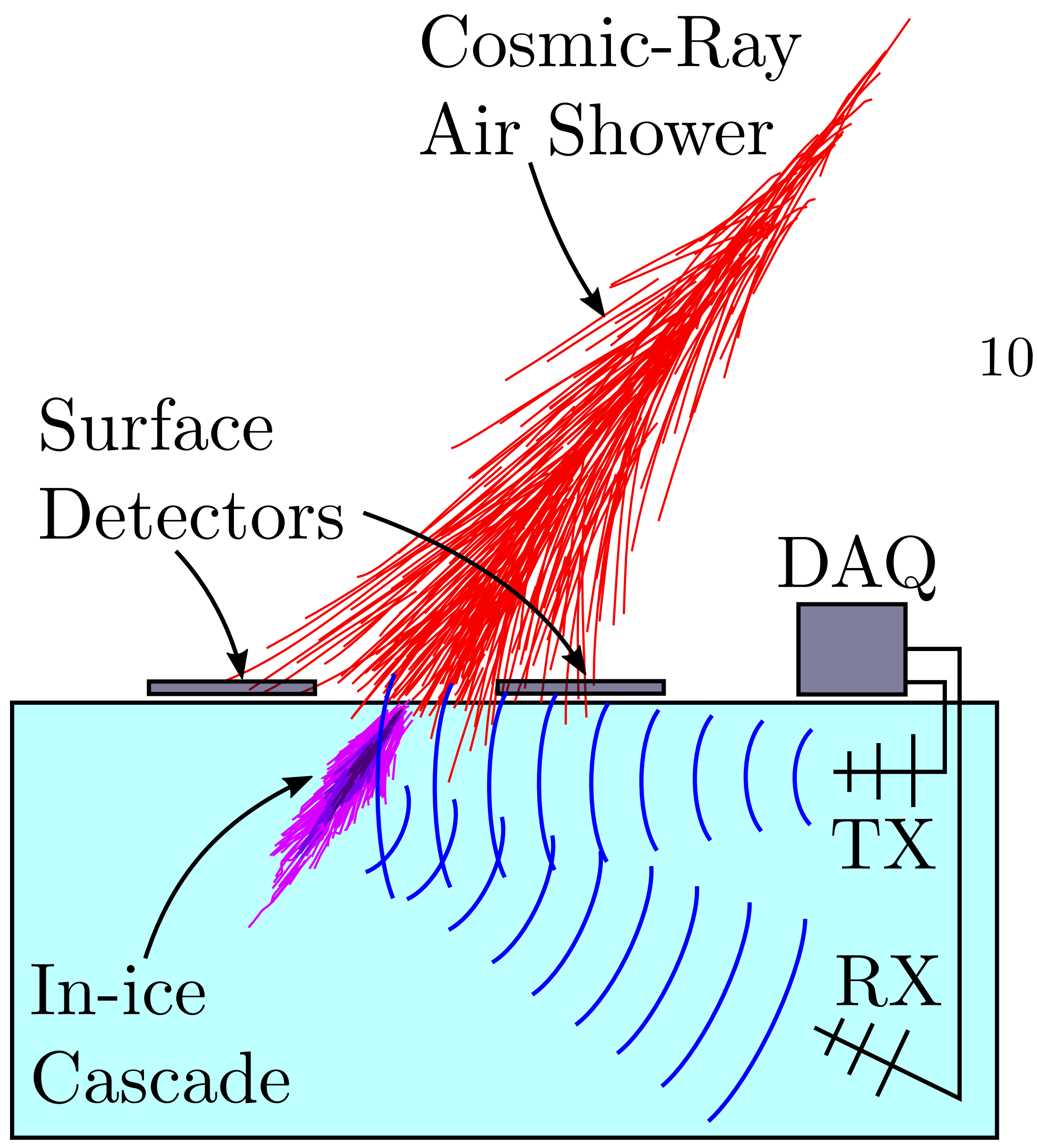
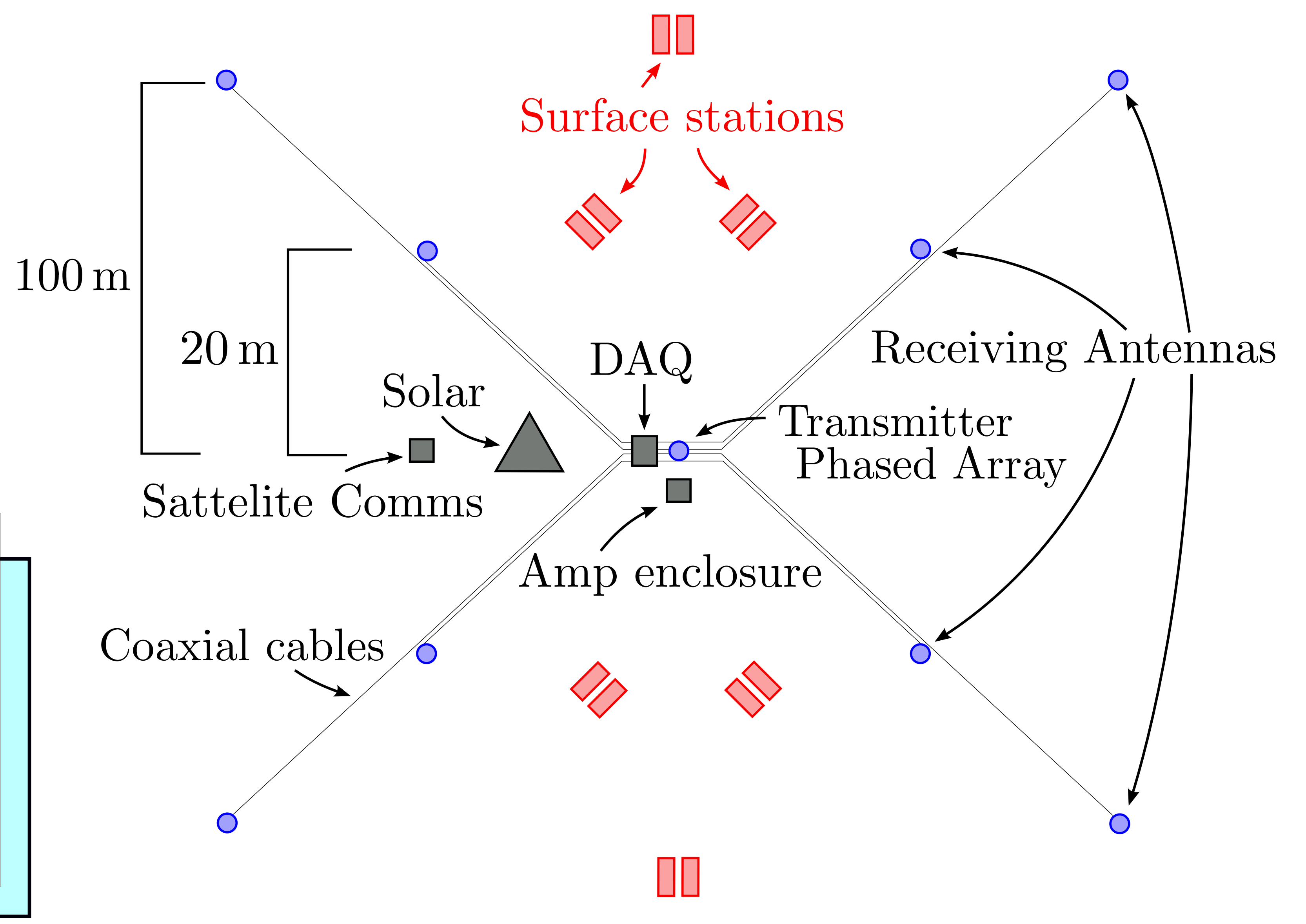
the RADAR ECHO TELESCOPE for COSMIC RAYS

Rose Stanley &
Simon De Kockere
On behalf of
the RET collaboration

Detection of in-ice particle cascades created by UHE cosmic ray air shower cores using RADAR echo techniques [1, 2, 3]

- Surface stations for triggering and independent reconstruction of the air shower, using scintillators and surface antennas
- Radar echo detector for detection and reconstruction of the air shower, using in-ice radio phased transmitters and receivers
- In situ test towards neutrino cascade detection





Surface stations

Triggering

- Ensures UHECR has entered radar detector volume
- Removes requirement of radar self trigger
- Data collected aids in development of radar self triggering routines
- Aim for 100% trigger efficiency at 10^{17} eV for air showers with $0^{o} < \theta < 30^{o}$

Triggering scheme:

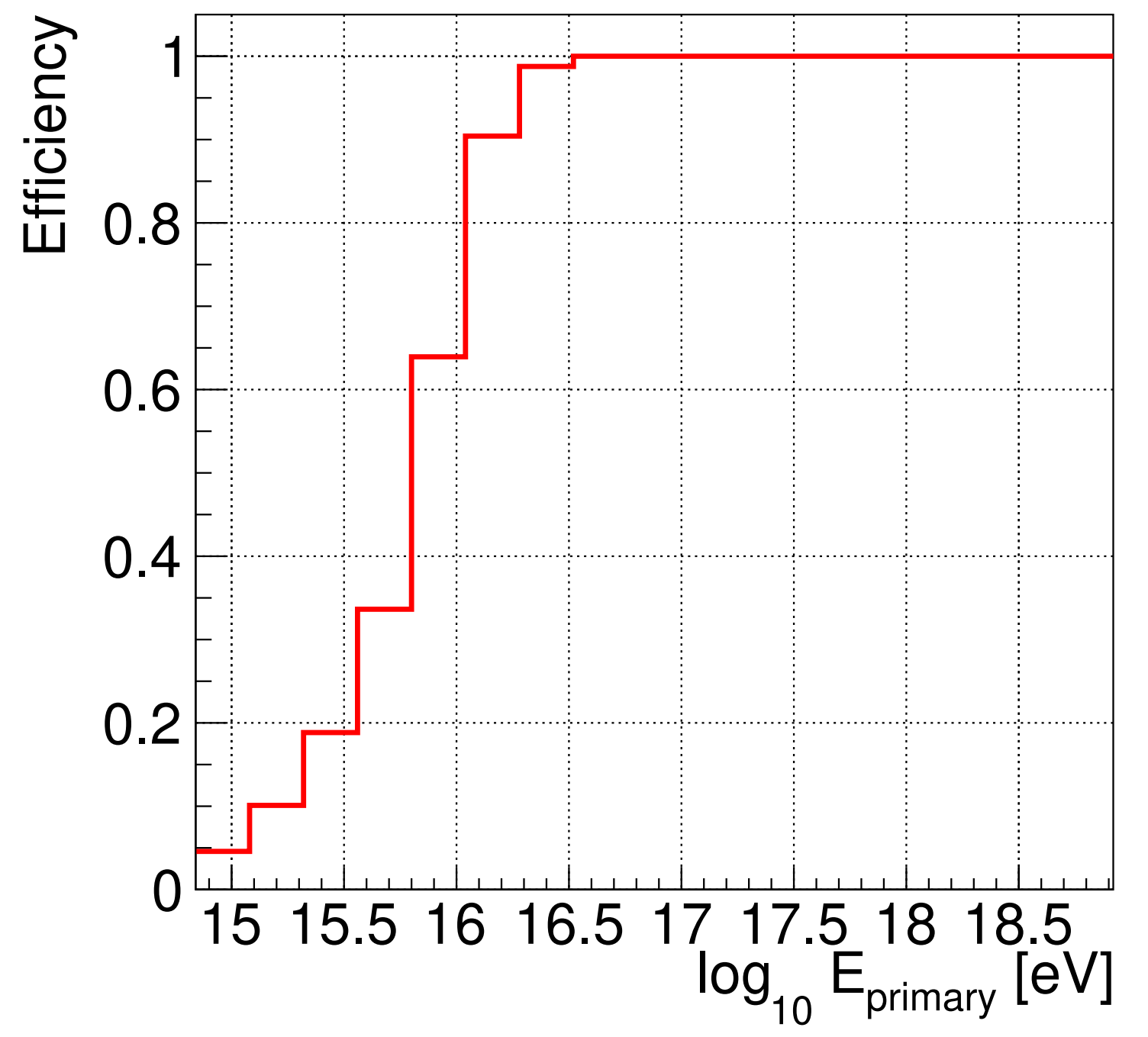
Both scintillators in one station trigger above 6 MeV (1 MIP) threshold

⬇

All stations in one cluster meet trigger requirements

⬇

Trigger sent to radar detector



Simulation of the trigger efficiency using CORSIKA, CoREAS and Geant4

Reconstruction

- Reconstruction of energy, core position and arrival direction independent of radar detector, using radio and particle information from surface detection
- Comparison and validation of radar detector reconstruction
- Studies to determine reconstruction technique and energy resolution ongoing

Prototyping

- Test system for communication and antenna read out triggering
  1) 1 MIP in both scintillators
  2) Coincidence detection in picoscope
  3) Particle data readout and antenna trigger
  4) Antenna read out 30-300 MHz
- Preliminary data collection for background filtering and reconstruction
- In collaboration with cross calibration array (**contribution 102388**)

Rooftop in Brussels (VUB)

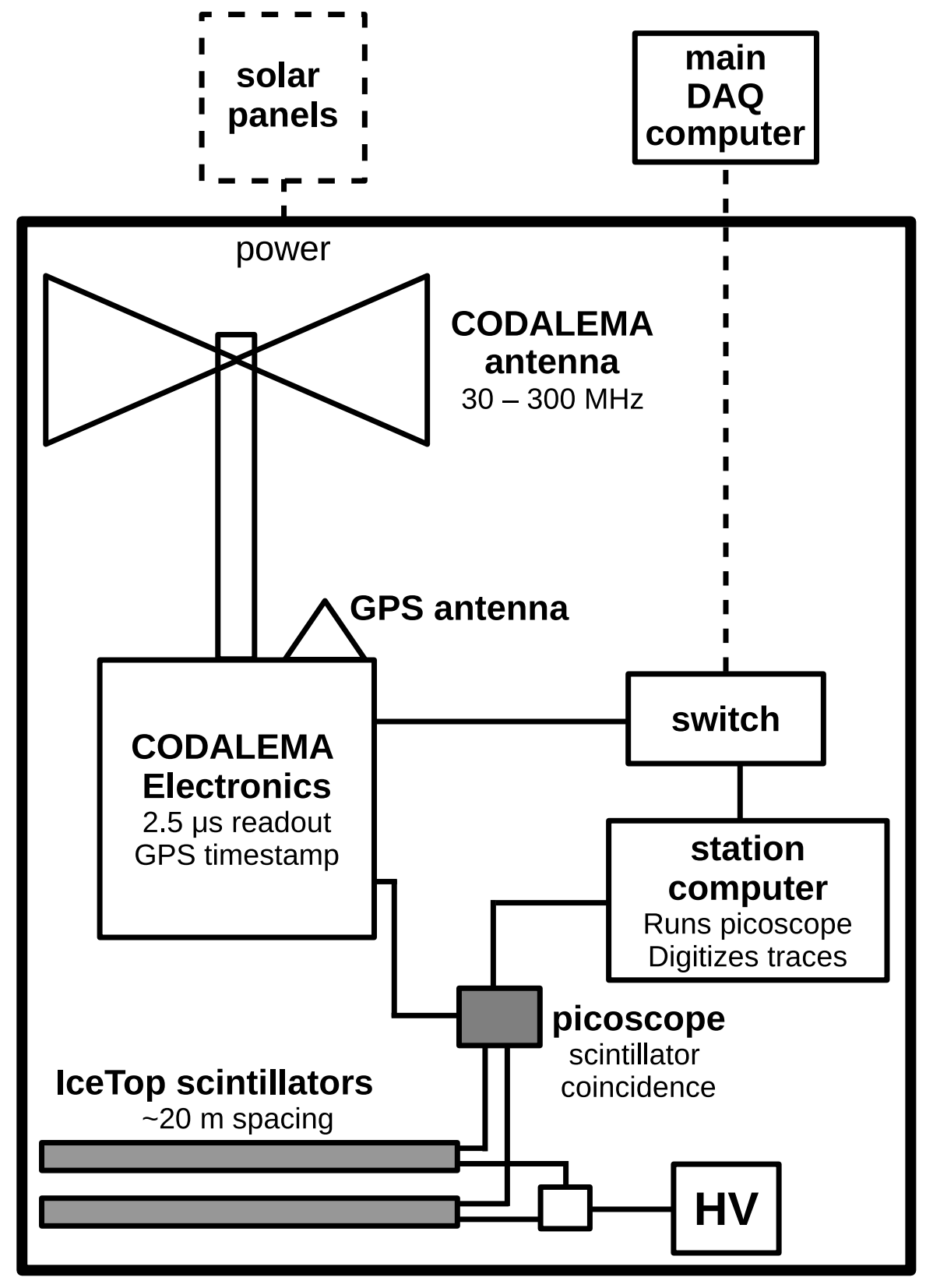


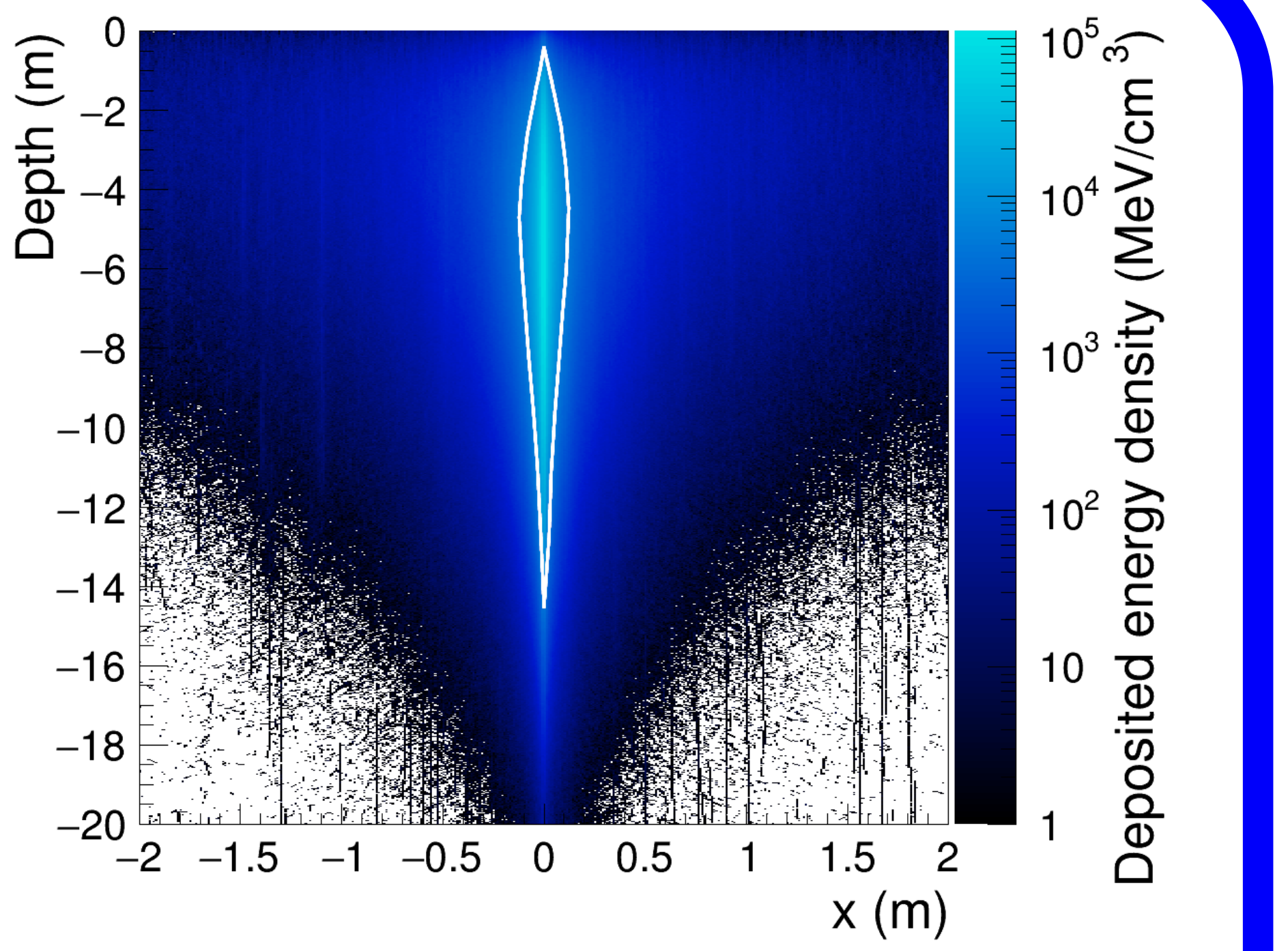
Diagram of test system

In-ice radar echo detector

In-ice cascade simulations

- Propagate CORSIKA particle output through ice using Geant4 with realistic ice density profile
- Convert deposited energy to number of free charges (50 eV = 1e⁻)
- Calculate plasma frequency $\omega_p = \sqrt{4\pi n_e q^2/m}$

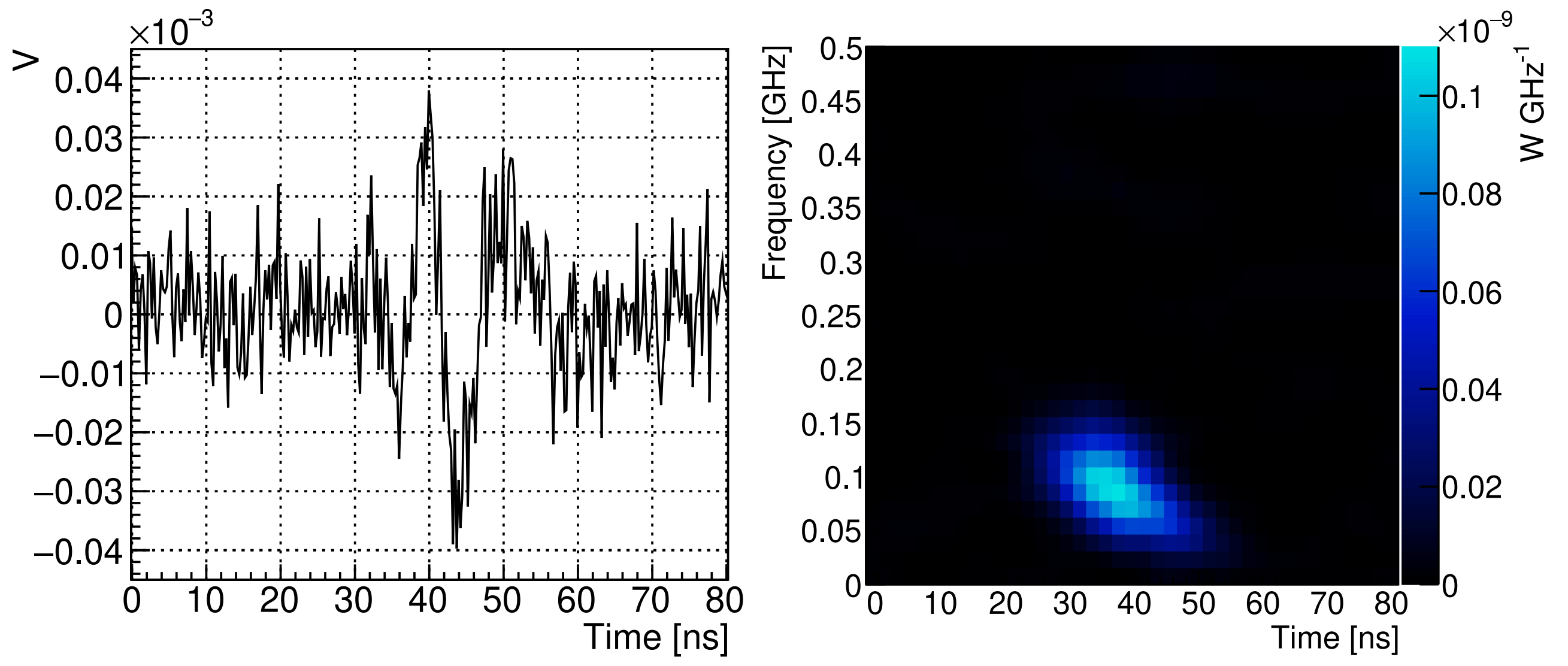
  ↳ Rule of thumb: transmission at $\omega < \omega_p$ will be reflected



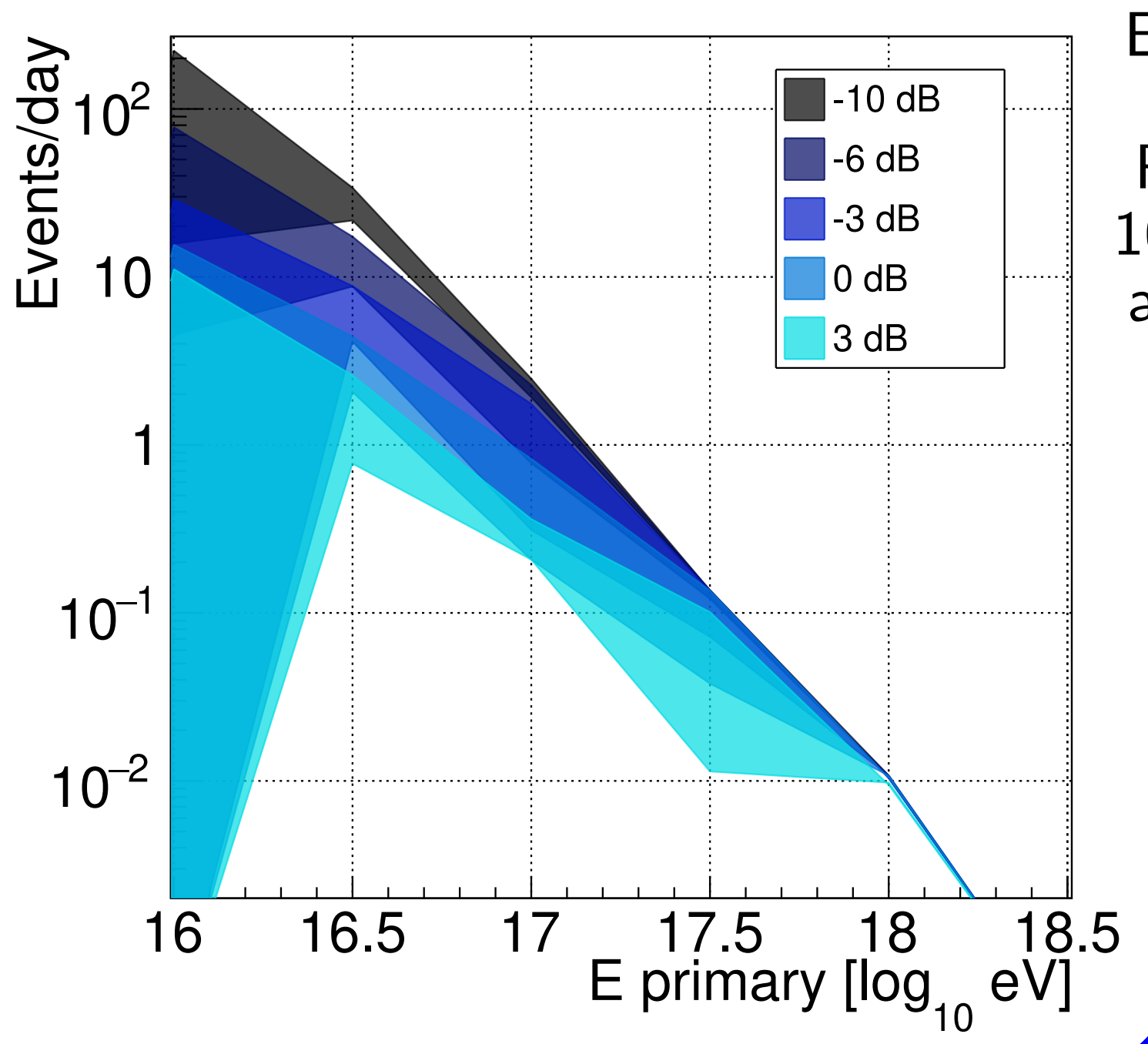
Slice of the in-ice deposited energy distribution for a primary proton with E = 10^{17} eV. White line shows region where $\omega_p > 100$ MHz.

RadioScatter simulations

- Calculates signal reflections on ionization deposits by in-ice cascades [4]
- Use energy deposits from Geant4 simulation as input to simulate overall sensitivity
  1) Get position on surface, primary energy (10^{16} - 10^{18} eV), and zenith angle (0^{o}, 15^{o}, 30^{o})
  2) Get corresponding Geant4 energy deposit
     - ↳ Only available in energy steps of half a decade
     - ↳ Use both the distribution at nearest energy below and nearest energy above primary energy
  3) Check if given signal-to-noise ratio is reached in reflection signal using RadioScatter
  4) Calculate expected event rate by taking into account cosmic ray flux, effective area, limited zenith angle aperture and surface trigger



RadioScatter event for a $10^{16.5}$ eV primary, using a 10 ns plasma lifetime and a 160 W transmitter at 100 MHz



Expected events per day for different signal-to-noise levels with respect to a thermal noise RMS of 8 μV. We use a 160 W transmitter at 100 MHz and a plasma lifetime of 10 ns. Upper and lower bounds correspond to the under and overestimation of the primary energies.

References

[1] K.D. de Vries, K. Hanson, and T. Meures, Astropart. Phys. 60, 25 (2015)
[2] S. Prohira et al., The Radar Echo Telescope for Cosmic Rays: Pathfinder Experiment for a Next-Generation Neutrino Observatory, arXiv:2104.00459
[3] S. Prohira et al., Phys. Rev. Lett. 124, 091101 (2020)
[4] S. Prohira and D. Besson, Nucl. Instrum. Meth. A922, 161 (2019)