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Search for compressed SUSY scenarios with the ATLAS detector

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Scenarios where multiple SUSY states are nearly degenerate in mass produce soft decay products, and they represent an experimental challenge for ATLAS. This contribution presented recent results of analyses explicitly targeting such "compressed" scenarios with a variety of experimental techniques. All results made use of proton-proton collisions collected at a centre-of-mass energy of 13 TeV with the ATLAS detector at the LHC.

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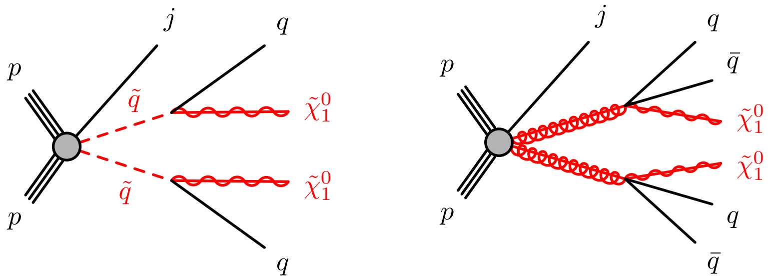

Figure 1: Production of pairs of squarks or gluinos in association with a hadronic jet (initial state radiation), the experimentally-striking signatures to search for SUSY scenarios with compressed mass spectra.

1. Introduction

Due to the unknown nature of the SUSY breaking mechanism and its scale, the masses of the superpartners are not fixed by the theory. The SUSY searches performed with the ATLAS experiment [1] address this issue through the use of complementary signal regions aiming at probing the whole SUSY parameter space. With this exhaustive approach, one unavoidably encounters scenarios where the difference in mass Δm between the superpartners produced in the hard scatter event, and the lightest superpartner (LSP) they decay into in the context of R-parity conserving models, is small. These scenarios are experimentally more challenging as the momentum of the decay products is reduced, making discrimination from Standard Model (SM) backgrounds more difficult. Beside purely-accidental small mass gaps, certain configurations of the MSSM parameters lead naturally to mass spectra in which several superpartners may have approximate mass degeneracy. This frequently occurs in the sector of gauginos [2], when the related superpotential mass terms ($|\mu|$, M_1, M_2) are well distinct and significantly larger than the electroweak scale (m_W); in that case three gauginos ($\tilde{\chi}_i^0, \tilde{\chi}_j^0, \tilde{\chi}_k^\pm$) have masses close to $|\mu|$, and two others ($\tilde{\chi}_i^0, \tilde{\chi}_j^\pm$) close to M_2.

Experimental sensitivity to scenarios with small Δm often relies on event topologies where the pair of superpartners is produced in association with a coloured initial state radiation (ISR), as illustrated in Fig. 1; if the ISR has large momentum, the recoil of the SUSY system, mostly transfered to the heavy LSPs present in the final state, leads to a characteristic signature of a hard hadronic jet back-to-back with significant missing transverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$). Such a strategy is employed as well in searches for direct production of Dark Matter, where the radiated recoiling object is either a photon or a hadronic jet [3, 4]. In the following we highlight a few recent results for squark or gluino production in the context of compressed mass spectra.

2. Inclusive production of squarks and gluinos

The extreme scenario corresponds to mass differences Δm of only a few GeV. In such cases, the other particles produced in the decay chain are too soft to be reconstructed, and the experimental signature is simply the presence of a single jet accompanied by large $E_{\mathrm{T}}^{\mathrm{miss}}$. The sensitivity of the dedicated "monojet" ATLAS search [4] reaches generic squark masses up to 800 GeV, or[1] gluino

[1] with a naive extrapolation from the sensitivity to squark-squark production, assuming that the fiducial acceptance is identical for gluino-gluino production

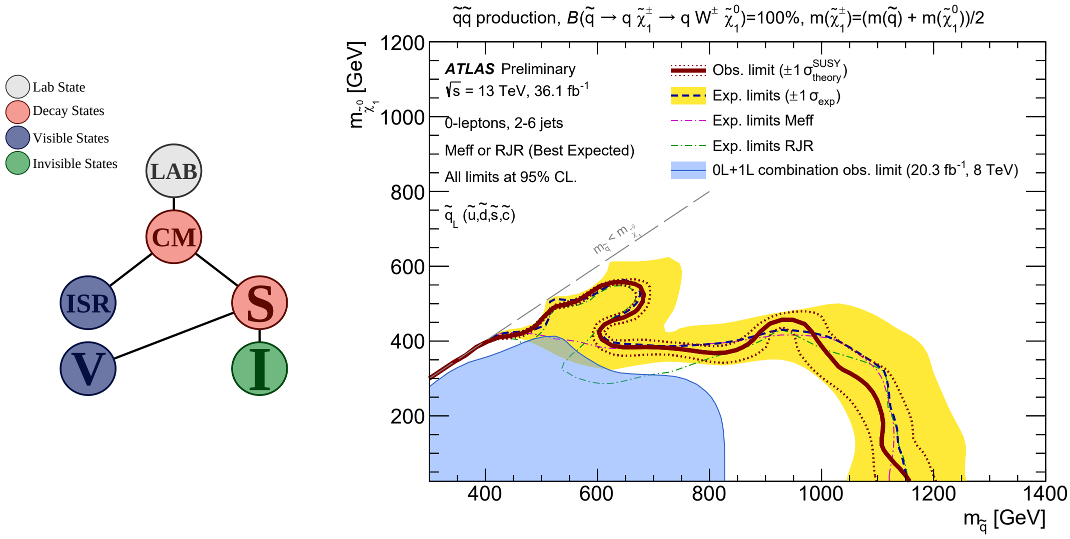

Figure 2: Limits on generic squark masses for $\tilde{q}\tilde{q}^*$ production with $\tilde{q} \to q'\tilde{\chi}_1^{\pm}$ decays obtained in Ref. [5]. The signal regions with best sensitivy to scenarios with heavy $\tilde{\chi}_1^0$ employ RJR variables with the categorization and combination of reconstructed objects as shown on the left diagram.

masses up to ~ 1 TeV. For that, events with up to four jets are selected, all well-separated from the reconstructed $E_{\mathrm{T}}^{\mathrm{miss}}$ in the azimuthal plane, and a fit of the $E_{\mathrm{T}}^{\mathrm{miss}}$ distribution between 250 and 1000 GeV is performed to search for BSM signals. This approach complements well the inclusive searches such as Ref. [5], which for direct decays $\tilde{q} \to q\tilde{\chi}_1^0$ and $\tilde{g} \to q\bar{q}\tilde{\chi}_1^0$ is sensitive to squark (gluino) masses only up to 400 GeV (700 GeV), when $\Delta m < 10$ GeV. However, the sensitivity of the monojet search degrades quickly when the mass gap Δm increases, as the reconstructed $E_{\mathrm{T}}^{\mathrm{miss}}$ originating from the transfer of the initial squark/gluino boost to the LSP decreases quadratically:

$$\frac{p_{\mathrm{LSP}}}{m_{\tilde{q}}} \approx \frac{1+\beta_{\tilde{q}}}{2} - \frac{1-\beta_{\tilde{q}}}{2}\left(\frac{m_{\mathrm{LSP}}}{m_{\tilde{q}}}\right)^2 + \mathscr{O}(\beta_{\tilde{q}}^2) \qquad (2.1)$$

For larger mass gaps the other products of the decay chain might be reconstructed. While this results in a further loss of acceptance for the monojet search, it offers the opportunity for a better discrimination between signal and background, through the presence of characteristic more complex signatures. For example, the search for bottom squark pair-production with $\tilde{b}_1 \to b\tilde{\chi}_1^0$ decays [6] relies on the presence of two b-tagged jets in the event, together with one light jet ($p_{\mathrm{T}} > 500$ GeV) and large $E_{\mathrm{T}}^{\mathrm{miss}}$ (> 500 GeV). This selection is completed by topological criteria reflecting what would be expected from signal events with ISR: the light jet, assumed to originate from the ISR parton, is required to be back-to-back with $E_{\mathrm{T}}^{\mathrm{miss}}$, and carry significantly larger momentum than the b-jets. This signal region provides good sensitivity to mass differences $20 < \Delta m < 50$ GeV, and allows to probe bottom squark masses up to 500 GeV, a limit similar to that obtained by the monojet search for very small Δm.

The particular topology of signal events may be further exploited by reconstructing the resonances originating from the direct decay of the superpartner produced in the hard scattering or from other heavy intermediates involved in the cascade decay of the latter. For that, recursive jigsaw reconstruction (RJR) techniques have been proposed (see references in [5]) as a systematic procedure to categorize and combine the reconstructed objects and their four-momenta based on the expected signal event topology (cf example in Fig. 2), and subsequently build a complete set of orthogonal discriminant variables. The inclusive ATLAS search for squarks and gluinos in zero-lepton final states [5] devised signal regions using RJR to complement other signal regions built with more traditional variables. The event selections employs RJR variables such as the fraction of boost transfered from the SUSY system to the invisible particles R_{ISR} (a quantity proportional to the $m_{\mathrm{LSP}}/m_{\tilde{q},\tilde{g}}$ ratio), the number of jets identified as decay products, the separation between the ISR and the invisible particles, various quantifiers of the energy scales involved and balance between objects. Figure 2 illustrates the gain in sensitivity that can be brought by the RJR-based signal regions: for squark-squark production with $\tilde{q} \to q'\tilde{\chi}_1^\pm$ decays, squark masses up to 150 GeV larger can be probed for $\Delta m \sim 100$ GeV, compared to traditional signal regions.

In cascade decays of squarks and gluinos, additional information, such as the production of leptons by the intermediate states, might be used to further reject SM backgrounds. For one-step decays $\tilde{q}/\tilde{g} \to q(q)\tilde{\chi}_1^\pm \to q(q)W\tilde{\chi}_1^0$, a dedicated signal region was employed in Ref. [5] for scenarios with $m_{\tilde{q},\tilde{g}} \approx m_{\tilde{\chi}_1^\pm} \gg m_{\tilde{\chi}_1^0}$: the lower average jet multiplicity, compared to scenarios with larger $\Delta m(\tilde{q}/\tilde{g}, \tilde{\chi}_1^\pm)$, is compensated by an explicit tagging of the hadronically-decaying boosted W boson. In searches targeting final states with light leptons, the sensitivity to SUSY scenarios with compressed mass spectra generally depends on the ability to reconstruct soft leptons. In ATLAS, performances of leptons reconstruction, identification and energy calibration have been assessed down to $p_{\mathrm{T}} = 4.5$ GeV (electrons) and 4 GeV (muons) for the analysis of Run 2 data. As the online lepton p_{T} thresholds to trigger data acquisition based solely on the presence of leptons are much larger, most searches relying on soft leptons select events with significant $E_{\mathrm{t}}^{\mathrm{miss}}$ (as present in ISR tologies), so that data acquisition is triggered purely by the presence of large $E_{\mathrm{T}}^{\mathrm{miss}}$.

Recent results include the one-lepton + jets search [7] which selects one electron (muon) with $7(6) < p_{\mathrm{T}} < n_{\mathrm{jets}} \times 5$ GeV, the upper bound helping rejecting SM background from on-shell vector boson production whose leptonic decays have a harder p_{T} spectrum. The same-sign leptons + jets search [8] uses leptons above 10 GeV and features a signal region with three leptons of identical charge, a background-free region that provides sensitivity to cascade decays of top squarks for $m_{\tilde{t}_1}$ up to 700 GeV for scenarios with a heavy $\tilde{\chi}_1^0$.

3. Compressed scenarios with top squarks

SUSY scenarios with a small mass difference between top squark and LSP may be more motivated a priori than those featuring generic squarks or gluinos, where the differences would be essentially accidental; indeed, naturalness arguments favor light top squarks (lighter than 1 TeV) to lessen the fine-tuning needed to suppress large radiative corrections to the Higgs bosons mass. Stringent experimental limits have however been set on top squark pair-production for light neutralinos, therefore plausible scenarios accommodating naturalness may involve heavier neutralinos. For this reason, particular care is taken in ATLAS searches for top squarks to optimize the experimental sensitivity over the whole ($m_{\tilde{t}_1}$, $m_{\tilde{\chi}_1^0}$) plane. The phenomenology of these scenarios is more diversified than for other squarks: as top squarks decay canonically to (heavy) top quarks, scenarios with $\Delta m < m_t$ involve 3- or 4-body decays $\tilde{t}_1 \to bf\bar{f}'\tilde{\chi}_1^0$, or FCNC decays $\tilde{t}_1 \to c\tilde{\chi}_1^0$. To probe the most compressed region (4-body decay), ATLAS searches [9, 10] rely on many of the techniques

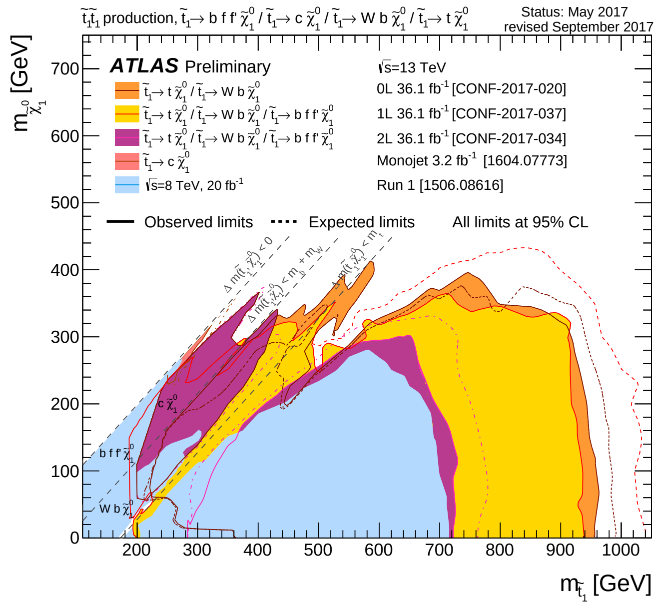

Figure 3: Summary of ATLAS exclusion limits on top squark pair production. Ref. [12].

evoked so far: selection of ISR topologies with back-to-back hard jet and $E_{\mathrm{T}}^{\mathrm{miss}}$, soft leptons (down to $p_{\mathrm{T}} = 4$ GeV for Ref. [9], 7 GeV for Ref.[10]), balance between $E_{\mathrm{T}}^{\mathrm{miss}}$ and jets/leptons (Ref. [10]). Ref. [9] also explicitly rejects $t\bar{t}$-background through an upper bound on the transverse mass of the event, or vetoing reclustered on-shell hadronic top decays. These selections reach a sensitivity to top squark masses up to 400 GeV (Fig. 3).

Another region of the parameter space that might be qualified of "compressed" is the region with $\Delta m \approx m_t$. The topology and kinematics of the top squark decay products, in these conditions, approach those featured by SM $t\bar{t}$ production, especially for smaller top squark masses for which the momentum transfered to the LSPs is not large. To target this challenging region, ATLAS searches deployed advanced techniques; Ref. [11] uses RJR variables and the final sensitivity is provided by a fit of the R_{ISR} distribution; Ref. [9] relies on boosted decision trees based on the kinematics of reconstructed hadronic and leptonic top quark decays. While the sensitivity in this region was poor with earlier 8 TeV searches, Fig. 3 shows that the recent results nicely closed the gap left open after Run 1. Finally, for $m_{\tilde{t}_1} \approx m_t$, additional constraints are provided by the measured $t\bar{t}$ cross-section [13], as well as the study of spin correlations in $t\bar{t}$ events [14], both of which would be affected by the existence of a light scalar top quark partner. These measurements performed at $\sqrt{s} = 8$ TeV allow to exclude top squark masses below 190 GeV.

Conclusion

Thanks to the Run 1 experience, the first Run 2 searches have already deployed a large arsenal of experimental methods to probe regions of the SUSY parameter space with compressed mass spectra. While only results concerning strong production were released, there are ongoing efforts to apply these techniques to probe direct $\tilde{\chi}_2^0\tilde{\chi}_1^\pm$ production for small $\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)$.

References

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

[2] S. P. Martin, *A Supersymmetry Primer*, *Adv. Ser. Direct. High Energy Phys.* **18** (1998) 1

[3] ATLAS collaboration, *Search for dark matter at $\sqrt{s} = 13$ TeV in final states containing an energetic photon and large missing transverse momentum with the ATLAS detector*, *Eur. Phys. J. C* **77** (2017) 393

[4] ATLAS collaboration, *Search for dark matter and other new phenomena in events with an energetic jet and large missing transverse momentum using the ATLAS detector*, ATLAS-CONF-2017-060, https://cds.cern.ch/record/2273876

[5] ATLAS collaboration, *Search for squarks and gluinos in final states with jets and missing transverse momentum using 36 fb^{-1} of $\sqrt{s} = 13$ TeV pp collision data with the ATLAS detector*, ATLAS-CONF-2017-022, https://cds.cern.ch/record/2258145

[6] ATLAS collaboration, *Search for supersymmetry in events with b-tagged jets and missing transverse momentum in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, arXiv:1708.09266[hep-ex], submitted to *JHEP*

[7] ATLAS collaboration, *Search for squarks and gluinos in events with an isolated lepton, jets and missing transverse momentum at $\sqrt{s} = 13$ TeV with the ATLAS detector*, arXiv:1708.08232[hep-ex], submitted to *Phys. Rev. D*

[8] ATLAS collaboration, *Search for supersymmetry in final states with two same-sign or three leptons and jets using 36 fb^{-1} of $\sqrt{s} = 13$ TeV pp collision data with the ATLAS detector*, arXiv:1706.03731[hep-ex], accepted by *JHEP*

[9] ATLAS collaboration, *Search for top squark pair production in final states with one isolated lepton, jets, and missing transverse momentum using 36 fb^{-1} of $\sqrt{s} = 13$ TeV collision data with the ATLAS detector*, ATLAS-CONF-2017-037, https://cds.cern.ch/record/2266170

[10] ATLAS collaboration, *Search for direct top squark pair production in final states with two leptons in $\sqrt{s} = 13$ TeV pp collisions with the ATLAS detector*, arXiv:1708.03247[hep-ex], submitted to *Eur. Phys. J. C*

[11] ATLAS collaboration, *Search for a scalar partner of the top quark in the jets plus missing transverse momentum final state at $\sqrt{s} = 13$ TeV with the ATLAS detector*, arXiv:1709.04183[hep-ex], submitted to *JHEP*

[12] ATLAS collaboration, *Summary plots from the ATLAS Supersymmetry physics group*, https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/SUSY, as of September 2017

[13] ATLAS collaboration, *Measurement of the $t\bar{t}$ production cross-section using e-mu events with b-tagged jets in pp collisions at $\sqrt{s} = 7$ and 8 TeV with the ATLAS detector*, *Eur. Phys. J. C* **74** (2014) 3109, addendum *Eur. Phys. J. C* **76** (2016) 642

[14] ATLAS collaboration, *Measurement of Spin Correlation in Top-Antitop Quark Events and Search for Top Squark Pair Production in pp Collisions at $\sqrt{s} = 8$ TeV Using the ATLAS Detector*, *Phys. Rev. Lett.* **114** (2015) 142001