Prospects of combined measurements of Higgs boson properties

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2016-08-31
Outline

- Outline
- LHC Schedule
- Run-1 highlights of Higgs boson measurements
- Run-2 first Higgs results
- Projections of Higgs boson results
  - LHC and ATLAS detector upgrades
  - Mass
  - Couplings
  - Rare decays
  - Di-Higgs production
LHC Schedule

- LHC operates very well: current data acquisition exceeds expectation
- Higher centre-of-mass energy means larger cross sections $ggF, VBF, VH: \sim \times 2$, $ttH \times 4$ (similar for associated backgrounds)
- Expect
  - $30 \, fb^{-1}$ at $13 \, TeV$ by end of 2016
  - $120 \, fb^{-1}$ at $13-13.5 \, TeV$ by end or Run-2, 2018
  - $\sim 300 \, fb^{-1}$ at $13-14 \, TeV$ by end of Run-3, 2023
  - $\sim 3000 \, fb^{-1}$ at $14 \, TeV$, HL-LHC, 2026-2037
I. Run-1 highlights

based on ~25 fb-1 7-8 TeV data
Run-1 Higgs boson highlights

$H \rightarrow \gamma \gamma$
5.0$\sigma$ (4.6$\sigma$)

$H \rightarrow ZZ^*$
8.1$\sigma$ (6.2$\sigma$)

$H \rightarrow bb$
1.7$\sigma$ (2.7$\sigma$)

$H \rightarrow \tau \tau$
4.5$\sigma$ (3.4$\sigma$)

$H \rightarrow WW^*$
6.8$\sigma$ (5.8$\sigma$)

$\sigma(H \rightarrow Z\gamma) < 11 \times SM$
$\sigma(H \rightarrow \mu \mu) < 7 \times SM$

Observed (expected) sign. from
JHEP 08 (2016) 045
## Run-1 Higgs boson results

### Higgs boson mass

<table>
<thead>
<tr>
<th>ATLAS and CMS</th>
<th>LHC Run 1</th>
<th>ATLAS $H \rightarrow \gamma\gamma$</th>
<th>CMS $H \rightarrow \gamma\gamma$</th>
<th>ATLAS $H \rightarrow ZZ \rightarrow 4l$</th>
<th>CMS $H \rightarrow ZZ \rightarrow 4l$</th>
<th>ATLAS+CMS $\gamma\gamma$</th>
<th>ATLAS+CMS 4l</th>
<th>ATLAS+CMS $\gamma\gamma+4l$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stat.</strong></td>
<td><strong>Syst.</strong></td>
<td><strong>Total</strong></td>
<td><strong>Total</strong></td>
<td><strong>Total</strong></td>
<td><strong>Total</strong></td>
<td><strong>Total</strong></td>
<td><strong>Total</strong></td>
<td><strong>Total</strong></td>
</tr>
<tr>
<td>124.70 ± 0.34</td>
<td>125.59 ± 0.45</td>
<td>125.07 ± 0.29</td>
<td>125.09 ± 0.24</td>
<td>125.15 ± 0.40</td>
<td>126.02 ± 0.51</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>( ± 0.31 ± 0.15)</td>
<td>( ± 0.42 ± 0.17)</td>
<td>( ± 0.25 ± 0.14)</td>
<td>( ± 0.21 ± 0.11)</td>
<td>( ± 0.37 ± 0.15)</td>
<td>( ± 0.43 ± 0.27)</td>
<td></td>
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</tr>
<tr>
<td>124.51 ± 0.52</td>
<td>124.70 ± 0.34</td>
<td>124.70 ± 0.34</td>
<td>125.59 ± 0.45</td>
<td>125.07 ± 0.29</td>
<td>126.02 ± 0.51</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( ± 0.52 ± 0.04)</td>
<td>( ± 0.31 ± 0.15)</td>
<td>( ± 0.31 ± 0.15)</td>
<td>( ± 0.42 ± 0.17)</td>
<td>( ± 0.25 ± 0.14)</td>
<td>( ± 0.43 ± 0.27)</td>
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<tr>
<td>126.02 ± 0.51</td>
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<td>126.02 ± 0.51</td>
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</tr>
<tr>
<td>( ± 0.43 ± 0.27)</td>
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<td>( ± 0.43 ± 0.27)</td>
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</tr>
</tbody>
</table>

**PRL 114 (2015) 191803**

- Precision of mass measurement: **0.2% 240 MeV**
- **Statistically limited**, especially for $ZZ^* \rightarrow 4l$: stat error $\approx 10 \times$ syst error
- Consistent with SM **spin/CP** expectation $0^+$

Alternative models (spin 2, negative parity, etc.) excluded at least 99.9% CL

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EpJC 75 (2015) 476

Dag Gillberg (Carleton)
Run-1 Higgs boson results

- The Higgs boson production and decay were studied using
  - Dedicated analyses in 7 different decay modes ($\gamma\gamma$, $ZZ^*$, $WW^*$, $bb$, $\tau\tau$, $Z\gamma$, $\mu\mu$)
  - Full Run-1 dataset: $\sim25$ fb$^{-1}$
  - All results are consistent with the Standard Model expectation
  - "Micro-anomalies": $H\rightarrow bb$ low by $\sim2.5\sigma$, $ttH$ high by $\sim2.3\sigma$

**ATLAS**

<table>
<thead>
<tr>
<th>$\sqrt{s}$</th>
<th>$\mu_{ggF}$</th>
<th>$\mu_{VBF}$</th>
<th>$\mu_{VH}$</th>
<th>$\mu_{ttH}$</th>
<th>$m_H$</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 TeV, 4.5-4.7 fb$^{-1}$</td>
<td>$1.23^{+0.23}_{-0.20}$</td>
<td>$1.23 \pm 0.32$</td>
<td>$0.80 \pm 0.36$</td>
<td>$1.81 \pm 0.80$</td>
<td>$125.36$ GeV</td>
</tr>
<tr>
<td>8 TeV, 20.3 fb$^{-1}$</td>
<td>$\tau\tau$</td>
<td>$\mu_{ggF}$</td>
<td>$\mu_{VBF}$</td>
<td>$\mu_{VH}$</td>
<td>$\mu_{ttH}$</td>
</tr>
</tbody>
</table>

**Signal strength ($\mu$)**

0.03 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8

- $\Gamma_H = 7$ TeV, $\mu_{ggF} = 7$ TeV, 4.5-4.7 fb$^{-1}$
- $\mu_{VBF} = 7$ TeV, 20.3 fb$^{-1}$

**ATLAS**

- $\sqrt{s} = 7$ TeV, 4.5-4.7 fb$^{-1}$
- $\sqrt{s} = 8$ TeV, 20.3 fb$^{-1}$

**$m_H = 125.36$ GeV**
Run-1 Higgs boson results

- **Differential cross sections** and normalized **shapes of kinematic distributions** measured both in individual channels (fiducial regions of $\gamma\gamma$, $ZZ^*$, $WW^*$) and combined ($\gamma\gamma+ZZ^*$), correcting for acceptances and branching ratio
- Higgs boson $p_T$, jet multiplicity, $m_\ell$, etc.
- “Micro-anomalies”: $p_{T,H}$ spectrum harder and more jets (see below)
- $p$-value for SM-agreement: 4% (8%) or better for norm+shape (shape-only)
II. Current Run-2 results

$H \rightarrow \gamma\gamma$, 13.3 fb$^{-1}$

$H \rightarrow ZZ^*$, 14.8 fb$^{-1}$

See talk by Yusheng Wu for details on the individual analyses
Extracted event yields after analysis selection (without further categorization) are converted to a production cross section:

\[ \sigma_{pp \rightarrow H} = \frac{n_{\text{data}}}{\varepsilon \mathcal{L}} \times \frac{1}{\mathcal{B}_{\text{SM}} A_{\text{SM}}} \]

Fiducial cross section

BR and acc.
Fiducial \rightarrow total extrapolation

Profile likelihood ratio fit with systematics implemented as ~200 nuisance parameters used

<table>
<thead>
<tr>
<th>Decay channel</th>
<th>Total cross section ((pp \rightarrow H + X))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(H \rightarrow \gamma \gamma)</td>
<td>(\sqrt{s} = 7) TeV (35^{+13}<em>{-12}) pb (30.5^{+7.5}</em>{-7.4}) pb (37^{+14}_{-13}) pb</td>
</tr>
<tr>
<td>(H \rightarrow ZZ^* \rightarrow 4\ell)</td>
<td>(\sqrt{s} = 8) TeV (33^{+21}<em>{-16}) pb (37^{+9}</em>{-8}) pb (81^{+18}_{-16}) pb</td>
</tr>
<tr>
<td>Combination</td>
<td>(34 \pm 10) (stat.) (33.3^{+5.5}<em>{-5.3}) (stat.) (59.0^{+9.7}</em>{-9.2}) (stat.)</td>
</tr>
<tr>
<td>SM predictions [7]</td>
<td>(19.2 \pm 0.9) pb (24.5 \pm 1.1) pb (55.5^{+2.4}_{-3.3}) pb</td>
</tr>
</tbody>
</table>

\(\sqrt{s}\) = 7 TeV, 4.5 fb\(^{-1}\)
\(\sqrt{s}\) = 8 TeV, 20.3 fb\(^{-1}\)
\(\sqrt{s}\) = 13 TeV, 13.3 fb\(^{-1}\) \((\gamma \gamma)\), 14.8 fb\(^{-1}\) \((ZZ^*)\)
Run-2 Higgs boson couplings

- Targeting Higgs production mode with dedicated analysis event categories: 13 for $\gamma\gamma$, 5 for $ZZ \rightarrow 4l$.
  - Combined fits for cross sections and coupling parameters performed using these categories.
- Global signal strength: $\sim 10\sigma$ ($8.6\sigma$) significance, $\mu = 1.13^{+0.18}_{-0.17}$
- Fitted production mode cross sections (below and right) consistent with SM expectation.

**ATLAS** Preliminary

$m_H=125.09$ GeV

$\sqrt{s}=13$ TeV, 13.3 fb$^{-1}$ ($\gamma\gamma$), 14.8 fb$^{-1}$ (ZZ)

- Observed 68% CL
- SM Prediction

*SM BR assumed*

**VBF vs ggF**

- SM
- Best fit
- 68% CL
- 95% CL
- $H \rightarrow \gamma\gamma$
- $H \rightarrow ZZ^{*} \rightarrow 4l$

**Parameter value norm. to SM value**

ATLAS Preliminary

$\gamma\gamma=13$ TeV, 13.3 fb$^{-1}$ ($\gamma\gamma$), 14.8 fb$^{-1}$ (ZZ)

$m_H = 125.09$ GeV
III. Projected results

- 120 fb\(^{-1}\) @ 13-13.5 TeV by end of Run-2, 2018
- ~300 fb\(^{-1}\) @ 13-14 TeV by end of Run-3, 2023
- ~3000 fb\(^{-1}\) @ 14 TeV, HL-LHC, 2026-2037 (Runs 4&5)
Detector upgrades

**HL-LHC**
- During the HL-LHC beam intensity will increase to $\times 7.5$ the design intensity
- Major detector detector upgrades needed

**Main detector improvements with implications on physics:**
- New **all-silicon tracker** with significantly improved fwd. coverage: $|\eta| < 4$ (now 2.5)
- Improved granularity of forward calorimeter
- Improved triggering capabilities
- New high-granularity timing detector in the forward region
- Will improve capabilities to suppress pileup, in particular in the forward region: $\rightarrow$ enhanced precision to study events with VBF topology
- Projections for Run-3 (300 fb$^{-1}$) and HL-LHC (3000 fb$^{-1}$) derived using MC hadron-level samples with detector smearing functions derived from full simulation of the expected upgraded detector and the correspond to the expected beam conditions
Goals for ATLAS Higgs physics program

- Improve precision on Higgs boson coupling and cross section measurements
- Establish rare Higgs decays
- Study Higgs self coupling
- Search for BSM signatures

Higgs boson mass

Run-1 result
\( \gamma\gamma \): ±0.43 (stat) ±0.27 (sys) GeV
\( ZZ^* \): ±0.53 (stat) ±0.04 (sys) GeV
ATLAS comb: ±0.36 GeV

due to smaller systematics, \( ZZ \) will drive the mass measurement by the end of Run-2 (120 fb\(^{-1}\)): ~±0.20 GeV

Expected event yields

<table>
<thead>
<tr>
<th>( \mathcal{L} ) [fb(^{-1})]</th>
<th>All</th>
<th>( H \rightarrow \gamma\gamma )</th>
<th>( H \rightarrow ZZ \rightarrow 4l )</th>
<th>( H \rightarrow WW^* \rightarrow l\ell l\ell )</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.3</td>
<td>0.75M</td>
<td>600</td>
<td>20</td>
<td>400</td>
</tr>
<tr>
<td>120</td>
<td>7M</td>
<td>6,000</td>
<td>200</td>
<td>4,000</td>
</tr>
<tr>
<td>300</td>
<td>17M</td>
<td>14,000</td>
<td>500</td>
<td>10,000</td>
</tr>
<tr>
<td>3000</td>
<td>170M</td>
<td>140,000</td>
<td>5,000</td>
<td>100,000</td>
</tr>
</tbody>
</table>

After full analysis selection
(rough approximation)
Higgs coupling measurements

**Precision on signal strength**

<table>
<thead>
<tr>
<th>ATLAS</th>
<th>Simulation Preliminary</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sqrt{s} = 14$ TeV: $\int L dt = 300$ fb$^{-1}$; $\int L dt = 3000$ fb$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>$H \rightarrow \gamma \gamma$ (comb.)</td>
<td>$\sim 9%$ $\sim 4%$</td>
</tr>
<tr>
<td>$H \rightarrow ZZ$ (comb.)</td>
<td></td>
</tr>
<tr>
<td>$H \rightarrow WW$ (comb.)</td>
<td></td>
</tr>
<tr>
<td>$H \rightarrow Z\gamma$ (incl.)</td>
<td></td>
</tr>
<tr>
<td>$H \rightarrow bb$ (comb.)</td>
<td></td>
</tr>
<tr>
<td>$H \rightarrow \tau \tau$ (VBF-like)</td>
<td></td>
</tr>
<tr>
<td>$H \rightarrow \mu \mu$ (comb.)</td>
<td></td>
</tr>
</tbody>
</table>

**Precision on Higgs coupling ratios:**

$\lambda_{XY} = \kappa_X / \kappa_Y$

ATLAS Simulation Preliminary

$\sqrt{s} = 14$ TeV: $\int L dt = 300$ fb$^{-1}$; $\int L dt = 3000$ fb$^{-1}$

- $\kappa_{gZ}$ $\sim 3.5\%$
- $\sim 2\%$

**Higgs coupling vs mass**

(Pr plot)

Global Higgs boson signal strength/rate precision (stat+exp. unc. only):
- $\rightarrow$ ICHEP, 13.3 fb$^{-1}$, 18% ($\gamma\gamma+ZZ$ only)
- $\rightarrow$ Run-2, 120 fb$^{-1}$, $\sim 7\%$ ($\gamma\gamma+ZZ$)
- $\rightarrow$ Run-3, 300 fb$^{-1}$, $\sim 5\%$
- $\rightarrow$ HL-LHC, 3 ab$^{-1}$, $\sim 2.5\%$
Di-Higgs and rare decays

The Higgs boson self coupling

$H \rightarrow \mu \mu$, 7.0$\sigma$ excess expected in 3 ab$^{-1}$
~21% error on rate

SM sensitivity (1$\sigma$) expected with ~70 fb$^{-1}$ (2018)

$H \rightarrow Z\gamma \rightarrow ee\gamma\gamma$
3.9$\sigma$ excess expected in 3 ab$^{-1}$
~25% uncertainty on rate

$HH \rightarrow \gamma\gamma bb$
1.3$\sigma$ excess expected w. 3 ab$^{-1}$ (8 events)

Combination with many other decay channels will improve the sensitivity.

ATL-PUB-2014-019
Higgs cross sections

- Measurements of fiducial and differential cross sections will be done in individual channels
  - Back-of-the-envelope precision of $\sigma(p_{TH}>100 \text{ GeV})$ for $\gamma\gamma+ZZ$ combination:
    $\sim40\%$, $\sim14\%$, $\sim5\%$ with $13.3 \text{ fb}^{-1}$, $120 \text{ fb}^{-1}$, $3000 \text{ fb}^{-1}$
- Simplified template cross sections provides natural way to combine different channels
  \rightarrow cross sections extracted via global fit
  - “Stage-0” measurements already performed for ICHEP 2016
  - “Stage-1” measurements as outlined in Yellow Report 4 are in progress
Measurements of fiducial and differential cross sections will be done in individual channels depicted in Fig. 3 and summarized as follows:

- For the measurements to have acceptance beyond 2.5, an additional bin Stage 0

Simplified template cross sections provide a simplified categorization of differential cross sections.

**Higgs simplified template cross section, “Stage-1” ggF categorization**

- **ggF**
  - = 0-jet
    - $p_T^H [0, 60]$ (with VBF cuts $p_T^{Hjj} < 200$)
  - = 1-jet (+)
    - $p_T^H [60, 120]$ (with VBF cuts $p_T^{Hjj} < 200$)
  - ≥ 2-jet
    - $p_T^H [60, 120]$ (with VBF cuts $p_T^{Hjj} < 200$)
  - ≥ 2-jet VBF cuts $p_T < 200$
    - $p_T^{Hjj} [0, 25]$
    - $p_T^{Hjj} [25, \infty]$

With this topology, the sum of the two contributions can be quoted as sensitivity to determine the gluon fusion and the VBF contributions to the gluon fusion contamination in the VBF selection. If the fit has no certainties into the measurement. The separation of the $N_p$ template cross sections avoids folding the associated theoretical uncertainties. This has several advantages:

1. Guiding principles in the definition of simplified hypotheses.

The result.

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1. Guiding principles in the definition of simplified hypotheses.

The result.
Summary

- LHC Run-2 currently delivers data beyond expectation
  - High-quality data being recorded by the ATLAS detector
- In ICHEP dataset, the Higgs boson was observed in the $\gamma\gamma+ZZ$ channels with $\sim10\sigma$ (8.6$\sigma$) observed (expected) significance
  - Preliminary measurements of the Higgs boson cross section and couplings examined in first Run-2 and are consistent with SM expectations
- Significant detector upgrades and improvements will be installed for HL-LHC phase: 2026-2035, during with we expect to collect 3 ab$^{-1}$ data
  - In particular improvements will be made to the forward region:
    - tracking extended to $|\text{eta}|<4$ + improved calorimetry and timing detector
    - increase acceptance for all physics objects
    - improve $E_T^{\text{miss}}$ resolution
    - in particular helpful for VBF topology
- Higgs physics remains a very important part of the LHC physics program
  - Improve precision of cross section and coupling measurements
  - Study Higgs self coupling
  - Search for rare decays and BSM signatures
References

- ATLAS Run-1 papers
  - $H \rightarrow \gamma\gamma$, $H \rightarrow ZZ \rightarrow 4l$, $H \rightarrow WW^*$, $H \rightarrow bb$, $H \rightarrow \tau\tau$
  - Mass (ATLAS+CMS), Spin/CP, couplings, differential, couplings (ATLAS+CMS)
- ATLAS Run-2 conference note for ICHEP 2016
  - ATLAS-CONF-2016-067, $H \rightarrow \gamma\gamma$
  - ATLAS-CONF-2016-079, $H \rightarrow 4l$
  - ATLAS-CONF-2016-081, $\gamma\gamma + ZZ$ combination
- ATLAS public projection, 300 and 3000 fb$^{-1}$
  - ATL-PHYS-PUB-2014-016, Higgs couplings
  - ATL-PHYS-PUB-2014-017, BSM Higgs
  - ATL-PHYS-PUB-2014-006, $H \rightarrow Z\gamma$
  - ATL-PHYS-PUB-2014-019, $HH \rightarrow bb\gamma\gamma$
- Full list: [https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults](https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults)
More Run-2 coupling results

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

![Graph showing coupling results normalized to SM values](image)

- **Observed 68% CL**
- **SM Prediction**

- \((\sigma \cdot B)_{ggF}^{ZZ}\)
- \((\sigma \cdot B)_{ggF}^{\gamma\gamma}\)
- \((\sigma \cdot B)_{VBF}^{ZZ}\)
- \((\sigma \cdot B)_{VBF}^{\gamma\gamma}\)
- \((\sigma \cdot B)_{VHhad}^{\gamma\gamma}\)
- \((\sigma \cdot B)_{VHlep}^{\gamma\gamma}\)
- \((\sigma \cdot B)_{top}^{\gamma\gamma}\)

Parameter value norm. to SM value

**Evidence for the vector-boson fusion production process is established at** \( p_s = 13 \text{ TeV} \), with a local **p-value** of ***5%***.

**Figure 5**: Measurement of \((\sigma \cdot B)_{ggF}^{ZZ}\), \((\sigma \cdot B)_{VBF}^{\gamma\gamma}/(\sigma_{ggF})\) and \((B_{\gamma\gamma}/B_{ZZ}\) compared to their SM expectation. The fit results displayed in Figure 5 are normalised to the SM predictions for the various parameters and the grey bands indicate the theoretical uncertainties in these predictions. The compatibility between the measurement and the SM prediction corresponds to a **p-value** of **5%**.
# Projected signal strengths uncertainties

<table>
<thead>
<tr>
<th>$\Delta \mu / \mu$</th>
<th>300 fb$^{-1}$</th>
<th>3000 fb$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All unc.</td>
<td>No theory unc.</td>
</tr>
<tr>
<td>$H \to \gamma \gamma$ (comb.)</td>
<td>0.13</td>
<td>0.09</td>
</tr>
<tr>
<td>(0j)</td>
<td>0.19</td>
<td>0.12</td>
</tr>
<tr>
<td>(1j)</td>
<td>0.27</td>
<td>0.14</td>
</tr>
<tr>
<td>(VBF-like)</td>
<td>0.47</td>
<td>0.43</td>
</tr>
<tr>
<td>(WH-like)</td>
<td>0.48</td>
<td>0.48</td>
</tr>
<tr>
<td>(ZH-like)</td>
<td>0.85</td>
<td>0.85</td>
</tr>
<tr>
<td>($tH$-like)</td>
<td>0.38</td>
<td>0.36</td>
</tr>
<tr>
<td>$H \to ZZ$ (comb.)</td>
<td>0.11</td>
<td>0.07</td>
</tr>
<tr>
<td>(VH-like)</td>
<td>0.35</td>
<td>0.34</td>
</tr>
<tr>
<td>($tH$-like)</td>
<td>0.49</td>
<td>0.48</td>
</tr>
<tr>
<td>(VBF-like)</td>
<td>0.36</td>
<td>0.33</td>
</tr>
<tr>
<td>(ggF-like)</td>
<td>0.12</td>
<td>0.07</td>
</tr>
<tr>
<td>$H \to WW$ (comb.)</td>
<td>0.13</td>
<td>0.08</td>
</tr>
<tr>
<td>(0j)</td>
<td>0.18</td>
<td>0.09</td>
</tr>
<tr>
<td>(1j)</td>
<td>0.30</td>
<td>0.18</td>
</tr>
<tr>
<td>(VBF-like)</td>
<td>0.21</td>
<td>0.20</td>
</tr>
<tr>
<td>$H \to Z\gamma$ (incl.)</td>
<td>0.46</td>
<td>0.44</td>
</tr>
<tr>
<td>$H \to bb$ (comb.)</td>
<td>0.26</td>
<td>0.26</td>
</tr>
<tr>
<td>(WH-like)</td>
<td>0.57</td>
<td>0.56</td>
</tr>
<tr>
<td>(ZH-like)</td>
<td>0.29</td>
<td>0.29</td>
</tr>
<tr>
<td>$H \to \tau\tau$ (VBF-like)</td>
<td>0.21</td>
<td>0.18</td>
</tr>
<tr>
<td>$H \to \mu\mu$ (comb.)</td>
<td>0.39</td>
<td>0.38</td>
</tr>
<tr>
<td>(incl.)</td>
<td>0.47</td>
<td>0.45</td>
</tr>
<tr>
<td>($tH$-like)</td>
<td>0.74</td>
<td>0.72</td>
</tr>
</tbody>
</table>
Expected precision on Higgs couplings

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Coupling</th>
<th>300 fb$^{-1}$</th>
<th>3000 fb$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Theory unc.:</td>
<td>Theory unc.:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>All</td>
<td>Half</td>
</tr>
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