Higgs properties measurement through $H \rightarrow ZZ^* \rightarrow 4l$ with the ATLAS Detector

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Higgs Productions and Decays

- ggH, ttH, bbH – Yukawa coupling
- VBF, VH – Gauge coupling

### Higgs Productions (NNLO QCD and NLO EW)

<table>
<thead>
<tr>
<th>Higgs Production</th>
<th>Cross section (pb) (\sqrt{s} = 8) TeV</th>
<th>Cross section (pb) (\sqrt{s} = 13) TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>ggF</td>
<td>19.27</td>
<td>48.5</td>
</tr>
<tr>
<td>VBF</td>
<td>1.58</td>
<td>3.78</td>
</tr>
<tr>
<td>WH</td>
<td>0.70</td>
<td>1.37</td>
</tr>
<tr>
<td>ZH</td>
<td>0.42</td>
<td>0.88</td>
</tr>
<tr>
<td>ttH</td>
<td>0.13</td>
<td>0.51</td>
</tr>
<tr>
<td>bbH</td>
<td>0.20</td>
<td>0.49</td>
</tr>
<tr>
<td>Total</td>
<td>22.30</td>
<td>55.53</td>
</tr>
</tbody>
</table>

Decay mode | Branching fraction [%]
---|---------------------
\(H \rightarrow bb\) | 57.5 ± 1.9
\(H \rightarrow WW\) | 21.6 ± 0.9
\(H \rightarrow gg\) | 8.56 ± 0.86
\(H \rightarrow \tau\tau\) | 6.30 ± 0.36
\(H \rightarrow cc\) | 2.90 ± 0.35
\(H \rightarrow ZZ\) | 2.67 ± 0.11
\(H \rightarrow \gamma\gamma\) | 0.228 ± 0.011
\(H \rightarrow Z\gamma\) | 0.155 ± 0.014
\(H \rightarrow \mu\mu\) | 0.022 ± 0.001
Higgs $\rightarrow$ ZZ* $\rightarrow$ 4$\ell$ Analysis

- Extremely clean – “Gold-plated” channel
  - Fully reconstructed final states
  - Good mass resolution ($\sim$ 1.6-2.4 GeV)
  - High S/B ratio ($\sim$ 2.2-2.4)
  - Low decay branching fraction (2.67%)

- Properties measurement
  - Higgs mass, width, spin, parity
  - Total and differential cross section
  - Couplings
Higgs $\rightarrow$ ZZ* $\rightarrow$ 4$\ell$ Selections

- Trigger match with single and/or di-lepton trigger
- **Four sub-channels:** 4e, 2e2$\mu$, 2$\mu$2e, 4$\mu$

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**Leptons and Jets requirements**

**Electrons**
- Loose Likelihood quality electrons with hit in innermost layer, $E_T > 7\text{GeV}$ and $|\eta| < 2.47$

**Muons**
- Loose identification $|\eta| < 2.7$
- Calo-tagged muons with $p_T > 15\text{ GeV}$ and $|\eta| < 0.1$
- Combined, stand-alone (with ID hits if available) and segment tagged muons with $p_T > 5\text{ GeV}$

**Jets**
- anti-$k_T$ jets with $p_T > 30\text{GeV}$, $|\eta| < 4.5$ and passing pile-up jet rejection requirements

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**Event Selection**

**QUADRUPLET SELECTION**
- Require at least one quadruplet of leptons consisting of two pairs of same flavour opposite-charge leptons fulfilling the following requirements:
- $p_T$ thresholds for three leading leptons in the quadruplet - 20, 15 and 10$\text{GeV}$
- Maximum of one calor-tagged or standalone muon per quadruplet
- Select best quadruplet to be the one with the (sub)leading dilepton mass (second) closest the $Z$ mass
- Leading dilepton mass requirement: $50\text{ GeV} < m_{12} < 106\text{ GeV}$
- Sub-leading dilepton mass requirement: $12 < m_{34} < 115\text{ GeV}$
- Remove quadruplet if alternative same-flavour opposite-charge dilepton gives $m_{\ell\ell} < 5\text{ GeV}$
- $\Delta R(\ell, \ell') > 0.10$ (0.20) for all same(different)-flavour leptons in the quadruplet

**ISOLATION**
- Contribution from the other leptons of the quadruplet is subtracted
- Muon track isolation ($\Delta R \leq 0.30$): $\Sigma p_T / p_T < 0.15$
- Muon calorimeter isolation ($\Delta R = 0.20$): $\Sigma E_T / p_T < 0.30$
- Electron track isolation ($\Delta R \leq 0.20$): $\Sigma E_T / E_T < 0.15$
- Electron calorimeter isolation ($\Delta R = 0.20$): $\Sigma E_T / E_T < 0.20$

**IMPACT PARAMETER SIGNIFICANCE**
- Apply impact parameter significance cut to all leptons of the quadruplet.
  - For electrons: $|d_0 / \sigma_{d_0}| < 5$
  - For muons: $|d_0 / \sigma_{d_0}| < 3$

**VERTEX SELECTION**
- Require a common vertex for the leptons
- $\chi^2/\text{ndof} < 6$ for 4$\mu$ and < 9 for others.
Estimated Backgrounds in Control Regions

- Main background is ZZ: estimated from MC simulation, scaled to theoretical xsection
- Reducible backgrounds: Zbb, Z+light jets, ttbar, using data-driven method

- Estimates agree with data in control regions where isolated & d0 requirements are removed for subleading pairs. Estimated background using data-driven methods by extrapolating to signal region using extrapolation factors.

<table>
<thead>
<tr>
<th>Background</th>
<th>Fit yield in CR</th>
<th>Extrapolation factor [%]</th>
<th>Yield in SR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z+heavy-flavour jets</td>
<td>348 ± 29</td>
<td>(0.60 ± 0.04)</td>
<td>2.10 ± 0.17 ± 0.13</td>
</tr>
<tr>
<td>tt</td>
<td>351 ± 14</td>
<td>(0.21 ± 0.03)</td>
<td>0.74 ± 0.03 ± 0.00</td>
</tr>
<tr>
<td>Z+light-flavour jets</td>
<td>10 ± 15</td>
<td>(2.3 ± 0.3)</td>
<td>0.24 ± 0.35 ± 0.03</td>
</tr>
<tr>
<td>WZ (MC-based estimation)</td>
<td></td>
<td></td>
<td>0.63 ± 0.31</td>
</tr>
</tbody>
</table>
H → ZZ* → 4ℓ Events

### Results

**Observed 10σ**

**Expected 8.6σ**

<table>
<thead>
<tr>
<th>Final State</th>
<th>Signal</th>
<th>Signal</th>
<th>ZZ*</th>
<th>Z + jets, tt</th>
<th>S/B</th>
<th>Expected</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>full mass range</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4μ</td>
<td>8.8 ± 0.6</td>
<td>8.2 ± 0.6</td>
<td>3.11 ± 0.30</td>
<td>0.31 ± 0.04</td>
<td>2.4</td>
<td>11.6 ± 0.7</td>
<td>16</td>
</tr>
<tr>
<td>2e2μ</td>
<td>6.1 ± 0.4</td>
<td>5.5 ± 0.4</td>
<td>2.19 ± 0.21</td>
<td>0.30 ± 0.04</td>
<td>2.2</td>
<td>8.0 ± 0.4</td>
<td>12</td>
</tr>
<tr>
<td>2μ2e</td>
<td>4.8 ± 0.4</td>
<td>4.4 ± 0.4</td>
<td>1.39 ± 0.16</td>
<td>0.47 ± 0.05</td>
<td>2.3</td>
<td>6.2 ± 0.4</td>
<td>10</td>
</tr>
<tr>
<td>4e</td>
<td>4.8 ± 0.5</td>
<td>4.2 ± 0.4</td>
<td>1.46 ± 0.18</td>
<td>0.46 ± 0.05</td>
<td>2.2</td>
<td>6.1 ± 0.4</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>24.5 ± 1.8</td>
<td>22.3 ± 1.6</td>
<td>8.2 ± 0.8</td>
<td>1.54 ± 0.18</td>
<td>2.3</td>
<td>32.0 ± 1.8</td>
<td>44</td>
</tr>
</tbody>
</table>
Analysis Strategy

ATLAS-CONF-2016-079

**m_{4\ell} [118-129] GeV**

- \( p_{T,j} > 30 \text{ GeV} \)
- 2 or more jets

- \( \geq 1 \) leptons (\( p_{T,\ell} > 8 \text{ GeV} \))
- 0jet
- 1jet
- \( m_{jj} < 120 \text{ GeV} \)
- \( m_{jj} > 120 \text{ GeV} \)

**Discriminant BDT-ZZ**
- BDT\_ZZ:
  - \( p_{T,\ell} \)
  - \( \eta_{\ell} \)
  - KD = log(ME_{HZZ}/ME_{ZZ})

**Discriminant BDT-1j**
- BDT\_1jet:
  - \( p_{T,j} \)
  - \( \eta_j \)
  - \( \Delta R_{4\ell} \)

**Discriminant BDT-2jVH**
- BDT\_2jet\_VH:
  - \( p_{T,j1} \)
  - \( p_{T,j2} \)
  - \( \eta_{j1} \)
  - \( \eta_{j2} \)
  - \( \Delta \eta_{jj} \)
  - \( \Delta R_{4\ell} \)
  - \( m_{jj} \)
  - min(\Delta R_{4\ell})

**Discriminant BDT-2jVBF**
- BDT\_2jet\_VBF:
  - \( p_{T,j1} \)
  - \( p_{T,j2} \)
  - \( p_{T,4\ell} \)
  - \( \Delta \eta_{jj} \)
  - \( \Delta R_{4\ell} \)
  - \( m_{jj} \)
  - min(\Delta R_{4\ell})

**Just counting**

**Dec.17, 2016**

H. Yang - Higgs->ZZ*->4l Properties Measurement
Higgs $\rightarrow$ ZZ* $\rightarrow$ 4$\ell$ BDT Outputs

BDT-ZZ: HZZ vs ZZ

BDT-1j: ggF vs VBF

BDT-2jVBF: ggF vs VBF

BDT-2jVH: ggF vs VH
Higgs→ZZ*→4ℓ Cross Section

Total and fiducial cross section measurement.

\[ \sigma^\text{tot} = \frac{N_S}{A \cdot C \cdot B \cdot L_{\text{int}}} \]
\[ \sigma^\text{fid}_{4\ell} = \frac{N_S}{C \cdot L_{\text{int}}} \]

Lepton definition

<table>
<thead>
<tr>
<th>Muons:</th>
<th>Electrons:</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p_T &gt; 6 \text{ GeV},</td>
<td>\eta</td>
</tr>
</tbody>
</table>

Pairing

- Leading pair: SFOS lepton pair with smallest \( |m_Z - m_{\ell\ell}| \)
- Sub-leading pair: Remaining SFOS lepton pair with smallest \( |m_Z - m_{\ell\ell}| \)

Event selection

- Lepton kinematics: Leading lepton \( p_T > 20, 15, 10 \text{ GeV} \)
- Mass requirements: \( 50 < m_{12} < 106 \text{ GeV}; 12 < m_{34} < 115 \text{ GeV} \)
- Lepton separation: \( \Delta R(\ell_i, \ell_j) > 0.1(0.2) \) for same (opposite) flavour leptons
- \( J/\psi \) veto: \( m(\ell_i, \ell_j) > 5 \text{ GeV} \) for all SFOS lepton pairs
- Mass window: \( 118 < m_{4\ell} < 129 \text{ GeV} \)

<table>
<thead>
<tr>
<th>Final state</th>
<th>measured ( \sigma^\text{fid}_{4\ell} ) [fb]</th>
<th>( \sigma^\text{fid,SM}_{4\ell} ) [fb]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4µ</td>
<td>1.28 ±0.48 +0.40</td>
<td>0.93 ±0.06 +0.06</td>
</tr>
<tr>
<td>4e</td>
<td>0.81 ±0.51 +0.51</td>
<td>0.73 ±0.05 +0.05</td>
</tr>
<tr>
<td>2µ2e</td>
<td>1.29 ±0.58 +0.58</td>
<td>0.67 ±0.04 +0.04</td>
</tr>
<tr>
<td>2e2µ</td>
<td>1.10 ±0.49 +0.49</td>
<td>0.76 ±0.05 +0.05</td>
</tr>
</tbody>
</table>

\[ \sigma^4\ell_{\text{fid,comb}} = 4.54^{+1.02}_{-0.90} \text{ fb} \]
\[ \sigma^4\ell_{\text{fid,sum}} = 4.48^{+1.01}_{-0.89} \text{ fb} \]
Total and fiducial cross section measurement at 13 TeV.

\[ \sigma_{\text{fid,comb}}^{4\ell} = 4.54^{+1.02}_{-0.90} \text{ fb} \]

\[ \sigma_{\text{fid,SM}}^{4\ell} = 3.07^{+0.21}_{-0.25} \text{ fb} \]

\[ \sigma_{\text{tot}} = 81^{+18}_{-16} \text{ pb} \]

\[ \sigma_{\text{tot,SM}} = 55.5^{+3.8}_{-4.4} \text{ pb} \]
The universal coupling strength scale factors:
- $K_F$ for all fermions
- $K_V$ for all vector bosons.

The $H \rightarrow ZZ^* \rightarrow 4\ell$ channel is not sensitive to the $K_F$ and relative sign of the two couplings, only a quadrant is shown in $K_V$-$K_F$ plane.

Assume SM Higgs with mass of 125 GeV, the fitted coupling scale factors are compatible with the SM predictions.
Higgs $\rightarrow$ ZZ* $\rightarrow$ 4$\ell$ Production Modes

Compatiblity between measured cross section and SM prediction is:
- 1.1$\sigma$ for ggF+bbH+ttH
- 1.4$\sigma$ for VBF+VH
Combining $\gamma\gamma$ and ZZ final states

The compatibility between measurement and SM prediction corresponds to a p-value of 21%.

<table>
<thead>
<tr>
<th></th>
<th>Best fit value (pb)</th>
<th>SM prediction (pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_{ggF}$</td>
<td>$47.8^{+9.8}_{-9.4}$</td>
<td>$44.5 \pm 2.3$</td>
</tr>
<tr>
<td>$\sigma_{VBF}$</td>
<td>$7.9^{+2.8}_{-2.4}$</td>
<td>$3.52 \pm 0.07$</td>
</tr>
<tr>
<td>$\sigma_{VH_{had}}$</td>
<td>$-2.5^{+2.9}_{-2.6}$</td>
<td>$1.36 \pm 0.03$</td>
</tr>
<tr>
<td>$\sigma_{VH_{lep}}$</td>
<td>$0.32^{+1.07}_{-0.79}$</td>
<td>$0.64 \pm 0.02$</td>
</tr>
<tr>
<td>$\sigma_{top}$</td>
<td>$-0.11^{+0.67}_{-0.54}$</td>
<td>$0.60 \pm 0.06$</td>
</tr>
</tbody>
</table>

**ATLAS-CONF-2016-081**
The compatibility between the measurement and SM prediction corresponds to a p-value of 11%.
The compatibility between measurement and SM prediction corresponds to a p-value of 43%.

The global signal strength is measured to be:

The local significance of Higgs boson is $10\sigma$ (exp: $8.6\sigma$)
Search for BSM Higgs

- Limits on the BSM parameters $K_{HVV}$, $K_{AVV}$, $\sin\alpha$ are derived with a fit of yields in different categories.

- $K_{SM}$ which scales SM interactions is fixed to unity. ggF production is fixed to SM value, but $Br(H\rightarrow ZZ^*)$ and BSM couplings are free parameters.

<table>
<thead>
<tr>
<th>Analysis category</th>
<th>Signal $ggF + bbH + t\bar{t}H$</th>
<th>VBF</th>
<th>WH</th>
<th>ZH</th>
<th>$ZZ^*$</th>
<th>$Z + \text{jets}, \bar{t}$</th>
<th>Total</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0$-jet</td>
<td>11.2 ± 1.4</td>
<td>0.120 ± 0.019</td>
<td>0.047 ± 0.007</td>
<td>0.060 ± 0.006</td>
<td>6.2 ± 0.6</td>
<td>0.84 ± 0.12</td>
<td>18.4 ± 1.6</td>
<td>21</td>
</tr>
<tr>
<td>$1$-jet</td>
<td>5.7 ± 2.4</td>
<td>0.59 ± 0.05</td>
<td>0.137 ± 0.012</td>
<td>0.091 ± 0.008</td>
<td>1.62 ± 0.21</td>
<td>0.44 ± 0.07</td>
<td>8.5 ± 2.4</td>
<td>12</td>
</tr>
<tr>
<td>2-jet VBF enriched</td>
<td>1.9 ± 0.9</td>
<td>0.92 ± 0.07</td>
<td>0.074 ± 0.007</td>
<td>0.052 ± 0.005</td>
<td>0.22 ± 0.05</td>
<td>0.24 ± 0.11</td>
<td>3.4 ± 0.9</td>
<td>9</td>
</tr>
<tr>
<td>2-jet VH enriched</td>
<td>1.1 ± 0.5</td>
<td>0.084 ± 0.009</td>
<td>0.143 ± 0.012</td>
<td>0.101 ± 0.009</td>
<td>0.166 ± 0.035</td>
<td>0.088 ± 0.011</td>
<td>1.6 ± 0.5</td>
<td>2</td>
</tr>
<tr>
<td>VH-leptonic</td>
<td>0.055 ± 0.004</td>
<td>&lt; 0.01</td>
<td>0.067 ± 0.004</td>
<td>0.011 ± 0.001</td>
<td>0.016 ± 0.002</td>
<td>0.012 ± 0.010</td>
<td>0.16 ± 0.01</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>20 ± 4</td>
<td>1.71 ± 0.14</td>
<td>0.47 ± 0.04</td>
<td>0.315 ± 0.027</td>
<td>8.2 ± 0.9</td>
<td>1.62 ± 0.07</td>
<td>32 ± 4</td>
<td>44</td>
</tr>
</tbody>
</table>
Search for Heavy Higgs

<table>
<thead>
<tr>
<th>Final state</th>
<th>ZZ*</th>
<th>Z + jets, t\bar{t}, WZ</th>
<th>t\bar{t}V, VVV</th>
<th>Expected</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>4\mu ggF-enriched</td>
<td>125 ± 10</td>
<td>0.95 ± 0.14</td>
<td>1.57 ± 0.09</td>
<td>127 ± 10</td>
<td>128</td>
</tr>
<tr>
<td>2e2\mu ggF-enriched</td>
<td>205 ± 17</td>
<td>2.5 ± 0.4</td>
<td>2.75 ± 0.17</td>
<td>211 ± 17</td>
<td>199</td>
</tr>
<tr>
<td>4e ggF-enriched</td>
<td>83 ± 7</td>
<td>1.47 ± 0.22</td>
<td>1.28 ± 0.08</td>
<td>86 ± 7</td>
<td>111</td>
</tr>
<tr>
<td>VBF-enriched</td>
<td>4.6 ± 2.8</td>
<td>0.18 ± 0.05</td>
<td>0.268 ± 0.016</td>
<td>5.1 ± 2.8</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>418 ± 35</td>
<td>5.1 ± 0.7</td>
<td>5.87 ± 0.35</td>
<td>429 ± 35</td>
<td>448</td>
</tr>
</tbody>
</table>
Search for Heavy Higgs

- BSM: two Higgs doublet model (2HDM); Electroweak singlet model (EWS)
- The maximum deviation from SM bkgd is found at a mass $\sim 705$ GeV with NWA, the global p-value is $\sim 1.9\sigma$.
- No significant excess has been observed.
Analysis using full datasets is still ongoing, please stay tuned!

Thank you!
Combined Higgs Mass

**ATLAS + CMS: PRL114 (2015) 191803**

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Channel</th>
<th>Total</th>
<th>Stat. (±)</th>
<th>Syst. (±)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ATLAS</strong></td>
<td>$H \rightarrow \gamma\gamma$</td>
<td>126.02 ± 0.51</td>
<td>± 0.43 ± 0.27</td>
<td></td>
</tr>
<tr>
<td><strong>CMS</strong></td>
<td>$H \rightarrow \gamma\gamma$</td>
<td>124.70 ± 0.34</td>
<td>± 0.31 ± 0.15</td>
<td></td>
</tr>
<tr>
<td><strong>ATLAS</strong></td>
<td>$H \rightarrow ZZ \rightarrow 4l$</td>
<td>124.51 ± 0.52</td>
<td>± 0.52 ± 0.04</td>
<td></td>
</tr>
<tr>
<td><strong>CMS</strong></td>
<td>$H \rightarrow ZZ \rightarrow 4l$</td>
<td>125.59 ± 0.45</td>
<td>± 0.42 ± 0.17</td>
<td></td>
</tr>
<tr>
<td><strong>ATLAS+CMS</strong></td>
<td>$\gamma\gamma$</td>
<td>125.07 ± 0.29</td>
<td>± 0.25 ± 0.14</td>
<td></td>
</tr>
<tr>
<td><strong>ATLAS+CMS</strong></td>
<td>$4l$</td>
<td>125.15 ± 0.40</td>
<td>± 0.37 ± 0.15</td>
<td></td>
</tr>
<tr>
<td><strong>ATLAS+CMS</strong></td>
<td>$\gamma\gamma+4l$</td>
<td>125.09 ± 0.24</td>
<td>± 0.21 ± 0.11</td>
<td></td>
</tr>
</tbody>
</table>

- **Higgs mass precision is better than 0.2%**.
- **PRL Editor Suggestion**

Dec.17, 2016  
H. Yang - Higgs→ZZ*→4l Properties Measurement
Higgs Properties Measurement

- Higgs Strength $\mu = 1.09 \pm 0.14$
- Spin/Parity: $0^+$
- Couplings: agree with SM predictions

Results are consistent with the SM!
Coupling scale factors

2-parameter benchmark model:

\[ \kappa_V = \kappa_W = \kappa_Z \]
\[ \kappa_F = \kappa_t = \kappa_b = \kappa_c = \kappa_\tau = \kappa_g \]

(Gluon coupling are related to top, b, and their interference in tree level loop diagrams)

Assume no BSM contributions to loops: \( gg \rightarrow H \) and no BSM decays (no invisible decays)

\[ \kappa_V = 1.09^{+0.07}_{-0.07} \]
\[ \kappa_F = 1.11^{+0.17}_{-0.15} \]

\( \kappa_F = 0 \) is excluded (>5\( \sigma \))

**Higgs Properties Measurement**

Dec.17, 2016

H. Yang - Higgs->ZZ*->4l Properties Measurement
Fermionic & Bosonic production

- Can also fit $\mu_V^f$ vs $\mu_F^f$ per decay:
  - $\mu_V^f = \mu_{VBF+VH}^f$
  - $\mu_F^f = \mu_{ggF+ttH}^f$

- $\mu_V/\mu_f$ can be measured in the different decay channels and combined:
  $$\mu_V/\mu_f = 1.06^{+0.35}_{-0.27}$$
  in agree with SM
The $Z \rightarrow 4\ell$ production was first observed at the LHC by ATLAS and CMS. It serves as a standard candle for $4\ell$ decay channel along the Higgs discovery.

- Cross section and BR measurement of the $Z \rightarrow 4\ell$ production provides
  - A SM test for a rare decay process, measurements of $\sigma(4\ell)$ and $\text{BR}(Z \rightarrow 4\ell)$
  - A complementary test of the detector response for $H \rightarrow 4\ell$ detection

\[
\text{BR}(\text{meas.}) = 3.20 \pm 0.25 \pm 0.13 \times 10^{-6}
\]
\[
\text{BR}(\text{SM NLO}) = 3.33 \pm 0.01 \times 10^{-6}
\]

Z/ZZ → 4l Productions

- Very rich physics: resonant Z→4l, H→ZZ*→4l, SM ZZ→4l
- Differential cross section measurements in m_{4l} and P_T for inclusive 4l (80<m_{4l}<1000 GeV)
- First try to constraint gg→4l contribution from data
- Theoretical predictions available at different level of corrections

**Theoretical Predictions:**
- qq → ZZ: Powheg (NLO)
- on-shell H: Powheg (NLO)
- gg → ZZ: MCFM (LO)
- H → 4l & on-shell qq → ZZ: NNLO QCD + NLO EWK