$A_{fb}/A_c$ and $A$ vs $M_{tt}$ in $tt$ Pair Production

The CDF-II Collaboration

including
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Universitat Karlsruhe: J. Wagner, T. Chwalek, W. Wagner
Single Particle Asymmetries

- Forward-backward asymmetry $A_{FB}$
  - chiral color (axigluons)
  - $Z'$

- Charge asymmetry $A_C$
  - Net top current
  - $5 \pm 1.5\%$ from NLO QCD

- If CP is good $A_C = A_{FB}$

Two Particle Asymmetry

- Rapidity difference
  - equivalent to $tt$ rest frame

\[
A_{FB} = \frac{N_t(y > 0) - N_t(y < 0)}{N_t(y > 0) + N_t(y < 0)}
\]

\[
A_c = \frac{N_t(y > 0) - N_{\bar{t}}(y > 0)}{N_t(y > 0) + N_{\bar{t}}(y > 0)}
\]

\[
\Delta Y = Y_t - Y_{\bar{t}}
\]

\[
A_{\Delta Y} = \frac{N(\Delta Y > 0) - N(\Delta Y < 0)}{N(\Delta Y > 0) + N(\Delta Y < 0)}
\]
Data Sample

- $L = 3.2 \text{ fb}^{-1}$
- $e/\mu \ E_t / p_t > 20 \text{ GeV}/c$, $|n|<1.0$
- MET > 20 GeV
- 4 jets $E_t > 20 \text{ GeV}/c$, $|n|<2.0$
- $\geq 1$ btag
- 776 events

- Backgrounds
  - W+jets w/h.f. or “mis”tag
  - +QCD + small EWK
  - 167.5 ± 41.8 events

- 608 tt events. S:N ~4:1
- for $\sigma_{\text{eff}} \sim 7.2 \text{ pb}$

<table>
<thead>
<tr>
<th>Process</th>
<th>Predicted Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>W+HF Jets</td>
<td>86.56 ± 27.40</td>
</tr>
<tr>
<td>Mistags (W+LF)</td>
<td>27.43 ± 7.70</td>
</tr>
<tr>
<td>Non-W (QCD)</td>
<td>33.44 ± 28.06</td>
</tr>
<tr>
<td>Single Top</td>
<td>7.82 ± 0.50</td>
</tr>
<tr>
<td>WW/WZ/ZZ</td>
<td>7.57 ± 0.74</td>
</tr>
<tr>
<td>Z+Jets</td>
<td>4.78 ± 0.59</td>
</tr>
<tr>
<td>Top</td>
<td>569.08 ± 78.81</td>
</tr>
<tr>
<td>Total Prediction</td>
<td>736.64 ± 89.22</td>
</tr>
</tbody>
</table>
Top Reconstruction

- Jet-parton assignment via $\chi^2$
  - Constraints: $M_W = 80.4 \text{ GeV}/c^2$ (n.b. $p_Z\nu$!), $M_t = 175 \text{ GeV}/c^2$, btag = b
  - Float jet $p_t$ within errors

Rapidity Variables

- each event has a leptonic and hadronic top decay
  - $Q_+ : t_{lep} + t_{bar_{had}}$
  - $Q_- : t_{bar_{lep}} + t_{had}$

- this analysis: hadronic top in the lab frame
  - $Y$ of $t_{had}$
  - charge of lepton from $t_{lep}$
  - use $-Q_\ast Y(t_{had})$
The Top Rapidity Distribution (-Q*Y)

- combined -Q*Y
  \( A_{FB} = +9.8 \pm 3.6 \% \)
- MC@NLO
  \( A_{FB} = +1.9 \pm 0.7 \% \)
Subtract (somewhat asymmetric) Backgrounds

**Backgrounds reconstructed as top**

![Diagram showing distributions of various processes](image)

<table>
<thead>
<tr>
<th>Process</th>
<th>&gt;4 jets</th>
</tr>
</thead>
<tbody>
<tr>
<td>W+HF Jets</td>
<td>-0.087±0.0052</td>
</tr>
<tr>
<td>Mistags (W+LF)</td>
<td>-0.044±0.0079</td>
</tr>
<tr>
<td>Non-W (QCD)</td>
<td>-0.017±0.036</td>
</tr>
<tr>
<td>Single Top</td>
<td>-0.16±0.012</td>
</tr>
<tr>
<td>WW/WZ/ZZ</td>
<td>0.1±0.032</td>
</tr>
<tr>
<td>Z+Jets</td>
<td>-0.01±0.014</td>
</tr>
<tr>
<td>Total Prediction</td>
<td>-0.059±0.0079</td>
</tr>
</tbody>
</table>
Unfold to the parton-level

- **dN/dY** : histogram
  - parton level bins \( j \) w/ contents \( P_j \)
  - data: in bins \( i \) w/ contents \( D_i \)

then

\[ D_i = M_{ij} \times \varepsilon_j \times P_j \]

where

- the \( \varepsilon_j \) are the acceptances for each bin
- the \( M_{ij} \) are the bin-to-bin migration ratios
- both measured with symmetric Pythia

the inverse propagates data to parton level

\[ P_j = x \varepsilon_j^{-1} \times M_{ji}^{-1} \times D_i \]

result is optimized when nbins = 4

<table>
<thead>
<tr>
<th>bin</th>
<th>( Y )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-2.0 to -0.4</td>
</tr>
<tr>
<td>2</td>
<td>-0.4 to 0.0</td>
</tr>
<tr>
<td>3</td>
<td>0.0 to 0.4</td>
</tr>
<tr>
<td>4</td>
<td>0.4 to 2.0</td>
</tr>
</tbody>
</table>
Measurements

- $Q^*Y$ (pp frame) with 3.2 fb$^{-1}$
  
  $A_{FB} = 0.19 \pm 0.07 \pm 0.02$

$\Delta Y$ (tt frame) with 1.9 fb$^{-1}$

$A_{FB} = 0.24 \pm 0.13 \pm 0.04$

D0 has measured

$\Delta Y$ (uncorrected) with 0.9 fb$^{-1}$

$A_{FB} = 0.12 \pm 0.08 \pm 0.01$

compare CDF $\Delta Y$ uncorrected

$A_{FB} = 0.11 \pm 0.04$
The $M_{tt}$ distribution  Bridgeman, Liss (CDF)

- A proper unfold to parton level
  - “no evidence of departure from SM”

CDF II Preliminary

CDF II Data, $\int L \approx 2.7$ fb$^{-1}$

CDF II Preliminary

SM Expectation

SM Uncertainties

CDF II Data, $\int L \approx 2.7$ fb$^{-1}$

Unfolded $M_{tt}$ [GeV/c$^2$]
Mass Dependence of the Asymmetry  M. Tecchio, T. Schwarz

- unfold in $M_{tt}$ and $A_{fb}$ for some mass cut
  - reconstructed data divided into 4 exclusive bins
    - low mass FW
    - low mass BW
    - high mass FW
    - high mass BW
  - backgrounds subtracted
  - selection bias, reco slews corrected simultaneously in mass and $Y$ with 2x2 unfold
  - parton level $A_{fb}$ for 2 mass bins “high and low”
  - can study as function of cut
$A_{fb}$ vs M unfold performance check

- **add 10% contribution (0.7 pb) of sequential Z’ at 450 GeV**
  - expected integral $A_{fb} \sim 2\%$

- **In $A_{fb}$ low mass cut scan**
  - sharp rise to 450
  - overshoot
  - settles back to integral
  - unfold works nicely

- **In $A_{fb}$ high mass cut scan**
  - starts above integral
  - asymptotes to Pythia symmetry as Z’ contribution fades
What do we expect?

- in qq frame the NLO effect has a linear mass dependence  
  - Almeida, Sterman, Vogelsang

\[
\Delta A_{FB} = 2.5\%
\]

\[
A_{FB}^0 = 3\%
\]

\[
NLO \text{ Model: } A_{FB} = A_{FB}^0 + (\Delta A_{FB}/\Delta M_{tt}) \times M_{tt}
\]

\[
\Delta M_{tt} = 100 \text{ GeV}
\]

350 GeV
Data Measurement with Mass Cut at 450 GeV

Asymmetry in low vs high $M_{tt}$ for $M_{tt}=450$ GeV

CDF II Preliminary

- Raw Data $L=3.2$ fb$^{-1}$
- Background
- Bkg. Sub. Data
- Corrected Data

Events

FW$_{low}$  BW$_{low}$  FW$_{high}$  BW$_{high}$

$A_{FB}$ in LAB Frame
Now Scan the Cut

• points: data
• dashed: Pythia reweighted with flat $A_{\cos \theta}$ asymmetry
  – $A = 19\%$
  – no mass dependence
• green: “NLO model”, Pythia reweighted with $A_{\text{FB}}$ linearly dependent on $M_{tt}$ as per fit to NLL calculation
• awaiting more data!
Now what?

- $A_{FB}$ in pp frame
  
  $A_{FB} = 0.19 \pm 0.07 \pm 0.02$

- Procedure for study of mass dependence

- It’s all $2\sigma$

- more studies with more data
  - $\Delta Y$ variable
  - understand systematics
  - $A_{FB}$ vs $M_{tt}$
  - $A_{FB}$ vs $Y$
  - asymmetries of decay products

- more data!!
Bonus Question

• Highest $Q^2$ prior test of C in strong interactions?

Test of charge-conjugation invariance in $\bar{p}p$ interactions

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Brookhaven National Laboratory, Upton, L.I., New York 11973
(Received 12 December 1977)

Using $\bar{p}p$ interactions at $\sqrt{s} = 5.44$ GeV we have tested for evidence of C noninvariance through a comparison of the transverse-momentum distributions of particle and antiparticle produced at 90° in the center of mass. We found an average charge asymmetry for pions with $p_t$ between 0.5 and 2.7 GeV/c of $\Delta = (N_+ - N_-)/(N_+ + N_-) = 0.006 \pm 0.009$. This corresponds to a limit on the magnitude of the C-violating (relative to C-conserving) amplitude of $|\text{Re}a| \leq 0.0045$.

• What’s the rub?
  • jets: don’t know the charge
  • proton collisions: don’t know the initial state

• $q\bar{q} \rightarrow t\bar{t}$ at the Tevatron is ideal