

Results from the Third Flight of ANITA

Abby Viereggs for the ANITA Collaboration

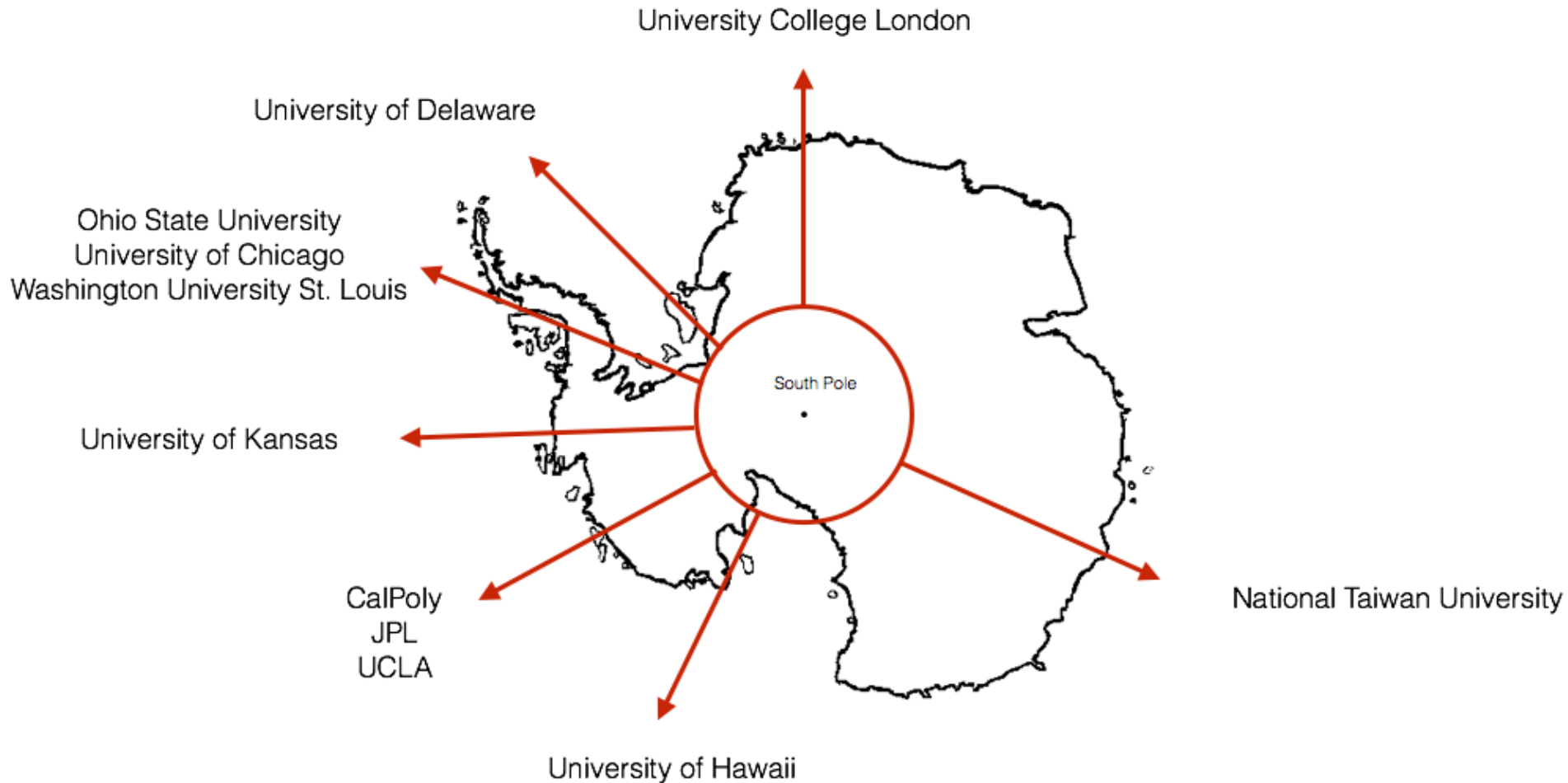
University of Chicago

ARENA, 2018

13 June 2018



ANITA Collaboration



11 institutions, ~50 collaborators spanning 18 time zones

ANITA-3 Deployment Team



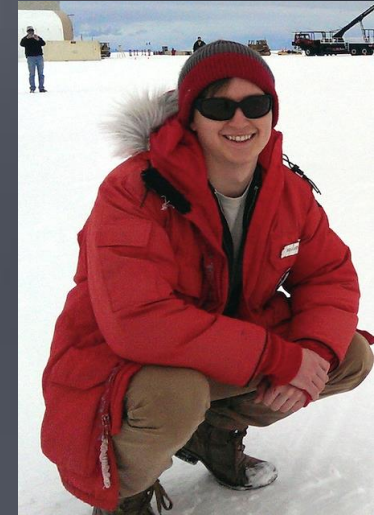
ANITA-3 Analyzers: Postdocs and Grad Students



Linda Cremonesi, UCL



Cosmin Deaconu, Chicago



Ben Strutt, UCL/UCLA



Oindree Banerjee, OSU



Jacob Gordon, OSU



Ben Rotter, Hawaii



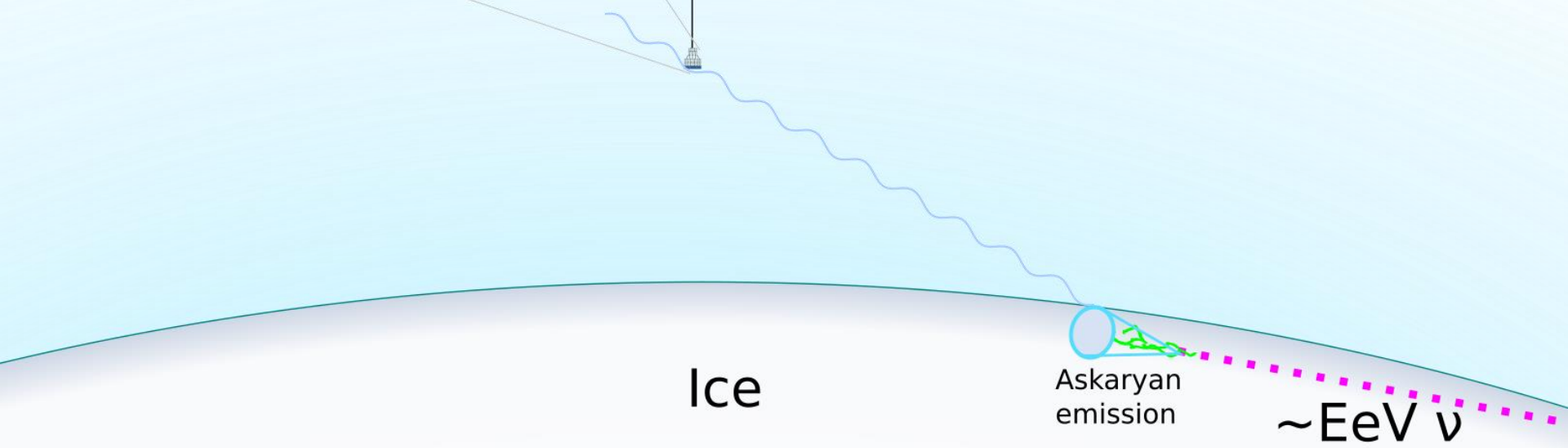
Sam Stafford, OSU⁴

1) Neutrino-Induced Askaryan Emission in Ice



Not to scale,
angles don't
reflect reality

- Signals are vertically polarized

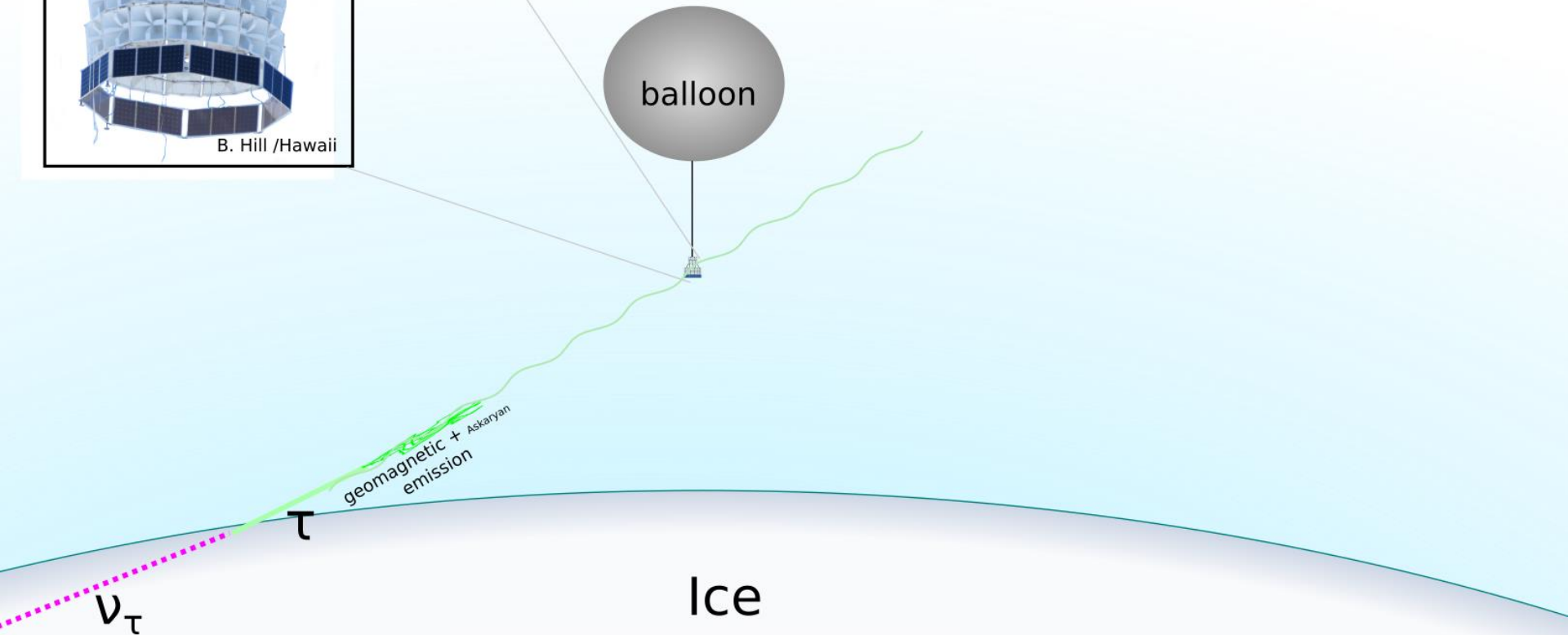


2) Radio Emission from Tau-Neutrino-Induced EAS



Not to scale,
angles don't
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- Signals are horizontally polarized
- Comes from below the horizon

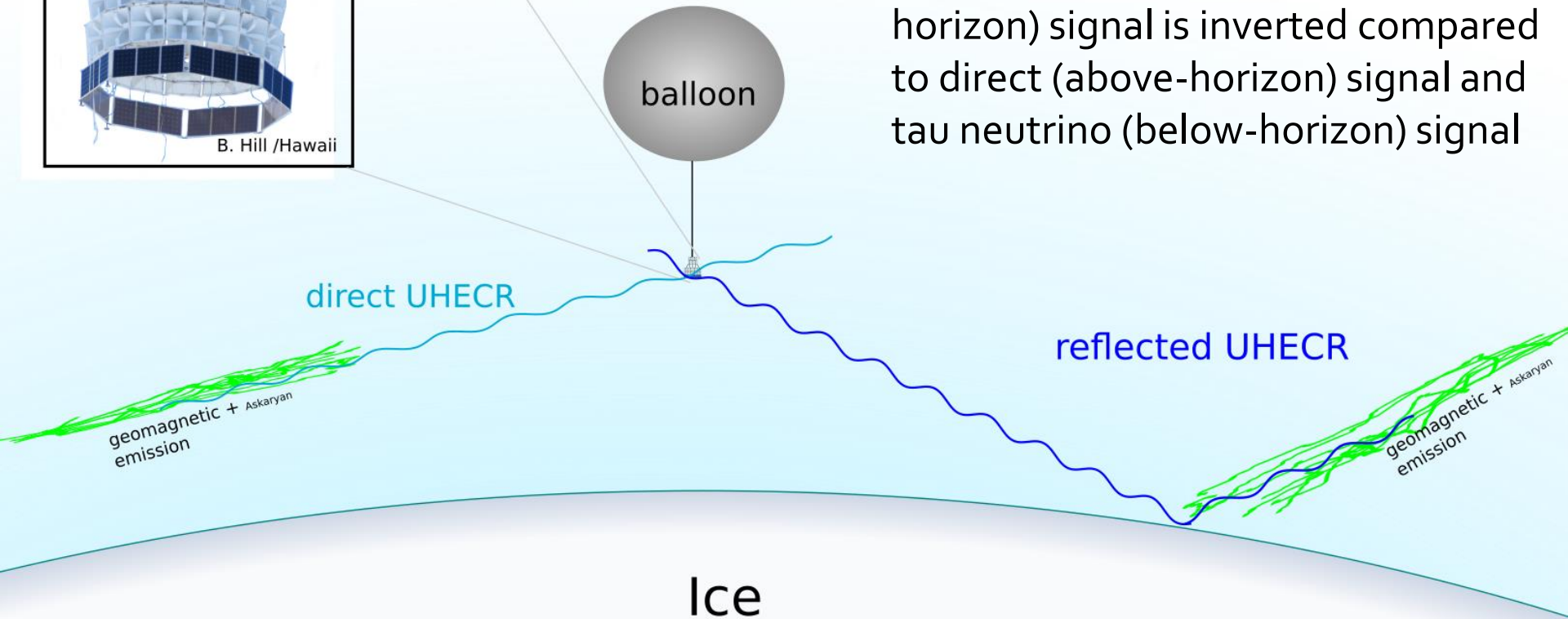


3) Radio Emission from Cosmic-Ray-Induced EAS



Not to scale,
angles don't
reflect reality

- Signals are horizontally polarized
- Polarity of reflected (below-horizon) signal is inverted compared to direct (above-horizon) signal and tau neutrino (below-horizon) signal



The ANITA Instrument

Telemetry (TDRSS and Iridium Antennas)

GPS Antennas

Instrument Box

NASA Instrument Box

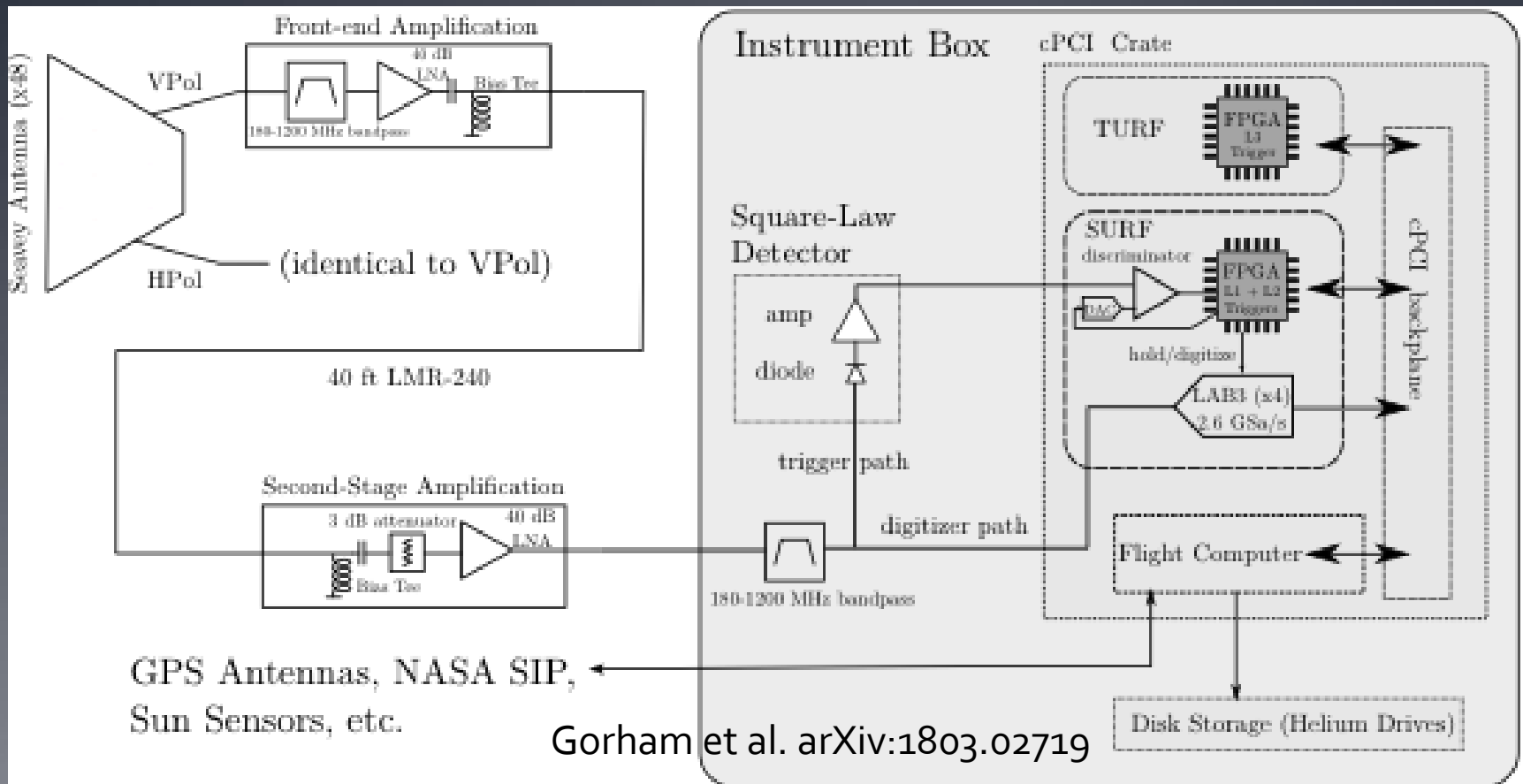
48 Quad-ridged
Horn Antennas (200-
1200 MHz)

Solar Panels







ANITA System Diagram

- 200-1200 MHz, 2.6 GSa/sec digitizers
- 50 Hz global trigger rate (coincidence between threshold-crossing triggers in adjacent antennas)

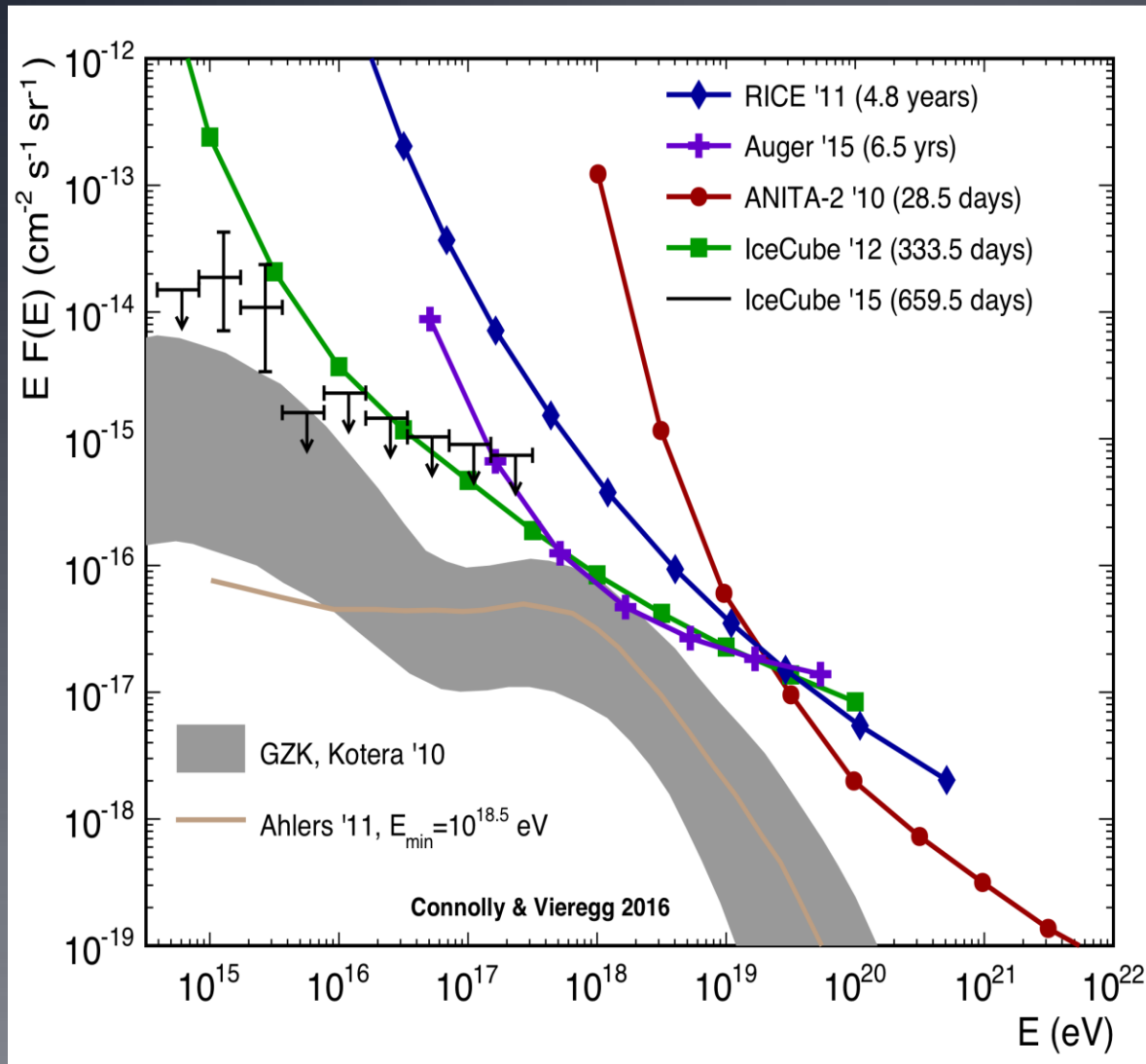


ANITA Timeline

ANITA-I	ANITA-II	ANITA-III	ANITA-IV	ANITA-V?
				
2006-2007	2008-2009	2014-2015	2016	?
35 days, 32 antennas	30 days, 40 antennas	22 days, 48 antennas	29 days, 48 antennas	???
Multi-band, Pol-independent trigger	Multi-band, VPol trigger	Full-band HPol + VPol trigger	Full-band, Lin-Pol trigger	Interferometric Trigger ?
Diffuse neutrino limit published, EASs detected and published	Diffuse neutrino limit published	Recent Results on the arXiv in March 2018	Analysis Ongoing	Proposed

Previous ANITA Diffuse Neutrino Results

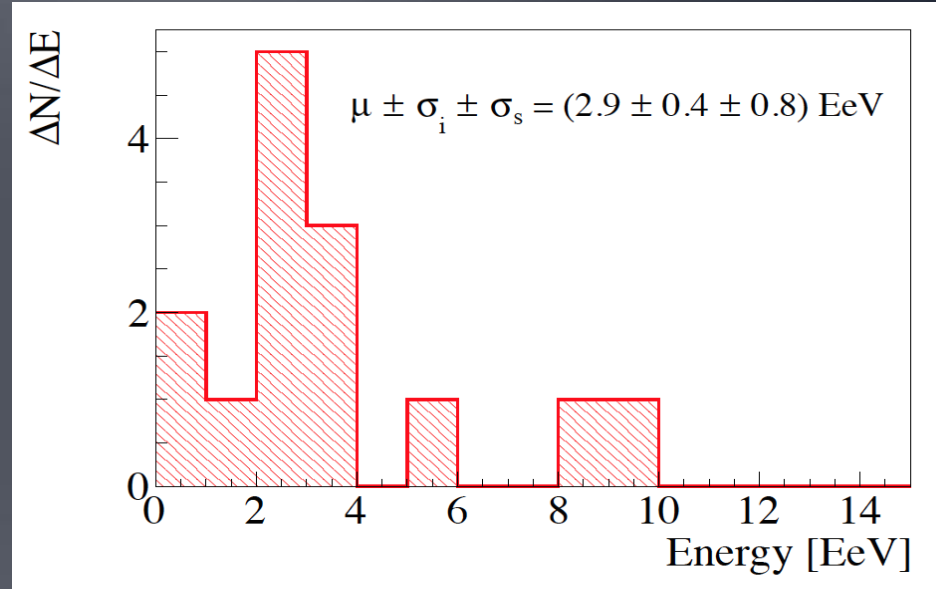
ANITA-II: best neutrino limit above $10^{19.5}$ eV



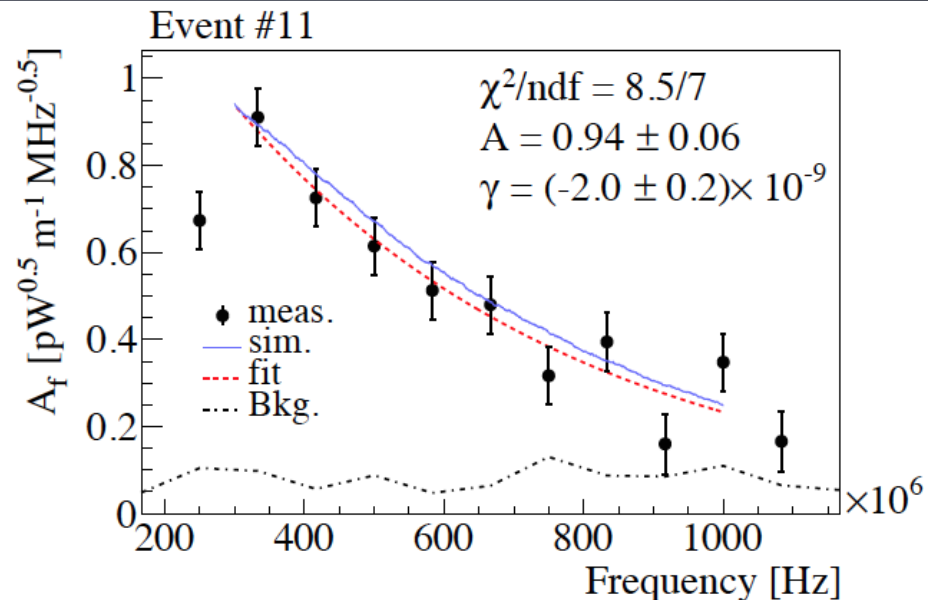
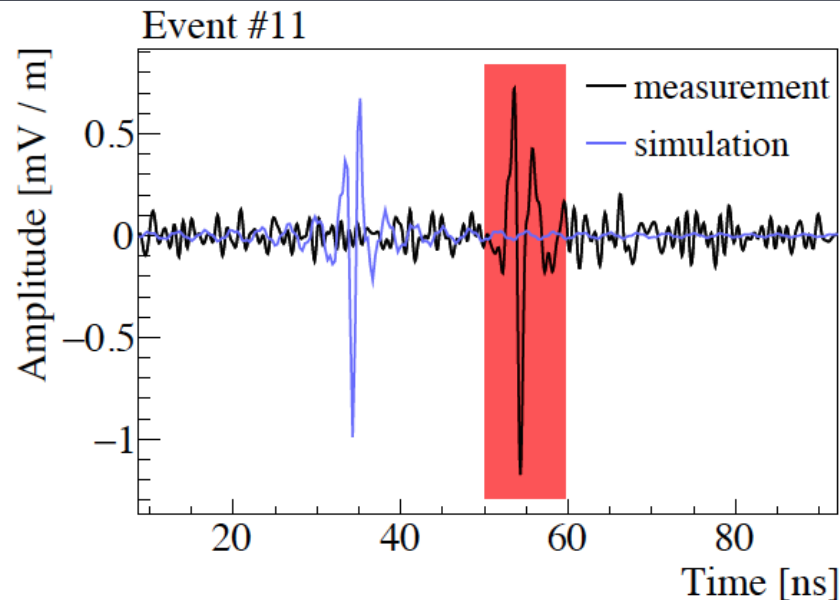
ANITA-II Limit from:
Gorham et al. PRD
2010

Previous ANITA Cosmic Ray Results

- ANITA-I: 16 UHECR events (14 reflected + 2 direct)
 - Using Auger flux, expected 16 reflected from MC simulation
 - Mean energy: 2.9 EeV
- ANITA-II: 4 more (3 reflected + 1 direct) consistent with UHECR events (no CR trigger!)



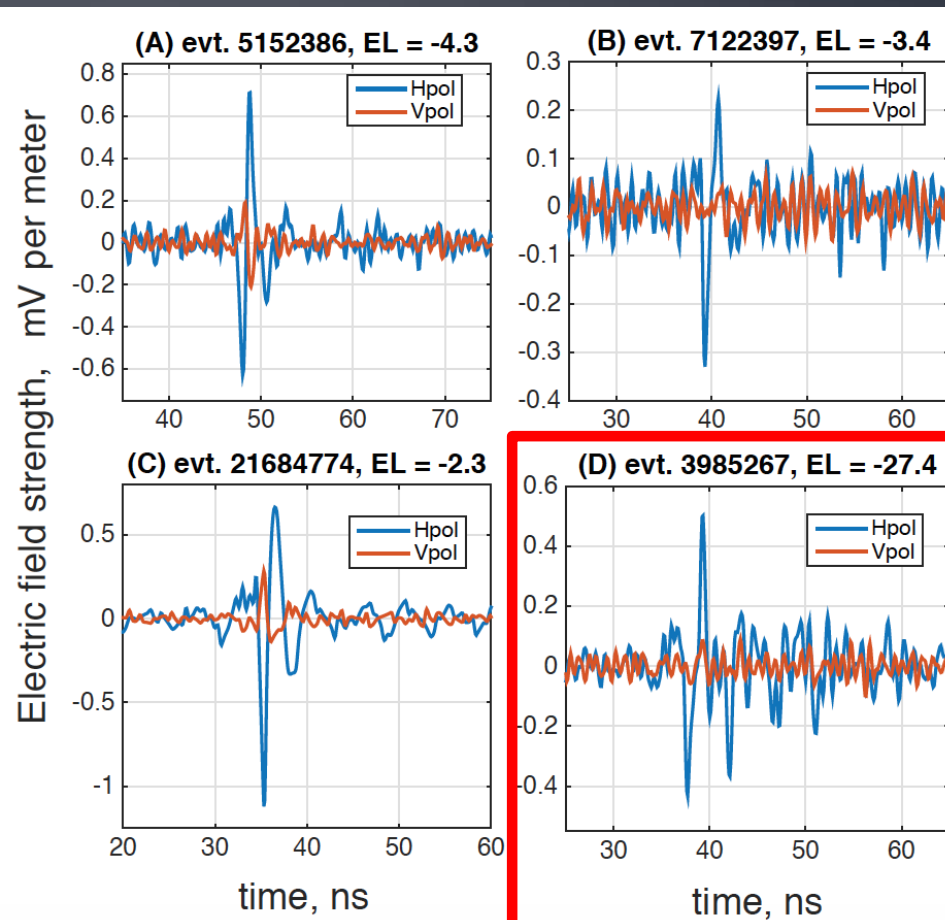
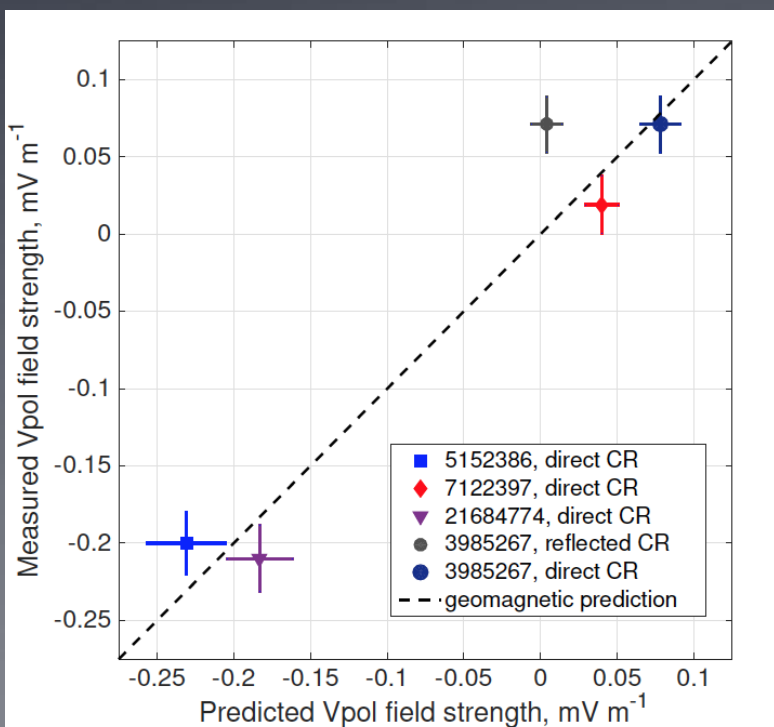
Hoover et al. PRL, 2010; Gorham et al., PRL 2016; Schoorlemmer et al. Astropart. Phys., 2016







Previous ANITA "Mystery Event" Results

- ANITA-I saw 1 "mystery event" that passes all cuts, and looks like the 3 direct UHECRs except that comes from below the horizon
- Background estimate (likelihood analysis, a posteriori) is 10^{-3} events
- What is this thing?
 - Consistent with tau neutrino hypothesis, except steeply upgoing
 - Energy estimate is 0.60 EeV

Gorham et al. PRL 2016



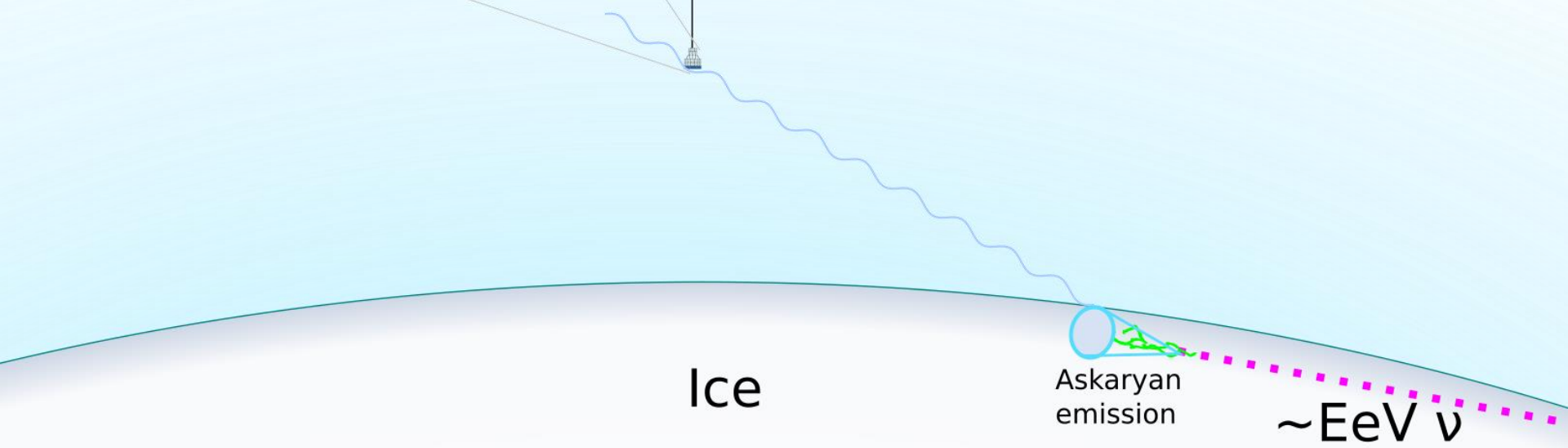
New: ANITA-III Results

ANITA-I	ANITA-II	ANITA-III	ANITA-IV	ANITA-V?
				
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ANITA-III Diffuse (Askaryan Neutrino Search)



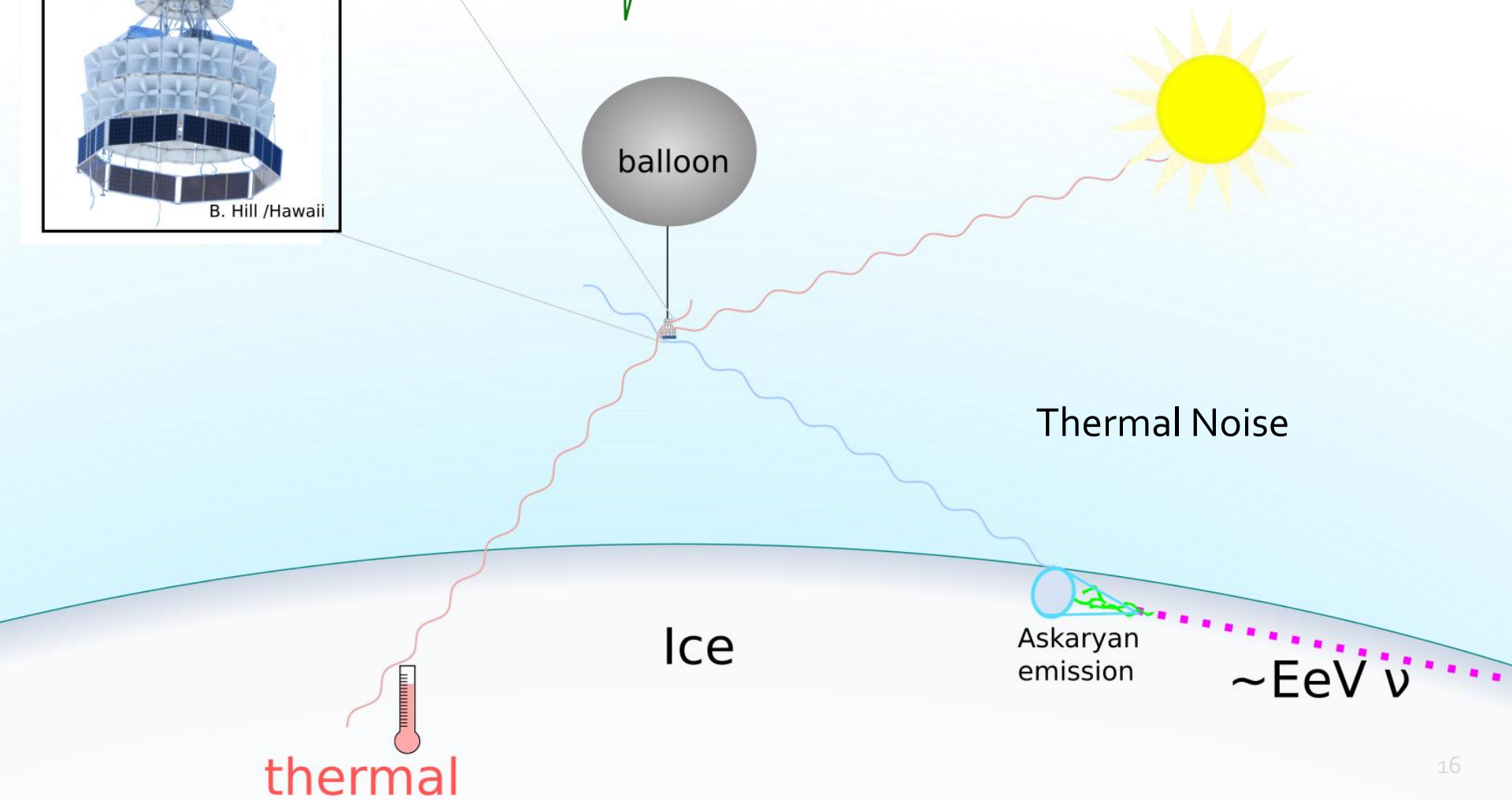
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angles don't
reflect reality



ANITA-III Diffuse (Askaryan Neutrino Search)



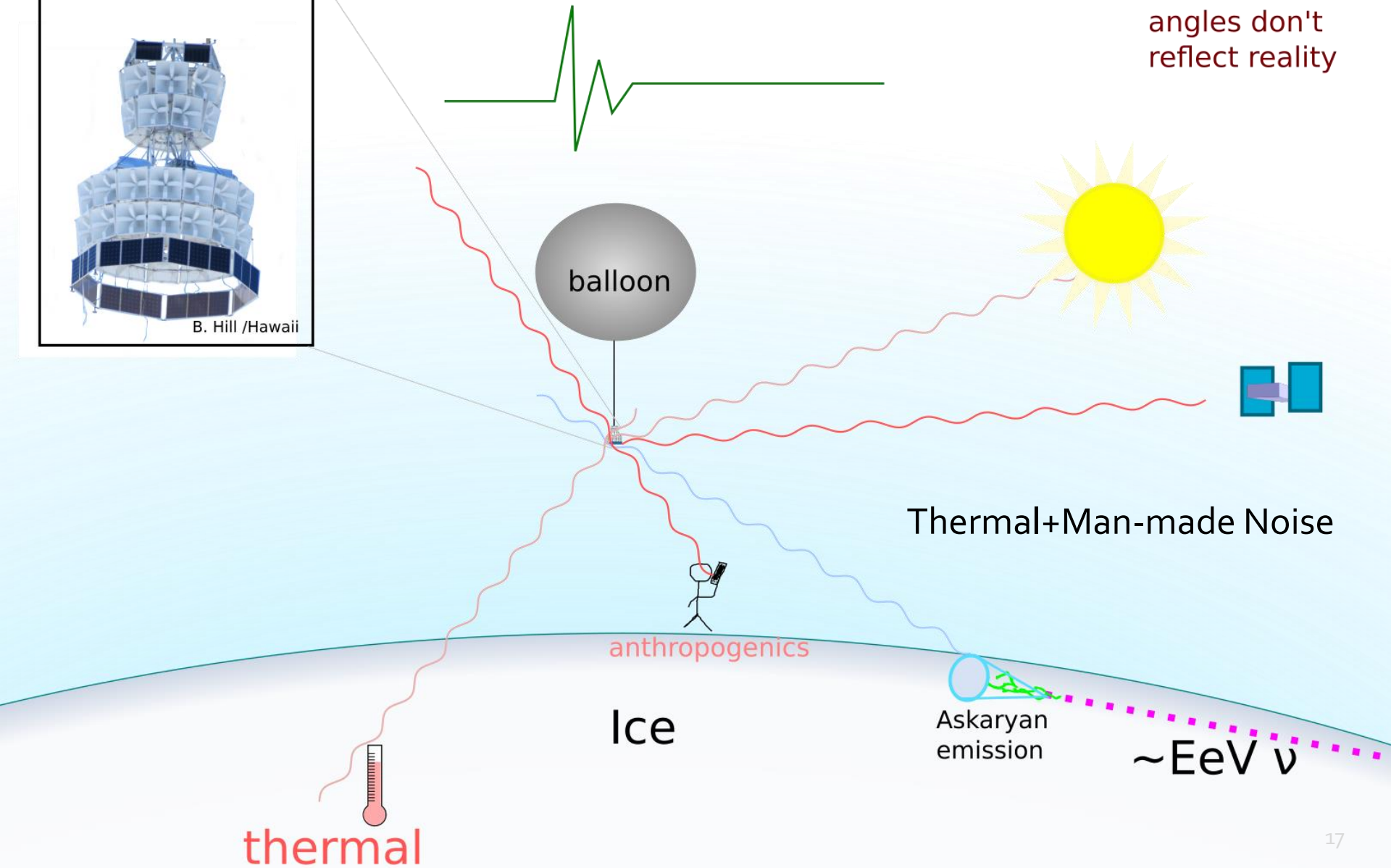
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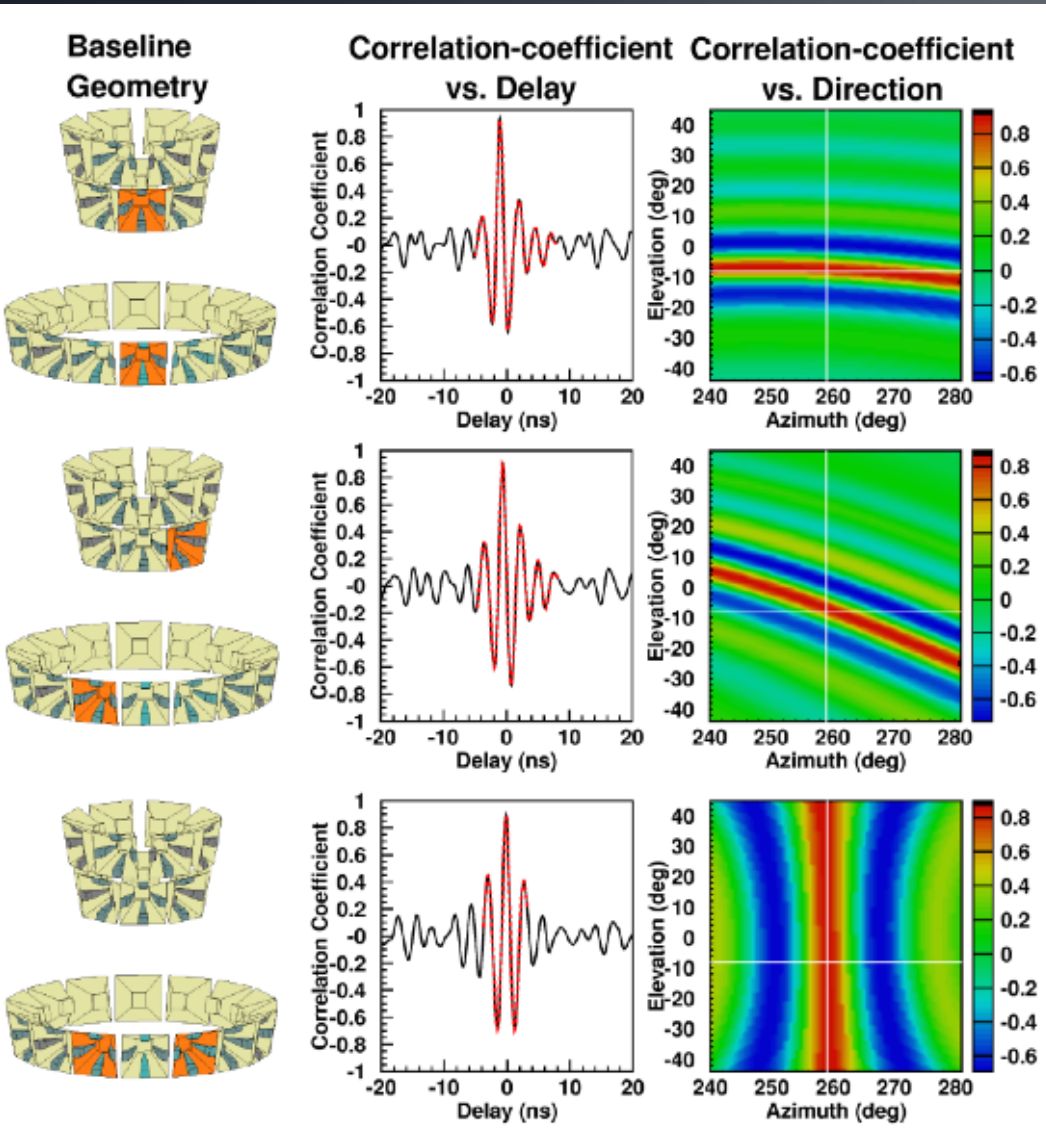
ANITA-III Diffuse (Askaryan Neutrino Search)



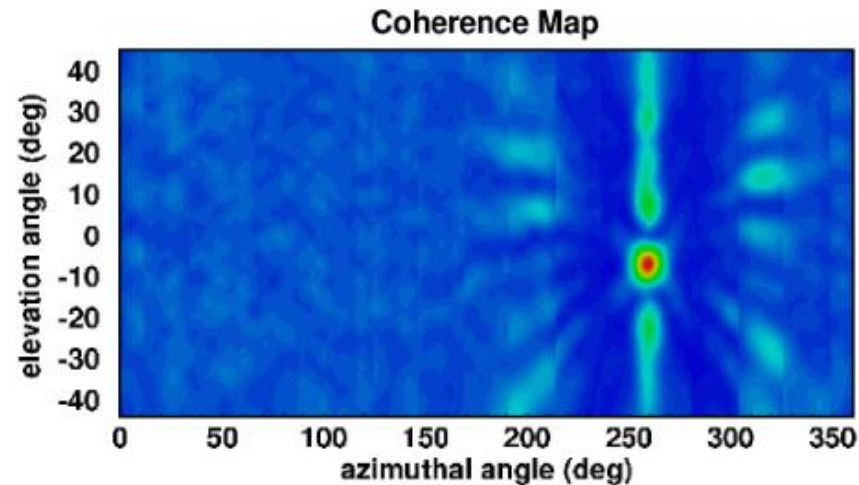
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The Interferometric Analysis Technique



- Use timing delays between antennas to determine direction
- Developed for fast, broadband signals for ANITA, now used by other experiments
- Good at distinguishing between signal-like (EAS or Askaryan neutrino) and thermal noise events

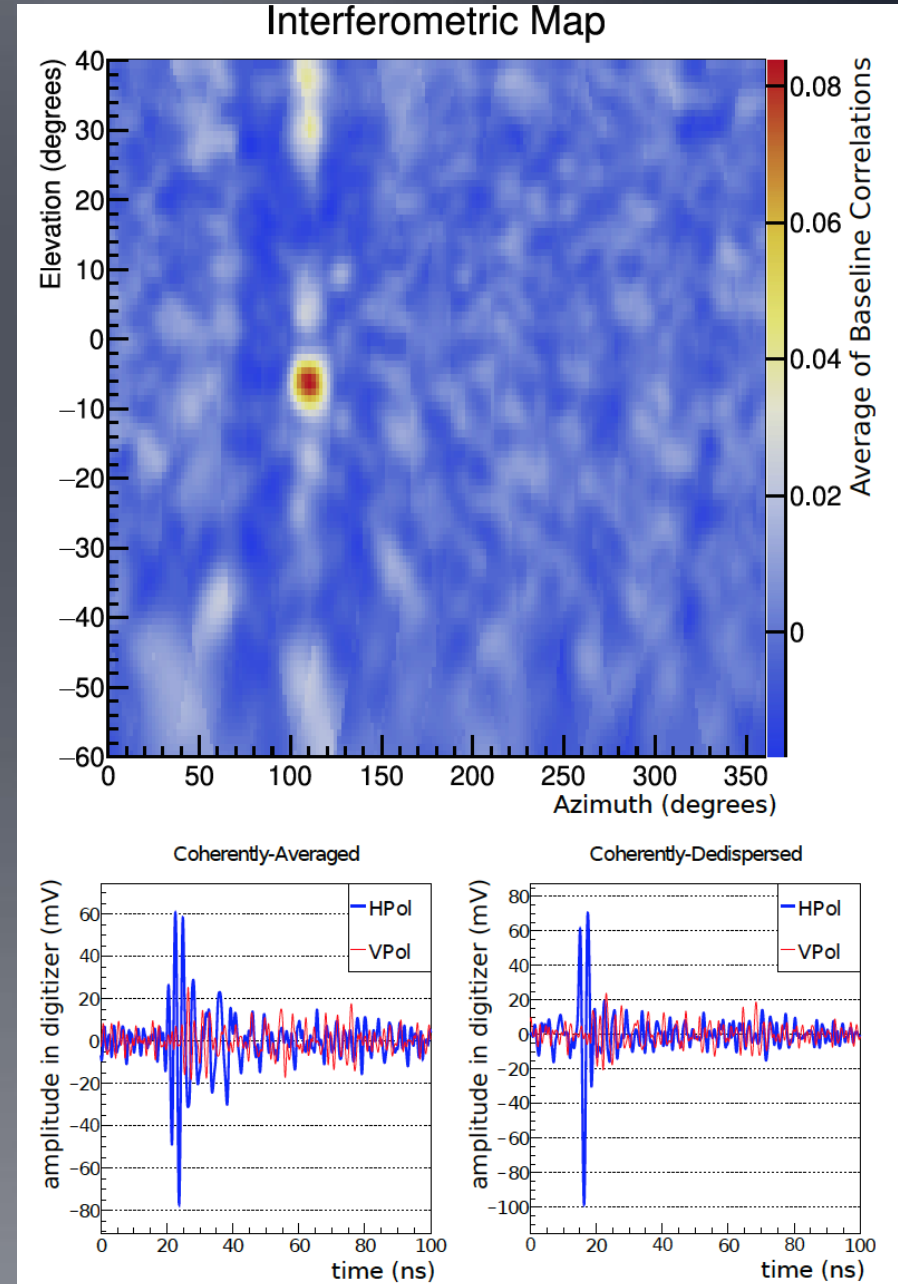


Romero-Wolf et al., JCAP 2015

Diffuse Neutrino Search Strategy

Simulated Event from MC

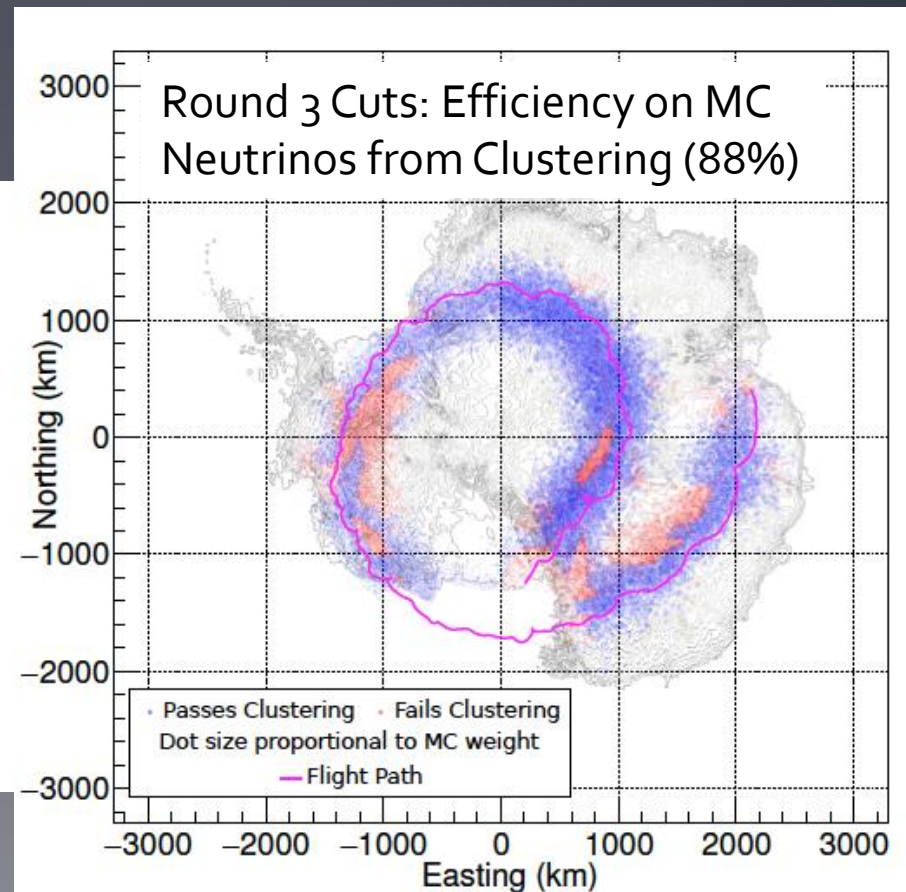
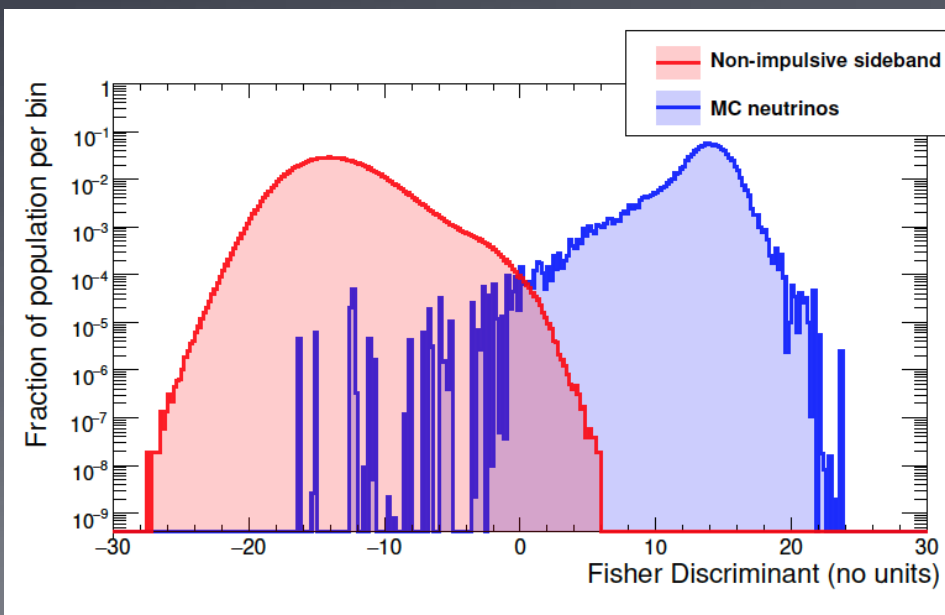
- Neutrinos are impulsive, broadband, isolated events
- 77 million triggers (expect ~few neutrinos)
- 3 separate blind analyses (leading to 4 PhDs!)
- 3 sources of background to battle:
 - Noise from onboard the payload
 - Thermal noise (99% of triggers)
 - Man-made noise



2 Clustering-Based Analyses

- 3-stage analysis:
 - Round 1) Separate onboard-noise-like events
 - Round 2) Separate thermal-noise-like events using interferometry, etc.
 - Round 3) Separate man-made-like noise events using clustering

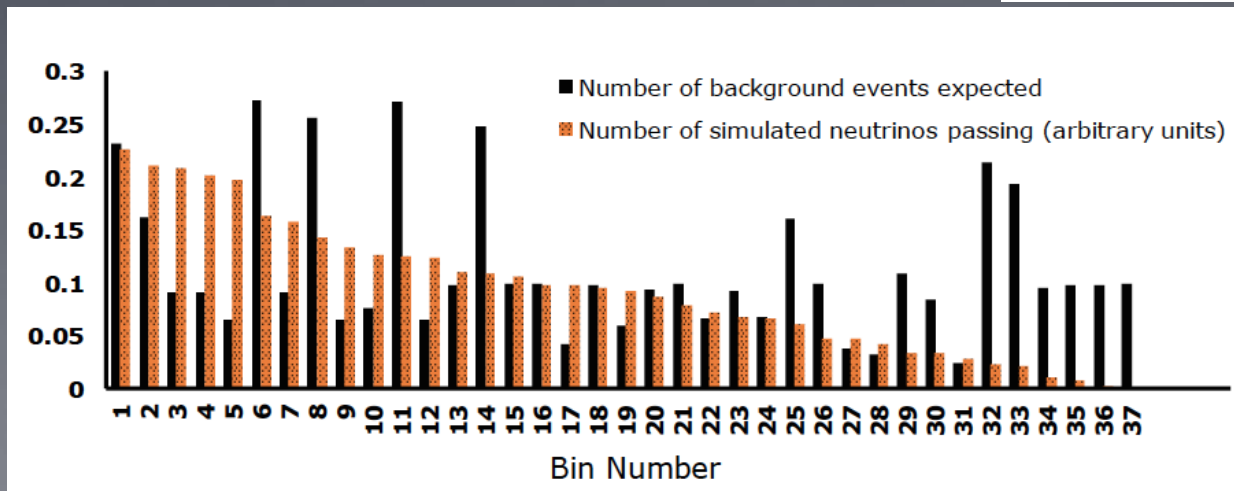
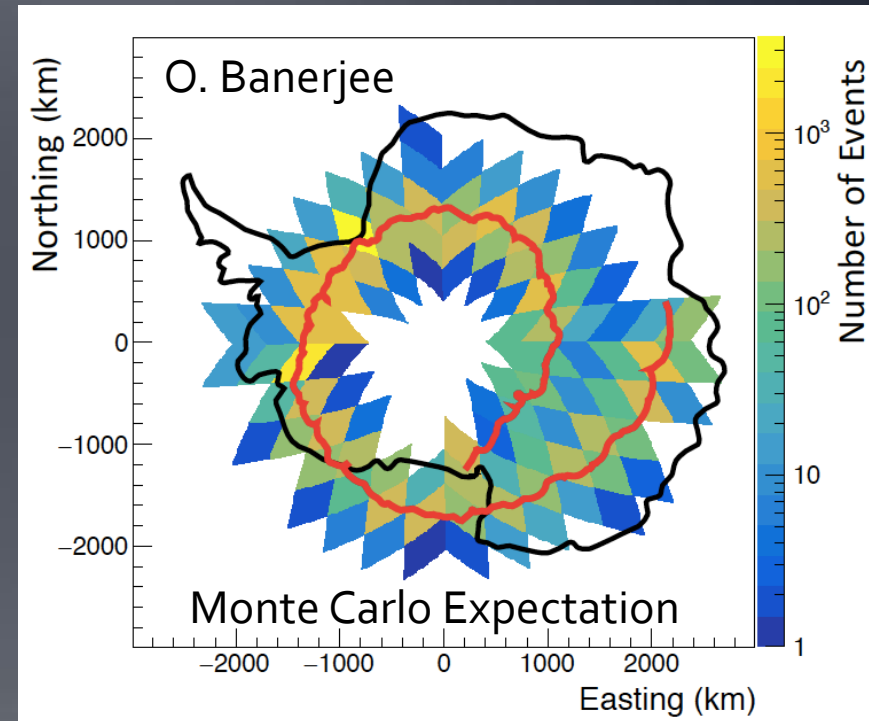
Round 1+2 Cut Separation (96% efficient)



New Analysis Approach:

1 Analysis Based on Geographic Binning

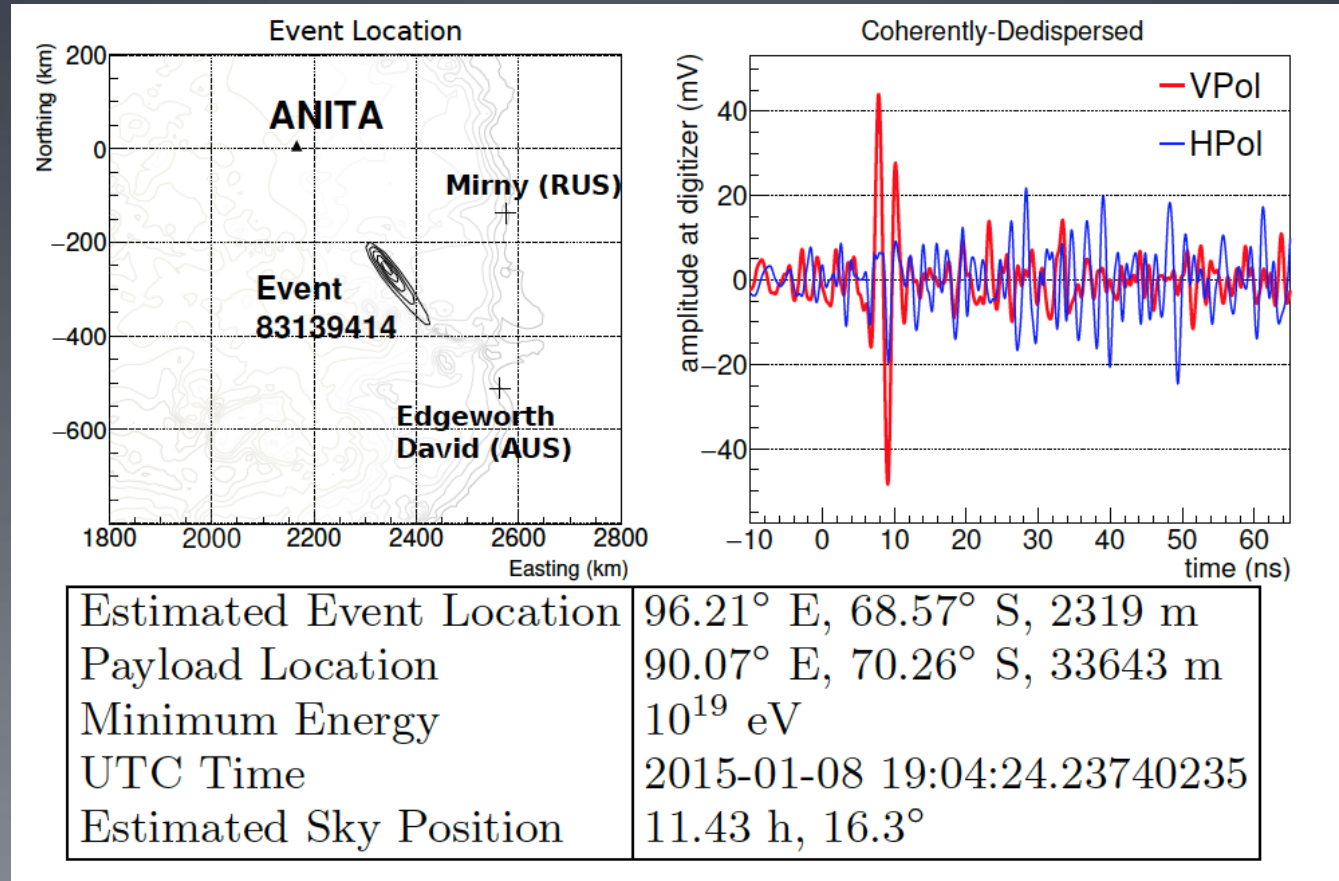
- Conduct an independent search in each HEALPix bin, set different cuts in different bins according to the properties of the events in that bin
- Background estimates and efficiencies calculated bin-by-bin
- Especially good for point source and transient searches



Gorham et al.
arXiv:1803.02719

Askaryan Neutrino Search Results

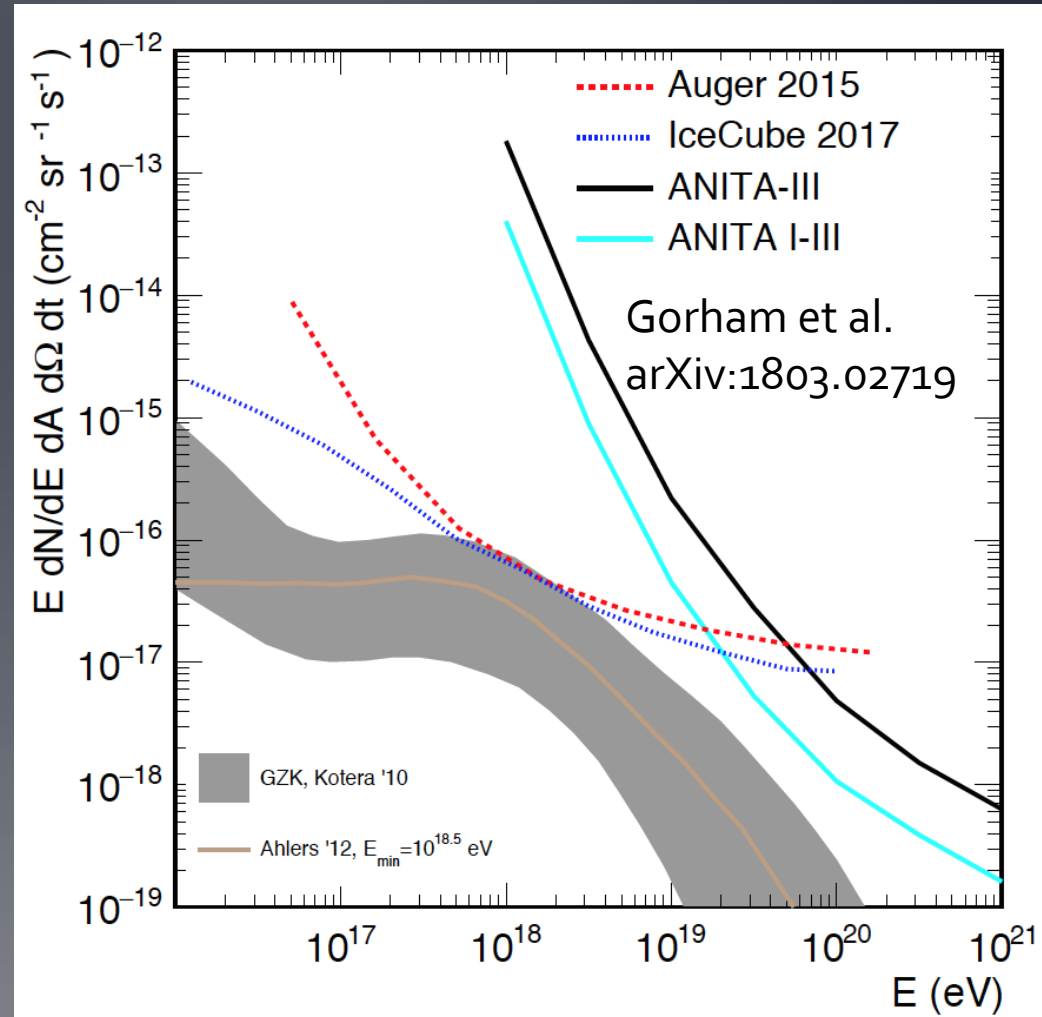
- For the most sensitive of the three analyses:
 - Total analysis efficiency: 84%
 - Total background estimate: $0.7^{+0.5}_{-0.3}$ events
 - 1 event in signal region



Gorham et al.
arXiv:1803.02719

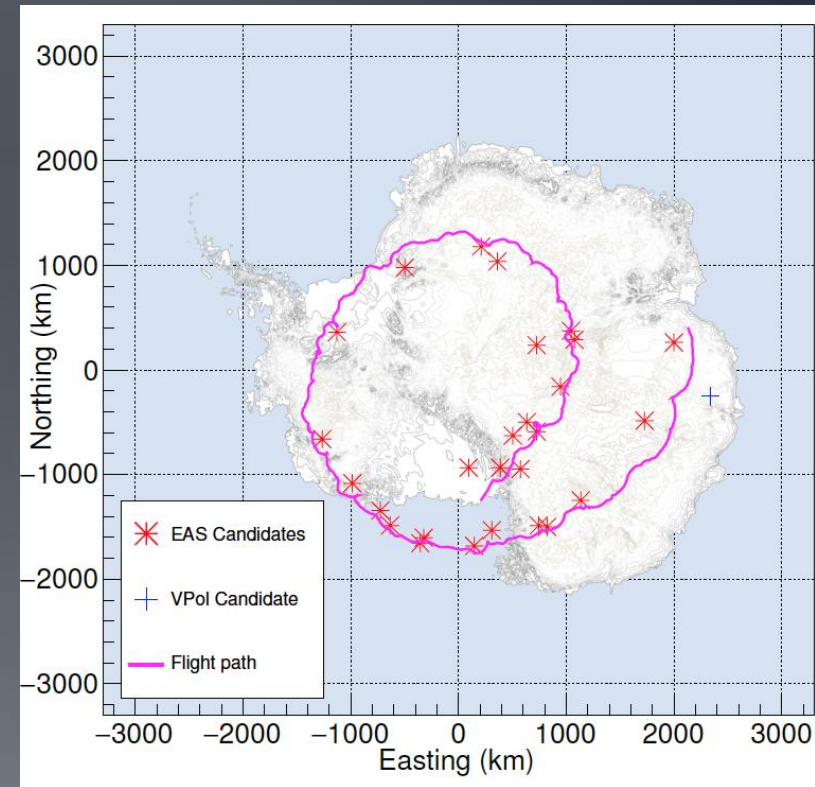
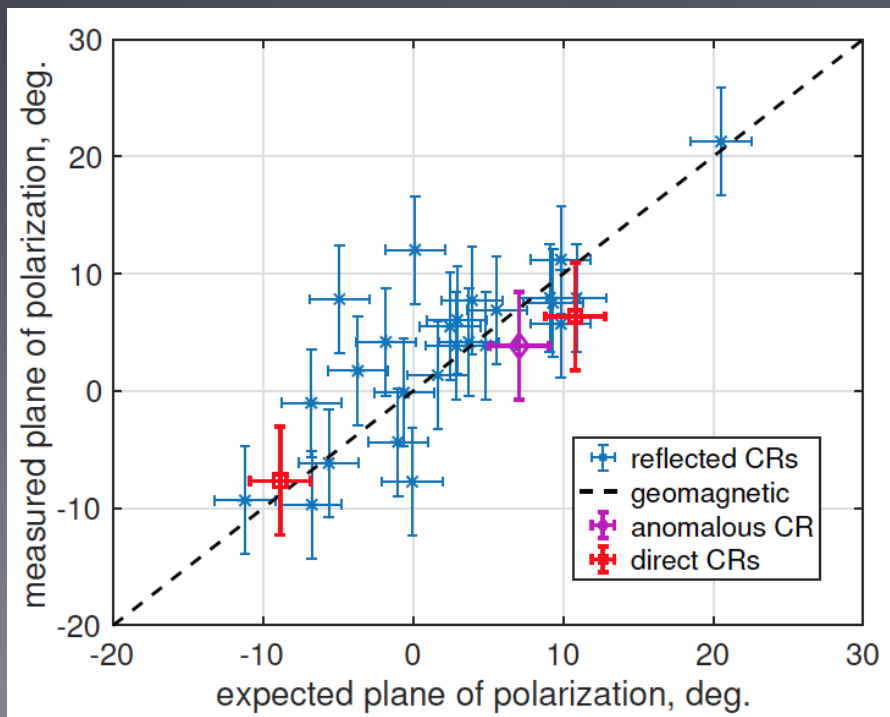
ANITA-3 Neutrino Flux Constraints

- ANITA-III suffered from significant man-made noise (mostly satellites that had been launched after ANITA-II), and therefore low livetime
- Combined ANITA constraints are the best above $10^{19.5}$ eV
- Analysis techniques have been significantly improved, and new techniques have been developed



ANITA-III Air Showers (Cosmic Rays + Tau Neutrinos)

- EAS Signals are horizontally-polarized (HPol)
- Performed additional dedicated EAS search using template matching
- ANITA-III: 28 (26 below-horizon +2 above-horizon) HPol events consistent with EAS observed
 - Simulation and energy estimate to come

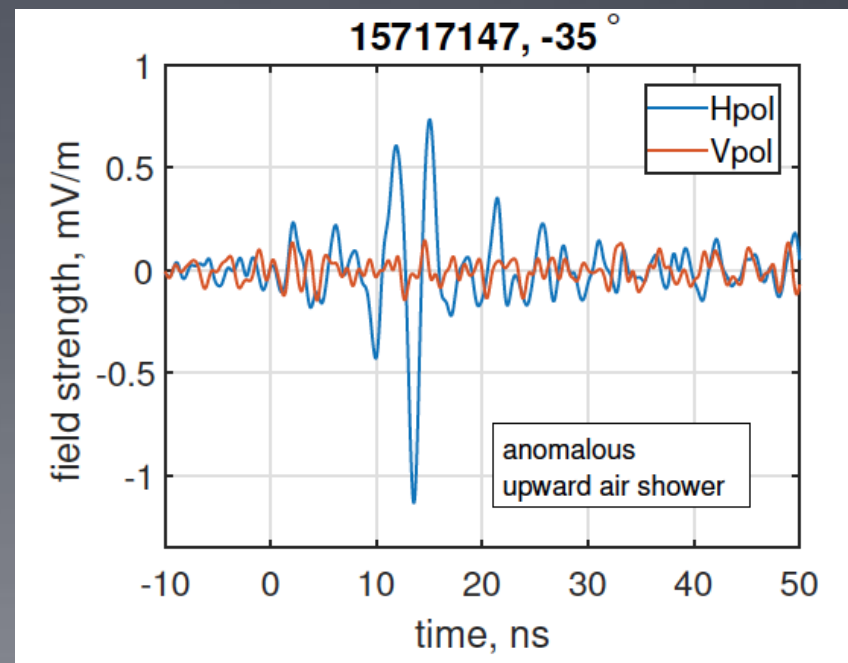
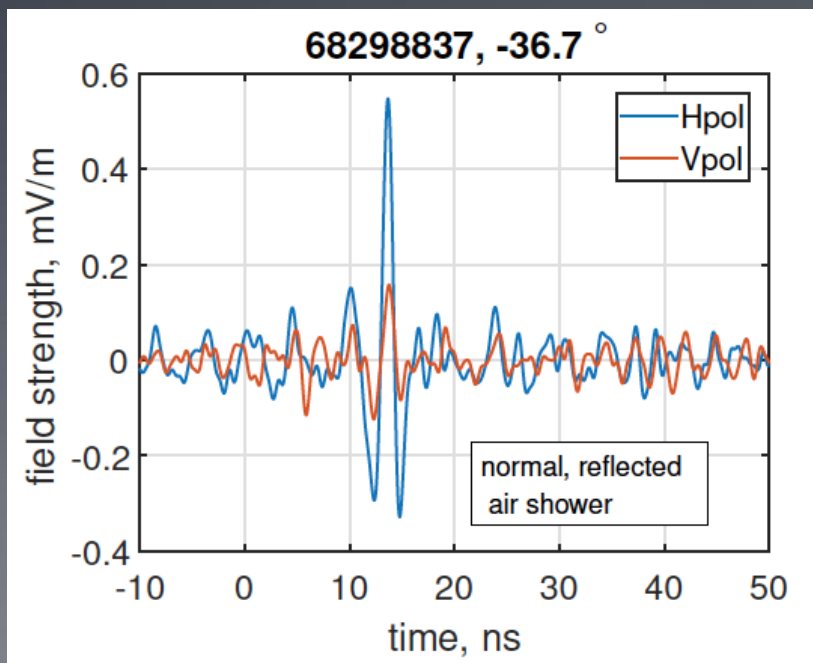


Gorham et al. arXiv:1803.02719

Gorham et al., arXiv:1803.05088

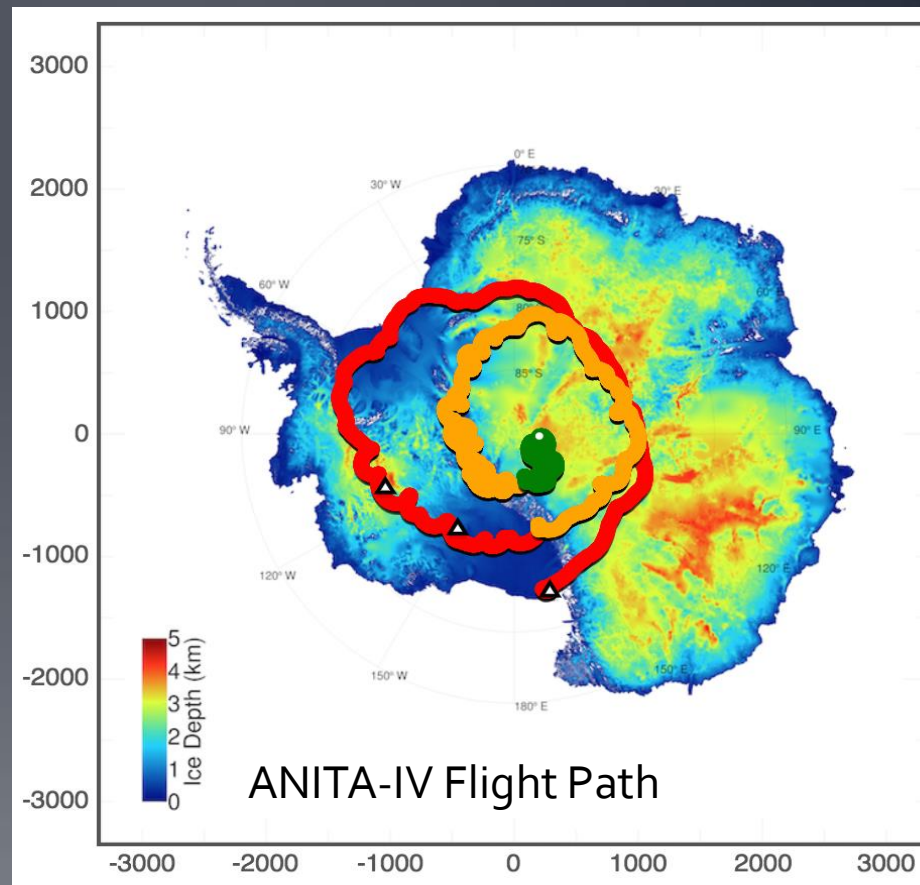
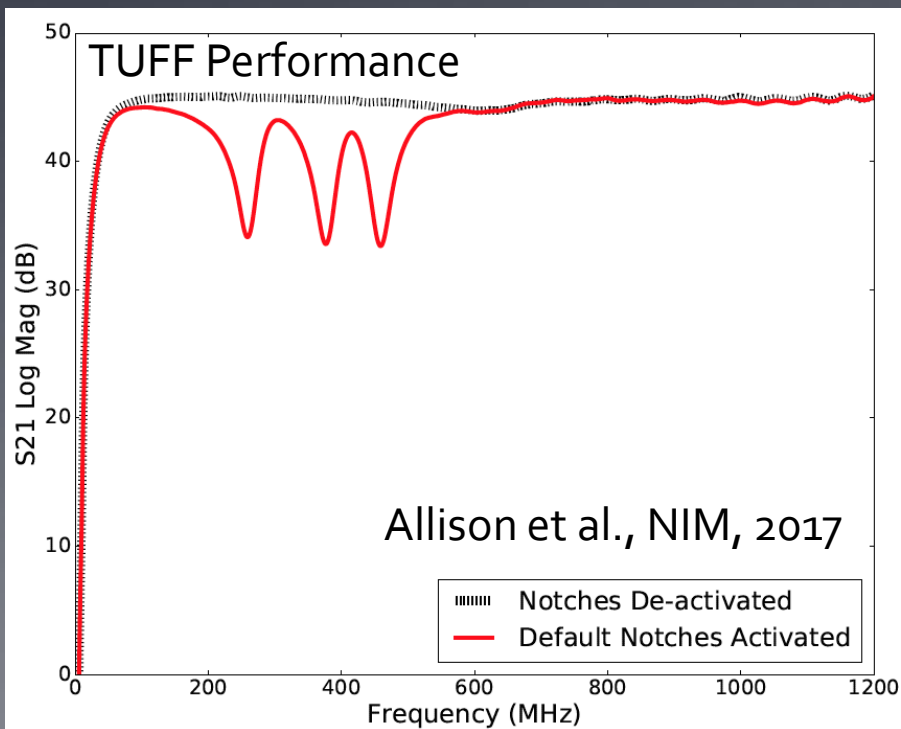
A Second "Mystery Event" in ANITA-III

- Polarity should be the same for all reflected cosmic ray events
- One of the 26 below-horizon air showers is NOT the same polarity as the rest
- Background estimate (a posteriori) is $< 10^{-2}$
- Sign of an upgoing (tau neutrino?) air shower?
- Problem: too steeply upgoing for standard model cross sections
- Energy estimate of 0.56 EeV



ANITA-IV: Flight in 2016-17

- New programmable notch filter to improve livetime (x2.8!)
- Expect 100's of EASs and a factor of a few sensitivity to neutrinos
- Stay tuned



Summary and Future

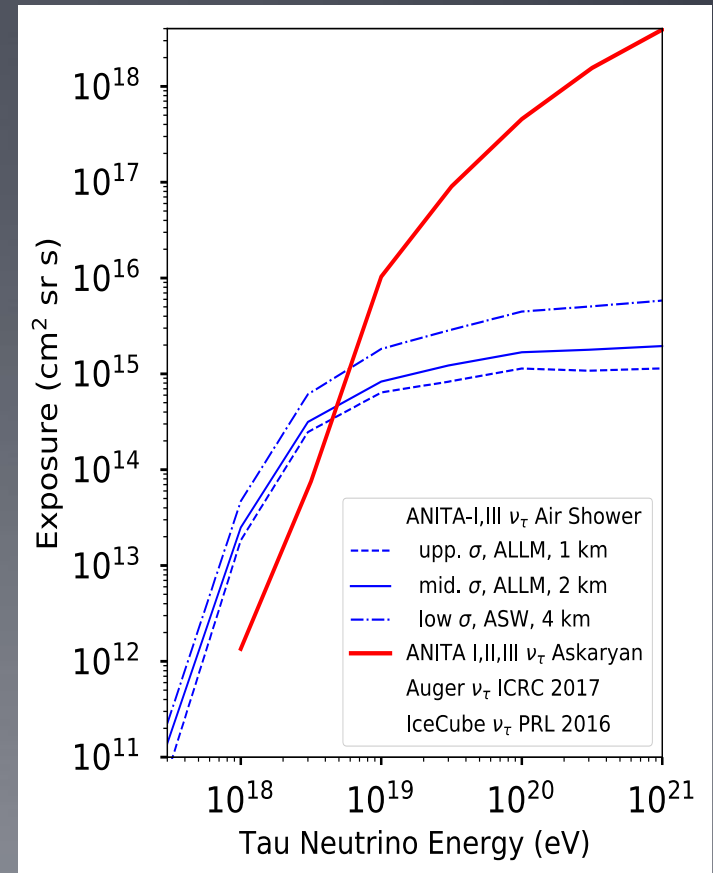
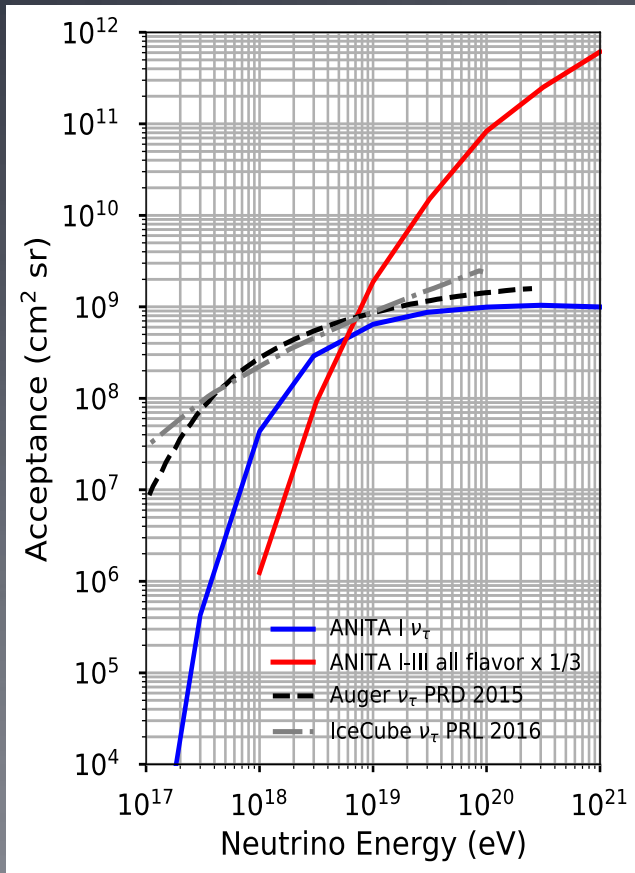
- ANITA has a rich physics program, with the best neutrino sensitivity at $10^{19.5}$ eV and above and self-triggered UHECR events $>10^{18}$ eV
- Published things I didn't talk about:
 - Lorentz invariance violation, Magnetic monopole searches, Neutrinos from GRBs, HiCal ice property measurements, etc.
- ANITA-IV is expected to be $\sim x_4$ better than ANITA-III and ANITA-I
 - If any mystery events are tau neutrinos, we should see more...
- ANITA-V will have new hardware! An interferometric trigger to reduce thresholds and increase sensitivity



ANITA Sensitivity to ν_τ -Induced Air

Acceptance comparable to
IceCube / Auger for energies $>$
 10^{19} eV

~ 2 month ANITA exposure
more than 2 orders of
magnitude lower than ~ 10
years of IceCube & Auger



Variations on the Exposure

