Search for Dilepton Resonances

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On behalf of the ATLAS Collaboration

Moriond EW 2019

$m_{\mu\mu} = 2.75\text{ TeV}$

$m_{ee} = 4.06\text{ TeV}$
Highest Mass // Events
2015-2018

$m_{\mu\mu} = 2.75$ TeV

$m_{ee} = 4.06$ TeV
Dilepton Resonant Search

- First ATLAS Run-2 result (139 fb$^{-1}$)!
- Search in $m_{ee}$, $m_{\mu\mu}$ spectra for a new resonance

Event Selection

- Two same flavor leptons $225 < m_{ll} < 6000$ GeV

Background

- Fit parametric function to data to model background - new in this analysis
- $f(m_{ll}) = a \cdot f_{BW,Z}(m_{ll}) \cdot (1 - x^c)^b \cdot x \sum_{i=0}^{3} p_i \log^i(x)$

Generic Signal

- Non-Relativistic BW $\otimes (\text{Gaus} + \text{CB})$, parameterized by pole mass and width
- Fiducial region ($m_{ll}^{\text{true}} > m_X - 2\Gamma_X$, $|\eta_{ll}| < 2.5$, $p_{T,\text{ll}} > 30$ GeV) used to obtain generic limits for a hypothetical $X$
Compatibility with background only hypothesis has been tested

0-width significance

Local significance for 0-width resonance

Largest excess: 264 GeV (2.3 local, ≈ 0 global significance)

Other widths

Combination of ee and µµ channels

Measured local significance as a function of pole mass ($m_X$) and signal width ($\Gamma_X/m_X$)
Model-independent limits are calculated for various width assumptions of signal shape

- Limits are re-interpretable to various models
- Limits are used to constrain HVT couplings (see backup)
Limits

- Model-independent limits are calculated for various width assumptions of signal shape
- Limits are re-interpretable to various models
- Limits are used to constrain HVT couplings (see backup)
First ATLAS full Run-2 result

Limits are interpretable for various models - there’s a framework to make it easy!

Link to full paper CERN-EP-2019-030
First ATLAS full Run-2 result

- Limits are interpretable for various models - there’s a framework to make it easy!
Backup
Dilepton Resonant Search

- Search in $m_{ee}$, $m_{\mu\mu}$ spectra for a new resonance
- Benchmark models for spin 0,1,2 resonances:
  - $Z'_\text{SSM}$, $Z'_\psi$, or $Z'_X$ from additional U(1) symmetry
  - $Z'_\text{HVT}$, from additional SU(2) symmetry
  - MSSM Scalar $H \rightarrow ll$
  - RS Graviton

Event Selection

- Two same flavor leptons
- Highest $E_T (p_T)$ $ee$ ($\mu\mu$) pair, favoring $ee$ over $\mu\mu$
- $225 < m_{ll} < 6000$ GeV

Background

- Fit parametric function to data to model background - new in this analysis
  \[ a \cdot f_{\text{BW},Z}(m_{ll}) \cdot (1 - x^c)^b \cdot x^{\sum_{i=0}^{3} p_i \log^i(x)} \]
  - $f_{\text{BW},Z}(m_{ll})$ is Breit-Wigner shape
  - $c=m_{ll}/\sqrt{s}$
  - $c=1/3$ (1) for $ee(\mu\mu)$
  - $a,b,p_i$ are determined by a fit

Generic Signal

- Non-Relativistic BW $\otimes (\text{Gaus}+\text{CB})$, parameterized by pole mass and width
- The Breit-Wigner models the physical width of the particle
- The gaussian+crystal ball models detector resolution, determined by MC ($\frac{m_{ll}^{\text{reco}}-m_{ll}^{\text{truth}}}{m_{ll}^{\text{truth}}}$)

- Fiducial region ($m_{Y}^{\text{true}} > m_X - 2\Gamma_X$, $|\eta_\ell| < 2.5$, $p_T^{\ell} > 30$ GeV) used to
Event Selection

At least one $pp$ interaction vertex is reconstructed

Primary vertex: highest $\sum p_T^2$ using tracks with $p_T > 0.5$ GeV

Electrons

- $E_T > 30$ GeV
- $|\eta| < 1.37$ or $|\eta| > 1.52$
- medium ID (93% efficient for $E_T > 80$ GeV)

Muons

- $p_T > 30$ GeV
- $|\eta| < 2.5$
- high-pt ID: three hits required in MS, some veto areas (69% $\eta$ averaged efficiency at 1 TeV)

- good muon selection: $q/p$ uncertainty passes $p_T$-dependent threshold

- $|z_0 \sin(\theta)| < 0.5$ mm constraint on the longitudinal impact parameter
- $|d_0/\sigma(d_0)| < 5(3)$ for $e(\mu)$ constraint on the traverse impact parameter

- Both $e$ and $\mu$ pass a 99% efficient isolation requirement

Event selection

- Must have two same-flavor leptons
- If additional leptons, pick same-flavor pair with largest $E_T$ ($p_T$) for $ee$ ($\mu\mu$)
- If two different flavors are found, $ee$ is used because of the better resolution
- For dimuon pairs, an opposite charge requirement is applied
**Data & MC**

### Data

**Used for:**
- Background modeling
- Limit setting

### MC

**Used for:**
- Testing background function
- Measuring resolution, acceptance
- Interpreting limits to a particular signal model/width

### Samples:

<table>
<thead>
<tr>
<th>Background Process</th>
<th>ME Generator and ME PDFs</th>
<th>PS and non-perturbative effect with PDFs</th>
</tr>
</thead>
<tbody>
<tr>
<td>NLO Drell–Yan</td>
<td>POWHEG-BOX [21,22, CT10 [23], PHOTOS</td>
<td>PYTHIA v8.186 [24], CTEQ6L1 [25,26], EvtGen1.2.0</td>
</tr>
<tr>
<td>$t\bar{t}$</td>
<td>POWHEG-BOX, NNPDF3.0NLO [27]</td>
<td>PYTHIA v8.230, NNPDF23LO [28], EvtGen1.6.0</td>
</tr>
<tr>
<td>Single top s-channel, $Wt$</td>
<td>POWHEG-BOX, NNPDF3.0NLO</td>
<td>PYTHIA v8.230, NNPDF23LO, EvtGen1.6.0</td>
</tr>
<tr>
<td>Single top t-channel</td>
<td>POWHEG-BOX, NNPDF3.04fNLO, MadSpin</td>
<td>PYTHIA v8.230, NNPDF23LO, EvtGen1.6.0</td>
</tr>
<tr>
<td>Diboson (WW, WZ and ZZ)</td>
<td>SHERPA 2.1.1 [29], CT10</td>
<td>SHERPA 2.1.1, CT10</td>
</tr>
</tbody>
</table>

<table>
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<th>Signal Process</th>
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<tr>
<td>LO Drell–Yan</td>
<td>PYTHIA v8.186, NNPDF23LO</td>
<td>PYTHIA v8.186, NNPDF23LO, EvtGen1.2.0</td>
</tr>
<tr>
<td>Randall–Sundrum $G^* \rightarrow \ell\ell$</td>
<td>PYTHIA v8.210, NNPDF23LO</td>
<td>PYTHIA v8.210, NNPDF23LO, EvtGen1.2.0</td>
</tr>
<tr>
<td>MSSM $gg \rightarrow H \rightarrow \ell\ell$</td>
<td>POWHEG-BOX, CT10</td>
<td>PYTHIA v8.212, CTEQ6L1, EvtGen1.2.0</td>
</tr>
</tbody>
</table>

March 16, 2019
Aaron White - University of Michigan
## Uncertainties

<table>
<thead>
<tr>
<th>Uncertainty source per channel</th>
<th>dielectron</th>
<th>dimuon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spurious signal for zero-width [events]</td>
<td>46 – 0.001</td>
<td>44 – 0.03</td>
</tr>
<tr>
<td>Spurious signal for 10% relative width [events]</td>
<td>146 – 0.006</td>
<td>122 – 0.04</td>
</tr>
<tr>
<td>Identification [% of $\epsilon$]</td>
<td>1 – 6</td>
<td>1 – 31</td>
</tr>
<tr>
<td>Isolation [% of $\epsilon$]</td>
<td>0.3 – 1.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Good muon requirement [% of $\epsilon$]</td>
<td>-</td>
<td>1 – 52</td>
</tr>
<tr>
<td>Luminosity [%]</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Energy scale [% of $\mu_G$]</td>
<td>0.4 – 0.7</td>
<td>-</td>
</tr>
<tr>
<td>Energy scale [% of $\mu_{CB}$]</td>
<td>$^{+0.5}_{-0.6}$ – 1.2</td>
<td>-</td>
</tr>
<tr>
<td>Electron energy resolution [% of $\sigma_G$]</td>
<td>$^{+17}<em>{-14}$ – $^{+68}</em>{-38}$</td>
<td>-</td>
</tr>
<tr>
<td>Electron energy resolution [% of $\sigma_{CB}$]</td>
<td>8 – $^{+17}_{-27}$</td>
<td>-</td>
</tr>
<tr>
<td>Muon ID (MS) resolution [% of $\sigma_G$]</td>
<td>-</td>
<td>$^{+1}<em>{-3}$ – 1 ($^{+4}</em>{-5}$ – 6)</td>
</tr>
<tr>
<td>Muon ID (MS) resolution [% of $\sigma_{CB}$]</td>
<td>-</td>
<td>$^{+0}<em>{-4}$ – $^{+3}</em>{-1}$ ($2$ – $^{+8}_{-9}$)</td>
</tr>
</tbody>
</table>
HVT Exclusion

- Limits on heavy vector triplet couplings
- HVT bosons can couple to fermions (f), leptons (l), and Higgs (h)
- Area outside of curves is excluded
- Single channel limits are approaching the strength of the 36 fb$^{-1}$ \( ll/ll \nu \) combination
Comparison

### New limit

**Channel**

<table>
<thead>
<tr>
<th>Channel</th>
<th>Excess</th>
<th>Deficit</th>
</tr>
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<tbody>
<tr>
<td>$ee$</td>
<td>$p_0$ $\sigma$ = 3.0, $m_X$ = 773 GeV, $\Gamma_X/m_X$ = 2.5%</td>
<td>$p_0$ $\sigma$ = -3.2, $m_X$ = 1957 GeV, $\Gamma_X/m_X$ = 4.0%</td>
</tr>
<tr>
<td>$\mu\mu$</td>
<td>$p_0$ $\sigma$ = 2.5, $m_X$ = 268 GeV, $\Gamma_X/m_X$ = 2.5%</td>
<td>$p_0$ $\sigma$ = -2.8, $m_X$ = 349 GeV, $\Gamma_X/m_X$ = 8.5%</td>
</tr>
<tr>
<td>$ll$</td>
<td>$p_0$ $\sigma$ = 2.3, $m_X$ = 264 GeV, $\Gamma_X/m_X$ = 0%</td>
<td>$p_0$ $\sigma$ = -2.9, $m_X$ = 1958 GeV, $\Gamma_X/m_X$ = 3.0%</td>
</tr>
</tbody>
</table>

### Old Limit

**link to paper**