SUSY Studies with Snowmass Point 5 mSUGRA Parameters

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Achievable precision of SUSY masses and kinematic endpoints measurements at ATLAS detector was estimated for mSUGRA Snowmass Point 5 parameters which give stop quark lighter than for any other mSUGRA point. Characteristic decays of left squark $\tilde{q}_L \to \tilde{\chi}_2^0\, q$, $\tilde{\chi}_2^0 \to \tilde{l}_R\, l$ and gluino $\tilde{g} \to \tilde{t}_1 t$ were analyzed.

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1 Introduction

Within Minimal Supergravity (mSUGRA) Supersymmetry breaking mechanism masses, mixings and decays of all SUSY and Higgs particles are determined in terms of four characteristic parameters and sign: scalar mass m_0, gaugino mass $m_{1/2}$, trilinear coupling A_0, ratio of the Higgs vacuum expectation values $\tan\beta$ and the sign of the supersymmetric Higgs mass parameter μ. Values of the Snowmass Point 5 (SPS 5) mSUGRA parameters [1] are: m_0 = 150 GeV, $m_{1/2}$ = 300 GeV, A_0 = -1000, $\tan\beta = 5$, $\mu > 0$. Huge negative value of A_0 is the main difference between SPS 5 and the other points of mSUGRA parameter space (LHCC [2], SPS [1]).

Main feature of this point is very light stop quark with mass of 236 GeV. Other masses are within the range limited by the mass of the lightest supersymmetric particle (LSP) which is the first neutralino (120 GeV) and the mass of the heaviest SUSY particle which is gluino (720 GeV) in the case of SPS 5. At SPS 5 squark and gluino production are dominant.

Masses and decays of all SUSY particles were obtained by using ISAJET 7.64 program. Top mass of 175 GeV was used. Sample of 12×10^6 SUSY events (σ = 41.13 pb) corresponding to L=300 fb^{-1} was generated with HERWIG 6.5 by using ISAWIG 1.2 as HERWIG - ISAJET interface. For background estimation sample of 8×10^6 $t\bar{t}$ events (σ = 833 pb [3]) was generated corresponding to L=10 fb^{-1}.

Generated events passed through ATLFAST detector simulation package. Jets were reconstructed with jet-cone algorithm with cone $\Delta R = 0.4$. Minimum transverse momenta for electron, mion and jet isolation are 5, 6 and 15 GeV, respectively.

Due to R parity conservation in mSUGRA model every SUSY event has a pair of massive LSPs which are stable and undetectable thus causing SUSY decay chains to be incomplete and not adequate for mass measurements. Masses of supersymmetric particles may be extracted from kinematic endpoints of invariant masses formed from subsets of decay products. This technique was applied on two different sets of cascade decays. First set considers decay of the left squark to second neutralino, where second neutralino decays to right slepton. Second set considers gluino decay to stop and top.

2 Leptonic signatures

At point SPS 5 left squark might be produced either directly or from gluino decay. Corresponding cross sections are: $\sigma(\tilde{q}_L\tilde{g}) = 4.73$ pb^{-1}, $\sigma(\tilde{q}_R\tilde{g}) = 5.06$ pb^{-1}, $\sigma(\tilde{g}\tilde{g}) = 2.38$ pb^{-1}, $\sigma(\tilde{q}_L\tilde{q}_L) = 1.64$ pb^{-1}, $\sigma(\tilde{q}_L\tilde{q}_R) = 2.05$ pb^{-1}. Analyzed left squark decay:

$$\tilde{q}_L \to \tilde{\chi}_2^0\, q \quad (33\%)\ ,$$
$$\tilde{\chi}_2^0 \to \tilde{l}_R\, l \quad (4\%)\ ,$$
$$\tilde{l}_R \to \tilde{\chi}_1^0\, l \quad (100\%)\ ,$$

involves masses: $m(\tilde{q}_L) = 644$ GeV ($\tilde{q}_L = \tilde{u}_L, \tilde{d}_L, \tilde{s}_L, \tilde{c}_L$), $m(\tilde{l}_R) = 191$ GeV ($\tilde{l}_R = \tilde{e}_R, \tilde{\mu}_R$), $m(\tilde{\chi}_2^0) = 226$ GeV, $m(\tilde{\chi}_1^0) = 121$ GeV. The same decay chain was analyzed in references [2], [4], [5], [6] for other points of mSUGRA parameter space.

From the three final state particles l^+, l^-, q invariant masses $M(ll)$, $M(llq)$, $M(lq)$ can be formed. Five kinematic endpoints might be measured: maximum dilepton invariant mass M_{ll}^{max}, maximum and minimum of $M(llq)$ invariant mass M_{llq}^{max} and M_{llq}^{min} where minimum considers events with the angle between leptons $> \pi/2$ (in the slepton rest frame), maximum of lower of the two l^+q, l^-q invariant masses $(M_{lq}^{low})^{max}$ and maximum of higher of the two l^+q, l^-q invariant masses $(M_{lq}^{high})^{max}$. Kinematic endpoints are functions of SUSY masses as given in the equations deduced from the energy and momentum conservation:

$$M_{ll}^{max} = \left[\frac{(M^2_{\tilde{\chi}_2^0} - M^2_{\tilde{l}_R})(M^2_{\tilde{l}_R} - M^2_{\tilde{\chi}_1^0})}{M^2_{\tilde{l}_R}}\right]^{1/2} = 93.4 \text{ GeV}$$

$$M_{llq}^{max} = \left[\frac{(M^2_{\tilde{q}_L} - M^2_{\tilde{\chi}_2^0})(M^2_{\tilde{\chi}_2^0} - M^2_{\tilde{\chi}_1^0})}{M^2_{\tilde{\chi}_2^0}}\right]^{1/2} = 511 \text{ GeV}$$

$$(M_{lq}^{low})^{max} = \left[\frac{(M^2_{\tilde{q}_L} - M^2_{\tilde{\chi}_2^0})(M^2_{\tilde{\chi}_2^0} - M^2_{\tilde{l}_R})}{M^2_{\tilde{\chi}_2^0}}\right]^{1/2} = 320 \text{ GeV}\,.$$

$$(M_{lq}^{high})^{max} = \left[\frac{(M^2_{\tilde{q}_L} - M^2_{\tilde{\chi}_2^0})(M^2_{\tilde{l}_R} - M^2_{\tilde{\chi}_1^0})}{M^2_{\tilde{\chi}_2^0}}\right]^{1/2} = 470 \text{ GeV}\,.$$

$$M_{llq}^{min} = 225 \text{ GeV}.$$

Characteristic signatures of the analyzed decay are two same flavour and opposite sign (SFOS) leptons, large missing transverse energy from undetected first neutralino and two high transverse momenta jets originating from left squark decay and from the decay of the sparticle produced with the left squark. In order to isolate signal and suppress Standard Model (SM) and SUSY background selection cuts were applied: missing transverse energy $E_{Tmissing} > 100$ GeV, two SFOS leptons with transverse momenta $p_T^{lepton} > 10$ GeV and at least four jets with transverse momenta $p_T(j1) > 150$ GeV, $p_T(j2) > 100$ GeV, $p_T(j3, j4) > 50$ GeV. SUSY background from the processes that accidentally have two SFOS leptons originating from two independent decays was suppressed by SFOS - OFOS distribution subtraction, where OFOS regards mass distribution of leptons with opposite flavour and opposite sign.

Dilepton invariant mass distribution was fitted (Figure 1) with Gaussian smeared triangular shape function $f(M) = \int_{-1}^{1} A \cdot \exp\left[-\frac{(M - M_{ll}^{max}\sqrt{\frac{1+x}{2}})^2}{2\sigma^2}\right] dx$, where σ, A and M_{ll}^{max} are fit parameters. Linear fit was applied to all other distributions (Figure 1). Results are presented in Table 1. Fit errors of the endpoints are up to 2%. Systematic errors from the uncertainty on the energy scale is 1% for the measurements involving jets and 0.1% for purely leptonic measurements.

Table 1. Fit results

Endpoint	Theory	Fit	Systematic error	Statistic error
M_{ll}^{max}	93.40	93.85	0.09	0.07
M_{llq}^{max}	511	525	5	11
$(M_{lq}^{high})^{max}$	470	472	5	1
$(M_{lq}^{low})^{max}$	320	326	3	7
M_{llq}^{min}	225	225	2	4

Fit and energy scale errors were both used for $\tilde{q}_L$, $\tilde{l}_R$, $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$ mass reconstruction. Corresponding mass distributions were obtained with the widths of 23 GeV for squarks and 14 GeV for the other sparticles. In that way SUSY masses can be extracted with the precision of 3% for left squark, 6% for second neutralino, 7% for right slepton and 12% for the first neutralino.

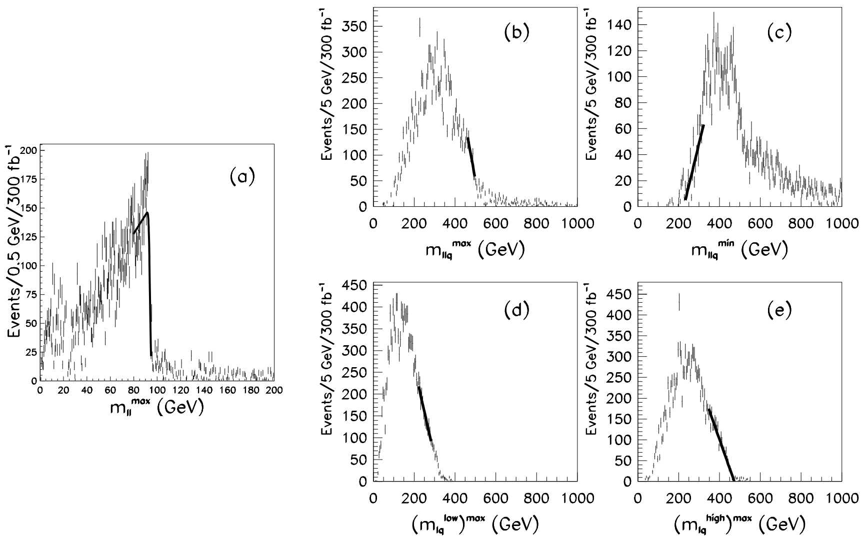

Figure 1. Fitted endpoints of invariant mass distributions: (a) ll maximum, (b) llq maximum, (c) llq minimum, (d) lower lq maximum, (e) higher lq maximum.

3 Stop signature

Stop quarks $\tilde{t}_1$ and $\tilde{t}_2$ are both result of the mixing of the $\tilde{t}_L$ and $\tilde{t}_R$ states. Stop $\tilde{t}_1$ is lighter than the other squarks because of the RGE running effect and its mass is related to the Higgs mass via radiative corrections. In the case of point SPS 5 $\tilde{t}_1$ is lighter than for any other point of mSUGRA parameter space [1], [2].

Stop quark may be produced either directly in $\tilde{t}_1\bar{\tilde{t}}_1$ pairs (50% of all SUSY production) or via gluino decay $\tilde{g} \to \tilde{t}_1\ t$ (40% of all $\tilde{g}$ decays). Stop is always decaying to b quark and the first chargino: $\tilde{t}_1 \to b\,\tilde{\chi}_1^{\pm}$. Due to very low transverse momenta of b quarks originating from $\tilde{t}_1$ decay it seems to be very difficult at the moment to isolate stop pair signal. Gluino decay chain:

$$\tilde{g} \to \tilde{t}_1\ t \to t\ b\ \tilde{\chi}_1^{\pm}\,,$$

with top quark decaying hadronically $t \to b\,W \to bjj$ can give a detectable signal. Relevant SUSY masses are: $m(\tilde{g}) = 719$ GeV, $m(\tilde{t}_1) = 236$ GeV, $m(\tilde{\chi}_1^{\pm}) = 226$ GeV.

Top - bottom invariant mass is at maximum when top and bottom are back-to-back in the rest frame of stop quark. Kinematic endpoint of tb mass distribution is a function of gluino, chargino and stop mass and is given in the equation:

$$(M_{tb}^{max})^2 = m_t^2 + \frac{m_{\tilde{t}_1}^2 - m_{\tilde{\chi}_1^\pm}^2}{2m_{\tilde{t}_1}^2}\{(m_{\tilde{g}}^2 - m_{\tilde{t}_1}^2 - m_t^2) + \sqrt{(m_{\tilde{g}}^2 - (m_{\tilde{t}_1} - m_t)^2)(m_{\tilde{g}}^2 - (m_{\tilde{t}_1} + m_t)^2)}\} = (255)^2 \text{ GeV}^2.$$

Signal selection criteria are based on the event characteristics: two b quarks originating from $\tilde{t}_1$ and t, large missing energy due to $\tilde{\chi}_1^0$ coming from $\tilde{\chi}_1^\pm$ decay, one very high p_T jet from $\tilde{q}_{L,R}$ squark produced with gluino, two not b not τ jets from W decay and no isolated leptons. In order to isolate signal and reduce SM and SUSY background selection cuts were applied: missing transverse energy $E_{Tmissing} > 200 \quad GeV$, two b jets with transverse momenta $30 < p_T(b1) < 150$ GeV and $30 < p_T(b2) < 50$ GeV, number of jets not tagged as b or τ jets > 3 with $p_T(j1) > 300$ GeV, $p_T(j2, j3, ...) > 30$ GeV and rapidity $|\eta| < 3$.

In order to determine top - bottom mass distribution endpoint t quark mass was reconstructed. Excluding the first most energetic jet, all other not b and not τ jets were combined in jj pairs and pairs with the invariant mass within $|m_{jj} - m_W| < 15$ GeV (W zone) were further combined with each of b jets. For bjj combination with mass closest to the top mass energy and momentum of jj pair were scaled so that $m_{jj} = m_W$ and the invariant mass m_{bjj} was recalculated. Combination bjj was regarded as a top candidate if $|m_{bjj} - m_t| < 30$ GeV. Top - bottom invariant mass M_{tb} was calculated if the angle between t and the other b was $\Delta R(tb) < 2$.

SUSY background from a fake W bosons was estimated by using sideband method [5]. Jet pairs with invariant mass within the interval $|m_{jj} - (m_W \pm 30)| < 15$ GeV (A and B zone) were scaled linearly to the W zone $|m_{jj} - m_W| < 15$ GeV and the same procedure for top - bottom reconstruction was repeated. "True" M_{tb} distribution was obtained when mass distributions from A and B zone were subtracted from the mass distribution from W zone, Figure 3. Expected shape of top - bottom invariant mass distribution is presented in Figure 2.

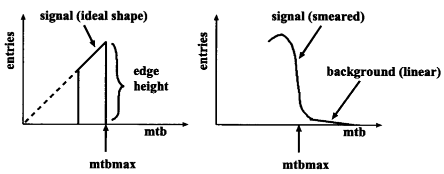

Figure 2. Expected M_{tb} shape: (a) ideal case and (b) real situation.

Mass M_{tb} distribution was fitted with the combination of Gaussian smeared triangular shape and linear function, where linear part applies for the remaining background behind the endpoint. Fit parameters are σ, A and M_{tb}^{max}, a and b:

$$f(M) = \int_{-1}^{1} A \cdot \exp\left[-\frac{(M - M_{tb}^{max}\sqrt{\frac{1+x}{2}})^2}{2\sigma^2}\right] dx \; + \; a \; + \; b \cdot M \; .$$

For the endpoint fit gives $(M_{tb}^{max})^{fit} = 260.0 \pm 0.5\,(stat) \pm 2.6\,(sys)$ GeV which is consistent with the calculated value of 255 GeV. Combining this endpoint with gluino and chargino masses obtained from the other measurements, stop mass can be directly extracted from the fit result.

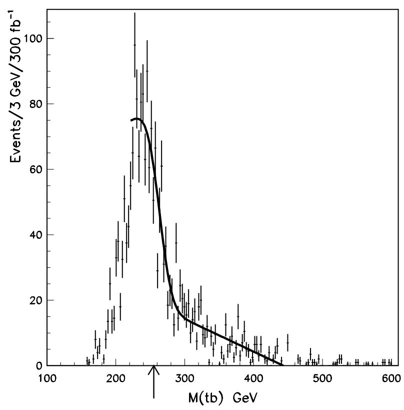

Figure 3. Fitted M_{tb} mass distribution. Arrow indicates calculated endpoint position.

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