Disappearing Tracks at the High-Luminosity LHC and future hadron colliders

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1 Disappearing Track searches for dark matter

Models with Dark Matter (DM), X^0, as a part of an electroweak (EW) multiplet are appealing for a minimal theoretical DM setup. It is customary to introduce a discrete parity under which all SM fields are even and the EW $n-$multiplet is odd, with spin s. In these models, electrically charged states $X^{\pm(\pm\cdots)}$ appear in the spectrum, and the charged-neutral mass split $\Delta = m_{X^+} - m_{X^0}$ is bound to be of about 200 MeV, with the actual value depending on n and s. This highly compressed spectrum sets the charged state in the long-lived regime [1], and hence the leading collider signature is given by the charged particle being produced in collider, living for a short distance of a few mm / cm and decaying into X^0 and a SM charged particle ($\pi^\pm$ or ℓ^+, depending on Δ). This SM charged particle ends up being very soft as X^0 takes away most of the energy in the process, and hence it often fails to pass reconstruction thresholds [2], thus giving the final state of "short charged-track $\to$ invisible", usually referred to as "disappearing tracks", which have been scrutinized by the pheno community in a series of recent works [5–12].

2 Reintepretation of the ATLAS study

The ATLAS [13] and CMS [14] collaborations have presented studies searching for disappearing tracks. In a recent article [15] we have re-interpreted the *current* ATLAS results, currently restricted only to supersymmetric models of Wino ($n = 3, s = 1/2$) and Higgsino ($n = 2, s = 1/2$), to a broader set of models, which include the cases of the inert two Higgs doublet model (i2HDM, $n = 2, s = 0$)(see e.g [16] and references therein), the minimal fermion DM model (MFDM, $n = 2, s = 1/2$) [17] and the minimal Spin-one Isotriplet Dark Matter model ($n = 3, s = 1$) [18]. We have found that the re-interpretation of these studies in these less favoured and less popular models gives the strongest constraints on its parameter space, probing dark matter masses much heavier than the current (and HL-LHC) mono-jet studies. As a byproduct of our work, the Python code used to carry out the reinterpretation has been published online in the LLP Recasting Repository [19] which is readily available for other groups interested in deriving the disappearing track constraints into arbitrary models.

3 Proposed projects

Since thermal dark matter is one of the most striking motivations to go beyond the Standard Model, and given that these models provide an economic explanation of its nature, our proposal is to further study two important directions, namely:

- Repeat the exercise for the latest CMS study [14]
- Extrapolate the current reach of ATLAS and CMS to the High-Luminosity LHC and future colliders.
- Explore DM kinematics for the models beyond the thermal DM scenarios and study collider sensitivity for this additional class of models.

The first case is very timely as, unlike in the ATLAS case, the CMS reinterpretation material has only been made public in July 2020. Given the differences in the inner tracking systems between both detectors and the different search strategies, a complete study of the CMS analysis is warranted.

In the second case we note that while there have been projections for HL-LHC [20] and FCC-hh within the European Strategy, those have only been made within the collaborations, and once again, restricted to the popular models only. The real challenge is to find a sound procedure to make an estimation of the background given by "fake short tracks" due to random combinations of hits from pile-up.

[1] There is an ongoing intense activity on studies for Long-Lived Particles (LLPs) at the LHC. We refer the reader to [1] for a review of the theoretical motivations for LLPs and to [2] for an overview of the existing LHC searches.

[2] For a strategy to reconstruct the final state pion at ATLAS, see [3] and for electron-proton colliders see [4].

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