PROCEEDINGS OF SCIENCE

Searches for strong production of supersymmetric particles with the ATLAS detector

Jiarong Yuan[a,b,*] **on behalf of the ATLAS collaboration**

[a] *Institute of High Energy Physics, Chinese Academy of Sciences, Yuquan Rd 19B, Beijing, China*

[b] *University of Chinese Academy of Science (UCAS), Yuquan Rd 19A, Beijing, China*

E-mail: jiarong.yuan@cern.ch

Supersymmetry (SUSY) provides elegant solutions to several problems in the Standard Model, and searches for SUSY particles are an important component of the LHC physics program. Naturalness arguments favour supersymmetric partners of the gluons and third-generation quarks with masses light enough to be produced at the LHC. This talk will present the latest results of searches conducted by the ATLAS experiment which target gluino and squark production, including stop and sbottom, in a variety of decay modes.

The European Physical Society Conference on High Energy Physics (EPS-HEP2025)
7-11 July 2025
Marseille, France

*Speaker

 ISSN 1824-8039 . Published by SISSA Medialab.

PoS(EPS-HEP2025)420

1. Introduction

The Standard Model (SM) of particle physics is the most successful theory describing the fundamental particles and their interactions. Although there is numerous experimental evidence supporting this theory, many major questions remain unsolved, such as the existence of dark matter, the hierarchy problem, and the grand unification. Various Beyond Standard Model (BSM) theories have been developed to address these issues, among which supersymmetry (SUSY) theory stands out as one of the most promising and popular theories, as it provides solutions to many of these questions and offers an elegant theoretical framework. According to SUSY, there is a superpartner for each SM particle with a spin differing by half a unit. The superpartners of the right-handed and left-handed top quarks mix and form the mass eigenstates $\tilde{t}_1$ and $\tilde{t}_2$, where $\tilde{t}_1$ is lighter. The superpartners of the Higgs and electroweak gauge bosons mix and produce the mass eigenstates of charginos ($\tilde{\chi}_i^{\pm}, i = 1, 2$ in order of increasing mass) and neutralinos ($\tilde{\chi}_j^0, j = 1, 2, 3, 4$ in order of increasing mass). To prevent the violation of lepton and baryon number, R-parity is introduced, defined as $R = (-1)^{3(B-L)+2s}$. With R-parity conserved, supersymmetric particles are always produced in pairs, and the lightest supersymmetric particle(LSP) is stable and is an excellent dark matter candidate. The latest results of searches for strong production of SUSY are presented [1]. The searches use a dataset of proton-proton (pp) collisions corresponding to an integrated luminosity of 139 fb^{-1} with the ATLAS detector at the Large Hadron Collider (LHC) at $\sqrt{s} = 13$ TeV[2, 3].

2. SUSY Searches

2.1 Search for new phenomena with top-quark pairs and large missing transverse momentum

A search for the direct pair production of stop, the supersymmetric partner of the top quark, is presented [4]. Each stop can decay via the two-body process $\tilde{t}_1 \to t\tilde{\chi}_1^0$ when $\Delta m(\tilde{t}_1, \tilde{\chi}_1^0) > m(t)$, or via the three-body process $\tilde{t}_1 \to bW\tilde{\chi}_1^0$ when $m(W) < \Delta m(\tilde{t}_1, \tilde{\chi}_1^0) < m(t)$. Scenarios with smaller $\Delta m(\tilde{t}_1, \tilde{\chi}_1^0)$, where top quark and W boson are off-shell, have been studied [5].

A multivariate classifier is used to identify the large-radius (large-R) jet from the top-quark decay. In addition, a NN-based algorithm, referred to as 'top-NN', is used to identify the combination of small-R jets associated with top-quark decay. Events are selected using the missing transverse momentum (E_T^{miss}) trigger with $E_T^{miss} > 230$ GeV, and the single-lepton trigger with E_T^{miss} in the range $[70, 230]$ GeV. All events are required to contain exactly one lepton with no other baseline light leptons or τ candidates. Events are classified into two exclusive categories: 'boosted' events with a large-R jet, and high-E_T^{miss} events with $E_T^{miss} > 230$ GeV and the absence of large-R jet. These categories target top quarks in different transverse momentum regions. Events are further split by the multiplicity of b-tagged jets [6] and the presence of a top-tagged large-R jet.

High-E_T^{miss} events are classified into '1b' or '2b' categories, and a lower bound on the number of light jets is used to ensure that top-NN-tagged jet combination contains at least two jets and an additional jet for leptonic top quark reconstruction. The hadronic top quark candidate corresponds to the jet combination with the highest top-NN output value, while the leptonic top quark consists of the lepton and the leading-p_T b-tagged (in '2b') or light jet (in '1b') not associated with the hadronic one. Boosted events are divided based on whether the large-R jet is top-tagged ('1t') or

not('0t'), and further by the location of b-tagged jets relative to the large-R jet. The '2b' events contain at least one b-tagged jet inside the large-R jet ($\Delta R(b, \text{large-R jet}) < 1.1$) and at least one outside. The '1b-had' ('1b-lep') events have at least one b-tagged jet inside (outside) the large-R jet, and none outside (inside). For these events, the hadronic top quark corresponds to the large-R jet, and the leptonic top quark is given by combining the lepton and leading-p_T b-tagged jet outside the large-R jet. The leading-p_T jet is used if a b-tagged jet is unavailable. In total, eight orthogonal categories are defined to maximize signal sensitivity. For each category, a neural-network-based event classifier (stop-NN) is used to distinguish signal and background. Each neural network is trained using all simulated events in the corresponding category, including both backgrounds and two-body decay signals. The signal regions (SRs) are defined by the criteria of the NN output, and the output value distributions in each category are used in the fit.

The dominant background processes are $t\bar{t}$,single-top and W+jets. Dedicated control regions (CRs) and validation regions (VRs) are defined using the NN output criteria. In CRs, the distribution of transverse mass (m_T) multiplied by the lepton charge is utilized in the fit, because of the characteristic endpoint around m_W of events with one leptonic W boson ($t\bar{t}$ − 1L,W+jets), and the charge asymmetry of W boson production. For single-top estimation, the boosted-2b-1t and boosted-2b-0t CRs are further split by a selection on the minimal stransverse mass ($m_{T2,min}(b+\ell, b, E_T^{miss})$) at 300 GeV, with the high-m_{T2} region enriched in single-top events. Although the $ttZ(\rightarrow \nu\bar{\nu})$ process has a small cross section, it is an important background, as its kinematic signatures are similar to the signal's. The validation of $ttZ(\rightarrow \nu\bar{\nu})$ process is performed using $ttZ(\rightarrow \ell\ell)$ events. Events are required to have exactly three signal leptons and no other baseline lepton. Two leptons are required to be of the same flavour and opposite charge, whose invariant mass $m_{\ell\ell}$ is in the range $[81, 101]$ GeV. The E_T^{miss} is recalculated with these two leptons subtracted. Good agreement between data and the SM prediction is observed in the NN output distributions in the high-E_T^{miss} regions.

No significant excess above the SM expectation is observed, and the exclusion limits are set at 95% confidence level (CL). This search excludes the signal scenarios with high neutralino masses and $\Delta m(\tilde{t}_1, \tilde{\chi}_1^0) \sim m(t)$, which were not covered previously [5]. The results of this search and the results from [7] are combined to derive exclusion limits, improving sensitivity at high $m(\tilde{t}_1)$ and in the region around $m(\tilde{t}_1, \tilde{\chi}_1^0) \sim (1100, 500)$ GeV.

2.2 Search for supersymmetry in final states with missing transverse momentum and charm-tagged jets

A search for final states containing charm-tagged jets and large E_T^{miss} is presented [8]. This search targets scenarios in which the top or charm squarks ($\tilde{t}_1/\tilde{c}_1$) are the lightest squarks. In SUSY models with minimal flavor-violating effects, the top squarks can decay into a charm quark and an LSP, and the charm squarks could be the lightest squark, which motivates searches for the pair production of top or charm squarks, with squarks decaying into a charm quark and an LSP. The kinematic signatures and production cross-sections for top and charm squark models are identical. The charm-tagging algorithm DL1r$_c$ is used to identify jets containing c-hadrons. This algorithm, which is optimized based on the b-tagging DL1r algorithm, provides an efficiency of 20% with b-veto.

Two sets of SRs are defined to cover different kinematic regimes: High-Mass and Compressed. These SRs are designed to be orthogonal: the High-Mass regions require the leading jet to be

c-tagged, while the Compressed regions require the leading jet not to be c-tagged. As signal models in this search are expected to have significant E_T^{miss}, all selected events must have $E_T^{miss} > 250$ GeV. Events with τ or light leptons are rejected due to the absence of leptons in the signal. Events with b-jets are vetoed to suppress top quark pair background. Besides, the minimum azimuthal angle separation between the up to four leading jets and the missing transverse momentum vector ($\vec{p}_T^{miss}$) is required to exceed 0.4 to suppress multijet backgrounds. Some other kinematic criteria are applied to reduce the dominant backgrounds. The High-Mass regions criteria exploit the energetic c-tagged jets and significant E_T^{miss}, while the Compressed regions criteria utilize the Recursive Jigsaw Reconstruction method to reduce SM backgrounds.

The dominant backgrounds, $Z(\rightarrow \nu\nu)$+jets and $W(\rightarrow \ell\nu)$+jets, are estimated in dedicated CRs. The $Z(\rightarrow \nu\nu)$+jets events in SRs are estimated using $Z(\rightarrow \ell\ell)$+jets events in dilepton CRs, in which two leptons are treated as invisible to mimic neutrinos for E_T^{miss} and all the other variables. The W+jets background in SRs is estimated using a set of one-lepton CRs.

No significant excess above the SM expectation is observed, and the exclusion limits are set at 95% CL. Squark masses up to 900 GeV are excluded with an LSP mass below 50 GeV, representing an improvement of about 100 GeV compared with the previous ATLAS search using c-tagging [9].

2.3 Reinterpretation of searches for flavour-violating supersymmetry into flavour-violating dark matter models

Weakly interacting massive particles are one kind of the most promising dark matter (DM) candidates. However, direct detection experiments and searches at the LHC fail to find evidence of their existence. The Dark Minimal Flavour Violation (DMFV) model assumes that DM consists of three flavours and introduces new flavour-violating couplings between SM quarks and the DM triplet, mediated by a new colored scalar mediator ϕ. The coupling matrix between the DM, ϕ and the SM is parameterized as $\lambda = U_\lambda D_\lambda$, where D_λ is a 3×3 diagonal matrix whose matrix elements $D_{\lambda,ii}$ represent the coupling strength between the mediator and the $i^{th}-$generation of DM particle and SM quarks. Several benchmark scenarios are considered with parameters favoured by the current constraints, leading to processes with final states containing tq+DM.

A search for direct pair production of top squarks with events containing a top quark, a charm quark and large E_T^{miss} is reinterpreted with the DM signals[10, 11]. In this analysis, four orthogonal SRs are defined, targeting different kinematic signatures. SRA targets signals with a large mass difference, $\Delta m(\tilde{t}_1, \tilde{\chi}_1^0)$, and requires a top-tagged large-R jet. SRB and SRC are optimized for intermediate mass difference, with events characterized by either a top-tagged large-R jet or a resolved topology. SRD targets the compressed region, in which $\Delta m(\tilde{t}_1, \tilde{\chi}_1^0) \approx m_t$. The events with an energetic initial state radiation light jet are selected, and a neural network is trained to distinguish signal and background.

The dominant background processes are Z+jets, $t\bar{t}$, W+jets and single-top, which are estimated using dedicated CRs. The $Z(\rightarrow \nu\nu)$+jets background in the SRs is estimated using $Z(\rightarrow \ell\ell)$+jets events in two-lepton CRs, where the two leptons are subtracted from the E_T^{miss} to mimic neutrinos. The $t\bar{t}$ and W+jets backgrounds in SRs are estimated using one-lepton CRs, with the lepton treated as a jet to mimic a hadronic τ in SR.

No significant excess above the SM expectation is observed. Exclusion limits at 95% CL are set on new mediator mass and its coupling strength, providing the first constraints for DMFV models

at the LHC. If DM mass is around 150 to 200 GeV, mediator masses up to about 1.2 TeV can be excluded for $D_{\lambda,11} \approx 2$. Furthermore, mediator masses in the range of 750 – 1100 GeV can be excluded for $D_{\lambda,11} \geq 1.75$ assuming a high DM mass of about 450 GeV.

3. Summary

The latest searches for strong production of SUSY particles are presented, based on 139 fb^{-1} of integrated luminosity of proton-proton collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector at the LHC. The observed data agree with the SM background expectations. These results are used to set upper limits on the cross-sections for BSM processes. Furthermore, exclusion limits are set on the masses of particles or the coupling to dark matter. For certain final states and models, results are reported for the first time.

References

[1] ATLAS Collaboration, *The quest to discover supersymmetry at the ATLAS experiment*, *Phys. Rept.* **1116** (2025) 261 [2403.02455].

[2] L. Evans and P. Bryant, *LHC Machine*, *JINST* **3** (2008) S08001.

[3] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, *JINST* **3** (2008) S08003.

[4] ATLAS Collaboration, *Search for new phenomena with top-quark pairs and large missing transverse momentum using* 140 fb^{-1} *of pp collision data at* $\sqrt{s}$ = 13 *TeV with the ATLAS detector*, *JHEP* **03** (2024) 139 [2401.13430].

[5] ATLAS Collaboration, *Search for new phenomena with top quark pairs in final states with one lepton, jets, and missing transverse momentum in pp collisions at* $\sqrt{s}$ = 13 *TeV with the ATLAS detector*, *JHEP* **04** (2021) 174 [2012.03799].

[6] ATLAS Collaboration, *ATLAS flavour-tagging algorithms for the LHC Run 2 pp collision dataset*, *Eur. Phys. J. C* **83** (2023) 681 [2211.16345].

[7] ATLAS Collaboration, *Search for a scalar partner of the top quark in the all-hadronic* $t\bar{t}$ *plus missing transverse momentum final state at* $\sqrt{s}$ = 13 *TeV with the ATLAS detector*, *Eur. Phys. J. C* **80** (2020) 737 [2004.14060].

[8] ATLAS Collaboration, *Search for supersymmetry in final states with missing transverse momentum and charm-tagged jets using* 139 fb^{-1} *of proton–proton collisions at* $\sqrt{s}$ = 13 *TeV with the ATLAS detector*, *JHEP* **02** (2025) 193 [2410.17824].

[9] ATLAS Collaboration, *Search for supersymmetry in final states with charm jets and missing transverse momentum in* 13 *TeV pp collisions with the ATLAS detector*, *JHEP* **09** (2018) 050 [1805.01649].

[10] ATLAS Collaboration, "Reinterpretation of searches for flavour-violating supersymmetry into flavour-violating dark matter models using 139 fb^{-1} of ATLAS Run 2 data." ATL-PHYS-PUB-2025-010, 2025.

[11] ATLAS Collaboration, *A search for top-squark pair production, in final states containing a top quark, a charm quark and missing transverse momentum, using the* 139 fb^{-1} *of* pp *collision data collected by the ATLAS detector*, *JHEP* **07** (2024) 250 [2402.12137].