RADAR ECHO TELESCOPE

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On behalf of:

RET collaboration

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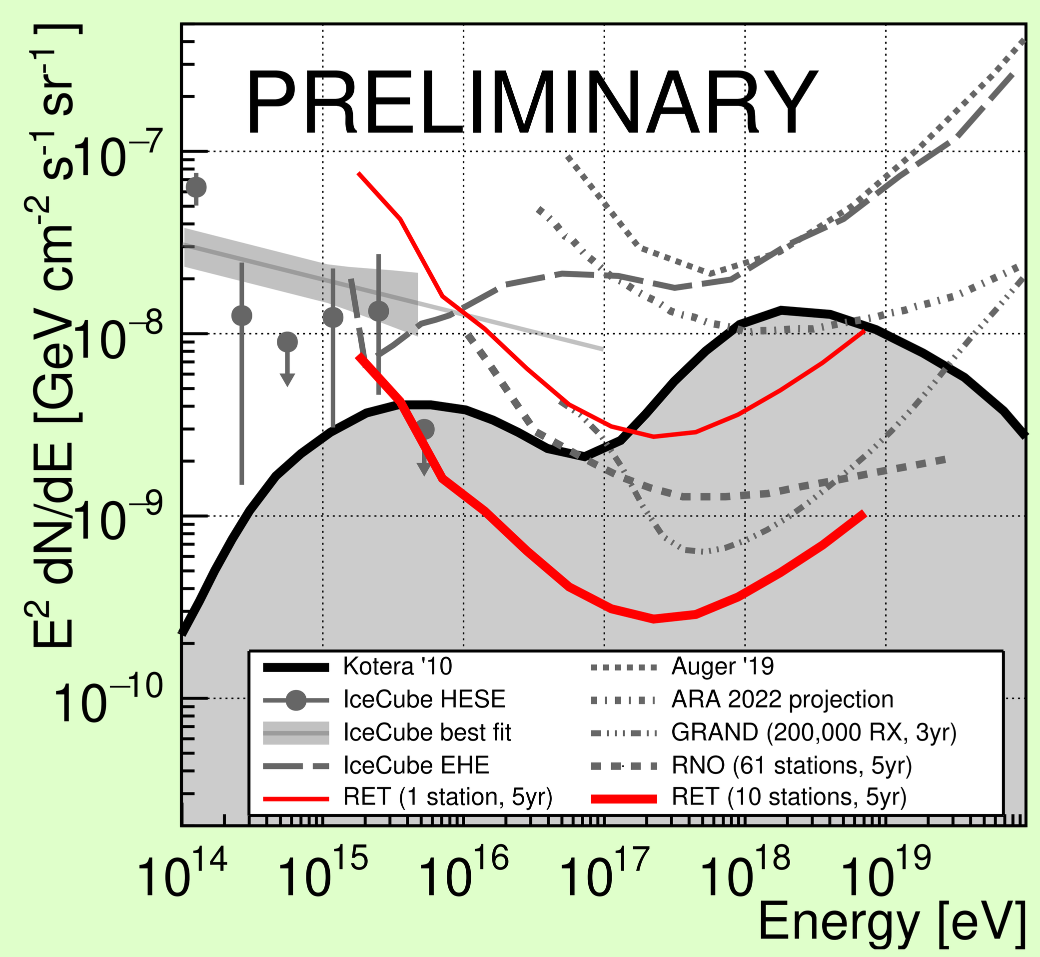
Introduction

The Radar Echo Telescope (RET) is a new proposed detector to target neutrinos with energies in excess of 10 PeV. Our international collaboration is developing the technology and expertise to deploy an in-ice radar system capable of detecting the ionization clouds left in the wake of ultra high-energy neutrino-induced cascades deep in the ice (RET-N), and from ultra-high-energy cosmic rays at the surface of the ice (RET-CR). We recently made the first definitive observation of a radar echo from a particle shower (**see poster abstract #478**) [1]. Here we describe the simulation efforts currently underway addressing all aspects of the radar detection problem.

Neutrino Sensitivity

- RET-N has good projected sensitivity to neutrinos with > 10 PeV energies
- Fully-featured, first-principles radar echo simulation code RadioScatter [3]
  - Particle-level
  - Harnessing power of Geant4

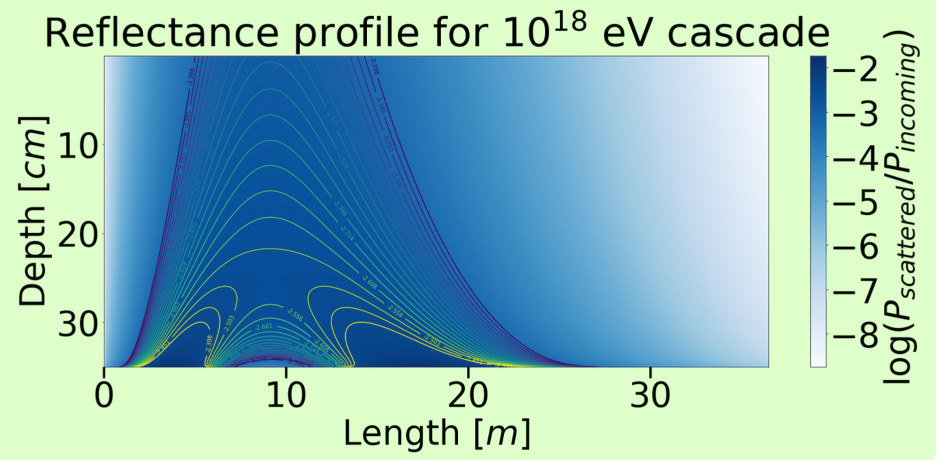


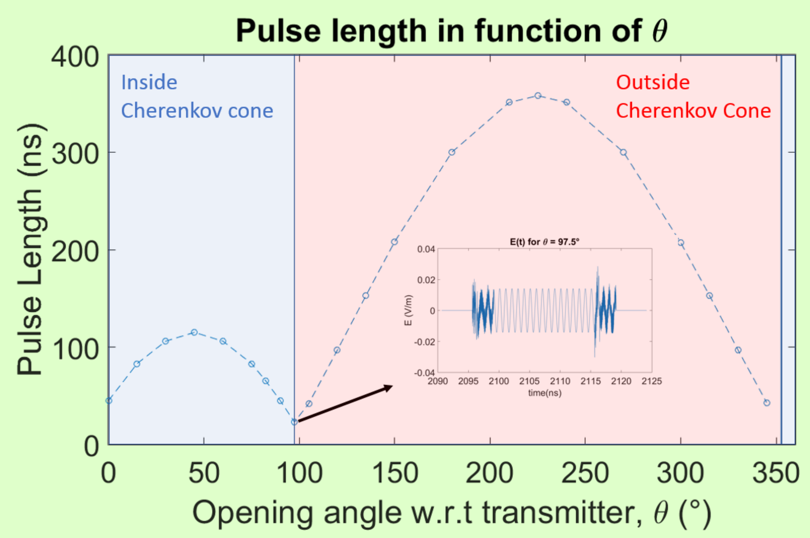
The neutrino sensitivity of the Radio Echo Telescope based on simulations using RadioScatter. One station is defined as a 40 kW transmitter (comparable to a small FM station) and 27 receiving antennas.

Macroscopic scatter models

- Radar echo simulation can be done using a macroscopic framework, reducing the cascade volume to a macroscopic collection of coherently scattering points [2]
- The expected signals depend highly on cascade position and direction, providing good handle on event reconstruction even at single antenna level and allowing for intuitive understanding of received signal's features

The computed reflectivity profile of a cascade for perpendicular plane-wave RF incidence. The different scattering regions across the surface/volume of the cascade can be seen.

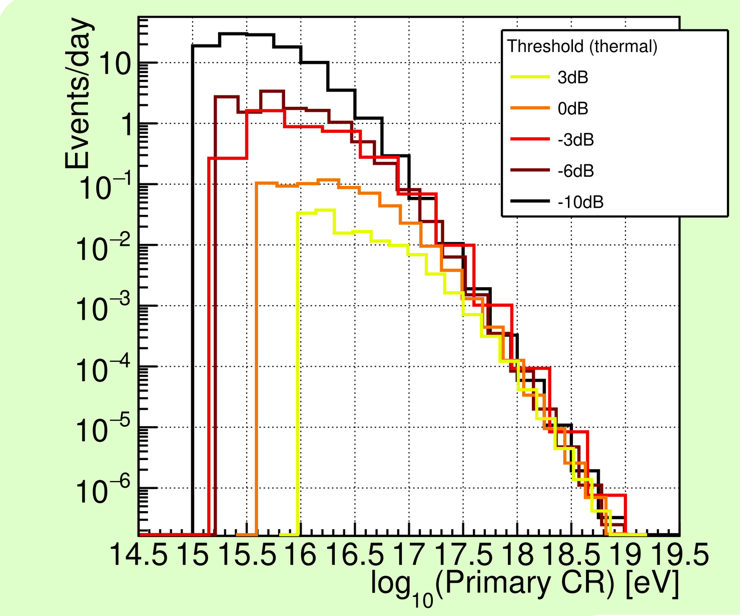




The pulse duration w.r.t. the cascade orientation. Two different regimes are seen, inside and outside the Cherenkov cone. As expected, the pulse length is minimised at the cone itself, where the associated electric field signal is fully coherent in phase.

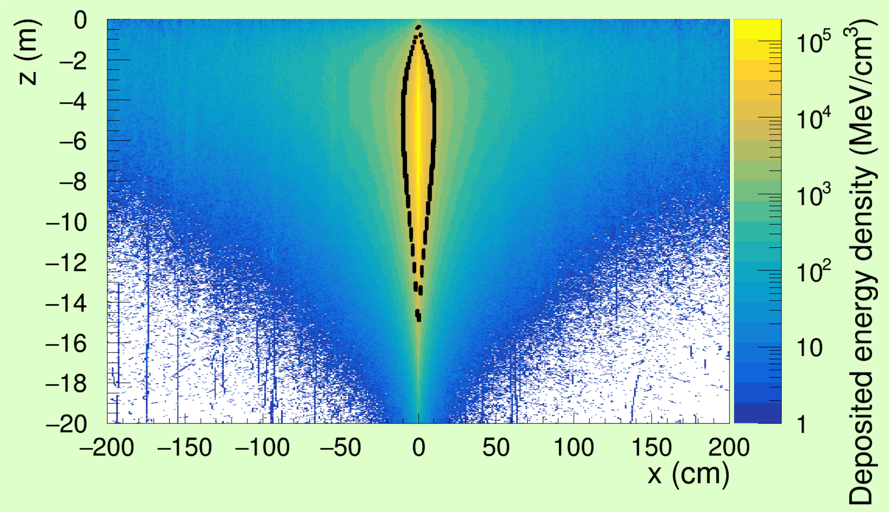
Cosmic Ray Sensitivity

- RET-CR will detect in-ice cascades from atmospheric cosmic ray cascades
- Event rate: > 1 event per day at 10 PeV
- Uses surface trigger, and serves as a testbed for RET-N

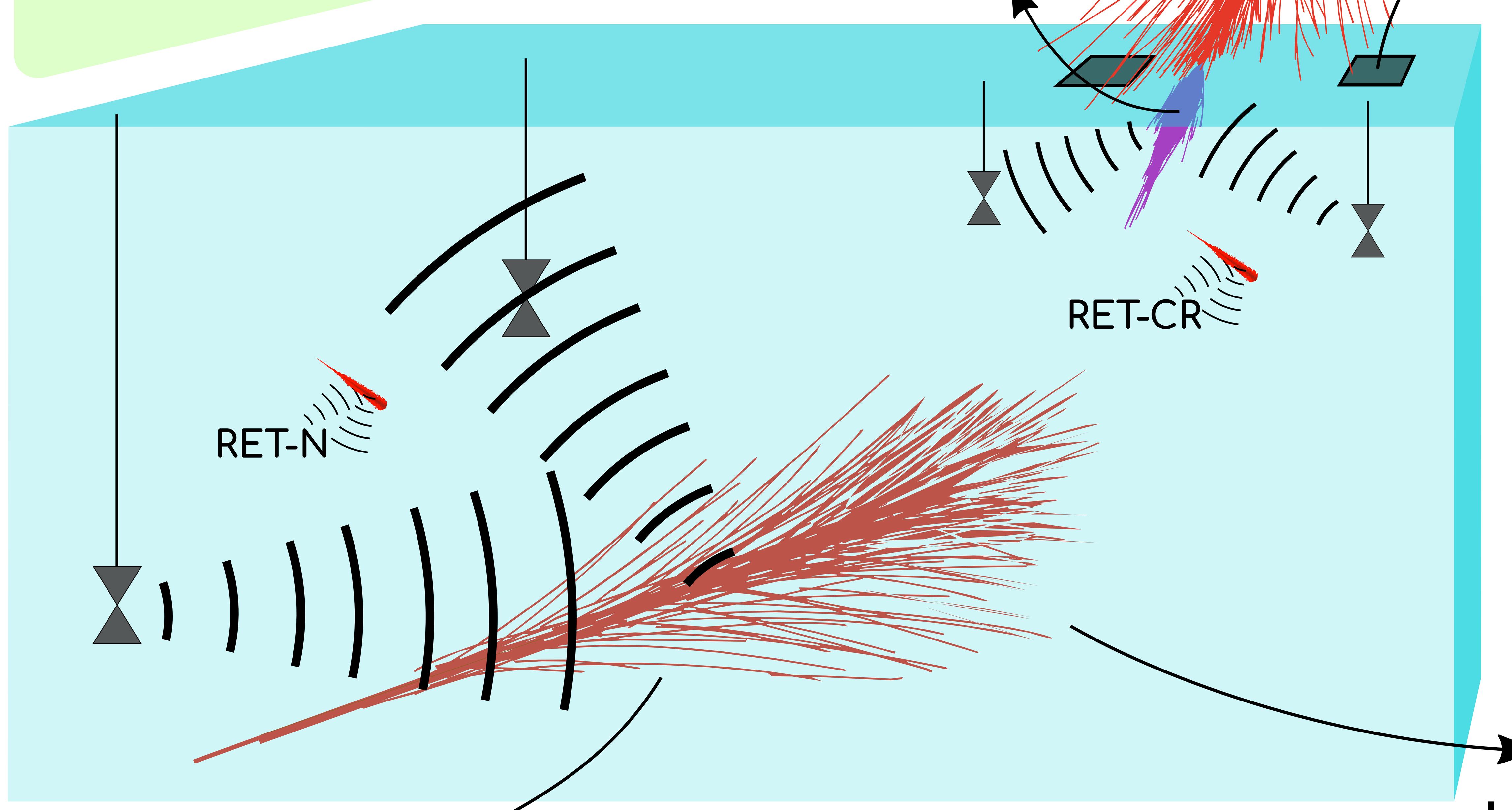


In-ice Particle Cascade from Air Showers

- Simulate air showers using CORSIKA
- Propagate through ice using Geant4
- Calculate deposited energy density and corresponding plasma frequency



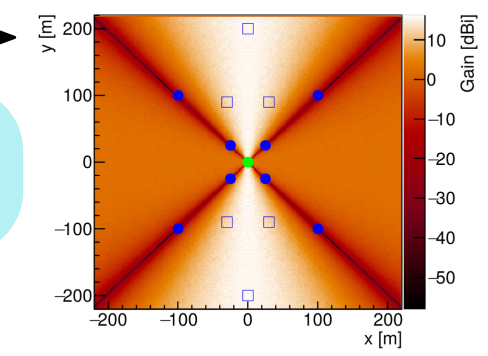
The deposited energy density in ice within a cm-wide slice along the z-axis for a 10^{17} eV proton induced air shower. The black line indicates the area in which the plasma frequency has a value larger than 100 MHz.



Surface Detector as External Trigger

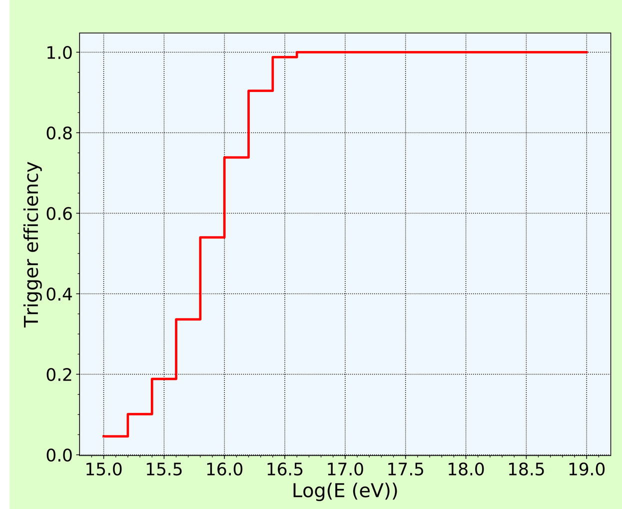
Layout

- 6 stations
  - 2 scintillators
  - 1 radio antenna
  - DAQ and power supply
- Each detector half above the illuminated region of RET-CR in-ice transmitter



Simulation

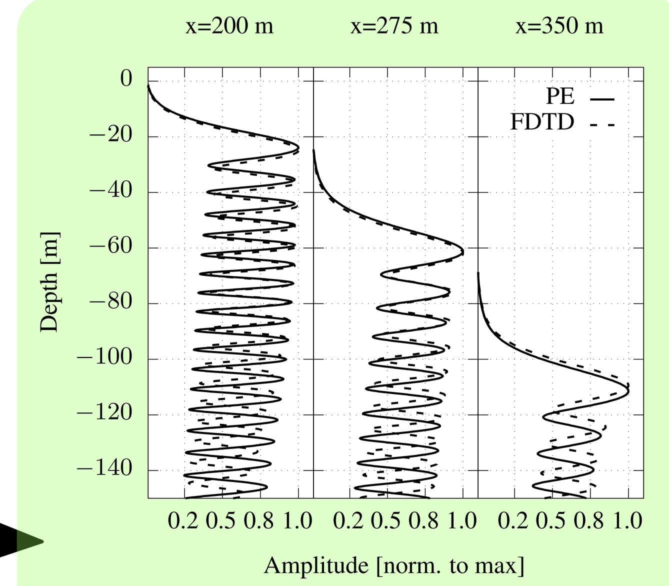
- Simulate air showers using CORSIKA
- Propagate through detector using Geant4
- Triggering if for all stations in one half
  - Deposit in scintillator ≥ 1 minimally ionising particle
  - Both scintillators in station with coincident deposit



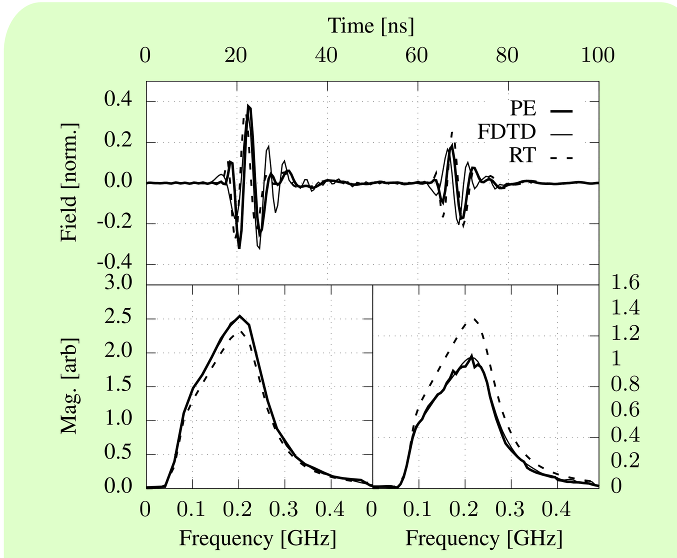
The trigger efficiency, leading to an expected event rate of order 10^6 per month for showers with $0 \leq \theta \leq 30°$. For larger zenith angles no significant energy deposit is expected in the ice. A radio trigger is currently under investigation and expected to have a cut off at 10^{16} eV.

Ice Properties

- Determine radio profile of near surface transmitters due to electrical properties of firn (top ~200 m of an ice sheet), extending existing studies to Antarctic ice [4], [5]
- Simulate using parabolic solver techniques, verifying against FDTD simulations (new paper: [6])
- Calculate max and time-dependent E-field accurately and efficiently as function of position
- Under development - to be included in future models and simulations



Comparison between paraProp (parabolic equation method, line) and meep (FDTD, point) at ranges of 200, 275, and 350 meters from the transmitter for a functional form of the in-ice n(z) profile for the South Pole, with an air boundary.



A time-domain comparison of the paraProp parabolic solver (thick line) and the meep FDTD solver (thin line). This is for a receiver placed at x, z = 100 m, -25 m and a transmitter depth of -30 m. The output pulse is a band-limited pulse from 90-250 MHz.

Conclusion

We presented a new, novel, radar detection technique to probe high-energy particle cascades in dense media. This method will be used in ice by the Radar Echo Telescope (RET). Fully-featured, first-principles radar echo simulations show that RET has a good projected sensitivity to neutrinos with > 10 PeV energies. Macroscopic scatter models show that the expected signals depend highly on cascade position and direction, providing good handle on event reconstruction. Proof of principle for this detection technique will be provided by detecting cosmic-ray air shower cores penetrating a high-altitude ice surface. For this, an additional surface component will be installed to trigger the radar DAQ using the radio emission and particle content of high-energy cosmic-ray induced particle cascades. We expect an event rate of order 10^4 per month.

References

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