Search for a Light Higgs Boson at ATLAS

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on behalf of the ATLAS Collaboration

Outline
• Introduction
• Higgs Search Strategy at ATLAS
• Results of Each Channel
• Summary
Introduction and Motivation

• Direct and indirect Higgs boson search
  – ATLAS+CMS excluded the range of $141 < m_H < 476$ GeV in 2011 summer (1.0-2.3 fb$^{-1}$)
  – LEP excluded up to 114.4 GeV
  – The preferred value is $94^{+29}_{-24}$ GeV, $m_H < 152$ GeV @ 95% CL from EW global fit

➔ If SM Higgs boson exists, light Higgs boson is preferred!!
Higgs Production and Decay

Higgs BR + Total Uncert

$\sqrt{s} = 7$ TeV

LHC HIGGS XS WG 2010

Physics at LHC - 2012 Vancouver
Higgs Production and Decay

**Analysis Status**

- $H \rightarrow \gamma \gamma$: $4.9 \text{fb}^{-1}(110 < m_H < 150 \text{ GeV})$
- $H \rightarrow WW \rightarrow llvl$: $4.7 \text{fb}^{-1}(110 < m_H < 600 \text{ GeV})$
- $H \rightarrow ZZ \rightarrow 4l$: $4.8 \text{fb}^{-1}(110 < m_H < 600 \text{ GeV})$
- $H \rightarrow \tau\tau$: $4.7 \text{fb}^{-1}(100 < m_H < 150 \text{ GeV})$
- $W/Z + H \rightarrow bb$: $4.6-4.7 \text{fb}^{-1}(110 < m_H < 130 \text{ GeV})$

* High mass region of WW and ZZ is covered by Alex’s talk*
**$H \rightarrow \gamma\gamma$**

- Di-photon trigger (trigger efficiency is 99% w.r.t. offline selection)
- Two isolated photons with $E_T(\gamma_1) > 40$ GeV, $E_T(\gamma_2) > 25$ GeV
- Candidate diphoton events are subdivided into 9 orthogonal categories (converted/unconverted, $\eta$ range, $p_T$ )

  ➔ Extract better $m_{\gamma\gamma}$ resolution and S/B region

- Robust $m_{\gamma\gamma}$ reconstruction against the pileup
  
  ➔ important to measure photon direction
  - Use conversion vertex and calorimetric information for converted photons
  - Use longitudinal information of EM calorimeter for unconverted photons
- Uncertainty on $m_{\gamma\gamma}$ mass peak ($\pm 0.7$ GeV)
Di-photon trigger (trigger efficiency is 99% w.r.t. offline selection)

Two isolated photons with $E_T(\gamma1) > 40$ GeV, $E_T(\gamma2) > 25$ GeV

Candidate di-photon events are subdivided into 9 orthogonal categories (converted/unconverted, $\eta$ range, $p_{Tt}$)

Extract better $m_{\gamma\gamma}$ resolution and S/B region

Robust $m_{\gamma\gamma}$ reconstruction against the pileup

- Important to measure photon direction
  - Use conversion vertex and calorimetric information for converted photons
  - Use longitudinal information of EM calorimeter for unconverted photons

Uncertainty on $m_{\gamma\gamma}$ mass peak ($\pm 0.7$ GeV)
$H \rightarrow \gamma\gamma$

- $m_{\gamma\gamma}$ distribution summed over all categories

95% CL limit on SM Higgs cross section divided by SM expectation

95% CL excluded region: 113-115, 134.5-136 GeV

Largest significance $2.8\sigma$ is observed at 126.5 GeV:

$(1.5\sigma$ with Look-elsewhere-effect for 110-150 GeV)
\[ \text{H} \to \text{ZZ}(*) \to 4l \]

**Clean signature**: Require 4 isolated leptons (4e, 4\(\mu\), 2e2\(\mu\))

- low background level: SM ZZ, Z+jets, ttbar
- Mass resolution: \(~1\text{-}2\%\) level (low mass region)
- Event Selection: \(|m_Z - m_{12}| < 15\text{ GeV}\), \(m_{34}\) selection is optimized depending on \(m_{4l}\) to improve signal-to-background ratio (20 < \(m_{34}\) < 115 GeV for \(m_{4l}=130\text{ GeV}\))

**ATLAS Simulation**

\[ m_{34} = 130\text{ GeV} \]

\[ \sigma = 1.98 \pm 0.03\text{ GeV} \]

fraction outside \(\pm 2\sigma\): 15%
Excess around 125 GeV due to 3 observed events

Highest local $p_0$
1.6% (obs:2.1σ, exp:1.3σ) at 125 GeV

With look-elsewhere-effect, this excess is not significant (~50%)
\[ H \rightarrow WW^* \rightarrow l\nu l\nu \]

- Most sensitive channel in \( 120 < m_H < 200 \) GeV
  - High signal yield but no full mass reconstruction possible due to 2\( \nu \)

- Signature: dilepton + \( E_T^{\text{miss}} \) rel + (0,1,2) jets
  - Event selection is optimized for each jet bin to maximize sensitivity (different background composition)

- Background suppression

<table>
<thead>
<tr>
<th>Selection</th>
<th>Suppression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two high-( p_T ) isolated lepton</td>
<td>W+jets, QCD</td>
</tr>
<tr>
<td>Large missing transverse energy</td>
<td>Z+jets, QCD</td>
</tr>
<tr>
<td>jet-bin specific: high ( p_T ) for 0jet b-jet veto for 1/2 jet, VBF cut for 2jet</td>
<td>Z+jets ttbar, single top</td>
</tr>
<tr>
<td>Topological selection (low ( \Delta \phi_{ll}, m_{ll} ))</td>
<td>SM WW</td>
</tr>
</tbody>
</table>

Background normalization is estimated in each control region (e.g. high \( m_{ll} \) for WW control region)
\[ m_T = \sqrt{\left( E_T^{ll} + E_T^{\text{miss}} \right)^2 - \left( P_T^{ll} + E_T^{\text{miss}} \right)^2} \quad E_T^{ll} = \sqrt{(P_T^{ll})^2 + m_{ll}^2} \]

No significant excess in all jet bins

95% CL excluded region

Observed: 133-261 GeV

Expected: 127-233 GeV
MVA in H→WW→ℓνℓν

• First result using MVA (BDT) in ATLAS Higgs search
  – Preselection: Same object selection, $E_T^{\text{miss}}$, $p_T^{ll}$ cut as $m_T$ fit analysis
  – Train signal vs. combined background (WW,WZ,ZZ, ttbar, single top and Z+jets) for 0,1jet separately in each mass point
  – 4 topological variables ($m_T$, $\Delta\phi_{ll}$, $m_{ll}$, $p_T^{ll}$) are used

NEW

Observed: 130-281 GeV
Expected: 127-255 GeV

95% CL excluded region

10% Sensitivity Improvement
Each sub-channel separated into different jet categories

- $\tau_{lep}\tau_{lep}$: H+2jets (VBF), H+2jets(VH), H+1jet, H+0jet (only $e\mu$-ch)
- $\tau_{lep}\tau_{had}$: H+2jets (VBF), H+1jet, H+0jets with low/high MET
- $\tau_{had}\tau_{had}$: H+1jet

3.2$\times\sigma_{SM}$ at 125 GeV (exp. 3.2$\times\sigma_{SM}$)
## W/ZH(→bbar)

### WH→lvbb
- one lepton (e,μ)
- \( E_{T}^{miss} > 25, \text{ GeV}, m_{T} > 40 \text{ GeV} \)

### ZH→llbb
- two leptons (ee, μμ)
- \( 84 \text{ GeV} < m_{ll} < 99 \text{ GeV}, E_{T}^{miss} < 50 \text{ GeV} \)

### ZH→vvbb
- \( E_{T}^{miss} > 120 \text{ GeV} \)
- \( p_{T}^{miss} > 30 \text{ GeV}, |\Delta\phi(E_{T}^{miss}, p_{T}^{miss})| < \pi/2, |\Delta\phi(E_{T}^{miss}, \text{jet})| > 1.8 \)

#### Two b-jets (45,25 GeV)

### Categorize events depending on vector boson \( p_{T}^{V} \) (\( p_{TV} \)) or MET (Boost VH Events)

<table>
<thead>
<tr>
<th>( p_{TV} ) range</th>
<th>( E_{T}^{miss} ) range</th>
</tr>
</thead>
<tbody>
<tr>
<td>( &lt;50, )50&lt; ( p_{TV} &lt;100, )100&lt; ( p_{TV} &lt;200, ) ( p_{TV} &gt;200 \text{ GeV} )</td>
<td>( 120&lt; E_{T}^{miss} &lt;160, )160&lt; ( E_{T}^{miss} &lt;200, ) ( E_{T}^{miss} &gt;200 \text{ GeV} )</td>
</tr>
</tbody>
</table>

### m_{bb} distribution in ZH→vvbb

- \( S/B \approx 0.09 \) in signal mass window

### 95% CL Limit combined all channels

- \( 3.5 \times \sigma \text{ SM} \) at 125 GeV

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ATLAS Preliminary

\( \int L \, dt = 4.6 \, fb^{-1}, s = 7 \, TeV \)

ZH \( \rightarrow \) \( VV + b \bar{b} \)

\( E_{T}^{miss} > 200 \text{ GeV} \)

\( m_{bb} \) distribution

<table>
<thead>
<tr>
<th>Events / 25 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
</tr>
<tr>
<td>18</td>
</tr>
<tr>
<td>16</td>
</tr>
<tr>
<td>14</td>
</tr>
<tr>
<td>12</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

\( m_{T} \) [GeV]

\( m_{bb} \) distribution

95% C.L. limit on \( \sigma_{SM} \)

\( m_{bb} \) [GeV]

\( m_{T} \) [GeV]
Summary

- Large low mass region is excluded in 2011 analysis

- ~2σ level excess in local $p_0$ is observed around 125 GeV in $H \rightarrow γγ$ and $H \rightarrow ZZ \rightarrow 4l$

- 8TeV run is going smoothly
  - More statistics (15-20 fb$^{-1}$) in 2012
  - ggF x-sec increase by 27% at 125 GeV
  - We have an answer, either discovery or exclusion, in the remaining low mass region this year
Summary

- Large low mass region is excluded in 2011 analysis

- ~2σ level excess in local p_0 is observed around 125 GeV in H→γγ and H→ZZ→4l

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2012
8TeV

Stay Tuned!!
Back up
ATLAS Data Taking in 2011

- Excellent LHC performance in 2011 (far beyond expectation)
- Peak luminosity: $3.7 \times 10^{33}$ cm$^{-2}$s$^{-1}$
- High luminosity $\Rightarrow$ high pile-up
- Very challenging for trigger, reconstruction of physics object, analysis strategies

5.3 fb$^{-1}$ recorded

20 reconstructed vertices!!

Summer 2011 ($\sim$2 fb$^{-1}$)

Last year

2012/6/8  Physics at LHC -2012 Vancouver
Excellent performance of ATLAS

• Data-taking efficiency : 93.5%
• High operational fraction of all sub-detectors : >95%
H → γγ

- mass resolution for each category
- observed μ for each category
- z position resolution is ~6mm for converted photon, ~15mm for unconverted photon

<table>
<thead>
<tr>
<th>Category</th>
<th>σ_{CB}</th>
<th>FWHM</th>
<th>N_S</th>
<th>N_D</th>
<th>S/B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unconverted central, low p_Tt</td>
<td>1.4</td>
<td>3.4</td>
<td>9.1</td>
<td>1763</td>
<td>0.05</td>
</tr>
<tr>
<td>Unconverted central, high p_Tt</td>
<td>1.4</td>
<td>3.3</td>
<td>2.6</td>
<td>235</td>
<td>0.11</td>
</tr>
<tr>
<td>Unconverted rest, low p_Tt</td>
<td>1.7</td>
<td>4.0</td>
<td>17.7</td>
<td>6234</td>
<td>0.02</td>
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<tr>
<td>Unconverted rest, high p_Tt</td>
<td>1.6</td>
<td>3.9</td>
<td>4.7</td>
<td>1006</td>
<td>0.04</td>
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<tr>
<td>Converted central, low p_Tt</td>
<td>1.6</td>
<td>3.9</td>
<td>6.0</td>
<td>1318</td>
<td>0.03</td>
</tr>
<tr>
<td>Converted central, high p_Tt</td>
<td>1.5</td>
<td>3.6</td>
<td>1.7</td>
<td>184</td>
<td>0.08</td>
</tr>
<tr>
<td>Converted rest, low p_Tt</td>
<td>2.0</td>
<td>4.7</td>
<td>17.0</td>
<td>7311</td>
<td>0.01</td>
</tr>
<tr>
<td>Converted rest, high p_Tt</td>
<td>1.9</td>
<td>4.5</td>
<td>4.8</td>
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<td>0.03</td>
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<tr>
<td>Converted transition</td>
<td>2.3</td>
<td>5.9</td>
<td>8.5</td>
<td>3366</td>
<td>0.01</td>
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<tr>
<td>All categories</td>
<td>1.7</td>
<td>4.1</td>
<td>72.1</td>
<td>22489</td>
<td>0.02</td>
</tr>
</tbody>
</table>
**H → WW → lνlν**

- MET modeling in high pile up condition

- WW control region, top control region
H→WW→lvlv

- H→WW \( p_0 \)
Other Categories in $H \rightarrow \tau\tau$

- $H \rightarrow \tau\tau (\tau_{lep}\tau_{lep})$

- $H \rightarrow \tau\tau (\tau_{lep}\tau_{had})$
$H \rightarrow \tau \tau (\tau_{lep}\tau_{lep}, \tau_{lep}\tau_{had}, \tau_{had}\tau_{had})$

- 95% CL upper limit for each channel
W/ZH($\rightarrow$bb)

- Top (low pt category), bottom (high pt category)

**ATLAS Preliminary**

- Data 2011
- Signal $\times$ 5 ($m_H = 120$ GeV)
- Total BG
- Top
- Z+jets
- W+jets
- Diboson

**ATLAS Preliminary**

- Data 2011
- Signal $\times$ 5 ($m_H = 120$ GeV)
- Total BG
- Top
- Z+jets
- W+jets
- Diboson
- Multijet

**ATLAS Preliminary**

- Data 2011
- Signal $\times$ 5 ($m_H = 120$ GeV)
- Total BG
- Top
- Z+jets
- W+jets
- Diboson

**ATLAS Preliminary**

- Data 2011
- Signal $\times$ 5 ($m_H = 120$ GeV)
- Total BG
- Top
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- Diboson

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2012/6/8

Physics at LHC - 2012 Vancouver
W/ZH($\rightarrow bb$)

- 95% CL upper limit for each channel