Dark Matter searches with the ATLAS Detector

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Dark matter could be produced at the LHC if it interacts weakly with the Standard Model. The search for dark matter can be performed either directly, by looking for a signature of large missing transverse momentum coming from the dark matter candidates escaping the detector, or more indirectly by looking for the intermediate mediators which would weakly couple the dark matter particles to the Standard Model. A broad and systematic search program covering these various possibilities with the ATLAS detector is in place: the talk will review the latest results of these searches and show their complementarity.

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Several astrophysical and cosmological anomalies observed in the universe are inconsistent with our current understanding of gravitation and particle physics [1]. The existence of a new non–luminous, non–interacting "Dark Matter" (DM) particle could explain these phenomena. Several theories [2] propose that dark matter will take the form of a weakly interacting massive particle (WIMP), which could couple very weakly to the Standard Model (SM) and might be produced in proton–proton collisions at the LHC.

If produced at the LHC, DM will not interact with any of the ATLAS Detector [3] systems. However, if DM is produced in association with an energetic visible recoil, it will result in an event with significant missing transverse momentum (E_T^{miss}). As such, searches for DM at the LHC target DM produced in association with visible particles.

There are many possible models for SM-DM interaction and a variety of corresponding signatures [4]. Many ATLAS searches use simplified models to describe the DM signal kinematics. Within the simplified model framework a mediator particle connects the SM quarks to dark matter WIMPs [5]. The model depends on five parameters: mass of the dark matter particles m_χ, mass of the mediator m_{med}, the flavor-universal coupling between the mediator and the quarks g_q, the coupling between the mediator and the leptons g_ℓ and the coupling between the mediator and dark matter particles g_χ.
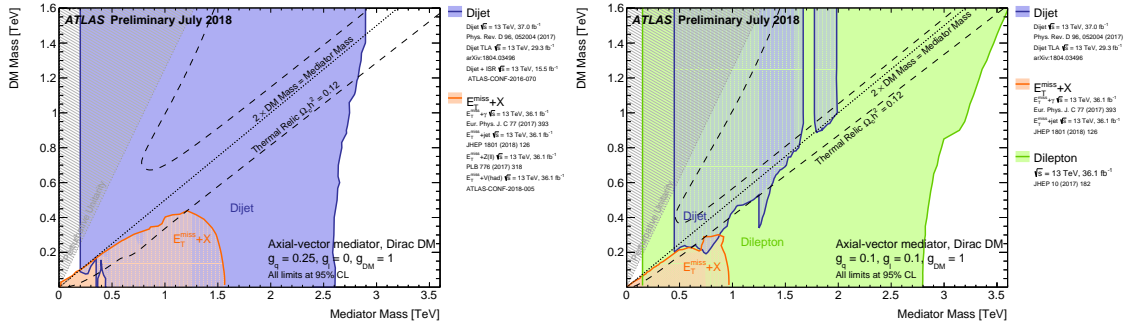

Figure 1: ATLAS E_T^{miss}+X and and di-fermion limits as a function of dark matter mass and mediator mass in the simplified model framework with an axial vector mediator for two different choices of coupling values [16]. The relative exclusion power of $E_T^{miss} + X$ and di-fermion searches have different dependencies on the couplings and masses in the model.

Although DM is invisible to the ATLAS detector, the creation of DM can be inferred when it is produced in association visible particles such as jets, photons, or electroweak bosons. This event topology is known as the $E_T^{miss} + X$ signature, and is typified by a visible particle X recoiling against the missing transverse momentum vector E_T^{miss}. The X can come from an initial state radiation (ISR) gluon [6], photon [7], or weak boson [8, 9]. At the LHC, the largest cross section is for gluon ISR. $E_T^{miss} + X$ searches look for new physics in signal regions composed of events with large missing transverse momentum, strict quality requirements on X, and a lepton veto to reduce $W \to \ell\nu$ and other background processes. Background processes are constrained using control regions constructed by inverting signal region vetoes. The signal appears as an excess in the tail of the E_T^{miss} distribution.
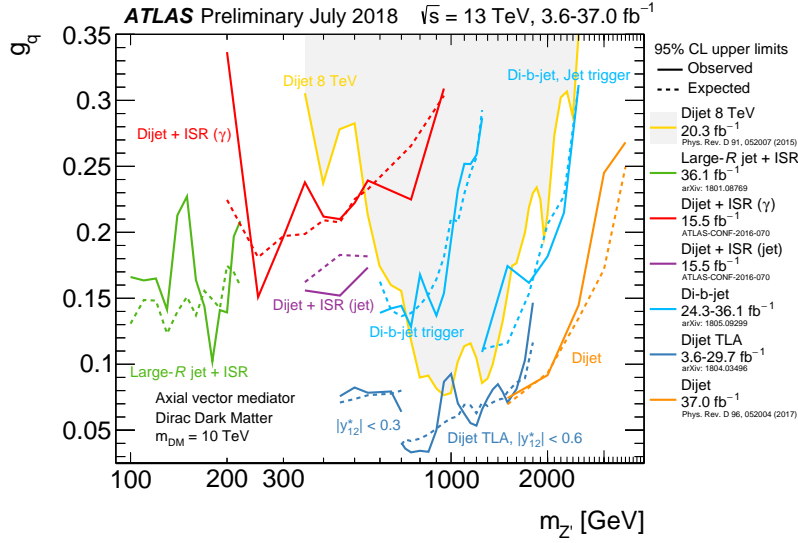
Figure 2: ATLAS limits in the coupling-mediator mass plane from dijet searches using 2012, 2015 and 2016 data [16].

Not all constraints on DM come from $E_T^{miss} + X$ signatures. The mediator can decay back to visible particles in addition to DM. Any signal would appear as a localized excess in the di-fermion invariant mass. It is natural to search for dijet resonances in events produced by proton–proton collisions. There are many different strategies to cover different regimes of dijet invariant mass, as shown in Figure 2. The typical "high-mass" search uses the traditional triggering strategy for dijet resonances and sets limits on the corresponding mass range [10]. These limits can be extended by triggering on an ISR photon or gluon recoiling against a dijet system [11, 12], using a Trigger-object Level Analysis (TLA) [13] to bypass the conventional trigger limitations, or requiring that the jets from the resonance are tagged as originating from b-quarks [14]. Additionally, the clean dilepton resonance signature provides powerful constraints even if mediator-lepton coupling is small [15]. Direct detection experiments set a limit on the rate of interactions between the local dark matter halo and atomic nuclei [5]. ATLAS limits can be reinterpreted using the simplified model framework and compared with direct detection limits as shown in Figure 3. LHC limits provide complementary exclusion of DM models at low values of m_χ.

ATLAS searches for new physics in $E_T^{miss} + X$ and dijet signatures provide powerful constraints on DM production. Between improving LHC limits and new direct detection experiments, sensitivity across most of the DM simplified model phase space will be achieved in the next few years [17]. If the dark sector interacts with quarks, it may be discovered here. If not, constraining this sector will have important ramifications for the future of DM detection efforts.

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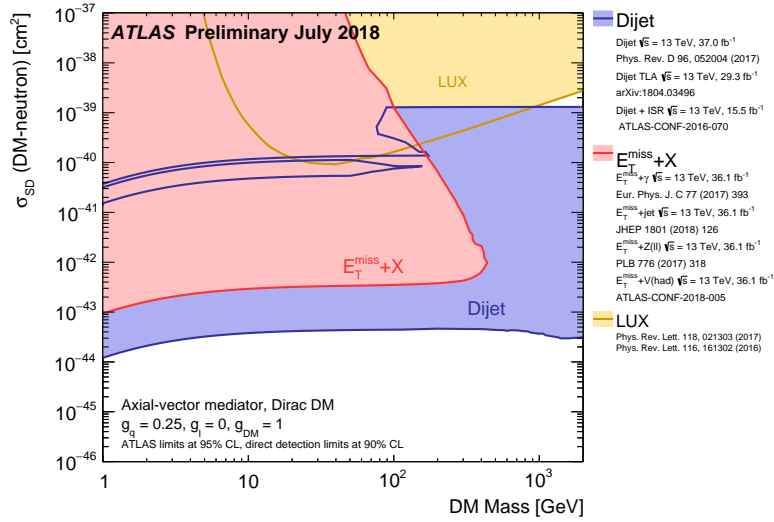
Figure 3: ATLAS limits reinterpreted as limit on DM-proton scattering cross-section [16]. The collider limits have complimentary with direct detection experiments at low dark matter mass.

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