Study of top-quark production and decay vertices at NLC

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Top-quark physics

Top-quark is already discovered
... no longer ‘search’ physics

It also has potential to search new physics

\[ m_{\text{top}} = 175 \text{ GeV} \quad \text{... Uniquely heavy} \]
\[ \Gamma_t = 1.4 \text{ GeV} \quad \text{... Decays very fast} \]

NLC is excellent and much cleaner place to do it
... than LHC!!
Top-quark anomalous coupling analysis

*Top-quark decays before forming a hadron*
→ Top spin information is transferred to its daughters
→ can probe the couplings with their angular distributions

At NLC, we can probe both top-production + decay couplings ⇣ can’t do at LHC!
Form Factors at $\gamma/Z^0 \rightarrow t\bar{t}$ vertex:
\[iM = \{\gamma^\mu F_{1V} + F_{1A} \gamma_5 + i\sigma^{\mu\nu} q_\nu/2m_t[ F_{2V} + F_{2A} \gamma_5]\} \]

\[SM(Z): \begin{bmatrix} \frac{1}{4} - \sin^2 \theta_W \sin \theta_W \cos \theta_W \\ -\frac{1}{4} \sin \theta_W \cos \theta_W \end{bmatrix} \]

\[\begin{bmatrix} (\frac{1}{4} - \sin^2 \theta_W \sin \theta_W \cos \theta_W) \sin \theta_W \cos \theta_W \\ 0 \end{bmatrix} \]

(\gamma): 2/3 0

$F_{2V}$: Electroweak Magnetic Dipole moment
$F_{2A}$: Electric Dipole moment .. Non-zero $\rightarrow CP$

Form Factors at $t \rightarrow bW$ vertex:
\[iM = ig/\sqrt{2}\{\gamma^\mu[F_{1L}^W P_L + F_{1R}^W P_R] + i\sigma^{\mu\nu} q_\nu/2m_t[ F_{2L}^W P_L + F_{2R}^W P_R]\} \]

\[SM: \begin{bmatrix} 1 \\ 0 \end{bmatrix} \]

\[\begin{bmatrix} 0 \\ 0 \end{bmatrix} \]
Depending on the W decay, there are 3 final states:

1) 2 leptons + 2 jets (both leptonic)
2) 1 lepton + 4 jets (1 leptonic 1 hadronic)
3) 6 jets (both hadronic)
Here we define the angles

Top decay angle

W decay angle

We want to measure these angles

Which one is $t$ or $\bar{t}$? … use charge of the lepton

4-momentum of the leptonic decayed top-quark

… from the opposite top-quark
In this analysis, we use $\text{tt} \rightarrow 4 \text{ jets} + 1 \text{ lepton (\mu or e)}$

Generate $\text{tt}$ events with Pandora-Pythia

$m_t = 175 \text{ GeV}, \ E_{CM} = 500 \text{ GeV}
\text{including QCD effect (parton shower), ISR+beamstrahlung}$

Beam polarization…

1) $P(e^-) = -0.8 \quad P(e^+) = 0 \quad \sigma_{\text{tt}} = 742 \text{ fb}$
2) No polarization \hspace{1cm} 565 \text{ fb}
3) $P(e^-) = +0.8 \quad P(e^+) = 0 \quad 398 \text{ fb}$
4) $P(e^-) = -0.8 \quad P(e^+) = +0.5 \quad 1078 \text{ fb}$

$\Rightarrow P_{\text{eff}} = 0.93$

• Generate 100 fb$^{-1}$ each \hspace{1cm} Through LCD Fast Detector simulator
• Reconstruct 4 jets by Jet-clustering (JADE)
  \hspace{1cm} \text{... use charged tracks + Neutral clusters}
  \hspace{1cm} \text{(charged/neutral cluster separation .. Perfect)}
• Reconstruct $W$ by 2 jets
• Reconstruct Top by $W + b$-jet (Apply $0.85 < \frac{E_{\text{3 jets}}}{E_{\text{beam}}} < 1.05$)
Flavor-tagging

To tag b-quark, we use mass-tag method

1. Reconstruct Secondary Vertex
2. Form 'P_{T}\text{-corrected mass}' of SV

\[ M_{\text{corr.}} = \sqrt{(M_{\text{vtx}}^2 + |P_{T\text{vtx}}|^2)} + |P_{T\text{vtx}}| \]

3. Identify heavy-quark signals with \( M_{\text{corr}} \)
Flavor tagging

heavy-quark

- $b$: $P_T$ corrected mass > 1.8 GeV
  - efficiency = 67%
  - purity = 95%

- $c+b$: $P_T$ corrected mass > 0.5 GeV
  - efficiency = 67%
  - purity = 97%

uds-quark

- $uds$: $N_{sig} = 0$
  - efficiency = 87%
  - purity = 79%
Selection efficiency::

- Event selection $\varepsilon = 60\%$
- Top selection $50\%$
- Flavor-tag $67\%$

Total $20\%$

Top-reconstruction performance::

- Purity $88\%$ (80\% without flavor-tag)
- Correct b-assign $86\%$ (53\%)
- Mass resolution $7.6$ GeV (10.0 GeV)
Reconstructed Angular Distributions

$\cos \theta$

$\Delta \theta (\theta - \theta_{\text{gen}})$

$\Delta \theta = 23 \text{mrad}$

$\cos \chi_t$

$\Delta \chi_t$

$\Delta \chi_t = 52 \text{mrad}$

$\cos \chi$

$\Delta \chi$

$\Delta \chi = 100 \text{mrad}$
Sensitivities to the couplings ($\gamma/z$ $t\bar{t}$ vertex)

This time, we only estimate

1) $F_{1A}^{Z,\gamma} \rightarrow \cos\theta$ asymmetry (using Maximum Likelihood)
2) $F_{1V}^{Z,\gamma} \rightarrow$ L/R asymmetry

1) Sensitivities to $F_{1A}^{Z,\gamma}$ for 100 fb$^{-1}$ (68% CL)

<table>
<thead>
<tr>
<th>$P(e^-)$</th>
<th>$F_{1A}^{\gamma}$</th>
<th>$F_{1A}^{Z}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.8</td>
<td>0.016</td>
<td>0.022</td>
</tr>
<tr>
<td>-0.8 $P(e^+) = +0.5$</td>
<td>0.013</td>
<td>0.019</td>
</tr>
<tr>
<td>No polarization</td>
<td>0.017</td>
<td>0.024</td>
</tr>
<tr>
<td>+0.8</td>
<td>0.016</td>
<td>0.026</td>
</tr>
</tbody>
</table>

2) Sensitivities to $F_{1V}^{Z,\gamma}$ using left-right asymmetry

$$A_{LR} = \left(0.335 \pm 0.017\right)/0.8 \quad \text{(for } |P_e| = 0.8\text{)}$$

$$\Rightarrow F_{1V}^{\gamma} : 0.071 \quad F_{1V}^{Z} : 0.050$$
\( P(e^-) = -0.8 \)

1) Without ISR, Beamstrahlung, parton-shower
2) With ..
3) With .. + Energy Flow (detector L)

<table>
<thead>
<tr>
<th></th>
<th>1)</th>
<th>2)</th>
<th>3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top efficiency</td>
<td>24%</td>
<td>20%</td>
<td>14%</td>
</tr>
<tr>
<td>Top purity</td>
<td>90%</td>
<td>87%</td>
<td>86%</td>
</tr>
<tr>
<td>( \Delta m_{\text{top}} )</td>
<td>5.8 GeV</td>
<td>7.6 GeV</td>
<td>9.4 GeV</td>
</tr>
<tr>
<td>( \Delta \theta )</td>
<td>14 mrad</td>
<td>23 mrad</td>
<td>39 mrad</td>
</tr>
<tr>
<td>( F_{1A}^\gamma ) sensitivity</td>
<td>0.014</td>
<td>0.016</td>
<td>0.018</td>
</tr>
<tr>
<td>( F_{1A}^Z )</td>
<td>0.020</td>
<td>0.022</td>
<td>0.026</td>
</tr>
</tbody>
</table>
Reconstructed W with 2 jets

With flavor-tag

Reconstructed top with 3 jets

With flavor-tag
Reconstructed Angular Distributions

$\cos \theta$

$\Delta \theta = 39 \text{ mrad}$
($\sim 23 \text{ mrad at perfect track-cls}$)

$\cos \chi_t$

$\Delta \chi_t = 76 \text{ mrad} (~52)$

$\cos \chi$

$\Delta \chi = 125 \text{ mrad} (~100)$
To Do

Estimate another coupling sensitivities
Compare 3 detector parameters (L, SD, P)
tt → 6 jets analysis
  (top-quark charge ID.. vertex charge of b-jet)
Kinematical constraint fit
:: Announce ::

We are going to release a new version LCD Root the next week

Can generate Pythia, Pandora, and Pandora-Pythia directly

Can read a SIO file directly

New detector parameter files (SD, L, P)

... Many thanks to Toshi