Search for leptoquark signatures with the ATLAS and CMS detectors

Francesco Romeo

On behalf of the ATLAS and CMS collaborations
Many models beyond the Standard Model - GUTs, Composite models, Technicolor - foresee new bosons that carry both lepton and baryon number. These are called ”LeptoQuark” (LQ)

Exact properties (spin, weak isospin, electric charge) depend on specific model
→ direct LQ searches at the LHC in the context of an effective model: Buchmüller-Rückl-Wyler model (BRW)

1. LQs interact with standard model fermions through coupling λ
2. LQs interaction preserves baryon and lepton number (to avoid inducing rapid proton decay)
3. LQs couple to a single chirality and generation of SM fermions at a time (in order to suppress flavour-changing neutral currents (FCNCs))

→ Three generations of LQs: LQ1, LQ2, LQ3
LQs production and decay

- *gg* fusion processes dominate. *q̅q* becomes increasingly important (contributing by $\sim 30\%$ of the total cross section at $M_{LQ} = 1.5$ TeV)
- Pair production is the dominant mechanism
- $\sigma$ for scalar LQ depend only on LQ masses

<table>
<thead>
<tr>
<th>LQ LQ</th>
<th>$\beta^2$</th>
<th>$\beta(1 - \beta)$</th>
<th>$(1 - \beta)^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st gen</td>
<td>$ee + jj$</td>
<td>$e\nu + jj$</td>
<td>n/a</td>
</tr>
<tr>
<td>2nd gen</td>
<td>$\mu\mu + jj$</td>
<td>$\mu\nu + jj$</td>
<td>n/a</td>
</tr>
<tr>
<td>3rd gen</td>
<td>$\tau\tau + bb,tt$</td>
<td>n/a</td>
<td>$\nu\nu + bb,tt$</td>
</tr>
</tbody>
</table>

$\beta$ generally unknown, but $\{\ell\ell, \ell\nu, \nu\nu\} + qq$ maximally produced for $\beta = 1, 0.5, \text{and} 0$ (as required in the BRW model and assumed in the results of this talk)

Expected high-pT objects in the final state

$S_T^{\ell\ell jj(\ell\nu jj)} = pT_{\ell_1} + pT_{\ell_2}(E_T) + pT_{j_1} + pT_{j_2}$
LQ1 and LQ2 in $\ell\ell jj$, $\ell\nu jj$ channels with ATLAS and CMS

$\ell\ell jj$
- $\ell$: $p_T > 30$ GeV, $|\eta| < 2.5$
- $\geq 2$ jets
- $M_{\ell\ell} > 40$ GeV

$\ell\nu jj$
- $M_T(\ell, E_T) > 40$ GeV
- $E_T > 30$ GeV
- Veto 2nd same flavour $\ell$ and different flavour $\ell$

Previous cuts are optimised for each signal mass point in CMS including $M_{\min}(\ell, jet)$ and $S_T$

$\ell\ell jj$
- Z+Jets from MC corrected by SF in $Z \rightarrow \ell\ell$
- enriched region

$\ell\nu jj$
- W+Jets and $t\bar{t}$ from MC corrected by SF in complementary CRs
- $40 < M_T < 120$ GeV and
- # of jets ($<4$, $\geq 4$)

CMS LQ1: PAS-EXO-12-041
CMS LQ2: PAS-EXO-12-042
Results for LQ1 in $eejj$, $e\nu jj$ channels with ATLAS and CMS

$eejj \ [\beta^2; \beta = 1]\quad$ ATLAS ($7\,\text{TeV}, 1.03\,\text{fb}^{-1}$) $e\nu jj \ [\beta(1 - \beta); \beta = 0.5]$
Limits for LQ1 in the $eejj$, $e\nu jj$ channels with ATLAS and CMS

**ATLAS (7 TeV, 1.03 fb$^{-1}$)**

- $eejj$ [$\beta^2; \beta = 1$] $< 660$ GeV at 95% CL
- $e\nu jj$ [$\beta(1-\beta); \beta = 0.5$] $< 570$ GeV at 95% CL

**CMS (8 TeV, 19.6 fb$^{-1}$)**

- $eejj$ [$\beta^2; \beta = 1$] $< 1005$ GeV at 95% CL
- $e\nu jj$ [$\beta(1-\beta); \beta = 0.5$] $< 845$ GeV at 95% CL

**Combined LQ1**

- $< 607$ GeV for $\beta = 0.5$

- Not possible to exclude 650 GeV, $\beta < 0.15$
Results for LQ2 in $\mu\mu jj$, $\mu\nu jj$ channels with ATLAS and CMS

$\mu\mu jj [\beta^2; \beta = 1]$  

ATLAS $(7 \text{ TeV}, 1.03 fb^{-1})$ $\mu\nu jj [\beta (1 - \beta); \beta = 0.5]$  

CMS $(8 \text{ TeV}, 19.6 fb^{-1})$
Limits for LQ2 in the $\mu\mu jj$, $\mu\nu jj$ channels with ATLAS and CMS

**ATLAS (7 TeV, 1.03 fb$^{-1}$)**

- $\mu\mu jj$ [$\beta^2; \beta = 1$] < 685 GeV at 95% CL
- $\mu\nu jj$ [$\beta(1-\beta); \beta = 0.5$] < 545 GeV at 95% CL

**CMS (8 TeV, 19.6 fb$^{-1}$)**

- Combined LQ1 < 594 GeV for $\beta = 0.5$
- Combined LQ2 LQ2 < 785 GeV for $\beta = 0.5$

**CMS Preliminary $\sqrt{s} = 8$ TeV, 19.6 fb$^{-1}$**

- Expected 95% CL upper limit
- Observed 95% CL upper limit
- $\int L dt = 1.03$ fb$^{-1}$

**ATLAS**

- Expected limit
- Observed limit
- $\beta (LQ \rightarrow \mu\mu)$ = 1.0
- $\beta (LQ \rightarrow \mu\nu)$ = 0.5

**Combined LQ2**

LQ2 < 785 GeV for $\beta = 0.5$

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Other LQ-like searches with CMS (8 TeV, 19.7 fb$^{-1}$)

**eejj**

- $W_R^\pm$ and $Z'$

- Left-Right Symmetric Model

- $SU_C(3) \otimes SU_L(2) \otimes SU_R(2) \otimes U(1)$

**eejj**

- Events / 200 GeV

- $M_{eejj}$ vs. $M_{W_R}$

- Theoretical expectations and observed limits

**μμjj**

- Events / 200 GeV

- $M_{μμjj}$ vs. $M_{W_R}$

- Theoretical expectations and observed limits

**Combined**

- Events / 200 GeV

- Combined $M_{eejj}$ and $M_{μμjj}$ vs. $M_{W_R}$

- Theoretical expectations and observed limits
LQ3 in the $\tau\tau bb$ channels with ATLAS ($7\,TeV, 4.7\,fb^{-1}$)

- $e, \mu, \tau_h$: $p_T > 25, 20, 30$ GeV; $|\eta| < 2.5$
- Veto 2nd $\ell$ with charge opposite to $e, \mu$
- $E_T > 20$ GeV
- $\geq 2$ jet ($\geq 1$ b-jet)
- $M(\tau_h, jet) > 90$ GeV

Main bkg $Z, W + \text{jets, } t\bar{t}$ from MC corrected w.r.t. data

**QCD (e$\tau_h$ channel)**
- Fitting $M_T(l, E_T)$ distribution
- QCD template from loose $\tau_h$ ID + SS region

**QCD ($\mu\tau_h$ channel)**

$N_A = N_B \times \frac{N_C}{N_D}$

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LQ3 and stop in the $\tau\tau bb$ channels with CMS ($8\ TeV$, $19.7\ fb^{-1}$)

- **LQ3 search**
  - $e,\mu$: $p_T > 30\ GeV$, $|\eta| < 2.1$
  - veto 2nd $\ell$ with charge opposite to $e,\mu$
  - $\tau_h$: $p_T > 50\ GeV$

- **Stop pairs search**
  - $\geq 2$ jet
  - of which $\geq 1$ b-jet
  - $M(\tau_h, jet) > 250\ GeV$
  - $\geq 1$ b-jet

LQ3: PAS-EXO-12-032

t$\bar{t}$ with a genuine $\tau_h$
from data $e\mu$ events
correcting by different BR
and object efficiencies

W,$Z$,t$\bar{t}$+Jets
with $\tau_h$ from Jets
FR[jet→$\tau_h$] ($p_T$) in $Z \rightarrow \mu\mu$
Reweight anti-isolated events

QCD
OS/SS method
**Limits for LQ3 in the $\tau\tau bb$ channel with ATLAS and CMS**

**ATLAS** $(7 \text{ TeV}, 4.7 \text{fb}^{-1})$

$LQ3 \rightarrow bb\tau\tau$

$< 534 \text{ GeV}$

at 95% CL

**CMS** $(8 \text{ TeV}, 19.7 \text{fb}^{-1})$

$LQ3 \rightarrow t\bar{t}$

$< 740 \text{ GeV}$ at 95% CL

$LQ3 \rightarrow t\nu$ from SUS-13-011

$\tilde{t} < 576 \text{ GeV}$ at 95% CL
LQ3 in the $\tau\tau tt$ channels with CMS ($8\,\text{TeV}, 19.7\,\text{fb}^{-1}$)

**Category A**
- $\mu$: $p_T > 25$ GeV, $|\eta| < 2.1$
- $\tau_h$: $p_T > 20$ GeV, $|\eta| < 2.1$, tighter ID
- $S_T > 400$ GeV,
- $\geq 2$ jets
- Same sign $\mu, \tau_h$

**Category B**
- $\mu$: $p_T > 30$ GeV, $|\eta| < 2.1$
- $\tau_h$: $p_T > 20$ GeV, $|\eta| < 2.1$, looser ID
- $S_T > 400$ GeV,
- $\geq 3$ jets, $E_T > 50$ GeV
- Veto evt of category A

LQ3: EXO-13-010

$p_T\tau_h$, $S_T$ optimised for each signal mass point
Sig events with prompt leptons (P). Bkg mainly dominated by fake leptons ($jet \rightarrow \tau_h$) (F)

**Category A**

$pT_{\tau_h}$, $S_T$ optimised for each signal mass point
Sig events with prompt leptons (P). Bkg mainly dominated by fake leptons ($jet \rightarrow \tau_h$) (F)

**Category B**

Correct fake tau candidates in MC

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Limits for LQ3 in the $\tau\tau tt$ channels with CMS

Combining categories A and B

$\sigma_{\text{LO}} \times \beta^2 \pm \sigma_{\text{theory}} (\beta=1)$

$\sigma_{\text{LO}} \times \beta^2$ versus $LQ_3$ Mass [GeV]

$\beta(LQ_3 \rightarrow \tau \tau)$ versus $LQ_3$ Mass [GeV]

BR-dependent limits include

$LQ_3 \bar{L}Q_3 \rightarrow bb\nu\nu \ [(1 - \beta)^2]$

[reinterpretation of a search for pair-produced scalar bottom (sbottom) quarks (SUS-13-018)]

$\rightarrow LQ3 < 724 \text{ GeV}$ for $\beta = 0$

and $480 \text{ GeV}$ over full $\beta$ at 95% CL

$LQ3 \rightarrow t\tau \ [\beta^2; \beta = 1]$

$< 634 \text{ GeV}$ at 95% CL
Conclusions

- LQ searches performed for all the three generations
- Upper limits are set on the mass of these particles
  (considering BRW model where \(\{\ell\ell, \ell\nu, \nu\nu\} + qq\) maximally produced for \(\beta = 1, 0.5, \text{and } 0\))

<table>
<thead>
<tr>
<th>(LQLQ)</th>
<th>(\beta^2)</th>
<th>(\beta(1 - \beta))</th>
<th>((1 - \beta)^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st gen</td>
<td>(&lt;1005) GeV ((ee + jj))</td>
<td>(&lt;845) GeV ((e\nu + jj))</td>
<td>n/a</td>
</tr>
<tr>
<td>2nd gen</td>
<td>(&lt;1070) GeV ((\mu\mu + jj))</td>
<td>(&lt;785) GeV ((\mu\nu + jj))</td>
<td>n/a</td>
</tr>
<tr>
<td>3rd gen</td>
<td>(&lt;740) GeV ((\tau\tau + bb)) (&lt;634) GeV ((\tau\tau + tt))</td>
<td>n/a</td>
<td>(&lt;724) GeV ((\nu\nu + bb)) (&lt;660) GeV ((\nu\nu + tt))</td>
</tr>
</tbody>
</table>

- Limits are also set in the plane \((\beta, M_{LQ})\)
  Not possible to exclude \(LQ1 \sim 650\) GeV, \(\beta < 0.15\)
  Discrepancy data/expectation observed also in other LQ-like signatures:
    LRSM, \(W_R \rightarrow eejj\)
- LQ searches sensitive to decays of SUSY particles:
  \(\tilde{t} < 576\) GeV at 95% CL
LQs with quantum numbers and decay modes in BRW model

<table>
<thead>
<tr>
<th>LQ type</th>
<th>$Q$</th>
<th>$T_3$</th>
<th>$F$</th>
<th>Decay mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_{0,L}$</td>
<td>$-1/3$</td>
<td>0</td>
<td>2</td>
<td>$e_L u_L, \nu_L d_L$</td>
</tr>
<tr>
<td>$S_{0,R}$</td>
<td>$-1/3$</td>
<td>0</td>
<td>2</td>
<td>$e_R u_R$</td>
</tr>
<tr>
<td>$\tilde{S}_{0,R}$</td>
<td>$-4/3$</td>
<td>0</td>
<td>2</td>
<td>$e_R d_R$</td>
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<tr>
<td>$S_{1/2,L}$</td>
<td>$-5/3$</td>
<td>$-1/2$</td>
<td>0</td>
<td>$e_L \bar{u}_L$</td>
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<tr>
<td></td>
<td>$-2/3$</td>
<td>$+1/2$</td>
<td>0</td>
<td>$\nu_L \bar{u}_L$</td>
</tr>
<tr>
<td>$S_{1/2,R}$</td>
<td>$-5/3$</td>
<td>$-1/2$</td>
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<td>$\tilde{S}_{1/2,L}$</td>
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<td>0</td>
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</tr>
<tr>
<td>$S_{1,L}$</td>
<td>$-4/3$</td>
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<tr>
<td></td>
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<td>0</td>
<td>2</td>
<td>$e_L u_L, \nu_L d_L$</td>
</tr>
<tr>
<td></td>
<td>$+2/3$</td>
<td>$+1$</td>
<td>2</td>
<td>$\nu_L u_L$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LQ type</th>
<th>$Q$</th>
<th>$T_3$</th>
<th>$F$</th>
<th>Decay mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{0,L}$</td>
<td>$-2/3$</td>
<td>0</td>
<td>0</td>
<td>$e_L \bar{d}_R, \nu_L \bar{u}_L$</td>
</tr>
<tr>
<td>$V_{0,R}$</td>
<td>$-2/3$</td>
<td>0</td>
<td>0</td>
<td>$e_R \bar{d}_L$</td>
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<tr>
<td>$\tilde{V}_{0,R}$</td>
<td>$-5/3$</td>
<td>0</td>
<td>0</td>
<td>$e_R \bar{u}_L$</td>
</tr>
<tr>
<td>$V_{1/2,L}$</td>
<td>$-4/3$</td>
<td>$-1/2$</td>
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</tr>
<tr>
<td></td>
<td>$-1/3$</td>
<td>$+1/2$</td>
<td>2</td>
<td>$\nu_L d_R$</td>
</tr>
<tr>
<td>$V_{1/2,R}$</td>
<td>$-4/3$</td>
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</tr>
<tr>
<td></td>
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<td>$+1/2$</td>
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<td>$e_R u_L$</td>
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<tr>
<td>$\tilde{V}_{1/2,L}$</td>
<td>$-1/3$</td>
<td>$-1/2$</td>
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</tr>
<tr>
<td></td>
<td>$+2/3$</td>
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<tr>
<td>$V_{1,L}$</td>
<td>$-5/3$</td>
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<td>0</td>
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<tr>
<td></td>
<td>$-2/3$</td>
<td>0</td>
<td>0</td>
<td>$e_L, \bar{d}_R, \nu_L \bar{u}_R$</td>
</tr>
<tr>
<td></td>
<td>$+1/3$</td>
<td>$+1$</td>
<td>0</td>
<td>$\nu_L, \bar{d}_R$</td>
</tr>
</tbody>
</table>
LO feynman diagrams for pair production scalar LQ

Dominant leading order diagrams for the pair production of scalar leptoquarks
More details on LQ1 and LQ2 background estimation with ATLAS

**QCD** Fitting $M_{\ell\ell}$, $E_T$ distributions for $\ell\elljj$, $\ell\nujj$.
QCD template where $\ell$ passes relaxed selection criteria

**$\ell\nujj$**

**W+Jets and $t\bar{t}$**

- from MC corrected by SF minimising $\chi^2$
- (data,MC) in CR1, CR2, CR3
- CR1, CR2 ($W+Jets$)
  - $40 < M_T < 120$ GeV
  - $S_T < 225$ GeV and
  - CR1: $\# \text{ jets} = 2$
  - CR2: $\geq 3$ jets
- CR3 ($t\bar{t}$): $\geq 4$ jets
LQ1 → eejj input variables for LLR (ATLAS)
LQ1 $\rightarrow e\nu jj$ input variables for LLR (ATLAS)
LQ2 → $\mu\mu jj$ input variables for LLR (ATLAS)
LQ2 → $\mu\nu jj$ input variables for LLR (ATLAS)
QCD estimation in LQ1, LQ2 (CMS)

QCD contribution is found to be negligible in LQ1, LQ2 CMS searches. Measurements with data-driven methods are performed in order to validate it.

**LQ1 → eejj**

\[ \text{FR}(\text{jet} \to e) = \text{tight } e/ \text{loose } e \]

Single photon trigger

1 loose \(e\) (suppress \(Z \to ee\)) and \(\geq 2\) jets

\[ \text{FR}(p_T; \eta): \]

\[ |\eta| < 1.442, 1.56 < |\eta| < 2, 2 < |\eta| < 2.5 \]

**QCD estimation**

Events passing loose, but tight \(e\)

Weighted by \(\text{FR}/(1-\text{FR})\)

QCD contributes up to 1% of tot bkg

**LQ1 → eνjj**

\[ \text{FR}(\text{jet} \to e) = \text{tight } e/ \text{loose } e \]

Same method of the \(eejj\) channel

**QCD estimation**

Events passing loose, but tight \(e\)

Weighted by \(\text{FR}/(1-\text{FR})\)

QCD contributes up to 3% of tot bkg

**LQ2 → μμjj**

**CR:**

Same-sign \(μ\)\(μ\) evt without \(μ\)-Iso

**QCD estimation**

\[ \text{CR} \times \text{OS/SS} \times \epsilon_{Iso} \]

\(\text{OS/SS}\) and \(\epsilon_{Iso}\) from MC

QCD contribute < 1% of tot bkg

**LQ2 → μνjj**

**CR:**

No \(μ\)-Iso, \(E_T < 10\) GeV

\[ \text{SF(data/MC) and } \epsilon_{Iso}\text{ from data} \]

**QCD estimation**

\(\text{MC with No } μ\)-Iso) \(\times \text{SF(data/MC) and } \epsilon_{Iso}\)

QCD contribute < 2% of tot bkg
More plots for LQ1 searches (CMS)

[Graphs showing distributions of events as a function of various variables, such as $m_{ej}$ and $m_{ej}^\text{min}$, for different selections and with contributions from various background processes indicated.]
More plots for LQ1 searches (CMS) (2)

Injected signal:
\( M_{LQ} = 650 \text{ GeV}, \beta = 0.075 \)

95% CL limits
- CMS eejj + evjj (Obs.)
- CMS eejj + evjj (Exp.)
- CMS eejj + evjj (Sig. Inj.)

Injected signal: 8 T eV, 19.6 fb\(^{-1}\)
Number of events after final $LQ_1 \rightarrow eejj$ selection (CMS)

Only statistical errors are reported (except in the "Total Background" column, where systematic uncertainties are also reported).

<table>
<thead>
<tr>
<th>$M_{LQ}$</th>
<th>LQ Signal</th>
<th>$Z + \text{Jets}$</th>
<th>$t\bar{t}$ (from data)</th>
<th>QCD (from data)</th>
<th>Other</th>
<th>Data</th>
<th>Total Background</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>13560.2 ± 80.1</td>
<td>462.2 ± 7.4</td>
<td>724.3 ± 19.8</td>
<td>5.282 ± 0.052</td>
<td>62.1 ± 4.6</td>
<td>1244</td>
<td>1253.94 ± 21.67 ± 30.08 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>350</td>
<td>6473.9 ± 33.3</td>
<td>332.1 ± 6.2</td>
<td>352.0 ± 13.8</td>
<td>3.215 ± 0.036</td>
<td>37.7 ± 3.6</td>
<td>736</td>
<td>725.10 ± 15.57 ± 24.99 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>400</td>
<td>3089.3 ± 15.0</td>
<td>203.2 ± 4.8</td>
<td>153.7 ± 9.1</td>
<td>1.696 ± 0.023</td>
<td>23.8 ± 2.9</td>
<td>389</td>
<td>382.40 ± 10.72 ± 15.00 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>450</td>
<td>1508.1 ± 7.2</td>
<td>112.9 ± 3.5</td>
<td>86.9 ± 6.9</td>
<td>0.890 ± 0.016</td>
<td>11.8 ± 2.0</td>
<td>233</td>
<td>212.44 ± 7.99 ± 13.33 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>500</td>
<td>767.4 ± 3.6</td>
<td>66.5 ± 2.7</td>
<td>47.2 ± 5.1</td>
<td>0.485 ± 0.011</td>
<td>7.4 ± 1.6</td>
<td>148</td>
<td>121.61 ± 5.96 ± 6.03 (syst)</td>
<td>1.8</td>
</tr>
<tr>
<td>550</td>
<td>410.5 ± 1.9</td>
<td>37.4 ± 2.1</td>
<td>25.8 ± 3.7</td>
<td>0.2758 ± 0.0084</td>
<td>3.7 ± 1.1</td>
<td>81</td>
<td>67.24 ± 4.40 ± 3.39 (syst)</td>
<td>0.7</td>
</tr>
<tr>
<td>600</td>
<td>225.7 ± 1.0</td>
<td>22.2 ± 1.6</td>
<td>14.2 ± 2.8</td>
<td>0.1527 ± 0.0065</td>
<td>3.12 ± 1.0</td>
<td>57</td>
<td>39.66 ± 3.35 ± 2.42 (syst)</td>
<td>2.1</td>
</tr>
<tr>
<td>650</td>
<td>125.85 ± 0.58</td>
<td>14.0 ± 1.2</td>
<td>5.4 ± 1.7</td>
<td>0.0760 ± 0.0040</td>
<td>1.05 ± 0.47</td>
<td>36</td>
<td>20.49 ± 2.14 ± 2.45 (syst)</td>
<td>2.4</td>
</tr>
<tr>
<td>700</td>
<td>72.88 ± 0.33</td>
<td>8.16 ± 0.93</td>
<td>4.3 ± 1.5</td>
<td>0.0448 ± 0.0029</td>
<td>0.21 ± 0.12</td>
<td>17</td>
<td>12.74 ± 1.80 ± 2.15 (syst)</td>
<td>0.9</td>
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<tr>
<td>750</td>
<td>43.10 ± 0.20</td>
<td>4.88 ± 0.69</td>
<td>1.55 ± 0.90</td>
<td>0.0258 ± 0.0023</td>
<td>0.078 ± 0.038</td>
<td>12</td>
<td>6.53 ± 1.13 ± 1.09 (syst)</td>
<td>1.6</td>
</tr>
<tr>
<td>800</td>
<td>26.17 ± 0.12</td>
<td>2.93 ± 0.52</td>
<td>1.04 ± 0.73</td>
<td>0.0193 ± 0.0022</td>
<td>0.078 ± 0.038</td>
<td>7</td>
<td>4.06 ± 0.90 ± 0.89 (syst)</td>
<td>1.1</td>
</tr>
<tr>
<td>850</td>
<td>15.978 ± 0.072</td>
<td>2.34 ± 0.48</td>
<td>0.52 ± 0.52</td>
<td>0.0111 ± 0.0015</td>
<td>0.042 ± 0.028</td>
<td>5</td>
<td>2.91 ± 0.71 ± 0.71 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>900</td>
<td>9.813 ± 0.044</td>
<td>1.23 ± 0.36</td>
<td>0.52 ± 0.52</td>
<td>0.0069 ± 0.0012</td>
<td>0.022 ± 0.020</td>
<td>3</td>
<td>1.77 ± 0.63 ± 0.37 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>950</td>
<td>6.086 ± 0.028</td>
<td>0.89 ± 0.29</td>
<td>0.00±1.14</td>
<td>0.00051 ± 0.00085</td>
<td>0.022 ± 0.020</td>
<td>1</td>
<td>0.912±1.178 ± 0.27 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>1000</td>
<td>3.860 ± 0.018</td>
<td>0.56 ± 0.22</td>
<td>0.00±1.14</td>
<td>0.000374 ± 0.00082</td>
<td>0.0225 ± 0.0025</td>
<td>1</td>
<td>0.567±1.162 ± 0.17 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>1050</td>
<td>2.576 ± 0.011</td>
<td>0.56 ± 0.22</td>
<td>0.00±1.14</td>
<td>0.000374 ± 0.00082</td>
<td>0.0225 ± 0.0025</td>
<td>1</td>
<td>0.567±1.162 ± 0.17 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>1100</td>
<td>1.6936 ± 0.0072</td>
<td>0.56 ± 0.22</td>
<td>0.00±1.14</td>
<td>0.000374 ± 0.00082</td>
<td>0.0225 ± 0.0025</td>
<td>1</td>
<td>0.567±1.162 ± 0.17 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>1150</td>
<td>1.1272 ± 0.0047</td>
<td>0.56 ± 0.22</td>
<td>0.00±1.14</td>
<td>0.000374 ± 0.00082</td>
<td>0.0225 ± 0.0025</td>
<td>1</td>
<td>0.567±1.162 ± 0.17 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>1200</td>
<td>0.7498 ± 0.0030</td>
<td>0.56 ± 0.22</td>
<td>0.00±1.14</td>
<td>0.000374 ± 0.00082</td>
<td>0.0225 ± 0.0025</td>
<td>1</td>
<td>0.567±1.162 ± 0.17 (syst)</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Number of events after final LQ1 → $e\nu jj$ selection (CMS)

Only statistical errors are reported (except in the "Total Background" column, where systematic uncertainties are also reported)

<table>
<thead>
<tr>
<th>$M_{LQ}$</th>
<th>LQ Signal</th>
<th>W+Jets</th>
<th>$tt$</th>
<th>QCD</th>
<th>Other</th>
<th>Data</th>
<th>Total Background</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presel</td>
<td>-</td>
<td>58284.8 ± 197.0</td>
<td>32196.7 ± 69.8</td>
<td>5950.5 ± 20.1</td>
<td>6590.8 ± 231.6</td>
<td>105164</td>
<td>103022.8 ± 312.6</td>
<td>NA</td>
</tr>
<tr>
<td>300</td>
<td>4765.5 ± 51.1</td>
<td>822.1 ± 22.4</td>
<td>1191.3 ± 12.0</td>
<td>117.9 ± 1.5</td>
<td>210.5 ± 7.7</td>
<td>2455</td>
<td>2341.9 ± 26.58 ± 329.79 (syst)</td>
<td>0.3</td>
</tr>
<tr>
<td>350</td>
<td>2168.4 ± 21.6</td>
<td>275.9 ± 14.5</td>
<td>441.4 ± 7.2</td>
<td>59.1 ± 0.97</td>
<td>102.1 ± 5.4</td>
<td>908</td>
<td>878.55 ± 17.08 ± 122.13 (syst)</td>
<td>0.2</td>
</tr>
<tr>
<td>400</td>
<td>971.1 ± 9.6</td>
<td>110.4 ± 7.8</td>
<td>184.2 ± 4.7</td>
<td>32.88 ± 0.69</td>
<td>51.5 ± 3.8</td>
<td>413</td>
<td>378.98 ± 9.91 ± 51.38 (syst)</td>
<td>0.5</td>
</tr>
<tr>
<td>450</td>
<td>469.7 ± 4.6</td>
<td>53.1 ± 5.8</td>
<td>74.7 ± 3.0</td>
<td>14.13 ± 0.42</td>
<td>25.7 ± 2.7</td>
<td>192</td>
<td>167.64 ± 7.06 ± 21.33 (syst)</td>
<td>0.8</td>
</tr>
<tr>
<td>500</td>
<td>232.7 ± 2.3</td>
<td>20.5 ± 3.3</td>
<td>34.4 ± 2.0</td>
<td>7.76 ± 0.30</td>
<td>15.3 ± 2.1</td>
<td>83</td>
<td>77.99 ± 4.41 ± 9.77 (syst)</td>
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</tr>
<tr>
<td>550</td>
<td>121.4 ± 1.2</td>
<td>8.6 ± 1.8</td>
<td>14.9 ± 1.4</td>
<td>3.89 ± 0.21</td>
<td>7.8 ± 1.6</td>
<td>44</td>
<td>35.24 ± 2.76 ± 4.31 (syst)</td>
<td>1.0</td>
</tr>
<tr>
<td>600</td>
<td>66.37 ± 0.66</td>
<td>2.3 ± 1.0</td>
<td>7.08 ± 0.93</td>
<td>2.29 ± 0.17</td>
<td>4.6 ± 1.2</td>
<td>28</td>
<td>16.27 ± 1.84 ± 2.03 (syst)</td>
<td>2.1</td>
</tr>
<tr>
<td>650</td>
<td>37.22 ± 0.37</td>
<td>0.41 ± 0.29</td>
<td>3.82 ± 0.70</td>
<td>1.18 ± 0.12</td>
<td>2.13 ± 0.92</td>
<td>18</td>
<td>7.54 ± 1.20 ± 1.07 (syst)</td>
<td>2.6</td>
</tr>
<tr>
<td>700</td>
<td>21.74 ± 0.21</td>
<td>0.41 ± 0.29</td>
<td>2.61 ± 0.60</td>
<td>0.85 ± 0.10</td>
<td>0.58 ± 0.24</td>
<td>6</td>
<td>4.45 ± 0.71 ± 0.74 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>750</td>
<td>12.90 ± 0.13</td>
<td>0.00 ± 0.04</td>
<td>1.75 ± 0.47</td>
<td>0.514 ± 0.091</td>
<td>0.27 ± 0.15</td>
<td>4</td>
<td>2.535 ± 0.091 ± 0.49 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>800</td>
<td>7.610 ± 0.075</td>
<td>0.00 ± 0.04</td>
<td>1.00 ± 0.37</td>
<td>0.317 ± 0.067</td>
<td>0.27 ± 0.15</td>
<td>3</td>
<td>1.696 ± 0.091 ± 0.31 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>850</td>
<td>4.713 ± 0.046</td>
<td>0.00 ± 0.04</td>
<td>0.90 ± 0.34</td>
<td>0.117 ± 0.029</td>
<td>0.140 ± 0.087</td>
<td>2</td>
<td>1.153 ± 0.091 ± 0.21 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>900</td>
<td>2.929 ± 0.028</td>
<td>0.00 ± 0.04</td>
<td>0.37 ± 0.21</td>
<td>0.076 ± 0.024</td>
<td>0.084 ± 0.069</td>
<td>1</td>
<td>0.530 ± 0.091 ± 0.10 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>950</td>
<td>1.839 ± 0.018</td>
<td>0.00 ± 0.04</td>
<td>0.37 ± 0.21</td>
<td>0.069 ± 0.023</td>
<td>0.084 ± 0.069</td>
<td>1</td>
<td>0.524 ± 0.066 ± 0.10 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>1000</td>
<td>1.306 ± 0.012</td>
<td>0.00 ± 0.04</td>
<td>0.37 ± 0.21</td>
<td>0.069 ± 0.023</td>
<td>0.084 ± 0.069</td>
<td>1</td>
<td>0.524 ± 0.066 ± 0.10 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>1050</td>
<td>0.9022 ± 0.0076</td>
<td>0.00 ± 0.04</td>
<td>0.37 ± 0.21</td>
<td>0.069 ± 0.023</td>
<td>0.084 ± 0.069</td>
<td>1</td>
<td>0.524 ± 0.066 ± 0.10 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>1100</td>
<td>0.6225 ± 0.0050</td>
<td>0.00 ± 0.04</td>
<td>0.37 ± 0.21</td>
<td>0.069 ± 0.023</td>
<td>0.084 ± 0.069</td>
<td>1</td>
<td>0.524 ± 0.066 ± 0.10 (syst)</td>
<td>0.0</td>
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<tr>
<td>1150</td>
<td>0.4308 ± 0.0032</td>
<td>0.00 ± 0.04</td>
<td>0.37 ± 0.21</td>
<td>0.069 ± 0.023</td>
<td>0.084 ± 0.069</td>
<td>1</td>
<td>0.524 ± 0.066 ± 0.10 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>1200</td>
<td>0.2971 ± 0.0022</td>
<td>0.00 ± 0.04</td>
<td>0.37 ± 0.21</td>
<td>0.069 ± 0.023</td>
<td>0.084 ± 0.069</td>
<td>1</td>
<td>0.524 ± 0.066 ± 0.10 (syst)</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Othe LQ-like searches with CMS

**eejj**

**μμjj**

**Combined**
Limits for LQ3 in the $\tau\tau bb$ channels with ATLAS

$LQ3 \rightarrow bb\tau\tau \rightarrow bbe\tau_h$

**ATLAS**

$\int L dt = 4.7 \text{ fb}^{-1}$

$\sqrt{s} = 7 \text{ TeV}$

$\text{Cross-section} [\text{pb}]$

- **Observed Limit**
- **Expected ± 1σ**
- **Expected ± 2σ**

$m_{LQ} \text{ [GeV]}$

$\begin{array}{c}
LQ3 \rightarrow bb\tau\tau \rightarrow bb\mu\tau_h \\
< 498 \text{ GeV at 95% CL} \\
LQ3 \rightarrow bb\tau\tau \rightarrow bb\mu\tau_h \\
< 473 \text{ GeV at 95% CL} \\
LQ3 \rightarrow bb\tau\tau \text{ [}\beta^2; \beta = 1\text{]} \text{ combined} \\
< 534 \text{ GeV at 95% CL}
\end{array}$
Limits for LQ3 and stop in the $\tau\tau bb$ channels with CMS

$LQ3 \rightarrow bb\tau\tau$ combined $e\tau_h, \mu\tau_h$

$LQ3 \rightarrow b\tau \ [\beta^2; \beta = 1] < 740 \text{ GeV} \text{ at } 95\% \text{ CL}$

$\tilde{t} < 576 \text{ GeV} \text{ at } 95\% \text{ CL}$