Search for $VH \rightarrow b\bar{b} + \not{E}_T$ at the Tevatron

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on behalf of the CDF and DØ collaborations

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Meeting of the APS Division of Particles & Fields
The quest for the Higgs

- SM has a broken symmetry
  - EWSB can be described by the Higgs mechanism
  - Prescribes observation of the Higgs boson
- Experimental evidence so far:
  - Direct searches at LEP exclude $m_H < 114$ GeV/$c^2$
  - Direct searches at Tevatron exclude $160 < m_H < 170$ GeV/$c^2$
  - Indirect constraints from precision measurements ($m_W$ and $m_t$) prefer low mass Higgs: $m_H < 163$ GeV/$c^2$
  - Efforts on low mass Higgs searches are key
Low mass Higgs searches

- Low mass SM Higgs production ($m_H < 135 \text{ GeV}/c^2$)
  - Decay dominated by $H \rightarrow b \bar{b}$
  - $gg \rightarrow H \rightarrow b \bar{b}$ difficult to see experimentally
- Rely on associated production, $WH$ and $ZH$
  - Obvious choices: identified leptons
    - $WH \rightarrow l \nu b \bar{b}$
    - $ZH \rightarrow ll b \bar{b}$
  - What’s left: invisible leptons
    - $WH \rightarrow (l)\nu b \bar{b}$
    - $ZH \rightarrow \nu \nu b \bar{b}$

Previous two talks

This talk

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DPF 2009, 07/27/09
The experiments
Analysis strategy

• Trigger on events with large missing $E_T$
• Select events with 2 or more jets
  • 3-jet events add sensitivity to $W \rightarrow \tau \nu$
• Exclude identified leptons
  • Ensures independent channel from other $VH$ searches
• Backgrounds by source of missing $E_T$
  • Instrumental: QCD multijet
  • Real: $W/Z+$jets, top, diboson
• After preselection cuts, apply further cuts to reduce background
  • Identify b-jets (CDF: secondary vertex tags, DØ: neural network)
  • Identify QCD background (CDF: neural network)

CDF preselection:
• Missing $E_T$$>50$ GeV
• 2 or 3 jets with $E_T$$>25$ GeV ($>35$ GeV for at least one jet)
• $\Delta R$ (jet1, jet2) $>1.0$

DØ preselection:
• Missing $E_T$$>40$ GeV
• 2 or 3 jets with $E_T$$>20$ GeV
• $\Delta \phi$ (jet1, jet2) $<165^\circ$
Identifying b-jets

- CDF- Two different secondary vertex tag algorithms: “SecVtx” (ST) and “JetProb” (JP)
  - 3 exclusive event categories depending on type of tags: ST+ST, ST+JP, ST
  - Most sensitivity from ST+ST category with single tags adding 10%
- DØ- Train neural net to identify b jets
  - Employ asymmetric cuts on tag output: one jet tagged at 73% efficiency, other at 48%
  - Found to provide best sensitivity to $H \rightarrow b\bar{b}$ signal
Background modeling

- After preselection, $S/B \sim 1/20,000$ (1/3,500 after tagging)
- Easy: real missing $E_T$
  - Top, electroweak
  - Model using simulation
- Difficult: instrumental missing $E_T$
  - QCD multijet (increased dramatically by allowing 3-jet events)
  - Model using data
  - Important to determine probabilities of (mis)tagging a light flavor jet
QCD rejection neural network

- Train neural network to separate multijet background from signal
- Exploit correlations amongst variables
  - $\Delta \phi$(jets), $\Delta R$(jets), missing $E_T$, etc.
- Train using simulated events
  - QCD with heavy flavor
  - 50/50 mixture of ZH and WH events
- Rejects 65% of multijet background at expense of only 5% of signal
Control samples: electroweak

- Check background modeling in events primarily with real missing $E_T$
  - Require one identified lepton
Control samples: QCD

- Check background modeling in events primarily with instrumental missing $E_T$
- CDF: Two QCD control regions
  - “Signal-like” region includes events cut by QCD reduction NN
Final samples

### CDF

<table>
<thead>
<tr>
<th>Process</th>
<th>ST</th>
<th>ST+ST</th>
<th>ST+JP</th>
</tr>
</thead>
<tbody>
<tr>
<td>QCD+Mistags</td>
<td>941±44</td>
<td>42.1±8.7</td>
<td>78±11</td>
</tr>
<tr>
<td>Single top</td>
<td>43.2±7.9</td>
<td>8.5±1.7</td>
<td>7.2±1.5</td>
</tr>
<tr>
<td>Top pair</td>
<td>124±17</td>
<td>27.4±4.3</td>
<td>27.1±4.6</td>
</tr>
<tr>
<td>Diboson</td>
<td>35.6±6.8</td>
<td>4.9±1.2</td>
<td>4.3±1.1</td>
</tr>
<tr>
<td>W+h.f.</td>
<td>297±130</td>
<td>11.0±6.5</td>
<td>21±11</td>
</tr>
<tr>
<td>Z+h.f</td>
<td>107±46</td>
<td>10.8±5.0</td>
<td>11.3±5.2</td>
</tr>
<tr>
<td>Total Exp</td>
<td>1548±146</td>
<td>105±13</td>
<td>149±17</td>
</tr>
<tr>
<td>Observed</td>
<td>1443</td>
<td>105</td>
<td>148</td>
</tr>
<tr>
<td>$ZH \rightarrow \nu \nu b \bar{b}$</td>
<td>2.1</td>
<td>1.0</td>
<td>0.8</td>
</tr>
<tr>
<td>$WH \rightarrow (l) \nu b \bar{b}$</td>
<td>1.8</td>
<td>0.9</td>
<td>0.7</td>
</tr>
<tr>
<td>$ZH \rightarrow (l)(l)b \bar{b}$</td>
<td>0.09</td>
<td>0.04</td>
<td>0.03</td>
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</tbody>
</table>

### DØ

<table>
<thead>
<tr>
<th>Process</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W+\text{jets}$</td>
<td>174.0</td>
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<tr>
<td>$Z+\text{jets}$</td>
<td>127.3</td>
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<tr>
<td>Top</td>
<td>95.2</td>
</tr>
<tr>
<td>Diboson</td>
<td>12.5</td>
</tr>
<tr>
<td>QCD</td>
<td>33.8</td>
</tr>
<tr>
<td>$HZ$</td>
<td>2.12±0.01</td>
</tr>
<tr>
<td>$HW$</td>
<td>1.58±0.01</td>
</tr>
<tr>
<td>Total</td>
<td>442±1.1</td>
</tr>
<tr>
<td>Observed</td>
<td>439</td>
</tr>
</tbody>
</table>

Signal expectation shown for $m_H=115 \text{ GeV}/c^2$
Final discriminant: CDF

- Train neural networks to discriminate signal from background
  - Separate NNs for 2-jet and 3-jet events
Final discriminant: DØ

- Boosted decision tree used to discriminate signal from background
  - Retained DT with larger weight to misclassified events
- Separate DTs trained for Run 2a and Run 2b datasets
Results

CDF Run II Preliminary, 2.1 fb\(^{-1}\)

- VH → γ\(γ\) + b\(b\) Expected (68\% CL)
- VH → γ\(γ\) + b\(b\) Expected (95\% CL)

Observed 95\% C.L. limit

Expected (95\% CL)

Expected (68\% CL)

Higgs Mass (GeV/c\(^2\))

Observed (expected) limit For \(m_H=115\) GeV/c\(^2\)

CDF: \(6.9 (5.6)\times\sigma_{SM}\)

DØ: \(7.5 (8.4)\times\sigma_{SM}\)
Conclusion

- Both CDF and DØ have completed searches for low mass Higgs events without identified leptons in 2.1 fb$^{-1}$ of data
  - CDF: A factor of ~2 improvement over method used in previous publication [PRL 100, 211801 (2008)]
- New analyses are on the way
  - Considerably more data already available
  - Trigger and b-tagging improvements
- Low mass Higgs search are one of the highest priorities at the Tevatron
  - Much more difficult experimentally at LHC energies