Introduction

One of the most promising channels for a direct measurement of the top quark Yukawa coupling is the one where the newly observed scalar boson is produced in association with a $t\bar{t}$ pair. In the standard model, the new boson decays mostly to $b\bar{b}$ leading to a $t\bar{t}bb$ final state which has an irreducible non-resonant QCD background of $t\bar{t}bb$. Measuring the cross section ratio allows us to cancel many experimental uncertainties. This measurement can also provide an important test of NLO QCD calculations.

Visible phase space at generator level

1. Two leptons ($\ell, \ell$) from W boson including leptonic tau decay.
   \[ p_T^\ell > 20 \text{ GeV}, \ |\eta_\ell| < 2.4 \]
2. At least four jets: anti-kt and distance parameter 0.5.
   \[ p_T^{j_1} > 20 \text{ GeV}, \ |\eta_{j_1}| < 2.5 \]
3. At least two b-jets identified seeking $b$-hadrons among their ancestors.

Event selection

1. At least one pair of two opposite sign isolated leptons
   \[ p_T^\ell > 20 \text{ GeV}, \ |\eta_\ell| < 2.4 \text{ and } M_{T} > 12 \text{ GeV} \]
2. Invariant mass $M_{bb} \notin [76, 106] \text{ GeV}$ and missing transverse energy $E_T > 30 \text{ GeV}$ ($\mu^+\mu^-, e^+e^-$)
3. At least four jets where at least two have been tagged as b jets
   \[ p_T^{j_1} > 30 \text{ GeV}, \ |\eta_{j_1}| < 2.5 \]

Background estimation

- Contributions from Drell-Yan are estimated from $Z$ candidates in data using the ratio of outside and inside $Z$ mass window in simulation.
- QCD is estimated from data using like-sign lepton pairs.

Data and MC comparison

$t\bar{t}bb = 105$ events

Systematic uncertainties

<table>
<thead>
<tr>
<th>Source</th>
<th>$\sigma_{t\bar{t}bb}$ [%]</th>
<th>$\sigma_{t\bar{ij}}$ [%]</th>
<th>$\Delta \sigma_{t\bar{t}bb}$ [%]</th>
<th>$\Delta \sigma_{t\bar{ij}}$ [%]</th>
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</thead>
<tbody>
<tr>
<td>Pileup</td>
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<td>JES &amp; JER</td>
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<td>8.0</td>
<td>5.0</td>
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<tr>
<td>$b$ tag ($b$ quark flavour)</td>
<td>15</td>
<td>&lt;0.1</td>
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<tr>
<td>$b$ tag (c quark flavour)</td>
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<td>&lt;0.1</td>
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<td>$b$ tag (light flavour)</td>
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<td>Ratio of $t\bar{t}bb$ and $t\bar{t}bj$</td>
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<td>&lt;0.1</td>
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<td>Eff. ($t\bar{c}\bar{c}$ fraction)</td>
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<tr>
<td>Total uncertainty</td>
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<td>22</td>
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</table>

Measurement

- Jets are ranked in decreasing order of the b-tagging discriminant.
- A simultaneous fit is performed to the b-tagging discriminant distributions of the 3rd and 4th jet.

\[
f(k, R) = k \cdot N_{bkg}^\text{MC} + N_{data\text{-driven}} + k \cdot N_{t\bar{t}bb}
\]

\[
+ \left[ R \cdot N_{t\bar{t}bb}^\text{norm} + R' \cdot N_{t\bar{t}bj}^\text{norm}
\]

\[
+ (1 - R - R') \cdot N_{t\bar{t}jj}^\text{norm,CL+tec}
\]

- $R$ is the ratio of $t\bar{t}bb$ over $t\bar{t}jj$ at the reconstruction level.
- $R'$ is the ratio of $t\bar{t}bj$ over $t\bar{t}jj$, when constraining the ratio $t\bar{t}bj/t\bar{t}bj$ to the MC prediction.

Efficiency correction:

\[
\varepsilon_{t\bar{t}bb} = 18.7\% \text{ and } \varepsilon_{t\bar{t}jj} = 7.2\%
\]

\[
\frac{\sigma_{t\bar{t}bb}}{\sigma_{t\bar{t}jj}} = \frac{\varepsilon_{t\bar{t}jj}}{\varepsilon_{t\bar{t}bb}} \cdot R
\]

Results

- Visible phase space

\[
\sigma_{t\bar{t}bj} = \begin{cases} 
0.022 \pm 0.003\text{(stat.)} \pm 0.005\text{(syst.)}, \ p_T > 20 \text{ GeV} \\
0.022 \pm 0.004\text{(stat.)} \pm 0.008\text{(syst.)}, \ p_T > 40 \text{ GeV}
\end{cases}
\]

- Full phase space: Top quark is treated as stable, i.e. no requirements on leptons and $b$-jets from top quarks but on additional jets.
- CMS measurement[1] and NLO calculation[2] are compared.

Conclusion

We have measured the cross section ratio $\sigma_{t\bar{t}bb}/\sigma_{t\bar{t}jj}$ in pp collisions at $\sqrt{s} = 8 \text{ TeV}$. Data and theory predictions are compatible within their uncertainties. More precise measurements are expected with more data and will be a useful input for t$H$ searches.

References