A feeble window on leptophilic dark matter

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In this paper we study a leptophilic dark matter scenario involving feeble dark matter coupling to the Standard Model (SM) and compressed dark matter-mediator mass spectrum. We consider a simplified model where the SM is extended with one Majorana fermion, the dark matter, and one charged scalar, the mediator, coupling to the SM leptons through a Yukawa interaction. We first discuss the dependence of the dark matter relic abundance on the Yukawa coupling going continuously from freeze-in to freeze-out with an intermediate stage of conversion driven freeze-out. Focusing on the latter, we then exploit the macroscopic decay length of the charged scalar to study the resulting long-lived-particle signatures at collider and to explore the experimental reach on the viable portion of the parameter space.

Introduction

As of today, the most conventional paradigm for dark matter (DM) has been the so-called Weakly Interacting Massive Particle (WIMP). WIMPs have been the main target of experimental searches, including collider experiments, direct and indirect DM detection. In the WIMP scenario, the DM is produced in the early Universe through the freeze-out mechanism, leading typically to the correct DM relic abundance for electroweak size couplings and masses. This is however not the only possibility to obtain the right DM abundance. By varying the DM mass, its coupling strength to the Standard Model (SM) and/or within the dark sector, one can generate DM through different mechanisms during the cosmological evolution of the Universe.

DM production in the early Universe

In this talk, we will focus on a simplified leptophilic DM model with a compressed DM/Mediator mass spectrum. For this model, we will discuss how DM can be produced in the early Universe. This will depend on the values of the model parameters. Changing these parameters, we can go continuously for freeze-in to freeze-out, two production mechanisms that are already well-know and studied extensively in the literature [1, 2, 3, 4, 5, 6, 7, 8]. Therefore, we will mainly focus on the intermediate stage of DM coannihilation freeze-out happening out of chemical equilibrium (CE) with the SM plasma, also called conversion driven freeze-out. Such a scenario has already been pointed out in [9] and mainly studied for dark matter coupling to quarks [9, 10]. Here instead we focus on the case of a leptophilic dark matter model. Conversion processes between the mediator and the dark matter will play a central role in defining the evolution of the DM abundance and they will have to be taken into account in the study of the DM/mediator Boltzmann equations.

Collider signatures

The feeble coupling of the DM to the mediator allows for a macroscopic decay length of the mediator that can be observed at colliders through e.g. charged and/or disappearing tracks. These are typical features of DM scenarios in which the DM abundance results from the freeze-in and conversion driven freeze-out. These production mechanisms can lead to distinctive and challenging signatures at colliders, including long lived charged particles and very soft signatures. In the freeze-in case, the DM coupling is so suppressed that the mediator mainly decays outside the detector giving rise to charged tracks. For conversion driven freeze-out, the slightly larger couplings involved can also give rise to disappearing tracks. The LHC community has Recently, The LHC community has devoted more attention to these long-lived particle signatures. We will discuss how searches for long-lived particles can constraint the model under study here. Notice also that due to the feeble coupling involved in the model, direct and indirect detection dark matter searches are challenging. Therefore, unconventional signatures at the LHC can hence provide the main experimental probes for the class of model studied here.

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