Highlights of ATLAS Search Results

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Searching for beyond standard model (BSM) physics has been one of the primary goals of the Large Hadron Collider (LHC). The LHC delivered 140 fb^{-1} data of high quality in Run 2, allowing the ATLAS experiment to expand and improve its search programme. The recent development in detector performance and analysis techniques have brought significant boosts to the search sensitivities. In this article, highlights of recent ATLAS search results are discussed and summarised.

1 Introduction

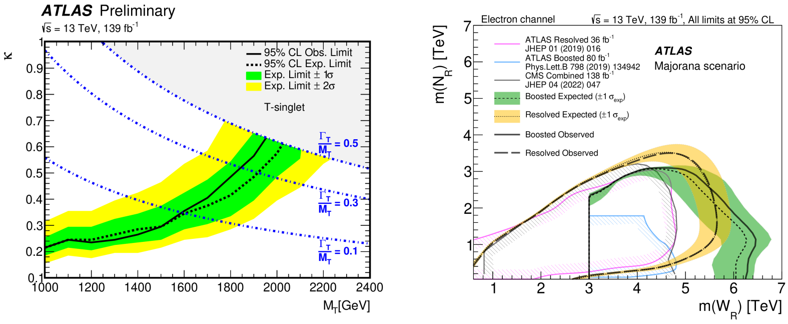
Many mysteries in particle physics, such as the hierarchy problem, the origin of dark matter (DM) and neutrino masses are still waiting for answers or hints from the Large Hadron Collider (LHC). ATLAS has conducted a comprehensive set of searches in the past years. Even though no evidence of BSM physics has been reported, those searches excluded a large part of the phase space for many models. For instance, the search for heavy particles in the di-jet final state has explored the mass up to 8 TeV. The ATLAS Run 2 data-taking has accumulated 140 fb^{-1} of high quality data. It is imperative to maximise its physics return. The searches discussed in this article are categorized into three scenarios: searches upgrading previous iterations using cutting-edge analysis techniques, searches filling the gaps between explored regions of phase space and searches considering challenging, completely uncovered signatures.

2 Full Run 2 Upgrades of Previous Results

The detector performance in ATLAS is continuously improving. For instance, the performance of bottom- and top-tagging has advance significantly in the past few years. In addition, the application of machine learning techniques have become very mature in physics analyses, enhancing the sensitivities. Even though previous analyses have explored similar final states, the full Run 2 upgrades of those searches will push the exclusion limits further. Three new search results are introduced in this section.

In the full Run 2 ATLAS vector-like quark search, the top partner masses with 50% decay width are excluded up to 1975 GeV for the singlet representation, considering $B(T \to Wb) = 0.5$, as shown in Figure 1a. Compared to the previous analysis probing the same final state, this analysis adopted an updated top-tagger and more optimised selections, achieving greatly improved sensitivities [1]. The ATLAS full Run 2 right-handed neutrino search sets the most stringent limits on the Keung-Senjanović process in the TeV W partner (W_{R}) mass region. This search considers both the "resolved" and "merged" cases, depending on the mass split between the W_{R} and the heavy neutrino (N_{R}). The "resolved" case uses well separated reconstructed objects while the "merged" case utilises a single object formed by several nearby objects. For Majorana neutrinos, in the muon channel, the limit on $m(W_{\mathrm{R}})$ reaches 6.4 TeV for $m(N_{\mathrm{R}}) = 1$ TeV, and the limit on $m(N_{\mathrm{R}})$ extends to 3.6 TeV for $m(W_{\mathrm{R}}) = 4.8$ TeV, as shown in Figure 1b [2].

Combination of different analyses offers a powerful way to constrain a given type of model. A recent ATLAS search is concentrated on final states with τ leptons and hadronic jets, providing interpretation including both the leptoquark and excited τ models. In particular, it is sensitive to $LQ \to c\tau^-$ ($\overline{LQ} \to \bar{c}\tau^+$) decays, as the analysis does not enforce any jets to be b-tagged. It comprises a critical piece in the leptoquark combination given this unique feature of the signal region selection. Masses below 1.3 TeV are excluded, assuming the branching ratio of their decays to the c-quark-τ-lepton pair is equal to one [3].



(a) (b)

Figure 1: Observed (solid line) and expected (dashed line) limits or contours on: (a) the singlet representation of a vector like top-quark[1]; (b) Majorana heavy neutrino on the $m(W_{\mathrm{R}}) - m(N_{\mathrm{R}})$ mass plane[2]

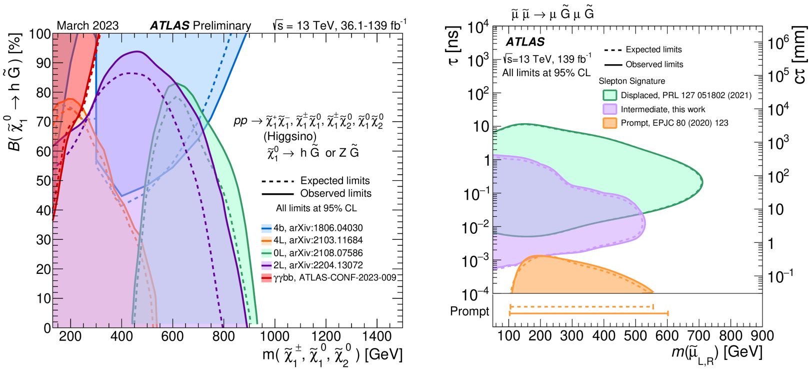
3 Dedicated Searches to Cover the Unexplored Regions

There have been many well motivated BSM models proposed by the theory community in the past decades. The number of free parameters in those models can be so large that a single search can only probe a subset of the parameter space and a particular combination of masses or couplings. Naturally, there are gaps between existing searches, and they have to be explored as new physics can hide there. The gap regions are usually hard to study so that special analysis strategies are essential.

In the realm of supersymmetry searches, there are various uncovered corners on specific parameter planes that are quite challenging. A recent ATLAS search for higgsinos considers the $b\bar{b}\gamma\gamma$ final state, taking advantage of the excellent mass resolution of the photons and the large $H \to b\bar{b}$ branching ratio. It successfully fills the gap in the low mass region, as seen in Figure 2a [4].

The gap between dedicated long-lived particle (LLP) searches and conventional searches is becoming increasingly important. A recent ATLAS search for micro-displaced muons is focused on this region using muons reconstructed by the standard algorithms, requiring the transverse impact parameter ($|d_0|$) of the muons to be between 0.1 and 3 mm. Control regions, validation regions, and signal regions are constructed using the muon $|d_0|$ and muon-pair mass. In the context of a smuon pair production, the gap between the conventional search and the dedicated LLP search is filled, as shown in Figure 2b [5].

Certain BSM models should be searched in various experiments. For instance, in models considering the hidden sectors, the dark photon mass can vary from Mev to TeV. A recent ATLAS search looks for dark photons in the $4l + X$ final state, where the four leptons are from two dark photons (A'). The average invariant mass of the two lepton pairs is used as the main observable. The four lepton mass is used to construct signal and control regions, while the lepton pair mass is used to suppress quarkonia background. This search excludes the much higher mass region compared to the results from the Belle collaboration [6].



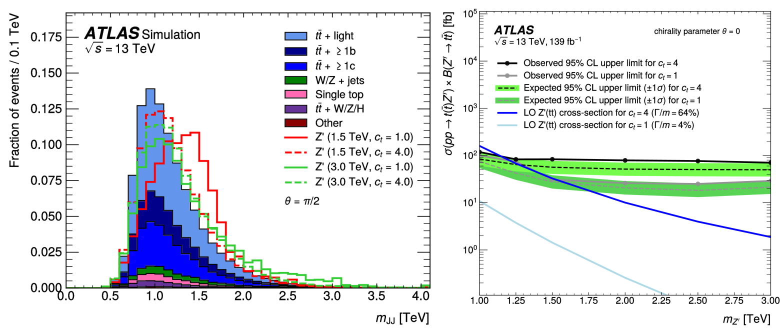
(a) (b)

Figure 2: (a): Exclusion contour of the higgsino pair production on the mass and branching ratio 2D plane[4]. (b): Exclusion contour of the smuon pair production on the mass and lifetime 2D plane[5].

4 Searches for New and Challenging Signatures

ATLAS is capable of studying an impressive amount of signatures, but there are signatures known to be very challenging. A signature can be strenuous because the traditional analysis techniques are not suitable. Analyses challenging those signatures can greatly broaden the ATLAS search programme. Two new searches will be covered in this section.

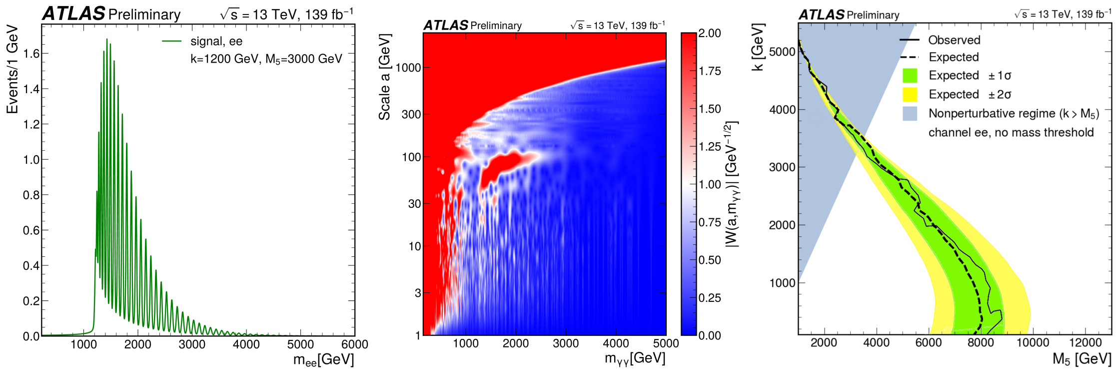
ATLAS has searched for heavy particles produced in association with two top-quarks, decaying to two top-quarks, i.e., top-philic heavy particles. The previous search considered the non-resonant production as the reconstructed $t\bar{t}$ mass is very broad as seen in Figure 3a. A recent ATLAS analysis takes the resonant production channel into account. A hybrid background estimation method is developed to overcome the difficulties in dealing with broad signals. A background template is obtained in an inclusive region first and then propagated to the signal region via simulation, in order to minimize the biases introduced by the broad signals. A global deviation scan is done first in a model agnostic way, observing no significant deviations from the background in data. The observed (expected) limits on the production cross-section range from 21 (14) fb to 119 (86) fb depending on the choice of model parameters, shown in Figure 3b. The results are limited by the modeling uncertainties [7].



(a) (b)

Figure 3: (a): Invariant mass distributions of the two large-R jets for different backgrounds and signal points. (b): Observed (solid line) and expected (dashed line) limits on the top-philic heavy particles as a function of mass[7].

Searches are typically performed using conventional observables such as the invariant mass as the one discussed above. A recent ATLAS search explores periodic signals for the first time. Such a signal is predicted in the clockwork (CW) or linear dilation (LD) framework [8]. Instead of having one peak in the invariant mass spectrum, a periodic signal predicts continuous narrow peaks, as illustrated in Figure 4a. The analysis applied a “continuous wavelet” transformation to separate the signal events from the background in a scalogram more efficiently, depicted in Figure 4b. Limits are set for the gravity scale, M_5, and the turn-on mass scale, k, shown in Figure 4c[9]. This search has not only pioneered this intriguing signature, but also demonstrated that the data can be analyzed in a non-traditional space.



(a) (b) (c)

Figure 4: (a): The di-electron mass spectrum of a periodic signal. (b): Scalogram of a signal + background sample. (c): Observed (solid line) and expected (dashed line) limits on the model parameters, M_5 and k[9].

5 Summary

The search programme at ATLAS is expanding in multiple fronts. Advanced detector performance and modern analysis techniques allow us to greatly enhance the sensitivities. The unexplored regions and the gaps are being filled with new searches applying unique search strategies. Last but not the least, ATLAS is pioneering brand new signatures that challenge traditional methods vastly, motivating us to think out of the box and experiment fresh new methodologies. In addition, more effective theory interpretations are carried out in precision SM measurements such as the lepton flavour violating top measurement [10]. There are many interesting ongoing searches besides the ones covered in this article, including exciting Run 3 results. More highlights are coming.

References

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