A search for WH Associated Production at the DØ experiment from \( pp \) Collisions with \( \sqrt{s} = 1.96 \) TeV

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On behalf of the DØ Collaboration
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Outline

- Physics Motivation
- SM Higgs Boson - Production Mechanism
- Experimental Apparatus
- Event Signature
- Data Sample and Event Selection
- Simulated Signal/Background Samples
- Tagging b-jets
- Data/Background Comparison
- Cross Section Limits
- Summary and Conclusions
Physics Motivation

- SM has been very successful
  - Top quark (discovered in 1995)
  - Model is still incomplete

- Existence of Higgs has major consequences
  - Relation to Boson Masses via Higgs Mechanism: $M_W/M_Z = \cos \theta_W$
  - A neutral Higgs boson $H^0$ predicted.
  - Interactions with the Higgs field can *generate* fermion masses

- SM Predicts neutral Higgs Boson which has not been verified experimentally
  - Since $H^0$ couples strongly to $W$ and $Z$ the best places to search for it are at Tevatron and LHC!
  - *Does not predict* the mass of the Higgs boson
  - Does predict its couplings to other particles e.g. *coupling to fermions*
  - $H^0 \rightarrow b\overline{b}$ is likely to be the decay mode for Higgs *discovery*
SM Higgs Boson – Production Mechanism

- SM Higgs couples to
  - massive W/Z Bosons
  - top/bottom quark
- Four main production channels are of interest at hadron colliders
- (W/Z) H channels have smaller QCD background
- NNLO theoretical cross-sections for WH are
  - 0.178 pb for 115 GeV Higgs
  - 0.086 pb for 140 GeV Higgs
Experimental Apparatus

- Recorded Luminosity: 1.68 fb\(^{-1}\) as of Oct 12\(^{th}\) 2006
- RunIIA - Apr 2002 - Feb 2006
- 174 pb\(^{-1}\) DØ Data - PRL for WH (e\(\nu\)bb) in 2005
- Results shown here are for 0.37 - 0.39 fb\(^{-1}\)
- 1.0 fb\(^{-1}\) analyses are currently in progress

Upgraded DØ Detector
Extended Muon Spectrometer
New Tracking System
Event Signature

Physics Level

Detector Level

- Isolated Lepton
  - electron/muon
- Large Missing Transverse Energy
  - MET or $E_T$
- Exactly two Jets (tagged as b-jets)
- Improved Signal/Background
Data Sample and Event Selection

- **Integrated Luminosity of the Sample**
  - 371 pb\(^{-1}\) - electron channel
  - 385 pb\(^{-1}\) - muon channel

- **Isolated Lepton**
  - \(p_T > 20\) GeV/c
  - |\(\eta\)| < 1.1 (for electron)
  - EM Fraction in Calorimeter > 90%
  - Isolation Fraction < 0.15
  - Tight Shower shape, \(\chi^2\) of JMx(7) < 50
  - Electron Likelihood > 0.70
  - Trigger requires one EM Object
  - |\(\eta\)| < 2.0
  - Hits in all layers of Muon System requires centrally matched track
  - Veto against cosmic muons
  - Isolated from Jets \(\Delta R(\mu, jet) > 0.5\)
  - Triggers require one muon object or a jet in addition to a muon

- **Neutrino (\(E_T\))**
  - Require \(E_T > 25\) GeV

- **Two Jets**
  - Exactly 2 jets required (to obtain improved signal/background ratio)
  - Reconstructed using 0.5 cone algorithm \(\Delta R = \sqrt{\Delta \eta^2 + \Delta \phi^2} = 0.5\)
  - |\(\eta\)| < 2.5
  - \(p_T\) (jets) > 20 GeV/c
# Simulated Signal/Background Samples

<table>
<thead>
<tr>
<th>Process</th>
<th>Generator</th>
<th>$\sigma \times BR$ [pb]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Wb\bar{b}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Wb\bar{b} \rightarrow e\nu b\bar{b}$</td>
<td>ALPGEN + PYTHIA</td>
<td>3.35</td>
</tr>
<tr>
<td>$Wb\bar{b} \rightarrow \tau\nu b\bar{b}$</td>
<td>ALPGEN + PYTHIA</td>
<td>3.35</td>
</tr>
<tr>
<td>$HW \rightarrow b\bar{b} + e\nu$, $m_H = 105$ GeV</td>
<td>PYTHIA (CS compliant)</td>
<td>0.0222</td>
</tr>
<tr>
<td>$HW \rightarrow b\bar{b} + e\nu$, $m_H = 115$ GeV</td>
<td>PYTHIA (CS compliant)</td>
<td>0.0150</td>
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<tr>
<td>$HW \rightarrow b\bar{b} + e\nu$, $m_H = 125$ GeV</td>
<td>PYTHIA (CS compliant)</td>
<td>0.0093</td>
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<tr>
<td>$HW \rightarrow b\bar{b} + e\nu$, $m_H = 135$ GeV</td>
<td>PYTHIA (CS compliant)</td>
<td>0.0045</td>
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<tr>
<td>$HW \rightarrow b\bar{b} + e\nu$, $m_H = 145$ GeV</td>
<td>PYTHIA (CS compliant)</td>
<td>0.0022</td>
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<tr>
<td>$HW \rightarrow b\bar{b} + \tau\nu$, $\tau \rightarrow e\nu$, $m_H = 105$ GeV</td>
<td>PYTHIA (CS compliant)</td>
<td>0.0039</td>
</tr>
<tr>
<td>$HW \rightarrow b\bar{b} + \tau\nu$, $\tau \rightarrow e\nu$, $m_H = 115$ GeV</td>
<td>PYTHIA (CS compliant)</td>
<td>0.0026</td>
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<tr>
<td>$HW \rightarrow b\bar{b} + \tau\nu$, $\tau \rightarrow e\nu$, $m_H = 125$ GeV</td>
<td>PYTHIA (CS compliant)</td>
<td>0.0016</td>
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<td>$HW \rightarrow b\bar{b} + \tau\nu$, $\tau \rightarrow e\nu$, $m_H = 135$ GeV</td>
<td>PYTHIA (CS compliant)</td>
<td>0.00078</td>
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<tr>
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<td>PYTHIA (CS compliant)</td>
<td>0.00038</td>
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<tr>
<td>$W + \text{jets}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Wj j \rightarrow e\nu + j j$</td>
<td>ALPGEN + PYTHIA</td>
<td>287.3</td>
</tr>
<tr>
<td>$Wj j \rightarrow \tau\nu + j j$</td>
<td>ALPGEN + PYTHIA</td>
<td>287.3</td>
</tr>
<tr>
<td>$Zj j \rightarrow e e + j j$</td>
<td>ALPGEN + PYTHIA</td>
<td>27.2</td>
</tr>
<tr>
<td>$\gamma^*/Z \rightarrow \tau\tau$, $m \in (60, 130)$ GeV</td>
<td>PYTHIA (CS compliant)</td>
<td>255.0</td>
</tr>
<tr>
<td>$W \rightarrow \tau\nu\tau$</td>
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<td>2775</td>
</tr>
<tr>
<td>$t\bar{t} \rightarrow b\bar{b} + \ell^+\ell^-, E_T, m_t = 175$ GeV</td>
<td>ALPGEN + PYTHIA</td>
<td>0.70</td>
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<tr>
<td>$t\bar{t} \rightarrow b\bar{b} + 2j + \ell^+\ell^-, E_T, m_t = 175$ GeV</td>
<td>ALPGEN + PYTHIA</td>
<td>2.90</td>
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<tr>
<td>Single top s-channel ($tb \rightarrow e\nu b\bar{b}$)</td>
<td>CompHEP + PYTHIA</td>
<td>0.115</td>
</tr>
<tr>
<td>Single top t-channel ($tq \rightarrow e\nu bq\bar{b}$)</td>
<td>CompHEP + PYTHIA</td>
<td>0.258</td>
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<tr>
<td>$WW \rightarrow l\nu j j$</td>
<td>PYTHIA</td>
<td>2.672</td>
</tr>
<tr>
<td>$WZ \rightarrow l\nu j j$</td>
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<tr>
<td>$WZ \rightarrow l l j j$</td>
<td>PYTHIA</td>
<td>0.243</td>
</tr>
<tr>
<td>$ZZ \rightarrow l l j j$</td>
<td>PYTHIA</td>
<td>0.205</td>
</tr>
</tbody>
</table>
Tagging b-Jets

- Tagging Jets with the using algorithm
  - Jet Lifetime Probability (JLIP)
- JLIP Probability constructed using tracks associated to jets with positive impact parameter in the transverse plane
- Define two exclusive samples
  - Double Tag (DT): 2 jets with JLIP probability < 1%
  - Single Tag (ST): 1 jet with JLIP probability < 0.1%
- Fake Rate (Negative Tag Rate) is ~ 3%
- Efficiency of Tagging
  - $33 \pm 4\%$ (ST) and $55 \pm 4\%$ (DT)
**Data/Background (Before b-tagging)**

\[ W(\rightarrow \ell \nu) + \geq 2 \text{ jets} \]

- Before b-tagging, the dominant background is \( W + \text{jets} \)
- All backgrounds except on are normalized absolutely (i.e., to the cross-section)
- \( W+ \text{jets} \) which is normalized to data after subtracting all other backgrounds
$W(\rightarrow \ell v) + \geq 2$ jets ($\ell = e$ and $\mu$)

- Total Expectation from Simulation: $7388 \pm 817$
- Observed Number of Data Events: $7388$
- QCD (Multijet) background estimated from Data: $850 \pm 231$
**Data/Background (Single and Double Tagged)**

\[ W(\to \ell \nu) + \geq 2 \text{ jets (} \ell = e \text{ and } \mu) \]

- Total Expectation from Simulation
  - Single Tag: 111.8 ± 17
  - Double Tag: 27.9 ± 4.2

- Observed Number of Data Events
  - Single Tag: 112
  - Double Tag: 25

- QCD (Multijet) background
  - Single Tag: 18.0 ± 6.3
  - Double Tag: 1.36 ± 0.6
Cross Section Limits

- No excess above the SM background
- Derive 95% CL Limits from Dijet mass
- Combine all four analyses to derive limits
  - Overall Expt. Systematic error 16 - 19 %
- Cross-section limits are
  - 2.4 pb (3.5 expected) for 115 GeV/c^2 Higgs boson

<table>
<thead>
<tr>
<th>Higgs mass</th>
<th>105 GeV</th>
<th>115 GeV</th>
<th>125 GeV</th>
<th>135 GeV</th>
<th>145 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>WH</td>
<td>0.4</td>
<td>0.27</td>
<td>0.17</td>
<td>0.09</td>
<td>0.04</td>
</tr>
<tr>
<td>WW, WZ, ZZ</td>
<td>3.3</td>
<td>2.5</td>
<td>1.1</td>
<td>0.4</td>
<td>0.15</td>
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<tr>
<td>Wbb</td>
<td>6.6</td>
<td>6.6</td>
<td>4.5</td>
<td>3.4</td>
<td>2.5</td>
</tr>
<tr>
<td>tt</td>
<td>3.9</td>
<td>4.3</td>
<td>4.4</td>
<td>4.5</td>
<td>4.5</td>
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<tr>
<td>Single top</td>
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<td>2.3</td>
<td>2.4</td>
<td>2.4</td>
<td>2.2</td>
</tr>
<tr>
<td>QCD / W or Z +jets</td>
<td>19.2</td>
<td>30.6</td>
<td>23.3</td>
<td>19.0</td>
<td>16.4</td>
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<tr>
<td>Total expectation</td>
<td>50.9</td>
<td>45.1</td>
<td>35.7</td>
<td>29.7</td>
<td>25.7</td>
</tr>
</tbody>
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<td>0.37</td>
<td>0.28</td>
<td>0.17</td>
<td>0.09</td>
<td>0.04</td>
</tr>
<tr>
<td>WZ</td>
<td>1.4</td>
<td>1.0</td>
<td>0.60</td>
<td>0.22</td>
<td>0.05</td>
</tr>
<tr>
<td>Wbb</td>
<td>4.2</td>
<td>3.6</td>
<td>3.0</td>
<td>2.4</td>
<td>2.0</td>
</tr>
<tr>
<td>tt</td>
<td>2.0</td>
<td>2.1</td>
<td>2.4</td>
<td>2.2</td>
<td>2.3</td>
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<tr>
<td>Single top</td>
<td>0.89</td>
<td>0.89</td>
<td>0.92</td>
<td>0.89</td>
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<tr>
<td>QCD / W or Z +jets</td>
<td>1.8</td>
<td>1.6</td>
<td>1.4</td>
<td>1.2</td>
<td>1.0</td>
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<tr>
<td>Total expectation</td>
<td>10.5</td>
<td>9.3</td>
<td>8.1</td>
<td>6.9</td>
<td>6.3</td>
</tr>
</tbody>
</table>

| Combined Cross section limit (pb) | 2.4 | 2.4 | 2.9 | 2.8 | 2.6 |
| Expected Cross section limit (pb) | 4.0 | 3.5 | 3.4 | 3.0 | 2.8 |

![Graph showing cross section limits](image)
Work in Progress - 1fb⁻¹ (WH) Analyses

- Analysis converging in both electron and muon channels
- Expect to have preliminary results in ~ 1 month
- Improved tagging using Neural Net b-tagging.
- Extending the analysis to include both central and end-cap calorimeters
- Combine the channels to set limits
Summary and Conclusions

- 95% C.L limits derived for \( \sigma(pp \rightarrow WH) \times B.R(H \rightarrow b\bar{b}) \) between 2.4 and 2.9 pb for Higgs masses between 105 and 145 GeV.
- Tevatron has delivered \( \sim 2 \) fb\(^{-1}\) of data as of Oct 2006.
- Sensitive to low mass Higgs @ 2 fb\(^{-1}\).
- Improvements in Analysis:
  - Neural Net Tagger
  - Neural Net Selection
  - TrackCalJets \( \rightarrow \) mass resolution
  - Include End-Cap Calorimeter
- Overall sensitivity expected to improve significantly.