Searching for SUSY at the Tevatron

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An overview of recent experimental searches for SUSY particles is presented. These searches are based on data collected by the CDF and the DØ experiments operating at the Fermilab Tevatron proton-antiproton collider with $\sqrt{s} = 1.96$ TeV. The review focuses on searches for squarks and gluinos in final states with missing transverse energy and jets. Emphasis will be given to the search for the gluino decaying into a sbottom and b quark with each sbottom decaying into a b quark and a neutralino. This scenario yields events containing 4 b-jets and missing transverse energy.

1 Introduction

Despite of its extraordinary success, the Standard Model (SM) is believed to be an effective "low energy theory" of a more fundamental theory. One attractive extension of the Standard Model is Supersymmetry (SUSY) [1], a spacetime symmetry that relates bosons to fermions and introduces for each SM particle a SUSY partner. SM and SUSY particles carry a value of +1 and -1 for R$-$parity respectively. Therefore in R$-$parity conserving theories SUSY particles are produced in pairs and they decay into SM particles and the lightest supersymmertic particle (LSP) which is stable and it would escape detection. One of the most interesting LSP candidate is the lightest neutralino χ_1^0 which might also explain dark matter in the universe. In this paper, we will consider only R-parity conserving searches where the presence of missing transverse energy is a powerful signature of SUSY.

At hadron collider we expect that gluinos and squarks would be copiously produced if they are sufficiently light. If squarks are lighter than gluinos then the squarks can decay to $\tilde{q} \rightarrow q\chi_1^0$. In most SUSY models, it is expected that the partners of the four lightest quark will have similar masses. On the contrary, the partners of the heaviest quarks could be the lightest squarks. The states $\tilde{q}_L$ and $\tilde{q}_R$ are the partners of the left-handed and right-handed quarks, which mix to form mass eigenstates $\tilde{q}_{1,2}$. The stop is expected to be light because of the large mass of the top quark. For scenarios with large $\tan\beta$ (the ratio of the vacuum expectation values of the two Higgs fields), the mixing can be quite substantial in the sbottom sector [2], so that the lighter sbottom mass eigenstate (denoted by $\tilde{b}_1$), could also be significantly lighter than other squarks.

In this paper we review current results form gluino-squark search from the DØ collaboration and gluino-sbottom searches from the CDF collaboration. The trigger for both searches required jets and significant missing energy.

2 Gluino and Squark searches

The DØ collaboration has performed a search for gluinos and squarks using 85 pb^{-1} collected in run II of the Tevatron. The selection cuts developed by the DØ collaboration aimed at enhancing the SUSY signal and rejecting the large standard model backgrounds. The analysis requires two jets in the event. The leading jet is required to be central ($|\eta| < 0.8$) and to have transverse momentum above 60 GeV/c. Events with an isolated electron or a muon with momentum above 10 GeV/c were rejected to decrease the electro-weak background. The QCD multi-jet background was significantly reduced by rejecting events were the missing transverse energy is parallel or antiparallel to a jet by requiring the minimum $\Delta\phi(\not{E}_T, jet) > 30^\circ$ and maximum $\Delta\phi(\not{E}_T, jet) < 165^\circ$. The final selection criteria were optimized by minimizing the expected cross section upper limit and requiring $\not{E}_T > 175$ GeV and the transverse energy of the jets $H_T > 275$ GeV.

In order to extract the SUSY signal, the standard model background must be calculated. The Electro-weak decays of W and Z boson were generated with the ALPGEN program, interfaced with PYTHIA for the simulation of initial and final state radiation and jet hadronization. The most significant backgrounds is due to $Z \to \nu\bar{\nu}$ + 2 jets. The QCD background was evaluated from the data using events with low $\not{E}_T$ and for $\not{E}_T > 175 GeV/c$ was found to be negligible.

The simulation of the production of squarks and gluinos was done with the PYTHIA Monte Carlo in the framework of mSUGRA. The K-factor for the various production processes was determined by Prospino[3]. The input parameters were chosen at the boundary of the Run I exclusion domain: $m_0 = 25$ GeV/c^2, $\tan\beta$=3, $A_0 = 0$, $\mu < 0$, and $m_{1/2}$ in the range 100 to 140 GeV/c^2 in 5 GeV/c^2 steps. Only squarks belonging to the first two generation were considered. The signal efficiency after these selection varies between 2 and 7 % as the $m_{1/2}$ increases from 100 to 140 GeV/c^2. The main systematic uncertainties are due to the 5.6 % uncertainty in the integrated luminosity and the uncertainty jet energy scale in the data and in the Monte Carlo which yields a $^{+20}_{-15}$% relative uncertainty on the signal efficiency and a $^{+77}_{-43}$% uncertainty on the SM background prediction. The systematic error on the signal and the Standard model backgrounds are about 10 % and 8% respectively. DØ observes four events while 2.7 ± 0.95 events were expected. Taking into account the signal efficiency, the systematic uncertainties and the integrated luminosity of 85.1 ± 5.5 pb^{-1}, cross section limits were set on the mSUGRA parameter space. The results are displayed in Fig. 1. This limits exclude a gluino mass of 333 GeV/c for a squark mass of 292 GeV/c. The corresponding most probable gluino-mass limit expected in this analysis is 338 GeV/c. The new analysis has already pushed the 95 % C.L> slightly beyond the Run I limits [4].

3 Gluino-Sbottom searches

The CDF collaboration has conducted a search for gluino-sbottom production using 156 pb^{-1} of data collected during Run II of the Tevatron. The analysis assumes a scenario where the sbottom is lighter than the gluino and relies on the large gluino pair production cross-section. Next to leading order calculation (NLO) using PROSPINO [3] predicts a cross-section of 2.04 pb for a gluino of mass 240 GeV/c^2 at $\sqrt{s} = 1.96$ TeV, which is large compared cross-section of

0.072 pb for sbottoms of the same mass. R-parity conservation is assumed and a neutralino with a mass of 60 GeV/c^2 is supposed to be LSP. A SUSY scenario where gluinos are pair-produced and then decay 100% into sbottom bottom ($\tilde{g} \to \tilde{b}_1 b$), followed by the sequential decay of the sbottom in bottom and lightest neutralino ($\tilde{b}_1 \to b\tilde{\chi}_1^0$) is assumed. Since the neutralinos escape detection, this leaves a signature of four b-jets and missing transverse energy ($\not{E}_T$).

The data sample is collected with a trigger that requires $\not{E}_T \equiv |\vec{\not{E}_T}| \geq 35$ GeV and two jet clusters. The missing transverse energy ($\not{E}_T$) is defined as the negative vector sum of the transverse energy in the electromagnetic and hadronic calorimeter. $\not{E}_T$ was required to be larger than 35 GeV and stringent selection criteria were applied. At the selection stage the data is dominated by QCD multijet, with the large $\not{E}_T$ resulting from jet mismeasurements or from semileptonic b-decays in which the neutrino escapes detection. In both cases the $\not{E}_T$ is aligned with mismeasured jets or b-jets. The $\not{E}_T$ in signal originates form the neutralinos from the sequential decay of the gluinos and is therefore not correlated to the jets. By requiring that the minimum $\Delta\phi(\not{E}_T, jet) > 40°$, the standard model background can be effectively reduced while keeping a large signal acceptance. A secondary vertex tagging algorithm is applied to identify b-jets and to reduce the background further.

Understanding of the standard model background is achieved by studying control regions neighboring the signal box. The regions are defined in terms of $\not{E}_T$ and the presence of high momentum isolated leptons. We expect our signal to have large $\not{E}_T$ and no leptons. The regions with low $\not{E}_T$ (35 GeV $< \not{E}_T <$ 50 GeV) with and without a lepton serve as control regions for the QCD multijet background. The control region with $\not{E}_T >$ 50 GeV and containing high transverse momentum isolated leptons is used to check the top and W/Z+jets/Diboson background.

ALPGEN [7] in combination with the HERWIG [8] event generator was used to estimate the acceptance of the W and Z boson background. The cross-sections at NLO were obtained using the MCFM [9] program. The top contributions and the QCD heavy flavor background were predicted using the PYTHIA [10] event generator. The QCD light quark contribution which originates from light quark jets being mis-identified as heavy flavor jets was estimated using a parametrization of the fake tag rate obtained from data. Various distributions in the control regions have been studied and found to be in agreement with observations.

The signal predictions were computed using the ISAJET [11] event generator with the CTEQ5L parton distribution functions.

CDF performs two analysis, one using exclusive single b-tagged events and the other requiring inclusive double b-tagged events. The single b-tag analysis is expected to have a better reach for a nearly mass degenerated gluino-sbottom scenarios since b-jets from gluino decays are very soft and less likely to be tagged. The double tag analysis suppresses the background more effectively and it is expected to perform better in the other kinematic regions. Fig. 2 shows the $\not{E}_T$ spectrum for both cases. The best signal sensitivity was achieved by requiring $\not{E}_T >$ 80 GeV, which was optimized using signal MC.

The signal acceptance systematic uncertainty for the exclusive single tag analysis (16.5% in total) was dominated by jet energy scale (10%), modeling of initial and final state radiation (7.5%), b-tagging efficiency (7%), luminosity (6%), Monte Carlo statistics (3%), trigger efficiency (2.5%), parton distribution functions (2%), and lepton veto (2%). The uncertainties for the inclusive double tag analysis were very similar, except the b-tagging efficiency systematics was increased.

The signal region was only analyzed after all the background predictions and selection cuts were finalized. Twenty one exclusive single b-tagged events were observed, which is in agreement with SM background expectations of 16.4 ± 3.7 events. Requiring inclusive double b-tag we observed 4 events, where 2.6 ± 0.7 were expected, as summarized in Table:1.

Since no evidence for gluino pair production with sequential decay into sbottom-bottom was

Table 1: Number of expected and observed events in the signal region.

Process	Exclusive Single B-Tag	Inclusive Double B-Tag
W/Z+jets/Diboson	5.66 ± 0.76(stat) $\pm$ 1.72(sys)	0.61 ± 0.21(stat) $\pm$ 0.19(sys)
TOP	6.18 ± 0.12(stat) $\pm$ 1.42(sys)	1.84 ± 0.06(stat) $\pm$ 0.46(sys)
QCD multijet	4.57 ± 1.64(stat) $\pm$ 0.57(sys)	0.18 ± 0.08(stat) $\pm$ 0.05(sys)
Total predicted	16.41 ± 1.81(stat) $\pm$ 3.15(sys)	2.63 ± 0.23(stat) $\pm$ 0.66(sys)
Observed	21	4

found, an upper limit cross-sections at 95% C.L. was computed using the Bayesian likelihood method. cross section limit and the exclusion plot as a function of the gluino and squark masses are shown Fig. 3). The results improve the existing limits significantly.

4 Conclusion

Searches for new physics have been performed by CDF and DØ. Even with a fraction of the data that it will be collected by the end of Run II of the Tevatron the two experiments are significantly improving current limits. No evidence for squark-gluino or for gluino-sbottom has been was found.

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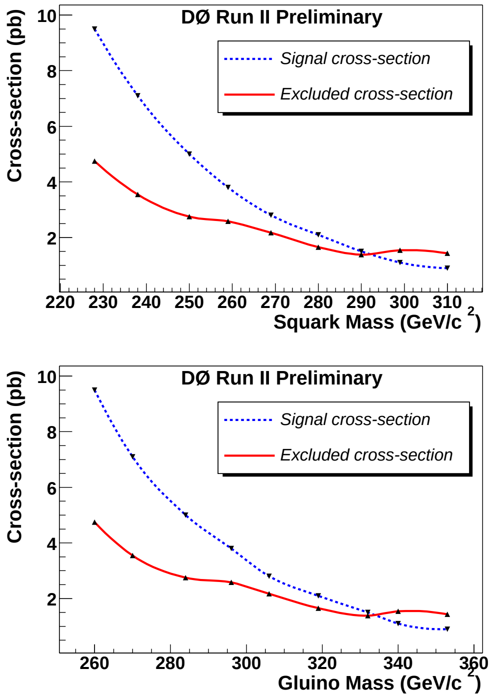

Figure 1: squark and gluino production cross section upper limit as a function of the average squark (top) and gluino (bottom) masses and theoretical expectations for $m_0 = 25GeV/c^2$, $A_0 = 0$, $\tan\beta = 3$ and $\mu < 0$

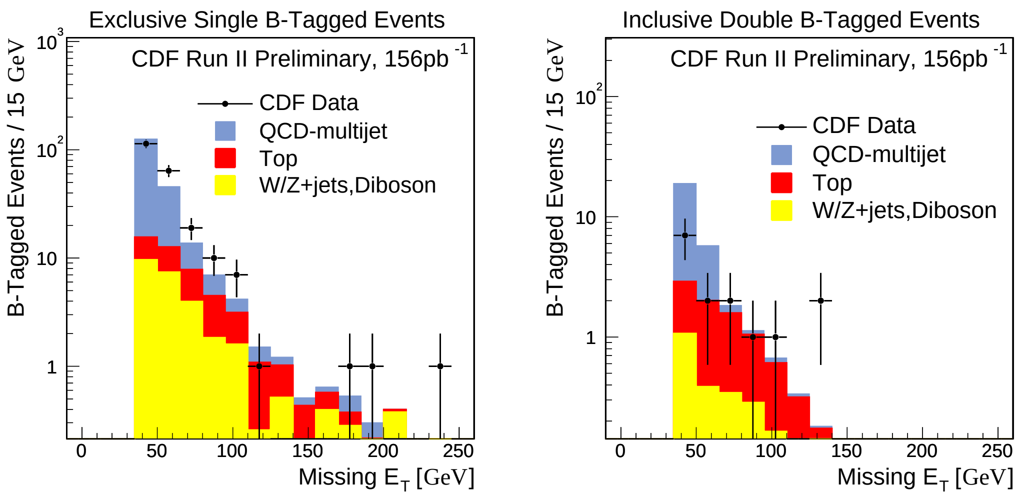

Figure 2: $\not\!\!E_T$ spectrum after vetoing events with high P_t isolated leptons, for exclusive single tagged events (left) and inclusive double tagged events (right).

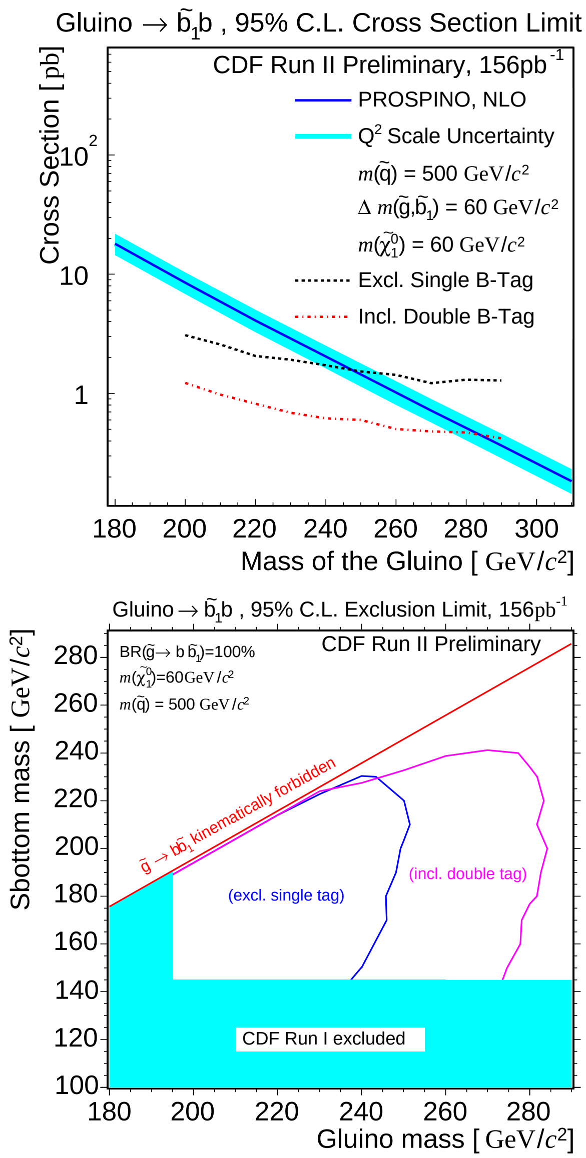

Figure 3: Left: 95% C.L. upper cross-section limit as a function of the gluino mass and for a constant mass difference $\Delta m(\tilde{g}, \tilde{b}_1) = 60\ \mathrm{GeV}/c^2$ between the gluino and sbottom. Right: 95% C.L. exclusion contours in the $m(\tilde{g})$ and $m(\tilde{b}_1)$ plane obtained requiring exclusive single b-tagged events and inclusive double b-tagged events.