**The ATLAS detector**

**Inner detector:**
- Pixel + SCT: $|\eta| < 2.5$
- TRT: $|\eta| < 2$
- $\sigma_{pT}/p_T \approx 3.8 \cdot 10^{-4} p_T \pm 1\%$

**Calorimetry:**
- LAr + Tile: $|\eta| < 3.2$
- FCAL: $|\eta| < 4.9$
- EM: $\sigma/E \approx 10\%/\sqrt{E} \pm 0.7\%$
- Hadronic: $\sigma/E \approx 50\%/\sqrt{E} \pm 3\%$

**Trigger:**
- 3 levels, rate reduction $40\text{MHz} \Rightarrow <500\text{Hz}$

**Muons:**
- RPC + TGC (trigger): $|\eta| < 2.4$
- MDT + CSC: $|\eta| < 2.7$
- Momentum resolution $<10\%$ up to $1\text{ TeV}$
Atlas data taking in 2011

- Excellent LHC performance
  - integrated luminosity: 5.6 fb$^{-1}$
  - peak luminosity: 3.6 $10^{33}$ cm$^{-2}$s$^{-1}$ → high pile-up
- Excellent ATLAS performance
  - high data taking efficiency (>93%)
Higgs production at the LHC

Higgs production at the LHC

Typical size of uncertainties (exact values depend on $M_H$):

<table>
<thead>
<tr>
<th></th>
<th>$ggF$</th>
<th>$VBF$</th>
<th>$WH/ZH$</th>
<th>$ttH$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>QCD scale:</strong></td>
<td>+12%</td>
<td>±1%</td>
<td>±1%</td>
<td>+3%</td>
</tr>
<tr>
<td><strong>PDF + $\alpha_s$:</strong></td>
<td>±8%</td>
<td>±4%</td>
<td>±4%</td>
<td>±8%</td>
</tr>
</tbody>
</table>

Gluon fusion

Vector boson fusion

Associated production with top pair
Higgs boson decays

- $M_H < 135$ GeV
  - $H \rightarrow \tau\tau$, $H \rightarrow bb$ dominate, $H \rightarrow WW^{(*)}$, $H \rightarrow ZZ^{(*)}$ and $H \rightarrow \gamma\gamma$ (small branching ratio but clean signature) are the most sensitive

- $M_H > 135$ GeV
  - $H \rightarrow WW$ and $H \rightarrow ZZ$ dominates ($H \rightarrow ZZ \rightarrow l\ell\nu\nu$ most sensitive)
Higgs boson search strategies

Summary of ATLAS search analyses:
- cut based strategies
- background estimates relies on data-driven techniques using control regions

<table>
<thead>
<tr>
<th>Channel</th>
<th>m_\text{H} range (GeV)</th>
<th>Background</th>
<th>L (fb^{-1})</th>
<th>s/b</th>
<th>Sensitivity (\sigma_{\text{SM}})</th>
<th>Reference*</th>
</tr>
</thead>
<tbody>
<tr>
<td>\text{Low-m}_\text{H} - good mass resolution</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H\rightarrow\gamma\gamma</td>
<td>110-150</td>
<td>\gamma\gamma, \gamma\gamma, jj</td>
<td>4.9</td>
<td>0.02</td>
<td>1.6-2.6</td>
<td>arXiv:1202.1414</td>
</tr>
<tr>
<td>H\rightarrow\text{ZZ}^{(*)}\rightarrow4\ell</td>
<td>110-600</td>
<td>\text{ZZ}^{(*)}, Z+\text{jets}, tt</td>
<td>4.8</td>
<td>1.5</td>
<td>0.6-9</td>
<td>arXiv:1202.1415</td>
</tr>
<tr>
<td>\text{Low-m}_\text{H} - limited mass resolution</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H\rightarrow\text{WW}^{(*)}\rightarrow\ell\nu\ell\nu</td>
<td>110-600</td>
<td>WW</td>
<td>4.7</td>
<td>0.3</td>
<td>0.2-8</td>
<td>CONF-2012-012</td>
</tr>
<tr>
<td>H\rightarrow\tau\tau</td>
<td>100-150</td>
<td>Z\rightarrow\tau\tau, tt</td>
<td>4.7</td>
<td>0.02</td>
<td>3-12</td>
<td>CONF-2012-014</td>
</tr>
<tr>
<td>VH, H\rightarrow bb</td>
<td>110-130</td>
<td>W/Z+\text{jets}, tt</td>
<td>4.7</td>
<td>10^{-3}</td>
<td>2.5-5</td>
<td>CONF-2012-015</td>
</tr>
<tr>
<td>\text{High-m}_\text{H}</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H\rightarrow\text{ZZ}\rightarrow\ell\nu\ell\nu</td>
<td>200-600</td>
<td>\text{diboson}, tt, Z+\text{jet}</td>
<td>4.7</td>
<td>0.3</td>
<td>0.5-2.5</td>
<td>CONF-2012-016</td>
</tr>
<tr>
<td>H\rightarrow\text{ZZ}\rightarrow\ell\nu jj</td>
<td>200-600</td>
<td>Z+\text{jets}, tt, \text{diboson}</td>
<td>4.7</td>
<td>0.5</td>
<td>0.9-9</td>
<td>CONF-2012-017</td>
</tr>
<tr>
<td>H\rightarrow\text{WW}\rightarrow\ell\nu jj</td>
<td>300-600</td>
<td>W+\text{jets}, tt, multi-\text{jets}</td>
<td>4.7</td>
<td>10^{-3}</td>
<td>1.8-5</td>
<td>CONF-2012-018</td>
</tr>
</tbody>
</table>

(Mainly focusing on the low-m_\text{H} region)

*) CONF-2012-XXX= ATLAS-CONF-2012-XXX
Higgs searches in the high mass region

The three channels sensitive to a high $m_H$ are: $H \rightarrow ZZ \rightarrow llvv$, $H \rightarrow ZZ \rightarrow lljj$, $H \rightarrow WW \rightarrow jjjj$

(WW $\rightarrow jjjj$ in M. Biglietti’s talk)

$H \rightarrow ZZ \rightarrow llvv$:  
most sensitive channel at high $m_H$

Limit extraction based on $m_T$

Exclusion Limit:  
260-460 GeV (Expected)  
320-560 GeV (Observed)

$H \rightarrow ZZ \rightarrow lljj$:  
Limit extraction based on $m_{lljj}$

Exclusion Limit:  
360-400 GeV (Expected)  
300-310; 360-400 GeV (Observed)
H→WW (*)→lvlv

(more in M. Biglietti’s talk)
Most sensitive channel 125<m_H<180 GeV

- Selection criteria (function of n-jet)
  - 2lep. \( p_T > 25(15) \) GeV, \( E_T^{miss} > 45 \) GeV, \( m_{ll} < 50(80) \) GeV,
  \( \Delta \Phi_{ll} < 1.8, \ p^l_T > 45(30) \) GeV, \( p_T^{tot} < 30 \) GeV, b-tag veto

- Background
  - WW \( \rightarrow \Delta \Phi_{ll} \) sidebands
  - top \( \rightarrow \) no tagging requirement
  - Z/W+jet \( \rightarrow \) control sample
    Z peak / reverted lepton ID

Exclusion Limit:
127-234 GeV (Expected)
130-260 GeV (Observed)
The golden channel

- High mass resolution
  - 1.5-2% @ 130 GeV
  - natural width dominates above 350 GeV

- High lepton performances
  - high lepton efficiency down to $p_T$ of 7 GeV
  - independent of pile-up
  - 0.2-2% uncertainty on signal yield
  - 0.6% uncertainty on $m_{4e}$ scale
  - lepton performance well modeled by sim.

$m_{4l} = 124.3$ GeV
$m_{2l} = 74.6, 45.7$ GeV
**Selection**

- 4 leptons, $p_T^{1,2,3,4}>20(7)$ GeV; $|\eta_e|<2.47$ and $|\eta_\mu|<2.7$; track and calorimeter isolation
- $m_{12} < m_Z \pm 15$ GeV $m_{34} > 15-60$ GeV (depending $m_H$)
- selection efficiency at $m_H=130$ (360) GeV: 27(60)% 4$\mu$; 18(52)% 2$\mu$2$e$; 14(45)% 4$e$

**Background**

- $ZZ^{(*)}$ $\rightarrow$ simulation (QCD: 5%; PDF+$\alpha_s$: 4-8%, 10% on $gg\rightarrow ZZ$)
- $Z+\text{jets}$ $\rightarrow$ control region without charge, isolation, and impact parameter criteria on the second lepton pair (40-45% uncertainty)
- top $\rightarrow$ $e^+\mu^-$ pair consistent with $m_Z$ and 2 additional same-flavor leptons
**H→ZZ(*)→4l: results**

**Expected exclusion limit:**
137-157, 184-400 GeV

**Observed exclusion limit:**
134-156, 182-233, 256-265, 268-415 GeV

---

<table>
<thead>
<tr>
<th>number of events in the full mass range</th>
<th>4μ</th>
<th>2e2μ</th>
<th>4e</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected</td>
<td>18.6±2.8</td>
<td>29.7±4.5</td>
<td>13.4±2.0</td>
</tr>
<tr>
<td>Observed</td>
<td>24</td>
<td>30</td>
<td>17</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Local significance of excess</th>
<th>125 GeV</th>
<th>244 GeV</th>
<th>500 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected</td>
<td>1.3σ</td>
<td>3.0σ</td>
<td>1.5σ</td>
</tr>
<tr>
<td>Observed</td>
<td>2.1σ</td>
<td>2.2σ</td>
<td>2.1σ</td>
</tr>
</tbody>
</table>

---

**Expected**

\[
\frac{\sigma}{\sigma_{SM}} = 1.3\sigma \quad 3.0\sigma \quad 1.5\sigma
\]

**Observed**

\[
\frac{\sigma}{\sigma_{SM}} = 2.1\sigma \quad 2.2\sigma \quad 2.1\sigma
\]
H → ZZ(*) → 4l: results

Expected exclusion limit:
137-157, 184-400 GeV

Observed exclusion limit:
134-156, 182-233, 256-265, 268-415 GeV
$H \rightarrow \gamma\gamma$

- **2 photons**
  - $ET(\gamma_1) > 40 \text{ GeV}$
  - $ET(\gamma_2) > 25 \text{ GeV}$

- **Powerful $\gamma$-jet separation**
  - $\eta$-strips (4mm)
  - $\Rightarrow \gamma \text{ vs } \pi^0 \rightarrow \gamma\gamma$

- **High mass resolution:**
  - Excellent energy resolution
  - Long segmentation
    - $\gamma\gamma$ angular separation
    - Z-vertex determination
9 categories: $\eta_\gamma \otimes$ conversion status $\otimes p_T$-thrust$^{\gamma\gamma}$

- Background composition tested on data
  - inverted photon isolation and ID criteria
  - fraction of true $\gamma\gamma = (71 \pm 5)\%$

- Background normalization from fit to $m_{\gamma\gamma}$ spectrum
  - simultaneous fit to the 9 categories
  - Exponential function (free slope and norm.)

- signal $m_{\gamma\gamma}$ mass modeling
  - sum of crystal ball (core)
  - Gaussian function (tails)
  - $\sigma_{CB}(m_H=120 \text{ GeV}) = 1.4-2.3\text{ GeV}$ (category dep.)
  - FWHM ($m_H=120 \text{ GeV}$) = 3.3-5.9GeV (category dep.)
  - mass scale uncertainty: 0.7 GeV ($m_H=120$ GeV)
**H→γγ: results**

- **s/b ≈ 2% @ m_H=125GeV**
  - **H→γγ yield ≈ 70 events**
  - **≈3000 observed events**

- **Main systematics uncertainties:**
  - Expected signal yield: ≈20%
  - **H→γγ mass resolution: ≈14%**
  - **H→γγ p_T modeling: ≈8%**
  - **background modeling: 0.1-7.9 events**

**Observed exclusion limit:**

113-115, 134.5-136 GeV

Unable to exclude the Higgs over the full range due to an excess of events observed at 126 GeV

- **local significance: 2.8σ (expected ~1.3σ)**
- **global 110<m_H<150GeV: 1.5σ**
**W/ZH**(ll,lv,vv)bb

11 categories: (ll,lv) $\otimes$ 4 $p_T$-bin $\oplus$ vv $\otimes$ 3 $E_T$-bin

High $p_T$-bin better s/b ratio

Limit extraction based on invariant mass $m_{bb}$ shape ($m_{lv} = m_W$)

- **Selection Criteria**
  - 2(l)lep., $E_T$-bin, $m_{ll}$ ($m_T$), $\Delta \Phi_{ll}$ at least(exactly) 2 jets; exactly 2 b-tags

- **Background**
  - top $\rightarrow$ shape: sim.; norm.: fit $m_{bb}$>150 GeV
  - W/Z+jet $\rightarrow$ shape: sim.; norm.: fit $m_{bb}$<85 GeV
  - multijet $\rightarrow$ reversed lepton ID; $\Delta \Phi(E_T, p_T)$
H \Rightarrow \tau\tau \Rightarrow (ll4\nu, lT_{had}3\nu, 2T_{had}2\nu)

12 categories: decay channel (ll4\nu, lT_{had}3\nu, 2T_{had}2\nu) and jet mult. (0-, 1-, 2-jet VH, 2-jet VBF)

Limit extraction based on invariant mass $m_{\tau\tau}$ shape (thanks to the collinearity of the $\tau$ decay products)

- **Selection criteria**
  - $2,1,0$lep.$+0,1,2T_{had},E_T^{miss},m_{ll}(m_T),\Delta\Phi_{ll}$, jet mult. 0,1,2

- **Background**
  - $Z \rightarrow \tau\tau$ norm from theory; shape from $Z \rightarrow \mu\mu$
  - fake leptons and $\tau$-jets:
    - ll4\nu: reversed lepton isolation
    - lT_{had}3\nu: same-sign charge
    - lT_{had}T_{had}2\nu: track multiplicity
Combination

\( W/ZH \rightarrow (ll, lv, vv) bb \)

H \( \rightarrow \gamma \gamma \)

H \( \rightarrow \tau \tau \)

Combined

H \( \rightarrow WW (\ast) \rightarrow lvlv \)

H \( \rightarrow ZZ (\ast) \rightarrow llll \)

H \( \rightarrow ZZ \rightarrow llvv \)
Combined exclusion limit

Expected exclusion limit at 95% CL: $120 < m_H < 555$ GeV
Observed exclusion limit at 95% CL: $110 < m_H < 117.5$ GeV
$118.5 < m_H < 122.5$ GeV
$129 < m_H < 539$ GeV

Observed exclusion limit at 99% CL: $130 < m_H < 486$ GeV
Combined exclusion limit: low $m_H$ region

Zoom in the low mass region

Expected exclusion limit at 95% CL: $120 < m_H < 555$ GeV
Observed exclusion limit at 95% CL: $110 < m_H < 117.5$ GeV
$118.5 < m_H < 122.5$ GeV
$129 < m_H < 539$ GeV
Observed exclusion limit at 99% CL: $130 < m_H < 486$ GeV
Combined $p$-value

Under the background-only hypothesis probability to observe such or a higher fluctuation than the observed one

Best fit signal strength $\mu = \sigma / \sigma_{SM}$
Combined p-value: low $m_H$ region

Zoom in the low mass region

Under the background-only hypothesis probability to observe such or a higher fluctuation than the observed one

Best fit signal strength $\mu = \sigma / \sigma_{SM}$

Observed local significance for $m_H = 126$ GeV is $2.5\sigma$ (expected $2.8\sigma$)

Best-fit signal strength at $m_H = 126$ GeV is $\mu = 0.9^{+0.4}_{-0.3}$

Global probability to observe such a fluctuation over 110-600 GeV (110-146 GeV not excluded at 99% CL by LHC) is 30% (10%)
Anatomy of the observed excess

- An excess is observed in the two high resolution channels:
  - $H \rightarrow \gamma\gamma$ (2.8$[1.4]\sigma$) and $H \rightarrow ZZ^{(*)} \rightarrow 4l$ (2.1$[1.4]\sigma$) combined $\Rightarrow$ 3.4$\sigma$ local significance

- No such an excess in $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$ (0.2$\sigma$/$[1.6]\sigma$), $H \rightarrow \tau\tau$, $H \rightarrow bb$
  - All channels combined: observed 2.5[$\text{expected 2.9}\sigma$] local significance
2012 perspectives

- **ATLAS expected sensitivity with** $5 \text{ fb}^{-1} @ 7 \text{ TeV}$ **is 3σ**
- **2 times ATLAS (ATLAS+CMS with 5 fb}^{-1} @ 7 \text{ TeV)** is 4σ
- **Gain in sensitivity from 7→8 \text{ TeV}** is 10% in significance (equivalent to 20% in luminosity)
- **Need about 12 \text{ fb}^{-1} @ 8 \text{ TeV}** for a 5σ discovery per experiment (after analysis optimization)
Conclusions

• ATLAS has performed great in 2011

• thanks to the excellent performance of LHC, ATLAS has collected 5.3fb⁻¹ of data

• ATLAS has confined the possible presence of a SM Higgs boson to small regions: $117.5 < m_H < 118.5$ GeV or $122.5 < m_H < 129$ GeV at 95% CL

• An excess is seen around 126 GeV with a (local) significance of $2.5\sigma$, however both signal and background only hypothesis are still alive

• More data are needed for a conclusive statement
Additional material
$H \rightarrow \gamma \gamma$: $m_{\gamma \gamma}$ in the 9 categories

- Unconverted central, low $p_T$
- Unconverted central, high $p_T$
- Unconverted rest, low $p_T$
- Unconverted rest, high $p_T$
- Converted central, low $p_T$
- Converted central, high $p_T$
- Converted rest, low $p_T$
- Converted rest, high $p_T$
- Unconverted transition
Search for the Standard Model Higgs Boson with the ATLAS detector

H→γγ: background modeling
H→ZZ(*)→4l: mass distributions
H→WW→lvjj

6 categories (e, μ)⊗(0-, 1-, 2-jet VBF)

Limit extraction based on invariant mass $m_{\nu j}$ shape ($m_{\nu} = m_{W}$)

- Background modeled from fit to lvjj mass spectrum
- Main systematics
  - jet energy scale and resolution (10-20%)
  - pileup (10-15%)
**H\rightarrow ZZ\rightarrow ll\nu\nu**

Most sensitive channel in high Higgs mass range, 4 categories (ee, \(\mu\mu\)) × (low, high-pileup)

Limit extraction based on transverse mass \(m_T\) shape \(\Rightarrow\) dependent on pile-up due to \(E_T^{miss}\)

- **Different selection for** \(M_H<280\) GeV & \(M_H>280\) GeV
  - cuts on: \(E_T^{miss}, m_\ell, \Delta\Phi_\ell, and \Delta\Phi(p_T^{miss}, p_T^{\ell})\) (boost), \(\Delta\Phi(p_T^{miss}, p_T^{jet})\) background rejection

- **Background**
  - ZZ \(\Rightarrow\) simulation (11\% norm. uncertainty)
  - WZ \(\Rightarrow\) 3-lepton events
  - top \(\Rightarrow\) e\(\mu\) events & \(m_\ell\) sidebands
  - W/Z+jet \(\Rightarrow\) ee, e\(\mu\) same-sign & low \(\Delta\Phi(p_T^{miss}, p_T^{jet})\)

Exclusion Limit: 260-460 GeV (Expected)
320-560 GeV (Observed)
H → ZZ → lljj

2 categories (>2 b-tag, 2 b-tag)

Limit extraction based on transverse mass $m_{lljj}$

- Different selection for $M_H < 300$ GeV & $M_H > 300$ GeV
  - cuts on: $E_T^{\text{miss}}$, $m_{ll}$, $m_{jj}$, $\Delta R_{jj}$ and $\Delta \Phi_{ll}$, $\Delta \Phi_{jj} < \pi/2$ (boost),

- Background
  - $Z$+jet $\rightarrow$ $m_{ll}$ sidebands
  - diboson $\rightarrow$ simulation (11% norm. uncertainty)
  - top $\rightarrow$ $m_{ll}$ sidebands
  - multi-jet $\rightarrow$ revert lepton ID (50% uncertainty)

Exclusion: 360-400 GeV (Expected)
300-310; 360-400 GeV (Observed)
Signal strength in individual channels
# Detector related systematic uncertainties

<table>
<thead>
<tr>
<th>Physics object</th>
<th>Source</th>
<th>Uncertainty on signal yield</th>
<th>Most affected channels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>luminosity</td>
<td>3.9%</td>
<td></td>
</tr>
<tr>
<td>Photon</td>
<td>efficiency</td>
<td>11%</td>
<td>$\gamma\gamma$</td>
</tr>
<tr>
<td></td>
<td>efficiency</td>
<td>&lt;3%</td>
<td>$4\ell$</td>
</tr>
<tr>
<td></td>
<td>energy scale</td>
<td>&lt;1%</td>
<td>$4\ell$</td>
</tr>
<tr>
<td></td>
<td>energy resolution</td>
<td>&lt;0.5%</td>
<td></td>
</tr>
<tr>
<td>Muon</td>
<td>efficiency</td>
<td>&lt;1%</td>
<td>$4\ell$</td>
</tr>
<tr>
<td></td>
<td>momentum resolution</td>
<td>&lt;1%</td>
<td></td>
</tr>
<tr>
<td>Jet</td>
<td>energy scale</td>
<td>up to 12%</td>
<td>$\tau\tau$, $b\bar{b}$, $lljj$, $lvjj$</td>
</tr>
<tr>
<td></td>
<td>resolution</td>
<td>up to 20%</td>
<td></td>
</tr>
<tr>
<td>b-tagging</td>
<td>efficiency</td>
<td>up to 15%</td>
<td>$bb$</td>
</tr>
<tr>
<td>$\tau$-jet</td>
<td>efficiency</td>
<td>up to 8%</td>
<td>$\tau\tau$</td>
</tr>
</tbody>
</table>