**Physics Prospects at the HL-LHC with ATLAS**

The High-Luminosity LHC aims to provide a total integrated luminosity of 3000 fb⁻¹ from proton-proton collisions at a collision energy of 14 TeV over the course of ~10 years, reaching instantaneous luminosities of up to $L = 7.5 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$, corresponding to an average of 200 inelastic p+p collisions per bunch crossing ($\mu = 200$). The upgraded ATLAS detector and trigger system must be able to cope well with increased occupancies and data rates. The performance of the upgrade has been estimated in full simulation studies, assuming expected HL-LHC conditions and a detector configuration intended to maximise physics performance and discovery potential at the HL-LHC, and is expected to be similar to current performance. Fast simulation studies have been carried out to evaluate the prospects of various benchmark physics analyses to be performed using the upgraded ATLAS detector with the full HL-LHC dataset.

### Detector Effects in Physics Prospects Studies

- Expected performance for different physics objects and trigger/DAQ derived from full simulation studies [2].
- Parameterised estimates of performance provided for physics prospects studies.
- “Smeared truth” simulations of analyses, with extrapolations from Run 1 and Run 2 for some performances.

### Benchmark Analyses

#### High energy: $t\bar{t}$ resonances

- Benefits from improved statistics for high $p_t$ events.
- High mass signal $\Rightarrow$ boosted top quark decays $\Rightarrow$ highly collimated jets.
- Search relies on a good reconstruction of boosted objects.
- Dependent on upgrade tracking performance in a dense environment for b-tagging and lepton isolation.

**Simulated search using benchmark resonance $Z' \to t\bar{t}$ [3]**

- Expected HL-LHC mass reach: $m_{Z'} \approx 4$ TeV.
- ATLAS Run 1 mass constraint (20.3 fb⁻¹): $m_{Z'} > 2.1$ TeV.

#### Rare processes: FCNC top decay

- Highly suppressed in Standard Model (rates $< 10^{-6}$).
- Detection would be sign of new physics.

**Expected sensitivity to FCNC top quark decays $t\rightarrow Zq$ and $t\rightarrow Hq$ [5]**

<table>
<thead>
<tr>
<th>Uncertainties</th>
<th>$t\rightarrow Zq$ channels</th>
<th>$t\rightarrow Hq$ channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>statistics only</td>
<td>(2.4 – 5.8) $\cdot 10^{-5}$</td>
<td>(0.6 – 1.2) $\cdot 10^{-4}$</td>
</tr>
<tr>
<td>statistics + systematics (A)</td>
<td>(12 – 41) $\cdot 10^{-5}$</td>
<td>(1.1 – 2.4) $\cdot 10^{-4}$</td>
</tr>
<tr>
<td>statistics + systematics (B)</td>
<td>(8.3 – 24) $\cdot 10^{-5}$</td>
<td>(1.1 – 2.4) $\cdot 10^{-4}$</td>
</tr>
</tbody>
</table>

- Systematics A extracted from Run 1 MC to data CR comparisons.
- Systematics B conservatively account for improvements to dominant theoretical and background normalisation uncertainties from HL-LHC statistics.
- Detector related systematics can be neglected.
- Lower impact of systematics on $t\rightarrow Hq$ sensitivity due to higher expected statistics and multiple fit regions.

**Strongest observed limits from Run 1 (ATLAS and CMS) [6, 7]:**

- $t\rightarrow Zq$ in final states with three leptons, $B(t\rightarrow Zq) \approx 50 \cdot 10^{-5}$.
- $t\rightarrow Hq$ with $H\rightarrow (\gamma\gamma, bb$ or multilepton), $B(t\rightarrow Hq) \approx 45 \cdot 10^{-4}$ and $B(t\rightarrow Hq) < 46 \cdot 10^{-4}$.

#### Precision measurements: VBF Higgs production

- Unique signature: jets in the forward region with large dijet invariant mass.
- Exploited to increase the signal to background ratio.

**Measurements prospects for VBF $H \rightarrow WW^* \rightarrow \ell\nu\ell\nu$ [4]**

- Expected precision depends on the tracker coverage.
- Increased tracker acceptance in $|\eta| \Rightarrow$ better pileup rejection.
- Analysis uses a central jet veto (CJV), so benefits from fewer pileup jets causing signal events being rejected by the CJV.
- Analysis also requires a $b$-jet veto, sensitive to b-tagging performance.

**Tracking coverage $\Rightarrow$ Expected precision**

| $|\eta| < 4.0$ | 12% |
| $|\eta| < 3.2$ | 18% |
| $|\eta| < 2.7$ | 22% |

* Neglecting theoretical uncertainties on ggf and VBF production.

The increase in tracker coverage allows precision measurement of VBF Higgs production even in a high pileup environment.

#### EWSB: Measuring $\lambda_{HHH}$ through Higgs pair production

Is the Higgs mechanism responsible for electroweak symmetry breaking (EWSB)? Extensive investigation of Higgs properties, such as the trilinear self-coupling, $\lambda_{HHH}$:

$\lambda_{HHH}$ interferes destructively with $\lambda_{HZZ}$,

so any deviation from expectation in $\lambda_{HHH}$ will modify non-resonant HH production.

**Non-resonant HH$\rightarrow b\bar{b}b\bar{b}$ production [8]**

- Low SM $\sigma$(non-resonant HH) $\Rightarrow$ use HH$\rightarrow b\bar{b}b\bar{b}$ channel for high BR.
- Upgrade b-tagging performance critical

**Expected constraints on $\lambda_{HHH}$ with and without systematic uncertainties:**

**Other HH channels [5], [10]**

- $HH\rightarrow b\bar{b}VV$ (cleaner signal and lower BR) $\Rightarrow 0.9 < \lambda_{HHH}/\lambda_{SM} < 7.7$
- $ttHH$: expected significance of $ttHH$ production $< 0.35$, at most a small contribution to self-coupling measurement.