Advanced reconstruction strategies for AERA

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on behalf of the Pierre Auger collaboration

Karlsruhe Institute of Technology (KIT), Institut für Kernphysik, Karlsruhe, Germany
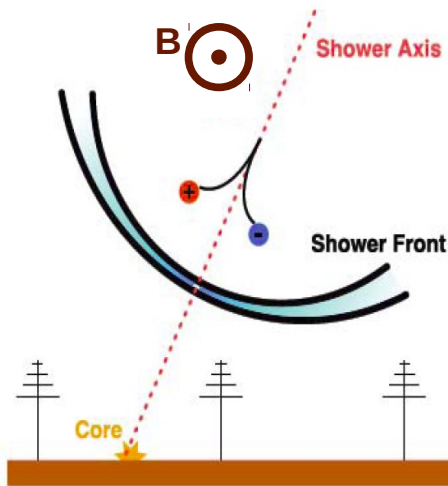
Outline
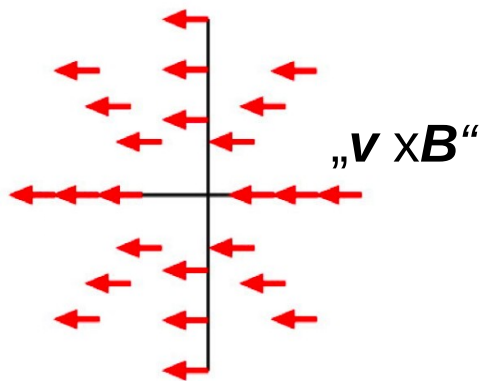
Radio emission
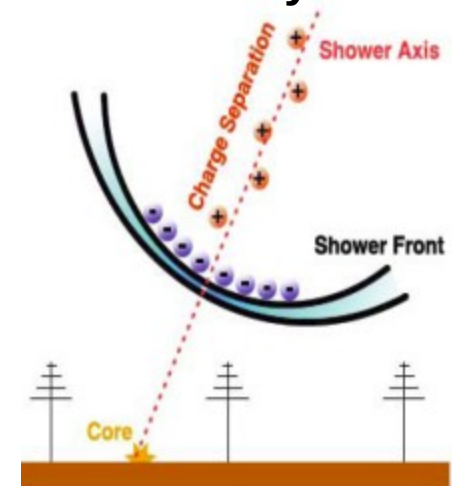Reconstruction tools
Summary and outlook

Radio emission mechanism

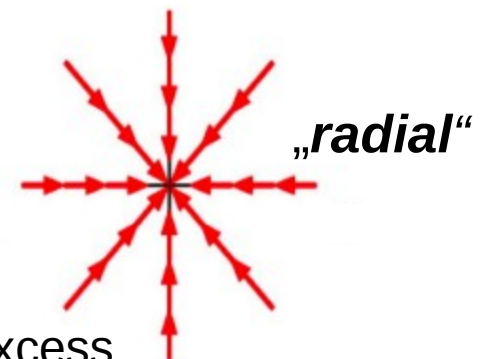**Geomagnetic effect**

Askaryan effect

Primary effect:
geomagnetic field induces
time-varying transverse currents

„v xB"

„radial"

Secondary effect:
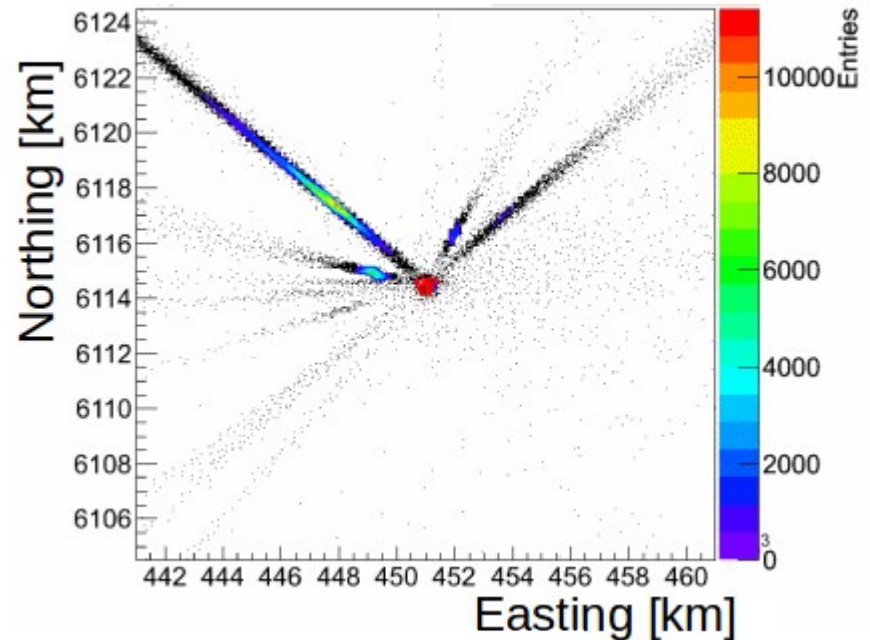time-varying net charge excess

Detection principle

Radio wavefront

Air shower

Radio station

Distribution of **RFI sources** in the AERA field

Northing [km] / Easting [km]
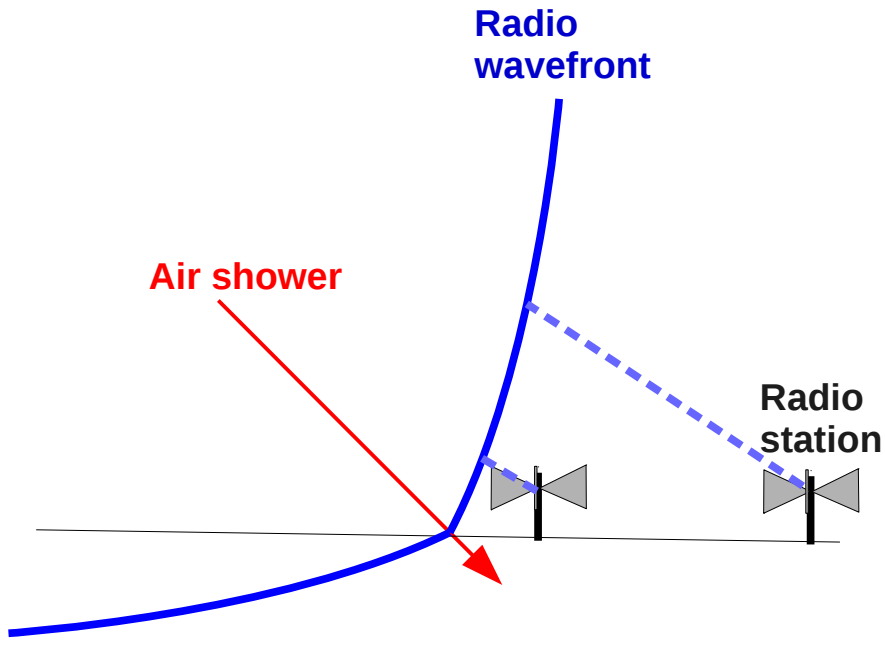
Direction of **air shower** is reconstructed from **radio wavefront** hitting 2D array of **radio stations**

Event selection:
Radio events externally triggered by Surface Detector (SD)
→ all stations are read-out
→ non-negligible false-positive radio pulses (**RFI source**)

We need to efficiently reduce the contamination of false-positive pulses
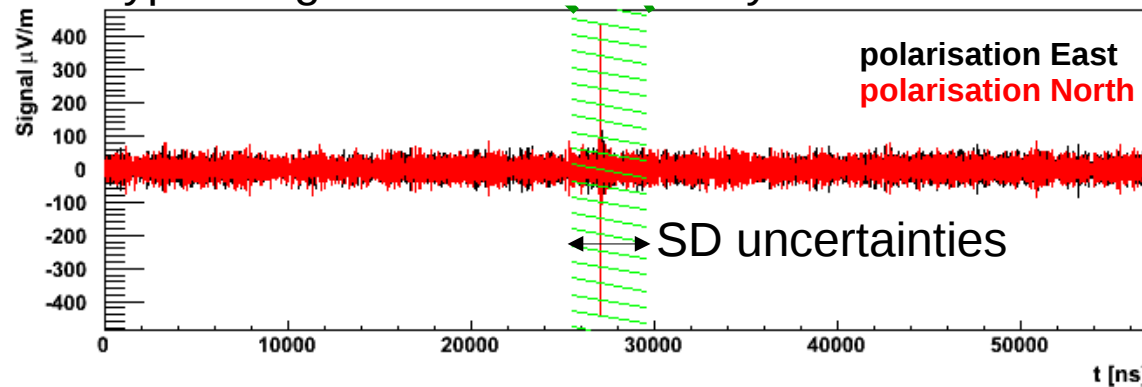
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Radio noise reduction

Radio wavefront

Air shower
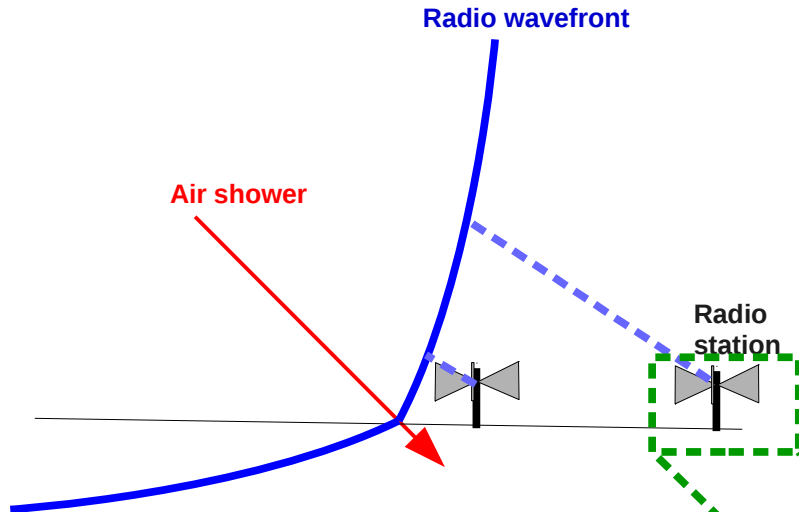
Radio station

Pulse selection:
- Search for radio pulses
  causality connected
  to SD reconstructed shower

Typical signal trace recorded by radio stations

polarisation East
polarisation North

SD uncertainties

Signal µV/m

t [ns]

Radio events are reconstructed with high signal-selection purity

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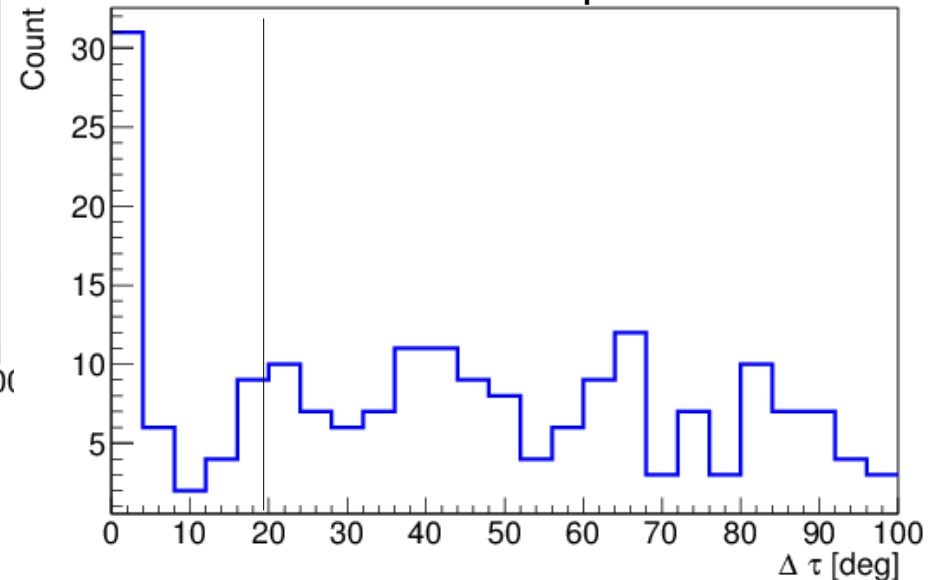Institut für Kernphysik, KIT Campus North

Performance of pulse selection

$\Delta\tau$ = angle between SD and AERA reconstructed air shower axes

Distribution of $\Delta\tau$ for the standard method
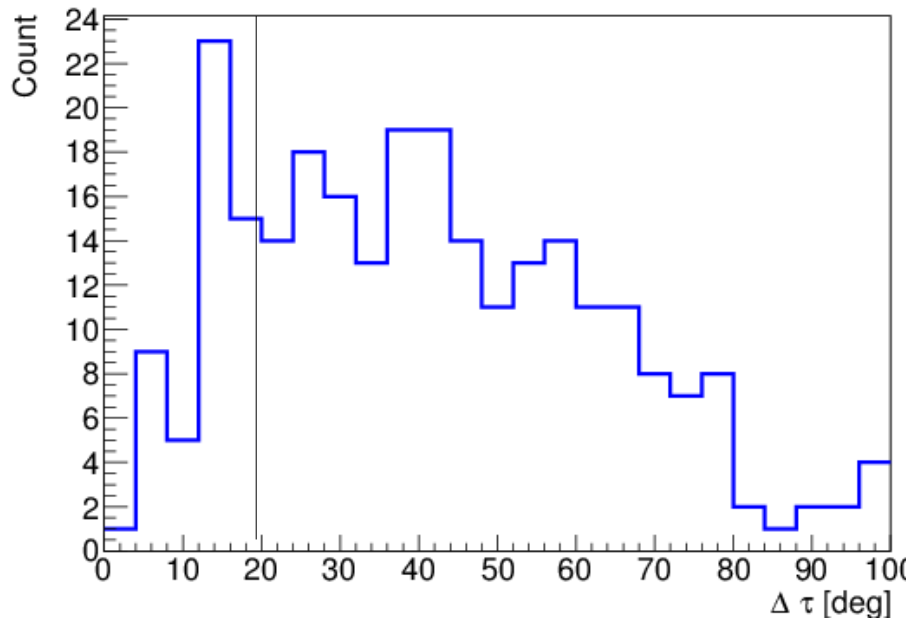
Distribution of $\Delta\tau$ for the pulse selection

Pulse selection results in a better AERA reconstruction

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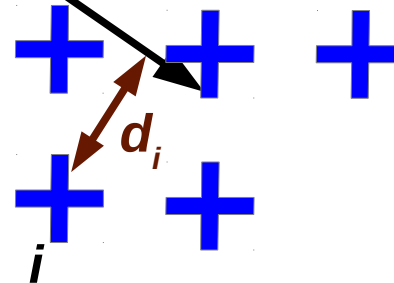
Cluster finder algorithm

Method:
- Sorts stations according to **euclidean distances** between SD axis and station positions
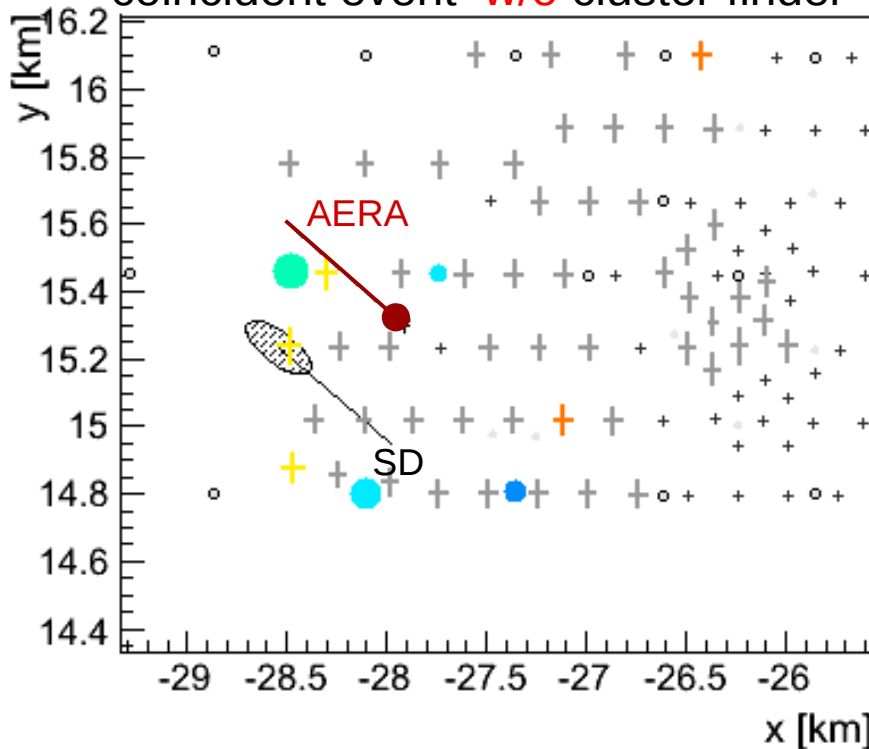- Rejects **isolated stations** i.e. discontinuity in the distribution

SD reconstructed air shower

d_i

i

Distance between SD axis and stations
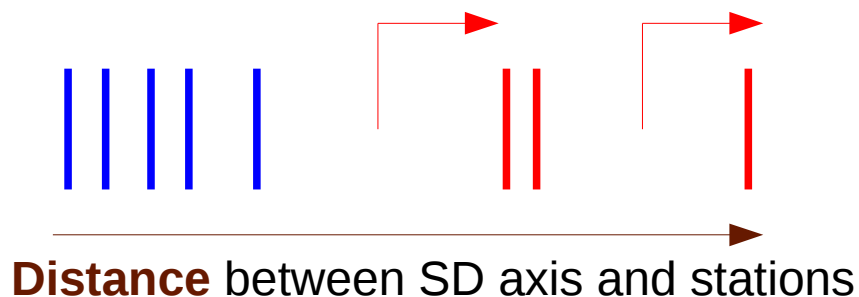
Algorithm selects **cluster of stations** caused by air shower

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Performance: cluster finder

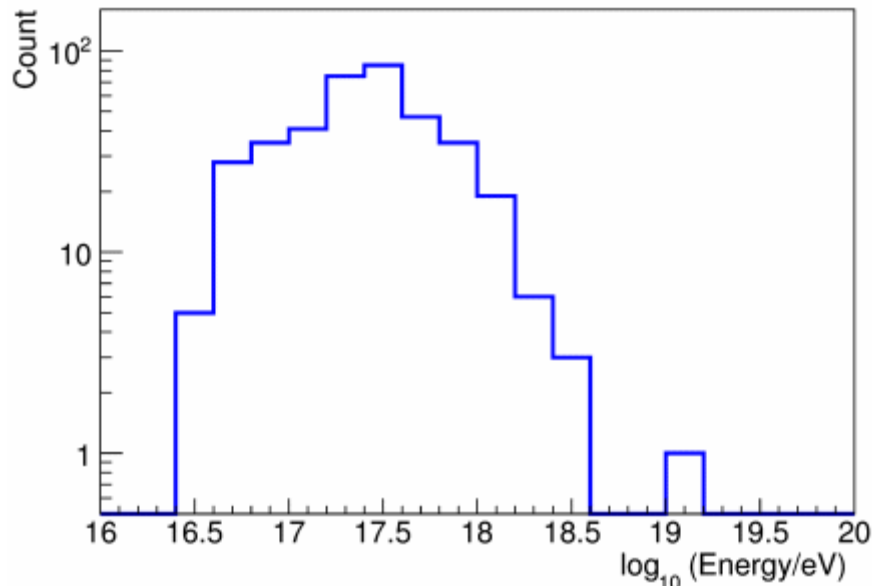Reconstruction of SD-AERA
coincident event w/o cluster finder

Reconstruction of SD-AERA
coincident event w/ cluster finder
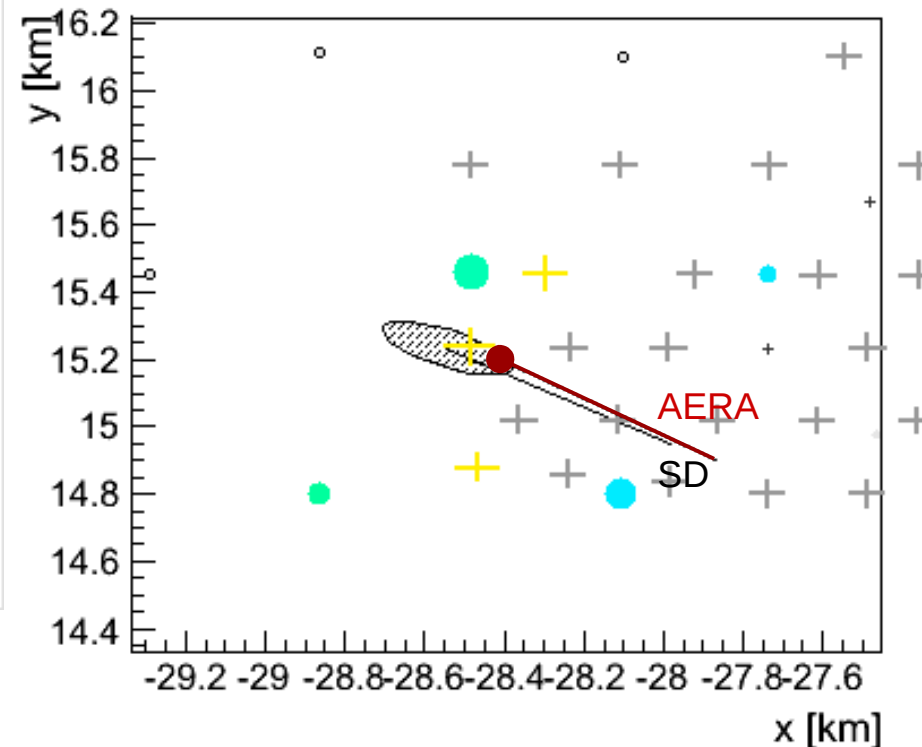
Cluster finder recovers more than **23%** of misreconstruted coincident events

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Direction and energy

Energy distribution of the coincidence events

Distribution of azimuth and zenith angles

Dataset: May – December 2013
SD-AERA coincident rate =
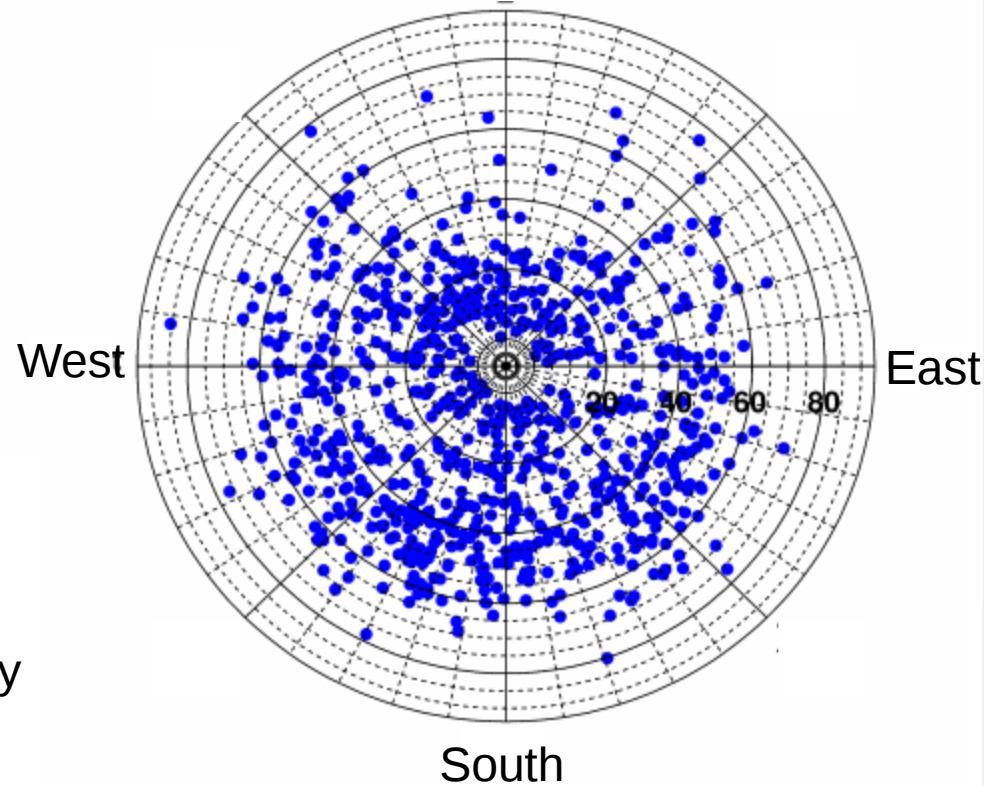   6.25 events / day
   → Still room for optimising efficiency

North-South asymmetry
          → **Geomagnetic effect**

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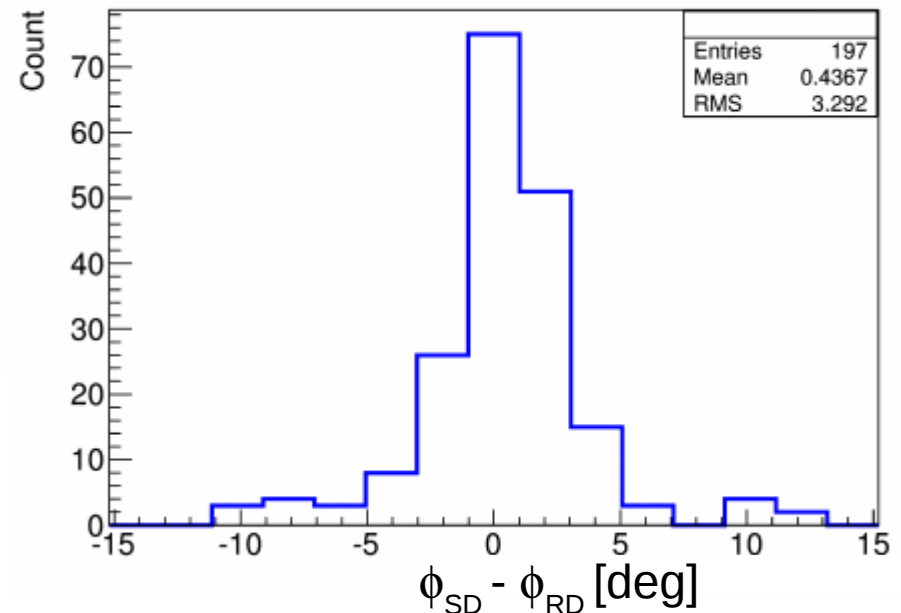# Performance: direction reconstruction

Distribution of error of **zenith** reconstruction
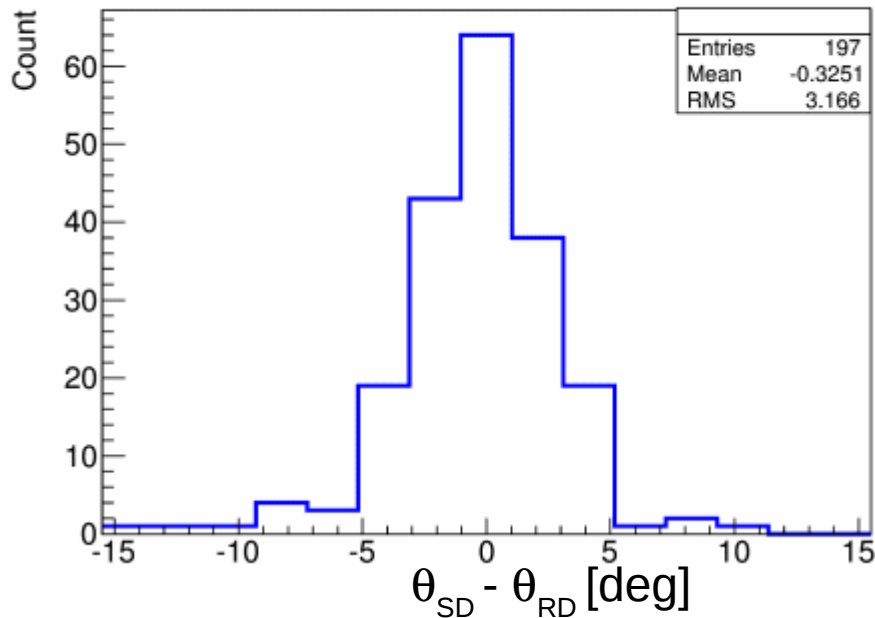
Distribution of error of **azimuth** reconstruction

Agreement between Radio Detector (RD) and SD direction reconstructions

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Energy reconstruction

Typical trace of measured raw voltage
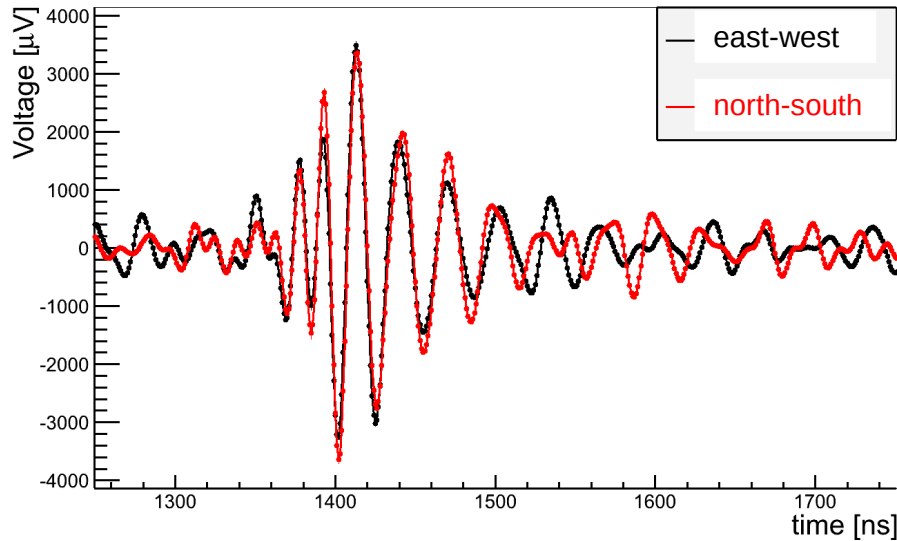
Reconstructed electric field vs time

Total signal strength
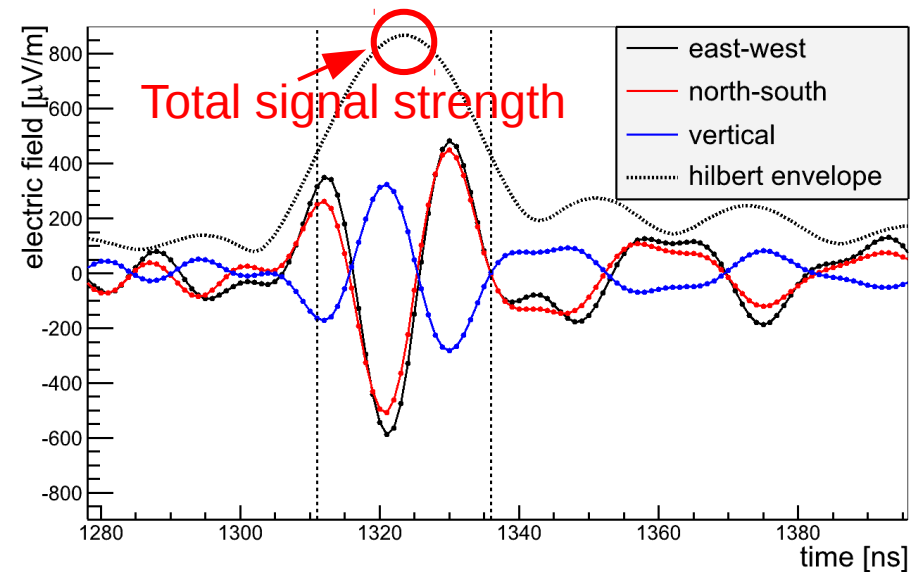
Reconstructed electric field is used to measure the signal strength

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Definition of an energy estimator

Typical reconstructed signal strength
as a function of distance to shower axis
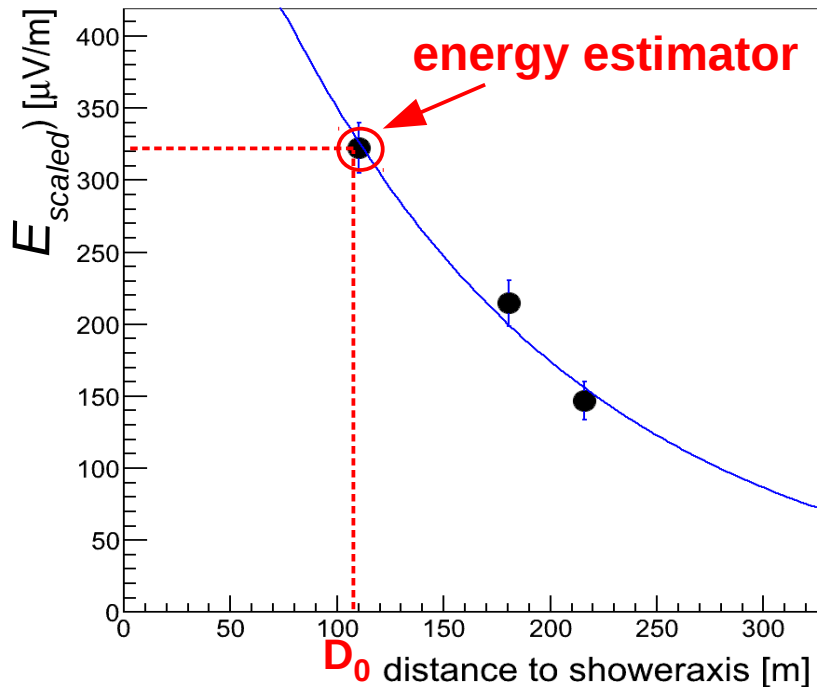
energy estimator

- correct Electric field for
  geomagnetic effect → E_{scaled}
- use exponential function
  to interpolate between data points

$$E_{scaled} = A \cdot exp(D/R_0)$$

Energy estimator:
   Strength of signal at optimal distance D_0
   is correlated to shower energy

energy resolution as a function of D_0

→ **use D_0 = 110m**

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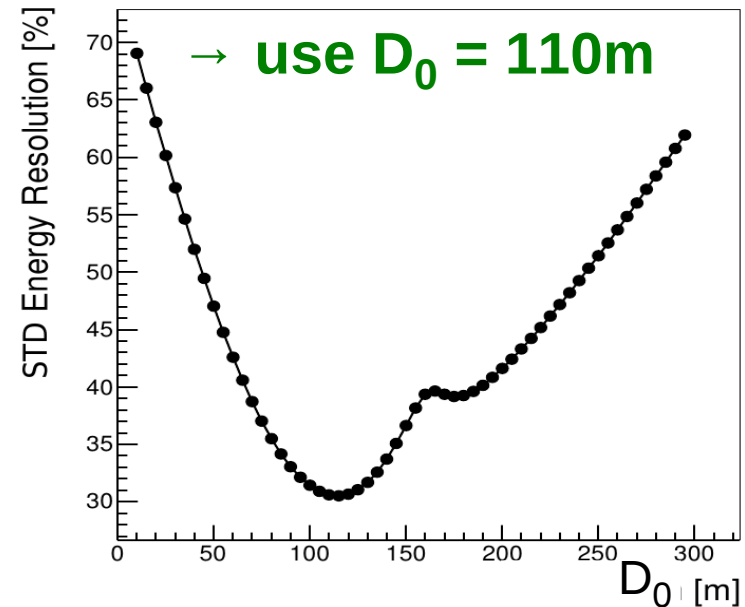
Performance: energy reconstruction

Measured SD energy vs energy estimator
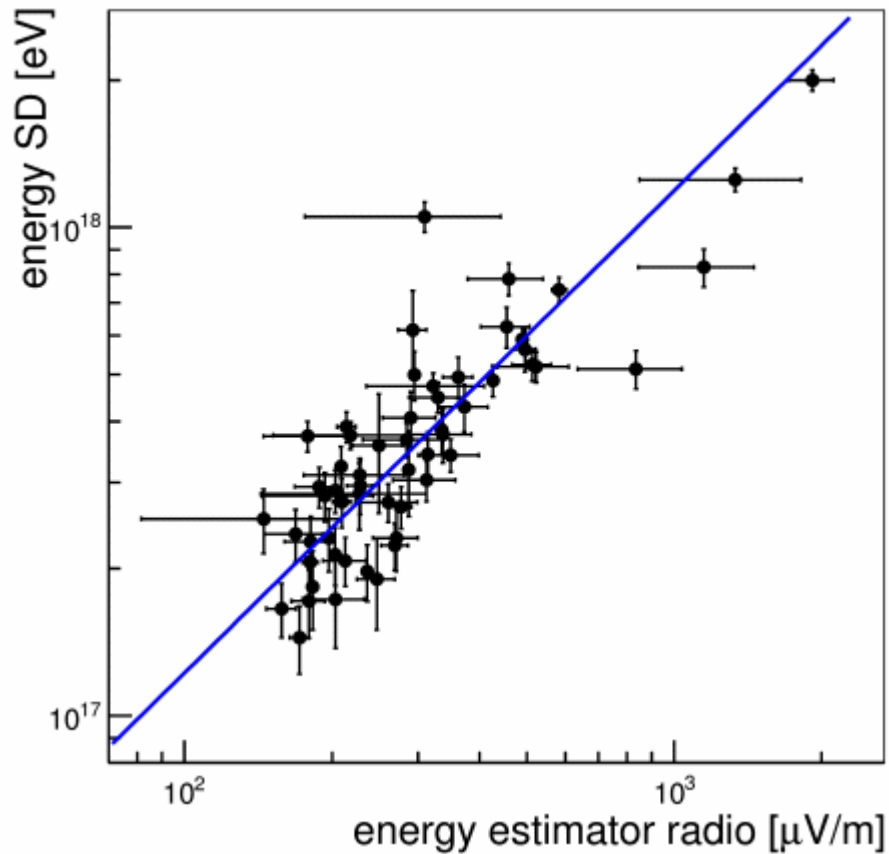
Distribution of error of energy reconstruction

Excellent correlation between measured SD energy and energy estimator

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Reconstruction of primary mass

Pulse shape analysis

Schematic view **Iron** and **proton** showers

Iron
Proton

X_{max}

X_{max}
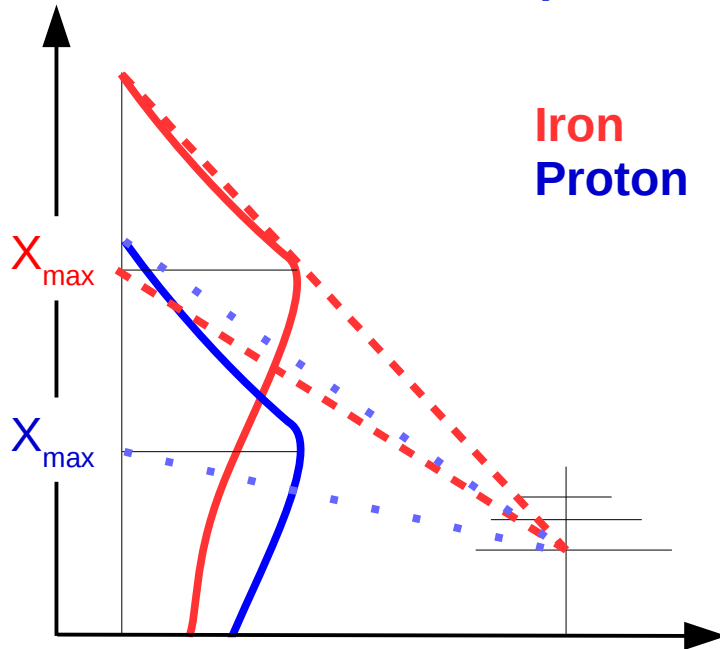
Power as a function of frequency

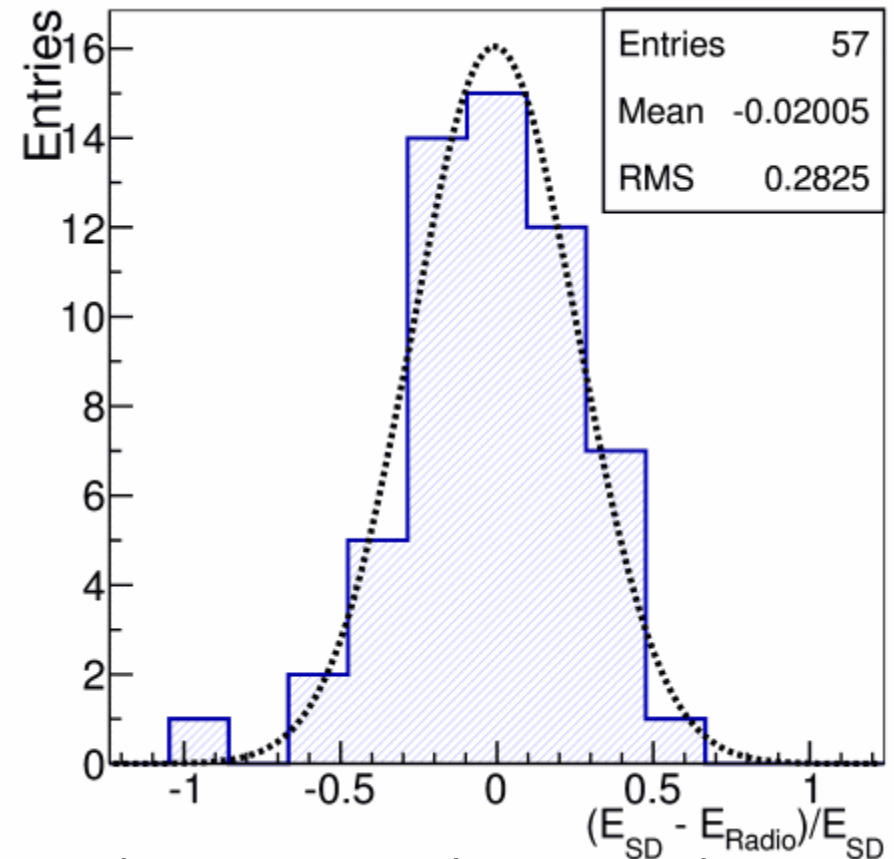**Iron**
Proton
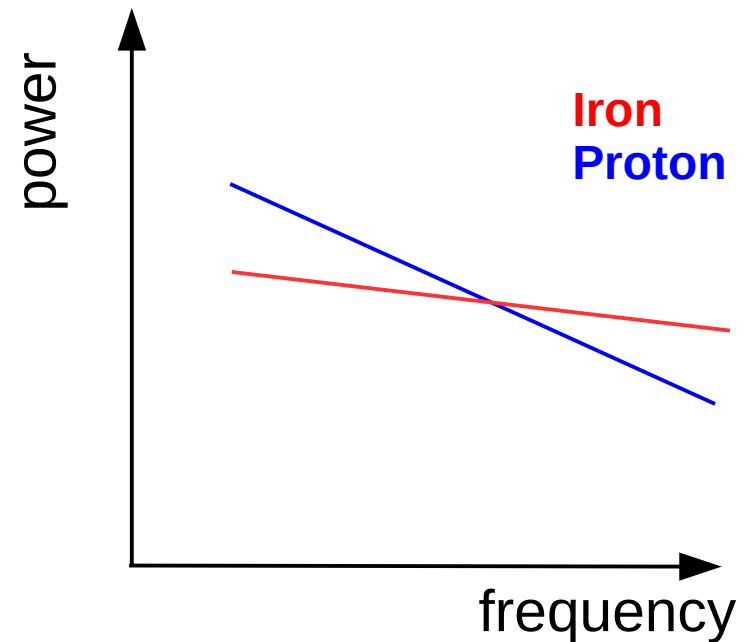
power

frequency

radio pulse of heavy nuclei is shorter
→ more power in the high frequencies

Stefan Grebe ARENA12

spectral slope is sensitive to X_{max}

Reconstruction strategies for AERA

Reconstruction of primary mass
Lateral Distribution Function (LDF) analysis

LDF for Iron, proton and gamma primaries
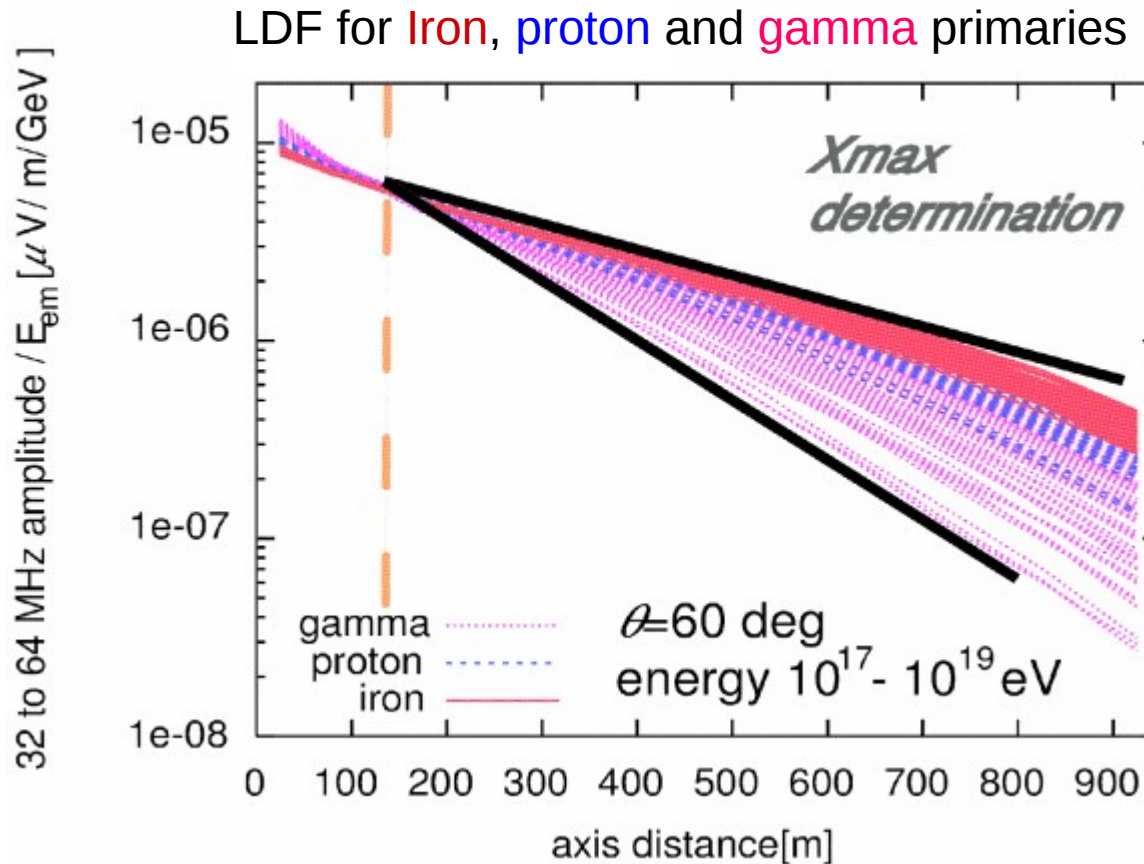
T. Huege,Ulrich,Engel (2008) Astrop.Ph. 30,96

The slope of LDF relates to Xmax

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Reconstruction of primary mass

Radio emission originates from a few kilometres in altitude
→ related to distance R_{max} to shower maximum X_{max}
→ Reconstruct the origin of radio emission

The flattening of the radio **wavefront** relates to the origin

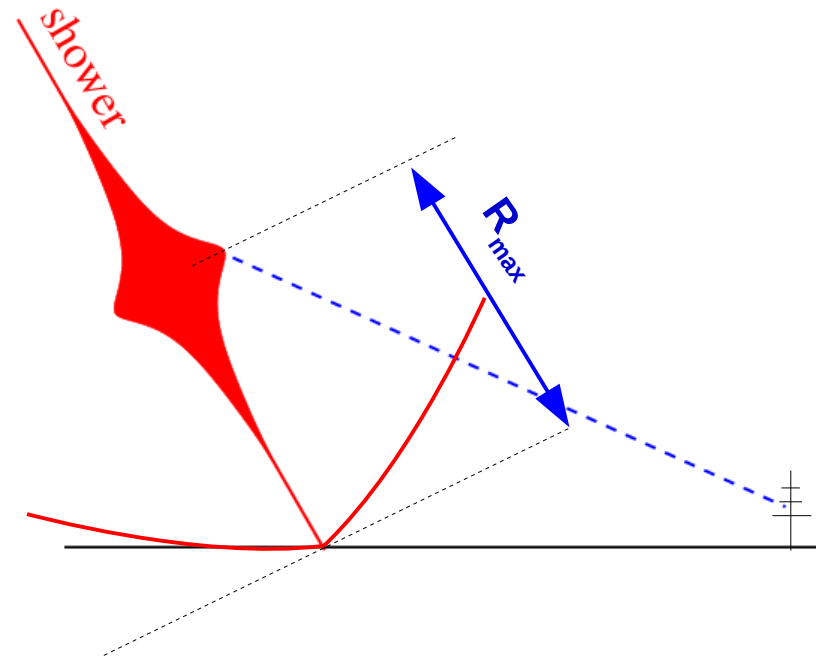Reconstruction strategies for AERA

Conical wavefront

Schematic of Conical wavefront
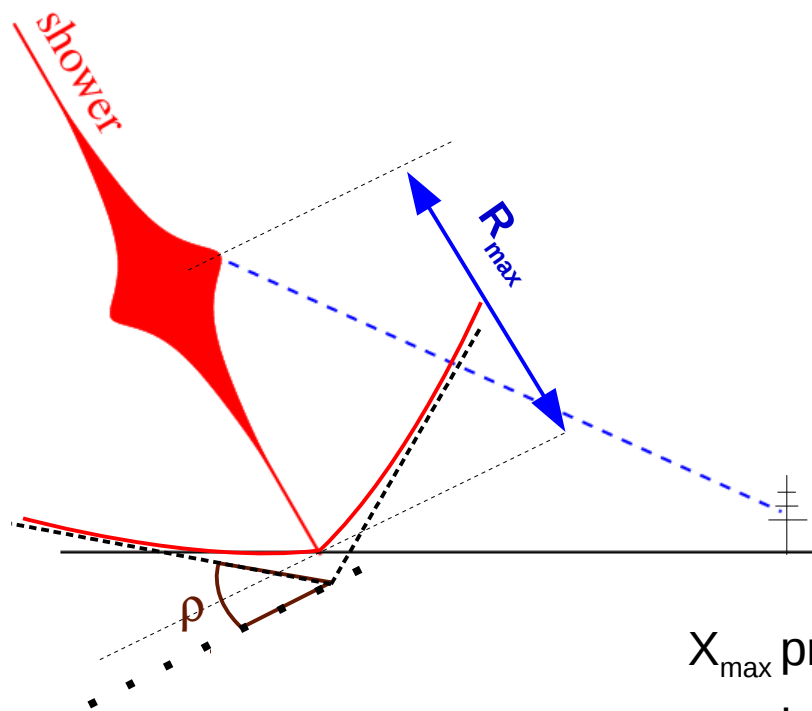
Distribution of true X_{max} vs cone angle ρ

REAS3 p
REAS3 Fe
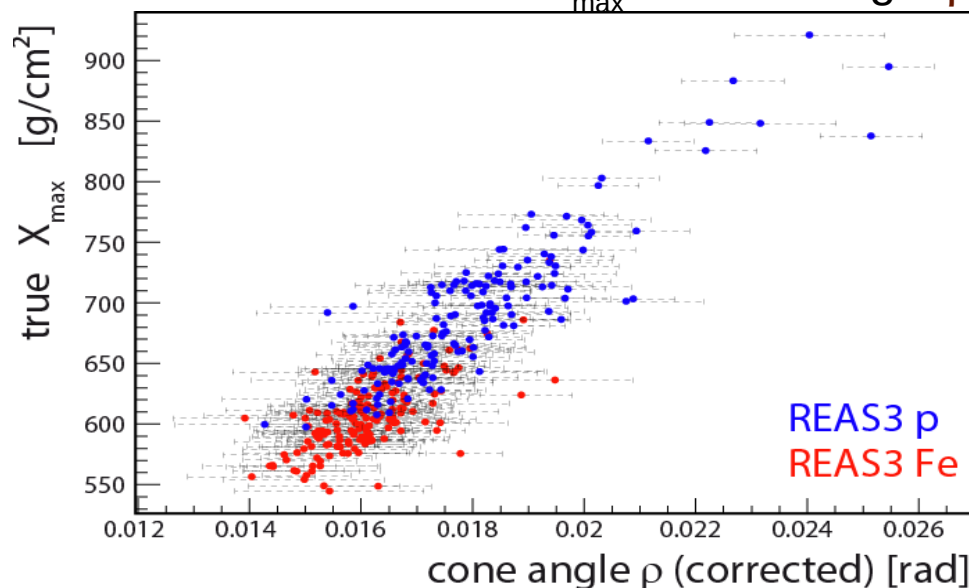
X_{max} proportional to ρ after correction for zenith angle

precision: ~30 g/cm²   simulations without noise

precision: ~200 g/cm²   LOPES measurements

R_{max} is independent from the arrival direction

$\rightarrow$ determine X_{max}

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Performance

Distribution of R_{max} vs X_{max} for experimental data and MC

Experimental data ●
MC events $\theta = 50^{o} \pm 2^{\circ}$
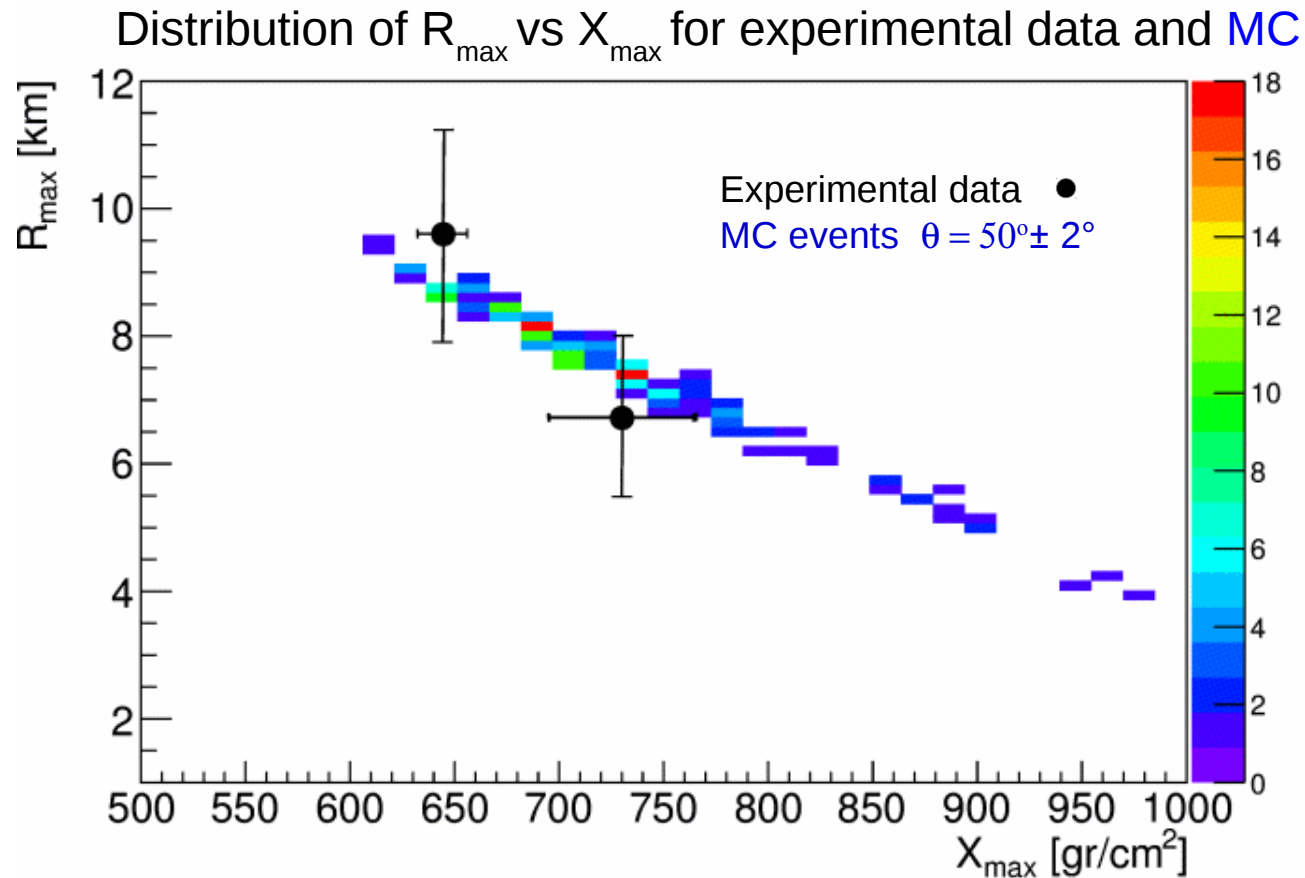
Experimental data: super-hybrid events

Agreement between experimental data and MC

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Summary and outlook

- Reconstruction strategies for air shower parameters,
  i.e. direction, energy and mass have been developed
- Air shower direction reconstruction:
    - Radio signal selection algorithms have been developed
        - pulse selection → high radio pulse selection purity
        - cluster algorithm → improves SD-AERA coincident rate by **23%**
    - High rate of coincident-event detection:
        → 6.25 coincident events / day
- Energy reconstruction:
    - high correlation between estimated radio energy
      SD measured energy
- Mass reconstruction:
    - Good correlation observed between flattening of
      radio wavefront and primary composition
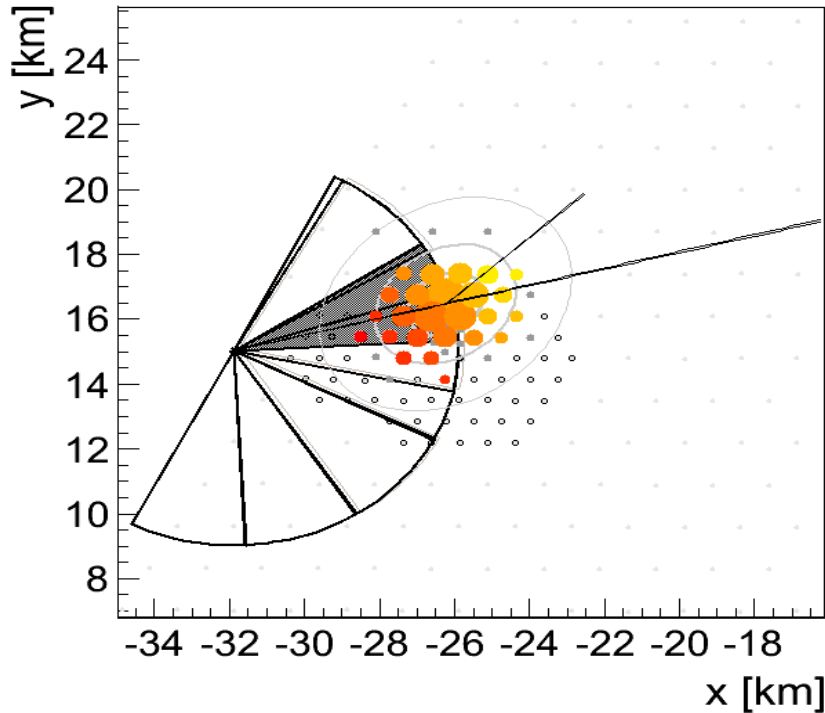
Outlook

- Unique opportunity to reconstruct air shower parameters
  running the reconstruction modules on full AERA dataset

Reconstruction strategies for AERA

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Spare slides

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Ultra high energy event

$$E = 2 \times 10^{19} \text{ eV}$$
$$\theta = 38^0$$

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