

Results of the Search for Ultra High-Energy Neutrinos with ANITA-II

Abby Goodhue Vieregg

UCLA

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(ANITA-II Launch Day in Antarctica)

ANITA Collaboration

University of California, Irvine

Ohio State University

University of Kansas

Washington University in St. Louis

University of Delaware

University of Minnesota

University of California, Los Angeles

University of Hawaii at Manoa

National Taiwan University

University College London

Jet Propulsion Laboratory

Stanford Linear Accelerator Center



Neutrinos: Ideal UHE Messengers

- Travel virtually unattenuated through the universe
 - Point back to sources
- Highest energy observation of extragalactic sources
 - Study very distant sources
- GZK Production: Cosmic ray protons ($E > 10^{19.5}$ eV) interact with CMB photons

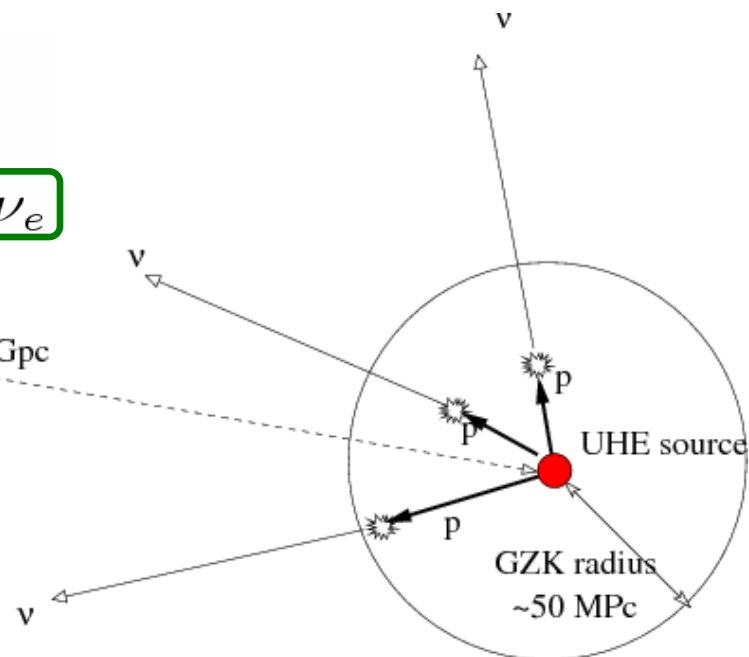
$$p + \gamma_{cmb} \rightarrow \Delta^+ \rightarrow n + \pi^+$$

$$\rightarrow \mu^+ + \nu_\mu$$

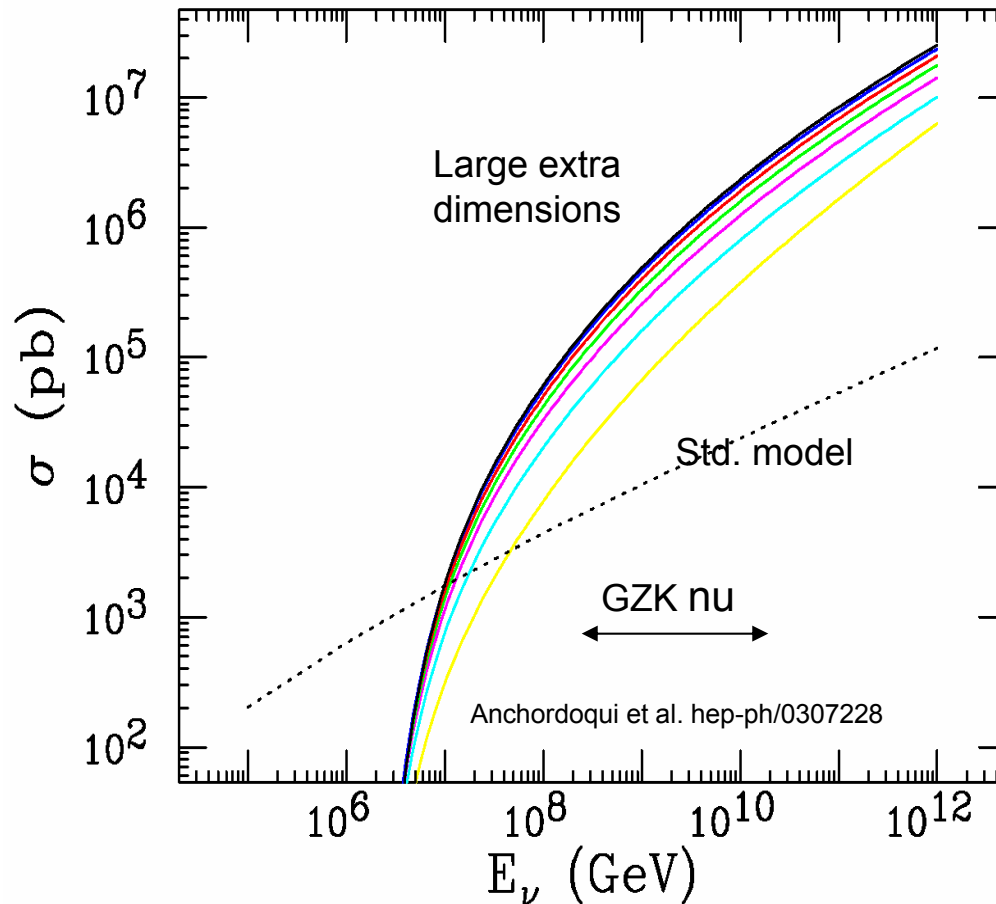
$$\rightarrow e^+ + \bar{\nu}_\mu + \nu_e$$

Earth

~ 1 Gpc



Neutrino Cross Section



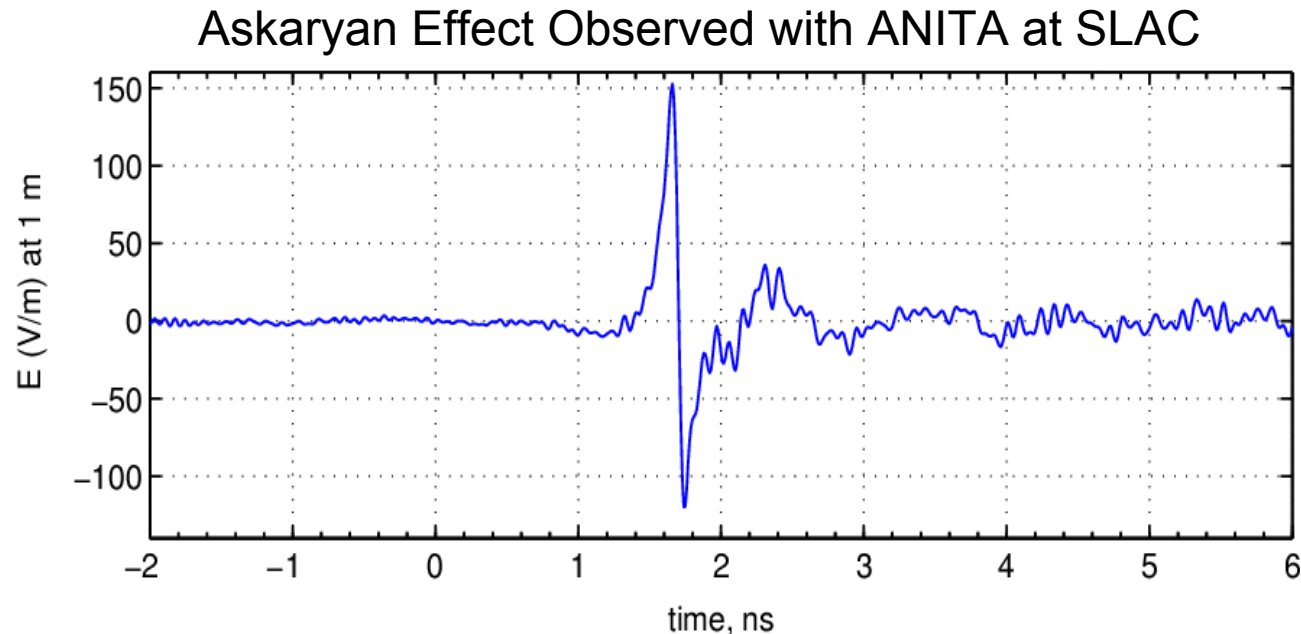
■ Weak interaction at E_{CM} not accessible to LHC: 200 TeV

■ $L_{\text{int}} \sim 250$ km

□ Use Earth-shielding as cross-section analyzer

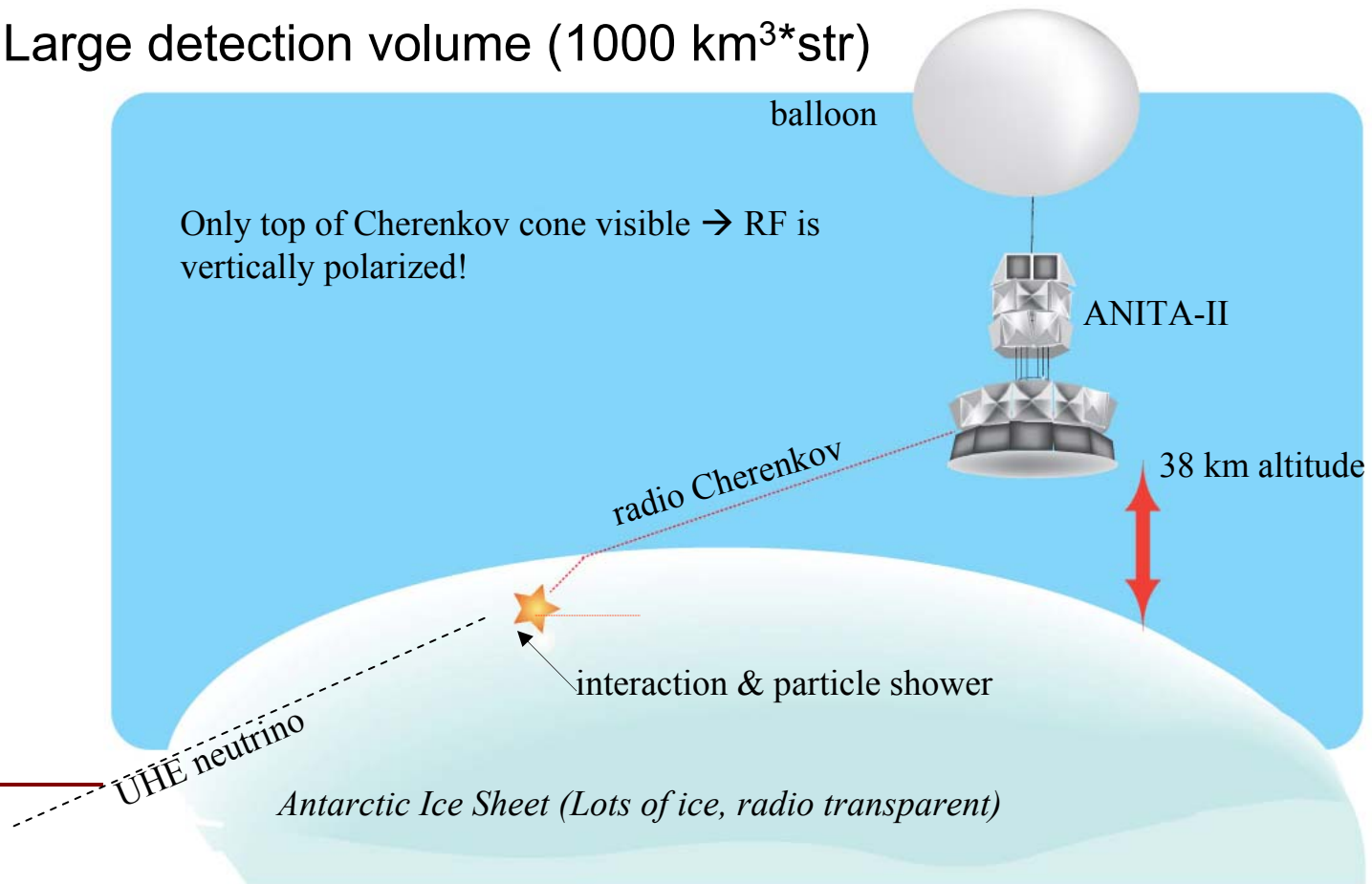
Detection Principle: The Askaryan Effect

- EM shower in ice \rightarrow moving negative charge excess
- Coherent radio Cherenkov radiation ($P \sim N^2$)



The ANITA Concept

- Neutrino signal characteristics:
 - Fast impulse
 - Vertically polarized
- Ice is radio transparent
- Large detection volume ($1000 \text{ km}^3 \cdot \text{str}$)



ANITA-I Results

(S. Hoover)

Vertical Polarization (neutrino search)

Expected Background

1

Observed Events

1

Horizontal Polarization (cosmic rays)

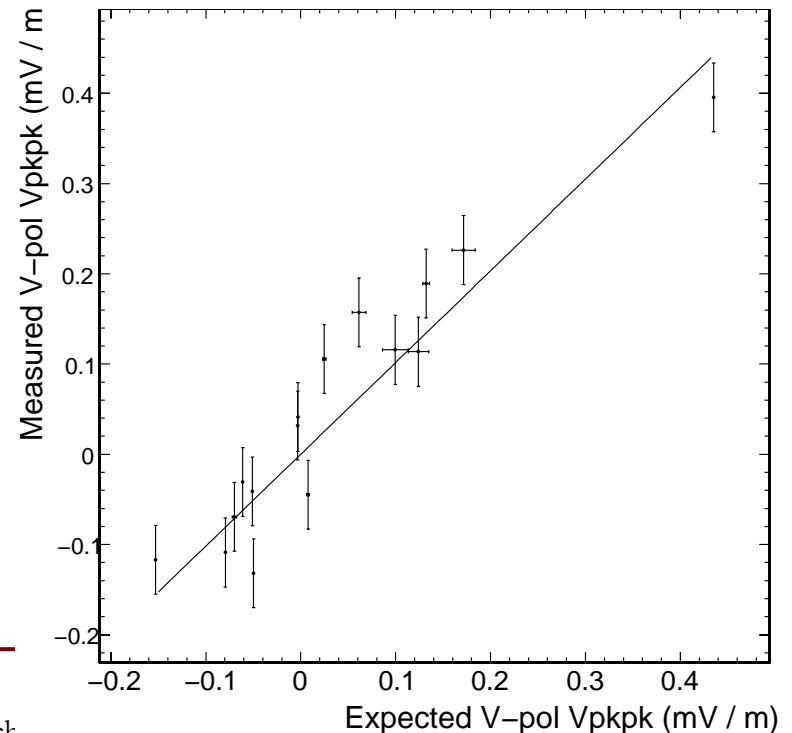
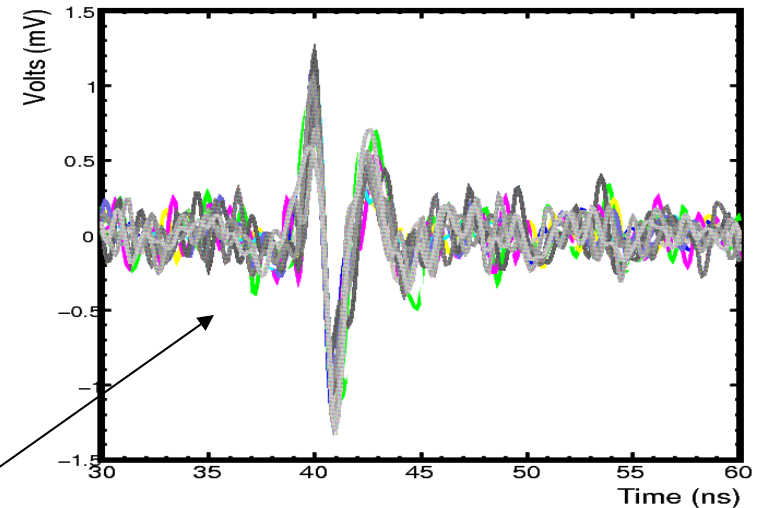
Expected Background

2

Observed Events

16

- Radio Synchrotron emission of CR air showers seen!
- Direction of geo-magnetic field determines polarization direction ($\mathbf{F} = q\mathbf{v} \times \mathbf{B}$)
→ Mostly Hpol in Antarctica
- CR Energy: order 10^{19} eV, work in progress



The ANITA-II Instrument



200-1200 MHz antennas

Improvements for ANITA-II:

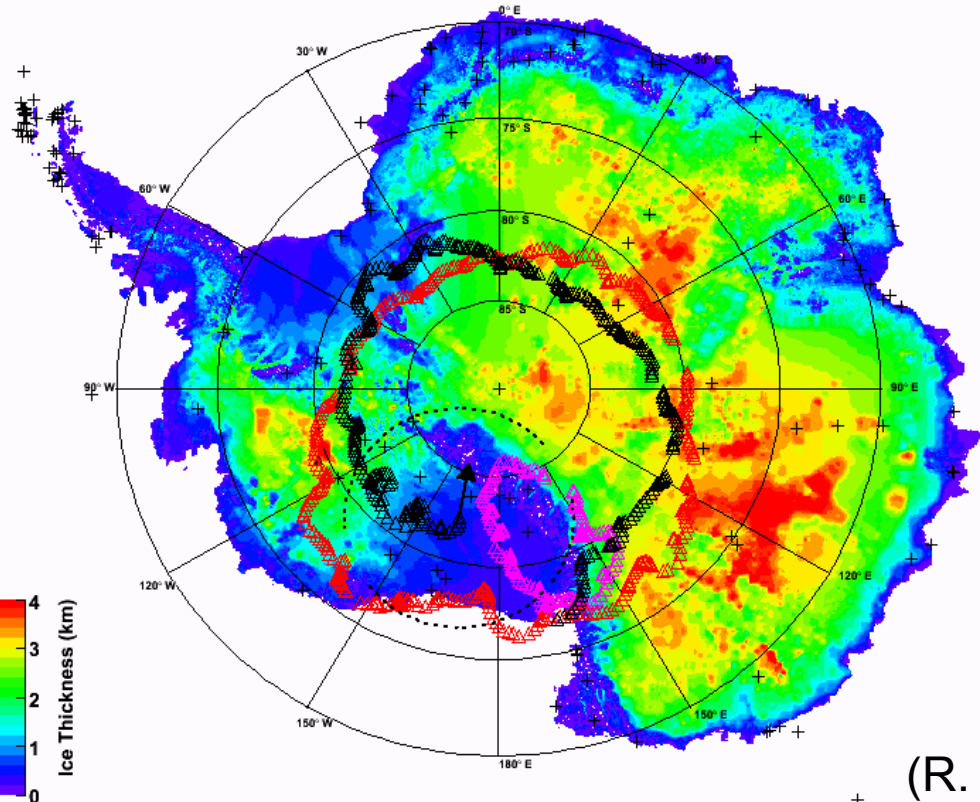
- Lower Energy Threshold (x 3 events)
 - Reduce front-end amplifier temp (20%)
 - Improve trigger efficiency (30%)
 - 8 more antennas (30%)
- Increased Exposure (x 2 events)
 - Directional trigger masking (30%)
 - Better flight path & more livetime (x 2)

Total improvement: > 5 in neutrino event rate

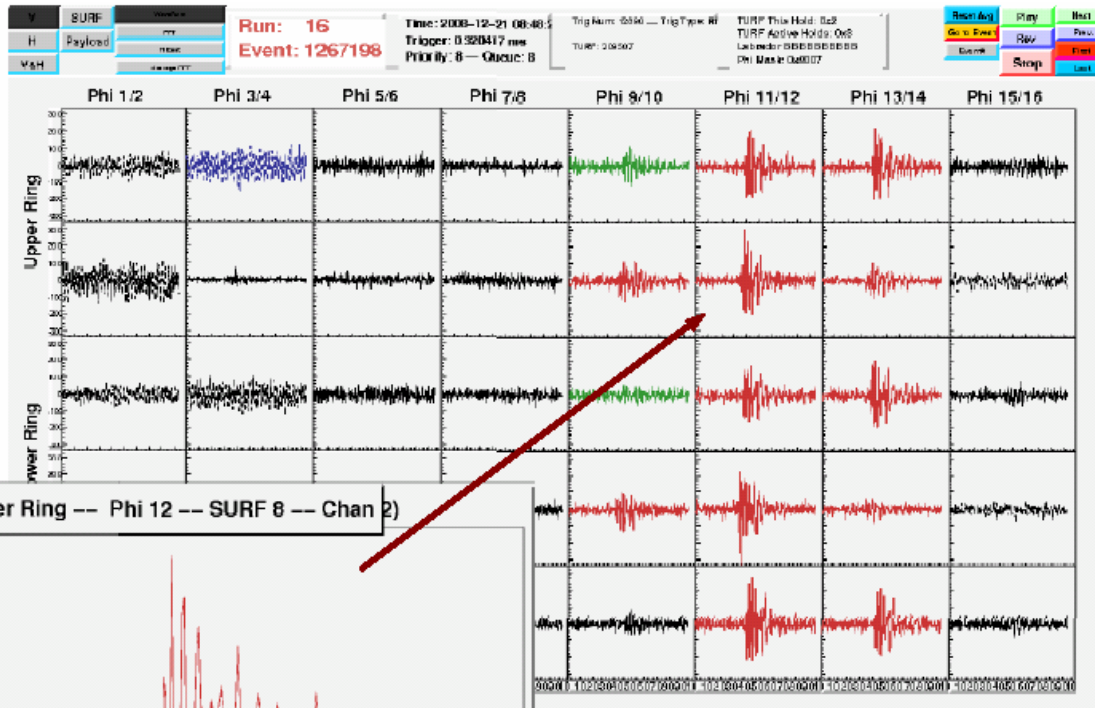
ANITA-II Flight



- 31 day flight
- Launched: Dec 21st 2008
- 27M events



Ground Calibration

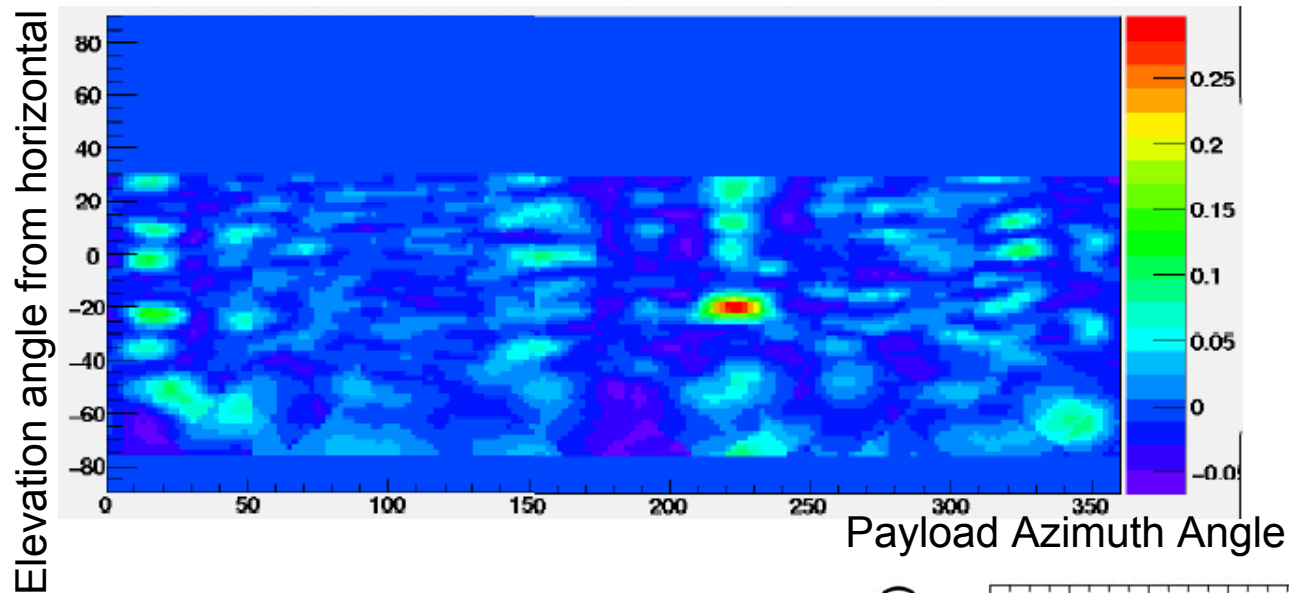


~115,000 Calibration impulses from a remote field site during flight.

Critical for analysis!

(R. Nichol)

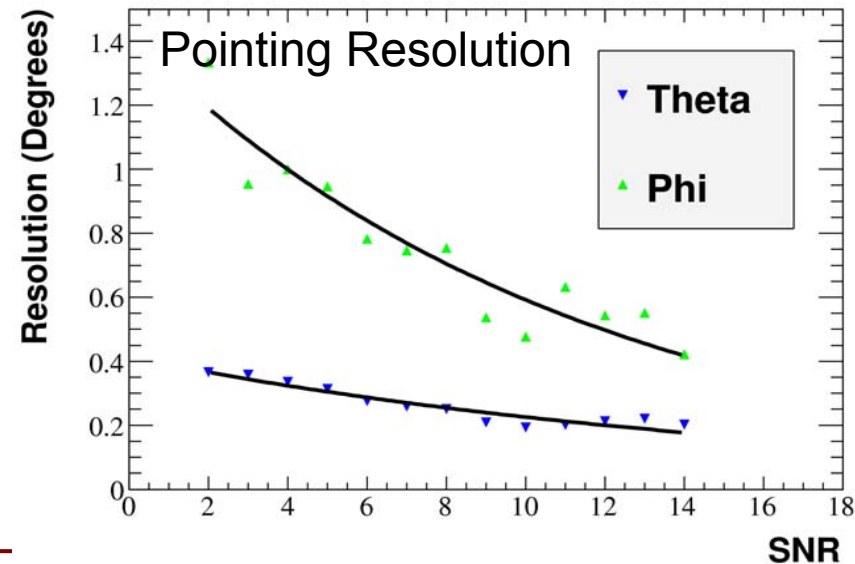
Pointing Events to the Ground



(Calibration
Pulser Event)

Making an Interferometric Image:

- calculate cross-correlation of antenna waveforms
- use timing delay given by direction
- sum over the whole payload



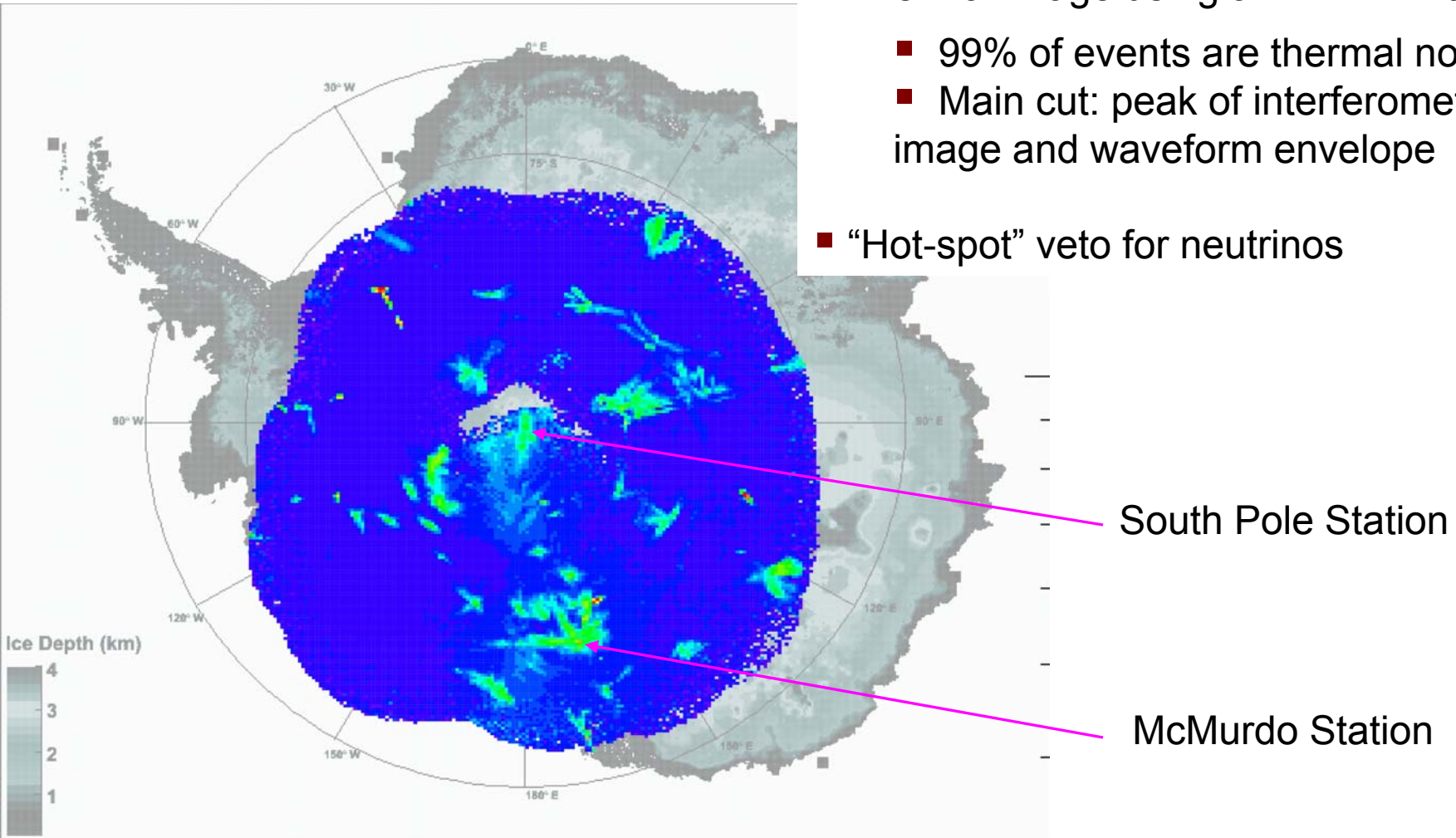
Blind Analysis Plan

- 2 methods of blinding
 - Hidden signal box
 - Event insertion
- Set cuts on sidebands
- Estimate background and efficiency
- Open hidden box, remove inserted events
- Separate HPol (cosmic rays) from VPol (neutrinos)



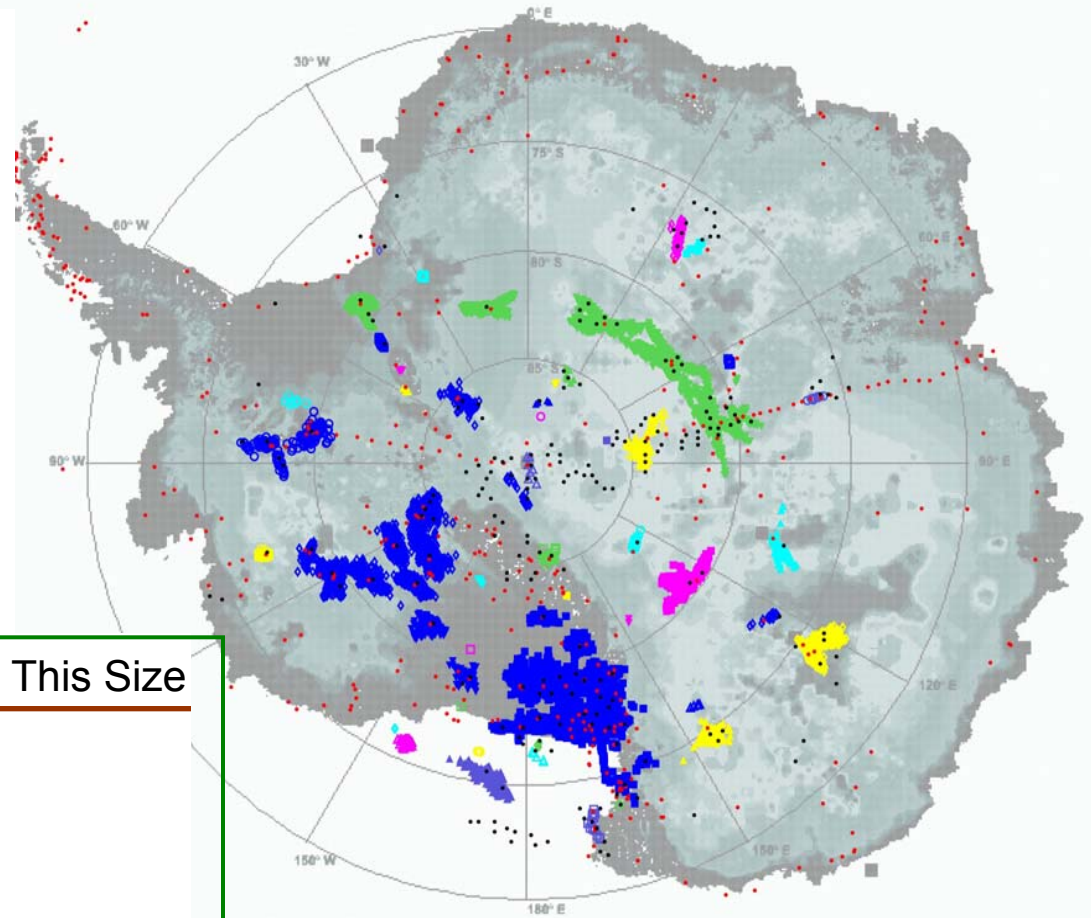
Lots of Man-Made & Thermal Noise

- Thermal image using all ANITA-II triggers
 - 99% of events are thermal noise
 - Main cut: peak of interferometric image and waveform envelope
- “Hot-spot” veto for neutrinos



Separation from Man-Made Events

- 300k events pass thermal cuts
- Cluster with:
 - Other events
 - Known bases of activity
 - “Hot-Spots”
- **Neutrinos are single, isolated events!**



Cluster Size	Number With This Size
<u>From Known Bases:</u>	
2-100	17
1 (Single Events)	7
<u>Not from Known Bases:</u>	
2-100	3
1 (Single Events)	? (Signal Box)

→ Estimate man-made background using cluster multiplicities

Unblinding

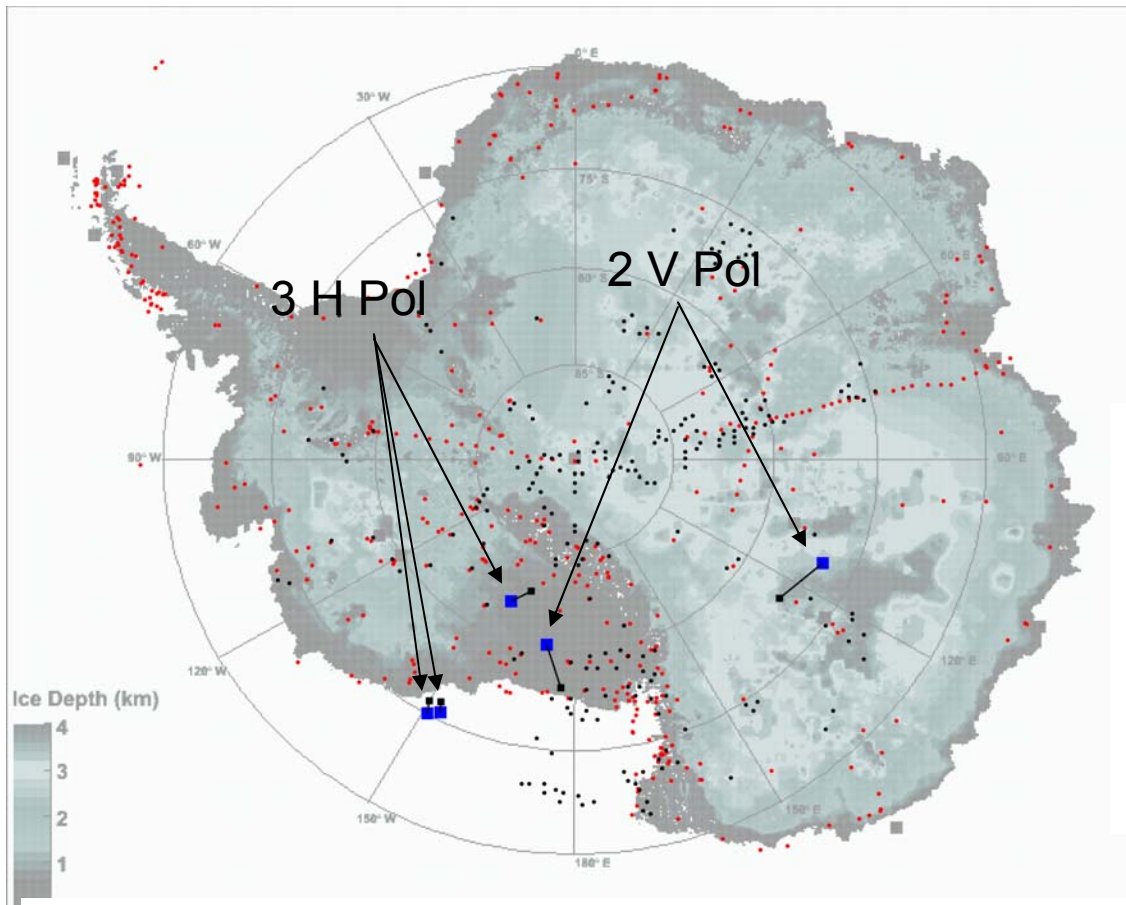
Cut requirement	Passed		Efficiency
	Vpol	Hpol	
Hardware-Triggered	$\sim 26.7\text{M}$		-
(1) Quality Events	$\sim 21.2\text{M}$		1.00
(2) Reconstructed Events	320,722		0.96
(3) Isolated Singles	2	3	0.64
Total Efficiency			0.61

Neutrino Bin Cosmic Ray Bin Analysis Efficiency

Background Estimate (Thermal + Man-made):

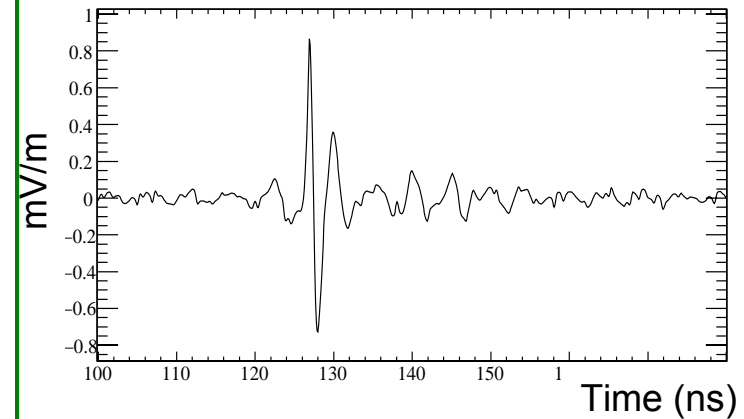
- V Pol (neutrino): 0.97 +/- 0.39 events
- H Pol (cosmic ray) : 0.57 +/- 0.19 events

Candidate Events

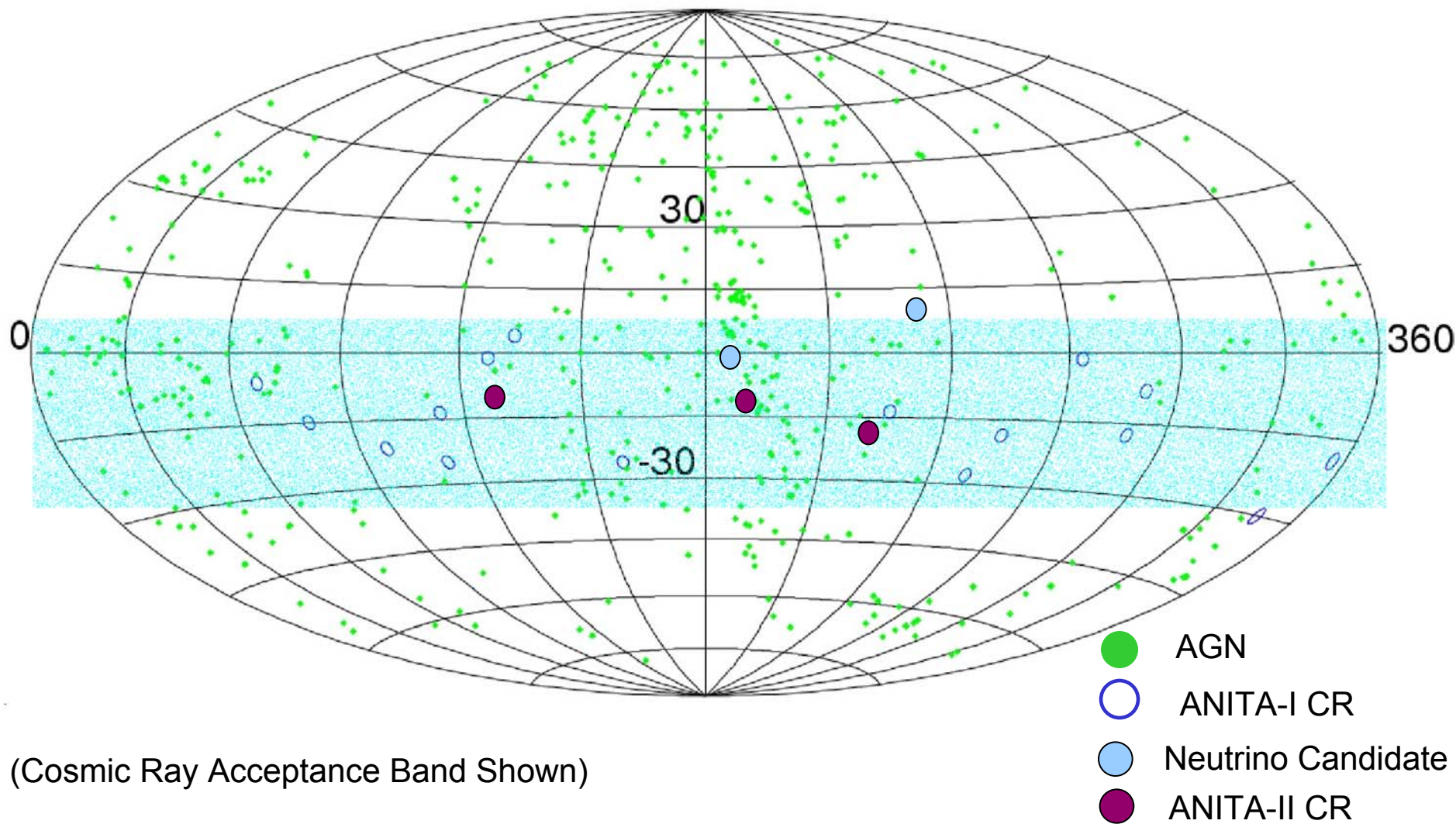


3 HPol events consistent with cosmic rays seen by ANITA-I !

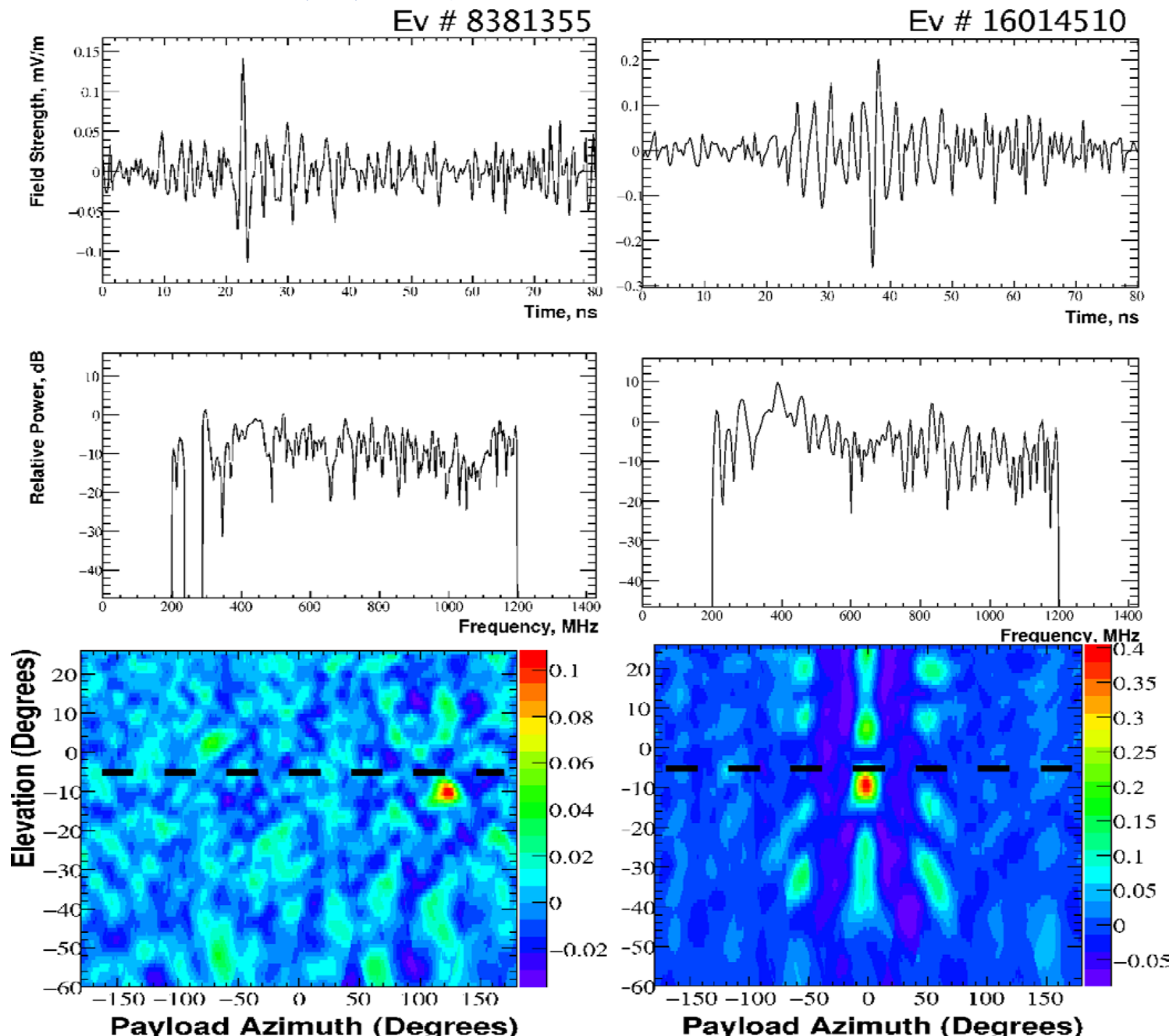
Example waveform:



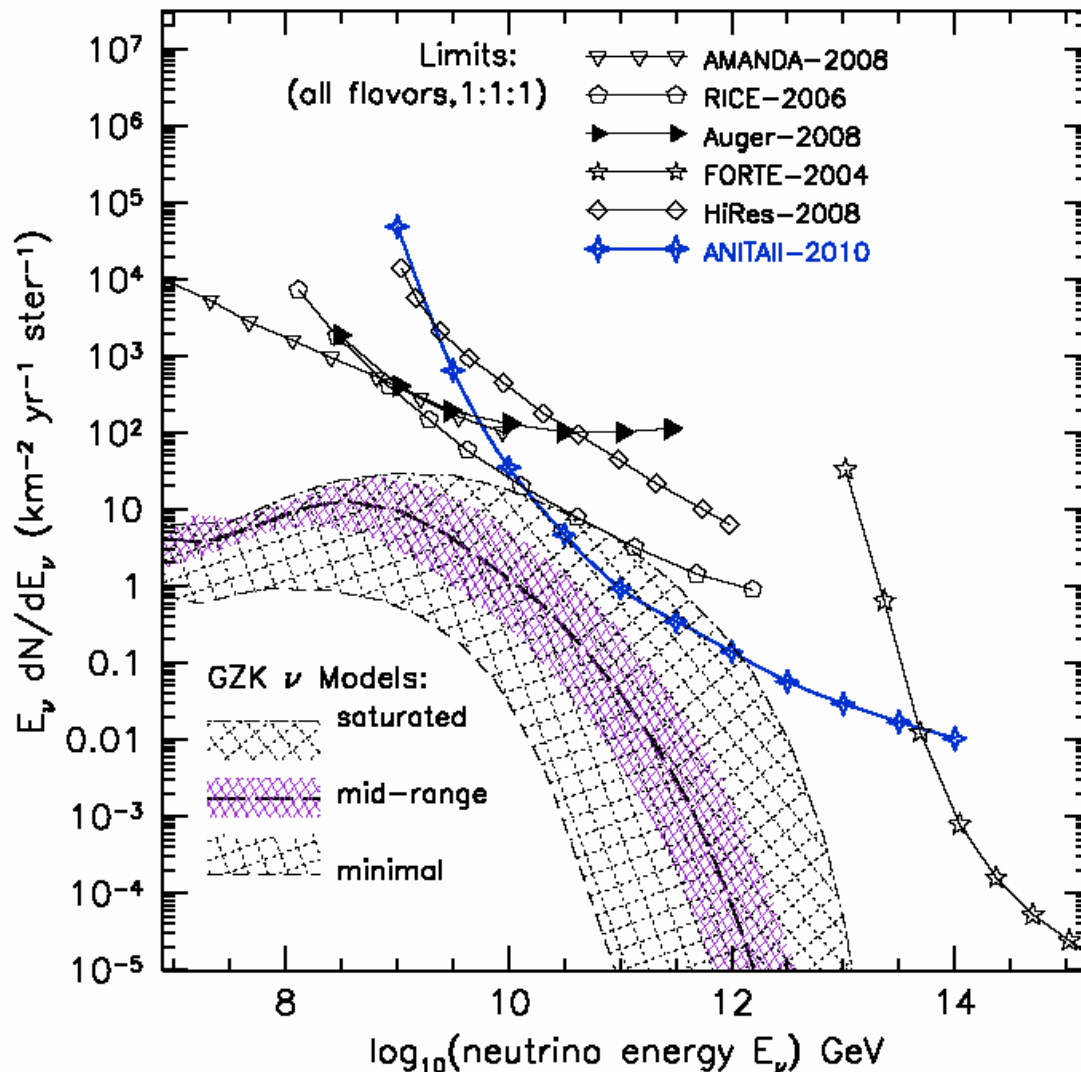
Cosmic Ray Sky Map



Neutrino Candidates



New Limit on the UHE Neutrino Flux



- 2 events on a background of 0.97 ± 0.39
- (Feldman-Cousins 90% CL)

Summary

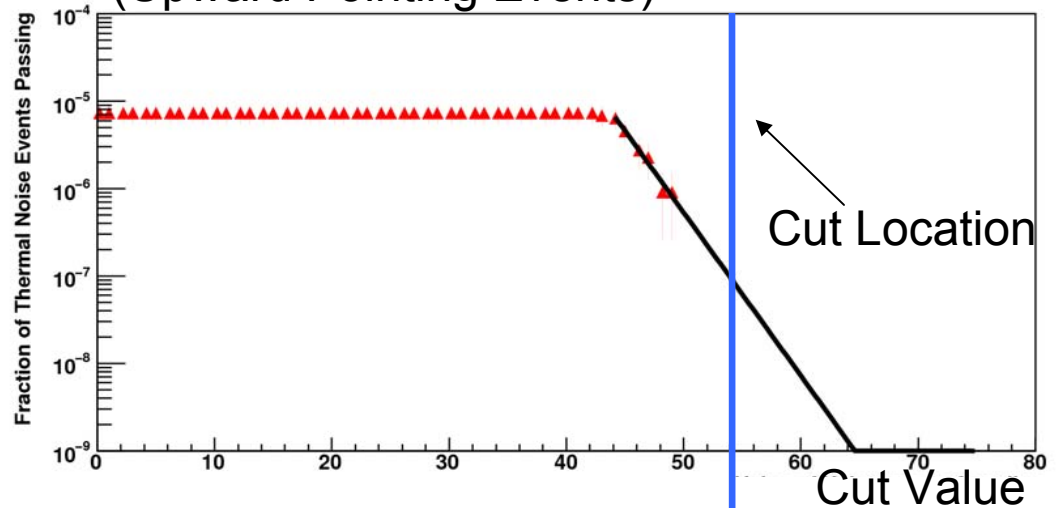
- 2 Neutrino Candidates on a background of 0.97 ± 0.39
- 3 cosmic ray events seen
- Set new constraints on flux of UHE neutrinos
- On the edge of seeing neutrinos?
→ ANITA-III will find out!



Separation from Thermal Noise

- 99% of triggers are thermal noise
- Main cut: peak value of the interferometric image and waveform envelope
- Allow 0.5 background events (from 21M triggers)

Rejection of Thermal Noise Sample
(Upward Pointing Events)



Efficiency on Calibration Events

