SUSY Higgs Searches in the bbb Final State

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On behalf of the CDF and D0 Collaborations
The Higgs Boson

- Consider the Electromagnetic and the Weak Forces
- Coupling at low energy: EM: \( \sim \alpha \), Weak: \( \sim \alpha/(M_{W,Z})^2 \)
  - Coupling strength governed by the same dimensionless constant
  - Difference due to the mass of the W and Z bosons
    - Electroweak symmetry: \( M_\gamma = M_Z = M_W \)
    - But photons massless and W/Z are massive?
- May postulate the Higgs mechanism for the breaking of electroweak symmetry
  - Results in massive vector bosons and mass terms for the fermions
  - Theory predicts a massive new particle called the Higgs boson!
SM particles have supersymmetric partners: differ by 1/2 unit in spin
SUSY has many attractive properties
  – Cancellation of Higgs mass divergence, coupling unification, etc
  – Lightest neutralino is a dark matter candidate
Requires larger Higgs sector than the single scalar of the SM
  – Simplest case: Minimal Supersymmetric Standard Model (MSSM)
Higgs in MSSM

• Instead of one scalar, get five:
  – Three neutral: h, H, A : (generically “φ”)  
  – Two charged: H^+, H^-
• Separate couplings for up-type and down-type fermions
• Properties of the Higgs sector largely determined by two parameters:
  – m_A : mass of pseudoscalar 
  – tanβ : ratio of down-type to up-type couplings
• Typically, m_h < m_A < m_H, and m_{H^±} ~ m_A
• For tanβ near 1, h is SM-like and light - LEP-II limits apply
• Larger tanβ shows more interesting behavior
  – A becomes degenerate with h or H (mass, couplings, etc) 
  – Other decouples, SM-like, mass around 120 GeV 
  – A + h/H production controlled by tanβ
• In the Standard Model, Higgs cross section is fixed – no free parameters
• In MSSM, production of A/h/H depends on tanβ – range of possibility
  – For the right value of tanβ, could already have discovery potential
Higgs at High $\tan\beta$

Processes involving bottom quarks (down-type) enhanced by $\tan^2\beta$

Boost from femtobarns to picobarns

Could be observable at Tevatron!

At large $\tan\beta$, decays into $b\bar{b}$ (90%) and $\tau\tau$ (10%) dominate
The 3b channel

- Search for the $b b \phi \rightarrow b b b b$ process
- Less cross section when requiring both $b$'s to be high-$p_T$
- Look for the Higgs + 1b case

**Signal:** Three b-jets (two forming a mass peak from Higgs decay)

Dawson, Jackson, Reina, Wackeroth
hep-ph/0603112
ppbar collisions at 1.96 TeV
Peak luminosity $10^{34}$ cm$^2$s$^{-1}$
Weakly integrated lum $\sim$50pb$^{-1}$
11 pb$^{-1}$ delivered (9pb$^{-1}$ on tape)
The CDF and D0 detectors

- Muon systems
- EM and Had Calorimeters
- Solenoid
- Tracker
- Silicon Vertex Detector
Identifying b jets

- lifetimes for b hadrons are $\sim 10^{-12}\text{ s}$
- travel a finite distance in the detector $\sim 500\mu\text{m}$
### 3b Analysis Roadmap

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<th>CDF</th>
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<tbody>
<tr>
<td><strong>Trigger</strong></td>
<td>Based on two jets and two displaced tracks (no matching)</td>
<td>Multi-jet trigger with b-tagging.</td>
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<tr>
<td><strong>Background</strong></td>
<td>Derive estimates for each flavor combination from the data → Use Pythia to check for bias</td>
<td>Background shape modeled from a combination of data and Alpgen. → Rate obtained from fits to data</td>
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<tr>
<td><strong>Discriminant</strong></td>
<td>• Look for an excess in the mass of the two leading jets ($m_{12}$) • Use tag mass ($m_{\text{tag}}$) information to understand flavor composition • Perform a two-dimensional fit to the data using these estimates • Tag mass information determines background composition • Look for Higgs in $m_{12}$ distribution</td>
<td>• Construct likelihood discriminant based on several angular and kinematic variables. • Cut on to improve s/b and highest likelihood value used to select jet pair for $m_{jj}$ • Use low likelihood region as control region • Look for Higgs in $m_{jj}$</td>
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D0’s Likelihood

Variables used to construct the likelihood:
• the angle between the leading jet in the pair and the total momentum of the pair
• $\Delta \eta$ and $\Delta \phi$ between the two jets in the pair
• the momentum balance in the pair
• the combined rapidity of the pair
• the event sphericity

$$D(x_1, \ldots, x_6) = \frac{\prod_{i=1}^{6} P^\text{sig}(x_i)}{\prod_{i=1}^{6} P^\text{sig}(x_i) + \prod_{i=1}^{6} P^\text{bkg}(x_i)}.$$ 

Cut on $D$ improves s/b and highest $D$ value is used to select jet pair to use for $m_{jj}$. 

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CDF’s use of mass ($x_{\text{tags}}$)

- Split events by flavor
- Characteristic $m_{12}$ spectra
- Second variable to help separate backgrounds from each other, and Higgs+bbb from ones with c/q
- Important categories are:
  - $bb + b : bbb$, Higgs
  - $bb + X : bbc$, bbq
  - $bX + b : bcb$, bbq
  - Naturally breaks into $m_1 + m_2$ and $m_3$
- Pack into 1D so overall templates are only 2D (technical reasons)
- Unstack 3x3 histogram into a 9-bin 1D histogram – “$x_{\text{tags}}$”
CDF uses 2D fit \((m_{12} \text{ and } x_{\text{tags}})\)

- The bbX events can be separated by third tag mass in \(x_{\text{tags}}\)

- Two lead jet tag masses separate bbB, bBb from bCb, bQb

- Separation out bbc and bbq by using \(m_3\)

- Templates are actually 2D histograms in both \(m_{12}\) and \(x_{\text{tags}}\)
  - Fit itself is also 2D
  - Only show projections for clarity
Combined detector acceptance and ID efficiency is about 1% for both experiments.
The Data

- Generally good agreement between data and background models
- Quantify agreement and set limits using pseudoexperiments
Max deviation from expected at 150 GeV/c²
Including the trials factor, 1-CL_b = 2.5% (1.9σ)
Corresponds to σ x BR ~ 15 pb

Max deviation from expected at 120 GeV/c²
Including the trials factor about 2.0σ

Analyses are similar and work is ongoing to combine!
Interpretation

- Previous limits for a resonance much narrower than the experimental resolution!
  - SM Higgs, new scalars, etc

- At tree level,
  \[ \sigma \times BR = 2\sigma_{SM}\tan^2\beta \times 90\% \]

- MSSM Higgs in high-\tan\beta scenarios not generally narrow

- Higgs properties are largely, but not completely, determined by \( m_A \) and \tan\beta

- Loop corrections introduce dependence on other SUSY parameters
High values of $\tan\beta$ also excluded by di-tau analyses and recent LHC results.
Summary

• CDF updated MSSM Higgs results in the 3b channel
  – Submitted for publication in PRD (arXiv:1106:4782)
• D0 published 3b search in PLB with 5.2 fb\(^{-1}\)
  \(\rightarrow\) Effort to combine results in progress.
• No significant excess observed, but some excess evident in both experiments
• Analysis is adaptable to other signal models besides MSSM Higgs
http://arxiv.org/abs/1106.4782
(Submitted to PRD)

http://arxiv.org/abs/1011.1931