Detecting Radio Emission of Air Showers - Using AERA and LOFAR

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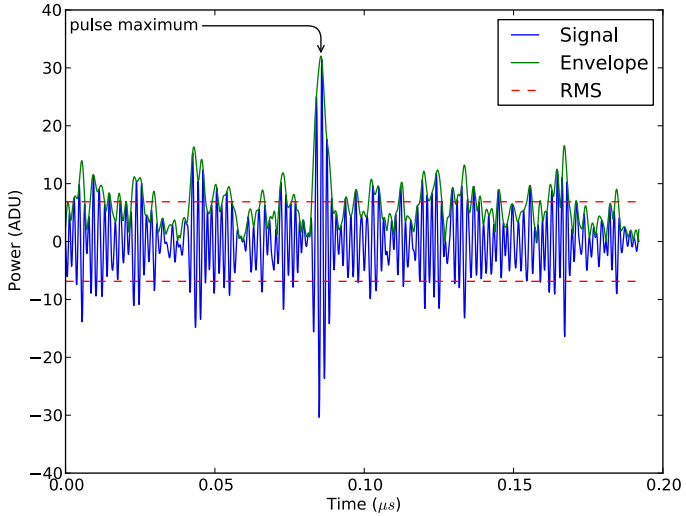
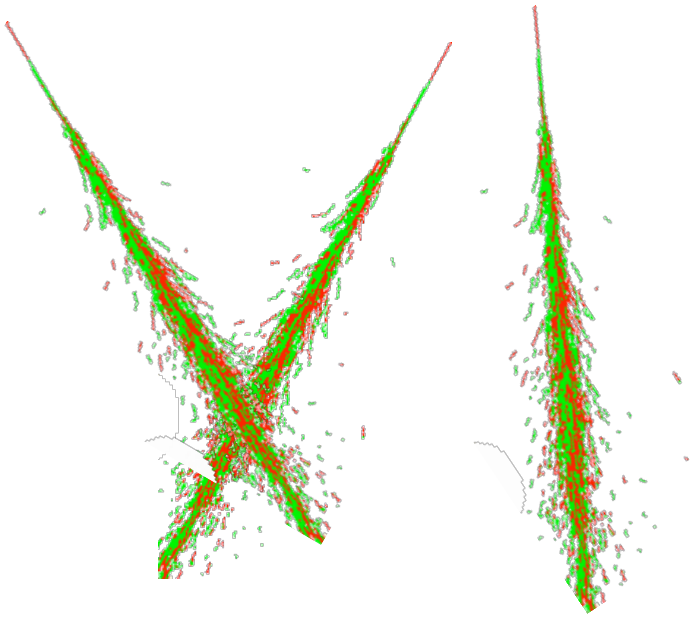
thanks to the Pierre Auger Collaboration and the LOFAR Cosmic Ray Key Science Project

What are we looking for?

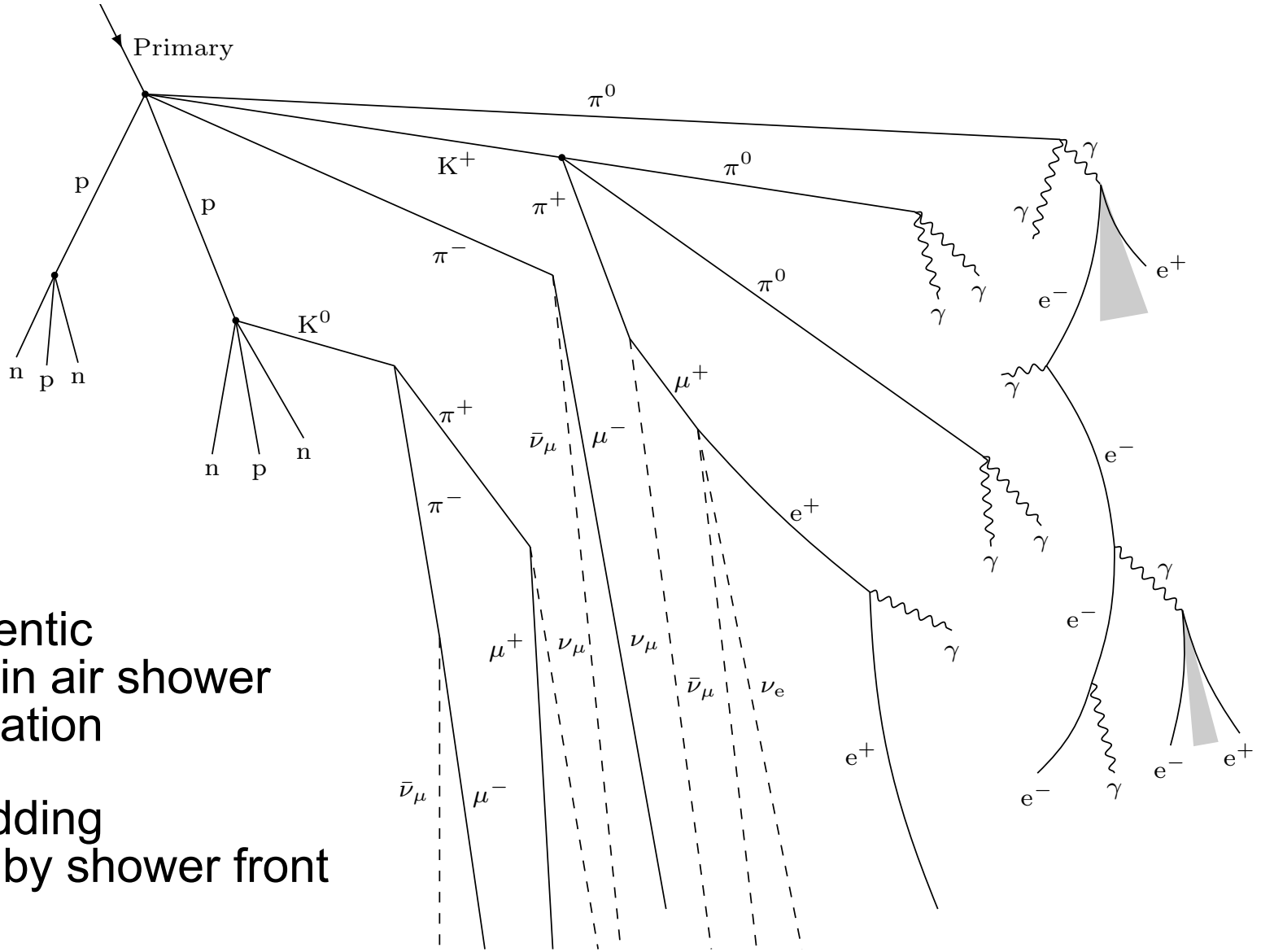
- What causes the radio emission and what are the mechanisms?
  - theoretical understanding
  - signal characteristics
  - comparison to simulations



- What can we contribute to cosmic ray and air shower physics?
  - open questions
  - experiments



Radio Emission from Air Showers



- Electromagentic component in air shower creates radiation
- Coherent adding determined by shower front

Radio Emission from Air Showers

Geomagnetic Field

Electromagnetic component resposible for radio emission

Emisson arises from:

- e+ and e- are accelerated in geomagnetic field
- e+ and e- are generated and annihilated -> charge variation
- more e- than e+ in the shower

Emisson is affected by:

- Superposition of emission
- Cherenkov effects

Why Radio Emission?

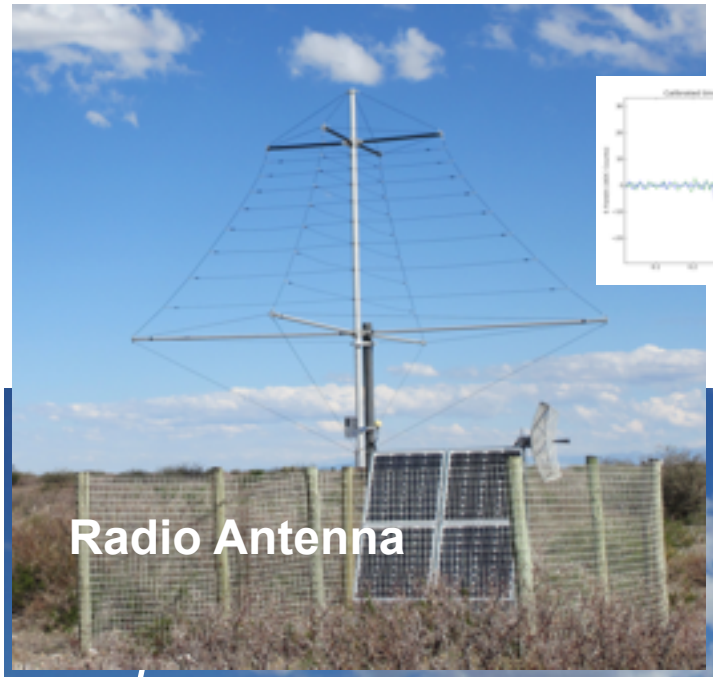
- Big questions about cosmic rays of the highest energies:
  - Where are sites of acceleration?
  - What particles are those cosmic rays?

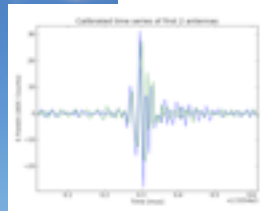
- Radio Detectors might be an efficient alternative method of measurement:

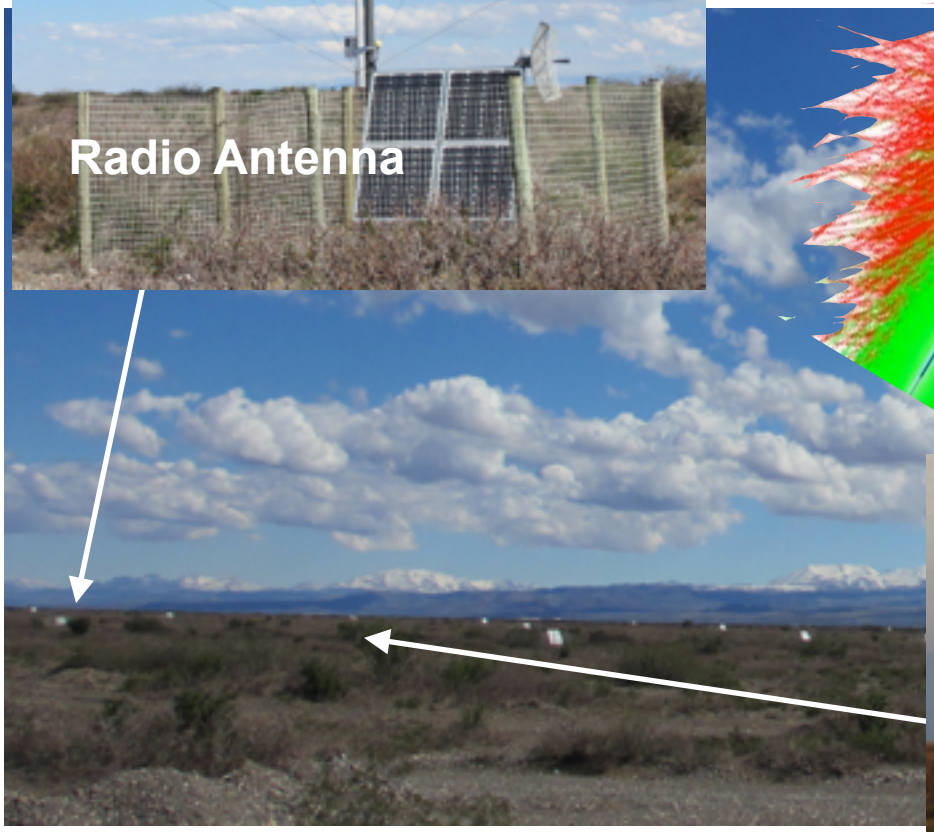
  - Radio emission is sensitive to composition

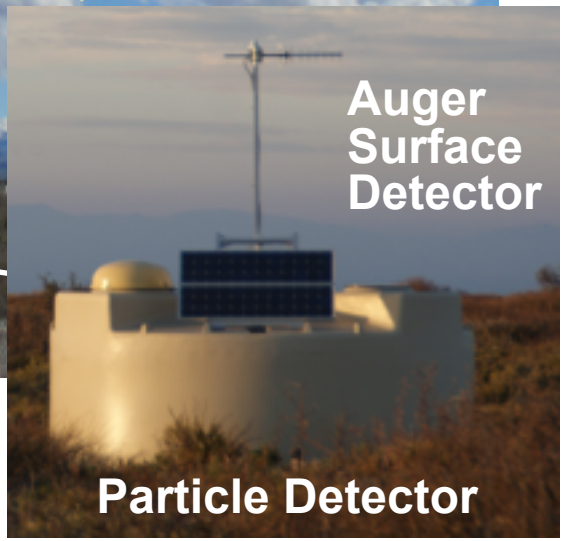
  - “traditional” methods: low duty-cycle (11%) and expensive

Measuring Cosmic Rays









Auger Engineering Radio Array

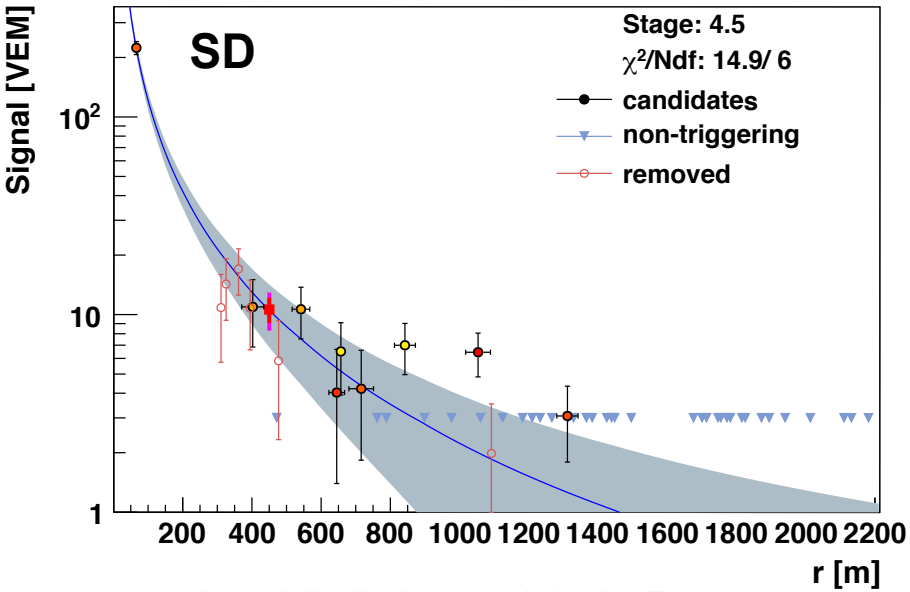
at Pierre Auger Observatory in Argentina

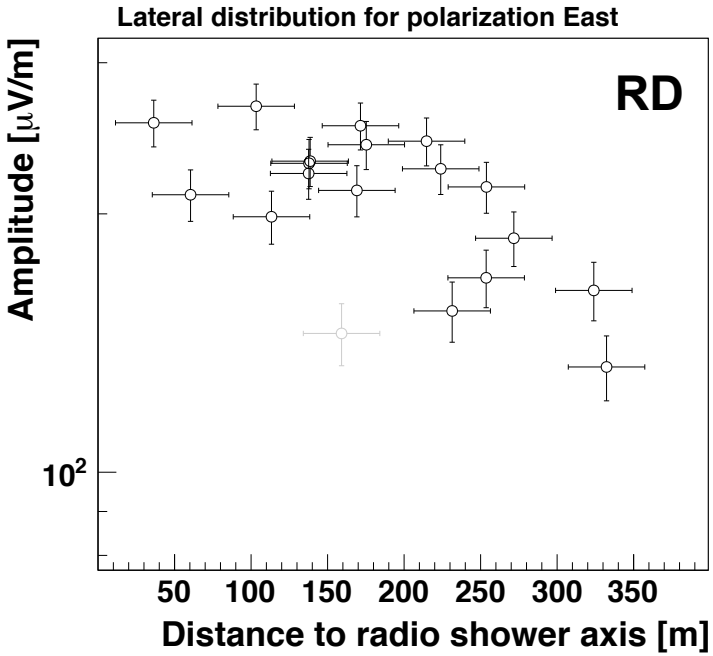
Radio Antennas

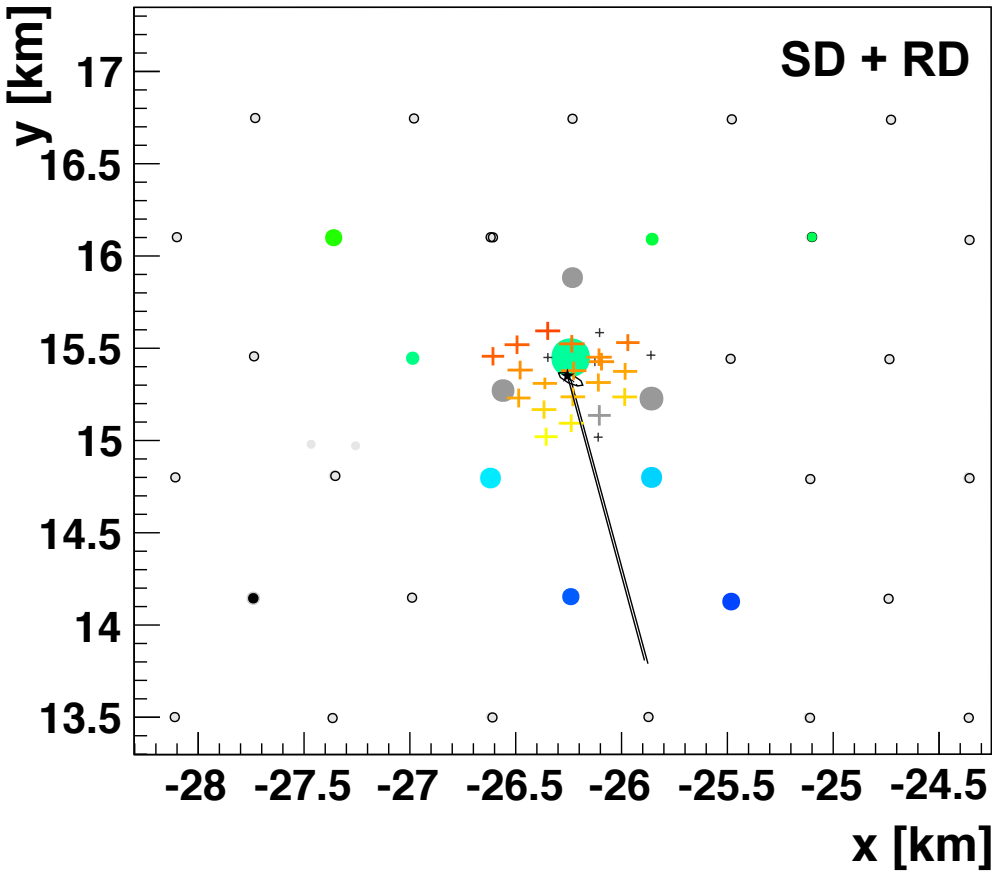
measure short duration pulses from air showers

Coincidence of more than one detector type = air shower

Example Events

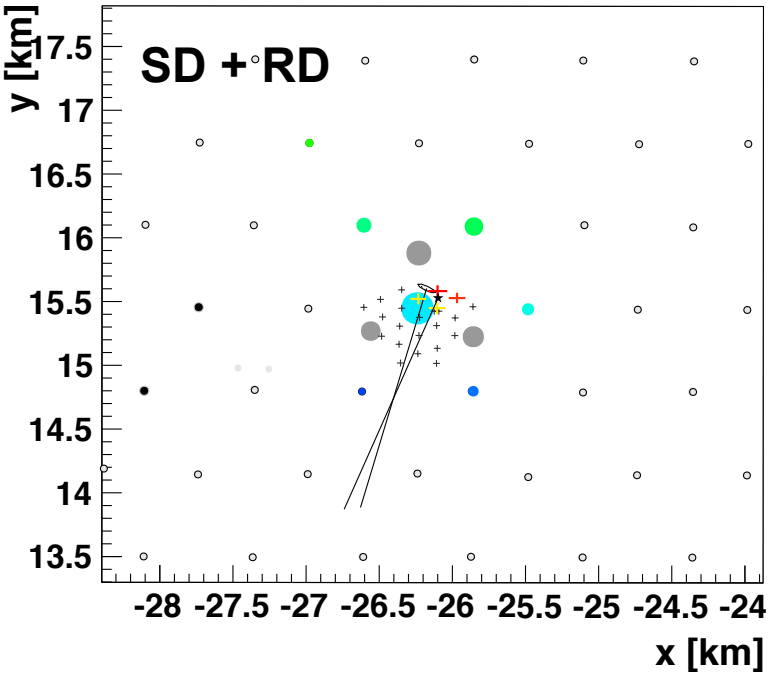


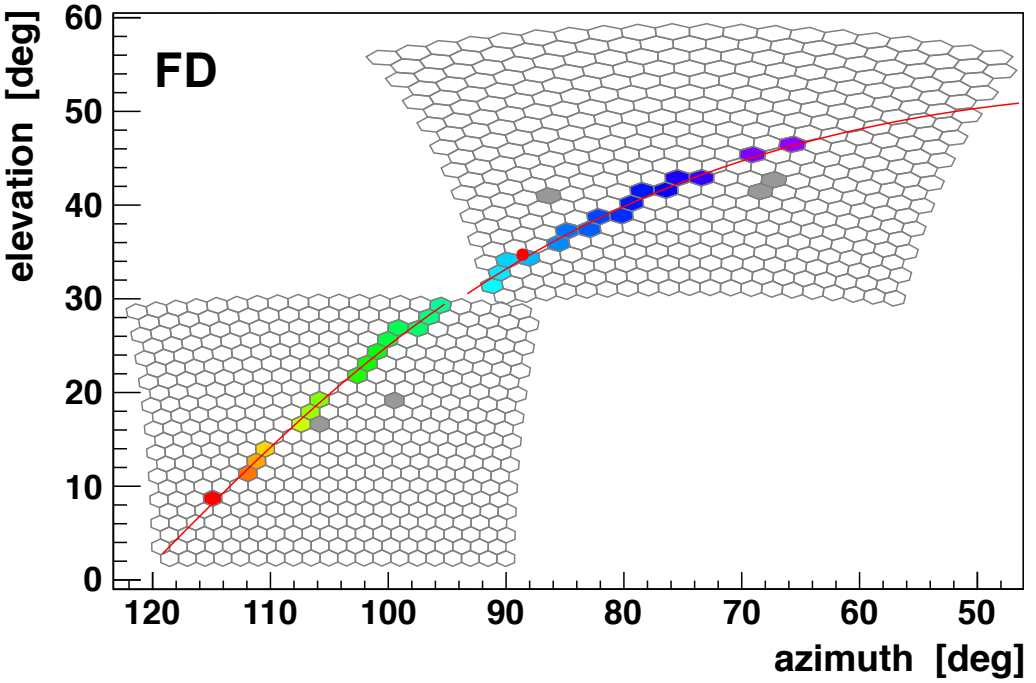




- Coincidence of Surface Detectors and Radio Array
- Cross check, whether pulse is originating from cosmic ray

Example Events



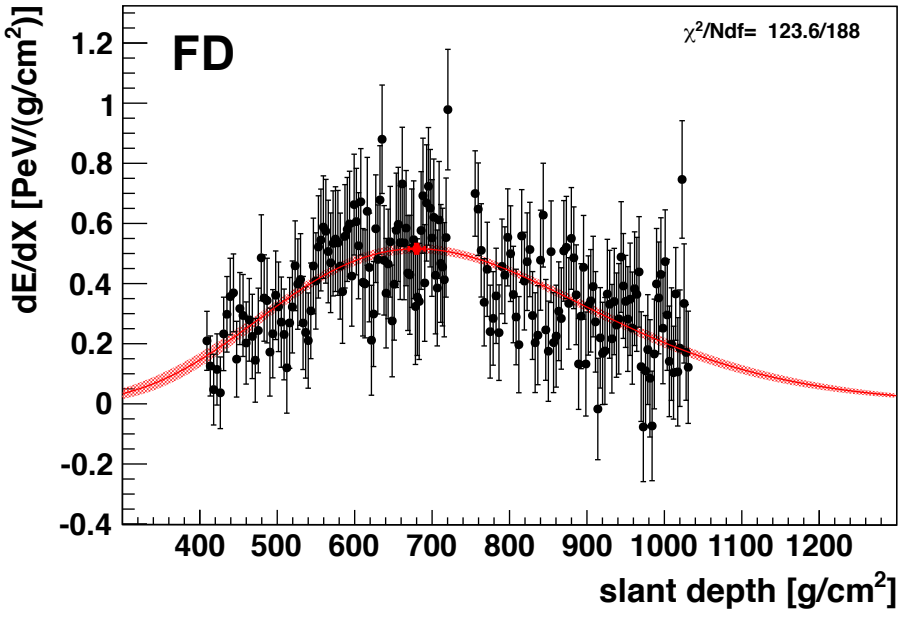


Super Hybrid Event

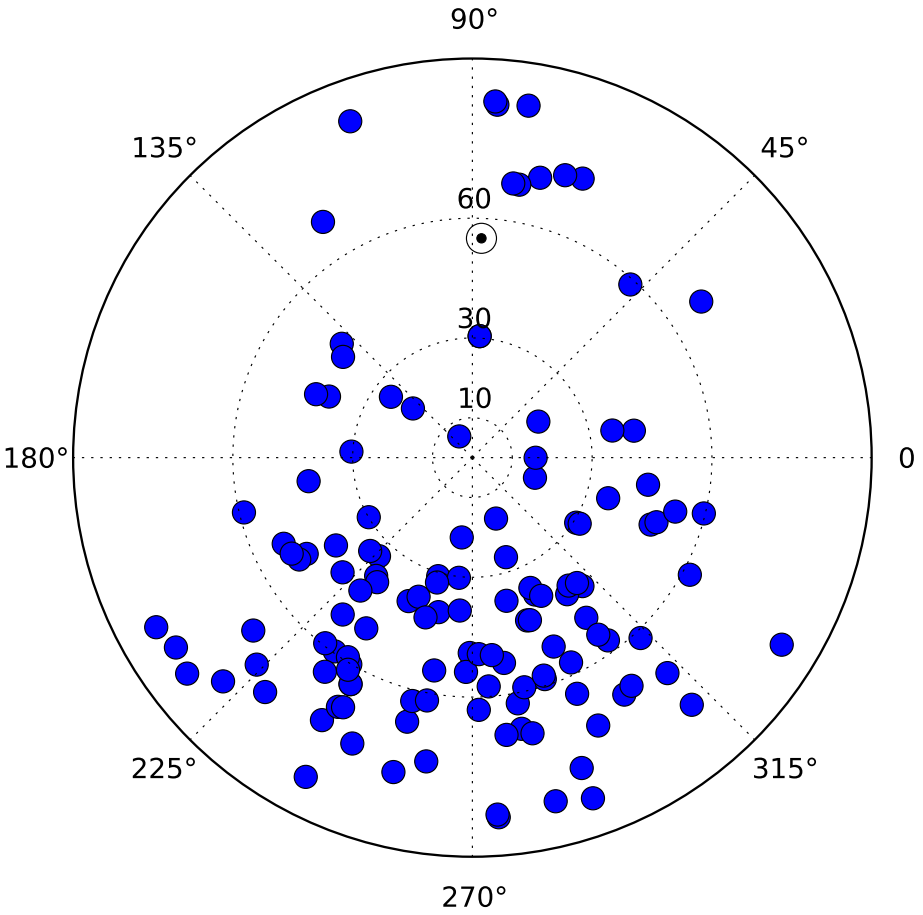
measured also in Fluorescence Detector

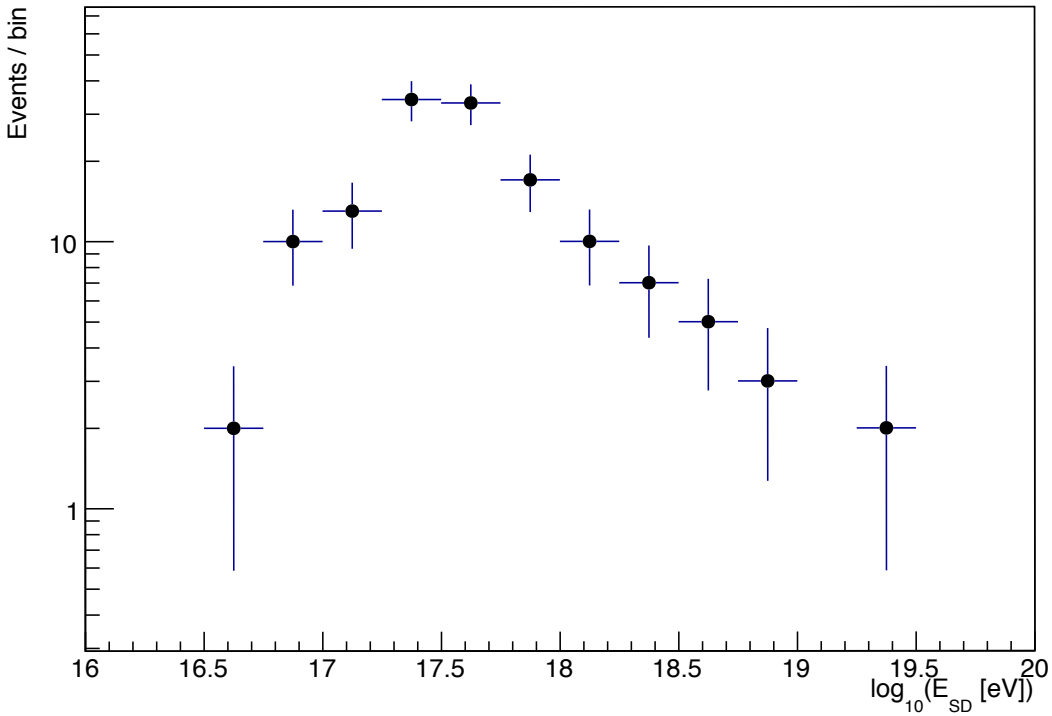
Energy(FD) = (3.09 +/- 0.12) 10^{17} eV

Energy(SD) = (2.77 +/- 0.36) 10^{17} eV



Radio Events

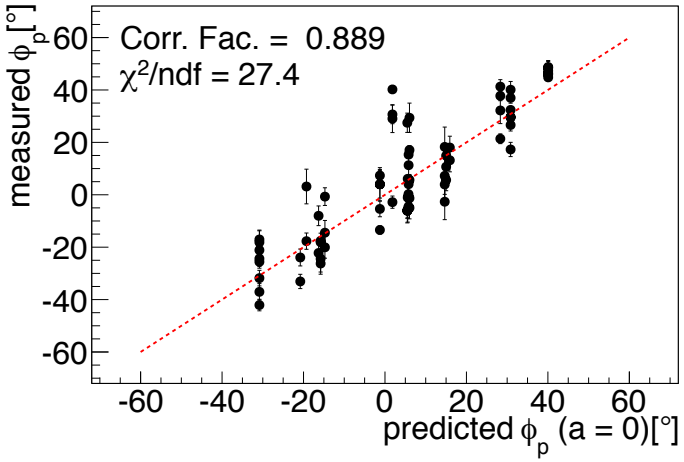




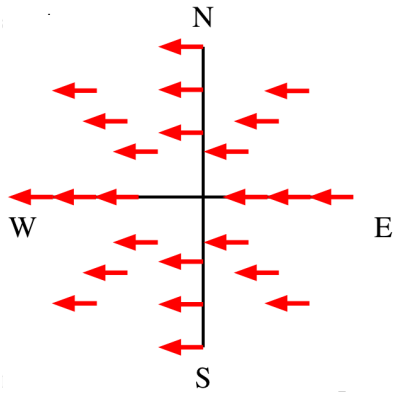
Data from May 2011 - September 2012

- Geomagnetic effect is clearly visible
- effects of trigger and dead time not corrected for

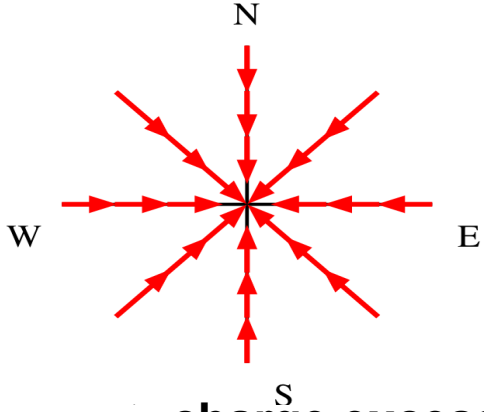
Emission mechanisms



geomagnetic effect only

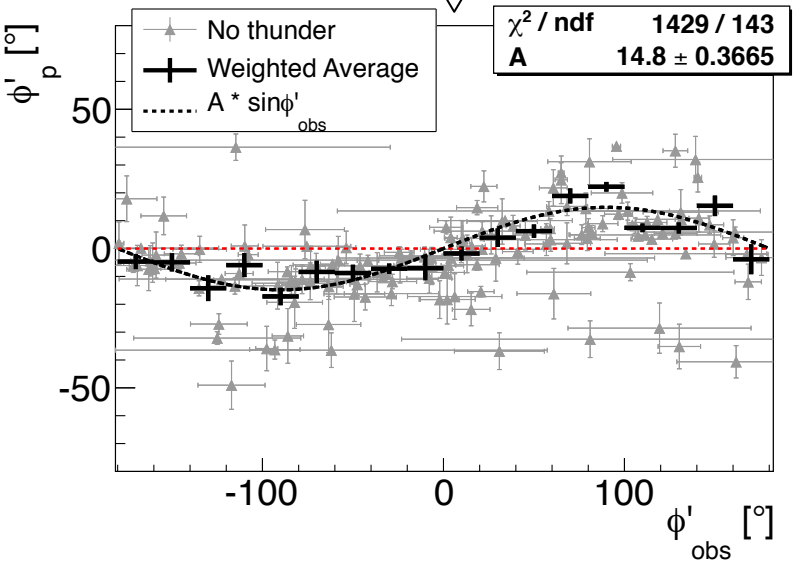


geomagnetic effect

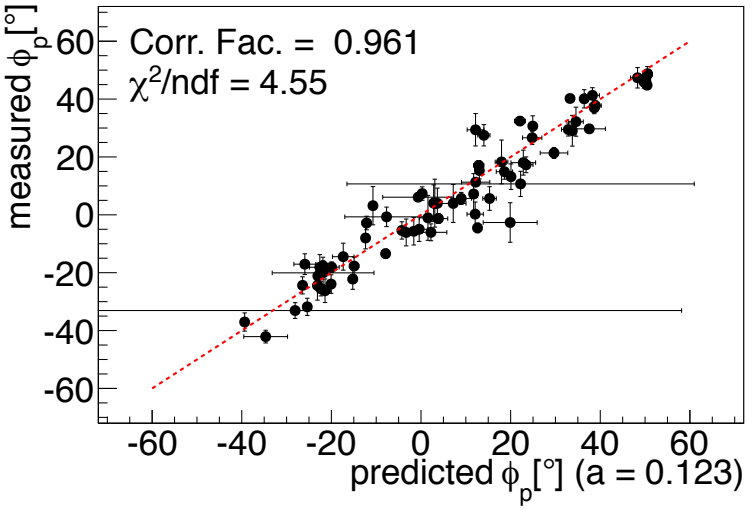


charge excess

deviations



Correction 12.3%



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H. Schoorlemmer, Nijmegen

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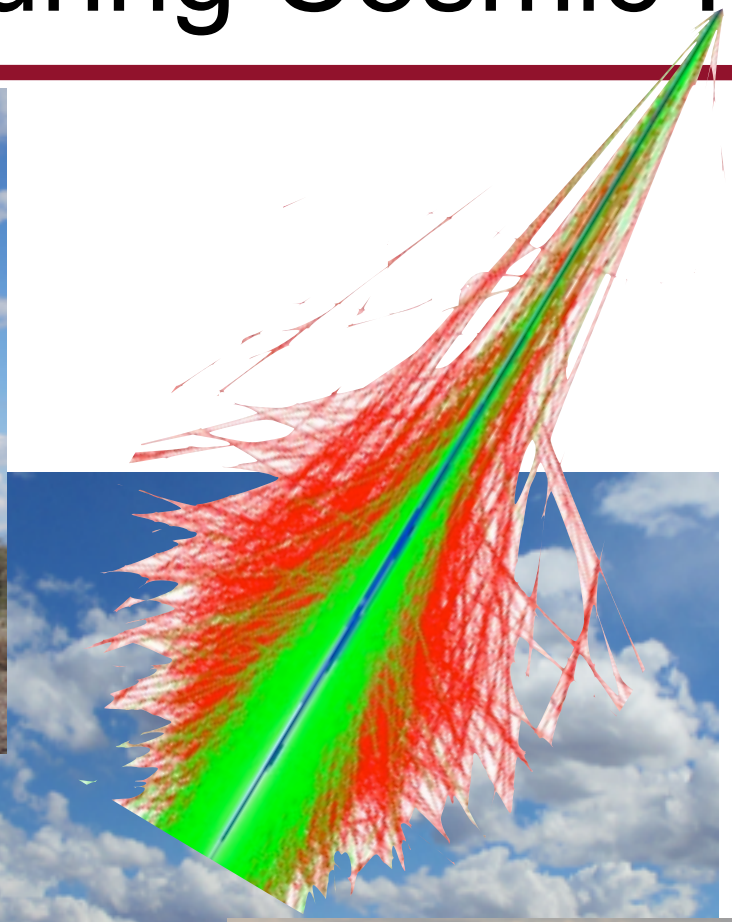

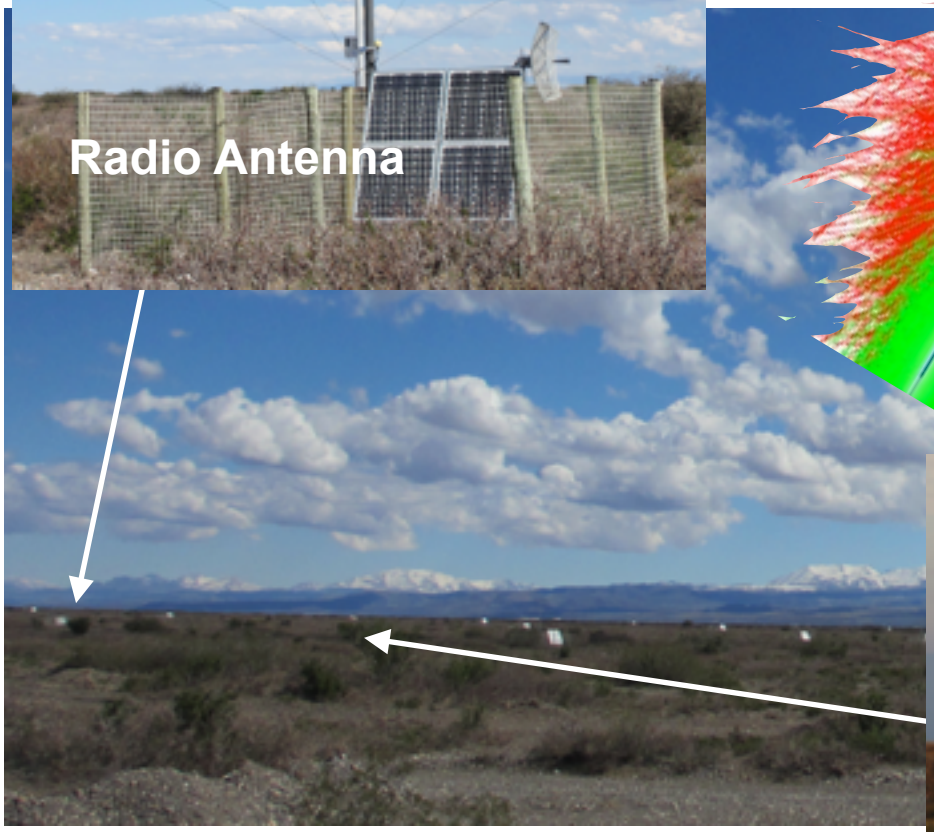

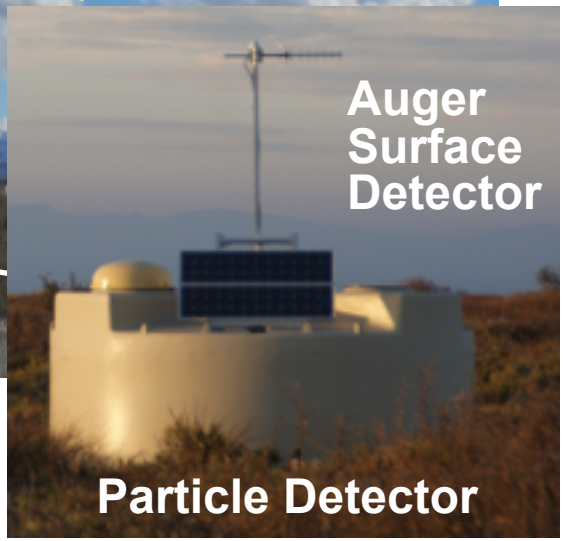

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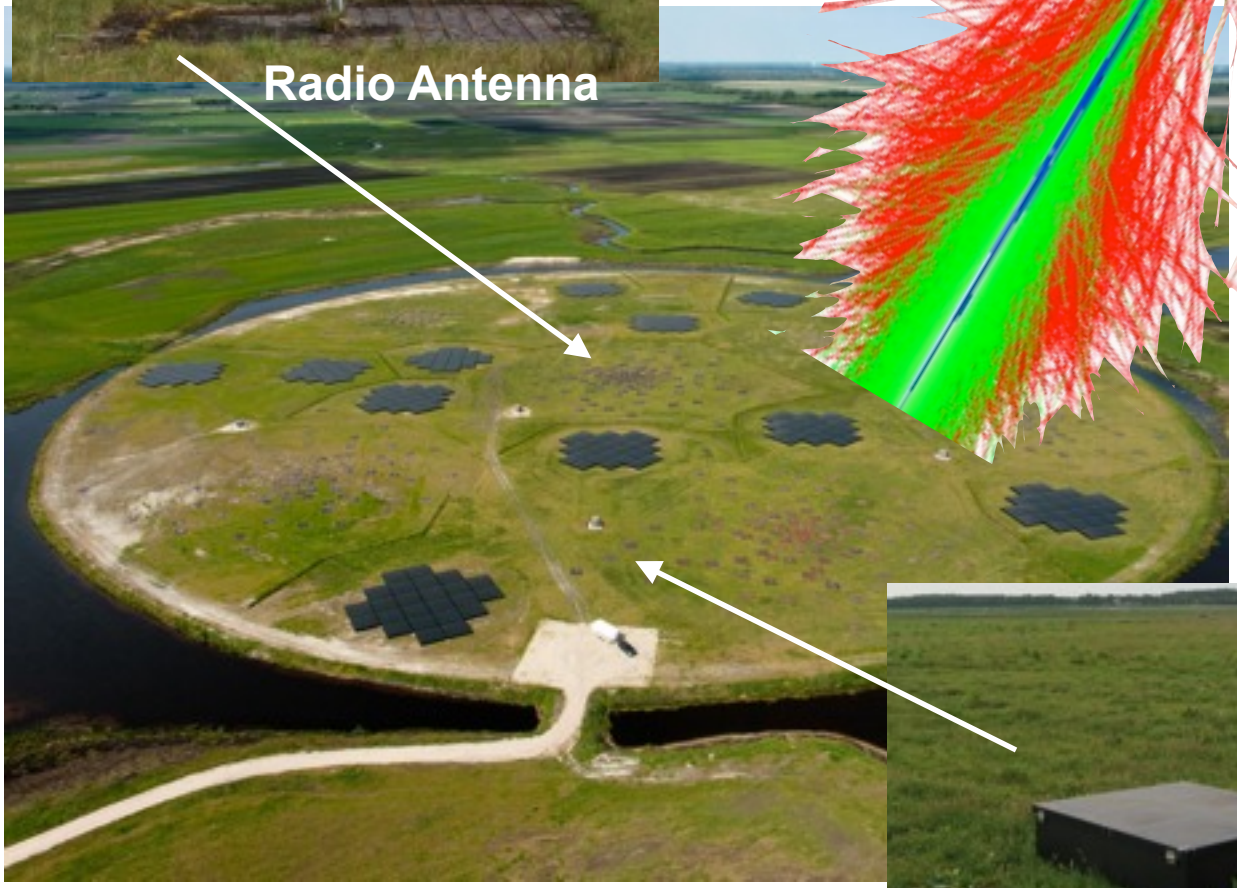

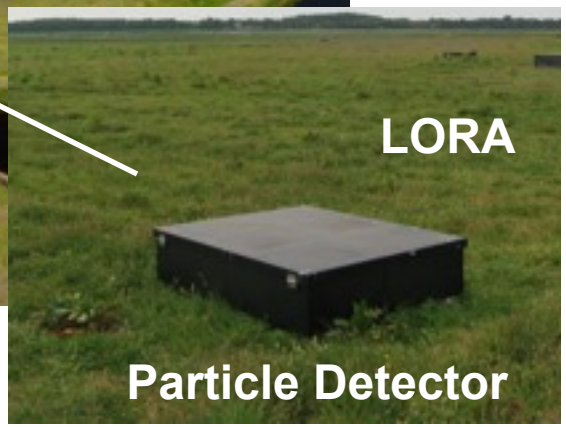

LOFAR - Low frequency array in Drenthe, Netherlands

Antenna electronics identify pulse and trigger

External trigger from LORA

Coincidence of more than one detector = air shower

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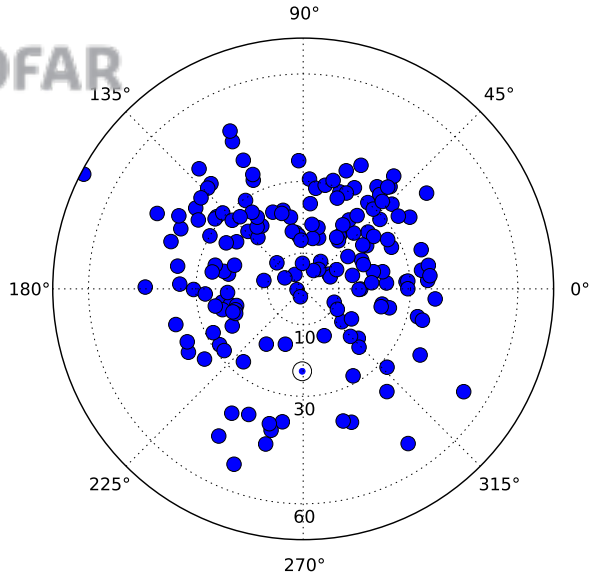
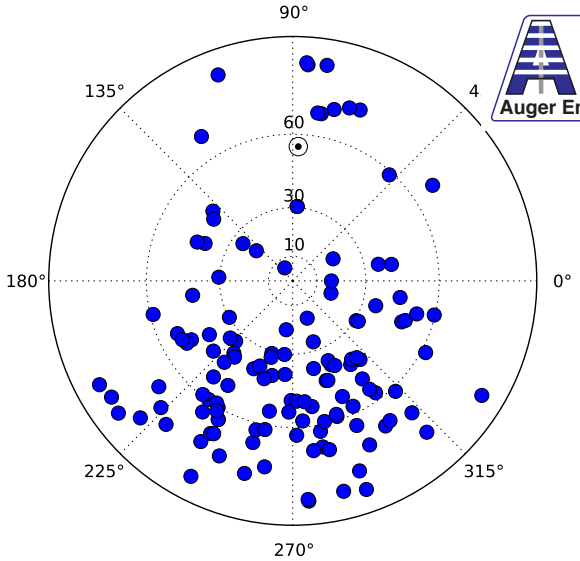
Location: LOFAR vs AERA

- Northern Hemisphere: Netherlands
- ~ 5 m above sea-level
- mostly humid, ground can be swamped
- flat, rain, but not so many thunderstorms
- magnetic field direction north, pointing down (60˚), 48 000 nT
- **Comparison: LOFAR Radboud Air Shower Array**

- Southern Hemisphere: Argentina
- ~ 1400 m above sea-level
- mostly dry, salty, sunny
- flat, **many thunderstorms**
- magnetic field direction (almost) north, pointing up (-40 ˚), 24 000 nT
- **Comparison: Fluorescence and Surface Detector of the Pierre Auger Observatory**

Location: LOFAR vs AERA





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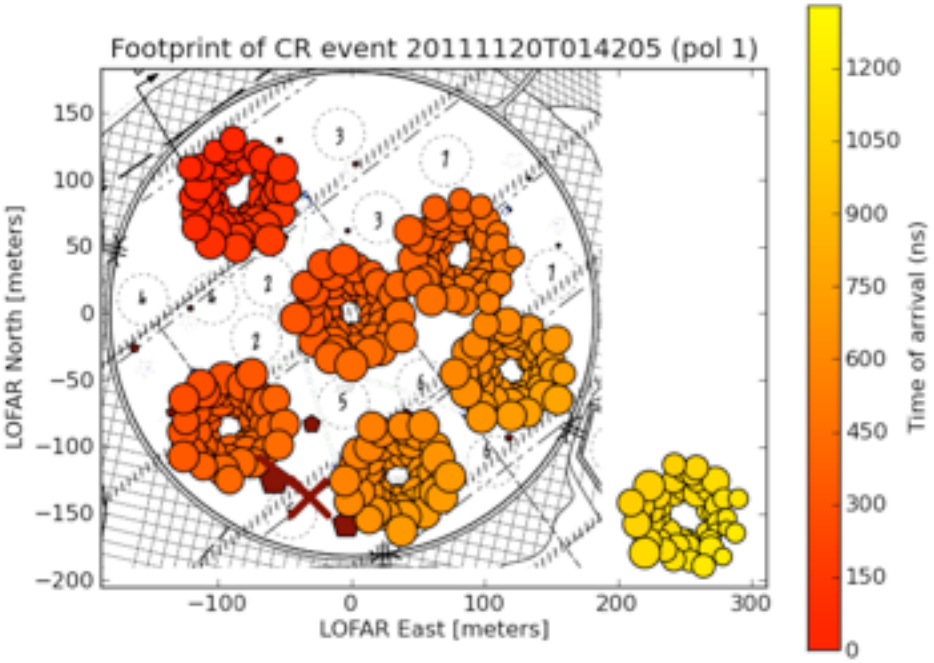
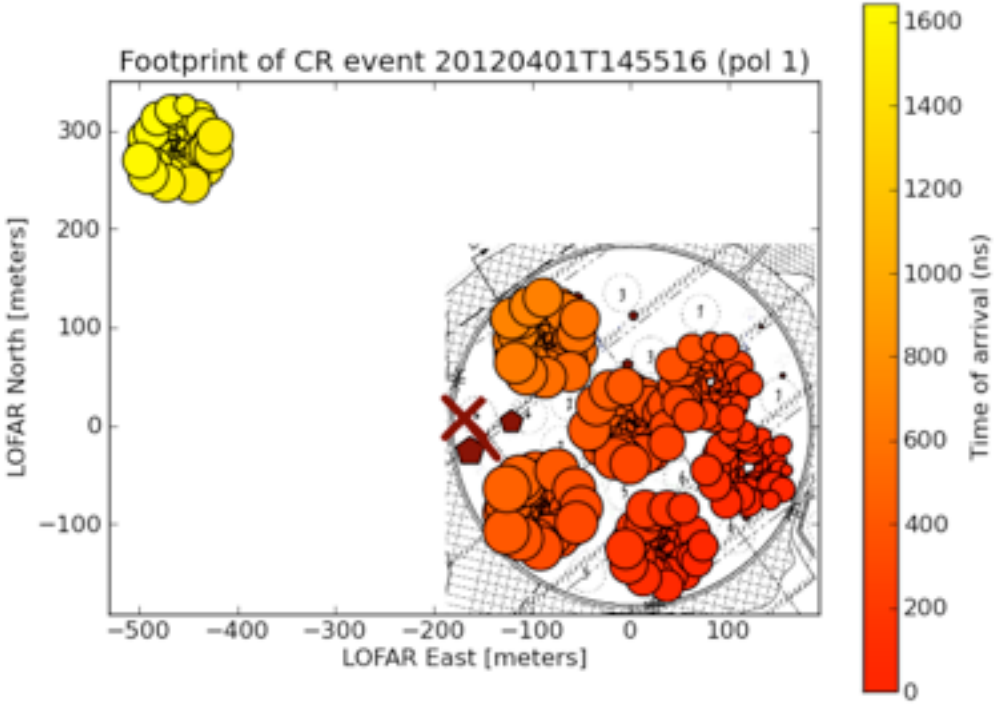
Cosmic Ray Data



- all stations can be triggered
- measurement of “large events” possible

- effective area limited by particle detectors
- antenna density is higher at LOFAR, but information for cross-check weaker



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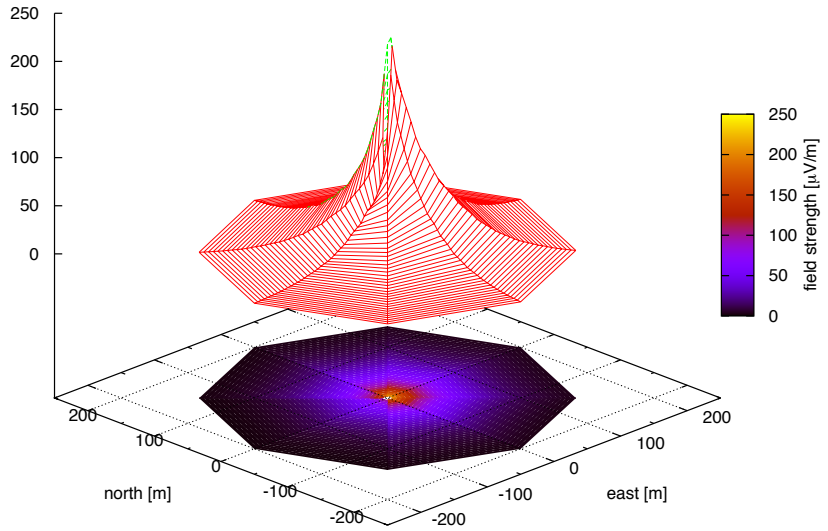
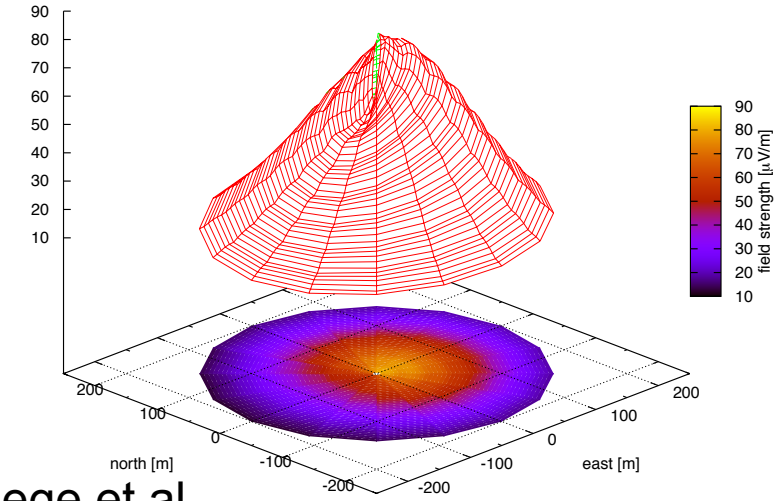
Sensitiviy to composition

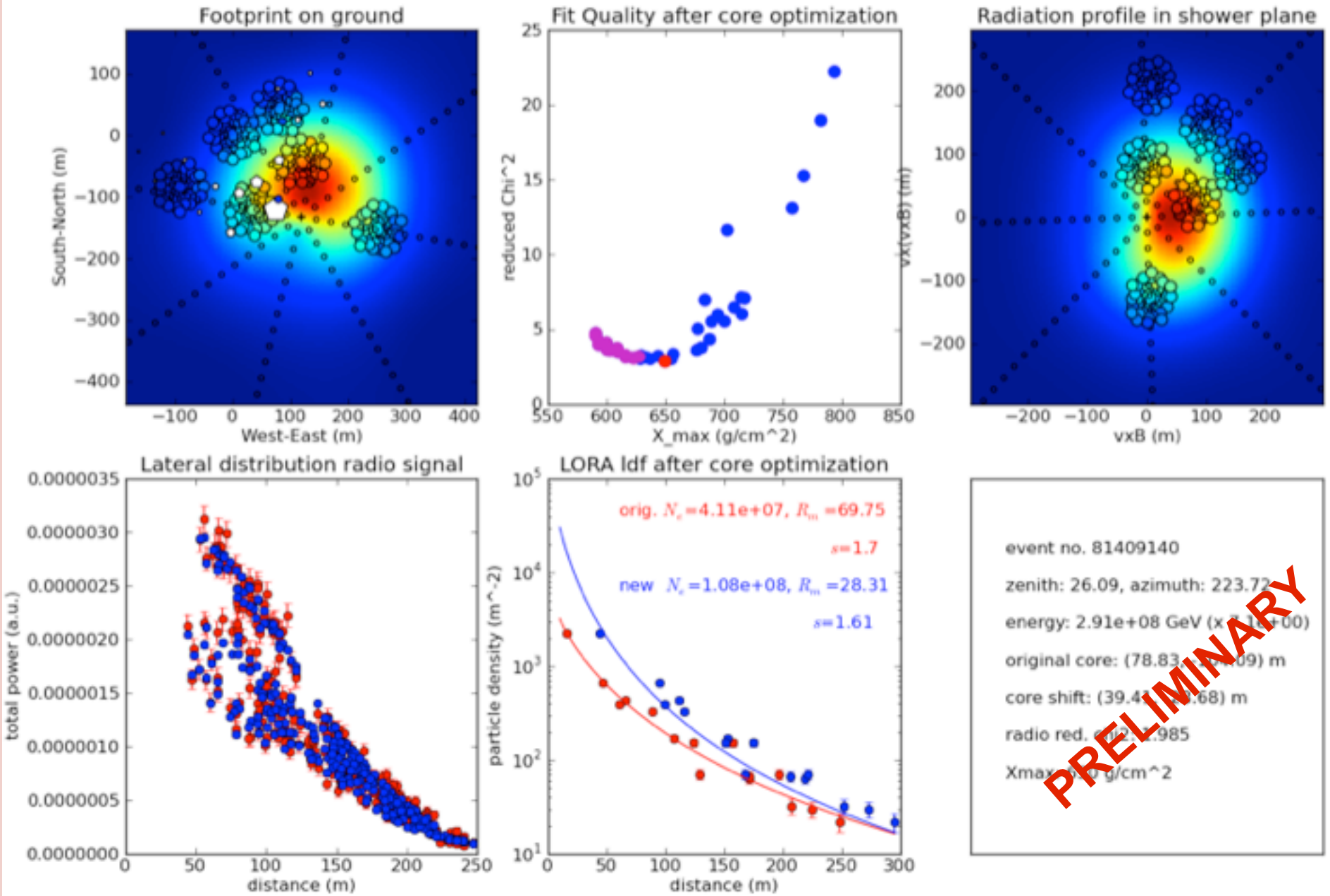
Full simulations of air shower





Huege et al

Sensitiviy to composition



S. Buitink, Nijmegen/Groningen

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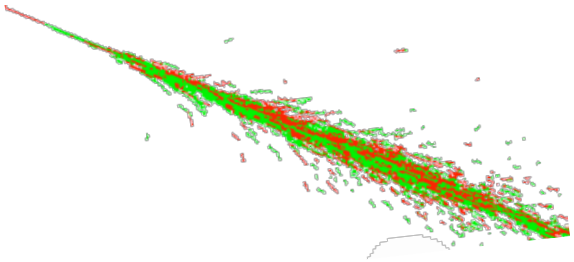
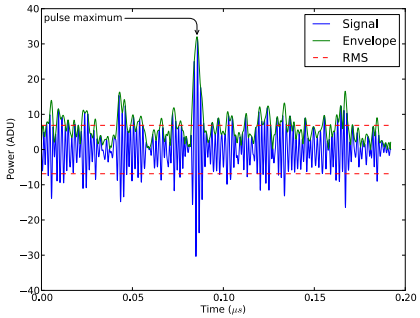
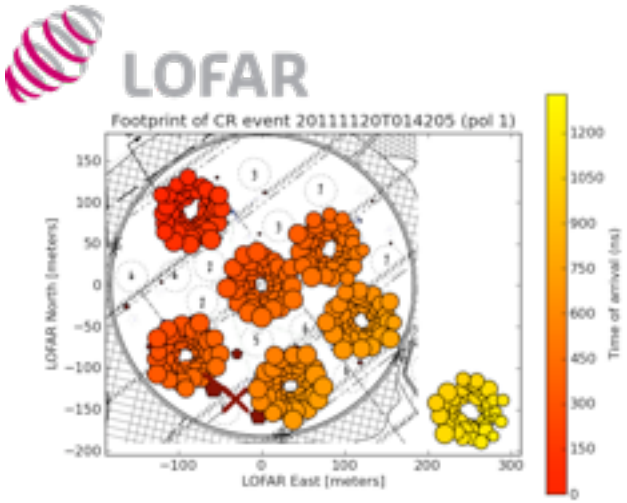
Conclusions

- We will now uncover the details about radio emission from air showers





- and what we can learn from it about air showers



complementary, synergies