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A Top-Down Approach to the Muon Puzzle: Validation of the method using the new EPOS LHC-R and QGSJET-III hadronic interaction models

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The muon content predicted by hadronic interaction models falls short of describing the data from multiple air shower experiments. This discrepancy, known as the Muon Puzzle, poses significant challenges for mass composition studies and limits our understanding of the origins and acceleration mechanisms of ultra-high-energy cosmic rays. The recent releases of the EPOS LHC-R and QGSJET-III models provide a new opportunity to investigate this divergence using a top-down approach to air shower simulations. This strategy consists of constraining the electromagnetic component of a simulated air shower by matching its longitudinal profile to that of an observed air shower. Consequently, any inconsistency found between the simulated and observed signal in ground particle detectors must originate from a mismatch in the muon content. In the present work, the top-down analysis is tested on a mock dataset that includes air showers simulated with EPOS LHC-R at around 10 EeV and reconstructed using the Pierre Auger Observatory framework. The top-down simulations are performed using QGSJET-III, considering proton, helium, oxygen and iron nuclei as primary particles. The quality of the method is assessed by comparing the true difference in muon content between the two models to that derived from the top-down simulations. Finally, a maximum likelihood estimation accounting for composition is performed to determine the overall hadronic rescaling required to adjust QGSJET-III in order to match the muon content of EPOS LHC-R.

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