With AugerPrime to the Phase 2 of the Pierre Auger Observatory

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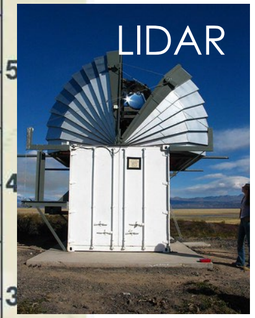
PIERRE AUGER OBSERVATORY

INFN Istituto Nazionale di Fisica Nucleare

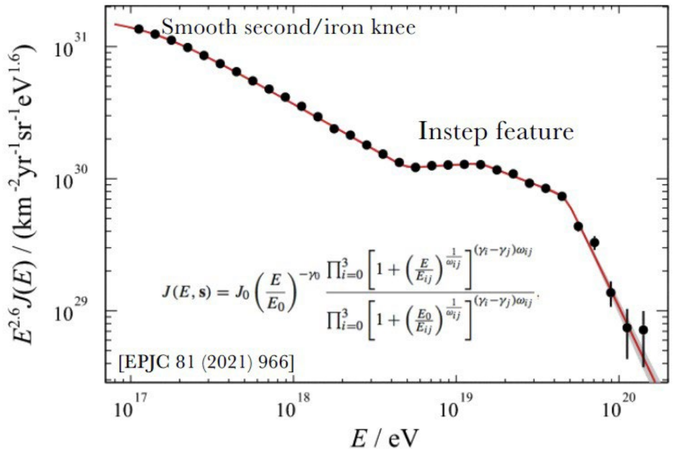
UNIVERSITÀ DEL SALENTO

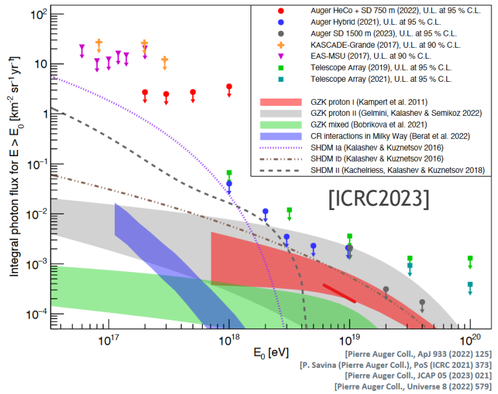
The Pierre Auger Observatory

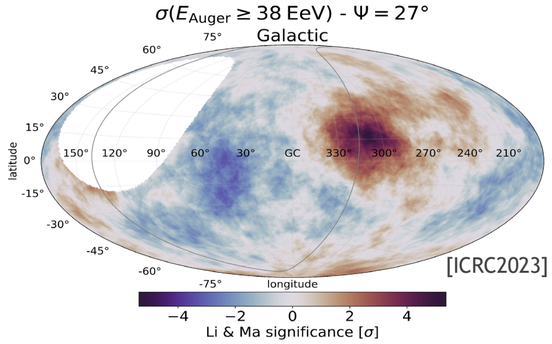
- **The largest cosmic ray observatory, designed as an hybrid detector**
  - **surface detector (SD)** : water Cherenkov detectors (WCD)
    - 1600 on 3000 km^2, 1.5 km spacing
    - 61 additional SD stations « Infill »
      - on 27.56 km^2 with 750 m
      - on 1,95 km^2 with 433m spacing
  - **Fluorescence detector (FD)**: optical telescopes
    - 24 in 4 buildings overlooking SD
    - 3 in 1 building overlooking the denser array
  - **Engineering arrays (infill)**=> multi-hybrid
    - Auger Engineering Radio Array (AERA)
    - Buried muon detectors
  - **Atmosphere measurements** and monitoring



Auger Phase I: Results





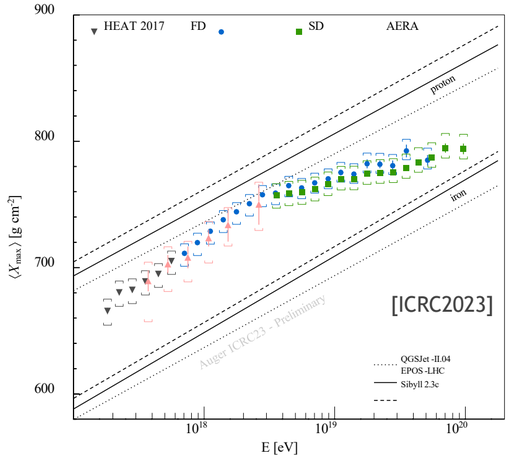


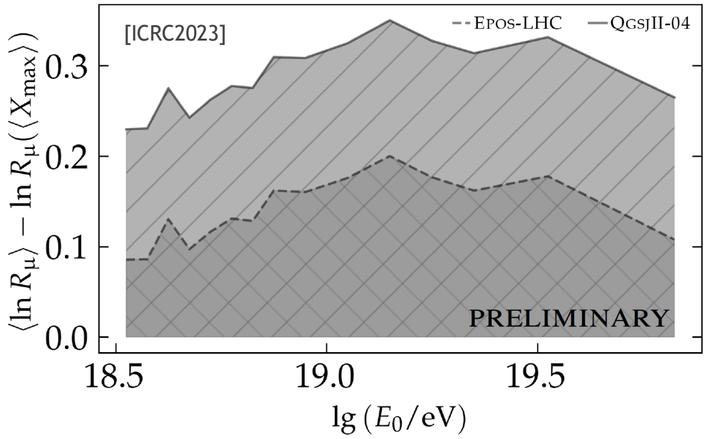
The largest exposure to UHECR
High quality measurements

- **Spectrum**
- **Composition**
- **Anisotropies**
- **Neutral searches and Multi-messenger physics**
- **Hadronic interactions**

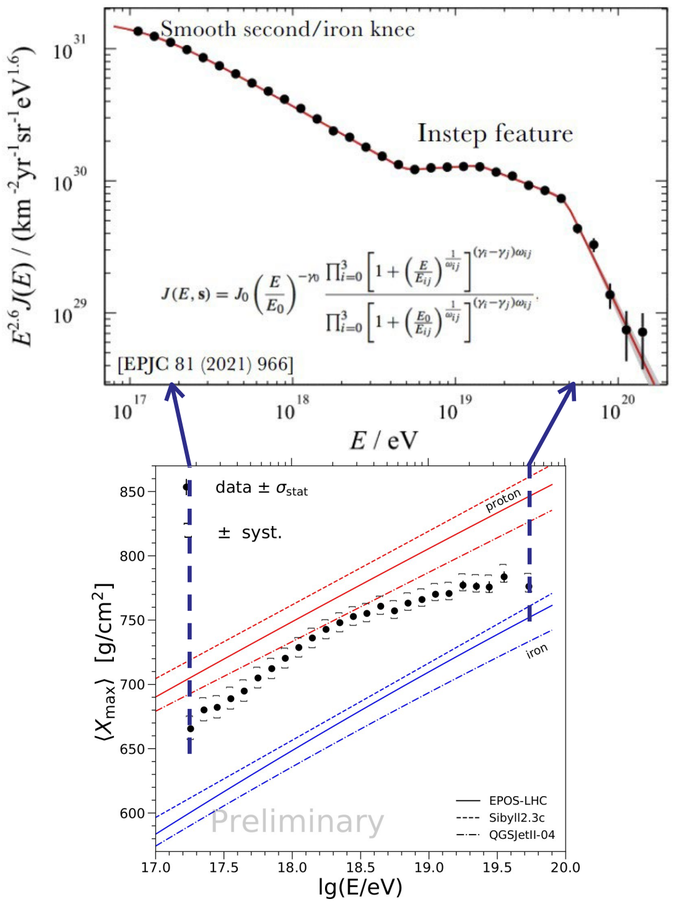
and more …

⇒ **Open questions**





AugerPrime key objectives



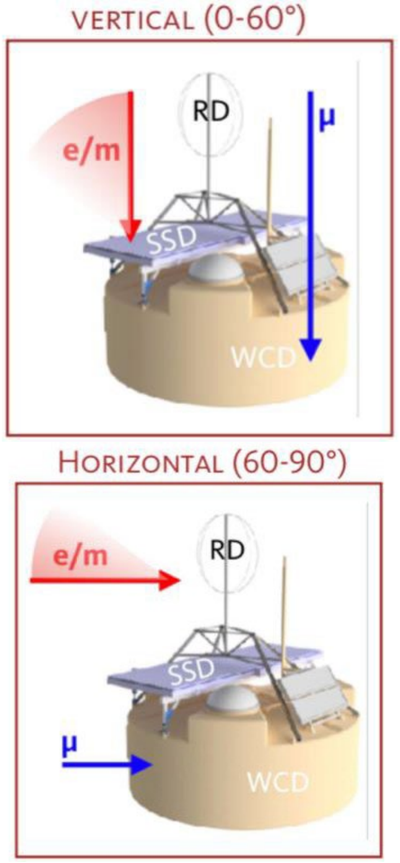
- **Composition measurement to the highest energies**
  - origin of the flux suppression
- **Event-by-event composition**
  - composition enhanced anisotropy studies
  - constraints on UHECR sources
  - particle astronomy?
- **Enhance sensitivity to γ-rays and ν fluxes**
  - exploring the potential of future experiments
- **Study of EAS and hadronic multiparticle production above √s=70 TeV**
  - address the inconsistencies in the muon content predicted/observed
  - particle physics beyond human-made accelerators
  - physics beyond the standard model

Number of muons: quantity that strongly correlates with primary mass.

Upgrade Key point : disentangling the muonic and electromagnetic components of the Extensive Air Showers

The AugerPrime Components

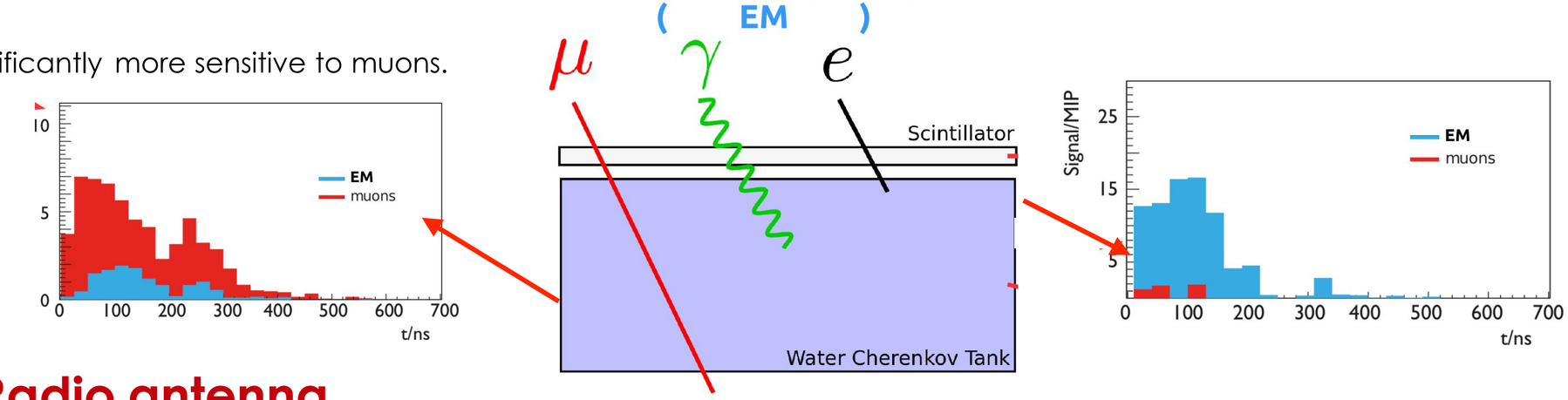
- **Complementary measurement of the shower particles**



→ Adding mass sensitivity to the SD : new detectors above WCD

- **Plastic Scintillator Surface Detectors (SSD)**

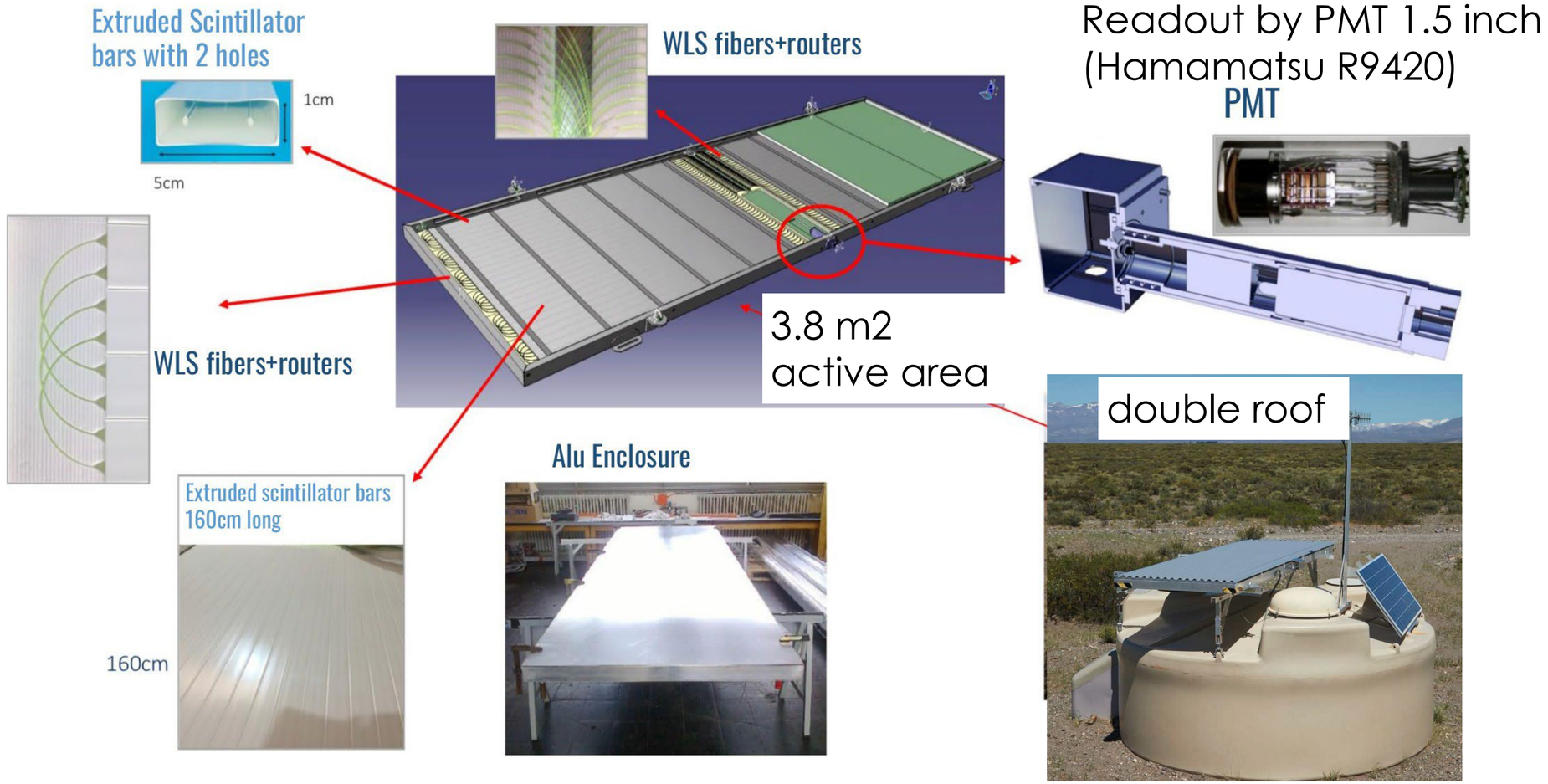
Significantly more sensitive to muons.



- **Radio antenna**
  - to measure the radio emission (30-80 MHz) of inclined showers
- **Additional small PMT in the WCD**
  - to increase the dynamic range
- **Underground Muon Detector (UMD)**
  - to measure N_μ in low energy shower (denser array)
- **New electronics**
  - to process / interface signals from all detectors

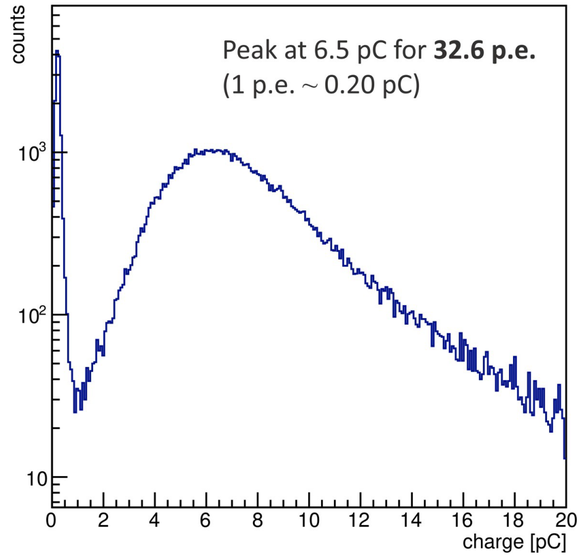
The Scintillator Surface Detector

- **Components**
  - Extruded scintillator bars (1600x50x10 mm), 2 x 24 per detector
  - WLS fibers (Kuraray 1 mm)



The Scintillator Surface Detector

- **Production and tests of SSD modules**
  - 1518 SSDs produced and tested in 6 European research institutes
- **Tests using atmospheric muons**
  - Light tightness
  - Minimum Ionizing Particles (MIP) unit for the signal calibration MIP/SPE to check the quality of SSD modules



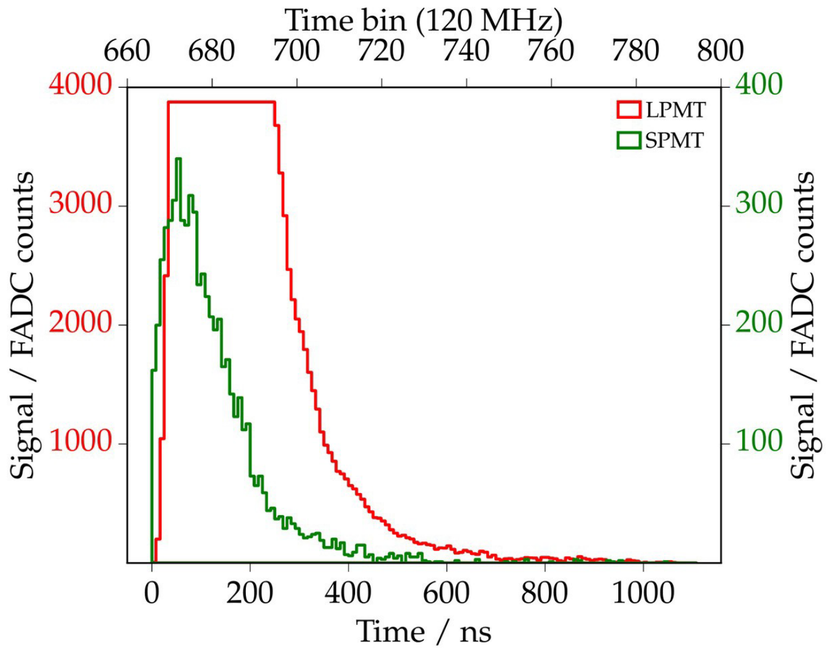
30 ± 2 pe. per MIP

- **Tests and validation of all SSD PMTs**
  - performed in 2 European research institutes
  - Linear response in a wide range

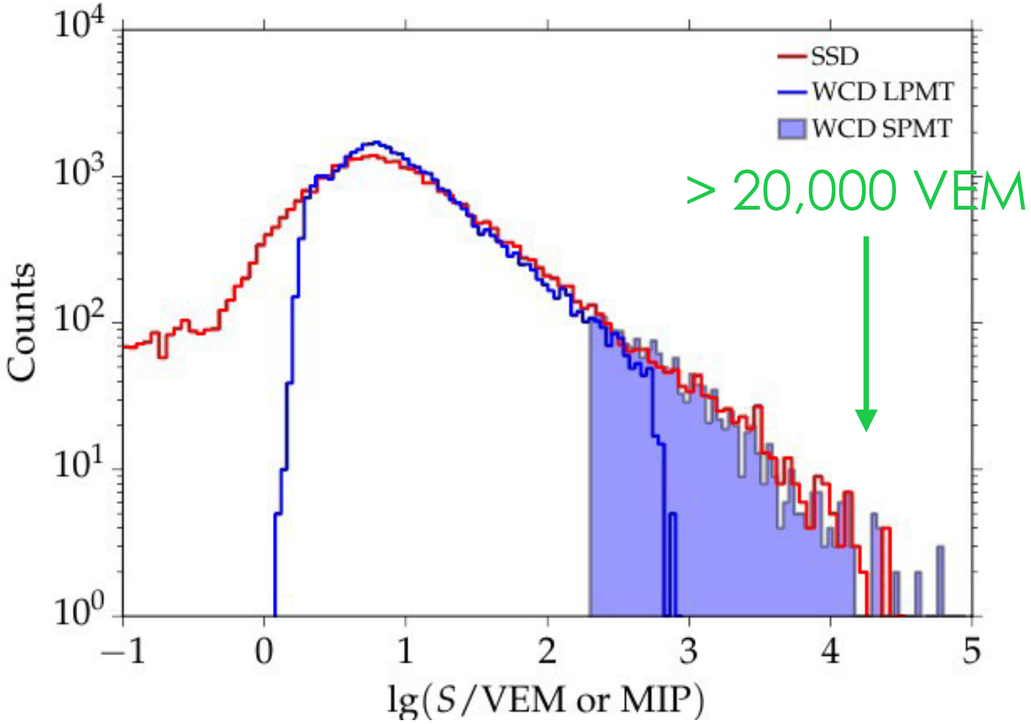
→ **Shipment to Argentina**

The Small PMT

- **4th PMT installed in each WCD**
  - Hamamatsu R8619 1-inch diameter PMT
  - passive base, power supply in a separate box
  - Linearity and gain curves of each SPMT carefully measured
  - active area ~100 times smaller, gain optimisation =>as close as 250 m from the shower core

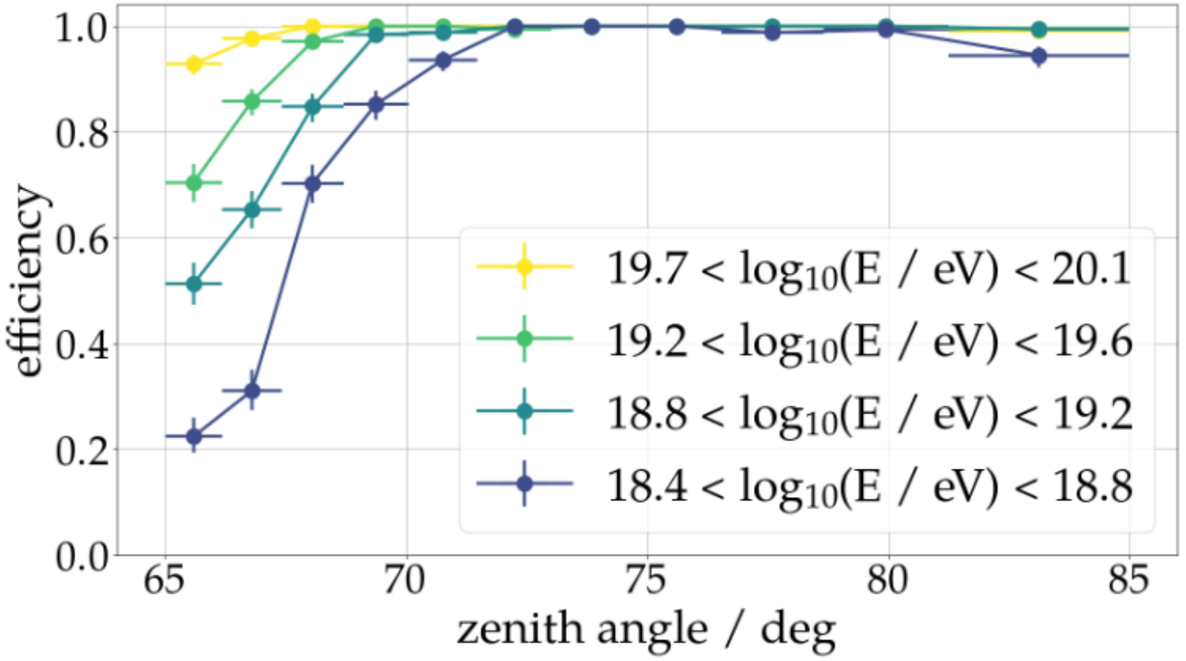


Extension of the dynamic range



The Radio Detector

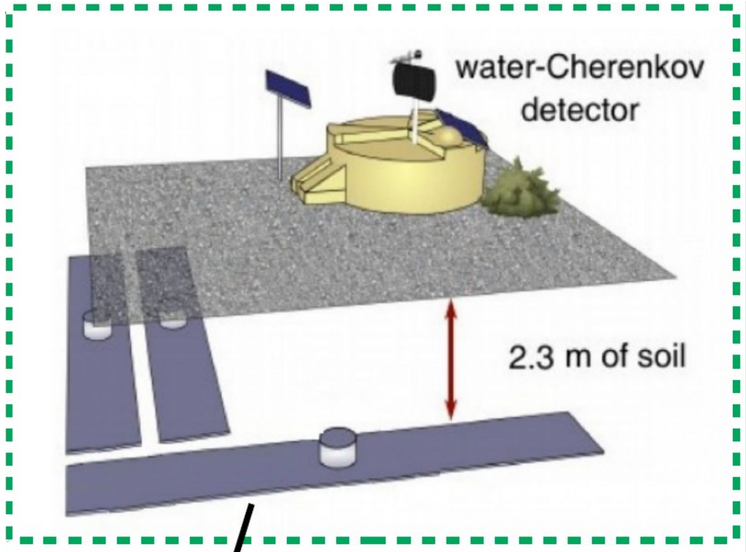
Radio Antenna (RD)

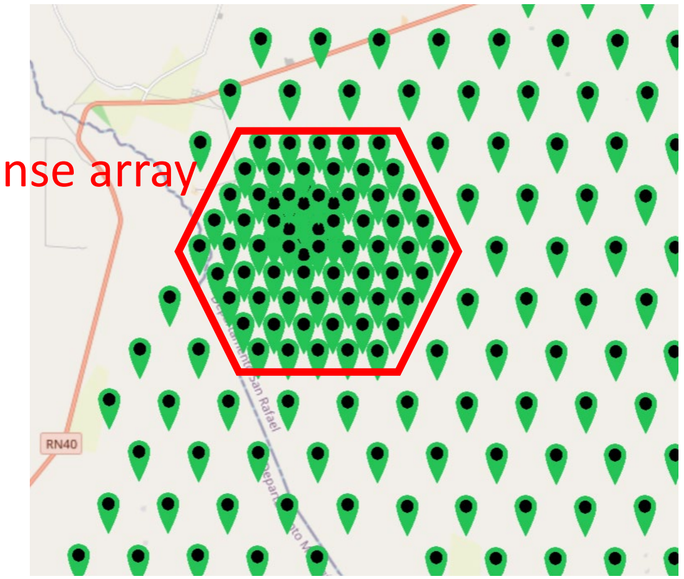


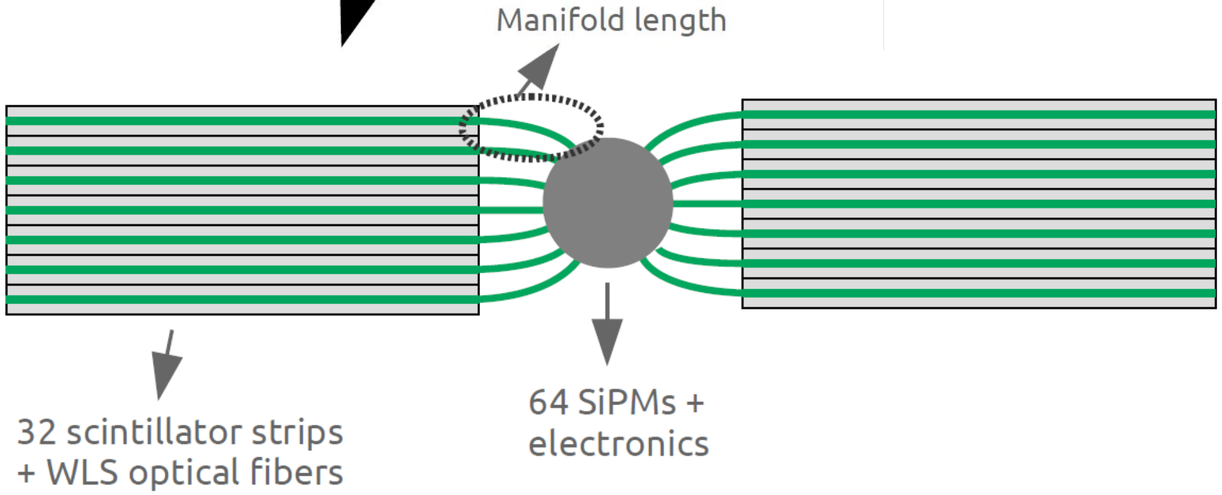
Simulated efficiency of the RD vs zenith angle.
The RD will cover a region of the sky that can not be explored with the SSD

Undergound Muon Detector

- **station general overview**



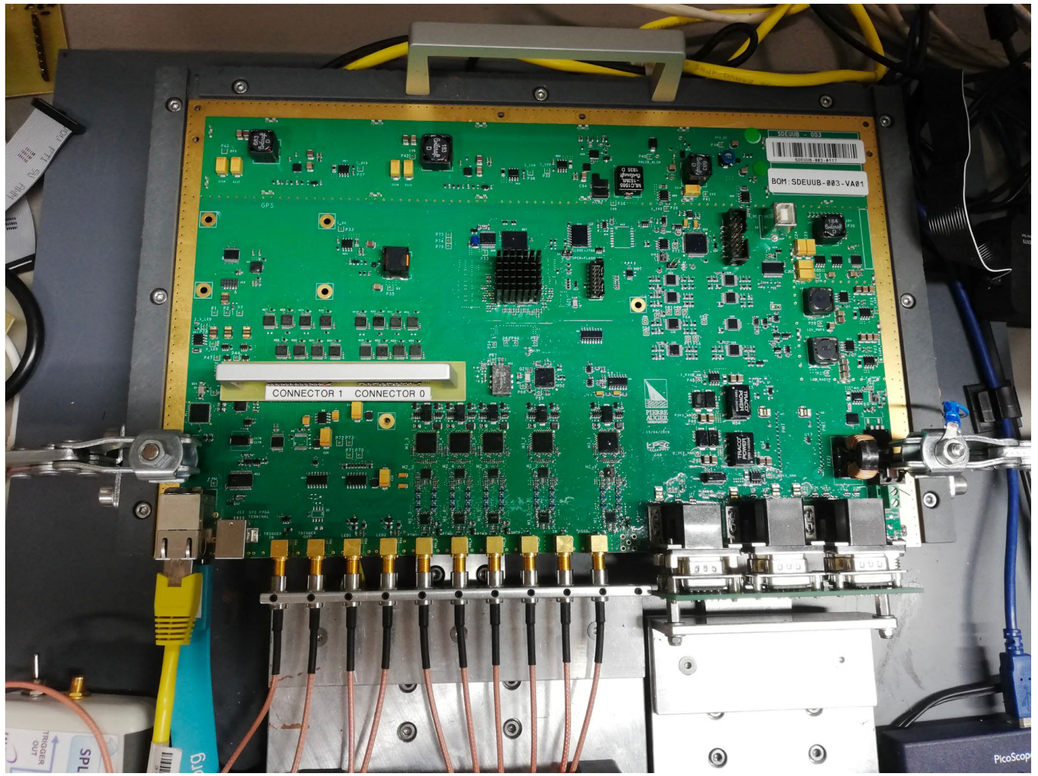




The Upgraded Electronics

- **onboard**
  - analog signal processing
  - triggering, calibration (WCD + SSD PMTs)
  - GPS time tagging, data acquisition
  - interface with UMD and RD systems
  - acquisition and communications via radio transmitter

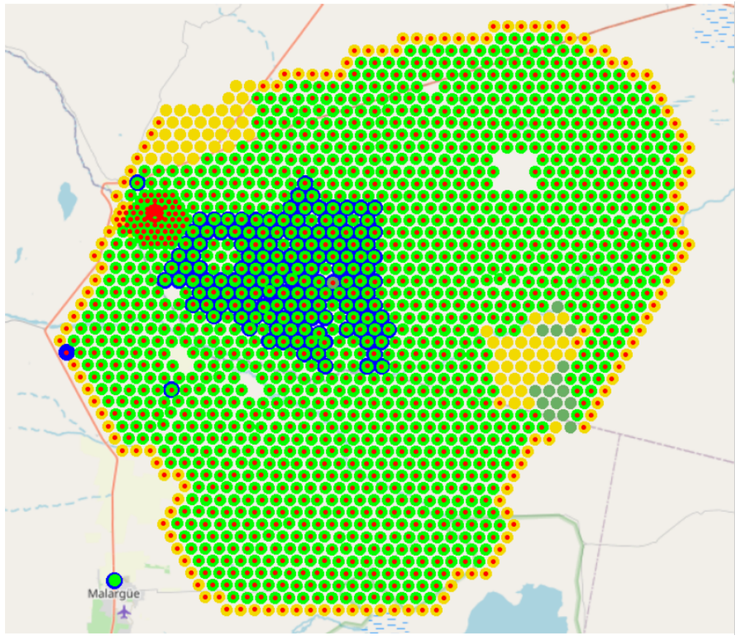
- **With respect to old electronics :**
  - faster ADCs (40 —> 120 MHz)
  - larger dynamic range (10 —>12 bits)
  - significantly more powerful FPGA
  - upgraded CPU (> 10 times faster)
  - backwards-compatibility
    - fit the enclosure of current electronics
    - accept the existing connection cables



- Production started on March 21
- Manufacturing: SITAEL SpA company
- tests after production
- Environmental Stress Screening tests in one European research institute

Status of the Deployment

- **SSD**
  - In spite of the Covid-19 pandemic, the deployment of the SSD was completed (except on the boarder)
  - end of deployment: march 2022
- **UUB, SSDpmt and sPMT**
  - Since 12/2020
  - end of the deployment: June 2023



UUB and sPMT

Not upgdraded

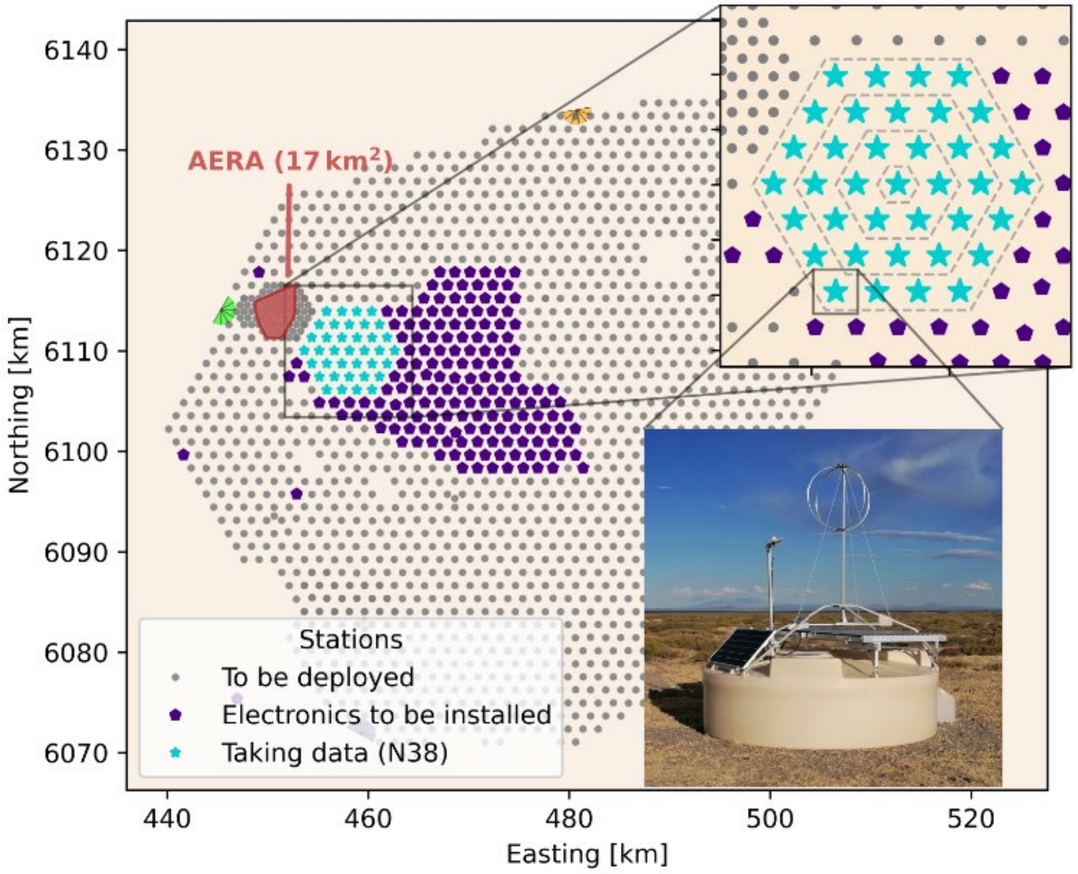
SSD, SSDpmt, UUB and sPMT

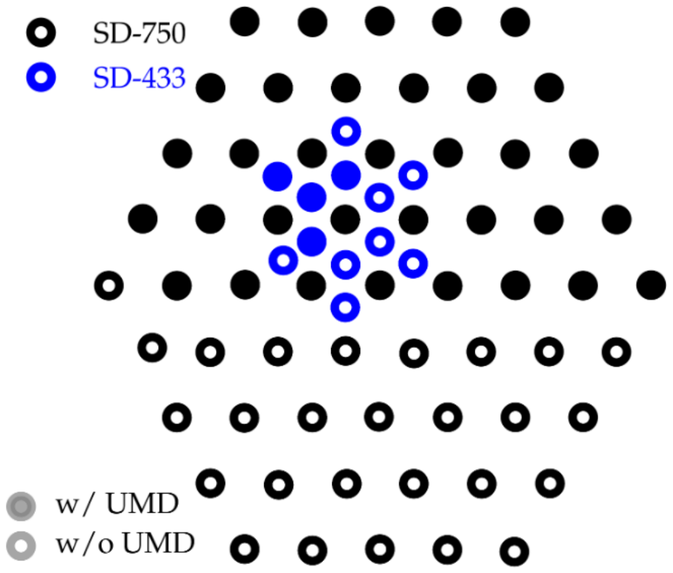
RD, SSD, SSDpmt, UUB and sPMT

Only SSD

Status of the Deployment

- **RD**
  - start 2023
  - end of the deployment for 2024
- **UMD**
  - The detector will be installed only in the dense area
  - 52 % of detectors installed and in acq

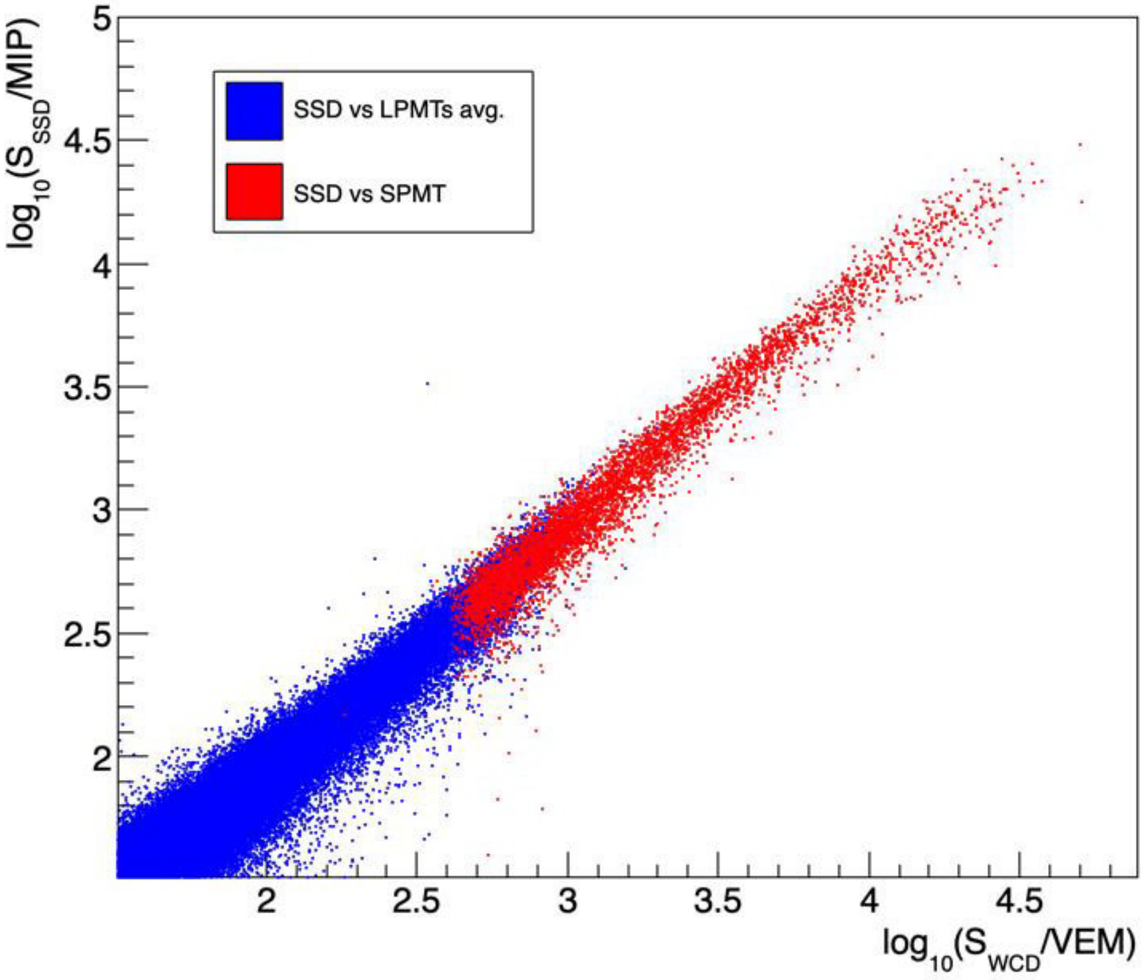




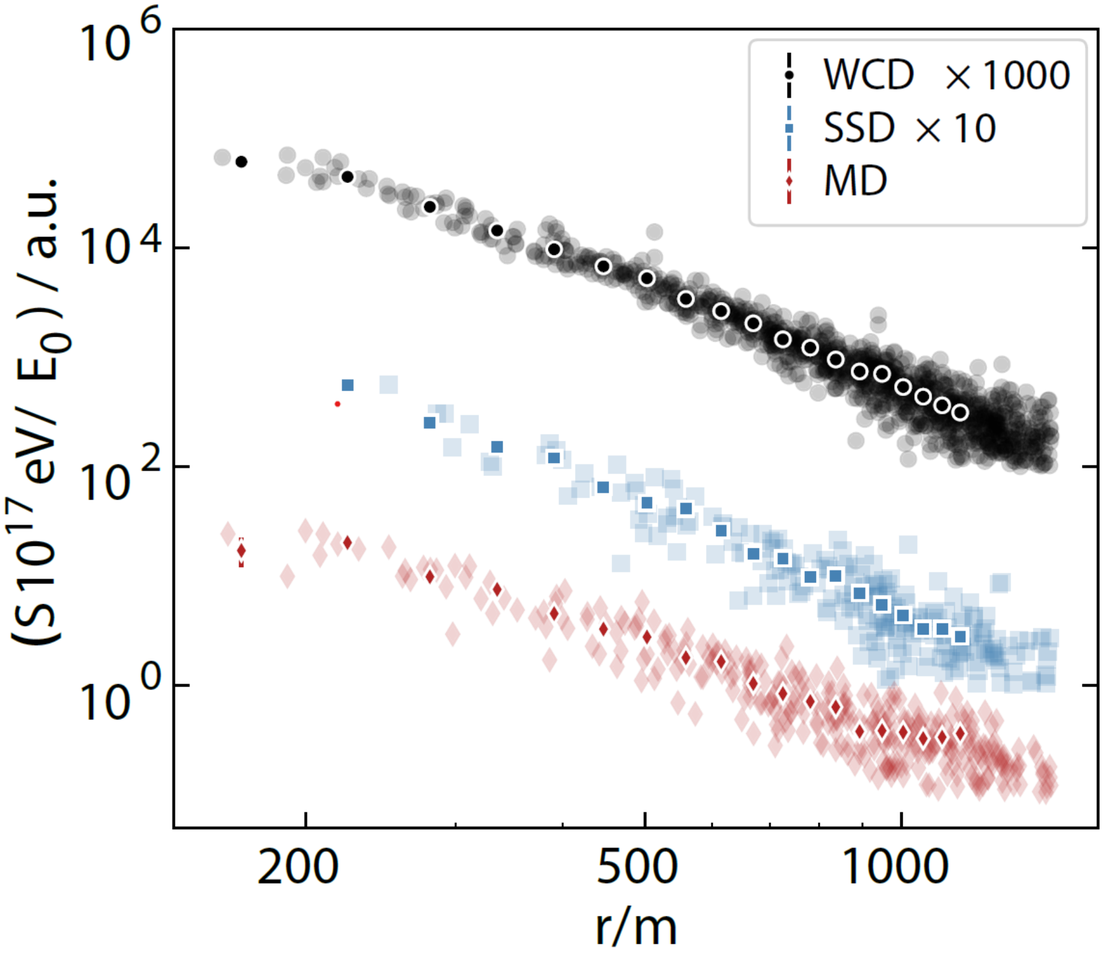
WCD w/sPMT vs. SSD and UMD

Signals measured in extensive air-shower events

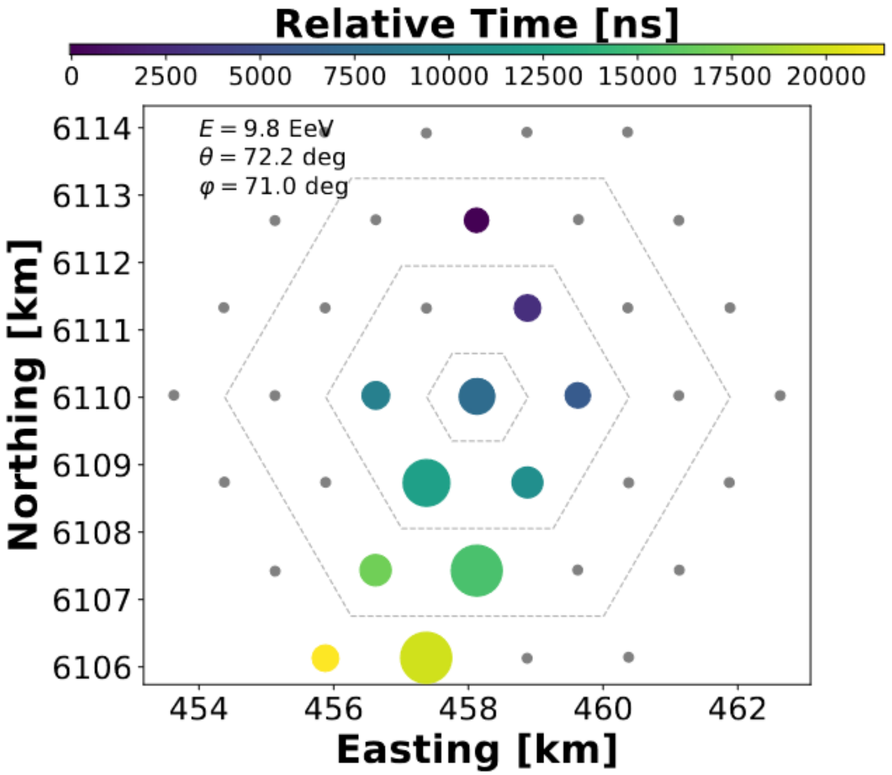
The signals in the WCD are measured up to saturation (around 700 VEM) by the large PMTs. With the sPMT **the dynamic range of the WCD is extended** up to 20,000 VEM. **Good correlation** between the calibrated **WCD and SSD signals**



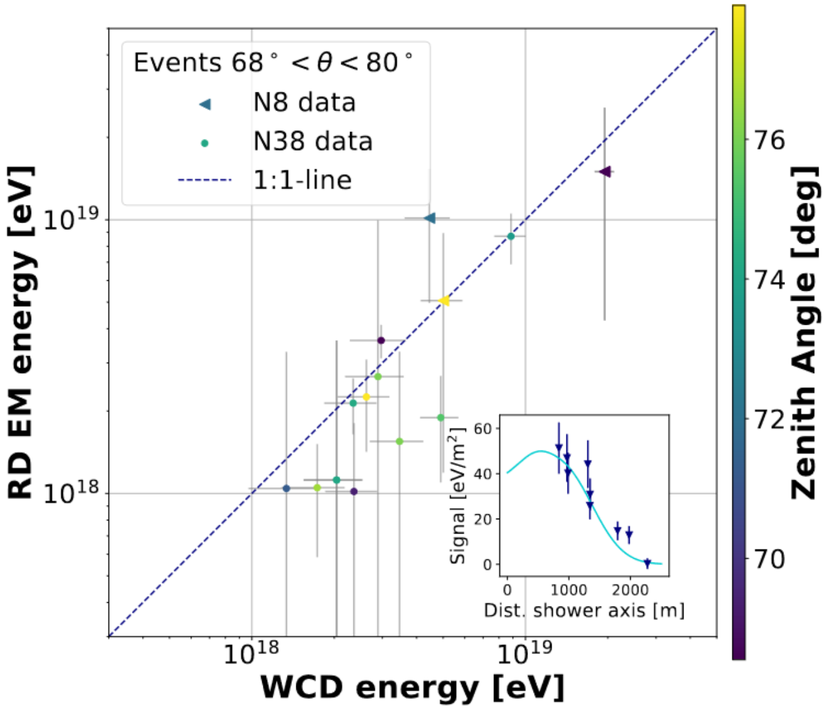
Average lateral distribution of station signals vs distance to the shower core for WCD, SSD and UMD. Different slopes in the lateral distribution are due to the different sensitivity of the detectors to e.m. and muonic components.



Radio Detector vs WCD

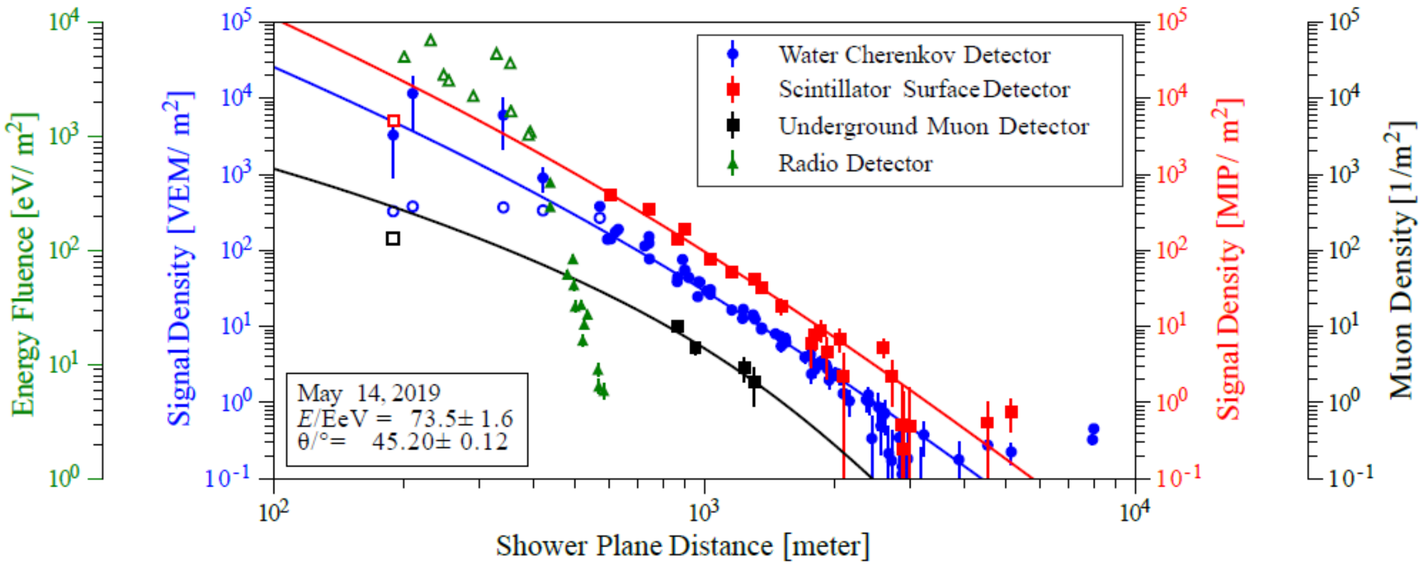


Radio footprint of the air shower. Each dot represents one detector stations, the colors indicate the arrival times, while the size represents the signal strength.

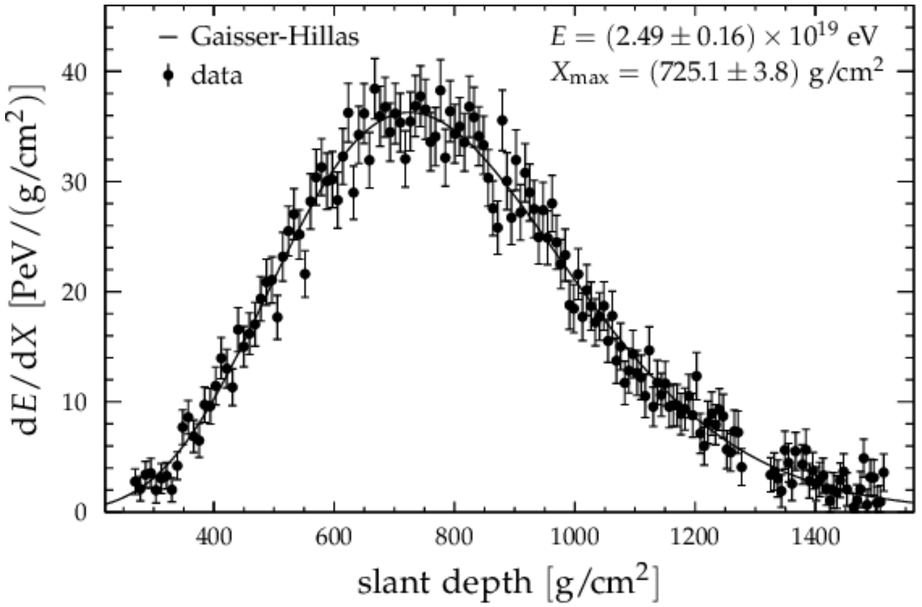


Comparison of the estimated energy of the particle detector and EM energy of the RD. The color scale indicates the reconstructed zenith angle.

The Phase II of the Pierre Auger Observatory is started



Event detected with different instruments at ground level



Fluorescence detector. Shower profile

Multi-Hibrid era of the Pierre Auger Observatory is started

THANKS

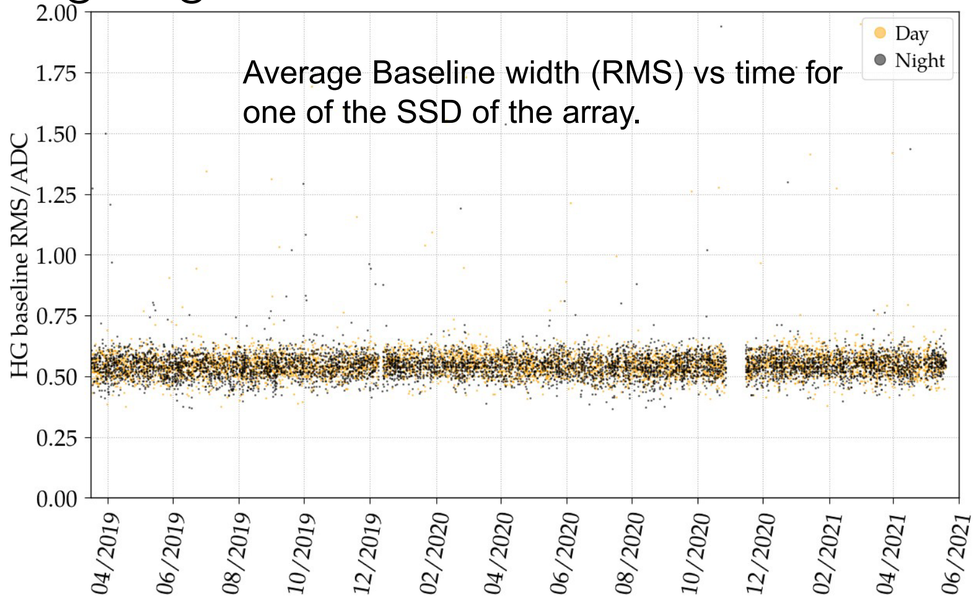
SSD in the field

All the Scintillator Detectors installed (installation finish at the begin of 2022)

- **Check SSD performance on site**

  Evolution of the RMS (in ADC counts) for the PMTs trace (HG channel) for a subsample of SSD of the array

Light tightness



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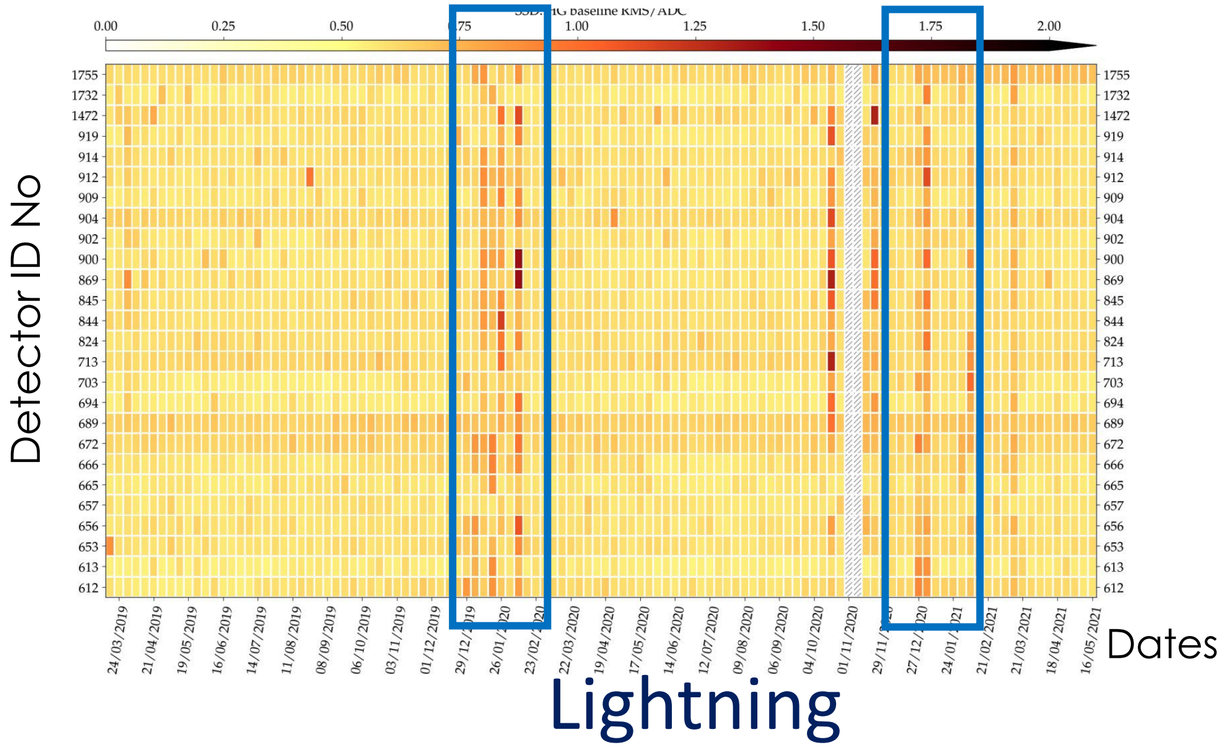

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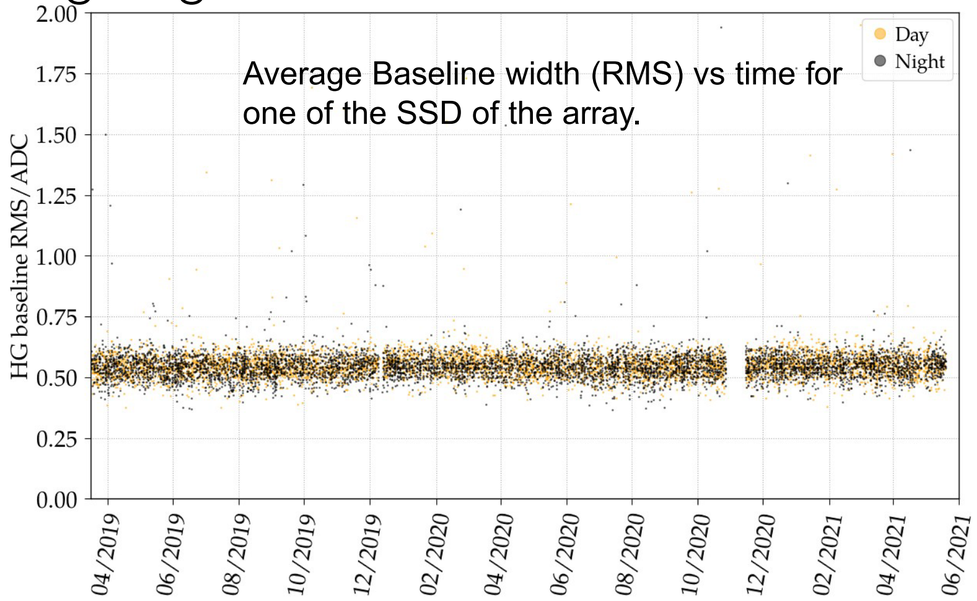

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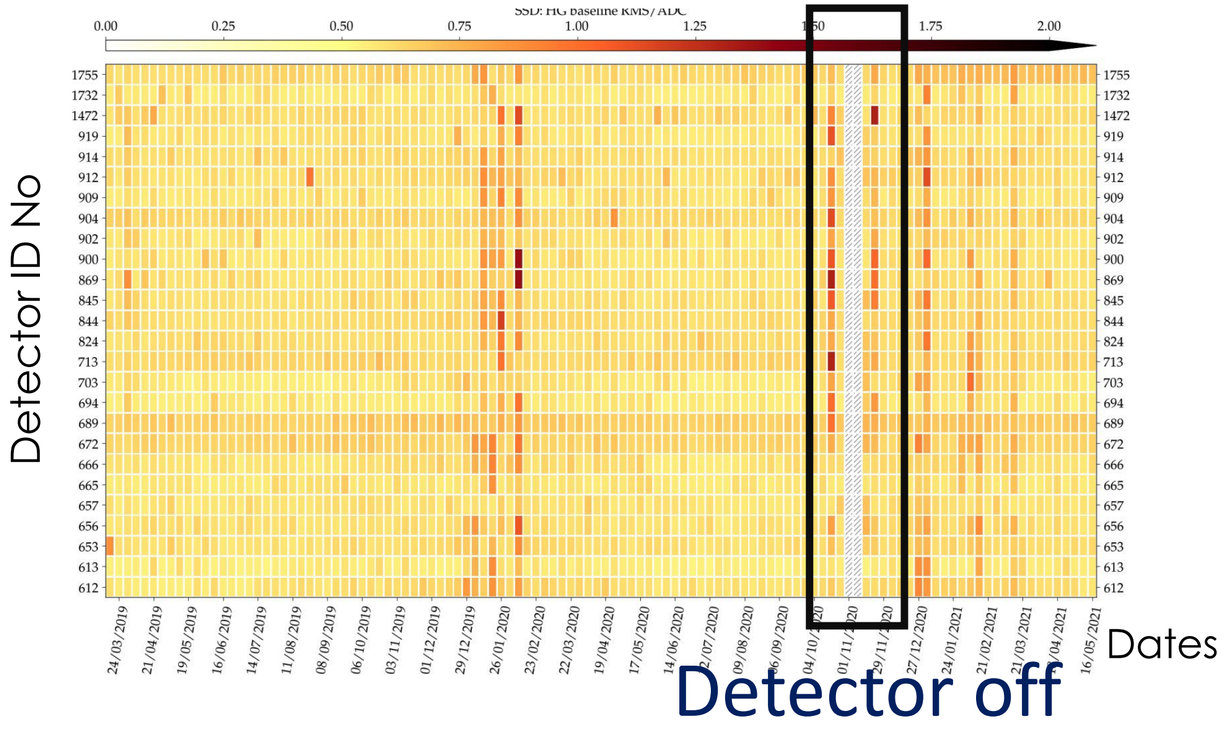

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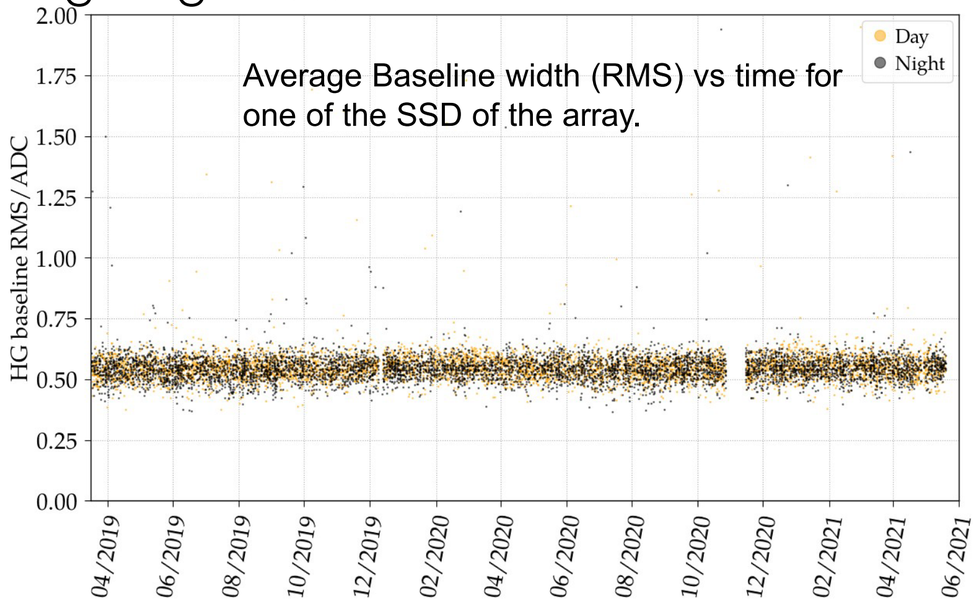
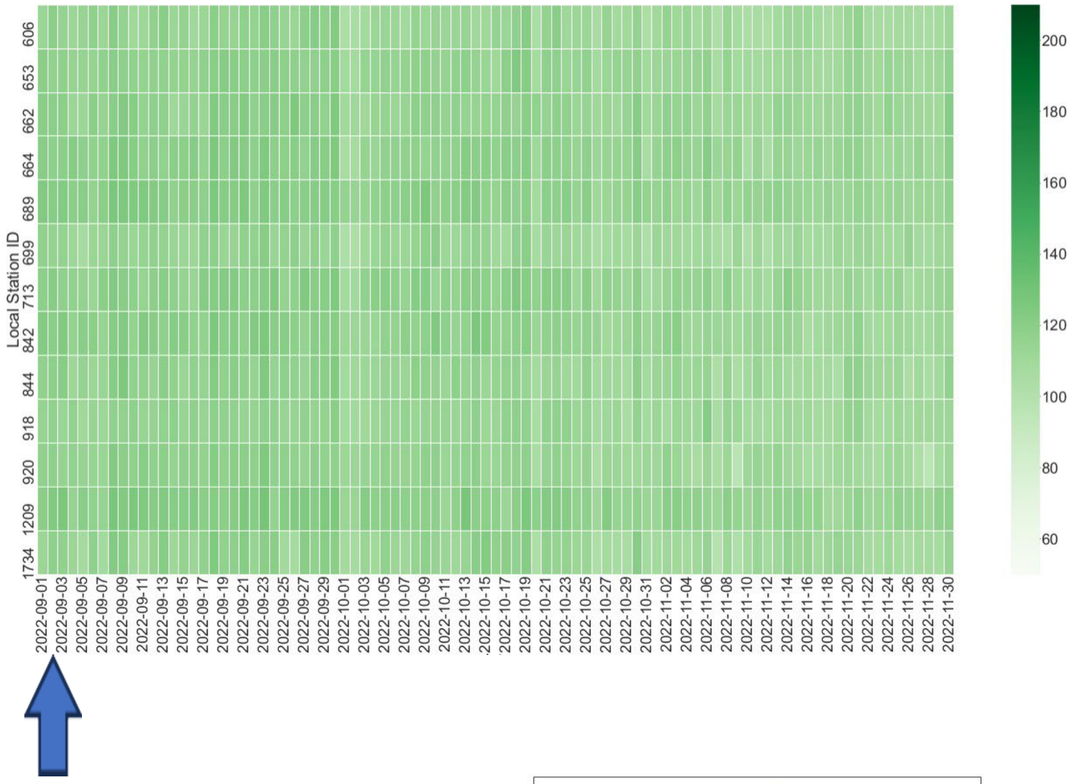
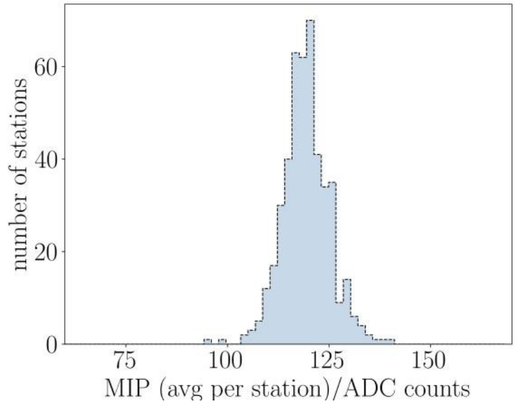


SSD in the field

- Daily mean value of the **MIP charge** shown for a subsample of stations during three months.
- **Stability** in time and a general **uniformity** among stations can be observed
- Distributions of the average MIP charge values for all upgraded detector on an example day of those studied in the maps
- **Distributions** have remained stable until the end of the deployment with small seasonal fluctuations (≲10%)





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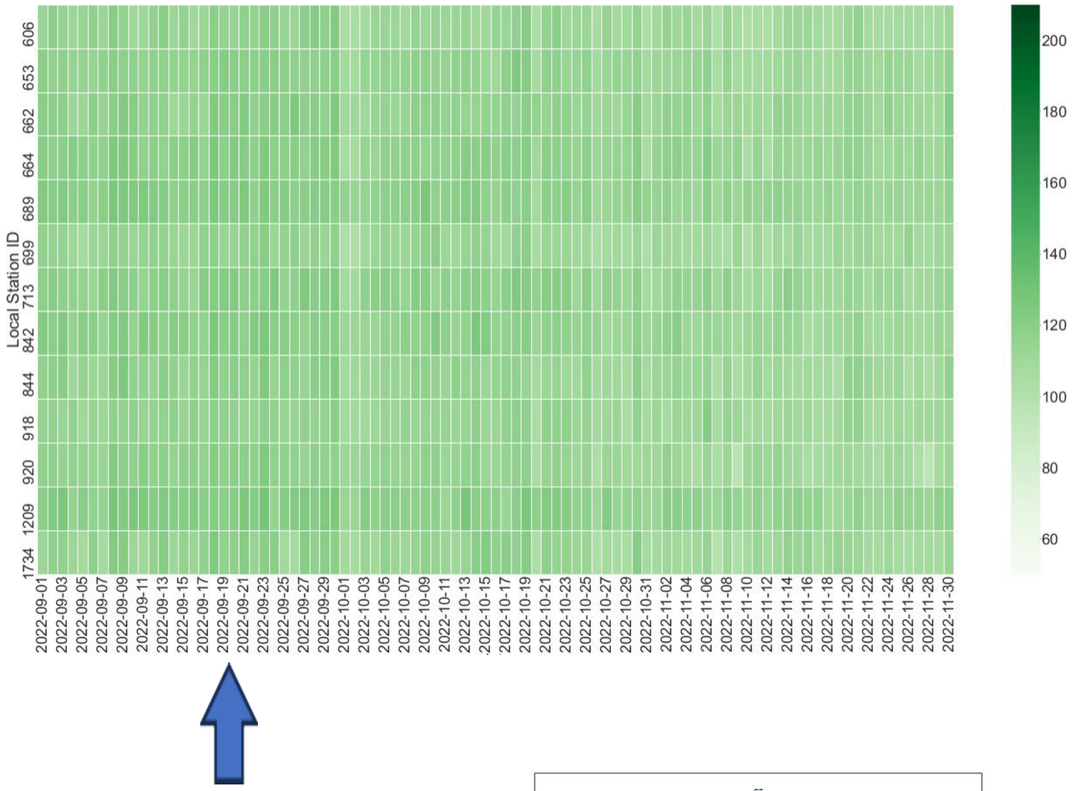

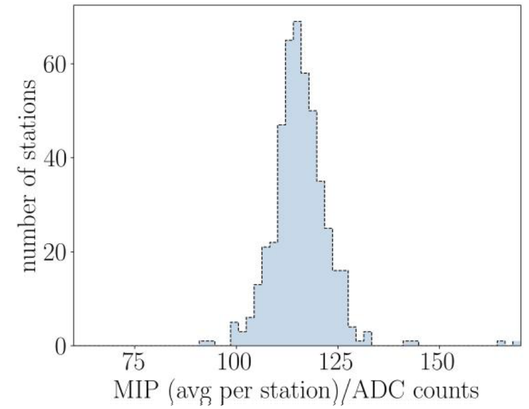

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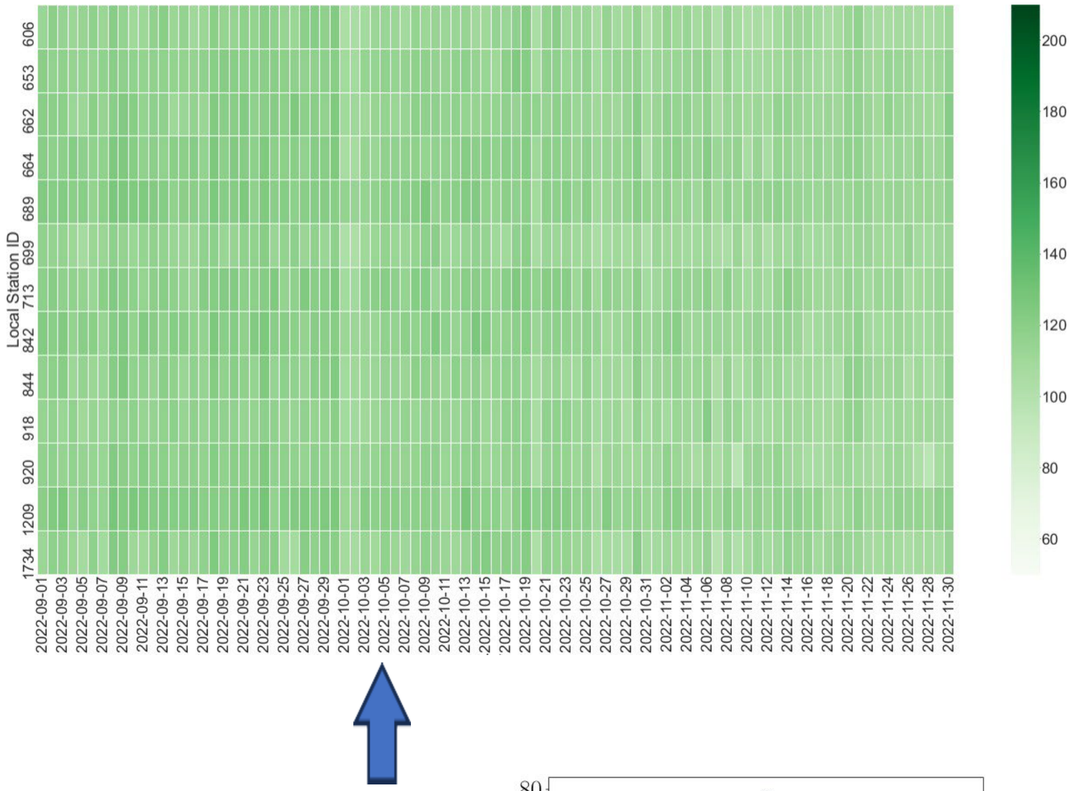

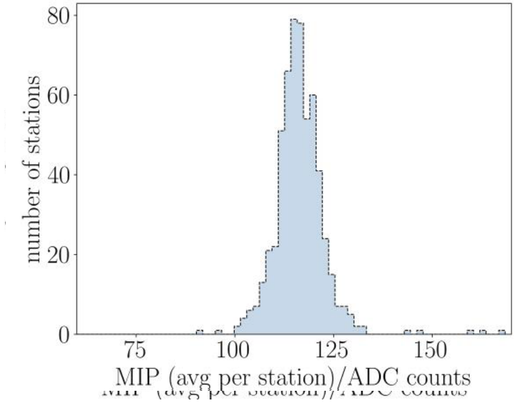

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