PROCEEDINGS OF SCIENCE

Searches for electroweak production of supersymmetric particles with the ATLAS detector

Takuya Nobe*on behalf of the ATLAS collaboration

International Center for Elementary Particle Physics (ICEPP), the University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033 Faculty of Science 10F, Japan

E-mail: Takuya.Nobe@cern.ch

The direct production of electroweak supersymmetric (SUSY) particles, including sleptons, charginos and neutralinos, is a particularly interesting area with connections to dark matter, the naturalness of the Higgs boson's mass, as well as recent anomalies on muon $g-2$ and W boson mass measurements. The small production cross sections at the LHC makes searches difficult despite relatively clean final states. This article highlights the recent results of searches performed by the ATLAS experiment in 139 fb^{-1} of pp collisions at the LHC at $\sqrt{s}$ = 13 TeV.

41st International Conference on High Energy physics - ICHEP2022
6-13 July, 2022
Bologna, Italy

*Speaker

https://pos.sissa.it/

PoS(ICHEP2022)189

1. Introduction

Searches for the electroweak production of the supersymmetric (SUSY) particles are some of the most important physics programs at the LHC Run 2. Considering R-parity conservation, the lightest supersymmetric particle (LSP) is a strong candidate of dark matter. The neutralino LSP mass is preferred to be below a few TeV to be consistent with the observed relic density of the dark matter in the universe. In addition, recent anomalies reported on the muon $g-2$ and W boson mass suggest $O(100)$ GeV slepton and/or neutralinos/charginos. These "light" electroweak SUSY particles are highly motivated and can be explored at the LHC. This article highlights some examples of the latest ATLAS [1] search results using pp collisions data at $\sqrt{s} = 13$ TeV, corresponding to the full Run-2 integrated luminosity of 139 fb^{-1}.

2. Direct pair production of smuons

The superpartner of the muon (smuon) plays an important role to explain the muon $g-2$ anomaly with SUSY. Several analyses have been performed targeting on direct smuon pair productions where a smuon decays to a muon and the LSP. Figure 1 shows the current ATLAS limits on the masses of smuon and bino-like neutralino LSP, assuming the left- and right-handed smuons to be mass-degenerated. The mass range of smuon was explored up-to about 600 GeV by the "$2\ell 0J$" analysis [3] for the scenarios of the large mass splitting between the smuon and the LSP (Δm). The region with small Δm was searched by the "soft 2ℓ" analysis [4]. The LEP searches had been the most sensitive for a region around $20 < \Delta m < 60$ GeV and put the upper limit on the smuon mass at around 100 GeV. As shown in the figure, this Δm region is still motivated by the muon $g-2$, and the search strategy has been reoptimized [5] ("2ℓ, $\Delta m \sim m(W)$" in the figure).

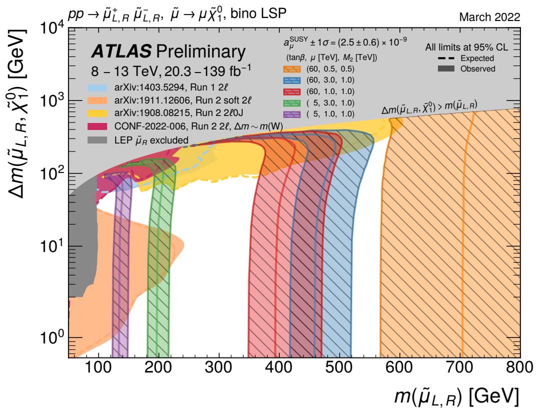

Figure 1: Exclusion limits at 95% CL based on 13 TeV data in the (Δm, $m(\tilde{\mu})$) plane for different analyses probing the direct production of smuons with decays to a muon and a bino-like neutralino [2]. The hatched bands indicate a few examples of regions that are compatible with the observed muon $g-2$ anomaly at the $\pm 1\sigma$ level, corresponding to the pMSSM parameters specified in the legend.

In the "2ℓ, $\Delta m \sim m(W)$" analysis, a same-flavor and opposite-sign lepton pair is required, and a variable $m_{\mathrm{T},2}$, which generalizes the transverse mass for symmetric event topologies where two identical particles each of which decays into a visible and an invisible product, is used to separate signals from the SM background. In this analysis, two leptons are assigned to the visible particle leg and the mass of the invisible particle is set to 100 GeV. Signal regions are categorized by the number of jets in the candidate event (SR-0J and SR-1J). The main sources of the SM backgrounds, WW, $t\bar{t}$, and $Z \to \tau\tau$, are flavor-symmetric backgrounds (FSB), i.e. the events with $e\mu$ have the same properties as those with ee and $\mu\mu$. A data-driven approach is employed using $e\mu$ events to estimate the FSB. Figure 2 shows the observed events in each $m_{\mathrm{T},2}$ bin compared with the estimated SM backgrounds. The absence of the significant data excess from the background estimation is interpreted as limits on the SUSY signals. As shown in Figure 1, the analysis excludes the range of $30 < \Delta m < 60$ GeV for the smuon mass of less than 120 GeV exceeding the LEP limits for the first time. Details of analysis and other interpretations are found in Ref. [5].

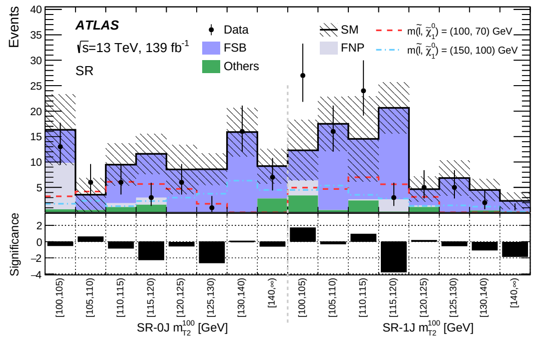

Figure 2: The observed number of events in each $m_{\mathrm{T},2}$ bin, together with the expected SM backgrounds in the "2ℓ, $\Delta m \sim m(W)$" analysis [5]. FSB and fake/non-prompt lepton (FNP) backgrounds are estimated by data-driven methods. "Others" include the non-dominant background sources, e.g. $t\bar{t} + V$, Higgs boson and Drell-Yan events. The uncertainty band includes systematic and statistical errors from all sources. Example distributions of two signal mass points are overlaid. The lower panel shows the significance in each bin.

3. Chargino/neutralino pair production directly decaying to the LSP

Chargino and neutralino pair productions have been searched under various SUSY models, primarily motivated by dark matter and naturalness of the Higgs mass. The simplest scenario is a wino-like chargino/neutralino pair production, each of which decays into bino-like neutralino LSP and W, Z or h bosons. Figure 3 shows the current ATLAS limits on that. To cover wide mass ranges, several analyses were performed requiring different decay modes of the W, Z and h bosons [6–8].

As an example, a search in the fully-hadronic final state mode ("0ℓ" analysis in the figure) [7] is discussed in this section. It employs a "boosted boson tagging" technique using the large-R jet substructure for the first time in the ATLAS SUSY analysis. It suppresses a huge amount of multijet background while keeping the signal efficiency, and makes it possible to apply the tight selection cuts on the kinematic variables, such as the effective mass m_{eff} and $m_{\mathrm{T},2}$ to maximize search sensitivity. The definitions of m_{eff} and $m_{\mathrm{T},2}$ are found in the caption of Figure 4. This is also thanks to the large branching fraction of the $W/Z/h$ bosons to hadrons. Events with two boson-tagged large-R jets and large $E_{\mathrm{T}}^{\mathrm{miss}}$ are selected. Technically, jets originating from $W \to qq$

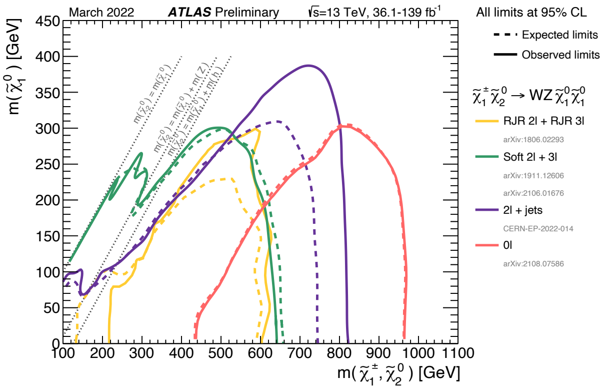

Figure 3: The expected and observed 95% CL exclusion limits for different analyses on $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ production with $\tilde{\chi}_1^\pm \to W^\pm \tilde{\chi}_1^0$ and $\tilde{\chi}_2^0 \to Z^0 \tilde{\chi}_1^0$ as a function of the $\tilde{\chi}_1^\pm$, $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$ masses [2]. The production cross-section is for pure wino $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$.

and $Z \to qq$ cannot be separated completely (here q denotes the light-flavor quarks) due to the resolution of mass reconstruction, and hence, we design an "inclusive" search requiring W- "or" Z-tagged jets. There is an advantage of using such an inclusive W/Z tagger, since various SUSY scenarios with the different fraction of the final-state bosons ($WW/WZ/Wh/Zh$) can be explored model-independently. $Z \to bb$ and $h \to bb$ taggers are prepared by requiring b-tagged sub-jets inside the large-R jets. The large-R jets with $70 < m < 100$ GeV and $100 < m < 135$ GeV are exclusively defined as Zbb-tagged and hbb-tagged jets. The boson tagging efficiencies are measured in the control sample data independently of the signal candidate events of the search, and those in the MC simulation are corrected with respect to the actual detector performance. Both $qqqq$ and $qqbb$ final states are considered in the different signal regions requiring the different number of W/Z- and Zbb/hbb-tagged jets in the event. The SM backgrounds with "background jets" mis-identified by the boson tagger, which do not contain W/Z-induced "signal jets", are estimated in the control region requiring to fail the boson tagger. The normalization factors of the backgrounds obtained in the control region are extrapolated to the signal region using the pre-estimated boson-tagger efficiencies and the uncertainties on them. The other background processes containing the signal jets originating from W/Z bosons are estimated by the MC simulation. Data agree with the SM background prediction as shown in Figure 4. As shown in Figure 3, the 0ℓ analysis uniquely covers the highest chargino/neutralino mass region with respect to the other final states. In Ref. [7], the results are interpreted under many SUSY models motivated by dark matter, muon $g-2$ anomaly, and so on, with the different fraction of the final state bosons. The signal efficiency has a small dependency on the fraction as designed.

4. Chargino/neutralino pair production decaying via stau

A search for charginos/neutralinos decaying to the LSP via stau, as shown in Figure 5, has been performed [9]. Considering the muon $g-2$ and W-mass anomalies in the framework of the MSSM, searches for a light stau are also highly motivated.

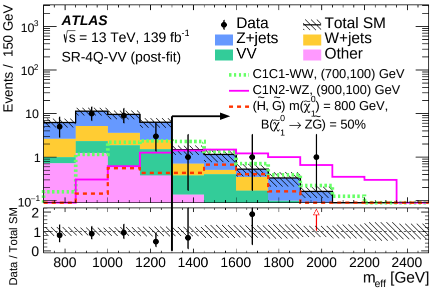

Figure 4: m_{eff} distribution in $qqqq$ channel (left) and $m_{\text{T},2}$ distribution in $qqbb$ channel (right) in the "0ℓ" analysis [7]. The SM background expectation is shown in a histogram stack. Distributions of a few representative signals are overlaid. The m_{eff} is the scalar sum of two large-R jets and $E_{\text{T}}^{\text{miss}}$ and the $m_{\text{T},2}$ is calculated by assigning two large-R jets as the visible particle leg. The bottom panels show the ratio of the observed data to the background prediction. The selection criterion for the variable shown by each plot is removed, while the arrow indicates the cut value used to define the region.

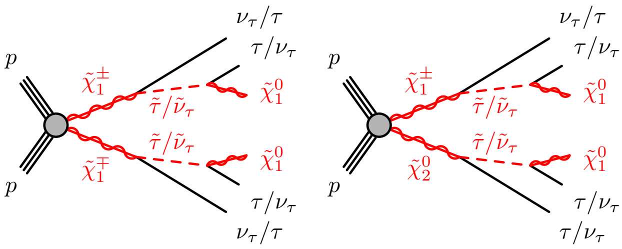

Figure 5: Representative Feynman diagrams of SUSY scenarios which are being searched for in the stau analysis [9]. In all cases, the subsequent decays contain a two τ-lepton final state. In the case of $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ production (right), the final state can contain more than two τ-leptons and both same-sign and opposite-sign pairs of τ-leptons can be identified.

At least two hadronically-decaying τs are required in the event. They are identified by a machine-learning-based classifier. The events are categorized into some channels of same-sign/opposite-sign and high-mass/low-mass topologies, and $m_{\text{T},2}$ is used as the final discriminant, which is calculated by assigning two τs as the visible particle leg. The main source of the SM background is $WZ \to \ell\nu\ell\ell$ and its contribution to the signal region is estimated by the MC simulation, but data/MC agreement is checked in the dedicated validation region. For W/Z+jets and top-quark backgrounds, the normalizations of the simulated samples are estimated in control regions. Multijet background with mis-identified "fake" τs are estimated in a data-driven way. The observed data events are one and four in low- and high-mass signal regions for the opposite-sign scenario, while 6.2 ± 2.0 and 4.0 ± 1.8 events are expected, and 14 and four in low- and high-mass signal regions for the same-sign scenario for 12.2 ± 4.8 and 5.0 ± 2.0 events expected. It is found that the analysis sensitivity does not depend on the stau mass so much. The limit on masses of chargino/neutralino and the LSP with the fixed stau mass to be the half of them is shown in Figure 6.

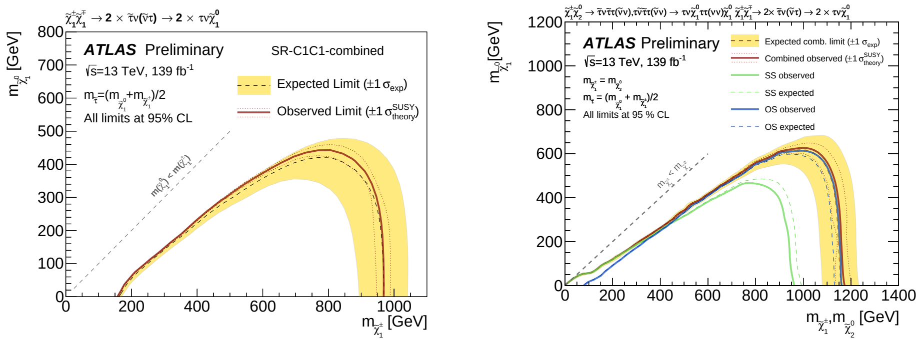

Figure 6: The expected and observed 95 % CL exclusion contours for simplified models with $\tilde{\chi}_1^+\tilde{\chi}_1^-$ production (left) and production of $\tilde{\chi}_1^+\tilde{\chi}_1^-$ and $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ (right) by the stau analysis [9]. The band around the expected limit shows the $\pm 1\sigma$ variations, including all uncertainties except theoretical uncertainties in the signal cross-section. The green curve is from the contribution of same-sign scenario, while the blue curve is from the contribution of opposite-sign scenarios, and the red curves are the combination of the channels.

5. Conclusions

Searches for "light" slepton and chargino/neutralino produced via electroweak processes at the LHC Run 2 in the range $O(100)$ GeV–$O(1)$ TeV are highly motivated, and recent ATLAS results are discussed in this article. Many other interesting results are found in the ATLAS web page [10]. We have just started to obtain the sensitivity to signals in the region of interest with the Run-2 data.

References

[1] ATLAS Collaboration, JINST **3** (2008) S08003.

[2] ATLAS Collaboration, ATL-PHYS-PUB-2022-013, https://cds.cern.ch/record/2805985/

[3] ATLAS Collaboration, Eur. Phys. J. C **80** (2020) 123.

[4] ATLAS Collaboration, Phys. Rev. D **101** (2020) 052005.

[5] ATLAS Collaboration, arXiv:2209.13935. https://arxiv.org/abs/2209.13935

[6] ATLAS Collaboration, arXiv:2204.13072. https://arxiv.org/abs/2204.13072

[7] ATLAS Collaboration, Phys. Rev. D **104** (2021) 112010.

[8] ATLAS Collaboration, Eur. Phys. J. C **81** (2021) 1118.

[9] ATLAS Collaboration, ATLAS-CONF-2022-042, https://cds.cern.ch/record/2815678.

[10] ATLAS Collaboration, Supersymmetry searches public results web page. https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults