Snowmass2021 - Letter of Interest

Collider Signals of FIMP Dark Matter with Heavy Mediators

Thematic Areas:

■ (EF10) BSM: Dark Matter at colliders
■ (CF1) Dark Matter: Particle Like
■ (TF9) Theory Frontier: Astro-Particle Physics and Cosmology

Contact Information:

Stefania Gori, University of California Santa Cruz, sgori@ucsc.edu
Bibhushan Shakya, CERN, bibhushan.shakya@cern.ch

Abstract: We intend to study collider signals of feebly interacting massive particle (FIMP) dark matter. We focus on scenarios with low reheat temperatures where the mediator particle connecting the dark matter to the Standard Model is too heavy to be produced in the early Universe, but can be produced at the LHC.

We are interested in studying scenarios of dark matter freeze in, which are characterized by gradual production of dark matter particles via feeble couplings with the thermal bath[1]. Due to such feeble couplings, the collider phenomenology of such setups generally involve production of long-lived parent particles that give displaced decays, see, e.g.[2–11] for existing studies in the literature.

In traditional studies of FIMP dark matter, dark matter is produced via decays of a heavy parent particle present in the early Universe, and the correct relic density from such gradual freeze in is obtained for couplings $\sim 10^{-10}$. In contrast, our focus is on scenarios where the feeble interaction is a consequence of a mediator whose mass is significantly higher than the reheat temperature of the Universe. As a consequence, the mediator abundance in the early Universe is negligible, and DM-SM interactions arise from integrating out the propagator, giving rise to higher dimensional operators that drive UV-freeze in production of dark matter[12]. We assume scenarios where the mediator is nevertheless within reach of high energy colliders such as the LHC, enabling collider probes of such freeze-in models, which are otherwise difficult to probe experimentally.

While there are interesting cosmological aspects of such scenarios, the collider signatures of such frameworks are quite interesting, and qualitatively very different from those expected from standard freeze-in scenarios. In particular, since the effective feeble coupling is a consequence of the mediator integrated out, the mediator-dark matter coupling is much larger than the typical $\sim 10^{-10}$ traditionally associated with FIMP scenarios, and can in principle be arbitrarily larger, depending on the reheat temperature. Such scenarios therefore allow for a wide range of displaced vertex lengths and a wide array of collider phenomenology.

We intend to study various realizations of the above setup, considering both s- and t-channel mediators, with several SM charge assignments. This can give rise to a wide variety of signals at the LHC, including fully visible, semi-invisible, and fully invisible final states. Since the mediators can be SM charged or neutral, this also gives rise to a variety of signatures, including possibilities of, e.g. disappearing charged tracks.

We also intend to explore realistic particle physics models where this framework can be naturally realized. This seems to occur in a diverse class of models, including supersymmetric models and neutrino portal models of hidden sector dark matter.

References

[1] L. J. Hall, K. Jedamzik, J. March-Russell and S. M. West, *Freeze-In Production of FIMP Dark Matter*, *JHEP* **03** (2010) 080, [0911.1120].

[2] R. T. Co, F. D'Eramo, L. J. Hall and D. Pappadopulo, *Freeze-In Dark Matter with Displaced Signatures at Colliders*, *JCAP* **1512** (2015) 024, [1506.07532].

[3] F. D'Eramo, N. Fernandez and S. Profumo, *Dark Matter Freeze-in Production in Fast-Expanding Universes*, *JCAP* **1802** (2018) 046, [1712.07453].

[4] J. M. No, P. Tunney and B. Zaldivar, *Probing Dark Matter freeze-in with long-lived particle signatures: MATHUSLA, HL-LHC and FCC-hh*, 1908.11387.

[5] G. Bélanger et al., *LHC-friendly minimal freeze-in models*, *JHEP* **02** (2019) 186, [1811.05478].

[6] M. Garny and J. Heisig, *Interplay of super-WIMP and freeze-in production of dark matter*, *Phys. Rev.* **D98** (2018) 095031, [1809.10135].

[7] G. Arcadi and L. Covi, *Minimal Decaying Dark Matter and the LHC*, *JCAP* **08** (2013) 005, [1305.6587].

[8] A. Ghosh, T. Mondal and B. Mukhopadhyaya, *Heavy stable charged tracks as signatures of non-thermal dark matter at the LHC : a study in some non-supersymmetric scenarios*, *JHEP* **12** (2017) 136, [1706.06815].

[9] L. Calibbi, L. Lopez-Honorez, S. Lowette and A. Mariotti, *Singlet-Doublet Dark Matter Freeze-in: LHC displaced signatures versus cosmology*, *JHEP* **09** (2018) 037, [1805.04423].

[10] K. J. Bae, M. Park and M. Zhang, *Demystifying Freeze-In Dark Matter at the LHC*, 2001.02142.

[11] S. Chakraborti, V. Martin and P. Poulose, *Freeze-in and Freeze-out of Dark Matter with Charged Long-lived Partners*, *JCAP* **03** (2020) 057, [1904.09945].

[12] F. Elahi, C. Kolda and J. Unwin, *UltraViolet Freeze-in*, *JHEP* **03** (2015) 048, [1410.6157].