Wtb Anomalous Top Couplings

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ATLAS Collaboration

Flavour in the Era of the LHC, 9th-11th October, CERN
Outline

- Introduction
- Probing the Wtb vertex
- New Observables
- Analysis & Systematic Errors
- New Combination of Observables
- Conclusions
**Introduction**

Studying the Wtb Vertex with $t\bar{t}$ events @ LHC

Production X-section:

$\sigma \sim 833\text{pb} @ 14\text{TeV}$

Semileptonic Topology:

- **Golden Channel**

- **Clean Topology:** $t\bar{t}$ back to back

Used for several studies

- $\geq 4$ jets, $\Delta R=0.4$
- $p_T>40\text{ GeV}$

- $p_T>20\text{ GeV}$

- 2 $b$-jets

- $t(\text{lep})$

- $W(\text{had})$

- $t(\text{had})$

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Introduction

Studying the Wtb Vertex with $t\bar{t}$ events @ LHC

Measure $W$ polarization ($F_0$, $F_L$, $F_R$) through:

\[
\frac{1}{\Gamma} \frac{d\Gamma}{d\cos\theta^*_\ell} = \frac{3}{8} (1 + \cos\theta^*_\ell)^2 F_R + \frac{3}{8} (1 - \cos\theta^*_\ell)^2 F_L + \frac{3}{4} \sin^2\theta^*_\ell F_0
\]

Using lepton angular distribution (with respect to top direction) in $W$ cm system:

Finite ($t,W$) width corrections have a negligible effect

$t,W$ on-shell Ok

SM(LO): $F_0=0.703$, $F_L=0.297$, $F_R=3.6\times10^{-4}$
(NLO): $F_0=0.695$, $F_L=0.304$, $F_R=0.001$

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Probing the $W_{tb}$ vertex

Anomalous Couplings in the $t \rightarrow bW$ decay:

\[ \mathcal{L} = -\frac{g}{\sqrt{2}} \bar{b} \gamma^\mu (V_L P_L + V_R P_R) t W^-_\mu \]

\[ -\frac{g}{\sqrt{2}} \bar{b} \frac{i \sigma^\mu\nu q_\nu}{M_W} (g_L P_L + g_R P_R) t W^-_\mu + \text{h.c.} \]

PRD45 (1992) 124:
- $f_1^R = V_R$
- $f_2^L = -g_L$
- $f_2^R = -g_R$

PRD67 (2003) 014009 ($m_b \neq 0$)

How to test these new couplings?

They affect the $F_0, F_L$ and $F_R$ and the angular distribution
Probing the Wtb vertex

- Sensitivity limited by systematic errors
  - Related theoretical observables are affected differently by systematic errors (experimental point of view)

- Several methods were used to test the ATLAS sensitivity:
  - Extract limits from measured $F_0, F_L$ and $F_R$;
  - Fit the angular distr. with new observables $\rho_R = F_R/F_0$ and $\rho_L = F_L/F_0$;
  - Fit with the known dependence with $V_R$, $g_L$ and $g_R$;
  - Use new Asymmetries and study their dependence with $V_R$, $g_L$ and $g_R$.

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New Observables

Anomalous Couplings in the $t \rightarrow bW$ decay

- Use $t \rightarrow bW$ decay in Semileptonic $t \bar{t}$ Events
- New observables $\rho_R = F_R/F_0$ and $\rho_L = F_L/F_0$
  - SM(LO): $\rho_L = 0.423$, $\rho_R = 0.0005$ (m_b ≠ 0)
  - (NLO): $\rho_L = 0.438$, $\rho_R = 0.002$
- New Angular Asymmetries: $A_{FB}$, $A_+$, and $A_-$
  - $A_t = \frac{N(x>t)-N(x<t)}{N(x>t)+N(x<t)}$
  - $A_{FB} = \frac{3}{4} [F_R - F_L]$
  - $A_+ = 3\beta [F_0 + (1 + \beta)F_R]$
  - $A_- = -3\beta [F_0 + (1 + \beta)F_L]$
  - SM(LO):
    - $A_{FB} = \ -0.2225$, $A_+ = 0.5482$, $A_- = -0.8397$
  - (NLO): $A_{FB} = -0.2269$, $A_+ = 0.5429$, $A_- = -0.8402$

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New Observables

Anomalous Couplings in the $t \rightarrow bW$ decay

- Dependence of $\rho_R = F_R / F_0$ and $\rho_L = F_L / F_0$ with new couplings:
  
  $\left( m_b \neq 0 \right)$

- Dependence of New asym $A_+$ and $A_-$ with new couplings:

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Analysis & Systematic Errors

New Discriminant Analysis for Semileptonic Channel:
(already presented in the previous meetings)

- Preselection: 1 lepton (p_T>25GeV, |η|<2.5)
  ≥4 jets (p_T>20GeV, |η|<2.5)
  2 b-jets and p_T>20GeV

- Discriminant Variables:
  \( m_W, m_{T(had)}, m_{T(lep)}, p_T-jets \)

- Likelihood Ratio:
  \[ L_S = \prod_{i=1}^{n} P_i^{\text{signal}} \]
  \[ L_B = \prod_{i=1}^{n} P_i^{\text{back}} \]

Statistics (10fb^{-1}):
- \( \Delta \) Signal: \( \varepsilon=9\% \) (220k)
- \( \Delta \) Back: 36k events

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Anomalous Couplings in the $t \rightarrow bW$ decay

Results for the different observables:

### Semileptonic Channel:

<table>
<thead>
<tr>
<th>Observable</th>
<th>$L = 10\text{fb}^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_0$</td>
<td>0.699 ± 0.004 (stat)</td>
</tr>
<tr>
<td>$F_L$</td>
<td>0.299 ± 0.004 (stat)</td>
</tr>
<tr>
<td>$F_R$</td>
<td>0.0021 ± 0.0030 (stat)</td>
</tr>
<tr>
<td>$\rho_L$</td>
<td>0.4274 ± 0.0080 (stat)</td>
</tr>
<tr>
<td>$\rho_R$</td>
<td>0.0004 ± 0.0021 (stat)</td>
</tr>
<tr>
<td>$A_{FB}$</td>
<td>-0.2231 ± 0.0035 (stat)</td>
</tr>
<tr>
<td>$A_+$</td>
<td>0.5472 ± 0.0032 (stat)</td>
</tr>
<tr>
<td>$A_-$</td>
<td>-0.8387 ± 0.0018 (stat)</td>
</tr>
</tbody>
</table>

Limits on Couplings (one at a time different from zero):

<table>
<thead>
<tr>
<th>$V_R$</th>
<th>$g_L = g_R = 0$</th>
<th>$g_L = 0$</th>
<th>$g_R = 0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_0$</td>
<td></td>
<td>[-0.141, 0.108]</td>
<td>[-0.0367, 0.0228]</td>
</tr>
<tr>
<td>$F_L$</td>
<td>[-0.204, 0.191]</td>
<td>[-0.175, 0.144]</td>
<td>[-0.0309, 0.0231]</td>
</tr>
<tr>
<td>$F_R$</td>
<td>[-0.0770, 0.146]</td>
<td>[-0.0666, 0.0346]</td>
<td></td>
</tr>
<tr>
<td>$\rho_L$</td>
<td>[-0.254, 0.206]</td>
<td></td>
<td>[-0.0275, 0.0227]</td>
</tr>
<tr>
<td>$\rho_R$</td>
<td><strong>-0.0282, 0.0987</strong></td>
<td><strong>-0.0455, 0.0129</strong></td>
<td></td>
</tr>
<tr>
<td>$A_{FB}$</td>
<td>[-0.118, 0.148]</td>
<td>[-0.0902, 0.0585]</td>
<td>[-0.0265, 0.0227]</td>
</tr>
<tr>
<td>$A_+$</td>
<td>[-0.140, 0.146]</td>
<td>[-0.112, 0.0819]</td>
<td><strong>-0.0213, 0.0164</strong></td>
</tr>
<tr>
<td>$A_-$</td>
<td>[-0.0664, 0.120]</td>
<td>[-0.0620, 0.0299]</td>
<td><strong>-0.0166, 0.0282</strong></td>
</tr>
</tbody>
</table>
New combination of observables

...but one can do better by combining the most sensitive measurements

$A_+, A_-, \rho_R$ and $\rho_L$
**New combination of observables**

Anomalous Couplings in the $t \rightarrow bW$ decay

**Correlations Taken into Account:** $A_+, A_-, \rho_R$ and $\rho_L$

1$\sigma$ Limits:

<table>
<thead>
<tr>
<th>$V_R$</th>
<th>$g_L$</th>
<th>$g_R$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_{\pm}, \rho_{R,L}$</td>
<td>$[-0.0195, 0.0906]$</td>
<td>$\times$</td>
</tr>
<tr>
<td>$A_{\pm}, \rho_{R,L}$</td>
<td>$\times$</td>
<td>$[-0.0409, 0.00926]$</td>
</tr>
<tr>
<td>$A_{\pm}, \rho_{R,L}$</td>
<td>$\times$</td>
<td>$\times$</td>
</tr>
<tr>
<td>$A_{\pm}, \rho_{R,L}$</td>
<td>$\times$</td>
<td>$[-0.0412, 0.00944]$</td>
</tr>
<tr>
<td>$A_{\pm}, \rho_{R,L}$</td>
<td>$[-0.0199, 0.0903]$</td>
<td>$\times$</td>
</tr>
</tbody>
</table>

**Studies with Full simulation under way (CSC):**

$g_L = -0.016 \pm 0.067$

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Conclusions

- The ATLAS sensitivity to anomalous couplings at the $Wtb$ vertex was presented for a luminosity of $10 fb^{-1}$. With this luminosity it is possible to constrain the anomalous couplings to the level of few % (taking into account the expected systematic errors).

- New observables were introduced ($A_+, A_-, \rho_R$ and $\rho_L$) which have proven to be more sensitivity to new couplings.

- The written contribution to the final report with all these results was sent to the contact persons.
**Conclusions**

**Wtb Anomalous Couplings in Top Quark Decays**

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**Abstract**

The sensitivity of the ATLAS experiment to \( Wtb \) anomalous couplings is studied with top quark pairs produced at the LHC which decay through the semileptonic channel, \( t \rightarrow W^+b, \bar{t} \rightarrow W^-\bar{b} \) with one of the \( W \) bosons decaying leptonically and the other hadronically. Several observables are discussed in order to achieve the best precision level on the measurement of the anomalous couplings. Combining the most sensitive observables, the precision achieved in the determination of \( Wtb \) anomalous couplings is of a few percent in the semileptonic channel alone.