Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Searching for Dark Matter with the ATLAS detector

To cite this article: N Ilic and on behalf of the ATLAS Collaboration 2020 *J. Phys.: Conf. Ser.* **1690** 012153

Journal of Physics: Conference Series **1690** (2020) 012153 doi:10.1088/1742-6596/1690/1/012153

Searching for Dark Matter with the ATLAS detector

N Ilic on behalf of the ATLAS Collaboration

CERN, Espl. Des Particules 1, 1211 Meyrin

E-mail: Nikolina.Ilic@cern.ch

Abstract. The presence of a non-baryonic dark matter component in the Universe is inferred from the observation of its gravitational interaction. If dark matter interacts weakly with the Standard Model it would be produced at the LHC, escaping the detector and leaving a large missing transverse momentum as their signature. The ATLAS detector has developed a broad program to directly search for Dark Matter. The results of recent searches on 13 TeV *pp* data, giving the details of analysis techniques and improvements used and their interpretation, are presented.

1. Introduction

Astronomical observations indicate that 27% of the mass-energy content of the universe consists of an unidentified, mysterious substance called Dark Matter. There are two approaches used by the ATLAS detector [1] to search for Dark Matter production at the Large Hadron Collider (LHC). The first relies on searching for Simplified Models that assume Dark Matter couples to Standard Model (SM) particles with a simplified mediator. The mediator can be a SM particle, such as Z and Higgs mediators, or beyond-SM mediators such as generic scaler or vector particles. The simplified models have been harmonized across different LHC experiments with the guidance of the LHC Dark Matter working group. The second approach is to search fully, theoretically complete models such as Supersymmetry.

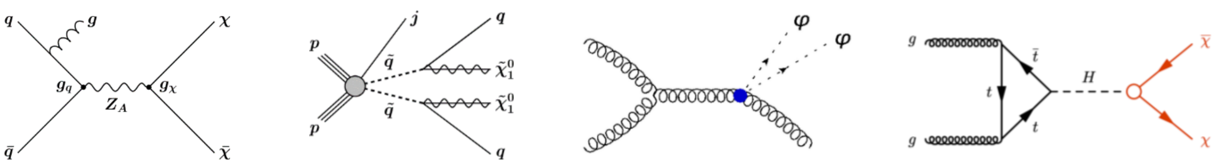
Although Dark Matter is not expected to interact with the material in ATLAS, its presence can be inferred through the detection of missing transverse energy (MET). MET is the sum of momenta in the transverse plane of the detector. Since MET is zero before a collision occurs in the z-plane of the LHC, if all particles are detected after the collision, it should remain zero. The presence of a large amount of MET therefore indicates an undetected particle that could originate from neutrinos or exotic particles such as Dark Matter. ATLAS searches therefore require the presence of large MET produced in association with a SM particle.

2. Dark Matter Searches in ATLAS

A subset of recent Dark Matter searches is described below. The general strategy for the searches described is to define a region rich in background events, referred to as a Control Region (CR) and use it to correct the imperfect Monte Carlo (MC) modelling of backgrounds by defining a normalization factor. The normalization factor represents the ratio of data to MC in the CR, and is use to correct the MC normalization in a signal rich region, referred to as a Signal Region (SR).

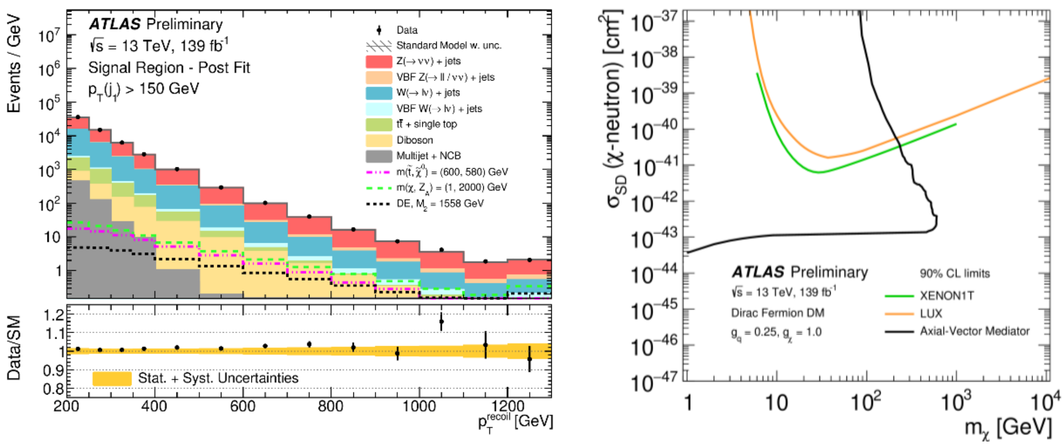
2.1. MET + Jet

Searching for MET produced with a high energy jet is a signature sensitive to a wide range of models such as simplified models with axial-vector, vector, pseudo-scalar mediators, Supersymmetry, effective field theory containing Dark Energy coupling to the SM, Higgs decaying to Dark Matter, and axion-like particles produced in association with a gluon (figure 1). The SR contains events with MET > 200 GeV, together with a jet whose momentum exceeds 150 GeV, and zero leptons. The main backgrounds consist of Z and W events whose momentum is balanced by hadronic recoil. The MET signature in these events results from either the neutrinos from the Z/W decay, or mis-modelled hadronic recoil. These backgrounds are estimated from dedicated CRs defined by requiring the presence of leptons. The hadronic recoil of the system is used as a main discriminating variable to differentiate between signal and background events. Figure 2 shows the modelling in the SR as well as an example of the limits placed on fermion dark matter particle. Limit plots for the remaining models can be found in [2]. No significant excesses are observed.



(a) (b) (c) (d)

Figure 1. Feynman diagrams for simplified models, Supersymmetry, effective field theory coupling to Dark Matter, and Higgs decaying to Dark Matter ((a) to (d)) [2].

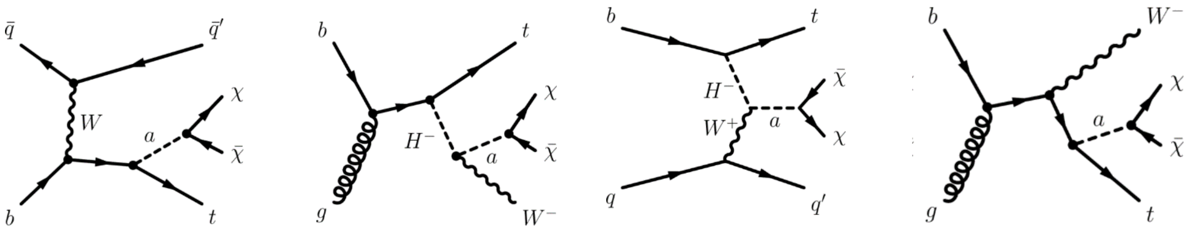


(a) (b)

Figure 2. The momentum of the hadronic recoil in the SR (a). The limits on the fermionic Dark Matter – neutrino cross section as a function of the Dark Matter mass, assuming a coupling to quarks of 0.25, and coupling to Dark Matter of 1.0. Limits from the Dark Matter experiments, LUX, and XENON1T are overlaid [2].

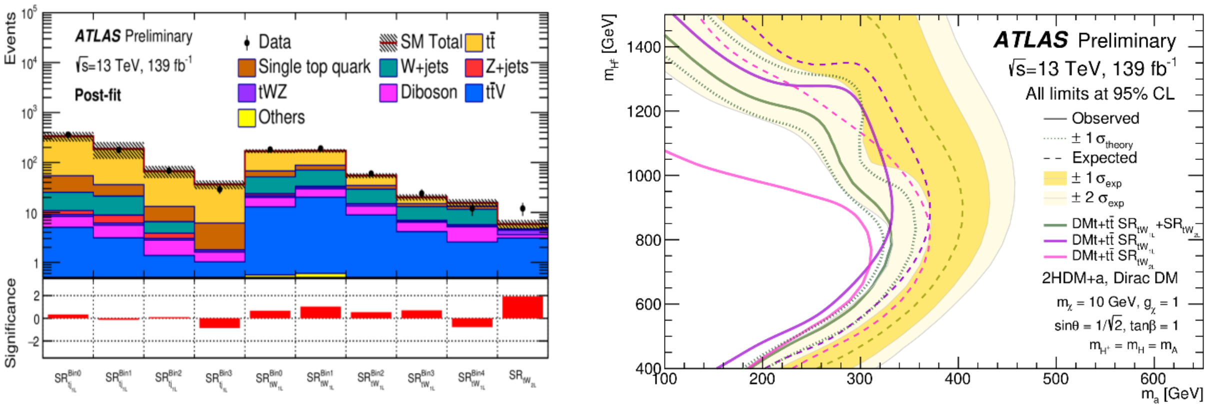
2.2. MET + Wt

Complete theories such as the 2 Higgs Doublet Model (2HDM), provide a chance to explore new signatures and a rich phenomenology as shown in figure 3. The theory predicts an additional five Higgs bosons ($h,\ H^{\pm},\ H^{0}, A$), and a pseudo-scalar particle, a, that couples to Dark Matter. The presence of the top quark and W bosons leads to final states with various combinations of leptons, jets, and b-jets which are used to define the SR. The first SR containing a top quark with jets, referred to as $SR_{tj_{1L}}$, consists of one lepton, 1-4 jets and 1-2 b-jets. The corresponding CR, containing mostly top quark events, is defined by using a Boosted Decision Tree (BDT) method. This method exploits the different shapes that background and signal distributions have in kinematic variables such as MET, the transverse mass, the number of jets, and the separation between the lepton and b-jet. The remaining two signal regions contain W bosons: $SR_{tW_{1L}}$ contains a lepton and at least three jets, one of which is a b-jet, while $SR_{tW_{2L}}$ contains 2 leptons, at least 1 jet and at least 1b-jet. The most discriminating variable in these two regions is the stransverse mass, and asymmetric stransverse mass which relates the transverse mass of dark matter particle to the transverse mass of the particle it decayed from. Figure 4 shows the various signal regions and their respective backgrounds, as well as a plot showing the limits on charged Higgs bosons ($H^{\pm}$) as a function of the pseudo-scalar mass, m_a. Additional limit plots are shown in [3]. No significant excesses are observed.



(a) (b) (c) (d)

Figure 3. Feynman diagrams for 2HDM models with decays to top quarks and W bosons [3].

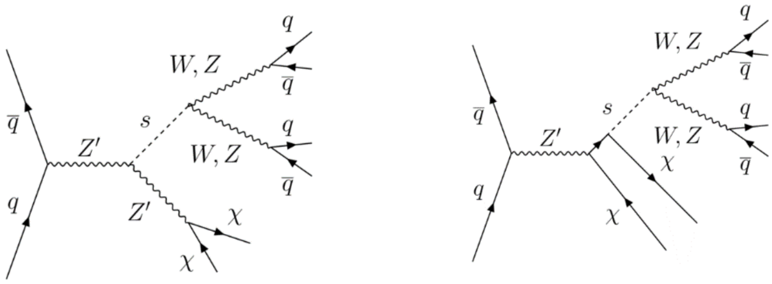


(a) (b)

Figure 4. The distributions in the SR and CR (a), and corresponding limit plots on the charged Higgs boson ($H^{\pm}$) as a function of the pseudo-scalar mass, m_a, for an assumed Dark Matter mass of 10 GeV, and Dark matter coupling of 1. The ratio of the vacuum expectation values of the Higgs Boson doublets, $\tan\beta,$ is assumed to be 1 [3].

2.3. MET + VV (hadronic)

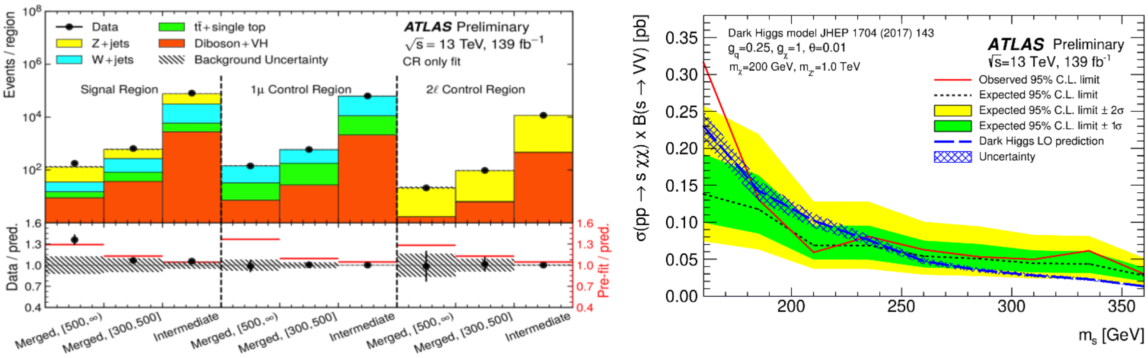
Another model that leads to previously novel signatures is a simplified model which predicts a dark Higgs boson, s, that couples to Dark Matter. The Feynman diagrams for this model are shown in figure 5. This signature includes two boosted vector bosons that decay hadronically. The hadronic decay channel is explored due to the high branching fraction. At high momentum the hadronic decays are very collimated. Since this signature is close to the granularity of limits of the detector, angular track information is used to improve the spatial resolution. This is accomplished by utilizing objects called Track Assisted Reclustered (TAR) jets. TAR jets are constructed by first identifying small-radius (radius 0.4) jets around the vector boson energy deposits. These input jets are then reclustered to large radius (radius 0.8) jets, and soft components from pileup are removed. Tracks from the inner detector are then matched to the small-radius jets, and their momentum is rescaled by the momentum of the jets. The jet properties, such as mass, are then calculated from the rescaled tracks. This ensures that a combination of calorimeter and inner detector information is used in order to exploit the optimal energy resolution of the measurement.



(a) (b)

Figure 5. Feynman diagrams for a simplified dark Higgs model [4].

TAR jets are then used to defined the SR, as shown in figure 6. The merged SR selects a TAR jet that contains both vector bosons inside, and a MET > 500 GeV. Another merged SR is defined with a lower MET threshold, namely 300 < MET < 500 GeV. Finally, an Intermediate SR is defined as encompassing a fraction of the vector bosons' energy in one TAR jet, and the remaining fraction is a small jet near the TAR jet. The main background from Z/W+jets is estimated from control regions that contain leptons. The distributions in the SR and CRs are shown in figure 6. The invariant mass of the vector bosons is used for background and signal separation and to derive the limit plot shown in figure 6. More distributions can be found in [4]. No significant excesses are observed.

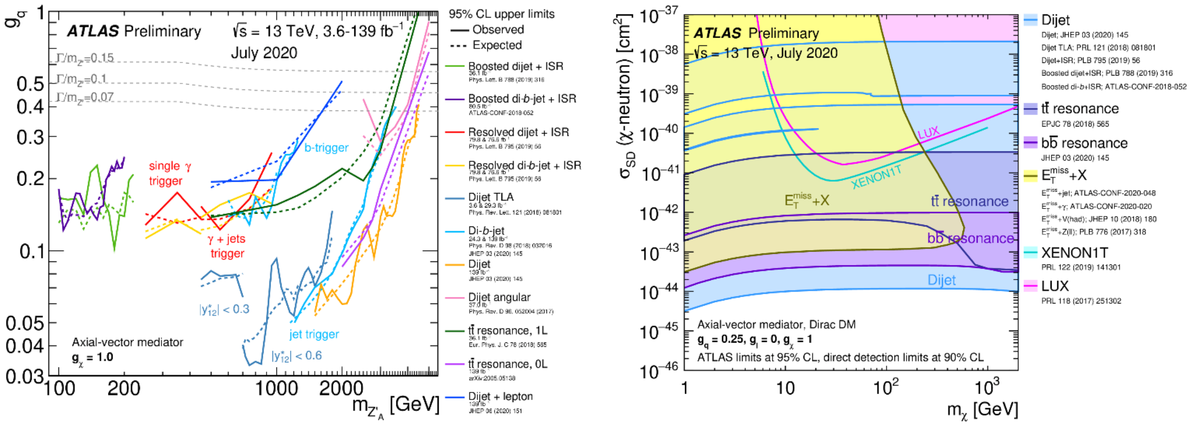


(a) (b)

Figure 6. The distributions in the SR and CR (a) and the limit on the cross section times branching ratio as a function of the dark Higgs mass, *s* [4].

2.4. Overlaying Plots

In addition to the searches presented, many other analyses are performed in ATLAS searching for different Dark Matter models in many final states. A subset of these analyses is overlaid to show limits on the Dark Matter to quark coupling as a function of the leptophobic axial-vector Z'_A mass, as shown in figure 7. The same figure shows limits on the cross section of the Dark Matter-neutrino scattering as a function of the leptophobic axial-vector mediator in simplified models. Similar overlaid spin-independent limits, and limits on other processes can be found in [7].



(a) (b)

Figure 7. Overlaid limit plots for Dark Matter to quark coupling as a function of the leptophobic axial-vector Z'$_A$ mass (a) and cross section of the Dark Matter-neutrino scattering as a function of the leptophobic axial-vector mediator in simplified models (b) [5].

3. Summary

A subset of ATLAS Dark Matter searches at the LHC were presented for various models, including simplified models, Supersymmetry and 2HDM. The separation of the signal from background was described. A subset of limits was shown, and no significant excess above the Standard Model were identified.

References

[1] Aad G *et al.* (ATLAS Collaboration) 2008 *J. Instrum.* **3** S08003

[2] Aad G *et al.* (ATLAS Collaboration) 2020 Search for new phenomena in events with jets and missing transverse momentum in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector *Preprint* ATLAS-CONF-2020-048 URL https://cds.cern.ch/record/2728058

[3] Aad G *et al.* (ATLAS Collaboration) 2020 Search for dark matter associated production with a single top quark in $\sqrt{s}$ = 13 TeV pp collisions with the ATLAS detector *Preprint* ATLAS-CONF-2020-034 URL https://cds.cern.ch/record/2727741

[4] Aad G *et al.* (ATLAS Collaboration) 2020 Search for Dark Matter Produced in Association with a Dark Higgs Boson Decaying to *WW* or *ZZ* in Fully Hadronic Final States Using pp Collisions $\sqrt{s}$ = 13 TeV Recorded with the ATLAS Detector *Preprint* ATLAS-CONF-2020-036 URL https://cds.cern.ch/record/2727743

[5] Aad G *et al.* (ATLAS Collaboration) 2020 Dark matter summary plots for s-channel mediators *Preprint* ATL-PHYS-PUB-2020-021 URL https://cds.cern.ch/record/2725266