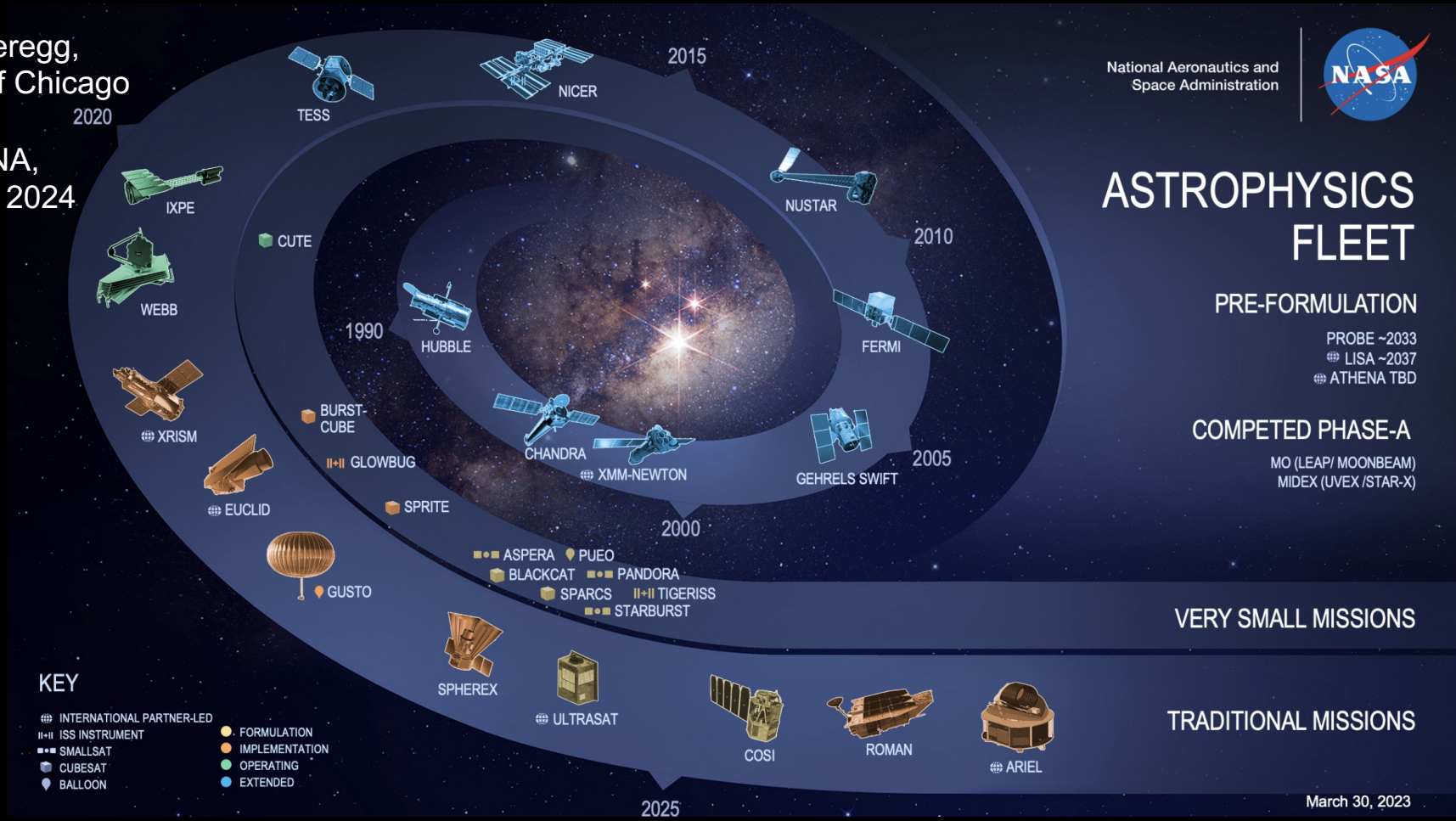
The Payload for Ultrahigh Energy Observations (PUEO)

Abby Vieregg,
University of Chicago

ARENA,
11 June 2024



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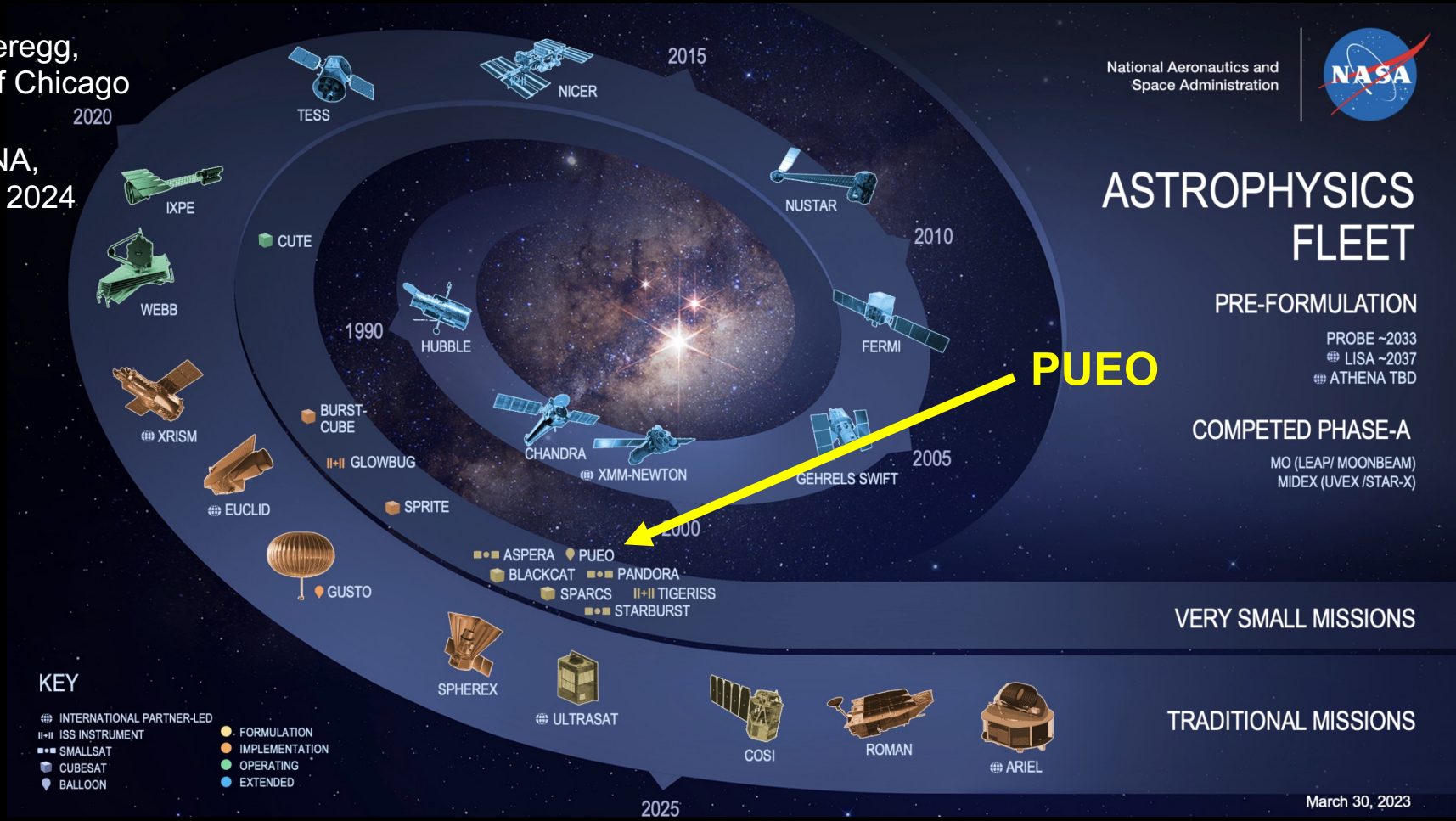
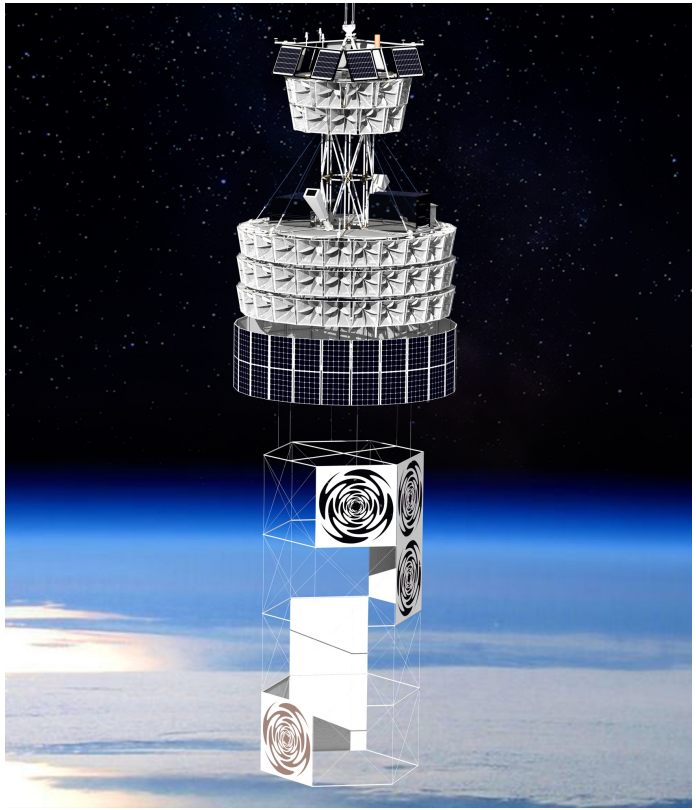


The PUEO Mission

PUEO is part of the inaugural class of NASA Astrophysics Pioneers Missions (cost cap $20M, 5-year missions), and the only Pioneers balloon so far

- Project start in February 2021
- Antarctic Long Duration Balloon Mission
- 1 year delay due to Antarctic Launch Opportunities: **Flight planned for the 2025-26 Austral summer.**



The PUEO Team

USC UNIVERSIDADE DE SANTIAGO DE COMPOSTELA

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WASHINGTON UNIVERSITY IN ST. LOUIS 1853

Queen Mary University of London

UNIVERSITY OF DELAWARE 1743

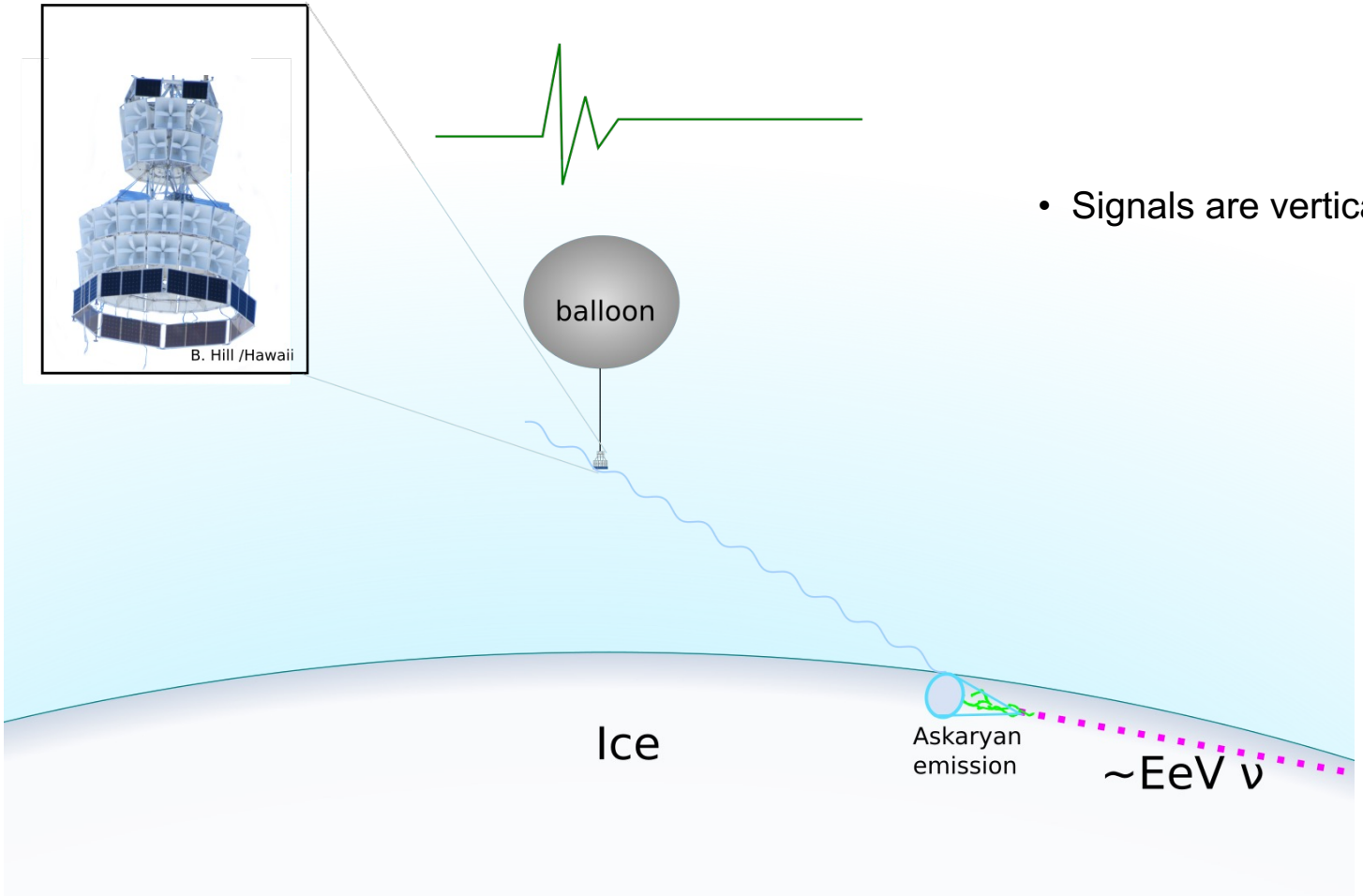
THE UNIVERSITY OF CHICAGO

PennState

National Taiwan University

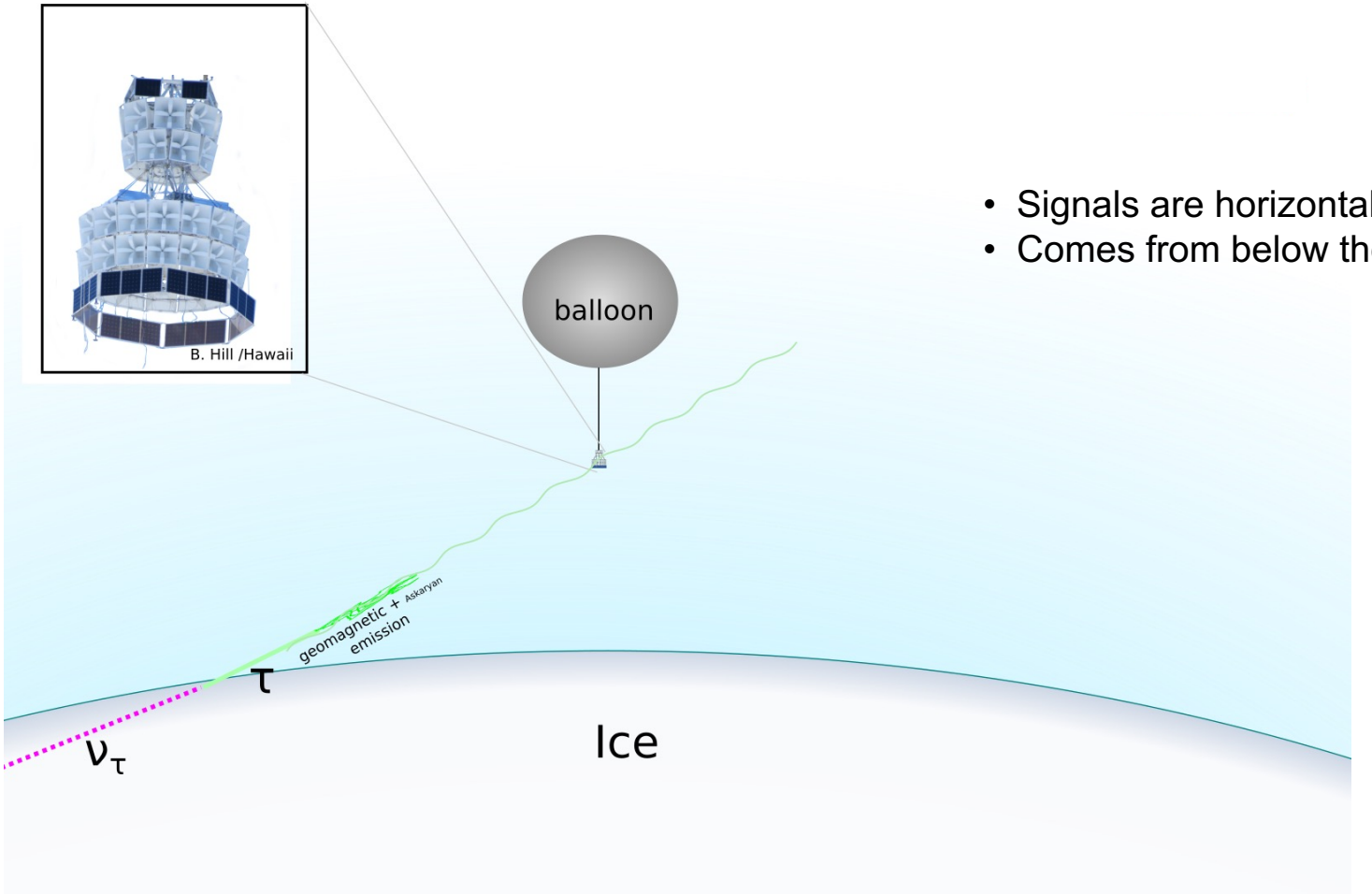
UCL

1) Neutrino-Induced Askaryan Emission in Ice



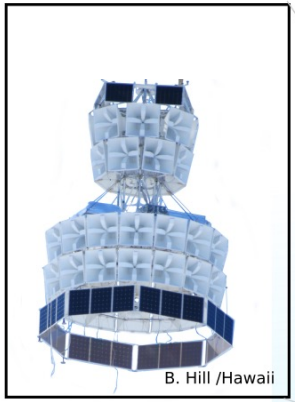
- Signals are vertically polarized

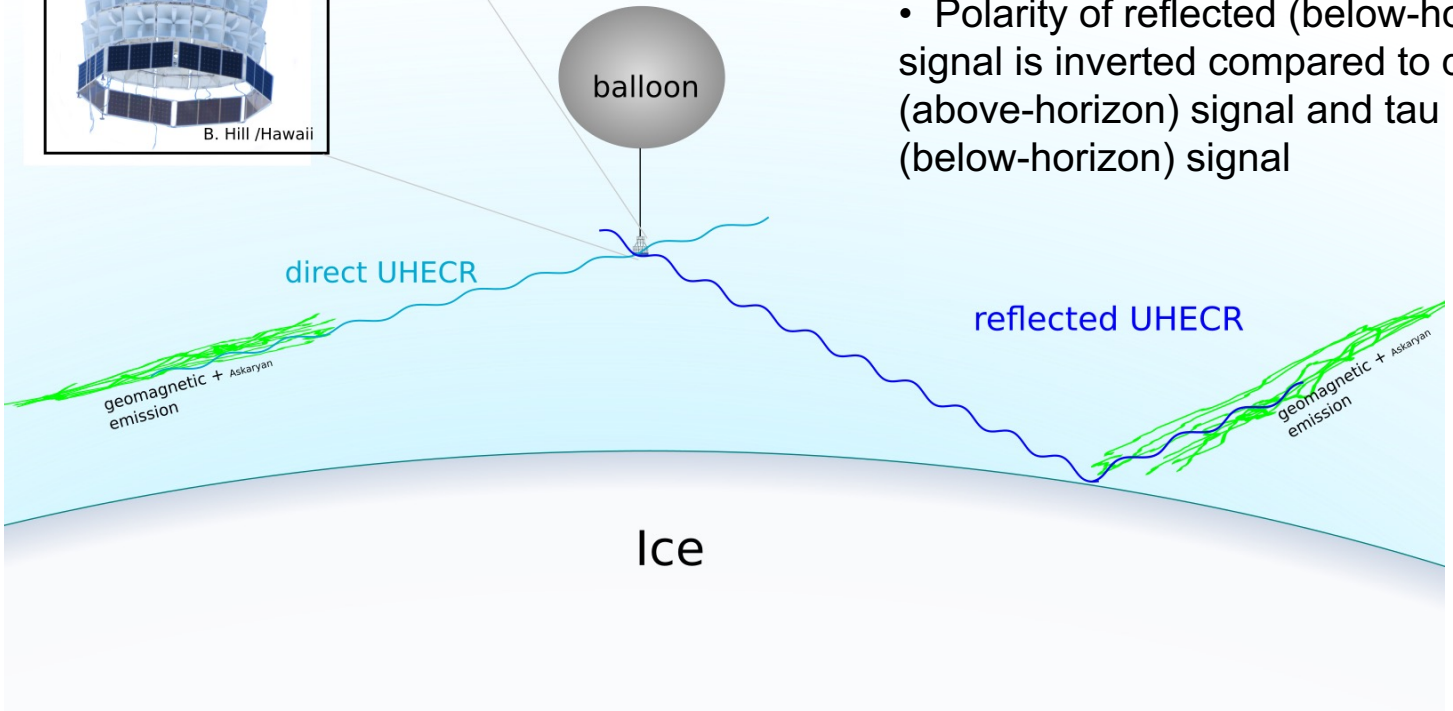
2) Radio Emission from Tau-Neutrino-Induced Air Showers



- Signals are horizontally polarized
- Comes from below the horizon

3) Radio Emission from Cosmic-Ray-Induced Air Showers





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

Building on the Success of ANITA

NASA Long Duration Balloon from Antarctica, four flights (2006-2016)

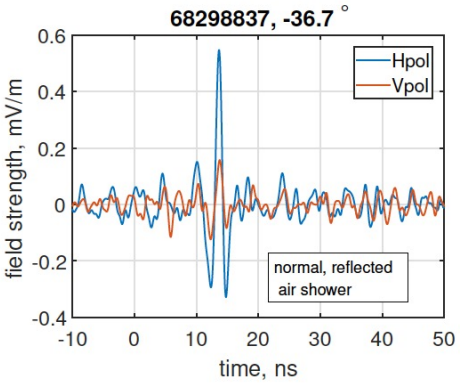
Instrument Overview:

- ~40 horn antennas, 200-1200 MHz
- Direction calculated from timing delay between antennas (interferometry)
- In-flight calibration from ground

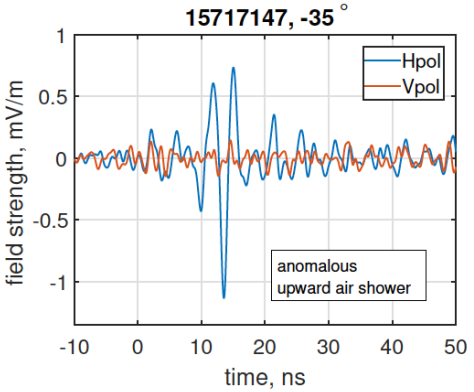
Results in a Nutshell:

- Askaryan channel: No excess seen above background (no discovery)
- ~100 UHE Cosmic Ray (>10^{18} eV) events detected over 4 flights
- Tau Air Shower Channel: Events seen?? ANITA-1 and -3 saw steeply upgoing events; ANITA-4 saw near-horizon events

Typical Cosmic Ray Event



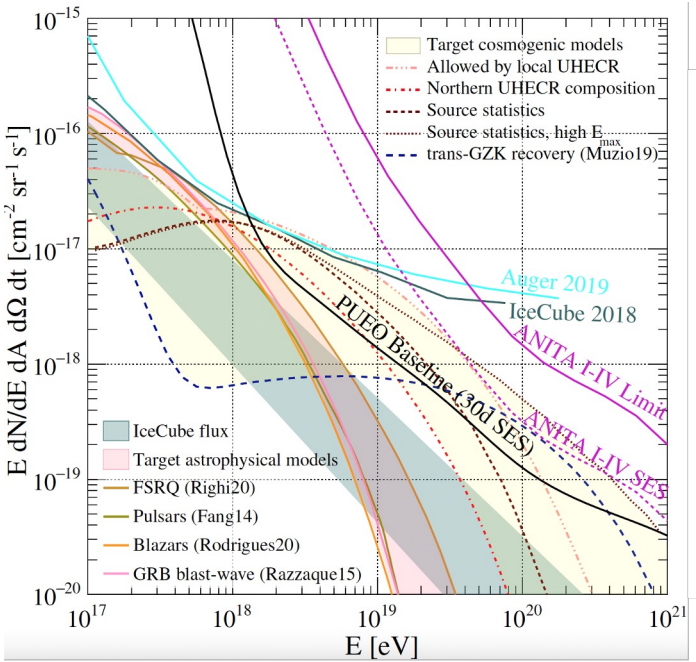
Mystery Event



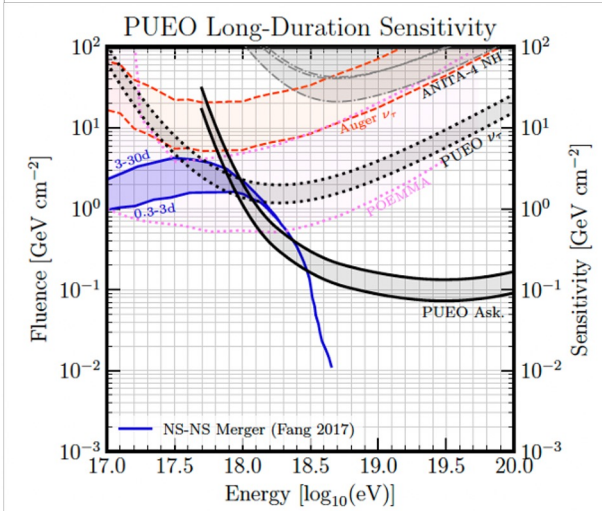
ANITA Coll., PRL 2018

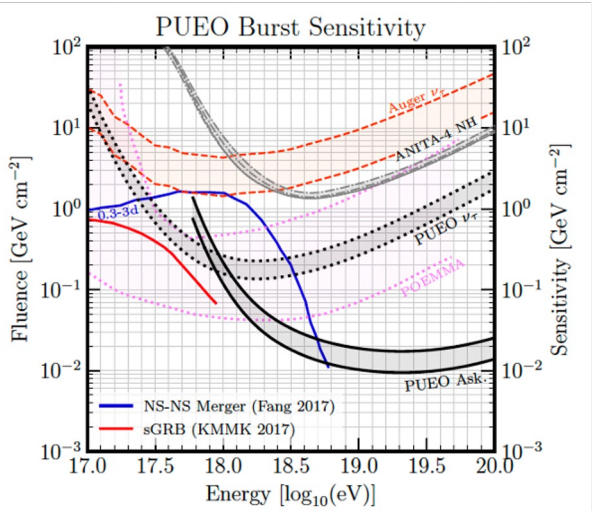
Science Reach of PUEO

Diffuse Flux Sensitivity of PUEO



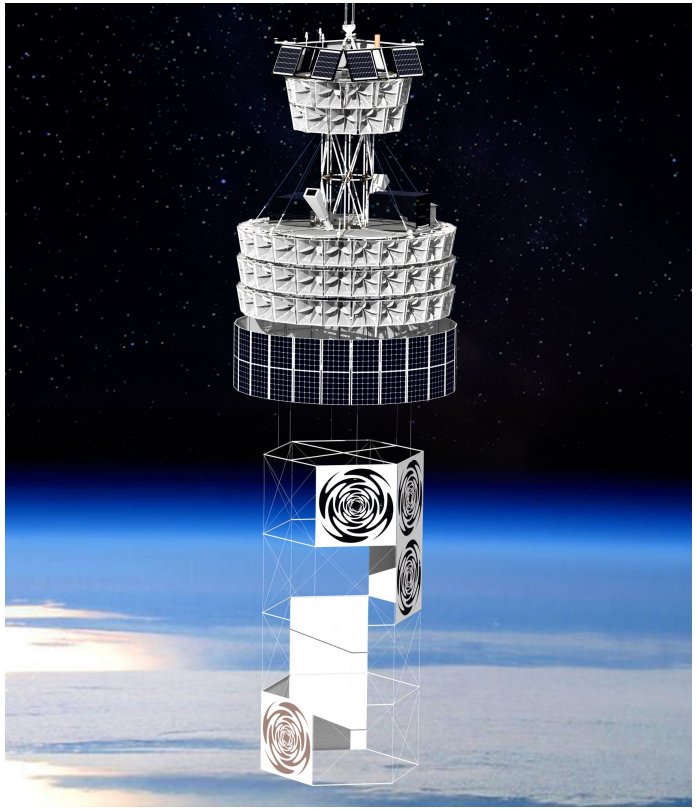
Transient Sensitivity, Long (Length of Flight) and Short (1000s)





The PUEO Payload

- 192-RF-Channel Main Instrument.
- 16-antenna, dual-polarization beamforming trigger
- 16-RF-Channel Low Frequency Instrument (see Y. Ku talk)
- Triply redundant 128 TB onboard data storage
- Command and control, data transfer to the ground
- Suite of navigation instruments: heading, pitch, roll, location
- Housekeeping/environment sensor system
- In-flight calibration from the ground and from a suite of hand-launched HiCal payloads
- (See K. McBride talk)



Why is PUEO So Much More Sensitive than ANITA?

More than an order-of-magnitude sensitivity increase enabled by:

- Interferometric phased array trigger with optimized trigger band
- x2 more antenna collecting area above 300 MHz
- Better performing antennas + RF chain

Other features that improve performance

- Real-time digital filtering
- Low frequency instrument (important for air shower events)

ANITA-III

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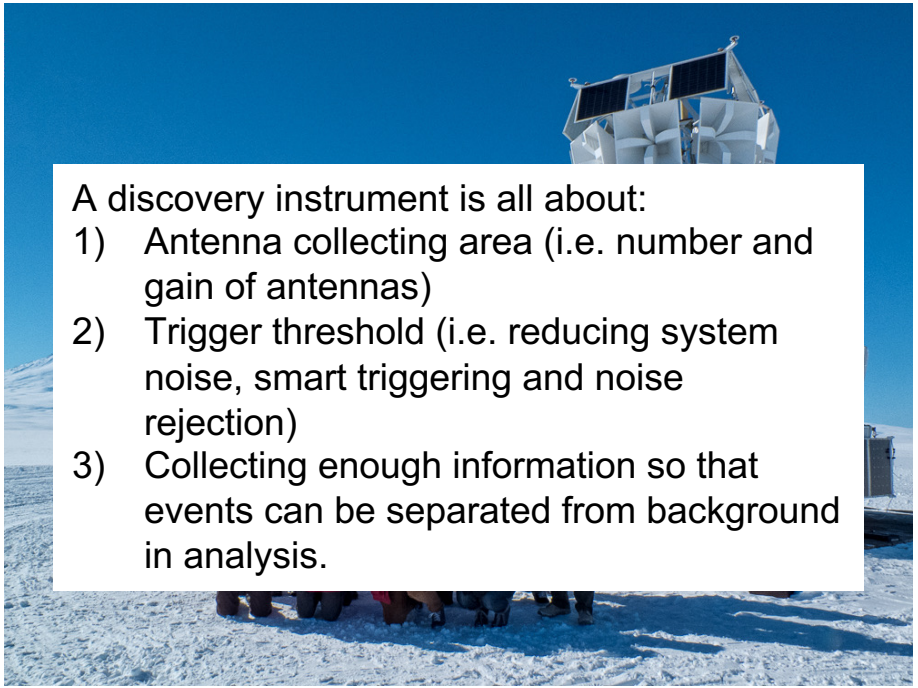
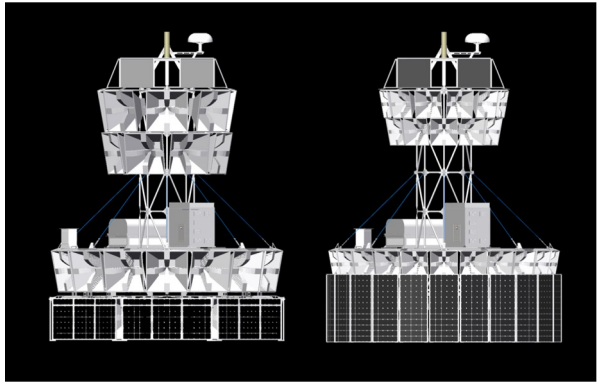
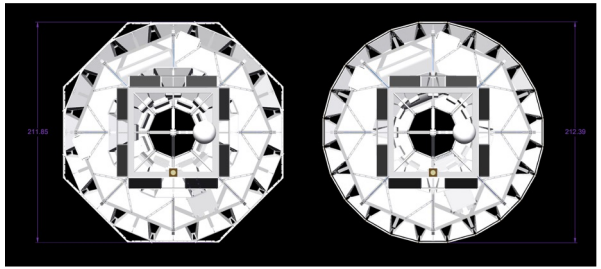


ANITA-III

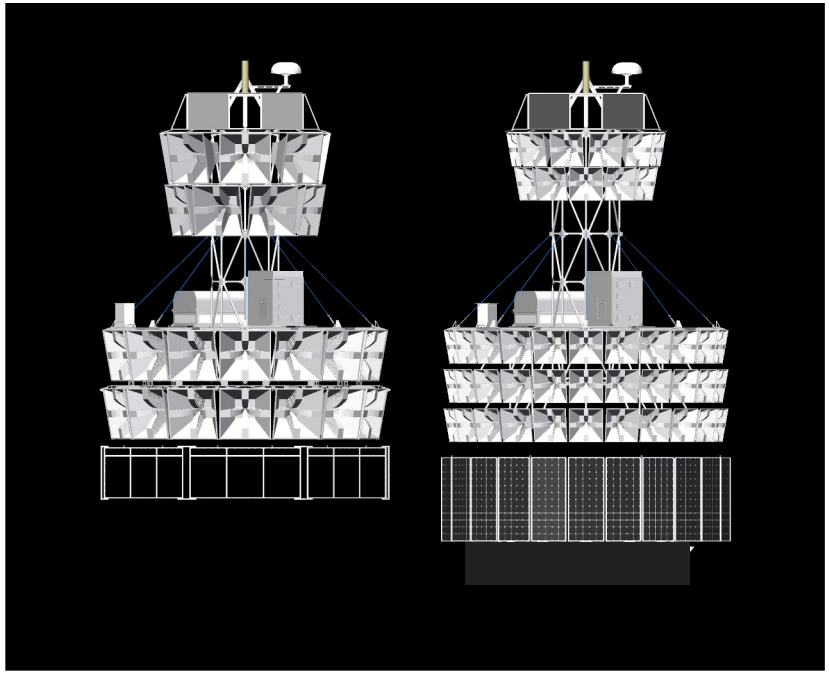
PUEO vs ANITA



ANITA PUEO



- 2/3x scaled antennas
- Nearly identical footprint
- Identical launch configuration



ANITA PUEO

Launch Envelope & Deployable Systems

A Fixed Launch Envelope

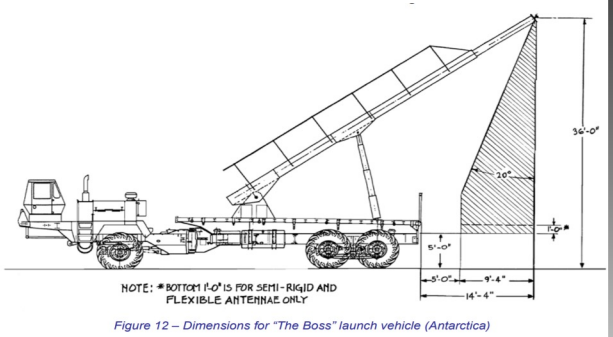
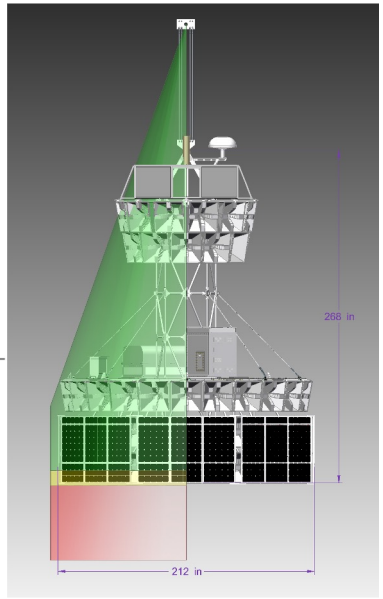
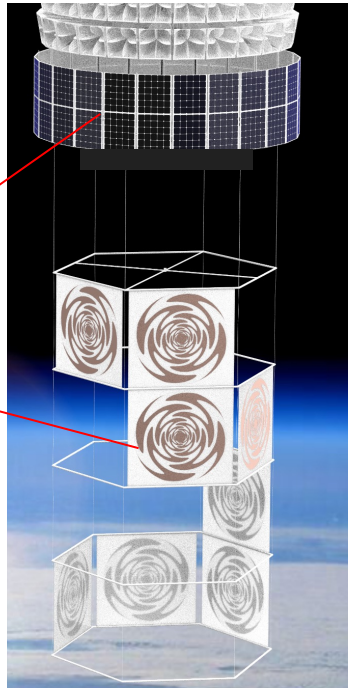


Figure 12 – Dimensions for "The Boss" launch vehicle (Antarctica)



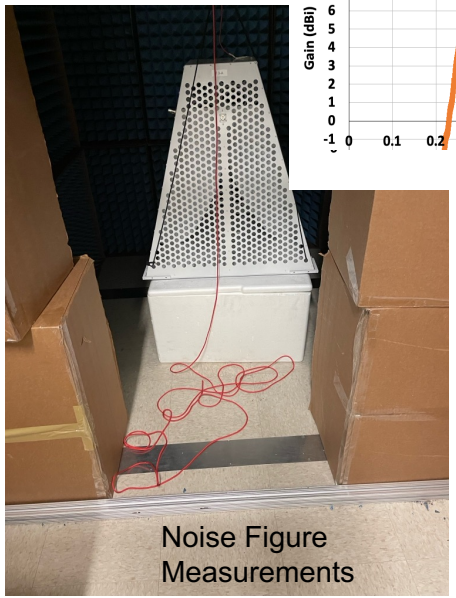
Deployable Systems: Maximizing science on a constrained platform

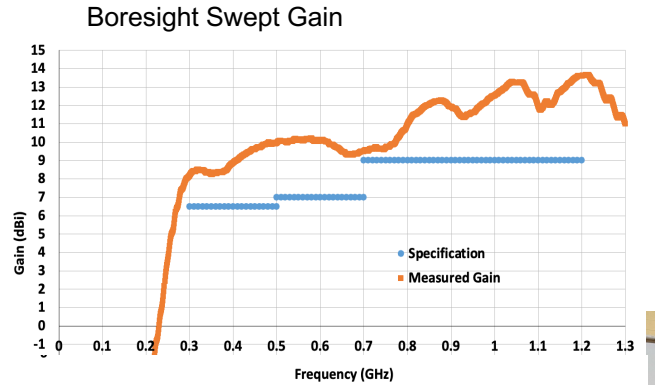
1. Science PV Array
2. LF Sinuous Antenna Array



Better Antennas

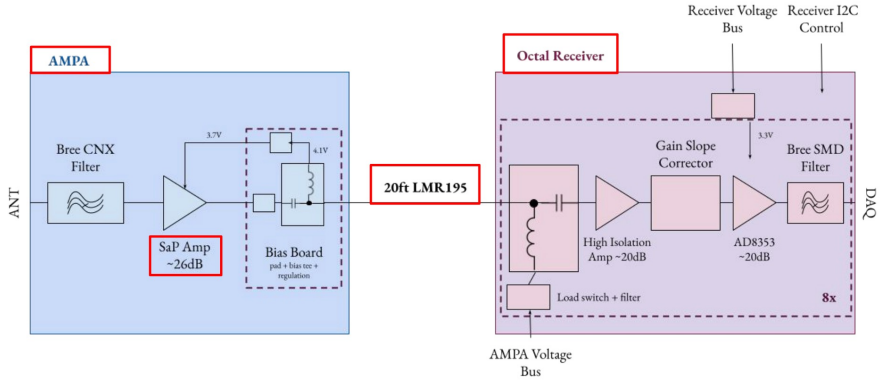
- 96 Quad-ridged horn antennas, 300-1200MHz
- Vendor selected: Toyon Antennas (these antennas are significantly better (i.e. higher gain while still meeting the bandwidth, size, and weight requirements) than the antennas we used on ANITA

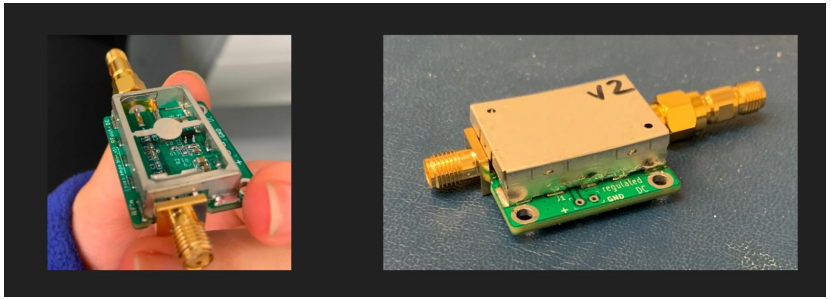

Noise Figure Measurements



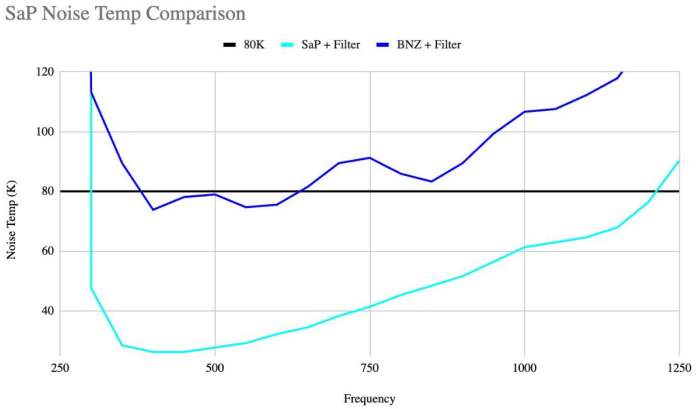

Swept Gain Measurements

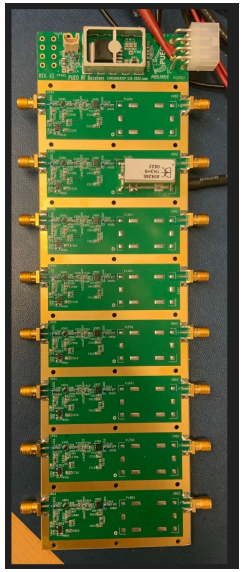
A Better RF Front-End





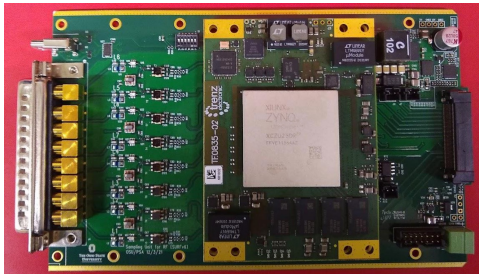
Switching to a new LNA: ~20% more neutrinos over design sensitivity



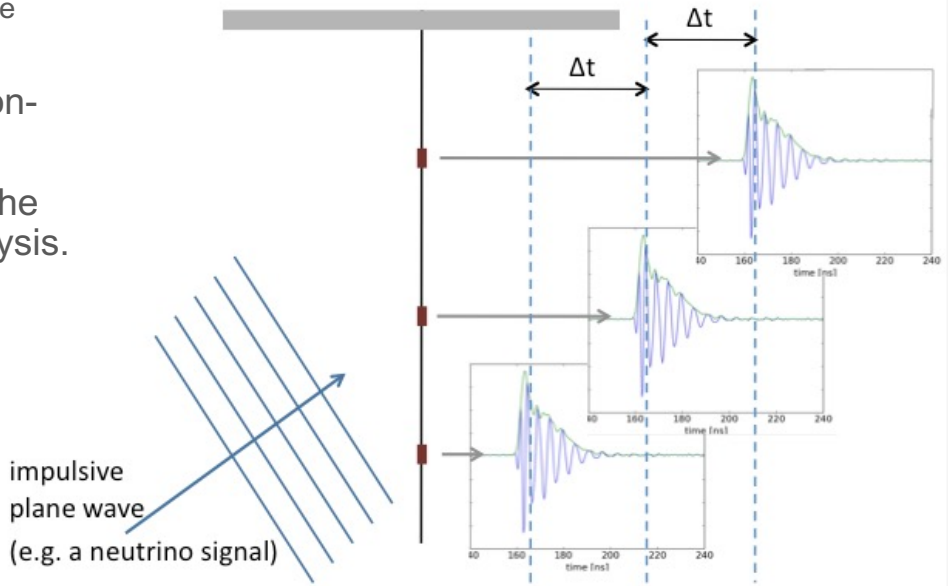


A Better Trigger Threshold

- PUEO incorporates an interferometric phased array trigger
  - Builds on successful demonstration on ARA at the South Pole
  - RNO-G also incorporates this type of trigger
- PUEO uses an RFSoC-based design in a conduction-cooled crate.
- Optimized trigger band: optimal trigger band is not the same as the optimal band to record signals for analysis.



3 Antenna Example, Side View



PUEO Outlook

- Planned Launch in December 2025
- PUEO opens up discovery space for ultra-high energy neutrinos that is not possible any other way: more than order of magnitude improvement over current best sensitivity