Tevatron High-mass Higgs Searches

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Higgs Hunting 2011 Workshop
Higgs Decay

- Low Mass
  - Focus on $H \rightarrow bb$
  - Also $H \rightarrow \tau\tau$ and $H \rightarrow \gamma\gamma$
- High Mass
  - Focus on $H \rightarrow WW$
  - Also $H \rightarrow ZZ$

Cross-Over Point
$(m_H \sim 135 \text{ GeV})$
Higgs Production at Tevatron

![Graph showing Higgs production processes]

SM Higgs production

- $gg \rightarrow h$
- $qg \rightarrow Wh$
- $qq \rightarrow qgh$
- $bb \rightarrow h$
- $gg,qq \rightarrow tth$
- $qq \rightarrow Zh$

$\sigma [fb]$ vs. TeV II
General Analysis Approach

- Step #1: Select an inclusive event sample that maximizes the acceptance for a potential Higgs signal
- Step #2: Carefully model all backgrounds and cross check using control regions in data
- Step #3: Use advanced analysis tools to separate signal from background based on event kinematics

Each Tevatron experiment expects to reconstruct/select roughly 8 events per fb\(^{-1}\) for \(m_H = 150\) GeV/c\(^2\)
H→WW→lνlν Higgs Search

• Basic event selection: two high $p_T$ leptons and large missing $E_T$
• Maximizing detector lepton acceptance is critical
• Still a few tricks up our sleeves
Recovering Nearby Lepton Pairs

- CDF modified its isolation algorithms to prevent self-spoiling of nearby lepton pairs
- The recovered events lie in our highest S/B region
Recovering Nearby Lepton Pairs

- Expected limits in CDF low-\(M_{ll}\) channel improved by more than a factor of three!
SM Backgrounds

- Need to separate small potential signal from large SM background contributions in our search channels
- Based on inclusive selection criteria $S/B \approx 0.015$ in the most sensitive search channels
Validating Background Models

- We define specific control regions to test modeling for each individual background (whenever possible)
- In the case of dibosons (WW, WZ, and ZZ), we are not able to define specific control regions so we use cross section measurements to validate our modeling of these processes – more on this later.

W+jets: same-sign dileptons

W+γ: same-sign dileptons (low M_{ll})

t-tbar: opposite-sign dileptons, 2+ jets, b-tag
Background Model Tunings

- In certain cases the MC modeling is insufficient and additional tunings are required
- Intermediate missing $E_T$ region shows data/MC disagreement
- Determine MC tuning in control region and apply to signal region
Special Considerations

• Also need to concern oneself about potential background events in odd regions of phase space that could mimic a Higgs signal
• Classic example is WW production through box diagram (small Tevatron cross section but events are more signal-like)
Special Considerations

- Low-$M_{ll}$ DY background events also sit in an very odd region of phase space
  - High $P_T$ leptons with low opening angle
  - Large missing $E_T$ implies mismeasured high $E_T$ jets
- Find that a large fraction of these events come from standard dijet production where $Z$ boson is radiated off a final state quark (not accounted for in Pythia)

Low $M_{ll}$ intermediate missing $E_T$ control region
Special Considerations

- Still working to obtain a good MC model for this special class of DY events
- Instead, data events in control region are used to obtain a model for signal region events (using a MC-based extrapolation)
Typically these add 10-20% in sensitivity beyond that obtained from optimized, cut-based analysis.
Multi-Layer Discriminants

• Several layers of multivariate discriminants are used in some cases to reduce large background components contained within inclusive candidate samples (with minimal loss of potential signal acceptance)
• In this case, DY in the D0 $H \rightarrow WW \rightarrow \mu \nu \mu \nu$ channel
Maximizing Sensitivity

- We optimize search sensitivity by dividing events into multiple analysis channels.
- This allows us to use separate, optimized discriminants for each channel based on:
  - specific signal contributions
  - specific background contributions
  - specific event kinematics
Both CDF and D0 both include events with same-sign leptons and events with hadronic tau candidates. CDF also separates out tri-lepton events for separate analysis.
High Mass Search Channels

<table>
<thead>
<tr>
<th>Channel</th>
<th>Main Signal</th>
<th>Main Background</th>
<th>Most Important kinematic variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>OS dileptons, 0 Jets</td>
<td>gg→H</td>
<td>WW</td>
<td>LR_{HW,WW}, ΔR_{ll}, H_T</td>
</tr>
<tr>
<td>OS dileptons, 1 Jet</td>
<td>gg→H</td>
<td>DY</td>
<td>ΔR_{ll}, m_T(l1,E_T), E_T</td>
</tr>
<tr>
<td>OS dileptons, 2+ Jets</td>
<td>Mixture</td>
<td>t-tbar</td>
<td>H_T, ΔR_{ll}, M_{ll}</td>
</tr>
<tr>
<td>OS dileptons, low M_{ll}, 0 or 1 Jet</td>
<td>gg→H</td>
<td>W+γ</td>
<td>p_T(l2), p_T(l1), E(l1)</td>
</tr>
<tr>
<td>SS dileptons, 1+ Jet</td>
<td>WH→WWW</td>
<td>W+Jets</td>
<td>E_T, \sum E_T^{jets}, M_{ll}</td>
</tr>
<tr>
<td>Tri-leptons, no Z candidate</td>
<td>WH→WWW</td>
<td>WZ</td>
<td>E_T, ΔR_{ll}^{close}, Type(lll)</td>
</tr>
<tr>
<td>Tri-leptons, Z candidate, 1 Jet</td>
<td>ZH→ZWW</td>
<td>WZ</td>
<td>Jet E_T, ΔR_{lj}, E_T</td>
</tr>
<tr>
<td>Tri-leptons, Z candidate, 2+ Jets</td>
<td>ZH→ZWW</td>
<td>Z+Jets</td>
<td>M_{jj}, M_T^H, ΔR_{WW}</td>
</tr>
<tr>
<td>OS dilepton, electron + hadronic tau</td>
<td>gg→H</td>
<td>W+Jets</td>
<td>ΔR_{llr}, τ id variables</td>
</tr>
<tr>
<td>OS dilepton, muon + hadronic tau</td>
<td>gg→H</td>
<td>W+Jets</td>
<td>ΔR_{llr}, τ id variables</td>
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Validation of Search Techniques

- Diboson cross section measurements based on the same tools and data samples used for the $H\rightarrow WW\rightarrow l\nu l\nu$ search provide an important cross check on our background modeling and analysis techniques.

$WW\rightarrow l\nu l\nu : \sigma(WW) = 12.1^{+1.8}_{-1.7} \text{ pb}$
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$ZZ \rightarrow ll\nu\nu : \sigma(ZZ) = 1.45 ^{+0.60}_{-0.51} \text{ pb}$
Systematic Uncertainties

- We consider uncertainties both on the overall normalization of each signal/background process and on the shapes of the final discriminant templates for each signal/background process.
- In the limit-setting procedure systematics are included as nuisance parameters, taking into account the correlations between different channels.

Using this approach we are able to further constrain our background uncertainties directly from the data.
Theoretical Uncertainties

- Since we combine searches focusing on different Higgs production and decay modes, cross section limits are given with respect to nominal SM predictions.
- This forces us to incorporate theoretical predictions and uncertainties for signal cross sections and branching ratios.
- Changed in each iteration to reflect recent theoretical developments.

Berger et al., arXiv:1012.4480v2

<table>
<thead>
<tr>
<th>channel</th>
<th>scale 0</th>
<th>scale 1</th>
<th>scale 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 jet</td>
<td>13.4%</td>
<td>-23.0%</td>
<td>-</td>
</tr>
<tr>
<td>1 jet</td>
<td>-</td>
<td>35.0%</td>
<td>-12.7%</td>
</tr>
<tr>
<td>2+ jets</td>
<td>-</td>
<td>-</td>
<td>33.0%</td>
</tr>
</tbody>
</table>

Stewart and Tackmann, arXiv:1107.2117v1
CDF/D0 H→WW→lνlν Limits

CDF Run II Preliminary

CDF

D0

7/29/11
Additional High-mass Channels

D0 H→WW→lvjj Analysis
Additional High-mass Channels

CDF H→4l Analysis
Conclusions/Outlook

• We continue to obtain large improvements in search sensitivity beyond that expected from simply adding more data
• We are on track to deliver high-mass Higgs search results next spring based on the full 10fb⁻¹ datasets that achieve our expected sensitivity goals