Status of CDF II Higgs Searches

HCP 2004

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Higgs at the Tevatron

Broken symmetry...is it the Higgs?

Can H be discovered at the Tevatron?
CDF Run I Limits

CDF PRELIMINARY Run 1

95% C.L. upper limits

$\sigma(p\bar{p} \rightarrow VH) \times BR(H \rightarrow b\bar{b})$ (pb)

Higgs Mass (GeV/c^2)

LEP EXCLUDED

Standard Model

VH combined

New world average fit $M_H = 117$ GeV

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CDF Ongoing Searches

- $\sqrt{WH \to \ell\nu bb}$
- $ZH \to \ell\ell bb$
- $ZH \to \nu\nu bb$
- $\sqrt{H \to WW^* \to \ell\nu\ell'\nu'}$
- Hbb$\to$ bbbb large $\tan \beta$
- $H \to \tau\tau$ large $\tan \beta$
- $H^+ \to \tau\nu$
- $t \to H^+b$ (direct, $B(t \to \ell\nu b)$)
- $\sqrt{H^{\pm\pm}}$ triplet
- LFV $H \to \tau\mu$
Double Charged Higgs

Additional Higgs triplet, e.g. SUSY LR \( \Rightarrow 10^2 < M_{H^{\pm\pm}} < 10^3 \) GeV

\( H^{++} \rightarrow \ell^+ \ell'^+ \) with coupling \( h_{\ell\ell'} \)

- \( h_{ee} < 0.07 \) LEP II
- \( h_{\mu\mu} < 0.25 \) \( (g-2)_\mu \)
- \( h_{e\mu} h_{ee} < 3 \times 10^{-7} \) \( \mu \rightarrow 3\mu \)
- \( h_{e\mu} h_{\mu\mu} < 2 \times 10^{-6} \) \( \mu \rightarrow e\gamma \)

Pair-produced at Tevatron via \( \gamma^* Z^* \)

Constraints allow prompt decays:
Signature: 2 same-sign \( \ell = e, \mu \) with \( M(\ell\ell) = M_{H^{\pm\pm}} \)
QCD derived from fakes in the data

W+jets rate from data, mass from MC

WZ $\sigma_{nnlo} = 4.0$ pb

$Z \rightarrow e^+ e^- (\gamma \rightarrow e^+ e^-)$

normalize BG to Z peak
expect $1.1 \pm 0.3 \ M < 80$
\[ H^{\pm \pm} \rightarrow \mu^{\pm} \mu^{\pm}, e^{\pm} \mu^{\pm} \]

**Background to same-sign \( \mu \mu \)**

- Jets
- W+Jets
- WZ

**Background to same-sign e\( \mu \)**

- Jets
- W+Jets
- WZ

expect \(0.9 \pm 0.4\) \(M < 80\)  
expect \(0.3 \pm 0.1\) \(M < 80\)
$H^{\pm \pm}$ Acceptance

\[
\text{(kinematic+geometric) } \times \epsilon_{trig}\epsilon_{ID} \quad \text{a central } \eta \text{ leptons}
\]

\[
a \mu \equiv \text{track+stub/m.i.}
\]
**H^{±±} Limits**

**100% Branching**

- 133 GeV  $ee \ H_L^{±±}$
- 136 GeV  $\mu\mu \ H_L^{±±}$
- 115 GeV  $e\mu \ H_L^{±±}$
- 113 GeV  $\mu\mu \ H_R^{±±}$

CDF Run 2 Preliminary

$\mathcal{L} \sim 240 \text{ pb}^{-1}$

Cross section $\times$ BR (pb) vs. $H^{±±}$ mass (GeV/c$^2$)

- **ee**
- **$e\mu$**
- **$\mu\mu$**

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limits are for exclusive decays; long-lived $H^{\pm\pm}$ search in progress.
SM Searches

Sensitivity

Understand detector & backgrounds. Best way is to do searches and set limits:

- $H \rightarrow WW^*$
- $HW$ production

Q: How sensitive are we relative to our expectations?
heavy $H \rightarrow WW$

signature for $M_H \gtrsim 135$ GeV $H \rightarrow WW^* \rightarrow \ell\nu\ell\nu$ (e,μ)

- exactly 2 $\ell^+\ell^-$ (suppress WZ)
- no jets (suppress WZ)
- $\not{E}_T > 25$ GeV (suppress DY)
- $\Delta\phi(\not{E}_T, \ell) > 20^\circ$ (mis-measured $E_T$)
- Z removal
Estimate from MC with theory $\sigma$:

- $WW \quad 13 \text{ pb}$
- $WZ \quad 4 \text{ pb}$
- $ZZ \quad 1.4 \text{ pb}$
- $t\bar{t} \quad 7 \text{ pb}$
- $DY \ LO \times k = 1.4$

$W + jets \rightarrow \text{fake } \ell \text{ from inclusive } \ell \text{ data}$

Apply $M_{\ell\ell}$ cut $^b$

$^a$ in good agreement with $\sigma^{CDF}$

$^b$ J=0 weak decay
### heavy H Search Results

<table>
<thead>
<tr>
<th>$M_H$</th>
<th>150</th>
<th>160</th>
<th>170</th>
</tr>
</thead>
<tbody>
<tr>
<td>WW</td>
<td>$3.8 \pm 0.5$</td>
<td>$4.5 \pm 0.5$</td>
<td>$5.4 \pm 0.6$</td>
</tr>
<tr>
<td>other</td>
<td>$0.9 \pm 0.2$</td>
<td>$1.3 \pm 0.4$</td>
<td>$1.9 \pm 0.5$</td>
</tr>
<tr>
<td>data</td>
<td>2</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>$\sigma_N$</td>
<td>95%</td>
<td>&lt; 9.8 pb</td>
<td>&lt; 6.2 pb</td>
</tr>
</tbody>
</table>

**signal:** $\Rightarrow \sim 0.2$ events
Partial Mass Reconstruction

CDF Run II Preliminary, $L_{\text{int}} \approx 200 \text{ pb}^{-1}$

$M_H = 180 \text{ GeV}$

$M_C \equiv \sqrt{P_{T\ell\ell} + M_{\ell\ell} + E_T}$
CDF Run II Preliminary, $L_{\text{int}} = 184 \text{ pb}^{-1}$

Exploit $J = 0$ resonance

$\sigma_{\text{fit}} 95\% \Rightarrow 5.6 \text{ pb} \quad M_{H} = 160, 170$
Golden Mode $WH \rightarrow b\bar{b}$

Signature:
- exactly 1 central $\ell (e\mu)$
- $E_T > 20$
- exactly 2 jets

jet cut optimization

CDF Run II Preliminary (162 pb$^{-1}$)

$m_h = 115$ GeV/c$^2$
WH Pre-tag backgrounds

CDF Run II Preliminary (162 pb⁻¹)

- Data
- Expected Total
- W+light flavors
- W+bb
- W+cc
- W+c+1p
- non-W

Events / 10 GeV/c²

Dijet Mass (GeV/c²)
WH Backgrounds

Derived from data as for top:

- $W + bb$, $W + cc$, $W + c$
- QCD

From theory (MC):

- top
- di-Boson
- $Z \to \tau\tau$

Mis-tags: derived from generic jet data “tag” rate = few % /jet
B-tag efficiency

derived from inclusive e sample further \( \bar{b}b \) enriched by vertex tag on 2nd jet.

scale factor \((82 \pm 6)\)%
WH with b-tagging

CDF Run II Preliminary (162 pb⁻¹)

- Data
- Mistags
- $W^\pm + b\bar{b}$
- $W^\pm + c\bar{c}$
- $W^\pm + c$
- Diboson and $Z^0 \rightarrow \tau^+ \tau^-$
- non-$W^\pm$
- $t\bar{t}$
- Single Top

Additional cuts:
- lepton: high-$P_T$, opp. sign track
- jets: no extra low-$E_T$
WH Dijet Mass

CDF Run II Preliminary (162 pb⁻¹)

- **W+2jets (Data)**
- **WH (m_h=115 GeV/c²)**
- **W+jets and non-W**
- **Top, Diboson and Z⁰ → τ⁺τ⁻**
- **WH×100**

Events / 10 GeV/c²

- Mean = 107.85 ± 0.25 GeV/c²
- Width = 18.69 ± 0.25 GeV/c²

Dijet Mass (GeV/c²)
Current Sensitivity

Acceptance with central $\eta$ leptons including all (kinematic+geometric) $\times \epsilon_{\text{trig}} \epsilon_{\text{ID}} \epsilon_{\text{tag}}$

$$= (1.7 \leftrightarrow 1.9) \pm 0.4 \%$$

CDF Run II Preliminary (162 pb$^{-1}$)

$\sigma(VH) \times \text{Br}(H \rightarrow b\bar{b})$ (pb)

$\sigma(VH) = 1.6 \sigma(WH)$
SM Higgs: Status

$\int L = 0.16 \, fb^{-1} \Rightarrow \text{Significant improvement over run I}$
Ultimate Sensitivity

Results of revised sensitivity study (CDF/D0) based on:
hit-level, GEANT simulation, measured trigger rates, 396 ns scenario (multiple interactions).

- MB $\sim \epsilon_b \times (0.90 \leftrightarrow 0.85)$
- lepton acceptance $\times 1.3$
- b-tagging
- di-jet mass resolution

Vertex and i.p. tagging (0 MB)
Improvements to $\delta M_{jj}$ versus $\#$ central jets: (1) tracking, (2) soft leptons, (3) global event variables (e.g. $E_T$)
$Z \rightarrow b\bar{b}$

CDF PRELIMINARY

$M_{jj}$ Run I $\mu$ triggers; Run II measure $\delta M_{jj}$
SM Higgs: Prospects

Higgs Sensitivity Study ('03)
statistical power only
(no systematics)

SUSY/Higgs Workshop ('98-'99)

5σ discovery
3σ evidence
95% CL exclusion

PRELIMINARY

m_H (GeV)

integrated luminosity (fb^{-1}/exp.)

80 100 120 140 160 180 200
Beyond SM Higgs: Prospects

Much work on $\tau$ (e.g. $H \rightarrow \tau\tau, H^+ \rightarrow \tau\nu$)

CDF measurements of $\sigma_W B(W \rightarrow \tau\nu)$, $B(W \rightarrow \tau\nu)/B(W \rightarrow e\nu)$
Conclusion

from $0.4\text{fb}^{-1} \Rightarrow 8\text{fb}^{-1}$

“It ain’t over ’till it’s over”

– Yogi Berra