Search for Exotic Phenomena Using Events with Same Charge Dileptons + b-Jets at 13 TeV with ATLAS

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on behalf of the ATLAS Collaboration

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Young Scientist Forum
Motivations for Search

- Standard Model backgrounds are low ($t\bar{t}+V$, Diboson, etc.)
- A variety of new and exotic physics can lead to our final state of interest, our focus is:
  - → **Vector-Like** $T$, $B$, and $T_{5/3}$ pair production (more on this in tomorrow’s BSM II)
  - → **4-top** $t\bar{t}t\bar{t}$ production via: contact interaction ($C_{4t}/\Lambda^2$), SM, and 2UED/RPP model
General Search Strategy

Run II priorities

- **Early Run II dataset** (2015 \(\sim 3.2 \text{ fb}^{-1}\)): check same signal regions for slight excess found in Run I *(plots shown in this talk are from this set of data)* → no excess in Run II found so far

- **Full Run II dataset** (2015+2016 \(\sim 36.1 \text{ fb}^{-1}\)): in progress, optimizing selections, data-driven background estimations, and signal regions

\(H_T = \text{scalar sum of lepton + jet } p_T\)
Backgrounds

Three major backgrounds:

- **Irreducible**: SM processes that produce real pairs of same-sign leptons and corresponding jets
  → Estimated with **MC**

- **Fake/non-prompt leptons**: leptons fakes by heavy flavored jets (most likely $b$-jets) or originating from sources other than hard scatter
  → Estimated with **data**

- **Charge mis-id**: charge mis-measured for electrons
  → Negligible for muons
  → Estimated with **data**
Select events with 2 tight leptons, must have the same charge

Select events with 3 tight leptons

Dilepton Channels

SSμμ

SSeμ

SSee

Trilepton Channels

μμμ

eμμ

eee

Proceed to signal region event selection: channels combined in eight high $H_T$, high $E_T^{miss}$ regions, broken up by $N_{bjets}$

$m_{ee} > 15$ GeV, veto range: $|m_{ee} - m_Z| < 10$ GeV
Major Systematic Uncertainties

- Charge mis-ID
- Uncertainties in data-driven bkg estimation methods
- Fake/non-prompt
- Other major systs

Total uncertainty in SRs $\sim 25\%$

Total uncertainty in SRs $\sim 54\%$

x-section, JES/JER, b-tagging eff, luminosity, etc.
- Modest excess from Run I unconfirmed so far in Run II
- 95% CL limits set on various signal models:
  - $|C_{4t}|/\Lambda^2 > 3.5 \text{ TeV}^{-2}$
    (shown left top)
  - $m_{T5/3} > 0.99 \text{ TeV}$ (pair prod. limit only)
    (shown left bottom)
  - $m_{VLB} > 0.83 \text{ TeV}$, $m_{VLT} > 0.78 \text{ TeV}$
  - $m_{KK} > 1.4 \text{ TeV}$

Both systematic and statistical uncertainties are shown.
Thank you!
BACKUPS
Production of Vector Like Quarks

**Pair production modes**

\[ gg, q \bar{q} \rightarrow Q \bar{Q} \]

where \( Q = T, B, T_{5/3}, B_{-4/3} \)

**Single production modes**

\[ gq \rightarrow T \bar{b}q', \]

\[ gq \rightarrow B(B_{-4/3}) \bar{b}q(q''), \]

\[ gq \rightarrow T(T_{5/3}) \bar{t}q' \]

where \( q \) and \( q' \) are light jets

- **SS+b-Jets Analysis:** focuses on \( T, B \) pair production and \( T_{5/3} \) pair and single production
  - Sensitivity to same-charge leptons in the final state is higher
### Signal Region Definitions

<table>
<thead>
<tr>
<th>Definition</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^\pm e^\pm + e^\pm \mu^\pm + \mu^\pm \mu^\pm + eee + ee\mu + e\mu\mu + \mu\mu\mu, N_j \geq 2$</td>
<td></td>
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<tr>
<td>400 &lt; $H_T$ &lt; 700 GeV</td>
<td></td>
</tr>
<tr>
<td>$N_b = 1$</td>
<td>$E_T^{\text{miss}} &gt; 40$ GeV</td>
</tr>
<tr>
<td>$N_b = 2$</td>
<td></td>
</tr>
<tr>
<td>$N_b \geq 3$</td>
<td></td>
</tr>
<tr>
<td>$H_T \geq 700$ GeV</td>
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<tr>
<td>$N_b = 1$</td>
<td>$40 &lt; E_T^{\text{miss}} &lt; 100$ GeV</td>
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<tr>
<td>$E_T^{\text{miss}} \geq 100$ GeV</td>
<td>SR4</td>
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<tr>
<td>$N_b = 2$</td>
<td>$40 &lt; E_T^{\text{miss}} &lt; 100$ GeV</td>
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<td>SR6</td>
</tr>
<tr>
<td>$N_b \geq 3$</td>
<td>$E_T^{\text{miss}} &gt; 40$ GeV</td>
</tr>
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</table>

- These are being re-optimized for use with the full 2015+2016 dataset
## Systematic Uncertainties

### Largest systematics on total background:

<table>
<thead>
<tr>
<th>Source</th>
<th>SR0</th>
<th>SR1</th>
<th>SR2</th>
<th>SR3</th>
<th>SR4</th>
<th>SR5</th>
<th>SR6</th>
<th>SR7</th>
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<tbody>
<tr>
<td>Cross section</td>
<td>8</td>
<td>11</td>
<td>26</td>
<td>13</td>
<td>9</td>
<td>27</td>
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<tr>
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<td>1</td>
<td>3</td>
<td>2</td>
<td>4</td>
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<tr>
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<td>2</td>
<td>2</td>
<td>2</td>
<td>&lt;1</td>
<td>1</td>
<td>&lt;1</td>
<td>3</td>
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<tr>
<td>$b$-tagging efficiency</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>2</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<tr>
<td>Fake/non-prompt leptons</td>
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<td>15</td>
<td>13</td>
<td>26</td>
<td>13</td>
<td>17</td>
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<tr>
<td>Charge misID</td>
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<td>3</td>
<td>7</td>
<td>5</td>
<td>3</td>
<td>6</td>
<td>5</td>
<td>8</td>
</tr>
</tbody>
</table>

### Largest systematics for typical signal (4-top SM)

<table>
<thead>
<tr>
<th>Source</th>
<th>SR0</th>
<th>SR1</th>
<th>SR2</th>
<th>SR3</th>
<th>SR4</th>
<th>SR5</th>
<th>SR6</th>
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<td>4</td>
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<tr>
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<td>2</td>
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<td>1</td>
</tr>
<tr>
<td>Luminosity</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>
Leptons can be **faked** by heavy and light flavor jets (most often from $b$-jets)

Leptons can be **non-prompt** if they don’t originate from primary hard-scatter

Estimated using: **Matrix Method**

$$
\begin{pmatrix}
N_{tt} \\
N_{t\bar{t}} \\
N_{\bar{t}t} \\
N_{\bar{t}\bar{t}}
\end{pmatrix} = M
\begin{pmatrix}
N_{rr}^{ll} \\
N_{r\bar{r}}^{ll} \\
N_{r\bar{r}}^{lr} \\
N_{r\bar{r}}^{fl}
\end{pmatrix}
$$

where

$$
M \equiv
\begin{pmatrix}
    r_1 r_2 & r_1 f_2 & f_1 r_2 & f_1 f_2 \\
    r_1 \bar{r}_2 & r_1 \bar{f}_2 & f_1 \bar{r}_2 & f_1 \bar{f}_2 \\
    \bar{r}_1 r_2 & \bar{r}_1 f_2 & \bar{f}_1 r_2 & \bar{f}_1 f_2 \\
    \bar{r}_1 \bar{r}_2 & \bar{r}_1 \bar{f}_2 & \bar{f}_1 \bar{r}_2 & \bar{f}_1 \bar{f}_2
\end{pmatrix}
$$

- **Calculate** $r$ and $f$, parameterized by lepton $p_T$, $\eta$, and $\Delta R_{\text{min}}(\ell, \text{jet})$
- **Invert matrix** $M$ and calculate $N$ tight leptons that are fake
- **Likelihood Matrix Method** used for stability in calculation

These backgrounds are modeled with **data**
Fake data-driven background

Poisson Likelihood Matrix Method

Apply $r$ and $f$ to the *loose* sample, use Matrix Method to calculate number of *fake* leptons in the *tight* sample

$$L = P(N_{tt}, N_{tt}^{\text{pred}}) P(N_{t\bar{t}}, N_{t\bar{t}}^{\text{pred}}) P(N_{\bar{t}t}, N_{\bar{t}t}^{\text{pred}}) P(N_{t\bar{t}}, N_{t\bar{t}}^{\text{pred}})$$

$$N_{tt}^{\text{fake}} = N_{rr}^{tt} + N_{rf}^{tt} + N_{ff}^{tt}$$

$$N_{tt}^{\text{pred}} = N_{rr}^{tt} + N_{rf}^{tt} + N_{fr}^{tt} + N_{ff}^{tt}$$

$$N_{tt}^{\text{pred}} = \frac{\langle r_1 \tilde{r}_2 \rangle}{\langle r_1 r_2 \rangle} N_{rr}^{tt} + \frac{\langle r_1 f_2 \rangle}{\langle r_1 f_2 \rangle} N_{rf}^{tt} + \frac{\langle f_1 \tilde{r}_2 \rangle}{\langle f_1 r_2 \rangle} N_{fr}^{tt} + \frac{\langle f_1 f_2 \rangle}{\langle f_1 f_2 \rangle} N_{ff}^{tt}$$

$$N_{t\bar{t}}^{\text{pred}} = \frac{\langle \tilde{r}_1 r_2 \rangle}{\langle r_1 r_2 \rangle} N_{rr}^{tt} + \frac{\langle \tilde{r}_1 f_2 \rangle}{\langle r_1 f_2 \rangle} N_{rf}^{tt} + \frac{\langle f_1 \tilde{r}_2 \rangle}{\langle f_1 r_2 \rangle} N_{fr}^{tt} + \frac{\langle f_1 f_2 \rangle}{\langle f_1 f_2 \rangle} N_{ff}^{tt}$$

$$N_{\bar{t}t}^{\text{pred}} = \frac{\langle \tilde{r}_1 \tilde{r}_2 \rangle}{\langle r_1 r_2 \rangle} N_{rr}^{tt} + \frac{\langle \tilde{r}_1 f_2 \rangle}{\langle r_1 f_2 \rangle} N_{rf}^{tt} + \frac{\langle f_1 \tilde{r}_2 \rangle}{\langle f_1 r_2 \rangle} N_{fr}^{tt} + \frac{\langle f_1 f_2 \rangle}{\langle f_1 f_2 \rangle} N_{ff}^{tt}$$

$$N_{t\bar{t}}^{\text{pred}} = \frac{\langle \tilde{r}_1 \tilde{r}_2 \rangle}{\langle r_1 r_2 \rangle} N_{rr}^{tt} + \frac{\langle \tilde{r}_1 f_2 \rangle}{\langle r_1 f_2 \rangle} N_{rf}^{tt} + \frac{\langle f_1 \tilde{r}_2 \rangle}{\langle f_1 r_2 \rangle} N_{fr}^{tt} + \frac{\langle f_1 f_2 \rangle}{\langle f_1 f_2 \rangle} N_{ff}^{tt}$$
Lepton charge can be mis-measured

- Only measured for electrons

Estimated using likelihood minimization

- Parametrized in electron $p_T$ and $|\eta_{clus}|$
- Estimation of charge flip-rate in ‘Z-peak’ region: $|m_{ee} - m_Z| < 10$ GeV using $Z \rightarrow ee$ events (no charge requirement)
- Apply event weight, $w$, on electrons in events matching signal region selection, but requiring opposite sign pairs

$$w = \frac{\varepsilon_1 + \varepsilon_2 - 2\varepsilon_1\varepsilon_2}{1 - (\varepsilon_1 + \varepsilon_2 - 2\varepsilon_1\varepsilon_2)}$$

These backgrounds are modeled with data

1 Muon charge is measured in both ID and MS, the ATLAS Muon system has a long lever arm, and muons have a small probability of radiating a photon