Unusual Events in the Third Flight of ANITA

T.C Liu, NTU

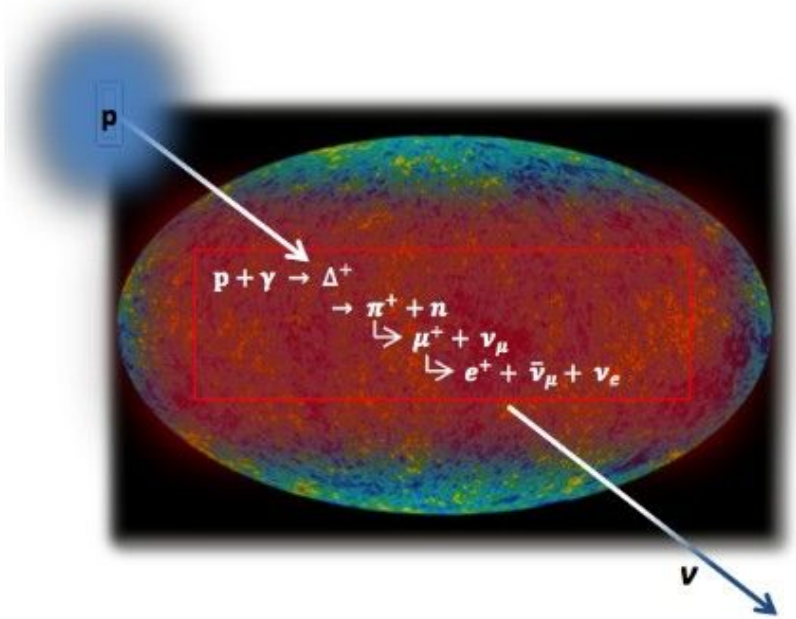
CYCU HEP seminar

ANITA Collaboration

ANtarctic Impulsive Transient Antenna

12 university, 3 countries

Science Motivation



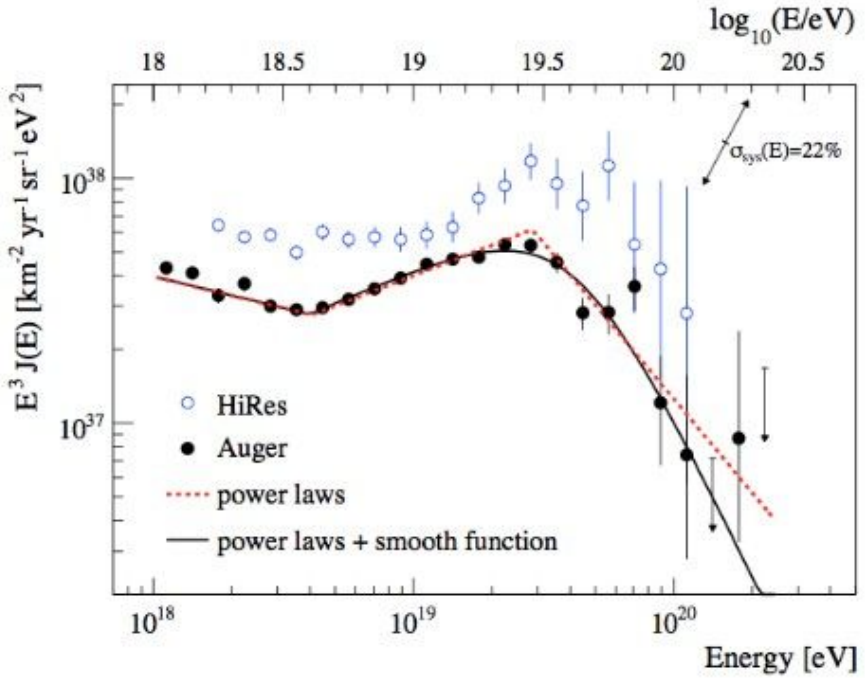
Auger and HiRes measurements of UHE cosmic rays consistent with GZK cut-off

Guaranteed GZK neutrino flux, but how large?

copy from Jonathan's slides

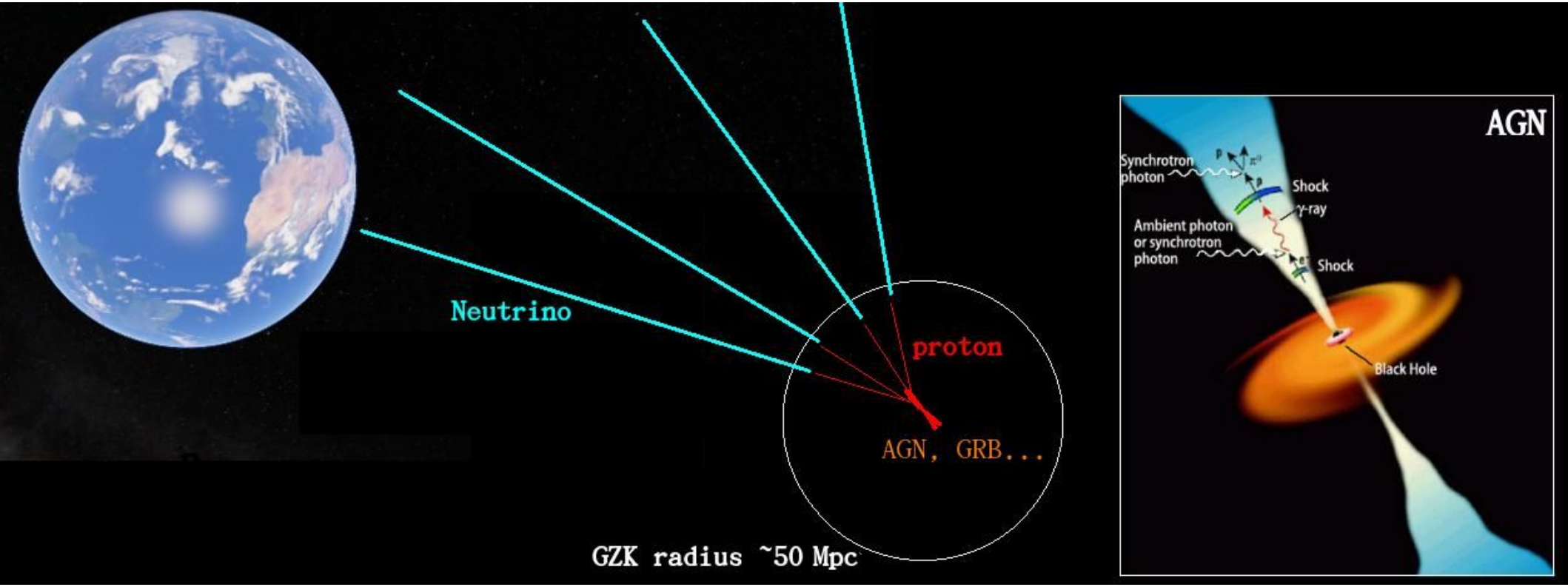
At energies above ~$10^{19.5}$eV cosmic rays will interact with CMB photons producing neutrinos

Process is known as the GZK effect



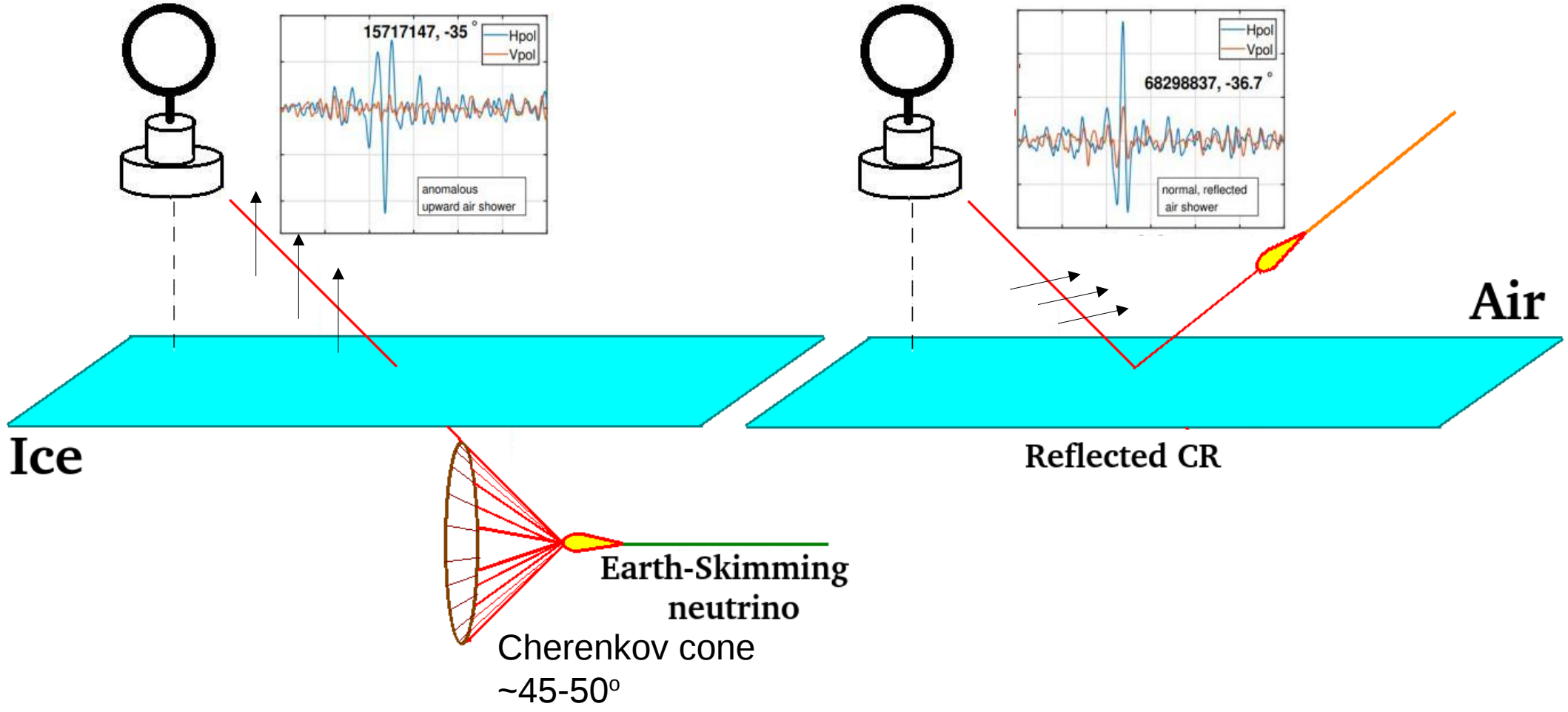
The Pierre Auger Collaboration (2010): Phys. Lett. B 685 (4–5): 239–246. HiRes Collaboration, Astropart. Phys. 32 (2009) 53.

Cosmogenic Neutrino

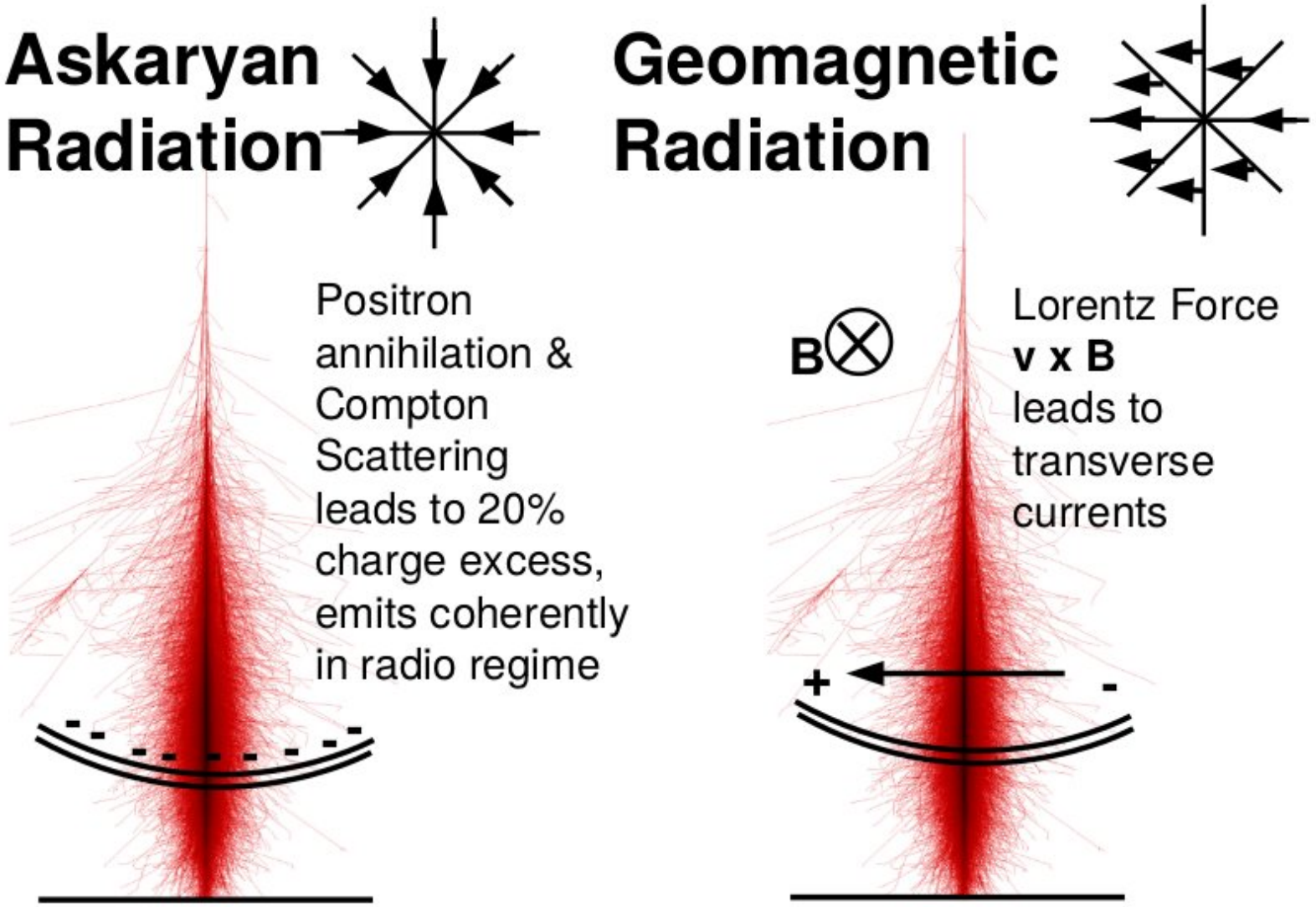


The UHE neutrinos can point back to the original UHE source without bending of B field.

Signal Type (Neutrino VS. EAS)

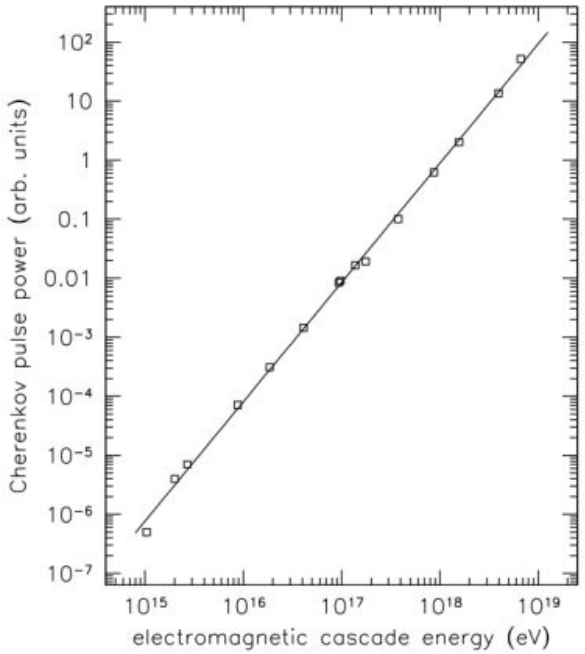


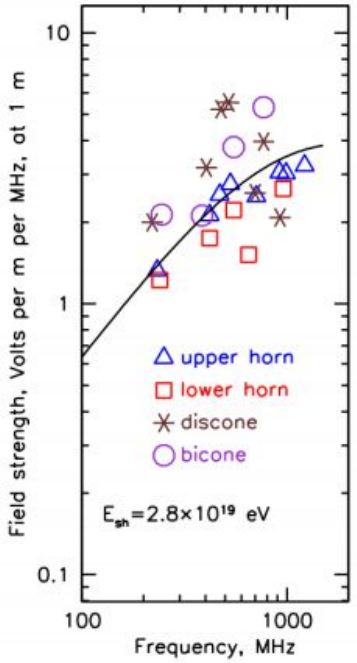
Askaryan & Geomagntic Radiation



Radio Emission from Askaryan Effect in Ice

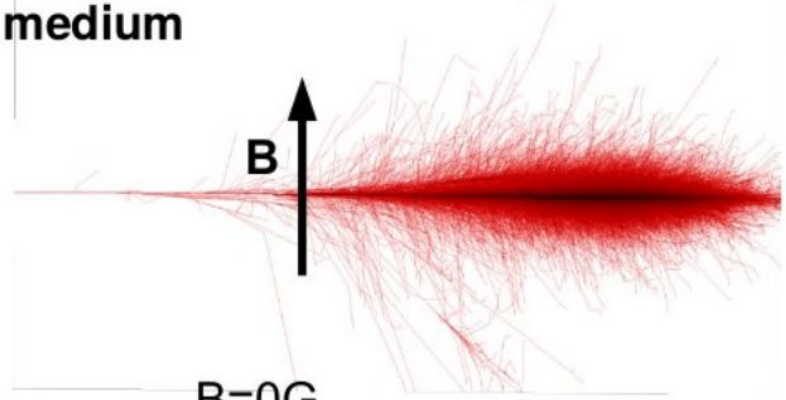
- Askaryan (charge-excess) radiation: Fast-moving charge in dielectric coherent emission ($\propto E^2$) at long (radio) wavelengths
- Charge excess from annihilation of positrons with electrons in material
- Confirmed in ice with SLAC beam test (Phys.Rev.Lett.99:171101,2007)
- Radio attenuation length in ice is ~ 1 km





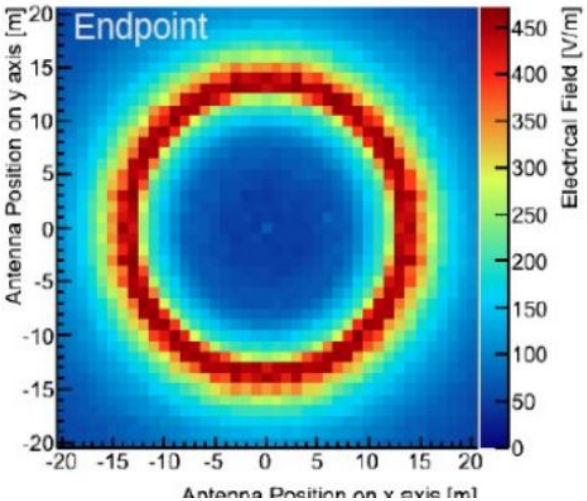
Geomagnetic Raditaion

Radio emission from a particle cascade in a dense medium

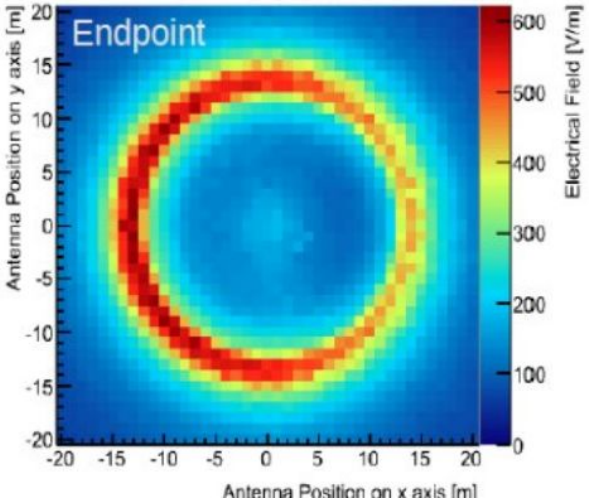


Observer facing cascade

B=0G

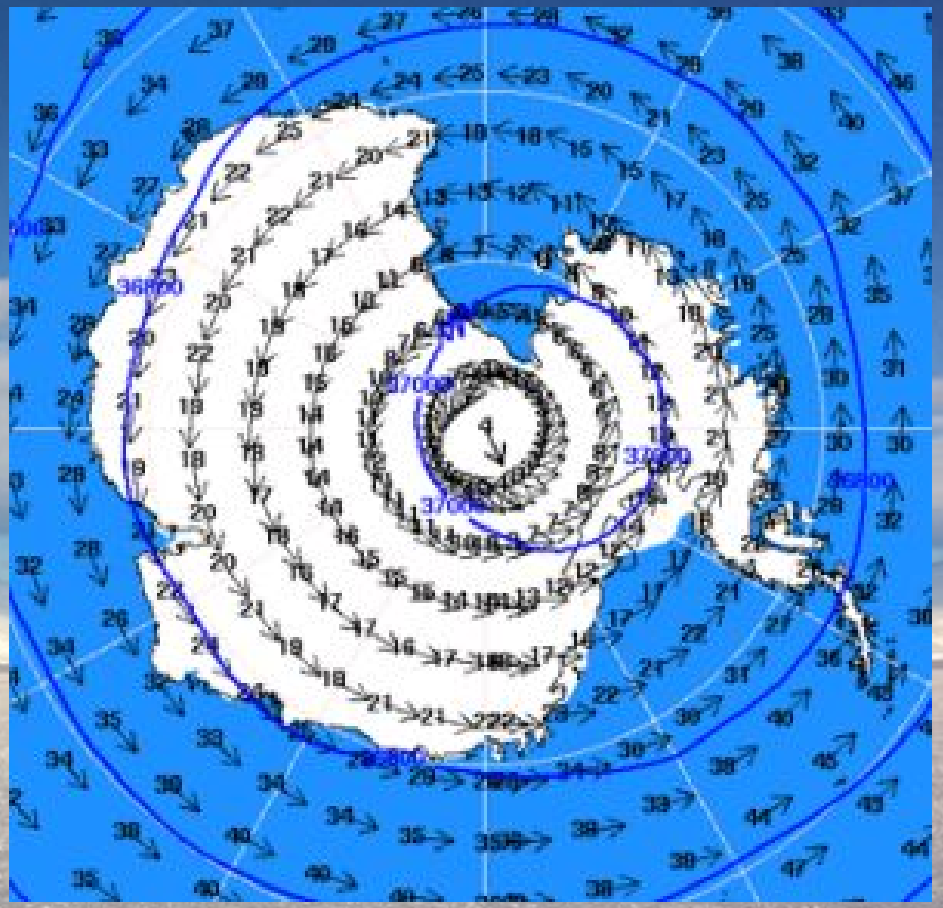


B=1000G



ANITA & Antarctica

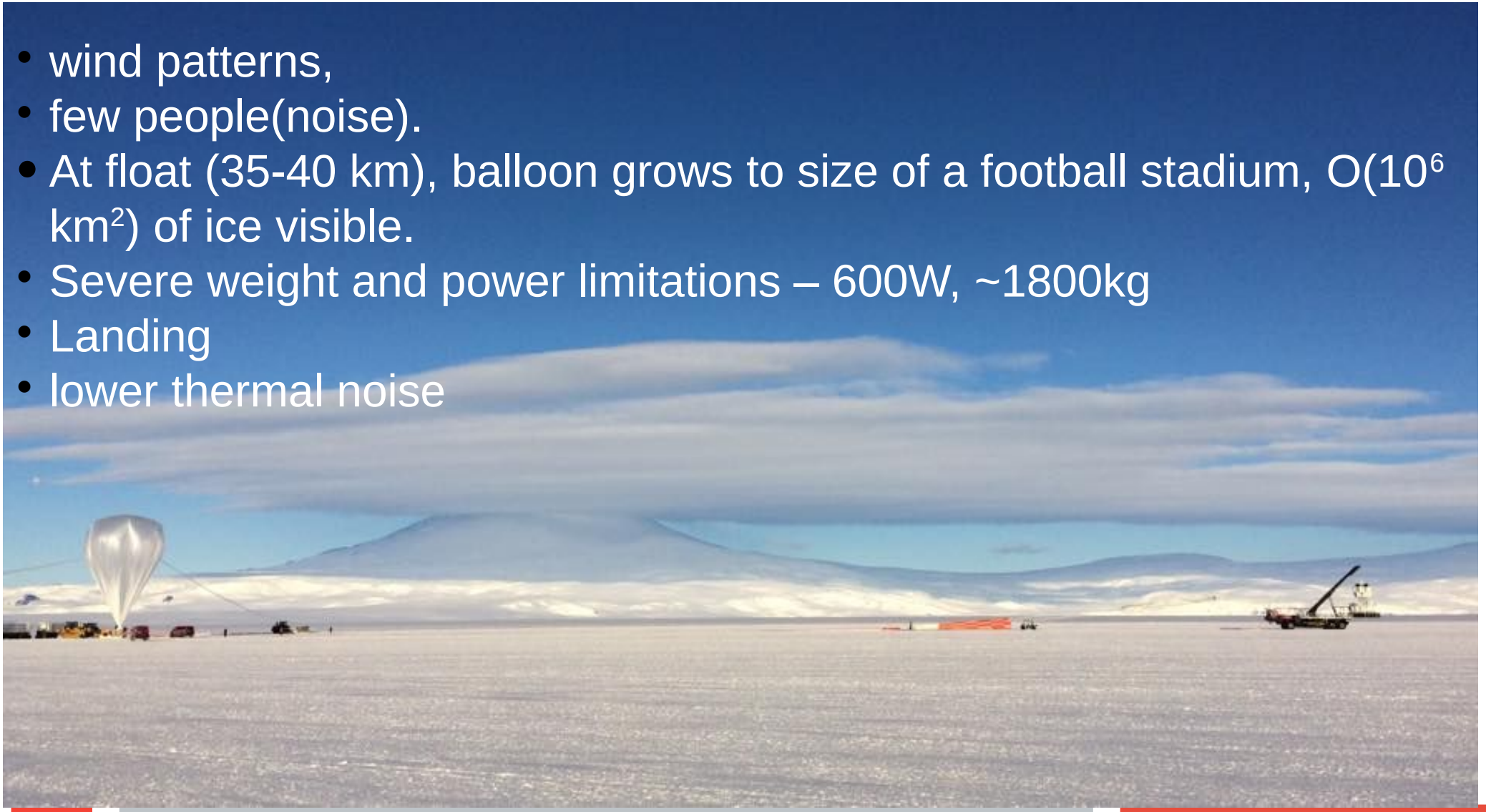
- wind patterns,



ANITA & Antarctica

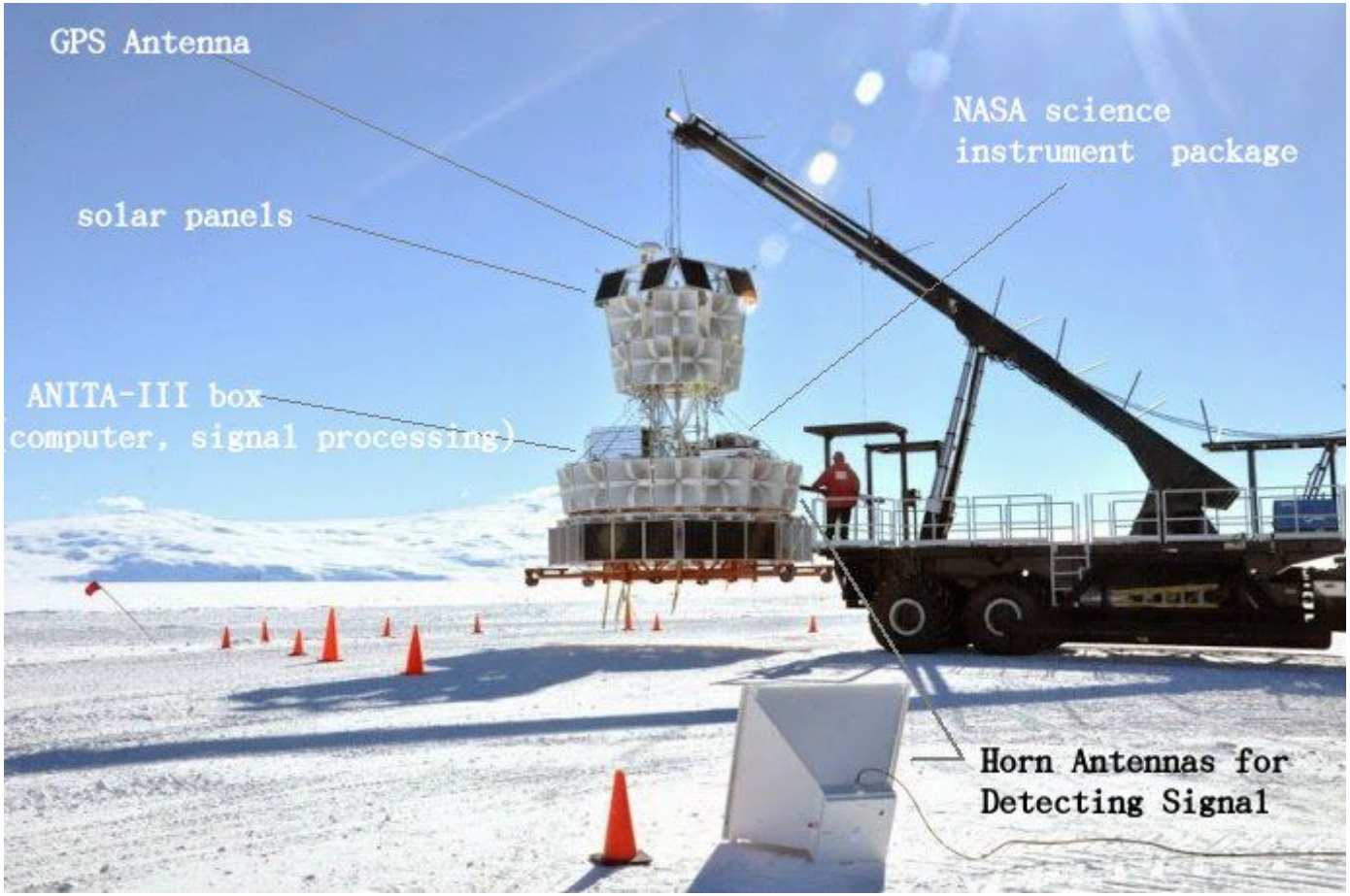
- wind patterns,
- few people(noise).

ANITA & Antarctica



- wind patterns,
- few people(noise).
- At float (35-40 km), balloon grows to size of a football stadium, O(10^6 km^2) of ice visible.
- Severe weight and power limitations – 600W, ~1800kg
- Landing
- lower thermal noise

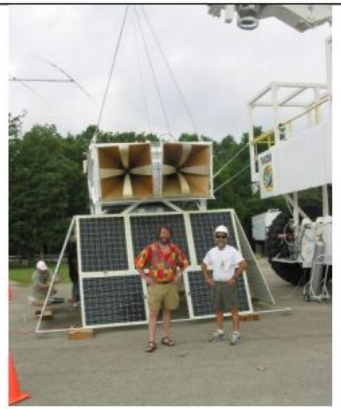
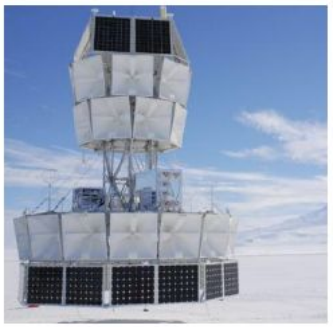
ANITA Instrument



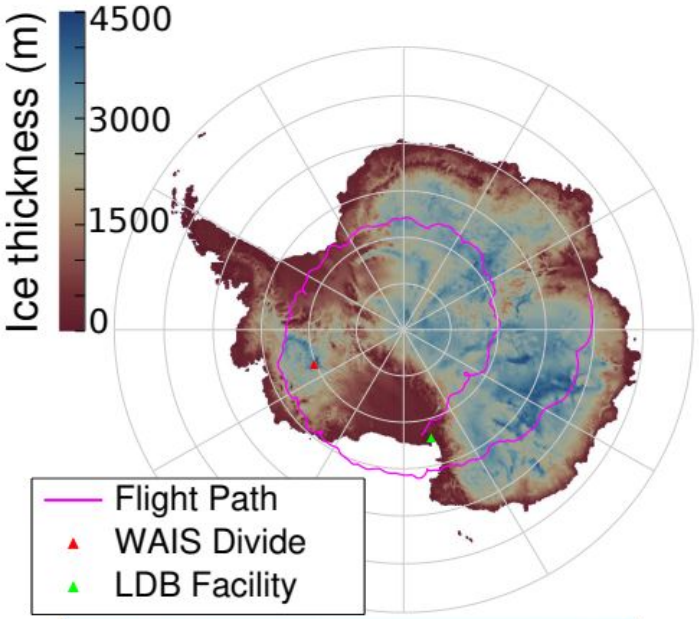
Signal (~ 180-1200 MHz) split into digitization and trigger paths

- Tunnel diode first-level trigger. FPGA takes O(105−6 Hz) singles rate → O(50 Hz) global rate
- Switched Capacitor Array digitizers, ~2.6 GSa/s, O(100 ns).

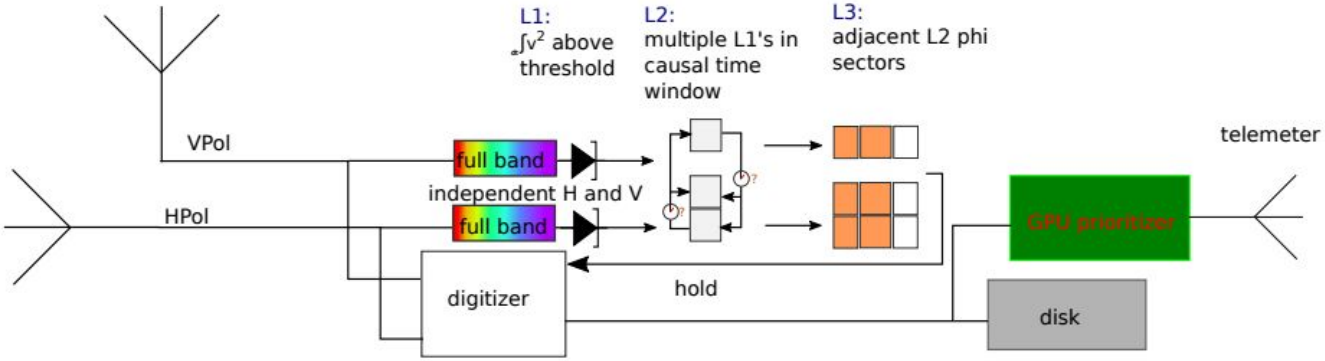
ANITAs

ANITA-Lite	ANITA-I	ANITA-II	**ANITA-III**	ANITA-IV
				
2003-2004	2006-2007	2008-2009	2014-2015	2016
18 days, 2 antennas	35 days, 32 antennas	30 days, 40 antennas	22 days, 48 antennas	29 days, 48 antennas
Piggy-back on TIGER	Multi-band, Pol-independent trigger	Multi-band, VPol trigger	Full-band HPol + VPol trigger	Full-band, Lin-Pol trigger
Analyzed	Analyzed	Analyzed	**Recently analyzed**	Analysis Ongoing

ANITA-III Flight (2014-2015)



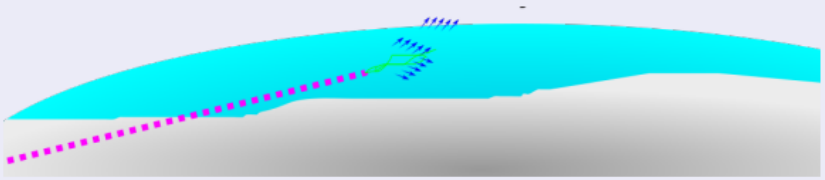
- Independent H + V trigger, with causal timing requirement between antennas
- Increased data rate with GPU prioritizer
- Complications from new military comm satellites → loss of volume, significant improvements to data analysis required.
- Calibration pulses sent from launch site (LDB Facility) and remote site (WAIS divide)



Signal vs. Background

Askaryan Emission from ν's

- Impulsive signal (few ns)
- Broadband
- Plane-wave
- Linearly polarized; mostly vertically-polarized (VPol) due to interaction geometry (Earth opaque to EeV ν's) and transmission through air-ice boundary (Fresnel coefficients).



Continuous Wave (CW) Signals

Anthropogenic narrow-band signals (from satellites and bases) contaminate most data

Thermal Noise

Incoherent random noise, that sometimes by chance looks impulsive

Self-triggered "payload blasts"

RF emission produced on payload; does not satisfy plane wave condition

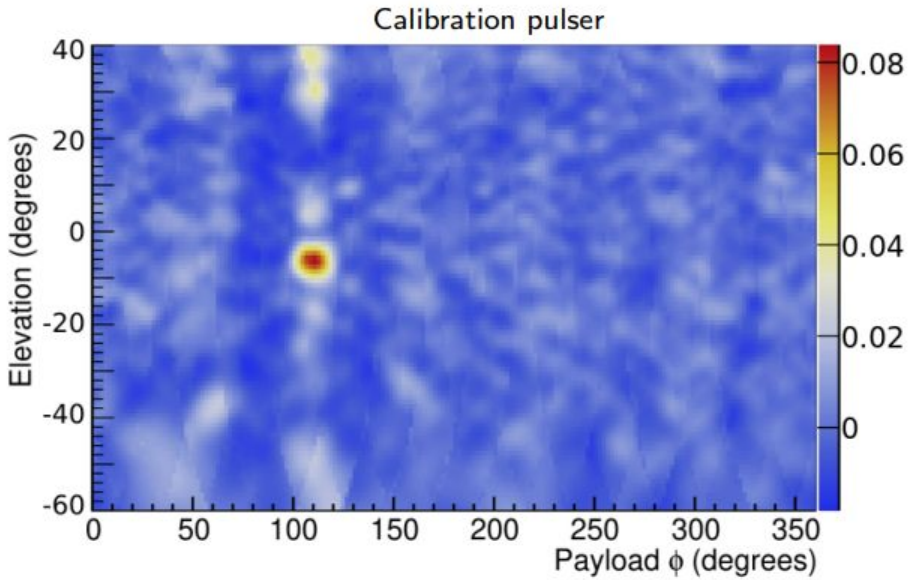
Impulsive Anthropogenic Emission

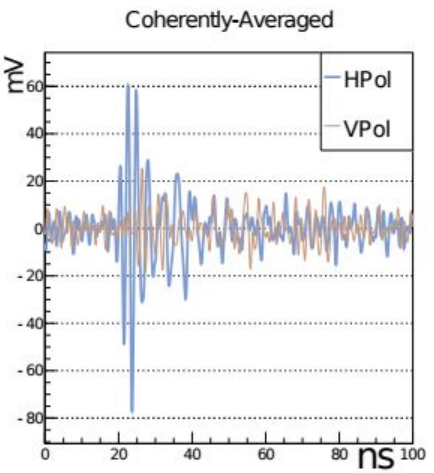
Transformers, engines, etc. produce broadband impulsive emission that can mimic ν's. These are the worst.

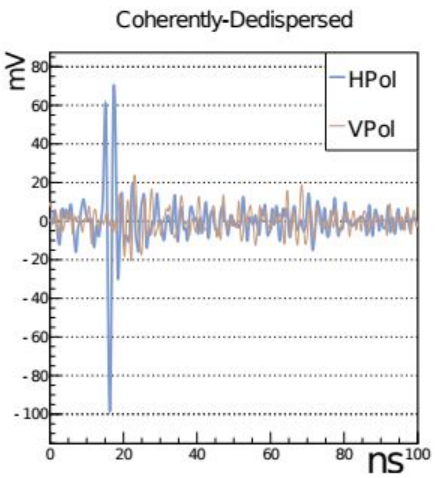
Analysis Processes

Three independent ν analyses for ANITA-III.
Basic flow:

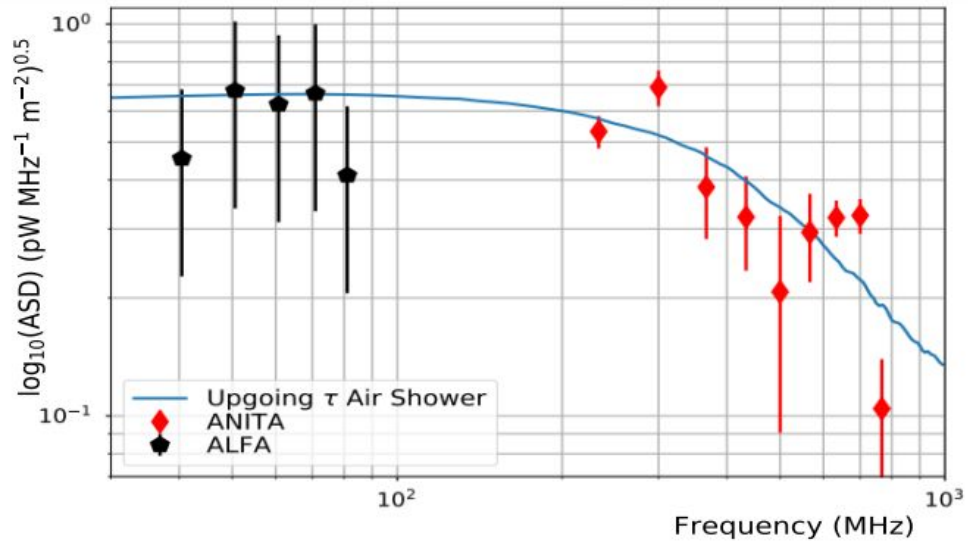
1. Filter waveforms (reduce CW) and remove events failing quality cuts
2. Form correlation map, where we calculate channel cross-correlations with different direction assumptions
3. From peaks of correlation map, form coherent waveforms, generate features (e.g. impulsivity, linear polarization fraction) used to cut out thermal noise
4. Use pointing information to point to continent; select regions with little anthropogenic activity.

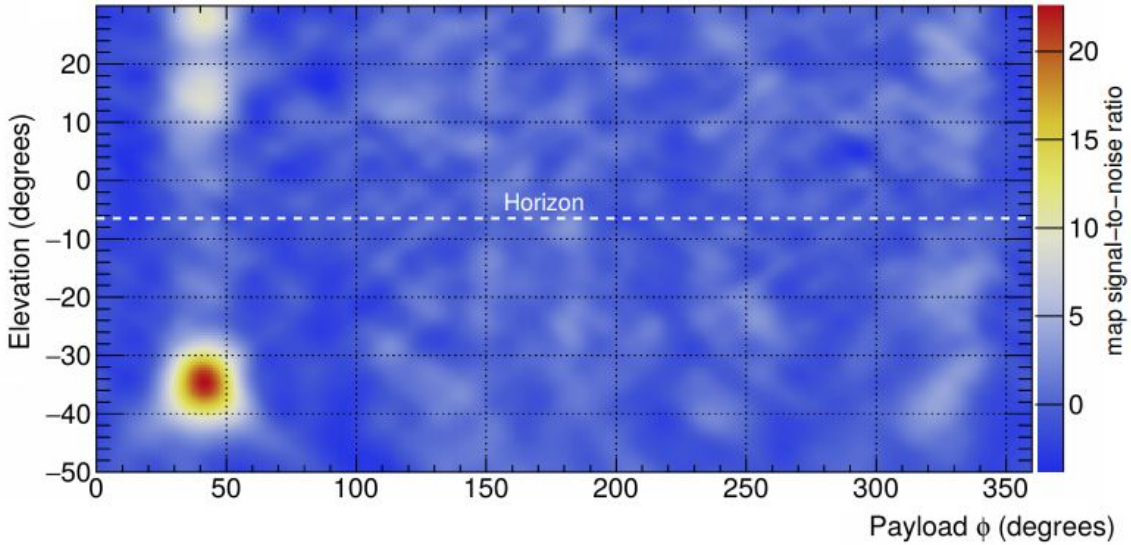






Event #15717147



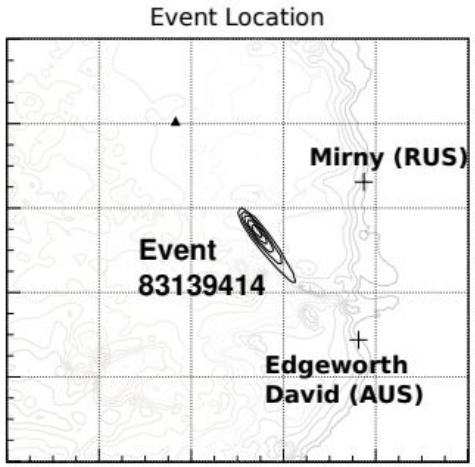


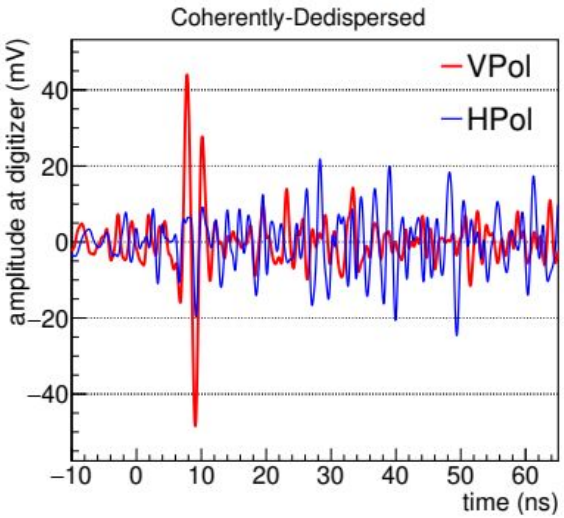
ANITA combined amplitude spectral density (ASD) for the event, from 50-800 MHz, including data from the ANITA Low Frequency Antenna (ALFA). A simulated upward-propagating extensive air shower spectral-density curve is overlain.

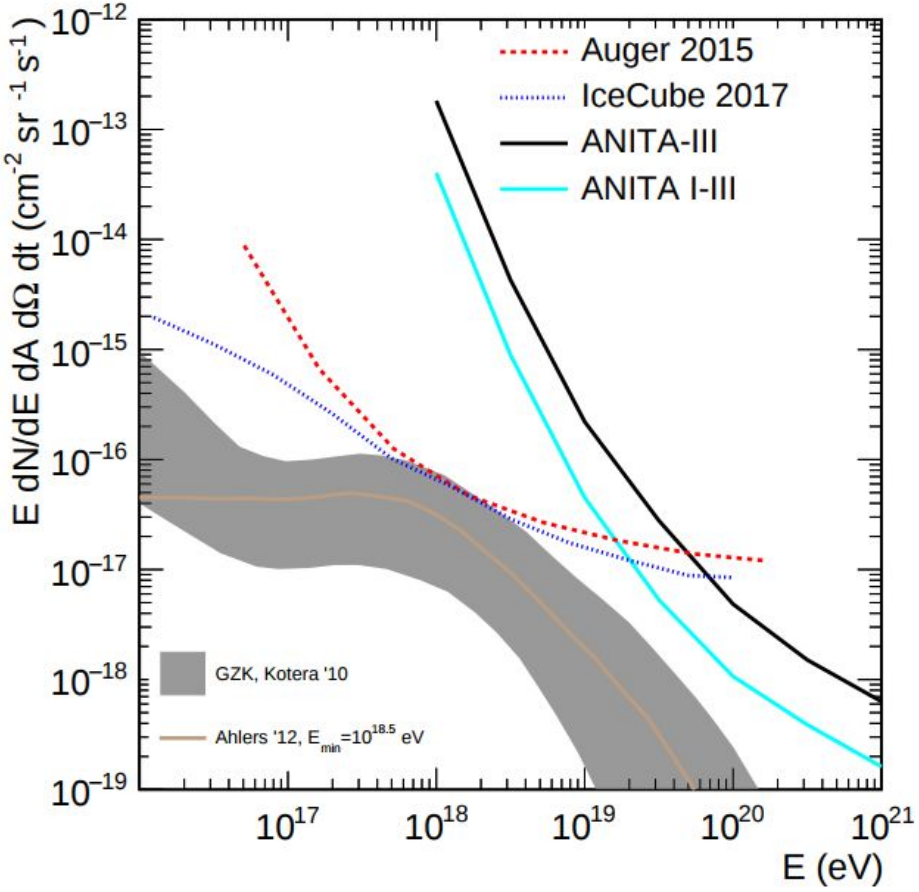
Right: Interferometric map of the arrival direction of the anomalous CR event 15717147.

ANITA-III Neutrino Event

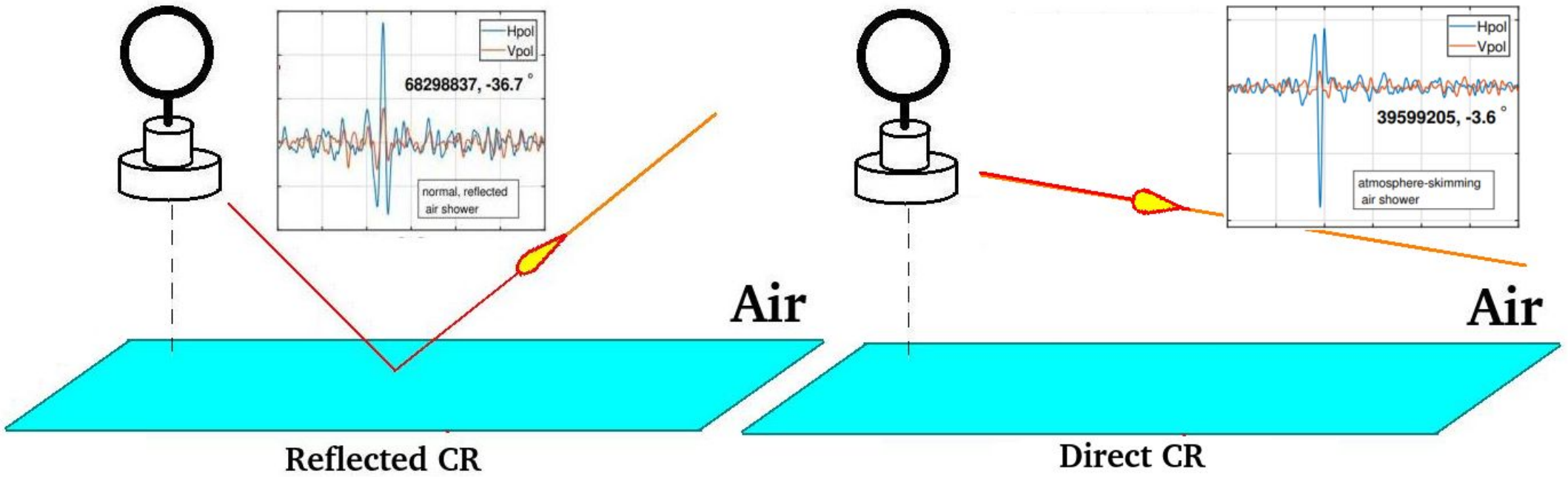
- arXiv:1803.02719 (submitted to PRD)
- Most sensitive search found one candidate on a background of $0.7^{+0.5}_{-0.3}$ events
- Consistent with background, so set limit, but the event looks pretty good (very isolated, very impulsive, thick ice, right polarization)







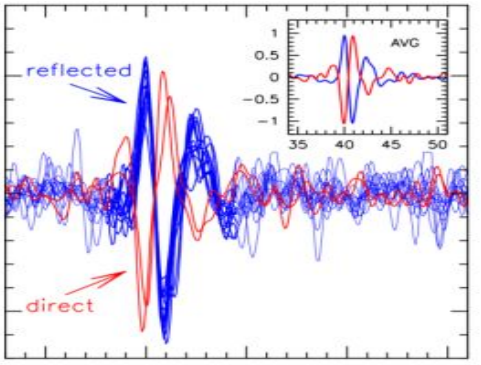
Radio Emission from Extensive Air Showers (EAS)



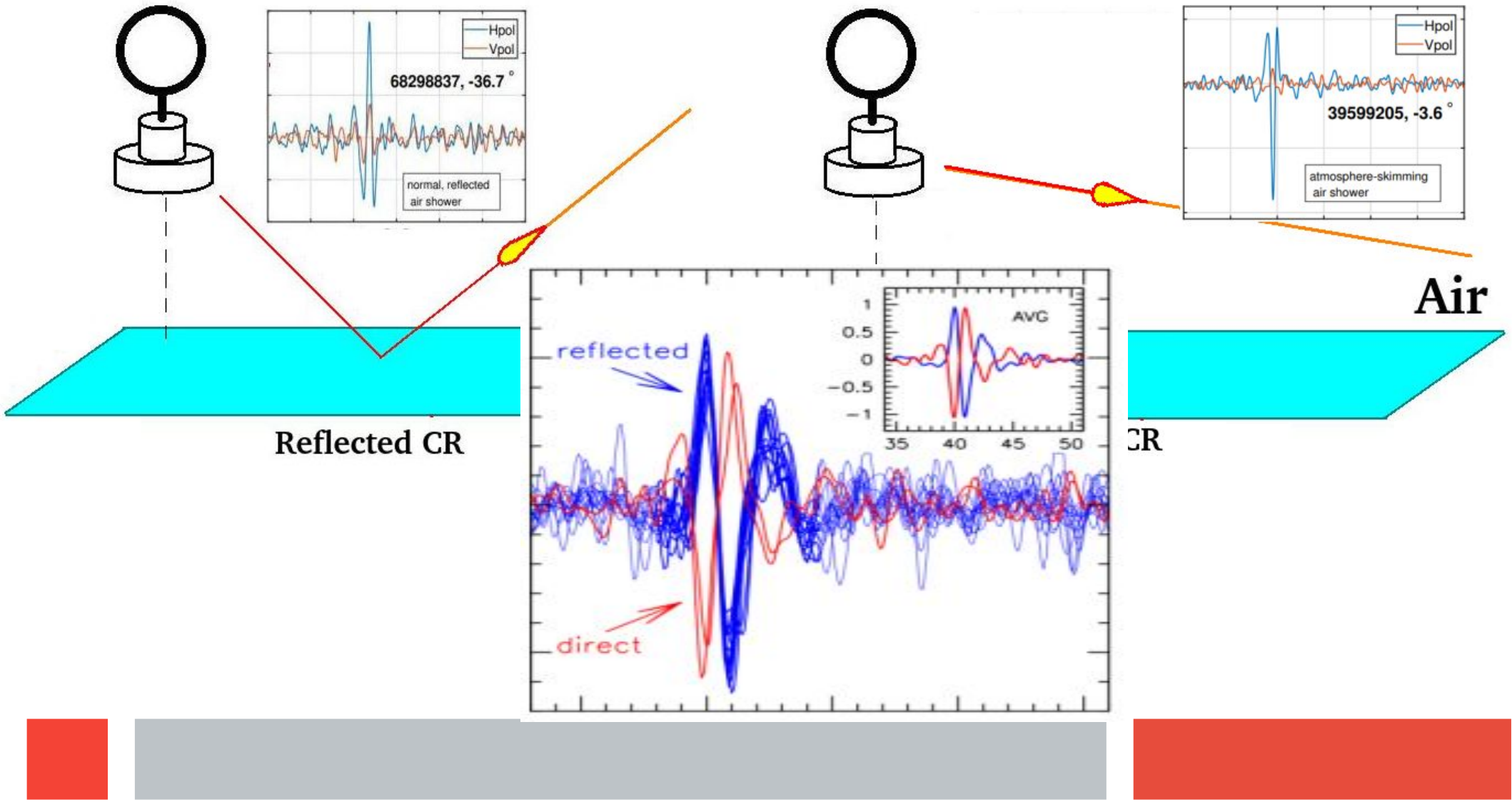
Earth's magnetic field separates charges in EAS's, produces radio emission

"Direct" ~horizontal CR's: miss ground.

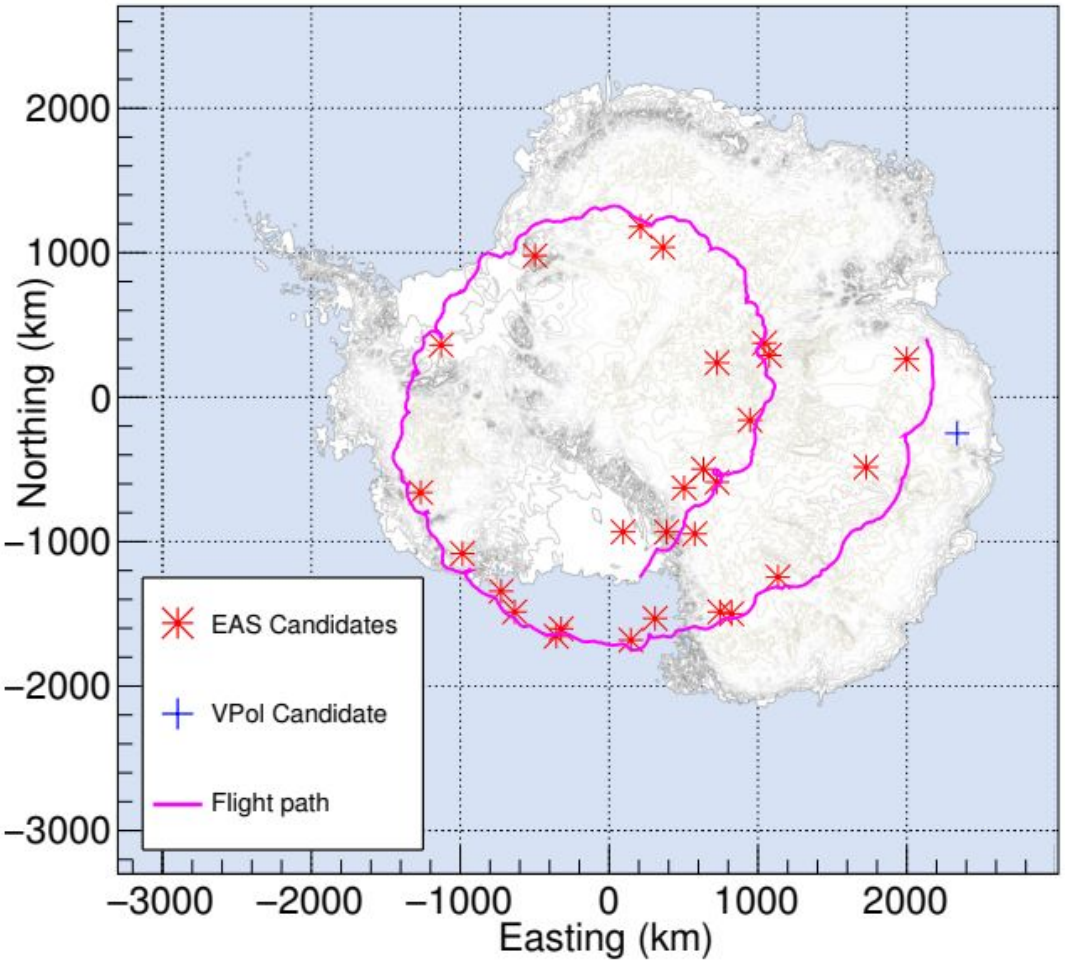
"Reflected" down-going CR's: point to ground, opposite polarity

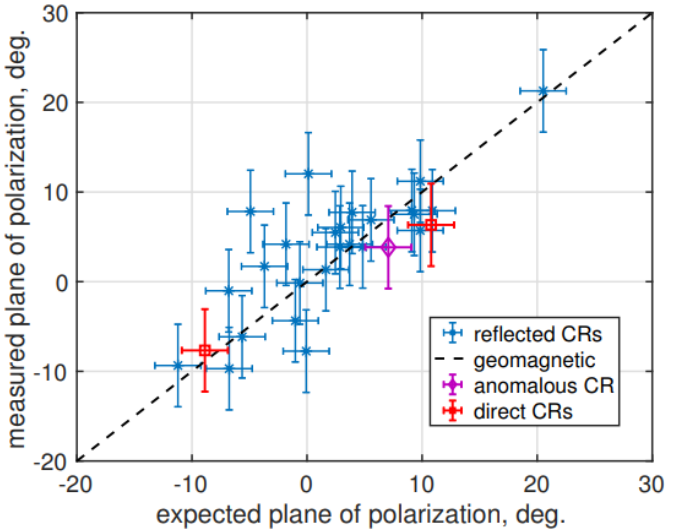


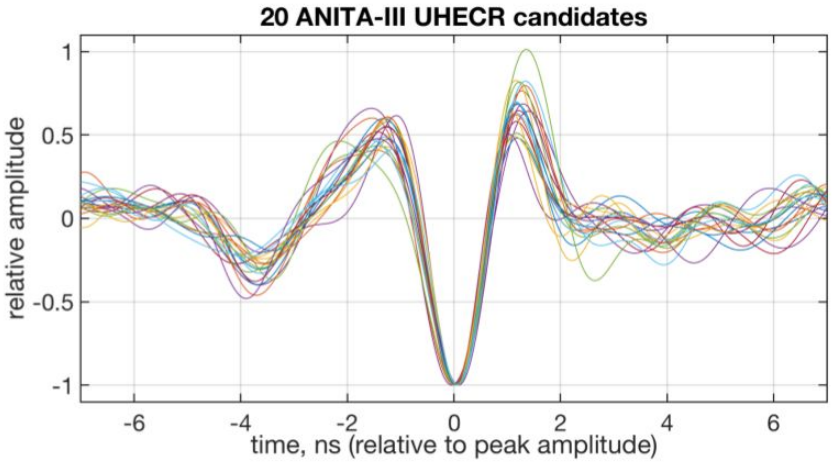
Radio Emission from Extensive Air Showers (EAS)



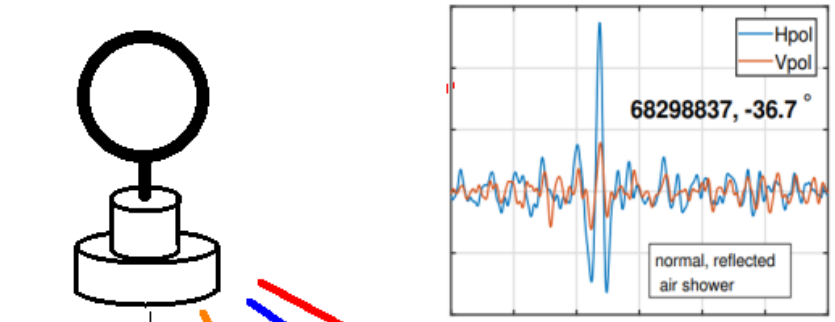
New 20 UHECR events of ANITA Flight



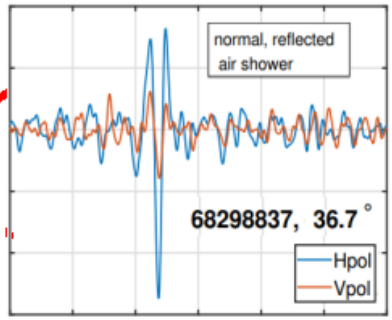




Events types of ANITA

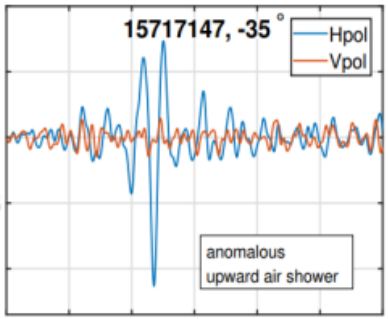


reflected signal



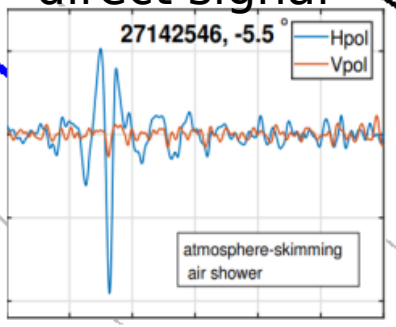
direct signal

Horizon



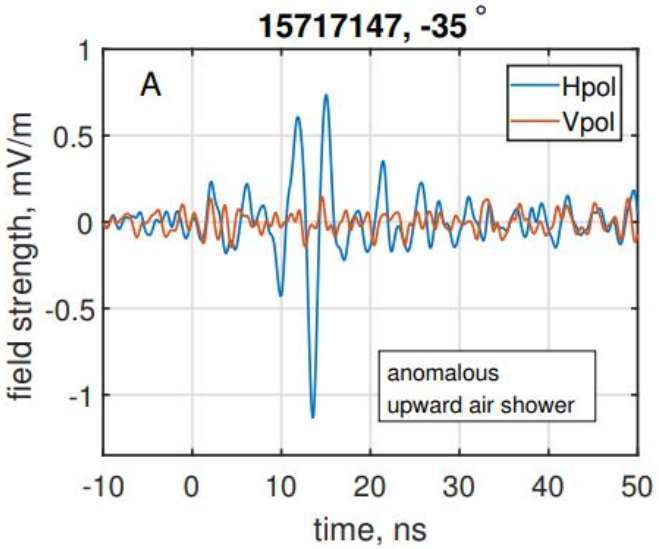
direct signal

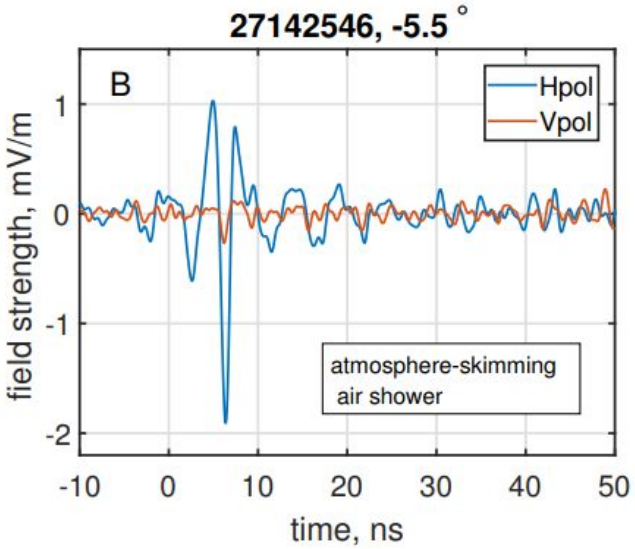
direct signal

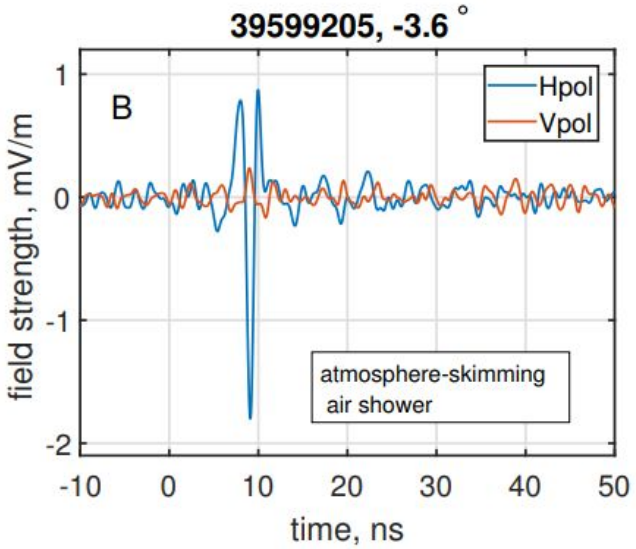


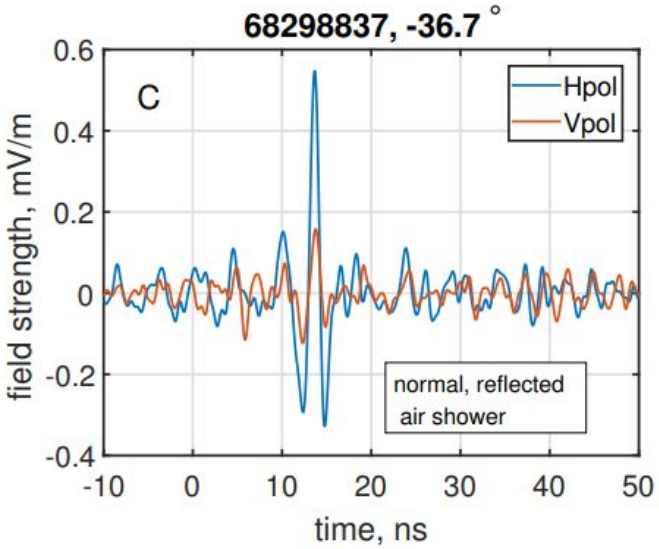
ice sheet

3 Tpyes of Event Signal









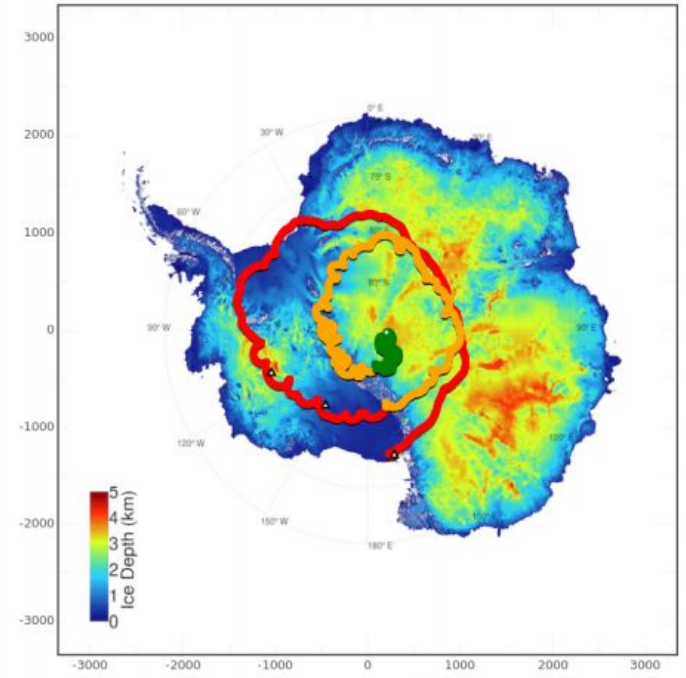
Anomalous event found in ANITA-I. Another found in ANITA-III (arxiv:1803.05088).

Mostly HPol, matches UHECR template, polarity consistent with direct cosmic ray event, but clearly points to ice.

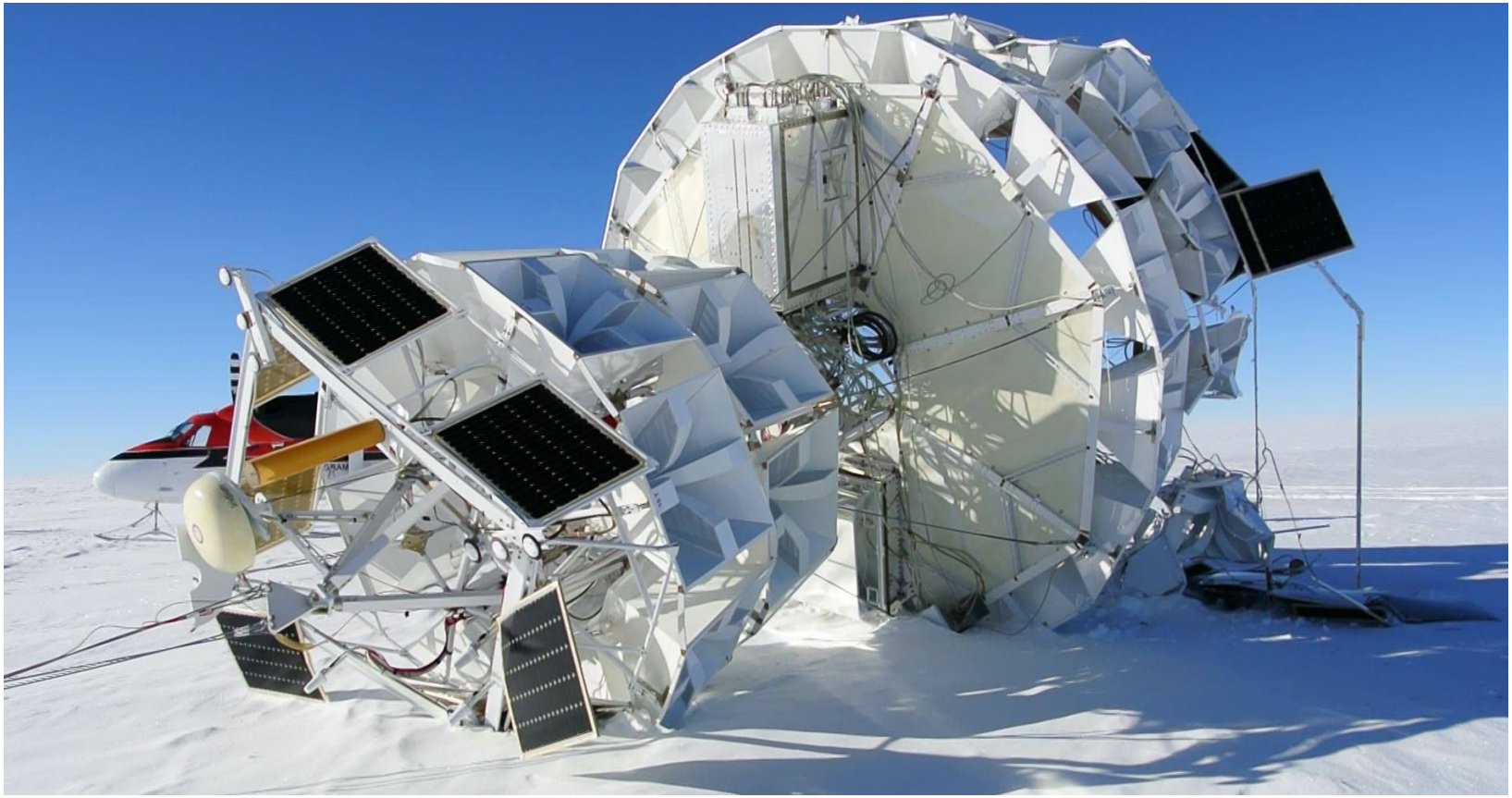
Would like to call it a τ candidate, but chord length through Earth in tension with SM cross-section and flux in tension with Auger and IceCube limits .

ANITA-IV(2016)

- ~100 million events recorded, under process of being analyzed.
- Key upgrades:
  - New trigger that requires linear polarization without preference for H or V (better sensitivity to non-SM νN cross-sections)
  - Dynamic, tunable hardware notch filters to reduce CW, greatly increasing livetime
- Analysis expected to be completed sometime this year.
  - Major analysis goal is to reduce anthropogenic background by using additional discriminators other than location.
  - Expectation is that it will be the most sensitive ANITA yet.



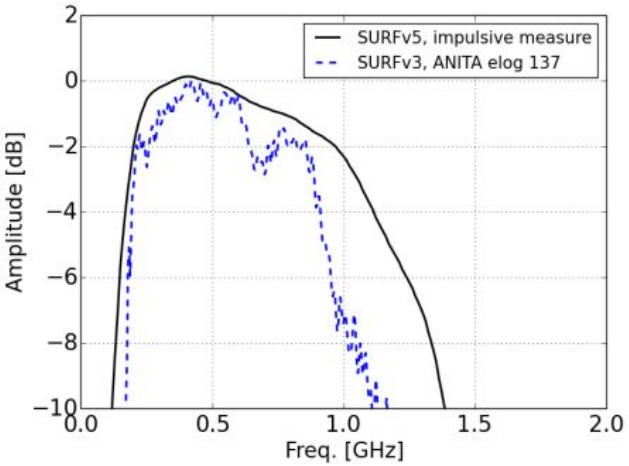
Recovery status of the ANITA-IV



ANITA-IV lunched on December, 2016 and landed about 170 nautical miles from South Pole Station. ANITA members flighted to the payload location using a ski-equipped Twin Otter aircraft on December,2017. At the payload site, people disassembled the instrument and ferry the parts back to South Pole for shipment to the US.

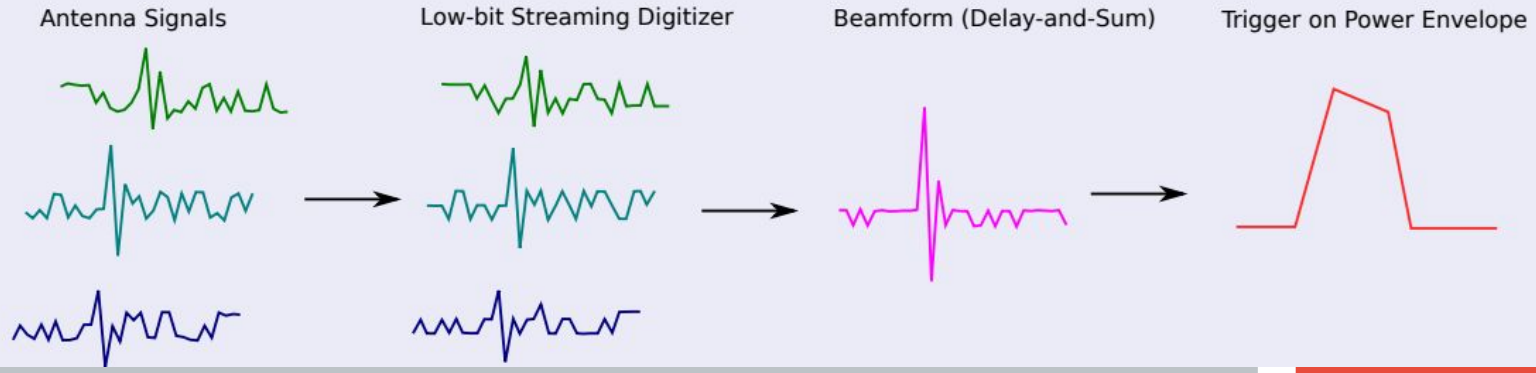
ANITA-V (2020?)

- Proposal submitted
- New digitizers, with more even sampling, better bandwidth, and longer length
- Beam-forming trigger (use interferometry in real time with a streaming digitizer)

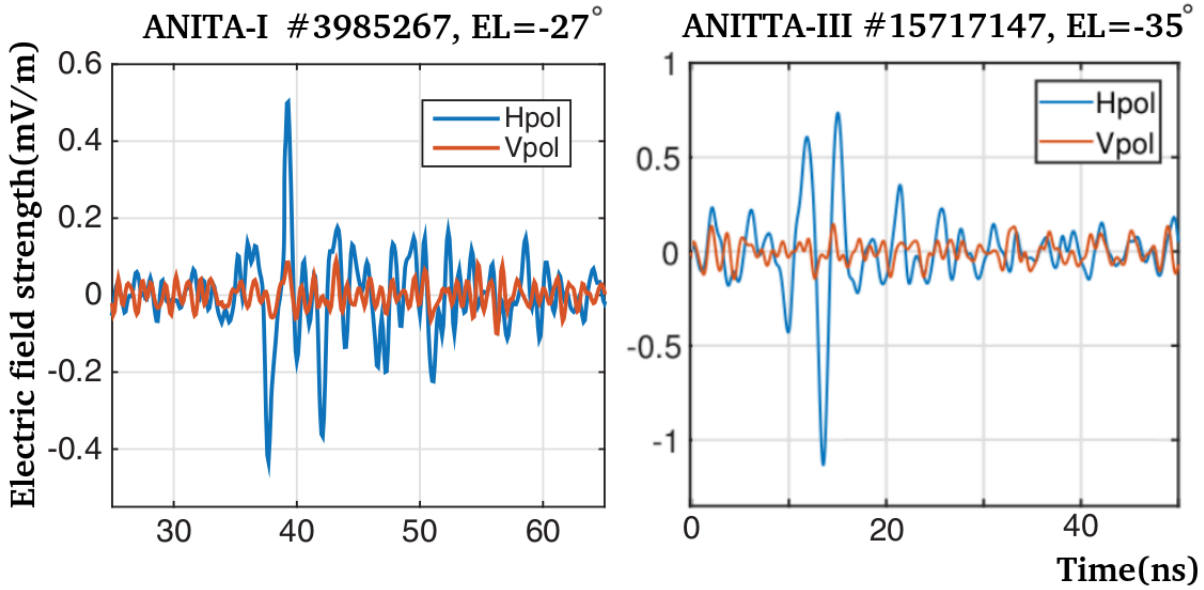


Old vs. new digitizer bandwidth. E. Oberla

Interferometric Trigger



up-going neutrino of ANITA-I & III

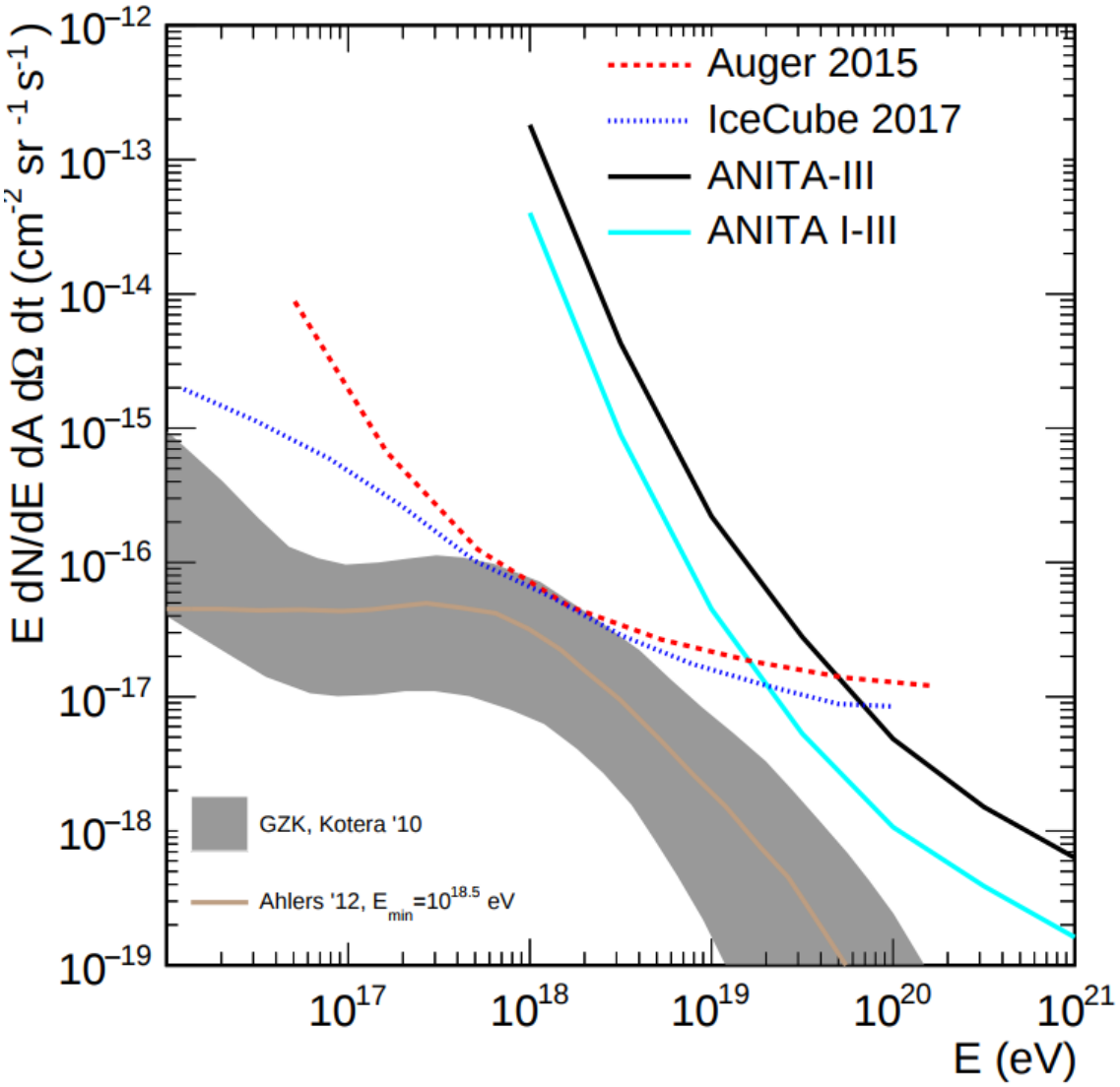


event, flight	3985267, ANITA-I	15717147, ANITA-III
date, time	2006-12-28,00:33:20UTC	2014-12-20,08:33:22.5UTC
Lat., Lon.[1]	-82.6559, 17.2842	-81.39856, 129.01626
Altitude	2.56 km	2.75 km
Ice depth	3.53 km	3.22 km
El., Az.	$-27.4 \pm 0.3°, 159.62 \pm 0.7°$	$-35.0 \pm 0.3°, 61.41 \pm 0.7°$
RA, Dec[2]	282.14064, +20.33043	50.78203, +38.65498
E_{shower} [3]	0.6 ± 0.4 EeV	$0.56^{+0.3}_{-0.2}$ EeV

Anomalous event found in ANITA-I. Another found in ANITA-III (arxiv:1803.05088).

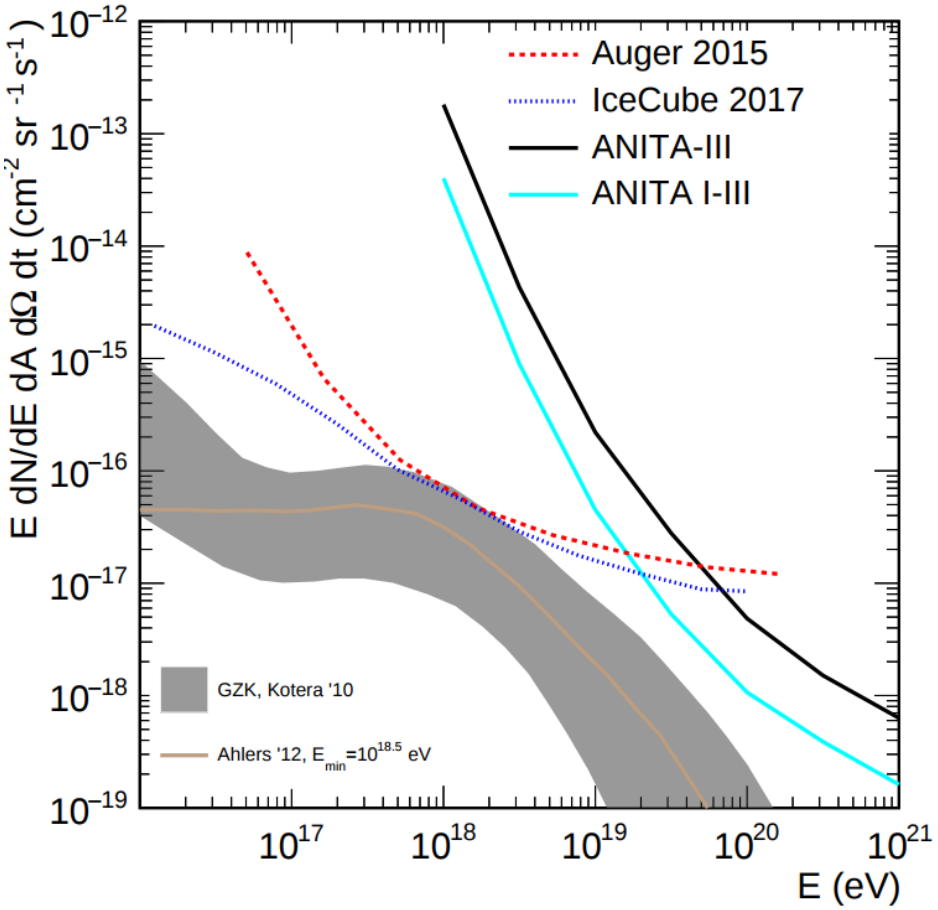
Mostly HPol, matches UHECR template, polarity consistent with direct cosmic ray event

New limits of ANITAs



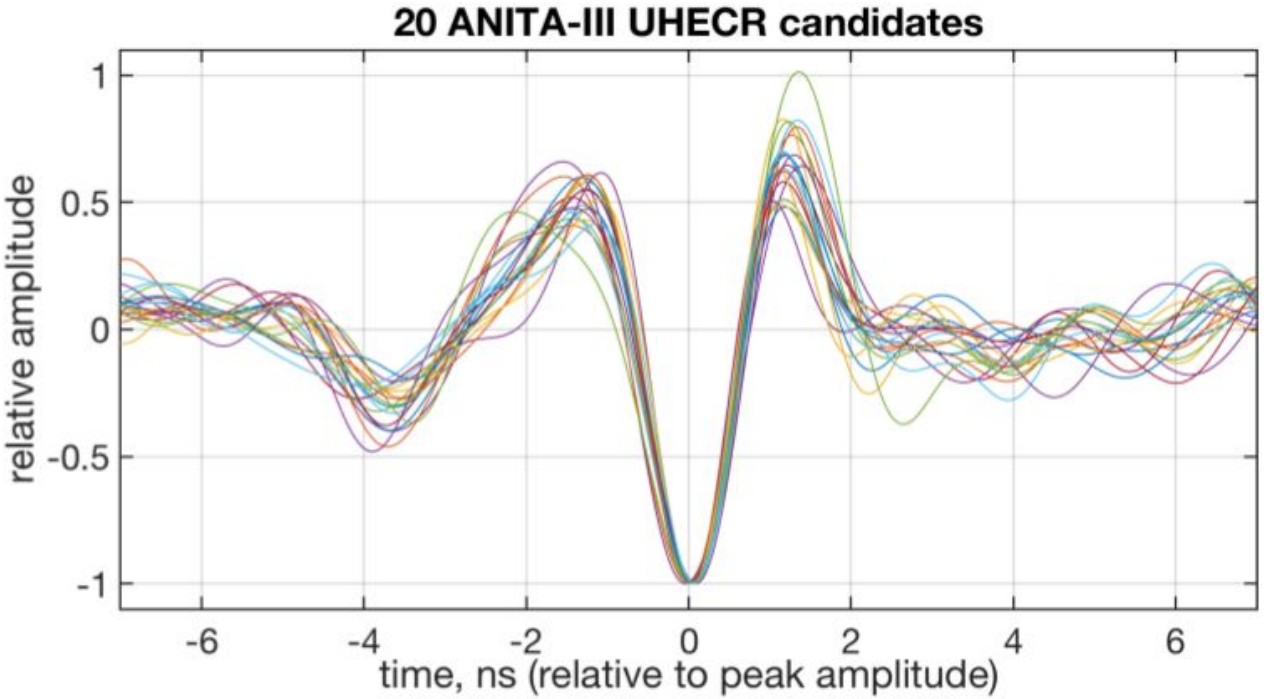
Conclusion

- **ANITA I-III combined set the best limits on UHE ν flux above $10^{19.5}$ eV.**



Conclusion

- ANITA I-III combined set the best limits on UHE ν flux above $10^{19.5}$ eV.
- **Many EAS's from CR's detected in ANITA-III.** One of the ANITA-III EAS's is anomalous in the same way as an event from ANITA-I.



Conclusion

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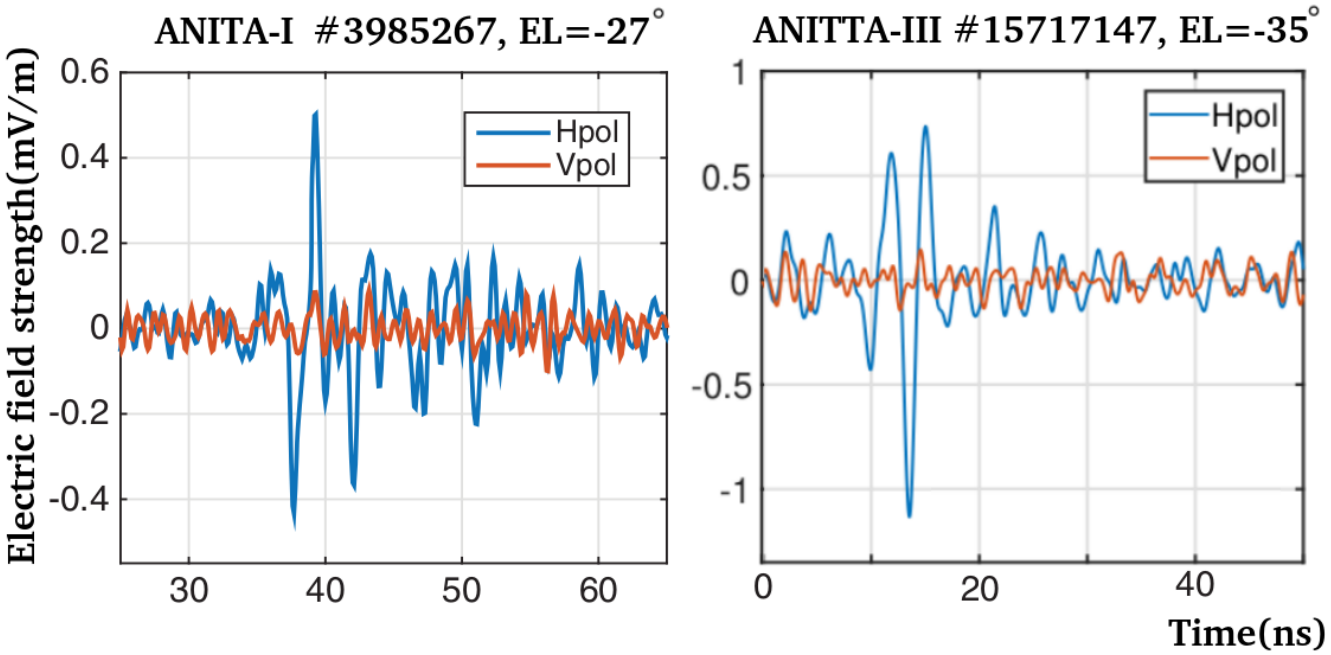

Conclusion

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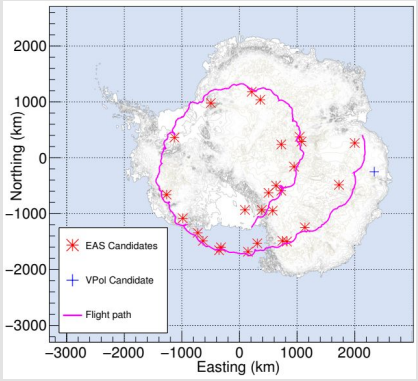
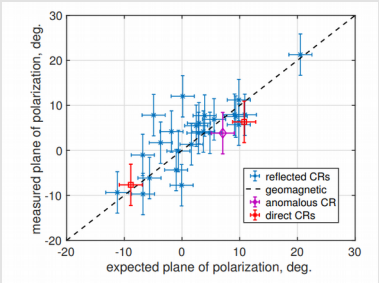
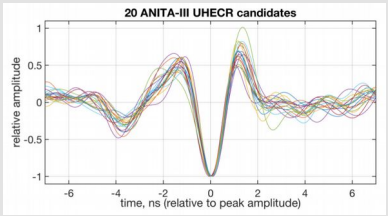
- Many EAS's from CR's detected in ANITA-III. One of the ANITA-III EAS's is anomalous in the same way as an event from ANITA-I.
- **Stay tuned for ANITA-IV, which should have bettersensitivity and hopefully shed some light on previous results.**
- **The proposed ANITA-V will have substantial hardware improvements.**



The EAS candidates(from three independent blind analysis) and the candidate neutrino event. Only EAS candidates with a good EAS template-correlation match and consistent polarization with the local geomagnetic field are shown on the map.



Geomagnetic correlation of 20 UHECR events detected in ANITA-III, with event planes-of-polarization determined via Stokes parameters for each event. The two above-horizon non-inverted CRs are shown in red, and the anomalous non-inverted, below-horizon CR-like event 15717147 is shown in magenta



Horizontally-polarized waveforms of 20 UHECR events detected in ANITA-III, with the polarity and amplitude all normalized to the peak.