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Prospectives for stop searches at ATLAS and CMS

F. Blekman, M. Milosavljevic

Abstract

The search for supersymmetric partners of the top quark, stop squark, could result in the early discovery of physics beyond the Standard Model at the LHC. We present here the searches for stop squark within the mSUGRA model at ATLAS and CMS detectors. Results of simulation studies are presented. Search for the light stop squark in the low mass SUSY model, originating from the gluino decay, using the final state tb invariant mass at ATLAS is described. Inclusive stop search in the intermediate scenario, using the events with top candidate, leptons and missing energy at CMS is also presented. The discovery prospects in both studies are focused at early data.

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Prospectives for stop searches at ATLAS and CMS

F. Blekman(1), M. Milosavljevic(2)
For the ATLAS and CMS Collaborations
(1) *Cornell University, USA*
(2) *Institute of Physics, Belgrade*

Summary. — The search for supersymmetric partners of the top quark, stop squark, could result in the early discovery of physics beyond the Standard Model at the LHC. We present here the searches for stop squark within the mSUGRA model at ATLAS and CMS detectors. Results of simulation studies are presented. Search for the light stop squark in the low mass SUSY model, originating from the gluino decay, using the final state tb invariant mass at ATLAS is described. An inclusive stop search a different, more intermediate mSUGRA scenario, using the events with top candidate, leptons and missing energy at CMS is also presented. Both studies focus on discovery prospects in early data.

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1. – Introduction

If supersymmetry (SUSY) exists at the week scale, it should be discovered straightforward by the ATLAS and CMS experiments at LHC energies. The most promising extension of the Standard Model, the Minimal Supersymmetric Standard Model (MSSM) does not assume any particular Supersymmetry breaking mechanism[1]. Currently most popular Supersymmetry breaking paradigm, mSUGRA, predicts that SUSY breaking happens in a hidden sector, which is then mediated to the visible sector described by MSSM via gravitational interactions. In the mSUGRA framework the masses, mixings, and decays of all SUSY particles are determined in terms of five parameters: the common scalar mass m_0, the common fermion mass $m_{1/2}$, the common trilinear coupling A_0 at the grand unification energy scale, the ratio $\tan\beta$ between the vacuum expectation values of the two Higgs doublets, the sign of the Higgsino mass parameter μ. 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. Exclusive supersymmetric signals may be extracted from the kinematic limits of various variables. Different regions of mSUGRA five dimensional parameter space have been proposed as SUSY benchmarks and studied at ATLAS and CMS.

2. – Light stop search at ATLAS

A possibility to observe light stop signal above the Standard Model background was analysed for the ATLAS benchmark point SU4 immediatly above the Tevatron reach. This point is defined in the framework of mSUGRA by the parameters: m_0 = 200 GeV, $m_{1/2}$ = 160 GeV, A_0 = - 400 GeV, $\tan\beta$ = 10, μ > 0. With a NLO production cross section of 402 pb and masses in the range 60 - 450 GeV, SU4 seems to be a promising scenario for SUSY searches with early data. In the SU4 scenario the stop squark is only 30 GeV heavier than its SM partner and decays to final states similar to those of top: $\tilde{t}_1 \to \tilde{\chi}_1^{\pm} b$ (BR=100%). The gauginos $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ have the similar mass, 30 GeV above the W boson mass and decay with almost identical branching ratios to the equivalent SM gauge bosons. A detailed analysis of the SU4 phenomenolgy is given in [2]. In order to extract light stop signal in the SU4 low mass SUSY 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 SU4 scenario, when gluinos are produced together with $\tilde{q}_L$ or $\tilde{q}_R$, decay (1) occurs in about 18% of all SU4 events. In the decay (1) the final state tb invariant mass distribution has the upper kinematic endpoint expected at $\sim$ 300 GeV. Kinematically equivalent decays are $\tilde{g} \to \tilde{b}_1 b \to tb\tilde{\chi}_1^{\pm}$ and $\tilde{g} \to \tilde{b}_1 b \to bbW\tilde{\chi}_1^{\pm}$ if bW invariant mass is close to the top mass. Standard Model backgrounds originate from the $t\bar{t}$, $W + jets$, $Z + jets$ and QCD processes.

Multijet events with missing transverse energy were analysed assuming only top quark decay into hadronic final states and with no assumptions on $\tilde{\chi}_1^{\pm}$ decays which are dominantly giving 2 additional light q jets. The highest p_T jet in the event is associated with a light q originating from the decay of $\tilde{q}_L$ or $\tilde{q}_R$ produced with the $\tilde{g}$.

In order to reconstruct kinematic endpoint of the final state tb invariant mass distribution in the decay (1), event selection was performed: at least 5 jets in the event with $p_T > 30$ GeV where the hardest jet is a light quark jet with $p_T > 100$ GeV; 2 and only 2 jets are tagged as b jets with $p_T > 50$ GeV and at least 2 light q jets are requested with $p_T > 30$ GeV; $E_T^{miss} > 150$ GeV, $M_{eff} > 400$ GeV, $E_T^{miss}/M_{eff} > 0.2$, where $M_{eff} = E_T^{miss} + \sum_{i=0}^{i=3} p_T(jet_i) + \sum p_T(lepton)$; $S_T > 0.1$. From the SM backgrounds,

TABLE I. – *The number of signal and remaining Standard Model background events and the total event yield at 200 pb^{-1}, before and after subtraction of hadronic W candidates using the W sidebands method. The last row gives the signal-to-background ratio. Only errors from the detector systematics are quoted.*

L = 200 pb^{-1}	Selection	$M(tb)$ without W sub.	$M(tb)$ with W sub.
SU4	963	267	120
$t\bar{t}$	99	9	4
QCD	6	3	2
Event yield	1068 ± 426	279 ± 109	126 ± 50
SU4 / B$_{SM}$	9.2 ± 4.1	22.3 ± 9.1	20.0 ± 8.3

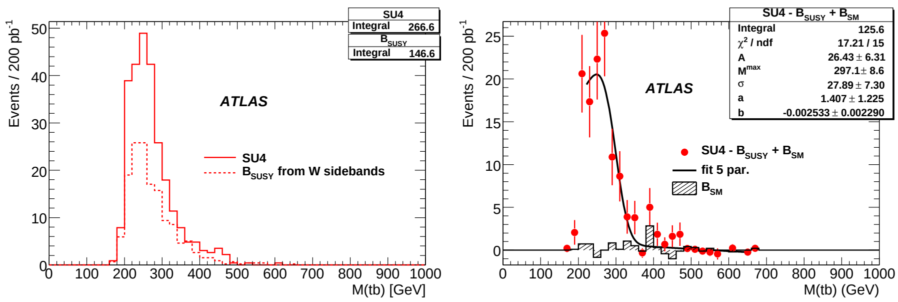

Fig. 1. – Reconstructed $M(tb)$ distributions in signal and SUSY combinatorial background events (left) and the fit of the sum of the reconstructed $M(tb)$ distributions in signal and the remaining SM events after the subtraction of the SUSY combinatorial background (right); all at 200 pb^{-1}.

only $t\bar{t}$ and QCD events satisfy selection criteria for the light stop search. Dominant detector performance systematic uncertainties originate from the jet and E_T^{miss} energy scale and resolution [3] and affect the number of selected SU4 and $t\bar{t}$ events by $\sim 40\%$. The W sideband method [4] is used to estimate SUSY combinatorial background originating from the SUSY processes where jet pairs accidentally have an invariant mass close to the W mass, thus faking W bosons. Corresponding event rates are listed in Table I. The signal $M(tb)$ distribution without the subtraction of the SUSY combinatorial background and the SUSY combinatorial background itself are plotted in fig. 1 (left). The sum of the final state $M(tb)$ distributions in signal and the remaining SM events after the subtraction of the SUSY background (fig. 1 (right)), is fitted to a triangular function smeared with a Gaussian in order to extract the endpoint. The position of the upper kinematic endpoint is $M^{max} = 297 \pm 9$ GeV with $\sigma = 28 \pm 7$ GeV corresponding to $\sim 10\%$ of the M^{max} value. The expected is 300 GeV.

3. – Inclusive stop search at CMS

The CMS collaboration also investigated the possible observation of Supersymmetry in the mSUGRA paradigm [5]. In the presented analysis we considered Supersymmetry being broken in the so-called *LM1* working point, identical to the post-WMAP benchmark point B' [6]. The *LM1* test point corresponded to the following values of the mSUGRA parameters

$$(2) \qquad m_0 = 60 \text{ GeV}, \; m_{1/2} = 250 \text{ GeV}, \; \tan\beta = 10, \; A_0 = 0 \text{ GeV and } \mu > 0.$$

The *LM1* scenario was defined such that the gluino mass was much larger than the squark masses, thus making $g \to \tilde{q}q$ the dominant gluino decay mode. In the analysis presented in this paper only decays involving a stop squark ($\tilde{t}$) were considered, where $\tilde{t}$ was required to decay as follows:

$$(3) \qquad \tilde{t_1} \to t + \chi_2^0 \to t + \tilde{l}_R + l \to t + l + l + \chi_1^0.$$

The scalar top quark was produced inclusively using the CMKIN package, interfacing the ISAJET and PYTHIA 6.225 generators[7, 8]. Only leptonic decays to electrons and muons were considered. The events were simulated and reconstructed with the full simulation of the CMS experiment. The used value of the top quark mass was $m_t = 175$ GeV.

The inclusive cross section for SUSY production was equivalent to $LO(NLO)$ $\sigma = 42(52)$ pb in the *LM1* scenario. In the analysis presented here, only decays involving scalar top quarks were included (eq. 3), which led to a drop in the cross section to $LO(NLO)$ $\sigma = 6.8$ (> 9) pb. The used simulation only made use of leading order matrix elements. A conservative estimate, using the NLO cross sections the inclusive K-factor of $K = 1.24$, was used to estimate the effect of next-to-leading order effect on inclusive mSUGRA top production.

The CMS analysis strategy was optimized for highest signal to background by a minimization of $(2 \times \sqrt{S+B} - \sqrt{B})$, where S was the number of signal events and B the number of background events. The optimization considered the set of selection criteria that was focused on the identification of top quarks in a sample equivalent to an integrated luminosity of $L = 1$ fb^{-1}. On lowest trigger level, we required at least one central jet with a transverse energy (E_T) over 88 GeV and 46 GeV of missing transverse energy (E_T^{miss}) or more. At higher trigger level these requirements were tightened to $E_T > 180$ GeV and $E_T^{\mathrm{miss}} > 123$ GeV, respectively.

In the offline reconstruction we reconstructed jet candidates with a 0.5 cone algorithm. Only jets with $E_T > 30$ GeV and $|\eta| < 2.5$ were included in the event selection. For the identification of jets coming from b-quark decays we used an algorithm based on the counting of tracks with a displaced impact parameter. The final event sample considered the presence of at least four reconstructed jet and a missing transverse energy of $E_T^{\mathrm{miss}} > 150$ GeV. In addition, one or more isolated lepton (e or μ) with $p_T > 5$ GeV/c and $|\eta| < 2.5$ was required to be present in the candidate event. This requirement was made to suppress QCD background.

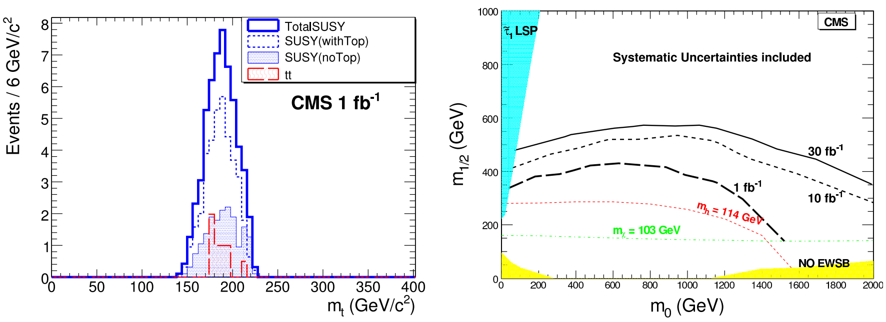

Fig. 2. – Reconstructed mass of the top candidate after all selection cuts (left) and reach for CMS searches in mSUGRA inclusive scalar top production, projected in the $(m_0, m_{1/2})$ plane (right).

The top quark signal was extracted from the combinatorial background using a constrained kinematic fit. The two, well defined, fit parameters were the mass of the W boson and top quark, where the top quark was expected to decay in a hadronic decay. Since the purpose of this study was not to measure the mass of the top quark or W boson, the use of this constraint was acceptable. The fit used a method called *Partitioned Matrix Method*, which is based on a χ^2 minimization where the constraints are taken into account by Lagrange multipliers. As a final event selection we required that the mass fit converged with $P(\chi^2) > 0.1$. To reject semileptonic $t\bar{t}$ events, the angle between the four-vector of the top candidate and the missing transverse energy was required to be $\Delta\phi < 2.6$ rad. The selection efficiency of the applied analysis was 0.7 %. Figure 2(left) shows the distribution of the top quark mass after all selection cuts. The SUSY contribution that contains top quark production (dashed line) was treated separately from the irriducible non-top SUSY background (solid thin line). Also shown is the very small contribution from $t\bar{t}$ events (filled).

After all analysis requirements, the remaining number of SUSY events which included top quarks was 38 events for an integrated luminosity of 1 fb^{-1}, while an irreducible background of 17 SUSY events without top quarks was expected for the same luminosity. The only remaining Standard Model background at 1 fb^{-1} consisted of a $t\bar{t}$ contribution of 5 events. The dominant systematic uncertainties in the presented analysis concerned the prediction of the Standard Model background. This uncertainty of 21% on the prediction of 5 SM background events consisted of significant contributions from the uncertainties b-quark identification and the energy scales of $E_T^{\rm miss}$ and the jet energy [5]. No events from $WW+$ jets, $ZW+$ jets, $Z+$ jets, single top nor QCD were observed to pass the selection cuts. The observed signal to background ratio was observed to be $S/B = 11$. With the results presented here for $L = 1$ fb^{-1}, it would already be possible to claim a discovery after an integrated luminosity of the order of 0.2 fb^{-1}.

For the same event topology, the CMS collaboration examined the reach for a 5σ discovery in the $(m_0, m_{1/2})$ plane. Figure 2 (right) shows the result of a study using the CMS fast simulation to span mSUGRA parameter space. The figure presents the expected CMS reach for a discovery in this event topology, for integrated luminosities of 1, 10 and 30 fb^{-1}. The systematic uncertainties on the Standard Model background are included.

4. – Discussion

The presented analyses represent the current status of the ATLAS and CMS collaboration's searches for Supersymmetric top production in mSUGRA symmetry breaking scenarios. The ATLAS analysis focused on part of the parameter space where it would be possible to make a very early discovery, while the CMS analysis was optimized for more a conservative Supersymmetric scenario, requiring larger data sets. A quick back-of-the-envelope examination for the sensitivity for the analyses during the Large Hadron Collider startup phase ($L = 20$ pb^{-1}, $\sqrt{s} = 10$ TeV) showed that both analyses were very much tuned for larger data samples so no clear conclusions could be drawn. After optimization of the analysis cuts, it might be possible that both analyses might be able to observe some, but most likely not significant, excess in a data set similar to the LHC startup sample.

5. – Conclusion

Both ATLAS and CMS collaborations expect to be able to confirm or exclude scalar top quark production in a collection of mSUGRA scenarios after $L = 0.2$ fb^{-1}. The ATLAS collaboration examined the SU4 scenario which, having heavily increased cross sections, already predicts the possibility to make an indirect gluino mass measurement with an accuracy of 10%. This indirect gluino mass measurement made use of the line shape of the invariant mass of the gluino decay products. The CMS collaboration presented a direct search in the LM1 mSUGRA scenario, providing exclusion limits for the entire $(m_0, m_{1/2})$ parameter space and for integrated luminosities of 1, 10 and 30 fb^{-1}.

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