Searches for exotic new physics in CMS

Andreas Hinzmann

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Orthodox Academy of Creta, Kolymbari (Greece)
CMS definition of Exotic: Beyond the Standard Model physics which is not simple SUSY or has an unusual signature

2013 at ICNFP
- Sequential Standard Model Z'/W'
- Excited quark q*, Axigluon/Coloron
- Microscopic black holes
- ADD extra dimensions

2014 at ICNFP
- Dark matter
- Long-lived particles (e.g. from SUSY)
- RS/Bulk extra dimensions
- Compositeness, Contact Interactions
- LeptoQuarks
## Exotic final states

CMS made public 48 Exotic (EXO+B2G) searches using 8 TeV data: 
[https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO](https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO)  
[https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G](https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G) 
Covering here a subset of recent searches from a variety of final states

<table>
<thead>
<tr>
<th>Year</th>
<th>Final States</th>
</tr>
</thead>
</table>
| 2013 | Di-lepton and Di-jet resonances  
Multi-jets  
Mono-jet and Mono-lepton  
Displaced jets  
Heavy quasi-stable charged particles | The “obvious” channels |
| 2014 | Di-lepton spectrum (EXO-12-020)  
Di-boson resonances (EXO-13-009, EXO-12-024)  
Mono-photon (EXO-12-047)  
tt+E_{T}^{miss} (B2G-13-004)  
LeptoQuarks (EXO-12-041, EXO-13-010)  
Displaced di-leptons (EXO-12-037, B2G-12-024) | The “more difficult” channels |
Exotic models: Contact interactions

- The SM fermions may be composite objects connected by a new interaction at higher energy scales.
- First evidence would be observation of contact interactions between quarks and/or leptons.
- Can probe new physics scale \( \Lambda \) higher than collider energy.
- Many possible combinations of interactions are probed.
- Interference terms with SM interactions have large effect on cross section.

![Diagram of contact interactions](image)

**Graph: Events/(10 GeV/c^2)**

- **Left-left isoscalar model**
- **Destructive interference**
- **PYTHIA simulation**

**Legend:**
- \( \Lambda = 9 \) TeV
- \( \Lambda = 11 \) TeV
- \( \Lambda = 13 \) TeV
- \( \Lambda = 15 \) TeV
- \( \Lambda = 17 \) TeV
- **DY**
Exotic signature: Di-lepton spectrum

- Main background Drell-Yan di-lepton estimated from POWHEG+Pythia6 NLO($\alpha_S$)+PS prediction and NLO EWK corrections
- Uncertainties on background slope important to search for an excess in the tail of the distribution
- Left-left iso-scalar contact interaction excluded for destructive (constructive) interference with SM:
  - di-muon: $\Lambda<12.0$ (15.2) TeV
  - di-electron: $\Lambda<13.5$ (18.3) TeV
Exotic models: Extra dimensions

- Hierarchy problem between EWK scale (~1 TeV) and Planck scale (~$10^{16}$ TeV). Why is Gravity so weak?
- Possible solution: Gravity can propagate in extra spatial dimensions making it appear weak.

- **Randall-Sundrum (RS)** warped extra dimensions decreases effective Planck scale to $\sim M_{Pl}e^{-k\pi R}$, where $R$ is the size of the extra dimensions.
- Signature: Kaluza-Klein (KK) excitations of gravitons, resonances ($G_{RS}$) decaying primarily to fermions.

- **Bulk** model also allows fermions to propagate in the bulk of the extra dimensions and explains in addition the flavor puzzle: Why are the SM Yukawa couplings to Higgs so different?
- Signature: Gravitons ($G_{Bulk}$) decay primarily to bosons.

- **ADD** model signature: Narrow-spaced resonances, leading to broad excess.
Exotic techniques: Jet substructure

- Challenge of searches for di-boson resonances above 1 TeV: Jets from $W \rightarrow qq'$ and $Z \rightarrow qq$ decays merge
- $2 \text{ TeV } G_{\text{bulk}} \rightarrow ZZ$, $p_T^Z \sim 1 \text{ TeV}$, $M_Z \sim 90 \text{ GeV}$
  \[
  \Delta R_{qq}^{\text{min}} \approx \Delta \theta_{qq}^{\text{min}} \approx 2 \frac{M_V}{p_{T,V}} \sim 0.2 < \text{ jet cone of } 0.5
  \]
- Use powerful discriminators based on jet substructure

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**Pruned-jet mass (GeV)**

- $10^6$ CMS, $L = 19.7 \text{ fb}^{-1}$, $\sqrt{s} = 8 \text{ TeV}$
- $G_{\text{bulk}} (1.5 \text{ TeV}) \rightarrow ZZ$ ($x \approx 2.94 \times 10^7$) (JHUGEN+PYTHIA)
- $G_{\text{bulk}} (1.5 \text{ TeV}) \rightarrow WW$ ($x \approx 1.52 \times 10^7$) (JHUGEN+PYTHIA)
- $W' (1.5 \text{ TeV}) \rightarrow WZ$ ($x \approx 8.51 \times 10^4$) PYTHIA
- $G_{\text{RS}} (1.5 \text{ TeV}) \rightarrow ZZ$ ($x \approx 1.34 \times 10^5$) HERWIG++
- $G_{\text{RS}} (1.5 \text{ TeV}) \rightarrow WW$ ($x \approx 7.15 \times 10^4$) HERWIG++

- Untagged data
  - MADGRAPH+PYTHIA
  - HERWIG++
  - CA pruned $R=0.8$

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**$N$-subjettiness ratio $\tau_{21}$**

- $10^6$ CMS, $L = 19.7 \text{ fb}^{-1}$, $\sqrt{s} = 8 \text{ TeV}$
- $G_{\text{bulk}} (1.5 \text{ TeV}) \rightarrow ZZ$ ($x \approx 2.94 \times 10^7$) (JHUGEN+PYTHIA)
- $G_{\text{bulk}} (1.5 \text{ TeV}) \rightarrow WW$ ($x \approx 1.52 \times 10^7$) (JHUGEN+PYTHIA)
- $W' (1.5 \text{ TeV}) \rightarrow WZ$ ($x \approx 8.51 \times 10^4$) PYTHIA
- $G_{\text{RS}} (1.5 \text{ TeV}) \rightarrow ZZ$ ($x \approx 1.34 \times 10^5$) HERWIG++
- $G_{\text{RS}} (1.5 \text{ TeV}) \rightarrow WW$ ($x \approx 7.15 \times 10^4$) HERWIG++

- Untagged data
  - MADGRAPH+PYTHIA
  - CA $R=0.8$
**Exotic signature: Di-boson resonances**

- Combine W and Z boson decay channels to leptons and quarks to maximize sensitivity over whole mass range
- Background in di-jet final state estimated from smooth fit

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**CMS, L = 19.7 fb⁻¹, √s = 8 TeV**

- High-purity doubly W/Z-tagged data

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**CMS (unpublished) L = 19.7 fb⁻¹ at √s = 8 TeV**

- Frequentist CL
- Observed (solid) / Expected (dashed)

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**EXO-12-024 / EXO-13-009**

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• We known it exists through gravitational effect
• Searched for through direct detection, indirect detection and at colliders
• Dark matter signatures at LHC:
  • Invisible stable particles in cascade decays. Example: lightest SUSY particle stable if R-parity conserved
  • Pair produced invisible particles. Higher order diagrams provide probe recoiling against DM pair

• Effective theory: collapse SM-DM interaction in effective 4-point operators
  • various operators possible
  • allows translation to elastic DM-nucleon cross section and comparison with direct searches
  • only valid if scale of theory much larger than collider energy
Exotic signature: Mono-photon

- Z→vvy background estimated from simulation and cross check with a data driven estimate from Z→llγ events
- Second sensitive channel for collider DM searches after mono-jet
- Particularly stringent limits on axial-vector operator
Exotic signature: $t\bar{t} + E_T^{\text{miss}}$

- Main background $t\bar{t}$ estimated from simulation validated in data pre-selection sample

- Channel sets most stringent limits on scalar interaction that depends on quark mass
Exotic model: LeptoQuarks

• Many models beyond Standard Model – GUTs, Composite models, Technicolor – predict new bosons that carry both lepton and baryon number, called LeptoQuarks (LQ)

• Benchmark model: Buchmüller-Rückl-Wyler (BRW):
  • LQ interactions preserve baryon and lepton numbers to conserve proton stability
  • LQs couple to single chirality and generation of SM fermions at a time in order to suppress FCNCs

• Pair production dominant

• There are three generations of LQs

• Free parameters: $m_{\text{LQ}}, \beta$

  \[
  \begin{align*}
  \text{BR}(LQ \rightarrow \ell q) &= \beta \\
  \text{BR}(LQ \rightarrow \nu q) &= 1-\beta
  \end{align*}
  \]

\[
\begin{array}{|c|c|c|c|}
\hline
\text{LQ}\bar{\text{LQ}} & \beta^2 & \beta(1-\beta) & (1-\beta)^2 \\
\hline
\text{1st gen} & ee + jj & ev + jj & n/a \\
\text{2nd gen} & \mu\mu + jj & \mu\nu + jj & n/a \\
\text{3rd gen} & \tau\tau + bb, tt & n/a & \nu\nu + bb, tt \\
\hline
\end{array}
\]
Exotic signature: LQLQ → eejj/evjj

- Selection optimized for each single mass point:
  - eejj: \( m_{ej} (= m_{LQ}), m_{ee}, S_T = \Sigma_{eejj} p_T \)
  - evjj: \( m_{ej} (= m_{LQ}), m_{T^e}, E_T^{miss}, S_T = \Sigma_{ejj} p_T + E_T^{miss} \)
- Main backgrounds from W+jets, Z+jets, tt estimated from data sideband
- Broad excess of 2.4-2.6 sigma observed
- Most prominent with \( M_{LQ} = 650 \) GeV selection
- However, excess not compatible with single LQ kinematics

EXO-12-041

02 Aug 2014
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Exotic signature: \( \text{LQLQ} \rightarrow \text{tt\tau} \)

- Main channel: same sign (SS) \( \mu\tau_{\text{had}} \)
- Second channel: OS \( \mu\tau_{\text{had}} \)
- Selection optimized for each single LQ mass point:
  \( \geq 2-3 \text{ jets}, S_T, E_T^{\text{miss}}, p_T(\tau_{\text{had}}) \)
- Main background from fake leptons obtained from loose isolation region in data

EXO-13-010
Exotic models: Long-lived particles

- Long-lived particles ($c\tau > 100\mu\text{m}$) can appear in many theories
- SUSY with small violation of R-parity, such that SUSY particles may have a long lifetime before decaying to SM particles
- Split SUSY with long-lived gluinos
- Hidden Valley
- Long-lived heavy Majorana neutrinos from $Z'$ decays

\[ \tilde{t} \rightarrow b e b \mu \]
Exotic techniques: Displaced di-leptons

• Flight length $100 \mu m < c \tau < 2 \text{cm}$ (inside inner pixel detector layer):
  • Standard reconstruction techniques work
  • Main discriminator: impact parameter of reconstructed leptons

• Flight length $c \tau > 2 \text{cm}$:
  • Special reconstruction techniques required
  • Main discriminator: secondary vertex significance from two tracks

• Trigger based on Muon system and ECAL, but not tracker
Exotic signature: Displaced $e\mu$

- Search for displaced opposite sign $e\mu$ pairs, no common vertex
- Main background from heavy flavor decays estimated from data using lepton isolation+charge sidebands

- Stop-pair production as benchmark: $\tilde{t}\tilde{t} \to b\bar{b}e\mu$
Exotic signature: Displaced $\mu\mu$/ee

- Search for $\mu\mu$ and $ee$ pairs from secondary vertex with significance >12
- Main background from tau lepton decays estimated from simulation validated in collinearity $\Delta \Phi$(vertex direction, di-lepton momentum) sideband
- Benchmark model: $H \rightarrow XX$, $X \rightarrow \mu\mu$/ee

EXO-12-037

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Conclusions

- CMS explores a large variety of exotic models and signatures
- Lots of progress in exploring difficult regions of parameter space with complicated final states
- Exotic techniques are advanced to perform these searches
- No evidence for exotic signatures so far
- In LHC Run II with 13/8 times more energy will repeat all searches in a yet a new territory

### 2014 at INCFP

- Di-lepton spectrum (EXO-12-020)
- Di-boson resonances (EXO-13-009, EXO-12-024)
- Mono-photon (EXO-12-047)
- $\tt+E_{T}^{\text{miss}}$ (B2G-13-004)
- LeptoQuarks (EXO-12-041, EXO-13-010)
- Displaced di-leptons (EXO-12-037, B2G-12-024)

The “more difficult” channels
More on: LQLQ $\rightarrow$ eejj/evjj

![Graphs showing the cross-sections for LQLQ → eejj and LQLQ → evjj as functions of M_{LQ} (GeV). The graphs compare the ATLAS and CMS exclusion limits with the expected and observed 95% CL upper limits.](image-url)
More on: LQLQ $\rightarrow$ eejj/evjj

![Histogram of eejj](#)

![Histogram of evjj](#)

- Data, $19.6 \text{ fb}^{-1}$
- LQ, $M = 650 \text{ GeV}, \beta = 1.0$
- $Z + \text{jets}$
- $t\bar{t}$ (from Data)
- Other backgrounds
- QCD multijets

CMS Preliminary

$\sqrt{s} = 8 \text{ TeV}$

$\min m_{ej}$ (GeV) [LQ $M = 650$ selection]

$N(\text{Events}) \times (100.0)/(\text{bin width})$
Table 4: Number of events after final eejj selection. Only statistical errors are reported, except in the “Total Background” column, where systematic uncertainties are also reported. The “Significance” column provides the significance of the excess observed in data with respect to the background prediction after accounting for the correlations of the systematic uncertainties; no signal hypothesis is included in the calculation.

<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>10538.4 ± 35.8</td>
<td>1556.6 ± 29.2</td>
<td>10.87 ± 0.10</td>
<td>303.8 ± 7.4</td>
<td>1244</td>
<td>12419.6 ± 46.8</td>
<td>NA</td>
</tr>
<tr>
<td>350</td>
<td>6473.9 ± 33.3</td>
<td>203.2 ± 4.8</td>
<td>155.7 ± 1.6</td>
<td>1.696 ± 0.023</td>
<td>37.3 ± 3.6</td>
<td>736</td>
<td>72510 ± 15.57 ± 24.99 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>400</td>
<td>3089.3 ± 15.0</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 ± 1.00</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>
</tr>
<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>0.0000 ± 0.00000001</td>
<td>0.00451 ± 0.00085</td>
<td>0.022 ± 0.020</td>
<td>1</td>
<td>0.912 ± 0.29 ± 0.27 (syst)</td>
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</tr>
<tr>
<td>1000</td>
<td>3.860 ± 0.018</td>
<td>0.56 ± 0.22</td>
<td>0.0000 ± 0.00000001</td>
<td>0.00374 ± 0.00082</td>
<td>0.0025 ± 0.0025</td>
<td>1</td>
<td>0.567 ± 0.16 ± 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>0.0000 ± 0.00000001</td>
<td>0.00374 ± 0.00082</td>
<td>0.0025 ± 0.0025</td>
<td>1</td>
<td>0.567 ± 0.16 ± 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>0.0000 ± 0.00000001</td>
<td>0.00374 ± 0.00082</td>
<td>0.0025 ± 0.0025</td>
<td>1</td>
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<td>0.0</td>
</tr>
<tr>
<td>1150</td>
<td>1.1272 ± 0.0047</td>
<td>0.56 ± 0.22</td>
<td>0.0000 ± 0.00000001</td>
<td>0.00374 ± 0.00082</td>
<td>0.0025 ± 0.0025</td>
<td>1</td>
<td>0.567 ± 0.16 ± 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>0.0000 ± 0.00000001</td>
<td>0.00374 ± 0.00082</td>
<td>0.0025 ± 0.0025</td>
<td>1</td>
<td>0.567 ± 0.16 ± 0.17 (syst)</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Table 5: Number of events after final $evjj$ selection. Only statistical errors are reported, except in the “Total Background” column, where systematic uncertainties are also reported. The “Significance” column provides the significance of the excess observed in data with respect to the background prediction after accounting for the correlations of the systematic uncertainties; no signal hypothesis is included in the calculation.

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<th>LQ Signal</th>
<th>$W+$Jets</th>
<th>$t\bar{t}$</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>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></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>2341.90 ± 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>59.11 ± 0.97</td>
<td>102.1 ± 5.4</td>
<td>908</td>
<td>878.55 ± 17.08 ± 122.13 (syst)</td>
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<tr>
<td>400</td>
<td>971.1 ± 9.6</td>
<td>110.4 ± 7.8</td>
<td>164.2 ± 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>
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<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>
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</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 ± 0.00</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 ± 0.504 ± 0.49 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>800</td>
<td>7.610 ± 0.075</td>
<td>0.00 ± 0.00</td>
<td>1.10 ± 0.37</td>
<td>0.317 ± 0.067</td>
<td>0.27 ± 0.15</td>
<td>3</td>
<td>1.696 ± 0.403 ± 0.31 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>850</td>
<td>4.713 ± 0.046</td>
<td>0.00 ± 0.00</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 ± 0.353 ± 0.24 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>900</td>
<td>2.929 ± 0.028</td>
<td>0.00 ± 0.00</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 ± 0.226 ± 0.10 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>950</td>
<td>1.839 ± 0.018</td>
<td>0.00 ± 0.00</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 ± 0.226 ± 0.10 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>1000</td>
<td>1.306 ± 0.012</td>
<td>0.00 ± 0.00</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 ± 0.226 ± 0.10 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>1050</td>
<td>0.9022 ± 0.0076</td>
<td>0.00 ± 0.00</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 ± 0.226 ± 0.10 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>1100</td>
<td>0.6225 ± 0.0050</td>
<td>0.00 ± 0.00</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 ± 0.226 ± 0.10 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>1150</td>
<td>0.4308 ± 0.0032</td>
<td>0.00 ± 0.00</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 ± 0.226 ± 0.10 (syst)</td>
<td>0.0</td>
</tr>
<tr>
<td>1200</td>
<td>0.2971 ± 0.0022</td>
<td>0.00 ± 0.00</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 ± 0.226 ± 0.10 (syst)</td>
<td>0.0</td>
</tr>
</tbody>
</table>
More on: LQLQ $\rightarrow$ eejj/evjj

Injected signal:
$M_{LQ} = 650$ GeV, $\beta = 0.075$