Multi-lepton SUSY searches with the ATLAS detector

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Abstract. We investigate the potential of the ATLAS detector to discover new physics events containing three leptons (e or μ). In the context of supersymmetric models, they could result from the direct production of gaugino pairs or from gauginos in decay chains accompanied by jets. In scenarios with heavy sfermions, direct gaugino production could be a discovery channel. Such searches are complementary to more standard strategies which rely more on jets.

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INTRODUCTION

Supersymmetry (SUSY) may be realized in a number of ways. In this study we use the minimal supergravity, mSUGRA, with conserved R-parity as an example signature. It is described by four parameters m_0,$m_{1/2}$,A_0, $\tan\beta$ and a sign.

In multi-lepton SUSY searches we are looking for final states with three or more leptons. If squarks and gluinos are light, then the gauginos are predominantly produced in their decay chains. Such events are characterized by a number of hard jets and large missing transverse energy ($\not{E}_{\mathrm{T}}$). In a non-typical benchmark point where squarks, sleptons and possibly also gluinos are heavy, direct gaugino production becomes important. In a scenario where sfermions and possibly also gluinos are beyond the LHC energy reach, direct gaugino production could be the discovery channel. Such events have typically low jet activity and relatively low $\not{E}_{\mathrm{T}}$ as the gauginos are mostly produced back to back.

Aiming at studying direct gaugino production, the so called Focus Point region is particularly interesting. The large m_0 pushes the $\tilde{q}$ and $\tilde{l}$ masses well above 1 TeV. Gauginos, on the other hand, are light and pair production of them dominates the SUSY cross section. The trilepton signal comes mainly from pairs of lightest chargino $\tilde{\chi}_1^{\pm}$ and second lightest neutralino $\tilde{\chi}_2^0$.

Table 1 lists the mSUGRA parameters of the studied ATLAS benchmark points. All Monte Carlo (MC) simulations used in this study were done with 14 TeV of center of mass energy.

The trilepton requirement gives a strong Standard Model (SM) background suppression. The following backgrounds were included in this study: $t\bar{t}$ and Zb with an additional lepton from semileptonic b-decay and SM diboson production, WZ, ZZ, WW, and Zγ with additional leptons from photon conversion. The cross sections may be found in [1].

TABLE 1. The mSUGRA parameters of the studied ATLAS benchmark points, labeled SUX. All cross sections are evaluated at leading order and at 14 TeV center of mass energy.

Point	m_0	$m_{1/2}$	A_0	$\tan\beta$	signμ	σ **[pb]**	k**-factor**	**Characteristics**
SU2	3550	300	0	10	$+$	4.86	1.48	Focus point region
SU1	70	350	0	10	$+$	7.43	1.46	Coanihilation region
SU3	100	300	-300	6	$+$	18.56	1.49	Bulk region
SU4	200	160	-400	10	$+$	262.00	1.54	Low mass point
SU8	210	360	0	40	$+$	6.44	1.35	Funnel region

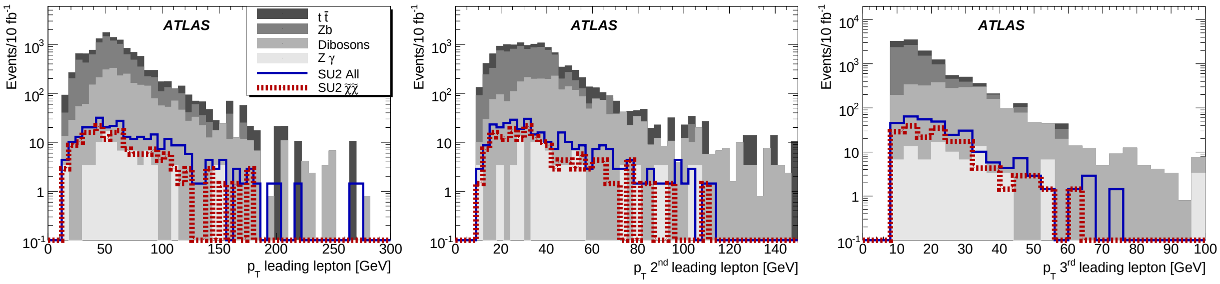

FIGURE 1. p_T distributions of the three leading leptons after requiring $N_l \geq 3$.

DIRECT GAUGINO PRODUCTION

Trilepton searches require an efficient selection of high quality leptons and at the same time powerful rejection of leptons from jets and leptonic b-quark decays. Electrons, muons and jets are required to have $p_T > 10$ GeV and be within the η-region $|\eta| < 2.5$. The lepton isolation cut requires less than 10 GeV of transverse energy deposited in the calorimeter in a cone with $\Delta R = 0.2$ around the track ($\Delta R \equiv \sqrt{\Delta\eta^2 + \Delta\phi^2}$). In addition, a lepton which overlaps with a jet within $\Delta R < 0.4$ is rejected.

Figure 1 shows the p_T distribution of the three leading leptons after the trilepton requirement.The typical low p_T of the third leading lepton in the $t\bar{t}$ and Zb background indicate that these are most probably from semileptonic b-decays.

The event selection optimized for direct gaugino pair production requires at least one pair of opposite sign, same flavour lepton pair (OSSF) (e^+e^- or $\mu^+\mu^-$) with $M_{l^+l^-} > 20$ GeV and in total three or more leptons. An extra isolation cut requires $p_{T\ \mathrm{track,max}}^{\Delta R=0.2} < 2$ GeV for electrons, $p_{T\ \mathrm{track,max}}^{\Delta R=0.2} < 1$ GeV for muons, where $p_{T\ \mathrm{track,max}}^{\Delta R=0.2}(\ell)$ is the maximum p_T of any track in a $\Delta R = 0.2$ cone around the lepton. Figure 2 (left) shows the invariant mass of OSSF pairs, $M_{l^+l^-}$, after these first three cuts. In order to reject backgrounds with a Z, the OSSF pair invariant mass is required to be outside the range $81.2\ \mathrm{GeV} < M_{\mathrm{OSSF}} < 102.2$ GeV. Figure 2 (center) shows the $\not{E}_T$ distribution after removing the Z-mass window. A minimum cut of 30 GeV is imposed on $\not{E}_T$. Figure 2 (right) shows the p_T of the leading jet after all cuts described so far. Based on this, we introduce the last cut which is optional. It rejects events if they have one or more jets with $p_T > 20$ GeV and is referred to as the *jet veto*.

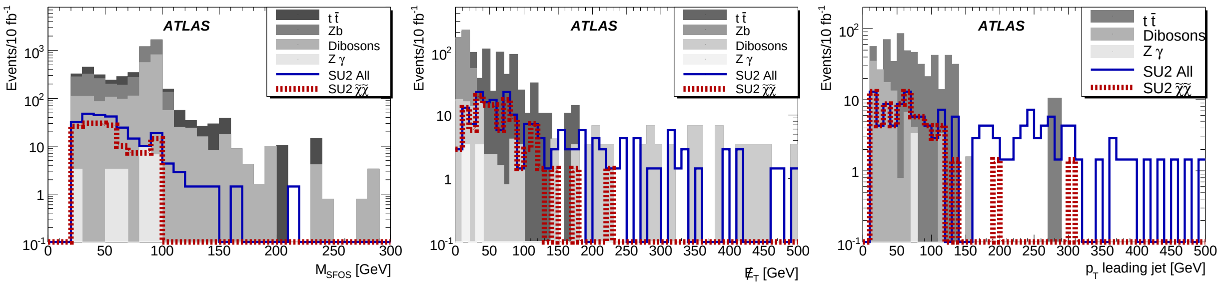

FIGURE 2. Invariant mass of OSSF pairs, $M_{l^+l^-}$, after the three first event selection cuts (left). $\not{E}_T$ distribution after removing the Z-mass window (center).p_T of the leading jet after all event selection cuts $\not{E}_T$(right). The cuts refer to the event selection cuts described in the text.

Applying this event selection, the discovery potential has been studied in terms of signal significance defined as

$$\mathscr{S} = \frac{S}{\sqrt{S+B}}$$

where S is the number of signal events and B is the number of background events. It has been studied for two cases. In the first we apply all cuts except the last jet p_T cut and call it therefore the *jet inclusive* case. The results for all selected SUSY events are labeled by the point name only, while the subset consisting of direct gaugino events is labeled $\chi\chi$. The other is with the jet p_T cut and is called the *jet veto* case. The results are labeled JV.

Table 2 lists the significance for 10 fb^{-1}and the corresponding required luminosity for a 5σ discovery for the Focus point and the Bulk point region. For the jet veto case, the Focus point region sample consists of direct gaugino events only, while in the jet inclusive case approximately 50% of the signal sample consists of such events. In the remaining events the leptons originate from long decay chains starting from a gluino. It is worth noting that the particular ATLAS benchmark point also has a significant gluino pair production cross section. The results for the jet inclusive case for the other benchmark pints are sumarized in Table 3.

TABLE 2. The signal significance and the corresponding required luminosity for a 5σ discovery for the Focus point and the Bulk point region. The results are given for three cases: jet inclusive event selection for all SUSY events (labeled with the point name) and for direct gaugino events ($\chi\chi$), and for the jet veto event selection (JV).

	Focus p.	Focus $\chi\chi$	Focus +JV	Bulk p.	Bulk $\chi\chi$	Bulk +JV
$\mathscr{S}$, 10 fb^{-1}	5.9	3.3	1.9	17	1.6	1.4
$\int dt\mathscr{L}$ for 5σ [fb^{-1}]	7	22	67	0.8	93	119

TABLE 3. Same results as in Table 2 for the jet inclusive case for the remaining benchmark points.

	Low mass	Coan.	Funnel
$\mathscr{S}$, 10 fb^{-1}	69	7.7	1.9
$\int dt\mathscr{L}$ for 5σ [fb^{-1}]	0.1	4.2	71

MULTI-LEPTON SUSY WITH JETS, 1 fb^{-1}

This *3-leptons + jet* analysis aims at multi-lepton production in association with jets. These events have a high cross section and could be observable even with the early data samples. To make the search feasible at an early stage, the strategy is to apply only a few and simple cuts. The results in this study are therefore given for 1 fb^{-1}.

In addition to the trilepton requirement (Cut 1), at least one jet with $p_T > 200$ GeV should be present in the event (Cut 2). Table 4 summarizes the results for the Focus point, Bulk point and the Low mass region. The quantity Z_n is the significance including the background uncertainty of 20% [1]. The effect of the single lepton triggers are included (efficiency $\sim$ 95%).

TABLE 4. Number of surviving events after Cut 1 and 2 for SUSY and SM background. All numbers normalized to 1 fb^{-1}.

Sample	Cut 1	Cut 2	S/B	$S/\sqrt{B}$	Z_n
Focus p.	35	13	1.1	3.7	2.7
Bulk p.	139	94	7.8	27.1	11.5
Low mass	1284	312	26.0	90.0	24.4
SM back.	1375	12	–	–	–

TRIGGER EFFICIENCY AND UNCERTAINTY

The trigger efficiency has been studied at the second level (`L2`) for single isolated lepton triggers, labeled `L2_e22i` and `L2_mu20`. The OR-combination of these two gives a high efficiency ($>$ 92%) as it is highly probable that at least one of the three leptons will have a relatively high p_T.

SUMMARY

In a heavy sfermions scenario, including the jet veto a 5σ discovery may be feasible after 71 fb^{-1}, while the jet inclusive analysis yields a 5σ discovery signal after less than $\sim$ 10 fb^{-1} for all except one studied benchmark point. Including the background uncertainty (20%), only the Low Mass point (SU4) has a 5σ discovery signal after $\sim$ 1 fb^{-1}.

The *3-leptons + jet* analysis with 1 fb^{-1} shows promising results and can be feasible at an early stage. The significance Z_n is above five for the Low Mass and Bulk points (SU4,SU3), even with 100% background uncertainty.

REFERENCES

1. ATLAS Collaboration, “Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics” in *arXiv:0901.0512v3*, CERN-OPEN-2008-020