 Searches for non-SM Higgs at the Tevatron

presented by

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For the CDF and D0 collaborations

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Overview

- Introduction
- MSSM Higgs:  
  - Neutral Higgs bosons  
  - Charged Higgs bosons
- NMSSM Higgs
- NLLP → bb
- Outlook

Tevatron continues to perform well  
~ 6.9 fb\(^{-1}\) delivered luminosity  
Peak initial lumi 3.5x10\(^{32}\) cm\(^{-2}\)s\(^{-1}\)  
Expect 10 fb\(^{-1}\) at end of RunII
**MSSM Higgs sector**

- **Two Higgs doublets**
  - 5 physical Higgs bosons
  - 3 neutral (h, A, H=φ)
  - 2 charged (H±)

- **Higgs sector described at tree level by two parameters:**
  - $m_A$ - mass of A
  - $\tan\beta$ - ratio of vacuum expectation values
  - Other parameters enter via radiative corrections

- **Coupling of neutral Higgs to b-quarks enhanced by $\tan\beta$:**
  - Production enhanced by $\tan^2\beta$
Neutral MSSM Higgs Searches

Search for Higgs decays:
\[ h \rightarrow \tau \tau \]
relatively clean signature
low BR \(~10\%\)
(b)bh \(\rightarrow\) (b)bbb
large multi-jet backgrounds
high BR \(~90\%\)
(b)bh \(\rightarrow\) (b)b\(\tau\tau\)
additional sensitivity at low \(m_A\)
reduced \(Z \rightarrow \tau \tau\) background

Good b and tau identification vital

Similar overall sensitivities \(\rightarrow\) combine
Neutral Higgs: \( h \rightarrow \tau \tau \)

- Isolated electron or muon + hadronic tau or electron + muon
- Main backgrounds: \( Z \rightarrow \tau \tau \), multi-jets, W+jets, \( Z \rightarrow ee/\mu \mu \), di-bosons
- \( M_{\text{vis}} \) used to derive cross section limits
Neutral Higgs: $bh \to b\tau\tau$

- Search in $\mu\tau_{\text{had}}$ channel (1.2 fb$^{-1}$)
  - isolated muons + opposite sign hadronic tau
  - at least one $b$-tagged jet

- Events selected using combination of NN($tt$) and likelihood (multi-jet)
  - discriminant output used in setting limits
Neutral Higgs: \( bh \rightarrow bbb \)

- **Signal**
  - At least 3 b-tagged jets
  - Peak in dijet mass spectrum

- **Background**
  - Multi-jet, predicted from data/MC

- **CDF: 2 fb\(^{-1}\), D0: 2.6 fb\(^{-1}\)**
  - Train and cut on kinematic likelihood (D0)
  - Separate 3, 4 and 5-jet channels (D0)
  - Use dijet invariant mass to set limits in \( \tan\beta - m_A \) plane

- **Final limits corrected for:**
  - Width: Not negligible at high \( \tan\beta \)
  - MSSM NLO Corrections: Strongest limits for Higgs mass term, \( \mu < 0 \)
Combinations

- New result from DØ - combining three signatures in neutral Higgs searches
- 19 sub-channels using between 1.0 and 2.6 fb\(^{-1}\)
- Strongest limit on neutral MSSM Higgs in \(\tan\beta - m_A\) plane to date at a hadron collider
- Combinations across experiments in progress
Charged Higgs → cs/τν

Search for H± in top decays

CDF: 2.2fb⁻¹, DØ: 0.9fb⁻¹
- Lepton + jet channel
- Di-jet mass used to set limit

Assume BR (H±→ cs)=1

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**nMSSM**

**Next-to-MSSM Higgs - richer model**

- Two additional pseudo-scalar Higgs bosons (s and a)
- Decay $h \rightarrow aa$ dominates

If $m_a < 2m_\tau$

- Dominant decay: $h \rightarrow aa \rightarrow \mu\mu\mu\mu$
  - Two pairs of collinear muons
- Limit from direct search from LEP:
  - $m_h > 82$ GeV
- Backgrounds: QCD, $Z/\gamma^* \rightarrow \mu\mu$

**Event Selection:**

- Two muons $\Delta R(\mu,\mu) > 1$
- ‘Companion’ tracks $\Delta R(\mu,\text{track}) < 1$

Set 95% limits in 2D mass window

- $\sigma \times \text{BR} \sim < 5 - 10 \text{ fb}^{-1}$ for $m_a = 0.2-3$ GeV

![Event Selection Diagram](image-url)
$nMSSM$

$m_a > 2m_\tau$: $h \rightarrow aa \rightarrow \mu\mu\tau\tau$
- $\mu$ decay suppressed
- $\tau$ decay dominates
- Back-to-back $\mu$ and $\tau$ pairs

- Backgrounds: QCD, $Z/\gamma^*+jets \rightarrow \mu\mu+jets$

- Event Selection
  - $\mu$ pair $\Delta R(\mu,\mu) < 0.5$, $m_{\mu\mu} < 20$ GeV
  - Missing $E_T > 25$ GeV

Set Limits @95% C.L. using di-muon mass
Search for NLLP → bb

- search for pairs of displaced secondary vertices, located 1.6-20 cm from the beam axis
- no significant excess found
- interpret as a limit on SM Higgs, decaying to a pair of Hidden Valley particles (neutral and long-lived), each decaying to a b quark pair

$M_H = 120$ GeV, $m_{HV} = 15$ GeV

$M_H = 120$ GeV
$M_{HV} = 15$ GeV
$L_d = 5$ cm
Outlook

- CDF and DØ both performing well

- Wide range of BSM Higgs searches with up to 4fb\(^{-1}\)
  - No BSM Higgs signal yet, but established and sensitive analyses:
    - Potential is there
    - More data available, will include rapidly

- Combinations across experiments underway

- New results with more data and improved analysis techniques coming soon!
Backup
CDF and D0 experiments

- Both detectors extensively upgraded for Run Ila
  - New silicon vertex detector
  - New tracking system
  - Upgraded $\mu$ chambers

- CDF: New plug calorimeter & ToF

- D0
  - New solenoid & preshowers
  - Run IIB: New inner layer in SMT & L1 trigger
Tau identification

- CDF: Isolation based
  - 1 or 3 tracks in variable size and isolation cone
  - Validated via W/Z measurements
    - Efficiency ~ 40-50%
    - Jet fake rate < 1%

- DØ: 3 NN’s for each τ type
  - Validated via Z’s

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<th>2</th>
<th>3</th>
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<td>Taus</td>
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B-jet identification

- MSSM Higgs → bb ~90% of time
  - Improves S/B by > 10

- Use lifetime information
  - Correct for MC/data differences
    - Measured at given operating points

CDF: Secondary vertex reconstruction
- Neutral network increases purity
- Tight = 40% eff, 0.5% mis-tag

DØ: Neural Net tagger
- Secondary vertex & dca based inputs, derived from basic b-tagging tools
- High efficiency, purity
- Tight = 50% eff, 0.5% mis-tag
**DO b-tagging**

Several mature algorithms used:
- 3 main categories:
  - Soft-lepton tagging
  - Impact Parameter based
  - Secondary Vertex reconstruction

Combine in Neural Network:
- vertex mass
- vertex number of tracks
- vertex decay length significance
- \(\chi^2/\text{DOF}\) of vertex
- number of vertices
- two methods of combined track impact parameter significances

![Graph showing b-jet efficiency vs. p_T for jet candidates with \(P_T > 15\) and \(\text{All}11\)]
B-tagging-(D0) certification

- Have MC / data differences - particularly at a hadron machine
  - Measure performance on data
    - Tag Rate Function (TRF) Parameterized efficiency & fake-rate as function of $p_T$ and $\eta$
    - Use to correct MC b-tagging rate

- b and c-efficiencies
  - Measured using a b-enriched data sample

- Fake-rate
  - Measured using QCD data
Neutral MSSM Higgs $\rightarrow \tau\tau$
Neutral MSSM Higgs $\rightarrow bbb$

- **Background Prediction**
  - Large multijet background
  - Theoretical cross sections very large errors

- **DØ: Sample Composition**
  - Fit MC to data over several b-tagging points

- **DØ: Background Shape**
  - Use double b-tagged data to predict triple b-tagged background

\[
S_{3\text{Tag}}^{\text{exp}}(D, M_{bb}) = \frac{S_{1\text{Tag}}^{MC}(D, M_{bb})}{S_{2\text{Tag}}^{MC}(D, M_{bb})} S_{2\text{Tag}}^{\text{data}}(D, M_{bb})
\]

3 b-tag background MC correction factor 2 b-tag data

- **DØ, L=1fb\(^{-1}\)**
  - 0 b-tags
  - 1 b-tag
  - 2 b-tags
  - 3 b-tags
Fermiophobic Higgs $\rightarrow \gamma \gamma$

- 95% CL limits on branching ratio
  - Extend sensitivity into $m_{hf} > 130$ GeV
    - Not accessible by LEP

Excluded $m_{hf} < 106$ GeV

Excluded $m_{hf} < 102.5$ GeV
MSSM benchmarks

Five additional parameters due to radiative correction

- $M_{\text{SUSY}}$ (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)

Two common benchmarks

Max-mixing - **Higgs boson mass**

- $m_h$ close to max possible value
  - for a given $\tan \beta$

No-mixing - **vanishing mixing in stop sector**

- $m_h$ → small mass
  - for $h$
MSSM evolution
Can project sensitivity as a function of analyzed luminosity

-5.5 fb⁻¹ analyzed in 2009
-10 fb⁻¹ analyzed in 2011

**Benchmark scenario:**
Assumes analysis design will remain similar to today’s designs
Assumes we achieve potential for known sources of improvement
We expect to improve a broad range of analysis aspects including: dijet mass resolution, detector acceptance, add missing channels