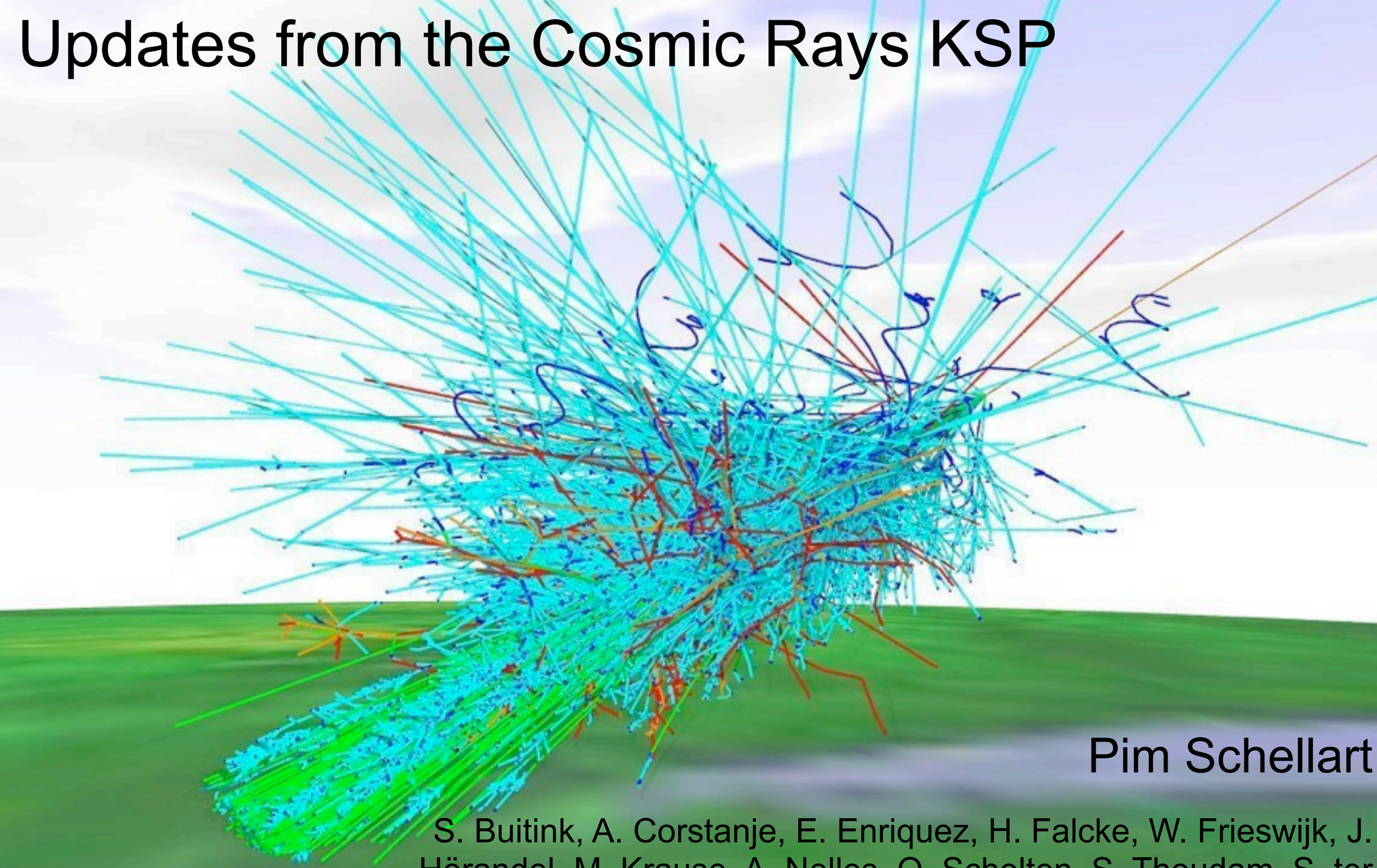
Updates from the Cosmic Rays KSP



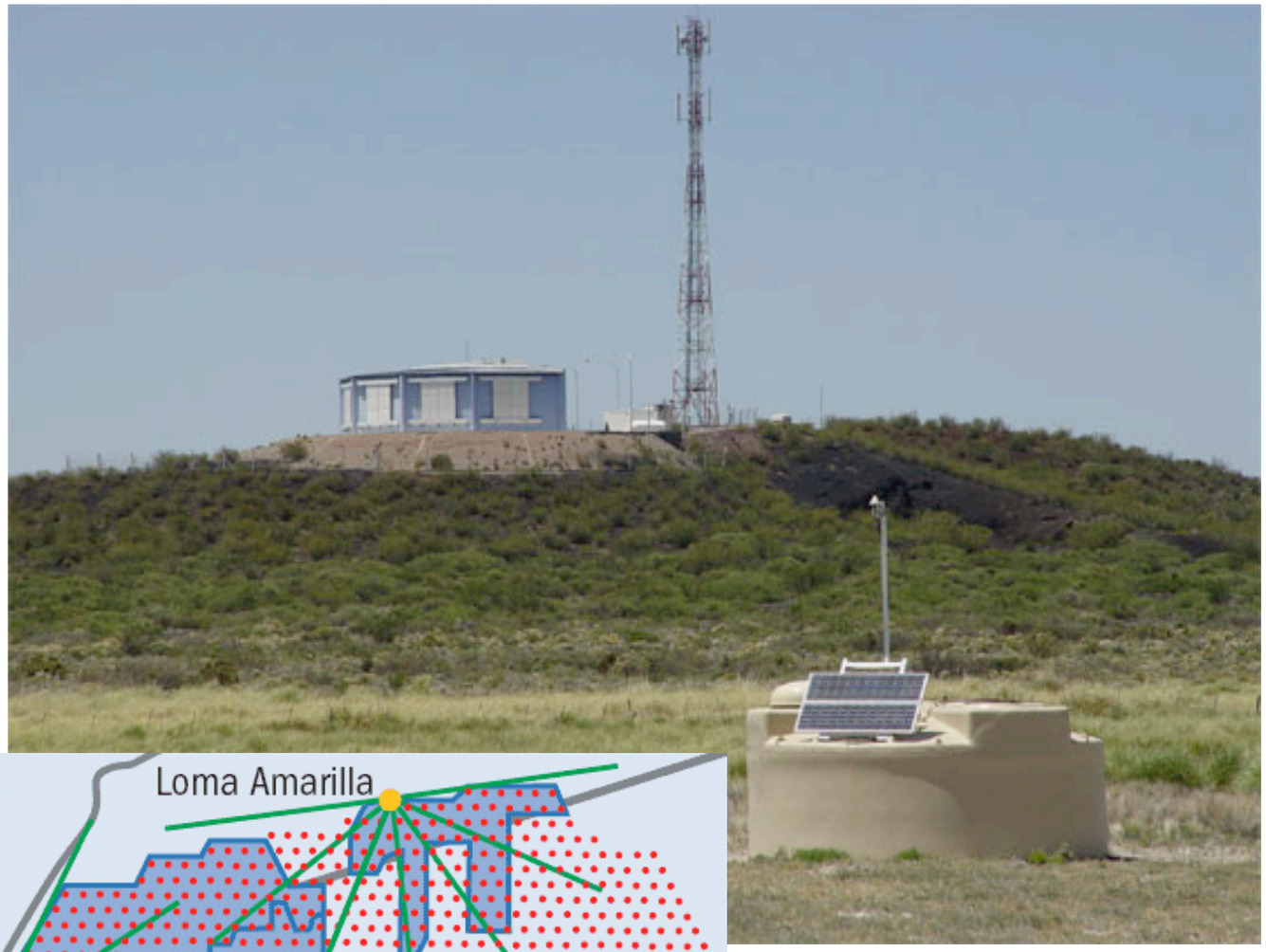
Pim Schellart

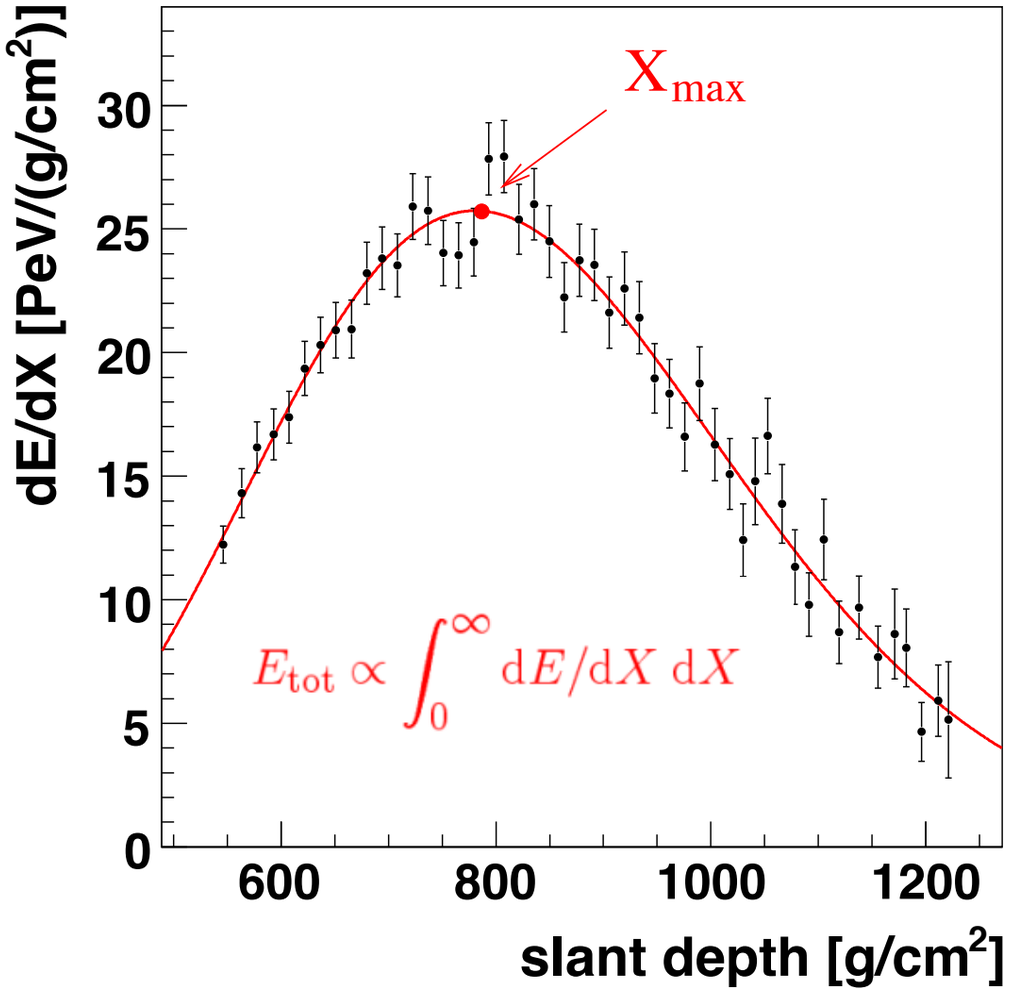
S. Buitink, A. Corstanje, E. Enriquez, H. Falcke, W. Frieswijk, J. Hörandel, M. Krause, A. Nelles, O. Scholten, S. Thoudam, S. ter Veen, M. van den Akker

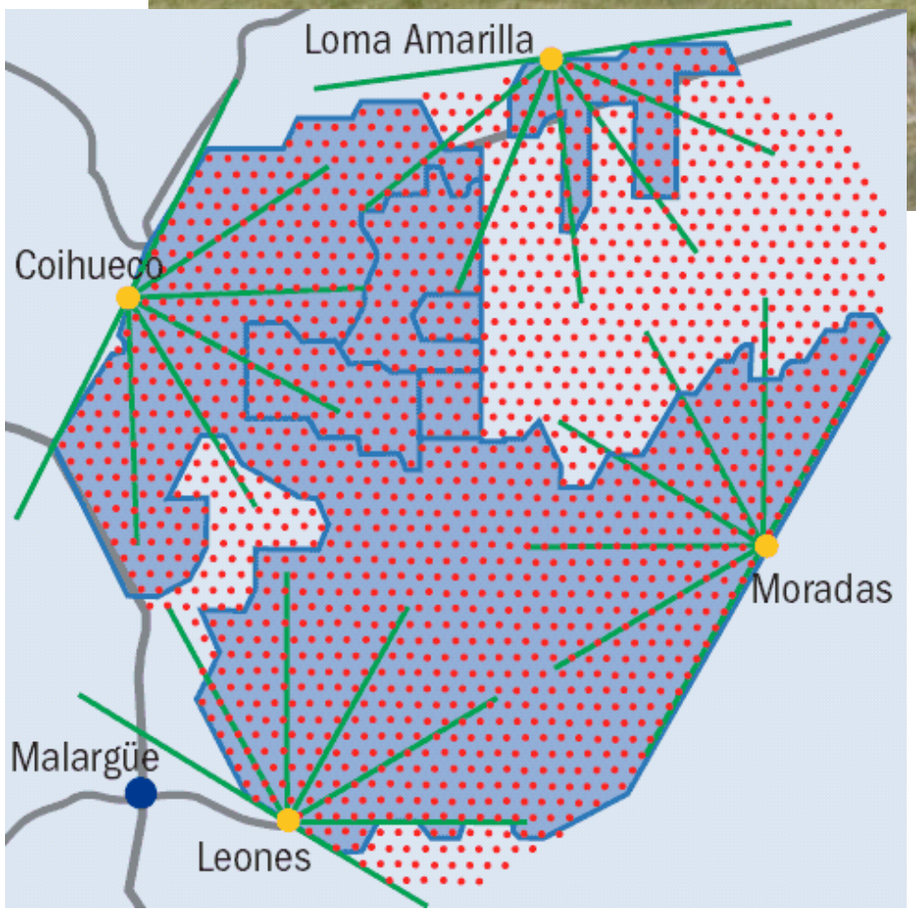
Cosmic Rays Key Science Project

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

Measuring cosmic ray composition







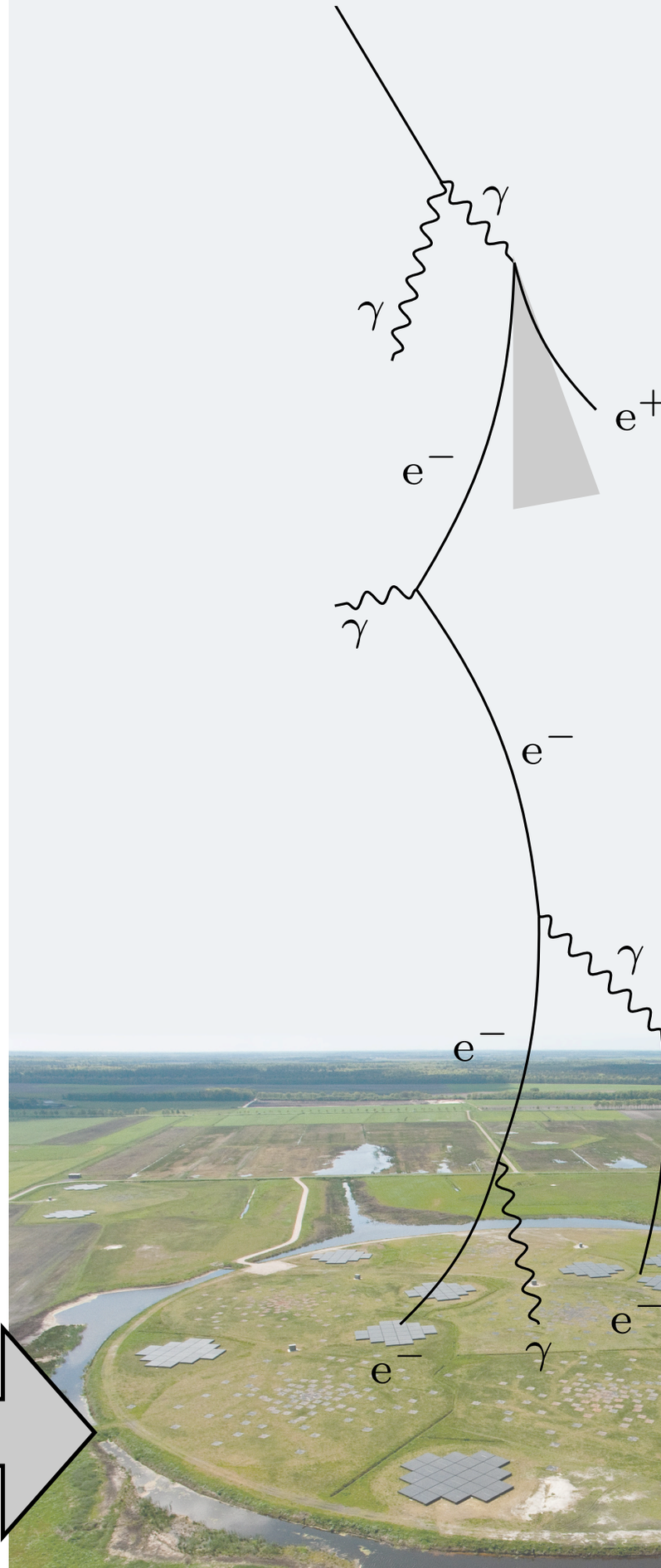
Fluorescence: good but 10% duty cycle

Image credit: The Auger Collaboration

10%? we can do better with radio!

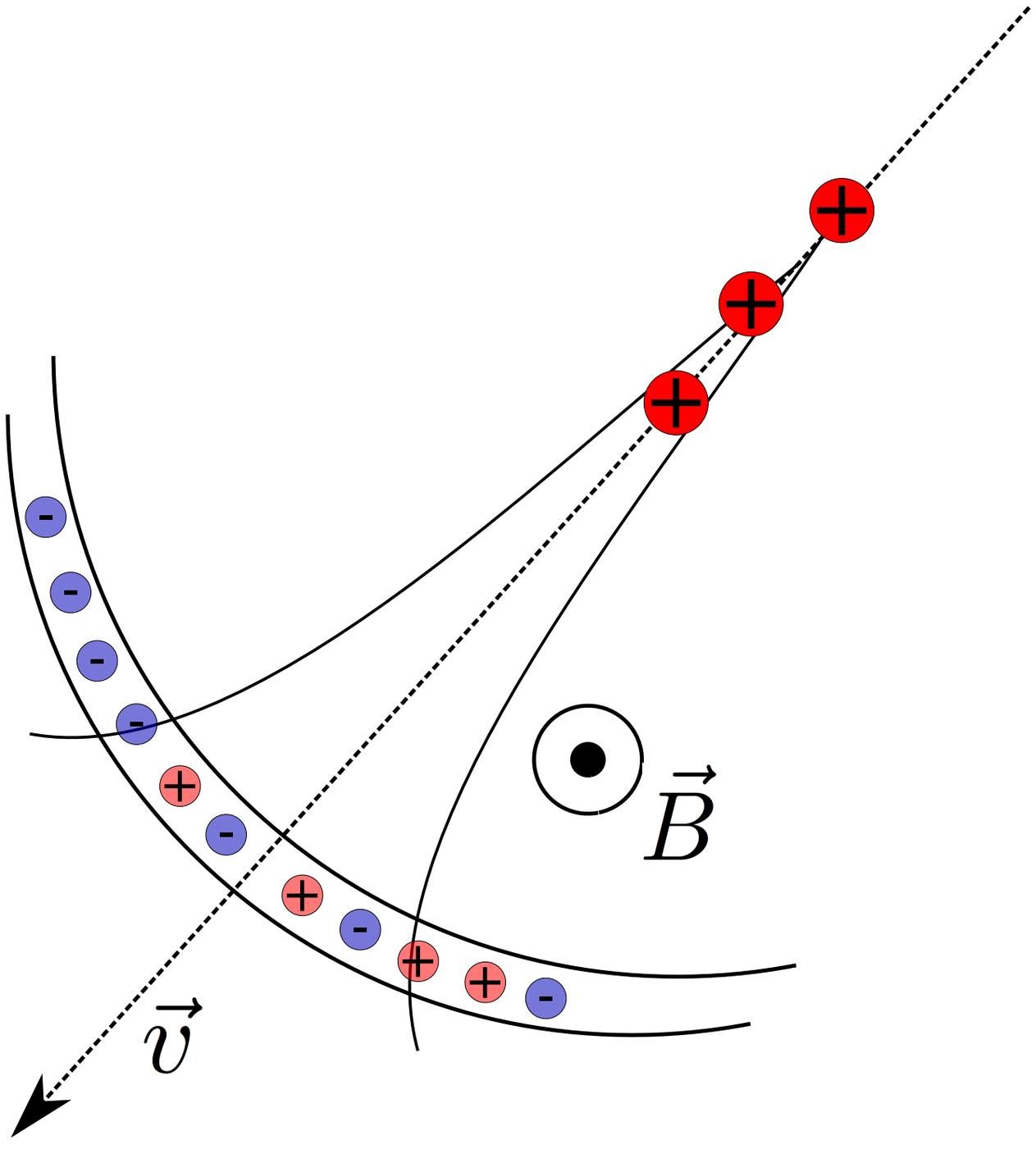
Goals:

- Detect radio emission from cosmic ray air showers
- Understand radio emission from cosmic ray air showers
- Use radio emission to study cosmic rays



Multiple emission mechanisms

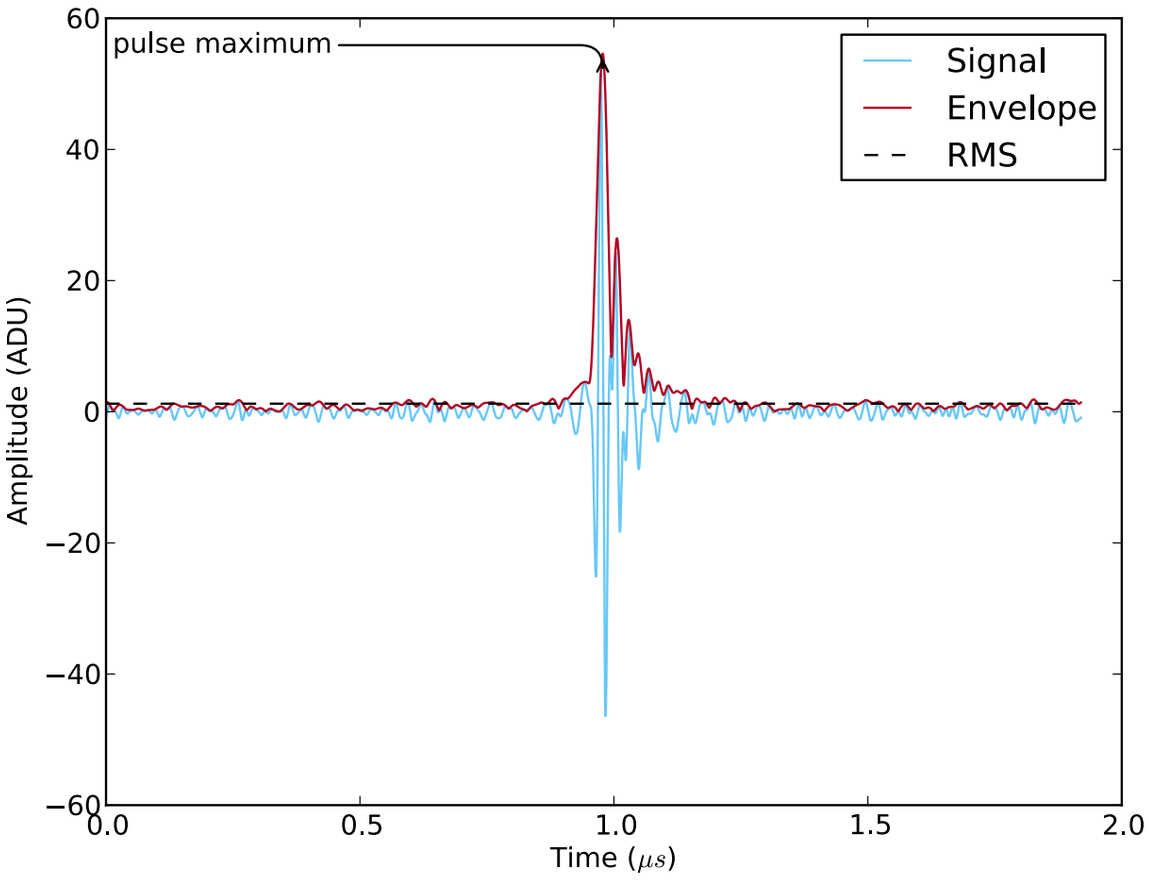
- Geomagnetic
  - Electrons and positrons are deflected in the geomagnetic field
  - Linearly polarized in v x B direction
- Charge excess
  - Negative charge buildup at shower front
  - Linearly polarized in radial direction away from shower axis
- Cherenkov effects

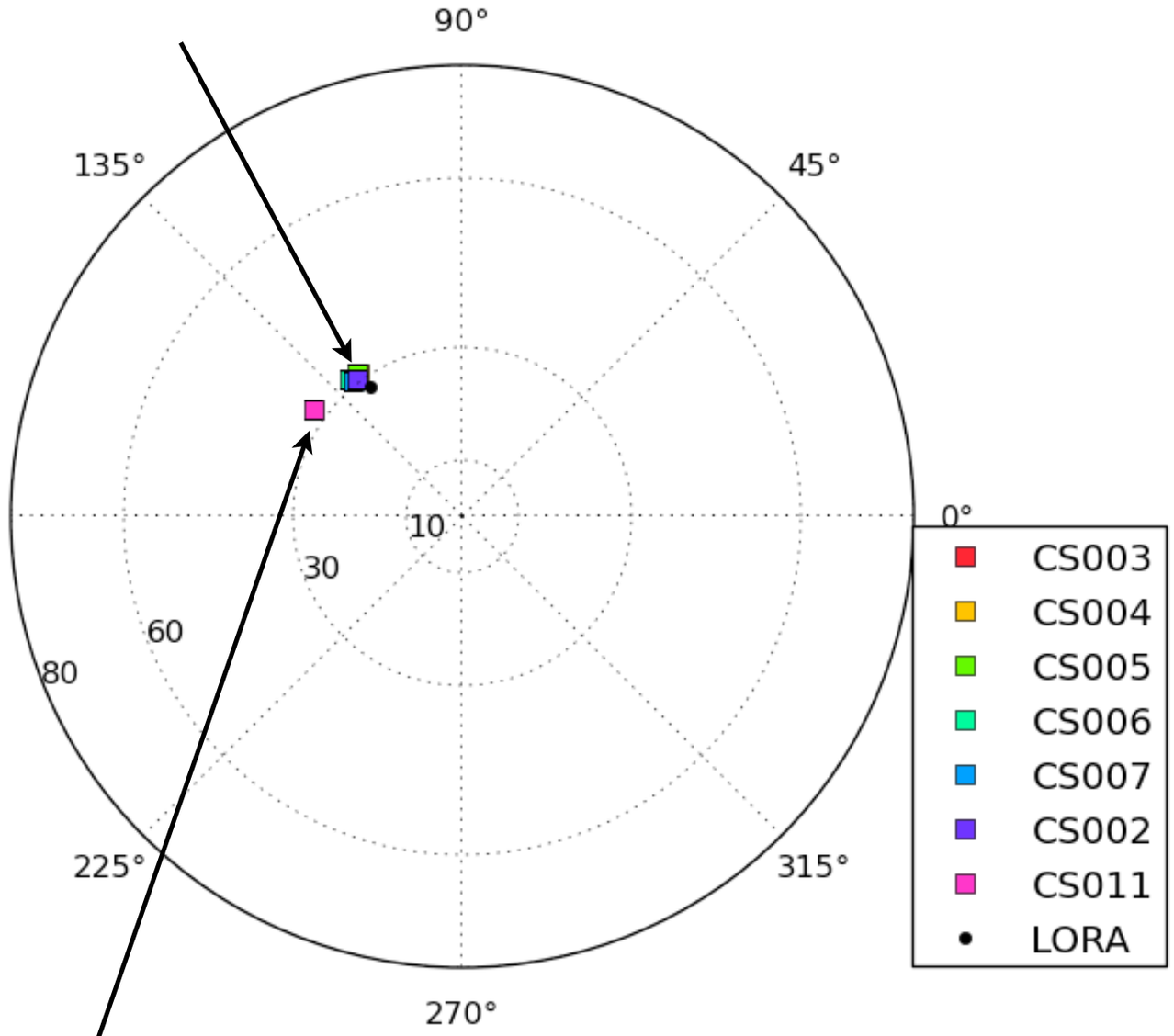


Automated detection pipeline (400+ showers measured)

Typical event:

Particle Detector & Radio Agree





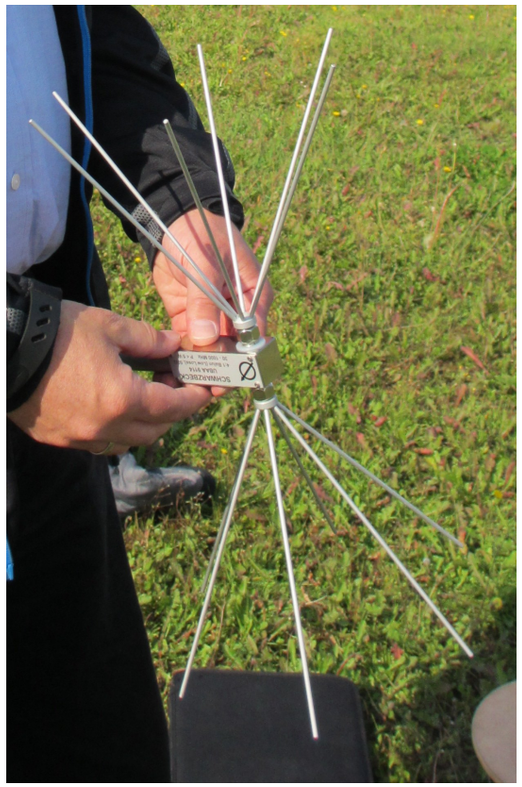
Single LBA dipole!

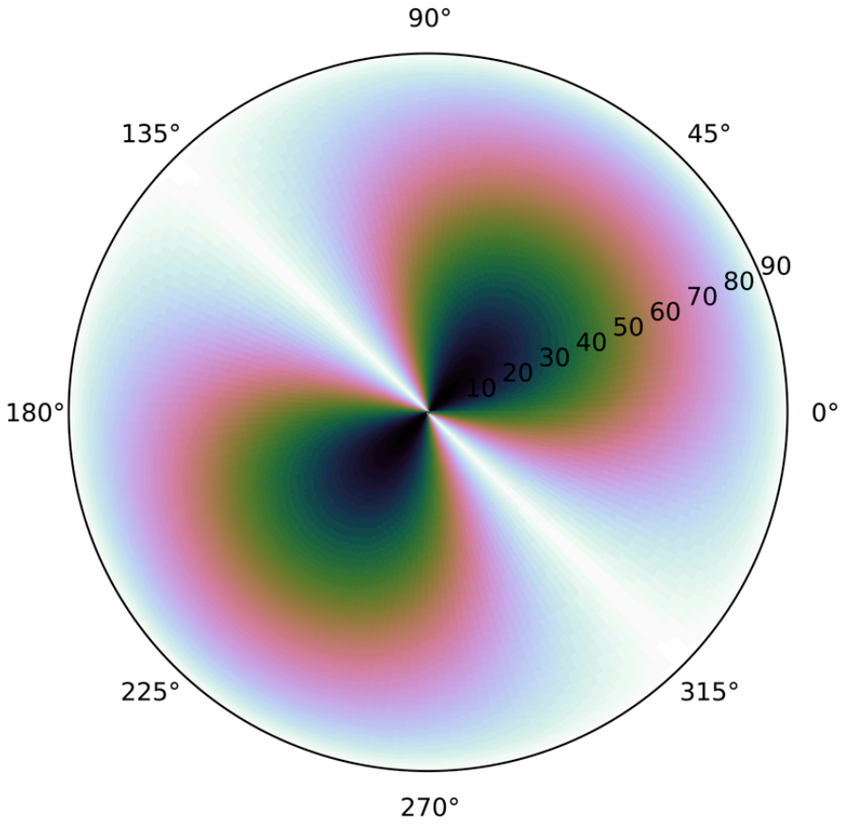
300+ measurement points

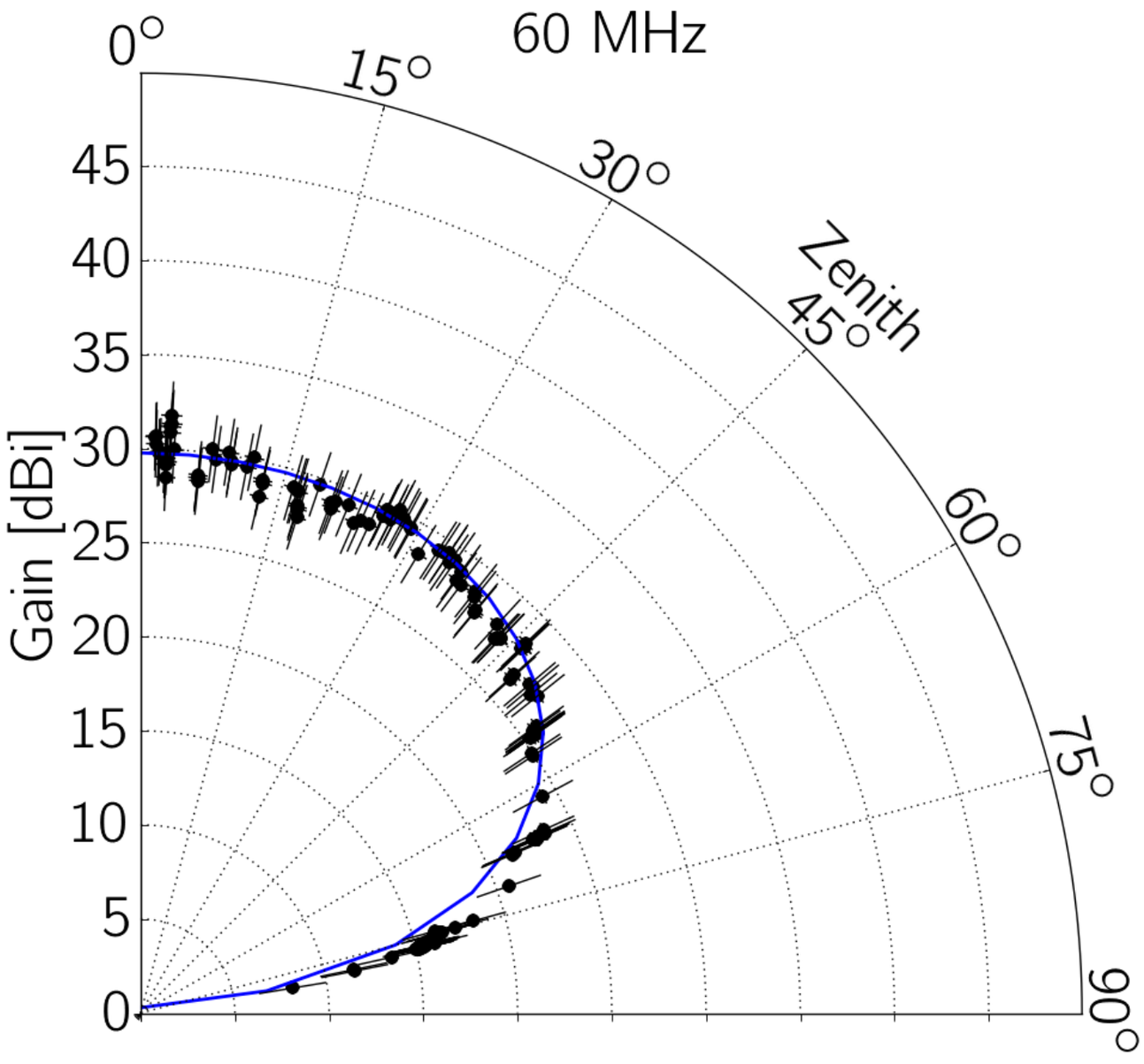
Curvature

Schellart et al. 2013

Antenna model verification



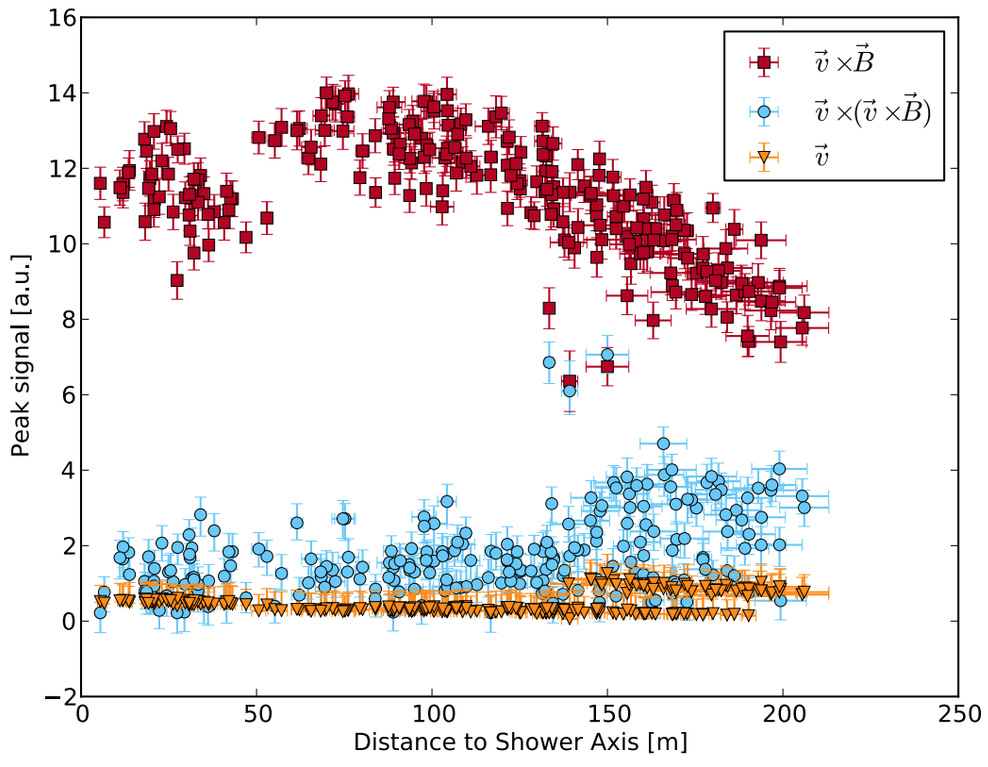


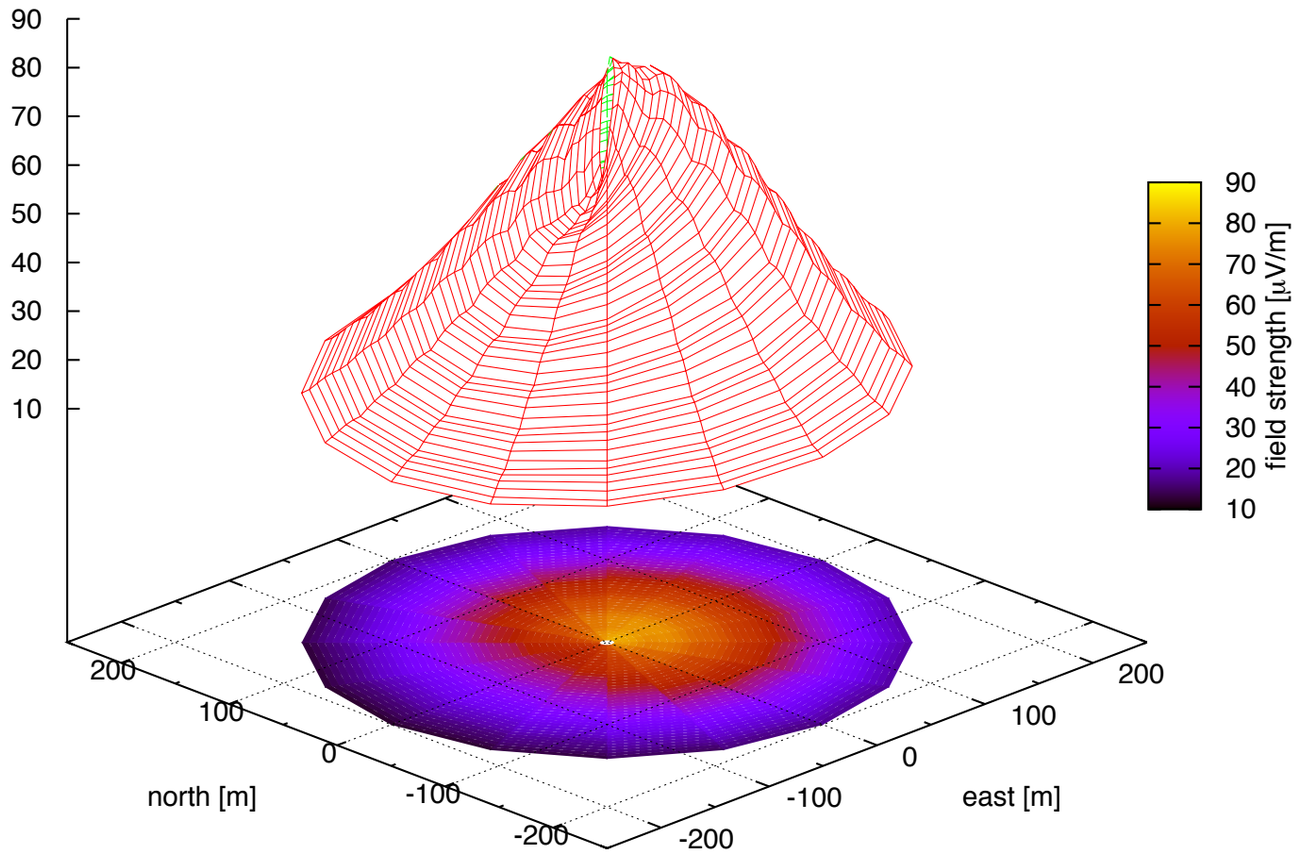


Master thesis M Krause (available soon)

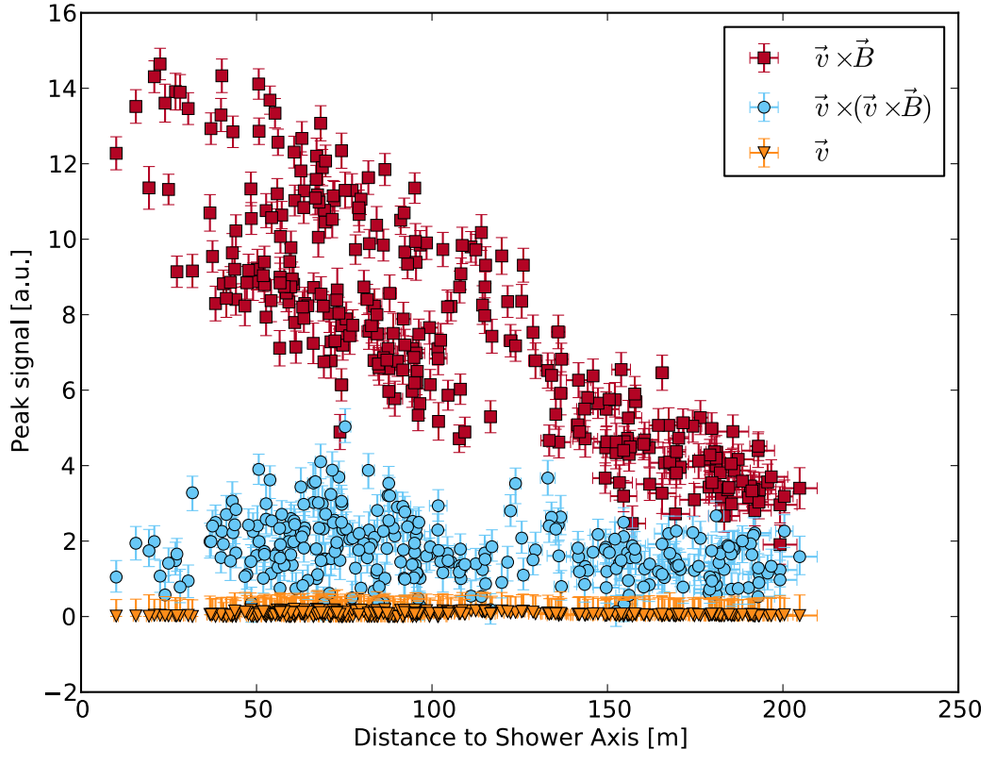
Complex polarization signature

There is a lot of information here...

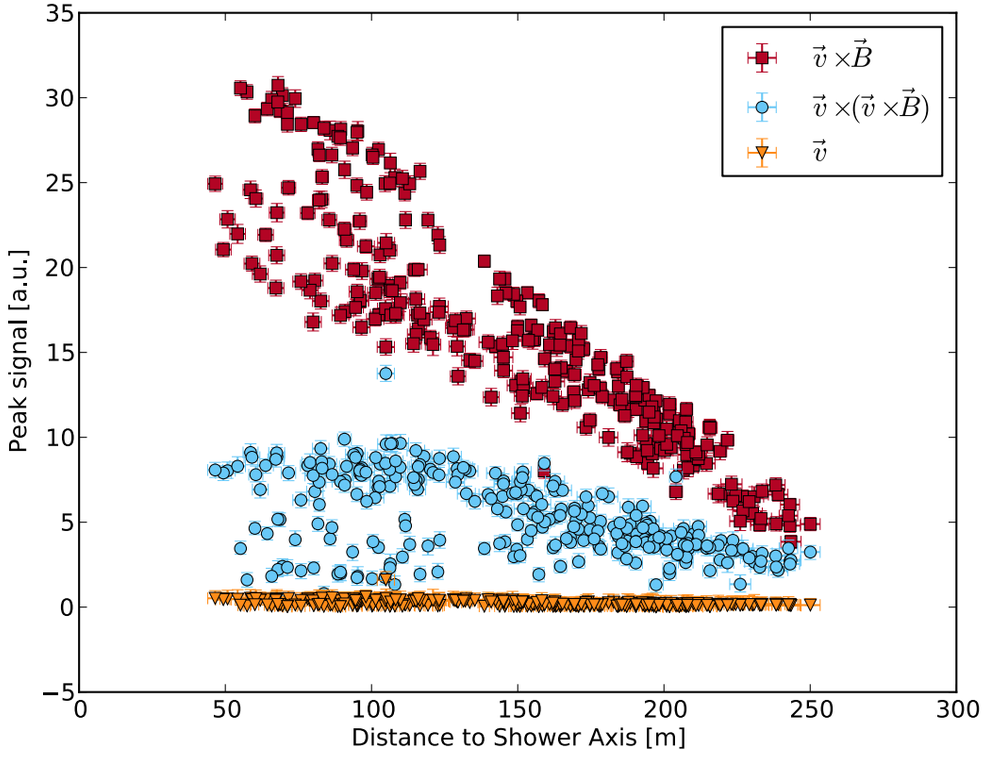




Schellart et al. (in prep)



CoREAS simulation Huege et al. 2013



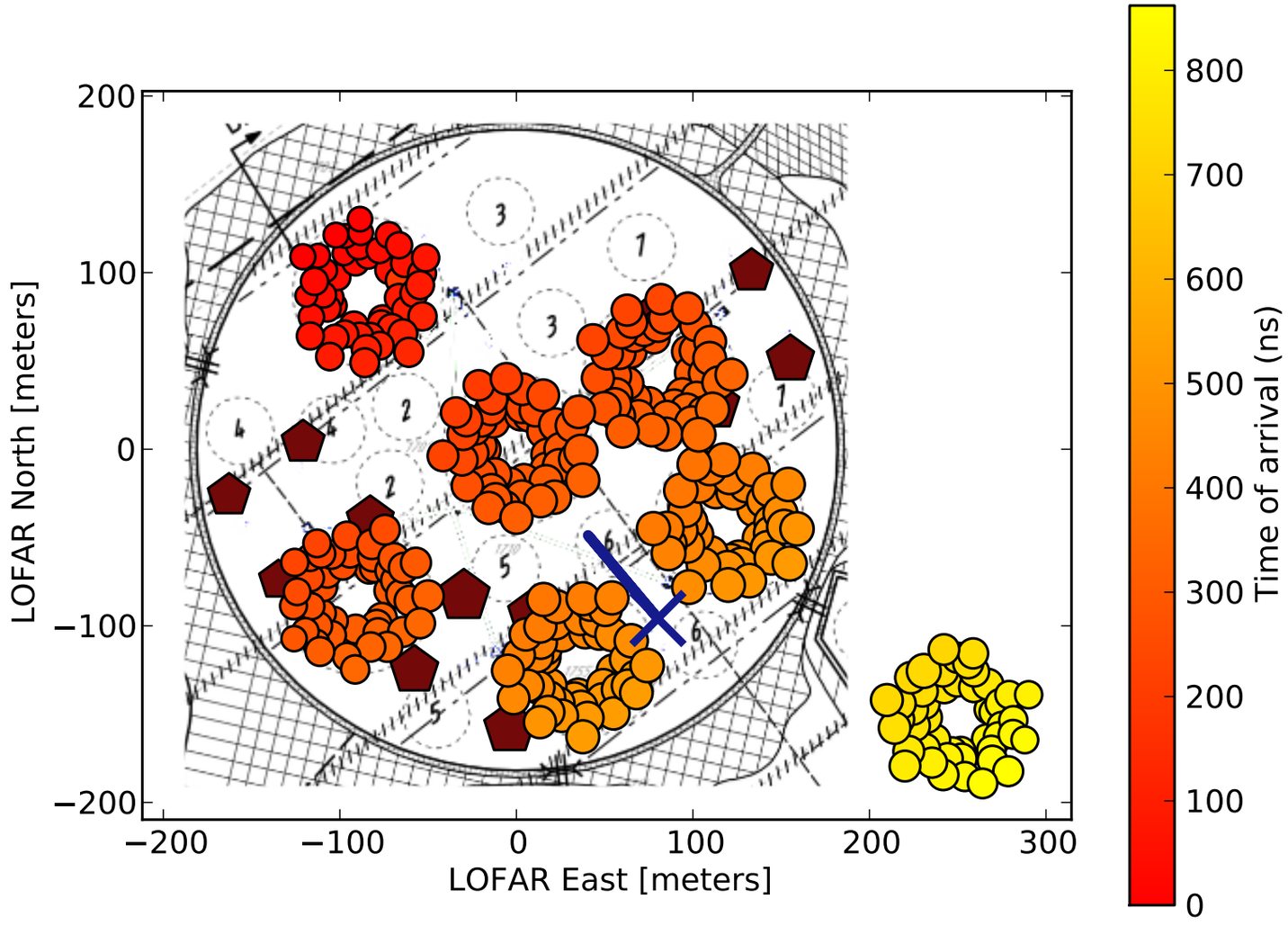
Wavefront curvature

- Subtracting the plane wavefront solution, treating curvature as a perturbation gives ~6 ns delays at edge of the array

- This can be directly measured with LOFAR

- Preliminary results point to hyperbolic wavefront shape

- Wavefront curvature may provide measurement of Xmax independent of pulse power (Schröder et al. ICRC 2011)



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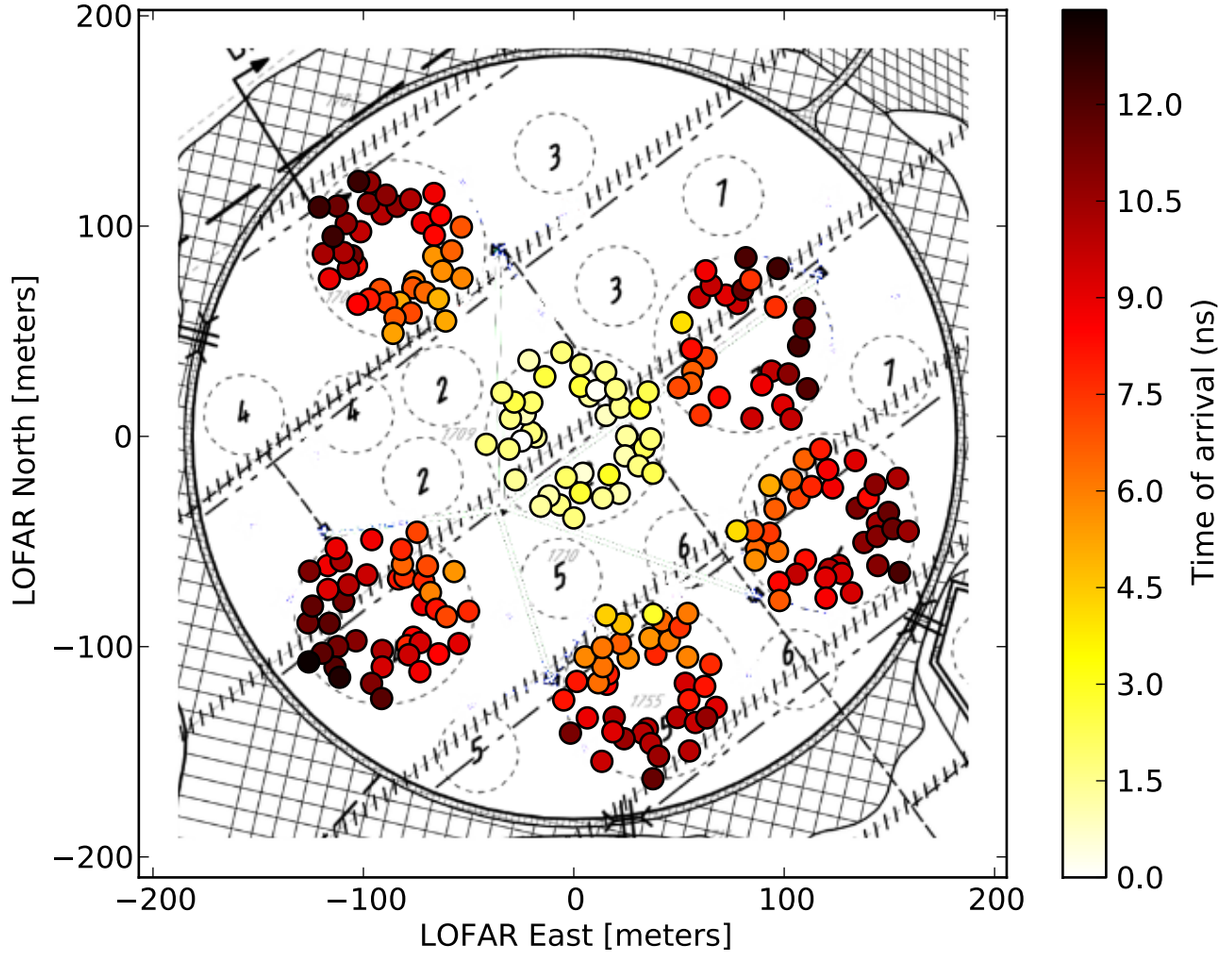

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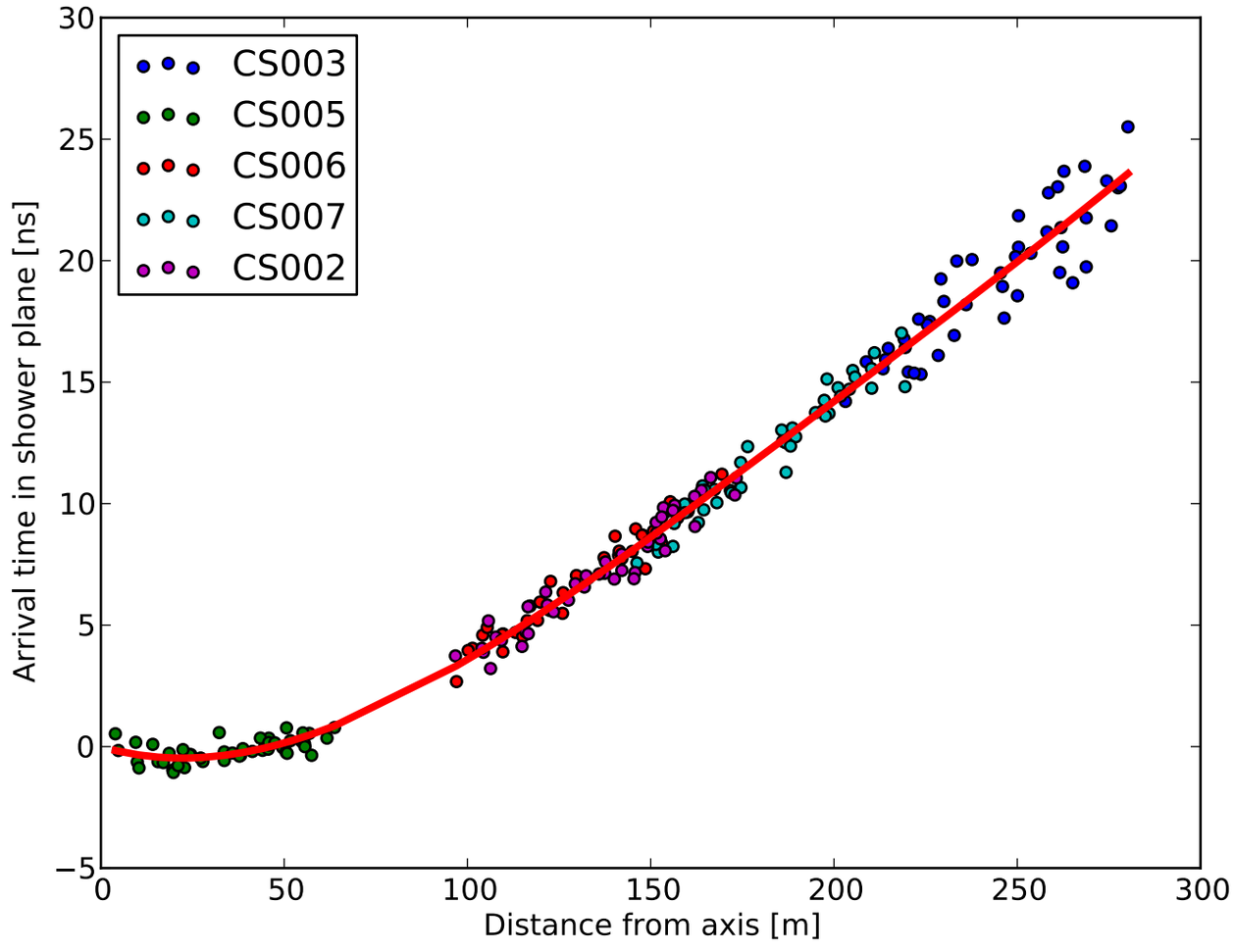
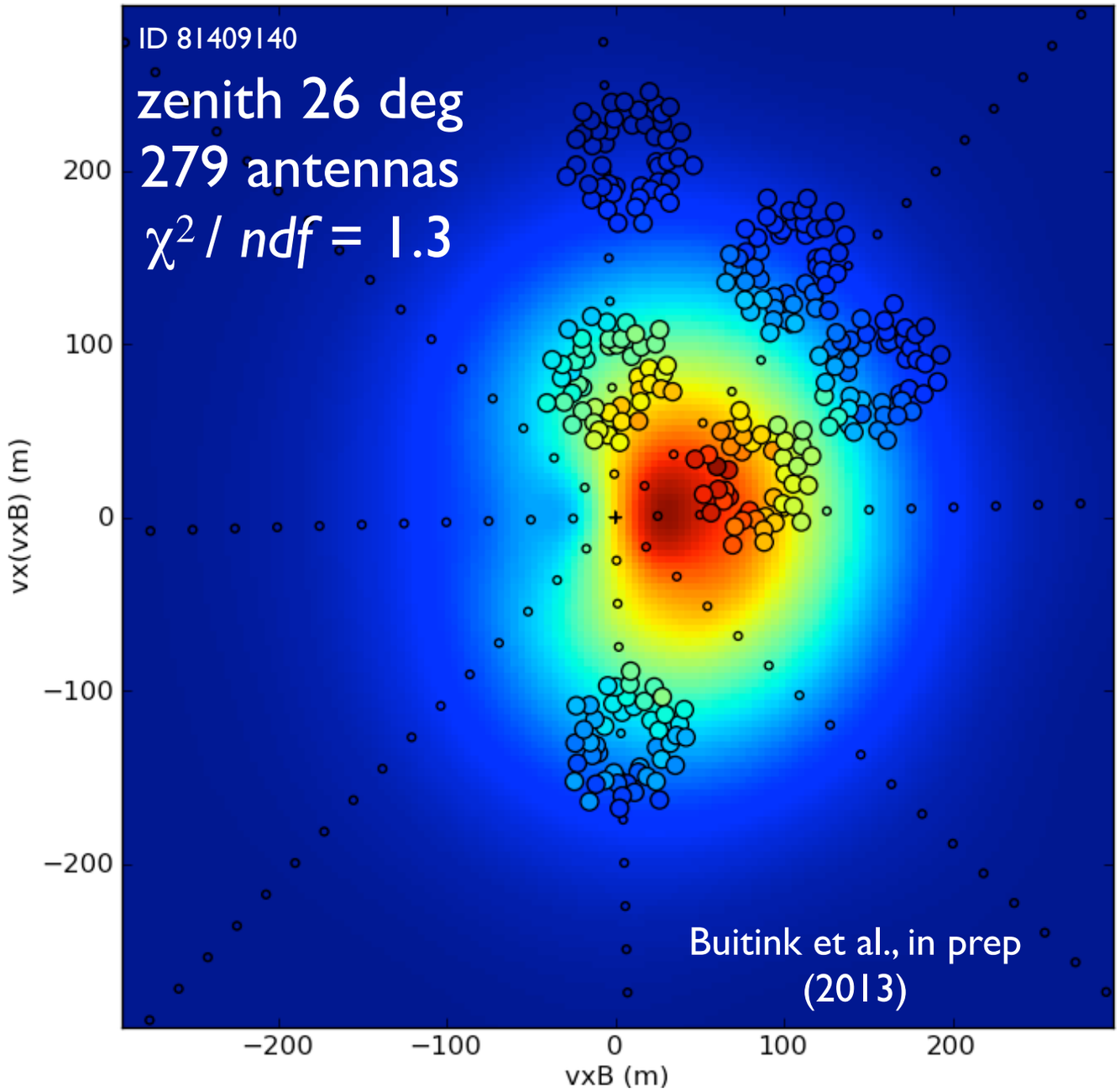
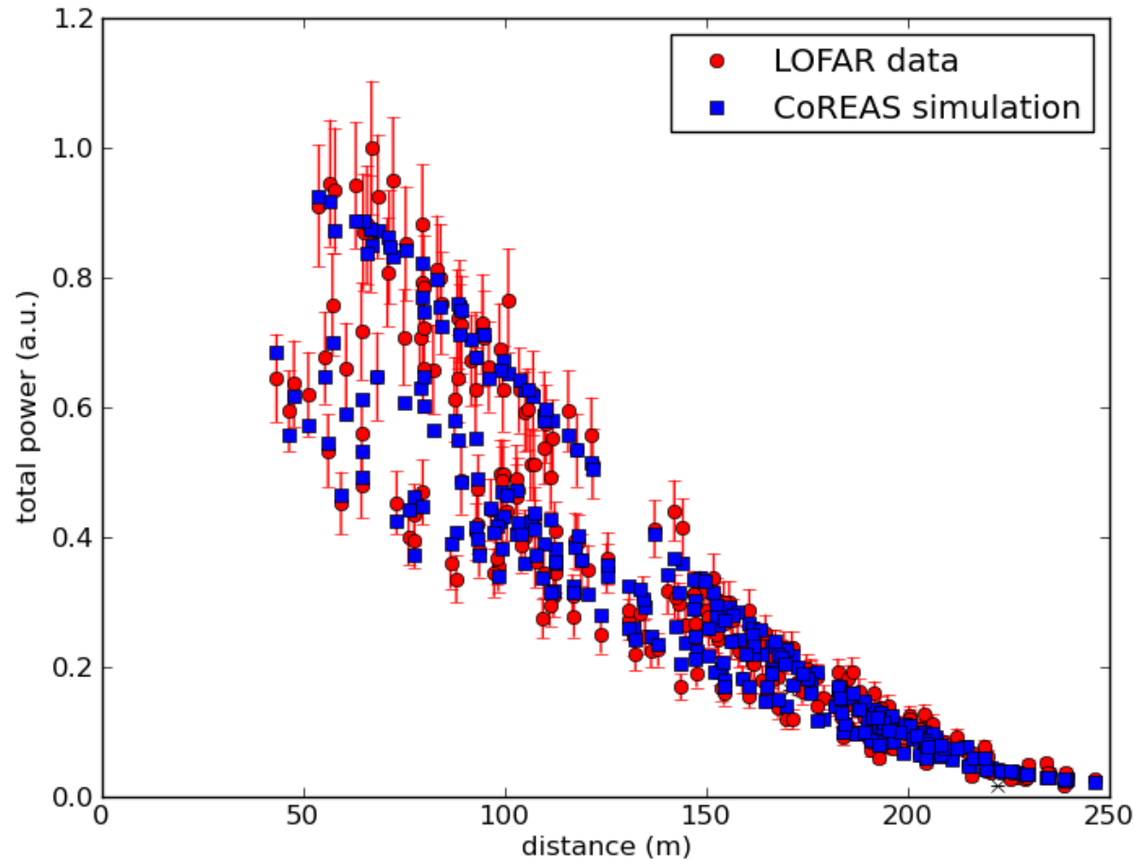
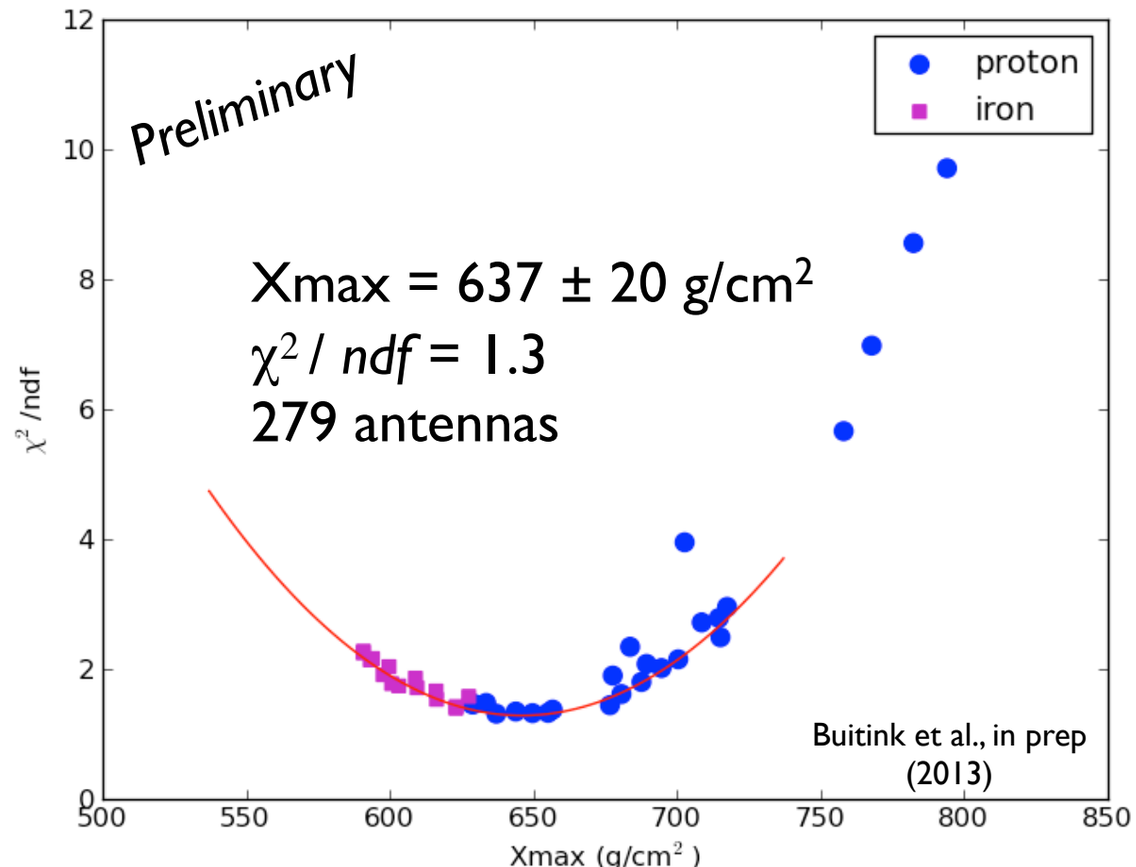


Corstanje et al. (in prep)

First ever radio measurements of Xmax!







Conclusions

- Detect radio emission from cosmic ray air showers
    - 400+ air showers detected with LOFAR using fully automated pipeline (Schellart et al. submitted to LOFAR publication committee)
- Understand radio emission from cosmic ray air showers
    - Polarization measurements allow disentangling of emission mechanisms (Schellart et al. in prep)
    - Wavefront curvature measurements indicate hyperbolic wavefront (Corstanje et al. in prep)
    - ***First measurements of air shower radio emission in HBA 110 - 240 MHz range where Cherenkov emission is expected to be stronger (Nelles et al. in prep)***
- Use radio emission to study cosmic rays
    - **First ever radio measurement of Xmax! (Buitink et al. in prep)**