Search for the Standard Model
Higgs Boson in $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ channel at D0

Outline:
- Motivation
- Backgrounds
- Multijet Removal
- $b$-tagging/MVA
- Result

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Rencontres de Moriond  EW 2012
Motivation

\[ Z \rightarrow \nu \bar{\nu} \ (\sim 20\%) \]

Also contribution from

\[ WH \rightarrow l\nu b\bar{b} \]

when lepton is not identified.

**Characteristic Signal:**

- Large MET from invisible Z decay.
- Two boosted, high \( p_T \) b-tagged jets.
- No identified leptons.

Very challenging due to large multijet background.
Backgrounds

SM backgrounds:

- W/Z + jets
- Diboson
- Top

Simulated from Monte Carlo

Instrumental backgrounds:

- Multijet events from mis-measured jets.
  - Large and difficult to model, Data based modeling.

Background modeling validated in control regions.
Backgrounds

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Multijet Removal

- Trained DT to separate signal from multijet background.
- Trained in untag channel of a sample of W/Z + heavy flavor jets events to avoid possible Higgs mass dependence.

- 17 variables used.
  MET, MET significance, angle between jets, jets pT sum etc.

Multijet rejection: ~94%
Signal efficiency: ~89%
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D0 Preliminary (9.5 fb⁻¹)

Moriond EW YSF 2012
Abhinav Dubey
b-tagging

A multivariate b-tagging algorithm is used.

Uses secondary vertex information.

Based on multivariate discriminant we select two high purity b-tag channels:

• a tight b-tag sample.
• a medium b-tag sample.
• Di-jet mass itself is not optimal for limit setting therefore we use a multivariate analysis for separation of remaining backgrounds.

• Trained DT to separate signal from signal like backgrounds in each b-tag channel.

• 22 variables used.

Di-jet mass, Event shapes, jets pT sum, relative position of jets and MET etc.

Final discriminant is used for limit setting.
Upper limit on SM Higgs production cross-section at 95% CL as function of Higgs mass (relative to the SM value).

For $m_H = 115$ GeV limit

- Observed = 2.5
- Expected = 3.0
THANK YOU
In Multijet events, MET tend to align with jets which is used for defining a sideband region.

We define a track based MET which is less sensitive to jet energy fluctuations.

- **Signal Region:**
  well separated jets and track MET in azimuthal plane.

- **Sideband Region:**
  track MET & jets closely aligned.

Sideband regions events are used as MJ in signal region.
Control Regions

EW Control Region:
Invert muon veto
W transverse mass cut

Multijet Control Region:
Reduced MET cut
Invert MET Significance cut
For MC, parametrization was done in events

\[ Z \rightarrow \mu^+\mu^- + \text{jets} \]

with same jet topology as signal

Validation of parametrization was done in events

\[ W \rightarrow \mu\nu + \text{jets} \]

Parametrization was tested in a control sample
Input to Multijet DT

Variables used in the MJ DT

\[ \Delta \phi(j_1, j_2) \]
\[ \eta \text{ of } j_1 \]
\[ \mathcal{E}_T \]
\[ \mathcal{E}_T \text{ significance} \]
\[ \min \Delta \phi(\mathcal{E}_T, j_{\text{all}}) \]
\[ \max \Delta \phi(\mathcal{E}_T, j_{\text{all}}) + \min \Delta \phi(\mathcal{E}_T, j_{\text{all}}) \]
\[ \max \Delta \phi(\mathcal{E}_T, j_{\text{all}}) - \min \Delta \phi(\mathcal{E}_T, j_{\text{all}}) \]
\[ \mathcal{H}_T (\text{vectorial sum of } j_{\text{all}} p_T) \]
\[ \mathcal{H}_T / H_T (\text{with } H_T \text{ the scalar sum of } j_{\text{all}} p_T) \]
\[ \text{Asymmetry between } \mathcal{E}_T \text{ and } \mathcal{H}_T \]
\[ \mathcal{E}_T \text{ component along the thrust axis} \]
\[ \mathcal{E}_T \text{ component perpendicular to the thrust axis} \]
\[ \text{Sum of the signed components of the dijet and recoil momenta along the thrust axis} \]
\[ \text{Sum of the signed components of the dijet and recoil momenta perpendicular to the thrust axis} \]
\[ \text{Centrality (ratio of the scalar sum of } j_1 \text{ and } j_2 \text{ } p_T \text{ to the sum of } j_1 \text{ and } j_2 \text{ energy}) \]
\[ \theta \text{ angle of the dijet system} \]
\[ \text{Polar angle of } j_1 \text{ boosted to the dijet rest frame with respect to the dijet direction in the laboratory} \]
Variables used in the SM DT

Dijet mass
Dijet transverse mass
\( j_1 \ p_T \)
\( j_2 \ p_T \)
Scalar sum of \( j_1 \) and \( j_2 \ p_T \)
\( \eta \) of \( j_1 \)
\( \eta \) of \( j_2 \)
\( \Delta \eta(j_1, j_2) \)
\( \Delta \phi(j_1, j_2) \)
\( \Delta R((j_1, j_2)) \)
\( p_T \) weighted \( \Delta R(j_1, j_{all}) \)
\( p_T \) weighted \( \Delta R(j_2, j_{all}) \)
\( H_T \)
\( H_T \) (vectorial sum of \( j_{all} \ p_T \))
\( H_T / H_T \) (with \( H_T \) the scalar sum of \( j_{all} \ p_T \))
\( \Delta \phi(E_T, \text{dijet}) \)
\( \theta \) angle of \( j_1 \) boosted to the dijet rest frame
Polar angle of \( j_1 \) boosted to the dijet rest frame with respect to the dijet direction in the laboratory
\( \min \Delta \phi(E_T, j_{all}) \)
\( \max \Delta \phi(E_T, j_{all}) + \min \Delta \phi(E_T, j_{all}) \)
Dijet \( p_T \)
\( \Delta \phi(E_T, j_1) \)
TABLE II: The number of expected signal, expected background and observed data events after the multijet veto, for the pre, medium and tight b-tag samples. The signal corresponds to $m_H = 115$ GeV, “Top” includes pair and single top quark production, and $VV$ is the sum of all diboson processes.

<table>
<thead>
<tr>
<th>Sample</th>
<th>ZH</th>
<th>WH</th>
<th>W+jets</th>
<th>Z+jets</th>
<th>Top</th>
<th>VV</th>
<th>Multijet</th>
<th>Total Background</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre b-tag</td>
<td>26.5</td>
<td>25.3</td>
<td>67098</td>
<td>25498</td>
<td>1885</td>
<td>3111</td>
<td>1815</td>
<td>99408</td>
<td>98980</td>
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<tr>
<td>Medium b-tag</td>
<td>9.8</td>
<td>9.2</td>
<td>3144</td>
<td>1071</td>
<td>742</td>
<td>234</td>
<td>261</td>
<td>5452</td>
<td>5453</td>
</tr>
<tr>
<td>Tight b-tag</td>
<td>8.6</td>
<td>8.1</td>
<td>444</td>
<td>252</td>
<td>373</td>
<td>55</td>
<td>8</td>
<td>1132</td>
<td>1039</td>
</tr>
</tbody>
</table>

TABLE IV: The observed and expected upper limits measured using 9.5 fb$^{-1}$ of data on the $(W/Z)H$ production cross section relative to the SM expectation as a function of $m_H$.

<table>
<thead>
<tr>
<th>$m_H$</th>
<th>100</th>
<th>105</th>
<th>110</th>
<th>115</th>
<th>120</th>
<th>125</th>
<th>130</th>
<th>135</th>
<th>140</th>
<th>145</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected</td>
<td>2.3</td>
<td>2.5</td>
<td>2.7</td>
<td>3.0</td>
<td>3.5</td>
<td>4.3</td>
<td>5.3</td>
<td>7.2</td>
<td>9.7</td>
<td>14.5</td>
<td>22.8</td>
</tr>
<tr>
<td>Observed</td>
<td>2.8</td>
<td>2.4</td>
<td>3.5</td>
<td>2.5</td>
<td>3.2</td>
<td>3.8</td>
<td>4.6</td>
<td>8.0</td>
<td>9.6</td>
<td>9.6</td>
<td>19.2</td>
</tr>
</tbody>
</table>
TABLE III: Systematic uncertainties in percent of the overall signal and background yields. “Jet EC” and “Jet ER” stand for jet energy calibration and resolution respectively. “Jet R&T” stands for jet reconstruction and taggability. “Signal” includes $ZH$ and $WH$ production and is shown for $m_H = 115$ GeV.

<table>
<thead>
<tr>
<th>Systematic Uncertainty</th>
<th>Signal (%)</th>
<th>Background (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Medium b-tag</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jet EC - Jet ER</td>
<td>0.9</td>
<td>1.9</td>
</tr>
<tr>
<td>Jet R&amp;T</td>
<td>2.9</td>
<td>2.9</td>
</tr>
<tr>
<td>b Tagging</td>
<td>0.6</td>
<td>3.7</td>
</tr>
<tr>
<td>Trigger</td>
<td>2.0</td>
<td>1.9</td>
</tr>
<tr>
<td>Lepton Identification</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>Heavy Flavor Fractions</td>
<td>-</td>
<td>8.4</td>
</tr>
<tr>
<td>Cross Sections</td>
<td>7.0</td>
<td>9.8</td>
</tr>
<tr>
<td>Luminosity</td>
<td>6.1</td>
<td>5.8</td>
</tr>
<tr>
<td>Multijet Normalization</td>
<td>-</td>
<td>1.1</td>
</tr>
<tr>
<td>Total</td>
<td>10.0</td>
<td>14.2</td>
</tr>
<tr>
<td><strong>Tight b-tag</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jet EC - Jet ER</td>
<td>1.4</td>
<td>1.8</td>
</tr>
<tr>
<td>Jet R&amp;T</td>
<td>2.7</td>
<td>3.0</td>
</tr>
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<td>7.8</td>
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<td>0.8</td>
<td>1.1</td>
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<tr>
<td>Multijet Normalization</td>
<td>-</td>
<td>0.2</td>
</tr>
<tr>
<td>Total</td>
<td>12.7</td>
<td>16.8</td>
</tr>
</tbody>
</table>