Combined CDF and DØ upper limits on MSSM Higgs boson production in pp collisions at 1.96 TeV

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For the DØ and CDF collaborations
DPF 2011
• The Tevatron

• Quick guide to the MSSM

• Object Identification

• Combinations
  – CDF and DØ
    • Inputs
    • Systematics
    • Limits
  – DØ
    • Inputs
    • Systematics
    • Limits
The Tevatron

Recorded: 10.3 fb$^{-1}$
Delivered: 11.5 fb$^{-1}$

Showing results with up to 7.3 fb$^{-1}$
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MSSM Higgs boson production

- Cover the 3 neutral Higgs $\phi = (h,H,A)$
  - charged Higgs results covered in other talk

- Large tan $\beta$ is preferred, leads to enhanced coupling to down type quarks and leptons

- Production/decay mechanism
  - $\phi b \rightarrow bbb$
  - $\phi b \rightarrow \tau\tau b$
  - $\phi \rightarrow \tau\tau$

- Branching Ratios
  - $BR(\phi \rightarrow bb) \sim 90\%$
  - $BR(\phi \rightarrow \tau\tau) \sim 10\%$
SUSY Parameters

• Tree level MSSM Higgs sector described by two parameters
  1. $M_A$
  2. $\tan \beta = \langle H_u \rangle / \langle H_d \rangle$

• Radiate corrections introduce dependence on other parameters

• Limits set in model independent case

• Excluded in $M_A, \tan \beta$ for two scenarios:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$m_h$-max</th>
<th>no-mixing</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu$</td>
<td>200 GeV</td>
<td>200 GeV</td>
</tr>
<tr>
<td>$M_{SUSY}$</td>
<td>1000 GeV</td>
<td>2000 GeV</td>
</tr>
<tr>
<td>$X_t$</td>
<td>2000 GeV</td>
<td>0 GeV</td>
</tr>
<tr>
<td>$M_2$</td>
<td>200 GeV</td>
<td>200 GeV</td>
</tr>
<tr>
<td>$M_3$</td>
<td>800 GeV</td>
<td>1600 GeV</td>
</tr>
</tbody>
</table>
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Object Identification: Taus

- Different tools for leptonic and hadronic tau decay

- $\mu,e$ use standard leptonic identification tools
- hadronic tau decay --- large jet background

- D0 and CDF have specific identification tools
Object Identification: Taus

- Define 3 types due to decay products
  - $\tau^\pm \rightarrow \pi^\pm \nu$
  - $\tau^\pm \rightarrow \rho^\pm \pi^0 \gamma \gamma$
  - $\tau^\pm \rightarrow a_1^\pm \rho^0 \pi^\pm \pi^-$

- Isolation cone
  - 1 Track
    - Calorimeter cluster
  - 1 Track
    - Calorimeter cluster
    - > 0 EM sub-cluster
  - > 1 Track
    - Calorimeter cluster
    - > 0 EM sub-cluster

- Remove background with NN

Efficiency = 65%  Fake rate = 2.5%
Efficiency = 50%  Fake rate < 1%
Object Identification: b-jets

Use lifetime information – corrected for data MC differences

CDF: Secondary vertex reconstruction
   NN increase purity
   40% efficiency, 0.5% mis-tag

DØ: NN tagger
   Secondary vertex and dca based inputs derived from basic b-tagging tools
   High efficiency and purity
   50% efficiency, 0.5% mis-tag
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    • Systematics
    • Limits
DØ and CDF Combination Inputs

• Last updated in 2009
• Using up to 2.2 fb\(^{-1}\) integrated luminosity
• Using just \(\phi\rightarrow\tau\tau\) decays

• **DØ:** \(\phi\rightarrow\tau\mu\tau\text{had}\)
  – 2.2\,\text{fb}^{-1} integrated luminosity
  – Released in 2008
  – combined with a DØ 1\,\text{fb}^{-1} covering \(\phi\rightarrow\tau_e\tau\mu,\tau_e\tau\text{had},\tau\mu\tau\text{had}\)

• **CDF:** \(\phi\rightarrow\tau_e\tau\mu,\tau_e\tau\text{had},\tau\mu\tau\text{had}\),
  – 1.8\,\text{fb}^{-1} integrated luminosity
  – Released in 2009
**DØ and CDF Combination Inputs**

- Select two high $P_t$ isolated leptons of opposite sign
- Look for excess in

\[
M_{vis} = \sqrt{(P_{\tau_1} + P_{\tau_2} + P_T)^2}
\]

**New 5.4 fb⁻¹ DØ result now out**
DØ and CDF Combination Inputs

- Model Independent Limits
  - $\sigma \times \text{BR}(\phi \rightarrow \tau\tau)$ at 95% CL level

**DØ Preliminary (1-2.2fb$^{-1}$)**

- Combined Exp.
- Combined Obs.
- RunIIa Exp.
- RunIIa Obs.

**MSSM Higgs $\rightarrow \tau\tau$ Search, 95% CL Upper Limit**

- Observed
- Expected 1σ band
- Expected 2σ band

**CDF Run II Preliminary, 1.8 fb$^{-1}$**

- Observed
- Expected 1σ band
- Expected 2σ band
DØ and CDF Combination Inputs

MSSM exclusions in $M_A$, $\tan \beta$ plane

MSSM Higgs $\rightarrow \tau \tau$ Search, 95% CL Exclusion

CDF Run II Preliminary, 1.8 fb$^{-1}$

$M_A$ (GeV/c$^2$)

$\tan \beta$

$M_h^\text{max}$, $\mu = +200$ GeV

DØ prel., 1-2.2 fb$^1$

Observed limit

Expected limit

LEP 2

No-mixing, $\mu = +200$ GeV

DØ prel., 1-2.2 fb$^1$

Observed limit

Expected limit

LEP 2

no mixing

$m_h^\text{max}$

$m_h^\text{max}$, $\mu < 0$

$m_h^\text{max}$, $\mu > 0$

no mixing
DØ and CDF Combination Limits

- Model Independent Limits
  - $\sigma \times \text{BR}(\phi \to \tau\tau)$ at 95% CL level

Limits in good agreement with expected, no significant excess seen. Correlation of systematics between experiments taken into account.
DØ and CDF Combination Limits

$m_h \text{ max}$

$m_h \text{ max, } \mu = -200 \text{ GeV}$

$m_h \text{ max, } \mu = +200 \text{ GeV}$

Tan $\beta$ width effects not expected to have large effect in this region

New combination out soon!
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• **Combinations**
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DØ Combination

Limits set on production cross section of Higgs boson in association with one or more b quark

Combine two channels:

bφ→bbb: 5.4 fb⁻¹ integrated luminosity
bφ→bττ: 7.3 fb⁻¹ integrated luminosity
DØ Combination

Inputs

**bφ -> bbb**

- Select 3 b-tagged jets
  - 3b jets greatly reduces background
- Background dominated multijet events
  - Predicted from data/MC
- Train discriminant to further separate signal
- Limits set using di-jet invariant mass

5.2 fb⁻¹ integrated luminosity
• Assume one tau decays hadronically and one to a muon
• 7.3 fb\(^{-1}\) integrated luminosity
• Builds on previous 2.7 fb\(^{-1}\) result
  • Improved systematic uncertainties
  • Improved trigger approach
• Combines discriminants \(D_{\text{MJ}}, D_{\text{tt}}, M_{\text{hat}}, \) \(\text{NN}_{\text{bb}}\) into likelihood

\[
M_{\text{hat}} = \sqrt{(E_{\tau \mu}^{\tau \text{had}} - p_{\tau \mu}^{\tau \text{had}} + P_T)^2 + |\vec{p}_{T}^{\tau \text{had}} + \vec{p}_{T}^{\tau \mu} + \vec{E}_T|^2}
\]
DØ Combination Inputs

- Model Independent Limits
  - $\sigma \times \text{BR}(\phi \rightarrow bb)$ or $\sigma \times \text{BR}(\phi \rightarrow \tau\tau)$ at 95% CL level

2.5 s.d. significance excess at 120 GeV in $b\phi \rightarrow bbb$
MSSM exclusions in $M_A$, $\tan \beta$ plane

$\mathbf{b}\phi \rightarrow \mathbf{b}\mathbf{b}\mathbf{b}$

$\mathbf{b}\phi \rightarrow \mathbf{b}\tau\tau$

$a)$ $m_h \text{ max, } \mu = -200 \text{ GeV}$

$D\phi$, $L = 7.3 \text{ fb}^{-1}$

$\mathbf{b}\phi \rightarrow \mathbf{b}\mathbf{b}\mathbf{b}$

$\mathbf{b}\phi \rightarrow \mathbf{b}\tau\tau$

$b)$ no mixing, $\mu = -200 \text{ GeV}$

$D\phi$, $L = 7.3 \text{ fb}^{-1}$

$\mathbf{b}\phi \rightarrow \mathbf{b}\mathbf{b}\mathbf{b}$

$\mathbf{b}\phi \rightarrow \mathbf{b}\tau\tau$
DØ Combination Limits

Model Independent Limits
• Range 90 – 300 GeV
• $BR(\phi \rightarrow \tau\tau) + BR(\phi \rightarrow bb) = 1$
  • set for 3 values of $BR(\phi \rightarrow \tau\tau) = 6\%, 10\%, 14\%$

Best limits from the Tevatron on a SUSY Higgs
DØ Combination Limits

Interpreted in two MSSM scenarios

$m_h$ max

no mixing

bbb channel remains the exclusive domain of Tevatron experiments
Conclusions

• Exciting new results out of the Tevatron
  – new results in
    • $\phi \rightarrow \tau\tau$
    • $b\phi \rightarrow bbb$
    • $b\phi \rightarrow b\tau\tau$
  – cover a wide range of channels using up to 7.3fb$^{-1}$

• DØ combination probing theoretically interesting regions.

• New DØ and CDF combination out soon!
Back Up
• Introduce symmetry between bosons and fermions
  • Solution to hierarchy problem
  • Dark matter candidate
  • GUT scale unification

• Simplest form: MSSM
  • Two Higgs doublets: $H_u, H_d$
  • After EW symmetry breaking: 5 Higgs Bosons $h, H, A, H^\pm$
New Result!

- Select two high $P_t$ isolated leptons of opposite sign
- Look for excess in

$$M_{vis} = \sqrt{(p_{\tau_h} + p_\mu + P_T)^2}$$

5.4 fb$^{-1}$ integrated luminosity
• Model Independent Limits
  • $\sigma \times \text{BR}(\phi \rightarrow \tau\tau)$ at 95% CL level
  • $M_a = 90 - 300$ GeV
bh \rightarrow bbb

\[ \text{DØ, 5.2fb}^{-1} \]

Cross section \times Br 95\% C.L. [pb]

- Expected
- Expected ±1 s.d.
- Expected ±2 s.d.
- Observed

Probability

- \( M_A = 120 \text{ GeV} \)
- \( M_A = 180 \text{ GeV} \)
- \( M_A = 240 \text{ GeV} \)

no mixing

\[ m_h \text{ max} \]
New Result!

• Look in di-jet mass spectrum
• Select events 3 or more b-tagged jets

• background modeled data driven tech in double tagged events
• separate background and signal using 2D fit

2.6 fb⁻¹ integrated luminosity
• Model Independent Limits
  • $\sigma \times \text{BR}(\phi \rightarrow bb)$ at 95% CL level
  • $M_a = 90 – 300$ GeV

D0: 2.5 s.d. significance excess at 120 GeV
CDF: > 2 sigma discrepancy 130-150 GeV
MSSM exclusions in $M_A$, tan $\beta$ plane

- **a)** $m_h$ max, $\mu=-200$ GeV, DØ, 5.2 fb$^{-1}$

- **b)** no mixing, $\mu=-200$ GeV, DØ, 5.2 fb$^{-1}$

**95% C.L. upper limits**
- Expected limit
- Observed limit

**Higgs width included**

**$m_h$ max scenario, $\mu = -200$ GeV ($\Delta_A=0.21$)**

**No loop effects ($\Delta_A=0$)**
New Result!

BR(\phi \rightarrow \tau \tau) \sim 10\%

- h \rightarrow \tau_e \tau_{\text{had}}: 3.7 fb^{-1} integrated luminosity
  - Specific discriminants for main backgrounds $D_{M\tau}, D_{tt}$

Even Newer Result!

- h \rightarrow \tau_\mu \tau_{\text{had}}: 7.3 fb^{-1} integrated luminosity
  - Improved systematic uncertainties
  - Improved trigger approach
  - Combined $D_{M\tau}, D_{tt}, M_{\hat{t}}, N_{bb}$ into likelihood
New Result!

- Model Independent Limits
  - $\sigma \times \text{BR}(\phi \rightarrow \tau\tau)$ at 95% CL level
  - $M_a = 90 - 300$ GeV

$$b\phi \rightarrow b\tau\tau$$
DØ and CDF Combination Systematics

Dominant effects
  – DØ – object Id, Trigger, luminosity, signal acceptance
  – CDF – object Id, luminosity, signal acceptance

• Correlated systematics
  – luminosity, tt and diboson production cross sections

• Uncorrelated systematics
  – multijet determination
  – calibration of fake rate, unvetoed ->ee conversions, b-tagging efficiency, mistag rates.