



# Searches for Scalar Top and Bottom Quarks at the Tevatron

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Searches for the supersymmetric partners of top and bottom quarks using data up to  $340 \text{ pb}^{-1}$  taken at the Tevatron  $p\bar{p}$  collider are described. We report on searches for scalar top quarks  $\tilde{t}$  in the decays  $\tilde{t} \rightarrow c\tilde{\chi}_1^0$  and  $\tilde{t} \rightarrow b\tilde{\nu}$  and for scalar bottom quarks  $\tilde{b}$  in the decay  $\tilde{b} \rightarrow b\tilde{\chi}_1^0$ . No evidence for a signal has been found, but improved exclusion regions have been derived in the framework of a generic minimal supersymmetric extension of the standard model.

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### 1. Introduction

A major consequence of the realization of supersymmetry (SUSY) in nature would be the existence of scalar partner particles of the standard model fermions. The pair-production of scalar quarks (squarks) at the Tevatron can proceed through gluon fusion or quark annihilation and could have a significant cross-section for relatively low squark masses.

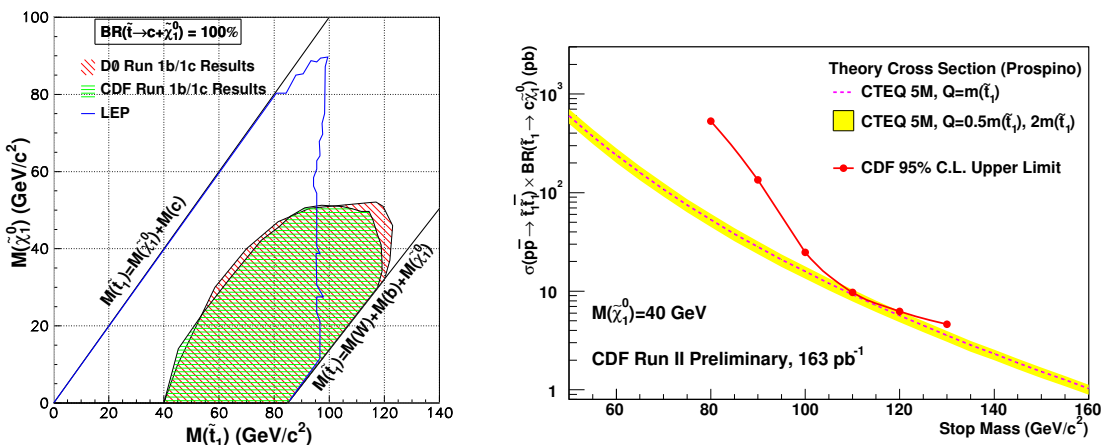
Large Higgs Yukawa couplings to the third quark generation induce a strong mixing between the supersymmetric partners of the two chirality states of the top (and bottom) quark, which leads to two physical states,  $\tilde{t}_1$  and  $\tilde{t}_2$  (and  $\tilde{b}_1, \tilde{b}_2$ ), of different mass [1]. Therefore the lightest scalar top quark  $\tilde{t}_1$  could possibly be much lighter than other squarks. At large values of  $\tan\beta$  a relatively light  $\tilde{b}_1$  is also expected.

If kinematically allowed, a squark will predominantly decay via  $\tilde{q} \rightarrow q\tilde{\chi}_1^0$ , leading to a topology of two jets and missing transverse energy [2]. In the case of the sbottom quark decay the background can be efficiently suppressed by requiring a  $b$ -tag. The two-body stop decays  $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$  and  $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^+$  are kinematically forbidden in the accessible parameter region at the Tevatron. Here, the most promising searches are based on the loop-induced decay  $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$  and the three-body decay  $\tilde{t}_1 \rightarrow bW\tilde{\chi}_1^0$ . The latter might be favored over the decay  $\tilde{t}_1 \rightarrow bW\tilde{\chi}_1^0$  due to the relatively weak constraint on the sneutrino mass  $M(\tilde{\nu}) > 43.7 \text{ GeV}$  [3].

### 2. Search for Scalar Top Quarks in the Decay $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$

The CDF and DØ Collaborations have searched for scalar top quarks decaying into  $c\tilde{\chi}_1^0$  in approximately  $90 \text{ pb}^{-1}$  of Run I data [4, 5]. The CDF collaboration also performed a preliminary measurement based on  $163 \text{ pb}^{-1}$  of Run II data.

Candidate events are selected requiring significant missing transverse energy  $\cancel{E}_T$  and two reconstructed jets. The DØ analysis does not attempt to identify the flavor of the jets, whereas the CDF measurements employ a heavy-flavor tag based on the probability that all the tracks in the



**Figure 1:** Exclusion limits for  $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$ . *Left:* 95% C.L. exclusion region as function of  $M_{\tilde{t}_1}$  and  $M_{\tilde{\chi}_1^0}$ . *Right:* Cross-section limit  $\tilde{t}_1\tilde{t}_1$  pair production for assumed  $M_{\tilde{\chi}_1^0} = 40 \text{ GeV}$  compared to NLO prediction.

jet come from the primary vertex. The background from  $W$  production in association with jets is suppressed by vetoing events with an isolated lepton. Other backgrounds are  $Z$  production in association with jets (with  $Z \rightarrow \nu\bar{\nu}$ ) and QCD multi-jet production. No excess over standard model background has been observed and exclusion limits as a function of  $M_{\tilde{t}}$  and  $M_{\tilde{\chi}_1^0}$  have been generically derived within the minimal supersymmetric extension of the standard model (MSSM) [6].

The limits are shown in Fig. 1, left, together with the combined LEP result [3]. The sensitivity of the Tevatron measurements decreases close to the kinematic limit  $M_{\tilde{t}} = M_{\tilde{\chi}_1^0} + M_c$  due to the minimal required transverse energy of the jets ( $E_T$ ) and  $\cancel{E}_T$ . CDF's preliminary Run II upper cross-section limits shown in Fig. 1, right, do not provide additional constraints on the stop mass, but projections based on integrated luminosities up to  $4 \text{ fb}^{-1}$  indicate sensitivities up to  $M_{\tilde{t}} \approx 175 \text{ GeV}$  at  $M_{\tilde{\chi}_1^0} \approx 100 \text{ GeV}$ .

### 3. Search for Scalar Top Quarks in the Decay $\tilde{t}_1 \rightarrow b\tilde{\nu}$

The best sensitivity for stop pair-production with subsequent decays  $\tilde{t}_1 \rightarrow b\tilde{\nu}$  is obtained in the  $e\mu$  channel. Its branching ratio is twice as large as for the  $ee$  or  $\mu\mu$  channels and the background from  $Z$  and Drell-Yan production is largely reduced.

In Run II, the only preliminary result so far has been obtained in the less preferred  $\mu\mu$  channel using  $340 \text{ pb}^{-1}$  of data, taken with the  $D\bar{D}$  experiment. To maximize the sensitivity close to the kinematic boundary, muons with transverse momenta as low as  $p_T(\mu_1) > 8 \text{ GeV}$  and  $p_T(\mu_2) > 6 \text{ GeV}$  for the leading and trailing muon, respectively, are accepted. In addition one jet with  $b$ -tag and  $E_T > 15 \text{ GeV}$  is required. After applying a  $Z$ -veto and a two-dimensional cut on  $\cancel{E}_T$  and the angle between  $\cancel{E}_T$  and the leading muon, the background is dominated by top pair-production. The systematic error is dominated by uncertainties in the jet energy scale and the  $b$ -tagging efficiency.

The shape of the scalar sum of the jet transverse energies  $H_T = \sum_{\text{jets}} E_T$  is used to further discriminate between the  $\tilde{t}\tilde{t}$  signal and the standard model  $t\bar{t}$  background. Cross-section limits are calculated with the likelihood ratio method [7] assuming a branching ratio  $BR(\tilde{t} \rightarrow b\tilde{\nu}) = 100\%$ . By comparing them to next-to-leading order predictions of the signal cross-section calculated using Prospino 2 [8], exclusion regions in the plane given by  $M_{\tilde{t}}$  and  $M_{\tilde{\nu}}$  are derived (cf. Fig. 2, left). Compared to previous measurements an additional region at low  $\Delta M(\tilde{t}, \tilde{\nu})$  has been excluded due to the low muon  $p_T$  requirements. A significant extension of the exclusion limit is expected from a pending analysis using the preferred  $e\mu$  channel.

### 4. Search for Scalar Bottom Quarks in the Decay $\tilde{b} \rightarrow b\tilde{\chi}_1^0$

$D\bar{D}$  has searched for sbottom pair-production in  $310 \text{ pb}^{-1}$  of data taken with a dedicated trigger designed for topologies with both significant  $\cancel{E}_T$  and jet activity, which is based on the vector sum of the jet momenta and acoplanarity.

The signal selection requires  $\cancel{E}_T$  and two or three reconstructed jets with one tight  $b$ -tag based on the jet lifetime probability. Events with more than three jets are rejected to minimize background from top pair-production and a veto on isolated  $e$ ,  $\mu$ , and tracks (originating from  $\tau$  decays) is applied to suppress vector boson production. Background from QCD multi-jet production has been shown to vanish for large  $\cancel{E}_T$ . The average  $\cancel{E}_T$  and jet  $E_T$  expected for the signal largely depends on

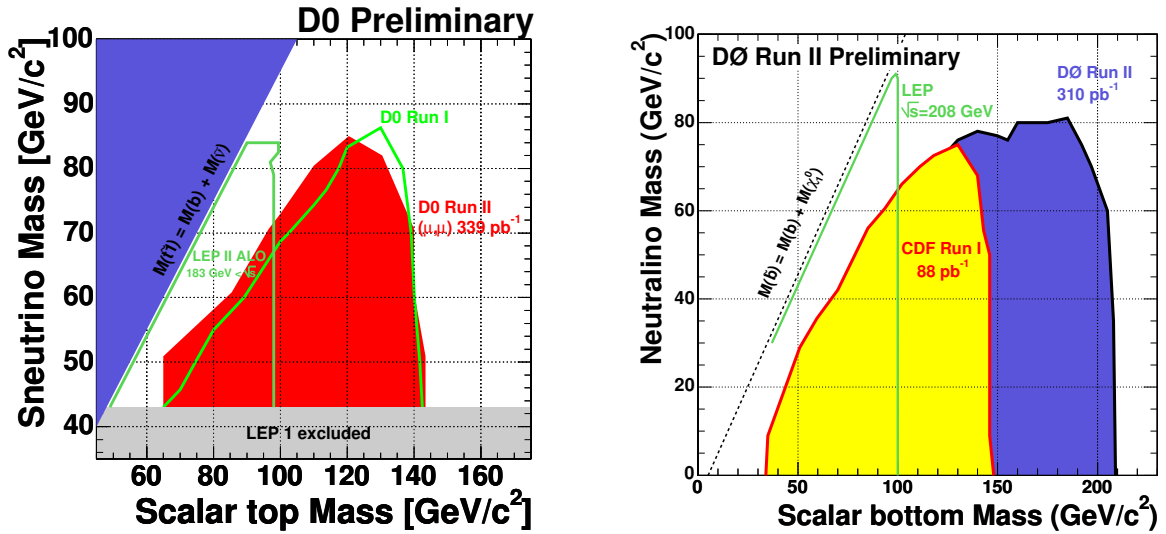


Figure 2: 95% C.L. exclusion regions for the  $\tilde{t}_1 \rightarrow b\tilde{\nu}$  (left) and  $\tilde{b} \rightarrow b\tilde{\chi}_1^0$  search (right).

the mass difference of sbottom quark and neutralino. Therefore three sets of cuts on these variables have been optimized for different assumed  $M_{\tilde{b}}$ .

As with the stop searches, the result is interpreted in the framework of generic MSSM and a 95% exclusion region in the  $(M_{\tilde{b}}, M_{\tilde{\chi}_1^0})$ -plane is derived, shown in Fig. 2, right. The excluded region is significantly increased compared to previous measurements [3, 4], corresponding to a gain of approximately 60 GeV in the sbottom mass limit at fixed  $M_{\tilde{\chi}_1^0}$ .

## 5. Conclusions

Searches for scalar top and bottom quarks at the Tevatron have now a significantly increased sensitivity compared to previous results obtained at LEP and Run I. This has been achieved not only because of the increased Tevatron luminosity and beam energy, but also due to strengthened heavy-flavor tagging and the ability to loosen the requirement on the lepton momenta. Further improvements are expected from an anticipated reduction of the jet energy scale uncertainty, the inclusion of additional decay channels, and with the increasing data set of Run II.

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