# Higgs Boson Cross Section Measurement in the $H \to ZZ \to 4\ell$ Channel with Early Run 3 ATLAS Data

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**FSP** ATLAS
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- Run 3 of the LHC began in July 2022 with an increased centre of mass energy of 13.6 TeV

- Production rate of Higgs bosons is expected to increase by $\sim 7-8\%$ at this higher energy

- Preliminary luminosity of Run 3 data in 2022 is $\sim 30.7$ fb$^{-1}$, allowing for the first Higgs boson property measurements in this new regime
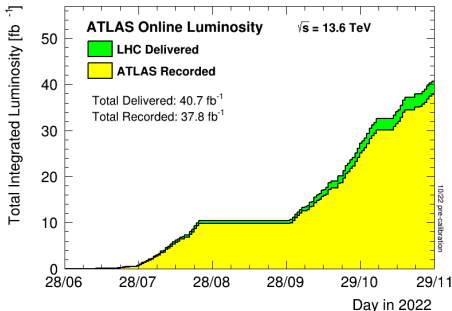
# $H \to 4\ell$ **Decay Channel**

- Characterised by a final state containing two pairs of oppositely charged leptons from the same primary vertex

- Four possible decay channels: $4\mu, 4e, 2e2\mu$ and $2\mu2e$

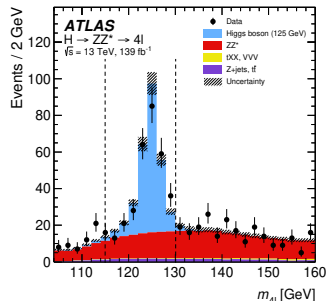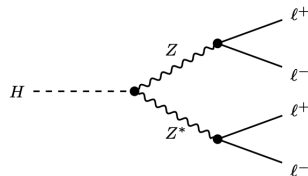- Event reconstruction requirements: $p_T^{l1} > 5$ GeV, $p_T^{l2} > 10$ GeV, $p_T^{l3} > 15$ GeV, $p_T^{l4} > 20$ GeV, $50 < m_Z < 106$ GeV, $12 < m_{Z*} < 115$ GeV, $115 < m_{4\ell} < 130$ GeV

- Sideband regions used to constrain dominant ZZ* background: $105 < m_{4\ell} < 115$ GeV, $130 < m_{4\ell} < 160$ GeV

- Clear signature allows for an early Run 3 measurement of the inclusive Higgs boson production cross section





(arxiv:2004.03447)

- Production cross section is measured in a fiducial phase space closely matching the detector acceptance and event reconstruction requirements

- Fiducial cross section, $\sigma_i^{\text{fid}}$, for each decay channel, $i$, is extracted using a template fit of the $\mathcal{P}_i(m_{4\ell})$ distribution, according to the number of reconstructed events, $N_i$, in the signal region:

$$N_i(m_{4\ell}) = \sum_i \epsilon_i \cdot \left(1 + f_i^{\text{nonfid}}\right) \cdot \sigma_i^{\text{fid}} \cdot \mathcal{P}_i(m_{4\ell}) \cdot \mathcal{L} + N_i^{\text{bkg}}(m_{4\ell})$$

(arxiv:2004.03447)

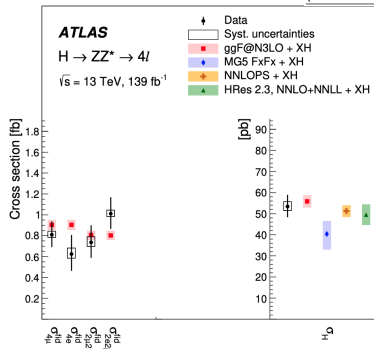$\sigma_i^{\text{fid}} = \sigma_i \cdot A_i \cdot \mathcal{B}$ = Parameter of Interest

$\mathcal{P}_i(m_{4\ell}) = m_{4l}$ signal shape

$N_i^{\text{bkg}}(m_{4\ell})$ = Background contribution

$A_i$ = Acceptance = $N_{\text{fid}}/N_{\text{tot}}$

$\epsilon_i$ = Reconstruction efficiency

$f_i^{\text{nonfid}}$ = Fraction of events outside the fiducial region which are reconstructed in the signal region



ATLAS
H → ZZ* → 4l
√s = 13 TeV, 139 fb⁻¹

Data
Syst. uncertainties
ggF@N3LO + XH
MG5 FxFx + XH
NNLOPS + XH
HRes 2.3, NNLO+NNLL + XH

# First Look at Run 3 Simulation

- Comparison of four-lepton mass distribution ($m_{4l}$) in Run 2 and Run 3 simulations with 30.7 fb$^{-1}$ in signal region $115 < m_{4l} < 130$ GeV:



- **Run 3 - All Signal**
- **Run 3 - ZZ* background**
- ------ **Run 2 - Sig + bkg (30.7fb$^{-1}$)**
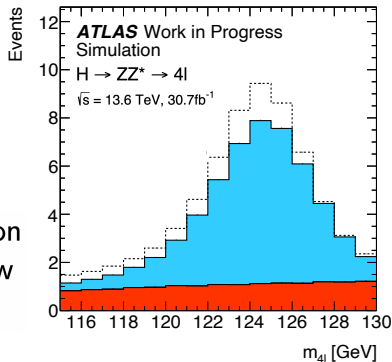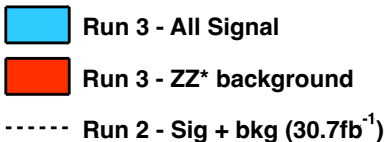
- Run 3 lepton performance calibration still in progress, especially in the low $p_T$ region

- This results in fewer Higgs bosons being reconstructed when compared to Run 2 data with the same integrated luminosity

- Feasibility of total fiducial cross section measurement studied for different amounts of integrated luminosity: 30, 20, 10 and 5 fb$^{-1}$

- Study is based on scaling the predictions of the Run 2 Monte Carlo (MC) simulation to different integrated luminosities

- MC events are reweighted to reflect the Run 3 muon reconstruction efficiencies as this was initially lower than the full Run 2 efficiency

- With 30 fb$^{-1}$, measurement is possible for the individual decay channels:



**ATLAS** Work in Progress
Simulation

| Channel | $\sigma_{fid}$ (13TeV) | + stat. err | - stat. err |
|---|---|---|---|
| inclusive | 3.345 | 17.9% | 16.4% |
| $4\mu$ | 0.884 | 30.5% | 26.4% |
| $4e$ | 0.885 | 44.3% | 36.2% |
| $2\mu2e$ | 0.788 | 42.0% | 34.5% |
| $2e2\mu$ | 0.788 | 36.9% | 31.1% |
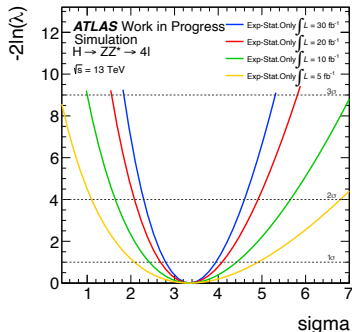
- ZZ* background normalisation can be estimated from data in the $m_{4\ell}$ sideband regions (instead of the purely MC-based prediction):

  $105 < m_{4\ell} < 115$ GeV and $130 < m_{4\ell} < 160$ GeV

- Introducing this extra degree of freedom increases the statistical uncertainty on the fiducial cross section by no more than $1 - 2\%$

# Comparison with Run 2 Measurement
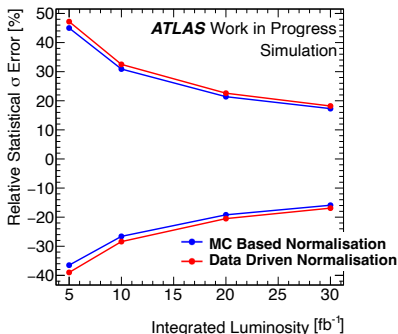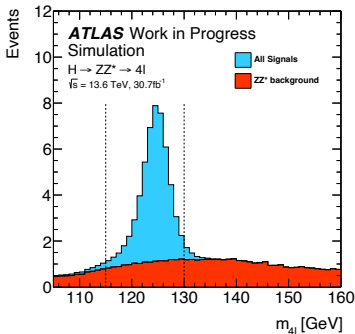
- Expected fiducial cross section precision from Run 2 and Run 3 simulations are compared

- So far, only statistical uncertainties are taken into account

- Statistical uncertainties are $\sim 1 - 3\%$ larger with Run 3 simulations due to fewer Higgs bosons being reconstructed

**ATLAS** Work in Progress
Simulation

| Channels | Run 2 MC, scaled to 30 fb$^{-1}$ | | | Run 3 MC, 30.7 fb$^{-1}$ | | |
|---|---|---|---|---|---|---|
| | $\sigma_{fid}$ | + Err. [%] | - Err [%] | $\sigma_{fid}$ | + Err. [%] | - Err [%] |
| inclusive | 3.345 | 17.5 | 16.1 | 3.588 | 18.1 | 16.5 |
| $4\mu$ | 0.884 | 29.6 | 25.6 | 0.945 | 30.1 | 26.0 |
| $4e$ | 0.855 | 44.3 | 36.2 | 0.955 | 47.9 | 38.1 |
| $2\mu2e$ | 0.788 | 41.6 | 34.3 | 0.843 | 44.8 | 36.0 |
| $2e2\mu$ | 0.788 | 36.7 | 31.0 | 0.844 | 36.8 | 30.8 |

# First look at Systematic Uncertainties

- Experimental systematic uncertainties related to muon and electron identification/reconstruction are also considered

- Up and down variations in $m_{4l}$ due to systematic uncertainties are considered relative to the nominal distribution

- Experimental systematics which have the largest impact are related to the muon isolation efficiency and electron identification efficiency:
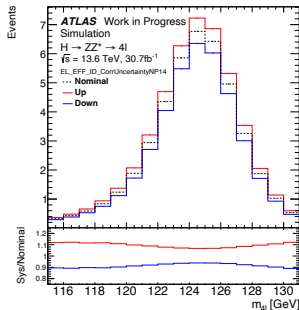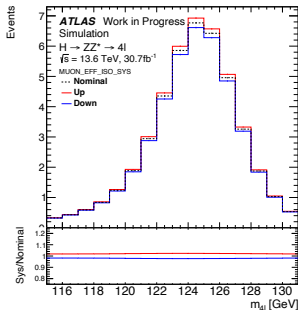
- Including systematic uncertainties increases the overall uncertainty on $\sigma_{fid}^{incl}$ by $\sim 2\%$

- Large systematic uncertainties for $e^-$ are conservative as the Run 3 lepton performance calibration is still in progress
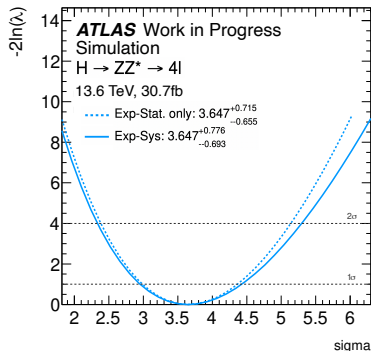


**ATLAS** Work in Progress
Simulation

| Channels | $\sigma_{fid}$ | Run 3 stat. only | | Run 3 with sys. | |
|---|---|---|---|---|---|
| | | + Err. [%] | - Err [%] | + Err. [%] | - Err [%] |
| inclusive | 3.647 | 19.6 | 18.0 | 21.2 | 18.9 |
| $4\mu$ | 0.964 | 31.5 | 27.4 | 32.3 | 27.6 |
| $4e$ | 0.965 | 48.7 | 39.0 | 59.0 | 42.4 |
| $2\mu 2e$ | 0.859 | 46.2 | 37.1 | 53.4 | 39.6 |
| $2e2\mu$ | 0.859 | 38.4 | 32.2 | 38.6 | 32.2 |

# Conclusion

- Run 3 of the LHC operating at an increased centre of mass energy, 13.6 TeV, increasing the Higgs boson production rate by $\sim 7 - 8\%$

- Expected statistical uncertainty on fiducial cross section in Run 3 $\sim 1 - 3\%$ larger than in Run 2

- This is expected to improve in the very near future as updated lepton identification and reconstruction is performed

- Future Plans:
    - Evaluate the impact of theoretical systematic uncertainties
        - $\rightarrow$ expected to be small with respect to experimental systematics
    - Update analysis with improved lepton performance and perform $\sigma_{fid}$ with Run 3 data from 2022
    - Differential cross section measurement with Run 3 data