Higgs Results from DØ

presented by

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On behalf of the DØ Collaboration

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Outline

- **Introduction**
  - Tevatron
  - DØ detector
  - Higgs production/sensitivity

- **Standard Model Higgs**
  - Limits on Wbb/WH
  - $\sigma(Z+b)/\sigma(Z+j)$ ratio
  - $H \rightarrow WW(\ast) \rightarrow l^+l^-\nu\nu$ searches

- **Higgs Beyond the Standard Model**
  - Limits on neutral SUSY Higgs at high $\tan\beta$
  - Limits on non-SM $h \rightarrow \gamma\gamma$ production
  - Limits on $H^{++}/H^-$

- **Summary**

Thanks to all colleagues for their contribution to these studies
Tevatron Performance (1)

Run II Integrated Luminosity

79% Average Efficiency
89% Current Efficiency

19 April 2002 - 7 June 2004

Delivered	Recorded
Tevatron Performance (2)

FY04 integrated luminosity

11/23/03  1/18/04  05/09/04

12 pb⁻¹ / week is also above the design projection

Measured Lumi

Design
Base

Start of Fiscal Year
The upgraded DØ detector

- **New** (tracking in B-field)
  - silicon detector
  - fiber tracker
- **Upgraded**
  - calorimeter, muon system
  - DAQ/trigger

Needed for Higgs searches!
EW constraints on Higgs

$M_H$ constrained in the Standard Model

**Old Top mass combination:**

\[
M_{\text{top}} = 174.3 \pm 5.1 \text{ GeV} \\
\log M_H = 1.98^{+0.21}_{-0.22} \\
M_H = 96^{+60}_{-38} \text{ GeV} \\
\text{or} < 219 \text{ GeV (95\% CL)}
\]

**New Top mass combination using new DØ Run I measurement:**

\[
M_{\text{top}} = 178.0 \pm 4.3 \text{ GeV} \\
\log M_H = 2.07^{+0.20}_{-0.21} \\
M_H = 117^{+67}_{-45} \text{ GeV} \\
\text{or} < 251 \text{ GeV (95\% CL)}
\]

(Procedure as in hep-ex/0312023)

**Direct searches at LEP2:**

$M_H > 114.4 \text{ GeV @95\%CL}$
SM Higgs Production

- Production cross sections are small: 0.1-1 pb depending on $M_H$

- $M_H < 135$ GeV: decay to $bb$
  - $gg \rightarrow H \rightarrow bb$ overwhelmed by QCD background
  - searches can be performed in $W/Z$ associated production with lower background
  - Best channels:
    - $WH \rightarrow l\nu bb$, $ZH \rightarrow \nu \nu bb$

- $M_H > 135$ GeV: decay to $WW$
  - $gg \rightarrow H \rightarrow WW(\ast) \rightarrow l^+l^-\nu\nu$ final states can be explored
    - clean, but small branching

We may have Higgs in our data already!

We may have Higgs in our data already!
SM Higgs Sensitivity

- New Higgs sensitivity study from CDF + DØ in 2003:

- Statistical power only
- Systematics not included

Improved sensitivity from refined analysis and detailed simulation

The SM Higgs is a challenge, understanding of bkgs critical!
Higgs Beyond the Standard Model

- Larger cross sections and/or cleaner search topologies
- MSSM
  - 5 physical Higgses:
    - Two CP-even scalars: h (lighter, SM-like) H (heavier)
    - CP-odd scalar: A
    - Charged Higgs pair: H±
  - At tree-level, two free parameters:
    - Ratio of vacuum expectation values: \( \tan \beta = \frac{\nu_u}{\nu_d} \)
    - One Higgs mass: \( m_A \)
- Other possibilities:
  - Left-Right Symmetric, Higgs Triplet models: Doubly Charged Higgs
  - SM extensions which suppress fermion couplings
    - Fermio-phobic or TopColor Higgs

Enhanced \( \sigma \) over \( H_{SM}^{bb} \) (prop. to \( \tan^2 \beta \))

**MSSM Higgs Main Decays**
- \( h/H/A \rightarrow bb \sim 90\% \)
- \( h/H/A \rightarrow \tau \tau \sim 10\% \)
- \( H^+ \rightarrow \tau \nu \sim 100\% \) (\( \tan \beta > 1 \))
B-jet tagging

- Essential for $H \rightarrow bb$ searches
- New for DØ in Run II

- Use track impact parameter (IP) measurements or secondary vertex reconstruction

- Several algorithms available

- Demonstrated good b-tagging capability up to $|\eta|<2.5$

Performance being improved
Motivation:
- Background to WH production

Event selection includes:
- Central isolated $e$, $p_T > 20$ GeV
- Missing $E_T > 25$ GeV
- $\geq$ two jets: $E_T > 20$ GeV, $|\eta| < 2.5$

2587 events in $L_{int} = 174$ pb$^{-1}$ of data

Simulations with Alpgen and Pythia through detailed detector response

Cross sections normalized to MCFM NLO calculations

Good understanding of data
- Require jets to be b-tagged:
  - use different b-tag algorithms
  - consistent results with all

- Observe 8, expect $8.3 \pm 2.2$
- Background dominated by top events

Good agreement between data and MC in both cases
W(→ev)bb production (3)

- Exactly two jets: suppress top production
- Observe 2 events, expect $2.5 \pm 0.5$
- Sample composition:

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncertainty(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet energy scale</td>
<td>14</td>
</tr>
<tr>
<td>Jet ID</td>
<td>7</td>
</tr>
<tr>
<td>b-tagging</td>
<td>11</td>
</tr>
<tr>
<td>Trigger &amp; e ID</td>
<td>5</td>
</tr>
<tr>
<td>EM scale</td>
<td>5</td>
</tr>
<tr>
<td>MC simulations</td>
<td>15</td>
</tr>
<tr>
<td>Total</td>
<td>26</td>
</tr>
</tbody>
</table>

(Systematics smaller for WH)

Set limit on production of:

$\sigma(Wbb) < 20.3 \text{ pb}$

$\sigma(WH) \times \text{Br}(H \rightarrow bb) < 12.4 \text{ pb}$

for $M_H = 115 \text{ GeV}$ at 95% C.L.

<table>
<thead>
<tr>
<th>Wbb</th>
<th>Wc(c)</th>
<th>Wjj</th>
<th>tt+t</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.4 \pm 0.4$</td>
<td>$0.3 \pm 0.1$</td>
<td>$0.10 \pm 0.03$</td>
<td>$0.6 \pm 0.2$</td>
<td>$0.10 \pm 0.03$</td>
</tr>
</tbody>
</table>
Z(→ee/µµ)b associated production (1)

- **Motivation:**
  - Background to ZH production
  - Benchmark for SUSY Higgs production via gb→bh
  - Probes PDF of the b-quark

- **Examples of ZQ (Zj) LO diagrams:**

- **Measure cross section ratio:**
  - $\sigma(Z+b)/\sigma(Z+j)$
  - Many uncertainties cancel

- **Data**
  - Correspond to integrated luminosity of 184 (ee), 152 (µµ) pb⁻¹

- **Event selection includes:**
  - Isolated $e/\mu$ with $p_T > 15/20$ GeV, $|\eta| < 2.5/2.0$
  - Z peak for signal, side bands for background evaluation
  - Jet $E_T > 20$ GeV, $|\eta| < 2.5$
  - At least one b-tagged jet

- **Simulations**
  - Performed with Pythia or Alpgen plus Pythia passed through detailed detector response

- **Cross sections** normalized to data

- **Relative b- and c-quark content** as given by MCFM NLO calculations
Z(\rightarrow ee/\mu\mu)b production (2)

- Transverse energy spectrum of b-tagged jets
  - QCD and mistag background estimated from data
  - MC: Pythia Zb normalized to data

- Measured cross section ratio Z+b/Z+j:
  - $0.024 \pm 0.05 \text{ (stat)} + 0.005 \text{ (syst)} - 0.004 \text{ (syst)}$
  - Theory: \sim 0.02 hep-ph/031202

- Systematics studies:

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet tagging</td>
<td>16</td>
</tr>
<tr>
<td>Jet energy scale</td>
<td>11</td>
</tr>
<tr>
<td>Bkgd. estimation</td>
<td>6</td>
</tr>
<tr>
<td>$\sigma(Z+c)/\sigma(Z+b)$</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
</tr>
</tbody>
</table>
$H \rightarrow WW(*) \rightarrow l^+ l^- \nu \nu$ ($l = e, \mu$)

- Event selection includes:
  - Isolated $e/\mu$
    - $p_T(e_1) > 12$ GeV, $p_T(e_2) > 8$ GeV
    - $p_T(e/\mu_1) > 12$ GeV, $p_T(e/\mu_2) > 8$ GeV
  - $p_T(\mu_1) > 20$ GeV, $p_T(\mu_2) > 10$ GeV
  - Missing $E_T$ greater than
    - 20 GeV ($ee$, $e\mu$); 30 GeV ($\mu\mu$)
  - Veto on
    - $Z$ resonance
    - Energetic jets
- Simulations done with Pythia passed through detailed detector response
  - Rates normalized to NLO cross section values
- Data correspond to integrated lumi. of ~180 ($ee$), 160 ($e\mu$) and 150 ($\mu\mu$) pb$^{-1}$
\[ H \rightarrow WW(*) \rightarrow l^+l^-\nu\nu \quad (l=e,\mu) \quad (2) \]

- Higgs mass reconstruction not possible due to two neutrinos

- Employ spin correlations to suppress the background
  - \( \Delta\phi(\ell\ell) \) variable is particularly useful

- Charged leptons from Higgs are collinear

Good agreement between data and MC
$H \rightarrow WW(*) \rightarrow l^+l^-\nu\nu$ ($l=e,\mu$)(3)

- **Number of events after selection**

<table>
<thead>
<tr>
<th></th>
<th>$ee$</th>
<th>$e\mu$</th>
<th>$\mu\mu$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Observed</strong></td>
<td>2</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td><strong>Expected</strong></td>
<td>$2.7 \pm 0.4$</td>
<td>$3.1 \pm 0.3$</td>
<td>$5.3 \pm 0.6$</td>
</tr>
</tbody>
</table>

- **Dominant Background in $e\mu$ sample**

<table>
<thead>
<tr>
<th></th>
<th>WW</th>
<th>W+jets</th>
<th>WZ</th>
<th>$tt$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Expected</strong></td>
<td>$2.51 \pm 0.05$</td>
<td>$0.34 \pm 0.02$</td>
<td>$0.11 \pm 0.01$</td>
<td>$0.13 \pm 0.01$</td>
</tr>
</tbody>
</table>

Signal acceptance is $\sim 0.02 - 0.2$ depending on the Higgs mass/final state

**Excluded cross section times Branching Ratio at 95% C.L.**

**DØ Run II Preliminary**

Excluded at LEP

4th Generation Model

Topcolor

Standard Model

Higgs of 160 GeV

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Neutral Higgs Bosons at High $\tan \beta$ in Multi-jet Events

- Event Selection:
  - Multi-jet data sample
  - At least 3 jets:
    - $E_T$ cuts on jets are optimized separately for different Higgs mass points, and for min. # jets required in the event
    - $\geq$ 3 b-tagged jets
  - Look for signal in the invariant mass spectrum from the two leading b-tagged jets
- Simulations performed with Pythia or Alpgen plus Pythia passed through detailed detector response
- Data correspond to integrated lumi. of $131 \text{pb}^{-1}$

$$gg, qq \rightarrow \phi + bb \rightarrow bbbb$$

$(\phi = h, H, A)$

$\text{BR}(\phi \rightarrow b\bar{b}) \sim 90\%$

Dijet Mass

(Higgs signal at 95% C.L. exclusion limit)
Neutral Higgs Bosons at High $\tan\beta$ in Multi-jet Events

Signal acceptance is $\sim 0.2 - 1.5\%$ depending on the Higgs mass/# of jets
Search for Non-SM Light Higgs in \( h \rightarrow \gamma \gamma \)

- Small in the SM
- Some extensions of SM contain Higgs w/ large \( B(h \rightarrow \gamma \gamma) \)
  - Fermiophobic Higgs: does not couple to fermions
  - Topcolor Higgs: couple to top (only non-zero fermion coupling)

Data correspond to integrated lumi. of 191 pb\(^{-1}\)

Event selection:
- 2 Isolated \( \gamma \) with \( p_T > 25 \) GeV, \( |\eta|<1.05 \) (CC) or \( 1.5<|\eta|<2.4 \) (EC)
- \( p_T^{\gamma \gamma} > 35 \) GeV

Data = 97.0
bkgd = 68.8 \( \pm \) 45.8
QCD = 64.0 \( \pm \) 45.7
DY = 3.0 \( \pm \) 3.0
\( \gamma \gamma = 1.8 \pm 0.1 \)

Dominant uncertainty in background estimation is the measurement of \( \gamma \) mis-ID rate (~30%)
Search for Non-SM Light Higgs in $h \rightarrow \gamma\gamma$

- No clear evidence of excess
- Perform counting experiments on optimized sliding mass window to set limit on $B(h \rightarrow \gamma\gamma)$ as function of $M_h$
**H++/H-- Search(1)**

- H++/H-- appear in LR symmetric and Higgs triplet models:
  - Leading order pair-production: \( q\bar{q} \rightarrow Z/\gamma^* \rightarrow H^+H^- \)
  - Dominant decay mode: like-signed leptons
- Same sign muon decays contain low SM background:
  - Clean environment for new physics search
- Select di-muon triggered events
- Muon identification requirements:
  - Isolated muons with an associated track from the central tracking system. The muon momentum is taken as the central track momentum
- Muons are required to have \( P_T > 15 \) GeV and \(|\eta| < 2\)

Di-muon mass spectra at various steps of the event selection procedure:

- Preselection (C1)
- Isolation Cut (C2)
- \( \Delta \phi \) cut (C3)
- Like-sign charges (C4)

[Graphs showing mass spectra at various steps of the event selection procedure]
H++/H-- Search (2)

- 2 candidates in L=107 pb⁻¹, expected bkg of 0.34 from SM
- Search assumes the H±± branching ratio to like-sign muons to be 100%
- Confidence level of the signal as a function of the H±± mass, for left- and right-handed Higgs bosons

\[ M_H > 116 \text{ GeV} \]

\[ M_H > 95 \text{ GeV} \]

- lh H++/--
- rh H++/--
- no candidates

DØ Run II prel.

L=106.6 pb⁻¹

LEP excl.
Summary

• The hunt for Higgs in DØ Run II data is on!
• The upgraded DØ detector is producing world class results
• Understanding of background processes progressing
• Result summary:
  - $\sigma(Wbb) < 20\; pb$
  - $\sigma(WH) \times \text{Br}(H \rightarrow bb) < 12\; pb\; (W \rightarrow e\nu)$
  - $\sigma(Z+b) / \sigma(Z+j) = 0.024 \pm 0.005$ (stat) $\pm 0.004$ (syst)
    - limits set on $\sigma(H) \times \text{Br}(H \rightarrow WW^{(*)})$
  - Search for Neutral Higgs in MSSM:
    - excludes $A/h/H$ for masses 90-150 GeV at high $\tan\beta$ ($>\sim 100$)
  - Search for $h \rightarrow \gamma\gamma$:
    - Limits are set for the Branching Ratio vs Mass for both Fermiophobic and TopColor models
  - $H^{++}/H^{--}$ Search:
    - Lower mass limits of 116 and 95 GeV for $H_L^{\pm\pm}$ and $H_R^{\pm\pm}$ decays to $\mu\mu$
    - Limits set are unmatched or superior to Run I

Many results already and more with increased stats are coming soon!