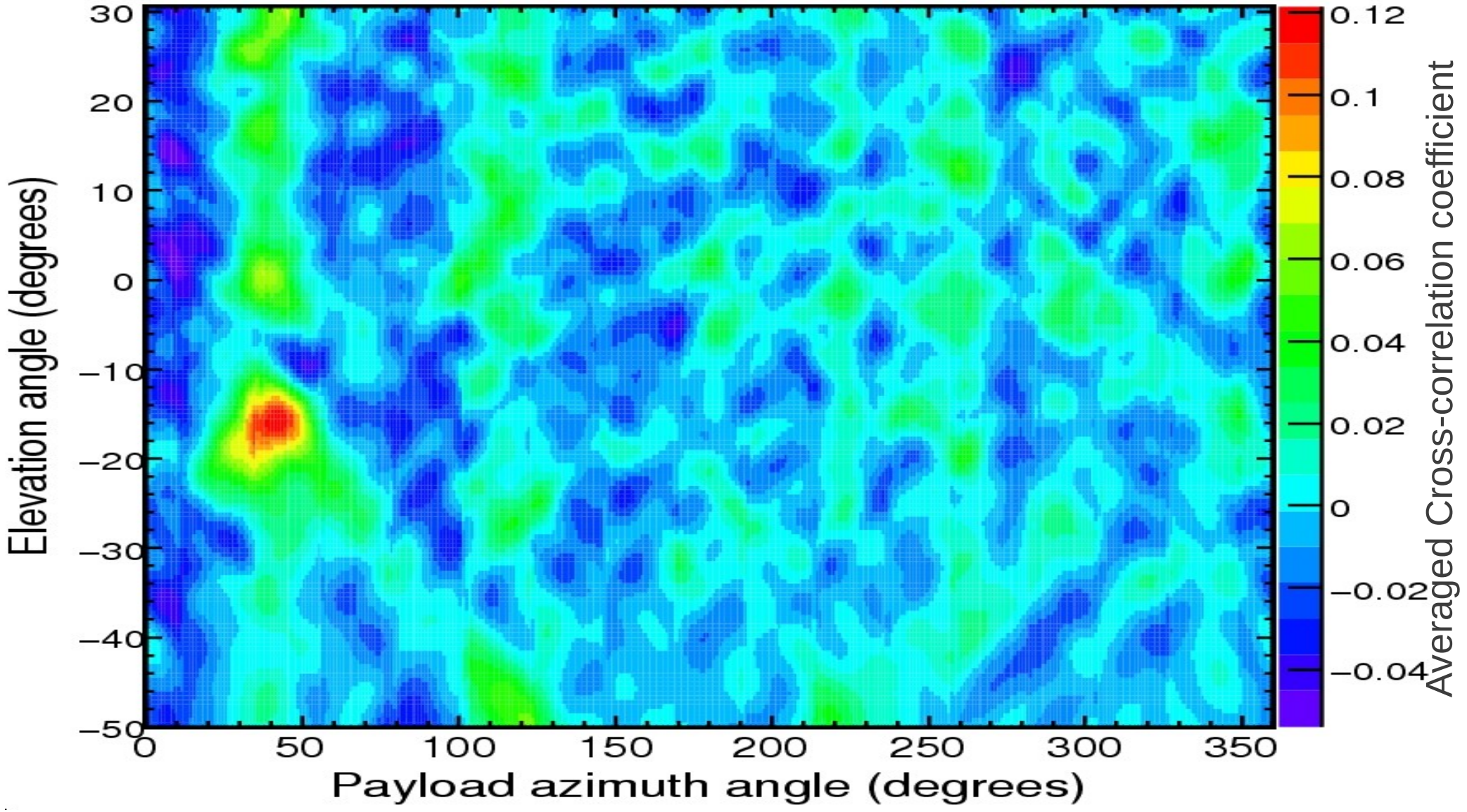


2-Antenna Interferometric Image



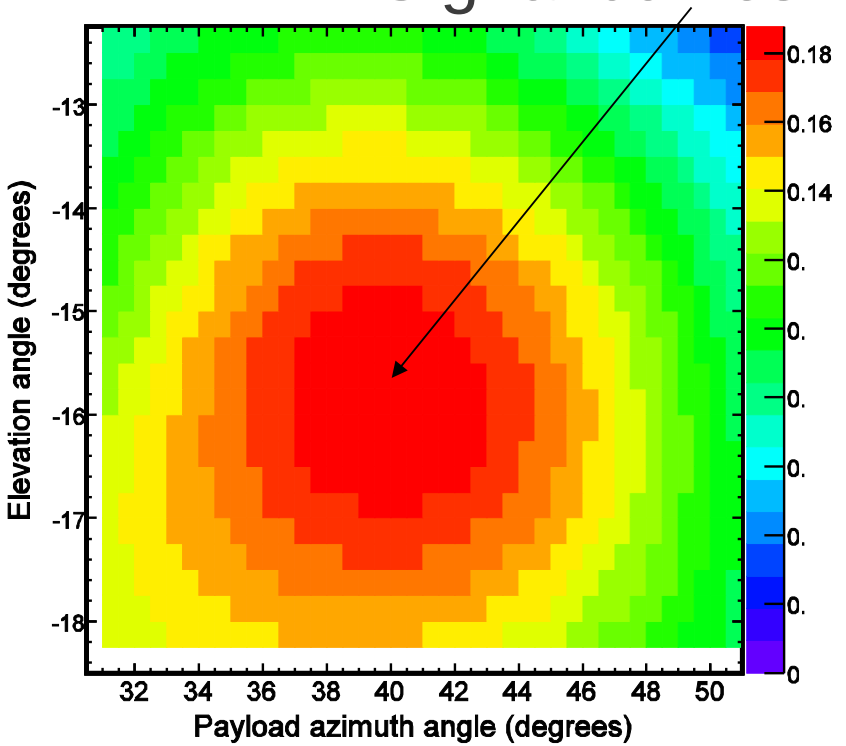
+ every other pair, all around the payload…

Full Payload Interferometric Image



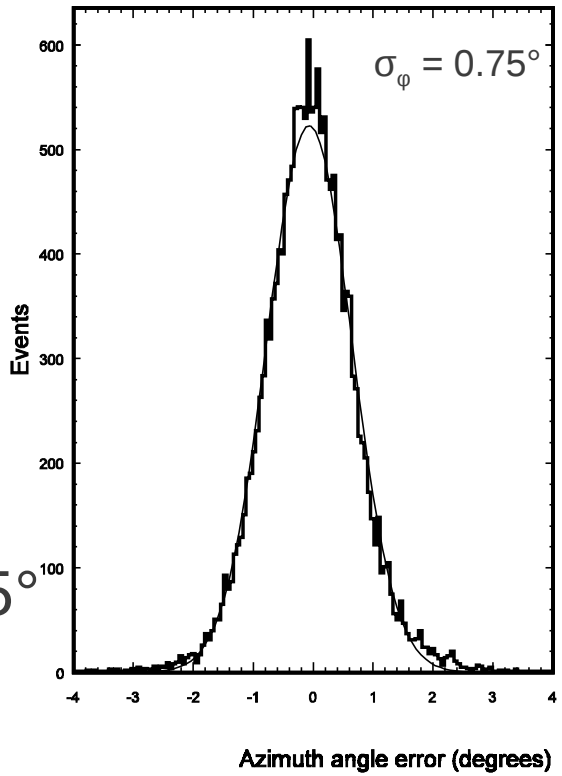
Pointing Resolution

Signal comes from peak of interferometric image

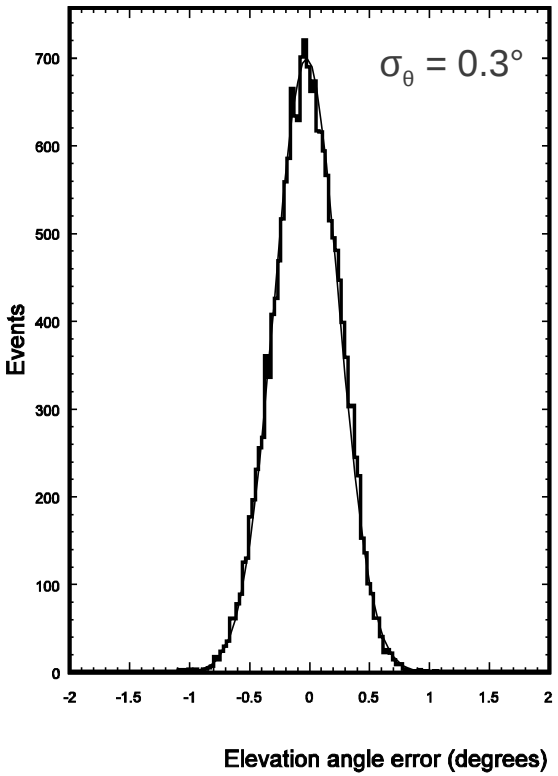


Pointing Error to Calibration Source

Azimuthal Error

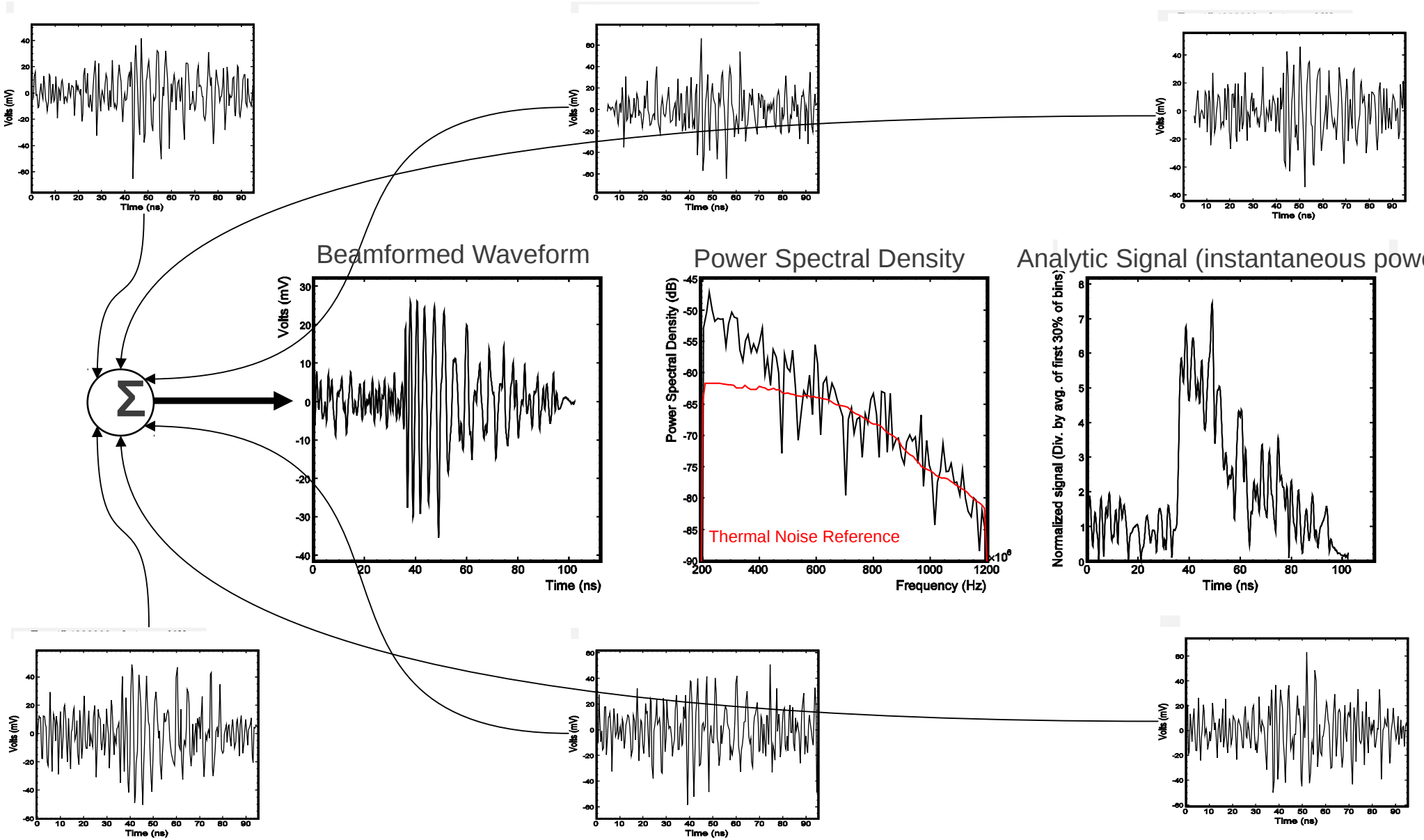


Elevation Error



- Azimuthal resolution ~ 0.75°
- Elevation resolution ~ 0.3°

Beamforming



Neutrino Results

- ANITA-1 sees no neutrinos
- UHE neutrino flux limits begin constraining models