Modeling Neutrino and Background Signals for the Payload for Ultrahigh Energy Observations (PUEO) Experiment

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Background

Detection Method

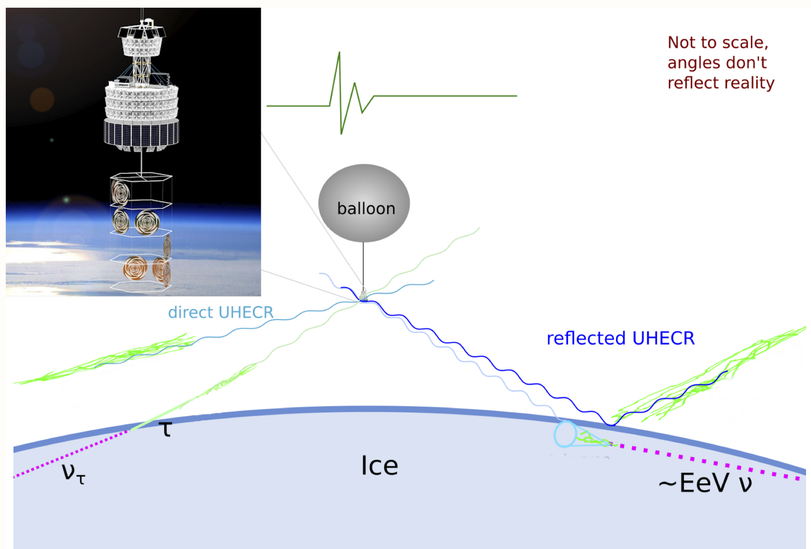

Figure 1: Diagram of radio observation of UHECR and neutrinos from altitude, image from C. Deaconu.

PUEO seeks to measure cosmic rays and neutrinos via radio emission:

- Ice-reflected emission from downward going CR
- Direct emission from above-the-limb CR
- Askaryan emission from in-ice neutrino interactions
- Direct emission from showers induced by neutrino-sourced τ-lepton decay in atmosphere

Previous ANITA Results

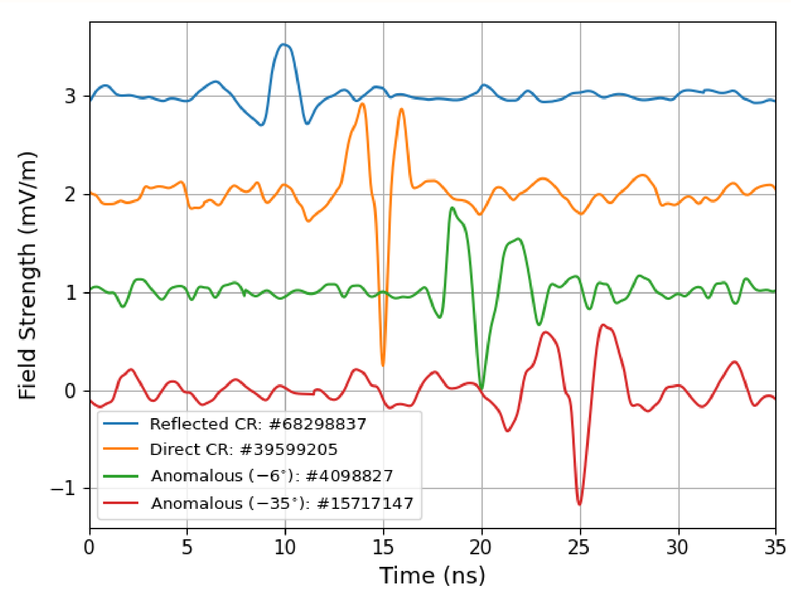

Figure 2: Different example waveforms observed during the flights of ANITA-I - ANITA-IV [1, 2, 3]

The predecessor to PUEO, ANITA (Antarctic Impulsive Transient Antenna), has set the strictest limits on the astrophysical neutrino flux above energies of 30 EeV, and recorded:

- 64 reflected cosmic ray candidates
- 7 direct cosmic ray candidates
- Below horizon candidates with un-inverted polarity:
  - 4 just below horizon (-6° elevation angle)
  - 2 steeply below horizon (-27.4° and -35°)

Science Goals of PUEO

- Detect the first astrophysical neutrino with an energy exceeding 1EeV or set strict limits
- Characterize the below horizon events observed by ANITA
- Ancillary studies, studies of ice properties

PUEO

Main Instrument

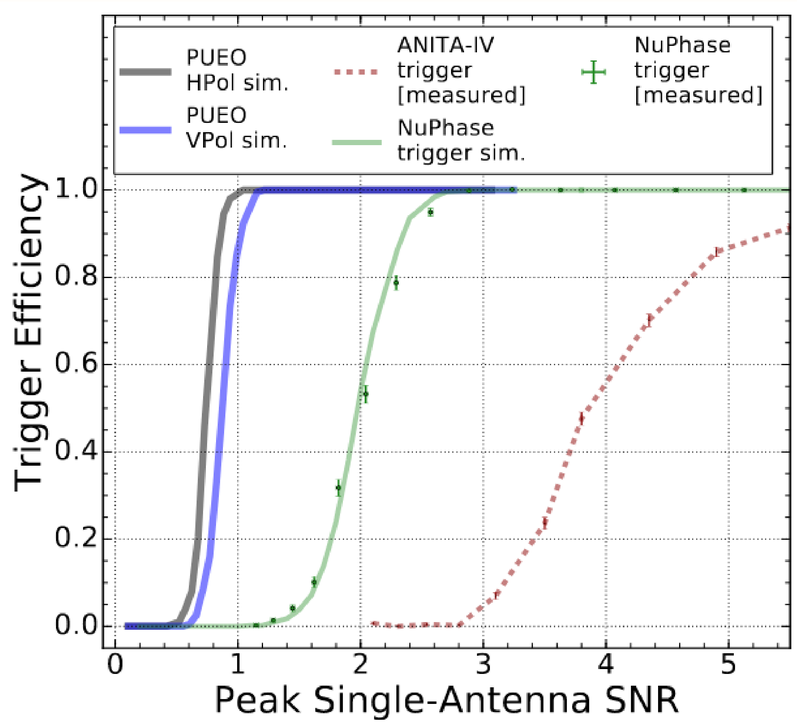

Figure 3: Simulated trigger efficiency of PUEO using a 16-antenna beamforming trigger compared to the trigger efficiency of ANITA-IV and ARA (Askaryan Radio Array) [4]

- 108 dual-polarization quad-ridge horn antennas, 300-1200 MHz bandwidth
  - Collecting area > 2X ANITA
- Donward-canted (10°) dropdown antenna ring improves sensitivity to upgoing EAS
- RFSoC's (Radio-Frequency System-on Chip) allow for improved filtering of anthropogenic noise
- Beamforming trigger allows for coherent addition of signals recorded in multiple antennas, improving the SNR

Low Frequency Instrument

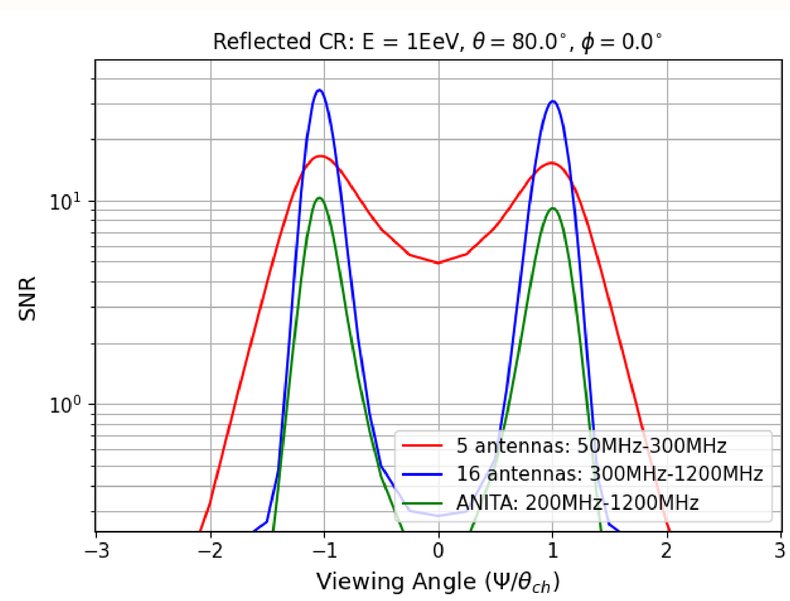

Figure 4: Integrated SNR of a reflected cosmic ray event as a function of viewing angle, assuming ANITA and PUEO antenna gain curves, and beamforming scaling SNR $\propto \sqrt{N}$

- 8 sinuous antenna dropdown array below main instrument, 50-300 MHz bandwidth
- Lower frequency bandwidth allows for amplified observational solid angle
  - Enhanced sensitivity to EAS
- Complementary and independent to main instrument
  - Coincident triggers
  - Better identification of signal versus background

Modeling

PUEOSim

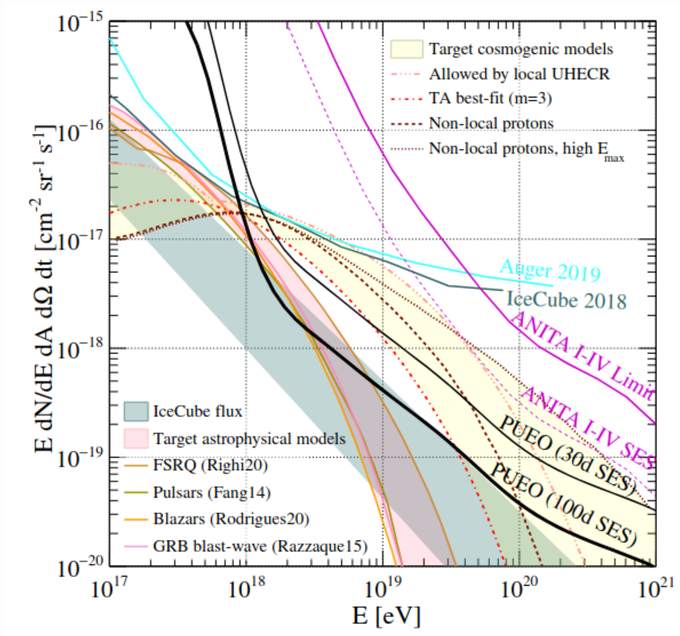

Figure 5: Simulated Single-Event-Sensitivity to cosmic neutrinos for PUEO, calculated via scaling of ANITASim [4]

PUEOSim is a Monte Carlo simulation package developed to model the signals and backgrounds for PUEO

- icemc [5] is used to model the Askaryan emission from neutrino interactions in ice
  - Neutrino survival probability = $\exp(-X_{tot}/X_{int})$
- Reflected CR and τ-lepton induced showers modeled using ZHAireS [6] being imported

νSpaceSim

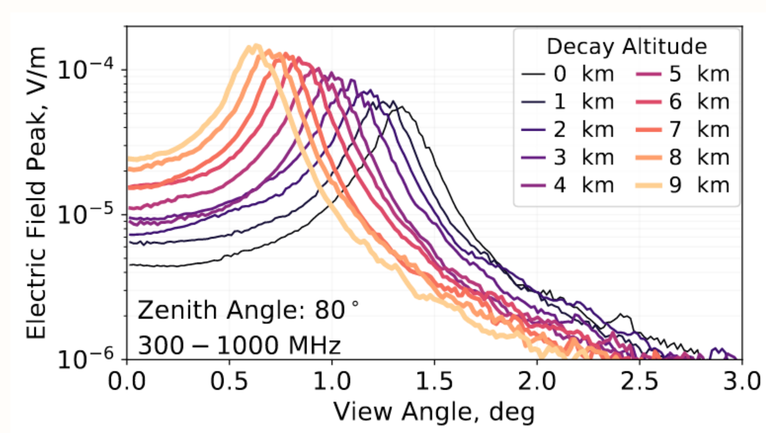

Figure 6: Maximum electric field value for τ-lepton induced air showers with an 80° zenith angle and varied decay altitudes generated by ZHAireS for use in the NuSpaceSim framework[7]

νSpaceSim [8] is an end-to-end simulation package that models optical and radio emission from neutrino-sourced upgoing EAS for sub-orbital and space based detectors

- Radio emission model generated from ZHAireS simulations and referenced via lookup tables
- Propagates neutrinos through the Earth with NuPyProp
- Reproduces ANITA sensitivity curves
- Above-the-limb CR being implemented

[1] P. Gorham *et al. Phys. Rev. Lett.*, vol. 117, no. 7, 2016.

[2] P. Gorham *et al. Phys. Rev. Lett.*, vol. 121, no. 16, 2018.

[3] P. Gorham *et al. Phys. Rev. Lett.*, vol. 126, no. 7, 2021.

[4] Q. Abarr *et al. JINST*, vol. 16, no. 08, p. P08035, 2021.

[5] L. Cremonesi *et al. JINST*, vol. 14, no. 08, p. P08011, 2019.

[6] J. Alvarez-Muñiz, W. R. Carvalho, and E. Zas *Astropart. Phys.*, vol. 35, no. 6, pp. 325–341, 2012.

[7] A. Romero-Wolf *PoS*, vol. ICRC2021, p. 1031, 2021.

[8] J. F. Krizmanic *et al. PoS*, vol. ICRC2019, p. 936, 2020.

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