Polarized radio emission from extensive air showers measured with LOFAR

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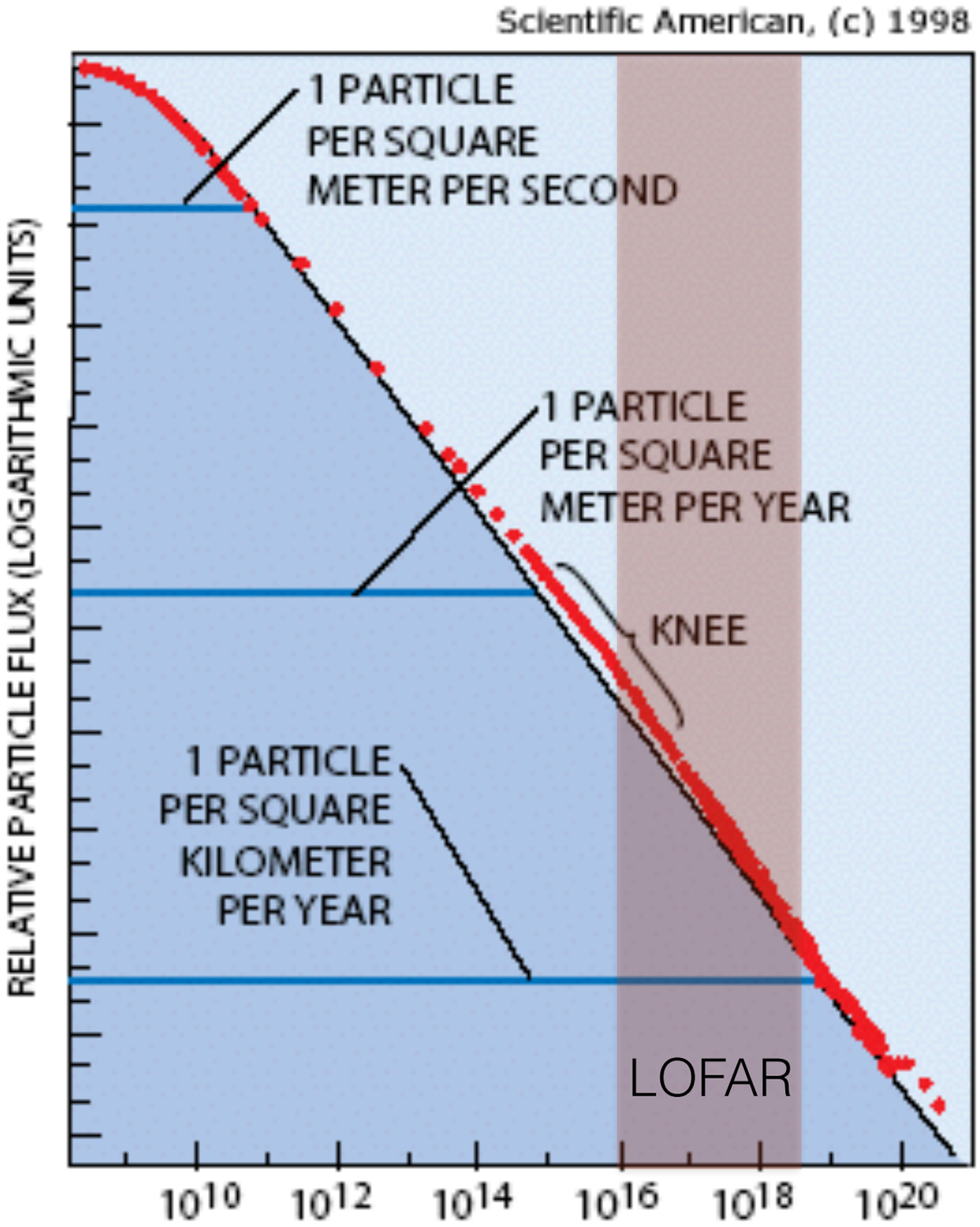
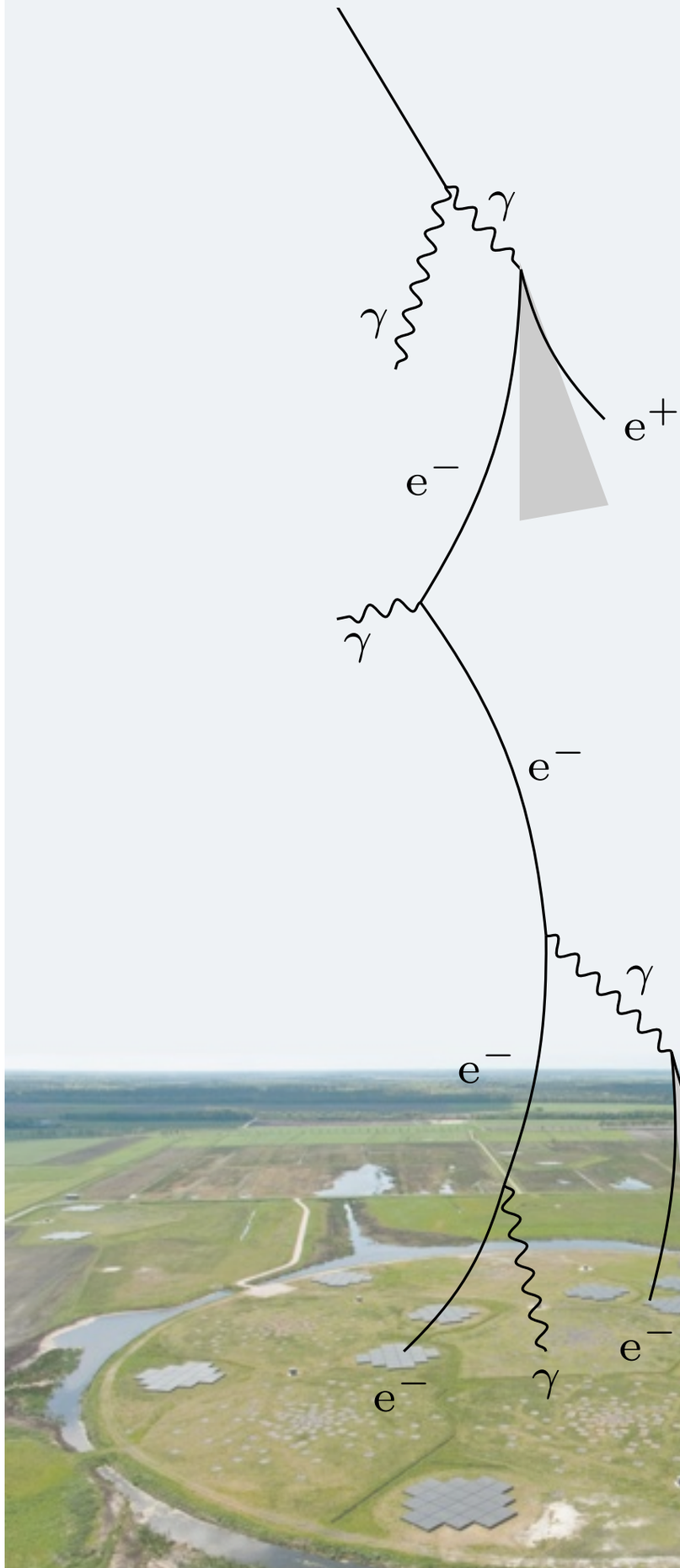
Cosmic Rays Key Science Project

Radboud University Nijmegen, ASTRON, NIKHEF, Max-Planck-Institut für Radioastronomie, Rijksuniversiteit Groningen

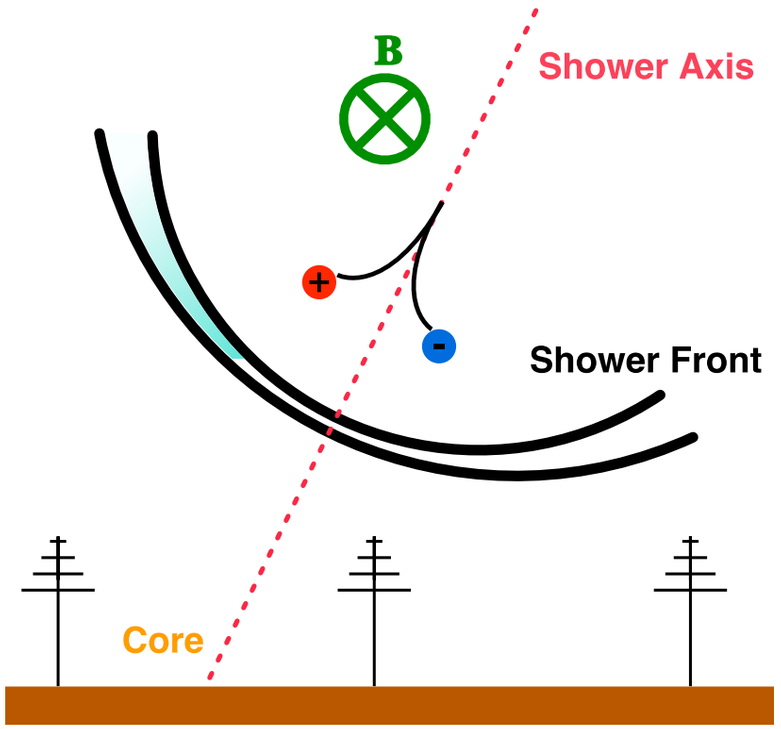
Radio emission from air showers

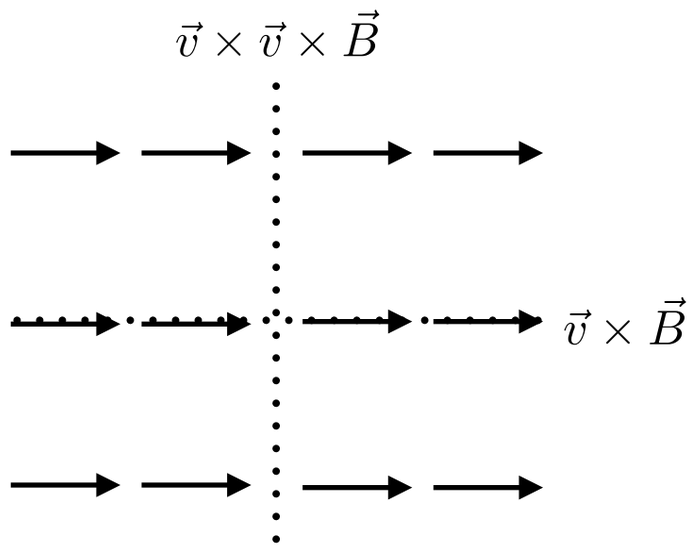




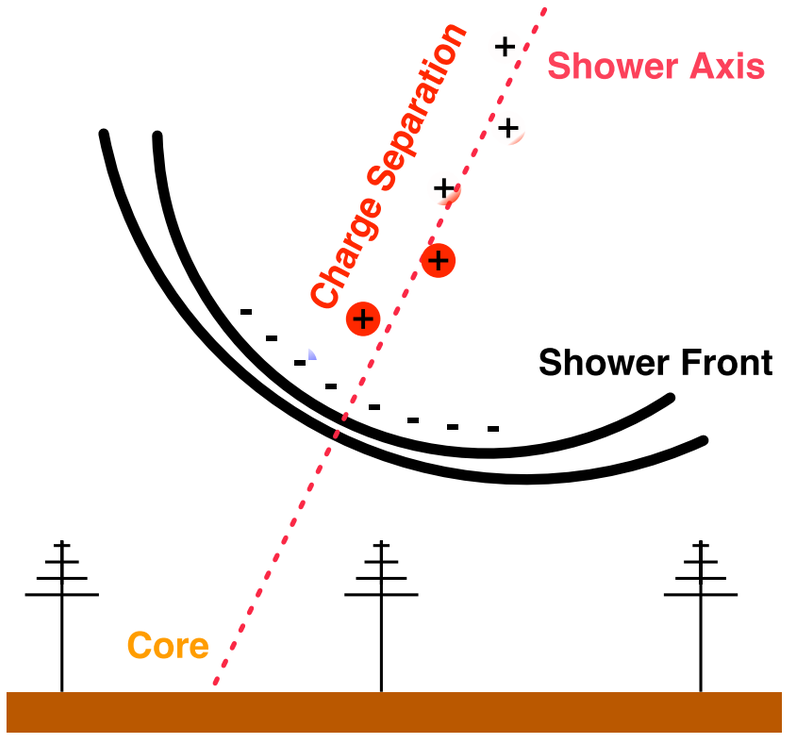
Two emission mechanisms

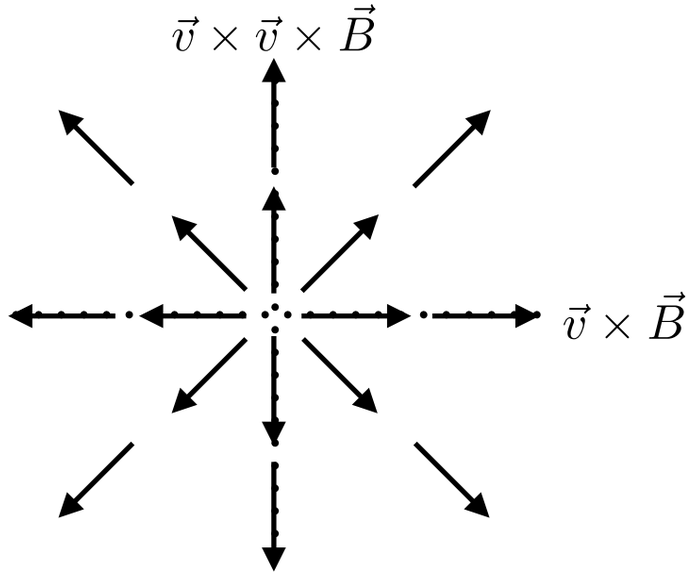
Geomagnetic





Charge-excess





Polarization angle depends on:

relative strength of contributions:

$$a \equiv \sin\alpha \frac{|E_{\mathrm{C}}|}{|E_{\mathrm{G}}|},$$

and, position in the shower plane:

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

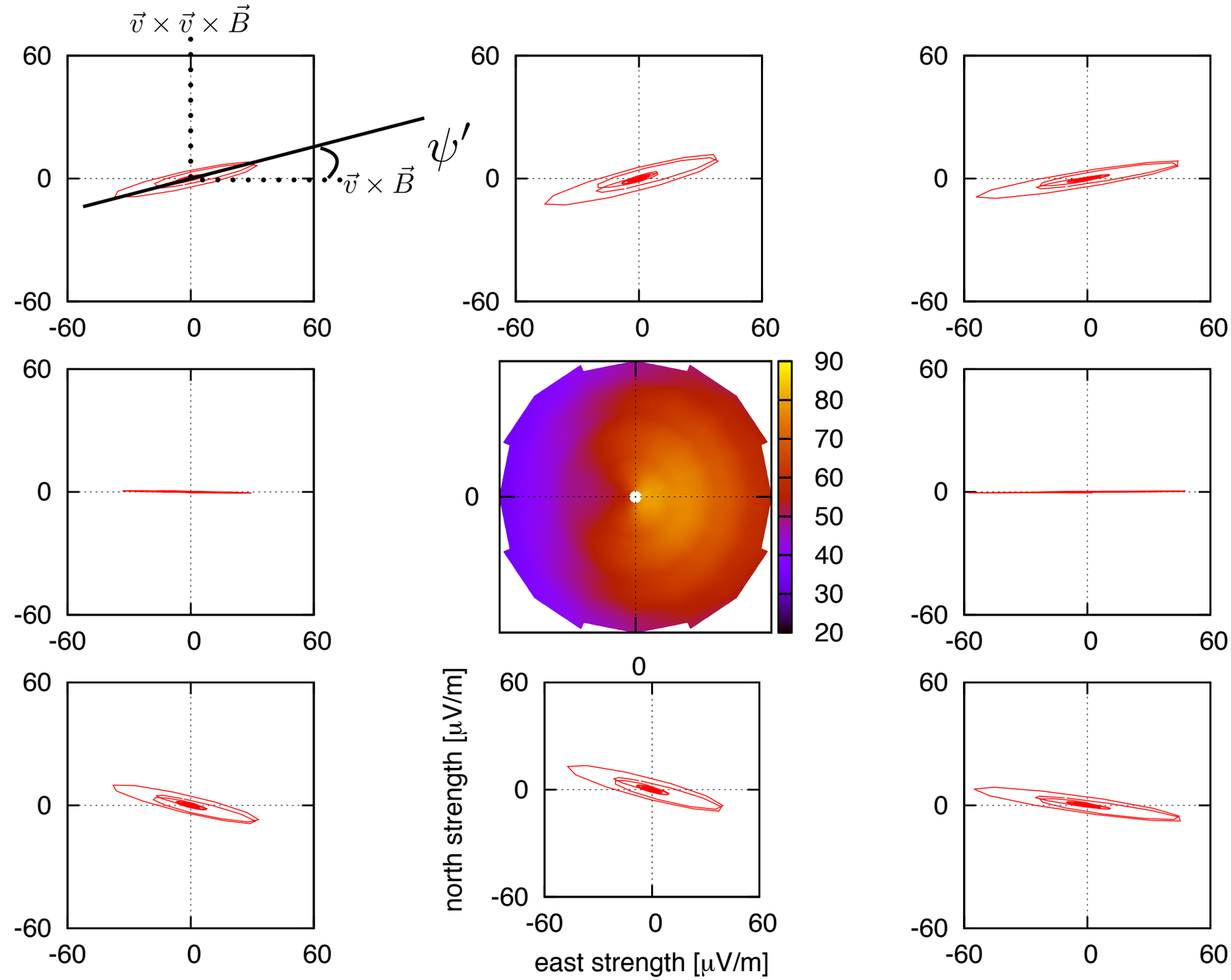
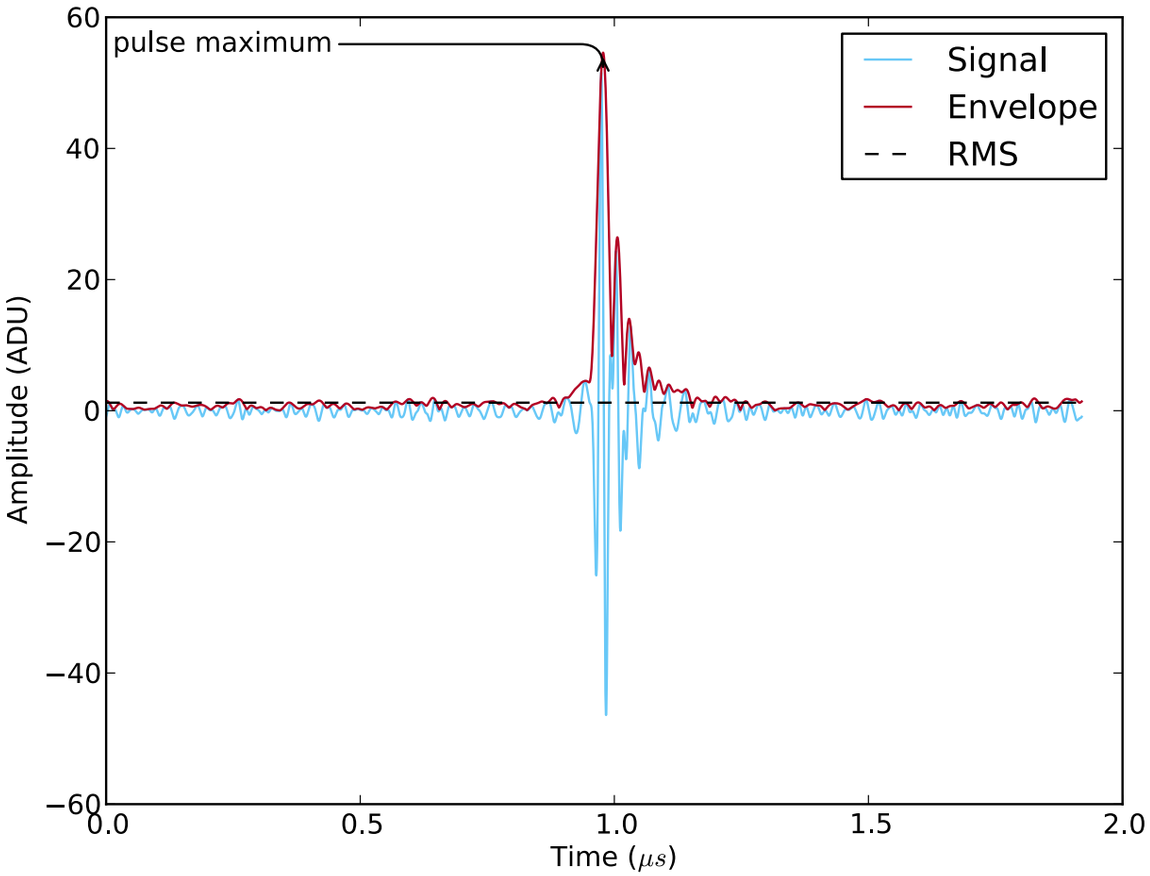


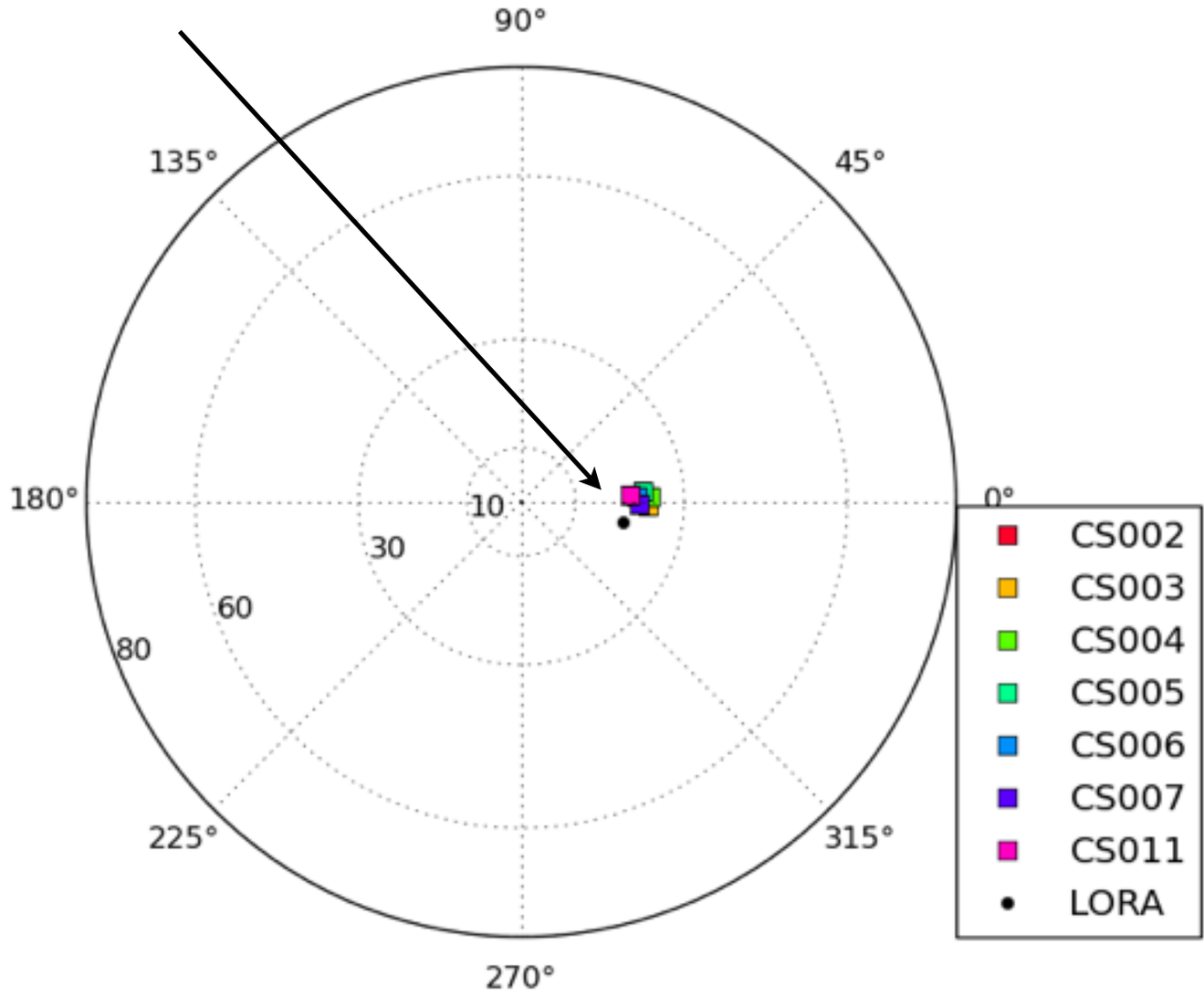
Image from Huege et. al 2013

Automated detection pipeline (400+ showers measured)

Typical event:

Particle Detector & Radio Direction Reconstruction





Single LBA dipole!
300+ measurement points

Schellart et al. 2013

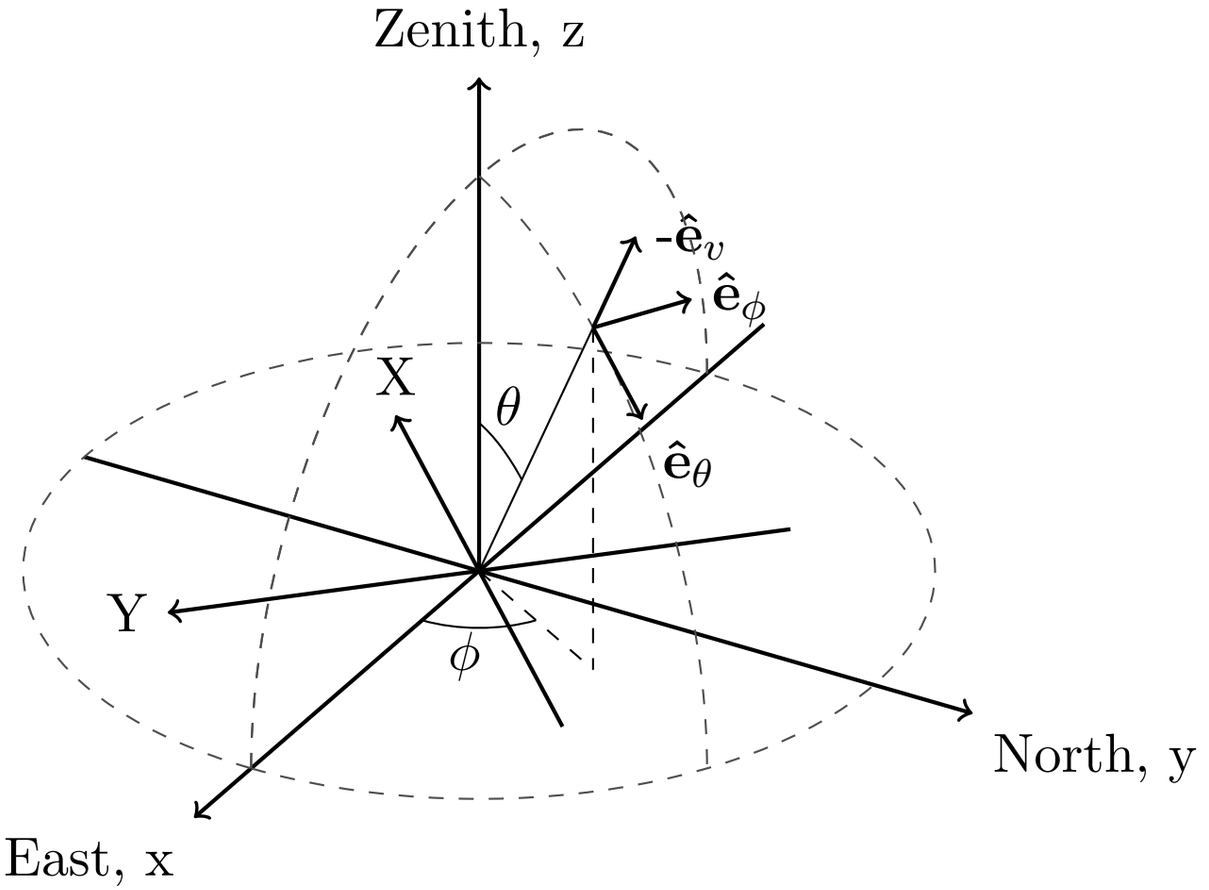
Use antenna simulation to reconstruct polarization

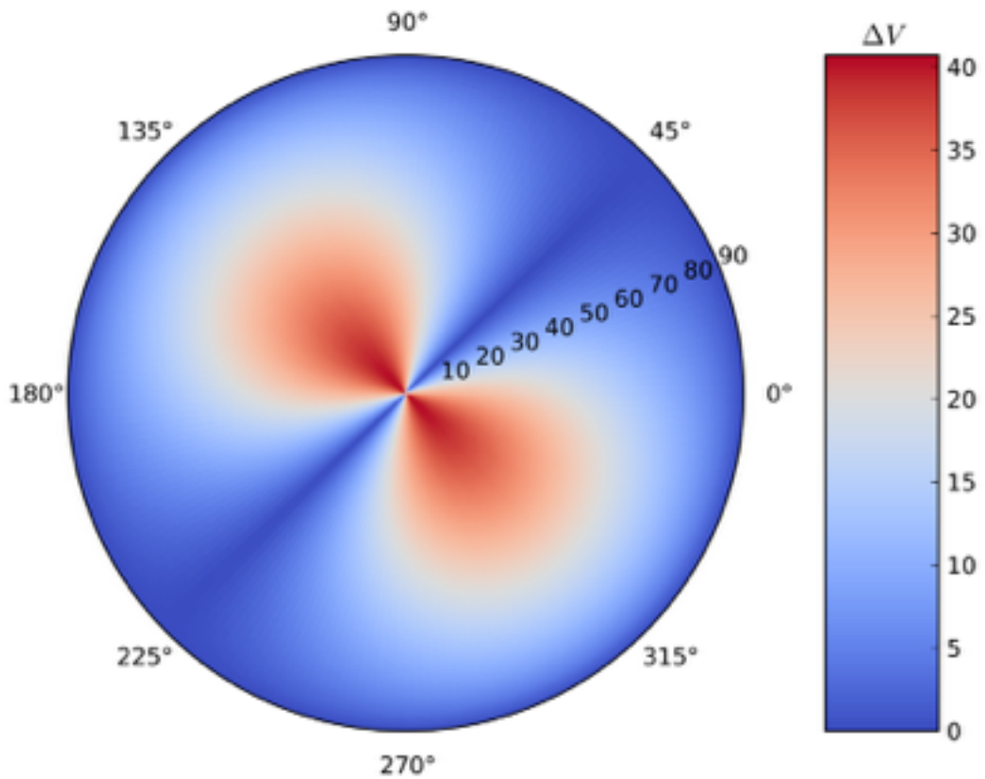
- WIPLD EM-simulation + electronics model (by Michel Arts @ ASTRON)

- Complex direction and frequency dependent gain per polarization per dipole

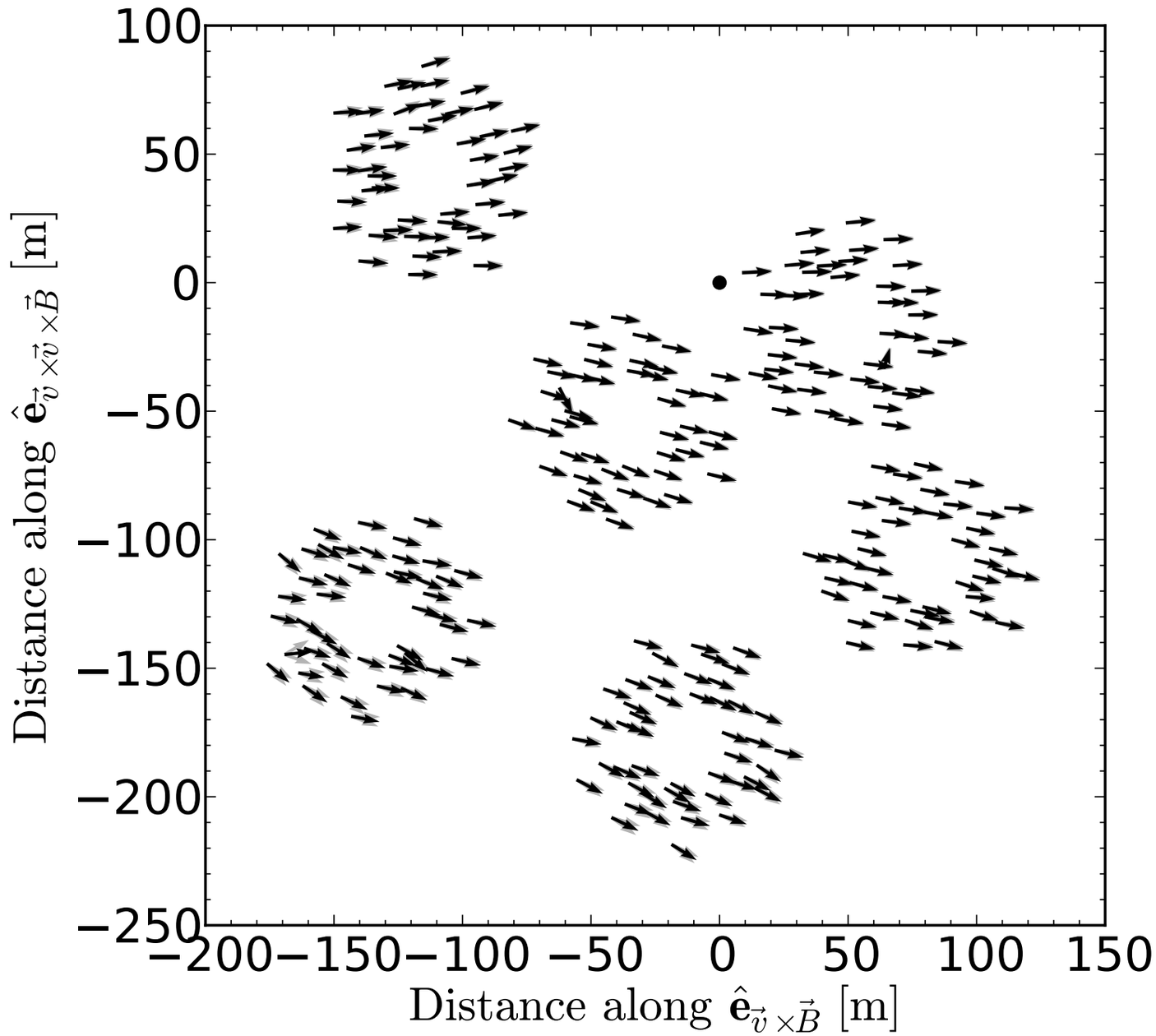
- **Interpolate directly** to get 2x2 complex Jones matrix for pulse direction

- Invert and multiply to get **E**(t)

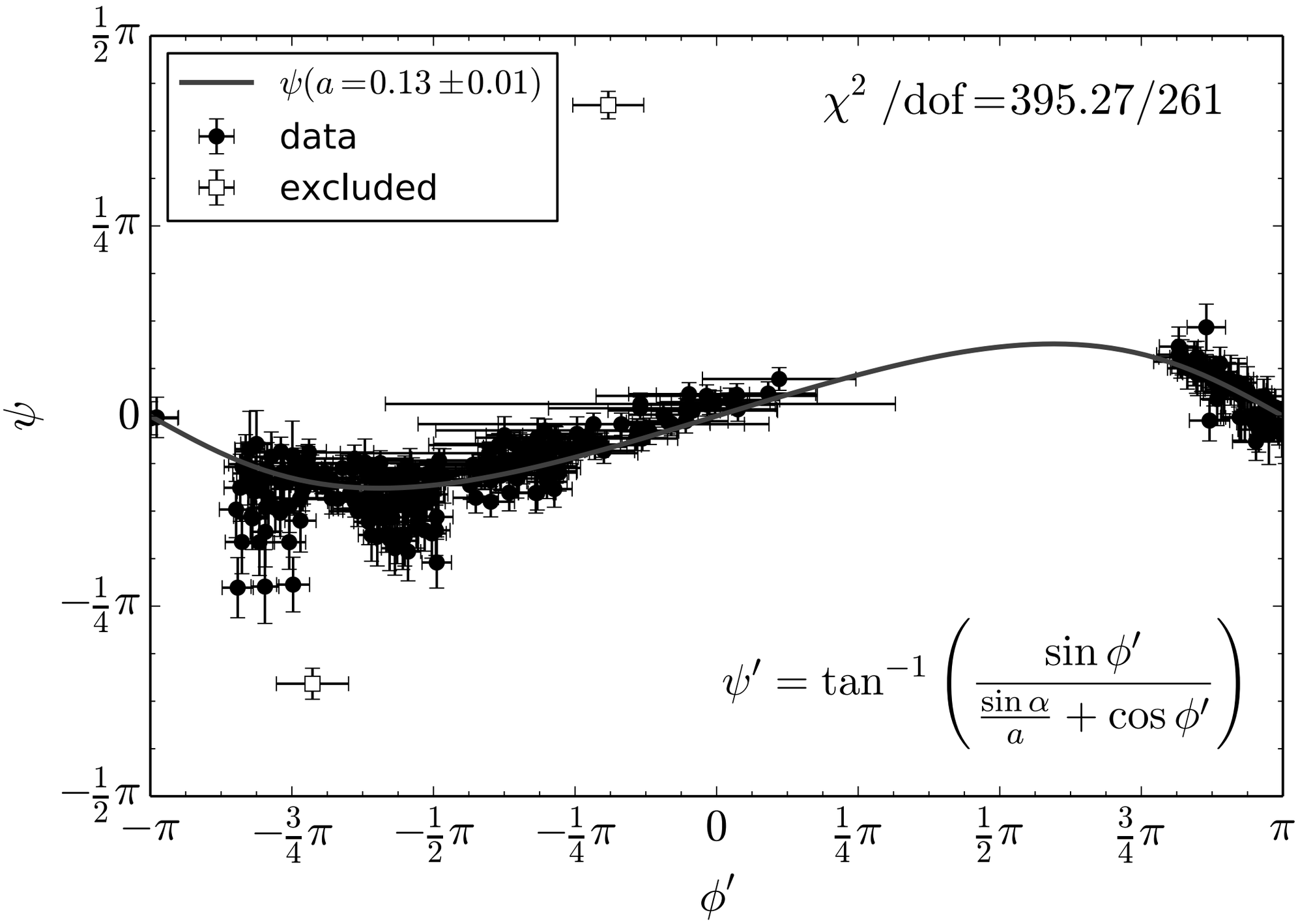




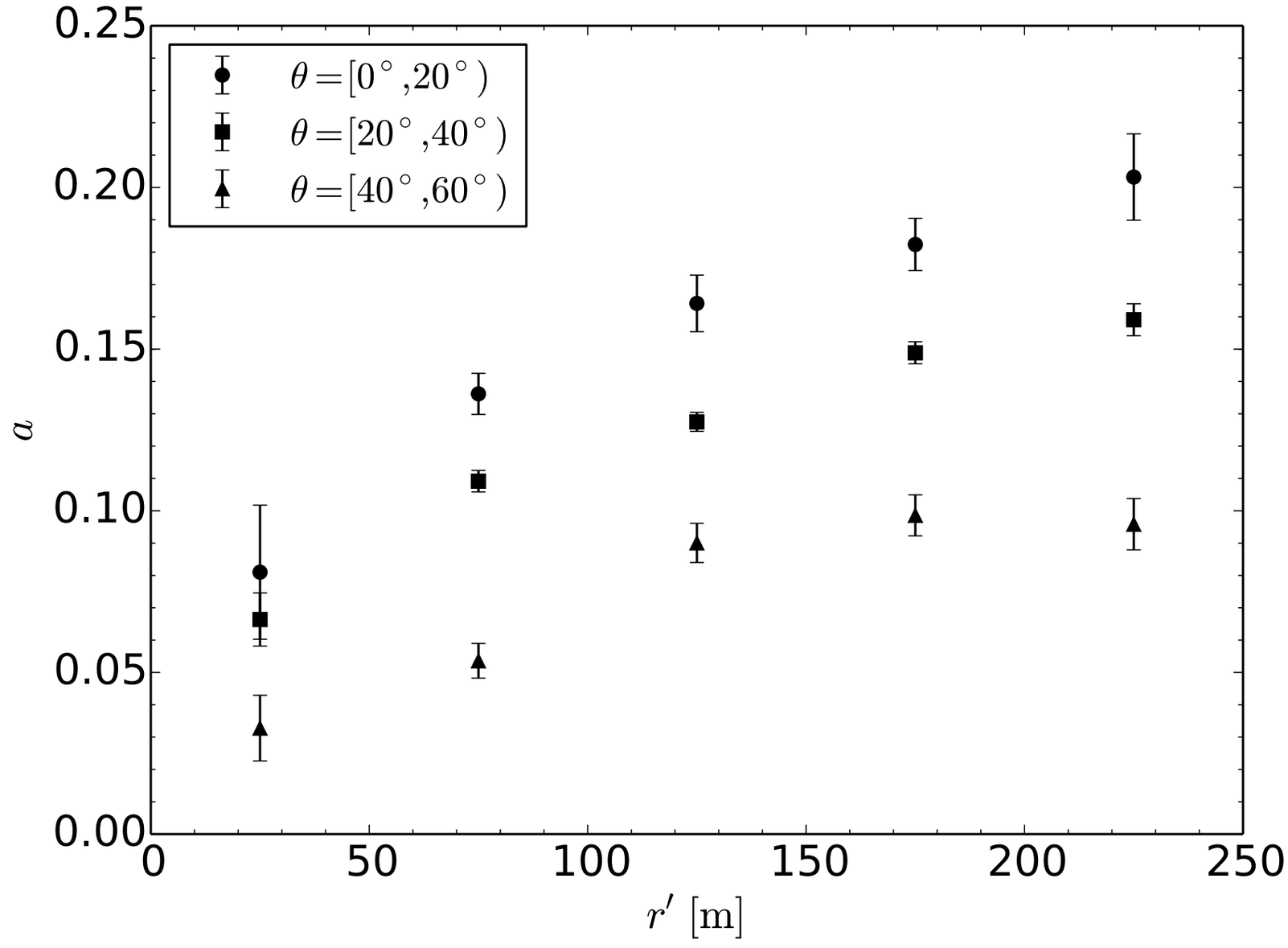
Observed polarization pattern



Charge-excess fraction



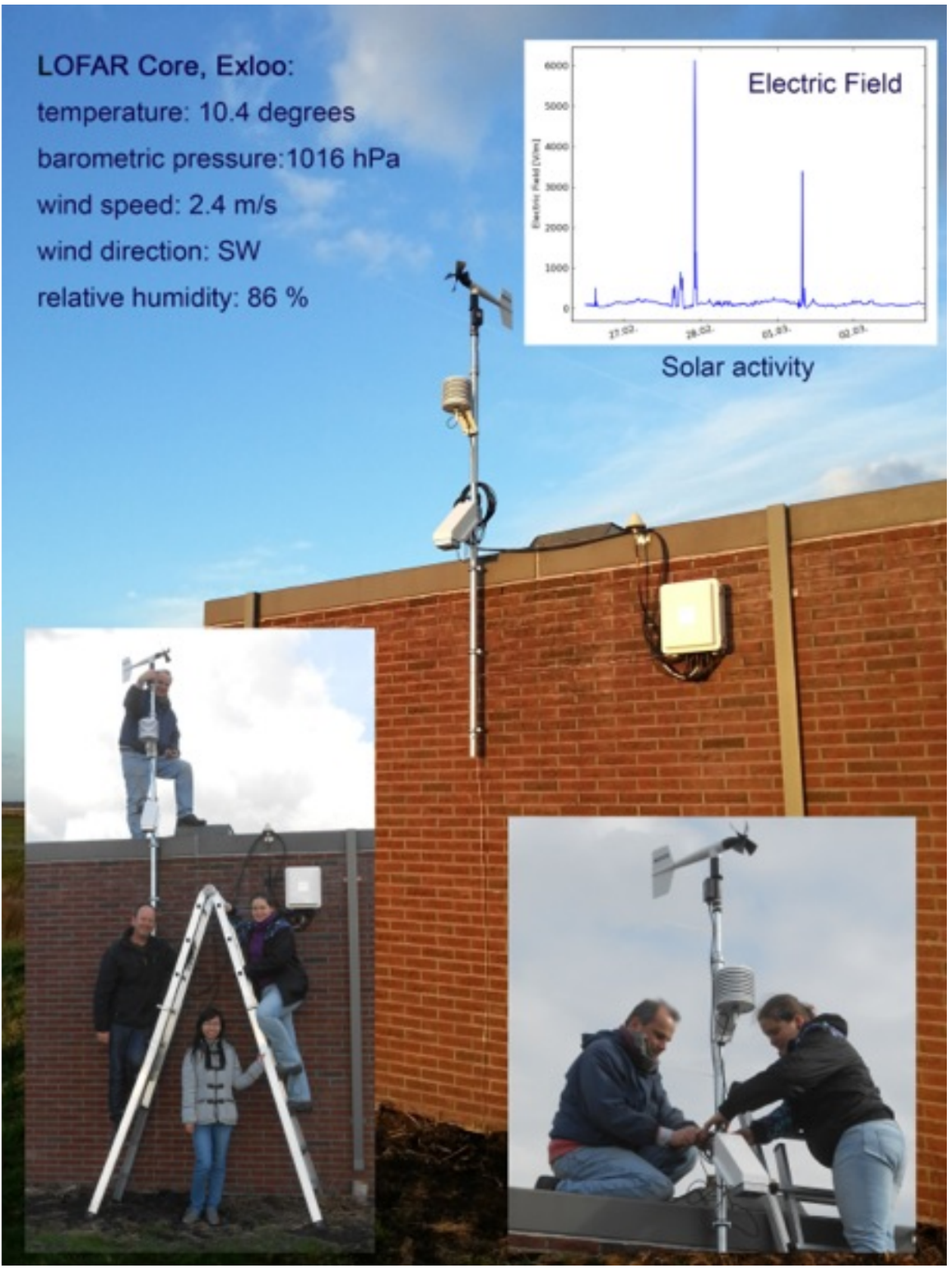
Confirmed predicted dependence on zenith angle and radial distance

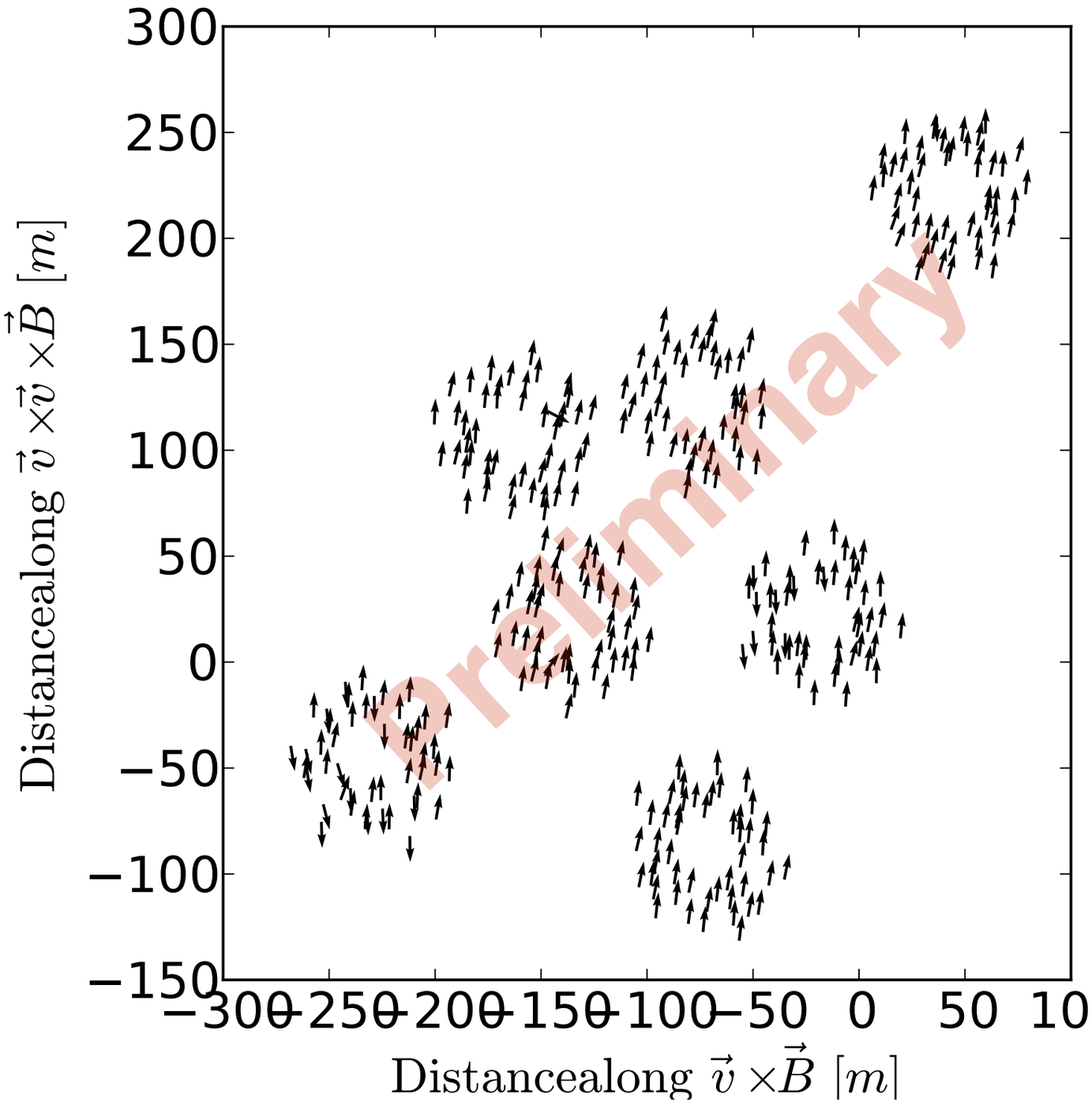


(Schellart et al. 2014, submitted to JCAP)

Made possible by high antenna density at LOFAR

Atmospheric electric fields





Conclusions

- Polarization measurements can be used to reconstruct relative contributions of emission mechanisms to air shower radio emission

- Uniquely high antenna density offered by LOFAR allows for first time confirmation of predicted radial and zenith angle dependence of charge-excess fraction (Schellart et al. 2014, submitted to JCAP)

- Strong atmospheric electric fields (thunderstorms) alter the observed polarization pattern