Top Cross Section Measurement at CDF

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Top Quark Physics

- Top quark first observation at Tevatron in 1995
- Existence Required by the SM: Spin 1/2 fermion, charge +2/3, weak-isospin partner of the b quark

- **Mass**: top is ~40x heavier than the bottom quark: only SM fermion with mass at the EW scale
  Large contribution in virtual fermionic loops

- Top decays before hadronization: $\Gamma \sim 1.4$ GeV $>\Lambda_{QCD}$
  Provide an unique opportunity to study a "bare" quark

*Is it the SM top?*
Budget approval pending for FY11 running

12 fb\(^{-1}\) delivered ~doubles the current dataset and results in analyses with about 10 fb\(^{-1}\)
Top Quark Production at Tevatron

Top Quark Production

In Pairs

\[ \sigma_{NLO} = 7.4^{+0.5}_{-0.7} \text{ pb} \]
JHEP 0809, 127 (2008)

Single

\[ \sigma_{NLO} = 3.4 \pm 0.4 \text{ pb} \]
PRD 74, 114012 (2006)

\[ m_{\text{top}} = 172.5 \text{ GeV} \]

Top Quark Decay

\[ \text{BR}(t \rightarrow Wb) \sim 100\% \]

s-channel

~ 85% ~ 30% ~ 15% ~ 70%

t-channel

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Top Quark Production at Tevatron

Top quarks are rare!

Small cross section: only 1 top pair in 10 billion inelastic collisions → for an integrated luminosity of ~1 fb$^{-1}$ around 7000 top pairs and 3500 single tops are expected.

Other processes appear as background...

...makes Single top especially difficult.
\( \sigma_{t\bar{t}} \) is an inclusive quantity that allows:

- test the SM: compare the experimental measurement with the QCD NLO prediction
- measuring \( \sigma_{t\bar{t}} \) is first thing you have to do before studying other top properties
- study clean top samples

Is also a probe to new physics (Massive gluons, \( Z' \), ...):

- anomalous \( t\bar{t} \) production rate
- compare cross-sections in different top decay channels

Allows careful evaluation of background for Higgs and new phenomena searches
How?

$$\sigma_{ttbar} = \frac{N_{\text{observed}} - N_{\text{background}}}{\varepsilon_{ttbar}(m_{top}) \cdot L}$$

- Event counting or fit of discriminating variable shape
- Number of expected background events
  Using Monte Carlo or data
- Signal selection efficiency
  using $ttbar$ Monte Carlo samples
  Pythia or Alpgen
- Recorded luminosity
  Channel dependent
Top Pair Production Signatures

- **Dilepton** (e or $\mu$) 5%
  - Low rate, low background (mainly Drell-Yan)
  - High purity

- **Lepton (e or $\mu$) + jets** 30%
  - Higher rate, manageable background (mainly W+jets)
  - Golden Channel

- **All hadronic** 44%
  - Large rate, large background (mainly QCD)
  - Lowest purity

**Hadronic Taus** (tau+lepton, tau+jets) (14%):
- Small rate and large background (mainly Multijets, W+jets)
- Challenging purity

**MET+jets** (“hybrid channel”):
- Focus on MET from $\nu$, catches what other channels miss (bkg mainly QCD, EWK+HF)
- Large acceptance to taus in the final state
**Selection:**

2 OS isolated leptons (e, μ) with ET ≥ 20 GeV  
jets with |η| < 2.5 and ET ≥ 15 GeV,  
at least one jet with ET ≥ 30 GeV  
Drell Yan veto  
MET ≥ 25 GeV

**Background Modeling:**

Drell Yan, diboson → use Monte Carlo  
Fakes, QCD → use data with same charge leptons

\[
\sigma_{\text{tt}} = 6.56 \pm 0.65 \text{ (stat)} \pm 0.41 \text{ (syst)} \pm 0.38 \text{ (lumi)} \text{ pb}
\]

Very clean \( \text{ttbar} \) sample!

CDF dilepton (4.5 fb\(^{-1}\)):
\[
\sigma_{\text{tt}} = 6.56 \pm 0.65 \text{ (stat)} \pm 0.41 \text{ (syst)} \pm 0.38 \text{ (lumi)} \text{ pb}
\]
\[
\Delta \sigma / \sigma = 13\%
\]
For the other channels, ttbar signature is not as clean as in the dilepton, need additional tools to identify top pairs decay products → **b-tagging**

**Secondary Vertex** tagging:
search a displaced secondary vertex among high impact parameter tracks using an iterative fit.

**Efficiency** is tuned on data:
- is around 50% for ttbar central b-jets
- mistag rate kept under 2% for tight SecVtx
Selection:
1 isolated lepton (e, μ) with ET>20 GeV
≥3 jets with |η|<2.0, ET>20 GeV
MET>25 GeV
≥1 SecVtx b-tagged jet
H_T > 250 GeV (Sum of the transverse energy of jets, lepton, and MET)

CDF lepton+jets b-tag (4.3 fb⁻¹):
σ_{ttbar} = 7.22 ± 0.35 (stat) ± 0.56 (syst)
± 0.44 (lumi)
Δσ/σ = 10.3%
Lepton + jets channel with b-tag

Selection:
1 isolated lepton (e, μ) with ET > 20 GeV
≥3 jets with |η| < 2.0, ET > 20 GeV
MET > 25 GeV
≥1 SecVtx b-tagged jet
H_{T} > 250 GeV

Largest Systematics:

- 6% luminosity uncertainty
- 5% uncertainty in correction to b-tagging modeling in MC
- 4% uncertainty in correction to W+HF MC

CDF lepton+jets b-tag (4.3 fb^{-1}):
σ_{ttbar} = 7.22 ± 0.35 (stat) ± 0.56 (syst)
± 0.44 (lumi)
Try a different, topological, approach using Neural Networks: Rely on identifying top events through kinematics as opposed to b-jet identification → no b-tag, same selection with no $H_T$ cut

**Kinematic Variables:**
- Total Sum Transverse Energy
- Aplanarity
- Sum $P_z / Sum Et$ of Jets
- Sum Jet Et Excluding Two Highest
- Minimum Di-Jet Mass
- Minimum Angle Between Two Jets
- Maximum Angle of a Jet

train NN to distinguish signal from background and fit templates to data

CDF lepton+jets NN (4.6 fb⁻¹):
$$\sigma_{tt\overline{t}} = 7.71 \pm 0.37 \text{ (stat)} \pm 0.36 \text{ (syst)} \pm 0.45 \text{ (lumi)} \text{ pb}$$

Largest systematics:
- 6% Luminosity
- 3% Jet Energy Scale

$\Delta \sigma / \sigma = 8.8\%$
Optimizing the analysis: reducing the largest systematics

- $\sigma_Z$ well known theoretically
- $Z$ well modeled in MC
- $Z$ small background
- Luminosity uncertainty can be **cancelled out** in ratio if we use the same triggers and data periods

measure:

$$R = \frac{\sigma_{ttbar}}{\sigma_{Z->ll}}$$

Get $\sigma_{ttbar} = R \sigma_{Z->ll} (th)$

**lepton+jets with b-tag and Z ratio (4.3 fb⁻¹):**

$\sigma_{ttbar} = 7.32 \pm 0.36 \text{ (stat)} \pm 0.59 \text{ (syst)} \pm 0.14 \text{ (Z theory)}$

$\Delta \sigma/\sigma = 9.6\%$

**lepton+jets with NN and Z ratio (4.6 fb⁻¹):**

$\sigma_{ttbar} = 7.82 \pm 0.38 \text{ (stat)} \pm 0.37 \text{ (syst)} \pm 0.15 \text{ (Z theory)}$

$\Delta \sigma/\sigma = 7.0\%$
**Selection:**
- Veto leptons and require low MET
- Require $6 \leq N_{jets} \leq 8$ in the signal region
- Use a NN (jet invariant masses, sphericity, aplanarity, …) to separate S/N
- Jet shapes variables allow to separate quark jets from gluon jets, big impact in the NN
- $\geq 1$ SecVtx b-tagged jets

**Technique:**
- Parameterize background b-tags from 4 Jet data, QCD dominated, using b-tag rates
- Use a kinematic fitter to reconstruct $M_{top}$ for each event
- From MC get $M_{top}^{reco}$ distribution for different values of the input top mass (templates)
- By fitting data to templates of Signal+Background get the number of ttbar events and measure cross section

CDF all hadronic ($2.9 \text{ fb}^{-1}$):

$$\sigma_{ttbar} = 7.21 \pm 0.50 \text{ (stat)} \pm 1.10 \text{ (syst)}$$

$$\pm 0.42 \text{ (lumi)} \text{ pb}$$

$\Delta \sigma/\sigma = 17.7\%$
Analysis focuses on MET from neutrino rather than on lepton identification, requires large Jet multiplicity, at least one btagged jet

**Selection**
- Require significant MET, $\text{MET}_{\text{Sigf}} > 3 \text{ GeV}^{1/2}$
- Veto well reconstructed leptons
- Require 4 or more jets
- Use a NN to discriminate S/N
- Parameterize background b-tags from 3 Jet data, QCD dominated
- Perform counting experiment on b-tags for events with $\text{NNout}>0.8$

Large acceptance to tau+jets events!
Orthogonal and complementary results with respect to other channels

CDF MET+jets (2.2 fb$^{-1}$):

$\sigma_{t\bar{t}b} = 7.99 \pm 0.55 \text{ (stat)} \pm 0.76 \text{ (syst)}$

$\pm 0.46 \text{ (lumi)} \text{ pb}$

$\Delta \sigma / \sigma = 13\%$
Overview and combination

Good agreement:
• among different channels
• with theoretical prediction

\[ \Delta \sigma / \sigma = 6.5\% \]

*(not yet updated with the latest results)
One more thing: $\text{ttbar+jet}$ cross section

- Important test of perturbative QCD, NLO effects
- at the LHC $\text{ttbar}$ will be produced with additional jets → background for many new physics signals
- use $b$-tagged events in the lepton+jets channel
- data-driven background
- 2D likelihood to simultaneously measure $\text{ttbar+jet}$ and $\text{ttbar}$ without jet cross sections

CDF result ($4.1 \text{ fb}^{-1}$):
$$\sigma_{\text{ttbar+jet}} = 1.6 \pm 0.2 \text{ (stat)} \pm 0.5 \text{ (syst)} \text{ pb}$$

Theory:
$$\sigma_{\text{ttbar+jet}} = 1.79^{+0.16}_{-0.31} \text{ pb}$$
Conclusions

• Reviewed CDF measurements of the top pair production cross section in different channels

• Experimental uncertainties in the various channels are comparable to the theoretical
• Uncertainty of the CDF combination is even better than the theoretical

• Cross sections are consistent with SM, but still plenty of room for new physics!
Selection:
2 OS isolated leptons (e, μ) with ET ≥ 20 GeV
jets with |η| < 2.5 and ET ≥ 15 GeV, at least one jet with ET ≥ 30 GeV

Can apply b-tagging to the dilepton channel

In addition to standard dilepton selection, require at least one SecVtX tag in the event and perform a counting experiment to get the cross section

CDF dilepton with b-tag (4.5 fb⁻¹):
σ_{ttbar} = 7.27 ± 0.71 (stat) ± 0.46 (syst) ± 0.42 (lumi) pb

Δσ/σ = 13%
Lepton+Jets NN variables
Jet Shapes in the all hadronic analysis

\[ M_\eta = \sqrt{\left[ \sum_{\text{tow}} \frac{E_{T_{\text{tow}}}}{E_T} \eta_{\text{tow}}^2 \right]} - \eta^2 \]

\[ M_\phi = \sqrt{\left[ \sum_{\text{tow}} \frac{E_{T_{\text{tow}}}}{E_T} \phi_{\text{tow}}^2 \right]} - \phi^2 \]

FIG. 1: Geometric average of the \( \eta \) scaled moments (\( \langle M_\eta^8 \rangle \), upper plot) and of the \( \phi \) scaled moments (\( \langle M_\phi^8 \rangle \), lower plot) for QCD multijet (solid histogram) and simulated \( t\bar{t} \) (dashed histogram) events with \( 6 \leq N_{\text{jets}} \leq 8 \).
- Silicon tracking
- Large radius drift chamber ($r=1.4m$)
- 1.4 T solenoid
- Projective calorimetry ($|\eta| < 3.5$)
- Muon chambers ($|\eta| < 1.0$)
- Silicon Vertex Trigger
The Tevatron Collider

- Circumference 6.8 km
- ppbar collisions at 1.96 TeV
- Run I (1987-1995)
- Run II (since 2001)
- Surpassed design luminosity

Peak Luminosity

\[ \sim 4 \times 10^{32} \text{ cm}^{-2}\text{sec}^{-1} \]