The AugerPrime upgrade of the Pierre Auger Observatory

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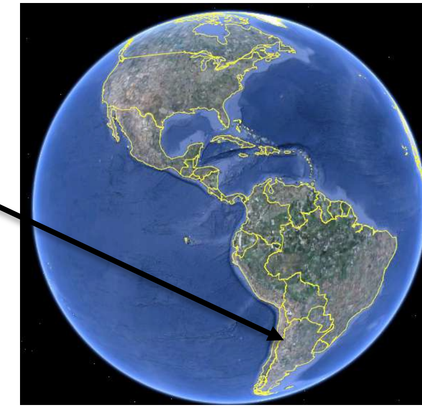
Outline

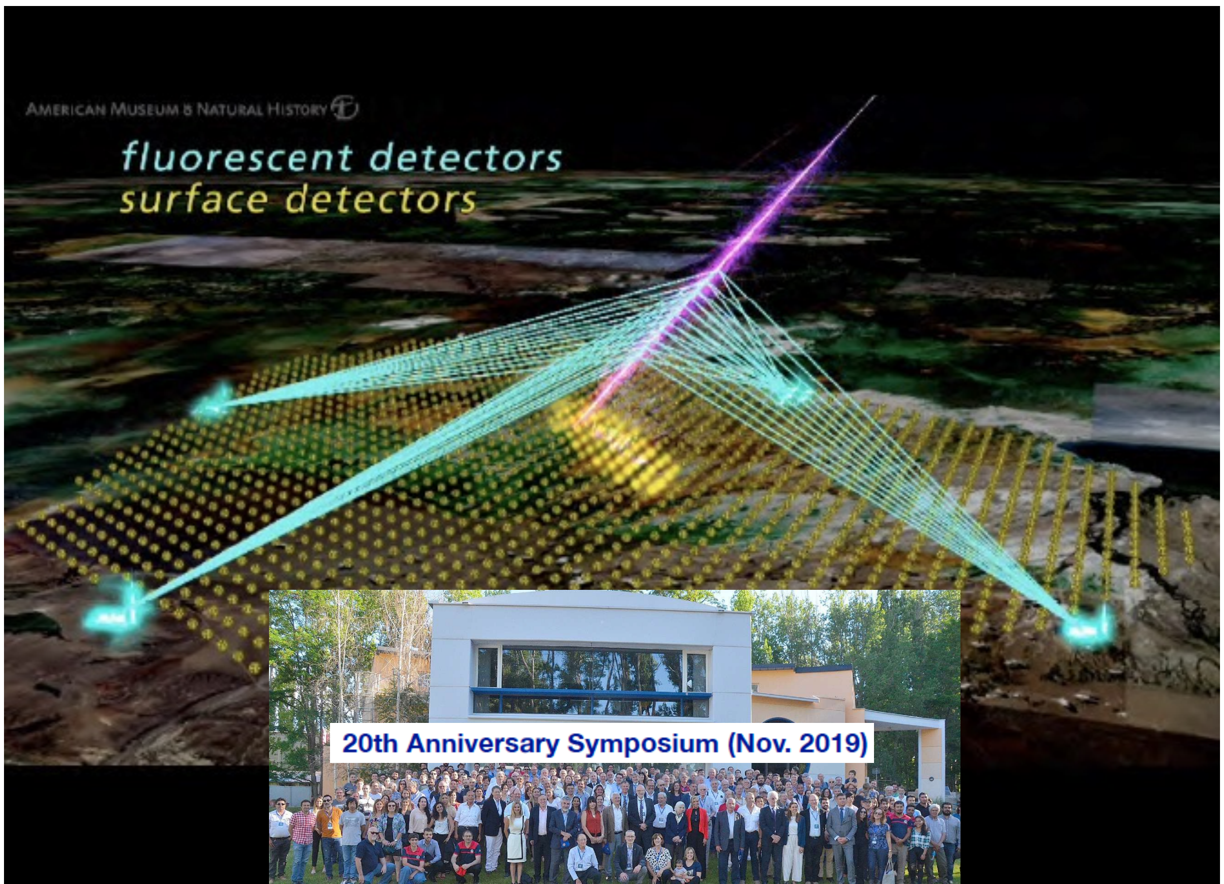
- The Pierre Auger Observatory
- AugerPrime physics goal
- AugerPrime components and design
- Performances
- Status of deployment
- Conclusions

The Pierre Auger Observatory

Pampa area at 1400 m altitude
Province Mendoza, Argentina



Hybrid measurement:
Surface detector array (SD) + Air fluorescence detectors (FD)



After 20 years, both SD and FD still operating with good performance.

Communication and power system running fine.

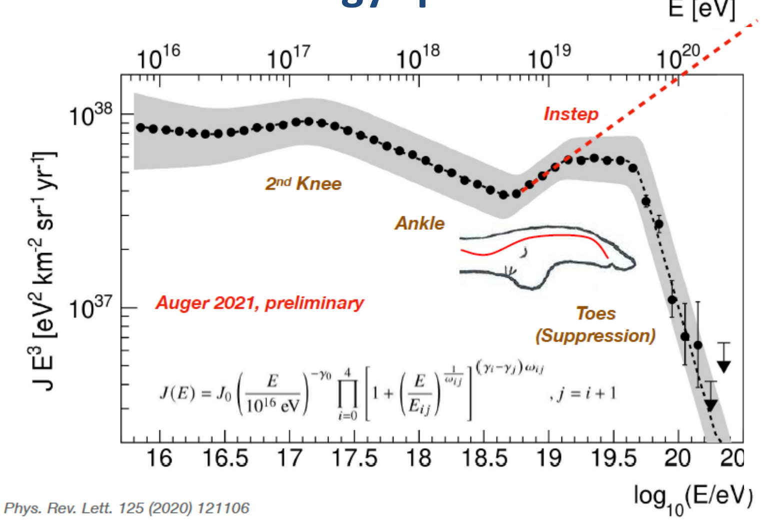
Good/necessary conditions for AugerPrime upgrade.

AugerPrime physics goal

Auger Phase I: Exposure 80,000 km^2 sr yr (vertical, highest quality)

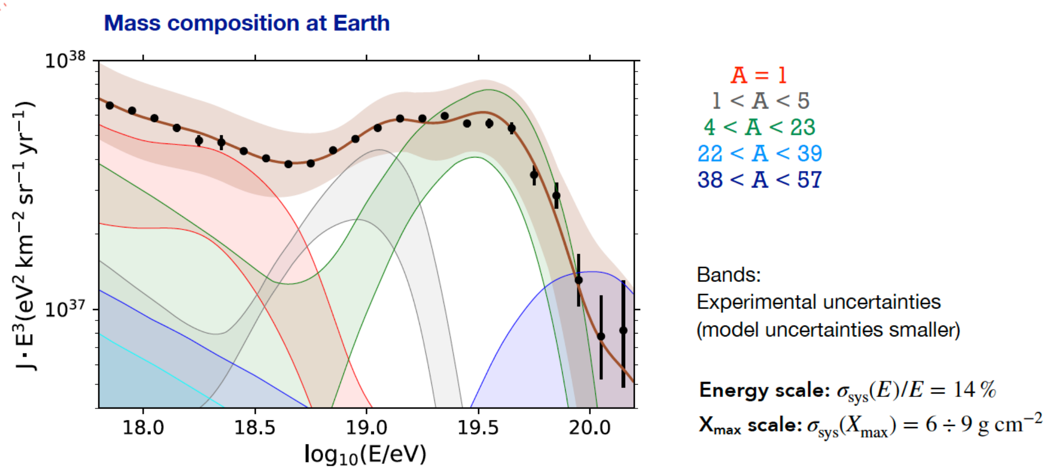
Several important results: energy spectrum, composition, anisotropies, limits for photons and neutrinos (see talk by O. Deligny)

Combined energy spectrum



Phys. Rev. Lett. 125 (2020) 121106
Phys. Rev. D102 (2020) 062005

Interpretation of flux and composition data



Flux suppression by factor of 100 observed
Unexpected feature of instep (inflection point) at 1.4x10^{19} eV

Flux suppression superposition of injection maximum energy and propagation losses

AugerPrime: composition measurement up to 10^{20} eV

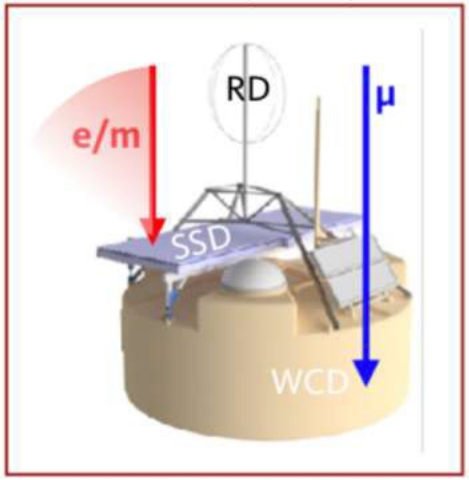
- Elucidate the mass composition and the origin of the flux suppression
- Composition selected anisotropy studies
- Much better understanding of new and old data

AugerPrime components and design

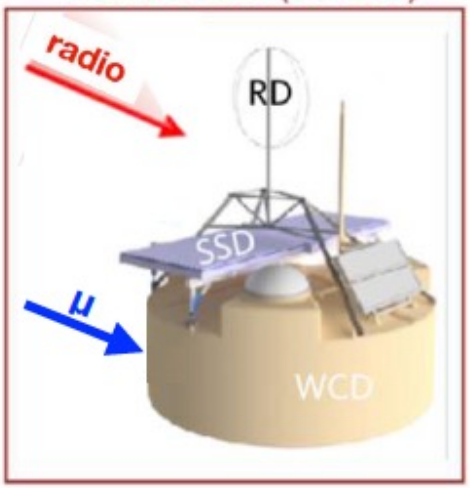
Components of AugerPrime

- A complementary measurement of the shower particles provided by a plastic scintillator plane (SSD) above the existing Water-Cherenkov Detectors (WCD)
- Additional Small PMT (SPMT) to increase the dynamic range of WCD
- New electronics that will process both WCD and SSD signals
- Radio Detector (RD) array for horizontal showers
- Underground Muon Detectors (UMD) for direct measurement of the shower muon content and its time structure (23 km^2 infill area)

VERTICAL (0-60°)



HORIZONTAL (60-90°)

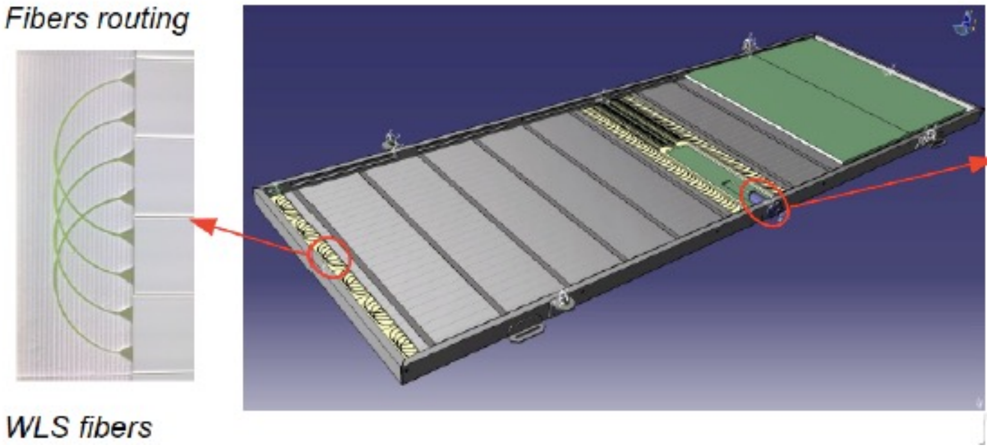


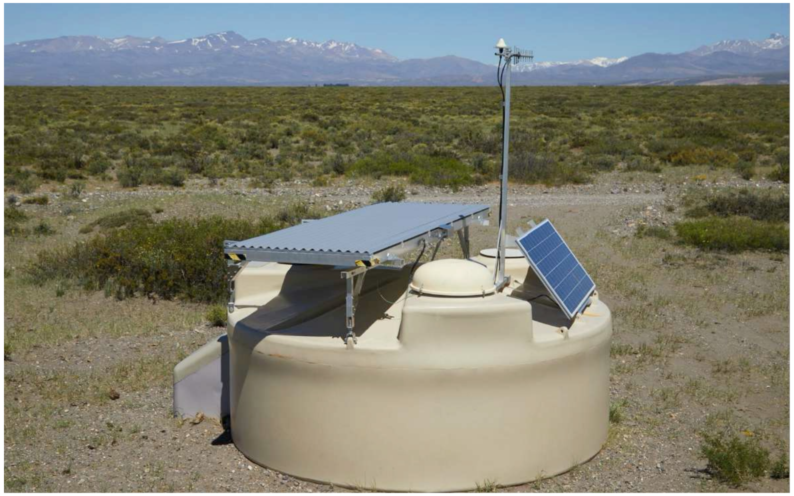
Auger Observatory Phase II

- Data taking 2022/23 – 2030
- AugerPrime (8 years, $\theta < 60^\circ$):
  40,000 km^2 sr yr (Phase II),
  80,000 km^2 sr yr (Phase I)
- Re-analysis of old data set (deep learning)

AugerPrime design report 1604.03637

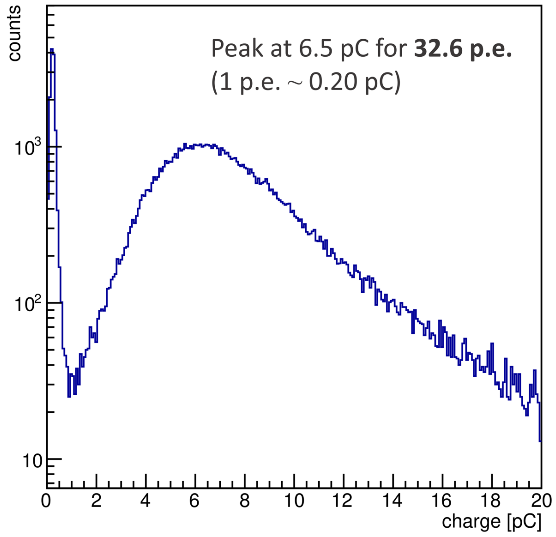
Scintillator detector





- Extruded scintillator bars (1600x50x10 mm)
- WLS fibers (Kuraray 1 mm), two per scintillator bar
- Two modules in one box per station, area about 4 m^2
- Readout by PMT (Hamamatsu R9420)
- Simple and robust construction with double roof for thermal insulation

Charge distribution measured for atmospheric muons
Minimum Ionizating Particle MIP = 30 p.e.

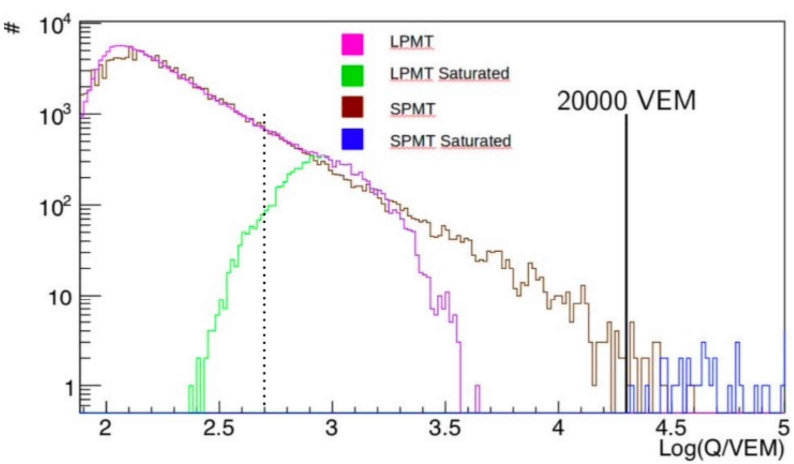


WCD and electronics

Increased WCD dynamic range by adding 1'' PMT (SPMT, Hamamatsu R8619) to the three 9" PMTs (Photonis XP1805) of the WCD.

WCD is calibrated by Vertical Equal Muons (VEM).

A dedicated selection of small local shower events is exploited to cross-calibrate the SPMT using the VEM-calibrated signals of the WCD PMTs.



Upgraded electronics:

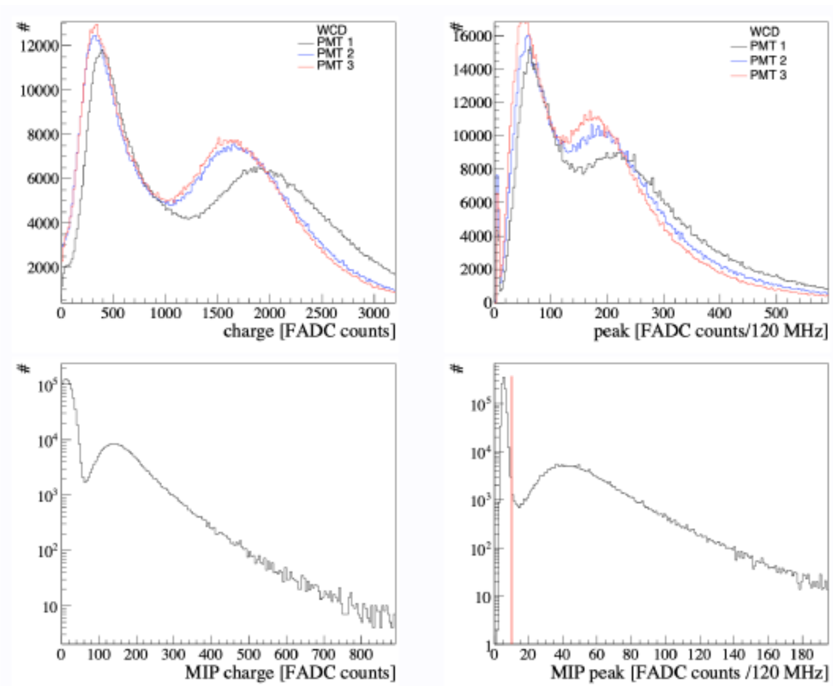
- Processes signals from WCD and SSD
- Interfaces RD and UMD
- Increases the data quality
  - Faster sampling of ADC traces (120 MHz)
  - Better timing accuracy (5 ns with new GPS)
  - Increased dynamic range (12 bits)
- Enhances the local trigger and processing capabilities (with a more powerful local station processor, FPGA Xilinx Zync-7020)
- Backwards compatible trigger allows to merge old and new data.

Upgraded Unified Board

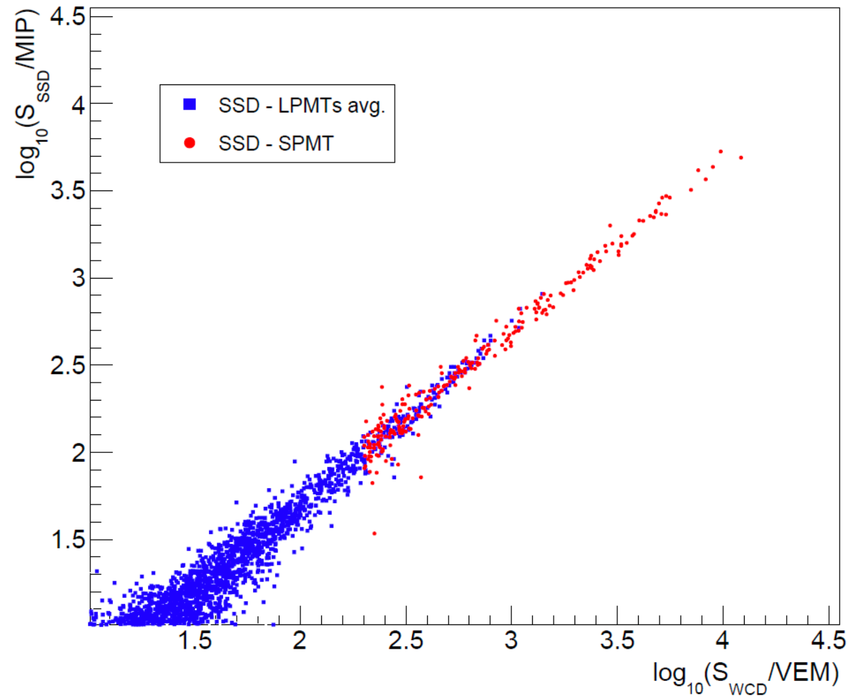
Dynamic range from fractions of VEM to >20000 VEM

Unambiguous determination of the particle density down to 250 m from the shower core

Calibration and dynamic range



ICRC2021, D. Nitz for The Pierre Auger Collaboration



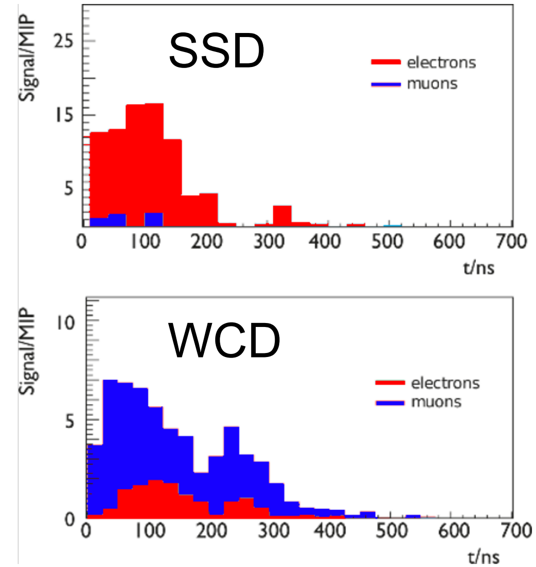
Calibration histograms:
Top - histograms show the muon charge (left) and peak (right) for the three WCD PMTs;
Bottom - The muon charge (left) and peak (right) in the SSD.

- Good correlation between WCD and SSD
- Dynamic range up to 20000 VEM for WCD and 20000 MIP for SDD -> 250m from the shower core

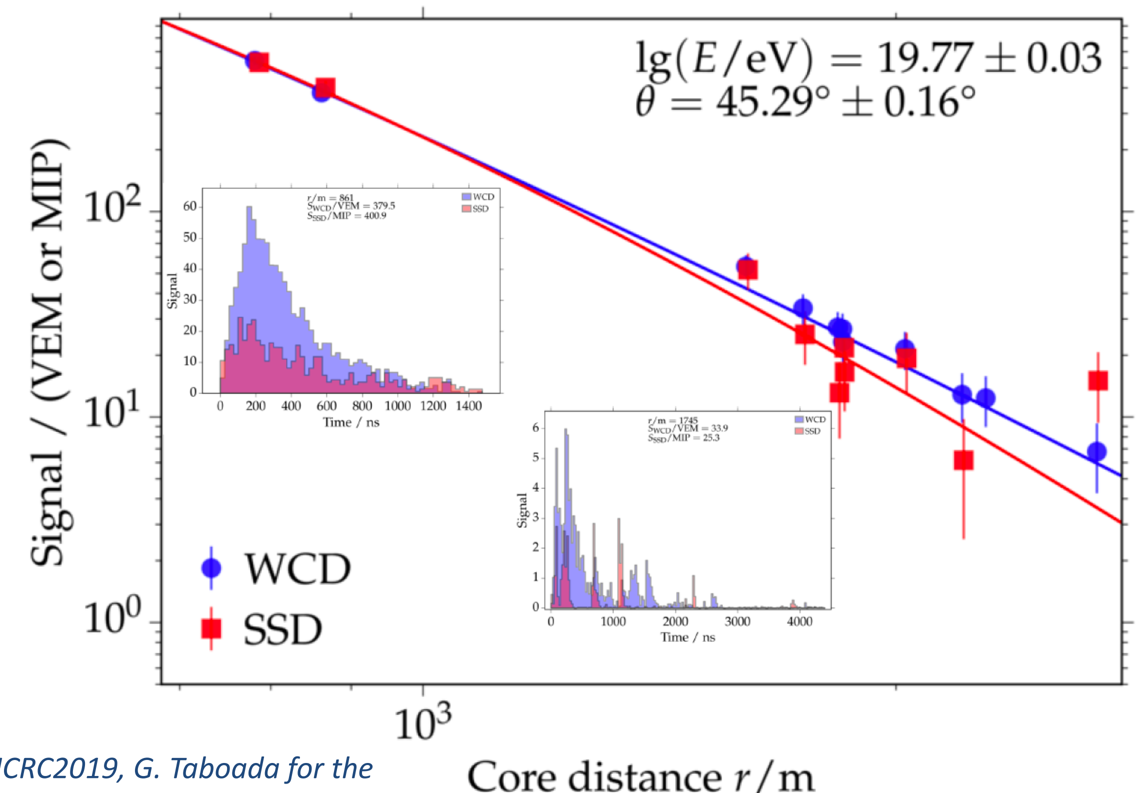
Signals from WCD and SSD

The complementary response of the SSD and the WCD allows us to disentangle the electromagnetic and muonic shower components -> Primary composition

Lateral Distribution Function (LDF):
Signal distribution measured at the ground as function of the distance to the shower core



ICRC2021, G. Cataldi for the Pierre Auger Collaboration

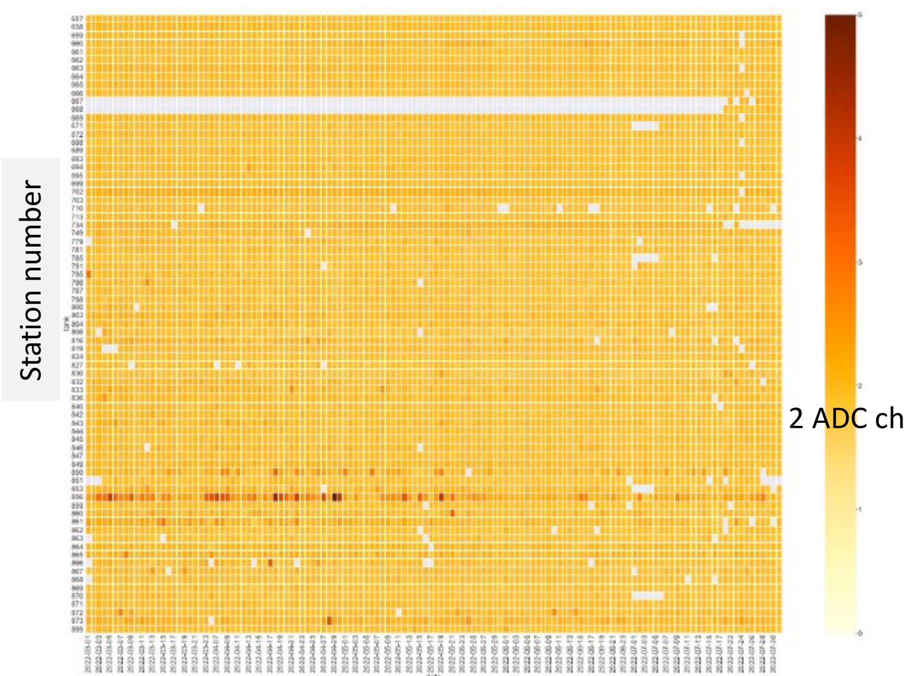


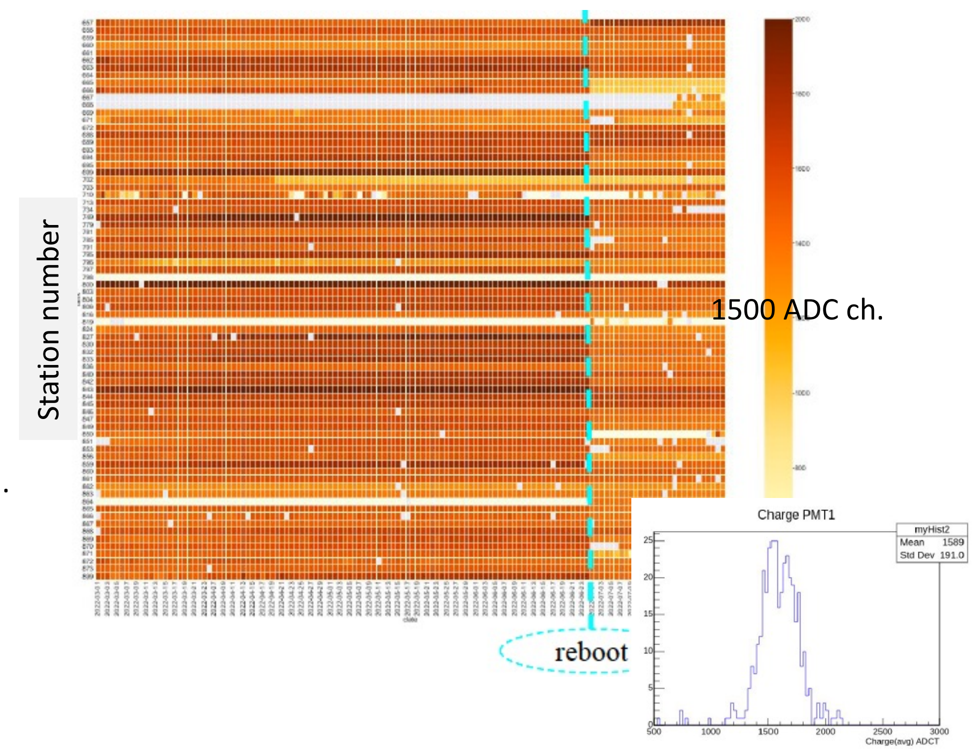
ICRC2019, G. Taboada for the Pierre Auger Collaboration

LDF of SSD has a steeper fall off due to the different response to shower particles.

Performance monitoring: WCD

- Stable and uniform performance for WCD
- Noise levels as expected: < 2 FADC channels (high-gain channel)
- Stable calibration with muons (VEM)
- All triggers running at 40 MHz (backwards compatible)

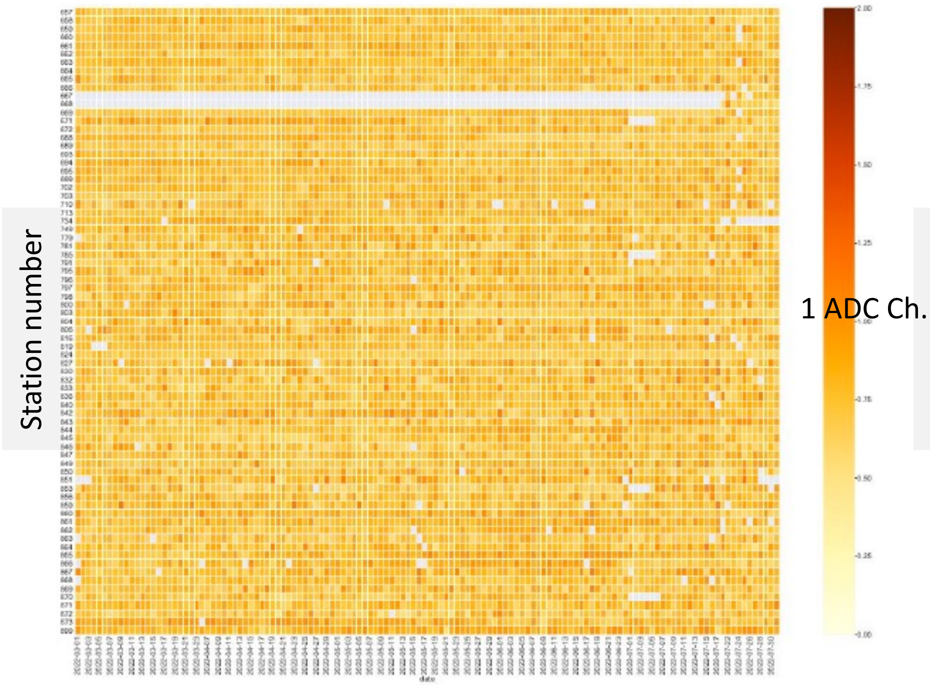


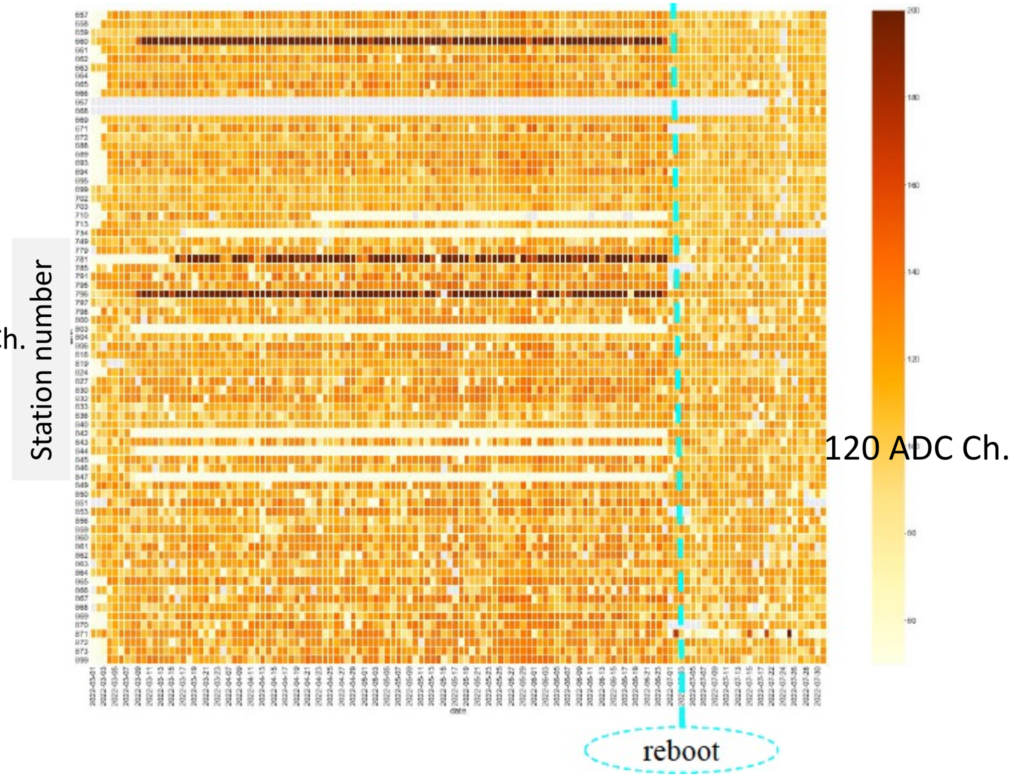


Large PMT1 baseline rms (high gain) and VEM charge, 1 March – 30 July (F. Convenga)

Performance monitoring: SPMT and SSD

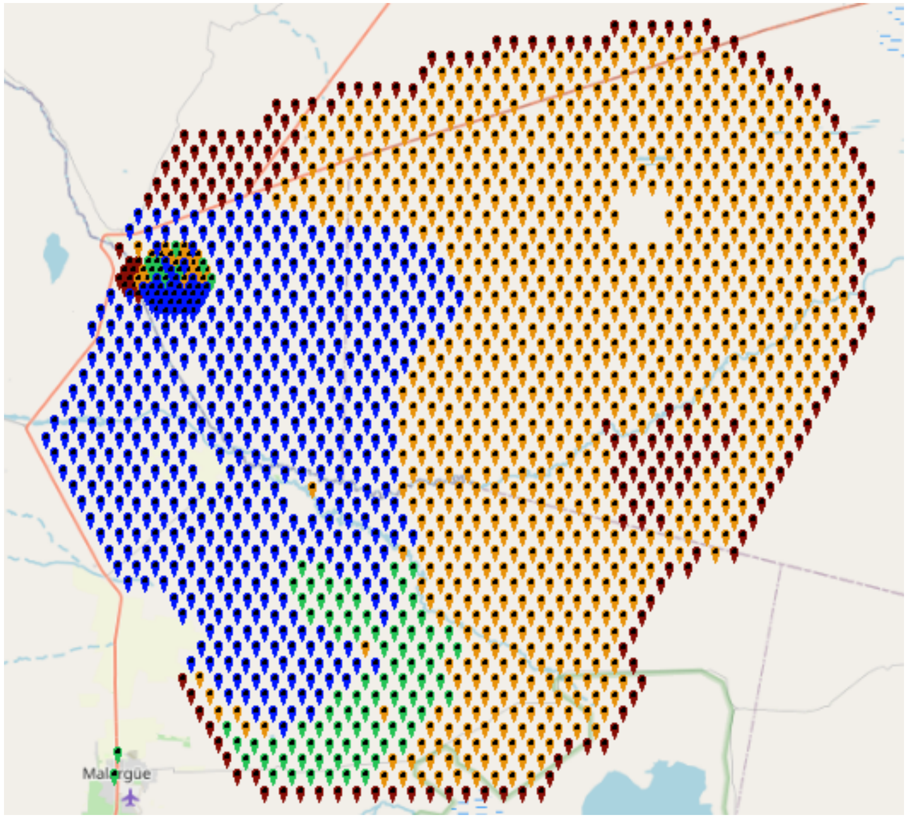
- Stable and uniform performance for SPMT and SSD
- Stable calibration of SSD with muons (MIP), average MIP 120 ADC Ch





SPMT baseline rms and SSD MIP charge, 1 March – 30 July (F. Convenga)

Status of deployment



Upgraded Surface Detector array

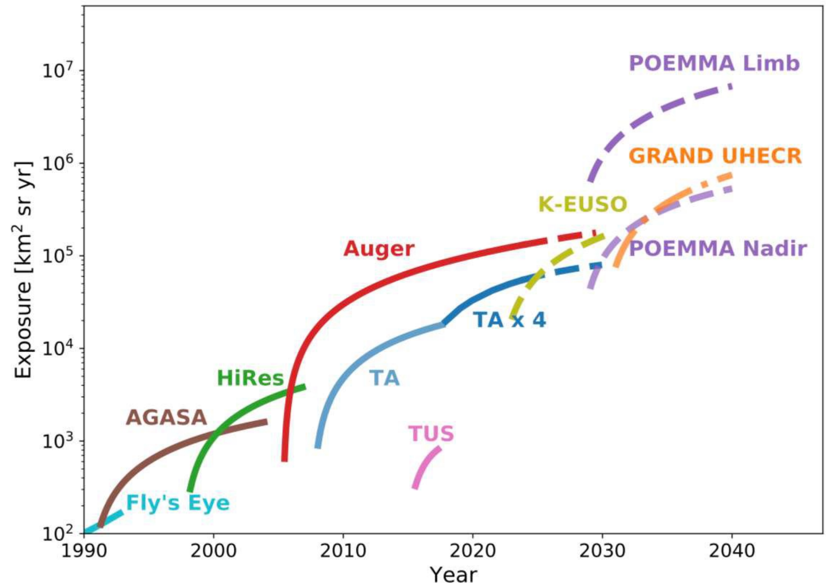
- All SSD detectors already deployed to the field
- 495 detector stations with SPMTs and electronics, 30% of the array (in blue)
- Area in green: deployment planned this month

Production of electronics boards started on March 21 and should be completed on November 22. Deployment will continue up to mid-23.

AugerPrime detector, May 2022

Conclusions

- AugerPrime goal: obtain enhanced composition information
- Deployment in progress, 30% of the upgraded Surface Detector already taking data
- Additional exposure 40,000 km^2 sr yr (vertical) expected, run until 2030
- Radio Detector will complement with horizontal observations
- Underground Muon Detector array also in progress
- Re-analysis of all data planned (Phase I and Phase II)



Exposure of CR experiments (Alves Batista et al, 1903.06714)

Cosmic rays are the primary particles that are produced by cosmic accelerators, their observation is important in the global multi-messenger picture.