



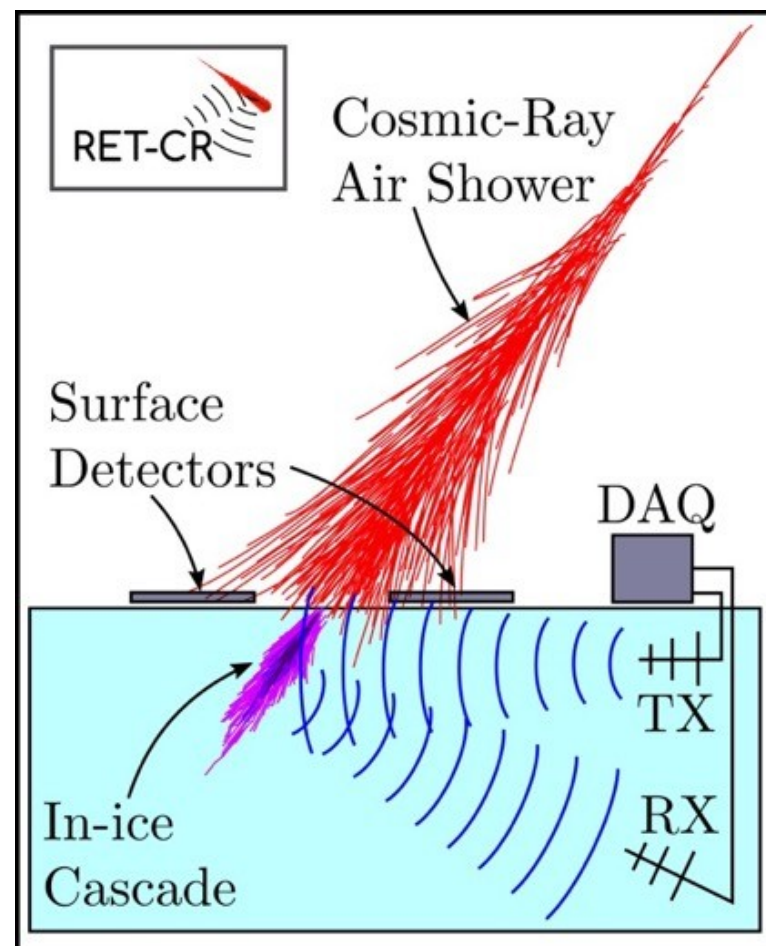
# Deployment and Status Update of the Radar Echo Telescope

**Dylan Frikken** on behalf of the Radar Echo Telescope collaboration



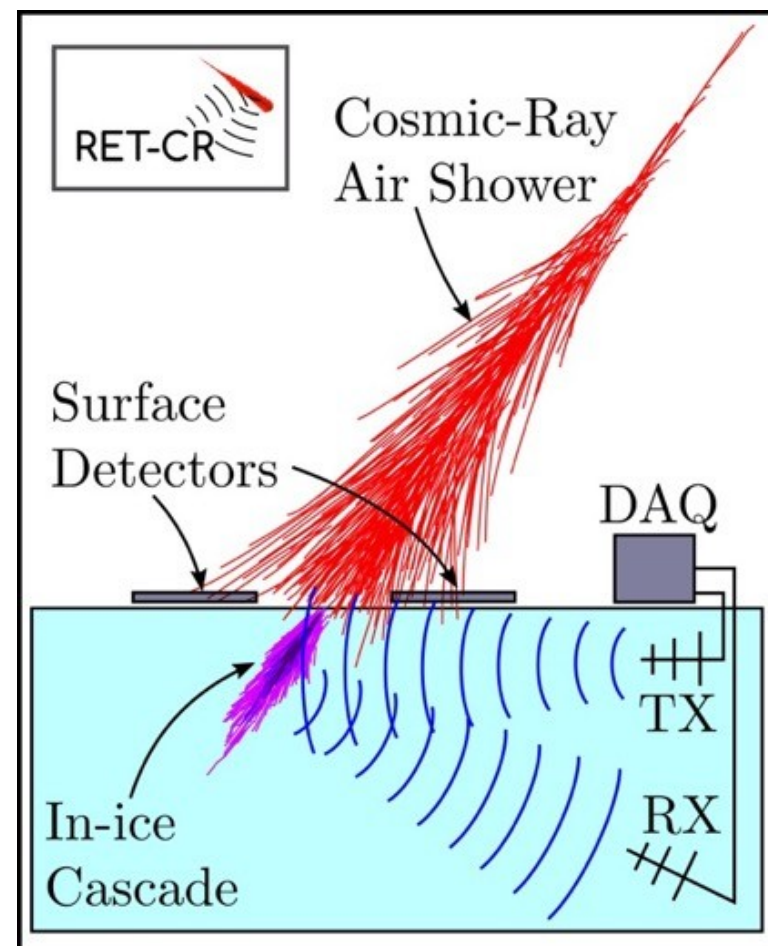
# Outline

- Radar Echo Telescope for Cosmic Rays (RET-CR)
  - Big picture
  - Detector geometry
  - Deployment
  - Initial performance
  - Analysis progress



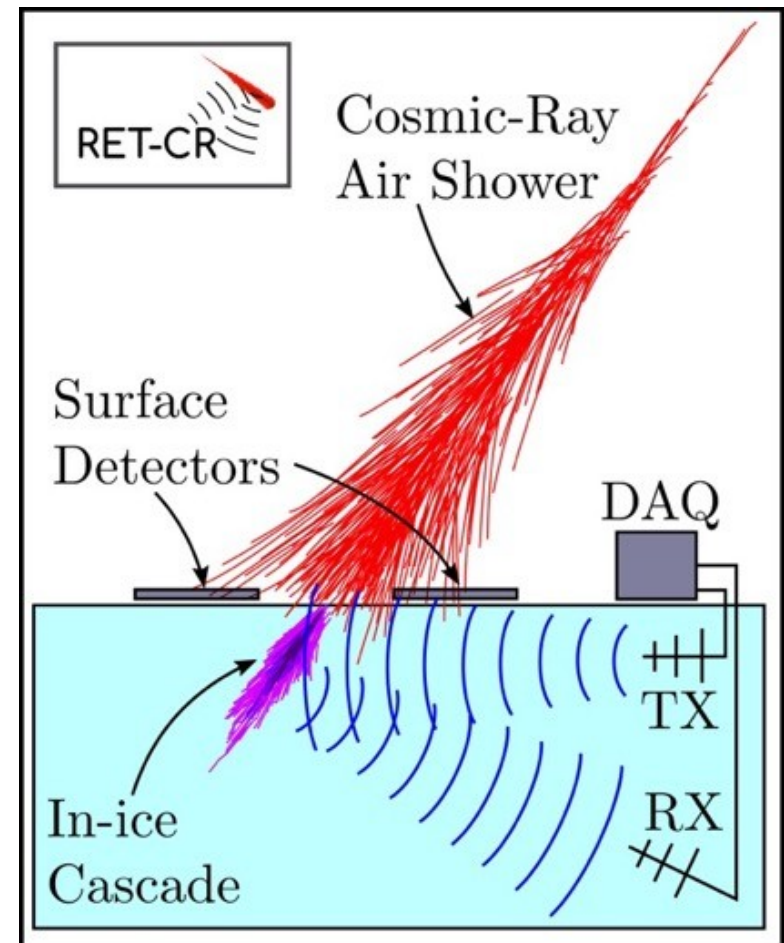
# The Radar Echo Telescope for Cosmic Rays

- Big picture:
  - Detect the ionization trail from a in-ice cosmic ray shower via active radar sounding
  - The UHE cosmic ray interaction rate is orders of magnitude higher than for UHE neutrinos
  - Use in-ice cosmic ray showers as an in-nature test beam to test the radar echo method for a future neutrino detector (RET-N)



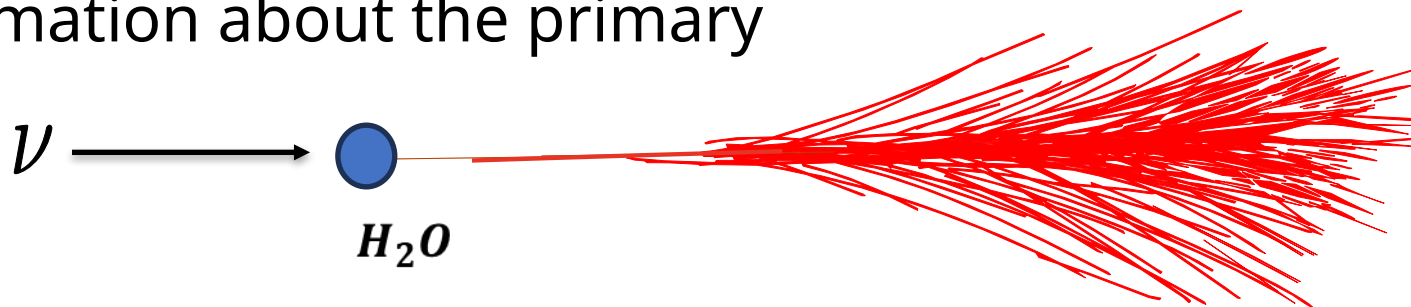
# What is the Radar Echo Telescope for Cosmic Rays?

- Principle of operation:
  - Surface detectors (scintillator panels) detect charged particles in the cosmic ray air shower
  - These scintillator panels trigger the system to take a snapshot of the in-ice radar system, and an above surface radio antenna array



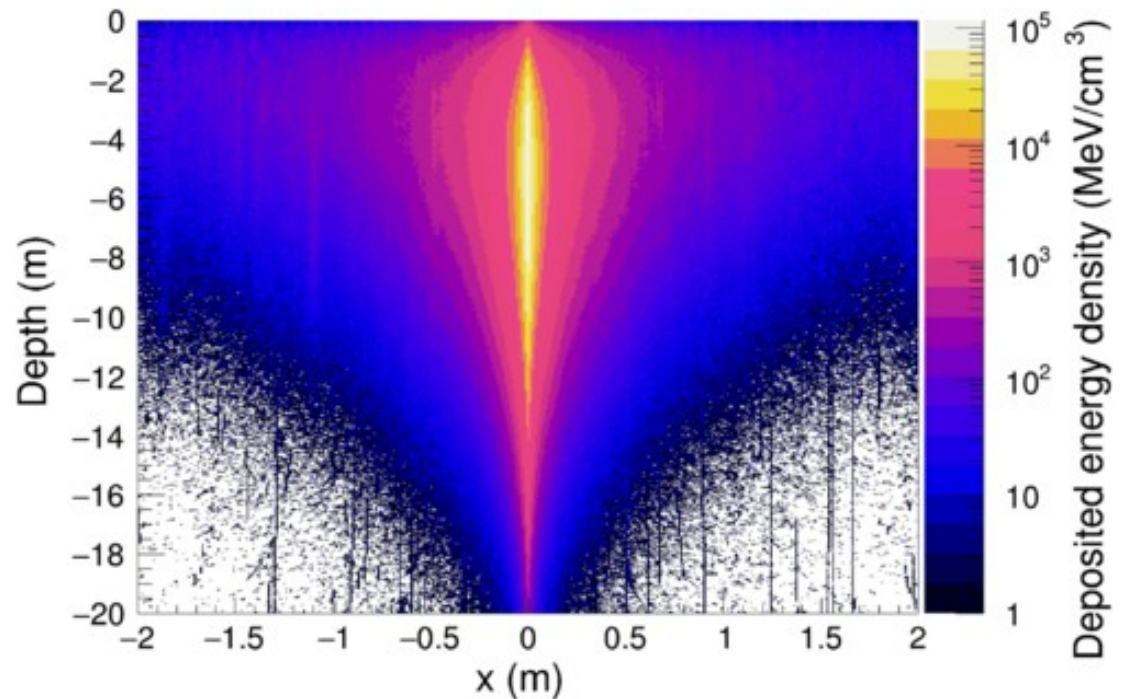
# Ionization Trail

- High-energy particle interactions create a cascade of relativistic particles
- These cascade particles lose energy to ionization leaving behind a short-lived blob of charge, called the **Ionization Trail**
  - The length of time this trail persists (the **Free Electron Lifetime**) depends on the material properties for free electrons
- The length and direction of this Ionization trail can tell us information about the primary



# In-Ice Cosmic Rays

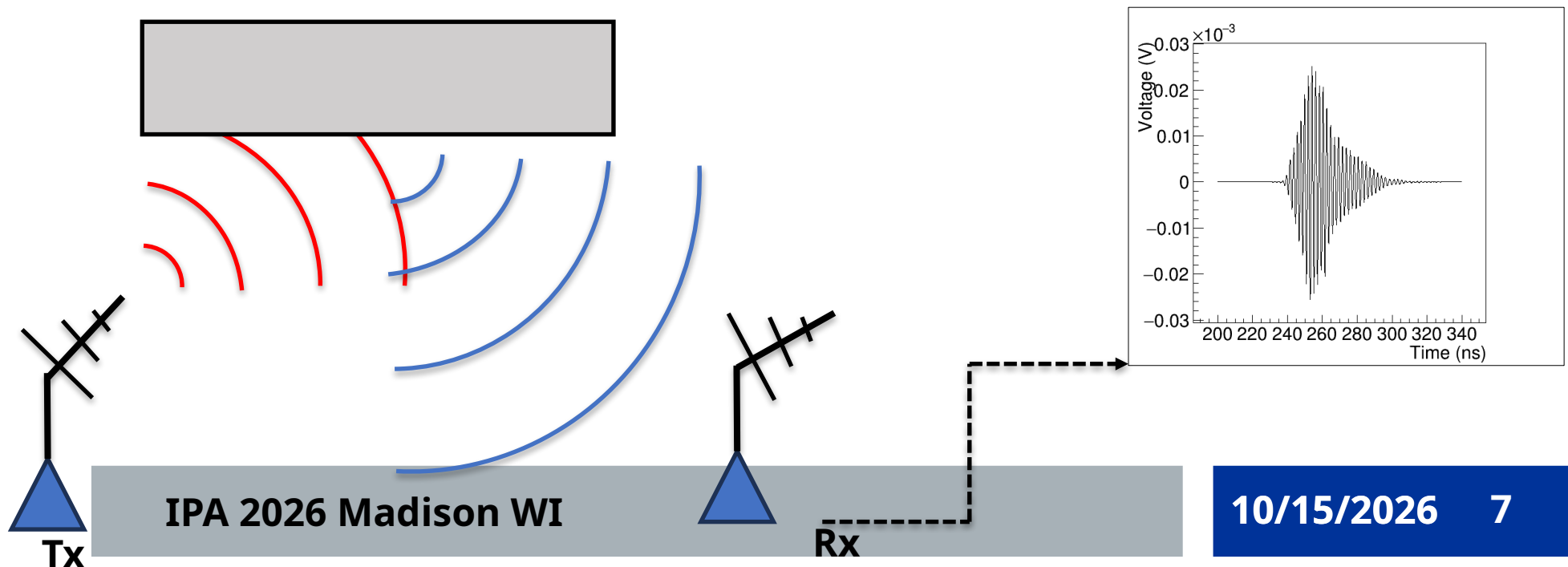
- At high elevation, the in-ice cascade contains a significant fraction of the total cosmic ray shower energy
- There is a relative abundance of high-energy cosmic rays compared to UHE neutrinos



<https://doi.org/10.1103/PhysRevD.106.043023>

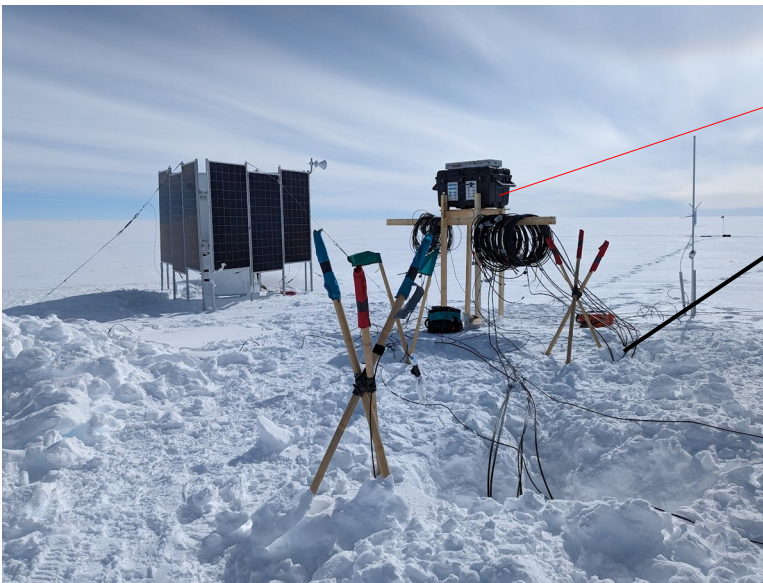
# Radar

- Basic concept:
  - A transmitter (Tx) broadcasts radio waves into a volume
  - Receiver(s) (Rx) monitor that volume
  - If some object that reflects radio is present in the volume, the transmitted signal will reflect into the receiver

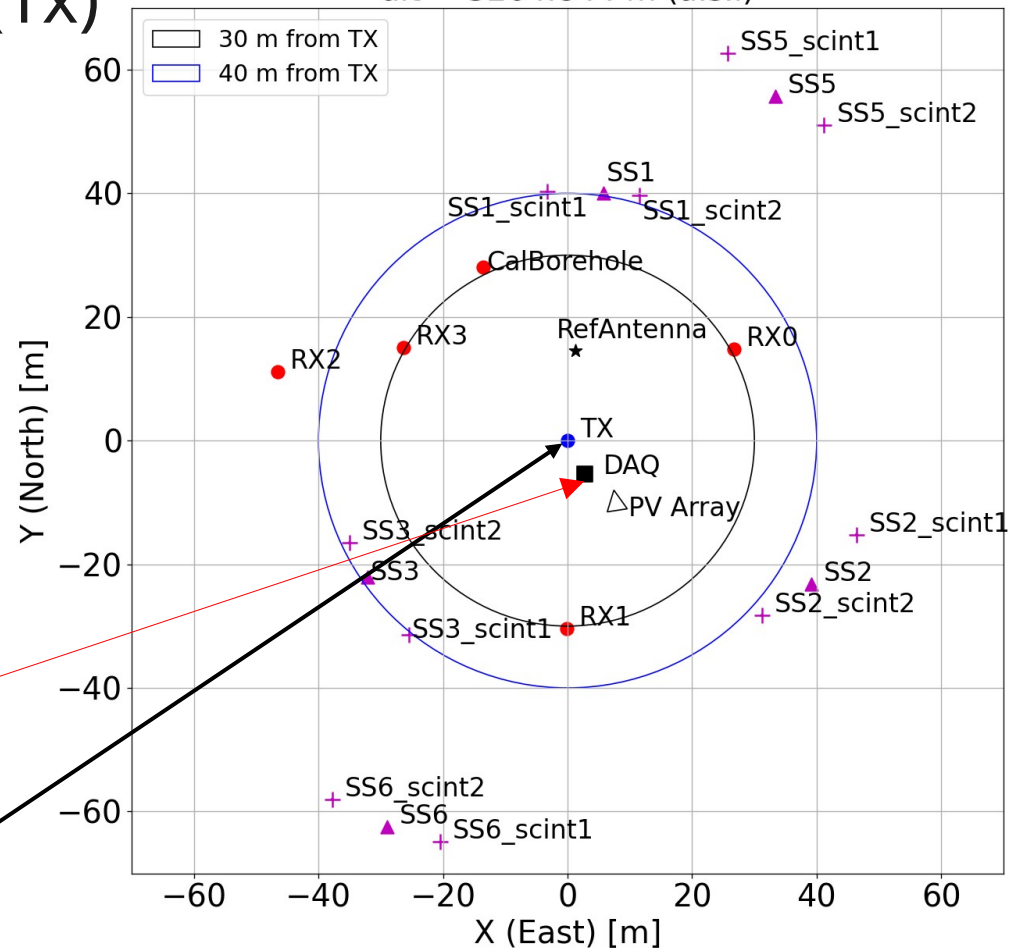


# RET-CR Layout

- Phased-Array Transmitter (Tx)
- Tx at center of geometry
- Tx broadcasting 182 MHz continuous sinewave (CW)
- Four receivers (Rx)
- Five surface stations

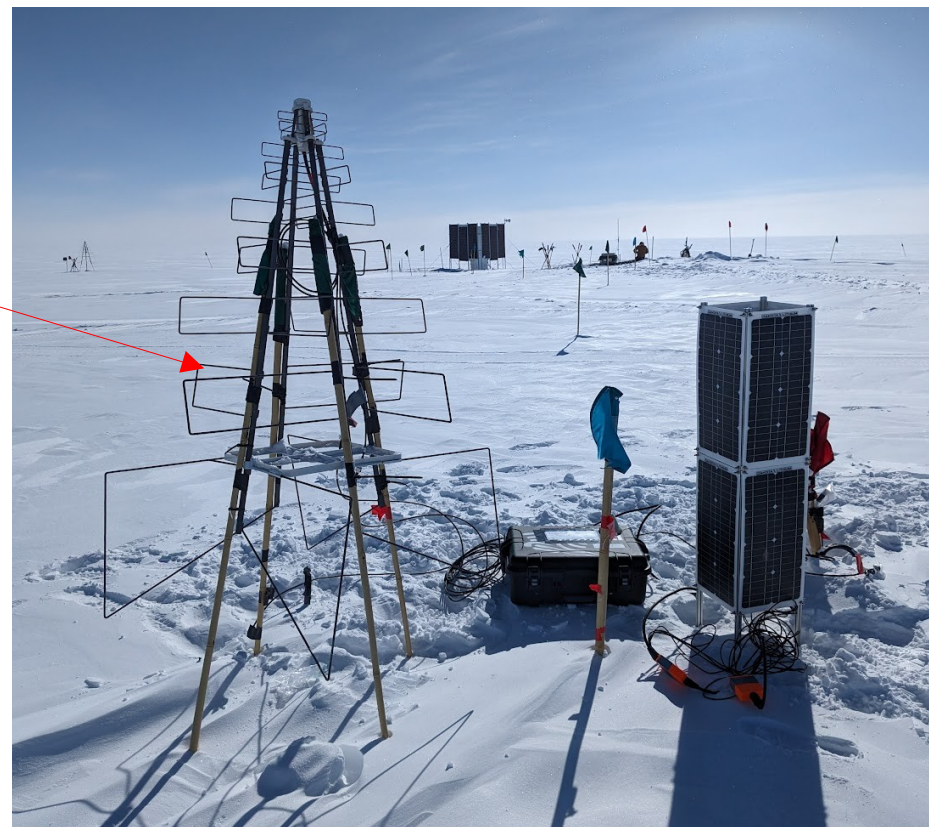
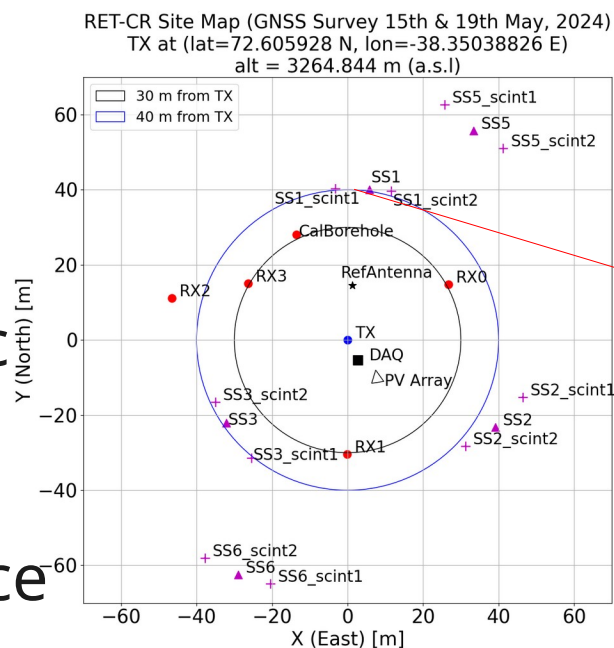


RET-CR Site Map (GNSS Survey 15th & 19th May, 2024)  
TX at (lat=72.605928 N, lon=-38.35038826 E)  
alt = 3264.844 m (a.s.l)



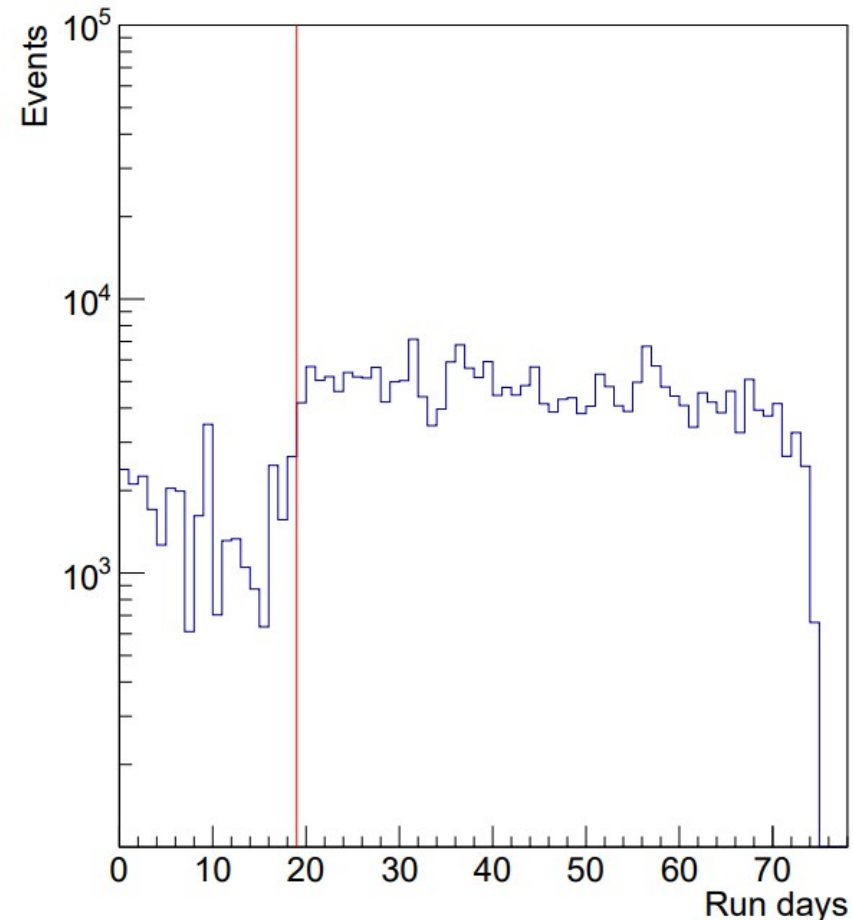
# RET-CR Surface Stations

- Five independent surface stations
- Two scintillator panels separated by 20 m
- One log-periodic dipole antenna
- The scintillator panels coincidence is sent to central station which forms low level trigger



# Initial Performance

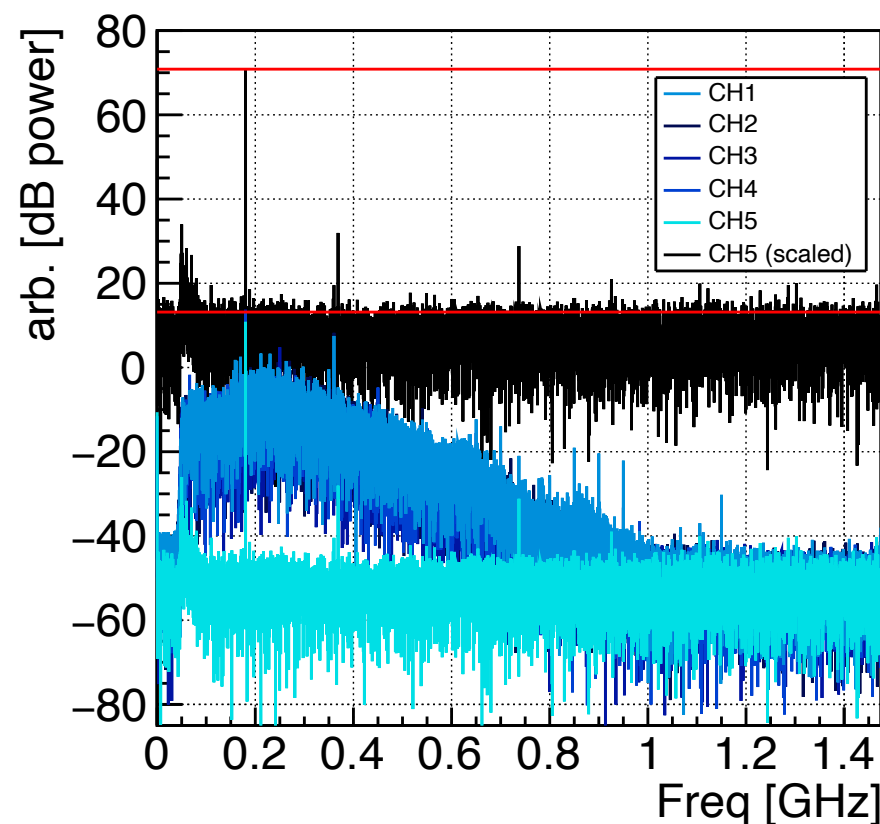
- Here we show the cosmic ray triggered events over the 2024 campaign
- This sample consists of all cosmic ray events which satisfied the surface station array requirements
- Most of this sample is cosmic rays with energy below the threshold for a radar echo measurement



A new triggering scheme was developed during the campaign, producing a flatter event rate (denoted with red line).

# Initial Performance

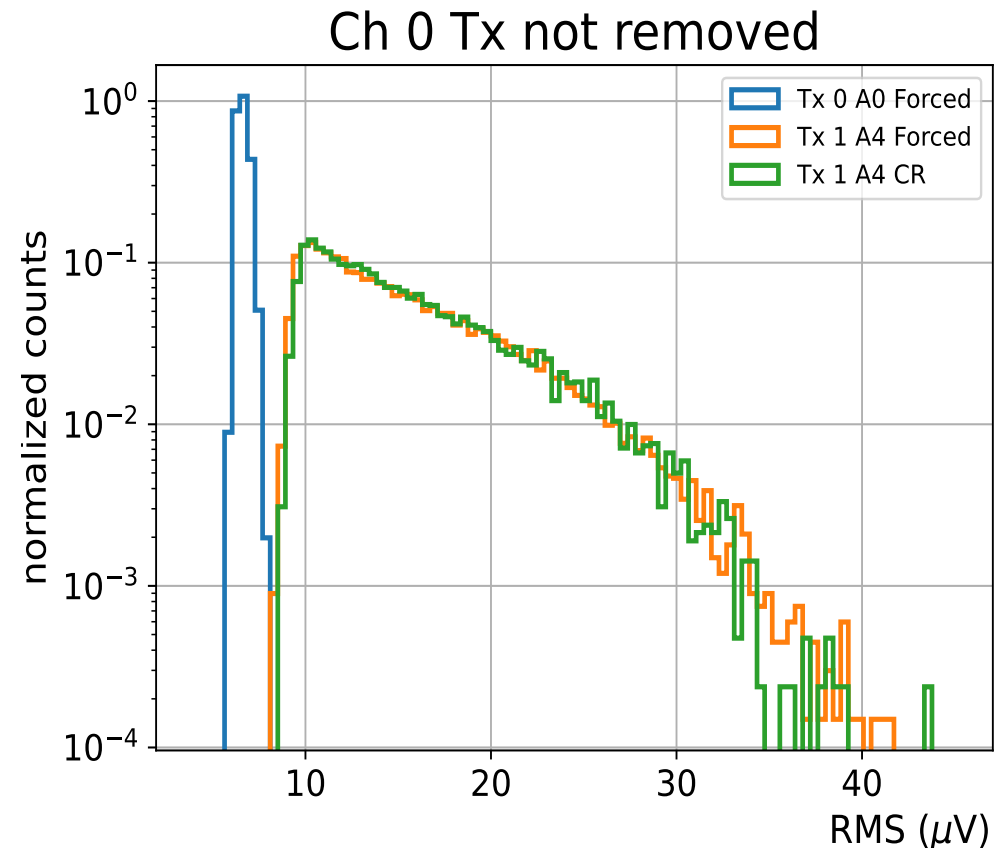
- We developed a Carrier Cancellation (CC) routine which mixes a calculated offset signal pre-amplification
- We show a  $\sim 60\text{dB}$  reduction in the transmitted signal to the Rx channels



CH5 (Teal) is an unamplified channel.  
Tx frequency 182Mhz

# Initial Performance

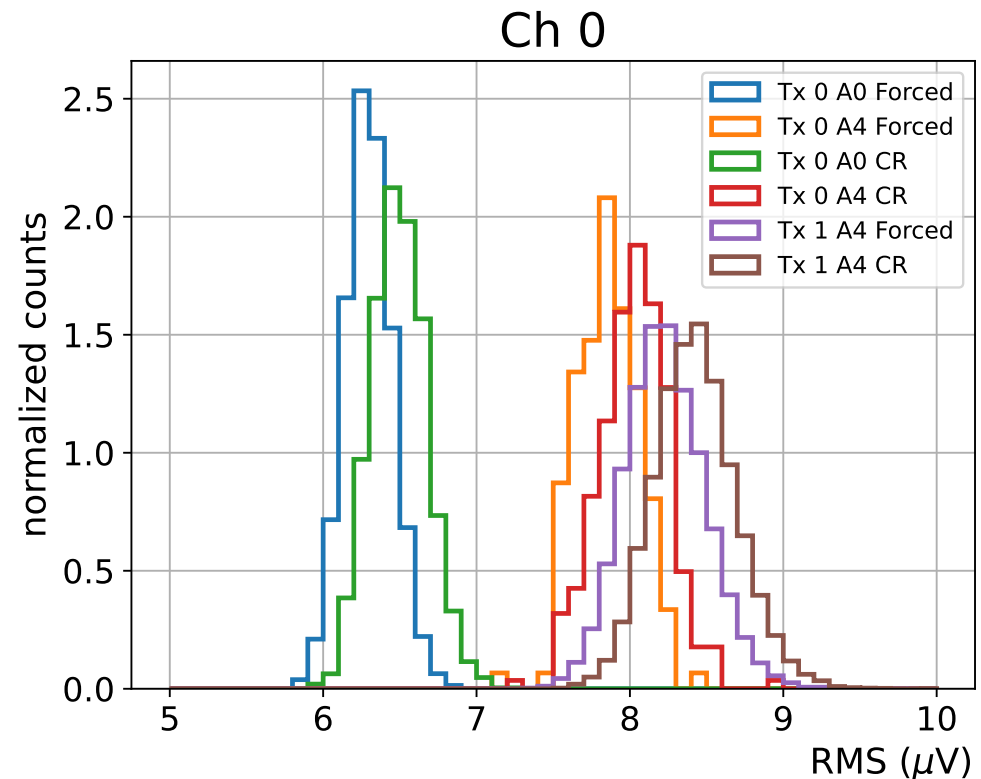
- Here we show the RMS for one Rx channel with Tx on and off
- The CC routine went out of phase lock over time, and was periodically relocked
- Thermal noise for our band is  $\sim 6\mu\text{V}$



Tx – Transmitter  
Rx – Receiving antenna

# Analysis Progress

- Here we show the event RMS broken down by detector configuration after excess Tx and background CW removal
- We show an RMS in our channels near thermal noise for our band
- We see a  $\sim 2\mu\text{V}$  increase from Tx Power amps (A4)

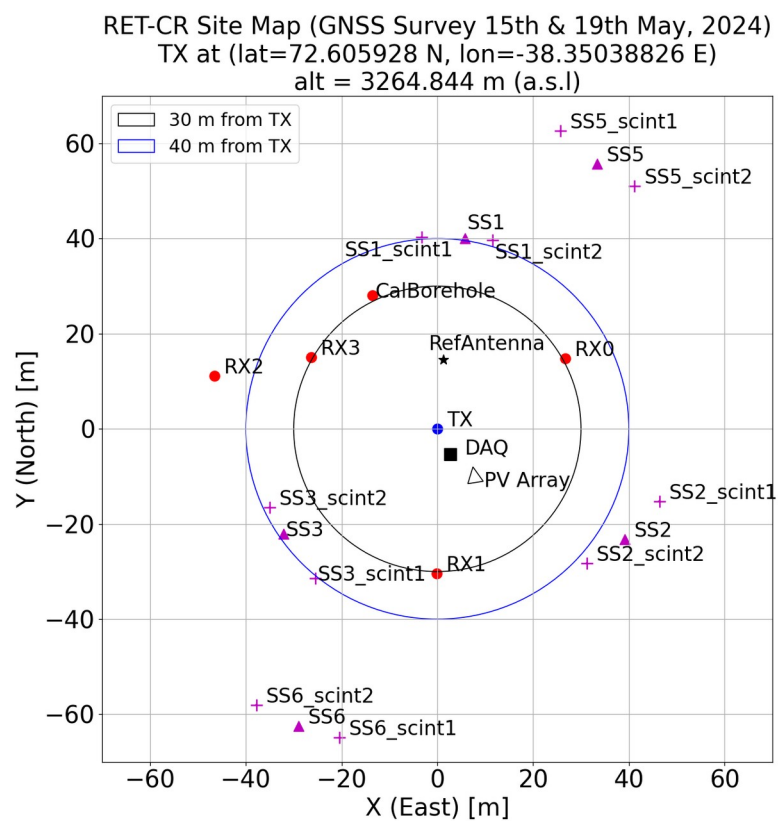


Legend Key:

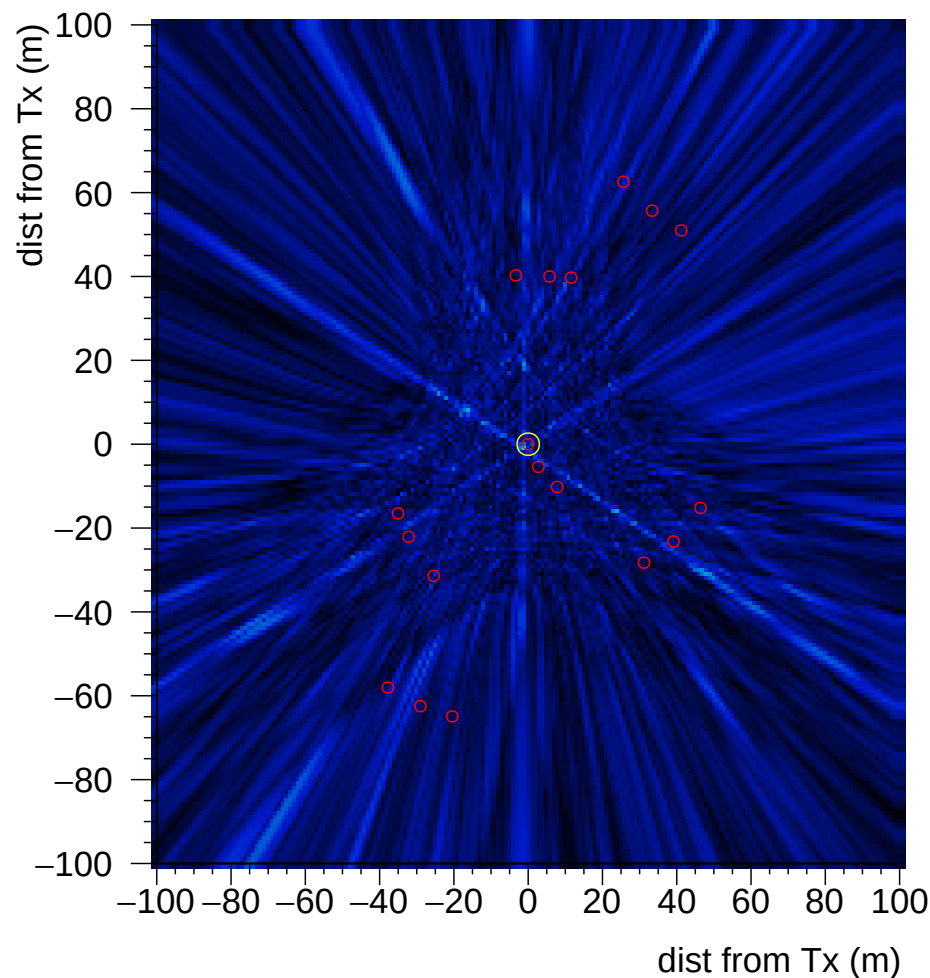
Tx (on/off) Tx amps on(N) Trigger Type

# Analysis Progress – Background Identification

- Here we show a forced trigger event which reconstructs to the Tx location

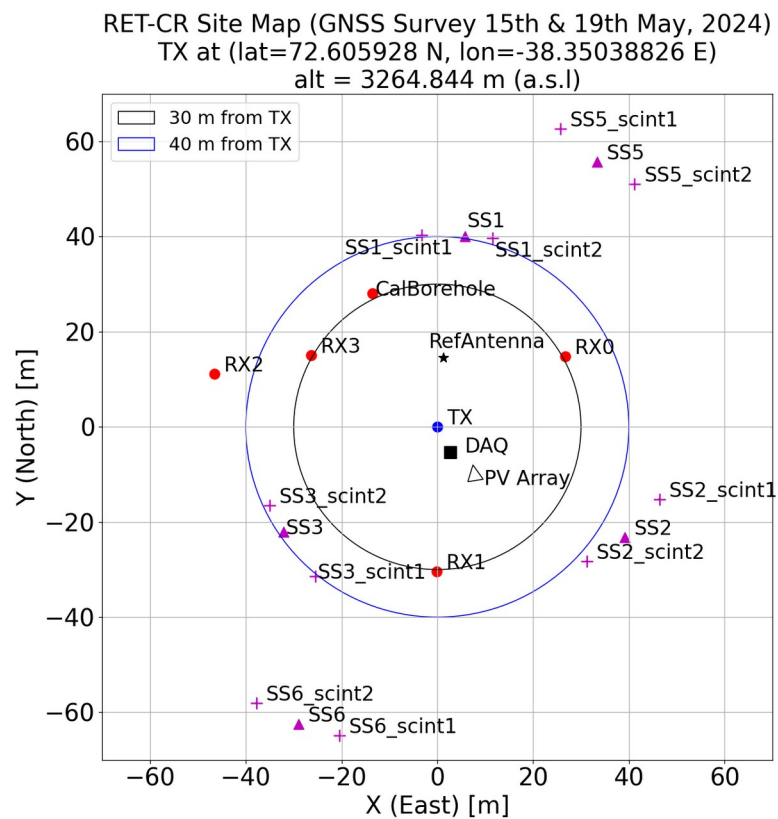


Tx Blip example

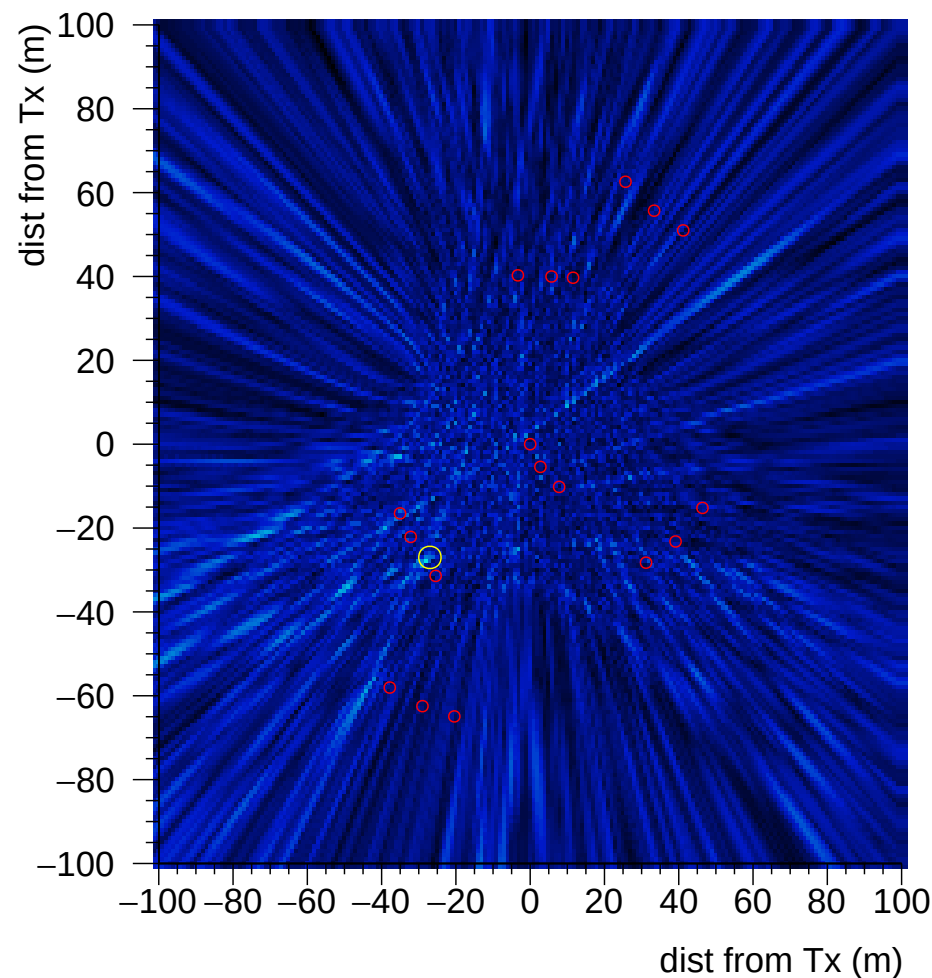


# Analysis Progress – Background Identification

- Here we show a forced trigger event which reconstructs to Surface station 3



scintillator panel example



# Analysis Progress - Conclusion

- We have been able to characterize the detector and its backgrounds to the level of thermal noise
- We are currently finalizing the analysis on a 10% burn sample, and aiming for a box opening in the near future
- A sub-threshold search is also planned and being prepared following the initial analysis results

# Thank you!

- RET Collaboration

The Ohio State University

IIHE/Vrije Universiteit Brussel & Université Libre de Bruxelles

University of Kansas

Penn State University

UW Madison

National Taiwan University

SLAC National Accelerator Laboratory

University of Chicago

Radboud University

Deutsches Elektronen-Synchrotron DESY

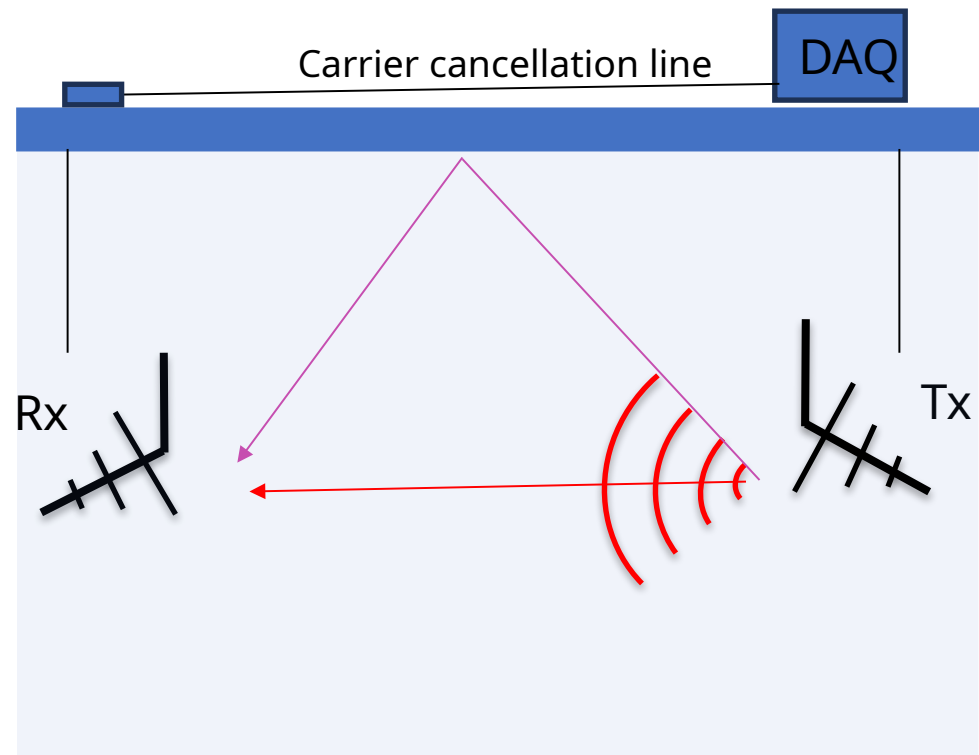
University of the Basque Country - EHU



**Backup**

# RET-CR Transmitter Cancellation

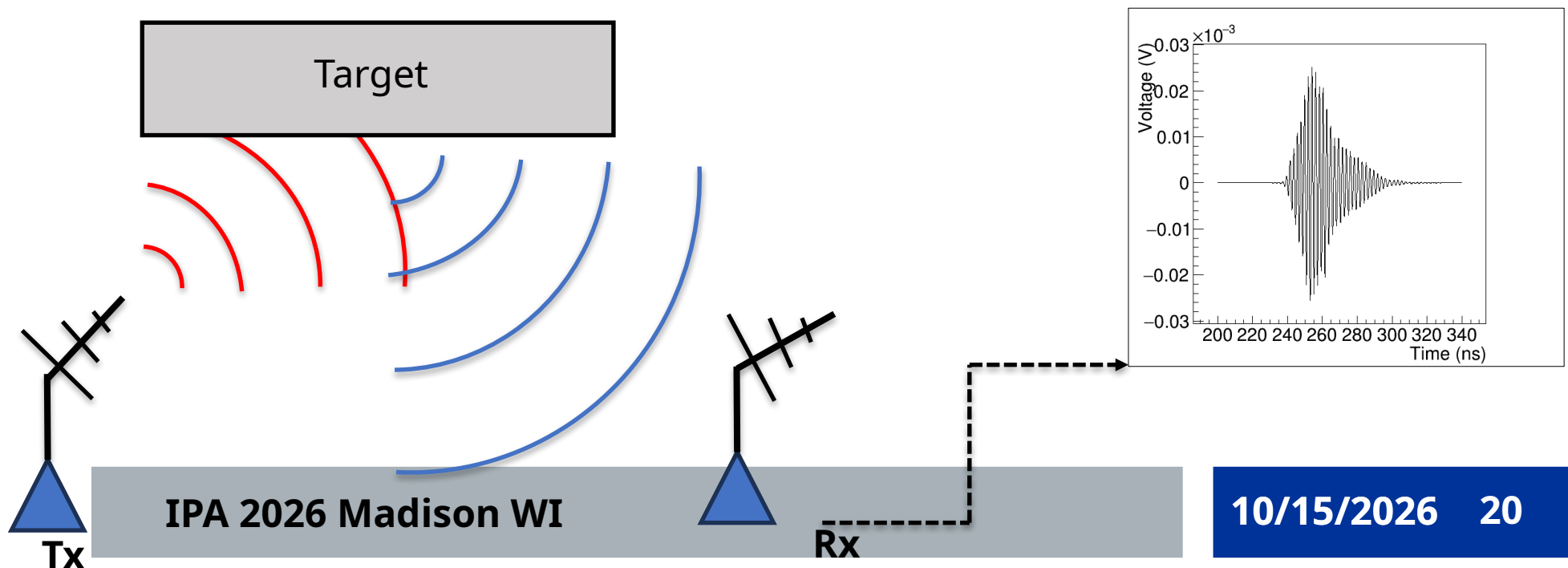
- Problem: high power transmitter close to receivers will saturate amplifiers
- Solution: cancel the direct and reflected transmit signal out of the receiver path
- Cancellation signal is input to Rx line before amplification



# Radar

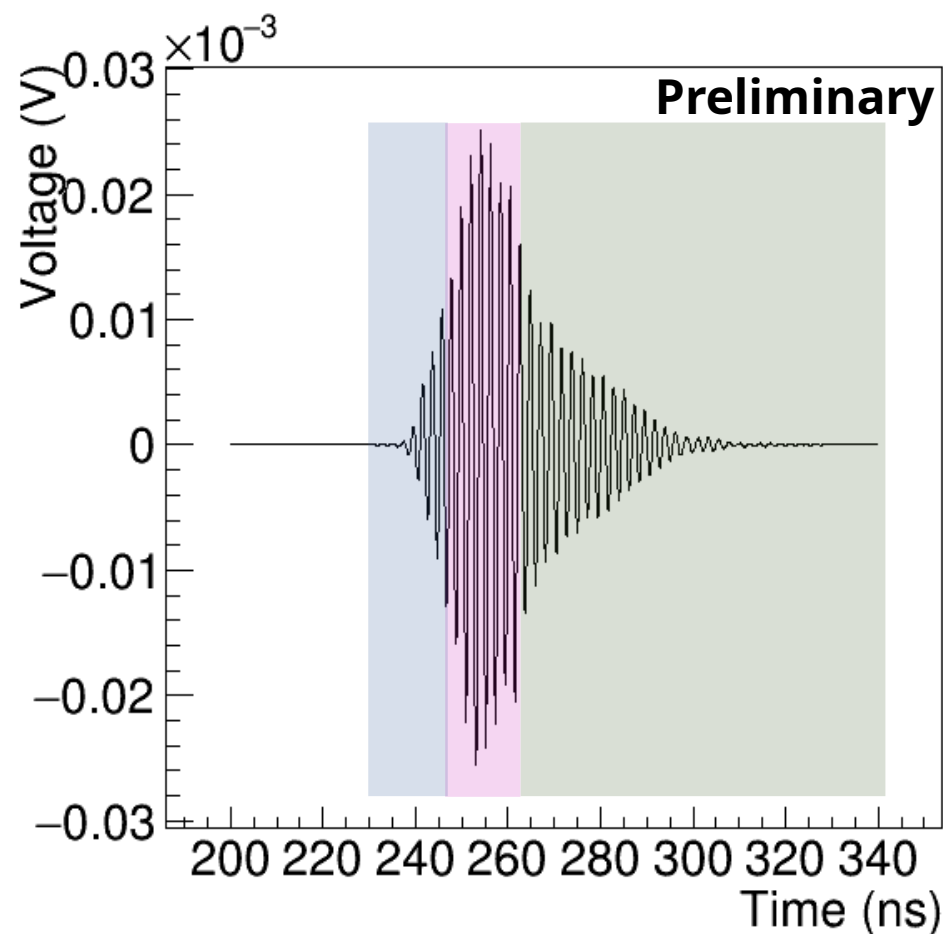
- Radar Cross Section

- How "detectable" is the target using radar?
- Dictates the amount of power of the reflected (blue) waves
- Ignores transmitted signal properties, media effects, and baseline distance
- Goal of stealth plane design is to minimize this value



# Investigation of Received Signal Properties

- RET simulated using RadioScatter (in-house radar reflection simulation with GEANT4) arXiv:1710.02883



- Three phases of a RET event:
  - Cascade development
  - Cascade as a static reflector
  - Recombination/Attachment