STUDIES OF A LOW MASS SUSY MODEL AT ATLAS WITH FULL SIMULATION*

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SU4 low mass SUSY model was analysed at ATLAS with full Geant4 simulation. With a production cross section of 270 pb and masses in the range 60–450 GeV, SU4 seems to be a promising target for SUSY searches with early ATLAS data. By establishing proper event selection criteria Standard Model backgrounds can be suppressed to the S/B level of about 3 in the inclusive searches, higher than 4 in the light stop search from the decay $\tilde{g} \to \tilde{t}_1 t$ and above 1 in the right squark search from $\tilde{q}_{\mathrm{R}}\tilde{q}_{\mathrm{R}}$ events.

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1. Introduction

ATLAS is studying with full Geant4 simulation a variety of benchmark SUSY models to optimise search sensitivity and measurement precision. SU4 low mass model has been chosen to be close to the limit of the Tevatron Run II reach. This model is defined in the framework of mSUGRA Supersymetry breaking paradigm where the masses, mixings and decays of all SUSY and Higgs particles are obtained by five parameters: the common scalar mass m_0, the common fermion mass $m_{1/2}$ and the common trilinear coupling A_0 at the grand unification energy scale, together with the ratio $\tan\beta$ between the vacuum expectation values of the two Higgs doublets and the sign of the Higgsino mass parameter μ. Parameters chosen to provide low masses for the SU4 model are:

$$m_0 = 200\,\mathrm{GeV}, \quad m_{1/2} = 160\,\mathrm{GeV}, \quad A_0 = -400\,\mathrm{GeV}, \quad \tan\beta = 10, \quad \mu > 0\,.$$

SU4 phenomenology is described in Section 2. Standard Model backgrounds originate from the $t\bar{t}$, $W+$ jets, $Z+$ jets and multijet processes. ATLAS

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DC2/Rome production datasets obtained by full detector simulation based on Geant4 package were used for SU4 signal and SM backgrounds.

Having high production cross section of 270 pb, inclusive SU4 signal may be observed above the Standard Model background processes at integrated luminosity of only $200\,\mathrm{pb}^{-1}$ (Section 3).

Due to R parity conservation in mSUGRA models every SUSY event has two lightest SUSY particles which are massive and stable but undetectable, thus causing SUSY decay chains to be incomplete and not adequate for mass measurements. Masses of the supersymetric particles may be extracted from the kinematic limits of various variables. This technique was applied on $\tilde{g} \to \tilde{t}_1 t \to \tilde{\chi}_1^{\pm} tb$ decay where the final state tb invariant mass distribution was reconstructed (Section 4) and on $\tilde{q}_\mathrm{R}\tilde{q}_\mathrm{R}$ events where the distribution of Cambridge m_{T2} variable [1] was reconstructed (Section 5).

2. Phenomenology

SU4 Monte Carlo events were produced with Jimmy generator. Production cross section and production rates are listed in Table I.

TABLE I

SU4 production cross section and event rates.

Production cross section is 270 pb					
event	σ (pb)	(%)	event	σ (pb)	(%)
$\tilde{g}\tilde{g}$	56	21	$\tilde{q}_\mathrm{L}\tilde{q}_\mathrm{L}$	13	5
$\tilde{g}\tilde{q}_\mathrm{L}$	53	20	$\tilde{q}_\mathrm{R}\tilde{q}_\mathrm{R}$	11	4
$\tilde{g}\tilde{q}_\mathrm{R}$	58	22	$\tilde{q}_\mathrm{L}\tilde{q}_\mathrm{R}$	11	4
$\tilde{\chi}^0$, $\tilde{\chi}^{\pm}$	14	5	$\tilde{t}_1\tilde{t}_1$	30	11

SU4 masses and decays were obtained by ISASUGRA 7.71 [2] where top mass of 175 GeV was used. All SU4 masses are within the range limited by the mass of the lightest SUSY particle which is the first neutralino $m(\tilde{\chi}_1^0) = 60\,\mathrm{GeV}$ and the mass of the heaviest SUSY particle which is the second stop squark $m(\tilde{t}_2) = 445\,\mathrm{GeV}$. Gluino and left and right squarks have close masses $m(\tilde{q}) \sim m(\tilde{g}) \sim 400\,\mathrm{GeV}$. Consequently, SU4 mass scale is

$$M_\mathrm{SUSY} = \min(m(\tilde{g}), m(\tilde{q})) \sim 400\,\mathrm{GeV}\,.$$

Masses of the squarks and the gauginos used in this analysis are: $m(\tilde{t}_1) = 206\,\mathrm{GeV}$, $m(\tilde{b}_1) = 360\,\mathrm{GeV}$ and $m(\tilde{\chi}_1^{\pm}) = m(\tilde{\chi}_2^0) = 113\,\mathrm{GeV}$.

The gluino is dominantly decaying to the 3rd generation $\tilde{q}q$: $\tilde{g} \to \tilde{b}_1 b$ (BR = 47%), $\tilde{g} \to \tilde{t}_1 t$ (BR = 42%), $\tilde{g} \to \tilde{b}_2 b$ (BR = 4%). Light stop is only 30 GeV heavier than its SM partner and decays to the final states similar to those of top: $\tilde{t}_1 \to \tilde{\chi}_1^{\pm} b$ (BR = 100%). Squarks $\tilde{b}_1$ and $\tilde{b}_2$ decay to $\tilde{t}_1 W$ with the probability of about 50% and the other decay channels have the 3rd generation quarks and gauginos $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ in the final state. Referring to the production rates from Table I, the majority of SU4 events (70%) is characterised by at least two b jets in the final state. The gauginos $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ have the same mass, 30 GeV above the W boson mass and decay with almost identical branching ratios to the equivalent SM gauge bosons. Transverse momenta of b and light q jets in true SU4 events are plotted in Fig. 1.

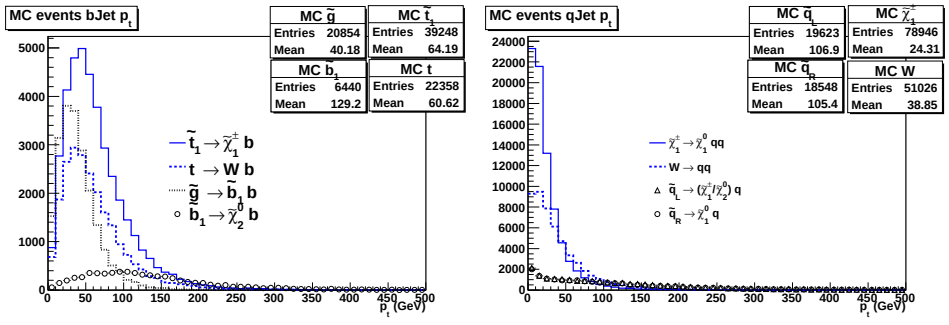

Fig. 1. Transverse momenta of b (left) and light q (right) jets in true SU4 events.

3. Inclusive searches

Inclusive searches are sensitive to gluino decays to 3rd generation squarks which occur in more than 60% of all SU4 events. In order to separate these events from the Standard Model backgrounds, selection cuts were applied on multijet events with missing transverse energy: at least 5 jets in the event

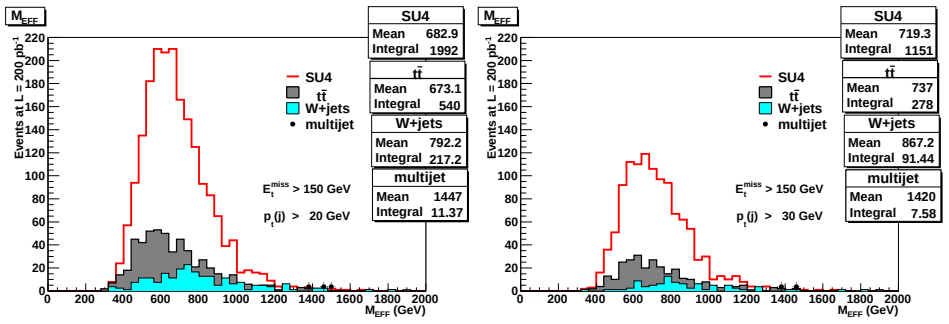

Fig. 2. M_{EFF} of the SU4 signal and SM backgrounds passing selection cuts with $p_{\mathrm{t}}(j) > 20$ GeV (left) and $p_{\mathrm{t}}(j) > 30$ GeV (right); all normalised to $L = 200\,\mathrm{pb}^{-1}$.

where $p_{\rm t}(j1) > 100\,{\rm GeV}$, the other jets have $p_{\rm t}(j) > 20$ (30) GeV and at least 2 jets are tagged as b jets; $E_{\rm t}^{\rm miss} > 150\,{\rm GeV}$ and $E_{\rm t}^{\rm miss}/M_{\rm EFF} > 0.2$. The effective mass of the event was defined as $M_{\rm EFF} = E_{\rm t}^{\rm miss} + \Sigma p_{\rm t}(j)$ where all reconstructed hadronic jets were used (Fig. 2).

Standard Model backgrounds are suppressed to the $\rm S/B_{SM}$ level of 2.82 for $p_{\rm t}(j) > 20\,{\rm GeV}$ and 3.36 for $p_{\rm t}(j) > 30\,{\rm GeV}$.

Mean value of the signal effective mass $\rm M_{EFF} \sim 700\,GeV$ is above the SU4 mass scale (Fig. 2).

4. Light stop search

In order to extract light stop signal in the SU4 low mass model, gluino decay to light stop and top

$$\tilde{g} \to \tilde{t}_1 t \to \tilde{\chi}_1^{\pm} tb\,, \tag{1}$$

was analysed. In the decay (1) the final state tb invariant mass distribution has the upper kinematic endpoint expected at $\sim 300\,{\rm GeV}$ (Fig. 3).

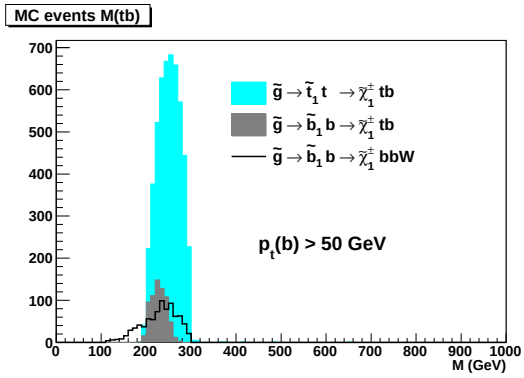

Fig. 3. The final state tb invariant mass distribution in true SU4 events for three kinematically equivalent decays: $\tilde{g} \to \tilde{t}_1 t \to \tilde{\chi}_1^{\pm} tb$ (BR = 42%), $\tilde{g} \to \tilde{b}_1 b \to \tilde{\chi}_1^{\pm} tb$ (BR = 10%) and $\tilde{g} \to \tilde{b}_1 b \to \tilde{\chi}_1^{\pm} bbW$ (BR = 22%) if bW invariant mass is close to the top mass. A 50 GeV cut on b jets transverse momenta was applied to suppress $\tilde{g} \to \tilde{b}_1 b$ final states.

Assuming top quark decay into hadronic final states $t \to Wb \to qqb$, event selection was performed on the set of events used for the inclusive searches. Selection cuts: at least 5 jets in the event where the highest $p_{\rm t}$ jet is a light q jet with $p_{\rm t}(j1) > 100\,{\rm GeV}$; at least 2 light q jets in the event with $p_{\rm t}(j) > 20\,{\rm GeV}$; strictly 2 jets tagged as b jets with $p_{\rm t}(b) > 50\,{\rm GeV}$; $E_{\rm t}^{\rm miss} > 150\,{\rm GeV}$, $M_{\rm EFF} > 400\,{\rm GeV}$ and $E_{\rm t}^{\rm miss}/M_{\rm EFF} > 0.2$.

Reconstructed tb invariant mass distribution is plotted in Fig. 4. Standard Model backgrounds remaining after selection cuts are $t\bar{t}$ and $W+$ jets processes which are suppressed to the S/B_{SM} level of 4.12 without and 2.95 with SUSY background subtraction. SUSY background is higher giving $S/B_{susy} = 1.38$. SUSY background was estimated by the W sideband method [3], [4].

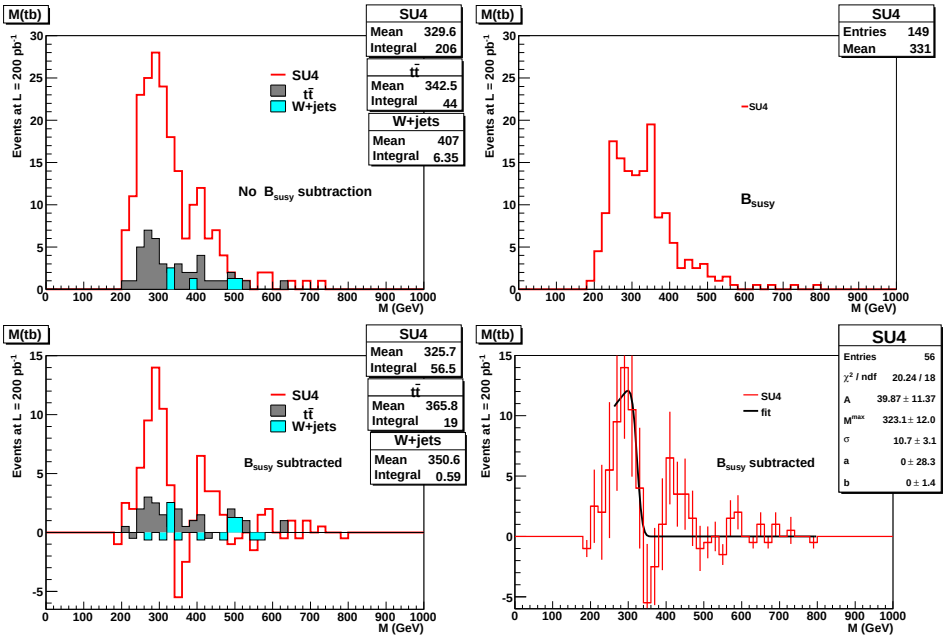

Fig. 4. Reconstructed $M(tb)$ distribution without and with SUSY background subtraction for the SU4 signal and SM backgrounds passing selection cuts (left). SUSY background and the fit of the signal $M(tb)$ distribution after SUSY background had been subtracted (right). The number of events is normalised to $L = 200\,\mathrm{pb}^{-1}$.

After SUSY background had been subtracted the SU4 signal $M(tb)$ distribution (Fig. 4) was fitted to the function:

$$f(M) = A \int_{-1}^{1} e^{-\frac{\left(M - M^{\max}\sqrt{\frac{1+x}{2}}\right)^2}{2\sigma^2}} dx + (a + bM)\,.$$

The kinematic endpoint obtained from the fit is $M^{\max}(tb) = 323 \pm 12\,\mathrm{GeV}$.

5. Right squark search

Right squark pair events represent 4% of SU4 production (Table I). As the decay $\tilde{q}_{\mathrm{R}} \to \tilde{\chi}_1^0 q$ has BR = 98%, $\tilde{q}_{\mathrm{R}}\tilde{q}_{\mathrm{R}}$ events are characterised by two energetic light q jets and the $E_{\mathrm{t}}^{\mathrm{miss}}$ from the two $\tilde{\chi}_1^0$. Cambridge m_{T2} variable is defined for the events with two undetectable decay products [1]. If applied to $\tilde{q}_{\mathrm{R}}\tilde{q}_{\mathrm{R}}$ events it is formed from the two final state light q jets. The distribution of the m_{T2} variable has the upper kinematical endpoint at the position of the mass of the decaying particle which is $\tilde{q}_{\mathrm{R}}$ in this case.

In order to separate right squark pair events from the SM backgrounds event selection was performed on pure hadronic events with $E_{\mathrm{t}}^{\mathrm{miss}}$: no b jets, no e, no μ and no τ leptons; 2 light q jets with $p_{\mathrm{t}}(j) > 100\,\mathrm{GeV}$, $|\eta(j)| < 2$ and the angle between them $\Delta R > 1$; $E_{\mathrm{t}}^{\mathrm{miss}} > 100\,\mathrm{GeV}$ and $E_{\mathrm{t}}^{\mathrm{miss}}/M_{\mathrm{EFF}} > 0.2$. Reconstructed m_{T2} distribution is plotted in Fig. 5. Absolutely dominant remaining SM background process is $W+$ jets which is decreasing S/B ratio to the level 1.08.

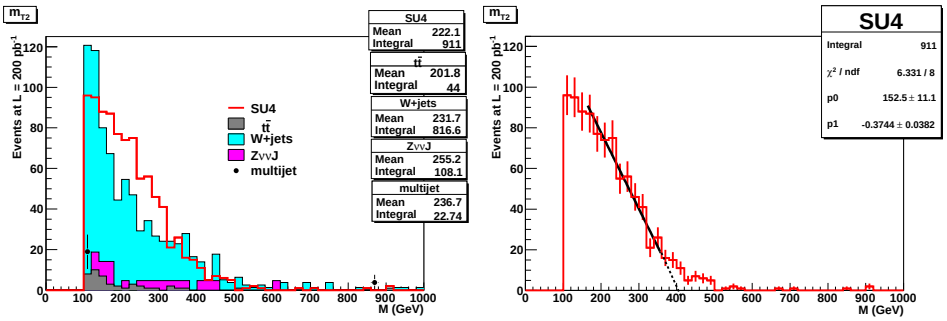

Fig. 5. Reconstructed m_{T2} distribution of the SU4 signal and SM backgrounds passing selection cuts (left) and the linear fit of the signal m_{T2} distribution (right).

The upper kinematic endpoint obtained from the linear fit (Fig. 5) of the SU4 signal m_{T2} distribution is $m_{T2}^{\mathrm{max}} = 407 \pm 11\,\mathrm{GeV}$.

6. Summary and conclusions

SU4 low mass SUSY model was studied at ATLAS with full Geant4 simulation. With a production cross section of 270 pb and masses in the range 60–450 GeV, SU4 is a promising target for SUSY searches with early ATLAS data. SU4 signal could be observed above the Standard Model background with only $200\,\mathrm{pb}^{-1}$ of data.

Inclusive searches are sensitive to gluino decays to 3rd generation squarks which occur in more than 60% of all SU4 events. Standard Model backgrounds originate from the $t\bar{t}$, $W+$ jets, $Z+$ jets and multijet processes.

By establishing proper event selection criteria SM backgrounds can be suppressed to the level S/B > 2.8. Mean value of the effective mass $M_{EFF} \sim 700\,GeV$ is above the SU4 mass scale $M_{SUSY} \sim 400\,GeV$.

In order to extract a light stop signal from the decay $\tilde{g} \to \tilde{t}_1\, t \to tb\tilde{\chi}_1^{\pm}$ the final state tb invariant mass distribution was reconstructed with a kinematic endpoint close to the expected position at 300 GeV. The S/B ratio is 4.12 for SM and 1.38 for SUSY background.

In order to extract a right squark signal from the right squark pair events the distribution of the Cambridge m_{T2} variable was reconstructed with a kinematic endpoint consistent to the SU4 right squark mass value of about 400 GeV. The S/B ratio is 1.08.

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