Searches For Non-SM Higgs at the Tevatron

Dr. Richard St. Denis
Glasgow University
On behalf of the CDF and D0 Collaborations
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Outline

● Variation on SM search: Fourth Generation and Fermiophobic Higgs
● MSSM Neutral Higgs
● Hidden Valley
H → WW: 4th generation models

4th Generation of Fermions:
- Heavy t' and b' quarks
- Heavy neutrino
- May alter EWK constraints

Gluon Fusion:
- Higgs is production: quark loop
- In SM mostly top contributes
- If 4th Gen exists – enhanced by ~9
- Branching ratios change too

- Exclusion range 123-202 GeV/c^2
- Expected: 129-212 GeV/c^2
- CDF by itself comparable to Tev combination

Previous results: (GeV/c^2)
- Expected: 125-218 (CDF+D0), 150-190ish (CMS)
- Observed: 131-204 (CDF+D0), 144-207 (CMS)
D0 h_f: Fermiophobic Higgs

- No fermion coupling: WH, ZH, VBF
- BR(h_f → γγ) = 6.2%, 33xSM, m_{Hf} = 110 GeV/c^2
- 2γ E_T > 25 GeV, |η| < 1.1, NN-id
- Systematics: ε_γ, ε_γjet; Lumi, γ-ID, PDF, Track Veto, σ_Z, σ_{γγ}
- BDT; Input: M_{γγ}, E_{T1γ}, E_{T2γ}, p_{Tγγ}, Δφ_{γγ}

**Background**

<table>
<thead>
<tr>
<th>Background</th>
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<tbody>
<tr>
<td>Z/γ → l^+l^-</td>
<td>3</td>
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<tr>
<td>γγ</td>
<td>53</td>
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<tr>
<td>γ – jet</td>
<td>30</td>
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<td>jet-jet</td>
<td>14</td>
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D0: Best $h_f$ Limit, $M_H < 112$ GeV/c$^2$

CDF: $106 \, (2.7 \, fb^{-1})$, D0 $102.5 \, (4.2 \, fb^{-1})$, LEP: $\sim 105$/per exp, combined: $109.7$ GeV/c$^2$
MSSM SUSY

- Two Higgs doublet fields $H_u,d$ couple to u- and d-type fermions
- $\tan \beta = \langle H_d \rangle / \langle H_u \rangle$ enhanced
- 5 Higgs Bosons: $H^0,h^0,A^0$; $H^\pm$

Light

SM-Like

- $h^0$
- $H^0$

Heavier

Cross section $\tan^2 \beta$ enhanced

- "Φ"
- $H^0 A^0$
- $h^0 A^0$ Degenerate: $x^2$

$M_h < 135 \text{ GeV/c}^2$

$\tan^2 \beta = 50^2 \times 2 = 5000$: fb $\rightarrow$ pb!
Decay: \( \phi^0 \rightarrow \tau^+ \tau^- (10\%) , \phi^0 \rightarrow bb (90\%) \)

Detection:

\[ b + \phi^0 \rightarrow b + bb: \text{Measure } M_{bb} \text{ and separate flavor} \]

\[ \phi^0 (b) \rightarrow \tau^+ \tau^- (b) + \text{charge conjugate} \]

 Measure Visible:
\[ M_{e\mu} \quad M_{e\tau_h} \quad M_{\mu\tau_h} \]
- Main backgrounds: $Z \rightarrow \tau\tau$, $W$+jets, dibosons
- One tau: semileptonic, $p_T > 10, 20$ GeV/c
- Other tau hadronic (CDF+D0) (and $\nu_\tau$): $p_T > 10, 20$ or semileptonic (CDF) $p_T > 6,10$ GeV/c
- Hadronic: Cone or NN Score (D0) with $\pi^\pm$, $\pi^\pm\pi^0$, 3-prong
- Reject non-$\tau\tau$ background
  - Lepton and missing energy inconsistent with $W$
  - $H_T$ cut (CDF) or $M_T$ (DØ)
Combined CDF and D0 Results

- Sensitivity and exclusion for $\tan \beta$ of order 30.
B-Jet Identification

CDF: displaced vertices with $L_{xy}/\sigma$ cut
- Vertex mass separation

DØ: combine vertex properties and displaced track info with NN
- Tag to $\eta$ beyond 2
DØ $\tau_\mu \tau_h b$ Results

Multivariate discriminate against multijet, top. One input shown, $M_{vis}$

No Signal: Limit on cross section and in $\tan\beta - m_A$ plane: Sensitivity $\sim 40$
DØ $\tau_e \tau_h b$ Results

Exclude, sensitive to $\tan \beta \sim 50$

New
Event Selection: 3 b-tagged jets, $E_t > 20$ GeV. Trigger tracks: $d_0 > 100 \ \mu m$

Search in mass of two lead jets $m_{12}$

Backgrounds are QCD events with two true b-tags, and a b/c/fake tag

Characteristic $m_{12}$ spectra

Start from $bb+\text{jet}$ data sample (corrected double-tags), weight events by flavor hypothesis

Fit the observed $m_{12}$ spectrum with the backgrounds and a Higgs shape
CDF 3b: Extra Discriminant

Improve prediction of total background $m_{12}$ using invariant mass, $m_j$, of tracks in each vertex

Unstack into 1D variable “$x_{\text{tags}}$” for plotting/fitting

$m_1+m_2 : bbb+bbx / bcb+bqb$

$m_3 : bbx / bbb+bcb+bqb$

Fits are 2D – $m_{12}$ vs $x_{\text{tags}}$
CDF 3b Results

Most significant excess @ 140 GeV/c²

No significant excess observed
Set limits on $\sigma \times \text{BR}$
MSSM Interpretation

Include effect of Higgs width (~20% for $\tan\beta = 100$)

Lose sensitivity (lower S/B)
Lowers event yield

Best limits obtained in scenarios with $\mu < 0$ (loop enhancements): sensitivity $\tan\beta = 60$
Invariant mass of the two leading jets $m_{bb}$ in triple-tagged events

Also Derive background shape from double-tagged sample

Uses two 6 dimensional likelihood discriminant, $D$: $\Delta \eta_{jj}, \Delta \phi_{jj}$, etc. for low (90-130) and high mass $\phi$

Check background prediction: $M_{bb}$ for $D<0.12$
DØ 3b

Largest deviation @ 120 GeV/c²

No significant excess observed

Set limits on $\sigma \times \text{BR}$

Excluded $\tan\beta \sim 50$ at lowest, 120 at 225. Sensitive to $\tan\beta \sim 45$
CDF Hidden Valley

New

Higgs decays to HV particle with $c\tau \sim 1$ cm:
modified Vertexing
Each HV decays to two b’s
A 4b final state: require 3 Trigger, Calibration as for MSSM bbb

Cut on variables based on reconstructed vertex:
$\zeta$: HV decay length
$\Psi$: Jet Impact Parameter

Signal: $\zeta,\psi > 0$, QCD bb Background $\zeta,\psi \sim 0$
CDF Hidden Valley

New

Results: 1 event, 0.3-0.5 expected; show for various lifetimes, Higgs masses, and HV particle masses

Predicted HV decay length

Observed ζ

Tagged Dijet ζ: CDF Run II Preliminary Lum = 5.8 fb⁻¹

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Summary

- CDF and DØ are looking hard for Higgs bosons in a variety of models beyond the standard model using advanced techniques in a harsh environment.
- Results today use 2.4-8.2 fb$^{-1}$ MSSM: sensitive to $\tan\beta \sim 30$. Full dataset, combined results could be sensitive to $\tan\beta \sim 20$.
- $4^\text{th}$ Generation excluded by CDF alone for $123 < m_H < 202$ GeV/c$^2$, CDF+D0: 131-204 GeV/c$^2$.
- Fermiophobic Higgs: When we find it, D0 says it has to be $M_{hf} > 112$ GeV/c$^2$ (CDF $M_{hf} > 106$ GeV/c$^2$).
- Hidden Valley explored but nothing seen yet: need to do more exploring.
Backup
D0 and CDF Detectors

- Silicon Tracking
- Fibre Tracker
- L Ar Calo. $|\eta|<4$
- Muon: $|\eta|<2$

- Silicon Tracking
- Open drift Cell Tracker
- Scintillator Calo. $|\eta|<3.2$
- Muon coverage $|\eta|<1.5$
Tevatron Lumi
Max: $0.4 \times 10^{33}$

10.2 fb$^{-1}$ Delivered

60-70 pb$^{-1}$/wk
- Tag Efficiency: 50-70% b, 0.5-5% light quark
- Orthogonal event samples
- Form matrix for 2 jet: Tight-Tight, Tight-Loose... Single Tag.
Higgs at High $\tan\beta$
Higgs at High $\tan\beta$

via top loop

$H = \text{SM Higgs}$

$\phi^0 = h/H/A$

here, $H = A$ or $h/H_{29}$
The $\phi \rightarrow bb$ Channel

- Inclusive $H \rightarrow bb$ is too hard due to QCD background
- Require one additional bottom quark jet besides the two from Higgs decay
  - “3b” channel best compromise between signal and background rates

Dawson, Jackson, Reina, Wackeroth
hep-ph/0603112
CDF 3b Alternative SUSY Scenario
CDF 3b Linear Scale

![Graph showing 95% C.L. upper limits for CDF Run II Preliminary (2.2/fb). The graph plots \( \sigma(p\bar{p} \rightarrow H + b\bar{b}) \times BR(H \rightarrow b\bar{b}) \) in pb against \( m_H \) in GeV/c^2. The graph includes expected limit, 1\( \sigma \) band, 2\( \sigma \) band, and observed limit.]
Items not covered

Doubly Charged Higgs:
- D0: $M(H_{L}^{++,--}) > 150 \text{ GeV/c}^2$, $M(H_{R}^{++,--}) > 127 \text{ GeV/c}^2$
- CDF: $M(H_{L}^{++,--}) > 133, 136, 115 \text{ GeV/c}^2$ (ee, e\(\mu\), \(\mu\mu\)), $M(H_{R}^{++,--}) > 113 \text{ GeV/c}^2$
- CDF: LFV $e\tau, \mu\tau$: $M(H^{++,--}) > 114, 112 \text{ GeV/c}^2$, long lived: $M(H_{L}^{++,--}) > 133 \text{ GeV/c}^2$,
  $M(H_{R}^{++,--}) > 109 \text{ GeV/c}^2$, $M(\text{Degenerate}) > 146 \text{ GeV/c}^2$

Charged Higgs:
- Direct search for decay to cs: CDF: $B(t \rightarrow H^+b) < 0.1$ to $0.3$
- $60 < m_{H^+} < 150 \text{ GeV/c}^2$
- Direct search for decay to $tb \rightarrow Wbb \rightarrow lvbb$: $\tan\beta$ of order $1, 5, 10,$
  $180 < m_{H^+} < 300 \text{ GeV/c}^2$, $\sigma \times \text{Br}$ $14$ to $5 \text{ pb}$
- General search for all $H^+$ decays considered in top decays.
Charged Higgs

CDF: use dilepton, l+jets (single and double-tagged), and lepton+tau σ’s
Consider $H^+ \rightarrow \tau \nu$, $c_s$, $t^*b$, $W^+b$
Map out allowed and excluded regions in $m_{H^+}$ vs $\tan\beta$ using CPsuperH and CDF simulation to predict effects on top σ’s

Search in top decays
$t \rightarrow H^+b$
DØ: ration of cross sections l+jets/dilepton
$BR(t \rightarrow H^+b) < 0.35$ @ 95%
CL (for $H^+ \rightarrow c_s$)
CDF $\tau\tau$ MSSM Interpretation

MSSM Higgs $\rightarrow \tau\tau$ Search, 95% CL Exclusion

CDF Run II Preliminary, 1.8 fb$^{-1}$

LEP 2

$m_h^{\text{max}}$

no mixing

$\mu < 0$

$m_A$ (GeV/c$^2$)

$\tan \beta$

MSSM Higgs $\rightarrow \tau\tau$ Search, 95% CL Exclusion

CDF Run II Preliminary, 1.8 fb$^{-1}$

LEP 2

$m_h^{\text{max}}$

no mixing

$\mu > 0$

$m_A$ (GeV/c$^2$)

$\tan \beta$