SUSY Higgs Searches at DØ, Tevatron

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(for DØ Collaboration)
Outline

- MSSM Higgs
- DØ & Tevatron
- DØ search for Neutral MSSM Higgs ($\Phi^0$)
  - $\Phi^0 b(b) \rightarrow b b b(b)$
  - $\Phi^0 X \rightarrow \tau^+ \tau^- X$
- Future Prospects
- Summary & Outlook
MSSM Higgs

- MSSM posits two complex Higgs doublet fields
  - \( H_u (H_d) \) couple to up- (down-) type fermions
  - 5 physical Higgs bosons
    - \( h, H \) (CP-even), \( A \) (CP-odd) and \( H^\pm \)
    - \( h \) predicted to be light: \( m_h < m_H \) and \( m_h \leq 130-140 \) GeV
    - LEP has the limit \( m_h \geq 92 \) GeV

- At tree level, two independent parameters:
  - \( m_A \)
  - \( \tan\beta = <H_u>/<H_d> \) : ratio of vacuum expectation values

- At large \( \tan\beta \), the coupling of \( h/H/A \) (\( \equiv \Phi^0 \)) with ‘down’-type quark, viz., bottom quark enhances over the SM one
  - The production cross-section enhancement by a factor of \( \tan^2\beta \)
MSSM Higgs

At high tan $\beta$, $A$ is almost degenerate with $h/H$

- $\sigma(A) \approx \sigma(h/H)$, $\Gamma(A) \approx \Gamma(h/H)$
- $\text{Br}(A \to bb) \approx \text{Br}(h/H \to bb) \approx 90\%$
  - Another 10% is $\text{Br}(A/h/H \to \tau^+\tau^-)$
- To search for $h/H/A (\equiv \Phi^0)$, $\Phi^0 b(b) \to bbb(b)$ and $\Phi^0 X \to \tau^+\tau^-X$ are the best channels

\[
\sigma(b\bar{b}A) \times BR(A \to b\bar{b}) \approx \sigma(b\bar{b}A)_{SM} \times \frac{\tan^2 \beta}{(1 + \Delta_b)^2} \times \frac{9}{(1 + \Delta_b)^2 + 9}
\]

\[
\sigma(b\bar{b}, gg \to A) \times BR(A \to \tau^+\tau^-) \approx \sigma(b\bar{b}, gg \to A)_{SM} \times \frac{\tan^2 \beta}{(1 + \Delta_b)^2 + 9}
\]

Radiative correction term, dependent on various parameters. 2 benchmark scenarios ("$m_h$-max" & "no-mixing") are studied.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$m_h$-max</th>
<th>no-mixing</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_{\text{SUSY}}$</td>
<td>1 TeV</td>
<td>2 TeV</td>
</tr>
<tr>
<td>$X_t$</td>
<td>2 TeV</td>
<td>0</td>
</tr>
<tr>
<td>$M_2$</td>
<td>200 GeV</td>
<td>200 GeV</td>
</tr>
<tr>
<td>$\mu$</td>
<td>$\pm 200$ GeV</td>
<td>$\pm 200$ GeV</td>
</tr>
<tr>
<td>$m_g$</td>
<td>800 GeV</td>
<td>1600 GeV</td>
</tr>
</tbody>
</table>

M. Carena et al., hep/ph-0511023
Upgraded DØ Run II detector

- Excellent Tracking system
  - Secondary vertex reconstruction; b-tagging
  - Track triggering and $\tau$ identification
- Hermetic calorimeter
  - Jet triggering & reconstruction
  - $\tau$ lepton identification
- Extended coverage for muon detector ($|\eta|<2.$)
  - Crucial for $\mu$ and $\tau$ identification

![Diagram of DØ detector upgrade](image-url)
Tevatron Performance

Run II Integrated Luminosity

\( \Phi^0b(b) \rightarrow bbb(b) \)

\( \Phi^0X \rightarrow \tau^+\tau^-X \)

Luminosity (fb)

1.41

1.18

Delivered

Recorded

19 April 2002 - 23 May 2006
**Φ^0_b(b) → bbb(b) Analysis**

- **260 pb^-1 of D0 data**
  - Multijet Trigger selection: ≥ 3 jets with \( E_T ≥ 15 \) GeV

- **Event Selection**
  - Optimised \( E_T \) threshold on leading jets for each Higgs mass point
  - Secondary Vertex (SVT) tagging for the b-jet selection: double and triple b-tagged events

- **Backgrounds**
  - QCD fake: jjjj (Data)
  - QCD heavy flavor (HF):
    - bbjj, ccjj, cccc, bbcc, bbbb (Data)
  - Other: Z(bb,cc), tt ... (MC)

- **Event Simulation**
  - SM Higgs ... PYTHIA
    - signal rate and kinematics adjusted to NLO cross section (PRL 94, 031902(2005) Dawson et.al)
  - Background
    - PYTHIA, ALPGEN, MADGRAPH

- **Look for the excess in dijet mass**
Estimation of “mis-tag” rate as a function of $p_T$ and $\eta$ from full multijet data i.e., events with $\geq 0$ b-tagged jets
- The “mis-tag” rate is corrected for heavy flavour component

Normalisation of HF MC from double b-tagged data

$(\text{double b-tagged data}) \times (\text{mis-tag rate}) = (\text{triple b-tagged backgrounds})$

Fitting dijet mass (from leading $E_T$ jets) distribution outside the signal region ($\pm 1\sigma$ around the peak) in the triple b-tagged events
No excess over background events observed

Limits on production cross section & tan\(\beta\) vs. \(m_A\) plane are set for two benchmark scenarios – “no mixing” & “maximal mixing”

- At 95% CL, limit on tan\(\beta\) is down to 50, depending on \(m_A\) and MSSM scenario  
  \[\text{PRL 95, 151801 (2005)}\]

For \(m_A=120\) GeV: \(\sigma < 31\) pb\(^{-1}\) @ 95% CL, \(\tan\beta < 55\) @ 95% CL (Max Mixing)
$\Phi^0 X \rightarrow \tau^+ \tau^- X$ Analysis

- Large production cross-section
- Jets from hadronic $\tau$-decays are distinct from the QCD ones

**Event signature – $\tau^+ \tau^-$**
- Hadronic decay of one of the $\tau$’s while the other one decays into electron or muon (electron/muon, $\tau$-jet and missing transverse energy)
- Both $\tau$’s decay into leptons (electron, muon and missing transverse energy)

**Backgrounds:**
- $Z^0$-production: largest irreducible background
- $Z^0/\gamma^* \rightarrow ee/\mu\mu$, multi-jet, $W \rightarrow l\nu+jet$ (rejected with $M_W < 20$ GeV), Di-boson ($WW, WZ, ZZ$), top pair production

- 325 pb$^{-1}$ of data, recorded by single electron/muon Trigger
- Final discrimination variable between signal and background through the reconstruction of visible mass,
  $$M_{vis} = \sqrt{(p_{\tau_1,vis} + p_{\tau_2,vis} + p_E)^2}$$

**Simulation**
- Pythia 6.2 (background), FeynHiggs 2.3 (Signal cross section)
Identification of $\tau$ lepton

- $\tau$-jet are quite narrow and have less number of tracks/neutral pions, in comparison with QCD jets. Three types of $\tau$'s are considered:
  - (Type 1) HAD
  - EM
  - (2) Track
  - $\pi^0$
  - (3) QCD-Jet

- Application of Neural Network for $\tau$ identification (Identical to $Z \rightarrow \tau^+\tau^-$ cross section measurement; [PRD 71, 072004 (2005)]) - Usage of profile, isolation, etc.
$$\Phi^0 X \rightarrow \tau^+ \tau^- X$$ Results

- Combination of three channels: $e^+\tau_h$, $\mu^+\tau_h$, $e^+\mu$
- Comparison between Signal, background and data after final event selection $[\sigma_{total} = \sqrt{\sigma_{stat}^2 + \sigma_{syst}^2}]$

<table>
<thead>
<tr>
<th></th>
<th>Data</th>
<th>Sum BGN</th>
<th>QCD</th>
<th>$Z \rightarrow \tau\tau$</th>
<th>$Z \rightarrow \mu\mu/ee$</th>
<th>W</th>
<th>Di-Boson</th>
<th>tt(bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^+\tau_h$</td>
<td>484</td>
<td>427.3 ± 55.3</td>
<td>199.5 ± 26.0</td>
<td>202.7 ± 26.3</td>
<td>10.2 ± 1.4</td>
<td>14.0 ± 1.9</td>
<td>0.54 ± 0.09</td>
<td>0.35 ± 0.05</td>
</tr>
<tr>
<td>$\mu^+\tau_h$</td>
<td>575</td>
<td>576.3 ± 61.5</td>
<td>62.2 ± 6.6</td>
<td>491.7 ± 52.6</td>
<td>4.6 ± 1.1</td>
<td>13.5 ± 1.6</td>
<td>3.05 ± 0.33</td>
<td>1.22 ± 0.14</td>
</tr>
<tr>
<td>$e^+\mu$</td>
<td>42</td>
<td>43.5 ± 5.3</td>
<td>2.1 ± 0.4</td>
<td>39.1 ± 5.0</td>
<td>0.63 ± 0.12</td>
<td>0.30 ± 0.20</td>
<td>0.99 ± 0.14</td>
<td>0.06 ± 0.02</td>
</tr>
</tbody>
</table>

Major Systematics
- Luminosity 6.5%
- JES ~3-3.7%
- Muon ID ~3%
- $\tau$ ID ~3.6%
- $\tau$ tracking ~2.7%
• Number of observed events are consistent with background-only hypothesis; no excess yet

• Cross section limits at 95% CL are estimated using the \( M_{\text{vis}} \) distribution for subdivided samples depending on “S/\sqrt{B}” e.g.,
  • Three types of \( \tau \) identification
  • \( M_W < 6 \text{ GeV}, 6 < M_W < 20 \text{ GeV} \)

\[
M_W^l = \sqrt{2 \cdot E^l \cdot E^\nu \cdot (1 - \cos \Delta \phi)}
\]

\[
E^\nu = E_T \times \frac{E^l}{p_T}; \Delta \phi = \angle(p_T^l, E_T)
\]

Submit to PRL: hep-ex/0605009
Combined Limit

Combination of two analyses viz., $\Phi^0 b(b) \rightarrow bbb(b)$ [260 pb$^{-1}$] & $\Phi^0 X \rightarrow \tau^+ \tau^- X$ [325 pb$^{-1}$] in four different scenarios viz., $(m_h^{\max}, \mu<0)$, $(m_h^{\max}, \mu>0)$ and (no-mixing, $\mu<0$), (no-mixing, $\mu<0$)
Future Prospects

- **Neural Network b-tagging**
  - Combination of 3 different tagging methodologies instead of SVT
  - Increase of 33% in efficiency for a fixed fake rate of 0.5%

- **Run IIb Upgrade**
  - Additional SMT layer (Layer 0): improvement in b-tagging
  - Improved Jet Triggering algorithm: higher trigger efficiency

- **Improved jet algorithm with the usage tracker information (Trackcal jet)**
  - More precise energy measurement of the constituent charged particles inside the jet
  - ~10% improvement in jet energy resolution crucial for higgs mass resolution
Summary & Outlook

- DØ has performed the search for MSSM neutral Higgs bosons using 260-325 pb⁻¹ of data recorded during Tevatron Run II
- No excess over the SM background processes is observed yet. Upper limits on MSSM higgs production cross section has been derived at 95% CL

- DØ Results on $\Phi^0X \rightarrow \tau^+\tau^-X$ search has comparable sensitivity with those of CDF
- Combination of $\Phi^0b(b) \rightarrow bbb(b)$ and $\Phi^0X \rightarrow \tau^+\tau^-X$ results has been performed by DØ → most sensitive to date.
- Additional search in $\Phi^0b(b) \rightarrow \tau^+\tau^-b(b)$ channel is being pursued by DØ
- DØ updates with 1.2 fb⁻¹ of data are upcoming
MSSM Higgs Search has very bright prospect during Tevatron Run II. It’s just the beginning. Stay tuned!