Search for the Higgs Boson in $H \rightarrow WW^* \rightarrow l^+\nu l^-\nu$ at DØ

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Search for the Higgs Boson in $H \rightarrow WW^* \rightarrow l^+\nu l^-\bar{\nu}$
Where is the Higgs

$\Delta \chi^2$ of the EW observables global fit

**VS. SM Higgs mass** $m_H$

* Higgs is the only Standard Model (SM) particle not discovered yet;
* Mass not predicted, but constrained by (in)direct searches;
* $m_H > 114.4$ GeV at 95% CL placed by LEP2 direct search;
* $m_H < 166$ GeV at 95% CL placed by global fit to ElectroWeak (EW) observables, with preferred mass $m_H = 85 \pm 39 - 28$ GeV at 68% CL;
* Tevatron currently is the unique place for the direct Higgs search.
Higgs Searches at Tevatron

- Tevatron is a $\bar{p}p$ collider, with $\sqrt{s} = 1.96$ TeV;
- Main production mechanism: gluon fusion: $gg \rightarrow H$ (0.8 - 0.2 pb); and $W/Z$ associated production: $WH$ and $ZH$ (0.2 - 0.03 pb);
- Higgs Decays:
  - $m_H < 135$ GeV, predominantly to $b\bar{b}$, due to the overwhelmed QCD BKGD, the $gg \rightarrow H \rightarrow b\bar{b}$ is not favored, the more promising processes are the $W/Z$ associated production which trigged by high $p_T$ leptons from $W/Z$;
  - $m_H > 135$ GeV, to $WW^*$ becomes dominant, especially the leptonic decays of the $W$-pair provide the most clean signal;
- the $H \rightarrow WW^* \rightarrow l\nu l'\nu$ ($l = e, \mu$, including those from $\tau$ decay) is the most favorite channel for the exploring of the "heavy" SM Higgs.
angular correlation between $W$'s (therefore between leptons) since they come from spin 0 Higgs;

**Signature:**

* two isolated High $p_T$ leptons, with the preference of pointing to the same direction;
* large missing transverse moment ($E_T$).
Tevatron at Fermilab

**Apparatus**

**DØ Detector**

Pseudorapidity ($\eta$) Coverage:

- **Calorimeter**: $|\eta| < 1.1$ by central part, $|\eta| < 4.2$ by two end parts
- **Muon**: $|\eta| < 2$
- **Tracker**: $|\eta| < 3$

Search for the Higgs Boson in $H \rightarrow WW^* \rightarrow l^+\nu l^-\bar{\nu}$
* Data was collected at DØ between April 2002 and February 2006, corresponding to $\mathcal{L} \sim 1\, fb^{-1}$
* Three separated analyses were performed using different skimmed dataset, aimed at the three different final states of $WW^*$ leptonic decay:
  * $H \rightarrow WW^* \rightarrow e^+\nu e^-\nu$, corresponding $\mathcal{L} \sim 950\, pb^{-1}$
  * $H \rightarrow WW^* \rightarrow \mu^+\nu\mu^-\nu$, corresponding $\mathcal{L} \sim 930\, pb^{-1}$
  * $H \rightarrow WW^* \rightarrow e^\pm\nu\mu^\mp\nu$, corresponding $\mathcal{L} \sim 950\, pb^{-1}$
* Major Background

**Signal ($m_H = 120, 140, 160, 180, 200\, GeV$) and most SM BKGD processes ($WW, W+\text{jets}/\gamma, WZ, ZZ, \text{Drell-Yan}, t\bar{t}$) generated with Pythia, QCD BKGD estimated from data.**
Event Selection (I)

1. Preselection: online trigger, lepton ID, two high $p_T$ leptons with opposite charges;

$$E_T \text{ for } e^+\nu e^-\nu \text{ Channel}$$

$$E_T \text{ for } e^\pm\nu e^\mp\nu \text{ Channel}$$

2. Cut on missing transverse energy $E_T$ to remove the QCD and Drell-Yan events;

3. Cut on the significance of missing transverse energy;
4. Cut on the di-lepton invariant mass to remove the BKGD with Z;
5. Cut on the sum of the leptons transverse momentum and missing transverse energy \((p_T^l + p'_T + E_T)\);

6. Cut on the min. transverse mass between each lepton and missing transverse energy (Min. \(m_T(p_T^l, E_T)\));

\[ p_T^{\mu^+} + p_T^{\mu^-} + E_T \]

7. Cut on the Scalar sum of jets transverse energy to remove \(t\bar{t}\) events;
Event Selection (IV)

$\Delta \phi(l, l')$ after preselection

$e^+ \nu e^- \nu$ Channel

$e^\pm \nu \mu^\mp \nu$ Channel

$\mu^+ \nu \mu^- \nu$ Channel

Preselection data

$\tau \tau \rightarrow Z$ QCD fakes

$W W$ ν \rightarrow W$Z

$e e \rightarrow t t$

$160 \text{ GeV Higgs (x10)}$

$\Phi \Delta$

$0 0.5 1 1.5 2 2.5 3$

$-210 -110 1 10 210 310 410$

$W W$

$Z W / Z Z$

$160 \text{ GeV Higgs (x10)}$

$\Delta \phi (e,e)$ (rad)

$\Delta \phi (e, \mu)$ (rad)

$\Delta \Phi (\mu \mu)$

Events / 0.1

$L = 930 \text{ pb}^{-1}$

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8. Cut on the di-lepton opening angle ($\Delta \phi(l, l')$).

$\Delta \phi(l, l')$ will also be used as the final discriminant variable to combine with other DØ search channels to evaluate the Higgs mass limit.
Observed/Expected number of candidate events for $m_H = 160$ GeV ($L \sim 950$ pb$^{-1}$)

<table>
<thead>
<tr>
<th></th>
<th>Data</th>
<th>All BKGD</th>
<th>WW</th>
<th>W+jet/γ</th>
<th>Z/γ</th>
<th>τ−τ+</th>
<th>WZ/ZZ</th>
<th>QCD</th>
<th>$H \to WW^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^-e^+$</td>
<td>10</td>
<td>10.3±0.6</td>
<td>7.0±0.2</td>
<td>1.4±0.6</td>
<td>0.0±0.0</td>
<td>1.1±0.1</td>
<td>0.8±0.1</td>
<td>0.06±0.02</td>
<td>0.415</td>
</tr>
<tr>
<td>$e^±\mu^±$</td>
<td>18</td>
<td>24.4±1.5</td>
<td>16.4±0.1</td>
<td>5.3±1.5</td>
<td>0.02±0.01</td>
<td>2.1±0.1</td>
<td>0.6±0.1</td>
<td>0.1±0.05</td>
<td>0.97</td>
</tr>
<tr>
<td>$\mu^-\mu^+$</td>
<td>9</td>
<td>9.8±0.8</td>
<td>6.6±0.1</td>
<td>1.0±0.4</td>
<td>0.6±0.4</td>
<td>0.5±0.1</td>
<td>0.5±0.1</td>
<td>0.6±0.6</td>
<td>0.35</td>
</tr>
</tbody>
</table>

* Observed data is well consistent with expected SM BKGD;
* The results from these three analyses are combined to evaluate the Higgs production Xsection ($\sigma$) × Branching ratio $BR(H \to WW^*)$ limits using the MCLIMIT method;
* Shadow region has been excluded at 95% CL;
* not sensitive enough to exclude SM Higgs, a factor of 4 away;
* $m_H$ between 150 to 185 GeV has been excluded for the 4th generation model.
* Searches for the Higgs boson via $H \rightarrow WW^* \rightarrow l^+\nu l^-\nu$ have been performed in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV, with $D\bar{O}$ detector at Tevatron;

* Three channels with different $WW^*$ leptonic decay modes were studied using data collected from April 2002 to February 2006, corresponding to the $L$ of the order of $1 \, fb^{-1}$;

* The number of observed events is consistent with what is expected from the SM background;

* Limits on the Higgs production cross section times the branching ratio $\sigma \times BR(H \rightarrow WW^*)$ have been set, Higgs mass between 150 to 185 GeV has been excluded for the 4th generation model;

* $D\bar{O}$ is continuously accumulating data, analysis sensitivity is keeping optimization, more exciting results are expected.