Bottom-quark Fusion Processes at the LHC for Probing $Z'$ Models and B-meson Decay Anomalies

Mykhailo Dalchenko

ICHEP2018 Seoul
Physics model and context

- Recent LHCb results show certain deviation from SM prediction for $R_K/R_{K^*}$
- Combining this results with other anomalies observed in $b \rightarrow s \mu \mu$ transition we can obtain up to $4\sigma$ tension with SM
- See Lorenzo Capriotti talk

New contributions to $b \rightarrow s \mu \mu$ transition can be explained in various BSM theories, in particular involving $Z'$
Physics model and context

New Physics contribution to B decays can be described by following Lagrangian:

\[ \mathcal{L} \supset \frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{e^2}{16\pi^2} C_9 O_9 + h.c. \]

where effective operator \( O_9 \),

\[ O_9 = (\bar{s}\gamma_\mu P_L b) (\bar{\mu}\gamma_\mu \mu) \]

stands for 4-fermion interaction:

and best fit value for corresponding Wilson coefficient is: \( C_9 = -1.56^{+0.46}_{-0.56} \)
Physics model and context

Minimal Lagrangian:

\[ \mathcal{L} \supset Z'_\mu \left[ g_\mu \bar{\mu} \gamma^\mu \mu + g_\mu \bar{\nu}_\mu \gamma^\mu P_L \nu + g_b \sum_{q=t,b} \bar{q} \gamma^\mu P_L q + \left( g_b \delta_{bs}^L \bar{s} \gamma^\mu P_L b + \text{h.c.} \right) \right] \]

Many models can produce such lagrangian, e.g. using VLQ:

- Selective $U(1)$ fermion charges to evade current LHC and LEP boundaries
- Only needs to couple to muons in leptonic sector and $b$-$s$ in fermionic sector
- Add muon neutrino and top quark couplings to preserve $SU(2)$
- Can also consider ditau decays
Production at the LHC

BFF: Bottom Fermion Fusion

Similarly, one can have Bottom-Strange fusion to probe:
Final states at the LHC

- Add up $Z'$ decays and ISR particles

$Z'$ decays:
  - di-quarks: pairs of $b$ and, if kinematically allowed, $t$ quarks
  - di-leptons
    - In principle, only muons and muon neutrinos will be enough
    - di-tau can be considered too

- ISR particles:

<table>
<thead>
<tr>
<th># ISR jets</th>
<th>process</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$b-b$ fusion</td>
<td>both $b$ from sea quarks</td>
</tr>
<tr>
<td>0</td>
<td>$b-s$ fusion</td>
<td>$b$ and $s$ from sea quarks</td>
</tr>
<tr>
<td>1</td>
<td>$b-b$ fusion</td>
<td>one $b$ from gluon splitting and one $b$ from sea quarks</td>
</tr>
<tr>
<td>1</td>
<td>$b-s$ fusion</td>
<td>one $b$ from gluon splitting and one $s$ from sea quarks</td>
</tr>
<tr>
<td>2</td>
<td>$b-b$ fusion</td>
<td>both $b$ from gluon splitting</td>
</tr>
</tbody>
</table>
Production XS matching B-anomalies

\[ g_b \delta_{bs} g_\mu \left(100GeV/m_{Z'}\right) \approx 1.3 \times 10^{-5} \]

\[
\sigma(pp \rightarrow Z' \rightarrow \mu \mu) \propto 2 g_b^2 (1 + k \delta_{bs}^2) g_\mu^2
\]

\[
\sigma(pp \rightarrow Z' \rightarrow b \bar{b}) \propto 3 g_b^4 (1 + k \delta_{bs}^2)
\]
Search strategy

- Focus on di-muon final state
- Use ISR jets to reduce the background contamination
- Main backgrounds:
  - SM Z + jets
  - Top pair production
- Ask for two opposite sign muons
- At least two jets with at least one b-tagged
  - Helps to remove DY
- Apply top mass bound and MET cuts
  - Reduce top pair contribution
- Select events with high leptonic activity (HT-LT<0)
# Search strategy

<table>
<thead>
<tr>
<th></th>
<th>preselection</th>
<th>$M_{\mu b}$</th>
<th>$H_T - L_T$</th>
<th>$E_T^{\text{miss}} / M(\mu^+ \mu^-)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t\bar{t}$</td>
<td>8%</td>
<td>17%</td>
<td>26%</td>
<td>27%</td>
</tr>
<tr>
<td>SM $Z$</td>
<td>0.2%</td>
<td>41%</td>
<td>32%</td>
<td>54%</td>
</tr>
<tr>
<td>$Z'$ 200</td>
<td>7%</td>
<td>60%</td>
<td>74%</td>
<td>89%</td>
</tr>
<tr>
<td>$Z'$ 350</td>
<td>10%</td>
<td>90%</td>
<td>90%</td>
<td>97%</td>
</tr>
<tr>
<td>$Z'$ 500</td>
<td>13%</td>
<td>92%</td>
<td>94%</td>
<td>98%</td>
</tr>
</tbody>
</table>

![Graphs showing percentage of events](image1)

![Graph showing $M(\mu^+ \mu^-)$](image2)

![Graph showing $H_T - L_T$](image3)
Limits estimation

- Provide shapes for each signal and background process
- Take into account shape uncertainties
- Use Profile Likelihood estimator
- Delphes-only simulation
- Systematic uncertainties aren’t accounted for
- Pile-up contribution is not accounted for
Projected sensitivity

We expect much improved sensitivity w.r.t. Inclusive searches around 200 GeV dilepton invariant mass