What CDF Can Say About the Higgs

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SM Higgs Production

- $gg \rightarrow H$ dominates but dijet background too big...

- $bb$ and $WW$ decay modes are best!

$WH+ZH \sim 300 \text{ fb at 115 GeV}$

Typical efficiencies $\sim 2\%$

A daunting proposition!
Top and W Masses

• initially at the Tevatron, we focus on measuring the mass of the W and top quark

• tight constraints on Higgs mass

• this is what CDF and D0 do best!

Lots of work to do on b tagging, jet energy reconstruction, mass reconstruction, understanding background...all of which is preparation for the direct Higgs search!
Suppose CDF and D0 measure the top and W masses as shown here:

This would be evidence for new physics!

Lots of work to do to get to this point... exciting prospect!

Or maybe it won’t be evidence for new physics?
Search Channels - Low Mass

For $m_H < 135$ GeV, $bb$ decays dominate:

- clearly need excellent $b$ tagging
- need optimal $bb$ mass resolution
- need to understand background shapes
CDF - b tagging

Layer 00, SVX-2 and ISL

Double-sided silicon microstrips: 800k channels

$r \sim 1.5 \text{ cm out to } \sim 50 \text{ cm}$

Extrapolation resolution:

$10\sim15 \mu \text{m}$

$\varepsilon_b \sim 53\%$ (top)

$\varepsilon_c \sim 3\%$  $\varepsilon_{q/g} < 1\%$
Run 2 $\nu$bb Result

- Select events with $p_T > 20$ GeV lepton triggers
- Require lepton, missing $E_T$, two jets with $E_T > 15$ GeV
- Demand at least one b-tagged jet

Very similar to top lepton plus jets selection

Acceptance $\sim$1.7%

Main backgrounds: Wbb, fakes

(thesis of Y. Ishizawa, Tsukuba)
Run 2 $\nu bb$ Result

Comparison of observed/expected:

<table>
<thead>
<tr>
<th>Background</th>
<th>$R^2 + 1$</th>
<th>$W^\pm + 2$ jets</th>
<th>$t\bar{t} + 1$</th>
<th>$t\bar{t} + 2$ jets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Events before tagging</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mistags</td>
<td>16.30 ± 1.30</td>
<td>14.07 ± 2.10</td>
<td>12.67 ± 0.77</td>
<td>10.81 ± 0.68</td>
</tr>
<tr>
<td>$W^\pm + bb$</td>
<td>13.40 ± 1.14</td>
<td>12.05 ± 2.19</td>
<td>10.76 ± 0.73</td>
<td>8.94 ± 0.68</td>
</tr>
<tr>
<td>$W^\pm + cc$</td>
<td>11.30 ± 1.21</td>
<td>5.19 ± 1.14</td>
<td>8.33 ± 0.74</td>
<td>0.39 ± 0.44</td>
</tr>
<tr>
<td>$W^\pm + c$</td>
<td>7.86 ± 2.08</td>
<td>7.86 ± 2.08</td>
<td>6.81 ± 1.82</td>
<td>0.89 ± 1.82</td>
</tr>
<tr>
<td>Diboson/$Z^0 \to \tau^+\tau^-$</td>
<td>2.25 ± 0.34</td>
<td>2.25 ± 0.34</td>
<td>1.58 ± 0.28</td>
<td>0.19 ± 0.28</td>
</tr>
<tr>
<td>QCD</td>
<td>10.31 ± 1.66</td>
<td>10.31 ± 1.66</td>
<td>8.68 ± 1.64</td>
<td>0.19 ± 1.64</td>
</tr>
<tr>
<td>$t\bar{t}$</td>
<td>5.05 ± 0.64</td>
<td>5.05 ± 0.64</td>
<td>3.76 ± 0.49</td>
<td>0.33 ± 0.49</td>
</tr>
<tr>
<td>Single top</td>
<td>3.16 ± 1.16</td>
<td>3.16 ± 1.16</td>
<td>2.31 ± 1.13</td>
<td>0.17 ± 1.13</td>
</tr>
<tr>
<td>Total Background</td>
<td>33.34 ± 1.74</td>
<td>60.55 ± 4.43</td>
<td>34.87 ± 2.10</td>
<td>34.87 ± 2.10</td>
</tr>
<tr>
<td>Observed positive tags</td>
<td>155</td>
<td>62</td>
<td>94</td>
<td>94</td>
</tr>
</tbody>
</table>

Higgs search

Top cross section
Run 2 $\nu\nu bb$ Result

Use $bb$ mass distribution for signal sensitivity

~16% resolution so far

We are not yet challenging the Standard Model:

- better resolution
- improved tagging
- need $\nu\nu bb$ channel
Search Channels - High Mass

New Run 2 result performed in context of WW analysis

\[ gg \rightarrow H \rightarrow WW \rightarrow ll\nu\nu \]

(ZHWW, WWZZWW)

(trileptons: rate too low)
Run 2 $\ell\nu\nu$ Result

Select events with two high-$p_T$ leptons ($ee$, $e\mu$, $\mu\mu$)

Main background: WW

Use dilepton invariant mass as discriminating variable:

(thesis of S. Chuang, Wisconsin)
### Run 2 $\ell\ell\ell$ Result

<table>
<thead>
<tr>
<th>$M_H$ assumed</th>
<th>140 GeV</th>
<th>150 GeV</th>
<th>160 GeV</th>
<th>170 GeV</th>
<th>180 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_{ll}$ cut (GeV)</td>
<td>55.0</td>
<td>57.5</td>
<td>62.5</td>
<td>70.0</td>
<td>80.0</td>
</tr>
<tr>
<td>DY ee</td>
<td>0.0000±0.0000</td>
<td>0.1501±0.1569</td>
<td>0.4201±0.2756</td>
<td>0.7202±0.3912</td>
<td>0.8703±0.4448</td>
</tr>
<tr>
<td>DY $\mu\mu$</td>
<td>0.1676±0.1073</td>
<td>0.1676±0.1073</td>
<td>0.2160±0.1217</td>
<td>0.3229±0.1576</td>
<td>0.4270±0.1878</td>
</tr>
<tr>
<td>DY tt</td>
<td>0.0052±0.0027</td>
<td>0.0074±0.0033</td>
<td>0.0140±0.0052</td>
<td>0.0219±0.0074</td>
<td>0.0263±0.0082</td>
</tr>
<tr>
<td>ttbar</td>
<td>0.0083±0.0052</td>
<td>0.0083±0.0052</td>
<td>0.0083±0.0052</td>
<td>0.0111±0.0061</td>
<td>0.0172±0.0081</td>
</tr>
<tr>
<td>ZZ</td>
<td>0.0224±0.0025</td>
<td>0.0252±0.0028</td>
<td>0.0312±0.0032</td>
<td>0.0428±0.0041</td>
<td>0.0639±0.0058</td>
</tr>
<tr>
<td>WZ</td>
<td>0.0832±0.0087</td>
<td>0.0963±0.0098</td>
<td>0.1187±0.0115</td>
<td>0.1462±0.0135</td>
<td>0.1844±0.0164</td>
</tr>
<tr>
<td>WW</td>
<td>3.5048±0.4099</td>
<td>3.8170±0.4463</td>
<td>4.4496±0.5201</td>
<td>5.3799±0.6285</td>
<td>6.4922±0.7583</td>
</tr>
<tr>
<td>fakes</td>
<td>0.3970±0.1225</td>
<td>0.4500±0.1398</td>
<td>0.5300±0.1638</td>
<td>0.6460±0.1946</td>
<td>0.8140±0.2529</td>
</tr>
<tr>
<td>total bg</td>
<td>4.1885±0.4495</td>
<td>4.7219±0.5177</td>
<td>5.7878±0.6447</td>
<td>7.2910±0.8146</td>
<td>8.8952±0.9759</td>
</tr>
<tr>
<td>HWW</td>
<td>0.1042±0.0122</td>
<td>0.1553±0.0182</td>
<td>0.2241±0.0262</td>
<td>0.2200±0.0258</td>
<td>0.1716±0.0201</td>
</tr>
<tr>
<td>S/sqrt(S+B)</td>
<td>0.0503</td>
<td>0.0703</td>
<td>0.0914</td>
<td>0.0803</td>
<td>0.0570</td>
</tr>
<tr>
<td>data</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>7</td>
<td>8</td>
</tr>
</tbody>
</table>
Run 2 $\ell\ell\ell$ Result

Perform likelihood fit using angular distribution

Extract 95% CL upper limit using Bayesian approach
We clearly have our work cut out for us...how long will it take?
Revised SM Higgs Reach Estimate

- Higgs Sensitivity Study (2003)
- combined CDF/D0 sensitivity

How much data will we get?
Tevatron Run 2 Projections

- “design” goal requires electron cooling in Recycler
- Tevatron running well in 2004 - may achieve $10^{32}$ soon

4-5 fb$^{-1}$ by LHC turn on?

September 2003: Run 2b silicon project cancelled! This degrades the projected reach substantially…
WH channel

- assume SHW-level b tagging but declining at large eta
- 10% mass resolution
- signal and background scaled by a factor of 1.6 to account for effect of neural network-type selection

To do this channel, need to control background shape very accurately.
ZH channel

- use NN for selection
- incorporate $llbb$ by scaling signal and background by 1.33
- QCD background from real data!
- sensitivity a bit better than SHW report
- significant acceptance from WH process!

Need to ensure that there is no acceptance overlap with $\ell\nu bb$ channel
Is there hope for SM Higgs?

Main impact of Run 2b silicon cancellation: poorer b tag efficiency.

Signal rate \( \sim \epsilon_b^2 \) and background is real b jets!

\[ \Rightarrow L_{\text{req}} \sim \epsilon_b^2 \text{ too!} \]

We are working at an operating point in b tagging where we maximize purity...but is this the right strategy?

Need new, more flexible b tagging algorithms!

I believe we will achieve 95% exclusion limits up to \( \sim 120 \) GeV mass.
MSSM Higgs at the Tevatron

Top row leads to enhanced production at large $\tan\beta$

$$\sigma(pp\to bbH/bbA/bbh) \propto \tan^2\beta$$
“Forward enhancement”?


Pole in cross section (related to b structure function) in case where one b goes forward.

\[ \sigma(bA) / \sigma(bbA) = 10 ! \]

Similar enhancement predicted for Z+b!

\[ \sigma(Zb) \cdot B(Z \rightarrow ll) = 0.9 \text{ pb} \]
**bH/bA/bh → bbb and ττb**

- 90% branching ratio
- difficult to trigger
- don’t know which pair
- lots of background

- trigger exists
- can reconstruct mass
- low background (Zb)
- 8% branching ratio

Results coming soon on both of these!
Doubly Charged Higgs

like sign lepton pairs:
• high efficiency
• low background

Search limits in the range of 10’s of fb!
Outlook
At the Tevatron we can address key scientific questions before LHC turn-on:

Is there a SM (or SM-like) Higgs up to masses of ~120-125 GeV?

Can we see evidence of high-tanβ-enhanced production of MSSM Higgs?

Is there evidence for other more exotic Higgs species?

It’s still exciting and it’s great preparation for the LHC!