Exotic Higgs Searches at the Tevatron

Michael Mulhearn
Columbia University

On Behalf of the CDF and DØ Collaborations

Moriond QCD 2008

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What do we mean by \textit{exotic} Higgs?

Total Higgs discoveries to date: 0

There is no \textit{experimental preference} for a Standard Model (SM) Higgs boson.

\textbf{Any Higgs boson is exotic!}

Tevatron Higgs searches covered in this talk:

- $H \rightarrow \gamma\gamma$:
  - Gluon-gluon fusion
  - Vector-boson fusion
  - Associated production
- Limits on a fourth generation and Higgs.
- Doubly-charged Higgs: $H^{\pm\pm}$
The Tevatron

36 bunches at 396 ns
\( f = 53.1 \text{ MHz} \)
\( \sqrt{s} = 1.96 \text{ TeV} \)

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$H \rightarrow \gamma\gamma$

- $H \rightarrow \gamma\gamma$ is a rare SM decay, but is enhanced in fermiophobic models.
  - top-color, large extra dimensions, MSSM loop corrections.
- **New DØ Search** optimized for SM gluon-gluon fusion:
  - Select events with two photons:
    - Reconstruct cluster in EM calorimeter: $p_T > 25$ GeV.
    - Veto on nearby track to distinguish $\gamma$ from $e$.
    - Require calorimeter isolation to distinguish $\gamma$ from jet ($j$):
      - Cuts based on EM energy surrounding cluster, and nearby hadronic energy.
      - Neural Network (NN) which combines three EM shower shape variables.
Primary backgrounds:
- $Z/\gamma^* \rightarrow e^+e^-$ with misidentified $e$.
- Direct QCD diphoton production.
- QCD jets faking photons:
  - $\gamma + j$ and $j + j$.
  - Neural Network provides excellent $j \rightarrow \gamma$ discrimination.

Determine efficiencies from control samples:
- $\gamma \rightarrow \gamma$, $e \rightarrow \gamma$, and $j \rightarrow \gamma$.

Monte Carlo estimation of $Z \rightarrow e^+e^-$ and direct QCD diphotons.

QCD jets faking photons: $\gamma + j$ and $j + j$.

Solve linear equation for true populations from tagged populations.

$$(N_{ff}, N_{fp}, N_{pf}, N_{pp}) = E \times (N_{jj}, N_{j\gamma}, N_{\gamma j}, N_{\gamma\gamma})$$

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Data / Monte Carlo Comparisons in $H \rightarrow \gamma\gamma$

DØ Run II Preliminary 2.27 fb$^{-1}$

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New DØ Results from $H \rightarrow \gamma\gamma$

- No excess over background observed, set a cross-section limit.
- Compare to Standard Model, can superimpose other theory curves.
- Use $CL_s$ limit setting procedure, a modified frequentist approach.
  - Treat each bin in each measurement as separate counting experiment.
  - Avoids unwarranted exclusion from background fluctuation: $CL_s = CL_{s+b}/CL_b$.
  - Systematics included as correlated fluctuations in expected signal and background.
**DØ H → γγ + X**

- Fermiophobic Higgs by vector-boson fusion or associated production:

  \[ \begin{align*}
    &q \rightarrow W,ZHq \\
    &q \rightarrow W,Zq \\
    &q \rightarrow \gamma \\
    &q \rightarrow W,Z\gamma \\
    &q \rightarrow H \gamma \\
  \end{align*} \]

- Two isolated photons with \( p_T > 25 \text{ GeV} \), backgrounds from templated fits.

\[
\begin{align*}
\text{Control Region} & \quad q_{T}^{\gamma\gamma} < 35 \text{ GeV} \\
\text{Signal Region} & \quad q_{T}^{\gamma\gamma} > 35 \text{ GeV}
\end{align*}
\]
New Results from DØ $H \rightarrow \gamma\gamma + X$

- Benchmark couplings: Gauge Bosons same as SM, zero for fermions.
- No excess over background observed, set limit with $CL_s$ method.
- This result: $m_H > 100$ GeV at 95% CL. (LEP $m_H > 109.7$ GeV.)
- But, improves limits on $Br$ above $m_H > 120$ GeV.

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CDF Fourth Generation and Higgs

• Interpret SM $H \rightarrow WW$ Higgs limit in context of a fourth generation.

• Production cross-section larger due to additional quarks with large mass.

• Result: $130 \text{ GeV} < m_H < 195 \text{ GeV}$ excluded at 95% CL.
Doubly-charged Higgs $H^{\pm\pm}$

- Doubly charged Higgs: left-right symmetric, Higgs triplet, little Higgs models.
  - CDF results:
    - $H^{++}H^{--} \rightarrow l^+l^+l^-l^-$
    - $H^{++}H^{--} \rightarrow \mu^+\mu^+e^+e^+$
    - $H^{++}H^{--} \rightarrow l^+\tau^+l^-\tau^-$
  - New DØ result:
    - $H^{++}H^{--} \rightarrow \mu^+\mu^+\mu^-\mu^-$.  

- Select two muons with $p_T > 15$ GeV.
  - Charge well determined, require minimum number of hits in tracker.
  - Muon isolation: sum of nearby energy and tracks.
  - $\Delta\phi(\mu_1, \mu_2) < 2.5$
  - Two muons have same sign.
  - One more muon passes above (except minimum hits.)
- From MC: $WZ, ZZ, WW, Z \rightarrow \mu^+\mu^-, t\bar{t}, Z \rightarrow \tau^+\tau^-$
- QCD background determined from data.
DØ Results from $H^{++}H^{--} \rightarrow \mu^+\mu^+\mu^-\mu^-$

- No excess observed, set cross-section limit with $CL_s$ method.
- Mass limit: $m_{HR} > 127$ GeV and $m_{HL} > 150$ GeV.
Conclusion

- Number of discovered Higgs (Exotic or Otherwise): 0
- Most analyses shown use first $1 - 2 \text{ fb}^{-1}$ of data.
- Expect up to $6 \text{ fb}^{-1}$ of data by 2009.
- Mature well-understood experiments with data pouring in!
- Renewed interest and much work improving Higgs sensitivity.
- No need to wait for a factor of two: *Exotic Higgs sensitivity is growing!*

CDF & DØ
The End

Backup Slides Follow
The DØ Detector for Run II

From North
Higgs Boson Production

SM Higgs Production at the Tevatron Run II

- $gg \rightarrow H$
- $q\bar{q} \rightarrow qqH$ (VBF)
- $ZH$
- $b\bar{b} \rightarrow H$
- $gg, q\bar{q} \rightarrow t\bar{t}H$

$\sigma$ [fb]

$m_H$ [GeV]

- Vector-boson-fusion also being considered, enhanced cross-section at LHC.

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Decays of the Higgs Boson

SM branching ratios

- Primary Decays:
  - $m_H < 135$ GeV: $H \rightarrow b\bar{b}$
  - $m_H > 135$ GeV: $H \rightarrow WW$

- $H \rightarrow b\bar{b}$ is difficult at a hadron collider:
  - $\sigma(gg \rightarrow H) \sim 1$ pb
  - $\sigma(q\bar{q} \rightarrow b\bar{b}) \sim 10^6$ pb

Figure by M. Schmitt