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CDF

A Search for the Top Quark Decaying to Charged Higgs in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV

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A Search for the Top Quark decaying to Charged Higgs in $p\overline{p}$ Collisions at $\sqrt{s} = 1.8$ TeV

Abstract

We present results of a search for the top quark decaying to a charged Higgs boson (H) in $p\overline{p}$ collisions at $\sqrt{s} = 1.8$ TeV at the Fermilab Tevatron. Using 4.1 pb^{-1} of data collected during the 1988-89 CDF run, we have searched for evidence of $t\overline{t}$ production assuming that t→ Hb and H→ $\tau\nu_\tau$. We find no evidence for this decay and are able to exclude regions in the (m_t,m_H) plane for different Br(H→ $\tau\nu_\tau$). We also interpret these results for the two Higgs doublet(THD) model.

1 Introduction

Charged Higgs bosons (H) exist if the Higgs sector of the standard model is not minimal and occur in many theories beyond the standard model [1] . The H couple to the same weak fermion (f) currents as the W with relative coupling strength O(m_f/m_W). If $m_H + m_b < m_t < m_W + m_b$ the the top quark decay will be mediated by an on-shell H rather than an off-shell W [2]. The H then decays to the heaviest available leptons ($\tau\nu_\tau$) or quarks ($c\overline{s}$) with the relative branching ratio unconstrained by the theory [3]. Previous searches at CDF for $t\overline{t}$ production have assumed a W decay and required at least one high transverse momentum (P_T) e or μ in the final state [4]. These searches are insensitive to an H mediated decay since the μ, e from the τ decay have low P_T. This paper investigates the case Br(H→ $\tau\nu_\tau$) > 0.5, since if the Higgs decays mostly to jets the signature is dominated by the high QCD background at $p\overline{p}$ experiments.

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The top quark mass is experimentally constrained $m_t > 55$ GeV [5], and $m_H > 45$ GeV [6] independent of the Higgs structure. UA1 and UA2 have excluded regions of the (m_t,m_H) plane for Br(H$\rightarrow \tau\nu_\tau$) = 0.5,1.0 [7].

2 Signature

We search for $p\bar{p} \rightarrow t\bar{t} \rightarrow H^+H^-b\bar{b}$ where one or both $H \rightarrow \tau\nu_\tau$. The final state signature is $\tau+ \geq 1jet + \not{E}_T$ We require the tau to decay hadronically in order to maximize sensitivity to the total $t\bar{t}$ branching ratio. The missing transverse energy ($\not{E}_T$) requirement is due to the neutrino in both the Higgs and tau decays and additionally gives good rejection of QCD background events.

3 CDF Detector and Data Set

The CDF detector has been described in detail elsewhere [8]. CDF is a general purpose detector with almost complete 4π coverage. A set of time projection chambers (VTPC) surrounding the beam pipe allows event vertex reconstruction with charged-particle tracking information over the pseudorapidity range $|\eta| < 3.25$. We define $\eta = -\ln\tan(\theta/2)$ where θ is the polar angle measured from the proton beam. The Central Tracking Chamber (CTC) is a 2.76m diameter cylindrical drift chamber operating inside a 1.412 T solenoidal magnetic field. The CTC tracks charged particles in the central region $|\eta| < 1.1$ and makes precision measurements of the corresponding transverse momenta. In the central region, electromagnetic (CEM) and hadronic (CHA) sampling calorimeters are used with a projective tower segmentation $\Delta\eta \times \Delta\phi = 0.1 \times 15^\circ$. In the plug ($1.1 < |\eta| < 2.4$) and forward ($2.4 < |\eta| < 4.2$) regions, calorimeters with a finer tower segmentation $\Delta\eta \times \Delta\phi = 0.1 \times 5^\circ$ are used.

We use a $\not{E}_T$ trigger which requires $\not{E}_T > 25$ GeV. In the fully reconstructed event we then require a leading calorimetric cluster with $E_T > 15$ GeV in the central ($0.1 < |\eta| < 1.0$) region of the detector ($t\bar{t}$ are produced centrally). The clustering algorithm used is a cone clustering algorithm with radius R=0.4 [9]. To reduce QCD background we veto dijet events by requiring that there be no clusters with $E_T > 10$ GeV azimuthally opposite the leading cluster ($\Delta\phi_{(Leading jet)-(jet with E_T > 10 GeV)} > 150^o$). Also the $\not{E}_T$ is required to be significant ($\not{E}_T/\sum E_T > 2.5$). We then require that at least one of the central clusters with $E_T > 15$ GeV be a hadronic τ as defined below, and at least one other cluster $E_T > 12$ GeV $|\eta| < 3.5$.

4 Hadronic τ algorithm

An hadronically decaying τ will produce a narrow (low mass) calorimeter cluster associated with an odd number of charged tracks. Since it is produced by a high mass (H) it is often isolated. Starting with a narrow cluster as described above we form two concentric cones about an axis defined from the event vertex to the E_T weighted cluster centroid. In the inner cone (7.5^o) we require a leading track with $P_T > 2.5$ GeV and count the number of tracks with $P_T > 1.0$ GeV. We then require that the cluster be isolated by demanding that there be no tracks with $P_T > 1.0$ GeV in the annulus between the inner and outer cones ($7.5^o - 17.5^o$). Electrons which pass these requirements are removed. Taus show a distinctive one and three surplus in the number of tracks in the inner cone. The track P_T thresholds are determined by requiring a low probability of an accidental overlap of a track from the underlying event. The cone sizes are fixed by requiring high rejection of QCD jets while maintaining good acceptance for taus in $t\bar{t}$ events. This algorithm is similar to that used in [10] to test lepton universality by measuring the ratio of cross-sections $\sigma(p\bar{p} \rightarrow W \rightarrow \tau\nu)/\sigma(p\bar{p} \rightarrow W \rightarrow e\nu)$ In this analysis the algorithm has been optimized for $t\bar{t}$ events in which taus are less isolated and have lower P_T. It gives a universality result consistent with [10].

5 Expected number of events

Table 1 shows the overall efficiency for a range of m_t,m_H combinations. The expected number of events is given assuming Br(t→Hb) = 1.0 and Br(H→ $\tau\nu_\tau$) =1.0. The calculation uses the ISAJET monte-carlo [11] which has been modified to take account of the polarisation of the tau [12]. The tau decay branching ratios are taken from [13] and the $t\bar{t}$ production cross-sections from [14] . All events are passed through the CDF detector simulation and are then subjected to the same event reconstruction algorithms that are applied to the data. The error quoted is a combined Poisson statistical error and Gaussian systematic error. The total systematic error is the sum in quadrature of the errors in table 2 where the values are computed for a typical case $m_t = 75, m_H = 65$.

6 Results

6.1 Subtraction of QCD background

Figure 1 shows the number of tracks in the inner cone for tau candidates in events which pass the selection criteria above. Also shown is the distribution for a normalized sample of QCD jets which pass the same tau algorithm requirements. A clear one track surplus is seen. The absence of a three track surplus is consistent with binning statistics. After subtraction of the QCD background we estimate that there are 36±16 events.

6.2 Estimate of W,Z background

The process $p\overline{p} \rightarrow W + jet \rightarrow \tau\nu_\tau + jet$ is a significant background. To estimate the number of events expected we measure the number of $p\overline{p} \rightarrow W + jet \rightarrow e\nu_e + jet$ events and multiply by the relative efficiencies for detecting $W \rightarrow \tau\nu + jet$ and $W \rightarrow e\nu + jet$ which is calculated with a monte-carlo assuming lepton universality [10]. The theoretical uncertainty in the absolute cross section cancels and the process $p\overline{p} \rightarrow W + jet \rightarrow e\nu_e$ has been previously studied [16]. We use the VECBOS [15] monte-carlo which reproduces $W + jet$ events reliably and estimate 33±6 events. There is also a small background of 3±1 events due to Z+jet production which is calculated using the ISAJET monte-carlo. Therefore the 36±16 observed $\tau + jet + \not{E}_T$ events can be accounted for by W,Z backgrounds.

6.3 Interpretation of results

We observe O±17 events from the decay of the top quark to the charged Higgs. Using table 1 we exclude regions of the (m_t,m_H) plane at 95% for the case Br(t→Hb) = 1.0 and Br(H→ $\tau\nu_\tau$) =1.0 (Figure 1). Also shown are the cases Br(H→ $\tau\nu_\tau$) =0.75,0.5. In figure 2 we exclude regions assuming the two Higgs doublet model(THD). The THD is the simplest non-minimal standard model Higgs structure. In this model the ratio of the non-zero vacuum expectations of the two doublets tan(β)=v2/v1 is the unconstrained parameter that determines the Higgs branching ratio. As described in [3] the dependance is determined by the arrangement of the couplings of quarks and leptons to the two doublets. We consider the case where the u,c,t quarks couple to one doublet and the d,s,b quarks and e μ, τ leptons couple to the other doublet. This is the model tested in [7]. In this model Br(H$\rightarrow \tau\nu_\tau$) = 0.5,0.75,0.95 for $\tan(\beta)$ = 1.2,1.65 and 2.5 respectively and the loss of sensitivity for $m_t \simeq m_W$ is due to resonant production of $t \rightarrow Wb$ [17] which decreases Br(t$\rightarrow$ Hb). However since Br(t$\rightarrow$Hb) is also weakly dependant on $\tan(\beta)$ the W decay is completely suppressed for large $\tan(\beta) > 15.0$.

7 Conclusions

We have found no evidence of $t\bar{t}$ production in which the top decays to a charged Higgs.We exclude most of the m_t, m_H plane where W decays of the top quark would be suppressed in the case where Br(H$\rightarrow \tau\nu_\tau$) is large. We also interpret these results for a particular case of the THD model.

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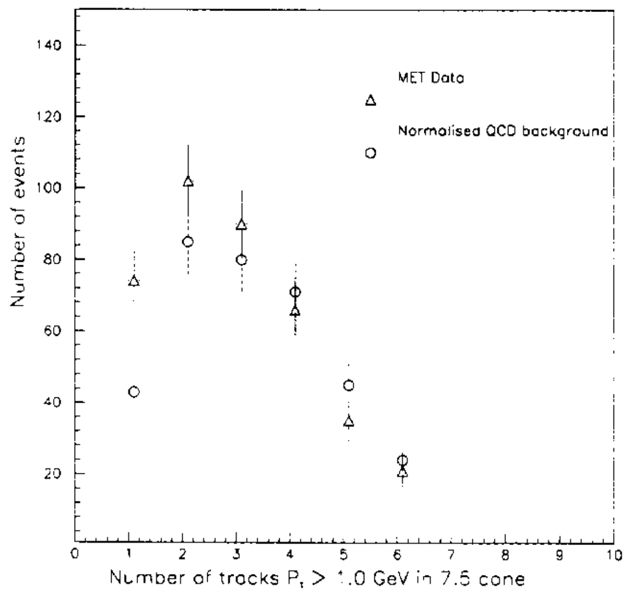

Figure 1: Number of tracks in 7.5° cone for CDF data and QCD background data

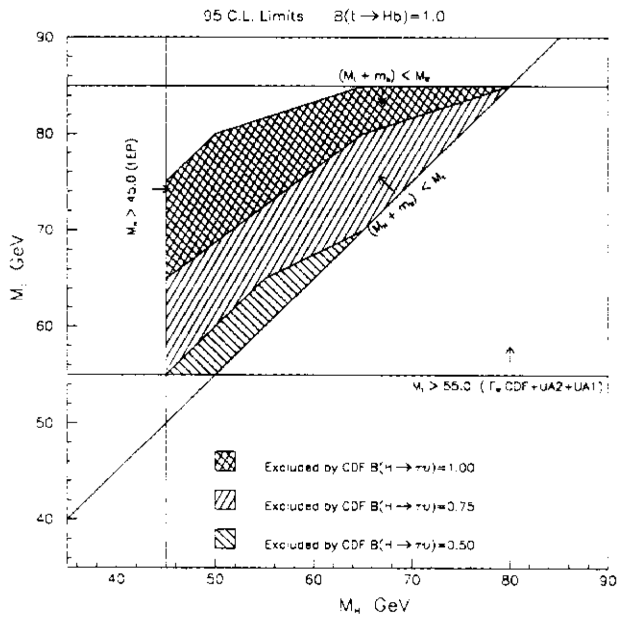

Figure 2: Regions of m_t, m_H plane excluded at 95 % for Br($t \to Hb$)=1.0

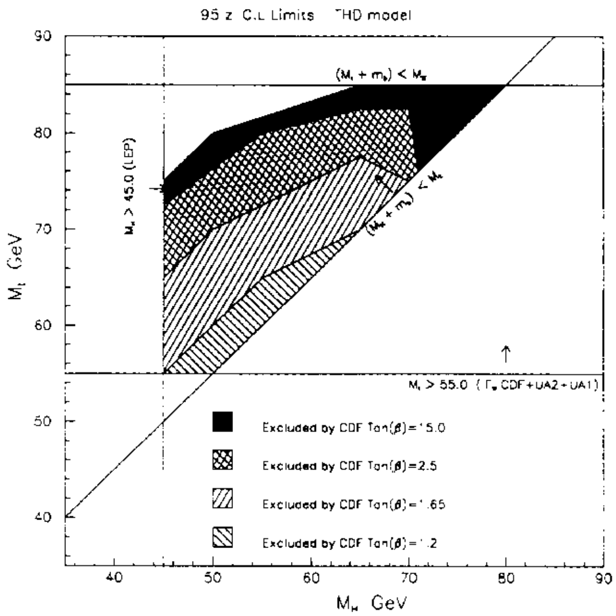

Figure 3: Regions of m_t, m_H plane excluded at 95 % for THD model

m_t	m_H	$A.\epsilon\%$	Expected
85	80	6.5	44±11
85	75	5.6	38± 9
85	70	4.9	34± 8
85	65	4.6	32± 8
85	60	4.1	28± 7
85	55	3.8	26± 7
85	50	3.4	24± 6
85	45	3.1	21± 6
80	75	5.7	54±13
80	70	4.8	45±11
80	65	4.3	41±10
80	60	3.9	36± 9
80	55	3.6	34± 8
80	50	3.1	29± 7
80	45	2.4	23± 6
75	70	4.6	60±15
75	65	4.0	53±13
75	60	3.7	49±12
75	55	2.8	37± 9
75	50	2.9	38± 9
75	45	2.5	33± 8
70	65	3.6	60±14
70	60	3.2	60±14
70	55	2.5	48±11
70	50	2.5	46±11
70	45	2.0	37± 9
65	60	2.8	77±18
65	55	2.6	71±18
65	50	2.3	63±15
65	45	2.0	54±13
60	55	2.4	97±24
60	50	1.7	70±18
60	45	1.6	66±18
55	50	1.5	97±25
55	45	1.3	84±21

Table 1: Overall acceptance.efficiency for different top and higgs masses. The expected number of events is calculated for1Br(t→Hb) = 1.0 Br(H→ τv_τ) =1.0 in 4.1 pb^{-1} of data

Systematic Error	%
Energy Scale	13
Modeling of Gluon Radiation	10
Trigger Efficiency	7
Integrated Luminosity	7
Monte Carlo Statistics	6
Tau decay branching ratio	4
Total	25

Table 2: Systematic error of overall acceptance.efficiency for $m_t = 75, m_H = 60$.