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SEARCH FOR DARK MATTER IN THE MONO-X FINAL STATES (X = JET, Z, W, H) WITH ATLAS [a]

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Dark Matter searches in the ATLAS Experiment, using LHC data, are perfomed analysing a wide number of experimental signatures. Among these, mono-X searches are a powerful tool since many models can be probed depending on the nature (jet, photon, vector boson, Higgs boson) of the Standard Model object which is used to identify and select the events. In this report a short introduction of the theoretical framweork is given, followed by three examples of different signatures that probe different theoretical models that describe an interaction between the Standard Model and Dark Matter.

1 Introduction

The nature of Dark Matter (DM) is one of the main open puzzles in fundamental physics: evidence of its existence comes from a range of different experiments and observations, but its constituents remain undiscovered. Searches for Dark Matter are conducted with experiments of many different kinds, relying on a number of different theoretical models [2]. All of the models share two basic assumptions. The first assumption is the particles are of a class known as weakly interacting massive particles (WIMPs). The second assumption is that there exists a non-gravitational interaction between DM particles and Standard Model (SM) particles. These assumptions allow to introduce a diagram of an interaction between DM and SM particles which can give rise to different processes, as shown in Fig. 1. Different strategies for DM searches exploit the processes arising from the diagram shown in Fig. 1, and among these, DM searches at colliders rely on direct production of DM particles. In this report a summary of the DM matter searches perfomed by the ATLAS Collaboration [1] in the mono-X signature is presented.

2 Search strategy

The existence of Dark Matter could give rise to many different processes and mono-X searches are based on a specific experimental signature: DM particles produced in the collision go through the detector without being detected giving rise to a large amount of $E_{\mathrm{T}}^{\mathrm{miss}}$ which is recoiling against a high-p_{T} SM object. The SM object, which can be of many kinds, is used to select and identify the events, while depending on its nature a number of different models and processes can be probed. The main underlying assumption in the mono-X signatures is that the mass of the DM mediator is larger than twice the mass of the DM particles, thus allowing the decay of the DM mediator to SM particles to be highly subdominant.

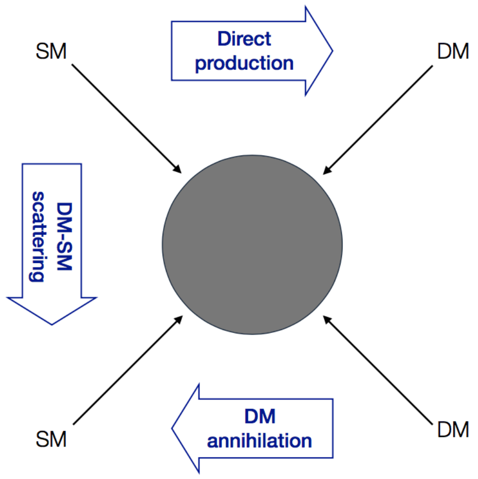

Figure 1 – Diagram of a generic non-gravitational interaction between Dark Matter particles and Standard Model particles. It can give rise to different processes: direct production of Dark Matter, scattering of Dark Matter particles on Standard Model particles and annihilation of Dark Matter particles.

2.1 Mono-jet searches

A first example of the searches for DM in the mono-X final state is the mono-jet search [3]: this analysis looks for events in which an energetic hadronic jet comes from initial state radiation (ISR), and in which a pair of DM particles is produced, as shown in Fig. 2. Here a high-p_{T} jet and a significant amount of missing transverse energy ($p_{\mathrm{T}}>$ 250 GeV and $E_{\mathrm{T}}^{\mathrm{miss}}>$ 250 GeV) are required to be recoiling against each other ($\Delta\Phi(\text{jet}, E_{\mathrm{T}}^{\mathrm{miss}}) > 0.4$). Up to three additional lower-p_{T} jets ($p_{\mathrm{T}}> 30GeV$) are allowed in the event.

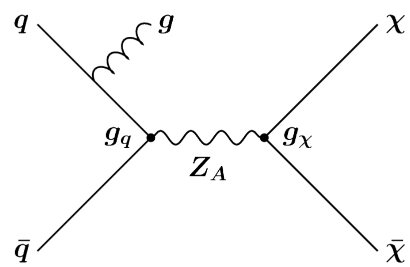

Figure 2 – Diagram of a signal model in the mono-jet analysis [3].

The main backgrounds of the analysis are Z+jets with the Z boson decaying to neutrinos and W+jets with the W boson decaying leptonically, but the lepton is not reconstructed; while the main systematics come from jet and $E_{\mathrm{T}}^{\mathrm{miss}}$ scale and resolution. On the theoretical side, the main systematic concerns the signal modelling.

The signal is expected to arise as an excess of events in the $E_{\mathrm{T}}^{\mathrm{miss}}$ spectrum, which is binned in order to enhance the sensitivity to different models. Results are shown in Fig. 3. Since no significant excesses of data over the expected background is found, limits on the signal hypotheses are set. These limits are shown as a function of the masses of the DM particle and of the DM mediator. Under specific assumptions, the results from collider experiments can be compared to the results obtained from direct searches and here a comparison with result obtained by the PICO-60 collaboration [4] is shown.

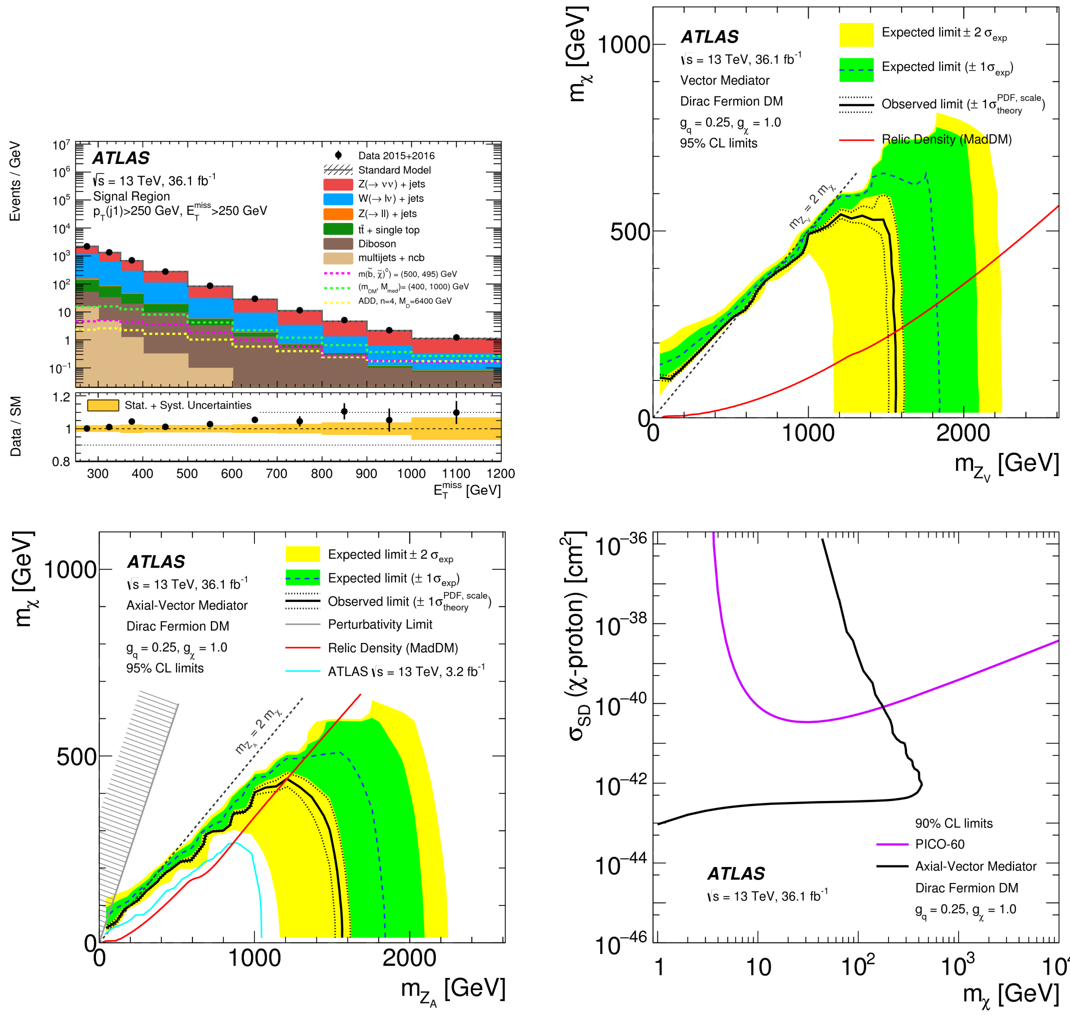

Figure 3 – Results of the mono-jet search: the final $E_{\mathrm{T}}^{\mathrm{miss}}$ spectrum (top left), the limits for a vector mediator (top right), the limits for an axial-vector mediator (bottom left), and a comparison of the ATLAS result with results from the PICO-60 experiment (bottom right) [3].

2.2 Mono-Higgs searches

A different interesting case in the mono-X topology is when the SM object in the event is an Higgs boson [5]. The coupling of the Higgs boson to SM particles is proportional to their masses, and therefore an Higgs boson production from ISR is highly suppressed. Because of this, mono-H analyses, while sharing the same topology as the mono-jet searches, are sensitive to completely different models. An example of a diagram of a signal process is shown in Fig. 4. Here the Higgs is part of a broader and more complex model (a Z'-2HDM model [7] in this case) in which the Higgs boson itself, the DM mediator and the DM particles are produced in the decay chain of an heavy resonance.

Depending on its p_{T} the Higgs boson is reconstructed either as a pair of b-tagged jets or as a single large-R jet in which two narrow track-jets are reconstructed. This bb system is required to recoil against a large amount of missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}} > 150$ GeV) and other soft jets are allowed in the event.

The background contamination strongly depends on the p_{T} range. Top quark production (Z+jets) is dominant at lower (higher) energies, and the main systematic uncertainties come from the modelling of these backgrounds. The events are categorised depending on the amount of $E_{\mathrm{T}}^{\mathrm{miss}}$ and the number of b-jets identified in the event.

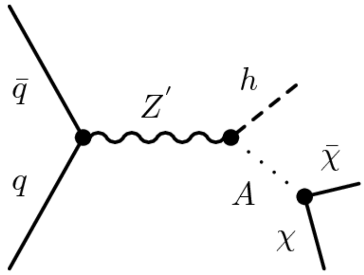

Figure 4 – Diagram of the signal process in mono-H search [5].

The signal is expected to appear as the Higgs boson peak in the m_{bb} distribution, since no Higgs boson production is expected from SM in this topology. Results are shown in Fig. 5. Since no excesses of data over the background expectations are observed, limits on the signal model are set. Limits are presented as a function of $m_{Z'}$ (the mass of the heavy resonance in the Z'-2HDM model) and m_A (the mass of the DM mediator).

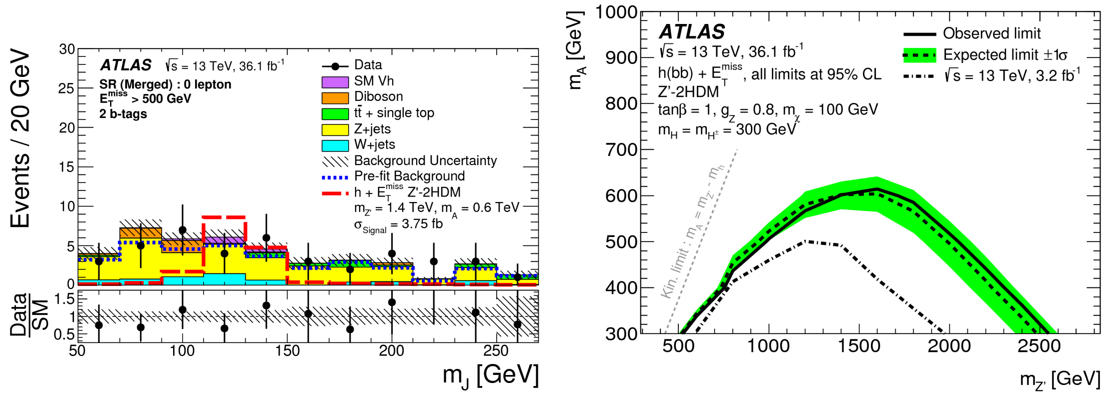

Figure 5 – Results of the mono-$H(bb)$ search: m_{bb} spectrum in the most sensitive analysis category (left) and the final limit (right) [3].

2.3 Mono-Z

The last analysis covered in this report is the mono-Z analysis [6]. Interestingly, events of this kind can be used to probe a number of different signal processes: the Z boson can be produced as an ISR, but here we focus on the ZH associated production shown in Fig. 6. The unique feature of this analysis is that the leptonic decay of the Z boson is used to probe any possible invisible decay of the Higgs boson, i.e. its decays to DM particles: $H \to \chi\chi$. The only invisible

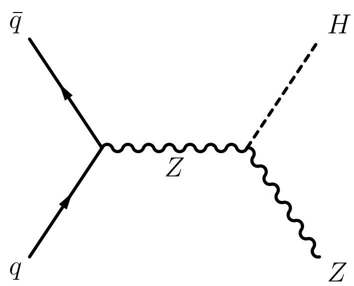

Figure 6 – Diagram of the ZH associated production [6].

decay of the Higgs boson foreseen in the SM is its decay to four neutrinos via the decay to a pair of Z bosons, $H \to ZZ^* \to \nu\nu\nu\nu$, whose branching ratio is of $O(10^{-3})$, and any direct coupling of the Higgs boson to DM would result in an enhancement of the measured invisible BR.

Events are required to contain a pair of opposite-sign same-flavour leptons used to reconstruct the Z boson which are recoiling against a large amount of missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}} > 90 GeV$). Jets are not vetoed.

The main systematics come from the jet/$E_{\mathrm{T}}^{\mathrm{miss}}$ energy scale and resolution, and the result is extracted fitting the $E_{\mathrm{T}}^{\mathrm{miss}}$ spectrum, shown in Fig. 7. ATLAS is still not sensitive to the SM

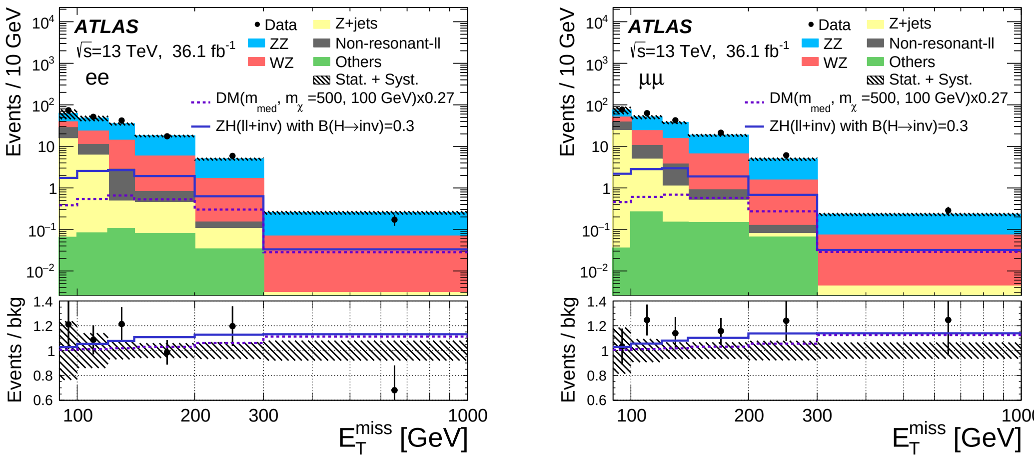

Figure 7 – $E_{\mathrm{T}}^{\mathrm{miss}}$ spectra in the mono-Z analysis [6].

model signal, but limits on an higher $BR(H \to \mathrm{inv.})$ can be set. The results for this search are presented as upper limits on the invisible branching ratio of the Higgs boson and are shown in table 1. The higher observed limit in the $\mu\mu$ channel is due to some overfluctuation of data

Table 1: Upper limits on the Higgs decay width to an invisible final state. $\pm1\sigma$ and $\pm2\sigma$ errors are shown for the expected limits [6].

	Obs. $BR(H \to \mathrm{inv.})$ Limit	Exp. $BR(H \to \mathrm{inv.})$ Limit
ee	59%	(51^{+21+49}_{-15-24})%
$\mu\mu$	97%	(48^{+20+46}_{-14-22})%
$ee + \mu\mu$	67%	(39^{+17+38}_{-11-18})%

compared to the background-only expectation, which is found not to be significant.

3 Conclusions

The existence of Dark Matter can be probed in many different ways, each having advantages and challenges. Mono-X signatures at collider experiments are a powerful search channel since under a limited amount of assumptions they allow to probe a number of different models depending on the nature of the SM object which is used to select and identify the events. Moreover the results obtained in the searches performed by the ATLAS Collaboration with LHC data can be reinterpreted allowing a direct comparison with results obtained by experiments performing direct searches for Dark Matter.

References

1. ATLAS Collaboration, 2008 JINST 3 S08003

2. D. Abercrombie et al, arXiv:1507.00966
3. ATLAS Collaboration, JHEP 01 (2018) 126
4. C. Amole et al, Phys. Rev. Lett. 118, 251301 (2017)
5. ATLAS Collaboration, PRL 119, 181804 (2017)
6. ATLAS Collaboration, Phys. Lett. B 776 (2017) 318
7. A. Berlin, T. Lin, L.-T. Wang, J. High Energy Phys. 06 (2014) 078