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Searches for squarks and gluinos at DØ

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Recent results obtained by the DØ Collaboration on searches for squarks and gluinos in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV at the Fermilab Tevatron collider are discussed. For the inclusive searches, events with multiple jets of hadrons and large missing transverse energy in the final state are studied within the framework of minimal supergravity and assuming R-parity conservation. Searches for the scalar top quark are studied in two final state topologies: with events of two charm jets and large missing transverse energy or leptons, jets and missing transverse energy. The data, corresponding to integrated luminosities of up to 2.1 fb^{-1}, show no excess of a signal above the expected background in any of the decay channels examined. Instead, upper limits at 95% Confidence Level on the squarks and gluino masses are derived.

1. INTRODUCTION

Supersymmetric models [1] are amongst the most promising fundamental theories to extend the Standard Model (SM) and describe physics at arbitrarily high energies. Each of the SM particles has a partner differing by a half-unit of spin. If R-parity [2] is conserved, supersymmetric particles are produced in pairs, and their decay leads to SM particles and to the lightest supersymmetric particle (LSP), which is stable. Cosmological arguments suggest that the LSP should be neutral and colorless. The lightest neutralino $\tilde{\chi}_1^0$, which is a mixture of the superpartners of the neutral gauge and Higgs bosons, fulfills these conditions. In the following, it is assumed that R-parity is conserved. Since the LSP is weakly interacting, it escapes detection and provides the missing transverse energy ($\not{E}_T$) signature. In $p\bar{p}$ collisions, squarks ($\tilde{q}$) and gluinos ($\tilde{g}$), the superpartners of quarks and gluons, would be abundantly produced, if sufficiently light, by the strong interaction, leading to final states containing jets and $\not{E}_T$. The limits discussed in this note have been obtained in the model of minimal supergravity (mSUGRA) [3].

2. INCLUSIVE SEARCH FOR SQUARKS AND GLUINOS

The inclusive searches for squarks and gluinos have been performed in three separate analyses [4]. The analysis strategy was to optimize for three benchmark regions of the mSUGRA parameter space. A "dijet" analysis was optimized at low m_0 for events containing a pair of acoplanar jets, as expected from $p\bar{p} \to \tilde{q}\bar{\tilde{q}} \to q\tilde{\chi}_1^0\bar{q}\tilde{\chi}_1^0$ and $p\bar{p} \to \tilde{q}\tilde{q} \to q\tilde{\chi}_1^0 q\tilde{\chi}_1^0$. A gluino analysis was optimized at high m_0 for events with at least four jets, as expected from $p\bar{p} \to \tilde{g}\tilde{g} \to q\bar{q}\tilde{\chi}_1^0 q\bar{q}\tilde{\chi}_1^0$. Finally, a 3-jets analysis was optimized for events with at least three jets, as expected from $p\bar{p} \to \tilde{q}\tilde{g} \to q\tilde{\chi}_1^0 q\bar{q}\tilde{\chi}_1^0$. The benchmark for this analysis is the case where $m_{\tilde{q}} = m_{\tilde{g}}$.

The SM processes leading to events with jets and real $\not{E}_T$ in the final state ("SM backgrounds") are the production of W or Z bosons in association with jets (W/Z+jets), of pairs of vector bosons (WW, WZ, ZZ) or top quarks ($t\bar{t}$), and of single top quarks. The neutrinos from the decays $Z \to \nu\bar{\nu}$ and $W \to \ell\nu$, with the W boson produced directly or coming from a top quark decay, generate the $\not{E}_T$ signature. While the $Z(\to \nu\bar{\nu})$+jets events are an irreducible background, most of the W boson leptonic decays leading to an electron or a muon were identified, and the corresponding events rejected. However, a charged lepton from W boson decay can escape detection or fail the identification criteria. Such W+jets events therefore exhibit the jets plus $\not{E}_T$ signature. Finally, multijet production also leads to a final state with jets and $\not{E}_T$ when one or more jets are mismeasured ("multijet background").

Each analysis required at least two jets and substantial $\not{E}_T$ ($\geq$ 40 GeV). In the "3-jets" and "gluino" analyses, a third and fourth jet were required, respectively. The transverse momenta of the jets up to the third jet had to be greater than 35 GeV and greater than 20 GeV for the fourth jet. The two leading jets (jets with largest transverse momenta) were required: to be confirmed by tracks originating from the primary vertex and to be in the central

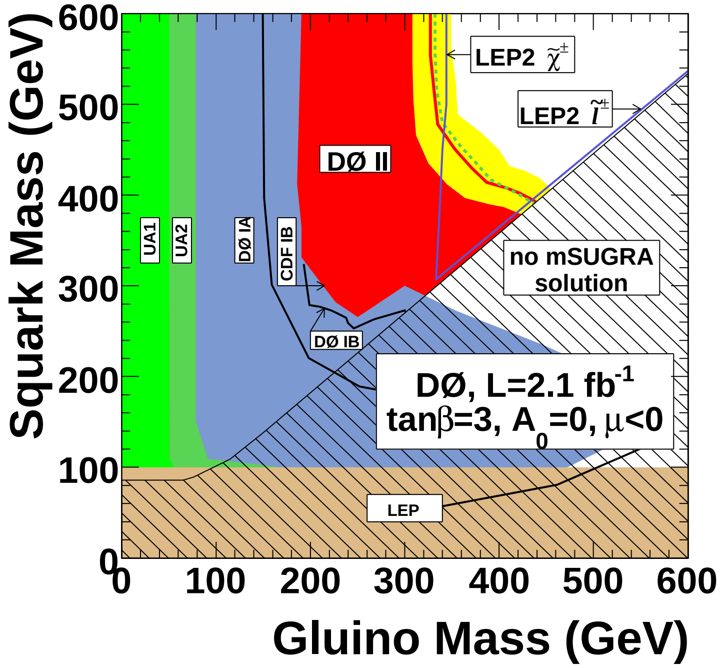

Figure 1: In the gluino and squark mass plane, excluded regions at the 95% C.L. by direct searches in the mSUGRA framework with $\tan\beta = 3$, $A_0 = 0$, $\mu < 0$. The thick (dotted) line is the limit of the observed (expected) excluded region. Whereas, the yellow band shows the effect of the PDF choice and of the variation of renormalization and factorization scale by a factor of two.

region of the calorimeter, $|\eta_{det}| < 0.8$, where $|\eta_{det}|$ is the jet pseudorapidity calculated from the detector center. The track confirmation requirement removes events with spurious $\not\!\!E_T$ due to the choice of an incorrect primary vertex. The acoplanarity, i.e. the azimuthal angle between the two leading jets, was required to be smaller than 165^0. In all three analyses, a veto on isolated electrons or muons with transverse momentum greater than 10 GeV was applied to reject background events containing leptonic decays. The azimuthal angles between the $\not\!\!E_T$ and the first and the second jet, ($\geq 90^0$ and $\geq 50^0$ respectively), were used to remove events where the energy of one jet was mismeasured, generating $\not\!\!E_T$ aligned with that jet. In the "dijet" analysis, the minimum azimuthal angle $\Delta\phi(\not\!\!E_T, \text{any jet})$ between the $\not\!\!E_T$ and any jet with $p_T > 15$ GeV was required to be greater than 40^0 to further suppress the multijet background.

The two final cuts on $\not\!\!E_T$ and on $H_T = \sum_{\text{jets}} p_T$, where the sum is over all jets with $p_T > 15$ GeV and $|\eta_{det}| < 2.5$, were optimized by minimizing the expected upper limit on the cross section in the absence of signal. The minimum ($\not\!\!E_T$, H_T) cuts were (225, 325), (175, 375) and (100, 400) GeV for the "dijet", "3-jets" and "gluino" analysis respectively. The multijet background contribution was estimated by fitting the $\not\!\!E_T$ distribution below 60 GeV with an exponential function, after subtraction of the SM background processes, and subsequently extrapolating this function above the chosen $\not\!\!E_T$ cut value. This contribution was found to be negligible and was conservatively ignored in the limit setting.

The numbers of events observed in the data are in agreement with the SM background expectation in the three analyses. The number of events passing at least one of the three analyses is 31 while the SM expectation is $32.6 \pm 1.7\ (\text{stat.})^{+9.0}_{-5.8}\ (\text{syst.})$ events. Fig. 1 shows the excluded domain at 95% C.L. in the gluino-squark mass plane with an integrated luminosity of 2.1 fb^{-1}. The observed (expected) limits on the squark and gluino masses are 392 (391) GeV and 327 (332) GeV. Limits were also derived for the particular case of $m_{\tilde{q}} = m_{\tilde{g}}$ where squarks and gluino masses below 390 GeV are excluded.

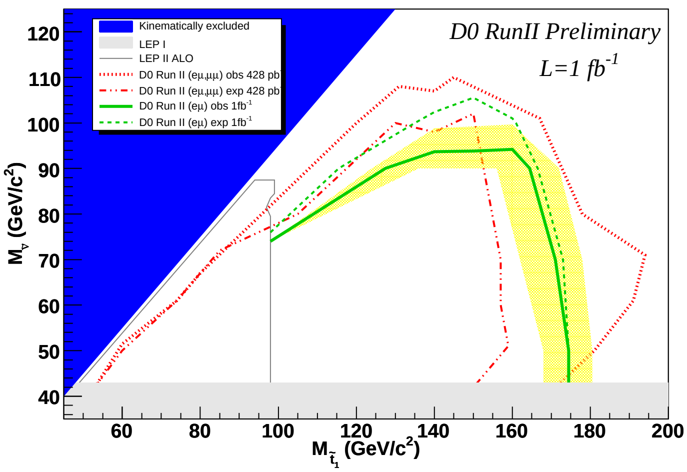

Figure 2: Region in the $\tilde{t}$–$\tilde{\chi}_1^0$ mass plane excluded at the 95% C.L. by the present search. The observed (expected) exclusion contour is shown as the green solid (dashed) line. The yellow band represents the theoretical uncertainty on the scalar top quark pair production cross section due to PDF and renormalization and factorization scale choice.

3. SEARCH FOR SUPERSYMMETRIC TOP QUARK IN JETS AND $\not\!\!E_T$ FINAL STATE

The mass splitting between the supersymmetric partners of the top quark ($\tilde{t}$) is proportional to the mass of the top quark. This can make one of the stops the lightest of all squarks. In this search [5], the stop quark is taken to be the next to the lightest supersymmetric particle and is assumed to decay into a charm quark and a $\tilde{\chi}_1^0$ via loop decay. The final state consists of two acoplanar charm jets and missing transverse energy. The backgrounds to this channel are similar as to the generic squarks and gluinos search and the multijet background is estimated in the same way as well, as described in the previous section.

The search strategy for $\tilde{t}$ involves three steps which include the application of the selection criteria on kinematical variables, heavy flavor tagging and optimization of the final selection depending on $\tilde{t}$ and $\tilde{\chi}_1^0$ masses. The selection cuts require exactly two jets, within $|\eta_{det}|$ of 1.5 and confirmed by tracks originating from the primary vertex. The leading and trailing jets have to have a transverse momentum more than 40 and 20 GeV respectively and separated by an azimuthal angle of less than 165^0. Events with isolated electrons, muons and tracks are removed to reduce the backgrounds with W decays. Several topological cuts on the combination of $\not\!\!E_T$ and H_T are further applied to reduce the multijet contribution with mismeasured $\not\!\!E_T$. To enhance the rate of events with charm jets in the final state at least one of the jets is required to be heavy flavor tagged with DØ's neural network (NN) based tagging tool. The requirement on the NN output is kept loose to get a high efficiency for detection of charm jets ($\approx 30\%$) with a $\approx 6\%$ probability for a light parton jet to be mistakenly tagged.

At the final stage of the analysis, additional selection criteria on three kinematic variables: $\not\!\!E_T$, H_T and $S = \Delta\phi_{max} + \Delta\phi_{min}$, where $\Delta\phi_{max}$ ($\Delta\phi_{min}$) is the largest (smallest) azimuthal separation between a jet and $\not\!\!E_T$, are optimized by maximizing the expected lower limit on the neutralino mass for a given $m_{\tilde{t}}$. In all cases a requirement of $\not\!\!E_T > 70$ GeV is imposed. No contamination remains from multijet background at this point in the analysis, which is therefore neglected while setting the limit. Using the assumption that $\tilde{t}$ decays into a charm quark and a neutralino with 100% branching fraction and the nominal $\tilde{t}$ pair production cross section, the largest $m_{\tilde{t}}$ excluded by this analysis is 155 GeV, for a neutralino mass of 70 GeV at the 95% C.L. The excluded region in the $\tilde{t}$–$\tilde{\chi}_1^0$ mass plane with 1 fb^{-1} of data is shown in Fig. 2.

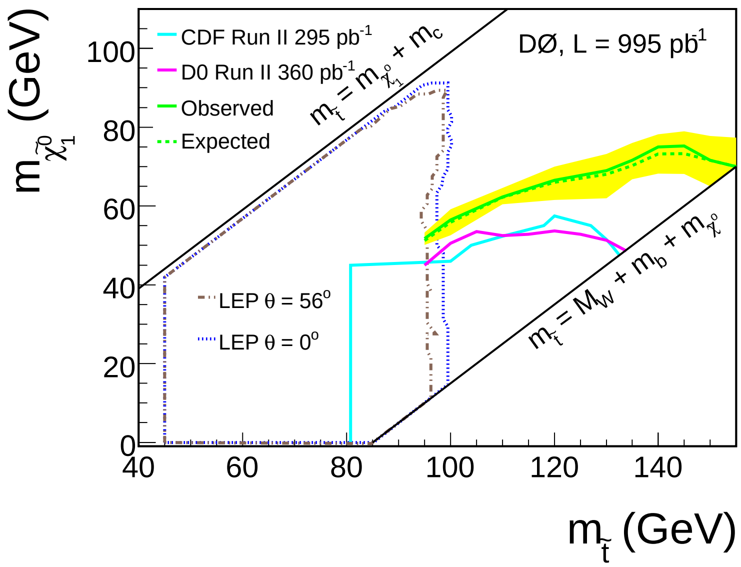

Figure 3: Exclusion limits in the stop mass versus sneutrino mass plane at the 95% C.L. The dashed green line is the expected limit and the full green line is the observed limit. The yellow band around the observed limit accounts for the effect of the stop cross section uncertainties.

4. SEARCH FOR SUPERSYMMETRIC TOP QUARK IN LEPTONS, JETS AND $\not\!\!E_T$ FINAL STATE

If the $\tilde{t} \to c\tilde{\chi}_1^0$ and $\tilde{t} \to b\tilde{\chi}_1^{\pm}$ modes are kinematically forbidden, then stop quarks will decay into a lepton, a bottom quark and a sneutrino via $\tilde{t} \to b\ell\tilde{\nu}$. The event signature for stop pair production will be two b jets, a pair of isolated leptons and missing transverse energy. A search is performed with 1.1 fb^{-1} of DØ data in the most sensitive channel where one lepton is a muon and the other one an electron [6], which has the largest branching ratio and the smallest backgrounds among the three leptonic decay modes.

The SM backgounds to this channel come from processes with isolated electron and muon pairs: $Z \to \tau\tau$, WW, WZ, ZZ, and $t\bar{t}$. The second background source is due to either mis-identified electrons, muons or jets, mismeasured $\not\!\!E_T$, or electrons or muons from multijet processes which pass lepton isolation requirements. This multijet background is estimated from data.

The selection cuts require events with an electron and a muon. Jets, electron and muon have to be isolated from each other. The analysis is using further a set of cuts on the azimuthal separation between the electron, muon and $\not\!\!E_T$ to reduce the multijet background. The $\not\!\!E_T$ is required to be larger than 30 GeV.

The exclusion limits have been derived from the shapes of the H_T and S_T distributions, where S_T is defined as the scalar sum of the electron, muon and missing transverse energy. The exclusion domain is shown in Fig. 3 in the $(m_{\tilde{t}}, m_{\tilde{\nu}})$ plane. For large mass differences, stop masses lower than 175 GeV are excluded.

References

[1] H.E. Haber and G.L. Kane, Phys. Rep. **117**, 75 (1985).
[2] P. Fayet, Phys. Lett. B **69**, 489 (1977).
[3] H.P. Nilles, Phys. Rep. **110**, 1 (1984).
[4] V.M. Abazov *et al.*, Phys. Lett. B **660**, 449 (2008).
[5] V.M. Abazov *et al.*, Phys. Lett. B **665**, 1 (2008).
[6] DØ Collaboration, 5598-CONF (2008).