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Search for Dark Matter produced in association with a Higgs boson decaying to b-quarks using the ATLAS detector

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Many extensions of the Standard Model predict the production of Dark Matter particles in association with Higgs bosons. This search examines the final state of missing transverse momentum accompanied by a $b\bar{b}$ pair originating from a Higgs boson decay. For this purpose, proton-proton collision data are used, which is produced at 13 TeV center-of-mass energy and recorded by the ATLAS experiment at the LHC, amounting to an integrated luminosity of 139 fb^{-1}. The increase in integrated luminosity in conjunction with several analysis optimizations result in a better sensitivity in comparison to previous iterations of the analysis. No significant deviation from the Standard Model is observed and the results are interpreted in the context of the Two-Higgs-Doublet models extended with an additional vector or pseudoscalar mediator.

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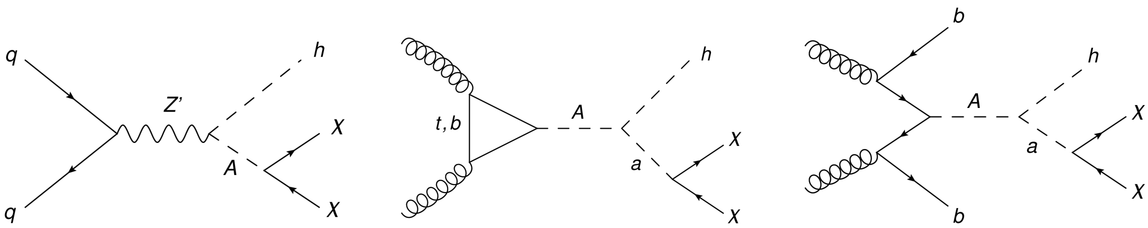
1. Motivation

Numerous astrophysical observations indicate the existence of Dark Matter (DM) [1]. This evidence relies on the gravitational force that DM exerts on visible matter. A new massive particle, which interacts neither via the electromagnetic nor the strong force, provides a compelling candidate for particle DM in explaining the observed phenomena.

The Large Hadron Collider (LHC) at CERN [2] collides proton-proton beams at high intensities and at a high center-of-mass energy. Therefore, it can produce heavy particles like the hypothetical DM particle. ATLAS [3] is one of the general-purpose detectors at the LHC that discovered the Higgs boson in 2012 [4].

In the Standard Model (SM), the coupling of the Higgs boson to other particles depends on their mass. Therefore, the Higgs boson could couple directly to DM particles. Detectors like ATLAS can not directly detect DM. If a collision produces DM in association with other particles, an imbalance in the transverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$) would be observed. Searches that target this signature are called $E_{\mathrm{T}}^{\mathrm{miss}}$+$X$ searches. The signature with a SM Higgs boson and $E_{\mathrm{T}}^{\mathrm{miss}}$ in the final state is one of these. The Higgs boson decay to b-quarks has the highest branching ratio and, therefore, is the most promising final state.

For interpreting the results, two variations of the Two-Higgs-Doublet model (2HDM), which extends the SM with a second Higgs doublet, are considered [5]. One variation is the Z'-2HDM which adds a heavy vector boson (Z') to the SM [6]. This is a simplified model which acts as a benchmark and is not renormalizable. The second variation is the 2HDM+a which adds a new pseudoscalar singlet [7, 8]. It is the simplest extension of a simplified pseudoscalar mediator model that is renormalizable and gauge-invariant. Furthermore, it has a rich phenomenology so that it can be targeted with different analysis strategies. Figure 1 shows the dominant Feynman diagrams for these models targeted in this analysis.



(a) **(b)** **(c)**

Figure 1: Dominant Feynman diagrams for the mono-Higgs signature production using the Z'-2HDM (a) and the 2HDM+a (b, c) models.

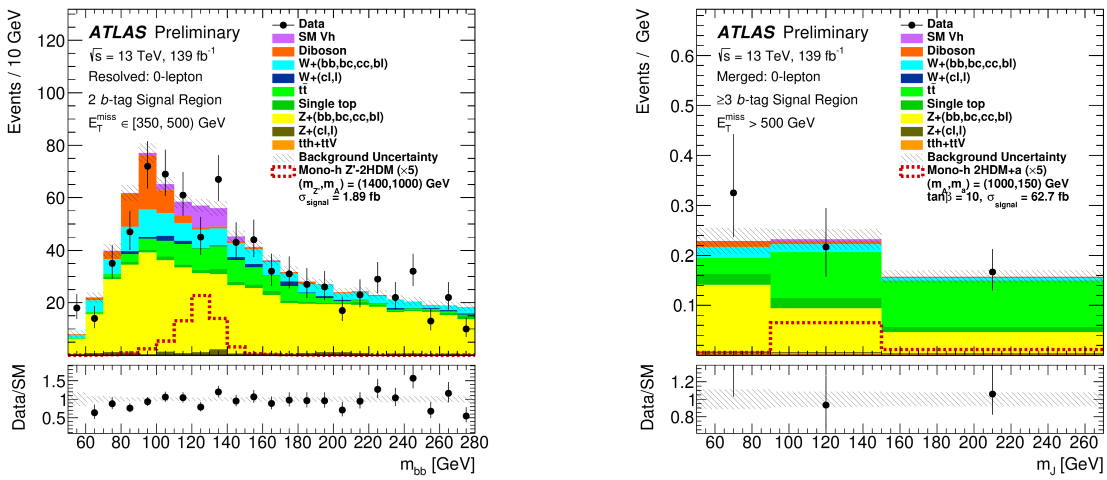
2. Analysis Strategy

Selected events are required to be $E_{\mathrm{T}}^{\mathrm{miss}}$-triggered and have $E_{\mathrm{T}}^{\mathrm{miss}} > 150\,\mathrm{GeV}$. Because the $E_{\mathrm{T}}^{\mathrm{miss}}$ and the SM Higgs boson are generally recoiling against each other, the magnitude of $E_{\mathrm{T}}^{\mathrm{miss}}$ is a proxy for how strongly boosted the Higgs boson decay products are. Therefore, in events with $E_{\mathrm{T}}^{\mathrm{miss}} < 500\,\mathrm{GeV}$ the Higgs boson candidate is reconstructed using two small-R ($R = 0.4$) particle flow jets [9] (resolved region), while for events with $E_{\mathrm{T}}^{\mathrm{miss}} > 500\,\mathrm{GeV}$ the boosted decay products are captured by one large-R ($R = 1$) jet (merged region) which is reconstructed using calorimeter clusters [10]. The two small-R jets are required to be b-tagged by the DL1-tagger [11]. For the b-tagging in the merged region variable-radius track jets [12] are used. These jets are ghost-associated [13] to the large-R jet and b-tagged using the DL1-tagger. The DL1-tagger is used at a working point with 77% identification efficiency. Events with an isolated lepton or a τ-decay are vetoed. All event selections are described in detail in [14].

The major backgrounds are W+jets, Z+jets and $t\bar{t}$-production. Control regions (CR) are constructed by inverting the isolated lepton veto to constrain the normalization of these backgrounds. For the CR constraining W+jets and $t\bar{t}$, exactly one isolated muon is required. Events containing two same-flavor opposite-charge leptons make up another CR that controls the Z+jets normalization.

3. Results

The final fit discriminant in the resolved signal region (SR) is the invariant di-b-jet mass, while in the merged SR it is the mass of the large-R jet. In the one-muon CR the charge of the muon is fitted, and in the two-lepton CR only the yield is used. Post-fit, the resolved region is dominated by systematic uncertainties related to jets and the modeling of top-quark processes. Data statistic limits the sensitivity of the merged region. Figure 2 shows the post-fit distributions for two of the nine SRs. The data show no significant deviation from the SM.



(a) Invariant di-b-jet mass distribution for the 2 b-tag, 350 GeV $< E_{\mathrm{T}}^{\mathrm{miss}} <$ 500 GeV region.

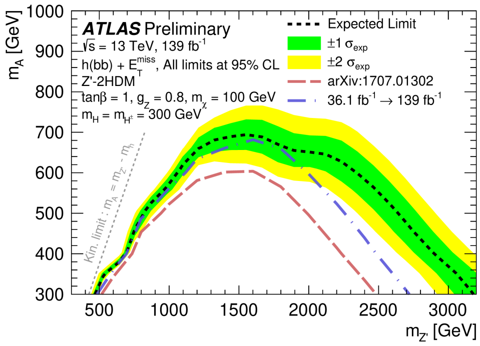
(b) Merged region large-R jet mass distribution for the $\geq$3 b-tag, $E_{\mathrm{T}}^{\mathrm{miss}} >$ 500 GeV region.

Figure 2: Selection of SR post-fit distributions [14].

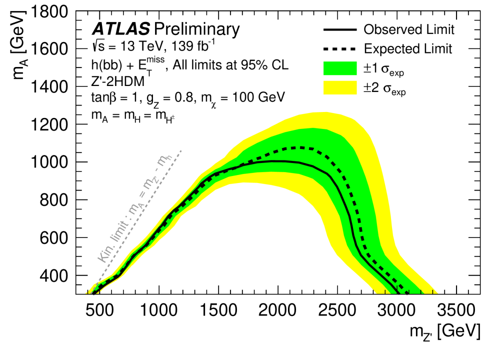
4. Interpretation

The results are interpreted in the context of the two 2HDM models and their exclusion contours are shown in Figure 3. Figure 3a shows that the obtained sensitivity extends that of the previous iteration [15]. The increase in collected data along with optimizations to the analysis strategy are the reason for this. A few of the analysis improvements are the following:

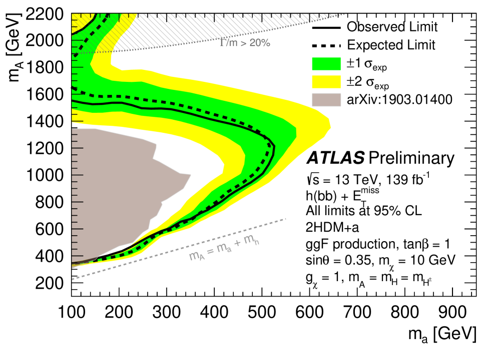
- Muon in jet correction: the decay of b-quarks via the weak force can produce muons. The momentum carried by these muons had not been taken into account in the jet reconstruction. By including the muon momentum in the reconstruction the mass resolution can be improved.
- E_T^{miss} binning: in the previous iteration only one E_T^{miss} bin was used in the merged region. Due to the increase in collected data, it is now possible to have two E_T^{miss} bins.
- Improved b-tagger: the DL1 b-tagger has a higher background rejection rate than the previously used MV2c10 [11]. It uses a deep neural network in contrast to the MV2c10, which is based on a boosted decision tree.



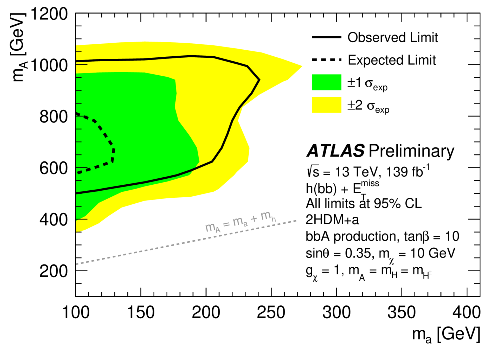
(a) Parameter convention used in the previous iteration ($m_H = m_{H^\pm} = 300$ GeV).



(b) New parameter convention ($m_H = m_{H^\pm} = m_A$).



(c) $\tan(\beta) = 1$.



(d) $\tan(\beta) = 10$.

Figure 3: Exclusion contours at the 95% confidence level for the Z'-2HDM (a, b) and the 2HDM+a (c, d) model [14].

5. Conclusion

This analysis presents the search for Dark Matter produced in association with a Standard Model Higgs boson decaying into $b\bar{b}$. The full Run 2 proton-proton collision dataset of 139 fb^{-1} collected at $\sqrt{s} = 13$ TeV by ATLAS at the LHC is used. Due to the increased dataset and improvements in the analysis strategy, the sensitivity compared to previous iterations is improved. No significant deviation from the SM is observed, and limits are set on the Z'-2HDM and the 2HDM+a model.

References

[1] D. Clowe, A. Gonzalez and M. Markevitch, "Weak lensing mass reconstruction of the interacting cluster 1E0657-558: Direct evidence for the existence of dark matter", Astrophys. J. 604 (2004) 596, arXiv: astro-ph/0312273 [astro-ph].

[2] L. Evans and P. Bryant (editors), "LHC Machine", 2008 JINST 3 S08001.

[3] ATLAS Collaboration, "The ATLAS Experiment at the CERN Large Hadron Collider", 2008 JINST 3 S08003.

[4] ATLAS Collaboration, "Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC", Phys. Lett. B716 (2012) 1-29, arXiv: 1207.7214 [hep-ex].

[5] G. C. Branco et al., "Theory and phenomenology of two-Higgs-doublet models", Phys. Rept. 516 (2012) 1, arXiv: 1106.0034 [hep-ph].

[6] A. Berlin, T. Lin and L.-T. Wang, "Mono-Higgs detection of dark matter at the LHC", JHEP 06 (2014) 78.

[7] LHC Dark Matter Working Group: Next-generation spin-0 dark matter models, Phys. Dark Univ. (2018) 100351, arXiv: 1810.09420 [hep-ex].

[8] M. Bauer, U. Haisch and F. Kahlhoefer, "Simplified dark matter models with two Higgs doublets: I. Pseudoscalar mediators", JHEP 05 (2017) 138.

[9] ATLAS Collaboration, "Jet reconstruction and performance using particle flow with the ATLAS Detector", Eur. Phys. J. C 77 (2017) 466, arXiv: 1703.10485 [hep-ex].

[10] ATLAS Collaboration, "Topological cell clustering in the ATLAS calorimeters and its performance in LHC Run 1", Eur. Phys. J. C 77 (2017) 490, arXiv: 1603.02934 [hep-ex].

[11] ATLAS Collaboration, "Optimisation and performance studies of the ATLAS b-tagging algorithms for the 2017-18 LHC run", ATL-PHYS-PUB-2017-013, 2017, url: `https://cds.cern.ch/record/2273281`.

[12] D. Krohn, J. Thaler and L.-T. Wang, "Jets with Variable R", JHEP 06 (2009) 059, arXiv: 0903.0392 [hep-ph].

[13] M. Cacciari, G. P. Salam and G. Soyez, "The Catchment Area of Jets", JHEP 04 (2008) 005, arXiv: 0802.1188 [hep-ph].

[14] ATLAS Collaboration, "Search for Dark Matter produced in association with a Standard Model Higgs boson decaying to b-quarks using the full Run 2 collision data with the ATLAS detector", ATLAS-CONF-2021-006 (2021).

[15] ATLAS Collaboration, Search for Dark Matter Produced in Association with a Higgs Boson Decaying to $b\bar{b}$ using 36 fb^{-1} of pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS Detector, Phys. Rev. Lett. 119 (2017) 181804, arXiv: 1707.01302 [hep-ex].