Measurements of UHE particles with the Radio Detector at Auger

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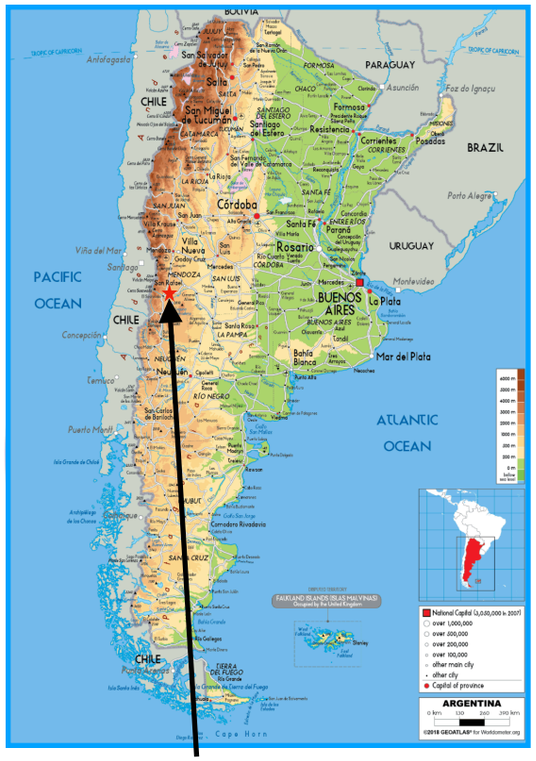
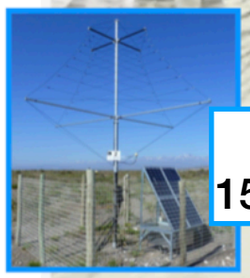
Radboud University

CAN meeting, June 28th 2024

The Pierre Auger Observatory



Pierre Auger Observatory
Province Mendoza, Argentina



AERA
153 antennas, 15 km²

LIDARs and laser facilities

Infill array (750/433 m grid)
61/19 stations, 23/2 km²

4 fluorescence detectors
(6 telescopes each)

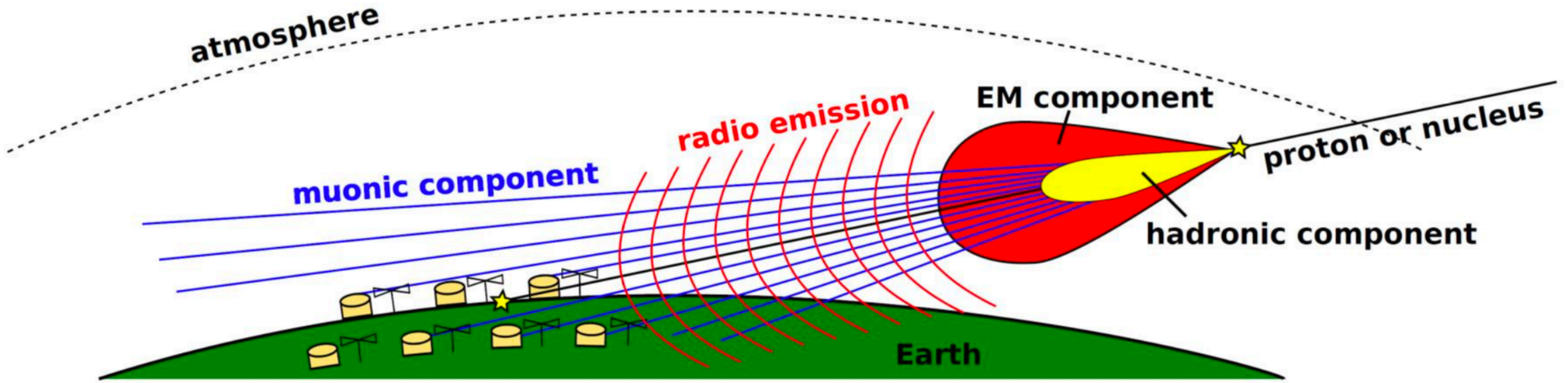
High Elevation Telescopes

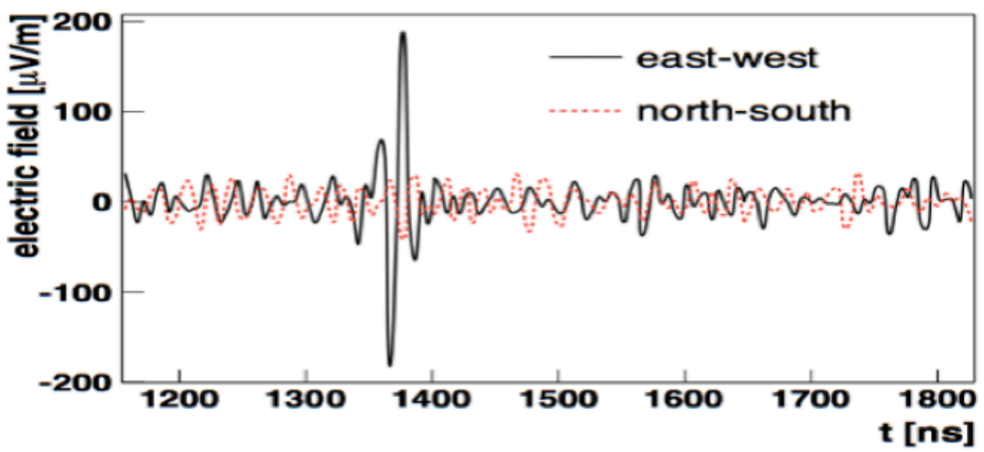
1660 surface detectors (1.5 km grid)
(3000 km² total)

- Water-Cherenkov tanks (WCD)
- Scintillation detectors (SSD)
- Radio antennas (RD)

**More than 500 members,
18 countries**

Radio emission from UHE particles

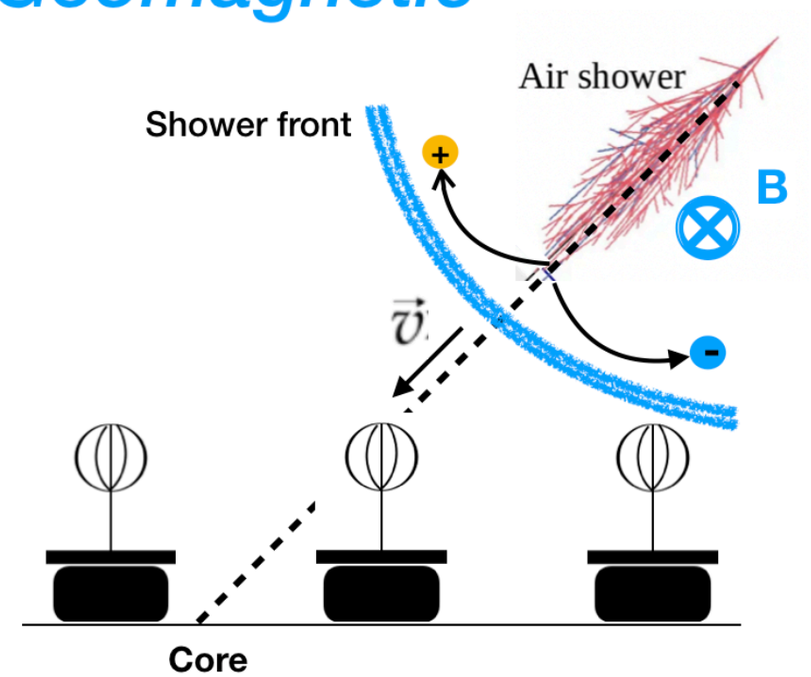


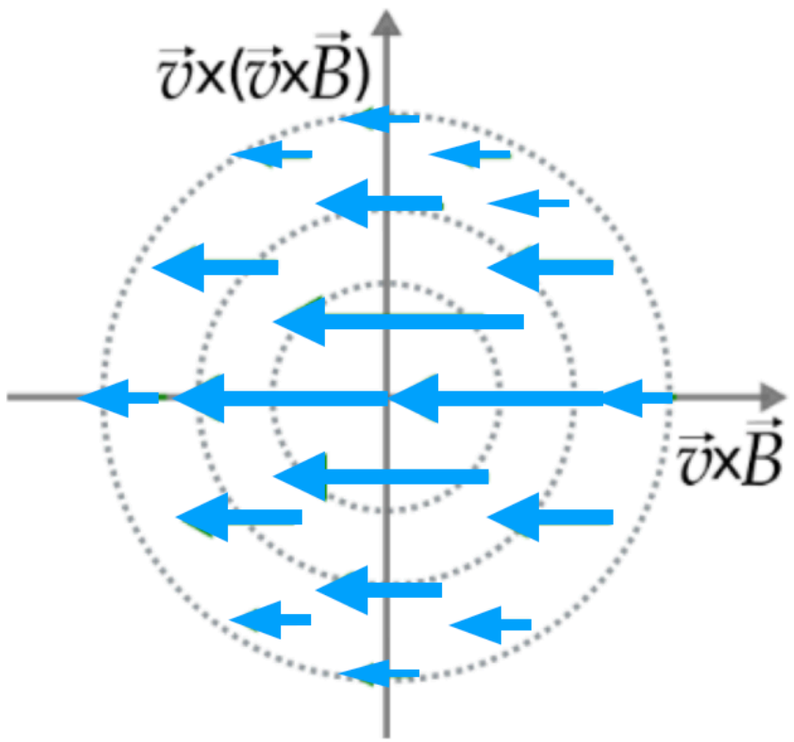


- Extensive Air Showers produced by Ultra-High-Energy particles interacting in the atmosphere emit very short, coherent and forward beamed radio pulses
- The new Radio Detector (RD) of the Pierre Auger Observatory measures these pulses in the 30-80 MHz band

Radio emission from UHE particles

Geomagnetic

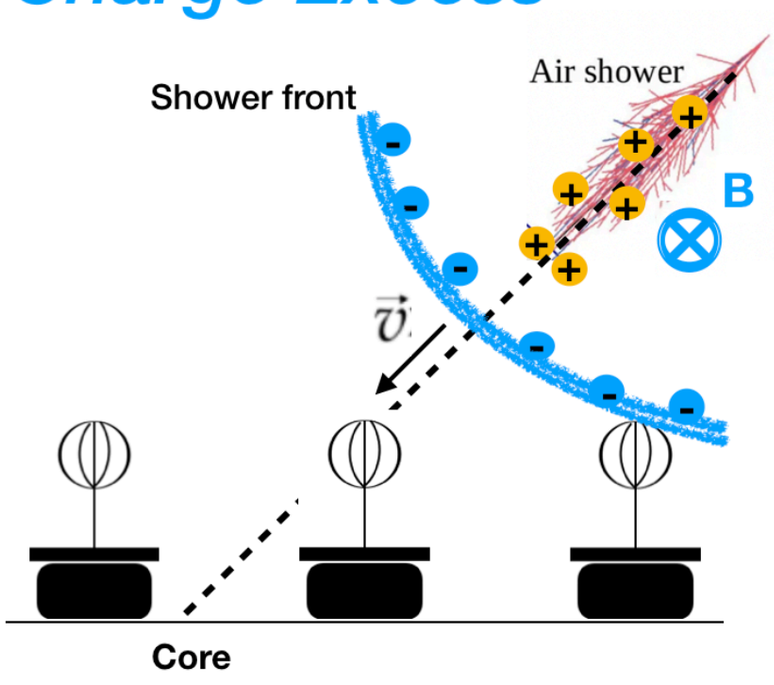


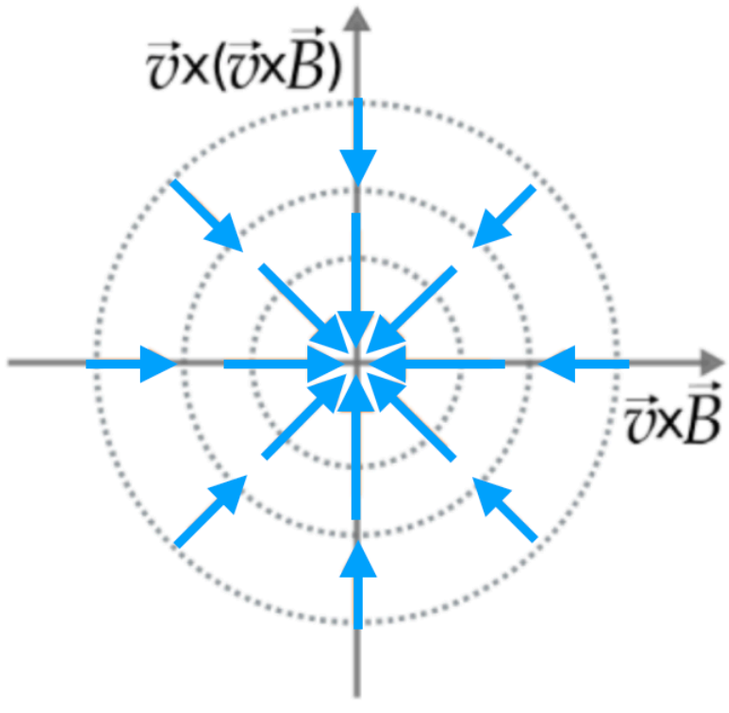


Primary mechanism:

transverse variable currents in the Earth's magnetic field

Charge Excess



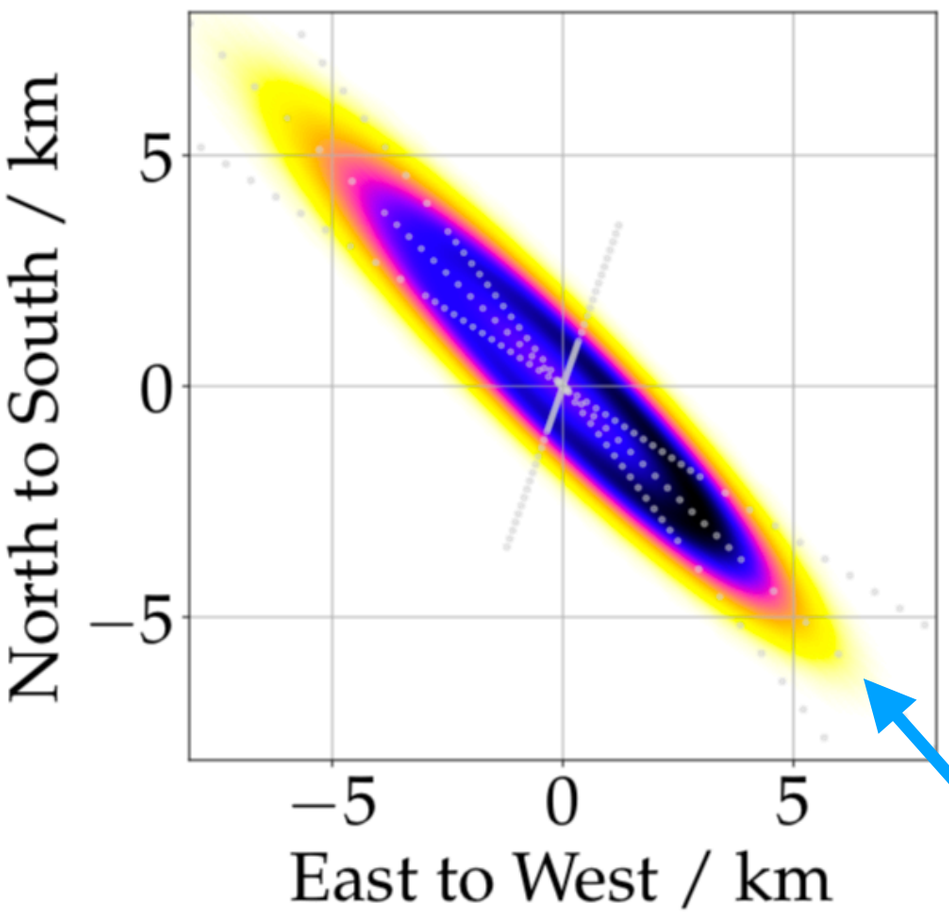


Secondary mechanism:

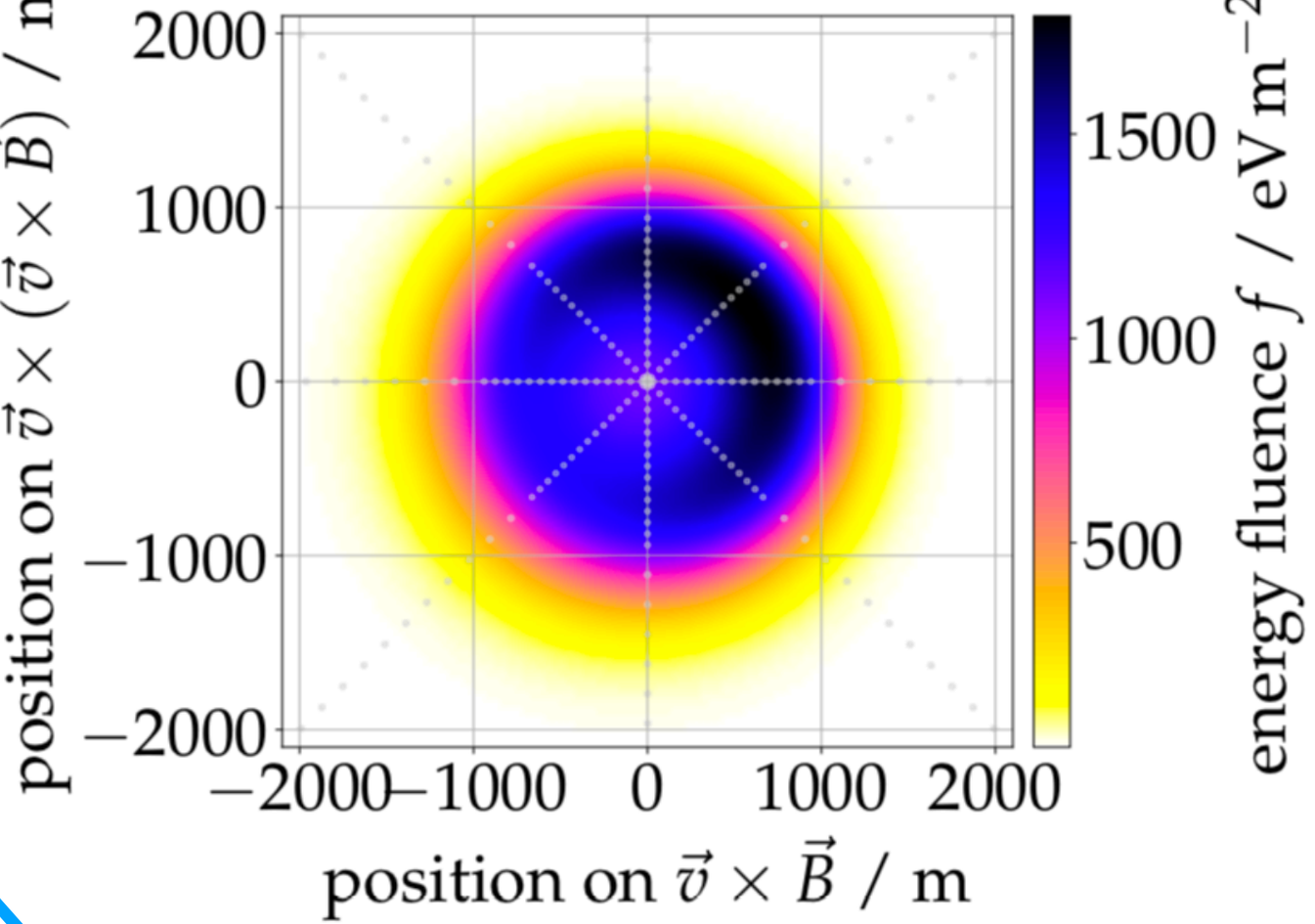
variable net charge excess (Askarian effect)

Radio emission footprint

Ground-plane



Shower-plane

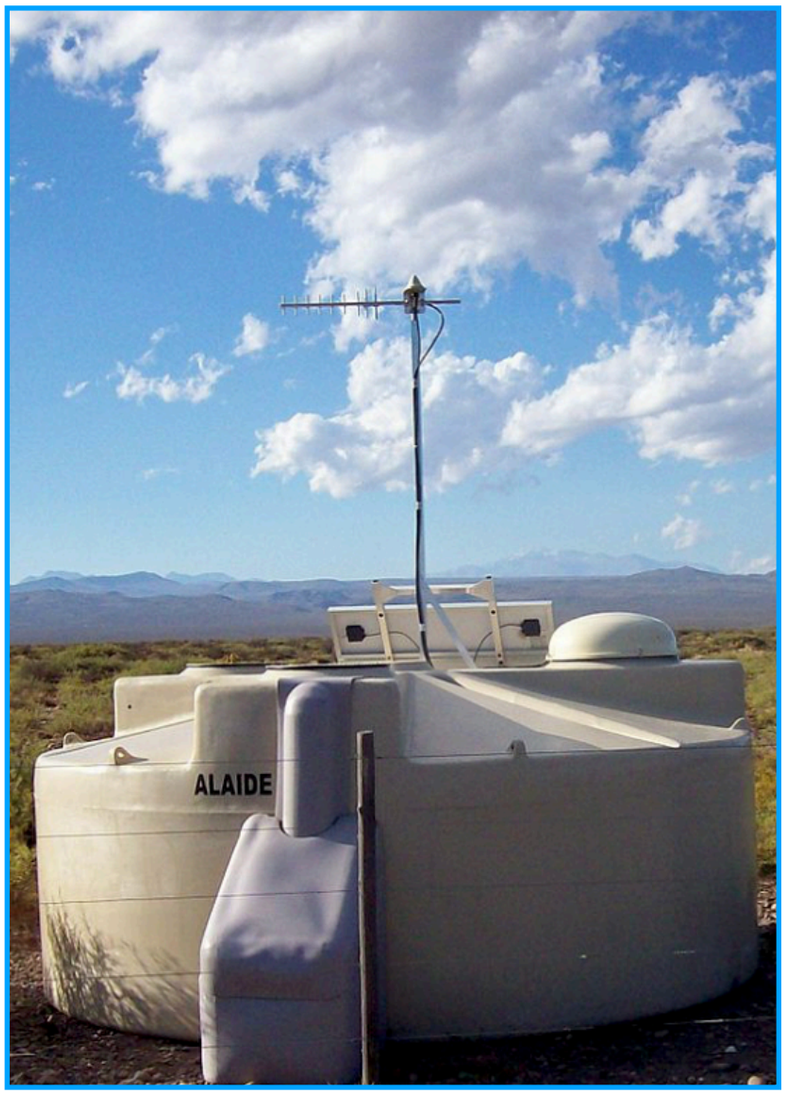


CoREAS simulated shower (80⁰ zenith)

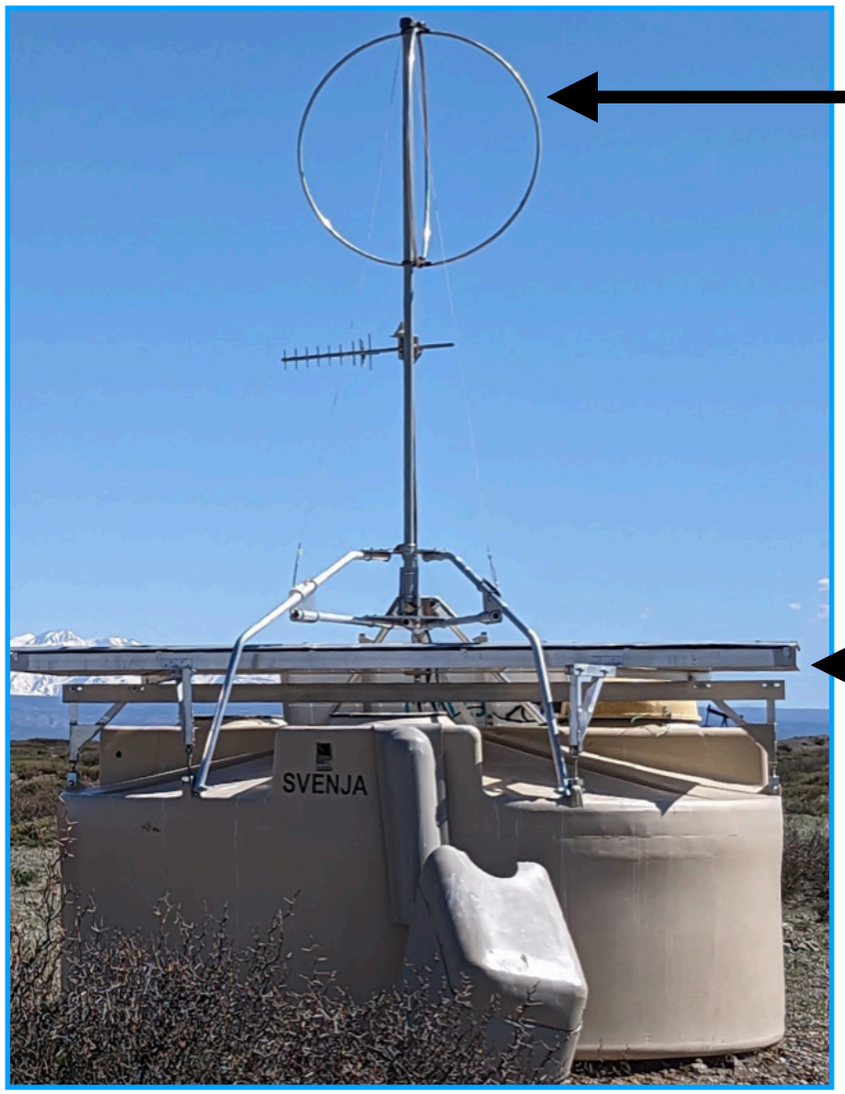
F. Schlüter, T. Huege, arXiv:2203.04364

The upgrade: AugerPrime

Before



After



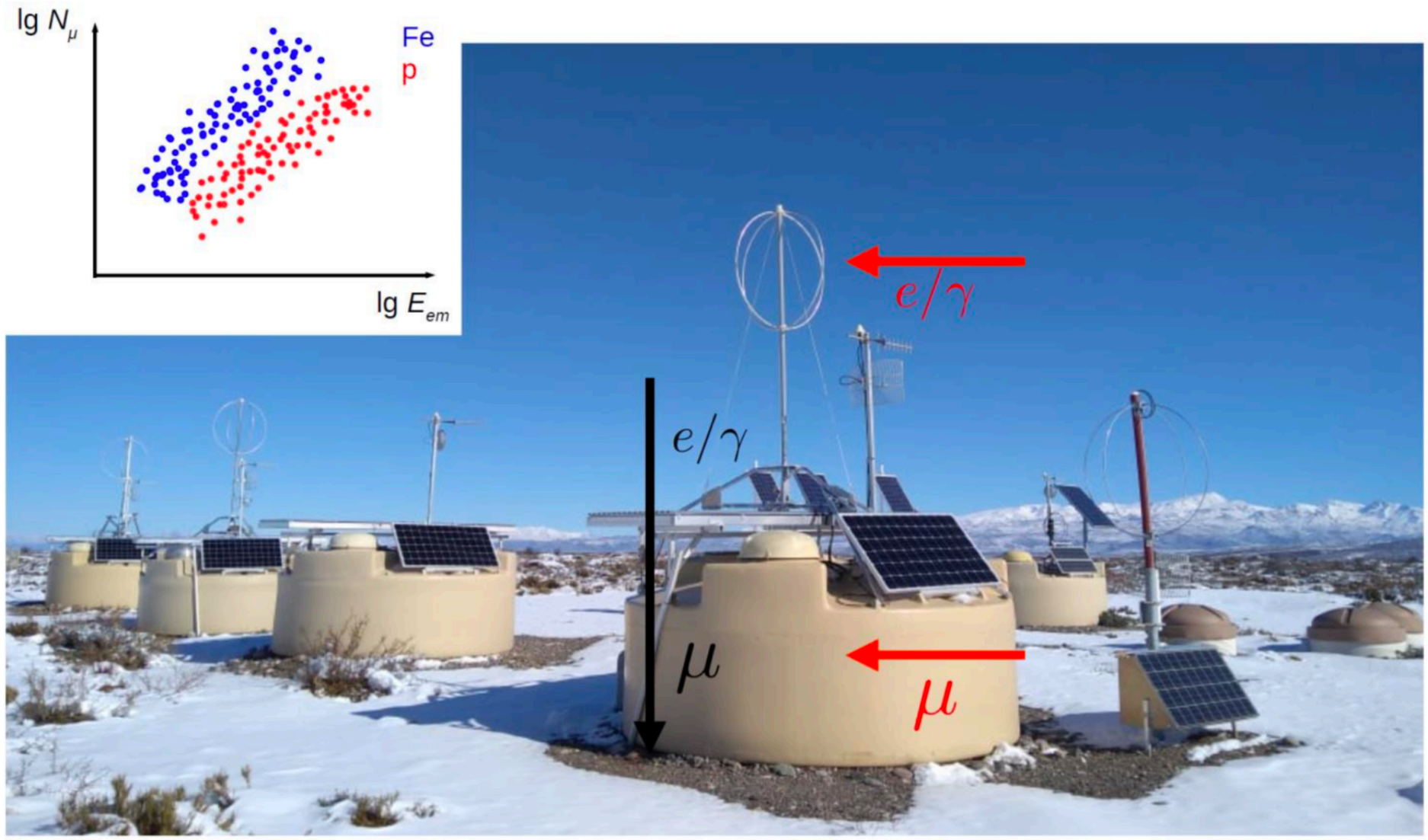
New:

Dual-polarised radio antena to detect EM component of horizontal air showers

Scintillator layer to help distinguish between electrons and muons in vertical showers

Improved readout electronics

The Auger Radio Detector

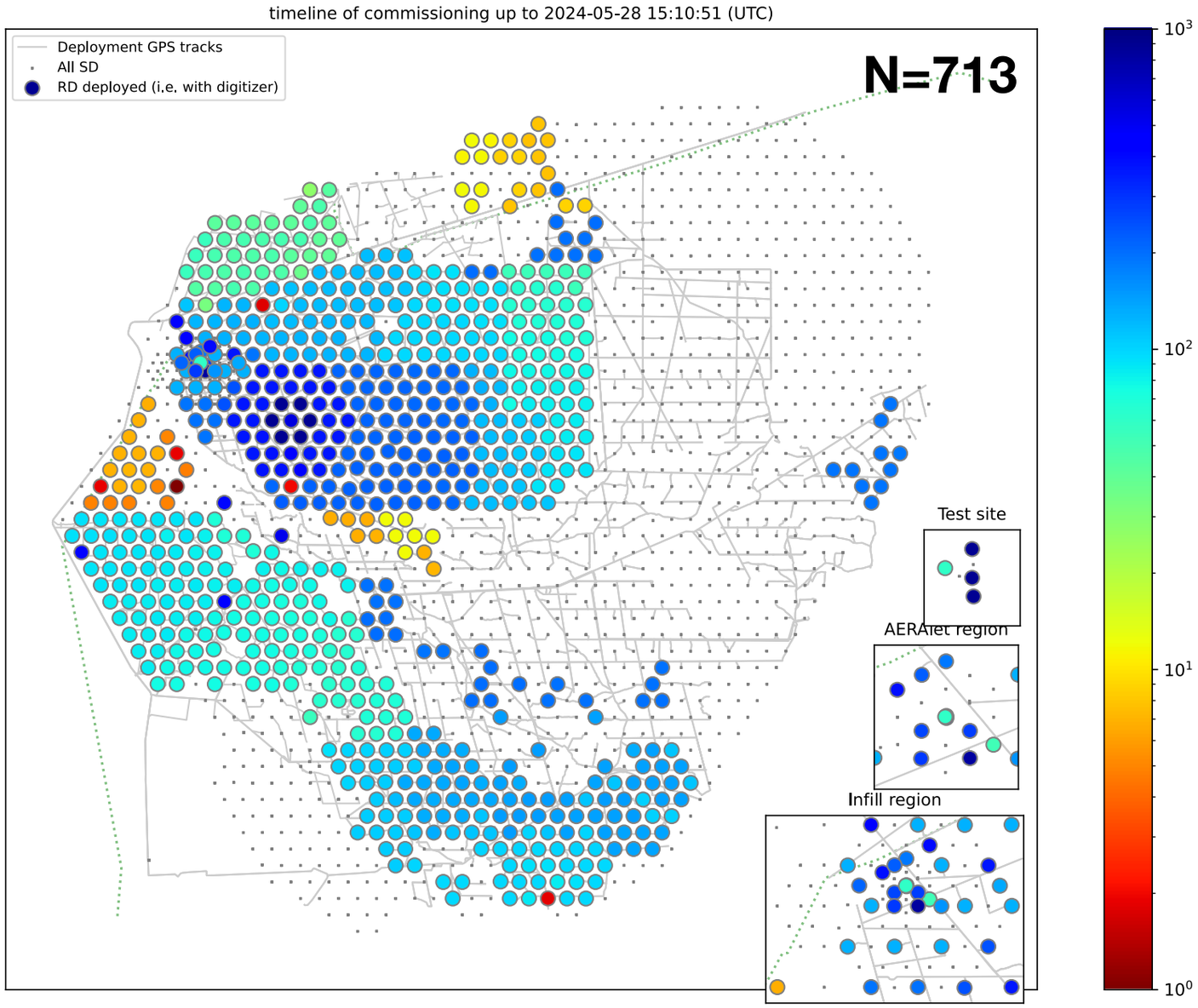


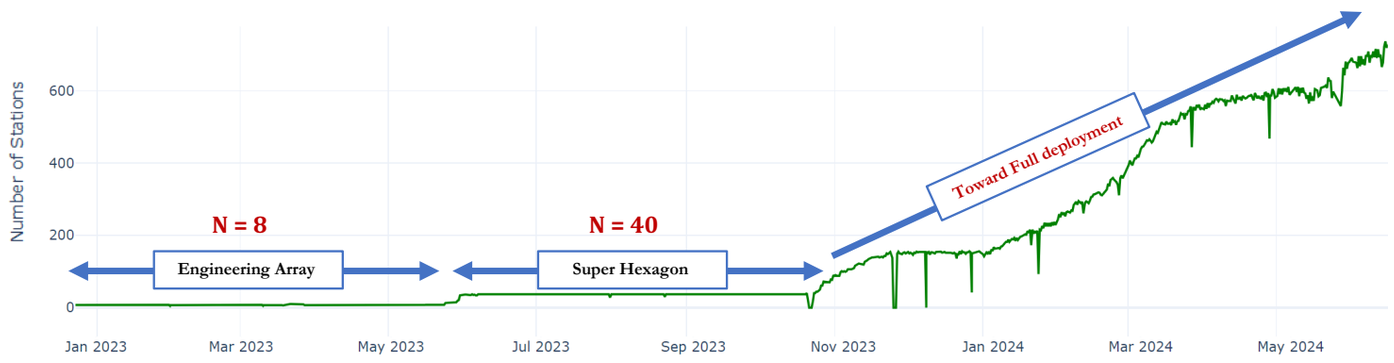
- Increased mass sensitivity for inclined air showers - RD measures EM component, WCD measures muons
- Increased sensitivity to photons and neutrinos - they have a strong EM component which we can measure with the RD

Radio Detector deployment (I)

Radio Detector deployment (II)

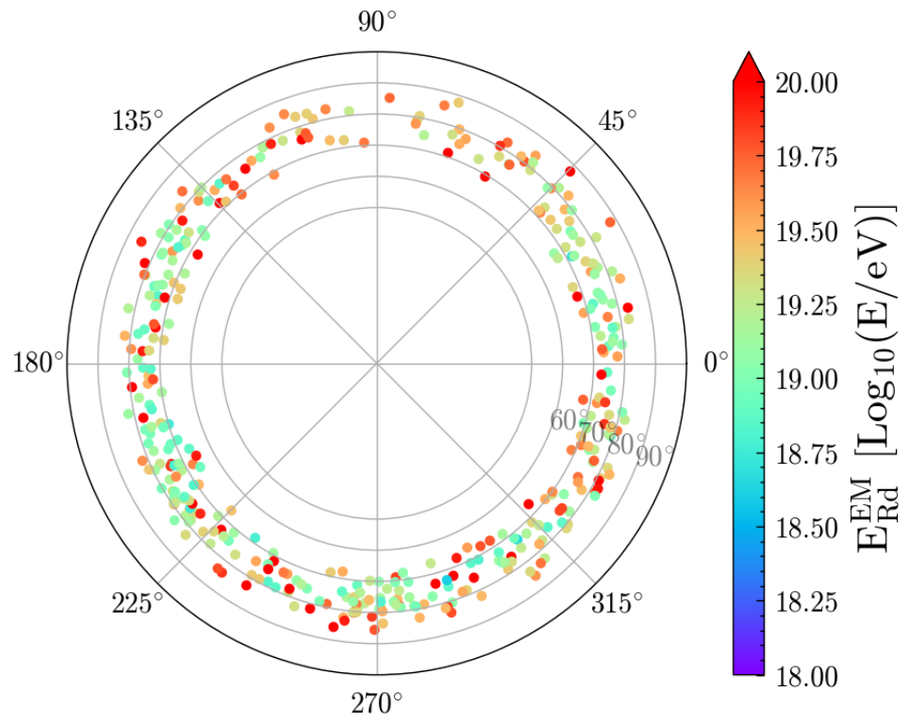
Radio Detector deployment (III)



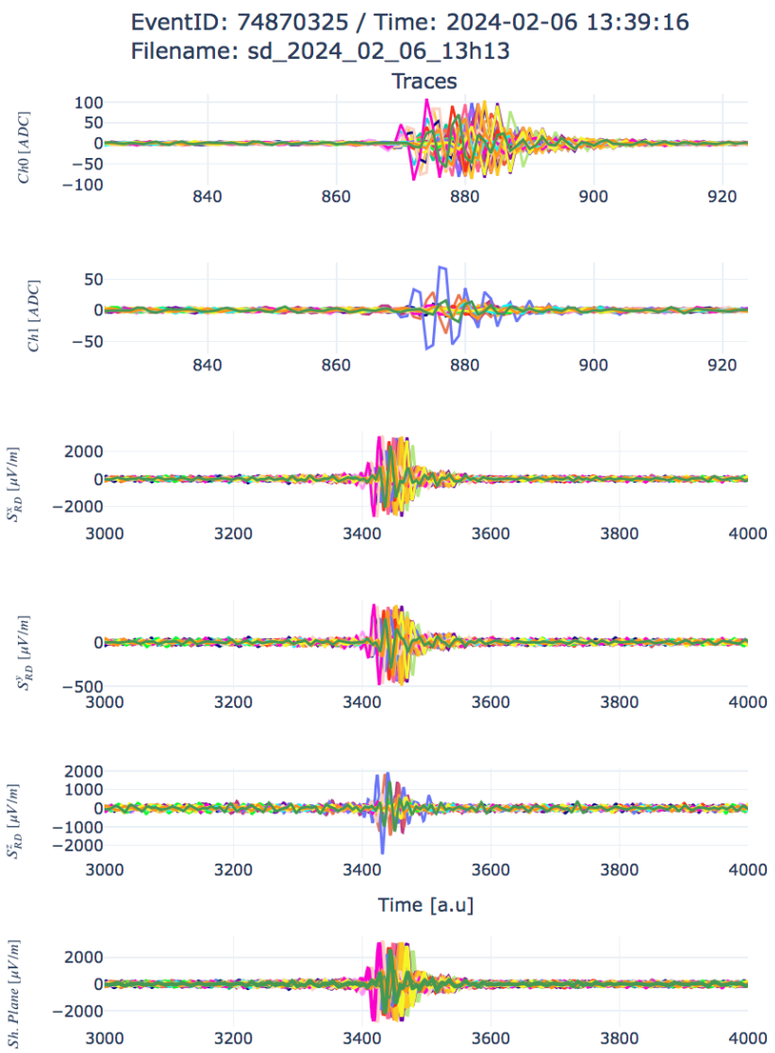


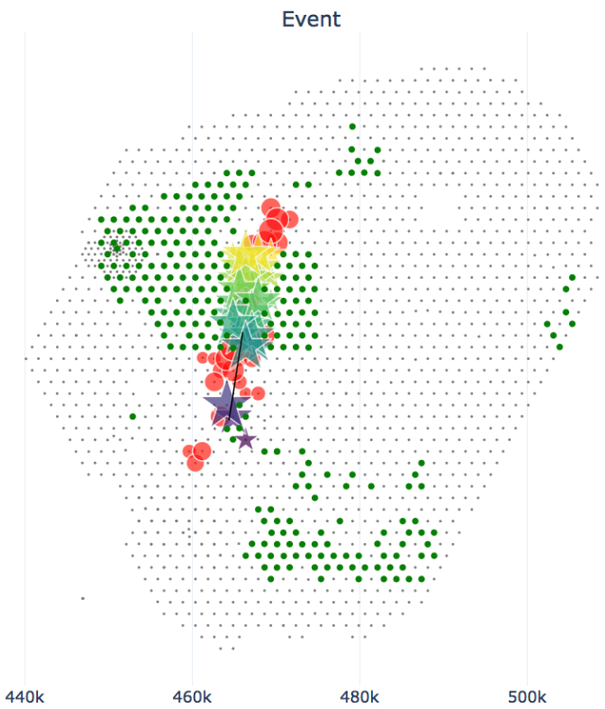
- More than 1200 antennas installed, 713 with digitisers and taking data

- More than 700 events reconstructed (triggered by the WCD)



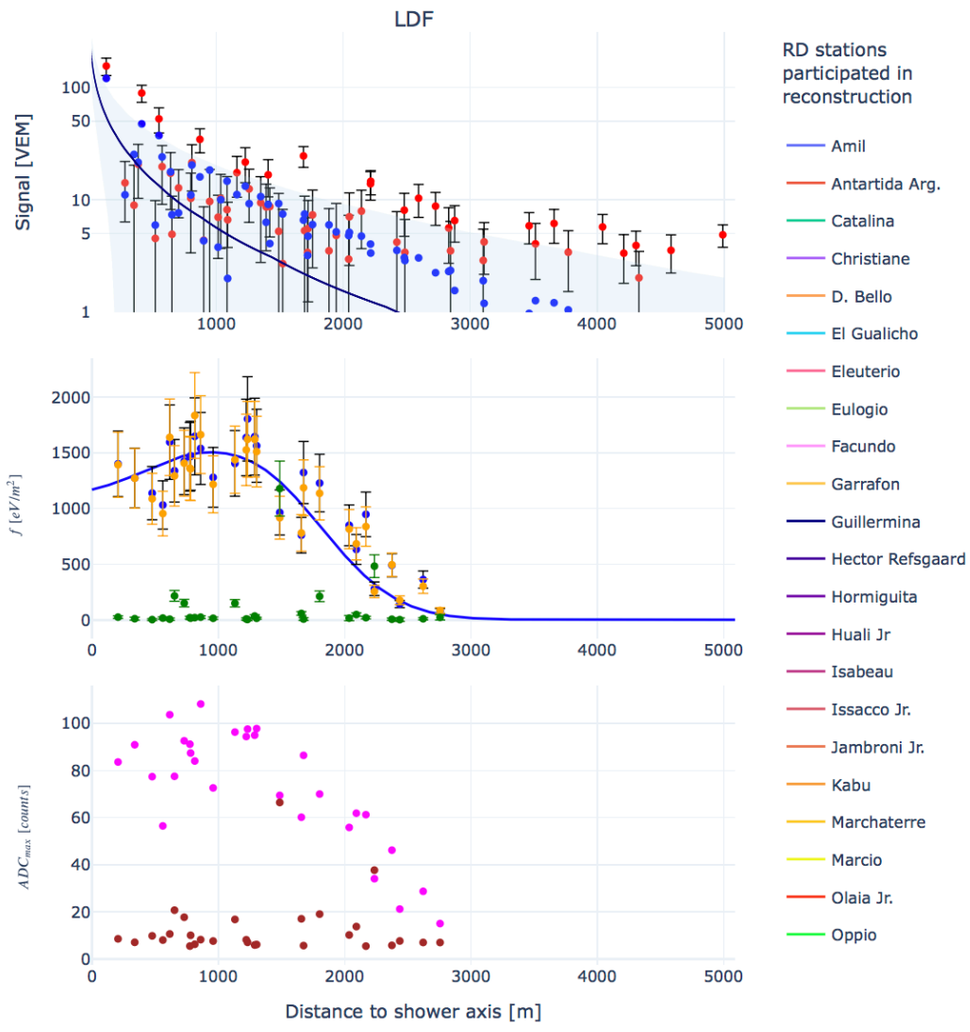
Auger RD measured shower (I)





WCD Reconstruction (61 stations)
$E_{SD} = 21.13 \pm 1.7\ EeV$
$\theta_{SD} = 85.8 \pm 0.1\ deg$
$\phi_{SD} = 260.6 \pm 0.0\ deg$
$N_{19} = 3.6 \pm 0.3$

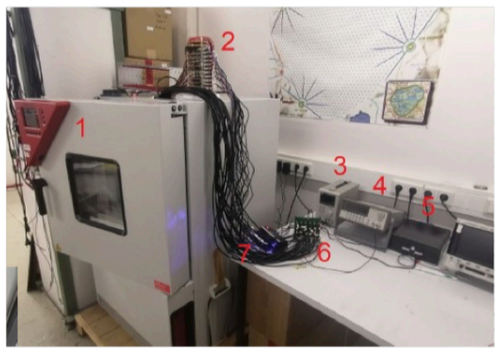
RD Reconstruction (29 stations)
$E_{RD} = 28.35 \pm 3.3\ EeV$
$\theta_{RD} = 85.8 \pm 0.0\ deg$
$\phi_{RD} = 260.6 \pm 0.0\ deg$
$TSFlag = 0, 0, 0, 0$



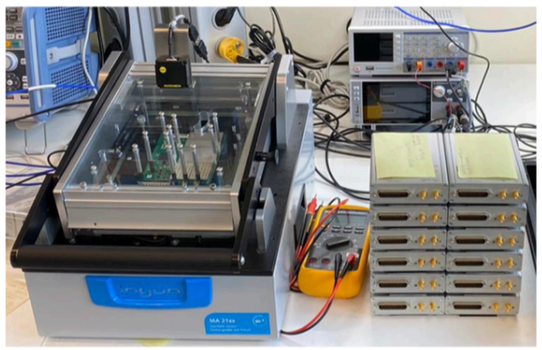
Trigger based on WCD for now, but we are working on a hybrid trigger which includes the radio signal

Calibration of the Radio Detector

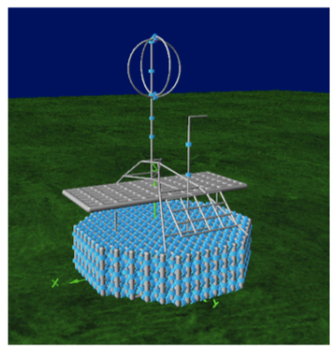
thermal cycling (aging)
LNA & digitizer

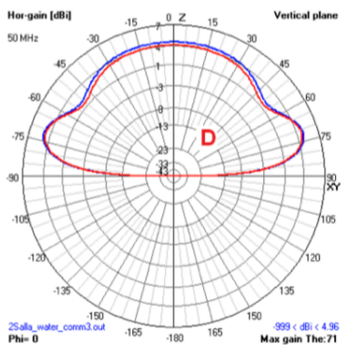


end-to-end calibration in lab
LNA & digitizer

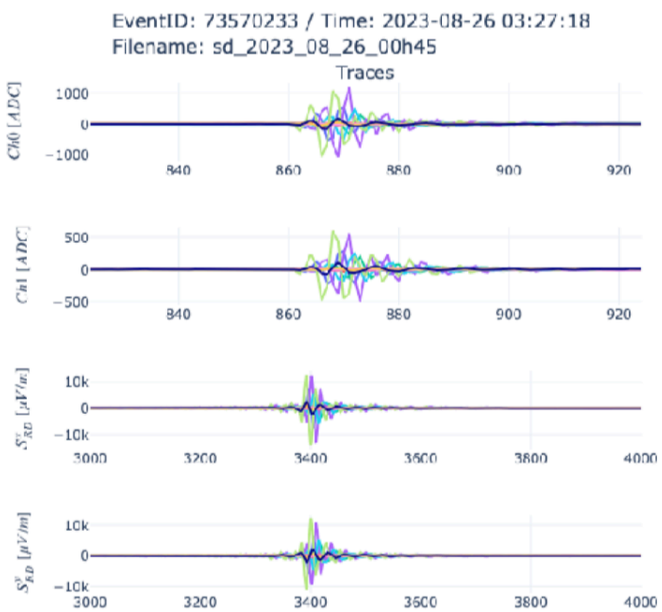


simulation of antenna pattern
NEC

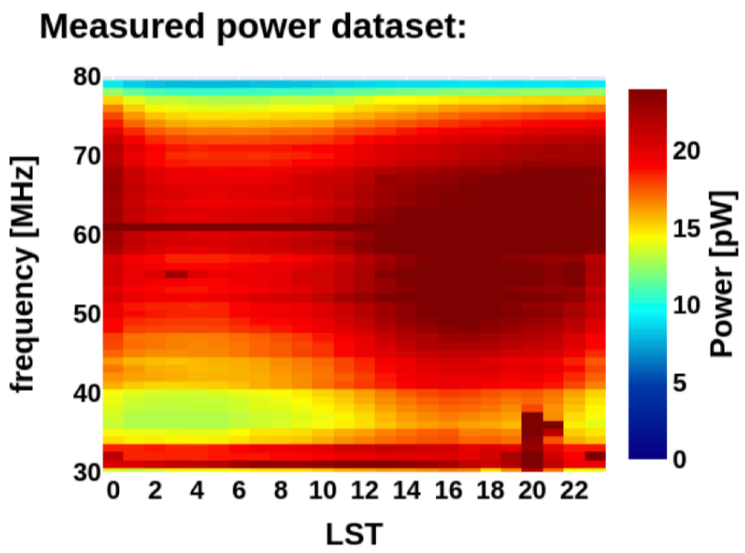




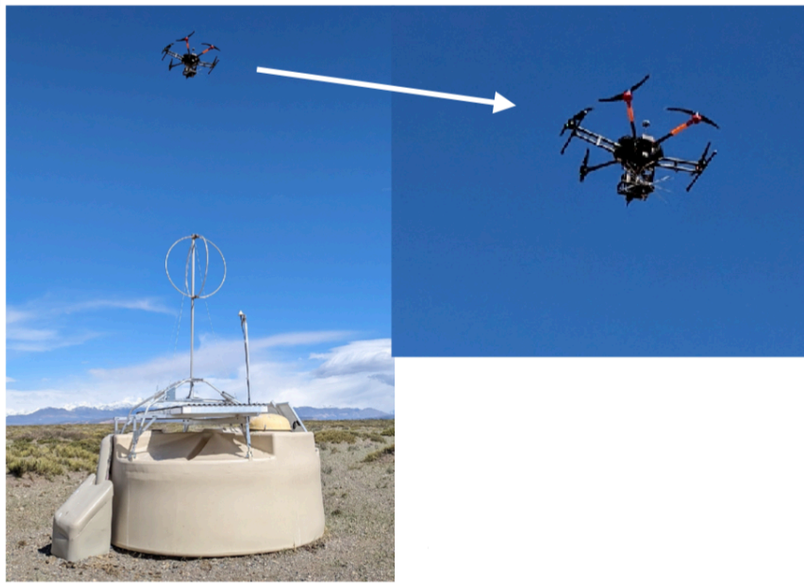
absolutely calibrated signals



Galactic emission

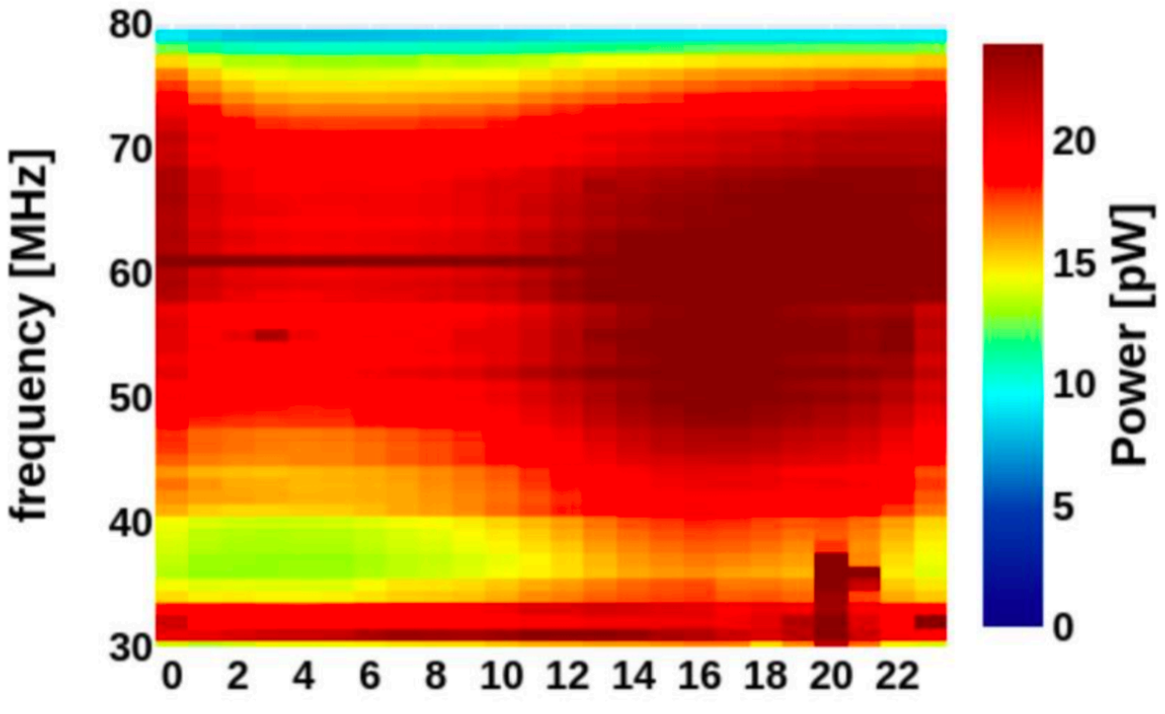


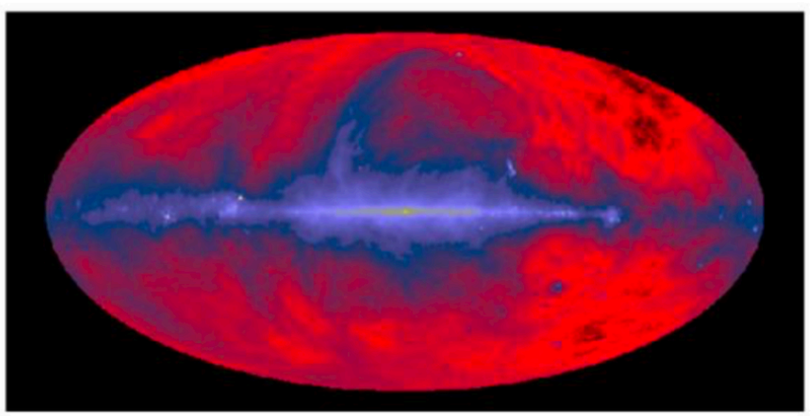
in-situ calibration with
reference antenna



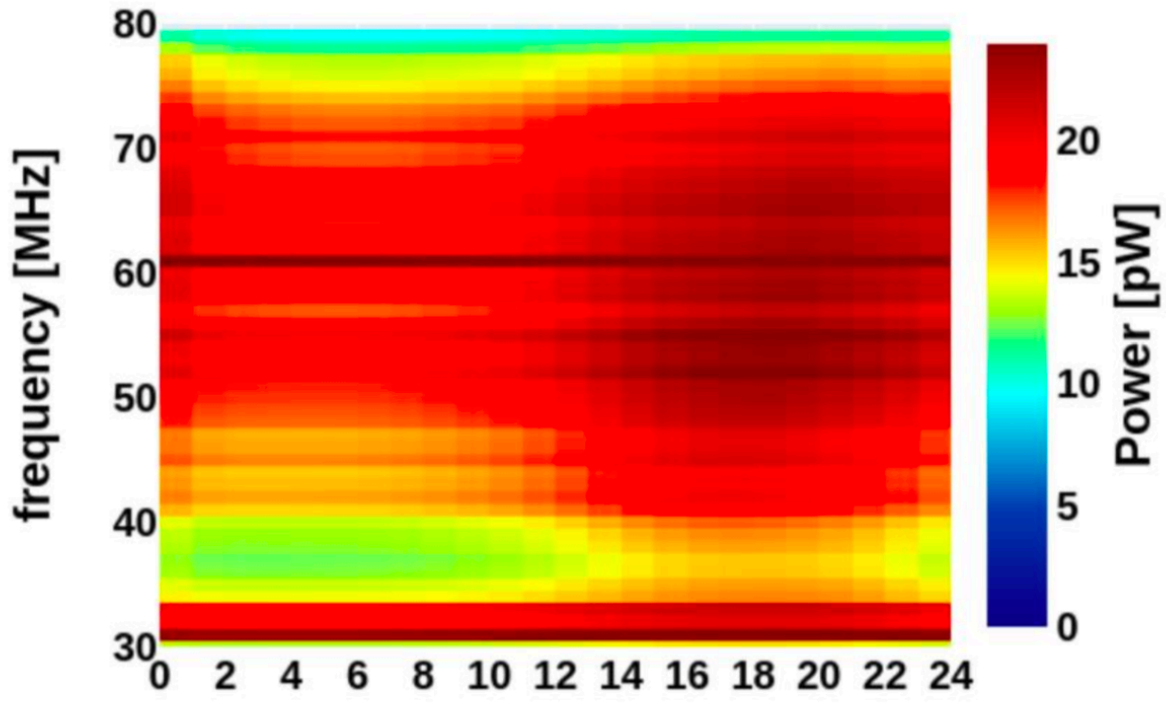
Measurement of Galactic Emission

Measured power dataset:





Simulated dataset + fitted noise

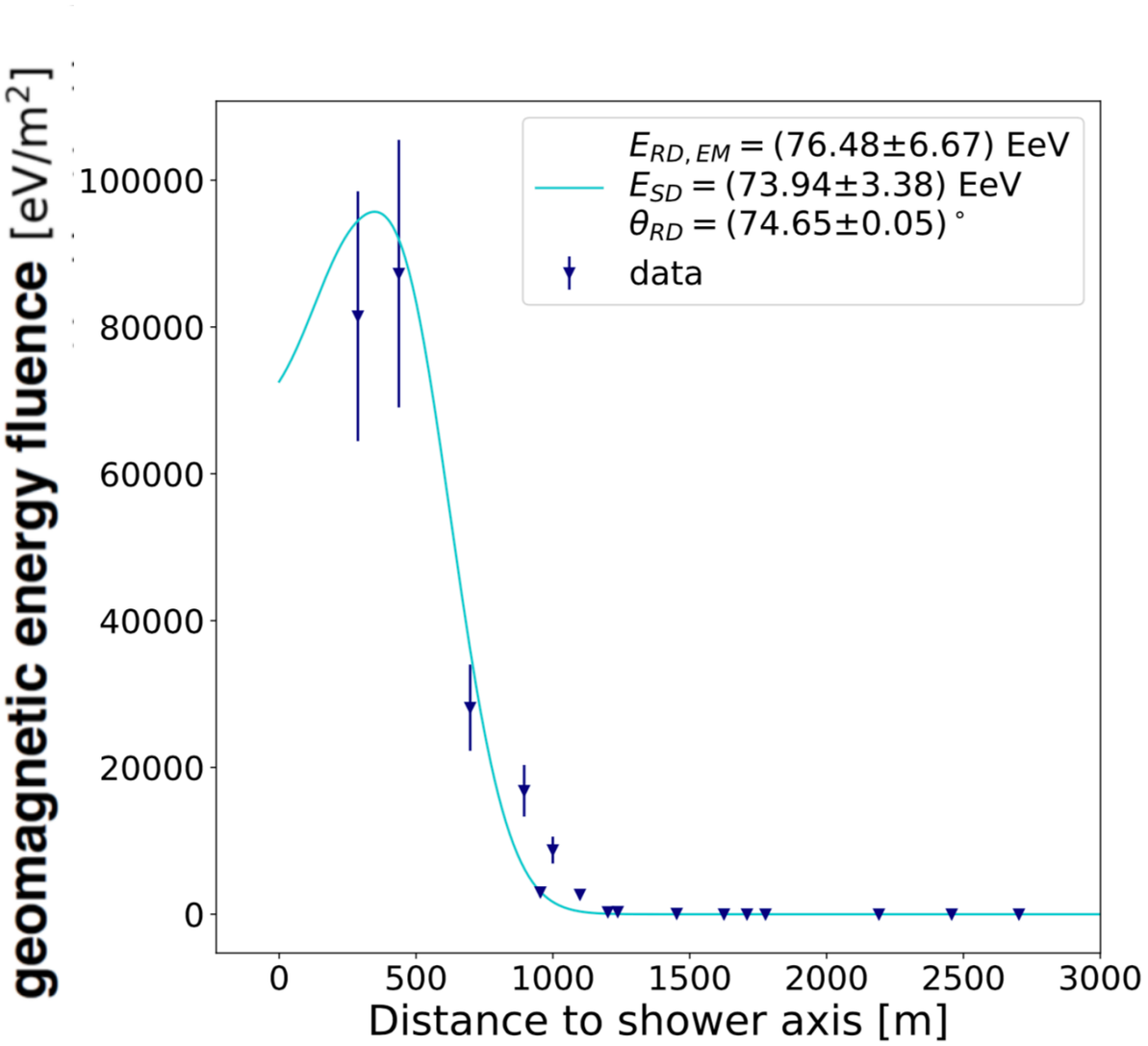


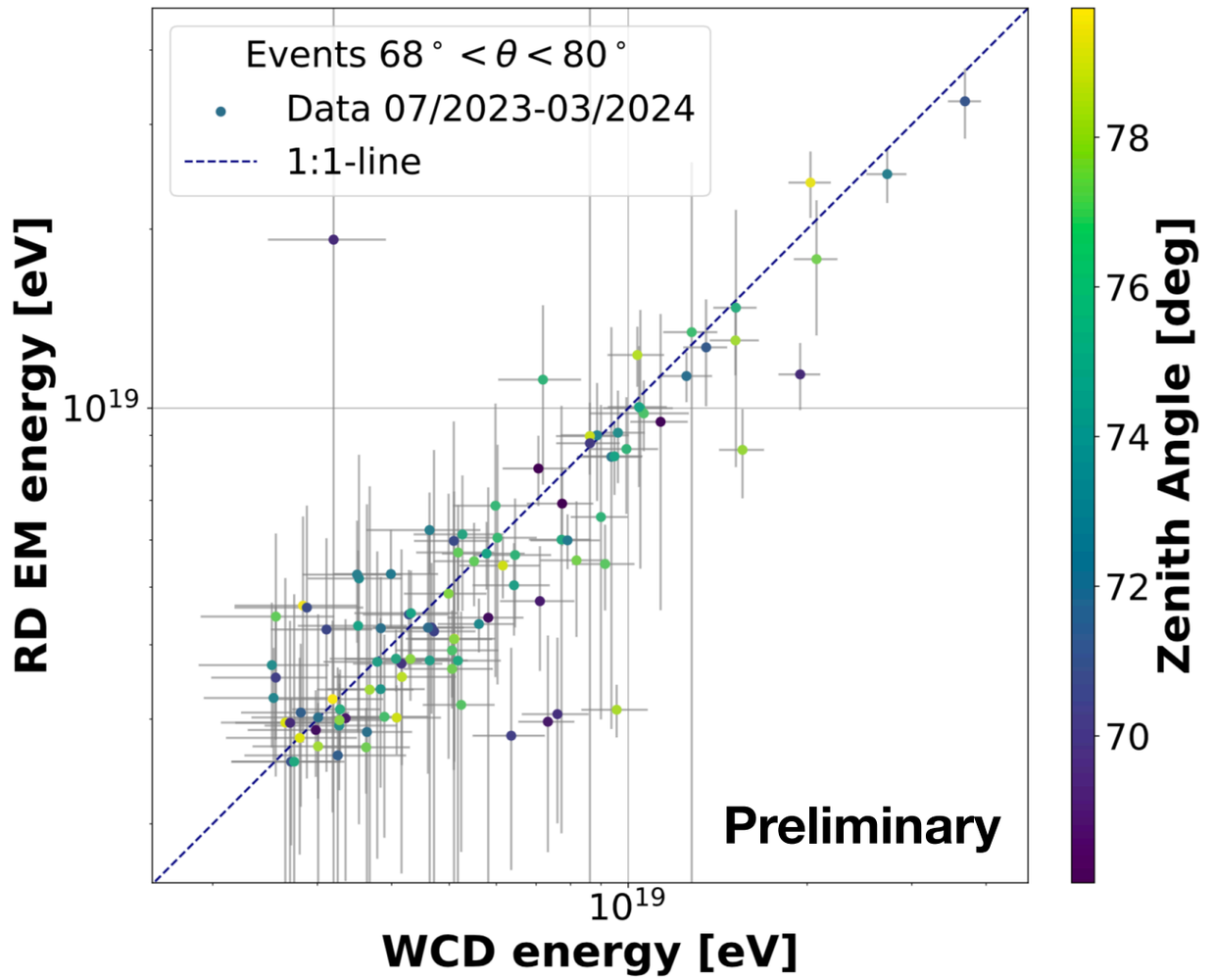
—> the „muon peak“ for radio
—> in-situ calibration
(implemented on FPGA)

systematic uncertainty ~10%

Galactic calibration constants from data agree within 5-10% with what we calculate from laboratory calibration and NEC2 simulations!

Hybrid measurements RD-WCD





Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

Signal model and event reconstruction for the radio detection of inclined air showers

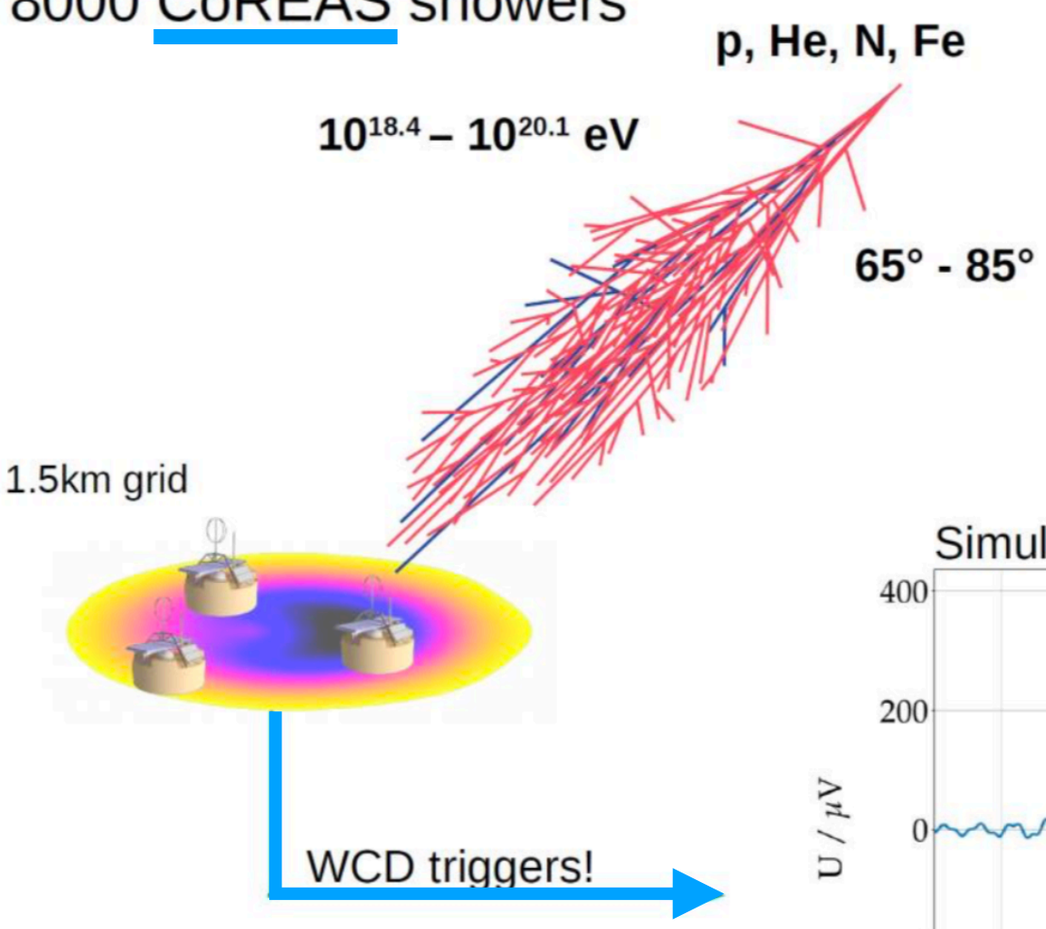
F. Schlüter[a,b,*] and T. Huege[a,c] JCAP01(2023)008

measurement of e/m energy by RD

—> full end-to-end verification of complete chain

Expected performance of RD

8000 CoREAS showers

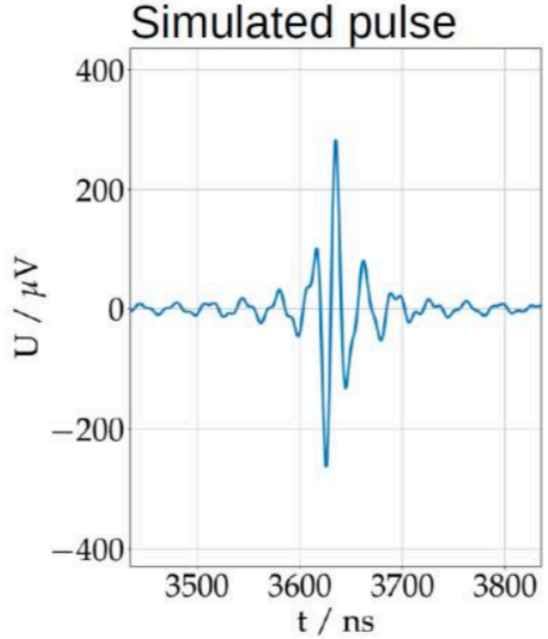


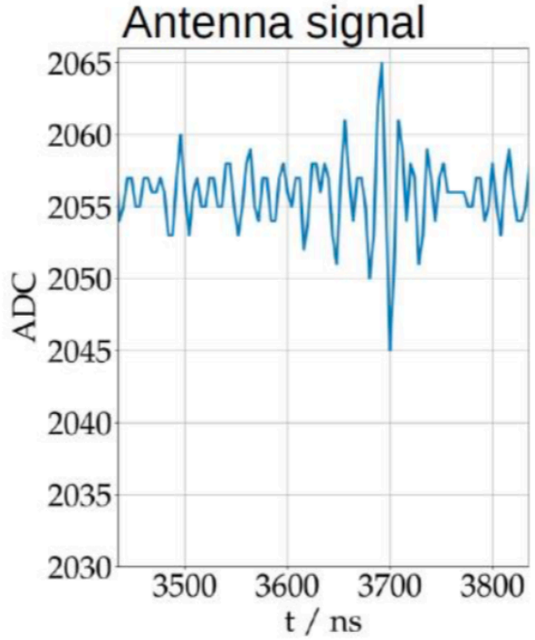
30-80 MHz

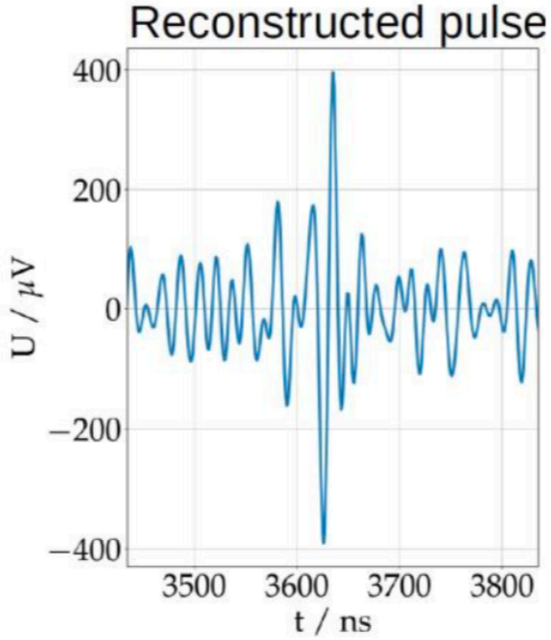
Simulate instrumental response

(directional response, analog gain, digitization, …..)

- Including uncertainties (σ_A = 5%)
- Measured noise

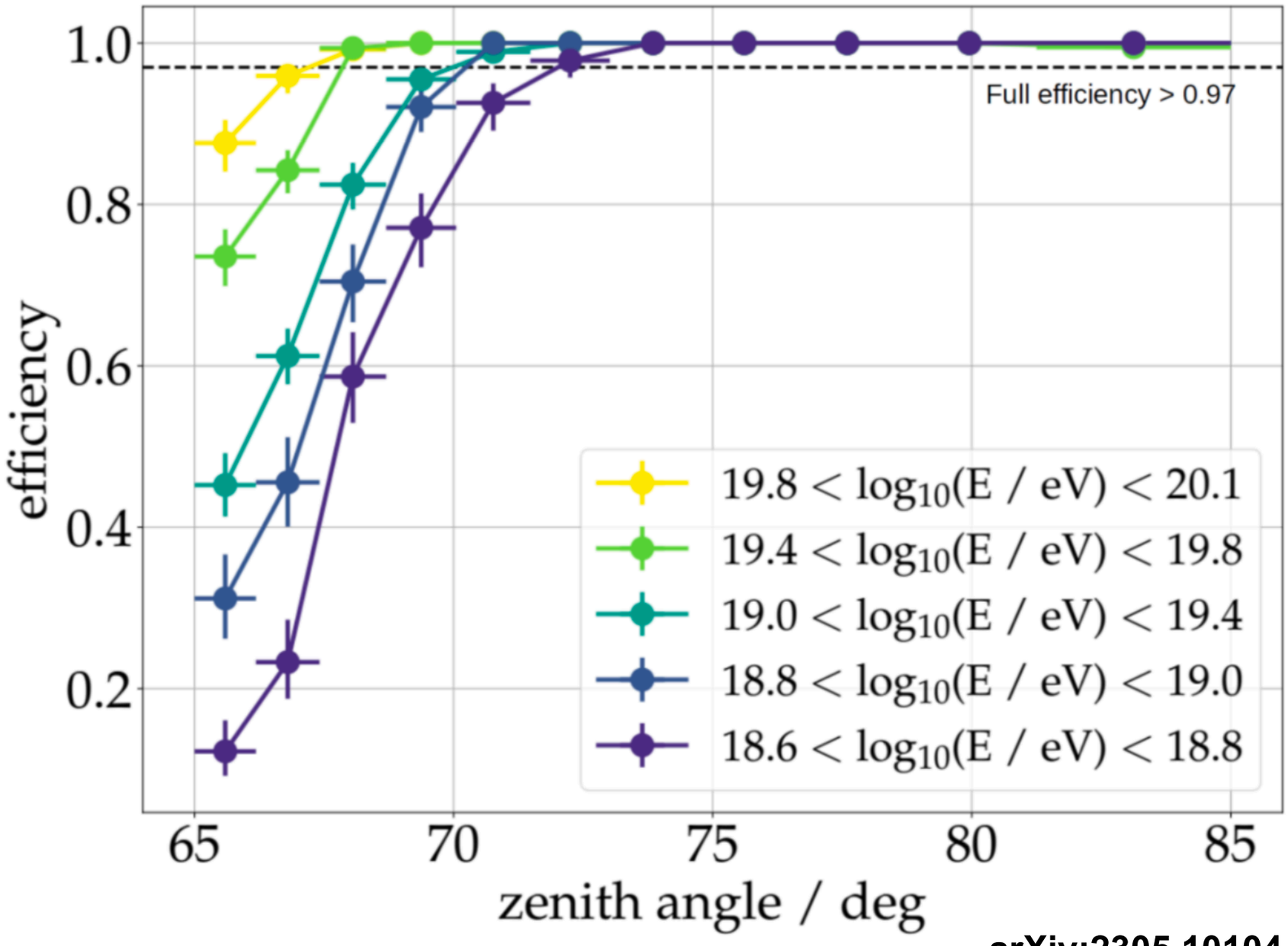






arXiv:2305.10104

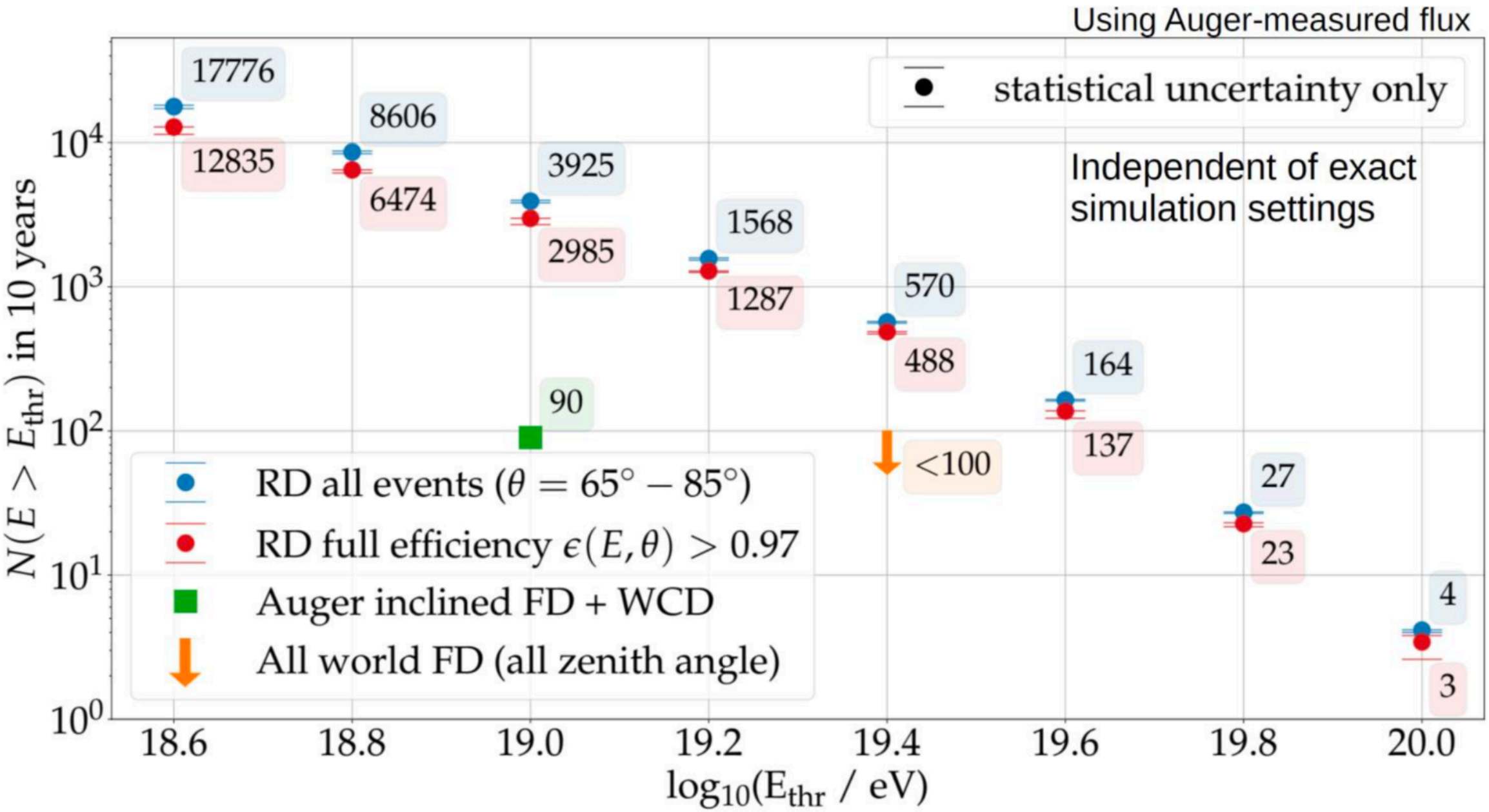
Expected detection efficiency for cosmic rays



arXiv:2305.10104

Requires measurable signal in at least 3 antennas

Expected event statistics in 10 years



arXiv:2305.10104

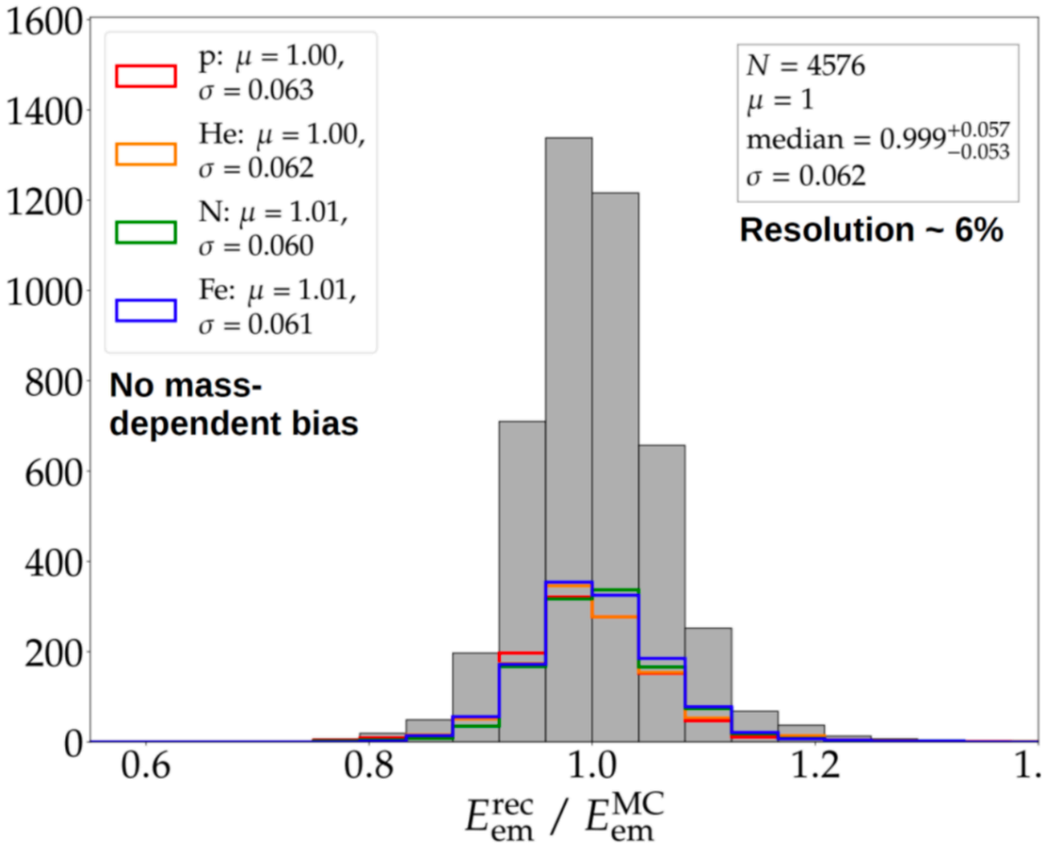
Integral spectrum from folding flux with aperture

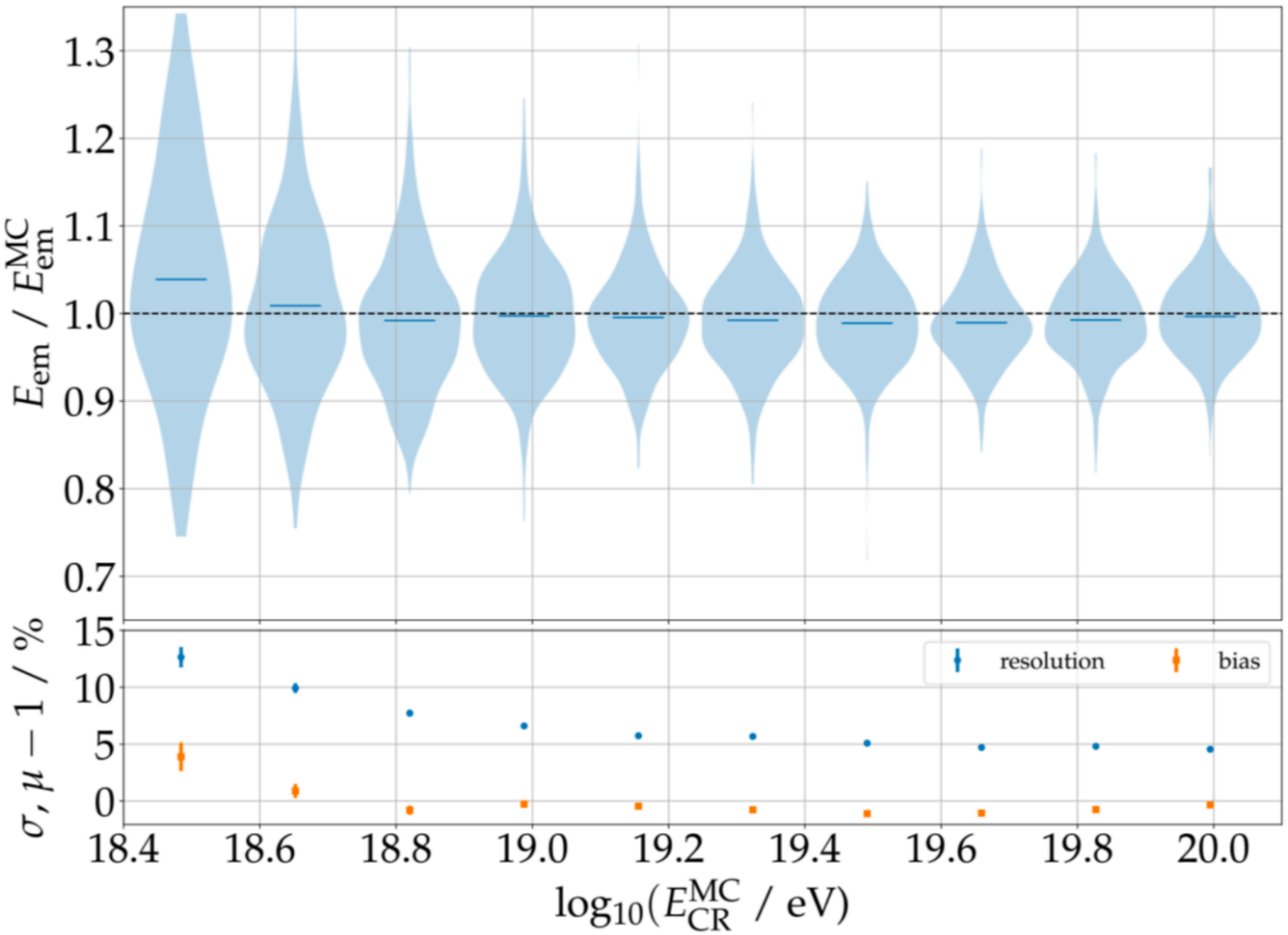
Expected energy resolution of the RD

Showers with at least 5 signal stations and θ > 68°

quality cuts: ~95% efficiency

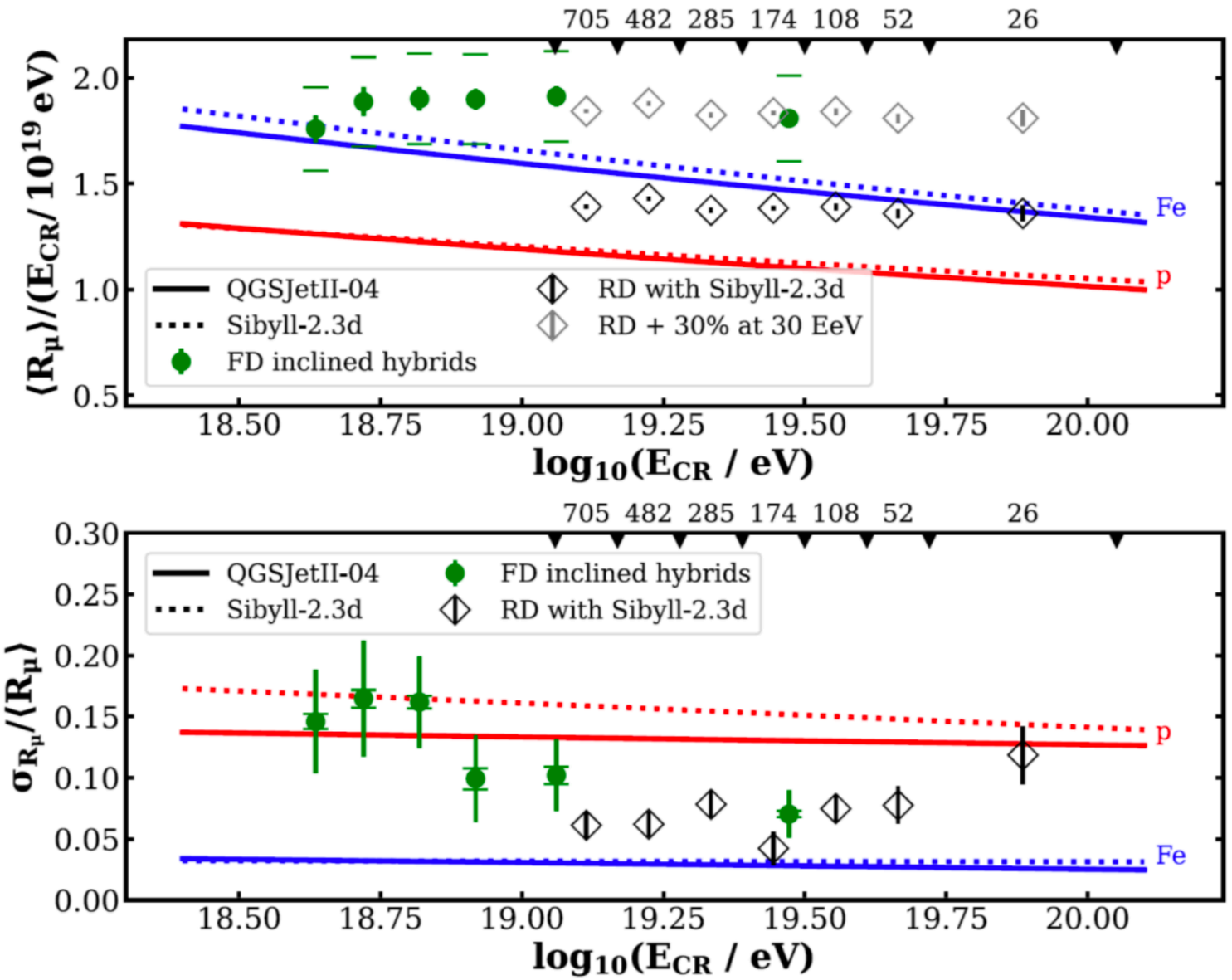
Resolution improves with energy





arXiv:2305.10104

Expected muon number measurements



- Very high-statistics measurements of muon number with WCD+RD at highest energies
- Especially measurement of the variation of the muon number with will be very powerful

Expected mass composition sensitivity with RD

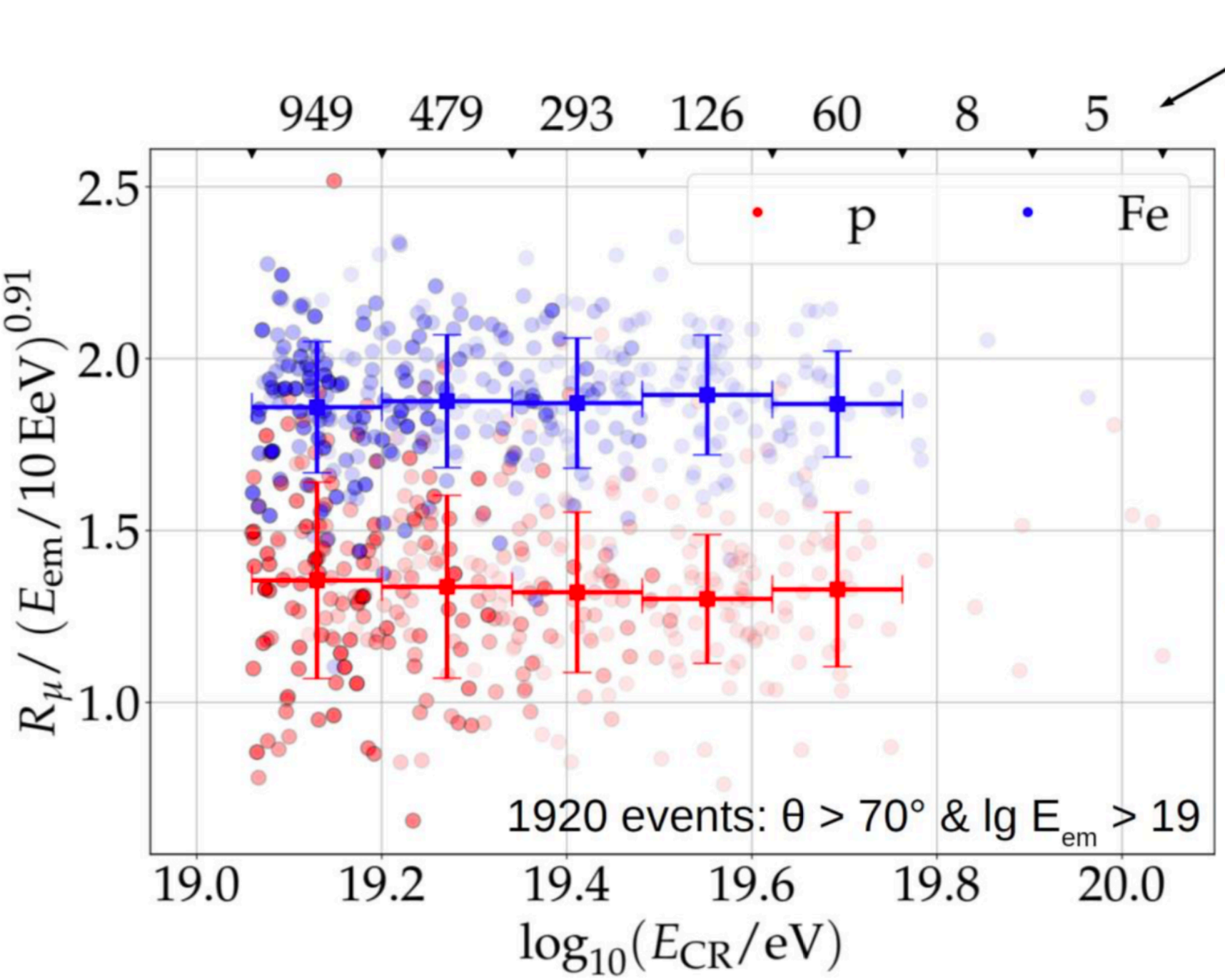


Figure of Merit:

$$FOM = \frac{|\langle r_p \rangle - \langle r_{Fe} \rangle|}{\sqrt{\sigma^2_{r_p} + \sigma^2_{r_{Fe}}}}$$

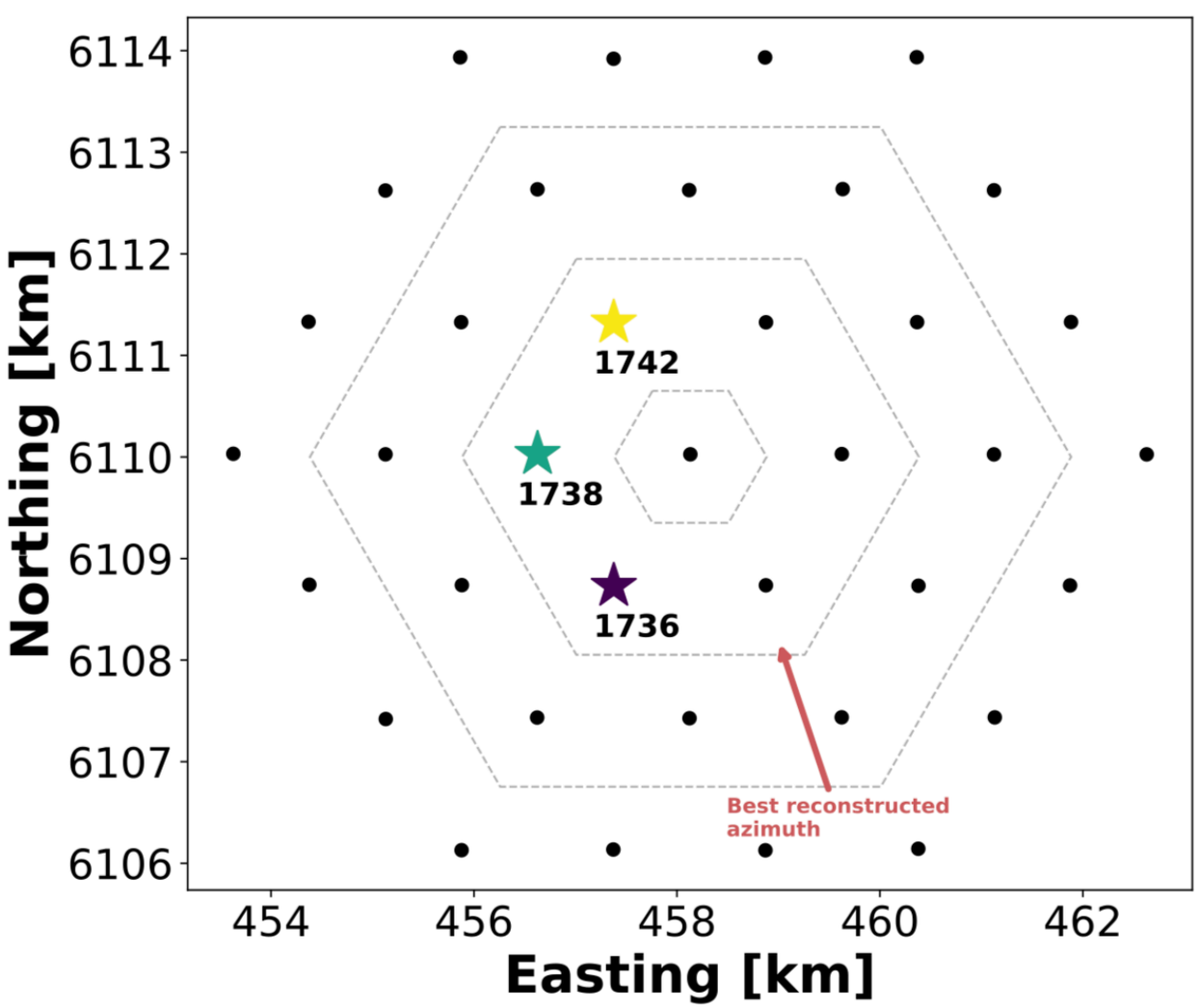
FOM = 1.61 ± 0.04

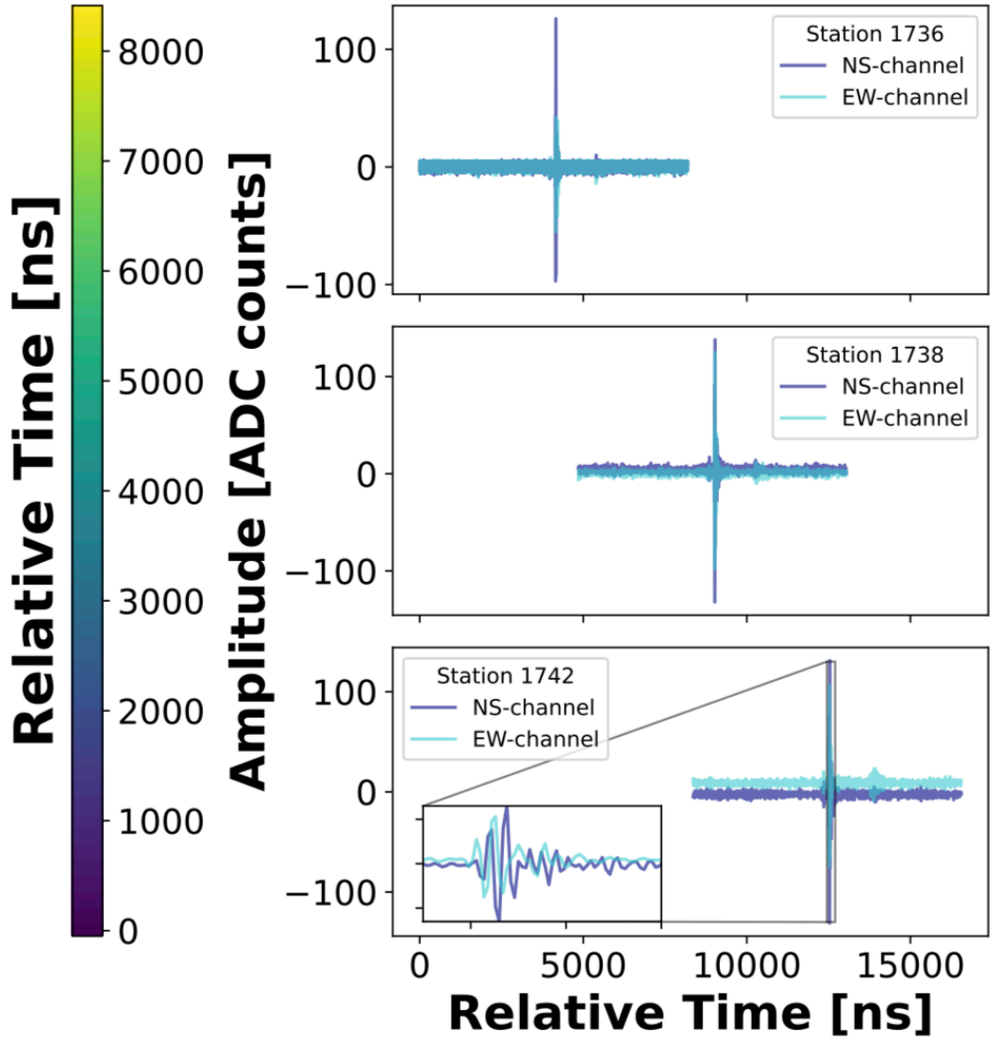
Equal to X_{max} with perfect resolution!

Goal for the Upgrade: 1.5

arXiv:2305.10104

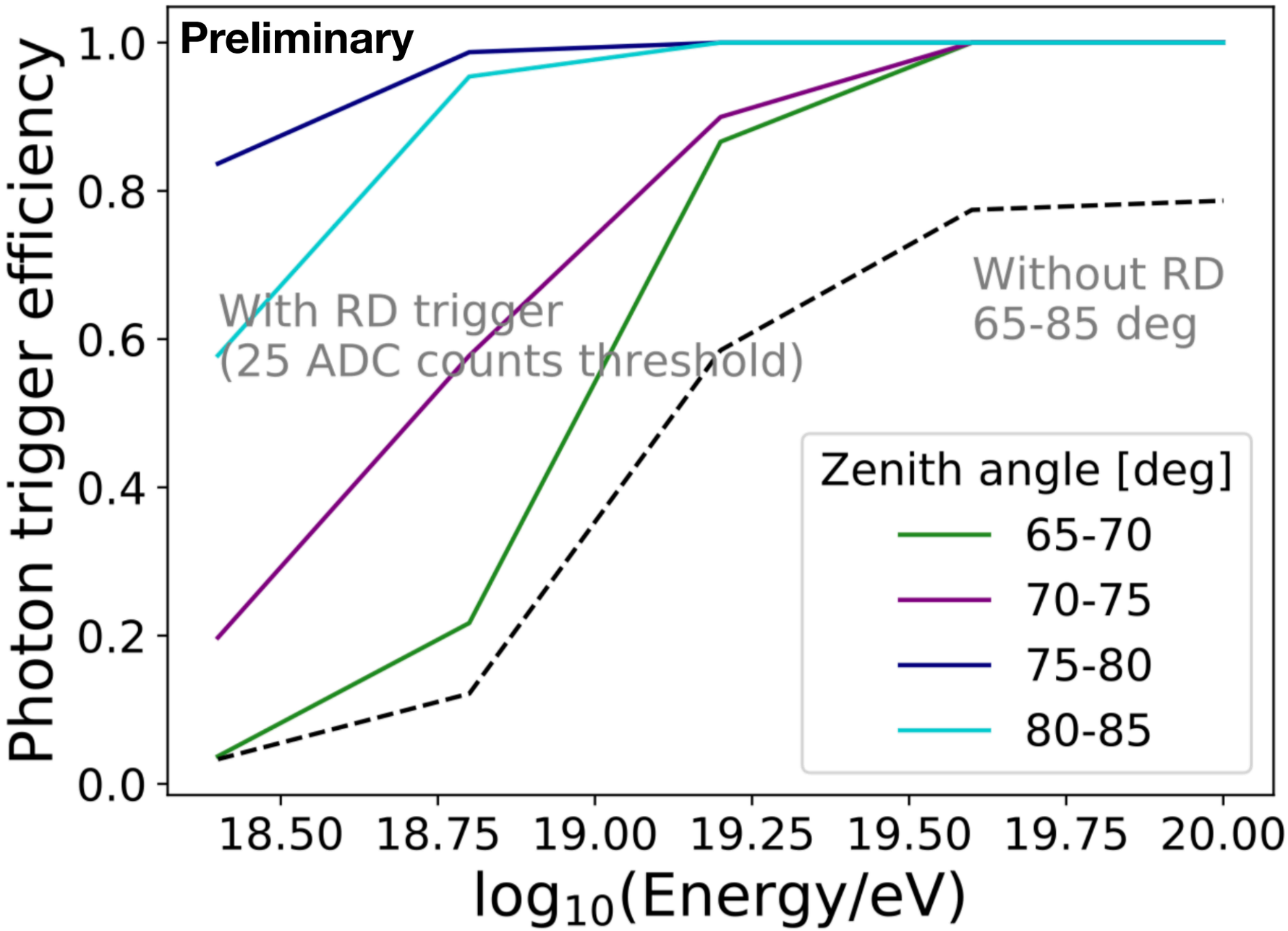
Radio trigger development





to improve the sensitivity to neutral particles (photons and neutrinos) an RD threshold trigger was successfully tested, leading to the observation of air shower-like events only triggered by the RD

Neutral particles detection with Auger



Neutral particles like photons and neutrinos have negligible particle footprint, but produce strong radio signal which can be used to trigger on

Summary

- Radio antennas provide clean measurements of the EM component of extended air showers produced by ultra-high-energy cosmic particles

- We are currently installing antennas on all 1660 surface detectors in Auger, RD deployment should be finished by the end of 2024

- This will increase our mass sensitivity for inclined air showers produced by cosmic rays

- Sensitivity to neutral particles - photons and neutrinos - is also expected to increase

- Stay tuned for new results from the largest radio array in the world soon!