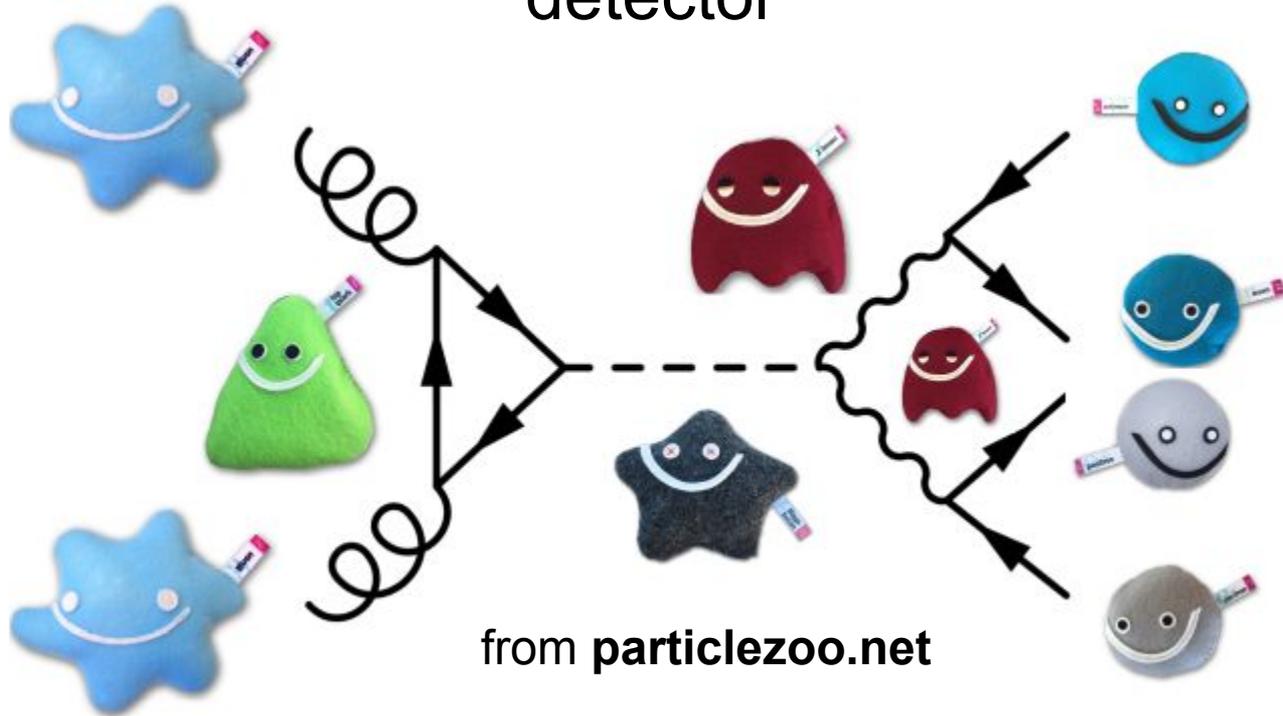


# Measurement of the four-lepton invariant mass spectrum in 13 TeV proton-proton collisions with the ATLAS detector\*



from [particlezoo.net](http://particlezoo.net)

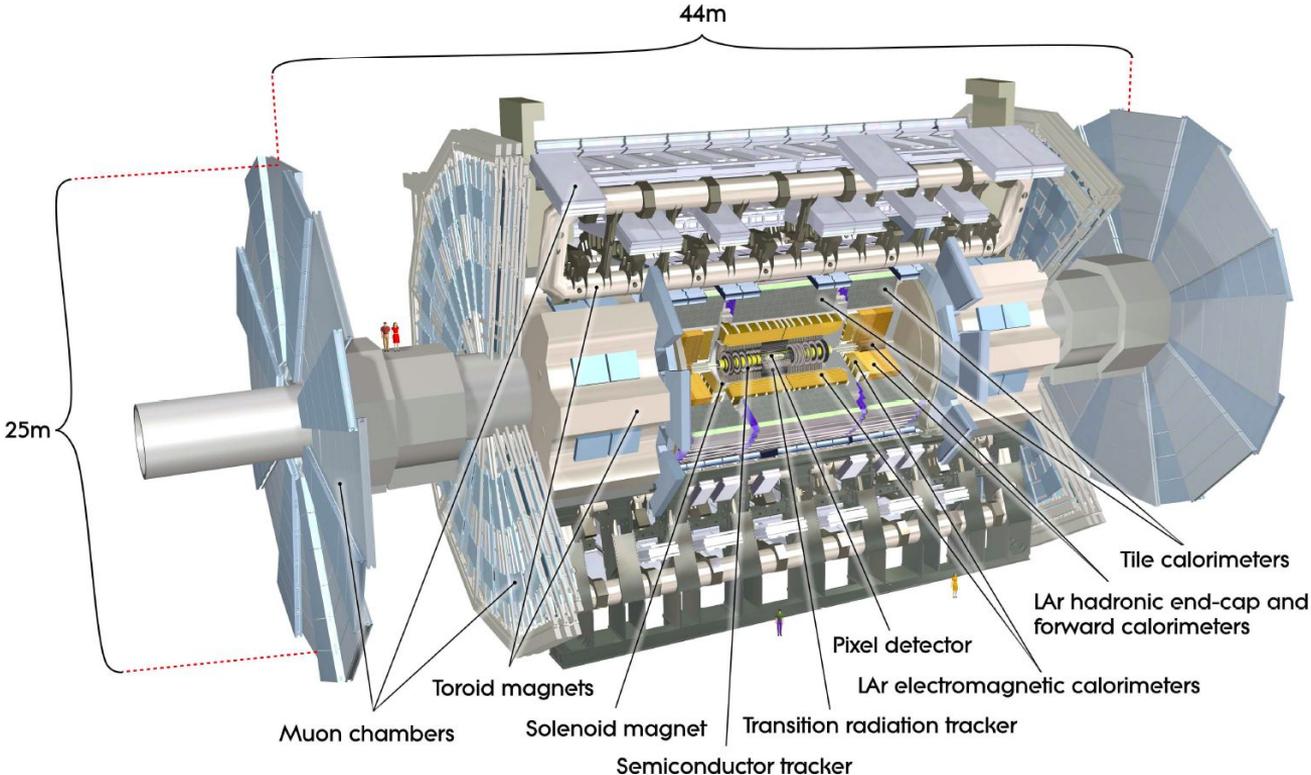


\*arXiv:1902.0  
5892 [hep-ex]

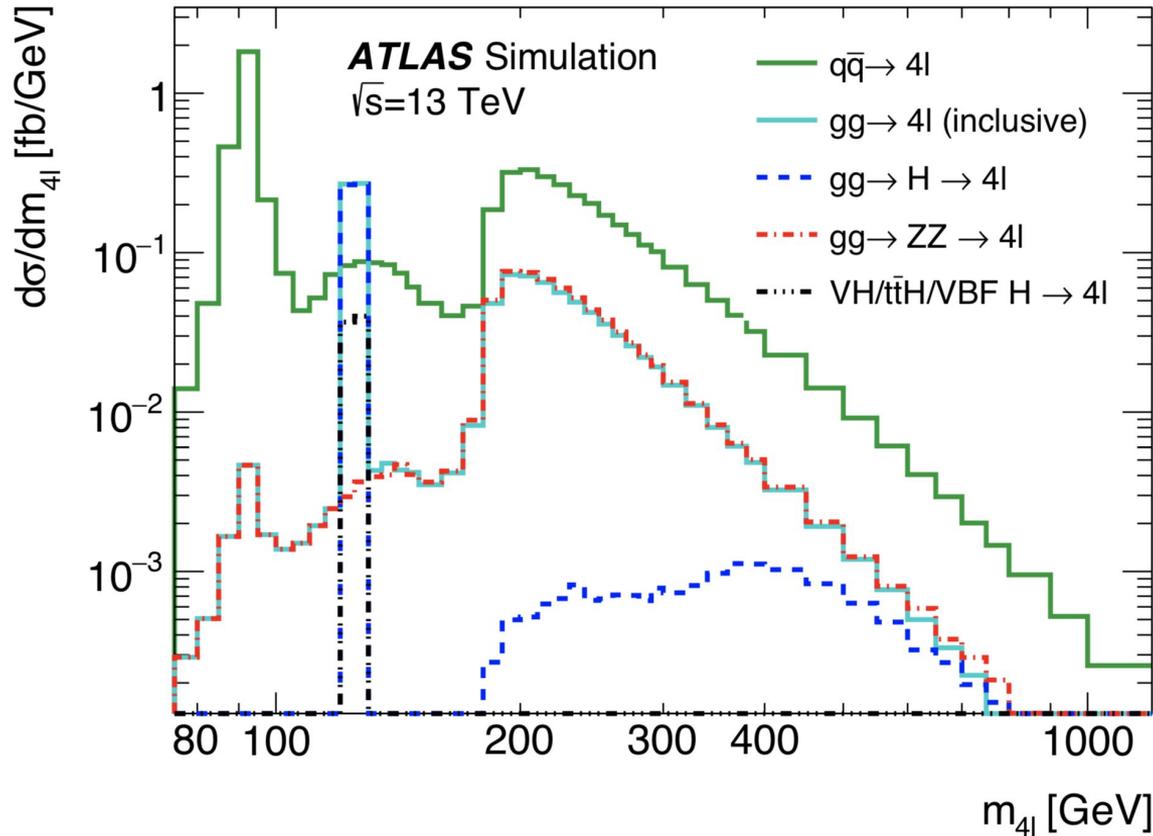
# Group B



# The ATLAS Experiment



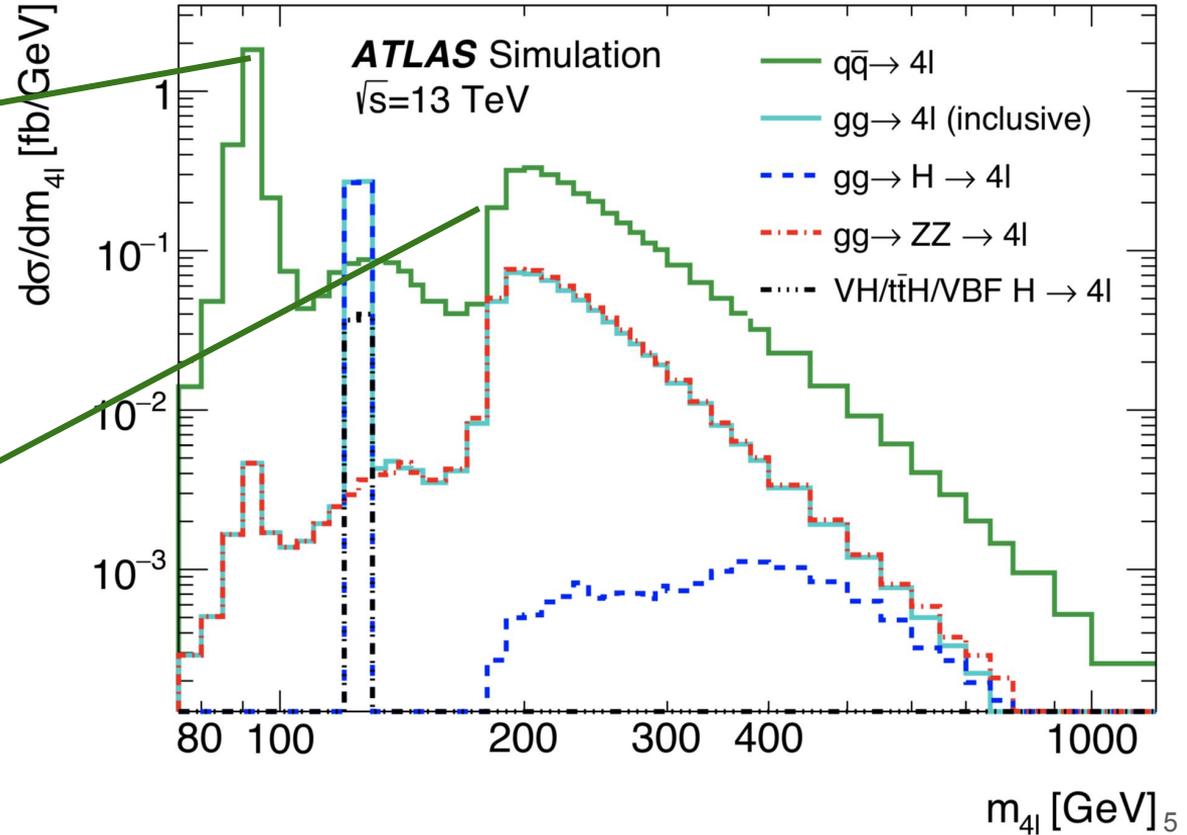
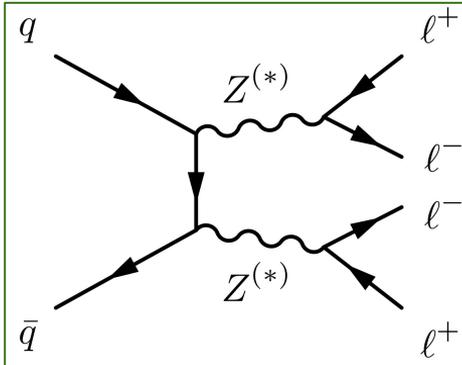
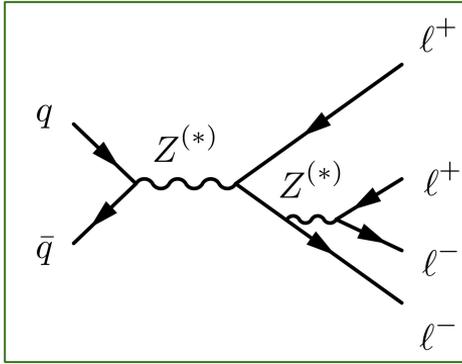
# Theoretical Prediction



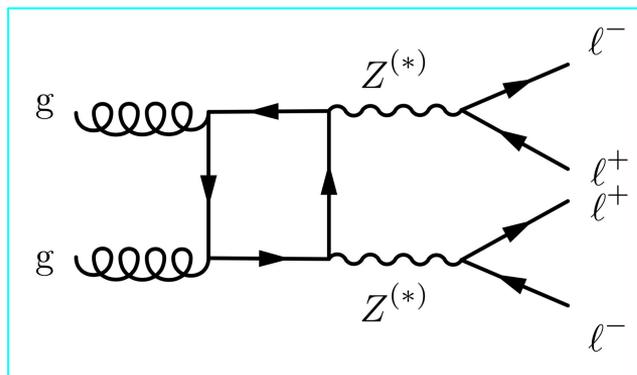
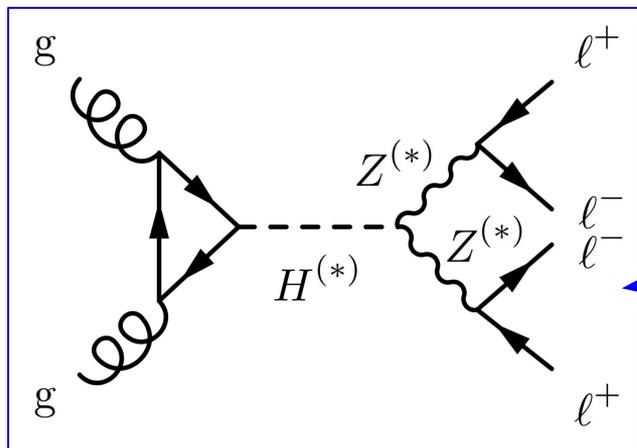
$$q\bar{q} \rightarrow 4l$$

$$gg \rightarrow 4l$$

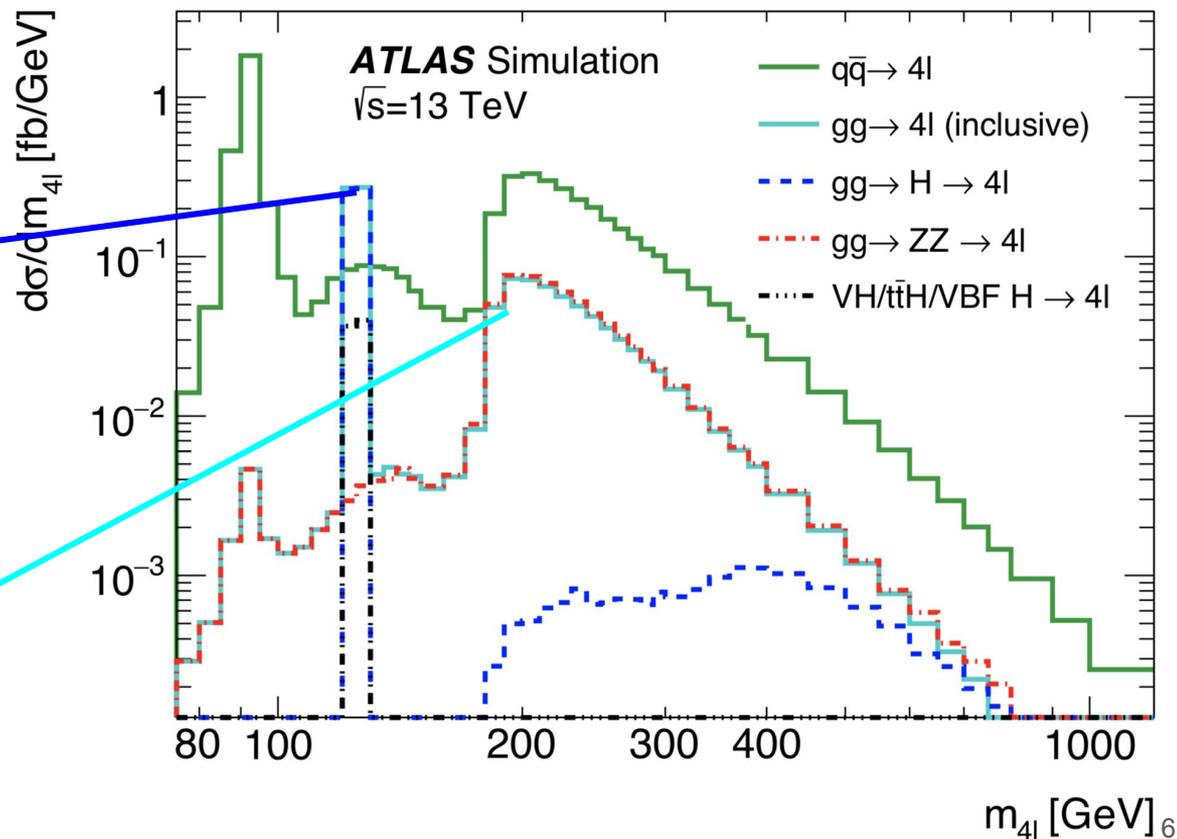
# Theoretical Prediction



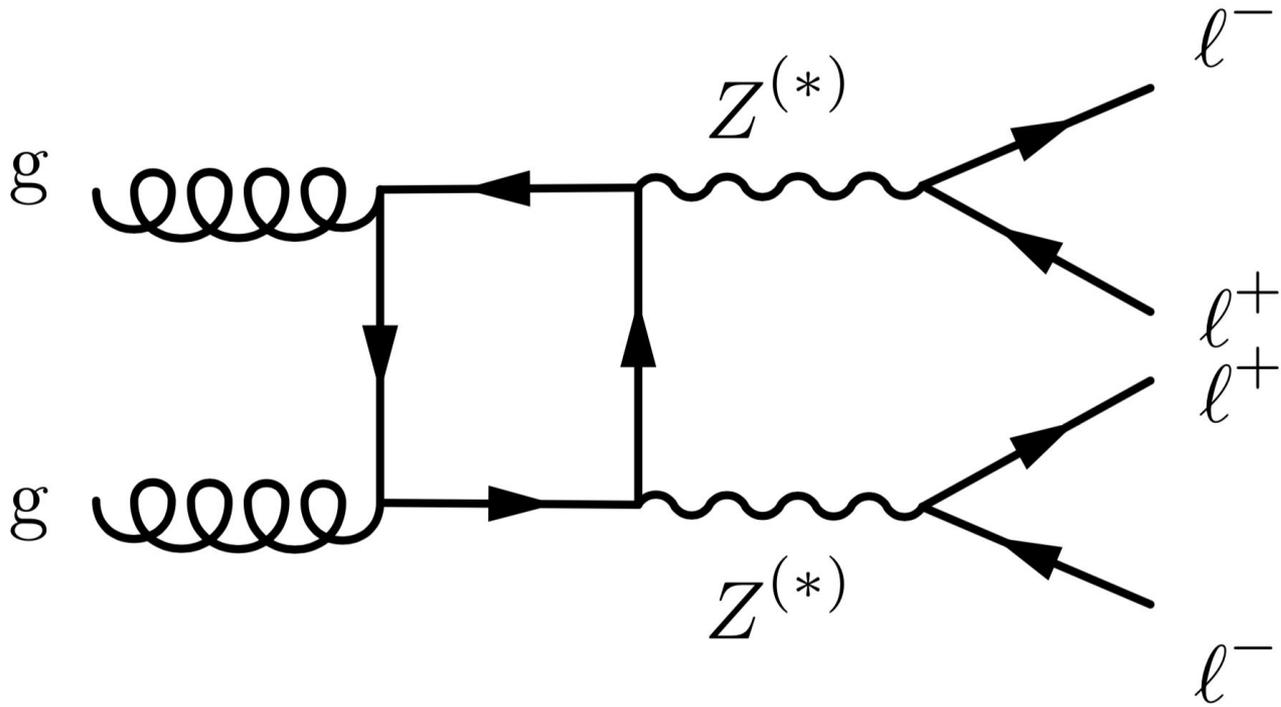
# Theoretical Prediction



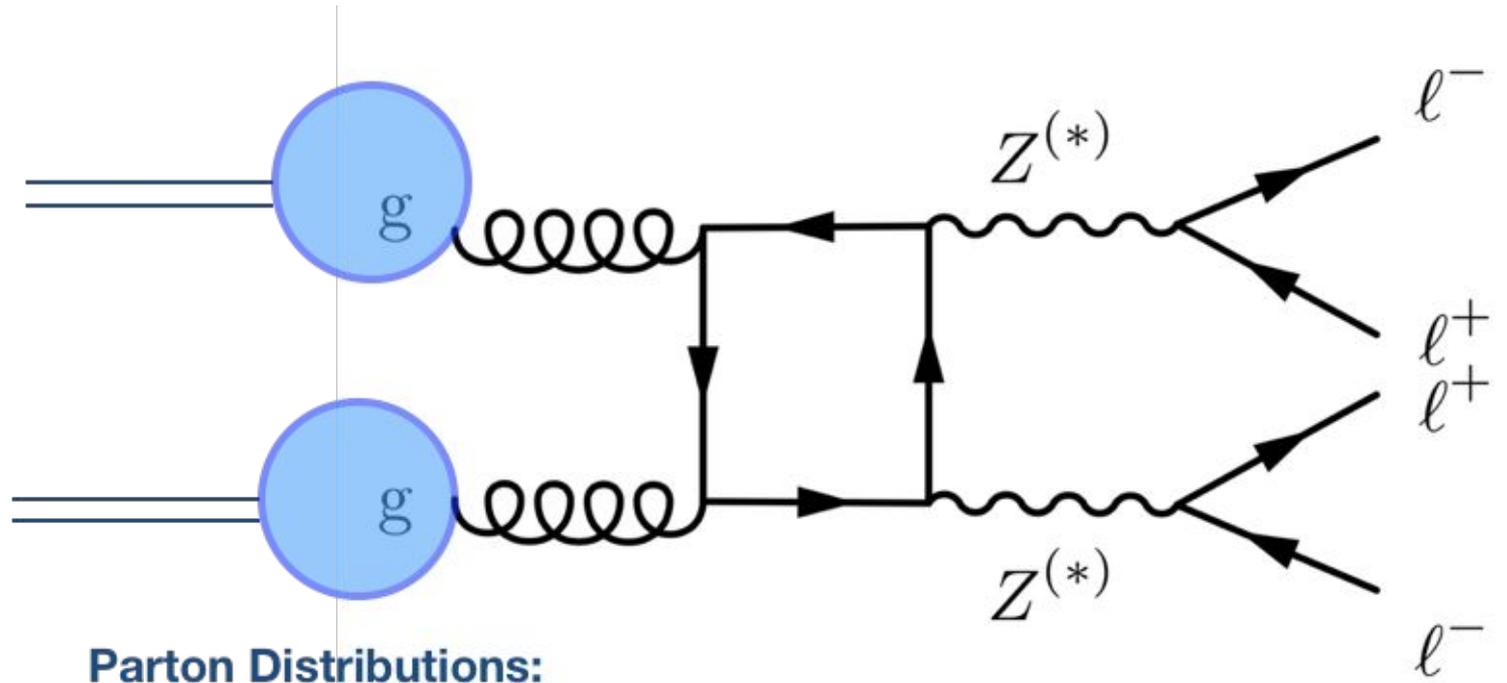
+ VH/ $t\bar{t}$ H/VBF H



# Simulation



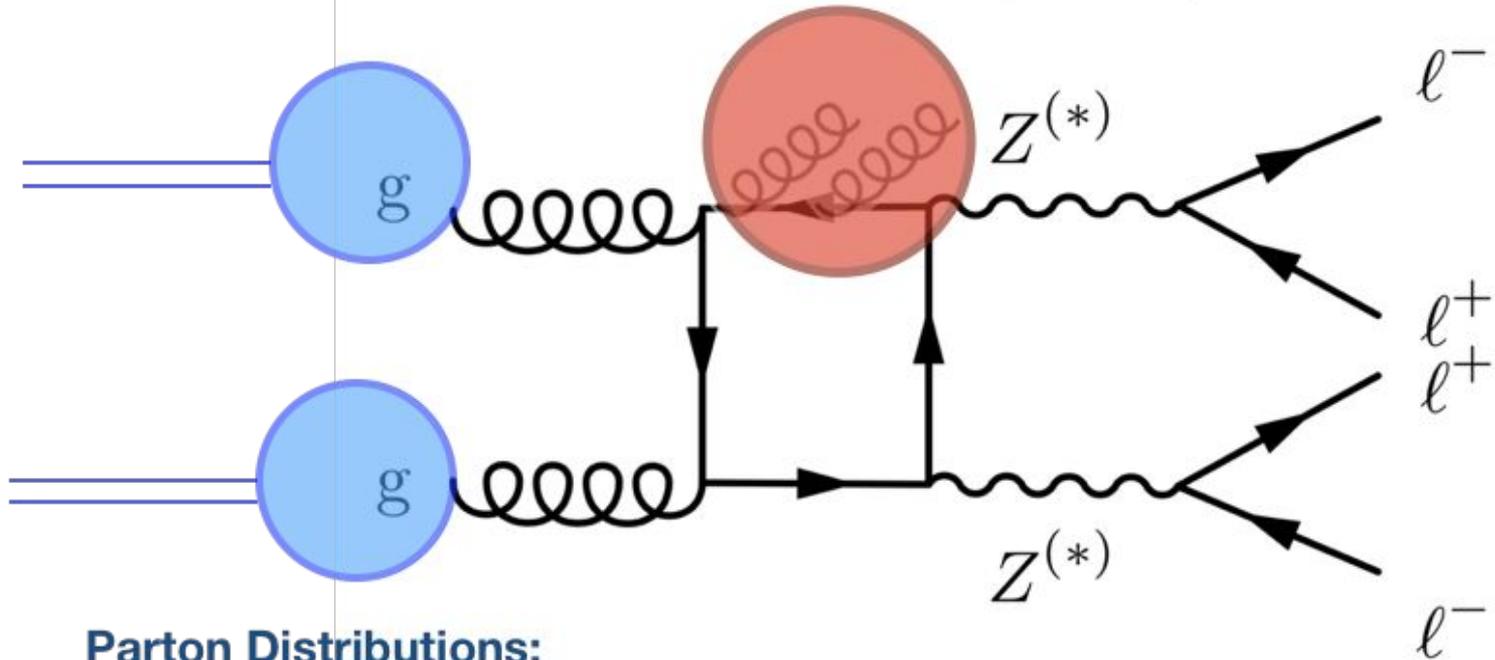
# Simulation



**Parton Distributions:  
NNPDF3.0 NNLO**

# Simulation

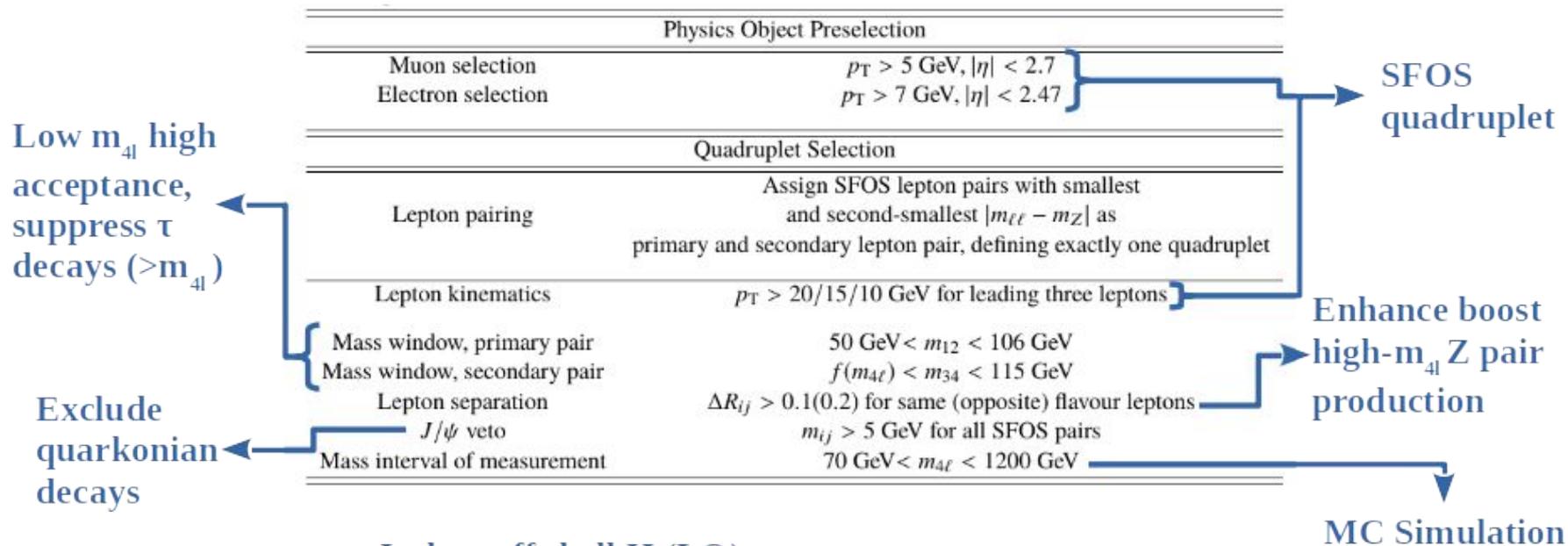
LO+ Parton Shower (SHERPA)+K-factor



Parton Distributions:  
NNPDF3.0 NNLO

+ Irreducible Background (ZWW, ZZW, ZZZ, tbarZ, tbarWW) Simulated with SHERPA

# Fiducial cross-section



Isolate off shell H (LO):

$$D_{\text{ME}} = \log_{10} \frac{\tilde{M}_{gg \rightarrow H^{(*)} \rightarrow ZZ^{(*)} \rightarrow 4\ell}^2(p_{1,2,3,4}^\mu)}{\tilde{M}_{gg(\rightarrow H^{(*)}) \rightarrow ZZ^{(*)} \rightarrow 4\ell}^2(p_{1,2,3,4}^\mu) + 0.1 \cdot \tilde{M}_{q\bar{q} \rightarrow ZZ^{(*)} \rightarrow 4\ell}^2(p_{1,2,3,4}^\mu)}$$

# Data Sample and Event Selection

Physics Object preselection		
	ELECTRONS	MUONS
Identification	<i>Loose</i> working point [23]	<i>Loose</i> working point [22]
Kinematics	$E_T > 7 \text{ GeV}$ and $ \eta  < 2.47$	$p_T > 5 \text{ GeV}$ and $ \eta  < 2.7$ $p_T > 15 \text{ GeV}$ if calorimeter-tagged [22]
Interaction point constraint	$ z_0 \cdot \sin \theta  < 0.5 \text{ mm}$	$ z_0 \cdot \sin \theta  < 0.5 \text{ mm}$
Cosmic-ray muon veto		$ d_0  < 1 \text{ mm}$
Quadruplet Selection		
QUADRUPLET FORMATION	Procedure and kinematic selection criteria as in Table 1	
LEPTON ISOLATION		
	ELECTRONS	MUONS
Track isolation	$\sum_{\Delta R \leq 0.2} p_T < 0.15 E_T^e$	$\sum_{\Delta R \leq 0.3} p_T < 0.15 p_T^\mu$
Calorimeter isolation	$\sum_{\Delta R=0.2} E_T < 0.2 E_T^e$	$\sum_{\Delta R=0.2} E_T < 0.3 p_T^\mu$
	<i>Contributions from the other leptons of the quadruplet not considered</i>	
LEPTON TRANSVERSE IMPACT PARAMETER		
	ELECTRONS	MUONS
	$d_0/\sigma_{d_0} < 5$	$d_0/\sigma_{d_0} < 3$
4 $\ell$ VERTEX FIT		
	$\chi^2/\text{ndof}$	$< 6 (4\mu)$ or $< 9 (4e, 2e2\mu)$

**FREE TIME**

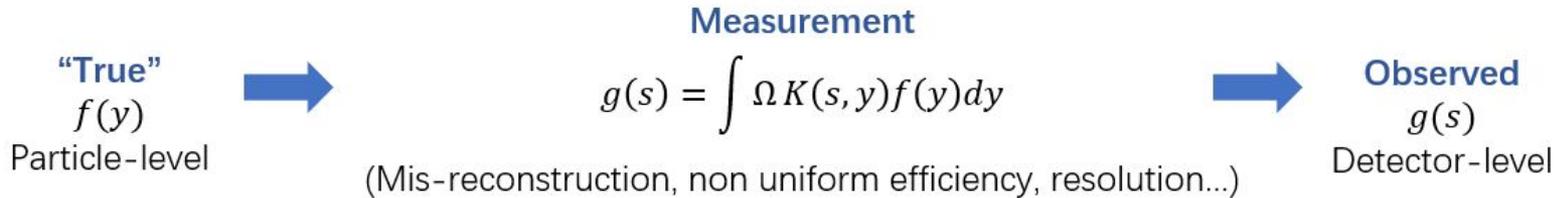
**EXCURSIONS**



2019 CERN Latin-American School

# Unfolding procedure

Corrects for **experimental effects**, allows direct comparison with particle-level predictions within fiducial phase space.

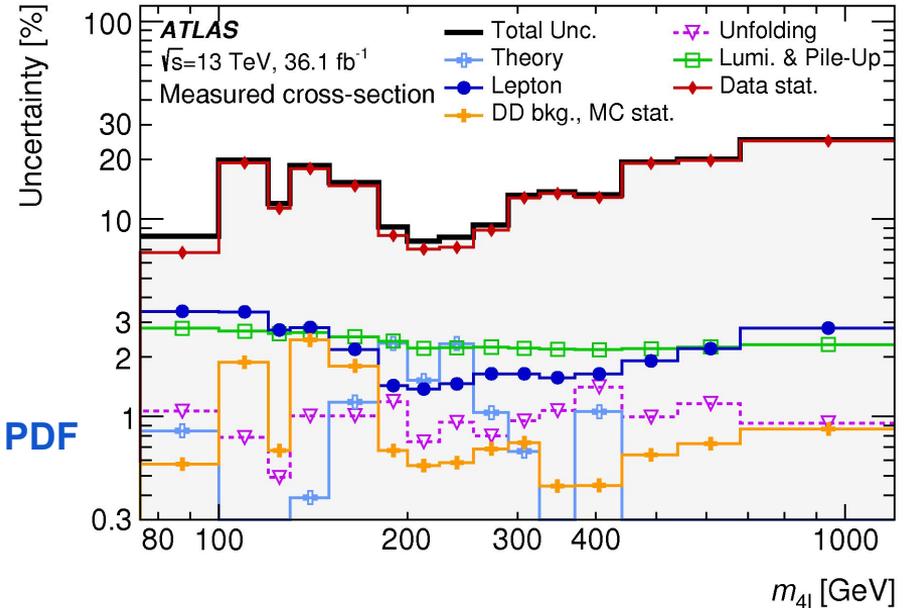


The **response matrix**  $K_{sy}$  consists of three contributions:

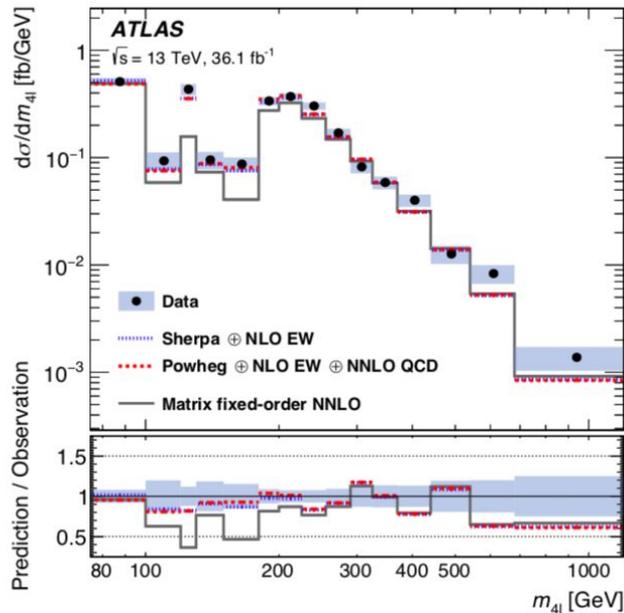
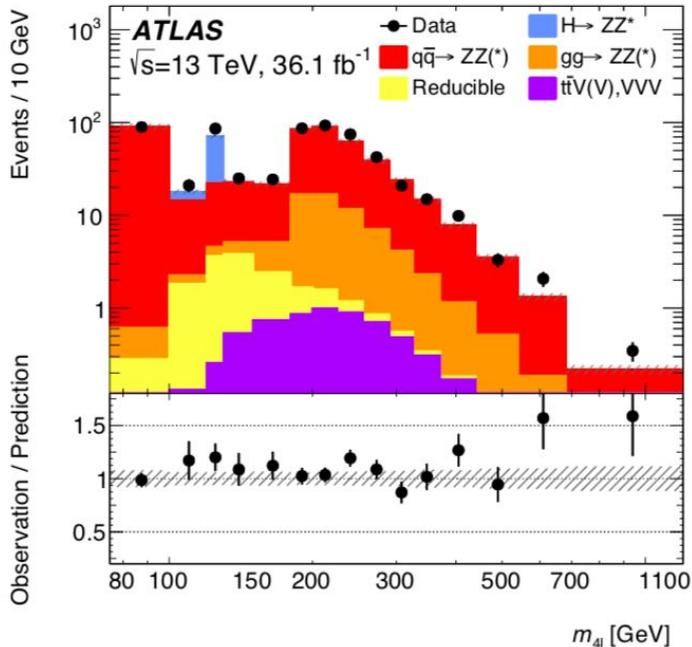
- **Reconstruction efficiency:**  
60-80% but lower (~30%) for lower  $m_{4l}$   $\frac{N_{fiducial \& \ detector}}{N_{fiducial}}$
- **Fiducial fraction:**  
Close to unity, ~90% for  $m_{4l} < 200$  GeV  $\frac{N_{fiducial \& \ detector}}{N_{detector}}$
- **Bin migration effects:**  
Fiducial purity (i=j) ~ 80%  $N_{fid,i} \rightarrow N_{det,j}$

# Uncertainties

- **Stats limited analysis (2000 Poisson pseudo-datasets).**
- **Lepton**
  - **electron and muon reco, ID and isolation efficiency.**
  - **resolution and scale uncertainties.**
- **Unfolding**
  - **Reco MC vs particle level distribution**
  - **Generator choice for qq->4l.**
- **Theoretical**
  - **Particle-level predictions.**
  - **Renormalisation and factorisation scales, PDF and parton showering.**
- **Luminosity**
  - **2015+2016 luminosity uncertainty ~ 2.1%**



# Results and Interpretation



$$\mu_{gg} \equiv \sigma_{gg \rightarrow 4\ell}^{\text{measured}} / \sigma_{gg \rightarrow 4\ell}^{\text{SM}}$$

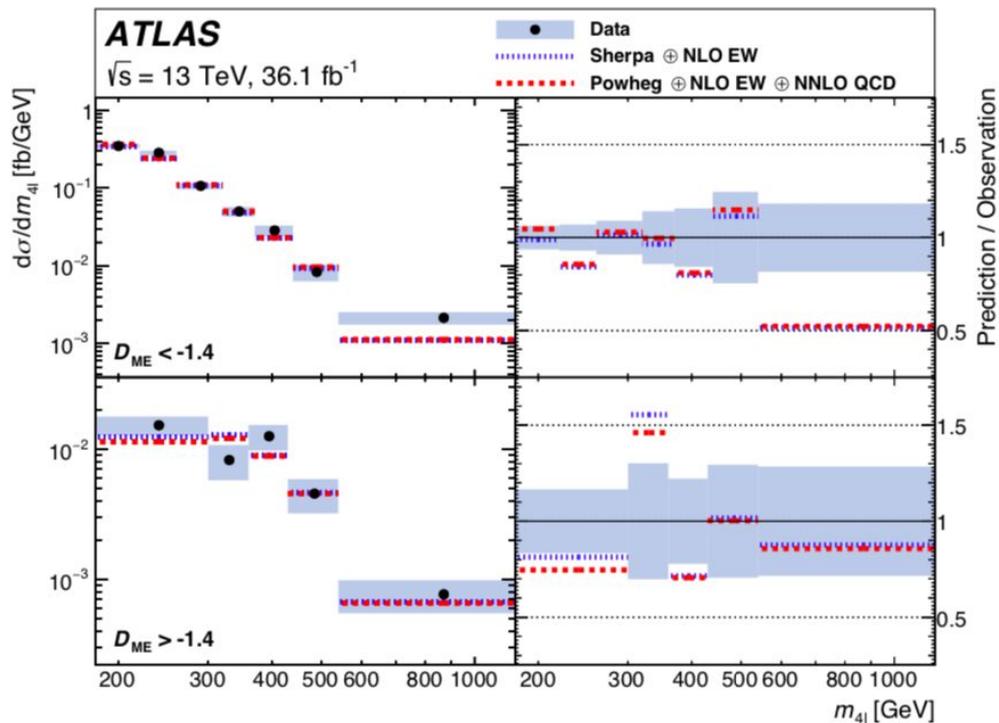
$$\mu_{gg} = 1.3 \pm 0.5$$

Expected value :  $1.0 \pm 0.4$

Measurement	$\mathcal{B}_{Z \rightarrow 4\ell} / 10^{-6}$
ATLAS, $\sqrt{s} = 7$ TeV and 8 TeV [8]	$4.31 \pm 0.34(\text{stat}) \pm 0.17(\text{syst})$
CMS, $\sqrt{s} = 13$ TeV [6]	$4.83_{-0.22}^{+0.23}(\text{stat})_{-0.29}^{+0.32}(\text{syst}) \pm 0.08(\text{theo}) \pm 0.12(\text{lumi})$
<b>ATLAS, <math>\sqrt{s} = 13</math> TeV</b>	<b><math>4.70 \pm 0.32(\text{stat}) \pm 0.21(\text{syst}) \pm 0.14(\text{lumi})</math></b>

# Results and Interpretation

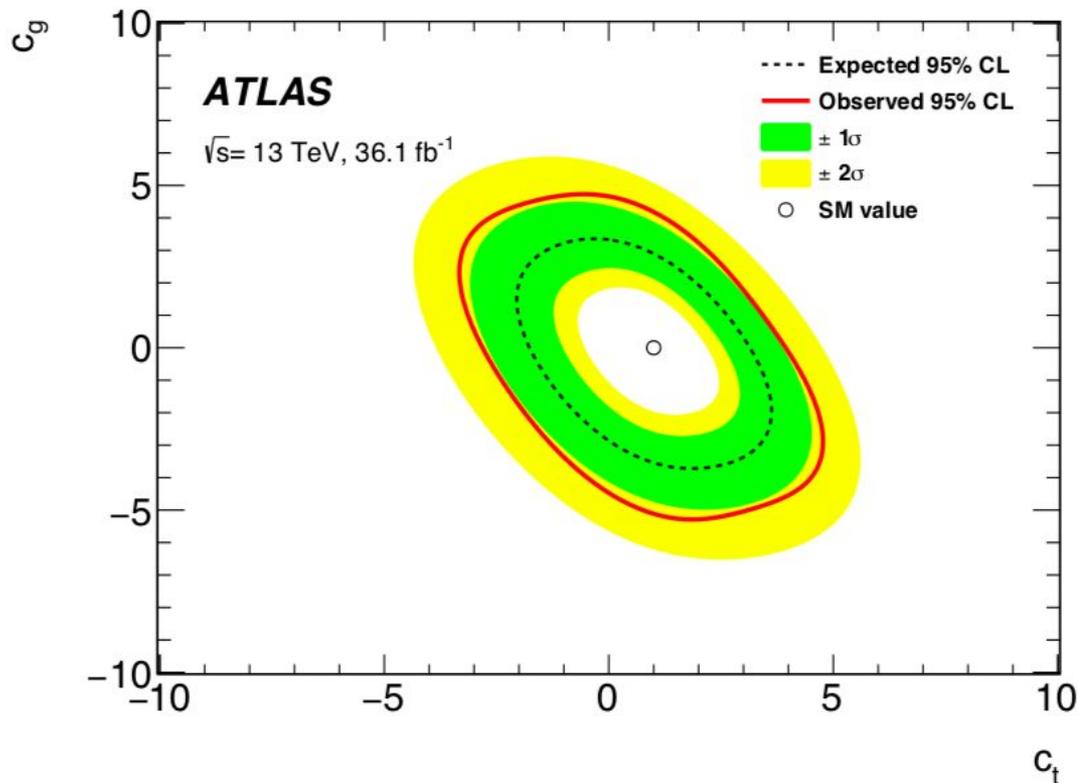
$$\mu_H^{OS} = \sigma_{gg \rightarrow H^* \rightarrow 4\ell} / \sigma_{gg \rightarrow H^* \rightarrow 4\ell}^{SM}$$



**Upper limit off-shell Higgs**  
 production (**95% CL**):

$$\mu_H^{OS} < 6.5$$

# Results and Interpretation

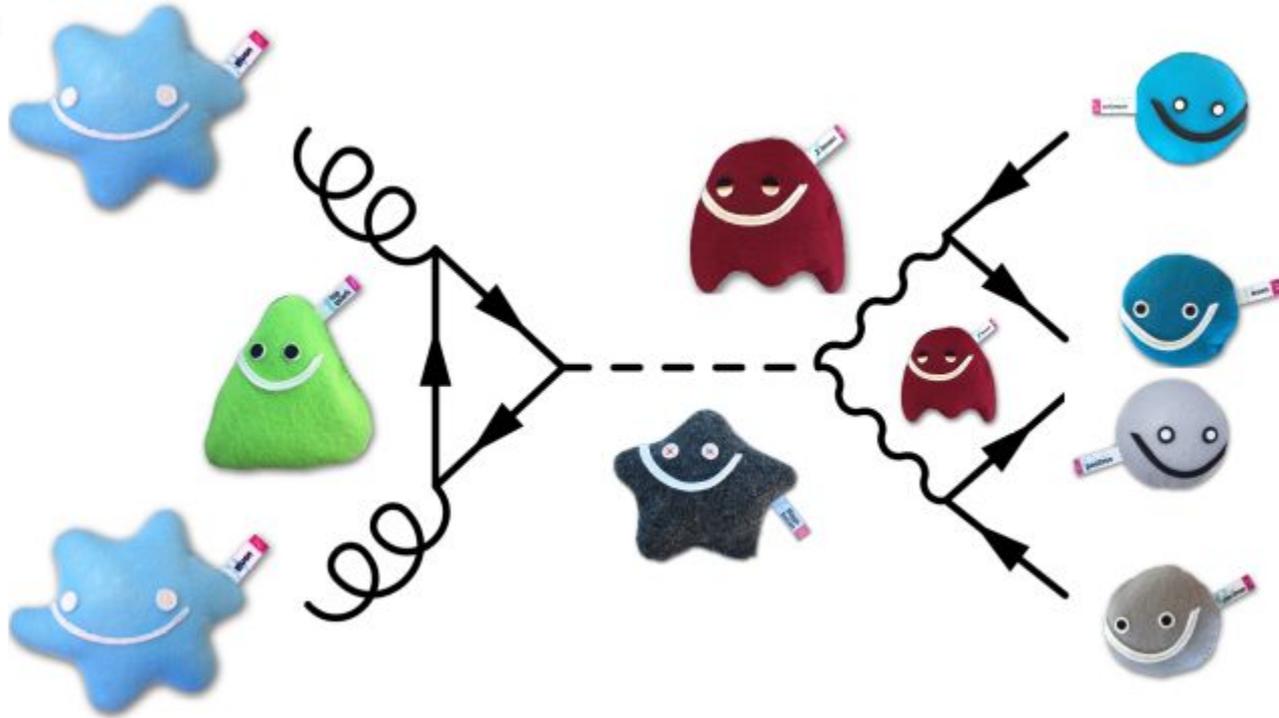


**Higgs** boson to **top** quark ( $C_t$ ) and **gluons** ( $C_g$ , zero in the SM) constrained.

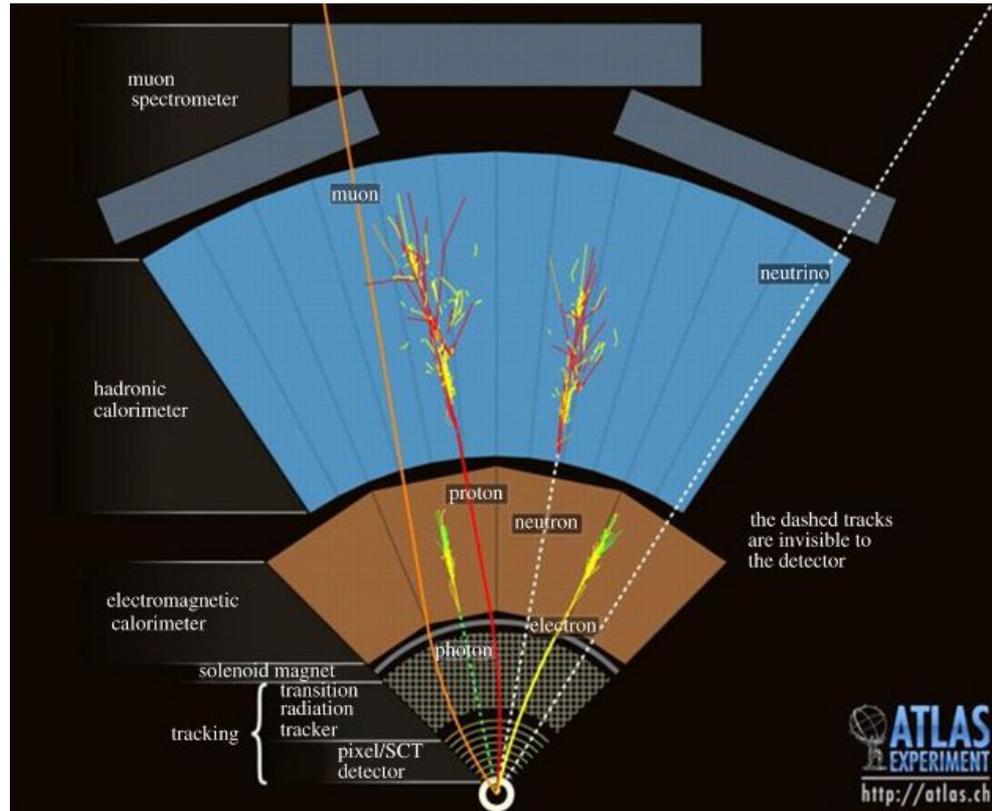
Parameter space which lies outside contour excluded @ **95% CL**.



back up  
after this page



# Back up: Experiment



# Back up: Data Sample

**Medium muons** The *Medium* identification criteria provide the default selection for muons in ATLAS. This selection minimises the systematic uncertainties associated with muon reconstruction and calibration. Only CB and ME tracks are used. The former are required to have  $\geq 3$  hits in at least two MDT layers, except for tracks in the  $|\eta| < 0.1$  region, where tracks with at least one MDT layer but no more than one MDT hole layer are allowed. The latter are required to have at least three MDT/CSC layers, and

**Loose muons** The *Loose* identification criteria are designed to maximise the reconstruction efficiency while providing good-quality muon tracks. They are specifically optimised for reconstructing Higgs boson candidates in the four-lepton final state [5]. All muon types are used. All CB and ME muons satisfying the *Medium* requirements are included in the *Loose* selection. CT and ST muons are restricted to the  $|\eta| < 0.1$  region. In the region  $|\eta| < 2.5$ , about 97.5% of the *Loose* muons are combined muons, approximately 1.5% are CT and the remaining 1% are reconstructed as ST muons.

# Back up: Results and Interpretation

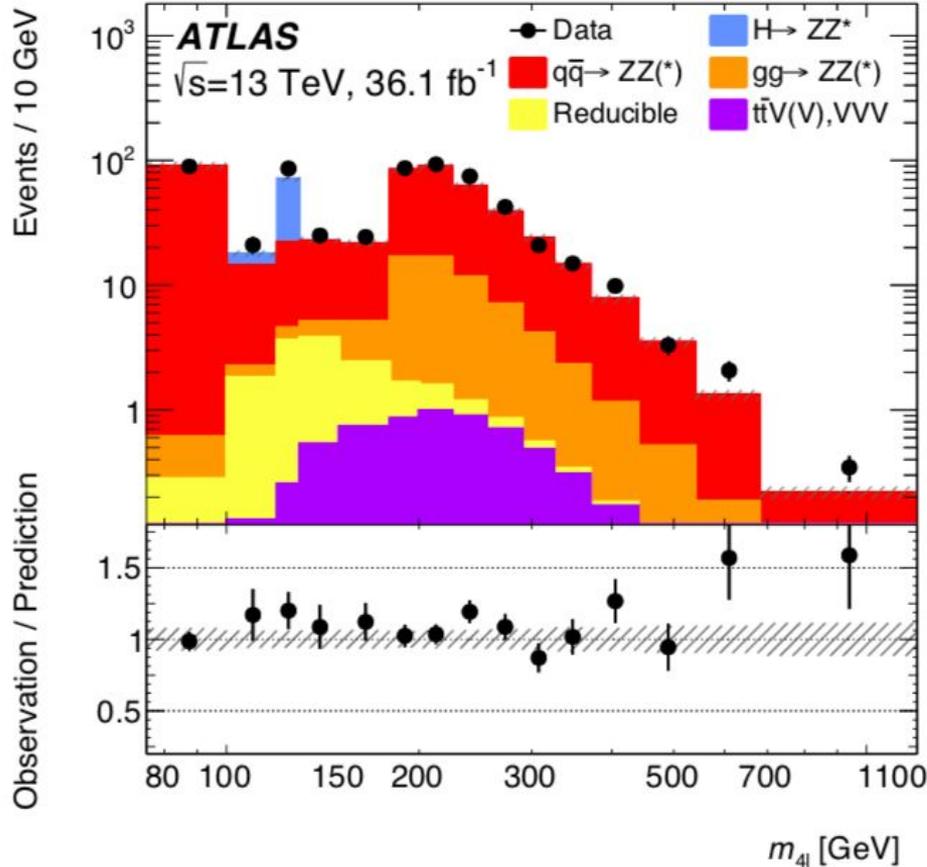
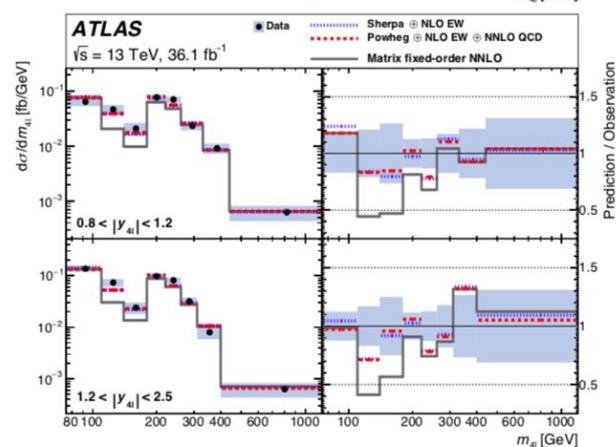
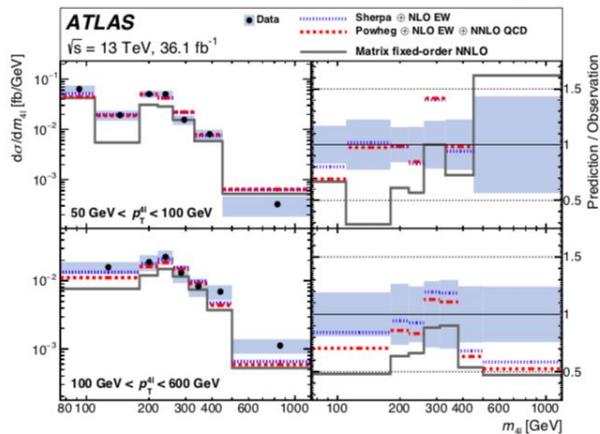
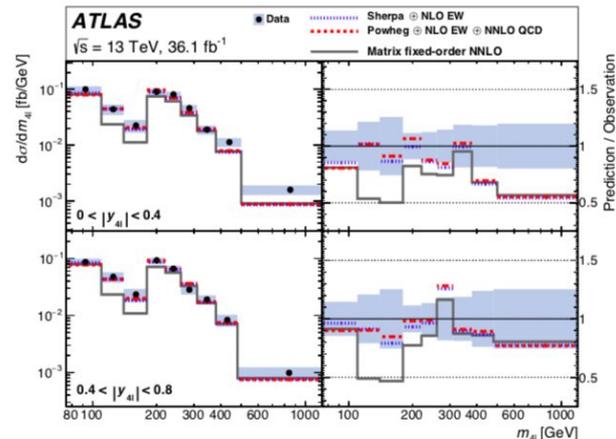
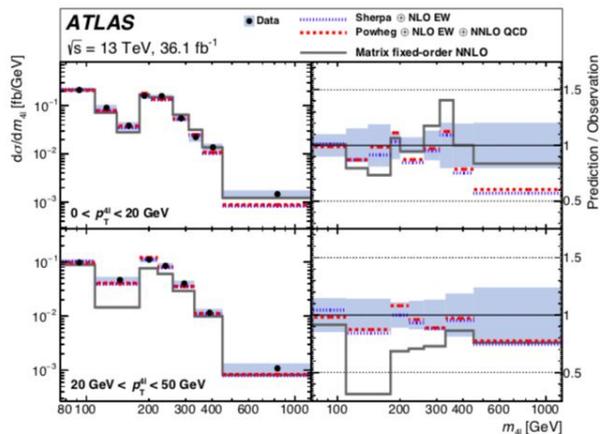
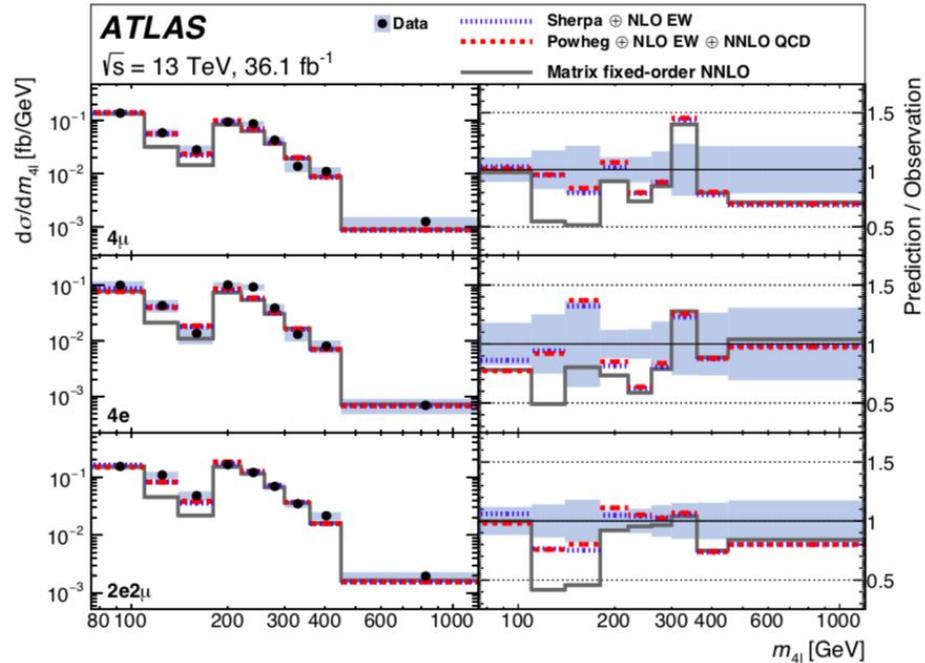


Fig.4. Distribution of events passing the selection as a function of the four-lepton invariant mass.

# Back up: Results and Interpretation



# Back up: Results and Interpretation



# Conclusions

m4l distribution using 36.1 fb<sup>-1</sup> p-p collision @ 13 TeV in ATLAS

Results consistent with SM predictions