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Anatomy of singlet-doublet dark matter relic: annihilation, co-annihilation, co-scattering, and freeze-in

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The singlet-doublet vector-like fermion dark matter model has been extensively studied in the literature over the past decade. An important parameter in this model is the singlet-doublet mixing angle ($\sin\theta$). All the previous studies have primarily focused on annihilation and co-annihilation processes for obtaining the correct dark matter relic density, assuming that the singlet and doublet components decouple at the same epoch. In this work, we demonstrate that this assumption holds only for larger mixing angles with a dependency on the mass of the dark matter. However, it badly fails for the mixing angle $\sin\theta < 0.05$. We present a systematic study of the parameter space of the singlet-doublet dark matter relic, incorporating annihilation, co-annihilation, and, for the first time, co-scattering processes. Additionally, the freeze-in parameter space is also explored. We found that due to the inclusion of co-scattering processes, the correct relic density parameter space is shifted towards the detection sensitivity range of the LHC and MATHUSLA via displaced vertex signatures.

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