Searches for dark matter with the ATLAS detector

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Abstract

The presence of a non-baryonic Dark Matter (DM) component in the Universe is inferred from the observation of its gravitational interaction. If DM interacts weakly with Standard Model (SM) particles it could be produced at the LHC. The ATLAS experiment has developed a broad search program for DM candidates in final states with large missing transverse momentum produced in association with other SM particles (light and heavy quarks, photons, Z and H bosons, as well as additional heavy scalar particles). The results of recent searches on 13 TeV pp data, their interplay and interpretation are presented.

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1 Introduction

Dark Matter (DM) searches are an important part of the LHC program and complement direct and indirect detection. If produced at the LHC's pp collisions, a feebly interacting DM particle yields final states with undetected objects and thus large missing missing energy carried away from the escaping DM candidate. IFiguren the ATLAS/LHC experiment [1], searches for DM are mainly framed by the DM simplified model and the Higgs portal (involving or not extended Higgs sectors). Both assume a mediator particle coupling DM to the SM ordinary matter and result in two main topology searches: single SM particle recoiling against the DM candidate and mediator resonant production and decay to a pair of SM particles. Specific searches for exotic Higgs decays and other Dark Sector particles are also increasingly relevant.

In the Simplified DM model [2], the DM candidate is assumed to be a massive weakly interacting (WIMP) Dirac fermion χ, and a new particle is postulated (spin-0 scalar/pseudoscalar or spin-1 vector/axial-vector) to mediate its interaction to the SM particle fields. The model has a minimal parameter set: the WIMP and mediator masses (m_χ, M_{med}), the mediator-WIMP couplings (g_χ) and the mediator-SM quarks/leptons couplings ($g_{q/\ell}$). The main topologies arising

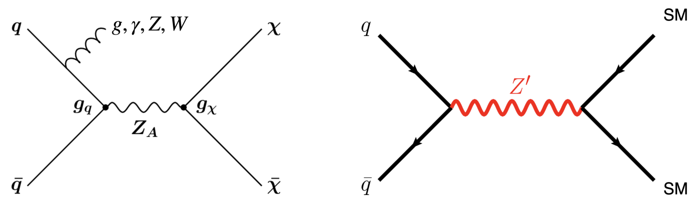

Figure 1: Example diagram of the (left) $\not{E}_T + X$ final state and (right) resonant mediator production and decay to SM particles.

in this framework are DM pair production (from mediator decay or through the $t-$ channel) and resonant mediator production and decay to SM particles. The later allows to reconstruct the mediator from the visible SM products (Figure 1 right) while the former is characterised by transverse momentum (p_T) imbalance from the undetected WIMPs, the so-called "missing transverse energy" $\not{E}_T$. Processes with SM particles ($X \equiv g, \gamma, Z, W$) from initial state radiation allow to trigger these $\not{E}_T + X$ signatures (Figure 1 left).

Furthermore, models coupling DM candidates to the Higgs sector motivate searches for Higgs invisible decays ($H \rightarrow \chi\bar{\chi}$). Extended Higgs sectors, such as the 2-Higgs Doublet Model (2HDM) family, either provide natural mediator candidates or these are added (eg. 2HDM+pseudoscalar mediator a) [3].

2 $\not{E}_T + X$ searches

$\not{E}_T + jet$ [4]: This search is sensitive to pseudoscalar and axial-vector mediators and is also re-interpreted in Dark sector models with long-lived particles (eg. dark photon). Events with $\not{E}_T >$ 200 GeV and a jet with $p_T >$150 GeV are analysed. The major SM backgrounds, $Z \rightarrow \nu\nu$ and $W \rightarrow \ell\nu$ that amount to 90%, are estimated with MC simulation and normalised to data in dedicated control regions of enhanced purity. This is a standard procedure adopted across the different analyses presented here. The signal hypothesis is tested in a simultaneous profile likelihood fit to the p_T of the system recoiling against the hadronic activity (p_T^{recoil} in Figure 2 left). Data and SM prediction agree within the small uncertainty of 2% and exclusion limits are set in the $\{m_\chi, M_{med}\}$ mass plane.

$\not{E}_T + Z(\ell\ell)$ [4]: Events with large $\not{E}_T$ and oppositely charged electrons/muons from Z decays are analysed. The channel is sensitive to vector/axial-vector decays to DM in the simplified model but also to Higgs portal signals ($H\chi\bar{\chi}$ and 2HDM+a) and therefore it is an important input to the 2HDM+a interpretation.

$\not{E}_T + t\bar{t}/b\bar{b}$ [4]: Final states with heavy quarks are important in models with minimal flavour violation where the mediator has Yukawa-like couplings to SM fermions and thus, proportional to the fermion mass. This signature is used to probe spin-0 mediators and search for Higgs invisible decays. The $t\bar{t}$ analyses involve different channels depending on the number of charged leptons from the $t\bar{t}$ decay. Their results are statistically combined.

$\not{E}_T + t(had)$ [4]: Such topologies arise in models predicting baryon number violation where coloured scalar mediators decay to a top-quark and a DM fermion, or predicting vector mediators with flavour-changing neutral couplings to the SM. High momenta top-quarks decaying hadronically are reconstructed as large-radius jets. 95% CL upper limits are set on the sig-

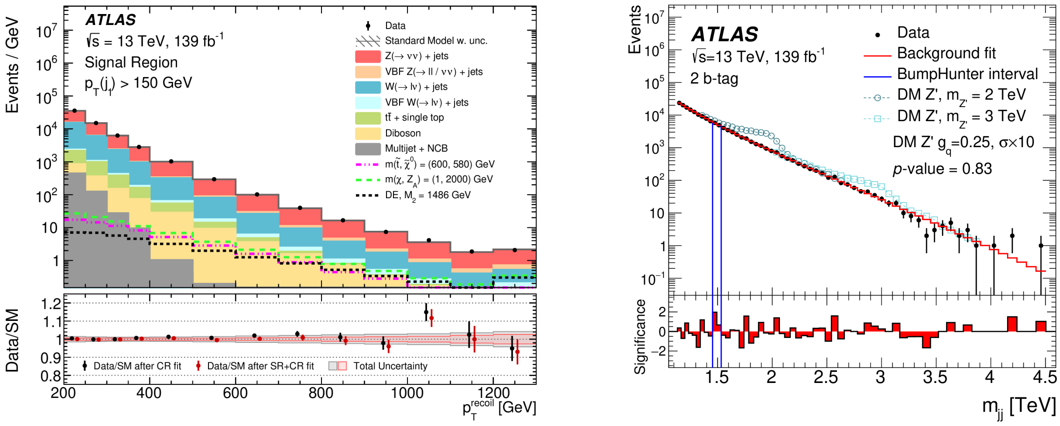

Figure 2: Distribution of (left) p_T^{recoil} for $E\!\!\!/_T + jet$ events and (right) m_{jj} for di-jets.

nal cross-section as a function of the mediator mass. Coloured scalar (vector) mediators are excluded up to 5 (2.8) TeV, assuming specific couplings and $m_\chi = 10$ GeV.

3 Mediator resonant searches

$jj/b\bar{b}$ [4]: Bump hunt is used to search for mediator resonances in the invariant mass spectrum of di-jet events (m_{jj} in Figure 2 right). Energetic jet pairs are used to probe masses between 1.1 and 8 TeV while an low-m_{jj} search is performed using trigger-level jets. This particular analysis estimates the QCD background with a falling spectra fit to real data. MC simulation is used to validate the modelling. Furthermore, final states are separated into jj and bb categories to gain sensitivity to mediator couplings to $b-$quarks.

4 Summary results and Conclusions

The results of the different final states of $E\!\!\!/_T + X$ and mediator searches are summarised [4]. Figure 3 left shows the 95% CL limits on the signal cross-section normalised to the theory prediction as a function of the scalar mediator mass m_ϕ, assuming $g_{\chi/q} = 1$ and $m_\chi = 1$ GeV. The $E\!\!\!/_T + t\bar{t}$ statistical combination provides the best limits, excluding m_ϕ <370 GeV. The results are similar for the pseudoscalar mediator.

Figure 3 right presents a preliminary combination of Run 1 and 2 $H \to inv$ searches [5]. In the SM, this corresponds to the $H \to ZZ^* \to 4\nu$ decays, which has a branching ratio of 0.1%. The observed upper limits are 11%, leaving $H \to \chi\bar{\chi}$ decays mostly unconstrained.

Exclusion limits on the $\{m_\chi, M_{med}\}$ plane are shown in Figure 4 left. $E\!\!\!/_T + jet$ is the most sensitive of the $E\!\!\!/_T + X$ final states, excluding axial vector masses up to 2.1 TeV for very light WIMPs, while masses up to 3.5 TeV are excluded with di-jet resonance searches. The results are similar for vector mediators (except for leptophilic scenarios, $g_\ell \neq 1$).

To compare with direct detection constraints, these results were translated into an equivalent nuclear scattering cross-section, shown in Figure 4 right as a function of m_χ. One observes complementary coverage of the parameter space (especially for low m_χ). More stringent limits are obtained in general, although these are very model dependent and conditioned to specific parameters.

The ATLAS/LHC Run 2 analyses provided a wealth of results on DM searches probing Simplified models, Higgs portal possibilities, extended Higgs/Gauge sectors and other proposals

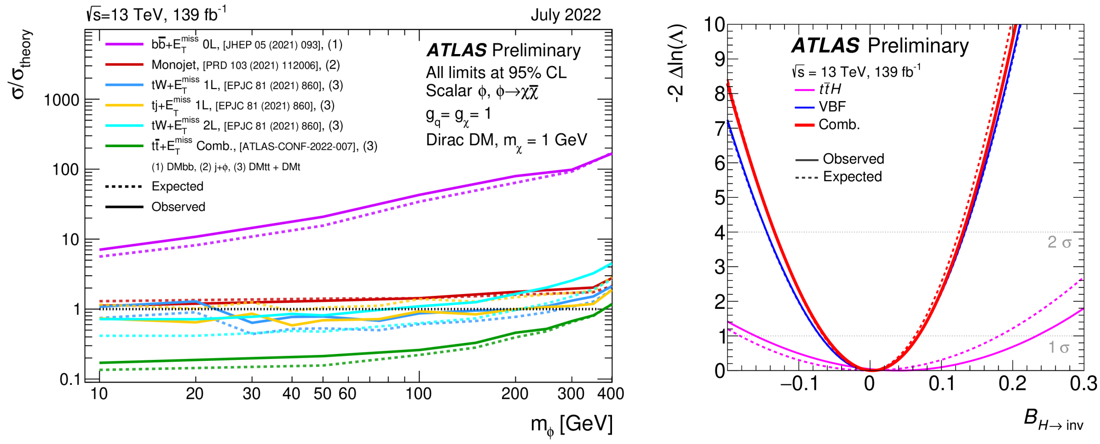

Figure 3: (Left) 95% CL limit on the signal cross-section normalised to the theory prediction as a function of the scalar mediator mass m_ϕ [4]. (Right) Negative logarithmic profile likelihood ratios as a function of the $H \to inv$ branching ratio [5].

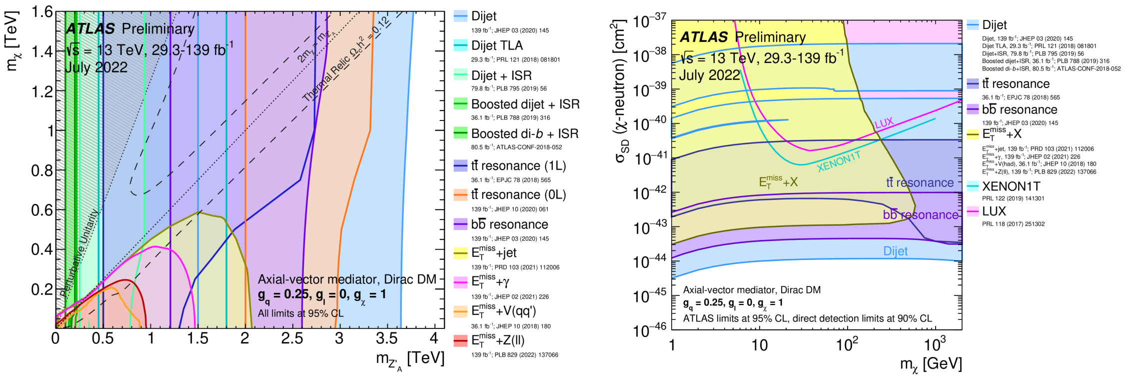

Figure 4: (Left) Exclusion limits on the $\{m_\chi, M_{med}\}$ plane (axial-vector) mediator. (Right) Exclusion limits expressed in terms of equivalent WIMP-neutron cross-section as a function of m_χ [4].

involving, e.g., new Dark sectors. No evidence of DM was found so far across a wide range of signatures and limits were put into the parameter space of the candidate models showing good complementary with direct detection. Attention is now being drawn to the analysis of the LHC Run 3 data which started already been collected.

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