# Physics prospects for an upgraded ATLAS detector at HL-LHC

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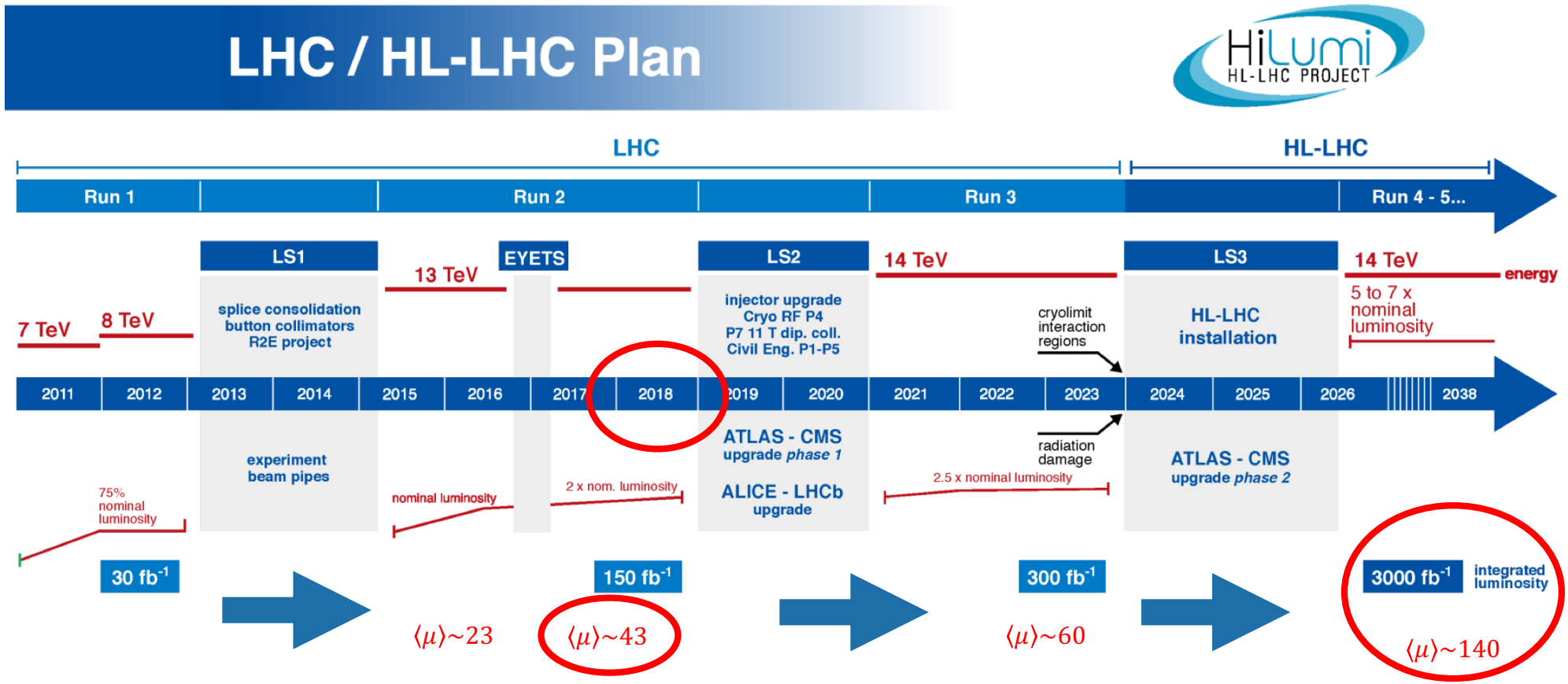
# Outline

- The High Luminosity LHC (HL-LHC)
- The ATLAS detector, present and planned upgrades
- Performance in the upgraded ATLAS detector
- Physics prospects for the upgraded detector
  - Higgs production
    - Higgs rare decays (e.g. $H \rightarrow \mu\mu$ )
    - Vector Boson Fusion (VBF) Higgs production
    - H → ZZ(*) → 4$l$ (differential cross-section measurement)
  - Search for heavy bosons
    - Search for W' bosons in the channel $W' \rightarrow l\nu$
    - Z' decaying to $t\bar{t}$ resonances
  - $W^{\pm}$ $W^{\pm}$ scattering (Vector-Boson Scattering)

- Disclaimer: due to time constraints, a lot of results can not be presented in this talk.
  - I will therefore focus mainly on more recent results which have only recently become available.

# The High Luminosity LHC

The Large Hadron Collider (LHC), designed to deliver p-p collisions at $\sqrt{s}$ = 14 TeV.




The High Luminosity LHC (HL-LHC) is expected to run at an average of 140 inelastic proton-proton collisions per beam-crossing ($\langle\mu\rangle = 140$).

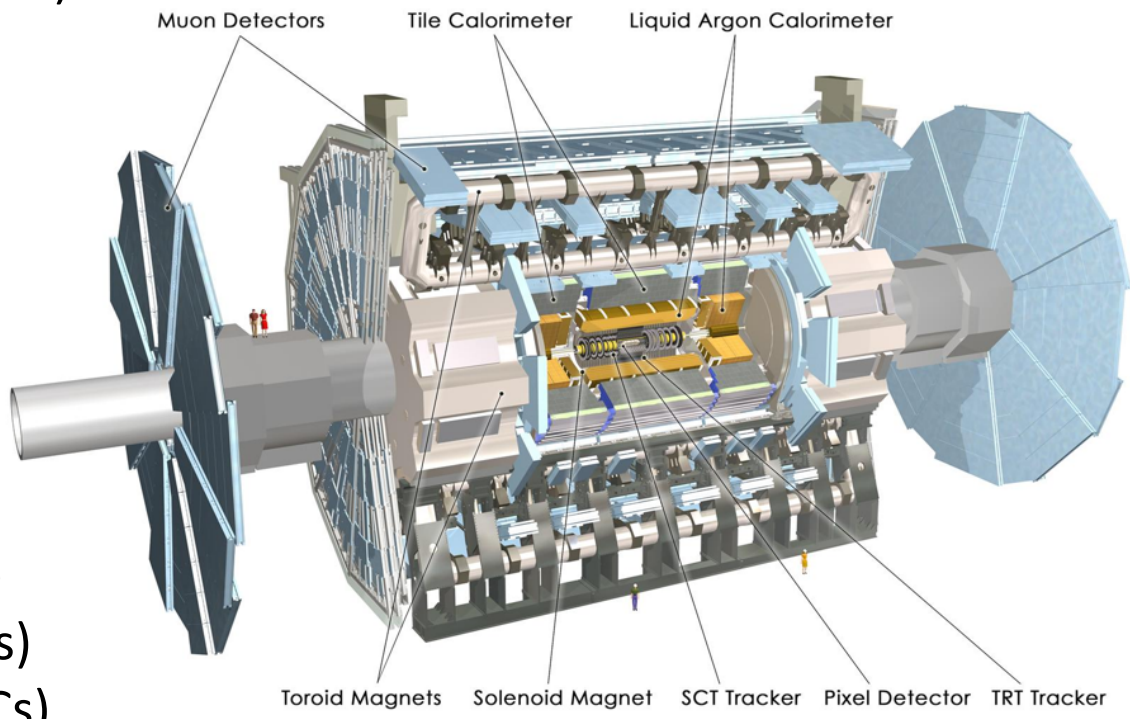
- With the possibility to be pushed to $\mu \sim 200$.

# The ATLAS detector, present and planned upgrades

**Current ATLAS (AToroidalLHC ApparatuS) detector**

- The Inner Detector (ID) tracking system
  - Transition radiation tracker (TRT)
  - Silicon Strip tracker (SCT)
  - Pixel detector
- Electromagnetic and hadronic calorimeters
  - Tile calorimeter
  - Liquid Argon calorimeter (LAr calorimeter)
- The Muon Spectrometer (MS)
  - Monitored Drift Tubes (MDTs)
  - Cathode Strip Chambers (CSCs)
  - Resistive Plate Chambers (RPCs)
  - Thin Gap Chambers (TGCs)

**Will mainly focus on the ID and the MS in this talk!**

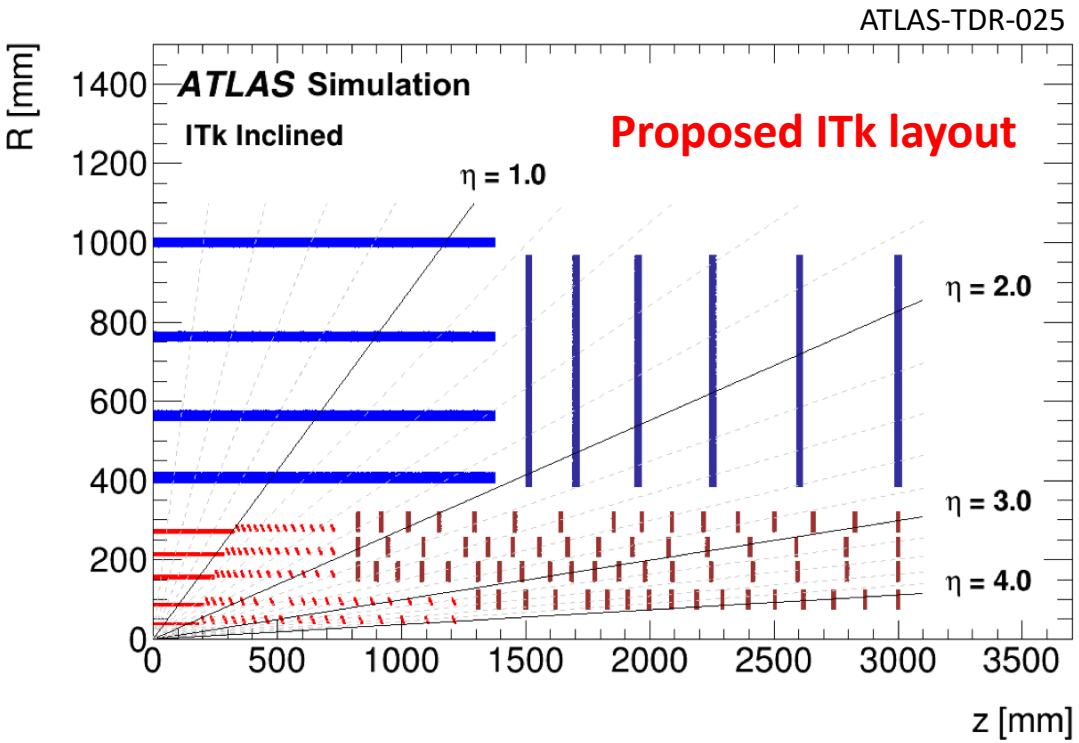


# The ATLAS detector, present and planned upgrades

**Upgrades**

The ID replaced with all-silicon tracker (ITk).

- Maintain tracking performance in high pile-up.
- Reduce impact of radiation damage.
- Pseudo-rapidity ($|\eta|$) coverage extended from 2.7 to 4.




Muon upgrades will extend the muon identification and acceptance to $|\eta| = 4$.

**Other upgrades** : Upgraded readout electronics for the LAr calorimeter and longer latency trigger system.

**Further options, under discussion** : High-Granularity Timing Detector and the forward muon tagger.

# Performance in the upgraded ATLAS detector

## ITk performance

- Similar track reconstruction efficiency to Run 2 in zero pile-up.
- Also independent of $\mu$.

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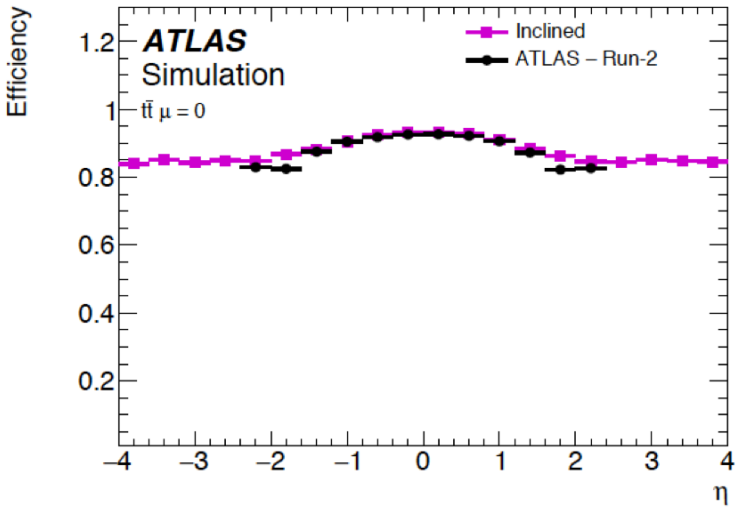


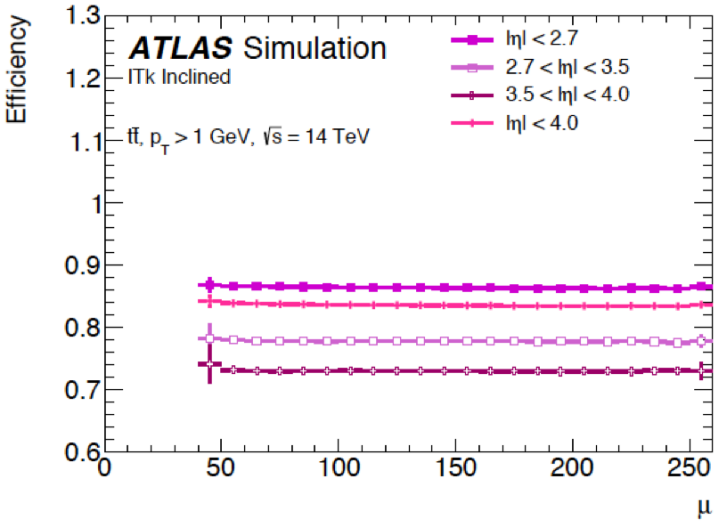


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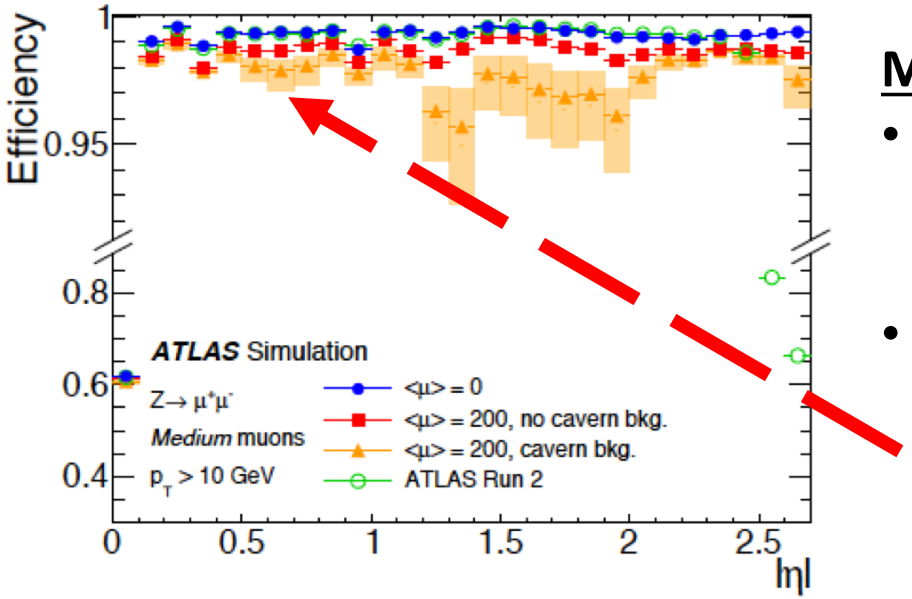


## Muon Spectrometer performance

- Maintained similar performance to Run 2 for reconstruction and identification efficiency for muons.
- In the barrel region the contributions from high pile-up and the cavern background result in an overall efficiency loss of less than 1.2%.

# Higgs production

## Higgs rare decays (e.g. H → $\mu\mu$)

Test SM predictions through Higgs to fermion couplings.

- Signature is a narrow invariant mass peak
  - Small, but not insignificant $\sigma \times BR$ of 12.6 fb at $\sqrt{s}$ = 14 TeV.
- Assuming 3,000 fb$^{-1}$, the total signal significance is $8.6\sigma$ compared to $2.3\sigma$ with 300fb$^{-1}$.

ATL-PHYS-PUB-2013-014

**Improvement of 25% in the signal resolution ~2 GeV**

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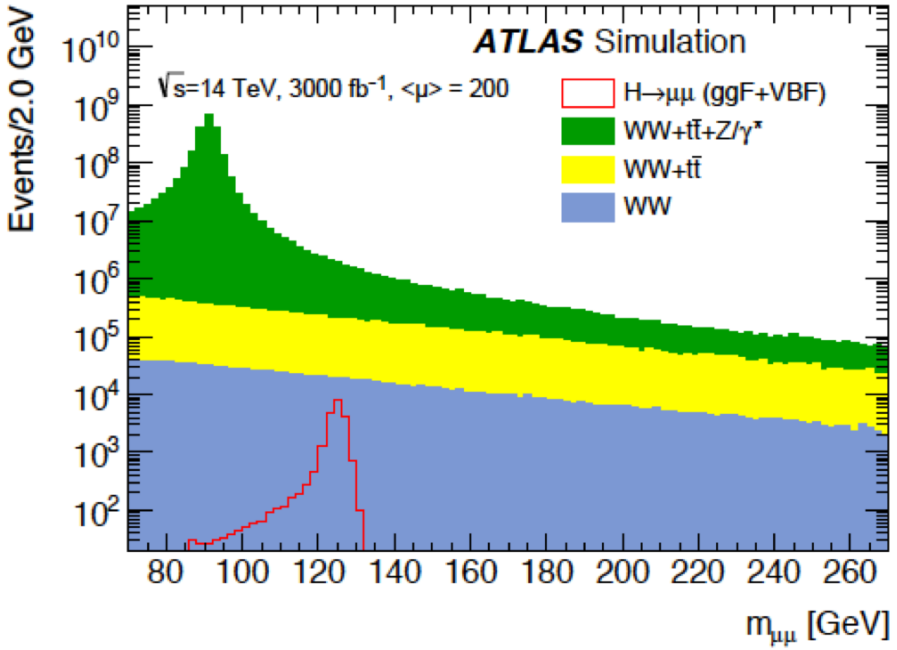


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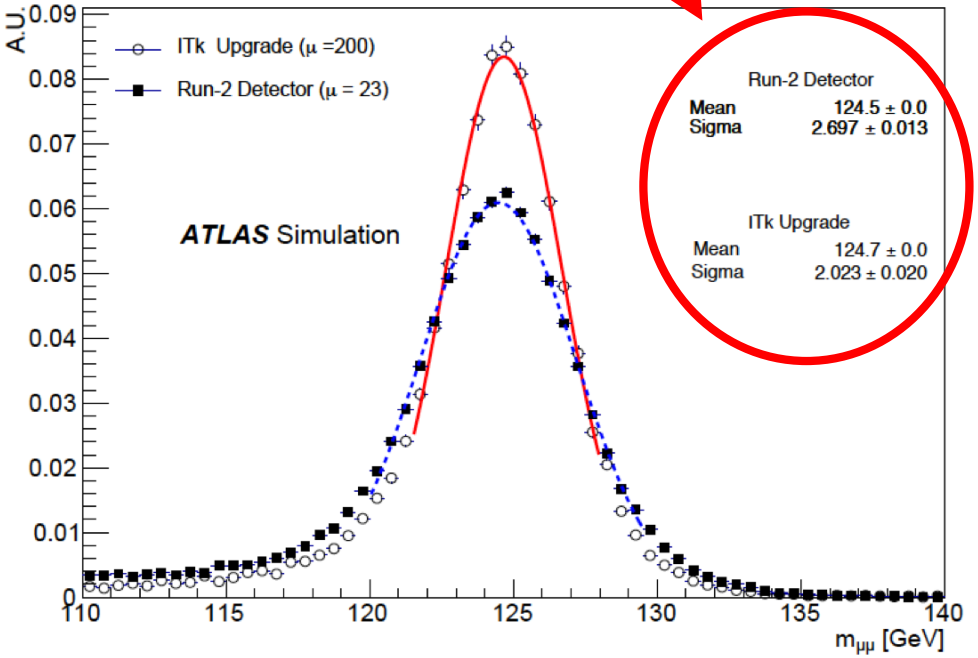
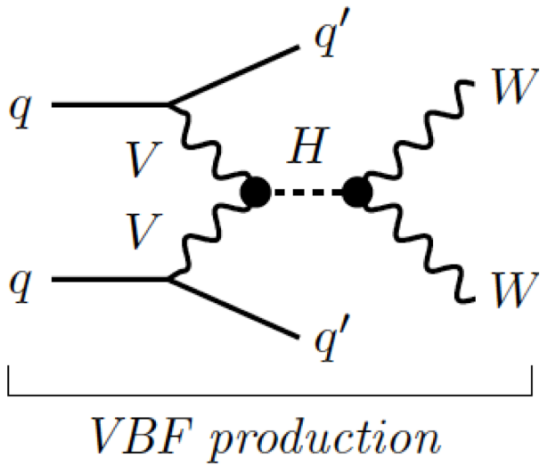


# Vector Boson Fusion (VBF) Higgs production

Signature – pair of jets in the forward region with large di-jet invariant mass – distinguishable from background processes.

- The measurement boils down to precision in the tracking and vertexing.




*VBF production*

**Example measurement for VBF, H → WW* → eνμν**

Large sensitivity to the angular coverage

- Primarily through b-jet veto and track confirmation for jets.

ATLAS-TDR-025

Precision on the visible cross-section measurement

| Tracking coverage | Expected precision |
|---|---|
| $\|\eta\| < 4.0$ | 12% |
| $\|\eta\| < 3.2$ | 18% |
| $\|\eta\| < 2.7$ | 22% |

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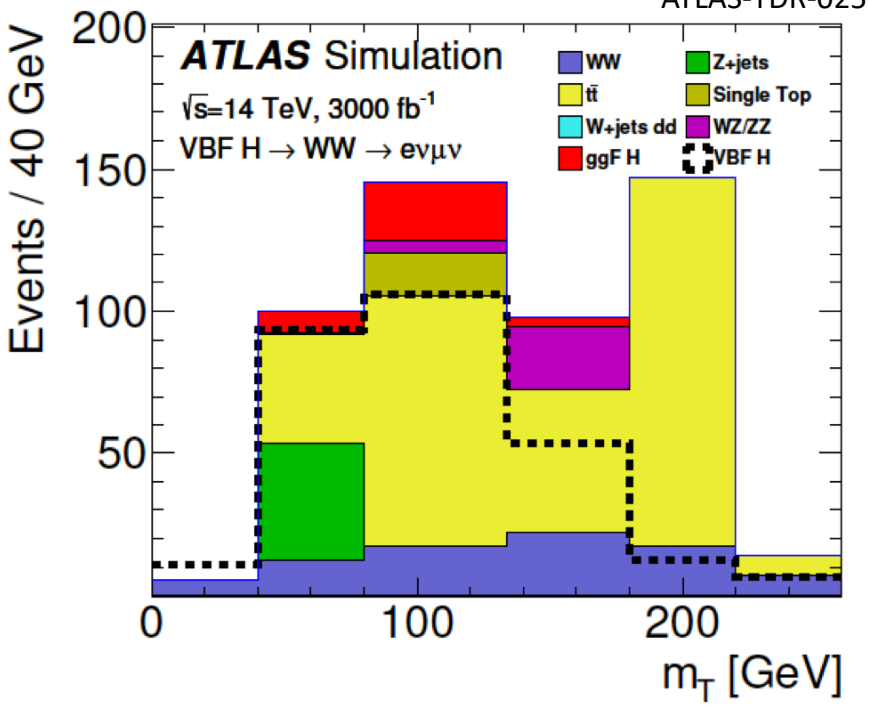


Compared to Run 1 result, with 5.8 fb$^{-1}$ of data

$\sigma_{VBF} \cdot B_{H\to WW^*} = 1.4^{+0.8}_{-0.6}(stat)^{+0.5}_{-0.4}(syst)$ pb.

- Improvement in precision from ~25% to 12%.

ATLAS-CONF-2016-112

# Higgs boson production with $H \rightarrow ZZ^{(*)} \rightarrow 4l$

**Differential cross-section measurement in Higgs boson rapidity ($H \rightarrow ZZ^{(*)} \rightarrow 4l$)**

For the first time, measurement of the cross-section as a function of rapidity in the high rapidity region.

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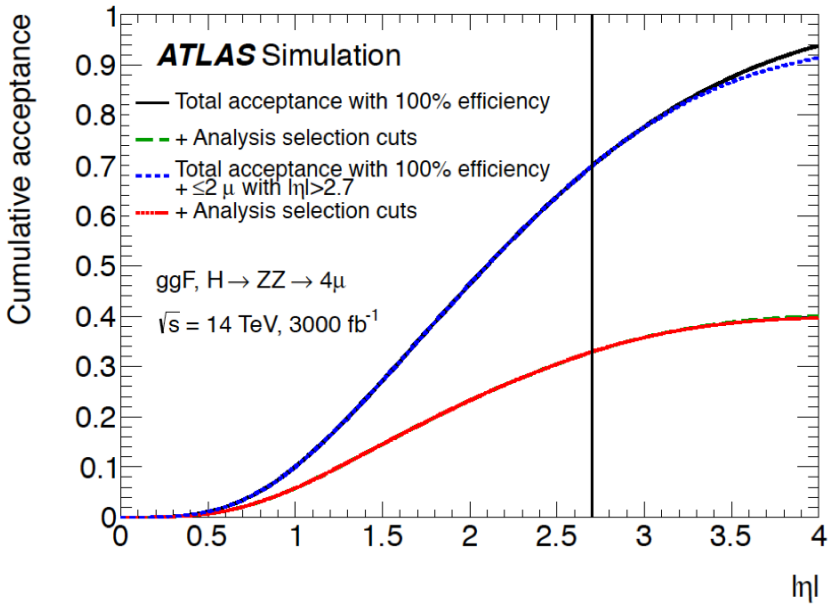


Acceptance gain of 22% from increasing $|\eta| < 2.7$ to $|\eta| < 4.0$.

Improvement on the current results based on 36.1 $fb^{-1}$ of data by more than a factor of six.

- Reaching an uncertainty that matches the current theory accuracy.

Total uncertainties on the differential distribution

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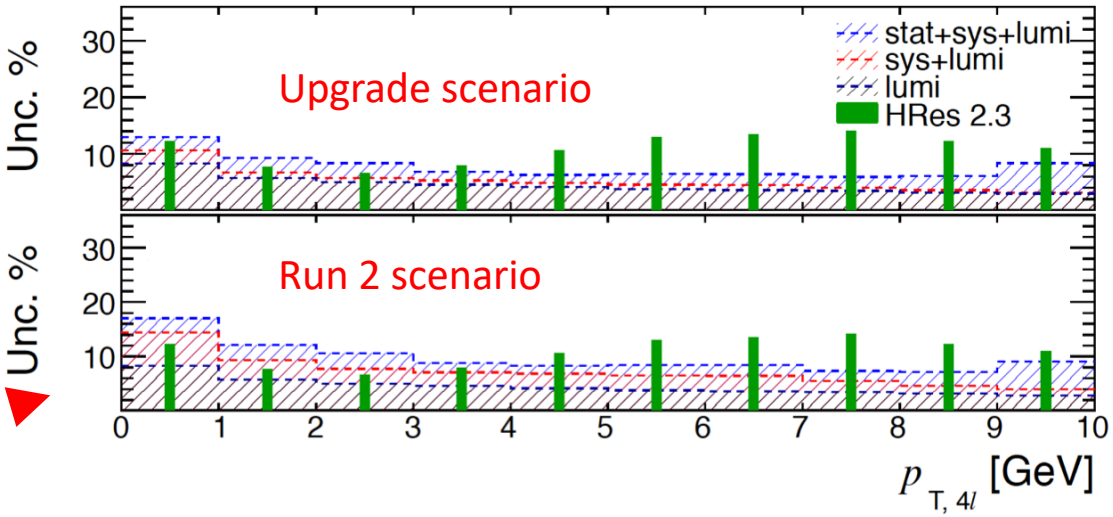

# Search for heavy bosons

## Search for W' bosons in the channel W' → $l\nu$

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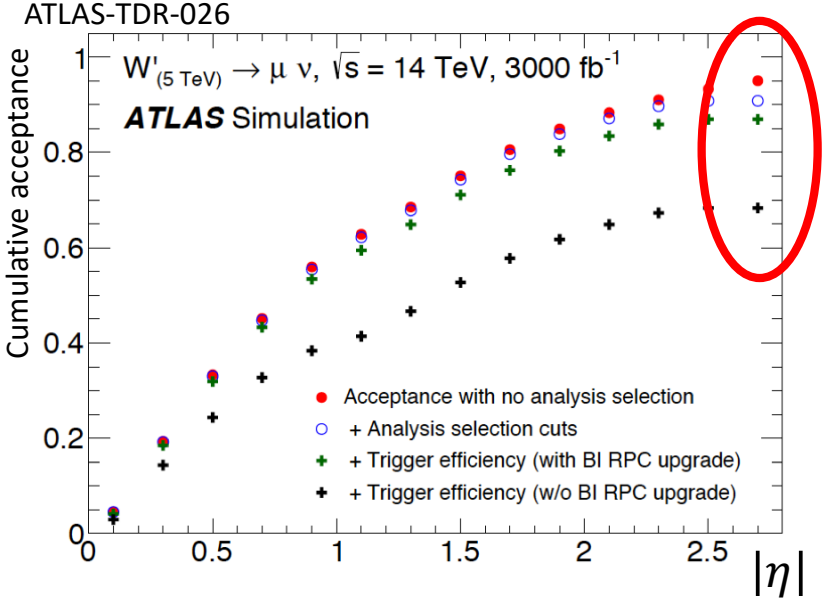



The gain in the muon trigger acceptance from ~70% to almost 90% due to Innermost Barrel layer (BI) upgrade.

## Search for Z' bosons in the channel $Z' \rightarrow t\bar{t}$

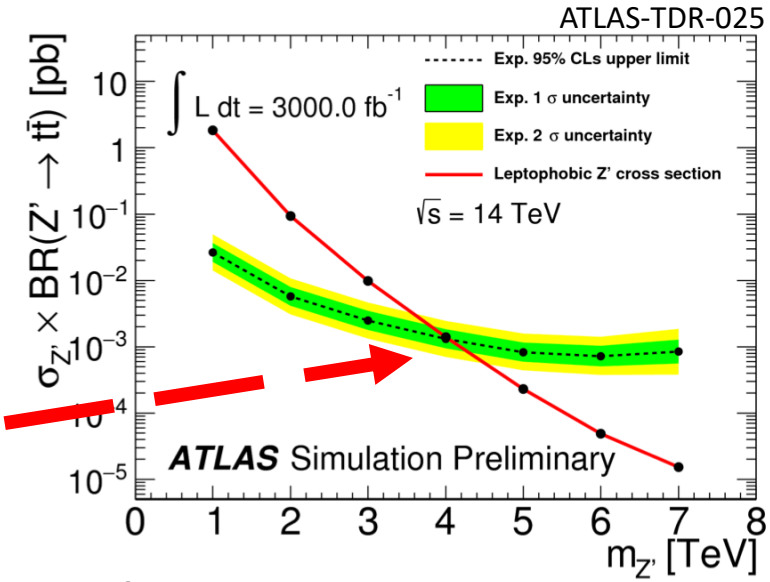
Require improved statistics for high $p_T$ events (boosted objects).

Statistical analysis to find the mass reach.

- Estimated to be 4 TeV assuming 3,000 fb$^{-1}$.
- Compared to the Run 1 mass reach of ~2.1 TeV with 20.3 fb$^{-1}$.

JHEP08 (2015) 148

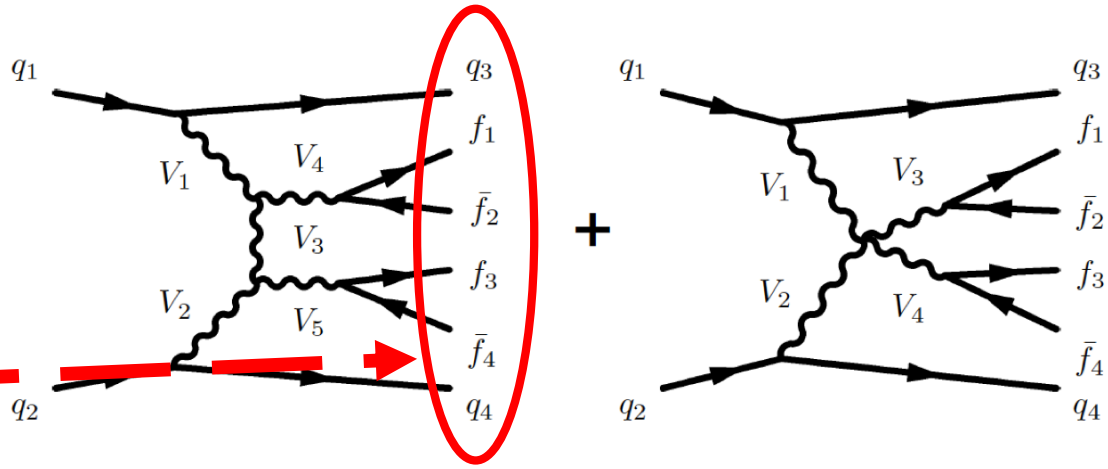
ATLAS-TDR-025



# $W^{\pm}W^{\pm}$ scattering (Vector-Boson Scattering)

Measure the cross-section for vector-boson scattering (VBS).

- Signature from interaction of two incoming partons. radiating bosons, which produce two jets and two massive bosons (e.g. $W^{\pm}W^{\pm}$ jj).




Numbers are with respect to the present detector

ATL-PHYS-PUB-2017-023

| | Signal variation | Background variation | Significance $Z_\sigma$ variation |
|---|---|---|---|
| Extending jet vertex requirement range | +12% | +14% | -1.9% |
| Extending lepton range | +3.0% | -7.7% | +17% |
| Combination | +14% | +7.3% | +15% |

The gain in significance obtained with tracking, electron, and muon reconstruction extension from $|\eta| < 2.7$ to $|\eta| < 4.0$ is 15%.

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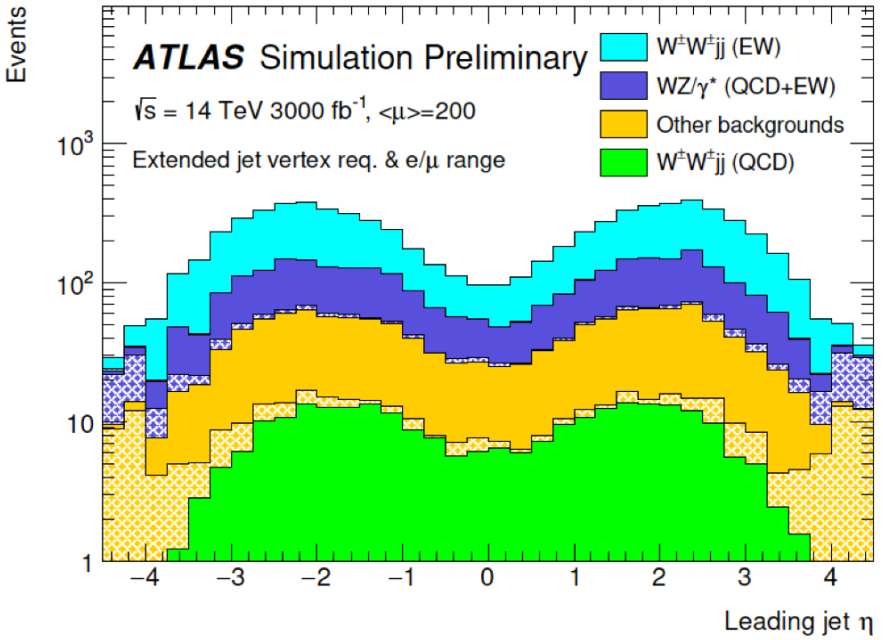


# Summary

Current plan

- Great year (2017) of data taking in ATLAS with over 45 $fb^{-1}$ of data recorded.
  - Plan to collect 300 $fb^{-1}$ of data by the end of Run 3.

Looking to the future the HL-LHC presents a great opportunity to probe new physics.

- Aiming for over 3,000 $fb^{-1}$ by the end of the HL-LHC running.
- Taking advantage of the increased statistics due to the increase of coverage in pseudo-rapidity as well as the increased luminosity.
  - Even when accounting for the new challenges introduced by the order of magnitude increase in pile-up.

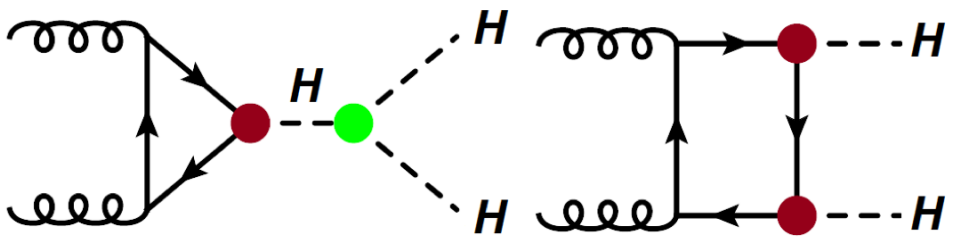
Thank you for your attention!

# Backup

# Di-Higgs production

$HH \rightarrow b\bar{b}b\bar{b}$

Largest branching ratio (33.3%)




(a) $\lambda_{HHH}$ dependent (self-coupling) diagram. (b) $\lambda_{HHH}$ independent (box) diagram.

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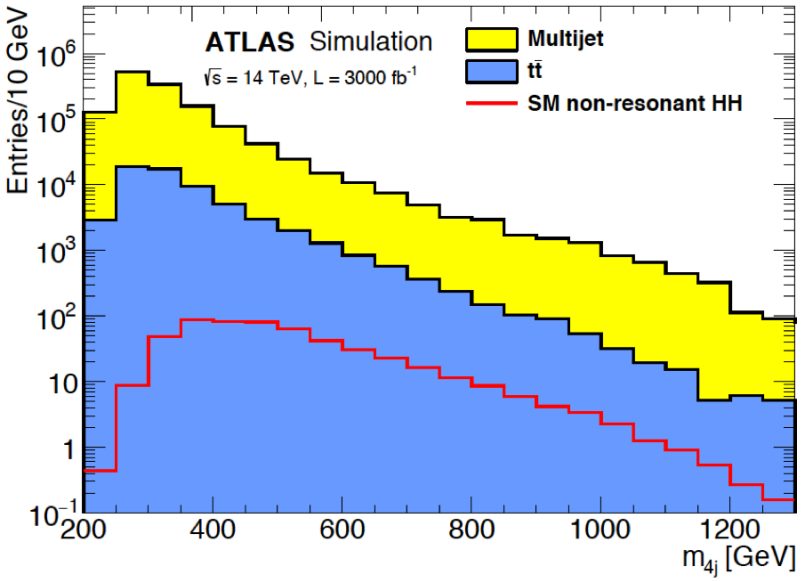


Higgs boson self-coupling, $\lambda_{HHH}$ changes both the total cross-section of $pp \rightarrow HH$ and the shape of the $m_{HH}$ distribution

- $m_{HH}$ distribution used to set limits on the cross-section

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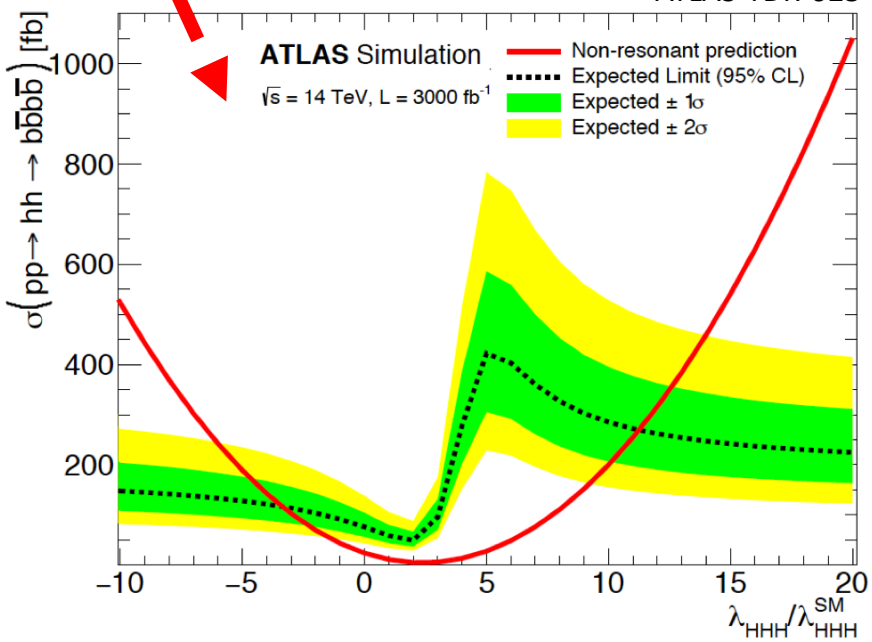



Using 13.3 $fb^{-1}$ of Run 2 data, a signal strength upper limit of $\mu = {}^{\sigma}/_{\sigma_{SM}} = 29$ was obtained

ATLAS-CONF-2016-049

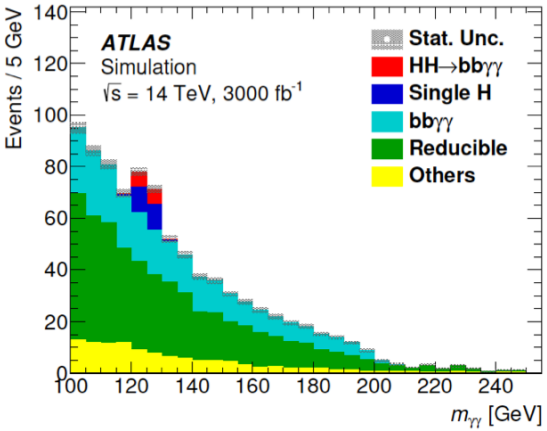
If systematic uncertainties remain as the same 2016 analysis, projected upper limit for the upgrade is equivalent to $\mu = 5.2$

ATL-PHYS-PUB-2016-024

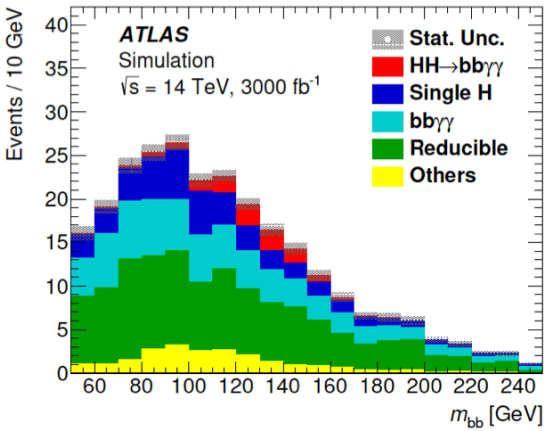
# Di-Higgs production

## $HH \rightarrow b\bar{b}\gamma\gamma$

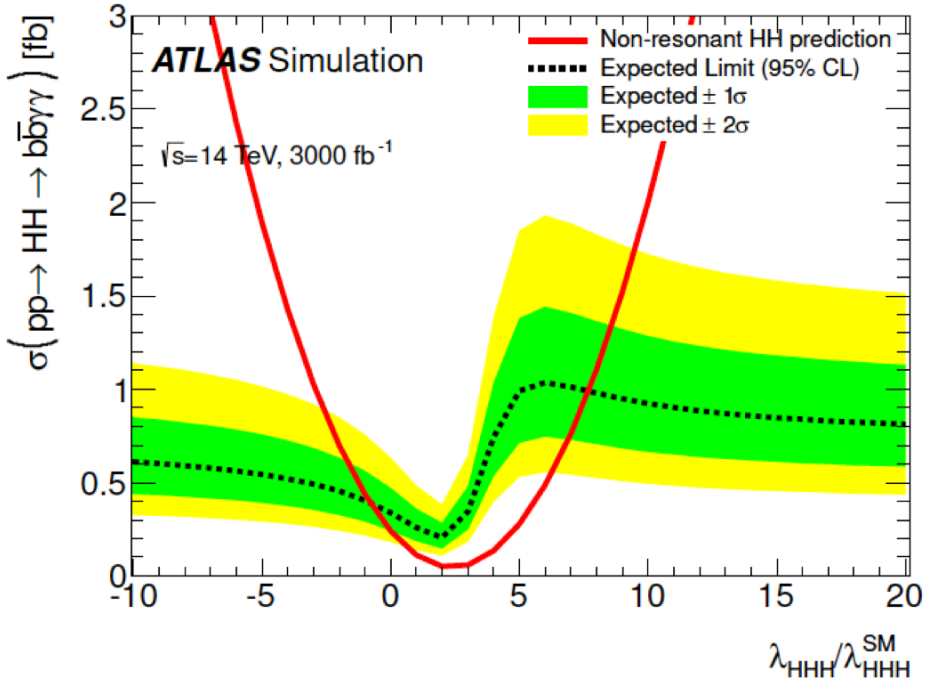
- Relatively small backgrounds - cleaner signal and narrow mass peak




(a) diphoton mass




(b) dijet mass




Expected significance of 1.05$\sigma$ for 3,000 fb$^{-1}$