New Methods For Finding Single-Top

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Why is single-top interesting?

- Cross-section measurement yields a measurement of $V_{tb}$
- Top quark plays "special" role in a variety of new physics models
- Is a background to other searches (Higgs, etc...)

\[ V_{tb} \]

- t-channel
  - 1.98 pb

\[ V_{tb} \]

- s-channel
  - 0.88 pb
# Numbers for a Sample Search

## Basic Cuts
- 1 lepton PT > 15 GeV, $|\eta| < 2.0$
- MET > 15 GeV
- 1 b-tagged jet with PT > 20 GeV, $|\eta| < 2.0$
- 1 other jet with PT > 20 GeV, $|\eta| < 3.$

## Advanced Cuts
- Same as basic cuts, except:
  - b-tagged jet PT > 60 GeV, other jet PT > 30 GeV
  - $M_{\text{top}}$ = invariant mass(blv): 160 GeV $< M_{\text{top}} < 190$ GeV
  - $HT = \text{PT}_{\text{lepton}} + \text{MET} + \Sigma_{\text{all jets}}$ (jet PT): 180 GeV $< HT < 250$ GeV

- Studies done with Madgraph + Pythia + Fast Detector Simulation for 4 fb$^{-1}$

## Signal-to-Background Ratios
- Basic sig:bkg ratio is 1:15
- Advanced sig:bkg is 1:4
- Systematics prevent discovery

<table>
<thead>
<tr>
<th>Channels</th>
<th>Events for Basic Cuts</th>
<th>Advanced cuts</th>
<th>Systematic Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>t-channel</td>
<td>443</td>
<td>32</td>
<td>&gt;15%</td>
</tr>
<tr>
<td>s-channel</td>
<td>192</td>
<td>16</td>
<td>&gt;10%</td>
</tr>
<tr>
<td>W+jets</td>
<td>6400</td>
<td>136</td>
<td>&gt;10%</td>
</tr>
<tr>
<td>tt</td>
<td>3200</td>
<td>48</td>
<td>&gt;10%</td>
</tr>
</tbody>
</table>

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1. $\bar{p}p$ initial state at Tevatron is CP invariant, but not C or P invariant separately
2. At leading order, processes that proceed through an s-channel gluon “forget” that they are not separately C and P invariant ($t\bar{t}$ and QCD)
3. Processes with W’s “remember” that they are not separately C and P invariant (single top and W+jets)
What t-channel looks like

- $\sim \frac{3}{4}$ of the time, top quarks are formed from $u\bar{g}$ initial state and boosted in proton direction, $\frac{1}{4}$ from $g\bar{d}$ and are boosted in anti-proton direction.

- Direction of jet is correlated with top spin, which is correlated with lepton direction.

Usually don’t see the $\bar{b}$!

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t-channel: $Q_{\text{lepton}} \ast \text{jet rapidity vs. } Q_{\text{lepton}} \ast \text{lepton rapidity}$

1. $Q_{\text{lepton}}$ is the sign of the charge of lepton
2. jet: highest PT non b-tagged jet
3. Under P or C: $x \leftrightarrow -x, \ y \leftrightarrow -y$
4. t-channel is not P or C invariant
5. Under CP, the plot is invariant

CDF has looked at $Q_{\text{lepton}} \ast \text{jet rapidity}$ by itself

Contours of Constant Cross-section

$Q_{\text{lepton}} \ast \text{jet rapidity}$

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1. Boosted in proton direction for W+ production, anti-proton direction for W-production
2. Final state is not P or C invariant
3. Jets from light quarks and gluons can be misidentified as b-jets

Contours of Constant Cross-section

\( \bar{x} > 0 \)
\( \bar{y} > 0 \)

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What $\bar{t}t$ looks like

1. Doesn’t tend to be boosted in either direction
2. Final state is both $P$ and $C$ invariant at leading order
What can be done with this?

- Fit, likelihood methods are possible
- We have pursued another approach

Region 1 (R1)

Region 2 (R2)

Under Parity, R1 $\Leftrightarrow$ R2

$Q_{\text{lepton}} \times \text{Jet Rapidity}$

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Parity Even and Odd Combinations of R1 and R2

1. $R1+R2 \Leftrightarrow R1+R2$ under P
2. $R1-R2 \Leftrightarrow -(R1-R2)$ under P
3. $\bar{t}t$ and QCD are zero for P odd combination
4. Systematic errors in $\bar{t}t$ and QCD largely cancel
5. $W+jets$ shape will have to be measured from data
6. For P odd combination, sig:bkg is better than 1:1!

### Numbers of Events for 4 fb-1 of data

<table>
<thead>
<tr>
<th>Channel</th>
<th>R1+R2</th>
<th>R1-R2</th>
</tr>
</thead>
<tbody>
<tr>
<td>t-channel</td>
<td>64</td>
<td>32</td>
</tr>
<tr>
<td>s-channel</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>W+jets</td>
<td>135</td>
<td>23</td>
</tr>
<tr>
<td>$tt$</td>
<td>96</td>
<td>0</td>
</tr>
</tbody>
</table>

Cuts: b-tagged jet $PT>45\text{GeV}$, jet $PT>35 \text{GeV}$

- $M_{top} =$ invariant mass(blv): $155 \text{ GeV} < M_{top} < 195 \text{ GeV}$
- $HT= P_{t_{lepton}} + MET + \Sigma_{all\,jets} (jet\,PT): \ 180 \text{ GeV} < HT < 250 \text{ GeV}$

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Conclusions

- Single-top discovery is challenging because of large backgrounds and large systematic uncertainties
- The jet - lepton correlation provides powerful discrimination between signal and background for t-channel production of single-top
- Parity odd combinations of regions connected by parity transformations yield sig:bkg ratios better than 1:1, with systematics in $t\bar{t}$ and QCD largely canceling
- $W$+jets is the challenge for this correlation, not $t\bar{t}$ or QCD. It will require collaboration between theory and experiment to model the $W$+jets jet rapidity vs. lepton rapidity shape
- Finding better cuts and better regions ($R1$, $R2$) will increase significance

Thanks to Gordon Watts, Andy Haas, Henry Lubatti
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Buffer
Sample Searches

Basic Cuts

- 1 b-tagged jet $P_T > 20$ GeV, $|\eta| < 2.0$
- 1 other jet, $P_T > 20$, $|\eta| < 3.5$
- 1 lepton $P_T > 15$, $|\eta| < 2.0$
- MET $> 15$ GeV

Advanced Cuts

- Same as Basic Cuts
- Construct $M_{top} = \text{invariant mass (blv)}$
- Define $HT = P_{T_{lepton}} + \text{MET} + \Sigma(\text{jet } PT)$
- $120 < M_{top} < 220$
- $170 < HT < 300$

* $\eta =$ rapidity

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Look at channels again
What QCD looks like

- Light quark and gluon jets are sometimes identified as leptons
- Energy mis-measurements can fake missing transverse energy (neutrino signature)
- Final state is both $P$ and $C$ invariant
What W+jets looks like

- Boosted in proton direction for W+ production, anti-proton direction for W- production
- Final state is not P or C invariant
- Jets from light quarks and gluons can be misidentified as b-jets
W+jets and $\bar{t}t$

Contours of Constant Cross-section

W+jets

$Q_{\text{lepton}} \times \text{Jet Rapidity}$

W+jets: small asymmetry, but large overall rate

$\bar{t}t$

$Q_{\text{lepton}} \times \text{Jet Rapidity}$

$\bar{t}t$: plot invariant under $P$