AugerPrime: The Pierre Auger Observatory Upgrade

D. Martello\textsuperscript{(a)} on behalf of the Pierre Auger Collaboration

(a) University of Salento and INFN Lecce
Some results from the Pierre Auger Observatory

Strong flux suppression above $4 \times 10^{19}$ eV

ICRC2017 Busan D. Martello
Some results from the Pierre Auger Observatory

The directions of the highest energy events are compatible with isotropy, but there is still hints for excess in some directions. Moreover there is an evident dipole for energies E>8 EeV.

Strong flux suppression above $4\times10^{19}$eV

Accepted for publication in JCAP
Some results from the Pierre Auger Observatory

The directions of the highest energy events is compatible with isotropy, but there is still hints for excess in some directions. Moreover there is an evident dipole for energies $E > 8 \times 10^{18.4}$ eV.

The trend of the He and N fractions as a function of energy has a strong dependence on the particular hadronic model used. However, the three hadronic models agree when estimating a null Fe abundance between $10^{18.3}$ eV and $10^{19.4}$ eV.

Strong flux suppression above $4 \times 10^{19}$ eV.
Some results from the Pierre Auger Observatory

The directions of the highest energy events are compatible with isotropy, but there is still hints for excess in some directions. Moreover, there is an evident dipole for energies $E > 8 \times 10^{19}$ eV.

The trend of the He and N fractions as a function of energy has a strong dependence on the particular hadronic model used. However, the three hadronic models agree when estimating a null Fe abundance between $10^{18.3}$ eV and $10^{19.4}$ eV.
The AugerPrime Science Case

The data collected after the upgrade must provide additional measurements to allow us to address the following key objectives:

1. The mass composition and the origin of flux suppression at the highest energies
   • Understanding the origin of the flux suppression will provide fundamental constraints on the astrophysical sources and will allow a more reliable estimates of neutrino and gamma-ray fluxes at UHE.

2. Proton contribution in the flux suppression region ($E > 4 \times 10^{19}$ eV)
   • 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 multiparticles production.
The strategy of the Upgrade

Measure with the Pierre Auger Observatory until 2025.

(*MOUs have been signed in Nov 2015*)

**The AugerPrime upgrade:**

1. Add a Surface Scintillator Detector (SSD) to measure the mass composition in combination with the Water Cherenkov Detectors (WCD).

2. Add a small PMT to increase the dynamic range of the WCD.

3. Upgrade the Surface Detector Electronics (SDE) to improve the performance of the WCD, acquire the SSD and the small PMT.

4. Add an Underground Muon Detector (AMIGA) to have a direct muon measurement and cross-check the SSD-WCD combined analysis.

5. Extended the Fluorescence Detector (FD) duty cycle to increase the statistics of the more energetic hybrid showers.
Complementarity of particle response used to discriminate electromagnetic and muonic components of air showers.

The Surface Scintillator Detector

100% duty cycle

WCD

SSD (3.8 m²)

1σ contour of the number of muons at maximum of the muon shower development vs the maximum of the e.m. component

θ = 38°
E = 5x10¹⁹ eV

E_{\text{pure}}/(\muon + E_{\mu} + E_{\text{had}})

ICRC2017 Busan D. Martello
SSD: The Surface Scintillator Detector

- Extruded Scintillator bars with 2 holes
- WLS fibers + routers
- Alu Enclosure
- Scintillator 3.8 m$^2$

Extruded scintillator bars 160cm long

WLS fibers + routers

(see: R. Smida, Scintillation Detector of AugerPrime, this conf.)
Extending the Dynamic Range: small PMT

Probability of having at least one saturated station in an event as function of energy.

The charge spectrum is extended by the signal obtained by the small PMT

Lateral Distribution of the signal sizes recorded in SD detectors with the help of an additional small PMT

(see: A. Castellina, The dynamic range of the AugerPrime Surface Detector, this conf.)
SD New Electronics

1. Increase of the data quality (better timing, dynamic range and μ identification):
   a) 10 FADC channels instead of 6
   b) faster sampling of ADC traces (40 → 120 MHz)
   c) more precise absolute timing accuracy (new GPS receiver)

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

3. Improved calibration and monitoring capabilities

4. New components:
   1. Connection to the SSD and any additional (R&D) detectors
   2. Additional small PMT

Totally back-compatible with the old design
(same power communications, hardware interfaces...)

(see: T. Suomijärvi, New Electronics for the Surface Detector of the Pierre Auger Observatory, this conf.)
The Underground Muon Detector

61 AMIGA muon detectors are planned to be deployed on a 750m grid (a total area of 23.5 km²). Plastic scintillators of 30m² are buried under 280 g/cm² of vertical mass to measure the muon component of the showers.

The underground muon detector (AMIGA) will provide a direct measurement of the number of muons and will permit to cross-check the SSD-WCD combined analysis.
Fluorescence Detector Operation

- The FD provides exceptional information about extensive air showers (model-independent energy reconstruction and direct measurement of the longitudinal development profiles)
- The main limitation of the FD is the duty cycle, currently at the level of 15%.

Duty cycle 15%

A significant increase of the duty cycle is possible by the extension of the FD operation to times at which a large fraction of the moon in the sky is illuminated. During such operations the PMT gain must be reduced (lower HV) to avoid an excessively high anode current.

Procedure successfully tested in one telescope for some nights.

10x reduced PMT gain by reducing supplied HV

Existing measured air showers have been analyzed with the standard reconstruction chain after adding random noise to the ADC traces.
The Engineering Array

12 upgraded stations in acquisition since October 2016 with new electronics, small PMT and different configuration of the SSD modules

- Two different solutions of HV and bases
  - SiPMs vs PMTs

Selected the PMT option with active base

9 stations in the Standard Array area plus three in the 750 km array

- Two different solutions of HV and bases
  - SiPMs vs PMTs

(see: Z. Zong, First Results from the AugerPrime Engineering Array, this conf.)
The Engineering Array

Event reconstructed with standard stations. The signals of the updated stations is shown (red). The SSD signal is shown just for reference (blue).

Near the core is dominant the e.m. component.
Conclusions

- November 2015: MoU signed to extend the Observatory data taking
- April 2016: AugerPrime approved by funding agencies
- October 2016: Engineering Array taking data!
- Oct 2016-Jun 2017: Evaluation of detectors
- September 2017 Detector construction start.
- Start the deployment in 2018
- Till 2025: Data taking (up to 40,000 km$^2$ sr yr)
Backup
Some results from the Pierre Auger Observatory

Scenario 1: dominated by the maximum energy at the source (preferred by data)

Scenario 2: dominated by propagation

Source
Spectral index

$0.96^{+0.08}_{-0.13}$

$2.04^{+0.01}_{-0.01}$
Science Impact of the upgrade

The Pierre Auger Collaboration, JCAP04(2017)038

From the combination of the SSD and WCD detectors with the support of the new electronics and of the small PMT will be possible to obtain mass sensitive parameters from the surface detector with high statistics also in the region of the cut-off.
Science Impact of upgrade

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

Scenario 1: almost no protons

A=1
A=5-22
A=2-4
A=26-56

• Standard scenario 1 (almost no protons)
• Scenario 1 with 10% protons added
SSD Measurement: Universality approach

The shower universality method predicts for the entire range of primary masses the air-shower characteristics on the ground using only three parameters: $E$, $X_{\text{max}}$ and $N_\mu$.

The parameter could be estimated from the integrated signal and the temporal structure of the signal measured in individual stations. Event by event basis.

Applying the Universality method it is possible to take into account the correlation between the WCD and the SSD. The parameters now are more $(X_{\mu\text{max}}, X_{\text{max}}, N_\mu)$ in the model.

This allows a measurement of the number of muons on a event by event basis and the relation between $X_{\mu\text{max}}$, $X_{\text{max}}$ and $N_\mu$ can be calibrated.
SSD: Matrix Inversion Method

Lateral Distribution Analysis

A parameterization of the LDF for the SSD was done using simulation.

\[
\begin{pmatrix}
S_{\text{top}} \\
S_{\text{bot}}
\end{pmatrix} = \begin{pmatrix}
a & b \\
1-a & 1-b
\end{pmatrix} \begin{pmatrix}
S_{\text{em}} \\
S_{\mu}
\end{pmatrix}
\]

Single Station Analysis

Simulated Fe LDFs fit for WCD and SSD

\[
A_{\text{wcd/m}} = 4.0 \\
\log_{10}(E_{\text{MeV}}) = 19.5 \\
\theta_{\text{MOM}}^2 = 36.0
\]

Composition: Fe

\[
f_{p,Fe} = \frac{\left|\langle S_{Fe} \rangle - \langle S_p \rangle \right|}{\sqrt{\sigma(S_{Fe})^2 + \sigma(S_p)^2}} \sim 1.5
\]

Figure of merit