Tevatron Top Physics

on behalf of the

and

and

Collaborations

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LHC 2008

Split

Photo: Reidar Hahn, artwork: Jan Lück
Overview

1995: Discovery of top quark

Is our top = SM top?

Top quark mass

New physics in top events?

<table>
<thead>
<tr>
<th>Top pair production</th>
<th>single top production</th>
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<td>strong interaction (QCD)</td>
<td>electroweak interaction</td>
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New physics in events with top signature?
Overview

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Is our top = SM top?
- cross section
  \((single \ top \ and \ top \ pair)\)
- Properties of production \((f_{ggf} \ asymmetry)\)
- Wtb-couplings
- Charge, lifetime, branching ratios

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\(strong \ interaction \ (QCD)\)

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\(electroweak \ interaction\)

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Top quark mass:
- Important SM parameter
  (constraints on Higgs mass)
- Precision measurement
- Are all results consistent?

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(QCD)
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- New resonances
- Anomalous top prod.
- New physics in decay

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New physics in events with top signature?
- fourth generation: t'
- SUSY partner: stop

Top pair production
strong interaction (QCD)

Single top production
electroweak interaction

LHC 2008, Split, 1.10.2008
Top Quark Production

Tevatron: proton anti-proton collisions at $\sqrt{s} = 1.96$ TeV

Top pair production:

SM: $\sigma = 6.7 \pm 0.8$ pb


- Quark anti-quark annihilation:
  $\approx 85\%$

- Gluon fusion:
  $\approx 15\%$

Single top production:

SM: $\sigma = 2.9 \pm 0.4$ pb


- T-channel:
  $\sigma_t = 1.98 \pm 0.25$ pb

- S-channel:
  $\sigma_s = 0.88 \pm 0.11$ pb
Decay of Top Quarks

$t \rightarrow bW \approx 100\%$

Top pairs:
- lepton+jets
  - BR ≈ 30%
  - moderate background

Single top:
- t-channel
  - BR ≈ 30%
  - moderate background

Single top: Leptonic W decay (e or μ)
(BR ≈ 21%)
Is our top = SM top?
Single Top Quarks - Cross Section

Experimental challenge:
Large background from W+jets
→ Use of multivariate techniques

CDF and DØ \(tb+q\bar{b}\) Cross Section

<table>
<thead>
<tr>
<th>Method</th>
<th>(2.7) fb(^{-1})</th>
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<tr>
<td>CDF Decision Trees</td>
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<tr>
<td>CDF Neural Networks</td>
<td>2.1 (+0.7) (-0.6) pb</td>
<td></td>
</tr>
<tr>
<td>CDF Likelihood Funcs.</td>
<td>2.0 (+0.9) (-0.8) pb</td>
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**CDF Combination**
\(2.2\) fb\(^{-1}\) submitted to PRL

- \(2.2\) \(+0.7\) \(-0.6\) pb

**DØ Decision Trees**
\(0.9\) fb\(^{-1}\)

- 4.9 \(+1.4\) \(-1.4\) pb

**DØ Matrix Elements**
\(0.9\) fb\(^{-1}\)

- 4.8 \(+1.6\) \(-1.4\) pb

**DØ Bayesian NNs**
\(0.9\) fb\(^{-1}\)

- 4.4 \(+1.6\) \(-1.4\) pb

**DØ Combination**

- 4.7 \(+1.3\) \(-1.3\) pb

*N. Kidonakis, PRD 74, 114012 (2006)*

\(m_{\text{top}} = 175\) GeV

**Observed p-value**

- \(3.7\) \(\sigma\)

*Z. Sullivan, PRD 70, 114012 (2004)*

\(m_{\text{top}} = 175\) GeV

- \(3.6\) \(\sigma\)

**Combination: Exp. p-value**

- \(4.9\) \(\sigma\)

*arXiv:0809.2581*

**Combination: Obs. p-value**

- \(3.7\) \(\sigma\)

*Phys. Rev. D78, 012005 (2008)*

- \(3.6\) \(\sigma\)

Strong evidence for single top at both Tevatron experiments
Top Pair Cross Section

**CDF Run II**

- Lepton+Track (L = 1.1 fb⁻¹): 8.3 ± 1.3 ± 0.7 ± 0.5 pb
- Lepton+Track: Vertex tag (L = 1.1 fb⁻¹): 10.1 ± 1.8 ± 1.1 ± 0.6 pb
- Dilepton (L = 2.8 fb⁻¹): 6.7 ± 0.8 ± 0.4 ± 0.4 pb
- Lepton+Jets; Kinematic ANN (L = 2.8 fb⁻¹): 6.8 ± 0.4 ± 0.6 ± 0.4 pb
- Lepton+Jets; Vertex Tag (L = 2.7 fb⁻¹): 7.2 ± 0.4 ± 0.5 ± 0.4 pb
- Lepton+Jets; Soft Electron Tag (L = 2.0 fb⁻¹): 7.8 ± 2.4 ± 1.5 ± 0.5 pb
- Lepton+Jets; Soft Muon Tag (L = 2.0 fb⁻¹): 8.7 ± 1.1 ± 0.9 ± 0.5 pb
- MET+Jets; Vertex Tag (L = 0.3 fb⁻¹): 6.1 ± 1.2 ± 0.8 ± 0.4 pb
- All-hadronic; Vertex Tag (L = 1.0 fb⁻¹): 8.3 ± 1.0 ± 2.0 ± 1.5 ± 0.5 pb
- CDF combined (L = 2.8 fb⁻¹): 7.0 ± 0.3 ± 0.4 ± 0.4 pb

**DØ Run II**

- l+jets & dilepton & tau+lepton*: 8.3 ± 0.46 ± 0.64 ± 0.45 pb
- l+jets (b-tagged & topological, PRL): 7.42 ± 0.53 ± 0.46 ± 0.45 pb
- l+jets (neural network b-tagged)*: 8.20 ± 0.52 ± 0.77 ± 0.50 pb
- dilepton (topological)*: 7.03 ± 1.12 ± 0.75 ± 0.43 pb
- l+track (b-tagged)*: 5.0 ± 0.5 ± 0.9 ± 0.3 pb
- tau+lepton (b-tagged)*: 7.32 ± 1.34 ± 1.20 ± 0.45 pb
- tau+jets (b-tagged)*: 5.1 ± 4.3 ± 0.7 ± 0.3 pb
- alljets (b-tagged, FRD): 4.5 ± 2.0 ± 1.4 ± 0.3 pb

Rel. uncertainty of σ: ~9%
Measurements in all channels and with different methods are consistent

\[ \sigma = 7.8 \pm 0.5 \text{(stat.)} \pm 0.6 \text{(syst.)} \pm 0.5 \text{(lumi)} \text{ pb} \]
Production via Gluon Fusion

- Sensitive to spin configuration:
  \(l + j\): Kinematic of prod. and decay (NN)
  \(ll\): Azimuthal angle difference between leptons

- Sensitive to radiation of soft gluons:
  \(l + j\): Number of tracks with small \(p_T\)

Lepton + jets

CDF Run II Preliminary (2 fb\(^{-1}\))

\(f_{gg} = 0.07^{+0.15}_{-0.07}\)

\(ll\): \(f_{gg} = 0.53^{+0.36}_{-0.38}\)

NLO: \(f_{gg} = 0.15 \pm 0.05\)

Measurements consistent with SM

arXiv:0807.4262
Forward-Backward Asymmetry

- SM: small asymmetry of ~5% caused by NLO ttX effects
- New physics (Z' or axigluons) might enhance asymmetry

**Corrected for acceptance and measurement dilutions:**

\[ A_{tt\bar{t}} = (24 \pm 13 \pm 4)\% \quad A_{\text{lab}} = (17 \pm 7 \pm 4)\% \]

**SM:** \[ A_{tt\bar{t}} = (6 \pm 1)\% \quad A_{\text{lab}} = (4 \pm 1)\% \]

Asymmetries larger than SM pred., but consistent with pred. within uncertainties
Wtb coupling

Wtb vertex \textit{(interaction Lagrangian)}

\[ \mathcal{L} = \frac{g_w}{\sqrt{2}} \left[ W^-_{\mu} \bar{b} \gamma^{\mu} (f_1^L P_L + f_1^R P_R) t - \frac{1}{m_W} \partial_{\nu} W^-_{\mu} \bar{b} \sigma^{\mu\nu} (f_2^L P_L + f_2^R P_R) t \right] + h.c. \]

SM couplings: \( f_1^L = 1, \ f_2^L = f_1^R = f_2^R = 0 \)

Non-SM couplings would affect:

- Single top production: \textit{Rate and kin. distributions}
- Top pair events:

W-helicity in top decay, sensitive variable \( \cos \Theta^* \):

\[ \theta^* \]

Angle between lepton and negative direction of top quark in W-Boson rest frame

\begin{tabular}{ | c | c | } \hline
\textbf{Coupling} & \textbf{Measured Value} \\ \hline
\( f_1^L, f_2^L \) & \( |f_1^L|^2 = 1.4^{+0.6}_{-0.5}, \ |f_2^L|^2 < 0.5 \) \\ \hline
\( f_1^L, f_1^R \) & \( |f_1^L|^2 = 1.8^{+1.0}_{-1.3}, \ |f_1^R|^2 < 2.5 \) \\ \hline
\( f_1^L, f_2^R \) & \( |f_1^L|^2 = 1.4^{+0.9}_{-0.8}, \ |f_2^R|^2 < 0.3 \) \\ \hline
\end{tabular}

Results consistent with SM
Wtb coupling: W-Helicity

SM prediction:

\[ f_0 = 0.7, \quad f_- = 0.3, \quad f_+ = 0 \]

\( f_0 \) = Longitudinal, \( f_- \) = left-handed, \( f_+ \) = right-handed

- Lepton+jets channel
- Combination of two analyses (template and convolution analysis)
- Use both W's in each event

CDF II preliminary, 1.9 fb\(^{-1}\)

**template analysis**

\[ f_0 = 0.66 \pm 0.16, \quad f_+ = -0.03 \pm 0.07 \]

\[ f_0 = 0.62 \pm 0.11 \quad \text{(SM f_+)} \quad f_+ = -0.04 \pm 0.05 \quad \text{(SM f_0)} \]

DO Run II Preliminary

\[ f_0 = 0.49 \pm 0.13, \quad f_+ = 0.11 \pm 0.07 \]

Results compatible with SM

LHC 2008, Split, 1.10.2008

Jeannine Wagner-Kuhr
Top Quark Mass
Tevatron Top Mass Combination

**Di-lepton**
- Use of top pair candidates in different decay channels

**Lepton+Jets**
- Calibrate jet energy scale with in-situ measurement of $W \rightarrow jj$ (l+j, all j)

**All hadronic**
- $l+j$: $p_T^l$, $L_{xy}$

Relative precision of top quark mass: 0.7%
Consistent results in all decay channels and for different methods

**Mass of the Top Quark (*Preliminary)***
- CDF-II di-l: $171.2 \pm 2.7 \pm 2.9$
- D0-II di-l: $174.4 \pm 3.2 \pm 2.1$
- CDF-II +j: $176.1 \pm 5.1 \pm 5.3$
- D0-II +j: $180.1 \pm 3.9 \pm 3.6$
- CDF-II all-|: $186.0 \pm 10.0 \pm 5.7$
- CDF-II all-|: $176.9 \pm 2.6 \pm 3.3$
- CDF-II trk: $175.3 \pm 6.2 \pm 3.0$
- Tevatron July’08: $172.4 \pm 0.7 \pm 1.0$ (stat) $\pm$ (syst)

$\chi^2$/dof = 6.9/11.0 (81%)
**Most Precise $M_{\text{top}}$ Measurements**

ME-method, in-situ calibration, use of neural networks

$M_{\text{top}} = (172.2 \pm 1.0 \pm 1.3) \text{ GeV}$

Relative precision of most precise individual top mass measurements: \(~1\%\)
New Physics in Top Events?
Top Pairs - Massive Resonances?

Sensitive variable: Reconstructed mass of top pair

Heavy gluon

General search

CDF Run II Preliminary 1.9 fb⁻¹

Leptophobic Z'

No hints for massive resonances in top pair production
Single Top – Massive Resonances?

Charged Higgs

Additional boson: $W'$

No hints for massive resonances in single top production
Top Pairs - Search for $H^+$ in Decay

- Search for $H \rightarrow cs$
- Sensitive variable: $M_{jj}$
- Search separately for $H \rightarrow cs$ and $H \rightarrow \tau \nu$
- Measure rate across several decay modes

Di-jet mass in top decays [CDF Run II Preliminary]

No hints for a charged Higgs in decays of top pair events
Search for FCNC

FCNC in top pair decays

\[ B(t \rightarrow Zq) < 3.7\% \text{ (95\% C.L.)} \]

Sensitive variable:

\( X^2 \) of kinematic fit with FCNC hypothesis

No hints for FCNC in top events

Use standard single top selection, but require \( N_{\text{jets}} = 1 \)

\( \sigma_{\text{ano}} < 1.8 \text{ pb, } \kappa_{\text{gtu}}/\Lambda < 0.025 /\text{TeV} \)

arXiv:0805.2109

New Physics in Events with Top Signature?
Heavy Top - \( t' \) & Top Partner - stop

- Search for a \( t' \) in events with top pair lepton+jets signature
- Sensitive variables: \( \text{Rec. } t' \text{ mass } M_{\text{reco}} \), total trans. energy in event \( H_T \)
- Search for a light stop in events with top pair di-lepton signature
- Sensitive variable: \( \text{Rec. stop mass } (\tilde{\chi}^0 + \nu) \) as pseudo-particle

No hints for new physics with top signature

CDF Run 2 (2.8 fb\(^{-1}\))
Preliminary
\( t' \rightarrow Wq, \geq 4 \) jets
\( H_T \text{ vs } M_{\text{reco}} \)

Observed 95\% CL
Summary

Most recent results on top quark physics from Tevatron:

- Our top quark behaves like the SM top quark
- Relative precision of top mass measurement: 0.7%
- No hints of new physics in top events
- No hints of new physics in events with top signature

Still potential to improve precision and sensitivity for new physics