Standard Model

Higgs Boson Searches at DØ

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University of Manchester / Fermilab
on behalf of the DZero Collaboration

DIS 2011, April 11 – 15
Tevatron and DØ

Tevatron collider at Fermilab

- proton anti-proton collisions at $\sqrt{s} = 1.96$ TeV
- Delivering $\sim 2.5$ fb$^{-1}$ every year

Collider experiments

- 2 general purpose detectors: CDF & DØ
- DØ analysed up to 8.2 fb$^{-1}$ (out of 10 fb$^{-1}$ delivered)
Tevatron and DØ

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Higgs Boson at Tevatron

Low Mass Higgs search

High Mass Higgs search

and many more channels included in recent Tevatron Higgs searches
Search Strategies
Maximise acceptance

- Improved lepton and b-jet identification algorithms
- Including events with lower quality objects as separate channels
- Exploiting decay modes with relatively lower branching ratios
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Sophisticated analysis techniques

- Improving background description and kinematic measurements
- Dedicated optimisation for categorised sub-samples
- Employing multivariate methods
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Experiments have always been improving results much more than the luminosity projection
Low Mass Higgs Search

b-quark jet

e.g. $WH \rightarrow lvbb$

leptons or missing $E_T$

two b-jets

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SM Higgs at DØ, DIS 2011

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Low Mass Higgs Search

b-quark jet

Powerful b-jet identification → x10^2 increase in S/B

e.g. WH → lνbb

leptons or missing E_T
two b-jets

DØ, 5.3 fb^-1 W+2jet / 1b-tag

DØ, 5.3 fb^-1 W+2jet / 2b-tag

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Improving Measurements

Sophisticated event variables

- Constrain dijet mass by $p_T$ balance in $ZH\rightarrow llbb$ system
- Significance of missing $E_T$

Extensive studies of background behaviour in control samples
Exploit All Decay Processes
Exploit All Decay Processes

Inclusive $H \rightarrow \gamma \gamma$
- Previously used $\gamma\gamma$ mass
- ~20% improvement from multivariate technique
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Signature of $\ell \tau_{\ell h} + jj$

- Several production and decay modes
- Good sensitivity over wide mass range
High Mass Higgs Search

e.g. $H \rightarrow WW \rightarrow l\nu l\nu$

two leptons

missing $E_T$
High Mass Higgs Search

H → WW, the most sensitive channel

- Clean signature of two leptons → inclusive search for all production modes
- Large missing $E_T$
- Use unique angular relation between the leptons

Correlation between leptons from H→WW decay different to pp→WW

\[ \begin{align*}
\text{data} & \quad Z+jets \\
\text{Diboson} & \quad W+jets \\
\text{Multijet} & \quad \text{ttbar}
\end{align*} \]

\[ \begin{align*}
\nu & \quad W^+ \\
\nu & \quad W^- \\
\nu & \quad e^+
\end{align*} \]
Separate lepton flavours
different physics & instrumental effects

Optimise in jet multiplicities

$\ell\ell + 0\ jet$: WW
$\ell\ell + 1\ jet$: Z+jet
$\ell\ell + \geq 2\ Jets$: tt
Categorising Samples

Separate lepton flavours
different physics & instrumental effects

Optimise in jet multiplicities

\( \ell \ell + 0 \text{ jet: WW} \)
\( \ell \ell + 1 \text{ jet: ZZ+jet} \)
\( \ell \ell + \geq 2 \text{ Jets: tt} \)

Same charge dileptons

- Associated Higgs production mode,
  \( W/ZH \rightarrow \ell^+\ell^- + \ldots \)
- Large instrumental backgrounds

\( M_{T_{min}}^{\text{min}} \) (GeV)

\( M(L, M) \) (GeV)

\( M(L_1, L_2) \) (GeV)

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SM Higgs at DØ, DIS 2011
Recovering Final States

<table>
<thead>
<tr>
<th>electron+jets</th>
<th>muon+jets</th>
<th>tau+jets</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e\tau$</td>
<td>$\mu\tau$</td>
<td>$\tau\tau$</td>
</tr>
<tr>
<td>$e\mu$</td>
<td>$e\tau$</td>
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</tr>
<tr>
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<td>$e\tau$</td>
<td>tau+jets</td>
</tr>
</tbody>
</table>

$W$ decay to dileptons (ee, $e\mu$), acquainting to recover SM Higgs at DØ, DIS 2011.
Recovering Final States

H → WW → ℓτ_h
Analyse different hadronic τ decays
Recovering Final States

**H → WW → ℓτ_h**

Analyze different hadronic τ decays

**H → WW → lν jj**

Reconstruct Higgs mass adding one neutrino

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Combine multiple variables using multivariate techniques

- One powerful discriminant to maximise signal-background separation
- More efficient event selection based on single variable

Input variables

- Kinematics of leptons, jets and missing $E_T$
- Lepton and b-jet “quality” variables
Multivariate Analysis

Combine multiple variables using multivariate techniques

- One powerful discriminant to maximise signal-background separation
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Input variables

- Kinematics of leptons, jets and missing $E_T$
- Lepton and b-jet “quality” variables
Systematic uncertainties in the measurements

- Low mass searches: b-jet identification, jet energy measurement, Heavy Flavour jets background modelling etc.
- High mass searches: lepton identification, luminosity measurement, jet and missing $E_T$ modelling, theoretical prediction etc.

Uncertainties on signal and background yields and shapes are reflected on the cross section limits
Systematic uncertainties in the measurements

- Low mass searches: b-jet identification, jet energy measurement, Heavy Flavour jets background modelling etc.
- High mass searches: lepton identification, luminosity measurement, jet and missing $E_T$ modelling, theoretical prediction etc.

Uncertainties on signal and background yields and shapes are reflected on the cross section limits

Background prediction and their uncertainties are constrained by a fit to the signal-free region

Tevatron combination
Summer 2010
Conclusions

Standard Model Higgs searches at the Tevatron continue to evolve

- Increased acceptance
- Improved control of backgrounds
- Sophisticated variables
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DØ Preliminary, \(\bar{L} = 6.1 \text{ fb}^{-1}\)
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Single experiment exclusion by CDF and DØ this winter

- Lower mass also becoming sensitive to the SM Higgs

DØ Preliminary, $L=6.1 \text{ fb}^{-1}$

SM Higgs Combination

March 7, 2011

DØ high mass combination
winter 2011

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SM Higgs at DØ, DIS 2011
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Further updates this summer

Expecting exciting results in the entire mass region
Back Up

back up
## DØ Results for All Channels

<table>
<thead>
<tr>
<th>channel</th>
<th>data analysed ([\text{fb}^{-1}])</th>
<th>expected limits (M_H = 115 \text{ GeV})</th>
<th>expected limits (M_H = 135 \text{ GeV})</th>
<th>expected limits (M_H = 165 \text{ GeV})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(ZH \rightarrow \nu\nu bb)</td>
<td>6.2</td>
<td>4.0</td>
<td>10.2</td>
<td>-</td>
</tr>
<tr>
<td>(ZH \rightarrow llbb)</td>
<td>6.2</td>
<td>5.7</td>
<td>14</td>
<td>-</td>
</tr>
<tr>
<td>(WH \rightarrow lvbb)</td>
<td>5.3</td>
<td>4.8</td>
<td>11.5</td>
<td>-</td>
</tr>
<tr>
<td>(H \rightarrow \gamma\gamma)</td>
<td>8.2</td>
<td>11.7</td>
<td>11.6</td>
<td>-</td>
</tr>
<tr>
<td>(l\tau_h jj)</td>
<td>5.4</td>
<td>12.8</td>
<td>12.9</td>
<td>12.3</td>
</tr>
<tr>
<td>(H \rightarrow WW \rightarrow l\nu l\nu)</td>
<td>8.1</td>
<td>8.6</td>
<td>2.7</td>
<td>0.97</td>
</tr>
<tr>
<td>(H \rightarrow WW \rightarrow l\tau_h +X)</td>
<td>7.3</td>
<td>96</td>
<td>20</td>
<td>6.6</td>
</tr>
<tr>
<td>(H \rightarrow WW \rightarrow lvjj)</td>
<td>5.4</td>
<td>20</td>
<td>26</td>
<td>5.1</td>
</tr>
<tr>
<td>(VH \rightarrow l^\pm l'^\pm +X)</td>
<td>5.3</td>
<td>20</td>
<td>9.6</td>
<td>8.5</td>
</tr>
</tbody>
</table>
Sophisticated algorithms to combine all the useful event information and their correlations to form a single discriminant

- Neural Networks
- Boosted Decision Tree
- Random Forest
- ...

Multivariate training

- **Inputs**: various kinematic information for signal and background samples
- The algorithm examines the signal and background events and characterises them based on their kinematics
- **Output**: a method to compute whether a given event is signal or bkgd-like

Recursive Pass/Fail tests on input kinematic variables