Cosmic-ray mass composition with the TA SD 12-year data

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Introduction

Telescope Array is the largest ultra-high-energy cosmic-ray experiment in the Northern hemisphere, operating since 2008 and located in Utah, USA. It observes the cosmic rays in the *hybrid* mode, which means that extensive air showers are registered both by a grid of surface detectors on the ground level and fluorescence telescopes, which overlook the sky above the array and asses the longitudinal development of an EAS.

The TA surface detector array (TA SD) is a square grid of scintillator detectors arranged to have a separation of 1.2 km between nearest-neighbors. Each detector is composed of two layers of 1.2 cm thick extruded scintillator each with 3 m^2 effective area. TA SD array is comprised of 507 detectors covering an area of approximately 700 km^2.

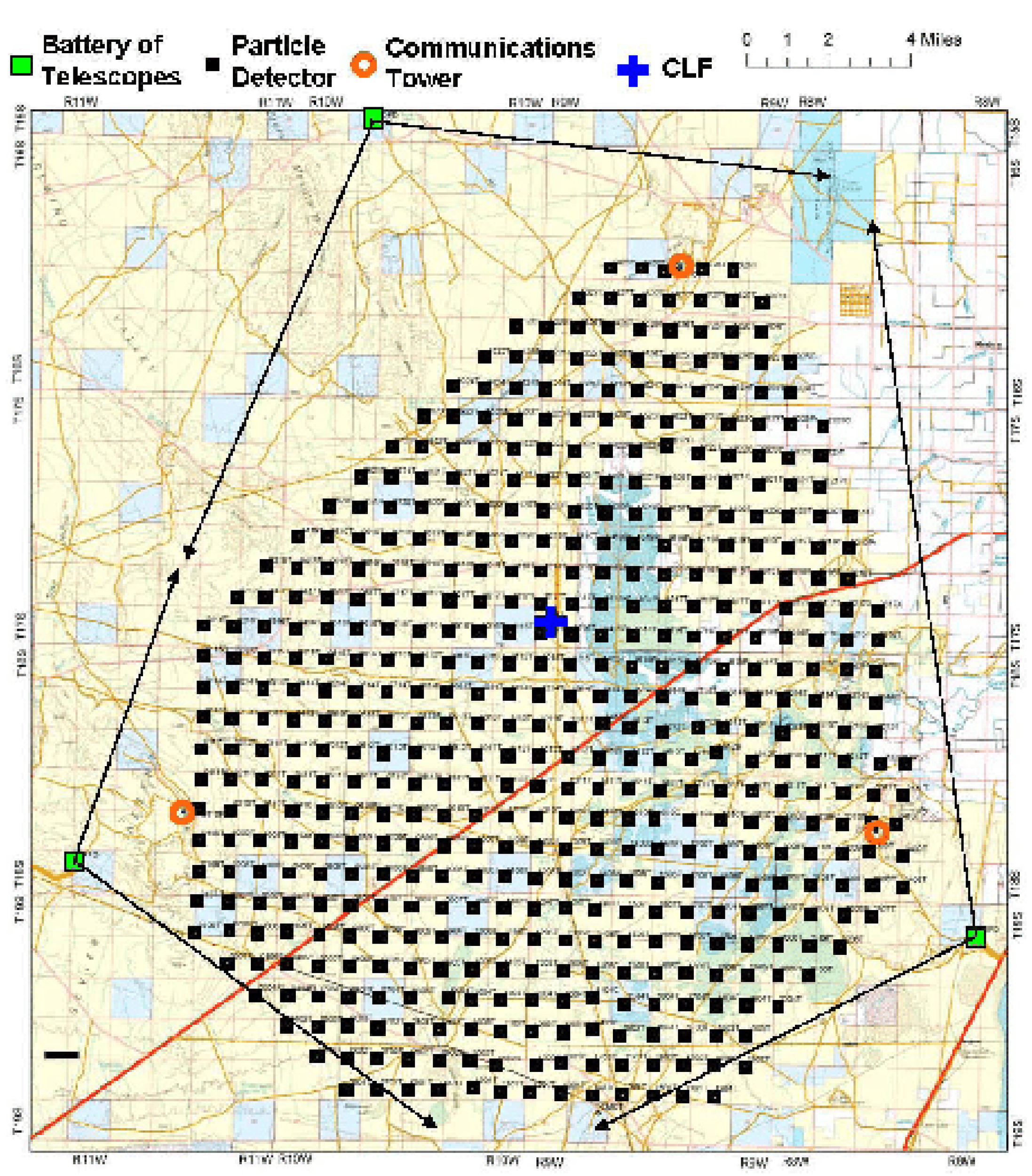

Figure 1:General scheme of the Telescope Array experiment. Surface detector station grid is shown with black squares, fluorescence telescope stations are shown with green squares, blue cross denotes the Central Laser Facility (CLF), communication towers are shown with orange circles.

Dataset and MC

We employ the 12-year data set from the TA surface detector, covering from 11th May 2008 up to 10th May 2020. After applying the quality cuts, the final dataset used for the analysis consists of 23 159 events in the energy range from 10^{18} eV to 10^{20} eV.

For the Monte-Carlo simulations, the CORSIKA package is used along with the QGSJET II-03 and QGSJET II-04 models for high-energy hadronic interactions [1, 2], FLUKA for low-energy hadronic interaction and EGS4 for electromagnetic processes with thinning and dethinning procedures applied.

Boosted Decision Trees

To discriminate between primaries, we implement the Boosted Decision Trees (BDT) [3] technique. BDTs are trained using a set of composition-sensitive observables which we derive for Monte-Carlo sets: "signal", in our case a set of events initiated by iron nuclei, and "background" one, corresponding to a proton MC set. The result of the BDT classifier is a single value ξ for each data and Monte-Carlo event. The value of ξ resides in the range $\xi \in [-1; 1]$, where $\xi = 1$ for a pure signal event and $\xi = -1$ – for a pure background event. The variable ξ is used in the following analysis to linearly transform ξ distrbutions to $\langle \ln A \rangle (E)$.

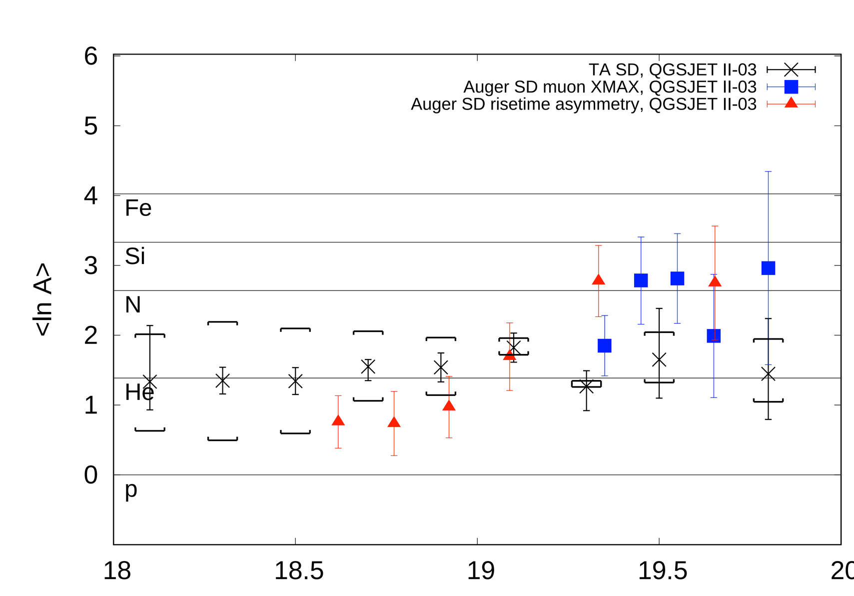

Figure 2:$\langle \ln A \rangle (E)$ for 12-year dataset derived with QGSJET II-03 (black crosses) compared with the PAO X^{μ}_{MAX} and risetime asymmetry results (blue squares and red triangles) [4].

Composition-sensitive observables

For each event, we reconstruct a set of 16 composition-sensitive observables:

1. Linsley shower front curvature parameter.
2. Area-over-peak (AoP) of the signal at 1200 m and AoP slope parameter [5]
3. Number of detectors hit.
4. Number of detectors excluded from the fit of the shower front by the reconstruction procedure.
5. $\chi^2/d.o.f.$ of the joint geometry and LDF fit. 1 S_b parameter for $b = 3$ and $b = 4.5$.
6. The sum of the signals of all the detectors of the event.
7. Asymmetry of the signal at the upper and lower layers of detectors.
8. Total number of peaks within all FADC (flash analog-to-digital converter) traces.
9. Number of peaks for the detector with the largest signal.
10. Number of peaks present in the upper layer and not in the lower.
11. Number of peaks present in the lower layer and not in the upper.
12. Zenith angle of an event.
13. Energy of an event.

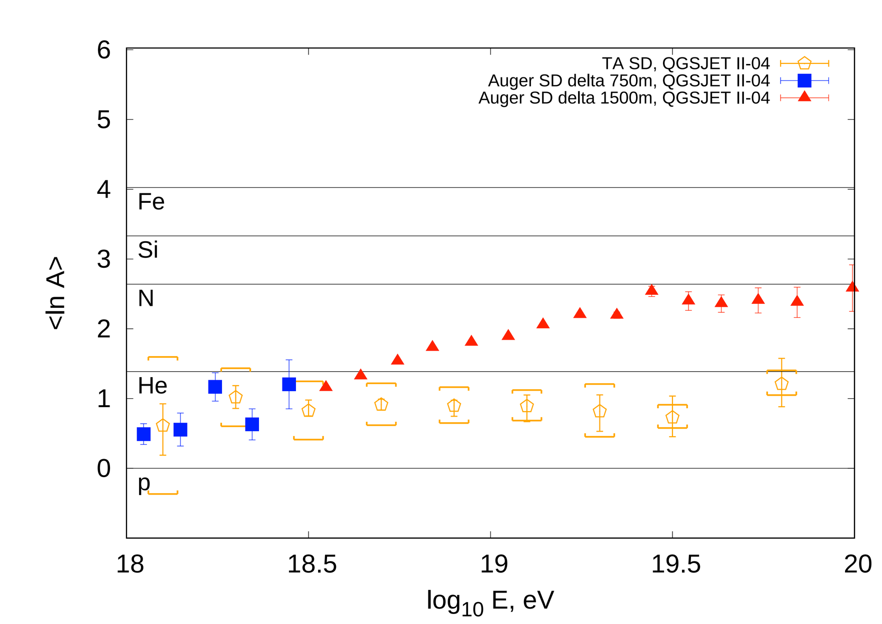

Figure 3:$\langle \ln A \rangle (E)$ for 12-year dataset derived with QGSJET II-04 (orange pentagons) compared with the PAO SD delta results (blue squares and red triangles) [6].

Conclusion

The average atomic mass of primary particles in the 12 year TA data shows no significant energy dependence and yields $\langle \ln A \rangle = 1.50 \pm 0.08(stat.) \pm 0.50(syst.)$ using QGSJET II-03 and $\langle \ln A \rangle = 0.90 \pm 0.05(stat.) \pm 0.30(syst.)$ using QGSJET II-04. Comparison with the PAO risetime asymmetry results [4] for QGSJET II-03 is shown in Figure 2. Comparison with the PAO SD delta asymmetry results [6] for QGSJET II-04 is shown in Figure 3.

References

[1] S. Ostapchenko, *QGSJET-II: Towards reliable description of very high energy hadronic interactions*, *Nucl. Phys. B Proc. Suppl.* **151** (2006) 143–146, [hep-ph/0412332].

[2] S. Ostapchenko, *Monte Carlo treatment of hadronic interactions in enhanced Pomeron scheme: I. QGSJET-II model*, *Phys. Rev. D* **83** (2011) 014018, [1010.1869].

[3] R. E. Schapire, *The strength of weak learnability*, *Mach. Learn.* **5** (July, 1990) 197–227.

[4] Pierre Auger collaboration, P. Abreu et al., *The Pierre Auger Observatory II: Studies of Cosmic Ray Composition and Hadronic Interaction models*, in *32nd International Cosmic Ray Conference*, vol. 3, p. 208, 7, 2011, 1107.4804, DOI.

[5] Pierre Auger collaboration, J. Abraham et al., *Upper limit on the diffuse flux of UHE tau neutrinos from the Pierre Auger Observatory*, *Phys. Rev. Lett.* **100** (2008) 211101, [0712.1909].

[6] C. J. Todero Peixoto, *Estimating the Depth of Shower Maximum using the Surface Detectors of the Pierre Auger Observatory*, in *36th International Cosmic Ray Conference (ICRC2019)*, vol. 36 of *International Cosmic Ray Conference*, p. 440, July, 2019.

Acknowledgements

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