Adjustments to Model Predictions of Depth of Shower Maximum and Signals at Ground Level using Hybrid Events of the Pierre Auger Observatory

Executive Summary

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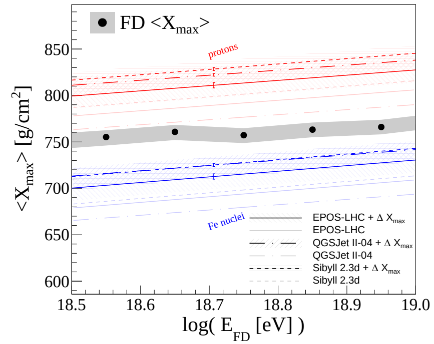
What is this contribution about?

We explore **ad-hoc adjustments to the predictions** of LHC-tuned hadronic interaction models which improve their consistency with the **2D distributions of the depth of air-shower maximum (X_{max}) and the signal in surface detectors**, and their zenith angle (θ) dependence, observed with the Pierre Auger Observatory.

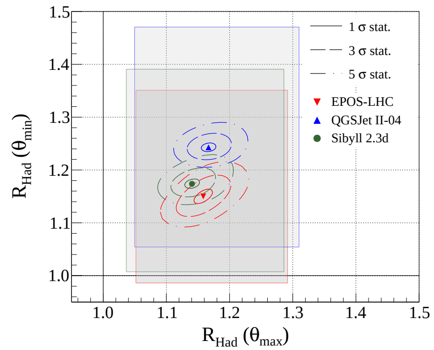


Why is it relevant/interesting?

For the first time, we investigate if corrections to the hadronic interaction models are needed **not only to the predictions of the signal at ground level** (such studies were performed in the past revealing the now well-established 'muon deficit' problem), **but also to their predictions of X_{max} and atmospheric attenuation**.

What has been done?

We performed a maximum likelihood fit of the observed two-dimensional distributions of $X_{\max}$ and signal at ground level in five θ bins within 60°, for each of the three hadronic interaction models (QGSJET II-04, EPOS-LHC, SIBYLL 2.3d), allowing for a global shift $\Delta X_{\max}$ of the predicted $X_{\max}$ and a rescaling R_{Had} of the hadronic component at ground level which depends on the zenith angle. The mass composition is fitted simultaneously by including the fractions of the primary nuclei in the fit parameters. The study is performed for the combined data of the fluorescence and surface detectors of the Pierre Auger Observatory in the energy range $10^{18.5} - 10^{19.0}$ eV, consisting of 2297 events.



What is the result?

The fit reaches its optimum value when the $X_{\max}$ predictions of the hadronic interaction models are shifted to deeper values, and the hadronic signal is increased at both extreme zenith angles. The resulting change in the composition towards heavier primary masses reduces the previously identified 'muon deficit' problem to $R_{\mathrm{Had}} \approx 15\% - 25\%$. Because of the size of the required corrections $\Delta X_{\max}$ and R_{Had}, and the large number of events in the sample, the statistical significance of a need for corrections is large, greater than $5\sigma_{\mathrm{stat}}$ even for the combination of systematic experimental shifts within $1\sigma_{\mathrm{sys}}$ that are the most favorable for the models.