Mass measurement in $H \rightarrow \gamma\gamma$ in ATLAS

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Higgs Hunting 2013
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Higgs couplings paper: https://cds.cern.ch/record/1559924
Higgs to Diphoton conf. note: https://cds.cern.ch/record/1523698
Introduction

- Higgs discovery in July 2012 $\rightarrow$ ATLAS measures its properties
- $m_H$ is measured in $H \rightarrow \gamma\gamma$ and $ZZ \rightarrow 4l$ channels
- $H \rightarrow \gamma\gamma$ channel has an excellent resolution on $m_H$
  - narrow mass peak
  - 80 (2011, 7TeV) + 395 (2012, 8TeV) expected signal events
• Event selection and categorization
  – 2 tightly identified and isolated photons ($E_T>40/30$ GeV, $|\eta|<2.37$ w/o crack)
  – 10 (7TeV) and 14 (8TeV) categories: better mass determination ~ 10%

• Signal modeling
  – function = CrystalBall + Gaussian
  – mass resolution is 1.6 GeV on average and varies ~ 1 GeV according to photon conversion status and $\eta$ region

• BG modeling
  – BG is obtained from fit to $m_{\gamma\gamma}$ distribution in data
  – function is different for each category (e.g. 4th order Bernstein polynomial for inclusive)

• Profile likelihood
  – likelihood is calculated from (S+B) fit to $m_{\gamma\gamma}$ distribution

$$-2 \ln \lambda(m_H) = -2 \ln \frac{L(m_H, \hat{\mu}, \hat{\theta})}{L(\hat{m}_H, \hat{\mu}, \hat{\theta})}$$

$m_H$: Higgs mass, $\mu$: signal strength (free)
$\theta$: Nuisance Parameters
Red line shows $\text{H} \rightarrow \gamma\gamma$ results

$m_H = 126.8 \pm 0.2 \text{ (stat)} \pm 0.7 \text{ (syst)} \text{ GeV}$

- Statistical uncertainty is smaller than systematic uncertainty
- Dominant systematics sources are photon energy scale uncertainties
- Systematics on the angle reconstruction is small
  - thanks to the MVA based vertex selection using “photon pointing” and tracks

$m_H = 126.8 \pm 0.2 \text{ (stat)} \pm 0.7 \text{ (syst)} \text{ GeV}$

- “Method” 0.4 GeV (next slide)
- “Material” 0.4 GeV (next-to-next slide)
- PreSampler 0.1 GeV Energy scale uncertainty of the presampler
- Other 0.4 GeV e.g. Difference of lateral leakage between electrons and photons, Uncertainty of direction of the photons
Final calorimeter energy scales are obtained from a comparison of \( Z \rightarrow ee \) line-shape between data and MC.

\( Z \rightarrow ee \) line-shape in 2011 data
\((E_T > 25 \text{ GeV}, |\eta| < 2.47)\)

- **Template Method**
  - Correction factors (\( \alpha \)) are applied to data
  - \( \alpha \) is determined such that \( m_{ee} \) shapes in data agree with the MC histograms

\[
E_{\text{Data}}' = \frac{E_{\text{Data}}}{1 + \alpha}
\]

- **Uncertainty Sources**
  - QCD di-jet contamination
  - Closure test
“Material” Systematics 0.4 GeV

- Energy scales of photons use extrapolation electron $\rightarrow$ photon
- If Geant4 material mapping is different from actual geometry, there is a mis-calibration for photons
  - shower development of photons is different from electrons

- Studies for material estimation
  - Hadron interaction
  - Calorimeter shower shape
  - ...

Radiation length

$|\eta|$

nominal geometry

material uncertainty

Nominal geometry

Geometry with different material budget

Energy scale comparison

Mass systematics due to material uncertainties 0.4 GeV
• Large $\mu$ and narrow mass peak are measured in observed data set
• Affect on mass measurement?
  • $\mu = 1.6 \pm 0.3$

- $m_H$ and $\mu$ are not correlated in $H \rightarrow \gamma\gamma$ channel

- The best fit value of mass resolution in observed $H \rightarrow \gamma\gamma$ resonance is narrower than expected by 1.8$\sigma$
  - $\sigma$: uncertainty of mass resolution
  - Toy MC study shows mass resolution doesn’t have influence on $m_H$ measurement
Summary

- $H \rightarrow \gamma\gamma$ channel shows $m_H$:
  
  $m_H = 126.8 \pm 0.2\,(\text{stat}) \pm 0.7\,(\text{syst})\,\text{GeV}$

- Dominated by systematic uncertainties
- Dominant systematics come from photon energy scale

Future plan

- New detector geometry
  - Updated by studies of material estimation
  - Improve the description of the $Z \rightarrow \text{ee}$ line-shape
- Improvement on intercalibration of each calorimeter layer
  - Reduce systematics on the presampler energy scale
<table>
<thead>
<tr>
<th>Category</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inclusive</td>
<td>4th order Bernstein polynomial</td>
</tr>
<tr>
<td>Unconverted central, low $p_{Tt}$</td>
<td>exponential of 2nd order polynomial</td>
</tr>
<tr>
<td>Unconverted central, high $p_{Tt}$</td>
<td>single exponential</td>
</tr>
<tr>
<td>Unconverted rest, low $p_{Tt}$</td>
<td>4th order Bernstein polynomial</td>
</tr>
<tr>
<td>Unconverted rest, high $p_{Tt}$</td>
<td>single exponential</td>
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<td>single exponential</td>
</tr>
<tr>
<td>Converted transition</td>
<td>exponential of 2nd order polynomial</td>
</tr>
<tr>
<td>Loose high-mass two-jet</td>
<td>single exponential</td>
</tr>
<tr>
<td>Tight high-mass two-jet</td>
<td>single exponential</td>
</tr>
<tr>
<td>Low-mass two-jet</td>
<td>single exponential</td>
</tr>
<tr>
<td>$E_T^{miss}$ significance</td>
<td>single exponential</td>
</tr>
<tr>
<td>One-lepton</td>
<td>single exponential</td>
</tr>
</tbody>
</table>
Comparison with $H \rightarrow ZZ \rightarrow 4l$

- Likelihood as a function of the mass difference, $\Delta m_H = m_H^{\gamma\gamma} - m_H^{4l}$
- The common mass $m_H$ is profiled over
- The signal strength parameters $\mu_{\gamma\gamma}$ and $\mu_{4l}$ can be changed independently

\[ \Delta m_H = 0 \] hypothesis by more than observed in the data is found to be at the level of 1.5% (2.4σ)