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Search for SUSY and RPV-SUSY at the Tevatron

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ABSTRACT: New results of searches for Supersymmetry from the DØ experiment are presented.

Fermilabs Tevatron, the highest energy hadron collider to date, has delivered ~ 130 pb^{-1} integrated luminosity between 1992 and 1996 at $\sqrt{s} = 1.8$ TeV (Run I). Since 1996, the Tevatron and its two detectors, CDF and DØ, have undergone considerable upgrade and restarted operation last spring (Run II). We report here new results of searches for Supersymmetry with the DØ detector in Run I and give prospects for Run II, where one expects 15 fb^{-1} integrated luminosity toward the end of 2006.

Supersymmetry (SUSY) is a hypothetical symmetry of Nature under the interchange of fermions and bosons [1]. It has been introduced to avoid quadratic divergences in the Higgs mass and to explain electroweak symmetry breaking. It is also one of the basic ingredients for unification of forces. This is the reason of its great popularity in spite that it has not received experimental confirmation yet.

In the minimal supersymmetric extension (MSSM) of the Standard Model (SM) each SM particle has one supersymmetric partner different by $\pm\frac{1}{2}$ in its spin. One assigns positive and negative R parity [2] to the SM particles and their partners (denoted by $\tilde{X}$), respectively. Two Higgs doublets are needed, which materialize into two charged and three neutral massive scalar bosons after electroweak symmetry breaking. Additional hypotheses are needed in order to reduce the large number of unknown parameters due to the fact that SUSY is a broken symmetry. The so-called "phenomenological" p-MSSM [1] and the m-SUGRA [3] models containing 19 and 5 new parameters, respectively, are used in the analyses presented below. Low energy experiments tell us that R-parity is approximately conserved. Possible small violation can be expressed by 48 new couplings. Again, in order to reduce the number of unknown parameters and to ensure proton stability, one usually assumes that only one of these couplings is dominant at a time.

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1. Direct Search for Charged Higgs

Indirect search of $t \to H^+b$ has been carried out previouseley by DØ [4] by looking for a decrease in $t\bar{t} \to W^+bW^-\bar{b}$. The direct search presented here is based on that $t \to H^+b$ followed by $H^+ \to \tau^+\nu$ is enhanced at high $\tan\beta$, where $\tan\beta$ is the ratio of the expectation values of the two Higgs doublet fields. Consequently, one expects high τ production in top decays as compared to the SM. Since τ's are identified by their hadronic decays, the experimental signature is $t\bar{t} \to (HH/HW)bb \to (4j/5j)\not{E}_T$, where $\not{E}_T$ denotes missing energy in the transverse plane. Accordingly, events were selected with $\not{E}_T > 25$ GeV, containing at least 4 jets in the transverse energy and pseudo rapidity range of 20< E_T <150 GeV and $|\eta|$ <2, respectively, with no more than 8 jets of E_T >8 GeV. A further selection using a feed-forward neural network (NN) with $\not{E}_T$ and two of the three eigenvalues of the normalized momentum tensor as input variables was applied. The event had to contain also at least one τ candidate identified as a narrow hadronic jet with 10< E_T <60 GeV.

Three candidate events have been found using a total integrated luminosity of $\mathcal{L}_{\mathrm{int}}$ = 62.2 pb^{-1}. The estimated number of background events amounts to 5.2±1.6, which can be broken into QCD multijets (3.2±1.5), $t\bar{t}$ (1.1±0.3), and W+jets (0.9±0.3). On the other hand, according to the 2-Higgs doublet model, one expects 14±1 events for a Higgs mass of M_H= 95 GeV and $\tan\beta = 150$. Exclusion limits have been obtained assuming $B(t \to W^+b) + B(t \to H^+b) = 1$, 0.3<tan$\beta$ <150, $m_H <$ 160 GeV and $B(t \to H^+b)$ <0.9. Figure 1 shows these limits obtained in the direct (present analysis) and indirect [4] search, as well as using the "Bayesian" and "Frequentist" technique [5].

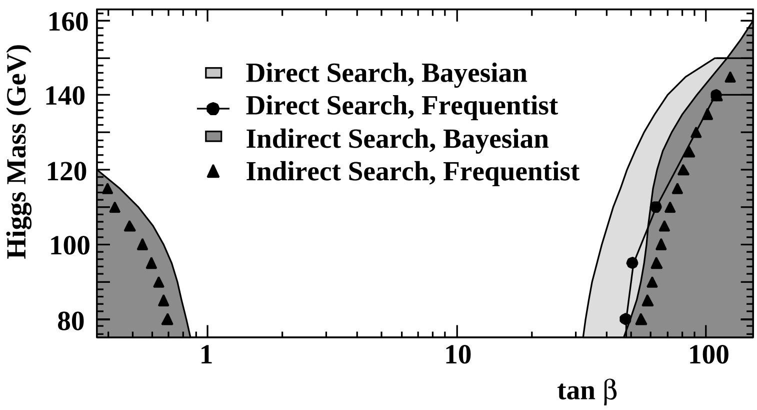

Figure 1: The 95% CL exclusion boundary in the $(M_{H^\pm}, \tan\beta)$ plane for $m_t = 175$ GeV and $\sigma(t\bar{t})$ = 5.5 pb.

2. Search for Light Scalar t-quark in $\tilde{t} \longrightarrow bl\tilde{\nu}$

Top s-quark may be light and copiously produced at the Tevatron if the mixing of $\tilde{t}_L$ and $\tilde{t}_R$ is large. Moreover, the decay chain $\tilde{t} \to \tilde{\chi}_1^+ b$; $\tilde{\chi}_1^+ \to l^+\tilde{\nu}$ dominates, when $\tilde{\nu}$ is the LSP, as is assumed in the present study. Events with more than one electron and muon of $E_T >$ 15 GeV accompanied by $\not{E}_T >$ 15 GeV, were selected. Additional cuts on the pseudorapidity and azimuthal angle of the leptons were applied: $\Sigma_\eta^{e\mu} = |\eta_e + \eta_\mu| < 2$ and $0.26 < \Delta_\eta^{e\mu} = |\phi_e - \phi_\mu| < 2.88$. In a data sample of $\mathcal{L}_{\rm int}$ = 108.3 pb^{-1} 11 events remained after the above selection. The instrumental and SM background totals to 13.4±1.5 which are due to QCD events where jets fake electrons, $Z(\rightarrow \tau^+\tau^-)$, WW, D–Y, $t\bar{t} \rightarrow e\mu\not{E}_T$. On the other hand, the p-MSSM model predicts 13.9±2.3 events for the masses $m_{\tilde{t}} = 120$ GeV and $m_{\tilde{\nu}} = 60$ GeV. This fact allows to exclude a large region in the ($m_{\tilde{t}}$,$m_{\tilde{\nu}}$) plane (Figure 2). If the process does not exist, one will be able to increase this limit upto $m_{\tilde{t}} \sim 230$ GeV and $m_{\tilde{\nu}} \sim 150$ GeV in Run II using 2 fb^{-1} of integrated luminosity.

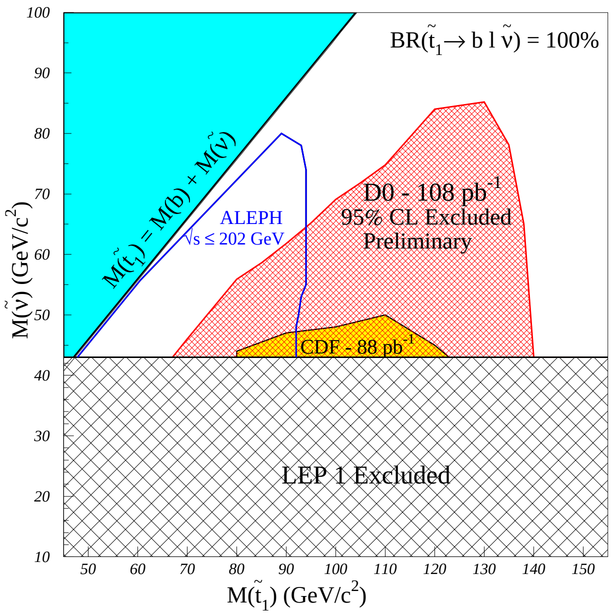

Figure 2: Excluded region at 95% CL in the ($m_{\tilde{t}}$,$m_{\tilde{\nu}}$) plane obtained by the present (DØ), CDF and LEP experiments.

3. Decay of $\tilde{\chi}_1^0 \longrightarrow \mu q q'$

One of the consequences of the violation of R-parity is that the LSP is unstable. Assuming the $\tilde{\chi}_1^0$ as the LSP and that among the 48 couplings only one is dominant (λ'_{2jk}, $j = 1, 2$, $k = 1, 2, 3$), one can expect events with 2 energetic muons and 4 energetic jets. Events with at least 4 jets (E_T >15 GeV) and 2 muons (p_T^1 >15 GeV, p_T^2 >10 GeV) have been searched for with additional restrictions on the invariant mass of the muon pair ($M_{\mu\mu} > 5$ GeV), on the scalar sum of the transverse momentum of the jets and muons ($H_T = \Sigma|p_T^{j,\mu}| < 150$ GeV) and on the aplanarity of the event ($\mathcal{A} > 0.03$). Using $\mathcal{L}_{\rm int}$ = 77.5 pb^{-1} of data no events passed the above selection. The expected SM background is 0.18±0.03(stat)±0.02(syst), the dominant components being $Z \longrightarrow \mu\mu + nj$ and $t\bar{t} \longrightarrow \mu\mu$. The obtained exclusion contour is shown in Figure 3 in the m-SUGRA parameter space. Also shown is the exclusion obtained earlier in the $2e$+$4j$ channel assuming nonzero λ'_{1jk} coupling [6]. If the process does not exist, one will be able to exclude $m_{1/2} < 300$ GeV in Run II.

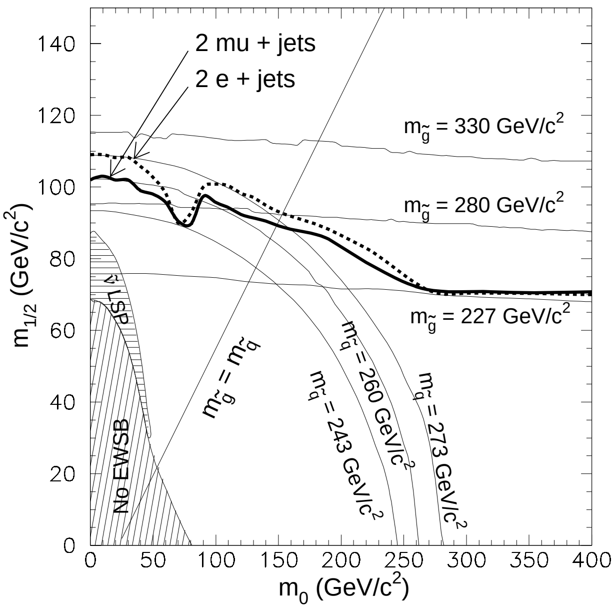

Figure 3: 95% CL exclusion contour in the (m_0,$m_{1/2}$) plane for $\tan\beta = 2$, $A_0 = 0$ and $\mu < 0$.

4. Search for Resonant s-Lepton Production

Another consequence of R-parity violation is single production of superpartners. Assuming that λ'_{211} is nonzero, DØ has searched for single production of the superpartners of the muon ($\tilde{\mu}$) and of the muon-neutrino ($\tilde{\nu}_\mu$). These particles decay directly or via charginos into muons (neutrinos) and to the LSP, which is assumed to be the lightest neutralino ($\tilde{\chi}_1^0$). At the end the LSP decays to a muon and two jets as explained in the previous paragraph. Consequently, the final state contains at least two muons and two jets. Accordingly, events were selected by requiring at least 2 isolated muons with E_T >20 GeV and $|\eta|$ <1.7, 2 isolated jets with E_T >20 GeV and $|\eta|$ <2.5, and $H_T \equiv \Sigma_{E_T^j>15} E_T^j$ >50 GeV. A further selection was applied on the output of a NN, which used as input the isolation parameters of the muons and jets as well as sphericity and aplanarity of the event. Using $\mathcal{L}_{\rm int} = 94$ pb^{-1} only 2 events survived the above selection. The expected SM background amounts to 1.01±0.02, the majority of which originates from Z+nj and $t\bar{t}$ production. On the other hand the total expected signal is 6.42±0.06 in the m-SUGRA space at m_0=200 GeV, $m_{1/2}$=243 GeV, $\tan\beta$=2, $\mu < 0$, $A_0 = 0$. Therefore a large part of the parameter space can be excluded depending on the value of the λ'_{211} coupling. An example is shown in Figure 4. If the process does exist, one will be able to reconstruct the produced s-lepton and determine its mass in Run II. On the contrary, if the process does not exist one will be able to increase the above limits by a factor 2–3, or alternatively, decrease the upper limit on the couplings down to ∼0.01 [7].

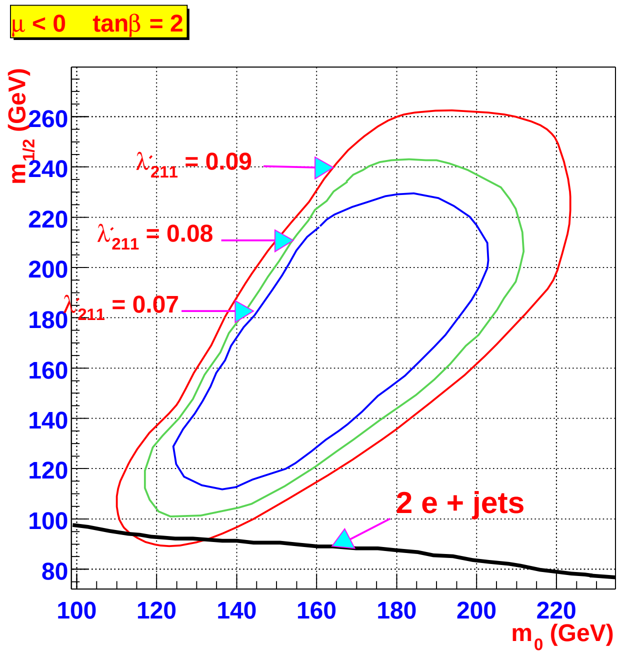

Figure 4: 95% CL exclusion contour in the m-SUGRA space obtained for various λ'_{211} couplings. Also shown is the exclusion obtained in the $2e$+$4j$ channel (see Figure 3).

In conclusion, no sign of SUSY was found in Run I data. The background considered in the searches is from the SM, i.e. background from SUSY itself could be neglected. Run II luminosity and the detector upgrade increases the sensitivity by factors of 2–3 in masses of SUSY particles. If SUSY finally will be found, one will have to refine most of the analyses in order to identify the underlying SUSY interaction and to measure its parameters.

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