Status of the Radar Echo Telescope for Cosmic Rays

TeVPA 2025

05/11/25

Isha Loudon, on behalf of the **Radar Echo Telescope** collaboration

RADAR ECHO TELESCOPE

fnrs LA LIBERTÉ DE CHERCHER

ULB UNIVERSITÉ LIBRE DE BRUXELLES

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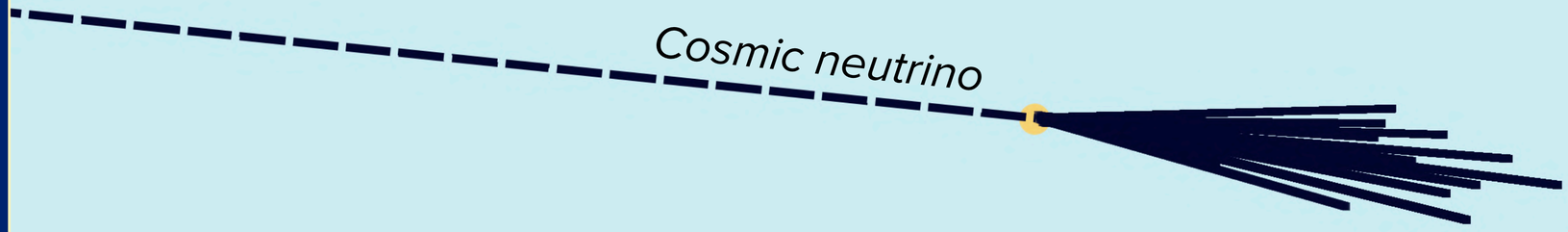
erc European Research Council Established by the European Commission

NSF

Radar detection of astrophysical particles

- Detections of cosmic neutrinos can inform...



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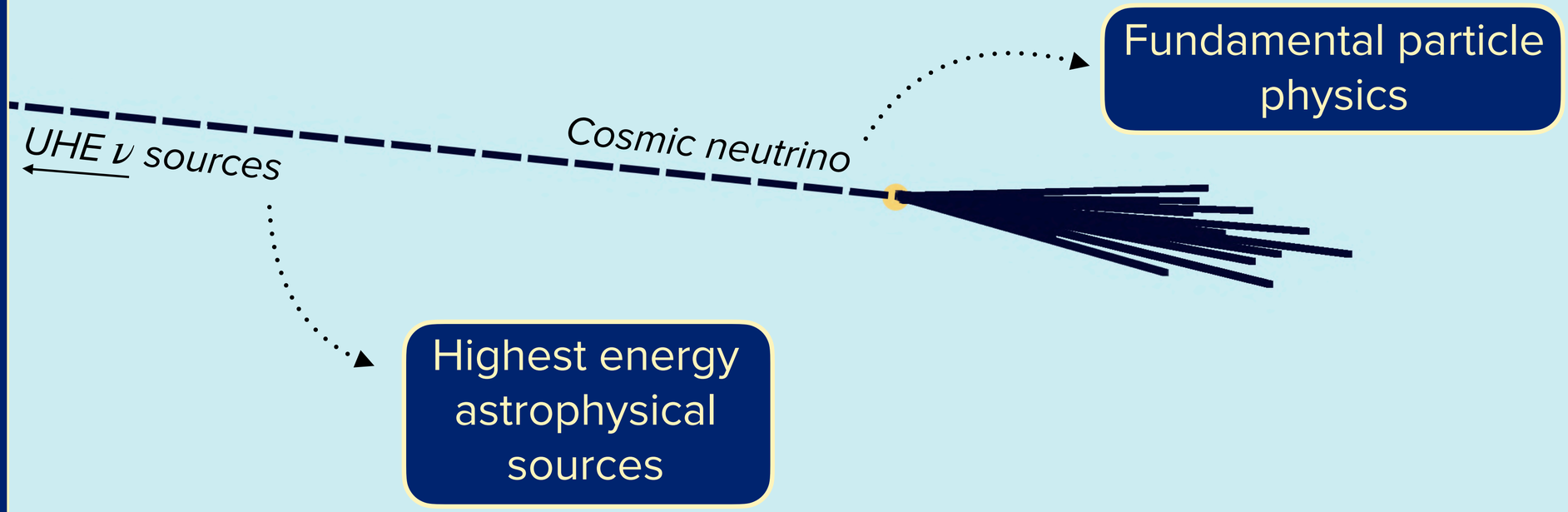

Radar detection of astrophysical particles

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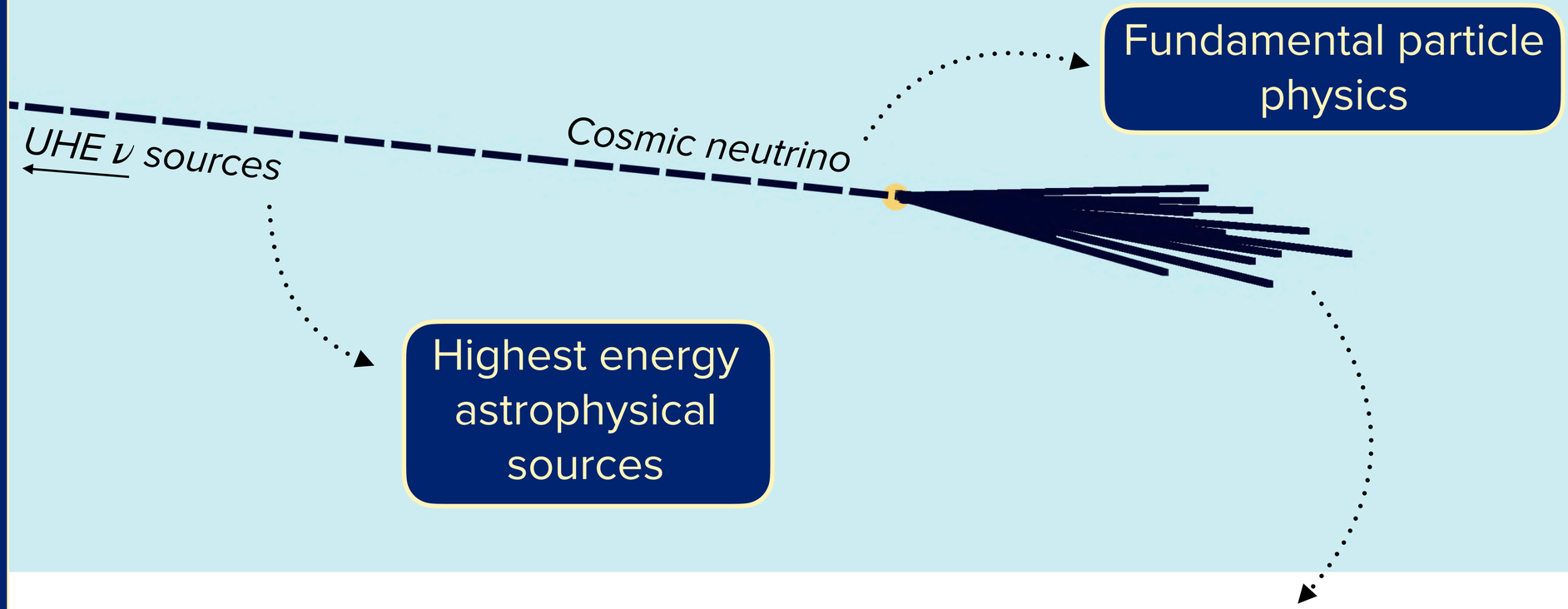
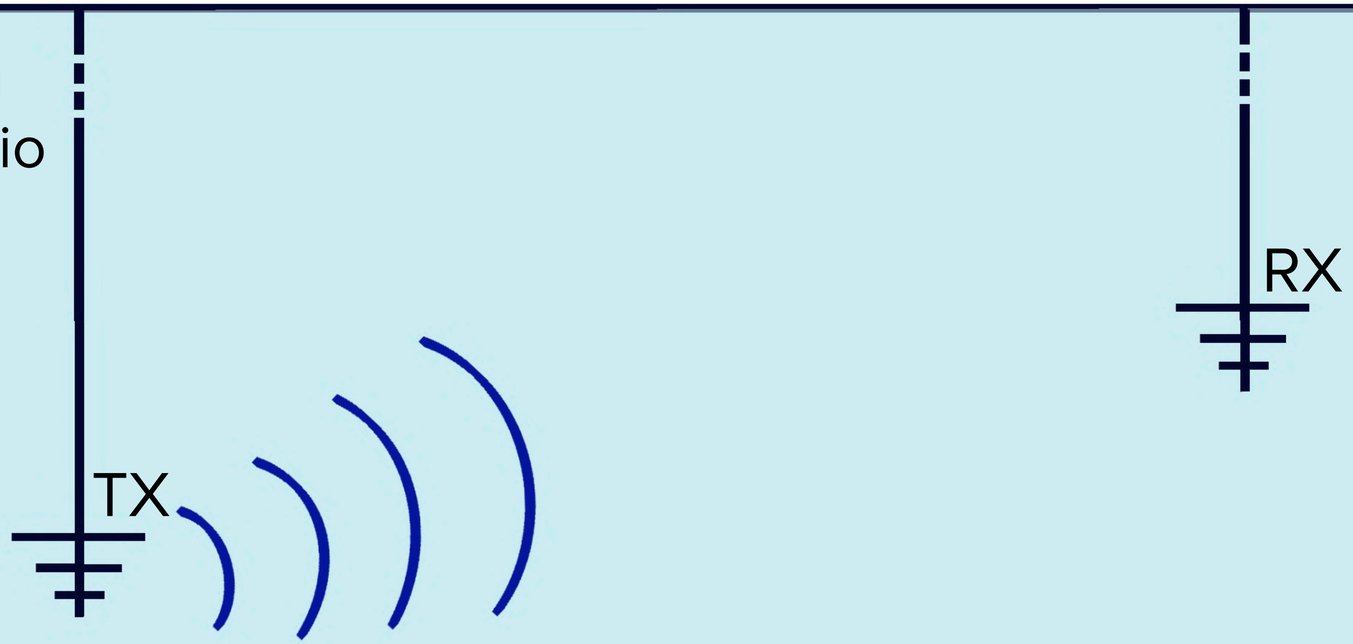


- High-energy particles interacting in ice produce **relativistic particle cascades**
- The developing cascade leaves a **trail of ionisation** in its wake

Radar detection of astrophysical particles

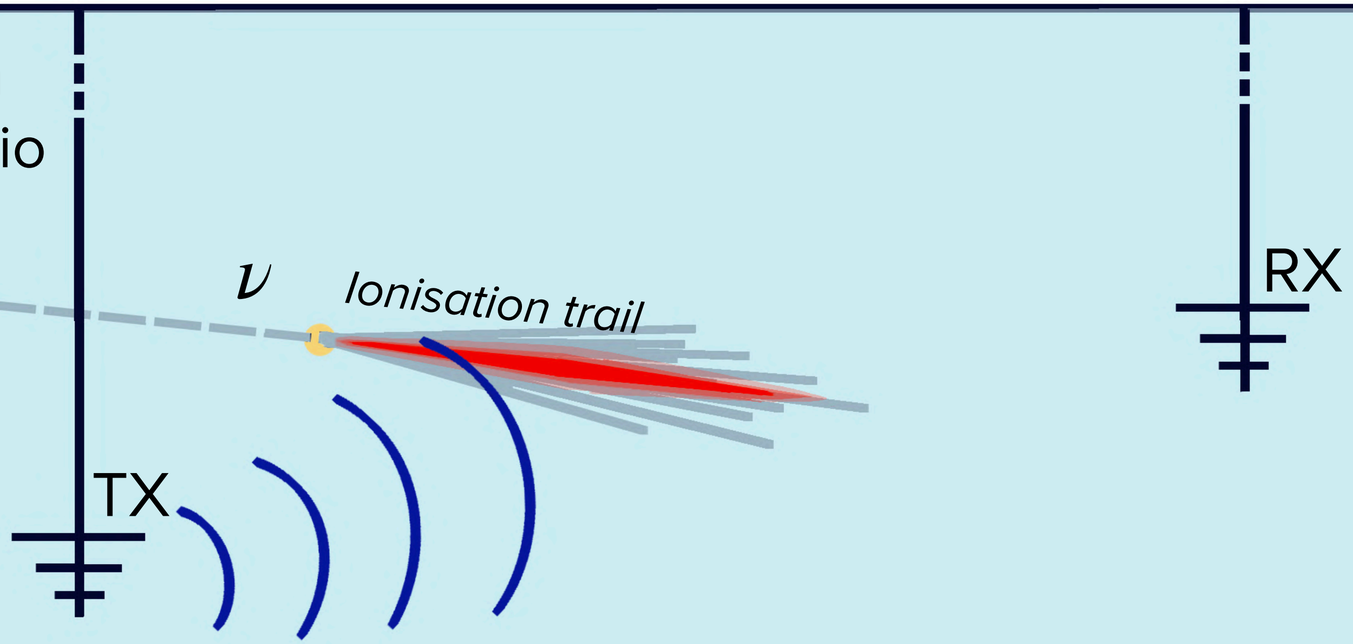
- The cascade's ionisation trail **reflects** incident radio waves



Radar detection of astrophysical particles

- The cascade's ionisation trail **reflects** incident radio waves

⇒ Allows them to act as a target in a radar system



Radar detection of astrophysical particles

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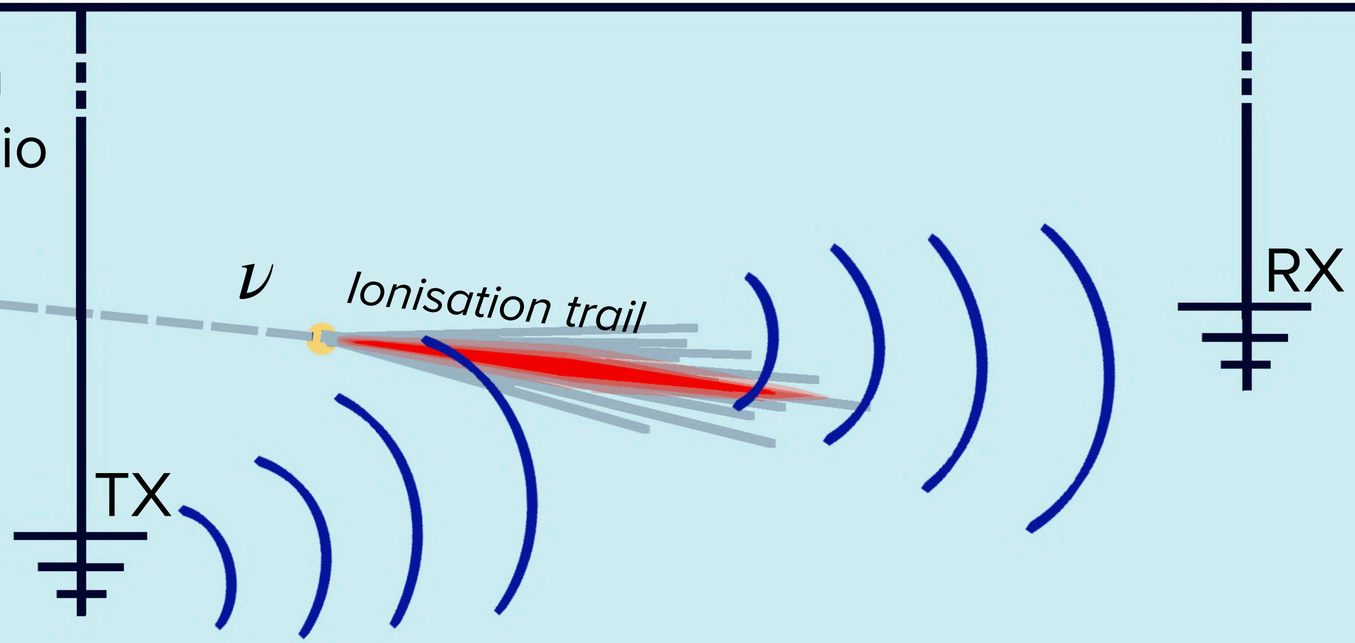


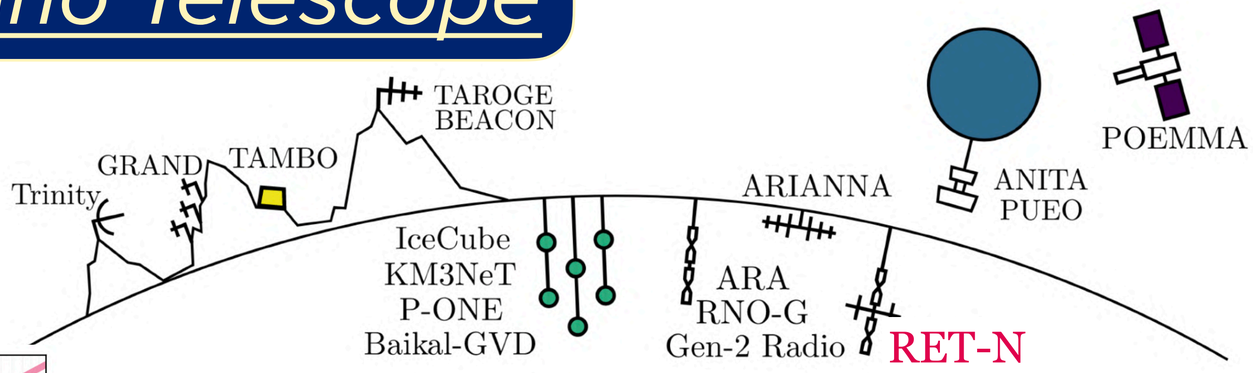
- RET aims to apply the radar method towards UHE neutrino detection with RET-N

RADAR ECHO TELESCOPE

- Radar allows for...
  - Large instrumented volume (radio)
  - Control over TX signal

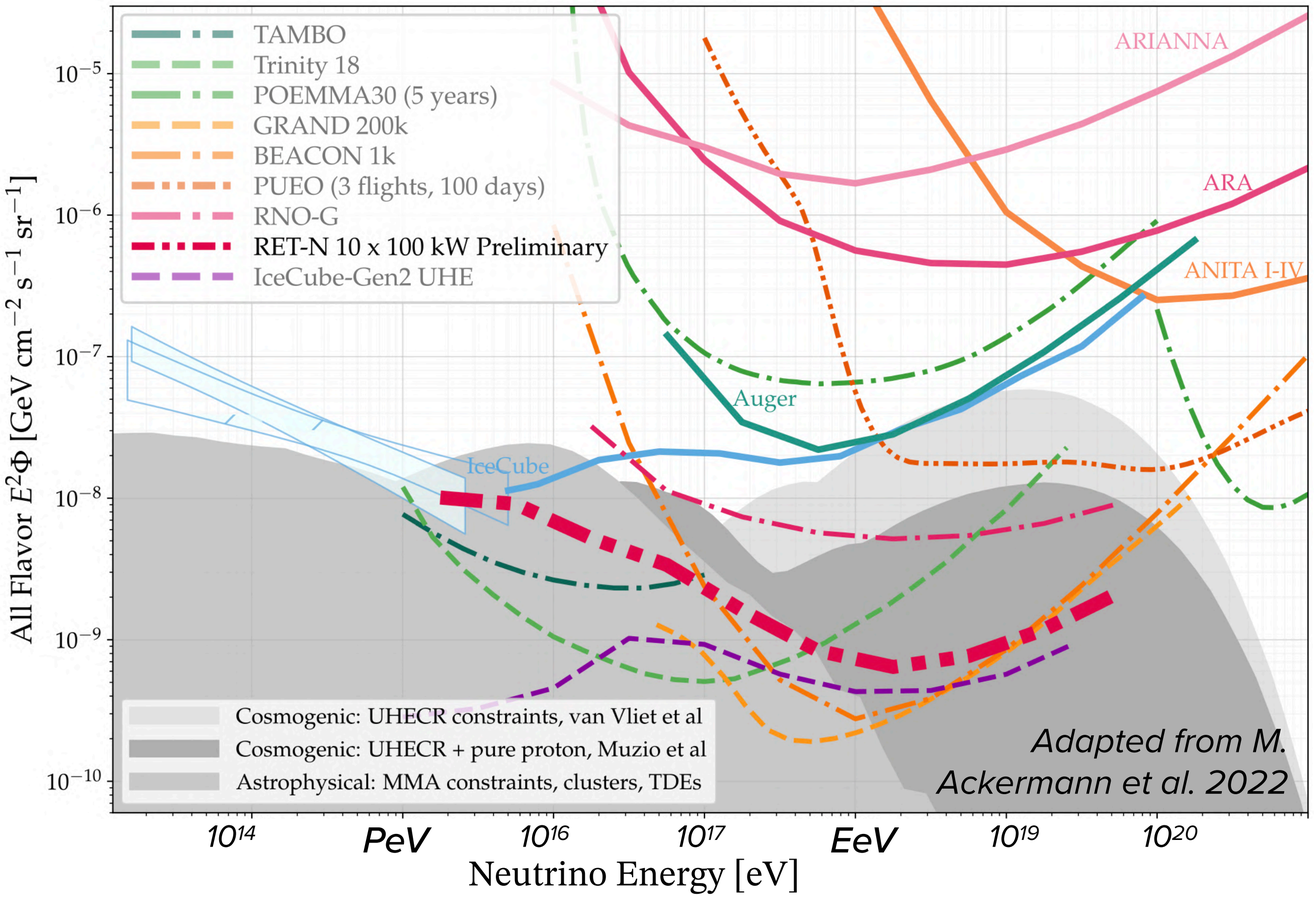
RET-N Neutrino Telescope

- Overcoming the lower ν flux at higher energies requires **new detection methods**



Adapted from I. Esteban, S. Prohira & J. Beacom 2022

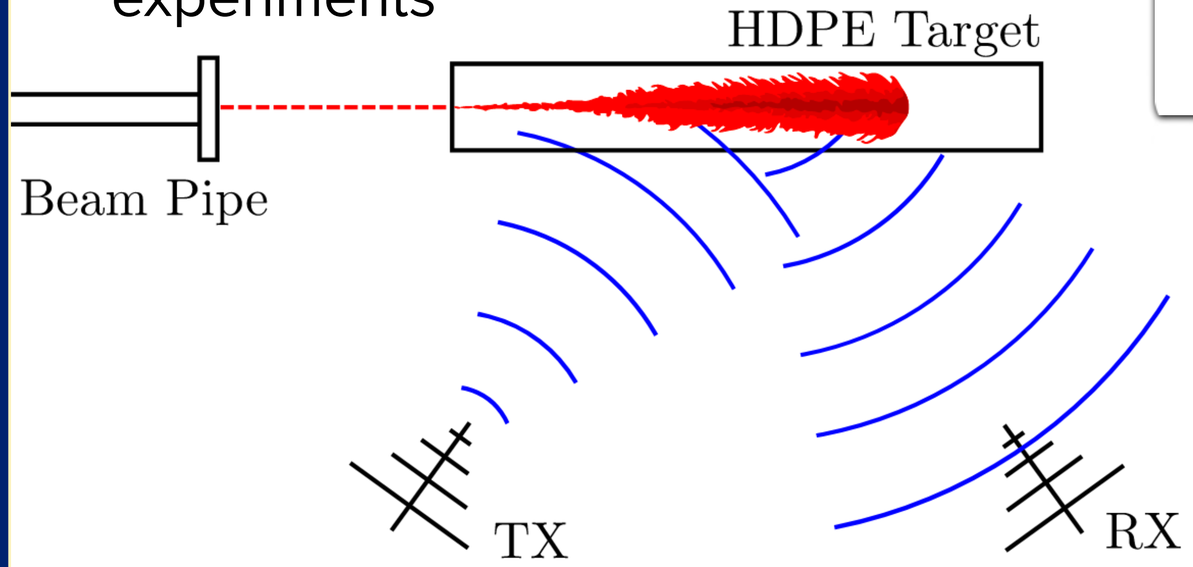
Diffuse flux, 1:1:1 Flavour Ratio



- **RET-N** bridges flux from **current detections** extending up to **EeV energies**
- Offers **complementary detections** with experiments using different detection techniques

Proof-of-concept

- Radar method has been demonstrated in SLAC laboratory experiments

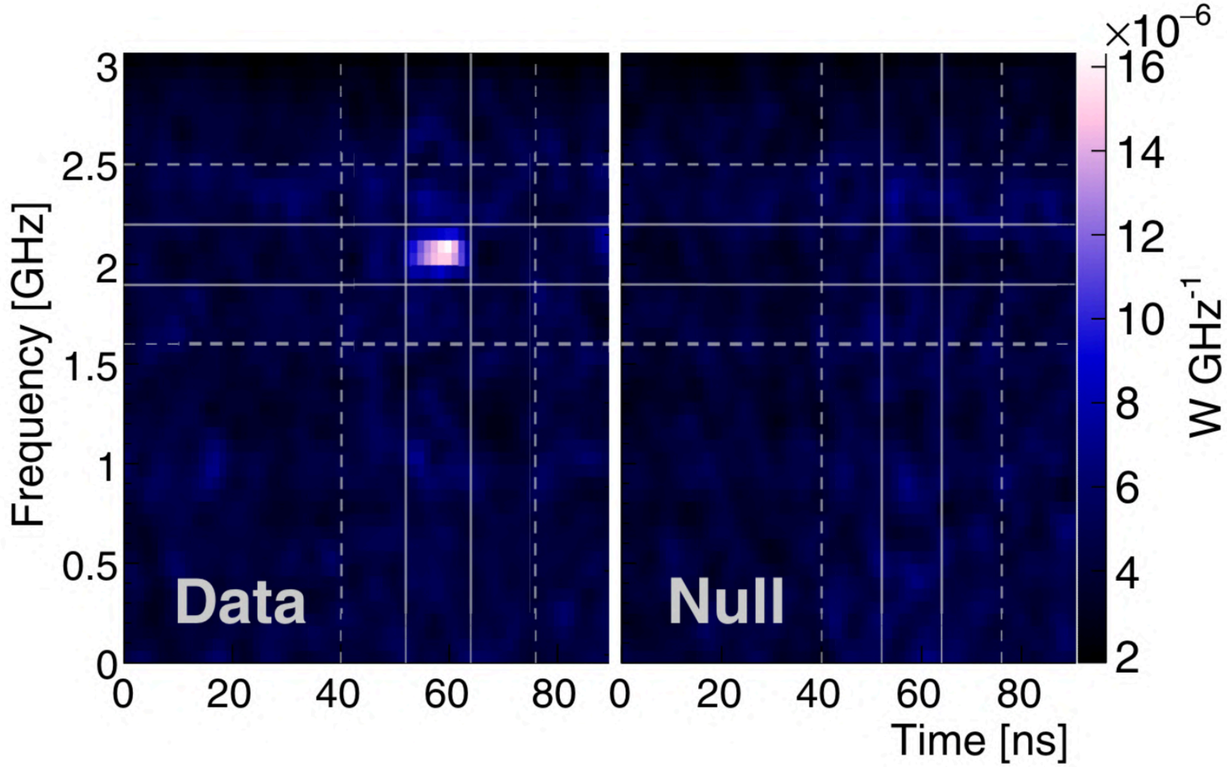


PHYSICAL REVIEW LETTERS **124,** 091101 (2020)

Editors' Suggestion | Featured in Physics

Observation of Radar Echoes from High-Energy Particle Cascades

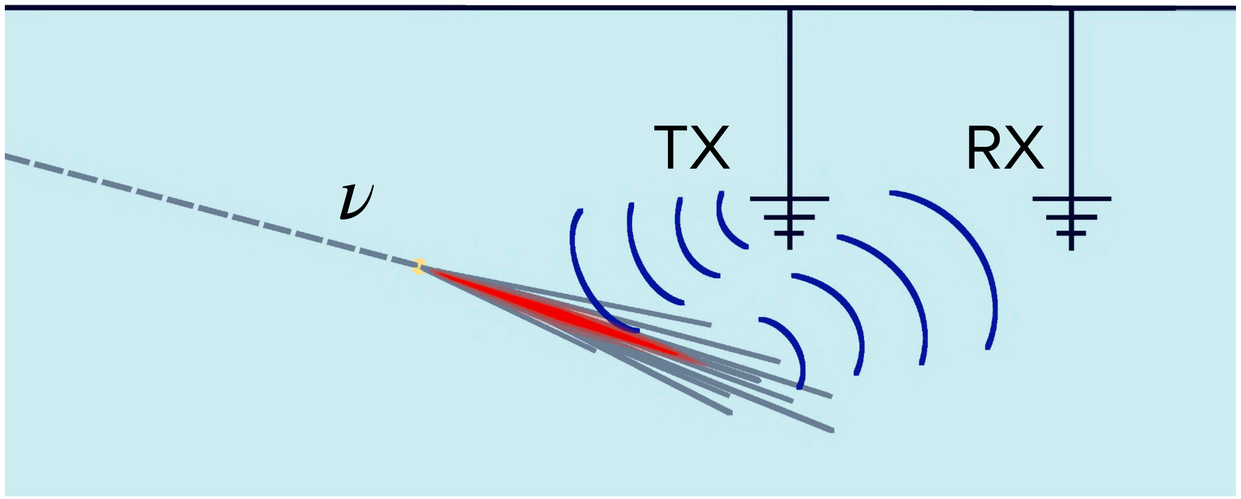
S. Prohira,[1,*] K. D. de Vries,[2] P. Allison,[1] J. Beatty,[1] D. Besson,[3,4] A. Connolly,[1] N. van Eijndhoven,[2] C. Hast,[5] C.-Y. Kuo,[6] U. A. Latif,[3] T. Meures,[7] J. Nam,[6] A. Nozdrina,[3] J. P. Ralston,[3] Z. Riesen,[8] C. Sbrocco,[1] J. Torres,[1] and S. Wissel[8]



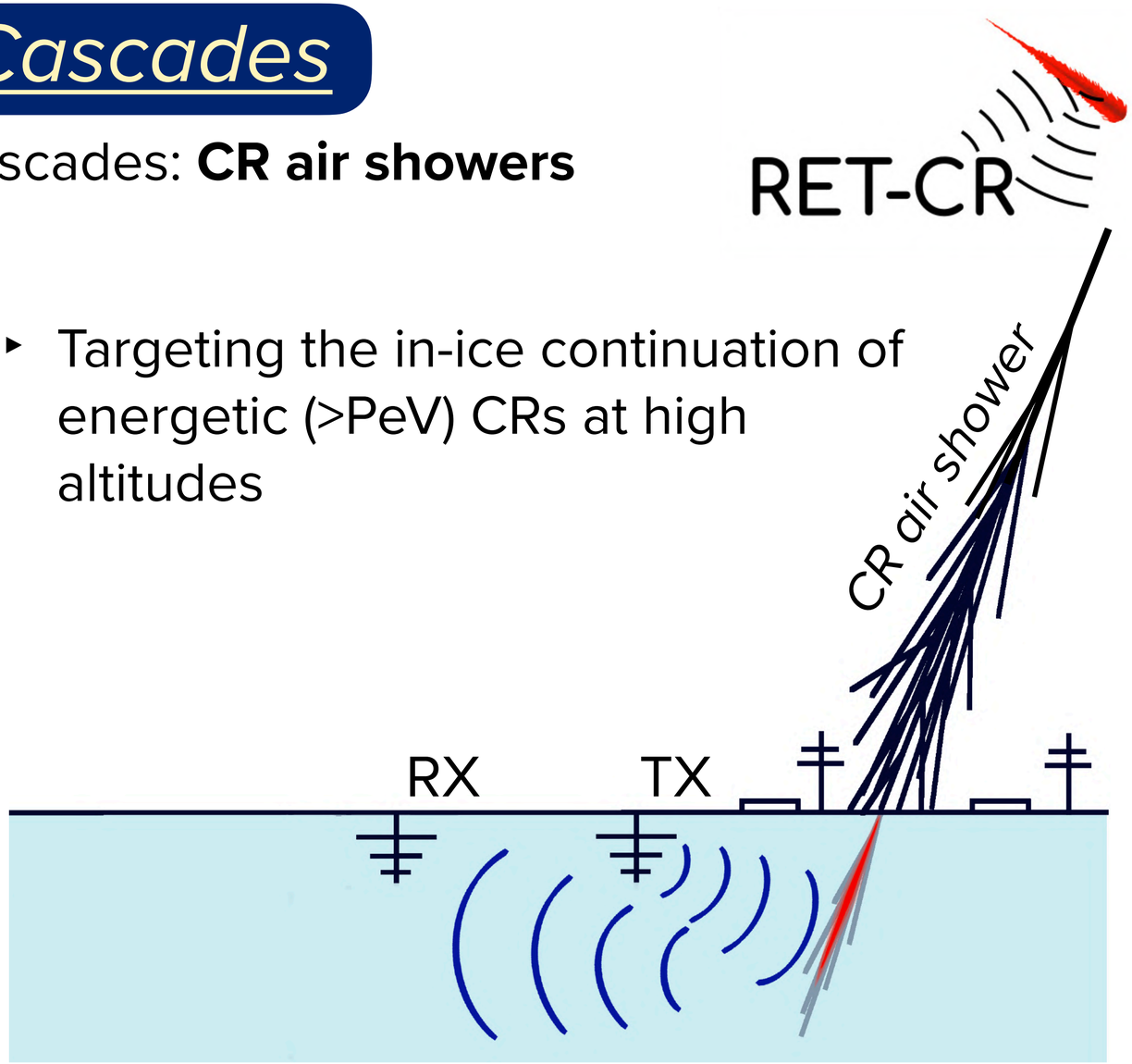
- Next step: RET-CR

In-ice CR Cascades

- Demonstrate method in-nature with natural cascades: **CR air showers**



- Targeting the in-ice continuation of energetic (>PeV) CRs at high altitudes

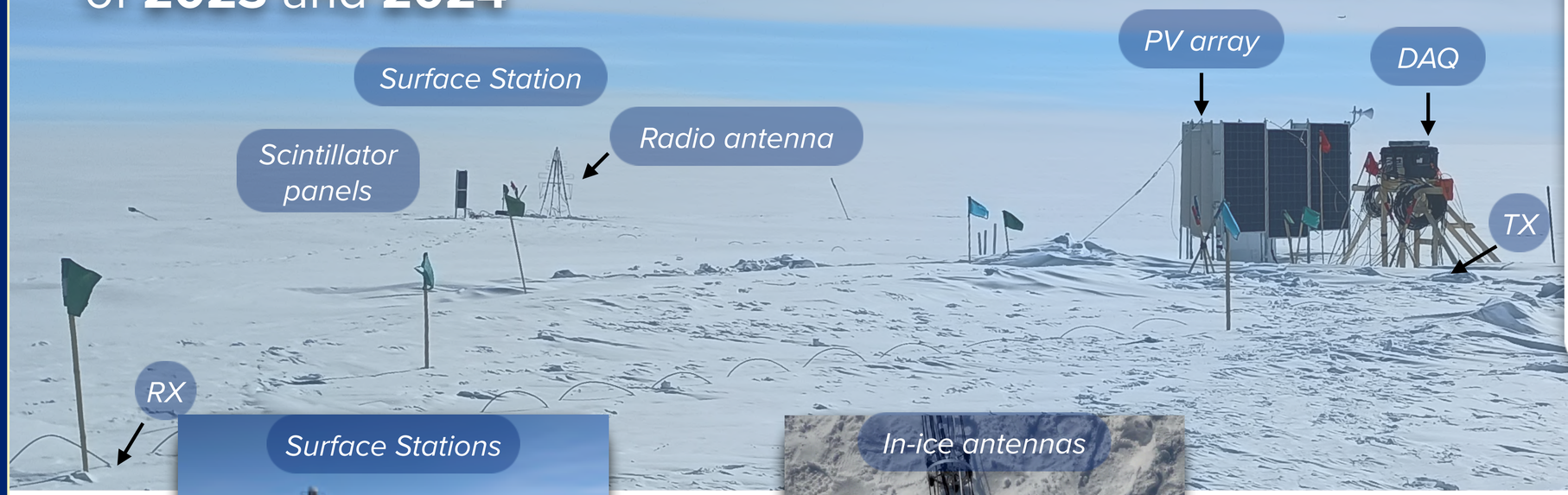


- These secondary CR cascades closely resemble those produced by neutrinos

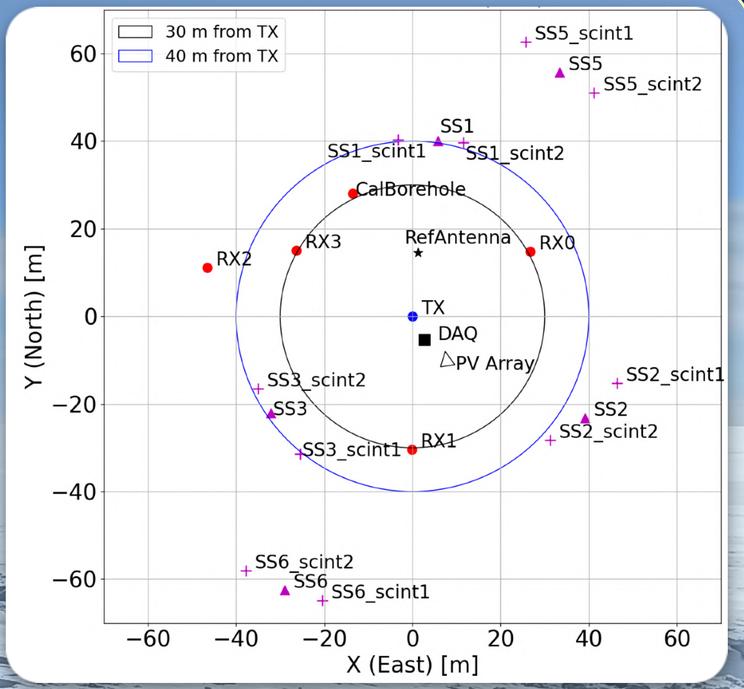
The successful detection of in-ice CR cascades will support targeting UHE neutrinos with the radar technique

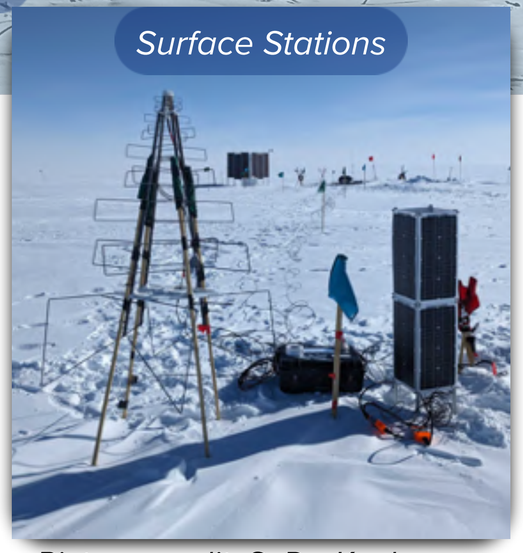
The RET-CR Experiment

- Situated near **Summit Station, Greenland** in summer of **2023** and **2024**



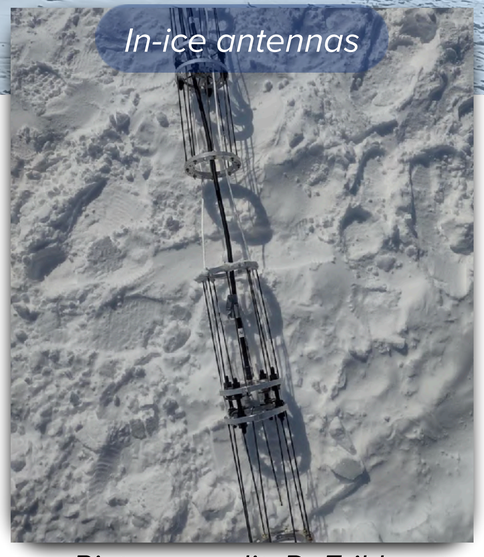
Picture credit: D. Frikken





Picture credit: S. De Kockere

Act as triggers for

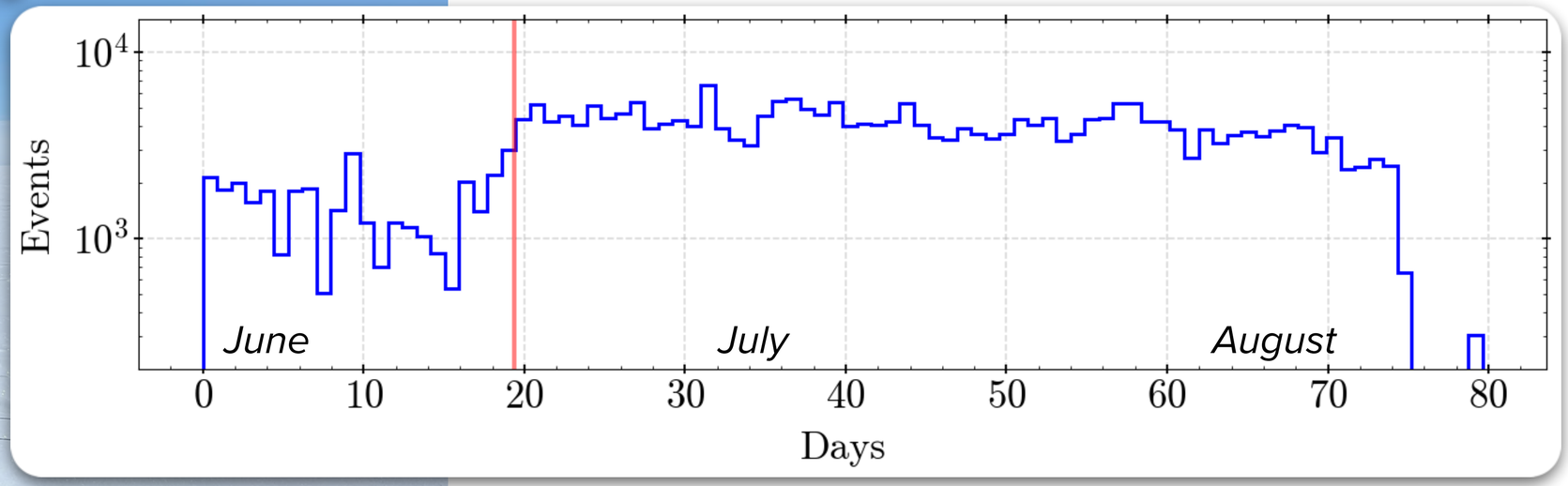


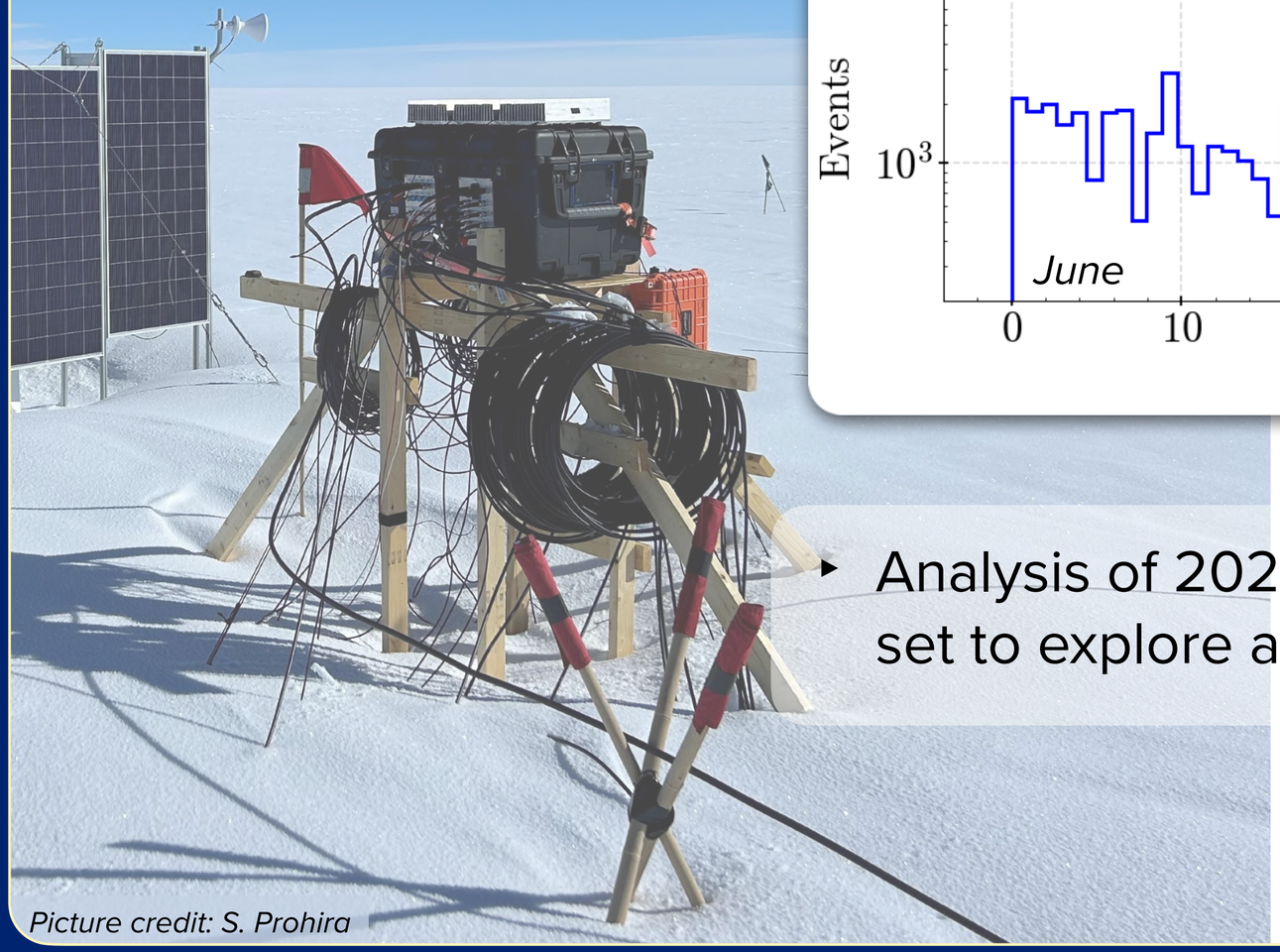
Picture credit: D. Frikken

- Use surface station detections to trigger and validate findings of the radar system
- Develop and test the hardware/ systems needed

The RET-CR Experiment

- RET-CR in 2024 ran for the full summer season, leading to O(10^5) CR triggers ⟶





Picture credit: S. Prohira

- Analysis of 2024 data ongoing; using 10% sample of full data set to explore analysis techniques ⟶ *D. Frikken, PoS ICRC2025 (2025) 257*

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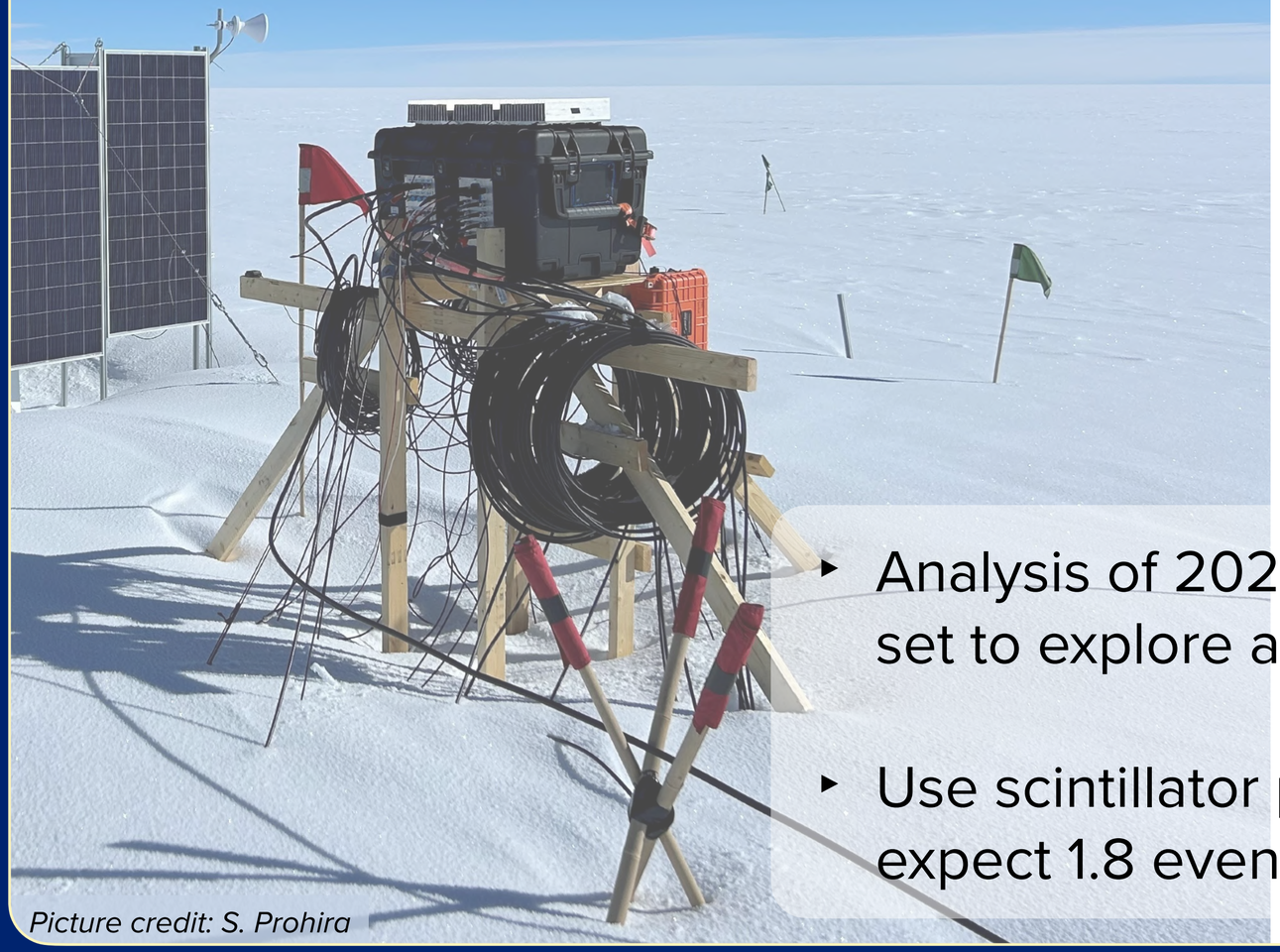

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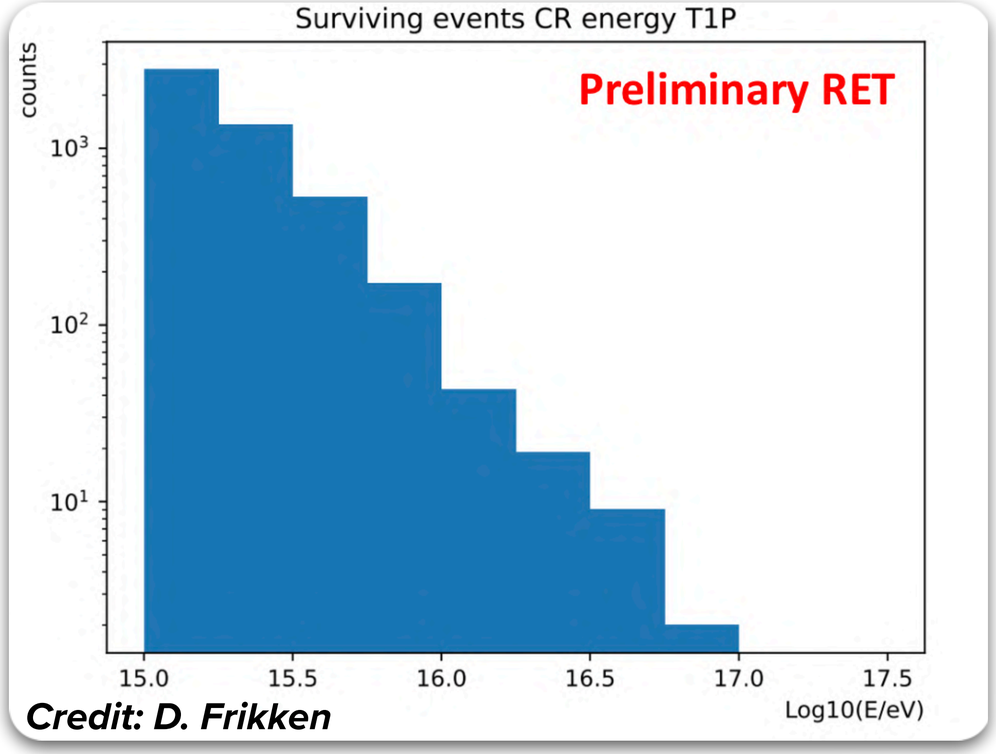

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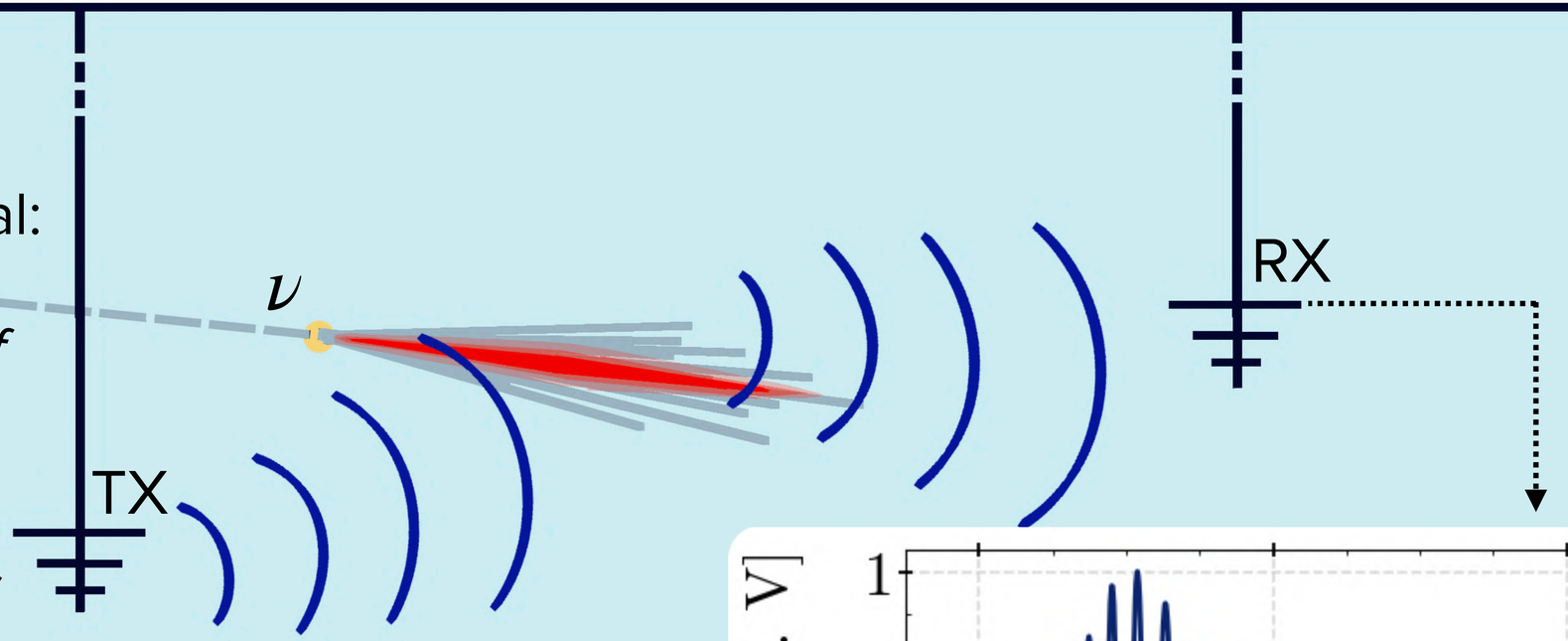
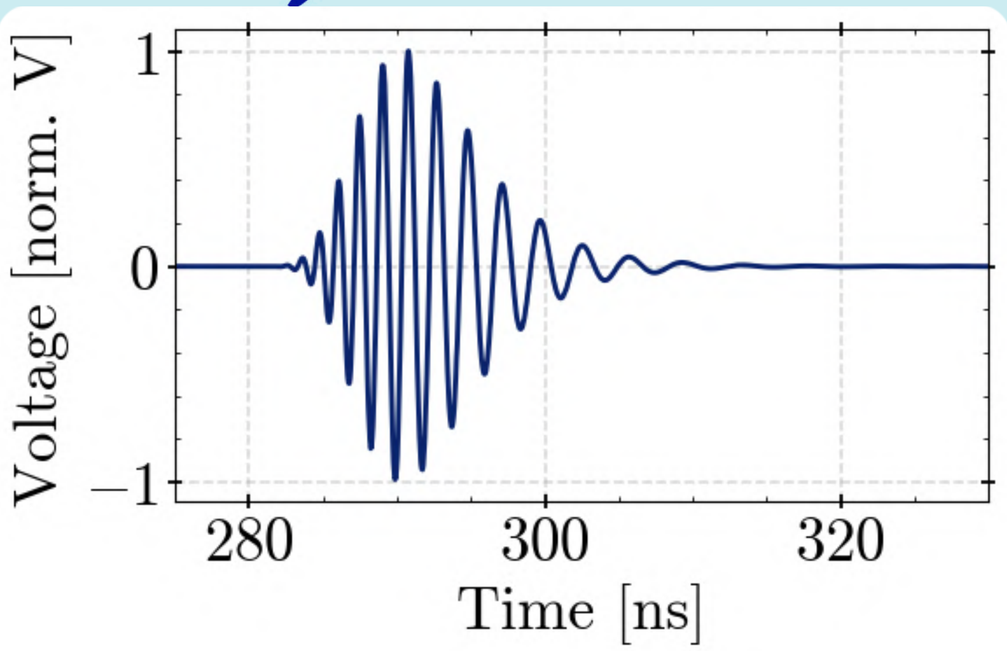
- Use scintillator panel data to obtain properties of the sample; expect 1.8 events with energies $E \geq 10^{17}$ eV

Modelling the radar signal

- Goal is to gain a detailed understanding of the radar signal:
  - *Aid the development of reconstruction techniques*
    - *Help inform layout of future detector*

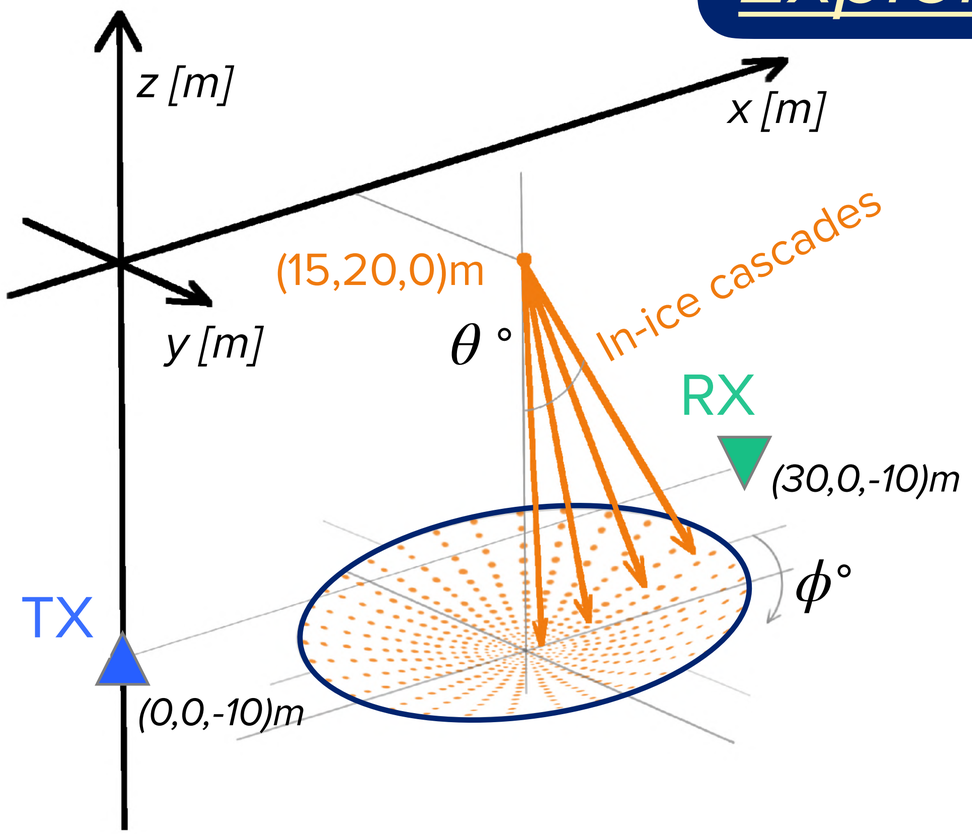




Two simulation approaches:

- **RadioScatter**: MonteCarlo, particle-level code
  S. Prohira and D. Besson, 2019
- **MARES**: semi-analytic, deterministic code
  E. Huesca Santiago et al. 2024

Exploring signal properties



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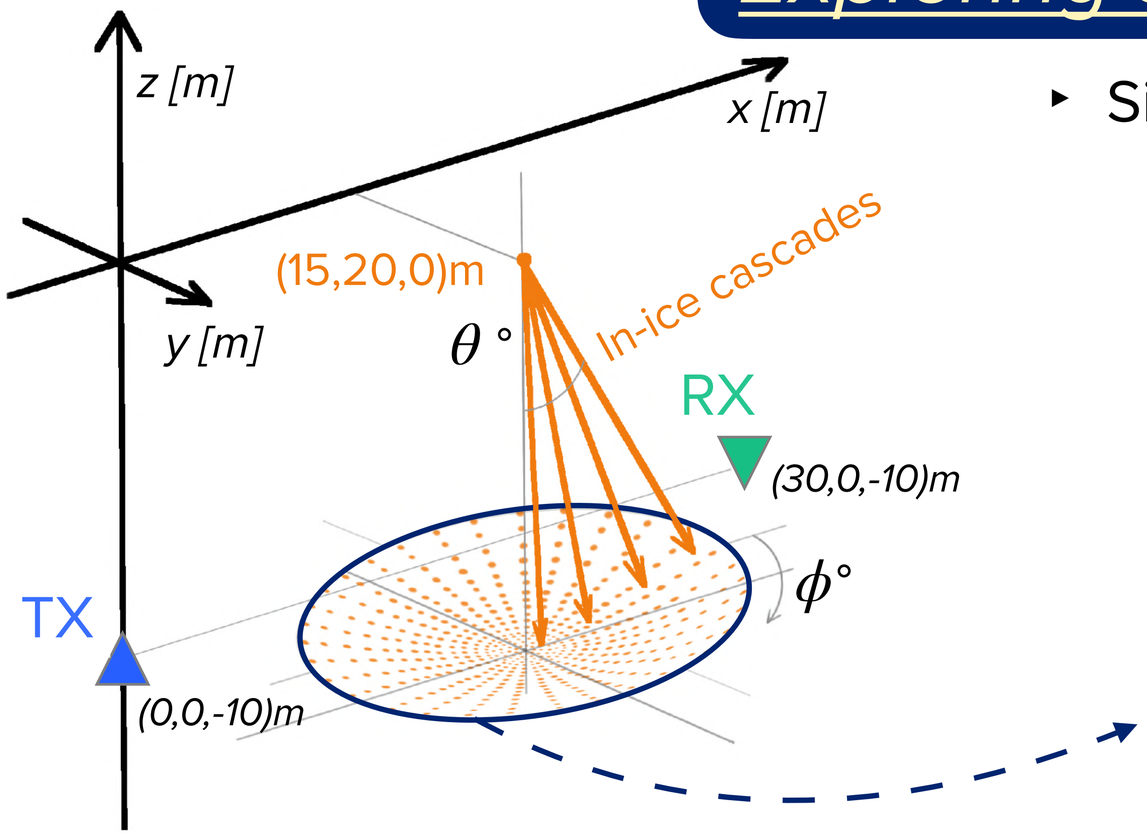
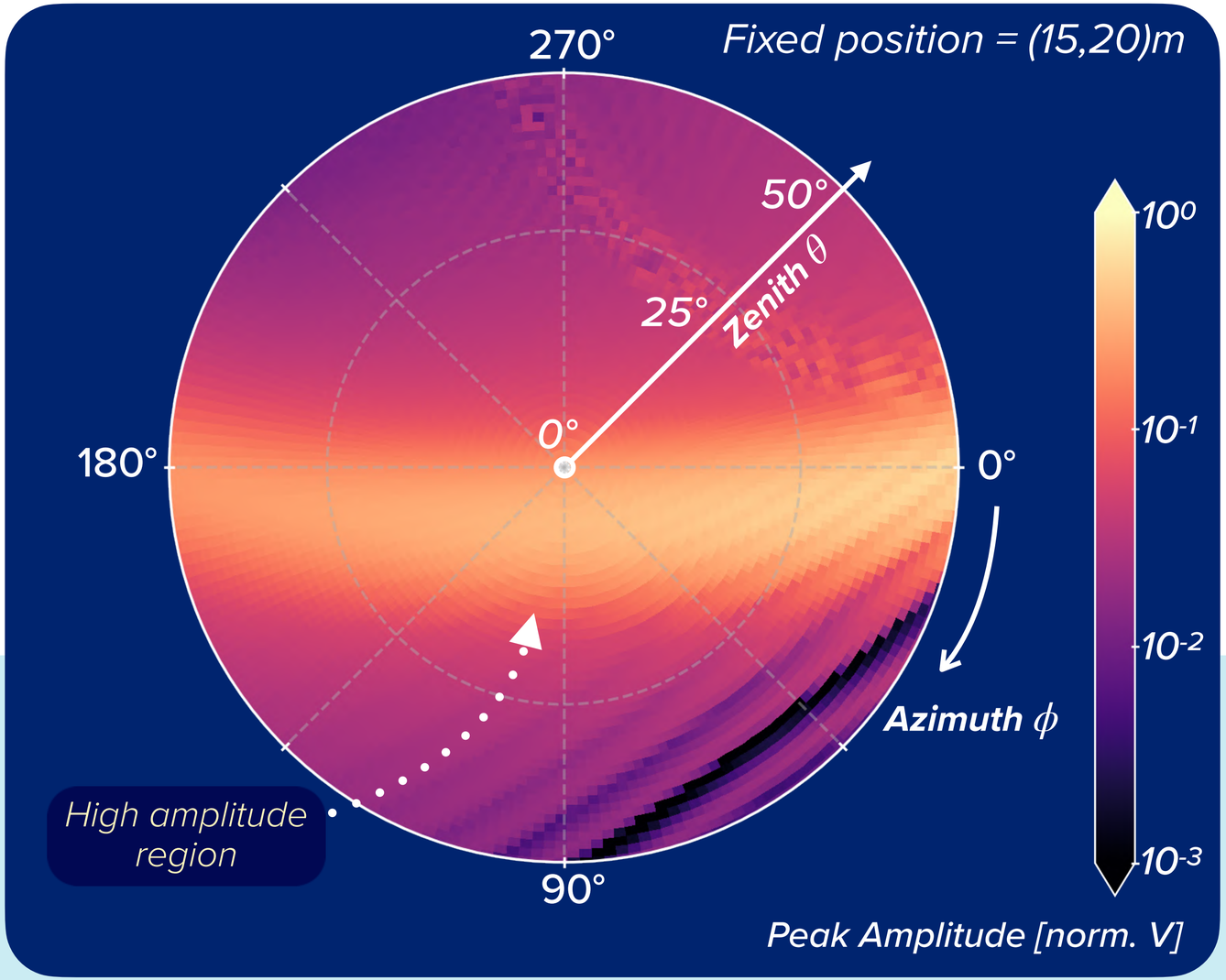
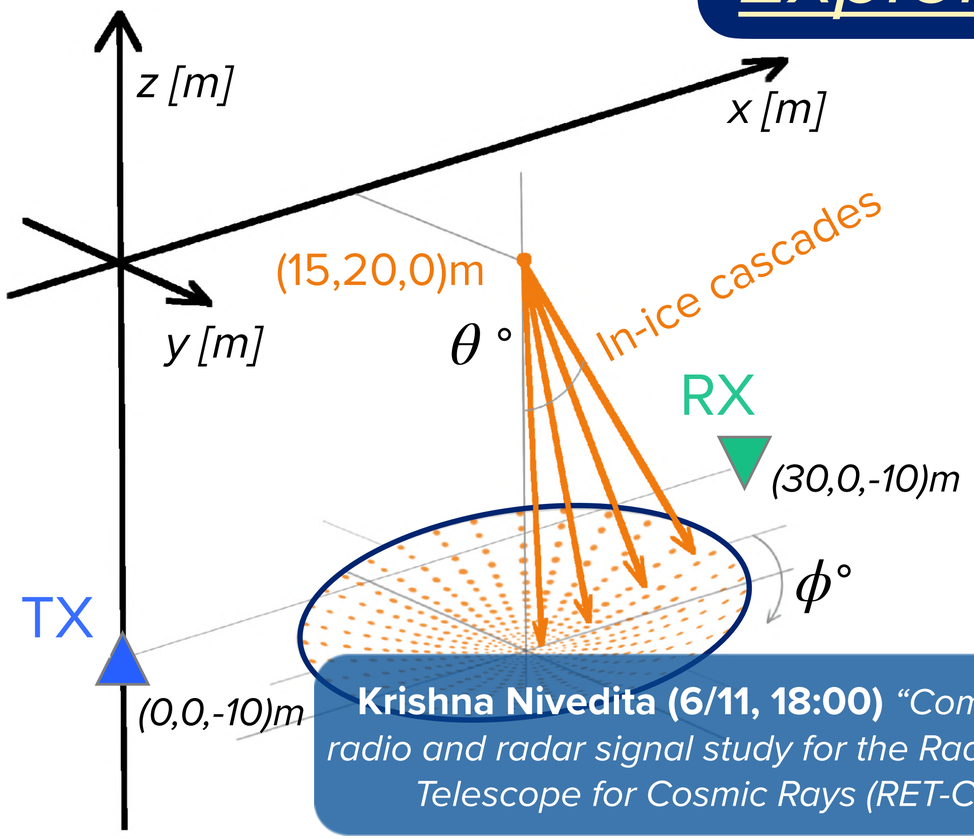


- Signal peak amplitude for cascade arrival direction



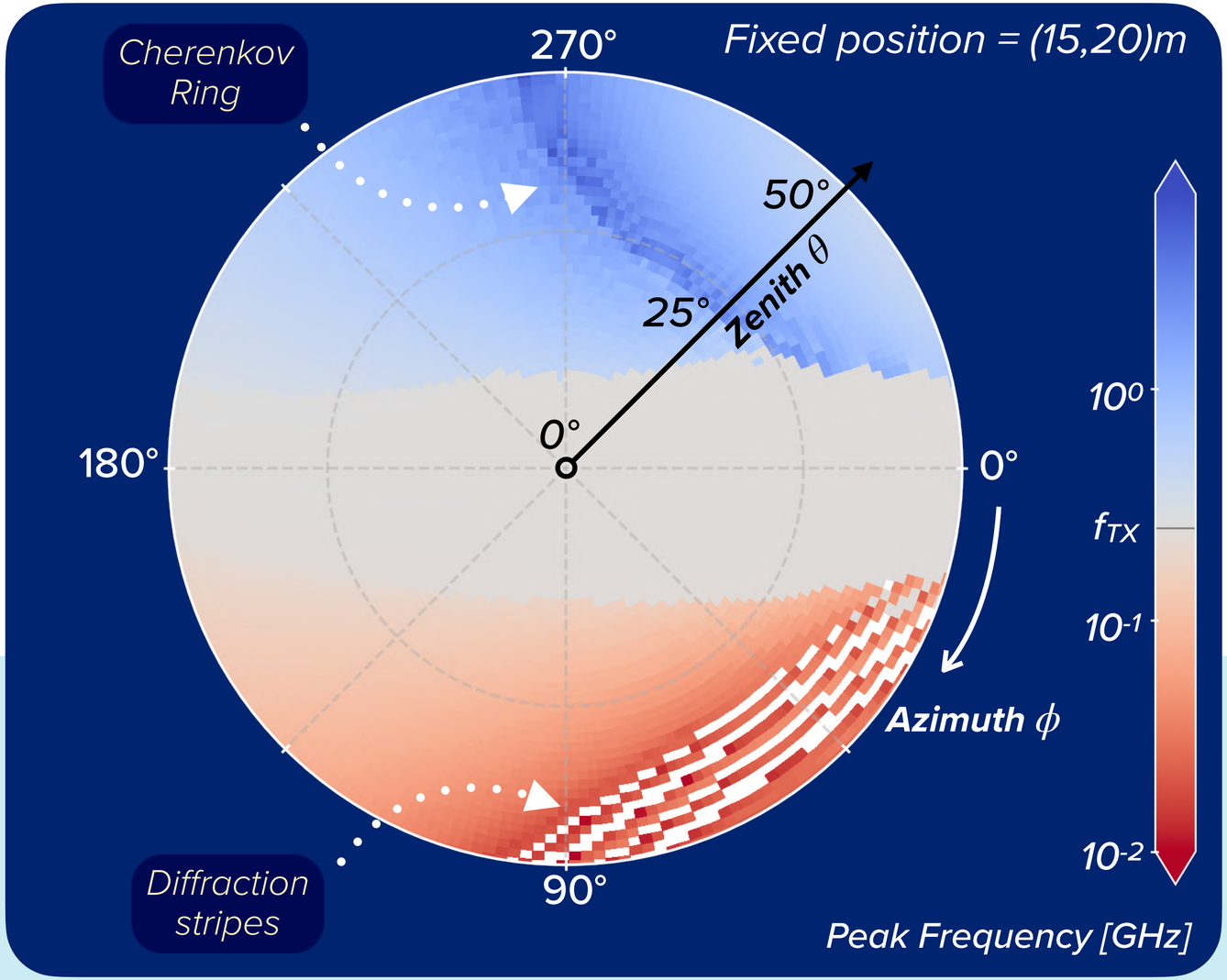
- Sample **signal arrival direction** to explore geometry-dependent effects
- Find signal amplitude to be linked to coherence effect

Exploring signal properties



Krishna Nivedita (6/11, 18:00) *"Combined radio and radar signal study for the Radar Echo Telescope for Cosmic Rays (RET-CR)"*

- Signal peak frequency for cascade arrival direction



- Signals exhibit strong **frequency shifts** relative to **both TX** and **RX** position
- Radar signals only; see contribution by K. Nivedita for combined signal study with CR radio emission

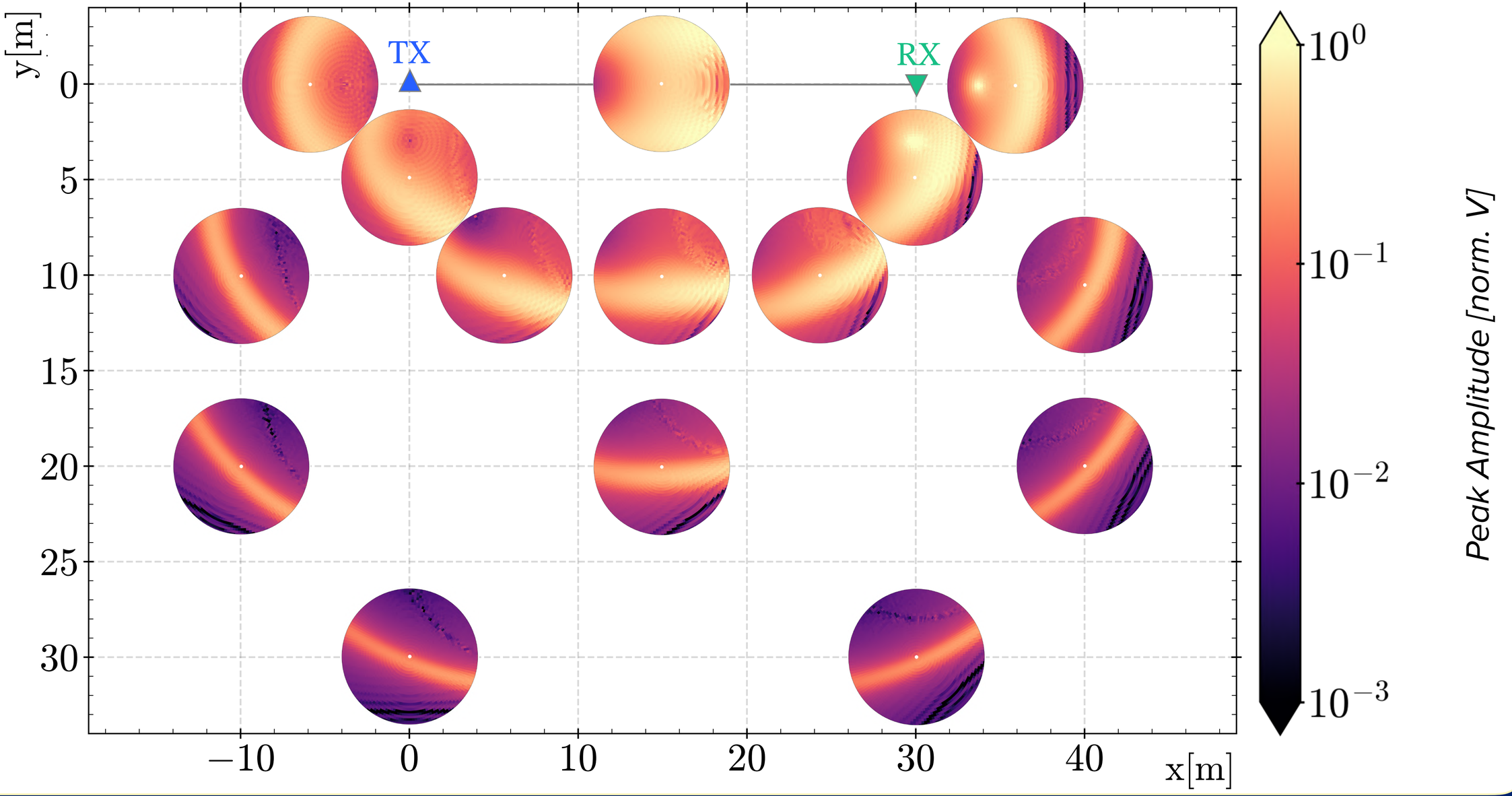
Summary

- Employing **radar** to detect **high-energy particles** interacting in ice
- Aim to use method to detect UHE cosmic neutrinos with **RET-N**

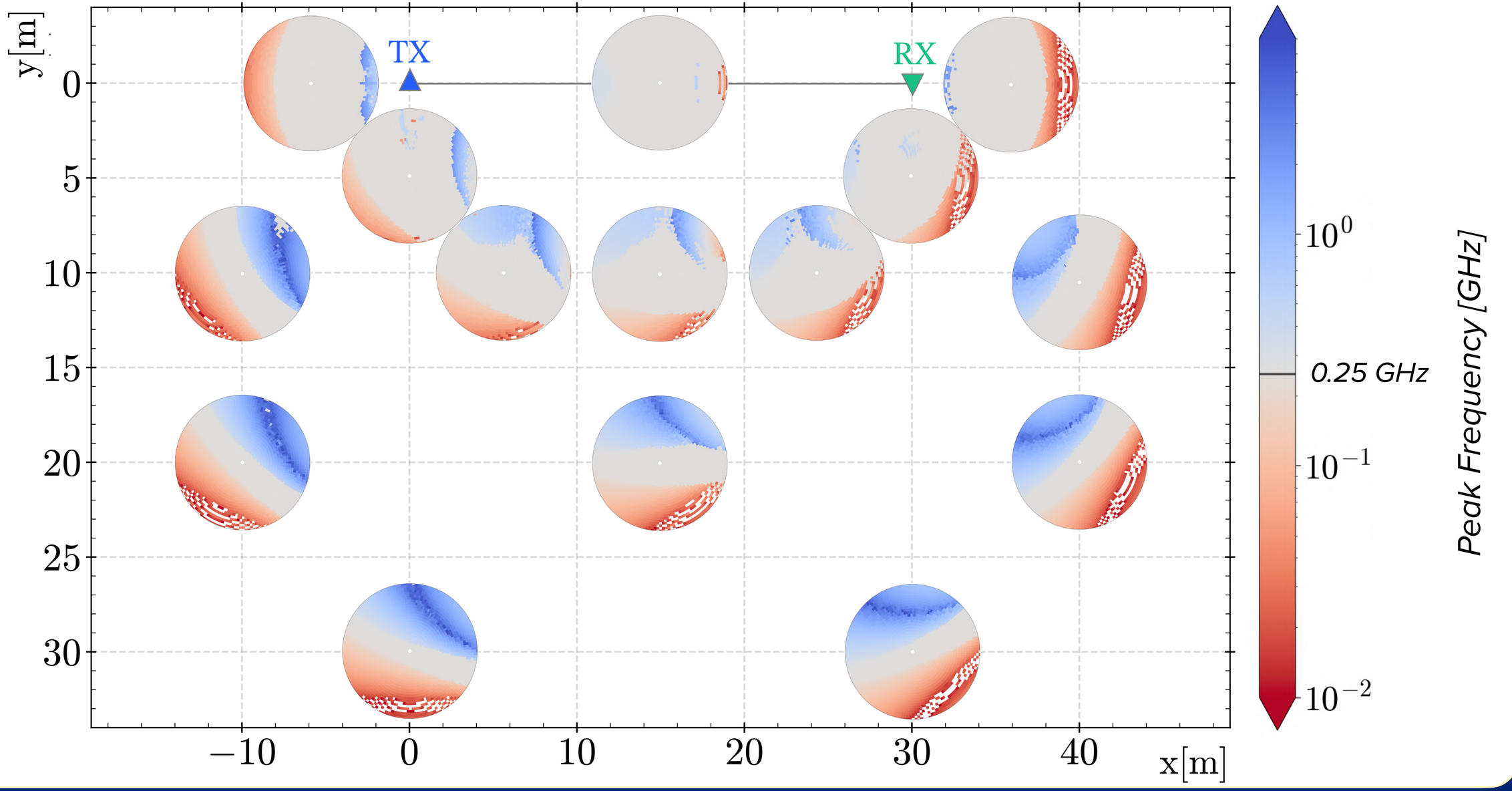
- Currently working on **demonstrating method in-situ**, with data analysis from RET-CR experiment underway… results soon!

Picture credit: D. Frikken

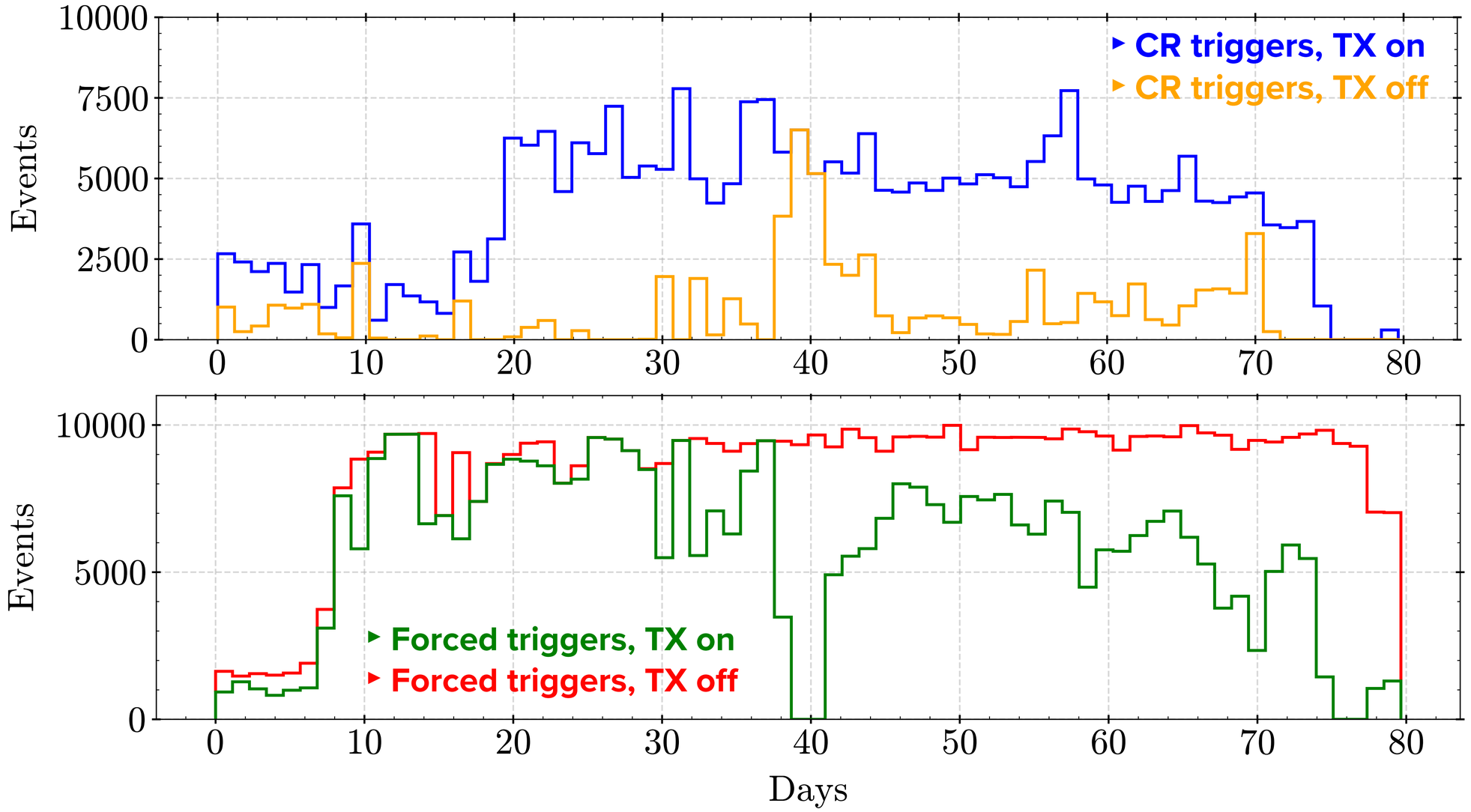
Amplitude


TX
RX
y[m]
0
5
10
15
20
25
30
−10
0
10
20
30
40
x[m]
10^{0}
10^{-1}
10^{-2}
10^{-3}
Peak Amplitude [norm. V]

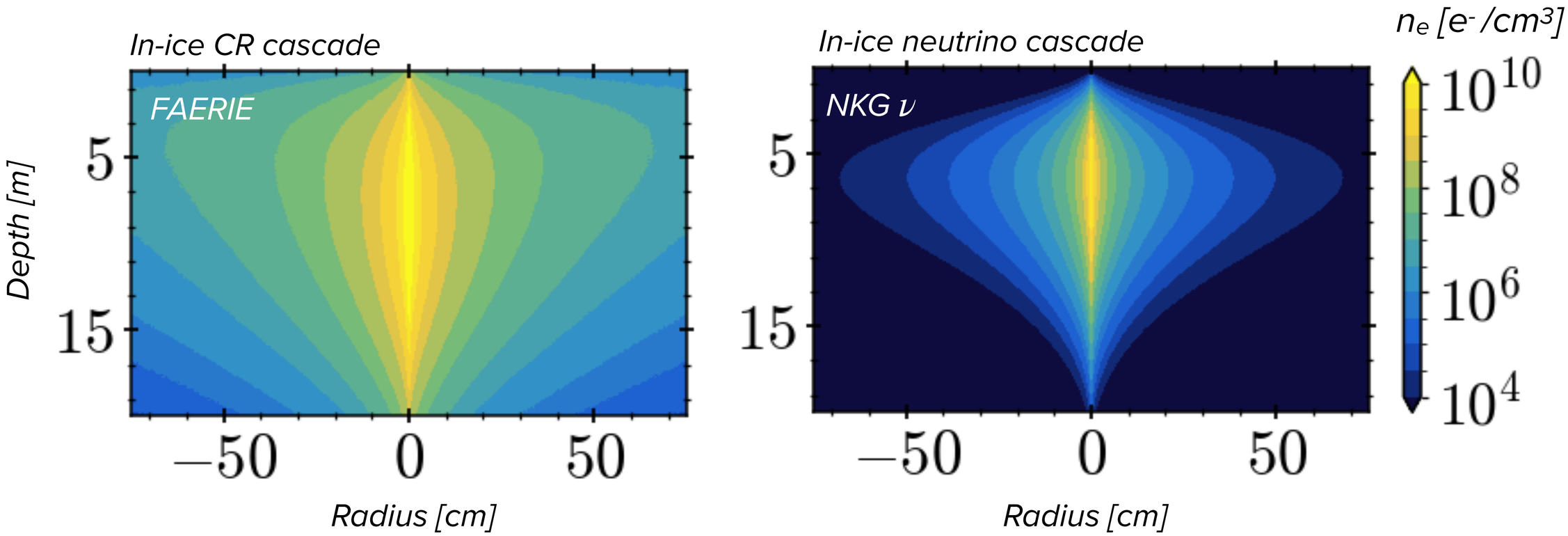
Frequency


TX
RX
y[m]
0
5
10
15
20
25
30
−10
0
10
20
30
40
x[m]
10^0
0.25 GHz
10^{-1}
10^{-2}
Peak Frequency [GHz]

RET-CR data subsets



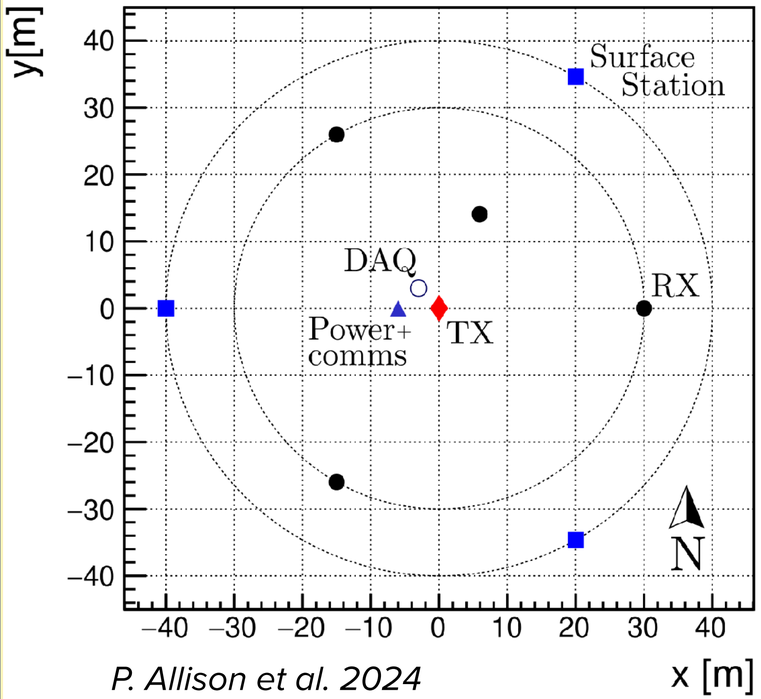
In-ice cascades



- 17.0 eV, proton shower
- Greenland ice density

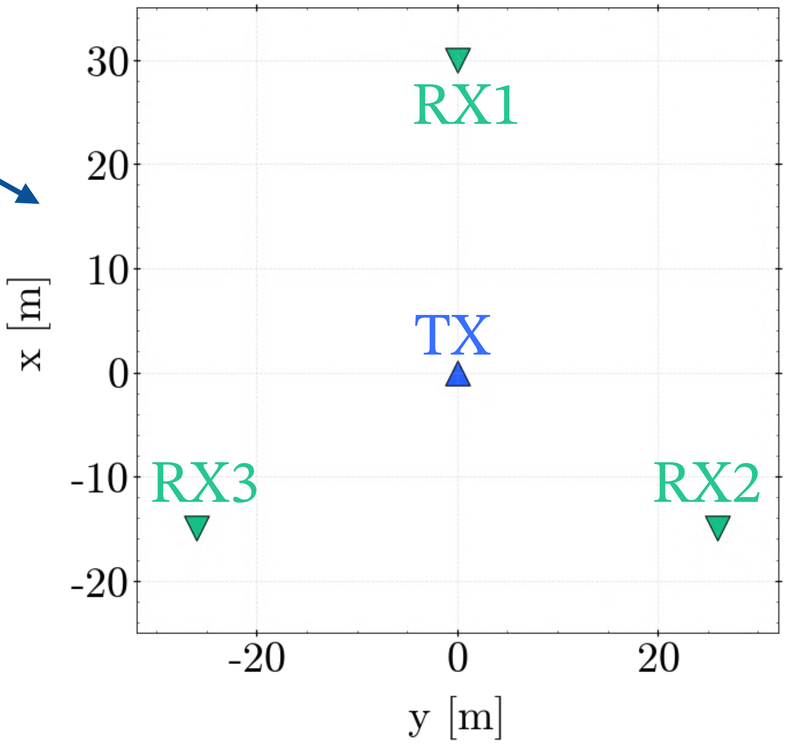
- ~1 PeV ν
- Constant ice density, 0.92 g/cm^3

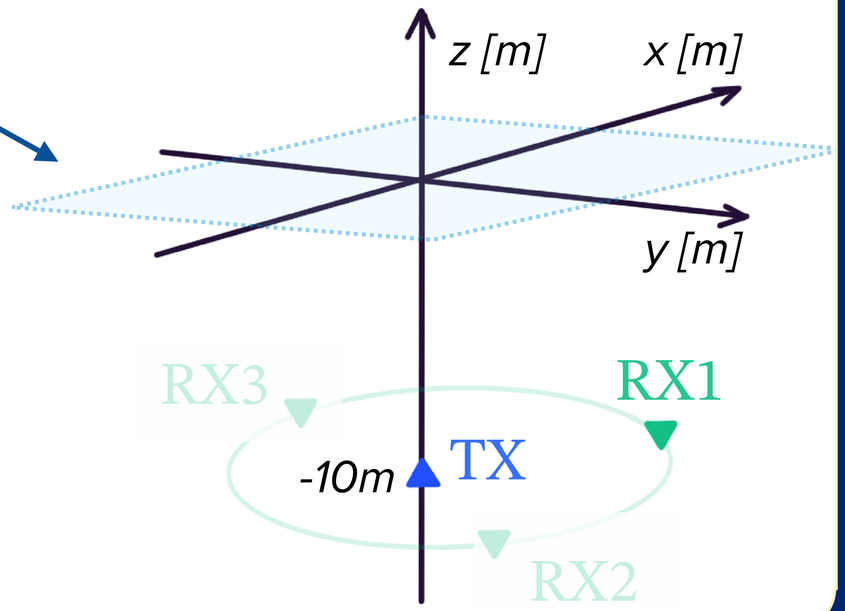
Antenna set-up



P. Allison et al. 2024

Using a detector setup within MARES resembling RET-CR as deployed in 2023





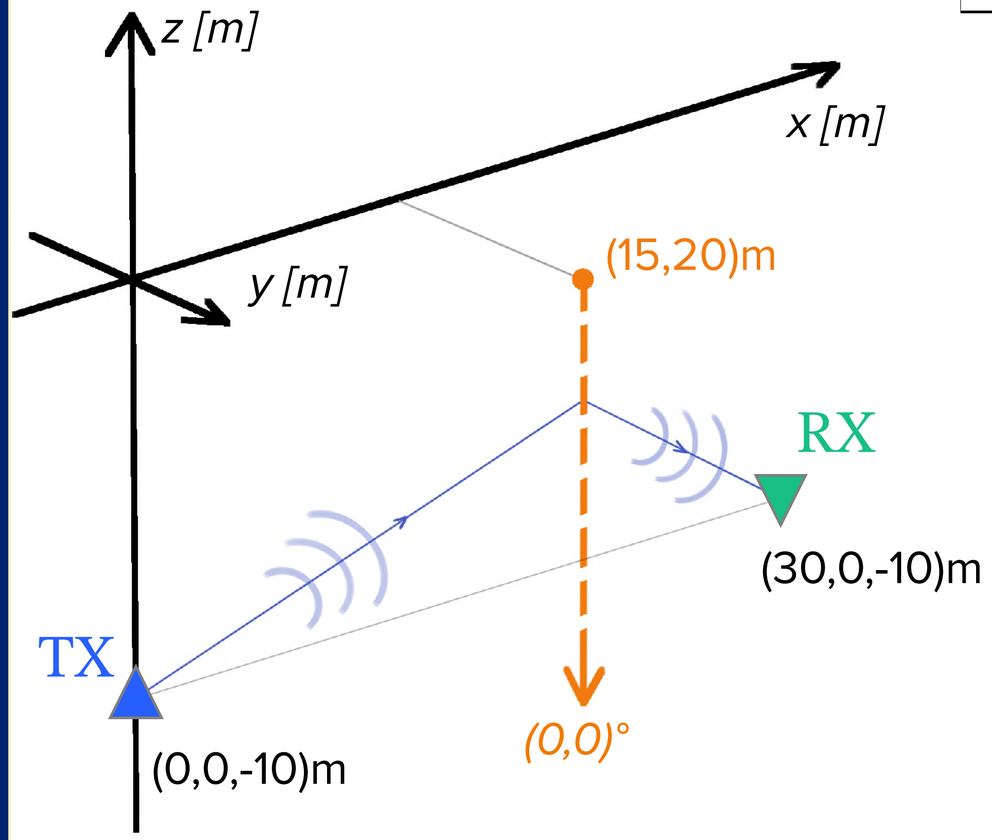
Detector Parameters:

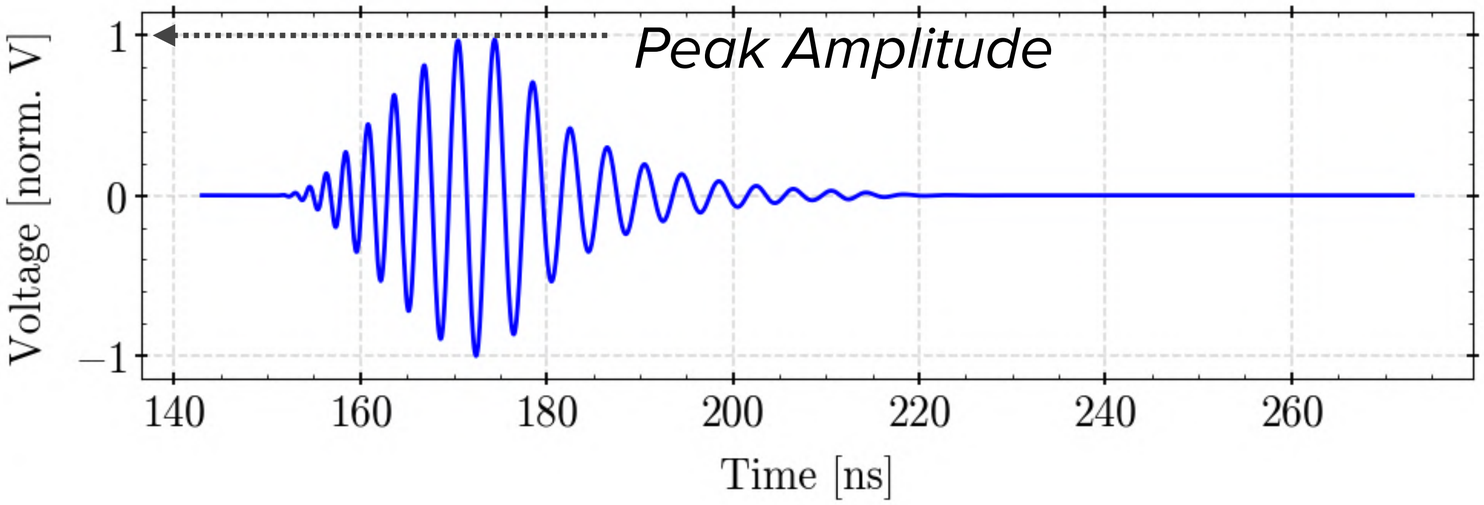
- TX frequency = 250 MHz
- Gain = 15 dBi
- Power = 50 W
- Zpol

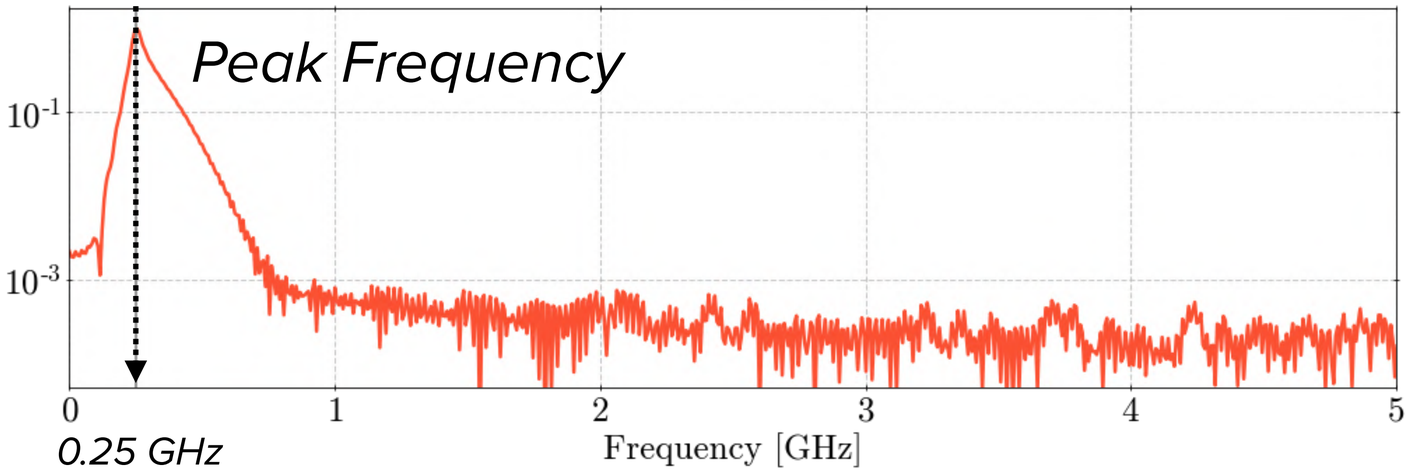
Antenna set-up

Radar signals simulated with MARES
⇒ *E. Huesca Santiago et al. 2024*
Macroscopic, semi-analytic code package

TX Frequency = 250 MHz
CS Energy = 20 PeV
Constant ice, n = 1.78



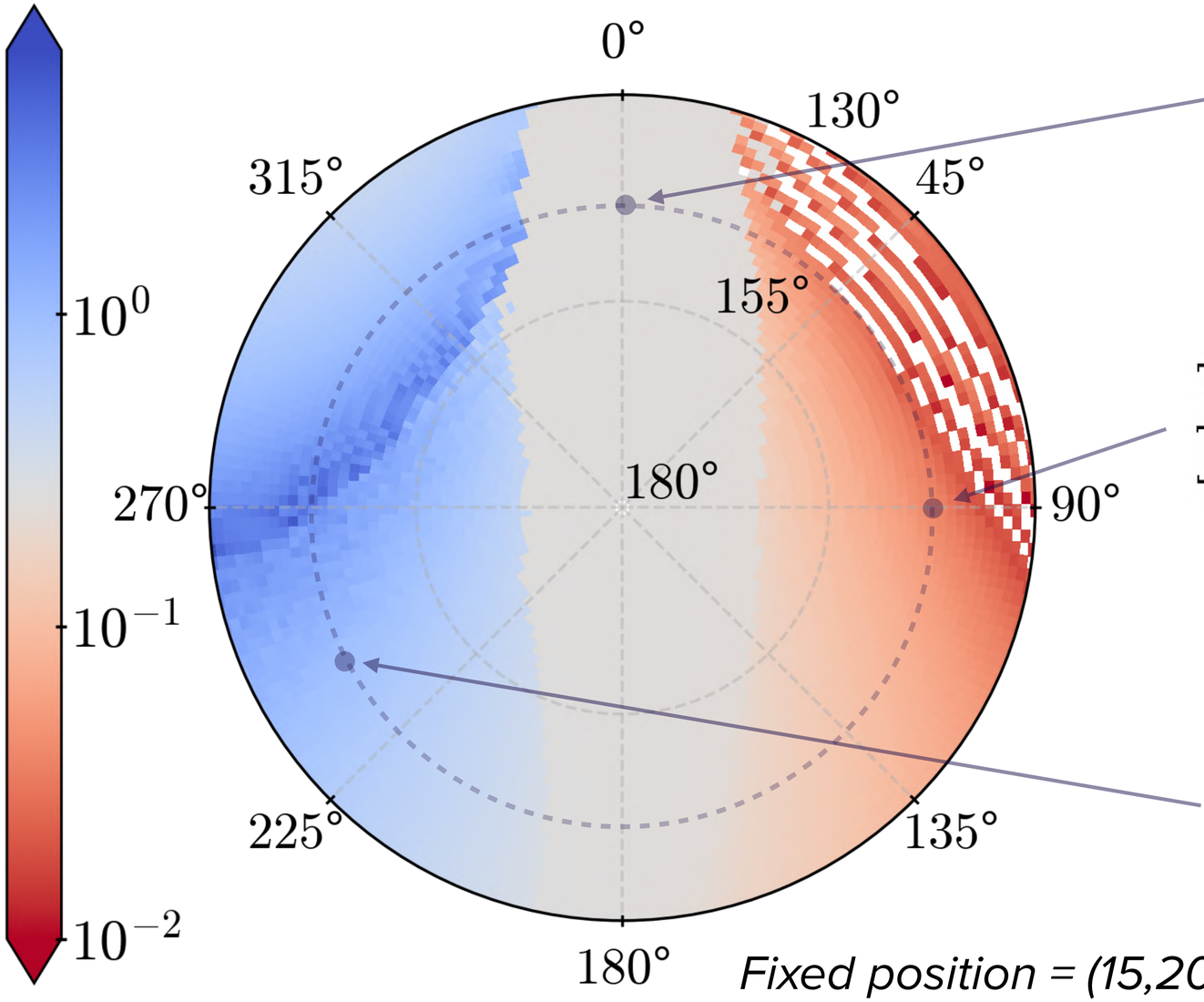




0.25 GHz
(TX frequency)

→ Focusing on effects of changing CS position and arrival direction on peak amplitude and frequency

Frequency shifts



Peak Frequency [GHz]

Fixed position = (15,20)m