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MSSM fits to the ATLAS 1 lepton excess

Kamila Kowalska[1,a], **Enrico Maria Sessolo**[2,b]

[1] Fakultät für Physik, TU Dortmund, Otto-Hahn-Str.4, 44221 Dortmund, Germany
[2] National Centre for Nuclear Research, Hoża 69, 00-681 Warsaw, Poland

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Abstract We use the framework of the p19MSSM to perform a fit to the mild excesses over the Standard Model background recently observed in three bins of the ATLAS 1-lepton + (b-)jets + E_T^{miss} search. We find a few types of spectra that can fit the emerging signal and at the same time are not excluded by other LHC searches. They can be grouped roughly in two categories. The first class is characterized by the presence of one stop or stop and sbottoms with mass in the ballpark of 700–800 GeV and a neutralino LSP of mass around 400 GeV, with or without the additional presence of an intermediate chargino. In the second type of scenarios the stop, lightest chargino, sbottom if present, and the neutralino are about or heavier than ∼650 GeV and the signal originates from cascade decays of squarks of the 1st and 2nd generation, which should have a mass of 1.1–1.2 TeV. For the best-fit scenarios, we compare the global chi-squared with several ATLAS and CMS searches with the corresponding chi-squared of the Standard Model expectation, showing that the putative signal is also favored globally with respect to the background-only hypothesis. We point out that if the observed excess persists in the next round of data, it should be accompanied by associated significant excesses in all-hadronic final-state searches.

1 Introduction

The LHC is now in the course of its second run, characterized by proton–proton collisions at the center-of-mass energy of 13 TeV. By August 2016, the ATLAS and CMS Collaborations had collected approximately 14 fb^{-1} of data and presented the results of their searches for new physics beyond the Standard Model (BSM) at the ICHEP conference [1] in Chicago. To some disappointment, in almost all of the hundreds of presented channels the number of observed events turned out to be in excellent agreement with the Standard Model (SM) expectation, so that no new physics seems to be present at the tested energy.

On the other hand, as is bound to happen given the enormous number of kinematical bins and final-state channels analyzed by the two collaborations to cover the parameter space of as many BSM models as possible, a few anomalies have emerged to small significance. In particular, the 1-lepton ATLAS search [2] shows a 3.3 σ excess of events in the so-called DM-low bin, and less significant 2.6 σ and 2.2 σ excesses in the bins called bC2x-diag and SR1, respectively. In this letter we dedicate some attention to these excesses, as they are appearing in one of the classic topologies designed to discover supersymmetry (SUSY), which arguably remains the most comprehensive and appealing scenario for BSM physics.

It is obviously extremely premature to get excited about an excess like this, as its statistical significance is relatively low and experience has shown time and again that background fluctuations of comparable strength do happen with some frequency, especially when many channels are analyzed. On the other hand, given the appeal that SUSY has held on the particle community for many years, we also think it is legitimate to wonder whether the ATLAS 1-lepton excess already points toward specific SUSY spectra, and in particular spectra more involved than the simplified models used by the experimental collaborations to interpret their results.

We address the question by performing a global fit to the bins showing the excess in the generic framework of the phenomenological Minimal Supersymmetric Standard Model (p19MSSM) [3], which is characterized by 19 independent parameters. We use a set of model points generated by the ATLAS Collaboration in Ref. [4], which satisfies a set of experimental constraints from the relic density, direct dark matter (DM) searches, Higgs sector measurements, electroweak and flavor physics, as well as includes the exclusion bounds from the 8 TeV LHC SUSY searches. We also use the state-of-the-art exclusion bounds from 11 other ATLAS

[a] e-mail: kamila.kowalska@tu-dortmund.de
[b] e-mail: enrico.sessolo@ncbj.gov.pl

SUSY searches based on 3.2 fb^{-1} and $\sim$14 fb^{-1} data, which were derived by one of us in Ref. [5]. We repeat that, while our analysis satisfies a genuine curiosity, the reader will have to keep in mind that it might prove a futile effort were the excess to disappear or lose significance in the next round of data.

It is important to note in this regard that the CMS search [6] equivalent to ATLAS 1-lepton does not show any significant excess over the SM background with $\sim$13 fb^{-1} of data. By recasting the CMS analysis we will show, however, that this is not in contradiction with the onset of a possible signal observed at ATLAS, as the kinematical variables used by CMS and the subsequent definitions of the signal bins differ from the ones of ATLAS and the compatibility between the two is not straightforward.

Recently, an analysis of the ATLAS 1-lepton excess was performed in Ref. [7]. The excess was fitted with simplified SUSY model spectra (SMS) characterized by moderately light stops decaying into a bino or, in alternative, higgsino lightest SUSY particle (LSP). The originating signal was confronted with two CMS hadronic searches [8,9]. It was concluded in [7] that the signal is consistent at 2σ with a spectrum characterized by a $\sim$750–800 GeV stop, a bino LSP and a higgsino next-to-LSP. We extend the analysis here by considering a broader range of possibilities for the SUSY spectrum, as embodied by our choice of using the p19MSSM points to fit the excess. We show that there exist additional spectra and decay chains that can equally well fit the 1-lepton excess, and for each found scenario we compare its global χ^2 with respect to a sample of LHC searches with the χ^2 of the background-only hypothesis, showing that all our scenarios are favored globally over the SM to some significance. We additionally provide possible signals for the next batch of LHC data and give a few comments on possible UV completions.

This paper is organized as follows. In Sect. 2 we outline the fitting procedure and we enumerate the constraints we impose on our model spectra. In Sect. 3 we present and discuss the main results of the fit and favored SUSY spectra. In Sect. 4 we evaluate the significance of the best-fit spectra globally with respect to the background-only hypothesis. We summarize our findings and conclude in Sect. 5. Additionally, we present two appendices dedicated, respectively, to the validation of the CMS 1-lepton search, and to the detailed breakdown of the chi-squared contributions of every bin in the most important searches considered in this paper.

2 Fitting procedure and constraints

We investigate in this paper whether the excess in events shown by the ATLAS 1 lepton + (b-)jets search [2] can be interpreted in the generic framework of the p19MSSM.

To fit the three excesses we use a set of model points provided by the ATLAS Collaboration in Ref. [4] and generated using methods similar to those presented in [3,10–12]. The set consists of points for which mass and trilinear parameters have been scanned up to a maximum value of 4 TeV, with the exception of the third generation trilinear soft coupling A_t, scanned in the range [−8 TeV, 8 TeV] to allow for the correct Higgs mass even when the stop mass is not very large. Phenomenological constraints from the relic density (upper bound), DM searches, Higgs and flavor physics, and electroweak precision data were taken into account, as was the impact of 22 ATLAS LHC searches at $\sqrt{s} = 7$ and 8 TeV with integrated luminosity of 20.3 fb^{-1}. The SUSY spectra were calculated with SOFTSUSY v.3.4.0 [13], and the decay branching ratios with SUSY-HIT v.1.3 [14]. MicrOMEGAs v.3.5.5 [15,16] and SuperIso [17] were used to evaluate dark matter, precision electroweak and flavor observables, while the lightest Higgs boson mass was calculated with FeynHiggs v.2.10.0 [18,19]. The resulting p19MSSM set contained 183,030 allowed model points. More details on the sampling procedure and implementation of the experimental bounds can be found in Ref. [4].

We proceed as follows. We start with the sample of points that is not at present excluded by the current ATLAS 13 TeV searches for SUSY particles, which was constructed in Ref. [5] out of the 183,030 initial points.[1] All points were there tested on-the-fly by recasting for the p19MSSM 11 direct ATLAS searches:

- ATLAS 0 leptons + 2-6 jets + $E_T^{\rm miss}$, 3.2 fb^{-1} [22], 13.3 fb^{-1} [23],
- ATLAS 1 lepton + jets + $E_T^{\rm miss}$, 3.2 fb^{-1}[24], 14.8 fb^{-1} [25],
- ATLAS 3 b-tagged jets + $E_T^{\rm miss}$, 3.2 fb^{-1}[26], 14.8 fb^{-1} [27],
- ATLAS 0 leptons + (b-)jets + $E_T^{\rm miss}$, 13.3 fb^{-1} [28],
- ATLAS 1 lepton + (b-)jets + $E_T^{\rm miss}$, 3.2 fb^{-1} [29],
- ATLAS 2 leptons + jets + $E_T^{\rm miss}$, 3.2 fb^{-1} [30],
- ATLAS 2 b-tagged jets + $E_T^{\rm miss}$, 3.2 fb^{-1} [31],
- ATLAS monojet + $E_T^{\rm miss}$, 3.2 fb^{-1} [32].

Detailed description of the recast procedure, as well as validations of the implemented searches, can be found in Ref. [5].

Additionally, there are a few CMS 13 TeV SUSY searches that should be taken into account as they provide results complementary to those of ATLAS, in particular the 1-lepton [6] and 0-lepton [33–35] searches. Reference [6] is similar to the ATLAS search presented in [2] but, in contrast to the ATLAS results, it does not show any significant excess in the kinematical bins. As was mentioned in Sect. 1, this does

[1] Other papers analyzing the impact of the most recent LHC bounds on natural SUSY spectra can be found in [20,21].

Table 1 Summary of the excesses observed in the ATLAS 1 lepton + (b-)jets + $E_T^{\rm miss}$ search [2]. The name of the bin, the number of observed and background events, as well as the significance of the excess are provided by the experimental collaboration. The number of signal events that fit the excess best is derived according to the procedure described in the text

Bin	Obs.	Bkg.	Sig.	σ (p-value)
SR1	37	24 ± 3	13.2	2.2 (0.012)
bC2x-diag	37	22 ± 3	15.2	2.6 (0.004)
DM-low	35	17 ± 2	18.1	3.3 (0.0004)

not automatically reflect an inconsistency between the two results, as the definitions of the bins in both searches are quite different, but one needs to make sure that the models that fit the ATLAS excess are not instead excluded by CMS. To evaluate the impact of the CMS 1-lepton search [6] on our model sample, we implemented it in our recast tool as well. The validation of the recast procedure against the experimental results is given in Appendix A.

The 95% CL bounds on the stop/neutralino, sbottom/neutralino SMS provided in the CMS 0-lepton analyses are in general more constraining than those of the equivalent ATLAS searches [23,28] in the part of the parameter space where the ATLAS 1-lepton excess can be fitted. Bounds obtained in 0-lepton searches tend to be fairly stable under variations of the decay channels, so that for most of our points we will take the CMS exclusion lines at face value. On the other hand, we will draw attention to a few spectra that could fit the ATLAS excess if they were not excluded by the CMS 0-lepton searches when the SMS bound is taken at face value. Those spectra are characterized by a significant reduction of the branching ratio to all-hadronic final states, so that there is some doubt on whether they are actually excluded or not, and the answer would require a detailed recasting of the CMS searches as was done in Ref. [5] for ATLAS. We refrain from doing this here, given the still premature nature of the ATLAS excess, and limit ourselves to pointing out in the text the presence of these points "of doubt".

We then proceed to perform a maximum likelihood estimate for the ATLAS 1 lepton + (b-)jets + $E_T^{\rm miss}$ search. A moderate excess shows up in 3 of the experimental bins [2], see Table 1. The bins are not statistically independent, and the same signal could be responsible for all 3 observed excesses. We limit ourselves to this hypothesis in this paper.

Indicating the observed number of events, the expected SM background, and the collaboration's estimate of the systematic uncertainty for each bin i as o_i, b_i, and δb_i, respectively, we seek the maximum of the likelihood function

$$\mathcal{L}_i = \frac{1}{\sqrt{2\pi}\,\delta b_i}\int {\rm d}b'\, {\rm e}^{-\frac{(b'-b_i)^2}{2\delta b_i^2}} \times \frac{{\rm e}^{-(s_i+b')}(s_i+b')^{o_i}}{o_i!}, \quad (1)$$

where s_i is the simulated signal for each bin, as a function of the points in the parameter space. The signals s_i are simulated in the usual way, following the procedure given, e.g., in [5]. We use PYTHIA 8 [36] for the hard-scattering event and showering and DELPHES 3 [37] for the detector properties' simulation. We fit to all bins by making use of the $\Delta\chi^2$ variable: $\Delta\chi_i^2 = -2\log(\mathcal{L}_{\rm i}/\mathcal{L}_0)$, where $\mathcal{L}_0$ corresponds to the background-only hypothesis for the bins that do not show an excess, and to the signal given in Table 1 otherwise. Since the kinematical bins considered in the ATLAS 1-lepton search are not independent we build a global statistics as

$$\Delta\chi^2_{\text{1-lep}} = \max_i\ \Delta\chi_i^2. \quad (2)$$

The sample of viable points fitting the excesses is narrowed down in a two-step procedure. First we identify the points that fit the excesses approximately at the 95% CL. In other words we require $\Delta\chi^2_{\text{1-lep}} \leq 3.84$. Given that the most significant excess in Table 1 is at most $3.3\,\sigma$, this first step allows a large number of points to survive. To further scale down the sample, we assume that the largest excess will yield in the near future a $5\,\sigma$ discovery. A simple rescaling of the integrated luminosity gives us an approximate estimate of the luminosity L' at which this might occur. Equating $\sqrt{L'/L_0} = 5\,\sigma/3.3\,\sigma$ yields, given the present luminosity of $L_0 = 13.2\ \text{fb}^{-1}$, a target $L' \approx 32\ \text{fb}^{-1}$. Thus, as a final step, we rescale o_i and b_i in the 3 bins presenting an excess by the target luminosity L' and subsequently fit to the maximum likelihood of Eq. (1) at the 95% CL. We present in the next section the best-fit spectra.

3 Spectra that fit the signal

Out of 183,030 p19MSSM model points allowed by the 8 TeV LHC data, 138,141 are not excluded after inclusion of the 13 TeV results. 1293 model points fit the excess observed by ATLAS 1 lepton + (b-)jets + $E_T^{\rm miss}$ 13.2 fb^{-1} search at the 95% CL, while 194 would produce a 5σ signal at the luminosity of $\sim$32 fb^{-1}. Out of those, 48 points are not excluded when the CMS 1- and 0-lepton searches are taken into account. These will be considered in the following as the allowed models.

The resulting spectra can be divided into a few categories, depending on the properties of the light particles present in the spectrum and the mechanism that allows one to fit the observed excesses. We describe them below, and summarize their features in Table 2 and in Fig. 1.

• *Right-chiral stop scenario.* The signal is consistent with the SMS employed by the experimental collaboration or similar spectra. The signal can be generated by the pair-produced stops decaying into a top quark and the LSP with BR($\tilde{t}_1 \to t\chi_1^0$) $\approx$ 100%, as exemplified in Table 2 by

Table 2 Benchmark-point models that fit the excess observed by the ATLAS 1 lepton + (b-)jets + E_T^{miss} search [2]. The mass of the light degrees of freedom in GeV, the branching ratio of the dominant decay yielding a hard lepton, and the goodness of fit according to Eq. (2) are shown

Benchmark	BP1	BP2	BP3	BP4	BP5	BP6
$m_{\tilde{t}_1}$	700	676	700	829	924	677
$m_{\tilde{b}_1}$	1100	1665	700	738	2259	683
$m_{\tilde{b}_2}$	2080	3245	3650	834	3227	2050
$m_{\tilde{q}_L}$	2520	2545	3630	3850	1080	1100
$m_{\chi_1^\pm}, m_{\chi_2^0}$	896	390	460	463	1010	914
$m_{\chi_1^0}$	386	369	453	434	760	665
$\text{BR}(\tilde{t}_1 \to t\chi_1^0)$	100%	72%	87%	82%		
$\text{BR}(\tilde{b}_1 \to t\chi_1^\pm)$			86%	28%		
$\text{BR}(\tilde{b}_2 \to t\chi_1^\pm)$				82%		
$\text{BR}(\tilde{q} \to q\chi_1^\pm \to q\, b\tilde{t}_1)$					56%	
$\text{BR}(\tilde{q} \to q\chi_1^\pm \to q\, t\tilde{b}_1)$						38%
$\Delta\chi^2_{\text{1-lep}}$	0.6	1.0	2.0	1.3	0.9	0.5

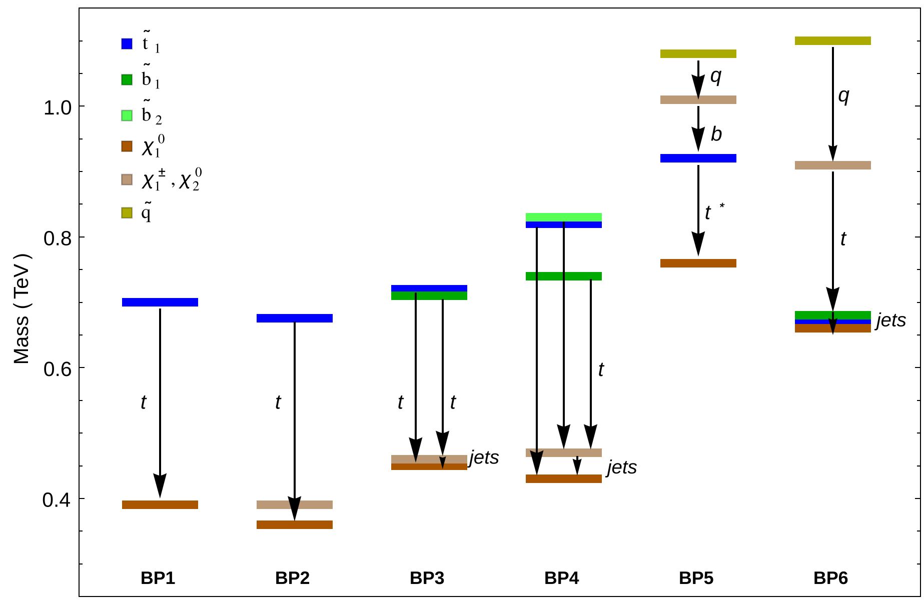

Fig. 1 Benchmark spectra that can fit the ATLAS 1 lepton + (b-)jets + E_T^{miss} excesses [2]. The *colors* are associated with each sparticle as described in the legend. We indicate the SM particle emitted at every step of the decay chain next to the corresponding arrow

the benchmark BP1. The table shows also the branching ratio of the mother sparticle into the channel that produces a hard lepton, and the χ^2 value of this point according to Eq. (2) (at the luminosity of 13.2 fb^{-1}). The stop in this scenario is moderately light and mostly right-chiral, with $m_{\tilde{t}_1} \approx 600 - 800$ GeV, and the source of the missing energy is a bino-like neutralino LSP with mass in the range ∼360–410 GeV. Note that spectra similar to this scenario were found to fit the signal in [7].

The model points of the ATLAS set [4] all yield an acceptable value for the relic abundance (at least within an upper bound), which means that when the LSP is bino-like the spectrum presents also additional light particles in mass close to $m_{\chi_1^0}$. In the case of BP1, these are a light right-chiral selectron and smuon with just about the same mass as the neutralino, which contribute to the early Universe co-annihilation with the LSP. Because their mass is almost degenerate with $m_{\chi_1^0}$, direct SUSY searches are not yet sensitive to the presence of these particles, and since they do not affect the fitted 1-lepton signal we do not indicate their presence in Table 2 and in Fig. 1.

Alternatively, there might be a light chargino (either wino- or higgsino-like) in the spectrum, which participates in co-annihilating with the neutralino in the early Universe, as exemplified in the spectrum of BP2 in Table 2. Although a light chargino is necessary for the relic density, it does not directly participate to producing a signal in the 1-lepton ATLAS search. It has the effect of mostly reducing the branching ratio into the $t\chi_1^0$ final state (because of a non-negligible $\text{BR}(\tilde{t}_1 \to b\chi_1^\pm)$) and thus allowing for a best fit involving a slightly lighter stop and neutralino than in BP1.

• *Stop/sbottom scenario.* The signal is consistent with the presence of relatively light, mostly left-chiral stops and sbottoms, with $m_{\tilde{t}_1} \approx m_{\tilde{b}_1} \approx$ 650–850 GeV, neutralino LSP (bino, higgsino, or an admixture) of mass ∼350–480 GeV, and the lightest chargino or second-lightest neutralino not far above the LSP. The ATLAS excess is fitted assuming pair-production of left-handed stops and sbottoms, with the subsequent decay chain depending on the mass splitting between $\tilde{t}_1$, $\tilde{b}_1$, and the light electroweakinos. Several possibilities are allowed: $\tilde{t}_1 \to t\chi_1^0$, $\tilde{t}_1 \to t\chi_{2,3}^0$, and $\tilde{b}_1 \to t\chi_1^\pm$, with branching ratios in all cases varying between 50 and 100%. The charginos and neutralinos just above the LSP decay to χ_1^0 and soft jets via an off-shell gauge boson (BR($\chi_2^0, \chi_1^\pm \to \chi_1^0 + \text{jets}$) ≈ 50–60%) so that the acceptance/efficiency for finding an isolated hard lepton in the event does not drop significantly. The benchmark point for this scenario is shown in Table 2 as BP3.

BP3 is at risk of being excluded by the CMS α_T search [35], as emerges by the interpretation of this search in the SMS T2bb with a light sbottom and the LSP. On the other hand, for BP3 the efficiency of the α_T search to all-hadronic final states is reduced by a factor 2.3 with respect to the T2bb SMS, due to the lepton veto. Only a full simulation of [35] can quantitatively assess the impact of the efficiency reduction on the 95% C.L. exclusion bound. As we explained in Sect. 2, performing a full simulation of every available search far exceeds the purpose of this paper, so that for the moment we limit ourselves to pointing out the existence of this possible tension.

The ATLAS signal can also be fitted when the right-chiral sbottom is light as well. In such a case different mass hierarchies can arise between $\tilde{t}_1$, $\tilde{b}_1$ and $\tilde{b}_2$, with all three sparticles contributing to the signal. The benchmark point for this scenario is shown in Table 2 as BP4.

• *Squark decay scenario.* There exists the possibility of fitting the signal with spectra moderately heavier than those considered so far. In the case where the right-chiral stop and the LSP lie above ∼600 GeV, the signal can be fitted in the presence of squarks of the first two generations with $m_{\tilde{q}_L} \approx$ 1.1 TeV, which can boost the production cross section. An example of this light squark spectrum is shown in Table 2 and Fig. 1 as BP5. The decay chain proceeds through $\tilde{q}_L \to \chi_1^\pm q \to b\,\tilde{t}_1\,q$ (with approximately 60% branching ratio) and the lepton tagged by the ATLAS search originates from the subsequent decay of the stop.

A variation of the above scenario, involving left-chiral stops/sbottoms instead, is presented as BP6. The hard lepton comes now from the decay of the chargino or second-lightest neutralino, as the cascade proceeds through $\tilde{q}_L \to \chi_1^\pm(\chi_2^0)\,q \to t\,\tilde{b}_1(\tilde{t}_1)\,q$, with a final soft decay of $\tilde{b}_1$ or $\tilde{t}_1$.

Note that, while in BP5 the spectrum must include additional light sleptons or squarks in mass very close to the LSP if the upper bound on the relic density is to be satisfied, BP6 contains all the ingredients in it, as the correct relic abundance results from co-annihilation with the lightest stop/sbottom.

• *Light gluino scenario.* There might be finally the possibility of fitting the ATLAS signal in the presence of a light gluino with mass in the ∼1.1–1.2 TeV range, if the stop has approximately the same mass of a higgsino LSP with $m_{\chi_1^0,\chi_1^\pm} \gtrsim 800$ GeV. This scenario is not excluded by the ATLAS searches described in Sect. 2. Gluino pair-production provides in this case a cross section of the right magnitude, and the decay chain follows $\tilde{g} \to t\,\tilde{t}_1$, with a subsequent decay of the stop to the LSP and a c-jet (with flavor changing loop-generated coupling). An exemplary spectrum is characterized by $m_{\tilde{g}} = 1160$ GeV, $m_{\tilde{t}_1} = 858$ GeV, and $m_{\chi_1^0} = 830$ GeV.

We do not report this scenario in Table 2 and Fig. 1 as it seems to be excluded by CMS all-hadronic searches [33–35] when the bound interpreted in the SMS T2bbbb is taken at face value. However, one must be aware that the acceptance/efficiency to all-hadronic final states is in this case reduced by a factor of 1.6 with respect to the T2bbbb SMS.

4 Approximate global analysis

The excess appearing in the DM-low bin of the ATLAS 1-lepton search shows a local significance greater than 3σ. We have shown in Sect. 3 that the excess admits an explanation in the context of the MSSM for several decay chains. On the other hand, one may wonder whether the emerging signal will maintain a noticeable significance with respect to the SM when other searches are considered and combined in an approximate global analysis. We attempt to do so in this section.

To begin with, let us notice that many of the kinematical bins constructed by the experimental collaborations show either downward- or upward fluctuations in the number of the observed events. It means that the SM (which corresponds to the background-only hypothesis) does not need to present the best fit to the observed data. To quantify to what extent the fit improves (or worsens) if a putative SUSY signal is assumed, we proceed as follows. For each search we construct a test statistics as in Eq. (2), where again $\Delta\chi_i^2$ are defined as $-2\log(\mathcal{L}_i/\mathcal{L}_0)$. In every bin i the numerator, $\mathcal{L}_i$, will either assume the value corresponding to a benchmark SUSY signal, s_i, or to the SM background, $s_i = 0$. The denominator, $\mathcal{L}_0$, will be instead given by the maximum likelihood value, obtained when $s_i \approx o_i - b_i$. Note that this approach may seem to differ from the one employed in the previous sections to fit the 1-lepton signal and to derive the exclusion bounds from the other ATLAS searches, where we always normalized the likelihood function to the background-only hypothesis. We do so for two reasons. First, we would like to have only positive test statistics. Second, it allows us

Table 3 Breakdown of the χ^2 contributions due to different searches for the background-only hypothesis (SM) and the benchmark points

Benchmark	SM	BP1	BP2	BP3	BP4	BP5	BP6
ATLAS 1-lepton	11.6	0.6	1.4	2.2	1.3	1.0	0.6
CMS 1-lepton	9.8	11.3	11.0	10.0	11.1	8.8	10.2
1-Lepton χ^2	21.4	11.9	12.4	12.2	12.4	9.8	10.8
1-Lepton σ	–	3.1	3.0	3.0	3.0	3.4	3.3
0 Leptons + (b-)jets [28]	4.6	1.7	4.2	1.9	1.4	4.1	5.6
1 Lepton + jets [25]	1.4	3.2	5.6	3.0	2.1	4.0	5.3
0 Leptons + 2–6 jets [23]	3.5	3.2	3.2	4.4	2.6	7.1	5.7
≥3 b-tagged jets [27]	5.0	3.1	6.7	2.9	2.4	5.0	4.4
2 b-tagged jets [31]	2.2	2.3	2.4	2.4	2.5	2.4	2.5
Total $\chi^2_{\rm add}$	38.1	25.4	34.5	26.8	23.4	32.4	34.3
1-Lepton $\sigma_{\rm add}$	–	3.6	1.9	3.4	3.8	2.4	1.9
Total $\chi^2_{\rm max}$	21.4	11.9	12.4	12.2	12.4	9.8	10.8
1-Lepton $\sigma_{\rm max}$	–	3.1	3.0	3.0	3.0	3.4	3.3

to quantify how far the SM predictions are from the data. One should also keep in mind that changes in the normalization factor result only in a shift of the χ^2 value, which affect in equal ways the signal and background-only hypotheses.

When combining the test statistics for individual bins, we always follow the experimental prescription. Thus, if for a given search the experimental collaboration explicitly states that the presented bins are independent, our test statistics will be the sum of the $\Delta\chi^2_i$; if, on the contrary, the experimental collaboration presents bins that are not independent, we construct the test statistics as is done in the experimental paper to derive the exclusion bounds. Depending on the search, this is given by Eq. (2) or some modifications of it. The quantity of relevance to assess the goodness of fit will be the relative difference between the global test statistics of the SM and that of the benchmark points.

In Table 3 we show the breakdown of the χ^2 values for the implemented LHC searches for the SM and for the postulated SUSY signals. In this presentation we do not consider the results from the 3.2 fb^{-1} analyses, if a higher luminosity update is available, and we also neglect searches that show a negligible χ^2 contribution. The complete χ^2 breakdown for every bin of every search considered in Table 3 can be found in Appendix B.

As expected, in the ATLAS 1-lepton search there is a large contribution to the SM χ^2 coming from the bin with the largest excess, DM-low. At the same time, the BSM signals fit all bins to good accuracy, as was discussed in Sect. 3.

For the corresponding analysis by CMS, the difference between the SM and the putative signals is not as marked, and it is encouraging to see that the benchmark points are not strongly disfavored with respect to the SM even in the absence of a noticeable excess above the background. Note that contributions to the SM χ^2 in the CMS search originate in some bins from an observed downward fluctuation of the background, in others from slight excesses. On the other hand, χ^2 contributions from the bins with downward fluctuations are smoothed out by large uncertainties in the background determination so that they do not significantly spoil the fit to the benchmark signals significantly. At the same time, the benchmark signals fit the small excesses better than the SM. The overall result is that in the CMS search the goodness of the fit is only slightly worse than in the SM, and for BP5 it is actually better.

To derive the total significance of the ATLAS excess after the CMS data is taken into account we combine both searches by adding the individual χ^2 contributions, as the results of the two collaborations can be safely assumed to be independent. The total significance, calculated from the chi-squared difference with the SM, is for all 6 benchmark points greater than 3σ.

When we add the other ATLAS searches to the global fit, the significance of the BSM signal with respect to the SM predictions can either improve or worsen, depending on the particular benchmark model. For the 0 lepton + b-jets search [28] almost all the models describe the experimental results better than the background-only hypothesis. That is once more due to several small excesses observed in this search that are better fitted by the putative SUSY signals than by the SM background. This could be a hint that the 1-lepton excess is a real phenomenon, but most likely the good fit results from the fact that both searches are optimized for stop production and the background determination is to some degree correlated in one and the other search.

All benchmark models show instead some tension with the 1 lepton + jets analysis [25]. The tension originates from one bin, optimized for squark pair production, in which no excess is observed. Kinematical cuts employed in this bin are very similar to those in the bin DM-low of the ATLAS 1-lepton search, so large signals for our benchmark models are to be expected. The tension is the strongest for the scenarios BP2 and BP6, where it reaches approximately the 2σ level. Note that these are the models that predict the largest signals in the DM-low bin. Additionally, models BP5 and BP6 are disfavored at 1.9 and $1.5\,\sigma$, respectively, by the all hadronic search [23]. That is also to be expected, as both of them present relatively light left-chiral squarks for which this search is optimized.

In the two bottom rows we present the total χ^2 for all the searches listed in Table 3, and the resulting total significance of the ATLAS 1-lepton excess. When combining the results of different analyses, we use two approaches. First, we assume that all ATLAS searches are statistically independent and we simply sum the corresponding χ^2 contributions. We mark the results thus obtained with the subscript "add". As a result, the significance of the 1-lepton excess decreases for BP2, BP5, and BP6.

As we have mentioned above, however, from the outside it is hard to gauge to what extent ATLAS searches, even the ones with different final-state topologies, can be considered independent from one another. The ATLAS Collaboration itself, in their global analysis of 20 searches based on the 8 TeV data [4], decided to employ for overall exclusion limits a so-called "best-of" strategy, which only uses the result of the analysis with the best sensitivity. To mimic the same approach, we also provide here significances based on the maximum χ^2 only, dubbed here as "max". Since we are not able to quantify the correlations between different ATLAS searches, we think it is safe to assume that the real significance lies somewhere in between the "add" and "max" scenarios.

One might wonder if the scenarios described above give rise to specific signatures at the LHC (besides a clear 1-lepton signal) that might help distinguish them from one another. Since all scenarios involve the production of sparticles with color charge, 0-lepton searches with different kinematical variables should produce a complementary, if weaker, signal when the integrated luminosity is increased by a factor $\sim$3 or more with respect to the amount of data presented at ICHEP.

In particular, by taking the 0-lepton ATLAS search [23] as an example, and rescaling there the SM background to $\sim$50 fb^{-1}, our numerical simulation shows bins with clear excesses above the background for BP5, BP6, and possibly BP3, where we have ordered the benchmarks by decreasing significance. With the same luminosity, BP1, BP2, and BP4 would still be indistinguishable from the background in a search like [23].

With $\sim$100 fb^{-1} BP5 and BP6 will probably produce a $>5\,\sigma$ discovery in the 0-lepton search, and significant excesses would appear for BP3 and BP2, in decreasing order of signal strength. Note, however, that even at this high luminosity, BP1 will remain difficult to observe in searches with a hard lepton veto, because of its large branching ratio to the 1-lepton final state, which allows for a clear fitting of our signal in the first place. The reader should also keep in mind that, at least for the data provided at $\sim$13 fb^{-1}, the corresponding CMS analyses have shown better sensitivity in the parameter space characterized by a moderately heavy LSP so that the benchmark points should appear earlier and to greater significance in a search like the CMS α_T.

Finding appropriate UV completions to the scenarios presented above is beyond the purpose of this paper, although it might become a necessary endeavor were the excesses to be confirmed in the next round of data. Models with light stops in general do not fare well with boundary conditions defined at the GUT scale, because the current bound on the gluino mass ($m_{\tilde{g}} \geq$ 1.6–1.8 TeV for the most common SUSY spectra) translates into a large renormalization of the stop mass at the low scale, independently of the initial choice for GUT-scale boundary conditions.

Gauge mediation remains a viable option, as it allows some freedom in the choice of the messenger scale, and in particular models with matter–messenger mixing like the one proposed in, e.g., [38] and several other papers, can easily produce right-chiral stops and binos in agreement with the spectrum of BP1. The remaining benchmark points, however, present more involved and often compressed spectra, which might prove more challenging from the model-building point of view.

5 Summary and conclusions

In this paper we have investigated the possibility that some mild excesses over the SM background that emerged in the bins of the ATLAS 1-lepton + (b-)jets + $E_T^{\rm miss}$ search reported at the ICHEP 2016 conference are due to the first appearance of supersymmetry. Working in the framework of the p19MSSM, we have determined a few different types of SUSY spectra than can explain the observed data and are not excluded by other direct searches for SUSY.

The most straightforward possibility (BP1 in Table 2 and Fig. 1) corresponds to the simplified model spectrum used by the ATLAS Collaboration for the interpretation of the search results, which can fit the putative signal with light right-chiral stops of about 600–800 GeV and a bino-like neutralino LSP with a mass of the order of $\sim$400 GeV. One of the advantages of this scenario, beyond its simplicity, is that it can be relatively easily embedded in known UV completions, for example models of gauge mediation with matter–messenger mixing terms in the superpotential that allow for light right-handed stops.

The signal can also be fitted if charginos of mass in between the stop and the neutralino are present in the spectrum (BP2), where in this case the stop can be slightly lighter than in BP1, as a light chargino has the effect of reducing the branching ratio to the 1-lepton final-state topology. Additional good fits can be achieved when the signal is produced by left-chiral stop/sbottoms, because of the boost in production cross section that arises by including the $\tilde{b}_1 \to t\chi_1^{\pm}$ topology (BP3), and when the right-chiral sbottom is also added to the light spectrum (BP4).

For an LSP of mass significantly above 400–500 GeV the acceptance for the signal produced by relatively light stops and sbottoms drops drastically. More complex spectra, however, involving associated production of light-generation squarks and electroweakinos with a mass of about 1.1 TeV and cascade decays to stops and sbottoms (BP5, BP6) can still produce the right signal even for a ∼700 GeV LSP, because of the increase in production cross section due to the presence of four degenerate "valence" squarks. These light valence squarks are in pole position to be probed by all-hadronic searches in the next round of the LHC data.

For all of the presented benchmark-point scenarios we have compared their global χ^2 with respect to the ATLAS and CMS searches listed in Table 3 with the corresponding χ^2 of the background-only hypothesis. Our computation shows that the signal hypothesis is, at least slightly, favored globally with respect to the SM, and this is true under different choices of test statistics.

On the other hand, we conclude by repeating once again that the analysis presented here is meant to investigate a possibility that might reveal itself as a statistical fluctuation. On the positive side, if the signal is real it will be confirmed with more data and the signatures described in Sect. 3 will be useful to distinguish one or the other scenario.

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Appendix A: Validation of the CMS 1 lepton search

In this appendix we provide the validation of our numerical simulation of the CMS search for direct top squark pair production in the single-lepton final state [6]. Validation of all other searches used in this paper and listed in Sect. 2 can be found in Appendix A of Ref. [5].

We check the consistency of our statistical analysis with the official bounds provided by CMS by comparing the 95% CL exclusion line, derived by the experimental collaboration in one of the SMS used for their result interpretation, with the line obtained with our code in the same SMS. The technical details of the experimental analysis can be found in [6].

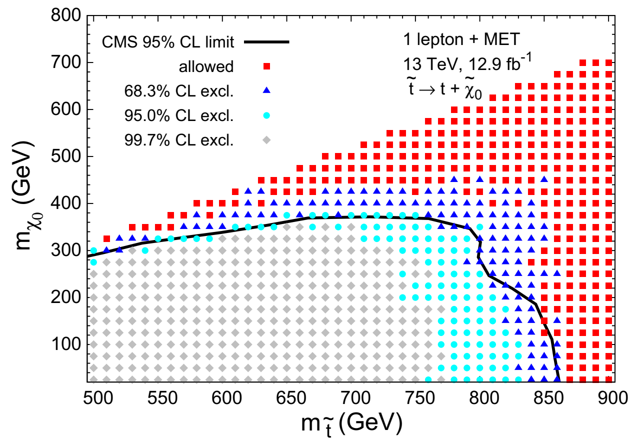

Fig. 2 Our simulation of the CMS 1-lepton search with 12.9 fb^{-1} of data for direct stop production and a decay $\tilde{t}_1 \to t\chi_1^0$. Points that are excluded at the 99.7% CL are shown as *gray diamonds*, at the 95.0% CL as *cyan circles*, and at the 68.3% CL as *blue triangles*. The points shown as *red squares* are considered as allowed. The *solid black line* shows the published 95% CL contour by CMS

The SMS analyzed here consists of a stop decaying into top quark and neutralino LSP. The experimental signature includes one lepton, jets and large amount of missing energy. The analysis is performed with the following pre-selection cuts:

- exactly one signal lepton with $p_T > 20$ GeV and $|\eta| < 2.4(1.44)$ for muons (electrons),
- at least 2 signal jets with $p_T > 30$ GeV and $|\eta| < 2.4$,
- at least 1 signal b-jet,
- missing energy $E_T^{\rm miss} > 250$ GeV.

The kinematical variables used to discriminate between the signal and the background are: azimuthal angle $\Delta\phi(E_T^{\rm miss}, \text{jet})$ between two leading jets and missing energy; the transverse mass m_T of the signal lepton and missing transverse momentum; the magnitude of the negative vectorial sum of the transverse momentum of jets with $p_T > 20$ in the event, $H_T^{\rm miss}$, and the variable $M_{\rm T2}^{\rm W}$ defined in [39]. To implement the latter in the recast tool, we used the C++ code provided in [39]. Fifteen exclusive signal regions are defined with various jet multiplicities and binned in $E_T^{\rm miss}$ and $M_{\rm T2}^{\rm W}$.

We present in Fig. 2 the validation of our simulation in terms of the exclusion limits in the parameter space $(m_{\tilde{t}_1}, m_{\chi_1^0})$ for the direct stop production scenario and a subsequent decay into top quark and neutralino LSP. Gray diamonds represent the points excluded by our likelihood function at the 99.7% CL, cyan circles are excluded at the 95.0% CL, and blue triangles are excluded at the 68.3% CL. The solid black line shows the 95% CL CMS exclusion limit, which we overlap for comparison.

Appendix B: Summary of all $\Delta\chi^2$ contributions

In Tables 4, 5, 6, 7, 8, 9, 10 we present the complete χ^2 breakdown for every bin of every search considered in Table 3. The s_i column shows the number of signal events simulated according to the procedure of Sect. 2. The total $\Delta\chi^2$ for each search is calculated following the prescription given in the experimental paper and summarized in the corresponding caption.

Table 4 Breakdown of the χ^2 contributions due to different signal bins of the CMS 1-lepton search [6] for the background-only hypothesis (SM) and the benchmark points. The total $\Delta\chi^2$ is given by the sum of each individual contribution. The collaboration has not labeled the bins by name. Nevertheless, we do provide an indicative label in column 1, based on the number of jets and the E_T^{miss} cut adopted

Bin	Obs.	Bkg.	SM	BP1		BP2		BP3		BP4		BP5		BP6	
			$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$
2j-250	72	58.6 ± 6.0	1.9	0.6	1.7	0.9	1.6	1.5	1.5	0.8	1.6	0.4	1.7	0.2	1.8
2j-350	7	12.2 ± 1.9	1.8	0.3	2.0	0.1	1.9	0.2	2.0	0.4	2.1	0.1	1.9	0	1.8
2j-450	5	3.7 ± 0.8	0.4	0.1	0.4	0.1	0.4	0	0.4	0.1	0.4	0	0.4	0.1	0.4
3j-250	35	38.0 ± 4.6	0.1	1.5	0.3	2.0	0.4	1.1	0.2	0.1	0.1	0.5	0.2	0.3	0.1
3j-350	9	10.4 ± 1.6	0.1	0.5	0.2	0.8	0.3	0.2	0.2	0.7	0.3	0.3	0.2	0.3	0.2
3j-450	6	5.3 ± 1.1	0.1	0.1	0.1	0.4	0	0.1	0.1	0	0.1	0	0.1	0	0.1
3j-550	3	3.0 ± 0.7	0	0	0	0	0	0.1	0	0	0	0.1	0	0.3	0
4j-250-low	121	141 ± 15	1.1	2.0	1.3	1.8	1.3	2.9	1.4	2.2	1.3	1.5	1.2	1.5	1.2
4j-350-low	22	26.6 ± 4.0	0.4	0.9	0.6	0.5	0.6	0.8	0.6	0.7	0.6	0.7	0.6	0.4	0.5
4j-450-low	9	6.6 ± 1.6	0.7	0.2	0.6	0	0.7	0.4	0.5	0.4	0.5	0.7	0.4	0.3	0.5
4j-250-high	44	43.3 ± 6.2	0	5.1	0.2	5.6	0.2	4.4	0.1	5.1	0.2	2.3	0	4.8	0.2
4j-350-high	11	14.2 ± 2.5	0.4	3.2	1.8	3.2	1.8	1.5	1.0	3.3	1.9	1.9	1.2	3.7	2.1
4j-450-high	5	4.8 ± 1.3	0	1.3	0.1	1.1	0.1	0.7	0	1.5	0.2	1.0	0	1.1	0.1
4j-550-high	1	1.7 ± 0.6	0.1	0.6	0.5	0.4	0.4	0.5	0.5	0.5	0.5	0.1	0.1	0.3	0.3
4j-650-high	3	0.92 ± 0.33	2.7	0.4	1.5	0.5	1.3	0.4	1.5	0.5	1.3	0.8	0.8	0.7	0.9
Total $\Delta\chi^2$			9.8		11.3		11.0		10.0		11.1		8.8		10.2

Table 5 Breakdown of the χ^2 contributions due to different signal bins of the ATLAS 1-lepton search [2] for the background-only hypothesis (SM) and the benchmark points. The total $\Delta\chi^2$ is given by the maximum of the individual contributions. The bins are labeled according to their ATLAS name

Bin	Obs.	Bkg.	SM	BP1		BP2		BP3		BP4		BP5		BP6	
			$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$
SR1	37	24 ± 3	4.5	11.4	0.1	9.8	0.3	8.3	0.6	8.6	0.5	9.9	0.2	10.9	0.1
tN_high	5	3.8 ± 0.8	0.4	3.2	0.5	4.5	1.4	2.4	0.2	3.0	0.4	4.0	1.0	3.3	0.6
bC2x_diag	37	22 ± 3	6.1	11.1	0.4	12.1	0.2	9.7	0.7	7.8	1.3	9.0	0.9	11.7	0.3
bC2x_med	14	13 ± 2	0.1	2.7	0.1	4.0	0.4	2.4	0.1	2.3	0.1	1.7	0	4.0	0.4
bCbv	7	7.4 ± 1.8	0	1.0	0.1	0.6	0	0.6	0	0.9	0.1	1.6	0.3	1.6	0.3
DM_low	35	17 ± 2	11.6	13.6	0.6	14.4	0.4	9.4	2.2	11.9	1.1	12.5	0.9	13.9	0.5
DM_high	21	15 ± 2	1.8	6.1	0	7.4	0.1	4.4	0.1	5.4	0	6.0	0	6.7	0
Total $\Delta\chi^2$			11.6		0.6		1.4		2.2		1.3		1.0		0.6

Table 6 Breakdown of the χ^2 contributions due to different signal bins of the ATLAS 0 leptons + 2–6 jets search [23] for the background-only hypothesis (SM) and the benchmark points. The total $\Delta\chi^2$ is given by the maximum of the individual contributions. The bins are labeled according to their ATLAS name

Bin	Obs.	Bkg.	SM	BP1		BP2		BP3		BP4		BP5		BP6	
			$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$
Meff_2j_0800	650	610 ± 50	0.5	5.7	0.4	8.4	0.3	6.7	0.4	8.4	0.3	17.1	0.2	20.0	0.1
Meff_2j_1200	270	297 ± 29	0.6	5.3	0.9	5.9	0.9	7.7	1.0	4.7	0.9	16.3	1.6	15.1	1.5
Meff_2j_1600	96	121 ± 13	2.2	3.9	2.9	4.5	3.1	6.5	3.5	2.0	2.6	13.7	5.3	10.9	4.5
Meff_2j_2000	29	42 ± 6	2.2	2.6	3.2	2.6	3.2	5.2	4.4	1.1	2.6	10.3	7.1	7.8	5.7
Meff_3j_1200	363	355 ± 33	0.1	7.7	0	11.2	0	17.1	0	7.8	0	42.9	0.8	31.5	0.4
Meff_4j_1000	97	84 ± 7	1.3	4.1	0.6	5.5	0.4	3.4	0.7	4.6	0.5	7.3	0.3	13.6	0
Meff_4j_1400	71	66 ± 8	0.2	6.0	0	7.4	0	5.1	0	6.2	0	8.8	0.1	15.9	0.8
Meff_4j_1800	37	27.0 ± 3.2	2.5	3	1.2	5.3	0.5	4.3	0.8	3.0	1.2	6.8	0.3	9.3	0
Meff_4j_2200	10	4.8 ± 1.1	3.5	0.9	2.3	2.0	1.2	1.4	1.7	0.9	2.3	1.5	1.6	2.6	0.8
Meff_4j_2600	3	2.7 ± 0.6	0.1	0.7	0	1.9	0.5	0.8	0	0.4	0	1.0	0.1	1.6	0.4
Meff_5j_1400	64	68 ± 9	0.1	4.7	0.4	5.4	0.5	5.9	0.6	3.6	0.3	14.7	2.2	12.1	1.6
Meff_6j_1800	10	5.5 ± 1.0	2.6	2.3	0.6	3.7	0.1	2.5	0.5	2.0	0.7	5.3	0	6.1	0.2
Meff_6j_2200	1	0.82 ± 0.35	0.1	0.2	0	0.7	0.1	0.4	0	0.2	0	0.6	0.1	0.8	0.2
Total $\Delta\chi^2$			3.5		3.2		3.2		4.4		2.6		7.1		5.7

Table 7 Breakdown of the χ^2 contributions due to different signal bins of the ATLAS 0 leptons + (b-)jets search [28] for the background-only hypothesis (SM) and the benchmark points. Bins 1, 2, and 3 are orthogonal to each other, and so are bins 4, 5, and 6. The total $\Delta\chi^2$ is given by $\max\{\sum_{i=1}^{3}\Delta\chi_i^2, \sum_{i=4}^{6}\Delta\chi_i^2, \Delta\chi_7^2, \Delta\chi_8^2, \Delta\chi_9^2, \Delta\chi_{10}^2, \Delta\chi_{11}^2\}$. The bins are labeled according to their ATLAS name

Bin	Obs.	Bkg.	SM	BP1		BP2		BP3		BP4		BP5		BP6	
			$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$
SRA-TT	8	5.2 ± 1.4	1.1	4.0	0.1	9.4	3.1	3.4	0	5.6	0.6	8.5	2.4	9.9	3.5
SRA-TW	5	5.7 ± 1.6	0	1.9	0.6	2.7	1.1	1.7	0.5	2.0	0.7	3.6	1.7	3.9	1.9
SRA-T0	16	11.3 ± 2.6	1.2	2.2	0.4	4.4	0	2.5	0.3	3.9	0.1	4.5	0	7.2	0.2
SRB-TT	17	10.6 ± 2.3	2.3	4.4	0.2	8.5	0.1	3.3	0.5	6.2	0	3.9	0.4	10.4	0.6
SRB-TW	18	16.7 ± 3.6	0.1	3.6	0.1	4.8	0.3	2.5	0	4.0	0.2	3.5	0.1	5.7	0.5
SRB-T0	84	60 ± 14	2.2	5.3	1.4	7.6	1.1	4.8	1.4	9.3	0.9	3.8	1.6	10.1	0.8
SRC-low	36	23.9 ± 7.5	1.8	0.7	1.6	1.9	1.3	0.7	1.6	1.4	1.4	0.3	1.7	1.5	1.4
SRC-med	14	9.4 ± 3.5	1.0	0.3	0.9	1.3	0.6	0.3	0.9	0.7	0.8	0	1.0	0.8	0.7
SRC-high	9	10.5 ± 3.7	0	0.5	0.1	1.2	0.2	0.1	0	1.1	0.2	0.2	0.1	1.1	0.2
SRE	9	7.1 ± 1.8	0.4	3.4	0.1	5.9	1.0	3.2	0.1	4.4	0.4	3.7	0.2	5.4	0.8
SRF	3	2.8 ± 1.0	0.1	2.0	0.5	3.6	1.8	1.8	0.4	2.0	0.5	5.4	3.7	5.2	3.5
Total $\Delta\chi^2$			4.6		1.7		4.2		1.9		1.4		4.1		5.6

Table 8 Breakdown of the χ^2 contributions due to different signal bins of the ATLAS 3 b-tagged jets search [27] for the background-only hypothesis (SM) and the benchmark points. For the first two bins the largest $\Delta\chi_i^2$ is chosen. The chi-squared of bins 3 and 4 are instead confronted in a pairwise manner with the chi-squared of bins 5, 6, and 7, and the combination with the largest contribution is selected. The total $\Delta\chi^2$ is given by the sum of the two partial chi-squared. The bins are labeled according to their ATLAS name

Bin	Obs.	Bkg.	SM	BP1		BP2		BP3		BP4		BP5		BP6	
			$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$
SR-Gbb-A	2	1.6 ± 0.7	0.2	0.3	0	3.9	2.6	0.4	0	0.6	0	0.9	0	1.3	0.2
SR-Gbb-B	15	21 ± 5	0.5	2.0	1.1	4.0	1.9	0.3	0.6	1.6	1.0	3.6	1.7	4.2	2.0
SR-Gtt-0L-A	1	0.94 ± 0.31	0	0.6	0.2	3.3	3.4	0.7	0.2	0.9	0.4	2.4	2.1	2.1	1.7
SR-Gtt-0L-B	11	5.0 ± 1.5	3.9	2.3	1.4	4.6	0.2	1.8	1.8	2.9	0.9	5.6	0	5.2	0.1
SR-Gtt-1L-A	1	1.0 ± 0.6	0.2	0	0.2	1.4	0.7	0	0.2	0.1	0.1	0.4	0	0.2	0
SR-Gtt-1L-B	2	1.1 ± 0.4	0.6	0.2	0.4	1.2	0	0.1	0.5	0.1	0.5	0.5	0.1	0.2	0.4
SR-Gtt-1L-C	4	7.0 ± 2.8	0.4	0.4	0.6	0.4	0.6	0.1	0.4	0.3	0.5	1.6	1.2	0.6	0.7
Total $\Delta\chi^2$			5.0		3.1		6.7		2.9		2.4		5.0		4.4

Table 9 Breakdown of the χ^2 contributions due to different signal bins of the ATLAS 1 lepton + jets search [25] for the background-only hypothesis (SM) and the benchmark points. The total $\Delta\chi^2$ is given by the maximum of the individual contributions. The bins are labeled according to their ATLAS name

Bin	Obs.	Bkg.	SM	BP1		BP2		BP3		BP4		BP5		BP6	
			$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$
GG 2J	47	46 ± 7	0	1.2	0	3.0	0	2.9	0	1.6	0	2.3	0	1.8	0
GG 6J bulk	32	24 ± 5	1.3	6.0	0.1	5.7	0.1	4.3	0.3	4.6	0.3	6.6	0.1	6.9	0
GG 6J high-mass	3	3.8 ± 1.2	0	1.0	0.4	3.2	2.2	1.4	0.7	1.1	0.5	2.4	1.4	1.9	1.0
GG 4J low-x	4	6.0 ± 1.6	0.4	0.9	0.8	4.2	3.7	1.9	1.5	1.5	1.2	1.9	1.5	1.8	1.5
GG 4J low-x b-veto	2	3.3 ± 1.2	0.2	0.1	0.3	0	0.2	0.1	0.3	0.1	0.3	0.4	0.5	0	0.2
GG 4J high-x	2	3.4 ± 0.9	0.4	0.5	0.7	0.4	0.7	0.4	0.7	0.3	0.6	1.0	1.2	0.9	1.1
SS 4J x=1/2	6	5.4 ± 1.7	0.1	7.1	3.2	9.5	5.6	6.8	3.0	5.8	2.1	7.9	4.0	9.2	5.3
SS 5J x=1/2	8	13.2 ± 2.5	1.4	0.6	1.8	0.4	1.6	0.5	1.7	0.3	1.6	0.9	1.9	0.7	1.8
SS 4J low-x	8	11.1 ± 2.7	0.4	1.3	0.9	3.2	1.9	2.8	1.7	1.9	1.2	1.5	1.0	4.5	2.8
SS 5J high-x	7	4.6 ± 1.4	0.9	2.4	0	3.4	0.1	1.1	0.3	2.5	0	2.1	0	2.1	0
Total $\Delta\chi^2$			1.4		3.2		5.6		3.0		2.1		4.0		5.3

Table 10 Breakdown of the χ^2 contributions due to different signal bins of the ATLAS 2 b-tagged jets search [31] for the background-only hypothesis (SM) and the benchmark points. The total $\Delta\chi^2$ is given by the maximum of the individual contributions. The bins are labeled according to their ATLAS name

Bin	Obs.	Bkg.	SM	BP1		BP2		BP3		BP4		BP5		BP6	
			$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$	s_i	$\Delta\chi_i^2$
SRA250	23	29 ± 5	0.6	0.8	0.8	1.8	1.1	1.0	0.8	3.0	1.4	0.4	0.7	1.2	0.9
SRA350	6	7.0 ± 1.2	0.1	0.6	0.2	1.1	0.4	0.6	0.2	2.0	0.9	0.3	0.2	0.8	0.3
SRA450	1	1.8 ± 0.4	0.3	0.4	0.7	0.4	0.7	0.2	0.5	1.2	1.6	0.1	0.4	0.4	0.7
SRB	6	12.0 ± 2.5	2.2	0.1	2.3	0.2	2.4	0.2	2.4	0.4	2.5	0.2	2.4	0.4	2.5
Total $\Delta\chi^2$			2.2		2.3		2.4		2.4		2.5		2.4		2.5

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