Search for the Standard Model Higgs Boson in $H \rightarrow WW \rightarrow l\nu l\nu$ with the ATLAS experiment
• SM Higgs Boson production and decay

• Analysis based on $4.7 \text{ fb}^{-1}$:

→ Introduction and selection

→ Background estimates
  - WW control region
  - ttbar and single top
  - Z+jets (ABCD method)
  - data-driven W+jets estimate

→ Systematic uncertainties

• Results and limits
Introduction

- Gluon fusion is the dominant mechanism for Higgs Boson production at present hadron colliders.
- Second most important process: vector boson fusion (VBF).
**Introduction**

\[ H \rightarrow WW \rightarrow l\nu l\nu \]

- very important at intermediate mass range
- clear signature of two high-\(p_T\), opposite sign leptons and large transverse missing energy
- challenging because complete reconstruction of invariant mass of the final system not possible
- advantage of VBF signature:
  Two hard jets in opposite detector hemispheres
- Important backgrounds are:
  - irreducible WW SM production
  - but also W+jets, Drell-Yan and Top (tt + single top) process
Introduction

Analysis presented is based on data corresponding to an integrated luminosity of $5.25 \text{ fb}^{-1}$ recorded by ATLAS during stable beams and for pp collisions at 7 TeV centre-of-mass energy in 2011.
Introduction

Pile-up challenge:
- 50 ns bunch spacing for ~all 2011 data
  - Substantial in- and out-of-time pileup
    average number of pileup events: $\mu \approx 6$, $\mu \approx 11.6$

Mean Number of Interactions per Crossing:
- data taken before and after the September Technical Stop where the $\beta^*$ was reduced from 1.5 m to 1.0 m.
- $\beta^*$ is the distance to the interaction point (IP) where the beam width has doubled
Event selection

Search for the Higgs boson in the $H\rightarrow WW^{*}\rightarrow l\nu l\nu$ decay mode with 4.7 $fb^{-1}$ of ATLAS data at $\sqrt{s} = 7$ TeV (ATLAS-CONF-2012-012) [link: http://cdsweb.cern.ch/record/1429660]

- Exactly two isolated leptons with opposite charge, leading lepton $p_T > 25$ GeV and subleading lepton $p_T > 15$ GeV
- Missing transverse energy
- 0, 1 or more then 2 accompanying jets

**Missing transverse energy $E_T^{\text{miss}}$**:

- Use cut on $E_T^{\text{miss}}(\text{rel})$ instead of normal $E_T^{\text{miss}}$
- Less sensitive to lepton momentum mis-measurement
- Rejects events where the $E_T^{\text{miss}}$ is pointing along the direction of a lepton or jet:

\[
E_T^{\text{miss}}(\text{rel}) = \begin{cases} 
E_T^{\text{miss}} & \text{if } \min[\Delta\phi(E_T^{\text{miss}}, l), \Delta\phi(E_T^{\text{miss}}, j)] > \pi/2 \\
E_T^{\text{miss}} \times \sin(\Delta\phi) & \text{if } \min[\Delta\phi(E_T^{\text{miss}}, l), \Delta\phi(E_T^{\text{miss}}, j)] < \pi/2 
\end{cases}
\]
Event selection

Search for the Higgs boson in the H->WW*->l_l_l_v decay mode with 4.7 fb$^{-1}$ of ATLAS data at $\sqrt{s} = 7$ TeV (ATLAS-CONF-2012-012) [link: http://cdsweb.cern.ch/record/1429660]

- Exactly two isolated leptons with opposite charge, leading lepton $p_T > 25$ GeV and subleading lepton $p_T > 15$ GeV
- missing transverse energy
- 0, 1 or more then 2 accompanying jets

**Background processes:**
- SM WW process is irreducible background
- Top (tt and single top) process
- Z/\gamma^*+jets events
- W+jets events
Event selection

- Single electron or muon trigger (p_T ≥ 20 GeV threshold)
- at least one primary vertex with at least 3 tracks

Event Selection

- Exactly two tight and isolated leptons, leading lepton p_T > 25 GeV
  subleading lepton p_T > 15 GeV
- Opposite charge
- m_{ll} > 12 GeV (10 GeV) for ee/μμ, (eμ)

Common selection
0-jet, 1-jet, 2-jets channel

Event selection histograms for ee, μμ, and eμ channels.
Event Selection

- Exactly two tight and isolated leptons, leading lepton $p_T > 25$ GeV
  subleading lepton $p_T > 15$ GeV
- Opposite charge, $m_{ll} > 12$ GeV (10 GeV) for $ee/\mu\mu, (e\mu)$
- $Z$ veto: $|m_{ll} - m_Z| > 15$ GeV for $ee/\mu\mu$

Common selection
0-jet, 1-jet, 2-jets channel
Event Selection

- Exactly two tight and isolated leptons, leading lepton $p_T > 25$ GeV, subleading lepton $p_T > 15$ GeV.
- Opposite charge, $m_{ll} > 12$ GeV (10 GeV) for $ee/\mu\mu$, $(e\mu)$.
- $Z$ veto: $|m_{ll} - m_Z| > 15$ GeV for $ee/\mu\mu$.
- $E^{\text{miss}}_{T,\text{rel}} > 45$ (25) GeV for $ee/\mu\mu$, $(e\mu)$.

**Common selection**

0-jet, 1-jet, 2-jets channel.
Event Selection

- Exactly two tight and isolated leptons, leading lepton $p_T > 25$ GeV, subleading lepton $p_T > 15$ GeV
- Opposite charge, $m_{ll} > 12$ GeV (10 GeV) for ee/$\mu\mu$, (e$\mu$)
- $Z$ veto: $|m_{ll} - m_Z| > 15$ GeV for ee/$\mu\mu$
- $E_T^{miss} > 45$ (25) GeV for ee/$\mu\mu$, (e$\mu$)

Common selection
0-jet, 1-jet, 2-jets channel

0jet bin: $WW$ and $Z$+jets are dominant backgrounds
1jet bin: Top is the dominant background
≥ 2jet bin: Top is the dominant background
Event selection

**Event Selection**

- Exactly two tight and isolated leptons, leading lepton $p_T > 25$ GeV
  subleading lepton $p_T > 15$ GeV

- Opposite charge, $m_{ll} > 12$ GeV (10 GeV) for ee/μμ, (eμ)

- Z veto: $|m_{ll} - m_Z| > 15$ GeV for ee/μμ

- $E_{T,rel}^{miss} > 45$ (25) GeV for ee/μμ, (eμ)

<table>
<thead>
<tr>
<th>0 jet:</th>
<th>1 jet:</th>
<th>≥ 2 jets:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet veto</td>
<td>b-jet veto</td>
<td>Central jet veto ($p_T &gt; 25$ GeV, $</td>
</tr>
<tr>
<td>$p_T(\ell\ell) &gt; 30$ (45) GeV</td>
<td>$p_T(\text{tot})^* &lt; 30$ GeV</td>
<td>b-jet veto</td>
</tr>
<tr>
<td>for eμ (ee/μμ)</td>
<td>$Z \rightarrow \tau\tau$ veto</td>
<td>$\eta (j1)^*\eta (j2) &lt; 0$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\Delta\eta (j1,j2) &gt; 3.8$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$m_{jj} &gt; 500$ GeV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$p_T(\text{tot})^* &lt; 30$ GeV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$Z \rightarrow \tau\tau$ veto</td>
</tr>
</tbody>
</table>

* $p_T(\text{tot})^*$: Vector sum of transverse momenta of the jets, the two leptons and MET

+ Common topological selection
Event selection

0 jet :

Jet veto

$p_T^{(ll)} > 30 \text{ (45) GeV}$

for $e\mu$ ($ee/\mu\mu$)

reduction of $Z+jets$ background

1 jet :

b-jet veto

$p_T^{(tot)} < 30 \text{ GeV}$

to suppress background events

with jets with $p_T$ below threshold

$Z \rightarrow \tau\tau$ veto
Event selection

Common topological selection:

Three signal regions are defined to optimize the selection for high signal acceptance

<table>
<thead>
<tr>
<th>Low mass selection</th>
<th>Intermediate mass selection</th>
<th>High mass selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_{H} &lt; 200$ GeV</td>
<td>$m_{H} = 200$ GeV – $300$ GeV</td>
<td>$m_{H} &gt; 300$ GeV</td>
</tr>
<tr>
<td>$m_{\ll} &lt; 50$ GeV for 0,1 jet</td>
<td>$m_{\ll} &lt; 150$ GeV</td>
<td>---</td>
</tr>
<tr>
<td>$m_{\ll} &lt; 80$ GeV for $\geq 2$ jets</td>
<td></td>
<td>---</td>
</tr>
<tr>
<td>$\Delta \phi(\ell\ell) &lt; 1.8$</td>
<td>$\Delta \phi(\ell\ell) &lt; 1.8$</td>
<td>---</td>
</tr>
</tbody>
</table>

- Azimuthal separation between signal leptons $\Delta \phi(\ell\ell)$ is a powerful discriminant against WW

- Leptons tend to emerge from interaction point in the same direction due to spin correlations in the WW system arising from the spin-0 nature of the Higgs boson
• SM Higgs production and decay

• Analysis based on $4.7 \text{ fb}^{-1}$:
  
  → Introduction and selection

  → Background estimates
    - WW control region
    - ttbar and single top
    - Z+jets (ABCD method)
    - data-driven W+jets estimate

  → Systematic uncertainties

• Results and limits
**WW control region** is defined by the same cuts as for the signal region, but:

- $m_{ll} > 80\text{ GeV}$ for $m_H < 200\text{ GeV}$
- For $ee/\mu\mu$, $|m_{ll} - m_Z| > 15\text{ GeV}$
  $\rightarrow$ effectively $m_{ll} > 105\text{ GeV}$
- Cuts on $\Delta\phi(\ell\ell)$ and $M_T$ are removed

- WW background is normalized by a simultaneous fit to numbers of observed events in the signal and control region

<table>
<thead>
<tr>
<th>WW CR</th>
<th>Signal</th>
<th>WW</th>
<th>$WZ/ZZ/W\gamma$</th>
<th>$tt$</th>
<th>$tW/tb/tq\bar{b}$</th>
<th>$Z/\gamma^*+\text{jets}$</th>
<th>$W+\text{jets}$</th>
<th>Total Bkg</th>
<th>Obs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-jet</td>
<td>0.1 ± 0.1</td>
<td>465 ± 3</td>
<td>25 ± 2</td>
<td>85 ± 2</td>
<td>41 ± 2</td>
<td>9 ± 2</td>
<td>48 ± 2</td>
<td>673 ± 5</td>
<td>698</td>
</tr>
<tr>
<td>1-jet</td>
<td>0.1 ± 0.1</td>
<td>126 ± 2</td>
<td>10 ± 1</td>
<td>83 ± 2</td>
<td>33 ± 2</td>
<td>9 ± 2</td>
<td>11 ± 1</td>
<td>272 ± 4</td>
<td>269</td>
</tr>
</tbody>
</table>

- Only statistical uncertainties associated with the number of events are shown
Top contribution in 0-jet channel: \( \sim 5\% \)

Number of top background events in the signal region estimated from:

- Top background yield in dilepton+\( E_T^{\text{miss}} \) + inclusive jets data
- Jet veto efficiency measured by b-tag control region
  (with a MC based correction to account for single top events)

\[
N_{\text{Est.}}^{\text{top}}(\ell\ell + E_T^{\text{miss}}, 0j) \approx N_{\text{Data}}^{\text{top}}(\ell\ell + E_T^{\text{miss}}) \times P_2^{\text{MC}} \times \left( \frac{P_1^{\text{Btag, data}}}{P_1^{\text{Btag, MC}}} \right)^2
\]

- Jet-veto survival probability \( P_1^{\text{Btag}} = \frac{N_{0j}^{\text{Btag}}}{N_{\text{all jets}}^{\text{Btag}}} \)
is determined from b-tagged sample
- \( P_2 \): fraction of top events passing the jet veto cut
**Top contribution in 1-jet-channel:** largest background

- **Definition of control region:**
  - b-jet veto is reversed
  - cuts on $m_{ll}$ and $\Delta \phi(\ell\ell)$ are removed

- Top background MC prediction is normalized to the data using the control sample

- Fitted normalization propagates to both WW control region and signal region

- Total uncertainty on estimated top background in signal region is $\sim 30\%$

<table>
<thead>
<tr>
<th></th>
<th>Top CR</th>
<th>Signal</th>
<th>WW</th>
<th>WZ/ZZ/Wγ</th>
<th>tt</th>
<th>tW/tb/tqb</th>
<th>Z/γ*+jets</th>
<th>W+jets</th>
<th>Total Bkg</th>
<th>Obs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-jet</td>
<td>1.1 ±0.1</td>
<td>21 ±1</td>
<td>1.5 ±0.2</td>
<td>422 ±4</td>
<td>165 ±3</td>
<td>6 ±2</td>
<td>negl.</td>
<td>615 ±6</td>
<td>675</td>
<td></td>
</tr>
</tbody>
</table>

- Only statistical uncertainties associated with the number of events are shown
The W+jets background contribution is estimated using a data control sample of events with two leptons:

- one lepton passing the identification and isolation criteria used in the analysis
- one lepton failing the above mentioned criteria but passing the loosened ones

**Estimated W+jets background**

\[
N_{\text{one id(from W)+one fake}} = \frac{N_{\text{id obj}}}{N_{\text{anti-identified}}} \times N_{\text{one id(from W)+one fakeable}}
\]

**Fake factor (Observable)**

W+jets control region to determine normalization

Apply same kinematic selection as signal region

The prediction of the W+jets contamination in the signal region is determined by scaling down the number of events in the data control sample by a normalization “fake factor”.
Summary: Data Driven Background Estimation

Backgrounds either partially or fully determined from data

\[ N_{\text{Signal Region}} = \alpha \times N_{\text{Control Region}} \]

Signal Region
- Higgs (VBF + ggF)
- WW
- \(tt + \text{single } t\)
- W jets

0j: estimate top background from b-jet survival probability

\[ \alpha_{WW} = \frac{N_{\text{WW}}^{\text{sig}}}{N_{\text{WW}}^{\text{ctrl}}} \]
\[ \alpha_{tt} = \frac{N_{\text{tt}}^{\text{sig}}}{N_{\text{tt}}^{\text{ctrl}}} \]
\[ \alpha_{Wj} = \frac{N_{Wj}^{\text{sig}}}{N_{Wj}^{\text{ctrl}}} \]

WW control
- WW
- \(tt + \text{single } t\)
- W jets

Top control
- \(tt + \text{single } t\)

\[ \beta_{tt} = \frac{N_{\text{top}}^{\text{ctrl}}}{N_{\text{top}}^{\text{tt}}} \]
\[ \beta_{Wj} = \frac{N_{Wj}^{\text{ctrl}}}{N_{Wj}^{\text{Wj}}} \]

1j: remove topological cuts, invert \(m_\parallel\) cuts

require 2nd lepton to fail tight but pass loose selection

remove \(\Delta \phi\) and \(m_T\) cuts,
• SM Higgs production and decay

• Analysis based on $4.7 \text{ fb}^{-1}$:
  → Introduction and selection
  → Background estimates
    - WW control region
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    - data-driven W+jets estimate

→ Systematic uncertainties

• Results and limits
Systematical uncertainties

Experimental uncertainties:

- Related to jet energy scale < 14% for jets with $p_T > 25$ GeV and $|\eta| < 4.5$
- Additional contributions from pile-up < 5% for jets with $p_T > 25$ GeV
- Electron efficiency uncertainties: 2-5%
- Electron/Muon momentum scale and resolution uncertainties < 1%
- Uncertainty on b-tagging efficiency 5% - 14% depending on jet $p_T$
Systematical uncertainties

Uncertainties on background estimates based on control regions:

<table>
<thead>
<tr>
<th>Total uncertainty on predicted background in signal region</th>
<th>0-jet channel</th>
<th>1-jet channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>WW background</td>
<td>10 %</td>
<td>24 %</td>
</tr>
<tr>
<td>Top background</td>
<td>23 %</td>
<td>30 %</td>
</tr>
<tr>
<td>(1 jet and ≥ 2 jets channel)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z/γ*+jets</td>
<td>56 %</td>
<td>25 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>W+jets</th>
<th>p_T &lt; 30 GeV</th>
<th>p_T &gt; 30 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>total uncertainty on fake factor</td>
<td>30-50 %</td>
<td>100 %</td>
</tr>
</tbody>
</table>
Systematical uncertainties

Theoretical uncertainties on signal production cross-section:

- **QCD renormalisation and factorisation scales are varied up and down by a factor of 2** independent uncertainties on ggF signal production are assumed for the inclusive cross section and the cross-section with at least one or two jets

  \[ \text{relative uncertainties depend on } m_H : \begin{align*}
  25 \% & \text{ at } 125 \text{ GeV for } H + 0\text{jet} \\
  37 \% & \text{ at } 125 \text{ GeV for } H + 1\text{jet}
  \end{align*} \]

- Uncertainty on VBF signal cross section in the H + 2jet channel and on acceptance associated with the jet veto requirement is around 5 %

- Uncertainty on cross-section of events produced via ggF in the H + 2 jet channel is around 25 %

Additional uncertainty due to Higgs line shape description in the POWHEG Monte Carlo

- Added in quadrature for both the ggF and VBF channel: \( 150 \% \times (m_H / 1 \text{ TeV})^3 \)

Relative PDF uncertainty on dominant ggF signal process is about 8 %
Outline

• SM Higgs production and decay

• Analysis based on 4.7 fb⁻¹:
  → Introduction and selection
  → Background estimates
    - WW control region
    - ttbar and single top
    - Z+jets (ABCD method)
    - data-driven W+jets estimate
  → Systematic uncertainties

• Results and limits
H+0 jet and H+1 jet analysis, ee + μμ + eμ

\[ m_T \text{ after all cuts} \]

signal \( m_H = 125 \text{ GeV} \)

\[ M_T = \sqrt{(E_{T}^{ll})^2 + (E_{T}^{\mu\mu})^2 - (p_{T}^{\ell\ell} + p_{T}^{miss})^2} \]
H+0 jet and H+1 jet analysis, ee + μμ + eμ

\[ m_T \text{ after all cuts} \]

signal \( m_H = 240 \text{ GeV} \)

\[
M_T = \sqrt{(E_T^{ll})^2 + (E_T^{\mu\mu})^2} - (p_T^{\ell\ell} + p_T^{miss})^2
\]
Final event numbers

<table>
<thead>
<tr>
<th></th>
<th>Signal</th>
<th>WW</th>
<th>WZ/ZZ/Wγ</th>
<th>t\bar{t}</th>
<th>tW/tb/tq\bar{b}</th>
<th>Z/γ* + jets</th>
<th>W + jets</th>
<th>Total Bkg.</th>
<th>Obs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-jet</td>
<td>(m_H = 125) GeV</td>
<td>25 ± 7</td>
<td>110 ± 12</td>
<td>12 ± 3</td>
<td>7 ± 2</td>
<td>5 ± 2</td>
<td>13 ± 8</td>
<td>27 ± 16</td>
<td>173 ± 22</td>
</tr>
<tr>
<td></td>
<td>(m_H = 240) GeV</td>
<td>60 ± 17</td>
<td>432 ± 49</td>
<td>24 ± 3</td>
<td>68 ± 15</td>
<td>39 ± 9</td>
<td>8 ± 2</td>
<td>36 ± 24</td>
<td>607 ± 63</td>
</tr>
<tr>
<td>1-jet</td>
<td>(m_H = 125) GeV</td>
<td>6 ± 2</td>
<td>18 ± 3</td>
<td>6 ± 3</td>
<td>7 ± 2</td>
<td>4 ± 2</td>
<td>6 ± 1</td>
<td>5 ± 3</td>
<td>45 ± 7</td>
</tr>
<tr>
<td></td>
<td>(m_H = 240) GeV</td>
<td>23 ± 9</td>
<td>99 ± 22</td>
<td>8 ± 1</td>
<td>73 ± 27</td>
<td>35 ± 19</td>
<td>6 ± 2</td>
<td>7 ± 7</td>
<td>229 ± 55</td>
</tr>
<tr>
<td>2-jet</td>
<td>(m_H = 125) GeV</td>
<td>0.4 ± 0.2</td>
<td>0.3 ± 0.2</td>
<td>neglig.</td>
<td>0.2 ± 0.1</td>
<td>neglig.</td>
<td>0.0 ± 0.1</td>
<td>neglig.</td>
<td>0.5 ± 0.2</td>
</tr>
<tr>
<td></td>
<td>(m_H = 240) GeV</td>
<td>2.5 ± 0.6</td>
<td>1.1 ± 0.7</td>
<td>0.1 ± 0.1</td>
<td>2.6 ± 1.3</td>
<td>0.3 ± 0.3</td>
<td>neglig.</td>
<td>0.1 ± 0.1</td>
<td>4.2 ± 1.7</td>
</tr>
</tbody>
</table>

The expected numbers of signal (\(m_H = 125\) GeV and 240 GeV) and background events after the full low \(m_H\) and intermediate \(m_H\) selections, including a cut on the transverse mass of \(0.75 m_H < m_T < m_H\) for \(m_H = 125\) GeV and \(0.6 m_H < m_T < m_H\) for \(m_H = 240\) GeV.

The uncertainties shown are the combination of the statistical and all systematic uncertainties, taking into account the constraints from control samples.
### Final event numbers

<table>
<thead>
<tr>
<th></th>
<th>Signal</th>
<th>$WW$</th>
<th>$WZ/ZZ/W\gamma$</th>
<th>$t\bar{t}$</th>
<th>$tW/tb/tqb$</th>
<th>$Z/\gamma^* + \text{jets}$</th>
<th>$W + \text{jets}$</th>
<th>Total Bkg.</th>
<th>Obs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_H = 125 \text{ GeV}$</td>
<td>$25 \pm 7$</td>
<td>$110 \pm 12$</td>
<td>$12 \pm 3$</td>
<td>$7 \pm 2$</td>
<td>$5 \pm 2$</td>
<td>$13 \pm 8$</td>
<td>$27 \pm 16$</td>
<td>$173 \pm 22$</td>
<td>$174$</td>
</tr>
<tr>
<td>$m_H = 240 \text{ GeV}$</td>
<td>$60 \pm 17$</td>
<td>$432 \pm 49$</td>
<td>$24 \pm 3$</td>
<td>$68 \pm 15$</td>
<td>$39 \pm 9$</td>
<td>$8 \pm 2$</td>
<td>$36 \pm 24$</td>
<td>$607 \pm 63$</td>
<td>$629$</td>
</tr>
<tr>
<td>$m_H = 125 \text{ GeV}$</td>
<td>$6 \pm 2$</td>
<td>$18 \pm 3$</td>
<td>$6 \pm 3$</td>
<td>$7 \pm 2$</td>
<td>$4 \pm 2$</td>
<td>$6 \pm 1$</td>
<td>$5 \pm 3$</td>
<td>$45 \pm 7$</td>
<td>$56$</td>
</tr>
<tr>
<td>$m_H = 240 \text{ GeV}$</td>
<td>$23 \pm 9$</td>
<td>$99 \pm 22$</td>
<td>$8 \pm 1$</td>
<td>$73 \pm 27$</td>
<td>$35 \pm 19$</td>
<td>$6 \pm 2$</td>
<td>$7 \pm 7$</td>
<td>$229 \pm 55$</td>
<td>$232$</td>
</tr>
<tr>
<td>$m_H = 125 \text{ GeV}$</td>
<td>$0.4 \pm 0.2$</td>
<td>$0.3 \pm 0.2$</td>
<td>negl.</td>
<td>$0.2 \pm 0.1$</td>
<td>negl.</td>
<td>$0.0 \pm 0.1$</td>
<td>negl.</td>
<td>$0.5 \pm 0.2$</td>
<td>$0$</td>
</tr>
<tr>
<td>$m_H = 240 \text{ GeV}$</td>
<td>$2.5 \pm 0.6$</td>
<td>$1.1 \pm 0.7$</td>
<td>$0.1 \pm 0.1$</td>
<td>$2.6 \pm 1.3$</td>
<td>$0.3 \pm 0.3$</td>
<td>negl.</td>
<td>$0.1 \pm 0.1$</td>
<td>$4.2 \pm 1.7$</td>
<td>$2$</td>
</tr>
</tbody>
</table>

The expected numbers of signal ($m_H = 125 \text{ GeV}$ and $240 \text{ GeV}$) and background events after the full low $m_H$ and intermediate $m_H$ selections, including a cut on the transverse mass of $0.75 \ m_T < m_H$ for $m_H = 125 \text{ GeV}$ and $0.6 \ m_T < m_H$ for $m_H = 240 \text{ GeV}$.

The uncertainties shown are the combination of the statistical and all systematic uncertainties, taking into account the constraints from control samples.
The expected numbers of signal ($m_H = 125\text{ GeV}$ and $240\text{ GeV}$) and background events after the full low $m_H$ and intermediate $m_H$ selections, including a cut on the transverse mass of $0.75 m_H < m_T < m_H$ for $m_H = 125\text{ GeV}$ and $0.6 m_H < m_T < m_H$ for $m_H = 240\text{ GeV}$.

The uncertainties shown are the combination of the statistical and all systematic uncertainties, taking into account the constraints from control samples.
The expected (dashed) and observed (solid) 95% CL upper limits on the cross section, normalized to the Standard Model cross section, as a function of the Higgs boson mass. Expected limits are given for the scenario where there is no signal.

In absence of a signal, one would expect to exclude a SM Higgs boson at 95 % CL in the range of: \( 127 < m_H < 234 \text{ GeV} \)

Mass interval excluded by measurement: \( 130 < m_H < 260 \text{ GeV} \)
Local p-value

The expected (dashed) and observed (solid) probabilities for the background-only scenario as a function of $m_H$.
Signal strength

Fitted signal strength parameter as a function of $m_H$ for the whole mass range

$\mu = 0.17 \pm 0.66$ at 125 GeV
Summary

- H->WW*-lℓνν analysis based on data corresponding to 4.7 fb⁻¹ of integrated luminosity recorded by ATLAS in pp collisions at √s = 7 TeV in 2011 has been presented.

- Background estimates have been shown.

- No significant excess of events over the expected background is observed.

- The observations exclude the presence of a Standard Model Higgs boson with a mass 130 < m_H < 260 GeV at 95% confidence level (expected limit in case of no signal: 127 < m_H < 234 GeV).

- Results for full 2011 dataset will be published in a paper soon.
Z + jets events mimic signal of 2 leptons and large (mismeasured) $E_T^{\text{miss}}$

- Use ‘ABCD’ method to estimate contribution, using 2D space of $E_{T,\text{Rel}}^{\text{miss}}$ and $m_{ll}$

$$A^\text{est} = \frac{C^\text{data}}{D^\text{data}} \times B^\text{data}$$

- Non-$Z/\gamma^*+$jets contributions subtracted using MC
0jet channel, ee + μμ + eμ

After jet veto

$H \rightarrow WW^{(*)} \rightarrow l\ell νν + 0 \text{ jets}$

$\ell = e, \mu$

$\sqrt{s} = 7\, \text{TeV}$, $\int L\, dt = 4.7\, \text{fb}^{-1}$

$H \rightarrow WW^{(*)} \rightarrow l\ell νν + 0 \text{ jets}$

$\ell = e, \mu$

$\sqrt{s} = 7\, \text{TeV}$, $\int L\, dt = 4.7\, \text{fb}^{-1}$

$H$ + 0-jet Channel

Jet Veto

$p_{T}^{\ell\ell} > 30\, \text{GeV}$

$m_{\ell\ell} < 50\, \text{GeV}$

$\Delta\phi_{\ell\ell} < 1.8$

$0.75\, m_{H} < m_{T} < m_{H}$
1 jet channel, ee + μμ + eμ

Before $M_{ll}$ cut

$H + 1$-jet Channel

1 jet

$b$-jet veto

$|p_T^{tot}| < 30$ GeV

$Z \rightarrow \tau\tau$ veto

$m_{\ell\ell} < 50$ GeV

$\Delta \phi_{\ell\ell} < 1.8$

$0.75 m_H < m_T < m_H$
## Cutflow

### Expected numbers of signal and background events for low $m_H$ selection

<table>
<thead>
<tr>
<th>Event Selection</th>
<th>Signal</th>
<th>WW</th>
<th>WZ/ZZ/Wγ</th>
<th>t$\bar{t}$</th>
<th>tW/tb/tq$b$</th>
<th>Z/γ* + jets</th>
<th>W + jets</th>
<th>Total Bkg.</th>
<th>Obs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H + 0$-jet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jet Veto</td>
<td>54.5 ± 0.2</td>
<td>1285 ± 79</td>
<td>106 ± 6</td>
<td>175 ± 12</td>
<td>95 ± 7</td>
<td>1038 ± 28</td>
<td>217 ± 4</td>
<td>2916 ± 115</td>
<td>2851</td>
</tr>
<tr>
<td>$m_{\ell\ell} &lt; 50$ GeV</td>
<td>43.8 ± 0.2</td>
<td>316 ± 20</td>
<td>48 ± 5</td>
<td>30 ± 2</td>
<td>19 ± 2</td>
<td>157 ± 13</td>
<td>69 ± 2</td>
<td>640 ± 34</td>
<td>644</td>
</tr>
<tr>
<td>$p_T^{\ell\ell}$ cut</td>
<td>38.8 ± 0.2</td>
<td>285 ± 18</td>
<td>41 ± 4</td>
<td>28 ± 2</td>
<td>18 ± 2</td>
<td>24 ± 7</td>
<td>49 ± 2</td>
<td>444 ± 27</td>
<td>441</td>
</tr>
<tr>
<td>$\Delta\phi_{\ell\ell} &lt; 1.8$</td>
<td>37.7 ± 0.2</td>
<td>279 ± 17</td>
<td>39 ± 4</td>
<td>27 ± 2</td>
<td>18 ± 2</td>
<td>23 ± 7</td>
<td>44 ± 1</td>
<td>429 ± 27</td>
<td>427</td>
</tr>
<tr>
<td>$H + 1$-jet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 jet</td>
<td>21.1 ± 0.1</td>
<td>390 ± 55</td>
<td>59 ± 4</td>
<td>1433 ± 80</td>
<td>430 ± 25</td>
<td>357 ± 17</td>
<td>82 ± 3</td>
<td>2752 ± 170</td>
<td>2707</td>
</tr>
<tr>
<td>b-jet veto</td>
<td>19.5 ± 0.1</td>
<td>360 ± 51</td>
<td>55 ± 4</td>
<td>401 ± 23</td>
<td>134 ± 8</td>
<td>333 ± 16</td>
<td>73 ± 3</td>
<td>1356 ± 92</td>
<td>1371</td>
</tr>
<tr>
<td>$</td>
<td>p_T^{\ell\ell}</td>
<td>&lt; 30$ GeV</td>
<td>13.0 ± 0.1</td>
<td>252 ± 35</td>
<td>33 ± 3</td>
<td>171 ± 10</td>
<td>78 ± 5</td>
<td>105 ± 8</td>
<td>35 ± 2</td>
</tr>
<tr>
<td>$Z \rightarrow \tau\tau$ veto</td>
<td>13.0 ± 0.1</td>
<td>246 ± 34</td>
<td>32 ± 3</td>
<td>165 ± 10</td>
<td>75 ± 5</td>
<td>85 ± 7</td>
<td>35 ± 2</td>
<td>638 ± 53</td>
<td>645</td>
</tr>
<tr>
<td>$m_{\ell\ell} &lt; 50$ GeV</td>
<td>10.2 ± 0.1</td>
<td>54 ± 7</td>
<td>14 ± 2</td>
<td>32 ± 2</td>
<td>18 ± 2</td>
<td>26 ± 4</td>
<td>12 ± 1</td>
<td>156 ± 14</td>
<td>171</td>
</tr>
<tr>
<td>$\Delta\phi_{\ell\ell} &lt; 1.8$</td>
<td>9.4 ± 0.1</td>
<td>49 ± 7</td>
<td>14 ± 2</td>
<td>30 ± 2</td>
<td>17 ± 2</td>
<td>13 ± 3</td>
<td>10 ± 1</td>
<td>134 ± 13</td>
<td>145</td>
</tr>
<tr>
<td>$H + 2$-jet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>opp. hemispheres</td>
<td>3.8 ± 0.1</td>
<td>46 ± 1</td>
<td>6 ± 1</td>
<td>138 ± 3</td>
<td>21 ± 1</td>
<td>34 ± 4</td>
<td>8 ± 1</td>
<td>253 ± 5</td>
<td>269</td>
</tr>
<tr>
<td>$</td>
<td>\Delta\eta_{jj}</td>
<td>&gt; 3.8$</td>
<td>1.8 ± 0.1</td>
<td>8.3 ± 0.4</td>
<td>0.9 ± 0.2</td>
<td>19.2 ± 0.8</td>
<td>2.2 ± 0.4</td>
<td>8.0 ± 0.9</td>
<td>1.5 ± 0.4</td>
</tr>
<tr>
<td>$m_{jj} &gt; 500$ GeV</td>
<td>1.3 ± 0.1</td>
<td>3.9 ± 0.3</td>
<td>0.4 ± 0.1</td>
<td>6.9 ± 0.4</td>
<td>0.7 ± 0.2</td>
<td>0.9 ± 0.4</td>
<td>0.7 ± 0.3</td>
<td>13.6 ± 0.8</td>
<td>13</td>
</tr>
<tr>
<td>$m_{\ell\ell} &lt; 80$ GeV</td>
<td>0.9 ± 0.1</td>
<td>1.1 ± 0.2</td>
<td>0.1 ± 0.1</td>
<td>1.1 ± 0.2</td>
<td>0.2 ± 0.1</td>
<td>0.3 ± 0.3</td>
<td>0.2 ± 0.2</td>
<td>2.9 ± 0.5</td>
<td>2</td>
</tr>
<tr>
<td>$\Delta\phi_{\ell\ell} &lt; 1.8$</td>
<td>0.8 ± 0.1</td>
<td>0.7 ± 0.1</td>
<td>0.1 ± 0.1</td>
<td>0.7 ± 0.2</td>
<td>negl.</td>
<td>0.3 ± 0.3</td>
<td>negl.</td>
<td>1.8 ± 0.4</td>
<td>1</td>
</tr>
</tbody>
</table>

**Signal is for $m_H=125$ GeV**
Object selection:

- **Electrons**: tight++ electrons with author 1 or 3
  
  $\text{Pt} > 15 \text{ GeV}, \ |\eta| < 2.47 \text{ excluding crack region}$

  object quality check

  impact parameter cuts: $\text{abs}(z0 \text{ w.r.t. PV}) < 1\text{mm}$, I.P. significance $< 10$

  Isolation: $\Sigma(P_{\text{track}}/P_{\text{e}}) < 0.13$, $\Sigma(E_{\text{calo}}/P_{\text{e}}) < 0.14$

  scale factors applied to MC
Selection details

- **Muons**: staco combined muons
  
  \[ \text{Pt} > 15 \text{ GeV}, \ |\eta| < 2.4 \]

  hits requirement in pixel, SCT, TRT following MCP recommendations
  impact parameter cuts: \( \text{abs}(z0 \text{ w.r.t. PV}) < 1\text{mm}, \text{I.P. significance} < 3 \)
  
  Isolation: \( \sum(P_T \text{ track}/P_T \mu) < 0.15, \sum(E_T \text{ calo}/P_T \mu) < 0.14 \)

  scale factors applied to MC

- **Jets**: Anti-kT jets with distance scale 0.4
  
  \[ \text{Pt} > 25 \text{ GeV}, \ |\eta| < 4.5 \]

  JVF applied
  
  b-tagging/veto: CombNN, 80% working point

- **overlap removal**
  
  - **e-e**: if \( \Delta R < 0.1 \), remove lower-PT electron
  
  - **e-\( \mu \)**: if \( \Delta R < 0.1 \), remove electron
  
  - **e-jet**: if \( \Delta R < 0.3 \) of selected jet, remove jet