ANITA 2 - A radio search for UHE neutrinos

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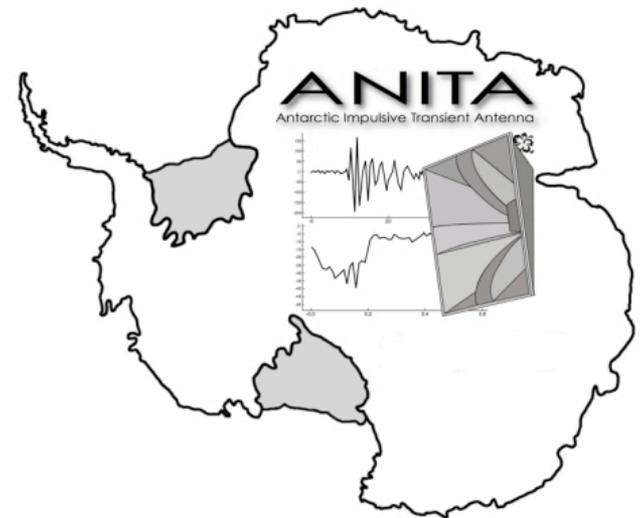
Why UHE Neutrinos?

- Only UHE messenger:
  - to travel ~Gpc unattenuated
  - known to point back to source
- GZK effect - 'guaranteed' source

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

$$p + e^- + \overline{\nu_e}$$

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

$$e^+ + \nu_e + \overline{\nu_\mu}$$
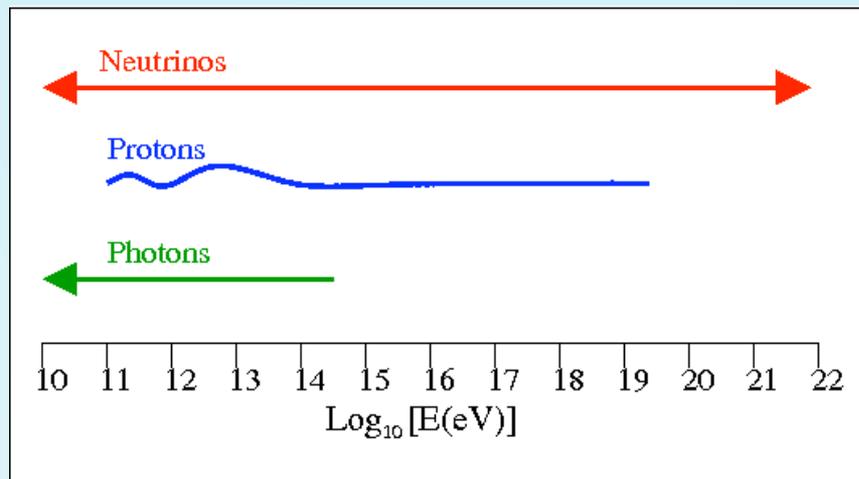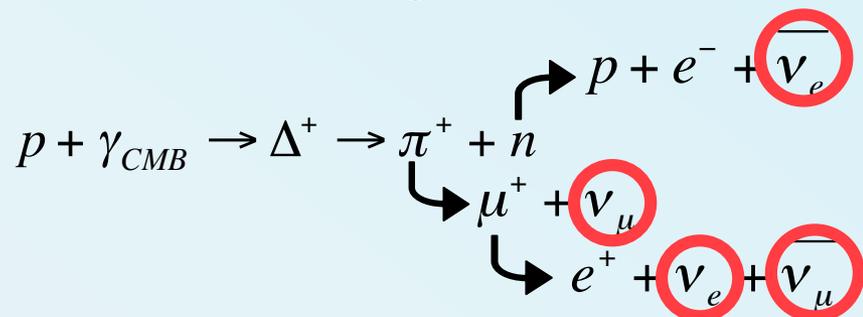
Sounds easy ….

- Low flux (0(1)event/km^2/year) -> Require huge interaction volume
- Optical techniques (IceCube etc) are not scalable for the highest (>10^{18}eV) energies
- …. New technique - radio Cherenkov

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ANITA concept

ν interaction causes EM shower, develops charge imbalance

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

A neutrino induced cascade produces a coherent radio Cherenkov pulse.

~680km to horizon -> 1.5x10^{6}km^3 interaction volume

Cosmic ray geo-synchrotron also observed (HPOL)

~37km

Antarctic ice sheet

1~4km

Refracted RF (VPOL)

Air

Ice

Cherenkov Cone at 56° in ice

Incident neutrinos With energies above ~0.5 EeV

Particle Cascade

ANITA-2 design

GPS antenna arrays

32 antennas over 2 layers

Lightweight aluminium gondola

ANITA instrument box - all data processing and storage units

Battery box

PV cell arrays

8 antennas deploy after launch

Signal received by antennas amplified then split for two paths:

• Trigger chain: 3 frequency sub-bands and full band sent to 3 level trigger system

• Sampling chain: signal acquisition unit samples waveforms at 2.6GSa/s

Analysis tools - event imaging

Time difference between antennas receiving pulse depends on angle of signal relative to payload
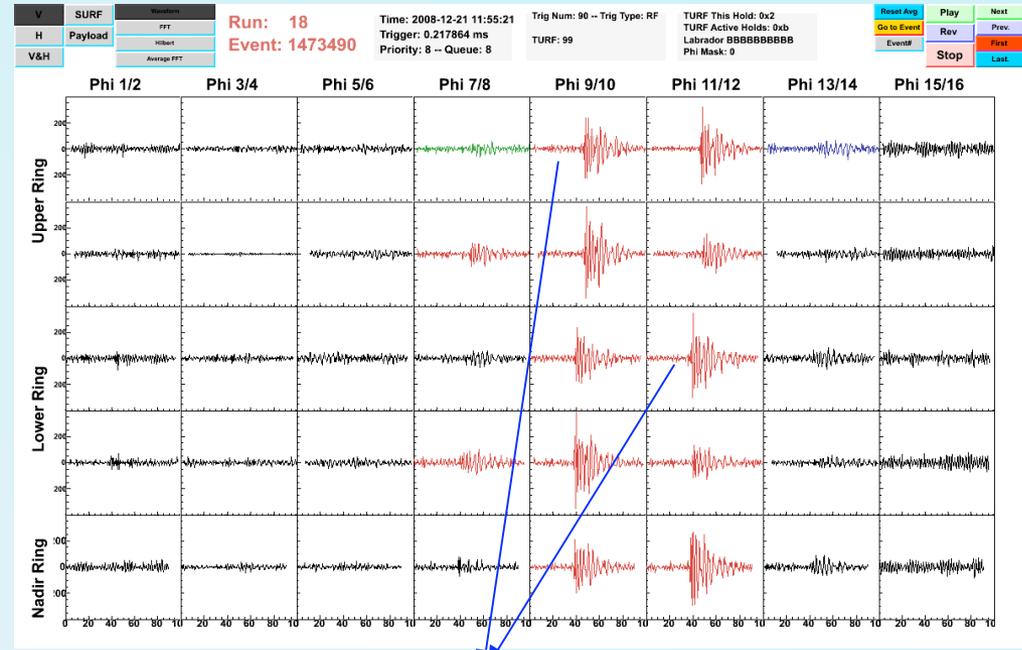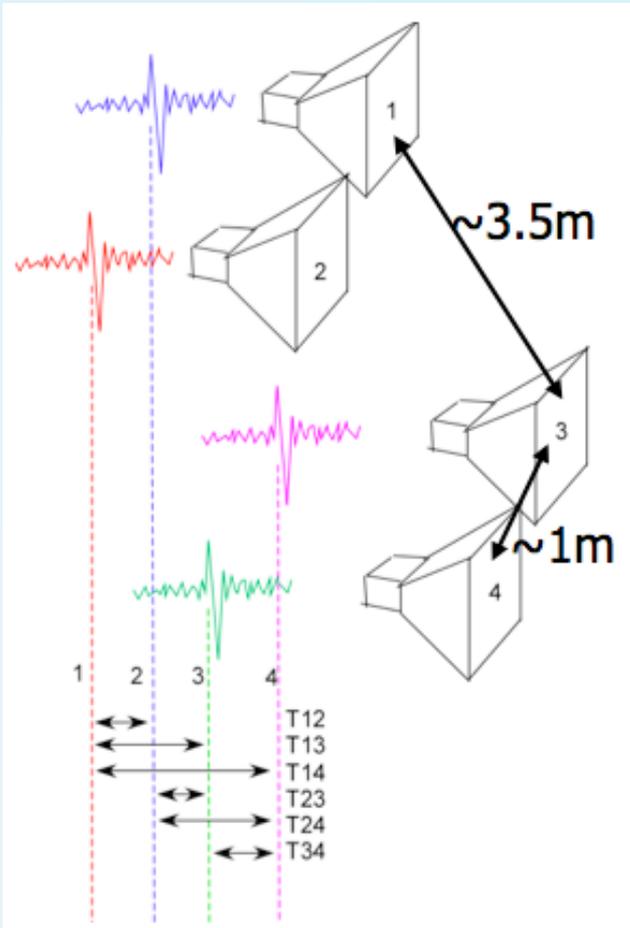
Cross correlation as a function of Δt between antennas - tells us how well matched two signals are

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Analysis tools - event imaging

- Correlation coefficient as a function of angle for antenna pairs:
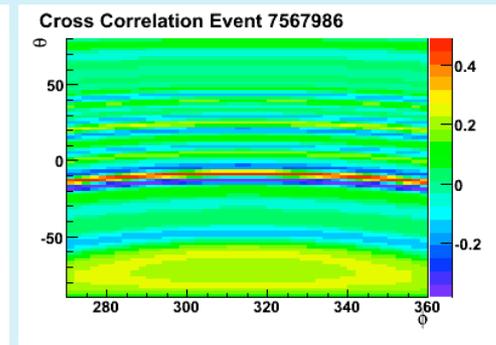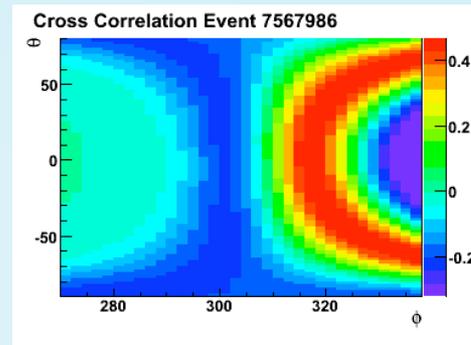
- Loop over all antenna pairs:
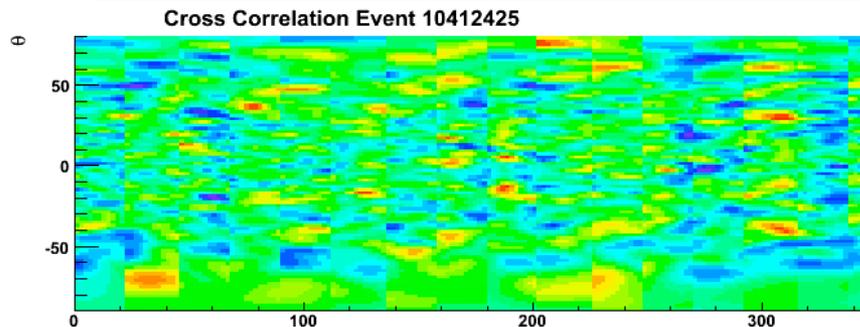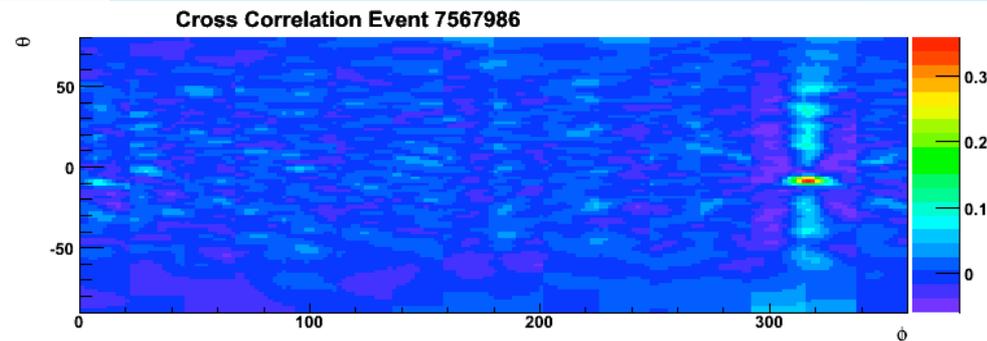
Thermal event   Pulsed event

Analysis tools - event filtering

Event spectra for run 17 ant 9V, starttime 1229849415

Narrowband noise seen in antenna 9 near McMurdo
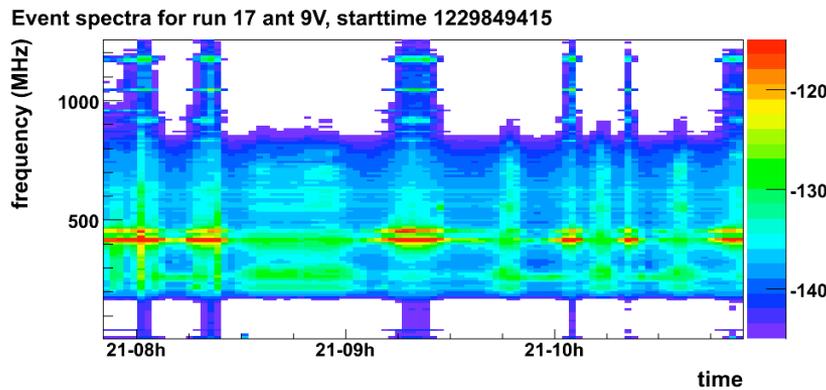
- Anthropogenic continuous wave (CW) signals can contaminate events, affecting the event image

- Adaptive filtering:
  - Locate narrowband CW by comparing to noise spectra
  - Filter these bands
  - Whiten filtered bands with thermal noise
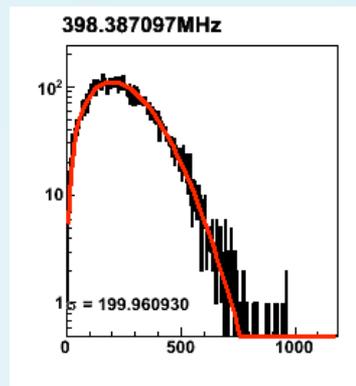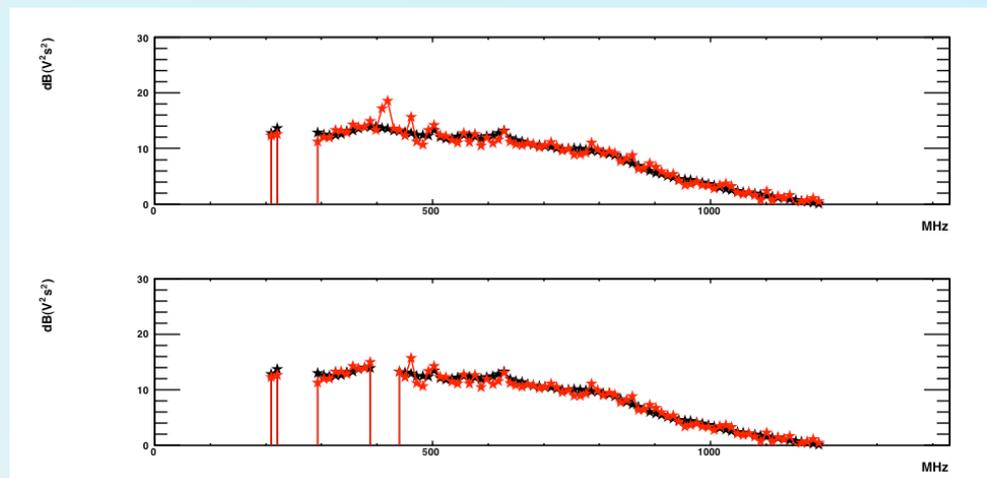
Black: noise baseline
Red: event spectrum

398.387097MHz

s = 199.960930

Amplitude of ~400MHz noise for channel 1V. Example of noise, used for whitening filtered bands.

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Analysis tools - a combination of cuts

Peak correlation coefficient (from image) vs peak envelope of summed waveform

Pulsed events (directional)

Thermal noise
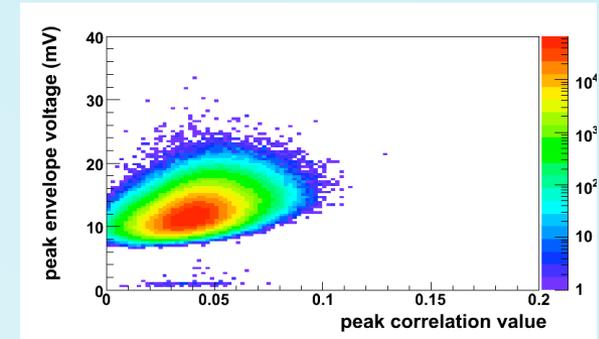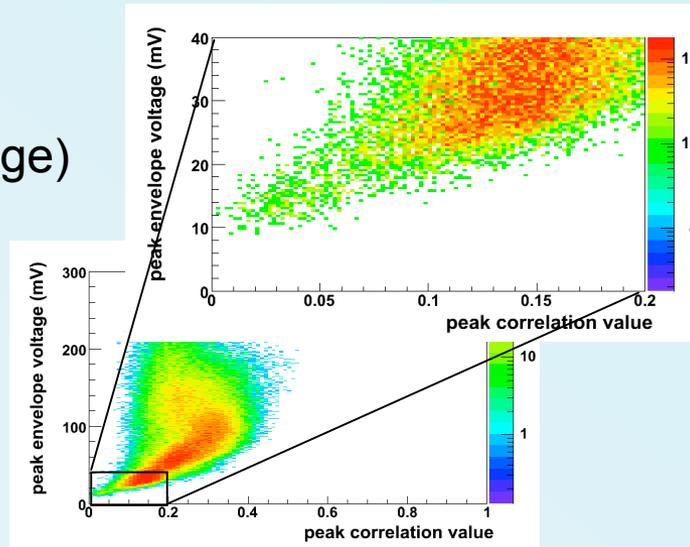
Ratio of 2nd:1st peak (from image)

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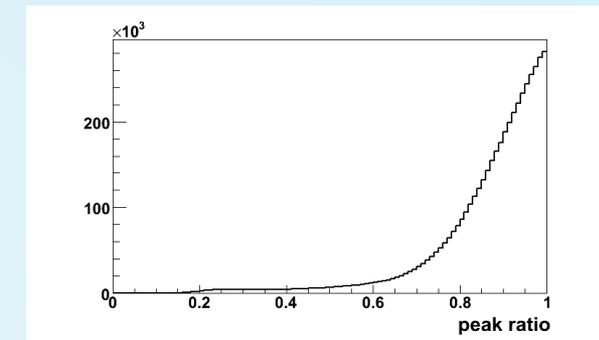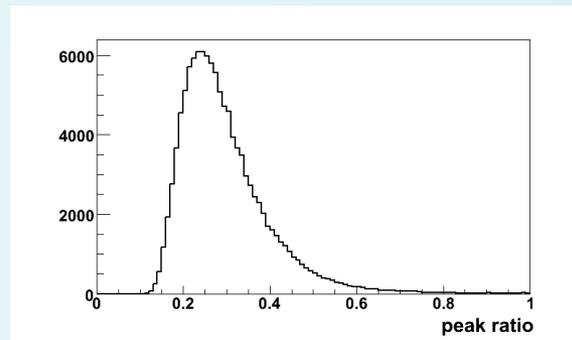
Analysis tools - event clustering

- Thermals (95% of ~20M events) rejected by pointing cuts ….
- Left with a sample (~10^5) of directional events - anthropogenic origin
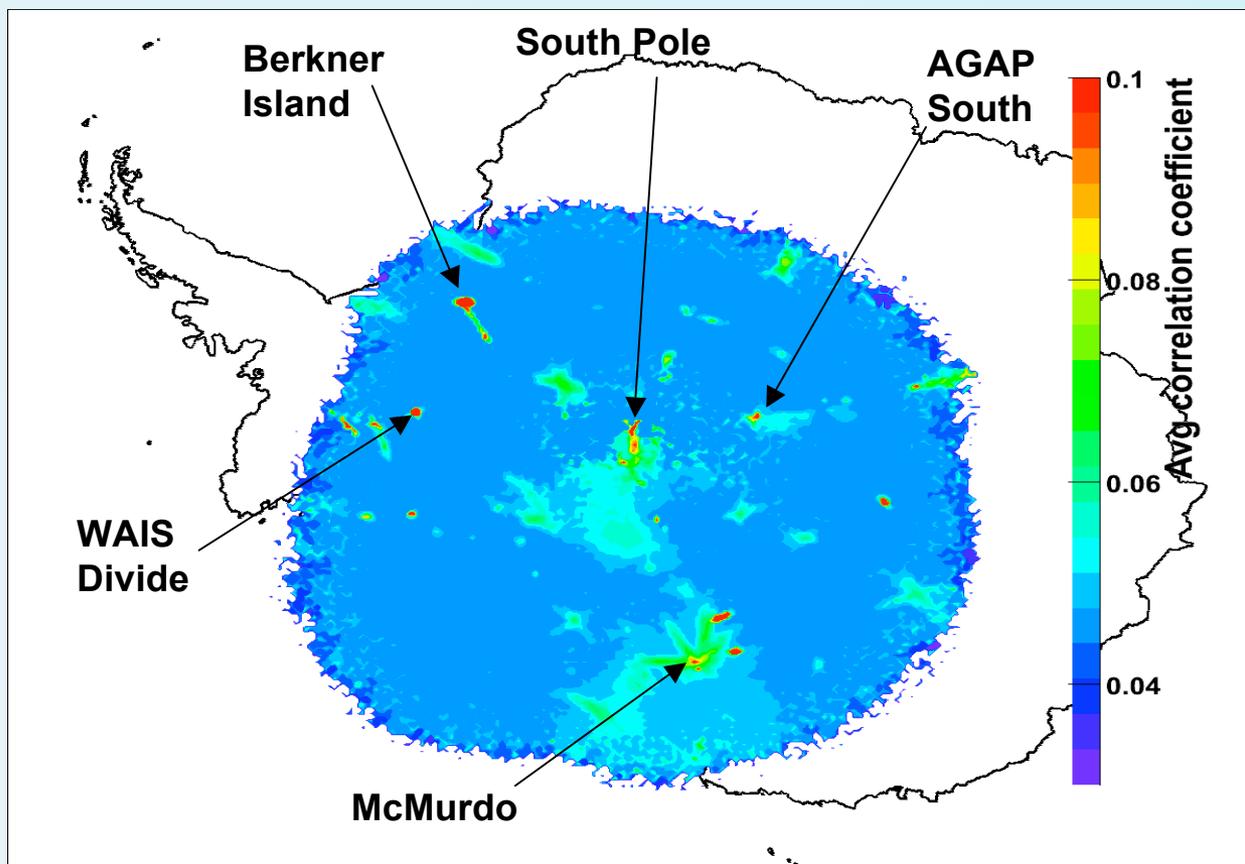
- Cluster events that:
  - Are close to a known base or other event (e.g. 40km)
  - Associated via LL to a base or another event (based on angular separation and resolution of ANITA)
- Can also create 'pseudo' bases
  - e.g. hotspot on correlation map

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ANITA 2 performance
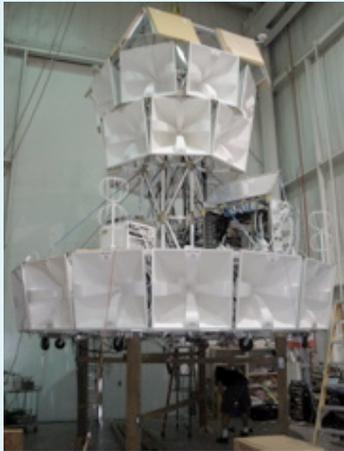
Testing on the ground:

50% trigger efficiency at pulse SNR of 3.33 (does not include noise introduced by signal signal chain)

Anita II Trigger Efficiency

Pulsing sectors 15, 16, 1
3dB additional attenuation
on phi sectors 15 and 1
Fit: $(1+erf(1.46*SNR+4.74))*0.50$

y-axis: Efficiency

x-axis: Pulse SNR

ground pulser resolution: ±0.62°

meas-exp φ (°)

ground pulser resolution: ±0.27°

meas-exp θ (°)
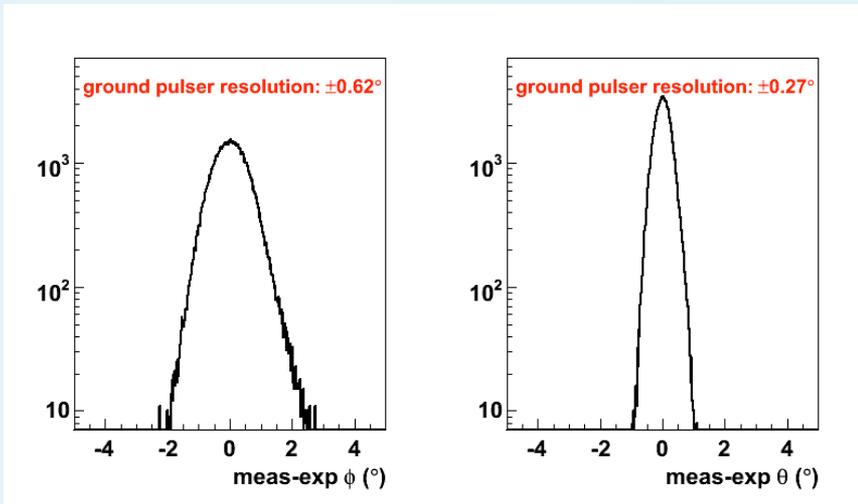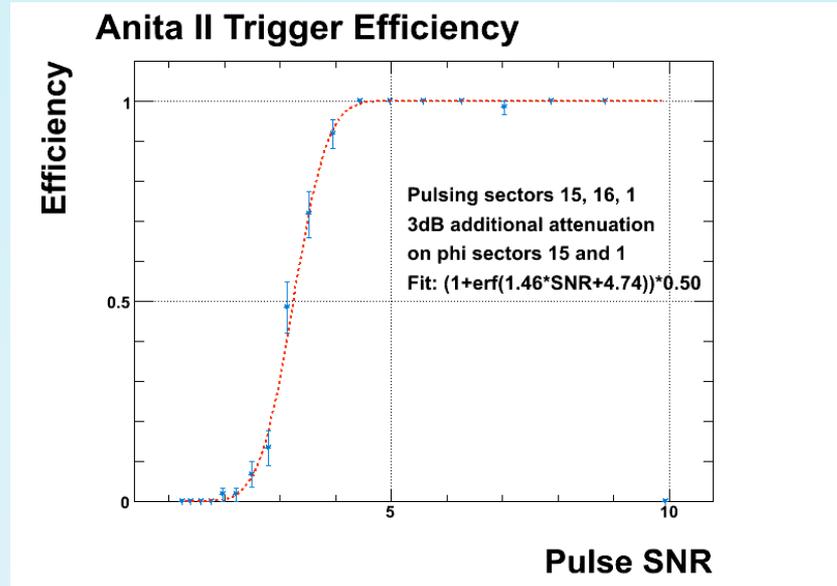
Testing in the air:

Waveform sampling at 2.6GSa/s -> sub degree pointing

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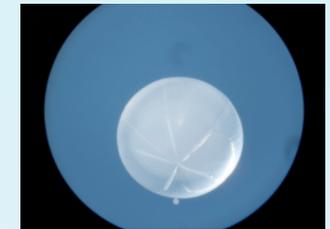
ANITA 2 results

- Events remaining after all cuts:
  - 2 VPOL (on expected background of ~1)
  - 3 HPOL (on expected background of ~0.7)
- ArXiv 1003.2691
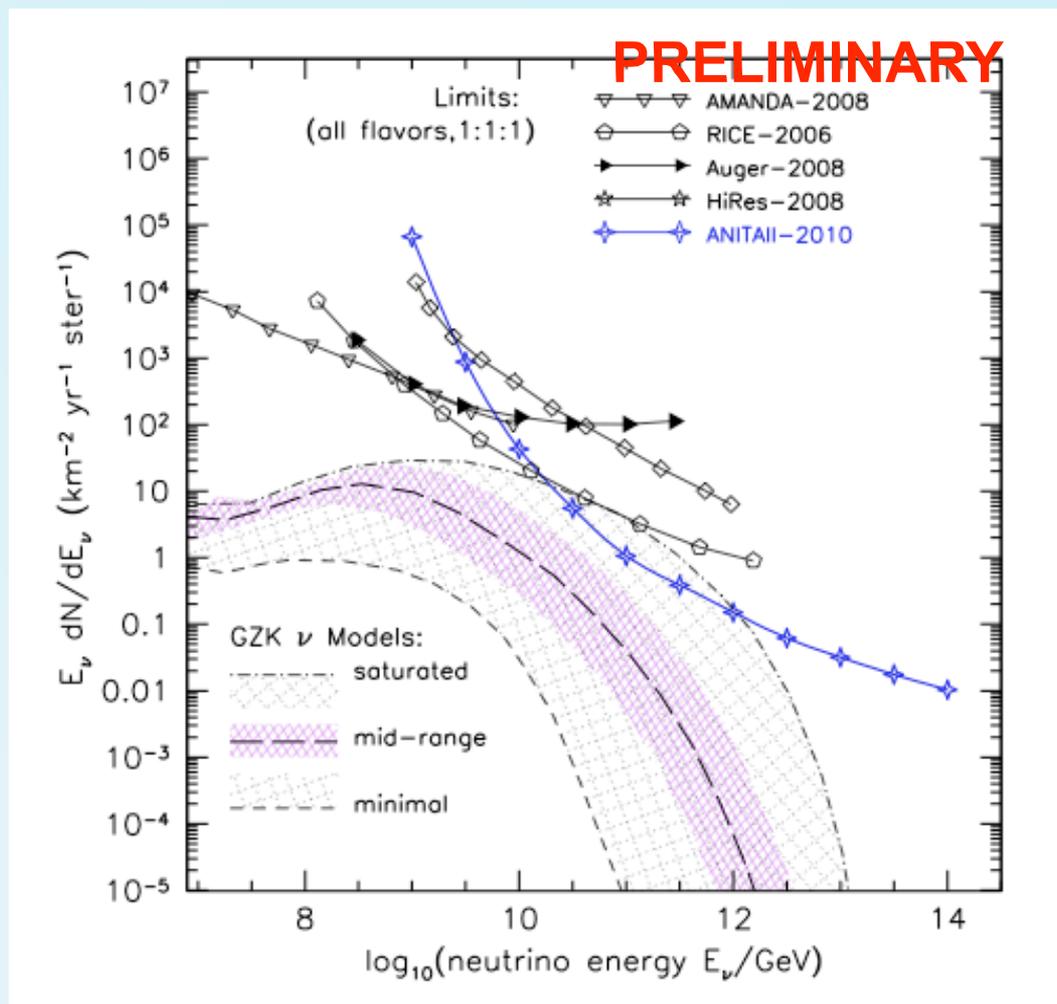
ANITA 1 cosmic ray results

- ANITA 1 observed no neutrino (VPOL) candidates (PRL 103, 051103)
- 16 isolated HPOL events were observed
  - Event polarisation consistent with geo-synchrotron from CR induced air showers
  - Average energy ~10^{19}eV
  - With optimisation could collect O(100) events per flight

PRELIMINARY
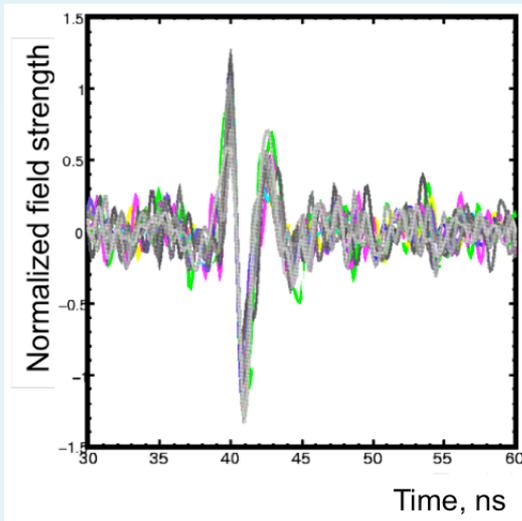
The 14 reflected events
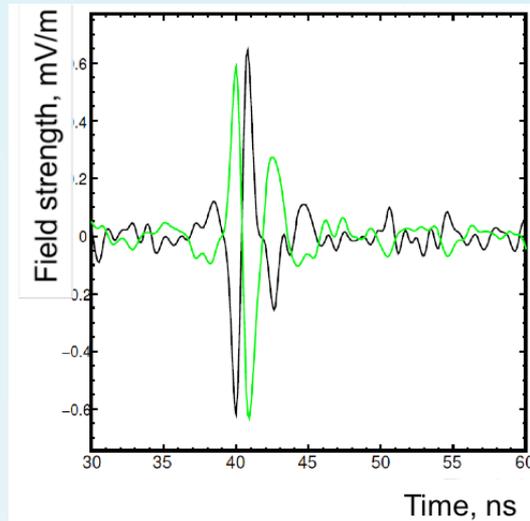
reflected events show 180˚ phase change

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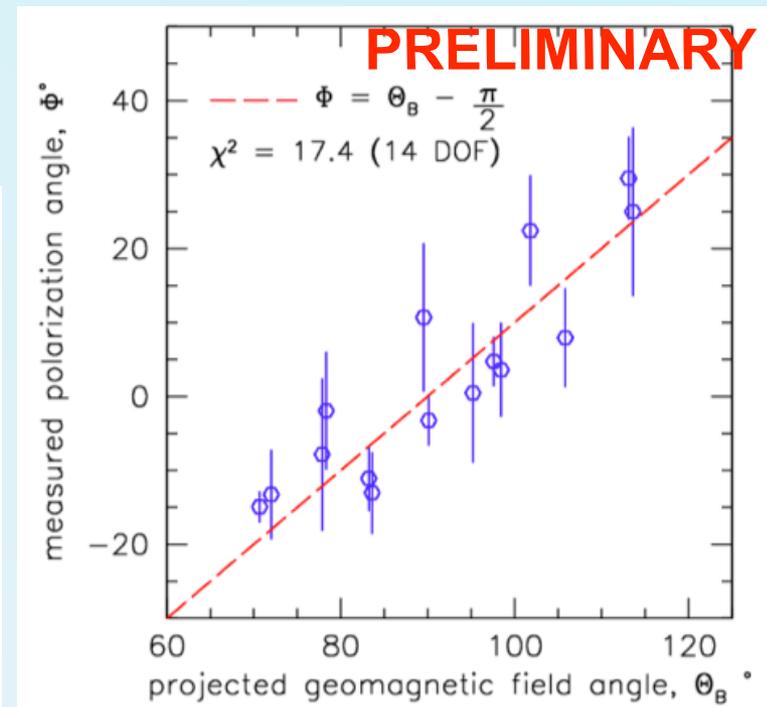
Summary

- 2 successful science flights have been completed

- Analysis tools have been demonstrated
  - ANITA has the angular resolution necessary for event imaging and clustering

- ANITA has set the best limit on UHE neutrino flux in its energy range and can observe UHE cosmic ray airshowers
  - Dedicated trigger for such events could be very productive

- 3rd flight is proposed (2012), will hopefully dig further into GZK models
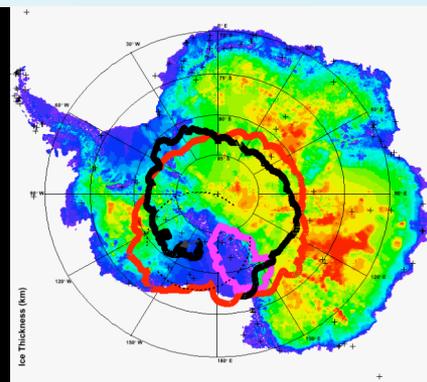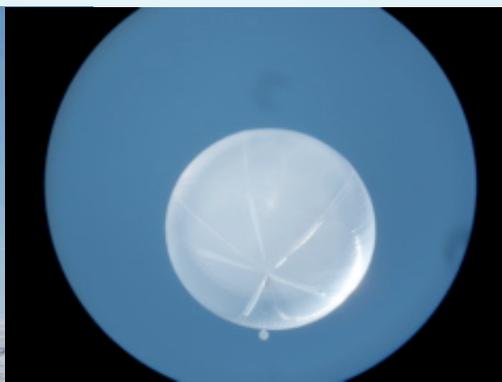
Askaryan effect

- 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 $>10^7e$
- Coherent emission over >cm wavelengths, amplitude goes with Z^2
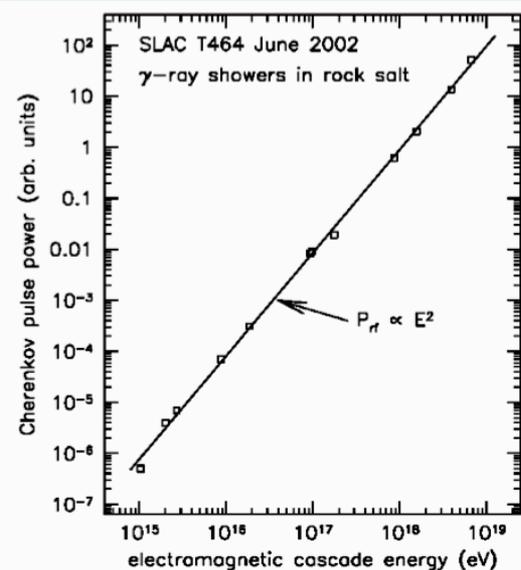
Confirmation of effect at SLAC in sand (Saltzberg et al. 2001), salt (Gorham et al. 2003, left) and ice (Gorham et al. 2007, right - photos P. Chen, C. Hast)

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Analysis tools

- Coherently summed waveform:
  - After filtering waveform take 5 sectors of payload pointing towards event
  - Time shift and sum waveforms - coherently summed waveform
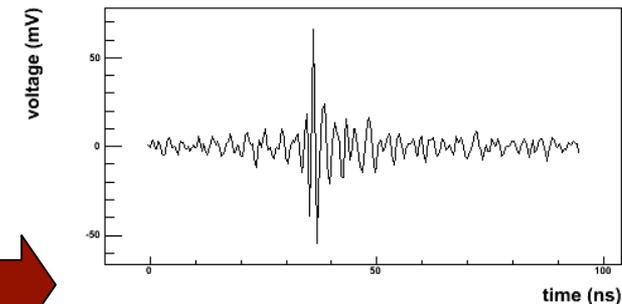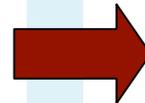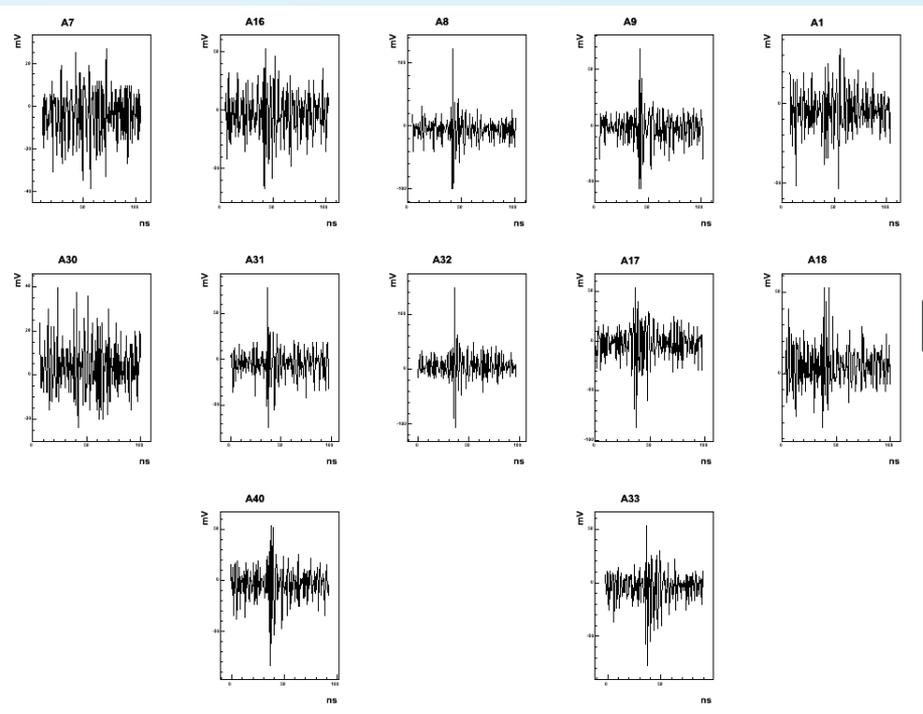
Coherently summed waveform
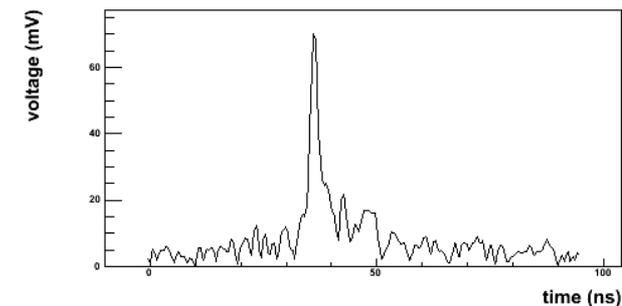
Waveform envelope

Event clustering - techniques

- Neutrino candidates must be isolated from bases and other events
- Use physical separation and log(likelihood) metric to cluster events

$$-2Log(L_{ab}) = \frac{\left(\left\|\theta_A(a) - \theta_A(b)\right\|\right)^2}{\sigma_{\theta A}^2} + \frac{\left(\left\|\phi_A(a) - \phi_A(b)\right\|\right)^2}{\sigma_{\phi A}^2} + \frac{\left(\left\|\theta_B(b) - \theta_B(a)\right\|\right)^2}{\sigma_{\theta B}^2} + \frac{\left(\left\|\phi_B(b) - \phi_B(a)\right\|\right)^2}{\sigma_{\phi B}^2}$$

- A and B are the payload locations for events a and b, σ is resolution
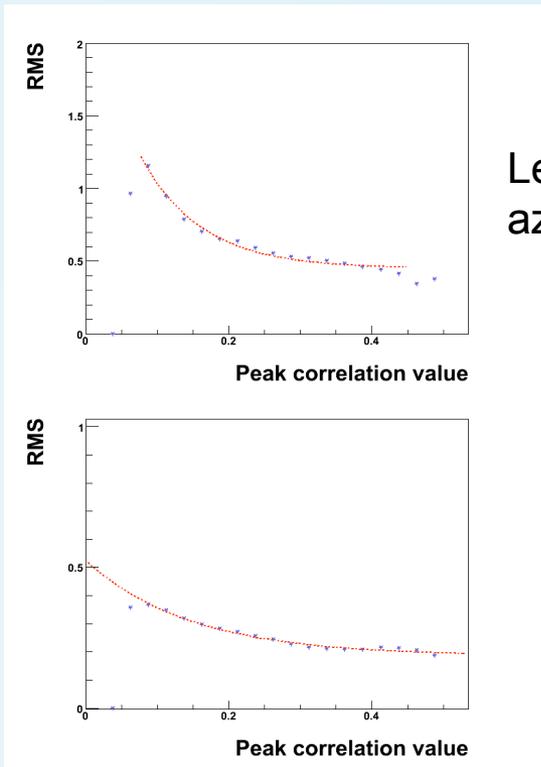
Left: pointing resolution for azimuth (top) and zenith (bottom)
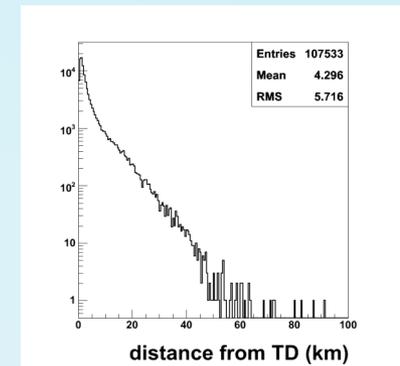
Right: physical separation (top) and LL distributions for an isolated, stationary RF pulser

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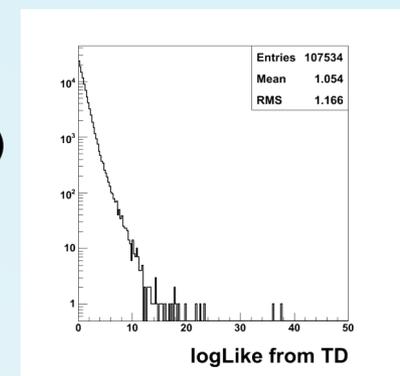
ANITA I neutrino results

- 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

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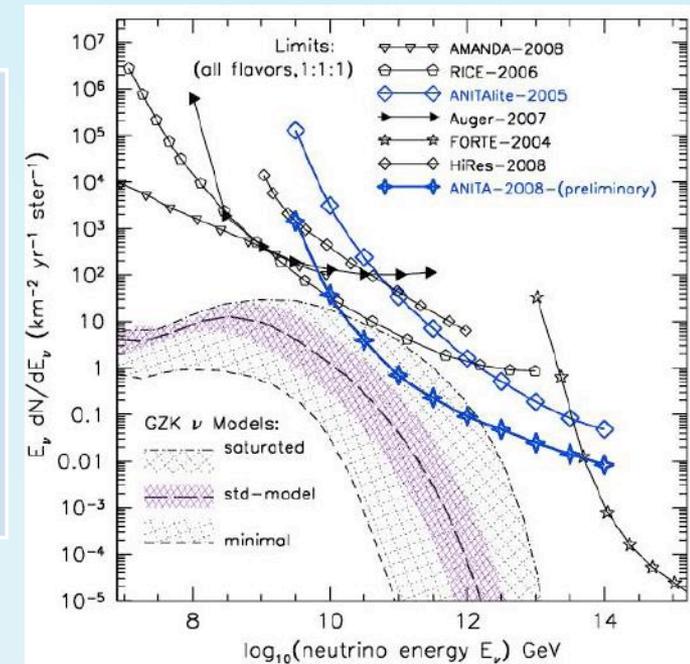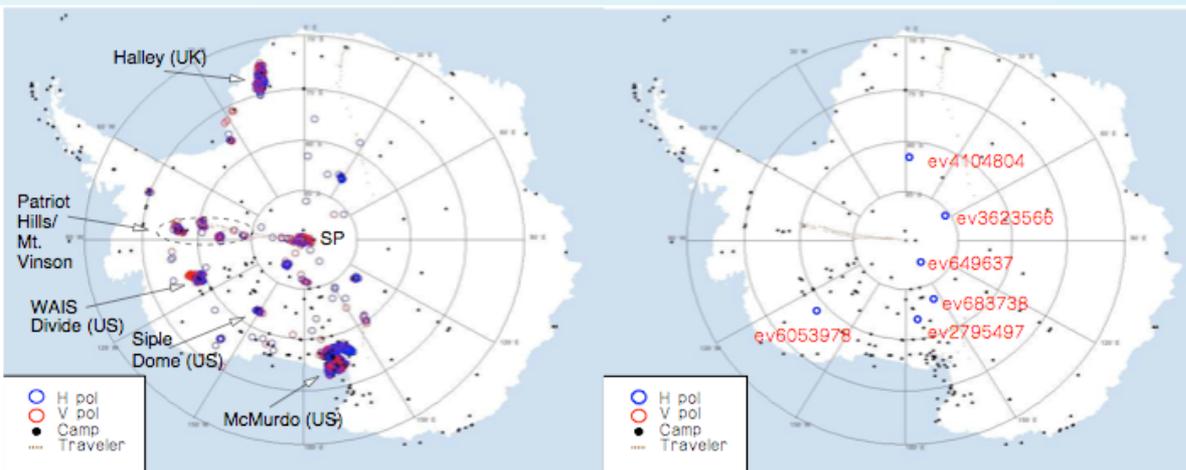
ANITA II neutrino locations