



Radio detection of air showers at the Pierre Auger Observatory

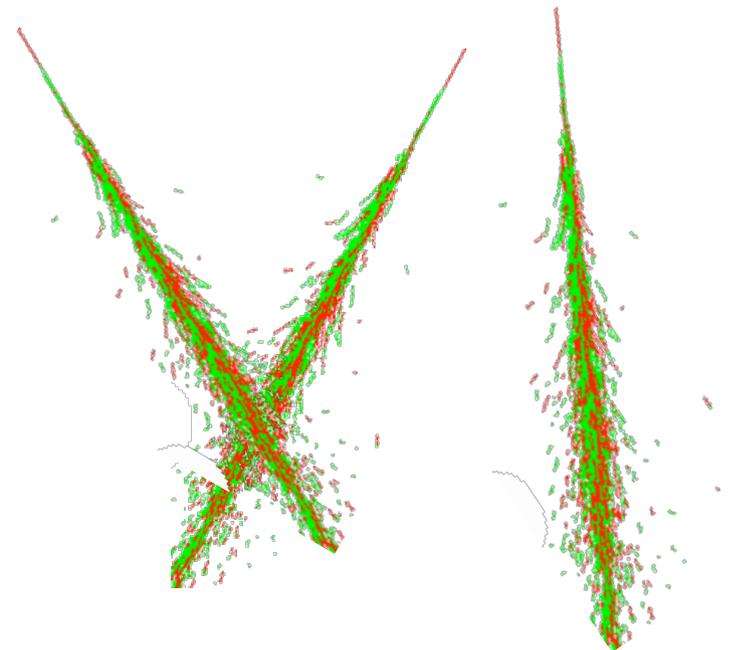
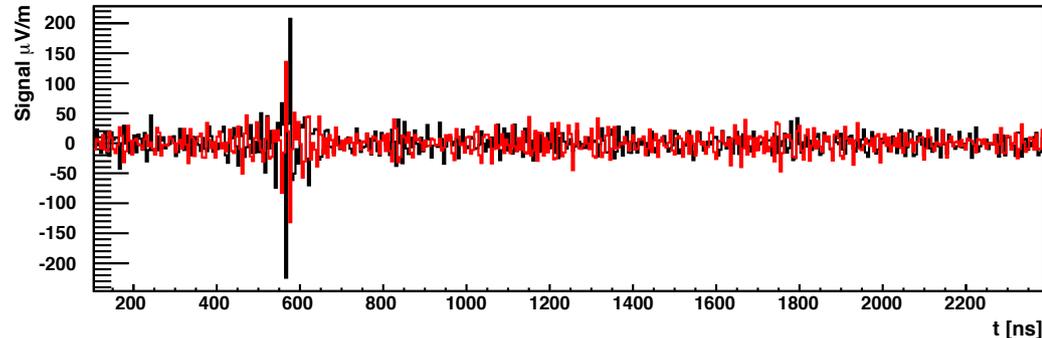
Anna Nelles
for the Pierre Auger Collaboration

Radboud University Nijmegen

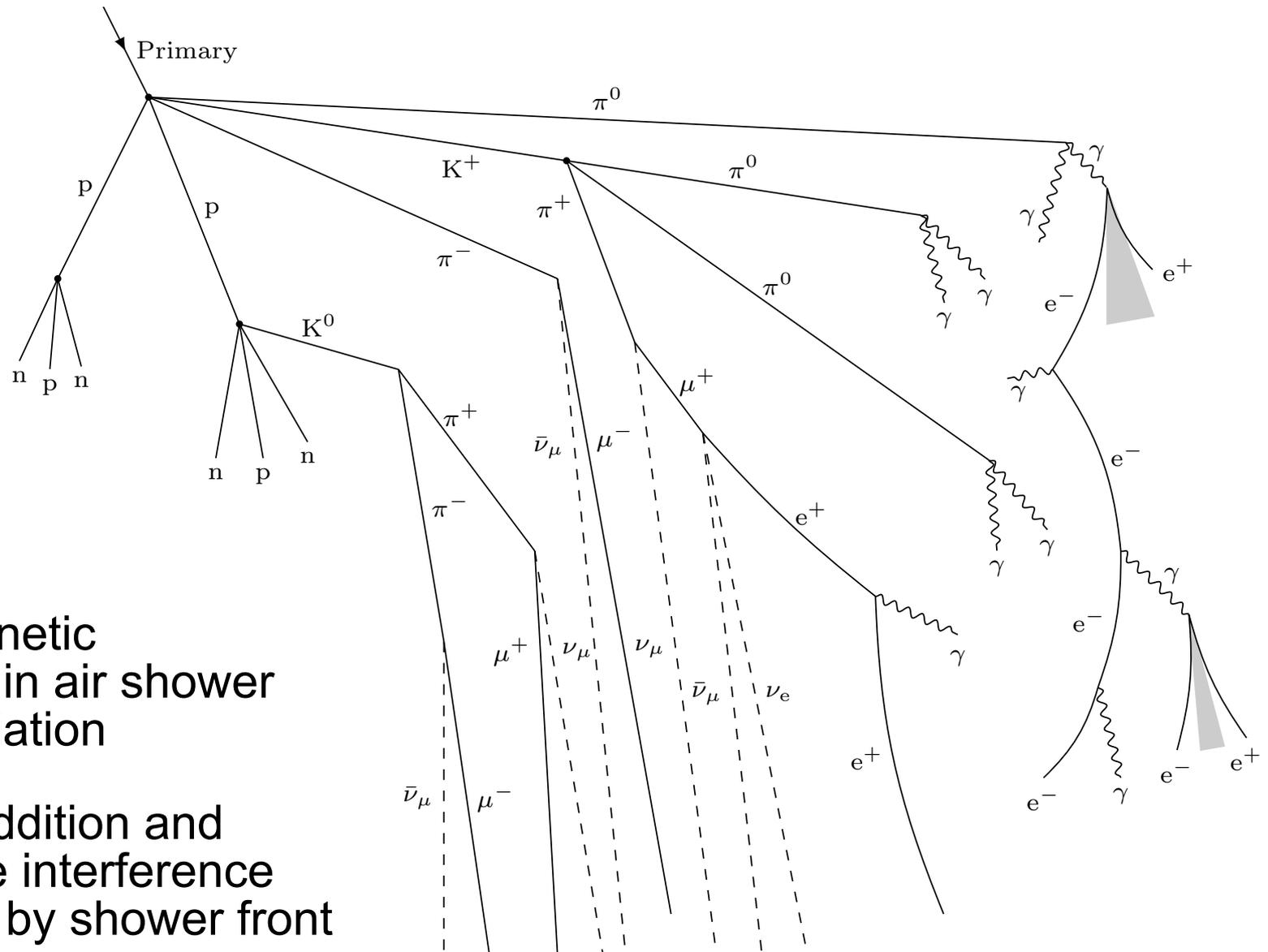


What are we looking for?

- What can measuring the radio emission contribute to cosmic ray physics?
- What causes the radio emission and what are the physics processes?
 - theoretical understanding
 - signal characteristics
- How is this measured at the Pierre Auger Observatory?
 - set-up
 - recent results

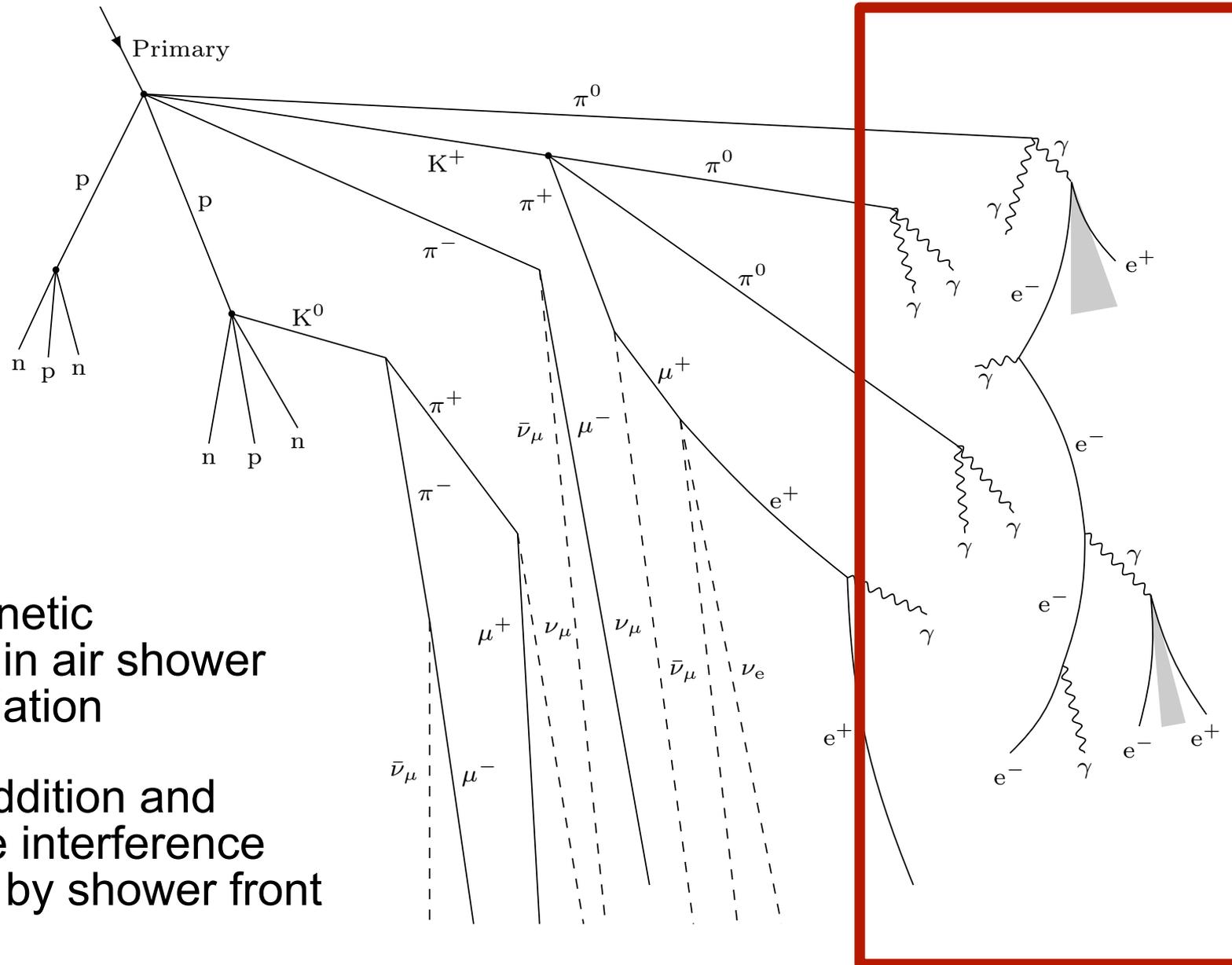


Radio Emission from Air Showers



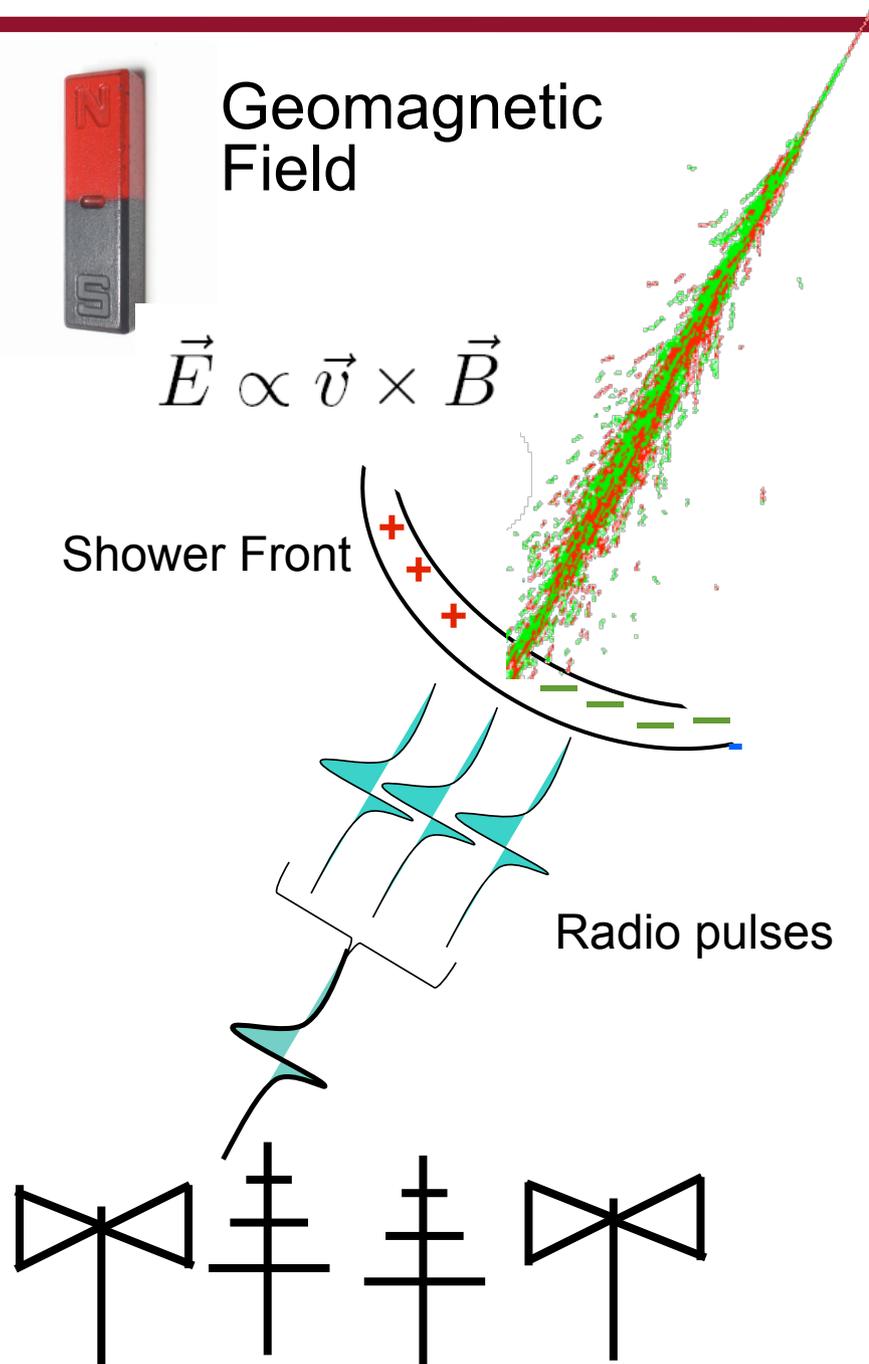
- Electromagnetic component in air shower creates radiation
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Radio Emission from Air Showers



Electromagnetic component responsible for radio emission

Emission arises from:

- e⁺ and e⁻ are accelerated in geomagnetic field (geomagnetic effect)
- more e⁻ than e⁺ in the shower (charge excess)

Emission is affected by:

- Superposition of emission
- Cherenkov effects

Askaryan (1962), Kahn & Lerche (1966), Allan (1971), Falcke & Gorham (2003), ...

Why Radio Emission?

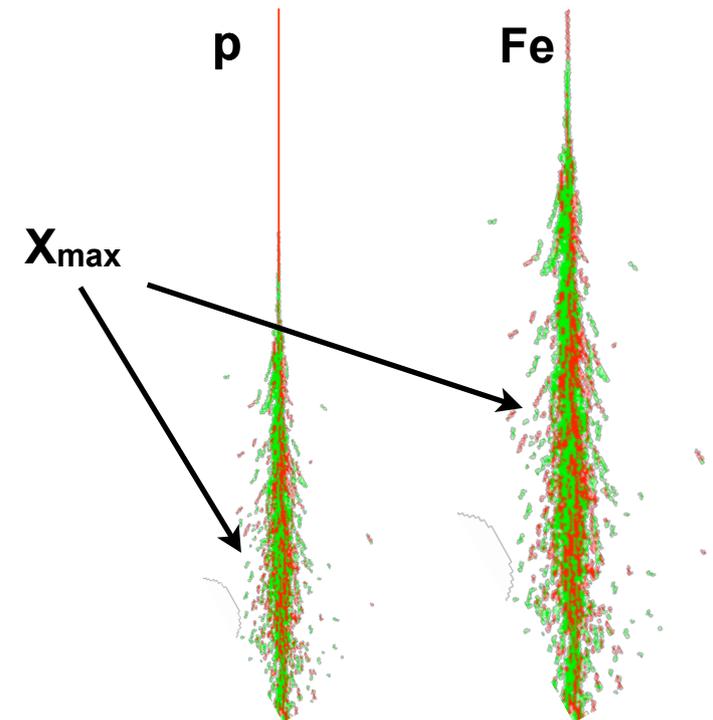
- Big questions about cosmic rays of the highest energies:
 - Where are the **sites of acceleration**?
 - What **type of particles** are these cosmic rays?
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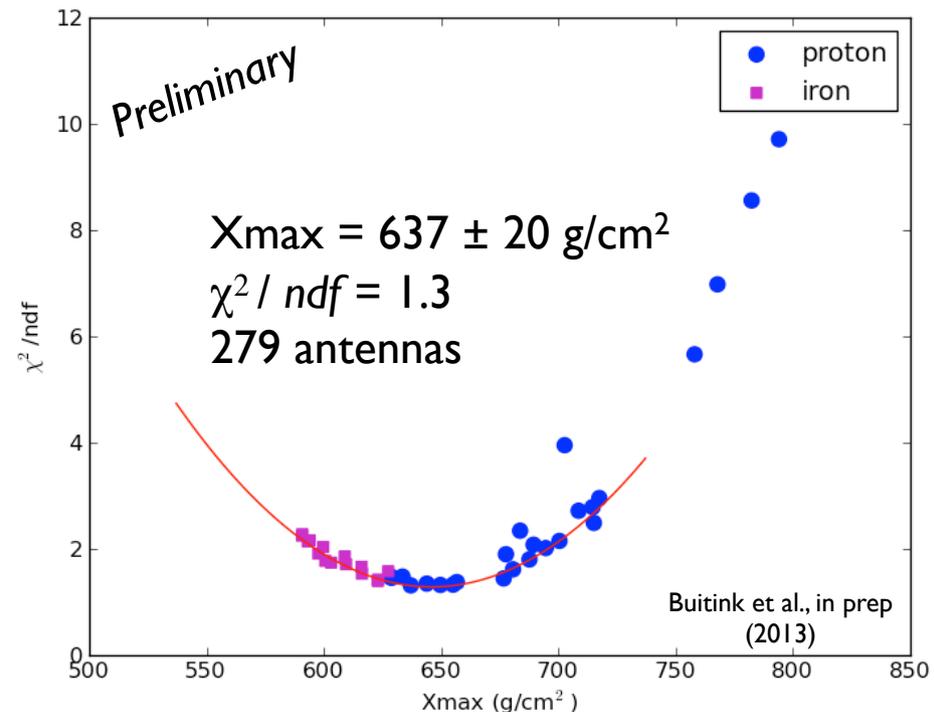
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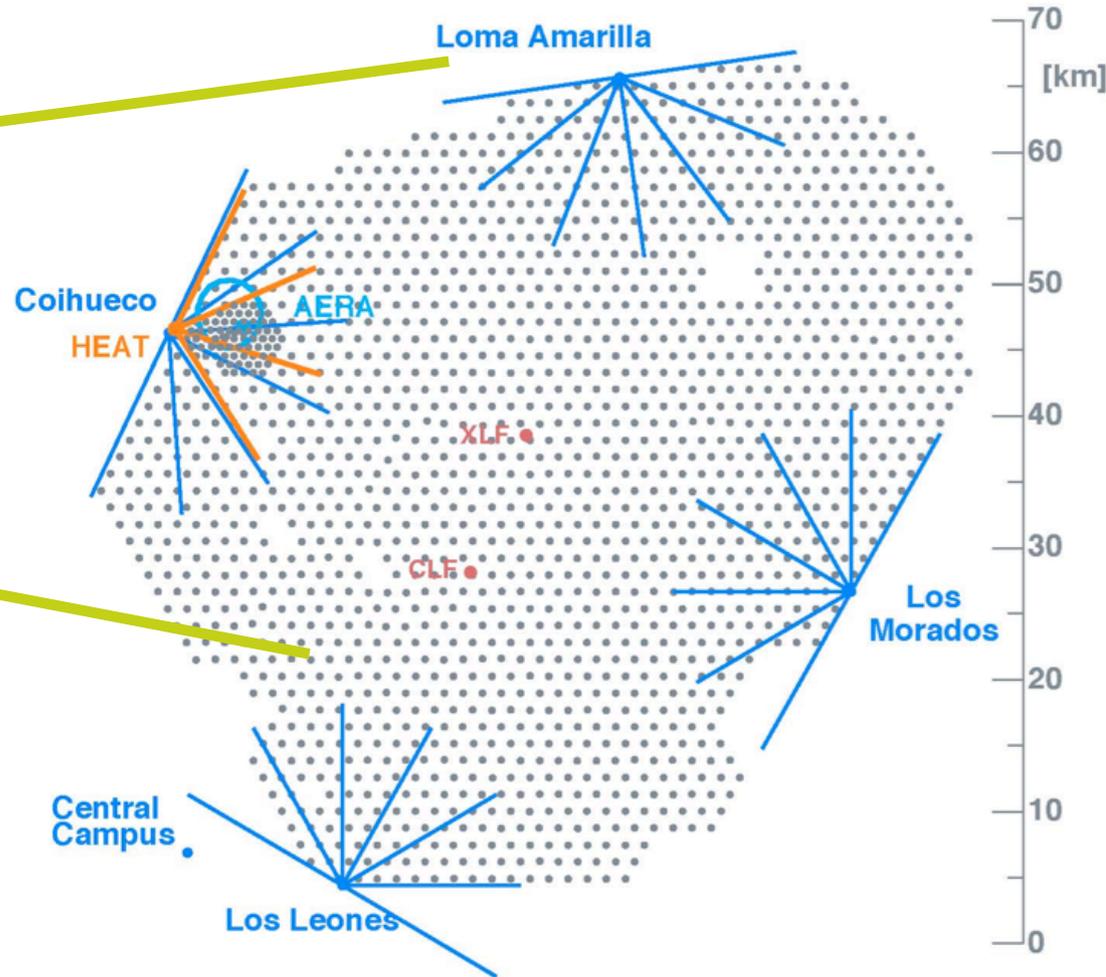
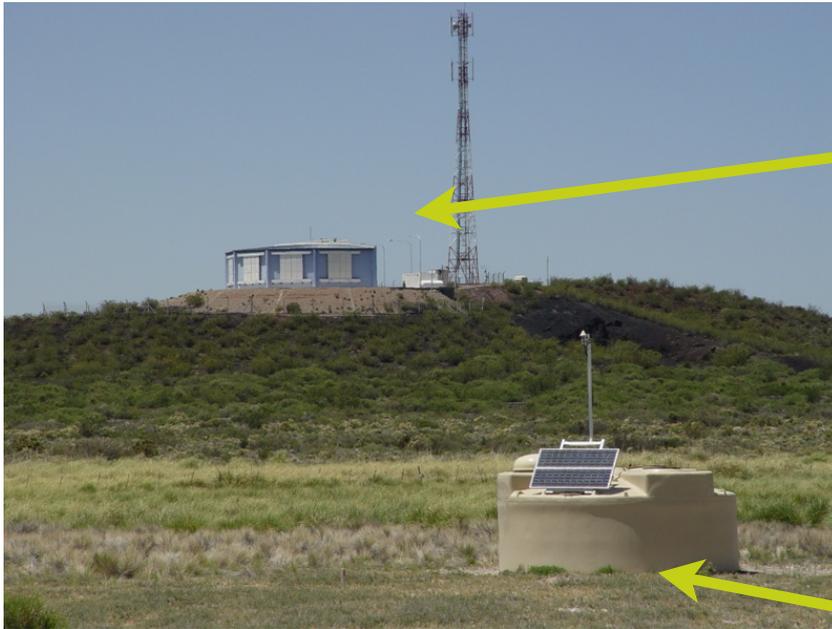
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LOFAR: Single event X_{\max} resolution



The Pierre Auger Observatory



Baseline Detectors:

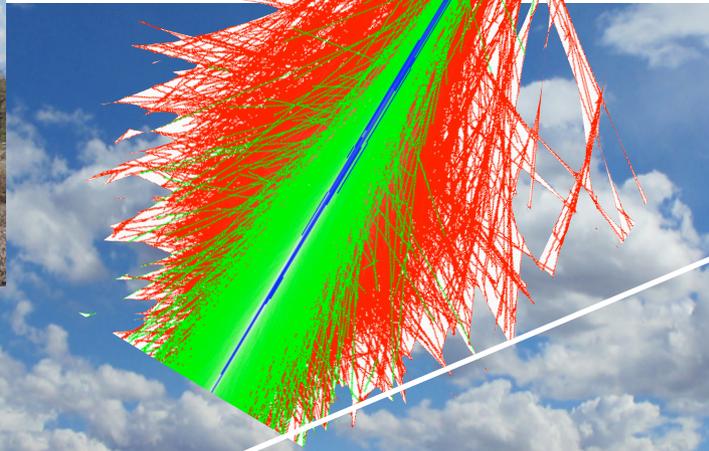
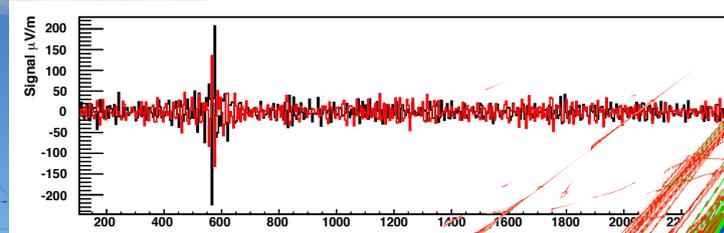
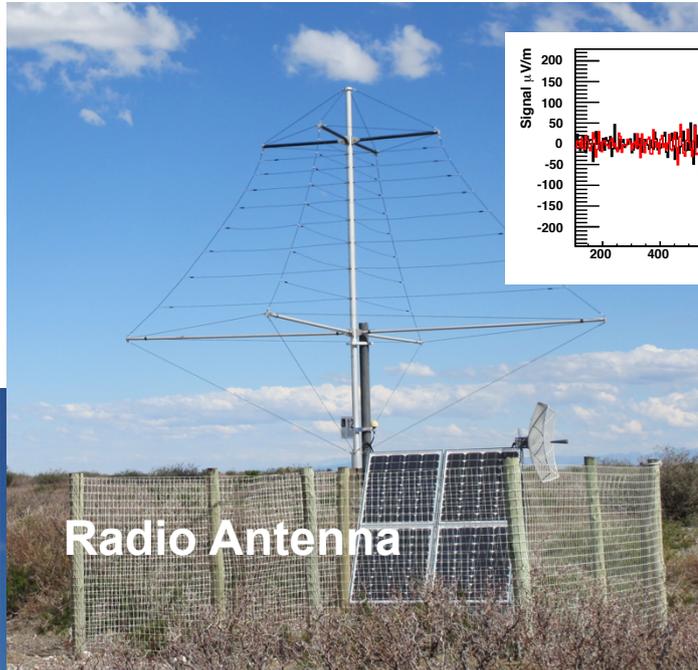
- **27 Fluorescence Telescopes**

- measuring UV emission in cloudless and moonless nights
- calorimetric measurement of air showers
- sensitive to shower development

- **1600 Water-Cherenkov Detectors**

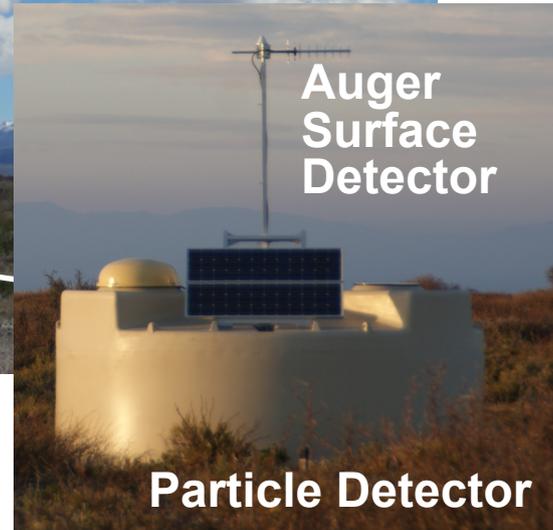
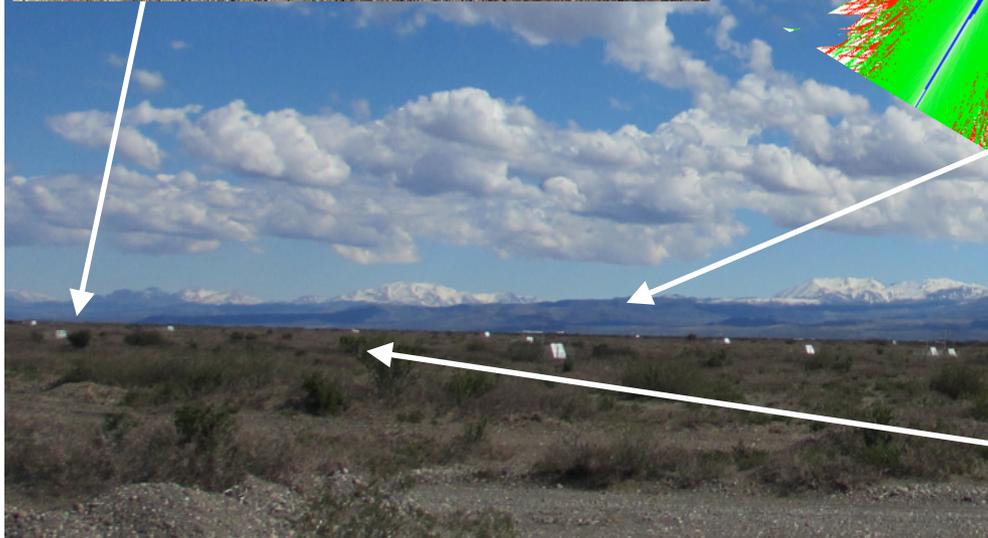
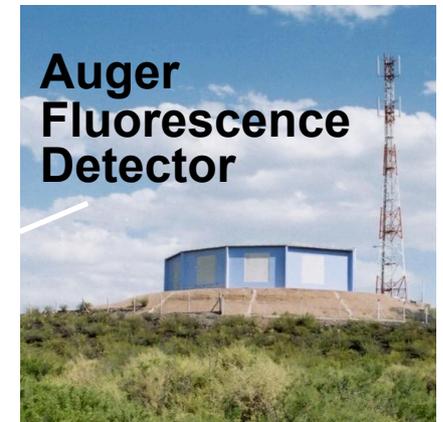
- ~100% duty-cycle
- snap-shot of shower development at ground level

Measuring the Radio Emission



**Auger Engineering
Radio Array (AERA)**

at Pierre Auger
Observatory in Argentina

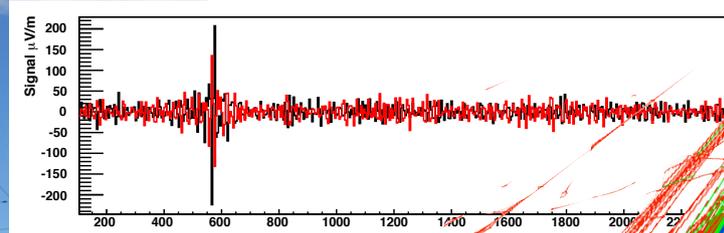
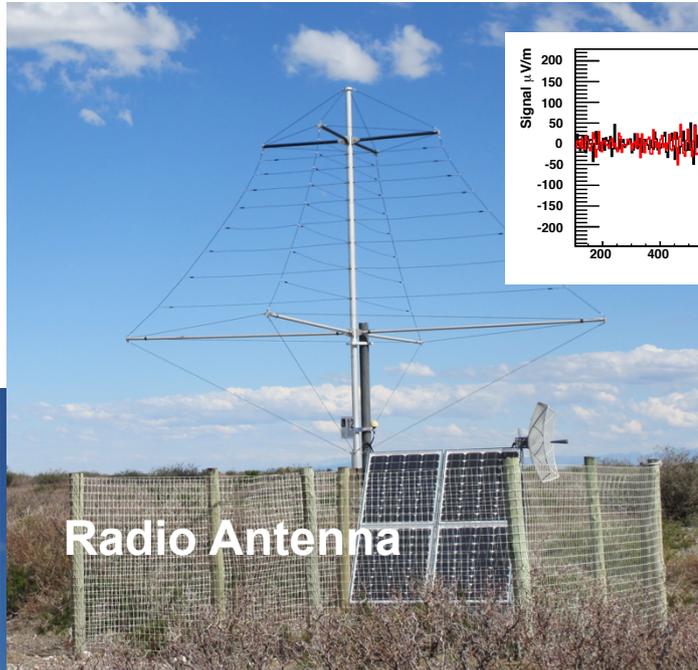


Radio Antennas

measure short
duration pulses

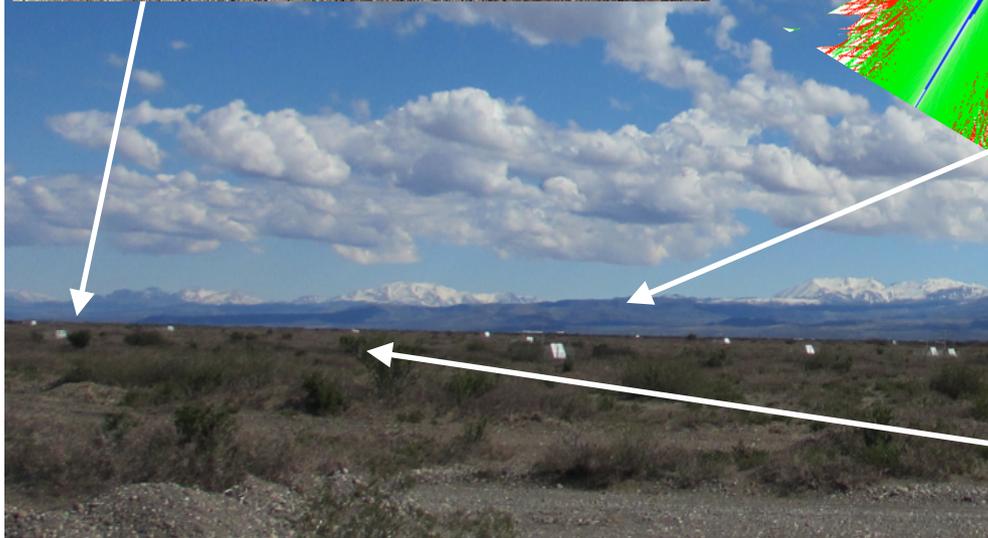
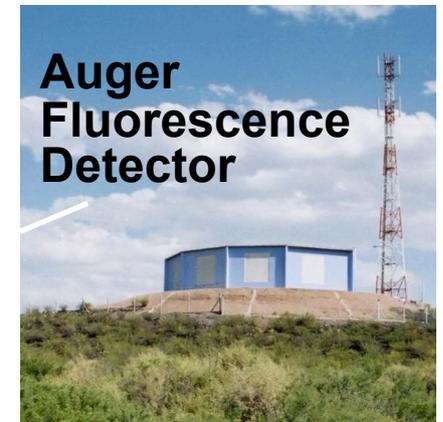
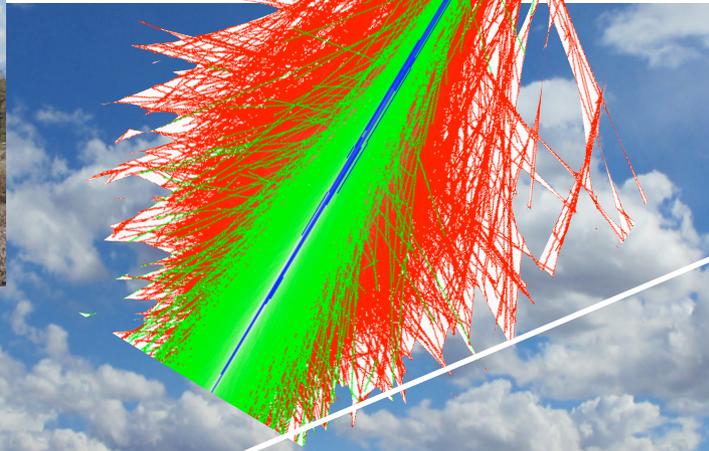
Coincidence of
radio and other
detector type
= air shower

Measuring the Radio Emission



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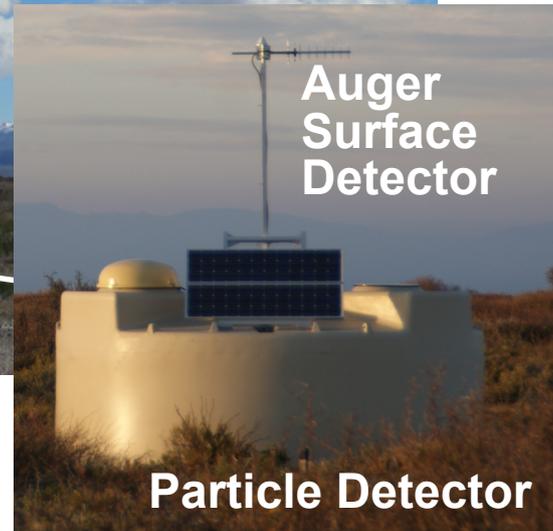
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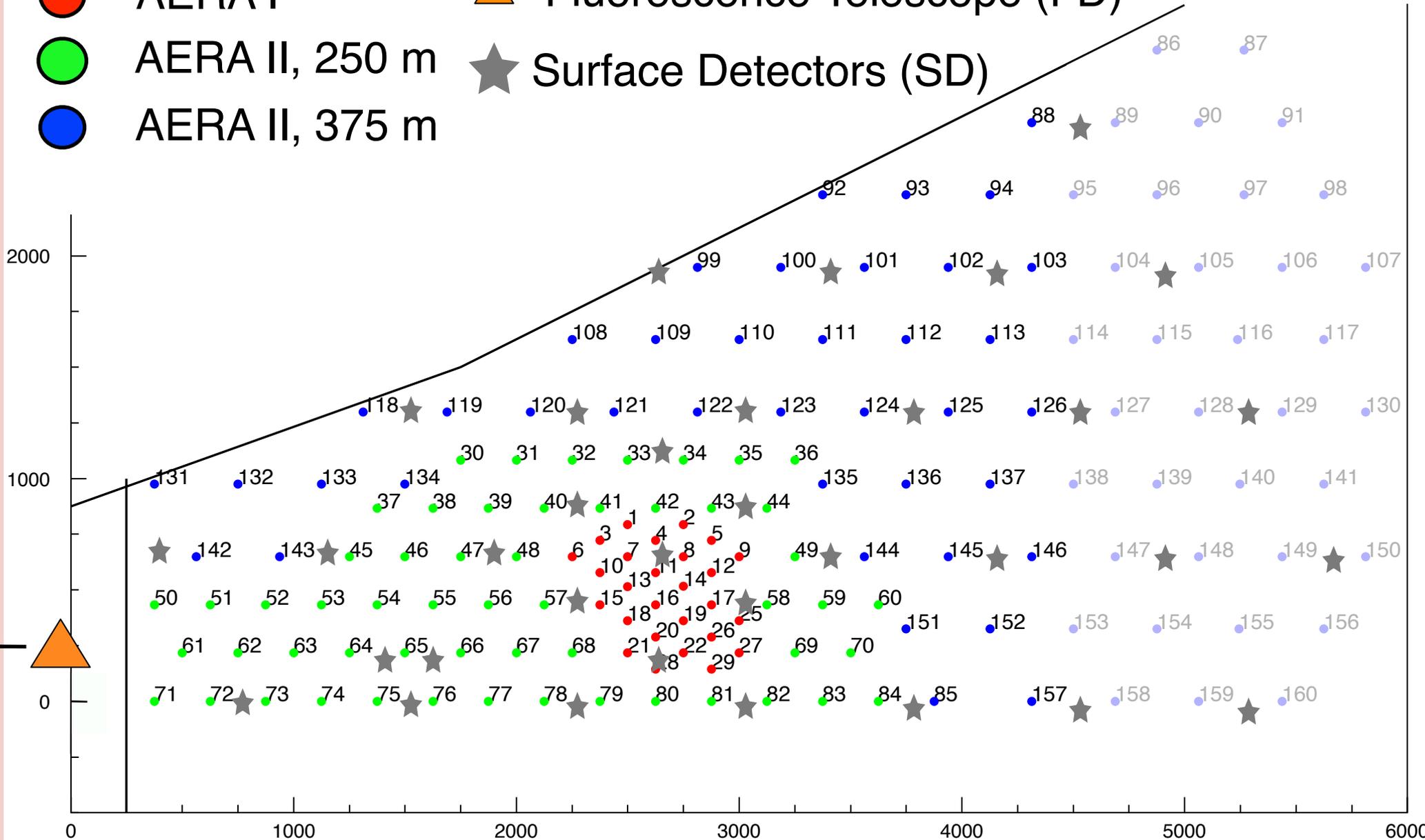
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+ other pathfinders for GHz observations

The Auger Engineering Radio Array

-  AERA I
-  AERA II, 250 m
-  AERA II, 375 m
-  Fluorescence Telescope (FD)
-  Surface Detectors (SD)



The Auger Engineering Radio Array



AERA I: Logarithmic-periodic dipole antenna LPDA

- Different versions of hardware are tested (30-80 MHz)
- Optimized: Filters, LNA, antenna, mechanics, RFI behaviour

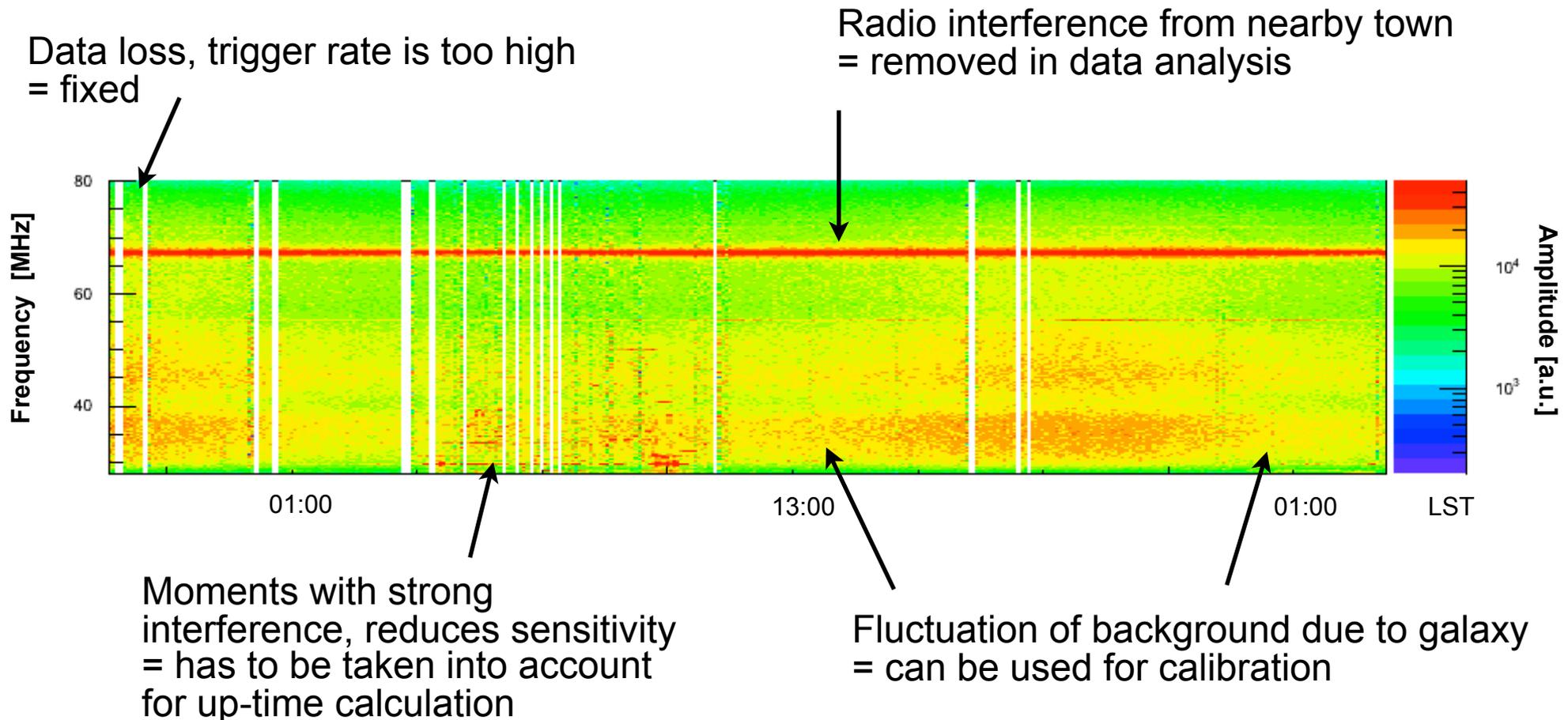


AERA II: Butterfly antenna

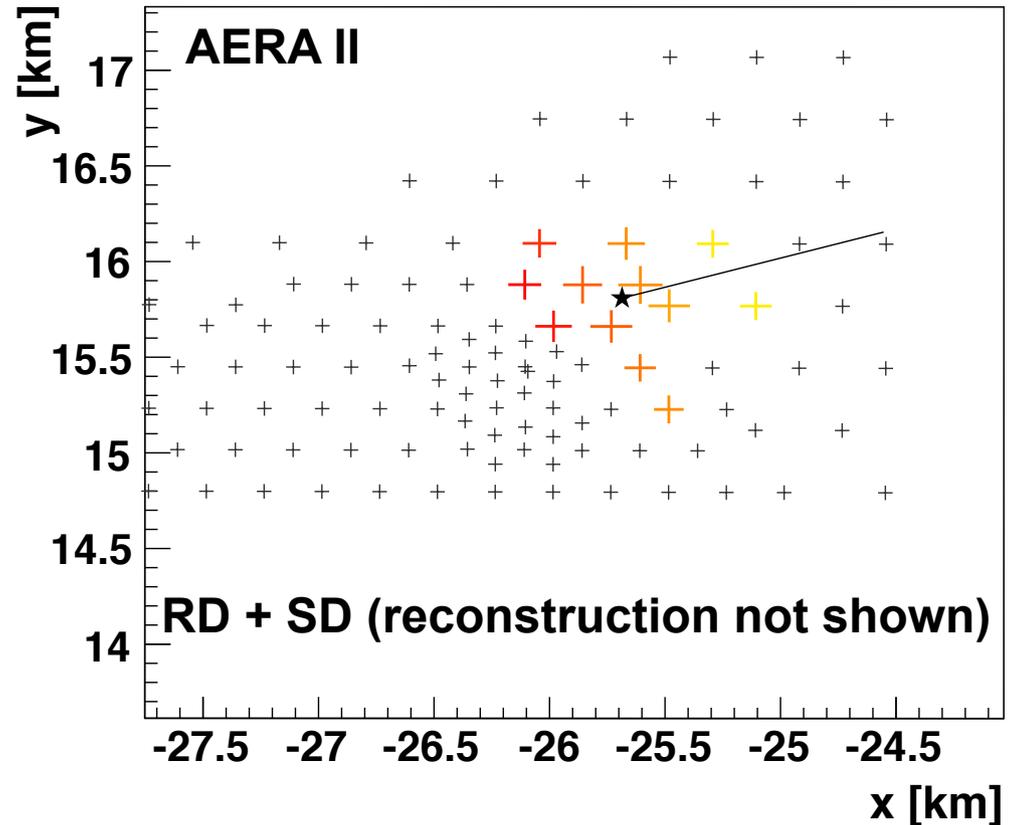
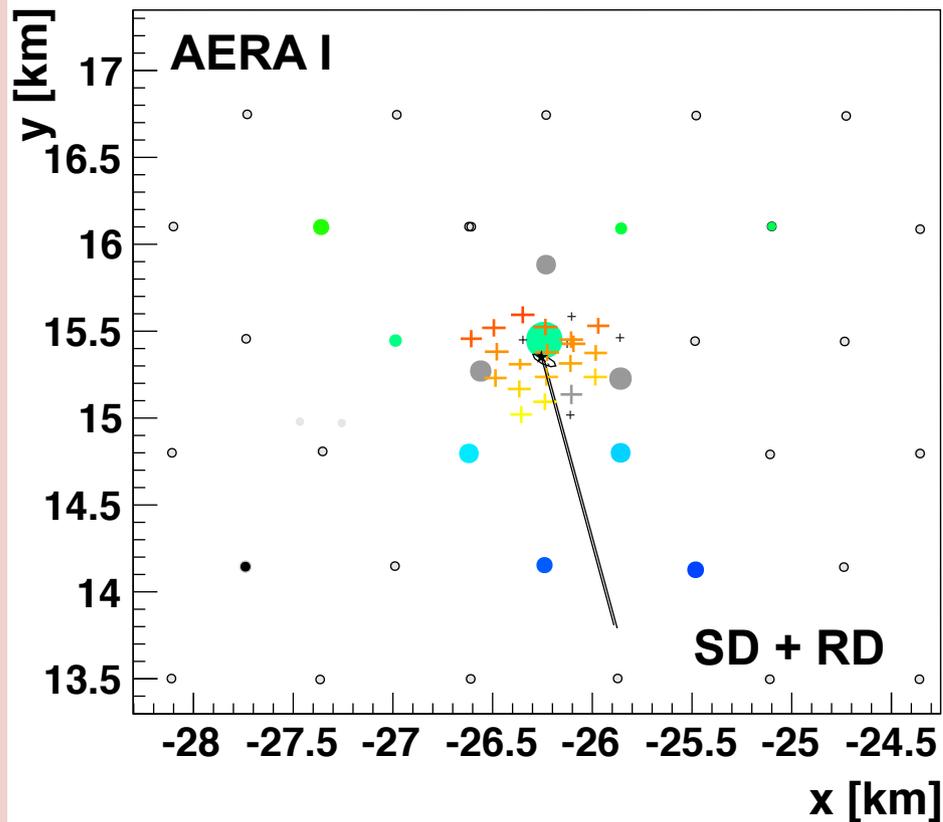
- Fully autonomous stations with **low power consumption** (~ 12 W)
- Continuous optimization for different detection schemes:
 - **self-trigger**
 - **external-trigger** on particle data
- All hardware effects are measured and corrected for in data analysis
- Database system to keep track of engineering changes
- Final data product is independent of characteristics of set-up

Monitoring: Radio Environment

- New detection technique needs continuous monitoring
- Automated tool implemented to monitor recorded data
- **Example:** background spectrum

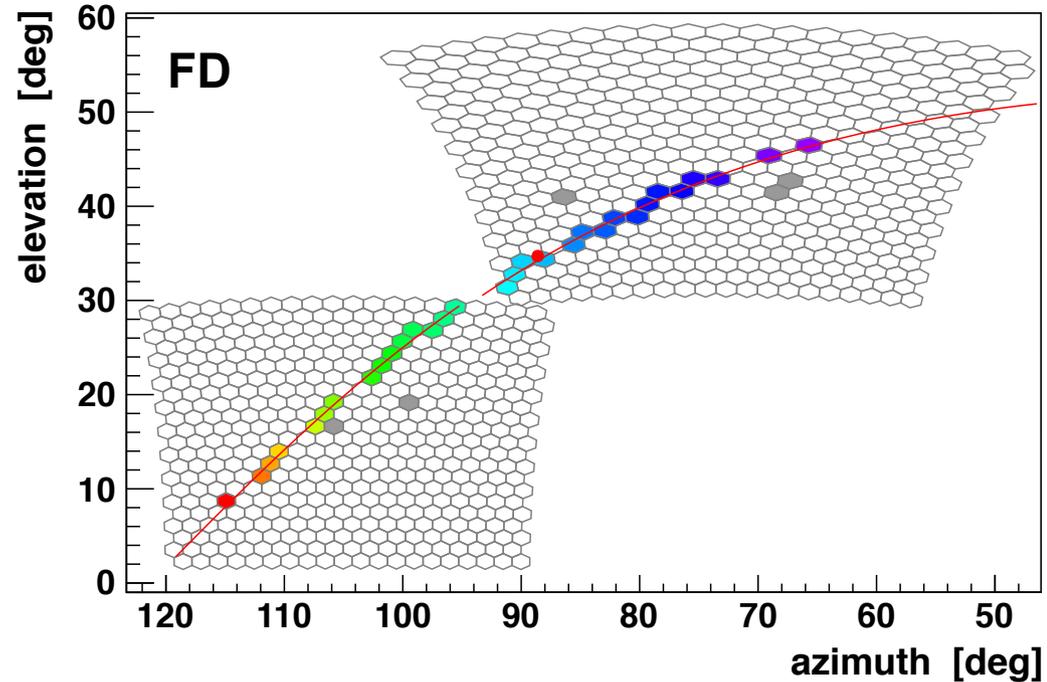
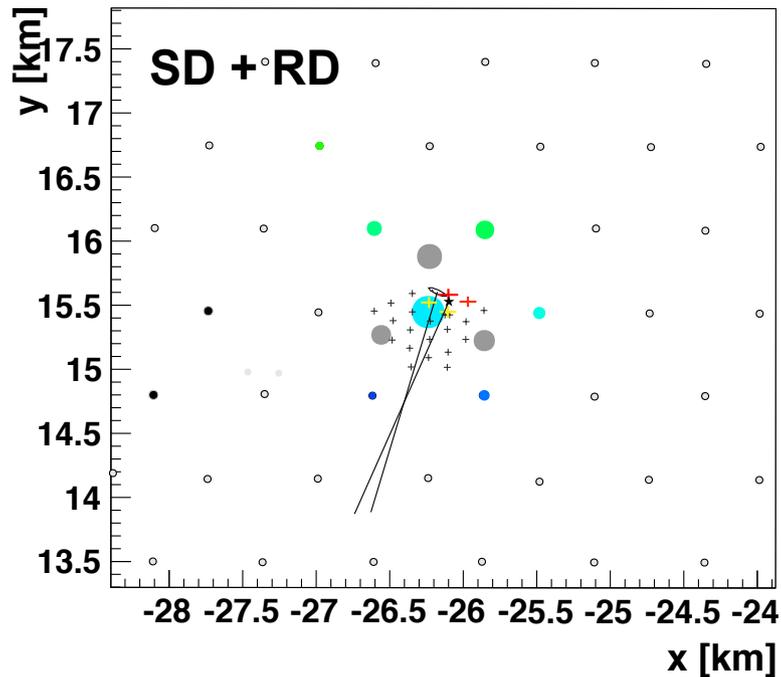


Example Events



- Coincidence of Surface Detectors and Radio Array
- Surface Detector information is used as cross check whether pulse is originating from cosmic ray (agreement of direction)

Example Events

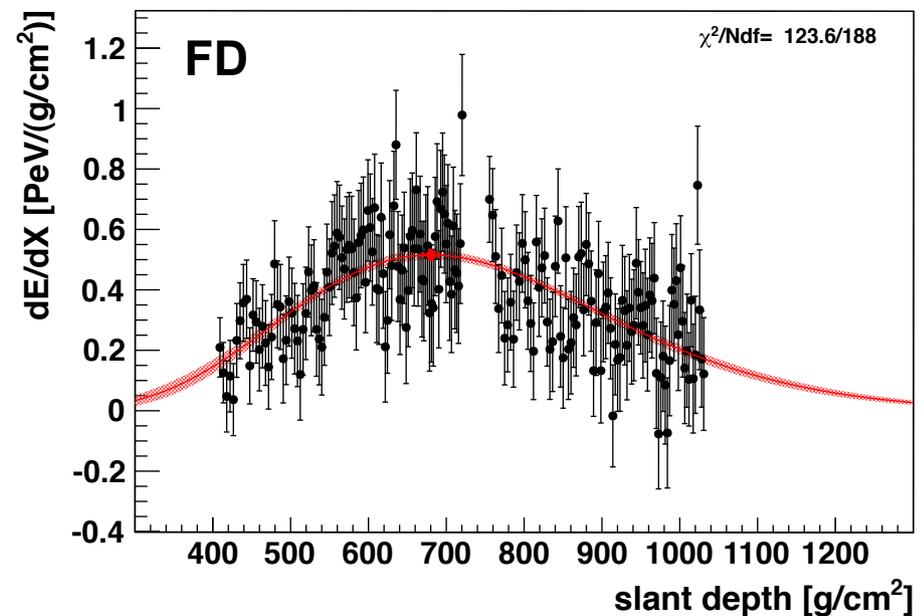


Super Hybrid Event

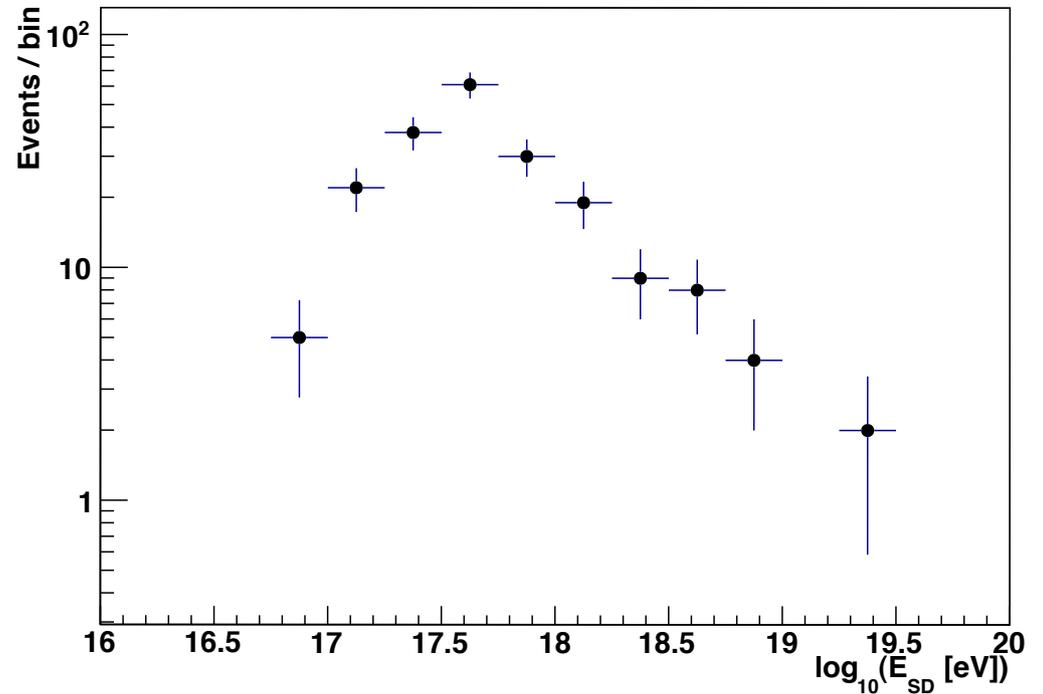
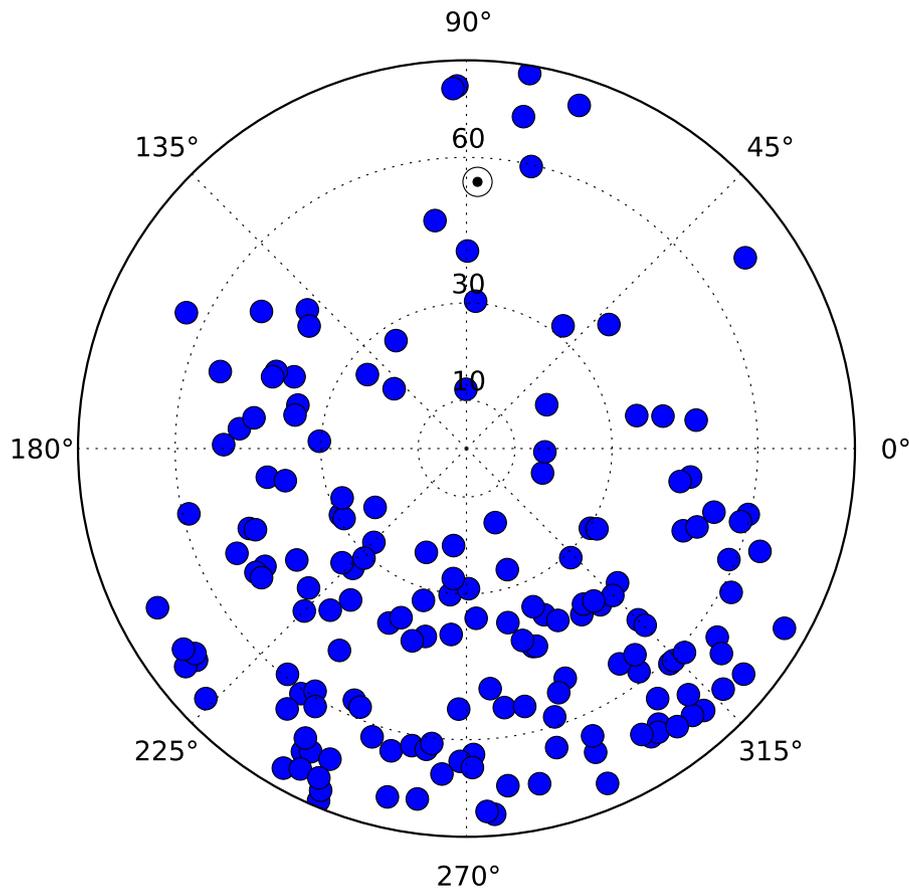
measured also in Fluorescence Detector

$$\text{Energy(FD)} = (3.09 \pm 0.12) 10^{17} \text{ eV}$$

$$\text{Energy(SD)} = (2.77 \pm 0.36) 10^{17} \text{ eV}$$



Radio Events



AERA I Data from May 2011 - April 2013

- ⊙ Direction of magnetic field at Auger
- Events detected in radio (self + ext. trig)

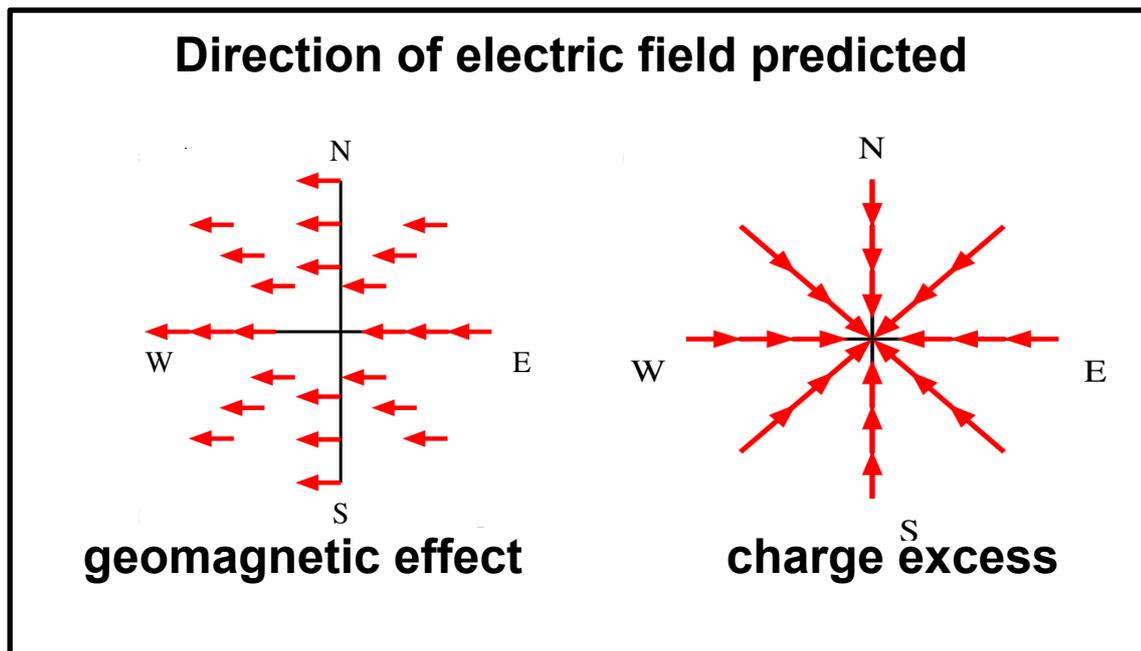
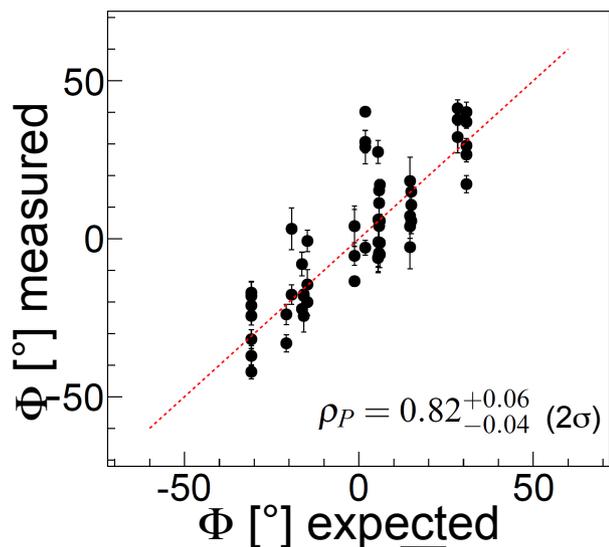
- Geomagnetic effect is clearly visible

$$\vec{E} \propto \vec{v} \times \vec{B}$$

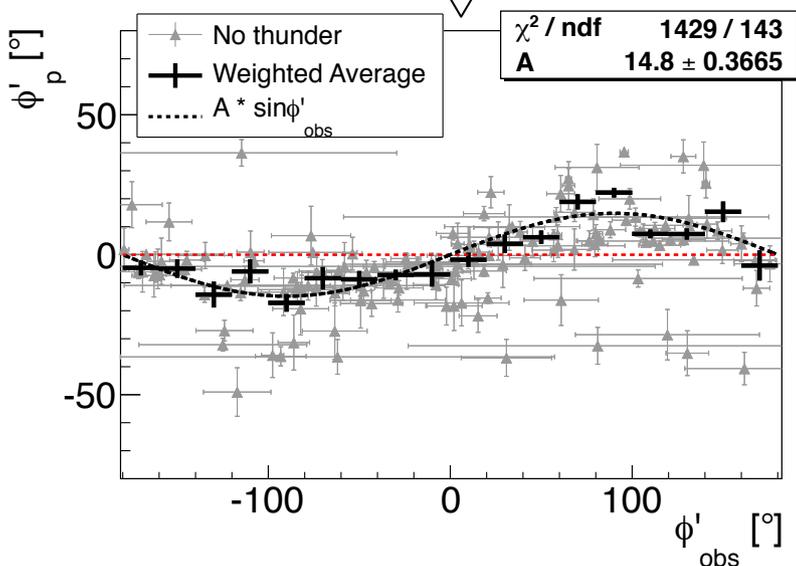
- Effects of trigger and dead time not corrected for, i.e. not a spectrum

Emission mechanisms

geomagnetic effect only

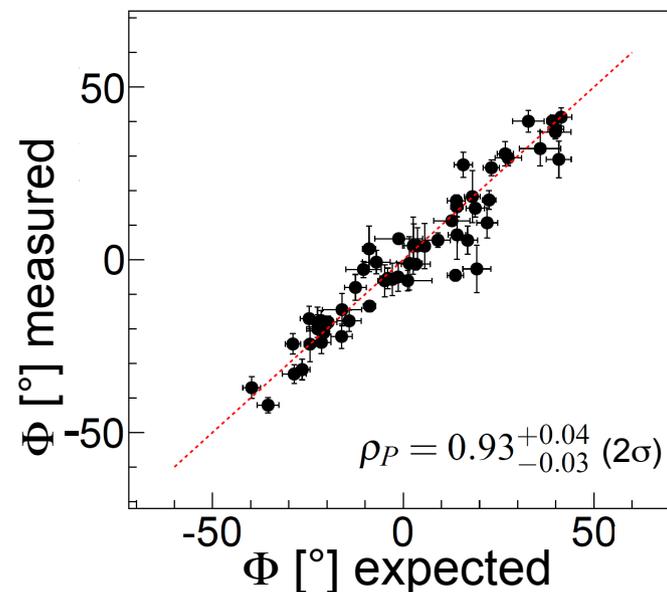


deviations



Correction 14%

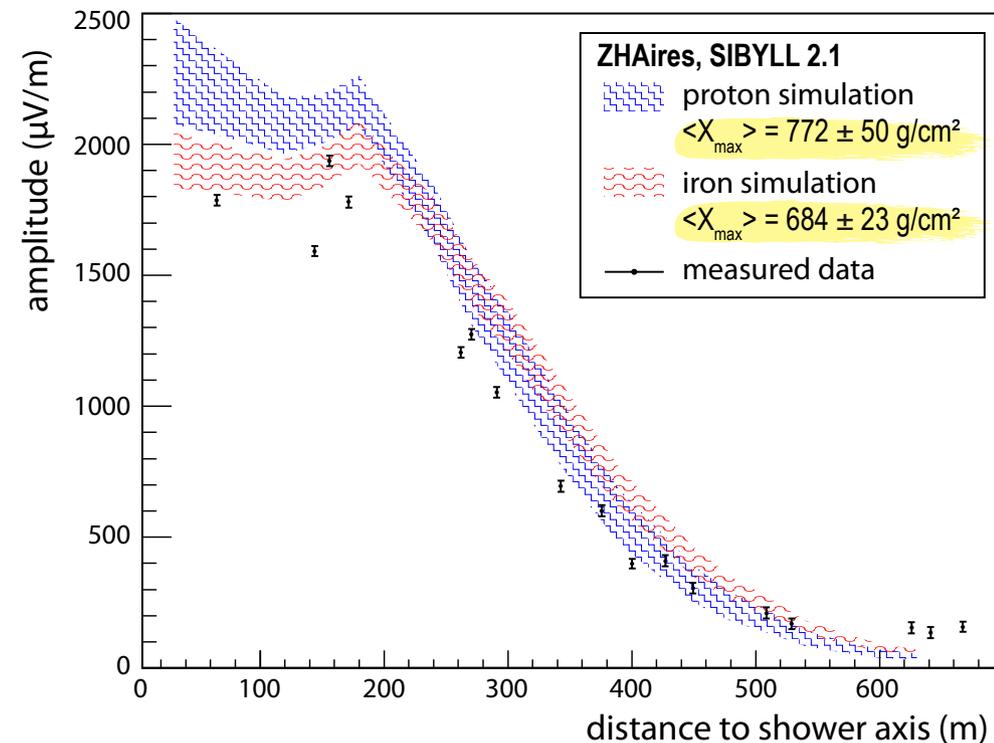
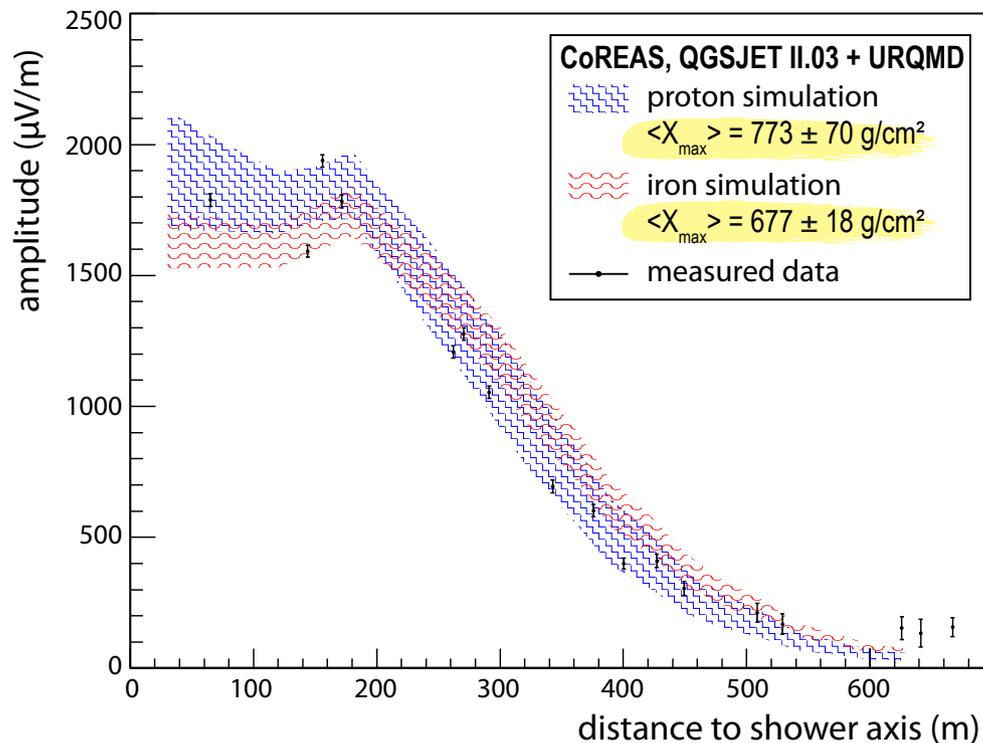
correcting for an Askaryan-like contribution



Simulations of radio emission

- Theories describing the emission processes are converging
- Simulations are essential tool for the study of the dependencies on shower parameters such as X_{\max}
- Several models available and can be tested with the data

AERA event compared to two different radio simulations



Conclusions

- Auger Engineering Array is testing radio-emissions of air showers at very high energies
- Excellent possibilities of cross-calibration with baseline detectors of Pierre Auger Observatory
- 124 stations currently deployed on 6 km²
- New array will significantly increase event statistics (x 6)
- First physics publications are underway
- Simulations nicely describe the data

