Searches for $H \rightarrow WW \rightarrow ll$

at DØ

Björn Penning
Tevatron and DØ

- RunII: 2001-200x
- Run IIb started about two years ago

The DØ-Detector

- Central tracking: silicon vertex detector and fibre tracker in 2T field
- Calorimeter: hermetic coverage $|\eta| < 4.2$, optimised for high-$p_T$ physics
- Muon System: excellent purity and coverage: $|\eta| < 2$

Average data-taking eff 2008: >90%
Results presented here based on ~3 fb$^{-1}$ of recorded luminosity

DØ Upgrade

peak lumi $>3 \times 10^{32}$ cm$^{-2}$s$^{-1}$

Run II Integrated Luminosity

- 5.08 fb$^{-1}$
- 4.43 fb$^{-1}$
**Higgs Production @ Tevatron**

- Cross Section Higgs production ($80 < m_H < 200$ GeV):
  - $\sigma(gg \rightarrow H) \approx 2 - 0.1 \text{ pb}$
  - $\sigma(q\bar{q} \rightarrow HW) \approx 0.6 - 0.02 \text{ pb}$

- Higgs Productions channels considered:
  - $gg \rightarrow H \rightarrow WW \rightarrow ll$
  - $qq \rightarrow H \rightarrow WW \rightarrow ll$

- Very clean signature:
  - two high $p_T$ leptons
  - high missing transverse energy

Search strategies function of decay & production channel:

- $m_H < 135$ GeV:
  - $b\bar{b}$ decay dominant
- $m_H > 135$ GeV:
  - $WW$ decay dominant
Event Selection

- Signal characterized by two oppositely charged high $p_T$ leptons and high missing transverse energy ($E_T^{\text{miss}}$)

  High transverse mass:
  Real $W$ event

  Low transverse mass:
  Mis-measured muon

$$E_T^{\text{Scaled}} = \frac{E_T^{\text{miss}}}{\sqrt{\sum \text{jets} \sigma_j^2 E_T^j}}$$

MET projected onto jet direction
Technical Side

Physics Department
University of Freiburg

- **Trigger**: dedicated set of Electron, Muon and MET triggers are used
  - Trigger efficiency is measured in data by *tag-and-probe method* and applied to MC

- Higgs masses analyzed: **115-200 GeV** using a 5 GeV mass grid

- QCD contribution estimated using data:
  - Calorimeter/Trk/Muon **isolations** to be failed
  - Extract QCD enriched sample in **likesign** data
  - Performing fit to \( p_T \) of the leptons

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**Graphs:**
- **\( p_T \)** distribution for **likesign** leptons
- Ratio plot showing data compared to various backgrounds

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Björn Penning, GradKoll Seminar 10/15/08
• All three analysis using full RunII data set, corresponding to 3fb\(^{-1}\). Data taken on 31\(^{st}\) of May was shown at ICHEP08.

• Preselection requirements:
  – opposite charge of the leptons
  – \(M_{\text{inv}} > 15\) GeV
  – lepton \(P_T\) cuts
    • \(l_\mu > 10\) GeV, \(l_e - P_T > 15\) GeV

• Applying only four relatively loose cuts to remove QCD, DY and EW backgrounds

<table>
<thead>
<tr>
<th>Analysis</th>
<th>(H \rightarrow WW \rightarrow \mu\mu)</th>
<th>(H \rightarrow WW \rightarrow e\mu)</th>
<th>(H \rightarrow WW \rightarrow ee)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preselection</td>
<td>(E_T^{\text{miss}} &gt; 20)</td>
<td>(e &gt; 15) GeV, (\mu &gt; 10) GeV, (M &gt; 15), opposite sign</td>
<td>(&gt; 7)</td>
</tr>
<tr>
<td>(E_T^{\text{miss} \text{ sig}})</td>
<td>(&gt; 5)</td>
<td>(&gt; 20)</td>
<td>(&gt; 6)</td>
</tr>
<tr>
<td>(M_T^{\text{min}})</td>
<td>(&gt; 20)</td>
<td>(&gt; 20)</td>
<td>(&gt; 30)</td>
</tr>
<tr>
<td>(\Delta \phi(l_1, l_2))</td>
<td>(&lt; 2.5)</td>
<td>(&lt; 2.0)</td>
<td>(&lt; 2.0)</td>
</tr>
</tbody>
</table>
• Very good data/MC agreement. MET sort of closure-test
- **Very nice agreement** on all cuts stages

<table>
<thead>
<tr>
<th></th>
<th>$\epsilon\mu$ pre-selection</th>
<th>$\epsilon\mu$ final</th>
<th>$ee$ pre-selection</th>
<th>$ee$ final</th>
<th>$\mu\mu$ pre-selection</th>
<th>$\mu\mu$ final</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z \rightarrow ee$</td>
<td>209.0 ± 3.0</td>
<td>0.72 ± 0.16</td>
<td>160463 ± 264</td>
<td>73.6 ± 5.1</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>$Z \rightarrow \mu\mu$</td>
<td>151.1 ± 0.6</td>
<td>2.14 ± 0.06</td>
<td>–</td>
<td>–</td>
<td>256432 ± 230</td>
<td>957 ± 14</td>
</tr>
<tr>
<td>$Z \rightarrow \tau\tau$</td>
<td>2312 ± 2</td>
<td>2.45 ± 0.05</td>
<td>835 ± 8</td>
<td>1.0 ± 0.3</td>
<td>1968 ± 11</td>
<td>5.5 ± 0.5</td>
</tr>
<tr>
<td>$t\bar{t}$</td>
<td>187.5 ± 0.2</td>
<td>0.25 ± 0.1</td>
<td>96.9 ± 0.2</td>
<td>28.5 ± 0.1</td>
<td>19.4 ± 0.1</td>
<td>10.1 ± 0.1</td>
</tr>
<tr>
<td>$W + jets$</td>
<td>163.4 ± 5.3</td>
<td>60.1 ± 3.2</td>
<td>174 ± 7</td>
<td>72.0 ± 4.3</td>
<td>149 ± 3</td>
<td>85.8 ± 2.1</td>
</tr>
<tr>
<td>$WW$</td>
<td>285.6 ± 0.1</td>
<td>108.0 ± 0.1</td>
<td>127.5 ± 0.4</td>
<td>45.7 ± 0.2</td>
<td>162.9 ± 0.5</td>
<td>91.3 ± 0.3</td>
</tr>
<tr>
<td>$WZ$</td>
<td>14.8 ± 0.1</td>
<td>4.9 ± 0.1</td>
<td>89.6 ± 0.8</td>
<td>7.6 ± 0.2</td>
<td>51.6 ± 0.5</td>
<td>16.2 ± 0.3</td>
</tr>
<tr>
<td>$ZZ$</td>
<td>3.47 ± 0.01</td>
<td>0.49 ± 0.01</td>
<td>73.5 ± 0.3</td>
<td>5.4 ± 0.1</td>
<td>43.0 ± 0.2</td>
<td>13.5 ± 0.1</td>
</tr>
<tr>
<td>Multi-jet</td>
<td>190 ± 168</td>
<td>1 ± 8</td>
<td>2322 ± 193</td>
<td>4.3 ± 8.3</td>
<td>945 ± 31</td>
<td>63.6 ± 8.0</td>
</tr>
<tr>
<td>Signal ($m_H = 160$ GeV)</td>
<td>9.0 ± 0.1</td>
<td>6.9 ± 0.1</td>
<td>4.40 ± 0.01</td>
<td>3.49 ± 0.01</td>
<td>4.7 ± 0.1</td>
<td>4.09 ± 0.06</td>
</tr>
<tr>
<td>Total Background</td>
<td>3516 ± 168</td>
<td>234 ± 9</td>
<td>164181 ± 327</td>
<td>238 ± 11</td>
<td>259770 ± 232</td>
<td>1242 ± 16</td>
</tr>
<tr>
<td>Data</td>
<td>3706</td>
<td>234</td>
<td>164290</td>
<td>236</td>
<td>263743</td>
<td>1147</td>
</tr>
</tbody>
</table>

- **Main bkgd sources:**
  - $WW$
  - $W+jets/\gamma$
- Training against all backgrounds
- 50% test and training each
- Input variables more or less well balanced
- NN trained using TMultiLayerPerceptron
NN distributions

- NN output shows **nice agreement** in all three analyses.
- For each Higgs mass point an individual NN is trained and applied.
Two types of systematics have been studied:

- **Flat Systematics**
  - related to overall normalization and efficiencies of the contributing physical processes.
  - Lepton efficiencies (2-8%)
  - Lepton momentum scale (2%)
  - Theoretical cross-sections (7-10%)
  - Jet→lepton fake rate (10%)
  - QCD normalization (30%)

- **Shape Systematics**:
  - uncertainties which impact the multivariate classification of events
  - Jet efficiency (6%)
  - Jet energy scale (7%)
  - Jet energy resolution (3%)
  - Inst. luminosity (0.3%)
  - Interaction region (1%)
  - Di-boson $p_T$ (5%)

leads to ~800 of these syst. plots per channel!

Change of NN when $p_T(WW)$ changes
• Large backgrounds, but under control
• Further understanding will improve sensitivity
Thinking out of the box

• For best possible performance one needs to constantly revisit and improve tools and reconstruction with increasing detector understanding.

• Increased lumi 1.2 to 2.8 fb\(^{-1}\) → expect improvement of \(\sqrt{2.3}=1.52\)

We have 2!
• Setting limits at 95% C.L. for each Higgs mass
• Using CLs method like LEPII

1.9 x SM

• Good Data/MC agreement
• In order two achieve maximal sensitivity CDF and DØ combine

• First Higgs exclusion @170 GeV for the Summer combination
Conclusion

• First time since LEP and generally at hadron machines SM Higgs sensitivity has been reached

• Working right now on paper and new combination based on 3 fb⁻¹:
  – Adding more Signal Samples (ZH, WH)
  – Improved existing systematics, added more
  – Tested statistical issues

• Looking forward to 4 fb⁻¹: not out of ideas...
  • New EM-ID
  • Adding Matrix-Elements
  • Adding more detector regions
  • More production samples

→~20% more sensitivity (if not more)

• More channels to be added (H→WWW, l+τ)

• Expecting to reach sensitivity for almost entire high mass Higgs
• Cross checks performed in many ways to ensure quality of selection:

• Selecting $W+$jets/$\gamma$ enriched background and testing various generators
Selection Cross Checks

NN at presel level

\( H_{161} \rightarrow WW \times 1c \)

\( Z \rightarrow \mu \mu \)

\( W + \text{jets}/\gamma \)

QCD

t\bar{t}

\( H_T \) lsgn

\( H_{161} \rightarrow WW \times 10 \)

\( Z \rightarrow e e \)

\( W + \text{jets}/\gamma \)

QCD

t\bar{t}
<table>
<thead>
<tr>
<th>Cut</th>
<th>Data</th>
<th>Sum Bkgd $H_{160} \rightarrow WW$</th>
<th>$Z \rightarrow ee$</th>
<th>$Z \rightarrow \tau\tau$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preselection</td>
<td>164290.00 ± 405.33</td>
<td>164181.30 ± 327.07</td>
<td>4.42 ± 0.00</td>
<td>160462.86 ± 264.03 835.23 ± 8.32</td>
</tr>
<tr>
<td>$E_T^{\text{Sig}}$</td>
<td>4968.00 ± 70.48</td>
<td>4954.73 ± 64.84</td>
<td>4.19 ± 0.00</td>
<td>4198.28 ± 25.71 149.90 ± 3.44</td>
</tr>
<tr>
<td>$E_T^{T}$</td>
<td>2852.00 ± 53.40</td>
<td>2763.96 ± 52.96</td>
<td>4.02 ± 0.00</td>
<td>2169.56 ± 18.20 100.83 ± 2.81</td>
</tr>
<tr>
<td>$M_{\text{min}}^T (l, E_T)$</td>
<td>837.00 ± 28.93</td>
<td>828.37 ± 15.18</td>
<td>3.85 ± 0.00</td>
<td>555.04 ± 9.67 1.78 ± 0.36</td>
</tr>
<tr>
<td>$\Delta\phi(e_1, e_2)$</td>
<td>236.00 ± 15.36</td>
<td>238.17 ± 10.64</td>
<td>3.51 ± 0.00</td>
<td>73.62 ± 5.08 1.01 ± 0.28</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Cut</th>
<th>$W + jet/\gamma$</th>
<th>$t\bar{t}$</th>
<th>$ZZ$</th>
<th>$WZ$</th>
<th>$WW$</th>
<th>$QCD$</th>
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<td>Preselection</td>
<td>174.04 ± 6.85</td>
<td>96.93 ± 0.23</td>
<td>73.54 ± 0.28</td>
<td>89.61 ± 0.82</td>
<td>127.50 ± 0.38</td>
<td>2321.59 ± 192.73</td>
</tr>
<tr>
<td>$E_T^{T}$</td>
<td>139.25 ± 5.99</td>
<td>88.82 ± 0.22</td>
<td>24.59 ± 0.16</td>
<td>32.86 ± 0.49</td>
<td>102.62 ± 0.34</td>
<td>218.40 ± 59.11</td>
</tr>
<tr>
<td>$E_T^{\text{Sig}}$</td>
<td>136.11 ± 5.91</td>
<td>65.91 ± 0.19</td>
<td>17.02 ± 0.13</td>
<td>23.82 ± 0.42</td>
<td>98.85 ± 0.34</td>
<td>151.87 ± 49.29</td>
</tr>
<tr>
<td>$M_{\text{min}}^T (l, E_T)$</td>
<td>102.12 ± 5.09</td>
<td>51.73 ± 0.17</td>
<td>11.20 ± 0.11</td>
<td>17.04 ± 0.36</td>
<td>82.55 ± 0.31</td>
<td>6.90 ± 10.51</td>
</tr>
<tr>
<td>$\Delta\phi(e_1, e_2)$</td>
<td>71.98 ± 4.27</td>
<td>28.54 ± 0.12</td>
<td>5.44 ± 0.08</td>
<td>7.63 ± 0.24</td>
<td>45.65 ± 0.23</td>
<td>4.31 ± 8.30</td>
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