Searches for resonant and non-resonant new phenomena from ATLAS

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on behalf of the
ATLAS Collaboration
Introduction: Resonant and non-resonant searches

Non-Resonant:
- Contact interactions can be found in a non-resonant search.
- Looks for an overall increase in total number of signal events.
- Can be mistaken for high energy QCD effects.

Resonant:
- Mediator particle decays can be found in a resonant search.
- Looks for a narrow or broad peak on top of a continuum.
Di-jet searches (resonant 8 TeV)

Event Selection

- Single jet trigger
- At least two jets in event
- \( m_{jj} > 250 \text{ GeV} \)
- Rapidity (y) of leading jets < 2.8
- Transverse momentums (\( p_T \)) > 50 GeV
- \( |y^*| = \frac{1}{2} |y_1 - y_2| < 0.6 \)

Phenomenological Models (limits [TeV])

- Excited quarks, \( q^* \): \( m_{q^*} > 4.06 \)
- Color-octet scalars, \( s_8 \): \( m_{s_8} > 2.70 \)
- Heavy \( W' \) gauge bosons \( m_{W'} > 2.45 \)
- Chiral \( W^* \) gauge bosons
  - \( m_{W^*} \) leptophobic: \( > 1.75 \)
  - \( m_{W^*} \) leptophilic: \( > 1.65 \)
- Quantum black holes \( m_{BH} > 5.66 \)
Di-jet Searches (non-resonant 8 TeV)

Event Selection:
- Single jet trigger
- At least two jets in event
- $m_{jj} > 600$ GeV
- Rapidity boost of system:
  \[ |y_B| = \frac{1}{2} |y_1 + y_2| < 1.1 \]
- $|y^*| = \frac{1}{2} |y_1 - y_2| < 1.7$

Scattering angle between two jets: $\chi \equiv e^{y_1 - y_2} = e^{2|y^*|}$

Models:
- Strong gravity
- Contact interactions
  \[ \Lambda > 8.1 \text{ TeV} \text{ (destructive interference)} \]
  \[ \Lambda > 12.0 \text{ TeV} \text{ (constructive interference)} \]
Di-lepton (resonant)

**Leptons:**
Normalized to data under Z peak

**Electrons:**
- Di-EM calorimeter clusters trigger
- Shower profile and leakage, tracking quality
- Calorimetric isolation

**Muons:**
- Single muon triggers
- Inner detector & Muon Spectrometer quality
- Track isolation
- Opposite sign

**Phenomenological Models** (and limits in [TeV])
- Sequential SM, $Z'_\text{SSM}$, $m_Z > 2.9$ TeV
- Grand Unification, $Z', \chi, \psi$, $m_Z > 2.62, 2.51$
- Z* Bosons, $m_{Z^*} > 2.85$ TeV
- Spin-2 Graviton, $(k/M_{\text{Pl}} = 0.1)$, $m_{G^*} > 2.68$ TeV
- QBH
  - ADD: $m_{th} > 3.65$ TeV
  - RS: $m_{th} > 2.24$ TeV
- Minimal Walking Technicolor Model
  - $M_A > 1.96$, $M_{R1} > 1.99$ (for $g = 2$)

**Leptons:**
Normalized to data under Z peak

**Electrons:**
- Di-EM calorimeter clusters trigger
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- Single muon triggers
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**Diagrams:**
- $Z' \rightarrow ee$
- $Z' \rightarrow \mu\mu$

**References:**
Di-lepton (non-resonant)

Contact Interactions
Coupling between $q_{L,R}$ and $\ell_{L,R}$ probed for contact interactions

Large extra spatial dimensions
The string scale $M_s$ is probed for interference and graviton effects

Leptons:
- $m_{\ell\ell} > 80$ GeV
- Background scaled to data in region $80$ GeV < $m_{\ell\ell}$ < $120$ GeV
- Control region for verification $120$ GeV < $m_{\ell\ell}$ < $400$ GeV

Electrons:
- Di-EM calorimeter clusters trigger
- Shower profile and leakage, tracking quality
- Calorimetric isolation
- Opposite sign

Muons:
- Single muon triggers
- Inner detector & Muon Spectrometer quality
- Track isolation
- Opposite sign

$\Lambda > 26.3$ TeV (L-R constructive)

$M_s > 5.0$ TeV (HLZ n=3 ADD)

QCD@LHC2015

September 2, 2015
Lepton + MET

Phenomenological Models (limits [TeV])
- SSM W' gauge bosons \( m_{W'} > 3.24 \text{ TeV} \)
- Chiral W* gauge bosons \( m_{W^*} > 3.21 \text{ TeV} \)
- Dark Matter Effective Field Theory (DM EFT):
  Various M* limits for different DM masses

Event Selection
- Single EM or muon trigger
- Electron: \( E_T \) and \( E_{T\text{miss}} > 125 \text{ GeV} \)
- Muon: \( p_T \) and \( E_{T\text{miss}} > 45 \text{ GeV} \)
- Isolated lepton

\[ m_T \equiv \sqrt{2p_T E_{T\text{miss}}(1 - \cos \phi_{\ell\nu})} \]
Lepton + jets

Event Selection

- Single electron, single muon, and large-radius jet triggers
- Isolated leptons with $E_T > 25$ GeV (e), $p_T > 25$ GeV (mu)
- Transverse mass: $m_T = \sqrt{2p_T E_T \text{miss} (1 - \cos \phi_{\ell \nu})}$
- $E_T \text{miss} > 25$ GeV
- $E_T \text{miss} + m_T > 60$ GeV
- Boosted Topologies (large-radius jet along with lepton + small jet)
- Resolved Topologies (four small-radius jets individually resolved)

Phenomenological Models (limits [TeV])

- Topcolour-assisted-technicolour $Z'_{TC_2}$
  
  $m_{Z'} > 1.8$ TeV

- Bulk RS Kaluza–Klein gluon, $m_{gKK} > 2.2$ TeV

- Bulk RS Kaluza–Klein graviton, no limits set

- Scalar resonance, no limits set

Accepted by JHEP (2015) arXiv:1505.07018
Di-photon

arXiv:1504.05511

- Randall-Sundrum (RS) Model of extra spacial dimensions, leading to spin-2 gravitons
  \[ m_{G^*} > 2.66 \text{ TeV} \ (k/M_{Pl} = 0.1) \]
  \[ m_{G^*} > 1.41 \text{ TeV} \ (k/M_{Pl} = 0.01) \]

- Di-photon trigger
- Calorimetric isolation
- Shower shape quality
**Phenomenological Models** (limits [TeV])

- QBH model \( M_{\text{th}} > 4.6 \) TeV
- Generic gaussian-shape, exclude \( m_g \) of 4 GeV (5% width, visible \( \sigma \) near 0.1)
- Excited-quark model \( m_{q^*} > 3.5 \) TeV

- One photon and one jet candidate, each with \( p_T > 125 \) GeV
- Central, isolated photon
- Pseudorapidity \( \Delta \eta = |\eta_\gamma - \eta_{\text{jet}}| > 1.6 \)
Multi-jets (8 TeV)

$H_T$ is defined as the scalar sum of $p_T$ of jets in the event

- High $H_T$ trigger, efficient $> 1.2$ TeV ($> 1.5$ TeV used in analysis)
- Three or more central jets with $p_T > 50$ GeV
- SM background estimated by low $H_T$ region extrapolation through generators PYTHIA 8, Herwig++, and ALPGEN MC
- Black holes and string balls searched for in most sensitive regions
Di-bosons

$ZV \rightarrow \ell\ell jj$

Resolved – high or low $p_T$ jets
Leptons or jets in mass window of $Z$, or $Z/W$

$ZV \rightarrow \ell\ell J$

Boosted – one large $Z/W$ boson jet

$m_{W'} > 1.59 \text{ TeV}$
$m_{G^*} > 740 \text{ GeV}$

$WV \rightarrow \ell\nu jj$

Resolved – high or low $p_T$ jets
Lepton + $E_T^{\text{miss}}$ or jets in mass window of $W$, or $Z/W$

$WV \rightarrow \ell\nu J$

Boosted – one large $Z/W$ boson jet

$m_{W'} > 1.49 \text{ TeV}$
$m_{G^*} > 760 \text{ GeV}$†

†see erratum
Di-bosons

$WZ \rightarrow \ell \nu \ell'$ (low and high mass regions defined with $m_W', \Delta \phi$)

Three charged tracks, $\Delta y$ separated $W, Z$ bosons
$m_W > 1.52$ TeV

$VV \rightarrow JJ$ (Boosted jets)

High $p_T$ boosted jets selected in regions orthogonal to other di-boson searches

PLB 737, 223 (2014)
arXiv:1406.4456

Submitted to JHEP
arXiv:1506.00962
New: Run-2 Results

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResultsRun2
Di-jets (13 TeV)

\( s = 13 \text{ TeV}, 80 \text{ pb}^{-1} \)

**ATLAS** Preliminary

- Data
- QBH, \( M_{\text{th}} = 6.5 \text{ TeV} \)
- SM
- Theoretical uncert.
- Total uncertainties

\(|y^*| < 1.7, |y_0| < 1.1\)

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**ATLAS** Preliminary

\( \sqrt{s} = 13 \text{ TeV}, 80 \text{ pb}^{-1} \)

Events

\( \chi \)

1/N dN/d\chi

\( m_{jj} > 3.4 \text{ TeV} \)

\( 3.1 < m_{jj} < 3.4 \text{ TeV} \)

\( 2.8 < m_{jj} < 3.1 \text{ TeV} \)

\( 2.5 < m_{jj} < 2.8 \text{ TeV} \)

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QCD@LHC2015
Multi-jets (13 TeV)

\[ \int L \, dt = 74 \, \text{pb}^{-1} \]
\[ \sqrt{s} = 13 \, \text{TeV} \]

**ATLAS Preliminary**

\[ n_{\text{jet}} \geq 3 \]

**ATLAS**

\[ \frac{\text{Events}}{0.1 \, \text{TeV}} \]

**CHARYBDIS2**

- Rotating black holes, \( n = 6 \)

\[ \int L \, dt = 74 \, \text{pb}^{-1} \]
\[ \sqrt{s} = 13 \, \text{TeV} \]

**ATLAS Preliminary**

- Expected (\( n_{\text{jet}} \geq 3 \))
- Observed (\( n_{\text{jet}} \geq 3 \))
- \( \pm 1 \sigma \)
- \( \pm 2 \sigma \)
- ATLAS \( \sqrt{s} = 8 \, \text{TeV} \)

**Data 2015**

- Data 2015
- Multijets
- \( M_b = 2.5 \, \text{TeV}, M_{th} = 6 \, \text{TeV} \)

**95% CL exclusion**

\[ 95\% \, \text{CL exclusion} \]
Conclusion

- Searches through many final states
- No significant excesses in any channels
  - Potential hints of new physics in di-boson channels
  - Very good agreement between data and Monte Carlo shapes in lepton + MET, di-lepton and multi-jets
- Excellent performance ATLAS Run-1
- New opportunities upcoming in Run-2
  - First data analyzed
  - Run-1 sensitivities should hopefully be exceeded by end of 2015
# Full Exotics search summary

| Model                          | $\ell$, $\gamma$ | Jets | $E^{\text{miss}}_T$ | $\mathcal{L} \text{dt} [\text{fb}^{-1}]$ | Limit         | Reference |
|-------------------------------|------------------|------|---------------------|------------------------------------------|--------------|
| ADD $G_{0K} + g/q$            | $\geq 1$, $\geq 1$ | Yes  | $20.3$              | $M_{0K}$                                   | $5.26$ TeV   | $n = 2$    |
| ADD non-resonant $\ell\ell$   | $2\ell, \mu^+$   |      | $20.3$              | $M_{\ell\ell}$                             | $4.7$ TeV    | $n = 3$ HZ |
| ADD $Q+\ell\ell$              | $1\ell, \mu^+$   |      | $20.3$              | $M_{\ell\ell}$                             | $3.8$ TeV    | $n = 5$    |
| ADD $Q\ell\ell$               | $2\ell, \mu^+$   |      | $20.3$              | $M_{\ell\ell}$                             | $5.82$ TeV   | $n = 5$    |
| ADD $Q\ell_2$                 | $2\ell, \mu^+$   |      | $20.3$              | $M_{\ell\ell}$                             | $4.7$ TeV    | $n = 6$    |
| ADD $Q\ell_2$                 | $2\ell, \mu^+$   |      | $20.3$              | $M_{\ell\ell}$                             | $5.0$ TeV    | $n = 6$    |
| ADD $Q$                       | $2\ell, \mu^+$   |      | $20.3$              | $M_{\ell\ell}$                             | $5.8$ TeV    | $n = 2$    |
| $R_1$, $G_{0K} \rightarrow \ell\ell$ | $2\ell, \mu^+$ |      | $20.3$              | $M_{\ell\ell}$                             | $5.8$ TeV    | $n = 2$    |
| $R_1$, $G_{0K} \rightarrow \gamma\gamma$ | $2\ell, \mu^+$ |      | $20.3$              | $M_{\ell\ell}$                             | $5.8$ TeV    | $n = 2$    |
| Bulk $RS$                      | $2\ell, \mu^+$   |      | $20.3$              | $M_{\ell\ell}$                             | $5.8$ TeV    | $n = 2$    |
| Bulk $RS$                      | $2\ell, \mu^+$   |      | $20.3$              | $M_{\ell\ell}$                             | $5.8$ TeV    | $n = 2$    |
| Bulk $RS$                      | $2\ell, \mu^+$   |      | $20.3$              | $M_{\ell\ell}$                             | $5.8$ TeV    | $n = 2$    |
| Bulk $BD_2$                    | $2\ell, \mu^+$   |      | $20.3$              | $M_{\ell\ell}$                             | $5.8$ TeV    | $n = 2$    |
| 2UED / RPP                    | $2\ell, \mu^+$   |      | $20.3$              | $M_{\ell\ell}$                             | $5.8$ TeV    | $n = 2$    |
| **Extra dimensions**          |                  |      |                     |                                           |              |            |
| **Gauge bosons**              |                  |      |                     |                                           |              |            |
| **DM**                        |                  |      |                     |                                           |              |            |
| **Other**                     |                  |      |                     |                                           |              |            |