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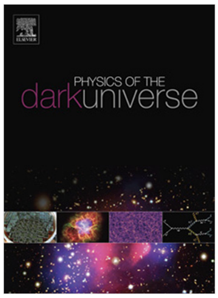

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Dark matter production in association with a single top-quark at the LHC in a two-Higgs-doublet model with a pseudoscalar mediator

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Abstract

The sensitivity of the LHC experiments to the associated production of dark matter with a single top is studied in the framework of an extension of the standard model featuring two Higgs doublets and an additional pseudoscalar mediator. It is found that the experimental sensitivity is dominated by the on-shell production of a charged Higgs boson, when this assumes a mass below 1 TeV. Dedicated selections considering one and two lepton final states are developed to assess the coverage in parameter space for this signature at a centre-of-mass energy of 14 TeV assuming an integrated luminosity of 300 fb^{-1}. For a pseudoscalar mediator, a, with mass 150 GeV and maximally mixed with the pseudoscalar of the two Higgs doublets, all values of $\tan\beta$ except for the range 3-15 can be excluded at 95% CL, if the $H^{\pm}$ mass is in the range 300 GeV-1 TeV. This novel signature complements the parameter space coverage of the mono-Higgs, mono-Z and $t\bar{t}$+$E_{\mathrm{T}}^{\mathrm{miss}}$ signatures considered in previous publications for this model.

Keywords: ATLAS, LHC, dark matter, missing energy, pseudoscalar mediators, top quark.

1. Introduction

The nature of the dark matter (DM) is one of the key open questions of contemporary physics, and its experimental investigation is the subject of a worldwide effort based on several different and complementary experimental techniques.

The search for particle DM produced at accelerators is an essential part of this program, and it is vigorously pursued at the CERN LHC, a proton-proton (pp) collider currently operating at a center-of-mass energy of 13 TeV. Since the DM particles are weakly interacting they would escape the detector unseen when produced in pp collisions at the LHC. The minimal experimental signature of DM production at a hadron collider thus consists in events with a visible final-state object X recoiling against missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}}$) associated with the undetected DM. Based on the LHC data collected between 2009 and 2016, the ATLAS and CMS collaborations have analysed a variety of such signatures involving jets of hadrons, photons, electroweak (EW) gauge bosons, top and bottom quarks as well as the Higgs boson in the final state [1–13]. Given the absence of a signal, upper limits on the production cross sections have been obtained. The corresponding $E_{\mathrm{T}}^{\mathrm{miss}}$ searches have been interpreted in the context of three different classes of theories: ultraviolet (UV) complete theories, simplified models (see the reviews [14–16] for a complete list of references), and effective field theories [17–22] . In particular, simplified models have become quite popular recently. They allow the study of the different possible signatures for DM production at the LHC focusing on the final state kinematics, and thanks to their very limited set of parameters, they provide a very effective mapping of the phenomenological space accessible to experimentation. While handy and in many cases useful, in general simplified models need to be employed with care. In some instances they might be too "simplified" to allow for an adequate investigation of the experimental potential of DM searches, as they sometimes neglect unique signatures which may arise from a more complete description of the interactions of DM with the standard model (SM). In addition, it might happen that specific research channels become explicitly sensitive to the UV completion. Glaring examples are given by violation of unitarity and gauge invariance, which points to the need for more complex extensions of the SM [23–28].

Focusing on the cases where the interaction with DM is mediated by a scalar or a pseudoscalar particle [29–34], a natural extension of the spin-0 simplified models is achieved by considering the mixing of the mediator with the Higgs boson. The experimental constraints on the Higgs boson couplings [35], however already severely constrain such a possibility. One way to relax the constraints from Higgs physics is to add to the SM a second Higgs doublet (2HDM). [36–40]. In this case the mediator that couples to DM can obtain its couplings to SM fermions from mixing with the second Higgs doublet.

In the case of a 2HDM and a pseudoscalar mediator that couples to Dirac DM (2HDM+a), a detailed phenomenological analysis of the resulting $E_{\mathrm{T}}^{\mathrm{miss}}$ signatures at the LHC has been performed in [39]. The conclusion drawn in that article is that the mono-Higgs and mono-Z signatures provide a very good and complementary coverage of the parameter space of the model, with a minor but relevant role for the associated production of DM and a top-anti-top pair (DM$t\bar{t}$). However