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Probing hadronic interactions at the 100 TeV scale with the Pierre Auger Observatory

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Extensive air showers produced by the interaction of ultra-high-energy cosmic rays ($E > 10^{18}$ eV) in the Earth's atmosphere provide a challenging yet unique channel to probe hadronic interactions at the 100 TeV center-of-mass energy scale. Over more than 20 years of operation, the Pierre Auger Observatory has delivered invaluable insights into the modeling of hadronic interactions at energies beyond human-made particle accelerators. Notably, predictions from current models of hadronic interactions yield a muon deficit that becomes more pronounced with energy when compared to measurements. Presently, the interpretation of the nuclear mass composition estimated from the muon content is in tension with that from direct measurements of the depth of the maximum of electromagnetic profiles. Yet, the measured fluctuations of the muon content of air showers are in agreement with model predictions. These findings hint at small deviations in hadronic models that accumulate throughout the whole shower development rather than at large errors in the calculation of the first hadronic interactions. Also, in an independent data-driven analysis, we show that the muon deficit can be alleviated if we allow for a shift of the predicted depth of the maximum of air-shower profiles by 20 - 50 g cm^{-2} towards a heavier mass composition. More recently, we have also provided an updated measurement of the proton-proton cross-section at center-of-mass energy 57 TeV and the first estimates of the neutron content of air showers by exploiting the late time signals at the surface scintillator detectors of AugerPrime, the present upgrade of the Observatory. With the advent of AugerPrime, we expect to deliver breakthrough results on the 100 TeV-scale hadronic interactions in the next decade.

Collaboration you are representing

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