Results from the Auger Radio Detector

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on behalf of the Pierre Auger Collaboration

IFLP (CCT La Plata-CONICET)

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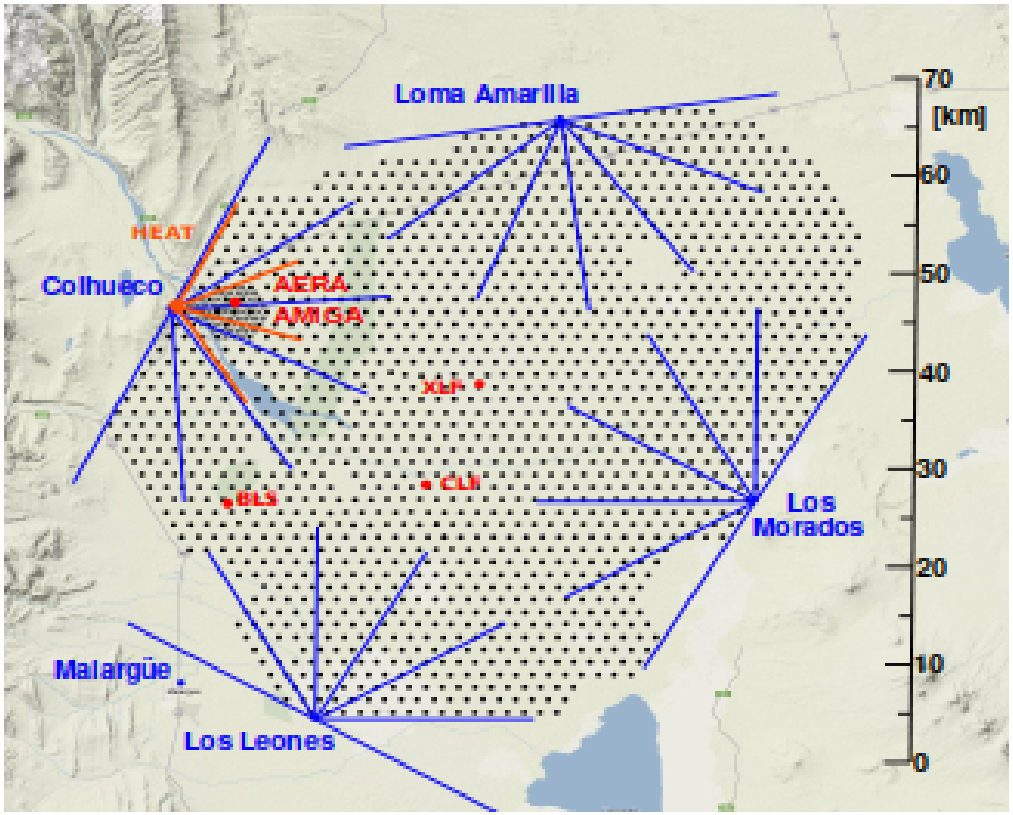
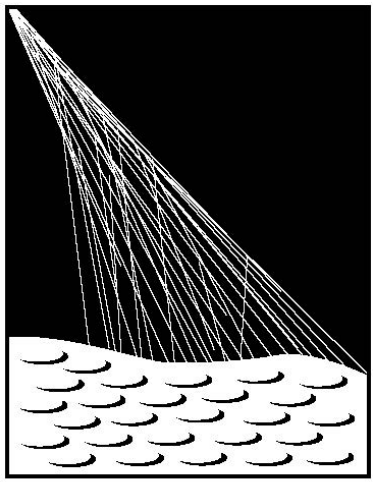
Content

Pierre Auger Observatory

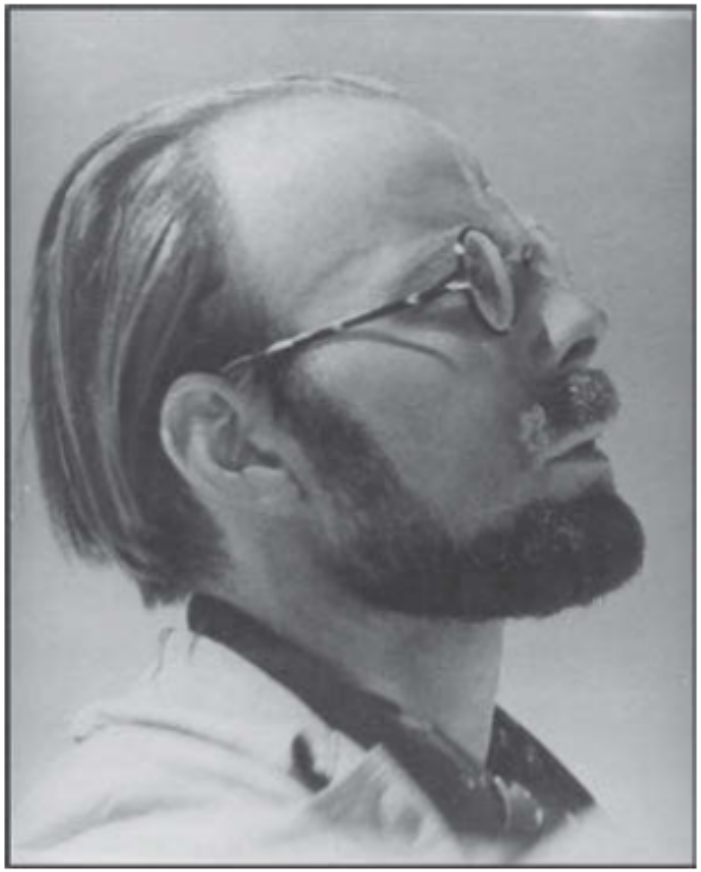
- The **Pierre Auger Observatory** is a world-renowned scientific facility located in Malargue, Mendoza province of Argentina.
- It is dedicated to the study of **ultra-high-energy cosmic rays (UHECRs)**, from $10^5\,TeV$ to beyond $10^8\,TeV$





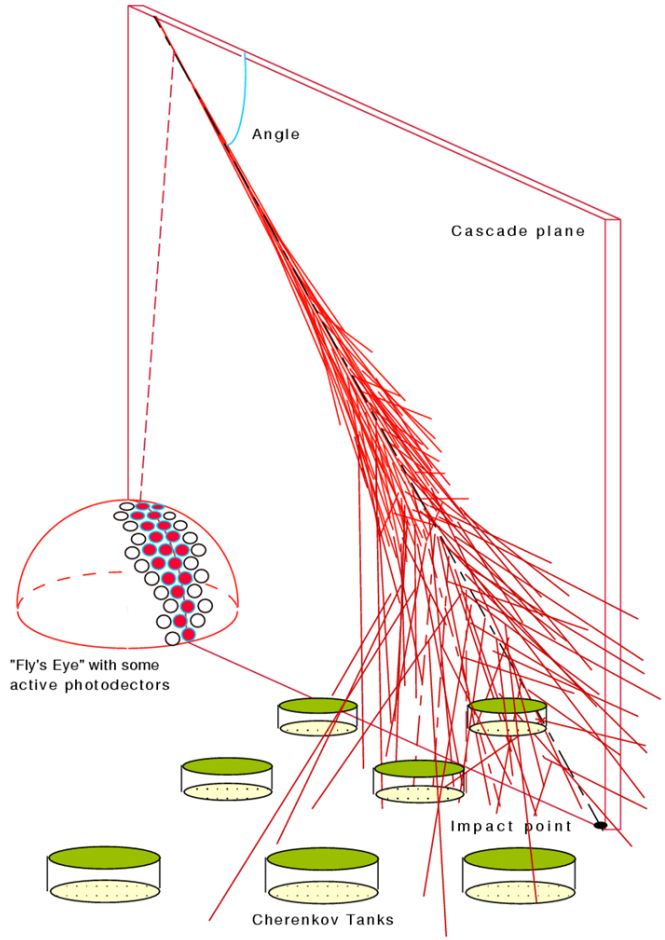
PIERRE
AUGER
OBSERVATORY

Important Features



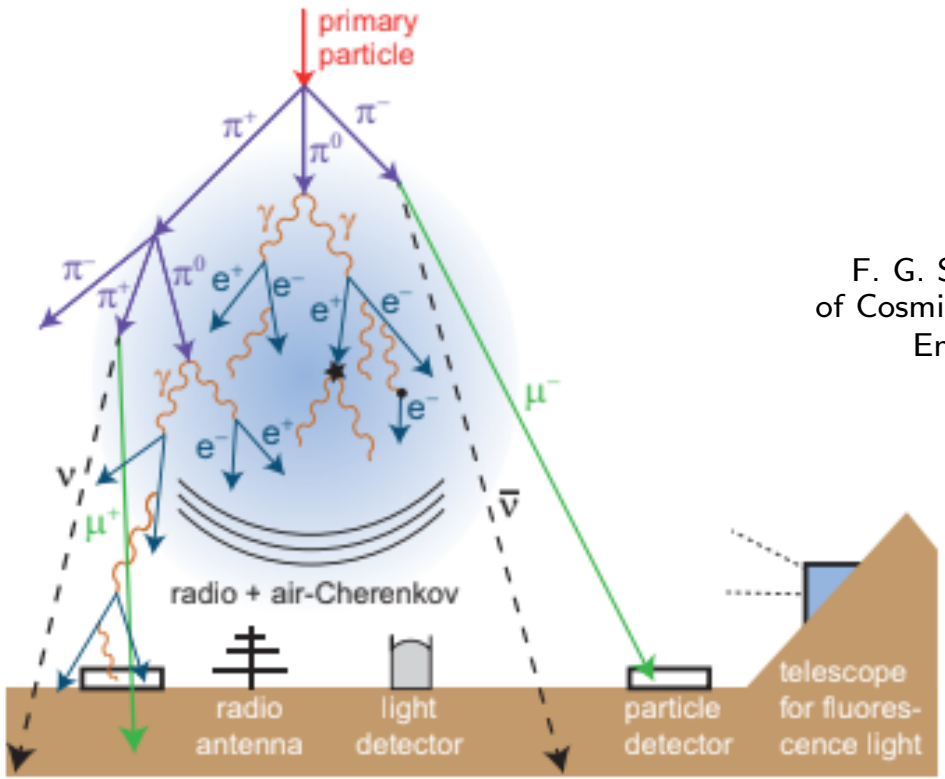
Pierre Auger: The observatory is named in honor Pierre Victor Auger.

Hybrid-Detection Approach: Including ground-based detectors, fluorescence detectors.



Cosmic Rays and Extensive Air Showers

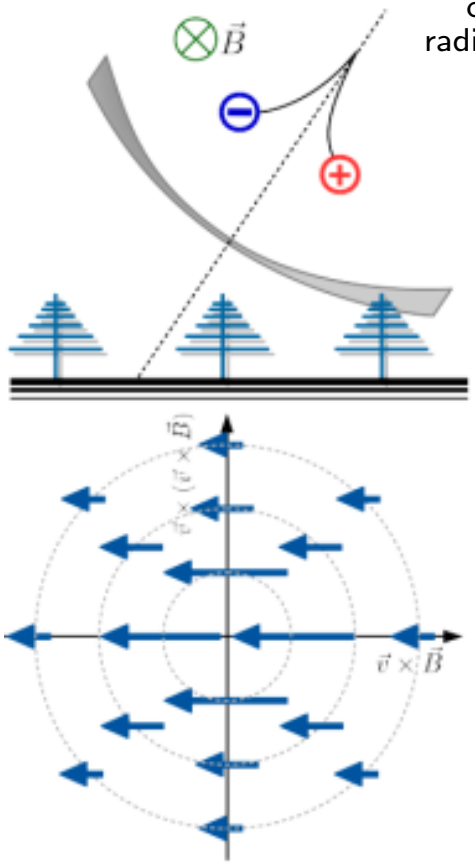
- **Cosmic rays** are high-energy particles originating from outer space which produce **extensive air showers**.
- Extensive Air Showers (EAS) are cascades of secondary particles initiated by high-energy cosmic rays in the Earth's atmosphere.
- A fascinating aspect of EAS is the emission of **radio waves** during their development.

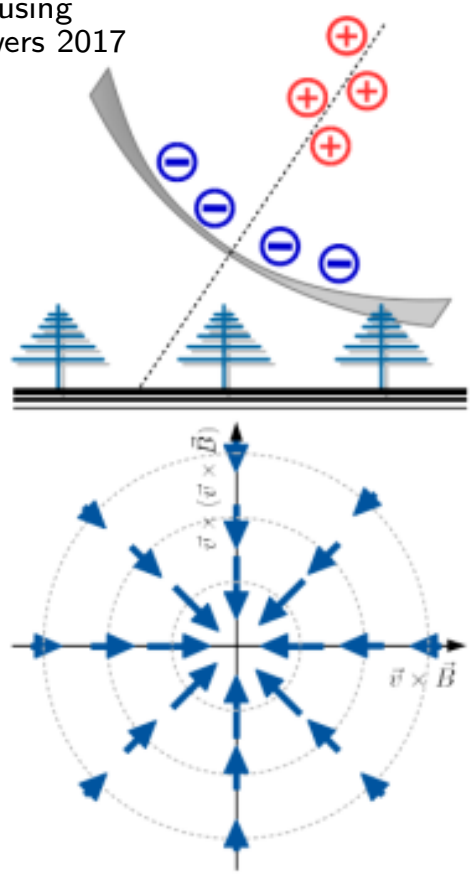


F. G. Schrder Radio Detection of Cosmic Ray Air Shower and High Energy Neutrinos 2017

Radio Emission Mechanism

Glaser, J. C. Absolute energy calibration of the Pierre Auger observatory using radio emission of extensive air showers 2017



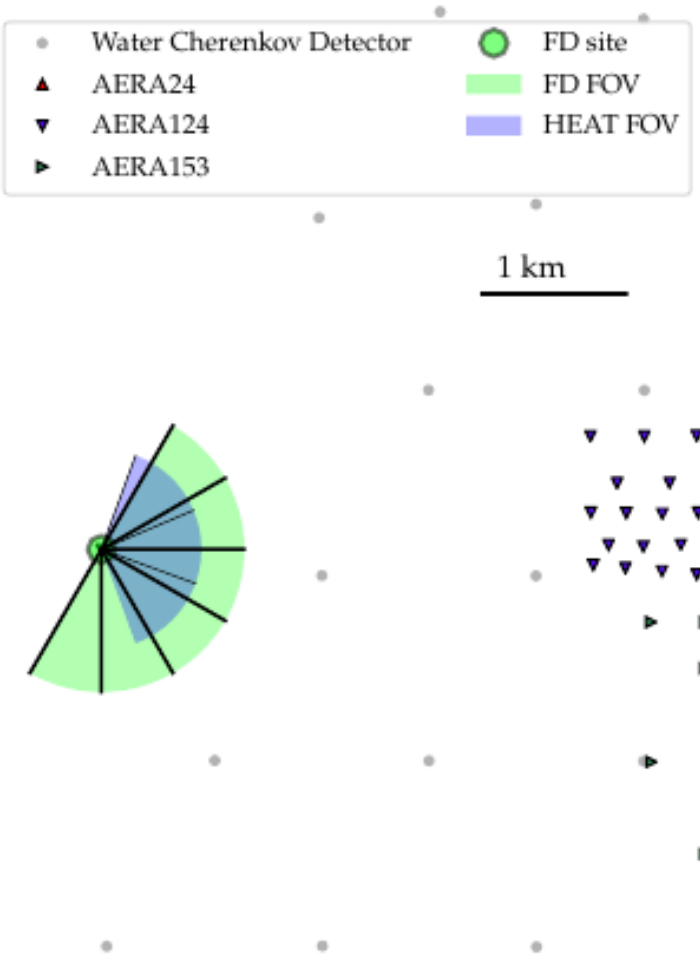


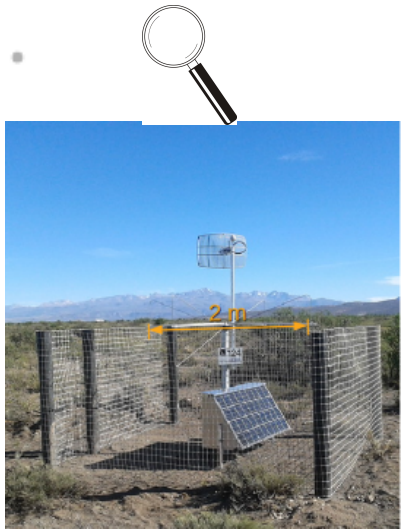
Geomagnetic Radiation effect contributes to the radio signal as charged particles move through the Earth's magnetic field.

Askaryan Effect, where high-energy charged particles produce coherent radio Cherenkov radiation as they travel through a dielectric medium like air.

Experimental Setup: AERA

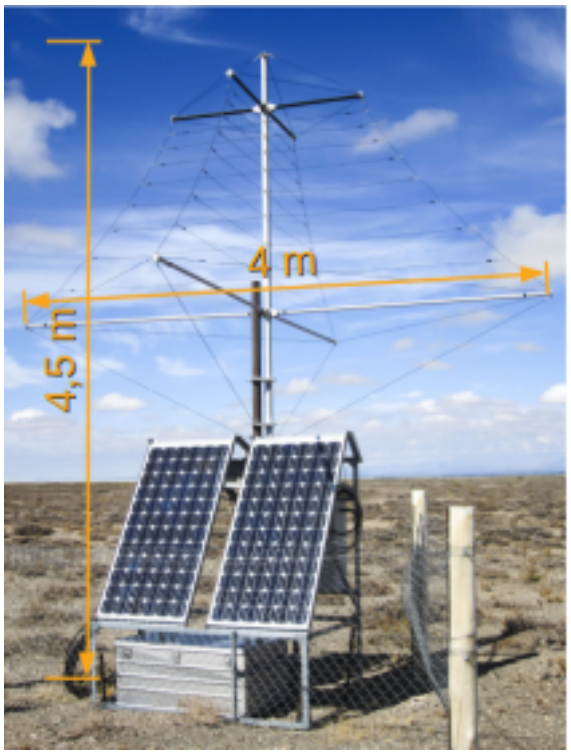
- Specialized **radio antennas arrays** are used to detect radio emission from EAS, such as the **Auger Engineering Radio Array (AERA)**.
- **AERA** has 153 antennas covering an area of $17 km^2$ that operates at frequencies between 30-80 *MHz*





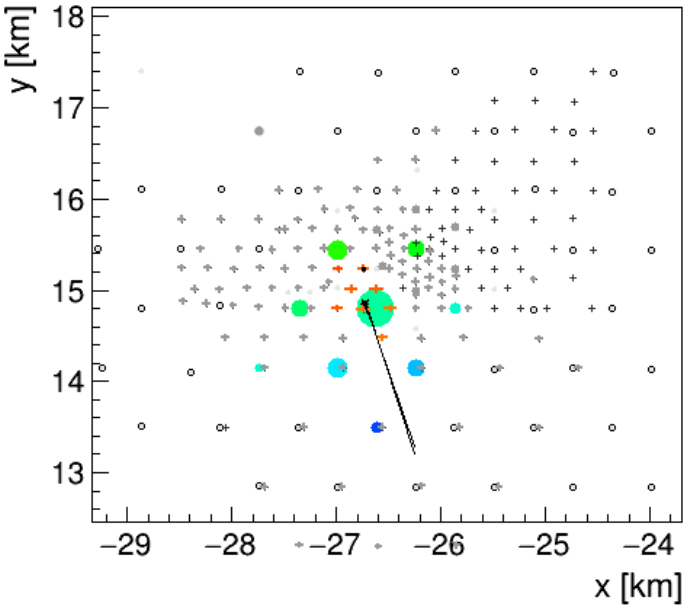
Advantages of Radio Detection

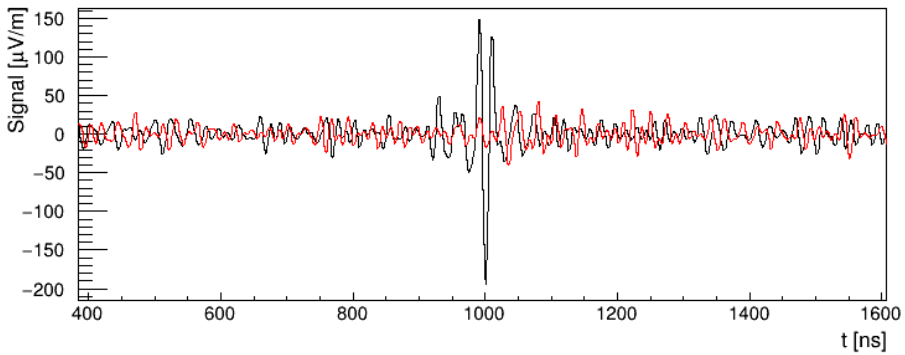
- Radio detection of EAS offers several advantages:
  - **All-Weather Observations**: Radio signals are not affected by cloud or aerosol conditions in the atmosphere.
  - **Large Detection Areas**: Radio arrays can cover extensive areas, increasing the chances of observing EAS events.
  - **Complementary Information**: Radio detection provides complementary data to other EAS detection methods, improving the accuracy of cosmic ray measurements.



Radio and FD event example

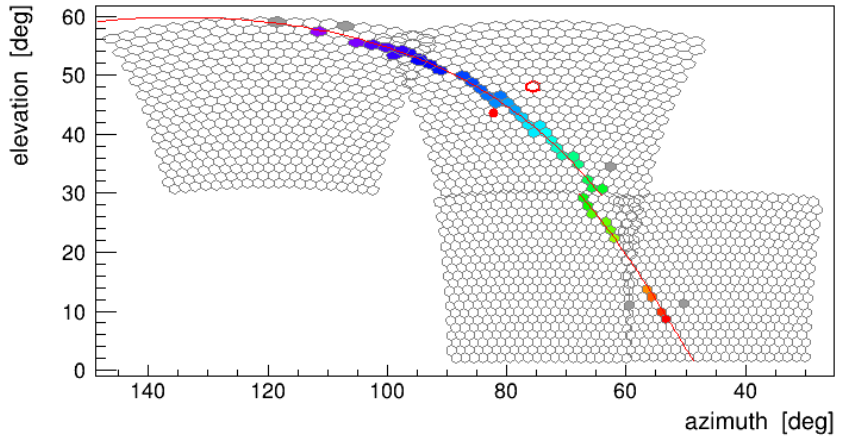
Radio Event

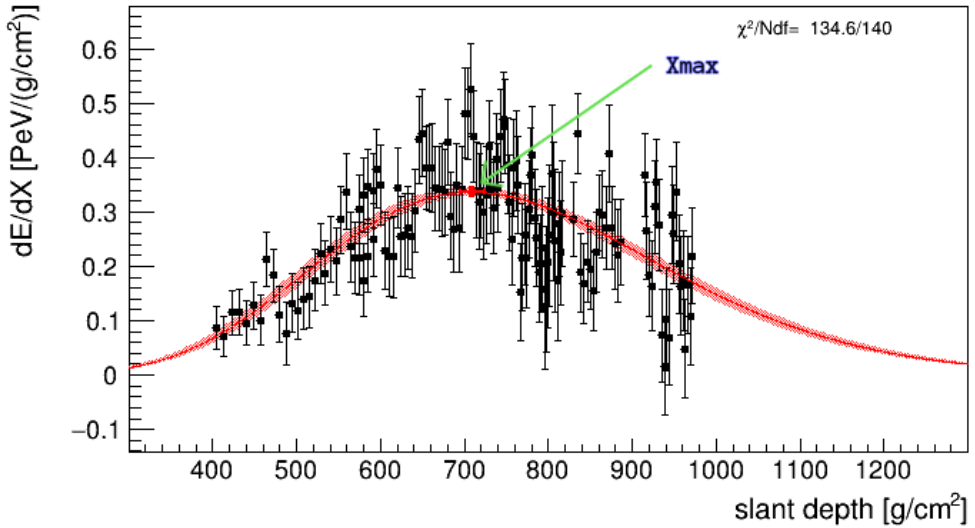




Black line: Polarisation East.
Red line: Polarisation North.

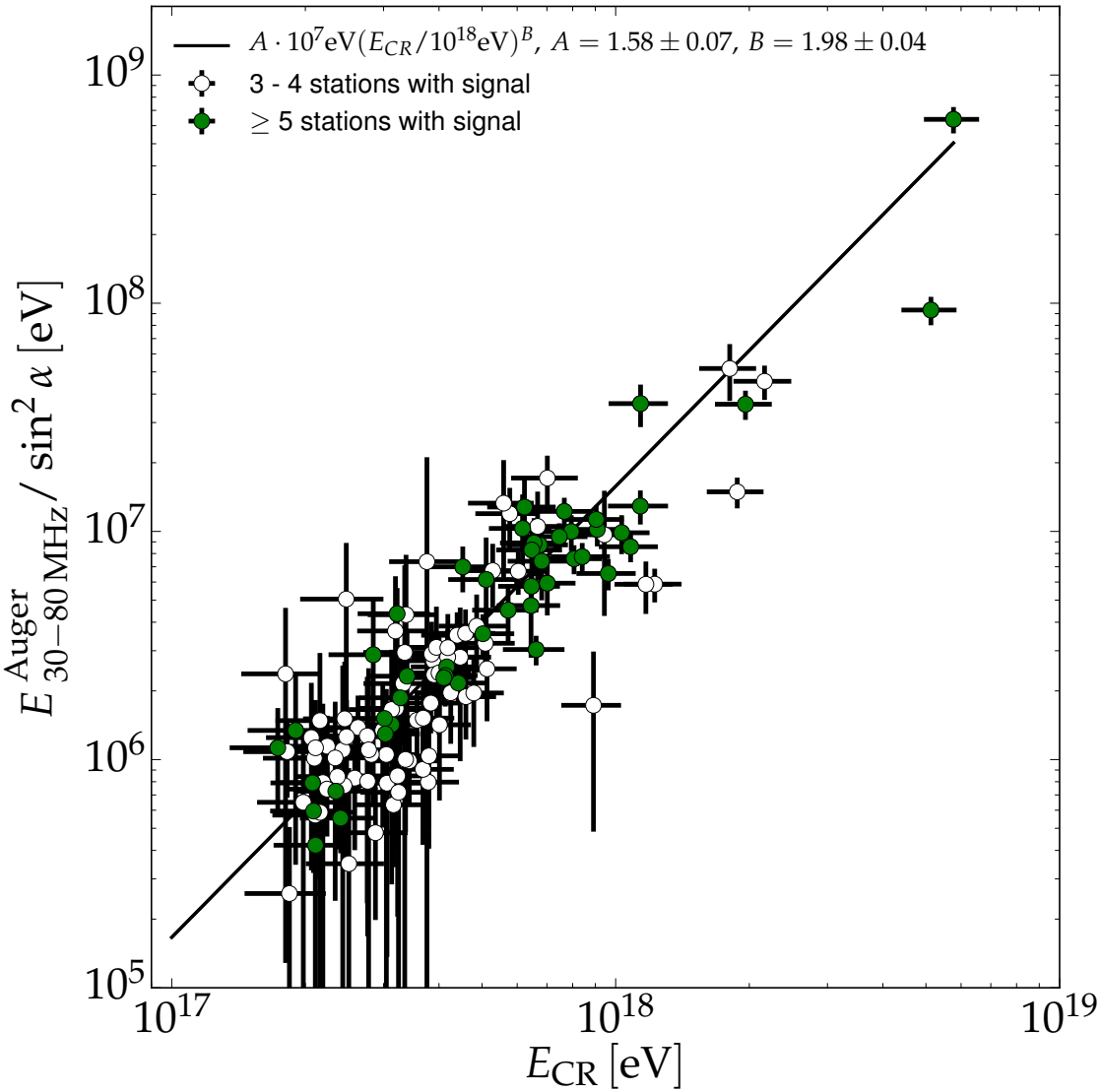
Fluorescence detector event





Cosmic Ray Energy

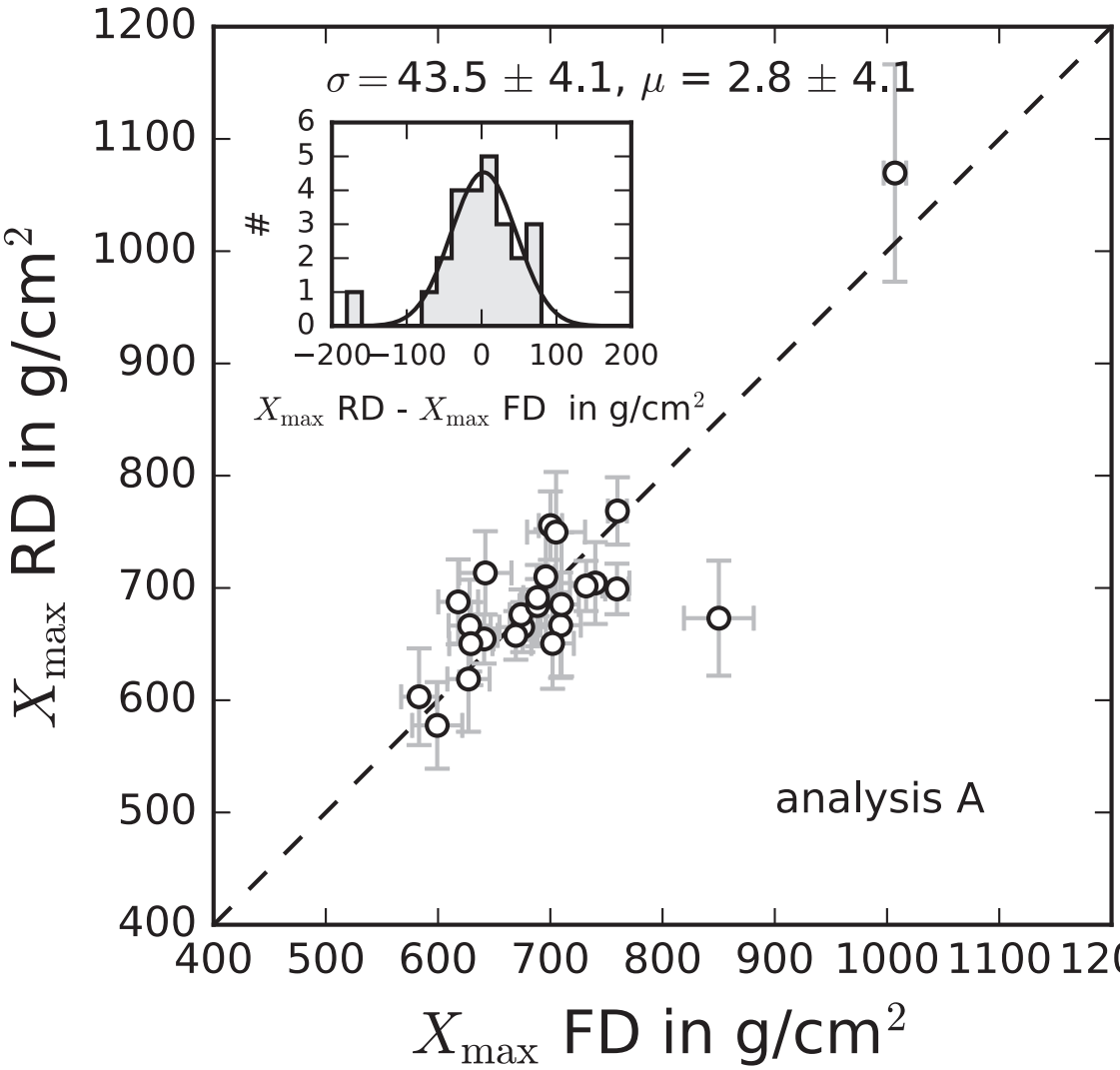
- Energy can be determined with a 17% resolution or better.
- AERA determinate **energy fluence**, we integrate to calculate the **radiation energy**.
- Radiation Energy provides a calibration curve of the energy scale of the Observatory.



A. Aab et al. (Pierre Auger Colaboration), Phys. Rev. Lett. **116**, 241101 (2016)

Mass composition sensitivity

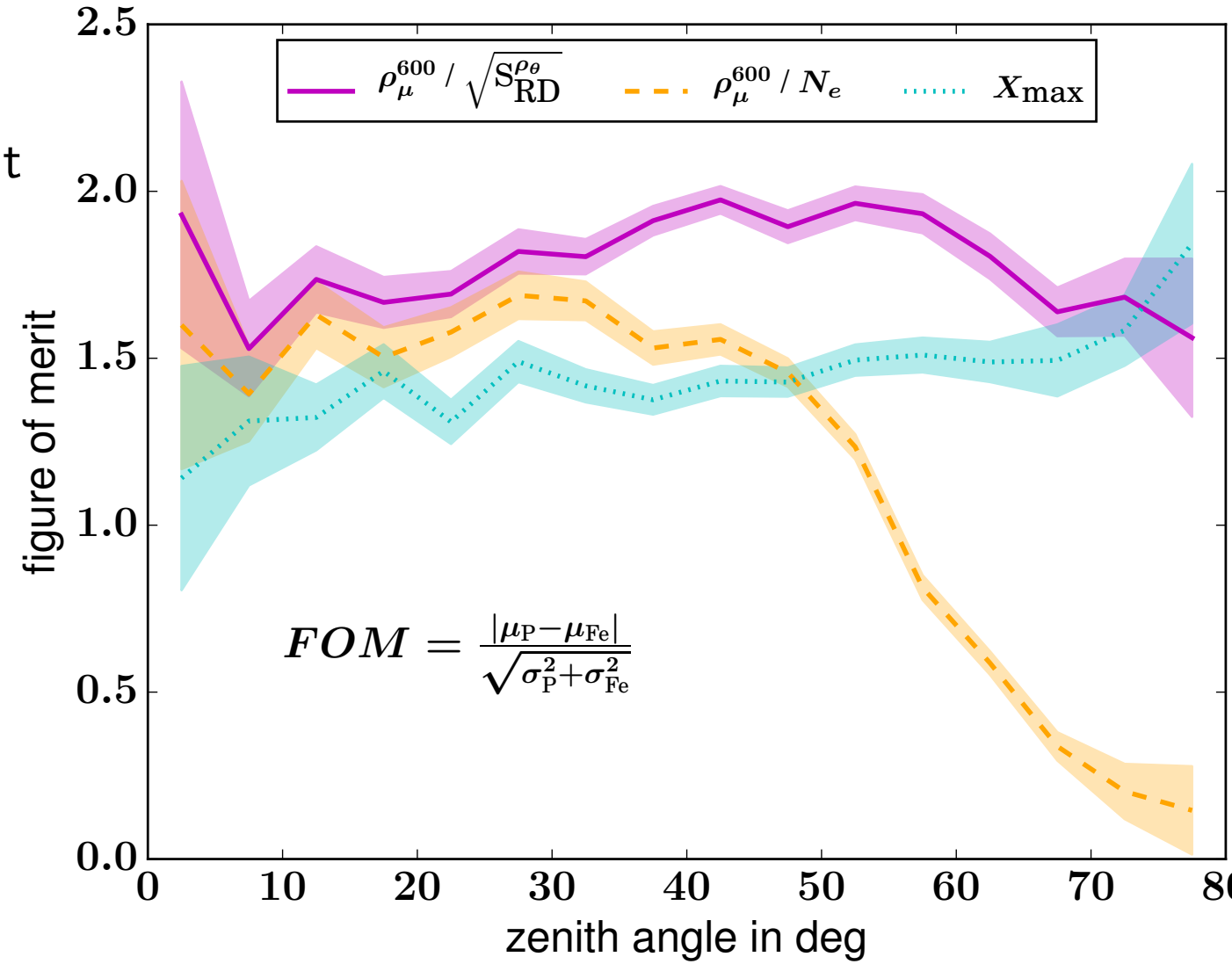
- Depth maximum X_{max} of an EAS.
- Radio signals are sensitive to X_{max}.
- X_{max} from AERA correlates well with the value from the Auger fluorescence detectors.
- Combined FD-radio resolution is $45 g/cm^2$.



E. M. Holt for the Pierre Auger Collaboration, Proc. 35th ICRC, Busan Korea, POS(ICRC2017) 492

Separation power between Iron and Proton induced showers

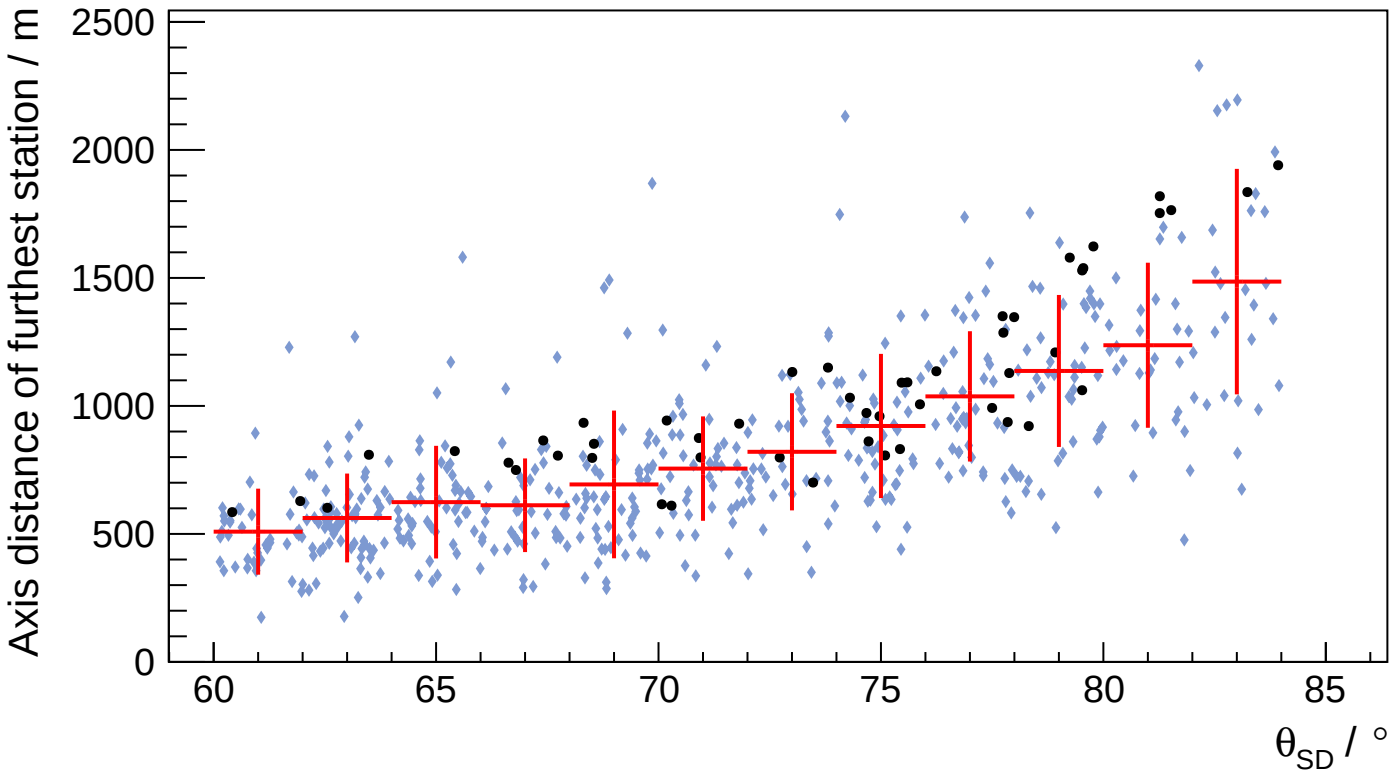
- Mass separation power of different mass estimators.
- ρ_μ^{600}: Muon density at 600m to the shower axis.
- $S_{RD}^{\rho_\theta}$:Radiation Energy.
- N_e: Number of electron on the ground.



E. M. Holt for the Pierre Auger Collaboration, Proc. of the 2018 ARENA conference

Inclined air showers

- For **inclined air showers**, the shower maximum is typically dozens of kilometers away.
- A grid constant of $1.5km$ is sufficient for their detection.
- This opens a possibility for mass-composition studies of inclined air showers.



A. Aab et al. (Pierre Auger Colaboration), JCAP **10**, 026 (2018)

AugerPrime Radio Detector Upgrade

- Based on these findings, we plan to enhance each of the 1600 water-Cherenkov detectors in the SD by incorporating a single radio antenna as part of the continuous AugerPrime upgrade.
- This implementation will expand the observatory's coverage of the sky and increase its exposure.
- In conjunction with the WCDs, this combination introduces new prospects for detecting rare primary particles, such as UHE photons and neutrinos, with a significantly elevated identification probability.

Conclusion

- AERA has shown us that radiation energy can be measured with precision and serves as a reliable estimator of energy.
- We also found a good agreement between the measurements of X_{max} using radio detection and the measurements using fluorescence detectors.
- We demonstrate that another approach to studying composition involves integrating radio measurements with data on the muonic component collected by AMIGA and the Auger Surface Detector.
- The AugerPrime Radio Detector exhibits remarkable sensitivity to the electromagnetic component of air showers, providing new insights into the reconstruction of primary mass, energy, and arrival direction for inclined showers.