Diboson Resonance Searches at ATLAS

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Diboson searches using full Run-2 ATLAS dataset, 139 fb$^{-1}$

- Search for diboson resonances in hadronic final states
  - arxiv link: 1906.08589

- Search for heavy diboson resonances in semi-leptonic final states
  - arxiv link: 2004.14636

- Search for the $HH \rightarrow b\bar{b}b\bar{b}$ process via vector-boson fusion production
  - arxiv link: 2001.05178
Search for diboson resonances in hadronic final states in $139 \text{ fb}^{-1}$ of $p p$ collisions at $\sqrt{s} = 13 \text{ TeV}$ with the ATLAS detector

The ATLAS Collaboration

Search for heavy diboson resonances in semileptonic final states in $p p$ collisions at $\sqrt{s} = 13 \text{ TeV}$ with the ATLAS detector

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VV hadronic and semi-leptonic Searches

- **VV** = WW, WZ or ZZ
  - \( V_h \rightarrow \) large-R jet (merged) or 2 small-R jets (resolved)
  - \( V_\ell \rightarrow \nu\nu, \ell\nu, \text{ or } \ell\ell \)

- Hadronic - \( V_h V_h \) (merged)
- Semi-leptonic - \( V_\ell V_h \)

- 3 production mechanisms, depending on final state
  - gluon-gluon fusion
  - Drell-Yan
  - vector boson fusion

- 3 benchmark models, depending on final state
  - Spin-0 radion (Randall-Sundrum)
  - Spin-1 vector (Heavy Vector Triplet)
  - Spin-2 graviton (Randall-Sundrum)
Hadronic Boson Identification

- Track-CaloCluster (TCC) jets improve substructure resolution
  - Use angular information from tracks and energy scale from calorimeter

- Dedicated W/Z taggers provide background discrimination
  - Tighter cuts at low \( p_T \), where background is highest

- Hadronic search
  - Cuts on mass, \( D_2 \), number of tracks

- Semi-leptonic search
  - Mass cut identifies boson candidates
  - \( D_2 \) separates high-purity, low-purity regions
VV Hadronic Background Estimation

- Fully hadronic final state
- Dominant background from QCD
  - Estimated entirely from data
- Parametric fit to $m_{JJ}$ spectrum
  - $\frac{dn}{dx} = p_1(1-x)^{p_2-\xi p_3} x^{-p_3}$, where $x \equiv \frac{m_{JJ}}{13\text{TeV}}$
  - $\xi$ chosen to minimise correlation between $p_2$ and $p_3$

- Fit validated using untagged data
- Distribution reweighted to match tagged data
- Mapping C$\rightarrow$A allows estimate of signal region B from D
VV Hadronic Results

- No significant excess found
- Search sets limits on benchmark models

Limits for different radion masses

<table>
<thead>
<tr>
<th>Mass [TeV]</th>
<th>Observed Limit [fb]</th>
<th>Expected Limit [fb]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>5.72</td>
<td>5.75</td>
</tr>
<tr>
<td>3.0</td>
<td>1.86</td>
<td>2.85</td>
</tr>
<tr>
<td>4.0</td>
<td>1.98</td>
<td>2.34</td>
</tr>
<tr>
<td>5.0</td>
<td>1.98</td>
<td>2.02</td>
</tr>
</tbody>
</table>
Semileptonic search has 40 total signal regions
- 0, 1 or 2 electrons/muons
- VBF or ggF/DY production
- merged or resolved $V_h$
- merged region split into high/low-purity
- ggF/DY $Z \rightarrow qq$ candidates split into $b$-tagged/untagged

Recursive Neural Network trained to separate VBF signal from ggF/DY
- Uses jets not part of $V_h$ reconstruction
- $D_2$ cut defines high/low-purity regions
- Multivariate $b$-tagging algorithm creates low-background tagged regions
VV Semi-leptonic Backgrounds

- V+jets dominates background in most regions
- Control region measurements constrain V+jets, $t\bar{t}$ backgrounds
- In 0-lepton channel transverse mass used instead of invariant mass
  \[ m_T = \sqrt{(p_T^J + E_T^{\text{miss}})^2 - (\vec{p}_T^J + \vec{E}_T^{\text{miss}})^2} \]
VV Semi-leptonic Results

- No significant excess found
- Search sets limits on benchmark models for each production mode

<table>
<thead>
<tr>
<th>Production process</th>
<th>Radion</th>
<th>HVT $W'$</th>
<th>$Z'$</th>
<th>Graviton</th>
</tr>
</thead>
<tbody>
<tr>
<td>ggF/DY</td>
<td>3.2 (2.9)</td>
<td>3.9 (3.8)</td>
<td>3.5 (3.4)</td>
<td>2.0 (2.2)</td>
</tr>
<tr>
<td>VBF</td>
<td>–</td>
<td>Model C</td>
<td>–</td>
<td>0.76 (0.77)</td>
</tr>
</tbody>
</table>
Search for the $HH \rightarrow b\bar{b}b\bar{b}$ process via vector-boson fusion production using proton–proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

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Dedicated search for VBF production
- Uniquely sensitive to $\kappa_{2\nu}$

Fully hadronic final state
- $H \rightarrow b\bar{b}$ branching ratio $\sim 58\%$
- Multijet background dominates

Resolved analysis
- 4 $b$-tagged central jets form Higgs candidates
- 2 forward jets from VBF process

Multivariate $b$-tagging algorithm suppresses QCD background
- Uses tracks associated to jet to look for signs of long-lived $b$-hadron decays
- Cut applied has 70% tagging efficiency, 0.3% light mis-tag rate

2 scalar resonance models considered
- Broad, $\Gamma/m_X \sim 10 - 20\%$
- Narrow, $\Gamma = 4$ MeV
Background estimated using events with 4 central jets, but only 2 $b$-tags

- 2-tag events weighted to match 4-tag kinematic distributions
- Weights defined in sideband region, away from Higgs peaks

Normalization of multijet and $t\bar{t}$ backgrounds set by sideband fit

Background estimation checked in validation region, between signal and sideband
No significant excess observed

Limits set on scalar resonance models and $\kappa_{2\nu}$
Diboson searches sensitive to many Beyond-the-Standard-Model theories

Improved limits set on Randall Sundrum and Heavy Vector Triplet models, as well as model-independent cross-sections
  - More data and improved techniques allow study of rarer production mechanisms, like vector boson fusion

No significant deviations from SM found
  - Many more results on the way! Stay tuned!

A few of the other ATLAS results being presented later today:
  - Beyond exclusive leptonic resonances (coming up next!)
  - Searches for resonances in hadronic final states
  - Searches for BSM Higgs
  - Measurements of inclusive multi-boson production
Backup
**VV semi-leptonic**

- Events categorized by number of leptons, production mechanism, merged/resolved
- RNN trained to separate VBF signal from ggF/DY
Backup

VV semi-leptonic

\begin{align*}
\text{ATLAS} & \quad \text{$s=13$ TeV, 139 fb}^{-1} \\
\sigma_{ggF} (pp \rightarrow R+VV) & \quad \text{[pb]} \\
\text{Observed 95\% CL} & \quad \text{Expected 95\% CL} \\
\text{Expected \pm 1\sigma} & \quad \text{Expected \pm 2\sigma} \\
\text{Bulk RS Radion} & \quad \text{2lep Expected 95\% CL} \\
\text{1lep Expected 95\% CL} & \quad \text{0lep Expected 95\% CL} \\
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