Results from ANITA

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on behalf of the ANITA Collaboration

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CIPANP 2018
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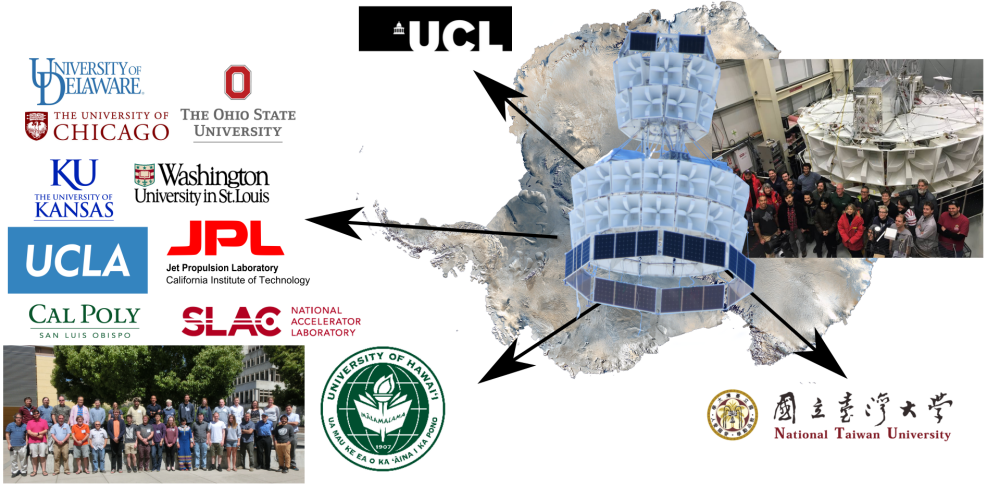
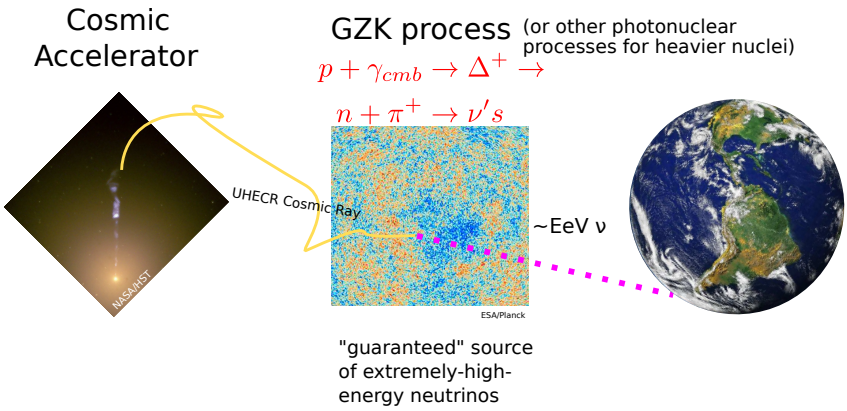
ANITA Collaboration

ANtarctic Impulsive Transient Antenna

12 institutes, 3 countries, 4 continents



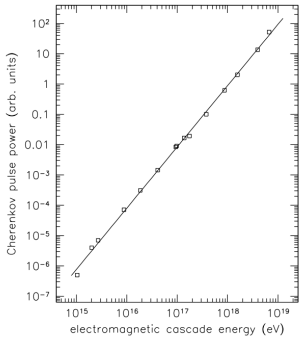
Science Motivation: Ultra-High-Energy ν's ($> EeV$)

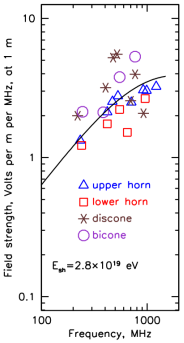


Both astrophysics (understand sources, composition) and high-energy physics (measure EeV cross-section) motivations. Expected flux is very low, so need big detector.

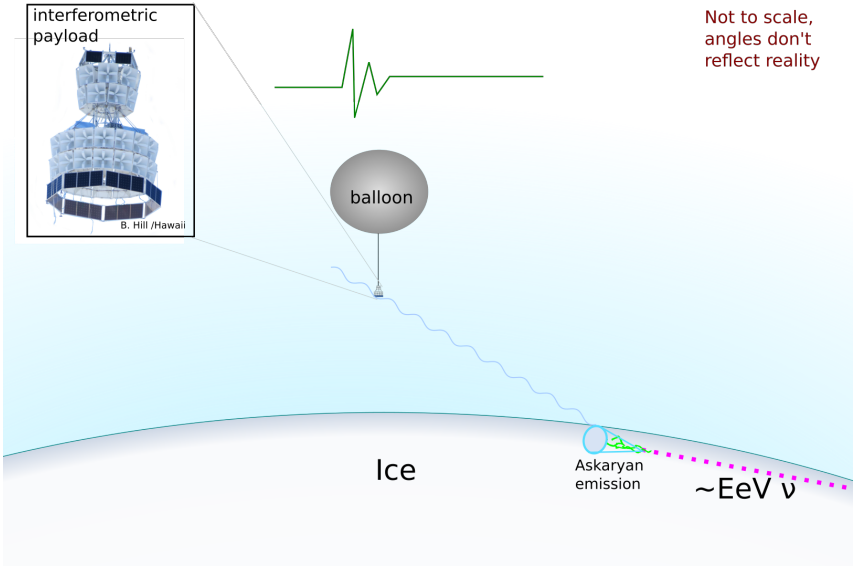
Detection Mechanism: Radio Emission from Askaryan Effect in Ice

- **Askaryan (charge-excess) radiation**: Fast-moving charge density in dielectric $\rightarrow$ coherent emission ($\propto E^2$) at long (radio) wavelengths
  - Charge excess from annihilation of positrons with electrons in material
  - At wavelengths larger than lateral width, don't resolve individual charges
- Confirmed in ice with SLAC beam test (Phys.Rev.Lett.99:171101,2007)
- Radio attenuation length in ice is $\sim$ 1 km





ANITA Experiment Concept



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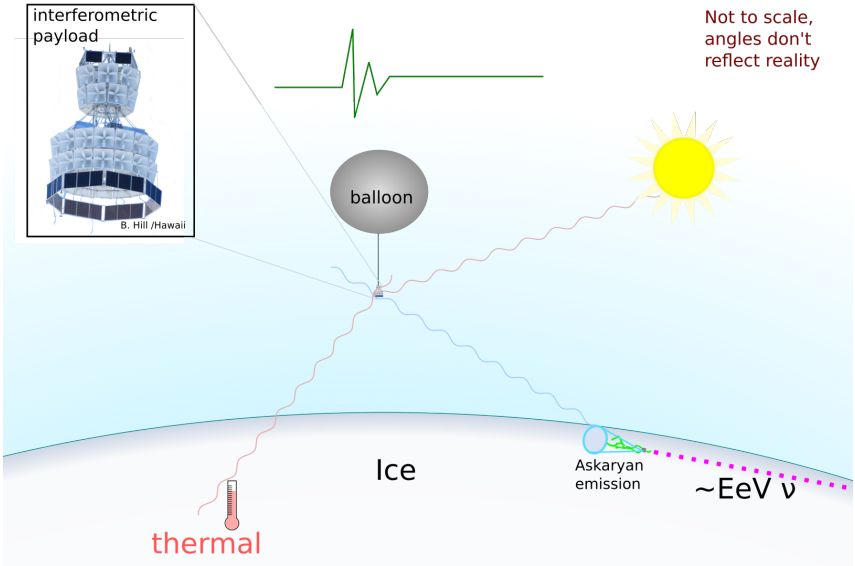

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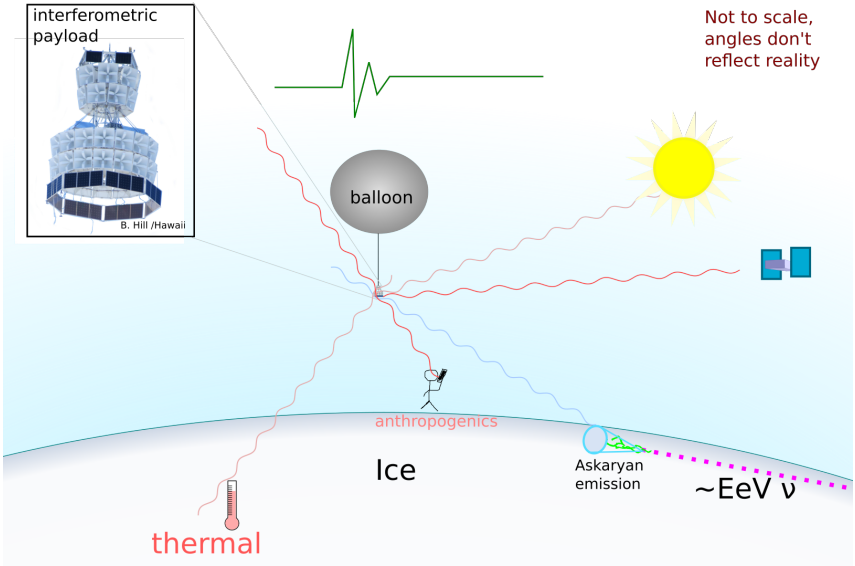
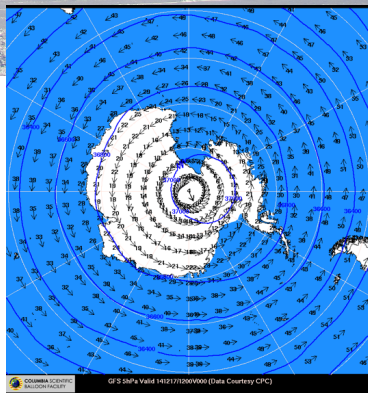


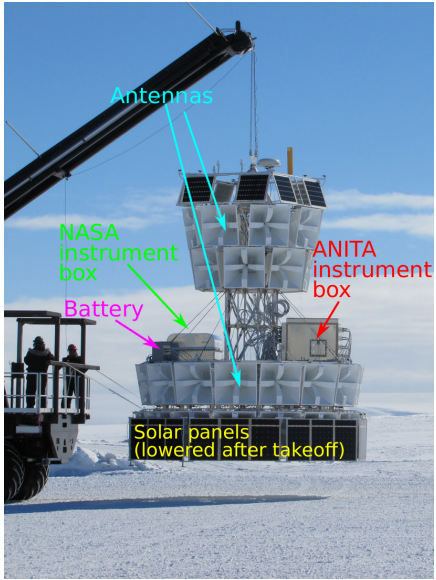
Antarctica: Land of Ice and Long-Duration Ballooning

- Go to Antarctica not just for ice but also for favorable wind patterns, perpetual sun, few people.
- At float (35-40 km), balloon grows to size of a football stadium, $\mathcal{O}(10^6\ \mathrm{km}^2)$ of ice visible.
- Severe weight and power limitations – 600W, 4000 lb

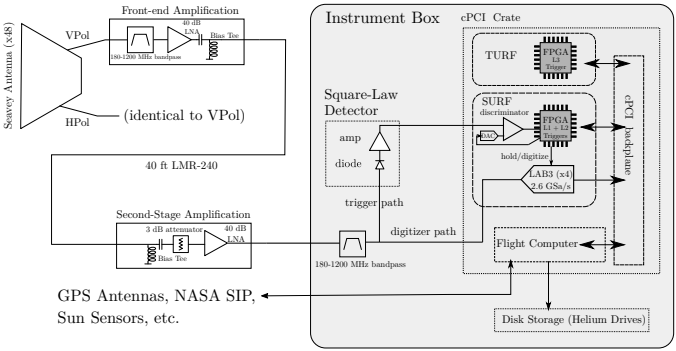


Wind patterns over Antarctica

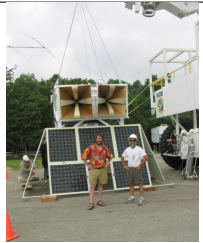
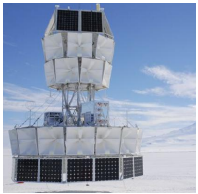
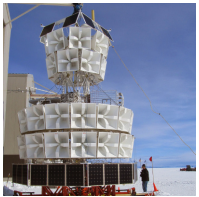
ANITA Instrument



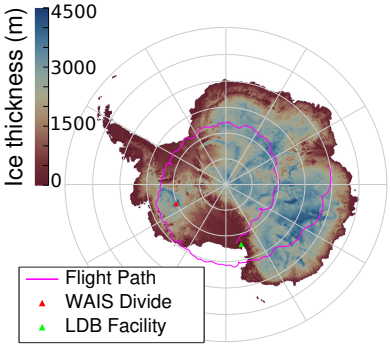
- Signal ($\sim$ 180-1200 MHz) split into digitization and trigger paths
  - Tunnel diode first-level trigger. FPGA takes $\mathcal{O}(10^{5-6}$ Hz) singles rate $\rightarrow \mathcal{O}(50$ Hz) global rate
  - Switched Capacitor Array digitizers, $\sim$2.6 GSa/s, $\mathcal{O}(100$ ns).



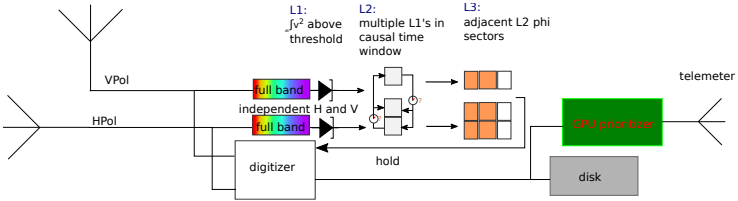
Timeline of Completed ANITA flights

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)



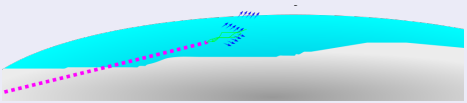
- Independent H + V trigger, with causal timing requirement between antennas
- Increased data rate with GPU prioritizer
- Complications from new military comm satellites → loss of volume, significant improvements to data analysis required.
- Calibration pulses sent from launch site (LDB Facility) and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



ν Signal and Backgrounds (Fake ν's)

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

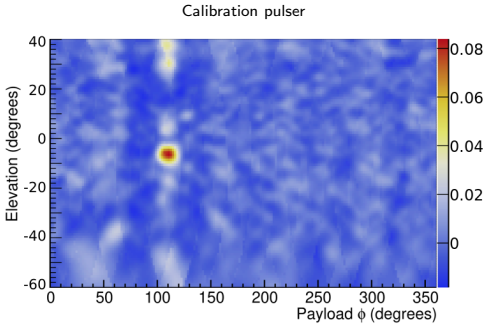
Impulsive Anthropogenic Emission

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

Sketch of analysis

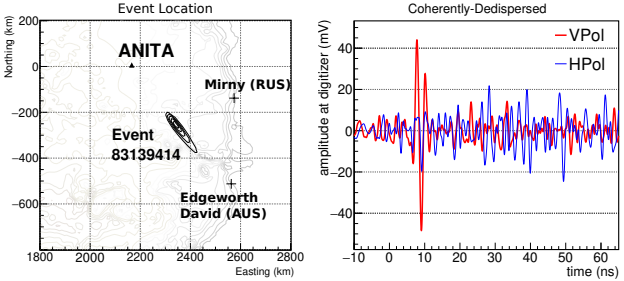
Three independent ν analyses for ANITA-III. Basic flow:

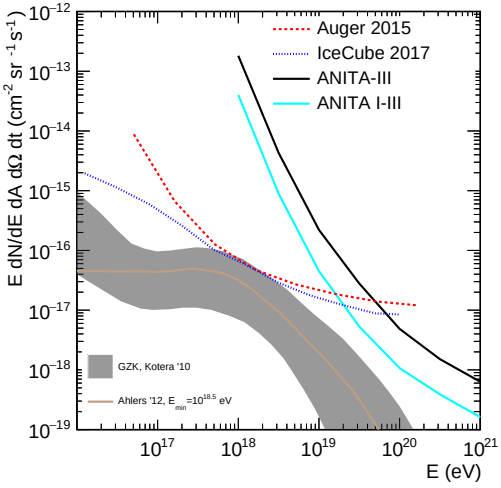
1. Filter waveforms (reduce CW) and remove events failing quality cuts
2. Form correlation map, where we calculate channel cross-correlations with different direction assumptions
3. From peaks of correlation map, form coherent waveforms, generate features (e.g. impulsivity, linear polarization fraction)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



ANITA-III Askaryan ν Results

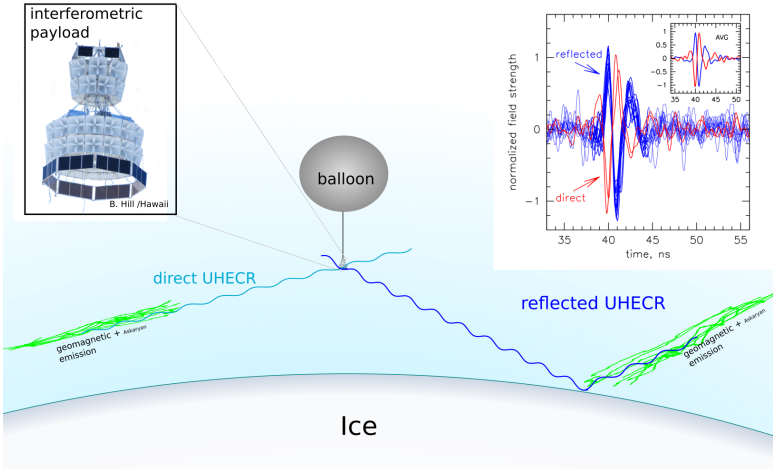
- arXiv:1803.02719 (submitted to PRD)
- Most sensitive search found one candidate on a background of $0.7^{+0.5}_{-0.3}$ events
- Consistent with background, so set limit, but the event looks pretty good (very isolated, very impulsive, thick ice, right polarization)





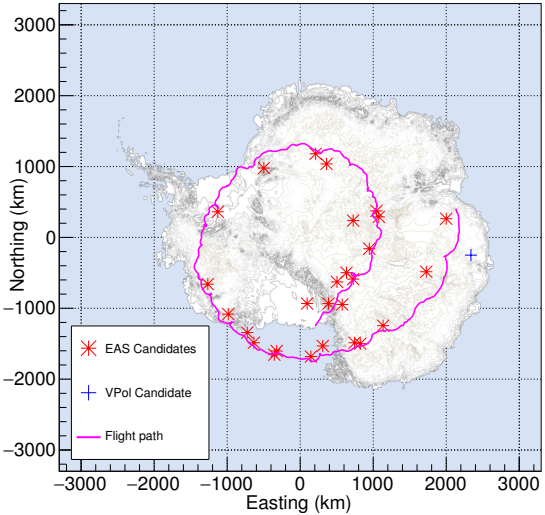
Another Signal: Radio Emission from Extensive Air Showers (EAS)

- 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**



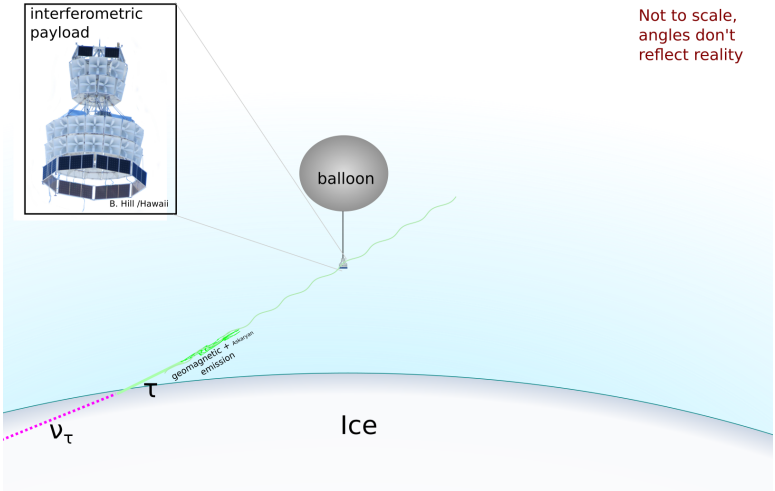
ANITA-III EAS Search

- Polarization from B-field and shower direction. B-field in Antarctica ∼vertical → mostly horizontally-polarized (HPol).
- Can check geomagnetic hypothesis by querying local magnetic field and checking consistency of polarization angle.
- Physics sideband for ν searches, but dedicated search also performed.
- Nearly 30 EAS candidates among all the ANITA-III searches.

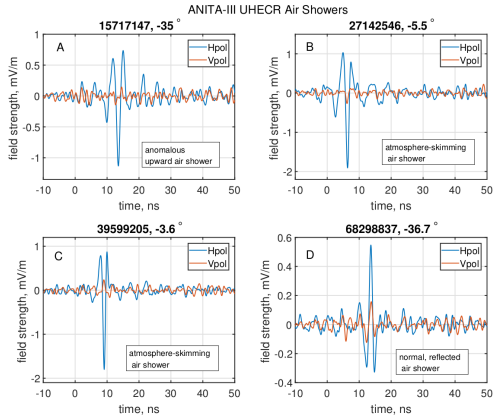


Sensitivity to Upward-Going τ Showers?

- ν_τ creates τ which escapes atmosphere and decays, producing shower
- Would have elevation of a reflected UHECR, but polarity of direct



Anomalous "Mystery" Events

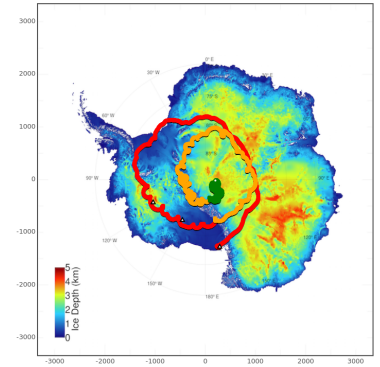


Top-Left: Anomalous A-III event
Top-Right, Bottom-Left: Direct UHECR candidates
Bottom-Right: A reflected UHECR candidate

- 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 .
- No satisfying interpretation yet; now that we have two events much harder to dismiss as a background.

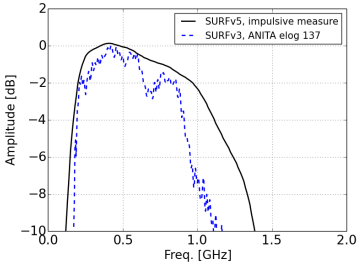
ANITA-IV (2016)

- ∼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.



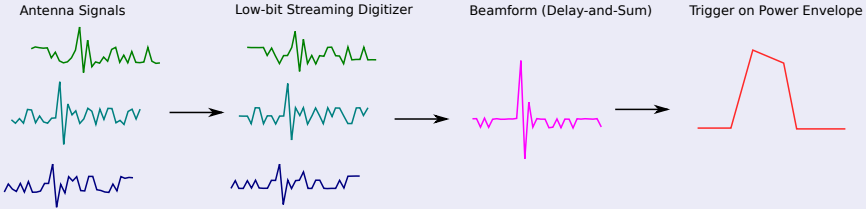
Future: ANITA-V?

- 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

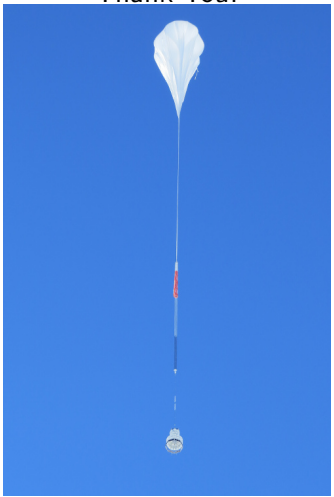
Interferometric Trigger



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.
- Stay tuned for ANITA-IV, which should have better sensitivity and hopefully shed some light on previous results.
- The proposed ANITA-V will have substantial hardware improvements.

Thank You!



Questions?

Backup Slides

(Some) Anomalous Event Explanations

ν_τ-induced EAS

+ Would produce upward-going EAS
- Chord through Earth not compatible with SM cross-section
- Tension with IceCube and Auger results

Funny reflection of UHECR EAS

+ Apparent upward-going EAS shower
- Hard to invert polarity but maintain coherence
- Would likely have seen effect in data from HiCal (trailing balloon with HV pulser)

Anthropogenic Background

+ No physics to explain
- We consider it unlikely

Askaryan Radiation from ν

+ Could produce impulsive emission
+ Not in tension with other results
- Polarization likely would be rare coincidence

Transition Radiation from UHECR EAS

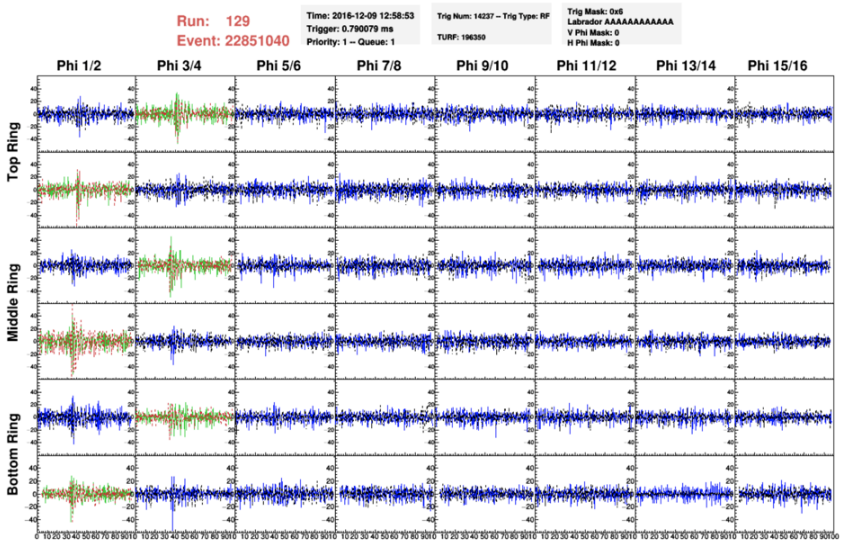
+ Could produce impulsive emission
- Random polarization, likely insufficient power

Some Other Exotic Particles (heavy ν DM, sterile ν)

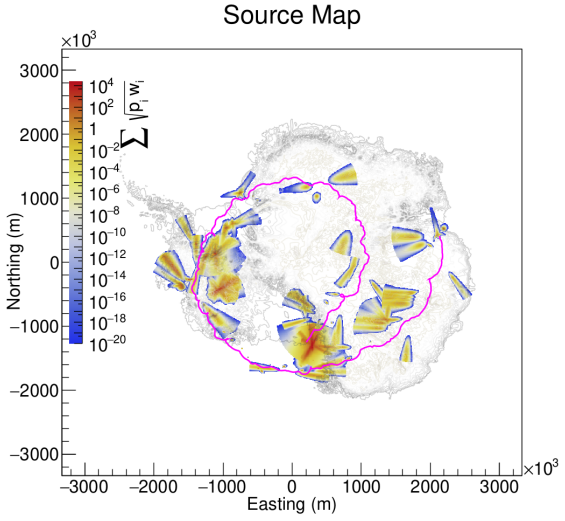
+ Could produce upward-going EAS
- New physics
- Tension with IceCube and Auger

The Raw Data (a Calibration Pulse, Not a ν)

- 48 dual-polarization horn antennas
- Sampled at $\approx$ 2.6 GHz's
- 100 ns per event
- 50 Hz global trigger rate
- $\mathcal{O}(10^7)$ RF triggers per flight (ANITA-III and IV)

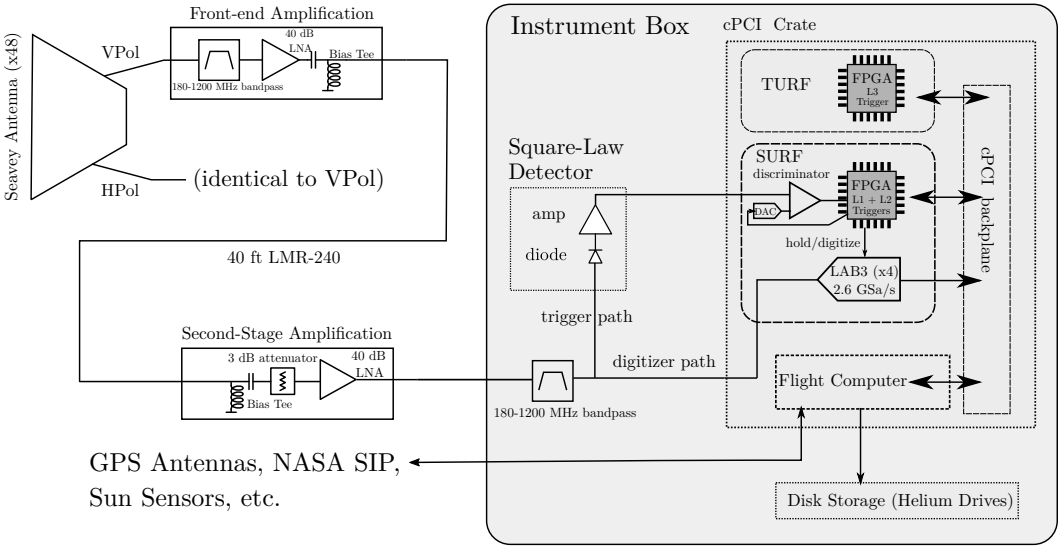


Using Spatial Information to Remove Anthropogenics

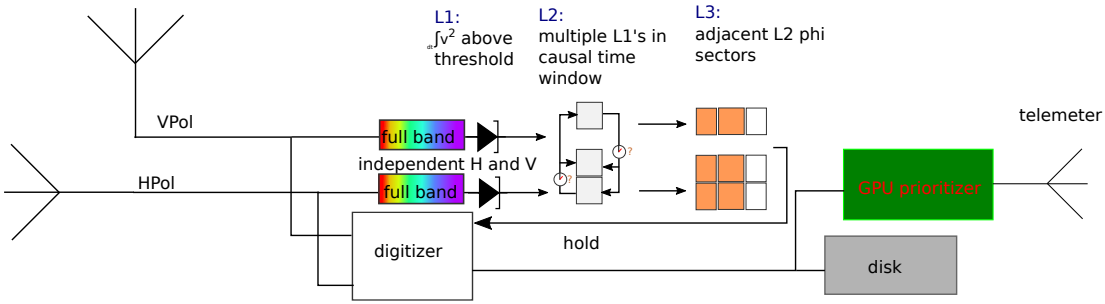


- We assume anthropogenic emission is spatially clustered on the continent, so we only consider isolated events as candidates.
- For each signal-like event, we measure a direction with some pointing resolution.
- One example clustering algorithm:
  - Project all interesting events to continent and accumulate to form a "clustering map." Use to compute overlap integral of each event with all other events.
  - Isolated events will have overlap integrals close to zero
- Other methods to tackle anthropogenics include pairwise event clustering or a binned continent analysis.

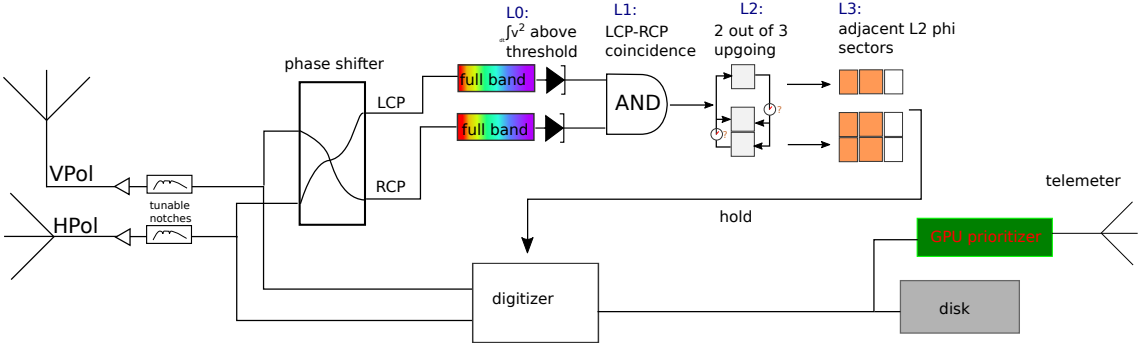
ANITA-III Block Diagram



ANITA-III Trigger



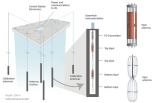
ANITA-IV Trigger



Askaryan Experiments

In-Ice Antennas

e.g. ARA, ARIANNA,RICE



Balloon

e.g. ANITA

Lunar Regolith

e.g. GLUE,NuMoon

volume

10^2 km^3 | 10^6 km^3 | 10^6 km^3

threshold

10 PeV | 100 PeV | 1 EeV | 100 ZeV