LHCHWG1: summary & outlooks

Alessandro Calandri[1], Alexander Karlberg[2], Bernhard Mistlberger[3], Hannah Arnold[4], Robin Hayes[5], Dermot Moran[6]

[1]Università & INFN Firenze, [2]University of Oxford, [3]SLAC, [4]Stony Brook University, [5]Nikhef, [6]CIEMAT

The 22nd workshop of the LHC Higgs working group - December 5, 2025

General introduction

- Activities developed in six sub-groups based on Higgs boson production modes
  - ggF, VBF, VH, ttH/tH, BR and off-shell (activities on bbH discussed in the context of WG3)
  - rich set of contributions at LHCHWG workshops in **WG1 plenary and parallel sessions**!
- WG1 twiki (link) and WG1 category including meetings/workshops (https://indico.cern.ch/category/5847/)
- **Several coordination roles changed in 2025 or are in the process of - thanks to all outgoing conveners for your activities and welcome to new conveners!**
  - **WG1**: R. Hayes (incoming ATLAS), H. Arnold (outgoing ATLAS)
  - **WG1**: D. Moran (incoming CMS), A. Calandri (outgoing CMS)
  - **ggF**: L. Urda (incoming CMS), A. Cappati (outgoing CMS)
  - **ggF**: Y. Huang (incoming ATLAS), R. Hayes (outgoing ATLAS)
  - **VBF**: C. Preuss (incoming TH), S. Ferrario Ravaso (outgoing, TH) + **call for nomination for ATLAS VBF convener taking over from Jiayi Chen, please contact Hannah if interested**
  - **ttH**: S. Wuchterl (incoming CMS), D. Valsecchi (outgoing CMS)
  - **ttH**: M. Kraus (incoming TH), M. Worek (outgoing TH)
  - **ttH**: M. Wiesemann (incoming TH), M. Zaro (outgoing TH)
  - **Off-shell**: D. Goncalves (incoming TH), E. Vryonidou (outgoing TH)
  - **VH**: M. Vitti (incoming TH), G. Ferrera (outgoing, TH)
  - **VH**: S. Zanoli (incoming TH), M. Lin (outgoing, TH)

2025 WG1 focus on Report 5

SciPost

LHC Higgs Working Group Reports

a series contained in SciPost Physics Community Reports

Collection Report 5

The LHC Higgs Working Group (LHCHWG) provides recommendations on predictions, modelling, and methods for the study of Higgs physics with data from the current and future LHC runs. The HL-LHC aims to collect about 1000 fb-1 of proton-proton collision data during Run 4 (2030–2033). What can we achieve with this dataset? What recommendations are needed for analyses? This information will be collected in this collection "Report 5", included in the series "LHC Higgs Working Group Reports" of SciPost Physics Community Reports.

Submissions to this Collection

Awaiting resubmission

- 2510.17413v1, The inclusive Higgs boson cros by Goutam Das, Sven-Olaf Moch (current version)

In refereeing

- 2508.09905v2, $gg \to ZH$: updated predicti by Benjamin Campillo Aveleira, Lo (current version)
- 2511.07905v1, Parametrisation and dictionary by Daniele Barducci, Matthew Fors (current version)
- 2511.02488v1, State-of-the-art electroweak H by Jens Braun, Pia Bredt, Gudrun (current version)
- 2510.24658v1, Higgs-Boson Decays: Updates by Emanuele Bagnaschi, Lisa Bierm (current version)
- 2510.18815v1, Modelling $b\bar{b}H$ producti by Christian Biello, Alessandro G (current version)

Refereeing in preparation

- 2508.00466v2, Rare few-body decays of the St by David d'Enterria, Van Dung Le (current version)

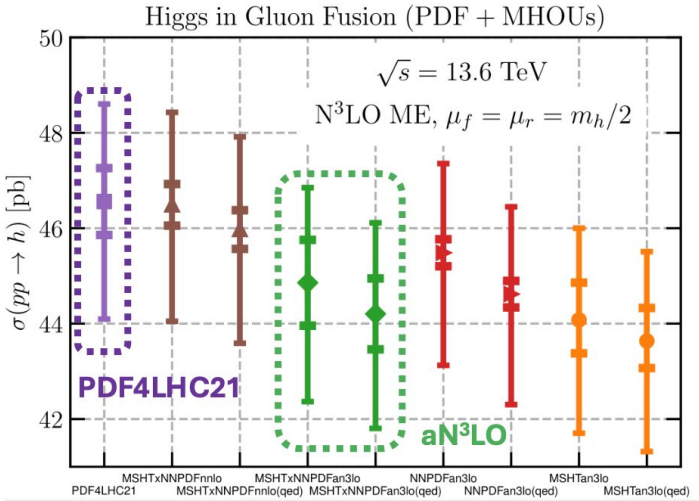
Publications in this Collection

- SciPost Phys. Comm. Rep. 14 (2025), Threshold improved ZH produ by Goutam Das, Chinmoy Dey, Medur, 2025-12-01
- SciPost Phys. Comm. Rep. 13 (2025), Higgs production via vector-bo by Gaetano Barone, Jiayi Chen, St, 2025-11-05
- SciPost Phys. Comm. Rep. 12 (2025), Theoretical modeling of QCD ra by Rafael Coelho Lopes de Sá, Mar, 2025-09-04
- SciPost Phys. Comm. Rep. 10 (2025), State-of-the-art cross section by Roger Balsach, Alessandro Brog, 2025-08-13

Higgs cross-section update for Report 5

A. Karlberg

- **TH uncertainties dominate Higgs signal strength extraction,** especially on the horizon of HL-LHC
- Updated xsec result numbers including PDF4LHC21 + no QED aN3LO PDF
- aN3LO PDF result in large corrections
- Sizeable differences MSHT vs NNPDF
  - PDF global fits, WG1 will follow-up



Uncertainties dominated by:

- ggF: PDF+α_s (1.6%+2.1%), PDF-TH (2.3%), and scale uncertainty (0.32-3.3%).
- VBF: PDF (2.1%) uncertainty.
- WH: PDF (1.6%) uncertainty.
- ZH: gg-induced scale uncertainty (4%). Recent results not included here (~factor 2 reduction). See also talk by S. Chatterjee.
- ttH: PDF+α_s (2.2%+1.6%).
- tH: scale uncertainty (6-15%).

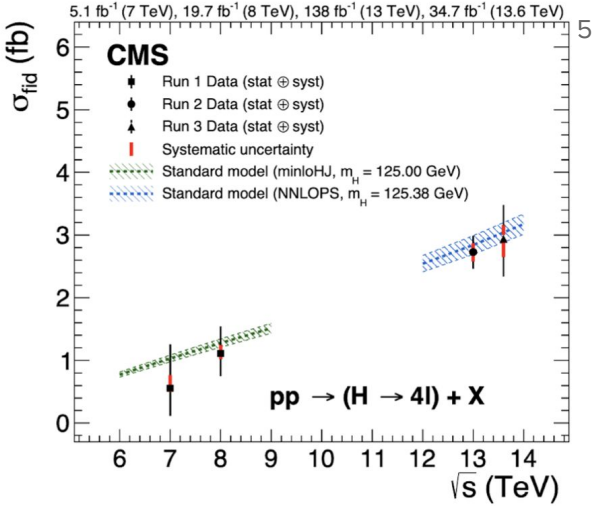
$\sqrt{s}$ [TeV]	Production cross section (in pb) for $m_H = 125$ GeV					
	ggF	VBF	WH	ZH	$t\bar{t}H$	tH
13.6	$52.1^{+6.9\%}_{-9.5\%}$	$4.11^{+3.3\%}_{-3.3\%}$	$1.47^{+2.4\%}_{-2.6\%}$	$0.954^{+5.6\%}_{-5.0\%}$	$0.592^{+4.3\%}_{-5.0\%}$	$0.085^{+8.5\%}_{-18\%}$
14	$54.5^{+7.0\%}_{-9.5\%}$	$4.32^{+3.3\%}_{-3.3\%}$	$1.52^{+2.3\%}_{-2.5\%}$	$0.995^{+5.6\%}_{-4.9\%}$	$0.639^{+4.3\%}_{-5.0\%}$	$0.092^{+8.0}_{-17\%}$

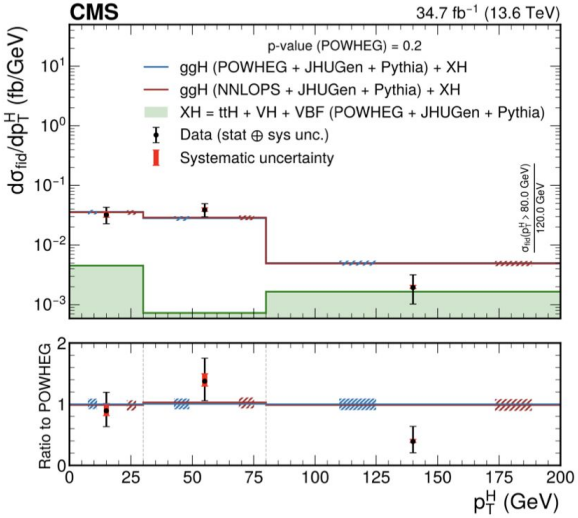
ggF: experimental overview

- **ATLAS**
  - differential NNLO accuracy via reweighting of Higgs rapidity from MINLO to HNNLO
- **CMS:**
  - updated ggF modeling to NNLOPS for Run 2/Run3 analysis
  - ggF modeling exhibits differences between Powheg and NNLOPS differentially in Higgs pt (especially for high pt)

S. Jones

- **Wishlist and way forward**
  - consistent ggF treatment across analyses, e.g. MiNNLOPS
  - check on high Higgs pt modeling and associated uncertainties
  - investigate gg+2j modeling especially in VBF phase-space (see talk by C. Preuss during WG1 parallel)





ggF: TH highlights & ggF contribution to R5

- **ME for H+j + N3LO (heavy-top-limit):** very important for Higgs boosted analyses
- **H+j with NLO EWK correction included:** xsec enhancement of 4-5%, pt-dependent effect

Uncertainties related to finite masses greatly reduced, QED evolution effects are now included in central recommendation

$$\delta(\text{theory}) = \delta(\text{scale}) + \delta(\text{EWK}) + \delta(t,b,c)$$
$$\delta(t,b,c) = \delta^{\text{scheme}}(t) + \delta^{\text{MHOU}}(t) + \delta^{\text{scheme}}(t\times b) + \delta^{\text{MHOU}}(t\times b) + \delta^{\text{MHOU}}(b,c,t\times c, b\times c)$$

±0.01 % ±0.17 % ±0.09 % ±0.17 % ±0.06 %

$$\delta(\text{PDF}+\alpha_s) = \sqrt{\delta(\text{PDF})^2 + \delta(\alpha_s)^2}$$

$\sqrt{s} = 13.6$ TeV						NNLO PDF				aN^{3}LO PDF	
M_H [GeV]	σ [pb]	δ(theory)	δ(scale)	δ(EWK)	δ(t, b, c)	δ(PDF + α_s)	δ(PDF)	$\delta(\alpha_s)$	δ(PDF–TH)	Δ [pb]	δ(PDF + α_s)
120.00	55.54	$^{+1.65}_{-4.66}$%	$^{+0.31}_{-3.32}$%	±1.00%	±0.34%	$^{+2.68}_{-2.27}$%	$^{+1.65}_{-1.65}$%	$^{+2.12}_{-1.57}$%	±2.42%	−2.56	$^{+1.73}_{-1.73}$%
122.00	53.97	$^{+1.66}_{-4.65}$%	$^{+0.32}_{-3.31}$%	±1.00%	±0.34%	$^{+2.68}_{-2.27}$%	$^{+1.65}_{-1.65}$%	$^{+2.11}_{-1.56}$%	±2.40%	−2.49	$^{+1.73}_{-1.73}$%
124.00	52.46	$^{+1.65}_{-4.65}$%	$^{+0.31}_{-3.31}$%	±1.00%	±0.34%	$^{+2.68}_{-2.26}$%	$^{+1.64}_{-1.64}$%	$^{+2.11}_{-1.56}$%	±2.37%	−2.43	$^{+1.74}_{-1.74}$%
124.60	52.02	$^{+1.65}_{-4.65}$%	$^{+0.31}_{-3.31}$%	±1.00%	±0.34%	$^{+2.67}_{-2.26}$%	$^{+1.64}_{-1.64}$%	$^{+2.11}_{-1.56}$%	±2.36%	−2.41	$^{+1.74}_{-1.74}$%
124.80	51.87	$^{+1.65}_{-4.65}$%	$^{+0.31}_{-3.31}$%	±1.00%	±0.34%	$^{+2.67}_{-2.26}$%	$^{+1.64}_{-1.64}$%	$^{+2.11}_{-1.55}$%	±2.36%	−2.41	$^{+1.74}_{-1.74}$%
125.00	51.72	$^{+1.65}_{-4.65}$%	$^{+0.31}_{-3.31}$%	±1.00%	±0.34%	$^{+2.67}_{-2.26}$%	$^{+1.64}_{-1.64}$%	$^{+2.11}_{-1.55}$%	±2.36%	−2.40	$^{+1.74}_{-1.74}$%
125.09	51.66	$^{+1.65}_{-4.65}$%	$^{+0.31}_{-3.31}$%	±1.00%	±0.34%	$^{+2.67}_{-2.26}$%	$^{+1.64}_{-1.64}$%	$^{+2.11}_{-1.55}$%	±2.36%	−2.40	$^{+1.74}_{-1.74}$%
125.20	51.58	$^{+1.65}_{-4.65}$%	$^{+0.31}_{-3.31}$%	±1.00%	±0.34%	$^{+2.67}_{-2.26}$%	$^{+1.64}_{-1.64}$%	$^{+2.11}_{-1.55}$%	±2.35%	−2.39	$^{+1.74}_{-1.74}$%
125.30	51.51	$^{+1.65}_{-4.64}$%	$^{+0.31}_{-3.30}$%	±1.00%	±0.34%	$^{+2.67}_{-2.26}$%	$^{+1.64}_{-1.64}$%	$^{+2.11}_{-1.55}$%	±2.35%	−2.39	$^{+1.74}_{-1.74}$%
125.38	51.45	$^{+1.65}_{-4.64}$%	$^{+0.31}_{-3.30}$%	±1.00%	±0.34%	$^{+2.67}_{-2.26}$%	$^{+1.64}_{-1.64}$%	$^{+2.11}_{-1.55}$%	±2.35%	−2.39	$^{+1.74}_{-1.74}$%
125.60	51.29	$^{+1.65}_{-4.64}$%	$^{+0.31}_{-3.30}$%	±1.00%	±0.34%	$^{+2.67}_{-2.26}$%	$^{+1.64}_{-1.64}$%	$^{+2.11}_{-1.55}$%	±2.35%	−2.38	$^{+1.74}_{-1.74}$%
126.00	51.01	$^{+1.65}_{-4.64}$%	$^{+0.31}_{-3.30}$%	±1.00%	±0.34%	$^{+2.67}_{-2.26}$%	$^{+1.64}_{-1.64}$%	$^{+2.11}_{-1.55}$%	±2.34%	−2.37	$^{+1.74}_{-1.74}$%
128.00	49.62	$^{+1.64}_{-4.63}$%	$^{+0.30}_{-3.29}$%	±1.00%	±0.34%	$^{+2.67}_{-2.26}$%	$^{+1.64}_{-1.64}$%	$^{+2.10}_{-1.55}$%	±2.32%	−2.31	$^{+1.74}_{-1.74}$%
130.00	48.28	$^{+1.64}_{-4.62}$%	$^{+0.30}_{-3.28}$%	±1.00%	±0.34%	$^{+2.67}_{-2.25}$%	$^{+1.64}_{-1.64}$%	$^{+2.10}_{-1.54}$%	±2.30%	−2.25	$^{+1.74}_{-1.74}$%

NNLO PDF: PDF4LHC21
aN^{3}LO PDF: MSHT20xNNPDF40

Estimate δ(PDF – TH) using NLO vs NNLO PDFs

Use NNLO vs aN3LO? (will be ~1.5x larger)

ggF: going beyond R5, EXP inputs/wishlist

Off-shell / high-mass regime (HZZ)

- Missing modelling of ggF + 2 jets in the off-shell region.
  Need samples that include full gg→H→ZZ + interference with gg→ZZ.
- K-factors outdated:
  YR4 provides gg→ZZ and gg→H K-factors only for 13.0 TeV (need 13.6 TeV)
  Clear guidance on how these should propagate into Run 3 systematic uncertainties.

Generator upgrades / MiNNLO (HWW, general)

- **ggF MiNNLOPS samples:**
  Most channels are already using them
  General recommendation emerging: CMS Higgs analyses should transition to MiNNLO.

Current status in channels

- **Hγγ**:
  Recently switched to POWHEG MiNLOPS → modelling considered stable and satisfactory.
- **Differential measurements (Hγγ, HZZ)**:
  Some analyses still rely on older generator setups

Generator coordination

- No major recent CMS-wide change in ggF modelling strategy.
- Conveners recommend contacting:
- Possible overlap of **ggF + 2 jets** with **VBF background** remains a relevant issue.

Boosted Higgs

- NLO EW corrections for ggF at high pTH, alter pTH shape?
- N3LO HTL H+j + matching to resummation
- Need to do better than NNLO HTL+NLO QCD for high pTH regime?
- Need extended cross-section recommendations, already looking at pTH > 1 TeV!

More Fiducial Recommendations

Theory appetite for producing fiducial cross section recommendations?

Recommendations for including signal/background interference in prod/decay?

VBF: experimental overview

- **Several inclusive VBF measurements in main H final states** - uncertainty dominated by PS both for VBF and ggF in VBF phase-space - one of the main topics of the VBF group (VBF2022, VBF2024)
- **Different treatment on PS uncertainty in ATLAS/CMS**
  - **ATLAS:** UE/PS using scale variations + differences across NLOPS (Powheg Box vs MG5_amcatNLO) + treatment of ggF background in VBF phase-space
  - **CMS:** PS variations of internal Pythia weights, no 2-point comparison until recently + studies to address definition of nominal Pythia showering (dipole recoil to restore color coherence)

ATLAS Run 2 Hττ

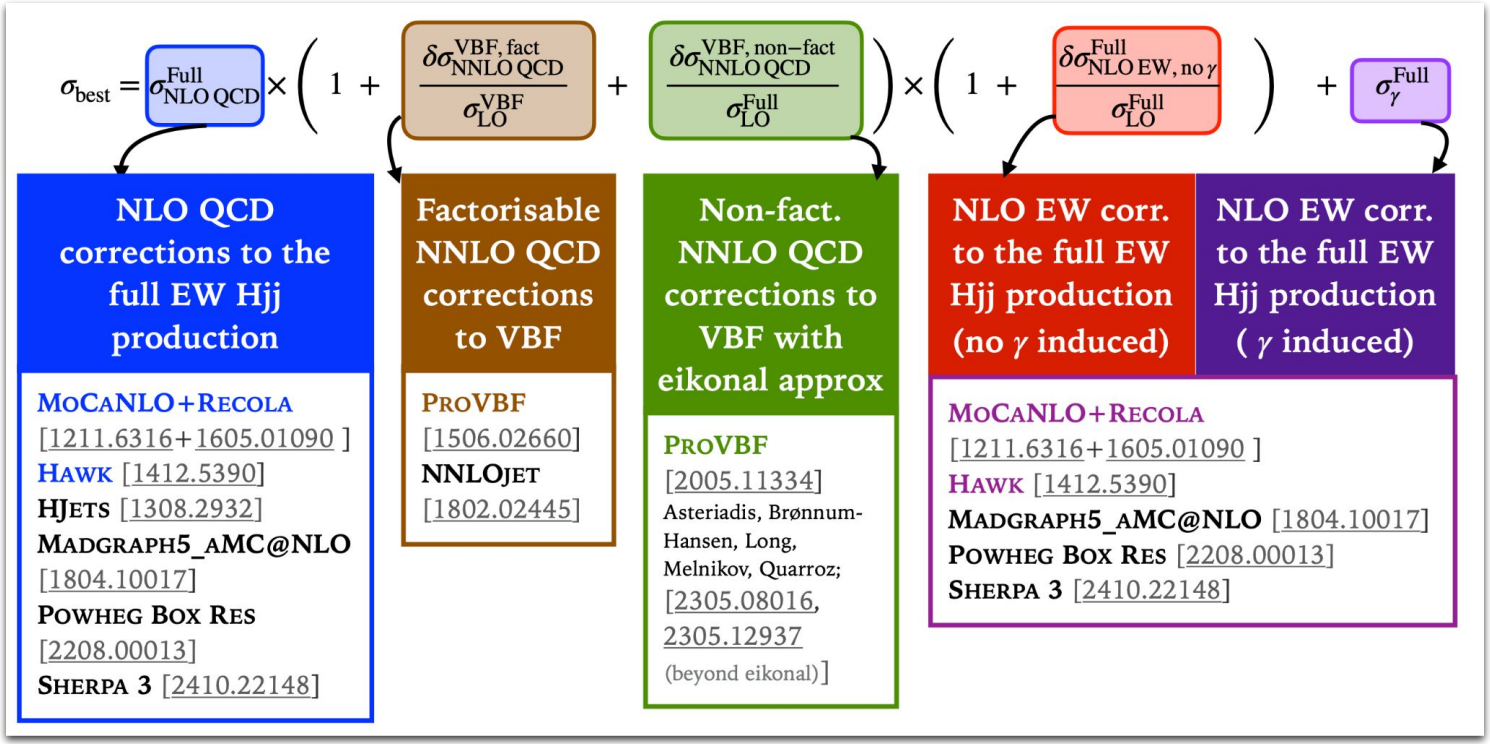
Production mode	ggF	ttH	VBF	VH
Best-fit value	0.94	0.77	0.93	0.91
Total uncertainty	±0.30	±0.97	±0.16	±0.62
Statistical uncertainty	±0.15	±0.82	±0.12	±0.52
Total systematic uncertainty	±0.26	±0.51	±0.11	±0.34
Samples size	±0.09	±0.32	±0.03	±0.25
Theoretical uncertainty in signal	±0.19	±0.14	±0.10	±0.13
Jet and $E_{\mathrm{T}}^{\mathrm{miss}}$	±0.12	±0.14	±0.03	±0.11
Hadronic τ-lepton decays	±0.05	±0.09	±0.01	±0.04
Misidentified τ-lepton background	±0.05	±0.05	±0.02	±0.11
Luminosity	±0.01	±0.01	±0.01	±0.02
Theoretical uncertainty in top-quark processes	±0.01	±0.30	–	±0.02
Theoretical uncertainty in Z + jets processes	±0.03	±0.07	–	±0.02
Flavour tagging	±0.02	±0.05	±0.01	±0.01
Electrons and muons	±0.02	±0.01	±0.01	±0.02

CMS Run 2 HWW

Uncertainty source	$\Delta\mu/\mu$	$\Delta\mu_{\mathrm{ggH}}/\mu_{\mathrm{ggH}}$	$\Delta\mu_{\mathrm{VBF}}/\mu_{\mathrm{VBF}}$	$\Delta\mu_{\mathrm{WH}}/\mu_{\mathrm{WH}}$	$\Delta\mu_{\mathrm{ZH}}/\mu_{\mathrm{ZH}}$
Theory (signal)	4%	5%	13%	2%	<1%
Theory (background)	3%	3%	2%	4%	5%
Lepton misidentification	2%	2%	9%	15%	4%
Integrated luminosity	2%	2%	2%	2%	3%
b tagging	2%	2%	3%	<1%	2%
Lepton efficiency	3%	4%	2%	1%	4%
Jet energy scale	1%	<1%	2%	<1%	3%
Jet energy resolution	<1%	1%	<1%	<1%	3%
$p_{\mathrm{T}}^{\mathrm{miss}}$ scale	<1%	1%	<1%	2%	2%
PDF	1%	2%	<1%	<1%	2%
Parton shower	<1%	2%	<1%	1%	1%
Backg. norm.	3%	4%	6%	4%	6%
Stat. uncertainty	5%	6%	28%	21%	31%
Syst. uncertainty	9%	10%	23%	19%	11%
Total uncertainty	10%	11%	36%	29%	33%

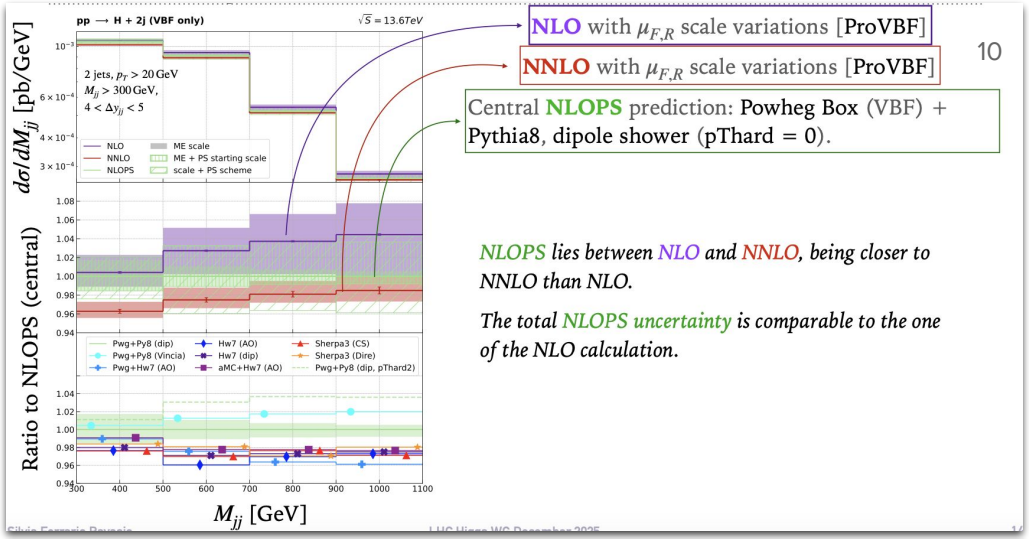
VBF: fixed-order predictions for fiducial xsec

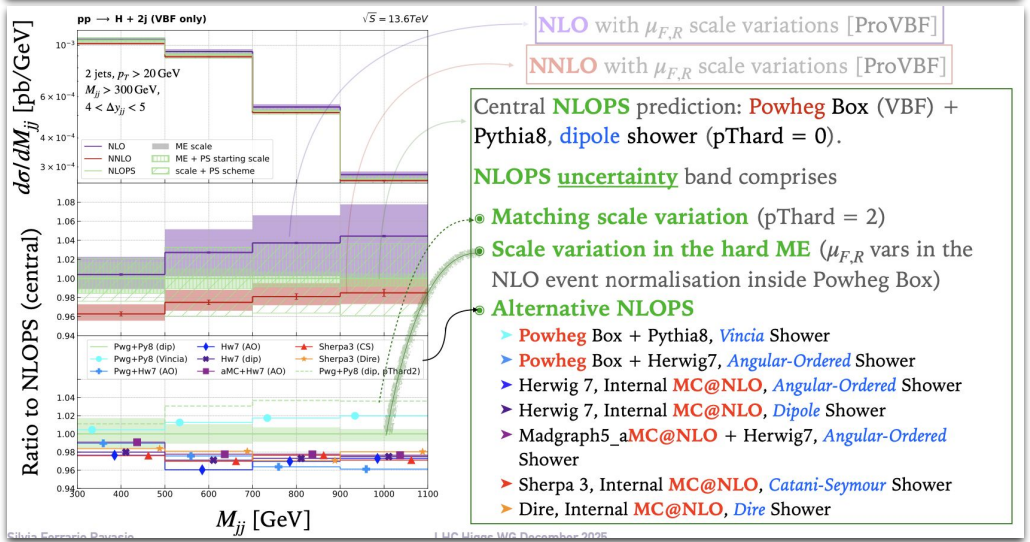
- **Dedicated contribution to Report 5 - Higgs production via vector boson fusion at the LHC**
  - recently published on SciPost [SciPost Phys.Comm. Rep. 13 (2025)]
  - provides recommendations for PS central values and uncertainties for EXP community
- **Studies on fixed-order predictions for inclusive/fiducial cross-section**



VBF: PS modeling

- **Comparison of different PS schemes for central values and uncertainty determination**
  - central NLO predictions using Powheg Box + P8 dipole shower
  - NLO PS uncertainty band defined as envelope of several effects
    - matching internal scale variations
    - scale variations due to hard ME component (factorisation/renormalisation scale variations)
    - comparison of alternative NLOPS showers w/ different schemes (angular-ordered, dipole, ...)





VBF: PS recommendations

- **Need to follow-up/implement common set of recommendation for Run 3 VBF Higgs analyses**
  - paves the way for consistent treatment of PS + uncertainty determination across experiment

Based on these observations, we propose the following recommendation for a more robust estimation of NLOPS uncertainty, which comprises both the matching and the shower variations:

1. Generate (at least) three predictions:
   - one with POWHEG-BOX and any PYTHIA 8 shower;
   - one with any HERWIG 7 shower; [Better with internal matching]
   - one with any SHERPA 3 shower.

   Make sure that at least one of these prediction is based on POWHEG matching, and one on MC@NLO matching.[13] Then, construct an envelope[14] out of these predictions.

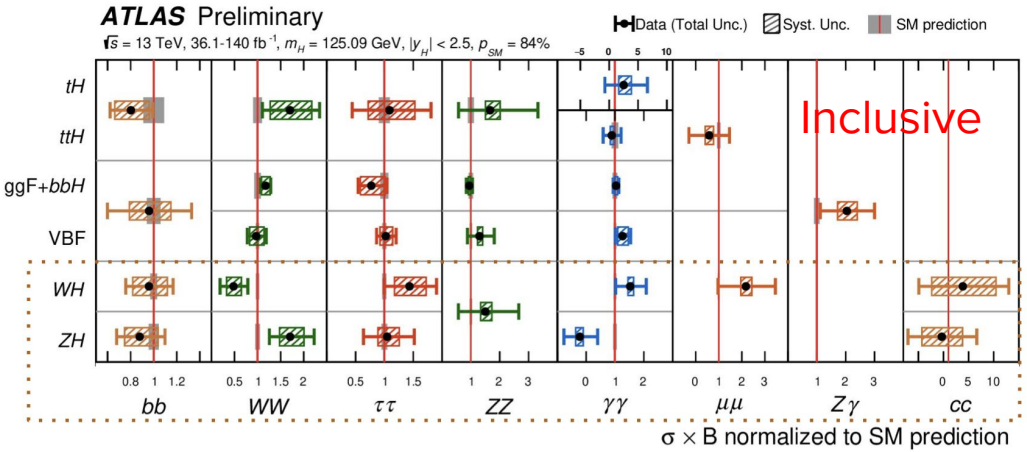
2. For one of the curves computed in step 1:
   - compute a shower starting scale variation band (or a `pThard` variation in the context of POWHEG-BOX +PYTHIA 8 matching);
   - compute the renormalisation and factorisation scale variation band, possibly including also scale variations in the shower.

   Sum these bands in quadrature and combine this uncertainty in quadrature with the first envelope uncertainty.

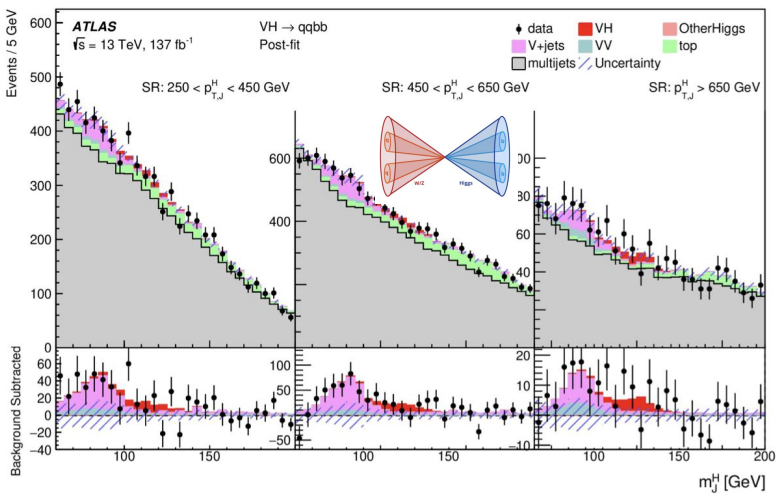
VH: experimental overview

S. Chatterejee

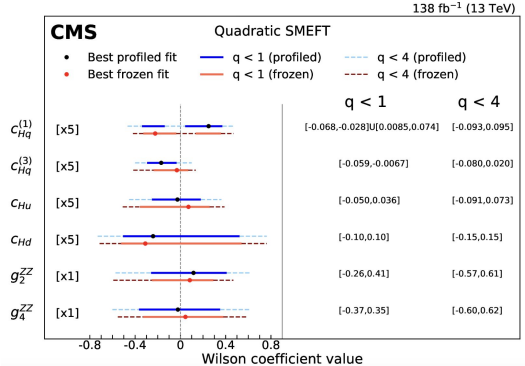
- **Several decay modes (Hbb dominates sensitivity) with various interpretations**
  - full Run 2 STXS measurements in bins of VPT + jet multiplicity
  - SMEFT/EFT effects or AC interpretations
  - new avenues: charge asymmetry, V(qq)H(bb)



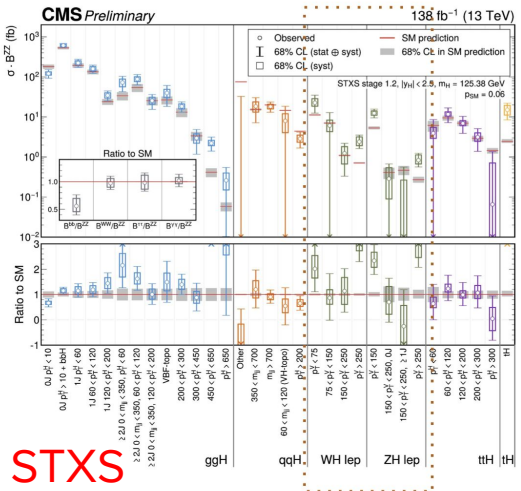
V(qq)H(bb)



EFT



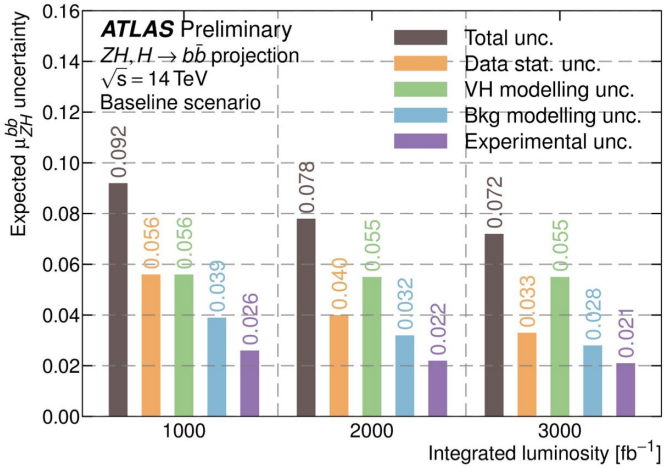
Stat ≈ exp sys ≈ TH sys

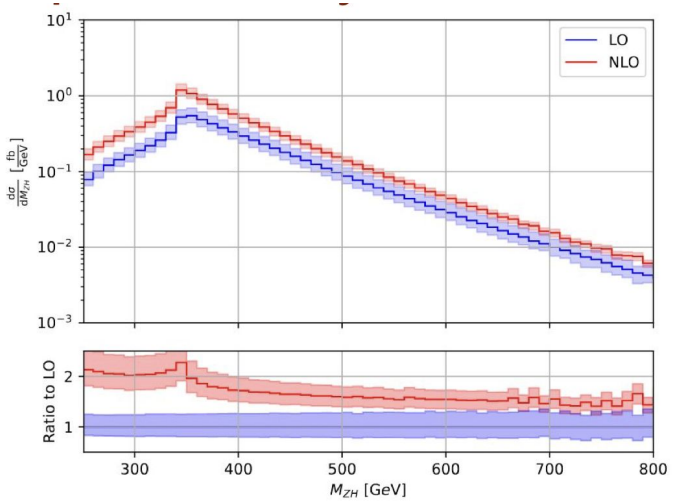


STXS

VH: updates on ggZH NLO predictions

- **Large (20-25%) scale uncertainty for ggZH @ LO- signal modeling dominates uncertainty budget at HL-LHC (assuming 50% reduction of modeling uncertainties)**
  - large NLO/LO k-factor with significant m(ZH) dependence
- **ggZH@NLO contribution to Report 5**
  - differential NLO predictions
  - unified predictions across methods
  - analytical calculation with full top mass dependence
  - introduction of top mass scheme dependence
  - reduction (25%-15%) of dominant scale uncertainties
- **Future: ggZH@NLO**
  - implementation available in Powheg within next few months + SMEFT effects
- **Additional activities on soft-gluon resummation for qq/gg ZH**
  - published in SciPost as contribution to R5
  - minimization of residual scale uncertainties for qq/gg

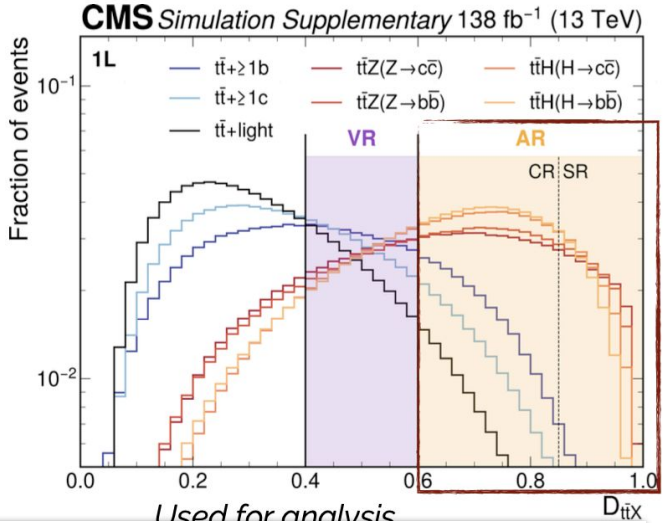




ttH/tH: overview & lessons learnt

S. Wuchterl

- **ATLAS and CMS performed <u>two versions</u> of Run 2 analyses targeting ttHbb/ttHc - several lessons learnt**
  - broken down tt+jets modeling (shape/rate nuisances) to improve fit flexibility and redefined tt+HF labeling
  - reduce background/kinematic extrapolation - only using tt+jets with high signal similarity by exploring DNN output nodes
    - ttH vs ttbb/ttcc correlation reduced to 10% from 50%



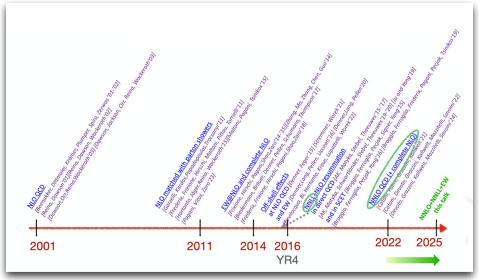
	ATLAS	CMS
V1	$t\bar{t}+\geq 1b$ (free floating) $t\bar{t}+\geq 1c$ (± 100%) $t\bar{t}+$ light (± 6%)	$t\bar{t}+\geq 1b$ free $t\bar{t}+\geq 1c$ free $t\bar{t}+$ light (± 6%) $t\bar{t}+j_{bb}, t\bar{t}+j_b$ relative ± 100% for gluon splitting
V2	$t\bar{t}+\geq 2b, t\bar{t}+j_{bb}, t\bar{t}+j_b$ free $t\bar{t}+\geq 1c$ free $t\bar{t}+$ light free	$t\bar{t}+\geq 2b, t\bar{t}+b$ free $t\bar{t}+\geq 2c, t\bar{t}+c$ free $t\bar{t}+$ light free

	ATLAS	CMS
V1	SR: BDT output CR: DR_{bb}^{ave} (1L) event yields (2L)	SR: ratio observable ttH/tt+>1b CR: event yield
V2	SR: ttH discr. CR: ttX_i discr.	SR: ttH discr. CR: ttX_i discri.

ttH/tH: NNLO+NNLL cross-section

- **Contribution for Report 5 - updated NNLO+NNLL cross-section calculation:** SciPost Phys.Comm. Rep. 10 (2025)

- **NNLO QCD (approximate) + inclusion of NLO EWK corrections**
  - reduced scale uncertainties to 3%
  - EWK corrections app. 2%
- **Soft-gluon resummation up to NNLL**
  - scale uncertainties reduced to 2%



$$\sigma^{\sqrt{S}=13.6\,\text{TeV},\,m_H=125.09\,\text{GeV}}_{\text{NNLO+NNLL+EW}} = 592.1\,\text{fb}\ \underbrace{{}^{+1.5\%}_{-2.2\%}}_{\Delta_\mu}\ \underbrace{\pm 2.2\%}_{\Delta_{\text{PDF}}}\ \underbrace{\pm 1.7\%}_{\Delta_{\alpha_s}}\ \underbrace{\pm 0.9\%}_{\Delta_{\text{virt}}},$$

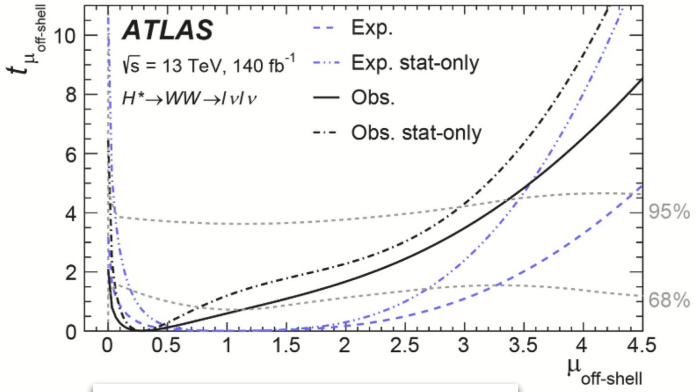
Input parameters as agreed in LHCHWG

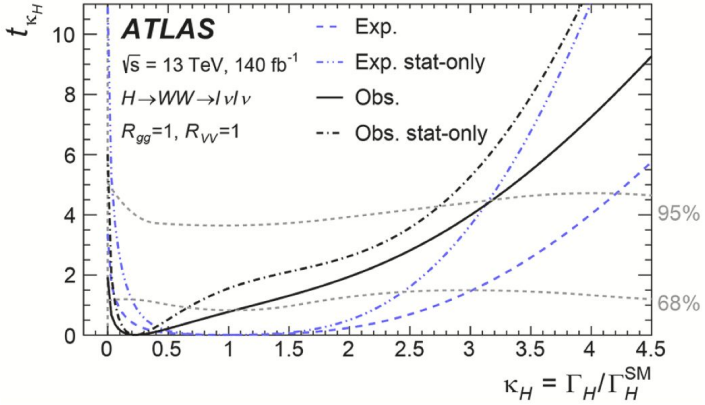
$\sqrt{S}$ [TeV]	m_H [GeV]	$\sigma_{\text{NNLO+EW}}$ [fb] $^{+[\%]}_{-[\%]}$	$\sigma^{\text{dQCD}}_{\text{NNLO+NNLL+EW}}$ [fb] $^{+[\%]}_{-[\%]}$	$\sigma^{\text{SCET}}_{\text{NNLO+NNLL+EW}}$ [fb] $^{+[\%]}_{-[\%]}$	$\sigma_{\text{NNLO+NNLL+EW}}$ [fb] $^{+[\%]}_{-[\%]}$
13.0	124.60	$533.8^{+1.1}_{-3.2}$	$534.4^{+0.6}_{-2.1}$	$534.1^{+0.5\ +1.6}_{-2.2\ -1.7}$	$534.2^{+1.6}_{-2.2}$
13.0	125.00	$530.2^{+1.2}_{-3.3}$	$530.8^{+0.6}_{-2.1}$	$530.5^{+0.7\ +1.7}_{-2.2\ -1.7}$	$530.6^{+1.7}_{-2.3}$
13.0	125.09	$528.4^{+1.1}_{-3.2}$	$529.0^{+0.6}_{-2.1}$	$528.7^{+0.5\ +1.6}_{-2.2\ -1.7}$	$528.8^{+1.6}_{-2.2}$
13.0	125.38	$524.5^{+1.1}_{-3.2}$	$525.1^{+0.6}_{-2.1}$	$524.8^{+0.6\ +1.6}_{-2.2\ -1.7}$	$524.9^{+1.6}_{-2.2}$
13.0	125.60	$521.7^{+1.1}_{-3.2}$	$522.2^{+0.6}_{-2.1}$	$521.9^{+0.5\ +1.6}_{-2.2\ -1.6}$	$522.1^{+1.6}_{-2.2}$
13.0	126.00	$517.2^{+1.1}_{-3.2}$	$517.7^{+0.6}_{-2.1}$	$517.5^{+0.5\ +1.6}_{-2.2\ -1.7}$	$517.6^{+1.6}_{-2.2}$
13.6	124.60	$598.9^{+1.0}_{-3.1}$	$599.5^{+0.5}_{-2.0}$	$599.2^{+0.3\ +1.5}_{-2.2\ -1.6}$	$599.3^{+1.5}_{-2.2}$
13.6	125.00	$592.0^{+0.9}_{-3.1}$	$592.7^{+0.5}_{-2.0}$	$592.3^{+0.2\ +1.5}_{-2.1\ -1.5}$	$592.5^{+1.4}_{-2.1}$
13.6	125.09	$591.7^{+1.0}_{-3.1}$	$592.3^{+0.5}_{-2.0}$	$592.0^{+0.2\ +1.5}_{-2.1\ -1.6}$	$592.1^{+1.5}_{-2.2}$
13.6	125.38	$588.4^{+1.0}_{-3.1}$	$589.0^{+0.5}_{-2.0}$	$588.6^{+0.3\ +1.6}_{-2.2\ -1.6}$	$588.8^{+1.5}_{-2.2}$
13.6	125.60	$585.6^{+1.0}_{-3.2}$	$586.2^{+0.5}_{-2.1}$	$585.9^{+0.4\ +1.6}_{-2.2\ -1.6}$	$586.0^{+1.6}_{-2.2}$
13.6	126.00	$580.1^{+1.1}_{-3.2}$	$580.7^{+0.6}_{-2.1}$	$580.4^{+0.4\ +1.6}_{-2.2\ -1.7}$	$580.5^{+1.6}_{-2.2}$
14.0	124.60	$642.1^{+0.8}_{-3.0}$	$642.7^{+0.5}_{-1.9}$	$642.4^{+0.2\ +1.3}_{-2.1\ -1.5}$	$642.6^{+1.3}_{-2.1}$
14.0	125.00	$638.4^{+0.9}_{-3.1}$	$639.0^{+0.5}_{-2.0}$	$638.6^{+0.3\ +1.5}_{-2.1\ -1.6}$	$638.8^{+1.5}_{-2.2}$
14.0	125.09	$635.6^{+0.9}_{-3.0}$	$636.3^{+0.5}_{-2.0}$	$635.9^{+0.2\ +1.4}_{-2.1\ -1.6}$	$636.1^{+1.4}_{-2.1}$
14.0	125.38	$634.6^{+1.0}_{-3.2}$	$635.3^{+0.5}_{-2.1}$	$634.9^{+0.3\ +1.6}_{-2.2\ -1.7}$	$635.1^{+1.6}_{-2.2}$
14.0	125.60	$630.2^{+1.0}_{-3.1}$	$630.9^{+0.5}_{-2.1}$	$630.4^{+0.3\ +1.6}_{-2.2\ -1.6}$	$630.7^{+1.5}_{-2.2}$
14.0	126.00	$623.6^{+0.9}_{-3.1}$	$624.2^{+0.5}_{-2.0}$	$623.9^{+0.3\ +1.5}_{-2.2\ -1.6}$	$624.1^{+1.5}_{-2.2}$

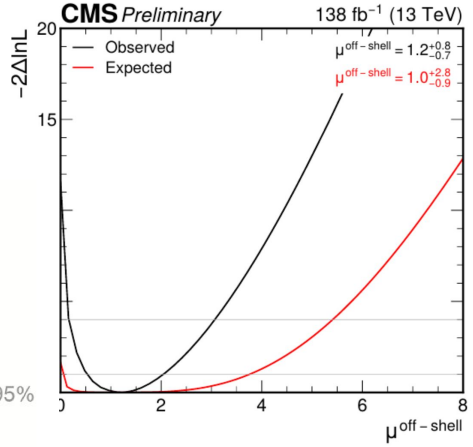
Off-shell: experimental summary

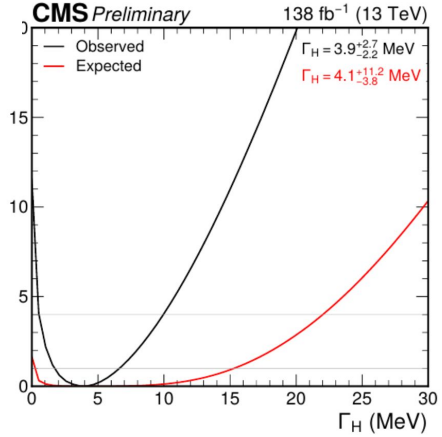
R. Roentsch

- **Vibrant developments on off-shell couplings and width measurements**
  - recent updates by **ATLAS/CMS on HWW decay**
  - TH uncertainties approaching limiting factor, especially for HL-LHC









ATLAS

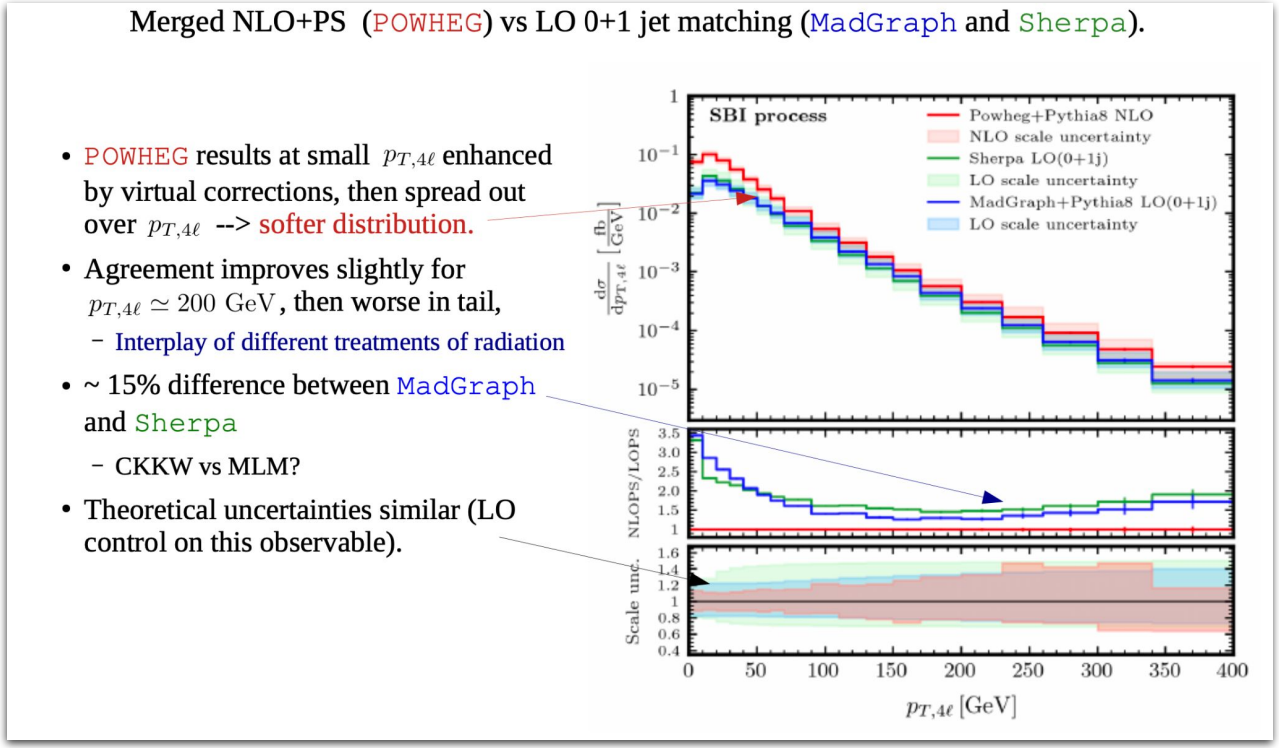
Statistical uncertainty	52%
MC stat. uncertainty	15%
Theory uncertainty	39%
- Theory background	22%
- Theory signal	34%
Experimental uncertainty	25%
- Jets	19%
- Leptons	5.3%
- Others	6.8%
- Misidentified leptons	3.1%
Background normalisation	7.6%

CMS

Uncertainty	Contribution to r	Contribution to $\mu_{\text{off-shell}}$
Luminosity	2%	3%
Theoretical	27%	29%
Experimental	8%	6%
Statistical	56%	56%
Other	4%	3%

Off-shell: modeling of additional radiation

- **Modeling for additional QCD radiation through parton shower (going beyond NLO)**
  - contribution to Report 5: SciPost Phys.Comm. Rep. 12 (2025)
  - comparison of several PS generators: merged NLO+PS (Powheg+Pythia) vs L0 + 0/1 jet matching (Sherpa, MG+Pythia)



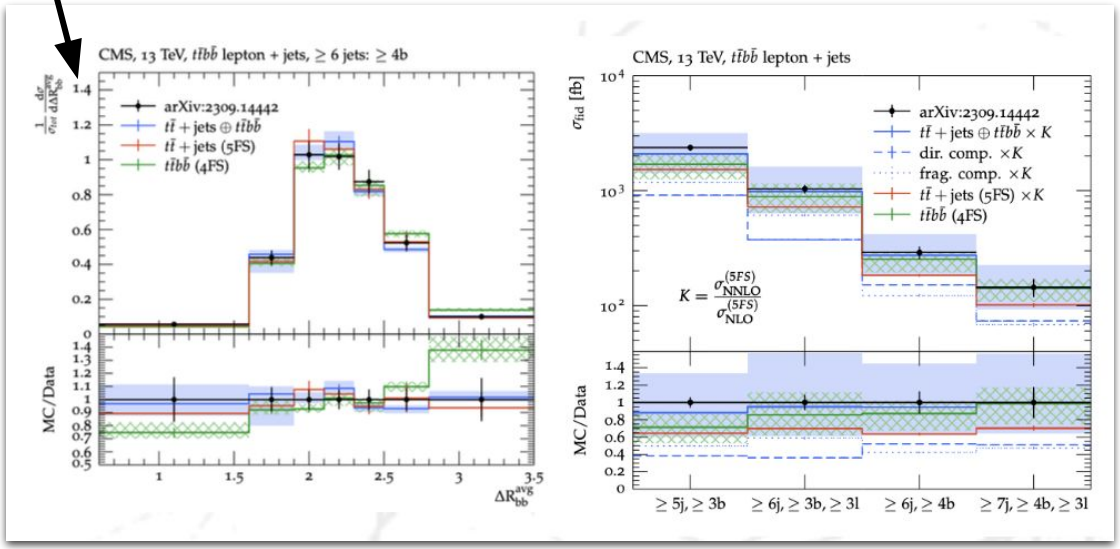
Conclusions and outlooks

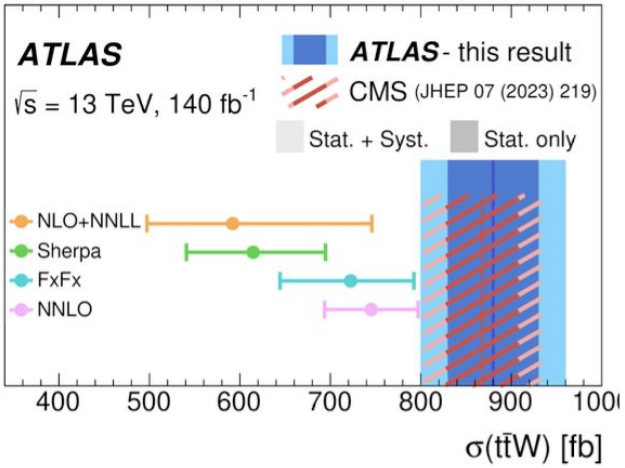
- **Several developments on all front for Report 5 projects - projects published/under review/being submitted**
- **Second wave of Report 5 projects in WG1 is shaping up** [lightning session]
  - e.g. H+c/H+b associated production
  - ggZH updated predictions at NLO also including SMEFT effects
  - ...
  - inclusion of new contributors is fundamental, please do reach out to us and/or sub-group conveners if you have proposal for additional projects
- **State-of-the-art cross section predictions at 13.6 TeV getting available**
  - Impact of N3LO PDF's in the calculation still under scrutiny
- **Several new EXP results and updated inputs from TH in terms of predictions/recommendations on various aspects**
  - fixed order calculations, parton shower schemes, uncertainties, ...
- **Thanks a lot to all sub-group and WG1 conveners as well as everybody involved in WG1 activities throughout 2025 - let's keep momentum for 2026!**

Backup slides

ttH/tH: the role of the background modeling

- **ttH analyses (ttHbb, ttHML) dominated by modeling uncertainties on tt+bb and tt+V**
- **Updated ttH(bb) results: 5FS inclusive tt + 4FS ttbb**
  - improved modeling in background-enriched CR's
  - new TH developments for tt+HF modeling and dedicated tt+HF in-situ measurements
- **Recent in-situ ttW/Z+j (EWK) measurement by ATLAS**

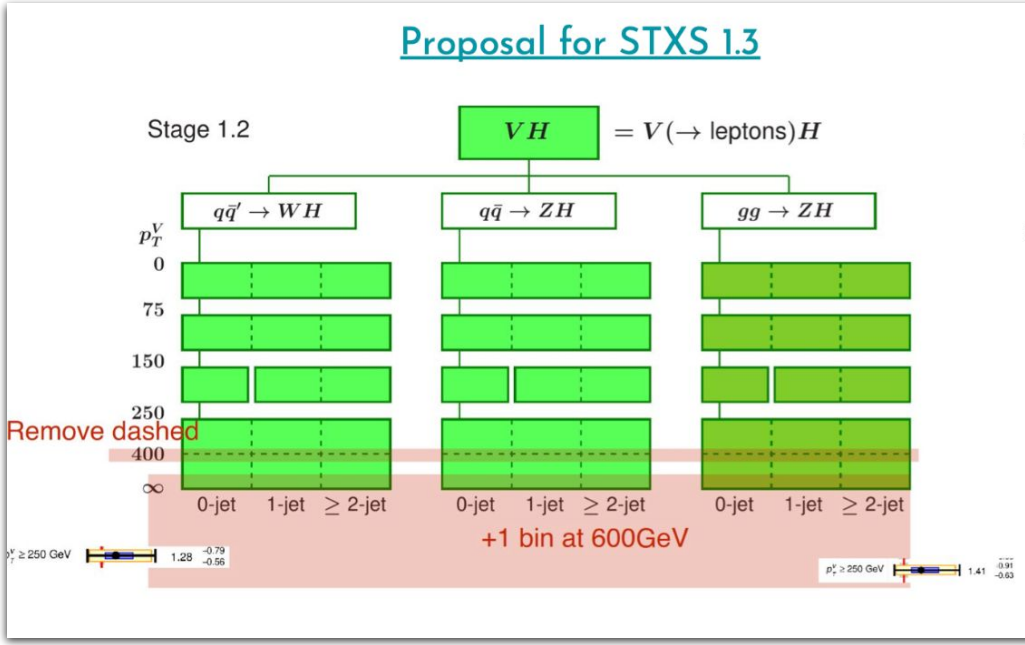


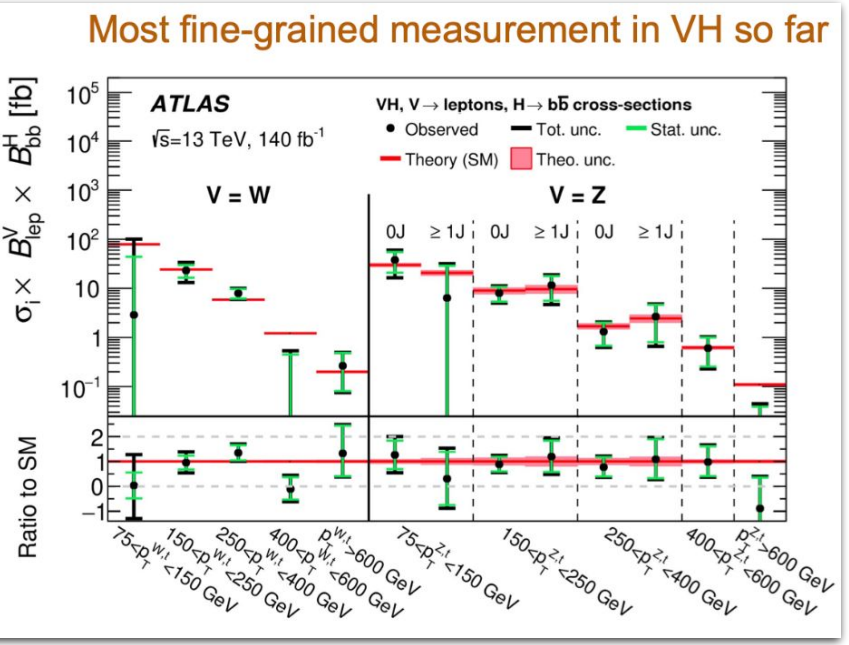


Process	Normalization factor (μ)
$t\bar{t}Wj_{EW}$	$0.9\ ^{+2.4}_{-3.0}$
$t\bar{t}Z$	$0.94\ ^{+0.14}_{-0.13}$
$t\bar{t}W_{QCD}$	$1.06\ ^{+0.28}_{-0.26}$

VH: looking at the future

- **STXS Stage 1.3 VH binning defined and being implemented by ATLAS/CMS for Run 3 analyses**
  - additional VPT split at 600 GeV to target boosted phase-space
  - include bin-migration and short/long-range correlation effects uncertainties on bin migrations





- **A lot more on the table for further developments on VH predictions and for EXP community**
  - TH: differential predictions in jet multiplicity, exclusive ggZH, full sim with NNLO+PS
  - EXP: explore more observables for STXS, V+jets background modeling across ATLAS/CMS