IIHE RET EFFORTS

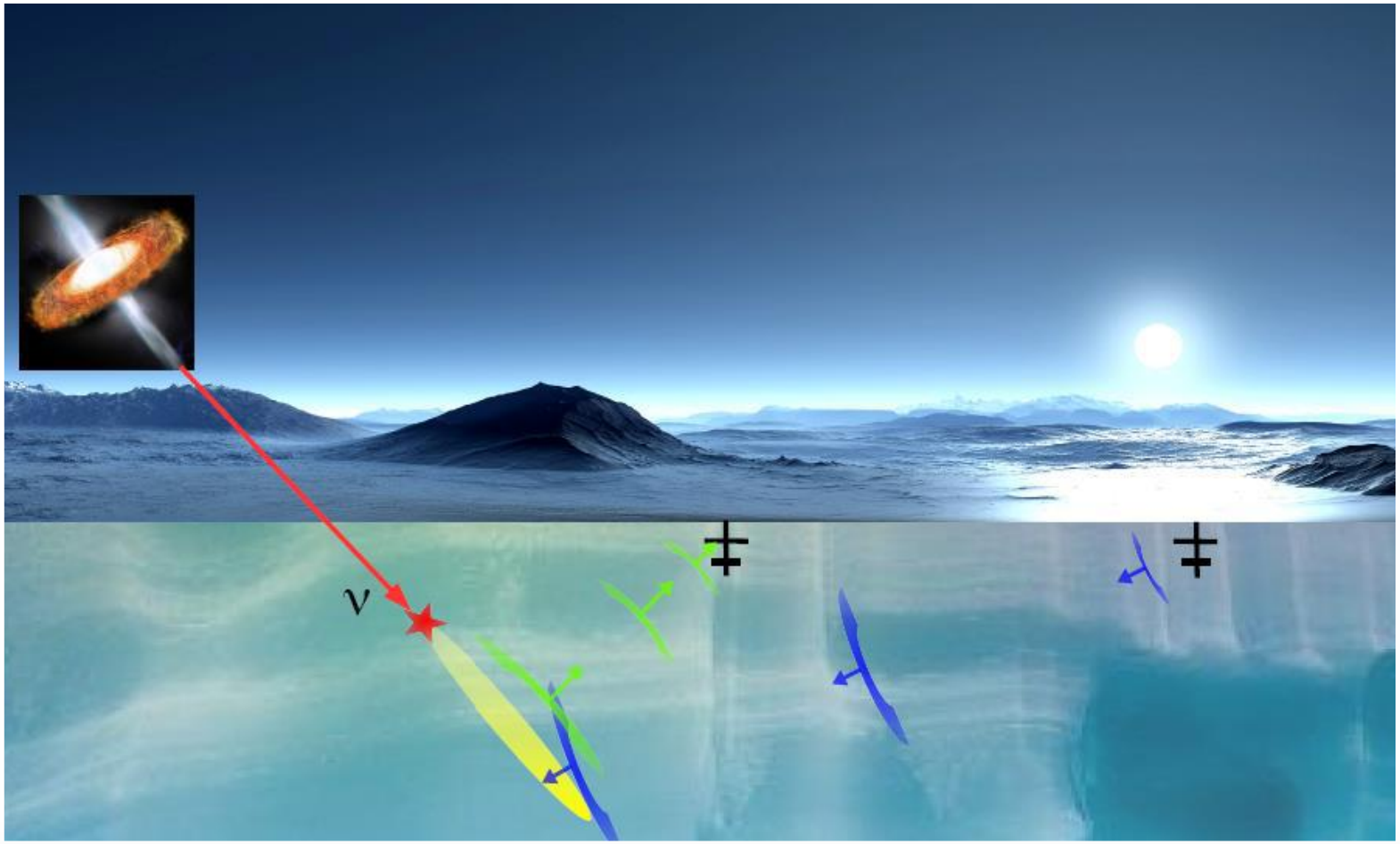
KRIJN D DE VRIES

ON BEHALF OF THE RADAR ECHO TELESCOPE COLLABORATION
WWW.RADARECHOTELESCOPE.ORG

VRIJE UNIVERSITEIT BRUSSEL
INTERUNIVERSITY INSTITUTE FOR HIGH ENERGIES

RADAR DETECTION OF HIGH-ENERGY PARTICLE CASCADES IN ICE

THE MAIN IDEA

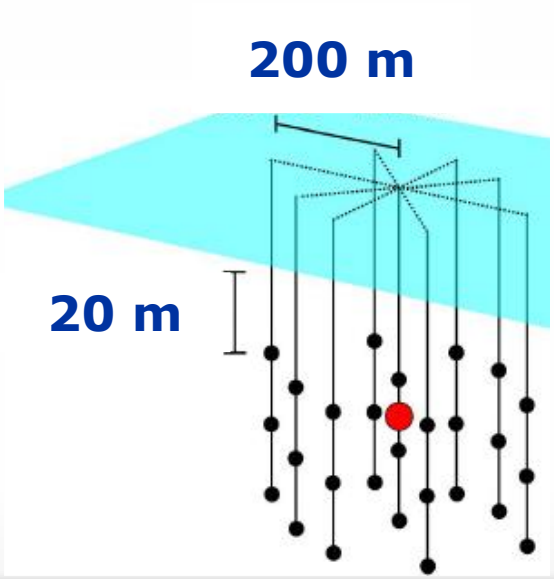


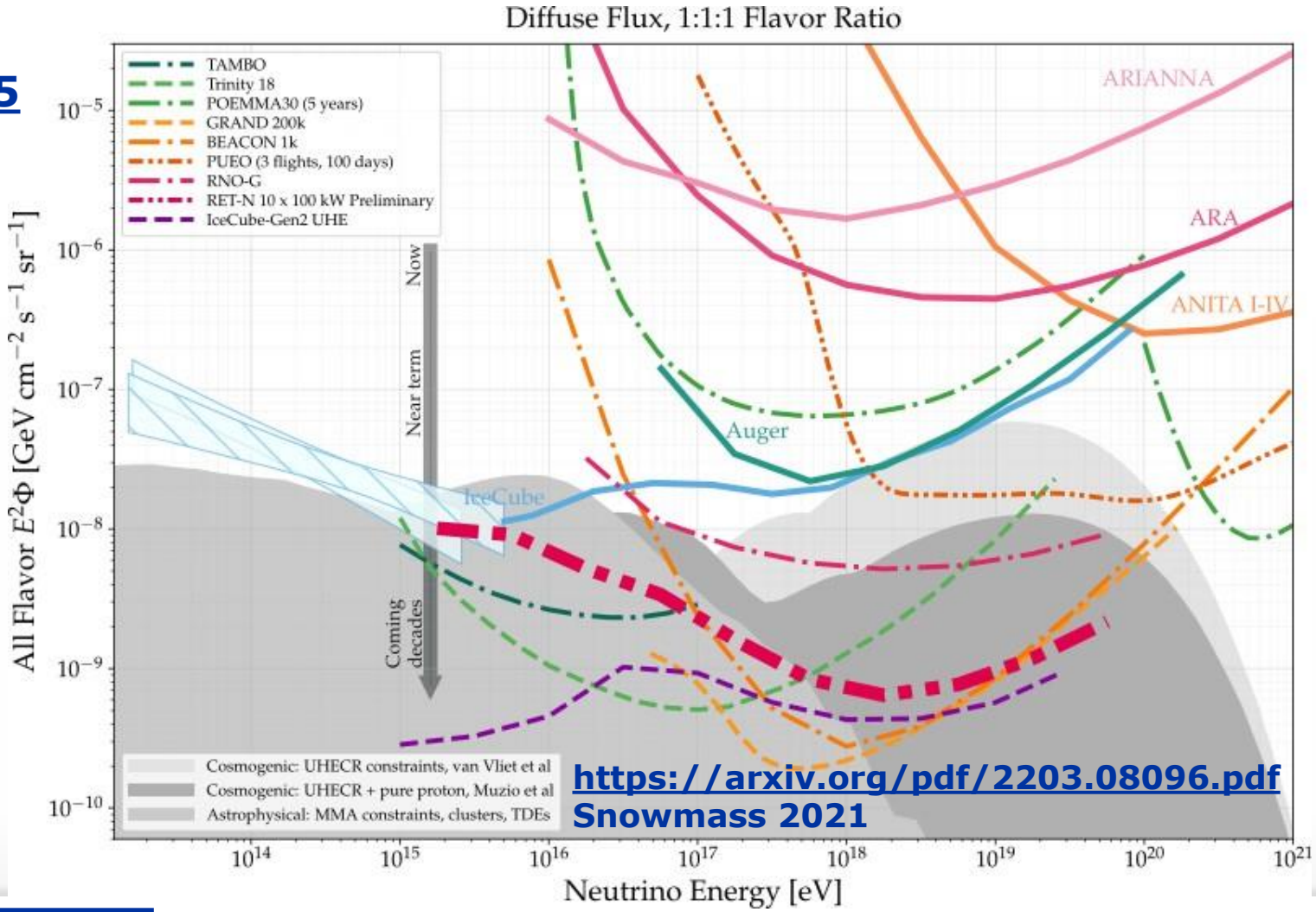
THE RADAR ECHO TELESCOPE FOR NEUTRINOS

WHY RADAR? PROBING THE PEV-EEV COSMIC NEUTRINO FLUX

- **10 x 100 kW effective (phased) transmitter @ 1.5 km depth.**

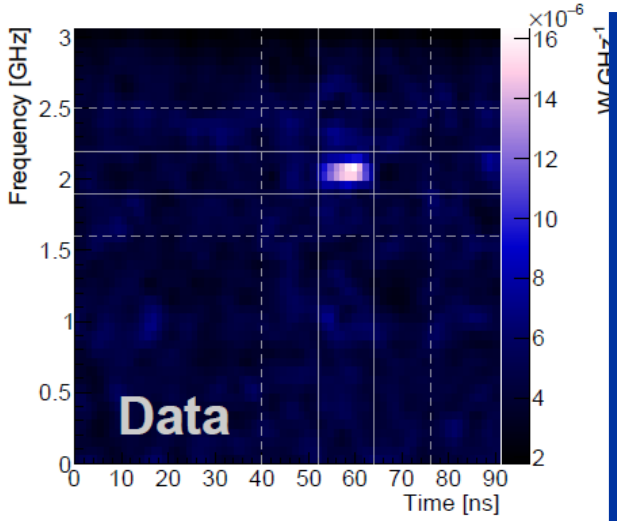
- **Trigger at 0 dB w.r.t. 50 MHz bandwidth thermal noise**





https://arxiv.org/pdf/2203.08096.pdf
Snowmass 2021

DETECTING HIGH-ENERGY PARTICLE CASCADES AT SLAC



First ever detection of a radar scatter from a high-energy particle cascade!!

→Let's see if we can detect a particle cascade in-situ

Observation of Radar Echoes from High-Energy Particle Cascades

S. Prohira, K. D. de Vries, P. Allison, J. Beatty, D. Besson, A. Connolly, N. van Eijndhoven, C. Hast, C.-Y. Kuo, U. A. Latif, T. Meures, J. Nam, A. Nozdrina, J. P. Ralston, Z. Riesen, C. Sbrocco, J. Torres, and S. Wissel

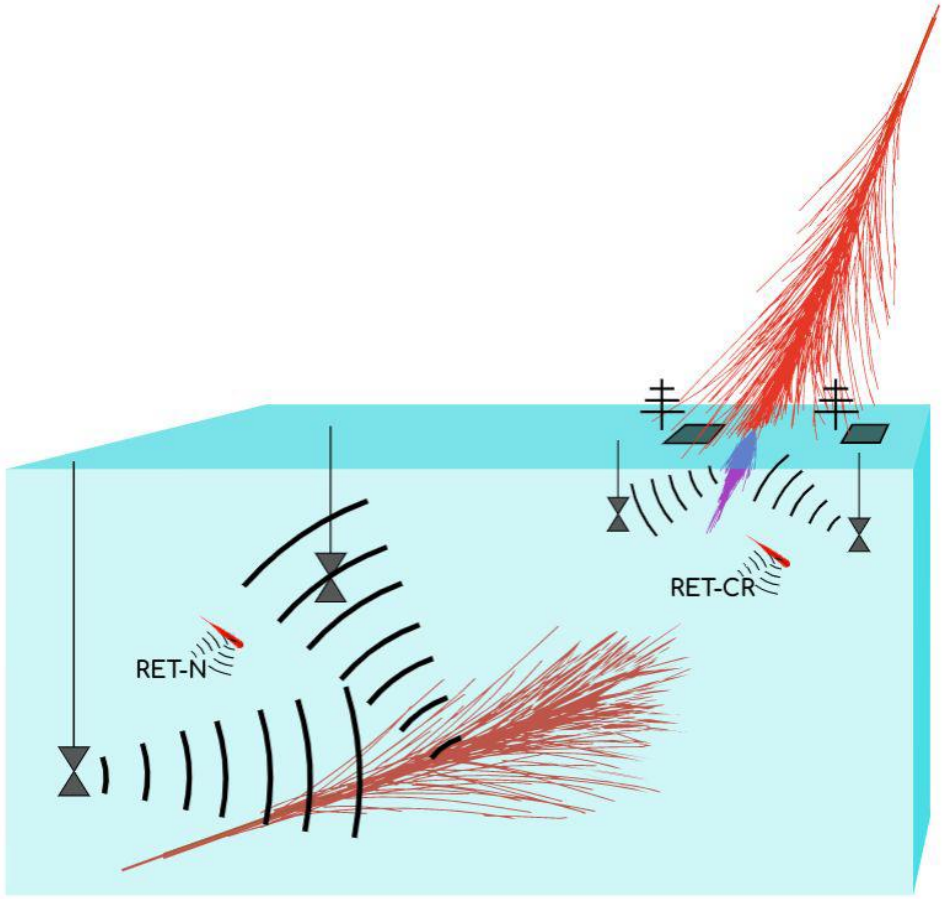
Phys. Rev. Lett. 124, 091101 (2020)

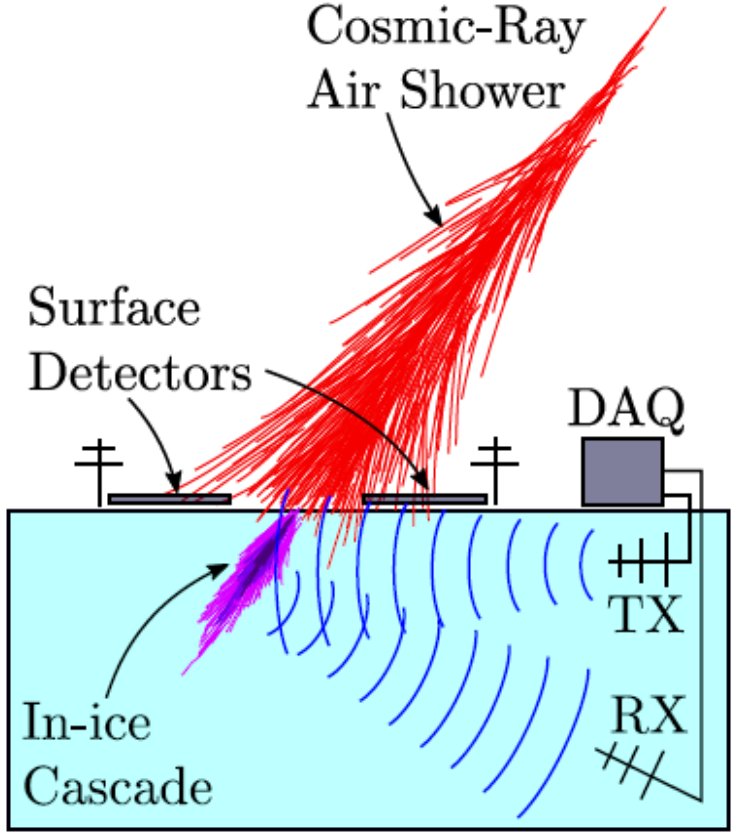
DETECTING PARTICLE CASCADES IN NATURE

THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

DETECTING PARTICLE CASCADES IN NATURE

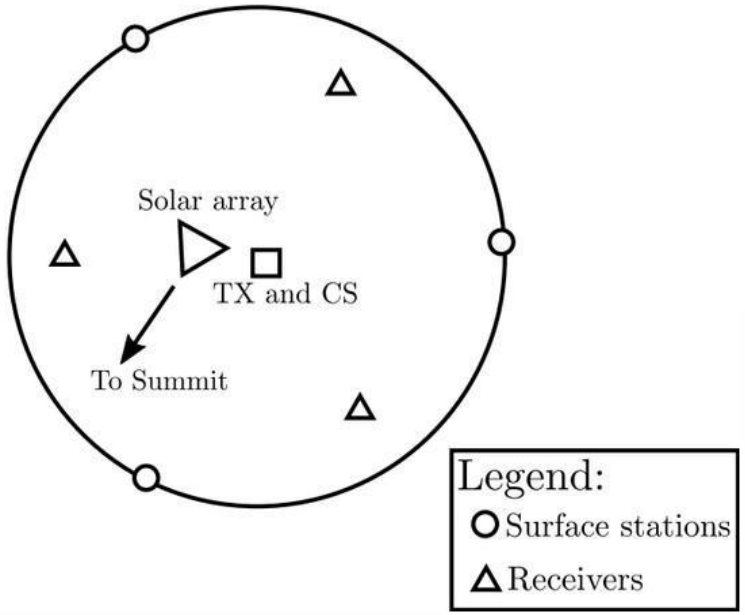


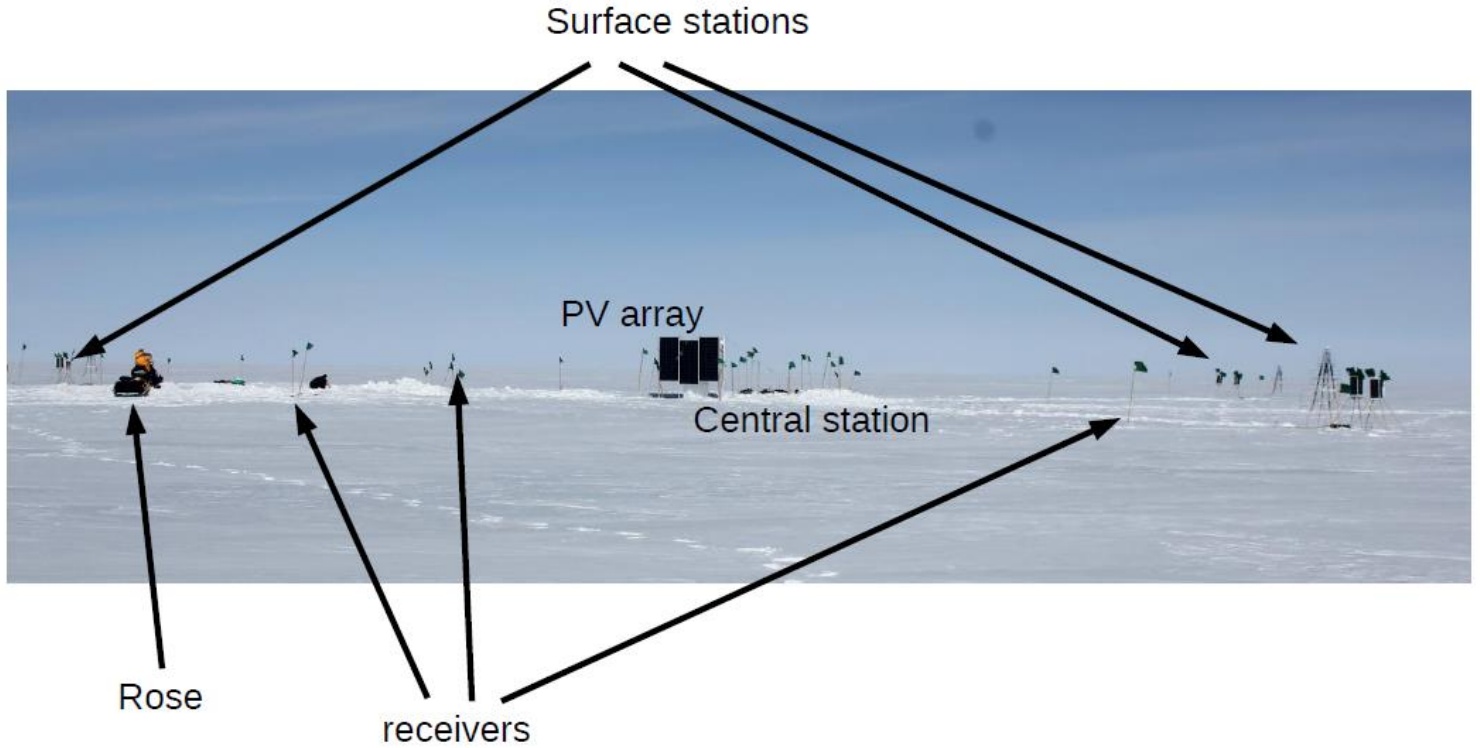


RET-CR paper: arXiv: 2104.00459 - Phys. Rev. D 104, 102006

THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

MAY 2023 DEPLOYMENT → MAY 2024 REDEPLOYMENT

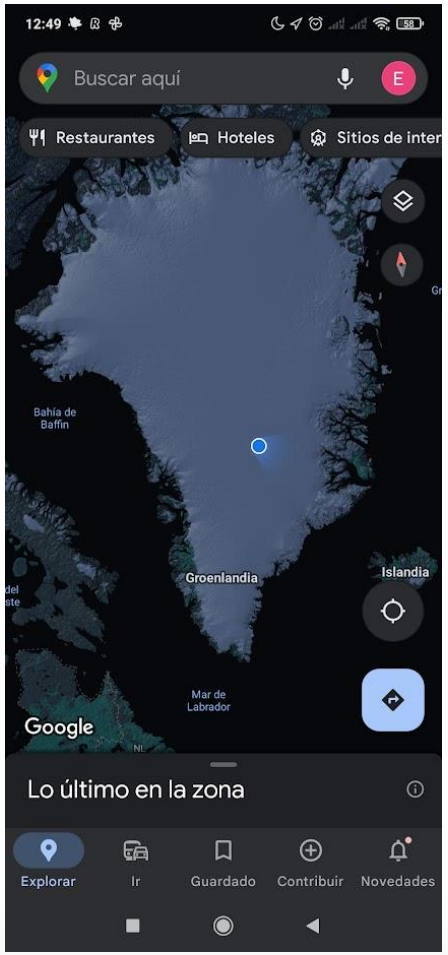




- **3x1.2kW solar array with charge control and battery bank.**
- **4 downhole strings with single reciever dipole at 10m depth.**
- **8 channel phased dipole array centered at 10m.**
- **5 surface stations (2 scintillator panels + 1 radio antenna each).**
- **GPS, WLAN link, etc.**

THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

MAY 2023-2024 DEPLOYMENT



THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

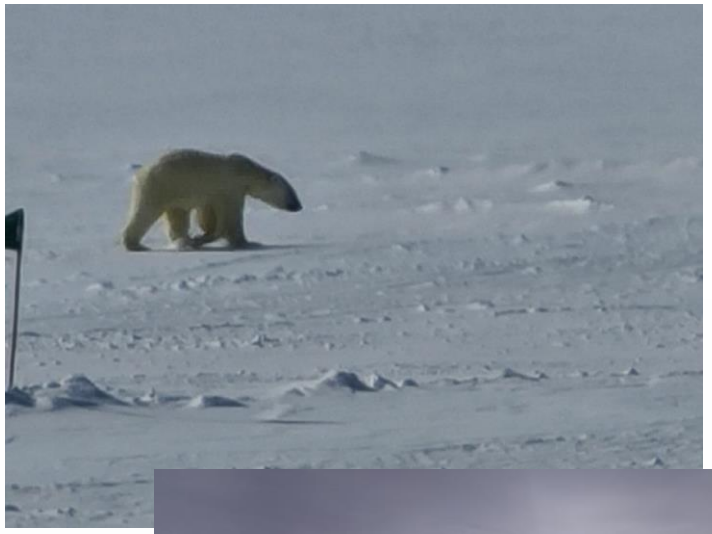
DEPLOYMENT

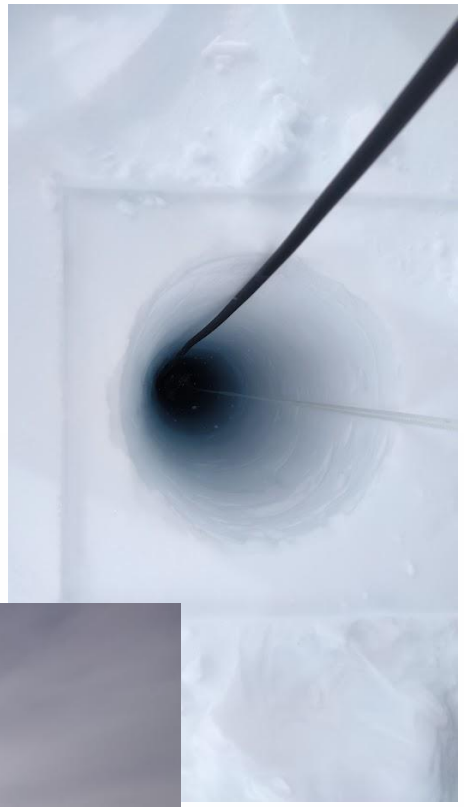
IIHE involvment in RET-CR deployment / retrieval teams:

Rose Stanley
Enrique Huesca Santiago
Simon de Kockere
Krijn de Vries
Katie Mulrey (former IIHE, currently Nijmegen)

THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

DEPLOYMENT





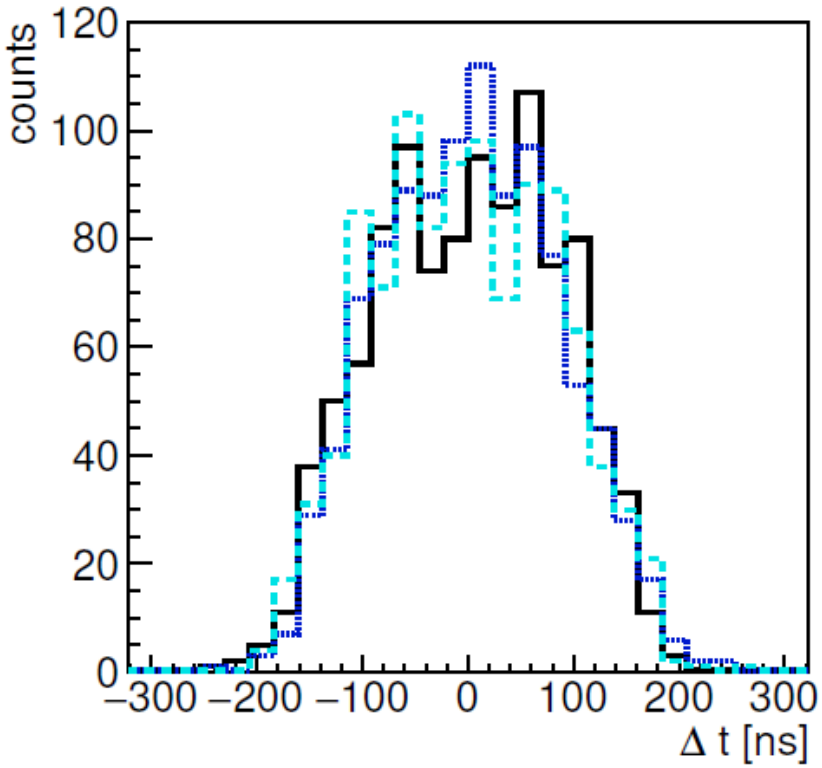
THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

MAY 2023 DEPLOYMENT

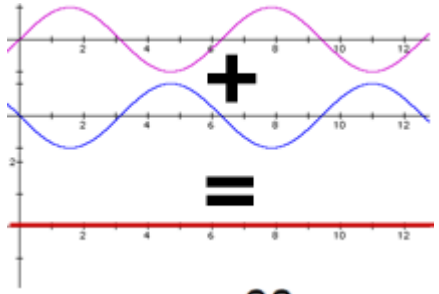
Several weeks of commissioning

- Surface trigger worked as expected
- 9 days of full operation
- Radar system worked as expected:
  - Transmitter carrier cancellation
  - Beam forming

- Overheating issues caused system shutdown
- System noise makes analysis tricky
- Both overheating and system noise have been mitigated for the **2024 data-taking run**

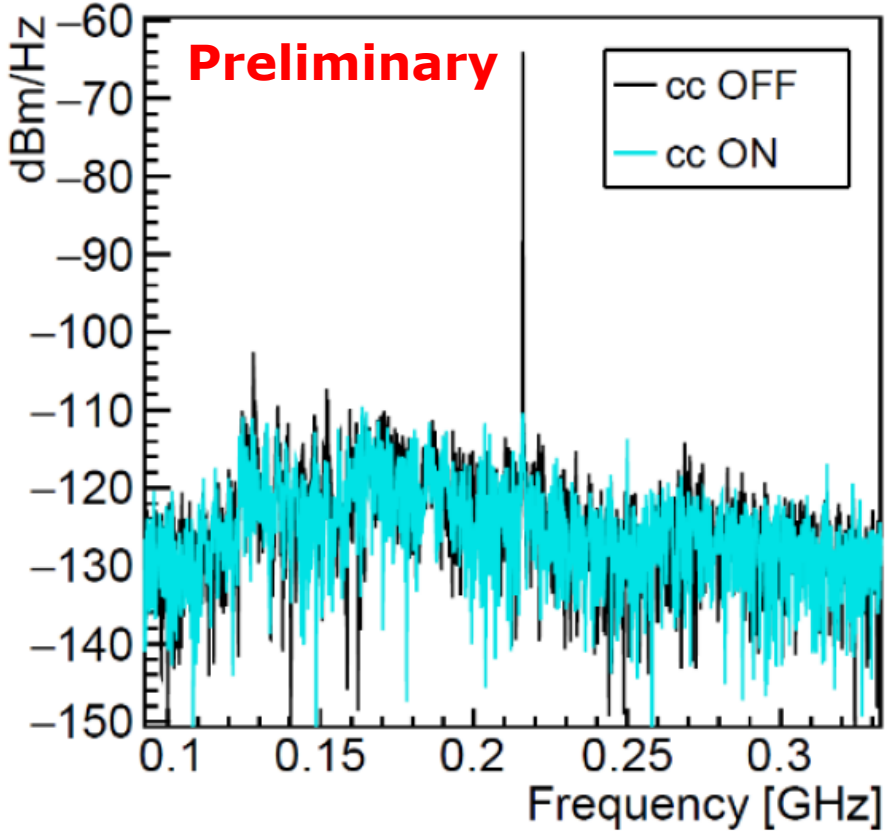


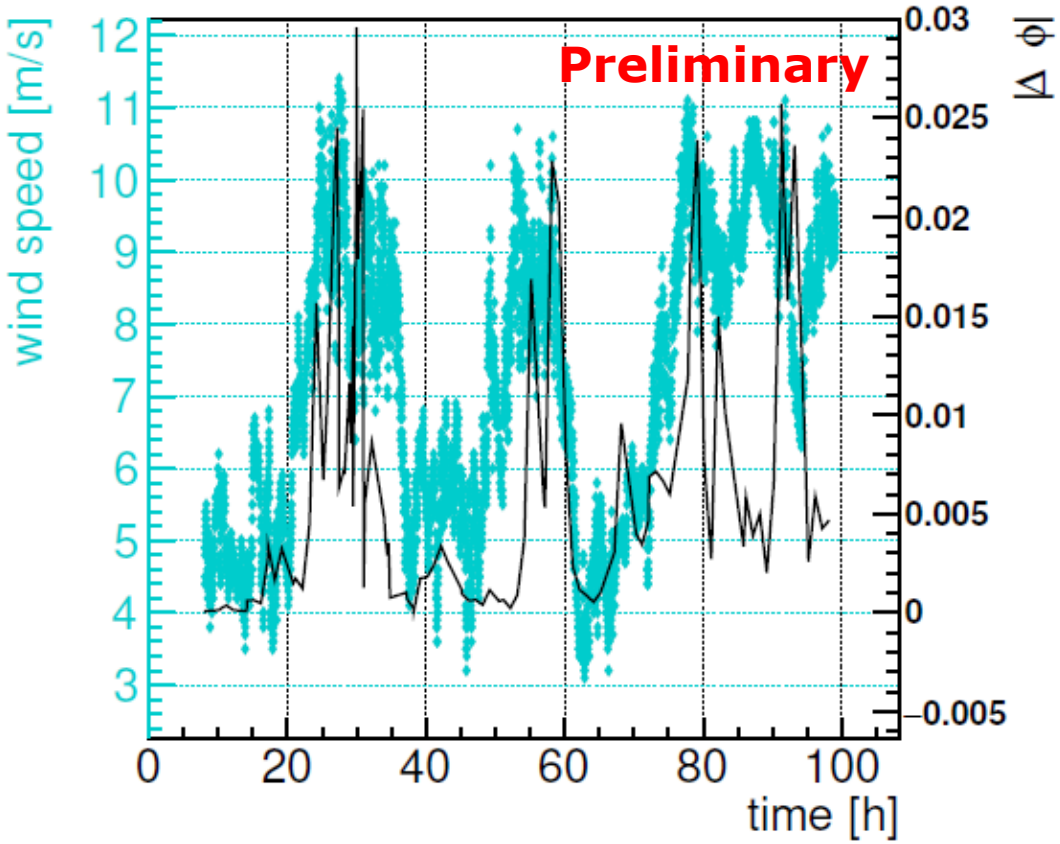
arXiv:2409.07511



THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

MAY 2023 DEPLOYMENT

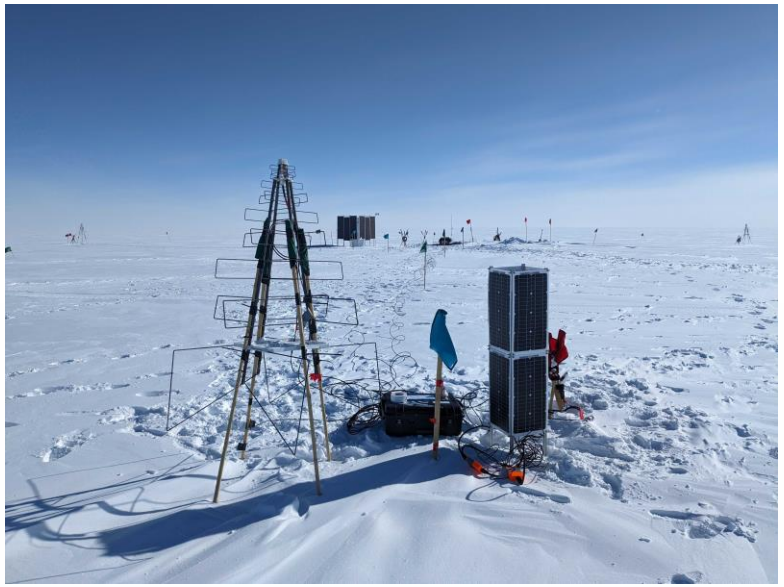




arXiv:2409.07511

THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

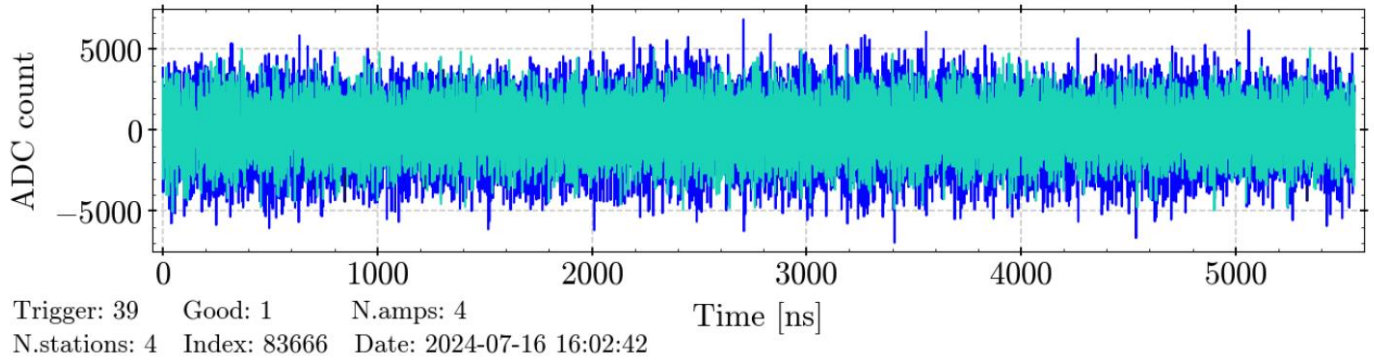
MAY 2024 DEPLOYMENT

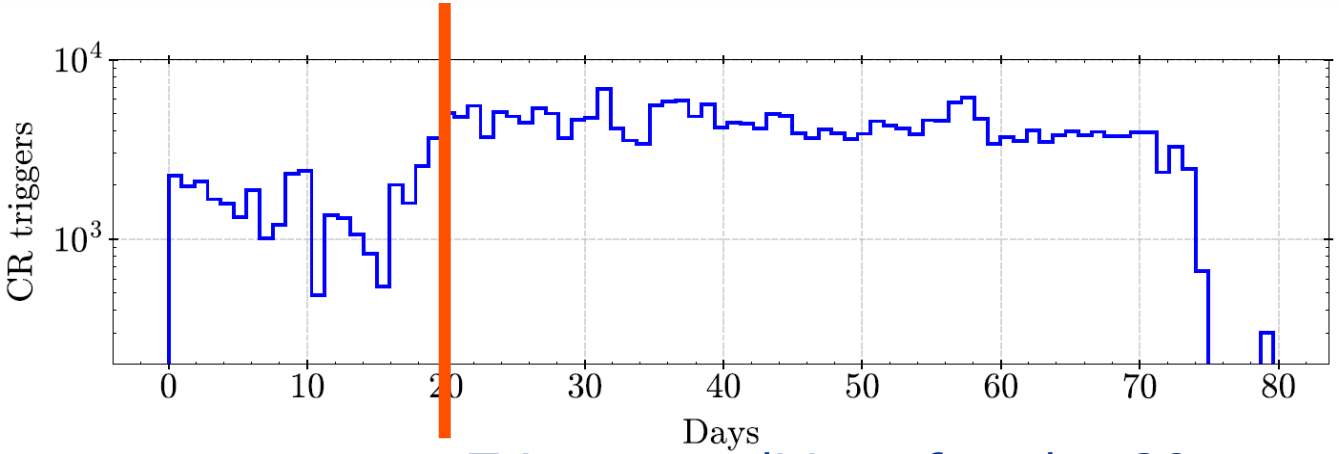


THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

2024 RUN

- **System operational from May 2024**
- **Physics data after commissioning from June-August 2024**
- **>100.000 Cosmic-ray triggered events.**
- **<u>Analysis ongoing, results coming soon!!</u>**





Trigger condition after day 20 ;
N-1 & N>2 stations trigger
N: the number of stations alive

Figs. by Isha Loudon

RF SCATTERING FROM PARTICLE CASCADES

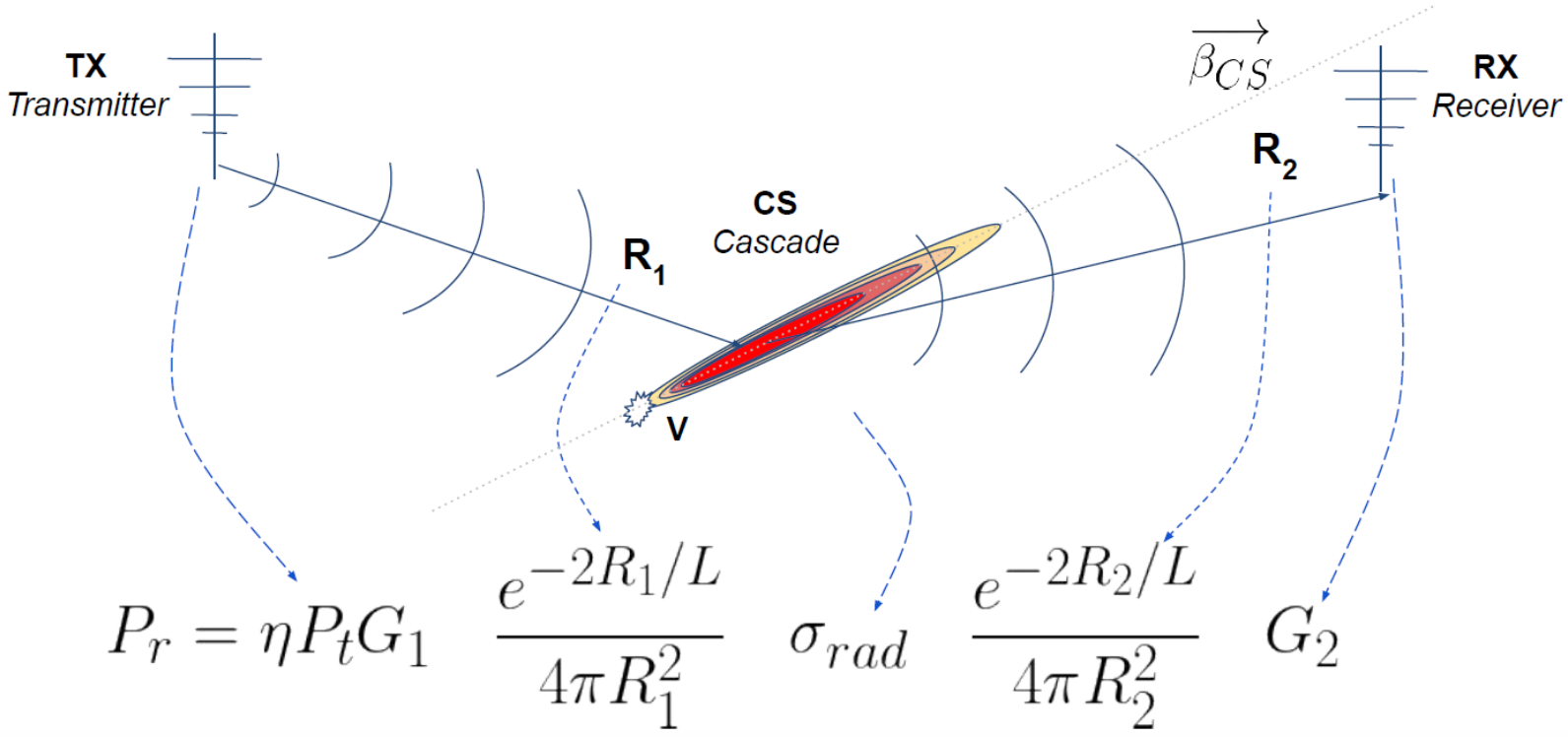
RADAR ECHO MODELLING

IIHE involvment in RET simulation/data Analysis:

Jethro Stoffels
Dieder van den Broeck
Krijn de Vries
Simona Toscano

New:
Jannes Loonen
Isha Loudon

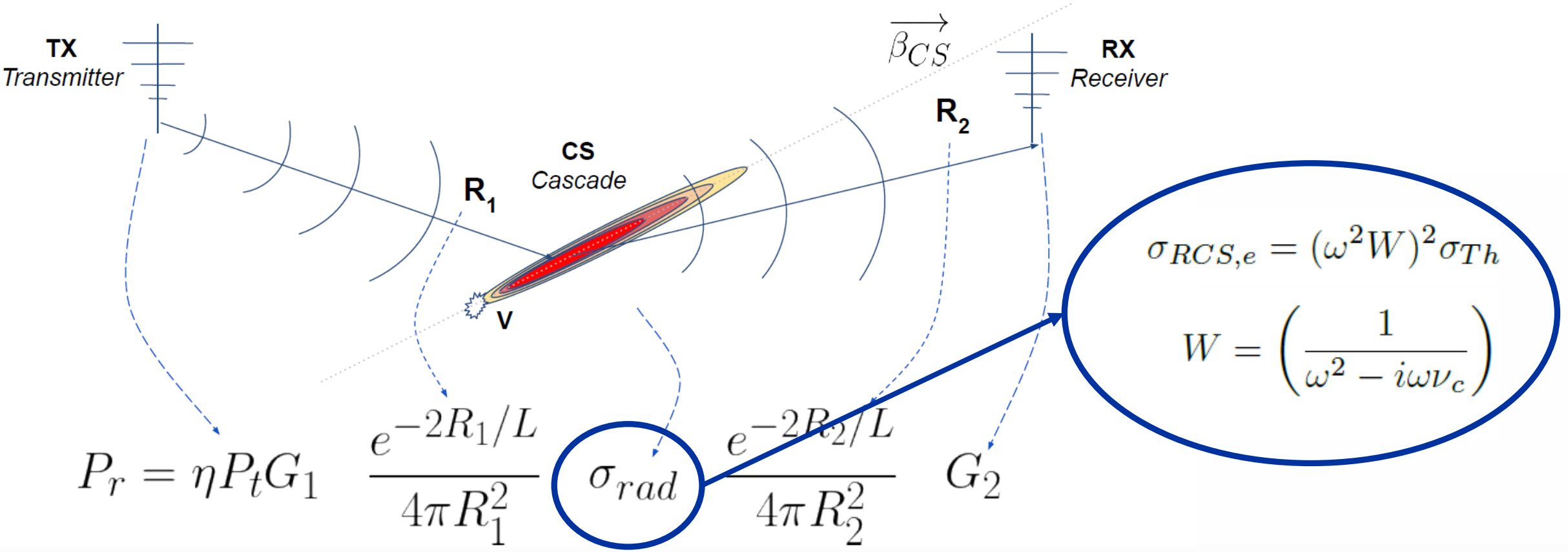
Former:
Rose Stanley (KUL)
Enrique Huesca Santiago (DESY)
Simon De Kockere (Public sector)
Uzair Latif (Public sector)
Katie Mulrey (Nijmegen University)



RF SCATTERING FROM PARTICLE CASCADES

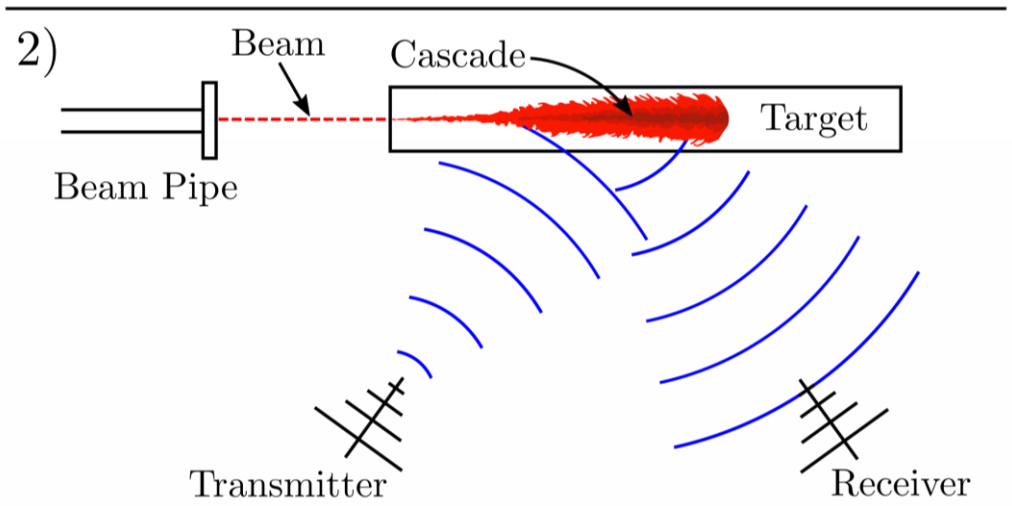
MARES RADAR ECHO SIMULATIONS IN-HOUSE DEVELOPED BY ENRIQUE HUESCA SANTIAGO

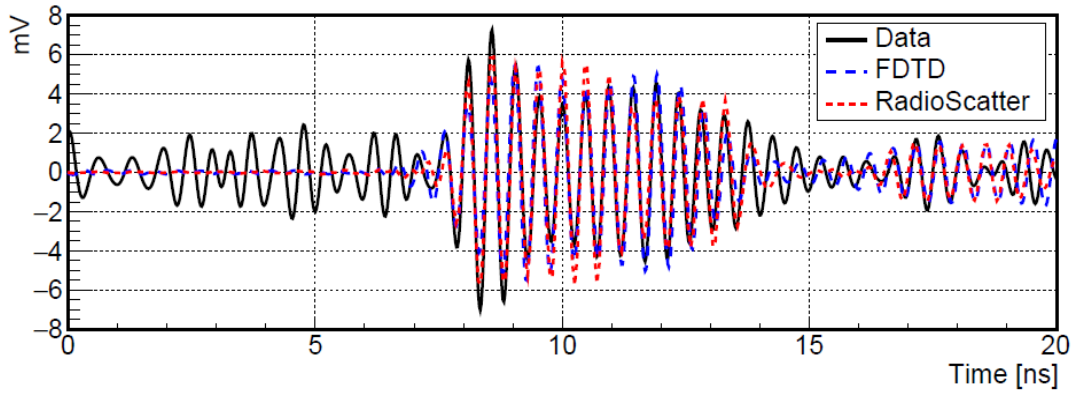
MARES: arXiv:2310.06731 ; Phys. Rev. D 109 (2024) 083012

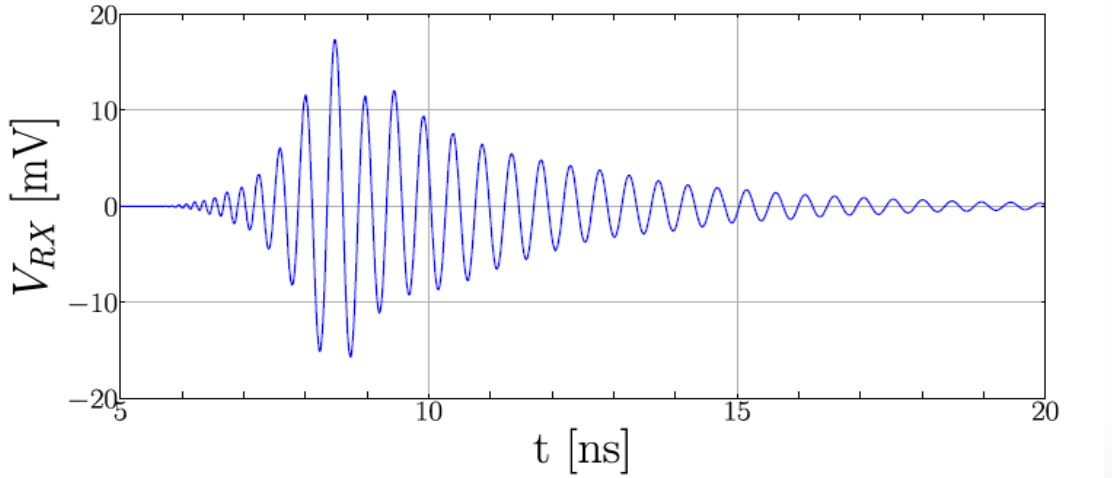


THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

SLAC-T576 VS FDTD/RADIOSCATTER/MARES



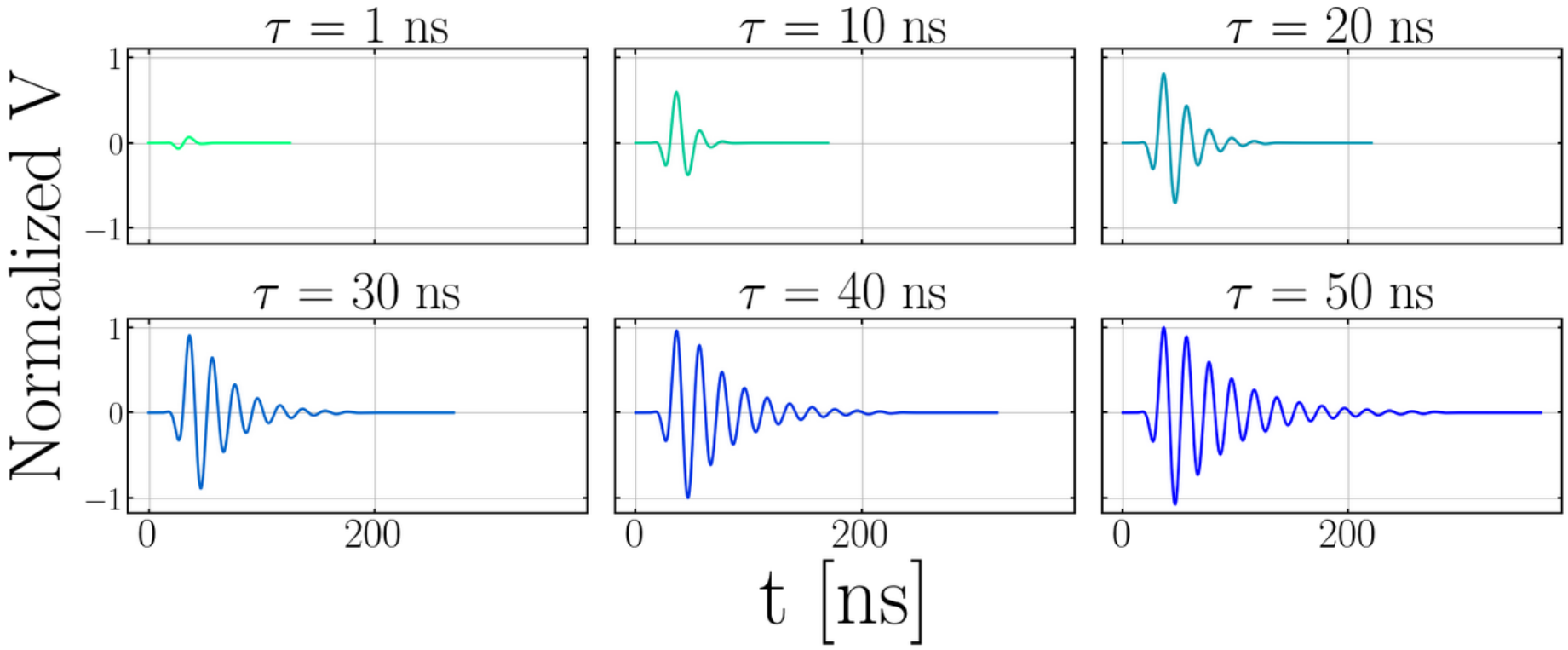




SLAC T-576: arXiv:1910.12830 ; PRL 124, 091101 (2020)
RadioScatter: arXiv:1710.02883 ; NIM-A 922 (2019) 161-170
MARES: arXiv:2310.06731 ; PRD accepted

THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

SIMULATIONS AND SIGNAL PROPERTIES: LIFETIME



MODELING AND UNDERSTANDING RADAR ECHOS FROM PARTICLE CASCADES

SIGNAL PROPERTIES: INTENSITY

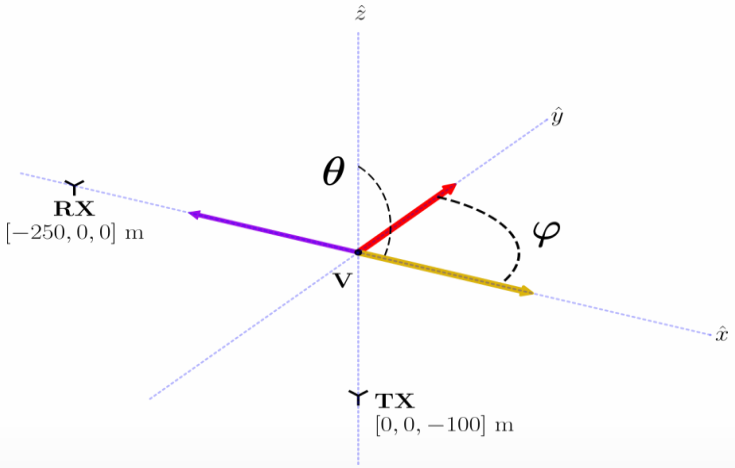
Credit: I. Loudon, J. Loonen
E. Huesca-Santiago, D. Frikken

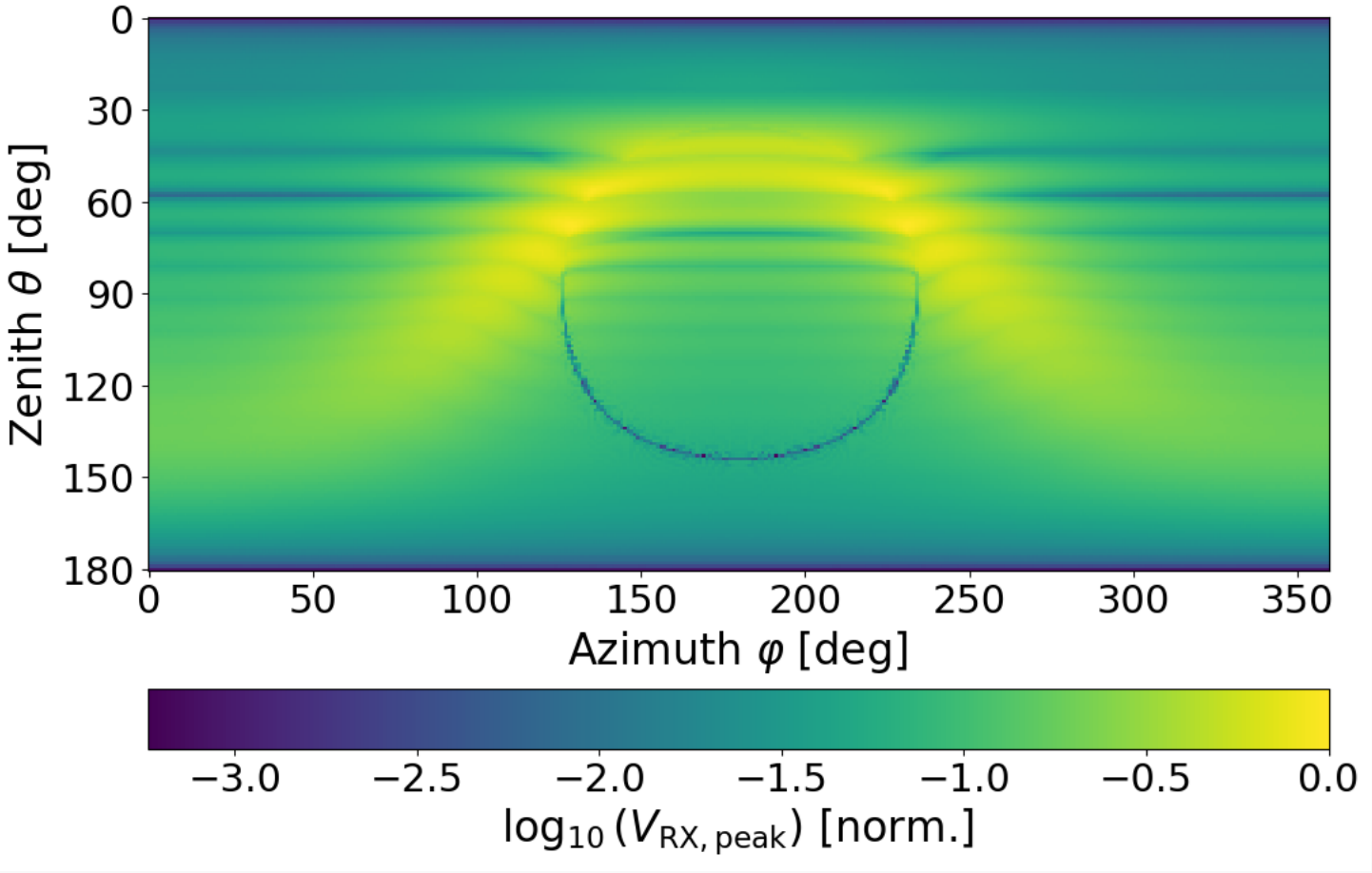
Features:

1) Cherenkov-like effect

2) Diffraction bands

3) High-intensity swirl





MODELING AND UNDERSTANDING RADAR ECHOS FROM PARTICLE CASCADES

SIGNAL PROPERTIES: FREQUENCY

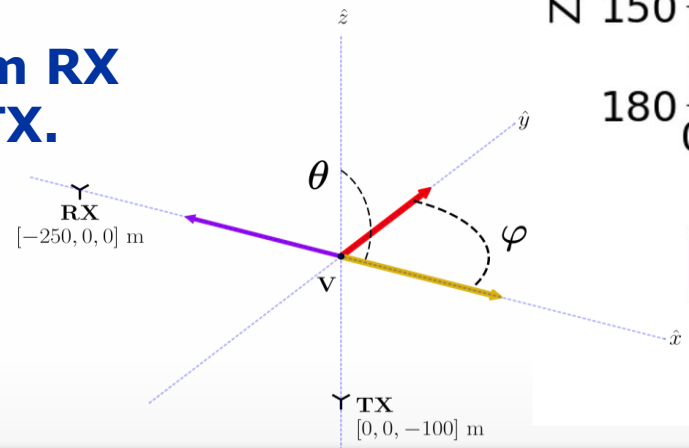
Credit: I. Loudon, J. Loonen
E. Huesca-Santiago, D. Frikken

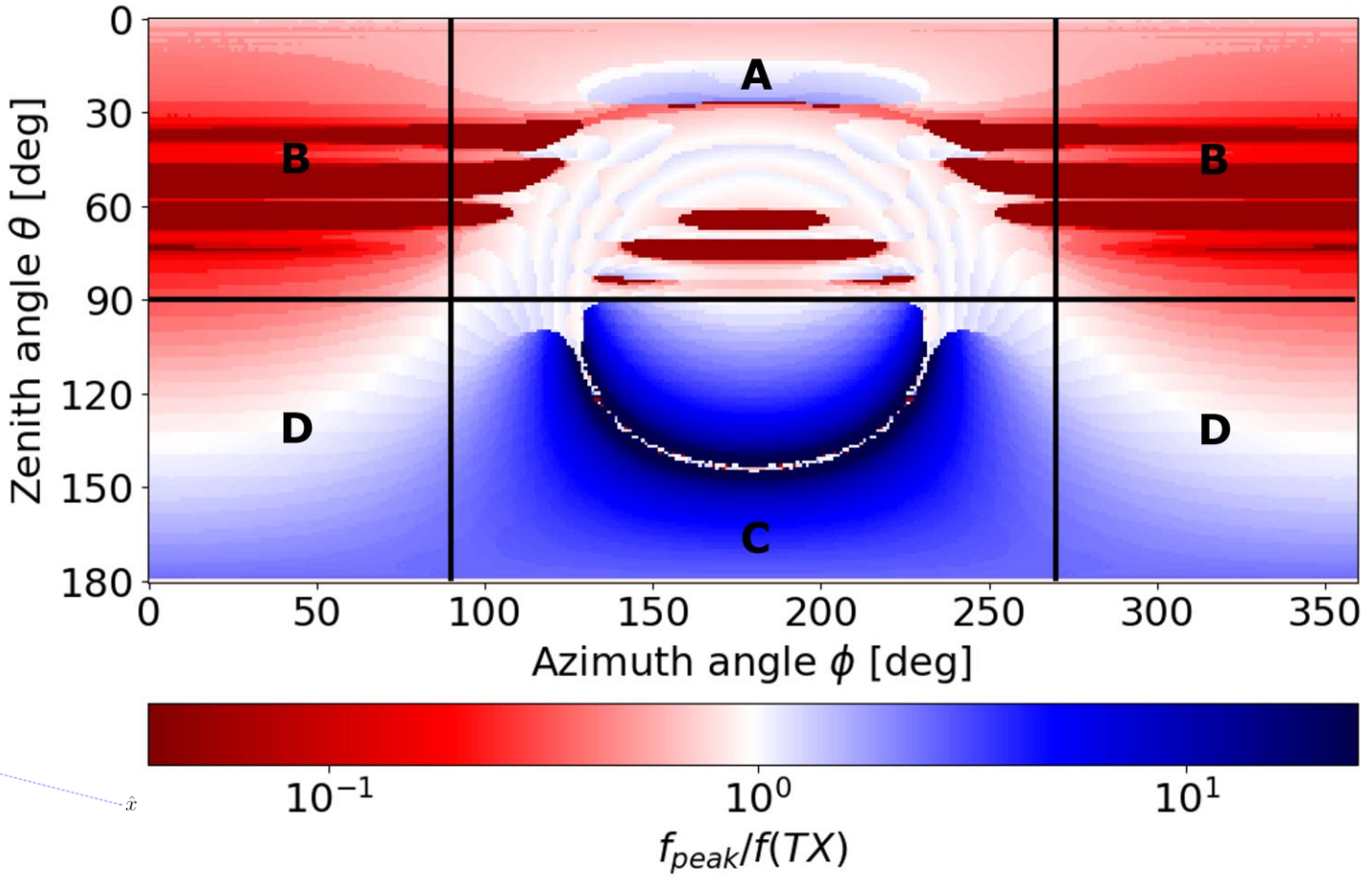
A: Towards RX,
Away from TX.

B: Away from RX
Away from TX.

C: Towards RX
Towards TX.

D: Away from RX
Towards TX.





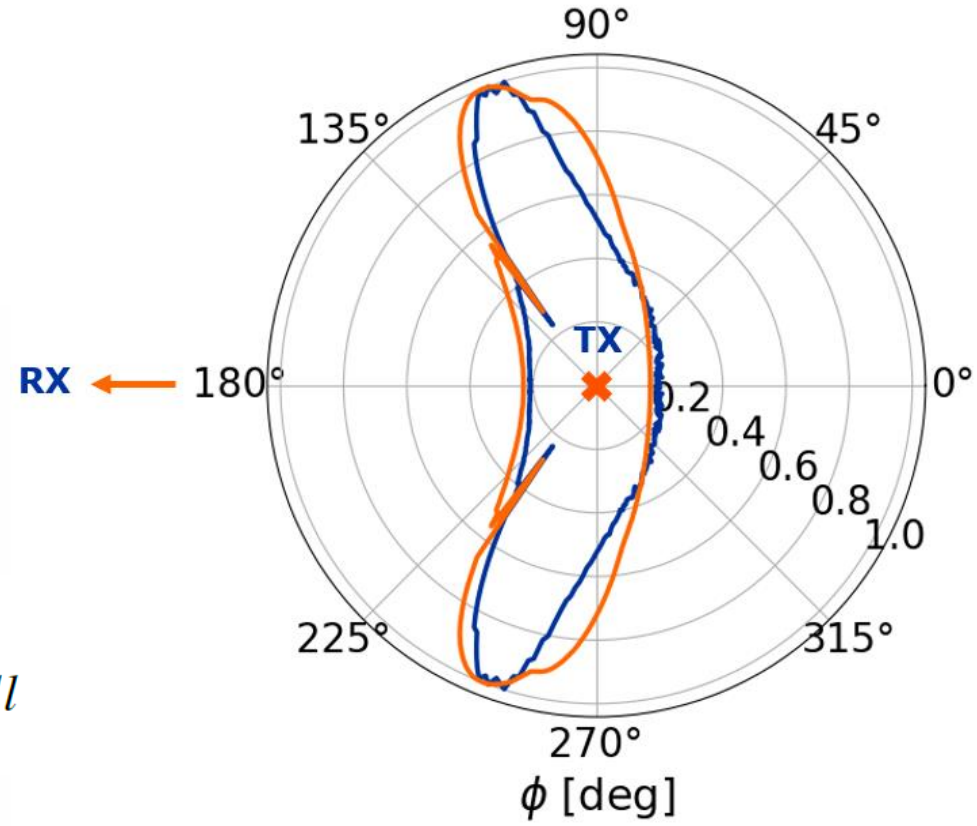
MODELING AND UNDERSTANDING RADAR ECHOS FROM PARTICLE CASCADES

SIGNAL PROPERTIES: PHASE ALIGNMENT

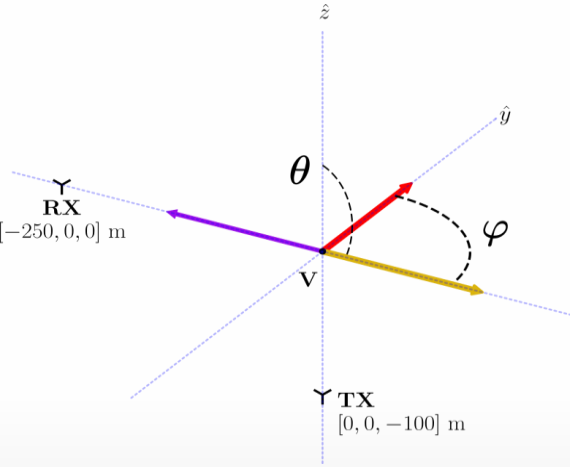
Orange: Simulation at fixed zenith angle of 90 degrees

Blue: Phase alignment measure:

$$C = \int \left(\cos(\varphi) \cdot \frac{n_{e^-}}{n_{max}} \right)_{norm} dl$$



PRELIMINARY
J. Loonen



Thanks!!

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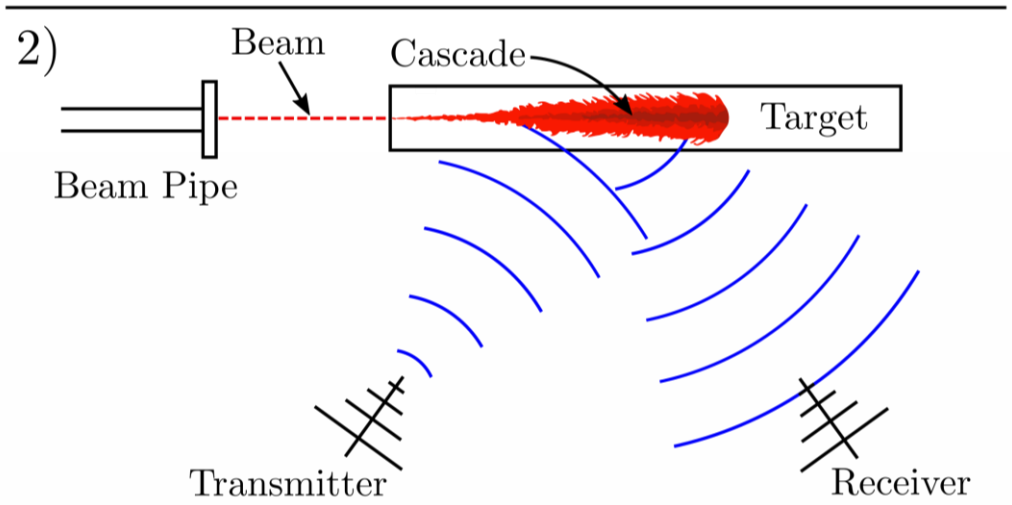
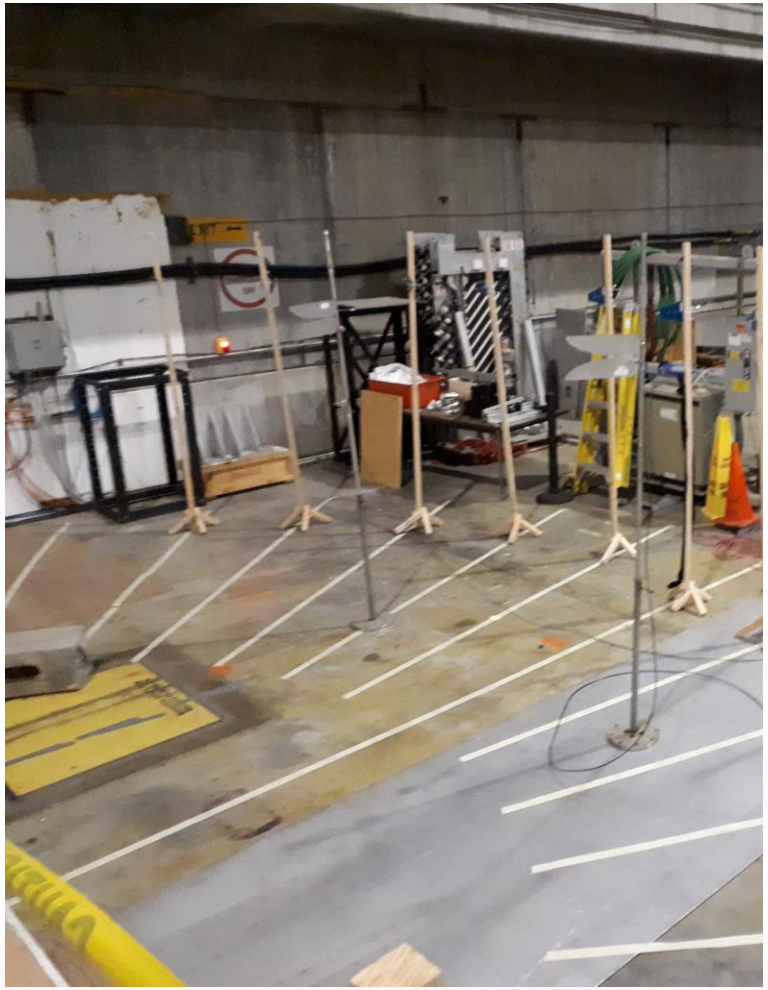
AR ECHO TELESCOPE for COSMIC RAYS

DETECTING HIGH-ENERGY PARTICLE CASCADES AT SLAC

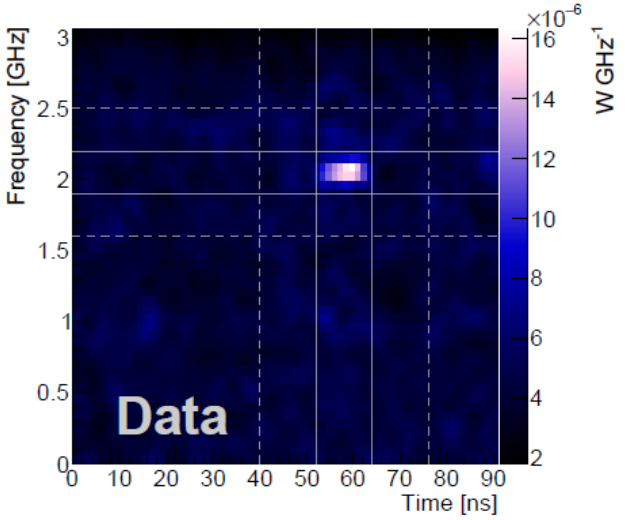
SLAC T-576 EXPERIMENT

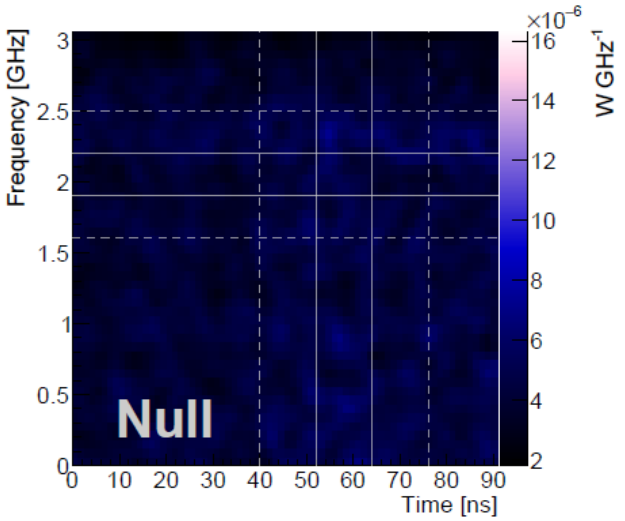


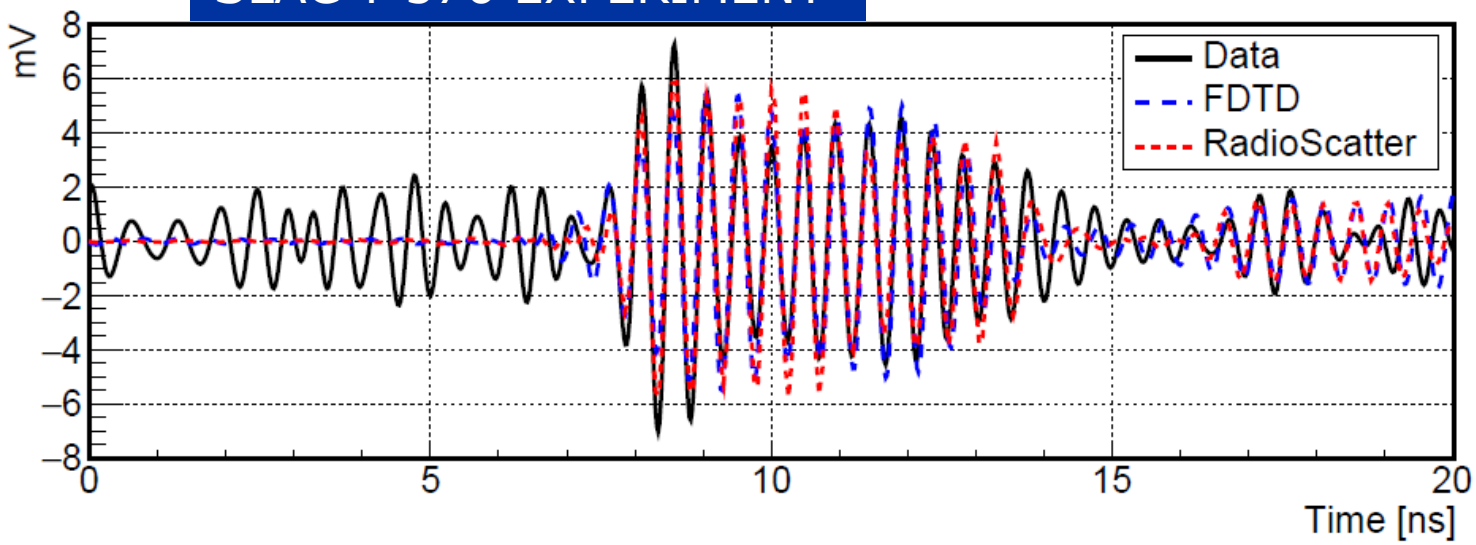


DETECTING HIGH-ENERGY PARTICLE CASCADES AT SLAC

SLAC T-576 EXPERIMENT







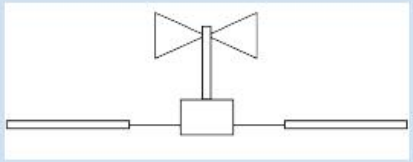
Difficult analysis due to **Askaryan and Transition radiation** backgrounds → Singular Value Decomposition to filter.

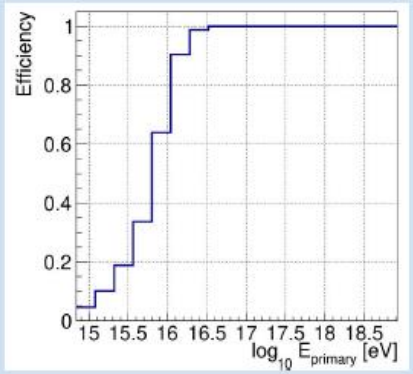
→ **Excellent agreement between data and simulations**

Method: S. Prohira, et al., Phys. Rev. D 100, 072003 (arxiv:1810.09914) || S. Prohira, 2020 J. Phys.: Conf. Ser. **1525** 012119 (arxiv:1910.11314)

THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

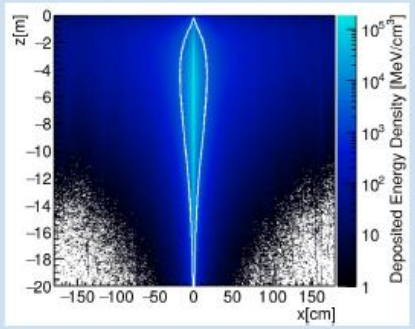
CR Surface Detector



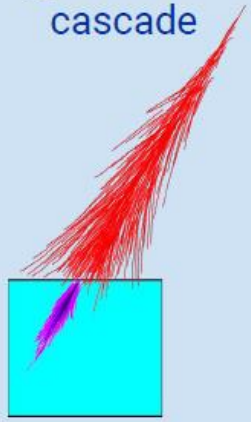


100% efficiency at $10^{16.5}$ eV

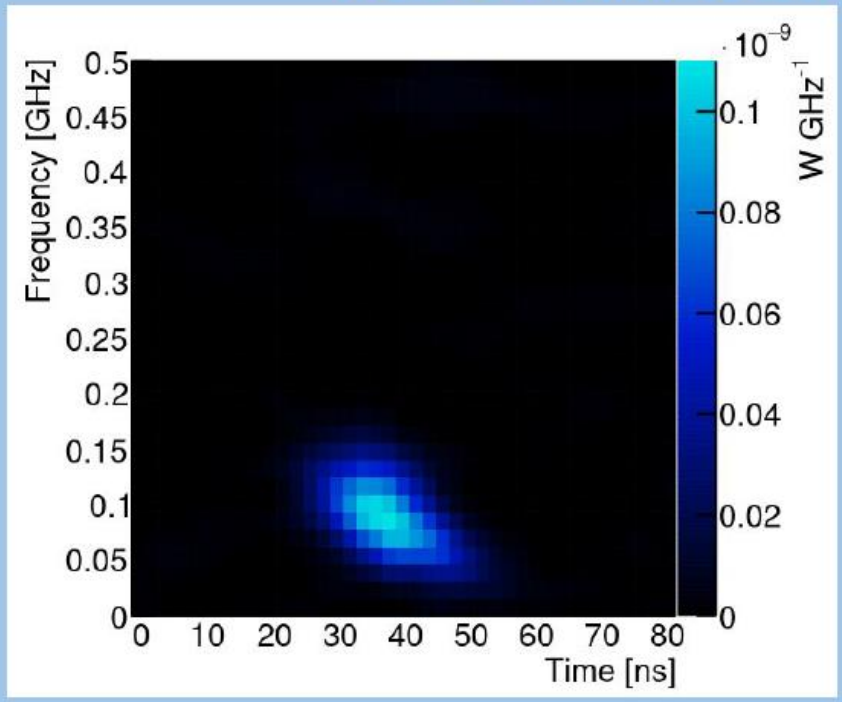
Air-ice transition



10% of primary energy in secondary cascade



In-ice Radar Detector



Simulations
- Radio Scatter 1.1.0

RadioScatter
- particle-level C++ code
- simulates radio scattering from ionization deposit

→ Interrogating frequency of 100 MHz
→ Data readout triggered by surface detector

R. Stanley, K. Mulrey **S. de Kockere** **S. Prohira**

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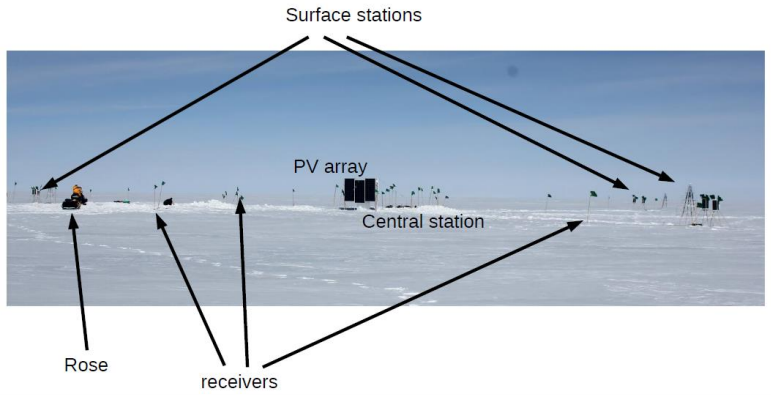
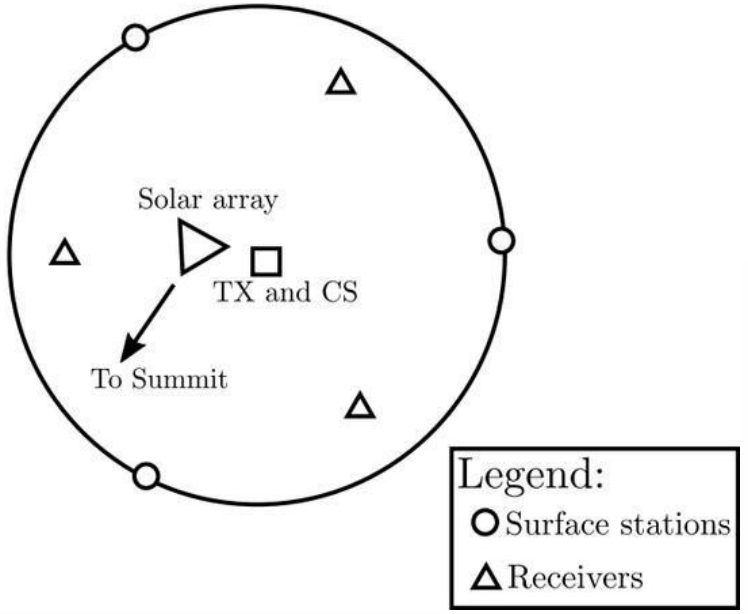
Slide from R. Stanley

THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

MAY 2023 DEPLOYMENT



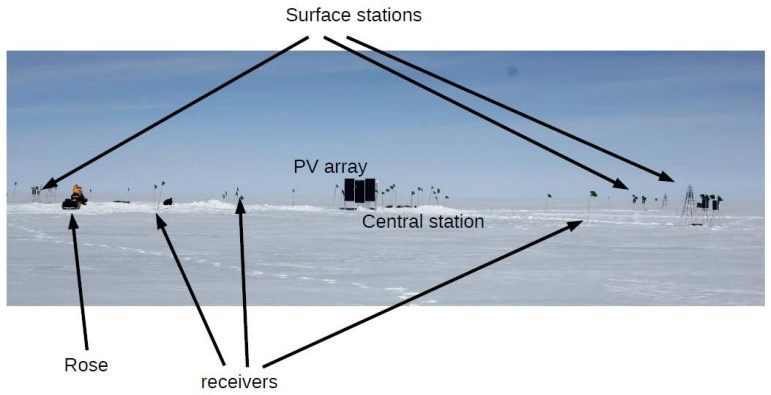


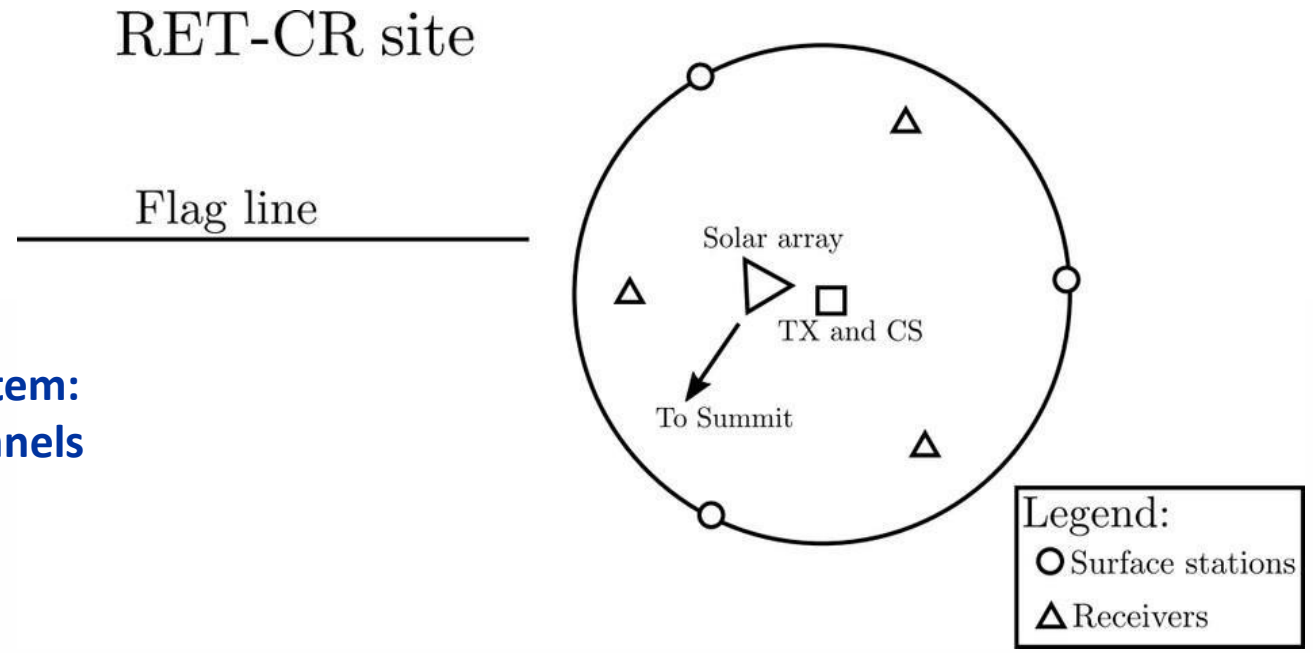
- **3x1.2kW solar array with charge control and battery bank.**
- **3 downhole strings with single Reciever dipole at 10m depth.**
- **8 channel phased dipole array centered at 10m. Currently 4 power amps (channels) operational.**
- **3 surface stations (2 scintillator panels + 1 radio antenna each).**
- **GPS, WLAN link, etc.**

Circle diameter 80 meters

THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

MAY 2023 DEPLOYMENT





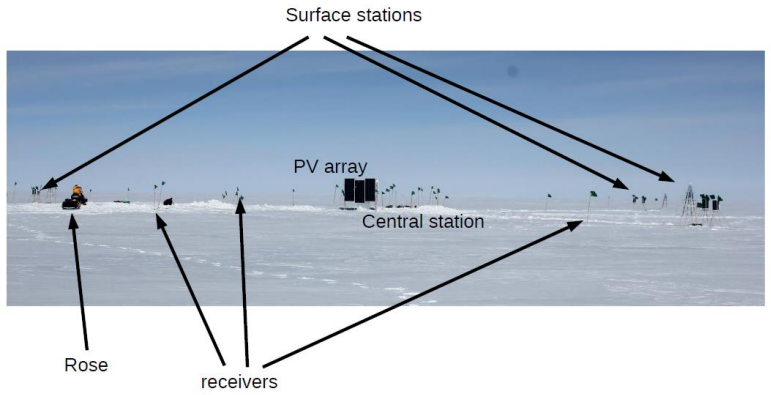
Radar in-ice system:

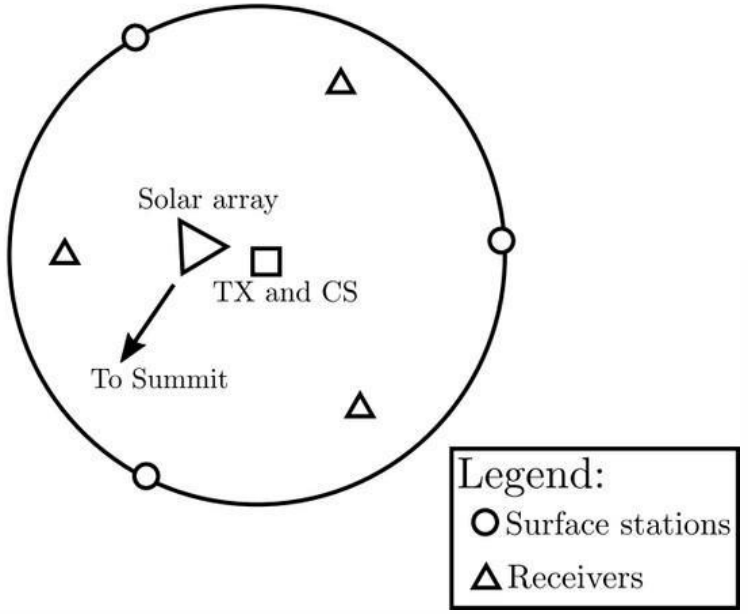
- 8 channel phased transmitter ; 4 receiver channels
- Active transmitter cancellation (TC).
- DAQ: xilinx zcu111 RFSoC development board,
- 8 channel ADC, 8 channel DAC.
- RFSoC clocked at ~ 3GHz.
- Custom-made board breaks out all 8 DAC channels and all 8 ADC channels.
- software controlled variable attenuator on DAC (up to 32 dB)
- 4 DAC channels used to actively cancel the TX signal in the RX channels

Circle diameter 80 meters

THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

MAY 2023 DEPLOYMENT





Circle diameter 80 meters

Surface system:

- 2 scintillator panels, LPDA
- Power system: 4x20W solar array, 10 Ah, 12V battery buffer
- SBC: raspberry pi with redundant storage, and electronics for readout of the scintillators and radio antenna.
- Comms: Ethernet cat-7 cable
- Trigger signal: separate cat-7 cable

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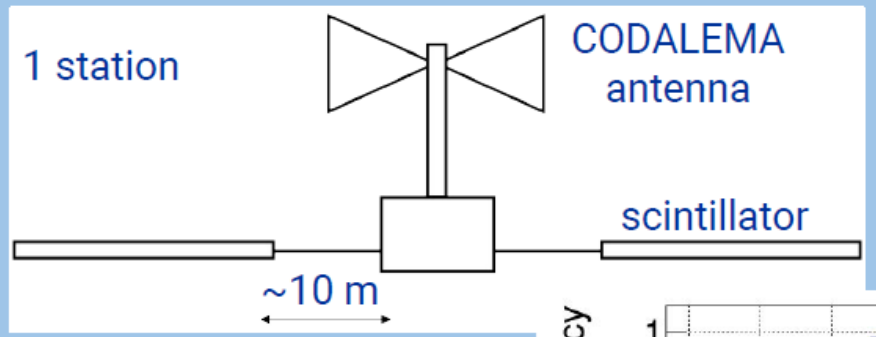
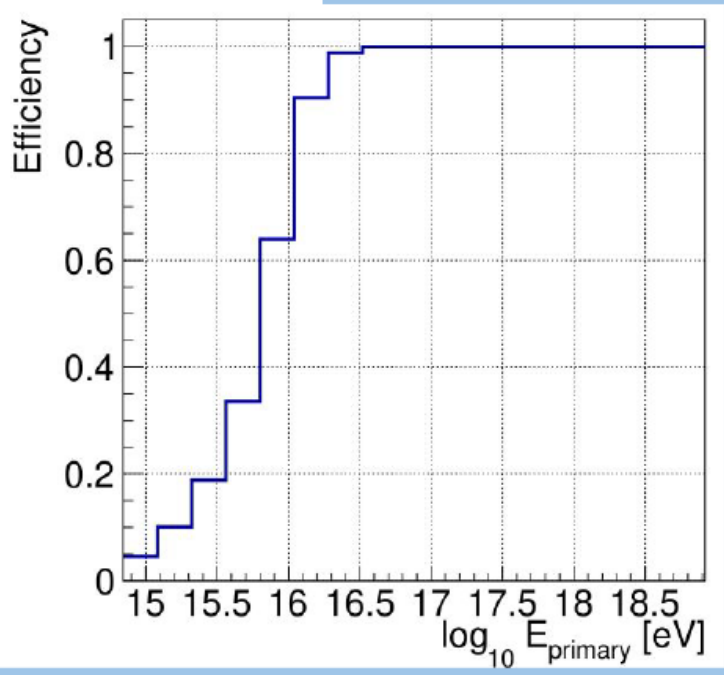
Cosmic Ray Surface Detector

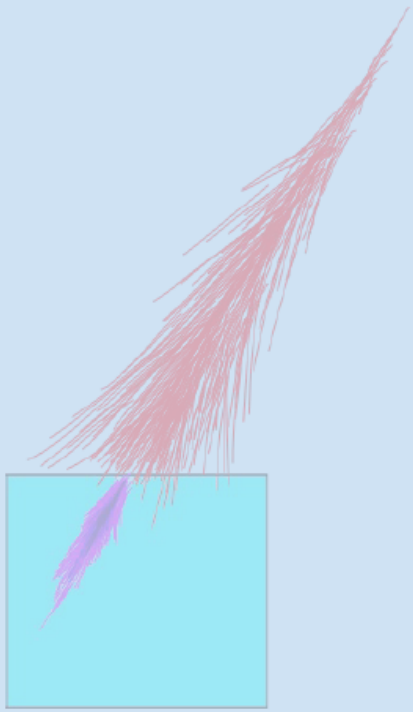


Simulations
- CORSIKA 7.7400 with QGSJETII-04 and URQMD 1.3cr
- CoREAS 1.4
- Geant4 9.6

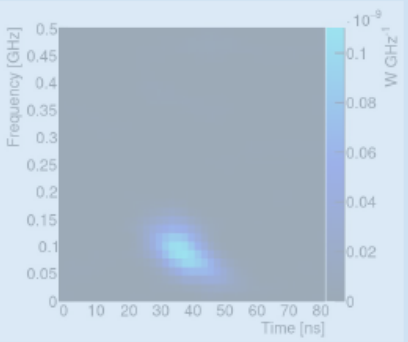
- ➔ Stations trigger independently
- ➔ 6 MeV threshold
- ➔ L0 trigger: both scintillators in one station
- ➔ L1 trigger: all stations within one cluster
- ➔ Trigger sent to radar detector



Air-ice transition



In-ice Radar Detector



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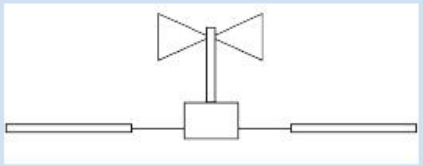
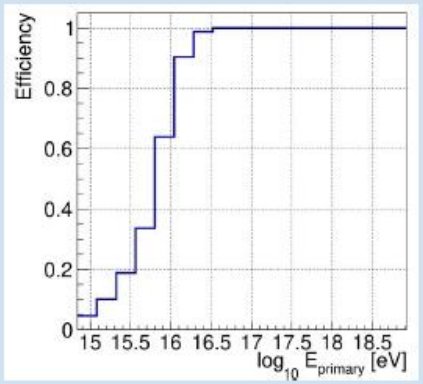
THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

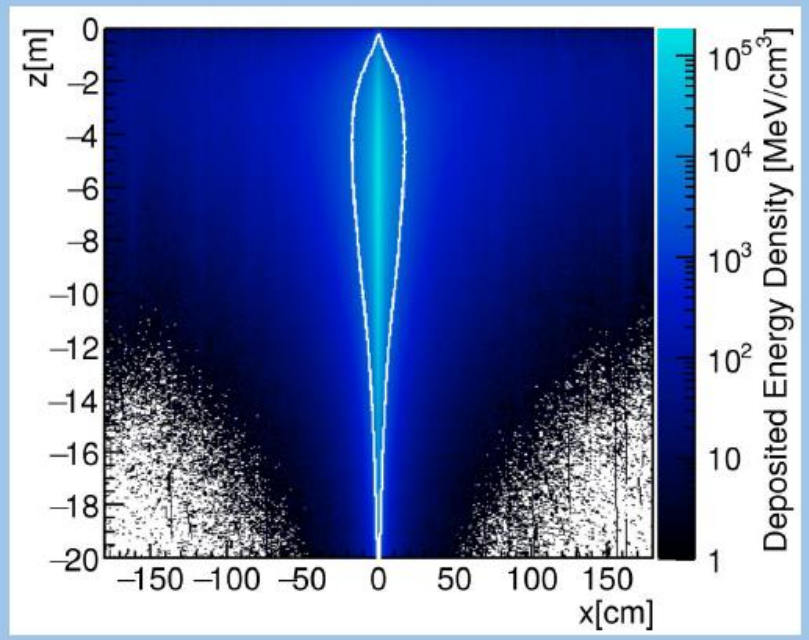
CR Surface Detector



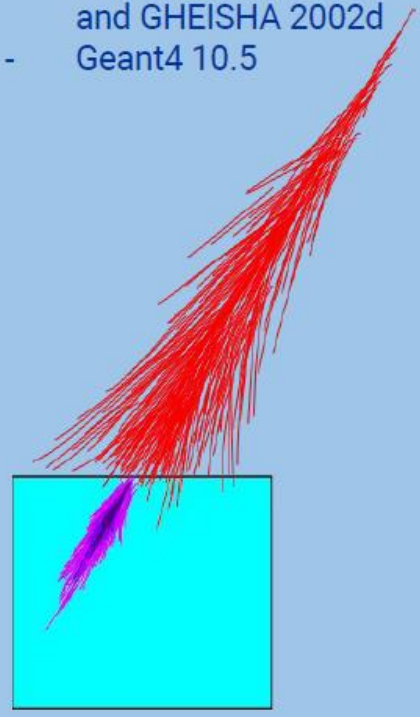


100% efficiency at $10^{16.5}$ eV

Air-ice transition



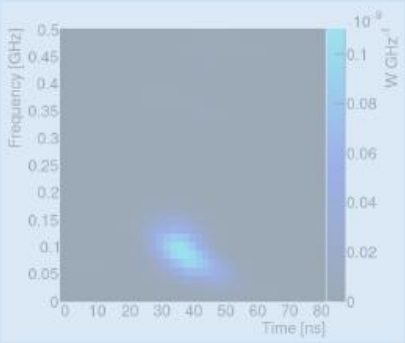
Simulations
- CORSIKA 7.7100 with QGSJETII-04 and GHEISHA 2002d
- Geant4 10.5



→ Approximately 10% of primary energy deposited into the ice at 2400 m

→ Secondary cascade in high elevation ice sheet

In-ice Radar Detector



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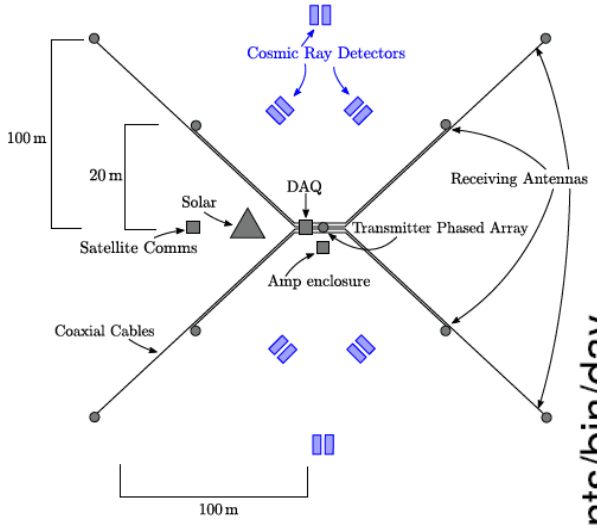
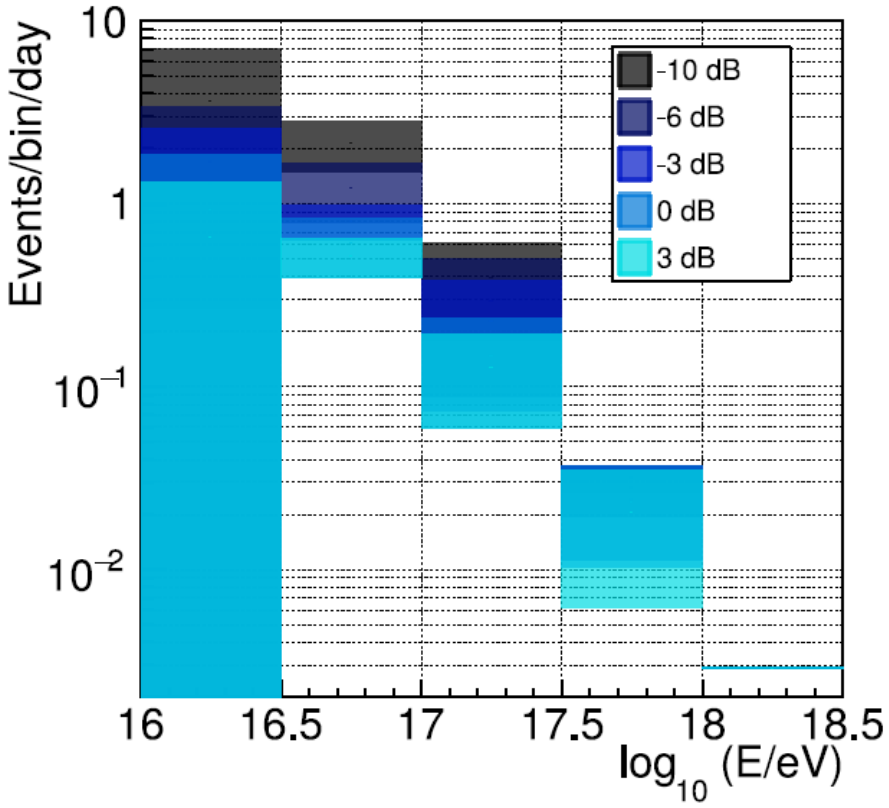
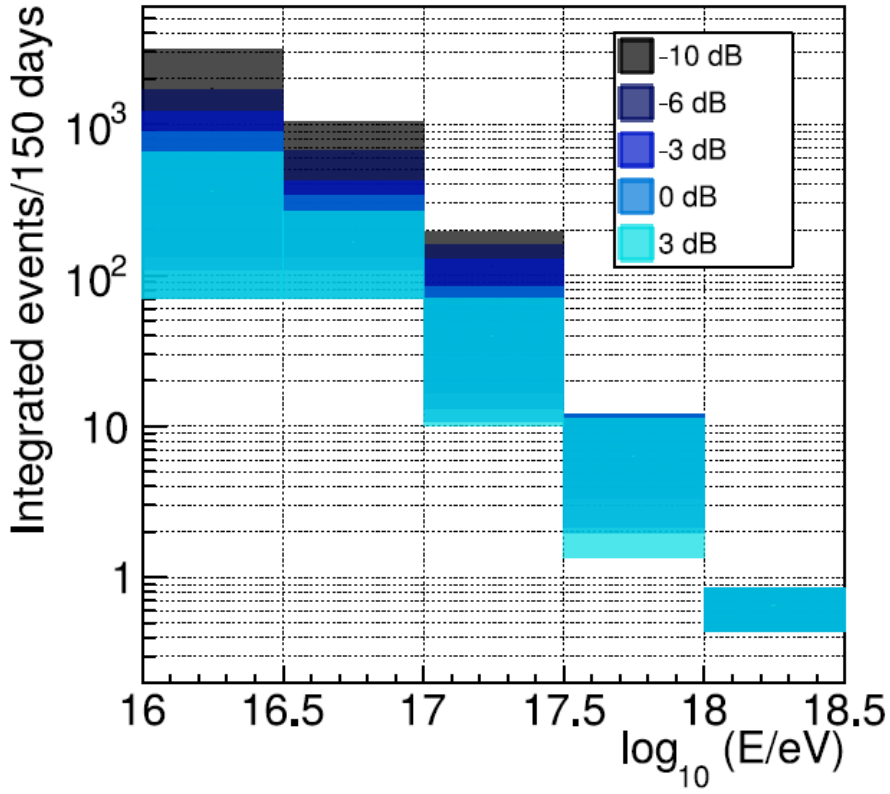
THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

DETECTING PARTICLE CASCADES IN NATURE







RET-CR paper: arXiv: 2104.00459 - Phys. Rev. D 104, 102006

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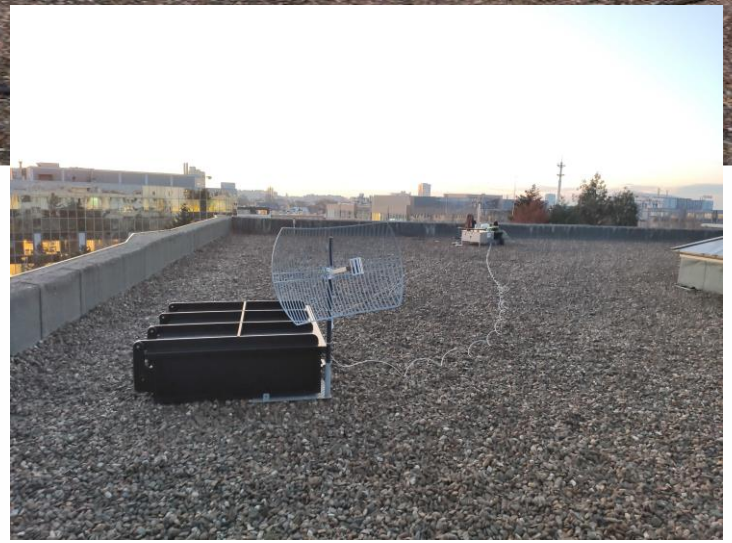
THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

SURFACE SET-UP AT VUB INSTALLED AND TAKING DATA



DETECTING HIGH-ENERGY PARTICLE CASCADES AT SLAC

SLAC T-576 EXPERIMENT