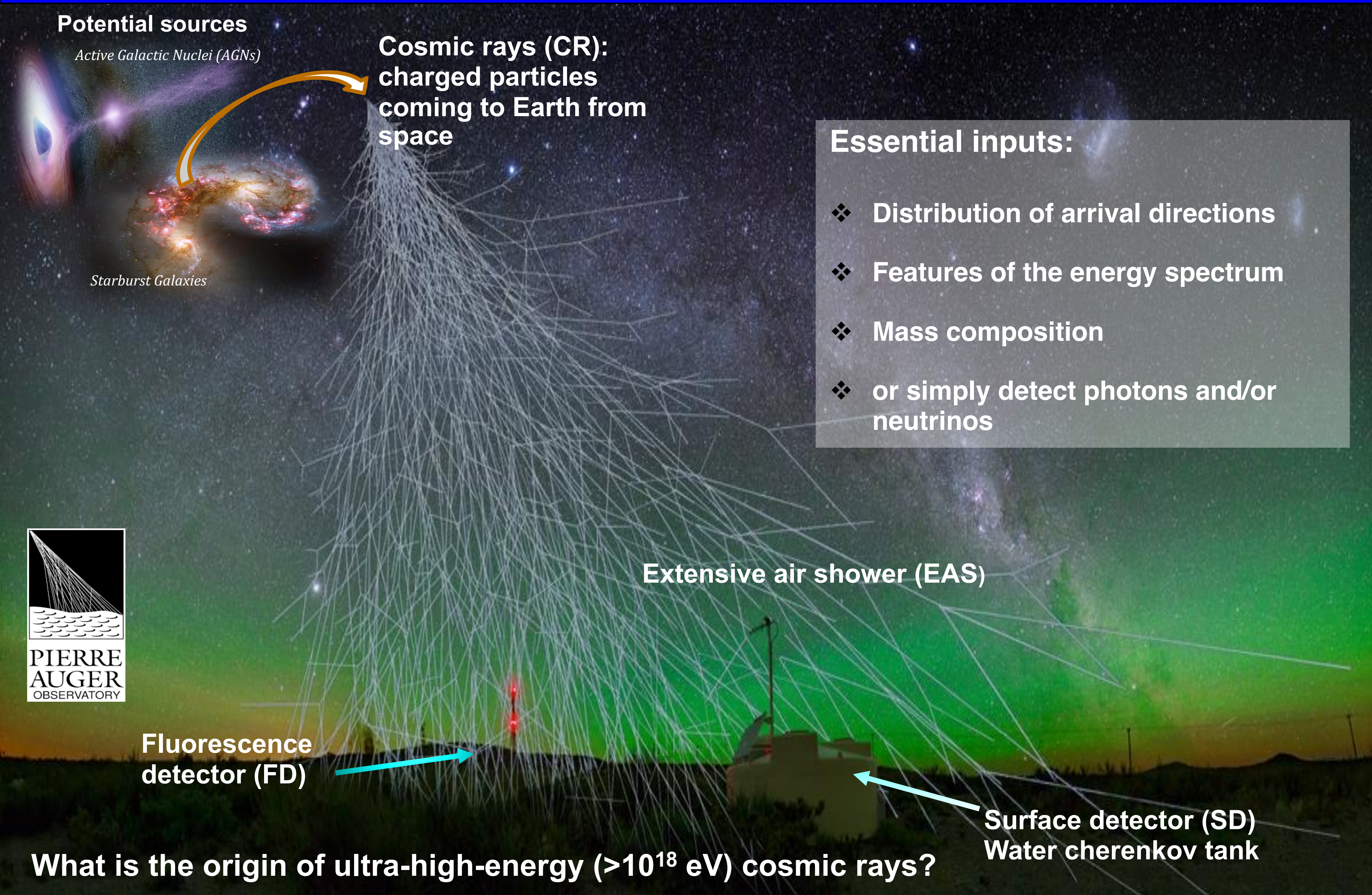
The Pierre Auger Observatory: Current Status and Expectations from its Upgrade



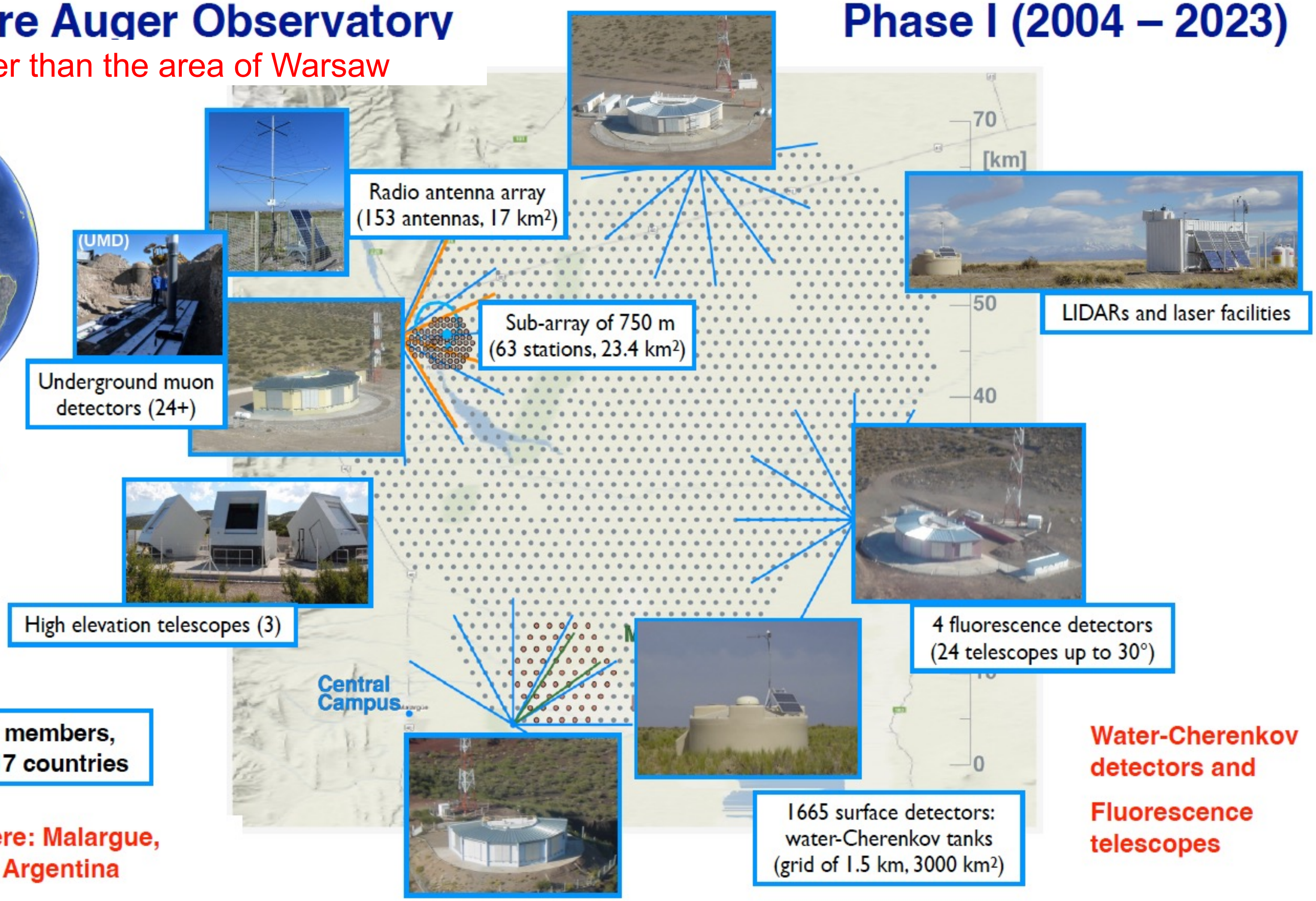
Pierre Auger Observatory: hybrid detector

Fluorescence detector (FD): 24+3

duty cycle 15%

Surface detector (SD): 1665 stations

duty cycle 100%



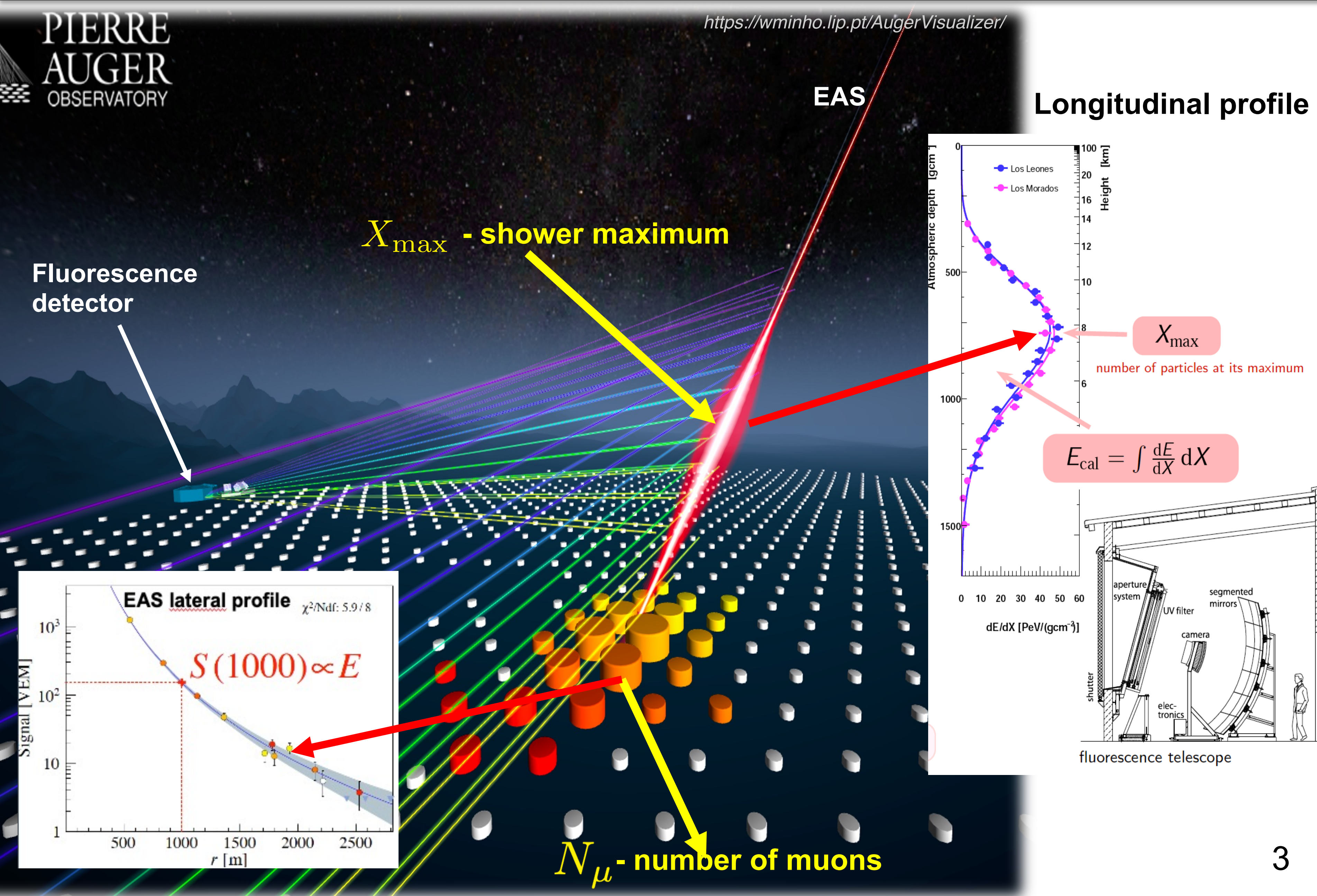
More than 400 members, 90 institutes, 17 countries

Southern hemisphere: Malargue, Province Mendoza, Argentina

Water-Cherenkov detectors and

Fluorescence telescopes

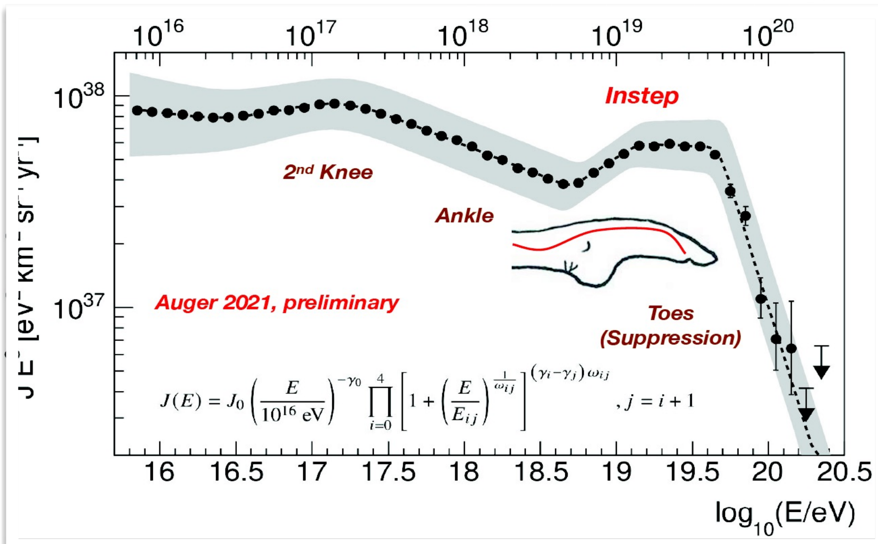
Air shower observables (hybrid observation)



Pierre Auger Observatory results from Phase I (2004-2023)

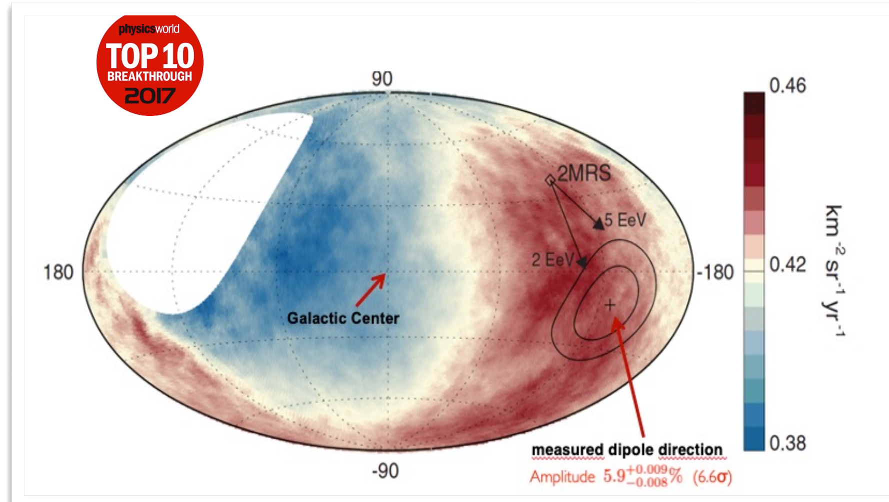
Precise measurement of the cosmic ray spectrum at the highest energies

Phys. Rev. Lett. 125 (2020) 121106 , Phys. Rev. D102 (2020) 062005
Eur. Phys. J. C81 (2021) 966



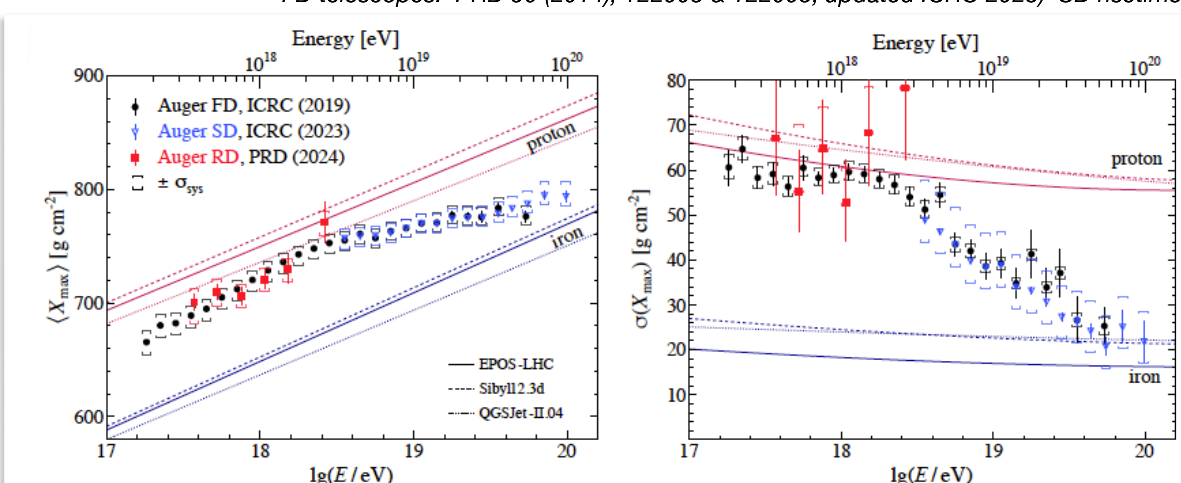
Observation of anisotropies in UHECR arrival directions (extragalactic origin)

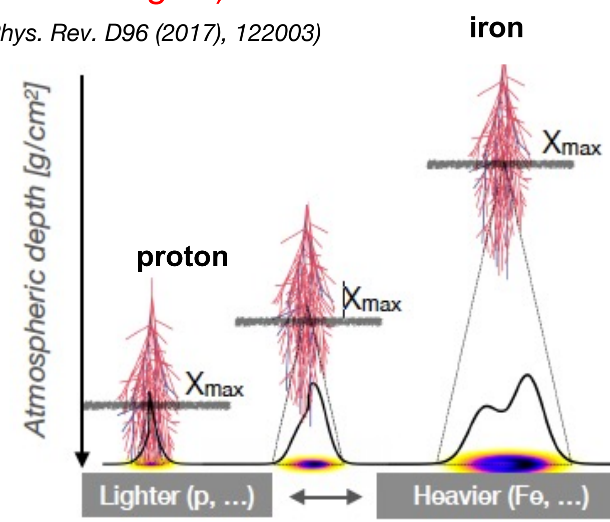
Science 357 (2017) 1266)



Mass composition results (heavier composition at highest energies)

FD telescopes: PRD 90 (2014), 122005 & 122005, updated ICRC 2023) SD risetime: Phys. Rev. D96 (2017), 122003)

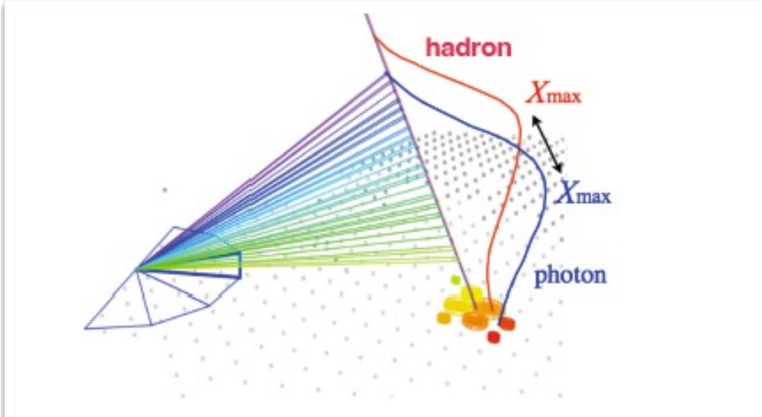




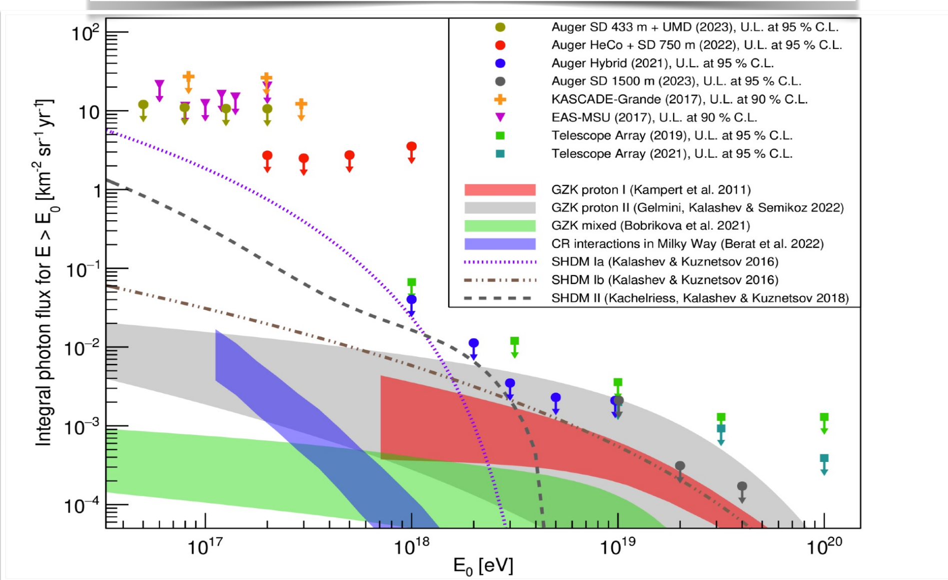
AERA/radio: PRL & PRD 2023) SD DNN: to appear in PRL & PRD)

Pierre Auger Observatory results from Phase I (2004-2023)

Multi-messenger physics – photons



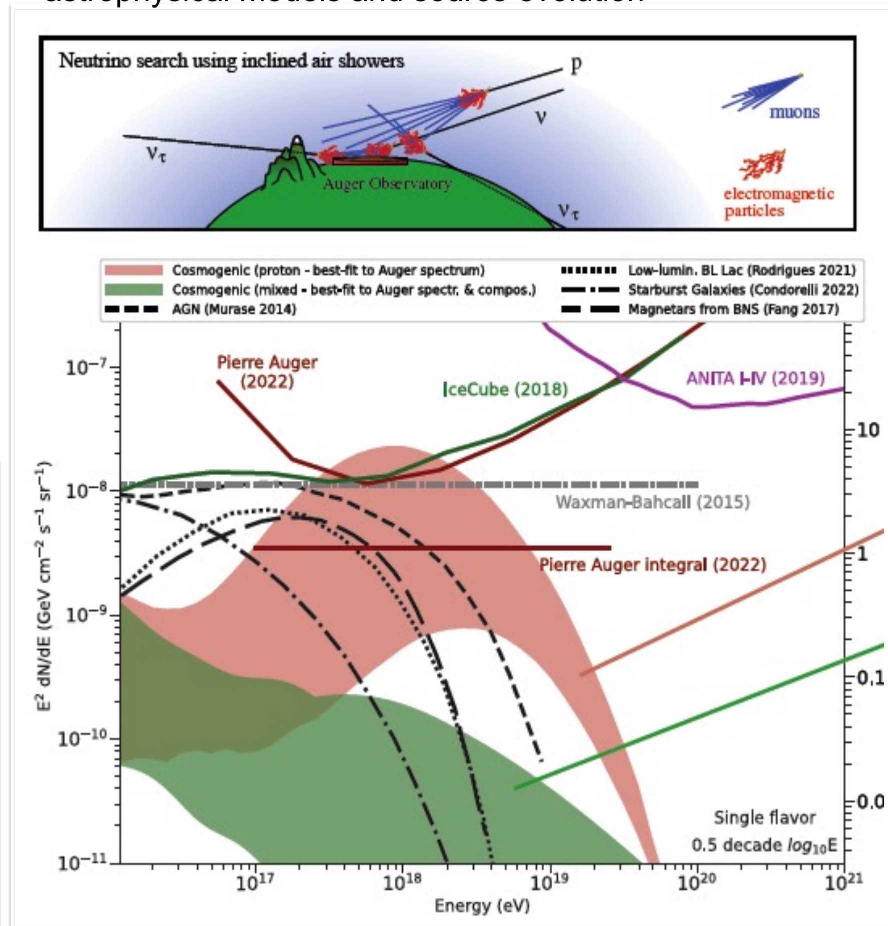
Photons interact deeper (larger Xmax), fewer muons (rise time, lateral slope)



No candidates: Super-heavy dark matter models are strongly constrained by Auger limits, significant increase of exposure needed to constrain GZK proton scenarios

Multi-messenger physics – neutrinos

No candidates: constraints on proton-dominated astrophysical models and source evolution



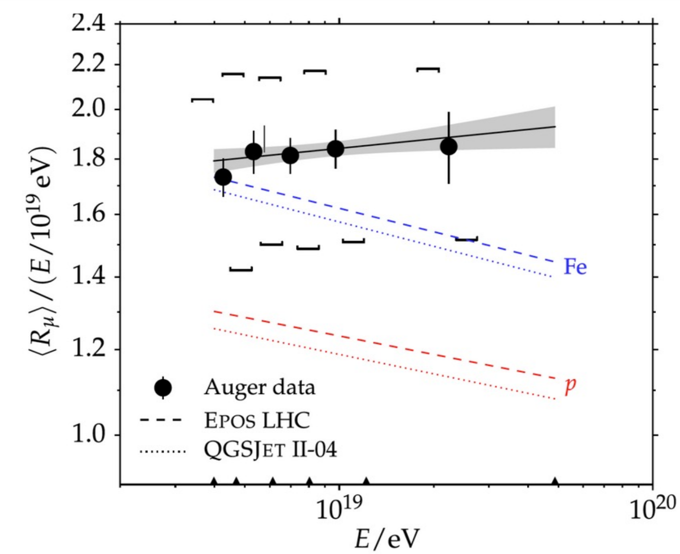
Chaitanya Priyadarshi, poster #112
Nataliia Borodai, poster #128

… and much more

Results from Phase I (2004-2023) trigerred new questions

- Surprising composition measurement: intermediate nuclei, neither pure protons nor iron
- Given new paradigm of UHECR composition evolving to heavier masses with increasing energy, need more sensitive measurements on event-by-event basis to:

- understand tensions with hadronic interaction models
  (see also talk by Jan Pękala at this conference and Megha Mogarkar poster #116)



The Pierre Auger Collaboration, PRD D91 (2015) 3, 032003

- achieve good event-by-event discrimination of light/heavy particles

- perform composition-enhanced, rigidity-based anisotropy studies

…and we need this with a very large exposure and composition sensitivity at all showers declinations

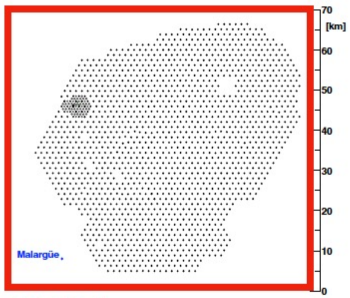
Upgrade of the observatory: AugerPrime

Phase I (2004 – 2023)

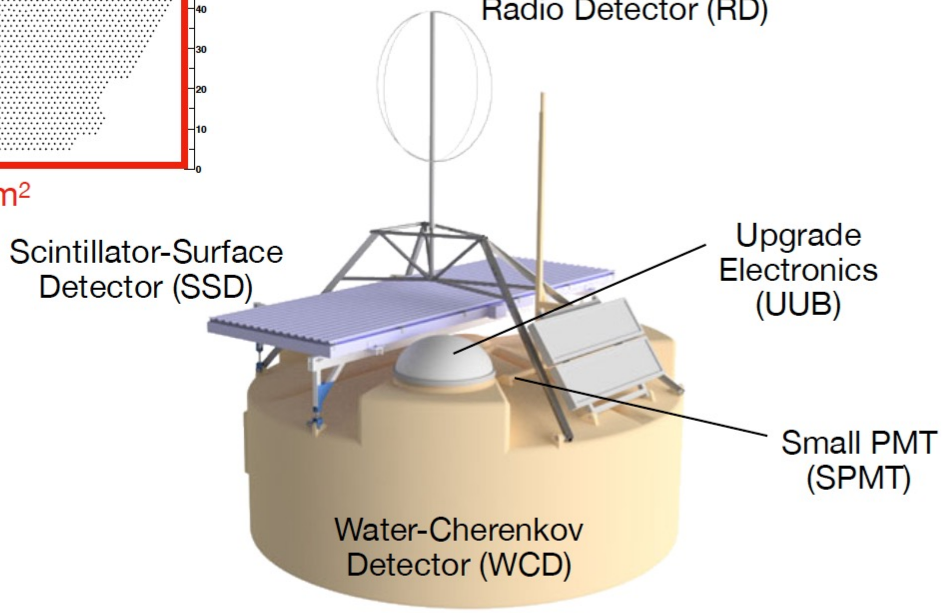
Phase II (from 2024)

Upgrade of the observatory: AugerPrime

AugerPrime surface detector

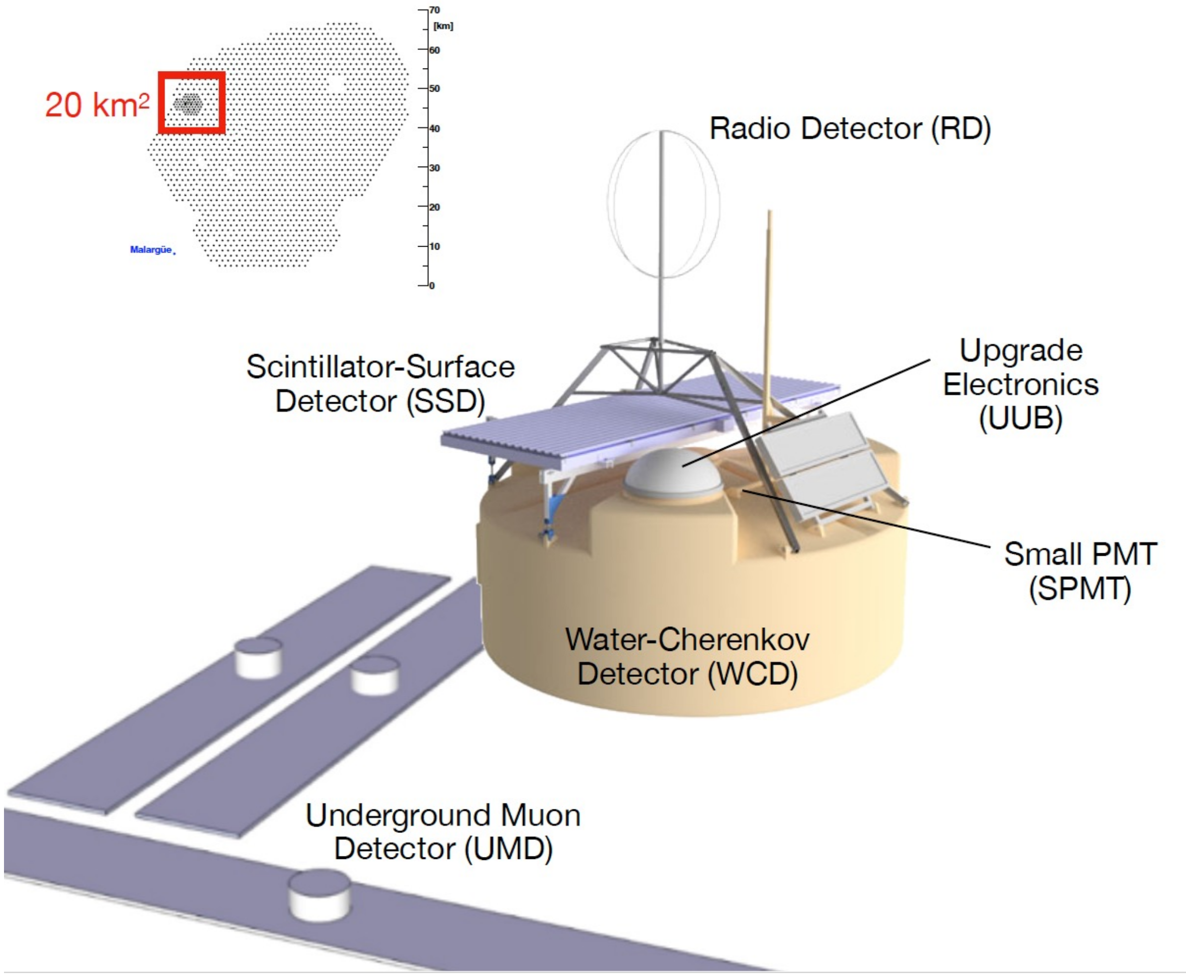


3000 km²

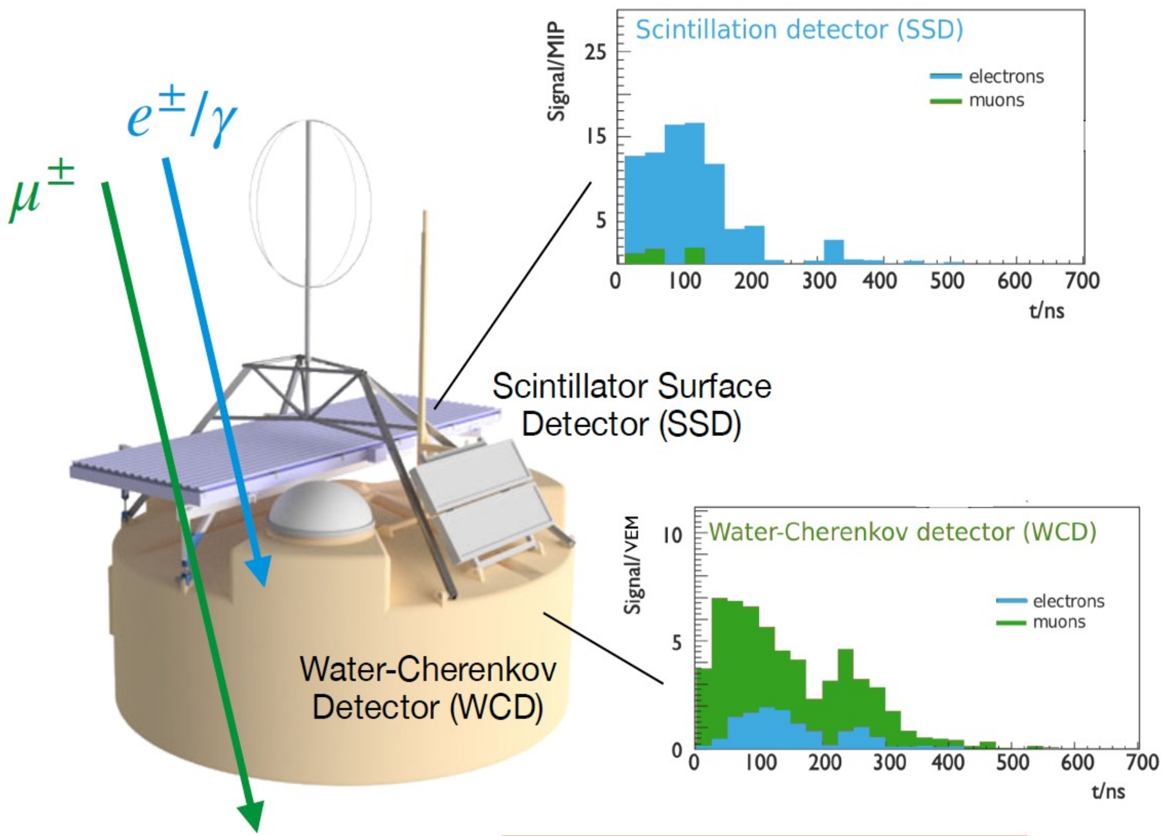


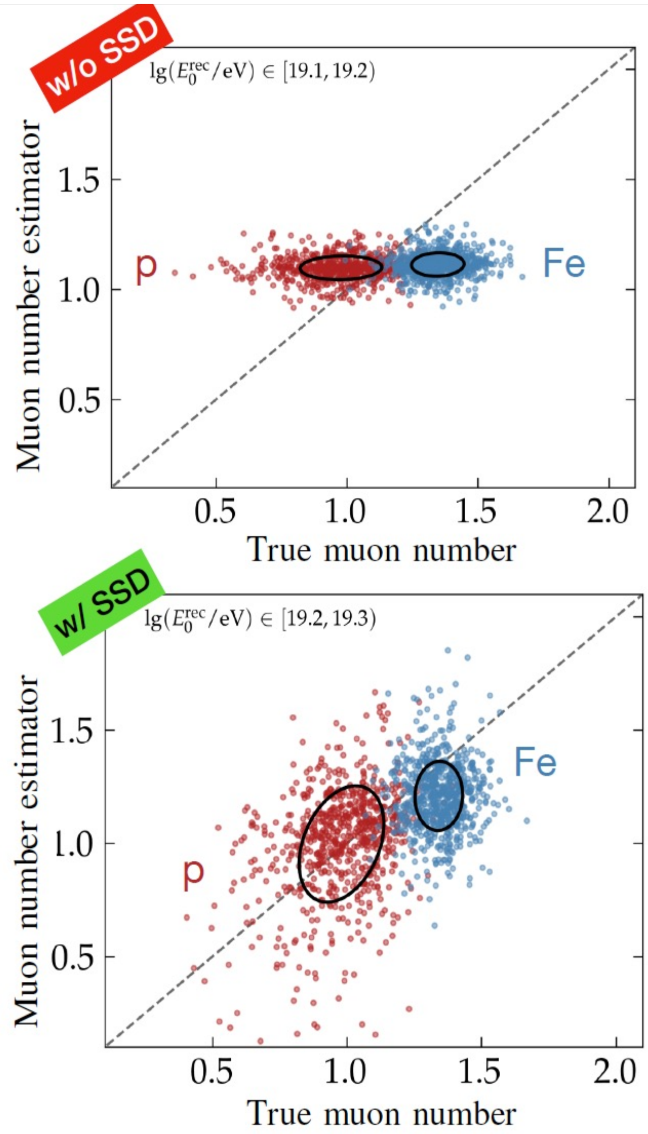
Upgrade of the observatory: AugerPrime

AugerPrime surface detector



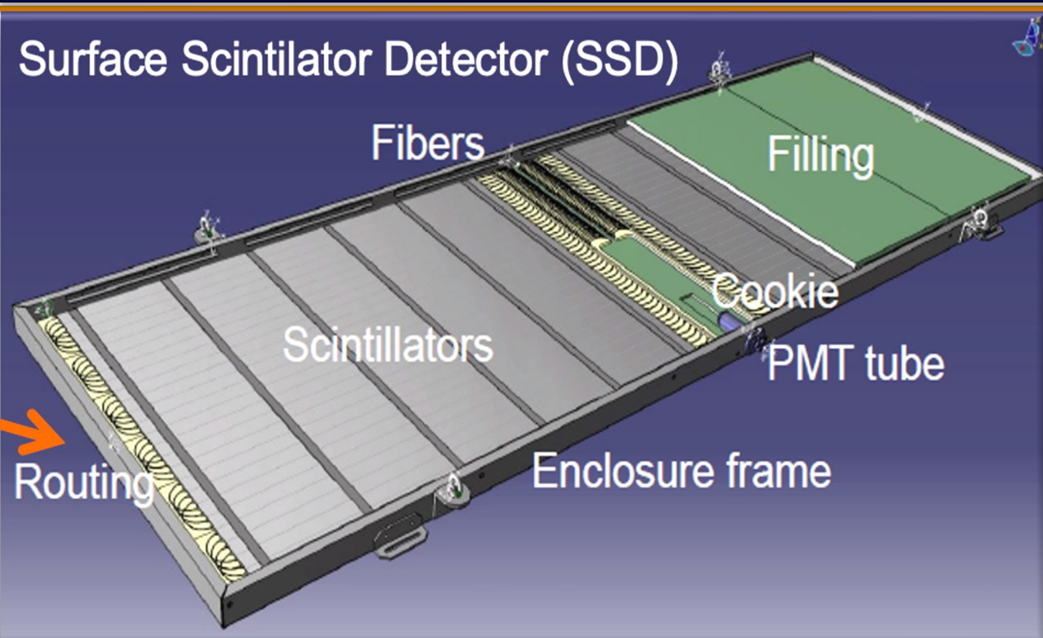
"Vertical" events | θ < 60°

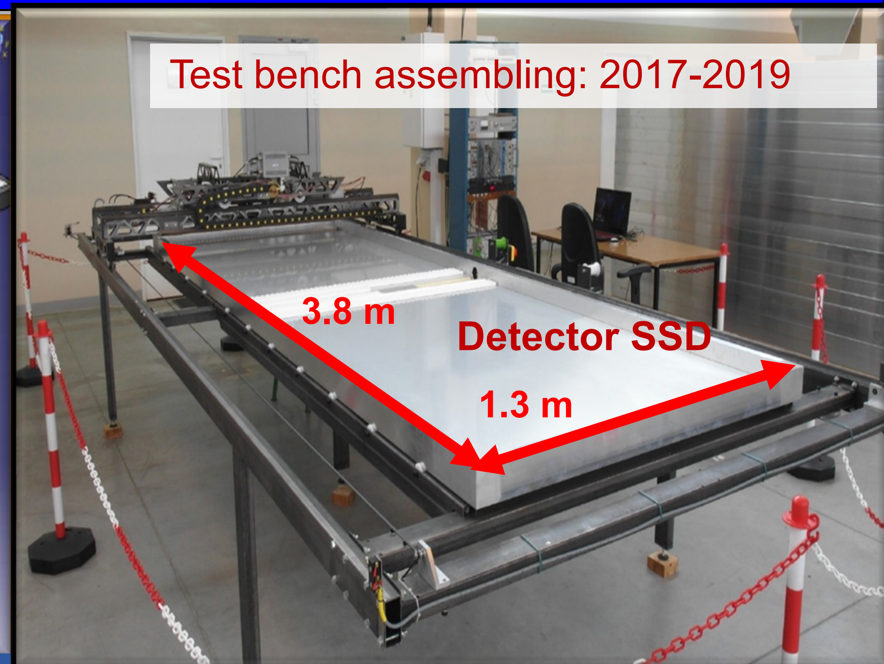




$$S_{\mu,\mathrm{WCD}} = a S_{\mathrm{WCD}} + b S_{\mathrm{SSD}}$$
$$S_{\mathrm{em,WCD}} = c S_{\mathrm{WCD}} + d S_{\mathrm{SSD}}$$

AugerPrime upgrade: contribution of IFJ PAN





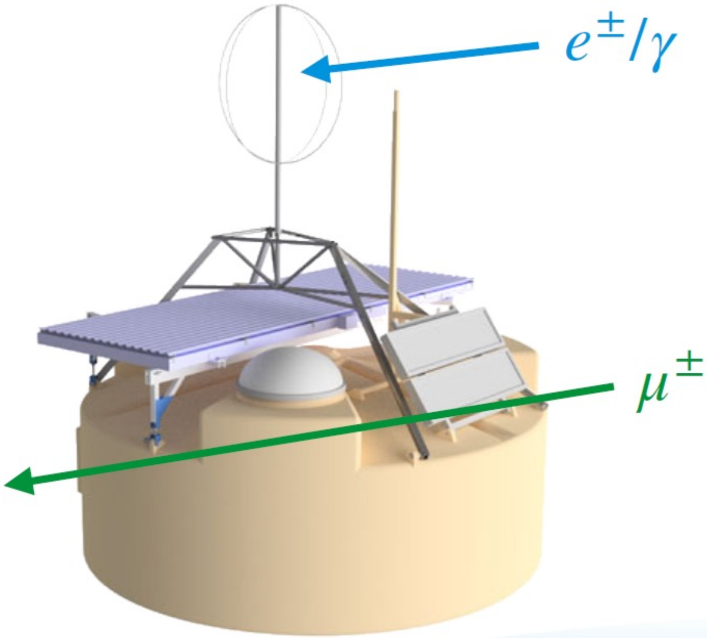
March 2021: the last container sent to Argentina

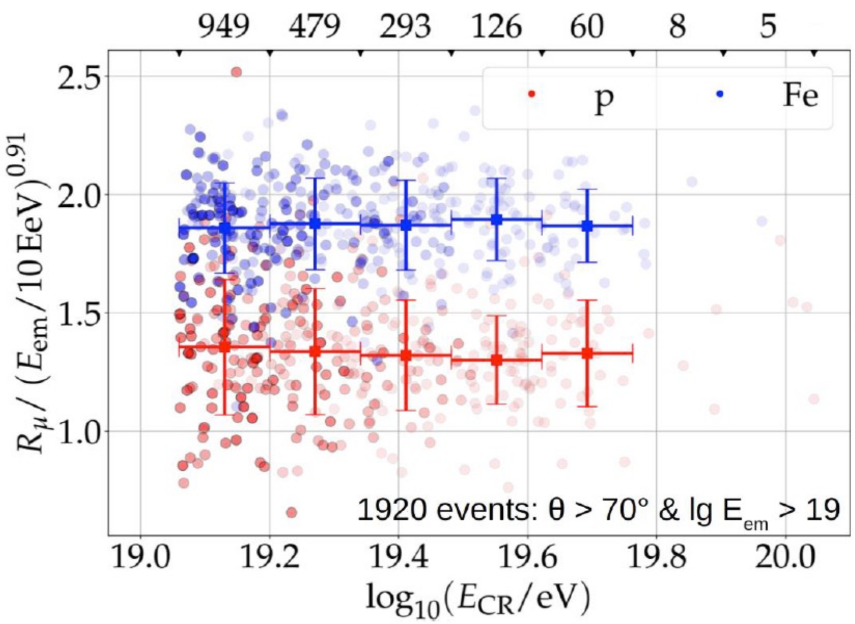
Deployment completed in mid-2023

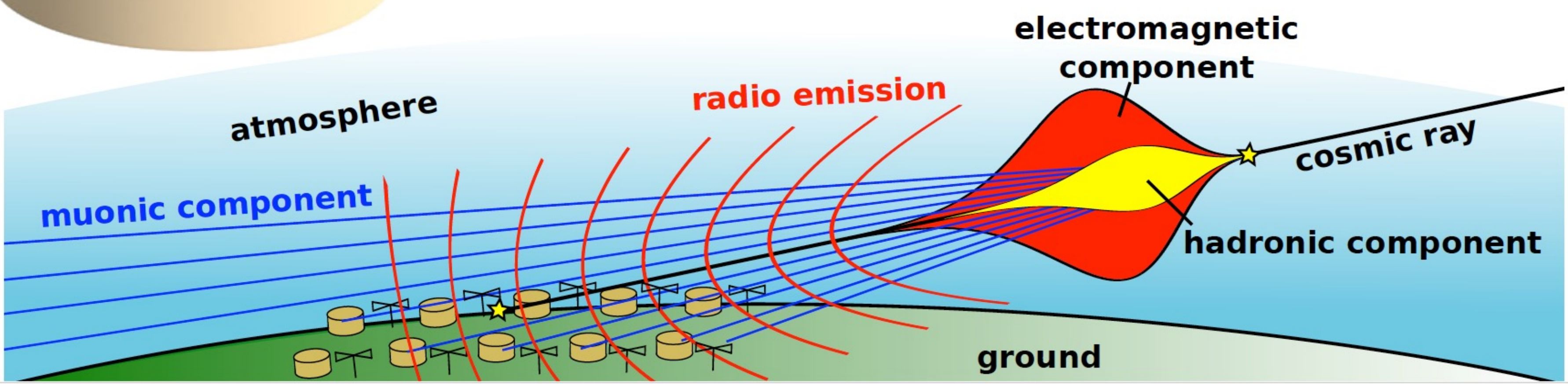
Together with engineers from IFJ PAN, 228 (out of 1519) SSD have been assembled and tested

Upgrade of the observatory: AugerPrime (radio detector)

“Inclined” events | θ > 65°

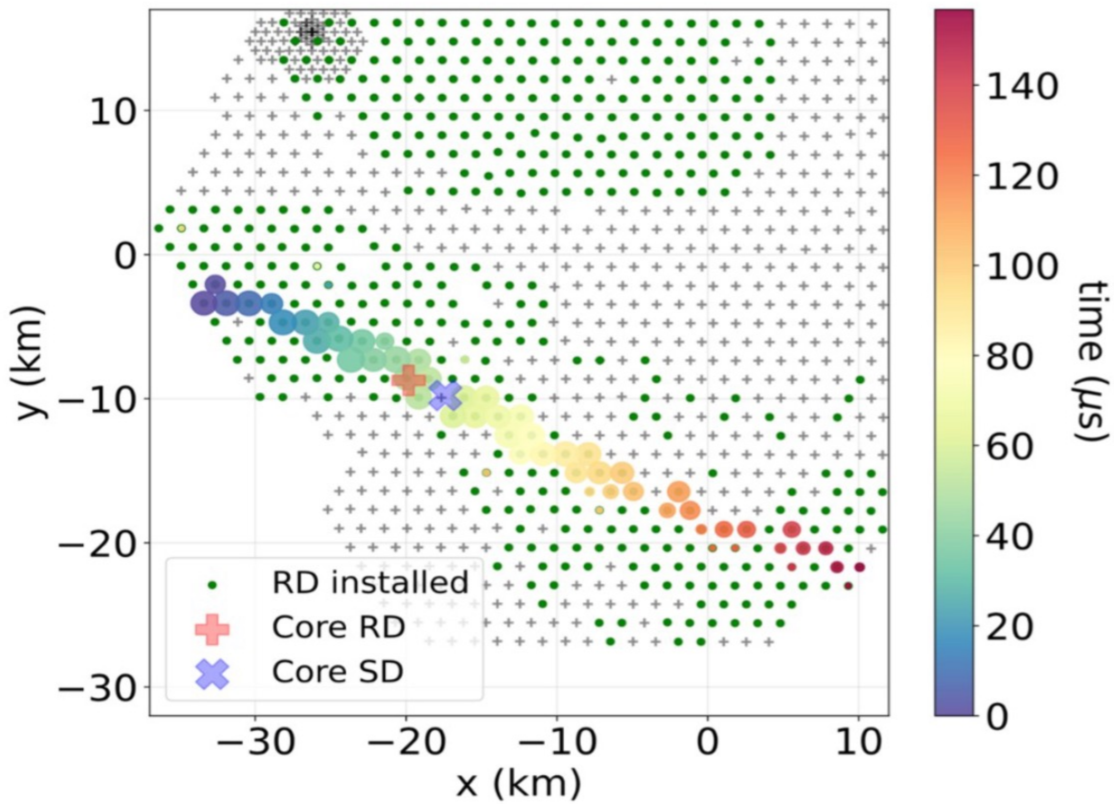




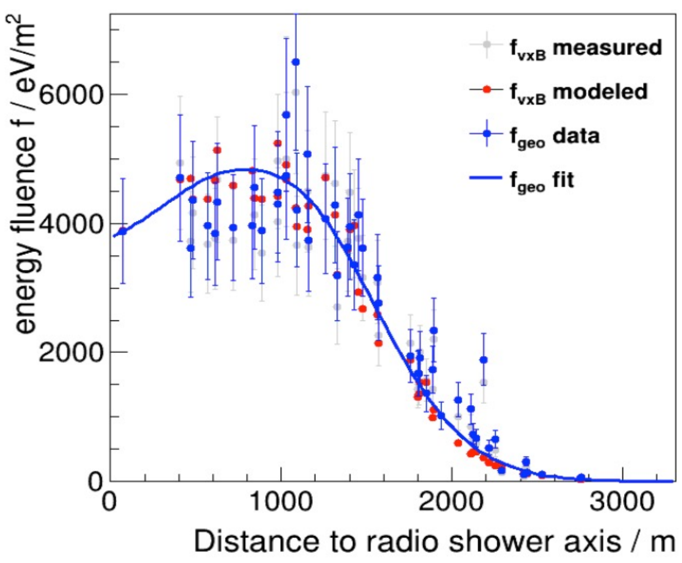


Upgrade of the observatory: AugerPrime (radio detector)

Coming online | Example "inclined" event



	RD	SD
Azimuth (deg)	156.99±0.01	157±0.1
Zenith (deg)	84.7±0.01	84.7±0.1
Energy (EeV)	36.23 ± 3.34	38.55 ± 2.92
Core X (km)	-19.8	-17.40±0.88
Core Y (km)	-8.73	-9.78±0.45



Upgrade of the observatory: AugerPrime (electronics)

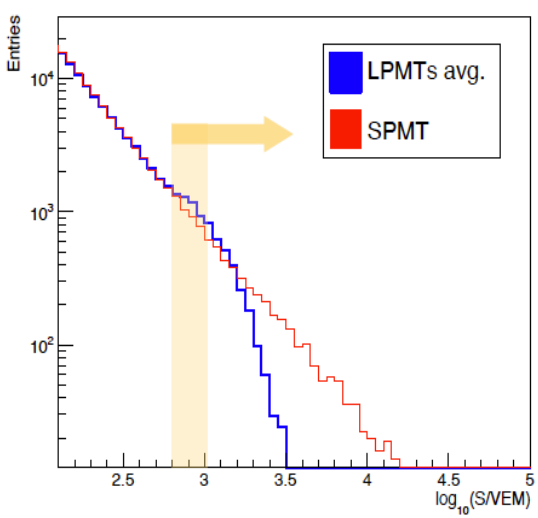
Upgrade Electronics (UUB) and Small PMT (SPMT)

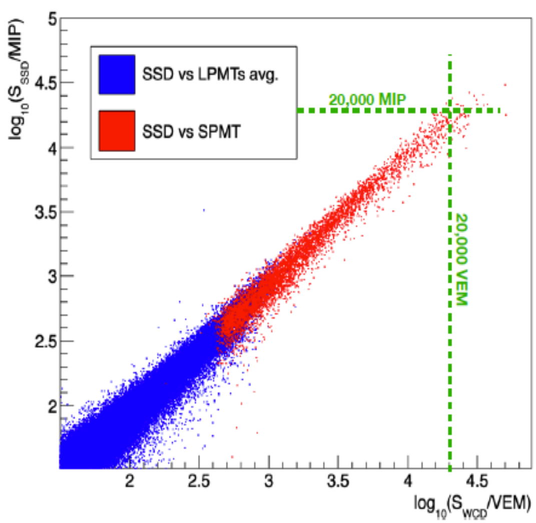
Improved timing/signal resolution

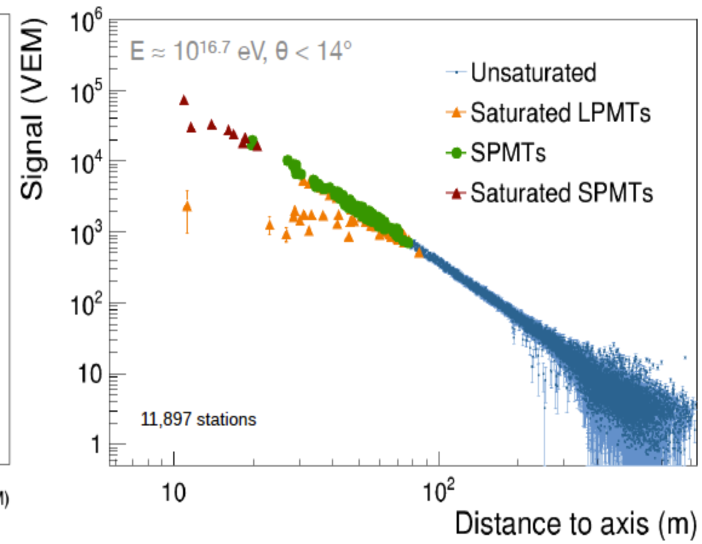
- 120 MHz sampling (previously 40 MHz)
- 5 ns GPS resolution (previously 8 ns)
- 12 bits dynamic range (previously 10 bits)

Improved dynamic range with small PMT

- Saturation at 200 m from axis at 100 EeV (previously ~600 m)
- Calibrated using local, low energy showers (rate of ~200/hour)
- Minimize difference between signal spectra of small and large WCD PMTs



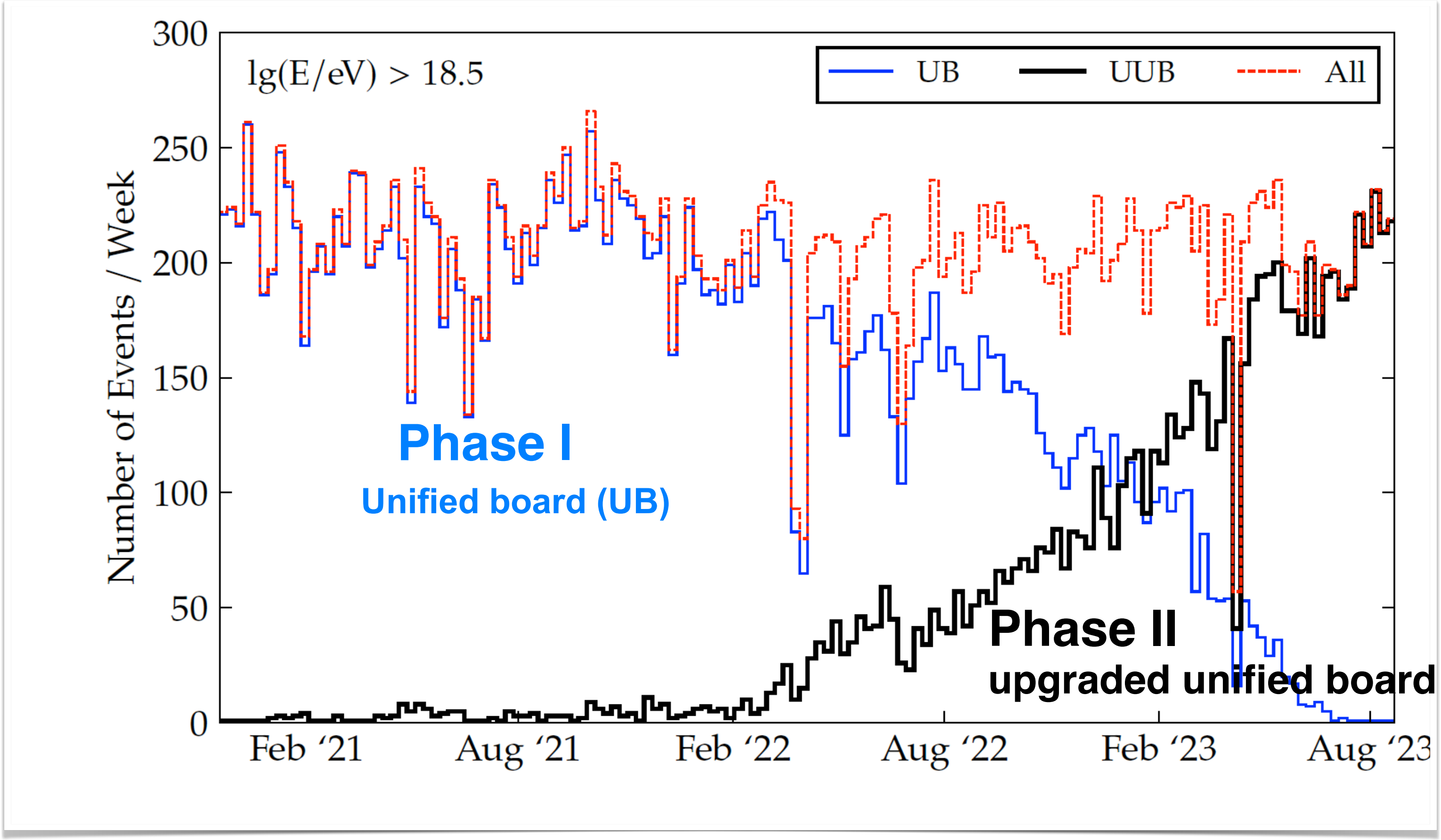




Upgrade of the observatory: AugerPrime (electronics)

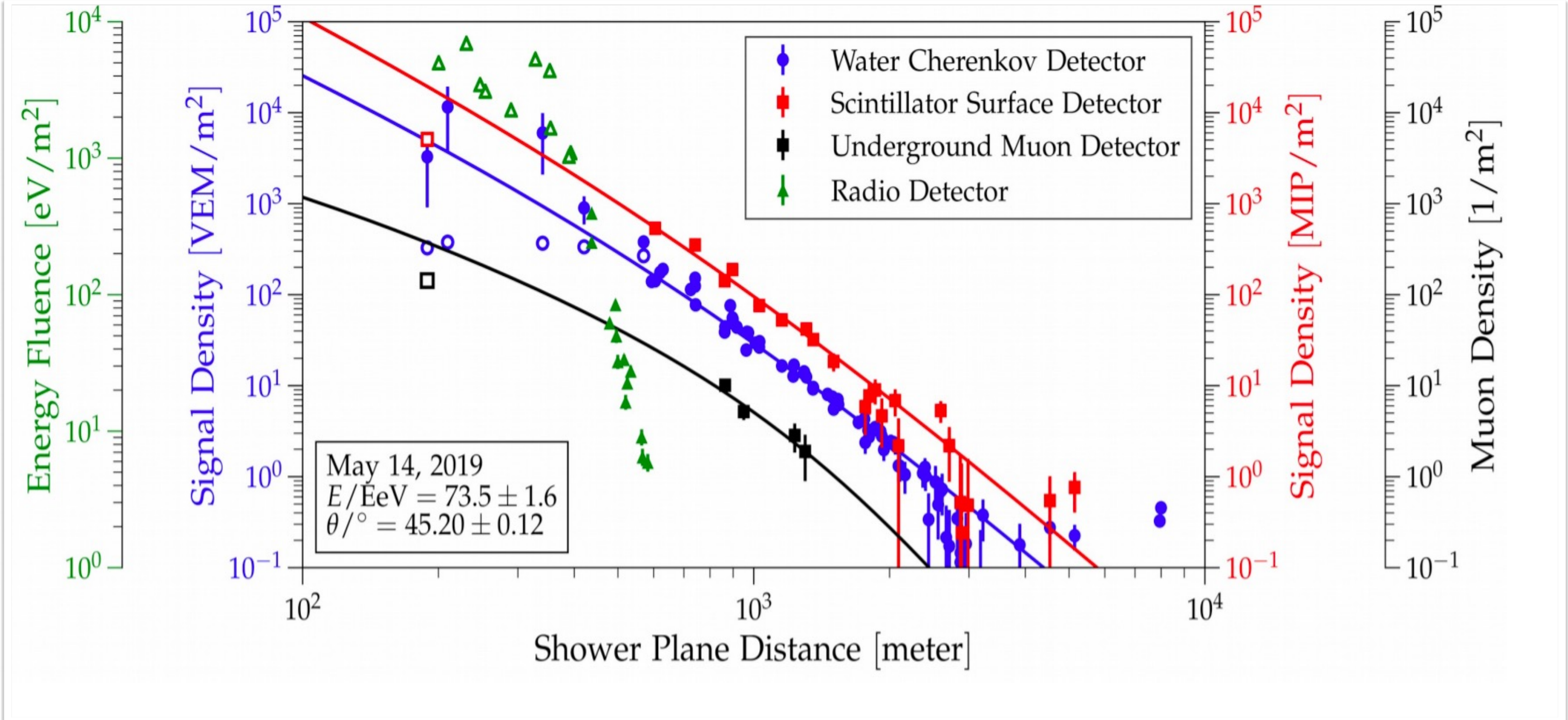
Trigger commissioning

- Currently operating triggers in "compatibility mode" with Phase I
- Purity of event-level triggers same as for Phase I
- Over 99.9% of events satisfying higher-level real shower selection get reconstructed
- Improved trigger algorithm deployed on stations and optimization of central data acquisition reduce downtime due to lightnings to <1%



Scientific data: next decade

Multihybrid data from AugerPrime



Extension of Auger data taking until 2035

Nov. 2023: AugerPrime review

Enthusiastic recommendation of the committee conveyed by the chair ***F. Halzen***

"We … unanimously and enthusiastically recommend to continue the experiment for at least ten years after 2025."

"I have no doubt that Auger will never disappear, it will reincarnate, this is a facility."

November 16, 2024: extension of International Agreement (IA) for Auger Phase II

Nov. 16, 2024: extension of IA

gov.pl

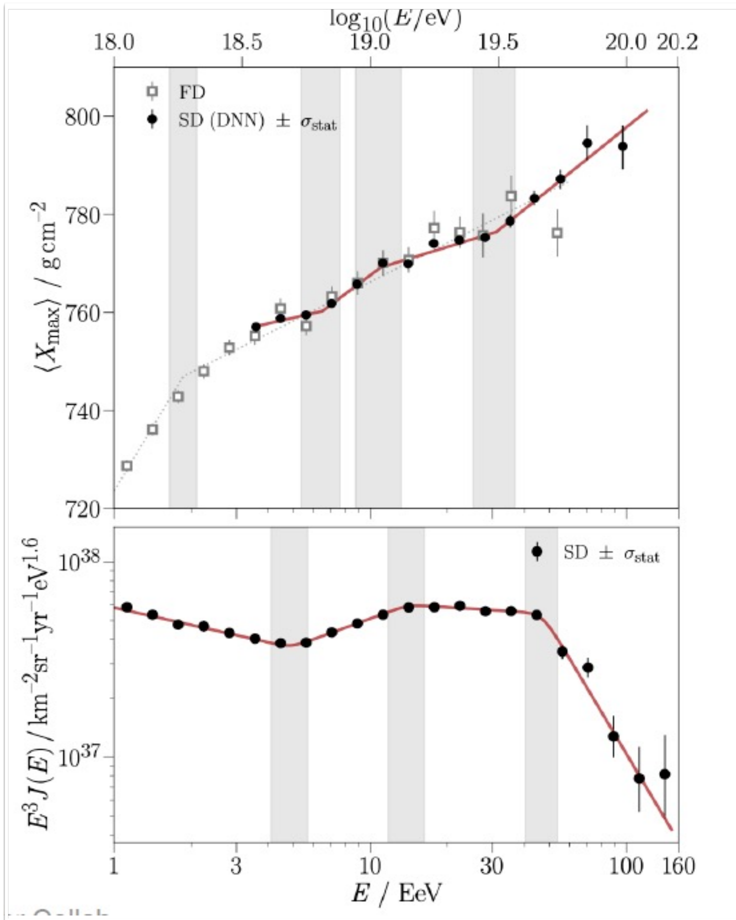
Polscy badacze w Obserwatorium Pierre Auger

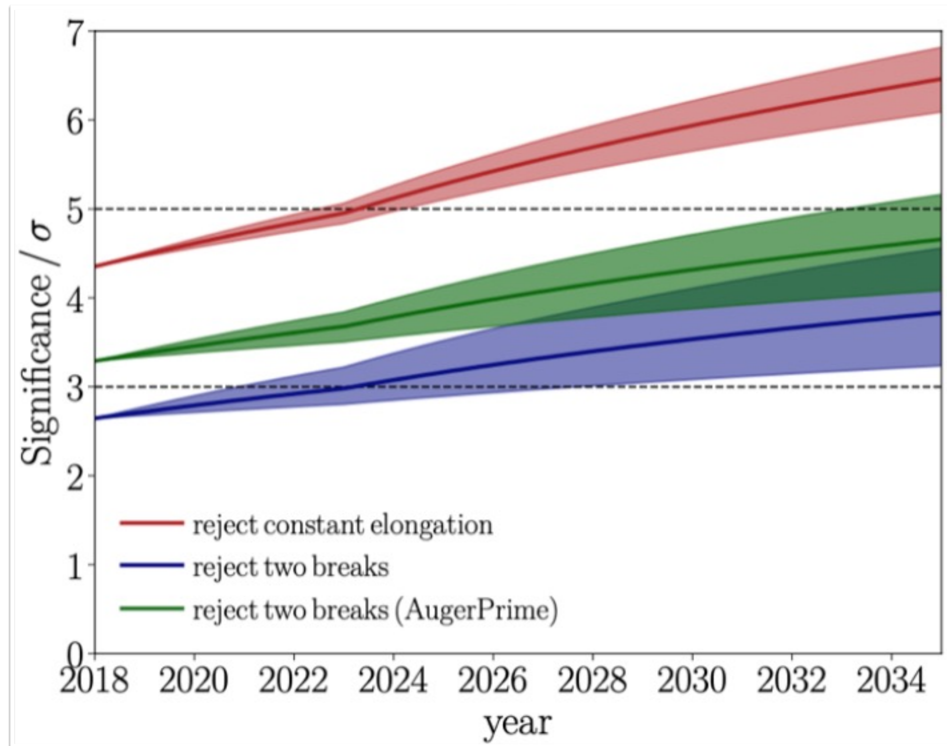
19.11.2024

Projekt, w którym uczestniczy ponad 400 naukowców z 17 krajów, wyróżnia się znaczącym wkładem polskich badaczy z Instytutu Fizyki Jądrowej PAN w Krakowie.

What is to come

Breaks in elongation rate



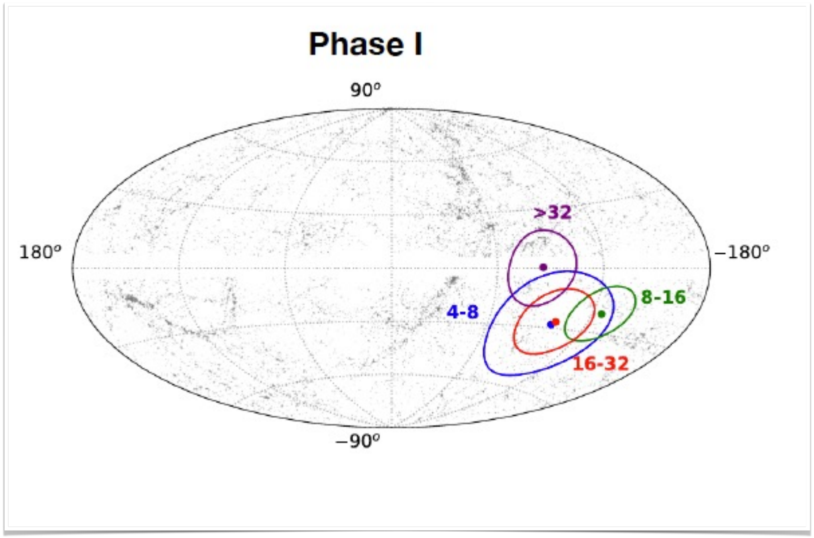


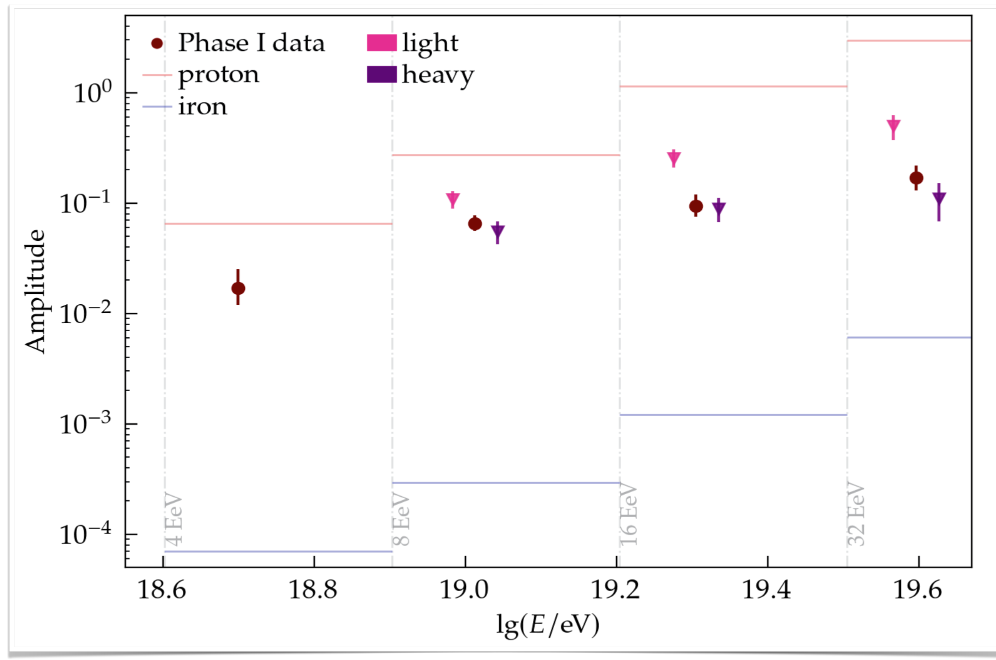
Auger Collab. Phys. Rev. D 111, 022003 (2025) & Phys. Rev. Lett. 134, 021001 (2025)

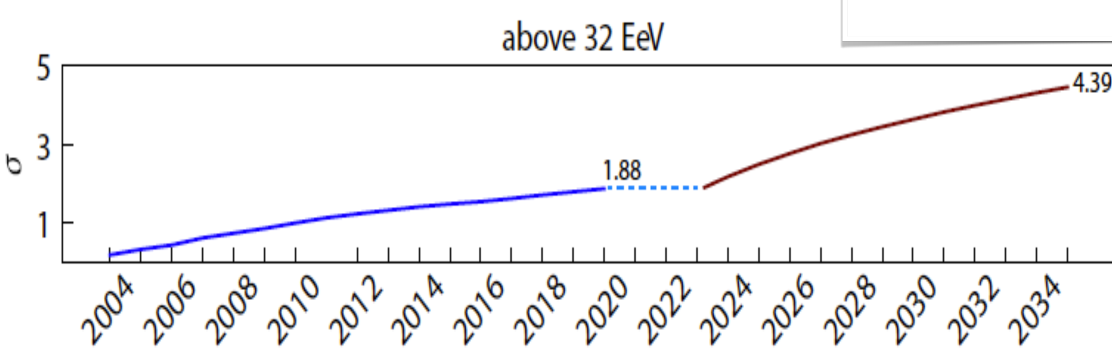
What is to come

AugerPrime allows probing mass dependence of arival directions

Depending on role of composition and source characteristics, allows establishment of mass dependence with significance within lifetime of experiment







Summary and Outlook

AugerPrime upgrade combines composition sensitivity at all showers declinations and with large aperture of surface detector array

- Phase II (with upgraded detectors) of the Observatory has started
- Will operate until at least 2035

Expect first physics results soon

Upgrade of the observatory: AugerPrime (radio detector)

- Dual polarized SALLA antenna

- 30-80 MHz • Calibration based on chain established in AERA

- Lab measurements of response of hardware components

- Simulation + drone measurement of directional response of full signal chain

- Milky Way radio emission source for absolute calibration

- Agreement between lab and galactic calibration within 5%

- Essentially no aging effects in calibration procedure (0.3 ± 1.4% / decade)