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Strangeness enhancements and the muon excess in extensive air showers

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Several high-energy cosmic-ray experiments have observed an excess of muons compared to theoretical expectations from air shower simulations based on standard hadronic interaction models. We investigate the potential of producing states of dense quark-gluon matter (so-called fireballs) to resolve the excess of muons on the ground for a given depth of the shower maximum. Adopting a phenomenological fireball model, we find that the inelasticity enhancement associated with the formation of a plasma state is in tension with data on the electromagnetic longitudinal shower development. We then restrict the fireball model to only enhance the strangeness produced in Standard Model hadronic interactions, and dub this model the strangeball model. Comparing with air shower measurements we find strangeball parameters that resolve the muon puzzle. Constraints from data on shower-to-shower fluctuations of the muon number require strangeness enhancements already at energies accessible to current-generation collider experiments. The strangeball
hypothesis leads to a 5–9% increase of the average fraction of energy retained in the hadronic cascade compared to predictions from current hadronic interaction models. A comparison with relevant measurements of the LHCf and LHCb detectors does not directly exclude this scenario, though the obtained tension with LHCb suggests a stringent test at 14 TeV.

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