Search for the SM Higgs Boson in $p\bar{p}$ Collisions at $\sqrt{s}=1.96$ TeV

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don behalf of DZero Collaboration

SUSY 2009, 5–10 June, Boston
SM Higgs Boson Search at DØ

- **DØ Experiment at Tevatron**
  - pp collisions @\(\sqrt{s} = 1.96\)TeV
  - 6fb\(^{-1}\) recorded by DØ (last week!)
  - Higgs searches presented today using up to 4.2fb\(^{-1}\) of data

- **Standard Model (SM) Higgs boson searches performed at DØ**
  - Low Mass: \(H \rightarrow bb, H \rightarrow \tau\tau, H \rightarrow \gamma\gamma\)
    → mostly with associated production (WH, ZH, ...) for additional signature
  - High Mass: \(H \rightarrow WW\)
    → powerful inclusive search + exclusive WH analysis in intermediate mass range
\[ \text{WH} \rightarrow l\nu \text{ bb} \] (1)

- **1 e/\mu + 2 b-jets + \text{E}_{T}^{\text{miss}}**
  - Increased signals acceptance
    - include forward e, multiple \( \mu \) triggers
  - SM background (\( W+\text{jets}, Wb\,\ldots \)) using MC, multijet contribution estimated from data

- **Split analysis** into \([e/\mu] \times [2/3 \text{jets}] \times [1/2 \text{b-tagged jet}]\) samples

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**Preselection**

**After b-tagging**

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WH → lv bb (2)

- Signal–Background discriminant using Neural Net
  - Trained on kinematic variables and Matrix Element discriminant
  - Additional +8% gain in sensitivity from ME
- Signal significance
  - Up to 1/100 after b-tagging → up to 1/10 in high NN region
ZH → ll bb

- $ee/\mu\mu + 2$ b-jets with constraint on di-lepton from Z mass
  - Increased lepton acceptance
    - electrons in previously non-fiducial region using dedicated algorithm
    - central track-only muons (not enough hits in muon system)
  - improvement equivalent to 15% increase in luminosity

**Graphs:**
- DØ Run II Preliminary (3.1 fb$^{-1}$)
  - Data, Z+jets, Z+HF, Top, Diboson, Multijet
  - $\mu+\mu$ ≥ 2 jets
- DØ Run II Preliminary (4.2 fb$^{-1}$)
  - Data, Z+jets, Z+HF, Top, Diboson, Multijet
  - $\mu+trk$ ≥ 2 jets
ZH $\rightarrow$ ll bb

- Kinematic fit in ll-bb system
  - All final states reconstructed $\rightarrow$ no missing component
    - constrain $M_{ee}$ to Z mass
    - transverse momentum conservation of ll-bb system
  $\rightarrow$ improve di-jet mass resolution by 4%, final sensitivity by 8%

- Boosted Decision Tree for final discriminants

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ZH → vv bb

- 2 b-jets + large $E_T^{\text{miss}}$ (lepton veto)
  - Data dominated by $V_{+}\text{jets}$ and multijets
- Electroweak enriched control sample
  - Invert muon veto → same event topology
  - Check trigger parametrisation and normalisation of MC

Analysis Sample (pre b-tag)

EW Control Sample (pre b-tag)
ZH → νν bb

- Multijet with $E_T^{\text{miss}}$ from mis-measured jet
  - Symmetric in $\Delta \phi (E_T^{\text{miss}}, p_{T\text{trk}}^{\text{miss}})$
  - $\rightarrow$ use $\Delta \phi > \pi/2$ to model multijet
- Set of cuts based on jet-$E_T^{\text{miss}}$ kinematics

- Boosted Decision Tree trained against SM backgrounds
  - $1/2$ of signal contributions from WH with undetected lepton
Higgs channels with τ leptons

- H → ττ has 2nd highest branching ratio at $M_H = 115\text{GeV}$
- VH channels miss out a sizable fraction to $W \rightarrow \tau\nu$ and $Z \rightarrow \tau\tau$

**WH → τ_{had}ν bb**

- Strategies similar to $ZH \rightarrow \nu\nu\tau\tau$
- Good hadronic τ ID important

**HX → τ_{had}τ_{μ} jj (no b-tag)**

- Include many channels:
  - $qqH \ (H \rightarrow \tau\tau)$, $ZH \ (Z \rightarrow \tau\tau, H \rightarrow bb)$,
  - $VH \ (V \rightarrow qq, H \rightarrow \tau\tau)$

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- Inclusive search for $\gamma\gamma$ resonance
  - Large background from direct $\gamma\gamma$
- Photon identification
  - Dedicated Neural Net trained with $Z \rightarrow ll\gamma$ data

- Background estimate from data
  - First estimate $\gamma^*/Z \rightarrow ee, \gamma+\text{jet}/\text{di-jet}$ and subtract from data
  - Side band fit to $M_{\gamma\gamma}$ for real $\gamma\gamma$
- Look for a narrow resonance over $\gamma\gamma$ continuum
Like-charged lepton pair (ee/\(e\mu/\mu\mu\)) + \(E_T^{\text{miss}}\)

- Like-charge → large reduction of SM bkgd.
- Instrumental background from multijet and \(Z \rightarrow l^+l^-\) due to charge mis-identification
  → estimated from data

Likelihood discriminant to combine few variables
$H \rightarrow WW$ (1)

- $ee/e\mu/\mu\mu$ (oppositely charged) + $E_T^{\text{miss}}$
  - Clean di-lepton signature
  - Inclusive signal search
- Large SM backgrounds
  - Dominant $\gamma^*/Z$ and irreducible non-resonant $WW$
**Cut Based Initial Selection**

- $E_T^{\text{miss}}$ and minimal $M_T(l, E_T^{\text{miss}})$ against $Z(\pm \text{jets})$ background
- $\Delta \phi(l,l)$ from the difference in spin correlation
  → powerful against all backgrounds including irreducible WW

**Neural Network**

- Input variables based on lepton kinematics & event topology

**At high NN region,**

$S/B \sim 1/3$
Uncertainties

- **Systematic uncertainties**
  - Affect normalisation + shape of the background expectation
  - Included in the calculation of Higgs cross section limit

- **Dominant uncertainties**
  - Low mass searches ($H \rightarrow bb$): total uncertainty $\sim 30$
    - $b$-tagging efficiency
    - Jet energy scale
    - $V$+jet & Heavy Flavor modeling
  - High mass searches ($H \rightarrow WW$): total uncertainty $\sim 10$
    - Theoretical cross section
    - Lepton efficiency
DØ Combined Limits

- Upper limits on Higgs cross section (as a ratio to SM expectation)
  - Last DØ combination for SM Higgs searches in March ’09
    - @115GeV: up to 6.7 (obs) with single channel → 3.7 (obs) combined
    - @165GeV: dominated by H→WW result, 1.3 (obs) limit
Conclusions & Outlook

- **SM Higgs search at DØ**
  - Covers many channels across the Higgs mass range
  - Improving results by increasing signal acceptance and using sophisticated analysis tools
  - Reaching the sensitivity to SM Higgs production cross section

- **Current Tevatron (CDF+DØ) combined limits exclude SM Higgs with $M_H = 160-170$GeV**

- **New results later this summer**
  - Increased dataset (up to $>5fb^{-1}$)
  - Many improvements already in place
  - Expect further exclusion of SM Higgs boson in high mass range + competitive limits in low mass
Back Up

back up
Cross Section Limits

- Set upper limits to the Higgs production cross section
  - Fit discriminant distributions using background (+ signal) expectation with Gaussian uncertainty

- Results from individual channel included in the DØ combination

<table>
<thead>
<tr>
<th>Production</th>
<th>Decay</th>
<th>Luminosity [fb⁻¹]</th>
<th>Limit (@M_H in GeV) exp / obs</th>
</tr>
</thead>
<tbody>
<tr>
<td>WH</td>
<td>lv bb</td>
<td>2.7</td>
<td>6.4 / 6.7 (115)</td>
</tr>
<tr>
<td>ZH</td>
<td>ll bb</td>
<td>4.2</td>
<td>8.9 / 9.1 (115)</td>
</tr>
<tr>
<td>Z(W)H</td>
<td>vv bb</td>
<td>2.1</td>
<td>8.4 / 7.5 (115)</td>
</tr>
<tr>
<td>Inclusive</td>
<td>τ + jets</td>
<td>0.9 - 1.0</td>
<td>28 / 29 (115)</td>
</tr>
<tr>
<td>ttH</td>
<td>tt bb</td>
<td>2.1</td>
<td>45/ 64 (115)</td>
</tr>
<tr>
<td>Inclusive</td>
<td>γγ</td>
<td>4.2</td>
<td>17.5 / 13.1 (120)</td>
</tr>
<tr>
<td>WH</td>
<td>W WW → l±l± X</td>
<td>3.6</td>
<td>10.7 / 18.4 (160)</td>
</tr>
<tr>
<td>Inclusive</td>
<td>WW → ll</td>
<td>4.2</td>
<td>1.7 / 1.3 (165)</td>
</tr>
</tbody>
</table>

Expected and Observed limits (ratio to SM) at best mass
Analysis Tools and Strategies

- **Improving object identification (ID)**
  - Sophisticated Neural Net b-jet tagging
  - New dedicated electron ID in Inter-Cryostat Region (ICR)

- **Increasing signal acceptance**
  - Looser cuts (e.g. central track only μ)
  - Wider coverage (e.g. ICR electrons)

- **Splitting into sub-channels**
  - Lepton flavour, # jets, b-tag operating pnt, ...

- **Multivariate techniques**
  - Likelihood, NN, BDT etc. to combine multiple kinematic variables
  - Matrix Element calculation from final state 4-vectors
**DØ Combined Limits**

- Log Likelihood Ratio

![Graph showing Log Likelihood Ratio](image)

*SM Higgs Combination*
*DØ Preliminary, L=0.9-4.2 fb⁻¹*

*March 5, 2009*

*100 110 120 130 140 150 160 170 180 190 200*

*m_H (GeV/c²)*