The impact of ttbar cross-section measurement with the first LHC data

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@ Berkeley Early-Data Workshop
May, 2009
The top quark, when it was finally discovered at Fermilab in 1995, completed the three generation structure of the Standard Model (SM) and opened up the new field of top quark physics. Viewed as just another SM quark, the top quark appears to be a rather uninteresting species. Produced predominantly, in hadron-hadron collisions, through strong interactions, it decays rapidly without forming hadrons, and almost exclusively through the single mode $t \rightarrow Wb$. The relevant CKM coupling $V_{tb}$ is already determined by the (three-generation) unitarity of the CKM matrix. Rare decays and CP violation are unmeasurably small in the SM. 

M.Beneke, I. Efthymiopoulos, M.L.Mangano, J.Womersley
Can Top change our perspective?

• Why is top so heavy (10 water molecules)? Any special role in EW symmetry breaking?
• Does it play even more fundamental role than Higgs mechanism + Yukawa coupling?
• If there is new physics signal lighter than top, does the top quark decay into them?
• Could non-SM physics first manifest itself in non-standard couplings of the top quark?
• Top quark can be measured at significant precision at the LHC to answer these questions.
• Top quark has been an extremely productive ground for speculation and searches at Tevatron.
New Physics via Top Decay

- Various decay modes make top physics interesting and useful
- The top interfere with a number of new physics signatures.
- Typical search modes:
  - Lepton + jets (e/µ)
  - Dileptonic
  - All hadronic
  - Tau channels
- E.g. If $m_W < m_{H^+} < m_t$ and $\tan\beta \gg 1$, top can decay into charged higgs, enhancing the $\tau$ lepton rate.
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<table>
<thead>
<tr>
<th>Name</th>
<th>Signature</th>
<th>BR</th>
<th>xsec at 10 TeV</th>
</tr>
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<tbody>
<tr>
<td>Fully Hadronic</td>
<td>jets</td>
<td>45.7%</td>
<td>191.5 pb</td>
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<tr>
<td>Lepton + Jets</td>
<td>$e +$ jets</td>
<td>17.2%</td>
<td>71.9 pb</td>
</tr>
<tr>
<td></td>
<td>$\mu +$ jets</td>
<td>17.2%</td>
<td>71.9 pb</td>
</tr>
<tr>
<td>Dilepton</td>
<td>$e\mu +$ jets</td>
<td>3.18%</td>
<td>13.3 pb</td>
</tr>
<tr>
<td></td>
<td>$\mu\mu +$ jets</td>
<td>1.59%</td>
<td>6.67 pb</td>
</tr>
<tr>
<td></td>
<td>$ee +$ jets</td>
<td>1.59%</td>
<td>6.67 pb</td>
</tr>
<tr>
<td>Tau + Jets</td>
<td>$\tau +$ jets</td>
<td>9.49%</td>
<td>39.8 pb</td>
</tr>
<tr>
<td>Lepton + Tau</td>
<td>$\tau + e/\mu +$ jets</td>
<td>3.54%</td>
<td>14.8 pb</td>
</tr>
<tr>
<td>Tau + Tau</td>
<td>$\tau + \tau +$ jets</td>
<td>0.49%</td>
<td>2.06 pb</td>
</tr>
<tr>
<td>total</td>
<td>all</td>
<td>100%</td>
<td>419 pb</td>
</tr>
</tbody>
</table>
Search for Charged Higgs

**FIG. 10:** Observed (blue) and expected (red) limit with one standard deviation band (yellow) on $\text{Br}(t \rightarrow H^+ b)$ as a function of charged Higgs mass for simultaneous fit of $\text{Br}(t \rightarrow H^+ b)$ and $\sigma^t\bar{t}$ in the tauonic model.

**FIG. 11:** Observed (blue) and expected (red) limit with one standard deviation band (yellow) on charged Higgs mass as a function of $\tan \beta$.
Search for Charged Higgs

Good tau/jet calibration and background control is essential for this search. 

Not a “Day-1 physics”
New Physics into Top

If new physics is leptophobic, they may couple strongly to top. Otherwise, dimuon is a clearer signature.
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**Good control of SM top and jet resolution & jet substructure. Not a “Day-1 physics”**
State of the Art at Tevatron

Cross-Section Measurement

- Semileptonic channel
  - High branching ratio (~36/81)
  - Event over-constrained
  - Manageable background

- Dileptonic channel
  - Low background
  - Low branching ratio (~9/81)
  - Event under-constrained

- Fully hadronic channel
  - Event fully constrained
  - Huge QCD and comb. background

- Lepton + Track
  - Highly inclusive
  - Different systematics for track performance.

8% precision all combined (summer 2008)
the availability of Monte Carlo event generator is somewhat limited. The current implementa-
tion is available in a number of flavors, Pythia (and others) at LO as predicted by [11].

For the first LHC data, the beam energy is likely to be 5+5 TeV in 2008, 7+7 TeV energy is that we will be able to use the Tevatron as shown in Fig. 2(left). As seen in Fig. 2(right), while the theoretical calculation for inclusive cross-section at 200 GeV and 1.96 TeV (right) [10], the top cross-section is a function of integrated luminosity. We will expect roughly 12 k single lepton events and 2 k dilepton events in electron + jets and electron production, electron + jets and electron + jets. As seen in Fig. 2(right), while the theoretical calculation for inclusive cross-section at 200 GeV and 1.96 TeV (right) [10], the top cross-section is a function of integrated luminosity. We will expect roughly 12 k single lepton events and 2 k dilepton events in electron + jets and electron + jets. As seen in Fig. 2(right), while the theoretical calculation for inclusive cross-section at 200 GeV and 1.96 TeV (right) [10], the top cross-section is a function of integrated luminosity. We will expect rough
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At 100 pb$^{-1}$, the top cross-section is a limited. The current implementation is available in a number of flavors, including the CDF Run I 0.11 fb$^{-1}$ and CDF Run II Preliminary 2.8 fb$^{-1}$.

Using the SM branching ratio of 0.108 for the leptonic decay of $b$-hadrons, the muon + jets decay branching ratio is 29.2% combined. The branching ratio for di-electron, di-muon and electron+muon dilepton decay modes combined is $\frac{1}{\sqrt{s}}\left(\frac{d\sigma}{dt}\right)$, where $\sigma$ is the total cross-section and $t$ is the momentum transfer. The additional measurement will lead to new insight into the theoretical calculation for inclusive cross-sections, which are a function of integrated luminosity. We will expect roughly 12 k single lepton events in the electron and muon channels. The bright side of lower start-up beam energy is that we will be able to measure top cross-section with yet another beam energy in addition to Run I and Run II at LO plus LL at higher multiplicity.
the availability of Monte Carlo event generator is somewhat limited. The current implementation is that we will be able to compute the cross-section by 55%, giving an approximate NNLO theoretical prediction and the mechanism of Figure 2: The approx. NNLO theoretical prediction and the mechanism of the muon + jets decay branching ratio is 29.2% combined. The branching ratio for di-electron, electron + jets and electron + jets dilepton decay modes combined is ~6% uncertainty (PDF + scale).
Approx NNLO calculation (14 TeV)

~6% uncertainty (PDF + scale)

CDF Run I
0.11 fb⁻¹

CDF Run II Preliminary
2.8 fb⁻¹

m_\ell [GeV]

√s [TeV]

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Strategy with the First Data

Do the simplest thing we can do, count the number of events

\[ N = L \sigma_{tT} BR \epsilon_{\text{trig}} \epsilon_{\text{lep}} A + B \]

- pray for a large number but expect large uncertainty may not be available quickly
- well known in SM
to be estimated from data
- sensitive to theoretical uncertainty
- part data driven, part MC driven

Realistically, e and mu single lepton and dilepton channels only. Taus, too difficult to calibrate. Fully hadronic too difficult to trigger.

Methods based on likelihood fit also studied. Different or superior systematic uncertainties.

Will show (14 TeV) studies from “Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics.” (a.k.a. CERN-OPEN-2008-20, “CSC”)
Obstacles with First Data

Numerous uncertainties that affect measurements with the early data:

• Trigger efficiency
• Non-uniform detector
• Lepton identification
• Missing Et calibration and tails
• Light/b jet energy scale
• QCD activity (MI, ISR/FSR)
• Beam related issues (Pile-up, Luminosity)
• PDF
• Background normalization
• other unknown unknowns

We have performance estimates but we won’t know much about the real detector and the real physics at 10 TeV until real data flows in.
Measuring Efficiency from Z

Low Pt single lepton triggers at low lumi is highly efficient (>90%) for tT. Their performance of the real detector need to be estimated from data. Z events are the most useful control sample for performance extraction but condition can be different in signal events.

eff (pt, eta & isolation)
Underlying Event and ISR/FSR

Why we won’t know until real data comes

QCD $2 \rightarrow 2$ process
- **TransMAX region**: hardest ISR/FSR
- **TransMIN**: beam-beam UE component
- **TransMAX - TransMIN**: ISR/FSR probe

UE tunings applied to LHC MC shows divergence with high pt jets. Need to constrain model parameters, need to know handles to evaluate uncertainties.

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One lepton with pT>20 GeV, Missing Transverse Energy > 20 GeV, at least 4 jets with pT>20 GeV of which 3 have pT > 40 GeV - “default” - 18% eff for muon channel

Look for trijet combination with highest pT and select those with dijet mass ~ Mw. Lose half using Mw cut

<table>
<thead>
<tr>
<th>Source of Unc.</th>
<th>Detail</th>
<th>Count Elec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistical</td>
<td>1262 sig evts</td>
<td>3.5%</td>
</tr>
<tr>
<td>Lepton ID</td>
<td>1% variation</td>
<td>1.0%</td>
</tr>
<tr>
<td>Trigger eff</td>
<td>1% variation</td>
<td>1.0%</td>
</tr>
<tr>
<td>W+Jet norm.</td>
<td>50% more</td>
<td>9.5%</td>
</tr>
<tr>
<td>JES</td>
<td>5%</td>
<td>9.7%</td>
</tr>
<tr>
<td>PDF</td>
<td>CTEQ error</td>
<td>2.5%</td>
</tr>
<tr>
<td>ISR/FSR</td>
<td>$\Lambda_{QCD}$ / cutoff</td>
<td>8.9%</td>
</tr>
</tbody>
</table>

Likelihood method: $\Delta \sigma / \sigma = (7(\text{stat}) \pm 15(\text{syst}) \pm 3(\text{pdf}) \pm 5(\text{lumi}))\%$

Counting method: $\Delta \sigma / \sigma = (3(\text{stat}) \pm 16(\text{syst}) \pm 3(\text{pdf}) \pm 5(\text{lumi}))\%$

Likelihood fit on top mass stable against background fluctuation but relies on good understanding of Mjjj shape. Counting method is sensitive to background normalization and jet energy scale.
Dileptonic Channels

Two lepton with pT>20 GeV, Missing Transverse Energy > 25 GeV (30 GeV for ee/mumu) at least 2 jets with pT>20 GeV remove ml~90 GeV (ee/mumu) 21% (emu), 15% (ee), 19% (mumu) ~1010 events in combined with 100pb⁻¹ at 10TeV

Source of Unc. | Detail | Avg All Chan
---|---|---
Statistical | 1010 sig evts | 3.5%
Lepton ID | 1% variation | 1.0%
Trigger eff | 1% variation | 1.0%
W+Jet | 50% | 2.9%
Bkg Model | 10% | 1.4%
JES | 5% | +4.6/-2.1%
PDF | CTEQ error | 2.4%
ISR/FSR | ΛQCD / cutoff | 2.3%

Cut and Count method: \( \Delta \sigma / \sigma = (4 \text{(stat)} \pm 5 \text{(syst)} \pm 2 \text{(pdf)} \pm 5 \text{(lumi)}) \%

Template method: \( \Delta \sigma / \sigma = (4 \text{(stat)} \pm 4 \text{(syst)} \pm 2 \text{(pdf)} \pm 5 \text{(lumi)}) \%

Treatment of systematic is symmetric to single lepton analysis. Significantly higher precision in dilepton analysis.
14 TeV > 10 TeV

10 TeV analysis ongoing. Analyses being re-evaluated / re-optimised for 10 TeV but nothing public yet. Look out for the summer conferences!
Conclusions

• There is no easy win with Top!
  • Cross section is large but first data is limited.
  • Very many uncertainties to be constrained from the data itself.
  • First top observation at LHC will be a huge step.
• Sensitivities to new physics exist in many places around top
  • Tevatron results are impressive and updated with increasing luminosity.
  • Estimated sensitivity of 9-18% (systematics dominate) is a good start for cross-section measurements. Dilepton analysis may have a kick start.
• Measurements in 10 TeV is interesting
  • Comparison with Tevatron and 14 TeV is very important.
  • Who knows what kind of surprise is waiting at 10 TeV?
• Impact of first top observation at the LHC? Incalculable.