



Fermi National Accelerator Laboratory

FERMILAB-Conf-97/213-E

CDF and DØ

Present Searches for Higgs Signatures at the Tevatron

L. Groer

For the CDF and DØ Collaborations

*Rutgers, The State University of New Jersey
Piscataway, New Jersey 08855*

*Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510*

August 1997

Presented at *Hadron Collider Physics XII*,
SUNY, Stony Brook, June 5-11, 1997

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PRESENT SEARCHES FOR HIGGS SIGNATURES AT THE TEVATRON*

L. GROER

*Department of Physics and Astronomy
Rutgers, The State University of New Jersey
Piscataway, New Jersey 08855 USA*

for the

CDF AND DØ COLLABORATIONS

August 19, 1997

We present results for various searches for signatures of standard and non-standard model Higgs boson decays conducted at the collider detectors CDF and DØ using $\approx 100 \text{ pb}^{-1}$ of integrated luminosity each from the Tevatron collider Run 1 (1992-96) at $\sqrt{s} = 1.8$ TeV. No evidence for a Higgs boson decay is found and various limits are set.

1. Introduction

Despite the enormous success of the standard model (SM) of particle physics, the mechanism of electroweak symmetry breaking is still unknown. The most popular mechanism to induce this symmetry breaking is spontaneous symmetry breaking of the $SU(2) \otimes U(1)$ electroweak gauge theory which results in the gauge bosons and fermions acquiring mass via the Higgs mechanism.¹ Another possible mechanism introduces dynamical symmetry breaking via technicolor interactions.² Both of these mechanisms predict the existence of a neutral heavy scalar (X^0) of unknown mass, which could be produced at the Tevatron through $p\bar{p} \rightarrow W^\pm/Z^0 + X^0$ with a production cross-section of the order of 0.1 pb to 10 pb. Various searches have been conducted at both CDF and DØ for this neutral scalar produced in as-

sociation with a heavy gauge vector boson.

Extensions to the SM also predict a charged Higgs boson (H^\pm) which, if lighter than the top mass, could allow large $\mathcal{B}(t \rightarrow H^+ b)$ which would compete with SM predictions of $\mathcal{B}(t \rightarrow Wb) \approx 1$. CDF has conducted searches for these decays.

The results reported here come from both collider detectors at the Tevatron, CDF and DØ, where each collected about 100 pb^{-1} of integrated luminosity during Run 1 (1992-96) from $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV.

2. Neutral Heavy Scalars (X^0)

In the mass ranges that the Tevatron searches are sensitive to ($M_{H^0} \approx 80 - 130 \text{ GeV}/c^2$), the SM predicts^{1,3,4} that H^0 decays preferentially to $b\bar{b}$. The Feynman diagram for the associated production processes, as well as the subsequent decay processes, searched for at the Tevatron are shown in Figure 1. Technicolor

*Submitted to Hadron Collider Physics XII, SUNY Stony Brook, June 5-11, 1997.

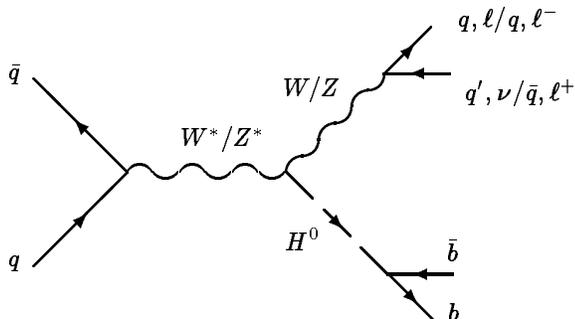


Figure 1: Feynman diagram of $p\bar{p} \rightarrow H^0 + W^\pm/Z^0$ associated production and subsequent decay.

models predict² that

$$p\bar{p} \rightarrow \rho_T^\pm \rightarrow W^\pm + \pi_T^0, \quad \pi_T^0 \rightarrow b\bar{b}$$

is also possible, where ρ_T and π_T^0 are technimesons. The strategy therefore for the neutral heavy scalar searches is to look for decay products of the associated vector boson and for b -jets from the scalar boson decay.

Both DØ and CDF search in the lepton + jets channels, looking for an isolated lepton and missing E_T (\cancel{E}_T) to identify the $W^\pm \rightarrow \ell^\pm \nu$ decay, and for jets, with b -tags, to identify the $X^0 \rightarrow b\bar{b}$ decays. CDF also searches in the multijets channel, trying to identify $W/Z \rightarrow qq$ and $X^0 \rightarrow b\bar{b}$ decays. DØ has a search looking for “bosonic” or “fermiophobic” Higgs (H_F) produced in association with a W or Z decaying to qq and H_F decaying to $\gamma\gamma$ (discussed in section 3).

The SM expectations for the production cross-section $\sigma(p\bar{p} \rightarrow W^\pm/Z^0 + H^0)$ at the Tevatron is less than 1 pb.⁴ As typical signal efficiencies in these searches are less than 2%, the current data set at the Tevatron is insufficient to set any mass limits on the SM Higgs but new physics cross-sections of about a few

$\times 10$ pb can be ruled out in the associated production channels.

2.1. Search for X^0 in Lepton + Jets

To identify the leptonic W decay, DØ looks for an isolated electron (muon) with $E_T \geq 25$ (20) GeV and $\cancel{E}_T \geq 25$ (20) GeV. To identify the neutral scalar, two or more jets with $p_T > 15$ GeV/ c are required and one of the jets must be tagged with a muon of $p_T > 4$ GeV/ c within a cone of $\Delta R < 0.5$. This helps tag the semi-leptonic decays of a b -quark and cuts the QCD background. Cleanup cuts are applied to remove $Z \rightarrow \mu\mu$. Twenty-seven ($12e, 15\mu$) events remain from 100 pb⁻¹ of Run 1 data.

Sources of background are W with jets produced by gluon radiation (13.9 ± 2.1), $t\bar{t}$ pair production (7.2 ± 2.5), multijet events with false lepton identification (4.2 ± 0.6) and $Z \rightarrow \mu\mu + \text{jets}$ events (0.2 ± 0.1). Combined, these give 25.5 ± 3.3 background events expected, which is consistent with the number observed.

The acceptance for identifying $W X^0$ events is calculated using Pythia Monte-Carlo simulations of $p\bar{p} \rightarrow W H^0 \rightarrow \ell\nu + b\bar{b}$ under the assumption of a neutral scalar with the spin and decay properties of a SM Higgs. Acceptances for the combined lepton channels range from 0.52% to 0.92% for M_{H^0} between 80 and 120 GeV/ c^2 with systematic uncertainties of ≈ 8.3 (14.6)% for electrons (muons). The acceptance includes $\mathcal{B}(W \rightarrow e(\mu)\nu)$.

A fit to the simple counting experiment, under the assumption of the SM H^0 decay, gives the $\sigma \cdot \mathcal{B}$ 95% C.L. upper limit shown in Figure 3.

A slightly better limit can be set by using kinematic information in the data. Signal events should exhibit a peak in the dijet invariant mass spectrum. No mass peak above background is seen in Figure 2 which is a plot comparing the 27 data points and the expected backgrounds. A binned maximum likelihood

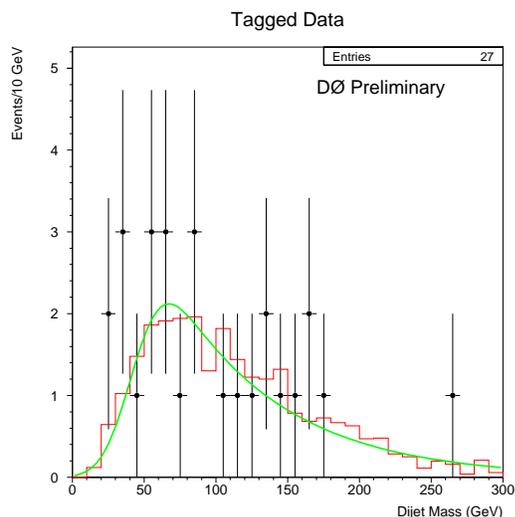


Figure 2: $D\bar{O}$ dijet invariant mass distribution for tagged data (points) and expected background (histogram). The smooth curve represents the parameterized background.

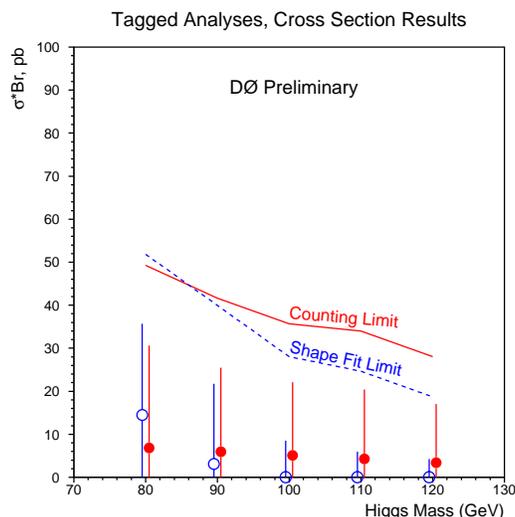


Figure 3: Fitted central values (filled dots - counting method, open dots - shape fit) and 95% C.L. upper limits on $\sigma \cdot \mathcal{B}$ for SM H^0 associated production search at $D\bar{O}$.

fit to the function $\mu_i = N[f_i^B(1 - \alpha) + f_i^S\alpha]$ is used to estimate the fraction, α , of signal events among the candidate 27 events. The fraction of background (signal) in the i^{th} bin is represented by f_i^B (f_i^S). This is done for a range of M_{H^0} values and the fit is consistent with zero in all cases. Upper limits at 95% C.L. are then set using the fitting technique. The fitted and 95% C.L. limits are shown in Figure 3.

CDF has performed a similar search looking for a central, isolated electron (muon) with E_T (p_T) > 20 GeV (20 GeV/ c) and $\cancel{E}_T > 20$ GeV to identify the W decay products. Two jets only are required with $E_T > 15$ GeV, $|\eta| < 2.0$, to identify the scalar decay. Either a single SVX b -tag (using a secondary vertex found in the CDF Silicon Vertex detector) is required or a double tag coming from two SVX tags or one SVX and one soft lepton tag (SLT) which indicates a semileptonic b -decay. A SLT

is a track of $p_T > 2$ GeV/ c associated with an electromagnetic calorimeter cluster or tracks in the muon chambers (indicating an electron or muon) within $\Delta R < 0.4$ of a jet and displaced from the primary vertex. Various other cuts are applied to remove Z 's, τ 's and top quark candidates.

From 109 pb^{-1} , 36 ($24e, 18\mu$) single tag events and 6 ($2e, 4\mu$) double tag events remain.

Background events come predominantly from the direct production of W bosons in association with heavy quarks ($Wb\bar{b}, Wc\bar{c}, Wc$), mistags due to track mismeasurements, and $t\bar{t}$ and single top production ($W^* \rightarrow t\bar{b}, gW \rightarrow t\bar{b}$).⁵ Other small backgrounds include $b\bar{b}$, diboson (WW or WZ) and Drell-Yan lepton pair production, and $Z \rightarrow \tau\tau$ decays. 30 ± 5 single tag and 3.0 ± 0.6 double tag background events are expected from all sources, which is consistent with the number observed in the data.

Pythia 5.7 Monte-Carlo is again used to

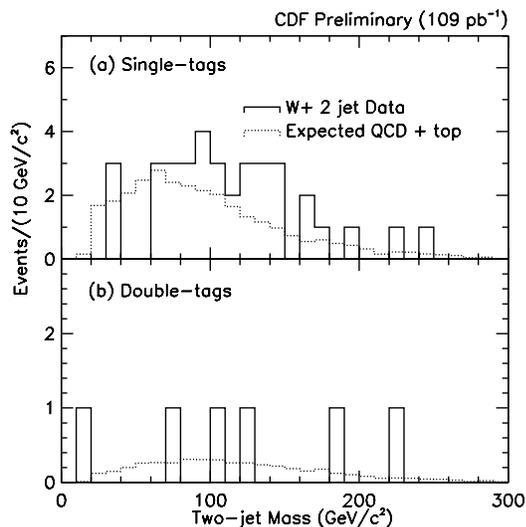


Figure 4: CDF dijet invariant mass distribution for single and double tags.

generate the $p\bar{p} \rightarrow WH^0 \rightarrow \ell\nu + b\bar{b}$ acceptance model for different M_{H^0} . Acceptances range from 0.53 to 1.1% for single tags and from 0.17 to 0.42% for double tags for $M_{H^0} = 70 - 120 \text{ GeV}/c^2$, including $\mathcal{B}(W \rightarrow e(\mu)\nu)$. Systematic uncertainties on the acceptance are $\approx 25\%$.

Figure 4 shows the dijet invariant mass distribution for the single and double tagged events and the background expectations. No mass peak is seen and the slight excess is consistent with a background fluctuation at the level of about one standard deviation.

The number and shape of the dijet mass distribution are fit to a function

$$\mu = f_{QCD}N_{QCD} + f_{top}N_{top} + f_{H^0} \cdot (\epsilon \cdot L \cdot \sigma \cdot \mathcal{B})$$

using a binned maximum likelihood method with the SM H^0 at various masses as a model. The contributions to the fit (shown in Figure 5 for a model with $M_{H^0} = 110 \text{ GeV}/c^2$) are the expected backgrounds from QCD and top and the signal (WH^0). Fits for the signal contribution are consistent with zero within about

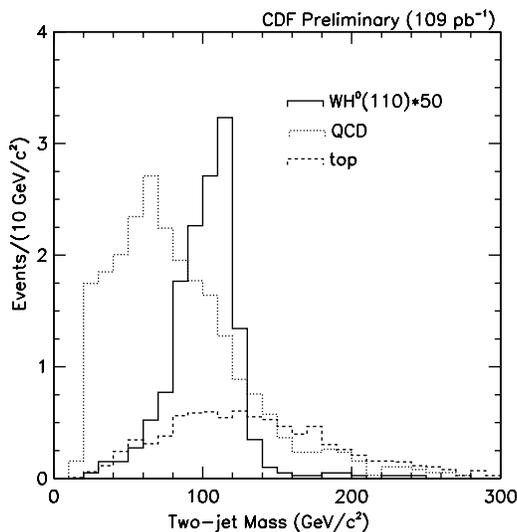


Figure 5: Signal (for $M_{H^0} = 110 \text{ GeV}/c^2$) and background contributions to the fit to data for CDF search. The WH^0 normalization scale has been blown up by a factor of 50.

a standard deviation. Upper limits at 95% C.L. can therefore be set for $\sigma \cdot \mathcal{B}$, shown in the combined results plot, Figure 6, as the CDF ($W \rightarrow \ell\nu$) line. CDF excludes $\sigma \cdot \mathcal{B} \gtrsim 20 \text{ pb}$, for $M_{H^0} = 75 - 125 \text{ GeV}/c^2$. This analysis has been submitted for publication.⁶

2.2. Search for X^0 in Multijets

CDF also conducts a search in the multijets channel for the associated production where the vector bosons decay hadronically and the neutral scalar decays to $b\bar{b}$. The strategy here is to reconstruct the $b\bar{b}$ invariant mass. CDF selects events with four or more jets ($E_T \geq 15 \text{ GeV}$, $|\eta| < 2.1$), two SVX b -tags and $p_T(b\bar{b}) \geq 50 \text{ GeV}/c$ which cuts against QCD background but is still very efficient for the signal. From 90.6 pb^{-1} (the CDF Run 1B sample), 589 events remain.

Background events are calculated to be mainly QCD multijets with b -decays. From

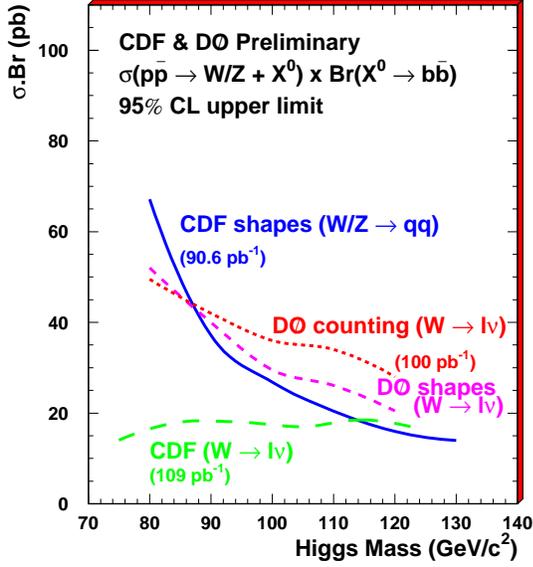


Figure 6: Combined limits on new heavy neutral scalar production at the Tevatron for Run 1.

the fit described below, 453 ± 25 events are expected for $M_{H^0} = 100 \text{ GeV}/c^2$. The other main sources of background are events with fake b -tags (estimated using tag rates from generic jet data to give 113 ± 11 events), $t\bar{t}$ production ($40.0^{+8.1}_{-7.1}$ events), $Z \rightarrow b\bar{b}/c\bar{c}$ + jets (12.5 ± 5.1 events) and W/Z produced with heavy flavor (2.3 ± 0.6 events).

Signal acceptances are calculated from Pythia 5.6 Monte-Carlo assuming the neutral scalar particle has the same spin and decay properties of the SM Higgs. Acceptances range between 0.6 and 1.7% for M_{H^0} in the range 70 to $140 \text{ GeV}/c^2$, including $\mathcal{B}(W/Z \rightarrow qq')$. Systematic uncertainties are about 45%.

A binned negative maximum likelihood fit is made to the shape of the observed b -tagged dijet invariant mass spectrum, fitting a combination of signal, QCD background, fake b -tags and top contributions with the function

$$\mu_i = N^{data} [\alpha N_i^{WH} + \beta N_i^{QCD} + \gamma N_i^{fakes} + \omega N_i^{top}].$$

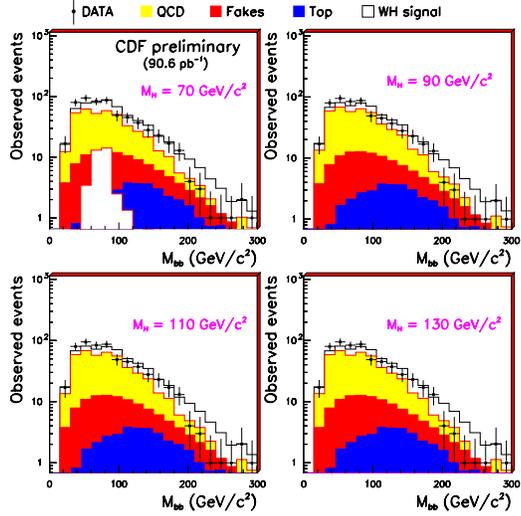


Figure 7: CDF b -tagged dijet invariant mass spectrum for multijets search. Fits for four different M_{H^0} (70, 90, 110, $130 \text{ GeV}/c^2$) are shown. Histograms are not cumulative. The upper histogram shows the total for all contributions.

Figure 7 shows the fit contributions. The QCD background and WH^0 signal contributions are allowed to float in the fit. The fitted contribution for signal is consistent with zero for all M_{H^0} . Upper limits at 95% C.L. can therefore be set for $\sigma \cdot \mathcal{B}$, shown in the combined limit plot, Figure 6, as CDF shapes ($W/Z \rightarrow qq$). As an example, this analysis excludes $\sigma \cdot \mathcal{B} > 30 \text{ pb}$ for $M_{H^0} = 100 \text{ GeV}/c^2$.

3. Search for “Bosonic” Higgs

“Bosonic” or “fermiophobic” Higgs (H_F) are predicted in some non-minimal Higgs models.^{4,7} Examples include two Higgs doublet models (model I type) where only one of the doublets couples to fermions and, more naturally, Higgs Triplet Models⁹ which maintain $\rho = (M_W/M_Z \cos\theta_W)^2 = 1$. There are therefore no tree-level couplings of H_F to fermions

and the H_F decays preferentially to the gauge vector bosons. For $M_{H_F} \lesssim M_W$, H_F decays predominantly to two photons ($\gamma\gamma$) via vector boson loops. Technicolor predictions also include a $\pi_T^0 \rightarrow \gamma\gamma$ decay.² The SM predicts that in this range $\mathcal{B}(H^0 \rightarrow \gamma\gamma) \simeq 0.001$ and H_F does *not* occur in the MSSM so this could be a very good signature of new physics. A bosonic Higgs with $M_{H_F} \lesssim 60 \text{ GeV}/c^2$ has been ruled out by LEP 1.^{4,8}

The production mechanism looked for at $D\emptyset$ is again associated production, with $p\bar{p} \rightarrow W^\pm/Z^0 + H_F \rightarrow qq'/q\bar{q} + \gamma\gamma$, and an attempt is made to reconstruct a mass bump of $M_{\gamma\gamma} > 60 \text{ GeV}/c^2$ from the two photons.

$D\emptyset$ looks for two electromagnetic (EM) energy clusters with E_T of γ_1 (γ_2) > 20 (15) GeV, and two jets with E_T of jet_1 (jet_2) > 20 (15) GeV, with $40 < M_{jj} < 150 \text{ GeV}/c^2$. Use of information in the shower shapes of the EM energy clusters, the fraction of EM energy in the calorimeters and requiring energy isolation and a clean “tracking road” where there are no hits in the tracking chambers associated with the photon clusters, all help to reduce the background and enhance the photon identification. From 101 pb^{-1} , 7 events remain, with none having $M_{\gamma\gamma} > 60 \text{ GeV}/c^2$.

The largest background comes from QCD multijets where a jet fragments (with probability $\sim 10^{-4}$) and produces an isolated EM shower. The background is estimated from the data and normalized to the excluded $M_{\gamma\gamma} < 60 \text{ GeV}/c^2$ background region. The expected background in the signal region $M_{\gamma\gamma} > 60 \text{ GeV}/c^2$ is 3.5 ± 1.3 events. Figure 8 shows the diphoton invariant mass for the candidate events and the background.

Pythia is used to generate the acceptance model with $p\bar{p} \rightarrow W/Z + H_F \rightarrow qq'/q\bar{q} + \gamma\gamma$. Acceptances range from 5.5% to 9% for M_{H_F} in the range 60 to 150 GeV/c^2 . Systematic and statistical uncertainties are $\approx 10\%$.

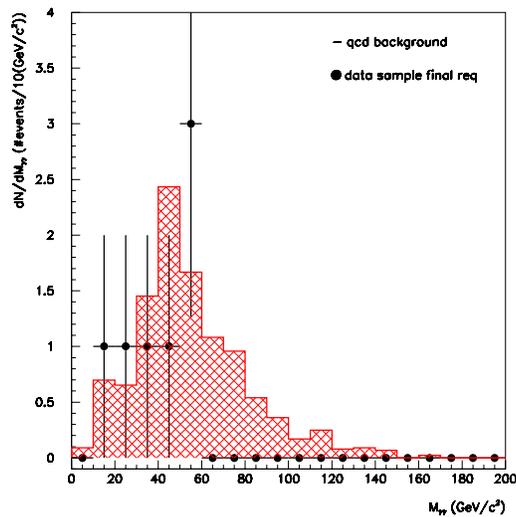


Figure 8: $D\emptyset$ diphoton invariant mass spectrum. No data events are in the signal region $M_{\gamma\gamma} > 60 \text{ GeV}/c^2$.

There are no events in the signal region so 90% and 95% C.L. upper limits on $\sigma(p\bar{p} \rightarrow W/Z + X^0 \rightarrow jj + \gamma\gamma)$ are set, shown in Figure 9. New physics processes with $\sigma > 0.4 \text{ pb}$ are excluded at 95% C.L.. Assuming SM coupling strengths between H_F and the weak gauge vector bosons,⁴ $M_{H_F} > 81$ (86) GeV/c^2 is excluded at 95 (90)% C.L..

4. Charged Higgs (H^\pm)

Many extensions to the SM, including supersymmetry and E(6) string models, predict an extended Higgs sector with more than one physical Higgs boson.¹ In particular, two SU(2) Higgs doublet models (model II type) predict that one of the Higgs doublets couples preferentially to up-type quarks and neutrinos and the other to down-type quarks and charged leptons. Five physical Higgs particles are predicted: two charged Higgs particles (H^\pm), two scalars (h^0 , H^0) and one pseudo-scalar (A^0). The predictions of these models depend on the

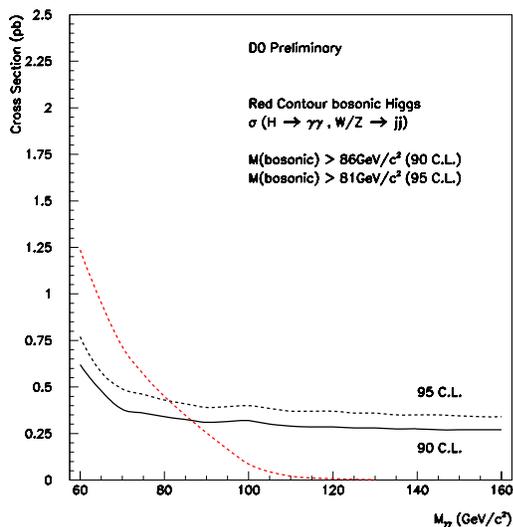


Figure 9: $D\bar{D}$ cross section limits for a bosonic Higgs boson decaying to photon pairs (solid line at 90% C.L. and dashed line at 95% C.L.). The dotted line is the theoretical calculation assuming SM coupling strengths between H_F and the weak gauge vector bosons.

parameters $\tan\beta$ which is the ratio of the vacuum expectation values of the two Higgs doublets, the mass of the charged Higgs (M_{H^\pm}) and the top mass (M_{top}). If $M_{H^\pm} < M_{top} - M_b$ then the top quark can decay to H^+b which competes with the SM decay mode W^+b . In these models, H^+ is predicted to decay predominantly to either $\tau^+\nu$ or $c\bar{s}$. The decay branching ratios of $t \rightarrow H^+b$ and $H^+ \rightarrow \tau^+\nu$ as a function of $\tan\beta$ are shown in Figure 10.

LEP 1¹³ has set model independent lower limits of $M_{H^\pm} > 44.1 \text{ GeV}/c^2$ and CDF has published previous results¹⁰ for large $\tan\beta$ values based on their Run 1A data sample of 19 pb^{-1} . LEP 2 is expected¹⁴ to exclude charged Higgs bosons with $M_{H^\pm} < 52 \text{ GeV}/c^2$.

CDF searches for $p\bar{p} \rightarrow t\bar{t}$ with at least one top decaying to H^+b , directly for large values of $\tan\beta$ ($\tan\beta > 10$) where $H^+ \rightarrow \tau^+\nu$ and indirectly for small values of $\tan\beta$ ($\tan\beta \lesssim 1$)

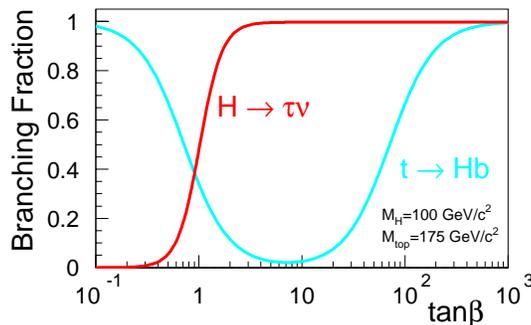


Figure 10: Branching fractions for $t \rightarrow H^+b$ and $H^+ \rightarrow \tau^+\nu$ for $M_{H^\pm} = 100 \text{ GeV}/c^2$.

where $H^+ \rightarrow c\bar{s}$.

4.1. Direct Search for H^\pm at High $\tan\beta$

CDF searches in events with large \cancel{E}_T for hadronically decaying tau lepton candidates which are narrow jets with one or three charged tracks. A sliding \cancel{E}_T isolation cut is used to help identify the H^\pm decay. Two other jets and at least one other lepton (e , μ or τ) or jet is required. All objects are required to have $E_T > 10 \text{ GeV}$ with $E_T > 20 \text{ GeV}$ for the leading tau candidate. One or more SVX b -tags are required to identify the b -decay. To gain acceptance for larger M_{H^\pm} where the b -quark is produced with less kinematic energy and falls below the E_T cuts, events that have two hadronic taus ($E_T > 30 \text{ GeV}$) that are not back-to-back and that did not pass the previous selection are also selected. $Z \rightarrow \ell\ell$ candidate events are removed. From 100 pb^{-1} , 7 events remain (6 $\tau jjjj$, 1 τjje and zero from the ditau channel).

The largest source of backgrounds are fake taus, mostly coming from narrow QCD jets with low track multiplicities. Using fake rates measured from generic jet data applied to the data sample, 5.4 ± 1.5 background events are expected for both channels combined. Electroweak processes such as $W/Z + \text{jets}$ and

diboson (WW , WZ , ZZ) production can be sources of real taus and Monte-Carlo estimates give 2.0 ± 1.6 background events. The total expected backgrounds are 7.4 ± 2.0 events for both channels, which is consistent with the number observed.

Isajet 7.06 is used to generate $p\bar{p} \rightarrow t\bar{t}$ with the subsequent decay of the top quarks to either Hb or Wb with $H \rightarrow \tau\nu$. The acceptance, as a function of $\tan\beta$ and M_{H^\pm} , is calculated by convoluting the acceptance for the various decay modes with their expected branching fractions. Acceptances range between 3% and 0.5% for M_{H^\pm} in the range 100 to 165 GeV/c^2 with a systematic uncertainty of 25%. An example of the number of expected signal events as a function of $\tan\beta$ is shown in Figure 11 for $M_{H^\pm} = 100 \text{ GeV}/c^2$ and two different values of the top production cross-section, $\sigma_{t\bar{t}} = 5.0 \text{ pb}$, motivated by theory and $\sigma_{t\bar{t}} = 7.5 \text{ pb}$, chosen to be 50% larger. Using the acceptance model, the counting experiment can exclude at 95% C.L. all models that predict more than 8.9 signal events.

Figure 15 shows the H^\pm mass limit as a function of $\tan\beta$ for $M_{top} = 175 \text{ GeV}/c^2$ for the direct search and the indirect search discussed in the following section. At large values of $\tan\beta$, $M_{H^\pm} < 158$ (147) GeV/c^2 is excluded for $\sigma_{t\bar{t}} = 7.5$ (5.0) pb.

This limit can be extended by including information from the top discovery¹¹ by allowing $\sigma_{t\bar{t}} \cdot \mathcal{B}(t\bar{t} \rightarrow W^+bW^-\bar{b})$ to remain consistent with the CDF published result, $\sigma_{obs} = 6.8_{-2.4}^{+3.6}$ pb. As $\tan\beta$ increases, $\sigma_{t\bar{t}}$ increases. The resulting limits are shown in Figure 12. This result has recently been published.¹²

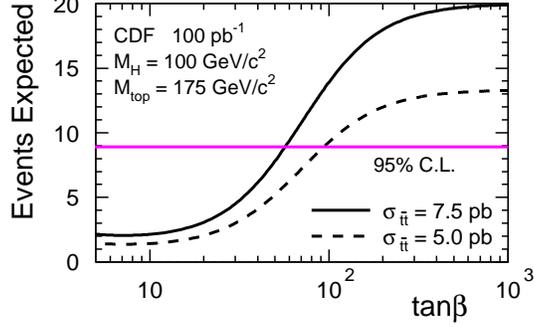


Figure 11: Number of H^\pm signal events expected as a function of $\tan\beta$ in CDF direct search for two different $t\bar{t}$ cross-sections (5.0 pb and 7.5 pb). Models with $N_{H^\pm} > 8.9$ are excluded at 95% C.L.

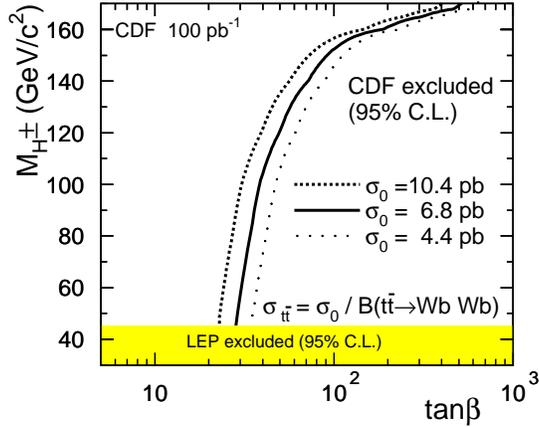


Figure 12: CDF H^\pm extended limit for large $\tan\beta$.

4.2. Indirect Search for H^\pm at Low $\tan\beta$

In regions of low $\tan\beta$, H^+ is predicted to decay predominantly to $c\bar{s}$. A direct search in this channel is difficult due to the large QCD backgrounds which obscure the H^\pm decays so CDF rather considers the impact a H^\pm would have on the top dilepton and lepton + jets search channels.¹¹

CDF searches for SM top decays ($t \rightarrow Wb$) by looking for the two leptonic decays of the W 's. Events with two opposite-sign, high p_T electrons or muons, $\cancel{E}_T > 25$ GeV and 2 jets ($E_T > 10$ GeV, $|\eta| < 2.0$) are selected. Nine events are observed with 2.2 ± 0.4 background events expected in 109 pb^{-1} from Run 1.

CDF also searches for one $W \rightarrow \ell\nu$ and one $W \rightarrow q\bar{q}'$ by selecting events with an isolated high- p_T electron or muon, $\cancel{E}_T > 20$ GeV and three or more jets ($E_T > 15$ GeV, $|\eta| < 2.0$). At least one positive SVX b -tag is also required to select against QCD backgrounds. Thirty-four events are observed with 10.4 ± 1.6 background events expected in 109 pb^{-1} from Run 1.

Table 1 show the number of events expected from the SM in each channel for two different values of $\sigma_{t\bar{t}}$ (5.0 and 7.5 pb), after background subtraction for non- $t\bar{t}$ processes. The numbers observed are consistent with SM expectations. The backgrounds in each channel are slightly higher than those in the standard top analyses, where the portion of the background calculated from data is corrected for its top content under the assumption that $\mathcal{B}(t \rightarrow Wb) = 1.0$.

Pythia 5.7 is used to generate $t \rightarrow H^+b/W^+b \rightarrow c\bar{s}/\tau\nu$ for the signal model. Acceptance ranges from 0.01% to 0.45% for the dilepton channel and 0.2% to 2.4% for the lepton + jets channel. Systematic uncertainties are about 12% to 20%. Figure 13 shows the acceptance for both channels as a function of $\tan\beta$ for $M_{H^\pm} = 120 \text{ GeV}/c^2$. Note that the acceptance drops very steeply towards low

	dilepton	lepton + jets
$\sigma_{t\bar{t}} = 5.0 \text{ pb}$	4.1 ± 0.5	20.0 ± 3.0
$\sigma_{t\bar{t}} = 7.5 \text{ pb}$	6.1 ± 0.7	30.0 ± 4.5
observed	6.8 ± 3.0	23.6 ± 6.0

Table 1: Expected number of signal SM $t\bar{t}$ events in 109 pb^{-1} for CDF dilepton and lepton + jets top search.

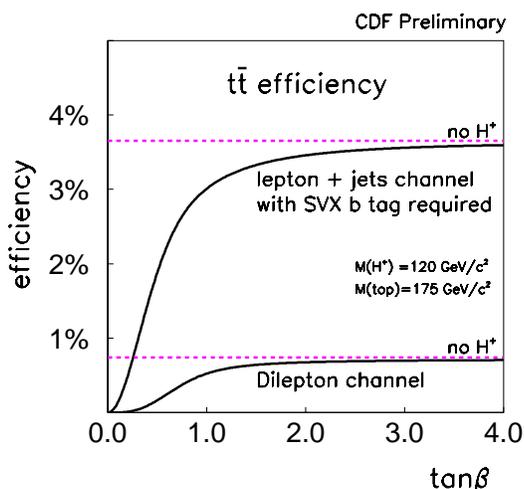


Figure 13: Acceptance in the dilepton and lepton + jets channels at CDF for a charged Higgs model with $M_{H^\pm} = 120 \text{ GeV}/c^2$. The dotted lines represent the acceptance for SM top decays in these channels.

$\tan\beta$ as here $\mathcal{B}(t \rightarrow H^+b) \simeq 1$ and $H^+ \rightarrow c\bar{s}$.

If H^\pm exists with low $\tan\beta$, then the production rates in the top dilepton and lepton + jets channels would be much lower than the corresponding rates predicted for SM top decays. Too many events have been observed in each of these channels for $\mathcal{B}(t \rightarrow H^+b)$ to be very large.^a The channels are combined by simply summing the number of dilepton and lepton + jets events.

^aFor example, only 1.4 dilepton and 12.3 leptons + jets events are expected for $M_{H^\pm} = 120 \text{ GeV}/c^2$, $\tan\beta = 0.6$ and $\sigma_{t\bar{t}} = 5.0 \text{ pb}$.

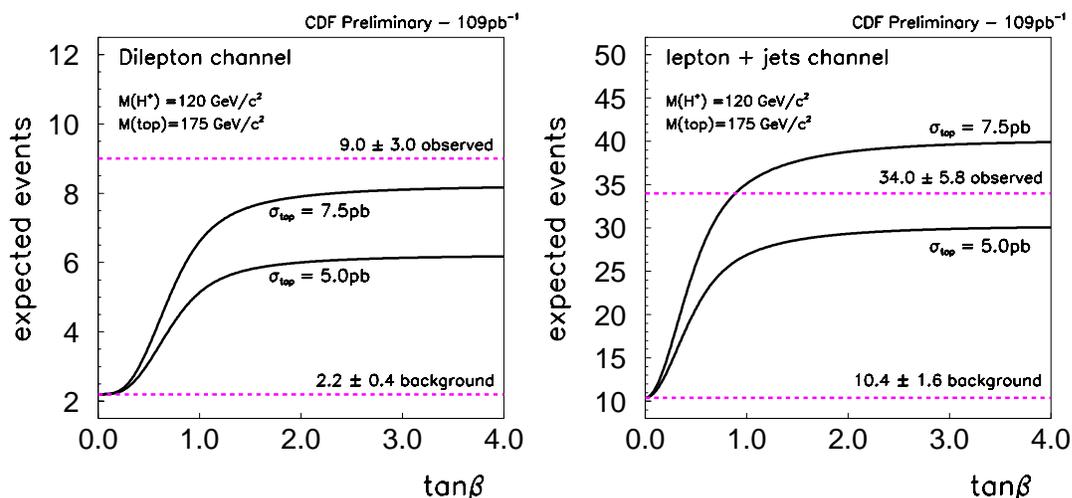


Figure 14: Number of events expected at CDF in the top dilepton and leptons + jets channels for a charged Higgs model with $M_{H^\pm} = 120 \text{ GeV}/c^2$ for $\sigma_{t\bar{t}} = 5.0$ and 7.5 pb . The number of events observed in the data and expected backgrounds are also shown.

CDF calculates the number of expected events from the signal model as a function of M_{H^\pm} and $\tan\beta$ and can exclude models which produce at least the number of observed events in less than 5% of pseudo-experiments. The number of events expected for a model with $M_{H^\pm} = 120 \text{ GeV}/c^2$ is plotted as a function of $\tan\beta$ for both channels in Figure 14.

CDF excludes $\mathcal{B}(t \rightarrow H^+ b) \gtrsim 25$ (50)% for $\sigma_{t\bar{t}} = 5.0$ (7.5) pb in the mass range $M_{H^\pm} = 60 - 165 \text{ GeV}/c^2$ at 95% C.L.. Mass limits for charged Higgs at 95% C.L. are shown in Figure 15 as a function of $\tan\beta$ for both CDF searches.

5. Conclusions

There is currently no evidence from the Tevatron collider Run 1 data for any Higgs decays. The Tevatron search limits are still about an order of magnitude above the expected SM H^0 associated production cross-section in $p\bar{p}$ collisions, therefore no mass limits can be set. However, limits on any new physics processes in

these channels have been set at about $\sigma > 20$ pb. Limits on the associated production of bosonic higgs with $\sigma > 0.4 \text{ pb}$ and mass limits of $M_{H_F} > 81 \text{ GeV}/c^2$ at 95% C.L. have also been set.

Limits almost up to the top mass have been set on the mass of charged Higgs bosons for large and small values of $\tan\beta$, as well as branching fraction limits for top quarks decaying via H^\pm .

The Tevatron collider Run 2 with center of mass energy $\sqrt{s} = 2.0 \text{ TeV}$ and with instantaneous luminosities of $\mathcal{L} \sim 2 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$ is scheduled to begin in 1999. Both detectors are undergoing substantial upgrades. DØ is currently installing a silicon vertex detector and solenoidal magnetic field and CDF is upgrading its silicon vertex system, which will enhance both their sensitivities to tagging b -quark decays, crucial in searching for Higgs particles.¹⁵ Both detectors expect to take about 2 fb^{-1} integrated luminosity over a couple of years of running and sensitivities

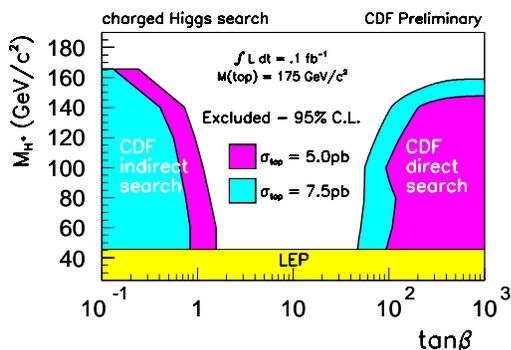


Figure 15: CDF H^\pm limits for direct and indirect search for two assumed $\sigma_{t\bar{t}}$.

to $\sigma(p\bar{p} \rightarrow WH^0)$ of $\mathcal{O}(1)$ pb are expected for intermediate mass Higgs of 80 – 130 GeV/c^2 .

Searches for non-minimal Higgs particles are also planned, looking for couplings both to fermions and vector bosons pairs. Studies indicate that we might be sensitive to H^+H^- pair production which will help extend the search region into the $\tan\beta \approx 10$ range as well as the $M_{H^\pm} > M_{top}$ regime.

The Tevatron Higgs program promises to be an exciting field in the coming years with good discovery potential before the LHC turn-on. See Drew Baden's talk¹⁶ from this conference for a much more extensive overview of the Tevatron's search potential in the next century.

Acknowledgements

I am indebted to the many people who provided me input for this talk. Thanks to Brendan Bevensee, John Hobbs, Bryan Lauer, Charles Loomis, Juan Valls, Rocio Vilar and Weiming Yao for patiently explaining their analyses and for their useful plots.

We thank the Fermilab staff and technical staffs of the participating institutions for their vital contributions.

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