Measurement of the Higgs properties in bosonic decay channels at 13 TeV in ATLAS

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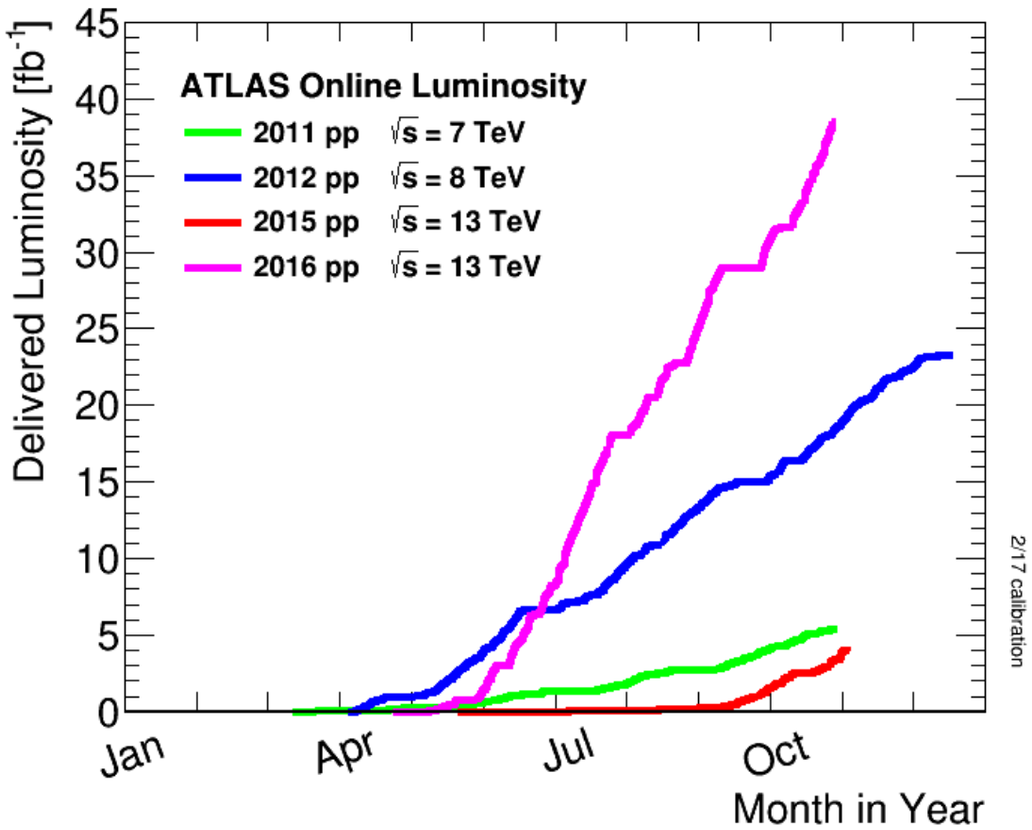
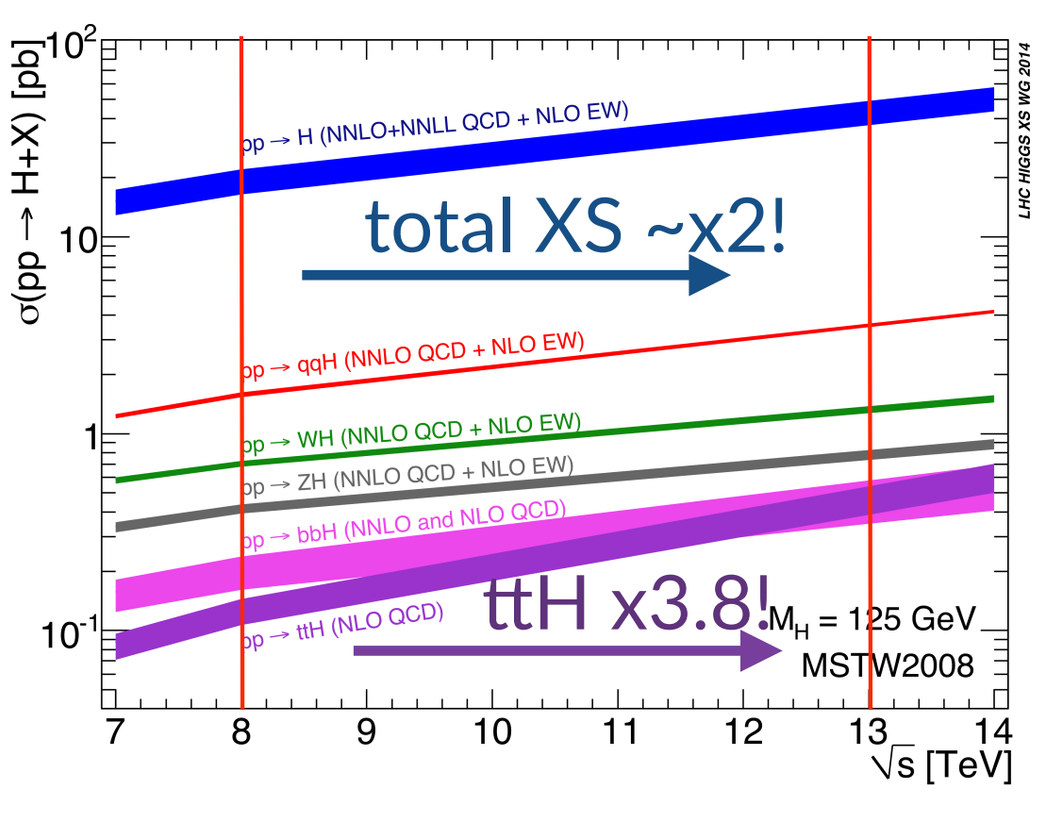
The Higgs Boson and the LHC

- In Run 2, higher energy and more statistics.
- By the end of 2016, total of 36.1 fb^{-1} of pp data.
- Latest theory from LHC-cross section working group, outlined in the Yellow Report 4. arXiv:1610.07922
  - New N^3LO QCD corrections in ggF.
- Latest and greatest measurements!
  - Results used in EFT frameworks and to calculate pseudo observables.

More Data!

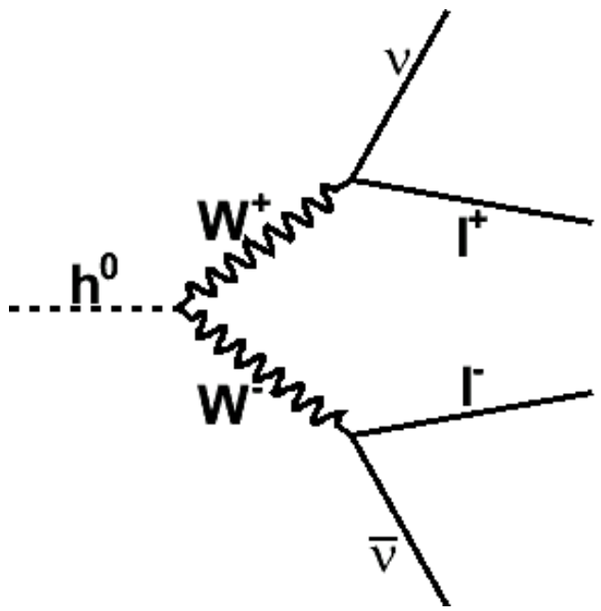


More Cross Section!

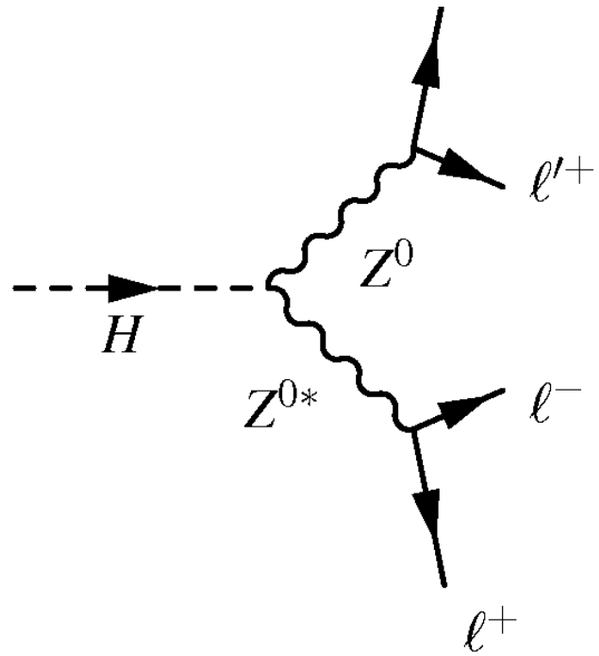


Bosonic Decay Modes of the Higgs

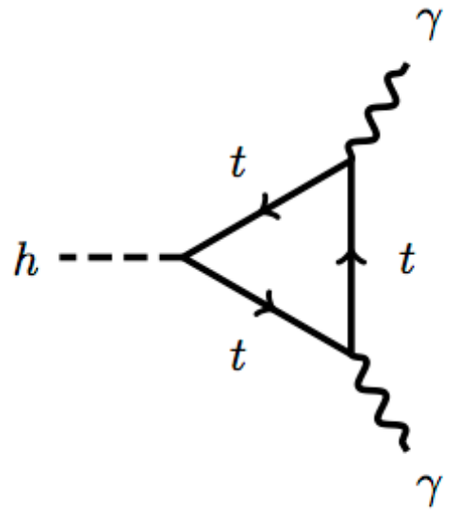
- WW :
  - Second highest BR of all Higgs decays.
  - Most precise measurement in Run 1.
- ZZ and γγ:
  - Fully reconstruct mass and kinematics of the Higgs.
  - Quark couplings measured indirectly through ggF prod mode, and γγ decay.

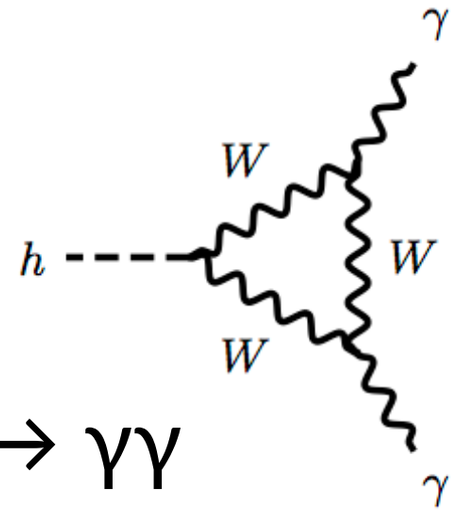


H→ WW→lνlν



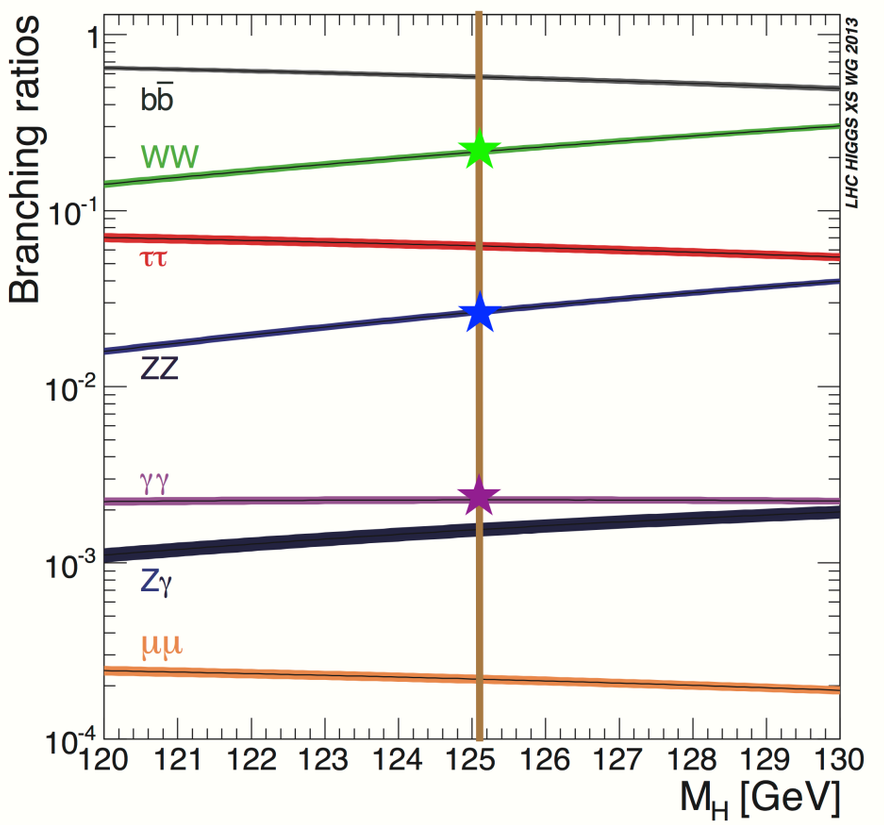
H→ ZZ→4l





H→ γγ

Branching ratios of the Higgs



Plot does not show additional BR to leptons for WW and ZZ.

for 36.1/fb of integrated luminosity…	# of Higgs
σ x L (all Higgs produced)	~1,987,555
σ x L x BR(H →WW →lνlν)	21108 (1.06%)
σ x L x BR(H →γγ)	4512 (0.23%)
σ x L x BR(H →ZZ →4l)	249 (0.01%)
σ x L x BR(H →sum(WW+ZZ+γγ))	25869 (1.30%)

Only considering l = e,μ. Numbers are before detector reconstruction and event selection.

- Of ~2 million Higgs, ~25,000 will decay to WW* →lνlν, ZZ* →4l, or γγ.
  - Numbers from Yellow Report 4: arXiv:1610.07922
- Event selection and reconstruction further reduce this by ~75-90%.

H → WW* → lνlν Selection

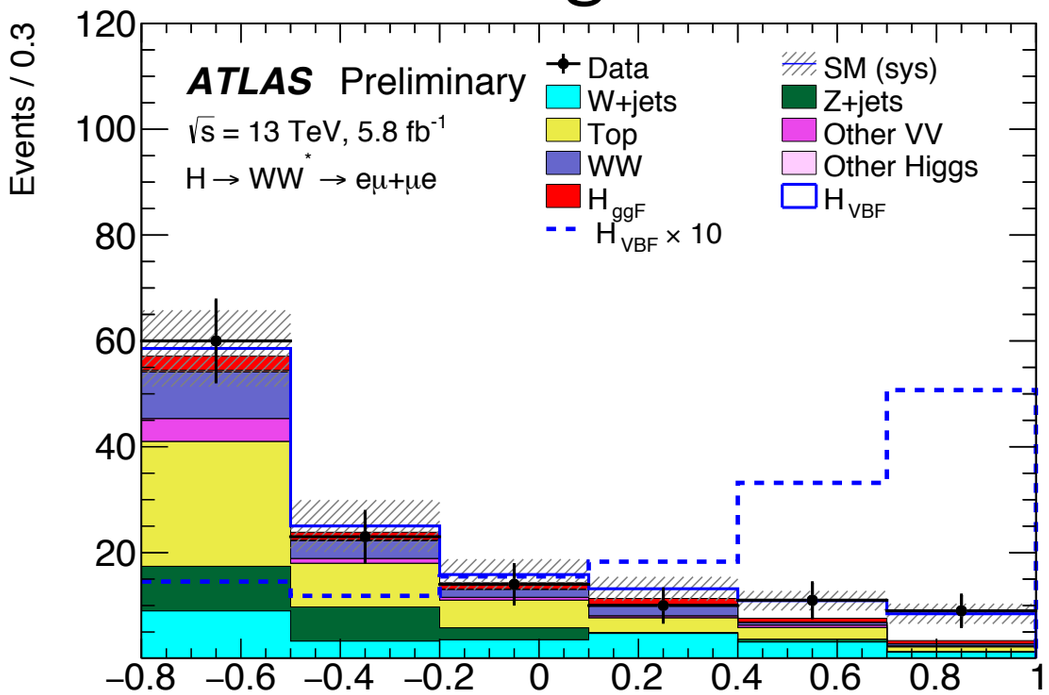
ATLAS-CONF-2016-112 - 5.8 fb^{-1}

- 5.8 fb^{-1} of data.
- VBF:
  - Opposite sign e and μ.
  - >= 2 jets.
  - Veto on 3 leptons.
- Main bkg: Top, WW/WZ, Z →ττ/jets
- VBF SR: uses BDT
  - H properties e.g. spin 0 = small $\Delta\varphi_{ll}$
  - VBF e.g. large m_{jj} and Δy_{jj}
  - others: m_{jj}, m_T, p_T^{Tot}, $\eta_l^{centrality}$
- Simultaneous likelihood fit in SR and CR.
- 1.9σ significance assuming H=125 GeV.

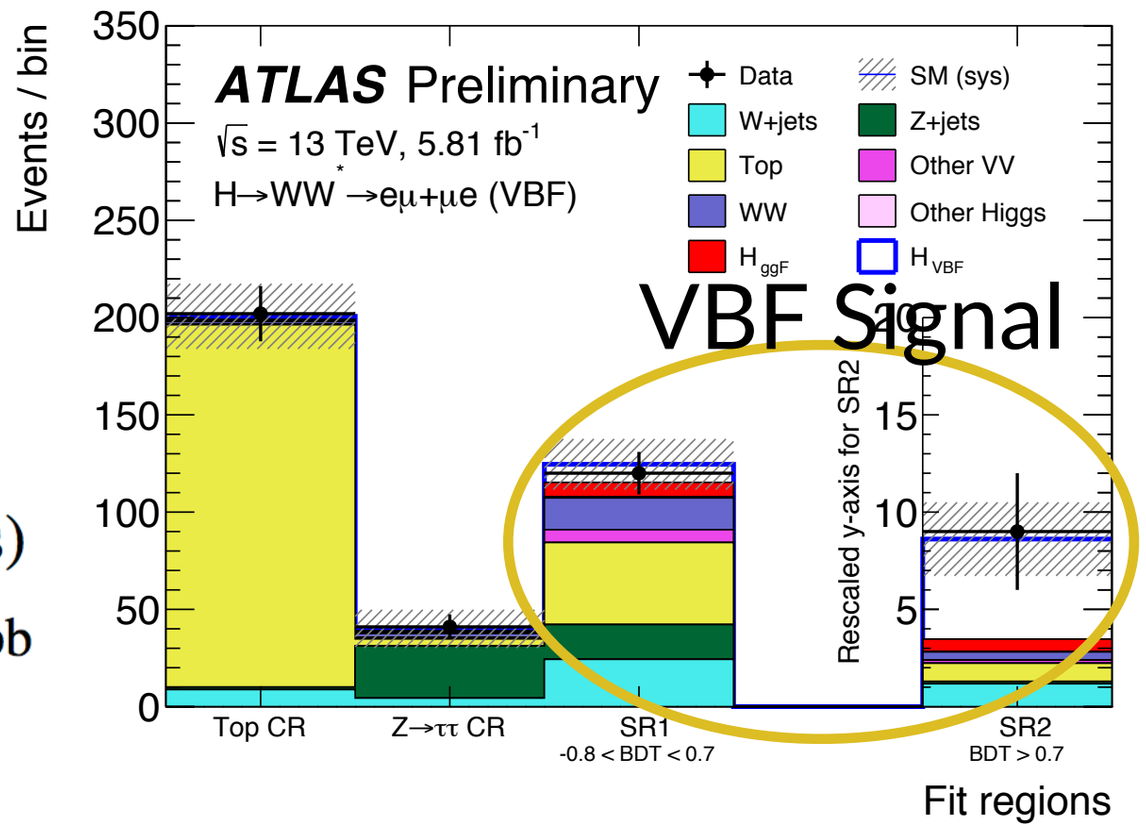
$$\mu_{\mathrm{VBF}} = 1.7^{+1.0}_{-0.8}(\mathrm{stat})^{+0.6}_{-0.4}(\mathrm{sys})$$

$$\sigma_{\mathrm{VBF}} \cdot \mathcal{B}_{H\to WW^*} = 1.4^{+0.8}_{-0.6}(\mathrm{stat})^{+0.5}_{-0.4}(\mathrm{sys})\ \mathrm{pb}$$

VBF signal BDT



VBF Signal

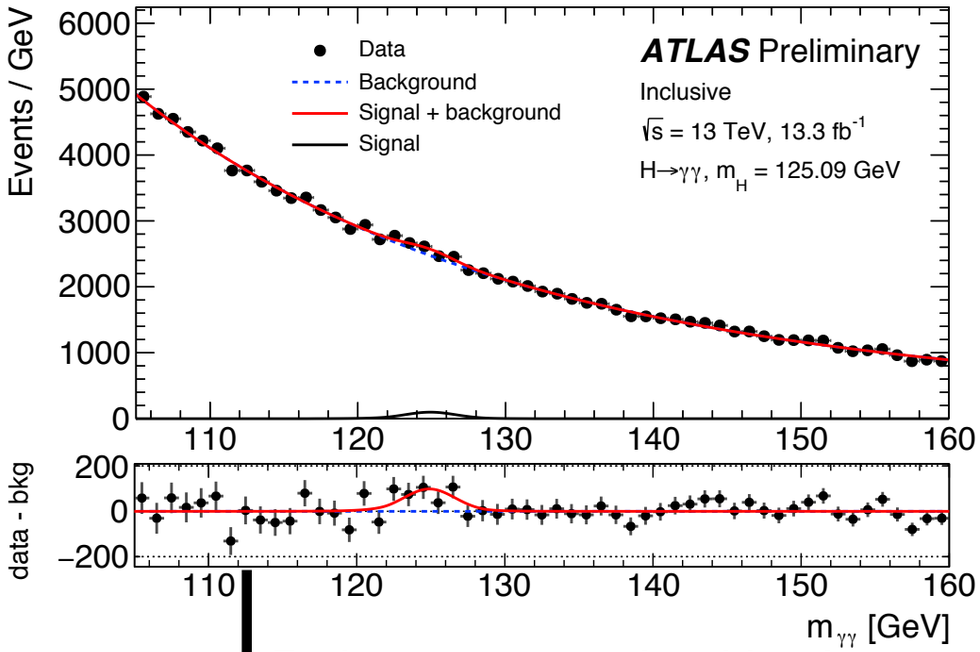


H → γγ Selection

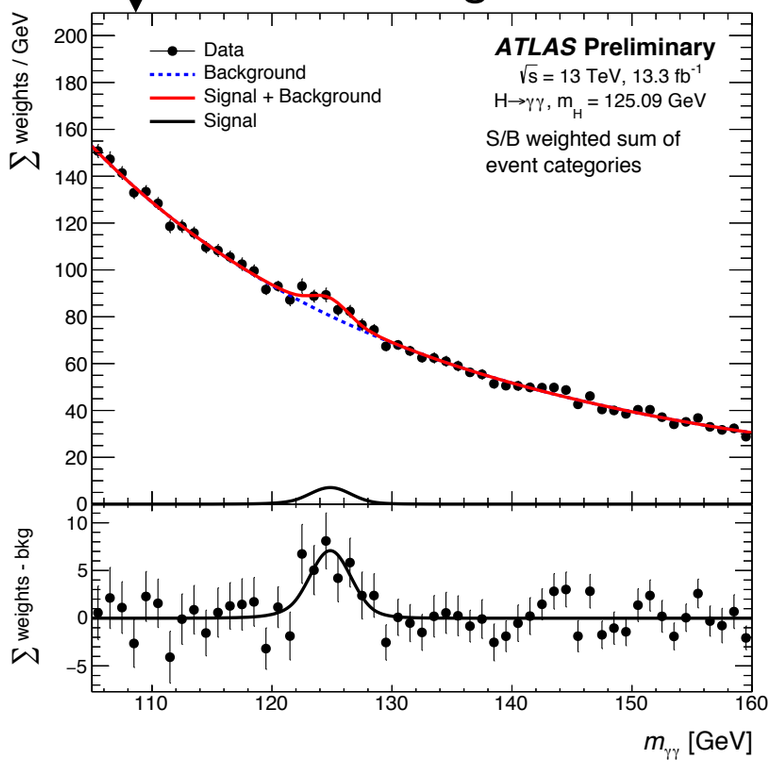
ATLAS-CONF-2016-067 - 13.3 fb^{-1}

	diphoton baseline	VBF enhanced	single lepton
Photons	$\|\eta\| < 1.37$ or $1.52 < \|\eta\| < 2.37$ $p_T^{\gamma_1} > 0.35\, m_{\gamma\gamma}$ and $p_T^{\gamma_2} > 0.25\, m_{\gamma\gamma}$		
Jets	- - -	$p_T > 30$ GeV, $\|y\| < 4.4$ $m_{jj} > 400$ GeV, $\|\Delta y_{jj}\| > 2.8$ $\|\Delta\phi_{\gamma\gamma,jj}\| > 2.6$	- - -
Leptons	-	-	$p_T > 15$ GeV $\|\eta\| < 2.47$

- σ x L x BR(H →γγ) = ~1662.
- Neural network selects a diphoton vertex (uses track/calo info).
- bkg: γγ (79%), γj (18.5%) and jj (2.5%).
- Exponential exp(pol2) fit to data used for bkg extraction.
- At 13.3 fb^{-1} 124,137 events pass selection, 439 H extracted → 0.3% purity.



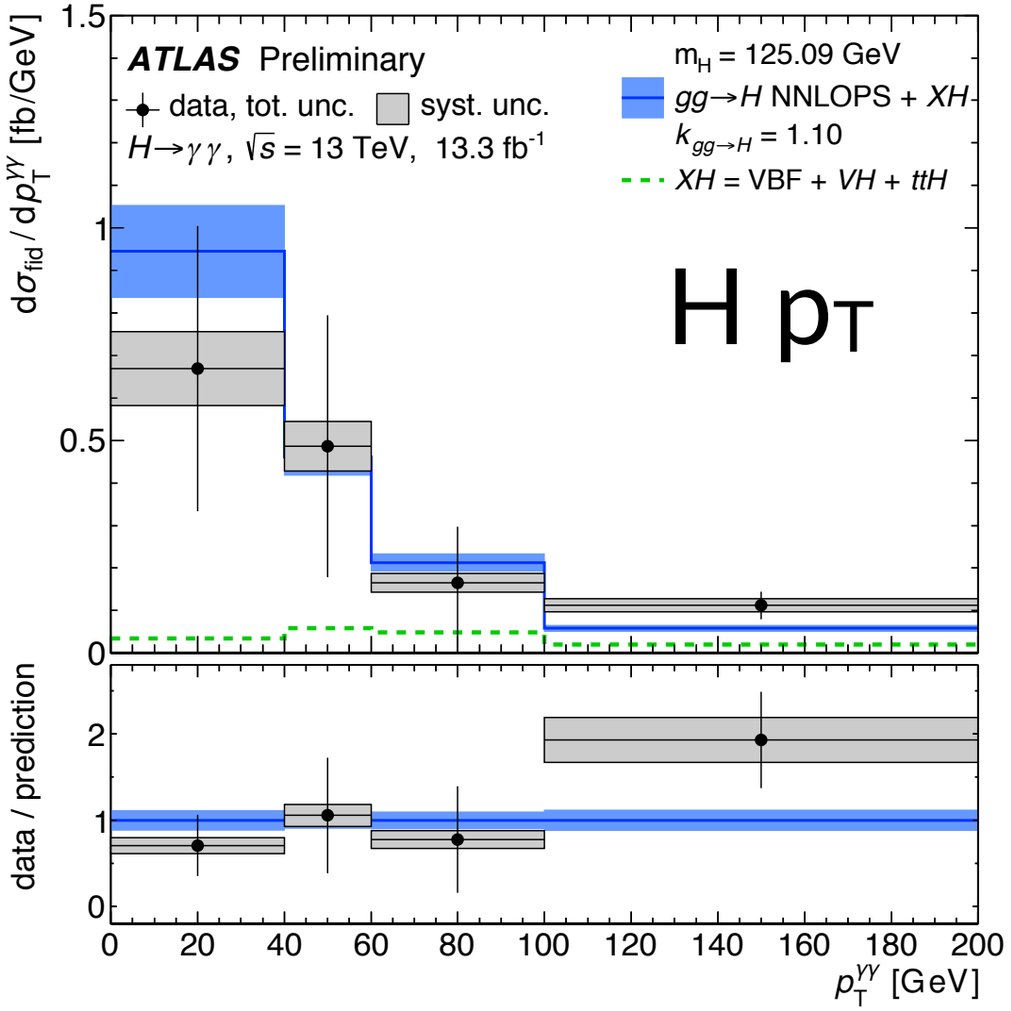
Each event is weighted by the signal-to-background ratio of the event category it belongs to.

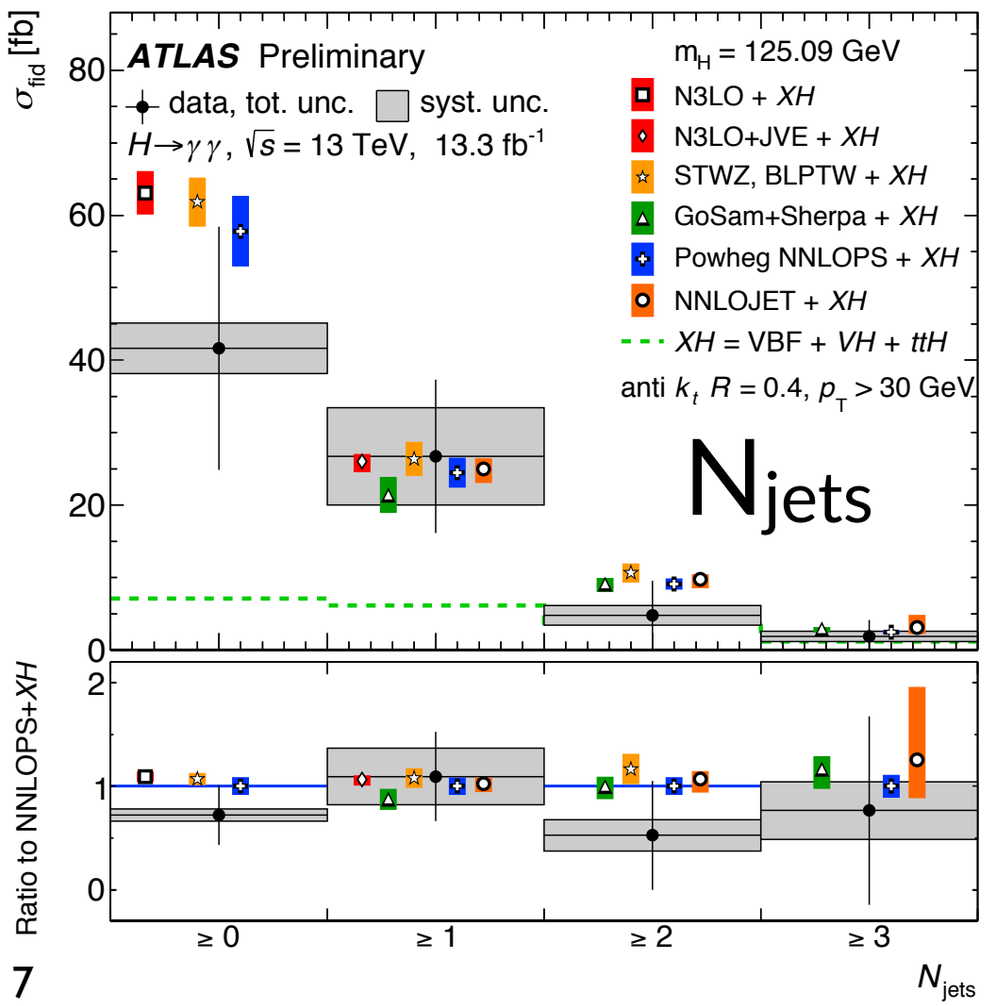


H → γγ Differential Cross Section

ATLAS-CONF-2016-067 - 13.3 fb^{-1}

- Baseline prediction Powheg NNLOPS (at QCD NNLO + EW NLO) in blue.
  - Normalized to N^3LO with k-factor.
- JVE+N3LO includes NNLL resummation of the p_T of the leading jet.
- STWZ-BLPTW is a NNLL+NNLO resummation for the pT of the leading jet, combined with a NLL+NLO resummation for the subleading jet.
- GoSam has NLO QCD accuracy in the inclusive 1, 2, and 3-jet region.

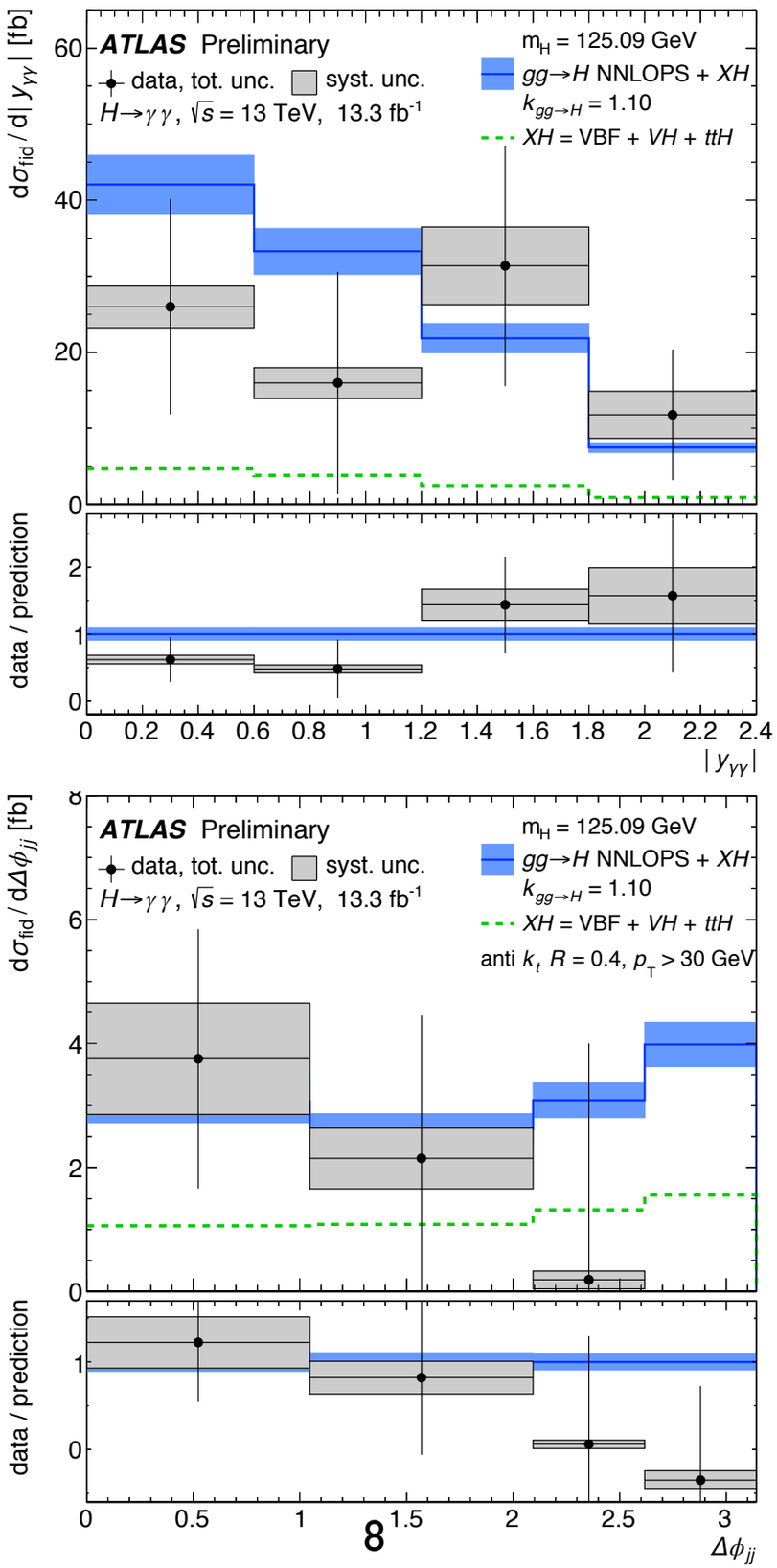


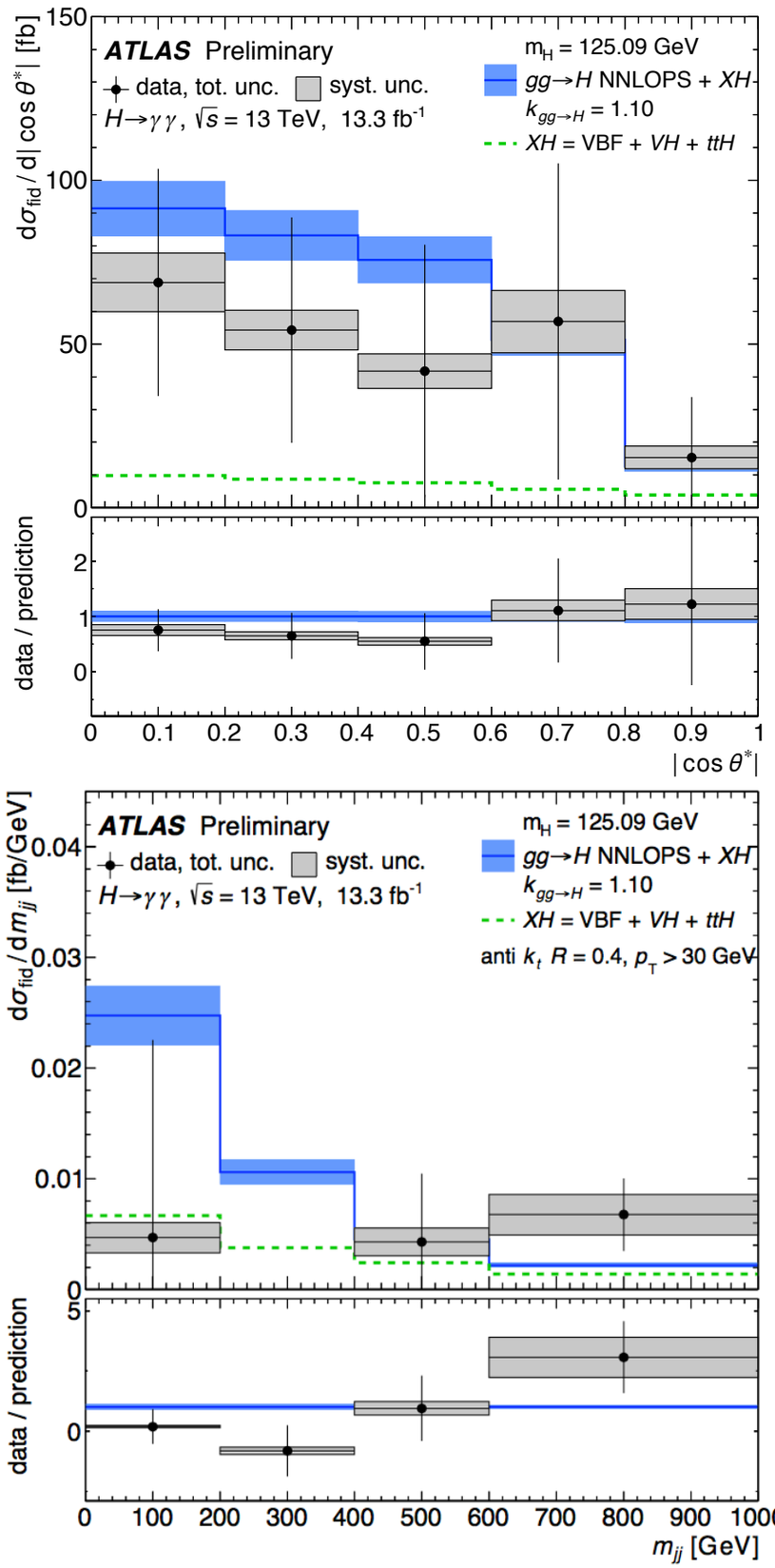


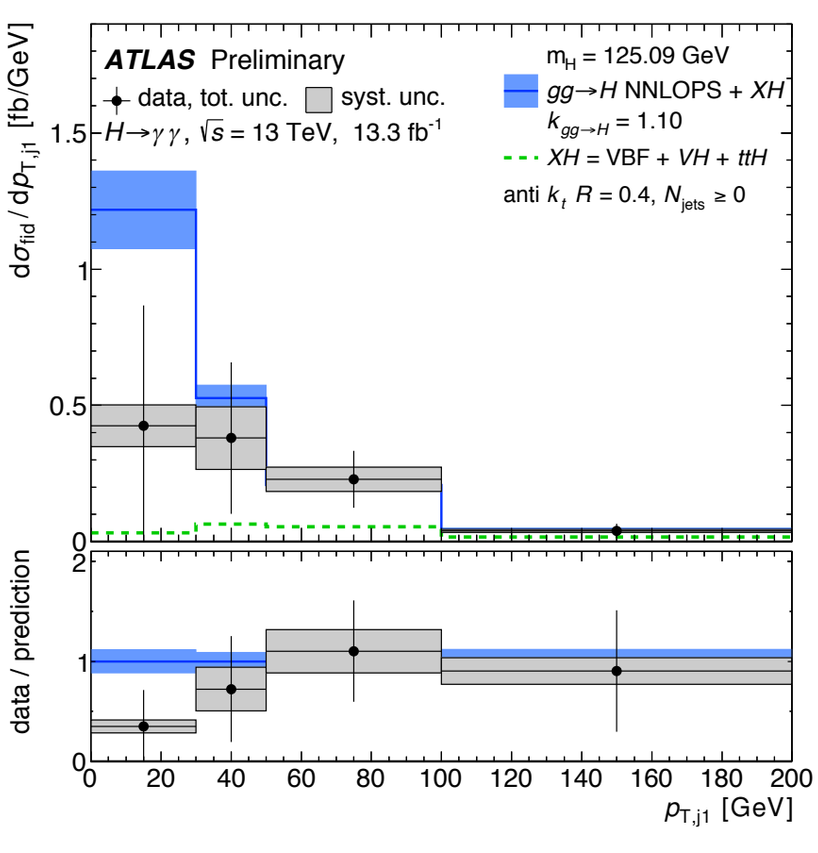
H → γγ Differential Cross Section

ATLAS-CONF-2016-067 - 13.3 fb^{-1}

- $|y_{\gamma\gamma}|$ probes PDF.
- $|\cos\theta^*|$ and $\Delta\varphi_{jj}$ test spin and parity.
- $p_{T,j1}$ is sensitive to models of parton radiation in ggF.



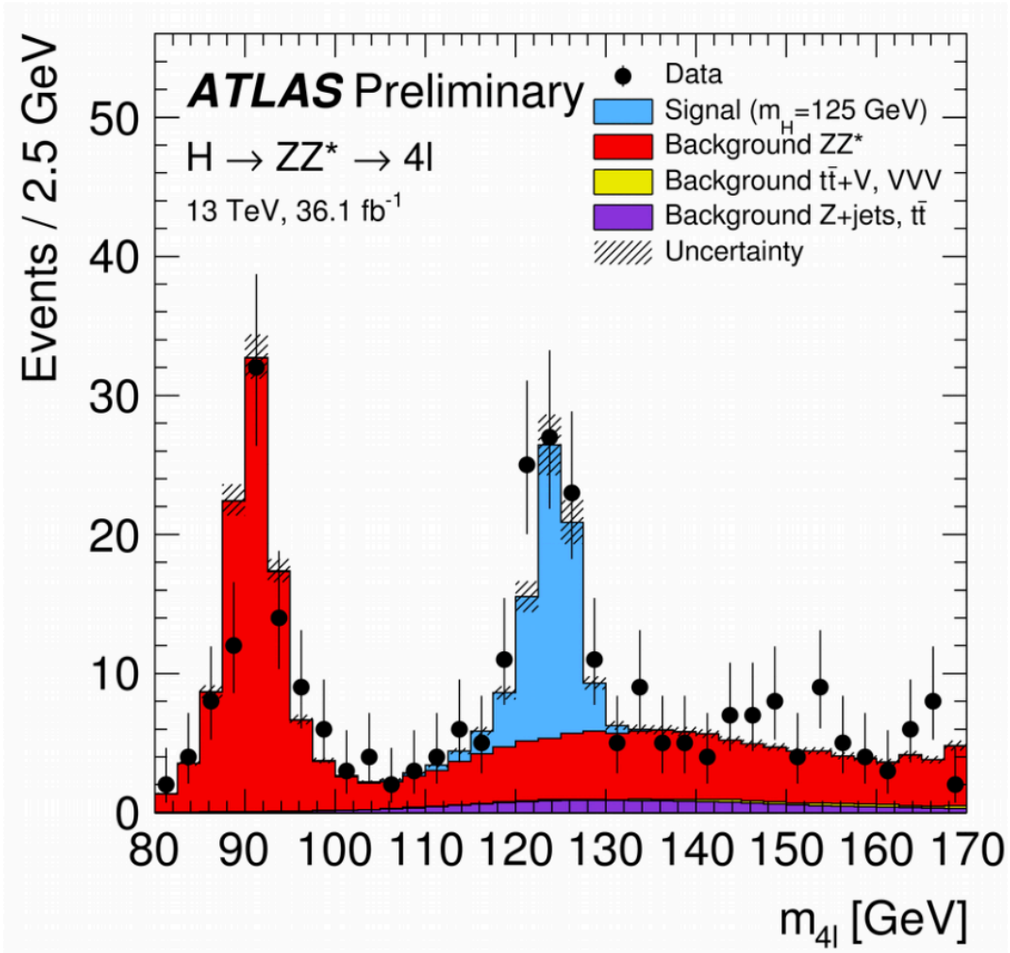




H → ZZ* → 4l Selection

ATLAS-COM-CONF-2017-047 - 36.1 fb^{-1}

Leptons and jets	
Muons:	$p_T > 5$ GeV, $\|\eta\| < 2.7$
Electrons:	$p_T > 7$ GeV, $\|\eta\| < 2.47$
Jets:	$p_T > 30$ GeV, $\|y\| < 4.4$
Jet-lepton overlap removal:	$\Delta R(\text{jet}, \ell) > 0.1$ (0.2) for muons (electrons)
Lepton selection and pairing	
Lepton kinematics:	$p_T > 20, 15, 10$ GeV
Leading pair (m_{12}):	SFOS lepton pair with smallest $\|m_Z - m_{\ell\ell}\|$
Subleading pair (m_{34}):	remaining SFOS lepton pair with smallest $\|m_Z - m_{\ell\ell}\|$
Event selection (at most one quadruplet per channel)	
Mass requirements:	$50 < m_{12} < 106$ GeV and $12 < m_{34} < 115$ GeV
Lepton separation:	$\Delta R(\ell_i, \ell_j) > 0.1$ (0.2) for same- (different-) flavour leptons
J/ψ veto:	$m(\ell_i, \ell_j) > 5$ GeV for all SFOS lepton pairs
Mass window:	115 GeV $< m_{4\ell} <$ 130 GeV



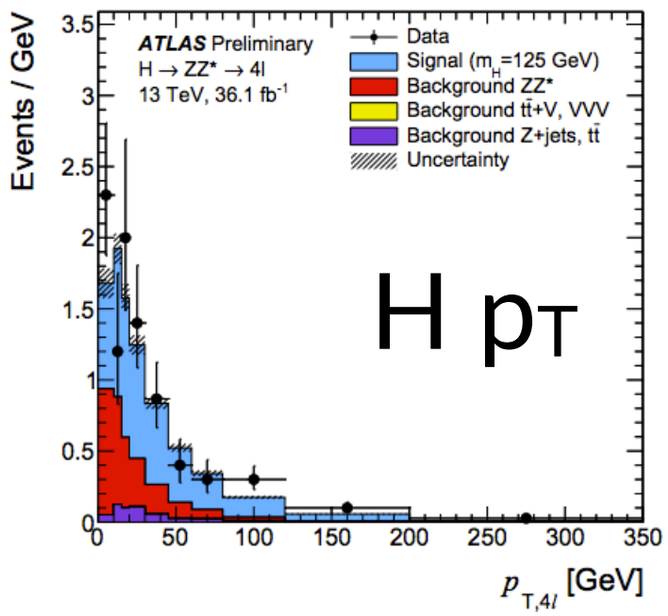
- σ x L x BR(H →ZZ →4l) = 249.
- Major bkg is ZZ* (84%).
- 4l channel has high signal to noise.
- H extraction done by fitting signal and bkg shapes to m_{4l} distribution.
- At 36.1 fb^{-1} looking at 115 < m_{4l} < 130, 102 events pass selection, and we expect 31 bkg events. Purity → 70%.

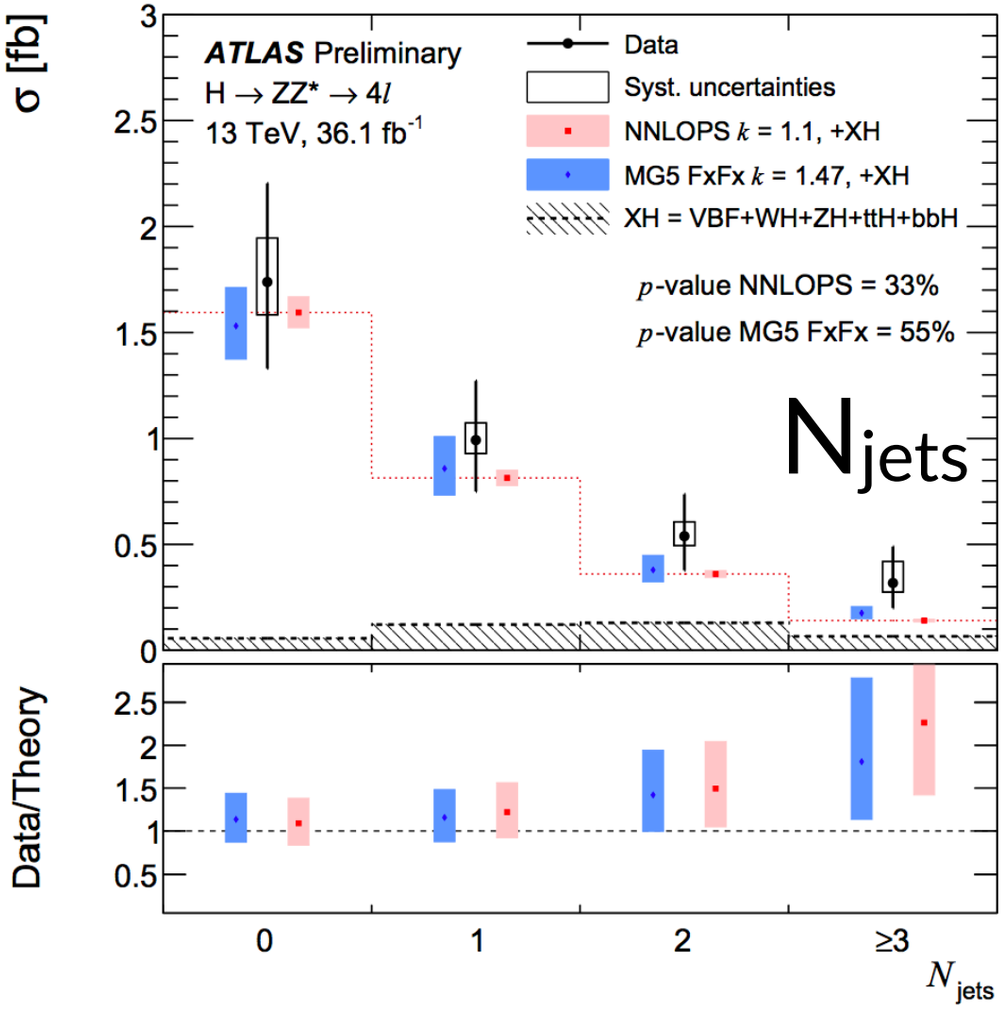
Final state	SM Higgs	ZZ^*	Z + jets, $t\bar{t}$ WZ, ttV, VVV	Expected	Observed
4μ	20.1 ± 2.1	9.8 ± 0.5	1.3 ± 0.3	31.2 ± 2.2	33
$4e$	10.6 ± 1.2	4.4 ± 0.4	1.3 ± 0.2	16.3 ± 1.3	16
$2e2\mu$	14.2 ± 1.4	7.1 ± 0.4	1.0 ± 0.2	22.3 ± 1.5	32
$2\mu2e$	10.8 ± 1.2	4.6 ± 0.4	1.4 ± 0.2	16.8 ± 1.3	21
Total	56 ± 6	25.9 ± 1.5	5.0 ± 0.6	87 ± 6	102

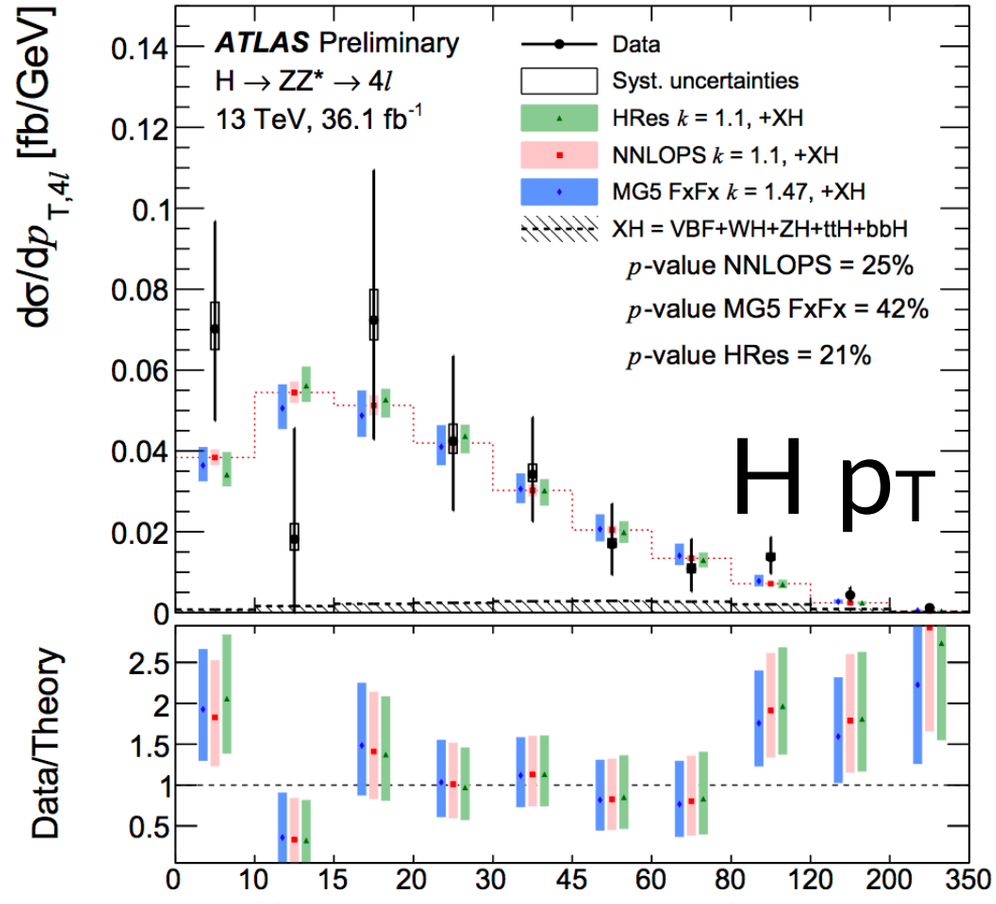
$H \rightarrow ZZ^* \rightarrow 4l$ Diff. Cross Section

ATLAS-COM-CONF-2017-047 - 36.1 fb^{-1}

- Baseline is NNLOPS again (this time in red.)
- Normalized to the N^3LO cross section with the listed k-factors.
- Compared with NNLO FxFx and HRes.
- Consistent with SM predictions.







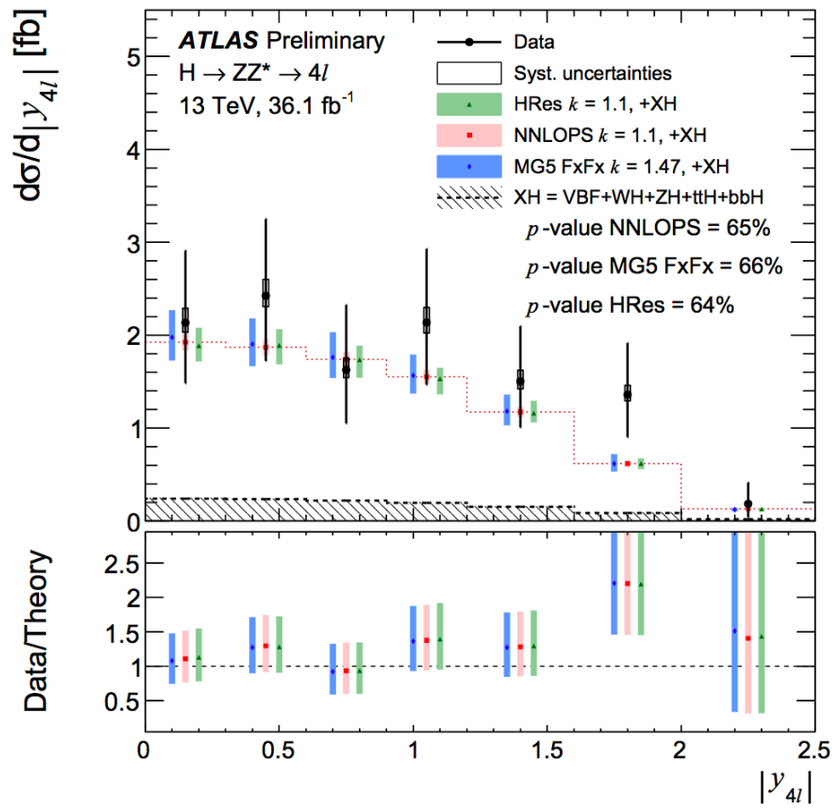
non-linear on x-axis!

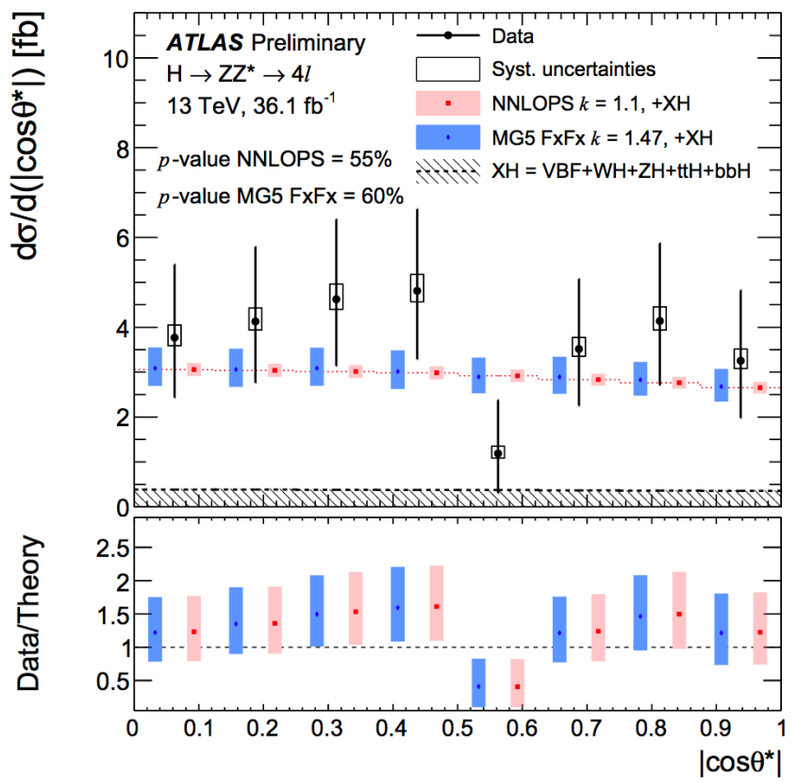
$H \to ZZ^* \to 4l$ Diff. Cross Section

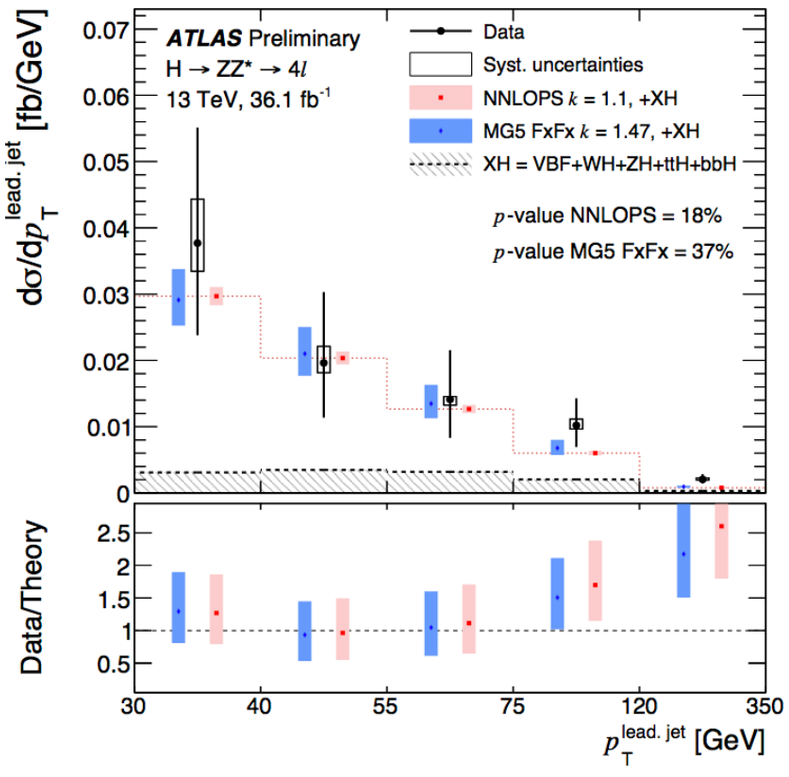
ATLAS-COM-CONF-2017-047

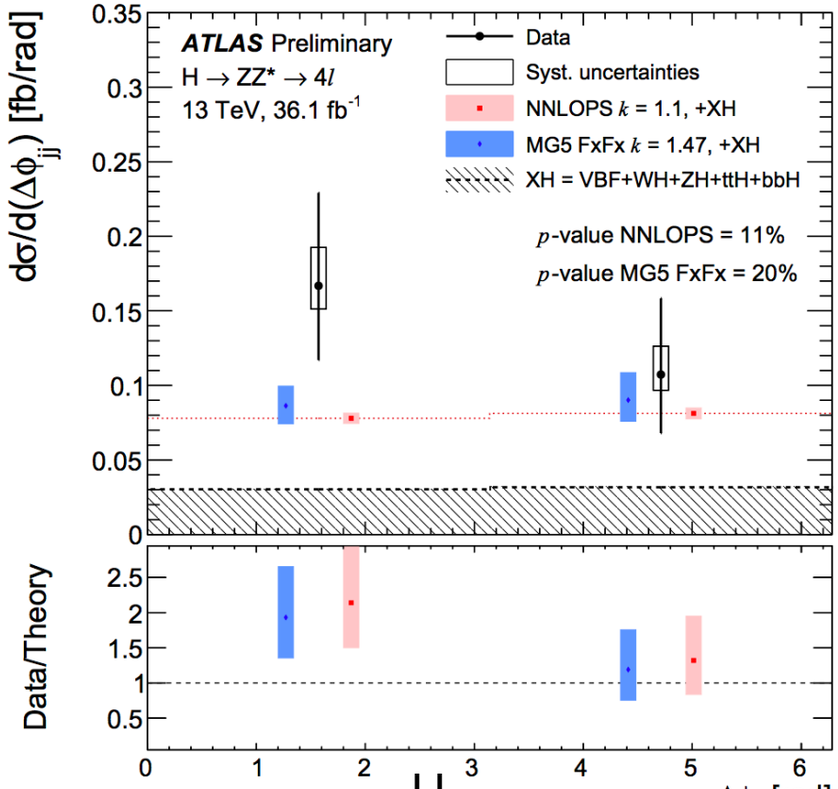
- 36.1 fb^{-1}

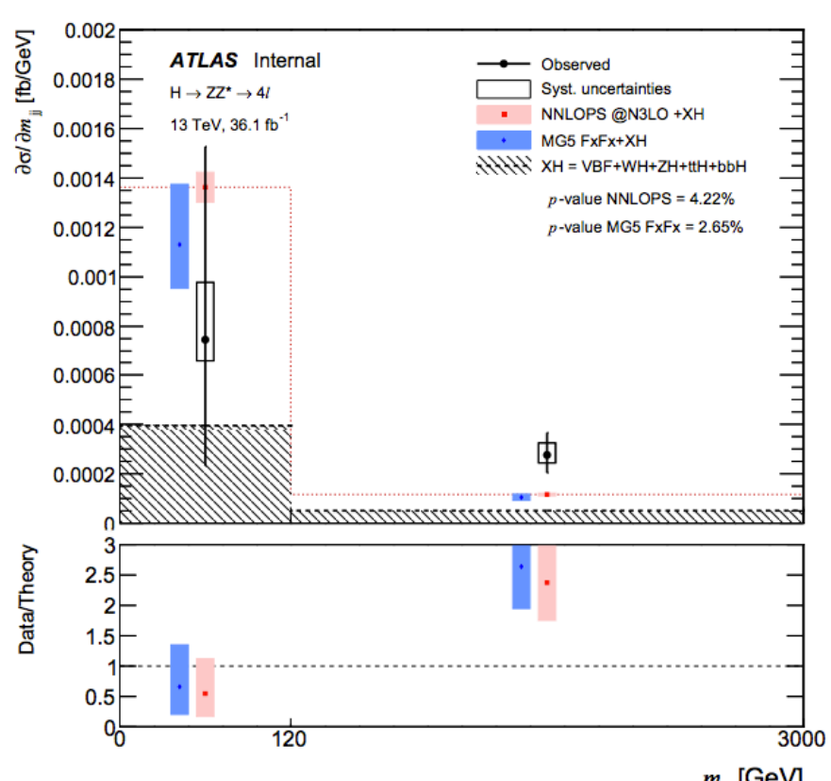
- $|y_{4l}|$ probes PDF.
- $|\cos\theta^*|$ and $\Delta\varphi_{jj}$ test spin and parity.
- m_{jj} is sensitive to different production modes









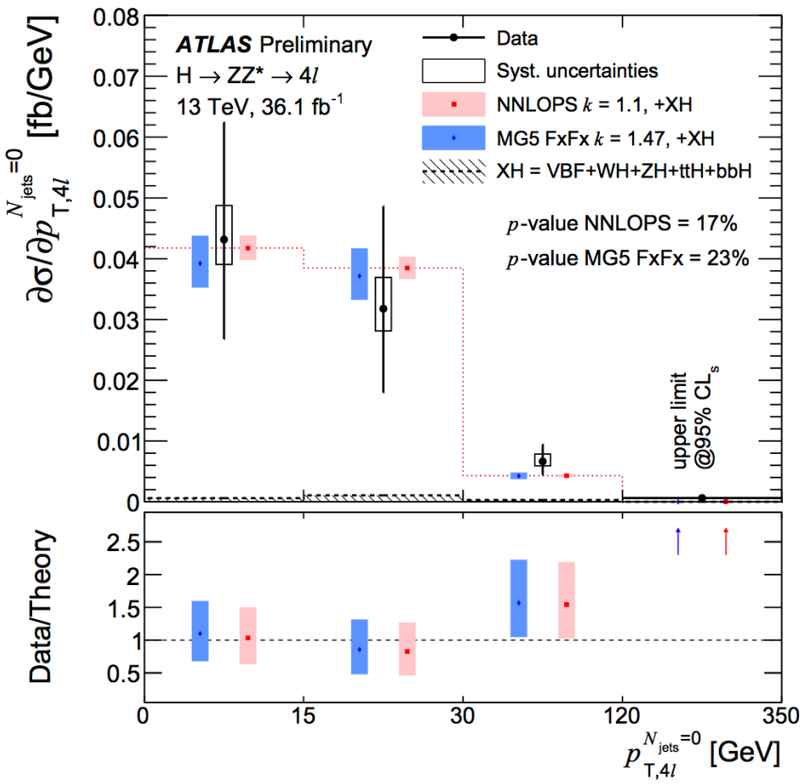


$H \rightarrow ZZ^* \rightarrow 4l$ Double Diff. XS

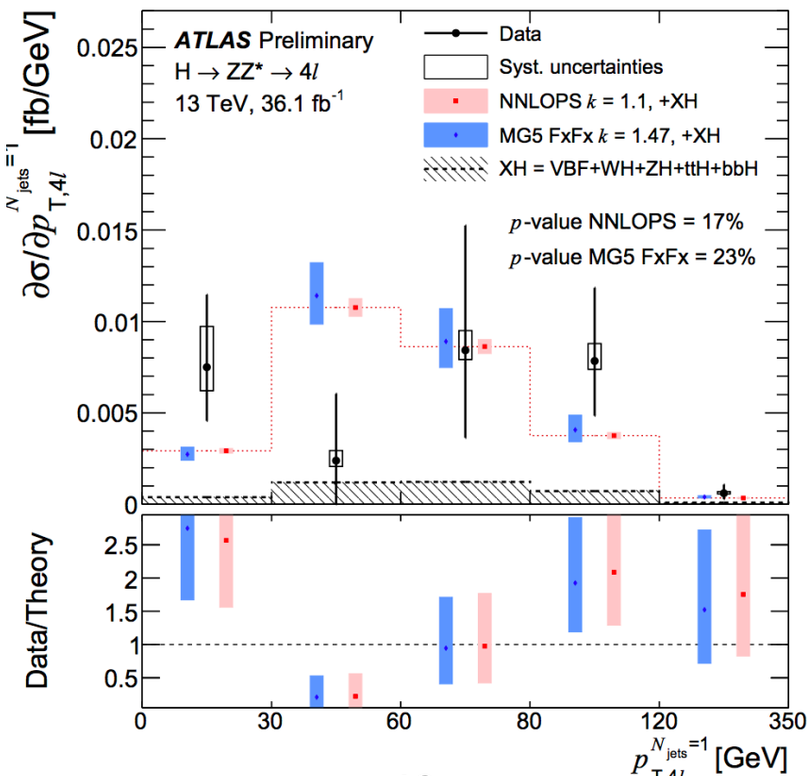
ATLAS-COM-CONF-2017-047 - 36.1 fb^{-1}

- pT distribution as a function of N jets.
- 2D cross section **p_T vs. N_{jets}** can be used to measured QCD perturbations by production mode.
- **Non-linear on x-axis!**

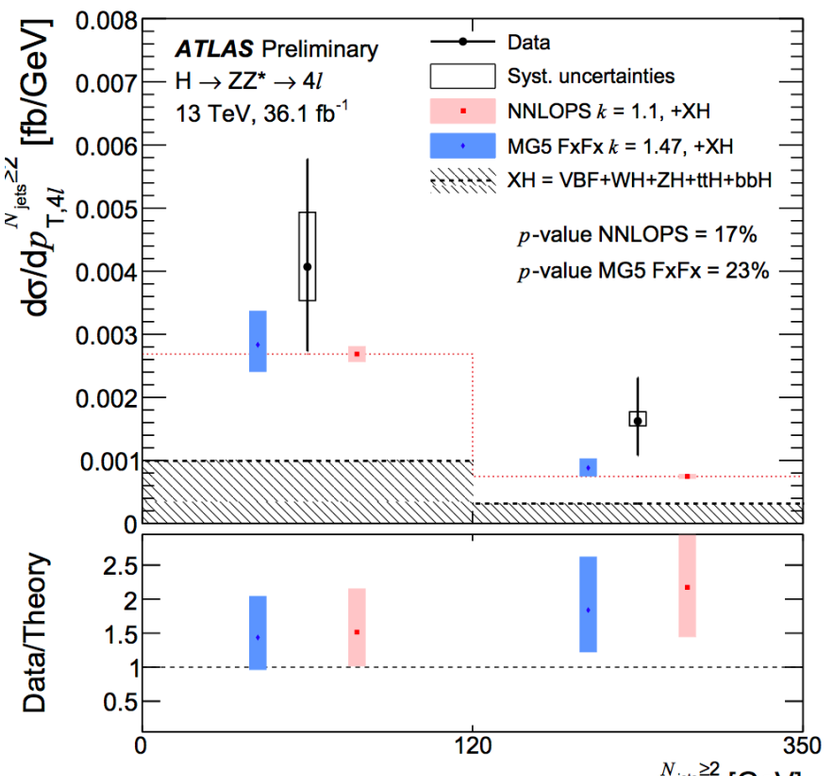
Njets = 0



Njets = 1



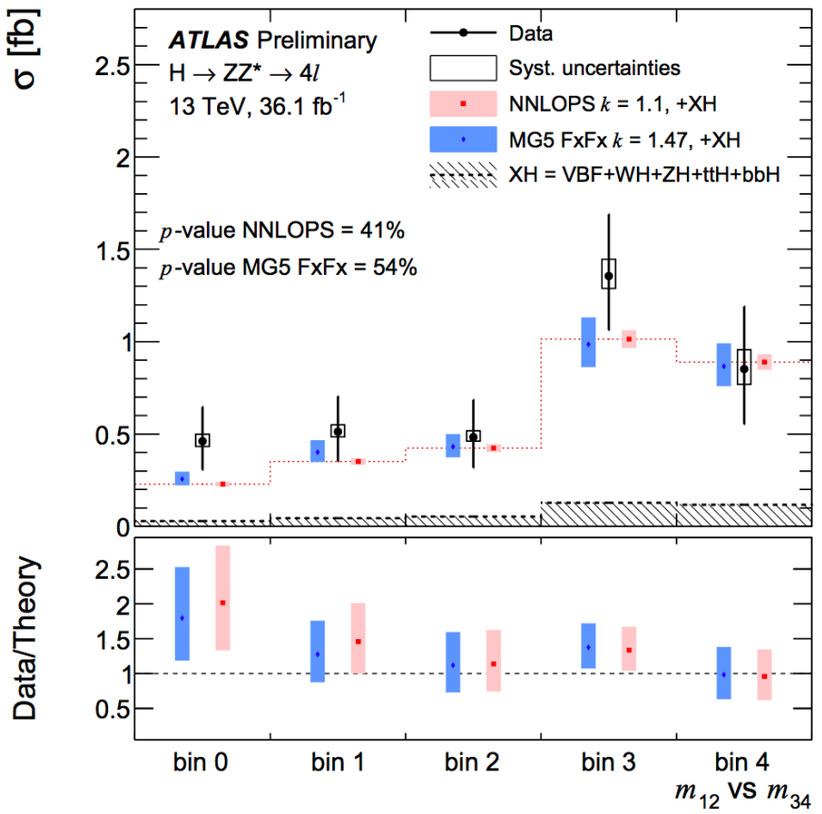
Njets >= 2

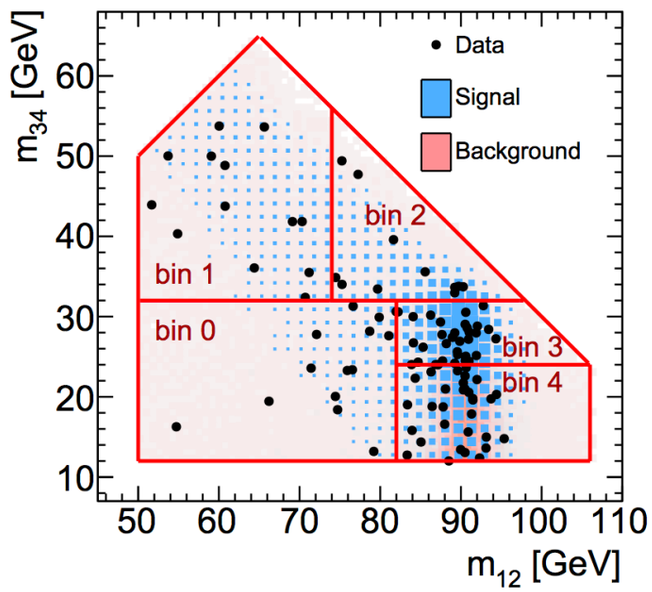


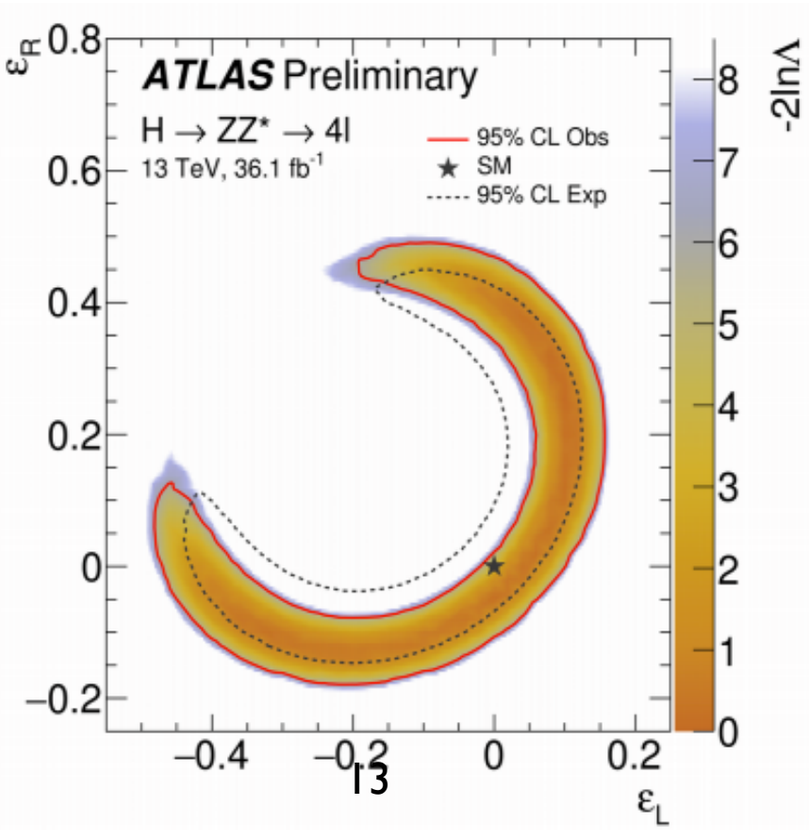
H → ZZ* → 4l Pseudo Observ.

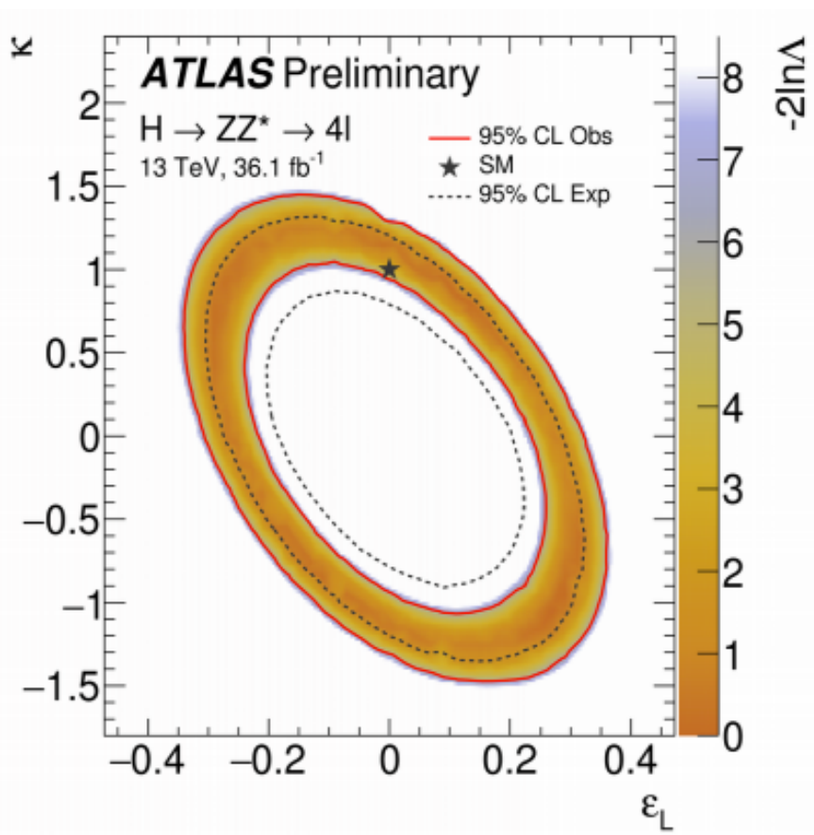
ATLAS-COM-CONF-2017-047 - 36.1 fb^{-1}

- **m_{12} vs. m_{34}** can be used to set limits on modified Higgs boson interactions, in the context of pseudo observables.
- PO independent variables in the absence of specific symmetry assumptions- Testing if such relations are verified by data.
- These limits are on contact terms between H and L-/R-handed leptons.







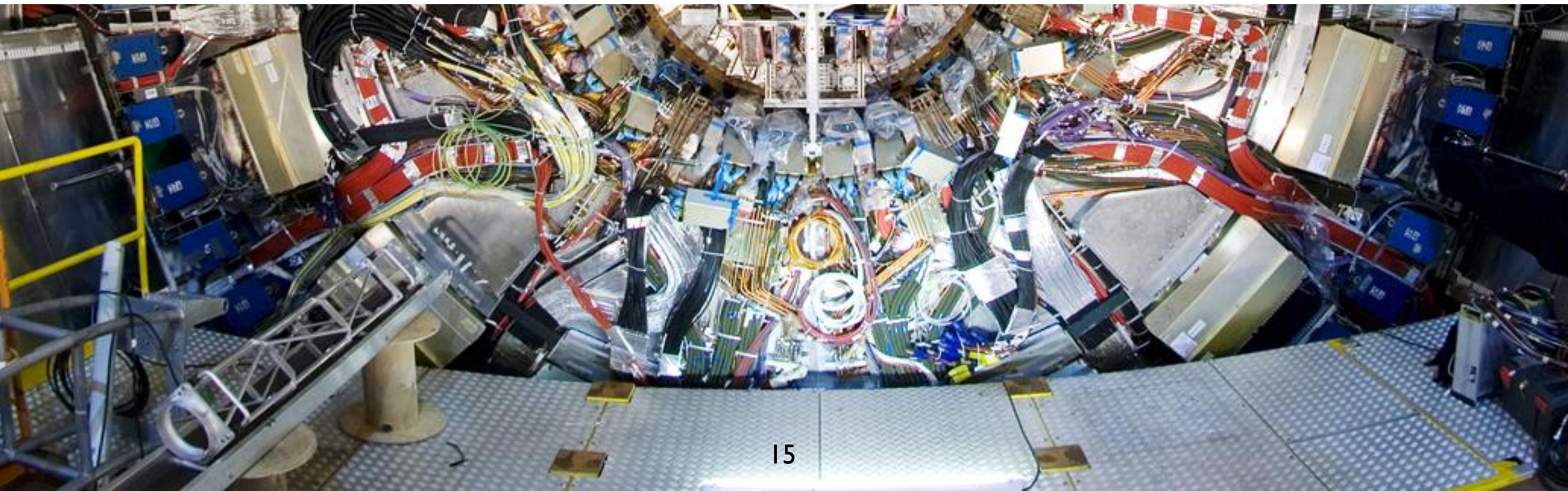


Conclusion

ATLAS has analyzed 36.1 fb^{-1} of pp collisions at 13 TeV, and so far, things are looking consistent with the Standard Model in the bosonic decay channels.

- Differential cross section measurements demonstrate a high resolution way to measure many Higgs properties.
- Other Higgs boson properties like mass and spin/CP will be calculated with 13 TeV data.
- A future combination of $H \rightarrow ZZ^*$, $H \rightarrow \gamma\gamma$ and possibly $H \rightarrow WW^*$, as well as a combination with CMS will constrain the statistical uncertainty even further.
- More than 100 fb^{-1} expected at the end of Run 2!

Thank You!



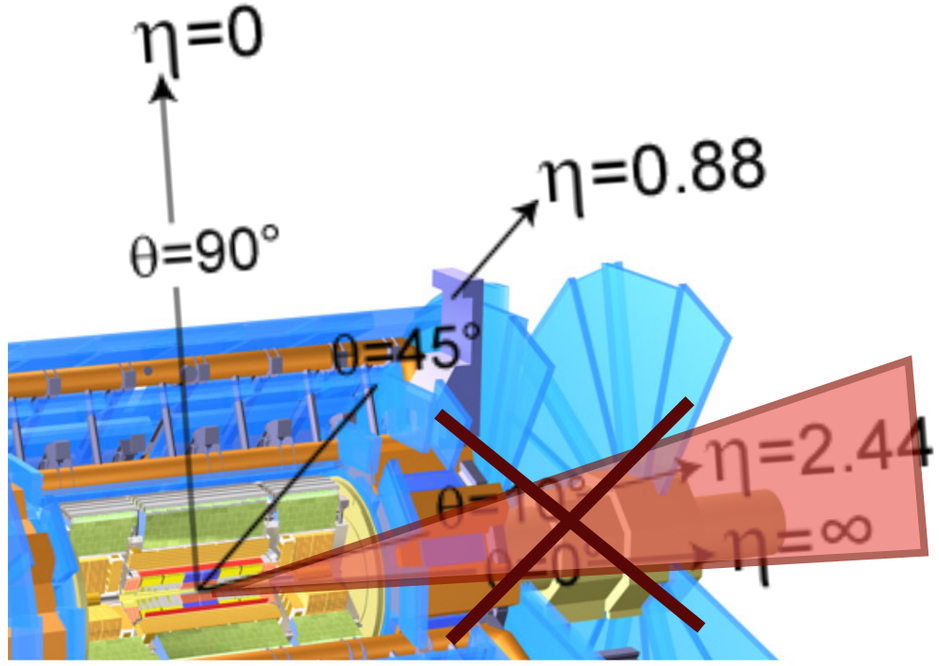
Fiducial Cross Section

- ‘Fiducial’ means cross sections within a phase space that ATLAS can directly measure.
- Theory predictions compared to the constrained fiducial phase space.

$$\frac{\mathrm{d}\sigma_i}{\mathrm{d}x} = \frac{\nu_i^{\mathrm{sig}}}{c_i \Delta x_i \int L\,\mathrm{d}t} \qquad c_i = \frac{n_{i,\mathrm{reco}}}{n_{i,\mathrm{fid}}}$$

numerator is reconstructed truth MC

- ν^{sig} is extracted signal events from data.
- Δx is the bin width.
- c is correction factor, derived from MC.
  - models detector effects
    - trigger, resolution, identification and reconstruction.
  - in Hγγ, c = 78.5% inclusively.
  - in HZZ, c = 53% inclusively.



can’t measure as well at high η