

IIHE activities at the Pierre Auger Observatory

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Joint HEP@VUB -- IIHE meeting, 23rd November 2021



The IIHE-Auger group

Belgium is a full member of the Auger Collaboration since 2018



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- ▶ Energy spectrum of cosmic rays
- ▶ Anisotropy of arrival directions and primary composition
- ▶ Calibration and performance of the surface detectors
- ▶ Search for ultra-high energy photons

With the **great support** from:

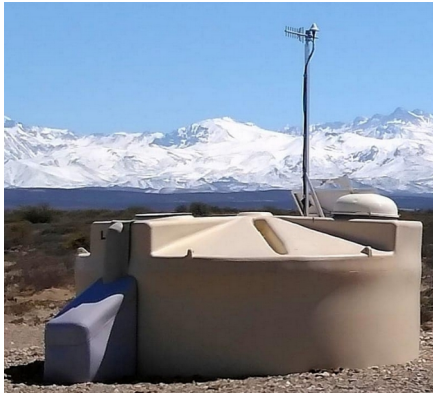


Dr. Daniela Mockler

Audrey Terrier
Sofie Van Den Bussche
Olivier Devroede
Denis Dutrannois
Stéphane Gérard
Romain Rougny
Shkelzen Rugovac
Adriano Scodrani



The Pierre Auger Observatory

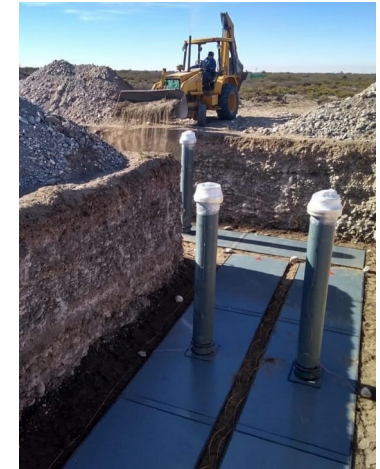
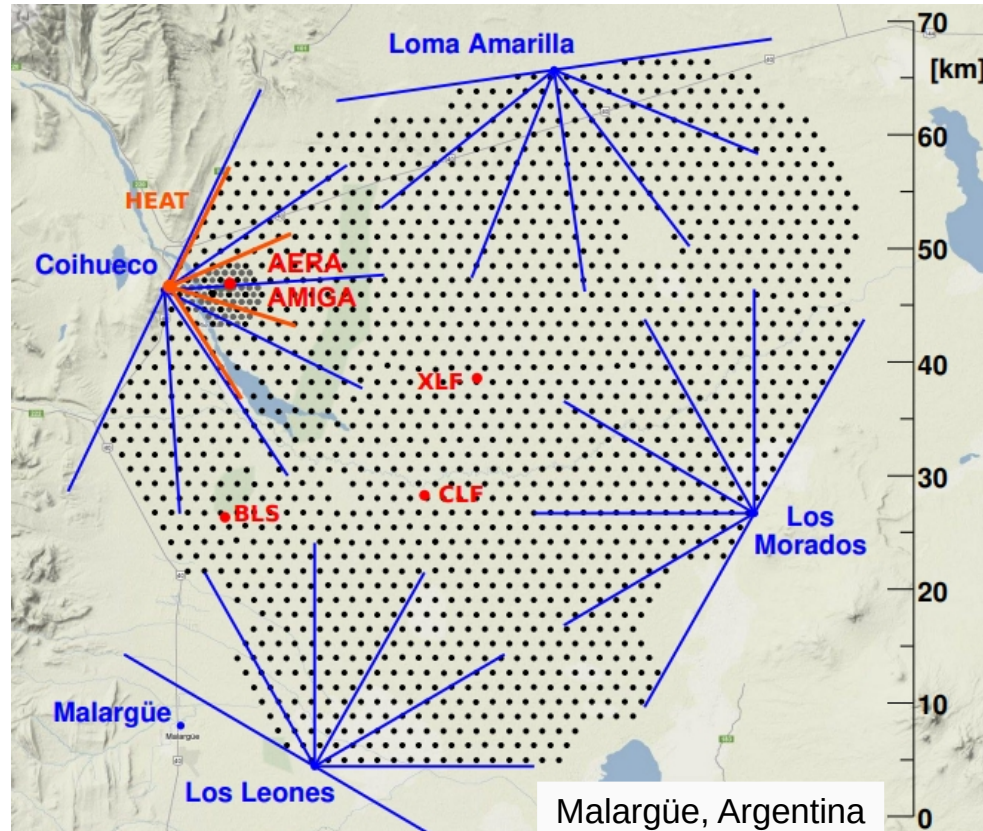


Surface detector (SD)

- 1500 m array
1600 stations
- 750 m array
61 stations
- 433 m array
19 stations

Extensions:

- Radio antennas (AERA)
- Atmospheric monitoring facilities (CLF, XLF, Lidar)

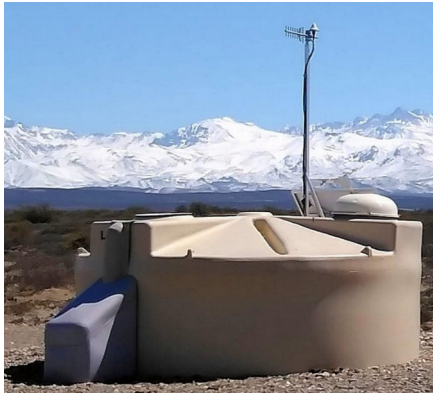


Underground muon detectors
>24 stations spaced by 750 m



Fluorescence detector (FD)
24 telescopes across 4 sites

The Pierre Auger Observatory

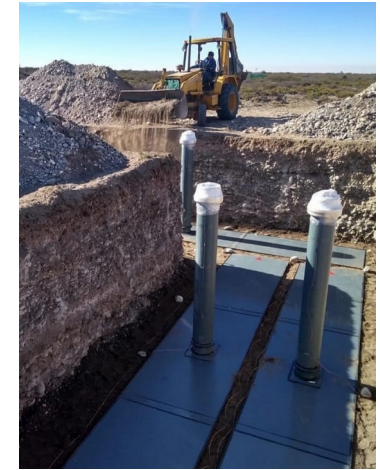


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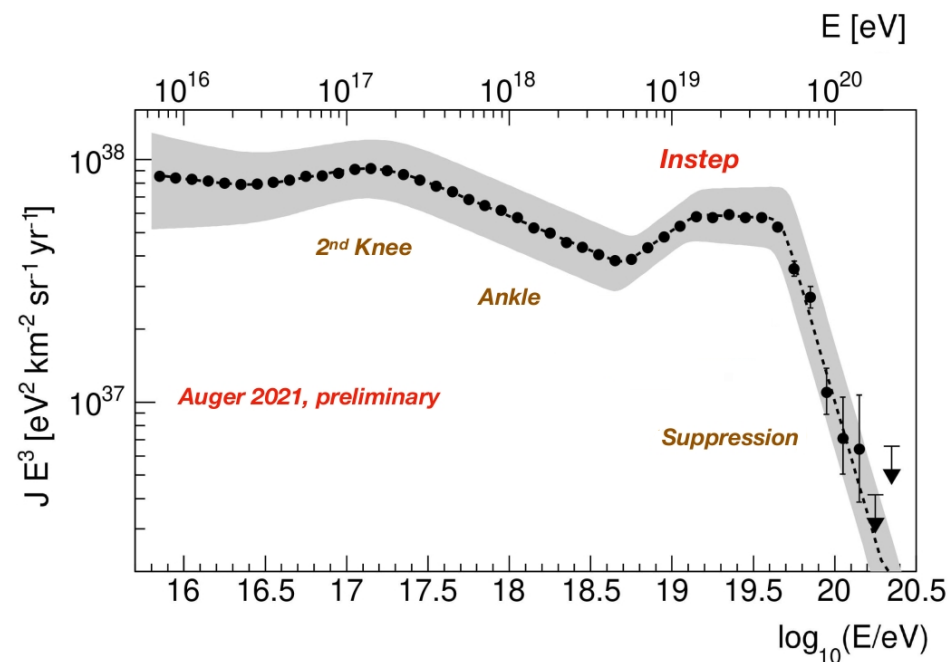
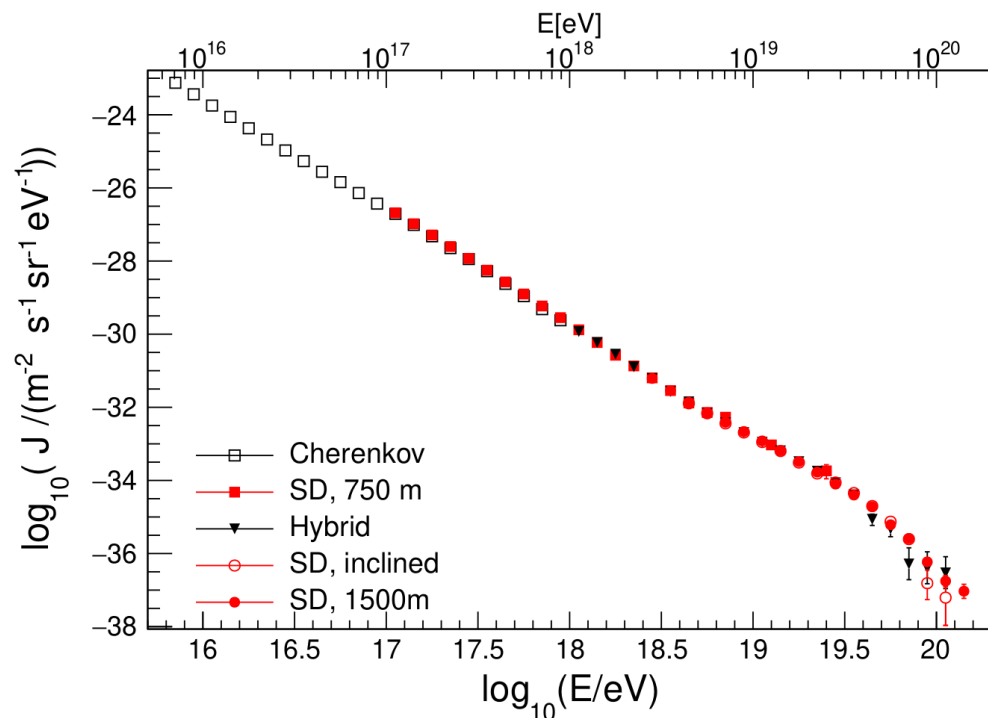


Underground muon detectors
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Fluorescence detector (FD)
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Highlight analysis: energy spectrum

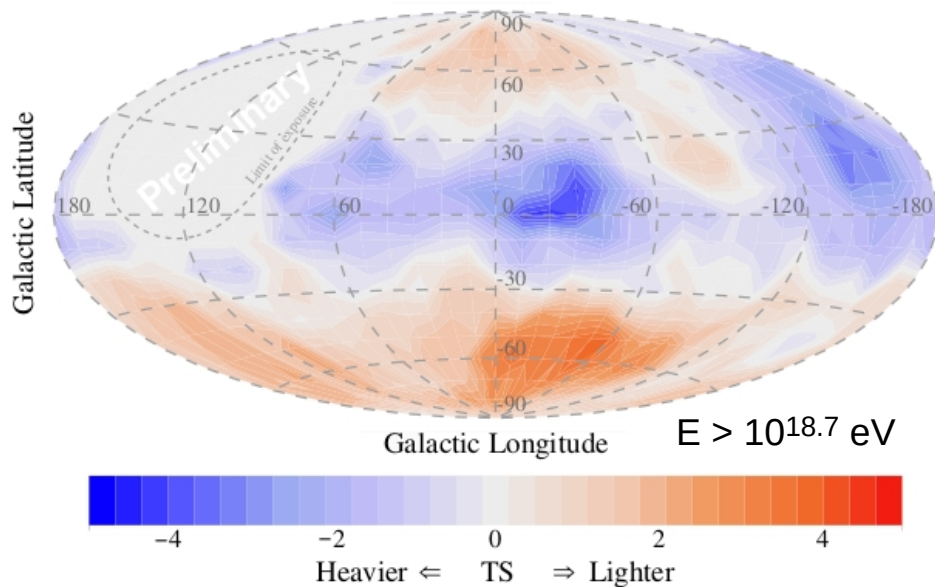


- ▶ Five different measurements with a common energy scale
- ▶ IIHE contributed to two SD spectra (in filled red)
- ▶ Very good agreement between the measurements

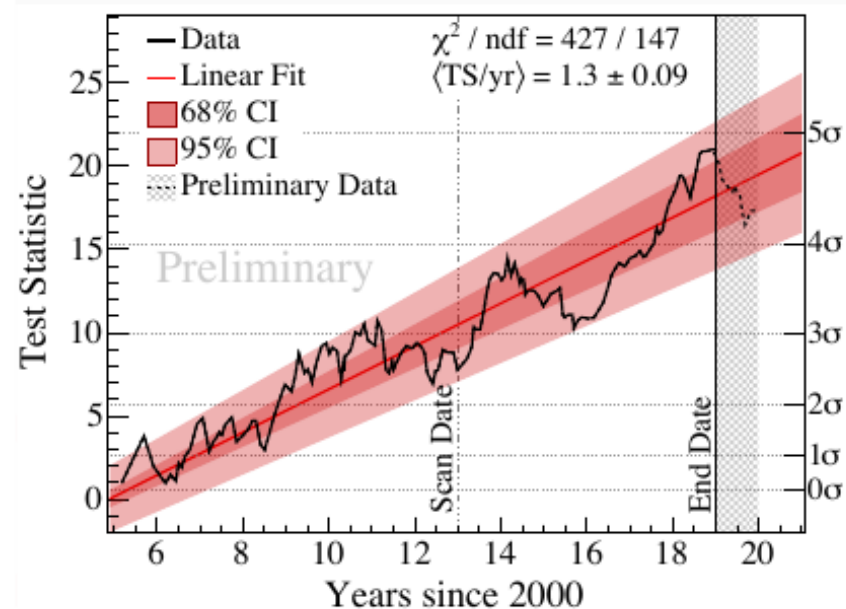
Presence of the second knee and a new feature:
the instep

Highlight analysis: composition distribution over the sky

Difference between mean X_{\max} on and off the Galactic plane?



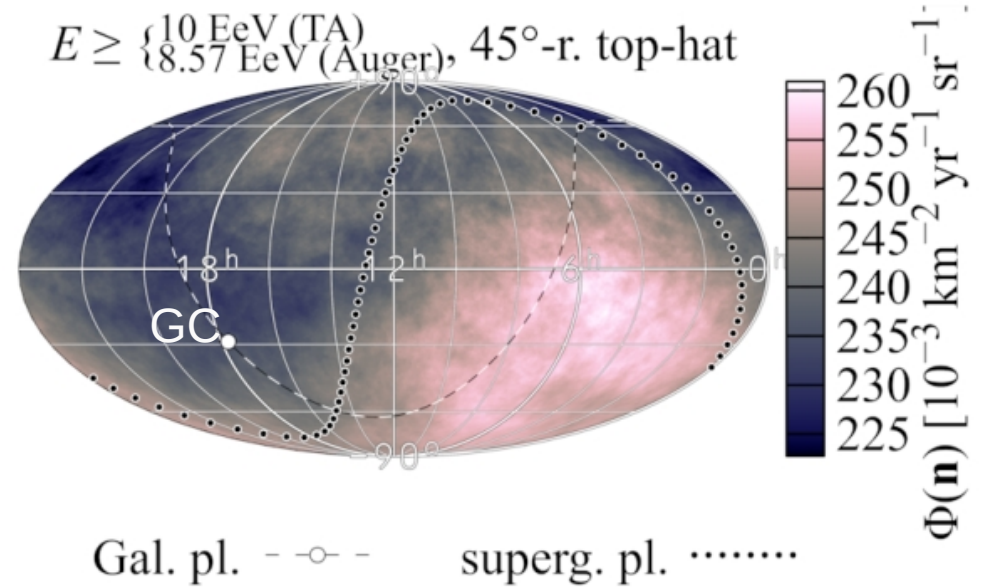
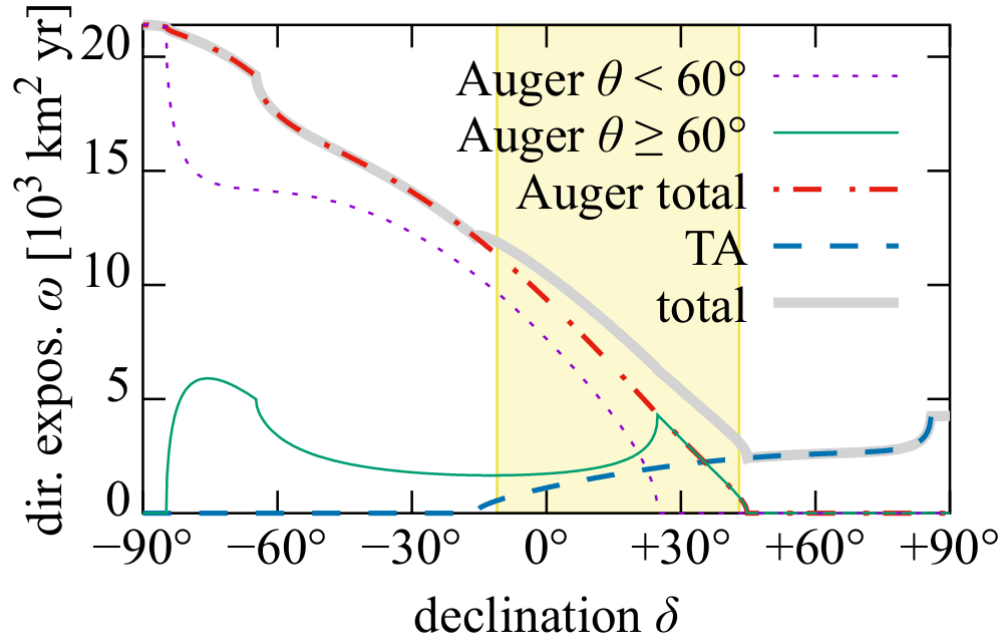
On-plane: $|b| < 30^\circ$
Off-plane: otherwise



- ▶ Source directions? (extra)-Galactic magnetic fields?
- ▶ **Still a hint (3.3 σ after accounting for systematics).** Need more data and/or sensitivity for confirmation

Highlight analysis: joint analysis between Auger & TA

ICRC21 308 (2021)
ICRC21 335 (2021)
ICRC21 375 (2021)



- ▶ Large-scale anisotropy with **full-sky coverage** (coll. with Peter Tinyakov)
- ▶ Cross-calibration of energy scales

- ▶ Better resolution of the dipole direction including TA
- ▶ Direction opposite to Galactic Center → **evidence of extragalactic origin**

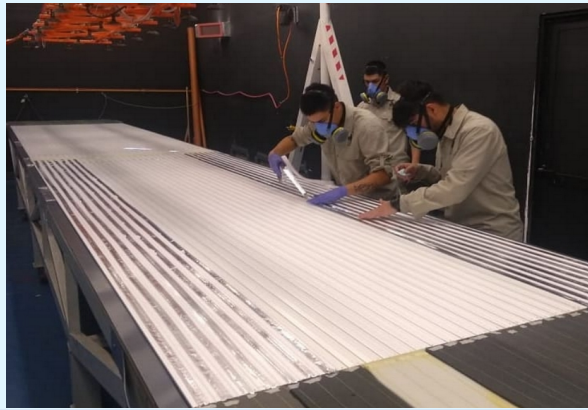
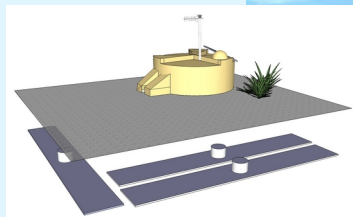


The Pierre Auger Upgrade - AugerPrime

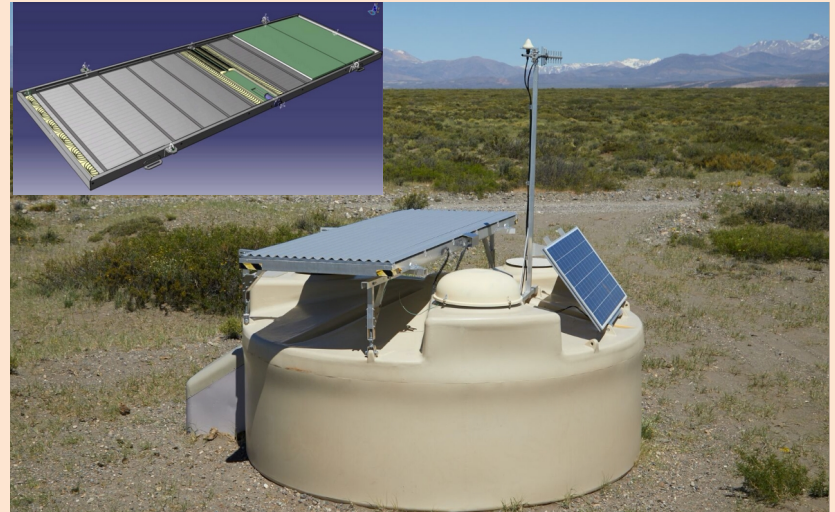
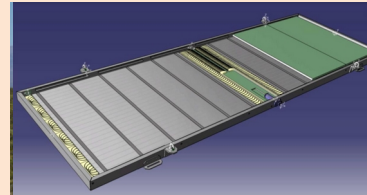
Aiming at a better separation between em and muonic air-shower components

- ▶ Improved mass composition sensitivity
- ▶ Particle physics with air-showers
- ▶ Ultra-high energy proton astronomy

Underground muon detectors (UMD)
30 m² plastic scintillators



Surface scintillation detectors (SSD)
3.8 m² plastic scintillators



+ improved SD electronics, radio antennas, etc

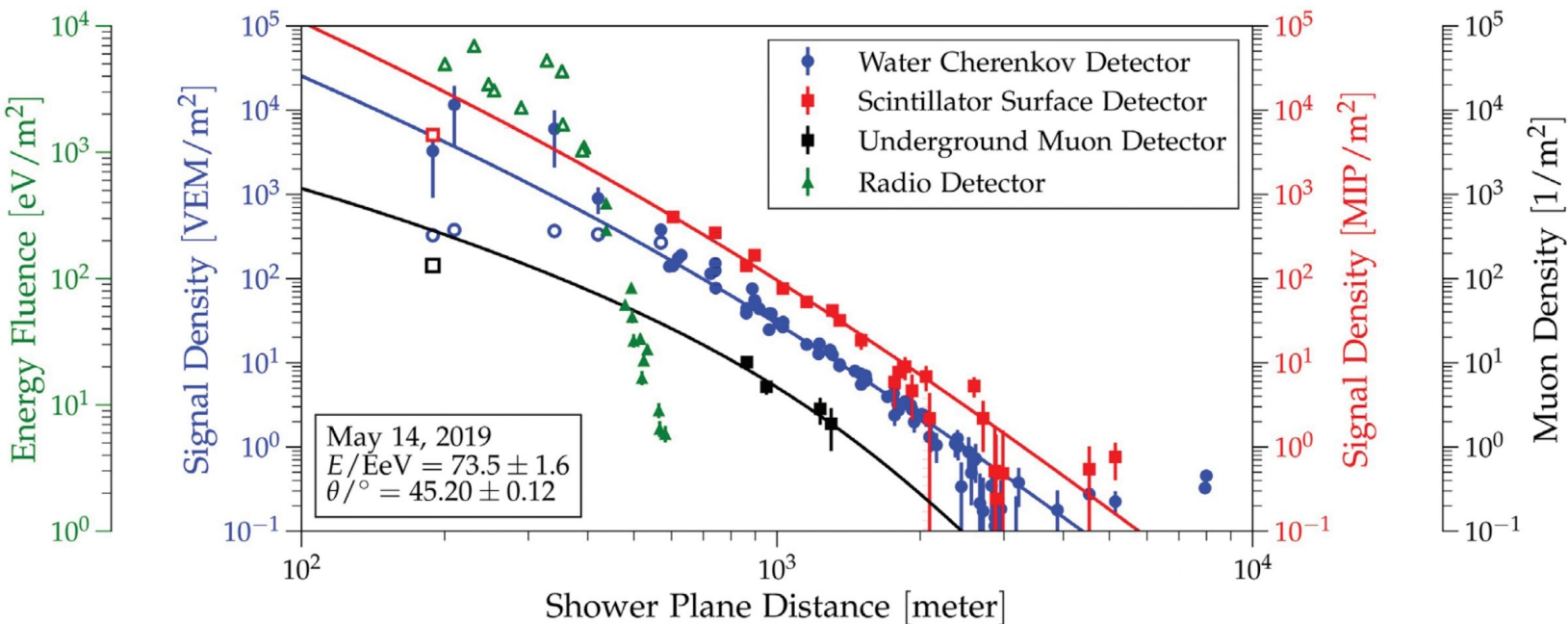
The Pierre Auger Upgrade - AugerPrime

Aiming at a better separation between em and muonic air-shower components

Surface scintillation detectors (SSD)
3.8 m² plastic scintillators

- ▶ Improved
- ▶ Partial
- ▶ Ultra

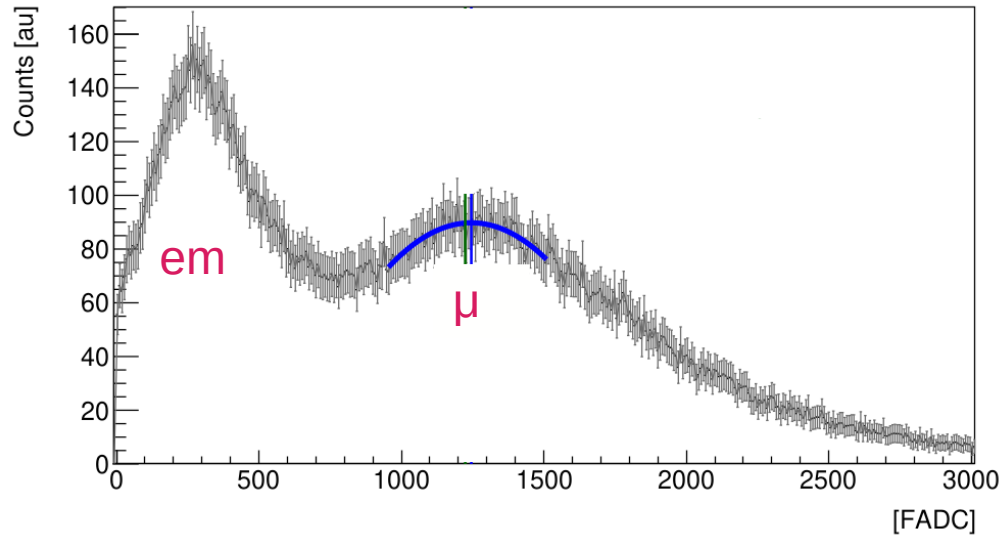
Underground muon detector (UMD)



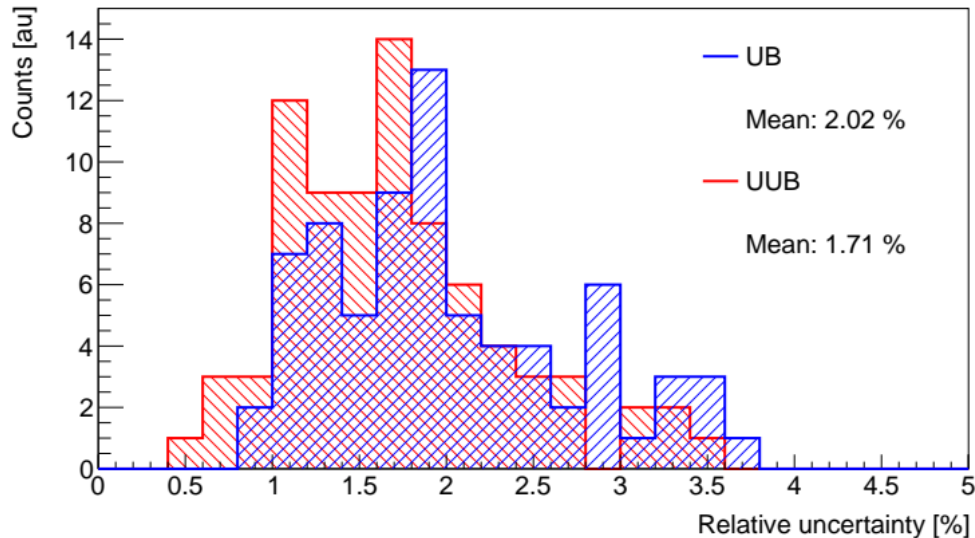
Deployment smoothly during pandemic
(SSD: 1398 installed, 99 remaining; UMD: 27 installed, 46 remaining)

+ improved SD and FD electronics, radio antennas, etc

Calibration of surface detectors

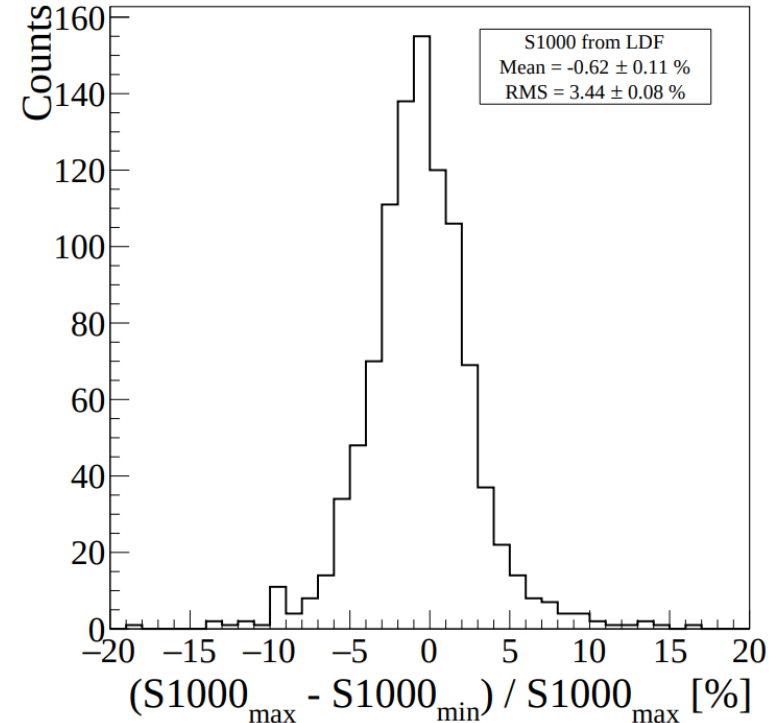
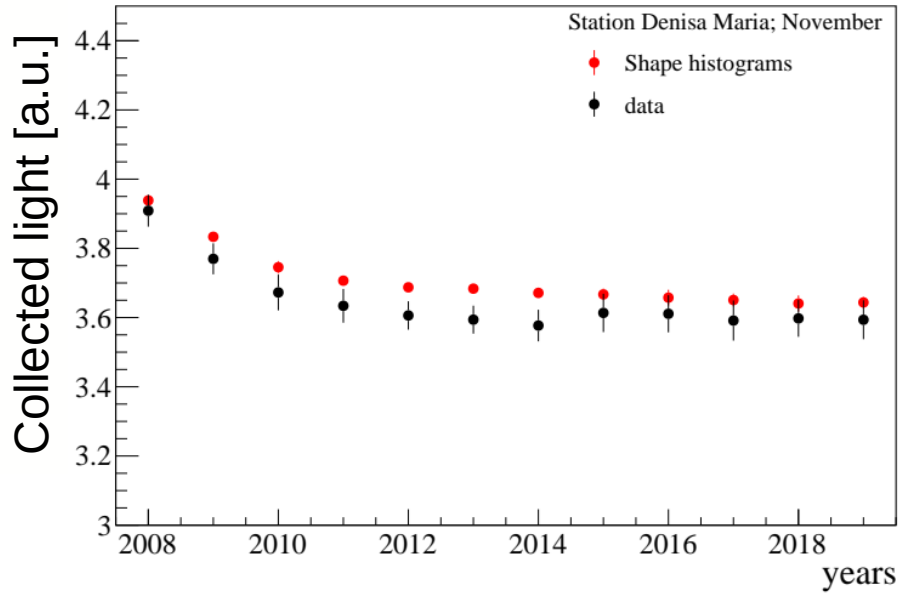


- ▶ Reference signal for SD calibration: [Vertical-Equivalent Muon \(VEM\)](#)
- ▶ Charge histograms of [background data](#) are acquired every minute in each station.
- ▶ Electromagnetic and muonic components are visible.



- ▶ We are developing a [new algorithm](#) to find the muon peak.
- ▶ Slightly better resolution in the muonic peak with the upgraded electronics (UUB)

Long-term performance of surface detectors



Negligible difference in SD energy estimator even in worst case scenario

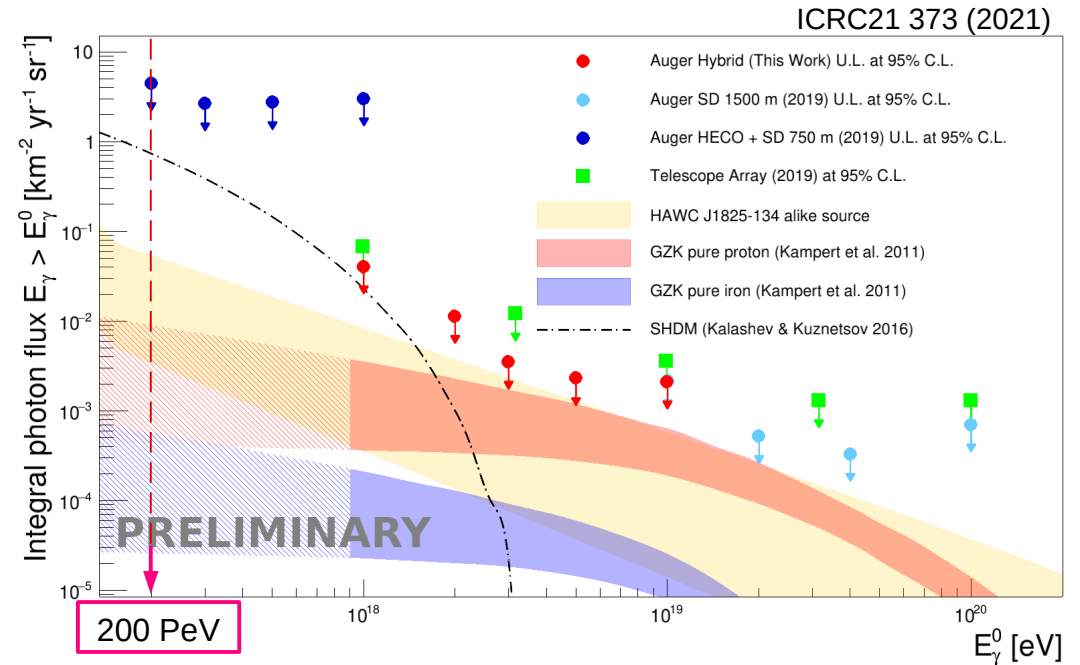
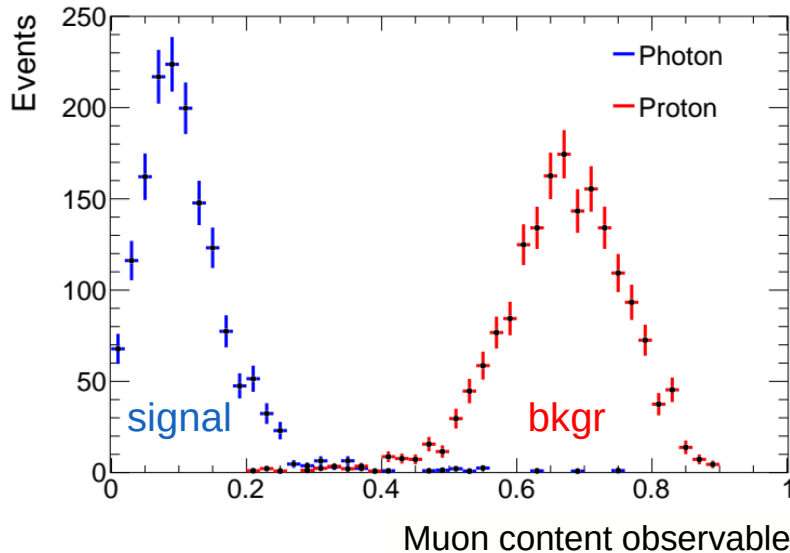
► More than 15 years of operation and expected to run for another decade: **SD response changes over time.**

► Modeling this feature with simulations by changing the **liner reflectivity** within the tank.

► **Goal:** **reducing the systematic uncertainties in SD mass composition estimators** by introducing this time-dependent detector behavior in simulations

Search for ultra-high energy photons in 20-300 PeV energy range

- ▶ Most energetic photons detected by the LHAASO (China) up to 1.4 PeV across 12 sources.
- ▶ 1-100 PeV only explored by northern observatories (e.g. KASCADE-Grande)
- ▶ The Auger Coll. imposed upper limits above 200 PeV, still above theoretical limits
- ▶ Background from charged cosmic rays (specially protons)

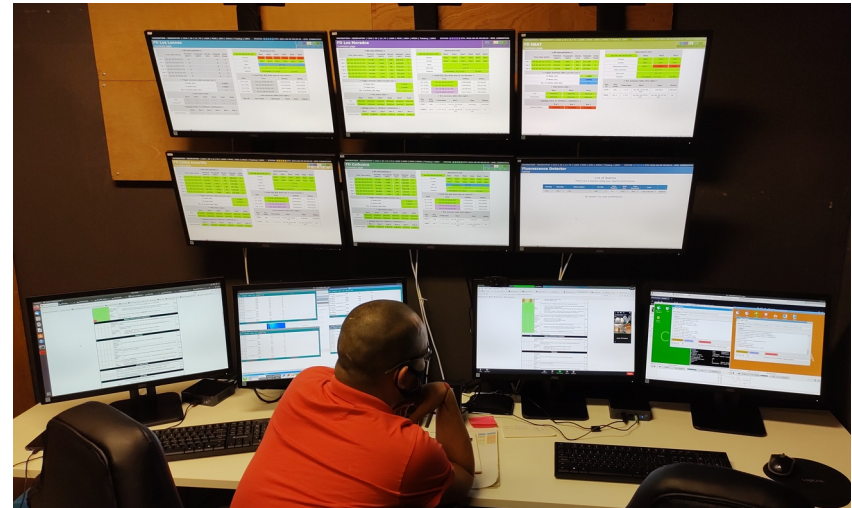
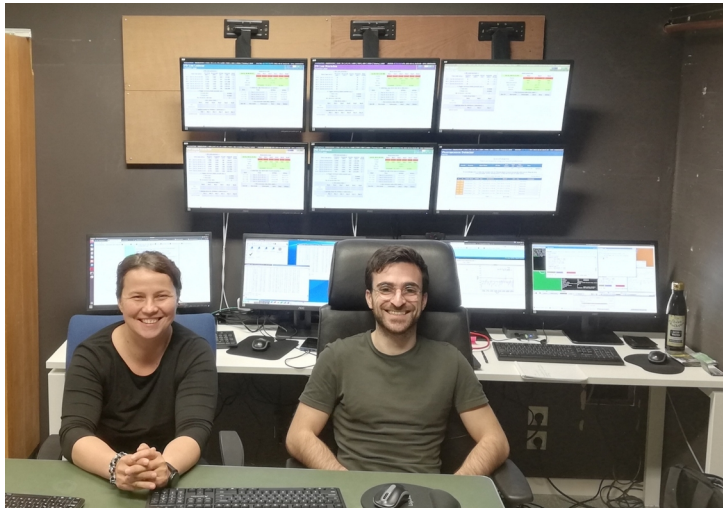


- ▶ **Goal:** photon search including the Underground Muon Detectors

Fluorescence detector control room

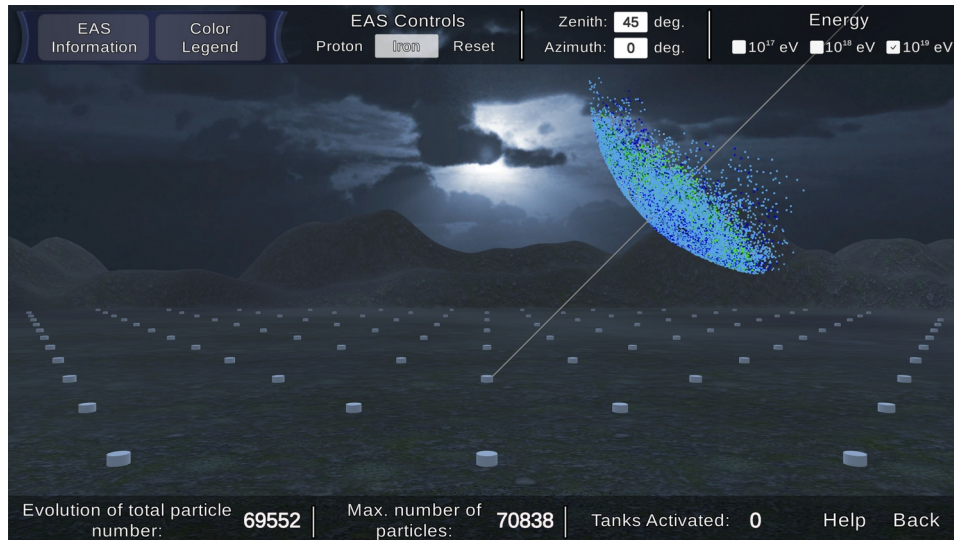


- ▶ FD telescopes require the presence of researchers for their operation.
- ▶ We have installed a remote control room in Brussels with the help from IT, Patrick De Harenne and Michael Korntheuer
- ▶ In June and July, we took care of the telescopes during **looong** nights (5 to 8 hours).

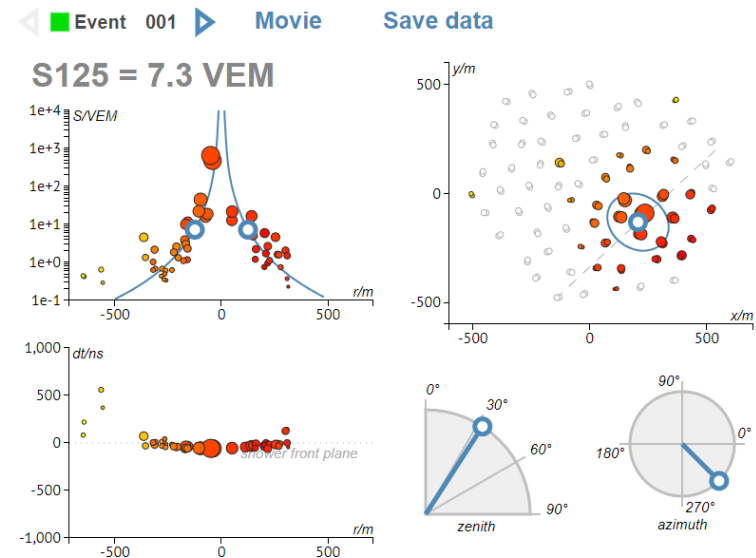


Astroparticle Physics Masterclass

- ▶ Fully online, directed to high-school students
- ▶ Cosmic rays included in plenary talks by Nick and Juanan
- ▶ Two activities using IceCube and Pierre Auger surface detectors



Pierre Auger Coll.



IceCube Coll.

Other activities

- ▶ Trip to Profondeville, a bit south of Namur. Forest, countryside and the Meuse river.
- ▶ Challenging colleagues with bowling session >:-D
- ▶ Organization and participation in 11th CosPa: Astrophysics and Astroparticle Physics in Belgium



<https://indico.ihe.ac.be/event/1533/>





Interdisciplinary
science



Backup

The Pierre Auger Observatory



Pierre Auger Observatory
Province Mendoza, Argentina



Underground muon detectors (24+)



Radio antenna array
(153 antennas, 17 km²)



Sub-array of 750 m
(63 stations, 23.4 km²)



LIDARs and laser facilities



High elevation telescopes (3)



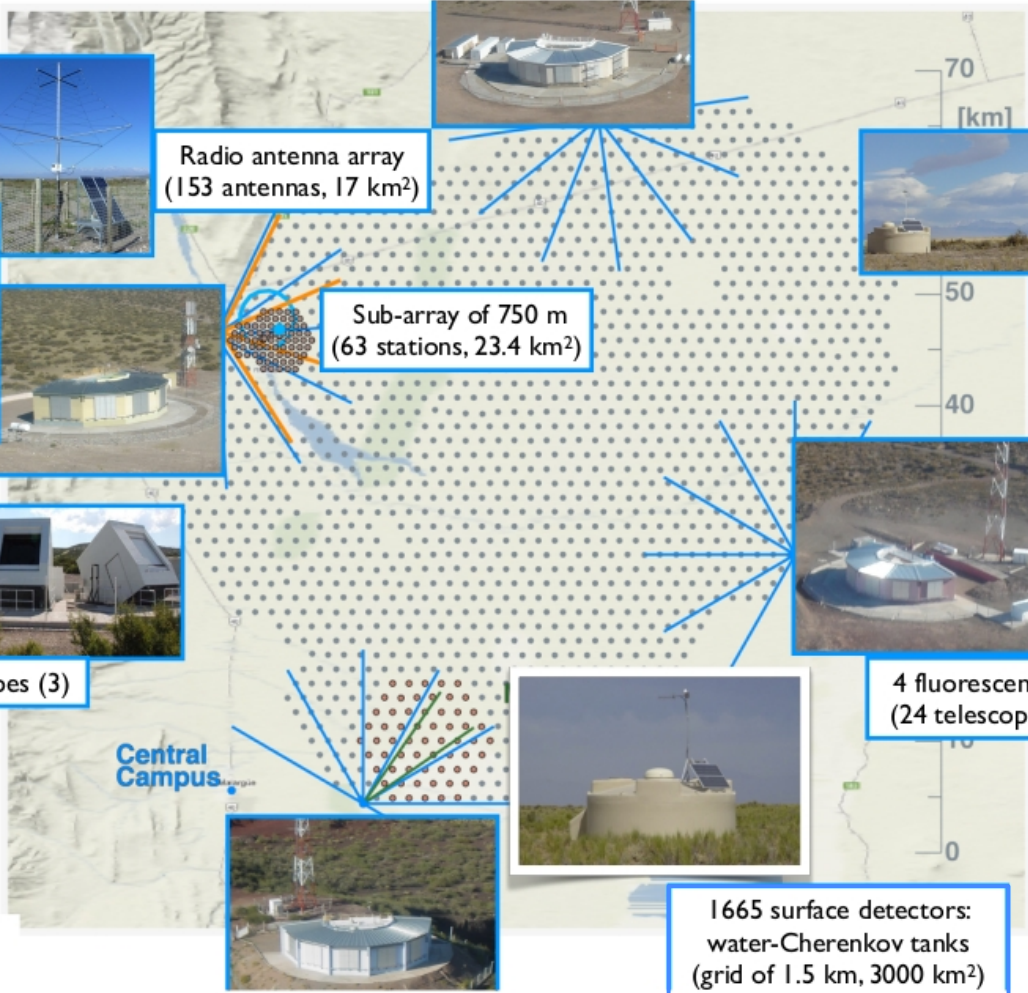
4 fluorescence detectors
(24 telescopes up to 30°)



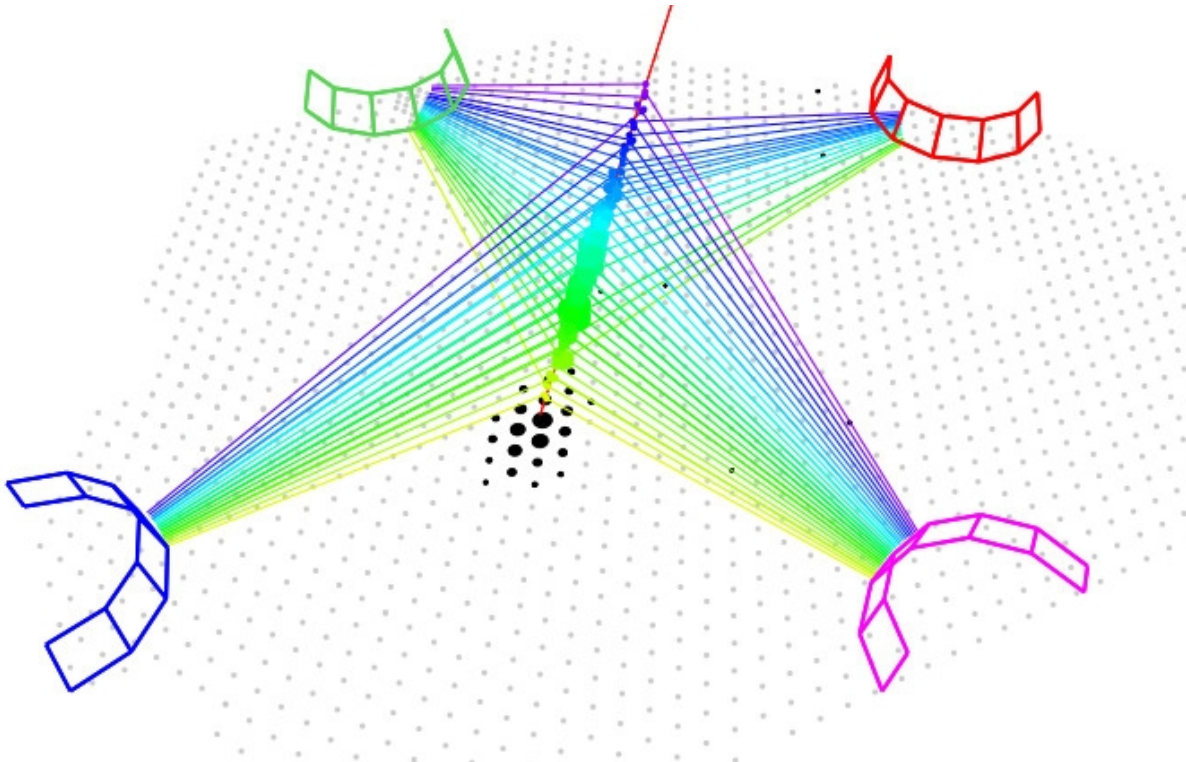
1665 surface detectors:
water-Cherenkov tanks
(grid of 1.5 km, 3000 km²)

Water-Cherenkov
detectors and
Fluorescence
telescopes

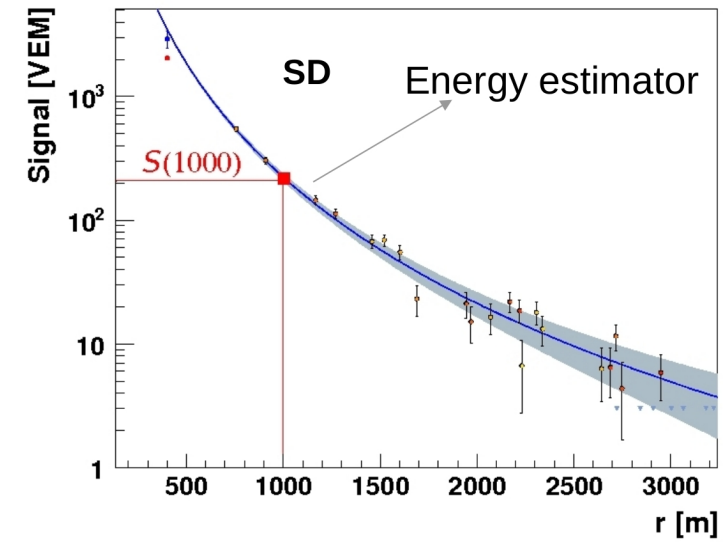
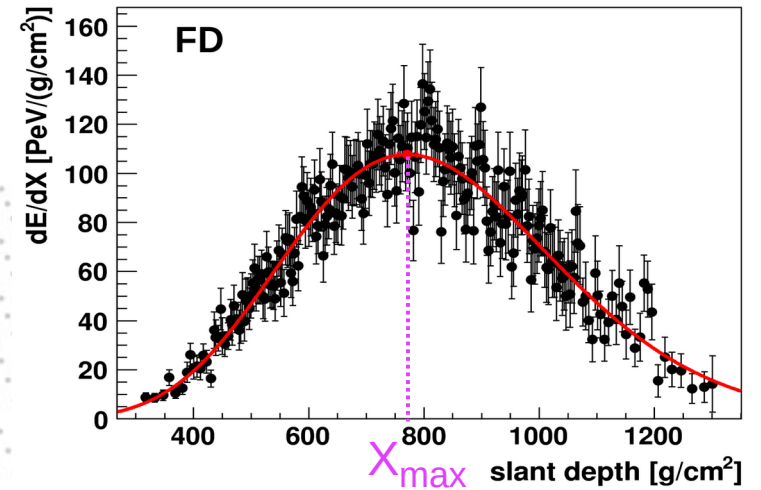
More than 400 members,
98 institutes, 17 countries



Hybrid detection of air-showers

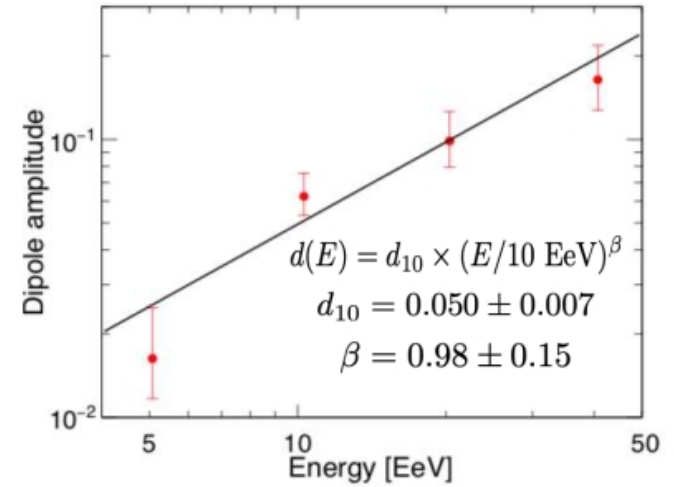
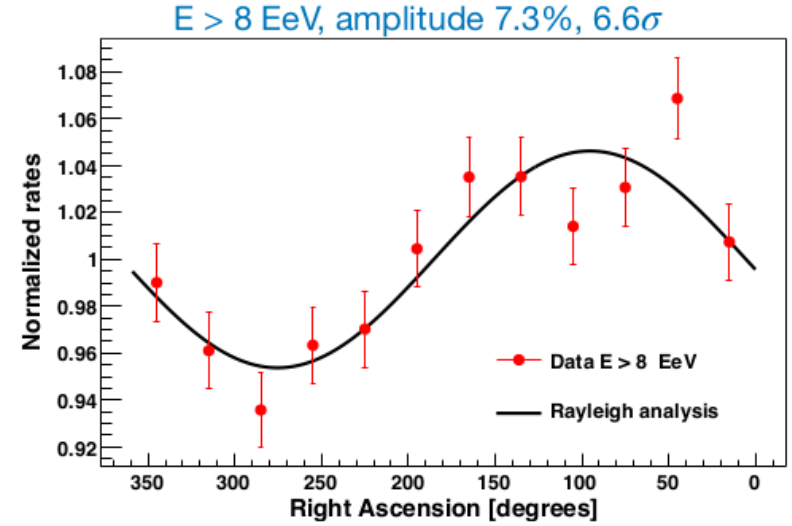
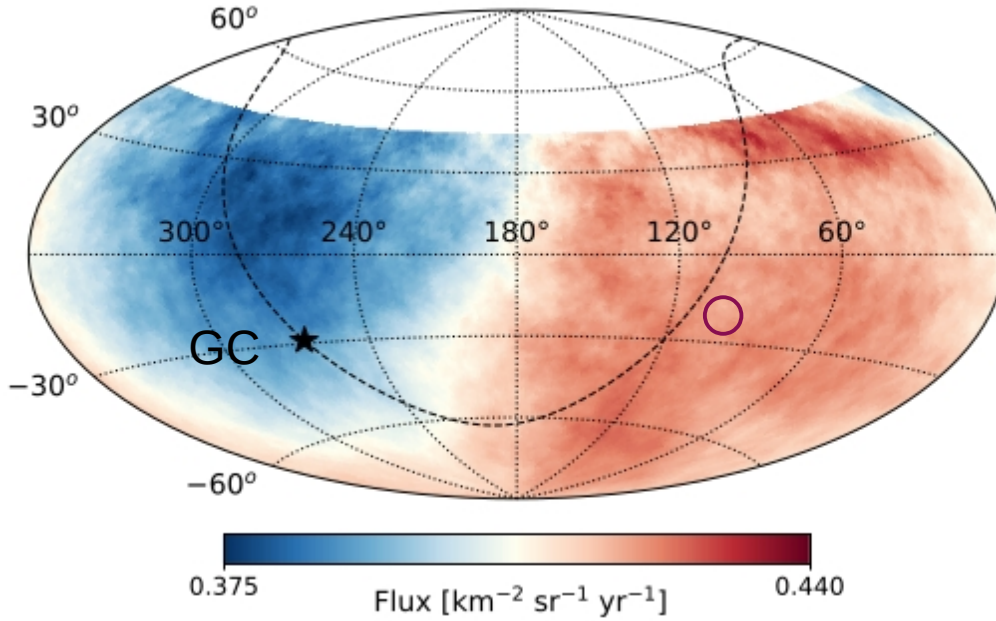


- ▶ Primary energy from the FD measurements
- ▶ Maximum of shower development X_{\max} is sensitive to the primary mass composition
- ▶ SD energy estimator calibrated against FD → SD-only reconstruction



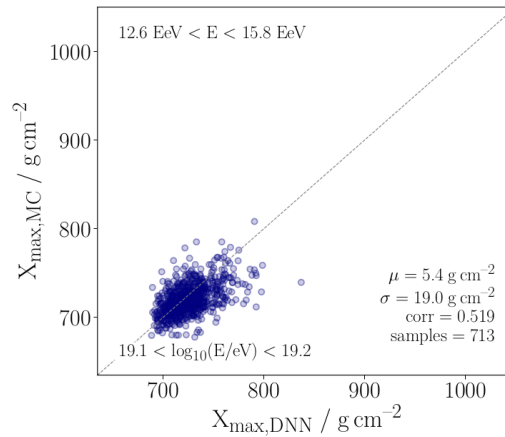
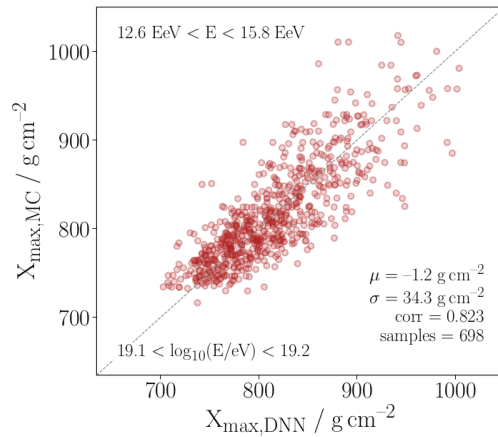
Highlight analysis: large-scale anisotropy

Auger-only analysis

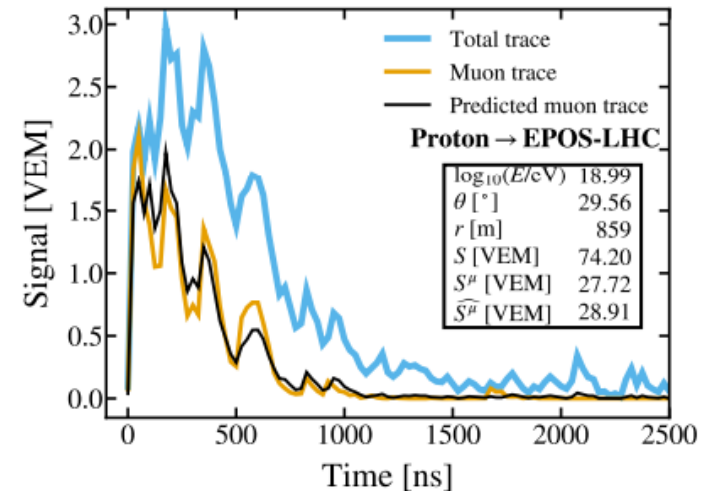
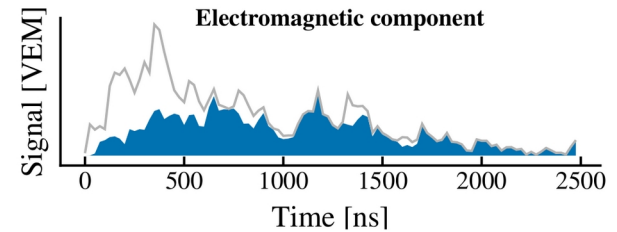
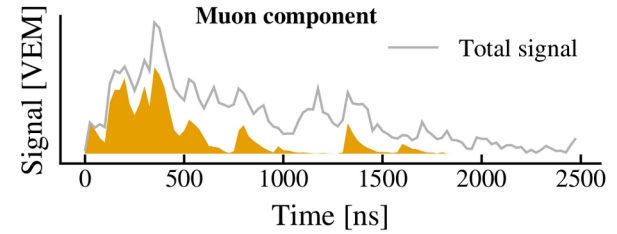


Outlook: Neural networks with AugerPrime

- ▶ Deep learning starting to be applied to Auger data
- ▶ Encouraging results with simulations regarding the longitudinal development of the shower and the SD trace disentanglement
- ▶ **Goal:** Muon content by neural networks exploiting SD + SSD information



The Pierre Auger Coll., JINST 16 P07019 2021



The Pierre Auger Coll., JINST 16 P07016 2021