Top pair production cross-section measurement in the dilepton channel at CDF

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for
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Outline

● Motivation
● Top quark signal
● Dilepton analyses
● Cross section results
● Conclusion
Motivation

Measurement of $\sigma(t\bar{t})$ is important:

- For testing the SM in the top quark sector:
  - top discovery is relatively new (EST 1995)
  - characterize production/decay mechanisms & kinematics
- Probe for physics beyond SM
  - non-SM production, $X \rightarrow t\bar{t}$
  - non-SM decay, $t \rightarrow Xb$
- $t\bar{t}$ event topology is a background for exotics searches
- Theoretical cross-section: NLO @ $\sqrt{s} = 1.96$ TeV for $M_{\text{top}} = 175$ GeV:
  \[
  \sigma_{t\bar{t}} = 6.7^{+0.7}_{-0.9} \text{ pb}
  \]
  (Bonciani et al. hep-ph/0303085)
Top quark signal

Pair production dominant:

85%  
85%  

In SM $BR(t \rightarrow Wb) \approx 100\%$

Dilepton channel (our signal):
- cleanest
- smallest background
- lowest rate

$t$-bar final states (topologies):

**Dilepton** ($BR = 11\%$)
2 leptons + 2 b-jets + missing-$E_T$

**Lepton + jets** ($BR = 44\%$)
1 lepton + 4 jets (2 b-jets) + missing-$E_T$

**All-hadronic** ($BR = 45\%$)
6 jets (2 b-jets), no missing-$E_T$

Search motivated by intriguing
Run I dilepton sample:
- 7 $e\mu$ events out of 9 total
- several events have larger $E_T^{miss}$ than expected
Measurement strategy for Run II

Two independent / complementary analyses:

“DIL” analysis (Run I-like)
• Second lepton uses traditional lepton ID in calorimeter, muon chambers
• Two well-identified leptons
• Higher purity, lower statistical significance

“LTRK” analysis (new)
• Second lepton is just track isolated in drift chamber (“tl”)
• Increase acceptance at expense of purity
  • Get ~hadronic τ & holes in lepton ID coverage
• Lower purity, higher statistical significance

Perform counting experiment for each:
$$\sigma_{t-\bar{t}} = \frac{N_{obs} - N_{bgnd}}{A \times \epsilon \int L dt}$$

Combine cross sections
Event Selection

Baseline selection: \((dilepton + E_T^{miss} + jets)\)

- **first lepton**: a high-pT electron or muon (trigger)
- **second lepton**: looser ID (DIL) or an isolated track with \(P_T > 20\) GeV (LTRK)
- opposite charge
- \(E_T^{miss} > 25\) GeV
- \(\geq 2\) jets: \(E_T > 15\) GeV, \(|\eta|<2.5\) (DIL) or \(E_T > 20\) GeV, \(|\eta|<2.0\) (LTRK)

Further background suppression:

- if \(E_T^{miss}\) co-linear with jet or lepton [\(\parallel\) or anti-\(\parallel\) with isolated track]
- **Z region**: ratio of \(E_T^{miss}\) to sum of jet \(E_T\)’s projected on \(E_T^{miss} < 8\) (DIL)
  \[E_T^{miss} > 40\) GeV (LTRK)
- \(H_T \equiv \text{(scalar sum of event energy)} > 200\) GeV (DIL)
Backgrounds

Instrumental backgrounds

- **Drell-Yan** \((Z/γ^* → ee, μμ)\)
  - False \(E_T^{\text{miss}}\) from mismeasured leptons, jets
- **Fake leptons**
  - \(W+\)jets with jet misidentified as a lepton
- Use data wherever possible

Physics backgrounds

- **Diboson** \((WW/WZ/ZZ)\) and \(Z/γ^* → ττ\)
  - Real leptons, \(E_T^{\text{miss}},\) jets
  - Evaluated using MC

*Understanding background composition in 0 jet & 1 jet gives confidence in the signal region (\(≥2\) jets)*
Events expected, observed

**Event count per jet bin**

<table>
<thead>
<tr>
<th>Event count</th>
<th>CDF II 200 pb⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>entries/jet bin</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>70</td>
</tr>
<tr>
<td>1</td>
<td>50</td>
</tr>
<tr>
<td>≥ 2</td>
<td>30</td>
</tr>
</tbody>
</table>

**Events expected, observed**

- **LTRK**
  - $WW, WZ, ZZ$
    - $N_{jet} = 0$: $21.8 \pm 5.5$
    - $N_{jet} = 1$: $6.3 \pm 1.6$
    - $N_{jet} \geq 2$: $1.2 \pm 0.3$
  - Drell-Yan
    - $N_{jet} = 0$: $26.5 \pm 9.8$
    - $N_{jet} = 1$: $16.4 \pm 6.0$
    - $N_{jet} \geq 2$: $4.2 \pm 1.6$
  - Fakes
    - $N_{jet} = 0$: $16.5 \pm 2.4$
    - $N_{jet} = 1$: $5.0 \pm 1.0$
    - $N_{jet} \geq 2$: $1.5 \pm 0.5$
  - Total Bkgd
    - $N_{jet} = 0$: $64.8 \pm 11.5$
    - $N_{jet} = 1$: $27.7 \pm 6.3$
    - $N_{jet} \geq 2$: $6.9 \pm 1.7$

- **DIL**
  - $H_T > 200$ GeV
    - $N_{jet} = 0$
      - $tt$: $0.3 \pm 0.2$
      - $W$ or $Z$: $0.1 \pm 0.0$
    - $N_{jet} = 1$
      - $tt$: $3.4 \pm 0.6$
      - $W$ or $Z$: $1.3 \pm 0.2$
    - $N_{jet} \geq 2$
      - $tt$: $11.5 \pm 1.8$
      - $W$ or $Z$: $8.5 \pm 1.2$

**Good agreement in 0j, 1j bins (control region)**
## Signal and Background Uncertainties

<table>
<thead>
<tr>
<th>Source of Uncertainty</th>
<th>LTRK</th>
<th>DIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lepton (track) ID</td>
<td>5%(6%)</td>
<td>5%</td>
</tr>
<tr>
<td>Jet energy scale – signal</td>
<td>6%</td>
<td>5%</td>
</tr>
<tr>
<td>Jet energy scale – background</td>
<td>10%</td>
<td>18-29%</td>
</tr>
<tr>
<td>Initial / final state radiation</td>
<td>7%</td>
<td>2%</td>
</tr>
<tr>
<td>Parton distribution functions</td>
<td>6%</td>
<td>6%</td>
</tr>
<tr>
<td>Monte Carlo Generators</td>
<td>5%</td>
<td>6%</td>
</tr>
<tr>
<td>WW,WZ,ZZ estimate</td>
<td>20%</td>
<td>20%</td>
</tr>
<tr>
<td>Drell-Yan estimate</td>
<td>30%</td>
<td>51%</td>
</tr>
<tr>
<td>Fake estimate</td>
<td>12%</td>
<td>41%</td>
</tr>
</tbody>
</table>
Cross section results

**Effective luminosity of 197 pb⁻¹**

**DIL:** \( A^{} \tau = (0.62 \pm 0.09)\% \)

\[
\sigma_{t\bar{t}} = 8.4^{+3.2}_{-2.7} \text{(stat.)}^{+1.5}_{-1.1} \text{(syst.)} \pm 0.5 \text{(lum.) pb}
\]

**LTRK:** \( A^{} \tau = (0.88 \pm 0.14)\% \)

\[
\sigma_{t\bar{t}} = 7.0^{+2.7}_{-2.3} \text{(stat.)}^{+1.5}_{-1.3} \text{(syst.)} \pm 0.4 \text{(lum.) pb}
\]

(assuming BR(W→ν)=10.8%)

- Both measurements are consistent with SM calculation
- Error is statistics-dominated → results to be combined
Cross checks

Various cross / sanity checks were performed:

✔ Identical analysis techniques reproduce the expected W and Z cross sections

✔ Number of like-sign events (fakes-dominated sample) observed agrees with prediction in all jet bins

✔ Number of b-tagged events (DIL: 7, LTRK: 10) consistent w/ that expected from top

✔ Cross section stable over a wide range of jet, lepton $E_T$ thresholds

✔ Measured cross section with a “lepton-lepton” subset of LTRK:

$$\sigma (t\bar{t}) = 8.5^{+4.5}_{-3.5} (stat) +^{1.8}_{-1.4} (syst) \pm 0.5(lum) \text{ pb}$$

→ Good agreement with DIL and LTRK
Combining the cross sections

• Combining two measurement reduces the largest uncertainty (statistics)

• Strategy: divide signal, background expectation and data into three disjoint regions:

LTRK-only, DIL-only and Common (overlap)

<table>
<thead>
<tr>
<th></th>
<th>Acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common</td>
<td>0.464%</td>
</tr>
<tr>
<td>DIL-Only</td>
<td>0.156%</td>
</tr>
<tr>
<td>LTRK-Only</td>
<td>0.411%</td>
</tr>
<tr>
<td>Total</td>
<td>1.031%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Background Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common</td>
<td>1.8</td>
</tr>
<tr>
<td>DIL-Only</td>
<td>0.9</td>
</tr>
<tr>
<td>LTRK-Only</td>
<td>5.1</td>
</tr>
<tr>
<td>Total</td>
<td>7.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common</td>
<td>11</td>
</tr>
<tr>
<td>DIL-Only</td>
<td>2</td>
</tr>
<tr>
<td>LTRK-Only</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
</tr>
</tbody>
</table>
Combination technique

\[ L = \prod_{\alpha} P(\alpha^{\text{obs}} | \alpha^{\text{pred}}(\sigma_{tt})) \]

\[ \alpha = \text{product over DIL-only, LTRK-only, overlap} \]

- Maximize combined Poisson likelihood for three regions
- Be conservative w/ systematics between regions
  - Treated as 100% correlated, distributed to give largest total systematic

\[ \sigma_{tt} = 7.0^{+2.4}_{-2.1} \text{(stat.)} +^{1.6}_{-1.1} \text{(syst.)} \pm 0.4 \text{(lum.) pb} \]

12% reduction in statistical error
Kinematic distributions

With larger statistics, we can start going beyond counting experiments to do shape tests on our selected sample.

Use larger statistics of LTRK to examine sample kinematics

KS = 75%

Data follow expected distribution of top + background

KS = 66%
Flavor distribution

Use DIL sample with two identified lepton

Consistent with expectation

<table>
<thead>
<tr>
<th>channel</th>
<th>Expected (scaled to 13 total obsv’d)</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>ee</td>
<td>3.3 ± 0.5</td>
<td>1</td>
</tr>
<tr>
<td>μμ</td>
<td>2.8 ± 0.5</td>
<td>3</td>
</tr>
<tr>
<td>eμ</td>
<td>6.8 ± 0.8</td>
<td>9</td>
</tr>
</tbody>
</table>
Conclusions

- We have measured the $t\bar{t}$ production cross section in the dilepton decay channel using 197 pb$^{-1}$ of Run II data.
- Our result is $(m_t = 175 \text{ GeV}/c^2, \text{BR}(W\rightarrow l\nu)=10.8\%)$:

$$\sigma_{t\bar{t}} = 7.0^{+2.4}_{-2.1}(\text{stat.})^{+1.6}_{-1.1}(\text{syst.}) \pm 0.4(\text{lum.}) \text{ pb}$$

consistent with NLO SM calculation of $\sigma = 6.7^{+0.7}_{-0.9} \text{ pb}$.

- Kinematics, flavor distribution of data also consistent with Standard Model expectation.
- Paper (arXiv:hep-ex/0404036) accepted by PRL.
Double-tagged top dilepton candidate

- An event with 2 jets and 2 muons
- Both jets show displaced secondary vertices from the interaction point: b jet candidates
Backup slides
Run I dilepton sample had some interesting features:

- 7 $e\mu$ events out of 9 total.
- Several events with large $E_T^{\text{Miss}}$.
- Measured $\sigma=8.2^{+4.4}_{-3.4}$ pb (to be compared with 5.2 pb theoretical).
- Something to watch in Run II!
Run I Dileptons: new physics?

\[ tt \rightarrow l\nu\tilde{\chi}_1^0 \]  

\{ \text{SM top or SUSY?} \}

Theory interest from hep-ph/9609313

Kinematics in Dilepton Events

- \( E_{\text{tMISS}} + E_{\text{l1}}(l_1) + E_{\text{l2}}(l_2) \) [GeV]
- \( \theta_{\text{l}} \) [deg]

\( t\bar{t} \) or cascade decay of squarks with masses around 300 GeV?
Run II Data sample

- We have 4 lepton/detection categories (triggers): each have different “good-run” requirements and luminosities
  - 202 pb\(^{-1}\) central electrons
  - 197 pb\(^{-1}\) central muons
  - 179 pb\(^{-1}\) central muon (extension region)
  - 180 pb\(^{-1}\) plug electrons (SVXII+ISL required)
- Effective luminosity is 197 pb\(^{-1}\)
What about $m_{\text{top}} = 178$ GeV?

- CDF & D0 released a new Run 1 combined top mass result (arXiv:hep-ex/0404010)
  
  $$m_{\text{top}} = 178 \pm 2.7(\text{stat}) \pm 3.3(\text{syst})\text{GeV/c}^2$$

- Top acceptances changes by $\sim 0.5\%/\text{GeV/c}^2$.

- Top cross section would go from $7.0 \rightarrow 7.1$ pb