Searches for High Mass Resonances at ATLAS

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on behalf of the ATLAS Collaboration

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LHC and ATLAS
LHC Run 2

- Increase in energy from $8 \rightarrow 13$ TeV
- Major new-physics sensitivity has opened up, **specially at high masses**
- Exceptional LHC performance in 2016 and 2017 following 13 TeV commissioning in 2015
- Integrated luminosity so far: 86 fb$^{-1}$ recorded (80 fb$^{-1}$ physics)
Exotic Diboson Searches

• Historically connected to electroweak symmetry breaking models

• Scenarios
  ➡ Spin 0: Heavy scalars in extended Higgs sector
  ➡ Spin 1: Extended gauge models ($W', Z'$ in SSM/HVT)
  ➡ Spin 2: Kaluza-Klein gravitons (bulk RS)

• Look into many final states:
  ➡ $VV, VH, HH, ZH (H\neq 125), XH, V\gamma, \gamma\gamma$ in leptonic, semi-leptonic and fully hadronic final states
  ➡ Some analyses also look at different production modes (qq/ggF/VBF/VH)
  ➡ $VV, V\gamma$ analyses assume narrow width resonances; $\gamma\gamma$ also look into larger width (4 MeV to 10% width)

<table>
<thead>
<tr>
<th></th>
<th>$W$</th>
<th>$Z$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charged leptons</td>
<td>~33%</td>
<td>~10%</td>
</tr>
<tr>
<td>Hadrons</td>
<td>~67%</td>
<td>~70%</td>
</tr>
<tr>
<td>Neutrinos</td>
<td>-</td>
<td>~20%</td>
</tr>
</tbody>
</table>
Boosted Boson Tagging

- Wide range of boson $p_T$: distinct topologies for hadronic decays
  - Resolved: 2 small R jets (jj), anti-$k_t$ R=0.4
  - Boosted: single large R jets (J), anti-$k_t$ R=1.0

- Jet grooming algorithm: trimming

- Boson tagging: 50% flat signal efficiency ($\sim 2\%$ QCD eff.)
  - Large-radius jet mass
  - Energy correlation variable $D_2^{\beta=1}$

More on Jason Veatch's talk
VV → JJ

ATLAS
$\sqrt{s} = 13$ TeV, 36.7 fb$^{-1}$

Data
Fit
Fit + HVT model B $m=1.5$ TeV
Fit + HVT model B $m=2.4$ TeV

WW SIGNAL REGION

$\chi^2$/DOF = 4.6/7

Events / 0.1 TeV

Events / 5 GeV

$\sqrt{s}=13$ TeV, 36.7 fb$^{-1}$

V+jets VR

$\eta_{V} < 30$

ATLAS

Observed 95% CL limit
Expected 95% CL limit
Expected limit ± 1σ
Expected limit ± 2σ
HVT model A, $g_\sigma = 1$
HVT model B, $g_\sigma = 3$
$WW \rightarrow \ell \nu q q$
**VW → ℓℓqq, ννqq**

**ATLAS**
- √s = 13 TeV, 36.1 fb⁻¹
- H → ZZ → ℓℓqq
- ggF cat. high-purity SR

**ATLAS**
- √s = 13 TeV, 36.1 fb⁻¹
- H → ZZ → ννqq
- VBF cat. high-purity SR

**ZZ ggF ℓℓqq - Boosted high purity**

**ZZ VBF ννqq - Boosted high purity**

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VV and VH Searches

• Complementarity in sensitivity amongst channels

**ATLAS** Preliminary
\( \sqrt{s} = 13 \text{ TeV}, 36.1 \text{ fb}^{-1} \)

95% C.L. exclusion limits

- HVT model B \( g' = 3 \)
- Observed
- Expected
- qq\( qq \)
- ll\( qq \)
- vvqq

\( \sigma(p p \rightarrow H \rightarrow W W, Z \rightarrow l^+ l^- ZZ) \) [pb]

\( m_W \) [TeV]

\( \sigma(p p \rightarrow H \rightarrow Z \rightarrow b \bar{b}, t \bar{t} \rightarrow b \bar{b}, c \bar{c}) \) [pb]

\( m_Z' \) [TeV]
$X \rightarrow Z\gamma$

**ATLAS**

$\sqrt{s} = 13$ TeV, 36.1 fb$^{-1}$

$\mu\mu$

$Z(\mu\mu)\gamma$ SIGNAL REGION

Events / 20 GeV

95% CL Upper Limit on $\sigma \times B$ [fb]

Local $p_0$

Global significance of largest deviation for $ee+\mu\mu$: 0.8 $\sigma$
\( X \rightarrow \gamma \gamma \gamma \)
Exotic Searches in ATLAS
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# Exotic Searches in ATLAS

## ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

<table>
<thead>
<tr>
<th>Model</th>
<th>$\mathcal{L} , \text{(fb)}$</th>
<th>$\text{Limit}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADD $G_{CKM}$ + $g/q$</td>
<td>0.0, $\mu$ 1, 4 $\nu$</td>
<td>Yes</td>
</tr>
<tr>
<td>ADD non-resonant $g$</td>
<td>2 $\gamma$</td>
<td>36.7</td>
</tr>
<tr>
<td>ADD $Q^{\text{BH}}$</td>
<td>2 $\gamma$</td>
<td>37.0</td>
</tr>
<tr>
<td>ADD $Q^{\text{BH}}$ + multiŋ$\nu$</td>
<td>2 $\gamma$</td>
<td>32.6</td>
</tr>
<tr>
<td>RCP $G_{CKM}$ + $g$</td>
<td>2 $\gamma$</td>
<td>36.7</td>
</tr>
<tr>
<td>Bulk $R_{G_{CKM}}$ + $WW \rightarrow q\bar{q}q$</td>
<td>1 $\mu$, 1 $\nu$</td>
<td>Yes</td>
</tr>
<tr>
<td>2UED + RFG $\nu_{H}$</td>
<td>1 $\mu$, 2, 2 $\gamma$, 1 $\nu$</td>
<td>Yes</td>
</tr>
<tr>
<td>$\text{Limit}$</td>
<td>$\text{Limit}$</td>
<td>$\text{Limit}$</td>
</tr>
<tr>
<td>$\mathcal{L} , \text{dt} = (3.2 - 37.0) , \text{fb}^{-1}$</td>
<td>$\sqrt{s} = 8, 13 \text{ TeV}$</td>
<td>$\sqrt{s} = 8, 13 \text{ TeV}$</td>
</tr>
</tbody>
</table>

### Reference

- ATLAS-CFP-2017-027
- ATLAS-CFP-2017-050
- ATLAS-CFP-2016-014
- ATLAS-CFP-2017-147
- ATLAS-CFP-2017-685
- 1410.4110
- 1409.0006
- 1409.0006

### ATLAS Preliminary

*Only a selection of the available mass limits on new states or phenomena is shown.

†Small-radius (large-radius) jets are denoted by the letter $j$ (J).

F. A. Dias
Looking ahead

• After the 8→13 TeV energy increase, no obvious new physics at high masses has been discovered so far
  ➡ More luminosity will not add a huge sensitivity improvement for the straightforward high-mass searches

• Looking beyond means new techniques, new ideas, and increased precision in the Standard Model measurements to look for deviations

https://hilumilhc.web.cern.ch/about/hl-lhc-project
Looking Ahead - TCC jets

- **Track-CalorCluster for jet substructure**
  - Correlates low-level objects (tracks, calorimeter energy deposits) before running jet algorithms
    - Different to ATLAS Particle Flow approach, which subtracts charged hadrons energy deposits
  - Improved resolution for substructure variables
Summary and Outlook

• Wide programme of searches for high mass resonances at ATLAS
  ➡ Probe beyond the Standard Model frontiers at multi-TeV scale
  ➡ Many more exciting analysis not covered here, please check the ATLAS public pages

• Even higher masses and lower couplings to be probed by the end of Run 2
  ➡ Expected luminosity $\sim 120 \text{ fb}^{-1}$ at 13 TeV centre-of-mass energy
  ➡ Improvements in object reconstruction (TCC jets, new b-tag algorithms,...) and analysis techniques (machine learning, reweighting,...)

• Stay tuned for what the next years are going to unveil!