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Probing Lorentz violation at ultra-high energies using air showers

In air showers initiated by ultra-high-energy cosmic rays in the Earth's atmosphere, even the secondary particles created in the start-up phase are produced at energies far above those accessible by other means. These high-energy particles can be used to search for New Physics, such as a violation of Lorentz invariance. We focus on isotropic, nonbirefringent Lorentz violation in the photon sector and and consider the two cases $\kappa < 0$ and $\kappa > 0$ (i.e., the velocity of photons is larger/smaller than the maximum attainable velocity of standard Dirac fermions). In both cases, processes that are forbidden in the standard, Lorentz-invariant theory ($\kappa = 0$) become allowed, in particular photon decay in the case $\kappa < 0$ and vacuum-Cherenkov radiation for $\kappa > 0$. Implementing these processes into air-shower simulations, we found that the development of an air shower at the highest energies can be significantly impacted, specifically the average atmospheric depth of the shower maximum $\langle X_{\text{max}} \rangle$ and its shower-to-shower fluctuations $\sigma(X_{\text{max}})$. Comparing these simulations to actual measurements, we were able to obtain much stricter bounds on this specific type of LV in the case $\kappa < 0$ than possible with previous methods. We discuss these limits and, in addition, present first results for the case $\kappa > 0$.

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