Influence of atmospheric electric fields on air-shower radio emission measured with AERA

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PIERRE AUGER OBSERVATORY

AERA
Auger Engineering Radio Array

Atmospheric Electric Fields

Very hard to parametrize the complex structures inside (thunder)clouds

Fair weather ~ 100 V/m on ground level, thunderclouds with extends of several km up to ~ 100 kV/m

Balloon soundings by Stolzenburg et al. found several layers with interchanging field polarity and variation on rather short time scale

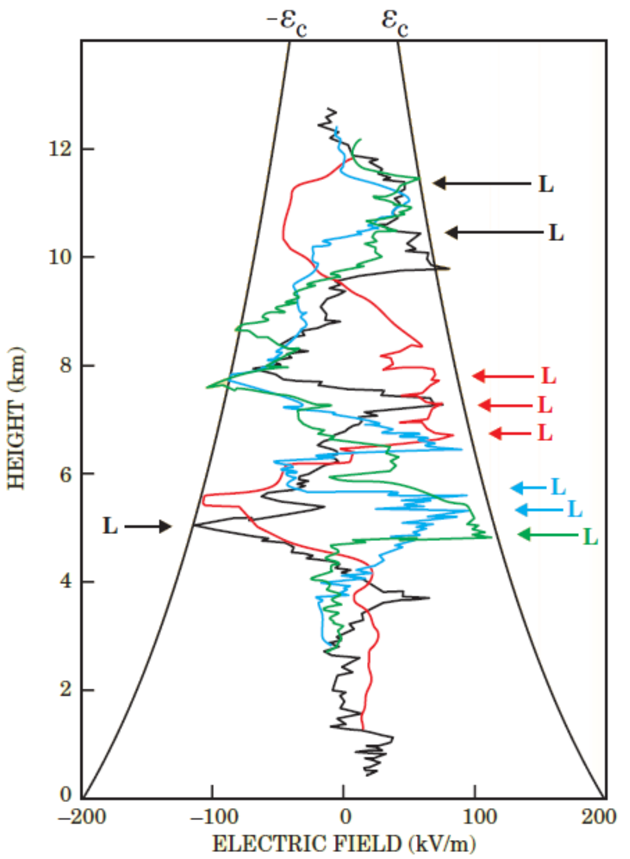
Clear influence of lightnings on field development

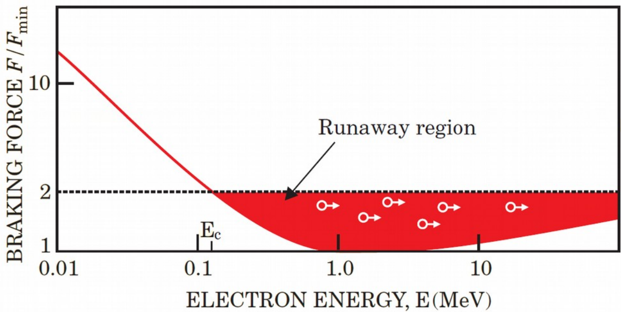
Free electrons from ionization can be accelerated and induce current pulse

Produce large number of slow thermal electrons, but can ionize molecules themselves

Runaway breakdown:

$$\varepsilon_c \approx 100 - 150 \text{ kV/m}$$





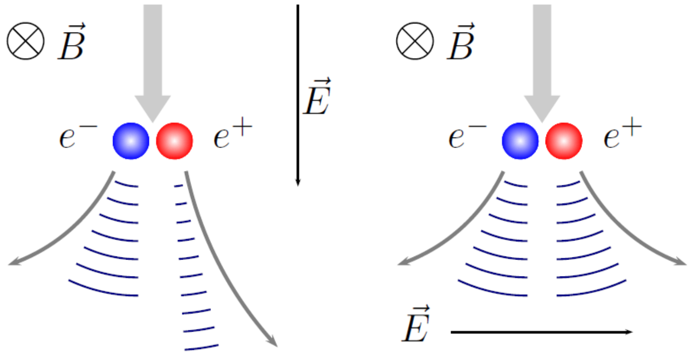
Radio Emission in strong atm. E-Fields

Strong atmospheric fields have significant influence on radio emission due to charge separation and acceleration of ionization electrons (Charman, 1967)

Effect similar to magnetic field

Accelerate only one particle type
→ asymmetry in the trajectory

Parallel: Perpendicular:

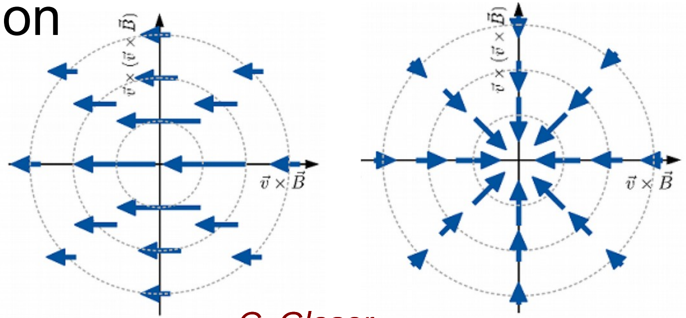


LOPES, Adv. Space Res. 48 (2011) 1295

Electric force in same/ opposite direction of Lorentz force
→ amplification or attenuation

Change in polarization pattern expected due to superposition of particle responses to magnetic and electric field

Altered amount of radially polarized emission due to increased charge excess contribution



C. Glaser

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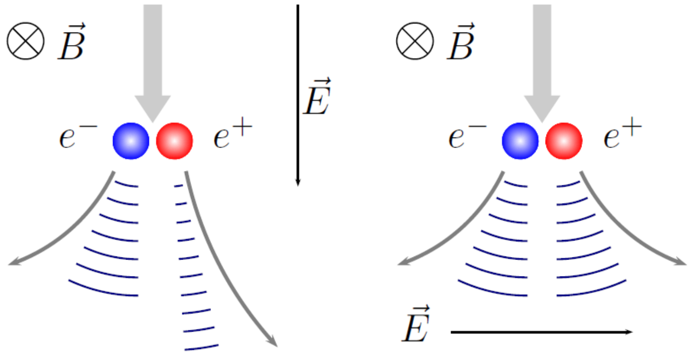

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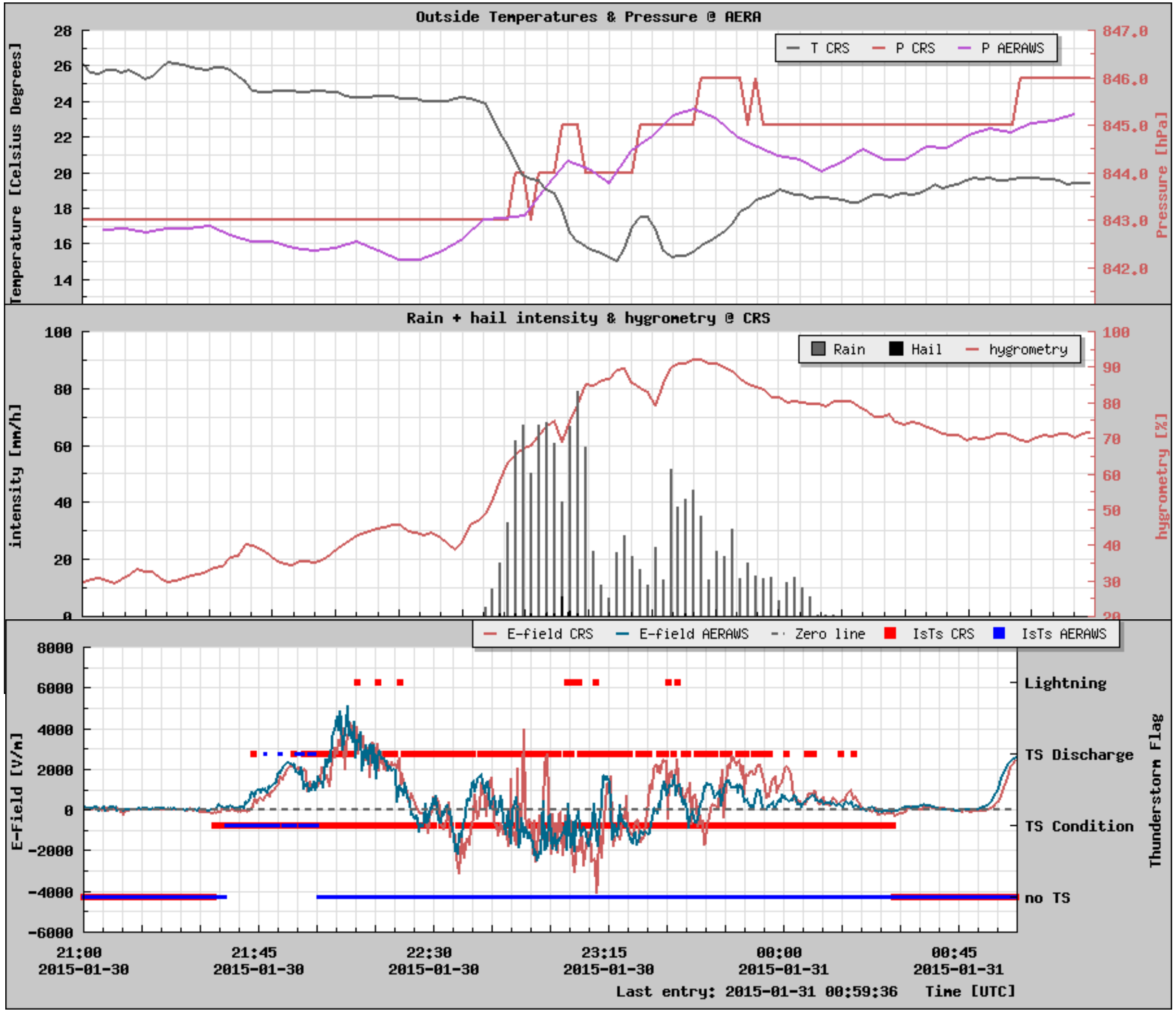
→ amplification or attenuation

Publications for experimental observations (not complete):

- Mandolesi, N., Morigi, G., & Palumbo, G. (1974, J. Atmos. Terr. Phys., 36, 1431)
- LOPES (Astron. & Astroph. 467 (2007) 385-394)
- LOFAR (Phys. Rev. Lett. 114 (2015), 165001)

Weather - Monitoring at AERA

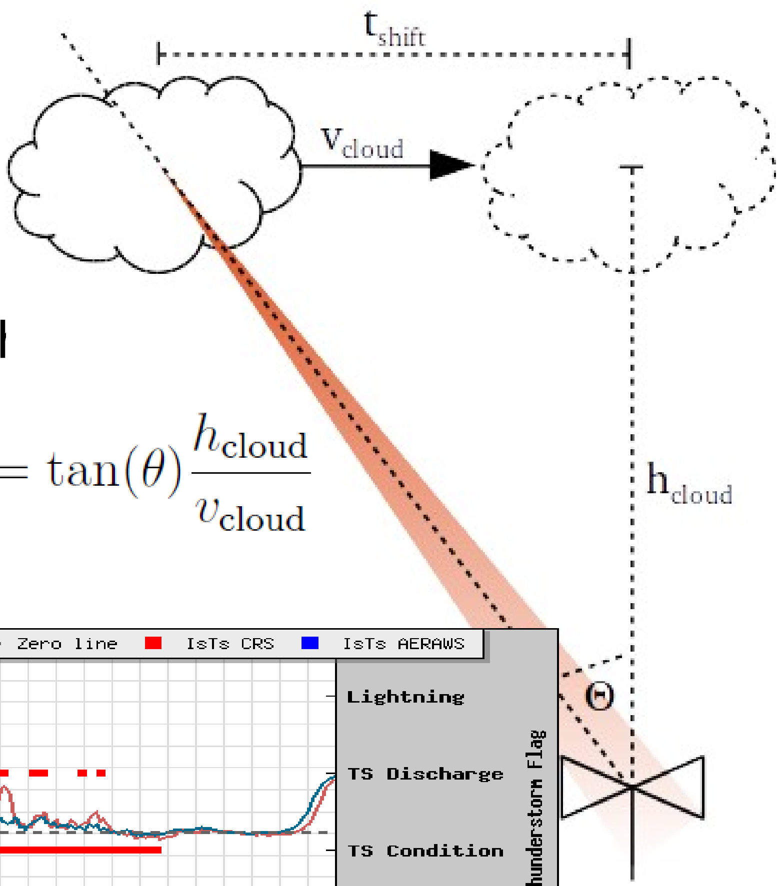


Field Strength Condition

Aim: distinguish ab/normal atmospheric conditions

E-Field measurement on ground, but effect on radiation field strength in emission region

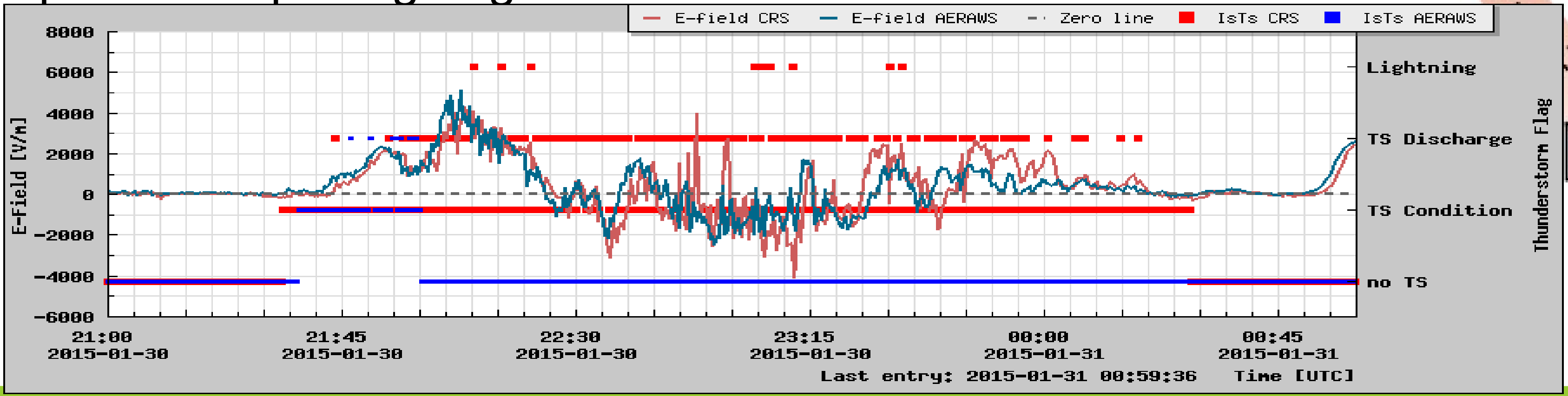
Estimate time interval with respect to shift due to shower inclination as well as cloud velocity and heigl assuming v_{cloud} = 50 km/h and h_{cloud} = 5 km



$$\tau_{\text{shift}} = \tan(\theta)\frac{h_{\text{cloud}}}{v_{\text{cloud}}}$$

Averaging interval: $\Delta\tau = \pm\ 30\ \text{seconds}$

corresponds to opening angle of ~ 10°



Data Selection

- Full set of externally triggered data from AERA Phase II (*measured dataset*)
- All events simulated with Corsika 7.400+CoREAS (iron primary used)
- Reconstructed with RdSimulationObserver
- Reconstructed shower energy compatible (*simulated dataset*)
- Distinct set of event cuts (*full set* vs. *quality set*)

	measured set	simulated set
# total events	**5303**	**4688**
$\theta > 55°$	1236	866
$\Omega > 3°$	562	107
Core not confined	1524	898
# RDS < 5	3170	40
$E_{RD} < 0$	481	16
$E_{RD,err} / E_{RD} > 20\%$	3445	8
$\sigma_{LDF} > 300m$	867	240
σ_{LDF} at ParLimit	304	16
no WS data	644	574
# events left	**450**	**416**

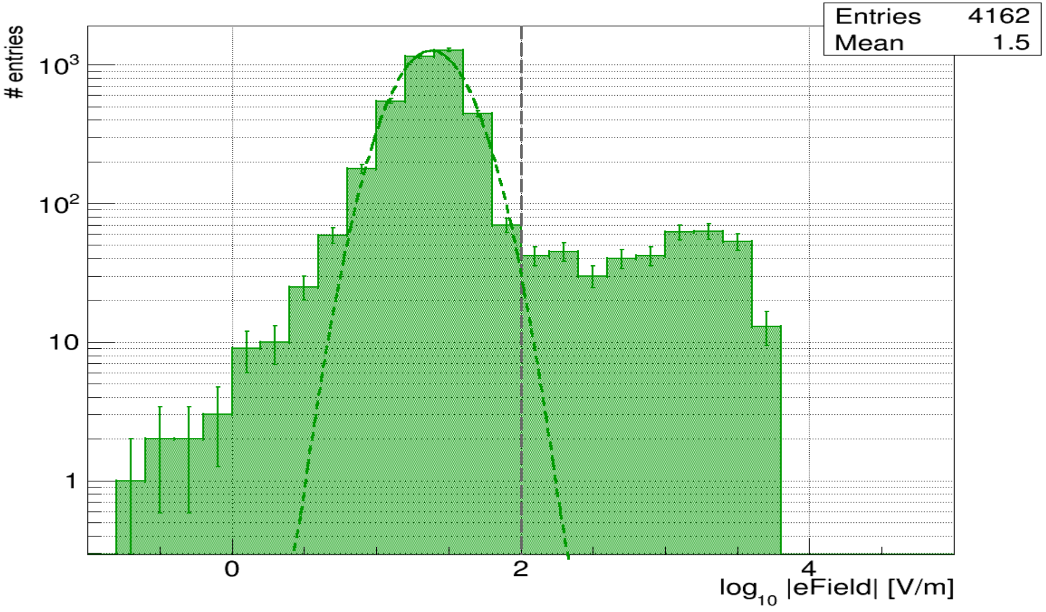
E-Field Threshold Analysis

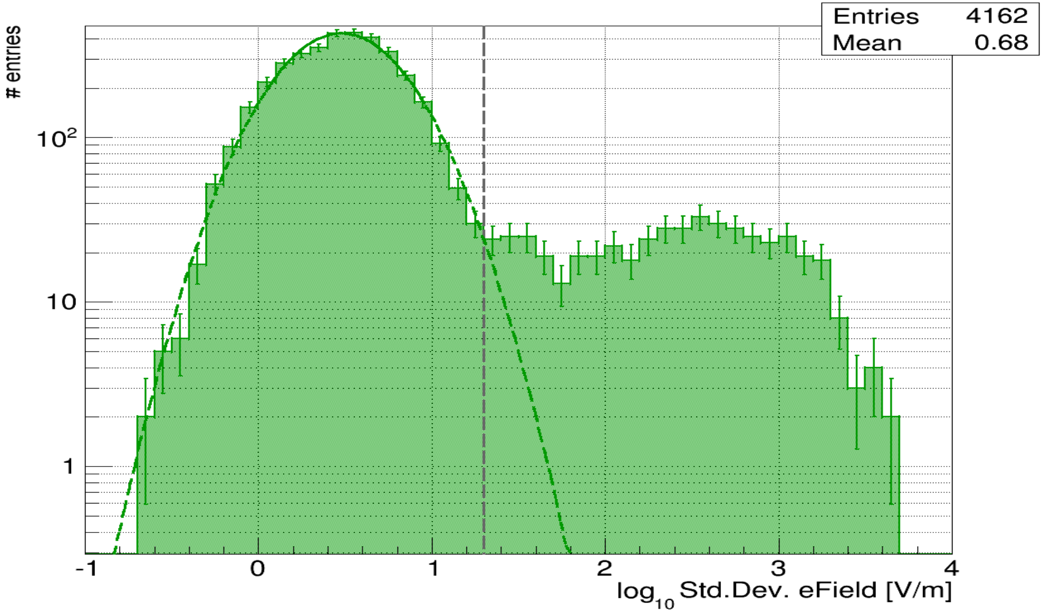
- Most of the events have been measured during normal conditions
- Extreme values up to several kV/m for both polarizations
- Define cuts at:

$$|\varepsilon_{\text{cut}}| \geq 100\ \text{V/m}$$

$$\sigma_{\varepsilon_{\text{cut}}} \geq 20\ \text{V/m}$$

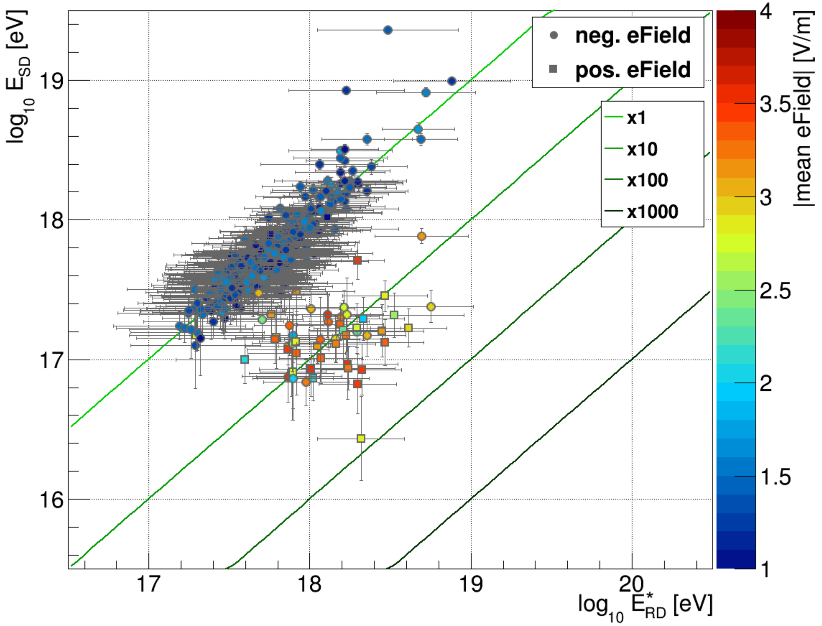
- Strongly correlated „by nature“

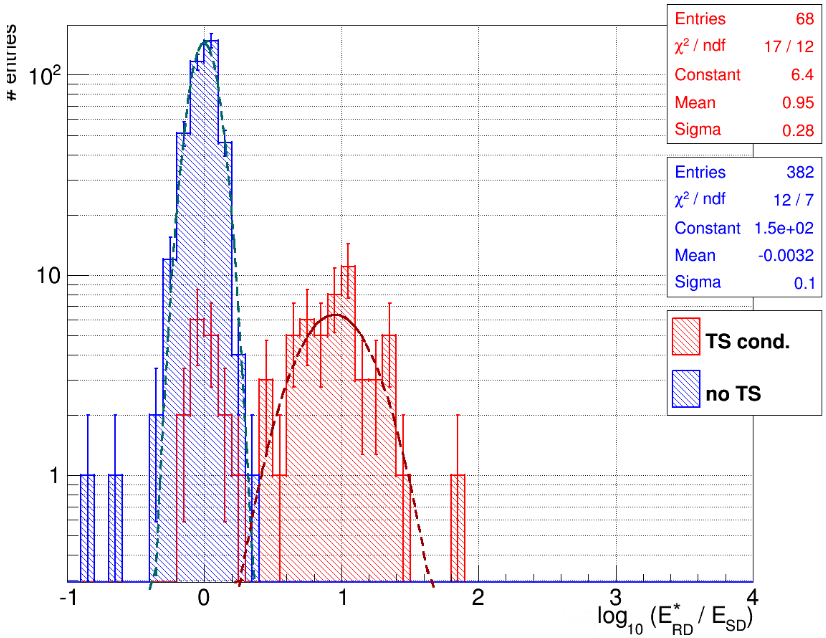




Energy Analysis SD / RD data

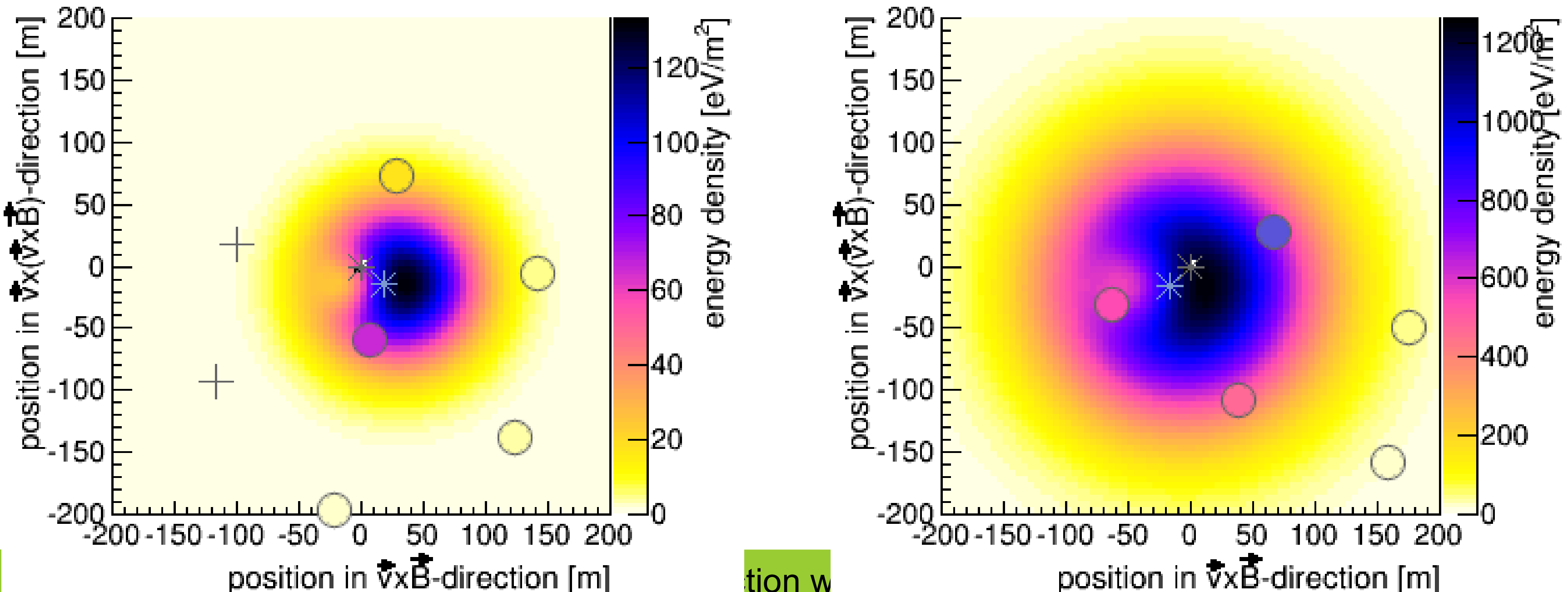
- Nice correlation for events measured during normal conditions, strong increase in reconstructed RD shower energy for TS cond.
- Mean amplification by one order of magnitude
- Many events would normally be below detection threshold
- TS cond. outliers most likely due to mis-identifaction
- No general gradients with respect to precise strength or polarity





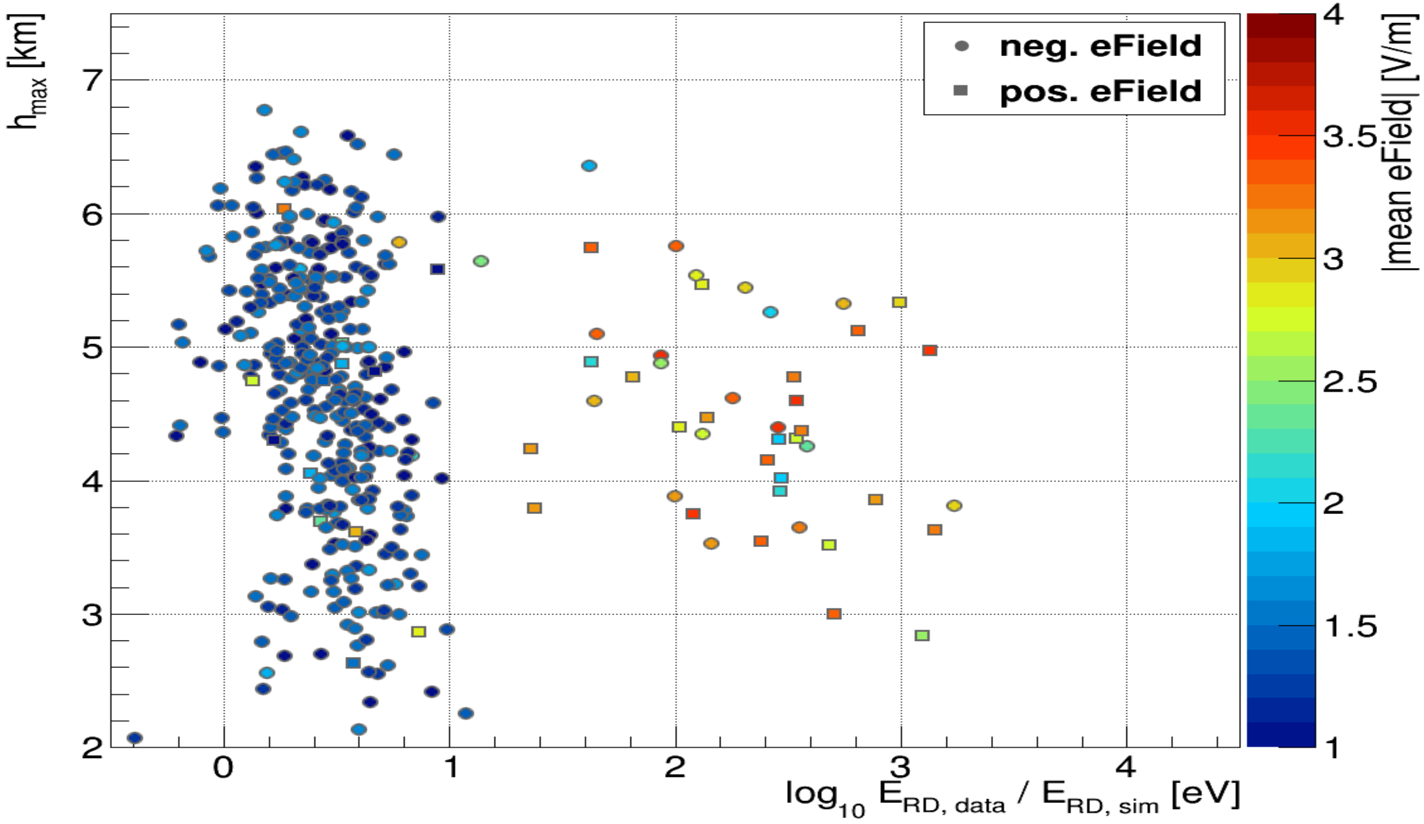
Twin Events

- Twin criteria: $$|\log_{10}(E_{\mathrm{twin},1}) - \log_{10}(E_{\mathrm{twin},2})| < 0.1$$ $$\Omega_{\mathrm{twin}} < 5°$$
- One measured during normal, one during TS conditions
- Signifcant increase in size of footprint (note different color scale)
- Low number of available pairs in this analysis, but promising approach for systematical detector studies (energy resolution, …)



Height of Shower Maximum

- Height of shower mainly between 3.5 km and 6 km
- Slight trend for higher amplification ratios at lower h_{max}



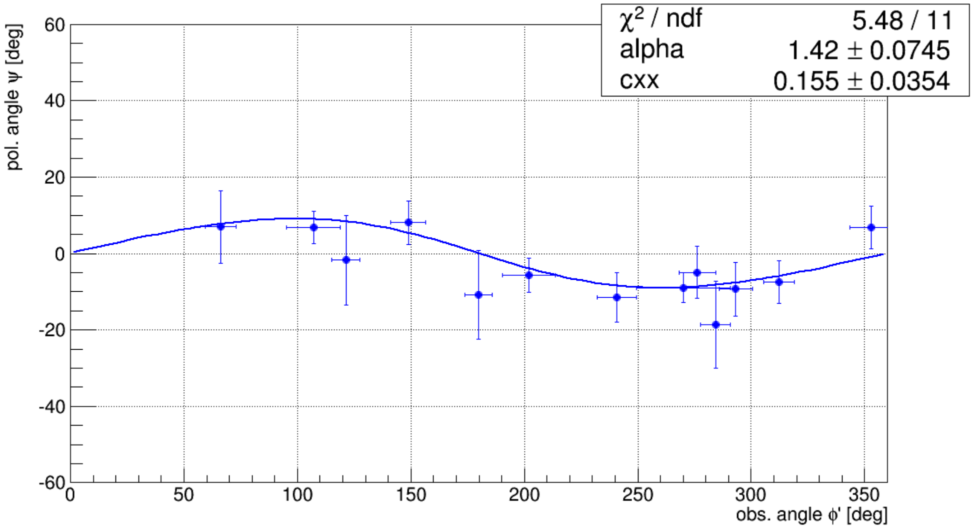
Polarization Pattern

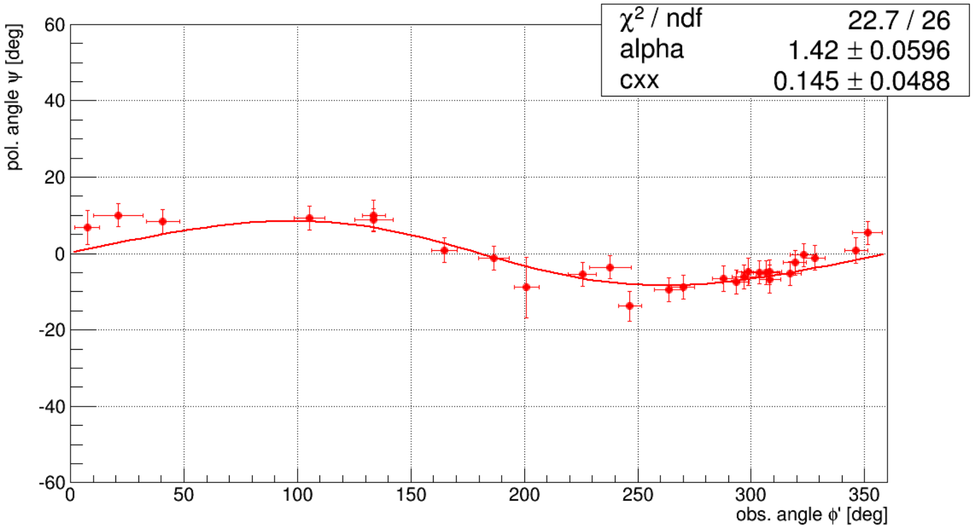
- Angle of polarization from Stokes parameters
- Identical to the one deduced from the emission contributions

$$\psi_p = \frac{1}{2}\tan^{-1}(S_2/S_1)$$

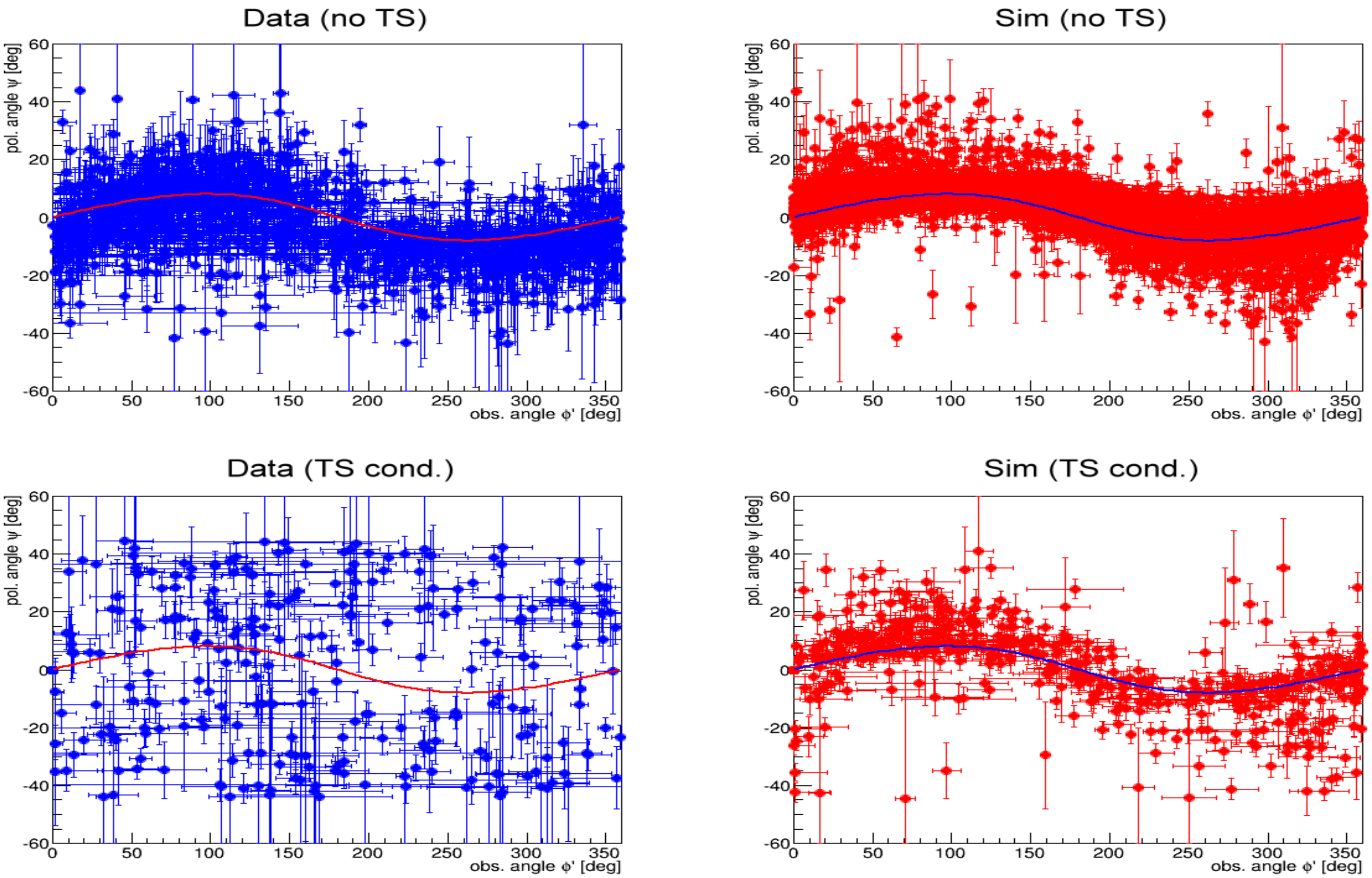
$$\psi = \tan^{-1}\left(\frac{\sin\phi'}{\frac{\sin\alpha}{a} + \cos\phi'}\right)$$

- Good agreement with theoretical expectation for events with normal atmospheric conditions
- Fit charge-excess fraction *a* (for events with sufficient #stations)





Polarization Analysis



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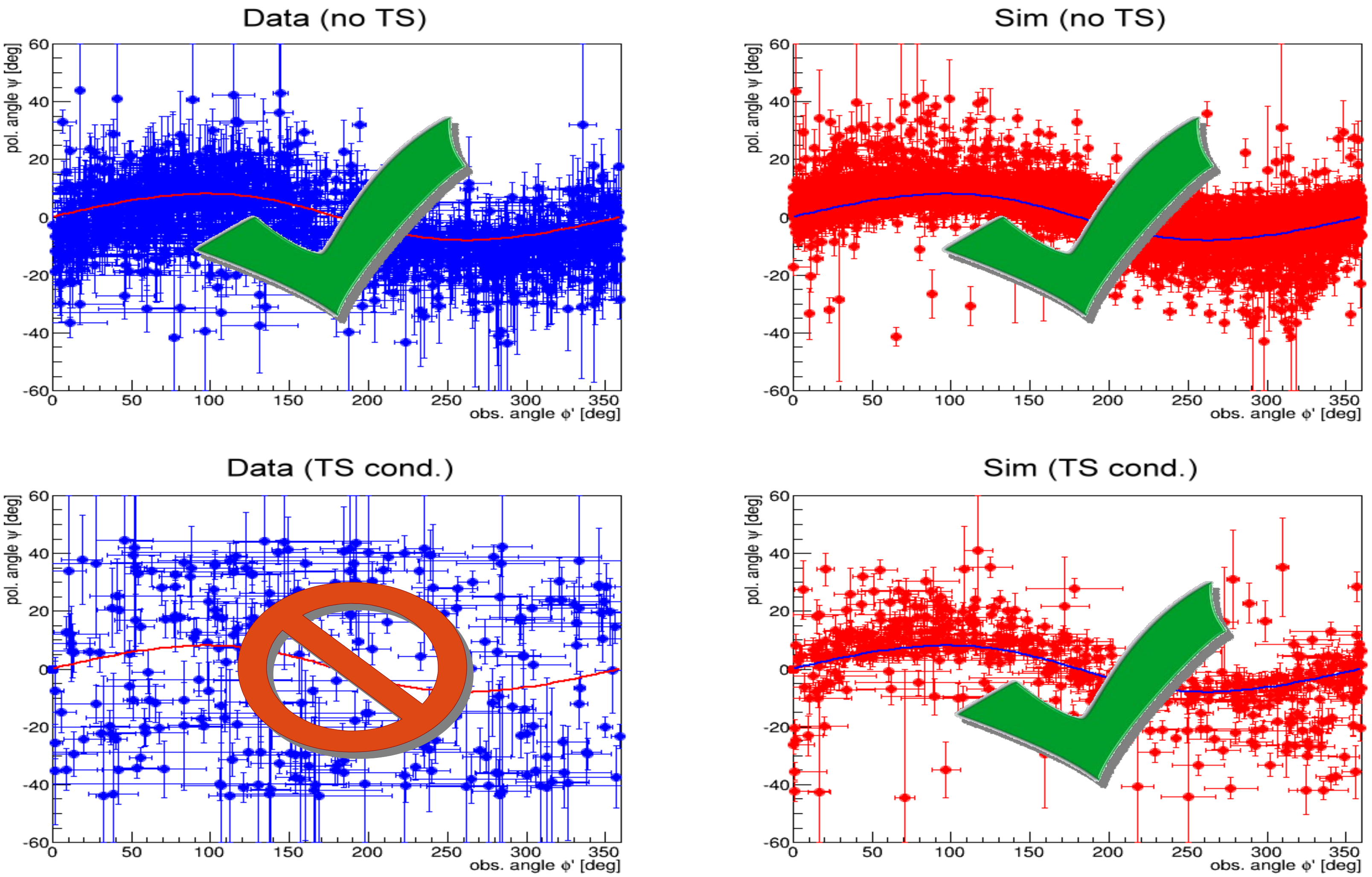
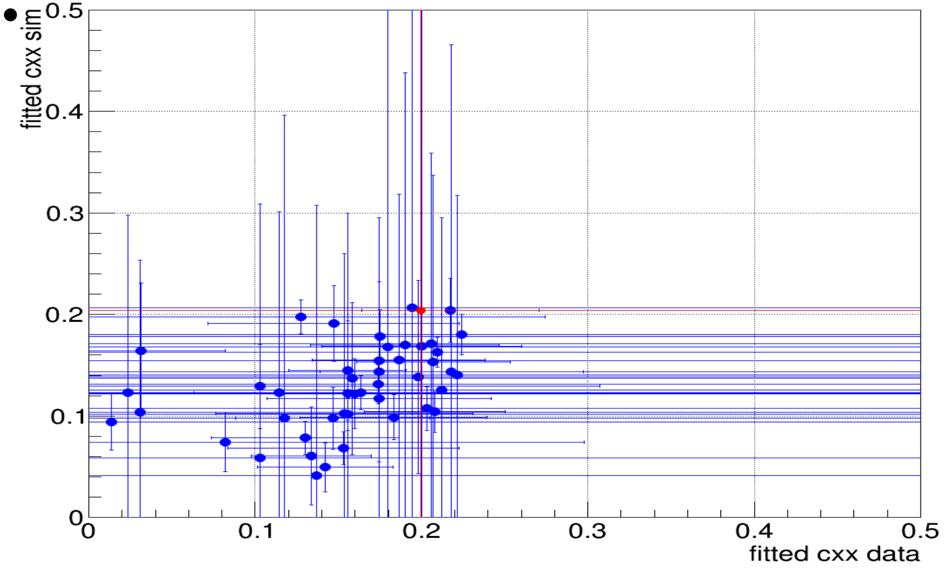
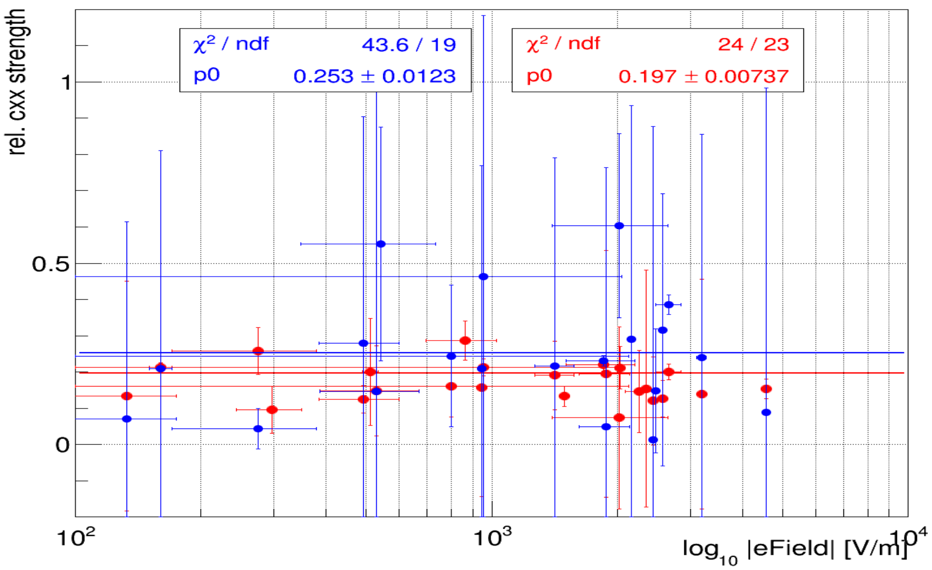
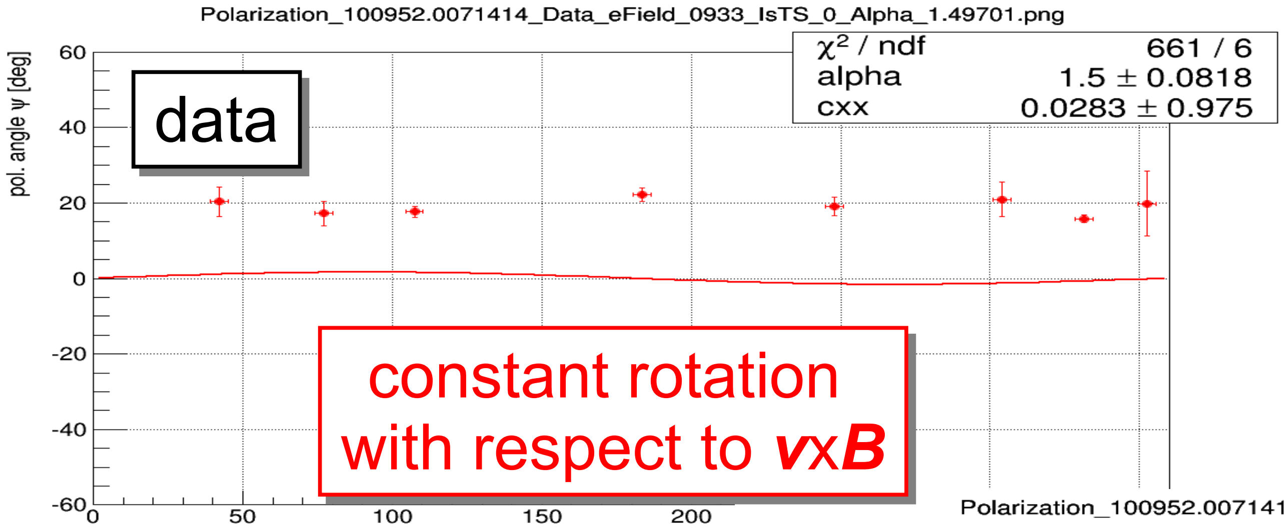


- Charge-excess fraction of *a* = 14 ± 2 % found at AERA
- Here for normal conditions 0 < *a* < 0.3, a_{data} slightly higher
- *a* not a constant value, includes dependencies like shower inclination or distance of the observer to the shower axis
- No statistically significant trend for the charge-excess fraction with increasing strength of the atmospheric field

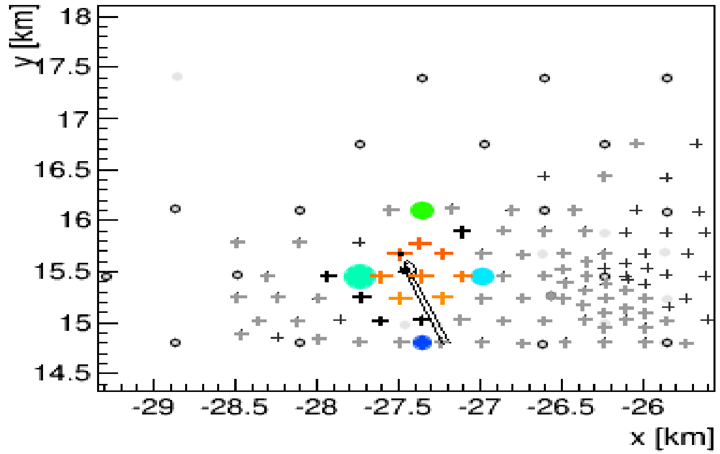


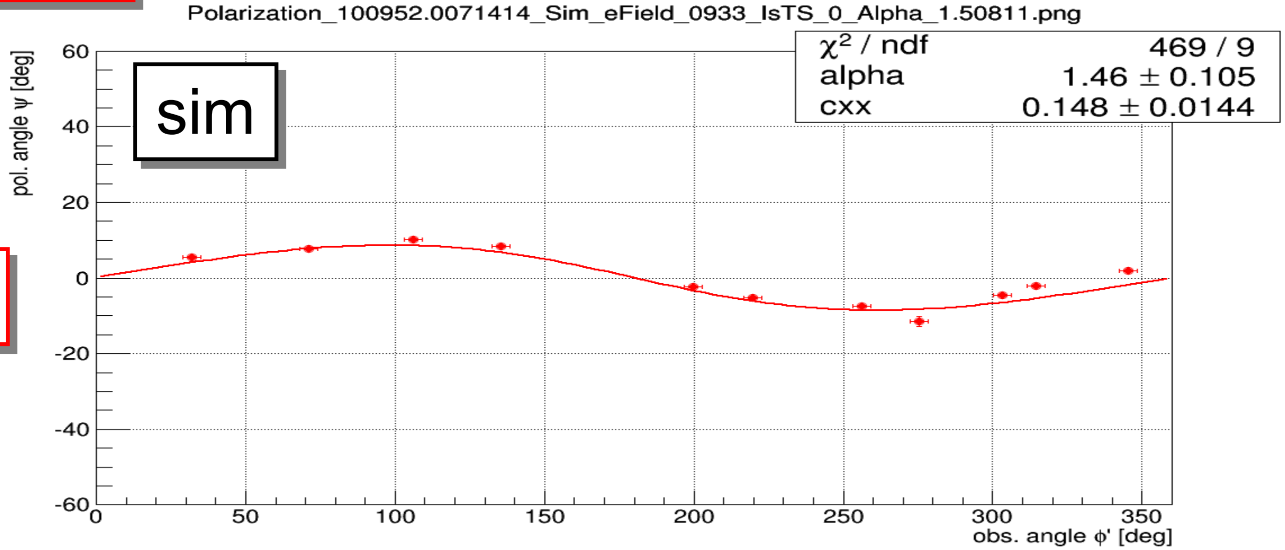


Polarization Example



constant rotation with respect to ***vxB***

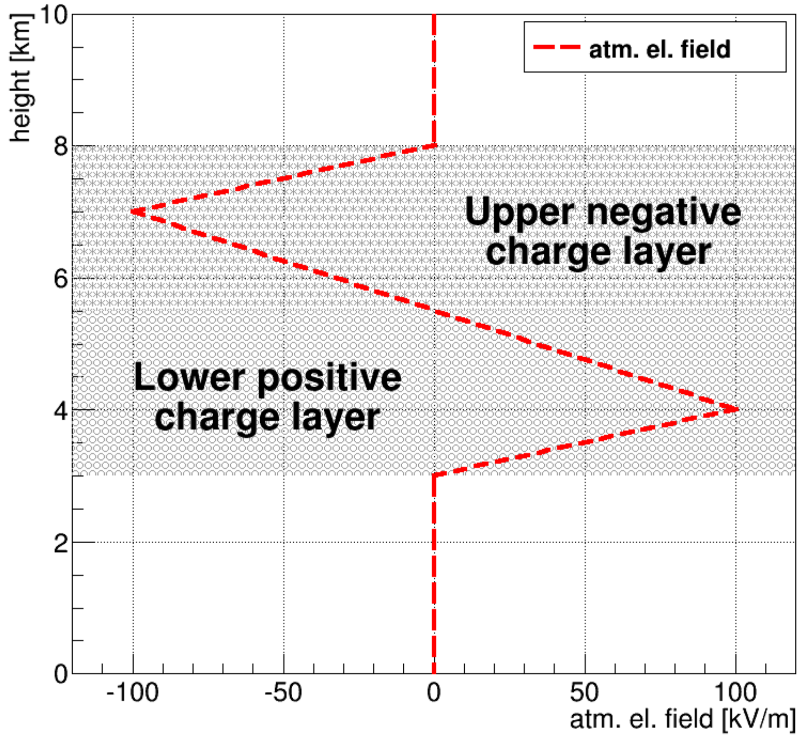




High eField: ~ 930 V/m

Simulation with Electric Field

- Beside basic agreement with expectations, some events were found with a completly different behaviour (not in simulations)
- A (rather poor) model of the atmospheric electric field was added to a re-simulation of some of these events

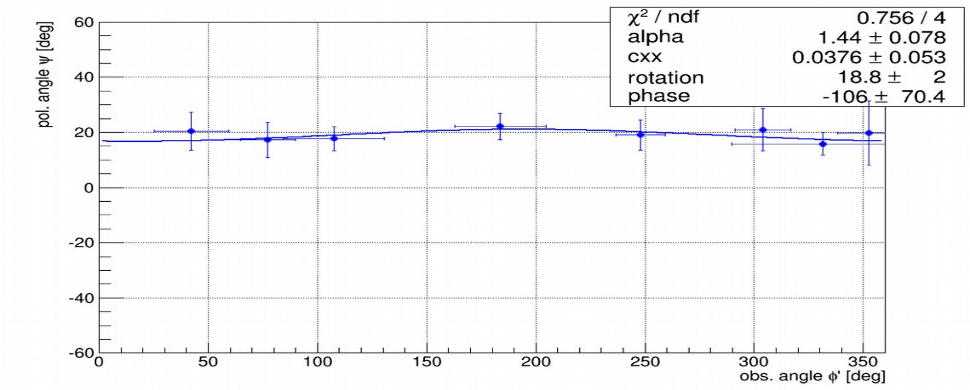


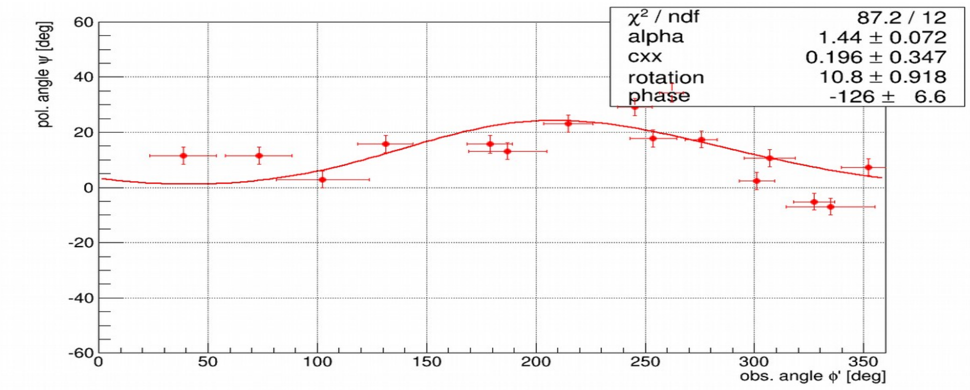
Polarization Pattern with Electric Field

- Upward shift of distribution of polarization angles corresponds to a global rotation with respect to the expected angle
- Added global shift δ and a phase ω to the fit function

$$\psi_{\mathrm{mod}} = \tan^{-1}\left(\frac{\sin(\phi' + \omega)}{\frac{\sin\alpha}{a} + \cos\phi'}\right) + \delta$$

- Modifications can be described by the addition of a uniformly aligned field configuration, but no common trends visible
- True field structure most likely way to complex





Atmospheric E-Field affect Radio-Emission of EAS

Criteria for E-Field determined

Amplification shown in twin-events and simulation

Polarization effect shown

Comparison with Simulations of simple 2-layer E-Field Model