Search for vector-like quarks pair production in the ATLAS experiment.

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on behalf of the Searches for New Physics group at LIP-Minho
New families of fermions are proposed for different BSM models.

New heavy chiral family is heavily constrained with the recent observation of the Higgs boson.

New family can be vector-like (left and right chiralities transform the same way under SU(2)).

\[ T_{L,R}, \quad B_{L,R} \]

\[ \begin{pmatrix} X \\ T \end{pmatrix}_{L,R}, \quad \begin{pmatrix} T \\ B \end{pmatrix}_{L,R}, \quad \begin{pmatrix} B \\ Y \end{pmatrix}_{L,R} \]
Search for pair production of new heavy quarks that decay to a Z boson and a third generation quark in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector

The ATLAS Collaboration

- CONF-note released with partial data-set (L=14fb$^{-1}$) last summer.

- Analysis already presented in several conferences.

- Part of a group of analyses searching for different decays of vector-like quarks.
Signal and background

Signal samples
- Signal samples produced with PROTOS and Pythia6.
- Mass points from 350 to 1100 GeV with steps on 50 GeV.
- VLB and VLT pair production have been generated.
- Singlet model for all mass points.
- Doublet model for 2 mass points for testing kinematic differences.

Background samples
- $t\bar{t}$: Powheg
- **Single-top**: Mc@NLO & AcerMC
- **W+jets**: Alpgen.
- **Diboson**: Sherpa (using Massive CB for WZ)
- **$t\bar{t}+V$**: MadGraph
- **Z+jets**:  
  - Baseline: Sherpa ($p_T$ sliced).
  - Cross-check: Alpgen.
Analysis strategy

- **Selection:**
  - Select a Z boson candidate: 2 OS-SF leptons (ee, µµ).
  - ≥ 2 jets
  - ≥ 2 b-jets (1 and 0 excl. as control regions)
  - \( p_T(Z) > 150 \text{ GeV} \)
  - \( H_T(\text{jets}) \geq 600 \text{ GeV} \)
  - \( M(Zb) \) -> Discriminant variable

![Graphs showing distributions of various variables such as b-tagged jet multiplicity, \( p_T(Z) \), and \( H_T(\text{jets}) \).]
Z boson candidate

Z inclusive region, \( \geq 2 \) jets

1 b-jet

\[
\begin{align*}
\text{ATLAS} & \quad \int_{\mathcal{L}} L dt = 14.3 \text{ fb}^{-1} \\
& \quad \sqrt{s} = 8 \text{ TeV} \\
& \quad \mu^+ \mu^- + ee
\end{align*}
\]

\[
\begin{align*}
\text{Entries / 1.5 GeV} & \quad \text{Data} & \quad \text{bkg} \\
\text{1 b-tag} & \quad 6000 & \quad 10000 \\
\text{1 b-jet} & \quad 4000 & \quad 8000 \\
\text{\geq 2 b-jets} & \quad 2000 & \quad 4000
\end{align*}
\]

\[
\begin{align*}
\text{m(Z) [GeV]} & \quad 80 & \quad 90 & \quad 100 & \quad 105 \\
\text{Data/bkg} & \quad 0.5 & \quad 1 & \quad 1.5 & \quad 2
\end{align*}
\]

\[\begin{array}{c}
\text{ATLAS} \\
\text{Preliminary} \\
\text{\int_{\mathcal{L}} L dt = 14.3 \text{ fb}^{-1}} \\
\text{\sqrt{s} = 8 \text{ TeV}} \\
\text{ee + \mu \mu}
\end{array}\]

\[
\begin{align*}
\text{Z+light} & \quad \text{Data} & \quad \text{bkg} \\
\text{Z+bottom} & \quad  \text{1 b-tag} \\
\text{t\bar{t}} & \quad  \text{1 b-jet} & \quad  \text{\geq 2 b-jets} \\
\text{Other bkg} & \quad \text{Uncertainty}
\end{align*}
\]
Z+jets corrections

Z inclusive region, ≥2 jets

- $p_T(Z)$ shows a mismodeling: over predict high $p_T$ Z boson.
- Assume only Z+jet is not well modeled.
- Derive correction in the 1-tag control region and apply it in the 2-tag signal region.

$$w = \frac{N_{\text{data}} - N_{\text{Other}}}{N_{Z+\text{jets}}}$$
Z+jets corrections

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≥2 b-jet (before correction)
**H_{T}(jets) after p_{T}(Z) requirement**

Z inclusive region, ≥2 jets, p_{T}(Z) > 150 GeV

1 b-jet (before correction)

≥ 2 b-jets (after correction)
Final selection - signal region

Z boson candidate, ≥ 2 jets, ≥ 2 b-jets, $p_T(Z) > 150$ GeV and $H_T$(jets) ≥ 600 GeV

ATLAS Preliminary

<table>
<thead>
<tr>
<th>$m(Z_b)$ [GeV]</th>
<th>Entries / 150 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
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<tr>
<td>200</td>
<td>2</td>
</tr>
<tr>
<td>400</td>
<td>4</td>
</tr>
<tr>
<td>600</td>
<td>6</td>
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<tr>
<td>1200</td>
<td>12</td>
</tr>
<tr>
<td>1400</td>
<td>12</td>
</tr>
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</table>

Data/bkg

<table>
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<tr>
<th>$m(Z_b)$ [GeV]</th>
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<tbody>
<tr>
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<td>0.5</td>
</tr>
<tr>
<td>200</td>
<td>1</td>
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<tr>
<td>400</td>
<td>1.5</td>
</tr>
</tbody>
</table>

ATLAS

\[ \int L dt = 14.3 \, fb^{-1} \]

$\sqrt{s} = 8$ TeV

ee + $\mu\mu$

<table>
<thead>
<tr>
<th>$m(Z_b)$ [GeV]</th>
<th>Data 2012</th>
<th>$Z\text{+light}$</th>
<th>$Z\text{+bottom}$</th>
<th>$t\bar{t}$</th>
<th>Other bkg</th>
<th>$B\bar{B} (600 \text{ GeV})$</th>
<th>$T\bar{T} (600 \text{ GeV})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<tr>
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<tr>
<td>1200</td>
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Uncertainty

≥ 2 b-tags

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</tr>
<tr>
<td>400</td>
<td>1.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$m(Z_b)$ [GeV]</th>
<th>$Z\text{+} \geq 2 \text{jets} (N_{\text{tag}} \geq 2)$</th>
<th>$p_T(Z) &gt; 150$ GeV</th>
<th>$H_T$(jets) &gt; 600 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>850 ± 240</td>
<td>58 ± 17</td>
<td>4.3 ± 1.8</td>
<td></td>
</tr>
<tr>
<td>3380 ± 470</td>
<td>301 ± 55</td>
<td>17.8 ± 4.8</td>
<td></td>
</tr>
<tr>
<td>1730 ± 320</td>
<td>31.1 ± 6.2</td>
<td>5.1 ± 1.4</td>
<td></td>
</tr>
<tr>
<td>190 ± 60</td>
<td>29.2 ± 7.0</td>
<td>3.0 ± 1.2</td>
<td></td>
</tr>
<tr>
<td>6,150 ± 620</td>
<td>419 ± 59</td>
<td>30.2 ± 5.3</td>
<td></td>
</tr>
<tr>
<td>6,097</td>
<td>386</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>$B\bar{B} (m_b = 600 \text{ GeV})$</td>
<td>31.0 ± 4.3</td>
<td>25.7 ± 3.6</td>
<td>19.8 ± 2.7</td>
</tr>
<tr>
<td>$T\bar{T} (m_T = 600 \text{ GeV})$</td>
<td>21.9 ± 2.8</td>
<td>17.1 ± 2.2</td>
<td>12.2 ± 1.7</td>
</tr>
</tbody>
</table>
QQ→μμbb candidate
Pair production limit at 95% CL (B quark)

Singlet

Doublet

$\sigma(pp \to B\bar{B})$ [pb]

$\sqrt{s} = 8$ TeV

$\int L dt = 14.3$ fb$^{-1}$

SU(2) singlet

$M_B > 645$ GeV

SU(2) $(B,Y)$ doublet

$M_B > 725$ GeV
Pair production limit at 95% CL (T quark)

**Singlet**

\[ m_T > 585 \text{ GeV} \]

**Doublet**

\[ m_T > 680 \text{ GeV} \]
2D BR plane exclusion at 95% CL (B quark)

\[ \text{Su}(2) \text{ singlet} \quad \text{Su}(2) \text{ (B,Y) doub.} \]

95% CL expected exclusion
95% CL observed exclusion

\[ \text{SU}(2) \quad \text{(B,Y) doub.} \quad \text{SU(2) singlet} \]

\[ \sqrt{s} = 8 \text{ TeV}, \int L \, dt = 14.3 \text{ fb}^{-1} \]

**ATLAS** Preliminary
2D BR plane exclusion at 95% CL (T quark)

ATLAS Preliminary
\( \sqrt{s} = 8 \text{ TeV}, \int L \, dt = 14.3 \text{ fb}^{-1} \)

- 95% CL expected exclusion
- 95% CL observed exclusion

SU(2) (T,B) doub. ▲ SU(2) singlet

\( m_T = 350 \text{ GeV} \)
\( m_T = 400 \text{ GeV} \)
\( m_T = 450 \text{ GeV} \)
\( m_T = 500 \text{ GeV} \)
\( m_T = 550 \text{ GeV} \)
\( m_T = 600 \text{ GeV} \)
\( m_T = 650 \text{ GeV} \)
\( m_T = 700 \text{ GeV} \)
\( m_T = 750 \text{ GeV} \)
\( m_T = 800 \text{ GeV} \)
\( m_T = 850 \text{ GeV} \)
Summary plots for VLQ pair production (B quark)
Summary plots for VLQ pair production (T quark)

\[ m_T = 350 \text{ GeV} \]
\[ m_T = 400 \text{ GeV} \]
\[ m_T = 450 \text{ GeV} \]
\[ m_T = 500 \text{ GeV} \]
\[ m_T = 550 \text{ GeV} \]
\[ m_T = 600 \text{ GeV} \]
\[ m_T = 650 \text{ GeV} \]
\[ m_T = 700 \text{ GeV} \]
\[ m_T = 750 \text{ GeV} \]
\[ m_T = 800 \text{ GeV} \]
\[ m_T = 850 \text{ GeV} \]
Vector-like quark pair production for B and T quark has been presented.

Part of a common effort between different groups and institutes searching for vector-like quark:
LIP, LBNL, Yale, Boston, Arizona.

We have a strong contribution in:

- Analysis inputs which are being used for other institutes collaborating in the Zb/t+X analysis.
- Development of Z+jets correction tools which are being used for the Zb/t+X analysis.
- Development of the full analysis framework for dilepton channel.
- Coordination of the analysis team and editorial work.
- Limit setting machinery central repository and configuration.