Search for Scalar Top Admixture in the $t\bar{t}$ Lepton+Jets Channel at DØ

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Abstract. A search has been performed for scalar top quark pair production in the lepton+jets channel in ≈ 1 fb^{-1} of data. Kinematic differences between the exotic $\tilde{t}_1\bar{\tilde{t}}_1$ and the dominant $t\bar{t}$ process are used to separate the two possible contributions. For scalar top quark masses of 145–175 GeV and chargino masses of 105–135 GeV we obtain upper cross section limits at 95% confidence level for $\tilde{t}_1\bar{\tilde{t}}_1$ production that are a factor of ≈7–12 higher than expected for the Minimal Supersymmetric Standard Model (MSSM).

PACS. 13.85.Rm Limits on production of particles – 14.65.Ha Top quarks – 14.80.Ly Supersymmetric partners of known particles

1 Introduction

1.1 Scalar Top Production and Decay

Scalar top (stop) quarks are mainly produced in pairs with essentially the same diagrams as top pairs. The theoretical cross section at a center of mass energy of 1.96 TeV for a stop quark of the mass 175 GeV is 0.579 pb [1]. As comparison, for a top quark of the same mass, the cross section is 6.77 pb [2]. The stop quark pair production cross section highly depends on the mass of the stop quark.

Even with the assumption that R-parity is conserved there are many possible decays for the stop quark. The branching ratios depend on the SUSY parameters chosen, in particular the masses of the supersymmetric particles involved. The decays $\tilde{t}_1 \to c\tilde{\chi}_1^0$ [3] and $\tilde{t}_1 \to b\ell^+\tilde{\nu}_\ell$ [4] have already been explored at DØ in Run II. Another important decay channel is the $\tilde{t}_1 \to b\tilde{\chi}_1^+$ channel considered in this analysis [5]. We consider six mass points, for which we vary the stop quark mass from 145 to 175 GeV and the chargino mass from 105 to 135 GeV, while keeping the neutralino mass fixed to 50 GeV.

1.2 Tevatron Collider and DØ Detector

The Tevatron collider is located at Fermi National Accelerator Laboratory (Fermilab) in Batavia, Illinois, USA. It collides protons and antiprotons at a center of mass energy of 1.96 TeV. As of July 2007 it has delivered 3.2 fb^{-1}, of which DØ recorded 2.72 fb^{-1}. The analysis presented uses approximately 900 pb^{-1}.

DØ is one of the two multi-purpose experiments at Fermilab [6]. Going from the inside out the main parts of the detector consist of a tracking system inside a magnetic field, a calorimeter, and a muon system. The detector allows for the reconstruction of tracks, vertices, electrons, photons, jets, missing transverse energy and muons to high pseudorapitidy regions.

2 Search for Scalar Top

2.1 Event Signature

As reported in Section 1.1 each of the produced stop quarks decays to a chargino $\tilde{\chi}_1^\pm$ and a b-quark. The chargino then decays to a W boson and a neutralino $\tilde{\chi}_1^0$. The subsequent decay of the W boson determines the event topology just as in top quark pair production ($t\bar{t}$) events. The resulting $\tilde{t}_1\bar{\tilde{t}}_1$ event signature is consequently very similar to the $t\bar{t}$ signature, thus making it possible for the $\tilde{t}_1\bar{\tilde{t}}_1$ signal to be contained in the $t\bar{t}$ event sample. The only difference to top pair production are the additional neutralinos in the event. For this analysis, we consider the decay channel with one W boson decaying to hadrons and the other one to leptons. It does not play a role whether the W boson is on-shell or off-shell, both scenarios produce the same signature. The resulting final state consists of one high-p_T lepton, missing transverse energy $\not\!\!E_T$ from the neutrino and the neutralinos, two b-jets, and two light quark jets. This will be referred to as lepton+jets channel. The analysis is performed separately in the electron+jets (e+jets) channel, where the lepton is an electron (including one from τ decay) and the muon+jets (μ+jets) channel, where the lepton is a muon (also including one from τ decay). The result of the two channels is then combined.

2.2 Background Processes

Because of their similarity to the signal $t\bar{t}$ events dominate the background and are very difficult to separate. The remaining background processes are common to both $\tilde{t}_1\bar{\tilde{t}}_1$ and $t\bar{t}$ events, of which QCD multijet production and W+jets dominate. Smaller contributions stem from Z+jets production, single top production and diboson production. For the common background processes the same methods as in DØ $t\bar{t}$ analyses are used to reduce and estimate them. The preselection preferably selects events containing real leptons, which reduces the QCD multijet background. The difference between the data with a looser lepton quality requirement and a tighter lepton quality requirement is used to estimate the remaining QCD multijet background. Also using data the W+jets is estimated before a requirement on the identification of a jet originating from a b-quark (b-jet) removes most of that background. The contribution of the smaller background processes is calculated from their theoretical cross sections. The exact treatment of the $t\bar{t}$ background is discussed in the next section, but its contribution is also derived from its theoretical cross section. Table 1 shows the number of expected signal events after the complete preselection for all six mass points, Table 2 shows the number of expected background events. Figure 1 shows the data-MC agreement for one variable, the missing transverse energy $\not{E}_T$, after the preselection with ≥4 jets and after b-tagging. The dominance of the $t\bar{t}$ background is clearly visible.

Table 1. Expected number of signal events after complete preselection for 913 pb^{-1} in the electron+jets channel and 871 pb^{-1} in the muon+jets channel.

$m_{\tilde{t}_1}/m_{\tilde{\chi}_1^\pm}$	e+jets	μ+jets
175/135	4.0	3.1
175/120	3.1	2.3
175/105	2.8	2.0
160/120	3.6	2.4
160/105	3.8	2.7
145/105	4.5	3.0

2.3 Limit Setting Procedure

Although we have already estimated the $t\bar{t}$ background using its theoretical cross section, we still need a discrimination variable to be able to separate it from the $\tilde{t}_1\bar{\tilde{t}}_1$ signal. Because of the additional neutralinos one might expect additional missing transverse energy $\not{E}_T$, but since the neutralinos tend to be back-to-back, this is not the case and $\not{E}_T$ looks the same in stop and top events. There are, however, minor differences in some distributions. Especially helpful is a kinematic fitter, which reconstructs events to a $t\bar{t}$ hypothesis. As an example, Figure 2 shows the top mass as reconstructed by the kinematic fitter in the μ+jets channel.

Table 2. Expected number of background events after complete preselection for 913 pb^{-1} in the electron+jets channel and 871 pb^{-1} in the muon+jets channel.

Background	e+jets	μ+jets
$t\bar{t}$	103.0	84.2
Wbb	8.5	11.1
Wcc	4.8	6.5
Wlight	3.8	4.0
Z+jets	2.8	3.3
single top	3.1	2.5
diboson	1.4	1.2
multijet	10.7	3.2
SUM	138.1	116.0
Data	133	135

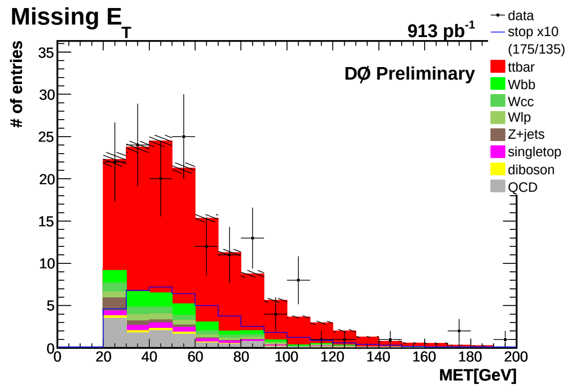

Fig. 1. Data-MC agreement for missing transverse energy $\not{E}_T$ in the e+jets channel after the preselection with ≥4 jets and b-tagging. The blue line shows the distribution for the 175/135 signal point ten times enhanced.

Comparing the $t\bar{t}$ in red to the blue line, which represents the signal, it can be seen that the distribution is very different for stop and top events. Combined into a likelihood discriminant the separation is even more pronounced as seen in Figure 3.

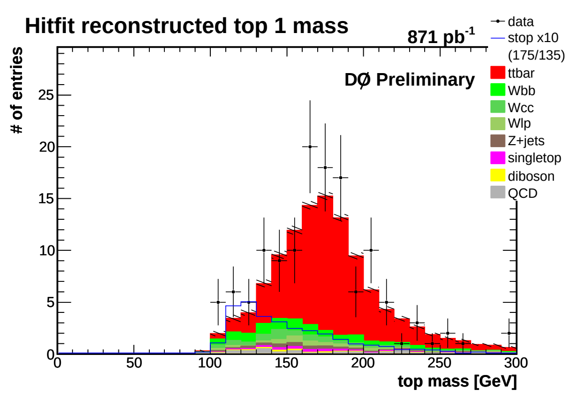

Fig. 2. Data-MC agreement for the reconstructed top mass in the μ+jets channel after the preselection with ≥4 jets and b-tagging. The blue line shows the distribution for the 175/135 signal point ten times enhanced.

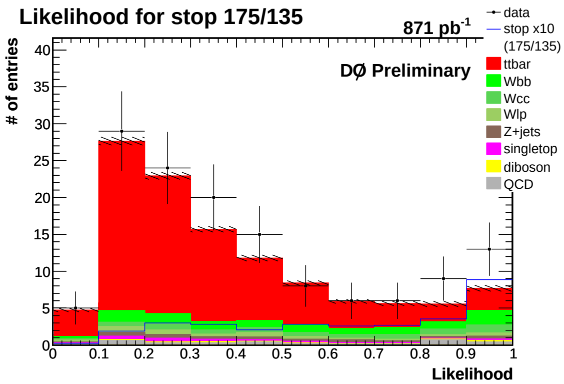

Fig. 3. Data-MC agreement likelihood discriminant in the e+jets channel after the preselection with ≥4 jets and b-tagging. The blue line shows the distribution for the 175/135 signal point ten times enhanced.

We use a Bayesian approach to extract limits from the likelihood discriminant distributions [7]. Under the assumption of a Poisson distribution for observed counts a binned probability function is formed. It is a product over all bins of the likelihood discriminant distribution and can be extended to combine the e+jets and μ+jets channels. For the signal cross section we assume a flat nonnegative prior probability. By integrating over the signal acceptances, background yields and integrated luminosity with Gaussian priors for each systematic uncertainty we obtain the posterior probability density as a function of the signal cross section. The limit at 95% confidence level is the point where the integral over the posterior probability density reaches 95% of its total.

The expected results are derived on the sum of all preselected background Monte Carlo samples without a $\tilde{t}_1\bar{\tilde{t}}_1$ contribution, but including the $t\bar{t}$ contribution according to its theoretical value of 6.77 pb. They are shown together with the observed limits and the theoretically predicted cross section in Table 3 for the e+jets and μ+jets channels combined.

3 Result and Conclusion

Table 3 shows the result for each mass point for e+jets and μ+jets channels combined. The first three columns show the masses of the stop quark, the chargino, and the neutralino. The fourth column gives the theoretically predicted cross section for $\tilde{t}_1\bar{\tilde{t}}_1$ production, the fifth column shows the expected and the sixth column the observed Bayesian limit at 95% confidence level on the $\tilde{t}_1\bar{\tilde{t}}_1$ cross section. The result is also illustrated in Figure 4. At this point we cannot exclude any of the stop masses, all observed limits are a factor of ≈7-12 above the theoretical predictions.

Table 3. SUSY particle masses in GeV, the theoretical $\tilde{t}_1\bar{\tilde{t}}_1$ cross section, and the expected and observed Bayesian limits at 95% confidence level on the $\tilde{t}_1\bar{\tilde{t}}_1$ cross section in pb for combined channels.

SUSY masses			theo	exp	obs
$m_{\tilde{t}_1}$ [GeV]	$m_{\tilde{\chi}_1^\pm}$ [GeV]	$m_{\tilde{\chi}_1^0}$ [GeV]	$\sigma_{\tilde{t}_1\bar{\tilde{t}}_1}$ [pb]	$\sigma_{\tilde{t}_1\bar{\tilde{t}}_1}$ [pb]	$\sigma_{\tilde{t}_1\bar{\tilde{t}}_1}$ [pb]
175	135	50	0.579	3.28	5.57
175	120	50	0.579	4.97	6.58
175	105	50	0.579	5.16	5.55
160	120	50	1.00	5.42	7.45
160	105	50	1.00	5.63	9.71
145	105	50	1.80	7.27	12.32

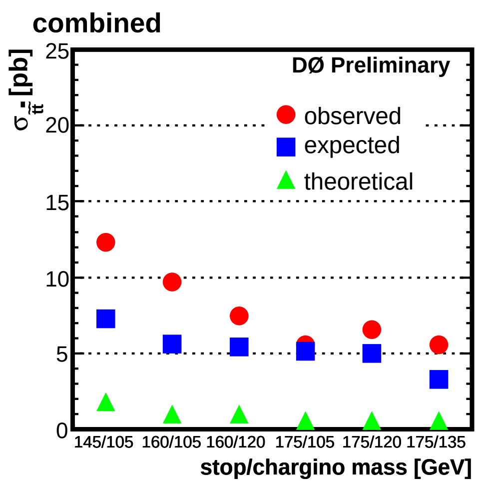

Fig. 4. Observed and expected Bayesian limits at 95% confidence level on the $\tilde{t}_1\bar{\tilde{t}}_1$ cross section and theoretical cross section for $\tilde{t}_1\bar{\tilde{t}}_1$ at each mass point for combined channels.

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