(signal) Parton shower uncertainties in ATLAS Higgs analyses

Valerio Dao *(CERN)*
for the ATLAS Higgs group

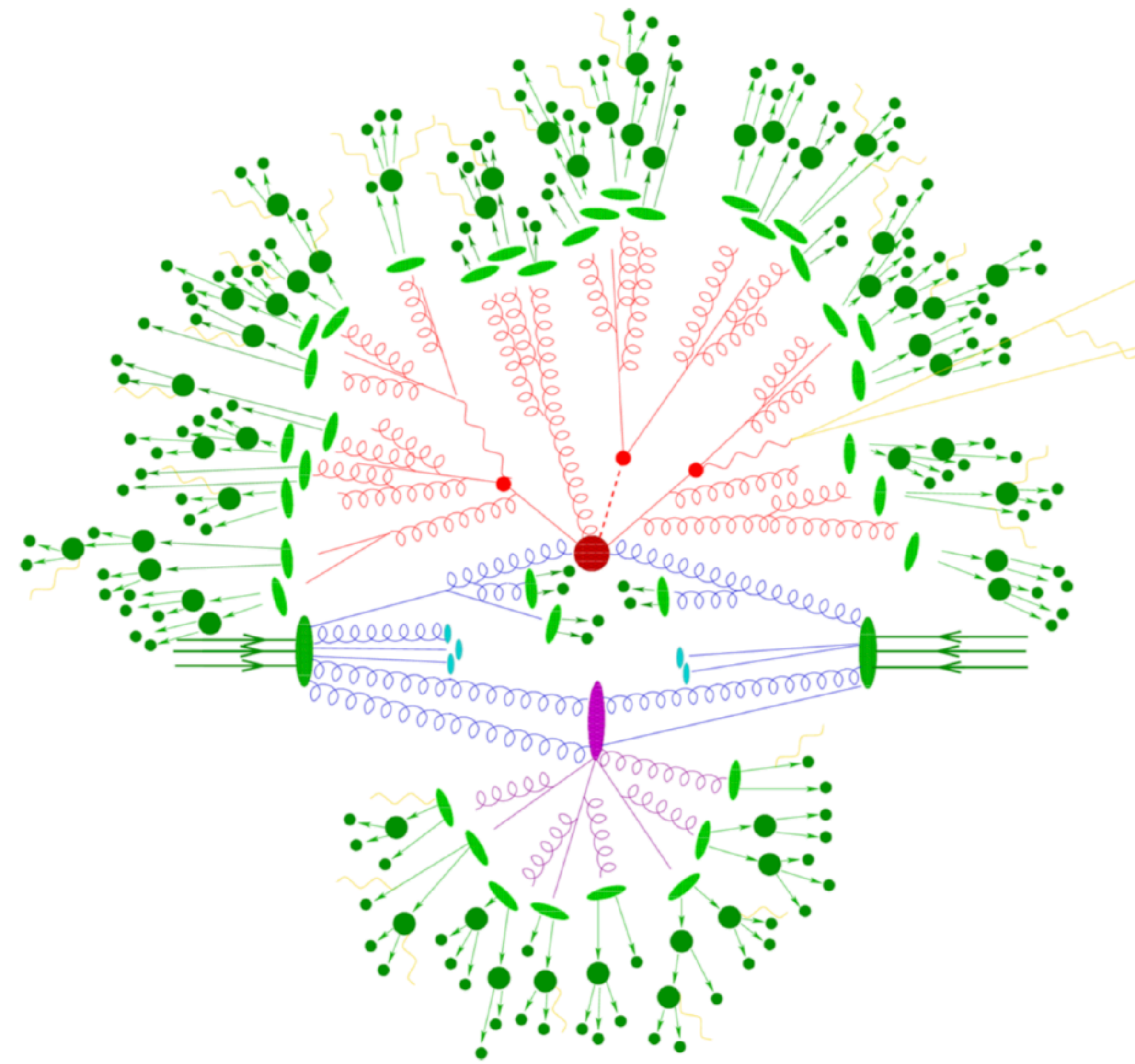
LHC Higgs WG1

27-06-2019

from C. Pandini's talk in November

What we call 'UEPS' uncertainty
~ aims at covering (approximately) several different effects
(with large interplays among them)

- hard interaction (*)
- final state radiation FSR
- initial state radiation ISR
- underlying event
- hadronisation
- hadron decay
- photon emission



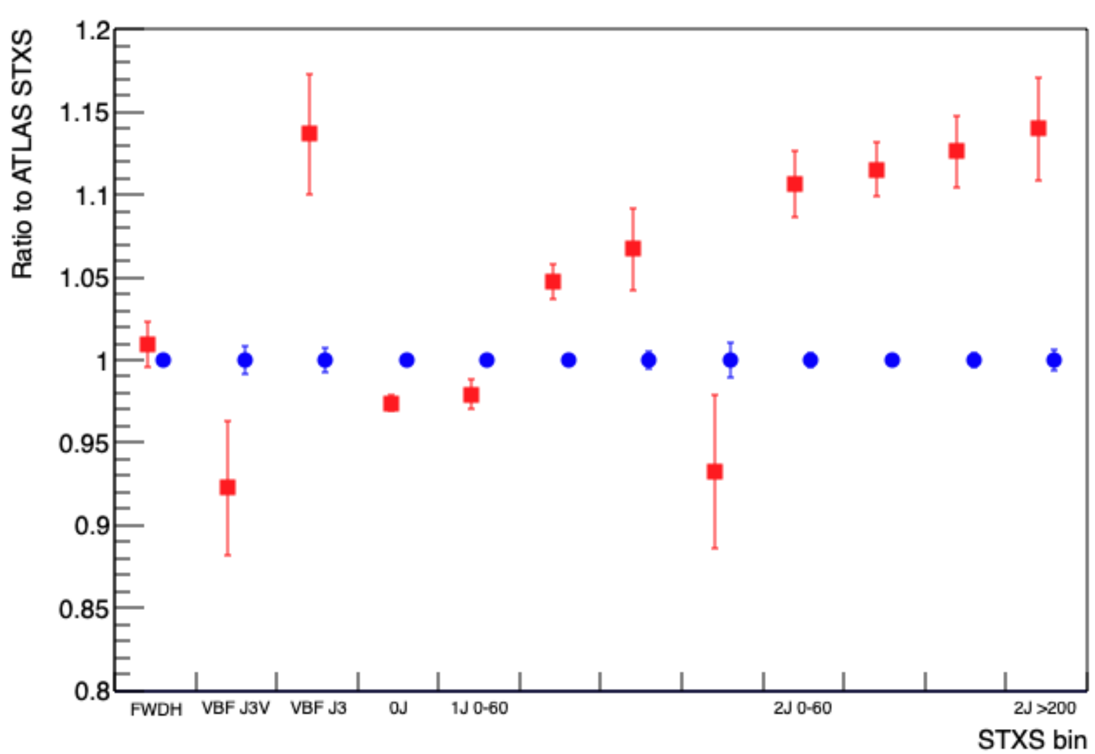
(*) estimated through scale uncertainties variations / comparison of different ME generators

PStune matters

- 2017 ATLAS-CMS comparison on ggH prediction in STXS bins (D. Gillbert, D. Sperka)

Stage-1 subprocess cross sections from NNLOPS (pb). Uncertainties are statistical uncertainties only.

Subprocess	CMS NLO PDF	CMS NNLO PDF	CMS NNLO PDF+ATLAS PS Tune	ATLAS
FWDH	4.31 ± 0.058	4.27 ± 0.056	4.27 ± 0.057	4.27 ± 0.01
VBF_J3V	0.25 ± 0.011	0.23 ± 0.01	0.27 ± 0.011	0.27 ± 0.00
VBF_J3	0.41 ± 0.013	0.41 ± 0.013	0.37 ± 0.012	0.36 ± 0.00
0J	26.53 ± 0.132	26.85 ± 0.134	26.95 ± 0.133	27.25 ± 0.03
1J_0-60	6.36 ± 0.058	6.58 ± 0.059	6.61 ± 0.059	6.49 ± 0.01
1J_60-120	4.71 ± 0.047	4.54 ± 0.046	4.58 ± 0.046	4.50 ± 0.01
1J_120-200	0.79 ± 0.018	0.75 ± 0.017	0.75 ± 0.017	0.74 ± 0.00
1J_200	0.14 ± 0.007	0.14 ± 0.007	0.17 ± 0.008	0.15 ± 0.00
2J_0-60	1.35 ± 0.025	1.29 ± 0.025	1.24 ± 0.024	1.22 ± 0.01
2J_60-20	2.08 ± 0.031	1.97 ± 0.029	1.89 ± 0.029	1.86 ± 0.01
2J_120-200	1.11 ± 0.021	1.08 ± 0.02	1.0 ± 0.02	0.99 ± 0.00
2J_200	0.48 ± 0.013	0.43 ± 0.012	0.43 ± 0.012	0.42 ± 0.00



- differences due to different Pythia tune between ATLAS and CMS have nn negligible impact on STXS bin predictions: still smaller than perturbative uncertainties

motivational slide

- a non leading uncertainty today can become the leading uncertainty of tomorrow (also very difficult to constrain on the signal itself)

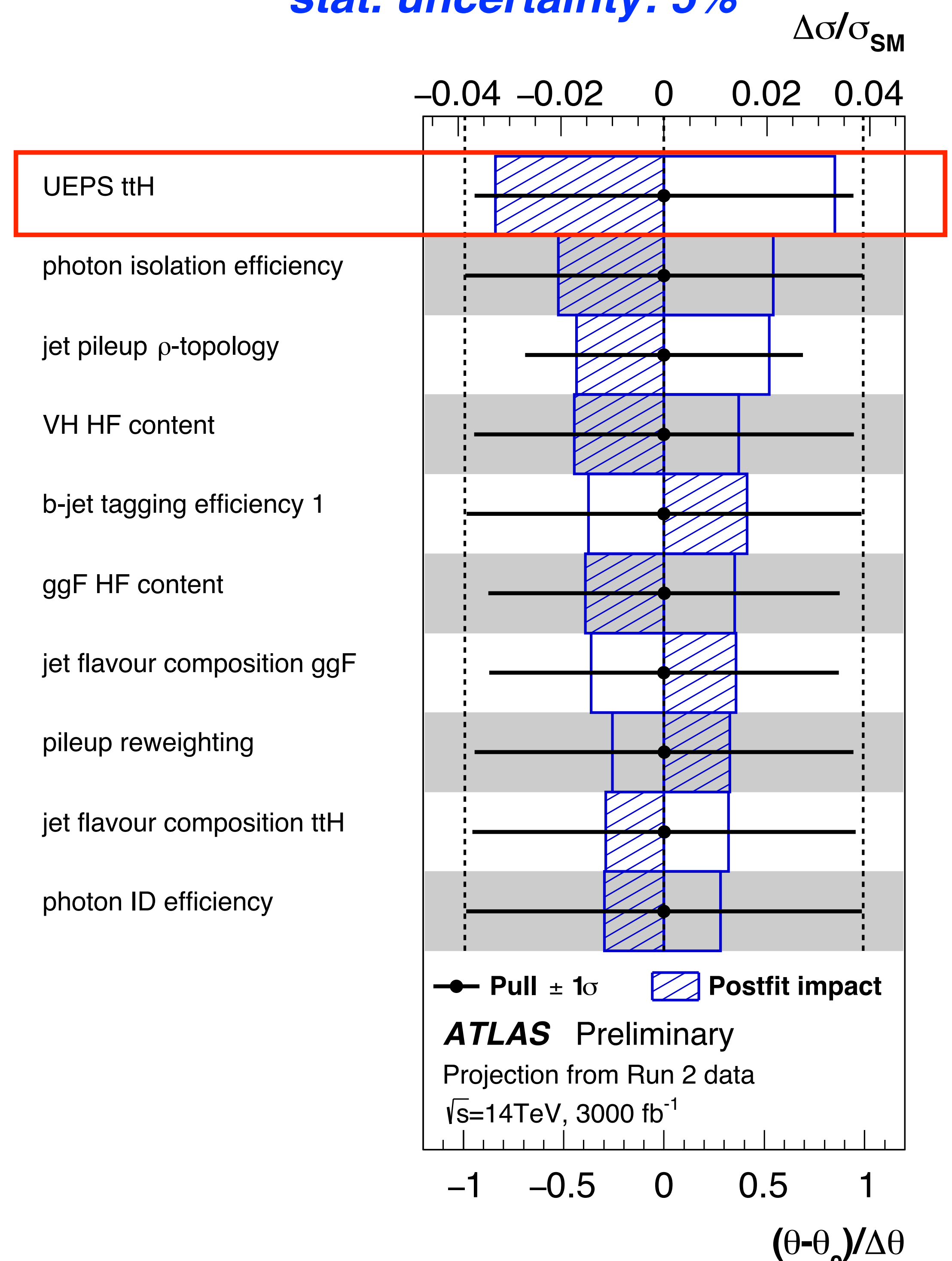
ttHyy: ATLAS 140 fb^{-1}

stat. uncertainty: 21%

Uncertainty source	$\Delta\sigma_{\text{low}}/\sigma$ [%]	$\Delta\sigma_{\text{high}}/\sigma$ [%]
Theory uncertainties	6.6	9.7
Underlying Event and Parton Shower (UEPS)	5.0	7.2
Modeling of Heavy Flavor Jets in non-$t\bar{t}H$ Processes	4.0	3.4
Higher-Order QCD Terms (QCD)	3.3	4.7
Parton Distribution Function and α_S Scale (PDF+α_S)	0.3	0.5
Non-$t\bar{t}H$ Cross Section and Branching Ratio to $\gamma\gamma$ (BR)	0.4	0.3
Experimental uncertainties	7.8	9.1
Photon Energy Resolution (PER)	5.5	6.2
Photon Energy Scale (PES)	2.8	2.7
Jet/E_T^{miss}	2.3	2.7
Photon Efficiency	1.9	2.7
Background Modeling	2.1	2.0
Flavor Tagging	0.9	1.1
Leptons	0.4	0.6
Pileup	1.0	1.5
Luminosity and Trigger	1.6	2.3
Higgs Boson Mass	1.6	1.5

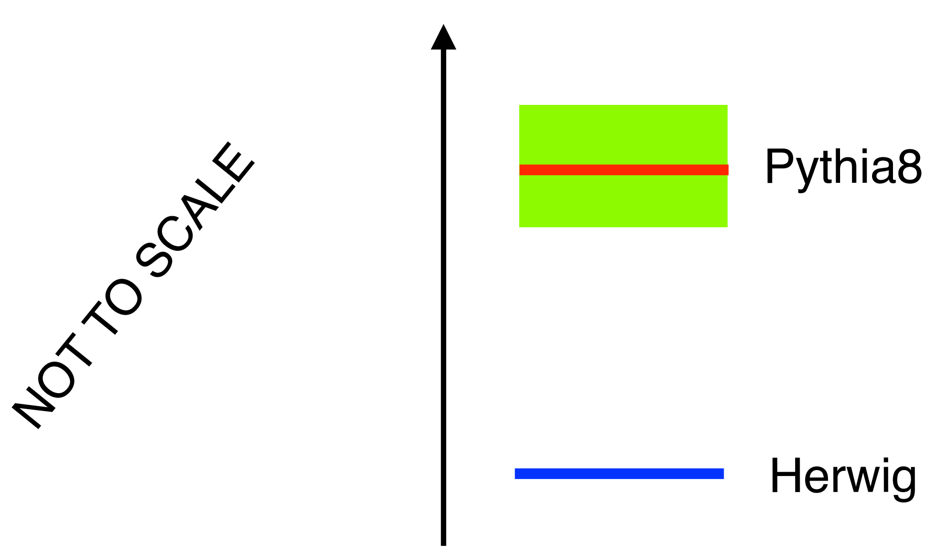
ttHyy: ATLAS 3000 fb^{-1}

stat. uncertainty: 5%



short summary

- Approaches in ATLAS:
  - ***compare 2 different shower generators*:**
    - typically: Pythia8 [nominal] VS Herwig
    - a lot of “things” varied at the same time: nominal tunes, transverse momentum/angular-ordered, string/cluster- hadronization model, different evolution variable, ...
  - ***consider internal variations of a given generator*:**
    - Pythia8 tune uncertainties from ATLAS data
    - more controlled variation of some generator parameters [more later]
    - used as additional source of uncertainty



- ***Spoiler alert***: difference between parton shower models typically much larger than internal generator variations
- Largest variation currently used as a conservative approach:
  - ***underestimating variations inside a given generator?***
  - ***mis-configuration of one of the 2?***
  - ***no unc. band on the second generator?***

Technical info

process	Nominal generator generator	alternative PS generator	additional unc.
ggH	Powheg (NNLOPS) + Pythia 8 (AZNLO)	Powheg (NNLOPS) + Herwig7 (UE-MMHT)	AZNLO tune uncs. + Pythia8 variations
VBF	Powheg + Pythia 8 (AZNLO)	Powheg + Herwig7 (UE-MMHT)	AZNLO tune uncs. + Pythia8 variations
VH	Powheg (MINLO) + Pythia 8 (AZNLO)	Powheg (MINLO) + Herwig7 (UE-MMHT)	AZNLO tune uncs. + Pythia8 variations
ttH	Powheg + Pythia 8 (A14)	aMC@NLO + Herwig++(UEEE5) VS aMC@NLO + Pythia 8 (A14)	

- General statement: *"any MC variation is implemented in the analyses as a nuisance parameter (NP) with gaussian constrain: the effect represent the 1-sigma change of the nuisance parameter".*

- necessary steps (in order of importance):
  - ***what is the impact of a given variation***
  - ***how to implement this in the fit:*** *how many nuisance parameters, correlation/decorrelation among samples/regions, etc* [generally more critical for bkgd processes where sometimes data has enough power to constrain such variations]

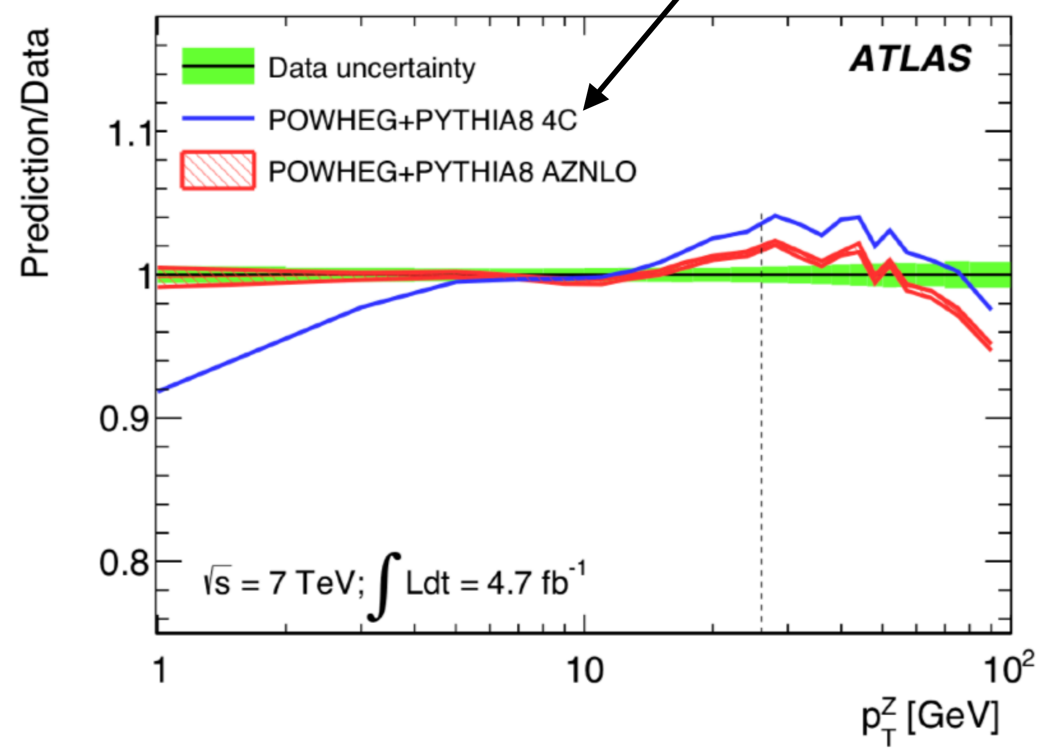
(*) published analyses uses Herwig 7.0.1, now switching to Herwig 7.1.3

Intermezzo: Pythia8 AZNLO tune

- Specific tuning of Powheg+Pythia8 (NLO+PS) with Z p_T 7 TeV data:
  - ***Z p_T <26 GeV***

	Pythia8	Powheg+Pythia8	Base tune
Tune Name	AZ	AZNLO	4C
Primordial k_T [GeV]	1.71 ± 0.03	1.75 ± 0.03	2.0
ISR $\alpha_S^{ISR}(m_Z)$	0.1237 ± 0.0002	0.118 (fixed)	0.137
ISR cut-off [GeV]	0.59 ± 0.08	1.92 ± 0.12	2.0
χ^2_{min}/dof	45.4/32	46.0/33	-

starting point (rapidity ordering on)



- 4 variations considered:
  - ***variation of "primordial kT" and "ISR cut-off":*** combined into 2 eigen-variations (tune uncertainties)
  - ***UE component:*** MPI cut-off
  - ***FSR component:*** renorm scale

AZNLO tune	primordial k_T	ISR cut-off
central	1.749	1.924
eigentune 1+	1.719	1.919
eigentune 1-	1.780	1.928
eigentune 2+	1.762	1.844
eigentune 2-	1.737	2.004

- *UE uncertainty:* Variation of the MPI Cut-off : between 1.91 to 2.05
- *FSR uncertainty:* Variation of the renormalization scale: 0.5 to 2

Intermezzo: tune comparison

courtesy of C. Pandini

Parameter	A14	Definition	Sampling range
SigmaProcess:alphaSvalue		The α_S value at scale $Q^2 = M_Z^2$	0.12 – 0.15
SpaceShower:pT0Ref		ISR p_T cutoff	0.75 – 2.5
SpaceShower:pTmaxFudge		Mult. factor on max ISR evolution scale	0.5 – 1.5
SpaceShower:pTdampFudge		Factorisation/renorm scale damping	1.0 – 1.5
SpaceShower:alphaSvalue		ISR α_S	0.10 – 0.15
TimeShower:alphaSvalue		FSR α_S	0.10 – 0.15
BeamRemnants:primordialKThard		Hard interaction primordial $k_\perp$	1.5 – 2.0
MultipartonInteractions:pT0Ref		MPI p_T cutoff	1.5 – 3.0
MultipartonInteractions:alphaSvalue		MPI α_S	0.10 – 0.15
BeamRemnants:reconnectRange		CR strength	1.0 – 10.0

Generator Tune name	AZNLO	Powheg+Pythia8 AZNLO
Base tune		4C
Pythia8 paramet		
primordial k_T	BeamRemnants:primordialKThar	1.75
ISR $\alpha_s^{ISR}(M_Z)$	SpaceShower:alphaSvalue	0.118
ISR cut-off	SpaceShower:pT0Ref	1.92
ISR α_s order	SpaceShower:alphaSorder	2
ISR limit	SpaceShower:pTmaxMatch	1
MPI cut-off	MultipartonInteractions:pT0Ref	2.00

Herwig7 native tune H7-UE-MMHT PS cutoff & hadronization

Parameter	H7-UE-MMHT
$p_{\perp,0}^{min}$ **[MPI cutoff]**	4.39
b	0.366
μ^2/GeV^2	2.30
$p_{disrupt}$	0.798
p_{reco}	0.4276

Practical info (2)

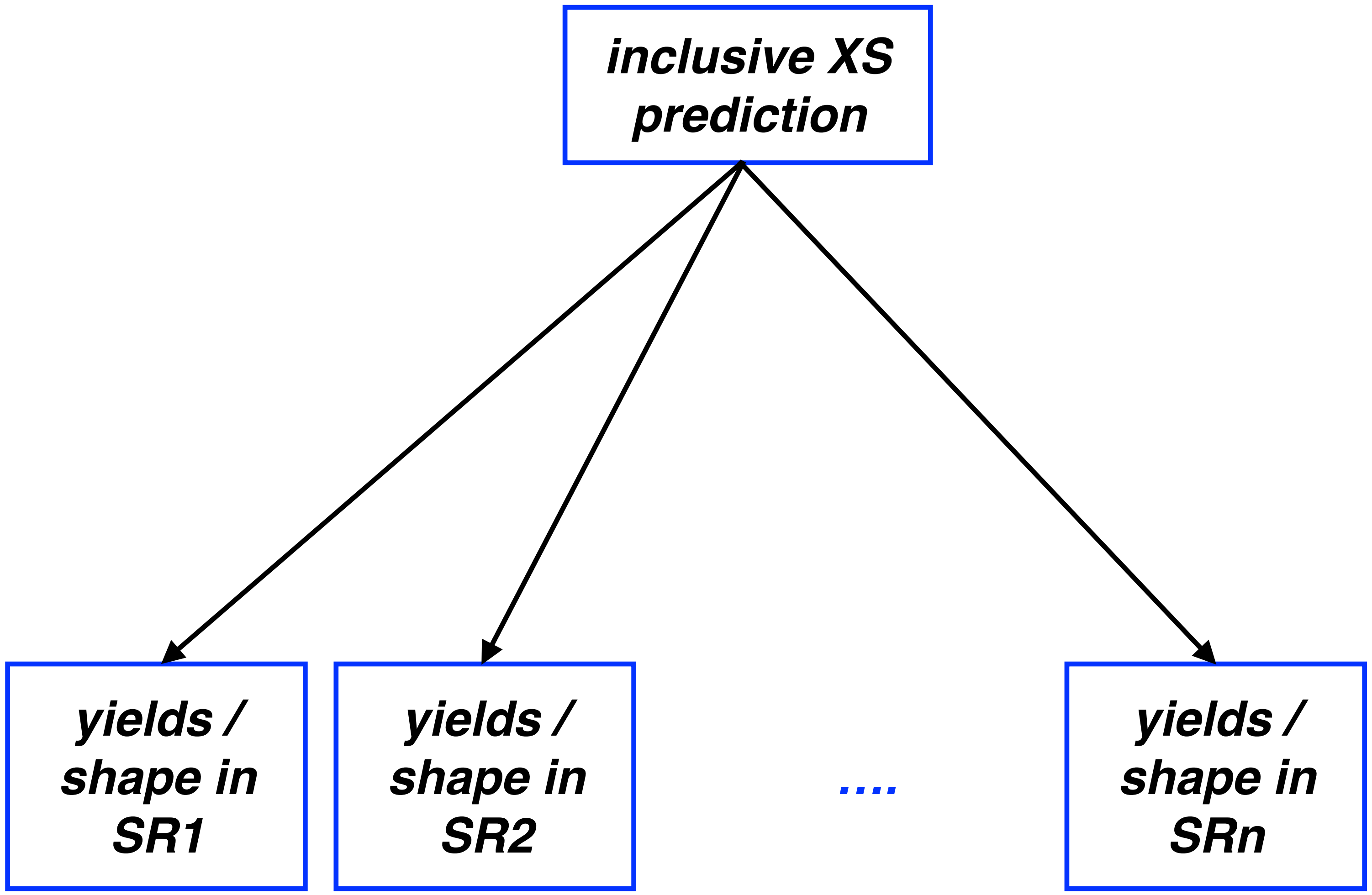
process	Nominal generator generator	alternative PS generator	additional unc.
ggH	Powheg (NNLOPS) + Pythia 8 (AZNLO)	Powheg (NNLOPS) + Herwig7 (UE-MMHT)	AZNLO tune uncs. + Pythia8 variations
VBF	Powheg + Pythia 8 (AZNLO)	Powheg + Herwig7 (UE-MMHT)	AZNLO tune uncs. + Pythia8 variations
VH	Powheg (MINLO) + Pythia 8 (AZNLO)	Powheg (MINLO) + Herwig7 (UE-MMHT)	AZNLO tune uncs. + Pythia8 variations
ttH	Powheg + Pythia 8 (A14)	aMC@NLO + Herwig++(UEEE5) VS aMC@NLO + Pythia 8 (A14)	

- all analyses uses Pythia8 VS Herwig as main uncertainty:
  - ***uncorrelated nuisance parameters among production modes***

- some analyses (H->ZZ, H->yy, VHbb) looked at effect of shower variations:
  - ***typically smaller than Pythia8 VS Herwig***
  - ***consider the overall effect as an additional NP or one NP for each tune variation***
  - ***fully correlated among production modes*** (when applicable)
  - ***additional ad-hoc implementation by analyses to better isolate the effects:*** VHbb separate overall effects from 2->3 j migration effect in 2018 paper

effect in the analysis

- *analyses are getting more and more precise (and therefore complex)*: many SR, multivariate shape for signal extraction or signal classification

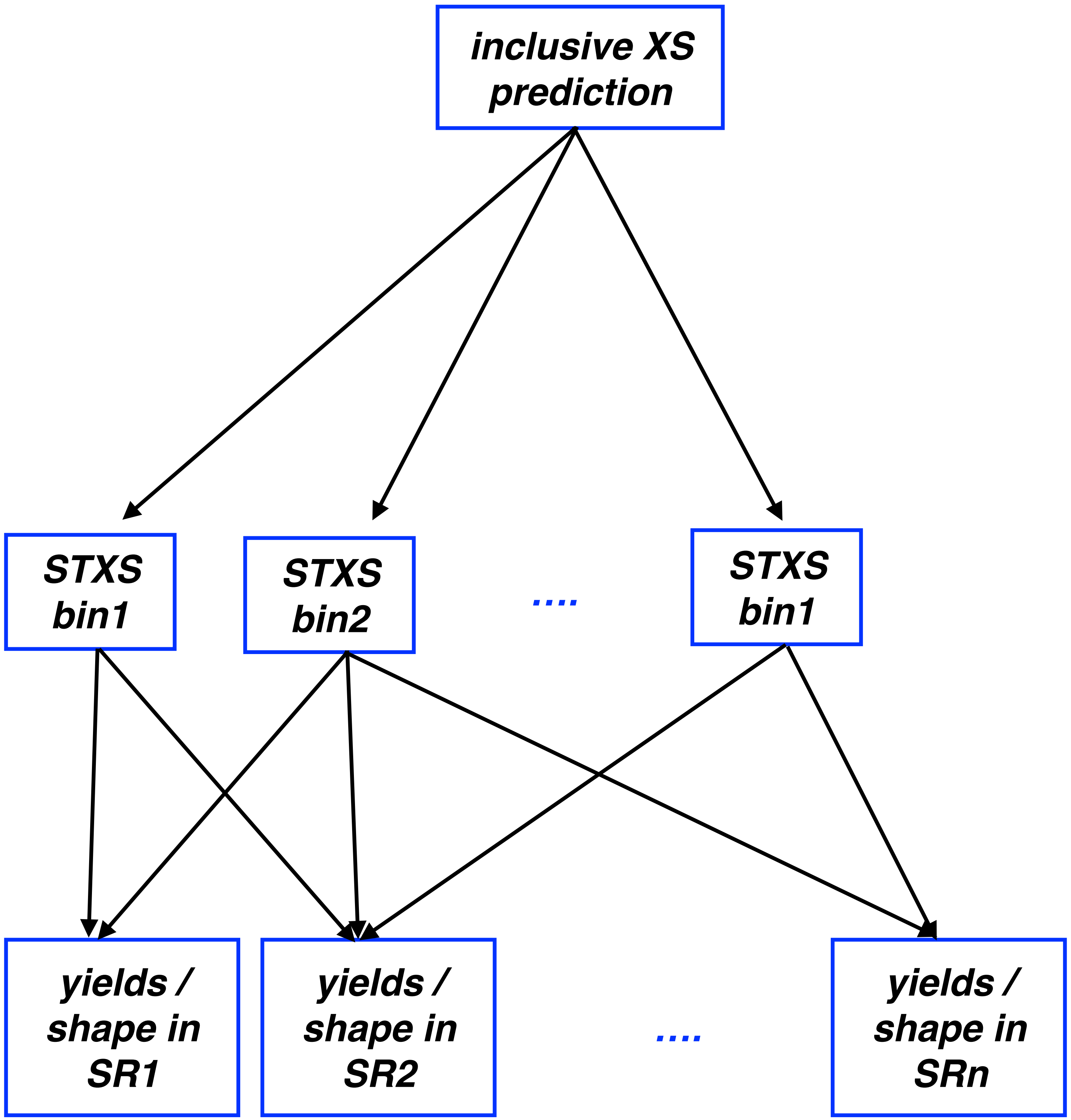


- ***event kinematic (FSR/ISR)***
- ***jet fragmentation (FSR/ISR/decay)***
- ***underlying events contamination***
- ***treatment of leptons***
- ***b-hadron production/decay (evtgen is used)***
- ***....***

- ***very cumbersome*** to document in a publication the effect of each sys in each regions/samples etc —> usual solution is quoting the impact on the final measurement: not necessarily straightforward to identify what is the reason for such impact

effect in the analysis (2)

- evaluating uncertainties in STXS bins can help pinging down the dominant effects (more later)



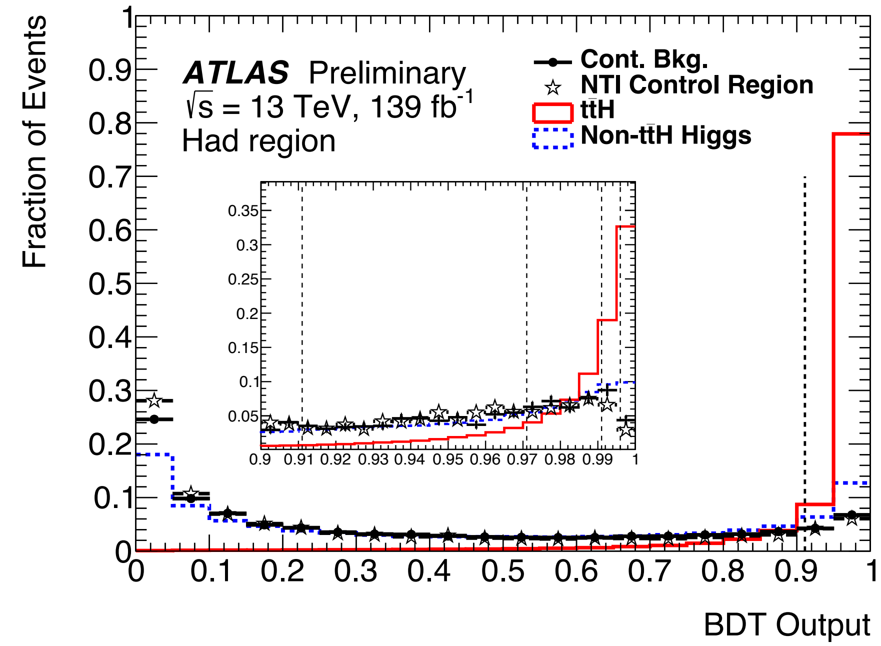
- ***event kinematic (ISR only)***
- ***jet fragmentation (ISR only)***
- ***underlying events contamination***

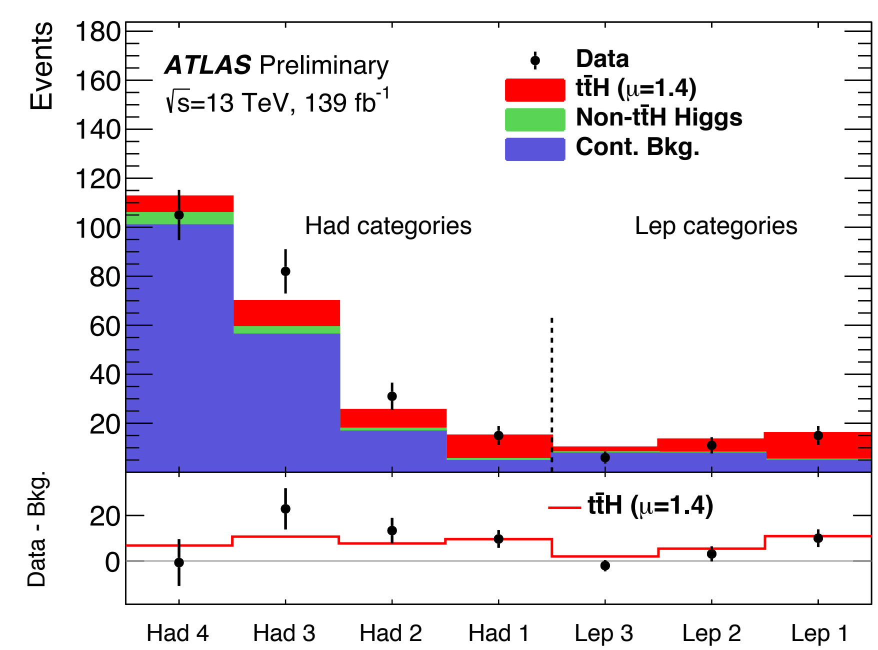
- ***event kinematic (FSR/ISR)***
- ***jet fragmentation (FSR/decay)***
- ***underlying events contamination***
- ***treatment of leptons***
- ***b-hadron production/decay (evtgen is used)***
- ***....***

some selected examples

- ***fit to $m_{\gamma\gamma}$ spectra in 8 regions defined by a cut on a BDT:***
  - UEPS is only aMC@NLO+Pythia8 VS aMC@NLO+Herwig++

Uncertainty source	$\Delta\sigma_{\rm low}/\sigma$ [%]	$\Delta\sigma_{\rm high}/\sigma$ [%]
Theory uncertainties	6.6	9.7
Underlying Event and Parton Shower (UEPS)	5.0	7.2
Modeling of Heavy Flavor Jets in non-ttH Processes	4.0	3.4
Higher-Order QCD Terms (QCD)	3.3	4.7
Parton Distribution Function and α_S Scale (PDF+α_S)	0.3	0.5
Non-$t\bar{t}H$ Cross Section and Branching Ratio to $\gamma\gamma$ (BR)	0.4	0.3
Experimental uncertainties	7.8	9.1
Photon Energy Resolution (PER)	5.5	6.2
Photon Energy Scale (PES)	2.8	2.7
Jet/$E_{\rm T}^{\rm miss}$	2.3	2.7
Photon Efficiency	1.9	2.7
Background Modeling	2.1	2.0
Flavor Tagging	0.9	1.1
Leptons	0.4	0.6
Pileup	1.0	1.5
Luminosity and Trigger	1.6	2.3
Higgs Boson Mass	1.6	1.5

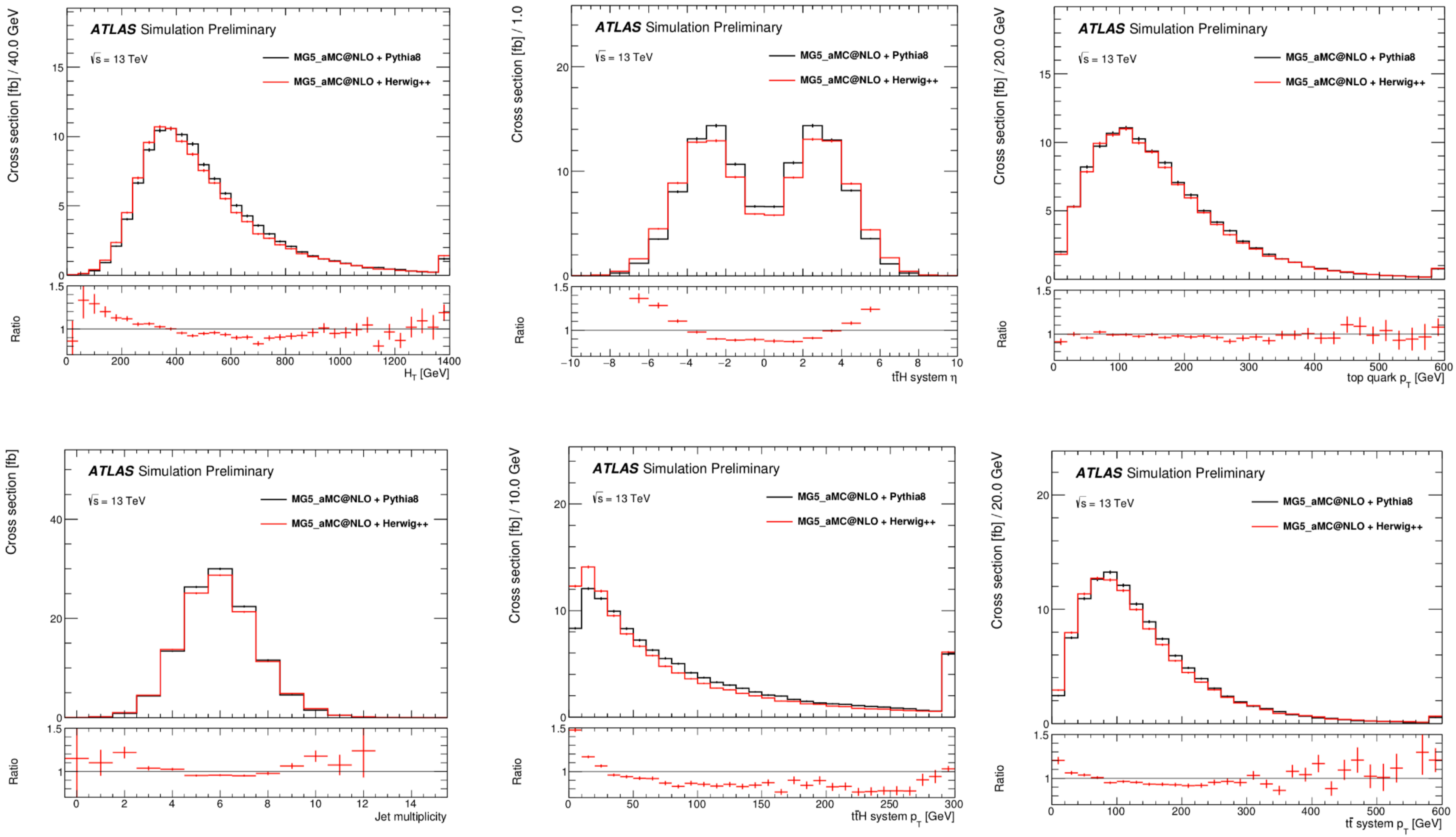


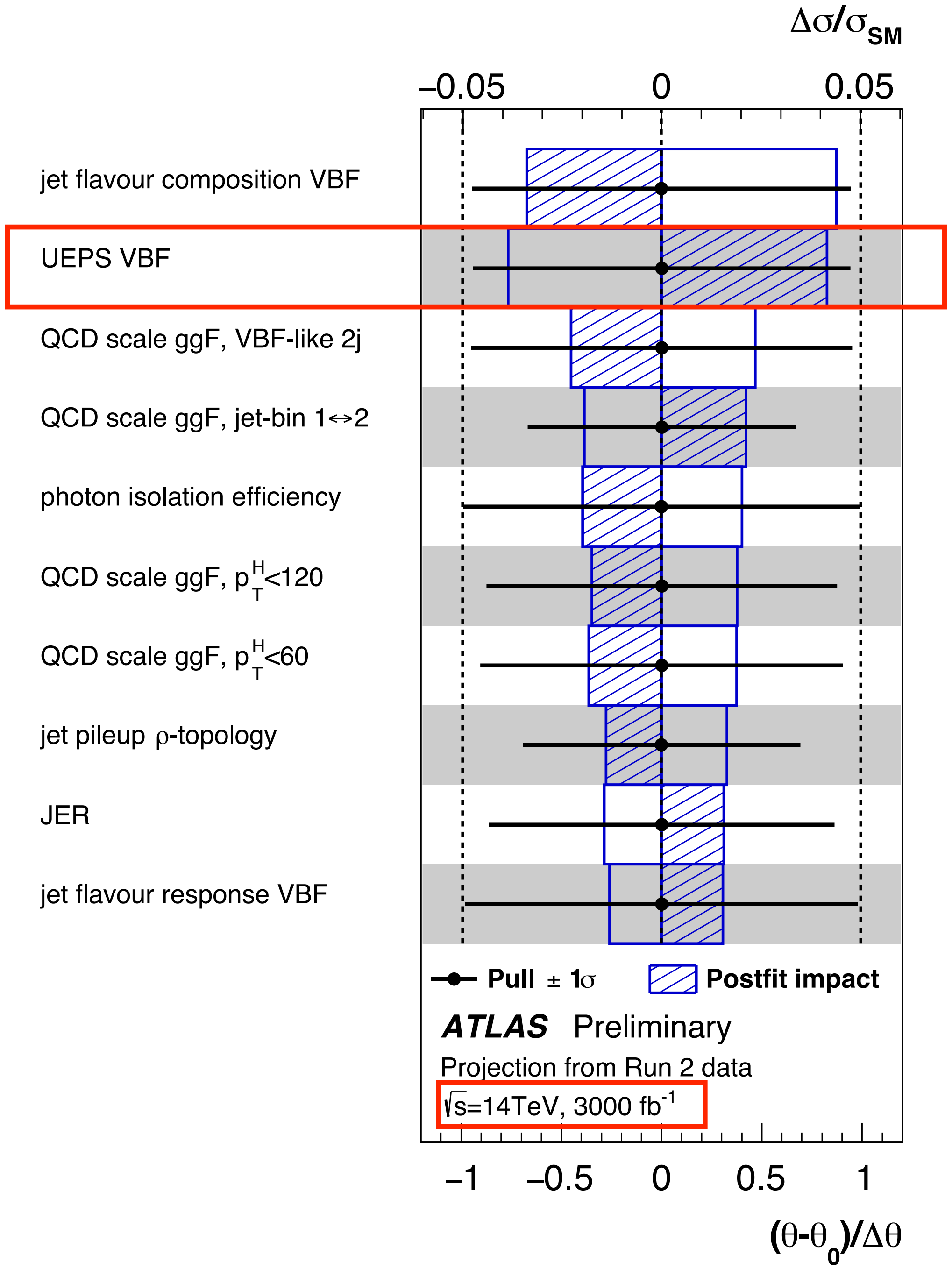


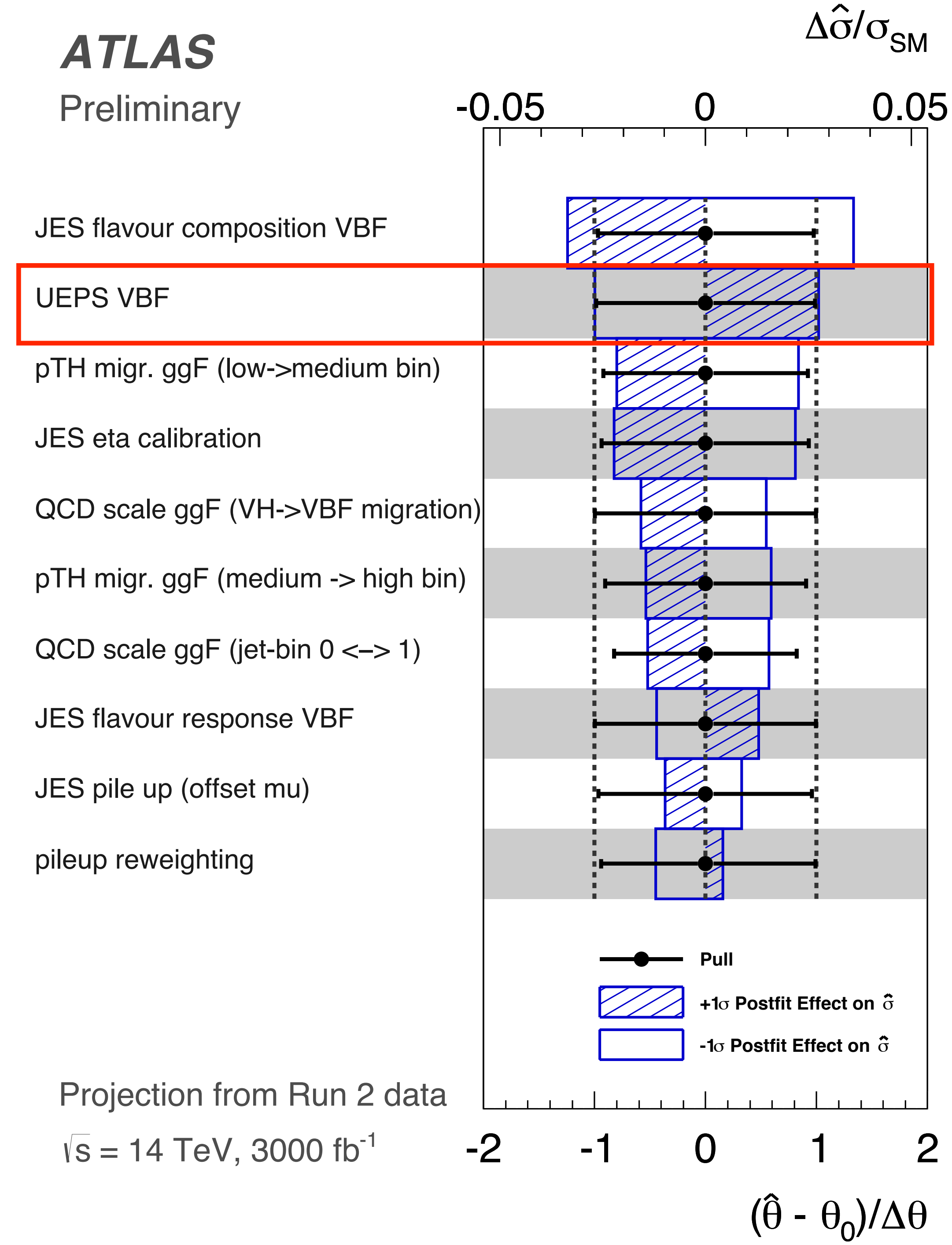
- ***Acceptance effects vary from +5% to -11% in the BDT bins***

ttH (cont)

- ***truth level comparison from ATL-PHYS-PUB-2016-005***



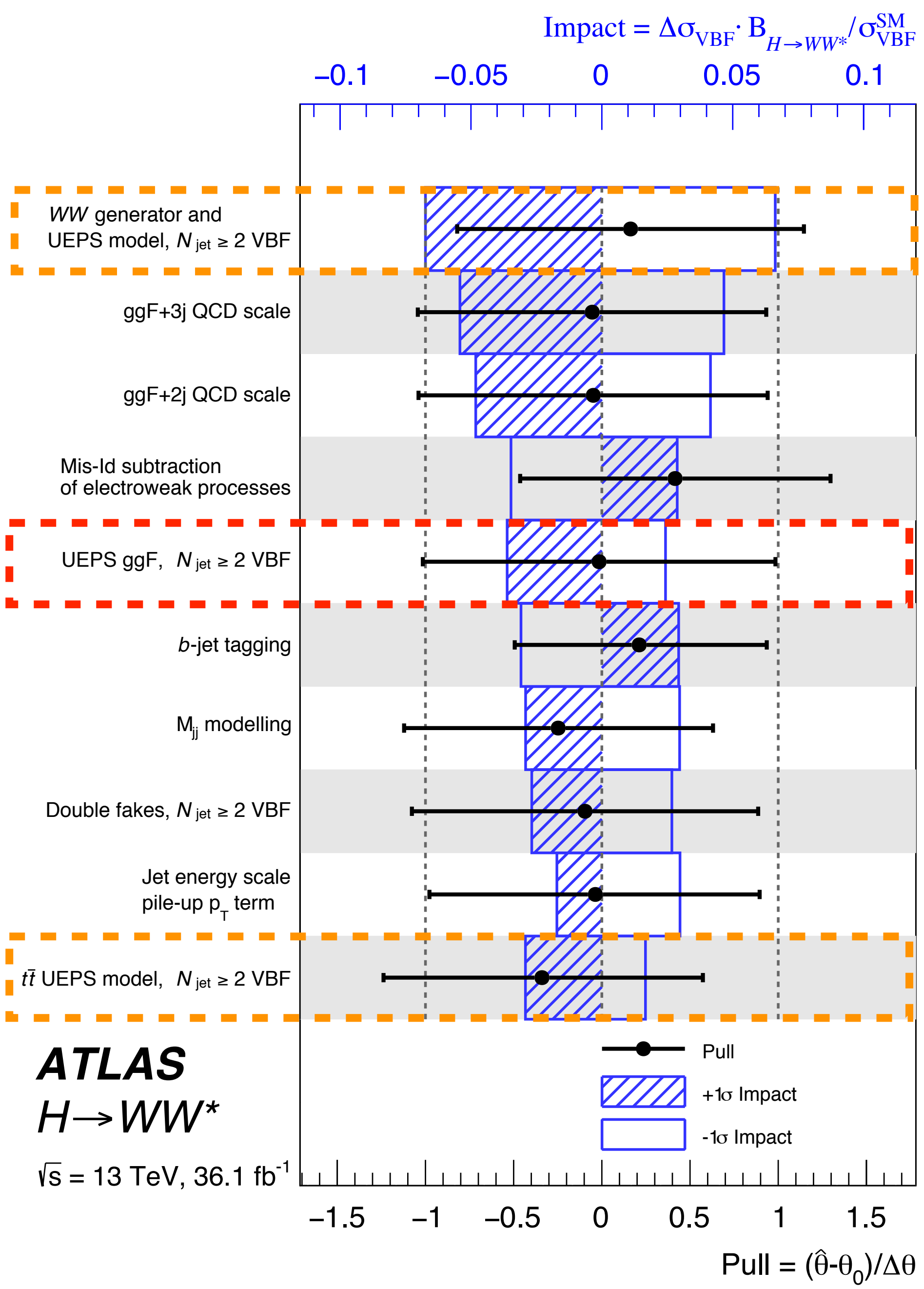


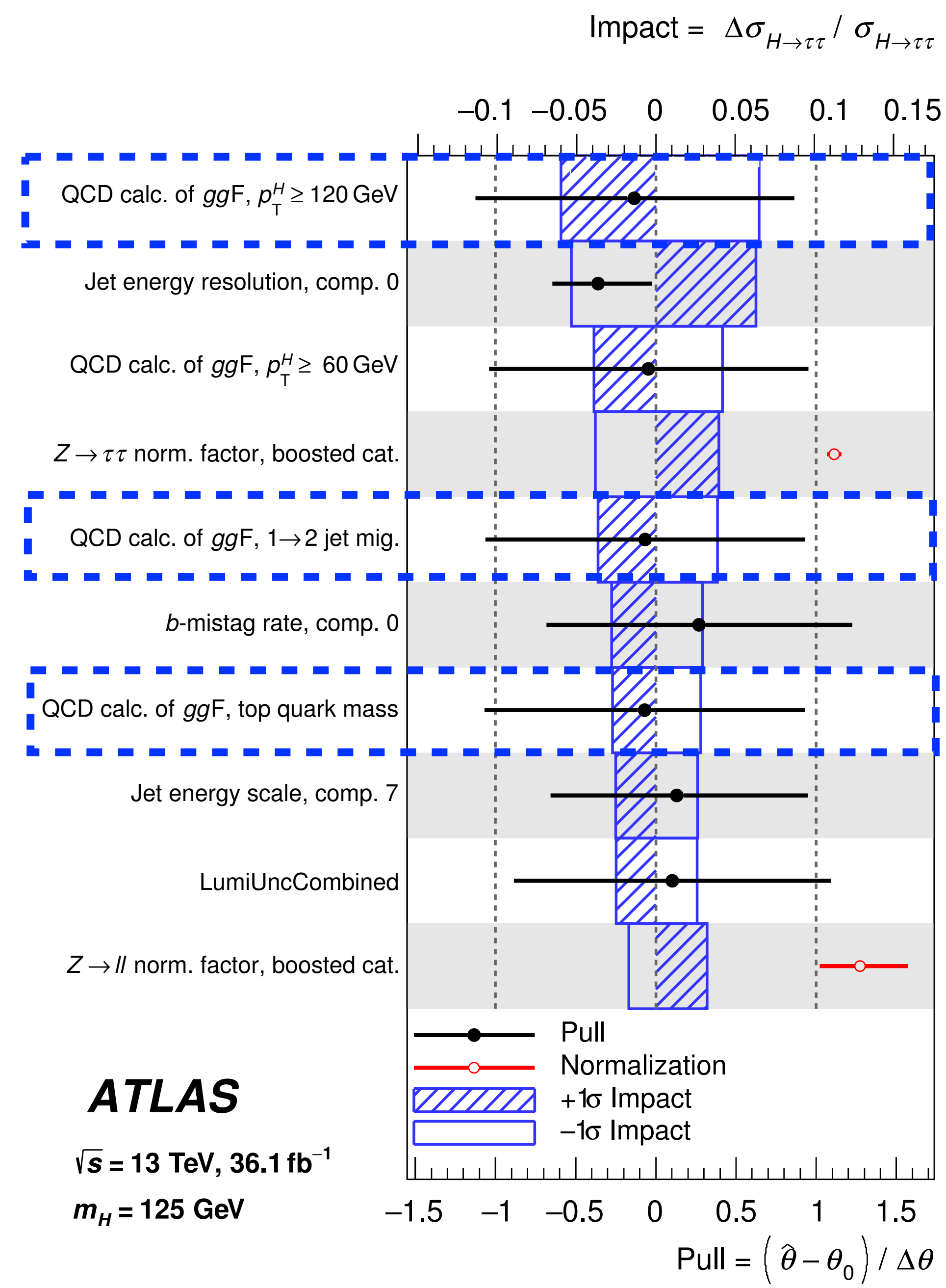


- 2 NP: Pythia VS Herwig and PSvariations (only for ggH)
- 1-18% effect signal acceptance
- 9% effect in VBF sample in SR

H->WW

H->ττ



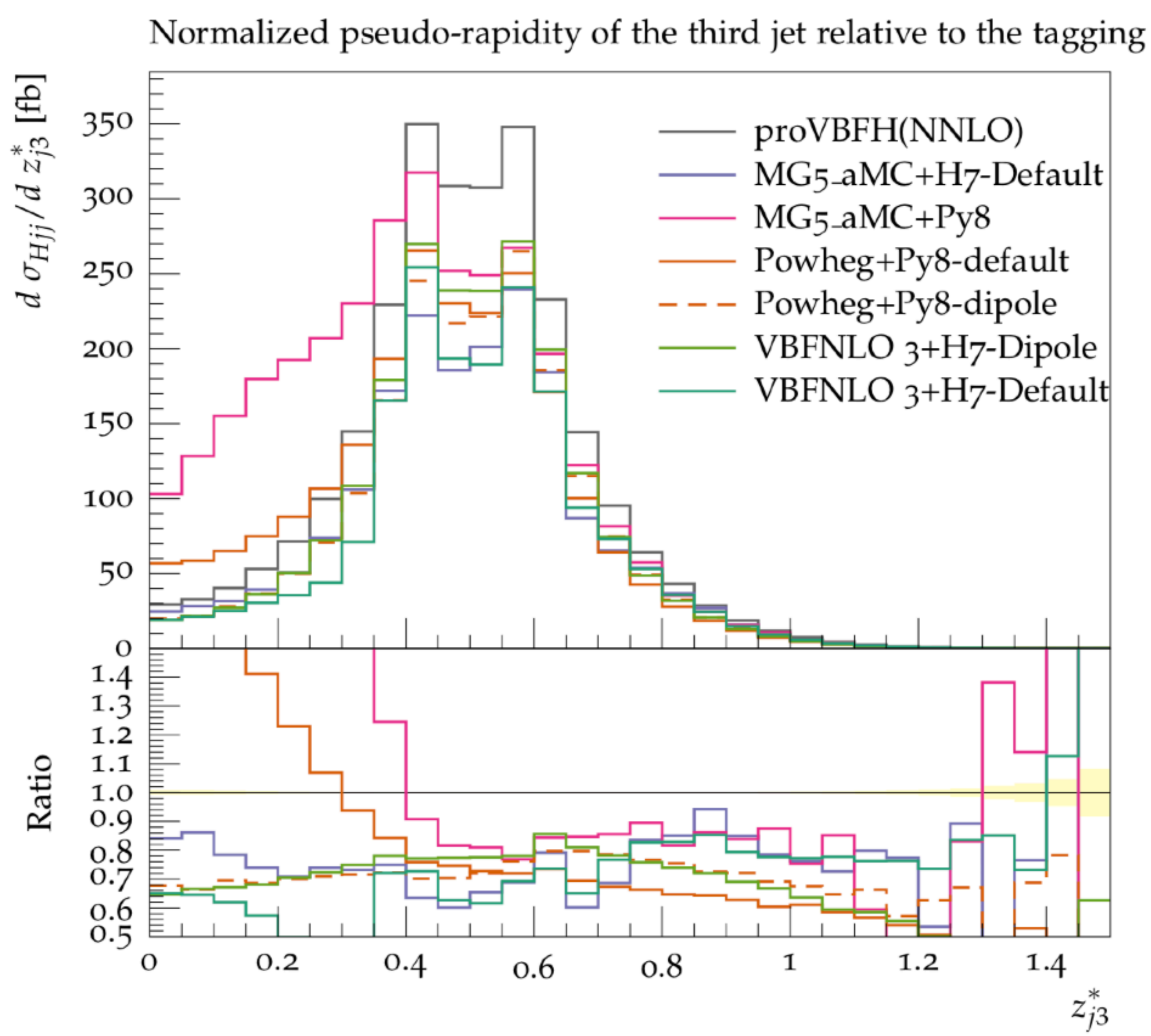


- ***Pythia VS Herwig dominates the VBF signal sensitivity due to ggH and bkgd contamination***

- ***Dominant signal unc. are higher order corrections rather than PSUE:***
  - Pythia8 VS Herwig7: 2%-26% on ggF acceptance, 2%-18% for VBF acceptance

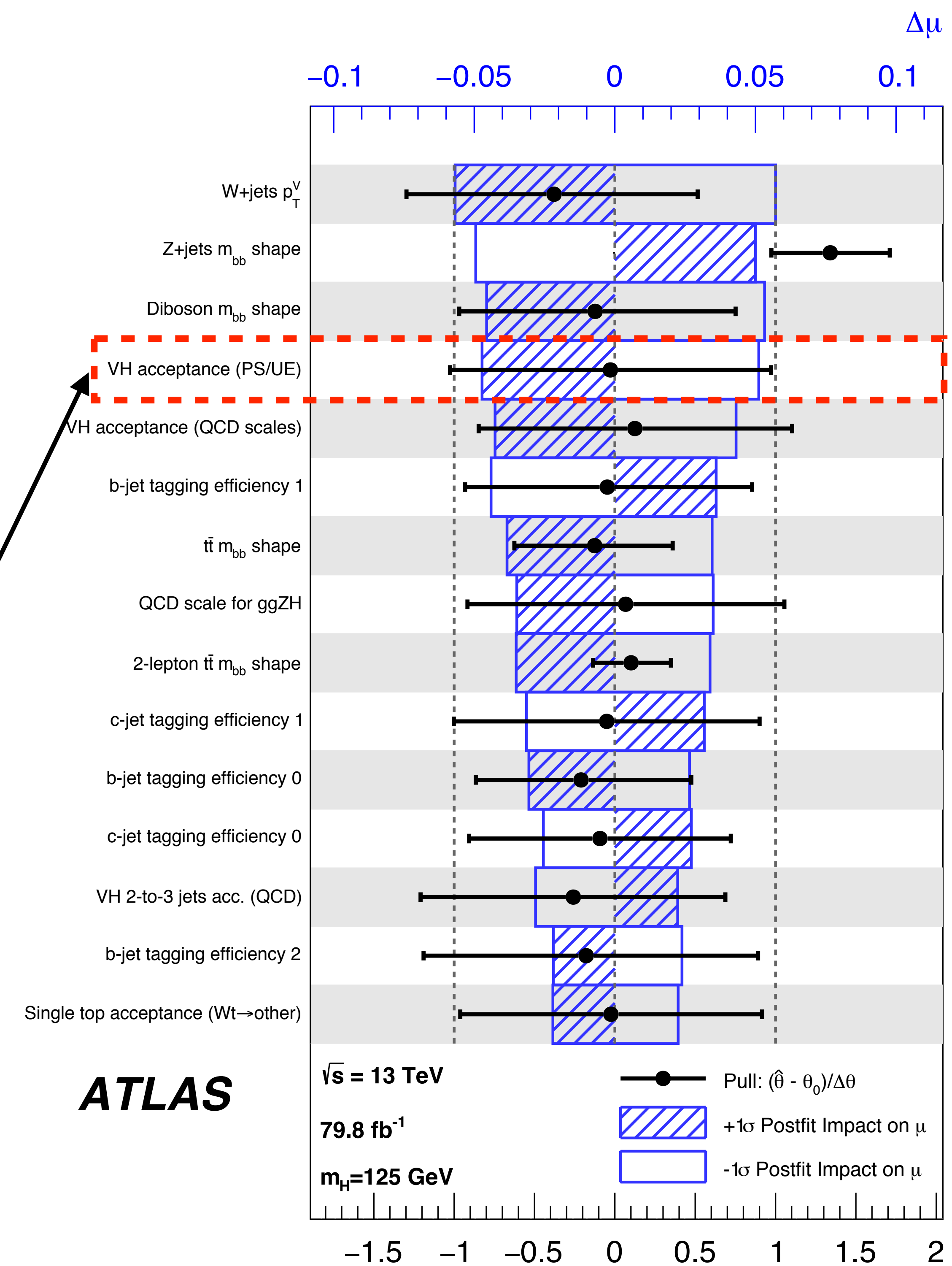
- *All VBF PS uncertainty are computed using the "default" version of Pythia8*

link



- ***Considering envelope of Pythia8 VS Herwig7 and sum in quadrature of Pythia8 shower variations:***
  - Pythia VS Herwig dominates everywhere
  - splitting *overall acceptance contribution* from *nJet migration*
  - prescription refined for the STXS paper (5 NP), but overall picture is unchanged

	Signal
Cross-section (scale)	0.7% (qq), 27% (gg)
Cross-section (PDF)	1.9% ($qq \to WH$), 1.6% ($qq \to ZH$), 5% (gg)
$H \to b\bar{b}$ branching fraction	1.7%
Acceptance from scale variations	2.5 – 8.8%
Acceptance from PS/UE variations for 2 or more jets	2.9 – 6.2% (depending on lepton channel)
Acceptance from PS/UE variations for 3 jets	1.8 – 11%
Acceptance from PDF+α_S variations	0.5 – 1.3%
m_{bb}, p_T^V, from scale variations	S
m_{bb}, p_T^V, from PS/UE variations	S
m_{bb}, p_T^V, from PDF+α_S variations	S
p_T^V from NLO EW correction	S



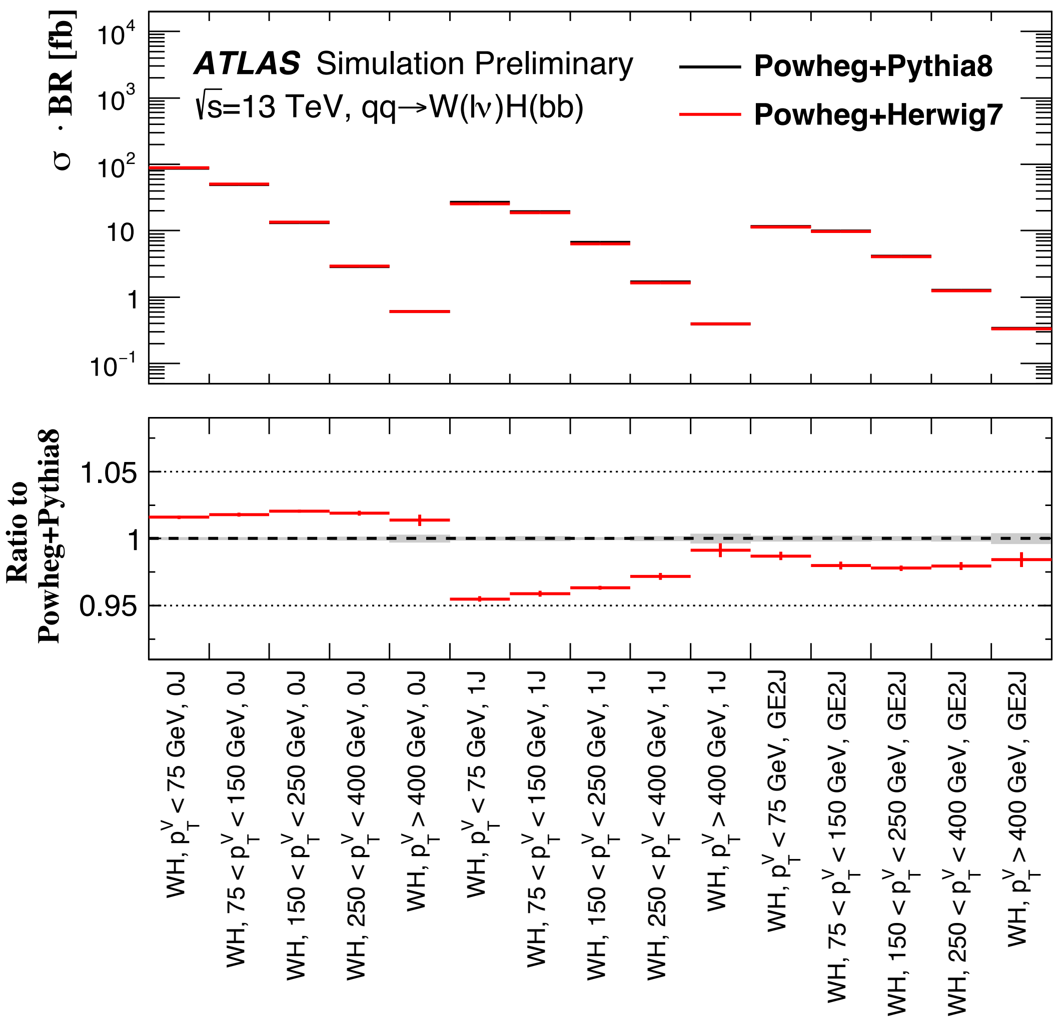
- ***Leading effect from overall acceptance common to most of the SR:***
  - effect on Higgs/V decays? (lepton / b-tagging)
  - impact on shape like m_{bb} is visible but not critical

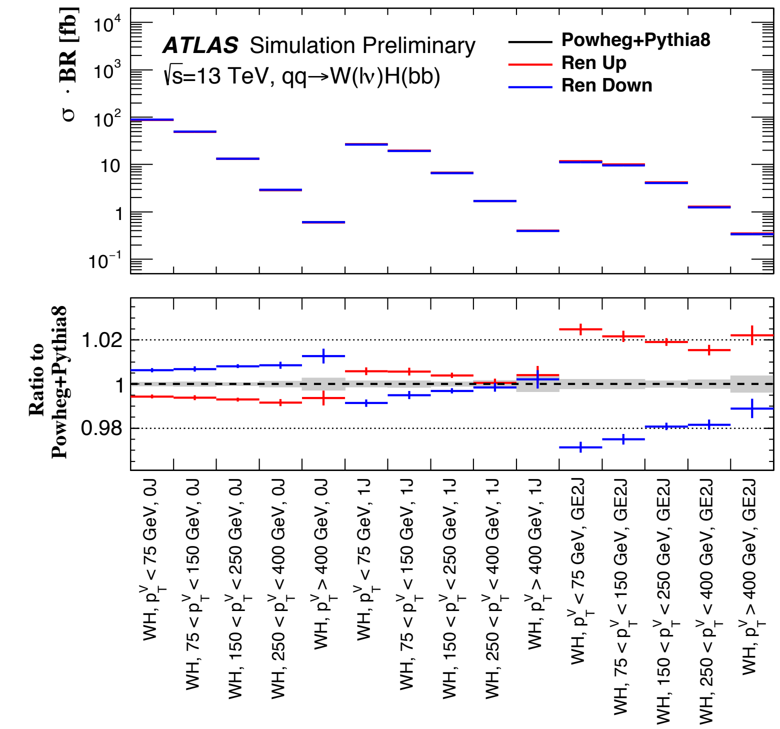
VH STXS

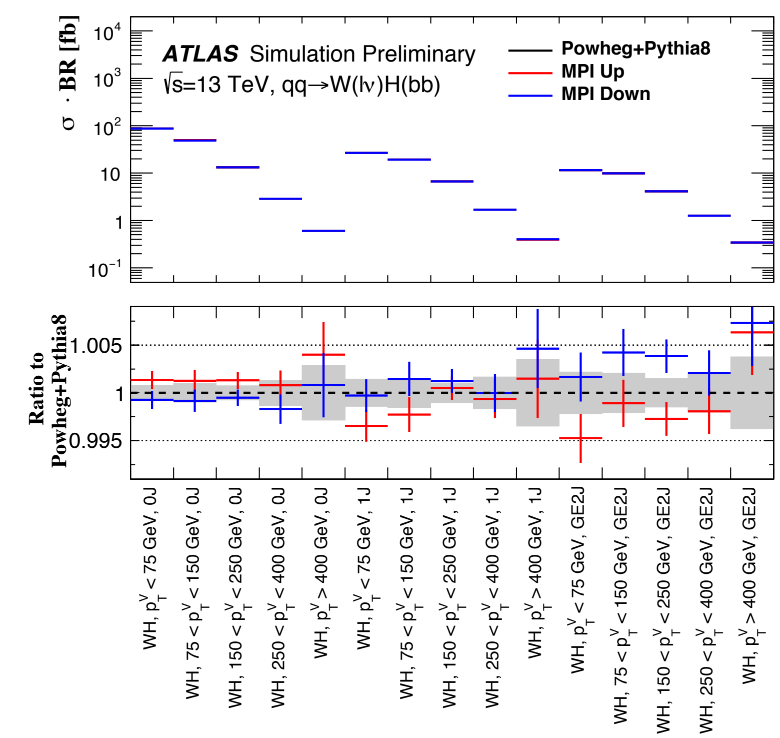
ATL-PHYS-PUB-2018-035

- ***documented impact of PS variations on STXS bins:***
  - not used in the prediction since extra radiation already covered by higher order corrections (scale unc. have O(10%))

Var1 and Var2 have practically 0 effect on these observables: expected?







- ***mild trend in V p_T, larger effects in nJet:***
  - effects much larger for ggZH since pure LO (backUp)

time for discussion

- ***not presented here due to time constraints:***
  - PS uncertainties on the background: specifically V+jets (HF), ttbar and tt+bb
  - correlation of PS uncertainties between signal and background (at least for ttbar we are using the same generator)
  - usage of generator internal shower weights in addition to specific tune uncertainties

BackUp

backgrounds

process	nominal generator	affected analyses
V+jets	Sherpa 2.2.1	VHbb (V+HF), H->$\tau\tau$, H->WW
diboson	Sherpa 2.2.2	H->WW, H->ZZ
ttbar	Powheg+Pythia8 (A14)	ttH(bb) [tt+HF], VHbb, H->WW, H->$\tau\tau$

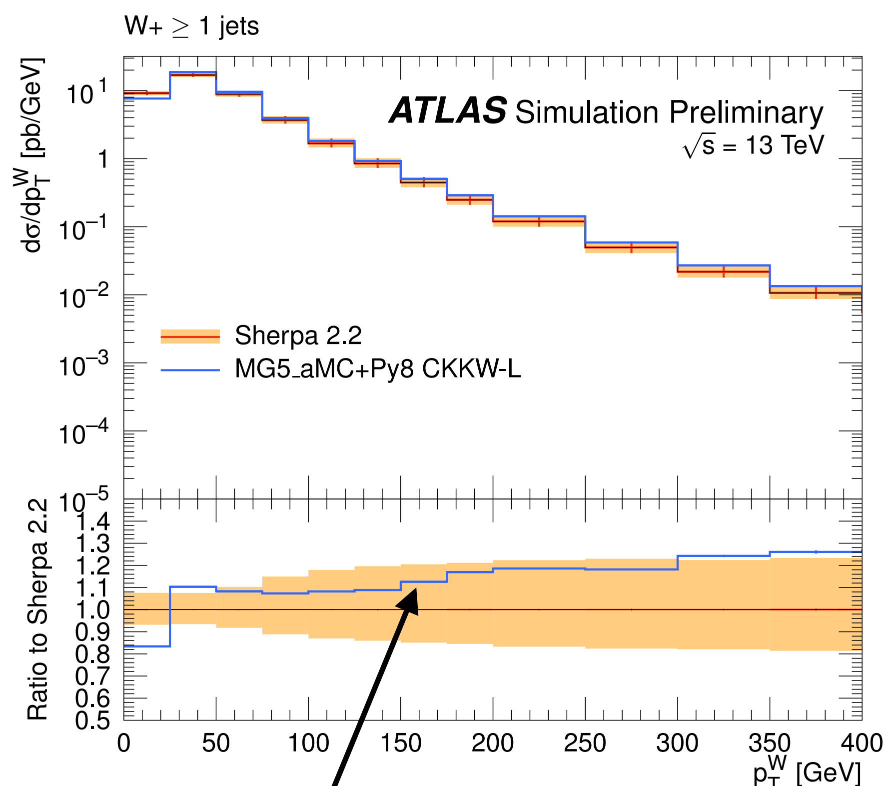
- ***Difference with respect to the signal case:***
  - bkgd usually normalised to data in suitable CR: reduce sensitivity to overall acceptance effects
  - shape effects / extrapolation between CR and SR are usually dominant
  - data has also the power to constrain some variations in situ. need some case in making sure that “pulls” and “constraints” from one region wildly propagates to other region creating possible biases and/or negating the effect of the variation. General approach:
    - decorrelating impact on a variation among samples (i.e. flavour composition in ttbar) or across regions (depending on the phase space coverage)
  - MC stat. limitations

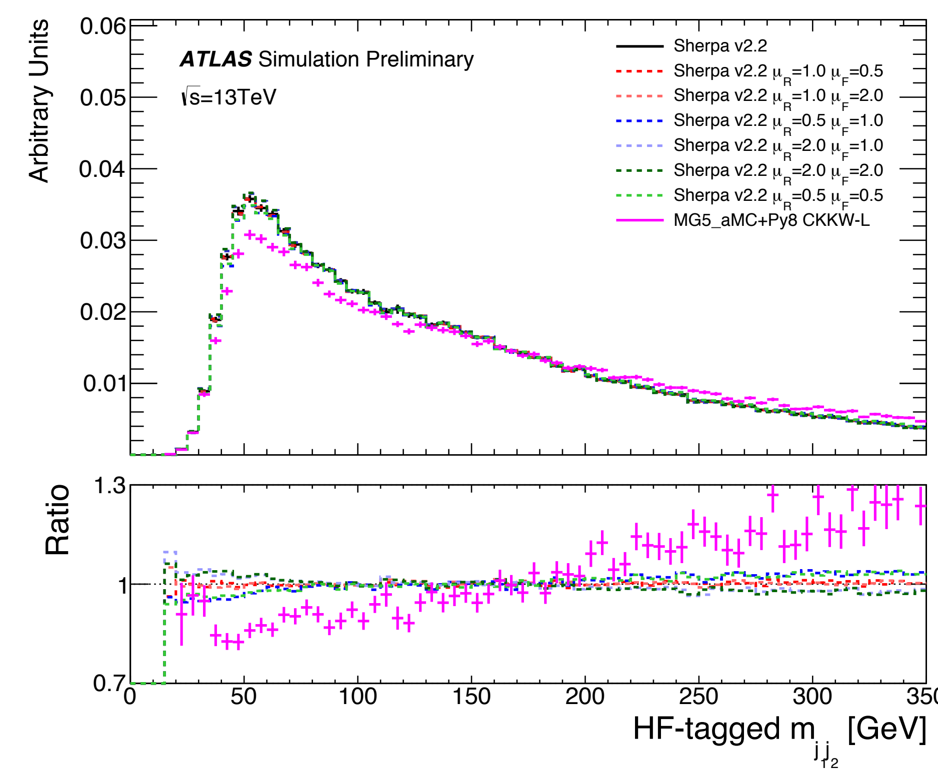
V+jets: sys

variation	
ME scales	mu_R, mu_F (internal weights), ckkw, qsf
generator comparison	comparison with MadGraph+Pythia8

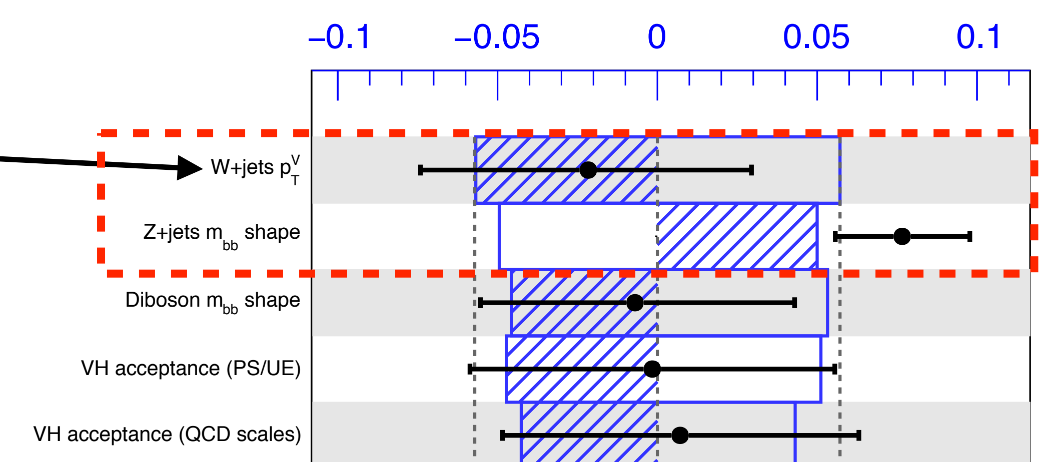
- ***many differences including precision of the calculation:***
  - 0,1,2@NLO+3,4@LO VS 0,1,2,3,4 @LO
- ***shape effect from SH-MG comparison much larger than Sherpa variations***

ATL-PHYS-PUB-2017-006



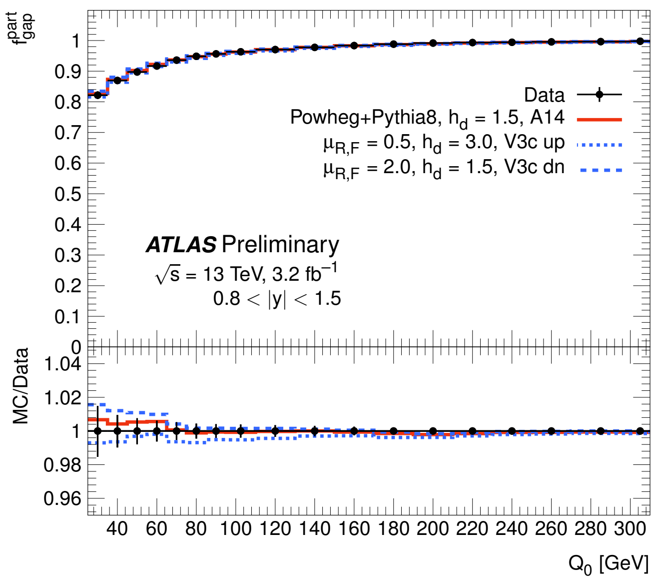


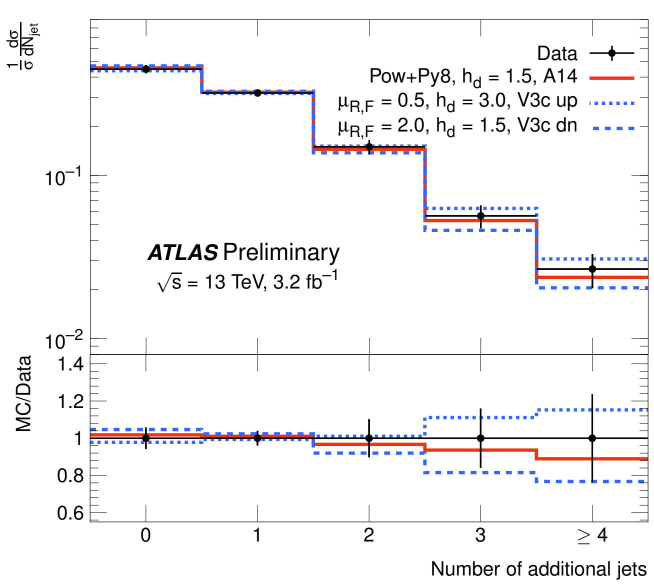
- ***MG-SH for Wpb spectrum was leading uncertainty in VHbb***

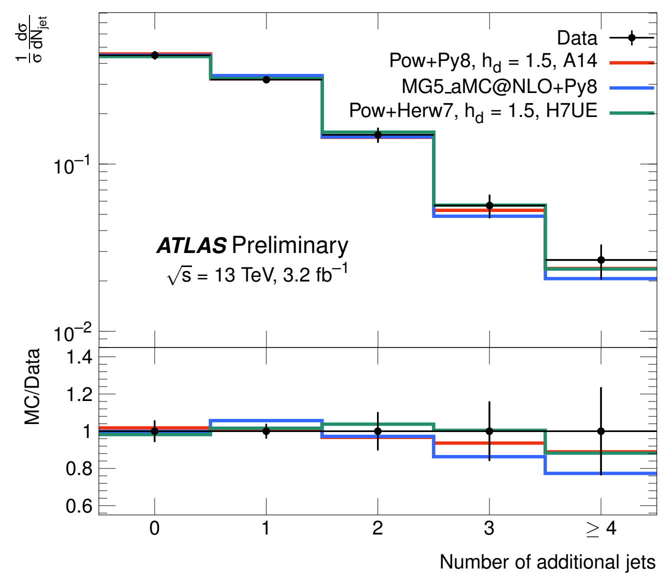


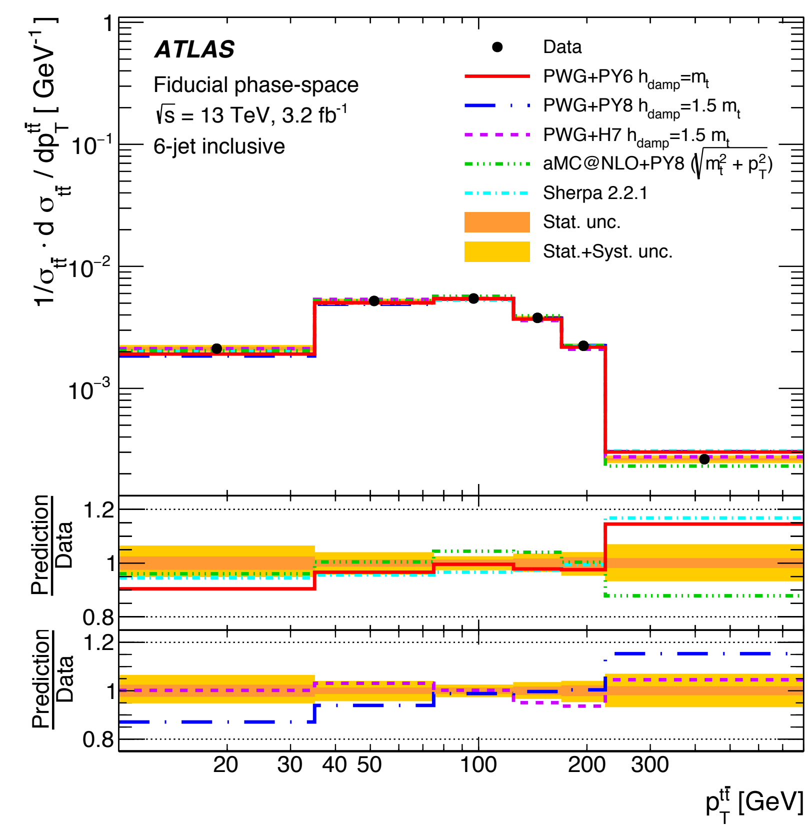
ATL-PHYS-PUB-2018-009

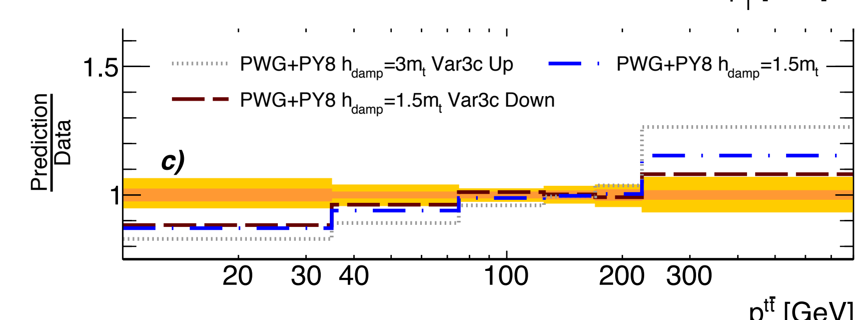
ME Gen.	PS/UE Gen.	ME PS/UE PDF	PS Tune	Matching
POWHEG-BOX r3026 (v2)	PYTHIA 8.230	NNPDF3.0NLO NNPDF2.3LO	A14	POWHEG ($h_{damp} = 1.5\ m_{top}$)
POWHEG-BOX r3026 (v2)	PYTHIA 8.230	NNPDF3.0NLO NNPDF2.3LO	A14 Var3c (Up)	POWHEG ($h_{damp} = 3.0\ m_{top}, \mu_{R,F} = 0.5$)
POWHEG-BOX r3026 (v2)	PYTHIA 8.230	NNPDF3.0NLO NNPDF2.3LO	A14 Var3c (Down)	POWHEG ($h_{damp} = 1.5\ m_{top}, \mu_{R,F} = 2.0$)
POWHEG-BOX r3026 (v2)	HERWIG 7.0.4	NNPDF3.0NLO MMHT2014lo68cl	H7-UE-MMHT	POWHEG ($h_{damp} = m_{top}$)









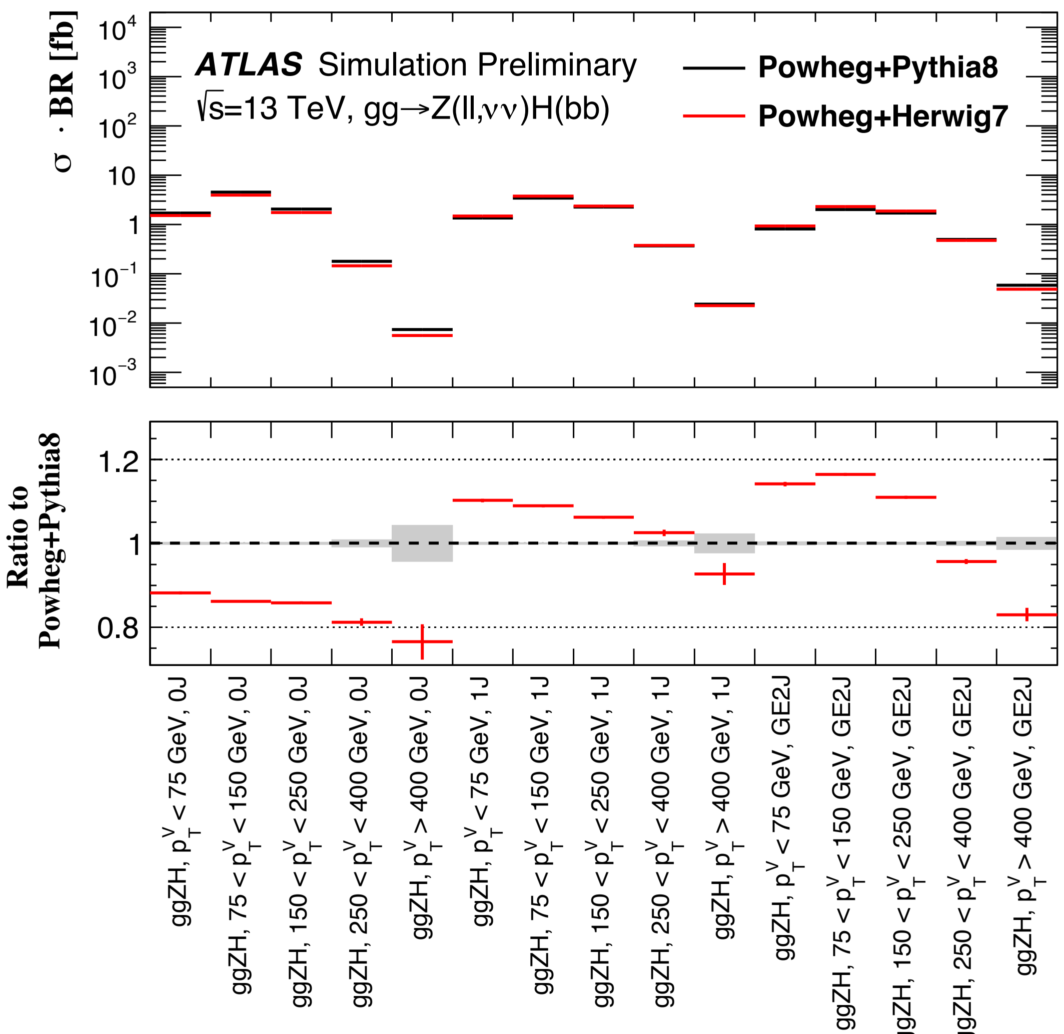


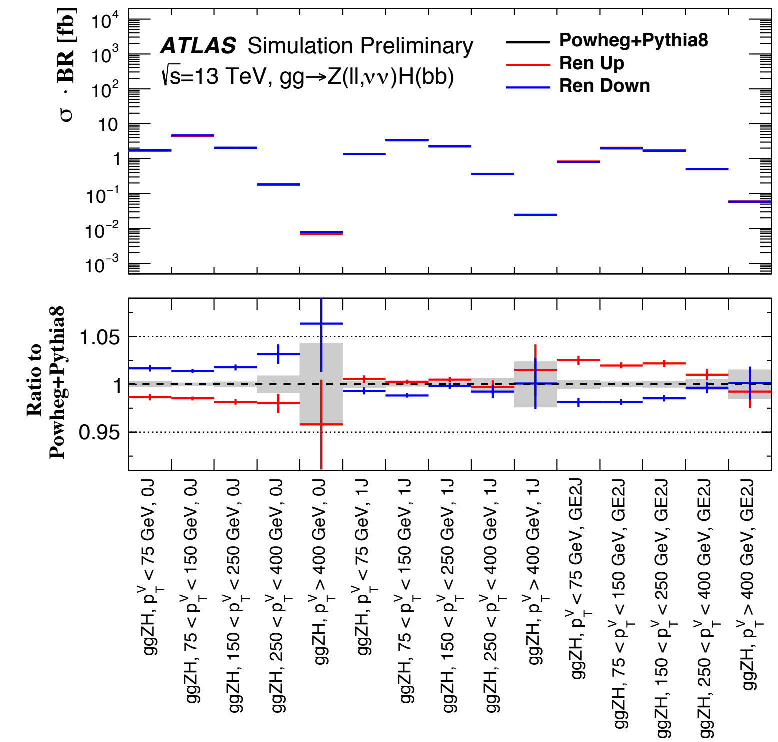
TOPQ-2017-01/

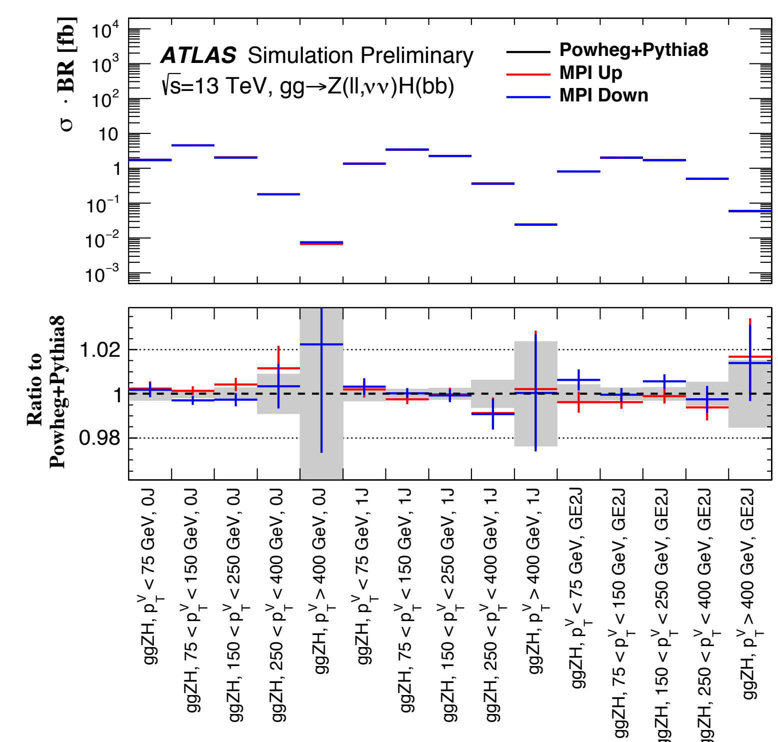
VH STXS: ggZH

- ***documented impact of PS variations on STXS bins:***
  - not used in the prediction since extra radiation already covered by higher order corrections (scale unc.)

Var1 and Var2 have practically 0 effect on these observables: expected?







A14: tune uncertainties

Param	+ variation	− variation
VAR1: MPI+CR (UE activity and incl jet shapes)		
`BeamRemnants:reconnectRange`	1.73	1.69
`MultipartonInteractions:alphaSvalue`	0.131	0.121
VAR2: ISR/FSR (jet shapes and substructure)		
`SpaceShower:pT0Ref`	1.60	1.50
`SpaceShower:pTdampFudge`	1.04	1.08
`TimeShower:alphaSvalue`	0.139	0.111
VAR3a: ISR/FSR ($t\bar{t}$ gap)		
`MultipartonInteractions:alphaSvalue`	0.125	0.127
`SpaceShower:pT0Ref`	1.67	1.51
`SpaceShower:pTdampFudge`	1.36	0.93
`SpaceShower:pTmaxFudge`	0.98	0.88
`TimeShower:alphaSvalue`	0.136	0.124
VAR3b: ISR/FSR (jet 3/2 ratio)		
`SpaceShower:alphaSvalue`	0.129	0.126
`SpaceShower:pTdampFudge`	1.04	1.07
`SpaceShower:pTmaxFudge`	1.00	0.83
`TimeShower:alphaSvalue`	0.114	0.138
VAR3c: ISR ($t\bar{t}$ gap, dijet decorrelation and Z-boson p_{T})		
`SpaceShower:alphaSvalue`	0.140	0.115

- *truth level comparison from* ***ATL-PHYS-PUB-2016-005***