PROCEEDINGS OF SCIENCE

Dark Matter searches with the ATLAS Detector

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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 particles it may be produced at the Large Hadron Collider (LHC), escaping detection and leaving large missing transverse momentum as its signature. New results from the Dark Matter search programme of the ATLAS experiment are presented, based on LHC proton-proton collision data collected at a center-of-mass energy of 13 TeV.

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1. Introduction

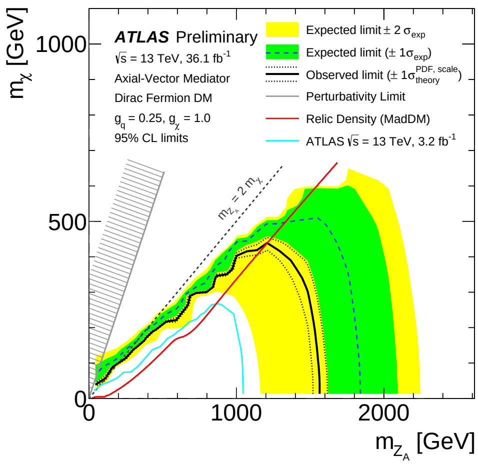
Investigating the particle nature of Dark Matter (DM), whose existence is supported by strong observational evidence[1], is one of the main goals of the ATLAS experiment at the Large Hadron Collider (LHC). ATLAS searches are based on various theoretical frameworks beyond the Standard Model (SM), such as simplified models[2, 3, 4, 5] which provide rather generic descriptions of the DM-SM interaction, or supersymmetric models. In this document, the most recent search results based on proton-proton collisions at 13 TeV are presented. The ATLAS detector is described elsewhere[6].

2. $E_{\mathrm{T}}^{\mathrm{miss}} + \mathbf{jets}$

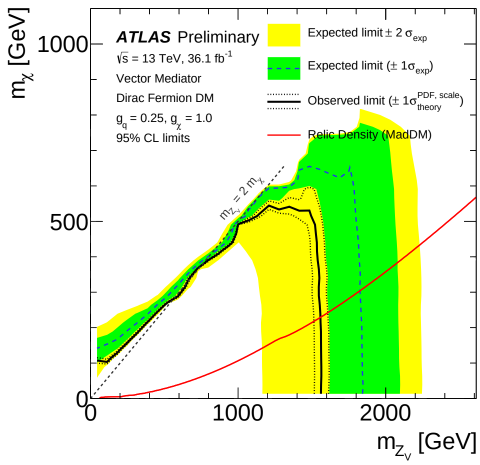
The highest sensitivity to scenarios where pairs of weakly-interacting DM particles are produced through the s-channel exchange of a mediator is provided by the final state with large missing transverse momentum, $E_{\mathrm{T}}^{\mathrm{miss}}$, recoiling against a high-p_{T} jet originating from the hadronisation of a gluon from initial-state radiation ("mono-jet"). The ATLAS search[7] is based on 36.1 fb^{-1} of collision data collected in 2015 and 2016. Events passing a $E_{\mathrm{T}}^{\mathrm{miss}}$ trigger are selected if they have at least one jet reconstructed with the anti-k_{T} algorithm[8] with radius parameter $R = 0.4$, with $p_{\mathrm{T}} > 250\,\mathrm{GeV}$ and pseudorapidity $|\eta| < 2.4$, $E_{\mathrm{T}}^{\mathrm{miss}} > 250\,\mathrm{GeV}$ and no electron or muon. Up to three additional jets with $p_{\mathrm{T}} > 30\,\mathrm{GeV}$ are allowed; the difference in azimuthal angle between $E_{\mathrm{T}}^{\mathrm{miss}}$ and any jets must be $\Delta\phi > 0.4$.

The dominant backgrounds to this search come from the $Z(\nu\nu) +$jets process and from the $W(\mu\nu) +$jets and $W(\tau\nu) +$jets processes, where the muon is not reconstructed or the τ lepton decays hadronically or into a neutrino and a charged lepton which escapes detection. Next-to-leading-order (NLO) QCD corrections and NLO electroweak corrections, supplemented by Sudakov logarithms at two loops, are applied to the simulated samples for the $W/Z +$jets processes as a function of the boson p_{T}, following the prescription of Ref. [9]. A simultaneous binned likelihood fit to the W/Z p_{T} distribution in four control regions enriched in $W(\mu\nu) +$jets, $W(e\nu) +$jets, $t\bar{t}$ and $Z(\mu\mu) +$jets events is used to derive a common normalisation factor for all the $W/Z +$jets backgrounds, and a separate normalisation factor for top-quark processes. Uncertainties due to the different effect of higher-order corrections to $Z(\nu\nu) +$jets, $W(\ell\nu) +$jets and $Z(\ell\ell) +$jets processes are taken into account across the full $E_{\mathrm{T}}^{\mathrm{miss}}$ spectrum, and have an impact of about 1% on the total background uncertainty in the signal region. Additional contributions come from the uncertainty on the muon and electron selection efficiencies and from the uncertainty on the jet energy scale and resolution. The total background uncertainty varies between 2% and 7%; no significant excess with respect to the SM prediction is observed.

Results are interpreted in terms of simplified models of DM-SM interaction, with the s-channel exchange of an axial-vector or vector mediator, with a coupling $g_q = 1/4$ to SM quarks and a coupling $g_\chi = 1$ to DM. Exclusion contours at 95% CL are presented in Fig. 1 for the two cases: mediator masses up to 1.55 TeV are excluded for low values of the DM mass. The case of pseudo-scalar interactions, with a mediator exchanged in the s-channel through a top-quark loop, was also considered, but the analysis has not yet enough sensitivity to a mediator coupling $g = 1$.



(a)



(b)

Figure 1: Observed and expected exclusion contours as a function of the DM mass m_χ and the mediator mass $m_{Z_{A(V)}}$, for the simplified model with an axial-vector (left) or vector (right) mediator. From Ref. [7].

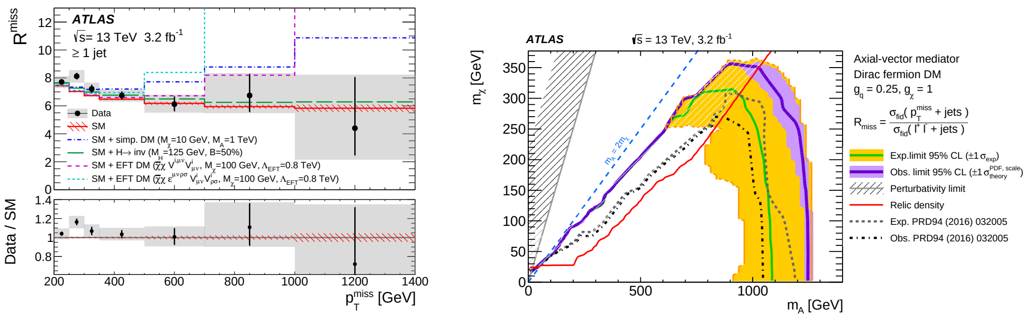
3. $Z(\nu\nu)+$jets$/Z(\ell\ell)+$jets cross-section ratio

Similar results can be obtained by comparing the measured differential $Z(\nu\nu)+\text{jets}/Z(\ell\ell)+$ jets cross-section ratios, corrected for detector effects, to predictions from new physics models. The ATLAS measurement[10], based on 3.2 fb^{-1} of collision data collected in 2015, studies both a mono-jet and a vector-boson fusion (VBF) topology. The measured ratio is expressed as a function of the boson p_{T} and, in the case of the VBF topology, the mass of the di-jet system and the difference in azimuthal angle between the two jets. Figure 2(a) shows such ratio as a function of the boson p_{T} in the mono-jet topology. A re-interpretation of these results in the context of the axial-vector model of Sec. 2, under the assumption that the detector effects are similar for both the SM backgrounds and this simplified model, is shown in Fig. 2(b).

4. $E_{\mathrm{T}}^{\mathrm{miss}}+Z(ee/\mu\mu)$

Final states with a Z boson decaying into electrons or muons and missing transverse momentum constitute another clear signature for the production of DM, where the Z boson may come for example from initial state radiation. The ATLAS search[11] is based on 36.1 fb^{-1} of data collected in 2015 and 2016. Events are selected with a pair of electrons or muons with invariant mass compatible with the decay from a Z boson, recoiling against $E_{\mathrm{T}}^{\mathrm{miss}} > 90\,\mathrm{GeV}$.

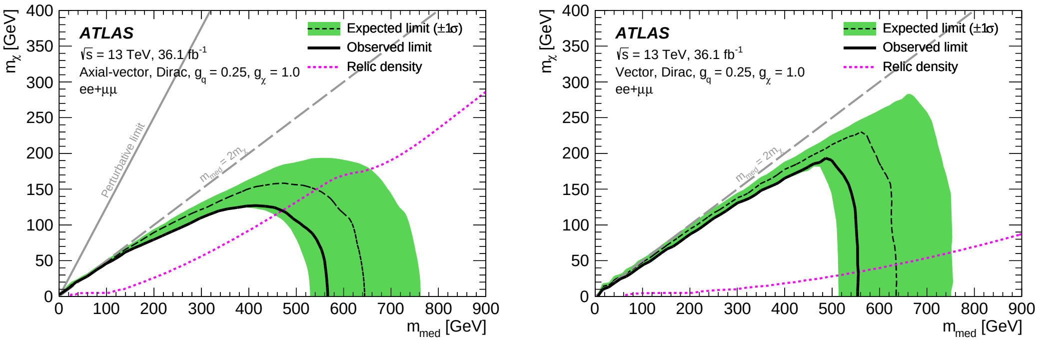
The dominant background, coming from ZZ production, is estimated from simulation; data-driven techniques are used to determine the WZ background, as well as the contribution from non-resonant backgrounds. The main uncertainties come from the modelling of the ZZ process, lepton momentum scale and resolution and uncertainties on the lepton reconstruction and identification efficiencies and jet energy scales.



(a) (b)

Figure 2: Left: measured ratio between the fiducial cross-sections for the $Z(\nu\nu)+$jets and $Z(\ell\ell)+$jets processes, R_{miss}, as a function of the boson p_{T}, for the mono-jet topology. Right: observed and expected 95% CL exclusion contours as a function of the DM mass m_χ and the mediator mass m_A, for the simplified model with an axial-vector mediator; expected results are compared to a mono-jet search performed with the same data. From Ref. [10].

No significant excess is observed with respect to the SM prediction. Fig. 3 shows the 95% CL exclusion contours for the simplified model with an axial-vector or vector mediator: mediator masses up to 560 GeV are excluded for low values of the DM mass.



(a) (b)

Figure 3: Observed and expected exclusion contours as a function of the DM mass m_χ and the mediator mass m_{med}, for the simplified model with an axial-vector (left) or vector (right) mediator. From Ref. [11].

5. Summary

Fig. 4 compares all ATLAS search results sensitive to the considered simplified model, including both searches for DM production in final states with $E_{\text{T}}^{\text{miss}}$ and direct searches for mediator decays into two jets. Results for axial-vector (vector) interactions with this specific choice of the couplings g_q and g_χ are expressed in terms of 95% CL limits on the spin-dependent (spin-independent) DM-proton (DM-nucleon) interaction cross-section, as a function of the assumed DM

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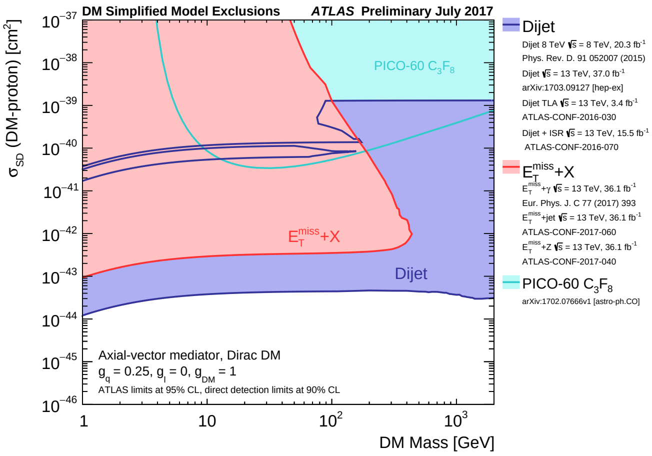
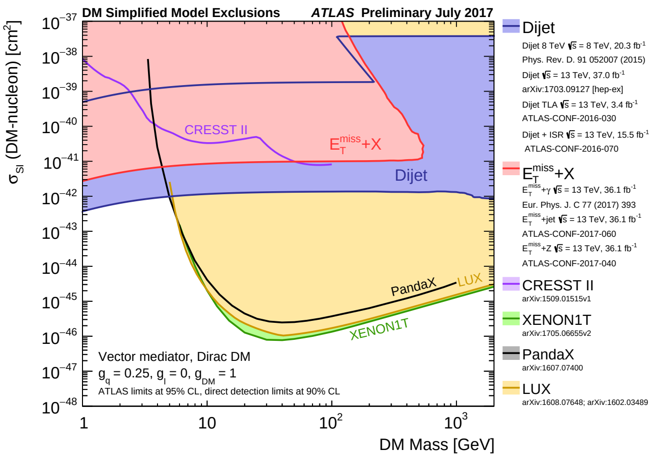
mass. Complementary results are obtained with respect to the ones from direct detection experiments for light DM.



(a)



(b)

Figure 4: Observed limit on the DM-proton (top) or DM-nucleon (bottom) interaction cross-section, as a function of the DM mass, for the simplified model with an axial-vector (top) or vector (bottom) mediator. From Ref. [12].

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