Probing Supersymmetry using Event Shape variables 
at 8 TeV LHC

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Abstract

We have revisited the prospects of Supersymmetry(SUSY) searches at the LHC with 7 TeV energy along with the prediction of the discovery potential at 8 TeV energy assuming an integrated luminosity 5 $fb^{-1}$ and 20 $fb^{-1}$ with mSUGRA/CMSSM as a model framework. We discuss further optimization of our selection strategy which is based on the hadronic event shape variables. Evaluating the standard model backgrounds and signal rates in detail we predict the discovery reach in the $m_0 - m_{1/2}$ plane for 7 TeV with 5$f b^{-1}$ luminosity. We also present the discovery reach for 8 TeV energy with an integrated luminosity 5$f b^{-1}$ and 20 $fb^{-1}$. A comparison is made between our results and the exclusion plots obtained by CMS and ATLAS. Finally, discovery reach in the gluino and squark mass plane at the 7 TeV and 8 TeV energy is also presented.

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1 Introduction

The Large Hadron Collider (LHC) at CERN has completed its run at 7 TeV center of mass energy accumulating about $5 fb^{-1}$ of data. While the early run focused primarily on reproducing the Standard model (SM) physics, it is heartening to see that as of now a huge amount of beyond standard model (BSM) physics has been probed, especially in the context of supersymmetry (SUSY).

Supersymmetry over the last three decades has emerged as a robust and leading candidate for BSM. It is rich in phenomenological signatures and is a major search program at the LHC. The experiments CMS and ATLAS have both published results with $\sim 4.5 fb^{-1}$ of data excluding a substantial region of parameter space from negative searches\cite{1,2} assuming one of the popular SUSY model, namely, constrained minimal supersymmetric standard model (CMSSM) or minimal supergravity model (mSUGRA)\cite{3}. For example, the current exclusion limit for gluino and squark mass is, $m_{\tilde{g}}, m_{\tilde{q}} > 1.2$ TeV for $m_{\tilde{g}} \sim m_{\tilde{q}}$ case, while $m_{\tilde{g}} > 800$ GeV for $m_{\tilde{q}} >> m_{\tilde{g}}$ case\cite{1,2}.

However, the process of encompassing a wider region of parameter space at a particular luminosity has been a constant quest for experimental and phenomenological study. Hence various methods have been devised to improve the signal sensitivity by suppressing the backgrounds as much as possible, since the processes that lead to SUSY signals have a minuscule cross section compared to the SM backgrounds. For instance, search analysis based on $\alpha_T$\cite{4} variable is particularly impressive in suppressing QCD background for dijet and as well as for multijet channels. In addition to this, the Razor variables\cite{5} adopted by CMS collaboration use a different selection of strategy to detect SUSY signals. Following these examples, we had tried to devise a new search strategy reported in Ref.\cite{6,7} which is proved to be robust for a vast region of parameter space in various SUSY models. We observed that this method is extremely effective for the regions of SUSY parameter space which yield events with higher multiplicity of hard jets. In our paper\cite{6}, we demonstrated the robustness of our proposed selection strategy for 7 TeV energy by analyzing the signal and SM background events in details with 1fb$^{-1}$ integrated luminosity.

However, in this current study we revisited our search strategy with a goal for further optimization to make this method more powerful. After scrutinizing the previous selection strategy and correlation of cuts\cite{6} very closely, we found redundancy of one of our cuts which is finally dropped from the present analysis without losing any signal sensitivity. In addition, we also update our study for 8 TeV LHC energy. In order to find the sensitivity of our search strategy we scan the entire region of mSUGRA/CMSSM parameter space and predict the discovery reach of SUSY signal. Moreover, we also compare our results with that from CMS and ATLAS for a given energy and luminosity.
We organize our paper as follows: In Sec. 2 discussing our selection variables we describe the search strategy. In Sec. 3 we present our results and summarize it in Sec. 4.

2 Signal and Background

In this current study we present our results assuming the mSUGRA/CMSSM as a model framework, which has been an extremely popular model of SUSY breaking for close to three decades \cite{3}. Its attractiveness and popularity derives from the fact that it requires least number of assumptions about the parameters at the Grand Unified(GUT) scale. One assumes that at the GUT scale there is a universal scalar mass $m_0$, a universal fermion mass $m_{1/2}$, and a universal trilinear coupling $A_0$. Along with these one has to provide the sign of the higgsino mass parameter $\mu$ and $\tan\beta$, the ratio of the vacuum expectation values of the two Higgs doublet, both of which are determined at the electro-weak(EW) scale. The entire spectrum at the EW scale is then generated as one runs down from the GUT scale to the EW scale via Renormalization Group Equations(RGE). The phenomenology at low energy is dependent on the couplings between various SUSY particles which drive the collider search strategies.

The mSUGRA/CMSSM is constrained by theoretical considerations like convergence of RGE’s, perturbative unitarity constraining $\tan\beta$ \cite{8}, as well as from non observation of SUSY particles in direct searches in collider experiments, like at LEP \cite{9} and LHC \cite{11,12}. It is assumed to preserve the discrete symmetry R-parity and provides lightest neutralino as a dark matter candidate which is assumed to be the lightest SUSY particle(LSP). The observed dark matter relic density in the universe along with low energy constraints arising from flavor physics restrict the mSUGRA/CMSSM parameter space to a large extent which has been reported in a large number of papers \cite{10}. Interestingly, in a recent analysis based on very latest results from flavour data, in particular from LHCb measurements on $B_s \to \mu^+\mu^-$ \cite{11}, it has been shown that the mSUGRA/CMSSM is constrained severely, particularly for large $\tan\beta$ scenario \cite{12}. Moreover, one of the most striking constraints may arise from the observation or non-observation of the light higgs boson which, as is indicative from the current data may well lie in the window 122-127 GeV \cite{13,14}, and will eventually rule out a large swath of the model parameter space. Again a number of phenomenological studies in the context of constraining the CMSSM parameter space \cite{15} has been carried out in this light and will provide directions to future of SUSY. However, for a direct search of SUSY in colliders, it is better to remain unbiased from the indirect constraints and perform an inclusive search in all regions of parameter space except the regions which are forbidden from theoretical considerations and the direct search limits from collider experiments \cite{9}.

At the LHC the primary production modes of SUSY particles are squark and gluino pairs
mediated by strong interaction initiated by quarks and gluons in the initial state. These
gluinos and squarks being massive decay immediately into heavier chargino and neutralino
states which further decay to give rise jets and leptons along with lightest neutralinos which
are LSPs and being undetectable experimentally lead to an imbalance in momentum at
the transverse plane. Hence the generic SUSY signature is often designated by \( n-jets+m-leptons+p_T \) (n,m=0,1,..). However, because of the depletion of branching ratio of SUSY
particles in leptonic channels, the signal rates in the pure hadronic decay channels are much
larger. Needless to say, that the jets \( + p_T \) channel is expected to yield the largest discovery
reach than others. In this current effort we focus primarily on this jets\( + p_T \) channel to
investigate discovery potential of SUSY at the current runs of the LHC. The major SM
backgrounds corresponding to this final state consist of QCD, top pair production(\( t\bar{t}+jets \)),
W/Z+jets with the hadronic decays of SM particles. As we know, the background cross
sections are larger by 6 or 7 orders of magnitude in comparison to signal cross sections, and
hence it is a non trivial task to isolate signal events from the rubble of these backgrounds.
As mentioned above, in a previous work we formulated a new strategy \[6\] with its own merit
to eliminate backgrounds to a large extent, particularly for the case where the signal has the
characteristic feature of a larger multiplicity of hard jets.

We use PYTHIA6 \[16\] to simulate signal and background processes due to \( t\bar{t} \), QCD. The
top pair production and QCD is simulated by slicing the entire phase space in \( p_T \) bins.
We use CTEQ6L \[17\] for parton distribution function to calculate cross sections setting
the factorization scale at \( Q^2 = \hat{s} \), where \( \sqrt{s} \) is the center of mass energy in the partonic
frame. Jets are reconstructed using FastJet \[18\] with an anti- \( K_T \) \[19\] algorithm using a
size parameter \( R=0.5 \). Jets are selected with a cut of \( p_T \geq 50 \text{GeV} \) and \( |\eta| \leq 3 \).
ALPGEN \[20\] is used to generate events for \( t\bar{t}+jets \), W/Z+jets, applying \( p_T \geq 20 \text{GeV}, |\eta| \leq 3 \) for final
state partons. Subsequently, PYTHIA6 \[16\] is used for parton showering imposing MLM
matching \[21\] with a jet \( p_T > 25 \text{GeV}, |\eta| \leq 2.5 \) and \( \Delta R = 0.7 \) to avoid double counting.

We pre-select events consisting jets and missing energy by imposing the following selection:

\[
p_T^j > 50 \text{GeV}, |\eta| < 3 \quad \text{and} \quad \hat{p}_T > 50 \text{GeV}.
\]  

In the light of current experimental data where the mSUGRA/CMSSM is pushed to higher
values of gluino and squark masses we choose two benchmark points in the \( m_0 \) and \( m_{1/2} \)
plane consistent with current collider constraints \[1\]? to demonstrate our search strategy.

In Table 1 we present the masses of relevant SUSY particles corresponding to these parameters space P1 and P2. We use Suspect interfacing with SUSYHIT \[22\] to generate
masses and branching ratios of SUSY particles corresponding to these benchmark points.

\( ^1\hat{p}_T \) is the transverse momentum of final state partons in the center of mass frame.
Table 1: Mass spectrum for benchmark point (P1) $m_0 = 1500$ GeV, $m_{1/2} = 310$ GeV, $\tan\beta = 10$. $A_0 = 0$, $\text{sgn}(\mu) \geq 0$, (P2) $m_0 = 620$ GeV, $m_{1/2} = 520$ GeV, $\tan\beta = 10$. $A_0 = 0$, $\text{sgn}(\mu) \geq 0$

The SUSY particle production cross sections are calculated at next-to-leading (NLO) level using PROSPINO \cite{23}. In the following section we recapitulate our selection variables \cite{6} very briefly.

- **Transverse Thrust (T):** The event shape variables describe the shape and geometry of the event \cite{24} and are used to understand various properties of it. For instance, these variables are studied to test few monte carlo models at the LHC \cite{25}. One of the event shape variable is the transverse thrust which is defined as \cite{24},

$$T = \max_{n_T} \frac{\sum_i |\vec{q}_{T,i} \cdot \vec{n}_T|}{\sum_i |\vec{q}_{T,i}|},$$

where the sum runs over all objects in the event with $\vec{q}_{T,i}$ being the transverse momentum component of each object and $\vec{n}_T$ is the transverse unit vector which maximizes this ratio. It is easy to convince oneself that for di-jet events the ratio is precisely 1 and for multijets $T$ is away from unity. Hence this provides an useful tool to suppress backgrounds with comparatively lower multiplicity of jets in the final state, predominantly for QCD and with some moderate effects on $t\bar{t}$ and $W/Z+$jets channels. This is clearly demonstrated in Fig.1 of Ref \cite{6}. A pleasing feature of transverse thrust is in the fact that it is infra-red safe \cite{24} and being a dimensionless quantity is expected to have less systematic errors. In practice, the transverse thrust is re-defined as $\tau = 1 - T$.

- **$R_T$:** The variable $R_T$ is defined as \cite{6},

$$R_T(n_j^{\text{min}}) = \frac{\sum_i n_j^{\text{min}} |\vec{p}_{T,i}^j|}{H_T}$$

with $H_T = \sum n_j |\vec{p}_{T}^j|$. The numerator runs up to a required minimum number of selected jets($n_j^{\text{min}}$) of the event, whereas for the denominator it is the total number of jets existing in that event. It is evident that the pattern of distribution of this variable as was pointed out in Ref. \cite{6}, depends on the multiplicity and hardness of jets. SUSY as we noted earlier is often characterized by hard multijet events in a wide region of parameter space and in addition, the sub-leading jets, are comparatively harder than that of the backgrounds. We make use of this distinguishing feature to separate the signal from the backgrounds using this variable. For instance, events where the total number of jets($n_j$) in the event is close to the
Figure 1: Comparison of $M_T(j_1, j_2)$ for $t\bar{t}$ and SUSY signal events subject to pre-selection cuts (Eq. 1) and with $\sqrt{S} = 8$ TeV. Parameter space P1 is used for SUSY.

required minimum number of jets ($n_{j_{\text{min}}}^\text{min}$), i.e $n_{j_{\text{min}}}^\text{min} \sim n_j$, then the numerator and denominator are almost identical, hence the ratio is close to unity, which is predominant in backgrounds as can be seen in the Fig.2 of Ref [6]. For signal processes, mostly $n_{j_{\text{min}}}^\text{min} << n_j$ with harder multijets, the ratio turns out to be away from 1 and the tail extends to well below 0.8. One can see that if we discriminate at $R_T(4) < 0.85$, a significant fraction of backgrounds can be eliminated with a little effect on the signal cross section.

- $M_T(j_1, j_2)$: We define this variable as the transverse mass between the two leading jets [6],

$$M_T(j_1, j_2) = \sqrt{2 \times p_T^{j_1} p_T^{j_2} (1 - \cos \phi(j_1, j_2))}$$ (4)

where $\phi$ is the azimuthal angle between the two leading jets. This variable is particularly useful in suppressing the top background where two leading jets are expected to be back-to-back mostly. On contrary, in SUSY events the two leading jets are hard and very likely to be distributed isotropically as compared to the background. Fig.1 clearly confirms this fact where we display the distribution of $M_T(j_1, j_2)$ for signal and $t\bar{t}$ background ignoring other SM backgrounds which are manageable without this cut. For this illustration we use P1 parameter space to obtain signal distribution and both are subject to pre-selection cuts, Eq.1. Clearly, a strong cut, for example, $M_T(j_1, j_2) > 450$ GeV can bring down $t\bar{t}$ background to a negligible level.
$\tau > 0.1, \ R_T(4) < 0.85, \ \mathcal{M}_{j_1,j_2} > 450$ GeV along with pre-selection cuts, Eq. (1). Parameter space P1 is used for SUSY.

- $p_T$: We calculate the total transverse missing momentum out of all visible particles with $p_T > 1$ GeV and $|\eta| < 3$. In SUSY process $p_T$ is expected to be hard.

A careful comparison of all distributions of $\tau, R_T(n_{\text{min}}^j), \mathcal{M}_{j_1,j_2}$ and $p_T$ for signal and backgrounds, we optimize the following set of cuts to reject backgrounds and isolate signal events,

$$\tau > 0.1, \ R_T(4) < 0.85, \ \mathcal{M}_{j_1,j_2} > 450 \text{ GeV}, \ p_T > 250 \text{ GeV}$$

(5)

In the next section we will discuss the impact of these cuts in both signal and background processes. Meanwhile, we make some comments about the correlation of cuts observed in our analysis.

In SUSY events the $H_T$ distribution in signal is expected to be on the higher side as jets emerging from cascade decays of heavier particles are more energetic than their SM counterparts and hence, it is used as one of the background rejection tool. Following this observation, in our previous analysis we also adopted this $H_T$ variable to eliminate SM backgrounds [6]. However, in this present study we investigate the correlation of $H_T$ variable with other cuts in more detail. In Fig. 2 we present the interplay of cuts by making a two dimensional plot in $p_T - H_T$ plane imposing selection on $\tau$ and $R_T(4)$, as Eq. (5) requiring at
least 4 jets in the event for both signal and all SM backgrounds. The $p_T - H_T$ distribution shown in Fig. 2 clearly reveals that signal events are located at the high $H_T (\approx 750 \text{ GeV})$ region and in addition, requiring $p_T > 250 \text{ GeV}$ it is possible to get rid of contamination due to the SM backgrounds. This exercise justifies the claim of dropping $H_T$ cut from our selection strategy. These features are in stark contrast to almost all multijet search strategies which requires a large $H_T$ cut in their analysis. One of the most important background to SUSY searches is the irreducible $Z(\rightarrow \nu \bar{\nu}) + \text{jets}$ background with multijets and a large amount of $p_T$. Using $R_T(4)$ we have successfully managed to suppress this background to a negligible level. It must also be emphasized that this variable being a dimensionless quantity is prone to less systematics, and is a fairly simple variable to implement in experiments.

3 Results and discussion

In order to understand the impact of our selection strategy as discussed in the previous section, we analyzed SUSY signal for two benchmark points shown in Table 1. One of the points (P1) corresponds to a lower gluino mass and a relatively higher squark mass in contrast to the other point (P2) where gluino and squark masses are almost equal. In Table 2, we summarize the cumulative effect of cuts for a center of mass energy 8 TeV. The production cross sections (CS) are presented in the second column of Table 2. It is to be noted that the signal cross sections are at the next-leading-order (NLO) level where as partially higher order corrections are taken into account by considering associated jets in the background processes. The 3rd column shows the number of events (N) generated and it is made sure that it corresponds to at least $5 fb^{-1}$ integrated luminosity. From the 4th column onwards the number of events due to cumulative effect of cuts are presented. Finally, in the last column, the number of events selected after all cuts including matching efficiencies (Eq. 5) are shown normalized to cross section for $5 fb^{-1}$ luminosity. In addition we also simulate signal and backgrounds with proper statistics for $20 fb^{-1}$ luminosity for which only final results are presented.

The benchmark points (P1 and P2) are so chosen as to reveal the difference in the type of event distribution for the two points. The first point P1 (Table 1) has a lower gluino mass and a comparatively higher squark mass which implies that the primary decay mode of gluino will be through $\tilde{g} \rightarrow t \chi_{1\pm_i}^0, t \chi_{1\pm_2}^0$ via virtual top squarks. With top decaying in the hadronic mode for about 2/3, it yields a large number of jets. We find as expected that the suppression due to the thrust cut ($\tau > 0.1$) for the signal is about 20% whereas for background it is the close to 90% for some cases, QCD in particular. The $R_T(4)$ selection variable is effective for multijet backgrounds and is reflected in the 5th column of Table 2. Eventually, the $M_T(j_1,j_2)$ cut as discussed previously is useful to get rid of the remaining top
| Process | C.S(pb) | N    | $\tau$ > 0.1 | $R_T^4$ $\leq$ .85 | $M_T(j_1,j_2)$ $\geq$ 450 GeV | $p_T$ $\geq$ 250 GeV | # of Events |
|---------|---------|------|--------------|---------------------|-----------------------------|----------------------|-------------|
| P1      |         |      |              |                     |                             |                      |             |
| $\bar{g}g$ | 0.087   | 20K  | 16809        | 9186                | 3840                        | 1025                 | 22.3        |
| $\bar{q}g$ | 0.023   | 20K  | 16474        | 9776                | 7363                        | 3458                 | 19          |
| P2      |         |      |              |                     |                             |                      |             |
| $\bar{g}g$ | 0.002   | 20k  | 17781        | 13650               | 6227                        | 3810                 | 1.73        |
| $\bar{q}g$ | 0.015   | 20K  | 14895        | 5286                | 3490                        | 2883                 | 10.5        |
| $\bar{q}q$ | 0.02    | 20k  | 10713        | 1068                | 451                         | 299                  | 1.3         |
| $t\bar{t}$ |         |      |              |                     |                             |                      |             |
| 5-200   | 85      | 0.3M | 147181       | 5738                | 133                         | 0                    | 0           |
| 200-500 | 10      | 0.1M | 29490        | 4518                | 328                         | 2                    | 1           |
| 500-inf | 0.13    | 20k  | 1986         | 248                 | 147                         | 9                    | 0.3         |
| $t\bar{t} + 1j$ | 79.6   | 136083 | 68854 | 3354 | 20 | 0 | 0 |
| $t\bar{t} + 2j$ | 39.6   | 192983 | 11110 | 1180 | 14 | 0 | 0 |
| $t\bar{t} + 3j$ | 14.7   | 14993  | 9802  | 2239 | 110 | 0 | 0 |
| $t\bar{t} + 4j$ | 4.5    | 12439  | 9192  | 3724 | 433 | 6 | 1.6 |
| QCD     |         |      |              |                     |                             |                      |             |
| 300-500 | 1267    | 2M   | 263823       | 11765               | 4409                        | 0                    | 0           |
| 500-800 | 67      | 0.3M | 32646        | 1720                | 1439                        | 0                    | 0           |
| 800-1500 | 3     | 0.1M | 8110         | 412                 | 394                         | 0                    | 0           |
| 1500-inf | 0.01  | 10k  | 496          | 10                  | 10                          | 0                    | 0           |
| W+2j    | 1665    | 220879 | 122079 | 2 | 0 | 0 | 0 |
| W+3j    | 436.2   | 99616 | 43712 | 3 | 0 | 0 | 0 |
| W+4j    | 105.3   | 68923 | 25324 | 342 | 36 | 0 | 0 |
| Z+2j    | 1670    | 120199 | 67406 | 0 | 0 | 0 | 0 |
| Z+3j    | 450     | 241202 | 106864 | 6 | 0 | 0 | 0 |
| Z+4j    | 110     | 39203 | 17706 | 133 | 10 | 0 | 0 |

Table 2: Number of events after each set of cuts for signal and background for $\sqrt{s} = 8$ TeV. In the last column, number of events are normalized for 5 fb$^{-1}$ luminosity.
Figure 3: Discovery reach requiring $S/\sqrt{B} \geq 5$ for $\tan\beta = 10$, $A_0 = 0$, $\text{sign}(\mu) = +1$. The two CMS(MT2 and Razor) \cite{27,28} and ATLAS \cite{2} exclusion plots are at 95\% C.L. The green shaded region is disallowed by theory and LEP constraints, red shaded region is forbidden by $\tilde{\tau}_1$ LSP condition.

background. However, in case of parameter space P1 i.e for high $m_0$ and low $m_{1/2}$, the mass differences among $\chi_1^\pm, \tilde{\chi}_2^0$ and $\chi_1^0$ are comparatively small resulting in less available energy for final state particles leading to a softer spectrum including soft $p_T$. As a consequence, the effect of $p_T(>250 \text{ GeV})$ cut is severe for signal in this case, as reflected in the penultimate column in Table 2. Hence, total acceptance efficiency turns out to be small yielding low signal sensitivity in this region.

The benchmark point P2 with $m_0$ and $m_{1/2}$ nearly equal, is different in the fact that the gluinos will preferentially decay to $\tilde{t}\tilde{t}$ with physical top squarks decaying further to $t\chi_{1,2}^0$. Hence the gluino decay will still yield a fair number of jets in the final states. The 1st two generation squarks will however decay predominantly to $q\chi_1^\pm$ with charginos decaying to $W\chi_1^0$. This channel therefore yields a less jet activity in most cases which is suppressed by the $R_T(4) < 0.85$, as can be seen from Table 2.

In Table 3 we show the total number of background and signal events after all selection cuts for two parameters points P1 and P2 normalizing to cross section at 5\text{fb}$^{-1}$ luminosity. We observe about 4(3) background events for integrated luminosity 5\text{fb}$^{-1}$ at 7(8) TeV energy against a handful of signal events yielding $S/\sqrt{B}$ more than 5 for two selected representative
Figure 4: Same as Fig. 3 but for tan$\beta$=50.

Table 3: First two rows(last row) present the number of signal and background events for 5$f_{b^{-1}}$(20 $f_{b^{-1}}$) luminosity subject to all selection cuts, (Eq. 1,5) corresponding to center of mass energies as shown.
signal parameters points P1 and P2. The suppression of background events indicate the robustness of our selection strategy.

Armed with this selection strategy, we attempt to find the potential discovery region in the $m_0 - m_{1/2}$ plane. We scan the $m_0 - m_{1/2}$ parameter space setting $A_0 = 0$, $\text{sign} (\mu) = +1$, $\tan \beta = 10$, 50 and estimate the signal rates applying cuts, Eq. 4 and 5. We require $S / \sqrt{B} \geq 5$ to claim discovery of SUSY signal for each set of parameters points for a given energy and luminosity. In Fig. 3 and Fig. 4 we present the discovery reach in the $m_0 - m_{1/2}$ plane for $\tan \beta = 10$ and $\tan \beta = 50$ respectively. In both the figures the shaded area along the x-axis are mainly disallowed by no-EWSB breaking condition as well as the limit on chargino mass($>102$ GeV) from LEP experiments [9]. On the other hand the shaded region along the y-axis are ruled out because $\tilde{\tau}_1$ appears to be LSP which is assumed to be forbidden because of offering LSP as a dark matter candidate which has to be neutral. We present our results for 7 TeV with 5 $fb^{-1}$ luminosity and 8 TeV energy with 5$fb^{-1}$ and 20 $fb^{-1}$ luminosity. The total background and signal cross sections are presented in Table 3. It is expected that the discovery reach for 8 TeV is higher and this enhancement occurs mainly due to the enhancement of sparticle production cross sections, approximately by a factor of 2. Notice that in the same plane we also delineate regions excluded at 95% C.L. by CMS and ATLAS at 7 TeV energy with 4.4$fb^{-1}$ and 4.7$fb^{-1}$ luminosity respectively. Note that for $\tan \beta = 50$ case, Fig. 4, exclusion plots are not available from both the experiments at this integrated luminosity. Notice that the two CMS exclusion plots are due to the two methods MT2 [27] and Razor [28] with almost same luminosity. The ATLAS exclusion plot is obtained by demanding the number of jets $\geq 6$ to $\geq 9$ along with $\cancel{p}_T$ in the final states [2], which is the similar type of final states where our search strategy is most sensitive. It is to be emphasized that in both CMS and ATLAS analysis, no isolated leptons, electrons or muons are required. It helps to suppress backgrounds, mainly due to $t\bar{t}$ and $W+$jets. However, in our analysis we do not require to veto any such events to suppress these backgrounds. It seems from these figures that our selection strategy works better for high $m_0$ values where as for low $m_0$ case it is comparable with other results. A naive comparison of our results with a recent paper of Ref. [29] which predicts the gluino mass up to $\sim 800$ GeV whereas our analysis claims it $\sim 1$ TeV for 7 TeV 5 $fb^{-1}$ luminosity in the high $m_0 (>1500$ GeV) region. It is to be noted that the signal rates in the paper [29] correspond to inclusive channel, but in our case it is due to the jets plus $\cancel{p}_T$ channel. It is true that at the high $m_0$, as discussed before, the $\cancel{p}_T$ in the events is softer and hence signal selection based on tight cut on $\cancel{p}_T$ suffers and sensitivity degrades very fast. However, in our case, instead of high $\cancel{p}_T$ cut, we exploit the multiplicity of jets in the events, which is on higher side in this high $m_0$ region due to the presence of heavy flavors(t,b quarks) in $\tilde{g}, \tilde{q}$, cascade decay chains as discussed previously. As a consequence, selections based on our strategy achieves better significance
than the others which are based on very hard cut on $p_T$ and $H_T$. On the other hand, towards the higher side of $m_{1/2}$ and comparatively low $m_0$ values, the masses of gluinos and squarks are close to each other, multiplicity of jets is relatively lower and hence our strategy suffers to some extent. We observed that the difference in $\tan \beta$ does not make a significant impact in the discovery reach, which is expected as rates in the hadronic channel is controlled by the cascade decays of the strong production process whereas $\tan \beta$ affects the electroweak processes. However, the differences are subtle and appear only in parts of parameter space which has $\tilde{\tau}_1$ as the next to LSP due to large $\tan \beta$ and hence yield $\tau$ leptons in the final state. This yields a lesser number of jets in some parts of parameter space which in our search strategy translates to a lower reach in large $\tan \beta$ region.

In order to understand the implication of this discovery region in $m_0 - m_{1/2}$ planes, we translate Figs. 3 and 4 to Figs. 5 and 6 respectively, which are in the physical $m_{\tilde{g}} - m_{\tilde{q}}$ mass planes. Clearly, both the figures display the discovery reach of masses of $\tilde{g}$ for the corresponding $\tilde{q}$ masses and vice versa for a given set of SUSY parameter space. We find that for nearly degeneracy case, $m_{\tilde{g}} \sim m_{\tilde{q}}$, it is possible to find SUSY signal for $m_{\tilde{g}}$ up to 1.2 TeV (1.35 TeV) for 7 TeV (8 TeV) energy with $5 fb^{-1}$ luminosity where as for larger masses of $\tilde{g}$, this reach goes down to 1 TeV (1.1 TeV) for the same energy range. This conclusion remains true for high $\tan \beta$, (Fig. 6) case as well. For higher luminosity options, say $20 fb^{-1}$ for 8 TeV energy this reach extends to $\sim 1.5$ TeV. Note that our predictions are based purely
Figure 6: Same as Fig. 5 but for tanβ=50.

from generator level analysis without taking care of any detector effects.

4 Summary

We have re-examined the prospects of SUSY searches in the jets plus missing energy channel at the LHC with 7 TeV energy and predicted the discovery reach for 8 TeV energy with 5 fb$^{-1}$ and 20 fb$^{-1}$ luminosity. We are familiar with the fact that the SUSY events are characterized by high multiplicity of comparatively harder jets for a wide region of parameter space. Exploiting this fact we devise our selection strategy based on the event shape variables, namely the transverse thrust(Eq. 2) and the other observables, Eq. 3 and 4, which are robust in dealing with SM backgrounds. As mentioned in Sec. 2, the $H_T$ cut is very effective and used by many SUSY analysis including by us in our previous study [6]. However, investigating the correlation of cuts used in the present analysis we observed that due to selections given by Eq. 5, signal events are distributed to very higher $H_T$ region implying the inefficiency of $H_T$ cut, and hence it is dropped from our selection strategy without paying any price for signal sensitivity.

Moreover, optimizing our selection strategy, we analyze the SM backgrounds in detail and showed that with our search strategy it is possible to reduce these to a negligible level retaining the signal to a large extent. Recall that, our search strategy works favorably in
the regions of parameter space which predict events with many harder jets. We predict the potential discovery regions in the $m_0 - m_{1/2}$ plane in the framework of mSUGRA/CMSSM for 7 and 8 TeV centre of mass energy and 5 fb$^{-1}$ and 20 fb$^{-1}$ luminosity. A naive comparison with the ATLAS, CMS exclusion plots at 7 TeV suggests that our analysis gives better sensitivity in the regions of parameter space in high $m_0$, and low $m_{1/2}$ viz, in regions where jet activity is significantly higher. We find based on our analysis, $m_{	ilde{g}}$ up to 1.35 TeV can be discovered for gluino and squark mass degeneracy case and otherwise up to 1.1 TeV for large squark masses for 8 TeV energy. For higher luminosity options, for instance $L = 20 fb^{-1}$ case, this discovery reach is extended to about 1.45 TeV. It must be noted that we have not vetoed any events consisting of leptons or do not apply any tagging of any special objects, like b-tag and so on. Since, two of our selection variables, namely $\tau$ and $R_T$, are a dimensionless quantities, so are expected to carry less systematic uncertainties.

As masses of SUSY particles in mSUGRA/CMSSM model gets pushed to a corner it is imperative to design search strategies that will access the edges of the SUSY parameter space. This will involve optimizing the signal to background ratio in large parts of the parameter space where the signal cross section is miniscule. In this study we have provided such a search strategy with its own merits of suppressing SM backgrounds to a negligible level. It must be emphasized that our strategy is not limited to mSUGRA/CMSSM but expected to work also in other models which yield a large number of jets, for instance non-universal gaugino mass model [7], no scale F-SU(5) [31] SUSY model [32].

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