BSM HIGGS PHYSICS AT THE TEVATRON

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OUTLINE

- Introduction
- MSSM Neutral Higgs
- MSSM Charged Higgs
- NMSSM Higgs
- Fermiophobic Higgs
- Running well, has delivered 10 fb\(^{-1}\) with more than 8 fb\(^{-1}\) recorded to tape

- Results shown use up to 5.2 fb\(^{-1}\)
MSSM Higgs

- Five Higgs bosons expected, $h$, $H$, $A$ and $H^\pm$
  - $h,H$ are neutral scalars, $A$ neutral pseudoscalar
  - $H^\pm$ charged higgs bosons
- Described at tree-level by two parameters
  - $m_A$ and $\tan \beta = \text{the ratio of the vacuum expectation values of up-type and down-type scalar fields}
MSSM Neutral Higgs

Neutral Higgs

- Large $\tan \beta$ leads to mass degeneracy between $h/A$ or $H/A$ and enhanced coupling to down-type fermions

Decays $\Phi \rightarrow b\bar{b} (90\%)$ and $\Phi \rightarrow \tau \tau (10\%)$

Three channels of interest

- $\Phi \rightarrow \tau \tau$: cleaner signature
- $\Phi b\rightarrow \tau \tau b$: very clean signature, but low cross section
- $\Phi b \rightarrow bbb$: high cross section
MSSM HIGGS->TAUTAU

- Three channels $\tau_e\tau_{\text{had}}$, $\tau_\mu\tau_{\text{had}}$, $\tau_e\tau_\mu$
- Backgrounds
  - $Z$, Drell-Yan, diboson, $W$: MC
  - QCD: fakes and sidebands from data
- Discriminate using visible mass $m_{\text{vis}} = \sqrt{(p_\ell + p_\tau + E_T)^2}$
  \[ m_{\text{vis}} = \sqrt{(p_e + p_\mu + E_T)^2} \]
- Combines two different ditau analysis
  - Run IIa: hadronic tau + electron/muon, electron +muon channel analysis with 1.0 fb
  - Run IIb: hadronic tau+muon, electron +muon channel analysis with 1.2 fb
- Uses visible mass as discriminator
TEVATRON DITAU COMBINATION

- Combines all CDF and DØ di-tau final state searches
- Same combination methodology as employed for SM combination

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<thead>
<tr>
<th></th>
<th>CDF</th>
<th>D0</th>
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<tbody>
<tr>
<td>τₑ + τ₇</td>
<td>1.8 fb⁻¹</td>
<td>1.0 fb⁻¹</td>
</tr>
<tr>
<td>τₑ + τ₇</td>
<td>1.8 fb⁻¹</td>
<td>1.0 + 1.2</td>
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<tr>
<td>τₑ + τµ</td>
<td>1.8 fb⁻¹</td>
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MSSM HIGGS-\(\rightarrow\)TAUTAUB

- Event selection for hadronic tau+muon + b-jet, using neural net tau ID and b-tagger
- Primary backgrounds are Z+jets, multijet and ttbar and are modelled from MC
- Uses neural net discriminator
- MSSM Neutral Higgs -> 3 b
  - Exploits the enhanced coupling to b-quarks present in the MSSM model
  - Suffers from large multi-jet backgrounds from QCD
MSSM HIGGS -> 3 B JETS

- Search for neutral Higgs decaying to $b\bar{b}$, produced in association with a $b$
- Requires 3 central high-$et$ jets with $b$-tags
- Background is essentially QCD heavy-flavor multi-jet production, background model based off two tag sample
MSSM HIGGS -> B JETS

- Selects for 3 or 4 central high pt jets, with at least 3 b-tags from a neural net based tagger
- Data driven backgrounds from two tag samples with SF from MC
- Construct likelihood discriminant from several kinematic variables
Limits for zero-width model are then corrected for Higgs width and MSSM tan β corrections in MSSM scenario.
MSSM HIGGS COMBINATION

- Combines three d0 analysis
  - Higgs->ditau, Higgs+b->ditau +b (new) and Higgs+b->3b

- Uses modified frequentist approach to set limits for benchmark MSSM scenarios
MSSM Charged Higgs (H±)

- Charged Higgs
  - Appears in $tt$ decay in place of $W^\pm$
  - Primarily sensitive to MSSM for low $\tan\beta$, leptophobic and high $\tan\beta$, tauonic and low $m_A$

![Diagram](image)
CHARGED HIGGS

- Search for $H^+ \rightarrow c\bar{s}$ in top decays, viable in MSSM for low $\tan \beta$
- Select for one high pt lepton, large $E_T$, 4 or more central jets with at least 2 b-tags

- Backgrounds from top, diboson, $Z +$ jets, $W +$ jets from MC. QCD backgrounds from data
- Binned likelihood fit used to extract signal limits
CHARGED HIGGS

- Considers two models
  - tauonic model \( (H^+ \rightarrow \tau \nu) \)
  - leptophobic model \( (H^+ \rightarrow c \bar{s}) \)

- Uses three orthogonal channels
  - lepton+jets requires \( \geq 3 \) central high-pt jets, one isolated central electron or muon and large met
  - lepton + tau and dileptons, one or two isolated high-pt central leptons, taus use neural network identifier, lepton+tau requires a b-jet

- Maximum likelihood fit similar to techniques of \( tt \) cross section used to set limits
NMSSM CHARGED HIGGS

- Next-to-minimal supersymmetric standard model (NMSSM) search, for charged higgs in top decays

- NMSSM contains two additional neutral Higgs and one additional neutralino, avoids some LEP limits

- Require exactly one lepton, three or more jets with at least one b-tag

- Backgrounds from $t\bar{t}$ and $W/Z+$jets taken from MC

- Use presence of taus identified by low-pt isolated tracks to distinguish from standard top decays, otherwise apply $t\bar{t}$ event requirements
NMSSM NEUTRAL HIGGS

- Search for NMSSM neutral higgs decaying to $\mu\mu\mu\mu$ or $\mu\mu\tau\tau$

- Select for two pairs of collinear muons or one pair of collinear muons, large $E_T$, and a muon or loosely isolated electron

- Primary backgrounds are multi-jet events and $Z+$jets
Fermiophobic Higgs

- Assumes no Higgs coupling to fermions
- Enhanced branching ratio to photons
- Same coupling to W and Z bosons as SM
Search for neutral Higgs produced in association with a $W$ using high-pt same sign leptons

Backgrounds from dibosons, conversions and fake leptons

Fermiophobic Higgs sensitivity at low mass

Uses a boosted decision tree to separate signal and background, followed by a bayesian approach to limits
Fermiophobic - Diphoton

- Low diphoton SM branching ratio (~0.2%) enhanced in fermiophobic models for low mass Higgs
- Diphoton signature is a very narrow peak
- High di-photon pt cut used (> 75 GeV/$c^2$) due to hard spectrum
- Background shape extracted from sidebands
Event selection requires two central photons and a \( p_{T\gamma\gamma} > 35 \text{ GeV} \).

**Backgrounds**

- Drell-Yan (MC)
- gamma+jet and di-jet (data)
- di-photon (sideband)
CONCLUSIONS

- Active and widespread program of BSM Higgs searches
- Updates underway in many channels
- Lots of data still to be utilized, the Tevatron has more to say about BSM Higgs
- For more see
  - http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm
BACKUP
The $x_{tags}$ variable is defined as

$$x_{tags} = \begin{cases} 
\max(m_3^{tag}, 2.99) & : m_1^{tag} + m_2^{tag} < 2 \\
\max(m_3^{tag}, 2.99) + 3 & : 2 \leq m_1^{tag} + m_2^{tag} < 4 \\
\max(m_3^{tag}, 2.99) + 6 & : m_1^{tag} + m_2^{tag} \geq 4 
\end{cases}$$

(1)

where $\max(a, b)$ returns the maximum of $a$ and $b$, and all quantities are in units of GeV/$c^2$. The net effect is to unstack a two-dimensional histogram of $m_1^{tag} + m_2^{tag}$ versus $m_3^{tag}$ into the one-dimensional variable $x_{tags}$, as illustrated in Figure 4.
**D0 - 3b search**

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**CDF - 3b search**

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**Table II**: Model independent 95% C.L. upper limits on the cross section times branching ratio for the combined 5.2 fb$^{-1}$ analysis.