# Air shower radio signal electric field orientation as measured with the Astroneu Cosmic Ray telescope.

S. Nonis
Physics Laboratory, School of Science and Technology
Hellenic Open University

# Outline

- ➢ Radio Frequency (RF) Electric Field production in Extensive Air Showers (EAS)
- ➢ ASTRONEU Air Shower Telescope – 3SDM-4RF station
- ➢ RF Analysis – Event Selection
- ➢ EAS Core Reconstruction
- ➢ Charge Excess to Geomagnetic Ratio (CGR) calculations
- ➢ Results from simulations and data analysis
- ➢ Conclusions & Outlook

# Radio Frequency (RF) Electric Field production in Extensive Air Showers (EAS)

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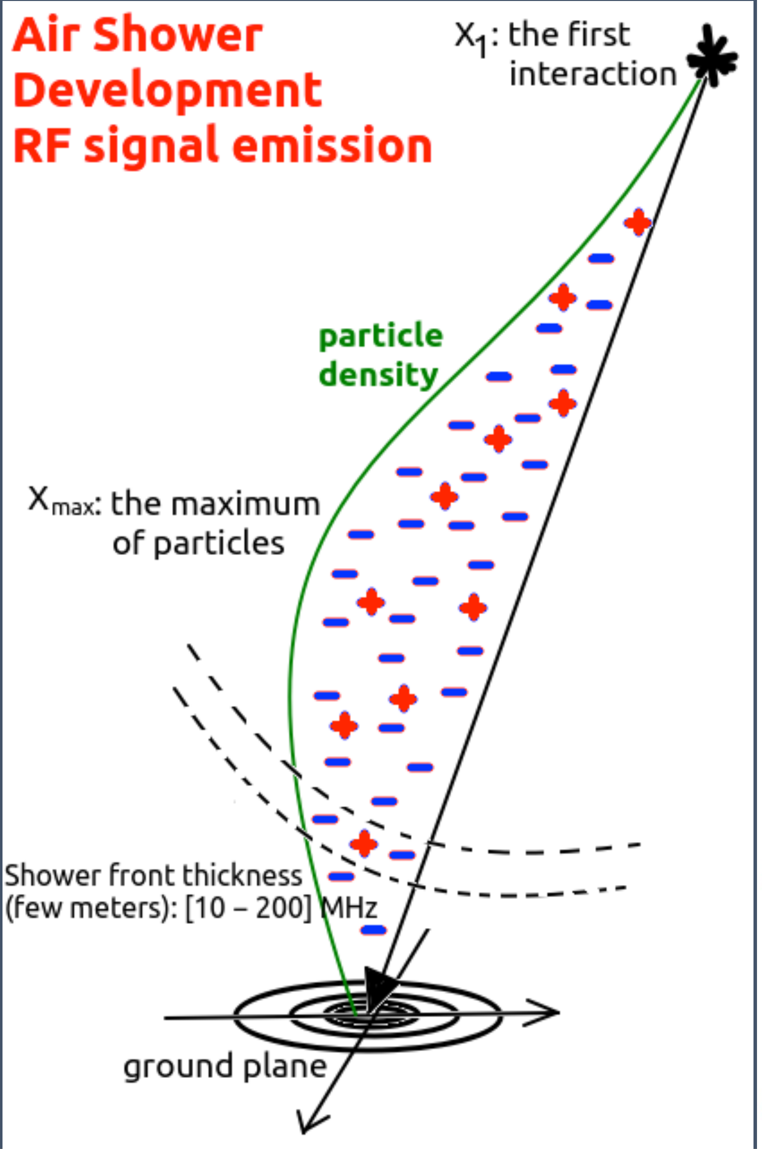
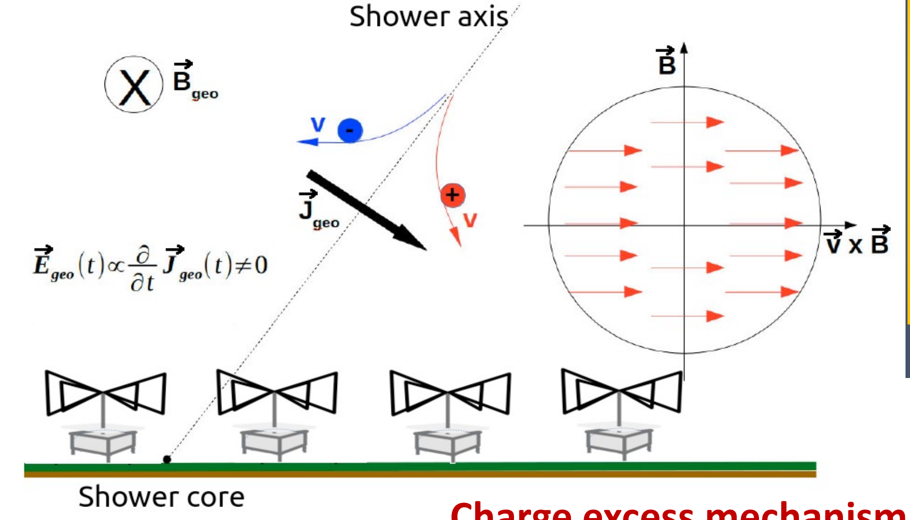
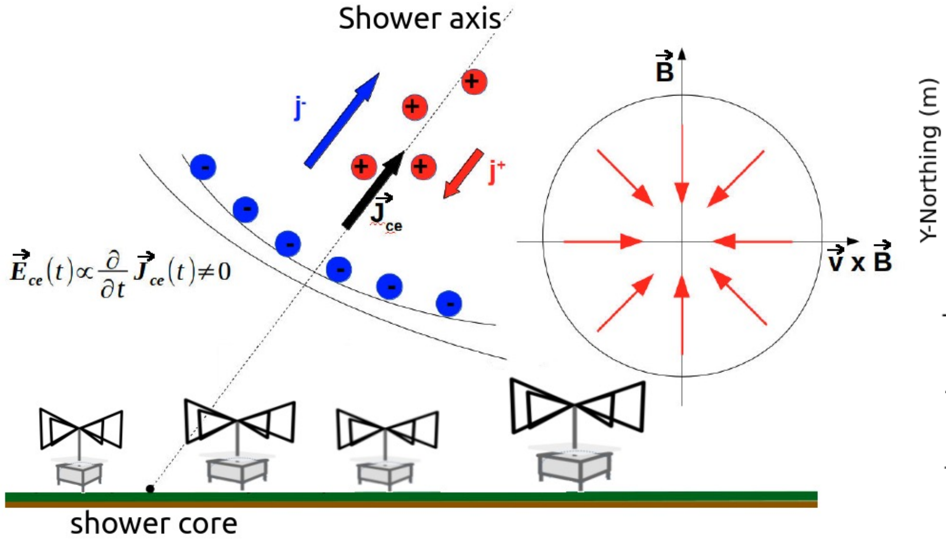


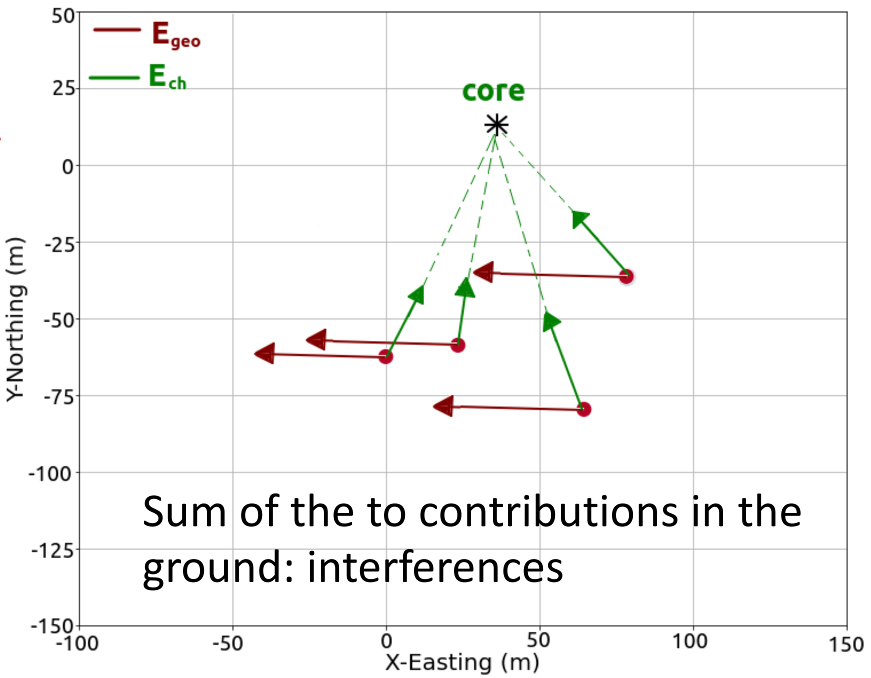

## Geomagnetic mechanism




## Charge excess mechanism

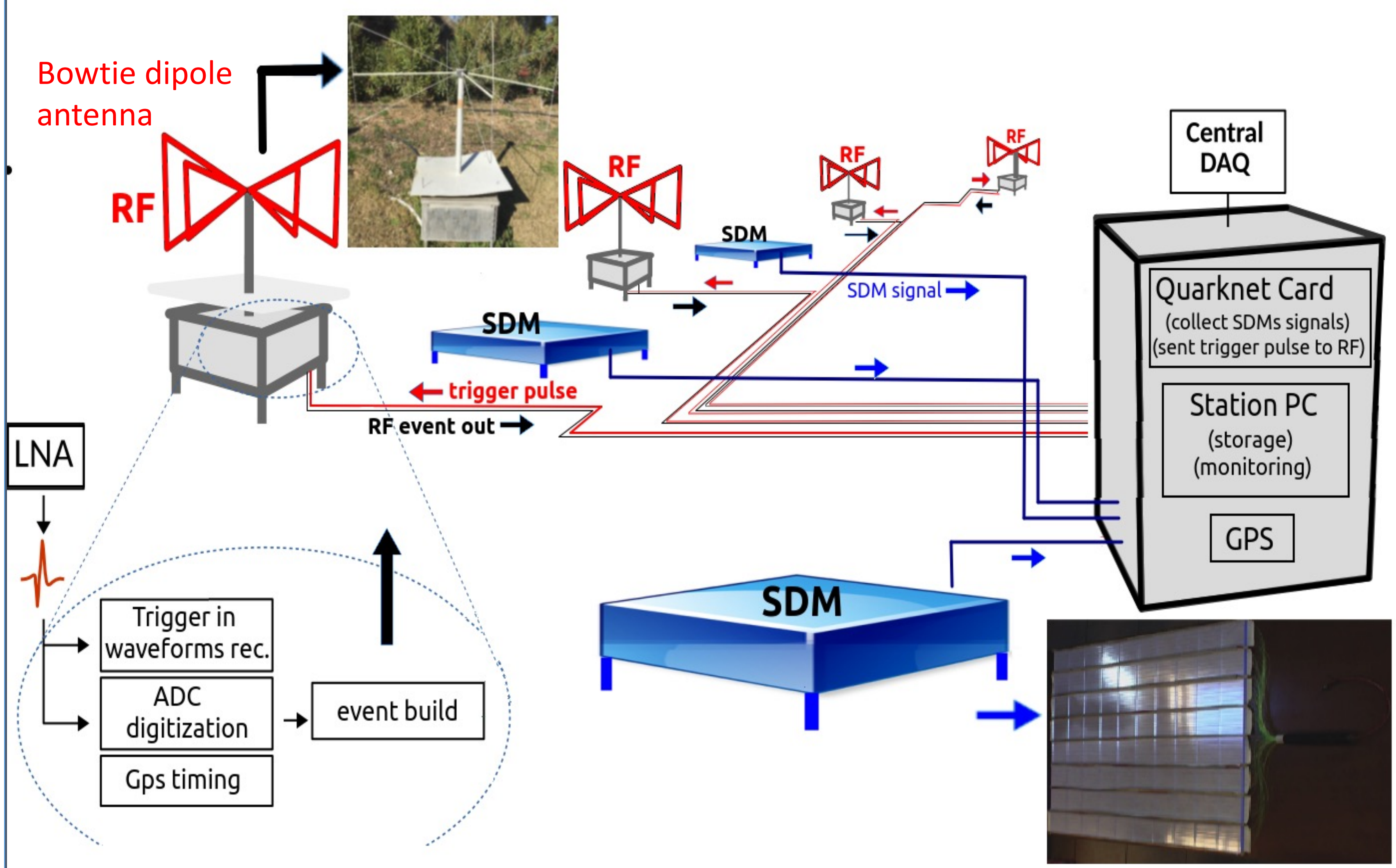


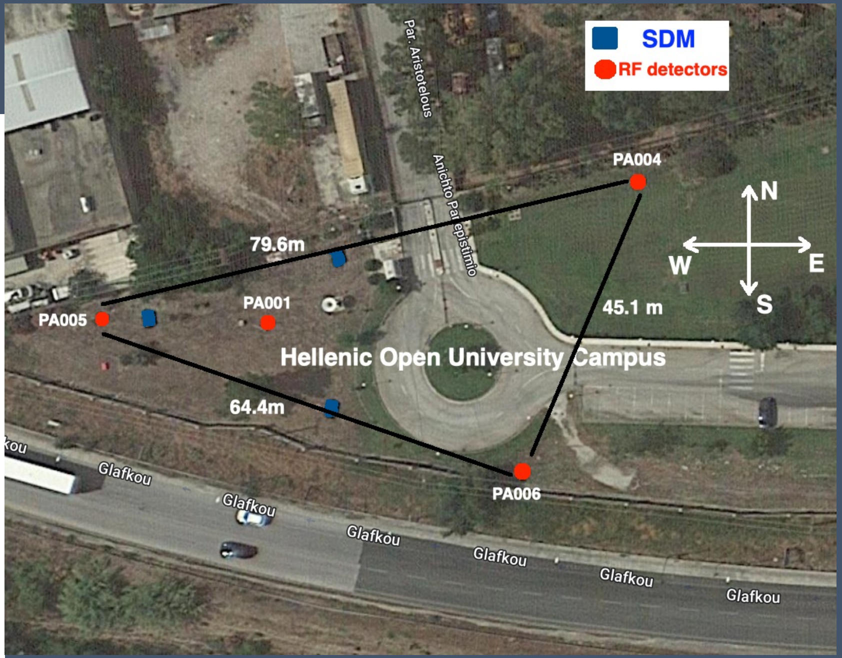

- Two mechanism polarized in different directions
- $\vec{E}_{geo}$ independent the point of observation
- $\vec{E}_{ch}$ direction to the shower core



# ASTRONEU Air Shower Telescope

## Instrumental Setup of ASTRONEU




### The experimental site - HOU campus

- 3 Stations
- Hybrid Air Shower detection
- Both particle (Scintillator Detector Modules) and RF (antennas) detectors.
- Station A → 3SDM-4RF

# RF Analysis – Event Selection

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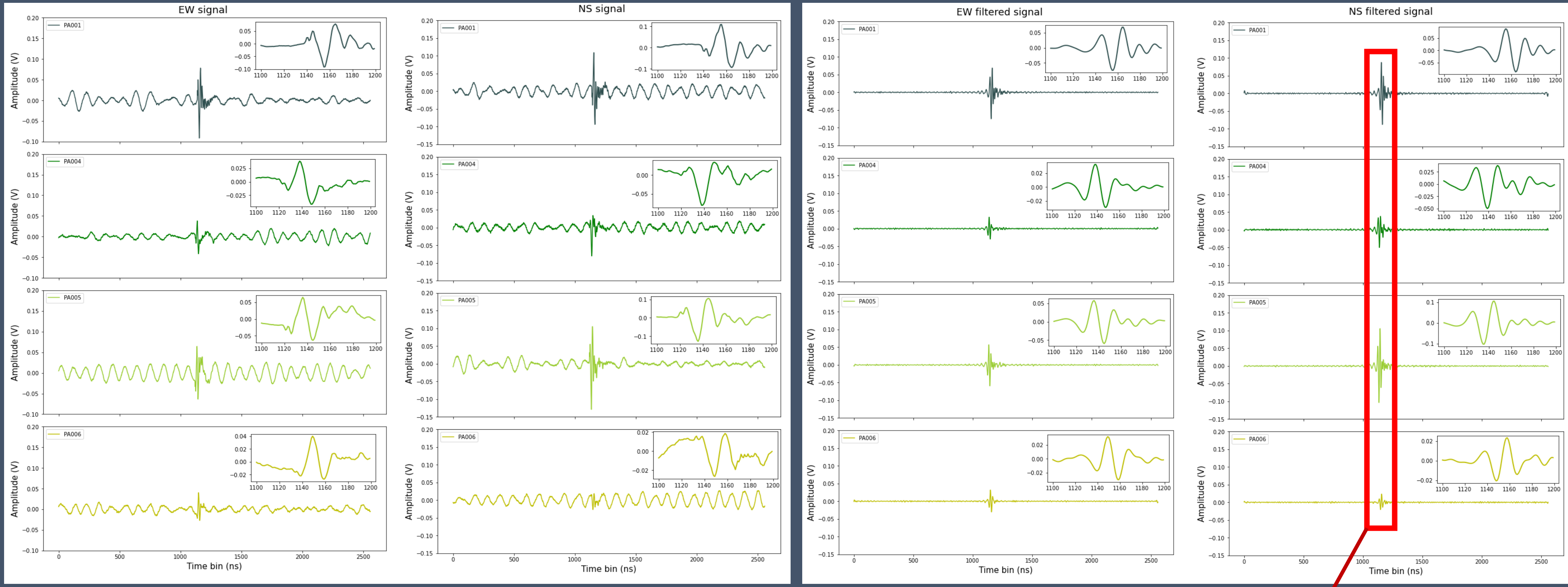
## Standard offline RF analysis pipeline



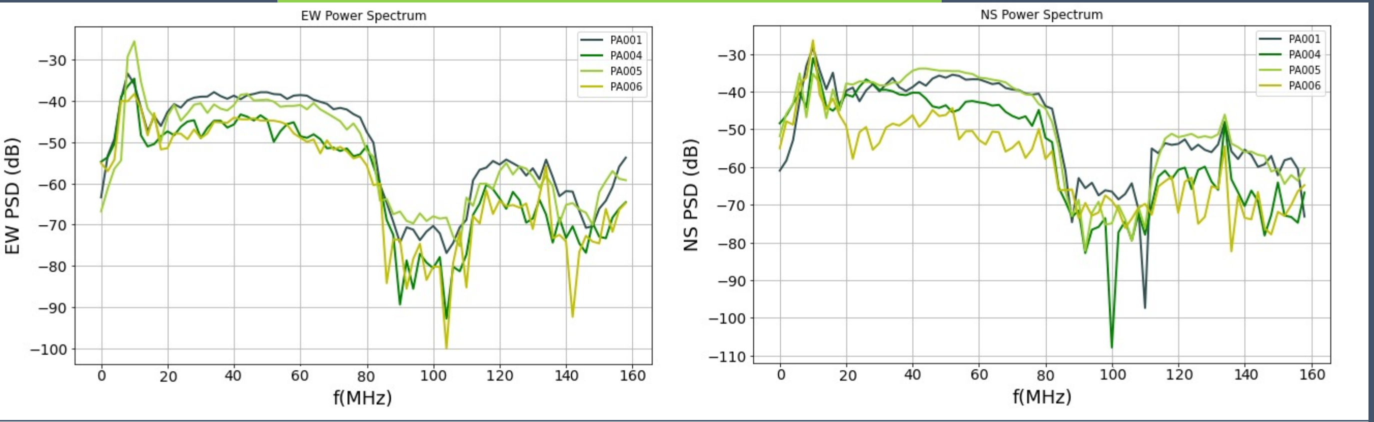

Signal filtering in 30-80 MHz → Signal to noise Ratio (SNR) calculation : SNR ≥ 6

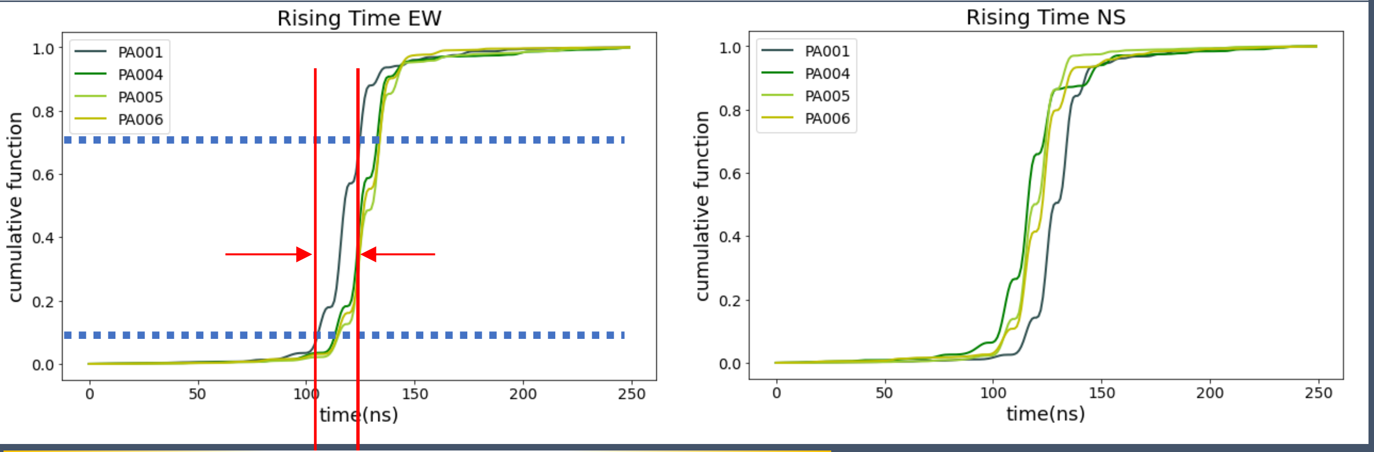
Signal window 250ns around the peak

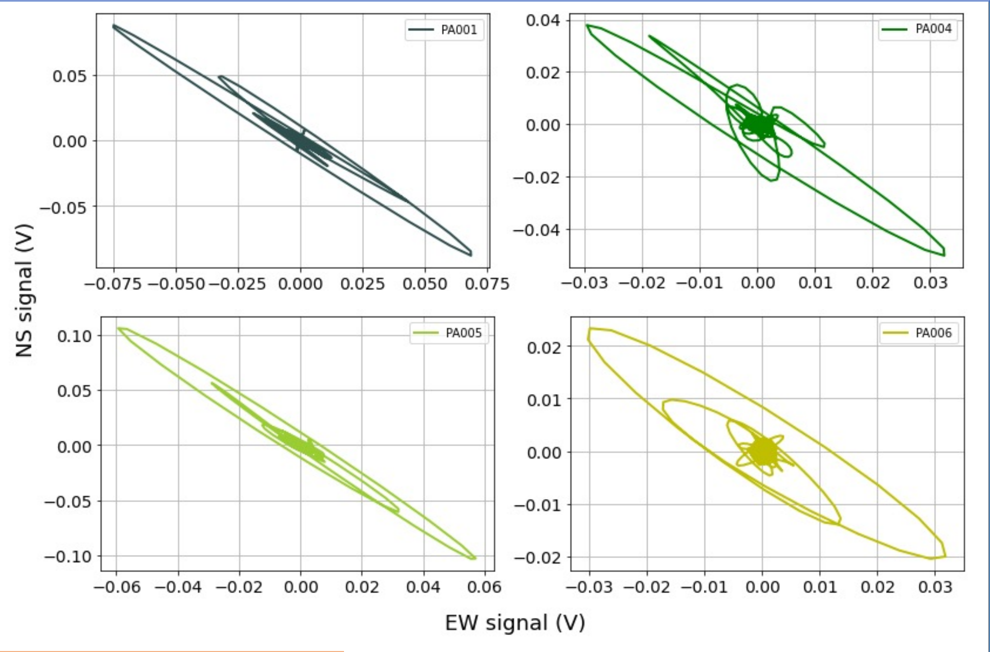
# RF Analysis – Event Selection



## Power Spectrum in 20-160 MHz




Rising Time = $R_t$=C(70%)-C(10%) ≤ 28 ns

$$C(i) = \frac{\sum_{k=1000}^{1000+i} V(k)^2}{\sum_{k=1000}^{1500} V(k)^2}$$

Reconstruction of zenith (θ) and azimuth (ϕ) angles of shower's axis.

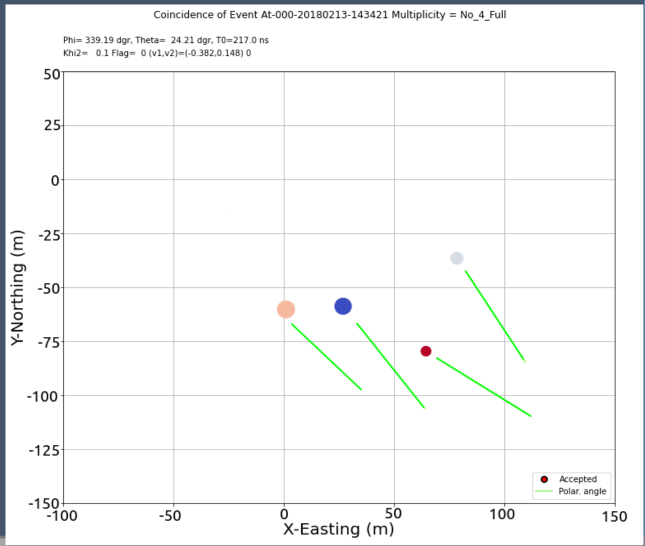
Polarization angle:
The angle between the Semi-major axis and EW direction

$$\tan(\varphi_p) = \frac{U}{Q} = \frac{E_{ns}}{E_{ew}}$$

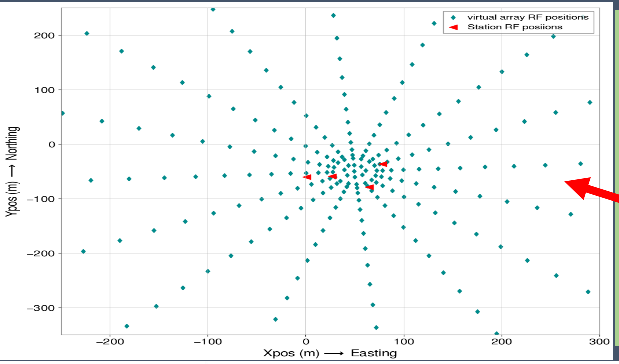
Degree of polarization

$$p = \frac{\sqrt{Q^2 + U^2 + V^2}}{I} \geq 0.85$$

Stokes parameters U,Q,V,I



# EAS Core Reconstruction – The method

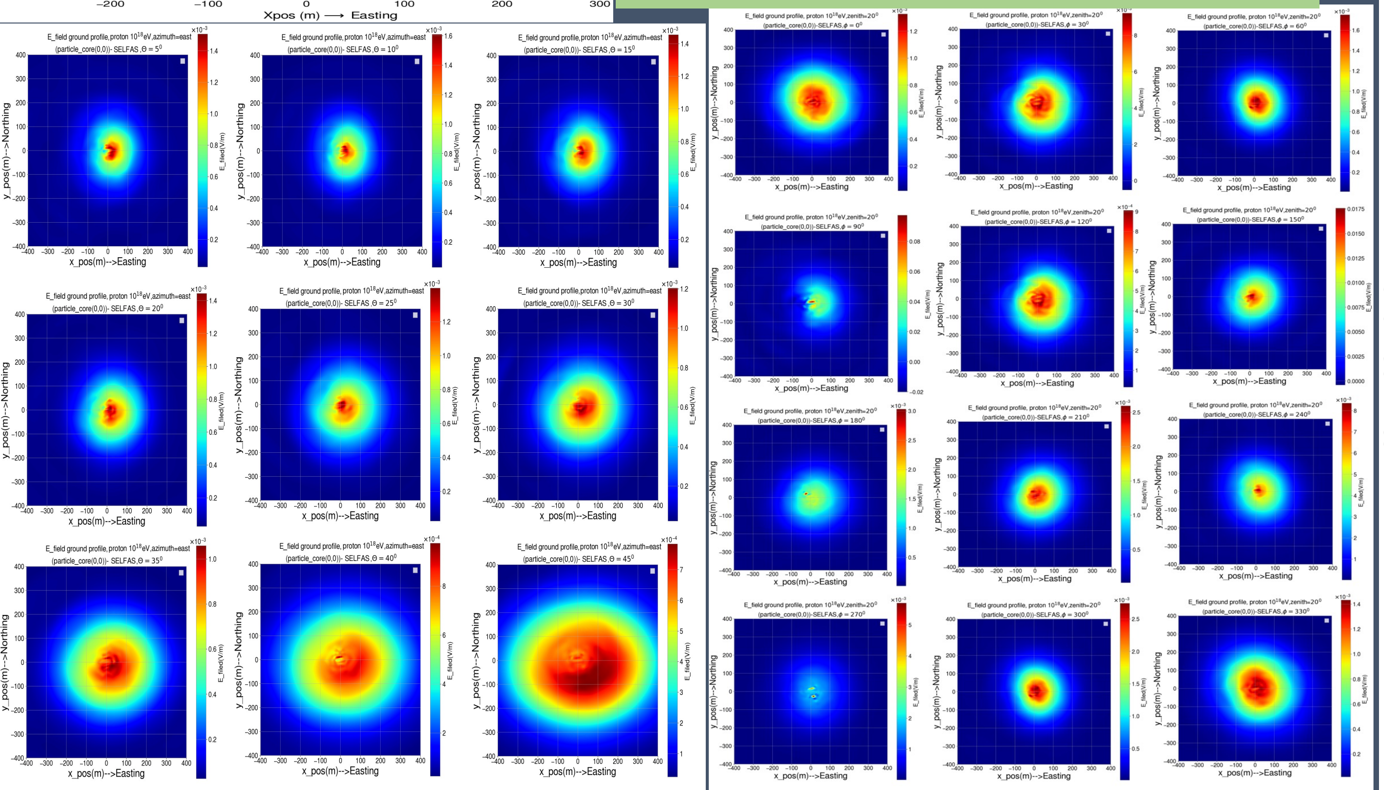



60 simulations (40p, 20Fe) with fix Energy, core and θ, ϕ (event) in a reasonable range of $X_{max}$, for a dense virtual array.
Calculate the average electric field map on the ground.

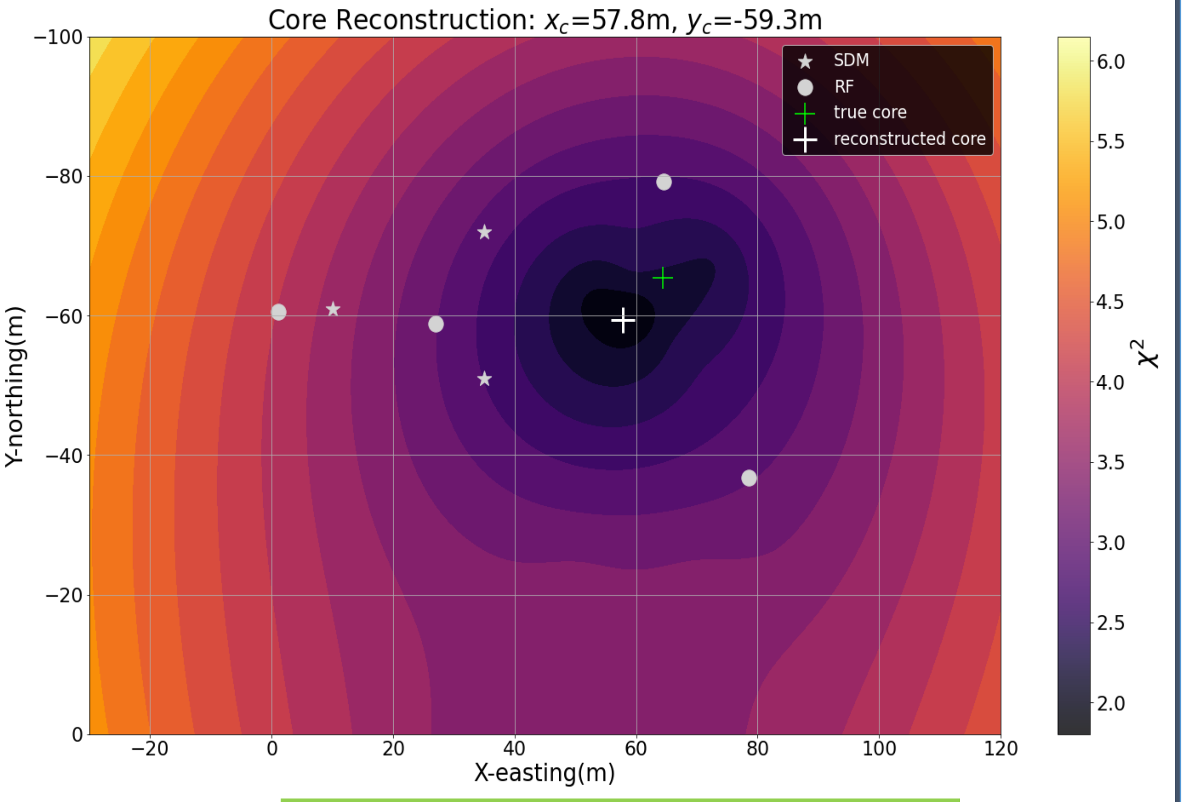
Moving the core and calculate the quantity $\chi^2$

$$\chi^2 = \sum_{i=1}^{N_{ant}=4} \left(E_{data}(x_{ant_i}, y_{ant_i}) - E_{sim}(x_{ant_i}, y_{ant_i})\right)^2 / \sigma_i^2$$

The minimum of $\chi^2$ correspond to the shower core.



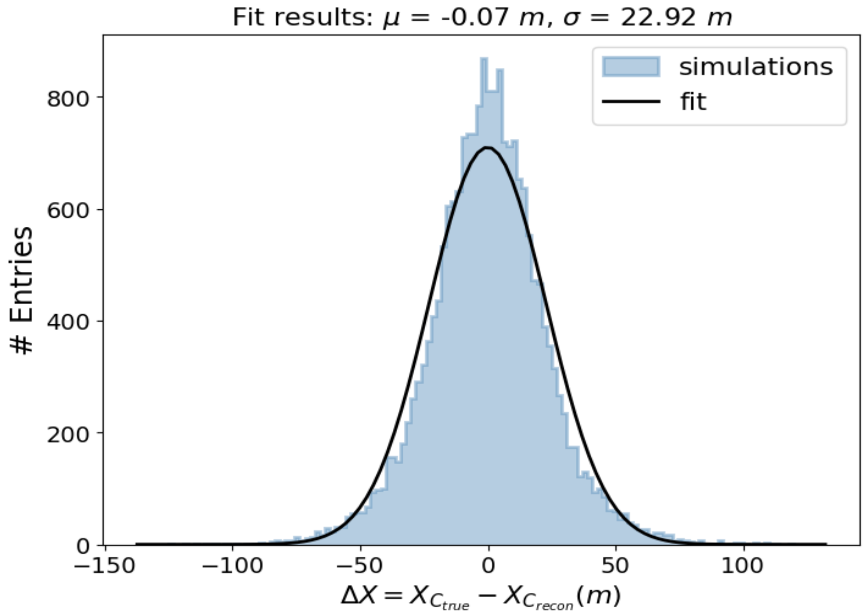

Average Electric field Map for different zenith and azimuth angles

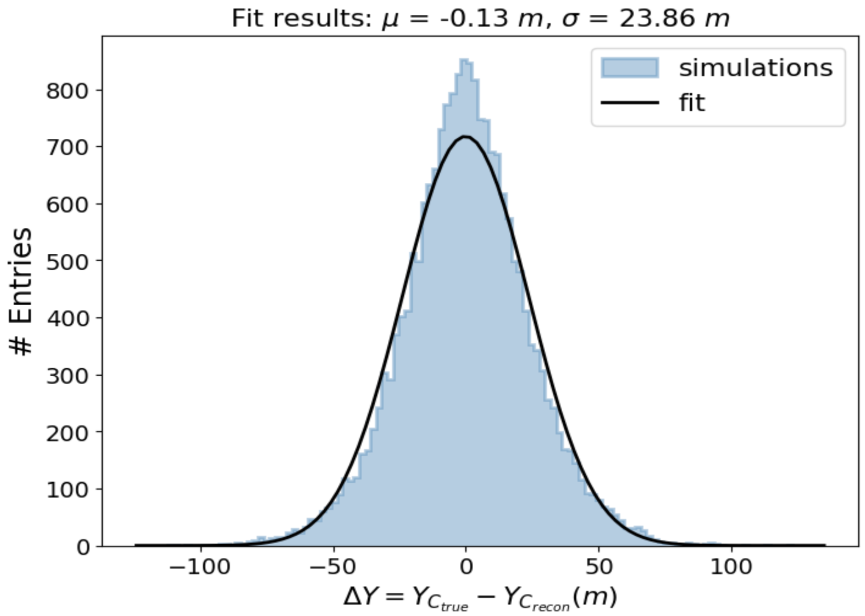



Example of core reconstruction

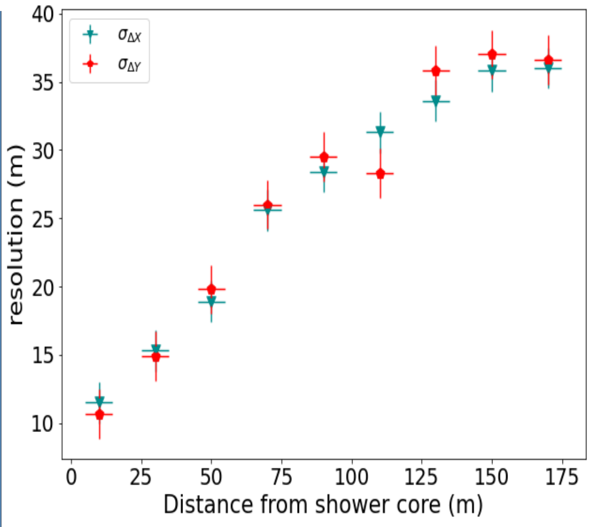
# EAS Core Reconstruction – Results

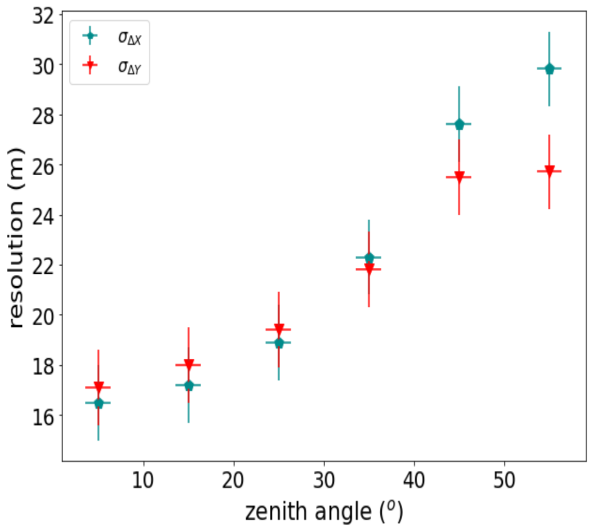


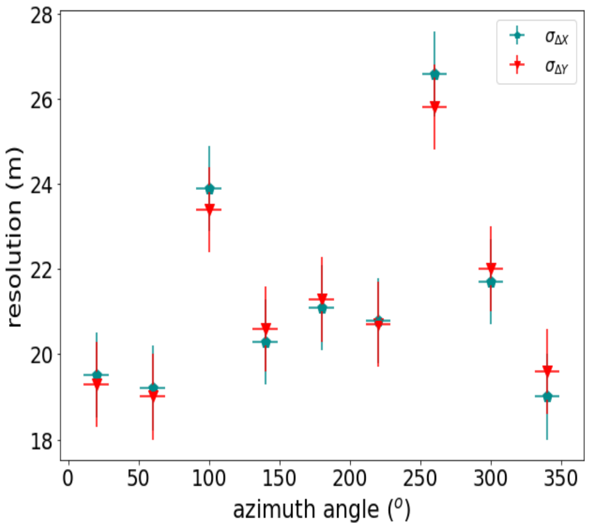



- 20500 events from simulations (Corsika-Selfas-Convolution with antenna response-Add background noise
- The true core is known and is distributed in a radius of 200m around the station's center
- $\Delta X = X_{C_{true}} - X_{C_{recon}}$ and $\Delta Y = Y_{C_{true}} - Y_{C_{recon}}$ distributions




- Core coordinates resolution as function of the distance from shower core, the zenith and azimuth angle

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# Charge Excess to Geomagnetic Ratio (CGR) calculations

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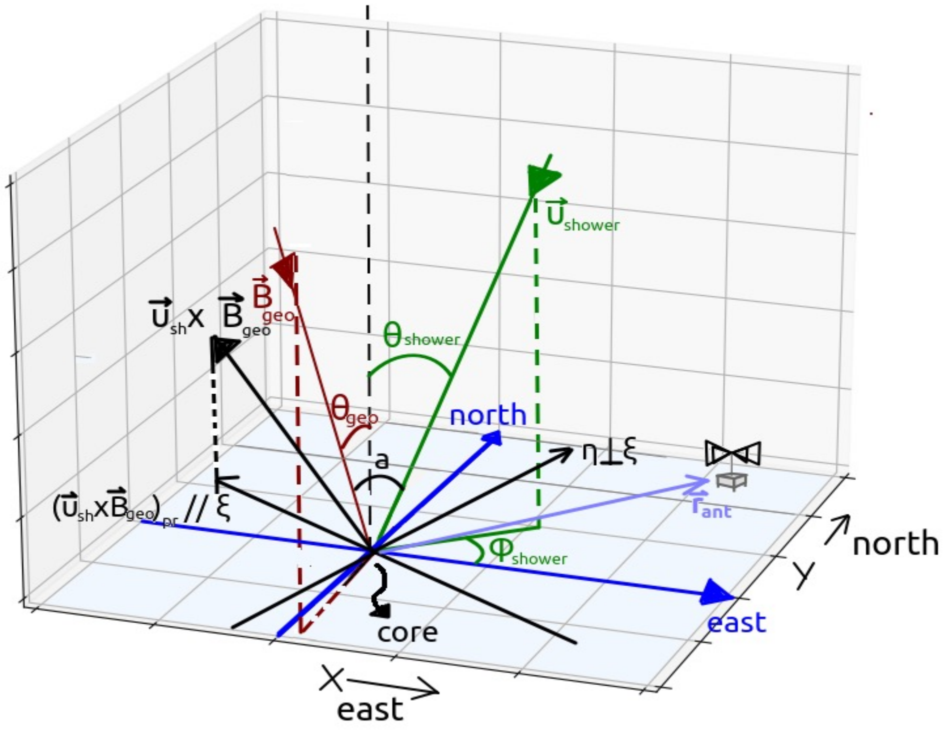
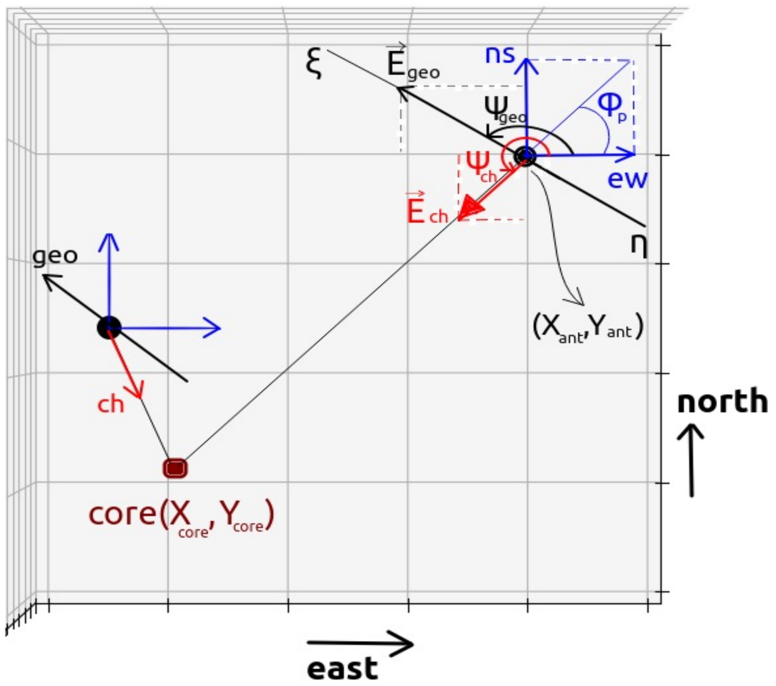



- The measured components of the electric field $|E_{ew}|$ and $|E_{ns}|$ can be expressed as a function of the two contributions.

$$E_{ew} = E_{geo}cos\psi_{geo} + E_{ch}cos\psi_{ch}$$
$$E_{ns} = E_{geo}sin\psi_{geo} + E_{ch}sin\psi_{ch}$$

Charge excess to Geomagnetic Ratio (CGR)

$$CGR = \frac{|E_{ch}|}{\frac{|E_{geo}|}{|sina|}} = \frac{|E_{ch}|}{|E_{geo}|}|sina|$$

α: Geomagnetic angle

- $$\frac{|E_{ns}|}{|E_{ew}|} = \frac{\left|sin\psi_{geo}+\frac{CGR}{|sina|}\cdot sin\psi_{ch}\right|}{\left|cos\psi_{geo}+\frac{CGR}{|sina|}\cdot cos\psi_{ch}\right|}$$, for $sin\psi_{ch}$, $cos\psi_{ch}$: $sin\psi_{ch} = \frac{Y_{core}-Y_{ant}}{r_{ant}}$, $cos\psi_{ch} = \frac{X_{core}-X_{ant}}{r_{ant}}$, $r_{ant} = \sqrt{(X_{ant}-X_{core})^2 + (Y_{ant}-Y_{core})^2}$

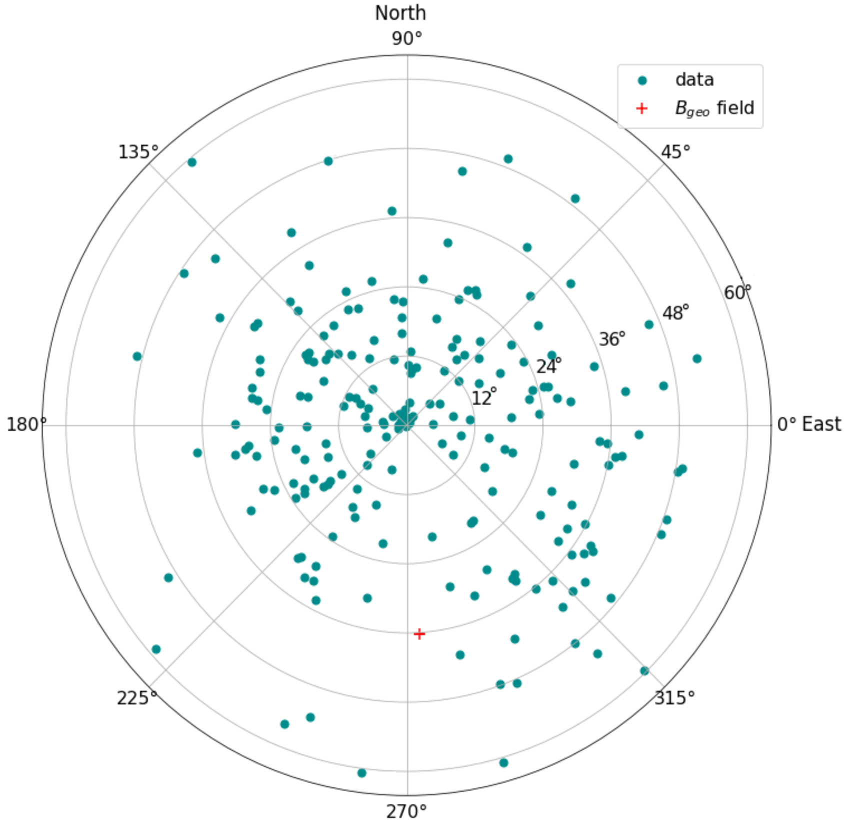
- The projection $\vec{v}_{sh}\times\vec{B}_{geo}$ in the ground, $cos\psi_{geo} = \left(\hat{e}_{v_{sh}}\times\hat{e}_{B_{geo}}\right)_{ew} = sin\varphi_{sh}sin\theta_{sh}cos\theta_{B_{geo}} - sin\varphi_{B_{geo}}sin\theta_{B_{geo}}cos\theta_{sh}$
- $sin\psi_{geo} = \left(\hat{e}_{v_{sh}}\times\hat{e}_{B_{geo}}\right)_{ns} = cos\theta_{sh}cos\varphi_{B_{geo}}sin\theta_{B_{geo}} - cos\varphi_{sh}sin\theta_{sh}cos\theta_{B_{geo}}$, $\theta_{sh}, \varphi_{sh}$ shower zenith, azimuth, $\varphi_{B_{geo}} = 273.54^o$, $\theta_{B_{geo}} = 34.67^o$

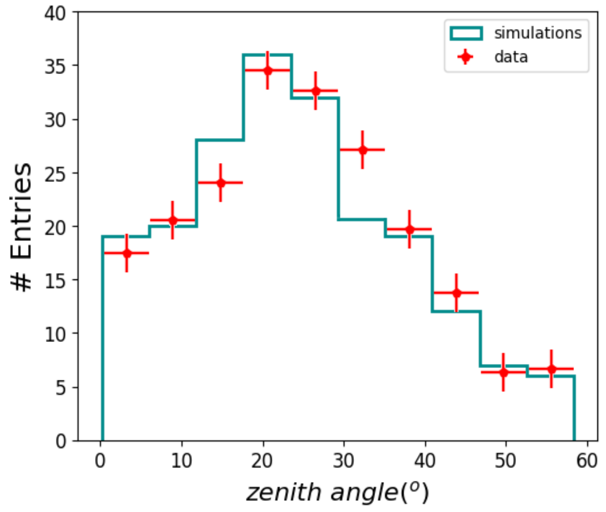
# Charge Excess to Geomagnetic Ratio (CGR)
# Data sample

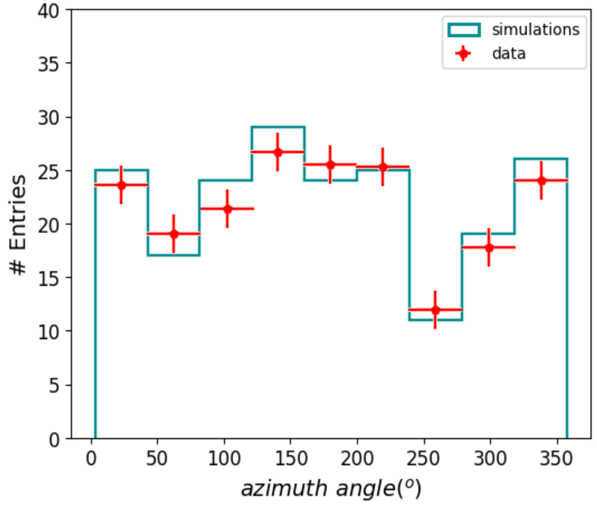


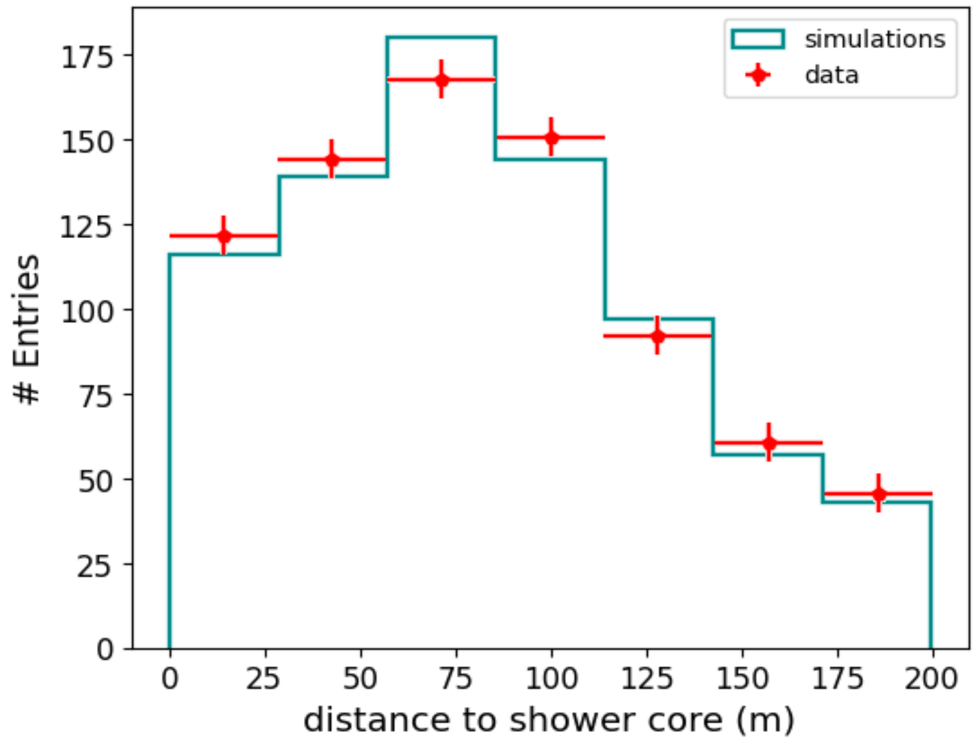
## RF simulations correlation with RF data

- 20500 simulated events with core in a radius of 200 m around the station’s center
- 200 events from 3SDM-4RF station (2017-2021)
- Comparison of the distributions for shower zenith, azimuth angles and distance from shower core.



# Charge Excess to Geomagnetic Ratio (CGR) Results

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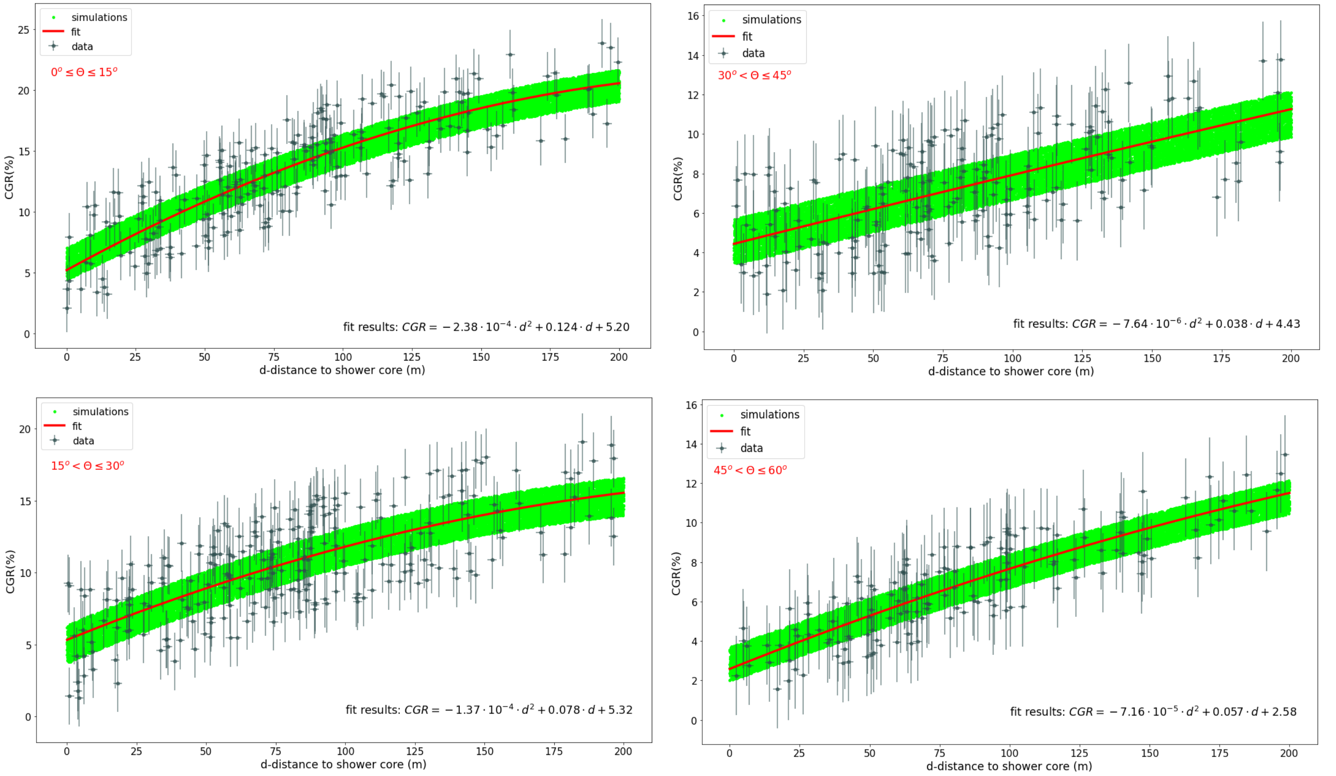
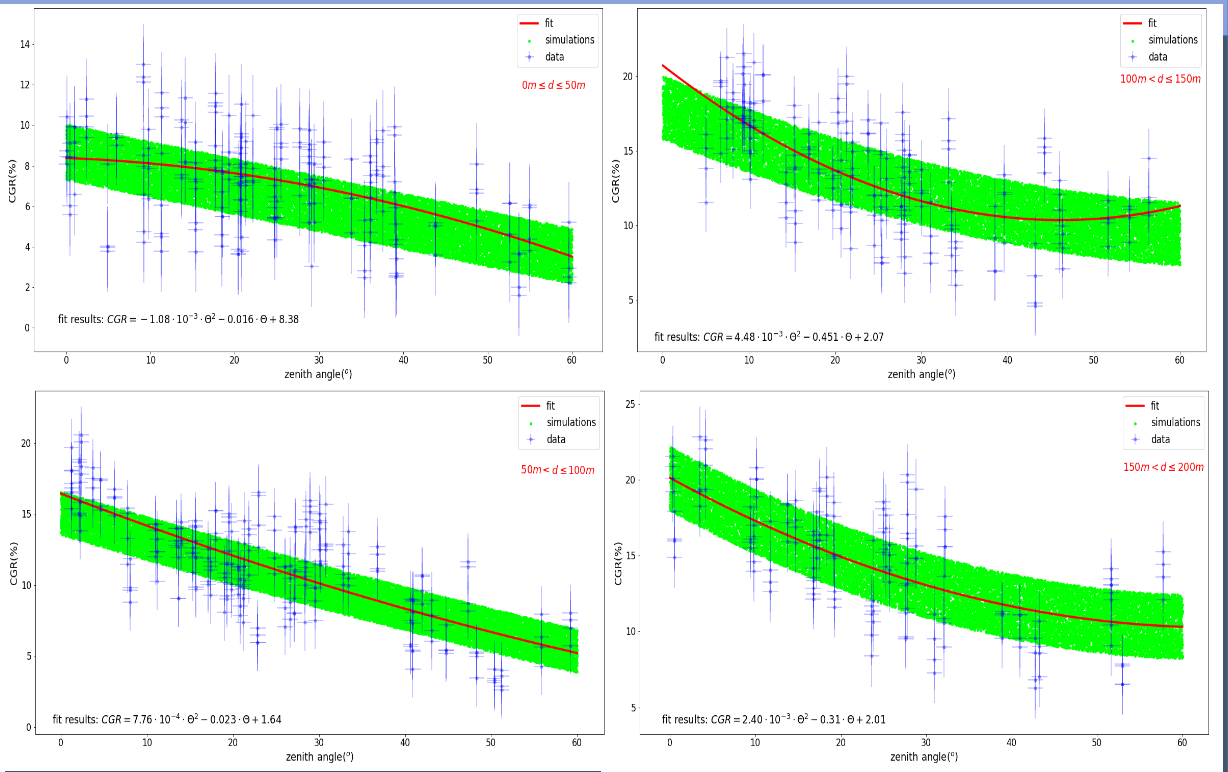
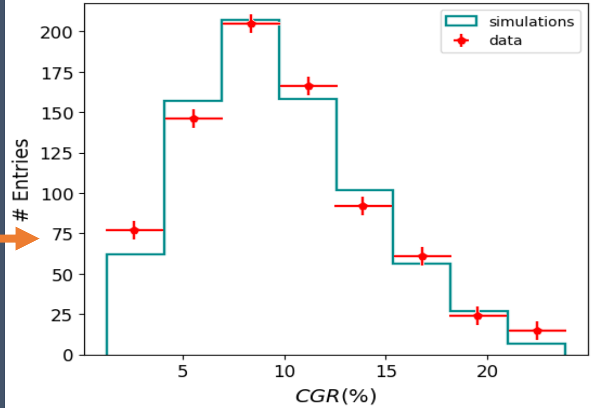



- CGR as a function of distance from shower core for four different zenith angle bins
- CGR as a function of zenith angle for four different distance from core bins
- The measured CGR values range from 3% (inclined shower near the core) to 24% for almost vertical showers at large distances (150-200 m).

- Distribution of the measured CGR as determined from simulations and data.



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# Conclusions & Outlook

- 200 shower events from 3SDM-4RF Astroneu station
- 20500 simulations events (same event selection criteria and analysis with data)
- Reconstruction the shower core using the RF signal and simulations
- Charge Excess to Geomagnetic Ratio (CGR) measurements
- Good agreement between data and simulations indicate that the method for core reconstruction is efficient
- CGR measurements can be used for an efficient noise rejection algorithm in a future self trigger mode
- CGR analysis can be used for RF detection in showers developed in dense media (Charge Excess mechanism is the main contribution in these cases)

Thank you for listening !!