A Measurement of
Top Charge Asymmetry at DØ

Work in progress

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Overview

Introduction:
• The standard model top asymmetry
• Key concepts

Analysis Ingredients:
• Analysis strategy
• The acceptance
• The dilution
• Fit procedure
• Less than preliminary fit results

Summary

Not a typical top analysis

Will focus on the unusual aspects of this analysis
At the Tevatron the top charge production asymmetry is visible as a forward-backward asymmetry. Much harder to measure it at the LHC (gluon fusion doesn’t help)

\[ A_{fb} = \frac{N_+ - N_-}{N_+ + N_-} \]

The top charge asymmetry has several contributions. All are interference terms of at least NLO:

1. An interference between:

2. An interference between:

3. Higher order terms (recently evaluated, hep-ph/0703120)
4. Interferences in \( qg \rightarrow tt \) diagrams (e.g. Flavor creation)
5. Interferences with mixed (electroweak neutral current + gluon) box diagrams

Some of these contributions tend to cancel out.

The top asymmetry varies greatly throughout phase space (see next slide). Which “A” are we measuring?
"Differential" Asymmetries

**top** asymmetry on the left;

**W+jets** asymmetry on the right

Reminiscent of the calculation by Bowen et. al. (hep-ph/0509267) stating that the $tt$ and $ttj$ asymmetries are approximately 6% and -7% (jet acceptance cuts: $p_T>20$GeV, $|\eta|<3$)

Theory papers usually ignore top decays in their jets, and ignore this effect.
Key Concepts

Acceptance:
Where, in phase space, are we measuring the asymmetry?
As we saw, this changes the standard model predictions for this asymmetry.

Dilution:
How well do we reconstruct the asymmetry?
Quantitatively:
If we reconstruct the sign correctly for a fraction, $p$, of the accepted events, how much of the asymmetry is visible?

$$d = 2p - 1$$

This is a reconstruction effect, so we would like to correct for it (as is the standard practice in asymmetry measurements).

BTW, the “dilution factor” gives the statistical significance:

$$D = (2p - 1)^2$$
Analysis Strategy

Measurement designed to reach a sensitivity comparable to the effect expected in the Standard Model (5-10%).

Using a kinematic fitter to reconstruct $\Delta Y = Y_e - Y_{\tau}$ according to the top pair hypothesis, object resolutions, $M_W$ & $m_{top} = 175$GeV

- 2-4 times stronger than just using the lepton’s rapidity

Selecting 4 jet events in the lepton+jets channel with a relatively loose b-tag (~84% efficient)

The usual practice is to correct from the observed asymmetry to the “true” (i.e. particle-level) asymmetry. This “unfolds” the reconstruction effects.

In this measurement, statistics suffice for only one bin.

→ Acceptance and reconstruction quality vary greatly within the bin.

Unfolding requires knowing the distribution of events within the bin → model dependence.

Instead, we’ll have a simple specification of our acceptance and dilution, with which the model predictions can be “folded” to predict the results of this measurement.
The Acceptance

Goal: A simple description of the region of phase space where signal events are accepted into the analysis.

The main issue is the difference between (fully-corrected) detector jets and particle-jets. Smaller effects are neglected. More studies of $b$-tagging required.

Jet Acceptance
Was studied in fully corrected ($\mu$ correction, scale, smearing, efficiencies) Monte Carlo.

$$A = f(p_T)g(|\eta|)$$

But that’s not so simple…
The Acceptance

**Goal:** A simple description of the region of phase space where signal events are accepted into the analysis.

The main issue is the difference between (fully-corrected) detector jets and particle-jets. Smaller effects are neglected. More studies of $b$-tagging required.

**Jet Acceptance**

Was studied in fully corrected ($\mu$ correction, scale, smearing, efficiencies) Monte Carlo.

\[ A = f(p_T)g(|\eta|) \]

The big approximation is to replace those fitted turn on curves with simple box cuts:

- $p_T > 21$ GeV and $|Y| < 2.5$
- built a parametrized MC on top of MC@NLO to evaluate the approximation

**Conclusion:**

- The systematic uncertainties on the expected asymmetry from using the simple acceptance description are 1% (absolute)
The dilution describes how well we reconstruct the asymmetry. Some dilution from misidentifying the lepton’s charge, in particular if this misidentification differs between the two sides of the detector. A small effect.

The geometric part was parametrized in $|\Delta Y_{\text{gen}}|$ and measured on Pythia Signal. Need to handle residual dependencies.

Most systematic effects enter through the dilution. They’re pretty small so far ☺

Includes Flavor Creation Diagrams

Systematics Uncertainties

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Top Mass Dependence

Jet Reconstruction

$b$-tagging
The Likelihood Discriminant

A likelihood that discriminated between top and W+jets events without biasing $|\Delta Y|$.

- leading $b$-jet $p_T$, fitter's $\chi^2$, $K_{\min}^t$, $M_{jj}$ (from hadronic $W$ according to the fitter).

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Fit Procedure

- The sample composition and the asymmetry are fitted simultaneously
- A simultaneous fit over two distributions:
  - the likelihood discriminant
  - the sign of the rapidity difference
- With four templates whose sum is fitted to data:
  - forward signal
  - backward signal
  - W+jets events
  - multijet events
    - relative fraction taken from the data
    - likelihood-discriminant and asymmetry distributions taken from the data

Other fit procedures, such as using an event-by-event likelihood, have more statistical power, but they gain it by giving more weight to signal-like events and/or those where $\text{sign}(\Delta Y)$ is well measured.

This particular fit method was chosen as it keeps the acceptance simple: All selected events have the same contribution to the fitted asymmetry.
The asymmetry has little correlation with the other fit parameters, up to 8%.

- the number of W+jets has little correlation as the reconstruction under the top pair hypothesis washes out the W asymmetry.

The fitted observable asymmetry: $A_{fb} = (12 \pm 8(\text{fit}) \pm x(\text{syst}))\%$

MC@NLO predictions:

<table>
<thead>
<tr>
<th>Generated Asymmetry</th>
<th>Asymmetries (in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generated Asymmetry</td>
<td>Fitted Turn Ons</td>
</tr>
<tr>
<td>Generated Asymmetry</td>
<td>0.97 ± 0.34</td>
</tr>
<tr>
<td>Generated Asymmetry</td>
<td>Simple Cuts</td>
</tr>
<tr>
<td>Generated Asymmetry</td>
<td>1.94 ± 0.30</td>
</tr>
<tr>
<td>Observable Asymmetry</td>
<td>Fitted Turn Ons</td>
</tr>
<tr>
<td>Observable Asymmetry</td>
<td>0.66 ± 0.27</td>
</tr>
<tr>
<td>Observable Asymmetry</td>
<td>Simple Cuts</td>
</tr>
<tr>
<td>Observable Asymmetry</td>
<td>1.27 ± 0.24</td>
</tr>
</tbody>
</table>

Includes errors on sample composition.

Exploring improvements that’ll change the nominal value.
Summary

Measuring the top charge production asymmetry within the **approximate acceptance**:
- 4+ jets with $p_T > 21\text{GeV}$ and $|\eta| < 2.5$
- highest jet $p_T > 37\text{GeV}$
- electron with $p_T > 15\text{GeV}$ and $|\eta| < 1.1$ or muon with $p_T > 18\text{GeV}$ and $|\eta| < 2$

The approximation cause an uncertainty of 1% (absolute) on the expected asymmetry.

The less than preliminary measured observable asymmetry: $A_{fb} = (12 \pm 8(\text{fit}) \pm x(\text{syst}))\%$

**MC@NLO predictions:**

<table>
<thead>
<tr>
<th>All $A_{fb}$s $\pm 1.00$ (acceptance)</th>
<th>Asymmetries (in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fitted Turn Ons</td>
</tr>
<tr>
<td>Generated Asymmetry</td>
<td>$0.97 \pm 0.34$</td>
</tr>
<tr>
<td>Observable Asymmetry</td>
<td>$0.66 \pm 0.27$</td>
</tr>
</tbody>
</table>

Reconstructing the asymmetry with the **dilution**:

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Exploring improvements that’ll change the nominal value
Back up slides
Data Modeling

Good data modeling in both channels. Here are a few sample sanity plots for both channels combined.

- **Lepton $p_T$**
  - Entries = 379
  - KProb: 0.287

- **$M_{l\nu}$**
  - Overflows put in edge bins
  - Entries = 379
  - KProb: 0.506

- **# $b$-tags**
  - Entries = 379
  - KProb: 0.485

- **Kinematic fitter’s $\chi^2$**
The top asymmetry arises from NLO contributions to top pair production.

Plots are from Kuhn & Rodrigo hep-ph/9807420
The W+jets Asymmetry

The main background is W+jets and is also asymmetric!

Asymmetric
(u & d PDFs, V-A vertex), even in the presence of additional radiation.

Only slightly asymmetric
(s PDF)
What to measure?

\[
F.O.M. = \int f(x) \left(2p(x) - 1\right)^2 \, dx
\]

Where \(p(x)\) is the tag's purity, in this case, the probability to choose the correct hemisphere.
Reconstructed W+jets Asymmetry

Breakdown may be useful for systematics (e.g. b-tagging RFs)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Fraction</th>
<th>Simulated Asymmetries (in %)</th>
<th>Reconstructed Asymmetries (in %)</th>
<th>MC@NLO-particle-level</th>
</tr>
</thead>
<tbody>
<tr>
<td>W plus jets</td>
<td>1.0</td>
<td>$25.7 \pm 2.3$</td>
<td>$3.9 \pm 2.4$</td>
<td>$21.98 \pm 0.34$</td>
</tr>
<tr>
<td>Wjjj</td>
<td>0.487 ± 0.012</td>
<td>$28 \pm 4$</td>
<td>$5 \pm 4$</td>
<td></td>
</tr>
<tr>
<td>WcJJJ</td>
<td>0.140 ± 0.008</td>
<td>$18 \pm 6$</td>
<td>$-1 \pm 6$</td>
<td>$0.2 \pm 1.3$</td>
</tr>
<tr>
<td>WcJJ</td>
<td>0.154 ± 0.007</td>
<td>$27 \pm 5$</td>
<td>$9 \pm 5$</td>
<td></td>
</tr>
<tr>
<td>WbJJJ</td>
<td>0.092 ± 0.004</td>
<td>$25.3 \pm 3.2$</td>
<td>$-0.2 \pm 3.4$</td>
<td>$13 \pm 4$</td>
</tr>
<tr>
<td>Wbbxx</td>
<td>0.127 ± 0.004</td>
<td>$21.6 \pm 2.9$</td>
<td>$-0.4 \pm 3.0$</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Simulated W asymmetries and reconstructed top pair asymmetries in W plus jets events, broken down by heavy flavor composition. The labels for additional jets are ‘j’ for a light (u,d,s, and g) jet, ‘J’ for a light or charm jet, and ‘x’ for any jet. The last column offers a comparison with the MC@NLO prediction, which was made with significantly different cuts as explained in the text.

Reconstruction as a top pair washes it out 😊

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Work in progress

Entries 4362
Mean 0.2501
RMS 0.8298

Entries 4362
Mean 0.05074
RMS 0.9244
Particle jets are reconstructed from stable particles excluding neutrinos (and W decay products in W+jets events) using the PXCONE algorithm. (with R=0.5, OVLIM=0.5, $p_T>3$GeV).

This yields flavor-independent turn ons, as desired.

\[
f(p_T) = \frac{1}{4} [1 + \text{erf}(a_0(p_T - x_0))] \cdot [1 + \text{erf}(a_1(p_T - x_1))]\]

Looking at $g(|\eta|)$ plots with various $p_T$ thresholds: factorization works much better than...
## Full Closure Test Results

<table>
<thead>
<tr>
<th>Sample</th>
<th>Asymmetries (in %)</th>
<th>Difference (absolute, in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fitted Turn Ons</td>
<td>Simple Cuts</td>
</tr>
<tr>
<td><strong>W boson + &gt; 1 jets</strong></td>
<td>23.62 ± 0.14</td>
<td>23.40 ± 0.13</td>
</tr>
<tr>
<td><strong>W boson + &gt; 2 jets</strong></td>
<td>23.20 ± 0.24</td>
<td>23.13 ± 0.23</td>
</tr>
<tr>
<td><strong>W boson + &gt; 3 jets</strong></td>
<td>24.4 ± 0.7</td>
<td>24.2 ± 0.7</td>
</tr>
<tr>
<td><strong>W boson + &gt; 4 jets</strong></td>
<td>30 ± 4</td>
<td>29 ± 4</td>
</tr>
<tr>
<td><strong>t\bar{t} for &gt; 4 jets</strong></td>
<td>1.31 ± 0.30</td>
<td>2.16 ± 0.26</td>
</tr>
<tr>
<td><strong>t\bar{t} for &gt; 5 jets</strong></td>
<td>−7.1 ± 0.7</td>
<td>−7.0 ± 0.6</td>
</tr>
<tr>
<td><strong>t\bar{t} for &gt; 6 jets</strong></td>
<td>−16.5 ± 1.8</td>
<td>−15.5 ± 1.6</td>
</tr>
<tr>
<td><strong>diluted W boson + &gt; 1 jets</strong></td>
<td>17.83 ± 0.12</td>
<td>17.73 ± 0.11</td>
</tr>
<tr>
<td><strong>diluted W boson + &gt; 2 jets</strong></td>
<td>17.59 ± 0.20</td>
<td>17.63 ± 0.20</td>
</tr>
<tr>
<td><strong>diluted W boson + &gt; 3 jets</strong></td>
<td>18.6 ± 0.6</td>
<td>18.3 ± 0.6</td>
</tr>
<tr>
<td><strong>diluted W boson + &gt; 4 jets</strong></td>
<td>21.7 ± 3.1</td>
<td>19.7 ± 3.4</td>
</tr>
<tr>
<td><strong>diluted t\bar{t} for &gt; 4 jets</strong></td>
<td>0.83 ± 0.24</td>
<td>1.44 ± 0.21</td>
</tr>
<tr>
<td><strong>diluted t\bar{t} for &gt; 5 jets</strong></td>
<td>−4.9 ± 0.5</td>
<td>−4.7 ± 0.5</td>
</tr>
<tr>
<td><strong>diluted t\bar{t} for &gt; 6 jets</strong></td>
<td>−10.7 ± 1.5</td>
<td>−10.3 ± 1.3</td>
</tr>
</tbody>
</table>

### Table 2: Effect of using simple box cuts to evaluate a model’s asymmetry. The last column lists the absolute difference for each sample, given in percent. The jets considered are those that pass either the fitted turn ons (in the second column) or the simple box cuts (in the third column). In the last two section “diluted” refers to samples weighted by the dilution factor, thus predicting the observable asymmetry after reconstruction effects.
The Best Variables

For each I list their names in my plots and how well each variable does for the main criteria on a scale of 1-5: (separation from W+jets, modeling, no |ΔY| bias).

(5,4,2) evLBPT – the leading b-jet’s pT
(5,4,3) chi2 – hitfit’s $\chi^2$ for the best jet assignment
(5,5,5) Mbb – invariant mass of the two b-jets selected in the best assignment
  • This can find $g \rightarrow bb$, but as hitfit’s assignment might be random in background, it probably works because in top decays the b-jets tend to be roughly back to back.

(3,5,4) lowestMqq – the event’s lowest invariant mass of two non b-tagged jets.
(3,5,3) Mjj – of the jets hitfit assigned to the W in the best assignment
(3,3,3) Ktmin – dR*min(pT) of the two closest jets
  • separates better than the minimal $P_{Trel}$. Why?
  • can avoid overall-JES dependence by normalizing in jets’ H or $H_T$. But this reduces separation. Using the 5-object H keeps some separation, but prefers central jets as $H_T/H$ is centrality!

(2,3,5) evH – energy sum of the jets and lepton
  • Bad data-MC agreement with 15 GeV jets, reasonable with 20GeV jets.
  • $H_T=$centrality*H offers a much better separation and an acceptable bias. Will use if 100% needed.

(1,4,3) aBPT – the pT asymmetry between those two jets.
  • Barely any separation, looking at it just because it has few correlations

BTW: Good variables that choose central tops: $\Delta Y_{j1,j2}$, Cosθ*1, dRmax, dRmax5, Ktmin/H
Fits to Likelihood Variables

Here are the two best variables:

<table>
<thead>
<tr>
<th>Variable</th>
<th>on s+b</th>
<th>on b.</th>
</tr>
</thead>
<tbody>
<tr>
<td>evLBPt</td>
<td>0.111</td>
<td>0.137</td>
</tr>
<tr>
<td>log(chi2)</td>
<td>0.114</td>
<td>0.105</td>
</tr>
<tr>
<td>log(lowestMqq)</td>
<td>0.051</td>
<td>0.051</td>
</tr>
<tr>
<td>Mbjj</td>
<td>0.070</td>
<td>0.095</td>
</tr>
<tr>
<td>log(evH)</td>
<td>0.029</td>
<td>0.039</td>
</tr>
<tr>
<td>Ktmin</td>
<td>0.071</td>
<td>0.068</td>
</tr>
<tr>
<td>aBPt</td>
<td>0.007</td>
<td>0.008</td>
</tr>
<tr>
<td>Mbb</td>
<td>0.040</td>
<td>0.047</td>
</tr>
<tr>
<td>Mjj</td>
<td>0.040</td>
<td>0.044</td>
</tr>
<tr>
<td>log(highestMqq)</td>
<td>0.031</td>
<td>0.043</td>
</tr>
</tbody>
</table>

Can also calculate a rough F.O.M. for the separation each variable gives using the fit and the distributions.

\[
p = \frac{P(x \mid \text{signal})}{P(x \mid \text{signal}) + P(x \mid \text{bkg.})}
\]

\[
d = 2p - 1 \quad D = d^2 = (2p - 1)^2
\]

\[
F.O.M. = \int D(x) f(x) dx
\]

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Choosing By F.O.M.

Can also choose a likelihood by trying them all.
I just reuse the same Figure Of Merit (at least it’s fast: 10 seconds).
To account for correlations, the probability comes from the distributions of L, not L itself; the separation is evaluated using the fractions I fitted to data in the previous iteration (with $M_{iv}$ & evLBPT).

#1: evLBPT+chi2+Ktmin+Mjj+highestMqq
#2: evLBPT+chi2+Ktmin+Mjj
#3: all but lowestMqq
#4: all but lowestMqq & H
#7: evLBPT+chi2+lowestMqq
+Mbjj+Ktmin+aBPT+Mbb
#10: evLBPT+chi2+
Mbjj+Ktmin+aBPT
#13: evLBPT+chi2+aBPT
$N_{\text{sig}} - A_{\text{fb}}$ Correlations

$N_{\text{sig}}$ and $A_{\text{fb}}$ are correlated in two ways:

- A larger $N_{\text{sig}}$ implies the observed asymmetry must be assigned to more events.
- Since $N_{\text{sig}} = N_+ + N_-$, a statistical fluctuation in, e.g., $N_+$ would increase both.
  - If $N_+ + N_-$ this cancels out with the similar effect from $N_-$. But they differ.

Untangling it by doing a simultaneous fit.

Need ensemble tests to prove whether cutting on the likelihood discriminate is acceptable.
Matched MC

Matrix element generator
Alpgen / Sherpa

Parton shower generator
Pythia / Herwig

Hard scatter partons

Particles

Detector simulation

LO calculations for 2→N hard processes

Only 2→2 hard processes

Resummed soft, collinear radiation.

Good at generating hard, large-angle processes
(calculates interference)

Weak on the “texture” of the QCD radiation
to avoid double counting of

Good at generating the details within a jet

Multijet events don’t describe data well
(and are hard to generate)

LON calculations for 2 → N hard processes

Only 2→2 hard processes

Resummed soft, collinear radiation.

Matrix element generator
Alpgen / Sherpa

Parton shower generator
Pythia / Herwig

Hard scatter partons

Particles

Detector simulation