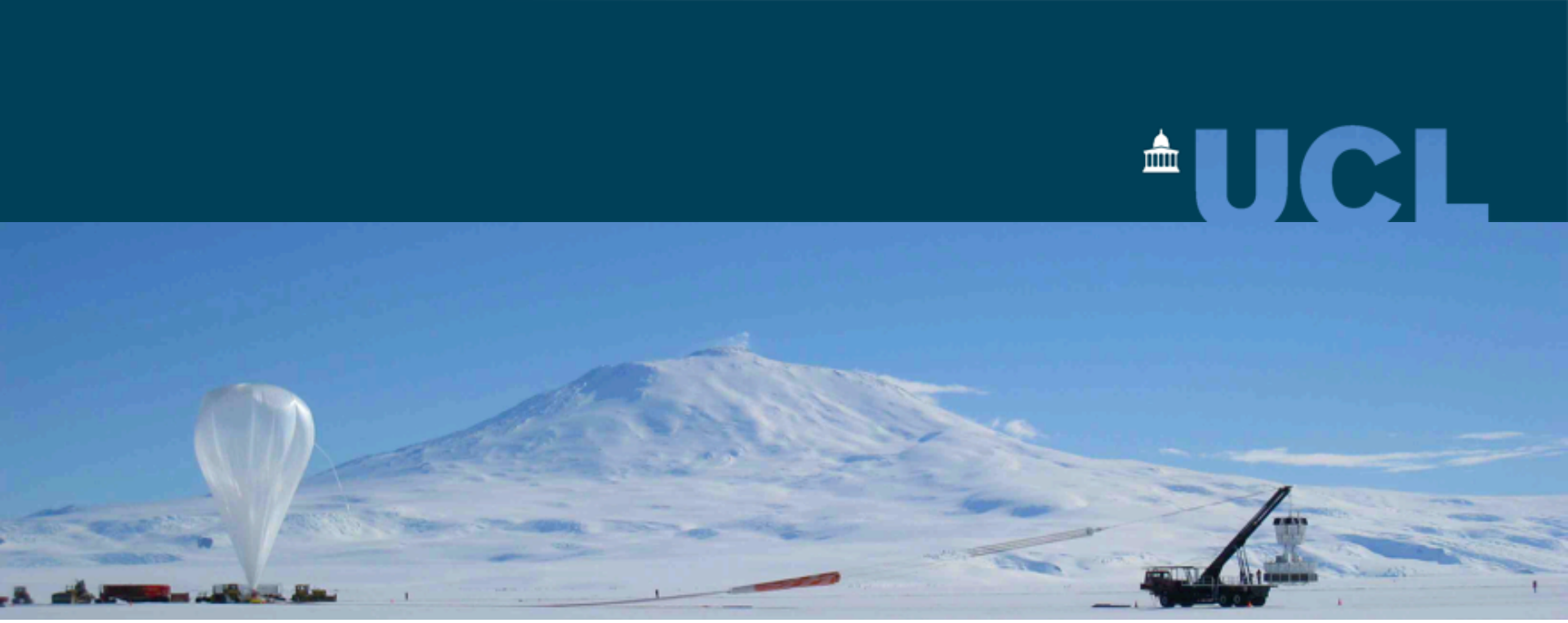
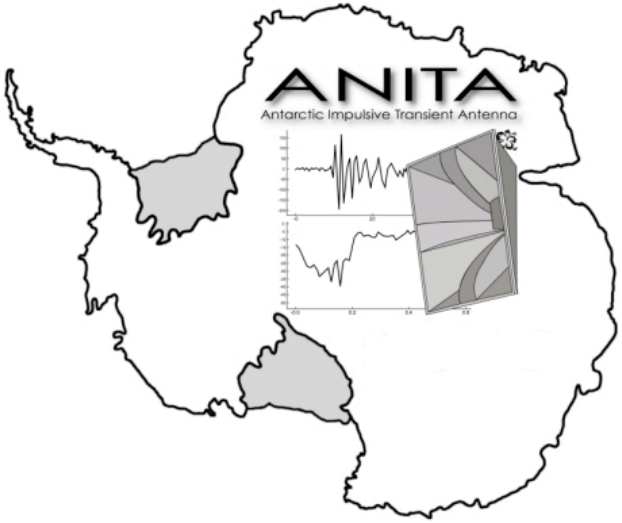


An observational limit on the UHE cosmic neutrino flux from the 2nd flight of the ANITA experiment

Matthew Mottram for the ANITA collaboration
University College London



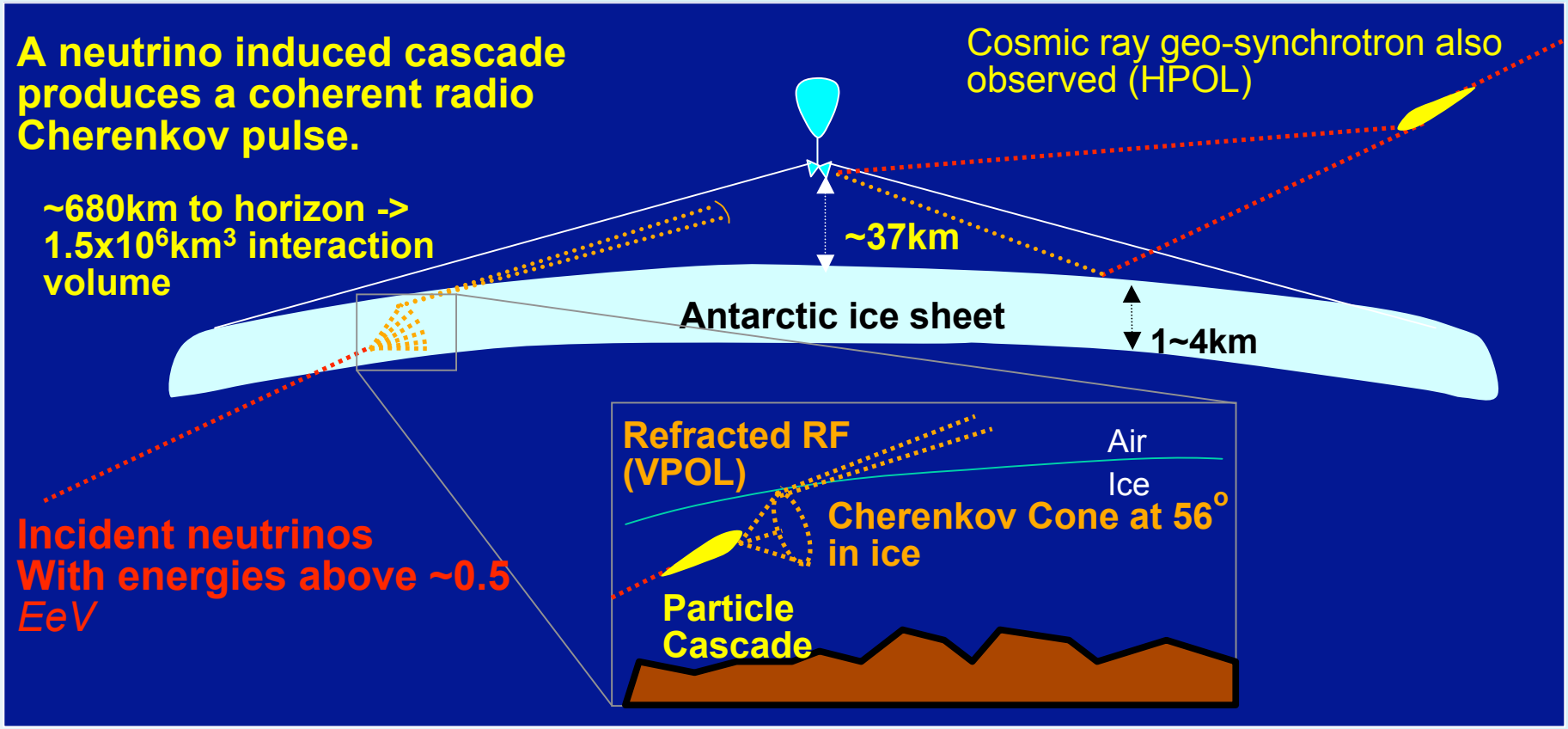
Outline

- Introduction to ANITA
- Analysis tools
  - Event reconstruction
  - Thermal noise rejection
  - Anthropogenic event rejection
- Analysis efficiency & background calculation
- Neutrino search results

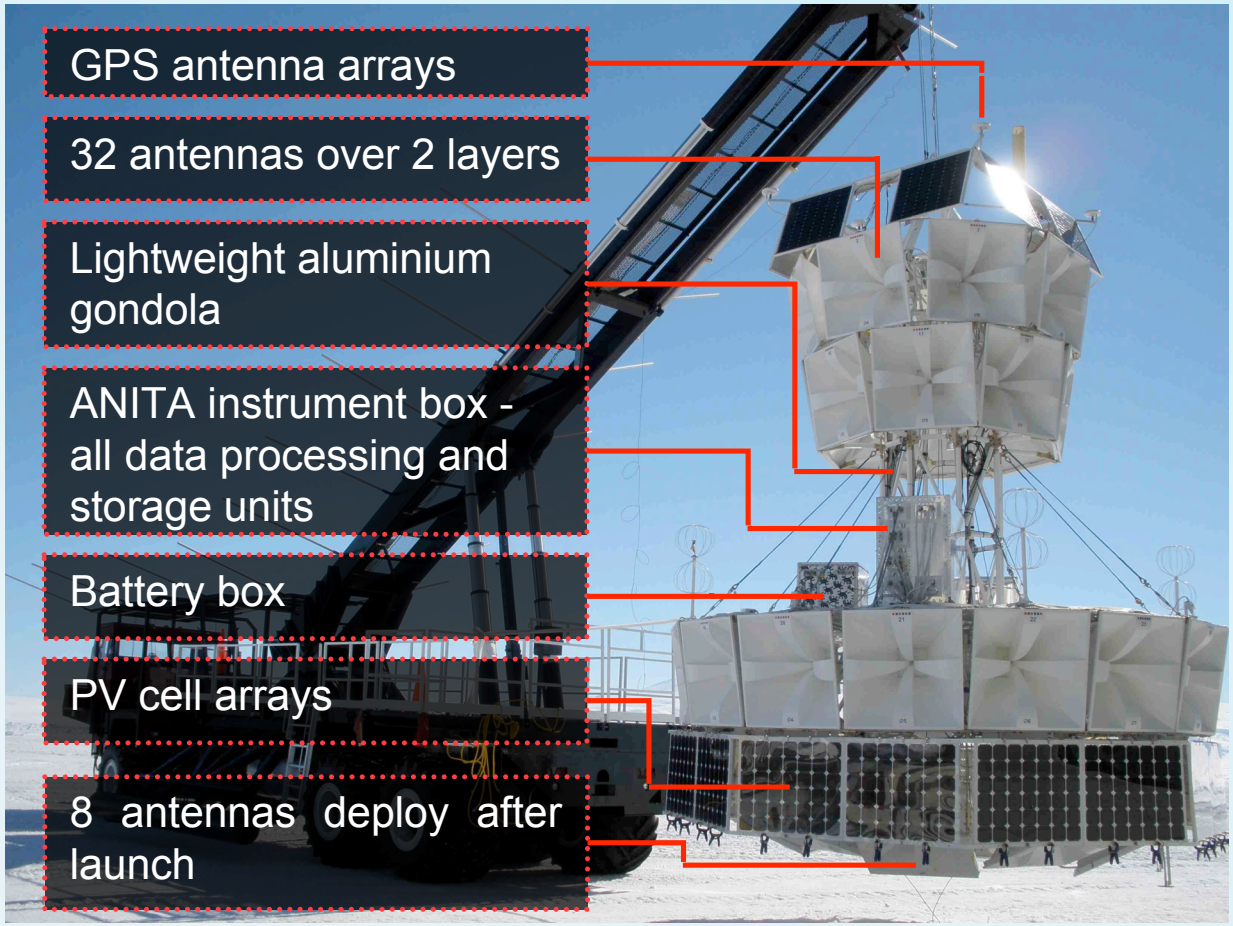
ANITA concept

ν interaction causes EM shower, develops charge imbalance

At GHz and lower frequencies Cherenkov radiation is coherent - strong radio pulse



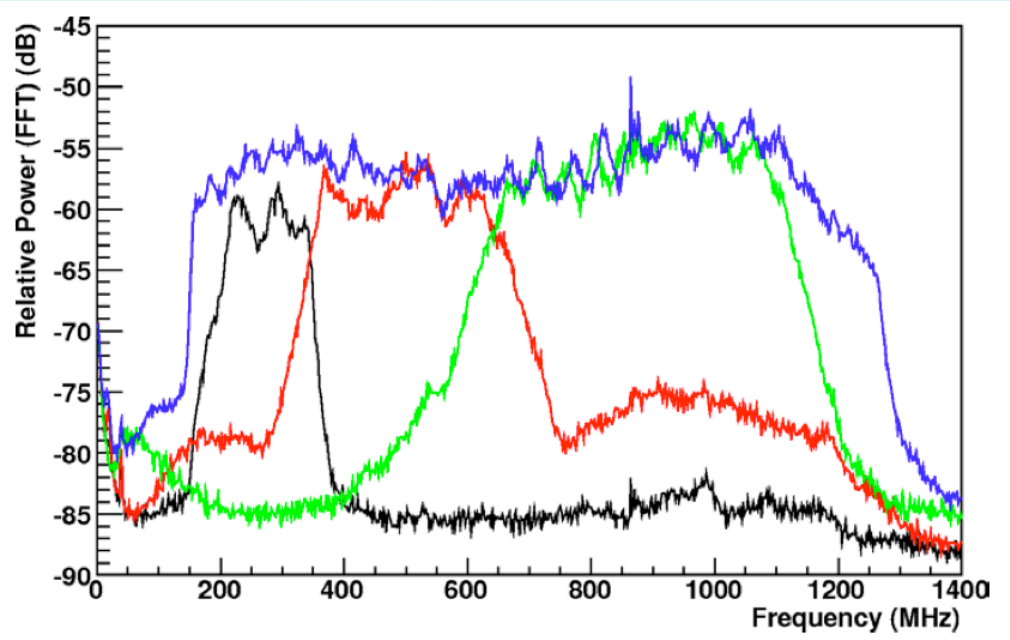
ANITA-2 design



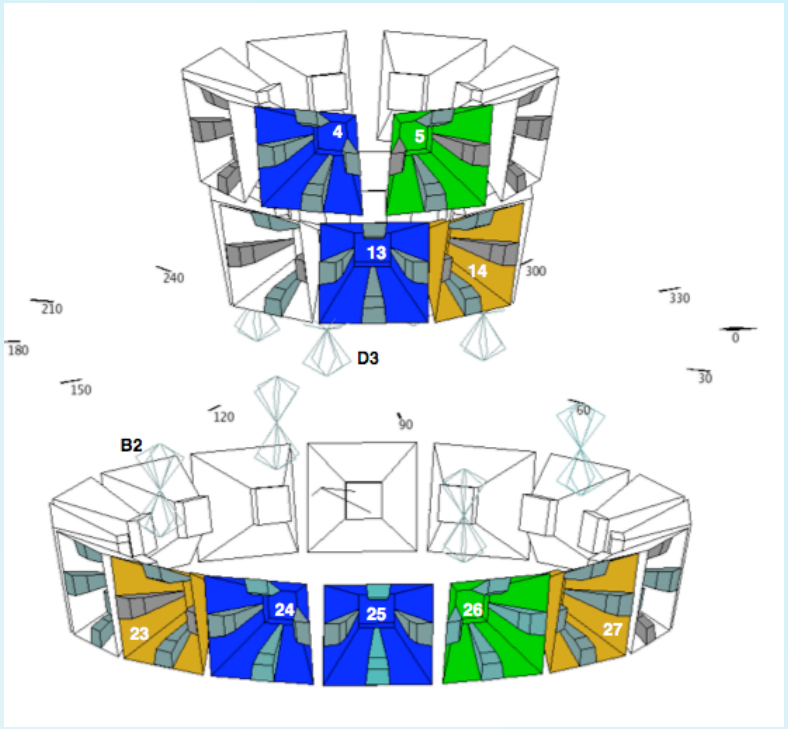
- Antennas 3dB point at 30º - full 360º coverage
- RF recorded in both VPOL and HPOL
- Telemetry (line of sight & satellite linkups) provide data relay and ability to send commands

Triggering and data acquisition

- Multi-level trigger system on VPOL channels:
  - L0: Sub-band power >2.6σ of noise level
  - L1: 2 of 3 sub bands + full band above threshold @ L0
  - L2: 2 of 3 'cluster' of antennas in a ring @ L1
  - L3: 2 of three rings trigger @ L2



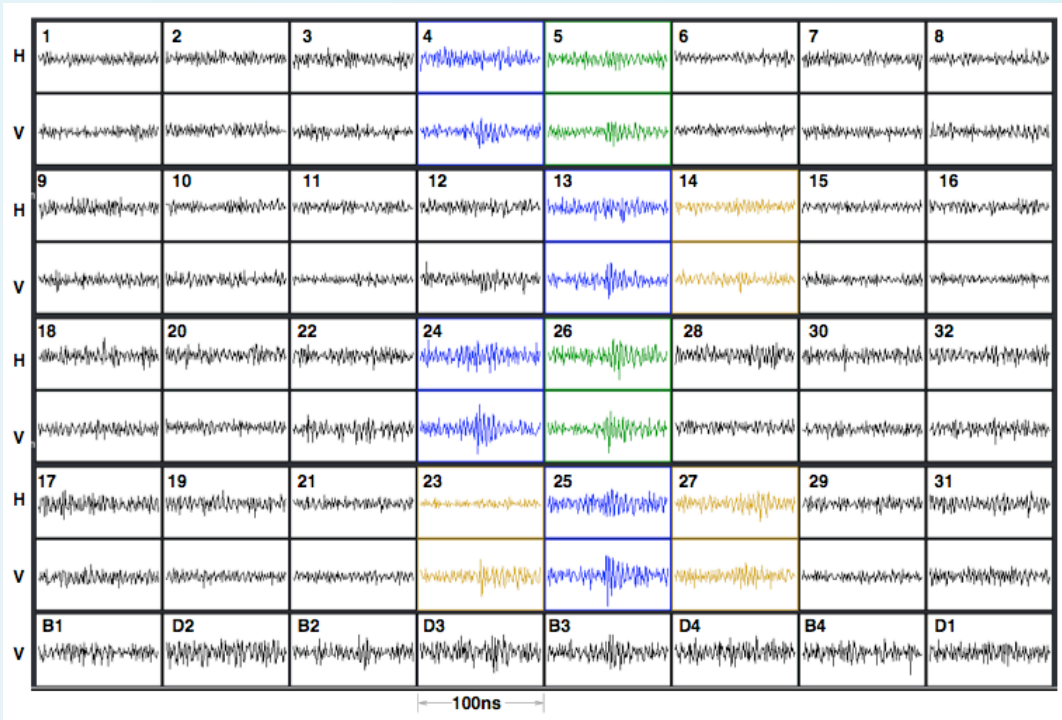
Low Mid High Full (ANITA 2)

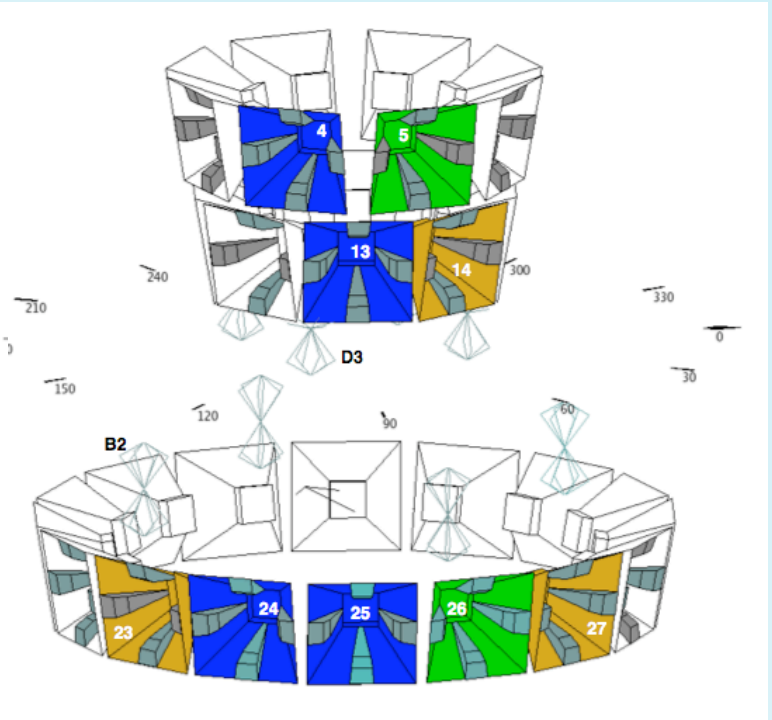


L1 L2 L3 (ANITA 1)

Triggering and data acquisition

- Data acquisition:
  - 40 antennas, 2 pols - 80 channels total
  - Sample RF at 2.6Gsa/s
  - 100ns waveforms, 260 samples





ANITA-2 improvements

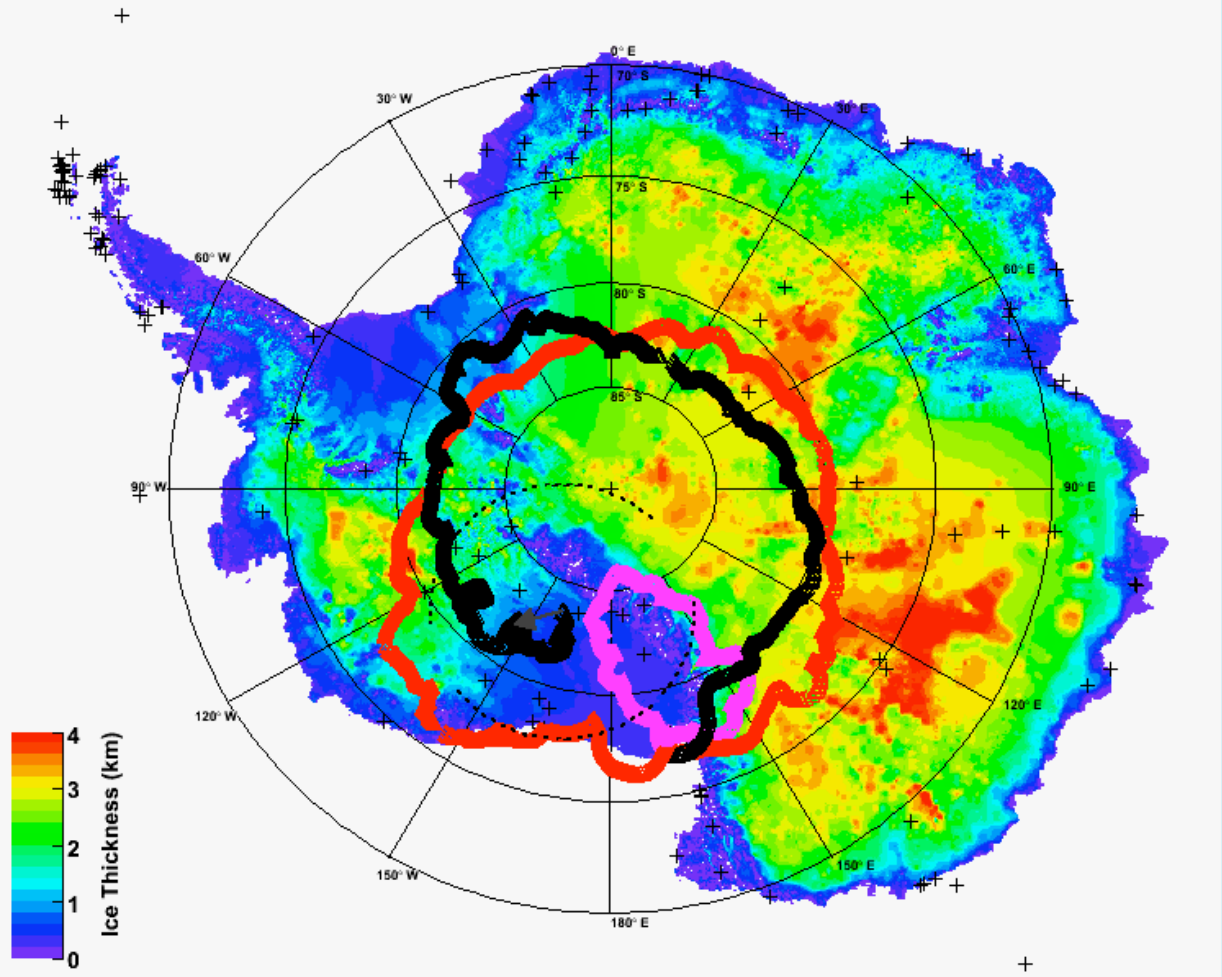
- How does ANITA-2 compare to ANITA-1?

Feature	ANITA-1	ANITA-2
Number of antennas	32	40 (drop downs added)
Triggering	LCP/RCP	V-POL only
Amplification	Thermal noise level	V-POL thermal noise reduction of ~40K
Data acquisition	5Hz global trigger	Up to 20Hz global trigger
Anthropogenic masking	Manual frequency band masking	Automated directional masking

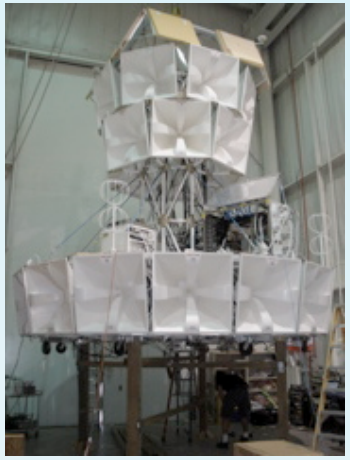
- Overall ~4x more sensitive VPOL impulses

ANITA-2 flight

- Launched 21/12/08
- Aloft for 31 days
- Took ~27M events (~21M RF triggers, ~6M cal pulses etc)
- Landed 22/01/09 with full recovery of instrument and data

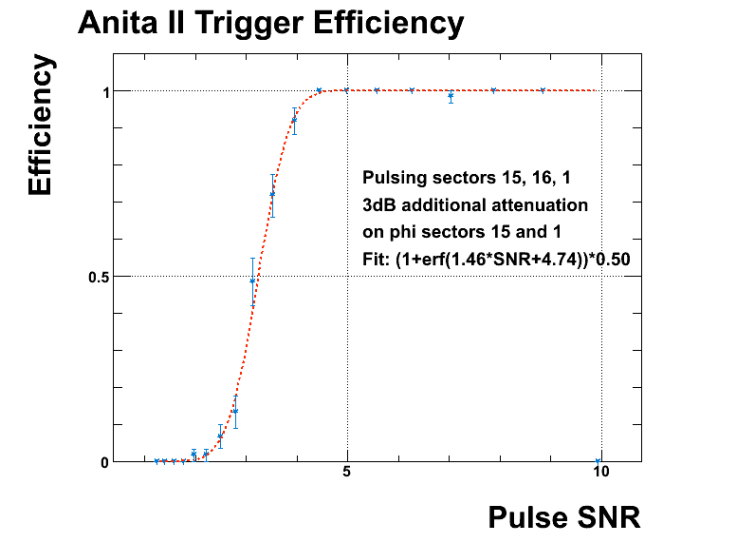


ANITA-2 performance



Testing on the ground:

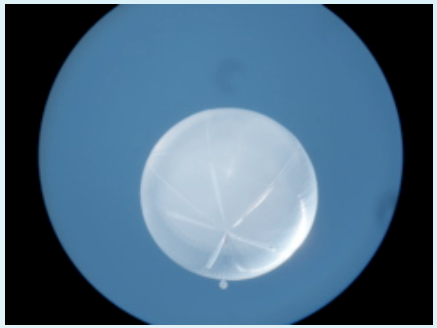
50% trigger efficiency at input pulse SNR of 3.33

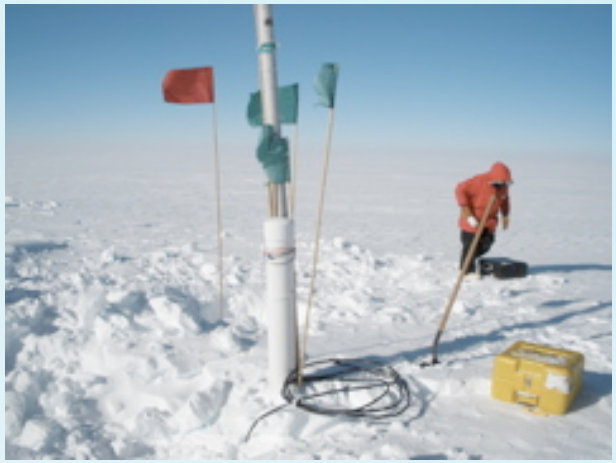


Testing in the air:

Ground pulsers in 2 locations:

- Taylor Dome (~200km from launch site)
- Williams Field (at launch site)



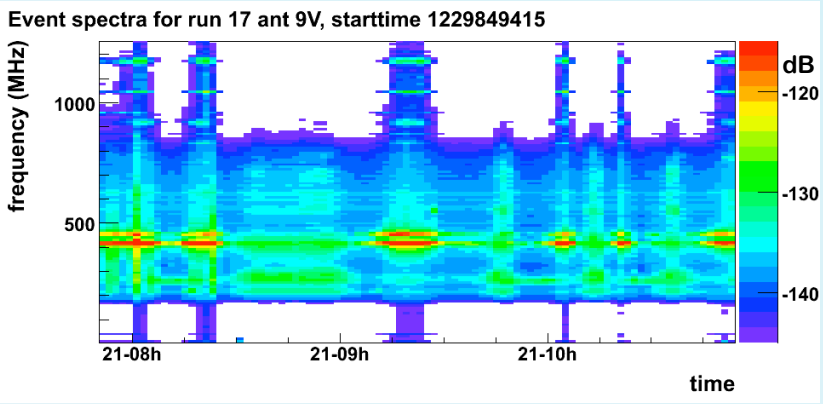


Left: Williams field Seavey pulser

Above: ANITA at flight altitude

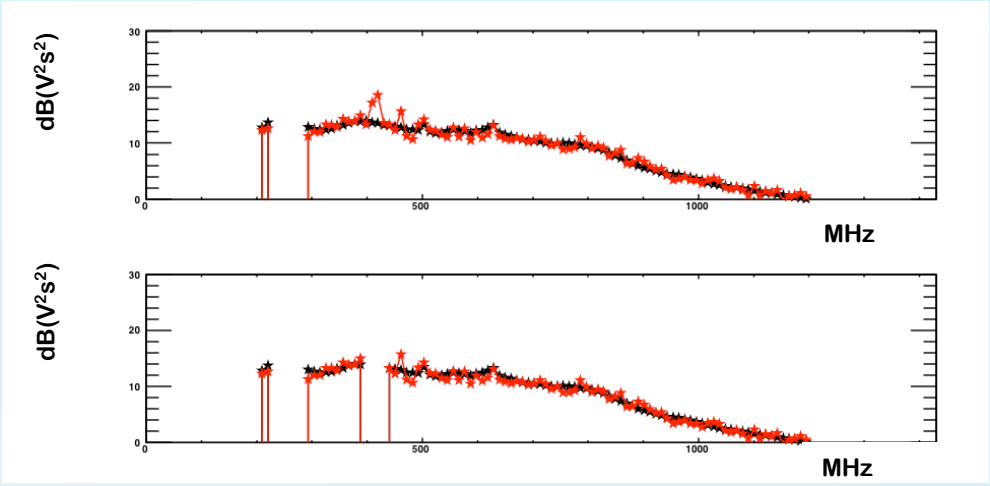
Right: Taylor Dome

Analysis tools - event filtering



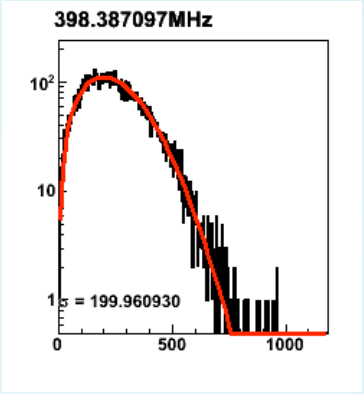
Narrowband noise seen in antenna 9 near McMurdo

- Anthropogenic continuous wave (CW) signals can contaminate events, affecting the event image



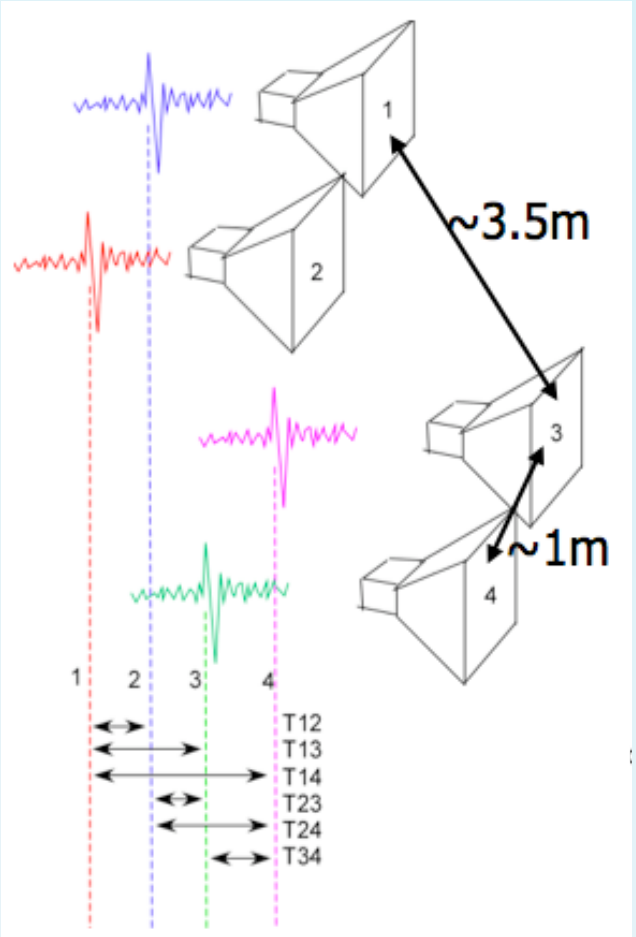
Black: noise baseline
Red: event spectrum

- Adaptive filtering:
  - Locate narrowband CW by comparing to noise spectra
  - Filter these bands
  - Whiten filtered bands with thermal noise

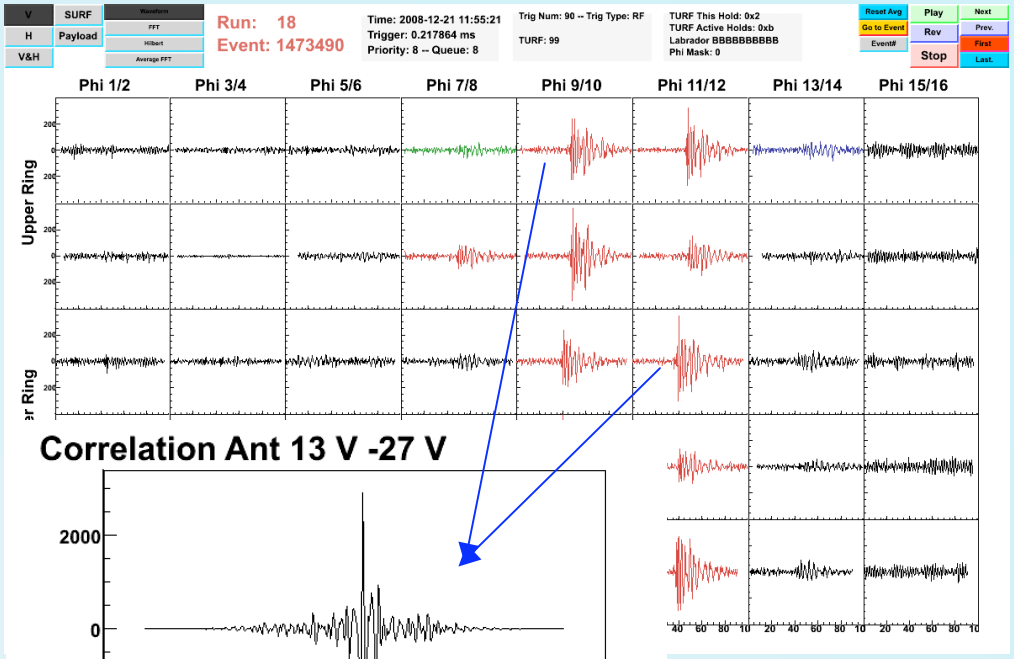


Amplitude of ~400MHz noise for channel 1V (after signal chain response). Example of noise, used for whitening filtered bands.

Analysis tools - event imaging



Time difference between antennas receiving pulse depends on angle of signal relative to payload

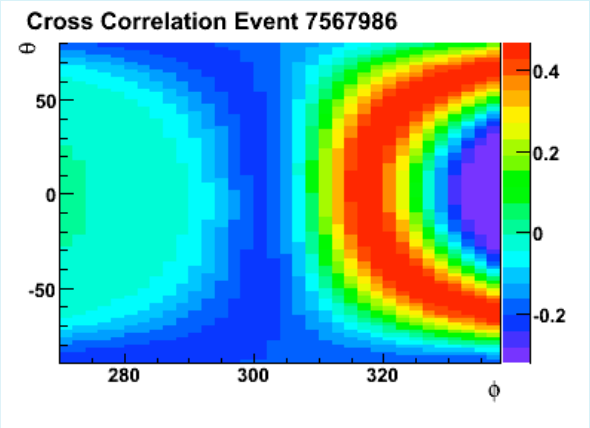


$$C(\theta,\phi) = \sum_{i \neq j} \psi_i * \psi_j \left[\tau_{ij}(\theta,\phi) \right]$$

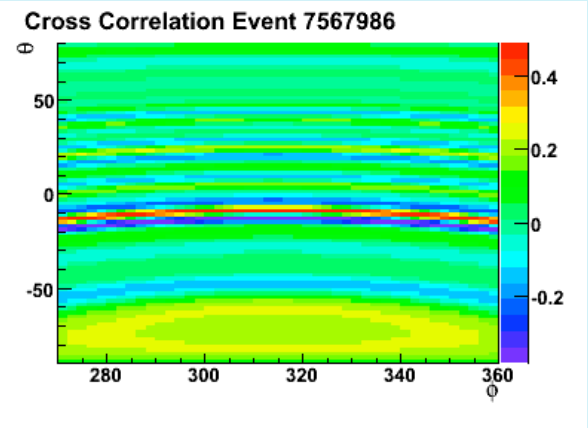
Cross correlation as a function of Δt between antennas - tells us how well matched two signals are

Analysis tools - event imaging

- Correlation coefficient as a function of angle for antenna pairs:

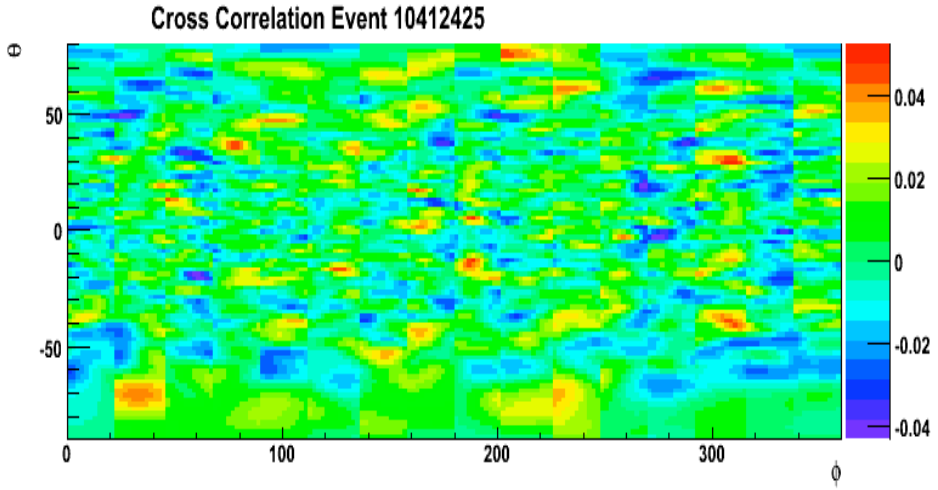


Adjacent pair

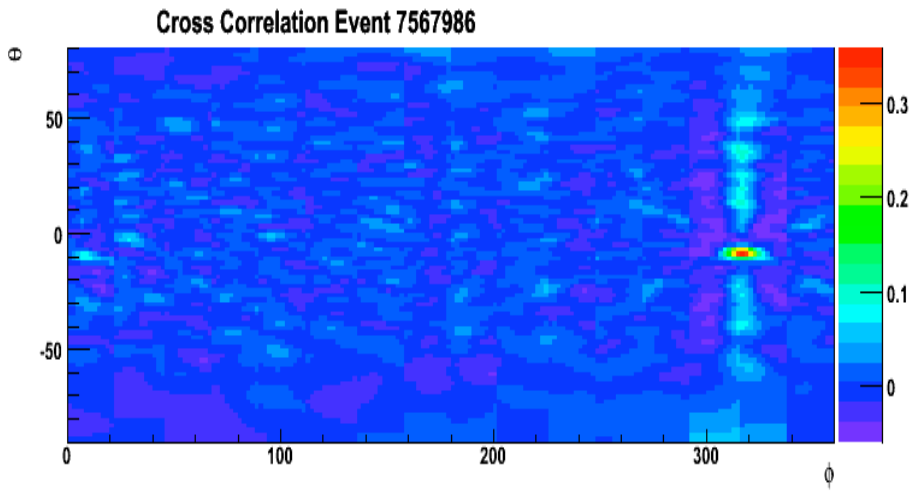


Upper & lower pair

- Loop over all antenna pairs:



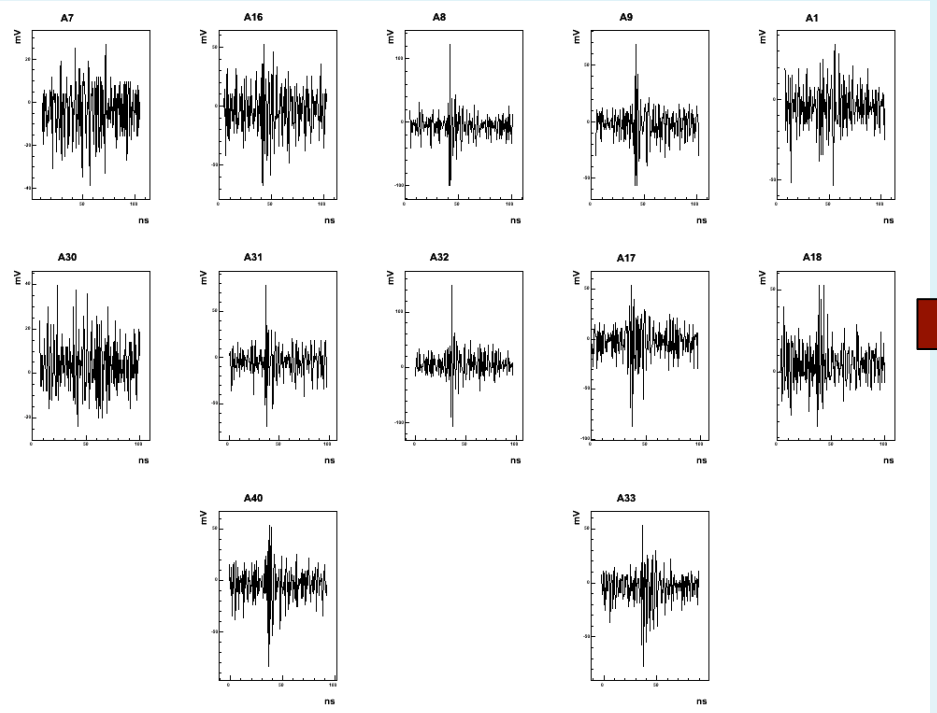
Thermal event

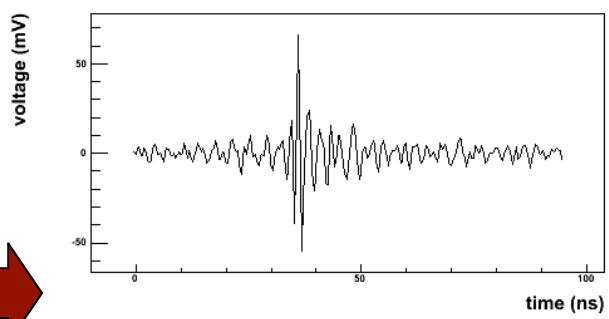


Pulsed event from Taylor Dome

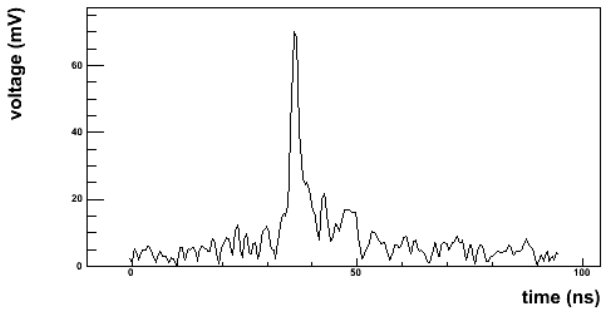
Analysis tools - coherently summed waveform

- From event image find ϕ and θ values of peak
- Create coherently summed waveform:
  - Use 5 ϕ sectors closest to peak
  - Apply time shift corresponding to ϕ and θ
  - Sum waveforms



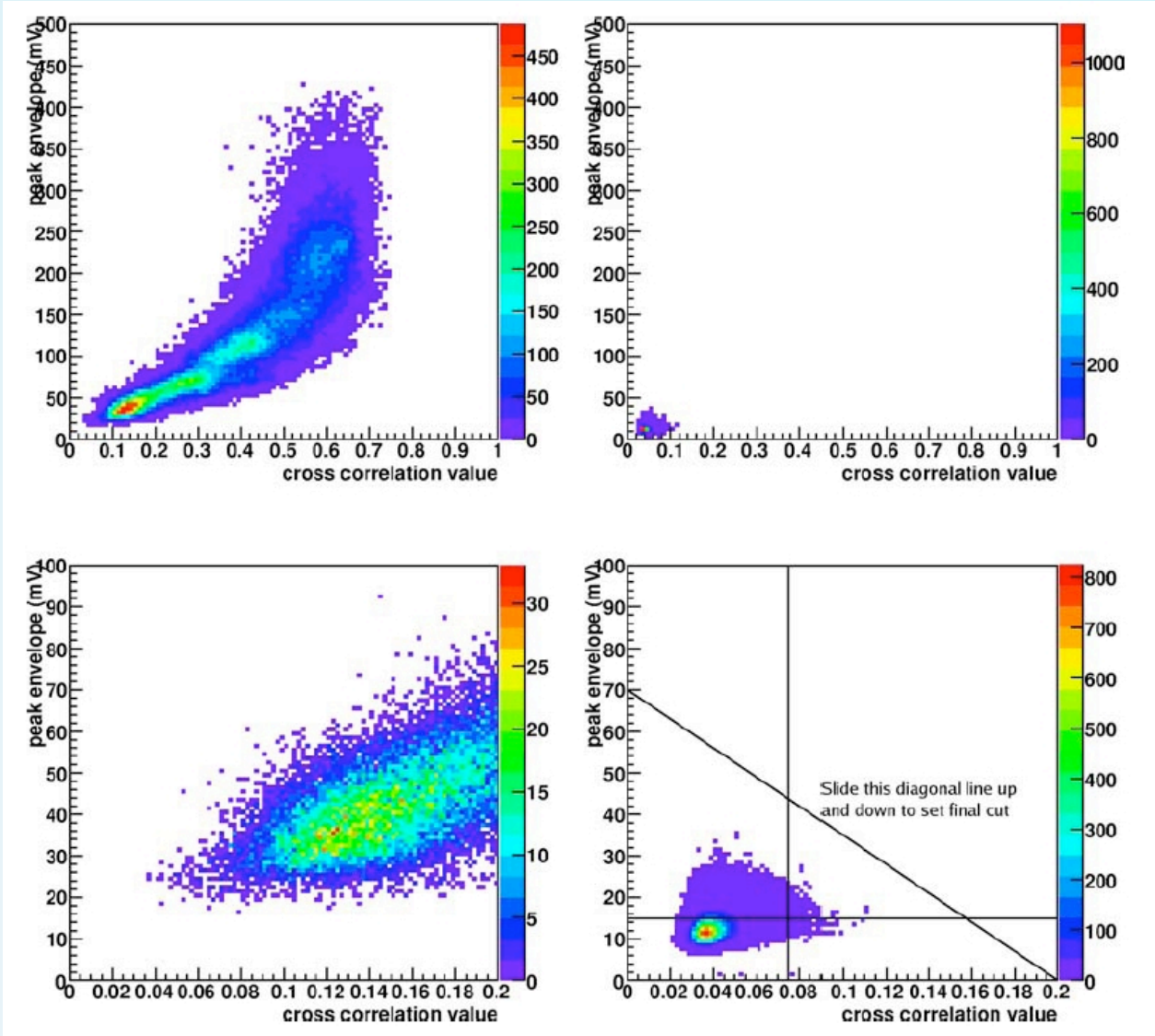


Coherently summed waveform



Waveform envelope

Analysis tools - a combination of cuts



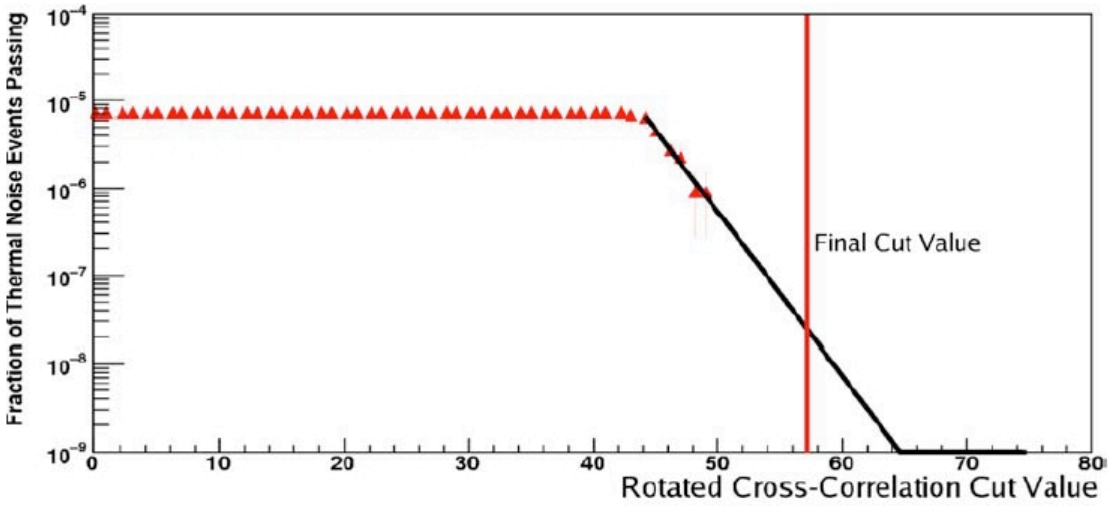
2D plots of number of events vs peak correlation and peak coherent envelope values

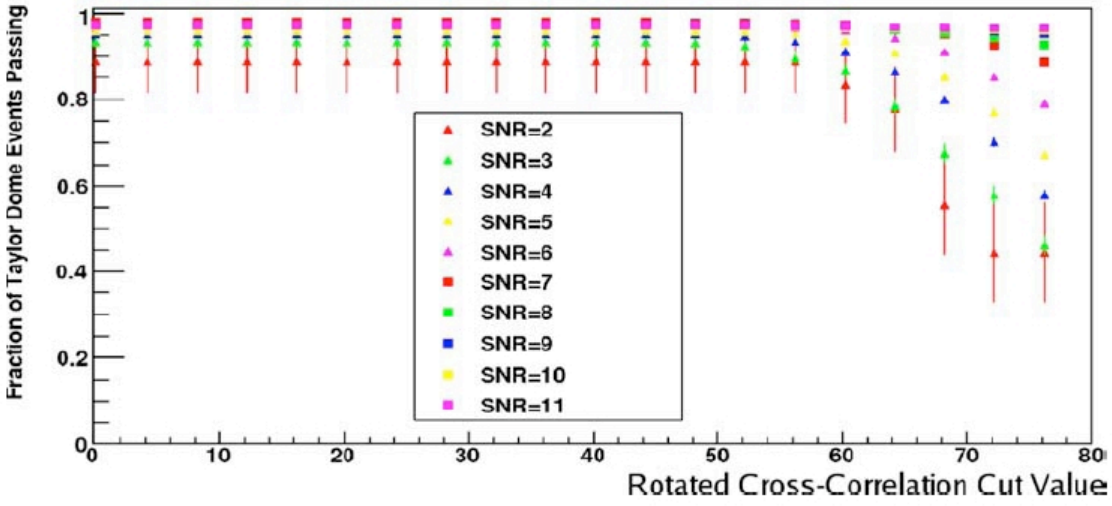
Left: pulsed events from Taylor Dome
Right: thermal noise events
(Lower panels are zoomed versions)

Linear combination used to eliminate thermals

Plots: A. Goodhue Vieregg

Combination cut





- Final cut uses a linear combination of peak coherently summed envelope and peak correlation value
- Extrapolate cut from noise events (up pointing triggers) to give rejection of all but 1 event in 20M
- Get 83% efficiency on the weakest pulsed events after all analysis cuts

Plots: A. Goodhue Vieregg

Analysis status

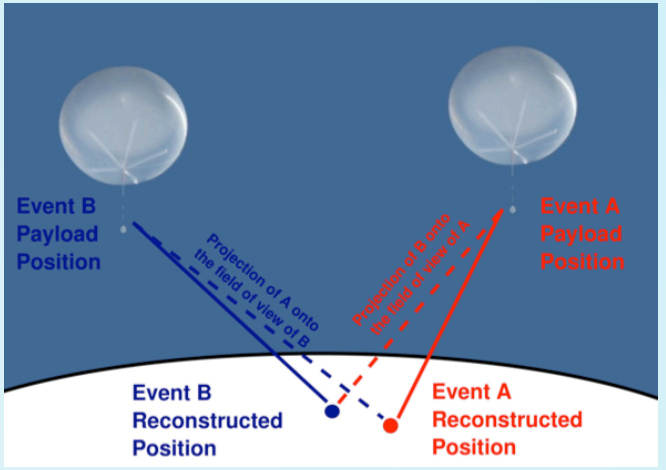
- After analysis cuts

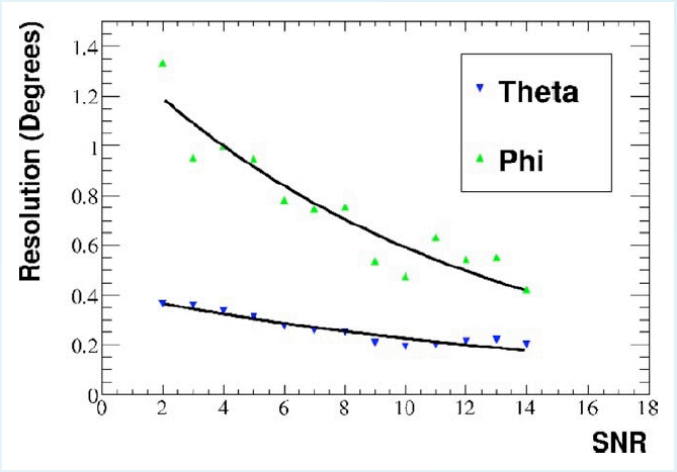
	Events cut	Events remaining
Total triggers	-	~26.7M
RF triggers	5.5M	~21.2M
Pass analysis cuts	~20.9M	~300k

- Have cut away thermal events
- Remaining background events will be of anthropogenic origin …

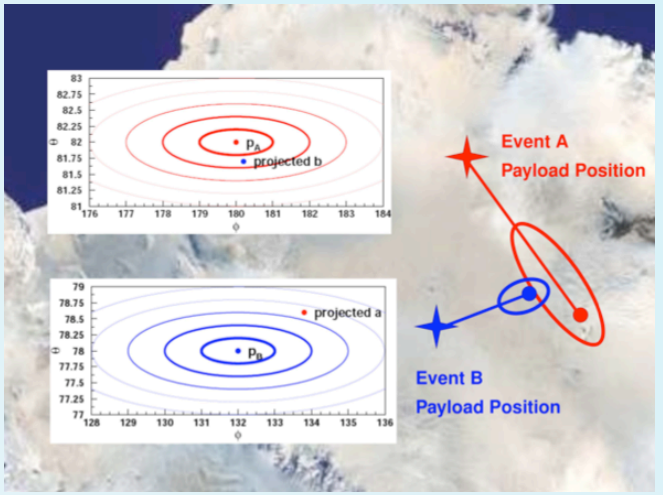
Analysis tools - event clustering

- Clustering:
  - Distance cut: exclude events within 40km of a base/event
  - Likelihood cut: exclude events within 5.5σ of the pointing resolution to a base/event



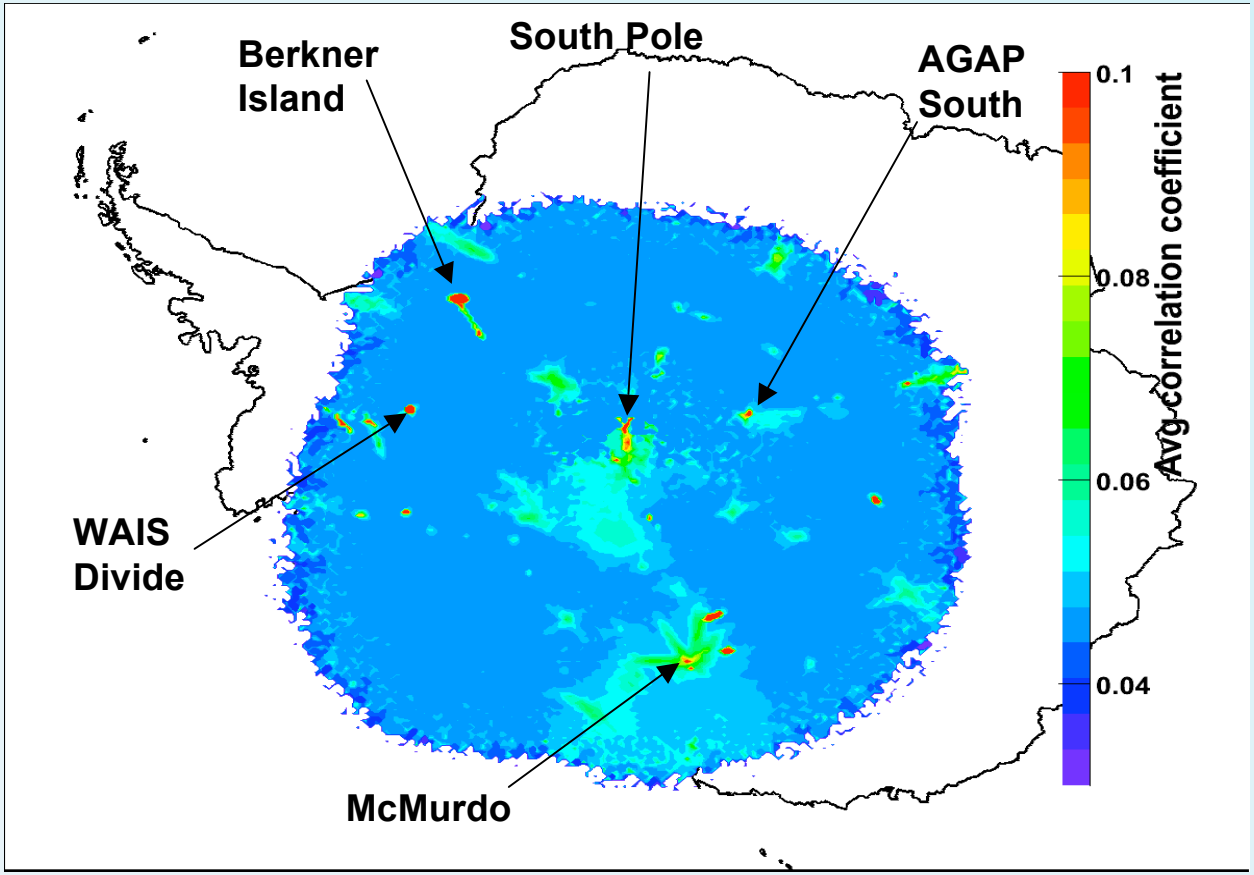


Above: pointing resolution of ANITA-2 (plot A Goodue Vieregg)



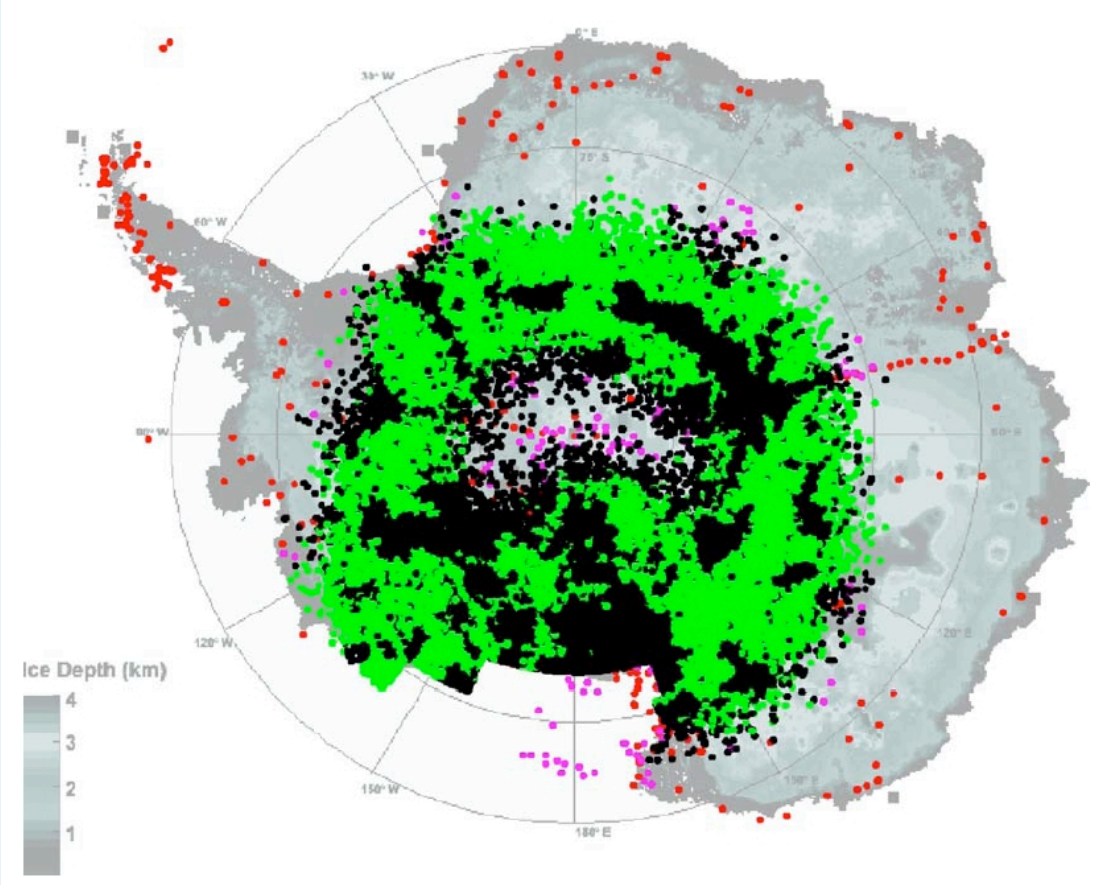
Analysis tools - event clustering

- In addition to known bases and events we also use
  - Flights & traverses (with timing information)
  - Unlisted sites with high mean correlation values



Analysis efficiency

- Test clustering with simulated neutrinos:
  - 60k MC neutrinos simulated with ANITA following 2nd flight path
  - 63.9% were not associated with a base/ANITA-2 event



60,000 MC neutrinos, black are clustered, green pass clustering cuts (plot A. Goodhue Vieregg)

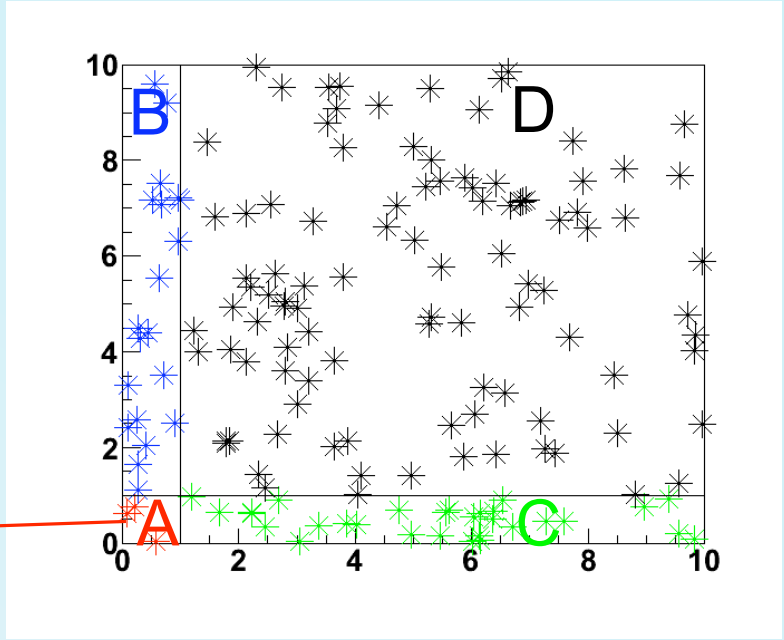
Analysis efficiency

- Showed earlier:
  - Reconstruction analysis efficiency of 83% on weakest pulses
  - For 10^{18}eV neutrinos this is ~93% reconstruction efficiency
- Clustering cuts limit overall efficiency
  - Had 63.9% efficiency on MC neutrinos passing clustering
- Final analysis efficiency for neutrinos of 61%
  - For ES&S baseline neutrino flux with 2 independent Monte Carlos

- Check on analysis efficiency:
  - 11 weak Taylor Dome pulses were inserted randomly into data sample
  - Events only inspected after unblinding
  - 8 of 11 pass reconstruction cuts
  - 2 of 8 pass clustering cuts

Background estimation

- It is possible to calculate the number of non-neutrino events that are not associated with a cluster (background events in the signal box) using various forms of the following method:



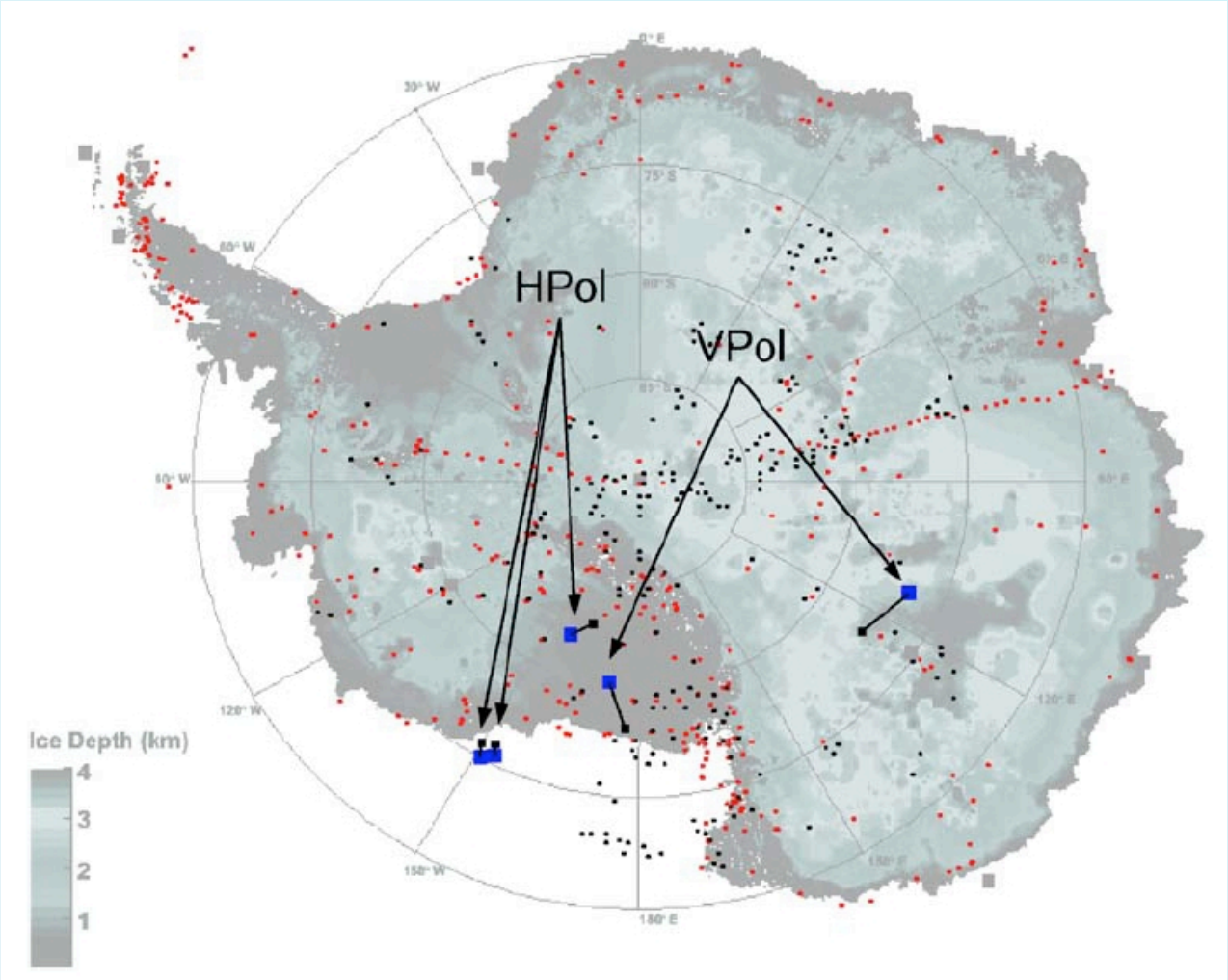
$$\frac{\text{Singles not from bases}}{\text{Singles from bases}} = \frac{\text{Clusters not from bases}}{\text{Clusters from bases}} \qquad \frac{A}{B} = \frac{C}{D}$$

Predicted background

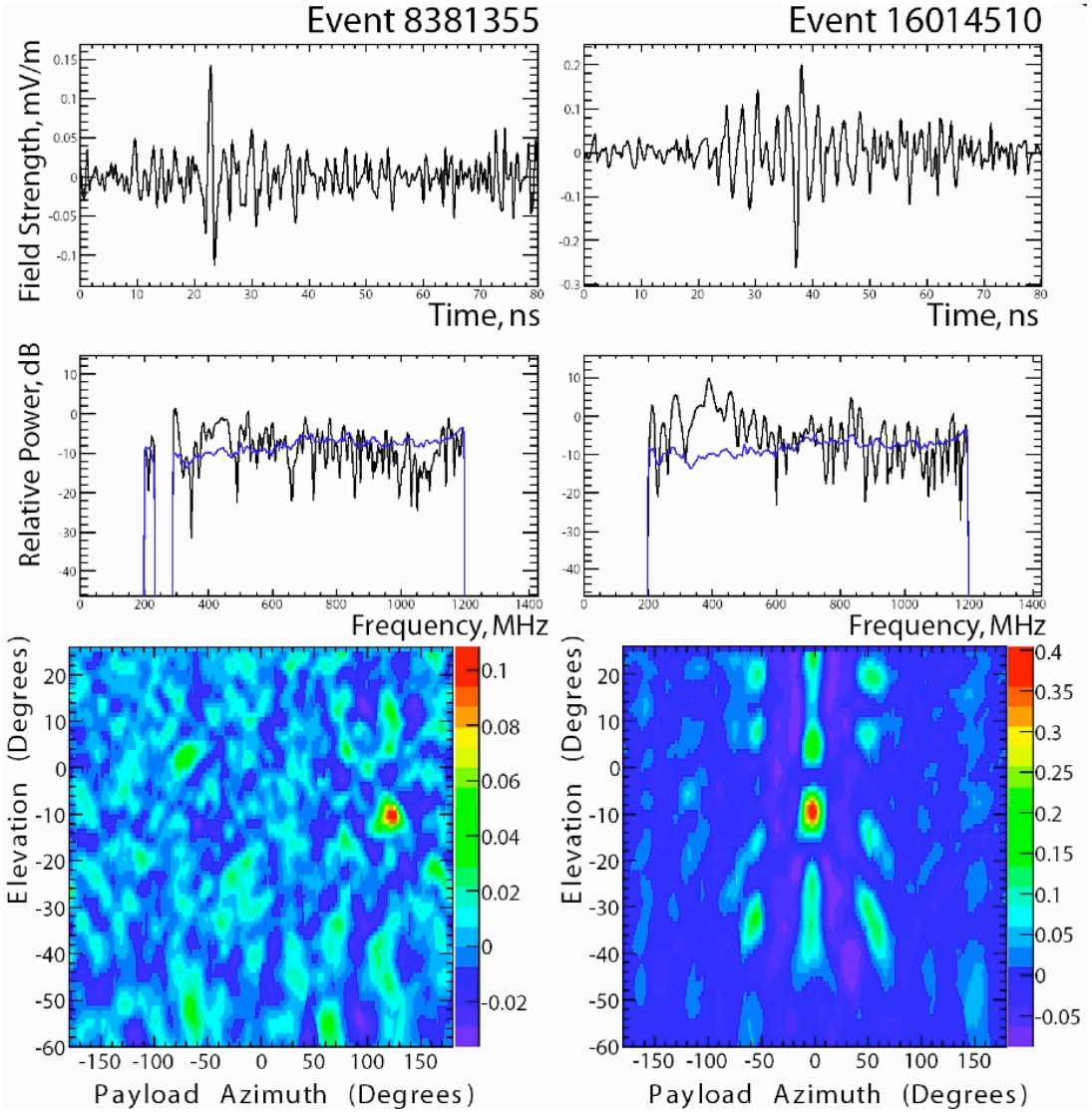
- A background estimate using 7 versions of the above gives:
  - HPOL background of 0.25±0.19 events
  - VPOL background of 0.65±0.39 events

Analysis results

- Remaining events in the signal box:
  - 2 VPOL events
  - 3 HPOL events (see talk by A. Romero-Wolf)



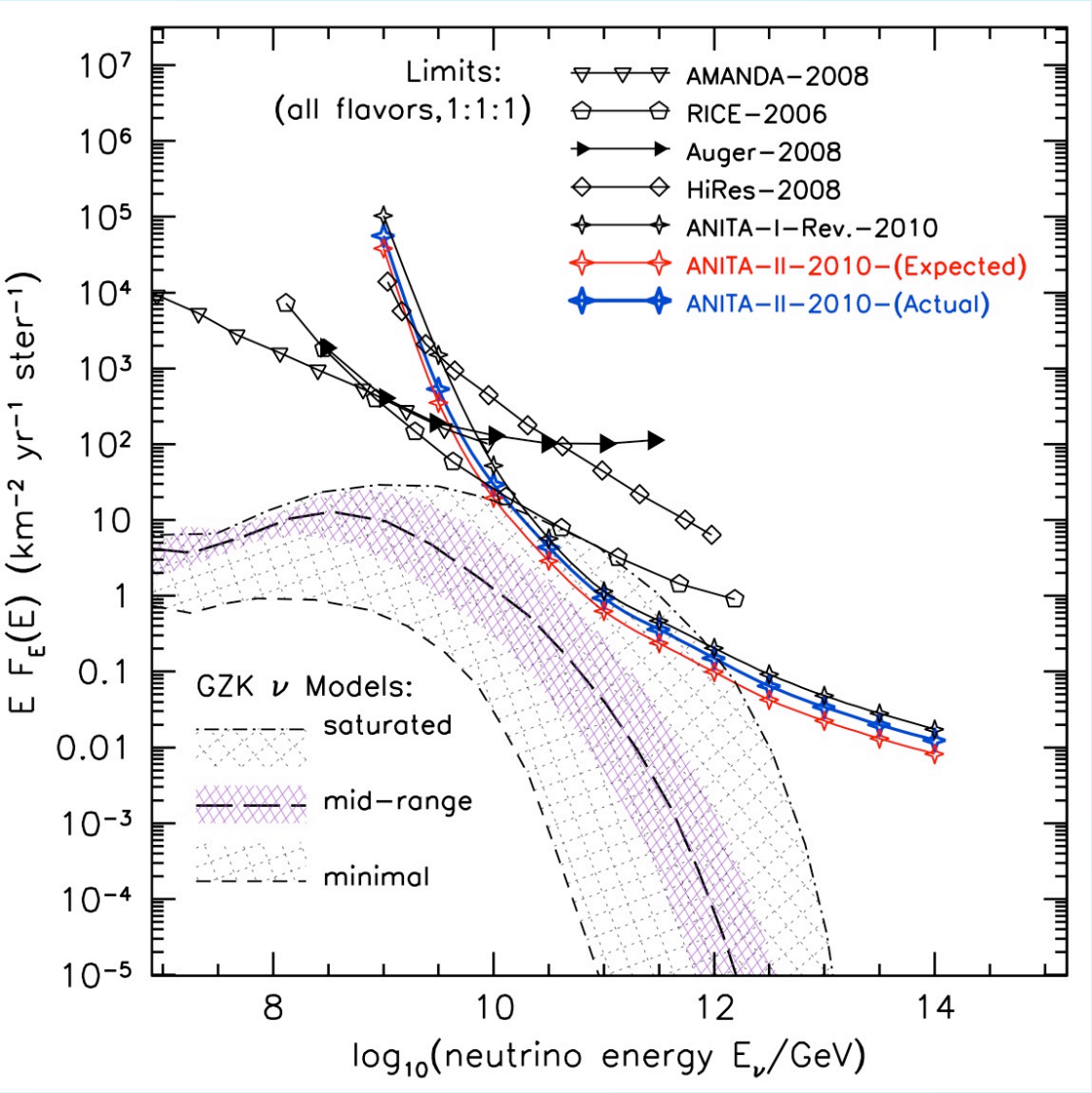
Candidate events - VPOL



- 2 candidate VPOL events:
  - Top: deconvolved coherently summed waveform
  - Middle: power spectrum
  - Bottom: cross correlation image

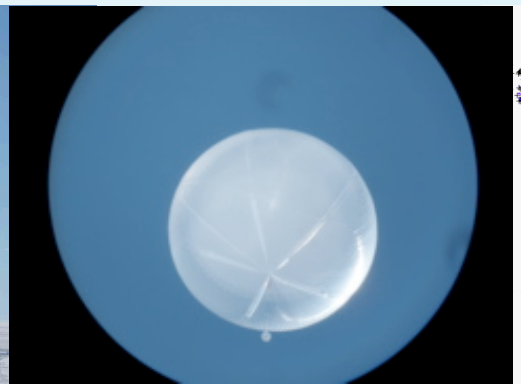
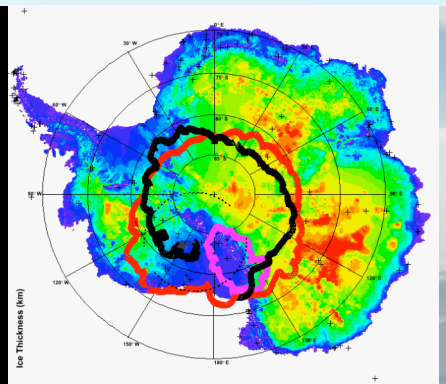
ANITA 2 results

- V-POL candidates are not sufficient for claim of detection
- ANITA-2 can set a new limit on the UHE cosmic neutrino flux
- ArXiv 1003.2961



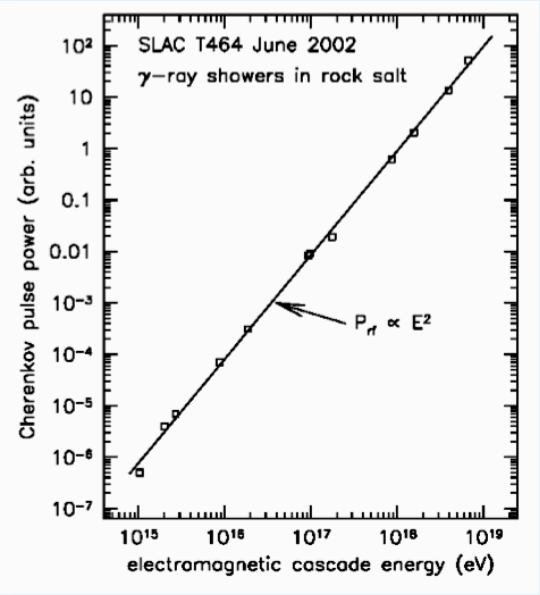
Summary

- 2 successful science flights have been completed
- Analysis tools have been demonstrated
- ANITA-2 observed 2 isolated vertically polarised impulsive events
- ANITA has set the best limit on UHE neutrino flux in its energy range
- 3rd flight is proposed (2012), will hopefully dig further into GZK models

Backup slides - Askaryan effect

- ν interaction causes EM shower, charge imbalance as it develops
  - e^+e^- annihilation, e^- scattered into shower (Compton)
  - 20% -ve charge excess
- Shower develops as a disk ~mm thick, ~cm wide
  - At >cm wavelengths shower looks like one charge
  - For 10^{19}eV ν this charge is $>10^7$e
- Coherent emission over >cm wavelengths, amplitude goes with Z^2



Confirmation of effect at SLAC in sand (Saltzberg et al. 2001), salt (Gorham et al. 2003, left) and ice (Gorham et al. 2007, right - photos P. Chen, C. Hast)

Backup slides - ANITA I neutrino results

- ANITA I results (PRL - before updated CR results)
  - No VPOL events - no neutrino candidates
  - 6 HPOL events - possibly cosmic rays (now 16, confirmed CR)
  - New limit set on UHE neutrino flux