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SEARCHING FOR TOP DECAYS TO CHARGED HIGGS BOSONS WITH THE SDC DETECTOR*

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ABSTRACT

We have studied the capabilities of the SDC detector to discover a charged Higgs boson in the decay $t \rightarrow H^+ b$ for the particular case $m_t = 250 \text{ GeV}/c^2$ and $m_{H^\pm} = 150 \text{ GeV}/c^2$. The two methods investigated both tag $t\bar{t}$ events by demanding a high- p_t lepton and two identified b -quark jets. In the first technique we search for an excess of τ leptons from $H^\pm$ decays; in the second, we look for a peak in the two-jet mass distribution resulting from $H^+ \rightarrow c\bar{s}$. In combination, these two techniques allow discovery of such a charged Higgs boson over the entire interesting range of two-Higgs-doublet model parameter space.

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MASTER

I. INTRODUCTION

One of the most attractive extensions of the standard Higgs sector contains two Higgs doublets and consequently both charged and neutral physical Higgs bosons^[1]. If the charged Higgs boson is lighter than the top quark, then the branching ratio for the decay $t \rightarrow H^+ b$ could be comparable to that for $t \rightarrow W^+ b$. These branching fractions depend on the couplings of the two Higgs doublets to the quarks and leptons. There are two possible models normally considered for these couplings consistent with the absence of flavor-changing neutral currents. In one model (Model-II in the notation of Ref. 1) the neutral component of one of the doublets is responsible for generating the mass of leptons and charge $-\frac{1}{3}$ quarks while the other generates the mass of charge $\frac{2}{3}$ quarks. This is the model predicted by minimal supersymmetry and will be the one considered here. The couplings of the charged Higgs bosons to fermions are entirely determined by the quark/lepton masses and by $\tan \beta = v_2/v_1$, where v_1 (v_2) is the vacuum expectation value of the Higgs field which couples to the down (up) type fermions. Therefore, $\tan \beta$ determines the branching fractions for $t \rightarrow bH^+$, $H^+ \rightarrow \tau\nu$, and $H^+ \rightarrow c\bar{s}$.

Figure 1: Branching fractions for the reactions $t \rightarrow H^+ b$ (solid) and $H^+ \rightarrow \tau\nu$, $c\bar{s}$, $c\bar{b}$ as a function of $\tan \beta$, using the Model-II formulae of Ref. 1. We have assumed $m_t = 250 \text{ GeV}/c^2$ and $m_{H^\pm} = 150 \text{ GeV}/c^2$.

The predicted branching ratios for $t \rightarrow H^+ b$ and for the various $H^\pm$ decay

modes as a function of the parameter $\tan\beta$ are shown in Fig. 1. Renormalization group analysis in the context of a typical grand unification scheme leads to a correct pattern of symmetry breaking with large m_t only if $\tan\beta$ is greater than 1^[1]; in addition very small values of $\tan\beta$ ($\lesssim 0.2$) would place the $H^+ \rightarrow t\bar{b}$ coupling in a non-perturbative regime for the large m_t value adopted here. One particularly important feature of Fig. 1 is that the branching ratios for $t \rightarrow H^+b$ and $H^+ \rightarrow \tau\nu$ tend to be anti-correlated for $\tan\beta$ below 10. For example, as $\tan\beta$ approaches 10, the t branching fraction to $H^\pm$ is approximately 1%, while the $H^\pm$ decays almost entirely into $\tau\nu$. Note also, that for small $\tan\beta$ the $\tau\nu$ branching ratio is quite small, and the $c\bar{s}$ mode will provide the best hope for $H^\pm$ detection.

We have investigated two methods for $H^\pm$ detection in $t\bar{t}$ events for the case $m_t = 250 \text{ GeV}/c^2$ and $m_{H^\pm} = 150 \text{ GeV}/c^2$ (these mass values were designated by the SSC Program Advisory Committee to be used in answering questions concerning detector performance). The first involved a search for an excess of τ leptons. This technique is most effective when the branching ratio of $H^+ \rightarrow \tau\nu$ is large. The other method was to reconstruct the hadronic decays $H^+ \rightarrow c\bar{s}$; it is only useful for smaller values of $\tan\beta$ where $t \rightarrow H^+b$ and $H^+ \rightarrow c\bar{s}$ are both large. In each case, events are triggered by requiring one t quark to decay via $t \rightarrow bW \rightarrow b\ell\nu$ yielding an isolated electron or muon (ℓ) with $p_t > 40 \text{ GeV}/c$ and $|\eta| < 2.5$. The isolation requirement used was that the energy (excluding that of the lepton) within a cone of radius $\Delta R \equiv \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.4$ about the lepton be less than 25% of the lepton momentum. The results do not depend critically on the precise isolation criterion. The ratio of lepton track momentum to the total energy within the cone of 0.4 is shown in Fig. 2(a). We assumed an efficiency for identifying electrons and muons of 85%.

The events are further selected by requiring two tagged b -jets (from the decay of the t and $\bar{t}$) with $p_t > 30 \text{ GeV}/c$ within $|\eta| < 2.0$. The efficiency for tagging the b -jets through secondary vertices is discussed in Ref. 2. The non- $t\bar{t}$ background coming from $Wb\bar{b}$, $Wc\bar{c}$, $Wc\bar{b}$ and $Wb\bar{c}$ final states, and satisfying these criteria is small even before the $H^\pm$ signal criteria are implemented.

II. METHOD 1: SEARCH FOR $H^+ \rightarrow \tau\nu$

In Method 1 we search for ℓ - τ events (*e.g.*, $t \rightarrow bW^+ \rightarrow b\ell^+\nu$, $\bar{t} \rightarrow [\bar{b}H^- \text{ or } \bar{b}W^-] \rightarrow \bar{b}\tau^-\nu$) in which the τ decays to a single $\pi^\pm$ (or $K^\pm$) with $p_t > p_t^{\text{cut}}$ ($p_t^{\text{cut}} = 40$ or $100 \text{ GeV}/c$). We do this because the most easily identified decay mode of the τ is the 1-prong decay $\tau^+ \rightarrow \pi^+\nu$ (or $\tau^+ \rightarrow K^+\nu$), for which the signature is an isolated charged hadron whose momentum (from tracking) and energy (from calorimetry) agree within errors. The isolation requirement used was that the energy (excluding that of the pion) within a cone of radius $\Delta R = 0.4$ about the

Figure 2: The ratio of measured single track momentum to energy within a cone of radius $R \equiv \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.4$. One-prong τ candidates. (a) Electron candidates. (b) Pions from τ decays.

pion be less than 25% of the pion momentum. The probability for a QCD jet with

$p_t > 40 \text{ GeV}/c$ to satisfy this requirement is approximately 0.1%^[3]. For one-prong τ candidates, the distribution of the ratio of pion track momentum to the total energy within a cone of 0.4 is shown in Fig. 2(b).

This study was performed using the Isajet 6.31 Monte-Carlo program, including a modification to produce the correct τ polarization in the decays of $W^\pm$ and $H^\pm$, as described below. The results were compared with Pythia 5.4 and also a parton-level generator, in both of which the τ leptons are produced unpolarized. The detector response was simulated by smearing the produced energy and momenta with the assumed calorimeter and tracking resolutions^[4]. Multiple event pile-up was not simulated, since it is not expected to affect our results at the nominal SSC luminosity. The main effect of multiple events would be to decrease slightly the efficiencies for observing isolated leptons and τ 's, but this should be a small effect for the p_t thresholds used in this study.

Implementation of the correct polarization correlations for the t quark decay chain is crucial in obtaining an accurate result. The coupling of W to $\tau\nu$ conserves chirality and the ν are left-handed, therefore (up to corrections of order m_τ/m_W) the τ^- (τ^+) are left- (right-) handed. In contrast, the $\tau^\pm$ from the decay of $H^\pm$ would have the opposite polarizations, since the $H^\pm$ is a scalar, and its couplings maximally violate chirality. In W decays, the τ polarization results in the preferred direction for emission of the $\pi^\pm$ being opposite the momentum of the τ . In $H^\pm$ decays, since the $\tau^\pm$ has the opposite polarization, the $\pi^\pm$ tends to be emitted parallel to the τ momentum. Consequently, the isolated pion p_t spectrum from the charged Higgs decay is shifted to higher p_t . Furthermore, since we have assumed a higher mass for the $H^\pm$ than the W , the p_t of τ 's from the $H^\pm$ decay is already larger on average than that from W decay. In short, both the polarization correlations and kinematic effects increase the effectiveness of the high- p_t cut on the isolated pion in enhancing the relative number of events containing a $H^\pm$.

III. UNIVERSALITY ARGUMENT IN THE SEARCH FOR $H^+ \rightarrow \tau\nu$

The most sensitive means of detecting the presence of the charged Higgs boson decaying to τ 's is to employ lepton universality in W decays. If t quarks can only decay to W^+b , then the observed number of $\ell^+-\ell^-$ events plus lepton universality in W decays allows us to compute the number of ℓ - τ events expected ($\equiv N_{\ell\tau}^{WW}$ where WW signifies that both t and $\bar{t}$ decayed to W 's). If instead top quarks can also decay to H^+b , we would detect an excess of ℓ - τ events over the universality prediction. This occurs because ℓ - τ events are enhanced, while $\ell^+-\ell^-$ events are depleted. This method is independent of the theoretical calculation of the $t\bar{t}$ cross section.

Figure 3: Efficiency for pions from τ decays to pass a p_t threshold cut in WW decays (light solid) and WH decays (dark solid).

If there is no charged Higgs boson, the number of $\tau^+ \rightarrow \pi^+ \nu$ (or $K^+ \nu$) events resulting from $t\bar{t} \rightarrow WWb\bar{b}$ with one W decaying to $\ell\nu$ (the trigger)^[5] and the other to $\tau\nu$, after imposing the above-mentioned cuts and triggers, is:

$$N_{\ell\tau}^{WW} = 2N_{t\bar{t}}B(W \rightarrow \ell\nu)B(W \rightarrow \tau\nu)e_{\ell-trig}e_{b-tag}B(\tau \rightarrow \pi\nu)e_{\tau\pi}. \quad (1)$$

$N_{t\bar{t}}$ is the number of $t\bar{t}$ events produced per SSC year and could be extracted from the measured value of $N_{\ell\tau}^{WW}$ if there is no $H^\pm$. Isajet yields the standard QCD prediction which is $N_{t\bar{t}} \approx 1.5 \times 10^7$, corresponding to $\sigma_{t\bar{t}} \approx 1.5$ nb. We assume the branching ratios $B(W \rightarrow \ell\nu)/2 = B(W \rightarrow \tau\nu) = 1/9$ and $B(\tau \rightarrow \pi\nu) = 11.5\%$. $e_{\ell-trig}$ is the efficiency for triggering on the electron or muon (including the p_t cut, η cut, and isolation criterion), e_{b-tag} is the efficiency for tagging the two b -jets, and $e_{\tau\pi}$ is the efficiency for observing the pion (or kaon) from the τ above a minimum p_t threshold. The efficiency factors obtained from Isajet are listed in the first column of Table 1. Fig. 3 shows the efficiency $e_{\tau\pi}$ as a function of the p_t cut on the isolated π .

If the top quark can also decay to $H^\pm b$, then we have additional final states containing $H^\pm W^\mp$ and $H^+ H^-$, where the mixture depends on the branching ratio $B_H \equiv B(t \rightarrow H^\pm b)$. The contribution from $H^+ H^- b\bar{b}$ final states can be ignored,

	WW events	WH events
$e_{\ell\text{-trig}}$	0.42	0.42
$e_{b\text{-tag}}$	0.12	0.12
$e_{\tau\pi} (p_t^\pi > 40 \text{ GeV})$	0.110	0.443
$e_{\tau\pi} (p_t^\pi > 100 \text{ GeV})$	0.025	0.136

Table 1: Triggering and tagging efficiencies.

because the lepton trigger then requires $H \rightarrow \tau\nu \rightarrow \ell\nu\bar{\nu}$, but in the range where $t \rightarrow bH^+$ is large, the branching ratio $B(H^+ \rightarrow \tau\nu)$ (and consequently the lepton trigger efficiency) is very small.

The number of observed $\ell\text{-}\tau$ events (from $W^\pm W^\mp b\bar{b}$ and $W^\pm H^\mp b\bar{b}$ final states) would therefore be

$$N_{\ell\tau} = N_{\ell\tau}^{\prime WW} + N_{\ell\tau}^{\prime WH} \equiv [(1 - B_H)^2 N_{\ell\tau}^{WW}] + [B_H(1 - B_H) N_{\ell\tau}^{WH}], \quad (2)$$

where

$$N_{\ell\tau}^{WH} = 2N_{t\bar{t}} B(W \rightarrow \ell\nu) e_{\ell\text{-trig}} e_{b\text{-tag}} B(H^+ \rightarrow \tau\nu) B(\tau \rightarrow \pi\nu) e_{\tau\pi}. \quad (3)$$

For the WH decays, the efficiency factors obtained from Isajet are given in the second column of Table 1. The efficiency for tagging the b -jets in the WH case is nearly identical to that for the WW case despite the large mass difference between the $H^\pm$ and $W^\pm$. As discussed at the end of the last section, the efficiency $e_{\tau\pi}$ for observing the pion or kaon above the p_t cut is substantially higher for the WH case than for the WW case, as shown in Fig. 3.

The parameter $\tan\beta$ of the two-doublet Higgs model enters the above equations via both B_H and $B(H^+ \rightarrow \tau\nu)$. For illustration, in Fig. 4 we compare the predicted (from universality) and observed p_t spectrum of the isolated pion coming from τ decay for the case $\tan\beta \approx 1.2$ (which yields $B(H^+ \rightarrow \tau\nu) \sim 0.50$ and $B_H \sim 0.23$) where the influence of the $H^\pm$ would be large. In this favorable case, the excess due to the $t \rightarrow H^+b$ decays over the universality prediction is more than a factor of four.

Since the number of $\ell^+\text{-}\ell^-$ events would be depleted by $(1 - B_H)^2$, our universality argument predicts that the number of $\ell\text{-}\tau$ events with an isolated single hadron (π^+ or K^+) is just $N_{\ell\tau}^{\prime WW}$ and the observed excess is $N_{\ell\tau} - N_{\ell\tau}^{\prime WW} = N_{\ell\tau}^{\prime WH}$. Then we can compute the statistical significance of this excess by simply comparing

Figure 4: (a) The transverse momentum distributions for isolated pions coming from $t\bar{t}$ events (see text). (b) Integrated number of isolated pions with $p_t(\pi) > p_t^{\text{cut}}$. The thin solid histograms are the predictions from universality (*i.e.* corresponding to the term $N'_{\ell\tau}{}^{WW}$ in Eq. (2)). The thick solid histograms would be the actual observed spectra if a charged Higgs is indeed present (corresponding to the sum of $N'_{\ell\tau}{}^{WW}$ and $N'_{\ell\tau}{}^{WH}$, see Eqs. (2) and (3)). These figures employ the branching ratios specified for $\tan\beta = 1.2$ in the text.

$N'_{\ell\tau}{}^{WH}$ to the universality prediction $N'_{\ell\tau}{}^{WW}$. In order to quantify the observability of this charged Higgs signal as a function of the Higgs model parameter $\tan\beta$, we compute the number of standard deviations by which the observed number of isolated pions exceeds the prediction from universality:

$$N_{SD} = \frac{N'_{\ell\tau}{}^{WH}}{\sqrt{N'_{\ell\tau}{}^{WH} + N'_{\ell\tau}{}^{WW}}} . \quad (4)$$

In Fig. 5, N_{SD} is plotted for p_t cuts on the isolated pion of 40 and 100 GeV/c, as obtained from Isajet. It is critical to keep track of the polarization of the τ 's in the Monte Carlo analysis; ignoring the polarization reduces the statistical significance by a factor of two. We have estimated that the backgrounds from $Wb\bar{b}$ reduce the number of standard deviations by less than 3%; all other W -jet-jet backgrounds together are smaller than this because the b -jet tagging requirement more than compensates for the larger production cross sections of some of these channels. Requiring five standard deviations above background, we conclude that after one year of SSC running we could detect the presence in top decays of the charged Higgs boson decaying to τ 's for all $\tan\beta > 0.5$. For smaller values of $\tan\beta$, where $B(H^+ \rightarrow \tau\nu)$ becomes small, we must employ the $H^+ \rightarrow c\bar{s}$ decay mode, to which we now turn.

IV. METHOD 2: SEARCH FOR $H^+ \rightarrow c\bar{s}$

A technique to determine the top mass by reconstructing the hadronic decays of the top quark $t \rightarrow bW$, $W \rightarrow u\bar{d}$ (or $c\bar{s}$) was described in a previous study^[6]. Here we have extended this technique to study a 250 GeV/ c^2 top quark decaying to H^+ (or W^+) with $H^+(W^+) \rightarrow u\bar{d}$ or $c\bar{s}$. As in Method 1 we trigger on $t\bar{t}$ events in which one of the top quarks decays via $t \rightarrow Wb$ and the W decays leptonically; we require an isolated electron or muon with $p_t > 40$ GeV/c and $|\eta| < 2.5$.

Using Isajet, jets are formed by clustering final-state particles (excluding neutrinos) appearing in the region $|\eta| < 3.0$ within a cone of radius $R < 0.6$. The cone size (0.6) is chosen such that the energy lost outside the jet cone approximately balances the energy entering the cone from the underlying event and initial/final state radiation. The 4-momenta of these jets are then smeared with an assumed jet resolution of $70\%/\sqrt{E} + 3\%$ to conservatively account for the SDC calorimeter resolution^[4] ($50\%/\sqrt{E} + 3\%$) as well as effects due to clustering^[6].

As in Method 1, we again require that two jets with $p_t > 30$ GeV/c be tagged as originating from b 's. The efficiencies for triggering and for tagging both b jets are the same as in Method 1 (listed in Table 1). Any two non- b jets within $|\eta| < 2.5$

Figure 5: Statistical significance, N_{SD} , see Eq. (4), of the excess of isolated pions due to $t \rightarrow H^+ b$, $H^+ \rightarrow \tau \nu$, and $\tau \rightarrow \pi \nu$ relative to expectations for $t \rightarrow W^+ b$ (assuming lepton universality) as a function of $\tan \beta$ (bottom labels). We require an isolated lepton with $p_t > 40$ GeV/c and compare results for p_t cuts on the isolated pion of 40 and 100 GeV/c. The upper labels give the $t \rightarrow H^+ b$ branching ratio, which reaches a minimum at $\tan \beta \approx 8$, see Fig. 1.

and $p_t > 20$ GeV/c are then used to form invariant mass combinations. In addition to the two b jets and the two jets from the $W^\pm$ or $H^\pm$, most events generated in Isajet contain additional jets due to initial- and final-state radiation. This is shown in Fig. 6, in which the average number of jets (including b jets) reconstructed with $|\eta| < 2.5$ and $p_t > 20$ GeV/c is about 6.

The invariant mass distributions for all pairs of non- b jets in WW events and WH events are plotted in Figs. 7(a) and 7(b), respectively. In both cases, the combinatoric background is substantial, arising primarily from two-jet pair selections in which one or both of the jets arise from the secondary radiation processes.

The combinatoric background can be reduced in a number of ways. For comparison with the procedure in Ref. 6, we tried requiring that the dijet system has substantial net p_t . For a p_t cut of 120 GeV/c, this is shown as the thin solid histograms in Figs. 7(a) and 7(b). The signal/background ratio is somewhat improved by this cut, at the cost of a large reduction in the signal. As a result, we have chosen not to use this cut.

Figure 6: The number of jets (including b jets) reconstructed per event in Isajet $t\bar{t} \rightarrow WHb\bar{b}$ events, with $p_t > 20$ GeV/ c , in the pseudo-rapidity interval $|\eta| < 2.5$.

Instead, we employ a technique that is very effective in reducing this combinatoric background: we restrict our dijet invariant mass plot to the two (non- b) jets with the highest transverse momenta that in combination with (either) one of the tagged b jets yield a net three-jet invariant mass ($M_{j\bar{j}b}$) smaller than 400 GeV/ c^2 . This latter requirement is simply for consistency, within errors, with the top quark mass $m_t = 250$ GeV/ c^2 which we assume will already have been measured by the two-lepton method of Ref. 7. Of course if we found a mass peak close to 400 GeV/ c^2 , we would modify this choice. This technique of choosing only the two highest p_t jets will eliminate a significant number of incorrect combinatoric choices involving radiatively generated jets or the wrong b jet. By “highest transverse momentum”, we mean an algorithm in which we chose the leading p_t jet, and then searched for the remaining jet with the highest p_t such that the dijet+ b mass was less than 400 GeV/ c^2 . If none satisfied this criterion, we began with the next-to-leading jet and again searched the remaining jets (and so on). The resulting dijet distribution is shown for the two cases in Fig. 8. The combinatoric background is severely reduced by only plotting one combination per event, and the above choice is usually the correct one.

This algorithm to improve the signal-to-background ratio can be used to accurately measure the top mass. If there were no contribution from hadronically

Figure 7: Two-jet invariant mass distribution for a sample of (a) $t\bar{t} \rightarrow WWb\bar{b}$ events and (b) $t\bar{t} \rightarrow WHb\bar{b}$ events. The thick solid histogram is for all pairs of non- b jets, and the thin solid histogram is for those pairs with a net system $p_t > 120$ GeV/c. The error bars shown correspond to the statistics for one SSC year.

Figure 8: Two-jet mass distribution, for samples of $t\bar{t} \rightarrow WWb\bar{b}$ events (thick solid) and $t\bar{t} \rightarrow WHb\bar{b}$ events (thin solid). Only one two-jet combination per event is plotted, that with the two highest- p_T non- b jets consistent with $m(\text{dijet}+b) < 400 \text{ GeV}/c^2$. The error bars shown correspond to the statistics for one SSC year.

decaying charged Higgs bosons (W bosons), the histograms of Fig. 9 would represent the three-jet invariant mass distribution in WW events (in WH events), where we have combined those two-jet pairs in the range $60 < M_{jj} < 100 \text{ GeV}/c^2$ ($125 < M_{jj} < 175 \text{ GeV}/c^2$) with each of the tagged b jets. The top mass peaks at $250 \text{ GeV}/c^2$ are clear with rather small combinatoric backgrounds.

The ideal technique to determine the statistical significance of the $H^\pm$ and $W^\pm$ mass peaks is to fit the dijet invariant mass distribution obtained from the data to the distributions obtained using a Monte Carlo that produces both WW and WH events (with a W or H decaying to jets). This will give a best value for the fraction of WH events in the data (or a limit on the amount of WH present). This value is determined by $B(t \rightarrow bH)$ and $B(H \rightarrow c\bar{s})$; hence using Fig. 1 one can determine the best value of $\tan\beta$. As an example, the two-jet invariant mass distributions obtained after imposing the selection criteria (and efficiencies) are shown in Fig. 10 for the particular cases of $\tan\beta = 0.2, 0.5, 1.0, 1.5$ (yielding $B_H = 0.91, 0.63, 0.30, 0.16$ and $B(H^+ \rightarrow c\bar{s}) = 0.997, 0.97, 0.66, 0.29$). For $\tan\beta = 0.5$ and 1.0 , the $W^\pm$ and $H^\pm$ mass peaks are both very prominent, and discovery of the $H^\pm$ is clearly possible. For $\tan\beta = 0.2$ the $W^\pm$ peak is weak,

Figure 9: Invariant mass distribution for three-jet combinations composed of the two highest- p_t non- b jets with each of the tagged b jets, in Isajet $t\bar{t}$ events. The thick solid (thin solid) histogram is for $WWb\bar{b}$ ($WHb\bar{b}$) events. The error bars shown correspond to the statistics for one SSC year.

but the $H^\pm$ peak remains substantial. The $H^\pm$ peak in the $\tan\beta = 1.5$ case is somewhat marginal, since the combinatoric background would have to be well understood to claim a signal. The statistical significance is quite high since the statistical errors (shown) are very small; however, in this case we would prefer to rely on Method 1 ($H^+ \rightarrow \tau\nu$) which is effective down to $\tan\beta = 0.5$.

Since our mass assumptions yield two reasonably well separated mass peaks, we have adopted a simple technique to roughly estimate the statistical significance of each peak. We consider the number of events in the two intervals $60 < M_{jj} < 100$ GeV/c^2 (W interval) and $125 < M_{jj} < 175$ GeV/c^2 (H interval). The background beneath the H peak has a contribution from both WW and WH events. Motivated by Fig. 8, we assume that the shapes of the combinatoric backgrounds in the WW and WH event samples are nearly the same. For a given value of $\tan\beta$ (see Fig. 10 (b), for example) we find the background beneath the $H^\pm$ peak by scaling the WW distribution to overlap the WH histogram on both edges of the H interval. This estimate is good to about 10%. The signal in the $H^\pm$ peak is then the number of events in the $H^\pm$ interval minus the estimated background. We follow the converse procedure in determining the number of events in the $W^\pm$ peak. For the two mass

Figure 10: Two-jet invariant mass plot after two-jet selection criteria are imposed, for the cases of (a) $\tan \beta = 0.2$, (b) $\tan \beta = 0.5$, (c) $\tan \beta = 1.0$, and (d) $\tan \beta = 1.5$. The plot is normalized to one SSC year of running. The dotted curve in (d) indicates the background determined as described in the text. The error bars shown correspond to the statistics for one SSC year.

intervals, the estimated ratios of signal and of background events to the number of events passing the trigger and event selection requirements in the WW and WH processes are shown in Table 2.

	WW events	WH events
W peak signal	0.230	0
H peak signal	0	0.301
W peak bkgnd.	0.086	0.085
H peak bkgnd.	0.157	0.188

Table 2: Ratios of signal and background event numbers to total number of events passing trigger and event selection requirements.

To quantify the statistical significance of the $H^\pm$ and $W^\pm$ mass peaks, we again plot the number of standard deviations above background as a function of $\tan\beta$:

$$N_{SD} = \frac{N_{above}}{\sqrt{N_{above} + N_{below}}}, \quad (5)$$

where N_{above} is the number of ‘excess’ events appearing above the background curve and N_{below} is the number below the background curve in the two mass intervals mentioned above. The resulting values for N_{SD} are plotted as a function of $\tan\beta$ in Fig. 11. The highest $\tan\beta$ value for which we could discover the charged Higgs by this method would depend critically on understanding the shape of the combinatoric background. To be conservative we should claim to see a signal only when the shape of the distribution is clearly different from the background. Hence, we argue that Method 2 is valid only for $\tan\beta < 1.5$.

For $\tan\beta$ below 0.2, where there are very few WW decays, the W mass peak would not be observable above the background, though the $H^\pm$ peak would still be significant (with 10,000 events for $\tan\beta = 0.2$ and 1000 events for $\tan\beta = 0.06$). Eventually for very small $\tan\beta$, the t branching fraction to W is very small, and the trigger rate decreases to the point where non- $t\bar{t}$ backgrounds (i.e. $Wb\bar{b}$ jet jet) become significant. For example, if the background to ‘standard’ $t\bar{t}$ production given the lepton and b tag requirements were 1% of that from $t\bar{t}$, then at $\tan\beta = 0.04$ the background and signal event rates would be the same, and it would be difficult to see the $H^\pm$ peak for $\tan\beta$ below this value. Based on an Isajet calculation^[8] we estimate the non- $t\bar{t}$ background to be less than 0.1%. For $\tan\beta < 0.013$ the signal event rate drops below 50 events per SSC year, so detection would be difficult even without non- $t\bar{t}$ background.

Figure 11: The statistical significance, N_{SD} of Eq. (5), of the charged Higgs (solid) and W boson (dotted) peaks in the two-non- b -jet invariant mass distribution as a function of $\tan \beta$. We assume one SSC year of running and have taken $m_t = 250$ GeV/ c^2 and $m_{H^\pm} = 150$ GeV/ c^2 .

V. CONCLUSION

We have examined the capability of the SDC detector to discover a charged Higgs boson in $t\bar{t}$ events in which one t decays to $H^\pm b$ and the other to $W^\pm b$. This study was performed in the context of a two-Higgs doublet model in which one Higgs doublet couples only to up-type quarks and the other only to down-type quarks and to leptons. In the particular case of $m_t = 250$ GeV/ c^2 and $m_{H^\pm} = 150$ GeV/ c^2 , discovery of the charged Higgs boson will be possible over the entire interesting range of parameter space. Detection of $H^\pm$ for $\tan \beta \gtrsim 0.5$ is possible through $H^+ \rightarrow \tau \nu$ decays, while for $\tan \beta \lesssim 1.5$ the decays $H^+ \rightarrow c \bar{s}$ can be employed. This study illustrates the importance of efficiently identifying b -quark jets and τ 's, and of measuring charged hadron momenta. The tracking system is therefore an essential ingredient for SDC in discovering charged Higgs bosons.

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4. I. Hinchliffe *et al.*, SDC Note SSC-SDC-100.
5. An ℓ in either $\ell^+\ell^-$ or $\ell\tau$ events can also originate from a leptonic τ decay. This contribution is small because of the combination of the branching ratio and the high- p_t cut on the lepton. Using Isajet, we find a correction to the predicted $\ell^+\ell^-$ rate from WW of approximately 10% for the $p_t > 40$ GeV/ c cut, and this correction can be determined with high precision. τ 's from H decays are not an important source of ℓ 's, because for $\tan\beta$ values where $B(t \rightarrow H^+b)$ is large, $B(H \rightarrow \tau\nu)$ is small.
6. R.J. Hollebeek, P.K. Sinervo and H.H. Williams, "Reconstruction of Top Quarks in an SSC Solenoidal Detector", SDC Notes SSC-SDC-30, SDC-90-00114 and SDC-90-00117; also the Solenoidal Detector Collaboration Expression of Interest, May 1990.
7. L. Galtieri *et al.*, SDC Note on two-lepton technique for measuring top mass.
8. Private communication from Edward Wang.

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