Top quark pair production at the Tevatron

Fabrizio Margaroli

On behalf of CDF and D0 collaboration
Top was discovered at Fermilab in 1995
Its mass much larger than any other fermion
Using the latest Tevatron-averaged $M_{\text{top}}$ 

$$L_{\text{Yukawa}} = -\lambda \bar{\psi}_L \Phi \psi_R$$

Yukawa coupling = 0.996±0.006

- What role does it play in EW symmetry breaking?
- Several authors point to a special role for the top quark

Lifetime shorter than hadronization time
→ only quark that decays before hadronizing
Top anti-top production is the dominant mode at a hadron collider

- QCD process: test pQCD NLO calculation
- First step in understanding selected top quark sample
- New physics in ttbar production or decays could appear as larger/lower $\sigma_{\text{tt}}$, or in different measured $\sigma_{\text{tt}}$ in different channels

$\sigma_{\text{tt}} = 7.5\text{pb}^*$

*$M_{\text{top}} = 172.5\text{GeV}, E_{\text{cm}} = 1.96\text{TeV}$
Fermilab’s Tevatron Run II $p\bar{p}$ collider at 1.96 TeV, running since year ‘01. Currently performing very well:

- New record in instantaneous luminosity $4 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$
- New record in delivered luminosity: $>2\text{fb}^{-1}$ per year
- Two multi-purpose, well-understood detectors CDF and D0

Top created in 1 in $O(10^{10})$ collisions at the Tevatron
How many?

Delivered 9.0 fb\(^{-1}\)
Acquired 7.6 fb\(^{-1}\)* (slightly less w/ silicon)
Almost 6 fb\(^{-1}\)* analyzed

*CDF shown here
Similar numbers for D0
Pair production decay signatures

- **Lepton+Jets**
  - large BR(30%)
  - good S/B ratio.

- **Dileptonic**
  - Highest S/B
  - lowest BR(5%)

- **All hadronic**
  - highest BR(44%)
  - Very large QCD background

Total acceptance 9%

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Tau modes
- explicit tau identification

MET + jets
- Lepton+jets and dileptonic decays where electron/muon is not id’ed.
  Large acceptance to taus

Total acceptance 13%
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Expect to analyze more than 30,000 top quarks by 2011

Total acceptance 13%
Quark/gluons hadronize and produce particle jets. B-jets identification very important for top physics

**Secondary vertex:** b-quark id’ed w long lifetime of the B mesons they form: identification through search of a secondary vertex within a jet:
- b-tag eff: $\sim 40\%$
- fake rate $\sim 0.5\%

**Neural Network** for flavor separation
- $L_{xy}$, vertex mass, track multiplicity, impact parameter, semi-leptonic decay information, etc...
Lepton+jets b-tagged

Counting experiment after background understanding:
- W+HF cross section underestimated in the MC: W+HF content measured in data in the 1 or 2 jet event sample
- b-tagging mistag rate measured in data, parametrization applied to W+jets
- CDF measures ratio of ttbar/Z→ll with the same trigger and use the theoretical Z cross section to remove the uncertainty due to luminosity measurement

D0 (L=4.3fb⁻¹): σ_{tt} = 7.93 ± 0.98 (stat+syst+lumi) pb
CDF(L=4.3fb⁻¹): σ_{tt} = 7.32 ± 0.71 (stat+syst+theory) pb
Lepton+jets topological

One step further: signal/background discrimination:
• $t\bar{t}$bar more energetic, central and isotropic than $W$+jets
• NN (CDF) or BDT (D0) input variables: $H_t$, aplanarity, sphericity, etc.
• cross section measurement: template fit of $t\bar{t}$bar and $W$+jets to the discriminant output
• CDF measures ratio of $t\bar{t}$bar/$Z\rightarrow ll$ with the same trigger and use the theoretical $Z$ cross section to remove the uncertainty due to luminosity measurement

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D0 (L=4.3 fb$^{-1}$): $\sigma_{t\bar{t}} = 7.70 \pm 0.75$ (stat+syst+lumi) pb
CDF(L=4.6 fb$^{-1}$): $\sigma_{t\bar{t}} = 7.82 \pm 0.55$ (stat+syst+theory) pb
Simultaneous S and B kinematic fit

Looser event selection, better constraint on backgrounds
- Use events with 1 lepton, ≥1 jet, ≥1 b-tag to measure signal cross section and background contributions.
- Templates: NN based flavor separator, N_{jets}, N_{btags}
- Fit simultaneously for $\sigma_{tt}$, W + heavy flavor fractions and systematics sources in situ
- Potentially very sensitive as more data is added

CDF Run II Preliminary 2.7 fb$^{-1}$

$\sigma_{tt} = 7.64 \pm 0.57\text{(stat+syst)} + 0.45\text{(lumi)}$ pb
Dileptonic channel

Signal/background discrimination
- CDF: Ht and MET significance cuts, or b-tagging
- D0: Ht cut and BDT trained against Z+jets and diboson

CDF Run II Preliminary (5.1 fb⁻¹)
- Data
- Bkgd ± 1σ uncertainty
- tt (σ = 7.4 pb)
- WW/WZ/ZZ
- DY
- Fake

CDF Run II Preliminary (4.8 fb⁻¹)
- Data
- Bkgd ± 1σ uncertainty
- tt (σ = 7.4 pb)
- WW/WZ/ZZ
- DY+HF
- DY+LF
- Fake

D0 (L=5.3 fb⁻¹):
\[ \sigma_{tt} = 8.4 \pm 0.5\text{(stat)} \pm 0.9\text{(syst)} \pm 0.7 \text{(lumi)} \text{ pb} \]

Pretag CDF (L=5.1 fb⁻¹):
\[ \sigma_{tt} = 7.4 \pm 0.6\text{(stat)} \pm 0.6 \text{(syst)} \pm 0.5 \text{(lumi)} \text{ pb} \]
All-hadronic channel

Both collaborations use b-tagging and multivariate techniques to isolate the signal from the overwhelming QCD background.

To measure the cross section:

- CDF cuts on NN output, scans the reconstructed $M_{\text{top}}$
- D0 scans the likelihood output

JES largest syst: CDF uses $W \to qq$ decays to constrain it.

Exploiting distinctive quark-jet vs gluon-jet features

D0 (L=1.0fb$^{-1}$): $\sigma_{tt} = 6.9 \pm 1.3 \text{ (stat)} \pm 1.4 \text{ (syst)} \pm 0.4 \text{ (lumi)} \text{ pb}$

CDF(L=2.9fb$^{-1}$): $\sigma_{tt} = 7.2 \pm 0.5 \text{ (stat)} \pm 1.0 \text{ (syst)} \pm 0.4 \text{ (lumi)} \text{ pb}$

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Top pair production at the Tevatron
Charged Higgs search

Cross section in different channels sensitive to new physics: in SM extension with extended Higgs sector (like MSSM or HDM) $t \rightarrow H^+ b$ can compete with $t \rightarrow Wb$. Strategy: compare number of events in $ljets$, $ll$ and $l+\tau$:

- $H^+ \rightarrow \tau \nu$ would increase $t\bar{t}$ events identified through taus
- $H^+ \rightarrow cs$ would give larger than expected lepton+jets events

![Graphs showing cross section and branching ratios](image1)

![Graphs showing cross section and branching ratios](image2)
Missing energy plus many jets

MET + jets: -alternative way to select tau channels, and recover unidentified e/mu (1/3tau, 1/3e, 1/3mu)

Independent from “lepton+jets” channel

- at least 3 strict identified jets, at least one b-tagged jet
- NN trained against background, NN > 0.8 background estimation:
  - b-tag rate/misrate evaluated from data in a 3 jet sample (small signal contamination)sample composition
  - Counting experiment - count number of b-tagged jet

$$\sigma_{tt} = 7.99 \pm 0.55\text{(stat)} + 0.76\text{(syst)} + 0.46\text{(lumi)} \text{ pb}$$
Many new particles can appear here

- Higgs! (ZH→ννbb)
- \( \tilde{t}\tilde{b} \rightarrow bb\chi^{0}\chi^{0} \)
- 3rd gen leptoquarks
- technicolor etc.

**ttbar cross section measurement here is**

- a test of the backgrounds for Higgs and NP
- independent from other measurements \( \rightarrow \) can be combined

Using same strategy as in search for ZH→ννbb:

- Suppress overwhelming QCD background using multivariate technique (NN)
- Isolate the signal from remaining backgrounds, likelihood scan of NN output

\[ \sigma_{tt} = 7.1 \pm 1.1 \text{ (stat+syst+lumi) pb} \]
Total cross section: summary

Good consistency among channels/experiments
Planning to combine CDF and D0 measurements to increase precision
tt\bar{t}+jets

Test of QCD prediction, sensitive to NLO effects
Most top events at the LHC will be produced with additional jets → substantial background for many new physics signals
Strategy: simultaneous fit of tt+0jet and tt+1jet
SM cross section is $\sigma_{tt} = 1.79^{+0.16}_{-0.31}$pb

$\sigma_{tt+\text{jet}} = 1.6 \pm 0.2 \text{ (stat)+0.5(syst)}$ pb

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Differential cross sections

After measuring total cross sections, measuring differential cross sections is an important step:

• test perturbative QCD in finer details
• probes non-SM production mechanisms
• Lepton+jets mode best here for high purity and large statistics
Search for boosted top quarks

Decays fully contained in jet cone happen with high top Pt (≥400GeV here)
- identification of the W decay and the b quark unfeasible
- jet has mass ~ M_{top} → very different from jets from lighter quarks or gluons

Cross section for events with Pt(top) ≥ 400GeV is a handful of fb

**all-hadronic decays:**
- two tops with mass ~ 175

**Lepton+jets decays:**
- one jet with mass ~ 175, large MET

Set limits on ttbar xsec < 55 fb @ 95CL (expected < 39 fb)
Summary

• Measurement of the total cross section with the Tevatron large dataset allowed
  – understanding of the sample composition fundamental to perform top properties measurements (mass, spin, charge, etc.)
  – precision in xsection measurement higher than (N)NLO
  – comparison among channels to probe exotic decays ($H^+$)
  – establishing the t\(\bar{t}\) background to new physics searches ($t\bar{t}+X$, resonant production through $Z'$, low mass Higgs, etc.)

• Studies of differential t\(\bar{t}\) xsections probe in a finer way (N)NLO QCD and resonant production

• Searching boosted top quarks allows studies of jets substructure and establish tools for searching Higgs and New Physics at the Tevatron/LHC
Summary

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• **Studies of differential ttbar xsections probe in a finer way (N)NLO QCD and resonant production**

• **Searching boosted top quarks allows studies of jets substructure and establish tools for searching Higgs and New Physics at the Tevatron/LHC**

Thank you!