Direction Reconstruction For the Radar Echo Telescope (RET)

Dylan Frikken on behalf of RET

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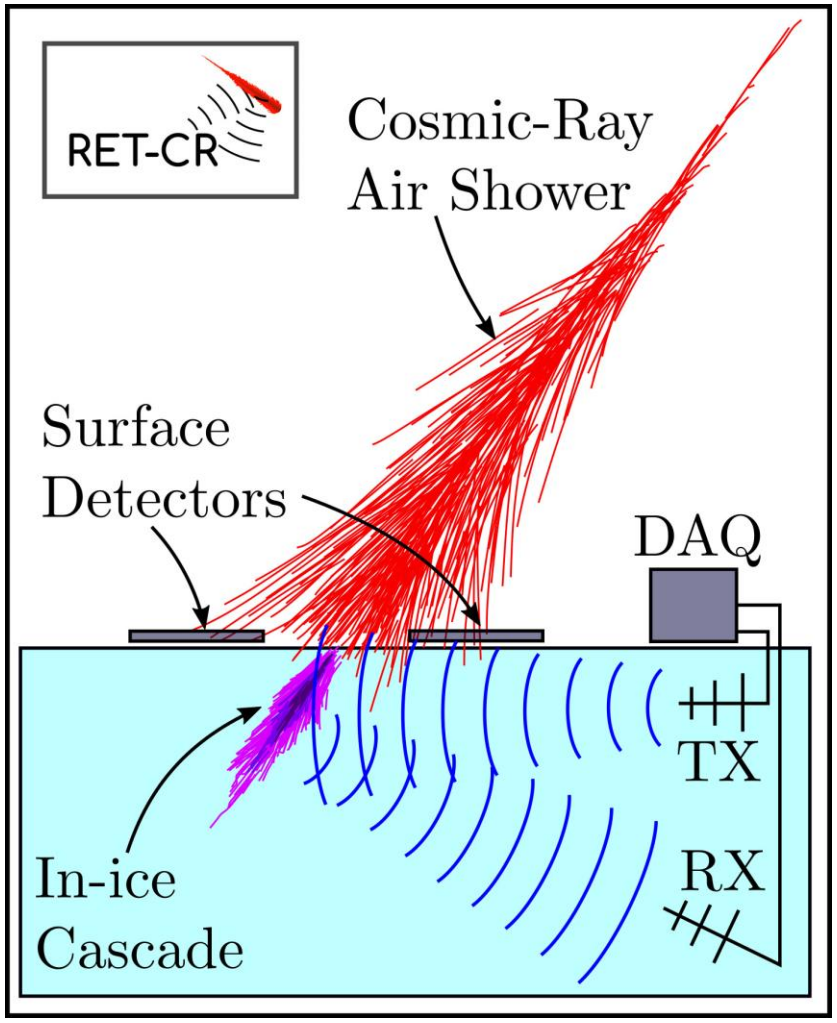
Outline

- What is the Radar Echo Telescope?
- Laboratory Studies and Method Verification
- Investigation of Received Signal Properties and Observables
- Using Signal Properties to Reconstruct Events
- Next Steps and Future Work

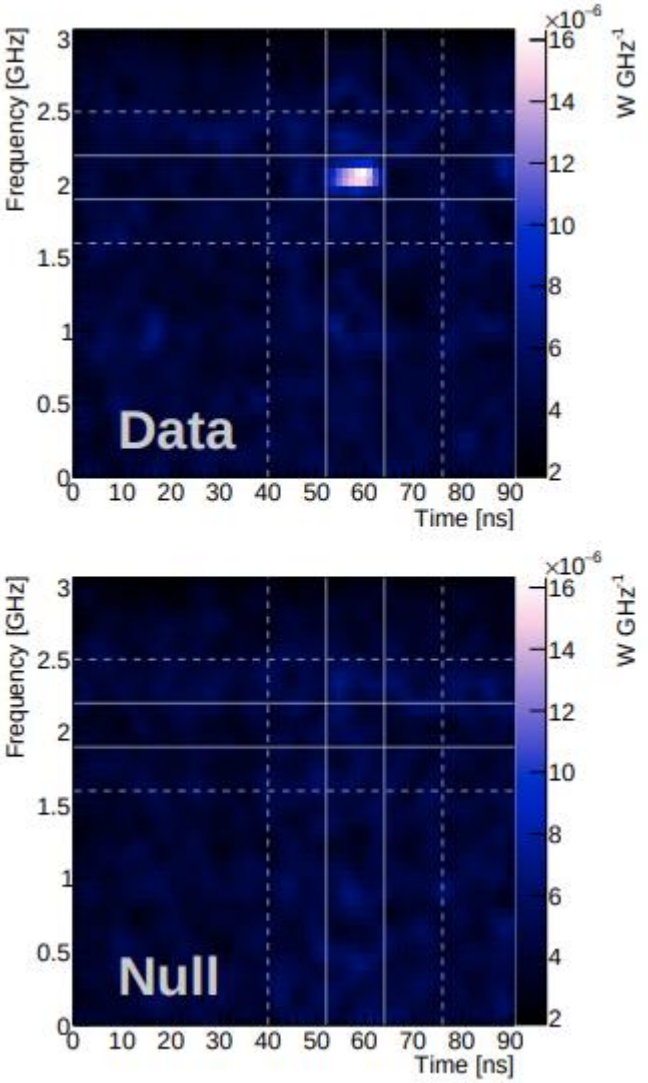
What is the Radar Echo Telescope?

- RET is an umbrella for 2 projects, RET-CR is a prototype to test the method on the in-ice core of cosmic ray air showers (right) and RET-N for neutrinos.
- RET-N is a new proposed system to target neutrinos with energies greater than 10^{16} electron volts (10 PeV), just above IceCube gen2 optical
- **Control of transmit signal and geometry leads to new observables**
- See contribution 85 for more info on RET



Laboratory Studies and Method Verification

- Used electron Beam dumped into plastic target to simulate neutrino interactions in ice
- First observation of Radar Echo off particle-shower induced ionization trail
- See contribution 85 for more info



PHYSICAL REVIEW LETTERS 124, 091101 (2020)

Editors' Suggestion | Featured in Physics

Observation of Radar Echoes from High-Energy Particle Cascades

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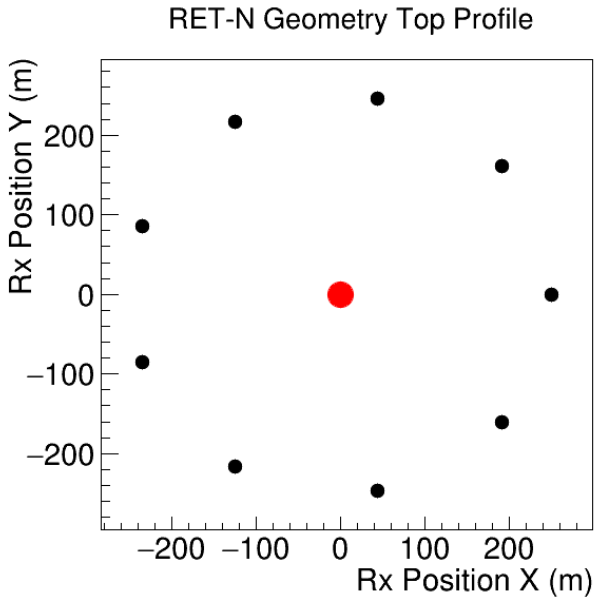
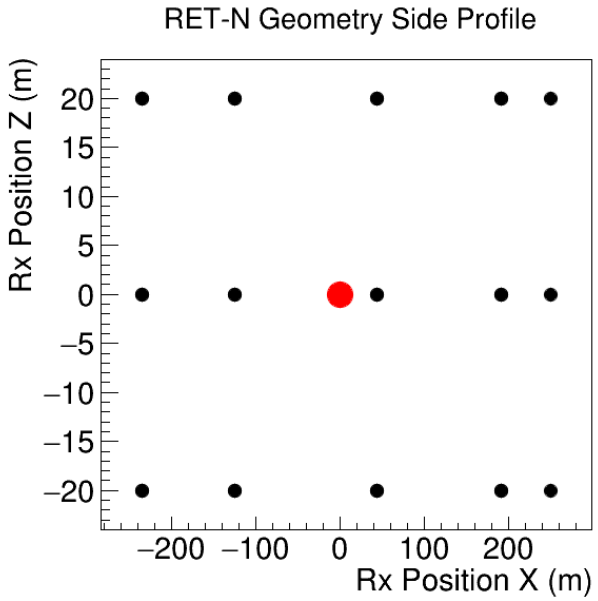
arXiv:1910.12830

RET-N Preliminary Geometry

- Buried in ice (~1500m)
- Phased-Array Transmitter (Tx)
- Tx at center of geometry
- Tx broadcasting 450 Mhz continuous Sine wave (CW)
- 27 Receivers (Rx)



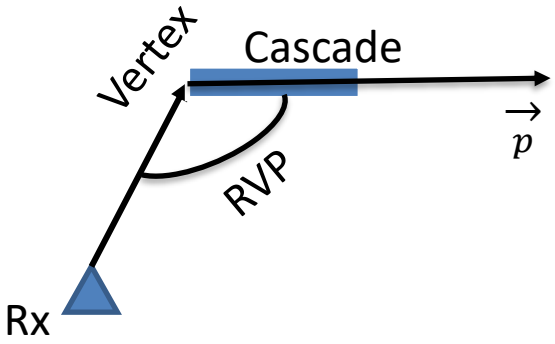


Position Z is relative to geometry center

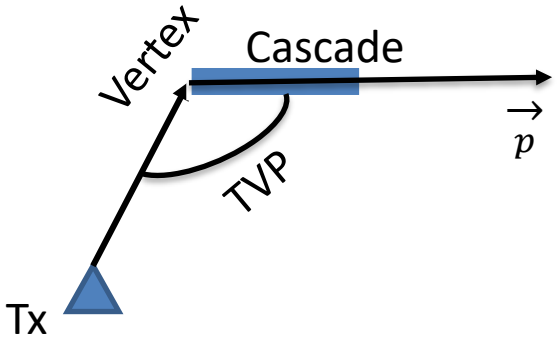
Red dot denotes Transmitter, black dots denotes receivers

RET-N Preliminary Geometry Definitions

- Angle RVP
  - Angle subtended by the receiver, cascade vertex, and cascade momentum direction

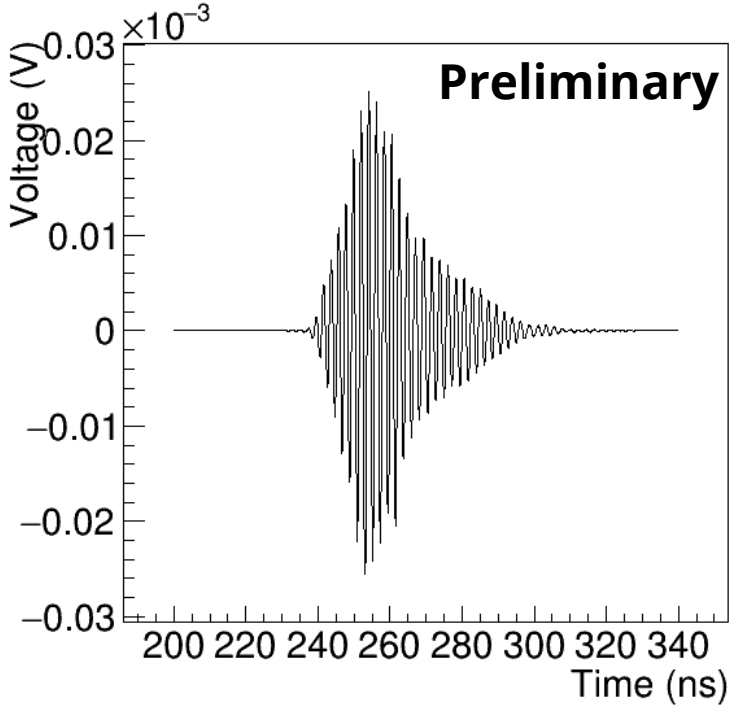


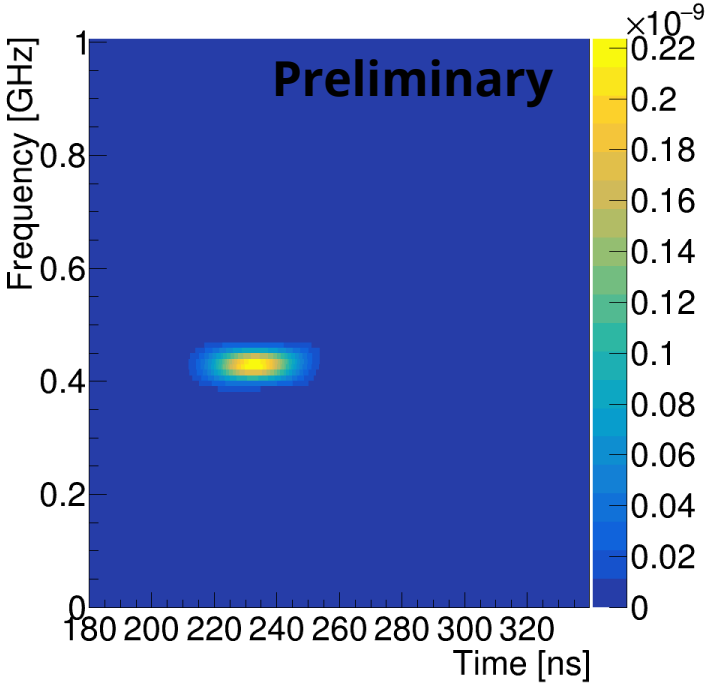
- Angle TVP
  - Angle subtended by the transmitter, cascade vertex, and cascade momentum direction



Investigation of Received Signal Properties

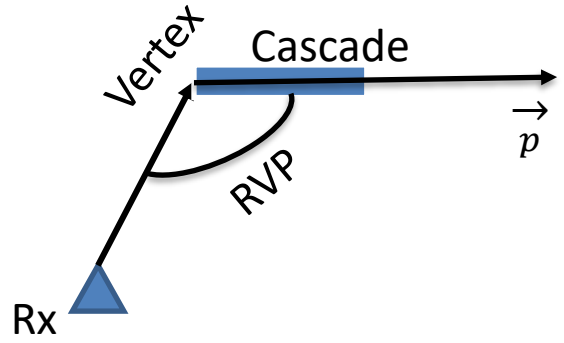
- RET simulated using RadioScatter (in-house radar reflection simulation with GEANT4) arXiv:1710.02883
- Left: Example event time domain waveform
- Right : Frequency-time plot (spectrogram) for example event



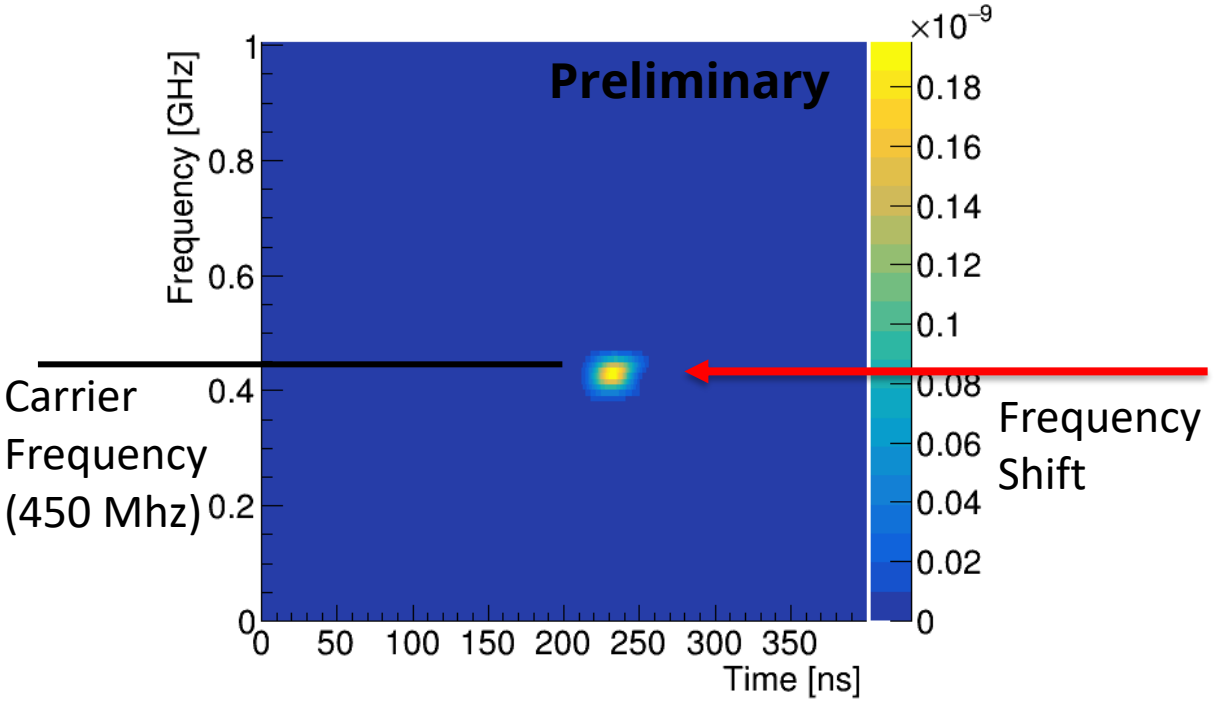


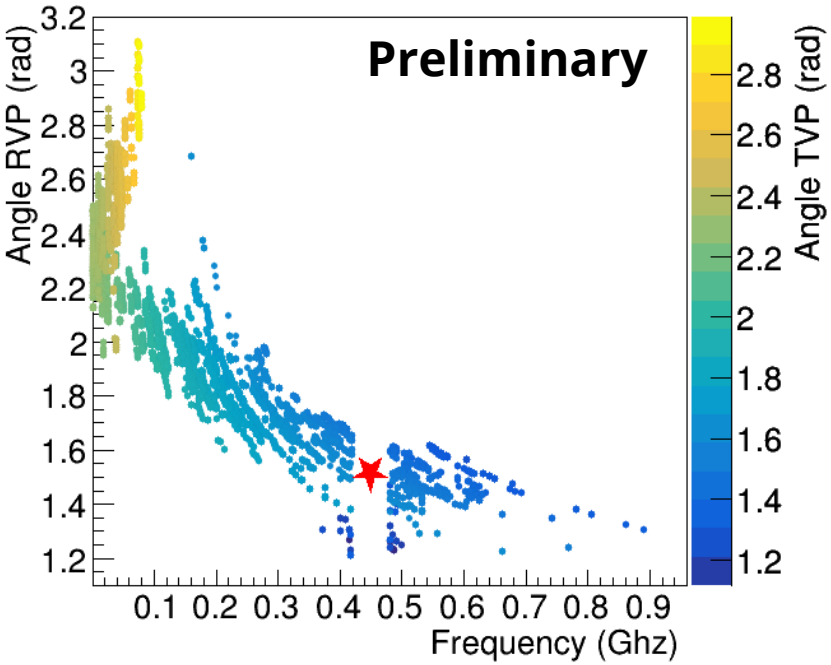
Investigation of Received Signal Properties

- Example of an event with a received signal with no frequency shift



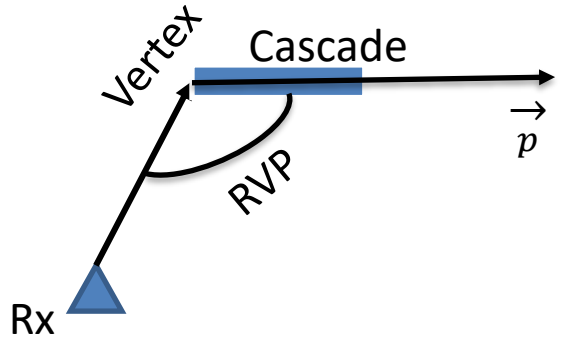
Red Star denotes this event



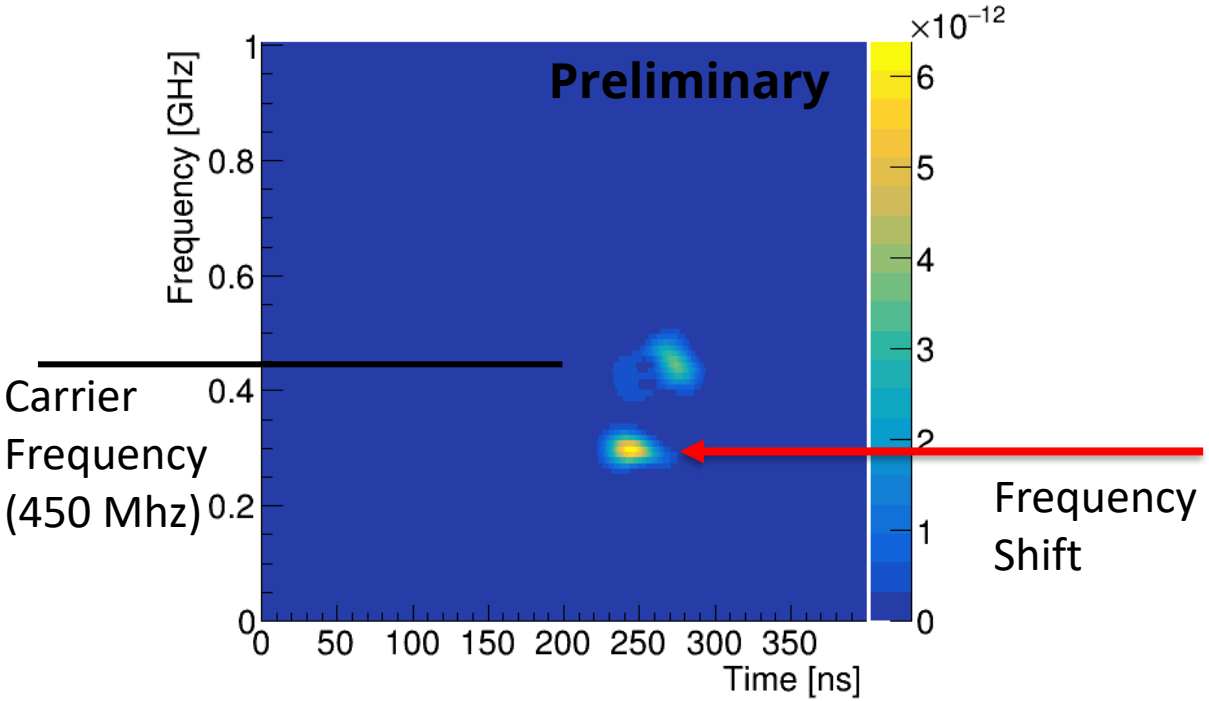


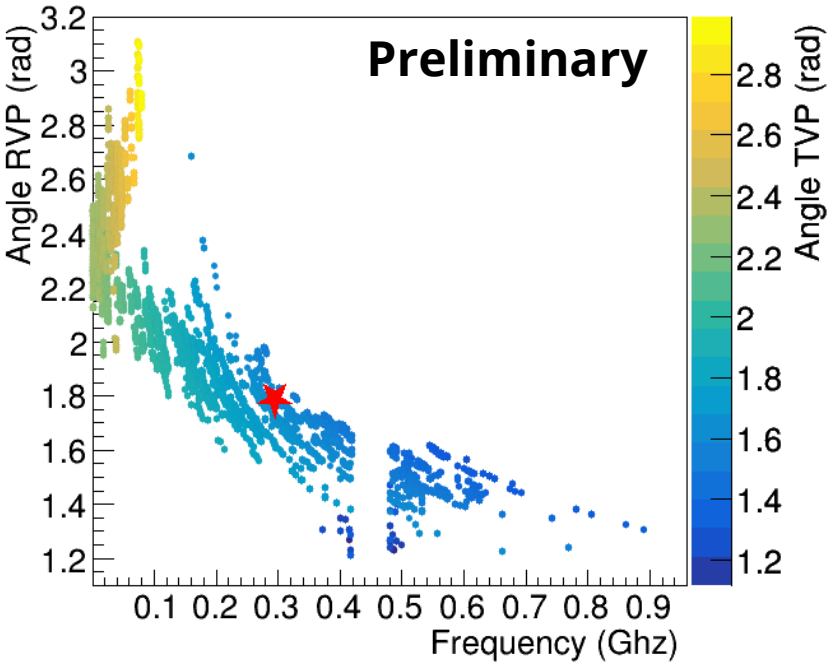
Investigation of Received Signal Properties

- Example of an event with a received signal with a down-shifted frequency



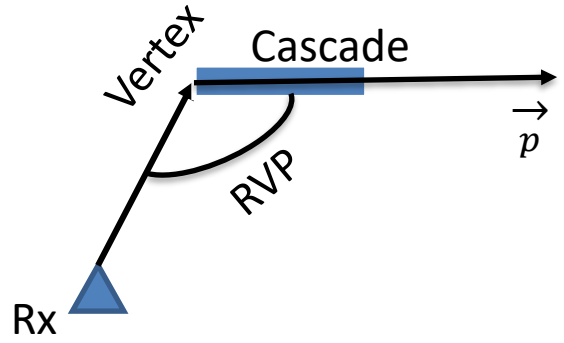
Red Star denotes this event



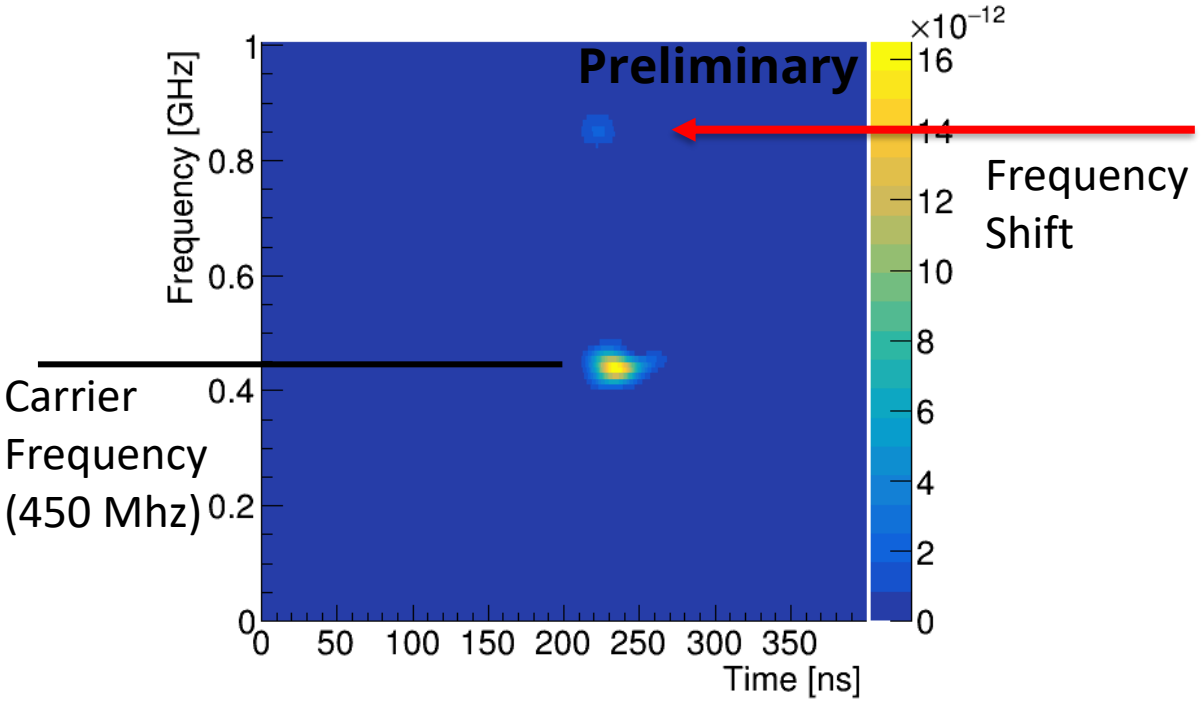


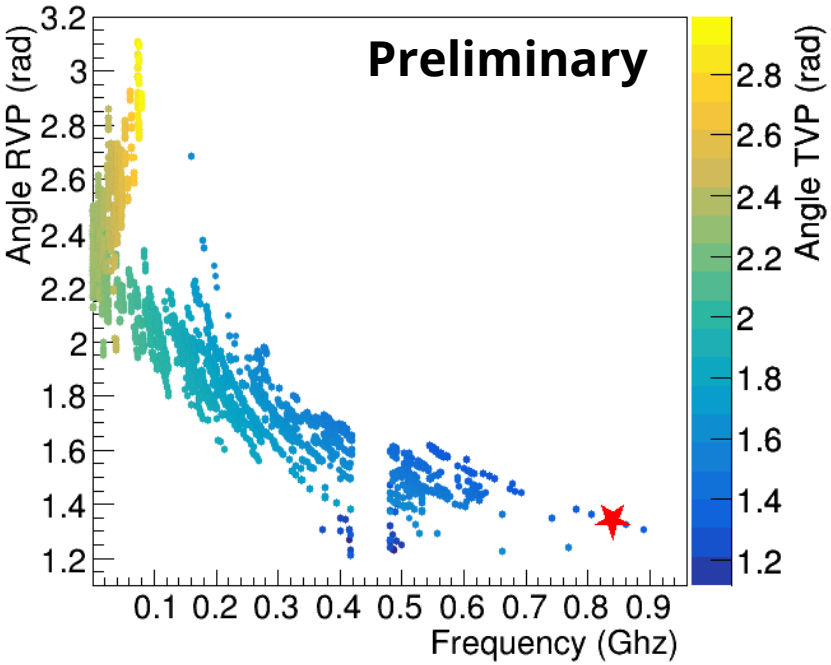
Investigation of Received Signal Properties

- Example of an event with a received signal with an up-shifted frequency



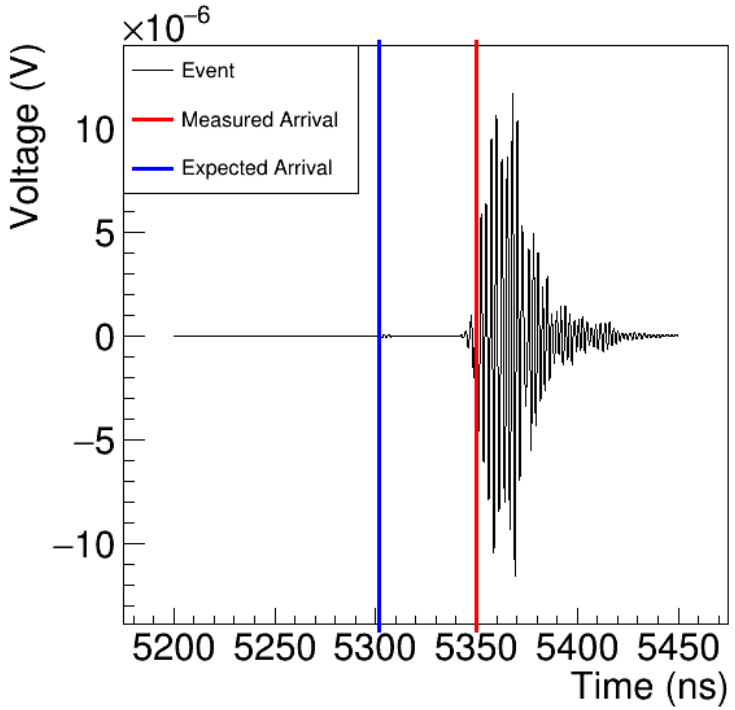
Red Star denotes this event



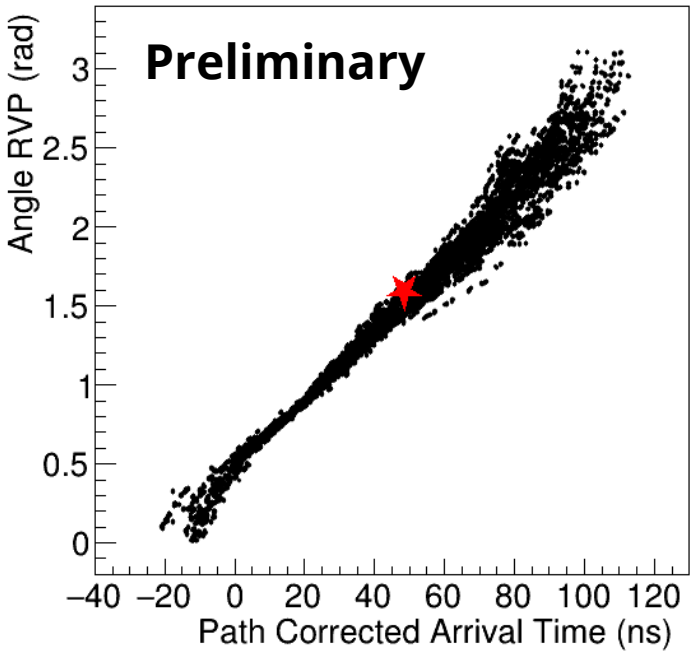


Investigation of Received Signal Properties

- Expected arrival time is the light travel time from interaction point to the receiver
- Path corrected arrival time is the difference between expected and measured arrival time

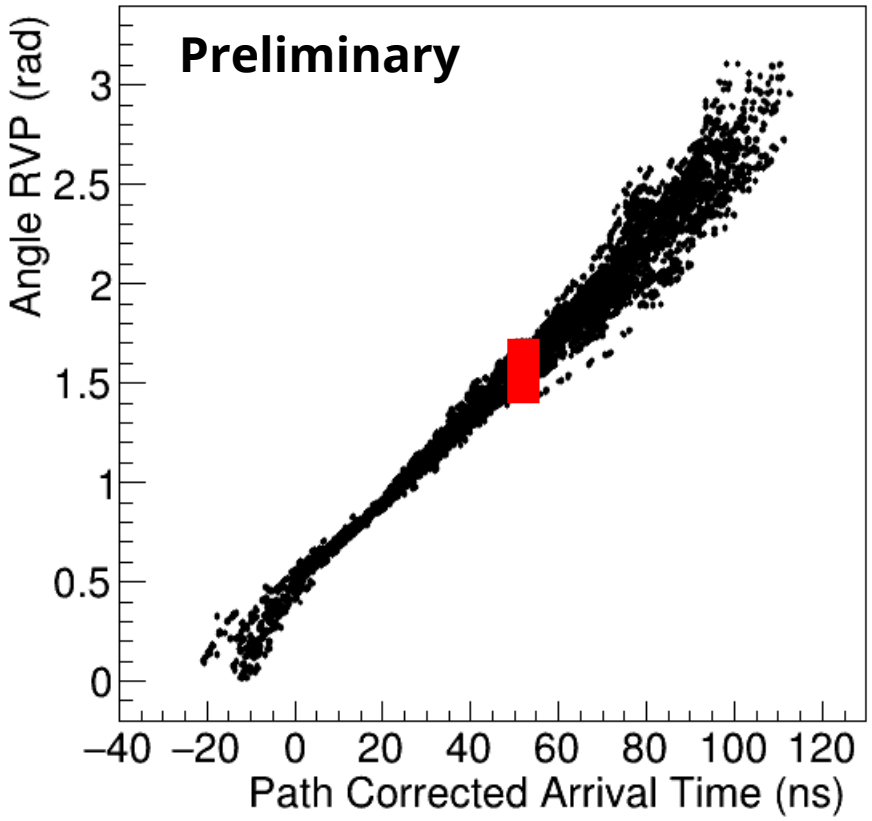


Red Star denotes this event



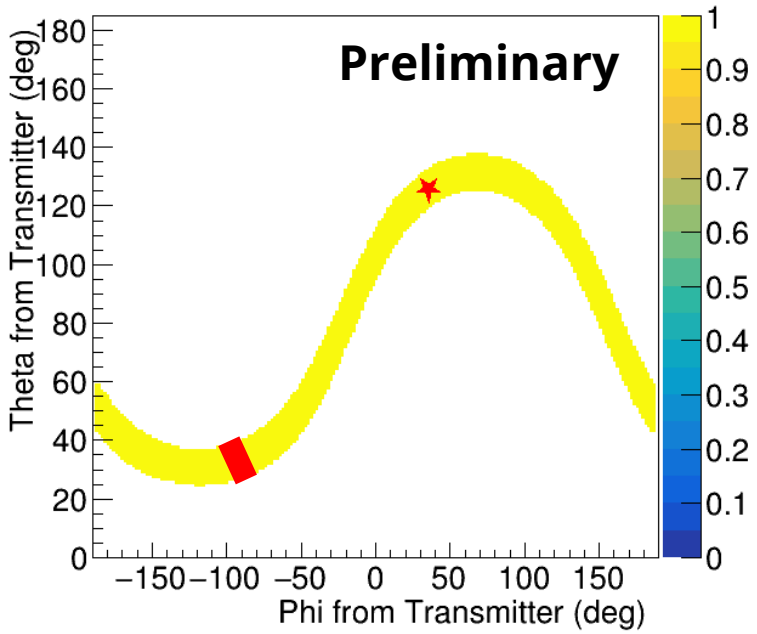
Using Signal Properties to Reconstruct Events

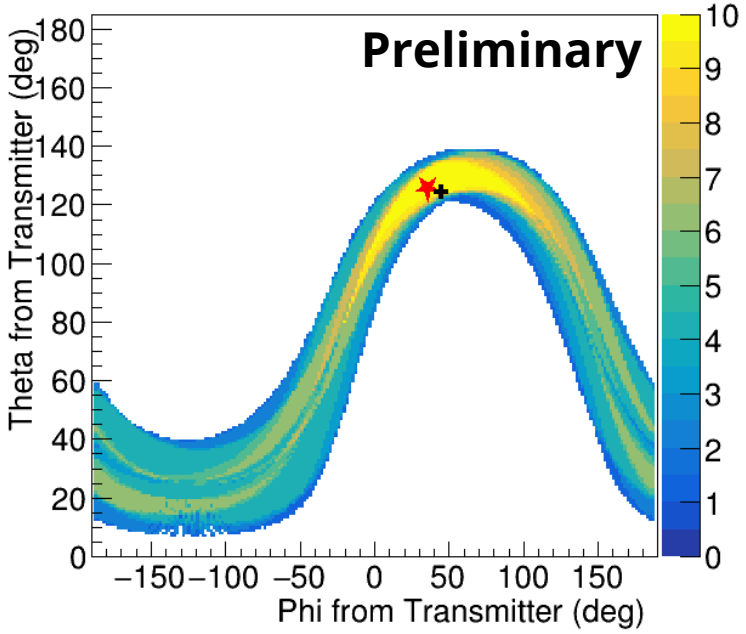
- Corrected arrival time is something we can use to determine direction
- Path corrected arrival time gives an error region in angle RVP for the event
- We take a single receiver from an event and calculate the path corrected arrival time and determine the allowed angle RVP (red rectangle on left plot.)



Using Signal Properties to Reconstruct Events

- Using the error band from the path corrected arrival time measurement (red rectangle), we make a single-antenna sky map (left) to determine event direction
- Done with multiple antennas (right), an overlapping region denotes event direction



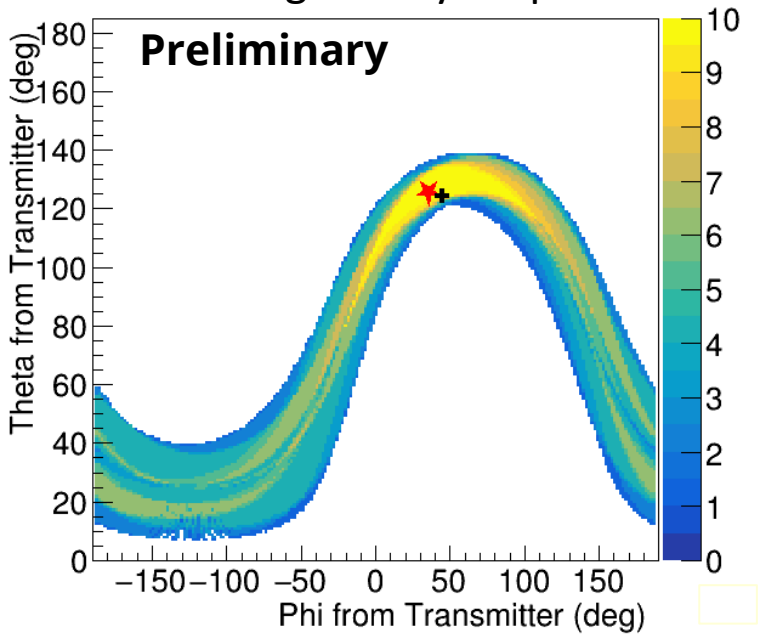


Red Star denotes true event location, black cross denotes best guess from sky map

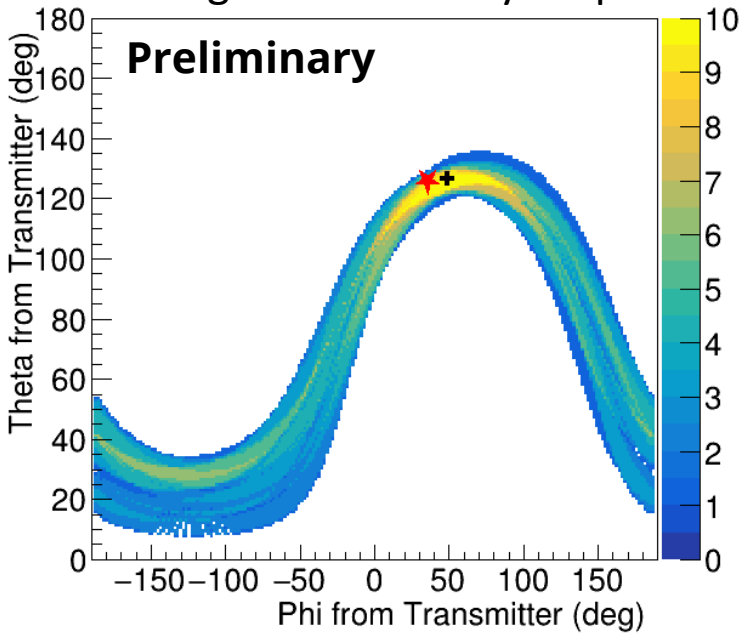
Using Signal Properties to Reconstruct Events

- This process can be iterated, by calculating the TVP angle of the overlapping region of the sky map
- The fit for allowed TVP angles constrains the arrival time plot, improving direction resolution

Original Sky Map



Single Iteration Sky Map

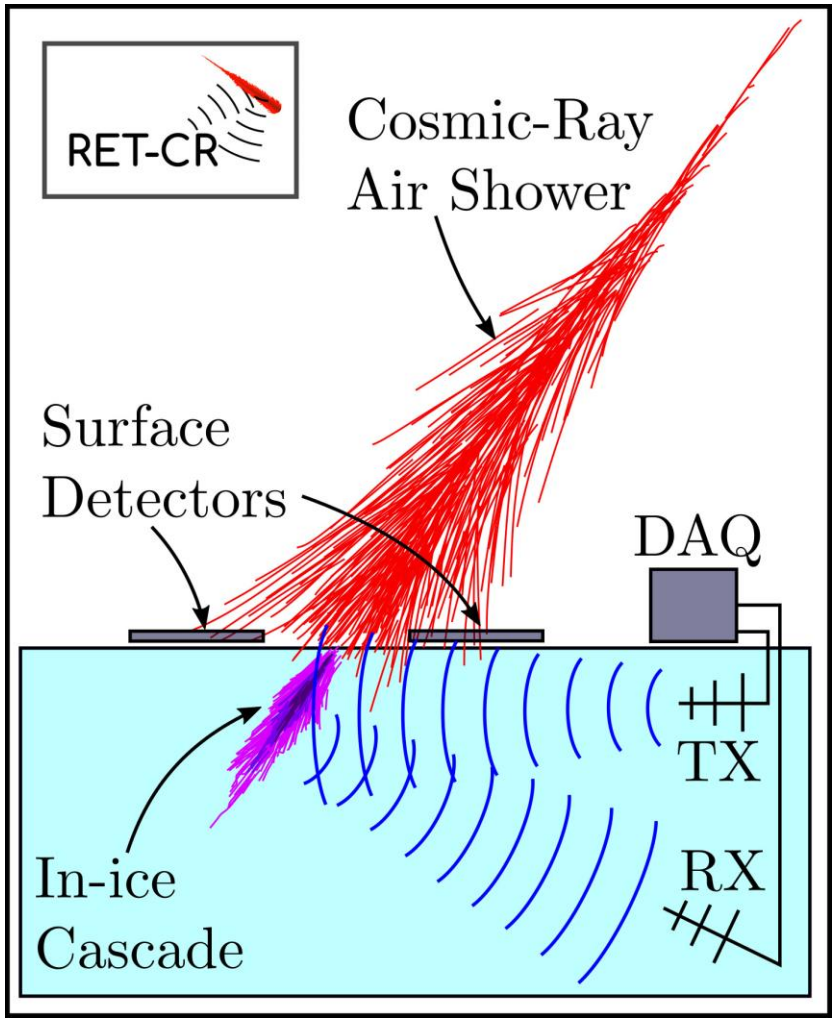


Using Signal Properties to Reconstruct Events

- Iterative techniques and folding in multiple observables can improve the resolution
- **Target resolution is ~1 degree for any geometry**
- Results of direction resolution to follow soon in publication

Next Steps and Future Work

- Continue hardware development and testing for a future RET-CR deployment
- Perform lab testing of triggering methods, continued in-situ with RET-CR
- **RET-CR is independently triggered**
- Use RET-CR data to further understanding of signal properties and test reconstruction methods



Thank you!

- Results of direction reconstruction to follow soon in publication.
- (Right) RET Collaboration

  The Ohio State University

  IIHE/Vrije University Brussels & Université Libre de Bruxelles

  University of Kansas

  Penn State University

  UW Madison

  National Taiwan University

  SLAC National Accelerator Laboratory

  University of Chicago

  Radboud University

RADAR ECHO TELESCOPE

(Backup) Alternate Frequency Response Plot