Higgs portal vector dark matter interpretation: review of Effective Field Theory approach and ultraviolet complete models

Mohamed Zaazoua[1], Loan Truong[2], Kétévi A. Assamagan[3], Farida Fassi[1]

[1] Mohammed V University in Rabat, Faculty of Science
[2] University of Johannesburg, Department of Mechanical Engineering Science
[3] Brookhaven National Laboratory (BNL)

Abstract: The Higgs portal-vector dark matter interpretation of the spin-independent dark-matter nucleon elastic scattering cross section, using the invisible Higgs decay width measured at the LHC, is presented. The Effective Field Theory approach and ultraviolet complete models have been used and details description are discussed. Hence, the inclusion of these theoretical scenarios in LHC public results in comparison with direct detection results is proposed. We investigate the dark matter in the sub-GeV mass range as well.

Introduction

The existence of a Dark Matter (DM) component of the universe is now firmly established, receiving astrophysical observations [1] showing strong evidence that DM exists. While the nature of the DM particles and their interactions remains an open question, it is clear that the viable candidates must lie in theories beyond the Standard Model (BSM). A particularly interesting class of candidates are weakly interacting massive particles (WIMP). They appear naturally in many BSM theories. Due to their weak-scale interaction cross-section, they can accurately reproduce the observed DM abundance in the Universe today [2]. At the LHC, experiments can explore Higgs portal scenarios in which the 125 GeV Higgs boson can achieve substantial coupling with WIMP candidates (such as singlet scalar S, vector V, fermion χ) thus inducing interaction between WIMP and nucleon while WIMP could be Higgs' invisible decay products [3]. Therefore, limits on the branching ratio from invisible Higgs decay can be used to interpret on spin-independent DM-nucleon elastic scattering cross section σ_{SI}(WIMP-N). That interpretation can complement and be compared with the direct and indirect DM particle candidate detection results [4]. The approach of using Effective Field Theory (EFT) is based on describing the unknown DM interactions with the Standard Model (SM) in a very economical way. This has attracted significant attention, especially because of its simplicity and flexibility which allows it to be used in vastly different search contexts. For the scalar and fermion WIMP candidates, EFT approach [5] can be safely used. Hence, the EFT approach is used in LHC Run–1 papers [6] (Figure 1). Unfortunately, the validity of this approach, as far as vector case has been questioned and the limitations to the use of EFT has been recognized by the theoretical and experimental communities [8]. The recent efforts to develop more model-independent approaches to DM searches stimulated this literature [9], in which the EFT approach is shown to come from a valid ultraviolet (UV) model and its results are viable. The UV completion models have been investigated in both scenarios: along with the EFT approaches and in a separate model with additional fermions [10].

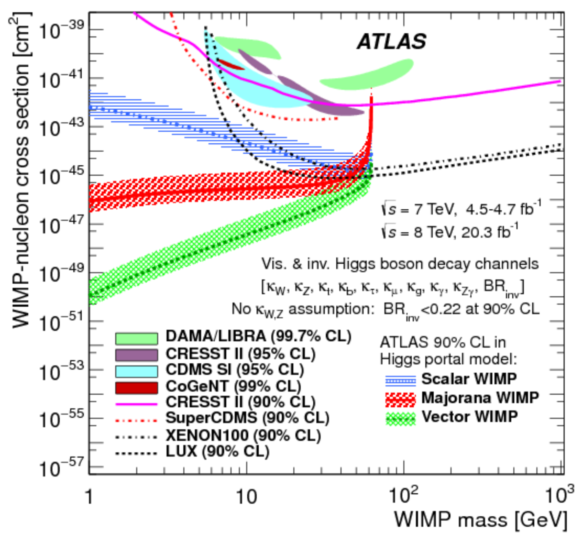

Figure 1. ATLAS upper limit at the 90% CL on the WIMP-nucleon scattering cross section in a Higgs portal model as a function of the mass of the dark-matter particle, shown separately for a scalar, Majorana fermion, or vector-boson WIMP. It is determined using the limit at the 90% CL of $BR_{inv} < 0.22$ derived using both the visible and invisible Higgs boson decay channels. The hashed bands indicate the uncertainty resulting from varying the form factor f_N by its uncertainty. Excluded and allowed regions from direct detection experiments at the confidence levels indicated are also shown [7]. These are spin-independent results obtained directly from searches for nuclei recoils from elastic scattering of WIMPs, rather than being inferred indirectly through Higgs boson exchange in the Higgs portal mode

References

[1] D. Clowe et al., A Direct Empirical Proof of the Existence of Dark Matter, The Astrophysical Journal 648 (2006) L109, issn: 1538-4357, url: http://dx.doi.org/10.1086/508162

[2] J. L. Feng and J. Kumar, The WIMPless Miracle: Dark-Matter Particles without Weak-Scale Masses or Weak Interactions, Phys. Rev. Lett. 101 (2008) 231301, arXiv: 0803.4196 [hep-ph]

[3] I. Antoniadis, M. Tuckmantel, and F. Zwirner, Phenomenology of a leptonic goldstino and invisible Higgs boson decays, Nucl. Phys. B707 (2005) 215, arXiv: hep-ph/0410165 [hep-ph]

[4] F. Petricca et al., “First results on low-mass dark matter from the CRESST-III experiment”, 15th International Conference on Topics in Astroparticle and Underground Physics (TAUP 2017) Sudbury, Ontario, Canada, July 24-28, 2017, 2017, arXiv: 1711.07692 [astro-ph.CO]

[5] A. Djouadi, O. Lebedev, Y. Mambrini, and J. Quevillon, Implications of LHC searches for Higgs–portal dark matter, Phys. Lett. B 709 (2012) 65, arXiv: 1112.3299 [hep-ph]

[6] G. Aad et al., Constraints on new phenomena via Higgs boson couplings and invisible decays with the ATLAS detector, JHEP 11 (2015) 206, arXiv: 1509.00672 [hep-ex]

[7] XENON10 collaboration, J. Angle et al., A search for light dark matter in XENON10 data, Phys. Rev. Lett. 107 (2011) 051301 [Erratum ibid. 110 (2013) 249901] [arXiv:1104.3088]

[8] S. Baek, P. Ko, and W.-I. Park, Invisible Higgs decay width vs. dark matter direct detection cross section in Higgs portal dark matter models, Physics Letters B (2014), issn: 0370-2693, url: http://www.sciencedirect.com/science/article/pii/S0370269314006984

[9] G. Arcadi, A. Djouadi, and M. Kado, The Higgs-portal for vector Dark Matter and the Effective Field Theory approach: a reappraisal, Phys. Lett. B 805 (2020) 135427, arXiv: 2001.10750 [hep-ph]

[10] A. DiFranzo, P. J. Fox, and T. M. P. Tait, Vector Dark Matter through a Radiative Higgs Portal, JHEP 04 (2016) 135, arXiv: 1512.06853 [hep-ph]