Simulation of radio signals from cosmic-ray cascades in air and ice as observed by in-ice Askaryan radio detectors

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VRIJE UNIVERSITEIT BRUSSEL

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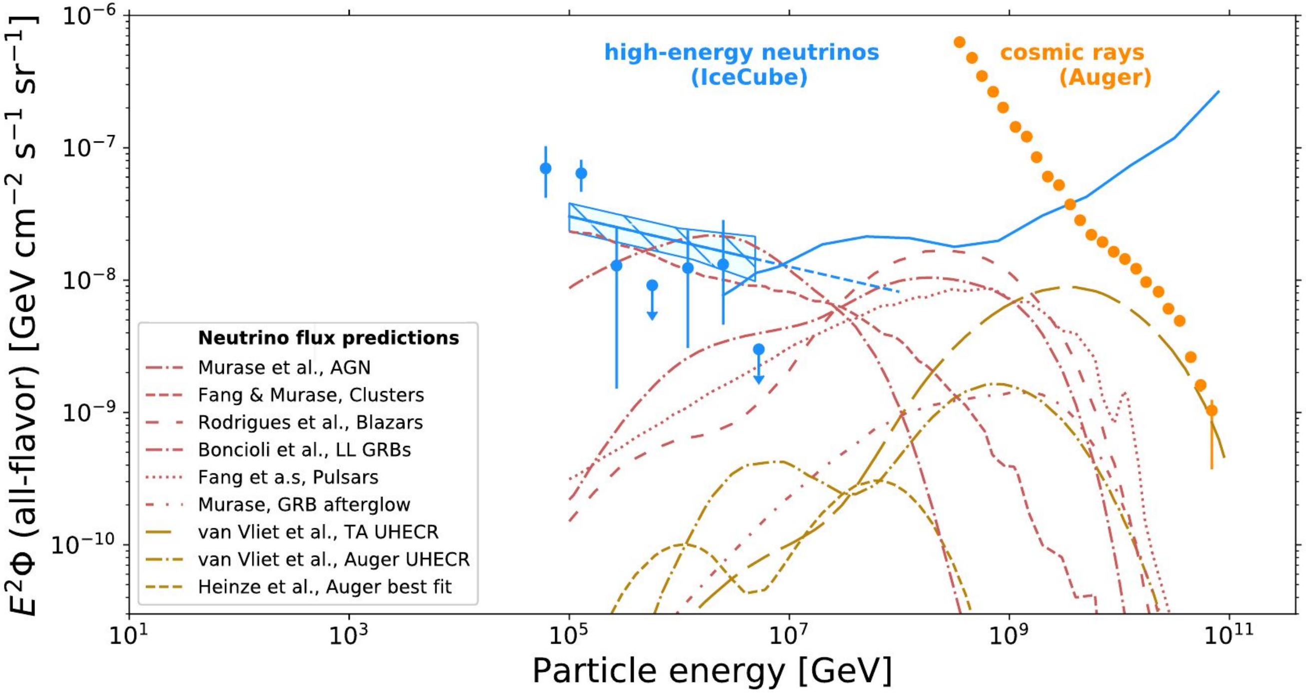
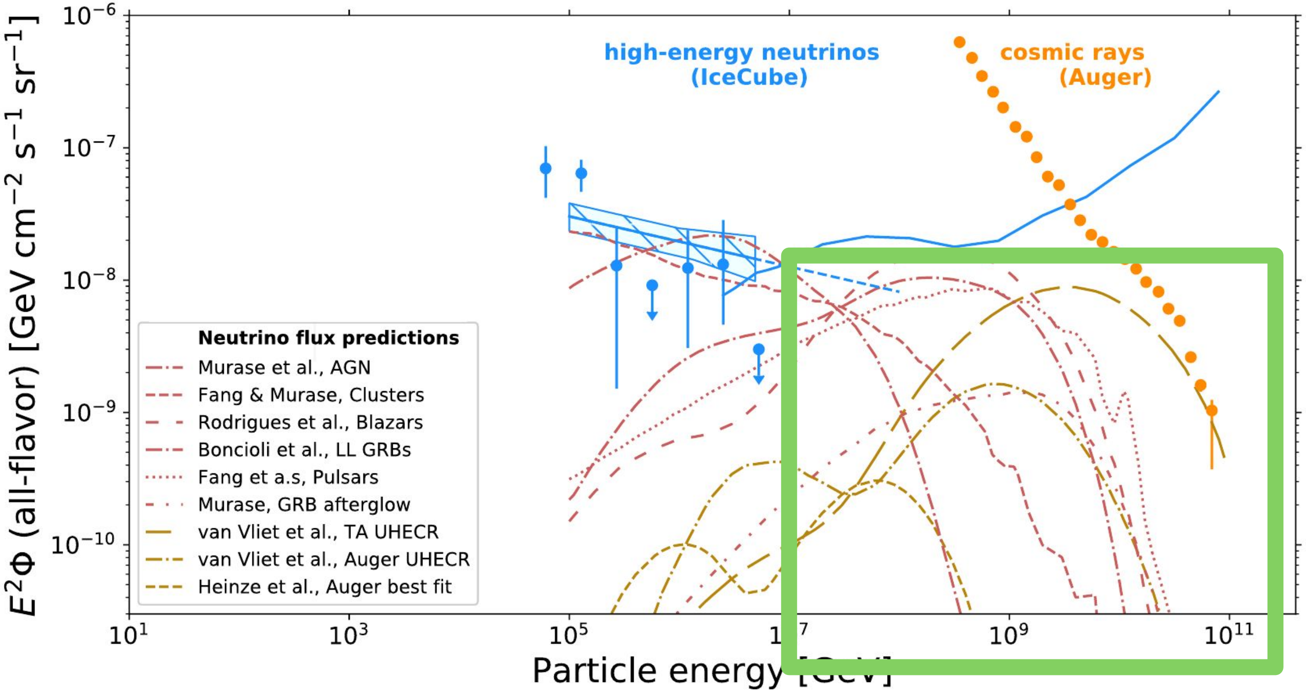
Introduction



From "Design and Sensitivity of the Radio Neutrino Observatory in Greenland (RNO-G)" by the RNO-G collaboration

Introduction



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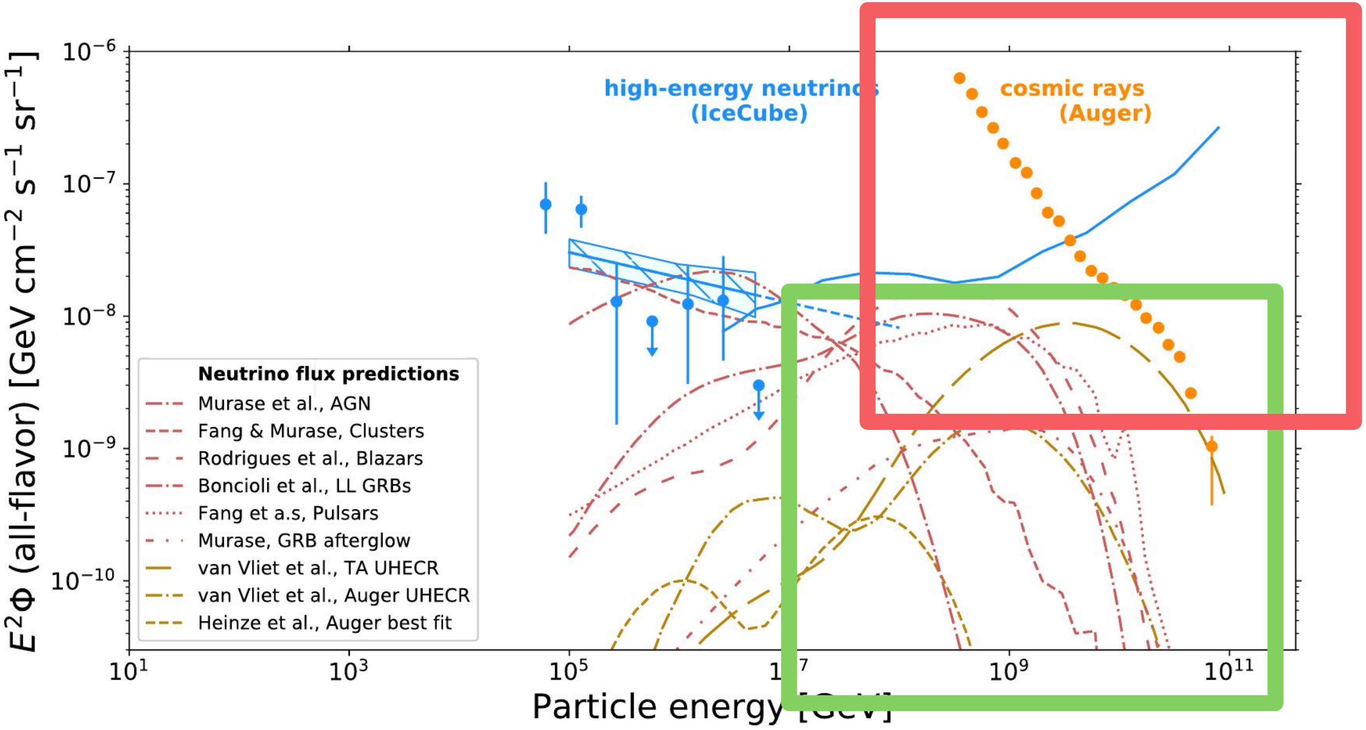
If in-ice radio arrays can detect this…

Introduction



...they should definitely be able to see this!

If in-ice radio arrays can detect this...

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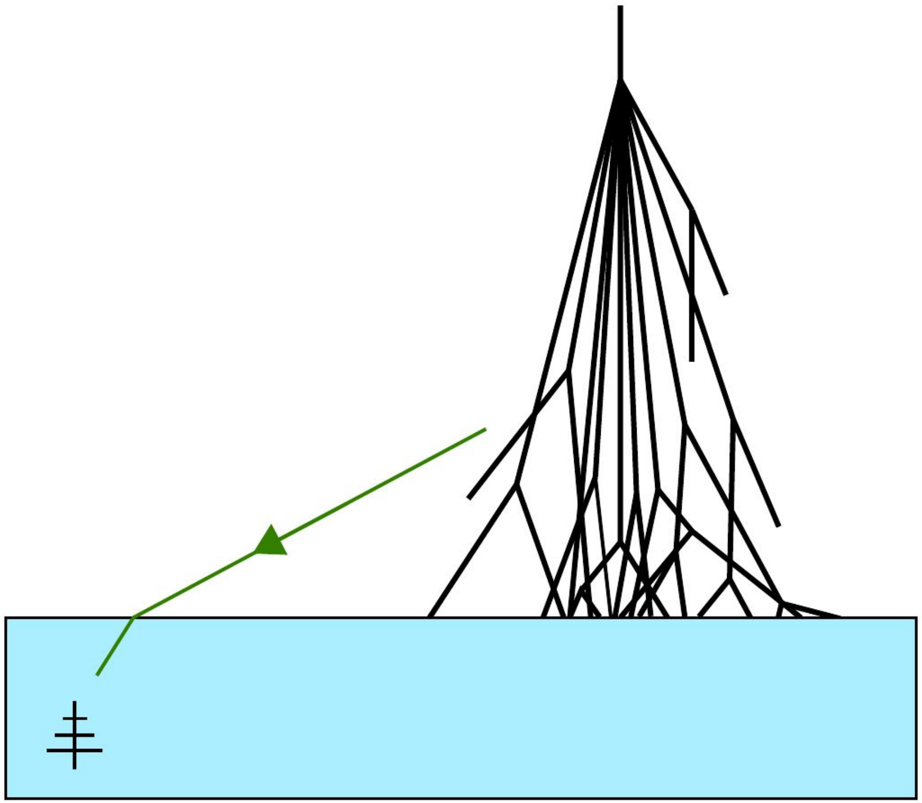
What to expect

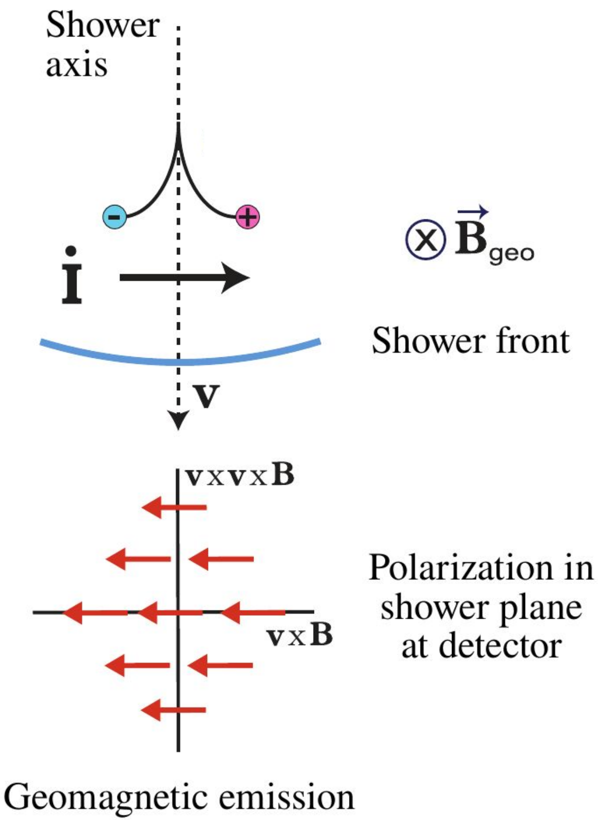
Radio emission during the cascade development **in air**



What to expect

Radio emission during the cascade development **in air**

- Geomagnetic emission

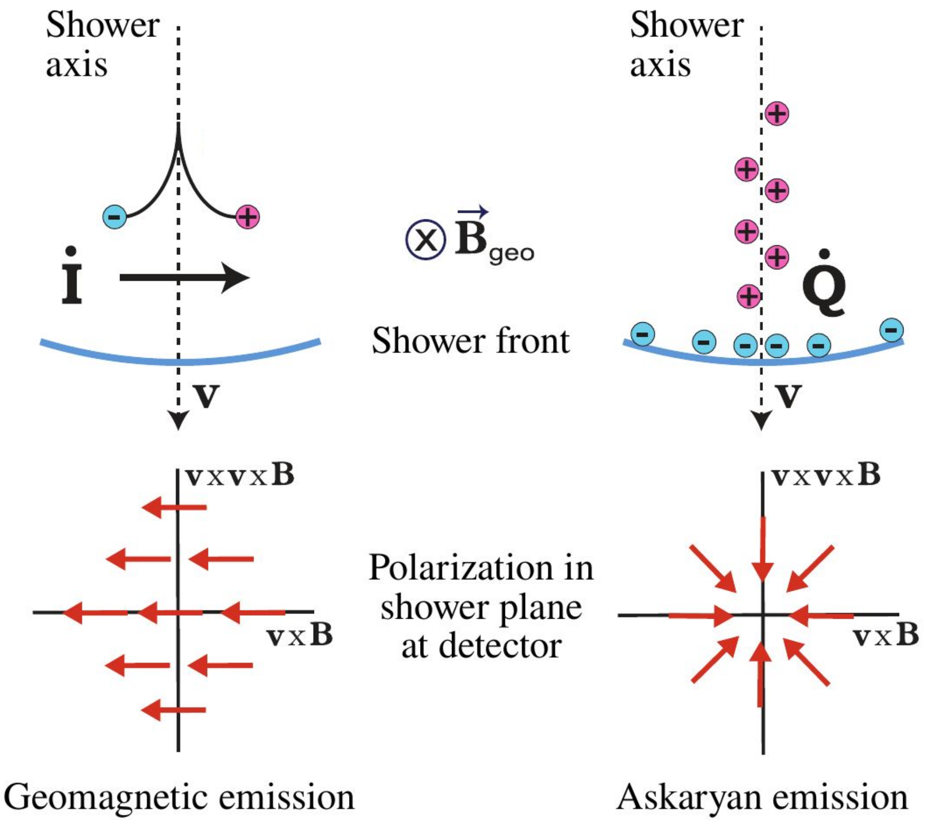


From "Status of the radio technique for cosmic-ray induced air showers" by F. Schröder

What to expect

Radio emission during the cascade development **in air**

- Geomagnetic emission
- Askaryan emission



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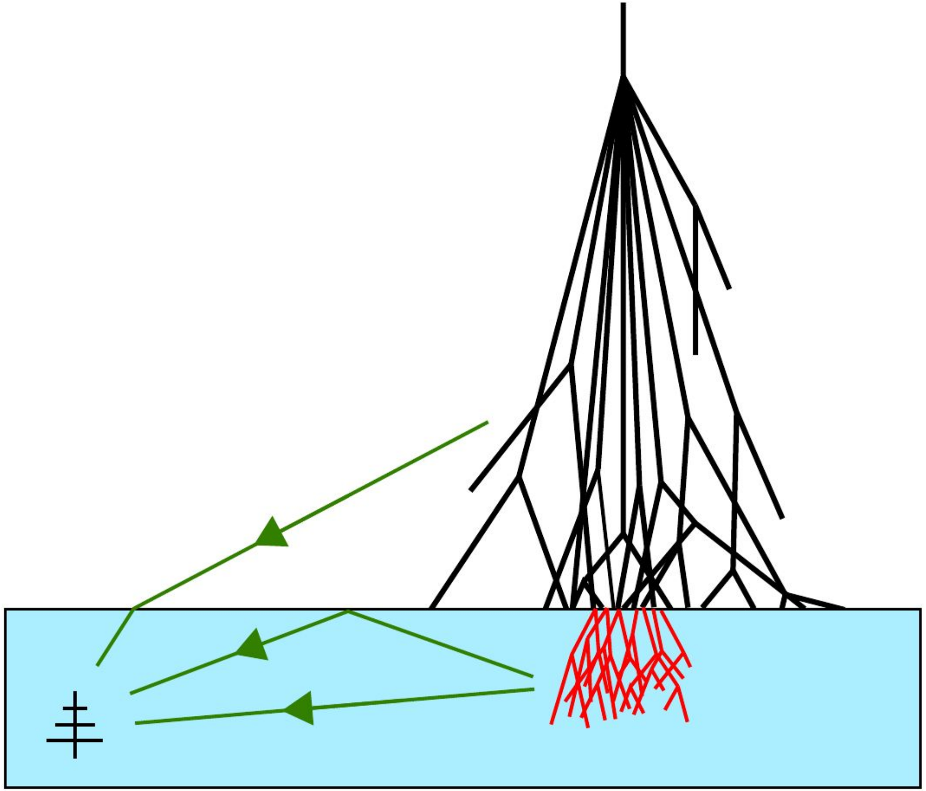
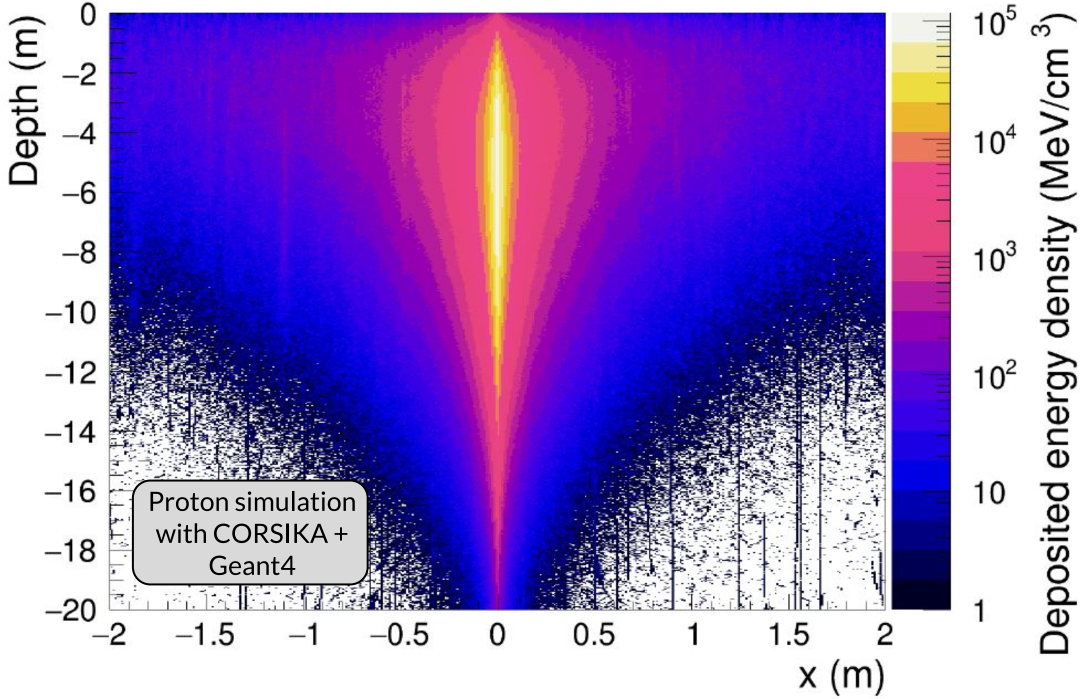
Radio emission during the cascade development **in ice**



What to expect

Energy deposited in the ice by 10^{17} eV proton shower at 2.4 km asl



From "Simulation of in-ice cosmic ray air shower induced particle cascades" by S. De Kockere et al.

What to expect

Radio emission during the cascade development **in air**

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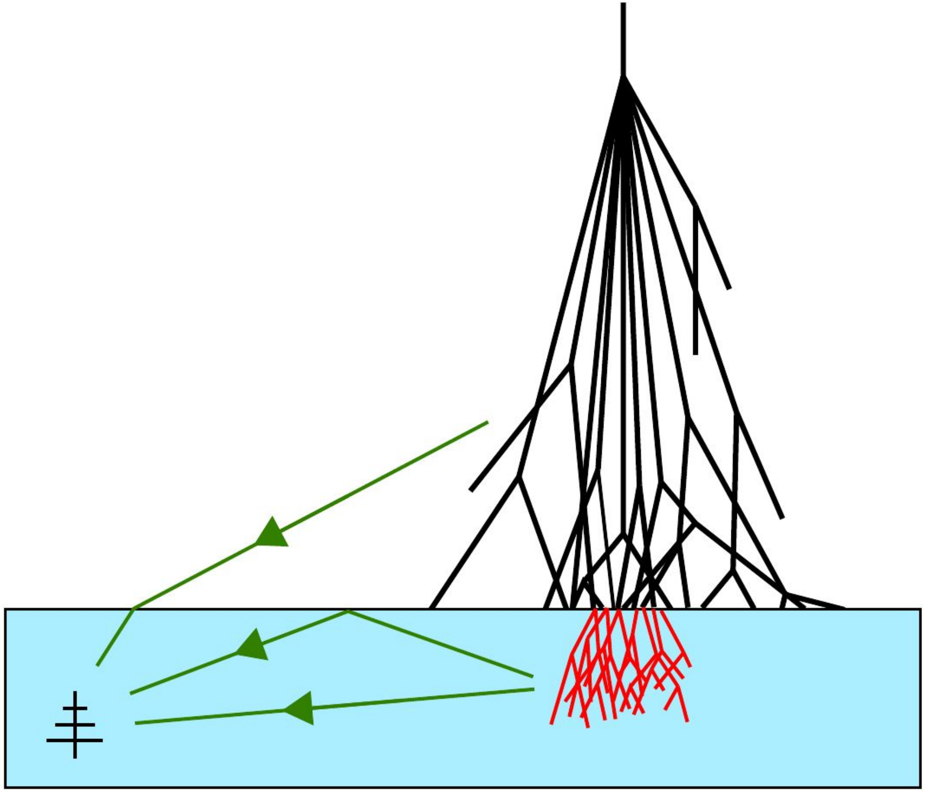
- Askaryan emission

Radio emission during the cascade development **in ice**

- Askaryan emission
- Neutrino-like!



What to expect

Radio emission during the cascade development **in air**

- Geomagnetic emission
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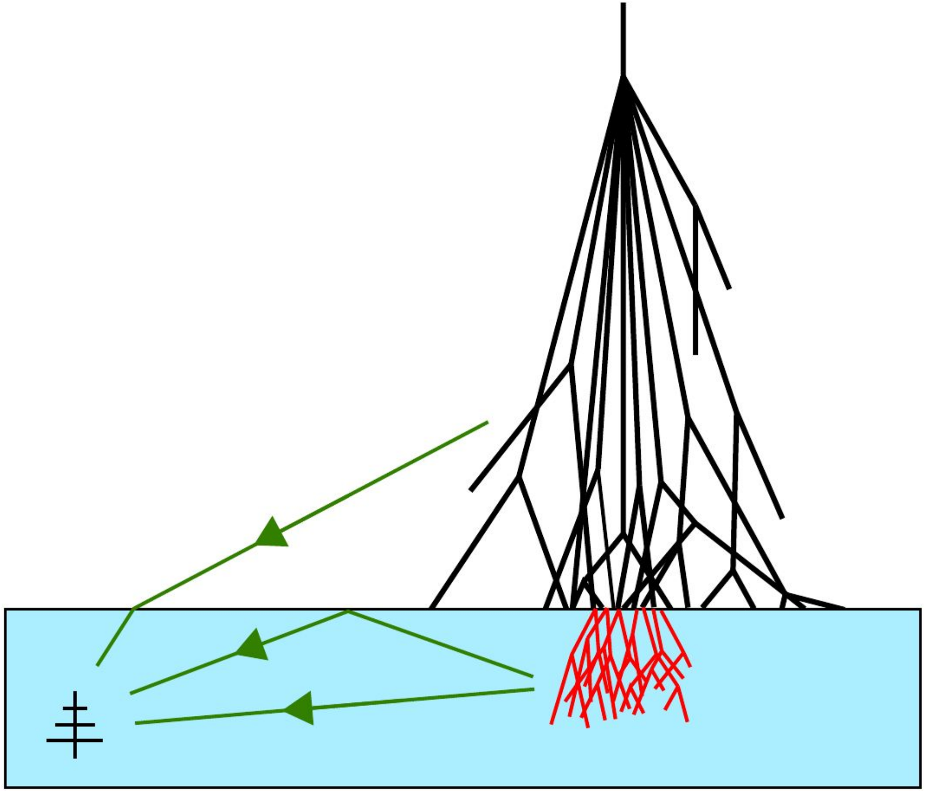
Radio emission during the cascade development **in ice**

- Askaryan emission
- Neutrino-like!

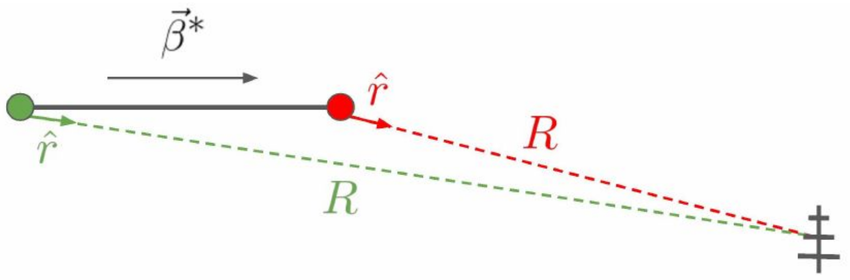
Important to understand, for in-nature **proof-of-concept** and **background identification**



Framework overview

Goal: simulation of radio emission from a full cosmic-ray particle cascade for in-ice detectors

$$\vec{E}_{\pm}(\vec{x},t) = \pm \frac{1}{\Delta t}\frac{q}{c}\left(\frac{\hat{r}\times[\hat{r}\times\vec{\beta}^*]}{|1-n\vec{\beta}^*\cdot\hat{r}|R}\right)$$



Monte-Carlo simulation of shower development

- In air: **CORSIKA** 7.7500
- In ice: **Geant4** 10.5

Calculation of radio emission during the cascade development using **Endpoint formalism**

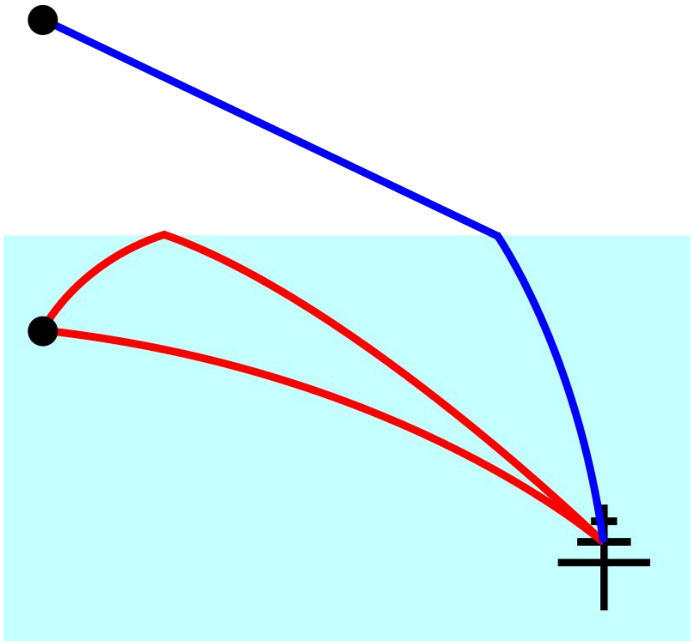
- In air: CoREAS
- In ice: based on code for T-510 experiment (radio emission from charged particle shower in high-density polyethylene at SLAC)

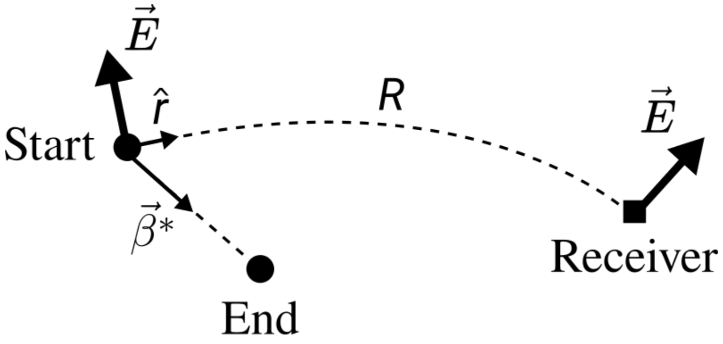
Framework overview

$$\vec{E}_{\pm}(\vec{x},t) = \pm\frac{1}{\Delta t}\frac{q}{c}\left(\frac{\hat{r}\times[\hat{r}\times\vec{\beta}^*]}{|1-n\vec{\beta}^*\cdot\hat{r}|R}\right)$$

Endpoint formalism modified for **ray-racing**:

- Air-to-ice transition (sudden change of index of refraction)
- In-ice propagation (changing index of refraction on short length-scales)

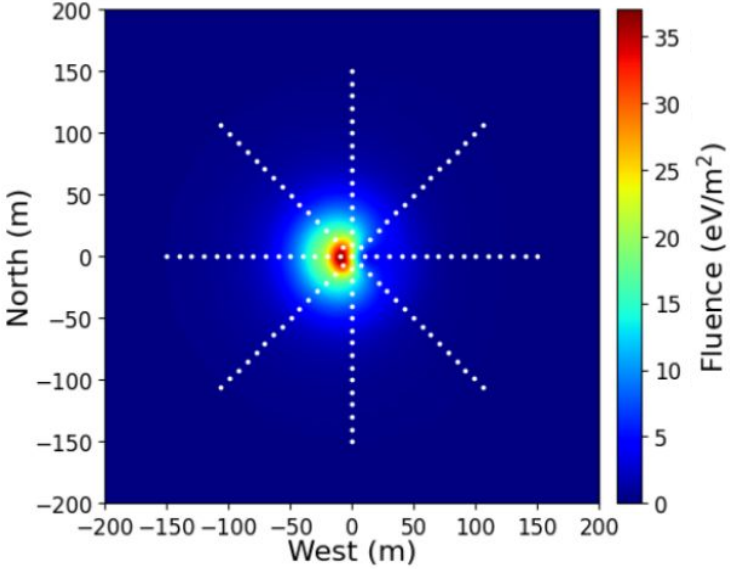


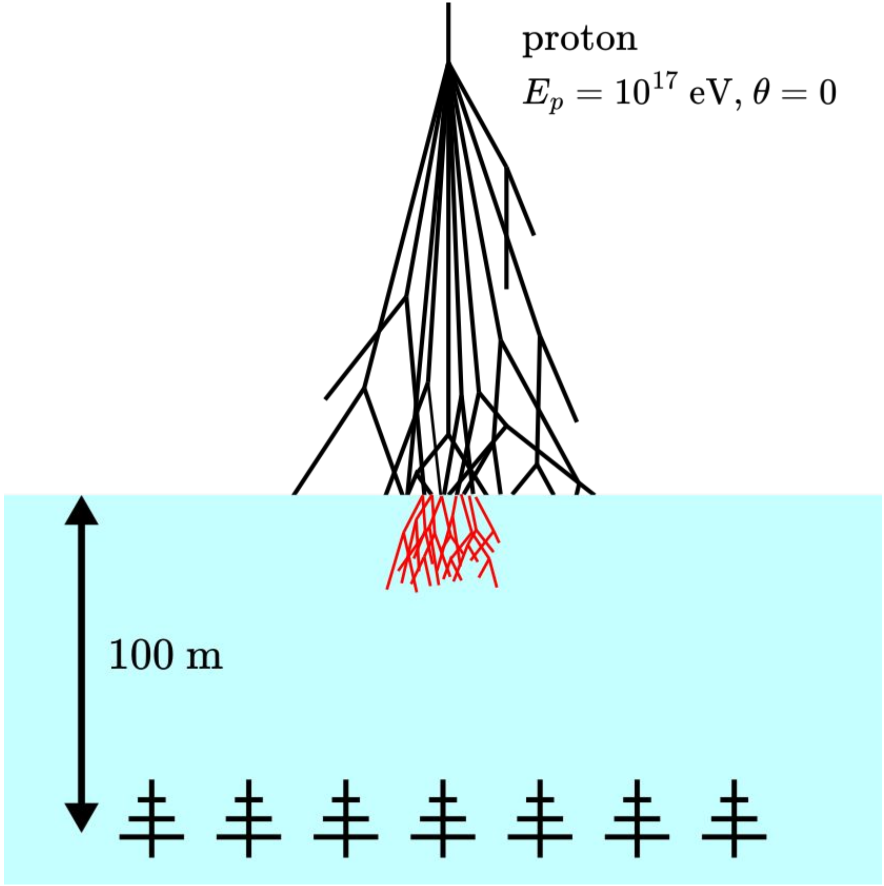


First results

$$\mathcal{F} = \epsilon_0 c_0 \int E^2(t)\mathrm{d}t$$

In-air emission





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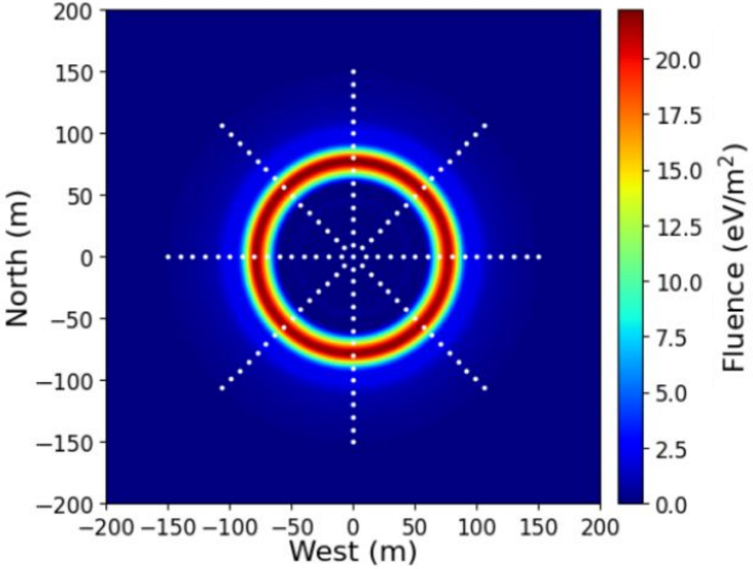
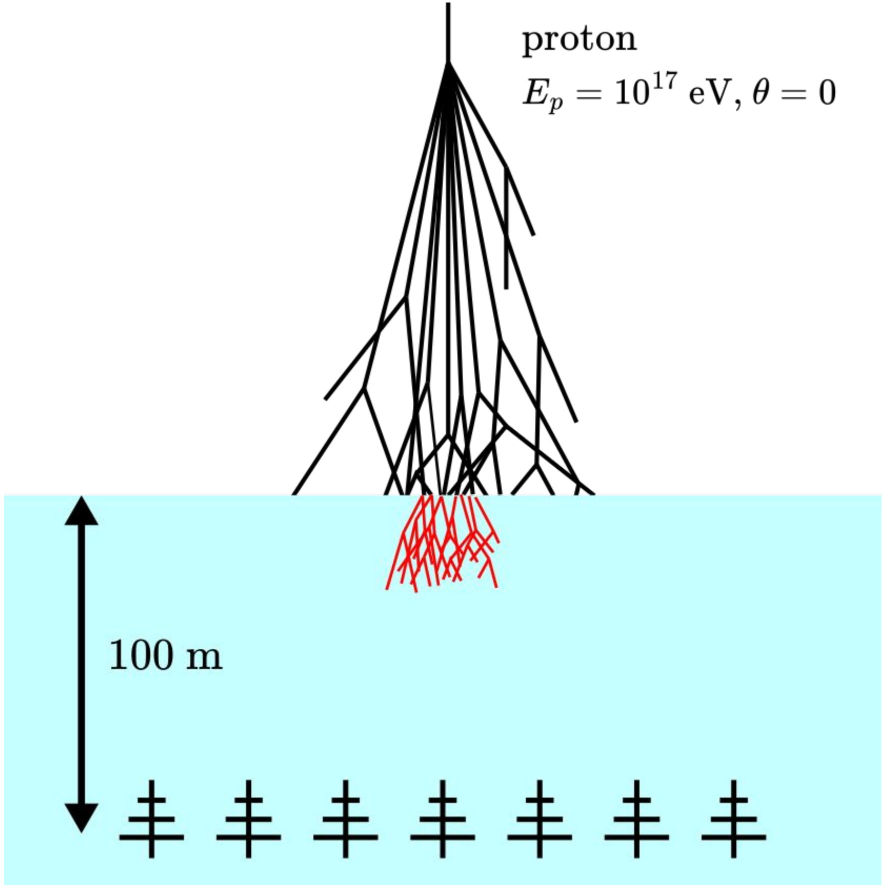
In-ice emission





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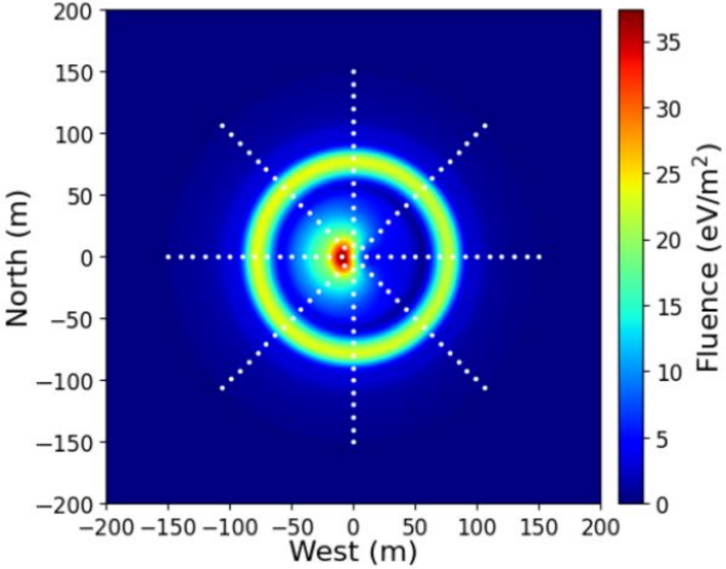
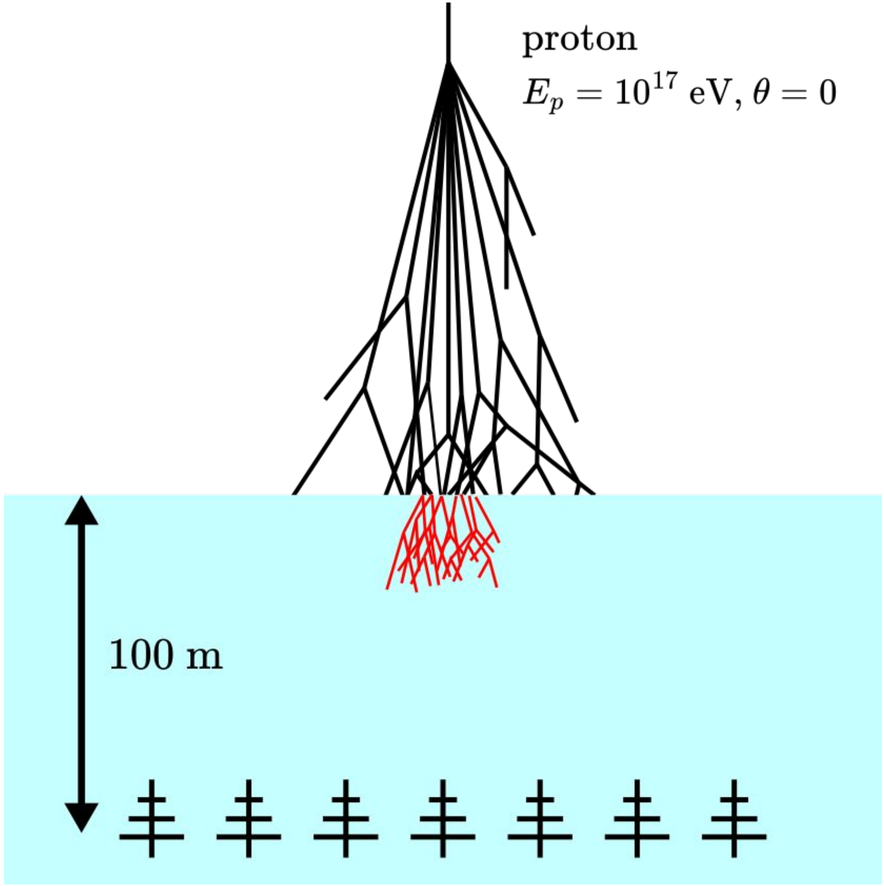
Total emission





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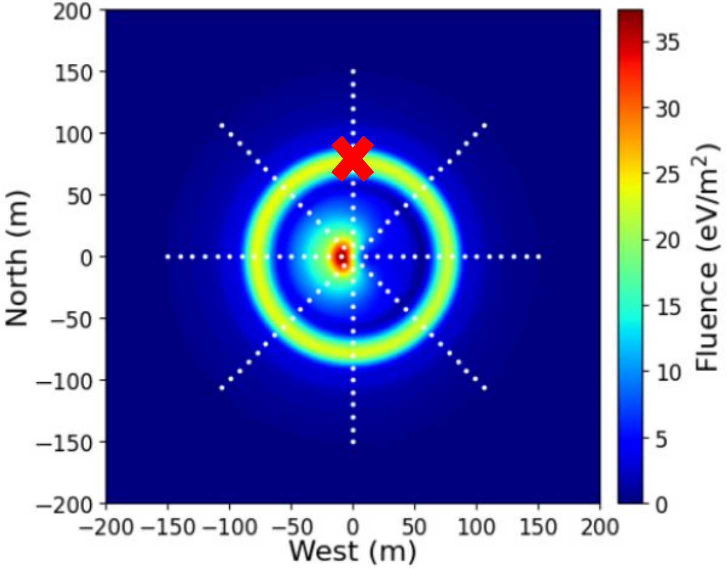
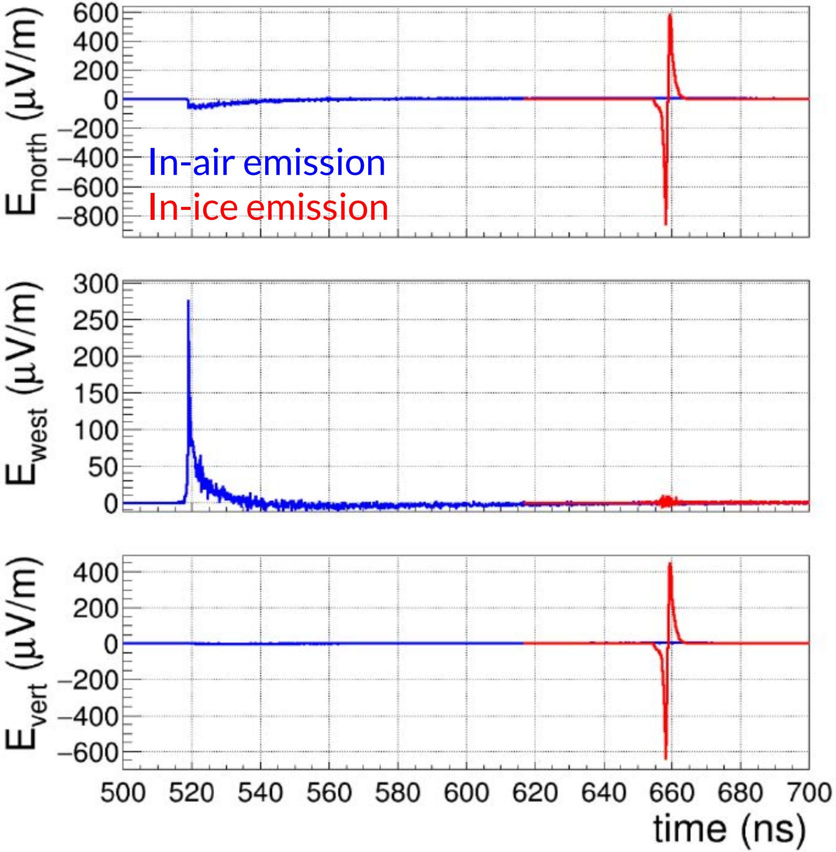


Electric fields at location in footprint indicated by the cross



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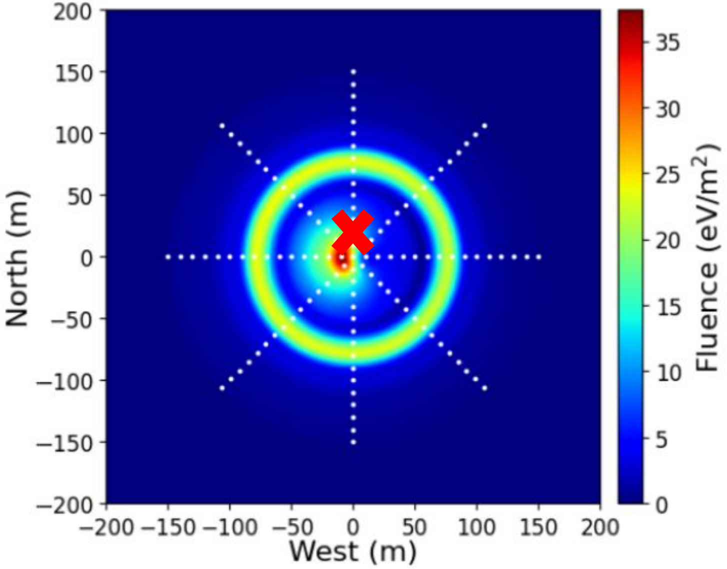

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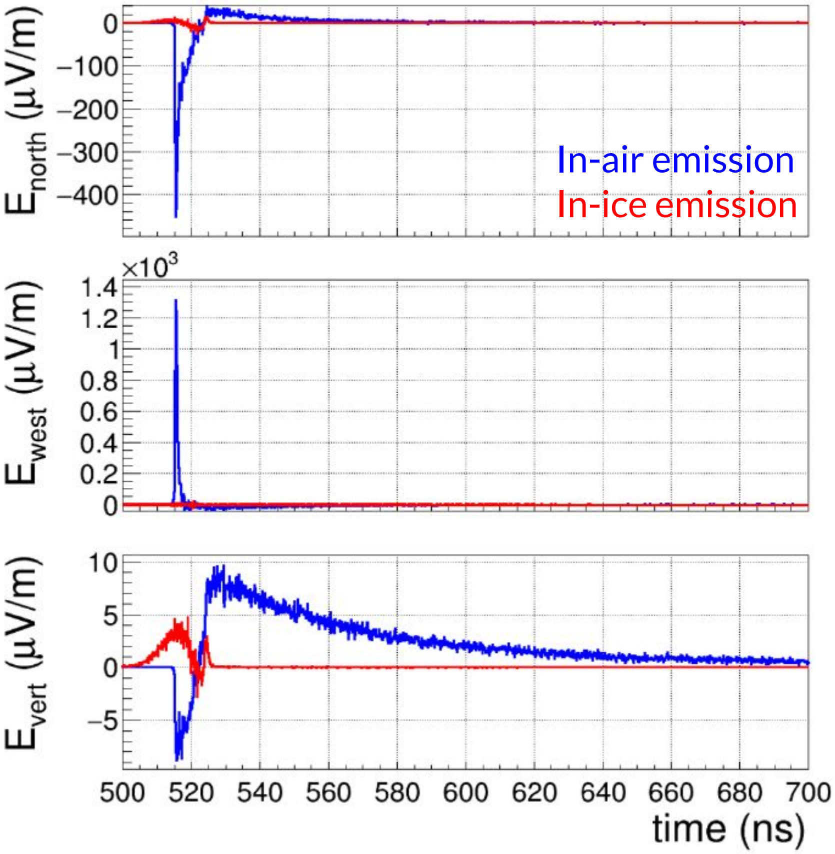
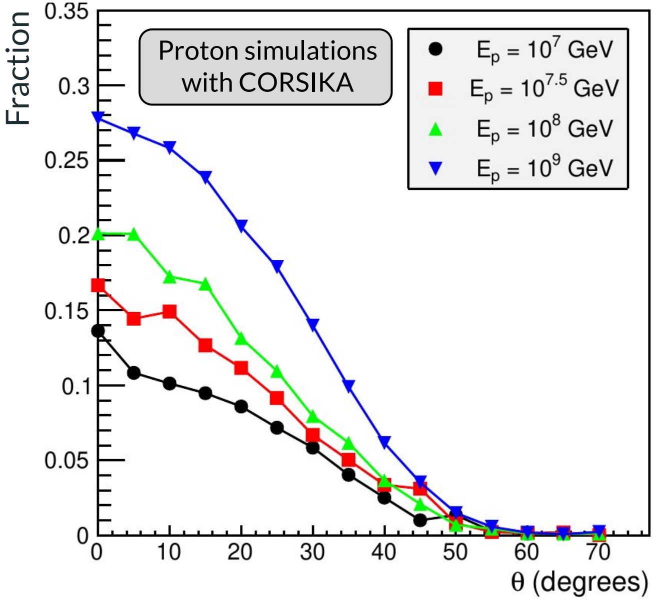


Thanks for your attention!

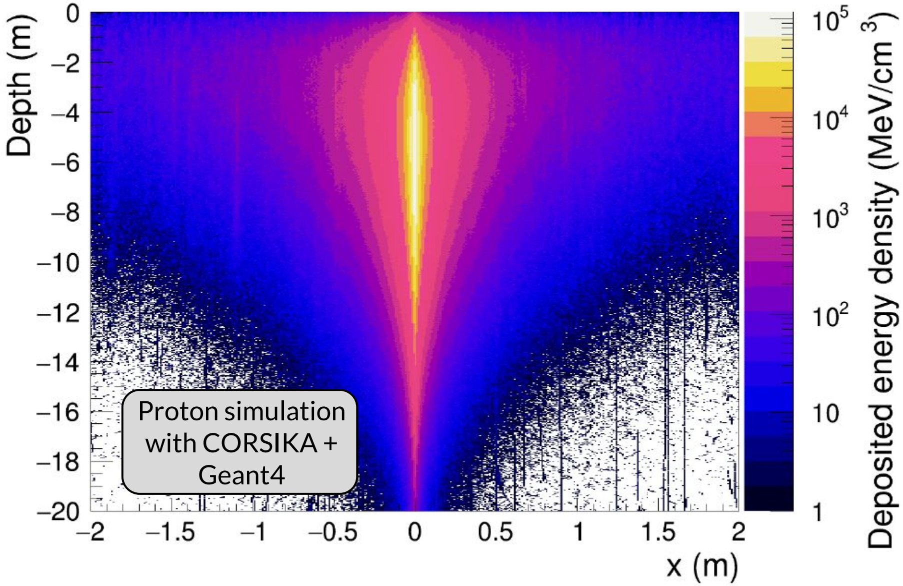
Back-up

What to expect

Fraction of the primary energy E_p within 100 cm from the shower axis at 2.4 km asl



Energy deposited in the ice by 10^{17} eV proton shower at 2.4 km asl



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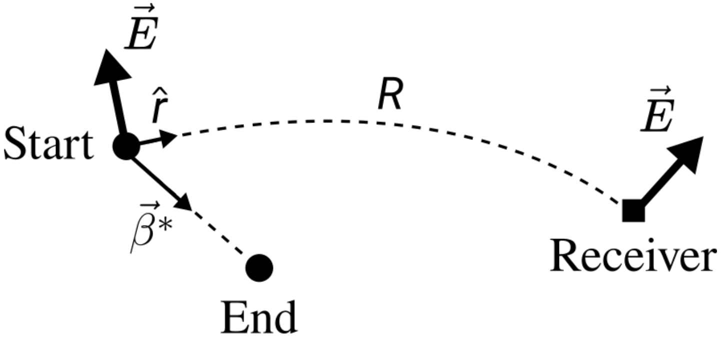
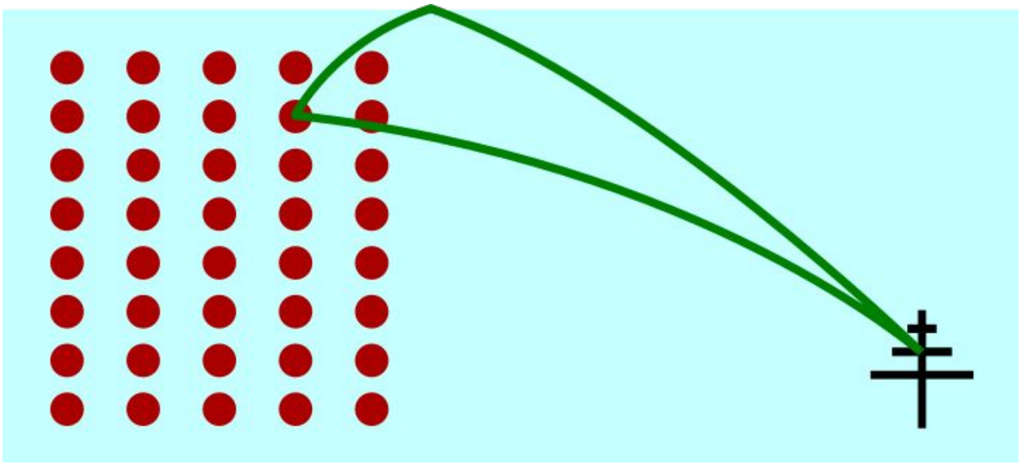
Endpoint formalism modified for **ray-racing**, to account for changing index of refraction (air to ice, but also in ice itself)

- Reinterpretation of the end-point formula
- Analytical ray tracing & interpolation tables





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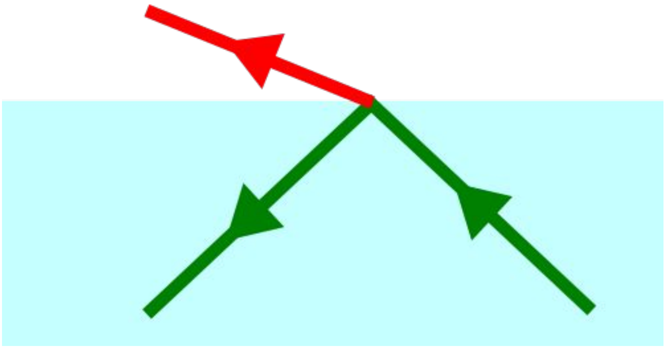
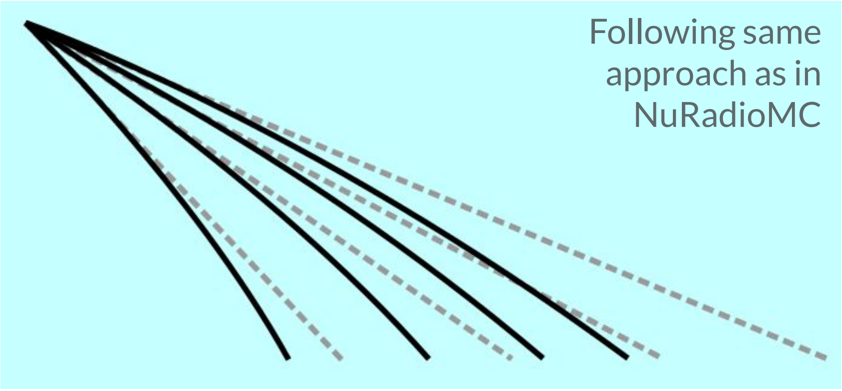
Endpoint formalism modified for **ray-racing**, to account for changing index of refraction (air to ice, but also in ice itself)

- Analytical ray tracing & interpolation tables
- Reinterpretation of the end-point formula
- Fresnel coefficients (air-ice transmission & ice-ice reflection)
- Focusing factor due to ray-bending





First results

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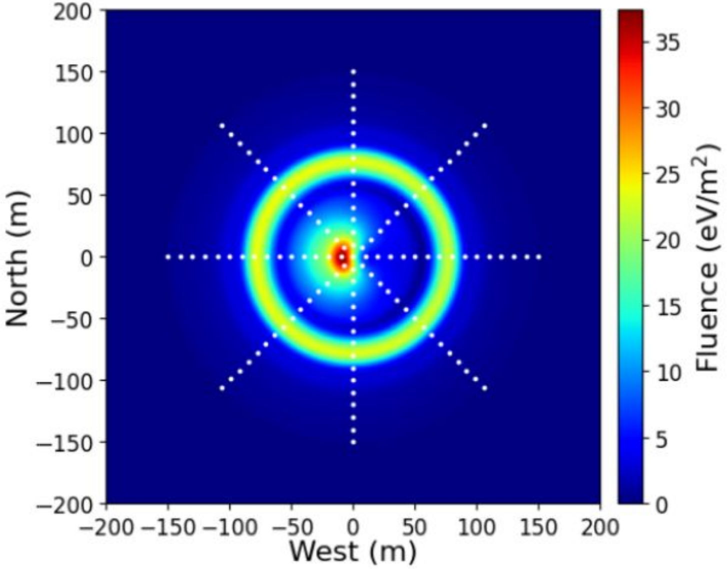
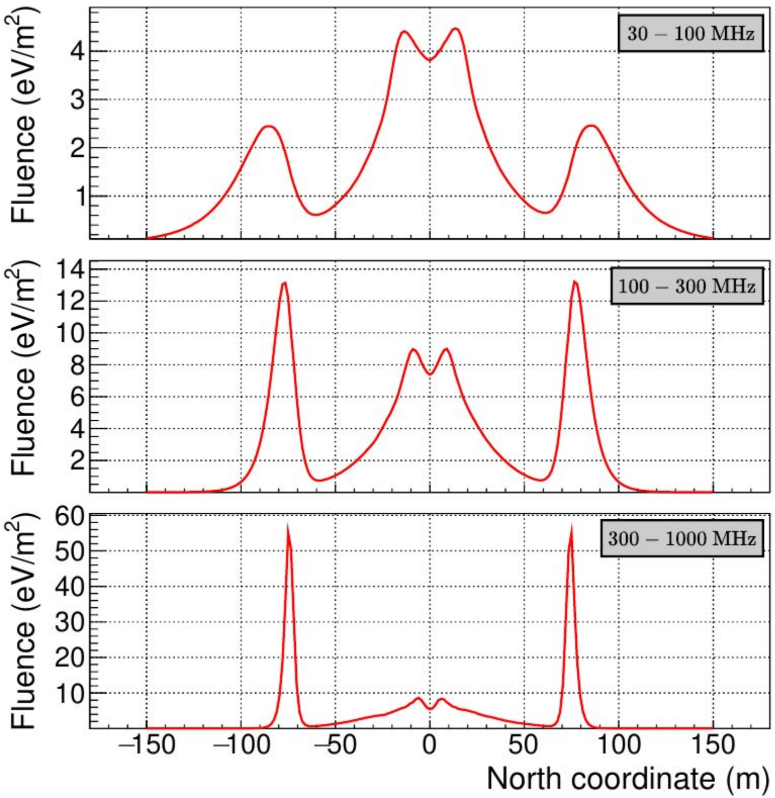
Total emission



Fluence along the North axis



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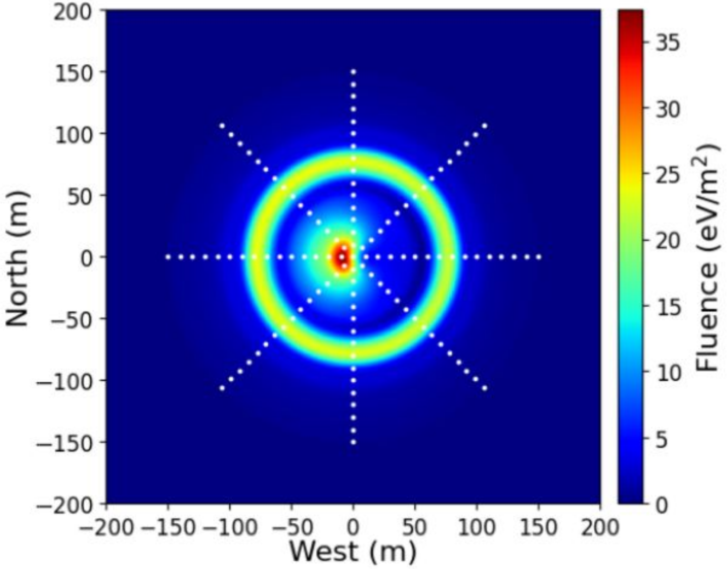
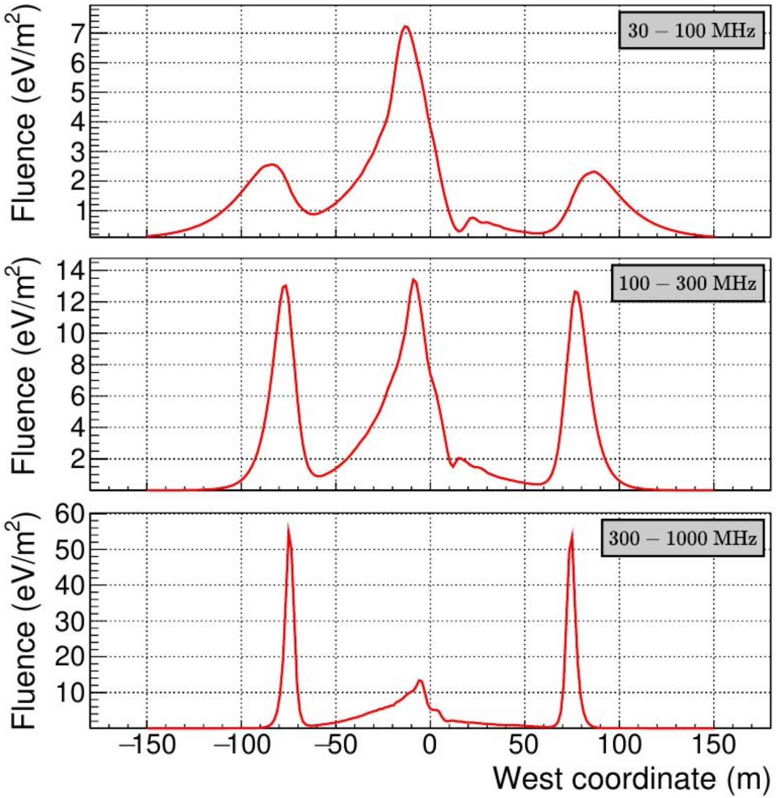
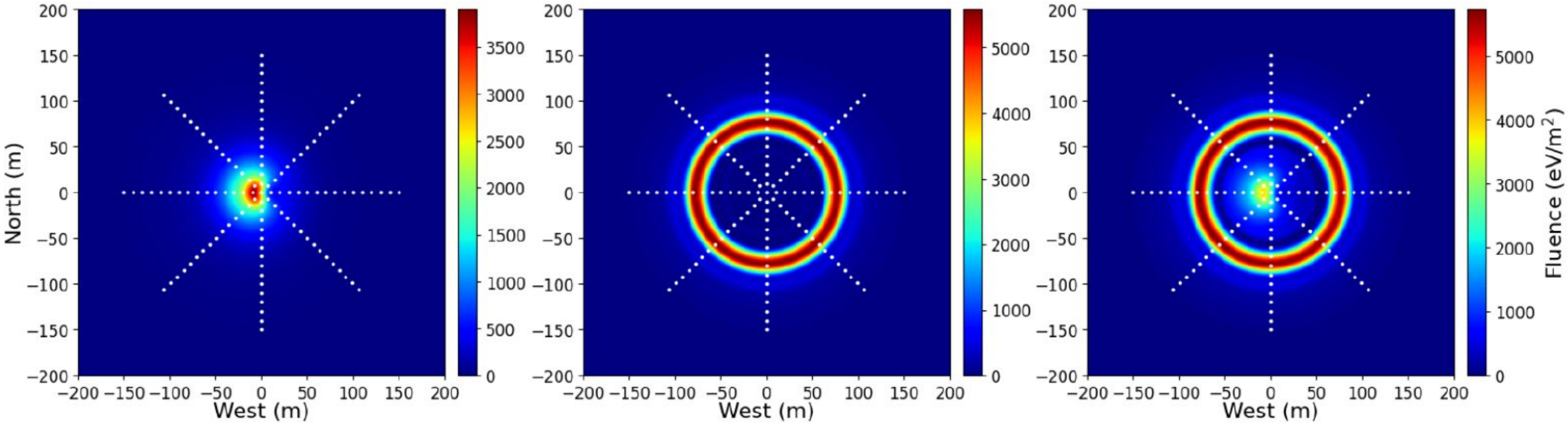


Fluence along the West axis



First results

Fluence for higher primary energy $(E_p = 10^{18}\ \mathrm{eV})$



In-air emission

In-ice emission

Combination