DØ Top Physics

Top Quark Pair Production Cross Section
Top Quark Mass
W Helicity
Top Quark B(t→Wb)
Search for Single Top Production

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The Top Quark

What makes the Top Quark so special?
• Completes the quark sector
• Large mass: $m_{\text{top}} \approx 180 \text{ GeV/c}^2$
  => Strongest coupling to Higgs
• Short lifetime $\tau \approx 4 \cdot 10^{-25}\text{s}$
  => No hadronisation
• Sensitive to physics beyond Standard Model
Top Quark Pair Production & Decay

- Tevatron $p\bar{p}$ collider is currently the world’s only source of Top Quarks
- Production rate increased wrt. Run I:
  - Increased centre of mass energy: 1.8 TeV → 1.96 TeV ⇒ $+30\% \sigma_{tt}$
  - Increased luminosity: Run I ~ 125 pb$^{-1}$, shown here ~ 160 pb$^{-1}$, ongoing: $\times 2$

- SM top decay $\approx 100\%$ Wb ⇒ Final states determined by W decay mode
  ⇒ 2 b-jets,
  ⇒ Up to two charged leptons/neutrinos
  ⇒ Up to four additional jets

all hadronic $\approx 46\%$, l+jets $\approx 44\%$, dilepton $\approx 10\%$

Need to reconstruct/identify:
- Electrons, muons, taus,
- Missing transverse energy
- Jets/b-jets
Top Quark Pair Production: Dilepton channels

- Signature: isolated high $p_T$ ee, $\mu\mu$, $e\mu$, $\geq 2$ jets, $E_T$
- Small branching ratios to ee, $\mu\mu$, $e\mu$
- Background:
  - $WW(\rightarrow ee, \mu\mu, e\mu) +$ jets
  - $Z(\rightarrow ee, \mu\mu) +$ jets
  - $Z(\rightarrow \tau\tau \rightarrow ee) +$ jets
  - $W +$ jets (jet fakes isolated $e,\mu$)
  - Multijet $b\bar{b}$ production (jets fake $e,\mu$)

<table>
<thead>
<tr>
<th>Category</th>
<th>ee</th>
<th>$\mu\mu$</th>
<th>$e\mu$</th>
<th>$ll$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z/\gamma^*$</td>
<td>0.15 $\pm$ 0.10</td>
<td>2.04 $\pm$ 0.49</td>
<td>0.47 $\pm$ 0.17</td>
<td>2.66 $\pm$ 0.53</td>
</tr>
<tr>
<td>WW</td>
<td>0.14 $\pm$ 0.08</td>
<td>0.10 $\pm$ 0.04</td>
<td>0.29 $\pm$ 0.06</td>
<td>0.53 $\pm$ 0.11</td>
</tr>
<tr>
<td>Fakes</td>
<td>0.91 $\pm$ 0.30</td>
<td>0.46 $\pm$ 0.20</td>
<td>0.19 $\pm$ 0.06</td>
<td>1.56 $\pm$ 0.36</td>
</tr>
<tr>
<td><strong>Total background</strong></td>
<td>1.20 $\pm$ 0.33</td>
<td>2.61 $\pm$ 0.53</td>
<td>0.95 $\pm$ 0.19</td>
<td>4.76 $\pm$ 0.65</td>
</tr>
<tr>
<td>Expected signal</td>
<td>1.39 $\pm$ 0.19</td>
<td>0.83 $\pm$ 0.15</td>
<td>3.77 $\pm$ 0.44</td>
<td>5.99 $\pm$ 0.50</td>
</tr>
<tr>
<td>SM expectation</td>
<td>2.59 $\pm$ 0.38</td>
<td>3.44 $\pm$ 0.55</td>
<td>4.73 $\pm$ 0.49</td>
<td>10.76 $\pm$ 0.83</td>
</tr>
<tr>
<td>Selected events</td>
<td>5</td>
<td>4</td>
<td>8</td>
<td>17</td>
</tr>
</tbody>
</table>

Dilepton: $\sigma_{t\bar{t}} = 14.3^{+5.1}_{-4.3} \text{ (stat)}^{+2.6}_{-1.9} \text{ (syst)} \pm 0.9 \text{ (lumi)} \text{ pb}$

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$\bar{t}t \rightarrow e\mu$ candidate event
Top Quark Pair Production: lepton + jets channel

- Signature: isolated high \( p_T \) lepton, \( E_T \), \( \geq 4 \) jets (no b-tagging used)
- Build multivariate discriminating variable based on event topology/kinematics (sphericity, aplanarity, ...), optimised for precision of the measurement
- Fit linear combination of multijets (misidentified leptons in data), \( W+4 \)jets and \( \bar{t}t \) to data

\( \mu+\text{jets}: 144 \, \text{pb}^{-1} \)
\( e+\text{jets}: 141 \, \text{pb}^{-1} \)

\[
\sigma_{p\bar{p}\rightarrow t\bar{t}+X} = 7.2^{+2.6}_{-2.4} \, \text{(stat)} \quad +1.6 \quad -1.7 \, \text{(syst)} \pm 0.5 \, \text{(lumi)} \, \text{pb}
\]
Top Quark Pair Production:
lepton + jets channel, b-tagging

Use same preselection as in topological analysis and add b-tagging:

for example: impact parameter based
tagging algorithm

b-tagging keeps ~ 60% t\bar{t} and ~ 4% W+jets
=> improved signal/background

combined e+jets (169 pb\(^{-1}\)) & \mu+jets (158 pb\(^{-1}\)) data:

\[ \sigma_{t\bar{t}} = 7.2^{+1.3}_{-1.2}^{(\text{stat})} +_{-1.4}^{+1.9}(\text{syst}) \pm 0.5 (lumi) \text{ pb} \]
Top Quark Mass

Measurements in l+jets channel (~160 pb⁻¹), use kinematic constrained fit, no b-tagging

→ Template method uses templates for signal and background mass spectra
→ Ideogram method uses analytical likelihood for event to be signal or background

**template method:**

$$m_t = 170.0 \pm 6.5_{\text{(stat)}}^{+10.5}_{-6.1} \, \text{(syst)} \, \text{GeV}$$

**ideogram method:**

$$m_t = 177.5 \pm 5.8_{\text{(stat)}} \pm 7.1_{\text{(syst)}} \, \text{GeV}$$

Systematical error dominated by jet energy scale => working on it!
Ongoing analyses use b-tagging => smaller uncertainties

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Top Quark Mass (II)

- First DØ Run II measurement in dilepton channel, using ~230 pb⁻¹
- Based on ll+jets preselection: 8 eµ, 5 ee events
- 6 particle final state, only 4 objects detected + unbalanced p_Tx, p_Ty => underconstrained problem
- Use hypothesized value m_t to solve for t¯t momenta (Dalitz & Goldstein, Phys Rev. D 45, 1531 (1992))
- Use solutions for weight distribution per event; peak gives mass estimator for each event
- Compare to signal and background templates using a binned maximum likelihood fit

\[
m_t = 155^{+14}_{-13}\text{(stat)} \pm 7\text{(syst)} \text{ GeV}
\]

comparable precision wrt. Run I

probability to observe ≤ 155 GeV if top mass is 175 GeV: 8%
W Helicity

Standard Model top decay: V-A interaction (like for all fermions)

W helicity states:

- **left-handed fraction:** $f_-$
- **longitudinal fraction:** $f_0$
- **right-handed fraction:** $f_+$

In Standard Model:

- $30\%$
- $70\%$
- $0\%$

⇒ Measure angular distribution of lepton wrt. top in W rest frame
⇒ Fix $f_0$ to Standard Model value
⇒ Determine $f_+$

$f_+ < 0.24$ (90\% CL) (with b-tagging)
Top Quark \( B(t \rightarrow Wb) \)

\[
R = \frac{B(t \rightarrow Wb)}{B(t \rightarrow Wq)}, \text{ in standard model: } R \approx 1.
\]

Compare single and double tagged \( \bar{t} \bar{t} \) events:
- One \( b \) jet identifies \( \bar{t} \bar{t} \),
- Another one allows to measure relative fraction of \( t \rightarrow Wb \)

use combined \( e+jets \) (169 pb\(^{-1}\)) & \( \mu+jets \) (158 pb\(^{-1}\)) data,
fit \( \bar{t} \bar{t} \) cross section and \( R \) simultaneously:

\[
R = 0.70^{+0.27}_{-0.24}(stat)^{+0.11}_{-0.10}(syst)
\]

68% and 90% C.L. contours
**Search for Single Top**

Produced via electroweak interaction:
- Sensitive to $V_{tb}$
- So far not observed, despite $\sigma \approx 0.4 \, \sigma_{ttbar}$
- Measure departure from Standard Model?

$\sigma_s = 0.88_{-0.06}^{+0.07} \, pb$

$s$-channel

$\sigma_t = 1.98_{-0.18}^{+0.23} \, pb$

$t$-channel

**signature:** similar to $t\bar{t} \, l+jets$, but lower jet-multiplicity $\Rightarrow$ b-tagging!

**background:** $W+jets$, $t\bar{t}$, $b\bar{b}$, multijets faking leptons, dibosons

Use combined $e+jets$ (169 pb$^{-1}$) & $\mu+jets$ (158 pb$^{-1}$) data for search.

![Graph](image)

s-channel < 19pb, t-channel < 25pb, combined < 23pb (95%CL)

still based on simple cut approach – ongoing analysis uses neural networks & decision trees

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Summary

• Tevatron runs smoothly, promising large future datasets
  (4-9 fb\(^{-1}\) until 2009)
• A wealth of analyses is being pursued, continuing to probe the validity of the Standard Model – so far no conflict seen
• Current analyses use twice the integrated luminosity and further improved analysis methods, many results are being reviewed for publication
• Working very hard towards new discoveries: single top, new physics
backup slides
Definitions of Topological Variables

Normalised momentum tensor

\[ M_{ij} = \frac{\sum_{n} p_{n}^{i} p_{n}^{j}}{\sum_{n} |\vec{p}_{n}|^{2}} \]

Eigenvalues:

\[ \lambda_1 \geq \lambda_2 \geq \lambda_3 \]

\[ \lambda_1 + \lambda_2 + \lambda_3 = 1 \]

- **Sphericity**: \( S = \frac{3}{2} (\lambda_2 + \lambda_3) \approx \text{summed } p_{T}^{2} \text{ wrt. event axis} \)
  - Dijet event has \( S \approx 0 \), isotropic event has \( S \approx 1 \)
- **Aplanarity**: \( A = \frac{3}{2} \lambda_3 \) = departure from planarity of event
  - Large values indicate spherical events
- **\( H_{T2}' = H_{T2}/H_{z} \)**: measures event centrality
  - \( H_{T2} \) = scalar sum of jet \( p_{T} \) (excluding leading jet)
  - \( H_{z} \) = scalar sum of \( |p_{z}| \) of jets, lepton and neutrino
  - \( H_{T2}/H_{z} \) – larger for central events
- **ktminprime**: measure of minimum jet \( p_{T} \) relative to another
  - Normalised by \( E_{T}^{W} = E_{T}^{\text{lepton}} + E_{T} \) to reduce JES dependence
  - Tends to be small for soft & collinear backgrounds
The Tevatron @ Fermilab

- pp collisions at $\sqrt{s} = 1.96$ TeV (Run I: 1.8 TeV)
- 36 bunches (396 ns spacing)
- Linac upgrade
- Main injector (150 GeV proton storage ring)
- Further improvements:
  - Antiproton "recycler" (begin June 2004)
  - Electron cooling (begin 2005)

Peak luminosity:
- 5 times higher than Run I
- 2.5 times higher than July 2003
- Reached Run IIa goal of 100E30
Tevatron will run until 2009
- Base line: 4 fb$^{-1}$
- Design: 9 fb$^{-1}$
The Run II DØ Detector

- New forward muon system
- New readout / trigger electronics
- New central tracking inside 2 T solenoid
  - Silicon vertex detector (=>b-tagging)
  - Scintillating fiber tracker

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