Limits on Charged Higgs using \( tt \) cross section measurements

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on behalf of the CDF Collaboration
**tt cross section measurements**

**Tevatron:**
- Top production in pairs
- Top decays to $t \to Wb$ before hadronizing
- Events Classified by the W decays:
  - "Dilepton" ($e, \mu$ well identified) (5% of total $tt$ pairs)
    - $tt \to b\ell\bar{\ell}b\ell\bar{\ell}$
  - "Lepton ($e, \mu$) + jets" (30%)
    - $tt \to b\ell bqq'$
  - "Lepton ($e, \mu$) + Had. Tau" (2%)
    - $tt \to b\ell\tau\nu, \tau \to$ hadronically
  - "All Jets" (45%) (not used here)
    - $tt \to bqq'bqq'$

Production cross section $\sigma$ calculated from:

\[
N^{obs} = N^{back} + \sigma \epsilon_{t\bar{t} \to WbWb} \int Ldt \quad \sim 193 \text{ pb}^{-1}
\]
Higgs sector

- SM neutral Higgs not yet found
- Extensions of SM based on a two doublet Higgs model (2HDM)
  - One couples to u-type quark and leptons, other to d-type quark and neutrinos
  - E.S.B results in 5 Higgs bosons, 3 neutral ($h^0, H^0, A^0$) and 2 charged ($H^\pm$)

Lagrangian: (diagonal CKM approx.)

$$L = \frac{g}{\sqrt{2}m_W} H^+ \left[ \cot(\beta) m_{u_i} \overline{u}_i d_i L + \tan(\beta) m_{d_i} \overline{d}_i d_i R + \tan(\beta) m_{l_i} \overline{l}_i l_i R \right] + H.c.$$  

Parameter space ($m_H, \tan(\beta)$) Determines the decays modes for top and $H^\pm$

<table>
<thead>
<tr>
<th>Top</th>
<th>( t \rightarrow W b )</th>
<th>( t \rightarrow H^+ b )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higgs</td>
<td>( H^+ \rightarrow \tau \nu )</td>
<td>( H^+ \rightarrow Wb b )</td>
</tr>
<tr>
<td>( tt \rightarrow W b Wb )</td>
<td>( tt \rightarrow W b Hb )</td>
<td>( tt \rightarrow Hb Hb )</td>
</tr>
</tbody>
</table>

| Channel | 1 | 3 | 6 |

- Large $H^+tb$ coupling at $\tan(\beta) \leq 0.3$ and $\tan(\beta) \geq 175$
New decay channels

- For each top quark we have 4 possible decay modes
  1) $t \rightarrow Wb$
  2) $t \rightarrow Hb \rightarrow \tau vb$
  3) $t \rightarrow Hb \rightarrow t^* bb \rightarrow Wb bb$
  4) $t \rightarrow Hb \rightarrow csb$

- The number of expected candidates $N^\text{exp}$ is

$$N^\text{exp} = N^\text{back} + \sigma \varepsilon_{tt} \int Ldt \quad \rightarrow \sim 193 \text{ pb}^{-1}$$

from MC

$$\varepsilon_{tt} = \sum_{i,j=1}^{4} \varepsilon_{i,j} B_i B_j$$

Branching fractions of each decay mode

$\varepsilon_{tt} = \varepsilon_{tt}(\{B_i\})$ Need to get the $B_i$ to find $\varepsilon_{tt}$

- Then compare $N^\text{obs}$ to $N^\text{exp}$ for each cross section measurement
Getting \{B_i\}

- **Higgs sector of type II 2HDM**: At tree level, a point in parameter space \((m_H, \tan(\beta))\) completely determines the decay modes of the top and Higgs.

![Graphs showing branching fractions for different Higgs masses and \(\tan(\beta)\) values.](image-url)
We use bayesian statistics

\[ P(\tan(\beta) \mid n_{ll}, n_{lj}, n_{l\tau}, m_{H}) = \frac{\int L(n_{ll}, n_{lj}, n_{l\tau}, m_{H} \mid \tan(\beta)) \pi(\tan(\beta))}{\int L(n_{ll}, n_{lj}, n_{l\tau}, m_{H} \mid \tan(\beta)') \pi(\tan(\beta)')d \tan(\beta)'} \]

Where the likelihood is

\[ L(n_{ll}, n_{lj}, n_{l\tau}, m_{H} \mid \tan(\beta)) = \frac{1}{N} \int_{0}^{\infty} \cdots \int_{0}^{\infty} \prod_{X = ll, lj, l\tau}^{1} G(\varepsilon_{XS}, \varepsilon_{XS})G(b_{XS}, b_{XS})d \varepsilon_{XS} d b_{XS} \]

and the \( \mu \)'s are

\[ \mu_{XS}^{u} = b_{XS} + L \sigma_{\text{prod}}^{u} \varepsilon_{XS}(\rho) \]

\[ \text{XS} = \{ "Dilepton", "Lepton+Jets", "Lepton+Had. Tau" \} \]

Integrate \( P(\tan(\beta)) \) over the maximum likelihood density to obtain the 95%CL
Number of expected events

- With SM only we would expect \( \{11, 66, 2\} \) events in \{“Dilepton”, “L+Jets”, “L+Had. Tau”\} cross section measurements.

- But we observe \( \{13, 57, 2\} \) events in data.
Tree level MSSM results

CDF Run II Preliminary
Excluded 95 %CL

$M_H$ (GeV) vs. $\tan(\beta)$

- SM Expected
- SM ± $\sigma$ Expected
- Excluded CDF Run II
- Excluded LEP

LEP (ALEPH, DELPHI, L3 and OPAL)

$t \rightarrow Hb$ search

$M_t = 175$ GeV
$\int L dt = 192$ pb$^{-1}$
Tree level MSSM comparison to Run I results

CDF Run II Preliminary
Excluded 95 %CL
$m_t = 175$ GeV
$L dt = 192$ pb$^{-1}$

LEP (ALEPH, DELPHI, L3 and OPAL)

$M_H$ (GeV)

$t \rightarrow Hb$ search

Direct search Run I
$\sigma_{tt} = 5.0$ pb

Indirect searches Run I
$\sigma_{tt}$ indep.

This study’s results
Model Independent

- Loop correction may significantly affect the BR’s, but we can deal with the BR’s directly, treating them as unknowns:
  \[ \beta = BR(H^+ \rightarrow c\bar{s}) \]
  \[ \alpha = BR(t \rightarrow H^+b) \]
  \[ \gamma = BR(H^+ \rightarrow Wb\bar{b}) \]
  \[ \delta \equiv BR(H^+ \rightarrow \tau\nu) = 1 - \beta - \gamma \]

- Probability of the diff BR’s given the obtained number of candidates:
  \[ P(\alpha, \beta, \gamma | n_{ll}, n_{lj}, n_{lt}) = \frac{L(n_{ll}, n_{lj}, n_{lt} | \alpha, \beta, \gamma) \pi(\alpha)\pi(\beta)\pi(\gamma)}{\int \int \int L(n_{ll}, n_{lj}, n_{lt} | \alpha', \beta', \gamma') \pi(\alpha')\pi(\beta'')\pi(\gamma')d\alpha'd\beta'd\gamma'} \]

- \(\pi(\alpha), \pi(\beta), \pi(\gamma)\) are the prior probability densities in the branching ratios. We take them uniform in this model independent study.

- Get the 95 % CL on \(P(\alpha|n_{ll}, n_{lj}, n_{lt})\)
Model Independent results

Limit does not depend on the model’s loop corrections to the BR’s!!
Model Independent results

Model Independent assuming $H \rightarrow \tau \nu$ only

$\text{BR}(H \rightarrow \tau \nu) = 1$ ; $\text{BR}(H \rightarrow c \bar{c}) = \text{BR}(H \rightarrow W b \bar{b}) = 0$

Limit does not depend on the model’s loop corrections to the BR’s!!
Conclusions

- We have set limits at tree level MSSM
  - Stricter than Run I limits done under same assumptions
  - Most restrictive limits to date

- We introduced “model independent” limits
  - Novel technique
  - Results independent of potentially large loop corrections

- Future Plans
  - Extend the reach to higher Higgs masses
  - Include loop corrections to the best of the current knowledge
  - Optimize the event selections for higher sensitivity