

# PROPERTIES OF TRANSITION RADIATION INDUCED BY PARTICLE SHOWERS

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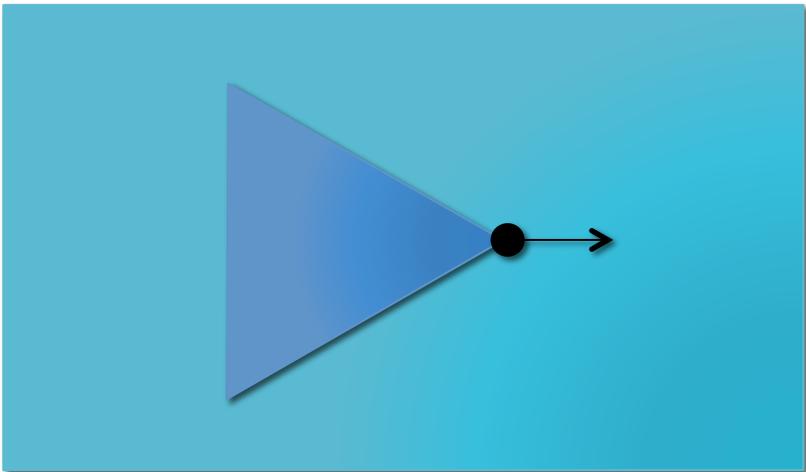
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University of Santiago  
de Compostela

# Introduction

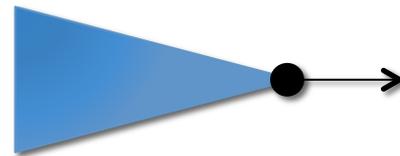
# Transition radiation

- Radiation emitted when a charged particle passes through inhomogeneous media, such as a boundary between two different media
- “Boundary matching of two Cherenkov cones”



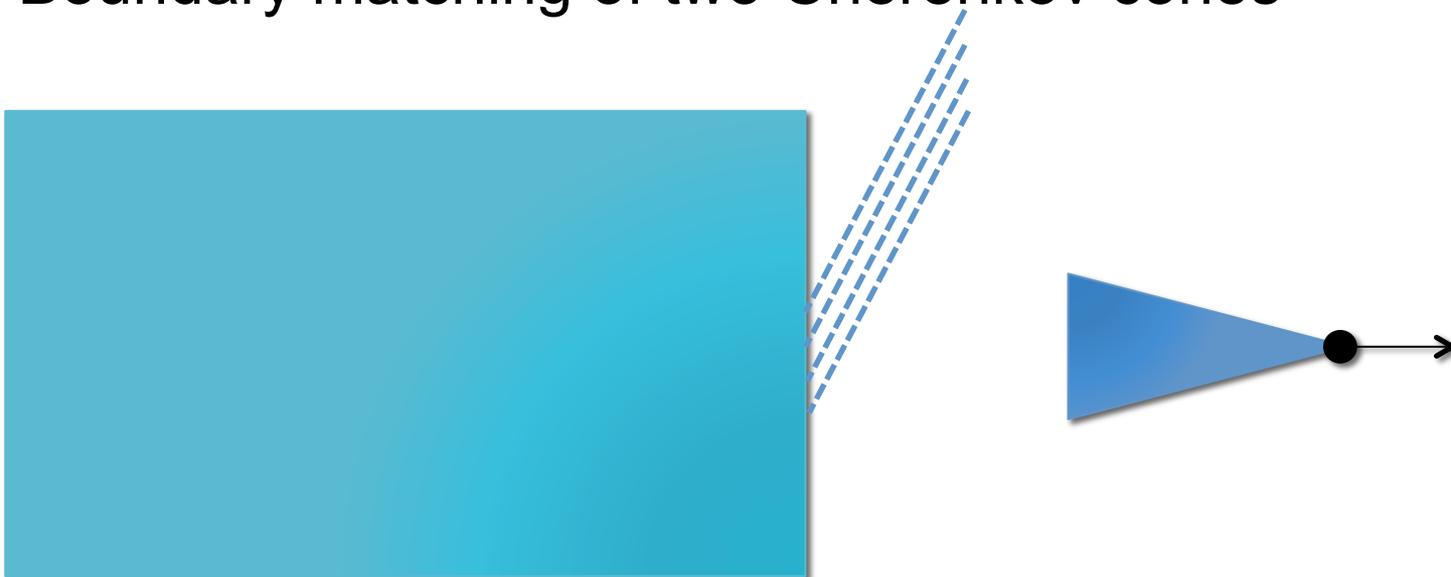
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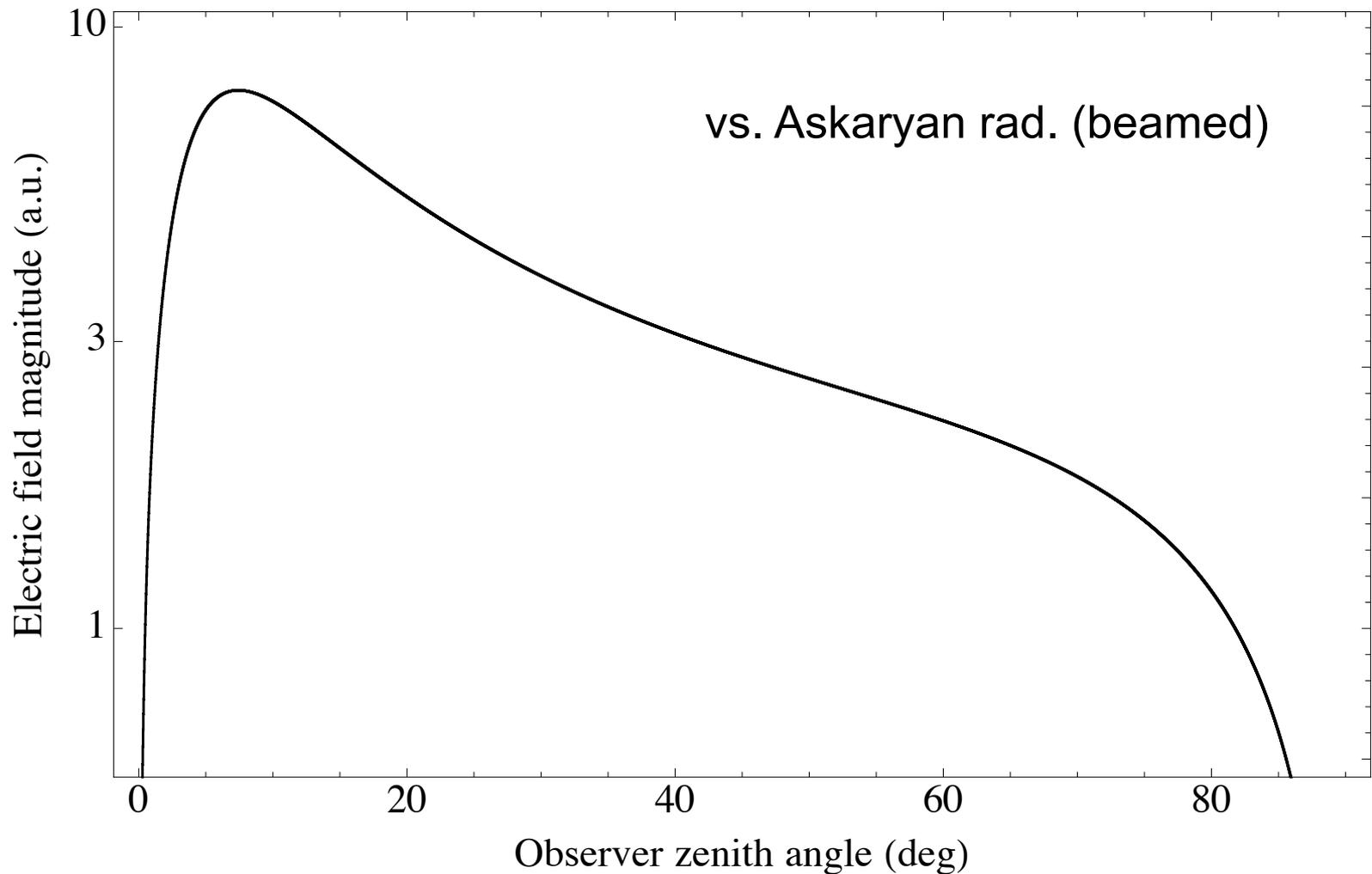


# Transition radiation

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- “Boundary matching of two Cherenkov cones”



# Single vertical electron (4 MeV)



# Why should we care?

- Signal detection by ARA, ARIANNA from air showers?
  - Background for experiments / measurement of CR

de Vries et al, 1503.02808

talk to Stijn Buitink

Thomas Meures



- Surprises
  - Ara – end of the talk

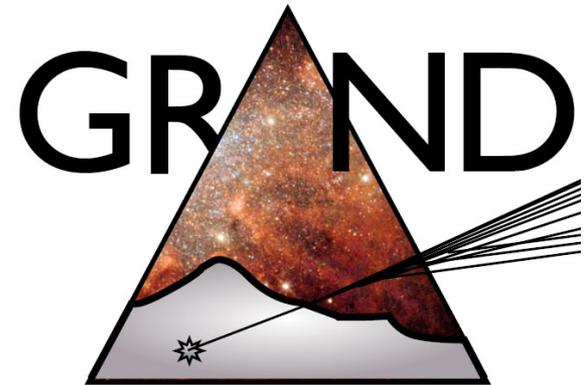
# Why should we care?

- Measure EeV neutrinos?

- GRAND experiment

Martineau-Huyhn et al, 1508.01919

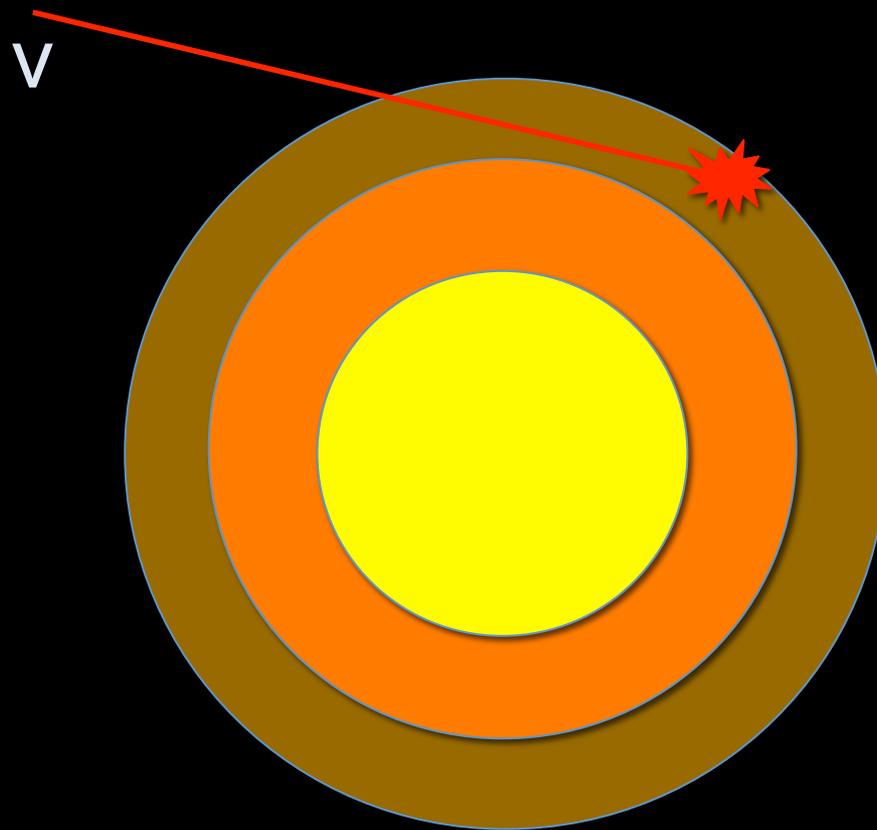
Ke Fang's talk today



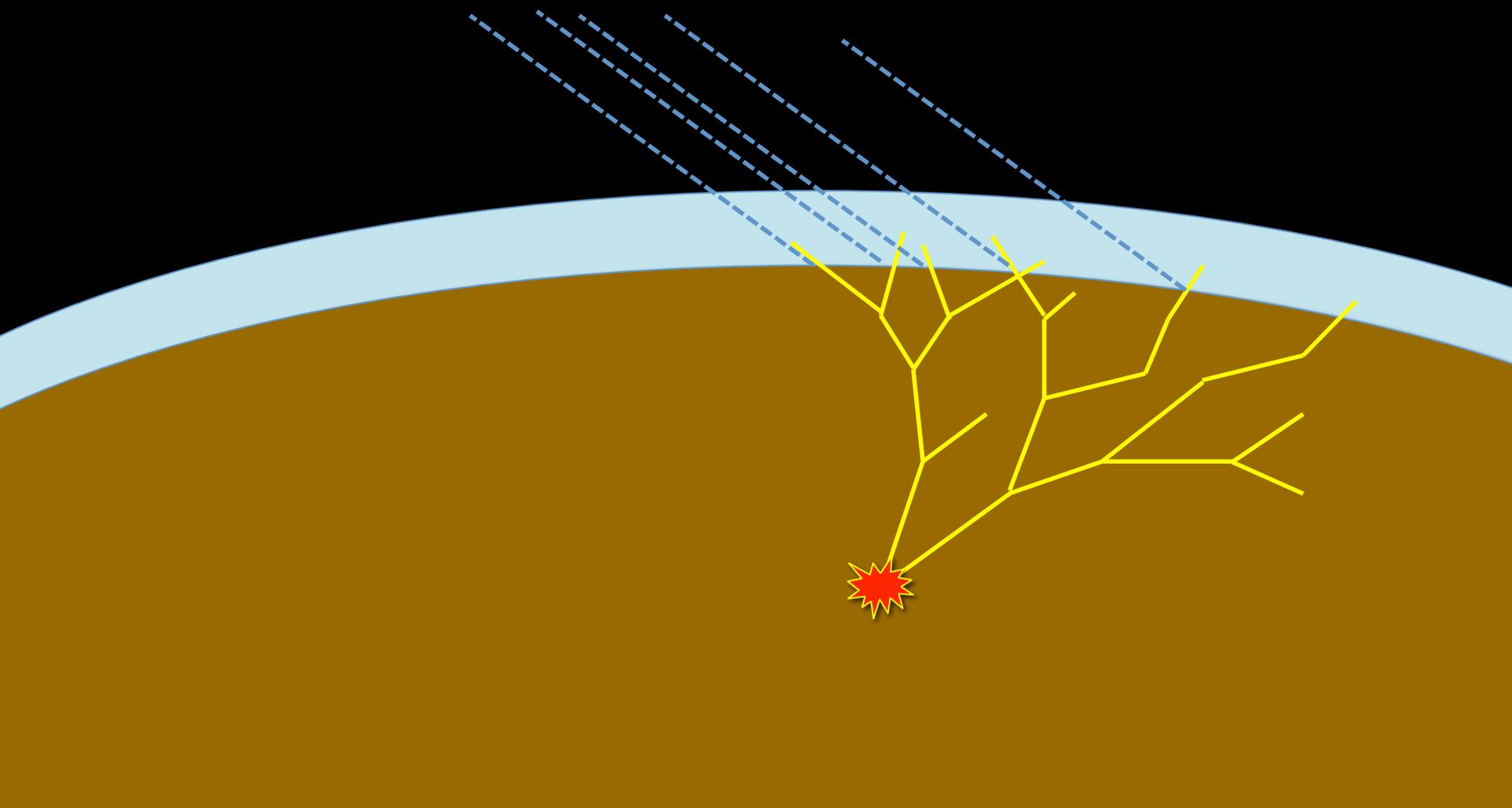
- Dedicated experiment?

- Work in progress to calculate apertures at EeV
    - Does not work for PeV neutrinos

# Neutrino detection



# Neutrino detection

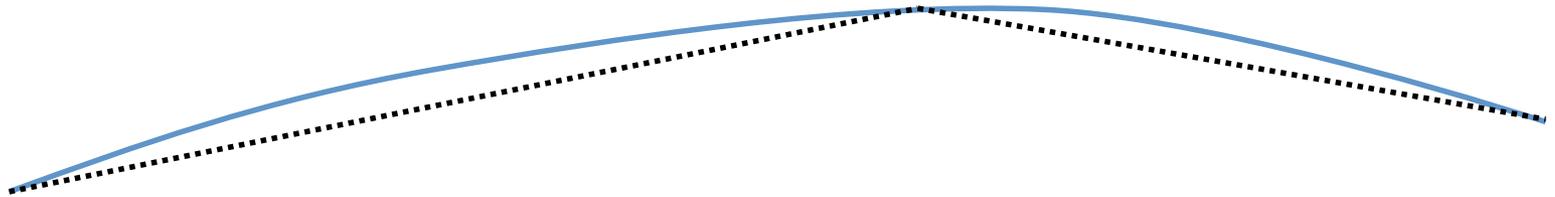


# Calculation of transition radiation

# Calculations: ZHS Monte Carlo

Zas, Halzen, Stanev, PRD 45, 362 (1992)

- Simulate a shower
- Particle trajectories  $\longrightarrow$  line segments

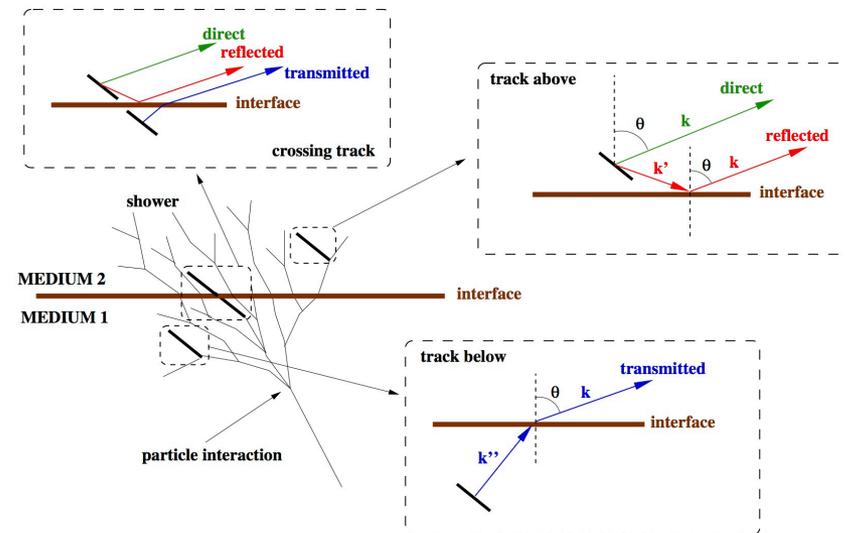


- Can calculate emission from line exactly (far-field)
- Superposition of contributions from all segments

# Calculations: ZHS-TR

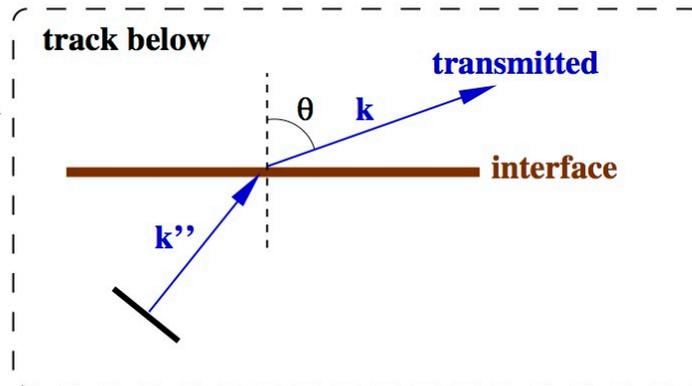
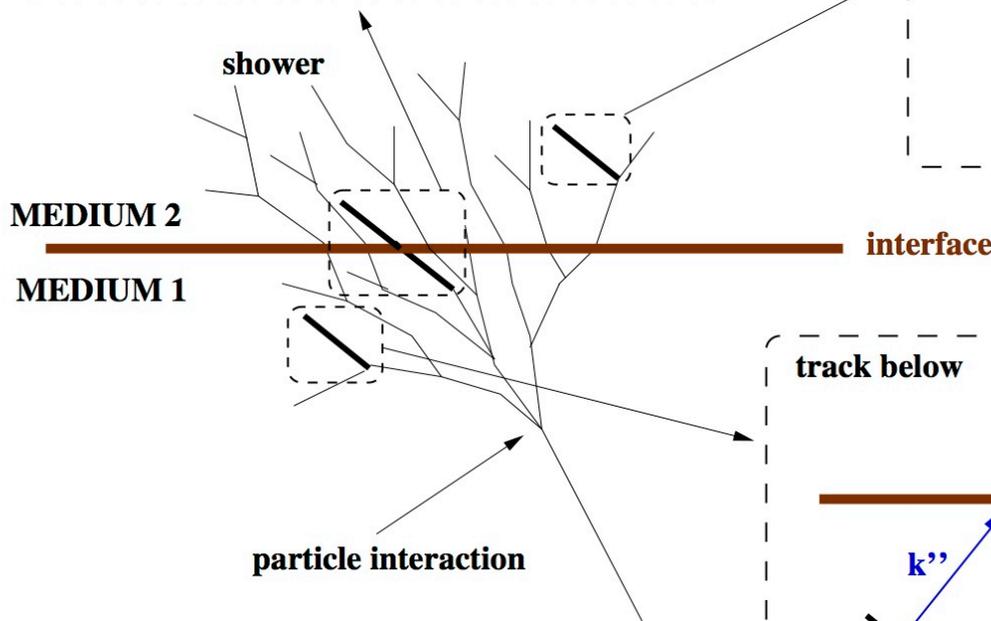
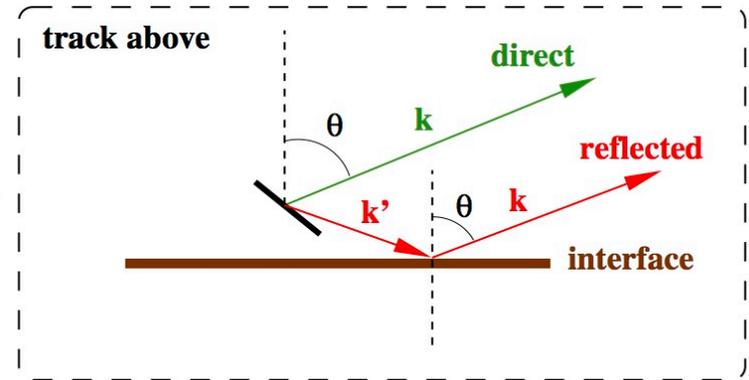
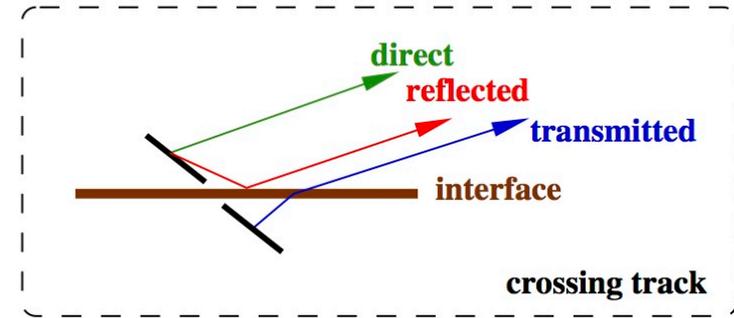
Motloch et al., 1509.01584

- Extra elements because of the boundary:
  - There is refracted and reflected radiation
  - Take Fresnel coefficients into account



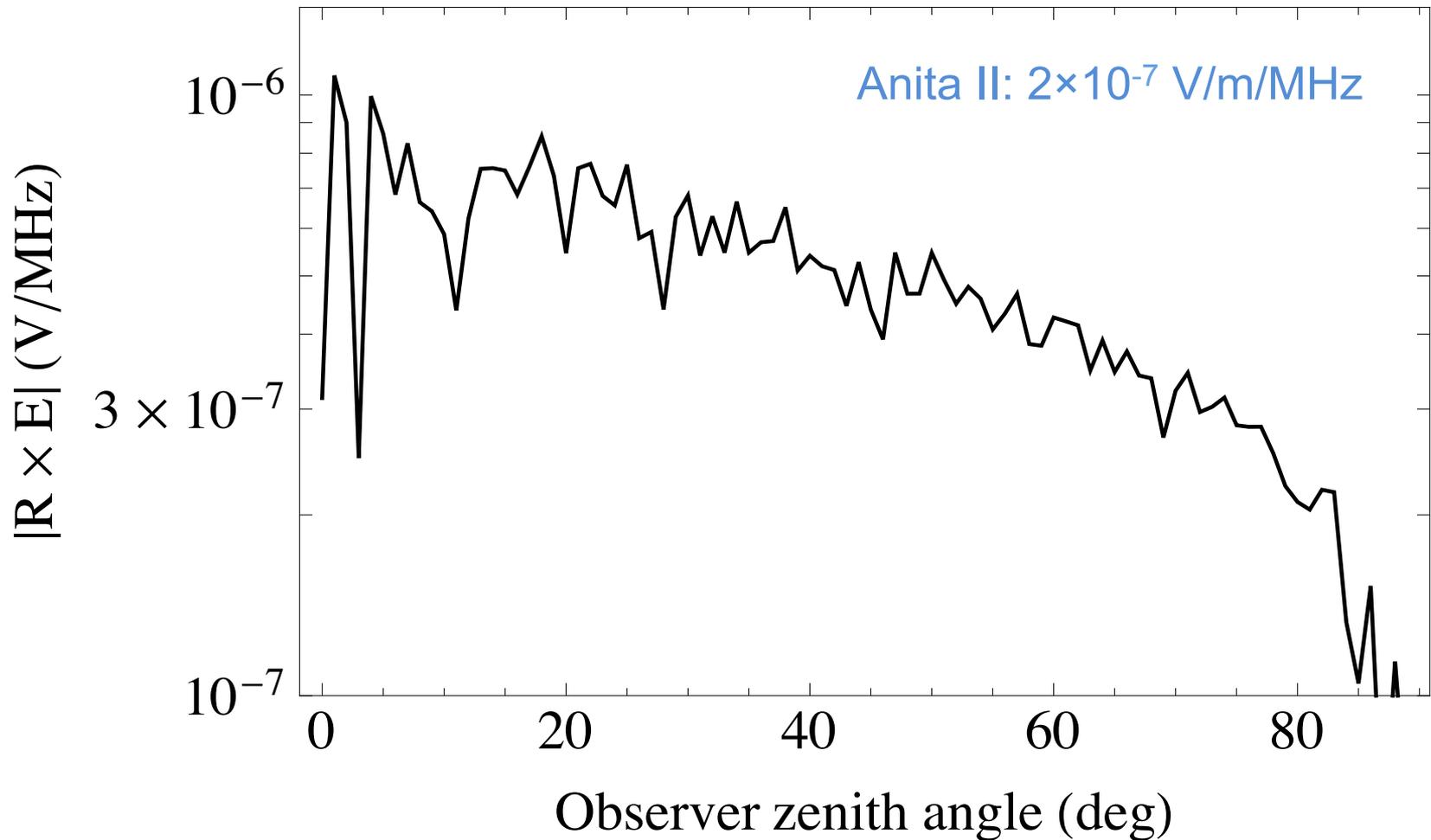
# Calculations: ZHS-TR

Motloch et al., 1509.01584

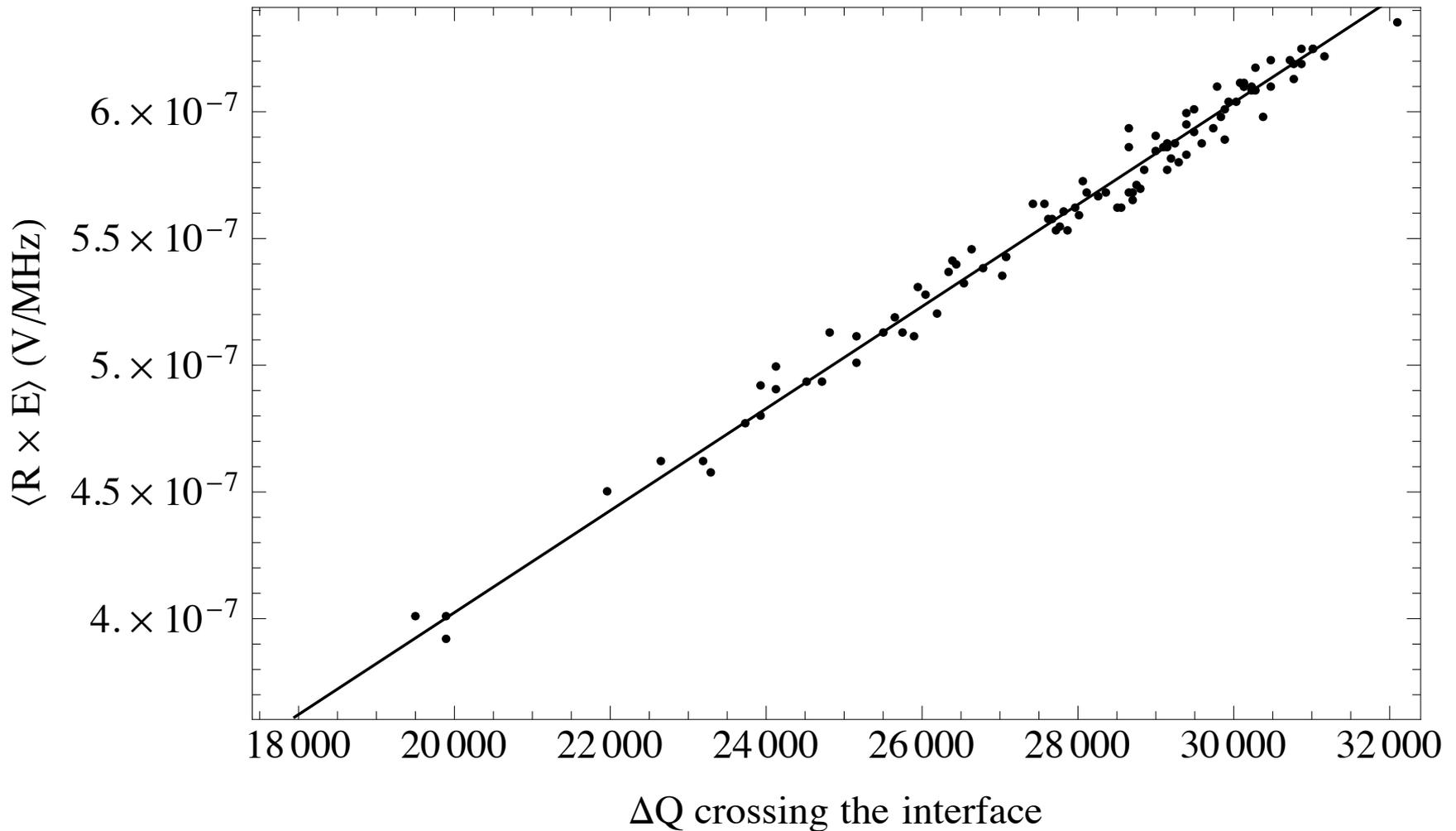


# Results on vertical showers

# Vertical, 0.1 PeV, ice to air, shower max., 1GHz



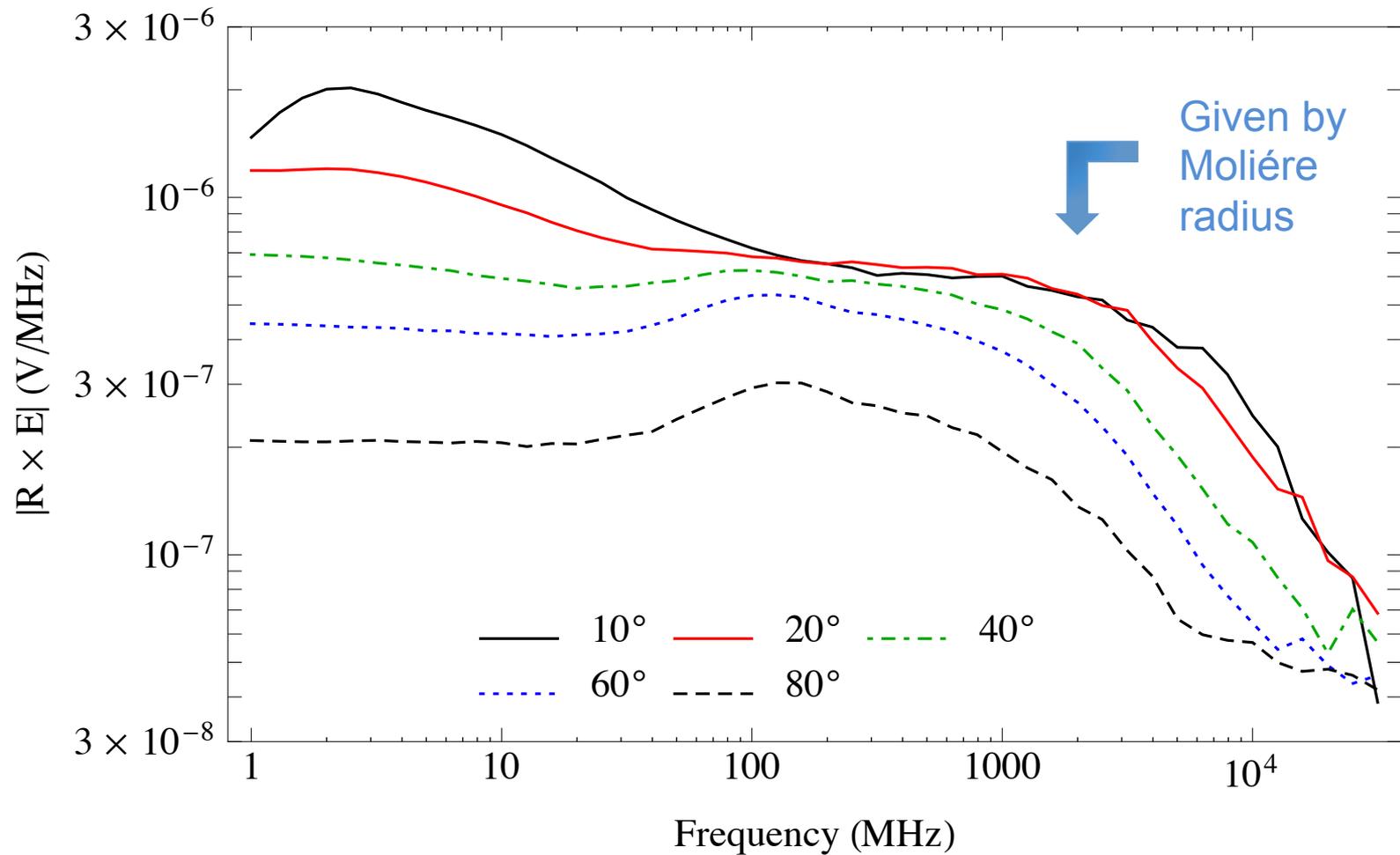
# Scaling with number of crossing particles



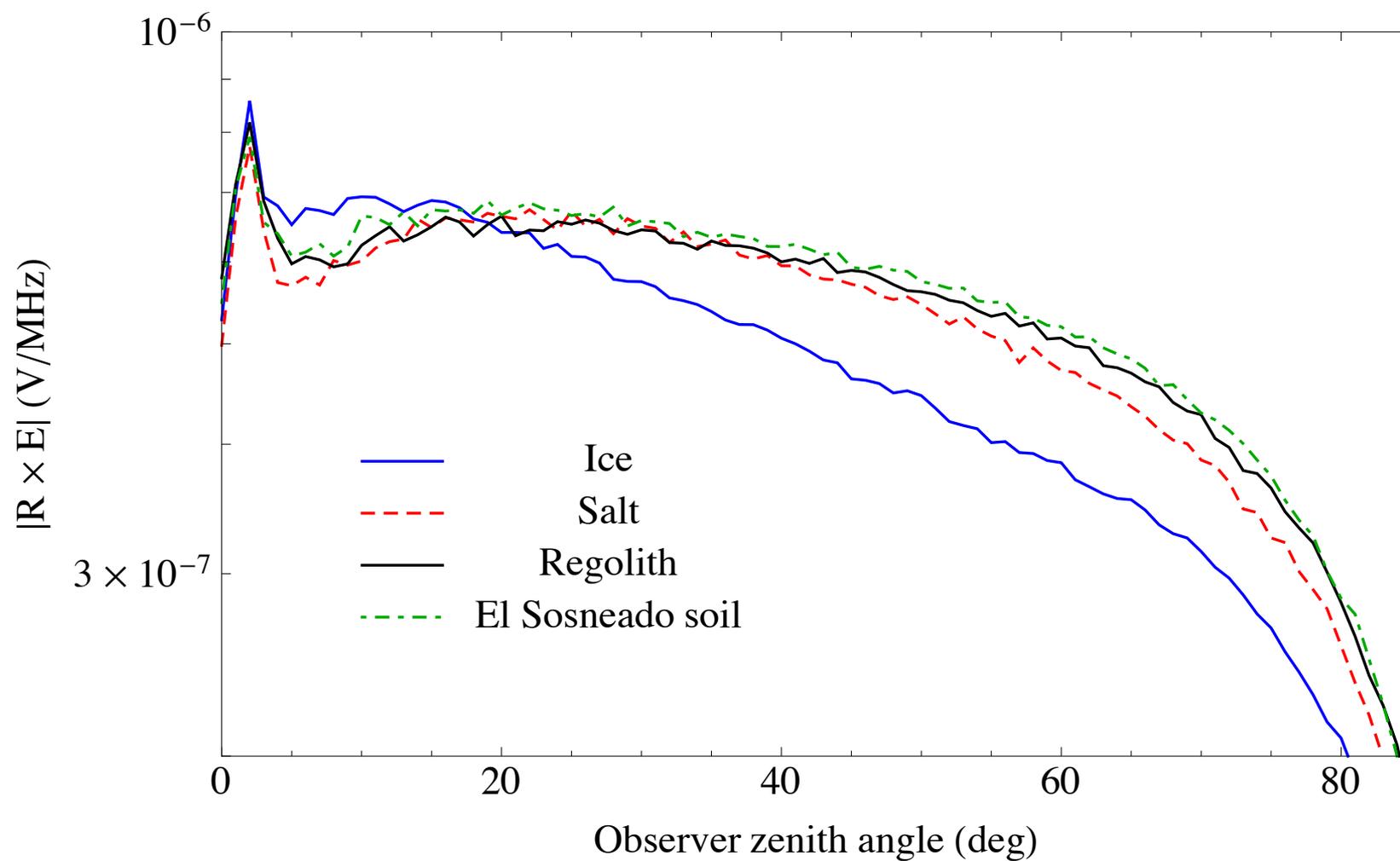
# Scaling with energy

- At high energies LPM effect which elongates the showers:
  - Weaker signal as less particles cross
  - Extended detection volume
- Signal at EeV only roughly 2400× stronger than at 100 TeV
  - Maximum observed  $|R \times E|$  was 1.5 mV/MHz

# Frequency spectrum (coherent)

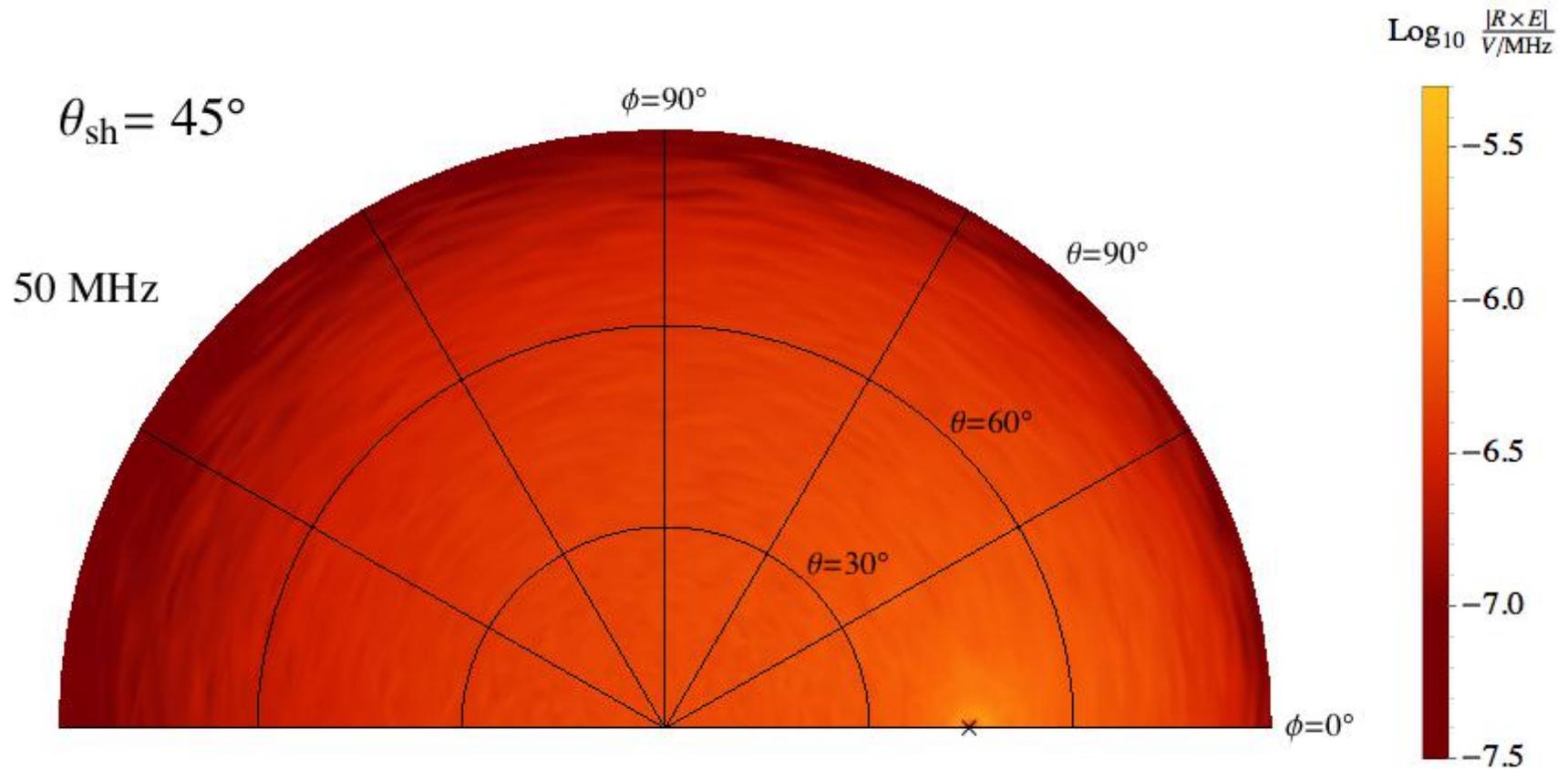


# Different media at 1 GHz

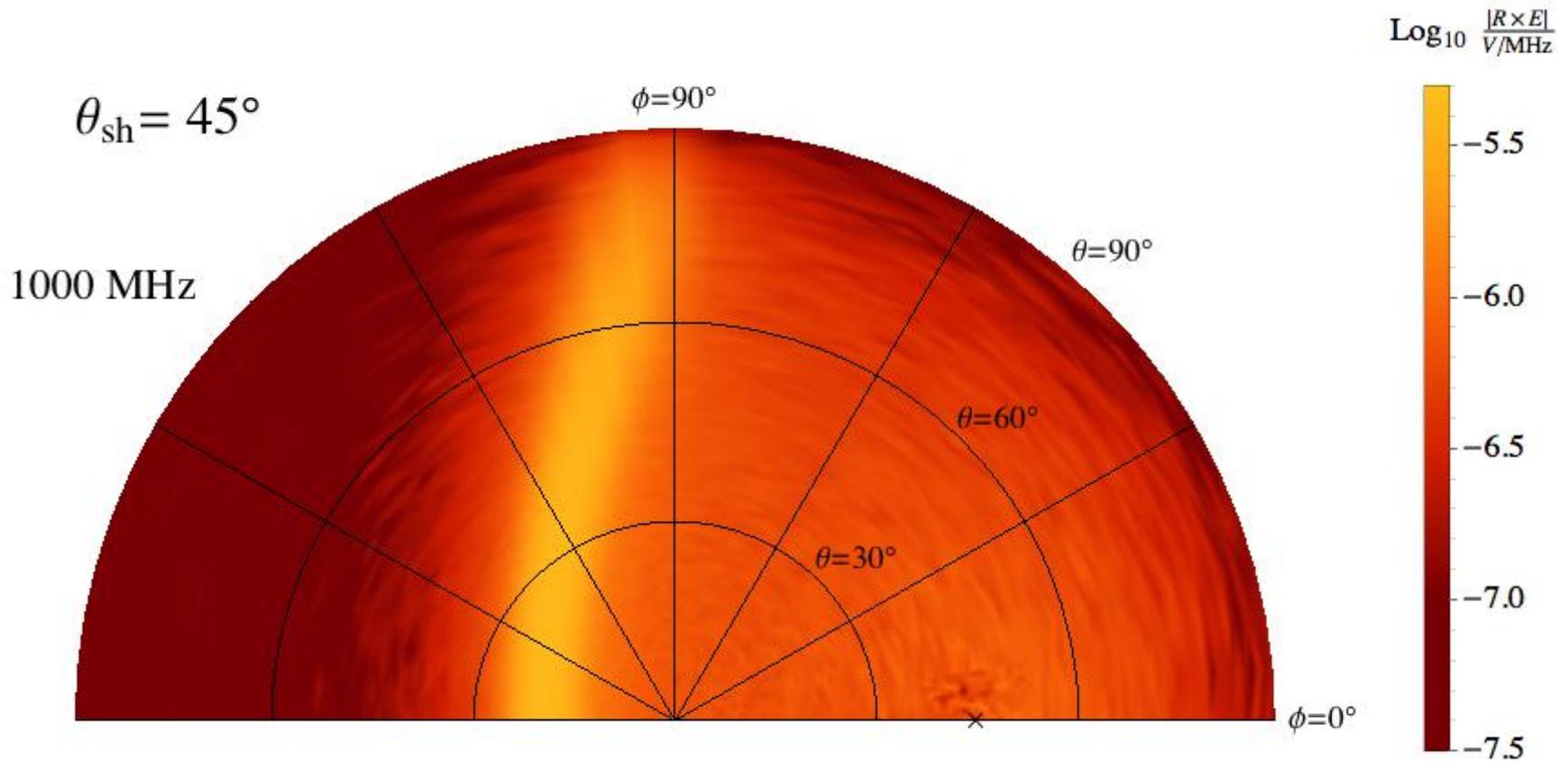


# Results on inclined showers

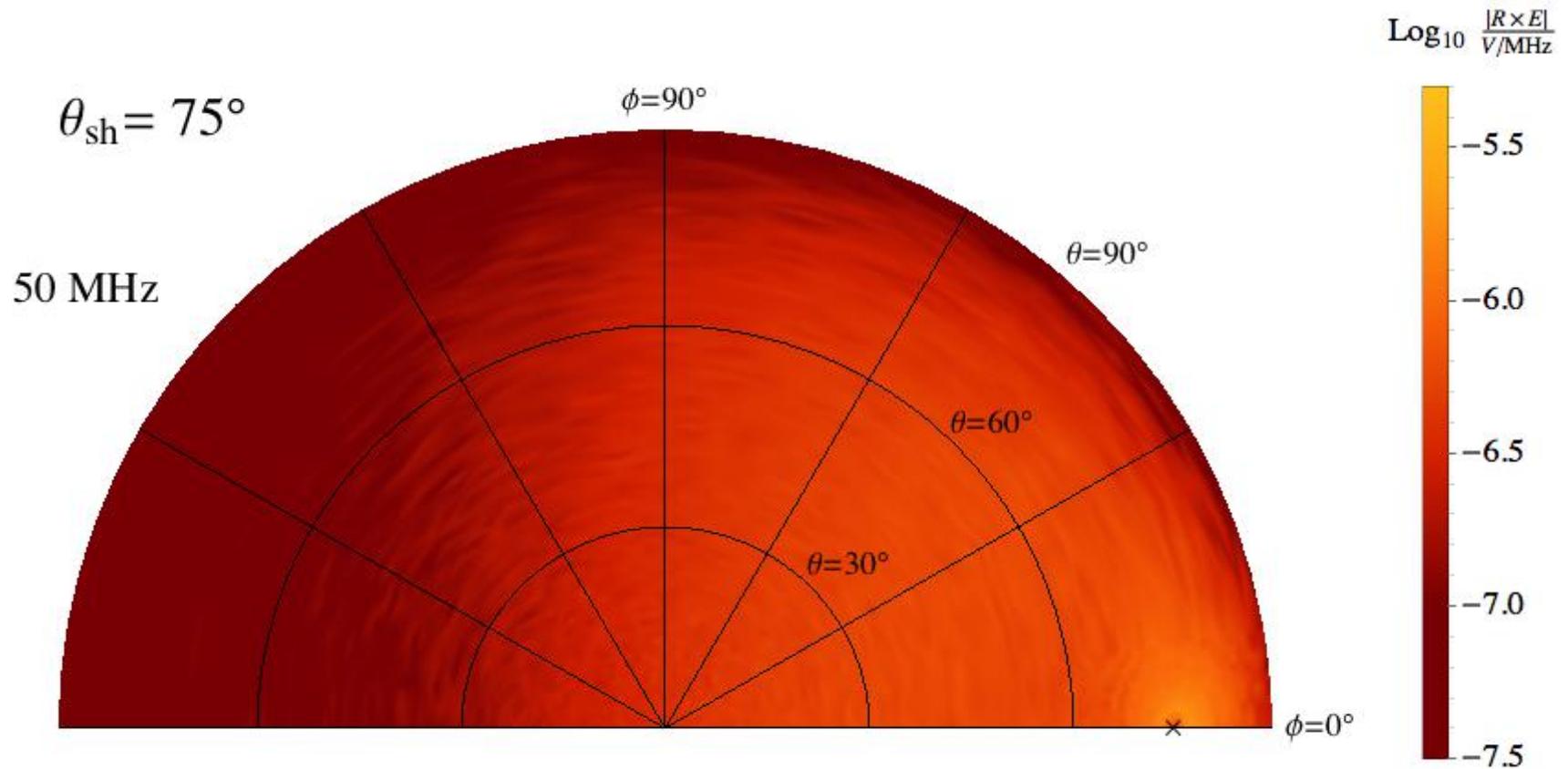
# 45° inclined, 0.1 PeV, ice to air, sh. max., 50 MHz



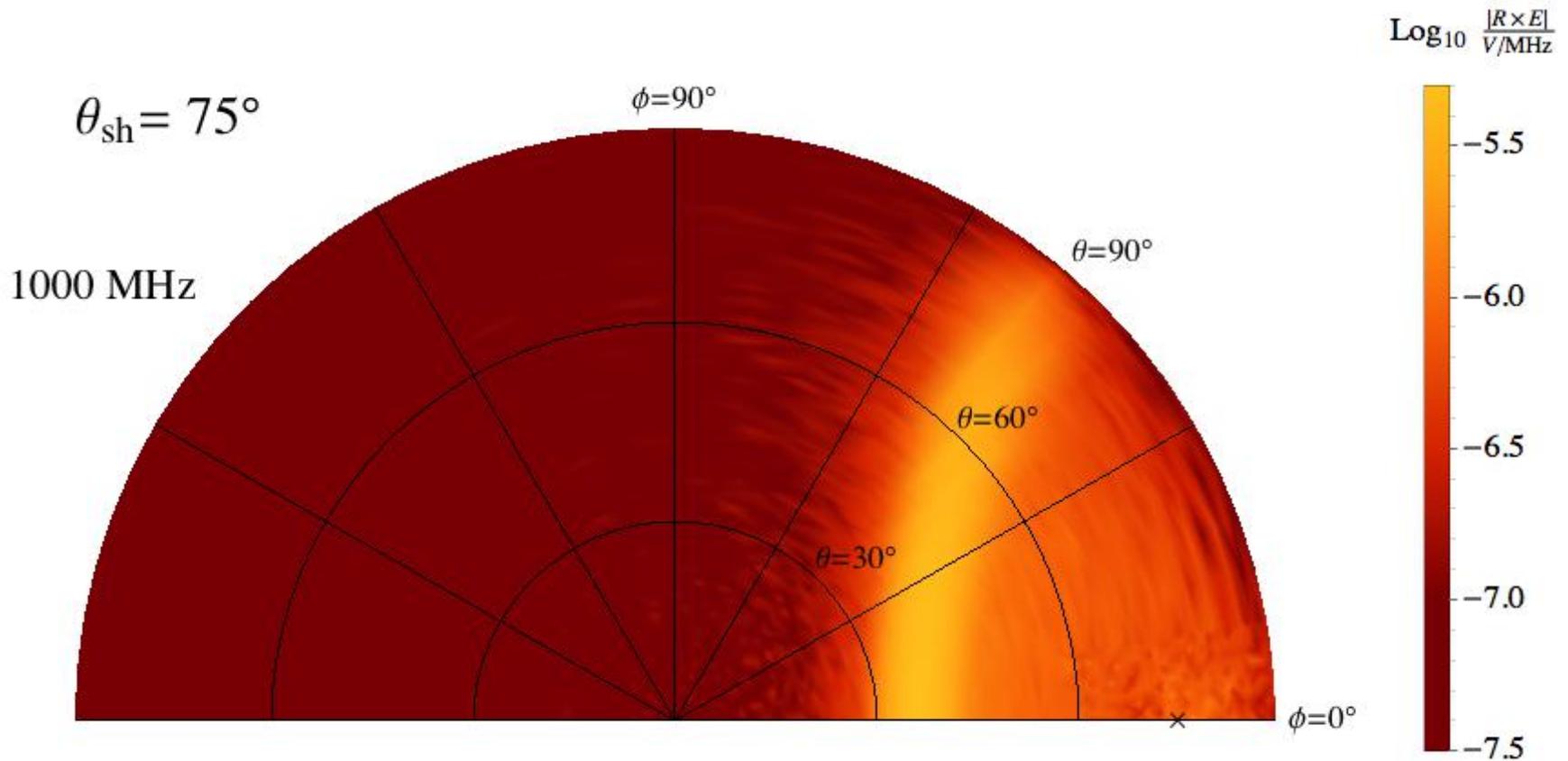
# 45° inclined, 0.1 PeV, ice to air, sh. max., 1 GHz



# 75° inclined, 0.1 PeV, ice to air, sh. max., 50 MHz



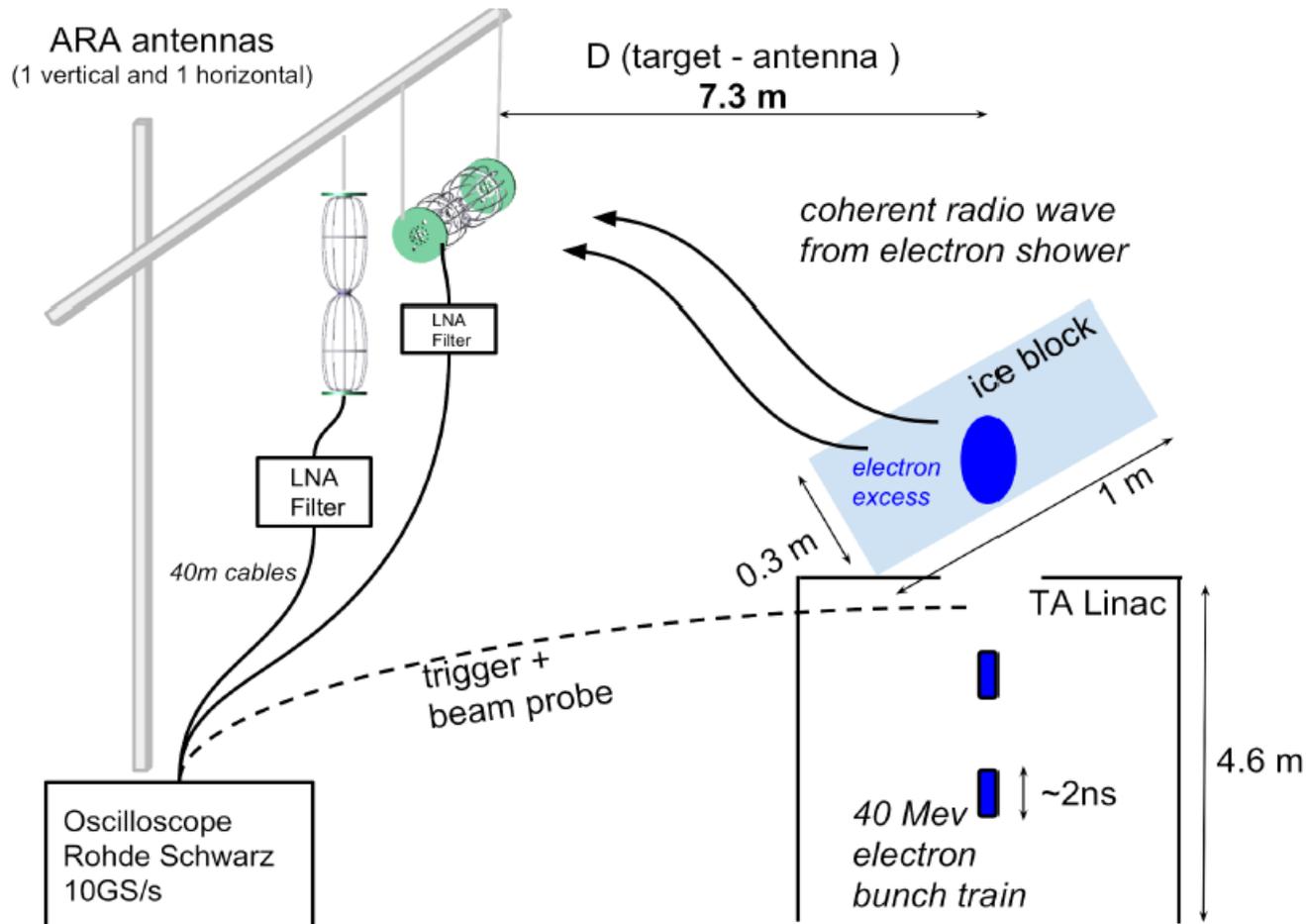
# 75° inclined, 0.1 PeV, ice to air, sh. max., 1 GHz



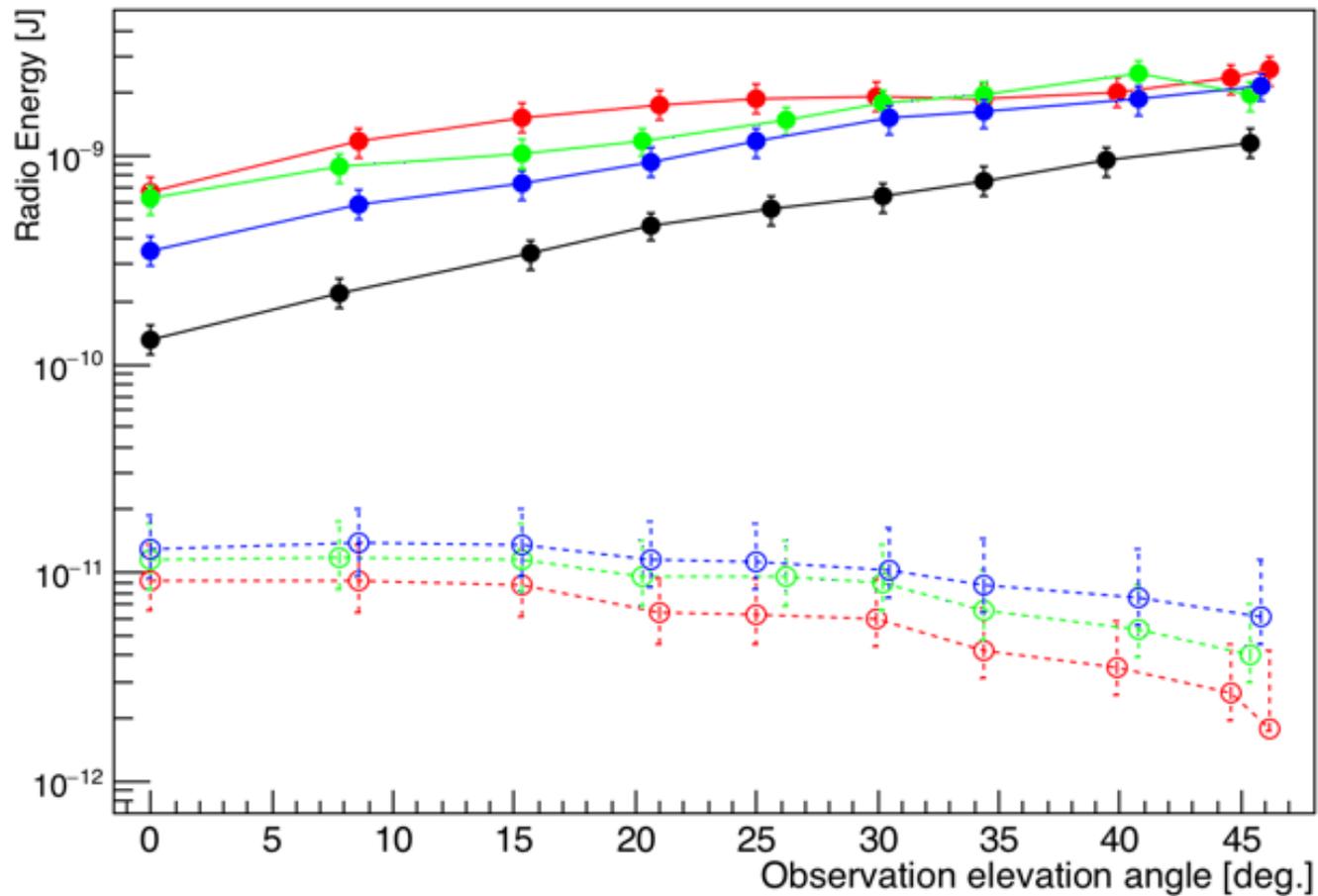
ARA

# ARA: Calibration

ICRC 2015: Gaïor et al. (1135)  
Mase et al. (1136)



# ARA: Theory $\neq$ experiment



# ARA: Development

- Need to include transition radiation, sudden appearance signal
- Still discrepancies – the shape of the signal correct, magnitude factor 4 too low
- Reflections?

# Conclusions

- Developed a way to calculate full radio emission from showers crossing between two materials
- Properties of vertical showers studied extensively – wide angular distribution, coherence up to 1 GHz, scaling with number of crossing particles
- Smaller angular range for highly inclined showers
- TR might be interesting for applications to neutrino detection (and is very interesting for ARA collaboration)

Thank you for your attention.

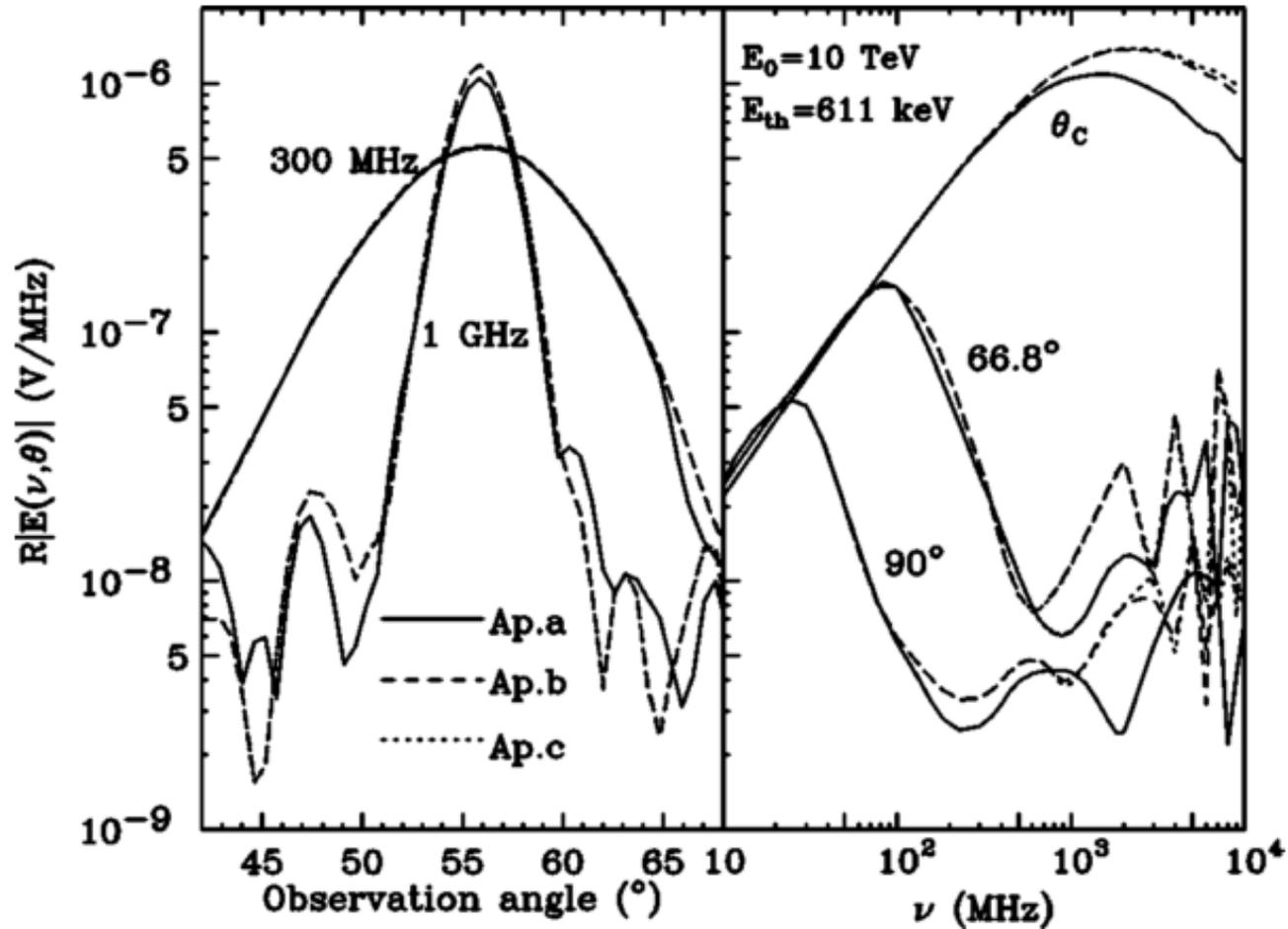
Thank you organizers for inviting me.

# Extras

# ZHS formula

$$\mathbf{E}(\omega, \mathbf{x}) = \frac{e\mu_r}{2\pi\epsilon_0 c^2} i\omega \frac{e^{ikR}}{R} e^{i(\omega - \mathbf{k} \cdot \mathbf{v})t_1} \mathbf{v}_\perp \left[ \frac{e^{i(\omega - \mathbf{k} \cdot \mathbf{v})\delta t} - 1}{i(\omega - \mathbf{k} \cdot \mathbf{v})} \right]$$

# Cherenkov angular distribution



# Where are contributions coming from?

