Top Cross Section Measurements at the Tevatron

Alison Lister
Université de Genève
On behalf of the CDF and D0 Collaborations
Over 10 fb$^{-1}$ delivered

Presenting today

Delivered To tape
Top Physics

Goal is to measure the top quark as precisely as possible at the Tevatron
Get a complete picture of the heaviest quark?
Signs of weakness of the SM?
Top Event Decays

- Standard Model
  - BR(t→Wb) ~100%
- Top events are characterised by the decay of the W boson

“Leptons” are only electrons and muons
Top Quark Pair Production Cross Section

Measurements differ in

- W-decay channel
- Analysis cuts
- Background composition
- Background estimation methods
- Luminosity determination

\[
\sigma_{t\bar{t}} = \frac{N_{\text{data}} - N_{\text{bck}}}{\epsilon \cdot A \cdot L}
\]

\(A\) : acceptance
\(\epsilon\) : efficiency
\(L\) : luminosity
Lepton+Jets Channel

- Fit the Neural Network based flavor separator and nJet spectrum
- Binned Poisson Likelihood fitter

Selection (standard CDF l+j)
- 1 lepton \( p_T > 20 \) GeV
- MET > 20 GeV
- \( \geq 1 \) jet ET > 20 GeV
- \( \geq 1 \) identified b-jet
- QCD veto cuts

Systematics
- For each source
  - Make additional templates
  - Compare event yields relative to nominal
  - Interpolated to a function
  - Included in fit as multiplicative factors to template normalisation

\[ \sigma_{\text{ttbar}} = 7.64 \pm 0.57^{\text{(stat+syst)}} \pm 0.45^{\text{(lumi)}} \text{ pb} \approx 9.5\% \]
3 methods
- Counting method using b-tagging
  - 24 independent measurements combined
  - \( W+\text{jets} \) constrained from data
- Kinematic method
  - ‘Random Forest’ of 200 decision trees
  - 6 input variables
  - Binned Max Likelihood fit to output
- Combined method
  - Use b-tagging and kinematic information
  - Constrain from data \( W+ \) heavy flavour relative to \( W+ \) light flavour
- Systematics as ‘nuisance parameters’ (normalisation only)

\[ \sigma_{\text{t\bar{t}} \to \ell+3\text{jets}} = 7.78 \pm 0.25^{+0.73}_{-0.59} \text{pb} \]
Dilepton Channel

- Selection
  - 2 opposite charge leptons
    - 1 isolated ‘tight’ lepton $p_T > 20$ GeV
    - 1 ‘looser’ lepton $p_T > 20$ GeV
  - $\geq 2$ jets
    - $E_T > 15$ GeV, $|\eta| < 2.5$
  - Missing transverse energy (MET) $> 25$ GeV
  - Z-veto and J/Ψ-veto
  - Summed transverse energy: $H_T > 200$ GeV
  - For b-tagged version: $\geq 1$ identified b-jet

- Dominant systematics
  - Jet corrections (~3.3%)
  - Lepton ID (~2.2%)
  - B-tagging (~4.1%)

\[
\sigma_{\text{pre-tag}} = 7.40 \pm 0.58_{\text{(stat)}} \pm 0.63_{\text{(syst)}} \pm 0.45_{\text{(lumi)}} \text{ pb}
\]
\[
\sigma_{\text{b-tag}} = 7.25 \pm 0.66_{\text{(stat)}} \pm 0.47_{\text{(syst)}} \pm 0.44_{\text{(lumi)}} \text{ pb}
\]
**Dilepton Channel**

- Similar event selection
  - Small changes but same principles
  - 2 ‘tight’ leptons

- **Final discriminant**
  - B-tagging Neural Network (NN) discriminant
  - Use the smallest value from the leading 2 jets

- Simultaneous fit in 4 regions
  - (ee, $\mu\mu$, e$\mu$) + 2 jets
  - e$\mu$ + 1 jet

- Systematics as Gaussian constrained nuisance parameters

\[ \sigma_{\|} = 7.36^{+0.90}_{-0.79} \text{ (stat + syst)} \text{ pb} \hspace{1cm} \sim 11\% \]

\[ \sigma_{\text{ttbar}} = 7.56^{+0.63}_{-0.56} \text{ (stat + syst)} \text{ pb} \hspace{1cm} \sim 8\% \]
Tau+Jets Channel

- World first
  - Previous measurements: tau+lepton+jets
- Investigate properties of only third generation fermions in single process
  - Looking for anomalous branching ratios to taus
- Semi-hadronic tau decays
  - Taus to leptons hard to distinguish from direct leptons
  - Reconstructed using a neural network
- Using multijet trigger: ≥4 jets
- Expect ~15% signal

\[ \sigma_{\text{ttbar}} = 6.9 \pm 1.2^{+0.8}_{-0.7} \text{(stat)} \pm 0.4 \text{(lumi)} \text{ pb} \quad \sim 9\% \]
MET + b-jets Channel

- Measuring the Top Pair background to Higgs search in MET+b-jet
- No lepton ID (veto on leptons)
- Require ≥1 identified b-jet
- Dominant background QCD
  - S:B is 1:15
  - From mis-measured jets leading to MET
  - From semi-leptonic b-quark decays
  - Reduced through a cut on a Neural Network (NN)
    - 15 input variables
    - S:B is 1:6
- Another NN isolates ttbar from other backgrounds
  - 5 input variables (incl. QCD NN)

\[ \sigma_{\text{ttbar}} = 7.12^{+1.20}_{-1.12} \, \text{(stat+syst)} \, \text{pb} \approx 16\% \]
Single Top Quark Production Cross Section

s-channel
$\sigma_{SM} \sim 1 \text{ pb}$

$\bar{q}'$ $q$ $W^+$ $t$

$\bar{b}$

t-channel
$\sigma_{SM} \sim 2.2 \text{ pb}$

$g$ $b$ $W$

$\bar{b}$ $t$

Associated production ($t$ and $W$) Negligible at the Tevatron
**Single Top**

- Measure s-channel and t-channel separately
  - Independent of relative rate

- Many different triggers combined
  - Maximise the acceptance

- ≥1 b-tagged jet
  - S:B 1:33 for 1 b-tag
  - S:B 1:50 for 2 b-tags

- Use 3 MVA techniques
  - Boosted Decision Trees
  - Bayesian Neural Network (BNN)
  - Neuroevolution of Augmented Topologies (NEAT)
  - Combined into an additional BNN (BNNComb)
    - Only ~70% correlated with each other
    - All treat s-channel as background for training

- Fit simultaneously s- and t-channel cross sections

\[
\begin{align*}
\sigma_{pp\rightarrow tqb+X} &= 2.90 \pm 0.59 \text{ pb} \\
\sigma_{pp\rightarrow tb+X} &= 0.98 \pm 0.64 \text{ pb}
\end{align*}
\]

**t-channel:**

~5.5 sigma

(4.6 exp)
Conclusions And Outlook

- Many precision top quark measurements being carried out at the Tevatron
- Precision of cross section measurements now similar to theoretical uncertainties
  - Single best measurement has total uncertainty of ~7%
  - Legacy measurements!!!
- All measurements are consistent with the Standard Model ... unfortunately 😊

DØ Run II

![Graph showing precision measurements](image)

**lepton+jets (topo + b-tagged, PRD)**
- Precision: 5.3 fb⁻¹
- Result: 7.65 ± 0.25 ± 0.75 pb

**dileptons (topo + b-tagged)**
- Precision: 5.3 fb⁻¹
- Result: 7.27 ± 0.45 ± 0.76 pb

**lepton+track (b-tagged)**
- Precision: 1.0 fb⁻¹
- Result: 5.0 ± 1.6 ± 0.9 pb

**tau+lepton (b-tagged)**
- Precision: 2.2 fb⁻¹
- Result: 7.32 ± 1.34 ± 1.20 pb

**tau+jets (b-tagged, PRD)**
- Precision: 1.0 fb⁻¹
- Result: 6.30 ± 1.15 ± 0.72 pb

**alljets (b-tagged, PRD)**
- Precision: 1.0 fb⁻¹
- Result: 6.9 ± 1.3 ± 1.4 pb

**m_{top} = 175 GeV**
- CTEQ6.6M

Assume m_t = 172.5 GeV/c²

**Dilepton**
- L = 5.1 fb⁻¹
- Result: 7.40 ± 0.58 ± 0.63 ± 0.45 pb

**Lepton+jets (topological)**
- L = 4.6 fb⁻¹
- Result: 7.82 ± 0.38 ± 0.37 ± 0.15 pb

**Lepton+jets (b-tagged)**
- L = 4.3 fb⁻¹
- Result: 7.32 ± 0.36 ± 0.59 ± 0.14 pb

**All-hadronic**
- L = 2.9 fb⁻¹
- Result: 7.21 ± 0.50 ± 1.10 ± 0.42 pb

**MET+3jets**
- L = 2.2 fb⁻¹
- Result: 7.99 ± 0.55 ± 0.76 ± 0.46 pb

**MET+2/3jets**
- L = 5.7 fb⁻¹
- Result: 7.11 ± 0.49 ± 0.96 ± 0.43 pb

*(stat) ± (syst) ± (lumi)*