Search for Supersymmetric Neutral Higgs Bosons at the Tevatron

Tim Scanlon

On behalf of the CDF and DØ Collaborations
• Introduction
  - Tevatron & experiments

• Neutral SUSY Higgs Searches
  - Minimal Supersymmetric SM
  - Fermiophobic Higgs

• Prospects & Conclusions

[ Thanks to all my Tevatron colleagues ]
Tevatron continues to perform well

- Over 3 fb$^{-1}$ delivered to each experiment
- Peak luminosities of $\sim 3 \times 10^{32}$

- Performance matching design
  integrated luminosity of $\sim 7-8$ fb$^{-1}$ by 2009
CDF and DØ experiments

- Both detectors extensively upgraded for Run IIa
  - New silicon vertex detector
  - New tracking system
  - Upgraded μ chambers

- CDF: New plug calorimeter & ToF

- DØ
  - New solenoid & preshowers
  - Run IIb: New inner layer in SMT & L1 trigger
Neutral SUSY Higgs

- Introduction

- **Minimal Supersymmetric Standard Model (MSSM)**
  - Introduction
    - Analysis Tools
  - Neutral Higgs bosons ($\phi$) searches
    $\phi \rightarrow \tau\tau$
    $b\phi \rightarrow b\tau\tau$
    $b\phi \rightarrow bbb$

- Fermiophobic Higgs

- Prospects & Conclusions

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Higgs bosons in the MSSM

- MSSM has 2 Higgs doublets
  - \( H_u \) (\( H_d \)) couple to up- (down-) type fermions
  - After EWSB 5 Higgs particles: \( h, H, A, H^+, H^- \)
    - \( h \) has to be light: \( m_h < \sim 140 \text{ GeV} \)
  - At tree level, 2 independent parameters: \( m_A \) and \( \tan \beta \)
    - \( \tan \beta \): Ratio of VEV’s = \( < H_u>/ < H_d> \)

- At large \( \tan \beta \):
  - Coupling of \( A, h/H \) to down-type fermions, e.g. \( b \)-quark, enhanced wrt SM
    - \( \rightarrow \) production amplitude \( \sim \tan \beta \rightarrow \) production cross section \( \sim \tan^2 \beta \)
  - \( h/H \) & \( A \) (denoted by \( \phi \)) \( \sim \) degenerate in mass \( \rightarrow \) further increase in cross-section

- For low & intermediate masses
  - \( \text{Br} (\phi \rightarrow bb) \sim 90\% \), \( \text{Br} (\phi \rightarrow \tau \tau) \sim 10\% \)
MSSM Higgs boson production

- Signatures
  - Higgs decays to 2 $\tau$'s
  - Further decays of $\tau$'s define final states
  - Higgs decays to 2 high $p_T$ b-jets/2 $\tau$'s
  - 1 or 2 associated b-quarks

- Good b-jet and $\tau$ identification vital

Similar overall sensitivities $\rightarrow$ Combine
**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**
- Neural Net - improves purity
- Inputs: track multiplicity, $p_T$, vertex decay length, mass, fit
- **Loose** = 50% eff, 1.5% mis-tag
- **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
- **Loose** = 70% eff, 4.5% mis-tag
- **Tight** = 50% eff, 0.5% mis-tag
• CDF: Isolation based
  - Require 1 or 3 tracks, $p_T > 1$ GeV in the isolation cone
    - For 3 tracks total charge must be $\pm 1$
    - $p_T^{\text{had}} > 15$ (20) GeV for 1 (3) prongs
    - $m^{\text{had}} < 1.8$ (2.2) GeV
  - Reject electrons via $E/p$ cut
  - Validated via W/Z measurements
  - Performance
    - Efficiency ~ 40-50%
    - Jet to $\tau$ fake rate ~0.001-0.005

• DØ: 3 NN’s for each $\tau$ type
  - Validated via Z’s

- $\tau^\pm \rightarrow \pi^\pm \nu$
- $\tau^\pm \rightarrow \pi^\pm \pi^0 \nu$
- $\tau^\pm \rightarrow \pi^\pm \pi^\pm \pi^0 (\pi^0) \nu$
Neutral MSSM Higgs → \( \tau\tau \) had/\( l \)

- **Main bkgds.**: \( Z\rightarrow\tau\tau \) (irreducible), multi-jet, W+jets, \( Z\rightarrow\mu\mu, \, ee, \, di-boson \)

- **DØ (μ channel only):**
  - Only 1 isolated \( \mu \) separated from hadronic \( \tau \) with opposite sign
  - \( m_W < 20 \) GeV removes most of remaining W+jets bkg.
  - Optimized NNs to separate signal from bkg.

- **CDF (μ, e, e+μ channels)**
  - Isolated e or \( \mu \) separated from hadronic \( \tau \) with opposite sign
  - Multi-jet background suppression: \( |p_T^l| + |p_T^{had}| + E_T > 55 \) GeV
  - Cut on relative directions of the visible \( \tau \) decay products and missing \( E_T \) removes W+jets bkg.
Neutral MSSM Higgs → \( \tau_l \tau_{\text{had}} \)

- **CDF**: Cross-section limits - derived from \( m_{\text{vis}} \) distribution
  - Observed limits weaker than expected due to an excess in data sample, but significance \( \leq 2\sigma \) once all search channels & windows considered

- **DØ**: Cross-section limits - derived from NNs for the different \( \tau \) types
Neutral MSSM Higgs $\rightarrow \tau_l \tau_{\text{had}}$

- Proceed to set limits
- $\sigma \times \text{Br} (\phi \rightarrow \tau \tau)$
Neutral MSSM Higgs → τ⁺τ⁻ had

- MSSM parameter space
  - Use no-mixing & $m_h^{\text{max}}$ benchmark scenarios
  - $90 < m_A < 200$ GeV,
  - $\tan\beta > 40 - 60$ excluded
Neutral MSSM Higgs → \( \tau_l \tau_{\text{had}} + b \)

- **DØ: ICHEP 2006** (344 pb\(^{-1}\))

- **Main bkgds.:** \( Z+(b) \)jets → \( \tau\tau/\mu\mu+(b) \)jets, multi-jet, \( tt \rightarrow bb\tau\mu, W+jets, WW \)

- **\( \mu \) channel only:**
  - 1 isolated \( \mu \) separated from the hadronic \( \tau \) with opposite sign
  - \( \tau \) identification: NN cuts optimised for analysis
  - 1 IP b-tagged jet
  - Optimized kinematic NN to separate signal from \( tt \) bkg.

- **No excess: Set Limits**
  - Limits set using \( m_{\text{vis}} \)
  - Competitive with bbb channel even with 1:9 branching ratio
Neutral MSSM Higgs $\rightarrow b\tau_l\tau_{\text{had}}$

- Limits in MSSM parameter space
  - Use no-mixing & $m_h^{\text{max}}$ benchmark scenarios

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Neutral MSSM Higgs $\rightarrow$ bb + b[b]

- **DØ: ICHEP ’06**
- $\geq 3$ b-tagged jets: $p_T > 40, 25, 15$ GeV
  - Invariant mass of 2 leading jets peaks at Higgs mass
- **Backgrounds from data**
  - Shape estimated from double-tagged di-jet mass spectrum
  - Rate normalized outside signal window
- **Agreement between data & predicted background** $\rightarrow$ set upper limits
- **Preliminary analysis being optimized**
  - New version this summer
Fermiophobic Higgs

- Introduction

- Minimal Supersymmetric Standard Model (MSSM)
  - Introduction
    - $b$-jet Identification
    - $\tau$ Identification
  - Neutral Higgs bosons ($\phi$) searches
    - $\phi \rightarrow \tau\tau$
    - $\phi \rightarrow b\tau\tau$
    - $b\phi \rightarrow bbb$

- Fermiophobic Higgs

- Prospects & Conclusions
Fermiophobic Higgs $\rightarrow 3\gamma + X$

- Some extensions of SM: coupling of Higgs to fermions suppressed
  - Searches previously carried out at LEP and Tevatron

- Search channel (2 Higgs Doublet Model):
  $$p\bar{p} \rightarrow h_f H^\pm \rightarrow h_f h_f W^\pm \rightarrow \gamma\gamma(\gamma) + X$$

- Backgrounds
  - Direct $3\gamma$ production (DTP)
  - Jets or electrons misidentified as $\gamma$
  - Estimated from data

- Cuts
  - $3\gamma$ with $|\eta| < 1.1$, $E_T^{1,2,3} > 30, 20, 15$ GeV
  - $H_T(3\gamma) > 25$ GeV
    - Rejects 3-particle events

- 0 events seen for 1.1 expected
• No excess, set limits:
  - 95% CL limit: $\sigma(hH^{\pm}) < 25.3\text{fb}$

• Exclusion on mass of $h_f$ for different charged Higgs masses ($m_{H^{\pm}}$) & $\tan\beta$
• Introduction

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Prospects - MSSM Higgs

- 1st results from 1fb⁻¹ show promising sensitivity
  - 2.5 fb⁻¹ data available
  - Many algorithmic/analysis improvements

- Short term (this summer)
  - New $b\phi \rightarrow b b + b(b)$
    - From both experiments
  - New MSSM combination
  - $b\phi \rightarrow b b + b(b)$ & $\phi \rightarrow \tau \tau$ & $b\phi \rightarrow b\tau\tau$

- Longer term
  - Up to $m_A \sim 250$ GeV for large $\tan\beta$
  - Down to $\tan\beta \sim 20$ for low $m_A$
  - Or discovery
Conclusions

• Tevatron and CDF/ DØ experiments performing very well

• Wide range of SUSY Higgs searches performed by CDF & DØ with up to 1 fb⁻¹ Run II data:
  - No signal observed in MSSM Higgs search, but already powerful!

• Updated CDF and DØ combinations soon
  - Rapid evolution in sensitivity
  - Over 2.5 times more data under analysis

Very exciting times ahead!
Backup slides
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
- chi2/DOF of vertex
- number of vertices
- two methods of combined track impact parameter significances
B-tagging - (DØ) 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

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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 \( \rightarrow \) small mass for \( h \)
CDF - MSSM Higgs $\rightarrow \tau_\ell \tau_{\text{had}}$

No excess seen in this channel