WG1: Summary and future directions

LHCHWG general meeting, Friday 3rd December 2021

John Campbell, Alexander Karlberg (TH),
Roberto Di Nardo (ATLAS), **Julie Malclès (CMS)**

WG1 overview

- WG1 focuses on:
  - SM Higgs cross-sections and branching ratios,
  - Modelling of main backgrounds for SM cross-section measurements,
- One subgroup per main 4 production modes,
- A subgroup dedicated to off-shell cross-section and interference with continuum bkg
- Additional subgroup to update Higgs branching fraction, generally less active due to sufficiently high-precision
  - Agreed recently to move BR to a “point-of-contact” rather than a subgroup (unless there are objections raised today)
  - Some ongoing activity on BRs within MSSM WG3 but with WG1 BR subgroup tools
- Increasing cross-talk with other WGs: STXS, (SM)EFT, BSM Higgs, ...

- Twiki: https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHWG1
- WG1 fall meeting: https://indico.cern.ch/event/1071695/

WG1 contributions

WG1 session

WEDNESDAY, 1 DECEMBER

13:00 → 15:15 **Wednesday Afternoon: Introduction + Working Group 1 session** 222/R-001

Conveners: Alexander Karlberg (University of Oxford) , John Campbell, Julie Malcles (Université Paris-Saclay (FR)) , Roberto Di Nardo (Università e Roma Tre (IT))

Mattermost discuss… zoom

13:00 **ggF - theory update**
Speaker: Stephen Philip Jones (University of Durham (GB))

13:10 **ggF - experimental results**
Speaker: Jonathon Mark Langford (Imperial College (GB))

13:25 **VBF**
Speaker: Antonio De Maria (Nanjing University (CN))

13:50 **VH**
Speaker: Alessandro Calandri (Eidgenoessische Technische Hochschule Zuerich (CH))

14:15 **tH/ttH: experiment summary**
Speaker: Josh McFayden (University of Sussex)

14:30 **tH/ttH: theory summary**
Speaker: Laura Reina (Florida State University (US))

14:50 **Offshell - theory summary**
Speaker: Nikolas Kauer (Royal Holloway, University of London)

15:00 **Offshell - experiment summary**
Speaker: Lailin Xu (University of Science and Technology of China

Cross topics: H+HH, STXS uncertainties, PDFs …

FRIDAY, 3 DECEMBER

13:00 → 15:10 **Friday Afternoon: Cross-cutting topics** 222/R-001

Mattermost discuss… zoom

13:00 **H and HH in the k_λ and EFT frameworks**
Speaker: Jorge de Blas (Universidad de Granada (ES))

13:30 **Cuts for two-body decays at colliders**
Speaker: Gavin Salam (University of Oxford)

14:00 **Higgs pT Spectrum and Total Cross Section with Fiducial Cuts at Third Resummed and Fixed Order in QCD**
Speakers: Johannes Michel (MIT CTP) , Markus Ebert (MIT)

14:30 **PDF4LHC update**
Speaker: Robert Samuel Thorne (University College London (UK))

This talk: selection of a few highlights among a large number of very interesting new studies/results presented.

Apologies if your favorite result is not shown.

ggF: experimental view

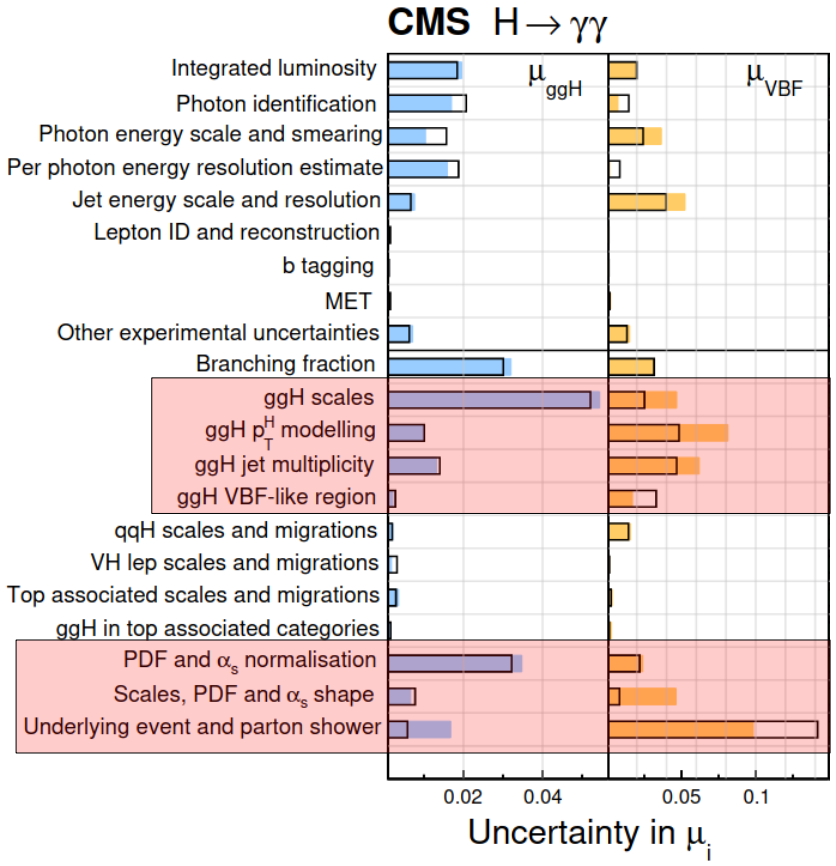
Jonathon Langford (EXP)

Wealth of data collected during Run 2 enabled many interesting analyses

- measure kinematics of ggF production mode: differential/STXS
- rare phase space regions e.g. boosted ggF(H→bb)
- using ggF to probe Higgs properties e.g. CP

High ranking systematics

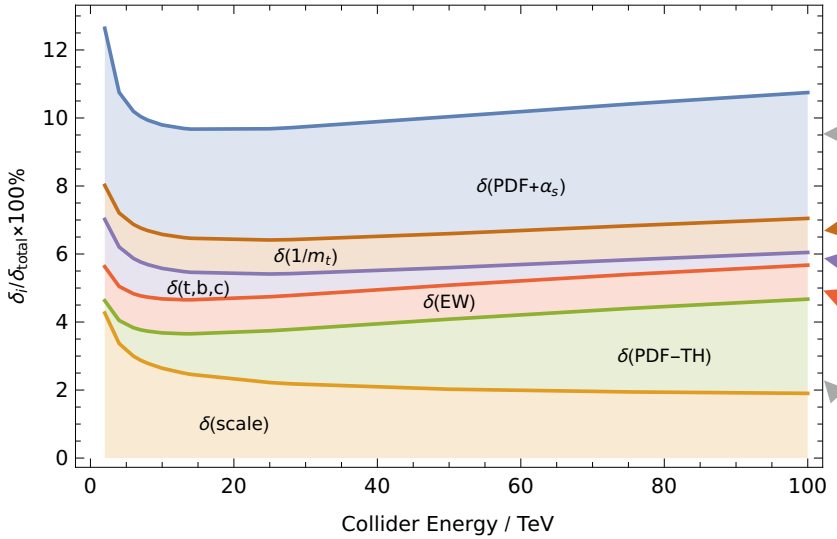
- **Theoretical uncertainties dominate ggF signal-strength measurement**
  - missing higher-order QCD terms
  - modelling of ggF kinematics in VBF phase space important for μVBF
- **Parton shower now dominant theory uncertainty in ggF cross-section measurement** ⇒ worth investing time + effort in consistent scheme



ggF inclusive: theory progress

Stephen Jones (TH)

Uncertainty budget for ggF



iHixs2: Dulat, Lazopoulos, Mistlberger 18

Progress is steadily beating down sources of TH uncertainty

Needs data/more accurate determination

Removed
Czakon, Harlander, Klappert, Niggetiedt 21

Can be removed (?) similar techniques

Reduced from ~1% to 0.6%
Becchetti, Bonciani, Del Duca, Hirschi, Moriello, Schweitzer 20; + Bonetti, Panzer, Smirnov, Tancredi, Melnikov, …

Missing N^3LO PDFs

New: NNLO QCD with impact of the finite top-quark mass on the inclusive cross section [arXiv:2105.04436]

Decreases σ_{tot} by −0.26 % @ 13 TeV compared to heavy top limit (HTL)

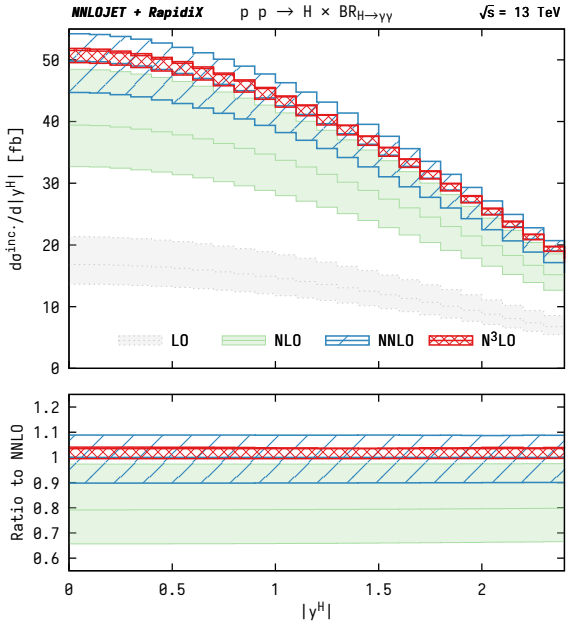
Future: technology could be used to include light quark mass effects ?

Mixed QCD-EWK corrections @NLO_{QCD} already discussed last year at the general meeting: [arXiv:2010.09451]

ggF differential: N3LO

Stephen Jones (TH)

Inclusive



ATLAS cuts

$p_T^{\gamma_1} > 0.35\ m_{\gamma\gamma}$

$p_T^{\gamma_2} > 0.25\ m_{\gamma\gamma}$

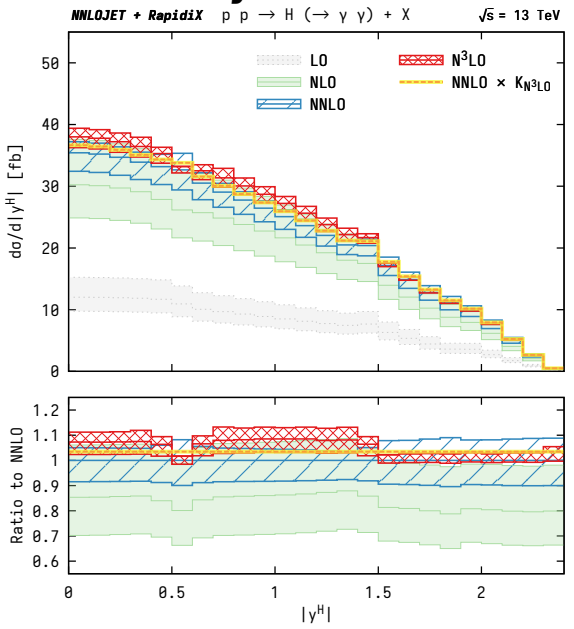
$|y^{\gamma}| < 2.37$

$1.37 < |y^{\gamma}| < 1.52$ (reject)

$\Delta R < 0.2$

arXiv:2102.07607

Fully Differential



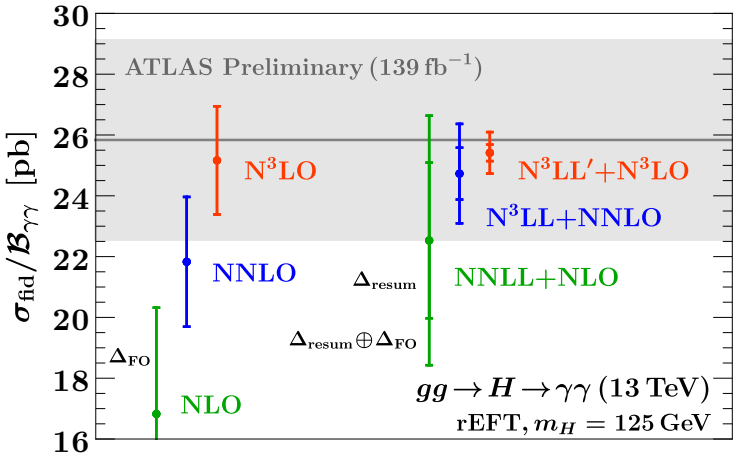
- Different cuts allow this behaviour to be cured/avoided

[see Gavin Salam presentation, arXiv:2106.08329v1]

- IR sensitivity can be avoided by resumming fiducial power corrections

[see Johannes Michel presentation, arXiv:2102.08039]
predictions for the gluon-fusion Higgs *pT* spectrum third resummed and fixed order (N3LL'+N3LO) including fiducial cuts.

- N3LO fully differential compared to NNLO x k-factor with ATLAS like cuts
- **For these cuts: naïve rescaling fails for** $|yH| < 1.5$
- **IR sensitivity @** $|yH| \sim 0.5$



ggF: future directions

Stephen Jones (TH)

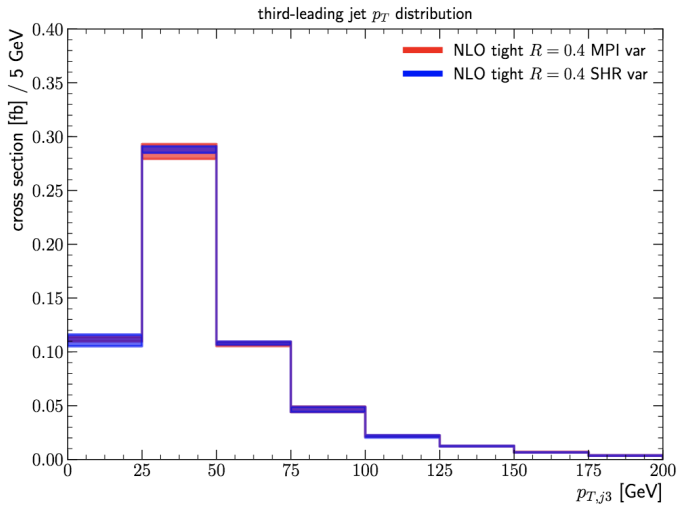
Jonathon Langford (EXP)

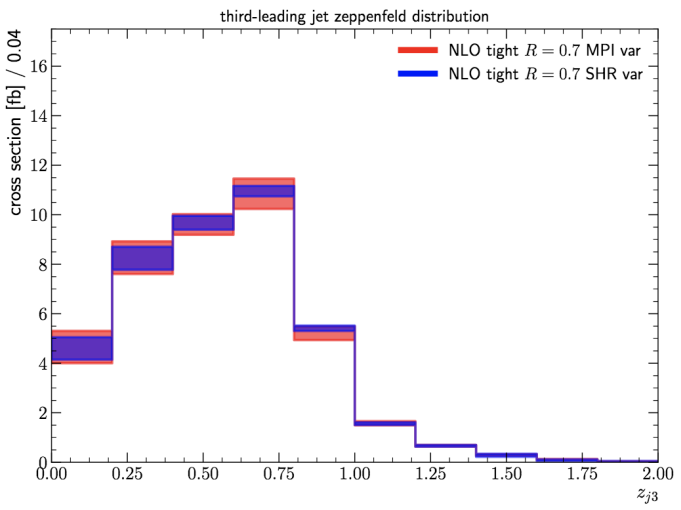
- **Short term:**
  - Update & publish boosted Higgs note (CERN-TH-2020-074). Results already available at last general meeting / already used in STXS 1.2 scheme
  - Update & publish the documentation on the STXS uncertainty scheme finalised with WG2
- **Medium term:**
  - **For ggF cross section measurements at 13.6 TeV, update the inclusive recommendation with:**
    - Exact mixed QCD-EW corrections
    - Top quark mass effects @ NNLO
    - N3LO QCD corrections (missing: b/c quark mass effects, PDF4LHC21)
  - **STXS/differential measurements:**
    - Targeting increasingly-difficult-to-model regions of phase space e.g. H+2jet
    - Require state-of-the-art tools for simulation e.g. [MiNNLO$_{PS}$]
- **Longer term:** parton shower uncertainties and associated systematics (now a dominant theory unc. for ggF)
  - PS modelling needs to be improved e.g. account for heavy quark masses in PS
  - Also require consistent treatment of PS systematics. ATLAS and CMS plan to spend some time on it to understand the differences and come up with a consistent scheme.
  - **Would need interest from the theory community on that direction too**

VBF: completed topics

Antonio De Maria

- Stage 1.2 Simplified Template Cross-Sections uncertainties (public tool, slides)
- Jet multiplicities merging and parton shower accuracy: detailed benchmark study comparing generators at NLO QCD matched with PYTHIA8 and HERWIG7 to NNLO. Uncertainties are typically below 10%, dominated by differences in normalisation rather than shapes for most observables [Eur. Phys. J. C 80 (2020) 8, 756]
- Effects of Multi-Parton Interactions (MPI) in VBF/VBS Z production. Variation of parameters controlling soft QCD (color reconnection, multi-parton interaction) [arXiv:2110.01623v1]





⇒ Effects can be comparable to shower variations in NLO matched prediction

VBF: possible future directions

Antonio De Maria

Gluon-gluon fusion background (among several possible future directions quoted in the talk)

- Modelling:
  - Best ggH background estimated using NNLOPS (2nd jet LO)
  - Recent work from HEJ suggests the cross-section is overestimated under VBF cuts
- Uncertainties:
  - Large contamination of theory uncertainties from ggHjj in VBF phase-space
  - Large higher order QCD corrections to Higgs boson production in association with jets in ggF higher multiplicities (>2 jets). Need to be considered in order to reach a reasonable theoretical accuracy (see slides)

- Closer collaboration with GGF and VH WG1 is required!

⇒ Proposal to organise a meeting (first quarter 2022) with a few talks, with contributions from ggF, VH and VBF, to get the ball rolling, if proponents agree?

VH (H → $b\bar{b}$): ggZH and V+jets

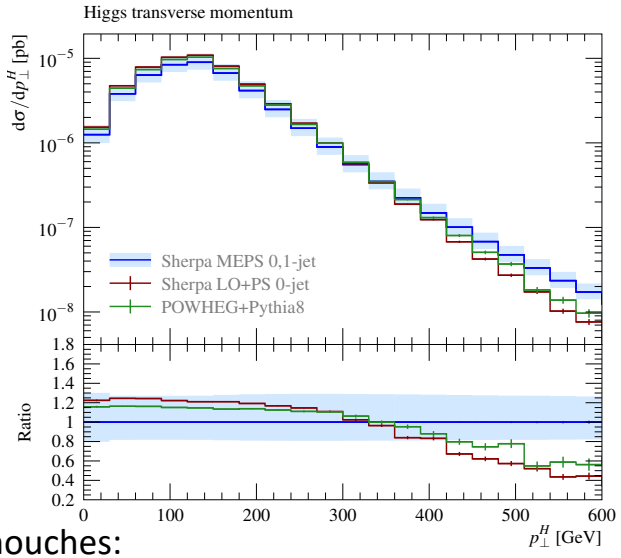
Alessandro Calandri

Recent ATLAS result on VH(H → $b\bar{b}$)

- Combined VH signal strength measured to <20% accuracy
- Now sensitivity for pT splitting and boosted regime

Signal modelling: ggZH

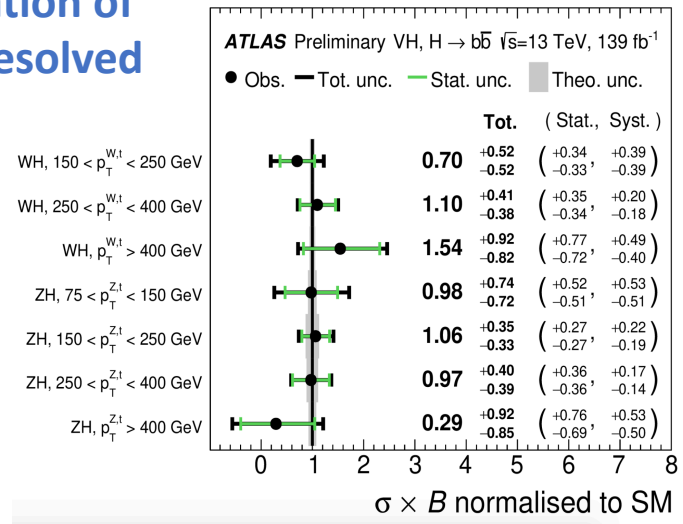
- ATLAS/CMS use ggZH@LO (QCD) from POWHEG, HO out of reach
  ⇒ large scale uncertainties
- **How to improve?** Explored multijet merging. Add 2 → 3 process available in Sherpa. Sizable modification of the $p_T V/p_T H$ spectra. Uncertainties underestimated? Ongoing: comparison of MadGraph/Sherpa in ATLAS.



Les houches:
https://arxiv.org/pdf/2003.01700.pdf

New: combination of boosted and resolved analyses

ATLAS-CONF-2021-051



Signal modelling: [A. Behring et al]

- NNLO QCD corrections to production and decay with b-quark mass dependence.
- Impact on m($b\bar{b}$) lineshape modelling, especially at high p_TW. Interesting to check if the effect is covered by PS uncertainties.

Background modelling: V+jets

- V+h.f.: main irreducible background. Theory prediction important for accuracy
- Data constrains V+jets prediction → choice of MC modelling/systematics scheme can impact the measurement significantly
- CMS result soon to be released. Plan a thorough comparison of the treatments of the V+jets background modelling in ATLAS/CMS and harmonisation next year

$t\bar{t}$H: experimental summary

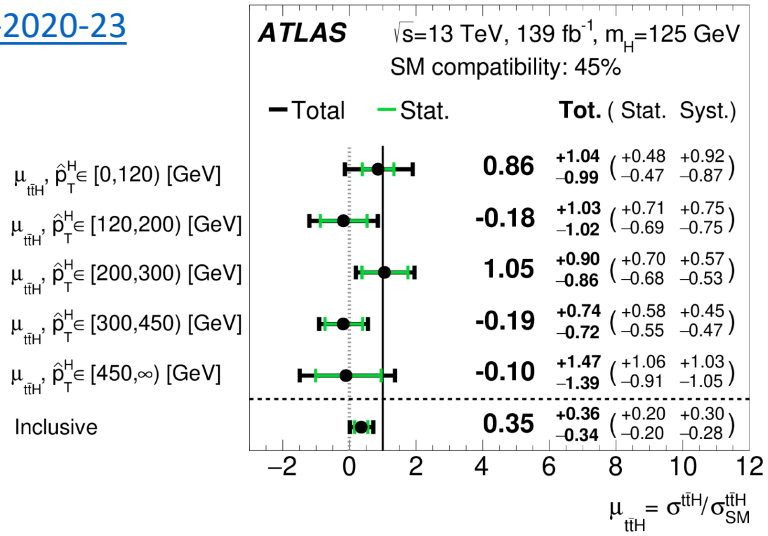
Josh McFayden (EXP)

$t\bar{t}$H(H → $b\bar{b}$)

Updated full run 2 ATLAS result with impact of systematic uncertainties reduced by about a factor two. Main improvements:

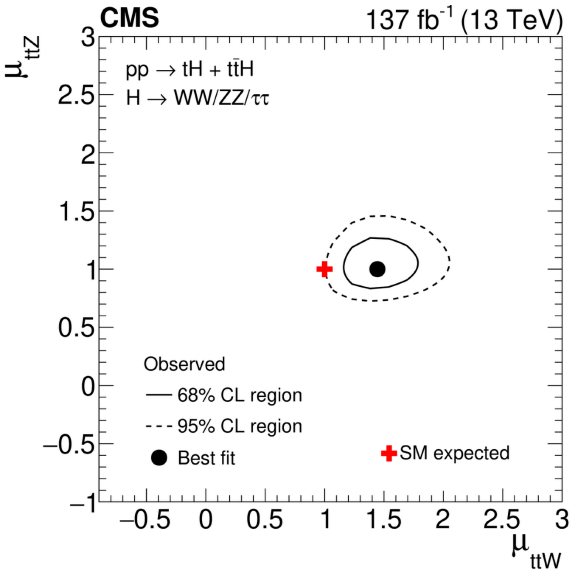
- Improved theoretical knowledge in $t\bar{t}$ + ≥1b modelling
- Much larger size of simulated event samples
- Refined b-tagging scale factors and jet energy scale and resolution measurements.
- **Sensitivity still very much dominated by $t\bar{t}$+b-jets modelling uncertainties, as in CMS**

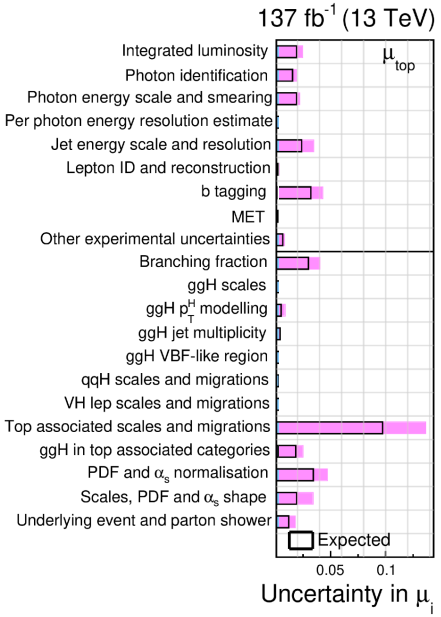
HIGG-2020-23



$t\bar{t}$H(H →multilep)

- $t\bar{t}$W extraction very important for analysis sensitivity
- $t\bar{t}$W significantly higher in data than in state of the art predictions, distributions not well modelled
- **Major uncertainty, important for overall sensitivity**





$t\bar{t}$H(H→γγ) stat. dominated

Signal model scale and UEPS uncertainties dominant for H→γγ

$t\bar{t}$H: theory summary

Laura Reina (TH)

Focus: theoretical modelling of background and signal, causing the largest systematic uncertainties

- **$t\bar{t}+b$ jets** [bckgr. to $t\bar{t}H(b\bar{b})$] – **wrapping up + outlook**
  - ↪ Comparison of NLO PS MC → Converged on new recommendation
    Used in recent analyses. Will be documented in a WG note + publication.
  - ↪ Study of **off-shell effects** in fully decayed $pp \to e^+\nu_e\mu^-\bar{\nu}_\mu b\bar{b}b\bar{b}$ including NLO QCD corrections.
- **$t\bar{t}W$** [bckgr. to $t\bar{t}H$(multileptons)] – **several new studies**
  - ↪ Tension between data and theoretical predictions:
    $\lambda_{t\bar{t}W}^{2lSS} = 1.56^{+0.30}_{-0.28}$ and $\lambda_{t\bar{t}W}^{3l} = 1.68^{+0.30}_{-0.28}$
  - ↪ Investigated impact of higher-order QCD and EW corrections.
  - ↪ Improved modelling of fiducial signatures including parton-shower and off-shell effects.
- **$t\bar{t}H/tH$** – **looking ahead**
  - ↪ Aim for default NLO QCD+EW in all PS event generators.
  - ↪ Include new elements in theoretical studies: off-shell effects, STXS, anomalous couplings (e.g. C$\not{P}$), EFT interpretation.
  - ↪ Towards NNLO QCD to bring further perturbative stability.

$t\bar{t}$H bkg modelling: $t\bar{t}$W

Laura Reina (TH)

$t\bar{t}$W modelling for $t\bar{t}$H (H → multi-leptons)

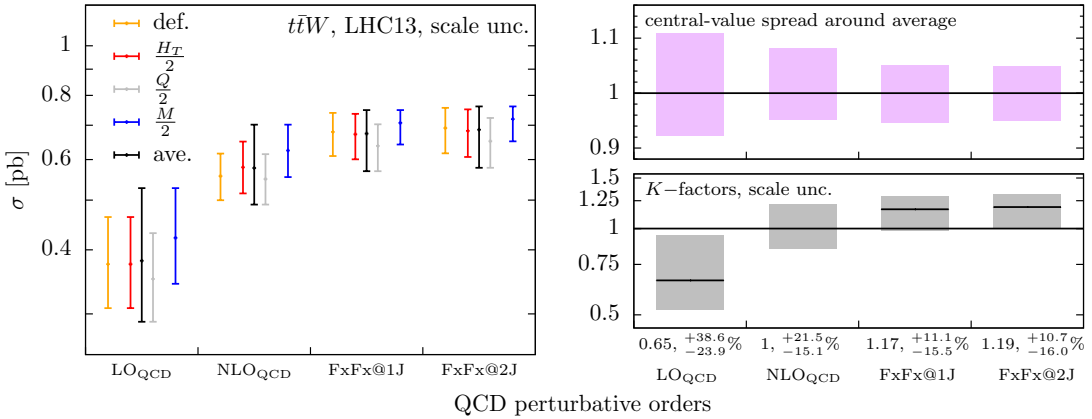
- **Several new theoretical developments pointing to sizable effects from higher-order QCD and EW diagrams,** strong indication that NNLO QCD corrections could bring better agreement. NLO QCD + Jet merging + EW moving in the right direction but still tension wrt ATLAS+CMS results.

- **Comparison of different NLO PS frameworks**
  Complementary NLO+PS prediction provided: first publicly available POWHEG-BOX implementation → now being tested by ATLAS/CMS. Baseline for theoretical systematics estimates.

- **Off-shell effects added and combined to PS to improve the modelling**

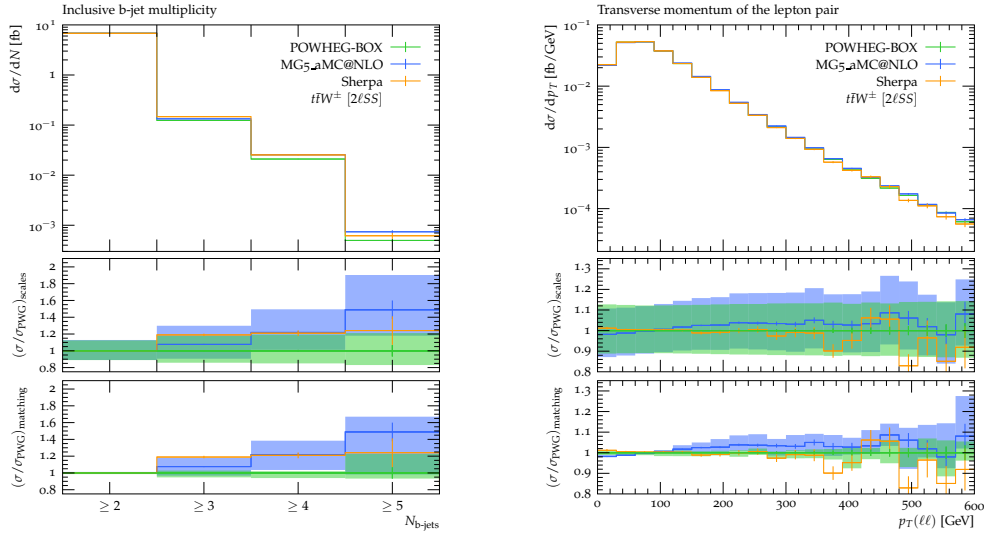
[Frederix & Tsinikos], arXiv:2108.07826

Cross sections of various QCD perturbative orders



Good agreement within theory uncertainties

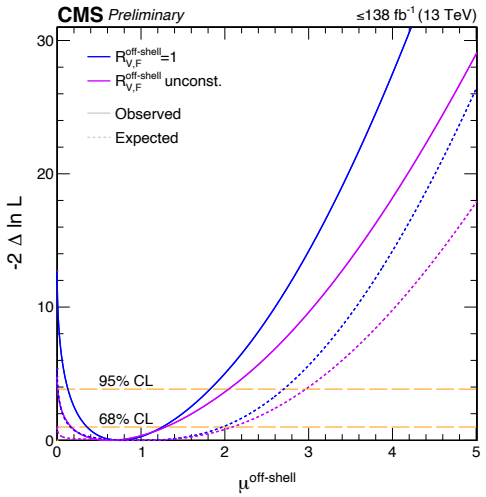
[Febres Cordero, Kraus, Reina] arXiv:2101.11808

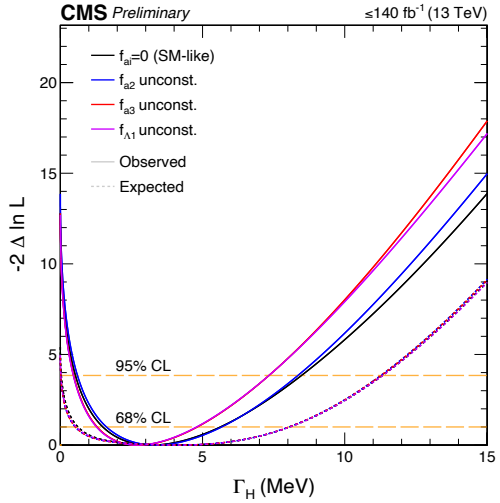


Offshell

Nikolas Krauer

Experiment: new measurement of the width of the Higgs boson with full run 2 data in CMS





Combination of: H→2l2v (offshell Full Run2)
+ H→4l (onshell Full Run2 + offshell '15-'16-'17)

- **Evidence for offshell production at 3.6σ**
- **Most precise Γ_H measurement to-date**

$$\Gamma_H = 3.2^{+2.4}_{-1.7}\ \text{MeV}$$

- **Fit** Γ_H , μ_V , μ_F offshell + anomalous couplings
- Similar measurement expected shortly from ATLAS

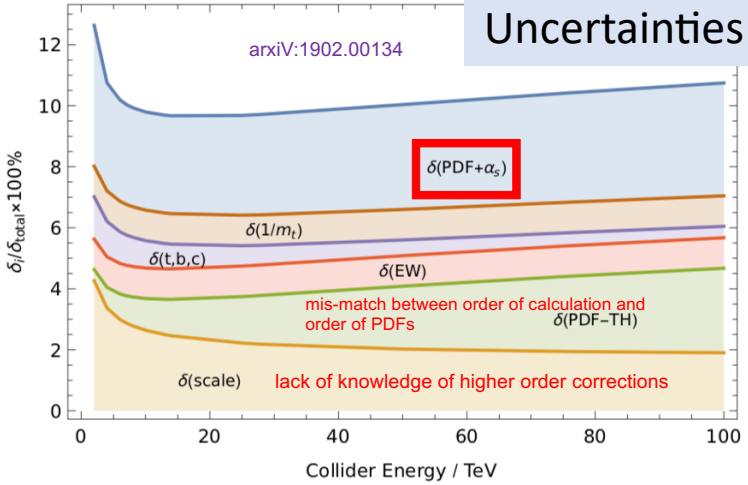
- **Theory: impressive progress towards higher-precision predictions for off-shell Higgs production!**
- **Progress on how off-shell Higgs can provide insights into BSM physics**
  - Detailed study on using off-shell observables to lift universal flat directions of on-shell Higgs rates
  - Clarification of theoretical aspects of SMEFT analyses facilitated (Higgs basis)
  - Tools (incl. 1-loop) for off-shell SMEFT computations validated & publicly available
  - Systematic analysis of the off-shell sensitivity to SMEFT operators initiated
- **Future directions:** comparative study of jet merging and parton showers for additional QCD radiation

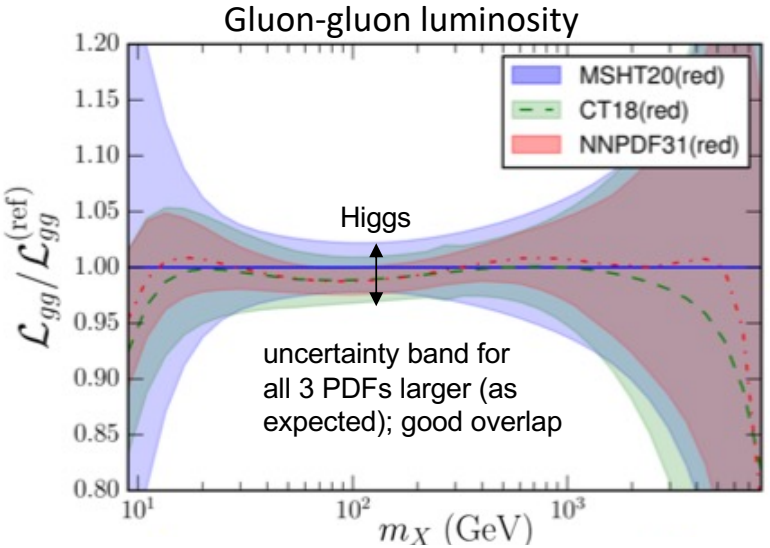
PDFs

Robert Thorne

Towards PDF4LHC21

Undergoing PDF benchmarking effort using new LHC data to be used for Run3





- Precision physics at the LHC, and specifically for Higgs boson production, requires precise determinations of PDFs and of $a_s(mZ)$
- In 2015, common benchmarking exercice for LHC Run 2 (PDF4LHC15)
- Several PDFs developments undergoing in different groups CT, NNPDF, MSHT. Most recent sets: NNPDF3.1, CT18, MSHT2020
- Determined from global fits to data from a wide variety of processes, both from fixed target and collider experiments
- A great deal of LHC information has now been included in global PDF fits: so time for benchmarking!

- Benchmarking and recommendation papers being prepared
- Timescale for the PDFs to be available: order of a month?
- Uncertainty expected to be the about the same than PDF4LHC15, more data but sometimes wider spread

Conclusion

Important activity in the WG1:

- **Large number of interesting new studies presented during the WG1 session**
- Future directions well identified within the groups

Documentation:

- **PS uncertainties: towards a common prescription?**
  - Plenty of relevant studies complete, or close to completion: benchmarks for VBF, soft QCD effects in VBF, ttbb, multijet merging for VH, off-shell studies…
  - Others needed or starting: ggF
  - Probably time to push for a proper documented recommendation on PS uncertainties
- **Cross-section results update?**
  - Time to update cross-section results? Enough new theoretical input (new calculations, PDF4LHC update)? Makes sense to have numbers at 13.6 TeV for Run3.
  - There has been interest from Snowmass in xsec numbers, we may want to consider coordinating the effort
  - Ultimate goal would be to document them in a WG note or an arXiv submission
  - Could also provide in a short timescale ad-interim values obtained with a simple interpolation in the twiki
  - **Launch a campaign for a full update with a dedicated meeting in the new year**

Thanks and welcome!

Many personnel changes in the ranks in the last six months. We're very grateful for the dedication of the outgoing conveners and welcome the **newcomers**, who have been already active over the past months.

- WG1 convener: thanks Fabrizio Caola and and welcome to **Alexander Karlberg**.
- BR: thanks Ansgar Denner for many years of service, welcome **Michael Spira**.
- ggF: thanks Andrea Massironi, welcome **Jonathon Langford**, **Stephen Jones**.
- VBF: thanks Yacine Haddad, welcome **Stephane Cooperstein**, **Mathieu Pellen**.
- VH: thanks Thomas Calvet, welcome to **Hannah Arnold.**
- ttH:
  - Thanks Joshuha Thomas-Wilsker, welcome **Sergio Sanchez Cruz**.
  - Also an early welcome to **Malgorzata Worek** and **Marco Zaro**, overlapping with Stefano Pozzorini and Laura Reina until they step down at the end of the year.
- Offshell: thanks Ulascan Sarica, welcome **Savvas Kyriacou**.

Thank-you to all for your work over the last few years!

Backup

BR Dalitz

Link to document

Not much need except for the Dalitz decay (under discussion)

In RUN1 it had been discussed that one should separate the following processes:

1. H → $\gamma + \gamma$
2. H → Z*/γ*+ γ-> $f\bar{f}$ + γ (Higgs Dalitz decay)
3. H → $f\bar{f}$
4. H → Z*+gamma* -> $f\bar{f} + f'\bar{f}'$

ATLAS and CMS did not come to agreement on Dalitz decay phase space definition via invariant mass

- Best would be to devise a reasonable set of cuts to define the different phase spaces and test these against reco acceptances
- This should be done in agreement by ATLAS and CMS
- HIG plans to organise a talk by theorists in a PAG meeting to discuss the BR from the theoretical point of view

STXS 1.2 uncertainties: ggF

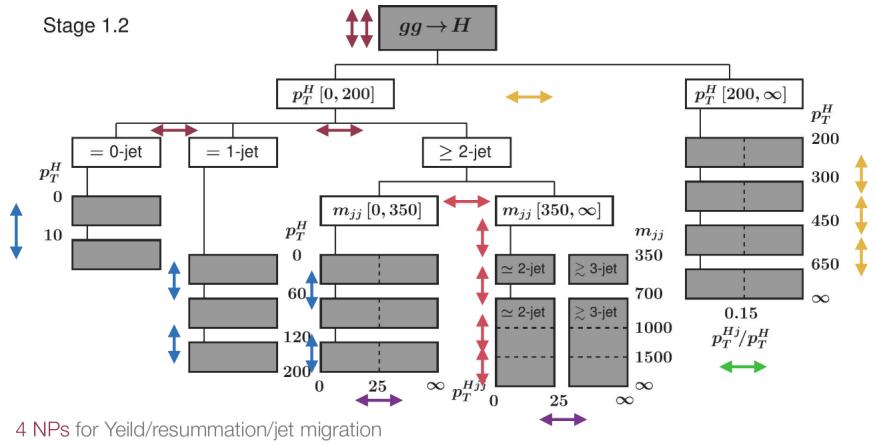
Goal: common prescription for stage 1.2 uncertainties

- A) Uncertainty in the measurement: σ_i
  - **within-bin migrations** i.e. kinematic/shape effects
  - affects the estimated experimental acceptance: $N_{\text{obs}} = \sigma \cdot \text{BR} \cdot (\epsilon \cdot \mathcal{A}) \cdot \mathcal{L}$
- B) Uncertainty in the interpretation: e.g. μ_i, κ, EFT
  - yield + **migrations across bin boundaries**
  - affects predicted cross section in a given bin

Proposal summary

(A): within-bin migrations, (B): across-bin migrations

- Defines (B) for interpretations, whilst capturing some of (A)



- 4 NPs for Yeild/resummation/jet migration
- 3/5 NPs for pTH migration below 200 GeV (extra if de-correlate 1/2 jet)
- 5 NPs for mJJ migration
- 4 NPs for High pTH migration
- 1/4 NPs for pTHj migration in high pTH region (depending on the correlation with pTH)
- 1/2/7 NPs for pTHjj migration (depending on the correlation with pTH/mJJ)

Jonathon Langford

New scheme

- evolution of the previous stage 1.0 scheme
- new/updated NP for stage 1.2 boundaries

Limitations

- Assumes within bin migrations (A) covered by dashed boundaries
- In some cases, **residual shape effects ⇒ proposal prescriptions**

bake shape effects into NPs versus scale variations (μR ,μF) keeping bin normalisation constant

Open questions for theorists:

- High p_T^H region: updated prediction? Treatment of m_t?
- VBF-like region: computation of p_T^{Hjj} uncertainties? H+3J@NLO?

Timeline and implication for next results

- Most uncertainties computed
- Aiming to finalise prescription in near future (~1 month)
- Implication for our full run2 results:
  - For existing results: not quantified, type A could be reduced in that scheme, no plan to update
  - Plan is to use it for upcoming full run 2 combinations and EFT interpretations: effect on interpretation (type B) expected to increase uncertainties wrt previous scheme

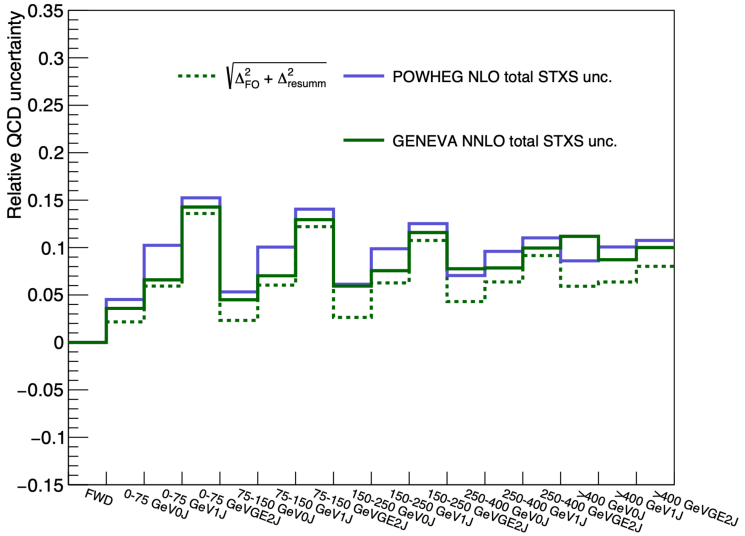
STXS 1.2 uncertainties: VBF, VH, ttH

Goal: common prescription for stage 1.2 uncertainties

Yacine Haddad

Uncertainties nearing finalization:

- qq→Hlν, Hll
  - Scheme unchanged since 2019
  - New computation of QCD uncertainties using GENEVA generator
- qq→Hqq
  - QCD uncertainties finalised, available as tool
  - EWK corrections and uncertainties included
- ttH
  - QCD uncertainties computed using similar technique as Hlν, Hll
  - Subleading PS and NLO matching uncertainties available



ttH

p_T(H) [GeV]	Δ_y (%)	Δ_{60} (%)	Δ_{120} (%)	Δ_{200} (%)	Δ_{300} (%)	Δ_{450} (%)	Total (%)
0-60	9.2	-9.2	0.0	0.0	0.0	0.0	13.0
60-120	9.2	2.0	-4.6	0.0	0.0	0.0	10.5
120-200	9.2	0.0	6.8	-1.3	0.0	0.0	11.5
200-300	9.2	0.0	6.8	7.1	-0.4	0.0	13.5
300-450	9.2	0.0	6.8	7.1	7.4	-0.1	15.4
450-inf	9.2	0.0	6.8	7.1	7.4	7.6	17.2

Timeline:

- Framework and results are in place
- Finalization of documentation and tools underway

ggF: mixed QCD-EWK corrections

Bernhard Mistlberger

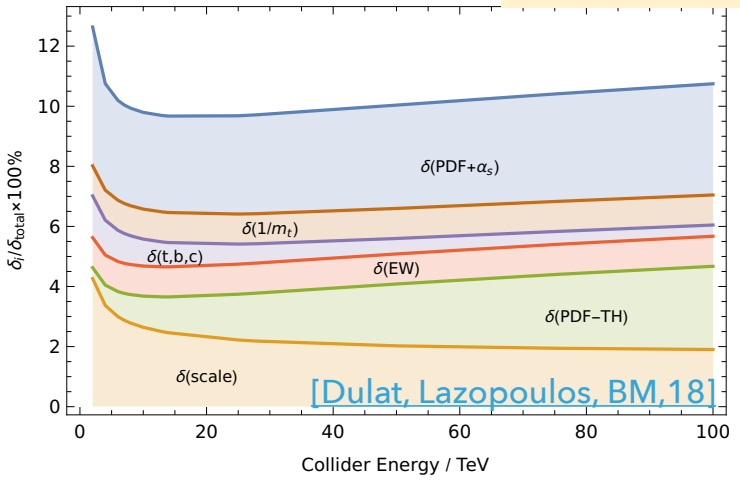
- Submitted to arXiv in october: https://arxiv.org/abs/2010.09451

- Exact NLO QCD corrections to the light-quark part of the mixed QCD-EW contributions to Higgs production via ggF with exact dependence on the weak boson mass

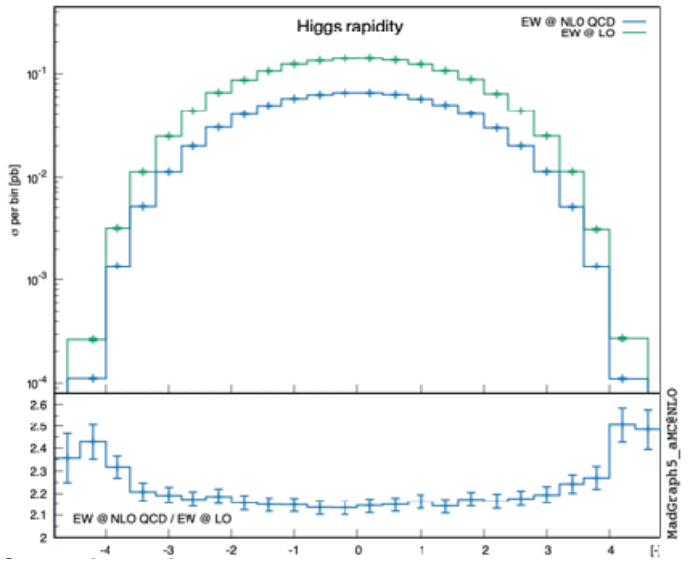
Motivation:
- Missing NLO-QCD corrections caused 1% uncertainty on total XS
- What is the impact of missing QCD/EWK corrections on differential distributions (Y, p_T)?

$\delta(\mathrm{EWK})$ **1 %** → **0.57 %**

- Improvement of the residual uncertainty by about a factor 2
- Flat k-factor versus rapidity



[Dulat, Lazopoulos, BM,18]



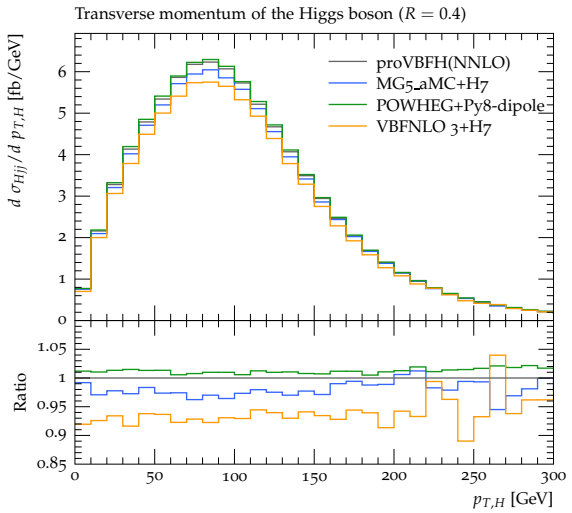
VBF: PS uncertainties

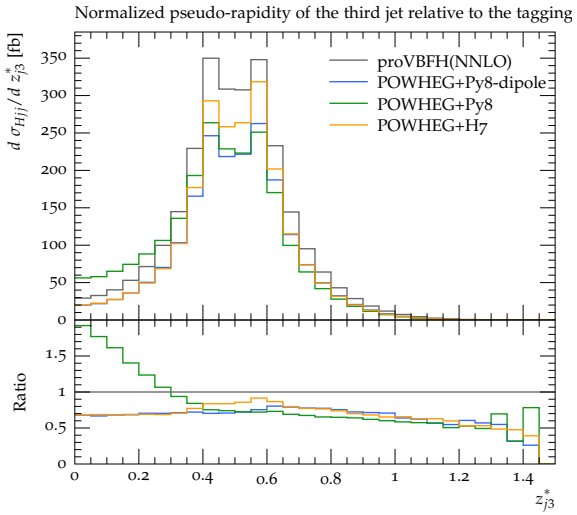
Detailed benchmark study: https://arxiv.org/abs/2003.12435

Simon Plätzer

Systematic investigation of parton shower and matching uncertainties for VBF

Compare generators at NLO QCD matched with PYTHIA8 and HERWIG7 with NNLO





Within typical VBF cuts, uncertainties on observables that are accurate to NLO: 10% level for rates and < for shapes

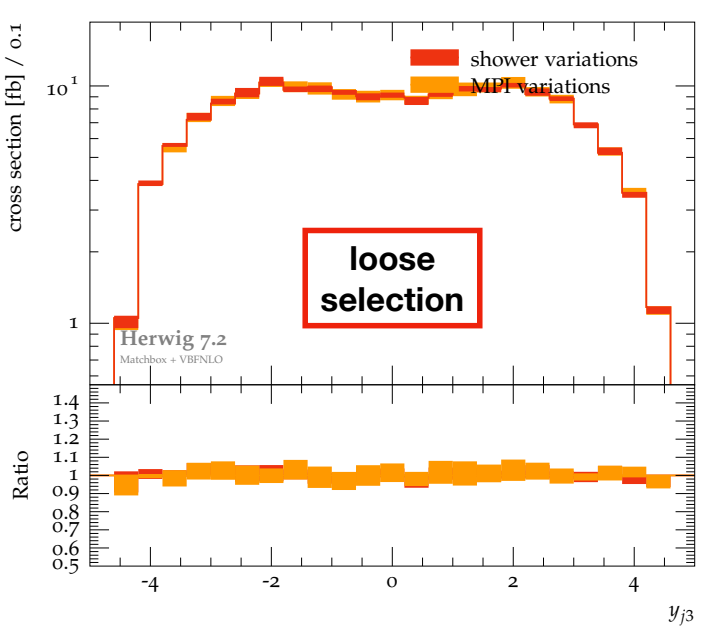
For observables sensitive to extra radiation effects uncertainties of about 20% are found

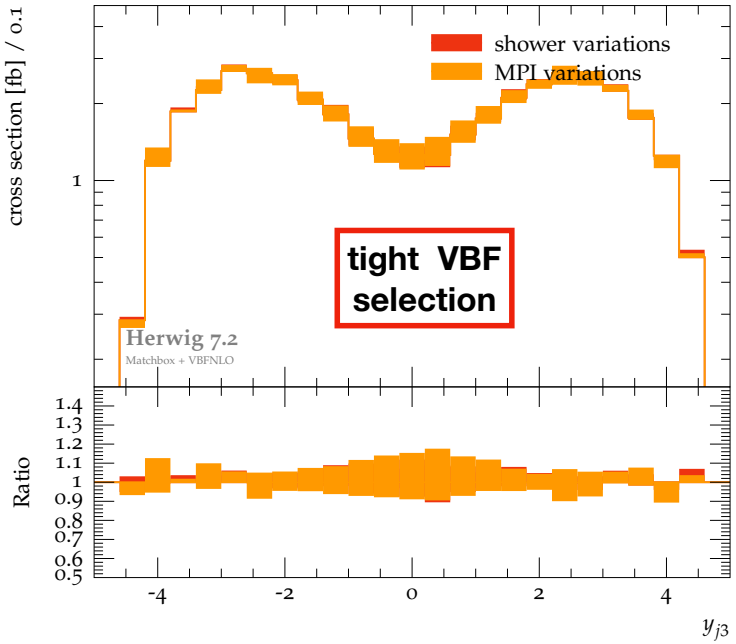
Uncertainties for simulation at NLO +PS based only on the variation of renormalisation, factorisation and shower scales systematically underestimates their true size.

VBF: future directions

Soft QCD:
variation of parameters controlling soft QCD (color reconnection, multi-parton interaction)

Simon Plätzer





- Effects can be comparable to shower variations
- Benchmark is VBF production but finding could be universal, what about other modes?

$t\bar{t}$H: experimental summary

Josh McFayden

- Inclusive signal strength measurements show that all channels apart from H→4l have similar sensitivities
- Most channels now moving focus to: **differential, CP and EFT interpretations**

	ATLAS	CMS
H→bb	$0.35^{+0.36}_{-0.34}$ HIGG-2020-23	$1.15^{+0.32}_{-0.29}$ CMS-PAS-HIG-18-030
H→multilep	$0.58^{+0.36}_{-0.33}$ ATLAS-CONF-2020-026 (80 fb^{-1})	$0.93^{+0.26}_{-0.23}$ Eur. Phys. J. C 81 (2021) 378
H→4l	$1.6^{+1.7}_{-1.1}$ Eur. Phys. J. C 80 (2020) 957	$0.04^{+0.76}_{-0.04}$ Phys. Rev. D 104 (2021) 052004
H→yy	$0.92^{+0.27}_{-0.24}$ ATLAS-CONF-2020-026	$1.35^{+0.34}_{-0.28}$ JHEP 07 (2021) 027

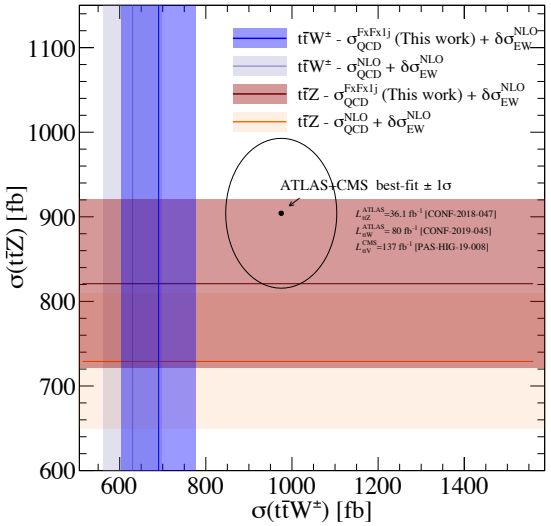
ttH: bkg modelling in multilepton

Laura Reina | Maria Moreno

ttW modelling for ttH(H → multi-leptons)

- k(ttZ) =1.03 ± 0.14 (stat+syst)
- **k(ttW) = 1.43 ±0.21(stat+syst)** [XS theory: 650 fb]
  consistent with other CMS and ATLAS measurements

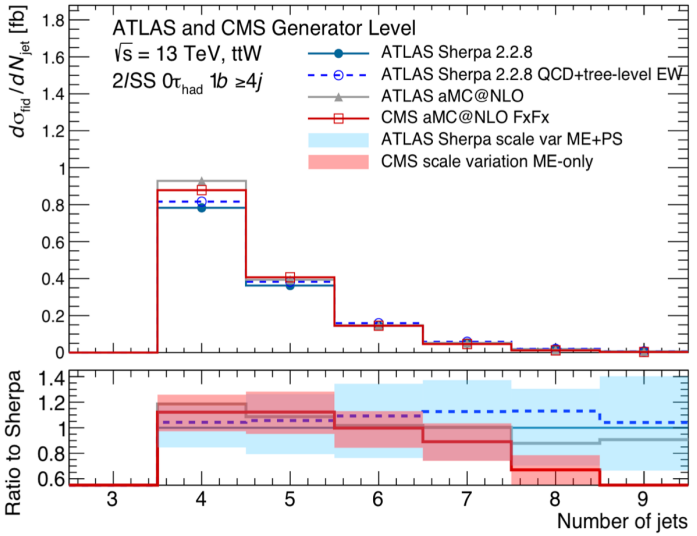
NLO QCD + jet merging +EW arXiv:2009.00032



- ttW modelling: important source of uncertainty in ttH multilepton
- ttW significantly higher in data than in state of the art predictions

- Several new theoretical developments pointing to sizable effects from higher-order QCD and EW diagrams. Need to explore partial NNLO?
- Ongoing work to provide complementary NLO+PS prediction (POWHEG-based)

- Ongoing effort comparing background modelling and estimation of theoretical uncertainties in ATLAS and CMS:
  - Aim to agree on common techniques to facilitate combination
  - Comparison of MC generator distributions at particle level
  - Fresh example plot from the workshop, public document imminent



ttH: bkg modelling in bb

ttbb modelling for ttH(H → bb)

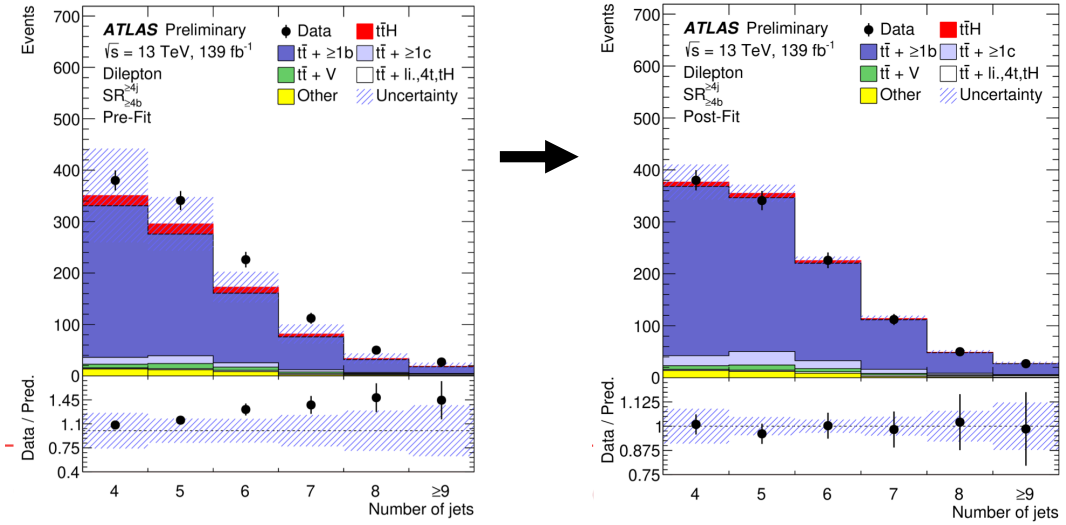
Laura Reina Maria Moreno

- Systematics dominated, dominant uncertainty: modelling of the tt+>1b dominant background
- Contribution in data also above state of the art predictions both in ATLAS and CMS by a factor 1.2 to 1.4 (floated)
- Shapes also not well reproduced, data driven tweaks

Several developments:

- Extensive comparison of NLOPS MC generators for tt+b jets background
- Important insight from NLO calculation of ttbb+jet [Buccioni et al. arXiv:1907.13624]
- Generators can now be tuned to reproduce features of extra radiation: agreed on two-step theoretical tuning of (μ_R , μ_{sh})
- Converging on final recommendation:
  - Will be documented soon in a publication and WG note
  - Reduced MC differences

Significant enhancement of ttbb XS (about 50% wrt YR4)



Mismodelling in jet multiplicity corrected in the fit (adjusting the amount of additional ISR radiation – see ranking plot in next slide)