Study of Scalar Top Quarks in the Neutralino and Chargino Decay Channel

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The scalar top discovery potential has been studied with a full-statistics background simulation at $\sqrt{s} = 500$ GeV and $\mathcal{L} = 500$ fb^{-1} for the TESLA project. The beam polarization is very important to measure the scalar top mixing angle and to determine its mass. The latest estimation of the beam polarization parameters is applied. This study includes e^+ polarization, which improves the sensitivity. For a 180 GeV scalar top at minimum production cross section, we obtain $\Delta m = 0.8$ GeV and $\Delta \cos\theta_{\tilde{t}} = 0.008$ in the neutralino decay channel, and $\Delta m = 0.5$ GeV and $\Delta\cos\theta_{\tilde{t}} = 0.004$ in the chargino decay channel.

Introduction

The study of the scalar top quarks is of particular interest, since the lighter stop mass eigenstate is likely to be the lightest scalar quark in a supersymmetric theory. The mass eigenstates are $m_{\tilde{t}_1}$ and $m_{\tilde{t}_2}$ with $m_{\tilde{t}_1} < m_{\tilde{t}_2}$, where $\tilde{t}_1 = \cos\theta_{\tilde{t}}\tilde{t}_L + \sin\theta_{\tilde{t}}\tilde{t}_R$ and $\tilde{t}_2 = -\sin\theta_{\tilde{t}}\tilde{t}_L + \cos\theta_{\tilde{t}}\tilde{t}_R$ with the mixing angle $\cos\theta_{\tilde{t}}$. We study the experimental possibilities to determine $m_{\tilde{t}_1}$ and $\cos\theta_{\tilde{t}}$ at a high-luminosity e^+e^- linear collider like the TESLA project [1] with polarized e^+ and e^- beams.

The simulated production process is $e^+e^- \to \tilde{t}_1\bar{\tilde{t}}_1$ with two decay modes $\tilde{t}_1 \to \tilde{\chi}^0 c$ and $\tilde{t}_1 \to \tilde{\chi}^+ b$. A 100% branching fraction in each decay mode is simulated. The first scalar top decay into a c-quark and the lightest neutralino results in a signature of two jets and large missing energy. The second investigated stop decay mode leads also to large missing energy and further jets from the chargino decay. The neutralino channel is dominant unless the decay into a chargino is kinematically allowed. Details of the event simulation with SGV [2] tuned for a TESLA detector [1] are given in Ref. [3]. The signals and a total of 16 million Standard Model background events are simulated (Table 1) for $\mathcal{L} = 500$ fb^{-1}.

Channel	$\tilde{\chi}^0 c\tilde{\chi}^0\bar{c}$	$\tilde{\chi}^+ b\tilde{\chi}^- b$	$eW\nu$	WW	$q\bar{q}$	$t\bar{t}$	ZZ	eeZ
(in 1000)	50	50	2500	3500	6250	350	300	3000

Table 1: Number of simulated signal and background events.

Neutralino Channel

The reaction $e^+e^- \to \tilde{t}_1\bar{\tilde{t}}_1 \to \tilde{\chi}^0 c\tilde{\chi}^0\bar{c}$ has been studied for a 180 GeV scalar top and a 100 GeV neutralino. After a preselection, 278377 background events remain [4,3]. In order to separate the signal from the background, the following selection variables are defined: visible energy, number of jets, thrust value and direction, number of clusters, transverse and parallel imbalance, acoplanarity and invariant mass of two jets [4,3]. An Iterative Discriminant Analysis (IDA) [5] optimized the selection. For unpolarized beams and 12% efficiency, 400 background events are expected.

The polarization of the e^+ and e^- beams at a future linear collider offers the opportunity to enhance or suppress the left- or right-handed couplings of the scalar top signal and to determine mass and mixing angle independently. The production cross section of each background process depends differently on the polarization. It is therefore important for a high-statistics analysis to study the expected background channels individually. The expected cross sections [6,7] are given in Table 2 for different beam polarization states. The IDA analysis was repeated for -0.9 and 0.9 polarization [3b]. Here, we recalculate all rates for the new machine polarization. Figure 1 shows the number of background events as a function of the signal efficiency for $-0.8/0.6$ (left) and $0.8/-0.6$ (right) polarization. For 12% detection efficiency, 1194 background events are expected leading to $\sigma_{\rm left} = 81.8 \pm 1.3$ fb, and 208 background events giving $\sigma_{\rm right} = 76.4 \pm 1.2$ fb, where $\Delta\sigma/\sigma = \sqrt{N_{\rm signal} + N_{\rm background}}/N_{\rm signal}$.

[a] speaker
[b] For a polarization of -0.9, 95% of the e^- are left-polarized. In the previous analyses [8,9,10,11] it was assumed that only 90% of the e^- were polarized.

Pol. of e^-	Pol. of e^+	$\tilde{t}_1\bar{\tilde{t}}_1$ CALVIN	$We\nu$ GRACE	WW WOPPER	$q\bar{q}$ HERWIG	$t\bar{t}$ HERWIG	ZZ COMPHEP
−0.8	0.6	0.0818	10.7	22.6	21.5	1.11	0.909
−0.9	0.0	0.0552	6.86	14.9	14.4	0.771	1.17
0	0.0	0.0535	5.59	7.86	12.1	0.574	0.864
0.9	0.0	0.0517	4.61	0.906	9.66	0.376	0.554
0.8	−0.6	0.0764	1.78	0.786	13.0	0.542	0.464

Table 2: Signal and background cross sections (pb) from different event generators for e^- and e^+ polarization states for $m_{\tilde{t}_1} = 180$ GeV and $\cos\theta_{\tilde{t}} = 0.57$. The Zee cross section is 0.6 pb.

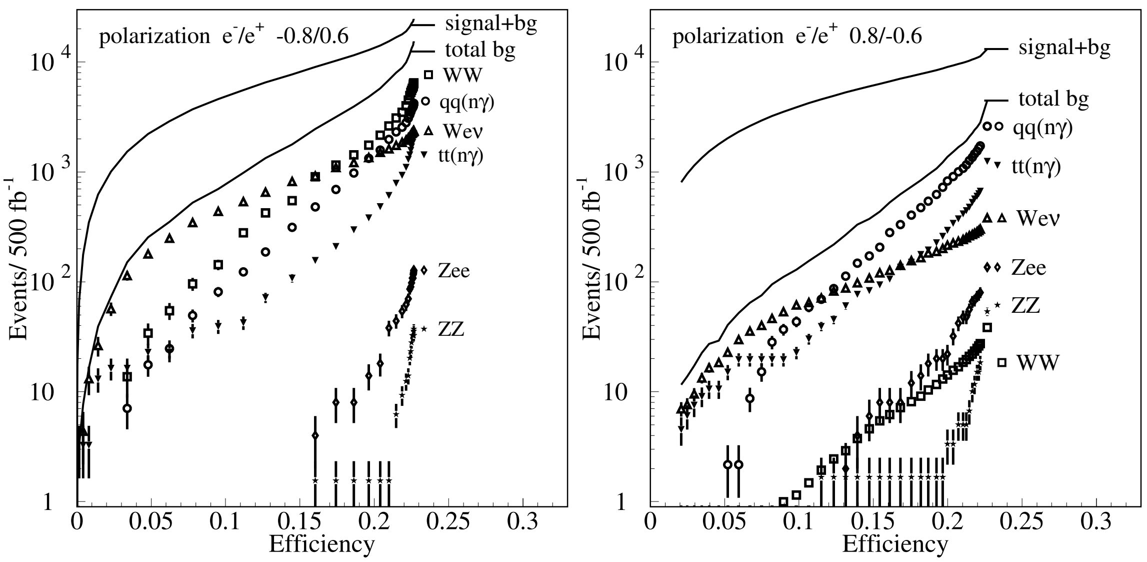

Figure 1: Background vs. signal efficiency for left- and right-polarization in the neutralino decay channel for a 180 GeV scalar top and a 100 GeV neutralino.

Chargino Channel

The reaction $e^+e^- \to \tilde{t}_1\bar{\tilde{t}}_1 \to \tilde{\chi}^+ b\tilde{\chi}^- \bar{b} \to \tilde{\chi}^0 W^+ b\tilde{\chi}^0 W^- \bar{b}$ has been studied with focus on the hadronic W decays for a 180 GeV scalar top, a 150 GeV chargino and a 60 GeV neutralino, where the chargino decays 100% into a W boson and a neutralino. A preselection similar to that for the study of the neutralino channel is applied and 209051 background events remain [3]. In order to separate the signal from the background, the following selection variables are defined: visible energy, number of jets, thrust value, number of clusters, transverse and parallel imbalance, and the isolation angle of identified leptons. For an unpolarized beam, Fig. 2 shows the final IDA output variable and the resulting number of background events as a function of the signal efficiency. For 12% efficiency, only 20 background events are expected. Allowing a background rate of 400 events, as in the neutralino channel, the efficiency is 44%, from which we derive the relative error on the cross section to be 0.75%. In this case the number of expected signal events is much larger than the expected background, thus no separate tuning of the IDA for left- and right-polarization is required. The background is neglected for the determination of mass and mixing angle. Note that the dependence of the background rates on the polarization has to be taken into account for stop masses closer to the kinematic threshold.

Results

For the neutralino and chargino decay channel of scalar top quarks, we have determined the expected Standard Model background rate as a function of the signal efficiency. The total simulated background of about 16 million events is largely reduced, which allows a precision measurement of the scalar top production cross section with a relative error of better than 2% in the neutralino channel and about 1% in the chargino channel. Based on experiences gained at LEP, we expect that detection efficiencies for other mass combinations are similar as long as the mass difference between the scalar top and the neutralino is larger than about 20 GeV. Figure 3 shows the corresponding error bands and the error ellipse in the $m_{\tilde{t}_1} - \cos\theta_{\tilde{t}}$ plane for both decay channels for 0.8/0.6 left- and right-polarization of the e^-/e^+ beams and a luminosity of 500 fb^{-1} each. The statistical errors are a factor 7 better in the neutralino channel and about a factor 14 better in the chargino channel than reported previously [8,9,10,11], and improve further when in addition e^+ polarization is included. Detailed results are given in Table 3. The highest statistical precision is obtained in the chargino channel with an error $\Delta m_{\tilde{t}_1} = 0.4$ GeV for $m_{\tilde{t}_1} = 180$ GeV and $\Delta\cos\theta_{\tilde{t}} = 0.003$ $\cos\theta_{\tilde{t}} = 0.570$. Based on the experience from direct searches at LEP, the systematic errors on the event selection are less than 1%; precise investigations require the detailed detector layout and a full simulation. The stop generator [12] has been interfaced with the SIMDET [13] simulation to allow an independent test of the detector simulation and related systematic errors. Another uncertainty could arise from the luminosity measurement, the measurement of the polarization, and the theoretical uncertainty of the production cross section, which will be determined in the future. A high-luminosity linear collider with the capability of beam polarization has a great potential for precision measurements in the scalar quark sector predicted by Supersymmetric theories.

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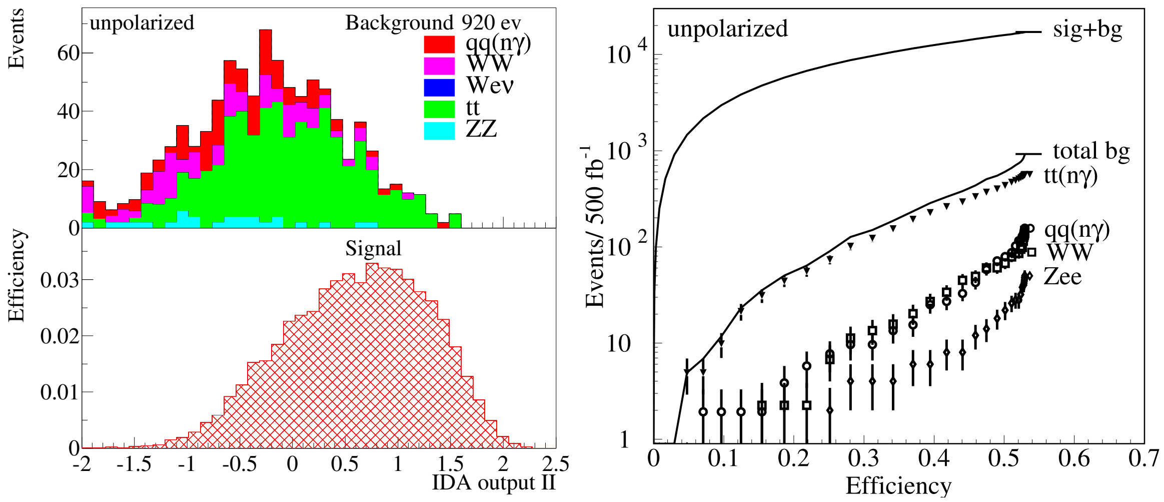

Figure 2: Final IDA output and background vs. signal efficiency in the chargino decay channel for unpolarized beams for a 180 GeV scalar top, a 150 GeV chargino and a 60 GeV neutralino.

Luminosity (fb^{-1})	e$^-$ Pol.	e$^+$ Pol.	(a) $\Delta m_{\tilde{t}_1}$	$\Delta\cos\theta_{\tilde{t}}$	(b) $\Delta m_{\tilde{t}_1}$	$\Delta\cos\theta_{\tilde{t}}$
10	0.8	0.0	7.0	0.06	7.0	0.06
500	0.9	0.0	1.0	0.009	0.5	0.004
500	0.8	0.6	0.8	0.008	0.4	0.003

Table 3: Expected errors on the scalar top mass and mixing angle from simulations with different luminosity and beam polarization in the neutralino (a) and chargino (b) channels. The 10 fb^{-1} analysis [8,9,10,11] used a sequential event selection; while the 500 fb^{-1} results in the neutralino [4] and chargino [3] channels are based on an IDA. The new result includes e$^+$ polarization.

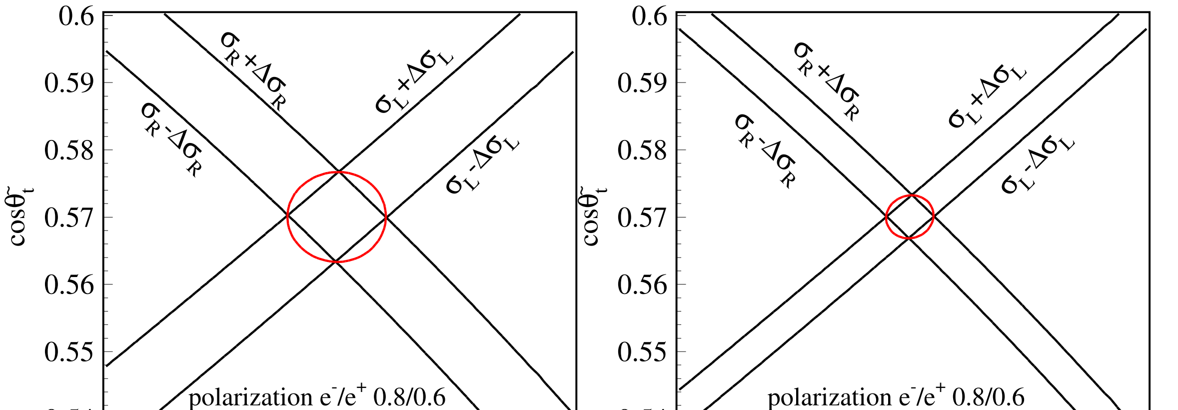

Figure 3: Error bands and the corresponding error ellipse as a function of $m_{\tilde{t}_1}$ and $\cos\theta_{\tilde{t}}$ for $\sqrt{s} = 500$ GeV and $\mathcal{L} = 500$ fb^{-1}. The dot corresponds to $m_{\tilde{t}_1} = 180$ GeV and $\cos\theta_{\tilde{t}} = 0.57$.