ATLAS Higgs and Supersymmetry Physics Prospects at the High-Luminosity LHC

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On behalf of the ATLAS Collaboration
EPS 2017
Outline

• The **High Luminosity**-LHC program
• **ATLAS Phase II Upgrade** program
• **Higgs** analysis prospect:
  - Higgs boson coupling
  - Higgs boson self-coupling
  - Higgs boson rare decays
  - VBF Higgs boson production
• **Supersymmetry** (SUSY) analysis prospect:
  - Stop pair direct production
  - Stau pair direct production
  - Chargino and neutralino direct production
• Conclusion
HL-LHC program

LHC / HL-LHC Plan
http://hilumilhc.web.cern.ch/about/hl-lhc-project

High Luminosity LHC (2024-2037)

Physics targets: precision measurements/rare decays/Beyond SM

<μ<sub>PU</sub>> → 20
<μ<sub>PU</sub>> ~ 23

30 fb<sup>-1</sup> 150 fb<sup>-1</sup> 300 fb<sup>-1</sup> 3000 fb<sup>-1</sup>

Table:

<table>
<thead>
<tr>
<th>HL-LHC mode</th>
<th>Peak Luminosity (cm&lt;sup&gt;-2&lt;/sup&gt; s&lt;sup&gt;-1&lt;/sup&gt;)</th>
<th>Mean number of interactions per bunch-crossing &lt;μ&lt;sub&gt;PU&lt;/sub&gt;&gt;</th>
<th>Integrated luminosity (fb&lt;sup&gt;-1&lt;/sup&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>5x10&lt;sup&gt;34&lt;/sup&gt;</td>
<td>140</td>
<td>3000</td>
</tr>
<tr>
<td>Ultimate</td>
<td>7.5x10&lt;sup&gt;34&lt;/sup&gt;</td>
<td>200</td>
<td>4000</td>
</tr>
</tbody>
</table>
ATLAS Phase II Upgrade Program (2024-2026)

• ATLAS Phase II upgrade: for performance and degradation/limitation
  -> maximize the physics performance and discovery potential of ATLAS
    - increased pile-up  
    - higher backgrounds  
    - higher trigger rates

-> Physics targets: precision measurements / rare decays / beyond SM

• Longer latency for Trigger System
• Upgrade electronics for Tile Calorimeter
• Inner detector with fully Silicon (strip and pixel) up to $|\eta| = 4$
• New Inner Muon barrel trigger chambers
• Options for: - forward muon tagger
  - timing detectors
Higgs Couplings

- Extrapolation from Run-1 analysis at $<\mu_{PU}> = 140$ (ATL-PHYS-PUB-2014-016)

**Run-1**

$\mu_{\gamma\gamma} = 1.17^{+0.28}_{-0.27}$  
($\Delta\mu/\mu \sim 0.23$)

$\mu_{ZZ} = 1.46^{+0.40}_{-0.30}$  
($\Delta\mu/\mu \sim 0.24$)

$\mu_{WW} = 1.18^{+0.42}_{-0.37}$  
($\Delta\mu/\mu \sim 0.33$)

With 3000 fb$^{-1}$:

- $W, Z$ couplings to 3%
- **Muon** coupling to 7%
- $t, b, \tau$ couplings to 8-12%

**Signal Strength**

$\mu = \sigma/\sigma_{SM}$
Higgs Self-coupling

- First opportunity to measure Higgs boson trilinear self-coupling
- $\sigma_{\text{NNLO}}(HH) \sim 40 \text{ fb} \rightarrow$ combine as many decay channels as possible
- Decay channels with $b$-jets have higher branching ratios

<table>
<thead>
<tr>
<th>Decay channel</th>
<th>Branching ratio (%)</th>
<th>$\sigma \cdot \text{Br} \ (\text{fb})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b\bar{b}+b\bar{b}$</td>
<td>33</td>
<td>12.9</td>
</tr>
<tr>
<td>$b\bar{b}+W^+W^-$</td>
<td>25</td>
<td>9.9</td>
</tr>
<tr>
<td>$b\bar{b}+\tau^+\tau^-$</td>
<td>7.4</td>
<td>2.9</td>
</tr>
<tr>
<td>$W^+W^+\tau^+\tau^-$</td>
<td>5.4</td>
<td>2.1</td>
</tr>
<tr>
<td>ZZ+$b\bar{b}$</td>
<td>3.1</td>
<td>1.2</td>
</tr>
<tr>
<td>ZZ+$W^+W^-$</td>
<td>1.2</td>
<td>0.48</td>
</tr>
<tr>
<td>$b\bar{b}+\gamma\gamma$</td>
<td>0.3</td>
<td>0.12</td>
</tr>
<tr>
<td>$\gamma\gamma+\gamma\gamma$</td>
<td>0.001</td>
<td>0.04</td>
</tr>
</tbody>
</table>

(Ref: ATLAS Simulation $\sqrt{s} = 14 \text{ TeV}$, $<\mu> = 200$, $t = 14$ TeV, $\text{Run-2}$)

Comparable light jets rejection: with $<\mu> = 200$ and Run-2
Higgs self-coupling

• HH -> bb γγ
  • Cut based analysis, ATLAS upgrade design y performance
  • SR: 9.5 signal, 91 total background

\[ Z_0 : 1.05 \sigma \quad (+/- 0.026 \text{ stat only}) \]
\[-0.8 < \frac{\lambda_{HHH}}{\lambda_{SM}} < 7.7 \quad (95\% \text{ C.L.} \text{, no syst.}) \]

• HH -> b\bar{b} b\bar{b}
  • Extrapolation from Run-2 analysis
  • Systematic as in 2016 (tt-bar, multi-jets bckg modeling)
  • Present exclusion limit : \( \mu = \frac{\sigma}{\sigma_{SM}} = 29 \)

<table>
<thead>
<tr>
<th>Jet Threshold [GeV]</th>
<th>Background Systematics</th>
<th>( \frac{\sigma}{\sigma_{SM}} ) 95% Exclusion</th>
<th>( \frac{\lambda_{HHH}}{\lambda_{SM}} ) Lower Limit</th>
<th>( \frac{\lambda_{HHH}}{\lambda_{SM}} ) Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 GeV</td>
<td>Negligible</td>
<td>1.5</td>
<td>0.2</td>
<td>7</td>
</tr>
<tr>
<td>30 GeV</td>
<td>Current</td>
<td>5.2</td>
<td>-3.5</td>
<td>11</td>
</tr>
<tr>
<td>75 GeV</td>
<td>Negligible</td>
<td>2.0</td>
<td>-3.4</td>
<td>12</td>
</tr>
<tr>
<td>75 GeV</td>
<td>Current</td>
<td>11.5</td>
<td>-7.4</td>
<td>14</td>
</tr>
</tbody>
</table>

ttHH->WbWb bbbb
ATL-PHYS-PUB-2016-023
HH-> bb τ⁻ τ⁺
ATL-PHYS-PUB-2015-046
-> BACK-UP
Higgs rare decays

- $H \rightarrow J/\Psi \rightarrow \mu^+\mu^- \gamma$ (with $<\mu_{PU}> = 140$, $L = 3000 \text{ fb}^{-1}$)
  - Higgs coupling to c-quark. Run-1 detector performances
  - MVA analysis $m_{\mu^+\mu^-\gamma}$ in [115, 135] GeV
  - 3 signal events and 1700 background (with no systematics)

- $\text{BR}(H \rightarrow J/\Psi \rightarrow \mu\mu \gamma)$: $44^{+19}_{-22} \times 10^{-6}$ (95% C.L.)
  - SM: $2.9 \pm 0.2 \times 10^{-6}$ (Run-1 Limit: $1.5 \times 10^{-3}$)

- $H \rightarrow \mu^+\mu^-$ (with $<\mu_{PU}> = 200$, $L = 300/3000 \text{ fb}^{-1}$)
  - Low BR, high $Z/\gamma^*$ background, high mass resolution
  - Based on Run-1 analysis (cut optim.), $m_{\mu^+\mu^-}$ in [110, 160] GeV
  - Total background shape and normalization data-driven
  - ITK-Upgrade -> improve mass resolution by 25% (w.r.t Run-2)

- $Z_0$: $2.3\sigma$ (300 fb$^{-1}$) $7.0\sigma$ (3000 fb$^{-1}$)
  - $\Delta\mu/\mu$: $46\%$ (300 fb$^{-1}$) $21\%$ (3000 fb$^{-1}$)
VBF Higgs production

- **Pile-up suppression:**
  - \(<\mu_{PU}> \sim 200\) 4.8 pu jets/event
  - \(R_{PT}\) based on charge vertex fraction
  - Applied to all non b-tagged jets with: \(p_T < 100\) GeV and \(|\eta|<3.8\)

- **H -> WW**
  - ATLAS performances: Run-1 (e/\(\mu\))
  - Jets and \(E_T^{\text{Miss}}\) from expected upgrade performance
  - Experimental systematic (no theo. syst. on signal)

- **H -> ZZ**
  - 2 jets( m(jj) > 130 GeV) ,
  - Main background ggF (separated via BDT) and qqZZ
  - Systematic only from signal QCD scale

### Table 4.5

<table>
<thead>
<tr>
<th>Tracking coverage</th>
<th>(\sigma(\text{H}\to\text{WW}^\ast)).</th>
</tr>
</thead>
<tbody>
<tr>
<td>(</td>
<td>\eta</td>
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<td>(</td>
<td>\eta</td>
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<tr>
<td>(</td>
<td>\eta</td>
</tr>
</tbody>
</table>

\(\Delta\mu: 0.144\) | 0.170

\(Z_0 : 11.1\) | 7.7

**Rejection factor 50**

\(~0.1\) pu jets/event
Supersymmetry Searches at HL-LHC

• Supersymmetry (SUSY) is one possible extension of the SM:
  - predicts bosonic/fermionic partner for existing fermion/bosons
  -> lightest SUSY particle is stable (if R-parity conservation) -> DM candidate
  -> Cancel out quadratic divergences in the Higgs mass corrections
  -> Can accommodate the gauge coupling unification

• Focus on HL-LHC benchmark studies:
  - 14 TeV, $<\mu_{PU}> = 200$, total integrated luminosity of 3000 fb$^{-1}$
  - smearing function for upgraded ATLAS detector simulation
  - truth level particle corrected for detector effects
  - assume 30% systematic on background
Stop pair direct production

• Cut based analysis, top decaying leptonically
• Small mass splitting among stop and neutralino
  -> ISR jets to boost the stop-system
• Final state with 2b-jets, isolated leptons and $E_T^{\text{Miss}}$
• Profile-likelihood-ratio test statistics for expected exclusions
• Run-1 exclusion: $[m_t, 191] \cup [230, 380]$ GeV

\[ \Delta M(\tilde{t}, \tilde{\chi}_1^0) = 173 \text{ GeV} \]

\begin{align*}
\text{BR}=1
\end{align*}

\begin{align*}
\text{Discovery up to 480 GeV} \\
\text{Exclusion up to 700 GeV}
\end{align*}
Stau pair direct production

- Extend the ATLAS exclusion scenario of combined $\tilde{\tau}_L \tilde{\tau}_L$ and $\tilde{\tau}_R \tilde{\tau}_R$ production with $\chi^0_1$ massless
- Cut based analysis: tau decaying hadronically, large $E_T^{\text{Miss}}$, low jet activity
- Main background: W+jets and tt-bar

5σ discovery sensitivity ($\tilde{\chi}^0_1$ massless):
- 100-500 GeV in $\tilde{\tau}$-mass for ($\tilde{\tau}_L \tilde{\tau}_L$ and $\tilde{\tau}_R \tilde{\tau}_R$) combined production
- 120-430 GeV for pure $\tilde{\tau}_L \tilde{\tau}_L$

Exclusion limit ($\tilde{\chi}^0_1$ massless):
- 700 GeV in $\tilde{\tau}$-mass for ($\tilde{\tau}_L \tilde{\tau}_L$ and $\tilde{\tau}_R \tilde{\tau}_R$) combined production
- 650 GeV for pure $\tilde{\tau}_L \tilde{\tau}_L$
- 540 GeV for pure $\tilde{\tau}_R \tilde{\tau}_R$ (Run-1: 109 GeV)

For stau mass of 200 GeV:
$\sigma(\tilde{\tau}_L \tilde{\tau}_L) \sim 0.02$ pb
$\sigma(\tilde{\tau}_R \tilde{\tau}_R) \sim 0.01$ pb
Direct chargino and neutralino production

- Extend the present ATLAS sensitivity to electro-weakinos mass range $O(100 \text{ GeV})$
- Simplified model:
  - $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ are wino-like and with equal mass
  - sleptons and sneutrino with high mass, SM Higgs
- Cut based and MVA analysis
- Main background: $tt$-bar

**5σ discovery sensitivity:**

- 950 GeV in mass $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ for $m(\tilde{\chi}_1^0) = 0$

**Exclusion limit:**

- 1310 GeV in mass $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ for $m(\tilde{\chi}_1^0) = 0$

$$\sigma^{\text{NLO}}(\tilde{\chi}_1^\pm \tilde{\chi}_2^0) \approx 0.005 \text{ pb } (@ 500\text{GeV})$$

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**MVA improvement**
Conclusions

• HL-LHC will represent a challenging environment for ATLAS:
  -> $\langle \mu_{PU} \rangle = 200$, large backgrounds, high radiation dose

• **Higgs and SUSY physics** program will benefit greatly from HL-LHC data and ATLAS Phase II Upgrade
  -> Can explore the $HH$ production mechanism
  -> Precise measurements of Higgs couplings
  -> Can extend the present sensitivities to heavy SUSY particles greatly

• The current expected ATLAS precisions at HL-LHC are still preliminary
  -> Better analysis techniques, better data-driven methods for background
  -> Theoretical uncertainties expected to decrease with time
BACK UP
### Summary of Higgs results at HL-LHC

<table>
<thead>
<tr>
<th>Channels</th>
<th>Result</th>
<th>HH final State</th>
<th>Significance Coupling limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>VBF H→WW*</td>
<td>$\Delta \mu/\mu \approx 14$ to 20%</td>
<td>$HH \rightarrow bb \gamma\gamma$ (stat)</td>
<td>$1.05 \sigma$ $-0.8 &lt; \lambda_{HHH}/\lambda_{SM} &lt; 7.7$</td>
</tr>
<tr>
<td>VBF H→ZZ*</td>
<td>$\Delta \mu/\mu \approx 15$ to 18%</td>
<td>$HH \rightarrow bb \tau^+\tau^-$ (stat+syst)</td>
<td>$0.6 \sigma$ $-4.0 &lt; \lambda_{HHH}/\lambda_{SM} &lt; 12.0$</td>
</tr>
<tr>
<td>ttH, H→γγ</td>
<td>$\Delta \mu/\mu \approx 17$ to 20%</td>
<td>$HH \rightarrow bbb\bar{b}$ (stat+syst)</td>
<td>$-3.5 &lt; \lambda_{HHH}/\lambda_{SM} &lt; 11.0$</td>
</tr>
<tr>
<td>VH, H→γγ</td>
<td>$\Delta \mu/\mu \sim 25$ to 35%</td>
<td>$ttHH, HH \rightarrow bbb\bar{b}$</td>
<td>$0.35 \sigma$</td>
</tr>
<tr>
<td>H→ Zy</td>
<td>$\Delta \mu/\mu \sim 30%$</td>
<td>$H\rightarrow ZZ^*\rightarrow4l$ (m(4l)&gt;220 GeV)</td>
<td>$\Gamma_{H} = 4.2^{+1.5}_{-2.1}$ MeV (stat.+syst.)</td>
</tr>
<tr>
<td>H→μ⁺μ⁻</td>
<td>$\Delta \mu/\mu \sim 15%$</td>
<td></td>
<td>Run-1: $\Gamma_{H} &lt; 22.7$ MeV</td>
</tr>
<tr>
<td>H→ J/ψ γ</td>
<td>BR &lt; $44 \times 10^{-6}$ @ 95% C.L.</td>
<td></td>
<td>ATL-PHYS-PUB-2015-024</td>
</tr>
</tbody>
</table>
Higgs self-coupling: 3000 fb$^{-1}$

- $t\bar{t}HH\rightarrow WbWb$ $b\bar{b}b\bar{b}$ with $<\mu_{PU}> = 200$
  - $\sigma(t\bar{t}HH) \sim 1$ fb
  - Cut based analysis, Final State: $HH\rightarrow b\bar{b}b\bar{b}$ $t\bar{t}\rightarrow b\bar{b}l\nuqq$
  - Signal Region ($\geq 5$ b jets): 25 signal, 7100 background (dominated by c-jets mis-tagged as b-jets)

  **Significance:** $\sim 0.35 \sigma$ (no systematics)

  -> small contribution

- $HH\rightarrow b\bar{b} \tau^- \tau^+$ with $<\mu_{PU}> = 140$
  - Different triggers/cuts for $\tau_{had}\tau_{hah}$ resp. $\tau_{had}\tau_{lep}$ channels
  - Constraint on $m(b\bar{b})$ and $m(\tau\tau)$
  - Systematic: 2% lumi., 3% for major bckg (Z+jets, tt-bar)
  - Combined channels yields: Signal: 48 Bckg.: 7810

  **Significance:** $\sim 0.60 \sigma$ (with syst.)

  $-4 < \lambda_{HHH}/\lambda_{SM} < 12$ (95% C.L. with syst)
Two approaches to study the HL-LHC physics performance with ATLAS

**Use of smearing functions:**
- Study detector performances for phys. objects (e, mu,...) with full MC simulations
- Apply ‘smearing functions’ to truth distributions for analysis, overlay PU jets

**Extrapolation** of Run-1/Run-2 results
- *Similar* detector performance and analysis approach as Run-1/Run-2
- *Scale* signal and background level to higher luminosity, c.o.m. energy

**Systematics** (will have ~x10 more higgs at HL-LHC than at the end of Run-2)
- *Theoretical*: from Run1/Run2
- *Experimental*: scaled to best guess for ATLAS upgraded detector at HL-LHC
Pile-up II: Photons

For combined average efficiency of 70% for isolated photons:

- Rejection factor of ~4000 for hard-scattered jets
- Rejection factor of ~14000 for pile-up jets
• For an electron identification efficiency of 69%, a jet rejection factor of about 4000 is obtained. Also, an electron charge mis-identification of about 0.26% has been evaluated for the first time.

• For 70% b-jet efficiency (with MV1 tagger):
  - light jet rejection of ~380 with $<\mu> = 200$ (best optimized Run-2 b-tagger has 380 at 70% eff.)

• Muon with Pt < 200 GeV greatly benefit from Itk momentum resolution
  - $B_s^0$ mass resolution in the $B_s^0 \rightarrow \mu^+ \mu^-$ will improve by a factor of about 1.65 (1.5) in the barrel (end-cap) region.

6/30/17
Pile-up suppression

• Typical jet selections require $p_T (\text{jet}) > 30 \text{ GeV, } |\eta(\text{jet})| < 3.8$

• With $<\mu_{\text{PU}}> = 200$ expected 4.8 pileup jets with $p_T > 30 \text{ GeV, } |\eta|<3.8$ per event

• Pile-up suppression with a parametrized track-confirmation requirement

• Applied to all non $b$-tagged jets with $p_T < 100 \text{ GeV and } |\eta|<3.8$

Analyses typically use factor 50 rejection

- $\sim 0.2$ pile-up jet per event

- 85-70 % efficiency on hard-scatter jets

CERNLHCC-2015-020
Figure 4.38: Signal resolution for $H \rightarrow \mu\mu$ signal events, the Run 2 resolution is compared to the HL-LHC with pile-up conditions corresponding to $\langle \mu \rangle = 200$. 

The low SM non-resonant $HH$ production cross section means that it is necessary to consider final states where at least one of the two Higgs bosons decays into a final state with a large branching ratio. The decay channel with largest branching ratio is $H \rightarrow b\bar{b}b\bar{b}$. Therefore, the high-performance $b$-tagging capability of the proposed upgraded tracker is of critical importance for these analyses. The SM non-resonant $HH$ production process is dominated by gluon-gluon fusion, leading to centrally produced Higgs bosons, hence the extended forward tracking capability of the ITk is not expected to lead to large improvements in sensitivity.
ATLAS Running Conditions

High particle density

High integrated radiation dose

Detector requirements to maximize benefits from high int. luminosity:
- Replace detector not sustaining integrated radiation dose
- Minimize pile-up effect (high granularity, fast timing)
- Higher trigger acceptance and event rate
- Improve or maintain current detector performances
Figure 4: Regions of the $(\cos(\beta - \alpha), \tan\beta)$ plane of four types of 2HDMs expected to be excluded by fits to the measured rates of Higgs boson production and decays. The confidence intervals account for a possible relative sign between different couplings. The expected likelihood contours where $-2\ln \Lambda = 6.0$, corresponding approximately to 95% CL ($2\sigma$), are indicated assuming the SM Higgs sector. The light shaded and hashed regions indicate the expected exclusions.
Analysis Techniques

ATLAS HL-LHC studies have to consider:
- upgraded ATLAS detector + trigger systems
- collision energy, $\sqrt{s} = 14$ TeV
- high pile-up, $<\mu_{PU}>$, of 140 or 200

- We use generator-level $\sqrt{s} = 14$ TeV Monte Carlo samples
- Overlay with jets from dedicated pile-up library
  - pile-up library contains fully simulated pile-up jets with $<\mu_{PU}> = 140$ or 200
- Reconstruct electron, muons, jets, photons and missing-$E_T$ from generator+overlay information

- To simulate the response of the detector:
  - smear $p_T$ and energy of reconstructed physics objects using smearing functions
  - apply reconstruction efficiencies for electrons, muons and jets

- To emulate triggers: apply trigger efficiency functions

- Smearing and efficiency functions determined from fully-simulated samples using ATLAS HL-LHC detector and high pile-up
  - Functions are dependent on $p_T$ and $\eta$

- Most analysis presented use single lepton or di-lepton triggers ($e, \mu$)
  - di-$\tau$ triggers and 4-jet triggers used for particular analyses

- Parametrised $b$-tagging (based on ATLAS Run 1 MV1 tagger) is performed on reconstructed jets

- This approach to ATLAS HL-LHC prospects studies has been validated on a limited number of physics studies comparing full simulation and the generator-level+smearing technique
Measure off-shell production of $H \rightarrow ZZ^* \rightarrow 4\ell$ with $m(4\ell) > 220$ GeV

Use $m(4\ell)$ shape and matrix element to discriminate between signal and background

- stat. uncertainties only: $\mu_{\text{off-shell}} = 1.00^{+0.23}_{-0.27}$
- stat.+syst. uncertainties: $\mu_{\text{off-shell}} = 1.00^{+0.43}_{-0.50}$

- Off-shell production used to constrain the Higgs boson width $\Gamma_H$

- For $\Gamma = \Gamma_{\text{SM}}$ combining with on-shell measurement, (assuming off-shell measurement dominates):

  \[ \Gamma_H = 4.2^{+1.5}_{-2.1} \text{ MeV (stat+sys)} \]

- Run 1 limit: $\Gamma_H < 22.7$ MeV at 95% CL ($WW, ZZ$)
Assuming $\Gamma_H$ is sum of SM widths, calculate uncertainties on Higgs boson couplings.

Deviations from the SM are quantified using $\kappa$ multiplier, in SM $\kappa_i = 1$, e.g.:

$$(\sigma \cdot BR)(gg \rightarrow H \rightarrow \gamma\gamma) = \sigma_{SM}(gg \rightarrow H) \cdot BR_{SM}(H \rightarrow \gamma\gamma) \cdot \frac{\kappa_g^2 \cdot \kappa_{\gamma\gamma}^2}{\kappa_H^2}$$

• Assume universal modifications to Higgs couplings to fermions ($\kappa_F$) and vector bosons ($\kappa_V$)

Table 2: Expected 95% CL lower limit on the Higgs boson compositeness scale with 300 and 3000 fb$^{-1}$ at $\sqrt{s} = 14$ TeV in the MCHM4 and MCHM5 models, each shown with and without the inclusion of theoretical uncertainties in the coupling measurements.
ATLAS HL-LHC Analysis Strategy

- Detector **performance** of different physics objects (e, μ, γ,...) with MC (Full Sim.)
- Parametrization to provide ‘smeared truth’ simulation to benchmark analysis
- Jets from **pile-up events** are overlaid on the hard-scatter events
- **Signals** from interactions in previous bunch crossings are added (calorimeter response)

**Extrapolation** of Run-1/Run-2 results

- **similar** detector performance and analysis approach as Run-1/Run-2
- **Scale** signal and background level to higher luminosity, c.o.m. energy

- **Systematics** (will have ~x10 more higgs at HL-LHC than at the end of Run-2)
  - **Theoretical**: from Run1/Run2
  - **Experimental**: scaled to best guess for ATLAS upgraded detector at HL-LHC

- **Pile-up suppression** (~factor 50) track-confirmation requirement (~0.2 p.u. jets/event)
Higgs Couplings

**Run-1**
\[ \mu = 1.17^{+0.28}_{-0.27} \quad (\Delta \mu / \mu \sim 0.23) \]
\[ \mu = 1.46^{+0.40}_{-0.30} \quad (\Delta \mu / \mu \sim 0.24) \]
\[ \mu = 1.18^{+0.42}_{-0.37} \quad (\Delta \mu / \mu \sim 0.33) \]

- Extrapolation from Run-1 analysis at \( <\mu_{PU}> = 140 \)
- *(ATL-PHYS-PUB-2014-016)*

With 3000 fb\(^{-1}\):
- \( W, Z \) couplings to 3%
- *Muon* coupling to 7%
- \( t, b, \tau \) couplings to 8-12%