Status of ATLAS Higgs Search

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On behalf of the ATLAS Collaboration

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Outline

• Standard Model Higgs production & decay at the LHC
• ATLAS Detector and data taking at 7 TeV
• Higgs search strategies & specifics
• Combined results & exclusion limits
• Fundamental ingredient of the Standard Model
• Pre-LHC era: $M_H < 114.5$ GeV (LEP), and $156 < M_H < 177$ GeV (Tevatron), excluded at 95% C.L.
• Several production mechanisms
• Primary goal of the LHC experimental program
• Standard Model Higgs properties are well known
• Only unknown is $M_H$: dictating different low / high mass search strategies

ATLAS @ LHC

- Superb LHC performance!
- Data quality requirements: 4.6 – 4.9 fb⁻¹

- Well suited for Higgs searches with very good tracking and calorimetry (e, γ, μ, and jets)
- Data distributed and analyzed on a Computing Grid infrastructure (WLCG)
Higgs search strategies

- Twelve decay channels / topologies considered:

<table>
<thead>
<tr>
<th>Higgs Decay</th>
<th>Subsequent Decay</th>
<th>$m_H$ Range</th>
<th>$L$ [fb$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H \rightarrow \gamma \gamma$</td>
<td>-</td>
<td>110-150</td>
<td>4.9</td>
</tr>
<tr>
<td>$H \rightarrow ZZ$</td>
<td>$\ell\ell\ell\ell$</td>
<td>110-600</td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td>$\ell\ell\nu\bar{\nu}$</td>
<td>200-280-600</td>
<td>4.7</td>
</tr>
<tr>
<td></td>
<td>$\ell\ell q\bar{q}$</td>
<td>200-300-600</td>
<td>4.7</td>
</tr>
<tr>
<td>$H \rightarrow WW$</td>
<td>$\ell\ell\ell\ell$</td>
<td>110-300-600</td>
<td>4.7</td>
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<tr>
<td>$H \rightarrow \tau^+ \tau^-$</td>
<td>$\ell\tau_{\text{had}} 3\nu$</td>
<td>110-150</td>
<td>4.7</td>
</tr>
<tr>
<td></td>
<td>$\tau_{\text{had}} \tau_{\text{had}} 2\nu$</td>
<td>110-150</td>
<td>4.7</td>
</tr>
<tr>
<td>$VH \rightarrow b\bar{b}$</td>
<td>$Z \rightarrow \nu\bar{\nu}$</td>
<td>110-130</td>
<td>4.6</td>
</tr>
<tr>
<td></td>
<td>$W \rightarrow \ell\nu$</td>
<td>110-130</td>
<td>4.7</td>
</tr>
<tr>
<td></td>
<td>$Z \rightarrow \ell\ell$</td>
<td>110-130</td>
<td>4.7</td>
</tr>
</tbody>
</table>

- Combination: profile likelihood ratio test statistic for signal strength $\mu = \sigma / \sigma_{SM}$ (Eur.Phys.J.C71:1554,2011)

- Full likelihood includes systematics and correlations


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arXiv:1202.1408
**Selection:** two isolated photons, $E_T > 40 \text{ GeV}$ (25 GeV) for leading (sub-leading)

**Backgrounds:** $\gamma\gamma$, $\gamma +j$, $j+j$ with jets passing $\gamma$ selection

**9 event classifications with different $S/B$ and $m_{\gamma\gamma}$ resolutions:** converted / non-converted, pseudo-rapidity regions, kinematics of diphoton system
• $m_{\gamma\gamma}$ distribution used for the limit setting (resolution crucial). Combining event classifications

• Largest excess at 126.5 GeV

• Significance: 2.8$\sigma$ local, 1.5$\sigma$ global (entire range)

• Observed exclusion: 113-115 GeV, 134.5-136 GeV
\[ H \rightarrow ZZ^{(*)} \rightarrow 4\ell \ (l) \]

- Selection: two same flavor opposite sign lepton pairs 4e, 2e+2\(\mu\), 4\(\mu\) (\(p_T > 7 \text{ GeV}\) with two leading \(p_T > 20 \text{ GeV}\)).
- Backgrounds: ZZ, Z+jets, ttbar
- Cuts on \(m_{12}\) and \(m_{34}\) (\(m_H\) dependent)

(control regions)
- $m_{4\ell}$ distribution used for the limit setting (good resolution in low mass region / Higgs width small)
- Largest excess at $m_H=125$, 244 and 500 GeV, with local significances of 2.1σ, 2.2σ and 2.1σ

- Comparable excess as observed in $H\rightarrow\gamma\gamma$ mode at ~125
- Selection: two isolated e or \(\mu\) with \(p_T > 20\) GeV within \(m_Z\) window and missing transverse energy \((E_T^{\text{miss}})\)
- Refined for different \(m_H\) regions and data taking periods
- Background: \(ZZ, WZ, WW,\) top, \(W + \text{jets}, Z + \text{jets}\)
- \(m_T\) distribution (from \(\ell\ell\) and \(p_T^{\text{miss}}\)) for the limit setting
- No significant excess observed, exclude 320-560 GeV
- Selection: two isolated e or $\mu$ with $p_T > 20$ GeV and two jets with $E_T > 25$ GeV within Z mass, and $E_T^{miss} < 25$ GeV.
- Refined for low/high Higgs mass and use of b-tagging
- Background: Z+jets, top, dibosons, QCD multijets
- $m_{\ell\ell jj}$ distribution used for the limit setting
- No significant excess observed, exclude 300-310 GeV, 360-400 GeV.
• Selection: two isolated ee, μμ, or eμ with pT>25 (15 GeV) for leading (sub-leading) with E_T^{miss} and Z veto.

• Separate 0, 1 and 2 jets (VBF)

• Background: WW, top, Z+jets, W+jets with data driven normalizations using control samples

• Further topological cuts and b-jet veto for top rejection.
• $m_T$ distribution used for the limit setting
• No significant excess, 130-260 GeV range excluded
• Expected exclusion range: 127-234 GeV (if no SM signal)
- Selection: isolated $e$ or $\mu$, two jets, and $E_T^{\text{miss}}$
- Extra jets (in addition to above) are used to separate gluon fusion and VBF
- Backgrounds: $W+$jets, $Z+$jets, QCD multijets, top, dibosons
- $m_{\ell\nu jj}$ used for the limit setting
• Selection: three event categories (leptonic and hadronic decays):

\[ H \rightarrow \tau\tau \rightarrow \ell\ell4\nu \]
\[ H \rightarrow \tau\tau \rightarrow \ell\tau_{\text{had}}3\nu \]
\[ H \rightarrow \tau\tau \rightarrow \tau_{\text{had}}\tau_{\text{had}}2\nu \]

• Isolated leptons and \( \tau \) hadronic candidate identified via narrow jets and low track multiplicity

• Separate 0, 1 and 2 jets (VBF)

• Background: \( Z+ \) jets (mainly from \( Z \rightarrow \tau\tau \)), top, dibosons, fakes
• For the limit setting: $m_{\tau\tau}$ is used (calculated using different techniques depending on event topology)

• Observed (expected) upper limits: between 2.5 (3.2) and 11.9 (7.9) x SM prediction
(W/Z) H → b ̅ b (I)

- Three event topologies:
  \[ WH \rightarrow \ell \nu b ̅ b \]
  \[ ZH \rightarrow \ell^+ \ell^- b ̅ b \]
  \[ ZH \rightarrow \nu \bar{\nu} b ̅ b \]

- W/Z selection with two b-tagged jets with ET>45 (25) GeV for leading (sub-leading)

- Exploit W and Z recoils against H, look at separate p_T and E_Tmiss regions

- Background: W/Z + jets, top, QCD multijets, dibosons
• $m_{bb}$ distribution used for the limit setting

• no significant excess, observed (expected) upper limits at 95% CL are from 2.7 (2.6) to 5.3 (5.1) $\times \sigma_{SM}$
Observed exclusion at 95%: 110-117.5, 118.5-122.5, 129-539 GeV. Expected exclusion range: 120-555 GeV.
Combined Results (II)

- Excess observed at $m_H = 126$ GeV from $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ^(*) \rightarrow 4\ell$

- Observed local significance 2.5$\sigma$ (2.9$\sigma$ expected) from all channels combined.

- Global probability of background fluctuation:
  30% in 110-600 GeV and 10% in 110-146 GeV range.
Conclusion

- Exciting new era for Higgs hunting
- SM Higgs seriously cornered to a very small region at 95% C.L.:

  **117.5-118.5 GeV or 122.5-129 GeV**

- Mass range excluded at 99% C.L.: 130-486 GeV
- Excess more compatible with a SM Higgs in the low mass region around 126 GeV. Need more data to confirm or deny.
- LHC operations in 2011 have been truly remarkable with outstanding ATLAS data taking efficiency, processing and analysis. Thanks to a few kilo-people.
- Looking forward for 2012 LHC running. **8 TeV collisions already started.** Higgs production x.s. increase of ~20% and expected integrated luminosity ~4 times more than 2011.
Acknowledgments

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SM Higgs properties

- Higgs branching ratios in the low mass region and width as a function of its mass
Combined Results (III)

- Observed and expected (dashed) 95% CL limits for all the individual channels used:
Combined Results (IV)

• Limits obtained with different combinations of channels:
Event Displays (I)

- Diphoton event with invariant mass of 126.6 GeV.
Event Displays (II)

• 4 muons event with invariant mass of 124.6 GeV.