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Discovery prospects of top squark in the ATLAS Experiment at HL-LHC(*)

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Summary. — Direct production of top squark pairs is one of the processes that are predicted by Supersymmetry (SUSY) at the LHC. One of the channels to search for this process targets the top squark decay in final states with two opposite-charge leptons (electrons or muons), hadronic jets and missing transverse momentum, investigated in previous searches using LHC Run 2 data. This contribution is about the discovery prospects of top squark in this channel with the ATLAS Experiment in the High Luminosity phase of the accelerator (HL-LHC), when the LHC is foreseen to reach a center-of-mass energy of 14 TeV and to collect an integrated luminosity up to 3000 fb^{-1}.

1. – Minimal Supersymmetric Standard Model (MSSM)

Supersymmetry (SUSY) is among the most important theories for Physics beyond the Standard Model (SM) widely searched for by the ATLAS Experiment [1] at the LHC. It postulates the existence, for each fermion or boson in the SM, of a superpartner with the same quantum numbers except the spin, which differs by 1/2. In these models, neutralinos ($\tilde{\chi}^0_{i=1\ldots4}$) and charginos ($\tilde{\chi}^{\pm}_{j=1,2}$) are mass eigenstates obtained by linear combination of the supersymmetric partners of the gauge and Higgs bosons, neutral and charged respectively. In order to conserve both lepton number L and baryon number B, a new quantum number is introduced, R-parity, defined as $R = (-1)^{3(B-L)+2S}$. When R-parity is assumed to be conserved, like in the Minimal Supersymmetric Standard Model (MSSM), a stable Lightest Supersymmetric Particle (LSP) is predicted. The lightest neutralino, $\tilde{\chi}^0_1$ is a possible LSP and Dark Matter candidate.

2. – Analysis aim

The present study aims to understand the discovery sensitivity of the lightest mass eigenstate of the top squark ($\tilde{t}_1$) decaying in 2, 3 and 4 bodies with 2 charged leptons (ee, $\mu\mu$, $e\mu$) in the final states in the ATLAS Experiment, by optimising the selections defined in a published analysis [2] on Run 2 data, which produced an exclusion contour

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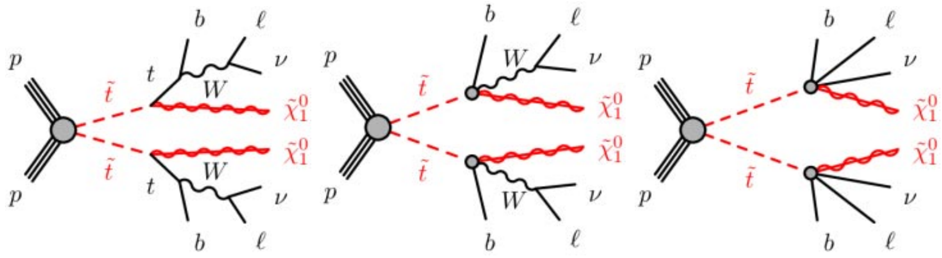

Fig. 1. – Diagrams of the three supersymmetrical decay models considered in [2], with two opposite charge leptons, jets and missing transverse energy in the final state. From left to right: the 2-bodies decay, the 3-bodies decay and the 4-bodies decay.

at 95% Confidence Level (CL) by applying selections targeting each decay. The decays, represented in fig. 1, are related to the difference in mass between $\tilde{t}_1$ and $\tilde{\chi}_1^0$ as follows:

$$\Delta m(\tilde{t}_1, \tilde{\chi}_1^0) > m(t) \quad \Rightarrow \quad \tilde{t}_1 \to t\tilde{\chi}_1^0 \quad \text{(2-bodies)} \tag{1a}$$

$$m(b) + m(W) < \Delta m(\tilde{t}_1, \tilde{\chi}_1^0) < m(t) \quad \Rightarrow \quad \tilde{t}_1 \to bW\tilde{\chi}_1^0 \quad \text{(3-bodies)} \tag{1b}$$

$$\Delta m(\tilde{t}_1, \tilde{\chi}_1^0) < m(b) + m(W) \quad \Rightarrow \quad \tilde{t}_1 \to bff'\tilde{\chi}_1^0 \quad \text{(4-bodies)} \tag{1c}$$

with the two fermions f and f' in $1c$ being, in this case, a lepton (anti-lepton) with its anti-neutrino (neutrino), and both W bosons decaying leptonically in both $1a$ and $1b$.

3. – Analysis strategy

For projection studies at HL-LHC the background contribution estimates are based on the results of the Run 2 analysis [2], where they were determined with a full detector simulation (GEANT4 [3]) and data driven corrections, and scaled to HL-LHC to account for increases in luminosity and cross sections. Signal predictions are based on a fast simulation, performed describing the layout and the response of the ATLAS detector, using the Run 2 layout and applying a set of smearing functions at truth level to final-state particles. The smearing functions have been determined from a full GEANT4 simulation of the ATLAS detector. The signal yields are computed with the cross sections expected at HL-LHC collision energy and for an integrated luminosity of 3000 fb^{-1}. The definitions of the Signal Regions (SRs) used in the published analysis have been optimised to HL conditions, by observing the N-1 distributions in the relevant kinematic variables and comparing the statistical significance of some representative benchmark signals with respect to increasingly tighter thresholds on the applied cuts. Statistical significance was evaluated with the following formula, where n represents the total number of expected signal+background events, b represents the number of expected background events and σ represents the uncertainty on the backgrounds:

$$Z_N = \sqrt{2\left(n \log\left[\frac{n(b+\sigma^2)}{b^2+n\sigma^2}\right] - \frac{b^2}{\sigma^2}\log\left[1+\frac{\sigma^2(n-b)}{b(b+\sigma^2)}\right]\right)}. \tag{2}$$

TABLE I. – *Definition of the 3-bodies Signal Regions from* [2] *and changes introduced in the optimisation targeting HL-LHC*

	$\mathrm{SR}_W^{3-\mathrm{body}}$		$\mathrm{SR}_t^{3-\mathrm{body}}$	
Lepton flavour	DF	SF	DF	SF
$p_T(\ell_1)$ [GeV]	> 25		> 25	
$p_T(\ell_2)$ [GeV]	> 20		> 20	
$m_{\ell\ell}$ [GeV]	> 20		> 20	
$\lvert m_{\ell\ell} - m_Z\rvert$ [GeV]	–	> 20	–	> 20
n_{b-jets}	$= 0$		≥ 1	
$\Delta\phi_\beta^R$ [rad]	> 2.3		> 2.3	
E_T^{miss} significance	$> 12 \to 15$		$> 12 \to 15$	
$1/\gamma_{R+1}$	$> 0.7 \to 0.85$		$> 0.7 \to 0.85$	
R_{p_T}	$> 0.78 \to 0.80$		$> 0.70 \to 0.78$	
M_Δ^R [GeV]	$> 105 \to 115$		$> 120 \to 140$	

4. – Optimization of the search for 2- and 3-bodies decays

The selection for the 3-bodies decay defines two SRs, respectively optimised for signals with $\Delta m(\tilde{t}_1, \tilde{\chi}_1^0) \sim m_W$ e $\Delta m(\tilde{t}_1, \tilde{\chi}_1^0) \sim m_t$, as shown in table I. Different kinematic variables are exploited, whose complete description and derivation can be found in ref. [2].

These selections have also been extended to the 2-bodies decay kinematic region, showing an increase in Z_N significance thanks to the applied optimisation, which can be seen in fig. 2.

5. – 4-bodies decay optimisation status

The selection for the 4-bodies decay defines two SRs, respectively optimised for signals with small or large $\Delta m(\tilde{t}_1, \tilde{\chi}_1^0)$, as shown in table II. Different kinematic variables are exploited, whose complete description and derivation can be found in ref. [2].

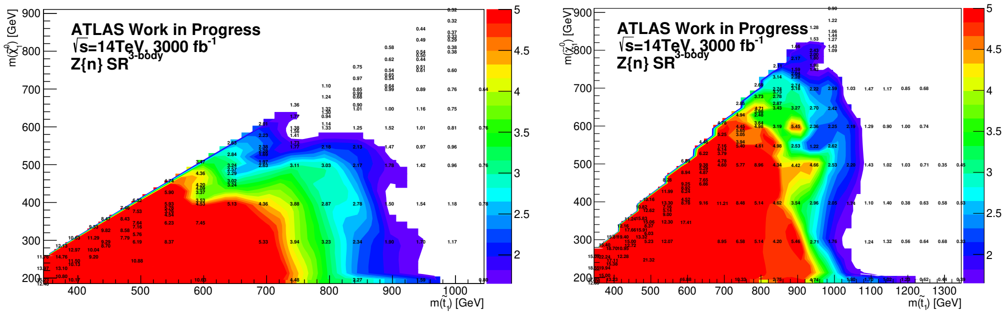

Fig. 2. – Z_N significance plots in HL conditions for the 2- and 3-bodies decay region, where $Z_N = 5$ corresponds to the possible $\tilde{t}_1$ discovery region and $Z_N = 1.65$ to the possible exclusion region at 95% CL: using the definitions of the SRs from [2] (left), using the optimised definition (right).

TABLE II. – *Definition of the 4-bodies Signal Regions from* [2] *and changes introduced in the optimisation targeting HL-LHC*

	$\mathrm{SR}^{4-\mathrm{body}}_{\mathrm{Small}\Delta m}$		$\mathrm{SR}^{4-\mathrm{body}}_{\mathrm{Large}\Delta m}$
$p_T(\ell_1)$ [GeV]	< 25		< 100
$p_T(\ell_2)$ [GeV]	< 10		$[10,\ 50]$
$m_{\ell\ell}$ [GeV]		> 10	
$p_T(j_1)$ [GeV]		> 150	
$\min \Delta R_{\ell_2,j_i}$		> 1	
E_T^{miss} significance	> 10		$> 10 \rightarrow 18$
$p_{T,boost}^{\ell\ell}$ [GeV]		$> 280 \rightarrow 450$	
E_T^{miss} [GeV]		$> 400 \rightarrow 500$	
$R_{2\ell}$	> 25		> 13
$R_{2\ell 4j}$	$> 0.44 \rightarrow 0.45$		$> 0.38 \rightarrow 0.44$

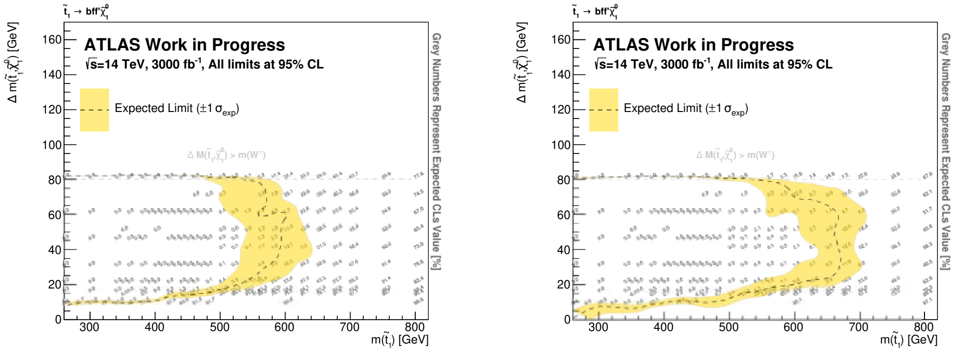

Fig. 3. – Exclusion contours at 95% CL in HL conditions for the 4-bodies decay region: using the definitions of the SRs from [2] (left), using the optimised definition (right).

The optimised definitions of the 4-bodies SRs produce a visible increase in Z_N significance in the interested kinematic region, with an analogous improvement in the expected exclusion contours. The latter is shown in fig. 3.

REFERENCES

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[2] ATLAS Collaboration, *J. High Energy Phys.*, **04** (2021) 165.
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