

The systematics of the theoretical studies of the muon excess in UHECR

The problem of the excess of muons in extensive air showers (EAS) from ultra-high energy cosmic rays (UHECR) in comparison to the simulation predictions, also known as the “muon puzzle”, stands as a bright signal of the incompleteness of our knowledge of high-energy cosmic ray physics. In principle, there are several ways to explain this phenomenon. One can suggest changes in the cosmic ray mass composition and energy spectrum, including the scenarios with exotic nature of the incoming particle. Another approach is to consider the modification of the hadronic interaction models for taking into account new effects, states of matter, and physics. Some studies investigate the possibilities of the non-hadronic origin of the muon excess.

This report presents a systematized review of the theoretical approaches and hypotheses aiming to solve the “muon puzzle”. A review for the important EAS properties, that should be considered when studying the muon production, is given. A brief examination of the proposed ways to explain the deficit of muons in the simulations is done. The main focus is placed on the modifications of hadronic interaction models, including those that attempt to consider the exotic states of matter.

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