Top Physics at the LHC

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The Top Quark in the Standard Model

Discovered in 1995 at the TeVatron, flurry of measurements
We still don’t know all about it

- Mass
- Top width ~1.5 GeV
- Electric charge $\frac{2}{3}$
- Spin $\frac{1}{2}$
- BR(t→Wb) ~ 100%
- Production mechanisms

Precision <2%
?
-4/3 excluded @ 94% C.L. (preliminary)
Not really tested – spin correlations
At 20% level in 3 generations case
FCNC: probed at the 10% level
Single Top: not yet observed

The LHC offers opportunity for further testing and precision measurements

9/11/06
Simona Rolli, PASCOS06
Talk Outlook

- Strong pair production
  - Standard top physics
  - Early top physics
- Top Properties
  - Mass, Charge, W polarization, top polarization
- Electroweak single top production
  - Analysis strategies
  - $V_{tb}$ measurements
- Using top for calibration purposes
  - Jet energy corrections, $b$-jets, missing energy
- A window to new physics
- Conclusions

Most of the results presented are based on ATLAS studies.
Strong Pair production at the LHC

Production: $\sigma_{tt}(\text{LHC}) \sim 830 \pm 100$ pb

Cross section LHC = 100 x Tevatron
Background LHC = 10 x Tevatron

$t+t$ production at the LHC

$q^+q^- (l=e, \mu)$ is the Golden channel

$\Rightarrow$ 2.5 million events/year

Decay
Top quark physics with b-tag

LHC is a top factory  Seeing top is easy

Selection: High $P_T$ Lepton
Large Missing $E_T$
4 high-$P_T$ jets (2 b-jets)

$\rightarrow$ signal efficiency few %
$\rightarrow$ very small SM background

- ‘Standard’ Top physics at the LHC:
  - b-tag is important in selection
  - Most measurements limited by systematic uncertainties

- ‘Early’ top physics at the LHC:
  - Cross-section measurement ($\sim$ 20%)
  - Decay properties
Top quark physics without b-tag (early phase)

Selection

- **semileptonic top**: $p_T$(lepton)$>20\text{ GeV}/c$, missing $E_T>20\text{ GeV}$
  - no b-tagging required
- **hadronic top**: $N_{\text{jet}}>4$, $p_T$(jet)$>40\text{ GeV}/c$ (0.4 cone algorithm)
- **3 jets with highest vector-sum** $p_T$ identified as top
  - of these, 2 leading jets in 3-jet rest frame identified as W

A top peak can be seen without b-tag requirement
Top Properties: Mass

**Lepton+jets**
- isolated lepton (e,\(\mu\)): \(p_T>20\text{GeV}/c, \mid\eta\mid<2.5\)
- missing \(E_T>20\text{GeV}\)
- at least 4 jets: \(p_T>20\text{GeV}/c\) (corrected), \(\mid\eta\mid<2.5\)
  - at least 2 light jets to reconstruct hadronic \(W\)
  - 2 b-tagged jets to select the bjj system with highest \(P_T\)
- very effective in background rejection (\(S/B=10^{-4}\rightarrow30\))
  - mainly from \(bb, W/Z+jets\) and \(Wbb\)

**Dileptons:**
- two opposite-signed leptons: \(p_T(\text{lepton})>20\text{GeV}/c, \mid\eta\mid<2.5\)
- missing \(E_T>40\text{GeV}\)
- 2 b-jets: \(p_T>25\text{GeV}/c\) (corrected), \(\mid\eta\mid<2.5\)
- Final state reconstruction
- 6 unknowns (neutrinos’ momenta), \(M_t\) hypothesis
  - conservation of transverse momentum
  - mass-constrain each l–\(\nu\) pair to \(M_W\)
  - mass-constrain each l–\(\nu\)–b-jet system to \(M_t\)
- weight assigned to each solution
  - based on comparison with MC
  - average weight over whole event sample
- \(M_t\) from solution with highest mean weight

---

**Fast simulation**
- \(L=10\text{fb}^{-1}\)
- \(\delta M_t(\text{stat})=0.04 \text{GeV}/c^2\)
- \(\delta M_t(\text{sys})=1.7 \text{GeV}/c^2\)

**Full simulation**
- \(L=10\text{fb}^{-1}\)
- \(\delta M_t(\text{stat})=0.05 \text{GeV}/c^2\)
- \(\delta M_t(\text{sys})=1.3 \text{GeV}/c^2\)
Top Properties: W Polarization

Top decays before hadronization

- spin information passed directly onto Wb
- SM predicts 70% longitudinal W and 30% left-handed W
  - depending on $M_t$ and $M_W$ only

- parametrize in terms of angle between
  - direction of W in top rest frame
  - direction of lepton in W rest frame

- Precision in measurements of the fractions $F_0$ (longitudinal) and $F_R$
- Unfold selection and detector effects

<table>
<thead>
<tr>
<th>Stat</th>
<th>Fast Simulation $L=10\text{fb}^{-1}$</th>
<th>$F_0$</th>
<th>$F_R$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMS (SL)</td>
<td>±0.023</td>
<td>±0.015</td>
<td></td>
</tr>
<tr>
<td>ATLAS (SL+DL)</td>
<td>±0.004</td>
<td>±0.003</td>
<td></td>
</tr>
<tr>
<td>CMS (SL)</td>
<td>±0.022</td>
<td>±0.053</td>
<td></td>
</tr>
<tr>
<td>ATLAS (SL+DL)</td>
<td>±0.016</td>
<td>±0.012</td>
<td></td>
</tr>
</tbody>
</table>
Top Properties: Charge

- Aimed at confirming $Q_t = 2/3$ SM hypothesis
  - non standard value $Q_t = -4/3$ not yet excluded
    - can arise from wrong W-b association
- Two procedures for direct measurement
  - Top e.m. coupling through photon radiation in tt events
    - gg initial state dominance at LHC reduces ISR
    - radiative tt production & (interfering) decay: x-section
    - radiative tt decay: reduced by requiring high $M(bj\gamma)$ or $M_T(lb\gamma)$
  - reconstruct charge of decay products (lepton/dilepton+jets)
    - easy for W boson ($Q_l$)
    - challenging for b-jets

$$Q_{jet} = \frac{\sum |Q_l| \vec{p}_jet \cdot \vec{p}_l}{\sum |\vec{p}_jet \cdot \vec{p}_l|^2}$$

- l-b association: $M_{lb} < M_t$
- Systematics underway

- Fast simulation
  - $Q_t = -4/3$
  - Systematics underway
  - $Q(b) = -0.109 \pm 0.007$
  - $Q(b) = 0.112 \pm 0.007$
Single Top at LHC

- All 3 contributing mechanisms in SM:
  - $W-g$ (t-channel)
  - $W+t$
  - $W^*$ (s-channel)

- Computation at NLO available for $W^*$ and $W-g$:
  - Increase of $\sigma(W^*)$ by $\sim 30\%$
  - Affect $p_T(jet)$ distribution, $H_T$ etc...

### Decay modes:
- $W^* : W^* \rightarrow t\ b\bar{b} \rightarrow (l^+\nu_l)\ b\bar{b}$
- $Wg: q'g \rightarrow t\ q\ b\bar{b} \rightarrow (l^+\nu_l)\ q\ b\bar{b}$
- $W+t: bg \rightarrow t\ W \rightarrow (l^+\nu_l)\ qq'$

### Common selection for all 3 single-top samples:
- 1 High $p_T$ Lepton + mET
- reduce non-$W$ events
- At least two high-$p_T$ jets
- reduce $W+jets$ events

#### Channel summary

<table>
<thead>
<tr>
<th>Channel</th>
<th>$\sigma \times BR$(pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W-g$</td>
<td>54.2</td>
</tr>
<tr>
<td>$W+t$</td>
<td>17.8</td>
</tr>
<tr>
<td>$W^*$</td>
<td>2.2</td>
</tr>
<tr>
<td>$tt\bar{t}$</td>
<td>246</td>
</tr>
<tr>
<td>$Wbb$</td>
<td>66.7</td>
</tr>
<tr>
<td>$W+jets$</td>
<td>3,850</td>
</tr>
</tbody>
</table>

- Single-top $\sim 22\%-26\%$
- $tt\bar{t}$ $\sim 38\%$
- $WQQ \sim 1.5\%$, $W+njets < 1/1000$
Why Single Top?

**Motivations**

- Properties of the Wtb vertex:
  - Determination of $\sigma(pp \rightarrow tX)$, $\Gamma(t \rightarrow Wb)$
  - Direct determination of $|V_{tb}|$
  - Top polarization

- Precision measurements $\rightarrow$ probe to new physics
  - Anomalous couplings
  - FCNC
  - Extra gauge-bosons $W'$ (GUT, KK)
  - Extra Higgs boson (2HDM)

- Single-top is one of the main background to ...

  ... Higgs physics...

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<table>
<thead>
<tr>
<th>M(top) = 175 GeV/c²</th>
<th>s-channel</th>
<th>t-channel</th>
<th>Associated tW</th>
<th>Combined (s+t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TeVatron $\sigma_{NLO}$</td>
<td>0.88 ± 0.11 pb</td>
<td>1.98 ± 0.25 pb</td>
<td>0.1 pb</td>
<td></td>
</tr>
<tr>
<td>LHC $\sigma_{NLO}$</td>
<td>10.6 ± 1.1 pb</td>
<td>247 ± 25 pb</td>
<td>62 ±17.4 pb</td>
<td></td>
</tr>
<tr>
<td>Run II 95% CL</td>
<td>CDF &lt;3.2 pb</td>
<td>&lt; 3.1 pb</td>
<td>NA</td>
<td>&lt; 3.5</td>
</tr>
<tr>
<td>D0 &lt; 5 pb</td>
<td>&lt; 4.4 pb</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
</tbody>
</table>

$\sigma_{t+s} = 2.9$ pb for m(top) = 175 GeV/c²
ATLAS analysis strategies

In the late ‘90 several studies were conducted to produce a physics TDR. Current studies are meant to devise analysis strategies for early data taking and the full statistics, using the latest software tools.

<table>
<thead>
<tr>
<th>Description of cuts</th>
<th>Cumulative Selection Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>W-g fusion</td>
</tr>
<tr>
<td>Pre-selection cuts</td>
<td>20.0</td>
</tr>
<tr>
<td>njets = 2, p_T &gt; 30 GeV</td>
<td>13.2</td>
</tr>
<tr>
<td>Forward jet; p_T &gt; 50,</td>
<td>4.3</td>
</tr>
<tr>
<td>m_{jj} &gt; 900 GeV</td>
<td>3.58</td>
</tr>
<tr>
<td>H_T &gt; 200 GeV</td>
<td>2.08</td>
</tr>
<tr>
<td>150 &lt; m_{jj} &lt; 200 GeV veto</td>
<td>1.64</td>
</tr>
<tr>
<td>Events/30 fb^{-1}</td>
<td>26 800 ± 1000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description of cuts</th>
<th>Cumulative Selection Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wt</td>
</tr>
<tr>
<td>Pre-selection cuts</td>
<td>25.5</td>
</tr>
<tr>
<td>njets = 3, p_T &gt; 50 GeV</td>
<td>3.41</td>
</tr>
<tr>
<td>nb-jet = 1</td>
<td>3.32</td>
</tr>
<tr>
<td>m_{jj} &lt; 300 GeV</td>
<td>1.43</td>
</tr>
<tr>
<td>65 &lt; m_{jj} &lt; 95 GeV</td>
<td>1.27</td>
</tr>
<tr>
<td>Events/30 fb^{-1}</td>
<td>6828 ± 269</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description of cuts</th>
<th>Cumulative Selection Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wt</td>
</tr>
<tr>
<td>Pre-selection cuts</td>
<td>27.0</td>
</tr>
<tr>
<td>njets = 2, p_T &gt; 30 GeV</td>
<td>15.7</td>
</tr>
<tr>
<td>nb-jet = 2</td>
<td>2.10</td>
</tr>
<tr>
<td>total sum of p_T &gt; 10 GeV</td>
<td>1.92</td>
</tr>
<tr>
<td>m_{jj} &gt; 200 GeV</td>
<td>1.92</td>
</tr>
<tr>
<td>150 &lt; m_{jj} &lt; 200 GeV</td>
<td>1.67</td>
</tr>
<tr>
<td>Events/30 fb^{-1}</td>
<td>1106 ± 40</td>
</tr>
</tbody>
</table>

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Wg channel

Selection criteria

- Number of jets: \( N(\text{jet}) = 2 \)
- Presence of a high-\( p_T \) b-tagged jets (\( p_T > 40 \text{ GeV/c} \))
  - Wg events have 1 b-jet escaping the acceptance
    - requires **only** 1 b-tagged jet
- Presence of a high-\( p_T \) forward jet
  - 1 jet with \( |\eta| > 2.5 \) and \( p_T > 50 \text{ GeV/c} \)
- Reconstruct \( M_{lb} \) within \( \pm 25 \text{ GeV/c}^2 \)
- Window in \( H_T \)

<table>
<thead>
<tr>
<th></th>
<th>( W^+ )</th>
<th>Wg</th>
<th>W+t</th>
<th>tt</th>
<th>WQQ</th>
<th>W+jets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Selection (%)</td>
<td>26.2</td>
<td>23.7</td>
<td>22.4</td>
<td>38.3</td>
<td>1.46</td>
<td>0.05</td>
</tr>
<tr>
<td>Selection ( \varepsilon ) (%)</td>
<td>0.22</td>
<td>0.44</td>
<td>0.023</td>
<td>0.007</td>
<td>0.006</td>
<td>0.0013</td>
</tr>
<tr>
<td>( N_{\text{event}}(30 \text{ fb}^{-1}) )</td>
<td>150</td>
<td>7,080</td>
<td>125</td>
<td>500</td>
<td>130</td>
<td>1,500</td>
</tr>
<tr>
<td>( \pm ) MC stat.</td>
<td>( \pm 6 )</td>
<td>( \pm 160 )</td>
<td>( \pm 13 )</td>
<td>( \pm 150 )</td>
<td>( \pm 40 )</td>
<td>( \pm 750 )</td>
</tr>
</tbody>
</table>

- \( N(\text{jet}) = 2 \) \( \rightarrow \) reduces \( tt \) by \( \sim 6 \) vs Wg
- 1 high-\( p_T \) fwd jet \( \rightarrow \) reduce \( tt \) (by \( \sim 5 \)), Wt(\( \sim 10 \)), Wjj(\( \sim 2 \))
- Great uncertainty on WQQ / W+jets backgrounds
s-channel

Selection criteria
- Number of jets: $N(\text{jet}) = 2$
- Presence of two high $p_T$ jets
- Presence of two central, high-$p_T$ b-tagged jets
  $\rightarrow Wq$ usually have 1 b-jet escaping the acceptance
- Reconstruct $M_{lvb}$ within $m_{top} \pm 25$ GeV/c$^2$
- Window in $H_T$

<table>
<thead>
<tr>
<th>Channel</th>
<th>$W^*$</th>
<th>Wg</th>
<th>W+t</th>
<th>tt</th>
<th>WQQ</th>
<th>W+jets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Selection $\varepsilon(%)$</td>
<td>26.2</td>
<td>23.7</td>
<td>22.4</td>
<td>38.3</td>
<td>1.46</td>
<td>0.05</td>
</tr>
<tr>
<td>Selection $\varepsilon(%)$</td>
<td>1.73</td>
<td>0.105</td>
<td>0.002</td>
<td>0.035</td>
<td>0.059</td>
<td>0.0001</td>
</tr>
<tr>
<td>$N_{\text{event}}(30$ fb$^{-1}$)</td>
<td>1,141</td>
<td>1,680</td>
<td>10</td>
<td>2,580</td>
<td>1,148</td>
<td>170</td>
</tr>
<tr>
<td>$\pm$ MC stat.</td>
<td>$\pm 7</td>
<td>\pm 48</td>
<td>\pm 3</td>
<td>\pm 150</td>
<td>\pm 38</td>
<td>\pm 85</td>
</tr>
</tbody>
</table>

- $N(\text{jet}) = 2$ $\rightarrow$ reduces tt by a factor ~ 20 vs $W^*$
- 2 high-$p_T$ b-jets $\rightarrow$ reduces WQQ by ~2 and Wg by ~8
- $M_{lvb}$ and $H_T$ $\rightarrow$ reduce non-top by ~2
Wt channel

Selection of a specific topology

- Number of high-$p_T$ jets $N_{jet}) = 3$
- Presence of a high-$p_T$ b-tagged jets
  $\rightarrow$ Only **one** b-jet in $W+t$ events
- Presence of a $W$-boson mass peak
  $\rightarrow$ requires $60 < M(j,j) < 90$ GeV/$c^2$
- Reconstruct $M_{jvD}$ within $\pm 25$ GeV/$c^2$
- Window in $H_T$ or Invariant Mass

\[
\begin{array}{|c|c|c|c|c|c|}
\hline
 & W^* & Wg & W+t & tt & WQQ & W+jets \\
\hline
\text{Pre-Selection } \varepsilon(\%) & 26.2 & 23.7 & 22.4 & 38.3 & 1.46 & 0.05 \\
\text{Selection } \varepsilon(\%) & 0.16 & 0.25 & 0.88 & 0.35 & 0.004 & 0.0003 \\
\text{N_{event}(30 fb^{-1})} & 105 & 4,050 & 4,720 & 26,300 & 90 & xxx \\
\pm \text{MC stat.} & \pm 5 & \pm 80 & \pm 80 & \pm 400 & \pm 20 & \pm 85 \\
\hline
\end{array}
\]

- $N(\text{jet}) = 3$ $\rightarrow$ reduces $Wjj$ & $WQQ$ $\sim 3.5$ wrt $W+t$
- $M(jj) \sim M_W$ $\rightarrow$ reduces $WQQ$/jets by $\sim 3$ wrt $W+t$
$\rightarrow$ Good knowledge of $tt$ background is mandatory

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\( V_{tb} \) Measurement

- **Indirect measurement**
  - based on CKM unitarity constraint (3 generations)

\[
\frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2} = \frac{BR(t \rightarrow Wb)}{BR(t \rightarrow Wq)}
\]

- **Direct measurement**
  - based on electroweak single top production (\( \sigma \propto |V_{tb}|^2 \))
    - measure yield of single top production
    - combine with \( BR(t \rightarrow Wb) \) and \( M_t \) (from tt channel)
  - unbiased test of 3-generation structure of SM
  - penalized by poor knowledge of \( W+jets, WQQ \) background
  - no systematic effects taken into account

<table>
<thead>
<tr>
<th>channel</th>
<th>S/B</th>
<th>uncertainties on ( \sigma )</th>
<th>( \Delta V_{tb}/V_{tb} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>stat (30fb(^{-1}))</td>
<td>theoretical</td>
</tr>
<tr>
<td>s-channel</td>
<td>0.55</td>
<td>5.6%</td>
<td>7.5%</td>
</tr>
<tr>
<td>t-channel</td>
<td>2.3</td>
<td>0.54%</td>
<td>11%</td>
</tr>
</tbody>
</table>
Top quark pair production as calibration tool

You can use production of top quark pairs to help calibrate LHC detectors in complex event-topologies

Yes  No  Cancel

→ A candle for complex topologies:
  - Calibrate light jet energy scale
  - Calibrate missing $E_T$
  - Obtain enriched b-jet sample
  - Leptons and trigger

Note candles: 2 W-bosons
2 top quarks
Calibrating jet energy scale

One of the most relevant systematic effects on $M_t$

- jet energy: measurement of parton energy
- 1% uncertainty on absolute JES induces $\delta M_t \sim 1 \text{GeV}/c^2$
- sizeable effects also from
  - $b$-jet energy scale
  - QCD radiation, underlying event, cone algorithm
- at start-up, 5÷10% uncertainty
  - test-beam data
- in-situ correction with $Z/\gamma$+jet
  - $p_T$ (jet) correction
  - residual mass shift (2% on $M_t$)
- $M_{jj} = M_W$ additional constraint on JES
- clean $W \rightarrow jj$ sample needed
  - 80% purity within $t\bar{t} \rightarrow l\nu+jets$

- goal: 2÷3% uncertainty in 1 year (target 1%)
- Alternative method: $P_T$ balance in $Z/\gamma +$ jet events

$M_{jj} = M_W$ additional constraint on JES

$P_T$ (jet) correction

Clean $W \rightarrow jj$ sample needed

$80\%$ purity within $t\bar{t} \rightarrow l\nu+jets$

Full simulation

$tt \text{ MC@NLO}$
Calibrating b-jets

- b-tagging techniques rely on:
  - impact parameter of decay tracks
  - primary/secondary vertex separation
  - soft leptons
    - targeting b and c semileptonic decays

- Typical performances:
  - efficiency ~60% on $p_T>40\text{GeV/c}$ jets
  - light flavour rejection $1/\epsilon_u \sim 200$

- Jets from b-quarks need specific corrections:
  - semileptonic decays of heavy-flavoured quark
    - neutrino induces a large shift on the jet energy
    - effect enhanced if lepton is muon (MIP)
    - jet direction affected as well as jet energy
Calibrating the missing energy

- $P_\mu$ (neutrino) constrained from kinematics: $M_W$ → known amount of missing energy per event

- Calibration of missing energy **vital** for all (R-parity conserving) SUSY and most exotics!

**Example from SUSY analysis**

- Perfect detector
- SUSY LSP or a mis-calibrated detector?

Range: $50 < P_T < 200$ GeV
A window to new physics?

Structure in $M_{tt}$

Interference from MSSM Higgses $H,A \rightarrow tt$ (can be up to 6-7% effect)

<table>
<thead>
<tr>
<th>$q = u, c$</th>
<th>$t \rightarrow Zq$</th>
<th>$t \rightarrow \gamma q$</th>
<th>$t \rightarrow gq$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$BR(L=10 fb^{-1})$</td>
<td>$3.4 \cdot 10^{-4}$</td>
<td>$6.6 \cdot 10^{-5}$</td>
<td>$1.4 \cdot 10^{-3}$</td>
</tr>
<tr>
<td>$BR(L=100 fb^{-1})$</td>
<td>$6.5 \cdot 10^{-5}$</td>
<td>$1.8 \cdot 10^{-5}$</td>
<td>$4.3 \cdot 10^{-4}$</td>
</tr>
</tbody>
</table>
Conclusions

1) Top quarks are produced by the millions at the LHC:
   → Almost no background:
      to measure top quark properties will be easy

2) Top quarks are THE calibration signal for complex topologies:
   → Most complex SM candle at the LHC
   → Vital input for detector commissioning/calibration

3) Top quarks pair-like and singly produced......
   as a window to new physics:
   → FCNC, SUSY, MSSM Higgs,
      Resonances, anomalous couplings
   Also important SUSY background
Backup Slides
Top Mass Now

All CDF measurements (last updated 07/26/2006)

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Value (GeV²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1 Dilepton (Run 700 pb⁻¹)</td>
<td>167.4 ± 10.3 ± 4.9</td>
</tr>
<tr>
<td>Run 1 Lepton+Jets (Run 150 pb⁻¹)</td>
<td>176.1 ± 5.1 ± 5.3</td>
</tr>
<tr>
<td>Run 1 All-hadronic (Run 300 pb⁻¹)</td>
<td>168.6 ± 10.6 ± 5.7</td>
</tr>
<tr>
<td>Dilepton: Matrix Element b-tag (N=300 pb⁻¹)</td>
<td>167.3 ± 4.6 ± 3.8</td>
</tr>
<tr>
<td>Dilepton: Matrix Element (N=300 pb⁻¹)</td>
<td>164.5 ± 3.9 ± 3.9</td>
</tr>
<tr>
<td>Dilepton: Combined (N=300 pb⁻¹)</td>
<td>167.9 ± 5.2 ± 3.7</td>
</tr>
<tr>
<td>Dilepton: weighting</td>
<td>170.7 ± 6.9 ± 3.7</td>
</tr>
<tr>
<td>Dilepton: σF (σF)</td>
<td>169.5 ± 7.2 ± 4.0</td>
</tr>
<tr>
<td>Dilepton: σF (σF)</td>
<td>169.7 ± 9.0 ± 4.0</td>
</tr>
<tr>
<td>Dilepton: σF (σF)</td>
<td>166.6 ± 7.0 ± 3.2</td>
</tr>
<tr>
<td>Dilepton: σF (σF)</td>
<td>173.2 ± 2.4 ± 3.2</td>
</tr>
<tr>
<td>Dilepton: σF (σF)</td>
<td>183.9 ± 13.5 ± 5.5</td>
</tr>
<tr>
<td>Lepton+Jets: Matrix Element</td>
<td>170.9 ± 1.6 ± 2.0</td>
</tr>
<tr>
<td>Lepton+Jets: Matrix Element</td>
<td>173.4 ± 1.7 ± 2.2</td>
</tr>
<tr>
<td>All hadronic: Matrix Element</td>
<td>174.0 ± 2.2 ± 4.8</td>
</tr>
<tr>
<td>All hadronic: Matrix Element</td>
<td>177.1 ± 4.9 ± 4.7</td>
</tr>
<tr>
<td>CDF Summer 2005</td>
<td>170.9 ± 1.4 ± 1.9</td>
</tr>
<tr>
<td>CDF Summer 2005</td>
<td>171.4 ± 1.2 ± 1.8</td>
</tr>
</tbody>
</table>

CDF Top Mass Uncertainty

- CDF Results
- Run IIa goal (TDR 1996)
- Scale Δ(stat) / Nc
- Fix Δ(syst) (assumes no improvements)

CDF and D0 best (last updated 07/26/2006)

- CDF Dilepton (L=1090 pb⁻¹) | 164.5 ± 3.9 ± 3.9
- D0 Dilepton (L=370 pb⁻¹) | 178.1 ± 6.7 ± 4.3
- CDF Lepton+Jets (L=1090 pb⁻¹) | 170.9 ± 1.6 ± 2.0
- D0 Lepton+Jets (L=370 pb⁻¹) | 170.3 ± 2.5 ± 3.8
- CDF All hadronic (L=1100 pb⁻¹) | 174.0 ± 2.2 ± 4.3
- Tevatron July'06 (CDF-D0 Run (+8 Average)) | 171.4 ± 1.2 ± 1.8

Gif and eps
Top Cross Section Now
### Top Properties Now

<table>
<thead>
<tr>
<th>Top quark production and decay properties</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>lepton+jets</strong></td>
</tr>
<tr>
<td><strong>lepton+jets</strong></td>
</tr>
<tr>
<td><strong>lepton+jets</strong></td>
</tr>
<tr>
<td><strong>dilepton</strong></td>
</tr>
<tr>
<td><strong>lepton+tau</strong></td>
</tr>
<tr>
<td><strong>dilepton, lepton+jets, single and double Vertex b-tags</strong></td>
</tr>
<tr>
<td><strong>dilepton, lepton+tau, lepton+jets single and double Vertex b-tags</strong></td>
</tr>
<tr>
<td><strong>lepton+jets</strong></td>
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</tbody>
</table>
### W Helicity

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Formula</th>
<th>$F_0 = 0.61 \pm 0.12$ (stat) + 0.04 (syst) $F_+ &lt; 0.11$ @ 95% C.L.</th>
<th>$F_+ &lt; 0.09$ @ 95% C.L. $F_0 = 0.59 \pm 0.12$ (stat) + 0.07-0.06 (syst) $F_+ &lt; 0.10$ @ 95% C.L.</th>
<th>$F_0 = 0.74 \pm 0.22$ -0.34 (stat+syst) $F_+ &lt; 0.27$ @ 95% C.L.</th>
<th>$F_+ &lt; 0.18$ @ 95% C.L.</th>
</tr>
</thead>
<tbody>
<tr>
<td>lepton+jets</td>
<td>$\cos \theta^*$</td>
<td></td>
<td>$M_{lb}^2$</td>
<td></td>
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</tr>
<tr>
<td>dilepton, lepton+jets</td>
<td>$M_{lb}^2$</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(Run II)</td>
<td></td>
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</tr>
<tr>
<td>lepton+jets</td>
<td>$\cos \theta^*$</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>dilepton, lepton+jets</td>
<td>Combined $\cos \theta^*$ and Lepton Pt spectrum</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Run I</td>
<td>$M_{lb}^2$</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**Plain English explanation**

- **lepton+jets**: $\cos \theta^*$ with $F_0 = 0.61 \pm 0.12$ (stat) + 0.04 (syst) $F_+ < 0.11$ @ 95% C.L.
- **dilepton, lepton+jets (Run II)**: $M_{lb}^2$ with $F_+ < 0.09$ @ 95% C.L.
- **lepton+jets** (again): $\cos \theta^*$ with $F_0 = 0.59 \pm 0.12$ (stat) + 0.07-0.06 (syst) $F_+ < 0.10$ @ 95% C.L.
- **lepton+jets** (third): Combined $\cos \theta^*$ and Lepton Pt spectrum with $F_0 = 0.74 \pm 0.22$ -0.34 (stat+syst) $F_+ < 0.27$ @ 95% C.L.
- **dilepton, lepton+jets (Run I)**: $M_{lb}^2$ with $F_+ < 0.18$ @ 95% C.L.