AugerPrime

Primary cosmic ray identification for the next 10 years

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The Pierre Auger Observatory

The primary goal is to study the most energetic cosmic rays in the Southern hemisphere, province Mendoza in Argentina.

Flat semi-desert area of 3000 km$^2$ (1300 – 1500 m a.s.l.)

Construction started in 2004 and was finished in 2008.

The Auger observatory consists of

* **Surface detector (SD):** 1660 stations
* **Fluorescence detector (FD):** 24 telescopes

Extensions:

* **High Elevated Auger Telescopes (HEAT)**
* **Underground muon detector (AMIGA)**

R&D activities: radio (AERA), GHz, etc.
Results of the Auger Observatory

Very strong flux suppression above $5 \times 10^{19}$ eV (caused by CR propagation or sources?)

Photon and neutrino upper limits (top-down models are excluded)

Mass composition change (but no data above $5 \times 10^{19}$ eV)

Deficit of muons

and many others...
Motivation for the upgrade

To provide additional measurements to allow us to address the following questions:

1. The origin of the flux suppression at the highest energies

   *Measurement of the mass composition beyond the reach of the FD.*

2. Proton contribution in the flux suppression region ($E > 5 \times 10^{19} \text{ eV}$)

   *Search of point sources and estimate the physics potential of existing and future cosmic ray, neutrino, and gamma-ray detectors.*

3. Fundamental particle physics at energies beyond reach of man-made accelerators

   *Study extensive air showers and hadronic multiparticle production.*

Mass composition measurement above $5 \times 10^{19} \text{ eV}$ with a sensitivity to the proton flux as small as 10%.
How to do it?

Measure with the Pierre Auger Observatory (designed 15 yrs ago) until the end of 2024. MOUs have been signed in Nov 2015.

Proposed upgrades:

1) Upgrade surface detector electronics & a small PMT

2) Scintillator SD (SSD) to measure the mass composition with 100% duty cycle

3) Finish AMIGA to have a direct muon measurement

4) Extended FD operation

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Event statistics will more than double compared with the existing data set, with the critical added advantage that every event will now have mass information.

| $\log_{10}(E/\text{eV})$ | $\frac{dN}{dt}|_{\text{infill}}$ [yr$^{-1}$] | $\frac{dN}{dt}|_{\text{SD}}$ [yr$^{-1}$] | $N|_{\text{infill}}$ [2018-2024] | $N|_{\text{SD}}$ [2018-2024] |
|-----------------------|-------------------------------|-------------------------------|------------------|------------------|
| 17.5                  | 11500                         | -                            | 80700            | -                |
| 18.0                  | 900                           | -                            | 6400             | -                |
| 18.5                  | 80                            | 12000                        | 530              | 83200            |
| 19.0                  | 8                             | 1500                         | 50               | 10200            |
| 19.5                  | $\sim 1$                      | 100                          | 7                | 700              |
| 19.8                  | -                             | 9                            | -                | 60               |
| 20.0                  | -                             | $\sim 1$                     | -                | $\sim 9$         |
1. Increase of the data quality (better timing, dynamic range and μ identification):
   a) faster sampling of ADC traces (40 → 120 MHz)
   b) more precise absolute timing accuracy (new GPS receiver)
   c) increase the dynamic range by adding a 1” PMT (SD PMTs are 9”)

2. Faster data processing and more sophisticated local triggers (more powerful processor and FPGA)

3. Improved calibration and monitoring capabilities

4. New components:
   a) Connection to the SSD and any additional (R&D) detectors
   b) Prolong lifetime and reduce failure rate

Prototype is being tested.
Complementarity of particle response used to discriminate electromagnetic and muonic components of air showers.

Both, $N_\mu$ and $X_{\text{max}}$, can be reconstructed from WCD and SSD.
Scintillator detector

Fibers routing

WLS fibers

Extruded scintillator bars (1600 x 50 x 10 mm)

Alu enclosure

Support frame

PMT/SiPM

Sunroof
The underground muon detector

61 AMIGA muon detectors (30 m²) are planned

Will be deployed on a 750m grid (a total area of 23.5 km²)
Standard FD operation

FD provides exceptional information (e.g. model-independent energy reconstruction & mass composition measurement).

The main limitation of the FD is its duty cycle (15% nowadays).

The current criteria for FD measurement:
1. The sun more than 18° below the horizon
2. The moon remains below horizon for longer than 3 hours
3. The illuminated fraction of the moon must be below 70%

Pierre Auger Coll., NIMA 798 (2015)

Measurement periods (~17 nights long), limit on the PMT illumination (i.e. no rapid aging), and the PMT response stays linear.

By relaxing criteria #2 and #3 the FD duty cycle can be increased by 50%, while keeping very high selection efficiency and reconstruction.
Extended FD operation

Clear sky, no moonlight  
40 times higher NSB (90% moon)

15% duty cycle

Increase by 50% by measurement during high night sky background

\[ E = 7 \times 10^{19} \, \text{eV} \]

10x reduced PMT gain by reducing supplied HV.

Successful test has been done last year.

Radomír Šmída – AugerPrime  \( E = 72 \pm 3 \, \text{EeV} \)
Conclusions and outlook

AugerPrime will allow a study of mass composition above $5 \times 10^{19}$ eV and address:

1. Origin of the flux suppression (GZK energy loss vs. maximum energy of sources)
2. Proton contribution of more than 10% above $5 \times 10^{19}$ eV? (particle astronomy, GZK $\gamma$ and $\nu$ fluxes $\rightarrow$ future experiments)
3. New particle physics beyond the reach of LHC?

Timeline for new SDE and SSD:

- Jul/Aug 2016: Engineering Array (12 stations)
- Nov 2016: Evaluation of detectors
- 2017-2018: Deployment
- Till Jan 2025: Data taking (up to 40,000 km$^2$ sr yr)

*Similar event statistics as collected so far will be reached with upgraded detectors.*

**Mass composition info on event-by-event basis**

Total cost: *about $12M (w/o AMIGA)*

The FD duty cycle extension will be evaluated after additional tests.