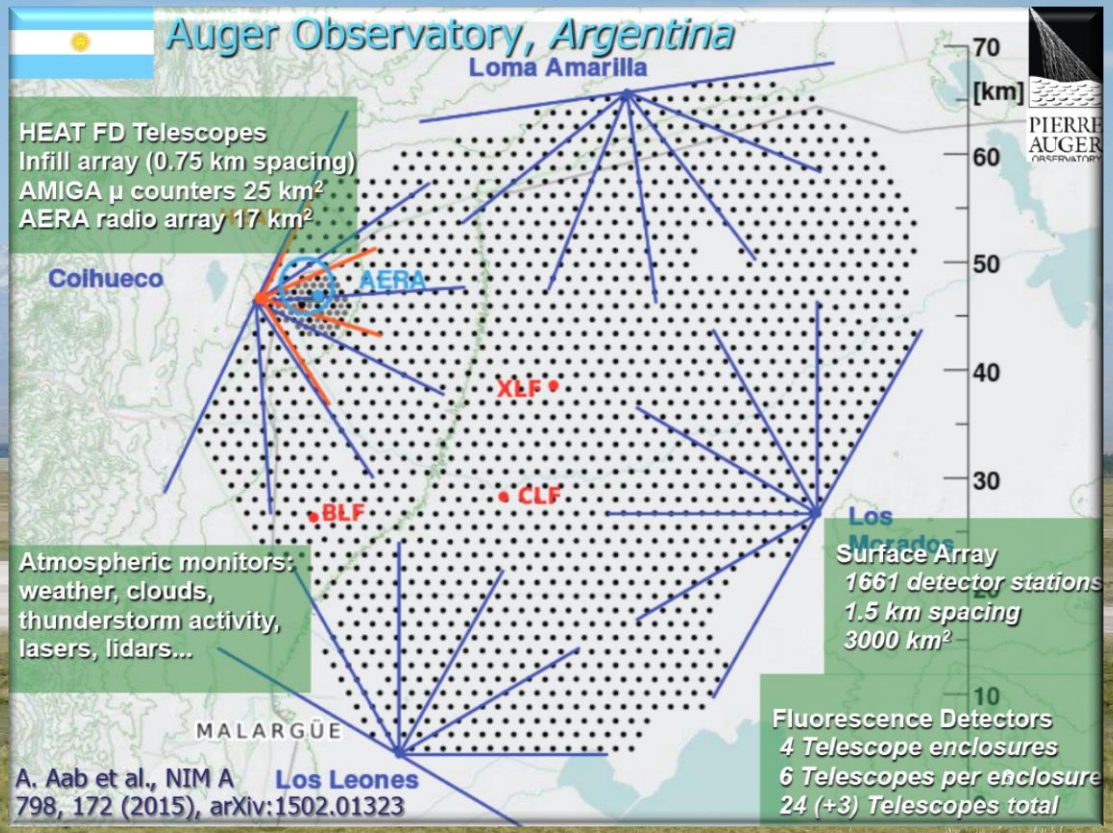
The AugerPrime Upgrade of the Pierre Auger Observatory.

Gabriella Cataldi *, for the Pierre Auger Collaboration
*INFN Lecce

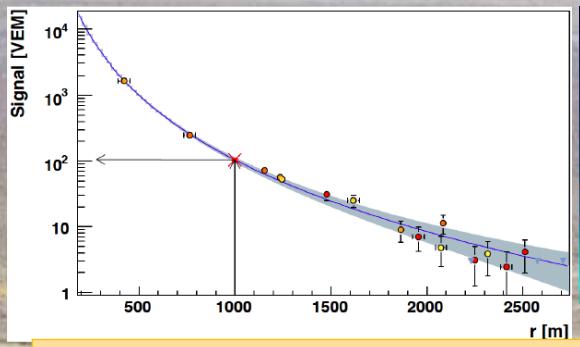
The Pierre Auger Observatory in Argentina

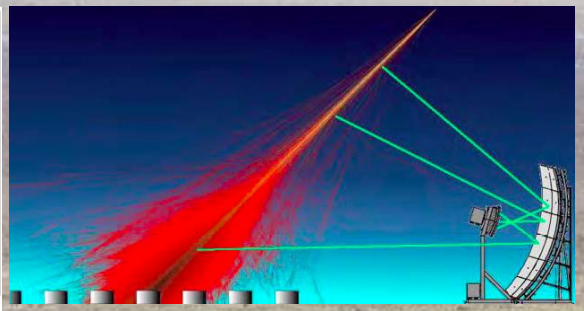


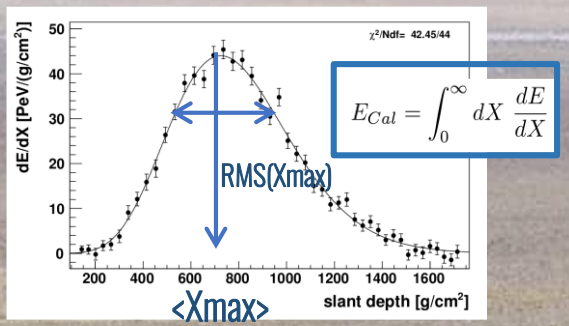
Indirect detection of cosmic ray through their atmospheric showers

A giant Observatory covering 3000 km^2 to compensate the very low flow at the highest energies.

The Auger Hybrid concept







SD provides:

- Huge aperture (100% duty cycle) easily calculable
- Large angular acceptance (showers up to 80°)
- Robust detectors
- Good angular resolution

FD provides:

- Fluorescence light emitted in proportion to energy deposit: -> Near calorimetric energy measurements
- A direct view of shower maximum (composition)
- Precise directions (hybrid method).
- But duty cycle is only 10-15%

Optimisation of Auger's hybrid data

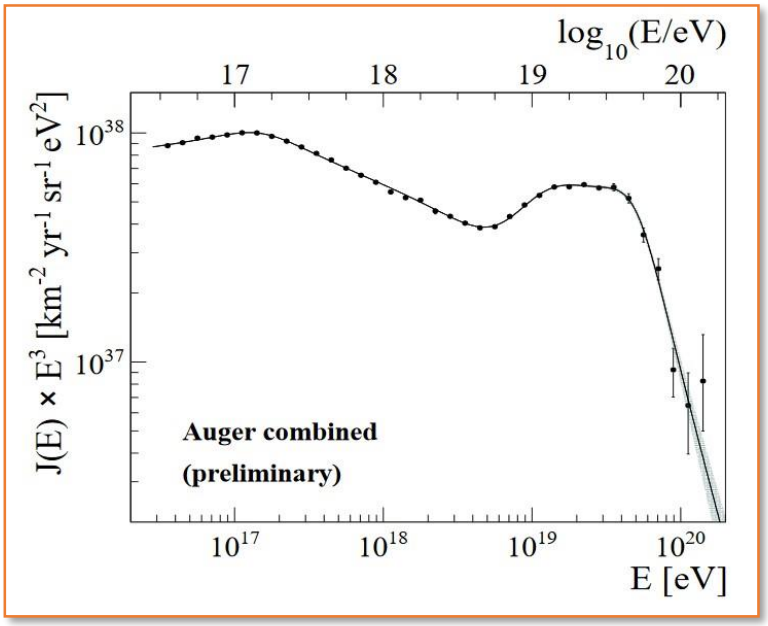
- FD calibrates SD energy scale that is used on the large statistic of SD events: minimal use of simulations when possible
- Various cross-check (directions, energy thresholds…)

The Pierre Auger Observatory associates the widest detection surface (3000 km²) together with the highest precision ever achieved

Scientific results from the PAO

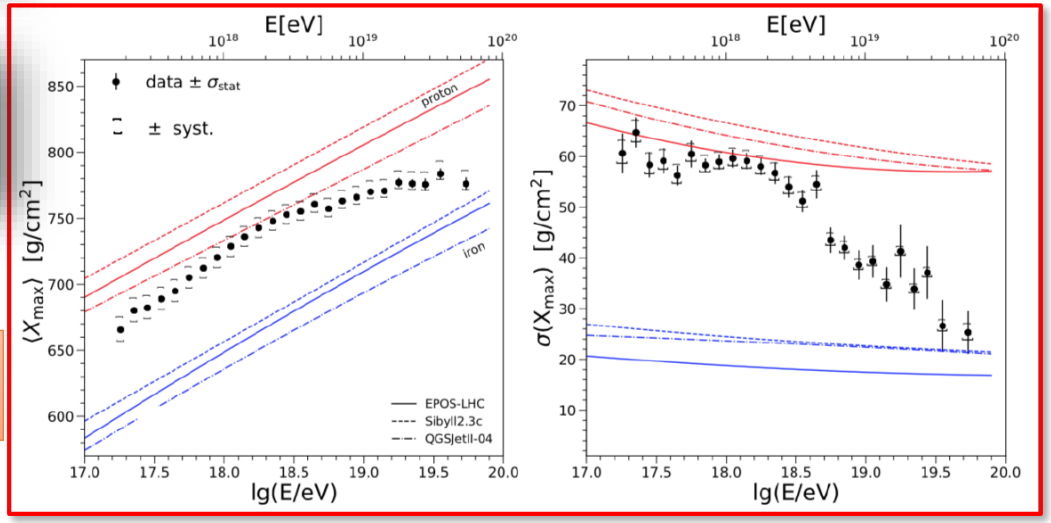
Energy Spectrum

- abrupt suppression above 5×10^{19} eV
- ankle
- clear observation of the second knee
- an indication of a further inflection point at E ~ 10 EeV



602. Probing hadronic interactions with measurements at ultra-high energies with the Pierre Auger Observatory
David Schmidt (Karlsruhe Institute of...)
31/07/2020, 08:25
08. Astro-particle Physic... | Talk | Astro-particle Physics an...

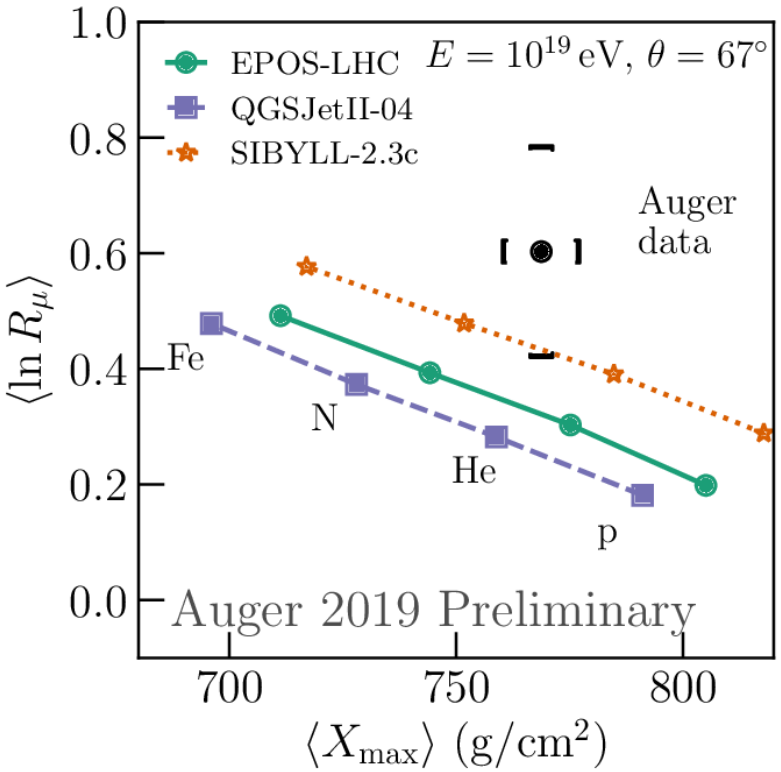
663. Multi-Messenger studies with the Pierre Auger Observatory
Mr Lukas Zehrer (University of Nova G...)
31/07/2020, 08:50
08. Astro-particle Physic... | Talk | Astro-particle Physics an...



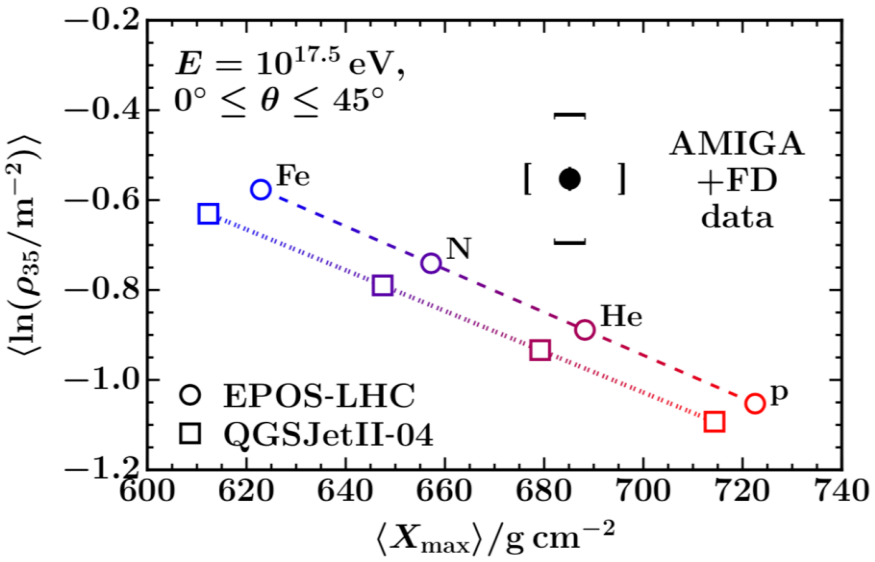
Mass Composition (<Xmax> and its fluctuations from FD)
Lighter composition up to ~2 EeV, heavier above this energy

Hadronic models: Muons deficit in simulated showers

Inclined data at 10^{19} eV



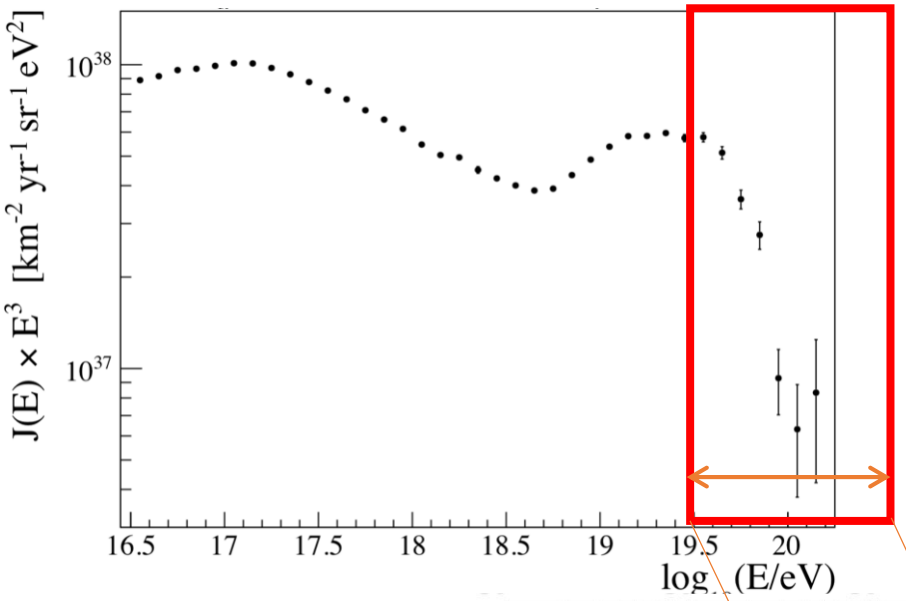
New Data with Amiga at $10^{17.5}$ eV

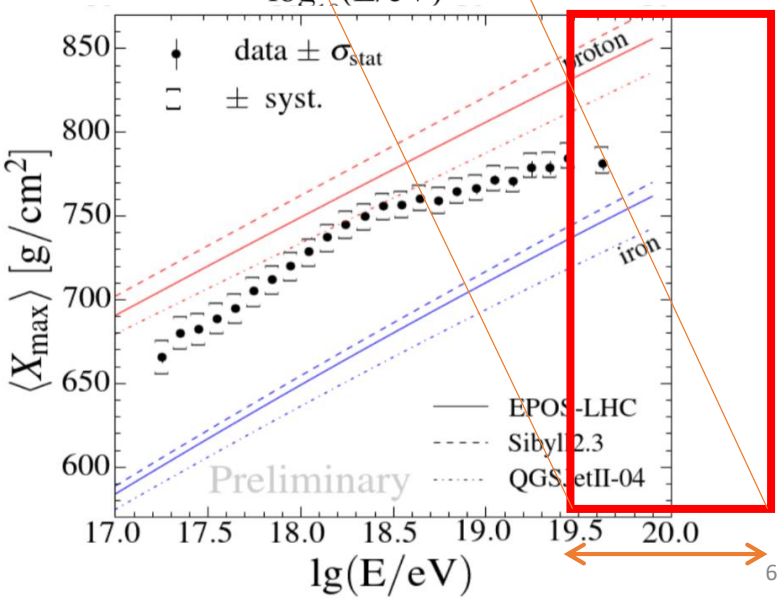


Even the latest simulations fail to reproduce muon densities
38% (53%) increase in <Nμ> at 1 EeV needed for EPOS-LHC (QGSJetII-04)

The Science Case for the Upgrade

- ✓ study the origin of the suppression
- ✓ select light primaries for charged particle astronomy
- ✓ provide better estimates of the neutrino and γ flux, as such establishing the potential of future CR experiments
- ✓ better measure the shower components to deepen the study of hadronic interactions at UHE and look for non standard physics





Extend operations to >2025, increasing the statistics

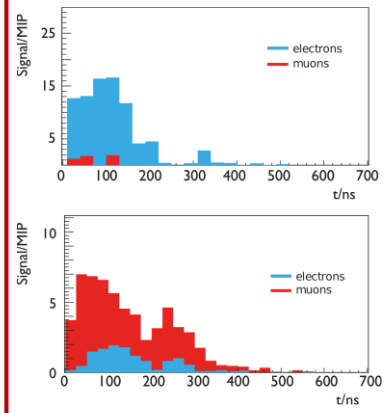
Improve the sensitivity to the composition at UHE : disentagle the electromagnetic and muonic components

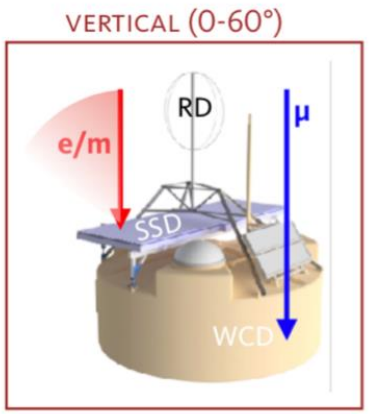
AugerPrime: The concept

Use complementary of response of detectors to discriminate muonic and em components on 3000km^2

Vertical showers

SSD





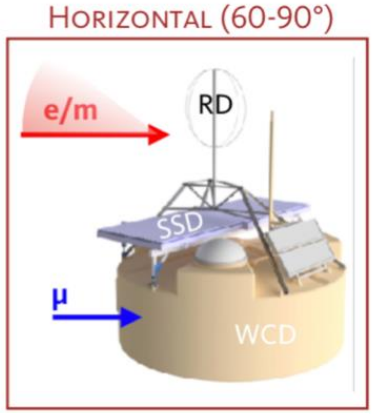
$S_{\mu,WCD} = a\, S_{WCD} + b\, S_{SSD}$

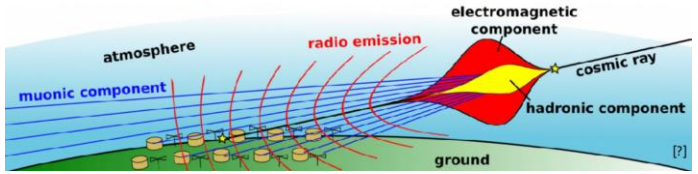
+

Horizontal showers

RADIO

Hybrid:
E_{rad} from radio
muons from WCD





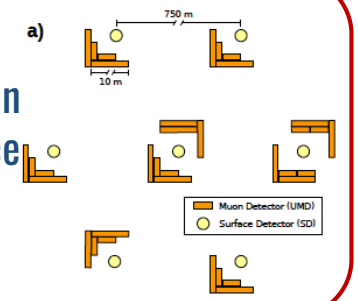
+

+ ✓ New electronics (faster)
✓ Addition of a small PMT in the WCD (extension of dynamic range)

+

AMIGA

61 Underground Muon Detectors in coincidence with 750 m array



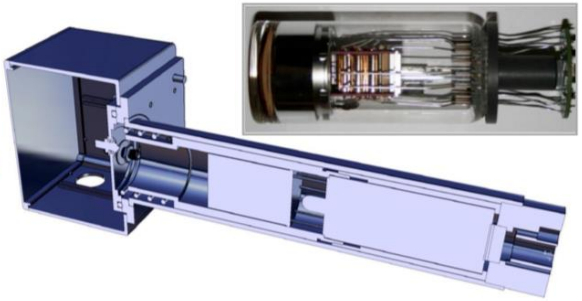
Extend operations to >2025, increasing the statistics

SSD:The detector

Extruded Scintillator bars with 2 holes

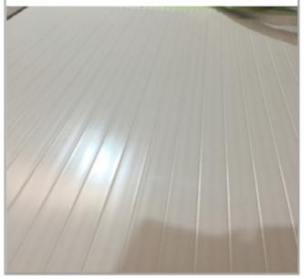
WLS fibers+routers

PMT



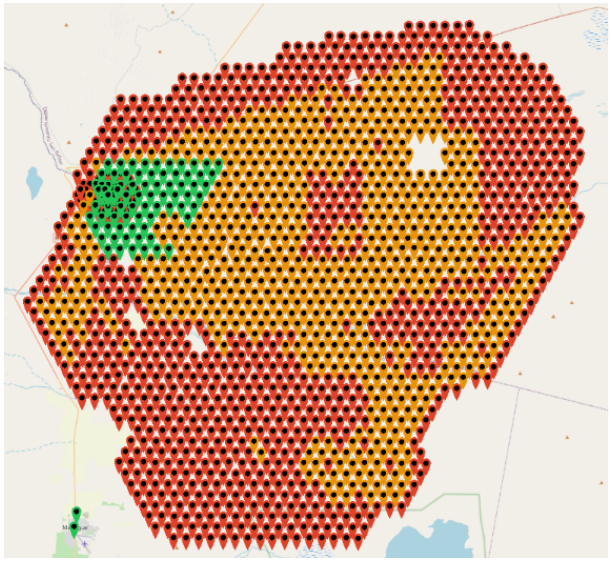
WLS fibers+routers

Extruded scintillator bars 160cm long



Alu Enclosure

AugerPrime: The upgrade



→ 12 upgraded stations (Engineering Array) since 2016 with new electronics, higher sampling, large dynamic range

→ the SSD preproduction array: 77 stations (since March 2019-old electronic 1 PMT missing)

→ 752 SSD stations already deployed (1500 in total)

→ Underground Muon detector

→ The largest radio detector (3000 km^2)

950. The Radio Detector upgrade of the Pierre Auger Observatory
Sijbrand De Jong
31/07/2020, 12:00
13. Detectors for Future F... Talk Detectors for Future Facil...

SSD Production

SSD production and testing

Nijmegen
Aachen
Grenoble
Krakow
Karlsruhe
Lecce

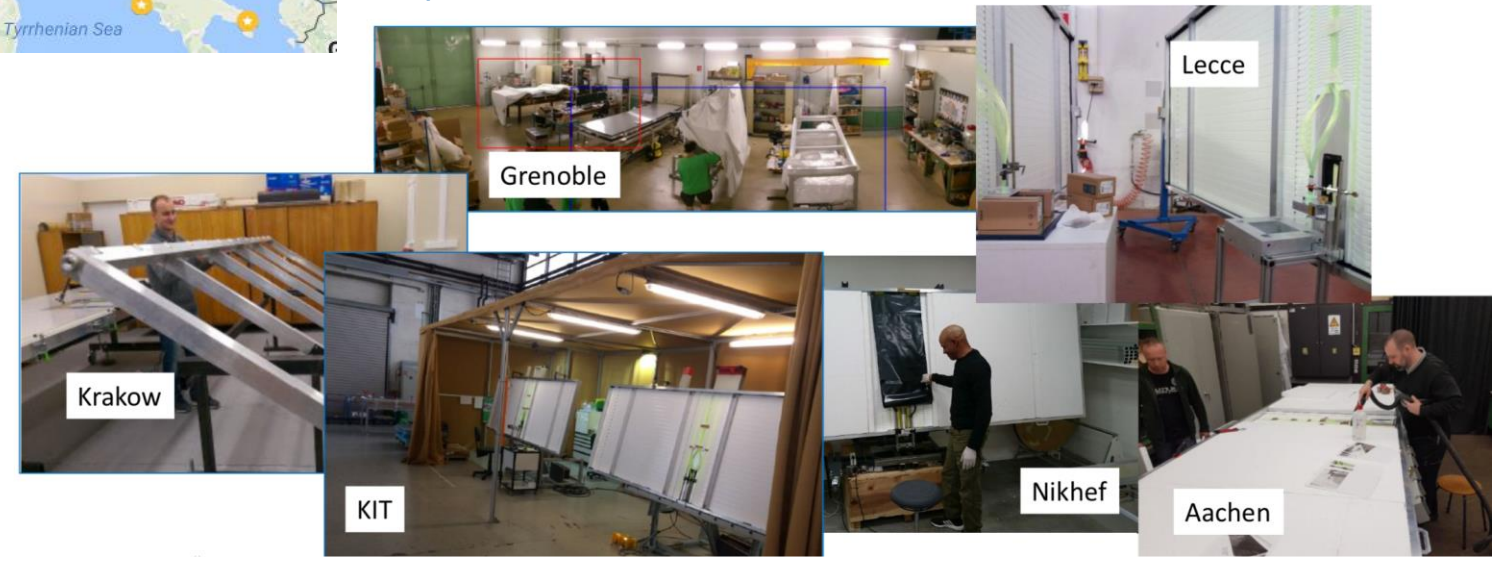
PMT testing

Wuppertal
Napoli

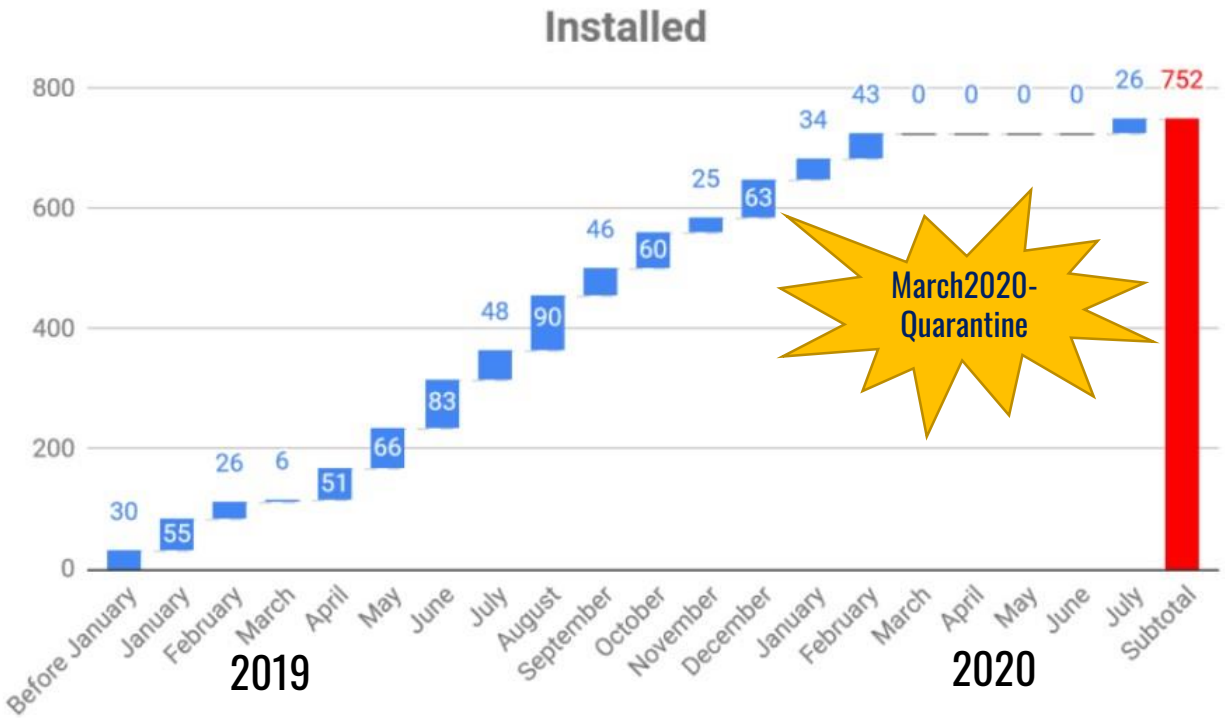
UUB testing (electronics)

Prague

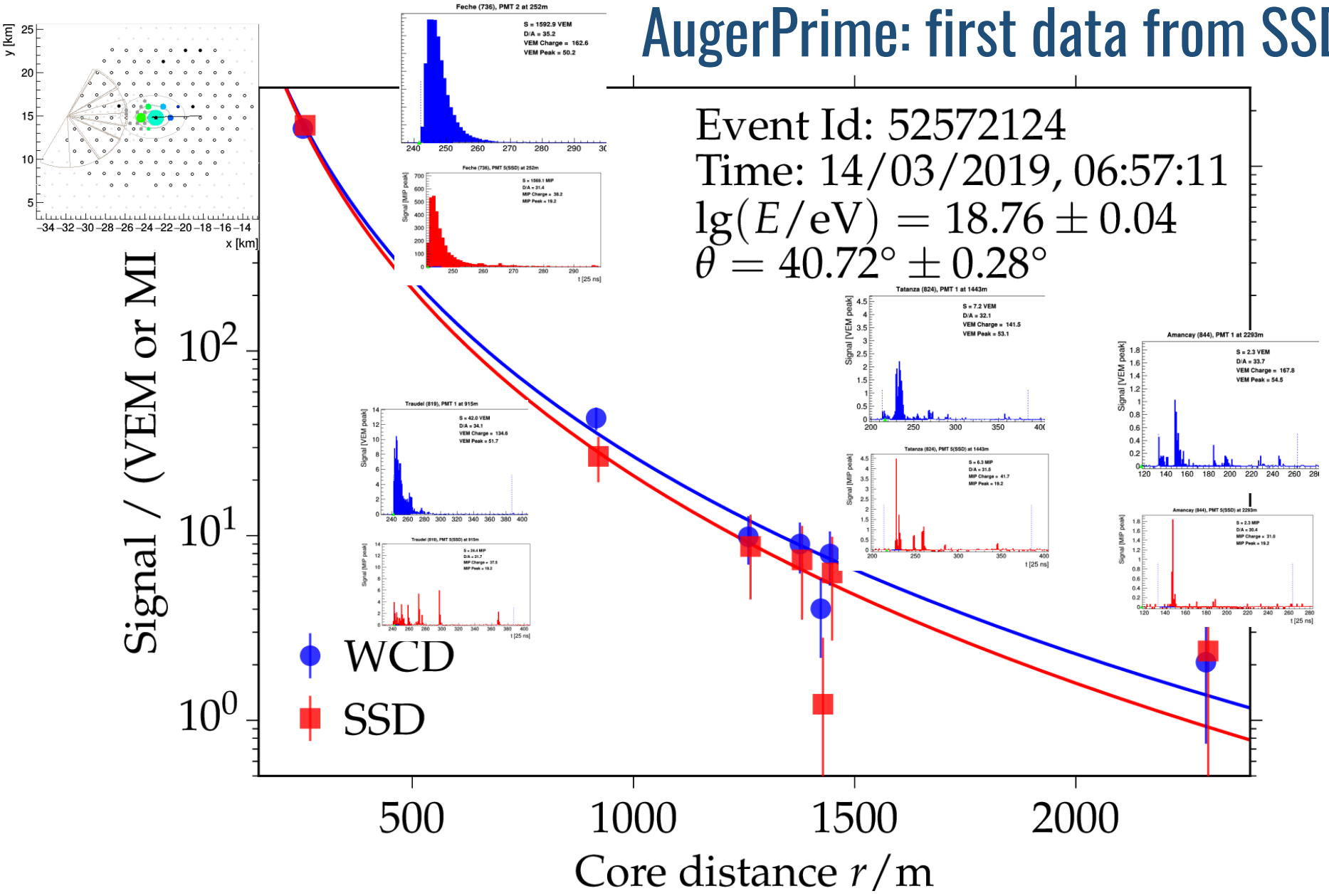
Other institutions are helping in the procurement and preparation of the parts.



SSD Deployment: in the field



AugerPrime: first data from SSD

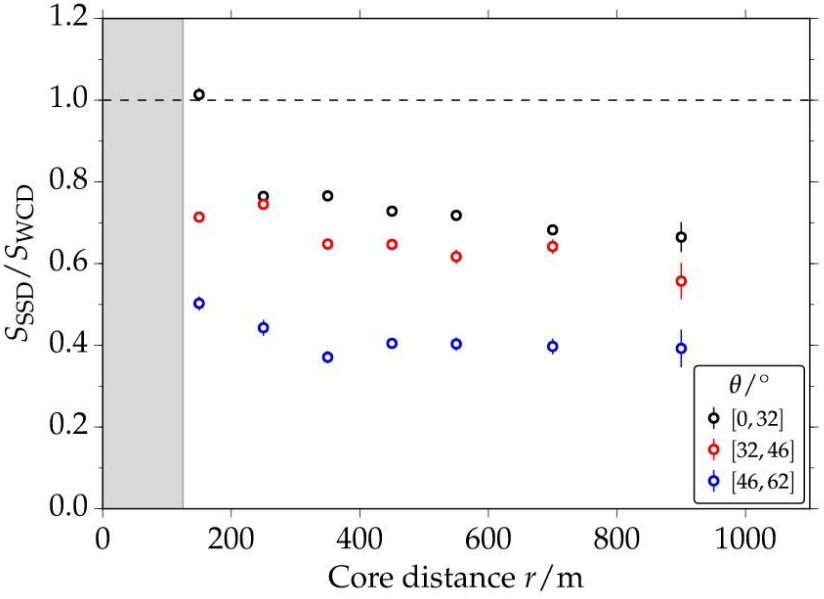


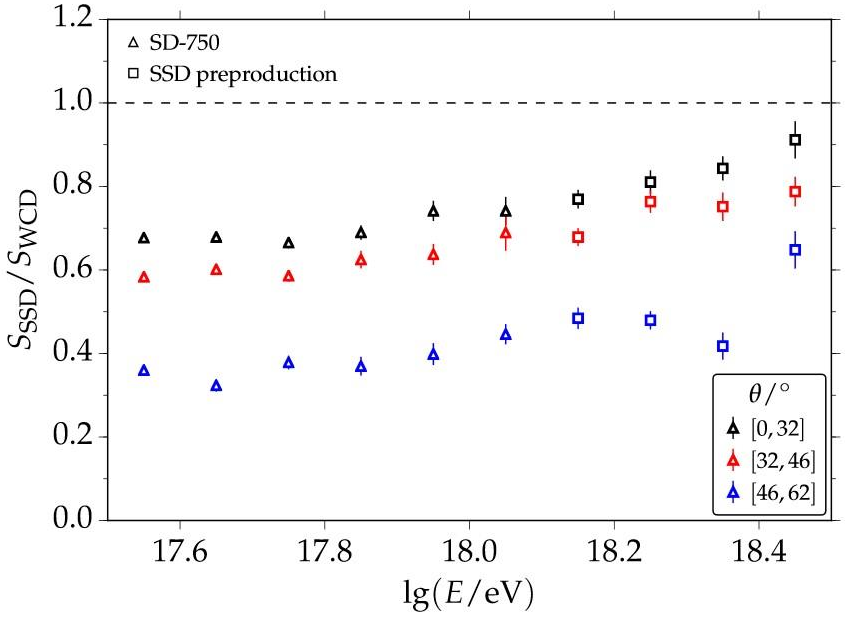
AugerPrime: first data from SSD

SSD and WCD Signal Ratios

77stations (since March 2019)

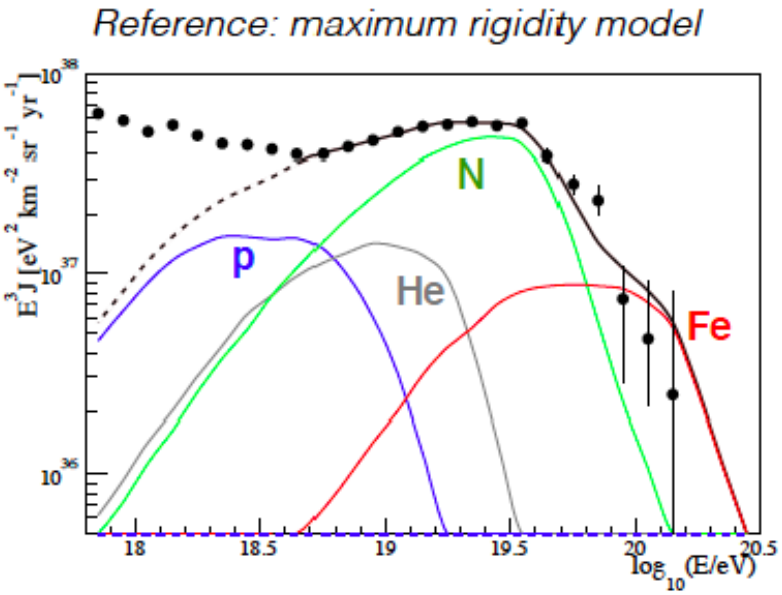
- ✓ The complementary response of SSD and WCD allows to disentangle of the electromagnetic and muonic shower components.
- ✓ At **smaller zenith angles** and **closer distances** the EM component has **bigger contribution** to the SSD signal.
- ✓ SSD signal becomes **more dominant** with **increasing energy** as EM component grows faster than muons.



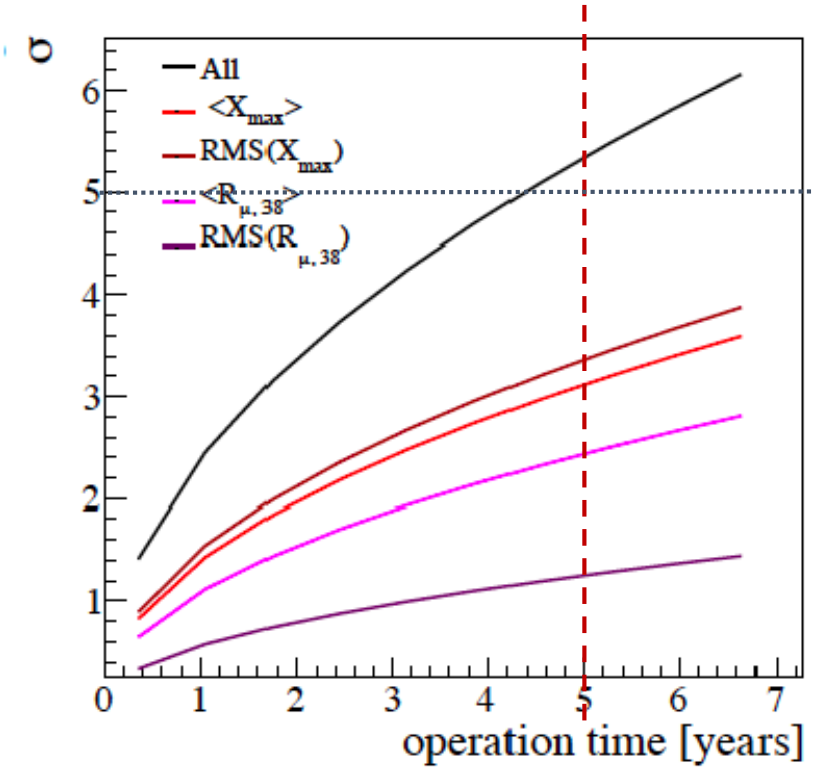


Science Impact of upgrade

- Physics reach: detection of 10 % proton contribution
- Significance of distinguishing scenarios with and without 10% of protons



- Standard scenario 1 (almost no protons)
- Scenario 1 with 10 % protons added



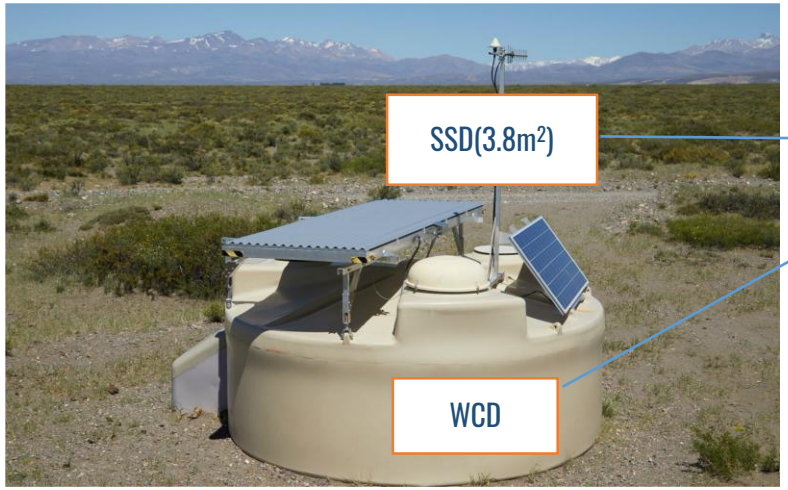
>5σ in 5 years of operations

Summary and Outlook

- Stations of the AugerPrime upgrade have been taking data since they were deployed
  - as part of the engineering array at the end of 2016. The results from the calibration have shown a good performance of the detectors as well as good agreement in the WCD signals comparing old and upgraded electronics.
  - as preproduction array of 77 SSDs in March 2019. The dependency of the signal ratio with zenith, energy and distance demonstrate the differences in the sensitivity of the two detectors to the different shower components.
- AugerPrime will allow a study of mass composition above 5 x 10^{19} eV and address:
  - Origin of the flux suppression (GZK energy loss Vs. maximum energy of sources)
  - Proton contribution of more than 10% above 5 x 10^{19} eV will be visible
    (particle astronomy, GZK γ and ν fluxes $\rightarrow$ future experiments)
  - Look for new particle physics beyond the reach of LHC

Backup slides

Scintillator Surface Detector Measurement



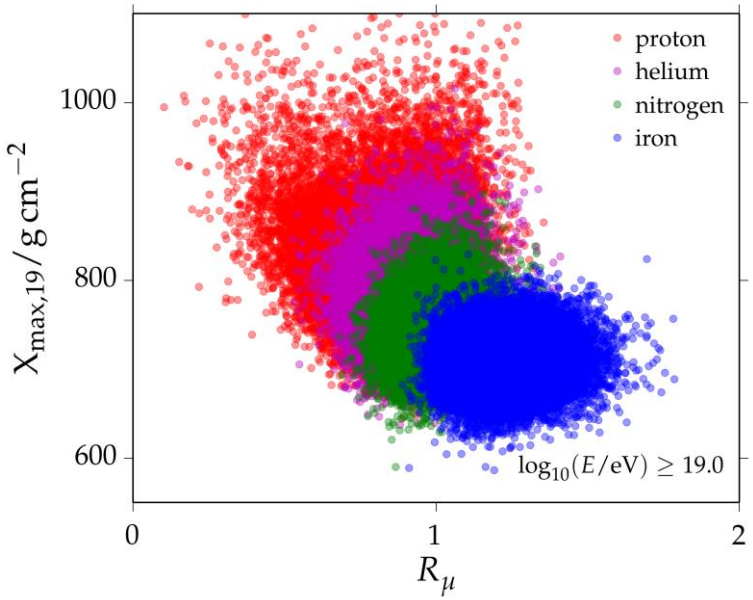
100% duty cycle

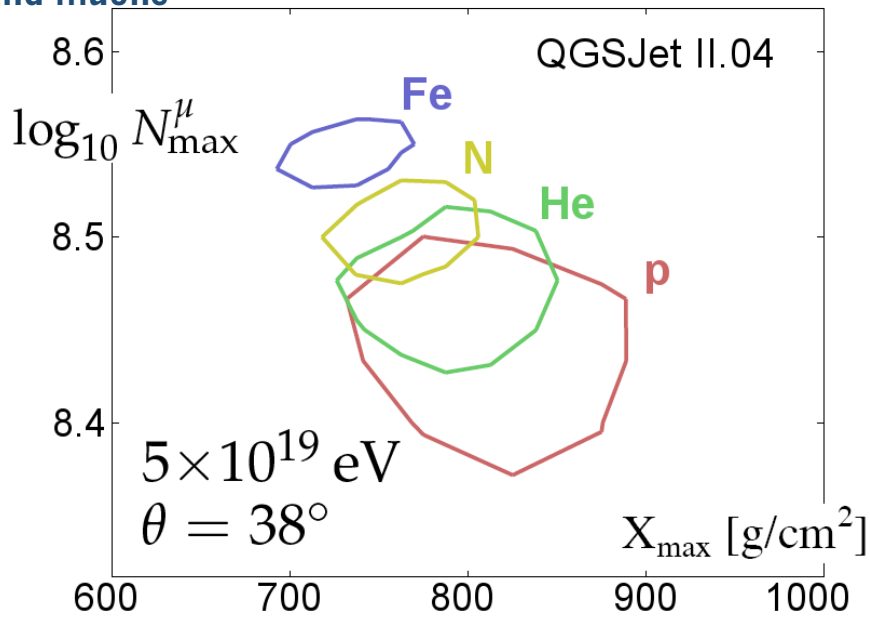
Complementarity of particle response used to discriminate electromagnetic and muonic components of air showers

with SD

main goal!

X_{max} and muons





1σ contour of the number of muons at maximum of the muon shower development

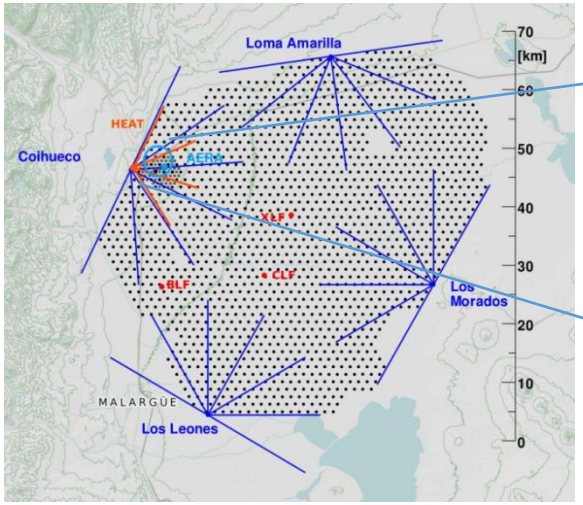
Measure muon component for composition

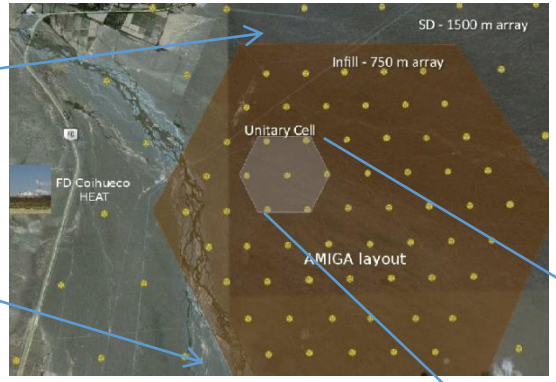
The Underground Muon Detector

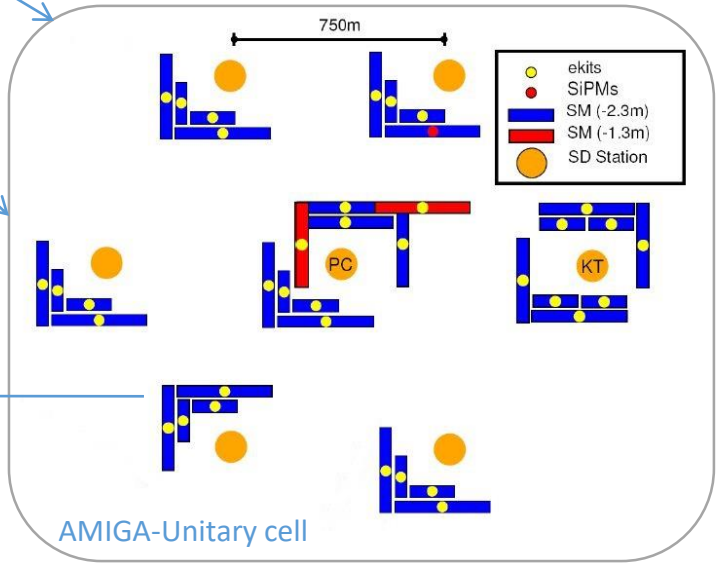
The UMD is required in the existing SD infill area of 23.5 km^2 in order to provide important direct measurements of the shower muon content and its time structure while serve as verification and fine-tuning of the methods used to extract muon information with the SSD and WCD measurements.

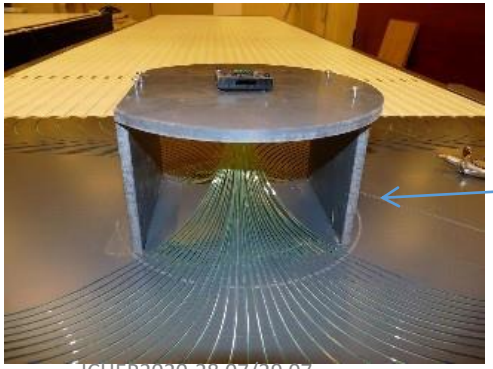
61 AMIGA muon detectors (30 m^2) are planned to be deployed on a 750m grid (a total area of 23.5 km^2)

AMIGA layout: an infill of surface stations with an inter-detector spacing of 750 m. Plastic scintillators of 30m^2 are buried under 280 g/cm^2 of vertical mass to measure the muon component of the showers. The Unitary Cell indicates the prototype area of the muon detector.







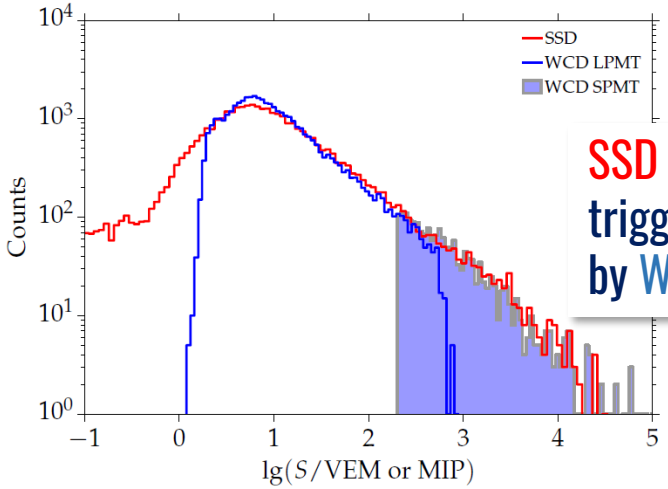


Electronics + SmallPMT Upgrade

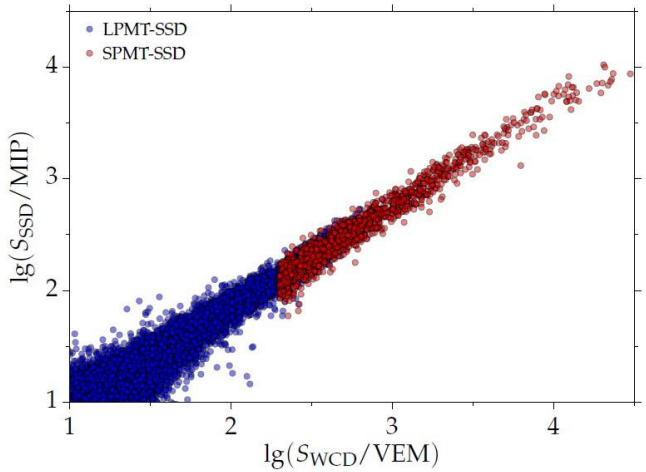
40 → 120 MHz ADC
10 → 12 bit
6 → 10+2 channels
(WCD, SSD, SPMT, radio)

12 → 4 ns GPS timing
similar power consumption
larger solar panels

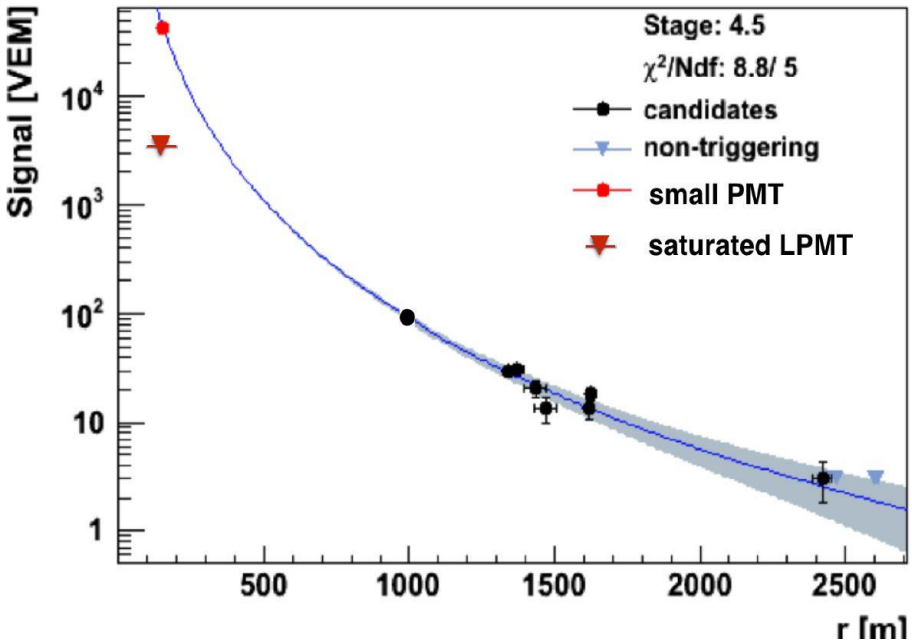
AugerPrime: Signals and dynamic range



SSD is triggered by WCD



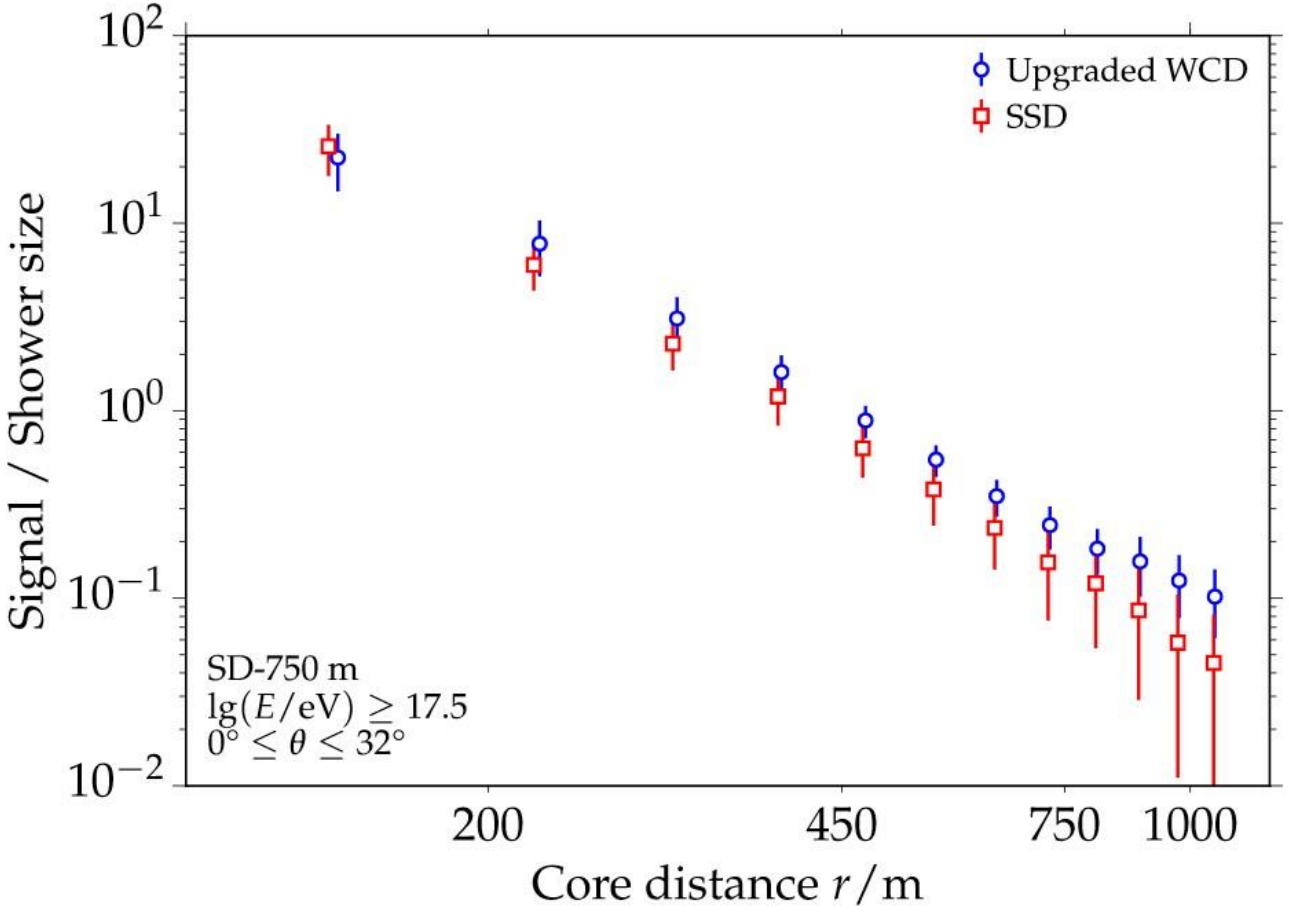
Good linearity in SSD and WCD



Example of Lateral Distribution Function for one event measured in the Engineering Array of AugerPrime

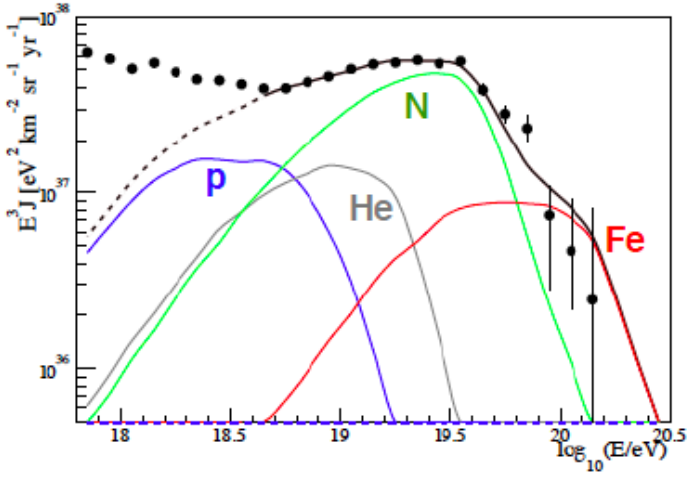
AugerPrime: first data from SSD

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



Science Impact of upgrade

Scenario 1: maximum rigidity model



Scenario 2: photo-disintegration model