Contribution ID: **217** Type: **not specified**

A probe into leptophilic scalar dark matter

Monday 23 August 2021 15:10 (20 minutes)

We revisit the scalar singlet dark matter (DM) accompanied by vectorlike dark leptons in two scenarios: in case I, the dark sector consists of a Dirac fermionic doublet; while in case II, a doublet fermion and a singlet. In both cases, the dark leptons couple with other dark sector particles and the Standard Model (SM) via gauge and Yukawa interactions. As a result, (i) new DM annihilation processes, including pair annihilation and coannihilation channels emerge, and (ii) new production channels for leptonic final states giving much enhancement in cross sections open up for DM searches in the LHC. In the former case, the mass splitting between the dark leptons is loop induced at best makes the distinction of the dark sector particles of different isospins a challenging task.

In the latter case, we alleviate the said limitation by introducing an extra singlet leptonic dark sector field. The "singlet-doublet mixing" produces an arbitrary mass splitting between the two components of the doublet in a gauge-invariant way, as well as provides a useful handle to distinguish between the dark sector particles of different isospins. As the dark leptons coannihilate non-trivially, the mixing effectively enhances the viable parameter space for the relic density constraint. In a low DM mass regime, with a non-zero mixing, it is possible to relax the existing indirect search bounds on the upper limit of the DM-SM coupling. From the analysis of the $3\tau + E_T^{\rm miss}$ and $\ell\tau + E_T^{\rm miss}$ channels for LHC at $\sqrt{s} = 13$ TeV, one ensures the presence of the mixing parameter between the dark sector particles of the theory by looking at the distinct peak and tail positions of the kinematic distributions, which remains a constant feature of the model. While both the channels present us the opportunity to detect the mixing signature at the LHC/HL-LHC, the former gives better results in terms of a larger region of mixing parameter. From the fiducial cross section, the projected statistical significance for the integrated luminosity, $\mathcal{L} = 3ab^{-1}$, are shown for a combined parameter region obeying all the existing constraints, where there is the best possibility to detect such a signature.

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Session Classification: Dark Matter and Astroparticle Physics

Track Classification: Dark Matter and Astroparticle Physics