Measurement of $B(t\to Wb)/B(t\to Wq)$ at DØ

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DPF 2006, Hawaii
October 30, 2006
Motivation

• $B(t \rightarrow Wb) \sim 100\%$ (from $V_{tb}$) in the Standard Model

• We can write the ratio $R = \frac{B(t \rightarrow Wb)}{B(t \rightarrow Wq)}$

\[
R = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2} = |V_{tb}|^2
\]

• The CKM matrix element $|V_{tb}|$ is constrained based on the assumptions: 1. The CKM matrix is unitary 2. Quark has the three generation structure

• $|V_{tb}|$ is bounded between 0.9990 and 0.9992

• $R$ measurement analysis provides a cross check of the assumptions and the SM prediction

• A deviated value of $R$ could lead us new physics such as a fourth quark generation
Top Quark and Background

Top-pair production

Lepton + jets
  • One W decays hadronically
  • One W decays leptonically

Dilepton
  • Both Ws decay leptonically

W+Jets

Contain a real lepton from W decay
Wjj ( j = g,u,d,s,c,b )

Misidentified multijet events ( QCD )

Contain fake isolated electron or muon

Diboson events

WW, WZ, ZZ
Dataset used in this analysis
0.23 fb$^{-1}$

Silicon Detector

Center of Mass Energy: 1.96 TeV
Event Selection

- Requirements
  - 1 isolated lepton (electron or muon) $p_T > 20$ GeV
  - High missing transverse energy from neutrino $E_T > 20$ GeV
  - Jets: one or more jets with $|y| < 2.5$ $p_T > 15$ GeV
  - No second high $p_T$ lepton

- b-jet identification (B-tagging)
  - Secondary vertex tagging algorithm
  - Three separate datasets: exactly one tagged jets, at least two tagged jets or zero tagged jets
Secondary Vertex Tagging Algorithm

• Find a decay length, $L$ for each vertex
• Define the decay length significance in transverse plane
  $$L_{\text{significance}} = \frac{L_{xy}}{\sigma_{L_{xy}}}$$
• If $L_{\text{significance}} > 7$, the event passes SVT algorithm
• Tag rate ~ 40%
• Mistag rate ~ 0.2%
Analysis Method

• Decide the ratio $R$ and $t\bar{t}$ cross section $\sigma$ simultaneously
• Separate final states with (electron, muon) (3, 4jets) (0, 1, 2tags)
• Expected event numbers are fitted to observed data numbers for the 1, 2 tag channels
• Due to small $t\bar{t}$ event numbers in the 0 tag channels topological likelihood discriminant is constructed

$$R = \frac{B(t \rightarrow Wb)}{B(t \rightarrow Wq)}$$

<table>
<thead>
<tr>
<th>b-tagged jet number</th>
<th>0</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet multiplicity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>not used</td>
<td></td>
<td>topological likelihood</td>
<td>fit to the observed event numbers</td>
</tr>
</tbody>
</table>

For electron (or muon) channel
t\bar{t} Event Tagging Probabilities

- t\bar{t} event tagging probability: fraction of identified t\bar{t} event number and total t\bar{t} event number
- If R is equal to 1 the branching fraction B(t \rightarrow Wb) is 100%
- If R is less than 1 the decay of the two top quarks in a t\bar{t} event can produce either 0, 1 or 2 b quarks
- The event tagging probabilities are derived separately for the three possibilities

Scenario 1  \( t\bar{t} \rightarrow W^+ b W^- \bar{b} \)  two b quarks
Scenario 2  \( t\bar{t} \rightarrow W^+ b W^- q_1 \)  one b quark one light quark
Scenario 3  \( t\bar{t} \rightarrow W^+ q_1 W^- \bar{q}_1 \)  two light quarks
tt̅ Event Tagging Probabilities

<table>
<thead>
<tr>
<th>number of b quarks in the final states</th>
<th>0</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>probabilities to obtain each of the three final states</td>
<td>$(1-R)^2$</td>
<td>$2R(1-R)$</td>
<td>$R^2$</td>
</tr>
</tbody>
</table>

$\text{tt} event tagging probability = \frac{\text{probability to have each final state physics issue}}{\text{probability to identify each final state detection issue}}$

$P_n^{\text{tag}}(\text{tt}, R) = R^2 P_n^{\text{tag}}(\text{tt} \rightarrow bb) + 2 R(1-R)P_n^{\text{tag}}(\text{tt} \rightarrow bql) + (1-R)^2P_n^{\text{tag}}(\text{tt} \rightarrow qlql)$

• Use tt̅ Monte Carlo to compute the event tagging probabilities

• No Monte Carlo samples for

  $\text{tt} \rightarrow W^+ b W^- q_l$

  $\text{tt} \rightarrow W^+ q_l W^- q_l$
**Scenario 2**

\[
\bar{t}t \rightarrow W^+ bW^- q_l
\]

\[
P_{\text{tag}}(\bar{t}t, R) = R^2 P_{\text{tag}}(\bar{t}t \rightarrow bb) + 2 R(1-R)P_{\text{tag}}(\bar{t}t \rightarrow bq_l) + (1-R)^2P_{\text{tag}}(\bar{t}t \rightarrow q_lq_l)
\]

- Use standard \( \bar{t}t \) Monte Carlo
- Consider a jet matching \( \bar{b} \) from \( \bar{t} \) as light jet
- Apply light jet tagging probability to the \( \bar{b} \)
- Apply \( b \) tagging probability to the other \( b \) jet from \( t \)
- Compute 0, 1 and 2 tag probabilities

**Scenario 3**

\[
\bar{t}t \rightarrow W^+ q_lW^- q_l
\]

- Use standard \( \bar{t}t \) Monte Carlo
- Apply light jet tagging probabilities to jets matching the \( b \) and \( \bar{b} \)
- Compute 0, 1 and 2 tag probabilities

standard \( \bar{t}t \) Monte Carlo

\[
\bar{t}t \rightarrow W^+ bW^- \bar{b}
\]
Maximum Likelihood Fit

- $R$ and $\sigma$ are obtained by a maximum likelihood fit to the observed number of events
- Eight different channels: electron or muon with 3 or $\geq 4$ jets and one or two tags

$$L = \prod_i P(N_{i}^{\text{obs}}, N_{i}^{\text{predicted}}(R, \sigma))$$

- Here $P(N^{\text{obs}}, N^{\text{predicted}})$ denotes the Poisson probability

R = 1  

R = 0.5
Treatment of 0 Tag Sample

• Total number of observed events in the 0 tag sample is too small to constrain R and \( \sigma \)
• Use topological discriminating variables and build likelihood

1. Sphericity
2. KTminP
3. Centrality
4. HT2P
Treatment of 0 Tag Sample

• Apply only in electron or muon with $\geq 4$ jets and 0 tag sample

\[
\mathcal{L} = \frac{S(x_1, x_2, \ldots)}{S(x_1, x_2, \ldots) + B(x_1, x_2, \ldots)}
\approx \frac{\prod_i S_i}{\prod_i S_i + \prod_i B_i} = \frac{\prod_i S_i / B_i}{\prod_i S_i / B_i + 1} = \frac{\exp \left( \sum_i (\ln \frac{S_i}{B_i}) \right)}{\exp \left( \sum_i (\ln \frac{S_i}{B_i}) \right) + 1}
\]
Final Binned Likelihood Fit

$N_{jet} = 3$

$N_{jet} \geq 4$

**Without 0-tag**

**With 0-tag**

**Improvement**

$\sigma \times B(t \rightarrow Wq)^2 (pb)$

95% C.L.

68% C.L.
Conclusions

• Results

First measurement of R in DØ
Good agreement with the standard model expectation
Topological likelihood in the 0 tag samples make significant improvement

\[
\frac{Br(t \rightarrow Wb)}{Br(t \rightarrow Wq)} = 1.03^{+0.19}_{-0.17} (\text{stat + syst})
\]

\[
\sigma_{t \bar{t}} = 7.9^{+1.7}_{-1.5} (\text{stat + syst}) \pm 0.5(\text{lumi}) \text{pb}
\]