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Dark-matter searches with the ATLAS experiment at the LHC

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Summary. — A review on recent searches for dark matter with the ATLAS experiment at the Large Hadron Collider is presented.

1. – Introduction

Astrophysical and cosmological observations provide clear evidence for the existence of dark matter (DM). The scenario with DM consisting of weakly interacting massive particles (WIMPs) is well motivated. In this context, searches for the production of DM particles χ at colliders are possible, exploring regions of the phase space which are complementary with those investigated by direct and indirect DM searches for several theoretical models. Recent ATLAS and CMS searches employ simplified DM models as benchmarks [1]. These models comprise a DM particle χ and a mediator. The model parameters are the mediator couplings g_{SM} and g_{DM}, the masses m_χ and m_{med}, and the spin-CP properties of the mediator. The width of the mediator is usually assumed to be minimal, *i.e.*, the lowest possible for the assumed couplings. Two main categories of DM searches at colliders can be identified: Mono-X searches, where a $\chi\overline{\chi}$ pair is produced in association with (at least) a particle which can measured by the detector, and Di-X searches, where the mediator decays to a pair of visible particles, appearing as a resonance.

2. – Mono-X searches

The DM particles leave the detector undetected. They recoil against particles or jets, usually produced as initial state radiation (ISR). Therefore, all searches for this kind of signature require a high missing transverse momentum E_T^{miss} in the event.

The ATLAS Collaboration recently published a search for $E_T^{miss} + \gamma$ final states on $36.1\,\text{fb}^{-1}$ of pp collisions at $\sqrt{s} = 13\,\text{TeV}$ [2]. A photon-based trigger is employed by the analysis. The dominant background is due to $V + \gamma$ events. A lepton veto is applied in the signal region (SR). Control regions (CR), where one or two e/μ are identified, are used to constrain those backgrounds with a data-driven technique. Backgrounds due to $\gamma +$ jet events or to misidentified electrons are also estimated with data-driven

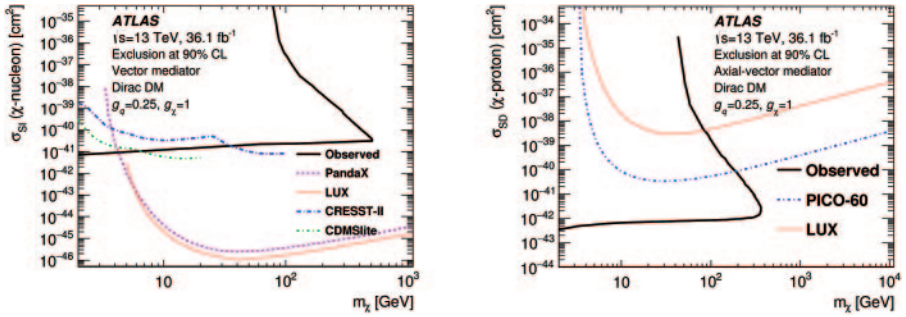

Fig. 1. – 90% exclusion limits on the cross-section for the χ-nucleon scattering for a simplified model with a vector (left) and axial-vector (right) mediator with couplings to quarks $g_q = 0.25$ and to DM g_χ =1, compared with results from direct searches.

techniques. A combined likelihood fit is performed simultaneously in the SR and in the CRs, separately for three E_T^{miss} regions, to estimate the background in the SR, which is found in agreement with the data. The results are used to place limits on simplified models with a vector or an axial-vector mediator, for a given choice of g_{SM} and g_{DM}, as a function of m_χ and m_{med}. They can be translated into limits on the χ-nucleon scattering cross-section [3], as shown in fig. 1. Direct and collider searches explore complementary phase space regions. Limits are presented also on an EFT $\gamma\gamma\chi\overline{\chi}$ interaction.

On the same dataset, ATLAS released two searches for DM in events with a SM Higgs boson h produced in association with E_T^{miss} in the $h \to b\bar{b}$ and $h \to \gamma\gamma$ [4] decay channels. Here the h cannot be produced as ISR due to the Yukawa suppression, and must thus be directly involved in the DM production mechanism.

The $h \to b\bar{b}$ search is performed both for events with two resolved jets (anti-k_T, $R = 0.4$), and for events with a boosted h, where a single fat-jet (anti-k_T, $R = 1.0$) is reconstructed. Jet trimming is used to reduce the pile-up contribution to the fat-jet energy. A b-tagging multivariate algorithm selection is applied to the two jets in the resolved regime, and to track-based jets inside the fat-jet. No electrons or muons are

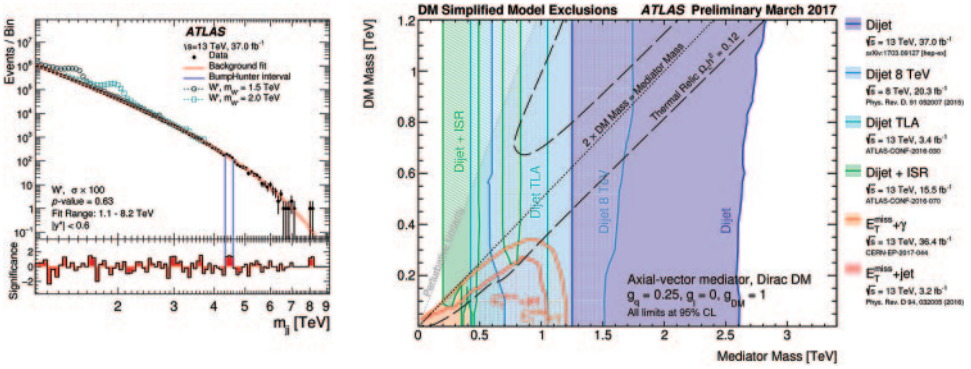

Fig. 2. – Left: invariant-mass spectrum of di-jet events from [6]; the bottom panel shows the significance of data fluctuations around background predictions. Right: constraints on a simplified model with an axial-vector mediator with couplings to quarks $g_q = 0.25$ and to DM g_χ =1 from recent ATLAS analyses.

allowed in the SR selection. Events with one or two e/μ are used as CRs to constrain the background, dominated by V + jets and $t\bar{t}$: a likelihood fit similar to that described for the γ + jet analysis is employed.

The $h \to \gamma\gamma$ search is performed by fitting analytical functions to the invariant-mass spectrum of the two photons. A possible resonant signal is searched for above the non-resonant background and the h contribution predicted by the SM.

Both analyses find no excess above the expected backgrounds, and, therefore, place limits on a simplified DM model, based on a 2 Higgs Doublet Model with an additional Z' mediator. The $h \to \gamma\gamma$ search also place limits on a model with the h radiated by a Z'_B mediator, which then decays into DM particles. The $h \to b\bar{b}$ search presents also limits for a DM + h production without additional model assumptions.

Other Mono-X searches have been performed on 13 TeV data with smaller datasets, in $E_T^{miss} + jet$, $E_T^{miss} + V$, $E_T^{miss} + b\bar{b}$ and $E_T^{miss} + t\bar{t}$ [5] events.

3. – Di-X searches

In the simplified models scenario, the DM mediator is produced in parton collisions at LHC, and can therefore decay to a pair of partons. Therefore, searches for new physics in di-jet events are potentially sensitive to these signals. A search for new physics on 37 fb^{-1} of 13 TeV data has been recently published [6]. This is based on a completely data-driven approach, where a functional sliding window fit is performed to produce an estimate of the smoothly falling QCD background. No excesses are found above the background, as shown in fig. 2 (left). Similar previous searches have been performed on smaller datasets, using either a photon/jet from ISR or a dedicated data stream storing partial information [7], to overcome the trigger limitations, therefore targeting lower mediator masses. All these results can be used to constrain a simplified model. This is shown in fig. 2 (right), where limits from Mono-X analyses are compared with those of the di-jet analyses mentioned before. The interplay between the two kinds of analyses strongly depends on model assumptions.

4. – Conclusion

A brief review of recent ATLAS dark-matter searches has been presented. Mono-X and Di-X searches offer a powerful complementarity for simplified DM models, and collider searches explore phase-space regions complementary to that of direct and indirect searches. With a LHC Run-2 dataset already bigger than Run-1 and more data being collected at this very moment, these searches are becoming more and more interesting.

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