Search for Technicolor Particles in association with $W^{\pm}$ boson at CDF

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for the CDF Collaboration

Outline

- Introduction
- Event Selection
- Background Estimation
- Technicolor Acceptance
- Results of Technicolor search
- Conclusion and Plan
Introduction (Tevatron and CDF detector)

- Currently $\sim 2 \text{ fb}^{-1}$ delivered,
  $\sim 1.6 \text{ fb}^{-1}$ recorded to tape
- Expect to collect $\sim 9 \text{ fb}^{-1}$ by 2009
- This analysis uses $\sim 1 \text{ fb}^{-1}$ data collected up to February 2006
Introduction and Motivation (Technicolor)

**Theoretical motivation**
- Technicolor theory provides electroweak symmetry breaking by predicting a new strong gauge theory and new fermions (techniquarks)
  - **Technipion (fermion-pair)** plays a role in Higgs boson.
    - e.g. Technicolor-Straw Man model for low-scale Technicolor (hep-ph/0605119)
- The most likely processes and search modes
  - $\rho_T^\pm \rightarrow W^{\pm} \pi_T^0 \rightarrow l^\pm \nu + b\bar{b}$,
    $\rho_T^0 \rightarrow W^{\pm} \pi_T^0 \rightarrow l^\pm \nu + b\bar{c}, b\bar{u}$
  - $\omega_T^0, \rho_T^0 \rightarrow \gamma \pi_T^0, \gamma \pi_T^0' \rightarrow \gamma b\bar{b}$,
    $\omega_T^0, \rho_T^0 \rightarrow e^+ e^-, \mu^+ \mu^-$

**Technicolor Cross section**
- Search region: $\rho_T^\pm$ 180-210 GeV, $\pi_T^0$ 95-125 GeV
- $\sigma(\rho_T^\pm \rightarrow W\pi_T^0) \times BR(\pi_T^0 \rightarrow b\bar{b})$: about 1~3 pb

**Previous analysis at CDF**
- First RunII results uses 160 pb$^{-1}$ → Set the cross section limit
- Use about **six times data!!**
Event Selection

- **Event Selection**

  - High $p_T$ central isolated electron or muon ($p_T > 20$ GeV)
  
  - Large missing $E_T$ ($E_T > 25\,(20)$ GeV for **one b-tag events** (two b-tag events))
  
  - Exact two high $E_T$ jets ($E_T > 15$ GeV with $|\eta| < 2.0$)
  
  - At least one jet to be identified as b-jet using silicon detector (b-tag)
  
  - Additionally apply b-tagging with Neural Network (**NN tag**) for exact one b-tagged events. (See Yoshiaki’s talk at Higgs Session on Oct 31)

- **Analysis Strategy**

  - Estimate both exact one b-tag (w/ NN tag) events and two b-tag events separately
  
  - Finally, one tag and two tag events are combined in calculating limit
Background Estimation

• Background Components
  
  – W+Light Flavors (mis-tagged event)
  
  – QCD fake events (Non-W events)
  
  – W+Heavy Flavors ($Wb\bar{b}, Wc^-c, Wc$)

  ⇐ Data based background

  – Z+Heavy Flavors ($Zb\bar{b}, Zc^-c, Zc$)

  ⇐ Data and MC based background

  – Top events ($t\bar{t}$ and single top)

  ⇐ MC based background

  – Diboson ($W^+W^-, W^{\pm}Z^0, Z^0Z^0$) and $Z^0 \to \tau\tau$
Background Summary

- Exact one b-tagged events on W+2jet

<table>
<thead>
<tr>
<th>Njet</th>
<th>2 jet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before b-tagging Events</td>
<td>13246</td>
</tr>
<tr>
<td>Mistag</td>
<td>47.7 ± 9.6</td>
</tr>
<tr>
<td>Wb¯b</td>
<td>132.3 ± 44.8</td>
</tr>
<tr>
<td>Wc¯c</td>
<td>39.3 ± 13.5</td>
</tr>
<tr>
<td>Wc</td>
<td>31.4 ± 8.3</td>
</tr>
<tr>
<td>Z+jets</td>
<td>10.8 ± 4.3</td>
</tr>
<tr>
<td>t¯t (6.7pb)</td>
<td>40.2 ± 6.2</td>
</tr>
<tr>
<td>Single top</td>
<td>24.2 ± 2.1</td>
</tr>
<tr>
<td>Diboson/Z→ ττ</td>
<td>14.4 ± 2.4</td>
</tr>
<tr>
<td>nonW QCD</td>
<td>16.8 ± 3.1</td>
</tr>
<tr>
<td>Total Bkg</td>
<td>357.0 ± 63.6</td>
</tr>
<tr>
<td>Observed events</td>
<td>341</td>
</tr>
</tbody>
</table>

- Observed data is consistent with estimated background for each jet bin
Background Summary

- Double b-tagged events on W+2jet

<table>
<thead>
<tr>
<th>Njet</th>
<th>2 jet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before b-tagging Events</td>
<td>14604</td>
</tr>
<tr>
<td>Mistag</td>
<td>3.2±0.5</td>
</tr>
<tr>
<td>Wbb</td>
<td>19.2±6.5</td>
</tr>
<tr>
<td>Wcc</td>
<td>3.0±1.1</td>
</tr>
<tr>
<td>Z+jets</td>
<td>1.9±0.8</td>
</tr>
<tr>
<td>tt (6.7pb)</td>
<td>10.5±2.3</td>
</tr>
<tr>
<td>Single top</td>
<td>4.7±0.8</td>
</tr>
<tr>
<td>Diboson/Z→ττ</td>
<td>1.2±0.2</td>
</tr>
<tr>
<td>nonW QCD</td>
<td>1.5±0.3</td>
</tr>
<tr>
<td>Total Bkg</td>
<td>45.2±8.4</td>
</tr>
<tr>
<td>Observed events</td>
<td>39</td>
</tr>
</tbody>
</table>

- Observed data is consistent with estimated background for each jet bin
- Not apply Neural net b-tagging
Signal Acceptance and Systematics

- **Signal Acceptance**

  ![Signal Acceptance Plots](image)

- **Expected Signal Event**
  
  \(m(\rho_T) \geq 200 \text{ GeV, } m(\pi_T) \geq 115 \text{ GeV}\) :
  
  - 12.1 event (1 tag w/ NNtag)
  - 4.7 event (double tag)

- **Systematics**

<table>
<thead>
<tr>
<th></th>
<th>1 tag w/ NNtag</th>
<th>double tag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lepton ID</td>
<td>~2%</td>
<td>~2%</td>
</tr>
<tr>
<td>Trigger</td>
<td>&lt;1%</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>ISR/FSR</td>
<td>6.7%</td>
<td>14%</td>
</tr>
<tr>
<td>PDF</td>
<td>1.7%</td>
<td>2.6%</td>
</tr>
<tr>
<td>JES</td>
<td>2.8%</td>
<td>3.9%</td>
</tr>
<tr>
<td>b-tagging</td>
<td>5.3%</td>
<td>16%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>9%</td>
<td>22%</td>
</tr>
</tbody>
</table>

0.8-1.0\% (one tag w/ NNtag), 0.3-0.4\% (double tag)
Reconstructed Mass

- Reconstructed mass on 1 tag w/ NNtag

- **Q value** is defined by \( Q = m(W+2\text{jet}) - m(\text{dijet}) - m(W) \)

- Observed data is consistent with total background estimate
- Observed data is consistent with total background estimate
Reconstructed Mass (2D plots)

- Set an upper limit on Technicolor production cross section by fitting dijet mass and Q value with 2D binned likelihood technique

- 2D plots on 1tag w/ NNtag for total background, data and one signal sample

CDF Run II Preliminary (955 pb⁻¹)

```
Total
```

```
data
```

```
m(ρ⁺)=200, m(π⁺)=115
```
Reconstructed Mass (2D plots)

- 2D plots on double tag for total background, data and one signal sample
Set Upper limit

2D Binned Likelihood Technique

- Event count in each bin is supposed to be ruled by Poisson statistics
- Utilize the maximum information in each bin by defining a likelihood as

\[
L(\sigma \times Br) = \int \int \prod_{i=1}^{N_{\text{bin}}} \prod_{j=1}^{N_{\text{bin}}} \frac{n_{ij}!}{\mu_{ij}^{n_{ij}}} G(N_{QCD}, \sigma_{QCD}) G(N_{Top}, \sigma_{Top}) G(N_{\text{sig}}, \sigma_{\text{sig}}) dN_{QCD} dN_{Top} dN_{\text{sig}}
\]

\[
\mu_{ij} = f_{ij}^{(QCD)} \cdot N^{(QCD)} + f_{ij}^{(Top)} \cdot N^{(Top)} + f_{ij}^{T} (\epsilon \cdot L \cdot \sigma(p\bar{p} \rightarrow \rho_T^\pm \rightarrow \pi^0 W) \cdot BR(\pi^0 \rightarrow b\bar{b}))
\]

Combined Likelihood

\[
L_{\text{com}}(\sigma \times Br) = L_{1\text{tag}}(\sigma \times Br) \times L_{2\text{tag}}(\sigma \times Br)
\]

\[
\beta = \frac{\int_{0}^{\alpha} L(\alpha) d\alpha}{\int_{0}^{\infty} L(\alpha) d\alpha} \rightarrow \text{set } \beta = 0.95
\]
Results

- Upper limit using $L_{com}(\sigma \times Br)$

![Graphs showing data and theoretical predictions for $m(\rho_T)$ at 180, 190, 200, and 210 GeV/c^2.]

♦ Exclude small region: $95 < \pi_T < 98$ GeV for $\rho_T = 190$ GeV
Results (cont.)

- Pseudo Experiment results

CDF RunII Preliminary (955 pb-1)

Observed limit is 2 $\sigma$ level higher than expected
Conclusion and Plan

- We set an upper limit on Technicolor production cross section using $\sim 1 \text{fb}^{-1}$.

- We exclude region:

  \[
  95 \text{ GeV} < m(\pi_T) < 98 \text{ GeV} \text{ for } m(\rho_T) = 190 \text{ GeV}
  \]

- The observed limit is worse than the expected. But the statistical significance of such excess is 2.6% even if Technicolor wasn't there.
  $\Rightarrow$ We need more DATA!!

Future plan

- 1.2 fb$^{-1}$ data is available by Winter Conference

- Try to optimize event selection
Backup Slide
The Source of Higher Observed Limit

- Higher observed limit come from 1 tag events (We don’t see it due to statistical limit in double tag events)

- This results seem stable (Already check shapes after changing event selection more tight or loose)

- Other many kinematic shapes have good agreements between data and expected background.
The parameter of Technicolor

- Main parameter of Technicolor in this analysis
  - $N_{TC} = 4$
  - $M_V = M_A = 200$ GeV
  - $Q_U = \frac{4}{3}$
  - $Q_D = Q_U - 1 = \frac{1}{3}$

- Generated mass

<table>
<thead>
<tr>
<th>$m(\rho_T) \backslash m(\pi_T)$</th>
<th>95 GeV</th>
<th>105 GeV</th>
<th>115 GeV</th>
<th>125 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>180 GeV</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>190 GeV</td>
<td>√</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200 GeV</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>210 GeV</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
</tbody>
</table>
Technicolor Cross Section

- Search region: $\rho_T^{\pm} \ 180-210 \text{ GeV}, \pi_T^0 \ 95-125 \text{ GeV} \leftarrow \text{Generate using PYTHIA MC}$
- Signal cross section (LO) is calculated from MC

\[ \frac{\sigma(\rho_T^{\pm} \rightarrow W\pi_T^0) \times BR(\pi_T^0 \rightarrow b\bar{b})}{b} \text{ is about } 1 \sim 3 \text{ pb} \]
Neutrino Solution

- Need to solve $P_z$ of neutrino to reconstruct $W + 2$ jet mass

**Procedure**

- Use the $W$ boson mass constraint in a lepton-neutrino system and solve the quadratic equation
  
  1) Take smaller $P_z$ from the two solutions $\sim 70\%$
  2) If there is no solution for $P_z$, we take real part as $P_z$ of neutrino $\sim 30\%$

Reconstructed $P_z$ vs. generator $P_z$ the difference of shape for each solution case.
Mass Distribution of Signal

- Dijet mass and $W + 2$ jet mass of signal sample ($p_T^\pm=200$ GeV, $\pi_T^0=115$ GeV)

\[ m(\rho^\pm_T)=200, \, m(\pi_T^0)=115 \]

\[ Q = m(Wjj) - m(jj) - m(W) \]

* $Q$ value is uncorrelated to dijet mass $\rightarrow$ apply $Q$ value and dijet mass in fitting.
Check Observed Limit

- Double tag observed limit and Pseudo experiments results

CDF Run II Preliminary (955 pb⁻¹)

<table>
<thead>
<tr>
<th>m(\rho^0) = 180 GeV</th>
<th>Data</th>
<th>PseudoExpt: 1σ</th>
<th>PseudoExpt: 2σ</th>
<th>Theory(LO)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>m(\rho^0) = 190 GeV</th>
<th>1σ</th>
<th>2σ</th>
<th>Theory(LO)</th>
</tr>
</thead>
</table>

| m(\rho^0) = 200 GeV | Data | PseudoExpt: 1σ | PseudoExpt: 2σ | Theory(LO) |

| m(\rho^0) = 210 GeV | Data | PseudoExpt: 1σ | PseudoExpt: 2σ | Theory(LO) |

† Observed limits are reasonable

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DPF (Hawaii), 11/1/2006  Page 22/15
• 1 tag w/ NN tag and Pseudo experiments results

† Observed limits are much higher than pseudo experiments unluckily
Event Display in Signal Region

- Central Muon event: #Run: 184377, #Event: 13093573

† Reconstructed dijet mass: 96.3 GeV, W+2jet mass: 222.1 GeV