Highlights from the Pierre Auger Observatory

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Abstract: The Pierre Auger Observatory is the world’s largest cosmic ray observatory. Our current exposure reaches nearly 40,000 km² str and provides us with an unprecedented quality data set. The performance and stability of the detectors and their enhancements are described. Data analyses have led to a number of major breakthroughs. Among these we discuss the energy spectrum and the searches for large-scale anisotropies. We present analyses of our $X_{\text{max}}$ data and show how it can be interpreted in terms of mass composition. We also describe some new analyses that extract mass sensitive parameters from the 100% duty cycle SD data. A coherent interpretation of all these recent results opens new directions. The consequences regarding the cosmic ray composition and the properties of UHECR sources are briefly discussed.

Keywords: Pierre Auger Observatory, Highlights, Ultra High Energy Cosmic Rays

1 The Pierre Auger Observatory

The Pierre Auger Collaboration is composed of more than 500 members from 19 different countries. The observatory, the world’s largest, is located in the southern part of the province of Mendoza in Argentina. It is dedicated to the studies of Ultra High Energy Cosmic Rays (UHECR) from a fraction of $EeV$ to the highest energies ever observed at several hundreds of $EeV$. The Observatory comprises several instruments working in symbiosis:

- A surface detector array (SD) of 1600 water Cherenkov detectors (WCD) arranged on a regular triangular grid of 1500 m and covering 3000 km².
- 4 sites with fluorescence detector (FD) (each site contains 6 telescopes for a total of 180⁰ azimuth by 30⁰ zenith field of view).
- A subarray, the Infill, with 71 water Cherenkov detectors on a denser grid of 750 m covering nearly 30 km². This subarray is part of the AMIGA extension that will also have buried muon counters at each 71 WCD locations (7 are in place).
- 3 High Elevation Auger Telescopes (HEAT) located at one of the fluorescence site dedicated to the fluorescence observation of lower energy showers.
- A subarray of 124 radio sensors (AERA, Auger Engineering Radio Array) working in the MHz range and covering 6km².
- A sub Array of 61 radio sensors (EASIER, Extensive Air Shower Identification with Electron Radiometer) working in the GHz range and covering 100km².
- Two GHz imaging radio telescope AMBER and MIDAS with respectively 14⁰x14⁰ and 10⁰x20⁰ field of views.

The three last items are R&D on the detection of extensive air showers using the radio emission of the EM cascade in the atmosphere.

In total the Auger collaboration has provided to this conference 32 contributions, including 3 contributions done in collaboration with the Telescope Array Collaboration (TA). These contributions describe the wide range of work in detector development, monitoring system and analysis tools as well as data selection.

Figure 1: Time evolution of the WCD triggered rates as a function of time. The three last items are R&D on the detection of extensive air showers using the radio emission of the EM cascade in the atmosphere.

Pierre Auger Observatory

Figure 2: Detection of PMTs which do not verify the quality criteria among the functioning ones, as a function of time.

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The most important parameters of the SD calibration are the peak current measured for a vertical muon, $I_{EM}$, and a horizontal muon, $I_{EH}$ (so-called area). The calibration procedure allows the conversion of one VEM in electronics units, $I_{EM}$ and $I_{EH}$, to an energy in the detector.

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The hybrid concept has been pioneered by the Auger collaboration, aiming to monitor with extreme precision both the detectors SD and FD, they form a specific data set called the hybrid. Such calibration allows the transfer of the high precision calorimetric information collected by the FD to the 100% of a few percent the hourly vertical aerosol optical depth time variation and must be followed most closely.

In Table 1, similar plots are available for the FD on the monitoring web pages, showing the on-time in quarter real-time for the entire telescope and diagnostic figures of merit.

Figure 7: Top: time evolution of the average hybrid on-time fraction for the four FD sites and HEAT. The thick gray line defines the scheduled data-taking time fraction limited to nights with less than 60% moon fraction. Figure 7: Bottom: the accumulated on-time since 1 July 2004 for the six telescopes of the Pierre Auger Observatory.

The Auger SD is equipped with an extensive set of instruments that measure the atmospheric conditions. These instruments allow us to determine within accuracies of a few percent the hourly vertical aerosol optical depth in the web interface displayed the stored quantities. The FD and hybrid on-time of each telescope as well as the accumulated are illustrated on the web interface.

Table 1: Summary of performance monitoring of the Pierre Auger Observatory.

<table>
<thead>
<tr>
<th>Combination</th>
<th>1500 m vertical</th>
<th>1500 m inclined</th>
<th>750 m vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pierre Auger Observatory performance monitoring system</td>
<td>04/04/2004 to 08/08/2008</td>
<td>01/11/2008 to 04/08/2012</td>
<td>08/08/2008 to 01/11/2012</td>
</tr>
<tr>
<td>Exposure [km² sr yr]</td>
<td>31645 ± 950</td>
<td>8027 ± 240</td>
<td>79 ± 4</td>
</tr>
<tr>
<td>Zenith angles [°]</td>
<td>0 - 60</td>
<td>62 - 80</td>
<td>0 - 55</td>
</tr>
<tr>
<td>HEAT</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Auger hybrid</td>
<td>0 - 60</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

4.3 Hybrid data quality

Thanks to the smooth running of the Observatory, the performance of the hybrid detector is demonstrated, functioning well using a sample of events fulfilling high reconstruction requirements, such as a reliable geometry reconstruction and accurate longitudinal profile and energy measurement.

In Fig. 8, the mean energy of the hybrid events at 10^18 eV with distance to the shower maximum between 18 and 23 km (corrected for the extra 5% on the entire hybrid sample) is shown as a function of time. This demonstrates the hybrid data long-term stability.

5. Conclusion

In Fig. 9 we show how the hybrid station fraction of our FD sites. Such monitoring allows for a precise determination of the experimental exposure as well as for a precise control of the data taking.

References

Changes in FD energies at 10^{38} eV

<table>
<thead>
<tr>
<th></th>
<th>Absolute fluorescence yield</th>
<th>New optical efficiency</th>
<th>Calibr. database update</th>
<th>Sub total (FD calibration)</th>
<th>Likelihood fit of the profile</th>
<th>Folding with the point spread function</th>
<th>Sub total (FD profile reconstruction)</th>
<th>New invisible energy</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-8.2%</td>
<td>4.3%</td>
<td>3.5%</td>
<td>7.8%</td>
<td>2.2%</td>
<td>9.4%</td>
<td>11.6%</td>
<td>4.4%</td>
<td>15.6%</td>
</tr>
</tbody>
</table>

Table 2: Changes in the shower energy at 10^{38} eV.

Changes to the shower energy at 10^{38} eV

Energy spectrum measured at the Pierre Auger Observatory

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Figure 1: The combined Auger energy spectrum compared to spectra from different astrophysical scenarios.

After energy calibration the exposure for each data set (hybrid, Infill, SD vertical and SD horizontal) is carefully evaluated on the basis of our precise monitoring systems. The corresponding spectra are shown in Fig. 3.

Those spectra are combined to form the Auger spectrum as shown in figure 4. The combination process relies upon a maximum likelihood method that allows for a normalization adjustment between the various spectra. The corrections, which are well within the normalization uncertainty of the individual spectra, amount to -6%, +2%, -1% and +4% respectively. The total number of events comprising the spectrum shown in figure 4 is about 130,000.

This unprecedented statistical accuracy allows clear identification of two features in the energy spectrum, the Ankle and a cut-off at the highest energy. At the Ankle the spectral index changes from -3.23 ± 0.05 to -2.63 ± 0.04 at a break point energy of 5 EeV. Above 20 EeV the spectrum starts to deviate from a simple power law and a flux suppression (a cut-off) is observed. At E_{50%} = 40 EeV the observed spectrum is half of what is expected from the extrapolation of the power law observed just above the Ankle. When compared to a simple continuance of a power-law, the significance of the cut-off is more than 20 sigma, however its origin, as that of the Ankle is yet to be determined.
These features can originate from interactions of the cosmic rays with the intergalactic radiation field (mainly the CMB) during their transport from their sources to the Earth. This is the case for example of the $e^+e^-$ pair or pion production (GZK) from protons off the CMB photons for the Ankle and the cut-off respectively or of the photo-disintegration of nuclei. Such features also can originate from the sources spatial distributions and/or their acceleration characteristics, in this case the Ankle could sign the transition from a Galactic dominated cosmic ray sky to an extra-galactic dominated one while the cut-off would directly reflect the maximum energy reachable by the sources themselves. Various scenarios have been put forward, combining these possible origins in various ways (see e.g. [45] for an overview).

The models shown in figure 4 assume either a pure proton or pure iron composition. The fluxes result from different assumptions of the spectral index $\beta$ of the source injection spectrum and the source cosmological evolution parameter $m$. The maximum energy of the source was set in these particular examples to 100 EeV and 300 EeV, the former describing better the data in the cut-off region. The model lines have been calculated using CRPropa [42] and validated with SimProp [48].

Despite its high statistical accuracy, the energy spectrum alone is not sufficient to distinguish between the various scenarios. There are simply too many unknowns (source distributions and evolution, acceleration characteristics, cosmic ray mass composition). Other observables such as anisotropies and mass composition parameters will have to be combined to disentangle the situation.

3 Mass composition

The hybrid nature of the Auger observatory allows for a very precise measurement of the shower longitudinal profile on a subset of less than 10% of the events (the hybrid data set). The combination of the FD and SD allows for a precise determination of the shower geometry which in turn allows measurement of the position of the maximum shower size ($X_{\text{max}}$) with an accuracy of better than 20 g/cm².

The updated (but preliminary) results regarding the evolution with energy of the two first moments of the $X_{\text{max}}$ distributions are shown in Fig. 5. When compared to the model lines, the data clearly indicate a change of behavior at a few EeV, i.e. in the Ankle region.

While predictions of different models may not be an accurate representation of nature for the absolute values of $X_{\text{max}}$, hence making it difficult to convert with confidence this data into mass values, they have similar predictions (within 20 g/cm² for $X_{\text{max}}$ and 10 g/cm² for $\sigma_{\text{X}_{\text{max}}}$) for those parameters. In particular, all models predict that for a constant composition the elongation rate (slope of the $X_{\text{max}}$ evolution) and $\sigma_{\text{X}_{\text{max}}}$ are also constant as a function of energy. This is at clear variance from the measurements themselves. Hence, under the hypothesis that no new interaction phenomena in the air shower development come into play in that energy range, the data clearly support that the composition evolves in the Ankle region.

While subject to the belief that current interaction models do represent reality, it is possible to convert the measured data into the first two moments of the $\ln A$ distribution at the top of the atmosphere [52]. This is shown in Fig. 6 using several hadronic interaction models [49, 50, 51]. From this conversion it is possible to interpret the aforementioned evolution as a change from light to medium light composition with a minimum in the average $\ln A$ just before the Ankle, i.e. between 2 and 3 EeV. Looking at the $\sigma^2_{\ln A}$ plot, one can also argue that the evolution is slow in terms of masses ($\sigma^2_{\ln A}$ stays below 2 in the whole range indicating that the mix is between nearby masses rather than between proton and iron) [7]. We also observed that for some model the central predicted variance of $\ln A$ is negative but this is not the case within our systematic uncertainties.

4 Hadronic Interactions

We have performed several analyses to extract a muon size parameter from the hybrid or SD data sets. These analyses [20, 21, 22, 23] all indicate that current hadronic interaction models predict muon sizes that are smaller (by at least 20%) than observed in the data, unless one assumes that the data is composed of pure iron which is in contradiction, according to the same models, with the observed $X_{\text{max}}$ distributions.

1. $\langle \ln A \rangle$ is 0 for pure proton and 4 for pure iron while $\sigma^2_{\ln A}$ is 0 for pure composition and 4 for a 50:50 p/Fe mix.
In [23] we have selected all showers (411) measured in hybrid mode with an energy between $10^{19.8}$ and $10^{20.2}$ EeV. For each of those showers, we have generated Monte Carlo events with similar energies selecting those which also matched the measured longitudinal profile. Then, for those matching events, the predicted lateral distribution of the signal has been compared to the data recorded by the SD.

The Monte Carlo predictions have been found to be systematically below the observed signals, regardless of the hadronic model being used. To match the lateral distributions we introduced two parameters that have been adjusted to the data. These parameters are $R_e$ which acts as a rescaling of the shower energy, and $R_p$ which acts as a muon size rescaling factor. The values that best reproduce the data are shown in Fig. 7 for a set showers from a mixed composition sample whose muon production depth $X_{\text{max}}$ and $X_{\text{max}}^{\#}$ data into $\langle \ln A \rangle$ using the same interaction model. The result of such conversion is shown on Fig. 8 for two models. In the first case, with EPOS-LHC, the two observables convert into an incompatible mass value.

According to the model-lattter [21], the absolute energies of the highest energy events do not represent the sample distribution but rather the upper limit to the absolute energies of the highest energy events. The lateral distribution could then simply point at collective effects of the nuclei interactions measured at the LHC. Of course, UHECR interactions atmosphere and HE nuclei interactions but collisions $X_{\text{max}}$ and $X_{\text{max}}^{\#}$ are not related through these mass values. The values of $R_e$ and $R_p$ are therefore the best estimations that can be obtained from the interaction data.

### Figure 6: Conversion to $\langle \ln A \rangle$ and $\sigma^2_{\ln A}$ using various hadronic interaction models. The red bands indicate the systematic uncertainties.[19].

![Figure 6: Conversion to $\langle \ln A \rangle$ and $\sigma^2_{\ln A}$ using various hadronic interaction models.](image)

#### 5 Anisotropies

The Auger collaboration has also performed extended analyses of the UHECR arrival direction distributions in several energy ranges and different angular scales [24–27]. Some particularly interesting results come out of the analysis of the first harmonic modulation in the right ascension distribution of the events [24]. The results of this analysis on the equatorial dipole amplitudes are shown on Fig. 9 for an extended range in energy covering nearly 4 orders of magnitude. While no clear evidence for anisotropy has been found yet it is remarkable to see that in the range above $10^{19.6}$ EeV the data into a $|\alpha| > 90.0^\circ$ interval does not show any significant anisotropic signals.
### Analysis at the sidereal frequency

To perform the first harmonic analyses as a function of energy, the choice of the size of the energy bins is important to avoid the dilution of a genuine signal with the background noise (lnA) using two different hadronic interaction models. The size of the energy bins for the analysis with the array EPOS-LHC (left) and QGSJetII-04 (right). While for EPOS-LHC was chosen to be $\log_{10}(E) = 0.3$ beQGSJetIII-04 present a more coherent conversion, EPOS-LHC offers a better description of the rapidity gap distribution of p-p collision at the LHC. The modification of this distribution in EPOS to better reproduce the LHC p-p data is represented by the estimated uncertainties using the model.}

#### Figure 8: Conversion of the $X_{\text{max}}$ and $X_{\text{max}}'$ observable from the models, and the pure dipole predictions. For the regular array one distribution of about 0.03% and 0.9%, while above 8 EeV the measured amplitude of (5.9±1.6)% has chance probabil-

#### Figure 3: Phase and the first harmonic in $\text{log}_{10}(E)$.
The upper limits on $d_1$ at 99% CL are given in Table 1 and shown in Fig. 2, together with previous results from EAS-TOP [7], ICE-CUBE [8] KASCADE [9], KASCADE-Grande [10] and AGASA [11], and with some predictions for the anisotropies arising from models of both galactic and extragalactic cosmic ray origin.

3 Phase of the first harmonic and prescription

In previous publications, the harmonic analysis of the EAS-TOP data as a function of energy and zenith angle yielded the following results: for various energy bins, a positive anisotropy signal was found within a global 5% confidence level (CL), for any of the following time bins: 0.25 EeV, 1 EeV, and 5 EeV. Predictions from different models are displayed in the figure. In red are the limits obtained from the Galactic model, and in blue from the extragalactic model. The upper limit in energy 0.25 EeV and the Gal model at few EeV energies, note that all reconstructed declinations are in the equatorial plane.

The bounds reported here already exclude the particular Galactic model (A) above the corresponding $d_1$ amplitude in the equatorial plane. This bound was obtained with the regular SD array from June 2011 to 2013, and the regular array from June 2011 to 2013.

• Using the infill data, an alignment of phases around the Janus feature is found, with an amplitude signal of 0.5% over the whole energy range. The alignment is significant at the 99% CL level.

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4 Conclusions

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Figure 12: An overall view of the Auger results showing the variety of the observables and the coherence of their behavior. The blue bands correspond to the Ankle region where features are observed in the spectrum, mass and anisotropy data. The red bands corresponds to the cut-off region where, unfortunately, due to the low duty cycle of the fluorescence technique the mass information is missing. For completeness the VCV correlation (from [55]) is also shown as an energy ordered plot. The onset of the correlation signal is visible at about 55 EeV.

[10] The Pierre Auger Collaboration, arXiv:1307.5059 contains all the Auger contributions to the 33rd ICRC listed below (all authors to be understood “for the Pierre Auger Collaboration”).
[12] Matias J. Tueros, Estimate of the non-calorimetric energy of showers observed with the fluorescence and surface detectors
Aerosol characterization at the Pierre Auger Observatory, CR-EX 705.


Carla Bonifazi, The monitoring system of the Pierre Auger Observatory: on-line and long-term data quality controls, CR-IN 1079.


Alexander Schulz, Measurement of the Energy Spectrum of Cosmic Rays above \(3 \times 10^{17}\) eV with the Pierre Auger Observatory, CR-EX 769.

Diego Ravignani, Measurement of the Energy Spectrum of Cosmic Rays above \(3 \times 10^{17}\) eV using the AMIGA 750 m Surface Detector Array of the Pierre Auger Observatory, CR-EX 693.

Vitor de Souza, An update on the measurements of the depth of shower maximum made at the Pierre Auger Observatory, CR-EX 751.

Eun-Joo Ahn, Inferences about the mass composition of cosmic rays from data on the depth of maximum at the Auger Observatory, CR-EX 690.

Diego García-Gámez, Observations of the longitudinal development of extensive air showers with the surface detectors of the Pierre Auger Observatory, CR-EX 694.

Inés Válio, A measurement of the muon number in showers using inclined events recorded at the Pierre Auger Observatory, CR-EX 635.

Balázs Kégl, Measurement of the muon signal using the temporal and spectral structure of the signals in surface detectors of the Pierre Auger Observatory, CR-EX 860.

Glennys R. Farrar, The muon content of hybrid events recorded at the Pierre Auger Observatory, CR-EX 1108.

Ivan Sidelnik, Measurement of the first harmonic modulation in the right ascension distribution of cosmic rays detected at the Pierre Auger Observatory: towards the detection of dipolar anisotropies over a wide energy range, CR-EX 739.

Rogerio M. de Almeida, Constraints on the origin of cosmic rays from large scale anisotropy searches in data of the Pierre Auger Observatory, CR-EX 768.

Benoît Revenu, Blind searches for localized cosmic ray excesses in the field of view of the Pierre Auger Observatory, CR-EX 1206.

Francisco Salesa Greus, Search for Galactic neutron sources with the Pierre Auger Observatory, CR-EX 1125.

Daniel Kuempel, Directional search for ultra-high energy photons with the Pierre Auger Observatory, CR-EX 669.

Pablo Pieroni, Ultra-high energy neutrinos at the Pierre Auger Observatory, CR-EX 697.

Federico Suárez, The AMIGA muon detectors of the Pierre Auger Observatory: overview and status, CR-IN 712.

Simone Maldera, Measuring the accuracy of the AMIGA muon counters at the Pierre Auger Observatory, CR-IN 748.

Frank G. Schröder, Radio detection of air showers with the Auger Engineering Radio Array, CR-IN 899.

Tim Huege, Probing the radio emission from cosmic-ray-induced air showers by polarization measurements, CR-EX 661.

Romain Gaëtor, Detection of cosmic rays using microwave radiation at the Pierre Auger Observatory, CR-IN 883.

Laura Valore, Measuring Atmospheric Aerosol Attenuation at the Pierre Auger Observatory, CR-EX 920.

Maria I. Micheletti, Aerosol characterization at the Pierre Auger Observatory, CR-EX 1081.

Johana Chirinos, Cloud Monitoring at the Pierre Auger Observatory, CR-EX 994.

Aurelio Tonachini, Observation of Elves at the Pierre Auger Observatory, CR-EX 676.

Gregory R. Snow, Education and Outreach Activities of the Pierre Auger Observatory, CR-IN 968.
