

# Anomalous Cosmic-ray Events from Below the Horizon In ANITA Data

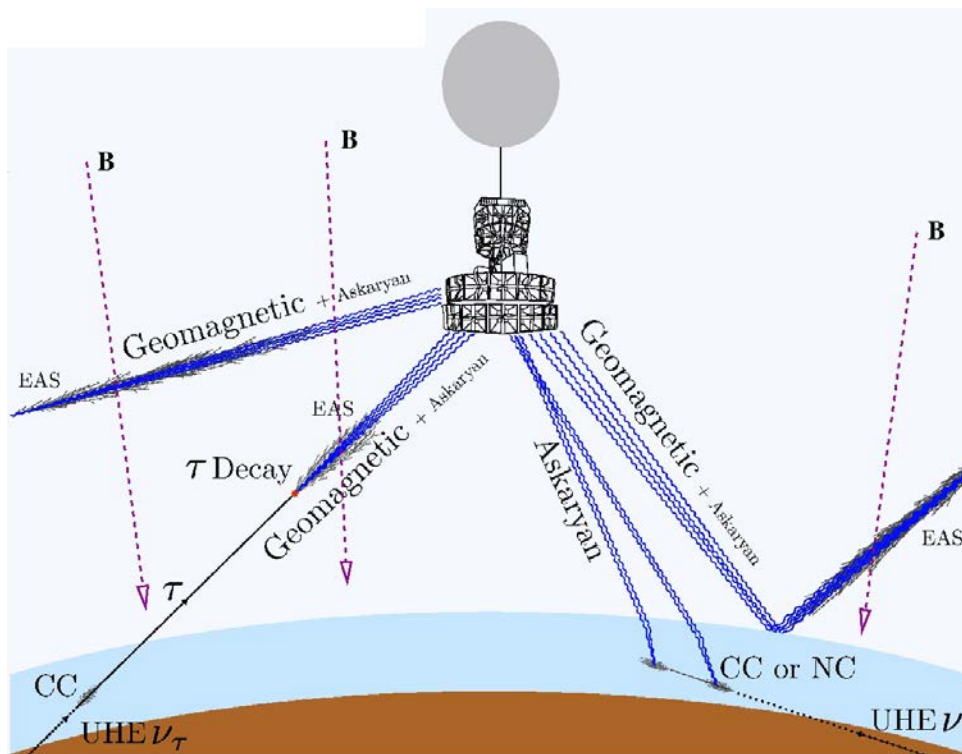
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The Ohio State University

Paris-Saclay AstroParticle Symposium

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# ANITA Concept



In-Ice Neutrino Askaryan

Reflected Atmospheric EAS

Direct Atmospheric EAS

Emerging Atmospheric EAS ( $\tau$ ?)

Key Observables:

Direction/Location

Impulsivity

Pulse Shape/Spectral Content

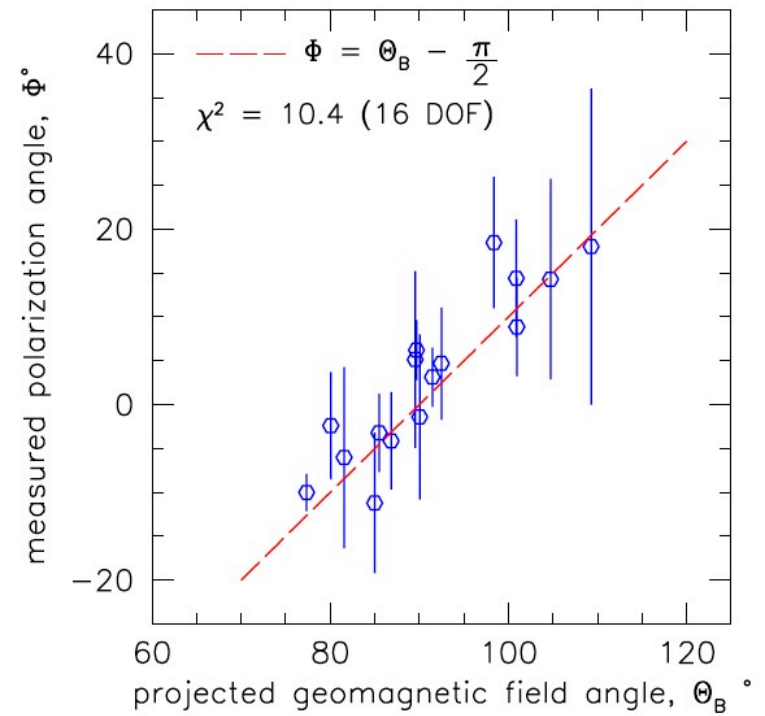
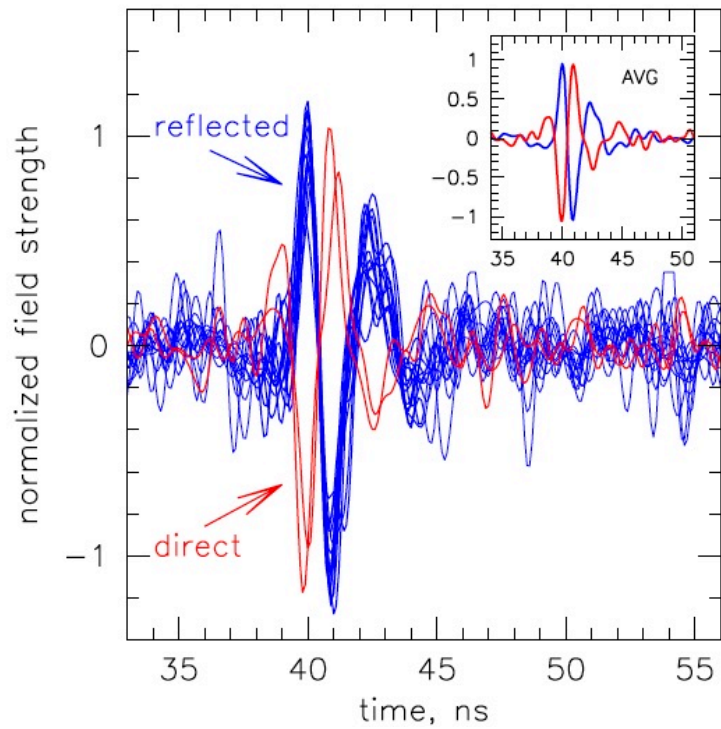
Polarization

Polarity

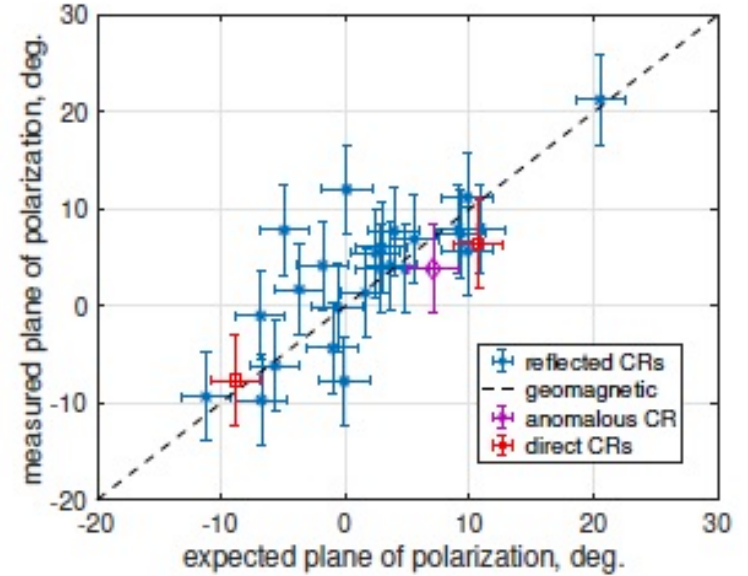
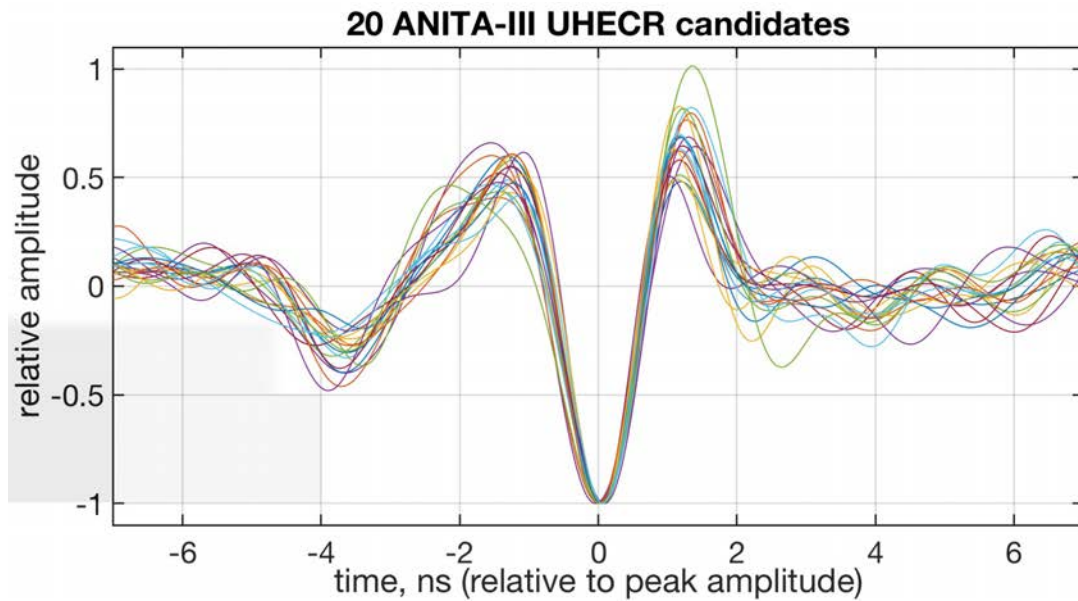
# ANITA Flight Summary

Flight	Dates	Duration (Livetime)	Trigger
ANITA-I	Dec. 14, 2006-Jan. 19, 2007	35 days (17.25 days)	LCP-RCP multiband trigger
ANITA-II	Dec. 21, 2008-Jan 20, 2009	31 days (28.5 days)	Vpol only single-band trigger
MUOS satellites began operation in 2012			
ANITA-III	Dec. 18, 2014-Jan. 8, 2015	22 days (7.5 days)	Vpol and Hpol single-band triggers
ANITA-IV	Dec. 2, 2016-Dec. 29, 2019	28 days (24.25 days)	LCP-RCP single-band trigger, notch filters

# ANITA-I Cosmic Rays

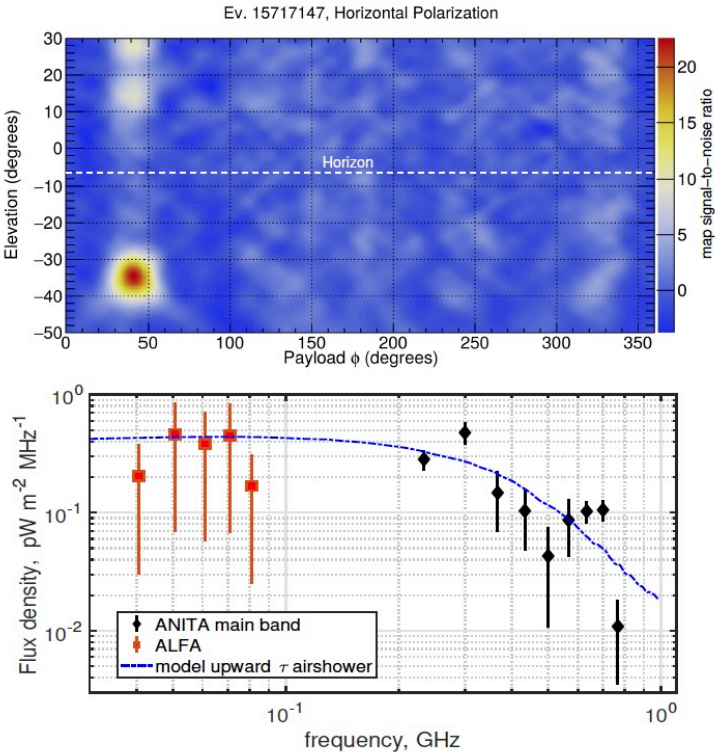
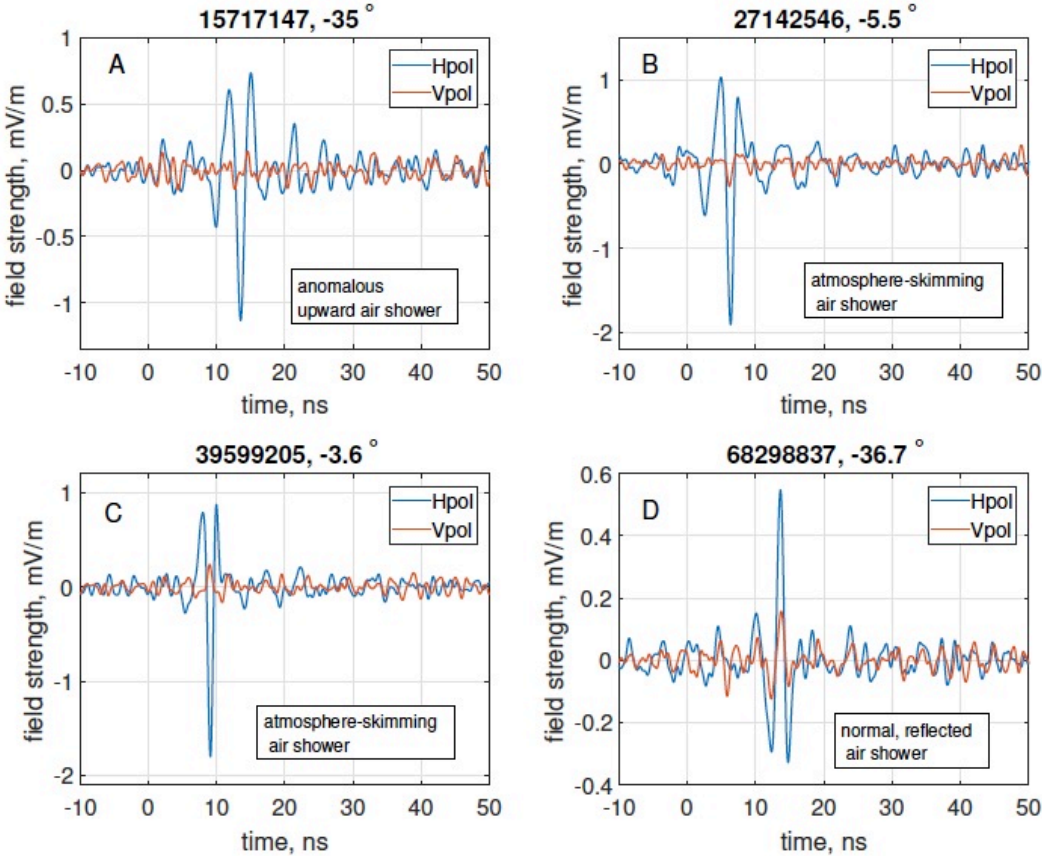


# ANITA-III UHECR Candidates



# ANITA-III Anomalous Event

ANITA-III UHECR Air Showers



# The ANITA-IV Instrument

48 Dual-polarization Quad-ridged Horn Antennas in 3 rings (top ring staggered).

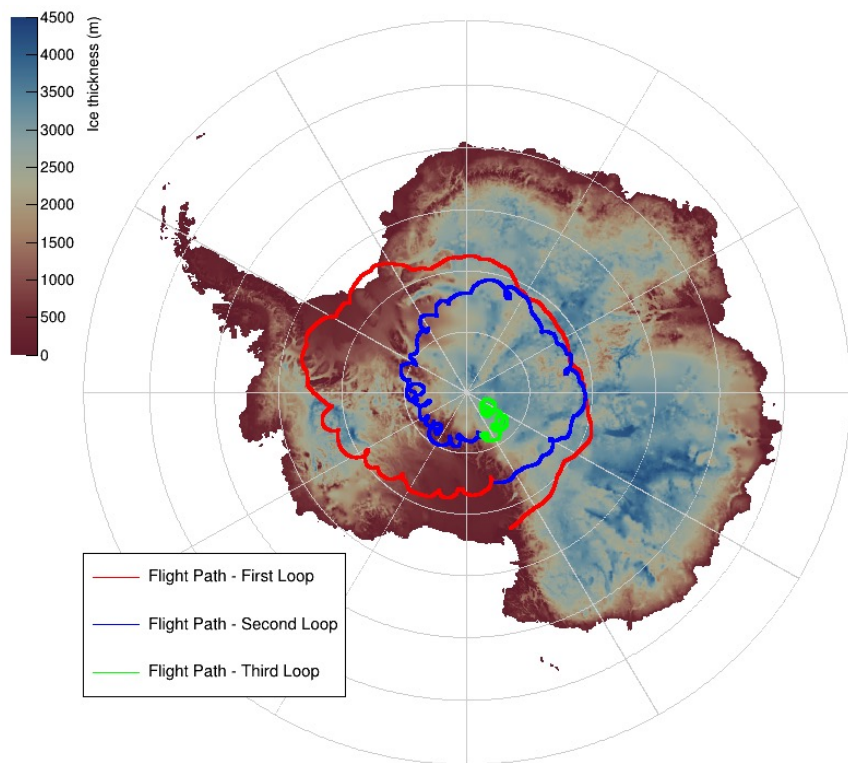
2.6 GSa/s sampling the 200 MHz-1200 MHz band.

Triggering using  $90^\circ$  Hybrids to form LCP-RCP waveforms. LCP-RCP coincidence requirement triggers on linearly polarized waveforms regardless of polarization angle while suppressing circularly polarized anthropogenic interference.

Tunable notch filters to suppress continuous wave backgrounds from military satellites and Antarctic bases.



# ANITA-IV Flight

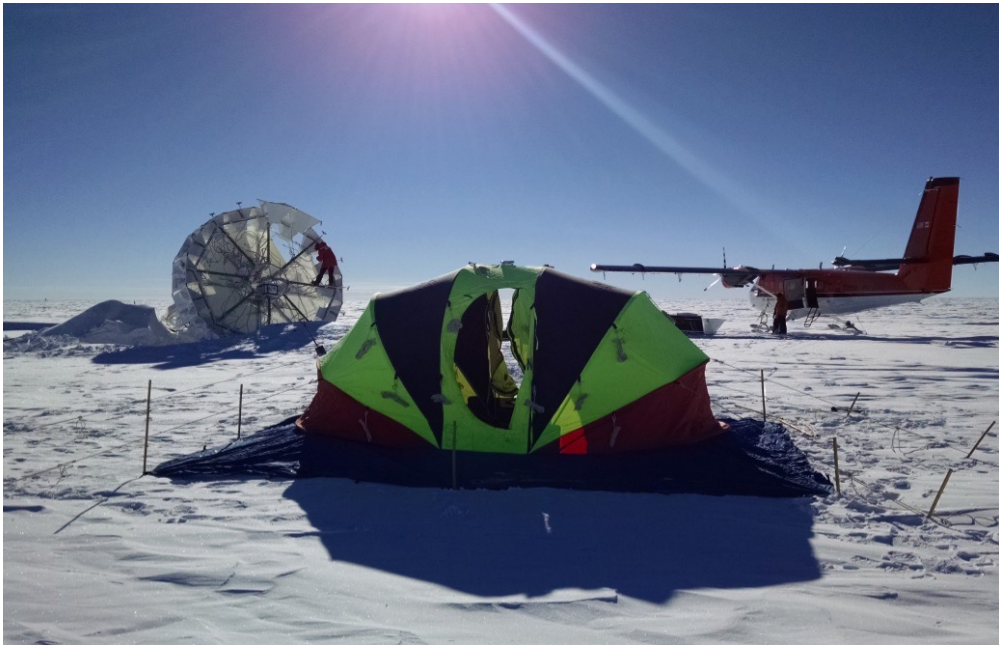


December 6, 2016—December 29, 2016 (28 days)

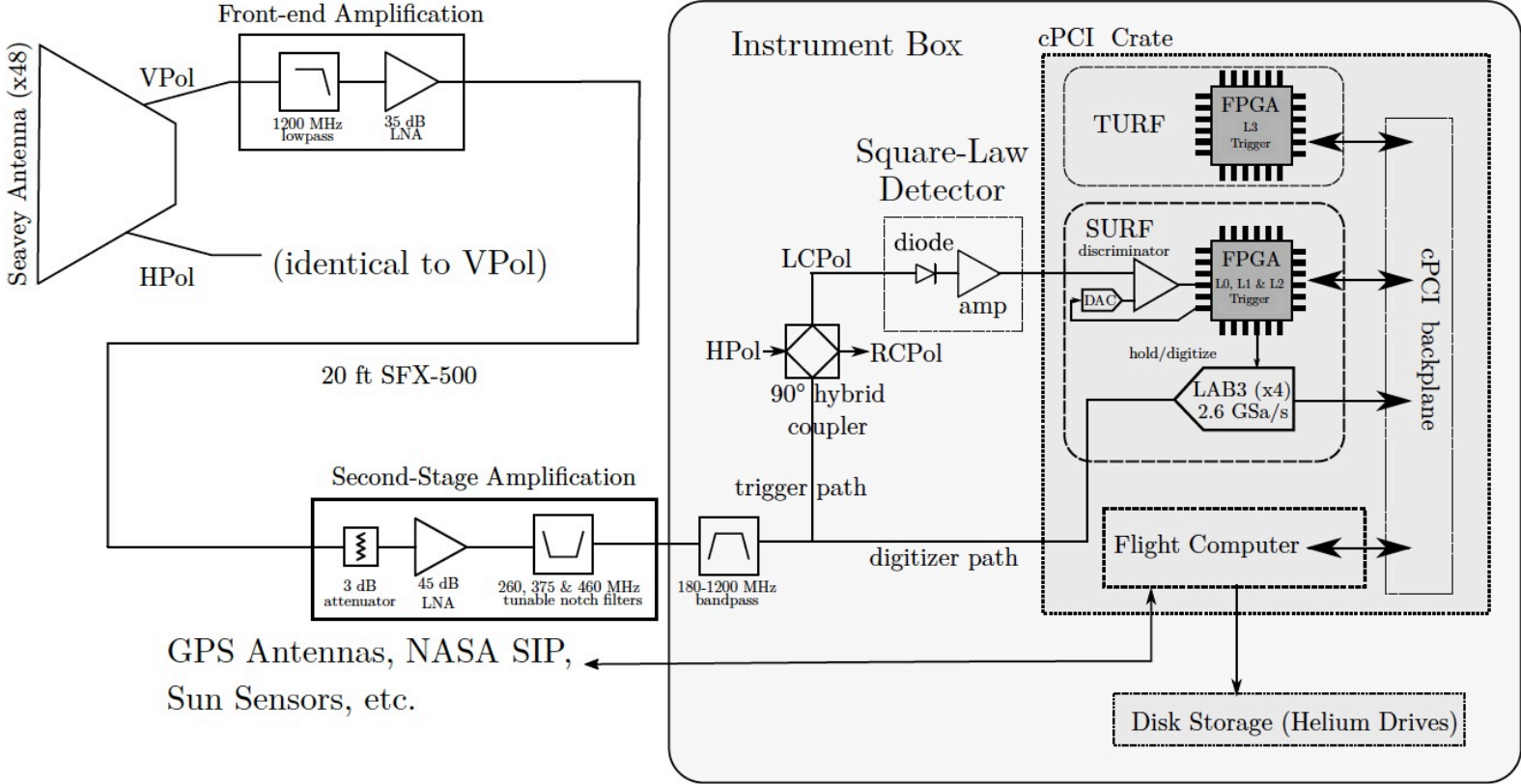




# ANITA-IV Recovery

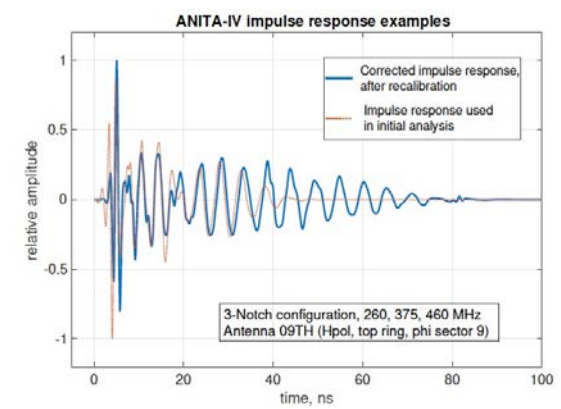
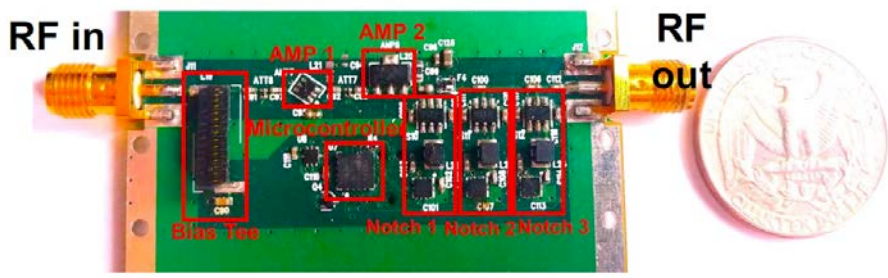
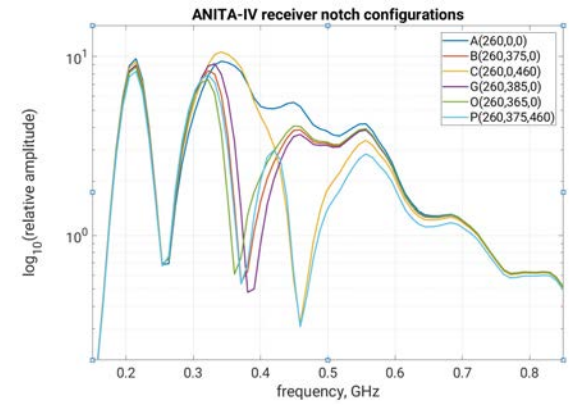
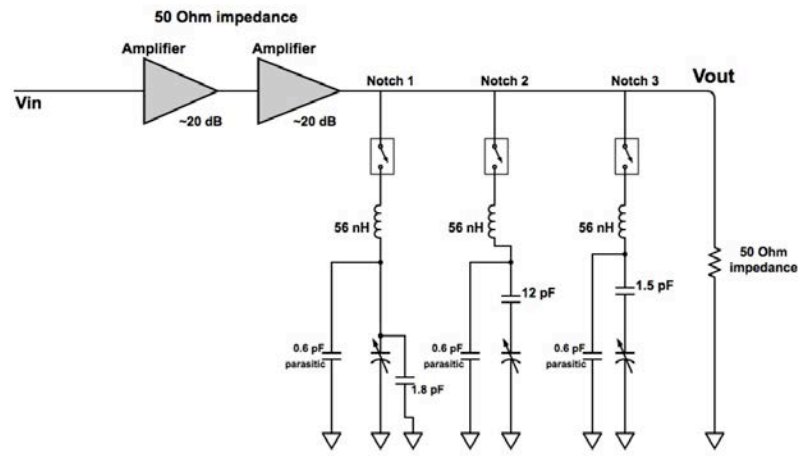


# ANITA-IV System Diagram

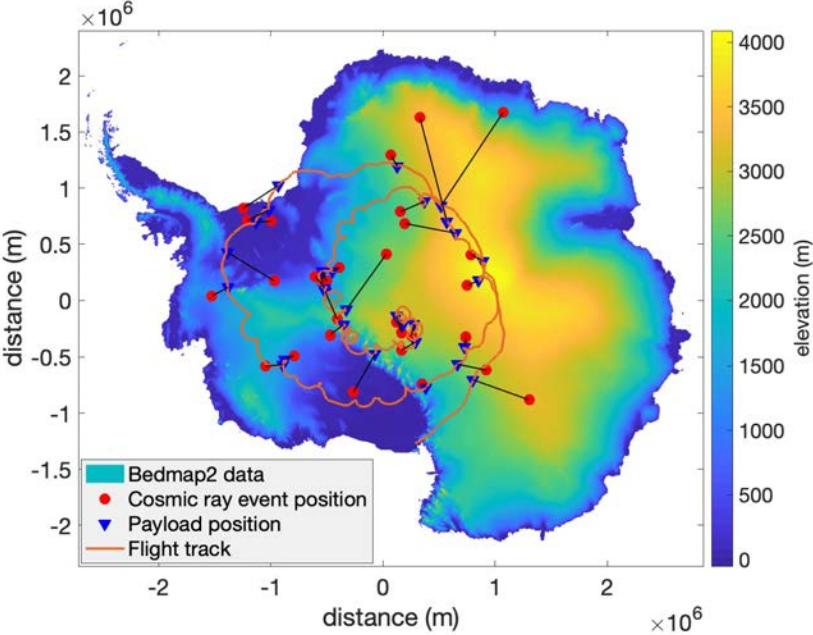


# ANITA-IV Tunable Filters (TUFFs)

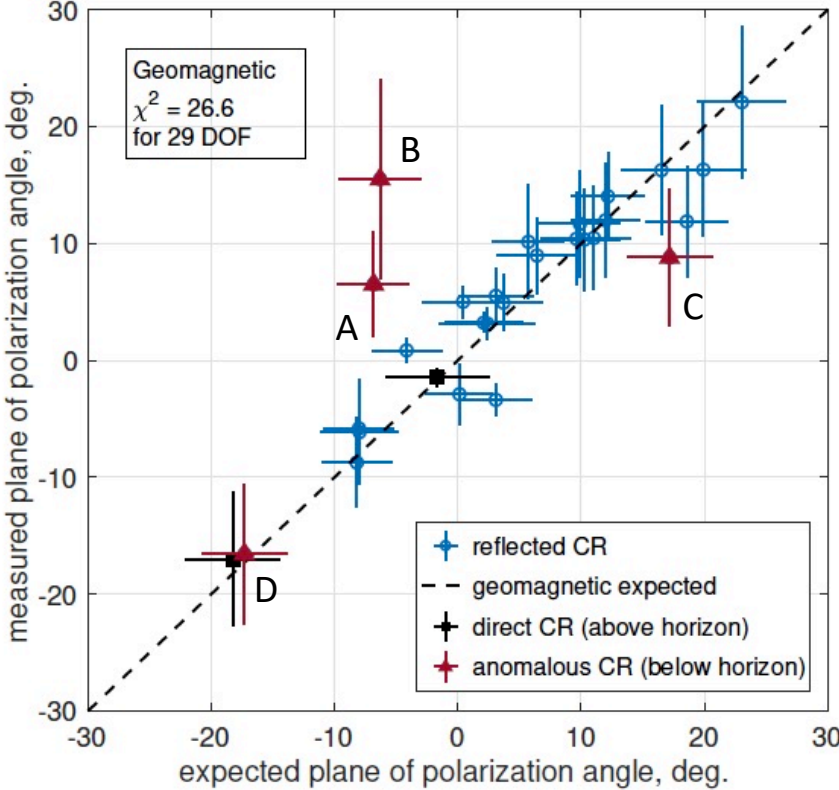
Notch 1: 260 MHz (military sats)  
 Notch 2: 360-390 MHz (MUOS sats)  
 Notch 3: 450 MHz (bases)



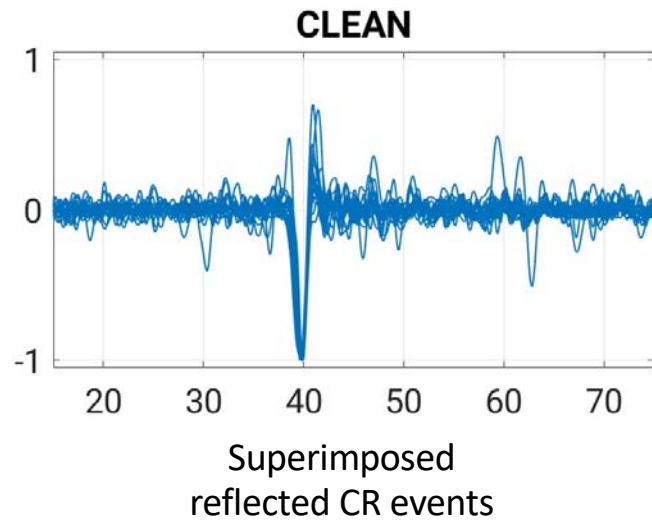
# ANITA-IV Cosmic Rays



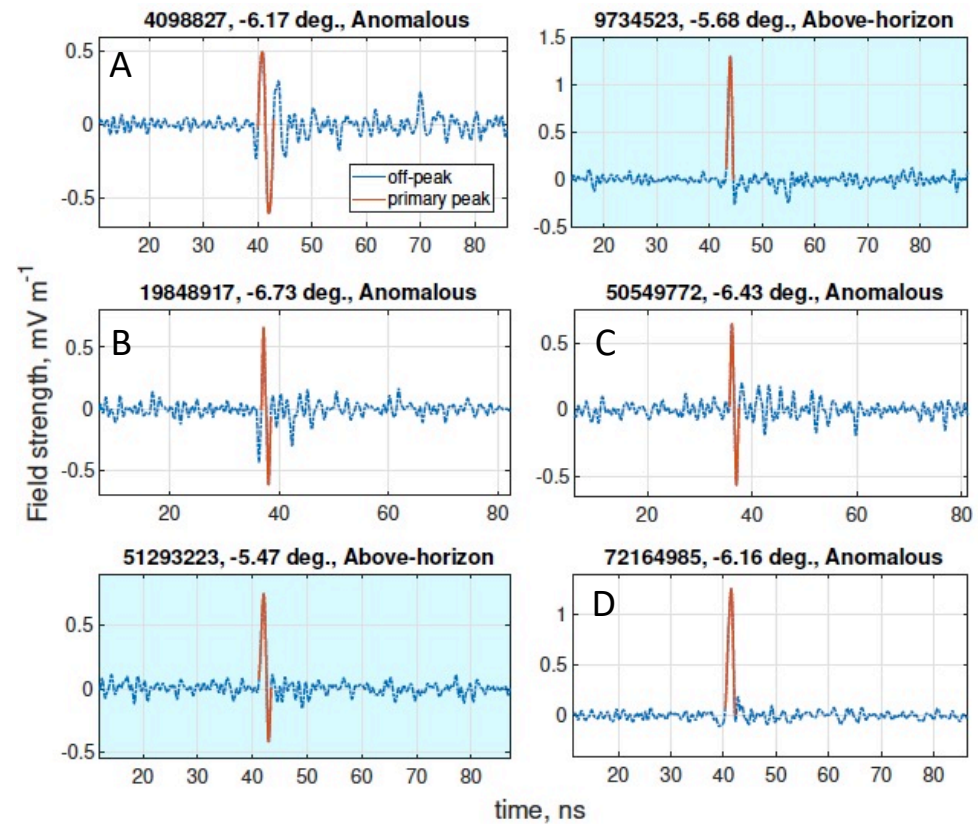
C



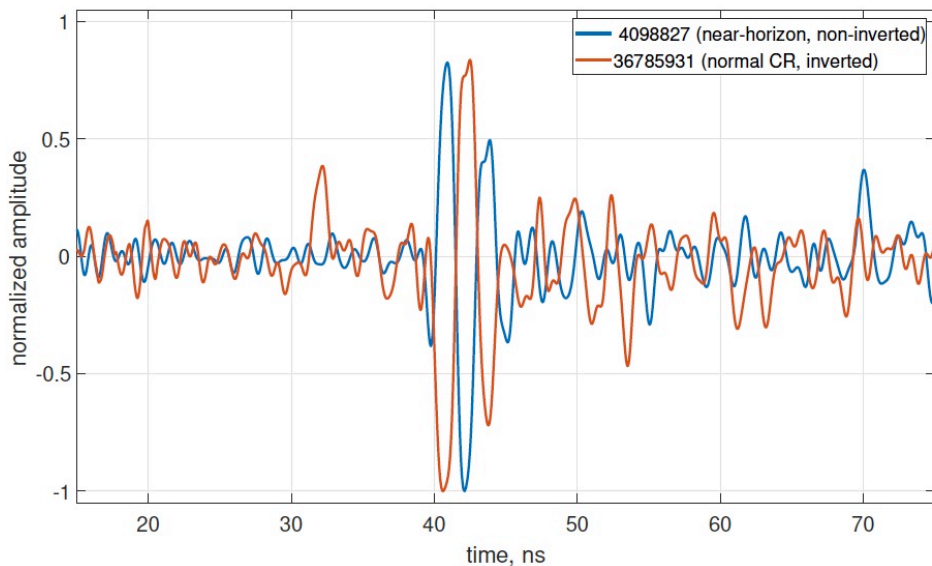
# ANITA-IV Non-inverted CR-like Events



## Near-Horizon Events



# Comparison of Three-Notch ANITA-IV Events



CLEAN deconvolution

Event A (4098827) was recorded with all three notch filters enabled.

A reflected cosmic ray event (36785931) recorded under the same conditions is anti-correlated with this event, confirming the polarity of event A.

# Possible Explanations of Observed Polarity

Surface/subsurface structures

Concave ice surface ellipsoids

Coherent backscattering

Stopping radiation

Emerging  $\tau$ -induced showers

Direct showers with very late interactions

Hpol component of in-ice

Askaryan emission

# PUEO Pioneer



PUEO is a successor experiment to ANITA under NASA's new Pioneer program for intermediate-scale missions. Flight planned in late 2024.

PUEO will employ a digital interferometric trigger using RFSoc technology.

PUEO also has a frequency cutoff at 300 MHz rather than 180 MHz, which allows us to use smaller antennas in increased number for larger effective area.

A low frequency instrument employing an array of sinuous antennas will improve cosmic ray and tau shower sensitivity.