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Cosmic-Ray Muon Energy Spectra at Large Depths

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Cosmic rays are fluxes of charged particles coming from interstellar space. When primary cosmic-ray particles enter the Earth's atmosphere, they interact with its nuclei and produce secondary particles, including muons. Due to their high penetrating ability, muons can reach the Earth's surface and even propagate to large depths underground. The energy spectrum of muons changes significantly after they pass through a large amount of matter. There are different methods for calculating the energy spectrum of underground muons, for example, Monte Carlo simulations. This method can provide high accuracy, but it requires large computational resources. In this work, an analytical method for estimating the muon energy spectrum at large depths is considered for different values of parameters related to electron-positron pair production, bremsstrahlung, photonuclear interactions, and ionization energy losses. The analytical muon energy spectrum was studied at different depths, and the influence of these parameters on the spectrum was estimated. Special attention was paid to the high-energy region, with muon energies of the order of TeV.

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