Inclusive search for SUSY in top final states at CMS

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An inclusive search for low mass SUSY using the top plus missing transverse energy signature at CMS is presented. A 5σ excess can be observed with $\sim$250 pb^{-1} at a particular low mass SUSY point. With the same analysis selection the 5σ discovery reach contours in the mSUGRA parameter space for 1 and 10 fb^{-1} are obtained.

I. INTRODUCTION

Although the standard model (SM) of the elementary particles explains precisely the data from the colliders, there are some remaining fundamental questions raised by the SM itself that don't have any explanation. For example radiative loop corrections to
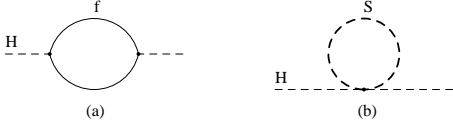

FIG. 1: Loops affecting the squared Higgs mass from (a) fermions trilinear couplings, (b) scalars quartic couplings [1].

the higgs mass like in figure 1 give a correction

$$\Delta m_H^2|_f = \frac{\lambda_f^2}{8\pi^2}[-\Lambda^2 + 6m_f^2 ln\frac{\Lambda}{m_f}] \qquad (1)$$

where Λ is the upper limit of the momentum. The leading term diverges quadratically (The **Quadratic Divergency Problem**). This divergence can be removed by introducing a cut-off scale on momentum. Its value is the higher limit of energy upto which SM is valid. Usually this limit is $M_{Pl} \equiv (8\pi G_{Newton})^{-1/2} = 2.4\times10^{18}$ GeV, at which gravity has a strength comparable to the other interactions and SM must be modified. This enormous disparity of scales between electroweak and M_{Pl} is not natural and is called the **hierarchy problem** [1]. If another scalar exists which couples to the Higgs by a quartic interaction of the form $-\lambda_S|H|^2|S|^2$ (see figure 1(b)), it contributes to the Higgs mass by:

$$\Delta m_H^2|_S = \frac{\lambda_S}{16\pi^2}[\Lambda^2 - 2m_S^2 ln\frac{\Lambda}{m_S}] \qquad (2)$$

It also generates a quadratic divergence, but because of Fermi statistics, its sign is opposite to the one of the fermions. Assuming there are two scalar partners for every fermion with couplings $\lambda_S = \lambda_f^2$ the quadratic divergences cancel exactly.

To solve the hierarchy problem this theory should contain nearly degenerate fermions and scalars and

adequately chosen couplings. It is exactly what **supersymmetry** (SUSY) postulates, the existence of supersymmetric partners for every SM particle, which have exactly the same quantum numbers and mass, but differ by 1/2 in their spin.

The super partners of the fermions are called with same name starting with "s", e.g stop, and the superpartners of bosons are called with same name ending with "ino", e.g wino.

SUSY particles have not been discovered yet, so they are not at the same mass as their SM partners. It means that supersymmetry is a broken symmetry and SUSY particles are heavier. There are different mechanisms to break this symmetry softly (without generating quadrative divergencies). Here we consider a very constrained scenario where gravity is responsible for SUSY breaking and the Z^0 mass is produced by radiative electroweak symmetry breaking. This model is called **mSUGRA**. The particle masses and branching ratios in mSUGRA are defined completely by only 5 parameters:

m_0 commom scalar mass at the Grand Unification Theories (GUT) scale.

$m_{1/2}$ commom gaugino mass at GUT scale.

A_0 commom trillinear coupling at GUT scale.

tanβ ratio of the vacuum expectation values for H_u and H_d.

sign(μ) μ is the higgs mixing parameter.

In the following the search for SUSY in a special channel in CMS [2] at the Large Hadron Collider (LHC) [3] which is going to start data taking in fall 2007 will be reviewed by one example emphasizing the role of the top quark as both signal and background.

II. CUT OPTIMIZATION IN A CMS TEST POINT

In CMS an inclusive search for SUSY is done by looking for events with a top quark in the final states [4]. For illustration a test point LM1 within the mSUGRA scenario is used. This point is defined by

$m_0 = 60$, $m_{1/2} = 250$, $A_0 = 0$, $tan\beta = 10$ and $\mu > 0$. The masses of the relevant particles (in GeV/c^2) are

$$m(\tilde{g}) = 611 \quad m(\tilde{t}_1) = 412 \quad m(\tilde{t}_2) = 576 \qquad (3)$$
$$m(\tilde{\chi}_1^0) = 120 \quad m(\tilde{b}_1) = 514 \quad m(\tilde{b}_2) = 535$$

In this point, the top quark can be produced inclusively in the decay of the $\tilde{t}$, $\tilde{b}$ and $\tilde{g}$ accompanied by a neutralino (the lightest supersymmetric particle (LSP)), which appears as a large missing transverse energy (MET, E_T^{miss}). So the idea is to see the excess in the number of the extracted top quarks, when a hard cut is applied on the missing transverse energy. To simulate the detector response, the full simulation based on GEANT4, OSCAR [5], is used . To extract the top quark, a two constraints kinematic fit is utilized [6]. It is very useful because firstly it has a quantitative feature to reject the fake top quarks (χ^2 probability, see figure 2) and also it can improve

FIG. 3: The difference between the energy of the reconstructed/fitted top and the generated top. Fitted jet combinations pass the probability cut(χ^2 probability > 0.05). The central parts of the distributions(-30,30) are fitted with a gaussian function(thick-blue lines) to emphasize and quantify the improvement in the resolution. The fit improves the resolution of the energy of the W and top quark by 37% and 48%, respectively. It also improves the bias. Distributions are made by 100k events of the inclusive $t\bar{t}$ sample.
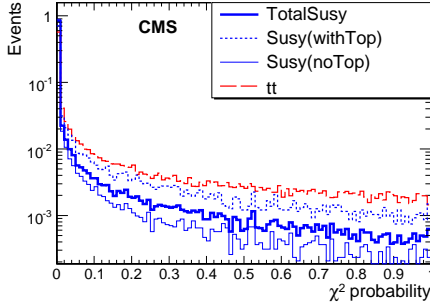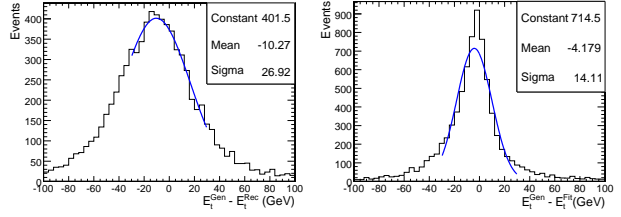

FIG. 2: χ^2 probability distribution for 200K events of the inclusive LM1 sample and 100K events of the inclusive $t\bar{t}$ sample. All plots are normalized to 1 to make the shape comparison easier. The fake top quarks (SUSY events without a generated top quark 'Susy(noTop)') are concentrated in the low probability region.

the kinematic features of the reconstructed top quark. Figure 3 shows the difference between the energy of the reconstructed (fitted) top quark and the generated top quark, when the generated top quark which is closer than $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.5$ to the reconstructed top quark decays hadronically and all its three partons have $E_T > 30$ GeV and $|\eta| < 2.5$.

The main background is semileptonic $t\bar{t}$ when there is a potentially high value for E_T^{miss} and a hadronically decaying top quark. In these events E_T^{miss} and the fitted top quark are almost back-to-back in the transverse plane. This feature is used to suppress the $t\bar{t}$ background. The cuts were optimized both to suppress the SM background and also increase the ratio of the SUSY events with a generated top quark 'SUSY(withTop)' against the SUSY events without a generated top quark 'SUSY(noTop)', although these two sources are used as the number of extracted signal

events. In order to do the mentioned suppressions the following cuts are applied:

1. The first level trigger (L1) L1JetMET [7] (a barrel jet with $E_T > 88$ and $E_T^{miss} > 46$ GeV).

2. The High Level Trigger (HLT) HLTJetMET (a barrel jet with $E_T > 180$ and $E_T^{miss} > 123$ GeV).
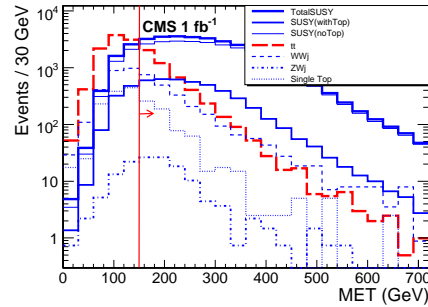
3. E_T^{miss}, > 150GeV, as shown in figure 4.

FIG. 4: E_T^{miss} distributions for different samples. Events are required to pass the Level 1 and High Level Trigger.

4. at least 4 jets, with at least one of them b-tagged, jets with $E_T^{uncorrected} > 30$ GeV and $|\eta| < 2.5$.

5. A convergent fit with χ^2 probability > 0.1. This cut is the most important cut to increase the ratio of SUSY(withTop) against the SUSY(noTop).

6. $\Delta\phi$ between the fitted top quark and the $E_T^{miss} < 2.6$. Figure 5 shows the distribution of this quantity for different samples.
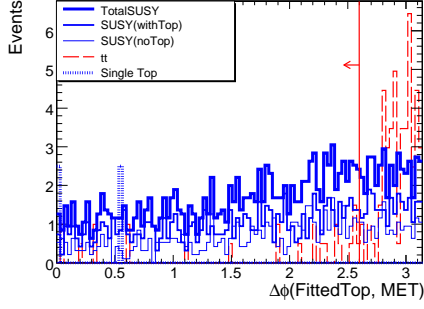
FIG. 5: The $\Delta\phi$ between the fitted top and the missing transverse energy. The distributions are made after applying the cut 5.

7. at least one isolated electron or muon with $P_T > 5$ GeV/c and $|\eta| < 2.5$. This cut is introduced to suppress the QCD multijet backgrounds.

After applying these cuts, the only remaining background is $t\bar{t}$. The ratio of the SUSY signal against the SM background is 11, when almost 70% of the extracted SUSY events have a generated top quark 'SUSY(withTop)'. Figure 6 shows the distributions
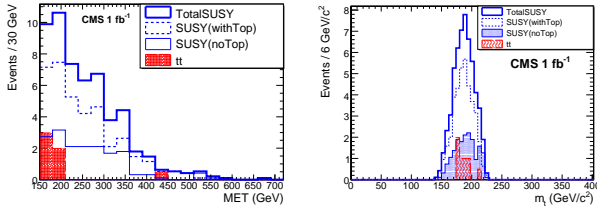

FIG. 6: Missing transverse energy (left) and the extracted top quark (right) after applying all cuts.

of missing transverse energy and the extracted top quark for different samples. It can be seen that the SUSY signal is well above the standard model ($t\bar{t}$) background. Including the systematic uncertainties on the background [8] we estimate that the minimum integrated luminosity for a 5σ discovery is ~0.25 fb^{-1}. Note that the analysis uses systematic uncertainties that are realizable with 1 fb^{-1} of data. For start-up (0.1 fb^{-1}) a separate study of the uncertainties needs to be performed.

III.   CMS REACH IN m_0-$m_{1/2}$ PLANE

To estimate the reach over the mSUGRA parameter space we apply the analysis selection path using the fast simulation and reconstruction of CMS, FAMOS

[9] and with appropriate validation using the detailed simulation.

The NLO cross section is calculated by PROSPINO [10], assuming only the $\tilde{g} - \tilde{g}$, $\tilde{g} - \tilde{q}$ and $\tilde{q} - \tilde{q}$ productions to be relevant. For 10 fb^{-1} the jet energy scale and b-tagging uncertainties expected are smaller compared to 1 fb^{-1} [7]. The jet energy scale relative uncertainty on the final result amounts to 11.3% while the relative systematic uncertainty from the b-tagging is 7% [7]. The total relative systematic uncertainty is 13.7%. The reach result for 1 and 10 fb^{-1} is shown in figure 7. The larger reach in the high m_0 region is

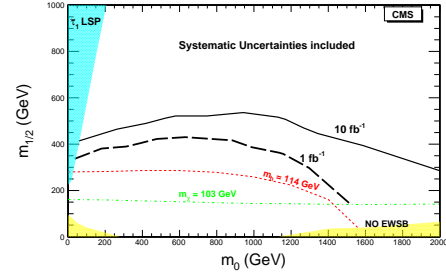FIG. 7: The CMS experiment reach for mSUGRA in top+E_T^{miss} final states in m_0-$m_{1/2}$ plane and for $\tan\beta = 10$, $A_0 = 0$ and $\mu > 0$. The shaded regions are excluded because either the $\tilde{\tau}_1$ would be the LSP or because there is no radiative electroweak symmetry breaking. The regions excluded by the LEP limit on the h^0 or the $\tilde{\chi}_1^\pm$ masses are delineated by dashed lines.

due to the dominant three body decay of the gluino to top quark in this region.

IV.   CONCLUSION

We present the observability study of low mass SUSY using an inclusive selection of events with a hadronically decaying top quark and large missing energy in the final state. We estimate that for the test point LM1 the 5σ discovery is achievable with 0.25 fb^{-1}. The CMS 5σ reach contours in the mSUGRA parameter space for 1 and 10 fb^{-1} are also given.

V.   ACKNOWLEDGMENTS

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