Status of Standard Model Higgs searches in ATLAS

Using the full datasets recorded in 2011 at $\sqrt{s}=7$ TeV and 2012 at $\sqrt{s}=8$ TeV: up to 10.7 fb$^{-1}$

Fabiola Gianotti (CERN), representing the ATLAS Collaboration
“This is how the Higgs boson could look”
We present updated results on SM Higgs searches based on the data recorded in 2011 at $\sqrt{s}=7$ TeV ($\sim 4.9$ fb$^{-1}$) and 2012 at $\sqrt{s}=8$ TeV ($\sim 5.9$ fb$^{-1}$)

Results are preliminary:
- 2012 data recorded until 2 weeks ago
- harsher conditions in 2012 due to ~ $x2$ larger event pile-up
- new, improved analyses deployed for the first time

$H \rightarrow \gamma\gamma$ and $H \rightarrow 4l$: high-sensitivity at low-$m_H$; high mass-resolution; pile-up robust
- analyses improved to increase sensitivity $\rightarrow$ new results from 2011 data
- all the data recorded so far in 2012 have been analyzed
  $\rightarrow$ results are presented here for the first time

Other low-mass channels: $H \rightarrow WW(\ast) \rightarrow l\nu l\nu$, $H \rightarrow tt$, $W/ZH \rightarrow W/Z$ bb:
- $E_T^{miss}$ in final state $\rightarrow$ less robust to pile-up
- worse mass resolution, no signal “peak” in some cases
- complex mixture of backgrounds
  $\rightarrow$ understanding of the detector performance and backgrounds in 2012 well advanced, but results not yet mature enough to be presented today
  $\rightarrow$ 2011 results used here for these channels for the overall combination
2012 data-taking so far ...

Fraction of non-operational detector channels: (depends on the sub-detector)
- few permil (most cases) to 4%

Data-taking efficiency = (recorded lumi)/(delivered lumi):
- ∼ 94.6%

Good-quality data fraction, used for analysis: (will increase further with data reprocessing)
- ∼ 93.6%

Peak luminosity in 2012:
- ∼ 6.8 x10^{33} \text{ cm}^{-2} \text{ s}^{-1}
2012 data-taking so far …

Peak luminosity in 2012: 
\[ \sim 6.8 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1} \]

ATLAS Online Luminosity \( \sqrt{s} = 8 \text{ TeV} \)

- LHC Delivered
- ATLAS Recorded

Total Delivered: 6.63 fb\(^{-1}\)
Total Recorded: 6.28 fb\(^{-1}\)

~ 90% of the delivered luminosity used for these results

(slightly larger fraction than in 2011):
- in spite of the very fresh data
- in spite of the harsher conditions
Luminosity delivered to ATLAS since the beginning

2012: 6.6 fb⁻¹ at 8 TeV
2011: 5.6 fb⁻¹ at 7 TeV
2010: 0.05 fb⁻¹ at 7 TeV
BIG THANKS

To the whole LHC exploitation team, including the operation, technical and infrastructure groups, for the OUTSTANDING performance of the machine, and to all the people who have contributed to the conception, design, construction and operation of this superb instrument.
The BIG challenge in 2012: PILE-UP

Experiment's design value (expected to be reached at L=10^{34}!)

\[ Z \rightarrow \mu \mu \] event from 2012 data with 25 reconstructed vertices
Huge efforts over last months to prepare for 2012 conditions and mitigate impact of pile-up on trigger, reconstruction of physics objects (in particular $E_T^{\text{miss}}$, soft jets, ..), computing resources (CPU, event size)

- Pile-up robust, fast trigger and offline algorithms developed
- Reconstruction and identification of physics objects (e, $\gamma$, $\mu$, $\tau$, jet, $E_T^{\text{miss}}$) optimised to be ~independent of pile-up $\rightarrow$ similar (better in some cases!) performance as with 2011 data
- Precise modeling of in-time and out-of-time pile-up in simulation
- Flexible computing model to accommodate x2 higher trigger rates and event size as well as physics and analysis demands

Understanding of $E_T^{\text{miss}}$ (most sensitive to pile-up) is crucial for $H \rightarrow WW(*) \rightarrow l\nu l\nu$, $W/ZH \rightarrow W/Zbb$, $H \rightarrow \tau\tau$

$E_T^{\text{miss}}$ resolution vs pile-up in $Z \rightarrow \mu\mu$ events before and after pile-up suppression using tracking information

Note: number of reconstructed primary vertices is ~ 60% number of interactions per crossings
**Trigger in 2012**

- Optimization of selections (e.g. object isolation) to maintain low un-prescaled thresholds (e.g. for inclusive leptons) in spite of projected x2 higher L and pile-up than in 2011
- Pile-up robust algorithms developed (~flat performance vs pile-up, minimize CPU usage, ...)

→ Results from 2012 operation show trigger is coping very well (in terms of rates, efficiencies, robustness, ..) with harsh conditions while meeting physics requirements

### Lowest un-prescaled thresholds (examples)

<table>
<thead>
<tr>
<th>Item</th>
<th>$p_T$ threshold (GeV)</th>
<th>Rate (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incl. e</td>
<td>24</td>
<td>70</td>
</tr>
<tr>
<td>Incl. $\mu$</td>
<td>24</td>
<td>45</td>
</tr>
<tr>
<td>$ee$</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>$\mu\mu$</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>$\tau\tau$</td>
<td>29,20</td>
<td>12</td>
</tr>
<tr>
<td>$\gamma\gamma$</td>
<td>35,25</td>
<td>10</td>
</tr>
<tr>
<td>$E_{T,\text{miss}}$</td>
<td>80</td>
<td>17</td>
</tr>
<tr>
<td>$5j$</td>
<td>55</td>
<td>8</td>
</tr>
</tbody>
</table>

Note: ~ 500 items in trigger menu!

Managed to keep inclusive un-prescaled lepton thresholds within ~ 5 GeV over last two years in spite factor ~ 70 peak lumi increase

**ATLAS** Trigger Operations
LHC Fill 2686 May. 31 2012
Starting Luminosity: $6.37 \times 10^{33}$ cm$^{-2}$s$^{-1}$
Ending Luminosity: $2.91 \times 10^{33}$ cm$^{-2}$s$^{-1}$

L1: up to ~ 65 kHz
L2: up to ~ 5 kHz
EF: ~ 400Hz

Optimization of selections (e.g. object isolation) to maintain low un-prescaled thresholds (e.g. for inclusive leptons) in spite of projected x2 higher L and pile-up than in 2011.

Pile-up robust algorithms developed (~flat performance vs pile-up, minimize CPU usage, ...).

Results from 2012 operation show trigger is coping very well (in terms of rates, efficiencies, robustness, ..) with harsh conditions while meeting physics requirements.
Efficiency of inclusive electron trigger ($E_T$ thresholds as low as 24) as a function of "pile-up".

Many improvements in $E_T^{\text{miss}}$ trigger: e.g. pile-up suppression, L2 fast front-end board sums instead of L1 only $\rightarrow$ same threshold as in 2011, sharper turn-on curve.

From $Z \rightarrow ee$ events

\[
\int L dt = 4.1 \, \text{fb}^{-1}, \, \sqrt{s} = 8 \, \text{TeV}
\]

$2012$ p-p Collision Data

$\Delta E_x [\text{GeV}]$

Events/GeV

$\int L dt \approx 275 \, \text{pb}^{-1}$

$\sqrt{s} = 8 \, \text{TeV}$

$\sigma(\text{EF-L2}) = 6.7 \, \text{GeV}$

$\sigma(\text{EF-L1}) = 10.2 \, \text{GeV}$

x-component resolution

Red: 2011

Blue: 2012

Offline $E_T^{\text{miss}}$ (GeV)
It would have been impossible to release physics results so quickly without the outstanding performance of the Grid (including the CERN Tier-0)

Number of concurrent ATLAS jobs Jan-July 2012

- Includes MC production, user and group analysis at CERN, 10 Tier1-s, ~ 70 Tier-2 federations → > 80 sites
- > 1500 distinct ATLAS users do analysis on the GRID

- Available resources fully used/stressed (beyond pledges in some cases)
- Massive production of 8 TeV Monte Carlo samples
- Very effective and flexible Computing Model and Operation team → accommodate high trigger rates and pile-up, intense MC simulation, analysis demands from worldwide users (through e.g. dynamic data placement)
Most recent electroweak and top cross-section measurements

- Important on their own and as foundation for Higgs searches
- Most of these processes are reducible or irreducible backgrounds to Higgs
- Reconstruction and measurement of challenging processes (e.g. fully hadronic $t\bar{t}$, single top, ..) are good training for some complex Higgs final states
SM Higgs production cross-section and decay modes

Note: huge efforts and progress from theory community to compute NLO/NNLO cross-sections for Higgs production and for (often complex !) backgrounds

√s=7 → 8 TeV:
- Higgs cross-section increases by ~ 1.3 for m_H ~ 125 GeV
- Similar increase for several irreducible backgrounds: e.g. 1.2-1.25 for γγ, di-bosons
- Reducible backgrounds increase more: e.g. 1.3-1.4 for tt, Zbb
→ Expected increase in Higgs sensitivity: 10-15%
Status of ATLAS searches ... until this morning

Results on the full 7 TeV dataset submitted for publication

Combination of 12 channels:
- $H \rightarrow \gamma\gamma$
- $W/ZH \rightarrow W/Z \, bb$ (3 final states)
- $H \rightarrow \tau\tau$ (3 final states)
- $H \rightarrow ZZ(*) \rightarrow 4l$
- $H \rightarrow WW(*) \rightarrow l\nu l\nu$
- $H \rightarrow ZZ \rightarrow llqq$
- $H \rightarrow ZZ \rightarrow ll\nu\nu$
- $H \rightarrow WW \rightarrow l\nu qq$

Excluded at 95% CL
111.4 < $m_H$ < 122.1 GeV (except 116.6-119.4)
129.2 < $m_H$ < 541 GeV

Expected if no signal: 120-560 GeV

Excluded at 99% CL
130.7 < $m_H$ < 506 GeV
Status of ATLAS searches ... until this morning

Consistency of the data with the background-only expectation (p-value)

2.9 σ excess observed for m_H ~ 126 GeV

Probability to occur anywhere over 110-600 (110-146 GeV): 15% (6%) (Look-Elsewhere Effect)

<table>
<thead>
<tr>
<th>Local significance</th>
<th>Observed</th>
<th>Expected from SM Higgs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>2.9 σ</td>
<td>2.9 σ</td>
</tr>
<tr>
<td>H \rightarrow \gamma\gamma</td>
<td>2.8 σ</td>
<td>1.4 σ</td>
</tr>
<tr>
<td>H \rightarrow 4l</td>
<td>2.1 σ</td>
<td>1.4 σ</td>
</tr>
<tr>
<td>H \rightarrow l\nu l\nu</td>
<td>0.8 σ</td>
<td>1.6 σ</td>
</tr>
</tbody>
</table>
What’s new in the results presented today?

Experience gained with the 2011 data propagated to reconstruction and simulation (improved detector understanding, alignment and calibration, pile-up, ...)

In particular: improved reconstruction and identification of physics objects $\rightarrow$ sizeable gain in efficiency for $e/\gamma/\mu$, pile-up dependence minimized, smaller systematic uncertainties

$\rightarrow$ Huge amount of painstaking foundation work!

Sensitivity of $H \rightarrow \gamma\gamma$ and $H \rightarrow 4l$ analyses improved using the following procedure:

- optimization only done on MC simulation
- then looked at 2012 data in signal sidebands and background control regions
  (note: large and sometimes not well-known backgrounds estimated mostly with data-driven techniques using background-enriched-signal-depleted control regions)
  $\rightarrow$ validate MC simulation
- signal region inspected only after above steps satisfactory

Improved analyses applied also to 2011 data $\rightarrow$ updated $H \rightarrow \gamma\gamma$, 4l results at 7 TeV

Presented here:

- $H \rightarrow \gamma\gamma$, 4l results with full $\sqrt{s}=7$ TeV and $\sqrt{s}=8$ TeV datasets (~10.7 fb$^{-1}$) and improved analyses
- new overall combination
  (all channels other than $H \rightarrow \gamma\gamma$, 4l based on 7 TeV data)
ATLAS: Status of SM Higgs searches, 4/7/2012

- **Main improvements in new analysis:**
  - 2 jet category introduced \( \rightarrow \) targeting VBF process
  - \( \gamma \) identification (NN used for 2011 data) and isolation
    \( \rightarrow \) Expected gain in sensitivity: + 15%
  - Background fit procedure also improved.

- **Crucial experimental aspects:**
  - Excellent \( \gamma \gamma \) mass resolution to observe narrow signal peak above irreducible background
  - Powerful \( \gamma \) identification to suppress \( \gamma j \) and \( jj \) background with jet \( \rightarrow \pi^0 \rightarrow \) fake \( \gamma \)
    (cross sections are \( 10^4 \text{--} 10^7 \) larger than \( \gamma \gamma \) background)

- **Expected gain in sensitivity:** 3%

- **To increase sensitivity,** events divided in 10 categories based on \( \gamma \) rapidity, converted/unconverted \( \gamma \); \( p_T \gamma \) (\( p_T^{\gamma \gamma} \) perpendicular to \( \gamma \gamma \) thrust axis): 2 jets
Mass resolution

\[ m_{\gamma\gamma}^2 = 2E_1 E_2 (1-\cos \alpha) \]

Present understanding of calorimeter E response (from Z, J/\psi \rightarrow ee, W \rightarrow ev data and MC):
- E-scale at \( m_Z \) known to ~ 0.3%
- Linearity better than 1% (few-100 GeV)
- “Uniformity” (constant term of resolution): ~ 1% (2.5% for 1.37<\( |\eta| < 1.8 \))

Stability of EM calorimeter response vs time (and pile-up) during full 2011 run better than 0.1%

Electron scale transported to photons using MC (small systematics from material effects)

Mass resolution not affected by pile-up

Mass resolution of inclusive sample: 1.6 GeV
Fraction of events in \( \pm 2\sigma \): ~90%
\[ m^2_{\gamma\gamma} = 2E_1E_2(1-\cos\alpha) \]

\( \alpha \) = opening angle of the two photons

High pile-up: many vertices distributed over
\( \sigma_z \) (LHC beam spot) \( \sim \) 5-6 cm
\( \rightarrow \) difficult to know which one has produced the \( \gamma\gamma \) pair

Primary vertex from:
- EM calorimeter longitudinal (and lateral) segmentation
- tracks from converted photons

\[ \sigma_z \sim 1.5 \text{ cm} \]

Measure \( \gamma \) direction with calo
\( \rightarrow \) get \( Z \) of primary vertex

Note:
- Calorimeter pointing alone reduces vertex uncertainty from beam spot spread of \( \sim \) 5-6 cm to \( \sim \) 1.5 cm and is robust against pile-up
  \( \rightarrow \) good enough to make contribution to mass resolution from angular term negligible
- Addition of track information (less pile-up robust) needed to reject fake jets from pile-up in 2j/VBF category
Fraction of converted and unconverted $\gamma$ vs pile-up is now stable (within 1%) → small migration between categories, accurate specific calibration

Data-driven decomposition of selected $\gamma\gamma$ sample

High $\gamma\gamma$ purity thanks to:

- $R_j \sim 10^4$
- $\varepsilon(\gamma) \sim 90\%$

$\gamma\gamma \sim 75-80\%$
$\gamma j \sim 20\%$
$jj \sim 2\%$

$E_T \sim 32$ GeV
$E_T \sim 21$ GeV
Photon isolation requirement: $E_T < 4$ GeV inside cone $\Delta R < 0.4$ around $\gamma$ direction. Pile-up contribution subtracted using an “ambient energy density” event-by-event approach.

If subtraction is not perfect, residual dependence of the isolation energy on the bunch position in the train observed, due to impact of out-of-time pile-up from neighbouring bunches convolved with EM calorimeter pulse shape.

Calorimeter bipolar pulse shape: average pile-up is zero over ~ 600 ns (~12 bunches)

Beginning of the train: no cancellation from previous bunches

Effect well described by (detailed !) ATLAS simulation

Corrected recently with improved subtraction algorithm
Selected diphoton sample

- Data 2011 and 2012
- Sig + Bkg inclusive fit ($m_H = 126.5$ GeV)
- 4th order polynomial

$m_\gamma$ spectrum fit, for each category, with Crystal Ball + Gaussian for signal plus background model optimised (with MC) to minimize biases
Max deviation of background model from expected background distribution taken as systematic uncertainty

Total after selections: 59059 events

Main systematic uncertainties

| **Signal yield** | ~ 20% |
| **Theory**       | ~ 10% |
| **Photon efficiency** | ~ 10% |
| **Background model** | |
| **Categories migration** | up to ~ 10% |
| **Higgs $p_T$ modeling** | up to ~ 6% |
| **Conv/unconv $\gamma$** | up to 20% (2j/VBF) |
| **Jet $E$-scale** | up to 30% (2j/VBF) |
| **Underlying event** | |
| **$H \rightarrow \gamma\gamma$ mass resolution** | ~ 14% |
| **Photon $E$-scale** | ~ 0.6% |
Excluded (95% CL): 112-122.5 GeV, 132-143 GeV
Expected: 110-139.5 GeV
Consistency of data with background-only expectation

<table>
<thead>
<tr>
<th>Data sample</th>
<th>$m_H$ of max deviation</th>
<th>local p-value</th>
<th>local significance</th>
<th>expected from SM Higgs</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>126 GeV</td>
<td>$3 \times 10^{-4}$</td>
<td>3.5 $\sigma$</td>
<td>1.6 $\sigma$</td>
</tr>
<tr>
<td>2012</td>
<td>127 GeV</td>
<td>$3 \times 10^{-4}$</td>
<td>3.4 $\sigma$</td>
<td>1.9 $\sigma$</td>
</tr>
<tr>
<td>2011+2012</td>
<td>126.5 GeV</td>
<td>$2 \times 10^{-6}$</td>
<td>4.5 $\sigma$</td>
<td>2.4 $\sigma$</td>
</tr>
</tbody>
</table>

Global 2011+2012 (including LEE over 110-150 GeV range): 3.6 $\sigma$
Fitted signal strength

Normalized to SM Higgs expectation at given $m_H (\mu)$

Best-fit value at 126.5 GeV: $\mu = 1.9 \pm 0.5$

Consistent results from various categories within uncertainties (most sensitive ones indicated)
$H \rightarrow ZZ^{(*)} \rightarrow 4l$ (4e, 4$\mu$, 2e2$\mu$)

$110 < m_H < 600$ GeV

- Tiny rate, BUT:
  - mass can be fully reconstructed $\rightarrow$ events should cluster in a (narrow) peak
  - pure: $S/B \sim 1$
- 4 leptons:
  $p_T^{1,2,3,4} > 20,15,10,7-6$ (e-$\mu$) GeV; 50 < $m_{12}$ < 106 GeV; $m_{34} > 17.5-50$ GeV (vs $m_H$)
- Main backgrounds:
  - $ZZ^{(*)}$: irreducible
  - low-mass region $m_H < 2m_Z$: Zbb, Z+jets, $tt$ with two leptons from b-jets or q-jets $\rightarrow l$
  $\rightarrow$ Suppressed with isolation and impact parameter cuts on two softest leptons

Crucial experimental aspects:
- High lepton acceptance, reconstruction & identification efficiency down to lowest $p_T$
- Good lepton energy/momentum resolution
- Good control of reducible backgrounds (Zbb, Z+jets, $tt$) in low-mass region:
  $\rightarrow$ cannot rely on MC alone (theoretical uncertainties, b/q-jet $\rightarrow l$ modeling, ..)
  $\rightarrow$ need to validate MC with data in background-enriched control regions

Main improvements in new analysis:
- kinematic cuts (e.g. on $m_{12}$) optimized/relaxed to increase signal sensitivity at low mass
- increased $e^\pm$ reconstruction and identification efficiency at low $p_T$, increased pile-up robustness, with negligible increase in the reducible backgrounds

$\rightarrow$ Gain 20% (4$\mu$) to 30% (4e) in sensitivity compared to previous analysis
High efficiency for low-\(p_T\) electrons (affected by material) crucial for \(H \rightarrow 4e, 2\mu2e\)

Improved track reconstruction and fitting to recover \(e^\pm\) undergoing hard Brem \(\rightarrow\) achieved \(\sim 98\%\) reconstruction efficiency, flatter vs \(\eta\) and \(E_T\)

Re-optimized \(e^\pm\) identification using pile-up robust variables (e.g. Transition Radiation, calorimeter strips) \(\rightarrow\) achieved \(\sim 95\%\) identification efficiency, \(\sim\) flat vs pile-up; higher rejections of fakes

Results are from \(Z \rightarrow ee\) data and MC tag-and-probe
High efficiency for low-$p_T$ electrons (affected by material) crucial for $H \rightarrow 4e$, $2\mu 2e$

Improved track reconstruction and fitting to recover $e^\pm$ undergoing hard Brem \to achieved $\sim 98\%$ reconstruction efficiency, flatter vs $\eta$ and $E_T$

- Total gain in reconstruction and identification efficiency for electrons from $H \rightarrow 4e$: $\sim 8\%$ average up to $15\%$ at $p_T \sim 7$ GeV
- Total acceptance $\times$ efficiency for $H \rightarrow 4e$: $\sim 23\%$ (+$60\%$ gain)

Re-optimized $e^\pm$ identification using pile-up robust variables (e.g. Transition Radiation, calorimeter strips) \to achieved $\sim 95\%$ identification efficiency, $\sim$ flat vs pile-up; higher rejections of fakes

Results are from $Z \rightarrow ee$ data and MC tag-and-probe
Muons reconstructed down to $p_T = 6$ GeV over $|\eta| < 2.7$

Reconstruction efficiency ~ 97%, ~ flat down to $p_T \sim 6$ GeV and over $|\eta| \sim 2.7$

Total acceptance x efficiency for $H \to 4\mu$: ~ 40% (+45% gain)

$2012 Z \to \mu\mu$ mass peak

$H \to 4\mu$ mass spectrum

Mass resolution ~ 2 GeV
H → 4l mass spectrum after all selections: 2011+2012 data

\( m(4l) > 160 \text{ GeV} \)
(dominated by ZZ background):
147 ± 11 events expected
191 observed

~ 1.3 times more ZZ events in data
than SM prediction → in agreement
with measured ZZ cross-section in 4l
final states at \( \sqrt{s} = 8 \text{ TeV} \)

Measured \( \sigma(ZZ) = 9.3 \pm 1.2 \text{ pb} \)
SM (NLO) \( \sigma(ZZ) = 7.4 \pm 0.4 \text{ pb} \)

Discrepancy has negligible impact on the
low-mass region < 160 GeV
(no change in results if in the fit ZZ is constrained
to its uncertainty or left free)
$H \to 4l$ mass spectrum after all selections: 2011+2012 data

Peak at $m(4l) \sim 90\, \text{GeV}$ from single-resonant $Z \to 4l$ production

Enhanced by relaxing cuts on $m_{12}$, $m_{34}$ and $p_T(\mu_4)$

Observed: 57 events
Expected: $65 \pm 5$
$H \rightarrow 4l$ mass spectrum after all selections: 2011+2012 data
The low-mass region

m_{4l} < 160 GeV:
Observed: 39
Expected: 34 ± 3
Reducible backgrounds from Z+jets, Zbb, tt giving 2 genuine + 2 fake leptons measured using background-enriched, signal-depleted control regions in data.

Typical control regions:
- **leading lepton pair (l_1 l_2)** satisfies all selections
- **sub-leading pair (l_3 l_4)**: no isolation nor impact parameter requirements applied

\[ l_3 l_4 = \mu\mu \rightarrow \text{background dominated by } \text{tt and Zbb in low mass region} \]

\[ l_3 l_4 = ee \rightarrow \text{background dominated by Z+jets in low mass region} \]

- Data well described by MC within uncertainties (ZZ excess at high mass ...)
- Samples of Z+"\(\mu\)" and Z+"\(e\)" used to compare efficiencies of isolation and impact parameter cuts between data and MC \(\rightarrow\) good agreement \(\rightarrow\) MC used to estimate background contamination in signal region
- Several cross-checks made with different control regions \(\rightarrow\) consistent results
4μ candidate with $m_{4\mu} = 125.1$ GeV

$p_T$ (muons) = 36.1, 47.5, 26.4, 71.7 GeV  \(m_{12} = 86.3\) GeV, \(m_{34} = 31.6\) GeV

15 reconstructed vertices
4e candidate with $m_{4e} = 124.6$ GeV

$p_T$ (electrons) = 24.9, 53.9, 61.9, 17.8 GeV  $m_{12} = 70.6$ GeV, $m_{34} = 44.7$ GeV
12 reconstructed vertices
2e2μ candidate with $m_{2e2μ} = 123.9$ GeV

$p_T (e,e,μ,μ) = 18.7, 76, 19.6, 7.9$ GeV, $m(\mu^+\mu^-) = 19.6$ GeV

12 reconstructed vertices
ATLAS: Status of SM Higgs searches, 4/7/2012

Excluded (95% CL): 131-162, 170-460 GeV
Expected: 124-164, 176-500 GeV

2011 data

2012 data

2011+2012 data
Consistency of the data with the background-only expectation

<table>
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<tr>
<th>Data sample</th>
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<th>local significance</th>
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</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>125 GeV</td>
<td>1.1%</td>
<td>2.3 $\sigma$</td>
<td>1.5 $\sigma$</td>
</tr>
<tr>
<td>2012</td>
<td>125.5 GeV</td>
<td>0.4%</td>
<td>2.7 $\sigma$</td>
<td>2.1 $\sigma$</td>
</tr>
<tr>
<td>2011+2012</td>
<td>125 GeV</td>
<td>0.03%</td>
<td>3.4 $\sigma$</td>
<td>2.6 $\sigma$</td>
</tr>
</tbody>
</table>

Global 2011+2012 (including LEE over full 110-141 GeV range): 2.5$\sigma$

Fitted signal strength

Best-fit value at 125 GeV: $\mu = 1.3 \pm 0.6$
Combining all channels together:

- $H \rightarrow \gamma\gamma$, 4l: full 2011 and 2012 datasets (~10.7 fb$^{-1}$) and improved analyses
- all other channels ($H \rightarrow WW(\ast)l\ell\nu$, $H \rightarrow \tau\tau$, $WH \rightarrow l\ell\nu\bar{b}b$, $ZH \rightarrow l\ell\nu \bar{b}b$, $ZH \rightarrow vv\bar{b}b$, $ZZ \rightarrow ll\nu\nu$, $H \rightarrow ZZ \rightarrow ll\ell\ell$, $H \rightarrow WW \rightarrow l\ell\nu\nu\nu$): full 2011 dataset (up to 4.9 fb$^{-1}$)
Combined results: exclusion limits

**Excluded at 95% CL**

- 110-122.6 GeV
- 129.7-558 GeV

**Expected at 95% CL if no signal**

- 110-582 GeV

**Excluded at 99% CL**

- 111.7-121.8 GeV
- 130.7-523 GeV
Combined results: consistency of the data with the background-only expectation and significance of the excess

Excellent consistency (better than 2σ!) of the data with the background-only hypothesis over full mass spectrum except in one region.
Combined results: the excess

Maximum excess observed at

- Local significance (including energy-scale systematics): 5.0 $\sigma$
- Probability of background up-fluctuation: $3 \times 10^{-7}$
- Expected from SM Higgs $m_H = 126.5$ GeV

Expected from SM Higgs at given $m_H$

Obs.  
Exp.

Global significance: 4.1-4.3 $\sigma$ (for LEE over 110-600 or 110-150 GeV)
Combined results: fitted signal strength

Normalized to SM Higgs expectation at given $m_H (\mu)$

Best-fit value at 126.5 GeV: $\mu = 1.2 \pm 0.3$

Good agreement with the expectation for a SM Higgs within the present statistical uncertainty
Combined results: sharing of the excess between years ...

Similar expected significances in both years (more luminosity and larger cross-section in 2012, but only two channels included)

<table>
<thead>
<tr>
<th></th>
<th>Max deviation at $m_H$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011 data</td>
<td>126 GeV</td>
</tr>
<tr>
<td>2012 data</td>
<td>127 GeV</td>
</tr>
<tr>
<td>Observed (exp.) significance</td>
<td>3.5 (3.1) $\sigma$</td>
</tr>
<tr>
<td></td>
<td>4.0 (3.3) $\sigma$</td>
</tr>
</tbody>
</table>

... and over channels

- Sensitivity (expected and observed) driven by “high-resolution” channels ($\gamma\gamma$, $4l$).
- “Low-resolution” channels ($l\nu l\nu$, $bb$, $\tau\tau$) crucial to understand the nature of the “signal”, measure its properties, and assess consistency of the overall picture.
Combined results: consistency of the global picture

Are the 4l and γγ observations consistent?

From 2-dim likelihood fit to signal mass and strength → curves show approximate 68% (full) and 95% (dashed) CL contours

Best-fit signal strengths, normalized to the SM expectations, for all studied channels, at $m_H = 126.5$ GeV,
Evolution of the excess with time

Energy-scale systematics not included
ATLAS plans to submit a paper based on the data presented today at the end of July, at the same time as CMS and to the same journal.

H→ WW(*) → lνlν channel: plan is to include results in the July paper.
H→ ττ, W/ZH → W/Z bb: first results with 2012 data expected later in the Summer.

MORE DATA will be essential to:
- Establish the observation in more channels, look at more exclusive topologies.
- Start to understand the nature and properties of the new particle.

This is just the BEGINNING!

We are entering the era of “Higgs” measurements.
First question: is the observed excess due to the production of a SM Higgs boson?

Note:
- We have only recorded ~ 1/3 of the data expected in 2012.
- The LHC and experiments have already accomplished a lot and much faster than expected.
Conclusions
We have presented preliminary results on searches for a SM Higgs boson using the full data sample recorded so far for $H \rightarrow \gamma\gamma$ and $H \rightarrow 4l$ ($\sqrt{s}=7, 8$ TeV, $\sim 10.7$ fb$^{-1}$) and the 2011 data ($\sqrt{s}=7$ TeV, $\sim 4.9$ fb$^{-1}$) for the other channels.

Impressive accomplishment of the experiment in all its components: first results with full 2012 dataset were available less than one week from “end of data-taking”, with a fraction of good-quality data used for physics of $\sim 90\%$ of the delivered luminosity.

We have looked for a SM Higgs over the mass region 110-600 GeV in 12 channels.

We have excluded at 99% CL the full region up to 523 GeV except $121.8 < m_H < 130.7$ GeV.

We observe an excess of events at $m_H \sim 126.5$ GeV with local significance $5.0 \sigma$.

- The excess is driven by the two high mass resolution channels: $H \rightarrow \gamma\gamma$ (4.5 $\sigma$) and $H \rightarrow ZZ^* \rightarrow 4l$ (3.4 $\sigma$).
- Expected significance from a SM Higgs: 4.6 $\sigma$.
- Fitted signal strength: $1.2 \pm 0.3$ of the SM expectation.

If it is the SM Higgs, it’s very kind of it to be at that mass $\rightarrow$ accessible at LHC in $\gamma\gamma, ZZ^* \rightarrow 4l, WW^* \rightarrow l\nu l\nu, bb, \tau\tau$. 

ATLAS: Status of SM Higgs searches, 4/7/2012.

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These accomplishments are the results of more than 20 years of talented work and extreme dedication by the ATLAS Collaboration, with the continuous support of the Funding Agencies.

More in general, they are the results of the ingenuity, vision and painstaking work of our community (accelerator, instrumentation, computing, physics)

ATLAS today’s main result (preliminary):

5.0 $\sigma$ excess at $m_{H^*} \sim 126.5$