INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

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SHORT ABSTRACT

After the Higgs discovery, the Large Hadron Collider (LHC) did not find any evidence of new physics. Despite the Standard Model (SM) being "the" theory for the elementary particles, there are still many unanswered questions that give a strong motivation for beyond the SM (BSM) theories. A particle candidate for dark matter (DM) is one such motivation, as its existence is beyond any doubt from various cosmological and astrophysical observations. In its pursuit, many theories have been proposed for DM origin, the most popular till date being the freeze-out mechanism, featuring Weakly Interacting Massive Particle (WIMP). Although WIMP can explain the observed DM relic density well, it fails to fit the direct detection constraints. This motivates the need for alternatives, featuring the non-WIMP cases.

This thesis focuses on three such non-WIMP scenarios having interesting implications in the DM dynamics and collider probes. In the first part, we discuss two multipartite WIMP scenarios of electroweak scale DM mass. Here, the interplay of stable DM components of different spins and isospins successfully evade the direct detection constraint, which is otherwise not possible in similar single component WIMP models. In the context of collider probe, we show that as a contrast with traditional cut-based MET analysis strategies in the literature, which was initially developed for SUSY analysis, a hard MET cut at low DM mass is not required in the non-SUSY models.

The second part includes two chapters. The first one focuses on reviving the very constrained scalar singlet DM (SDM) model of electroweak scale by extending the dark sector with additional vector-like dark lepton doublet. This induces DM coannihilation and adds additional channels to pair annihilation and all these alleviate the severe direct detection constraints on standard SDM. We also discuss the possible collider probe with multilepton final states and τ-tagging at the LHC using the ROOT based Boosted Decision Tree (BDT) classifier Toolkit for Multivariate Analysis (TMVA). In the second chapter, we add an extra vector-like singlet in the dark sector of the previous chapter. This simple extension helps to do away with ad-hoc addition of new scale of spontaneous symmetry breaking to lift the degeneracy of the lepton doublet components. Furthermore, the mixing between the same-charge dark leptons become a key factor to distinguish between the dark leptons of different isospins, which has not been discussed much in the literature. We discuss how the mixing leaves a positive impact on various search prospects of DM such as indirect detection and collider probe. The proper choice of final states in the LHC features this mixing effect substantially and a significance study is done for future luminosities.

In the third part, we discuss a minimalistic BSM scenario which identifies different areas of the parameter region for electroweak scale DM mass, where DM relic density is controlled by either non-thermal (freeze-in) or thermal (freeze-out) DM dynamics or their admixture. For suitable parameters, it gives a quantitative estimate of the limiting case where the transition between the above regimes takes place. As a natural consequence of the model arrangement, one or more long-lived particles (LLP) are produced. The DM dynamics often dictates the LLP characteristics and the signatures substantially change from one case to another leading to exotic signatures such as cascade decays of LLPs and kinked charged tracks. The model also features right-handed neutrinos which account for neutrino mass through Type-I seesaw mechanism, that requires it to be long-lived as well. The search prospects for such neutral LLP giving displaced vertex signatures are also discussed for the LHC and future detectors.