Design of the PUEO Payload

Keith McBride for the PUEO collaboration

06/12/2024

The Payload for Ultrahigh Energy Observations

Science Goal

What is the nature and cosmic distribution of the astrophysical accelerators that produce the highest energy particles in the universe?

Objective

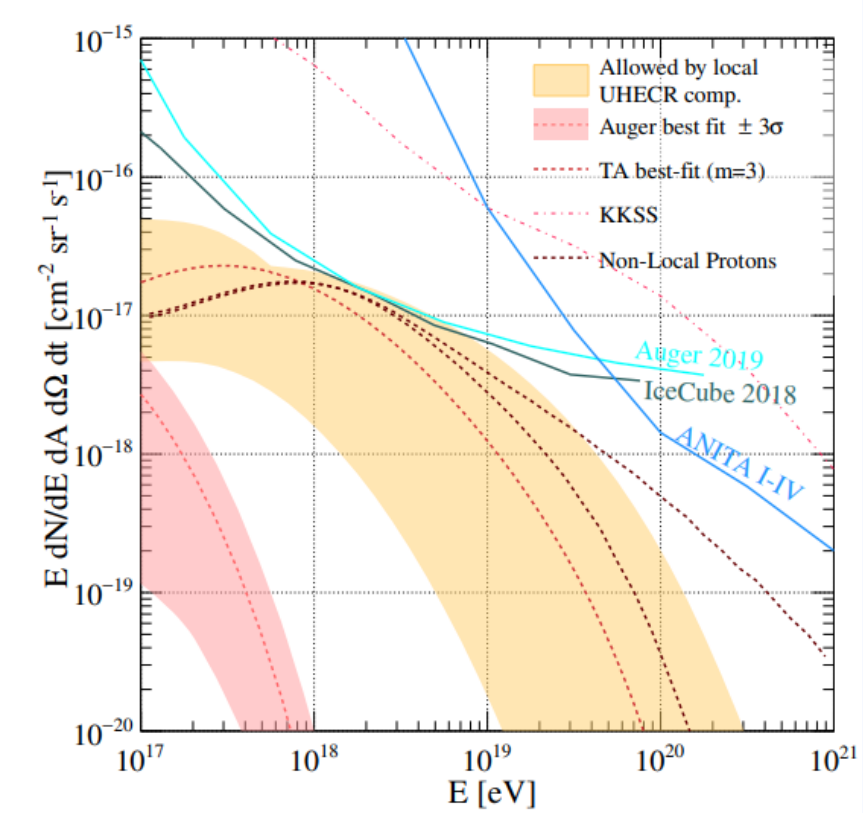
Characterize the cosmologically distant source populations including transient/flaring sources

Measure

Neutrino fluxes, energy, direction (sky map) and flavor*

*see Christoph's talk

Cosmin Deaconu ICRC 2023



Askaryan signal

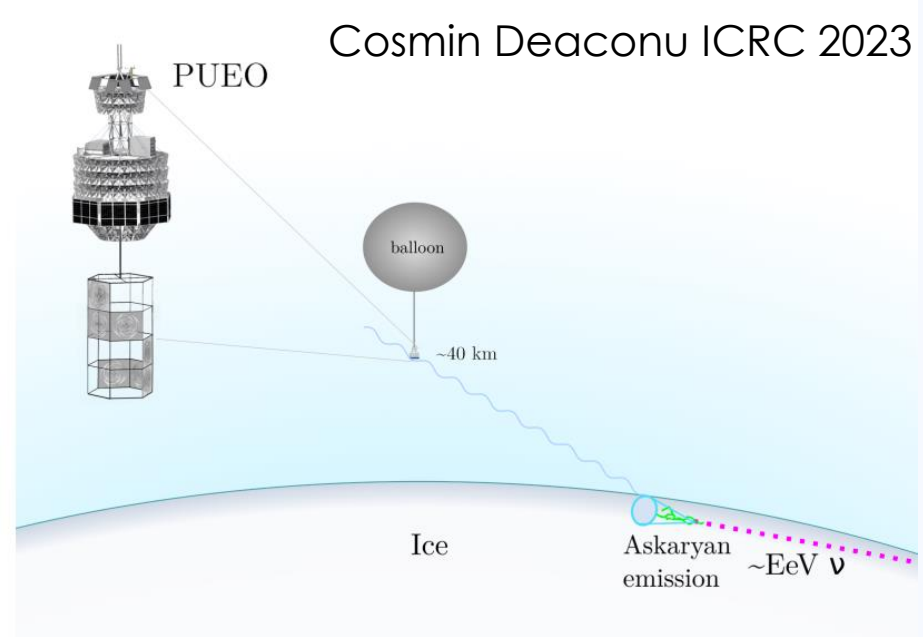
Askaryan pulse in ice and propagation to payload

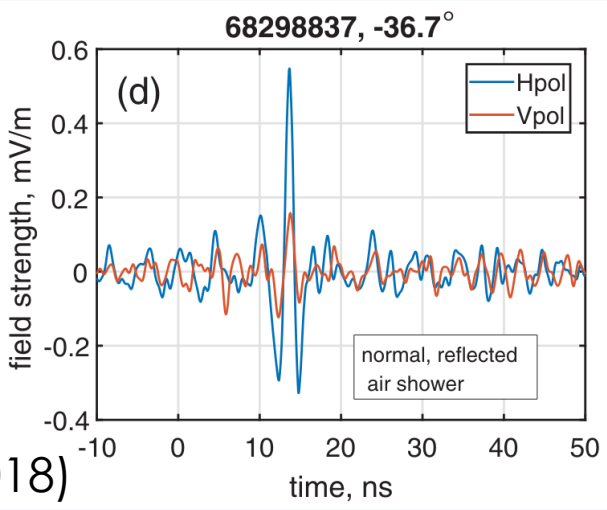
Design PUEO to:

A. Reconstruct the Electric field vs time
- E.g. ANITA geomagnetic signals

B. Neutrino direction
- Precision pointing -> sky map

C. Large effective area





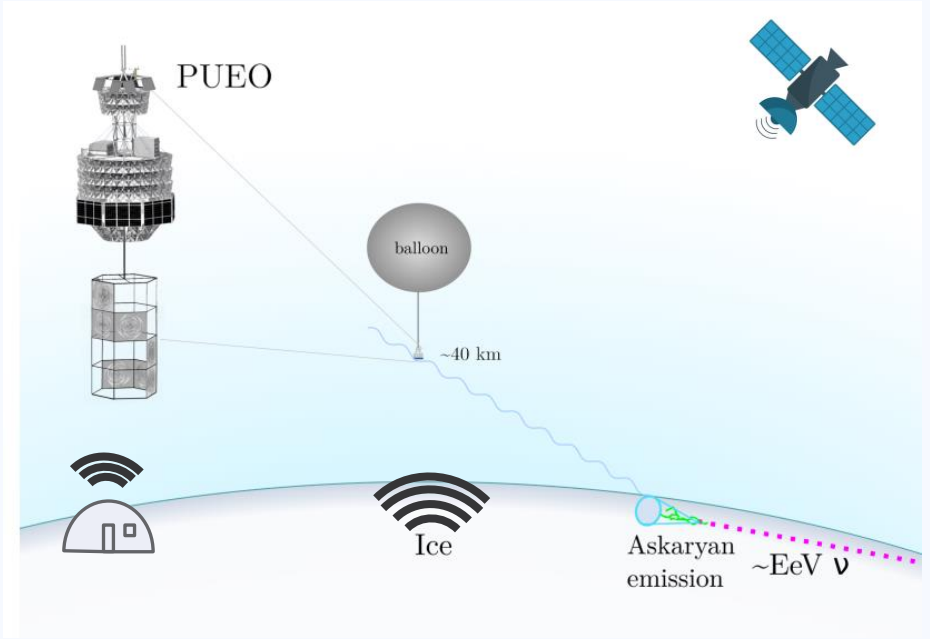
*Cosmic ray event
PRL 121, 161102 (2018)

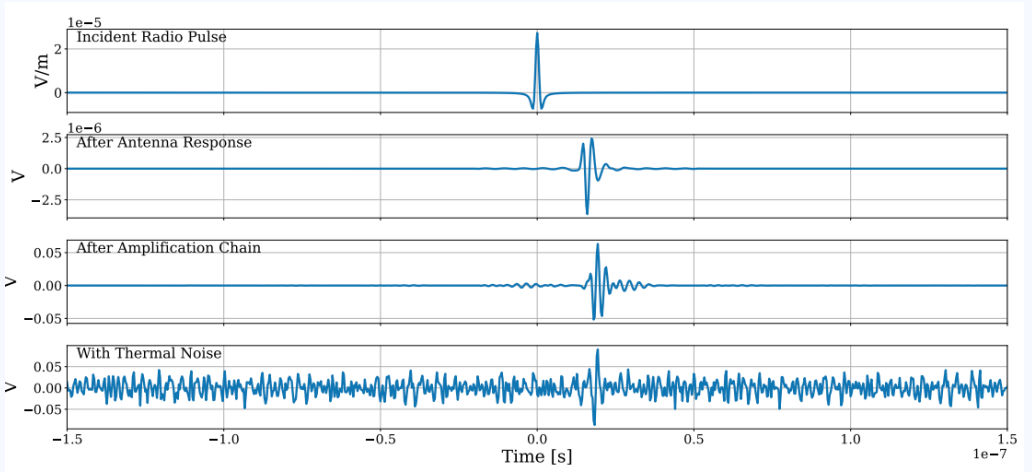
Backgrounds to mitigate

1. Thermal noise* – ice (can't get rid of it, in fact we need it)

2. Anthropogenic- on continent (bases) or space (satellites)
   - Digital notch filters
   - Increase the low frequency (LF) cutoff on main instrument compared to ANITA

3. Payload noise
   - EMI mitigation strategies e.g. Faraday housing electronics, EMI gasketing, etc





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The overall design of PUEO

Main Instrument – large number of antennas (192 channels)
- Collecting area
- Quad-ridged horn, dual polarized

Low frequency deployable instrument

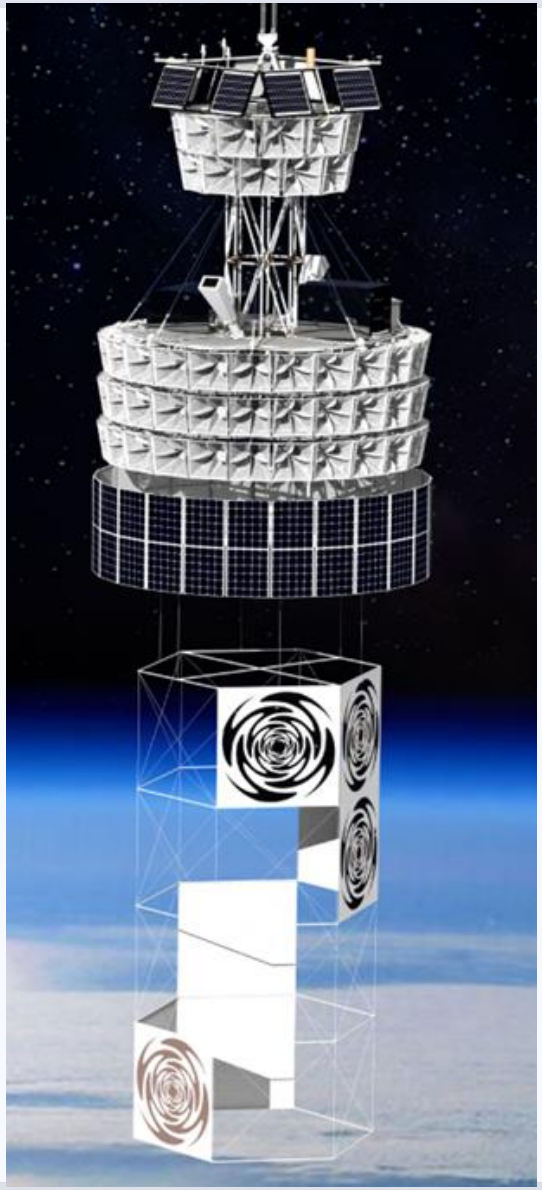
Large azimuthal coverage – 24 phi sectors
- 2π acceptance

Phased-array trigger

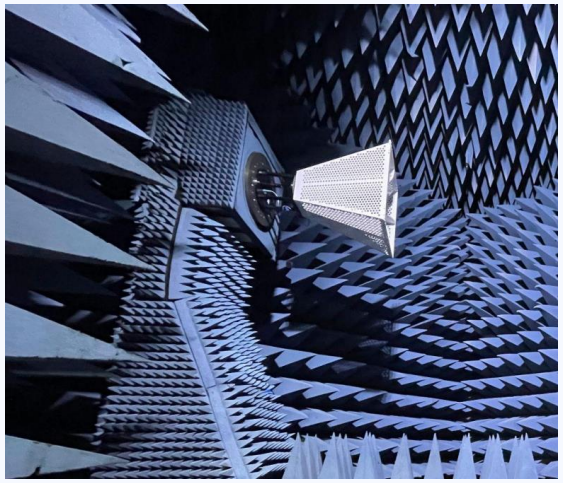
Navigation system

Power system – omni PV

RF enclosure for all electronics



Main Instrument antennas

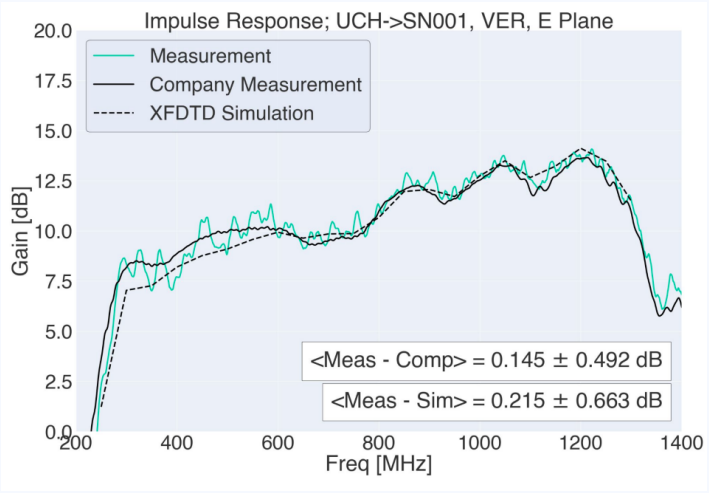


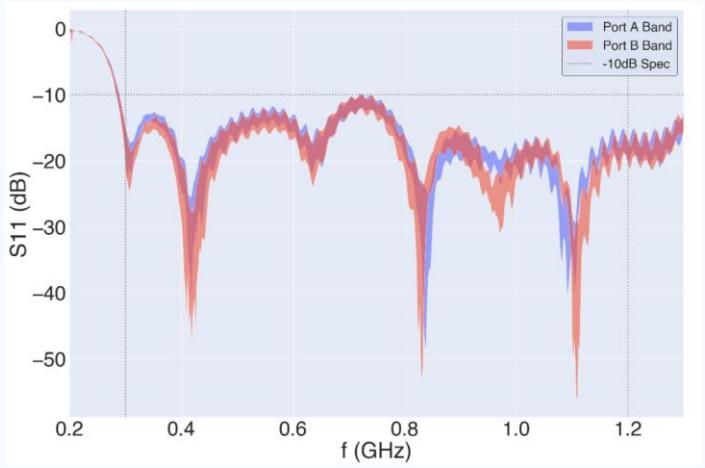
Dual polarization

Custom-designed by Toyon:

- Beampattern
- Gain across band
  - Bandwidth 300-1200 MHz
  - Compared to ANITA: 200-1200 MHz

-> Ongoing characterization of each antenna here at UC





Credit Martin & Mackey

Main Instrument – RF chain and MIE

Expected uV scale Askaryan signal at the antenna outputs

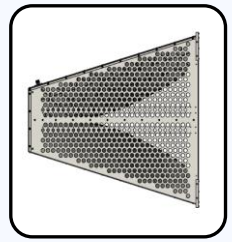
For DAQ, amplification and filter
- Gain (voltage) ~70dB

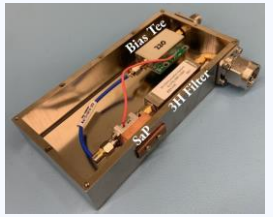
TV testing of RF chain components

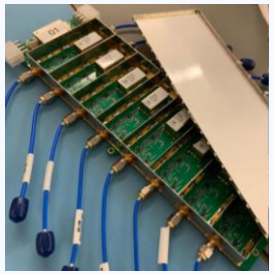
Enclosure for mitigation of RF pickup (-80dB)

->Ongoing qualification

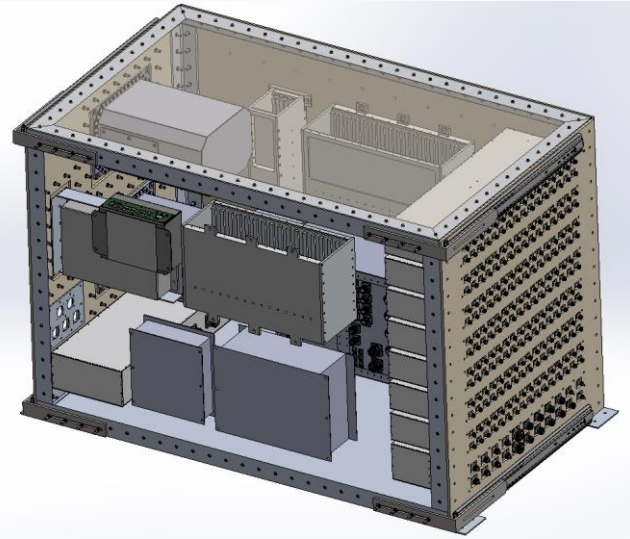
here at UC



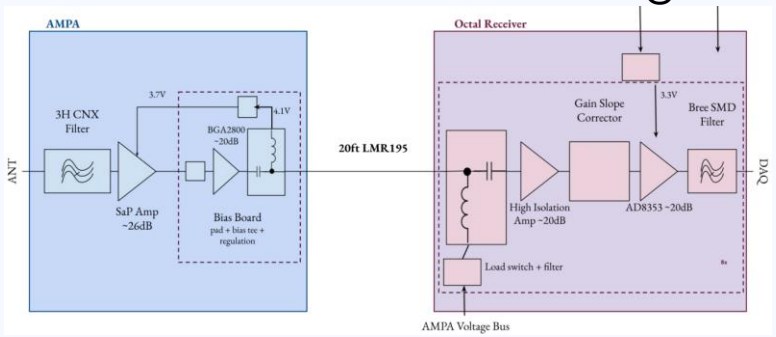




Main Instrument Enclosure

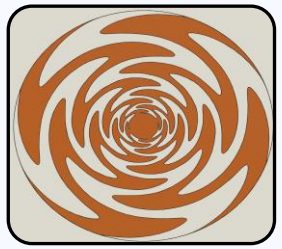


RF Chain diagram

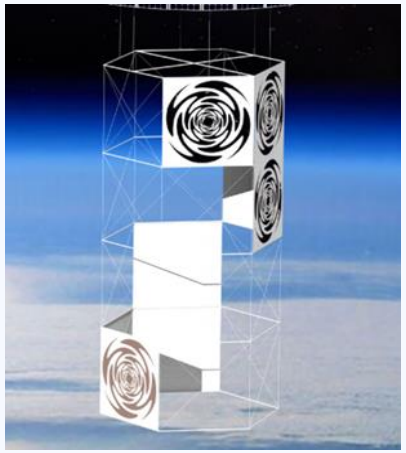


Credit R. Scrandis

Low Frequency Instrument



LF Antennas



8 dual polarized sinuous antennas deployed after launch

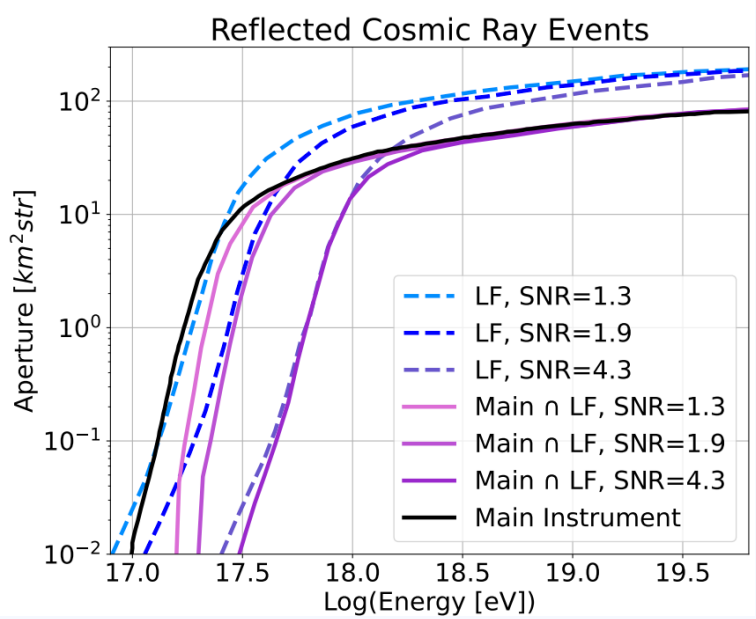
50-300MHz band with separate amplification chain

LF DAQ hardware is similar to Main Instrument

- Firmware filtering TBD

Cosmic ray shower aperature increase with LF

More in the next talk by Yuchieh



Kaeli Hughes ICRC 2023

DAQ and beamforming

Central component – RFSoC (x8 ADC 3 Gsps)
- low power trigger and digitizer system

SURF PCBs – x8 channels with 12 bit ADC samples

Beamforming done with 5 bit conversion post-filter
- E.g. Dual biquad+FIR filters then Automatic Offset and Gain Control ("12-to-5") algorithm
- Boost for Askaryan signal

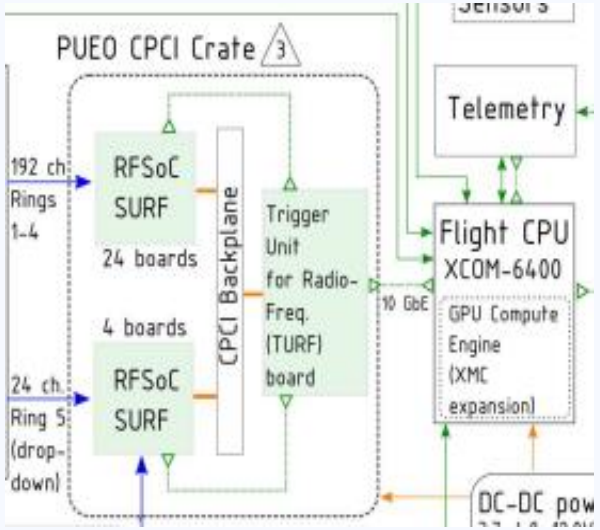
Firmware trigger optimization – ongoing study

-> Level 1 delay-and-sum beamforming of 8 channels (2 phi sectors of 1 Pol)

-> Level 2 Repeat with 4 phi sectors

-> Level 3 Above threshold post-removal of CW digitally

Sampling Unit for Radio Frequencies



Navigation suite

To achieve design goals of 50 meters precision in Lat, Long, altitude and 0.05° in heading, pitch, and roll there are many nav systems being integrated

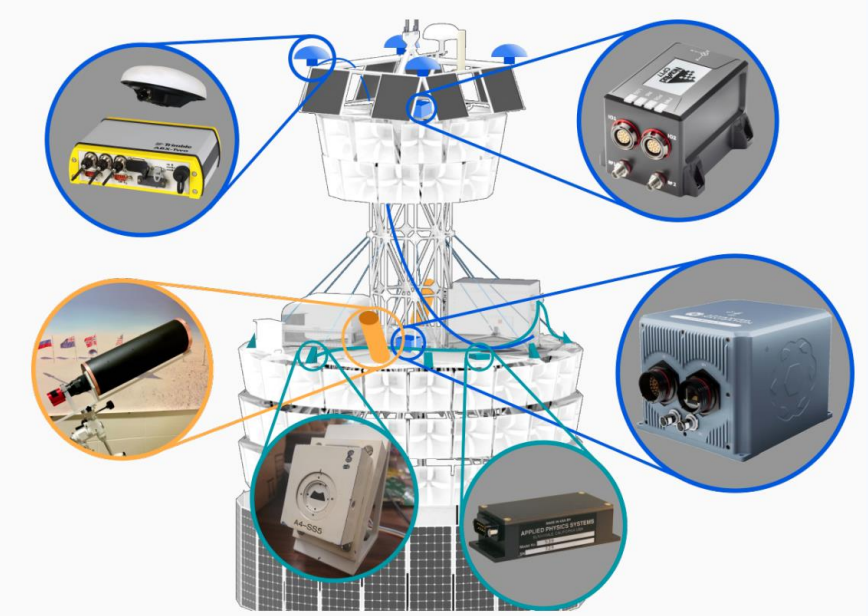
Inertial Navigation Systems (INS)

- 2 unique units: both independently spec'ed for 0.01 deg in pitch, roll, and heading

Differential GNSS unit

Star trackers and an omnidirectional sun sensor array

Magnetometer



Credit Quin Abarr

HiCal-3 and ground calibration

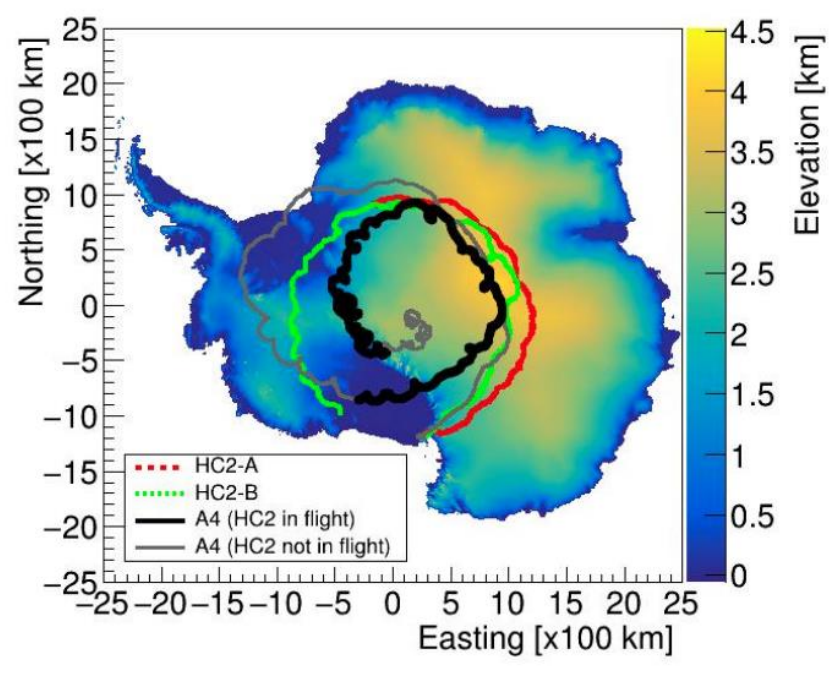
PUEO's ability to measure the energy and pointing of neutrinos is boosted by calibration pulses

HiCal-3 (x2) will be flown on separate balloons to accompany PUEO

- Based around the successful HiCal-2 with ANITA-IV
- V/H Pol pulses for calibration during flight
- Reflected and direct measurements

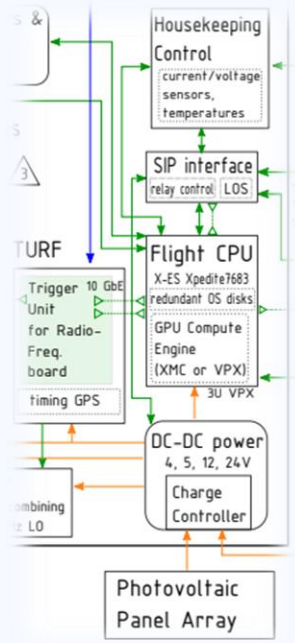
Ground system calibration

- Sites at McMurdo and WAIS Divide Siple Dome



Credit Steven Prohira

Flight computer, power, hsk

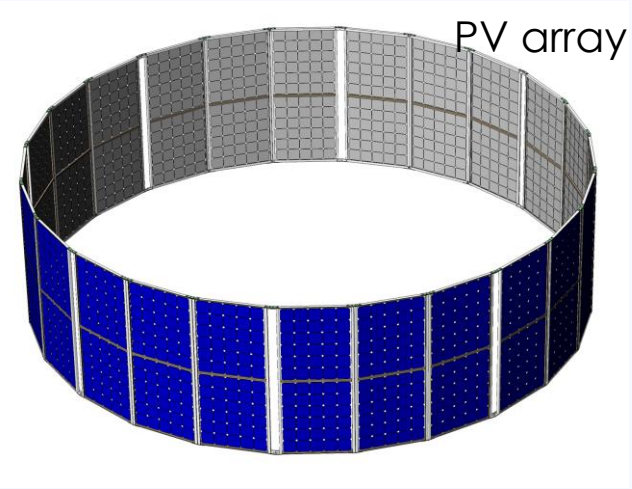


0.5MB events at 100Hz expected event rate

- Events are 12 bit ADC in window*(192 MI + 16 LF channels)
- 10GBe provides event data to SFC
- Triply redundant 128TB storage
- Prioritizer with GPU -> downlink data in flight

Power and Housekeeping

- PV array expected to provide 1800W
- Control system for RF bank
- Temperature monitoring



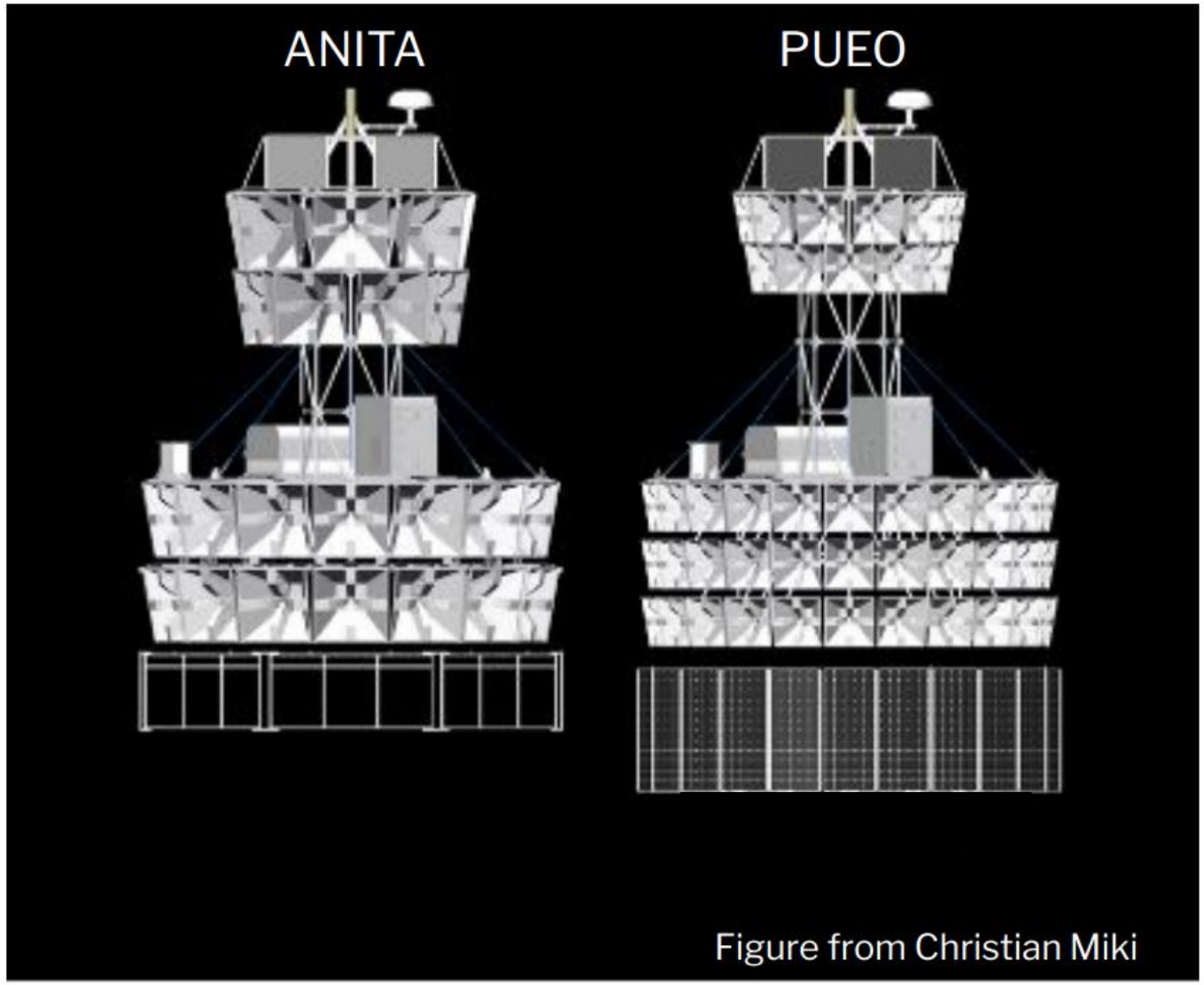
PUEO compared to ANITA

PUEO

4600lbs science

With everything 7000lbs

34.43H MCF (8000lbs max)



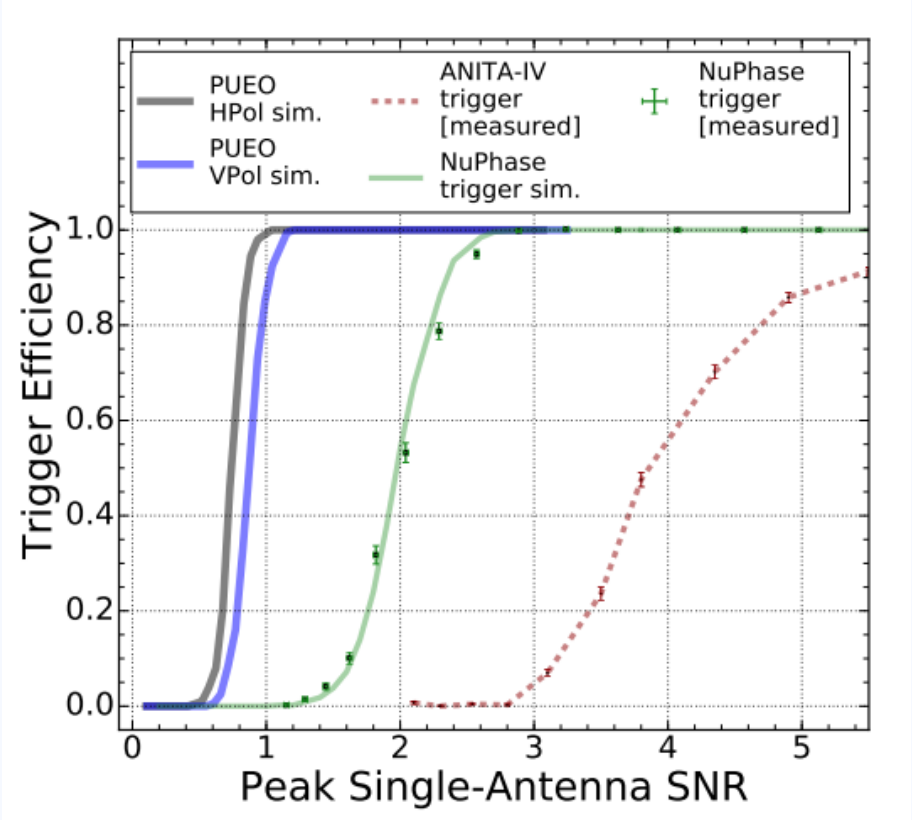
PUEO simulation studies

Simulations show design goals being met
- beamforming trigger
- real antenna responses incorporated

Higher effective SNR by combining channels at the L1 trigger
- Digitization + trigger on RFSoC enables improvement over ANITA SNR

Single event Askaryan channel shown

Ongoing simulation studies
- Including MI and LF full chain responses



Quin Abarr ICRC 2023

Conclusion

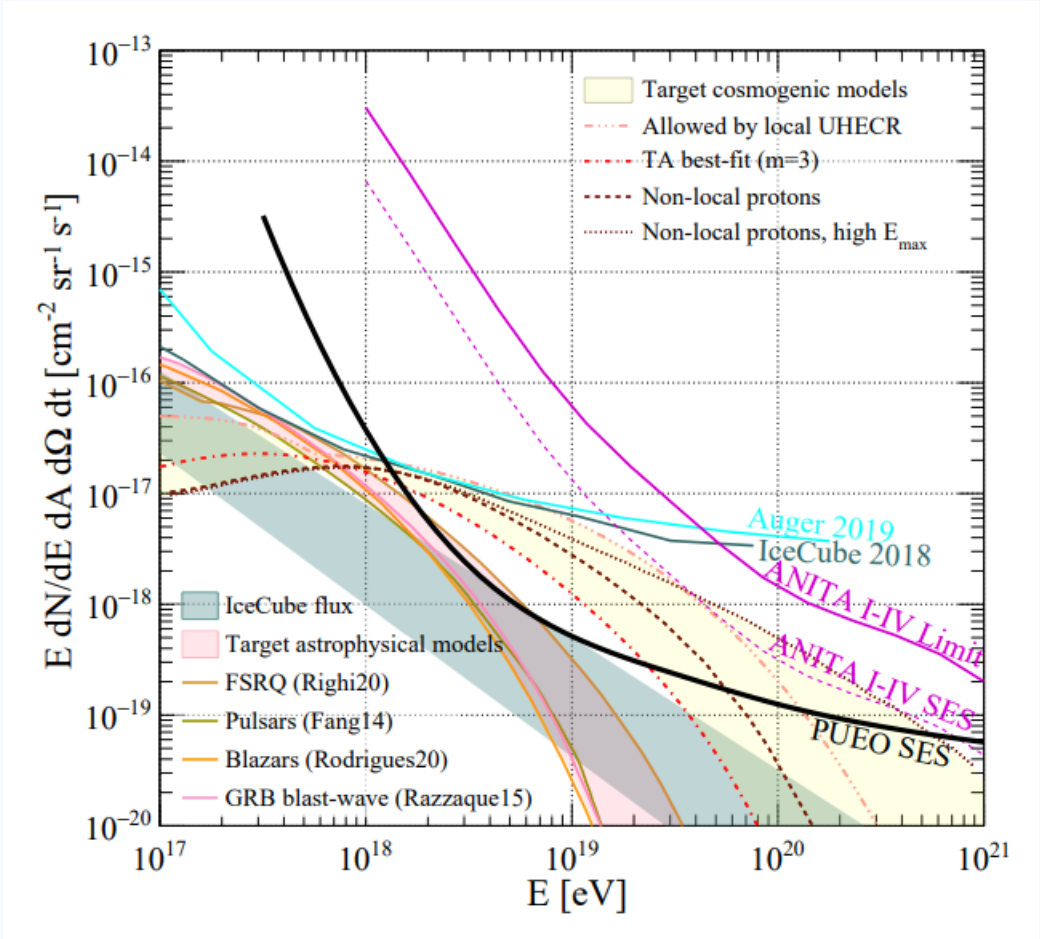
LDB mission designed with 60 day capacity, expecting launch in Dec 2025

Significant heritage from ANITA missions

Major improvement in sensitivity comes from:

- Smaller antennas and more of them
- Beamforming trigger and digitizer system with RFSoC technology
- Lessons learned on the many successful ANITA flights

PUEO will teach us about the highest energy accelerators in the universe!



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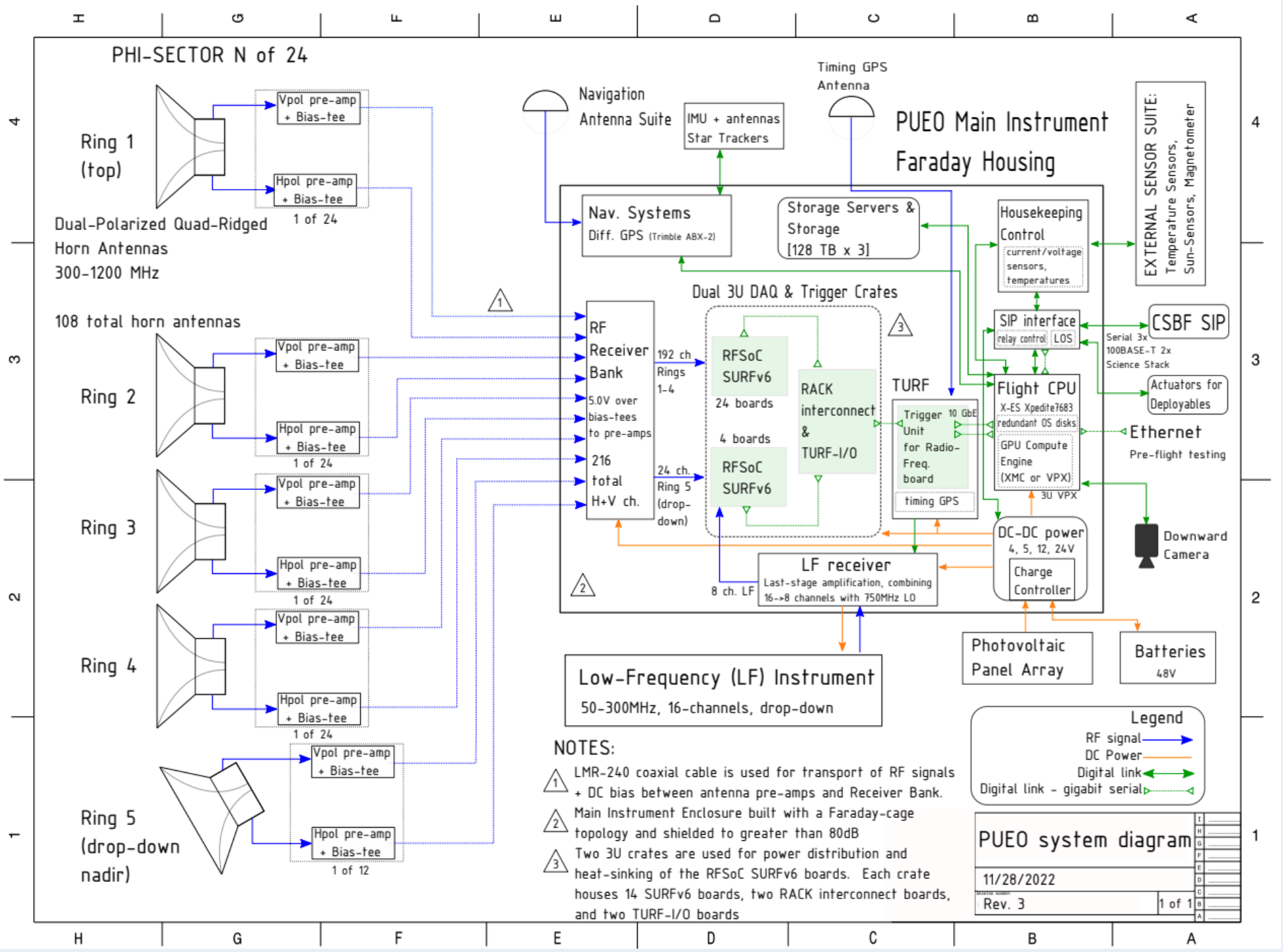
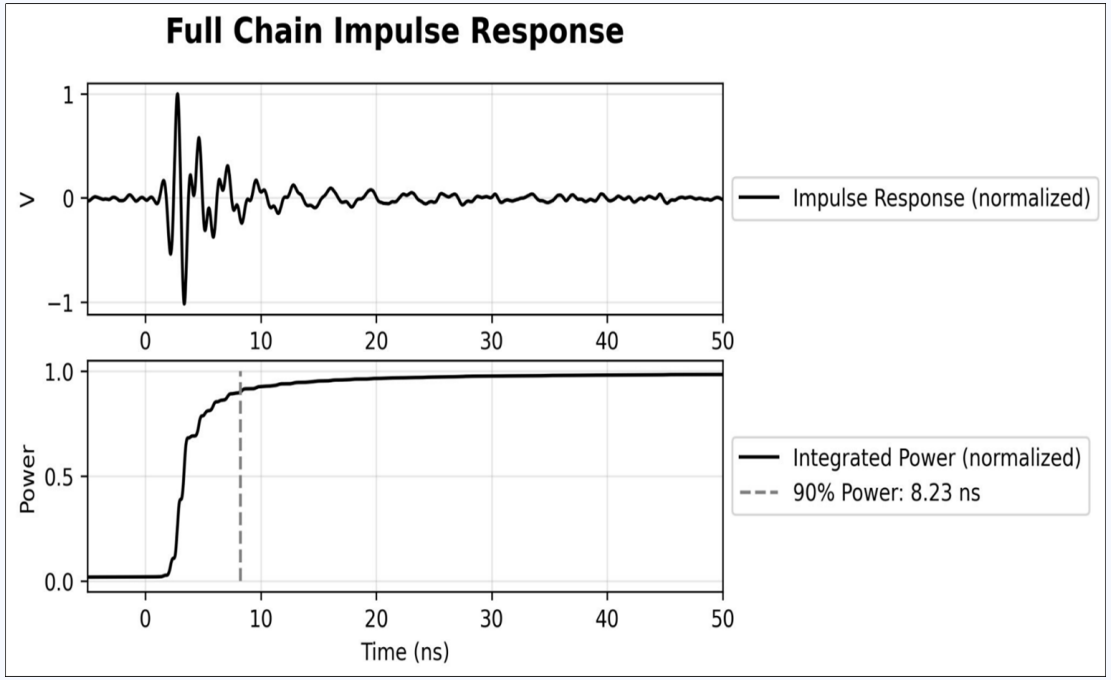
Thank you!

Backup big


PHI-SECTOR N of 24
Ring 1 (top)
Vpol pre-amp + Bias-tee
Hpol pre-amp + Bias-tee
1 of 24
Dual-Polarized Quad-Ridged Horn Antennas 300-1200 MHz
108 total horn antennas
Ring 2
Ring 3
Ring 4
Ring 5 (drop-down nadir)
Vpol pre-amp + Bias-tee
Hpol pre-amp + Bias-tee
1 of 24
1 of 12
Navigation Antenna Suite
IMU + antennas Star Trackers
Timing GPS Antenna
PUEO Main Instrument Faraday Housing
EXTERNAL SENSOR SUITE: Temperature Sensors, Sun-Sensors, Magnetometer
Nav. Systems
Diff. GPS (Trimble ABX-2)
Storage Servers & Storage [128 TB x 3]
Housekeeping Control
current/voltage sensors, temperatures
Dual 3U DAQ & Trigger Crates
RF Receiver Bank
5.0V over bias-tees to pre-amps
216 total H+V ch.
192 ch Rings 1-4
24 ch. Ring 5 (drop-down)
RFSoC SURFv6
24 boards
4 boards
RACK interconnect & TURF-I/O
TURF
Trigger Unit for Radio-Freq. board
timing GPS
10 GbE
SIP interface
relay control
LOS
CSBF SIP
Serial 3x 100BASE-T 2x Science Stack
Flight CPU
X-ES Xpedite7683
redundant OS disks
GPU Compute Engine (XMC or VPX)
3U VPX
Actuators for Deployables
Ethernet
Pre-flight testing
Downward Camera
DC-DC power
4, 5, 12, 24V
Charge Controller
LF receiver
Last-stage amplification, combining 16->8 channels with 750MHz LO
8 ch. LF
Low-Frequency (LF) Instrument
50-300MHz, 16-channels, drop-down
Photovoltaic Panel Array
Batteries
48V
Legend
RF signal
DC Power
Digital link
Digital link - gigabit serial
NOTES:
1 LMR-240 coaxial cable is used for transport of RF signals + DC bias between antenna pre-amps and Receiver Bank.
2 Main Instrument Enclosure built with a Faraday-cage topology and shielded to greater than 80dB
3 Two 3U crates are used for power distribution and heat-sinking of the RFSoC SURFv6 boards. Each crate houses 14 SURFv6 boards, two RACK interconnect boards, and two TURF-I/O boards
PUEO system diagram
11/28/2022
Rev. 3
1 of 1



RF chain, preliminary