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Mixed hidden sector/visible sector dark matter and observation of CP odd Higgs at HL-LHC and HE-LHC

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It is very likely that similar to the case of visible matter, dark matter too is composed of more than one stable component. In this work we investigate a two-component dark matter with one component from the visible sector and the other from the hidden sector. Specifically we consider a $U(1)_X$ hidden sector extension of MSSM/SUGRA where we allow for kinetic and Stueckelberg mass mixing between the two abelian $U(1)'s$, i.e., $U(1)_X$ and $U(1)_Y$. We further assume that the hidden sector has chiral matter which leads to a Dirac fermion as a candidate for dark matter. The lightest neutralino in the visible sector and the Dirac fermion in the hidden sector then constitute the two components of dark matter. We investigate in particular MSSM/SUGRA models with radiative breaking occurring on the hyperbolic branch where the Higgs mixing parameter μ is small (order the electroweak scale) which leads to a lightest neutralino being dominantly a higgsino. While dark matter constituted only of higgsinos is significantly constrained by data on dark matter relic density and by limits on spin independent proton-DM scattering cross section, consistency with data can be achieved if only a fraction of the dark matter relic density is constituted of higgsinos with the rest coming from the hidden sector. An aspect of the proposed model is the prediction of a relatively light CP odd Higgs A (as well as a CP even H and a charged Higgs $H^{\pm}$) which is observable at HL-LHC and HE-LHC. We perform a detailed collider analysis search for the CP odd Higgs using boosted decision trees in $\tau_h\tau_h$ final states and compare the discovery potential at HL-LHC and HE-LHC. We show that while several of the points among our benchmarks may be observable at HL-LHC, all of them are visible at HE-LHC with much lower integrated luminosities thus reducing significantly the run time for discovery. Thus the discovery of a CP odd Higgs would lend support to the existence of the hyperbolic branch, a small μ and point to the multi-component nature of dark matter. It is also shown that a part of the parameter space of the extended model can be probed in the next generation direct detection experiments such as XENONnT and LUX-ZEPLIN.

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