

THE RADAR ECHO TELESCOPE

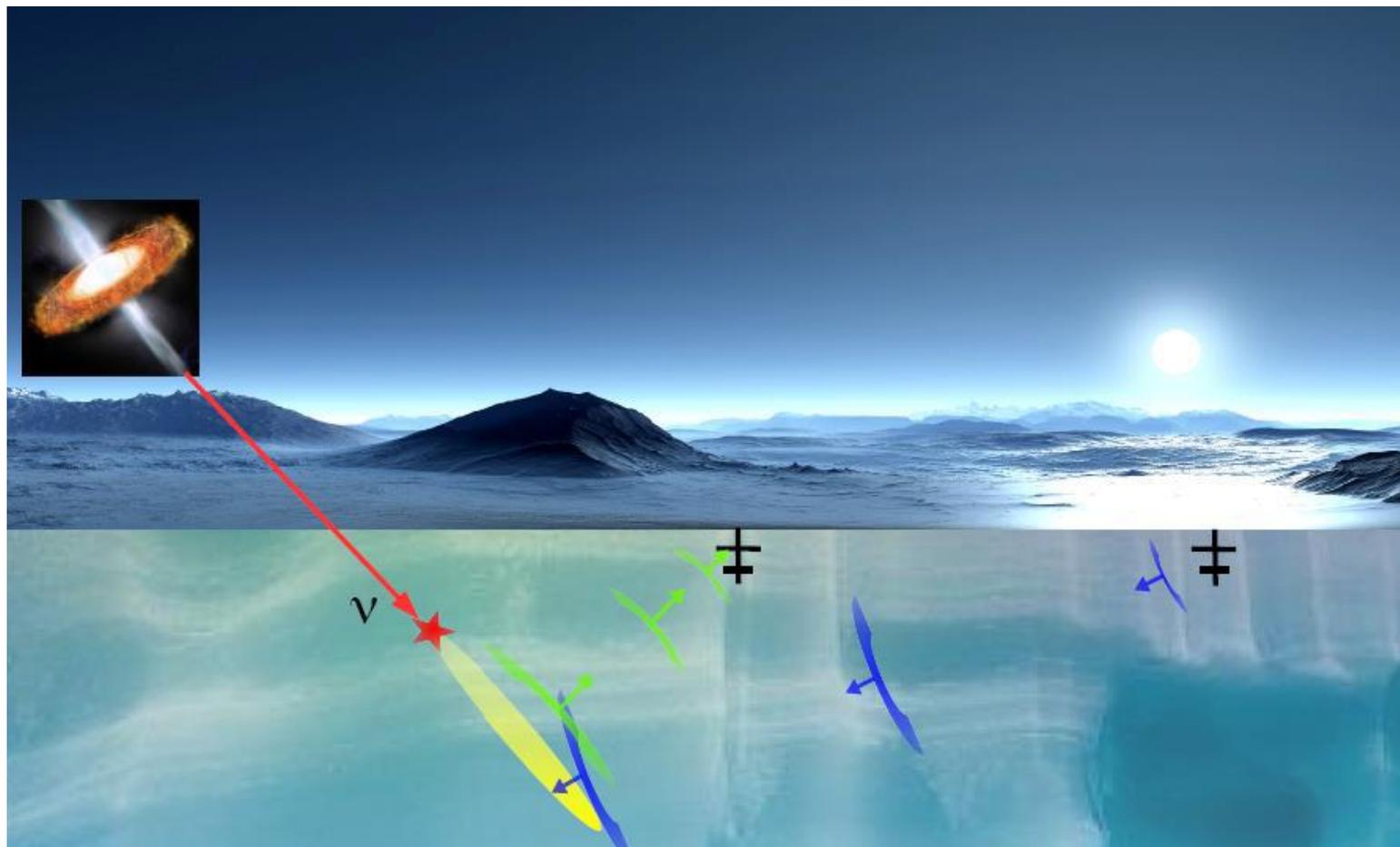
KRIJN D DE VRIES ON BEHALF OF THE RET COLLABORATION
WWW.RADARECHOTELESCOPE.ORG

VRIJE UNIVERSITEIT BRUSSEL



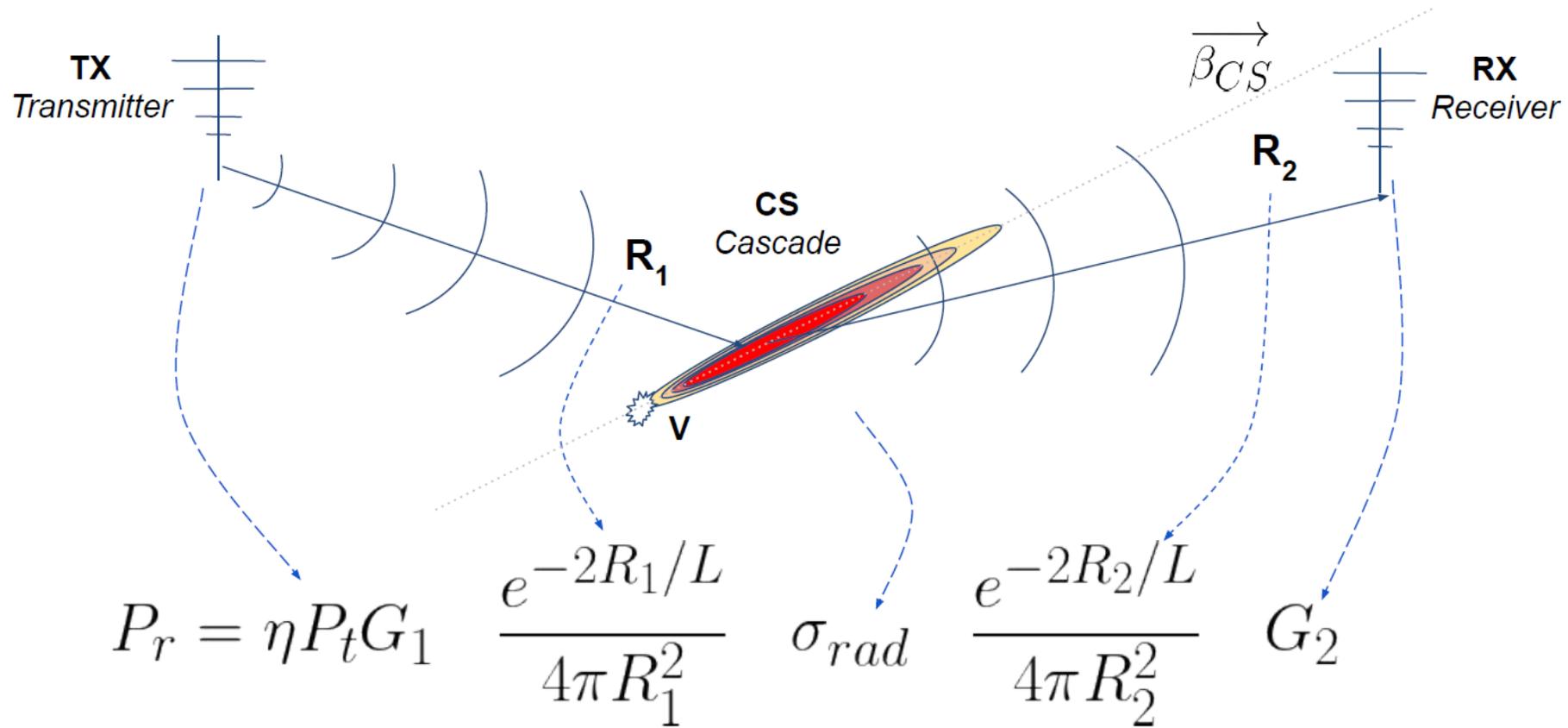
RADAR DETECTION OF HIGH-ENERGY PARTICLE CASCADES IN ICE

THE MAIN IDEA



RF SCATTERING FROM PARTICLE CASCADES

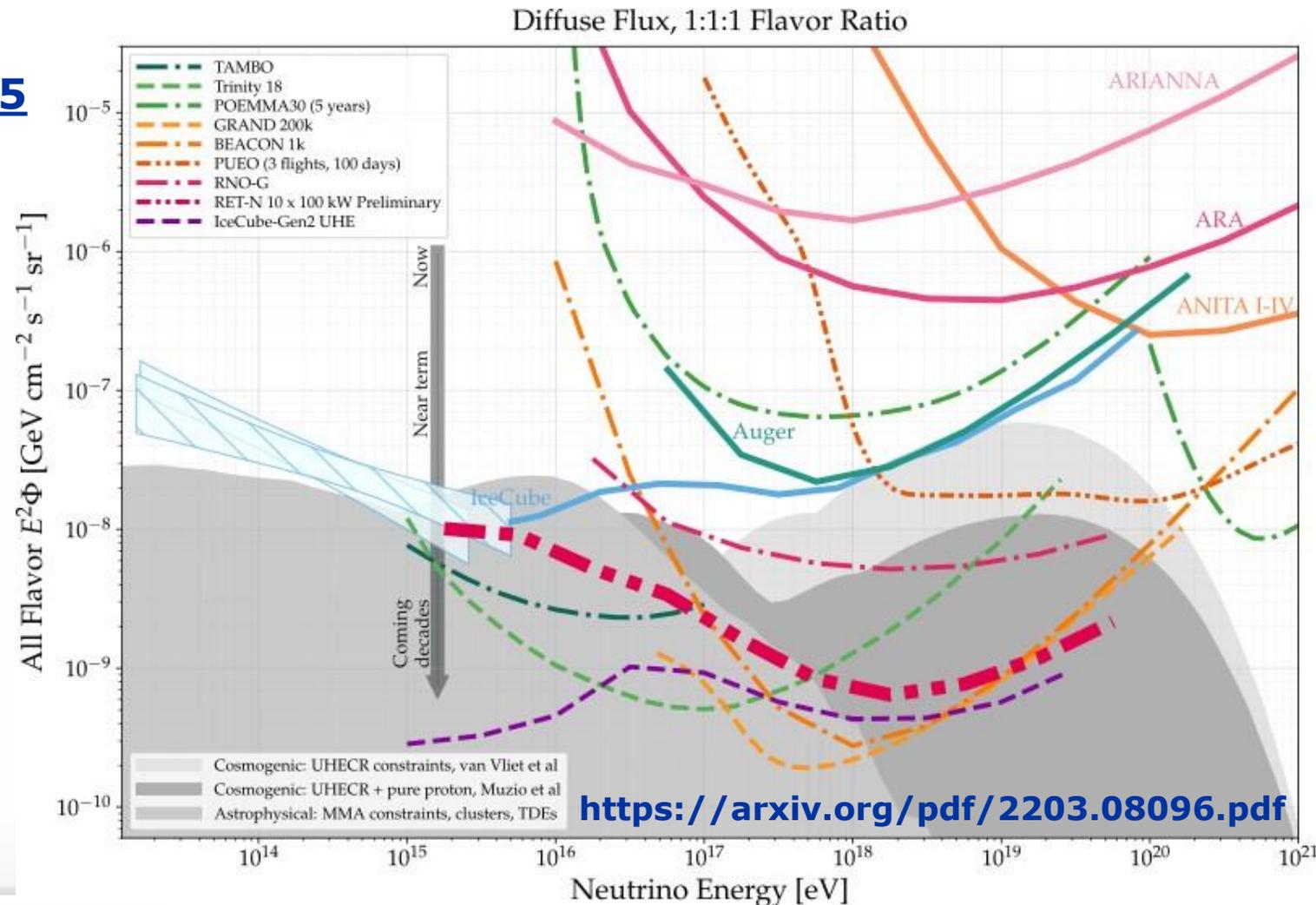
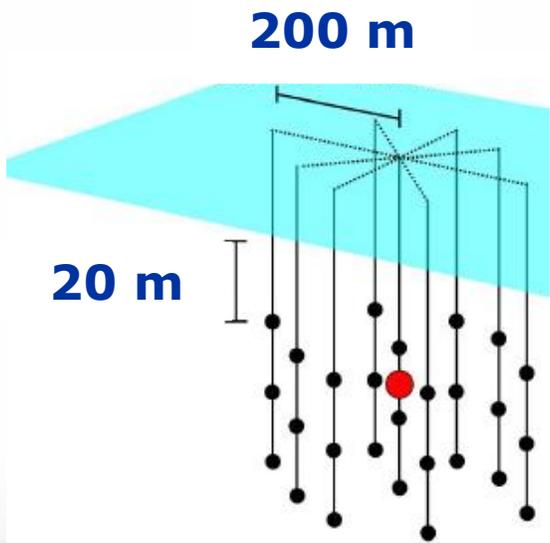
RADAR ECHO MODELLING: TALK ENRIQUE HUESCA SANTIAGO THIS AFTERNOON



THE RADAR ECHO TELESCOPE FOR NEUTRINOS

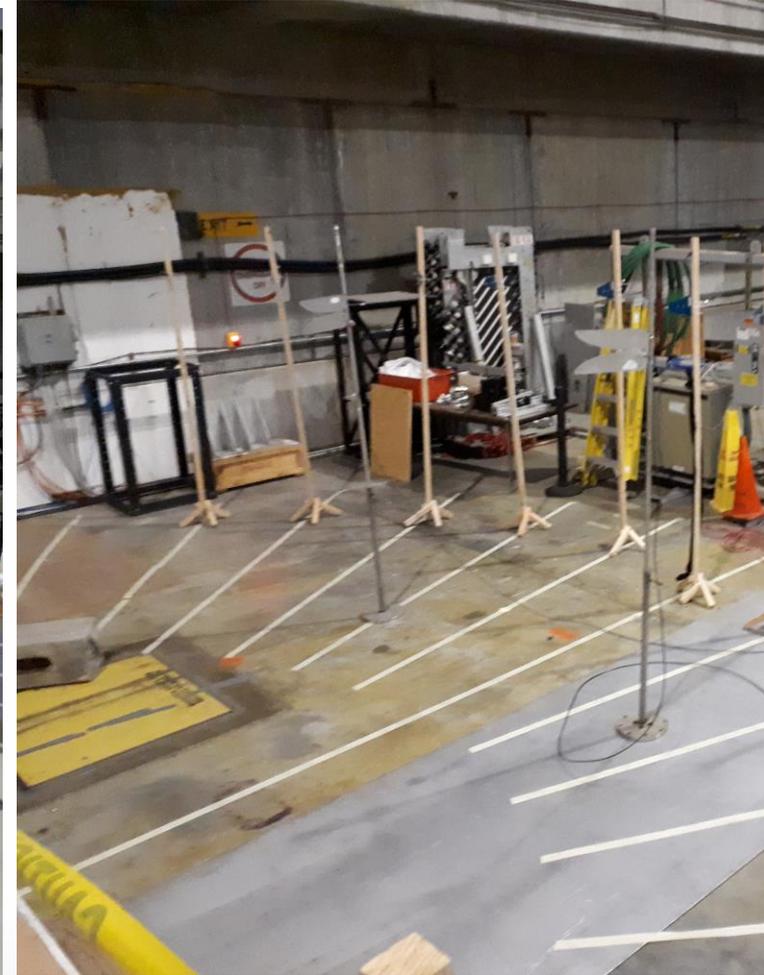
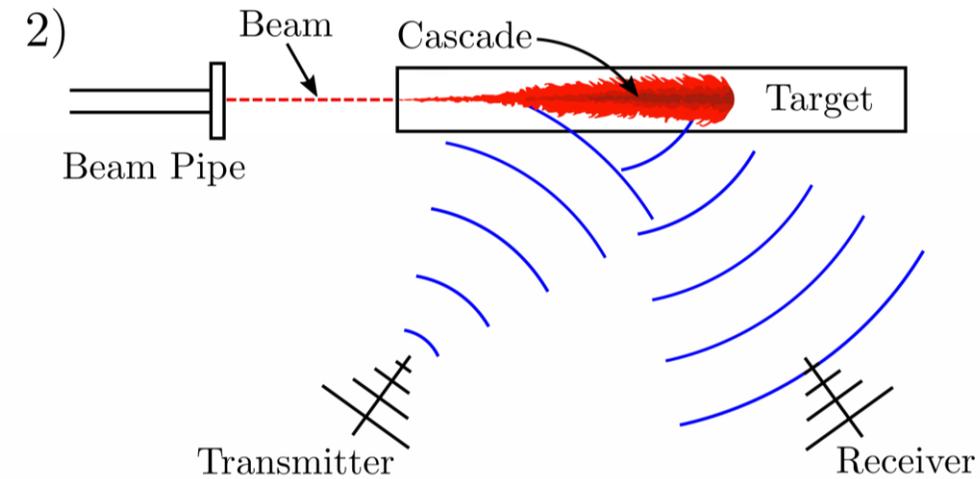
WHY RADAR? PROBING THE PEV-EEV COSMIC NEUTRINO FLUX

- **10 x 100 kW effective (phased) transmitter @ 1.5 km depth.**
- **Trigger at 0 dB w.r.t. 50 MHz bandwidth thermal noise**



DETECTING HIGH-ENERGY PARTICLE CASCADES AT SLAC

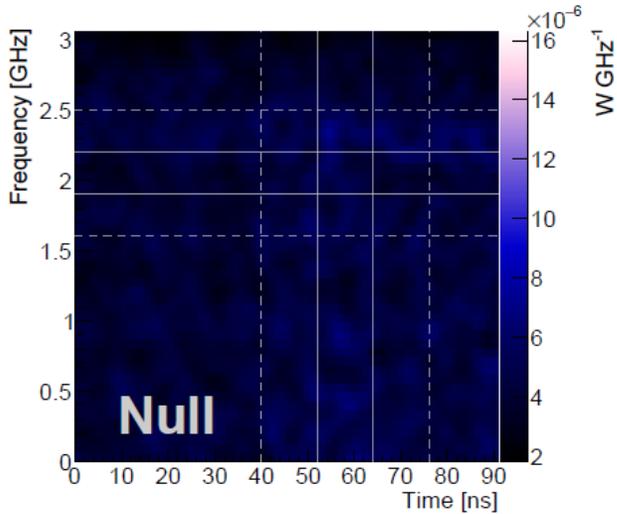
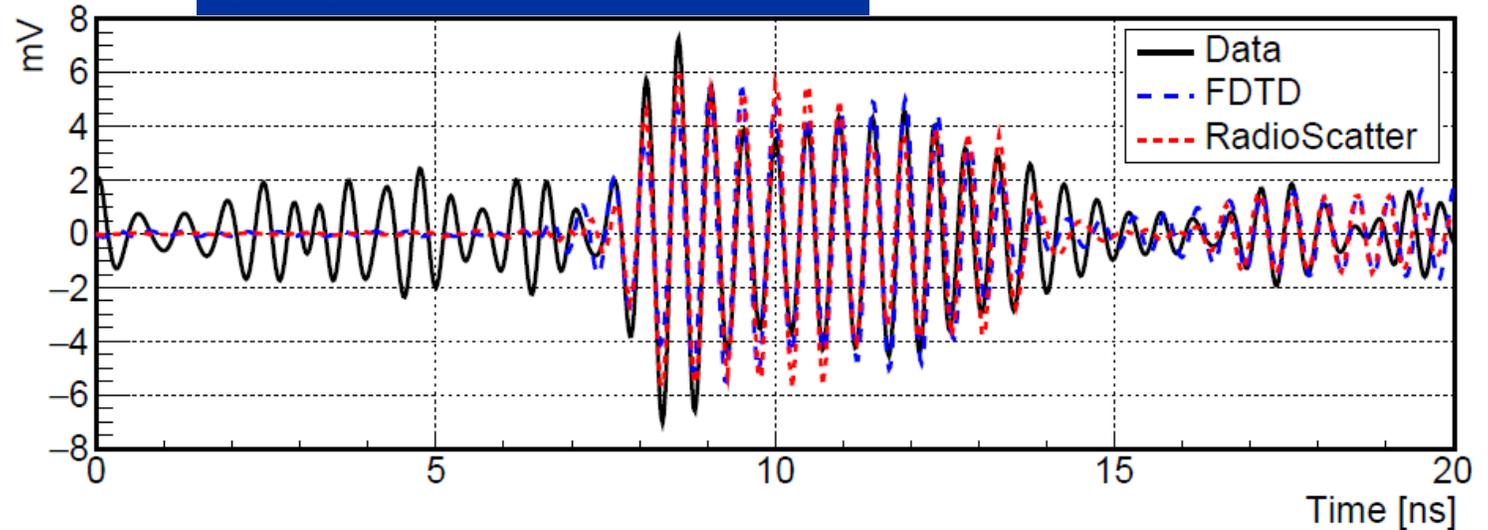
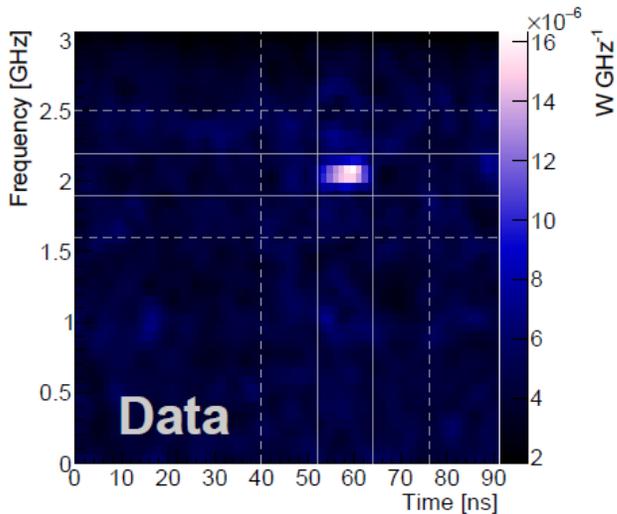
SLAC T-576 EXPERIMENT



APS/Alan Stonebraker

DETECTING HIGH-ENERGY PARTICLE CASCADES AT SLAC

SLAC T-576 EXPERIMENT



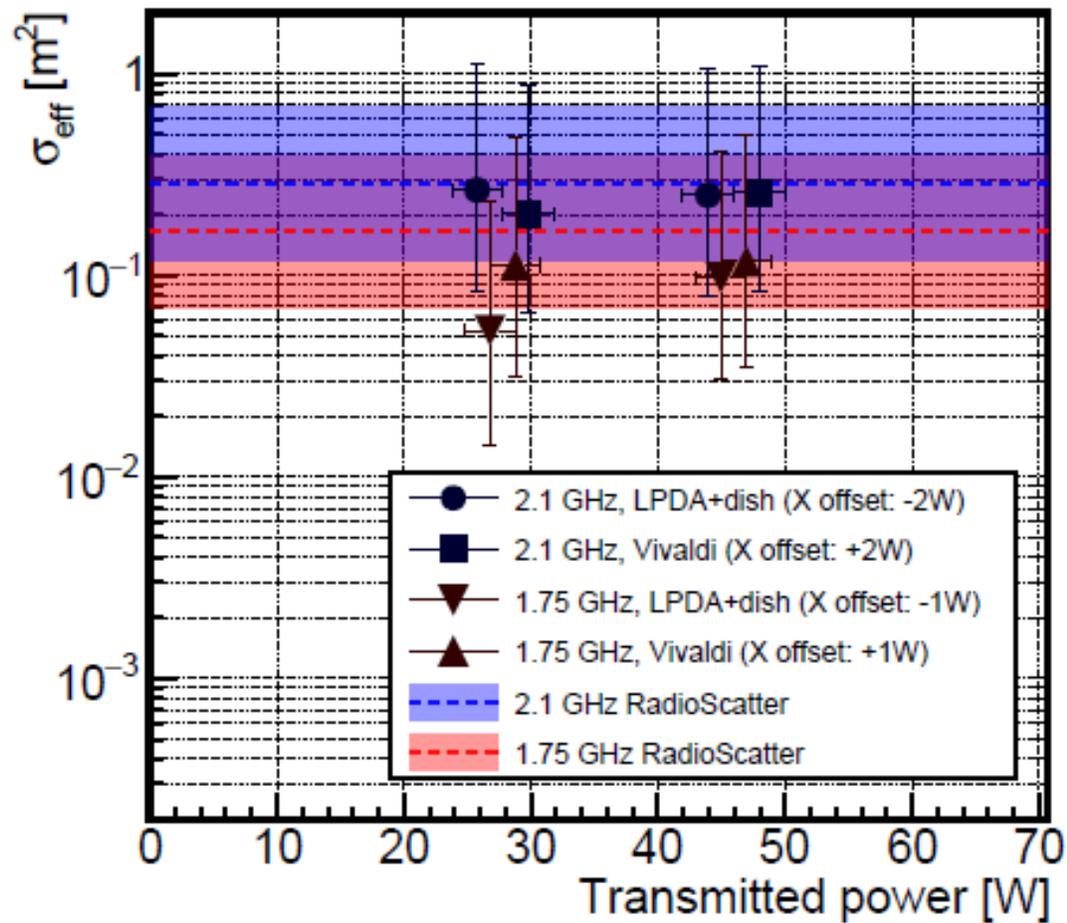
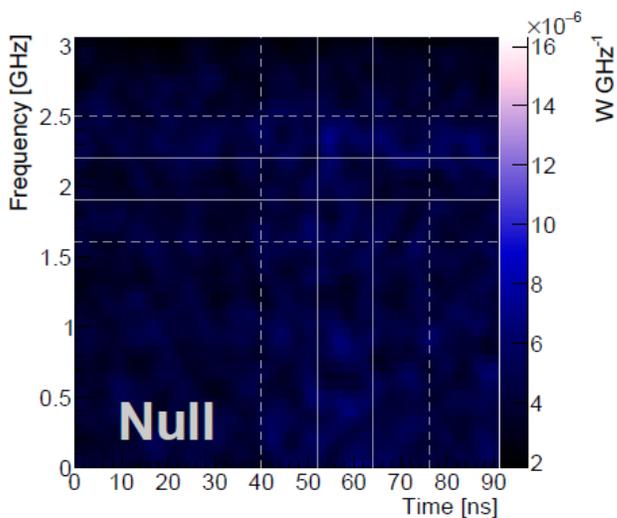
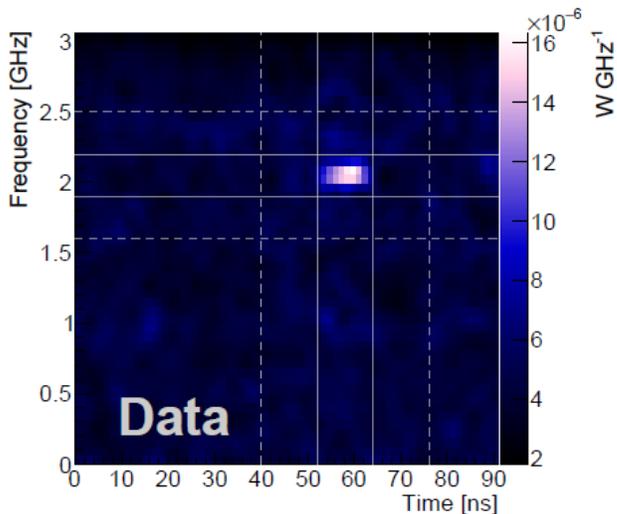
Difficult analysis due to **Askaryan and Transition radiation** backgrounds → Singular Value Decomposition to filter.

→ **Excellent agreement between data and simulations**

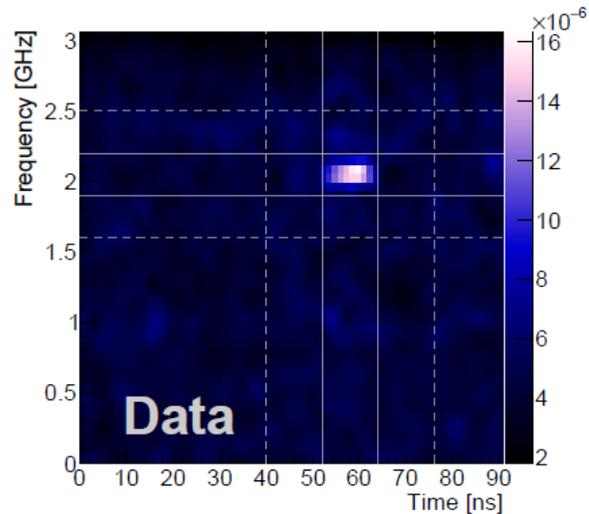
Method: S. Prohira, et al., [Phys. Rev. D 100, 072003 \(arxiv:1810.09914\)](#) || S. Prohira, [2020 J. Phys.: Conf. Ser. 1525 012119 \(arxiv:1910.11314\)](#)

DETECTING HIGH-ENERGY PARTICLE CASCADES AT SLAC

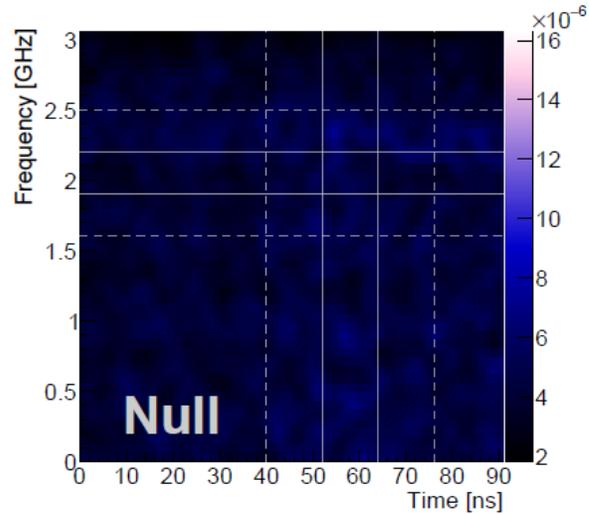
SLAC T-576 EXPERIMENT



DETECTING HIGH-ENERGY PARTICLE CASCADES AT SLAC



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



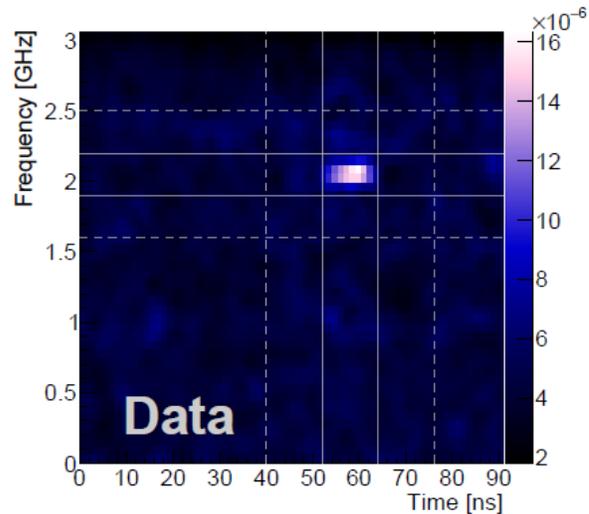
Observation of Radar Echoes from High-Energy Particle Cascades

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)

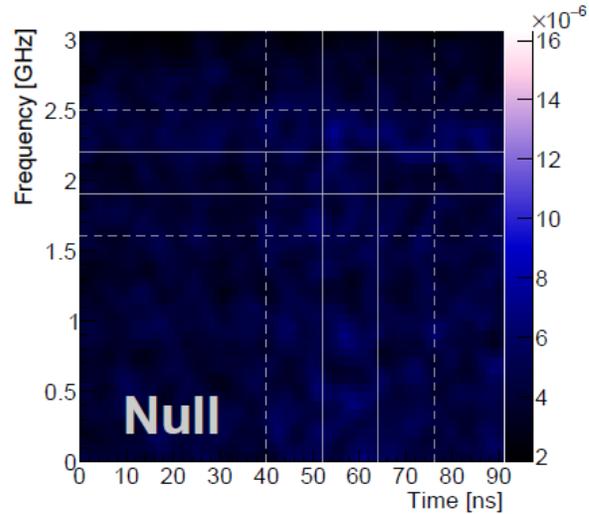
<https://arxiv.org/pdf/1910.12830.pdf>

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

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DETECTING PARTICLE CASCADES IN NATURE

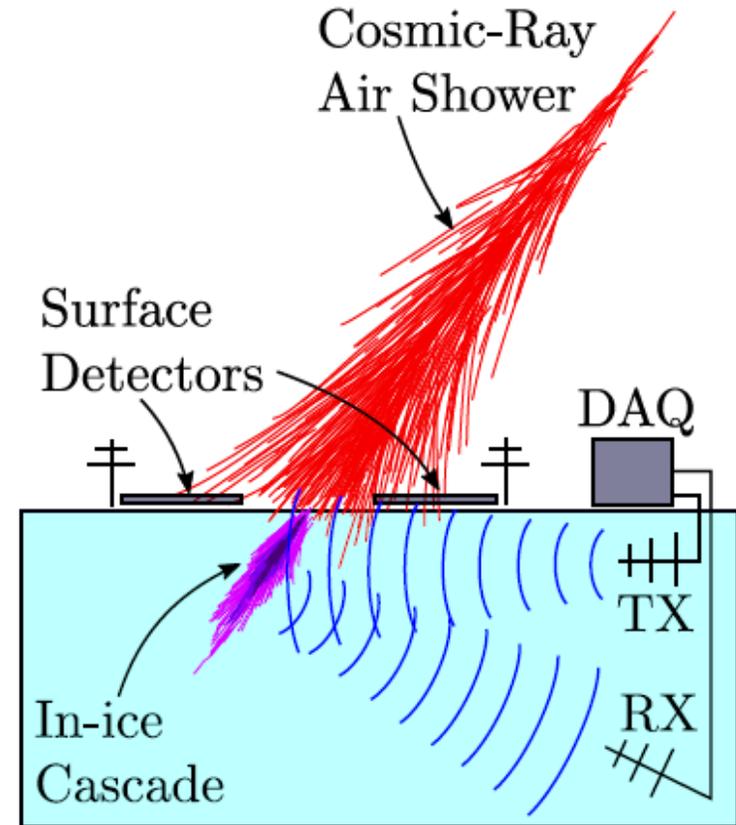
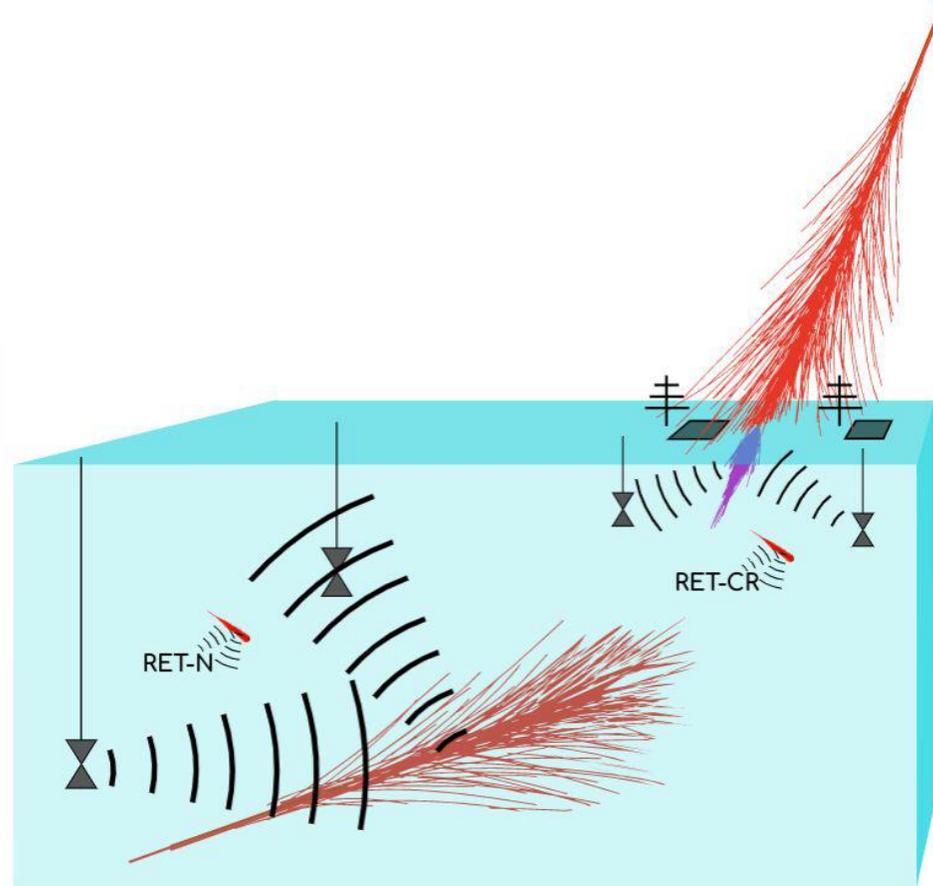
THE RADAR ECHO TELESCOPE FOR COSMIC RAYS



Radar detection of high-energy particle cascades
-- KD de Vries (VUB)
May, 6, 2021 | 10

THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

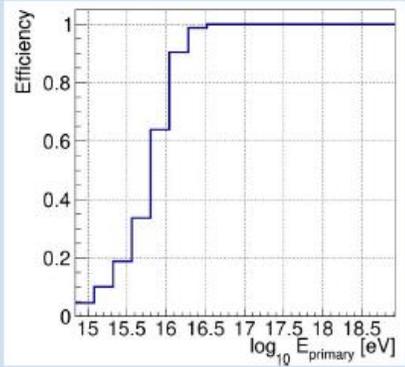
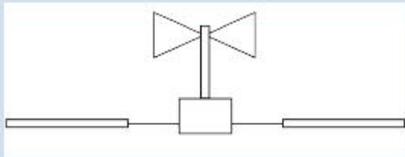
DETECTING PARTICLE CASCADES IN NATURE



[RET-CR paper: arXiv: 2104.00459 - Phys. Rev. D 104, 102006](https://arxiv.org/abs/2104.00459)

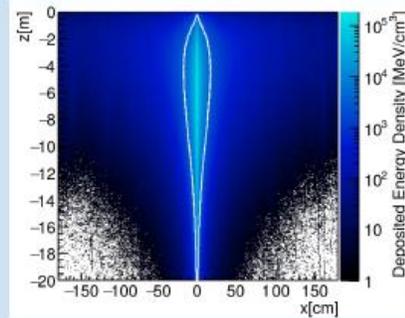
THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

CR Surface Detector

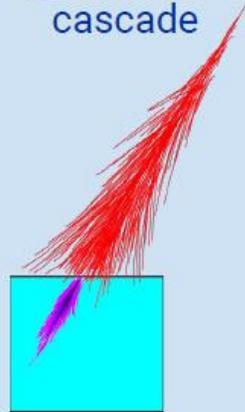


100% efficiency at $10^{16.5}$ eV

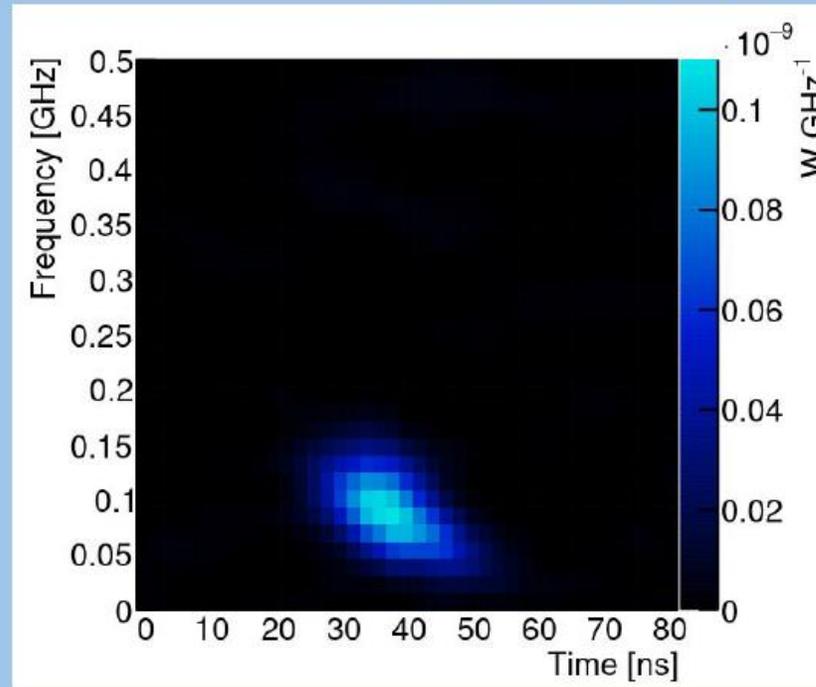
Air-ice transition



10% of primary energy in secondary cascade



In-ice Radar Detector



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

Simulations

- Radio Scatter 1.1.0

RadioScatter

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

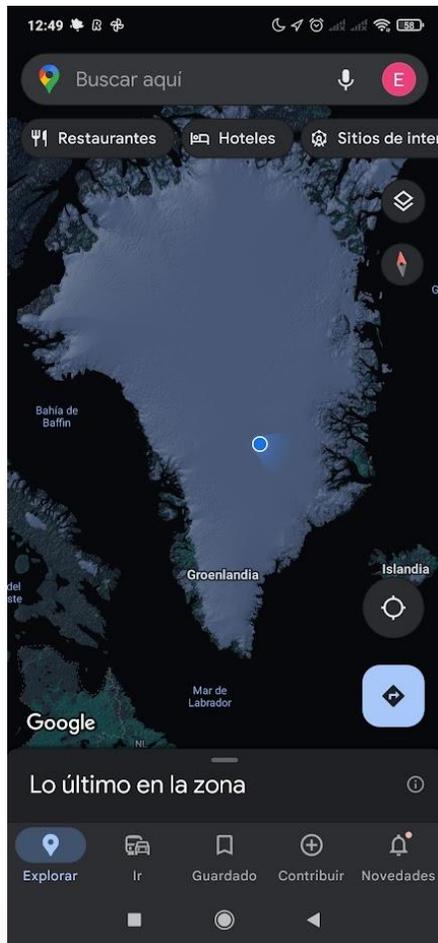
R. Stanley, K. Mulrey

S. de Kockere

S. Prohira

THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

MAY 2023 DEPLOYMENT



THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

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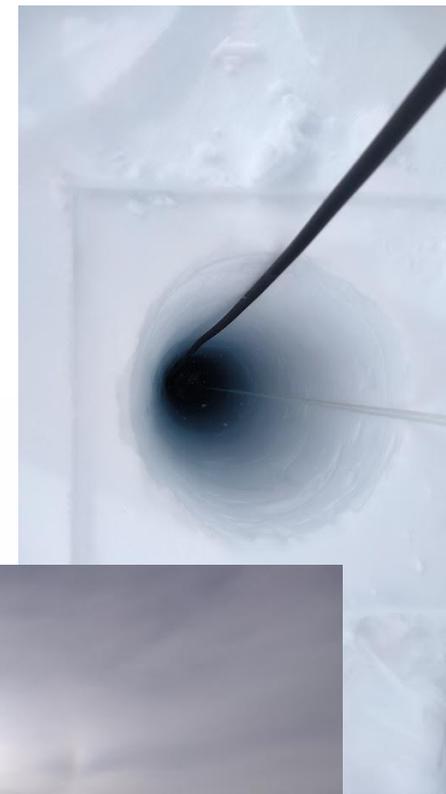
RET-CR Deployment team:

Steven Prohira
Rob Young
Dylan Frikken
Rose Stanley
Enrique Huesca Santiago



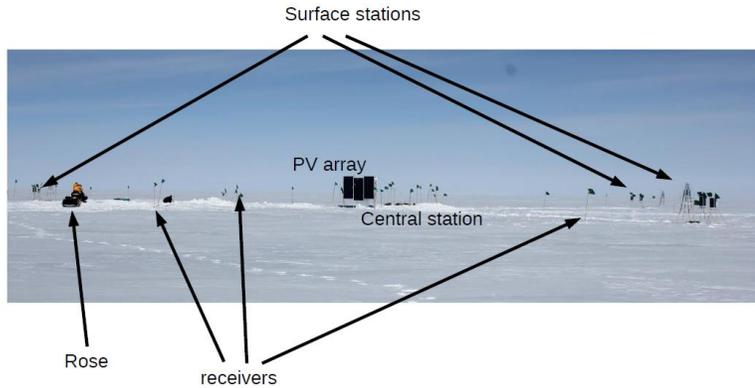
THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

MAY 2023 DEPLOYMENT



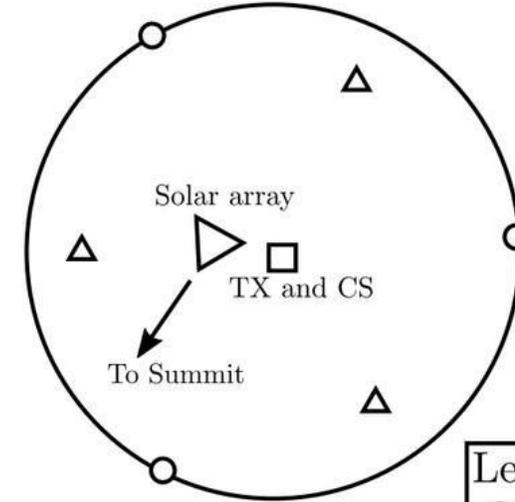
THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

MAY 2023 DEPLOYMENT



RET-CR site

Flag line



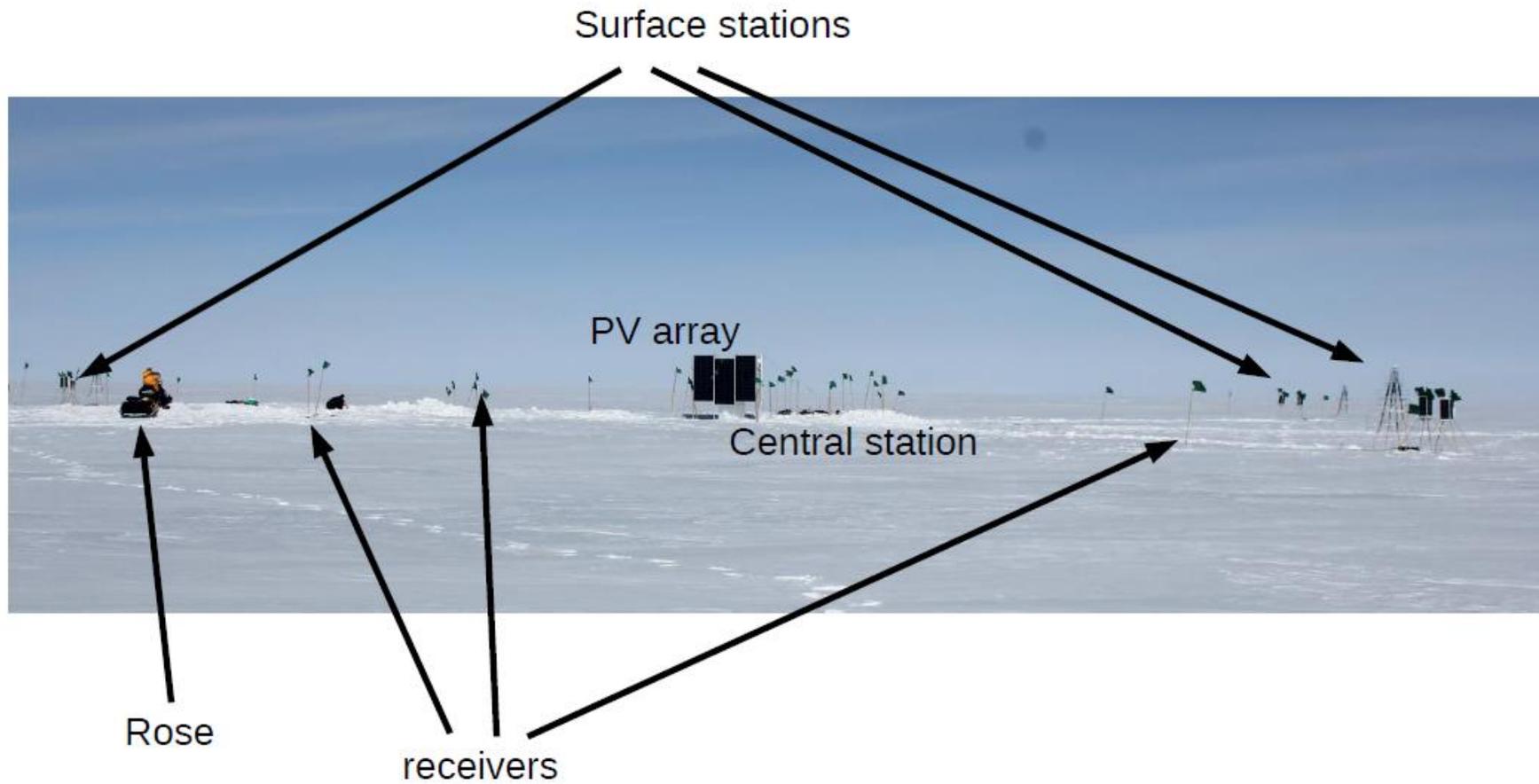
Legend:
○ Surface stations
△ Receivers

Circle diameter 80 meters

- **3x1.2kW solar array with charge control and battery bank.**
- **3 downhole strings with single Receiver 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.**

THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

MAY 2023 DEPLOYMENT



**System running and fully
operational.
First results coming soon!!**



VRIJE
UNIVERSITEIT
BRUSSEL

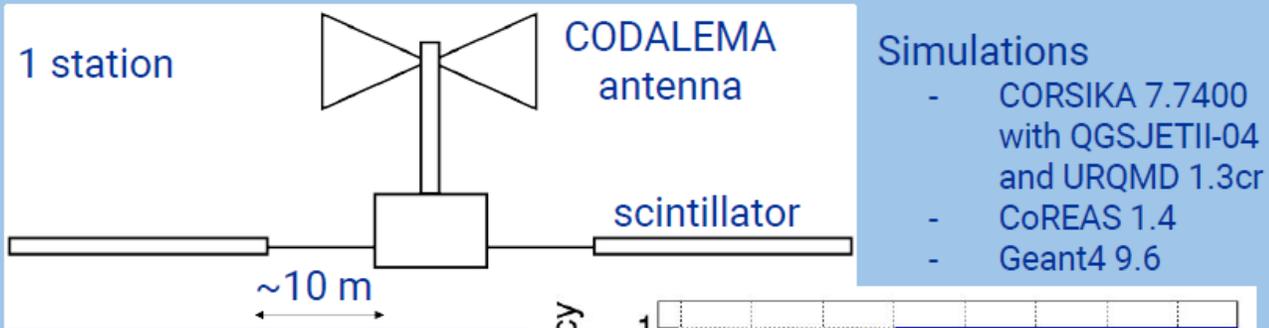


European Research Council
Established by the European Commission



THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

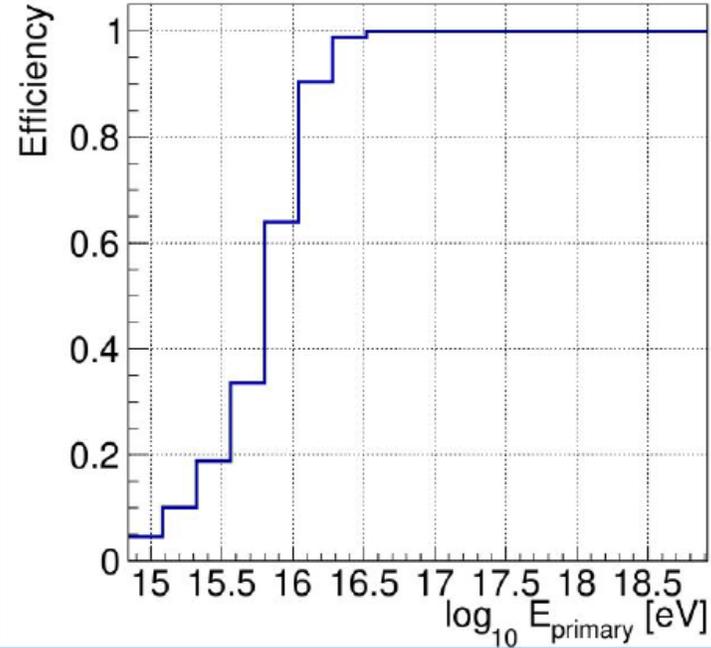
Cosmic Ray Surface Detector



Simulations

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

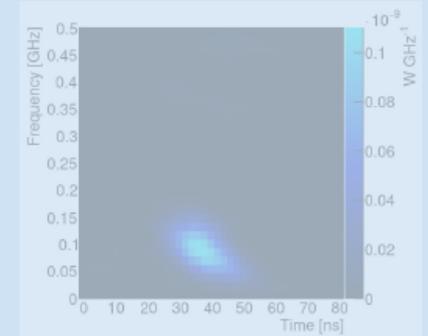
- Stations trigger independently
- 6 MeV threshold
- L0 trigger: both scintillators in one station
- L1 trigger: all stations within one cluster
- Trigger sent to radar detector



Air-ice transition



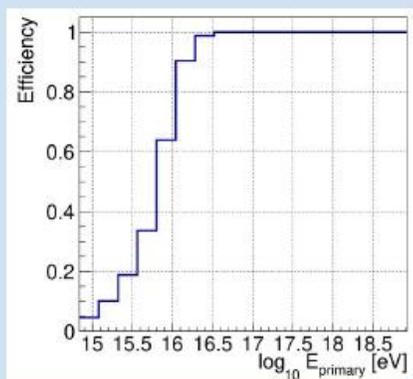
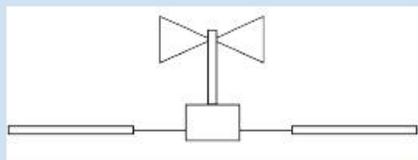
In-ice Radar Detector



R. Stanley, K. Mulrey

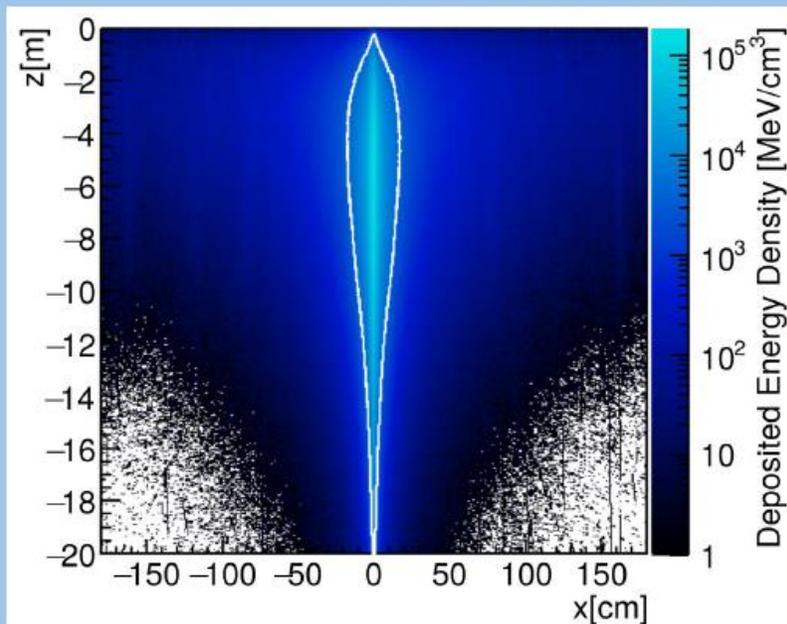
THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

CR Surface Detector



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

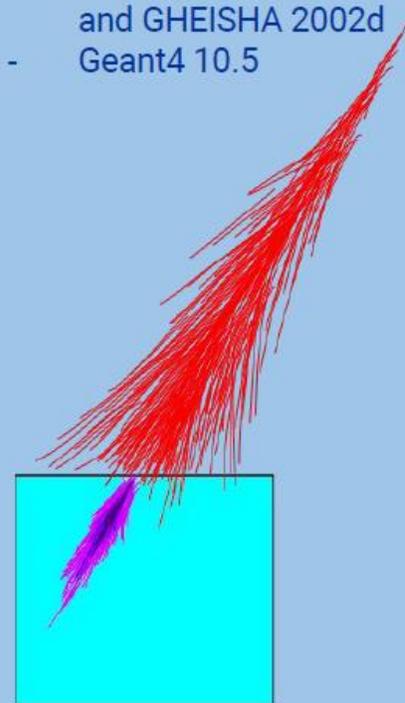
Air-ice transition



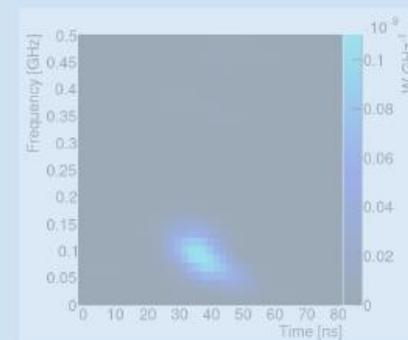
- Approximately 10% of primary energy deposited into the ice at 2400 m
- Secondary cascade in high elevation ice sheet

Simulations

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



In-ice Radar Detector



R. Stanley, K. Mulrey

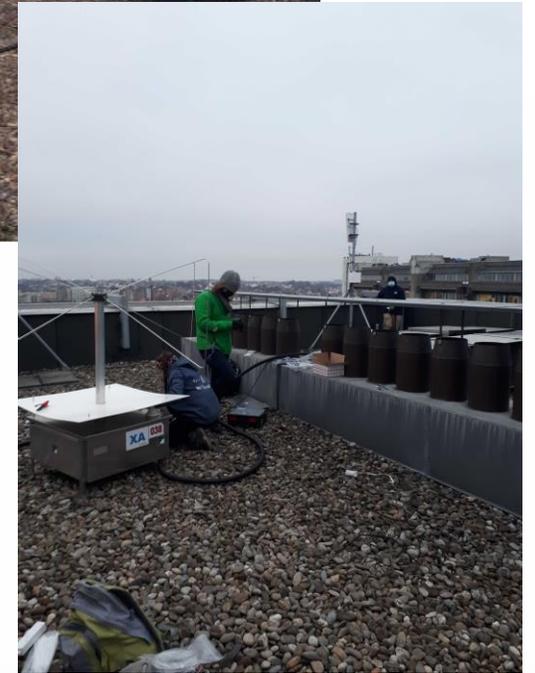
S. de Kockere

Slide from R. Stanley

Radar detection of high-energy particle cascades
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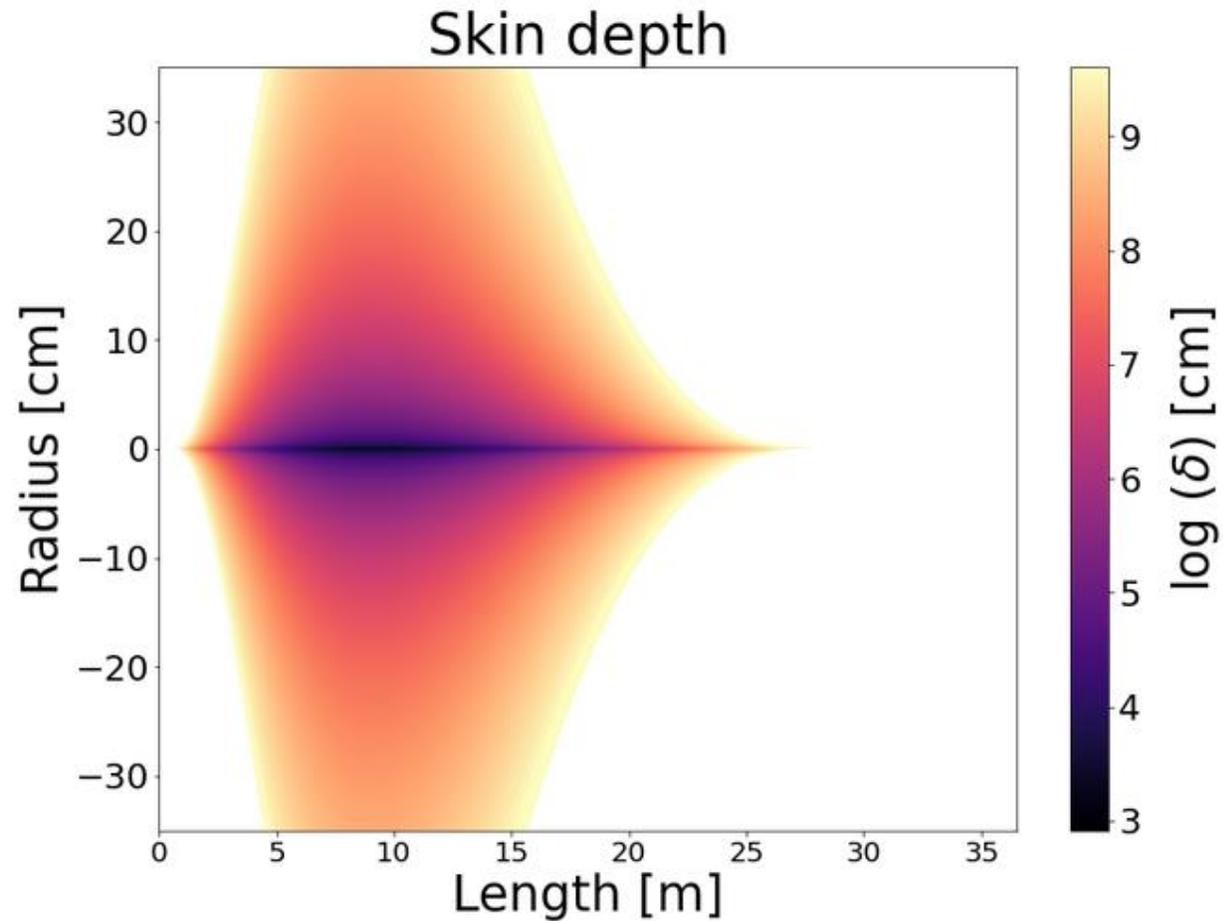
THE RADAR ECHO TELESCOPE FOR COSMIC RAYS

SURFACE SET-UP AT VUB INSTALLED AND TAKING DATA



RF SCATTERING FROM PARTICLE CASCADES

SKIN DEPTH AND EFFECTIVE SCATTERING SIZE



→ Effective scattering size
~1-100 cm²

Fig: Enrique Huesca Santiago ; 1 EeV shower energy

RF SCATTERING FROM PARTICLE CASCADES

WHAT SCATTERS?

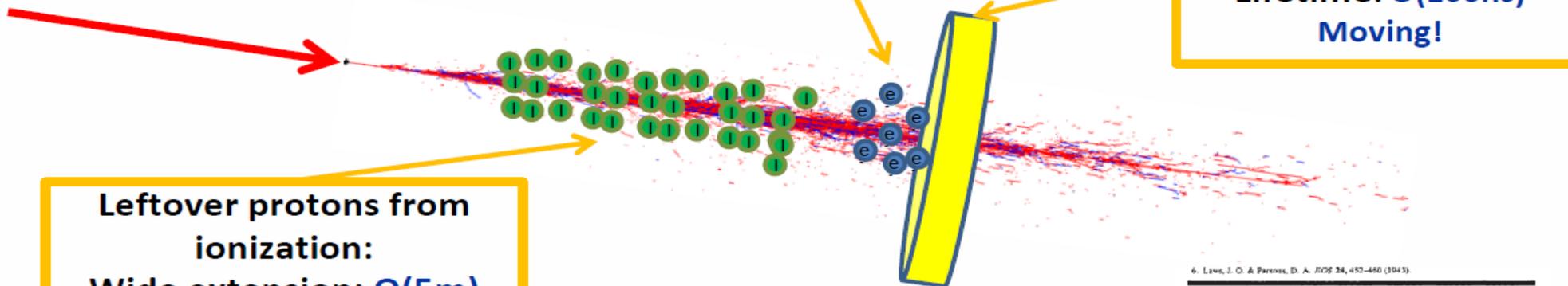
Leftover electrons from ionization:
Extension: $O(30 \text{ cm})$
Lifetime: $O(1-20 \text{ ns})$

Shower front electrons:
Extension: $R_L = O(10 \text{ cm})$
Lifetime: $O(100 \text{ ns})$
Moving!

Leftover protons from ionization:
Wide extension: $O(5 \text{ m})$
Lifetime: $O(10-1000 \text{ ns})$

Ionization numbers come from Physical Chemistry research!

Figure from arXiv:1210.5140v2



6. Lous, J. O. & Parsons, D. A. *JOPF* 24, 482-480 (1943).

Proton mobility in ice

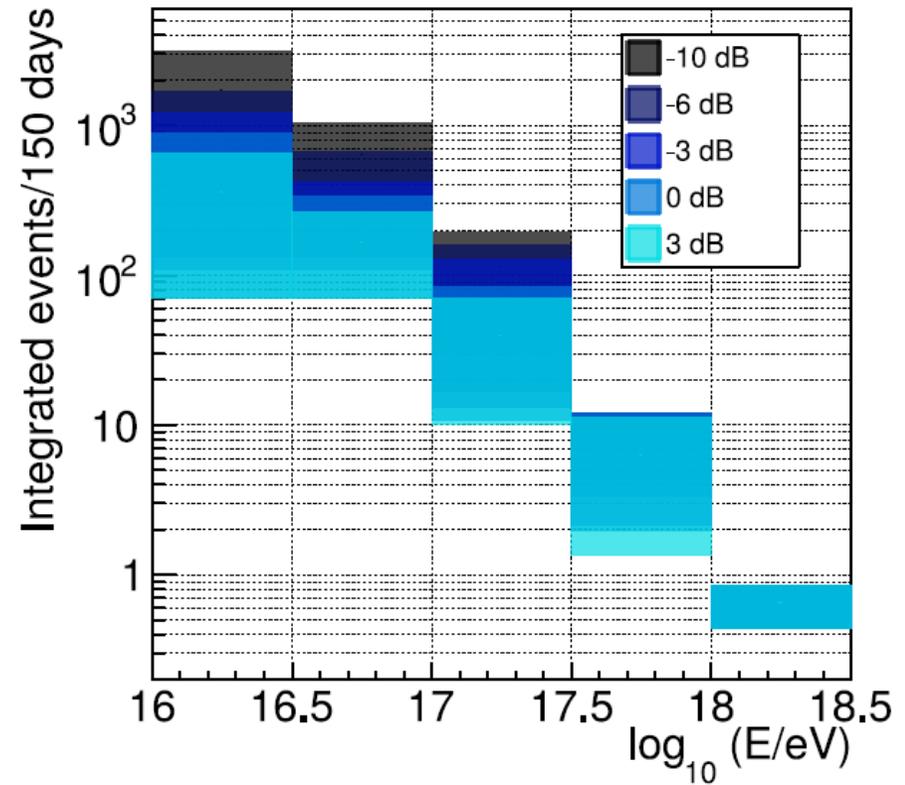
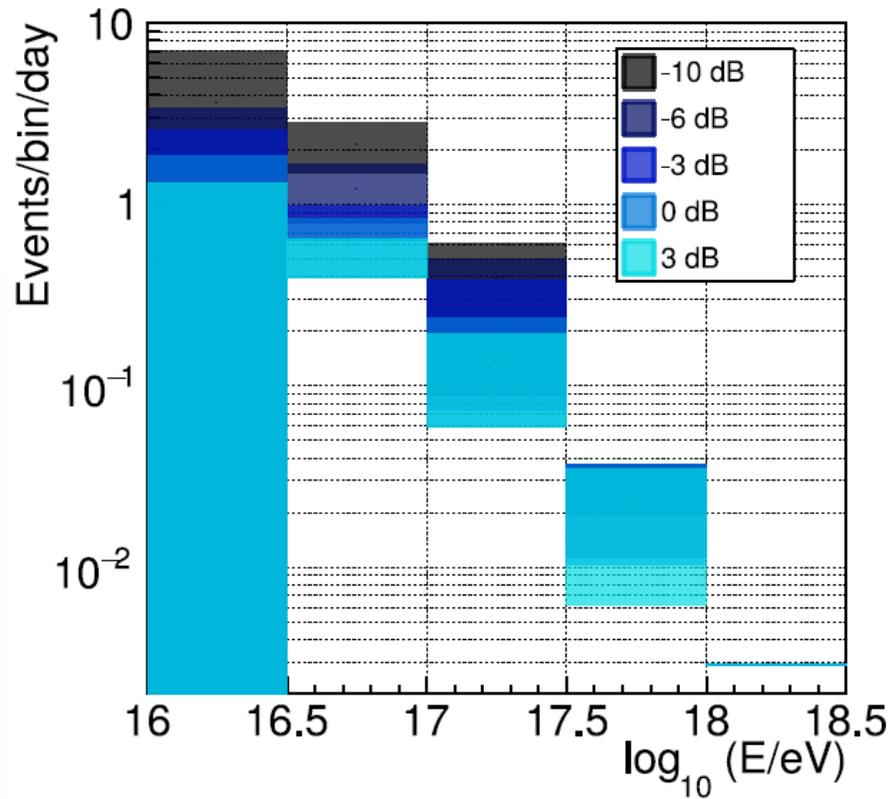
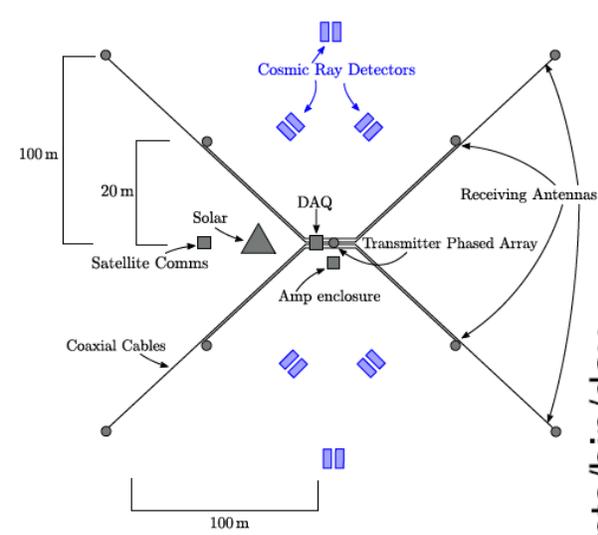
Marinus Kunst & John M. Warman

Interuniversitair Reactor Instituut, Mekelweg 15, 2629 JB Delft, The Netherlands

Ice is frequently taken as a model when factors controlling proton transport in hydrogen-bonded molecular networks are discussed. Such discussions have increased with the acknowledgement that proton transfer across cell membranes may play a significant part in energy conversion and storage in biological systems¹⁻⁴ and that this transfer may involve hydrogen-bonded chains spanning the membrane.^{5,6} However, there is still much

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[RET-CR paper: arXiv: 2104.00459 - Phys. Rev. D 104, 102006](https://arxiv.org/abs/2104.00459)