PROCEEDINGS OF SCIENCE

Missing E_T searches for dark sectors with ATLAS

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Recent results from the ATLAS experiment on a variety of signatures that can arise from particles belonging to dark sectors have been presented. The searches are performed exploiting the 139 fb^{-1} dataset collected by the ATLAS detector during LHC Run 2, at a centre of mass energy of 13 TeV. No evidence of new physics has been found; stringent exclusion limits have been set on a variety of models involving dark sectors.

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1. Introduction

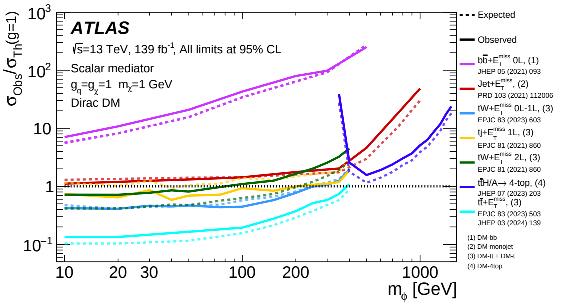
Over the last decades, the existence of dark matter has been confirmed through multiple cosmological observations, however, the particle nature of dark matter remains elusive, and multiple possibilities for complex dark sectors have been proposed. The ATLAS Collaboration [1] has been performing a series of searches for such physics beyond the Standard Model (BSM) at the Large Hadron Collider (LHC) [2].

Missing E_{T} ($E_{\mathrm{T}}^{\mathrm{miss}}$) is an imbalance of momentum in the transverse plane, usually resulting from undetected particles. Missing E_{T} is a clear proxy to BSM physics in colliders, as it provides direct and model-independent signatures of BSM and helps in reducing SM backgrounds. The latest results from ATLAS using missing E_{T} signatures are presented, including searches for dark matter mediators and supersymmetry (SUSY).

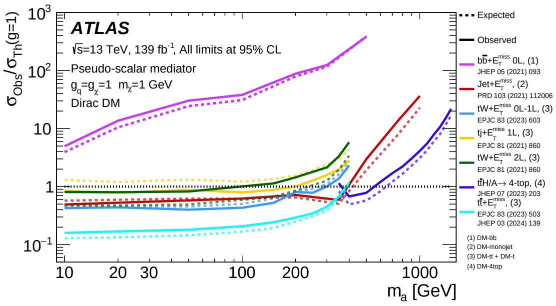
2. Constraints on dark matter models involving an s-channel mediator

This analysis gives a reinterpretation of the recent ATLAS searches in the context of s-channel dark matter simplified models [3]. As benchmark models, simplified models with a Dirac fermion with a spin-0 or spin-1 mediator have been considered. Here, only the results for the spin-0 mediator model are highlighted, as it involves missing E_{T} signatures. The considered models for spin-0 are scalar and pseudo-scalar mediators with nominal coupling values.

Results from several analyses, mostly involving $E_{\mathrm{T}}^{\mathrm{miss}}$ plus heavy flavour quarks, have been reinterpreted to set limits on the benchmark spin-0 mediator model [4–11]. Figures 1a and 1b show the limits on the observed cross section of the mediator as a function of its mass, for scalar and pseudo-scalar mediator models respectively. For both models, the combination of searches targeting $t\bar{t} + E_{\mathrm{T}}^{\mathrm{miss}}$ signatures has the most stringent limit in regions with low mediator mass.



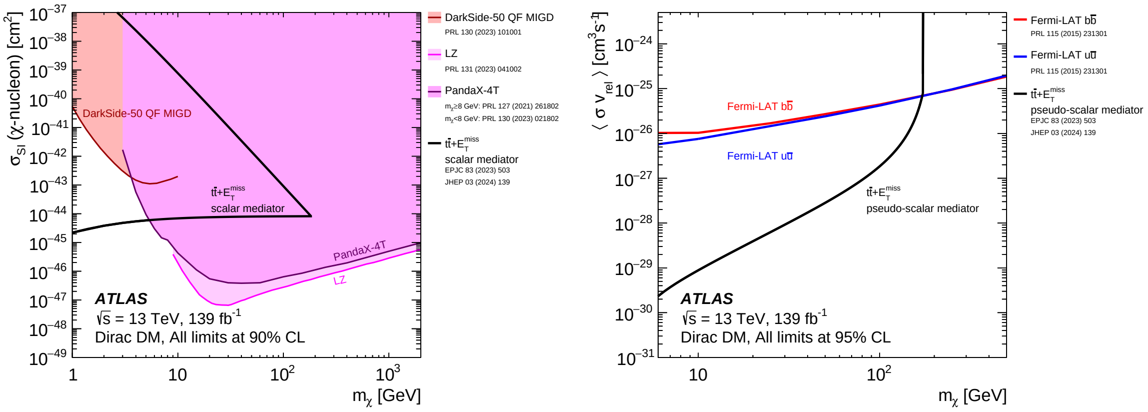
(a) Scalar



(b) Pseudo-scalar

Figure 1: Exclusion limits set on the observed cross section of the mediator as a function of its mass, for scalar and pseudo-scalar mediator models [3]. $t\bar{t} + E_{\mathrm{T}}^{\mathrm{miss}}$ combination sets the most stringent limit for both models in low mass mediator regions.

For the $t\bar{t} + E_{\mathrm{T}}^{\mathrm{miss}}$ combination, the limits at their highest excluded mass have been further compared to those from direct detection experiments as shown in Figures 2a and 2b. It has been confirmed that the limits of this analysis extend beyond the direct detection limits for low dark matter mass, for considered benchmark spin-0 mediator models.



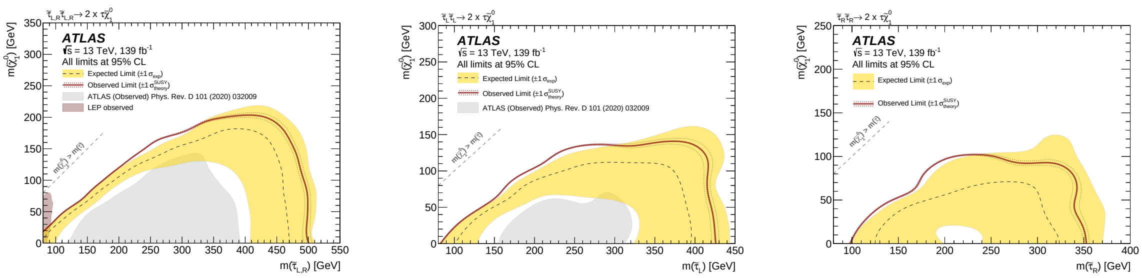
(a) Scalar **(b)** Pseudo-scalar

Figure 2: Exclusion limits by $t\bar{t} + E_T^{\text{miss}}$ combination compared to limits from direct detection experiments, for scalar and pseudo-scalar mediator models [3].

3. Search for electroweak SUSY production in final states with two τ-leptons

Of the three scenarios targeted in this search, two involve E_T^{miss}+ di-τ signatures. Both search for processes involving the stau ($\tilde{\tau}$), the SUSY partner of the τ-lepton.

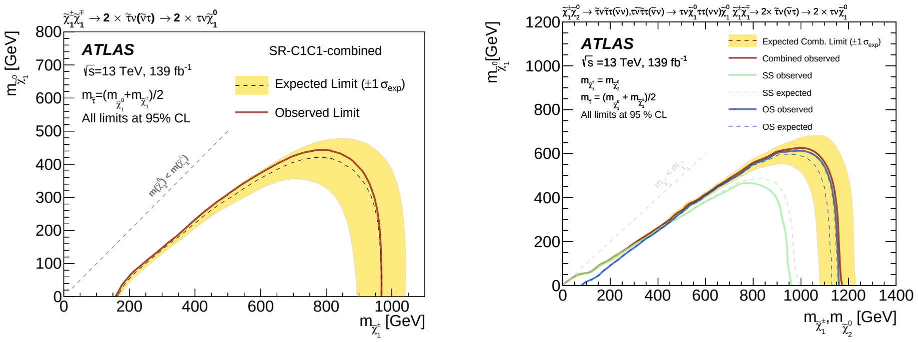
The first scenario considers the direct production of $\tilde{\tau}_L\tilde{\tau}_L$ and $\tilde{\tau}_R\tilde{\tau}_R$, with each of the staus decaying to a tau-lepton and the lightest neutralino ($\tilde{\chi}_1^0$). Four signal regions are defined depending on $m(\tilde{\tau})$ and $\Delta m(\tilde{\tau}, \tilde{\chi}_1^0)$, and a boosted decision tree (BDT) utilizing the event kinematics have been trained in each of the regions to separate the signal and background processes. No significant deviations from the Standard Model has been observed, and exclusion limits have been set on inclusive $\tilde{\tau}_{L,R}\tilde{\tau}_{L,R}$, $\tilde{\tau}_L\tilde{\tau}_L$ and $\tilde{\tau}_R\tilde{\tau}_R$ production as shown in Figure 3. The introduction of BDTs has contributed to significant improvement in sensitivity in comparison to previous results, particularly in regions with small $\Delta m(\tilde{\tau})$.



(a) $\tilde{\tau}_{L,R}\tilde{\tau}_{L,R}$ **(b)** $\tilde{\tau}_L\tilde{\tau}_L$ **(c)** $\tilde{\tau}_R\tilde{\tau}_R$

Figure 3: Observed (red line) and expected (black dashed line) 95% CL exclusion limits set for direct stau production [12]. Solid grey areas show excluded regions by previous searches.

The second scenario considers the direct production of mass-degenerate electroweakinos of $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ and $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$, with each of the electroweakinos decaying solely through intermediate staus or tau sneutrinos. No significant excess in data has been observed. Figure 4 shows the limits set on the intermediate stau scenario considering only $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ production and both $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ and $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$ productions, excluding chargino masses up to 970 GeV and 1160 GeV respectively. For the latter, sensitivity in the small $\Delta m(\tilde{\tau}, \tilde{\chi}_1^0)$ region has been improved by the addition of a channel with two same-sign τ-leptons.



(a) Only $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ **(b)** $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ and $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$

Figure 4: Observed (red line) and expected (black dashed line) 95% CL exclusion limits set for intermediate stau scenario [12].

4. Search for nearly mass-degenerate higgsinos using low-momentum mildly displaced tracks

This search targets SUSY scenarios in which the higgsinos are light compared to other SUSY particles, strongly motivated by the *natural* solution from SUSY to the hierarchy problem. In such cases, the light electroweakinos $\tilde{\chi}_1^0, \tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ form a nearly mass-degenerate, higgsino-like triplet. Owing to this mass degeneracy nature, the decay length of $\tilde{\chi}_1^{\pm}$ could reach $O(0.1\text{–}1\text{ mm})$ for target mass splitting of $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0) \approx 0.3\text{–}1$ GeV. The search targets higgsino pair production signatures with high $E_{\mathrm{T}}^{\mathrm{miss}}$ from two $\tilde{\chi}_1^0$s and a mildly displaced pion track from $\tilde{\chi}_1^{\pm} \to \tilde{\chi}_1^0\pi^{\pm}$.

Two signal regions, categorized by the transverse impact parameter significance $S(d_0) = |d_0|/\sigma(d_0)$, are defined. No significant deviation from the Standard Model have been observed for both of the signal regions. Figure 5 shows the exclusion limit set on the targeted higgsino scenario. The observed limit peaks at $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0) = 0.6$ GeV for which the mass reach extends up to $m(\tilde{\chi}_1^{\pm}) = 170$ GeV.

5. Electroweak SUSY production interpreted within the pMSSM

This analysis reinterprets eight ATLAS electroweak SUSY searches [15–22] in the context of a 19-parameter phenomenological MSSM (pMSSM) model. The sensitivity of these searches to the pMSSM phase space is interpreted by the fraction of excluded models, evaluated with a framework consisting of pMSSM parameter scan, sampled model generation and particle/detector-level CL$_s$ evaluation. For the pMSSM parameter scan, in addition to a general "EWKino" scan, a "BinoDM" scan is performed to oversample models with bino-like LSP, which is likely to fail the external dark matter (DM) constraints.

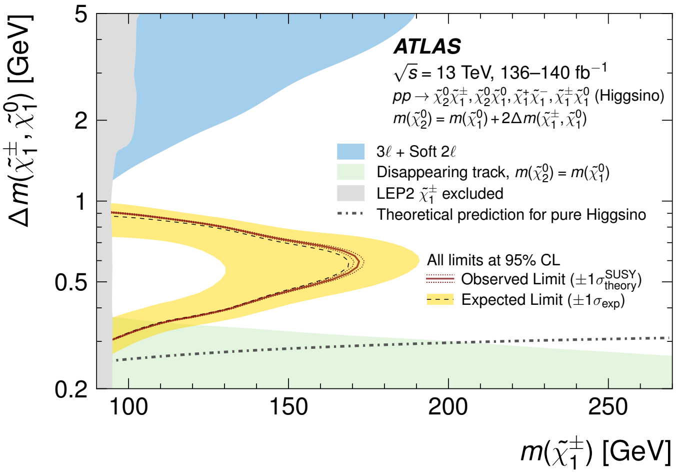
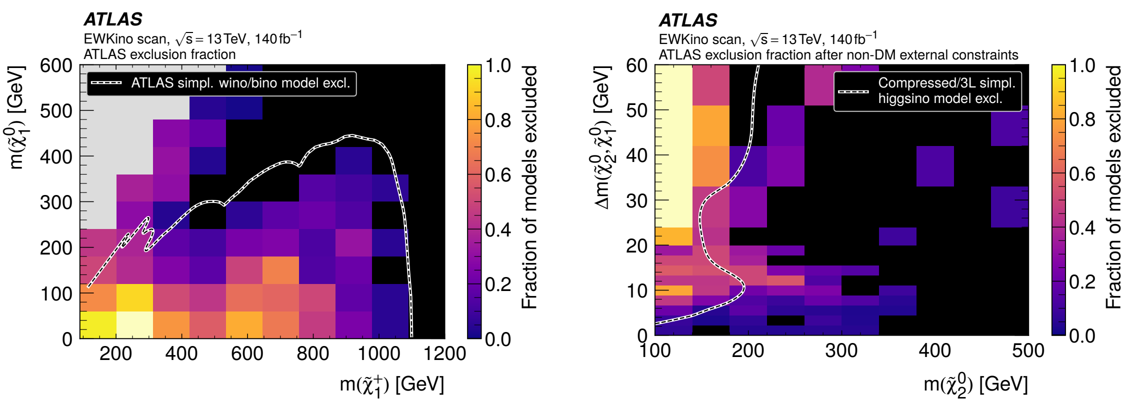


Figure 5: Observed (red line) and expected (black dashed line) 95% CL exclusion limits on the simplified higgsino model set by the search with mildly displaced tracks [13].

Figures 6a and 6b show the fraction of pMSSM models excluded by the ATLAS Run 2 searches, obtained from a general EWKino scan. In the former, all considered models are included, and the envelope of the relevant FullHad [15], 2L2J [18] and 3L [19] exclusion limits for a scenario with wino-like $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ and bino-like $\tilde{\chi}_1^0$ is overlaid. In the latter, only models passing non-DM external constraints are considered, and the exclusion limit of the relevant compressed search [21] for simplified higgsino model is overlaid. It has been seen that in general, constraints on electroweakino masses from the ATLAS searches are weaker in the pMSSM, as the assumptions made on simplified models are relaxed.



(a) $m(\tilde{\chi}_1^{\pm})$–$m(\tilde{\chi}_1^0)$ plane (all considered models)

(b) $\Delta m(\tilde{\chi}_1^{\pm}), -m(\tilde{\chi}_1^0)$ plane (satisfying non-DM external constraints)

Figure 6: Fraction of EWKino scan models excluded by the ATLAS Run 2 results [14]. Bins in grey have no models to consider, while for bins in cream (black), all models are (not) excluded.

6. Conclusion

A collection of latest search results from the ATLAS experiment involving missing E_{T} signatures have been summarized. Outstanding results have been obtained by the introduction of new analysis techniques and by having a deeper understanding of the collected data. Although no significant deviations from Standard Model predictions have been observed, each of the results has the potential to provide guideposts for future searches for dark, "yet to be seen" sectors.

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