Latest Higgs Physics results from the ATLAS experiment

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Overview

- Higgs at the LHC
- Run 1 highlights
- Higgs to bosons
- ttH
- Higgs to bb
- Rare decays
- Outlook and conclusions
Higgs production at the LHC

From 8 TeV to 13 TeV: factor 2 in $\sigma$ except $ttH$: factor 4
Higgs decays @ 125 GeV

- **Lepton/had modes**
  - Very broad peak
  - VBF best, $Z^0$ BG

- **Ok statistics**
  - Only lepton modes
  - No mass peak

- **High statistics**
  - Only 4l, low stat
  - No BG
  - Narrow peak

- **High statistics**
  - Ok stats
  - High BG
  - Narrow peak

- **High statistics**
  - High BG
  - Broad mass peak

- **Pie chart**
  - bottom/anti-bottom 57%
  - W+W- 21%
  - 2 gluons 9%
  - tau/anti-tau 6%
  - charm/anti-charm 3%
  - ZZ 3%
  - $W^+W^-$ 0.2%
  - $Z^+Z^-$ 0.2%
  - others 0.6%
Run 1 - Higgs mass

- Use $\mu\mu$ and $\gamma\gamma$ only
- $M_H = 125.09 \pm 0.24$ GeV
- 0.2 % precision
Run 1 - Higgs discovery and couplings

**ATLAS** Preliminary

- $m_H = 125.36$ GeV

**H → γγ**

- $\mu = 1.17^{+0.27}_{-0.27}$

**H → ZZ* → 4l**

- $\mu = 1.44^{+0.40}_{-0.33}$

**H → WW* → llνν**

- $\mu = 1.09^{+0.23}_{-0.21}$

**W, Z H → b¯b**

- $\mu = 0.5^{+0.4}_{-0.4}$

**H → ττ**

- $\mu = 1.4^{+0.4}_{-0.4}$

Total uncertainty $\pm 1\sigma$ on $\mu$

- $m_t = 125.36$ GeV

- $\mu = \sigma / \sigma_{SM}$

- released 12.01.2015

September 16  
N de Groot – BND2015  
6
Run 1 - Spin and parity measurement

SM Higgs is spin 0 and positive parity

Decay angles are sensitive to the spin and parity of the Higgs boson

These are input to a multivariate analysis (BDT or NN)

Test SM hypothesis $0^+ \text{ against alternative}$

Clear preference for $0^+ \rightarrow \text{It's a Higgs}$
HIGGS TO BOSONS
• Signature: 2 isolated photons, narrow peak, falling background
• Main BG: $\gamma\gamma$ and $\gamma$-jet
• All production modes included
• Fit to $m_{\gamma\gamma}$ spectrum
• Dominant systematic: $\gamma$ energy scale/resolution bg model

Precision run 2 already better than run 1
Fiducial Cross section: 
$\sigma = 43.2 \pm 14.9 \pm 4.9$ fb
$H \rightarrow \gamma\gamma$

- Signature: 2 isolated photons, narrow peak, falling background
- Main BG: $\gamma\gamma$ and $\gamma$-jet
- All production modes included
- Fit to $m_{\gamma\gamma}$ spectrum
- Dominant systematic: $\gamma$ energy scale/resolution bg model

Differential distributions: $p_t$, $\eta$, #jets
Precision run 2 already better than run 1
Fiducial Cross section:
$$\sigma = 43.2 \pm 14.9 \pm 4.9 \text{ fb}$$
• Signature: 4 isolated leptons, narrow peak, flat background
• Main BG: ZZ
• All production modes included
• Fit to $m_{4l}$ spectrum

Fiducial Cross section: 
$\sigma = 4.54^{+1.02}_{-0.90} \text{ fb}$
**H→γγ and ZZ* combination**

- Combine the inclusive samples
- 10 σ observation (8.6 σ exp)
- \( \mu = 1.13 \pm 0.18 \) 

Similar precision as run 1

**ATLAS** Preliminary  
\( m_t=125.09 \) GeV  
\( \sqrt{s}=13 \) TeV, 13.3 fb\(^{-1}\) (γγ), 14.8 fb\(^{-1}\) (ZZ)

**Parameter value norm. to SM value**

\( \sigma \cdot B \) values for different processes:
- (σ · B)
- (σ · B)
- (σ · B)
- (σ · B)
- (σ · B)
- (σ · B)

ATLAS-CONF-2016-081

9/9/16  
N de Groot - Corfu
**ttH (H → bb)**

**Motivation:** direct probe of ttH Yukawa coupling

**Strategy:**
- Benefits from 13 TeV
- High BR H → bb, 58%
- 4b jet final state, 1 lepton + 2 or 2 leptons
- Categorize events in #jets, #b’s #leptons
- Use multivariate techniques to boost S/B
- Dominant backgrounds tt + HF
- Dominant error tt+HF modeling
ttH \ (H \rightarrow \ bb) \\

Motivation: direct probe of ttH Yukawa coupling

Strategy:
• Benefits from 13 TeV
• High BR $H \rightarrow bb$, 58%
• 4b jet final state, 1 lepton + 2 or 2 leptons
• Categorize events in $\#$jets, $\#b$’s $\#$leptons
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• Dominant backgrounds $tt + HF$
• Dominant error $tt+HF$ modeling
Motivation: direct probe of $t\bar{t}H$ Yukawa coupling

**Strategy:**
- Benefits from 13 TeV
- High BR $H \to bb$, 58%
- 4b jet final state, 1 lepton + 2 or 2 leptons
- Categorize events in #jets, #b’s #leptons
- Use multivariate techniques to boost S/B
- Dominant backgrounds $t\bar{t} + HF$
- Dominant error $t\bar{t}+HF$ modeling
ttH multilepton

Strategy:
- Benefits from 13 TeV
- Clean signature, low BG
- 2 jet final state, 1-2b, 2-4 leptons, 0-1 τ
- Upper limit 95% C:L $\mu < 4.9$ (2.3 exp)
ttH combination

**Significance:**

Run 2: $\sigma = 2.8$ (1.8 exp)

Run 1: $\exp \sigma = 1.5$

Already more sensitive
HIGGS TO BB
Strategy:
- High BR $H \rightarrow bb$
- Use lepton(s) from $Z$, $W$ (or missing $E_t$ for $Z \rightarrow \nu\nu$)
- Use multivariate techniques for good S/B
- Dominant backgrounds $t\bar{t}$ and $Z+b$
- Best discrimination from $m_{bb}$ and $\Delta R_{bb}$
**Strategy:**

- High BR $H \rightarrow bb$
- Use lepton(s) from $Z$, $W$ (or missing $E_t$ for $Z \rightarrow \nu\nu$)
- Use multivariate techniques for good S/B
- Dominant backgrounds $tt$ and $Z+b$
- Best discrimination from $m_{bb}$ and $\Delta R_{bb}$

![Diagram of VH (H→ bb)](Diagram shows a decay process involving $W$, $Z$, and neutrinos, indicating the discrimination from $m_{bb}$ and $\Delta R_{bb}$.)

**ATLAS** Preliminary $\sqrt{s}=13$ TeV, $\int L dt=13.2$ fb$^{-1}$

<table>
<thead>
<tr>
<th>2 lepton</th>
<th>1 lepton</th>
<th>0 lepton</th>
<th>Combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tot.</td>
<td>$-0.24^{+0.90}_{-0.84}$</td>
<td>$0.25^{+0.94}_{-0.92}$</td>
<td>$0.47^{+0.73}_{-0.69}$</td>
</tr>
<tr>
<td>(Stat.)</td>
<td>$+0.64+0.63$</td>
<td>$-0.58-0.60$</td>
<td>$+0.59+0.44$</td>
</tr>
<tr>
<td>Syst.</td>
<td>$-0.79-0.74$</td>
<td>$-0.64-0.67$</td>
<td>$-0.73-0.69$</td>
</tr>
</tbody>
</table>

**Best fit $\mu=\sigma/\sigma_{SM}$ for $m_H=125$ GeV**

<table>
<thead>
<tr>
<th>0 lepton</th>
<th>Combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZH</td>
<td>$0.15^{+0.67}_{-0.64}$</td>
</tr>
<tr>
<td>WH</td>
<td>$0.33^{+0.95}_{-0.92}$</td>
</tr>
<tr>
<td>Combination</td>
<td>$0.21^{+0.51}_{-0.50}$</td>
</tr>
<tr>
<td>$+0.36+0.36$</td>
<td>$-0.35-0.36$</td>
</tr>
<tr>
<td>$-0.79-0.74$</td>
<td>$-0.70-0.68$</td>
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**ATLAS** Preliminary $\sqrt{s}=13$ TeV, $\int L dt=13.2$ fb$^{-1}$

**Best fit $\mu=\sigma/\sigma_{SM}$ for $m_H=125$ GeV**
**Strategy:**
- High BR $H \rightarrow bb$
- Use forward tagging jets and rapidity gap
- Use BDT to improve S/B (still poor)
- Dominant backgrounds QCD, $Z \rightarrow bb$
- Fit to $m_{bb}$

**Result:**
$\mu = -0.8 \pm 1.3 \pm 1.8$
Limit: $\mu = 4.4 @95\%CL$

arXiv:1606.02181
VBF (H→ bb) + γ

**Strategy:**
- High BR H→ bb,
- Use forward tagging jets and rapidity gap
- Clean-up with photon
- Use BDT to improve S/B
- Fit to m_{bb} in BDT bins

**Result:**
Limit: μ = 4.0 @95%CL (fit
Cross check with Z→ bb + γ
RARE AND FORBIDDEN DECAYS
Higgs→μ⁺μ⁻

- Very rare decay in SM, BR ~ 2 x 10⁻⁴
- First probe of Higgs coupling to 2nd generation fermions
- Very clean signature with 2 muons
- Large background from Z/γ*

**Strategy:**
- Separate VBF (S/√B ~ 0.28) from rest (S/√B 0.09-0.23)
- Look for peak in m_μμ spectrum
Higgs → μ⁺μ⁻

- Very rare decay in SM, BR ~ 2 x 10⁻⁴
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- Separate VBF (S/√B ~ 0.28) from rest (S/√B 0.09-0.23)
- Look for peak in m_{μμ} spectrum

**Limits**

<table>
<thead>
<tr>
<th></th>
<th>95% CL limit x SM (expected)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1</td>
<td>7.1 (7.2)</td>
</tr>
<tr>
<td>Run 2</td>
<td>4.4 (5.5)</td>
</tr>
<tr>
<td>Combined</td>
<td>3.5 (4.5)</td>
</tr>
</tbody>
</table>
Look for \( H \rightarrow \mu \tau \) and \( H \rightarrow e \tau \)

Small excess seen by CMS in run 1

Calculate invariant mass with MMC

Main BG \( Z \rightarrow \tau \tau \)

95\% CL Limits:

- \( H \rightarrow e \tau : 1\% \)
- \( H \rightarrow \mu \tau : 1.4\% \)

JHEP 1511 (2015)
arXiv:1604.07730
Outlook and conclusions

• Run 2 made an impressive start
• Higgs sample matching or exceeding run 1 already
• Many results, many more to come
  – Look for WW and $\tau\tau$ updates
  – Differential distributions
  – Higgs as a probe
  – CP studies
  – End 2016 2-6 x Run 1 Higgs sample, end 2018 8-20x

Higgs physics is becoming precision Standard Model physics