DØ note 5598-CONF

Version: 1.1
Authors: Ph.Gris and F.Tissandier

Send comments to d0-run2eb-015@fnal.gov
by Tuesday, March 4, 2008

Search for pair production of the supersymmetric partner of the top quark in the $\tilde{t}_1\bar{\tilde{t}}_1 \rightarrow b\bar{b}e^{\pm}\mu^{\pm}\tilde{\nu}\bar{\tilde{\nu}}$ decay channel at D0

The D0 Collaboration
URL http://www-d0.fnal.gov
(Dated: 26th February 2008)

Abstract

A search for the lightest supersymmetric partner of the top quark, $\tilde{t}_1$, produced in $p\bar{p}$ collisions at $\sqrt{s}$=1.96 TeV has been performed using the DØ detector at the Fermilab Tevatron collider. Assuming the decay $\tilde{t}_1 \rightarrow bl\tilde{\nu}$ is dominant, leads to a final state with missing energy, an electron and a muon. A good agreement with standard model expectation has been observed in a dataset corresponding to an integrated luminosity of 1.1 fb^{-1}. New limits at 95% confidence level in the plane ($m_{\tilde{t}_1}$,$m_{\tilde{\nu}}$) have been set.

Preliminary Results for Winter 2008 Conferences

I. INTRODUCTION

Supersymmetry (SUSY) [1] is one of the most promising ways to solve crucial problems of the Standard Model (SM). This spacetime symmetry links bosons to fermions by introducing supersymmetric partners (sparticles) to all SM particles. Hence the quark helicity states $\mathrm{q_R}$ and $\mathrm{q_L}$ have scalar partners $\tilde{\mathrm{q}}_\mathrm{R}$ and $\tilde{\mathrm{q}}_\mathrm{L}$. But whereas $\tilde{\mathrm{q}}_\mathrm{R}$ and $\tilde{\mathrm{q}}_\mathrm{L}$ are supposed to be mass eigenstates for the two first generations, a strong mixing may appear for the third one, leading to a hard splitting between the mass eigenstates. The result is that the lightest SUSY partner of the top quark, stop $\tilde{t}_1$, may be light enough to be produced at the Tevatron.

In a $p\bar{p}$ collider, scalar top pairs are expected to be produced via gg fusion and $q\bar{q}$ annihilation. If R-parity is conserved and if the $\tilde{t}_1$ is lighter than the top quark, $\tilde{t}_1$ may decay into $b\tilde{\chi}_1^+$, $c\tilde{\chi}_1^0$, $bl\tilde{\nu}$ or $b\tilde{l}\nu$. The $b\tilde{\chi}_1^+$ and $b\tilde{l}\nu$ channels tend to be disfavored by LEP searches [2]. A search of the decay $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$ has been previously reported by D0 [3]. In this document, we present the search for the scalar top quark decaying to $bl\tilde{\nu}$.

In our search we assume that the sneutrino is the LSP. In that case, production of scalar top pairs will result in a final state with two opposite-sign leptons, two b-jets and missing energy that comes mainly from undetected sneutrinos. In this study we explore the $e\mu$ final state: $b\bar{b}e^\pm\mu^\pm\tilde{\nu}\bar{\tilde{\nu}}$. A similar search using one-third of the integrated luminosity was reported previously [4].

II. DATA AND MONTE CARLO SAMPLES

The data used in this analysis were collected from April 2002 to February 2006. Low p_T eμ triggers were chosen so as to be sensitive to low mass differences between the stop and the sneutrino. The total integrated luminosity is (1100±71) pb^{-1}. Trigger efficiencies were estimated from data.

For the simulation of the three-body decays of the $\tilde{t}_1$, the Monte Carlo generators Comphep [5] and Pythia 6.4 [7] were used for the generation of the particles and the hadronization of the quarks. We assumed that the decay $\tilde{t}_1 \rightarrow bl\tilde{\nu}$ occured through a virtual chargino $\tilde{\chi}_1^\pm$ with a branching ratio of 100% and that the width of the sneutrino was close to zero. We considered a range of stop mass points from 60 to 200 GeV/c^2 in steps of 10 GeV/c^2. The sneutrino masses extend from 40 to 140 GeV/c^2 in steps of 10 to 20 GeV/c^2. For each mass point, 10,000 events were generated. The nominal theoretical cross section for the production of scalar top pairs, shown on Fig. 1, was obtained from Prospino2 [8] with CTEQ6.1M PDF's and for a renormalization scale and a factorization scale, μ_{rf}, equal to the stop mass. The uncertainty associated with the PDF's, estimated following [6], was combined quadratically with the variation obtained when μ_{rf} was modified by a factor of 2 or 0.5. The relative uncertainties range from 17 to 20%.

Background events arise from two independent sources. Physics background comes from standard model processes with isolated electron and muon pairs, namely: $Z/\gamma^* \rightarrow \tau^+\tau^-$, WW, WZ, ZZ and $t\bar{t}$. This background was simulated with Pythia. Channels involving the Z boson have been reweighted as a function of the p_T of the Z to reproduce the experimental differential cross section $d\sigma(Z)/dp_T$. The second background source is due to either mis-identified electrons, muons or jets, mismeasured $\not{E}_\mathrm{T}$, or electrons or muons from multijet processes which pass lepton isolation requirements that are presented below. These backgrounds, which are labeled as instrumental in this paper, are estimated from data.

III. EVENT SELECTION

In each event we require a reconstructed primary vertex with $|z_{vtx}| < 60$ cm, at least one muon of $p_T > 8$ GeV/c and one electron of $p_T > 15$ GeV/c.

A. Muon and Electron identification

A muon candidate in the region $|\eta| < 2$ is selected using the following criteria:

- wire and scintillator hits in the inner and the outermost layers of the muon detector, matched to the central tracking detector,

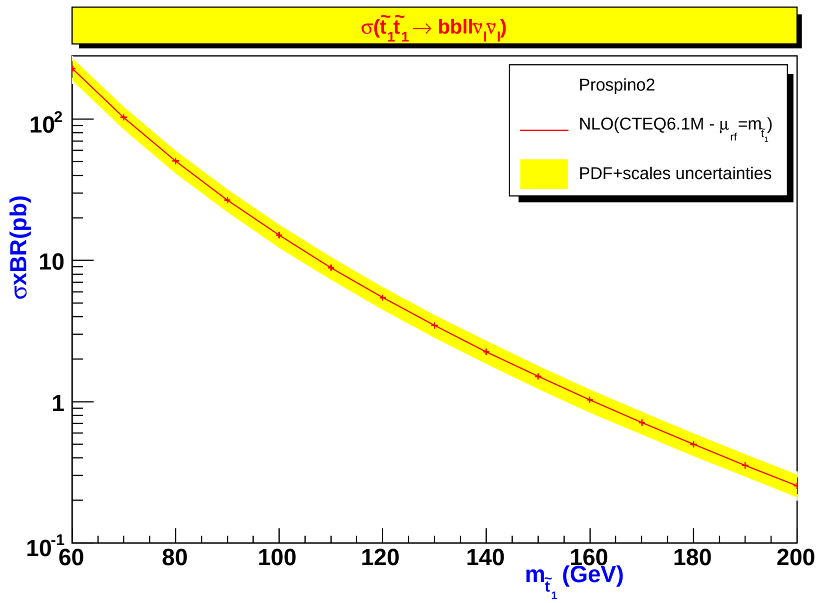

Figure 1: PROSPINO NLO Cross section as a function of the stop mass. The yellow band denotes the uncertainty on the theoretical predictions (PDF and renormalization and factorization scales).

- timing cuts to reject cosmic muons,
- at least one hit in the silicon tracker,
- isolation from calorimeter energy: $E(0.4) - E(0.1) < 2.5$ GeV, where $E(R)$ is the transverse energy measured in the calorimeter in a radius $R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ around the muon,
- isolation from other tracks: $\sum_i^{R=0.5} p_T(i) < 2.5$ GeV/c, where the sum runs over all charged tracks in a cone of radius $R = 0.5$ around the muon.

An electron candidate satisfies the following criteria:

- the ratio of the electromagnetic (EM) energy to the total shower energy should be greater then 0.9,
- isolation from the other energy deposit in the calorimeter $[E(0.4) - E_{EM}(0.2)]/EM(0.2) < 0.15$ where $E(R)$ and $E_{EM}(R)$ are the total and EM energy, deposited in a cone of radius R centered around the electron candidate,
- the lateral and the longitudinal shapes of the EM energy should correspond to those of an electron.

A likelihood discriminant combining the energy deposited in the calorimeter and the associated track is used to reduce contamination from photons and jets faking electrons. Good electrons have a likelihood value greater than 0.85 and a track p_T greater than 8 GeV/c. Only central electrons ($|\eta_{det}| < 1.1$) are considered.

Jets are reconstructed from the energy deposition in the calorimeter towers using the RunII cone algorithm [9] with radius $\Delta R = 0.5$. Only jets with $p_T > 15$ GeV/c are considered. The $\not{E}_T$ is calculated using all calorimeter cells, corrected for the energy calibration of the reconstructed jets and for the momentum of reconstructed muons.

Events with electron candidates sharing the same track with any good muon candidate were rejected. The electron and muon in an event are required to be isolated from each other ($\Delta R(e,\mu) > 0.5$) and from a potential jet ($\Delta R((e,\mu), jet) > 0.5$).

B. Selection cuts

The selection cuts that have been applied to the analysis are listed in Table I, along with the number of events surviving at each step for the data, for each background component, and for two signal samples ($m_{\tilde{t}_1}$ = 140 GeV/c^2 and $m_{\tilde{\nu}}$ = 110 GeV/c^2; $m_{\tilde{t}_1}$ = 170 GeV/c^2 and $m_{\tilde{\nu}}$ = 90 GeV/c^2). The instrumental background is estimated from data. An exponential fit is performed to the $\not\!\!E_{\rm T}$ distribution in the range 0-35 GeV, after substraction of the standard model contribution.

Table I: Number of data and MC events selected at the various stages of the analysis. Errors are statistical only.

	Cut0 1 electron 1 muon	Cut1 $\not\!\!E_{\rm T} > 30$ GeV Sig($\not\!\!E_{\rm T}$) > 4	Cut2 $\Delta\phi(e, \not\!\!E_T) > 0.4$ rad $\Delta\phi(\mu, \not\!\!E_T) > 0.4$ rad	Cut3 $M_T(\mu, \not\!\!E_T) > 20$ GeV/c^2 $M_T(e, \not\!\!E_T) > 20$ GeV/c^2 $\Delta\phi(e, \not\!\!E_T) + \Delta\phi(\mu, \not\!\!E_T) > 2.9$ rad
Instr. bkg	211 ± 15	22 ± 5	15 ± 4	13 ± 4
$Z/\gamma^* \to \tau^+\tau^-$	461 ± 6	23 ± 1	5.9 ± 0.6	1.0 ± 0.3
WW	52.3 ± 0.7	33.6 ± 0.6	31.7 ± 0.6	31.0 ± 0.6
WZ	7.1 ± 0.3	4.9 ± 0.3	4.3 ± 0.2	4.0 ± 0.2
ZZ	1.66 ± 0.08	0.74 ± 0.05	0.59 ± 0.05	0.49 ± 0.05
$t\bar{t}$	30.0 ± 0.7	23.7 ± 0.6	20.0 ± 0.5	16.8 ± 0.5
total bkg	763 ± 15	108 ± 5	78 ± 4	66 ± 4
data	767	108	72	64
$m_{\tilde{t}_1}$ = 140 GeV/c^2 $m_{\tilde{\nu}}$ = 110 GeV/c^2	34 ± 1	10.8 ± 0.8	8.6 ± 0.7	6.9 ± 0.6
$m_{\tilde{t}_1}$ = 170 GeV/c^2 $m_{\tilde{\nu}}$ = 90 GeV/c^2	26.5 ± 0.7	19.5 ± 0.6	17.7 ± 0.6	16.7 ± 0.5

Cut0 corresponds to the requirement of one electron and one muon (with the above selection criteria) in the event. To remove a large part of the instrumental background as well as events coming from $Z/\gamma^* \to \tau^+\tau^-$, the missing transverse energy $\not\!\!E_{\rm T}$ is requested to be greater than 30 GeV (Cut1 - Fig. 2) and its significance greater than 4. The $Z/\gamma^* \to \tau^+\tau^-$ background is further reduced by suitable selections on $\Delta\phi(e, \not\!\!E_T)$ and $\Delta\phi(\mu, \not\!\!E_T)$ (Cut2 - Fig. 3). Leptons from $Z/\gamma^* \to \tau^+\tau^-$ events and poorly reconstructed leptons from the instrumental background events are correlated with $\not\!\!E_{\rm T}$. This gives rise to higher event populations at high and low values of the azimuthal angle difference between the leptons and $\not\!\!E_{\rm T}$ with a low value of the angular difference for one lepton being correlated with a high value for the others. The transverse mass between the leptons and $\not\!\!E_{\rm T}$ has low values for these events. To remove this background a selection is applied on the transverse masses as well as on the sum of the ϕ differences between the leptons and $\not\!\!E_{\rm T}$ (Cut3).

IV. RESULTS

Signal efficiencies reach a value of 9% for large mass differences but decrease to negligible values for $\Delta m = m_{\tilde{t}_1} - m_{\tilde{\nu}} = 20$ GeV/c^2 (see Fig. 5 in the appendix).

The expected number of background and signal events depend on several measurements and parametrizations which each introduce a systematic uncertainty: luminosity (6.1%), electron identification efficiency (5.5%), muon identification and isolation efficiencies (0.7-2%), jet energy scale (12-16%), instrumental background (20%). These systematic errors (except the luminosity and the instrumental background) are obtained by varying sequentially each affected quantity within $\pm 1\sigma$, where σ accounts for the relative efficiency resolution between data and simulation, before any selection. The instrumental background systematic uncertainty is estimated estimated by varying exponential fit parameters within $\pm 1\sigma$ of their errors.

A good agreement between data and SM expectation has been observed. Therefore upper limits at 95% C.L. on the production cross section of stop pairs may be evaluated. For this we have used the frequentist approach implemented in the TLimit program [10]. To increase our sensitivity

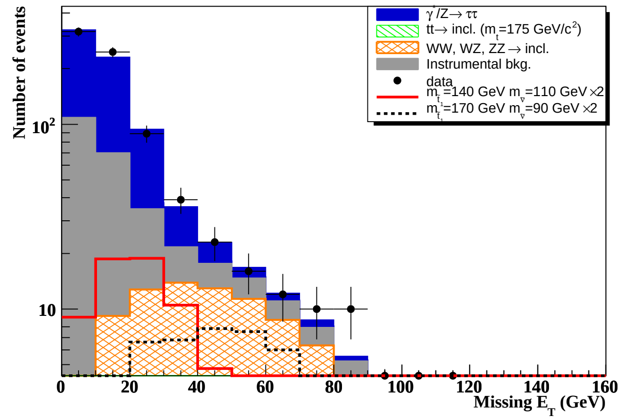

Figure 2: The missing transverse energy distribution after Cut0 for data (dots), simulated (filled areas) background and signal expectations for $m_{\tilde{t}_1} = 140$ GeV/c^2 and $m_{\tilde{\nu}} = 110$ GeV/c^2 (solid line) or $m_{\tilde{t}_1} = 170$ GeV/c^2 and $m_{\tilde{\nu}} = 90$ GeV/c^2 (dashed line). The signal has been enhanced for display purposes.

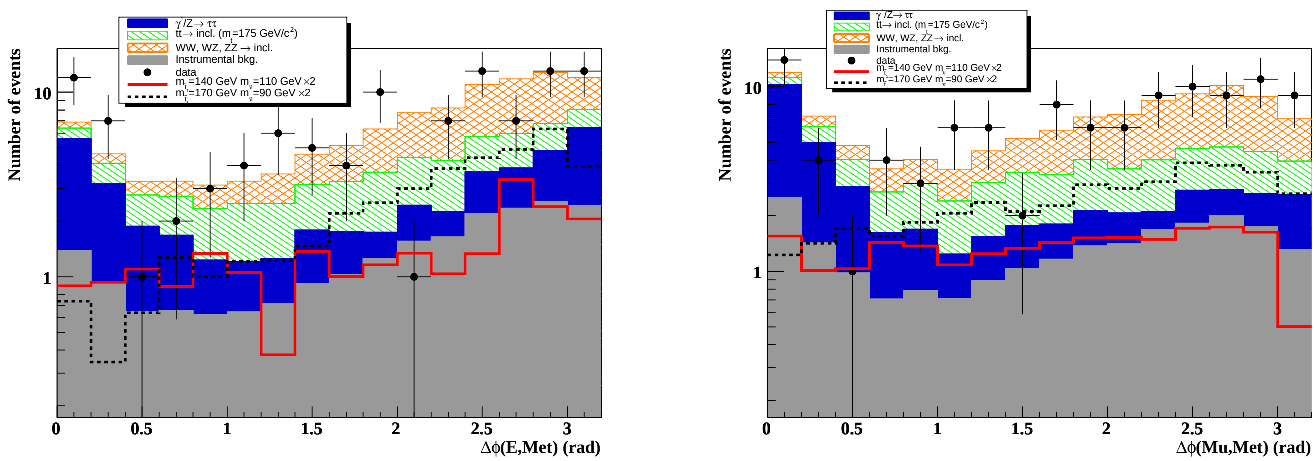

Figure 3: The $\Delta\phi(\mathrm{e},\not{E}_T)$ and $\Delta\phi(\mu,\not{E}_T)$ distributions for data (dots), simulated (filled areas) background and signal expectations for $m_{\tilde{t}_1} = 140$ GeV/c^2 and $m_{\tilde{\nu}} = 110$ GeV/c^2 (solid line) or $m_{\tilde{t}_1} = 170$ GeV/c^2 and $m_{\tilde{\nu}} = 90$ GeV/c^2 (dashed line), after Cut1. The signal has been enhanced for display purposes.

to the stop signal, two topological variables were used: S$_T$, defined as the sum of the muon p_T, the electron p_T and the missing transverse energy, and H$_T$ which is equal to the p_T sum of the jets. The distributions of these variables after Cut3 are given on Fig. 6 in the appendix. WW and instrumental background populate low values of S_T and H_T while top pairs have large values for both variables. The signal distribution depends on the mass values with low values of $\Delta m = m_{\tilde{t}_1} - m_{\tilde{\nu}}$ having low values of S_T and H_T. Hence the systematic uncertainty coming from the instrumental backgrounds affect low $\Delta m = m_{\tilde{t}_1} - m_{\tilde{\nu}}$ signal points. The limit calculation was performed for each set of masses. The following bins have been used to compute the limits: $S_T : 0-70, 70-120, > 120$ and $H_T : 0-15, 15-60, 60-120, > 120$. The first bin in H_T corresponds to events without jets. The number of events for each (S_T, H_T) bin are given in the appendix in Tables II and III. The exclusion domain is shown in Fig. 4 in the plane ($m_{\tilde{t}_1}$,$m_{\tilde{\nu}}$). The effect of the cross section uncertainties (PDF's and renormalization and factorization scales) is represented by a band around the observed limit. For large mass differences, a stop mass lower than 185 GeV/c^2 is excluded. A sensitivity up to $\Delta m = m_{\tilde{t}_1} - m_{\tilde{\nu}} = 20$ (30) GeV/c^2 is observed for stop masses of 100 (140) GeV/c^2.

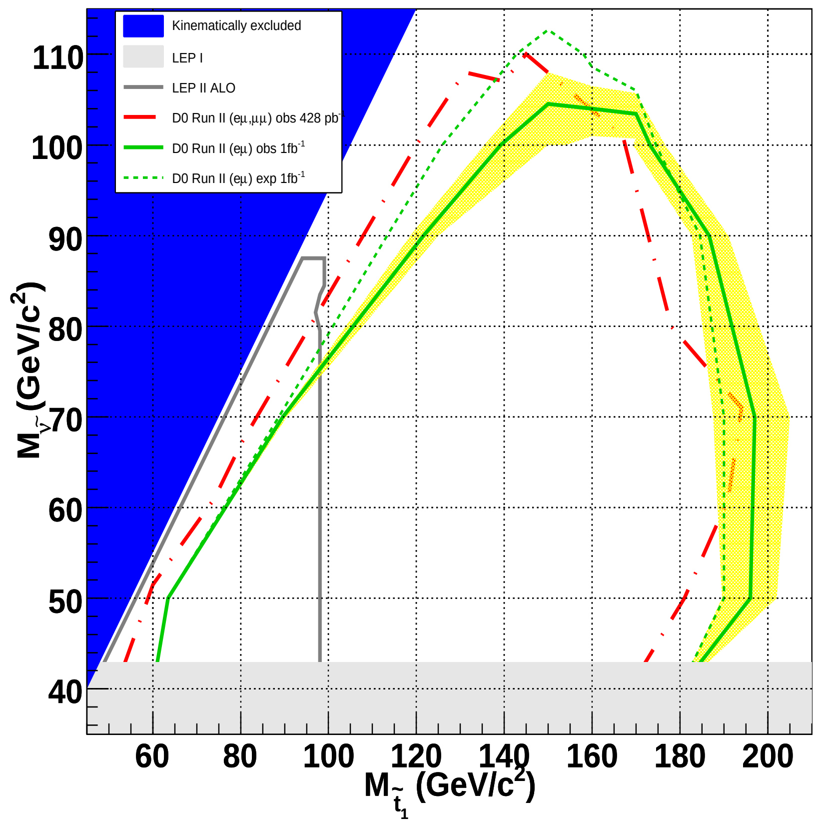

Figure 4: The 95% C.L. exclusion in the stop mass versus sneutrino mass plane. Dark blue and light grey areas represent the kinematically forbidden region and the LEP I exclusion respectively. The dark grey full line is the LEP II exclusion. The red dotted line denotes the observed limit [4] with 428 pb^{-1} ((e, μ) and (μ,μ) channels combined). The thick and the dashed green lines represent the exclusion limits with 1.1 fb^{-1} for the (e, μ) channel. The dashed line is the expected limit and the full line is the observed limit. The yellow band around the observed limit denotes the effect of the stop cross section uncertainties.

V. CONCLUSION

A search for stop pair production in $p\bar{p}$ collisions at 1.96 TeV has been performed in a data sample of 1.1 fb^{-1}. The final state considered was one electron, one muon and large missing transverse energy. No deviation from the standard model expectation has been observed. Exclusion domains in the plane ($m_{\tilde{t}_1}$,$m_{\tilde{\nu}}$) have been obtained extending the sensitivity beyond existing limits [4].

Acknowledgments

We thanks the staffs at Fermilab and collaborating institutions, and acknowledge support from the DOE and NSF (USA); CEA and CNRS/IN2P3 (France); FASI, Rosatom and RFBR (Russia); CAPES, CNPq, FAPERJ, FAPESP and FUNDUNESP (Brazil); DAE and DST (India); Colciencias (Colombia); CONACyT (Mexico); KRF (Korea); CONICET and UBACyT (Argentina); FOM (The Netherlands); PPARC (United Kingdom); MSMT (Czech Republic); CPC Program, CFI, NSERC and WestGrid Project (Canada); BMBF and DFG (Germany); SFI (Ireland); Research

Corporation, Alexander von Humboldt Foundation, and the Marie Curie Program.

---

[1] P. Fayet and S. Ferrara, *Supersymmetry*, Phys. Rep. 32 (1977), p. 249.
H.P. Nilles, *Supersymmetry, supergravity and particle physics*, Phys. Rep. 110, 1 (1984).
[2] http://lepsusy.web.cern.ch/lepsusy/www/squarks_summer04/stop_combi_208_final.html.
[3] Search for Scalar Top Quarks in Acoplanar Charm Jet + Missing Energy Events - D0note 5436-CONF.
[4] Search for the lightest scalar top quark in events with two leptons in $p\bar{p}$ collisions at $\sqrt{s}$=1.96 TeV - Phys. Lett. B 659:500-508, 2008.
[5] A.Pukhov *et al.* CompHEP - User's manual for version 3.3 arXiv:hep-ph/9908288.
A.S. Belyaev *et al.* CompHEP - PYTHIA interface arXiv:hep-ph/0101232.
[6] J.Pumplin *et al.* JHEP07 (2002) 012 D.Stump *et al.* JHEP10 (2003) 046.
[7] T.Sjostrand, S.Mrenna and P.Skands JHEP05 (2006) 026.
[8] W.Beenaker, R.Hoepker,M.Spira hep-ph/9611232 - http://www.ph.ed.ac.uk/ tplehn/prospino.
[9] G.C Blazey *et al.*, in *Proceedings of the Workshop: QCD and Weak Boson Physics in Run II*, edited by U.Baur, R.K. Ellis, and D. Zeppenfeld, Fermilab-Pub-00/297 (2000).
[10] http://root.cern.ch/root/html/TLimit.html and references therein.

Appendix

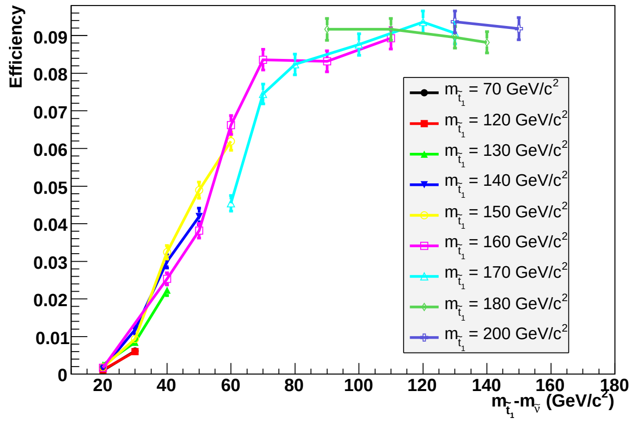

Figure 5: Selection efficiency for stop masses from 70-220 $\mathrm{GeV/c^2}$ after Cut3 as a function of the mass difference between the stop mass and the sneutrino mass $\Delta \mathrm{m} = \mathrm{m}_{\tilde{t}_1} - \mathrm{m}_{\tilde{\nu}}$.

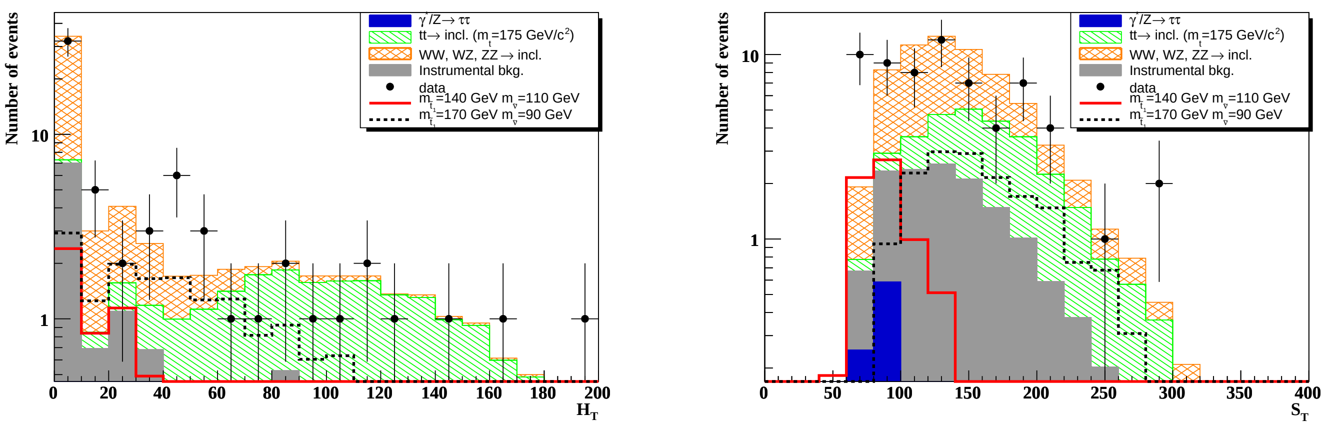

Figure 6: The H_T (left) and S_T (right) distributions for data (dots), simulated (filled areas) background and signal expectations for $m_{\tilde{t}_1} = 140~\mathrm{GeV/c^2}$ and $m_{\tilde{\nu}} = 110~\mathrm{GeV/c^2}$ (solid line) or $m_{\tilde{t}_1} = 170~\mathrm{GeV/c^2}$ and $m_{\tilde{\nu}} = 90~\mathrm{GeV/c^2}$ (dashed line), after Cut3.

Table II: Number of data and MC events for S_T and H_T bins. Errors are statistical only.

H_T	S_T 0-70 Data	0-70 MC	70-120 Data	70-120 MC	>120 Data	>120 MC
0-15	1	0.3± 0.3	18	14± 2	13	20± 2
15-60	1	0.3± 0.3	7	5± 1	11	8± 1
60-120	0	0± 0	0	1.6± 0.6	8	9± 1
>120	0	0.01± 0.01	0	0.9± 0.4	5	7± 1

Table III: Number of signal events ($m_{\tilde{t}_1} = 170$ GeV/c^2, $m_{\tilde{\nu}} = 90$ GeV/c^2) for S_T and H_T bins. Errors are statistical only.

H_T	S_T 0-70 S	0-70 S/B	70-120 S	70-120 S/B	>120 S	>120 S/B
0-15	0.02± 0.02	0.07	0.29± 0.08	0.02	2.6± 0.2	0.13
15-60	0.01± 0.01	0.025	1.6± 0.2	0.32	6.2± 0.3	1.29
60-120	0.01± 0.01	-	1.1± 0.1	0.68	3.5± 0.3	0.39
>120	-	-	0.26± 0.07	0.30	1.0± 0.1	0.14