A search for the top quark decaying to charged Higgs in $p\overline{p}$ Collisions at $\sqrt{s} = 1.8$ TeV

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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. Assuming that $H^+ \to \tau\nu_\tau$ is the dominant H^+ decay mode, we exclude regions of the (m_{H^+},m_t) plane for values of the $B(H^+ \to \tau\nu_\tau) =$ 0.5,0.75 and 1.0. We interpret the results in terms of the parameter $\tan\beta$ in the two Higgs doublet Model.

The top quark continues to elude discovery. The most recent limit on the top mass is $m_t > 113$ GeV/c^2, assuming the standard model decay, $t \to$ W^+b [1]. However, in several models in which the Higgs sector is expanded to include charged Higgs scalars (H^+), the decay $t \to H^+b$ is possible. These models include the non-minimal standard model and theories beyond the standard model such as supersymmetry and technicolor [2]. In these models, if the top mass lies in the range $m_{H^+} + m_b < m_t < m_W + m_b$, then the decay $t \to H^+b$ can dominate over $t \to$ W^+b [3]. The H^+ is expected to decay to the heaviest available leptons ($\tau\nu_\tau$) or quarks ($c\overline{s}$), with relative branching ratio unconstrained by the theory. For example, in the simplest version of the non-minimal standard model, there are two Higgs doublets and the branching ratio $B(H^+ \to \tau\nu_\tau)$ depends on the parameter $\tan\beta$, which is given by the ratio of the non-zero vacuum expectation values for the two doublets [4]. Independent of the Higgs structure, the top quark and charged Higgs masses are experimentally constrained: $m_t > 55$ GeV/c^2 [5] and $m_{H^+} > 45$ GeV/c^2 [6] . In addition, UA1 and

UA2 have excluded regions of the (m_{H^+},m_t) plane for $B(H^+ \rightarrow \tau\nu_\tau) = 0.5$ and 1.0 [7].

In this letter we present the results of a search for the decay $t \rightarrow H^+b$ using a hadronic τ signature, for cases in which the branching ratio $B(H^+ \rightarrow \tau\nu_\tau) > 0.5$. The data for this study were recorded in 1988-89 using the Collider Detector at Fermilab (CDF) in the Fermilab Tevatron $p\overline{p}$ collider. The data correspond to an integrated luminosity of 4.2 ± 0.3 pb^{-1}. We first describe those aspects of the CDF that are relevant to this search, and we define the experimental signature with particular emphasis on the hadronic τ algorithm. We then demonstrate that we would expect a significant number of events in the search region, using this signature. Finally we present limits on the values of m_{H^+} and m_t, and we interpret these limits in terms of the two Higgs doublet model.

The CDF is described in detail elsewhere [8]. It is a general purpose detector with almost complete 4π calorimeter coverage. Charged particle tracking is accomplished by a set of time projection chambers (VTPC) surrounded by a large cylindrical drift chamber (CTC) inside a 1.412 T solenoidal magnetic field. The VTPC provides z-vertex reconstruction and r-z tracking over the pseudorapidity range $|\eta| < 3.25$, where the z axis is along the beam line. The CTC provides precise momentum reconstruction and excellent two track resolution for particles in the range $|\eta| < 1.2$. In the central region ($|\eta| < 1.1$), electromagnetic and hadronic sampling calorimeters are used with a projective tower segmentation, $\Delta\eta \times \Delta\phi = 0.1 \times 15^\circ$, where ϕ is the azimuthal angle. In the intermediate ($1.1 < |\eta| < 2.4$) 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.

In order to search for $p\overline{p} \rightarrow t\overline{t}X \rightarrow H^+H^-b\overline{b}X$, we rely upon the characteristic features of both the $H^+ \rightarrow \tau\nu_\tau$ decay and the hadronic decay of the τ. These features include the presence of highly collimated, isolated clusters of hadrons from the τ decays and the substantial missing transverse energy ($\not\!\!E_T$) [9] from the neutrinos from both the H^+ and τ decays. We begin the search by selecting events passing a hardware trigger that was originally designed to select $W \rightarrow e\nu$ decays; this trigger required $\not\!\!E_T > 25$ GeV, in coincidence with one or more electromagnetic clusters with $E_T > 8$ GeV. After offline reconstruction, we place a significance cut on $\not\!\!E_T$ ($\not\!\!E_T/\sqrt{\sum E_T} > 2.5\ \sqrt{\mathrm{GeV}}$), and we require at least one central calorimeter cluster [10] with $E_T > 15$ GeV and $0.1 < |\eta| < 1.0$. To veto QCD dijet events, we require that there be no other cluster with $E_T > 10$ GeV azimuthally opposite the leading cluster ($|\Delta\phi| > 150^o$). To complete the event selection, we require that at least one of the central clusters with $E_T > 15$ GeV be a hadronic τ decay candidate as defined below, and that there be at least one other cluster with $E_T > 12$ GeV and $|\eta| < 3.5$. The additional cluster can be from a b jet, a hadronic τ or a jet from the $H^+ \rightarrow c\bar{s}$ decay in the case $B(H^+ \rightarrow \tau\nu_\tau) < 1.0$.

We now describe the hadronic τ algorithm and demonstrate its consistency using an independent sample of $W \rightarrow \tau\nu$ candidates. A hadronically decaying τ should produce a narrow (low mass) calorimeter cluster associated with an odd number of charged tracks. In addition, τ's from the decay $H^+ \rightarrow \tau\nu_\tau$ should be well isolated. Starting with a cluster with $E_T > 15$ GeV and $0.1 < |\eta| < 1.0$, we form two concentric cones about an axis defined by the E_T weighted cluster centroid. In the inner cone (7.5^o) we require a leading charged track with $p_T > 2.5$ GeV/c [11] and define $\mathrm{N}_{\mathrm{track}}$ as the number of tracks with $p_T > 1.0$ GeV/c. In the annulus between the inner and outer cones ($7.5^o - 17.5^o$) we demand that there be no additional tracks with

$p_T > 1.0$ GeV/c. Electron candidates that pass these requirements are removed. The track p_T thresholds are determined by requiring a low probability (< 1 %) of accidental overlap of a track from the underlying event. The cone sizes are fixed by requiring good rejection of QCD jets while maintaining high acceptance for τ's in $t\bar{t}$ events. This algorithm accepts 65 % of τ's and rejects 87 % of QCD jets which have formed a cluster with $E_T > 15$ GeV and $0.1 < |\eta| < 1.0$. This algorithm is similar to that used in [12] to test lepton universality by measuring the ratio of cross-sections $\sigma(p\bar{p} \to W \to \tau\nu)/\sigma(p\bar{p} \to W \to e\nu)$. In the current analysis the algorithm has been optimized for $t\bar{t}$ events, in which τ's are less isolated and have lower p_T. To demonstrate the distinctive one and three prong signature expected of τ decays, fig. 1 shows the $\mathrm{N}_{\mathrm{track}}$ distribution for $W \to \tau\nu$ candidates from an independent data set. The $\mathrm{N}_{\mathrm{track}}$ distribution for a QCD jet background sample is also shown. This distribution is normalized to the sum over 2, 4, 5 and 6 prong bins for the $W \to \tau\nu$ candidates. After this background has been subtracted, the estimated number of $W \to \tau\nu$ events is consistent with the previous measurement of lepton universality by the CDF collaboration, namely $g_\tau/g_e = 0.97 \pm 0.07$ [12].

Applying the hadronic $\tau + \geq 1$ jet $+ \not{E}_T$ signature requirement to Monte Carlo data sets, we show in Table I the expected number of $t \to H^+b$ events for a range of (m_{H^+},m_t) combinations assuming $B(t \to H^+b)$ =1 and $B(H^+ \to \tau\nu_\tau)$ =1. The overall efficiency is calculated using the ISAJET [13] Monte Carlo, modified to take account of the τ polarization [14] . The τ decay branching ratios are taken from the CELLO measurement [15], and the $t\bar{t}$ production cross-sections are taken from the lowest theoretical estimates of Nason *et al.* [16]. The Monte Carlo events are passed through the CDF detector simulation and then subjected to the same event reconstruction algorithms that are applied to the data. The errors quoted are the Poisson statistical errors combined in quadrature with the Gaussian systematic uncertainties. The total systematic uncertainties depend on (m_{H^+},m_t) and are typically of order 20-25 %. The main sources of systematic uncertainty are as follows. First there is a 13-15 % uncertainty in the overall efficiency due to the uncertainty in the jet energy scale and the low energy calorimeter response (see ref. [17]). Second, there is a 5-15 % uncertainty in the efficiency of the jet requirement associated with the modelling of initial and final state gluon radiation. Third, there is a 5-7 % systematic uncertainty in the modelling of the CDF trigger efficiency. Fourth, the uncertainties in the τ decay branching ratios add another 4-6 % to the systematic uncertainty. Finally there is a 7 % uncertainty in the total integrated luminosity. We combine these uncertainties in quadrature to define the overall systematic uncertainty.

We now describe the results of our search. We observe 391 candidate events which pass our selection criteria. These include a large background from QCD events and smaller backgrounds from vector boson decays. Figure 2 shows the $\mathrm{N}_{\mathrm{track}}$ distribution for τ candidates in events which pass the selection criteria above. Also shown is the distribution for a sample of QCD jets that pass the same τ algorithm requirements. This distribution is normalized to the sum over the 2,4,5 and 6 prong bins of the τ candidates. A one track surplus is seen. The absence of a three track surplus is consistent with the statistical uncertainty in the ratio of one to three prongs expected from τ's . After subtraction of the QCD background we estimate that there are 36±16 events.

The process $p\overline{p} \rightarrow W + jet, W \rightarrow \tau\nu$ is a significant background. To estimate the number of events expected, we multiply the observed number of $p\overline{p} \rightarrow W + jet, W \rightarrow$

$e\nu$ events by the ratio of detection efficiencies for $W \rightarrow \tau\nu + jet$ and $W \rightarrow e\nu + jet$, using the VECBOS Monte Carlo [18] and assuming lepton universality in W decays [12]. From this analysis we estimate a background of 33±6 $W \rightarrow \tau\nu + jet$ events in the τ candidate sample; we also estimate a background of 3±1 events due to Z+jet production. We conclude that the 36±16 observed τ + $\geq$ 1 jet + $\not{E}_T$ events can be accounted for by W,Z backgrounds.

After subtraction of the W,Z background we obtain 0±17 event candidates for the decay of the top quark to a charged Higgs. Using Table I, we exclude regions of the (m_{H^+},m_t) plane at 95% confidence limit. This is shown in fig. 3 for the cases $B(t \rightarrow H^+b) = 1.0$ and $B(H^+ \rightarrow \tau\nu_\tau)$ =1.0, 0.75, 0.50.

We also interpret these results in terms of the two Higgs doublet model [19]. In this model, both $B(t \rightarrow H^+b)$ and $B(H^+ \rightarrow \tau\nu_\tau)$ are functions of $\tan\beta$ [4], and so we exclude the same region of the (m_{H^+}, m_t) plane but in terms of $\tan\beta$ rather than the branching ratios. The explicit dependence of $B(t \rightarrow H^+b)$ and $B(H^+ \rightarrow \tau\nu_\tau)$ on $\tan\beta$ is determined by the arrangement of the couplings of quarks and leptons to the two doublets. We consider the case that 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 [20]. This arrangement is also that of the minimal supersymmetric extension of the standard model and is the model tested in ref. [7]. Fig. 4 shows the excluded region for this version of the model.

In conclusion, we have found no evidence for $t\bar{t}$ production in which the top decays to a charged Higgs for values of the branching ratio $B(H^+ \rightarrow \tau\nu_\tau) > 0.5$. We exclude most of the (m_{H^+}, m_t) plane where $t \rightarrow W^+b$ decays of the top quark would be suppressed. We interpret these results for a particular case of the two Higgs doublet model [21].

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[1] P. Tipton *et al.*, CDF Collaboration, Proceedings of the XVI International Symposium on Lepton Photon Interactions, Ithaca, New York, 1993.

[2] J. Gunion *et al.*, The Higgs Hunter's Guide (Addison-Wesley, New York, 1990).

[3] S.L. Glashow and E.E. Jenkins, Phys. Lett. B **196**, 233 (1987).

[4] V. Barger, J.L. Hewett and R.J.N. Phillips, Phys. Rev. D **41**, 3421 (1990).

[5] CDF Collaboration, F. Abe *et al.*, Phys. Rev. D **44**, 29 (1991);

UA2 Collaboration, J. Alitti *et al.*, Phys. Lett. B **276**, 354 (1991);

UA1 Collaboration, C. Albajar *et al.*, Phys. Lett. B **253**, 503 (1991).

[6] ALEPH Collaboration, D. Buskulic, *et al.*Phys. Rep. **216**, 253 (1992);

DELPHI Collaboration, P. Abreu *et al.*, Phys. Lett. B **241**, 449 (1990);

L3 Collaboration, O. Adriani *et al.*, Phys. Lett. B **294**, 457 (1992);

OPAL Collaboration, M. Z. Akrawy *et al.*, Phys. Lett. B **242**, 299 (1990).

[7] UA2 Collaboration, J. Alitti *et al.*, Phys. Lett. B **280**, 137 (1992);

UA1 Collaboration, C. Albajar *et al.*, Phys. Lett. B **257**, 459 (1991).

[8] CDF Collaboration, F. Abe *et al.*, Nucl. Instrum. Methods Phys. Res. Sect. A. **271**, 387 (1988).

[9] Missing transverse energy is defined as

$\not\!\!E_T \equiv \left([\sum_i E_{\mathrm{Ti}} \times \sin\phi_i]^2 + [\sum_i E_{\mathrm{Ti}} \times \cos\phi_i]^2\right)^{1/2}$

where the sum is over calorimeter towers.

[10] In the offline analysis we use a cone clustering algorithm with radius

$\mathrm{R} = \sqrt{|\Delta\phi|^2 + |\Delta\eta|^2}$=0.4.

See CDF Collaboration, F. Abe *et al.*, Phys. Rev. D **45**, 1448 (1992).

[11] p_T denotes the momentum component transverse to the beam axis.

[12] CDF Collaboration, F. Abe *et al.*, Phys. Rev. Lett. **68**, 3398 (1992).

[13] F.E. Paige and S. D. Protopopescu, Report No. BNL-38034, 1986 (unpublished). We used version 6.36.

[14] B. K. Bullock, K. Hagiwara, A. D. Martin Phys. Rev. Lett. **67**, 3055 (1991).

[15] CELLO Collaboration, H. J. Behrend *et al.*, Z. Phys. C **46**, 537 (1990).

[16] R. K. Ellis, Phys. Lett. B **259**, 492 (1988).

[17] CDF Collaboration, F. Abe *et al.*, Phys. Rev. D **45**, 3921 (1992).

[18] F.A. Berends *et al.*, Nucl. Phys. B **357**, 32 (1991).

[19] V. Barger and R.J.N. Phillips, Phys. Rev. D **41**, 884 (1990).

[20] " A Search for the Top Quark decaying to a Charged Higgs in $p\overline{p}$ Collisions at $\sqrt{s} = 1.8$ TeV " Colin P. Jessop, Ph.D Thesis, Harvard University, Cambridge USA (1993).

[21] Other cases of the two Higgs doublet model are tested in ref. [20].

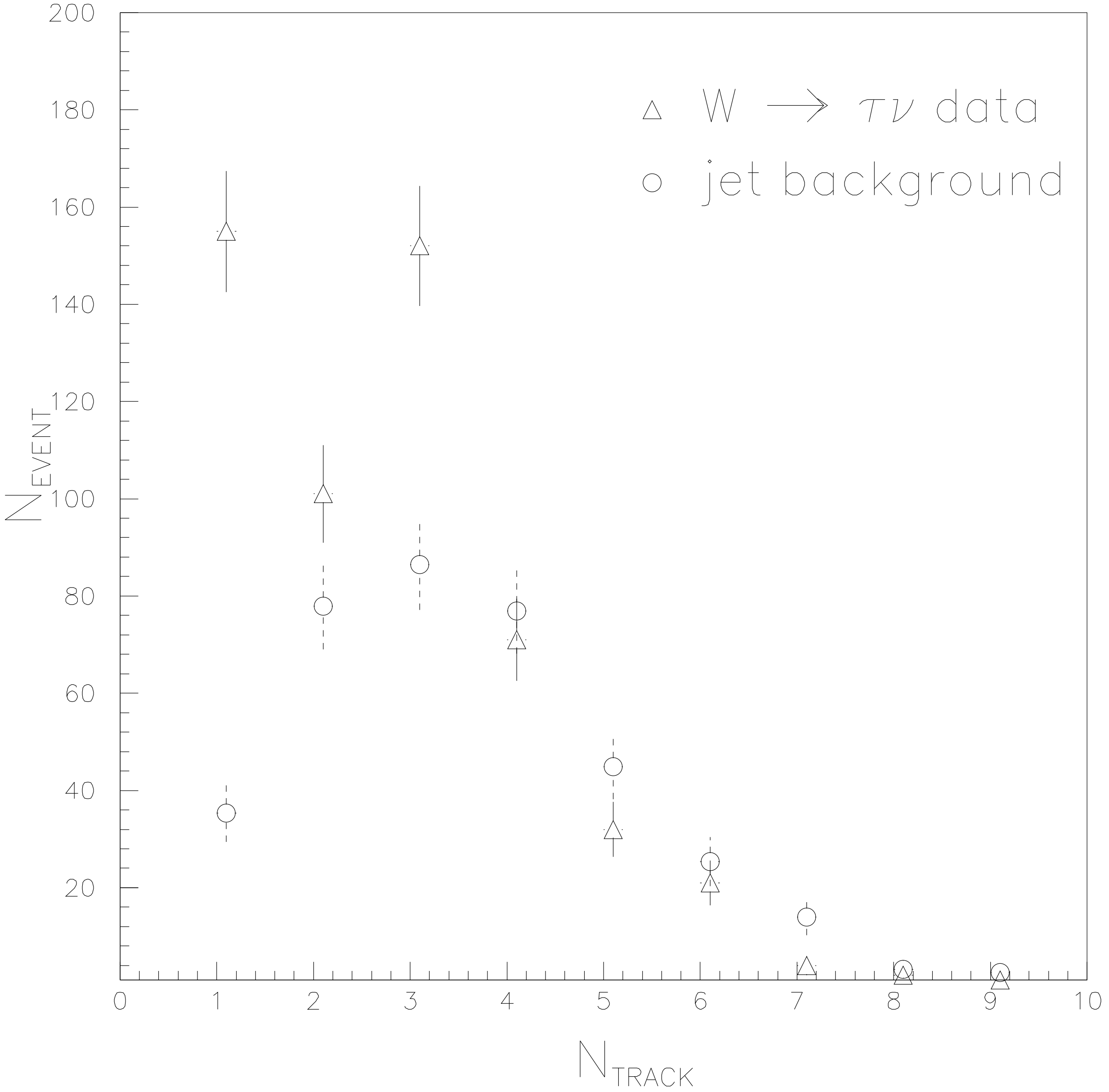

FIG. 1. $\mathrm{N}_{\mathrm{track}}$ distributions for the $W \rightarrow \tau\nu$ data sample and the normalized QCD background sample.

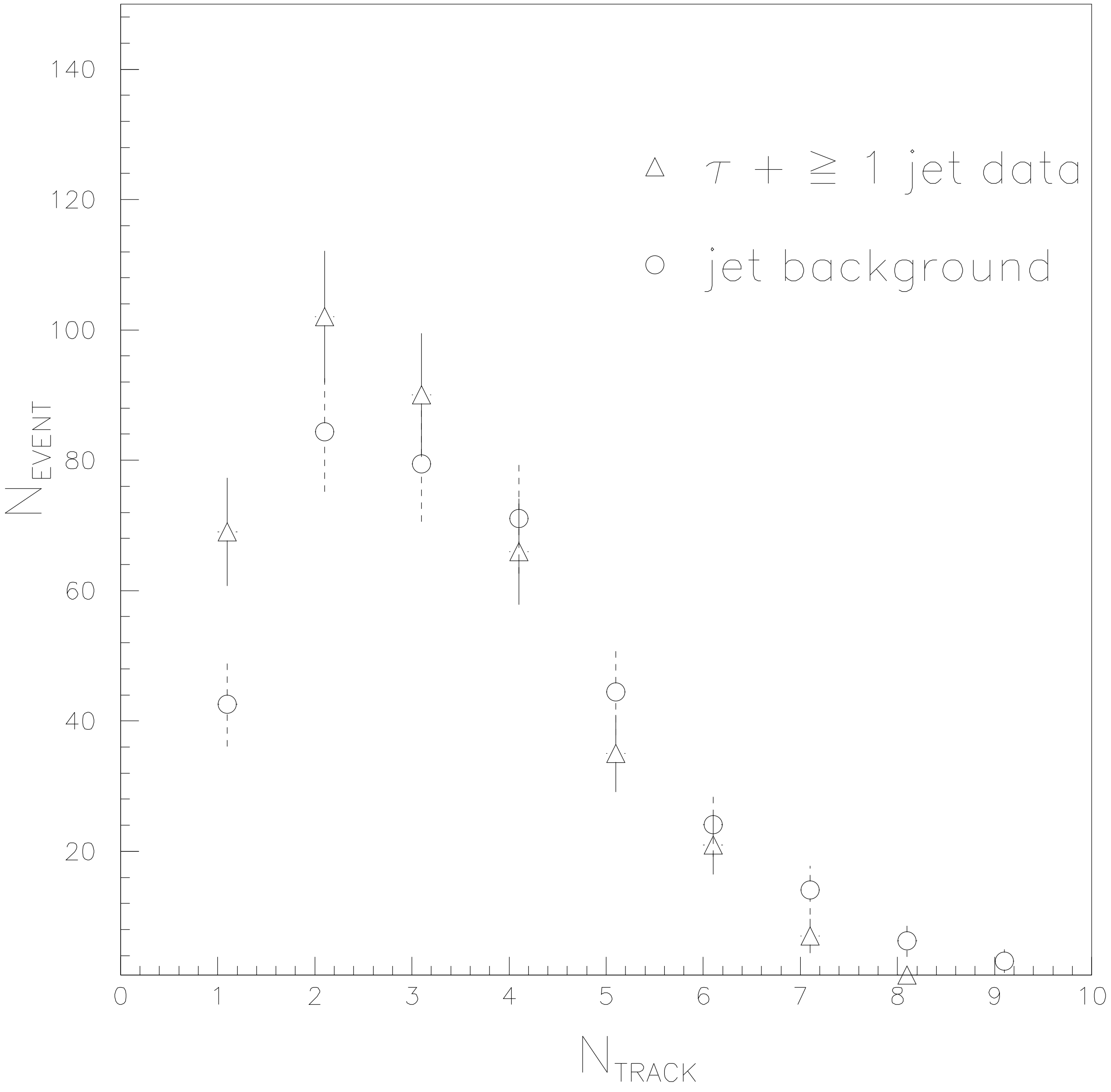

FIG. 2. N_{track} distributions for the $\tau+ \geq 1jet$ data sample and the normalized QCD background sample.

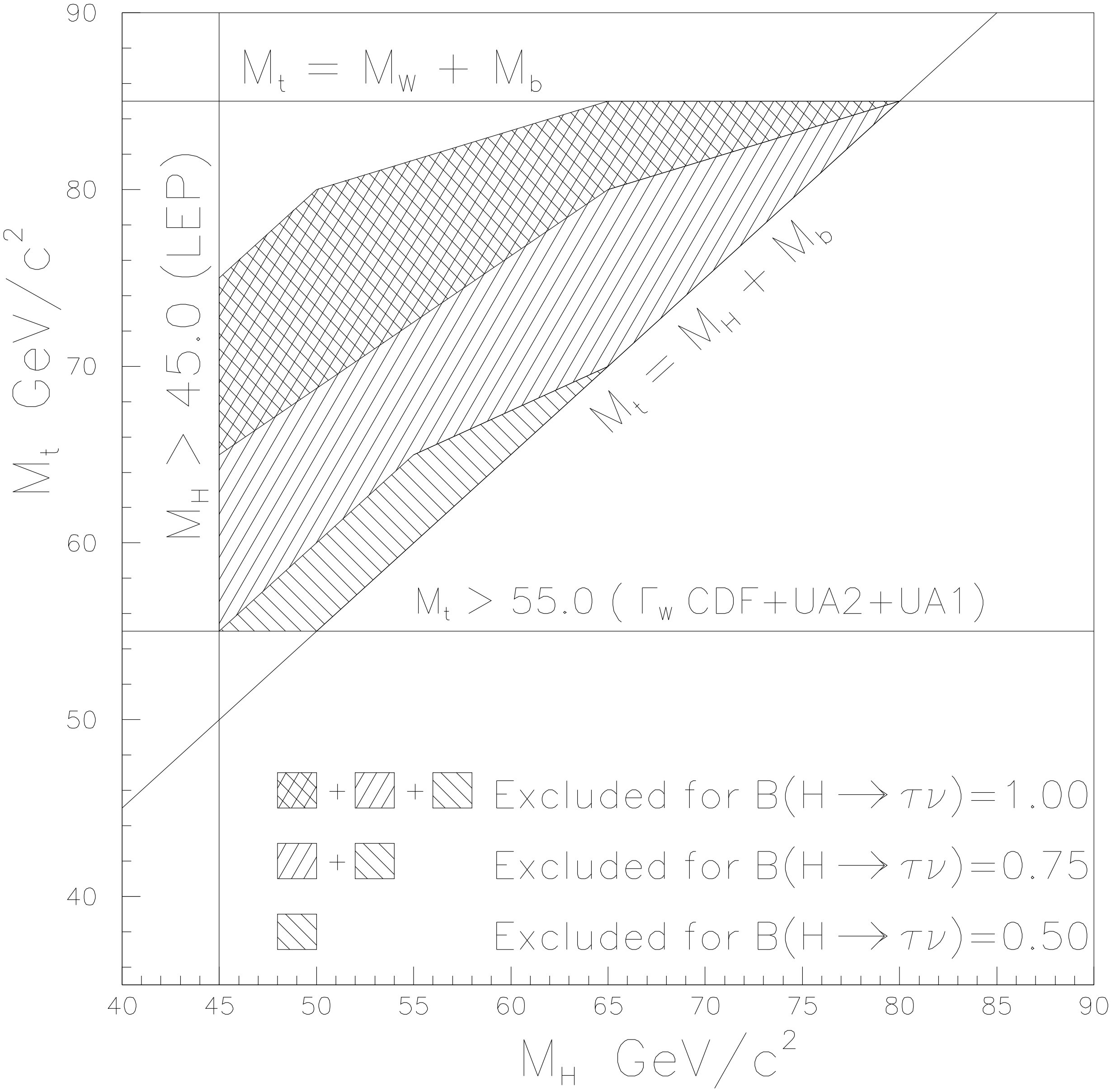

FIG. 3. Regions of the (m_{H^+}, m_t) plane excluded at 95 % C.L. for $B(t \to H^+ b)$=1.0.

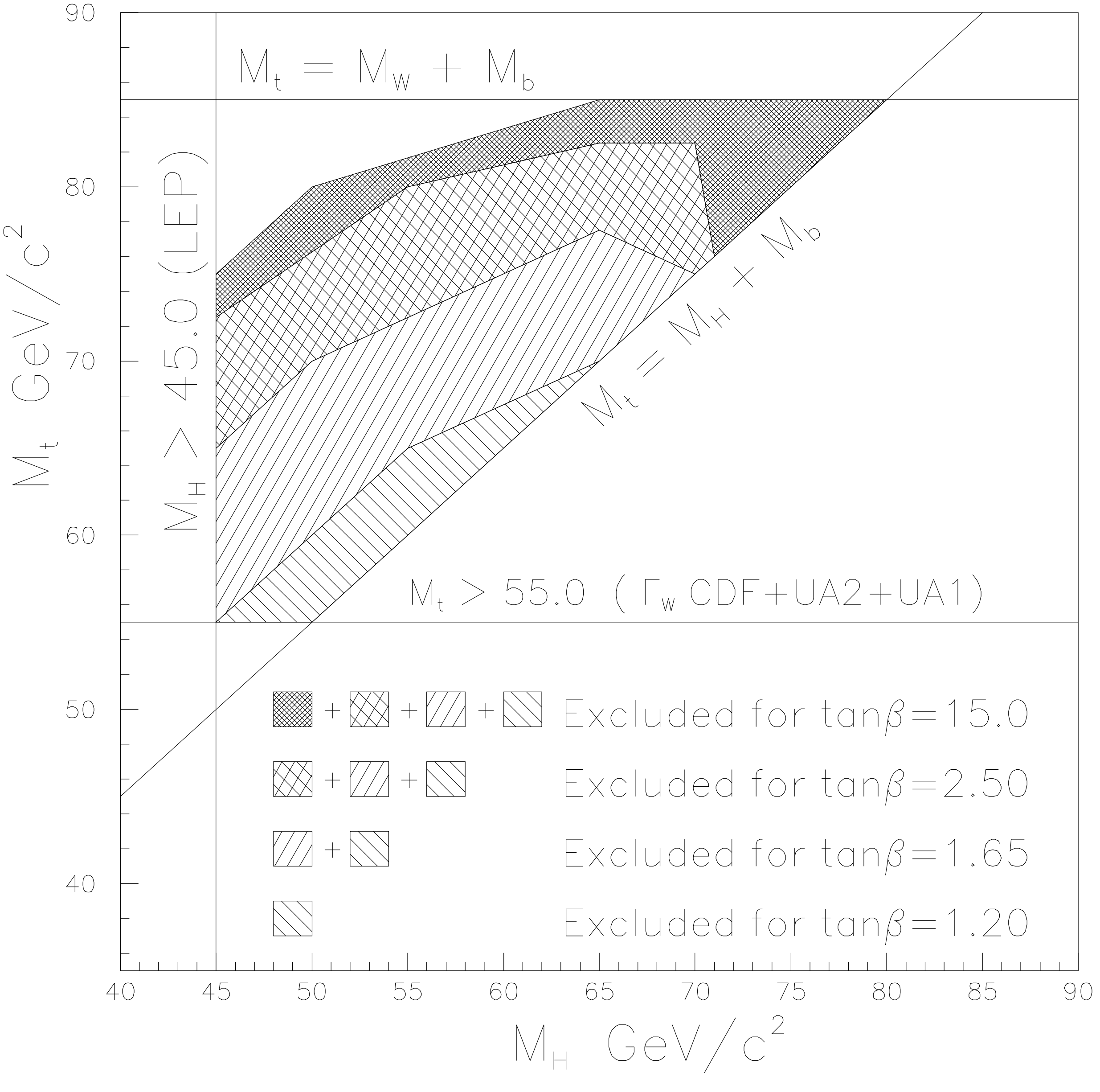

FIG. 4. Regions of the (m_{H^+}, m_t) plane excluded at 95 % C.L. for the two Higgs doublet model.