Development of a Signal Model and Reconstruction Framework for GRAND for the Purpose of an Autonomous Radio Trigger

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Structure

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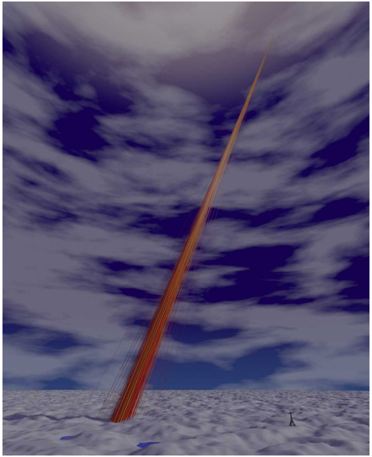
Radio Emission of Extensive Air Showers

- Ultra-high energy (UHE) cosmic rays induce particle showers when entering the atmosphere
- Secondary electrons and positrons emit radio waves due to geomagnetic field
- Emitted along the shower axis
  $\Rightarrow$ ground-based radio antennas



Source: arXiv:2112.11761

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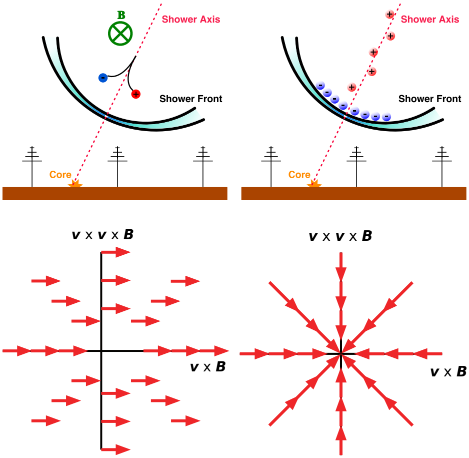
Radio Emission of Extensive Air Showers: Emission Mechanisms

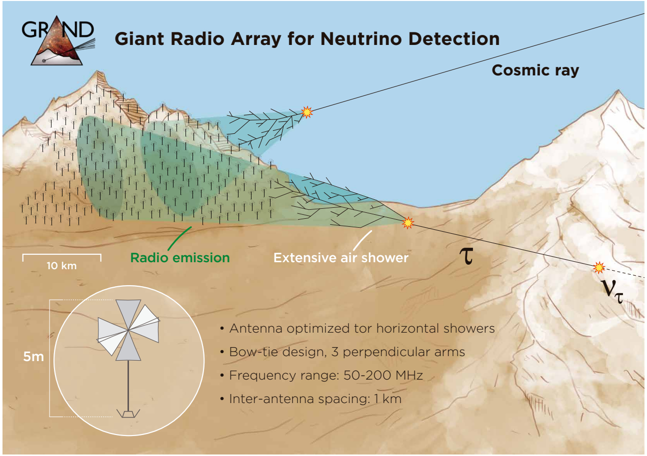
- **Geomagnetic emission**
  Charge separation in geomagnetic field
- **Charge excess emission**
  Accumulation of negative charges at shower front
- Overall polarisation pattern
  ⇒ asymmetric footprint



Source: arXiv:1601.07426

GRAND and the NUTRIG Project: Detection Principle

- Future radio observatory for UHE neutrinos and cosmic rays
- Antennas will cover an area of 200 000 km^2



Source: arXiv:1810.09994

GRAND and the NUTRIG Project: Radio Self-Trigger

- **NUTRIG:** A collaboration between astroparticle physics institutes in Karlsruhe and Paris to develop a radio self-trigger
- Level-one trigger: Single antenna, flags possible CR signals
- Level-two trigger: Based on signal model and array response, decides between cosmic-ray signal or noise

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Signal Model for Inclined Air Showers

Signal Model:

- Use air shower and detector simulations to model the antenna response to the radio signal
- Includes: Energy fluence, polarisation, signal arrival time, frequency

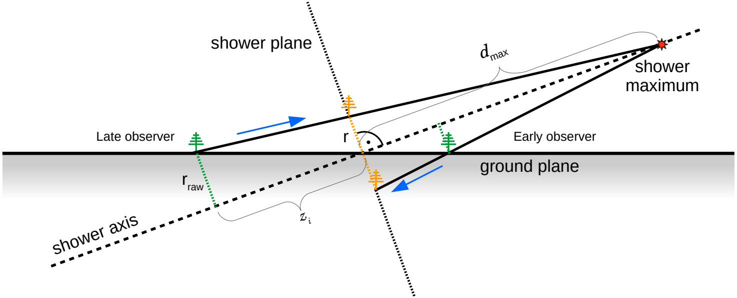
Goals:

- Adapt existing signal models to GRAND, e.g. from Pierre-Auger Observatory
- Account for GRAND's wider frequency band as well as site atmosphere, altitude and magnetic field

Signal Model for Inclined Air Showers: Early-late Correction

- First step for signal model of inclined showers
- Antennas projected into shower plane
- Reduces signal differences from source distance

Early-late correction for simulating inclined showers



Source: arXiv:2203.04364

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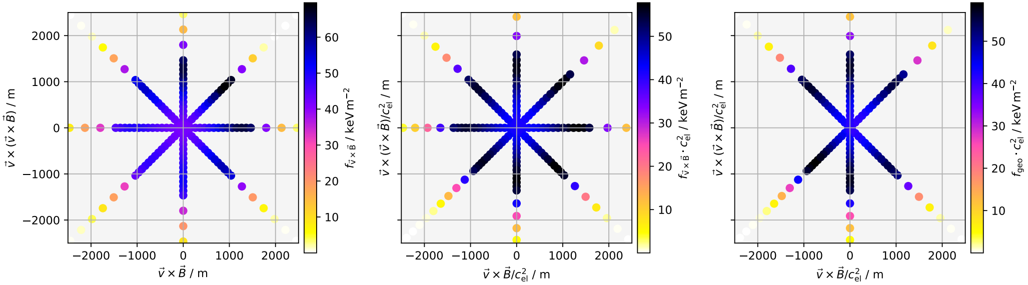
Signal Model for Inclined Air Showers: Early-late Correction

Zenith angle $\theta = 85°$



Early-late correction visualised in radio footprints

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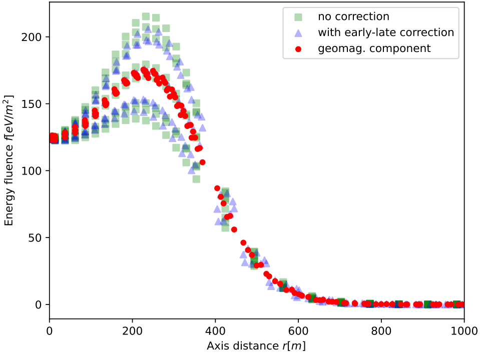
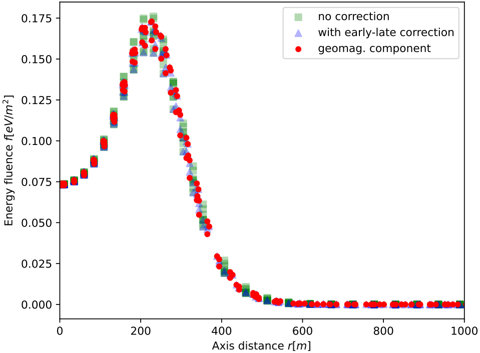
Signal Model for Inclined Air Showers: Lateral Distance Function

Zenith angle $\theta = 65°$





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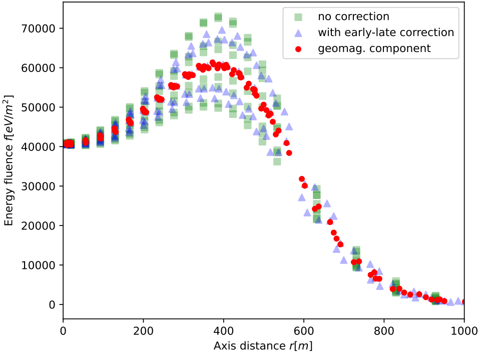
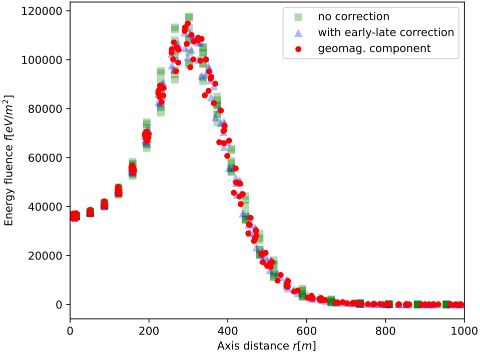
Signal Model for Inclined Air Showers: Lateral Distance Function

Zenith angle $\theta = 72^\circ$





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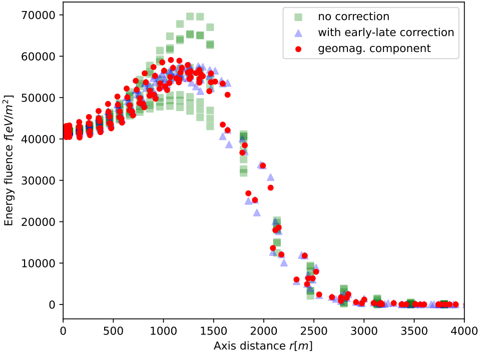
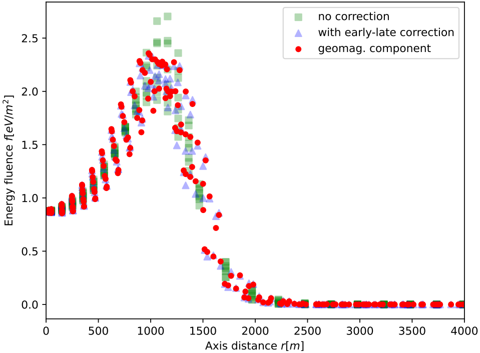
Signal Model for Inclined Air Showers: Lateral Distance Function

Zenith angle $\theta = 85°$





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Outlook and Goals

Next steps for the **Signal Model**:

- Isolate geomagnetic emission by parametrising the charge excess
- Fit geomagnetic LDF specifically for GRAND for reconstruction of shower electromagnetic energy
- Account for wider frequency range and site specific parameters

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Outlook and Goals

Event Reconstruction:

- Determine the cosmic-ray parameters from the detected signal of an event
- Parameters: Cosmic-ray energy, arrival direction, depth of maximum, particle type

Overall Goals:

- Use the signal model and detector simulations for event reconstruction
- Generate signal data that can be used to evaluate a trigger algorithm