Higgs Differential Cross-Section Measurements

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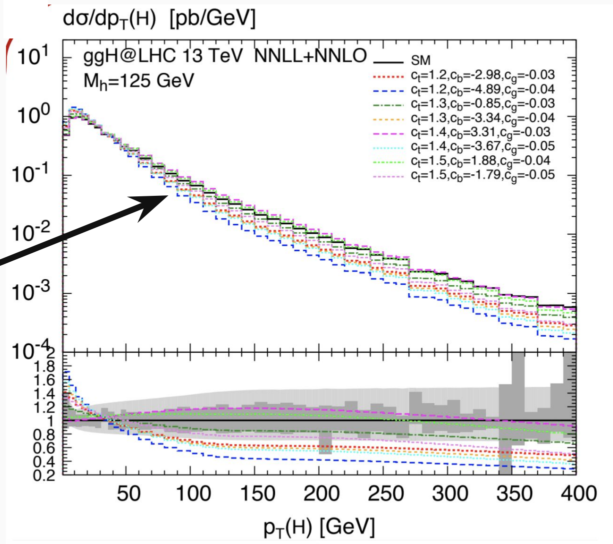
Introduction

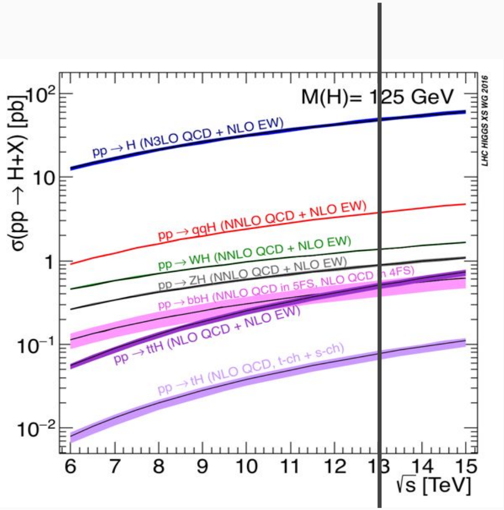
- Higgs Physics program of LHC experiments has been focussing on properties measurement in past years.
- With Run-II dataset, there is a great opportunity to perform more “precision” measurements in various phase-space corners using Higgs boson as benchmark
  - **Differential Fiducial XS measurements → minimum theory and model dependence**

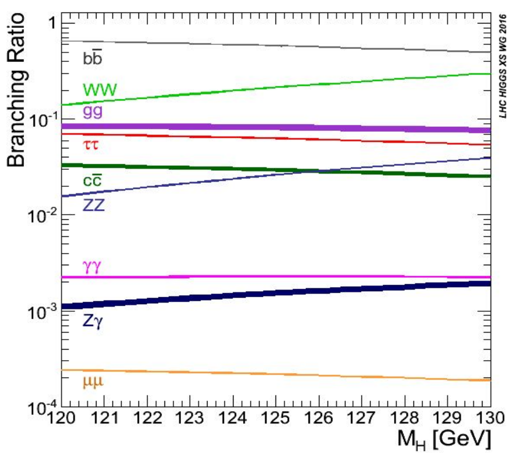
- Most of the analyses are already updated with full Run-II luminosity.

Higgs boson distribution shapes are sensitive to “new Physics”



explore the unknown Physics using known





Focus of this talk

- Focus is on full Run-II differential results from CMS and ATLAS experiments.

Analysis	Experiment	Reference
$H \rightarrow \tau\tau$	CMS	HIG-20-015
Boosted $H \rightarrow bb$	CMS, ATLAS	ATLAS-CONF-2021-010, JHEP12(2020)085
$H \rightarrow ZZ \rightarrow 4l$	CMS, ATLAS	HIG-19-001, Eur. Phys. J. C 80 (2020) 942
$H \rightarrow \gamma\gamma$	CMS*, ATLAS	HIG-19-015, ATLAS-CONF-2019-029
$H \rightarrow ZZ \rightarrow 4l + H \rightarrow \gamma\gamma$	ATLAS	ATLAS-CONF-2019-032
$H \rightarrow WW \rightarrow 2l2\nu$	CMS	HIG-19-002

* inclusive only

$H \rightarrow \tau\tau$

H→ττ : Overview

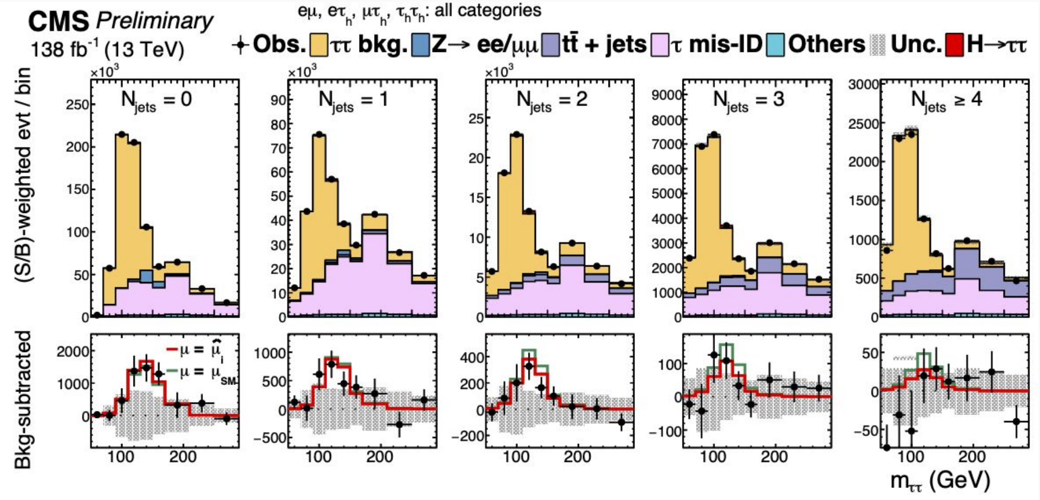
CMS

- With high B.R. (6%) for Higgs at 125 GeV, H→$\tau\tau$ is an important channel for measurement of Higgs boson properties specially in pT and njets variables.
- Variables considered : pT(H), NJets, leading jet pT
- All final states considered except the fully leptonic same flavour (ee and $\mu\mu$)
- Events in $\tau_h\tau_h$ final state are required to have at least one jet with pT > 30 GeV
- **First Differential measurement in this decay mode.**

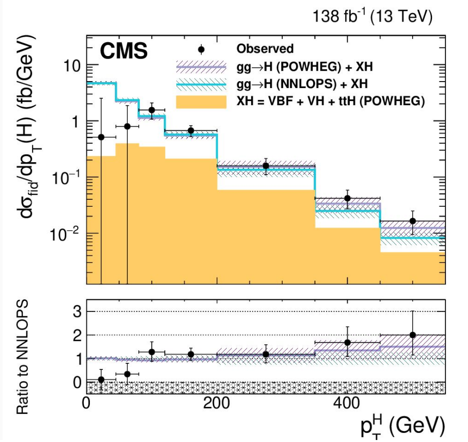
The fit is done on the mass of the $\tau\tau$ system ($m_{\tau\tau}$), reconstructed with a simplified matrix-element algorithm

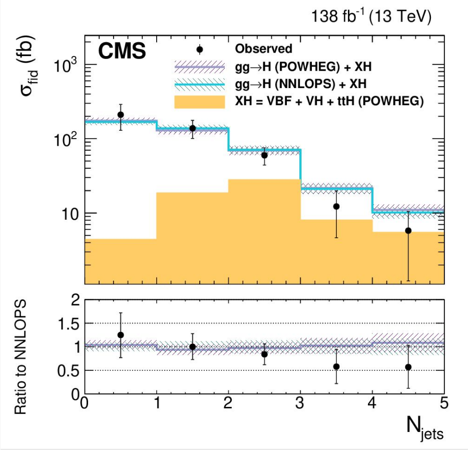
Main backgrounds :

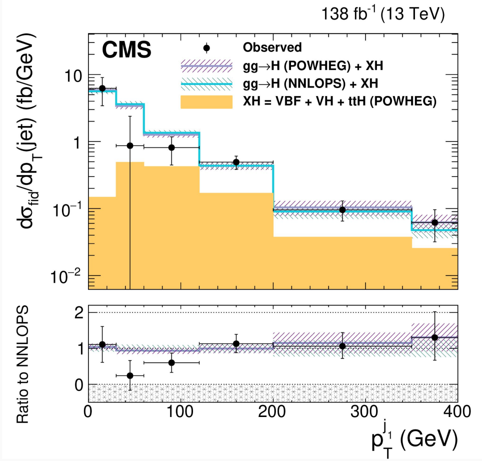
- Z→$\tau\tau$, Top and di-Boson
  - Estimated using tau-embedded samples → replace muons from di-muon data sample by simulated taus
- Jets mis-identified as τ_h
  - Misidentification probability estimated in data from QCD, W+Jets and top CRs as function of pT$^{\tau}$ and njets



H→ττ : Results







- ➔ Results are compared with Powheg and also Powheg weighted with NNLOPS
- ➔ Measurement is inclusive in production modes
- ➔ Good agreement with SM expectation
  - ◆ p(pT_H) = 17%, p(Njets) = 71%, p(pTj1) = 45%
- ➔ Fiducial cross-section is extracted from Njets
  - ◆ σ^{fid} = 426 ± 102 fb (σ_{SM}^{fid} = 428 ± 27 fb)

Unfolding is embedded into likelihood

$$\mathcal{L} = \prod_i Poisson\left(n_i; \sum_j R_{ij}(\theta)\,\mu_j + b_i\right) \cdot \mathcal{C}(\theta) \cdot \mathcal{K}(\mu)$$

Migration matrix

Particle level signal strength

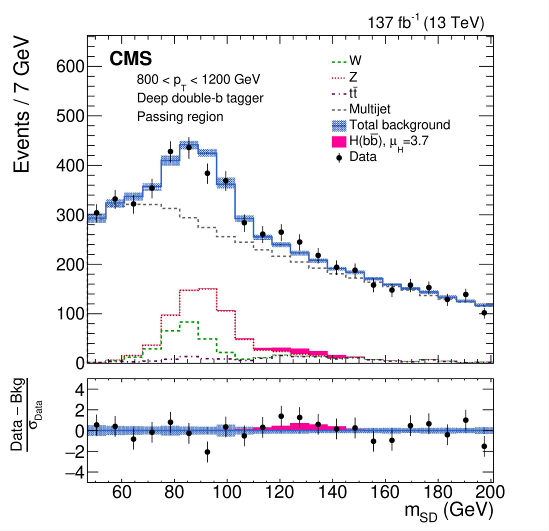
Regularization term (optional), Tikhonov scheme in this analysis

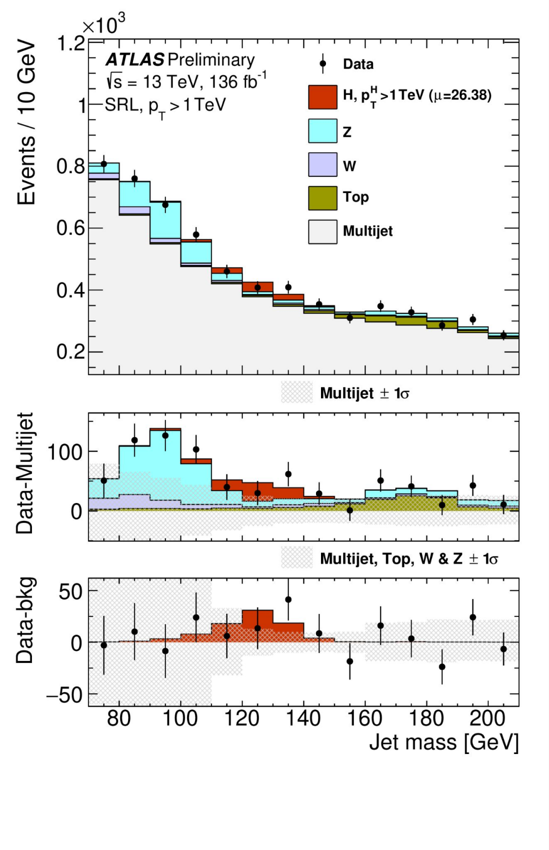
Boosted H $\rightarrow$ bb

Boosted H→bb : Overview

- ➔ H→bb has the highest branching ratio (~ 58%)
  - ◆ High BR compensates for the drop in Xsec at high pT
  - ◆ can probe quasi point-like couplings within ggF loop structure
- ➔ High QCD background makes this analysis very challenging
- ➔ Boosted topology of Higgs decay has been used in this analysis
  - ◆ Merged jet with large radius with 2 sub-jets

- Jet mass distribution is used to extract the signal
- **ATLAS selection :**
  - $pT_{j1} > 450$ GeV
  - $pT_{j2} > 250$ GeV
  - Two prong sub-jet structure is considered
  - 2 sub-jets are required to pass b-tag requirement
- **CMS :**
  - $pT_{j1} > 450$ GeV
  - dedicated MVA tagger

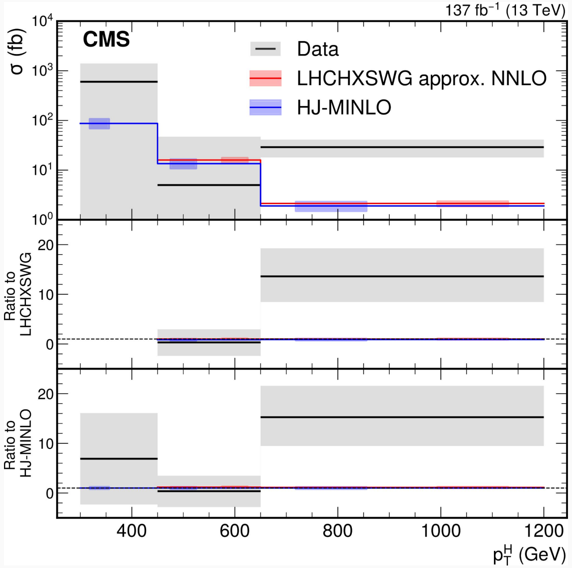


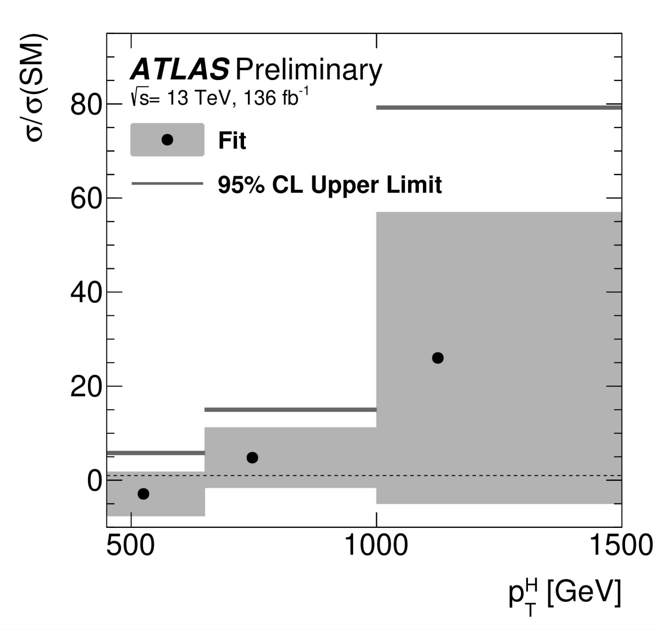


H→bb : Results

- ➔ CMS considered ggF only as signal, rest production modes are considered as background.
- ➔ ATLAS considered inclusive production with no attempt to reject non-ggF contributions

Measurement is dominated by statistical uncertainties





- HJ-MINLO is used for prediction
- Also compared with NNLO prediction from LHCHXSWG

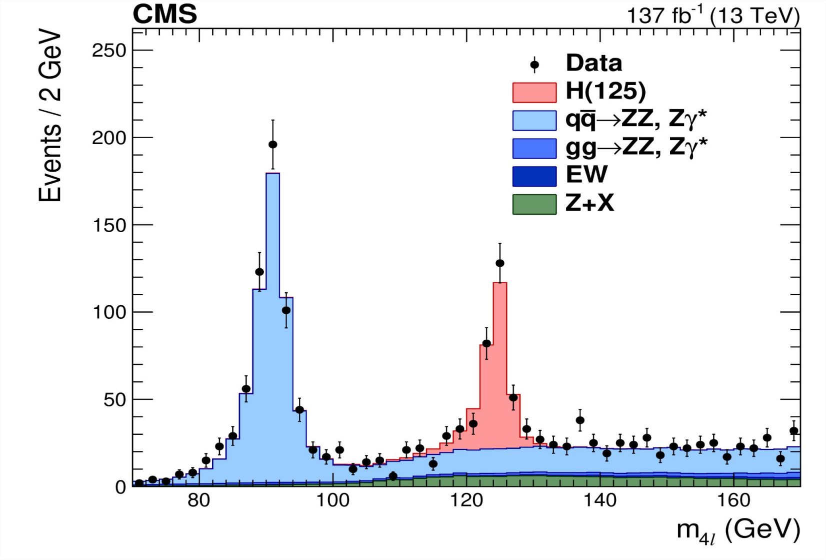
CMS has 2.6σ excess in highest pT bin which is reduced to 1.8 sigma when all bins considered simultaneously

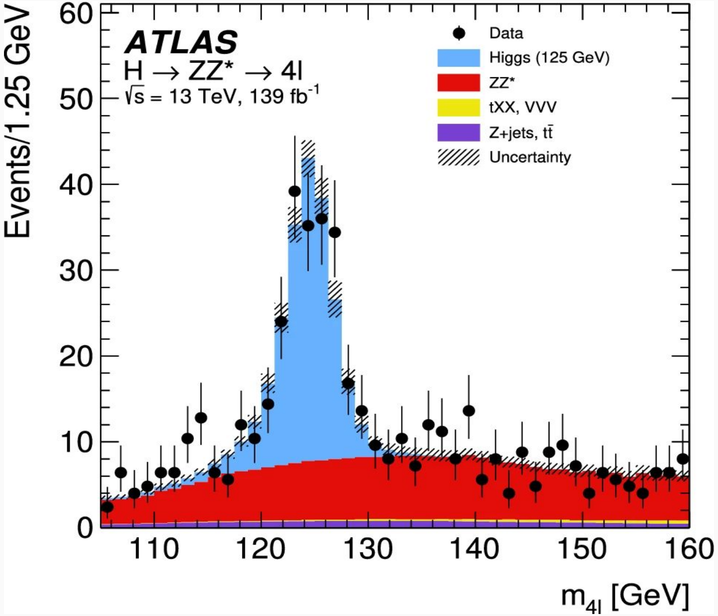
- POWHEG+MINLO is used for ggF prediction
- POWHEG-Box V2 for VBF and gg→VH, ttH
- POWHEG-Box V2 + MINLO for qq → VH

$H \rightarrow ZZ^* \rightarrow 4l$

H→4l Overview

➔ Clean signature with 4 identified & isolated leptons → high S/B





➔ Backgrounds :
- ◆ Irreducible : qq→ZZ and gg→ZZ estimated from MC
- ◆ Reducible : Z+X estimated from data

➔ Signal extraction :
- ◆ No event categorization and kinematic discriminant
- ◆ Simultaneous fit for m_{4l} in all final states.
- ◆ Unfolding embedded in the likelihood fit

➔ Backgrounds :
- ◆ Irreducible : qq→ZZ and gg→ZZ estimated from MC with norm from data in m_H bands

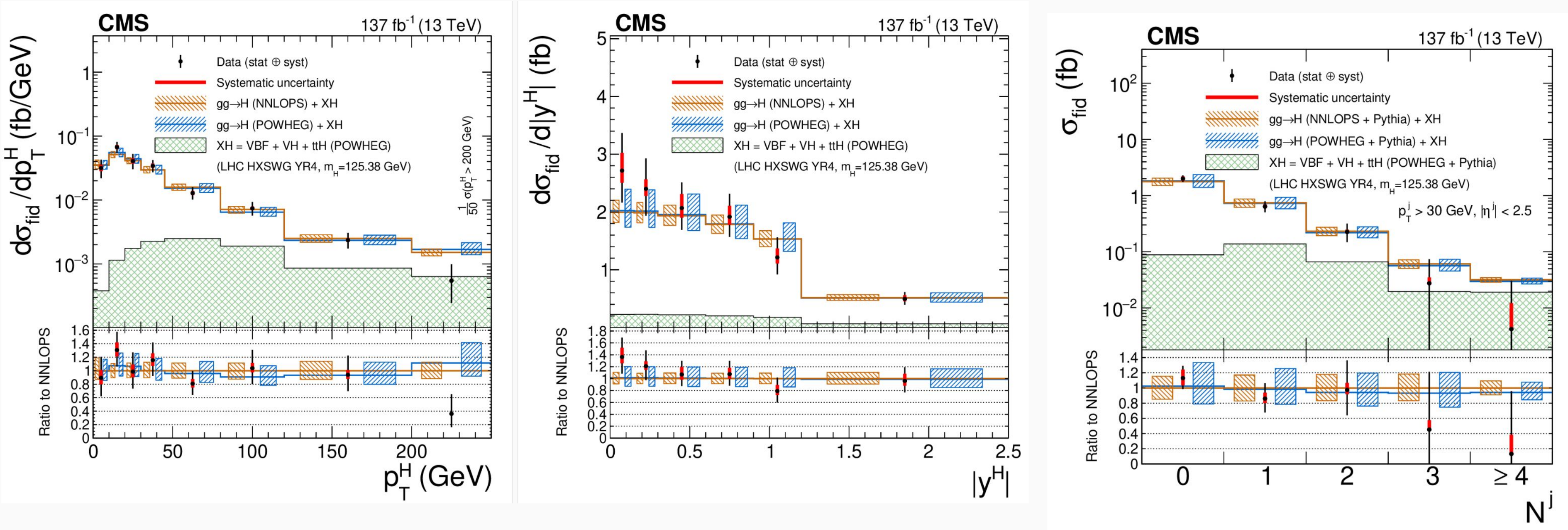
➔ Signal extraction :
- ◆ Simultaneous fit for m_{4l} in all final states.
- ◆ MATRIX unfolding (embedded in likelihood) is used without regularization

Results : CMS

- ➔ Differential cross section measured for pT(H), |y(H)|, N(jet), pT(jet)
- ➔ Compared to predictions from POWHEG and NNLOPS
- ➔ Dominant systematics are the experimental ones. Theoretical uncertainties are sub-dominant
- ➔ fiducial volume is defined to match closely the reconstruction level selection

$$\sigma_{\text{fid}} = 2.84^{+0.34}_{-0.31} = 2.84^{+0.23}_{-0.22}\,(\text{stat})^{+0.26}_{-0.21}\,(\text{syst})\,\text{fb}$$

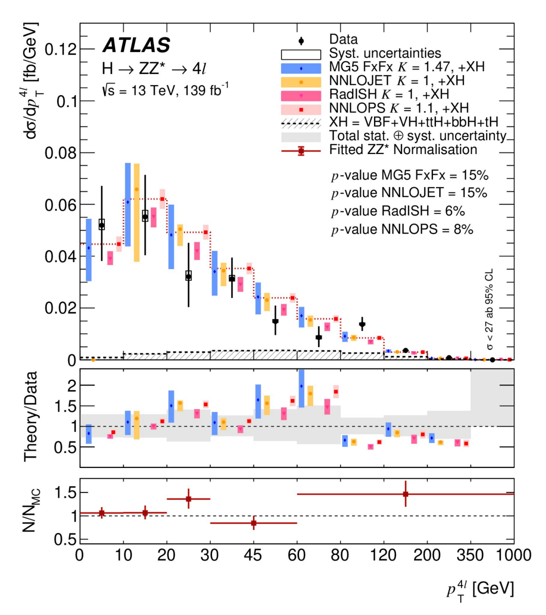
SM Expectation:
2.84 ± 0.15 fb

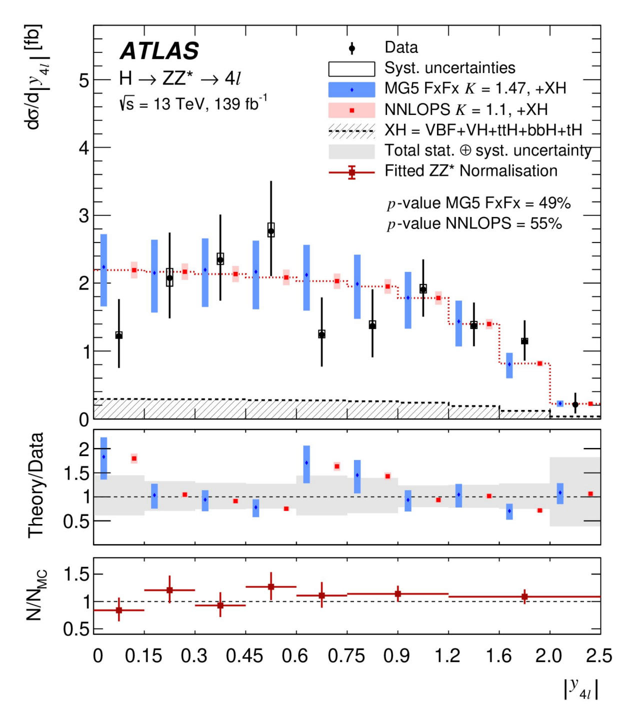


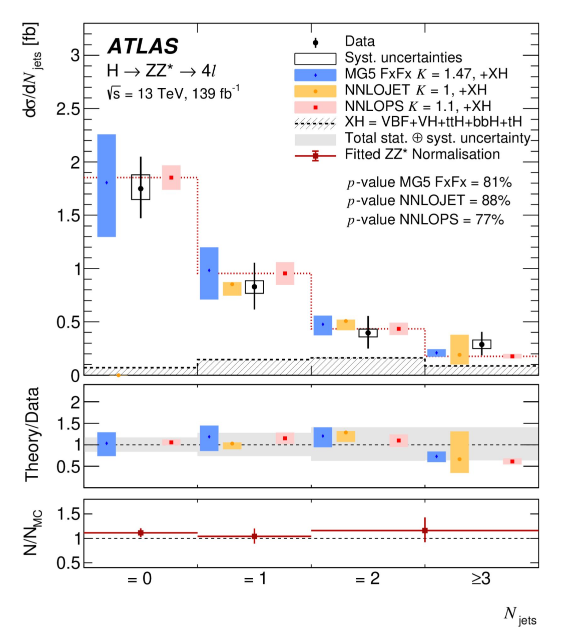
Results : ATLAS

➔ ATLAS measured 20 observables :
- **Higgs system :** pT(4l), Y(4l), m12, m34, 5 final state angular variables
- **Jet Variables :** N_Jets, N_bjets, pT(j1), pT(j2), mjj, angular separation (**ϕ**,**η**)
- **Higgs + 1/2 jets :** pT and invariant mass
- **Double Differential :** 8 variables

All the results are compatible with SM

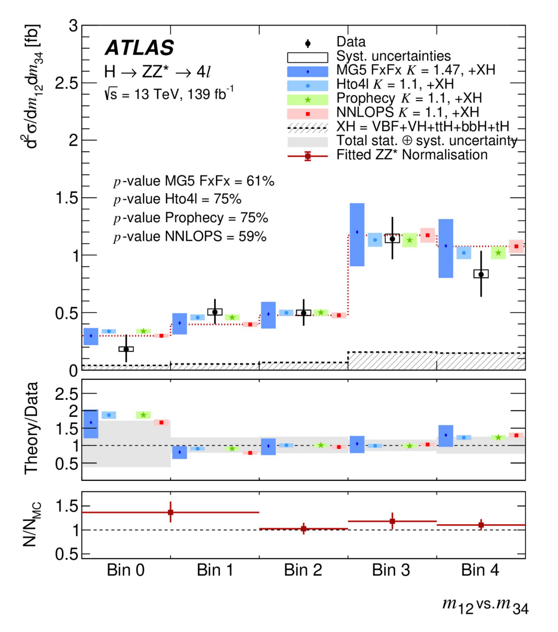


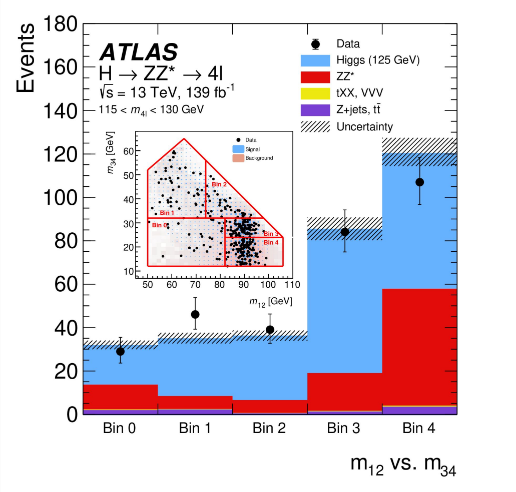


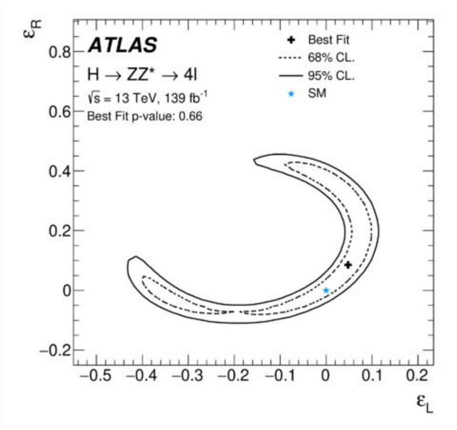


Double differential and Pseudo-Observable interpretation

flavour-universal contact terms

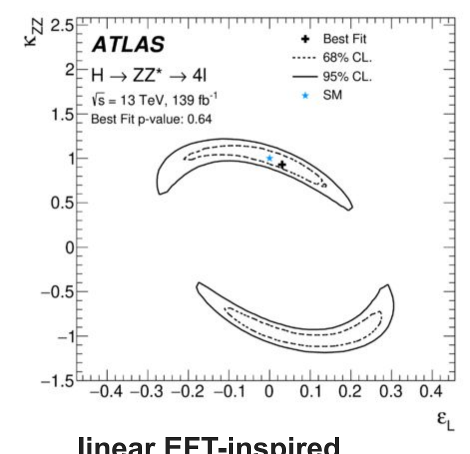






- $m_{12} \rightarrow$ on-shell Z
- $m_{34} \rightarrow$ off-shell Z

Results are compatible with SM

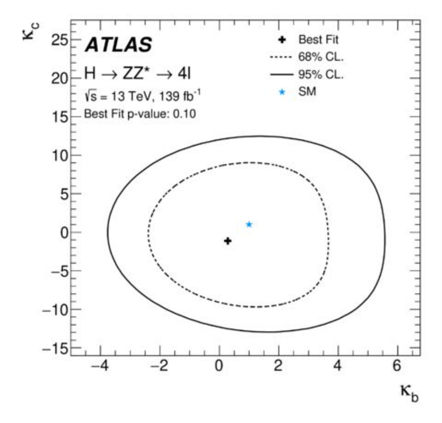


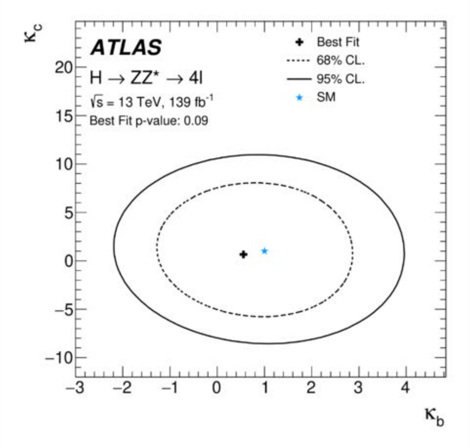
linear EFT-inspired

- Starting from **m_{12} vs m_{34}**, different pseudo-observables are measured which describes the contact interactions between **H, Z and right/left handed leptons** → 4 scenarios considered
- Contact terms have same Lorentz structure as SM → only affects invariant mass distributions

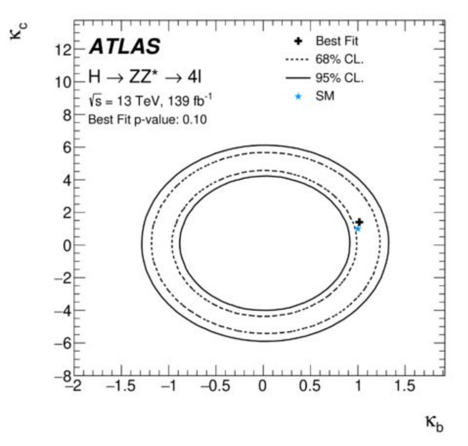
Constraints on Yukawa Coupling

- Higgs to t-quark and b-quark couplings have been established directly by both experiments but they can also be indirectly constrained using pT(H) spectrum
  - More important for Higgs to charm-quark coupling.





- The fiducial cross section is parameterised as a function of the k_c and k_b values in each measured bin of pT(H).
- Theoretical uncertainties for gg and qq induced processes are recalculated for pT(H) < 10 GeV because of large variations seen there.



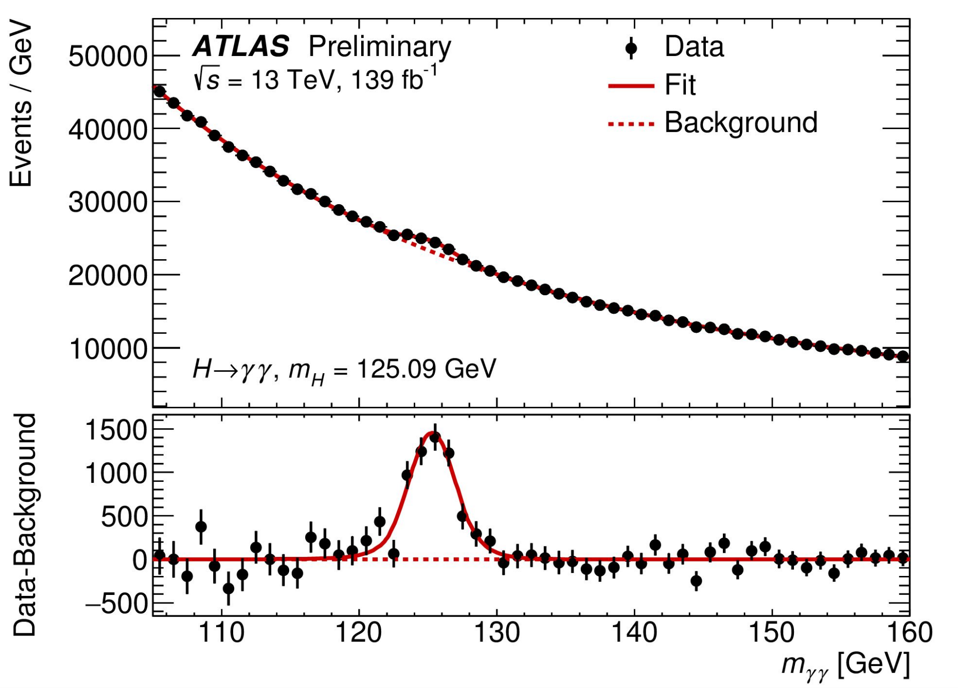
Three scenarios considered in the order of increasing the model dependency :

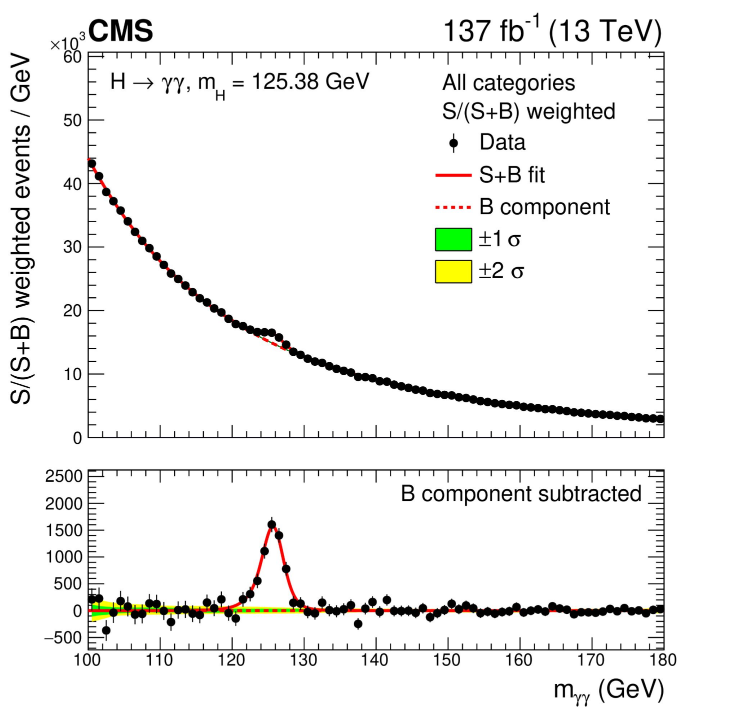
1. only pT(H) shape is used to constrain k_c and k_b
2. the predicted cross-section is used
3. both the prediction of the pT(H) differential cross section and the modification to the branching ratio due to the k_c and k_b values are used.

Results are compatible with SM

$H \to \gamma\gamma$

H→γγ : Overview



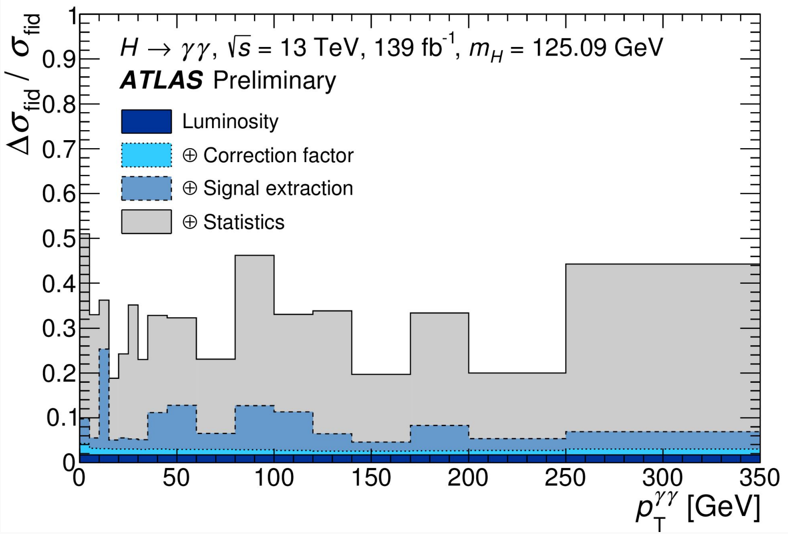


- High resolution channel with small branching ratio (~0.2%)
- Look for narrow resonance peak over the smoothly falling di-photon background
- Signal is extracted by parameterised fit of $m_{\gamma\gamma}$ distribution for each category.

H→γγ : Fiducial differential Xsec

ATLAS

- The reconstruction level data yields are unfolded to particle level using bin-by-bin correction factor
- Matrix unfolding is used a check



- 6 variables are used for measurement covering Higgs kinematics, exploration of CP effects.
- Results are interpreted also in EFT framework

$$\sigma_{\mathrm{fid}} = \frac{N^{\mathrm{sig}}}{c_{\mathrm{fid}} \mathcal{L}_{\mathrm{int}}}$$

$$\left(\frac{d\sigma}{dx}\right)_i = \frac{N_i^{\mathrm{sig}}}{c_{\mathrm{fid},i}\, \Delta x_i \mathcal{L}_{\mathrm{int}}},$$

C_{fid} = correction factor for detector efficiency and resolution, estimated using signal MC

Δx_i = bin width for ith bin for variable x

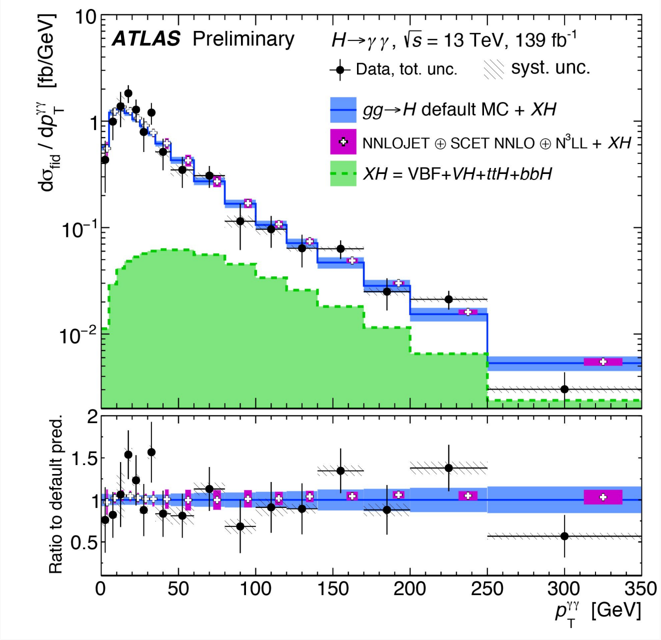
Fiducial Definition

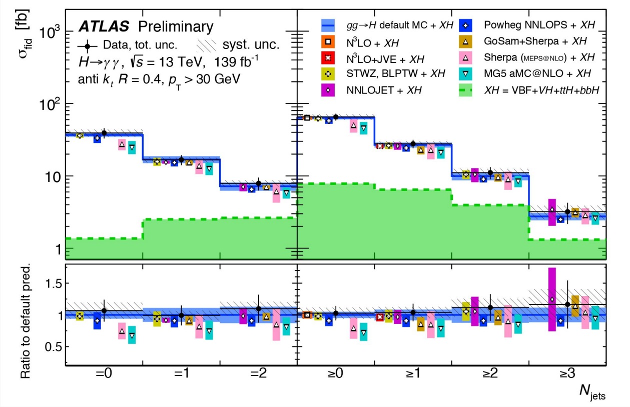
Objects	Fiducial definition
Photons	$\lvert\eta\rvert < 2.37$ (excluding $1.37 < \lvert\eta\rvert < 1.52$), $\sum p_T^i / p_T^\gamma < 0.05$
Jets	anti-k_t, $R = 0.4$, $p_T > 30$ GeV, $\lvert y\rvert < 4.4$
Diphoton	$N_\gamma \geq 2$, 105 GeV $< m_{\gamma\gamma} <$ 160 GeV, $p_T^{\gamma_1}/m_{\gamma\gamma} > 0.35$, $p_T^{\gamma_2}/m_{\gamma\gamma} > 0.25$

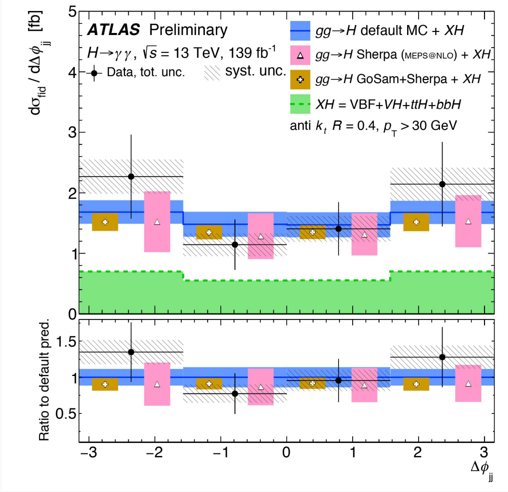
$$\sigma_{\mathrm{fid}} = 65.2 \pm 4.5\,(\mathrm{stat.}) \pm 5.6\,(\mathrm{syst.}) \pm 0.3\,(\mathrm{theo.})\ \mathrm{fb}$$

σ_{SM} = 63.6 ± 3.3 fb

H→γγ : Results

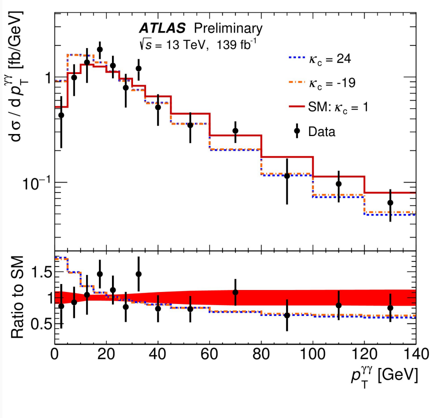






- pT distribution is measured until 350 GeV in order to probe the top-quark mass effects on gluon loop

- Finer binning at low pT in order to probe the charm-quark Yukawa couplings



- The distributions are compared with latest MC predictions

- $\Delta\phi_{jj}$ variable is sensitive to CP properties of Higgs boson.

H→γγ : EFT Interpretation

- Higgs-boson interactions are investigated following an effective field theory (EFT) approach.
  - additional CP-even and CP-odd interactions can change the Higgs kinematics and associated jet multiplicity from SM
- **Two different EFT basis were used:**
  - SILH basis for Higgs effective Lagrangian
  - The Warsaw basis for SMEFT Lagrangian

$$\mathscr{L}_{EFT} = \mathscr{L}_{SM} + \sum_{i,D} \frac{c_i^{(D)}}{\Lambda^{D-4}} \mathscr{O}_i^{(D)}$$

Wilson coefficients

- 1D and 2D limits are obtained by fitting one or two Wilson coefficients at a time and keeping the others at 0.

$$\mathcal{L}_{\rm eff}^{\rm SILH} \supset \bar{c}_g O_g + \bar{c}_\gamma O_\gamma + \bar{c}_{HW} O_{HW} + \bar{c}_{HB} O_{HB} + \tilde{c}_g \widetilde{O}_g + \tilde{c}_\gamma \widetilde{O}_\gamma + \tilde{c}_{HW} \widetilde{O}_{HW} + \tilde{c}_{HB} \widetilde{O}_{HB}$$

$$\mathcal{L}_{\rm eff}^{\rm SMEFT} \supset \overline{C}_{HG} O'_g + \overline{C}_{HW} O'_{HW} + \overline{C}_{HB} O'_{HB} + \overline{C}_{HWB} O'_{HWB} + \widetilde{C}_{HG} \widetilde{O}'_g + \widetilde{C}_{HW} \widetilde{O}'_{HW} + \widetilde{C}_{HB} \widetilde{O}'_{HB} + \widetilde{C}_{HWB} \widetilde{O}'_{HWB}$$

Coefficient	Observed 95% CL limit	Expected 95% CL limit
$\bar{c}_g$	$[-0.26, 0.26] \times 10^{-4}$	$[-0.25, 0.25] \cup [-4.7, -4.3] \times 10^{-4}$
$\tilde{c}_g$	$[-1.3, 1.1] \times 10^{-4}$	$[-1.1, 1.1] \times 10^{-4}$
$\bar{c}_{HW}$	$[-2.5, 2.2] \times 10^{-2}$	$[-3.0, 3.0] \times 10^{-2}$
$\tilde{c}_{HW}$	$[-6.5, 6.3] \times 10^{-2}$	$[-7.0, 7.0] \times 10^{-2}$
$\bar{c}_\gamma$	$[-1.1, 1.1] \times 10^{-4}$	$[-1.0, 1.2] \times 10^{-4}$
$\tilde{c}_\gamma$	$[-2.8, 4.3] \times 10^{-4}$	$[-2.9, 3.8] \times 10^{-4}$

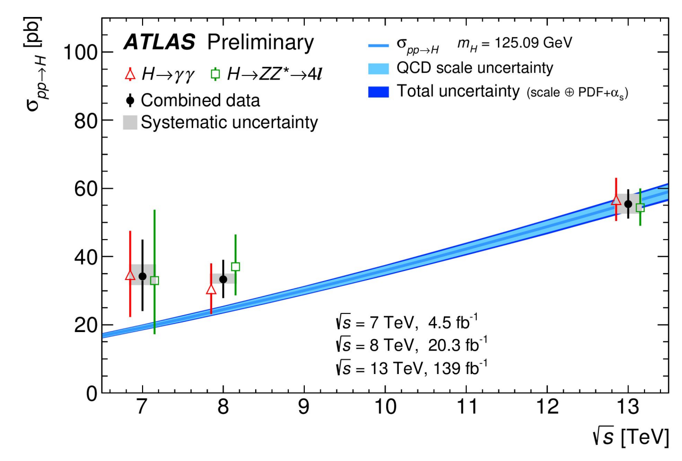
Coefficient	95% CL, interference-only terms	95% CL, interference and quadratic terms
$\overline{C}_{HG}$	$[-4.2, 4.8] \times 10^{-4}$	$[-6.1, 4.7] \times 10^{-4}$
$\widetilde{C}_{HG}$	$[-2.1, 1.6] \times 10^{-2}$	$[-1.5, 1.4] \times 10^{-3}$
$\overline{C}_{HW}$	$[-8, 2, 7.4] \times 10^{-4}$	$[-8.3, 8.3] \times 10^{-4}$
$\widetilde{C}_{HW}$	$[-0.26, 0.33]$	$[-3.7, 3.7] \times 10^{-3}$
$\overline{C}_{HB}$	$[-2.4, 2.3] \times 10^{-4}$	$[-2.4, 2.4] \times 10^{-4}$
$\widetilde{C}_{HB}$	$[-13.0, 14.0]$	$[-1.2, 1.1] \times 10^{-3}$
$\overline{C}_{HWB}$	$[-4.0, 4.4] \times 10^{-4}$	$[-4.2, 4.2] \times 10^{-4}$
$\widetilde{C}_{HWB}$	$[-11.1, 6.5]$	$[-2.0, 2.0] \times 10^{-3}$

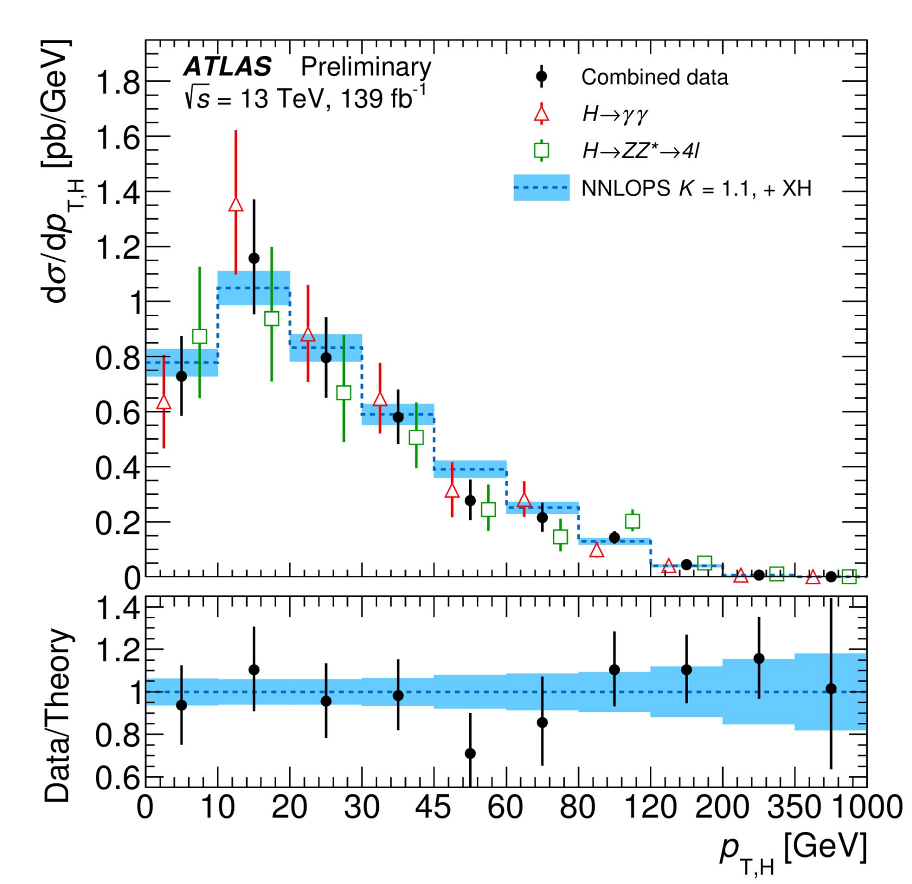
$$H \rightarrow ZZ^* \rightarrow 4l \quad + \quad H \rightarrow \gamma\gamma$$

Results

ATLAS

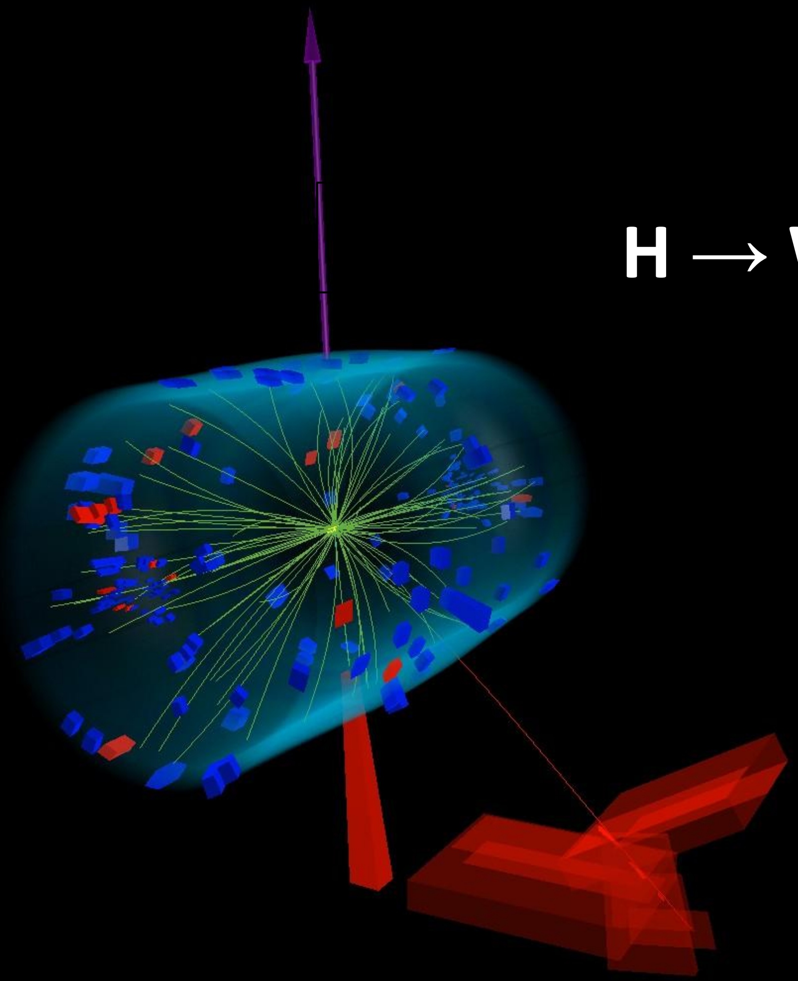
- H→ZZ*→4l and H→$\gamma\gamma$ are combined for full Run-II luminosity.
- Corrections are applied to individual channel yields accounting for luminosity, detector effects, fiducial acceptances, and branching fractions.
- The value of the Higgs boson mass is assumed to be 125.09 GeV
- The gluon fusion (ggF) distributions are obtained using POWHEG NNLOPS





CMS Experiment at LHC, CERN
Data recorded: Sat Jul 21 23:51:56 2018 CEST
Run/Event: 320023 / 82136704
Lumi section: 65
Orbit/Crossing: 16947668 / 2247

H → WW



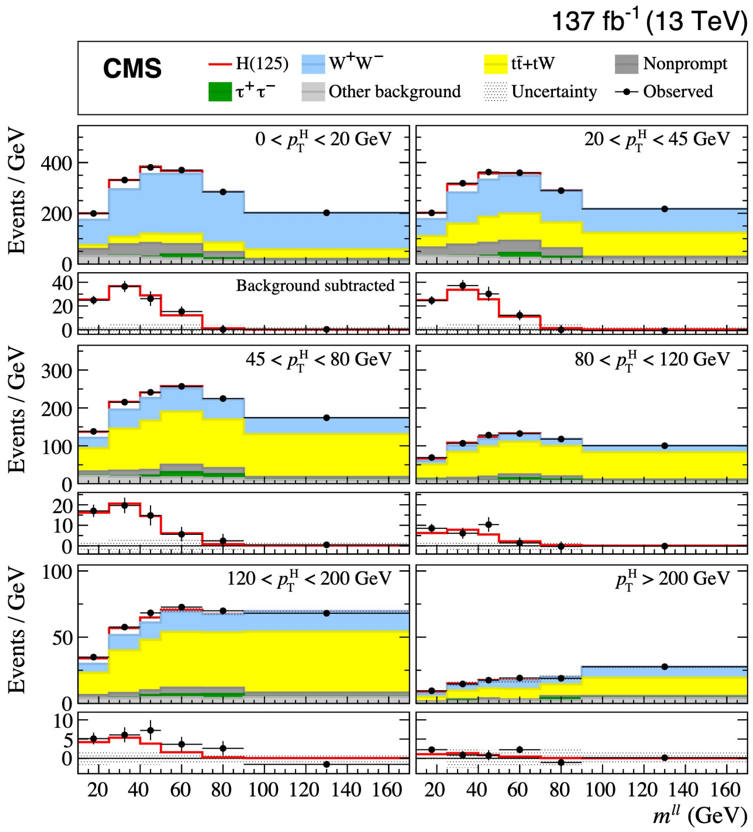
H→WW Overview

CMS

- ➔ With second Highest B.R. for Higgs at 125 GeV, H→WW is an important channel for measurement of Higgs boson properties.
- ➔ Fully leptonic decay with different flavour leptons
- ➔ **Main backgrounds :**
  - ◆ WW → estimated from MC
  - ◆ Top → shape from MC and norm from control region in data
  - ◆ non-prompt leptons → data-driven

Signal Extraction :

- ➔ 2D template fit of m^{ll} : m_T in bins of pT_H and jets
- ➔ Events are further categorized using lepton flavour and pT
- ➔ Unfolding embedded into likelihood function
- ➔ Regularization applied for pT_H measurement → added as a penalty term in likelihood



H→WW : Fiducial and Differential Xsec

- We measured differential & fiducial cross-sections in H→WW with full Run-II data (137 fb^{-1})
- The variables considered for measurement are : transverse momentum of Higgs (**p_T^H**), number of jets (**N_{jets}**)
- Only e-mu final states with ggH production are considered in order to reduce the backgrounds.
- Similar strategy as previously discussed is also followed for this analysis.

p_T^H (GeV)	**N_{jets}**
0 - 20	= 0
20 - 45	= 1
45 - 80	= 2
80 - 120	= 3
120 - 200	>= 4
>= 200	

Binning scheme HIG-19-002

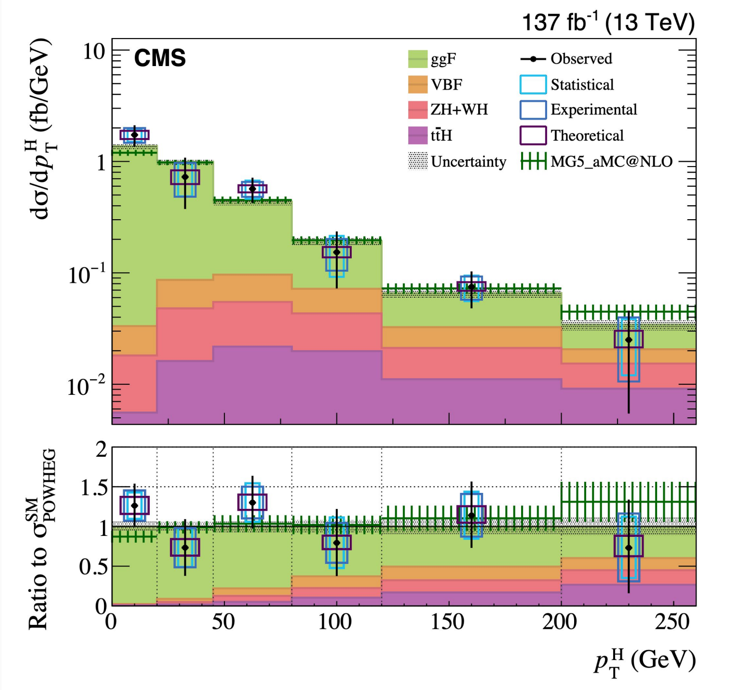
Fiducial region definition

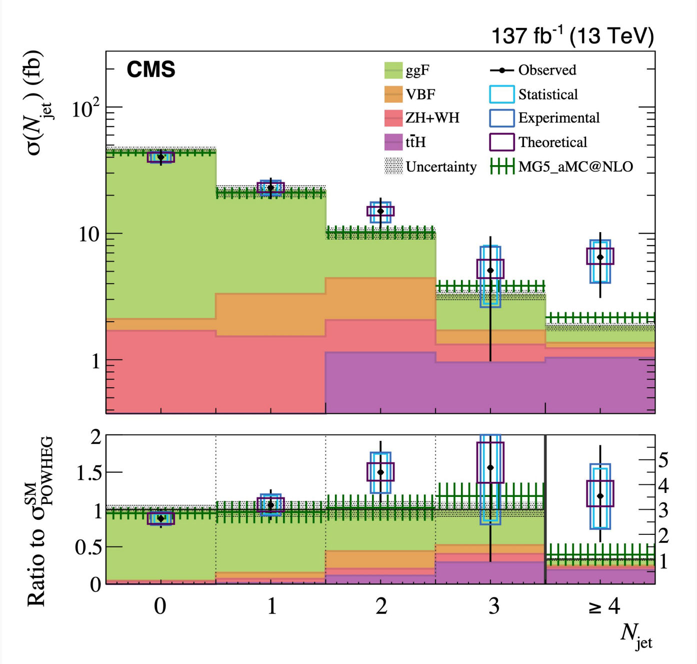
Lepton origin	Direct decay product of H → WW
Lepton flavor and charge	Different flavor, opposite charge
Leading lepton p_T	$p_T^{\ell_1} > 25\,\mathrm{GeV}$
Trailing lepton p_T	$p_T^{\ell_2} > 13\,\mathrm{GeV}$
Pseudorapidity of the leptons	$\|\eta\| < 2.5$
Dilepton mass	$m^{\ell\ell} > 12\,\mathrm{GeV}$
Dilepton transverse momentum	$p_T^{\ell\ell} > 30\,\mathrm{GeV}$
Transverse mass of trailing lepton	$m_T^{\ell_2} > 30\,\mathrm{GeV}$
Higgs transverse mass	$m_T^H > 60\,\mathrm{GeV}$

$$\sigma^{SM} = 82.5 \pm 4.2\,\mathrm{fb}$$

H→WW : Fiducial and Differential Xsec

$$\mu^{\text{fid}} = 1.05 \pm 0.12 \left(\pm 0.05\,(\text{stat}) \pm 0.07\,(\text{exp}) \pm 0.01\,(\text{signal}) \pm 0.07\,(\text{bkg}) \pm 0.03\,(\text{lumi})\right),$$
$$\sigma^{\text{fid}} = 86.5 \pm 9.5\,\text{fb}.$$





- Uncertainties are of the same order as di-photon analyses in #jets and similar in high p_T^H
- More variables can be added for next iteration of analysis
- Binning in low pTH region are determined by p_T^{miss} resolution

Summary & Outlook

- ➔ Higgs Physics is in precision measurement “era” and Run-II data gives great opportunity to probe it.
- ➔ Most of the inclusive measurements are already systematic limited with partial Run-II dataset.
  - ◆ Although differential measurements are still limited by statistics.
- ➔ First Differential results from $H\rightarrow\tau\tau$ channel are presented.
- ➔ Higgs boson is being used as a tool to look for Physics BSM.

- ➔ All analyses are being updated with full Run-II luminosity
- ➔ Preparing for Run-3 → can go differential per production mode.

Stay Tuned !!

Thanks to Dept of Energy, USA for the funding and support

Thank you for your attention !

Back up

H⟶4l : Fiducial Region def.

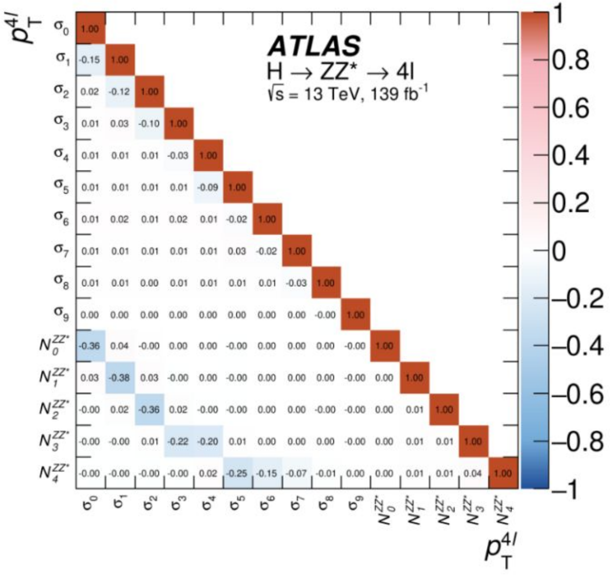
ATLAS

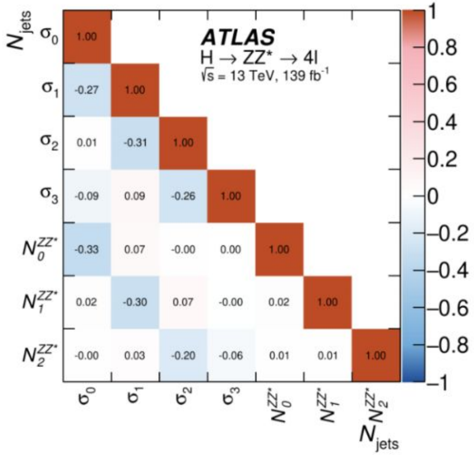
Leptons and jets	
Leptons	$p_T > 5$ GeV, $\|\eta\| < 2.7$
Jets	$p_T > 30$ GeV, $\|y\| < 4.4$
Lepton selection and pairing	
Lepton kinematics	$p_T > 20, 15, 10$ GeV
Leading pair (m_{12})	SFOC lepton pair with smallest $\|m_Z - m_{\ell\ell}\|$
Subleading pair (m_{34})	Remaining SFOC lepton pair with smallest $\|m_Z - m_{\ell\ell}\|$
Event selection (at most one quadruplet per event)	
Mass requirements	50 GeV$< m_{12} <$ 106 GeV and 12 GeV$< m_{34} <$ 115 GeV
Lepton separation	$\Delta R(\ell_i, \ell_j) > 0.1$
Lepton/Jet separation	$\Delta R(\ell_i, \text{jet}) > 0.1$
J/ψ veto	$m(\ell_i, \ell_j) > 5$ GeV for all SFOC lepton pairs
Mass window	105 GeV$< m_{4\ell} <$ 160 GeV
If extra lepton with $p_T > 12$ GeV	Quadruplet with largest matrix element value

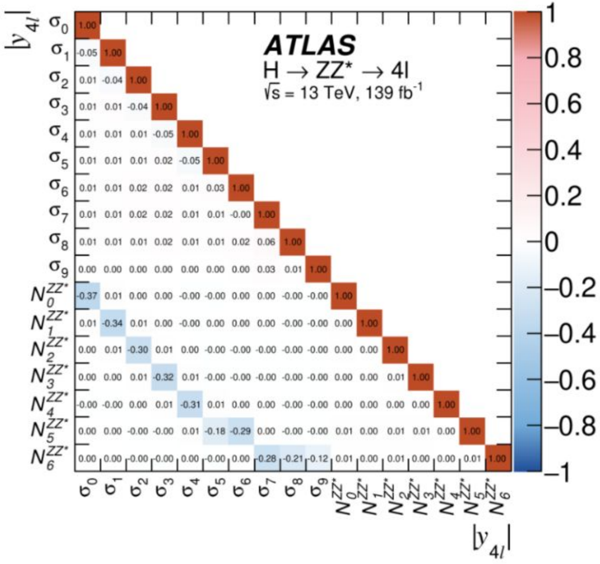
CMS

Lepton kinematics and isolation	
Leading lepton p_T	$p_T > 20$ GeV
Next-to-leading lepton p_T	$p_T > 10$ GeV
Additional electrons (muons) p_T	$p_T > 7(5)$ GeV
Pseudorapidity of electrons (muons)	$\|\eta\| < 2.5\ (2.4)$
Sum of scalar p_T of all stable particles within $\Delta R < 0.3$ from lepton	$< 0.35 p_T$
Event topology	
Existence of at least two same-flavor OS lepton pairs, where leptons satisfy criteria above	
Inv. mass of the Z_1 candidate	$40 < m_{Z_1} < 120$ GeV
Inv. mass of the Z_2 candidate	$12 < m_{Z_2} < 120$ GeV
Distance between selected four leptons	$\Delta R(\ell_i, \ell_j) > 0.02$ for any $i \neq j$
Inv. mass of any opposite sign lepton pair	$m_{\ell^+\ell'^-} > 4$ GeV
Inv. mass of the selected four leptons	$105 < m_{4\ell} < 140$ GeV

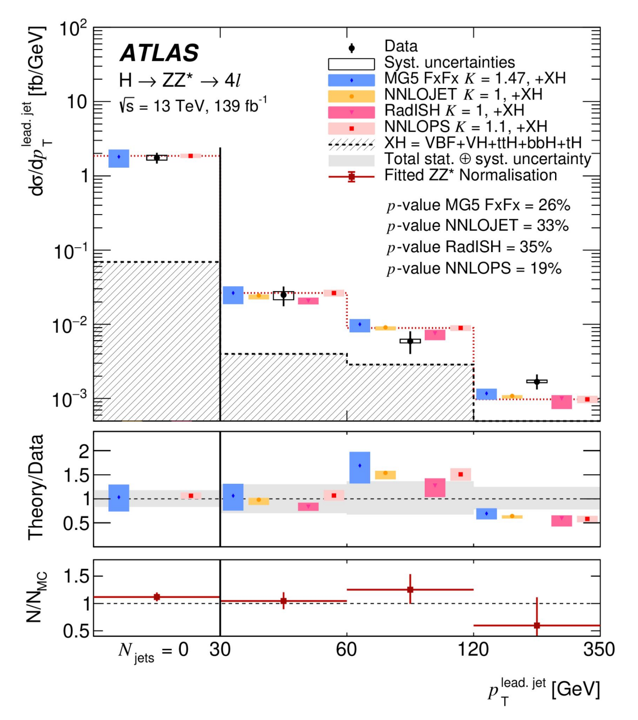
H⟶4l : Correlation Matrices

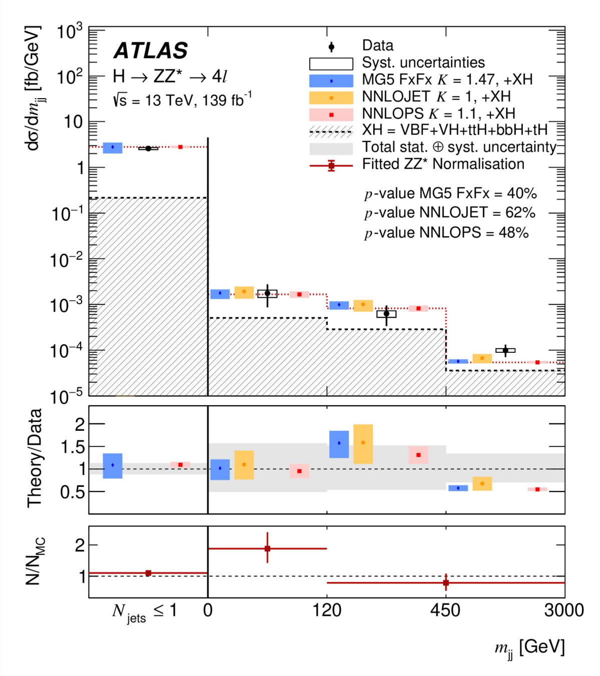


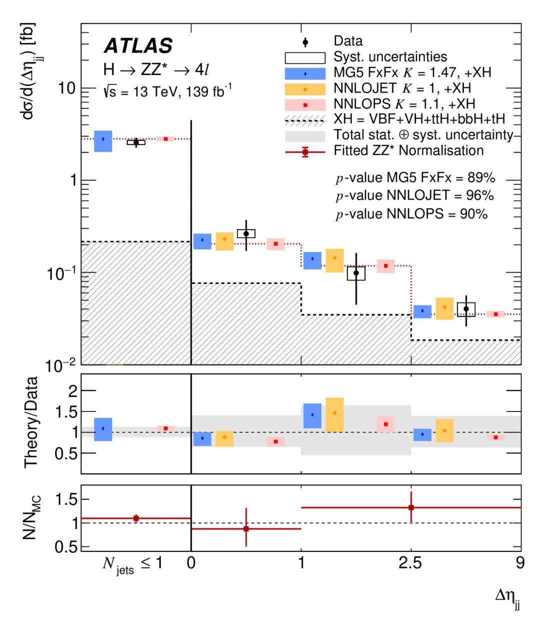




Results H→4l : ATLAS

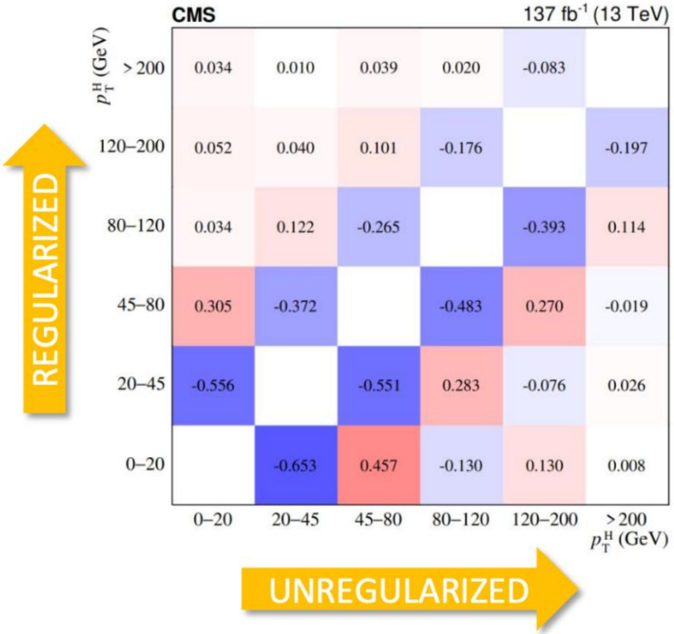


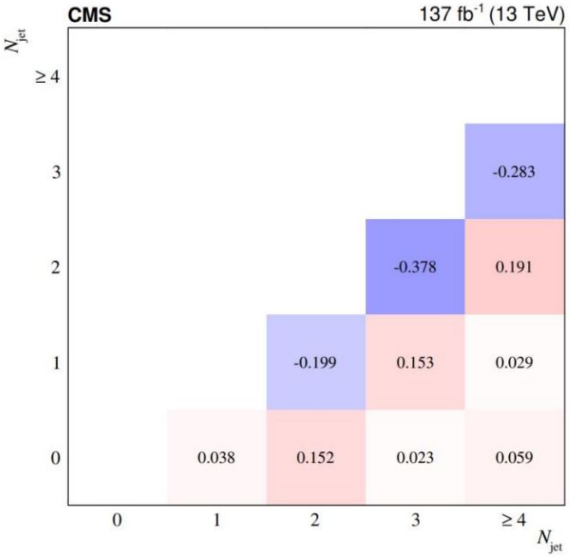




- Not all variables are shown here.

H⟶WW : Correlation Matrices





Correlations among the unfolded signal strength modifiers

H⟶γγ : Fiducial Region def.

ATLAS

Objects	Fiducial definition
Photons	$\lvert\eta\rvert < 2.37$ (excluding $1.37 < \lvert\eta\rvert < 1.52$), $\sum p_T^i / p_T^\gamma < 0.05$
Jets	anti-k_t, $R = 0.4$, $p_T > 30$ GeV, $\lvert y\rvert < 4.4$
Diphoton	$N_\gamma \geq 2$, $105\,\text{GeV} < m_{\gamma\gamma} < 160\,\text{GeV}$, $p_T^{\gamma_1}/m_{\gamma\gamma} > 0.35$, $p_T^{\gamma_2}/m_{\gamma\gamma} > 0.25$

- The sum on p_T^i is extended to all charged particles within $\Delta R = 0.2$ of the photon

CMS

Phase space region	Observable	Bin boundaries								
	$p_T^{\gamma\gamma}$ (GeV)	0	15	30	45	80	120	200	350	∞
	N_{jet}	0	1	2	3	4	∞			
Baseline	$\lvert y^{\gamma\gamma}\rvert$	0	0.15	0.3	0.6	0.9	2.5			
$p_T^{\gamma_1}/m_{\gamma\gamma} > 1/3$	$\lvert\cos(\theta^*)\rvert$	0	0.1	0.25	0.35	0.55	1			
$p_T^{\gamma_2}/m_{\gamma\gamma} > 1/4$	$p_T^{\gamma\gamma}$ (GeV), $N_{\text{jet}} = 0$	0	20	60	∞					
$\lvert\eta^\gamma\rvert < 2.5$	$p_T^{\gamma\gamma}$ (GeV), $N_{\text{jet}} = 1$	0	60	120	∞					
$\text{Iso}_{\text{gen}}^\gamma < 10\,\text{GeV}$	$p_T^{\gamma\gamma}$ (GeV), $N_{\text{jet}} > 1$	0	150	300	∞					
	$N_{\text{jet}}^{\text{b}}$	0	1	2	∞					
	N_{lepton}	0	1	2	∞					
	p_T^{miss} (GeV)	0	100	200	∞					
1-jet	$p_T^{j_1}$ (GeV)	0	45	70	110	200	∞			
Baseline + ≥1 jet	$\lvert y^{j_1}\rvert$	0	0.5	1.2	2	2.5				
$p_T^j > 30\,\text{GeV}$, $\lvert\eta^j\rvert < 2.5$	$\lvert\Delta\phi^{\gamma\gamma,j_1}\rvert$	0	2.6	2.9	3.03	π				
	$\lvert\Delta y^{\gamma\gamma,j_1}\rvert$	0	0.6	1.2	1.9	∞				
	$p_T^{j_2}$ (GeV)	0	45	90	∞					
2-jets	$\lvert y^{j_2}\rvert$	0	1.2	2.5	4.7					
Baseline + ≥2 jets	$\lvert\Delta\phi^{j_1,j_2}\rvert$	0	0.9	1.8	π					
$p_T^j > 30\,\text{GeV}$, $\lvert\eta^j\rvert < 4.7$	$\lvert\Delta\phi^{\gamma\gamma,j_1j_2}\rvert$	0	2.9	3.05	π					
	$\lvert\overline{\eta}_{j_1j_2} - \eta_{\gamma\gamma}\rvert$	0	0.5	1.2	∞					
	$m^{j_1j_2}$ (GeV)	0	100	150	450	1000	∞			
	$\lvert\Delta\eta^{j_1,j_2}\rvert$	0	1.6	4.3	∞					
VBF-enriched	$p_T^{j_2}$ (GeV)	0	45	90	∞					
2-jets + $\lvert\Delta\eta^{j_1,j_2}\rvert > 3.5$, $m^{j_1j_2} > 200\,\text{GeV}$	$\lvert\Delta\phi^{j_1,j_2}\rvert$	0	0.9	1.8	π					
	$\lvert\Delta\phi^{\gamma\gamma,j_1j_2}\rvert$	0	2.9	3.05	π					

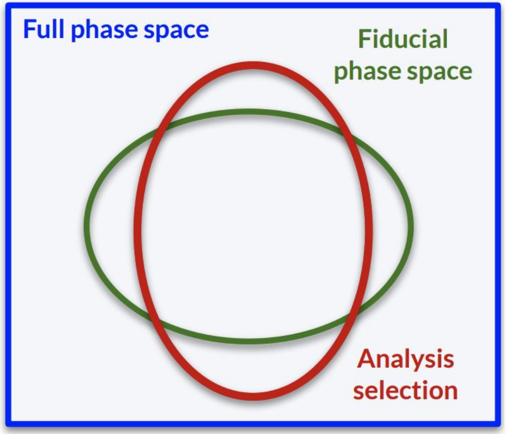
H→ττ : Fiducial region

CMS

- $e\tau_h$ $(\mu\tau_h)$:
  - Electron (muon) $p_T > 25(20)$ GeV and $|\eta| < 2.1$
  - Visible τ_h $p_T > 30$ GeV and $|\eta| < 2.3$
  - $m(e/\mu, \vec{p}_T^{miss}) < 50$ GeV
- $\tau_h\tau_h$:
  - Visible τ_h $p_T > 40$ GeV and $|\eta| < 2.1$
  - At least one jet with $p_T > 30$ GeV
- $e\mu$:
  - Leading (subleading) lepton $p_T > 24(15)$ GeV
  - Lepton $|\eta| < 2.4$
  - $m_T(e\mu, \vec{p}_T^{miss}) < 60$ GeV

Momenta of photons radiated within $\Delta R = 0.1$ of a lepton are added to the lepton's momentum

Differential vs STXS



- More information can be extracted from fiducial differential cross section measurements.
- **Differential:** measure cross section in bins of some observables (pT H, #jets, …)
- **Fiducial:** extrapolate the measurement to a restricted phase space that matches as closely as possible the experimental selections.

- Reduce model dependence avoiding the extrapolation to the full phase space
- Long measurement lifetime and easy comparison with different theories
- Limited to 1-2 variables at the same time
- Hard to combine different channels without extrapolating to the full phase space
- Non trivial to include complex variables (e.g. DNNs) in the fiducial phase space

- **Simplified Template Cross Sections → complementary to differential measurements**
  - Measure cross sections in pre-defined template bins per production mode.
- No fiducial phase space (only $|y_H| < 2.5$)
- possible to combine different decay channels
- Larger extrapolation uncertainties