Search for Neutral Higgs Bosons in Multi-jet Events at DØ

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*on behalf of the*
DØ Collaboration

DPF 2006 - Hawaii
Oct. 31, 2006
MSSM Higgs Theory

- **Two Complex Higgs Doublets** needed to avoid anomalies
- **Eight Degrees of Freedom** minus $W^+, Z^0$ longitudinal polarization states $\rightarrow$ Five scalars predicted: $h, H, A, H^+, H^-$
- **Assume CP-conservation**: $h, H$ are CP-even, $A$ is CP-odd
- At tree-level, two independent Parameters:
  - $m_A$
  - $\tan\beta = \text{ratio of VEV's}$
  - $M_{\text{SUSY}}$ (parameterizes squark, gaugino masses)
  - $X_t$ (related to the trilinear coupling $A_t \rightarrow$ stop mixing)
  - $M_2$ (gaugino mass term)
  - $\mu$ (Higgs mass parameter)
  - $m_{\text{gluino}}$ (comes in via loops)

These 5 parameters intervene via radiative corrections
(cf M. Carena et al., hep-ph/051123)
Interesting feature of MSSM scenario:

\[ [m_h, m_H] \approx m_A \text{ at high } \tan \beta \]

Br(A\(^0\) \rightarrow bb) \sim 90\% \text{ and } Br(A\(^0\) \rightarrow \tau^+\tau^-) \sim 10\% \text{ almost independent of } \tan \beta.

There are two ways to calculate the signal production at a pp\bar{p} collider:
- pp\bar{p} \rightarrow bbh (4-flavor scheme)
- pp\bar{p} \rightarrow bh (5-flavor scheme): use b-PDF

Both methods now agree at NLO

Kinematics and cross-sections are weighted to the NLO distributions (from MCFM)
The Tevatron at Fermilab

DØ

88% average efficiency

4-8 fb$^{-1}$ expected by end of 2009

Run I: 100pb$^{-1}$

This talk: 950pb$^{-1}$

through 18 February 2006
The Run II DØ Detector

Recently upgraded!

Layer 0 now inserted and fully readout

Calorimeter clustering in Level 1 trigger!

Tracker
Solenoid Magnet

Muon Scintillators
Muon Chambers

η = 0
η = 1

Shielding

Calorimeter
Toroid

protons

3 Layer Muon System

Electronics
Preshowers

Layer 0 now inserted and fully readout

Recently upgraded!
b-Jet Tagging

Several mature algorithms used:

3 main categories:
- Soft-lepton tagging
- Impact Parameter based
- Secondary Vertex reconstruction

Vertex Tagging (transverse plane)

(Signed) Track Impact Parameter (dca)

Decay Length ($L_{xy}$)

Hard Scatter

Impact Parameter (dca)

Combine in Neural Network:
- vertex mass
- vertex number of tracks
- vertex decay length significance
- chi2/DOF of vertex
- number of vertices
- two methods of combined track impact parameter significances

TIGHT (eff=48%, fake=0.3%)
Triggering

- A very difficult signature to trigger on!
  - No high-\(p_T\) leptons, or large mET

- Trigger on jets
  - 3 calorimeter towers / clusters at Level1/2
  - 3 jets with \(p_T>25,25,15\) GeV at L3

- And use the fact that they are \(b\) jets, at Level3
  - Reconstruct central tracks
  - Compute a combined event probability based on the impact parameter (IP) of the tracks
    - More \(b\)'s -> more high IP tracks -> smaller non-\(b\) probability
    - Require the event's non-\(b\) probability < 5%

- Measure trigger efficiencies in data
  - model the trigger effects in the Monte Carlo

<table>
<thead>
<tr>
<th>Trigger List</th>
<th>Higgs boson mass (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td>v9</td>
<td>87(\pm2)</td>
</tr>
<tr>
<td>v10</td>
<td>84(\pm2)</td>
</tr>
<tr>
<td>v12</td>
<td>58(\pm2)</td>
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<tr>
<td>v13</td>
<td>60(\pm2)</td>
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<tr>
<td>v14.0-7</td>
<td>58(\pm2)</td>
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<tr>
<td>v14.8-9</td>
<td>62(\pm2)</td>
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<tr>
<td>Overall</td>
<td>60(\pm2)</td>
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</table>
Event Selection / Analysis Method

- About 75 million events in initial data sample
- Jets considered in $|\eta|<2.5$
  Primary Vertex $|Z| < 35 cm$ (b-tag acceptance)
- Require at least 3 jets with $p_T>40, 25, 15$ GeV
  - No more than 5 jets with $p_T>15$ GeV
- Require at least 3 b-tagged jets

**Signal:**
- Invariant mass of leading jets is peaked at $m_A$

**Backgrounds (determined from data):**
- Shape estimated from the double b-tagged data sample (taking into account the kinematic bias from requiring a 3rd b-tag)
- Normalized outside the “signal region” (for each candidate mA and tanB)

<table>
<thead>
<tr>
<th>Higgs boson mass (GeV)</th>
<th>100</th>
<th>110</th>
<th>120</th>
<th>150</th>
<th>170</th>
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<td>8.8</td>
<td>9.7</td>
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<td>9.2</td>
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</table>
Triple b-tagged Background

1. Double b-tagged data sample
   - Calculate TRF

2. Double b-tagged data sample
   - Apply TRF to un-b-tagged jets

3. Triple b-tagged background shape
   - Fit outside the signal region to data

Tag-rate-function (TRF)
Data vs. Background

- Data agrees well with the predicted background from the TRF method
- Will set upper tanB limits on various Higgs masses using the CLs (LEP Higgs) method
- Acceptance systematics: (Total: ~17%)
  - Trigger efficiency
  - Kinematic cuts
  - Modeling of NLO effects
  - b-Tagging efficiency
- Background systematics: (Total: ~2.5%)
  - Statistics of TRF
  - Shape of TRF

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<th>120</th>
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<tr>
<td>Total</td>
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<td>17.3</td>
<td>17.0</td>
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<td>18.0</td>
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</table>
Limits

MSSM Higgs bosons

$\tan \beta$ at $m_A$ (GeV)

Cross section (pb)

$DØ$ Expected
$DØ$ Measured
$\tan \beta = 80$

$10^3$

$10^2$

$10$

$80$ $100$ $120$ $140$ $160$

$100$ $110$ $120$ $130$ $140$ $150$ $160$ $170$

$DØ$ Run II Preliminary

Observed
Expected

$10^2$

$10$
Monte Carlo Cross-checks

- Use ALPGEN+Pythia to produce simulated background samples
  - Cross-section uncertainties are 50-100% due to renormalization/factorization scale dependence at leading-order
- Useful for understanding the background shapes and physics composition of the background
- Can check the ratio of observed triple and double b-tagged events with what is expected from MC
- Checks the modeling of the trigger turn-ons
- All distributions roughly agree between data / MC

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**Double b-tagged**

- $mbb$ vs $m_{o1}$

**Triple b-tagged**

- $mbb$ vs $m_{o1}$

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Conclusions

- New limits in the mA / tanB plane from the search for neutral Higgs bosons in the MSSM
- Many new techniques used, such as:
  - Level3 event b-tagging: needed to remain within bandwidth limitations as luminosity increased
  - Neural Net b-tagging (offline): light-jet backgrounds reduced by a factor of ~3
  - State-of-the-art MC modeling of backgrounds used as a cross-check
- This analysis will be extended using new data
  - Expect up to 8 fb\(^{-1}\) by 2009
  - Will use the newly commissioned Layer0 of silicon -> better b-tagging!
  - Use of new L1 calorimeter trigger will enable efficient collection of multi-jet events at high luminosity
- Possible to exclude up to mA\(\sim\)250 GeV for high tanB, and down to tanB\(\sim\)20 for low mA by the end of Run II
  - Will continue to combine with A->tautau and bA->btautau channels
  - Will eventually combine with CDF