VH STXS Uncertainties: Status/Plans

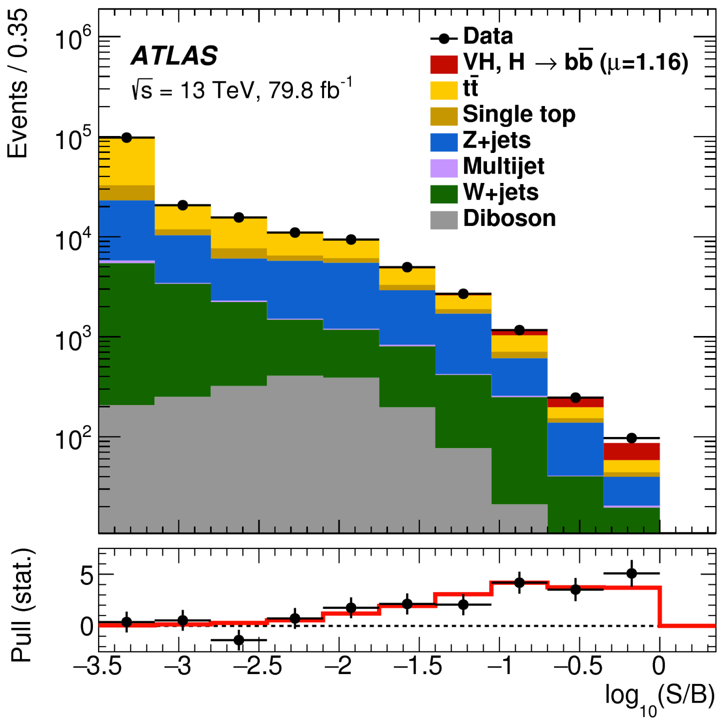
Thomas Calvet, Giancarlo Ferrera, Chris Palmer, Carlo Pandini, Emanuele Re, Frank Tackmann, Ciaran Williams

16 October 2019
Princeton University

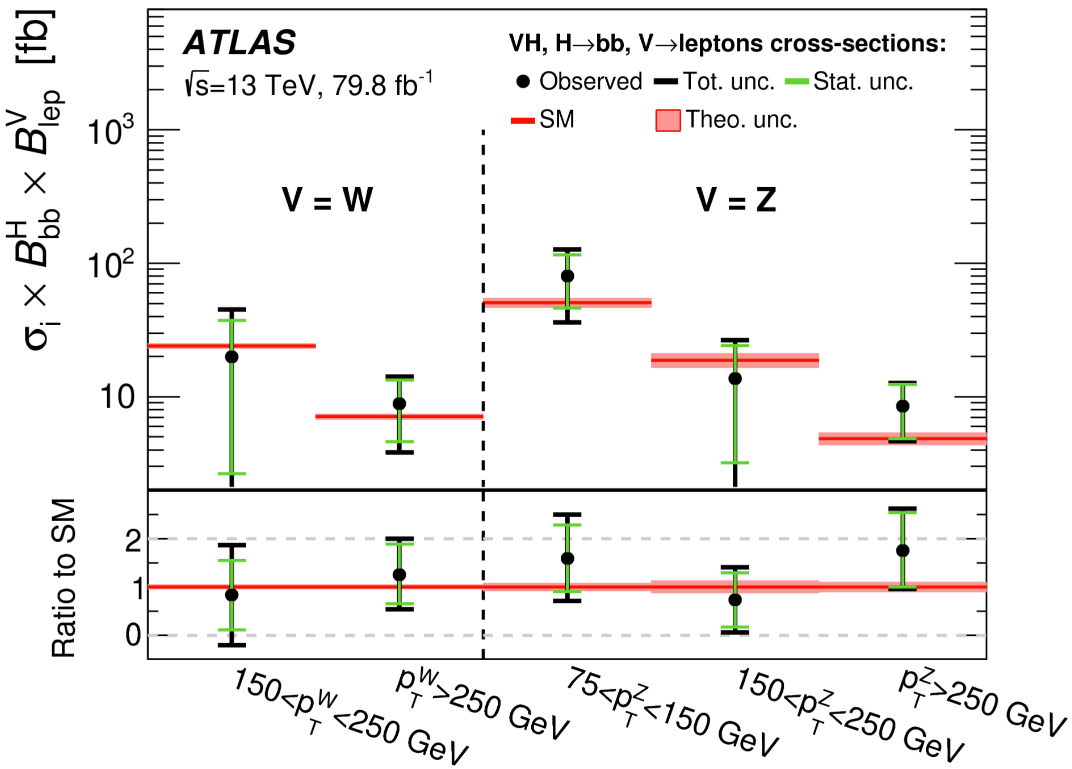
Overview

- Summary of current prescription (stage 1.1, arXiv:1906.02754)
  - QCD perturbative uncertainties treated
    - Next step: EW, QCD non-perturbative
  - Use-case: ATLAS VHbb 2016+2017 STXS
    - https://indico.cern.ch/event/740110/contributions/3225257/attachments/1768332/2872545/calvet_VHbbSTXSunc_181210.pdf
  - Discussion from CMS cross check during the summer
- Plans and on-going efforts
  - Making/using public MC using setup as close as possible to ATLAS/CMS setup (MC code, PDF, mass/width parameters, etc)
  - Building a public tool to evaluate uncertainties and correlation scheme given arbitrary VH prediction
- Other open topics

From Signal Strength to STXS



Phys. Lett. B 786 (2018) 59

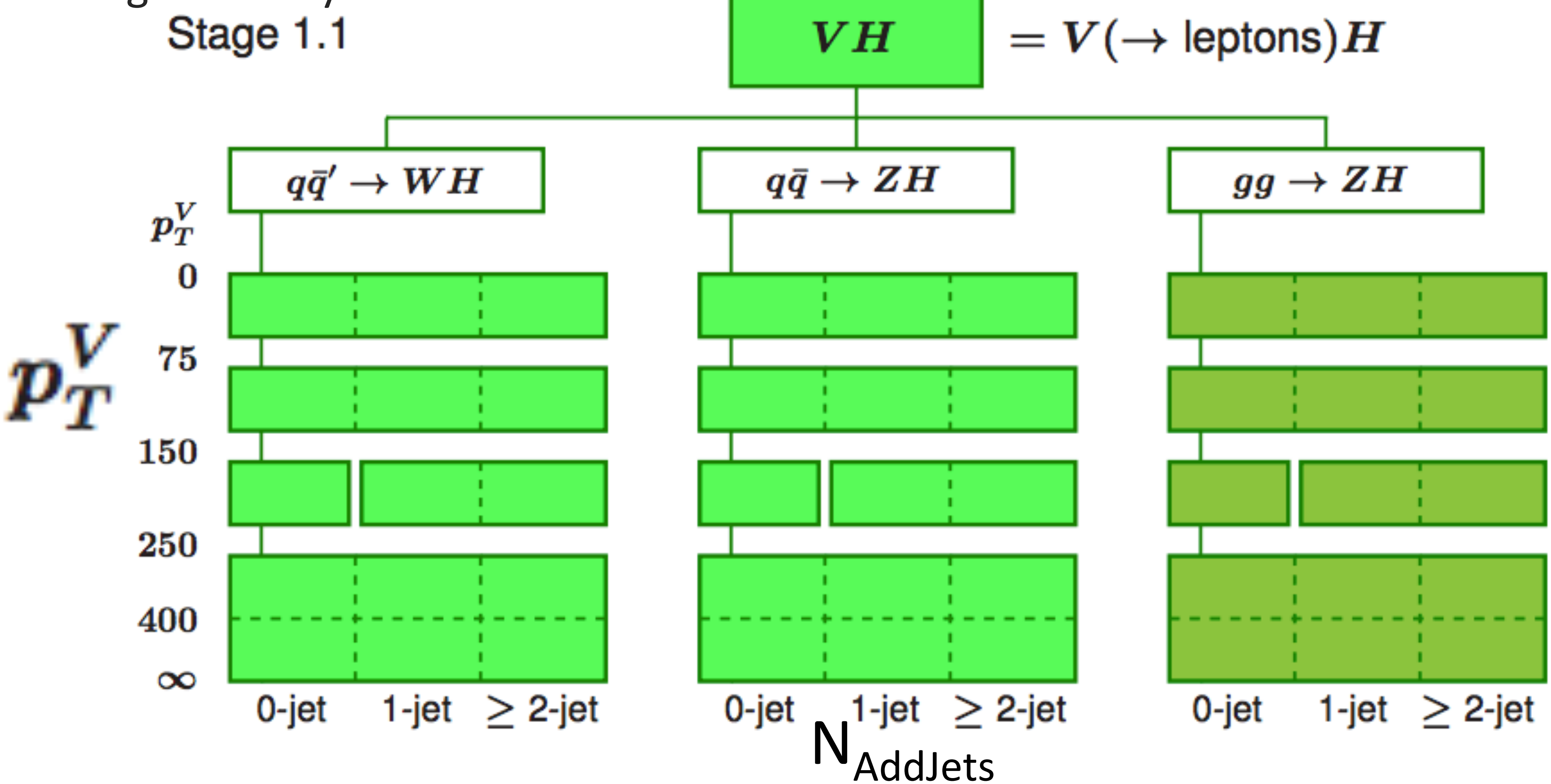


JHEP 05 (2019) 141

- The VH STXS measurements in ATLAS/CMS are/will be driven by the Higgs to bb excess in VHbb search.
- ATLAS produced the first major VH results of Run 2 in late 2018 using the same data (2015-2017) used for the observation of VH and Hbb.

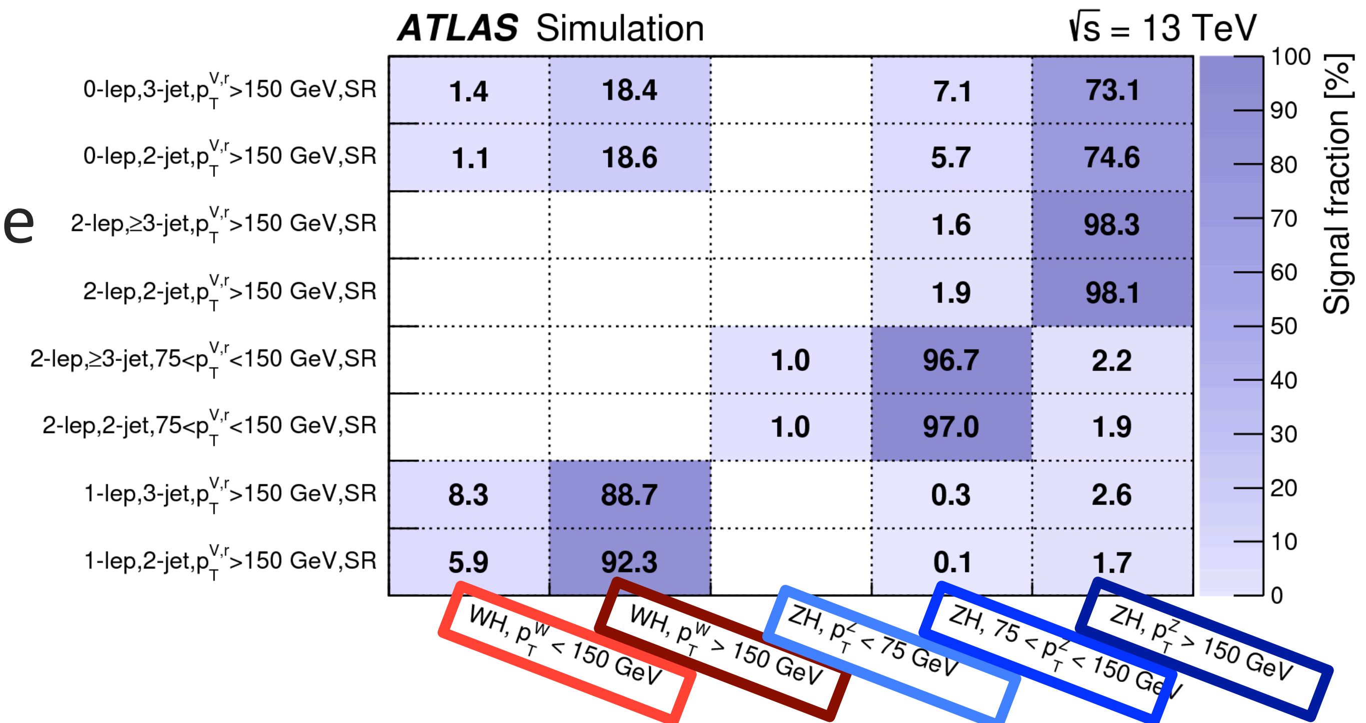
STXS Stage 1.1 Targets

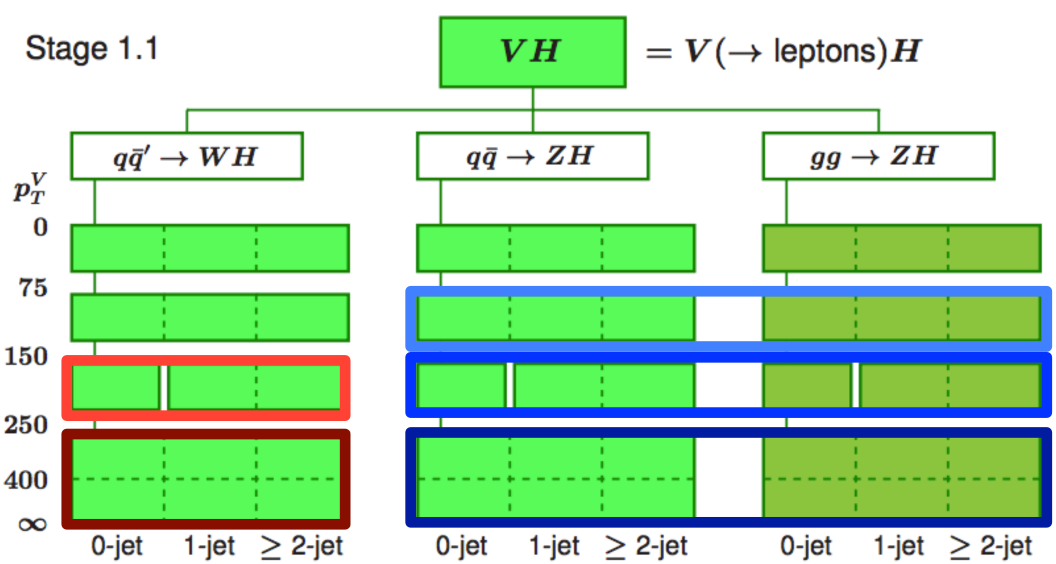
- Divide signal into bins of VPT and number of additional jets.
  - The solid-line boxes are the optimistic set of distinguishable processes.
  - The dashed lines are meant for the estimation of uncertainties on a finer granularity

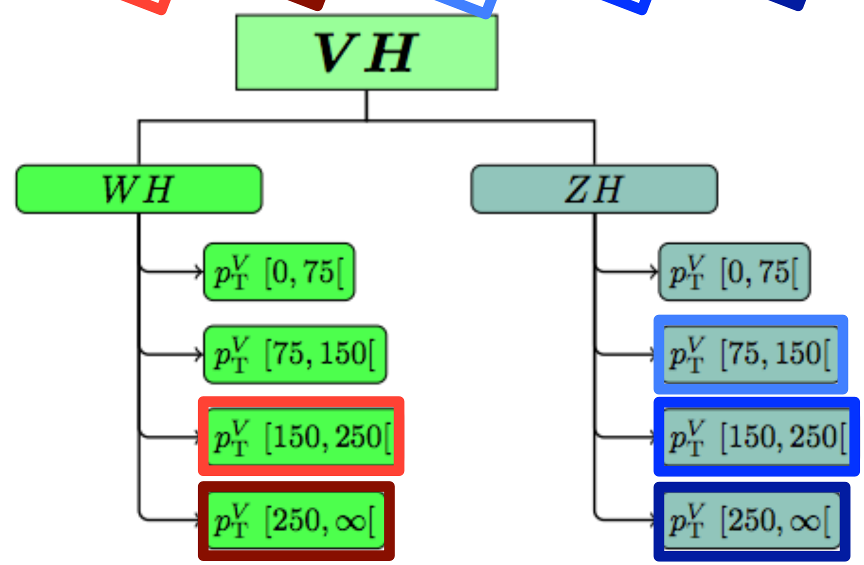


ATLAS binning in first result

- In reality bins must be merged or left unmeasured because of experimental limitations and/or low signal yields.

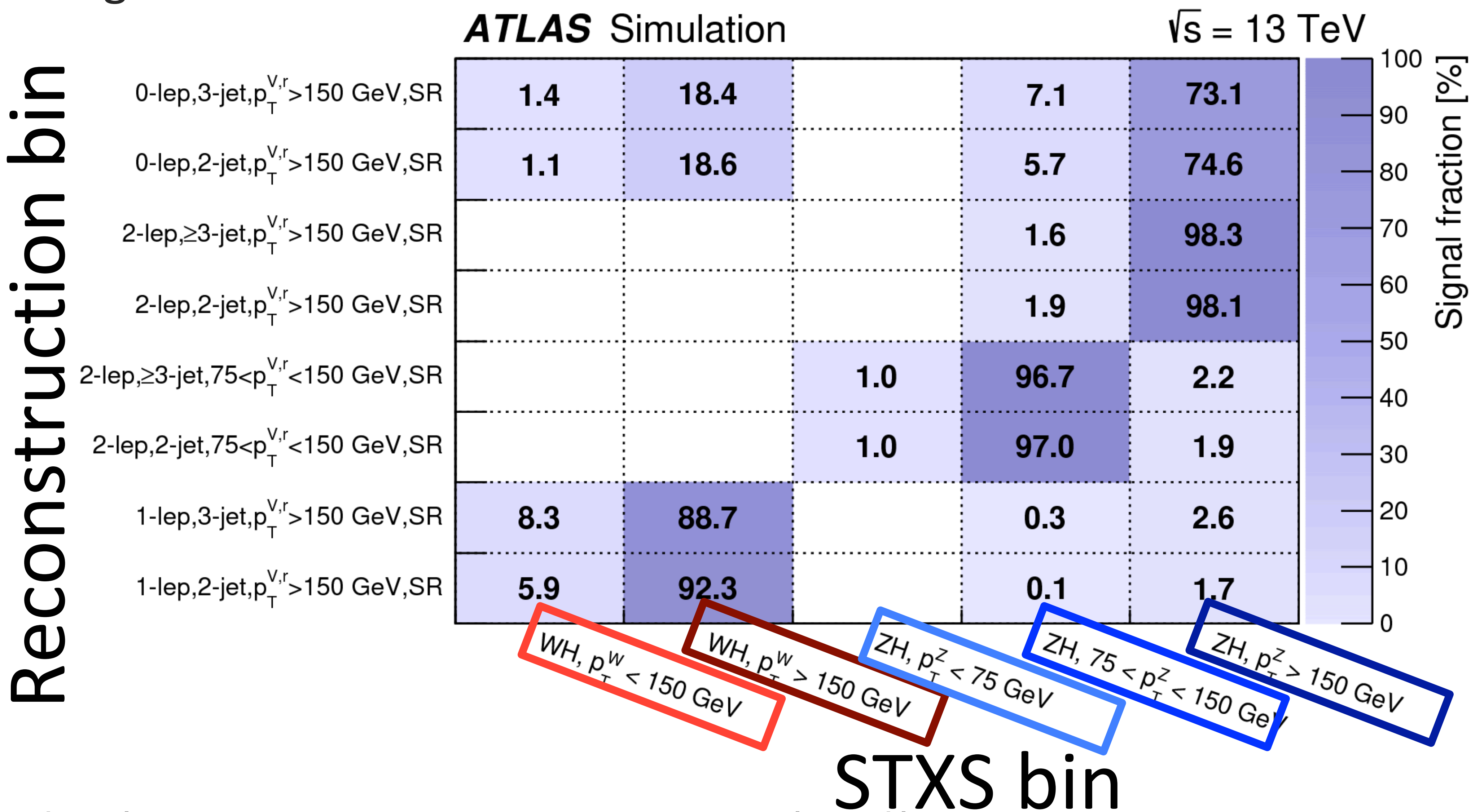






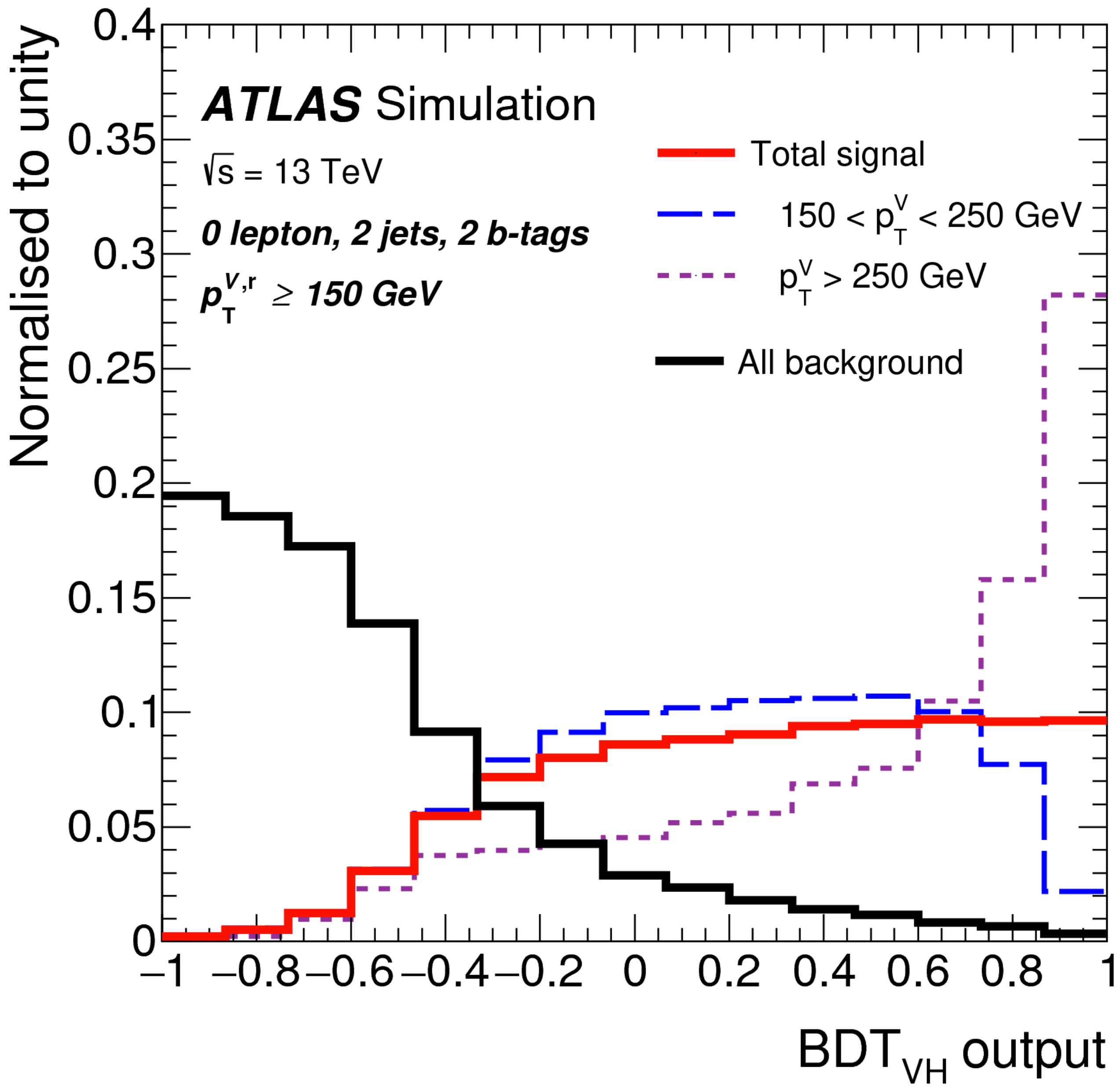
Generator vs Reconstruction

- Perfect reconstruction would reduce the problem to optimizing significance in each bin.



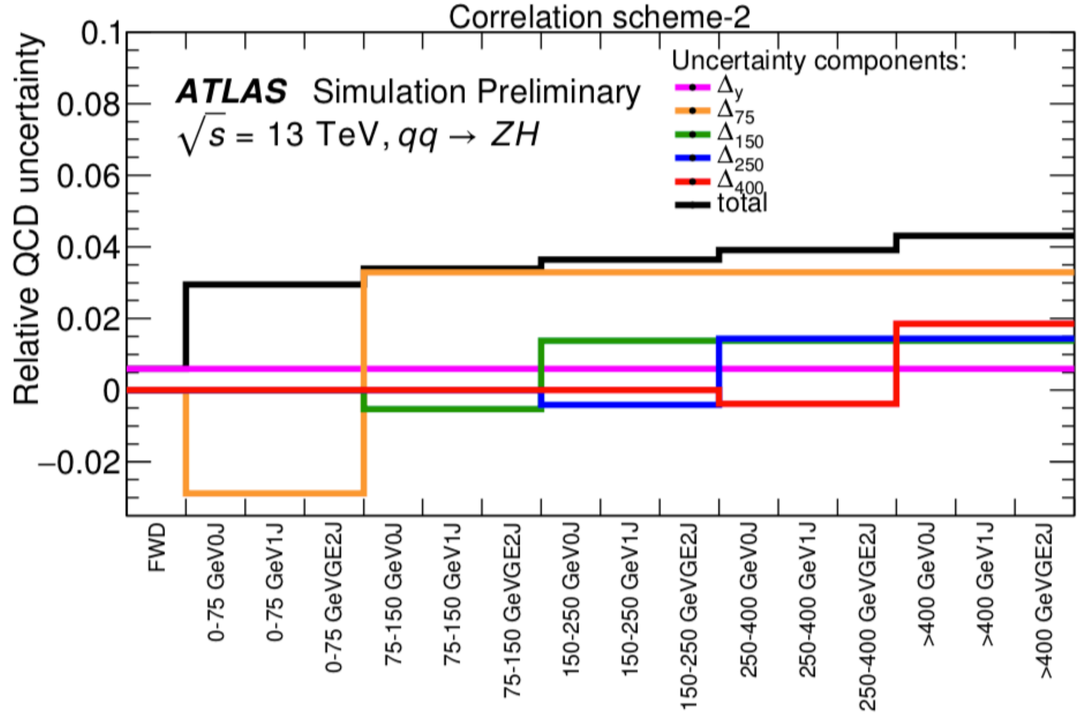
Discrimination VPT Built-in

- The VHbb machine learning (ML) outputs already leverage the transverse momentum of the vector boson.
- Not pictured for CMS but also true in CMS analysis.
- There is also some difference (less) in discriminator shapes based on $N_{AddJets}$.



Migration in full Stage 1.1

- Variations from QCD scale are decomposed into category migrations among VPT and N_{Jet} bins.



- Total normalization:
  - Chapter I.5.2C of the CERN Yellow Report 4

p_T^V bin [GeV]	Δ_{75}	Δ_{150}	Δ_{250}	Δ_{400}
[0, 75[	$-\Delta_{75}/\sigma_{[0,75[}$	0	0	0
[75, 150[	$+\Delta_{75}/\sigma_{[75,\infty[}$	$-\Delta_{150}/\sigma_{[75,150[}$	0	0
[150, 250[	$+\Delta_{75}/\sigma_{[75,\infty[}$	$+\Delta_{150}/\sigma_{[150,\infty[}$	$-\Delta_{250}/\sigma_{[150,250[}$	0
[250, 400[	$+\Delta_{75}/\sigma_{[75,\infty[}$	$+\Delta_{150}/\sigma_{[150,\infty[}$	$+\Delta_{250}/\sigma_{[250,\infty[}$	$-\Delta_{400}/\sigma_{[250,400[}$
[400, ∞[	$+\Delta_{75}/\sigma_{[75,\infty[}$	$+\Delta_{150}/\sigma_{[150,\infty[}$	$+\Delta_{250}/\sigma_{[250,\infty[}$	$+\Delta_{400}/\sigma_{[400,\infty[}$

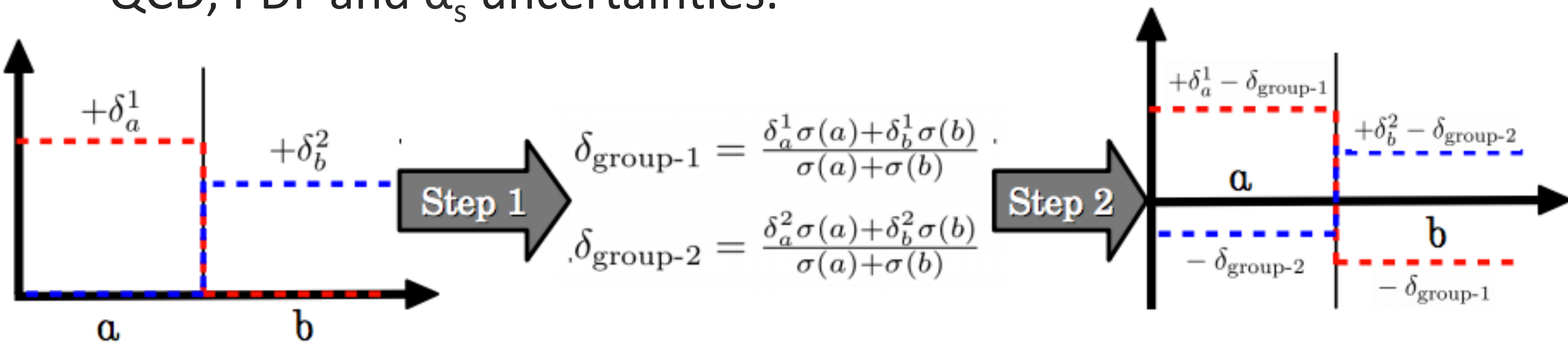
Merging bins/deriving uncertainties

- The full set of stage 1.1 migration uncertainties are used to derive the subsequent STXS bin uncertainties.

$$\delta_{\text{group}} = \frac{\sum_{t\in\text{group}} \delta_t \sigma_t}{\sum_{t\in\text{group}} \sigma_t}$$

- This procedure applies equally to QCD, PDF and α_s uncertainties.

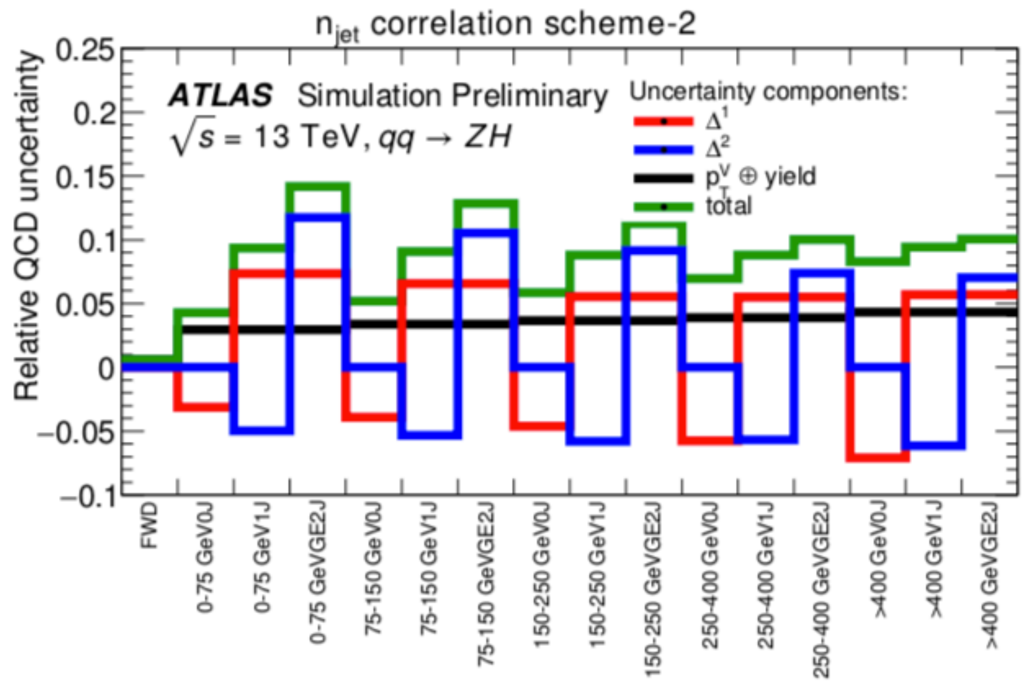
$$\delta_{t\ \text{residual}} = \delta_t - \delta_{\text{group}}$$



- The total uncertainty is the sum of the δ_{group}s.

Summary of Uncertainties

- The same type of scheme is used to assess the uncertainty among Njet bins.
  - Tends to be larger than the uncertainty from VPT migration.
- Overall, QCD uncertainties tend to dominate



	qq→WH	qq→ZH	gg→ZH
QCD	3-4%	7-12%	37-100%
PDF+α_s	~2%	~1.5%	~3%
Total	~4%	7-12%	37-100%

CMS cross check and discussion

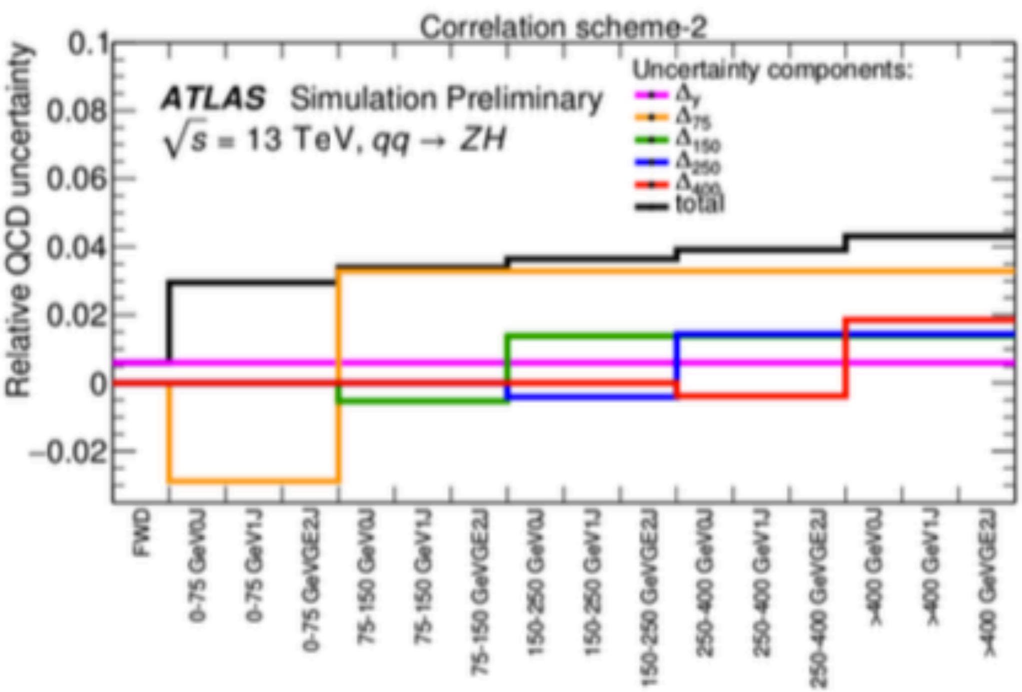
- Earlier this year CMS (Adinda de Witt) produced a cross check of a QCD scale uncertainty comparing to public documents and found some disagreement.
- Upon sharing the plots and discussing the procedure, the main difference appeared to be if distributions were renormalized after reweighting by QCD scale weights or not.
  - ATLAS did not re-normalize after re-weighting
  - CMS DID re-normalize.
- Although both prescriptions have merit, the current recommendation is to NOT re-normalize.
- On the CMS side, Adinda de Witt and Aliya Nigamova (DESY) are moving forward on testing this prescription and making an initial pass on VH group MC as a cross check.

Preliminary checks with public MC

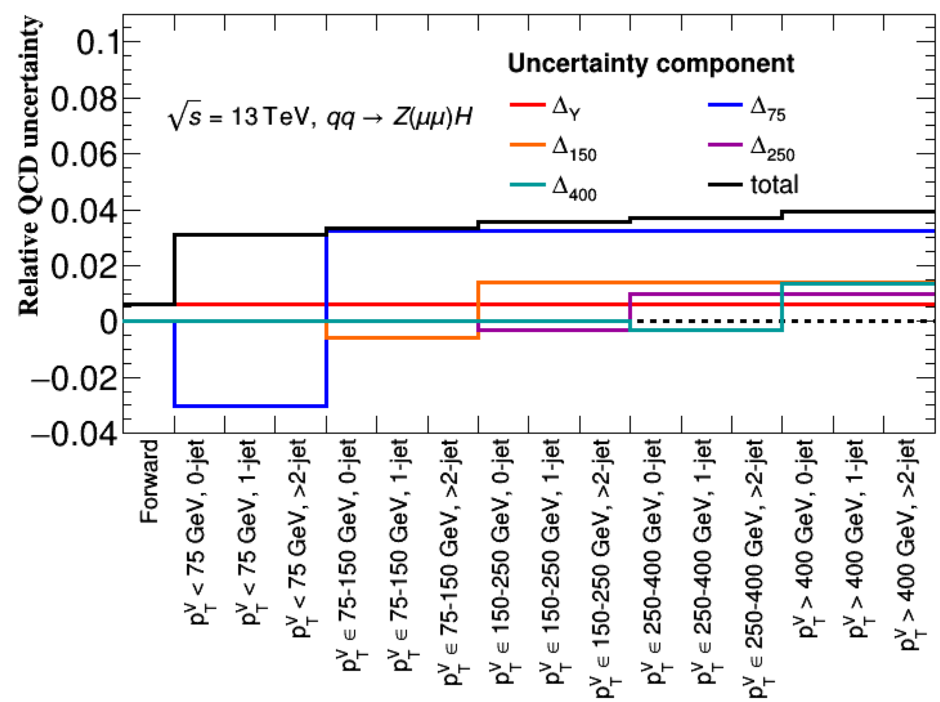
- Emanule Re produced some signal MC with POWHEG MiNOL HZJ showering with pythia and computed differential cross sections per QCD variation.
- Thomas ran a script inspired by the ATLAS code to compute the migrations.

Comparing QCD scale uncertainties (Δ)

ATLAS Public Results



Preliminary results with public MC

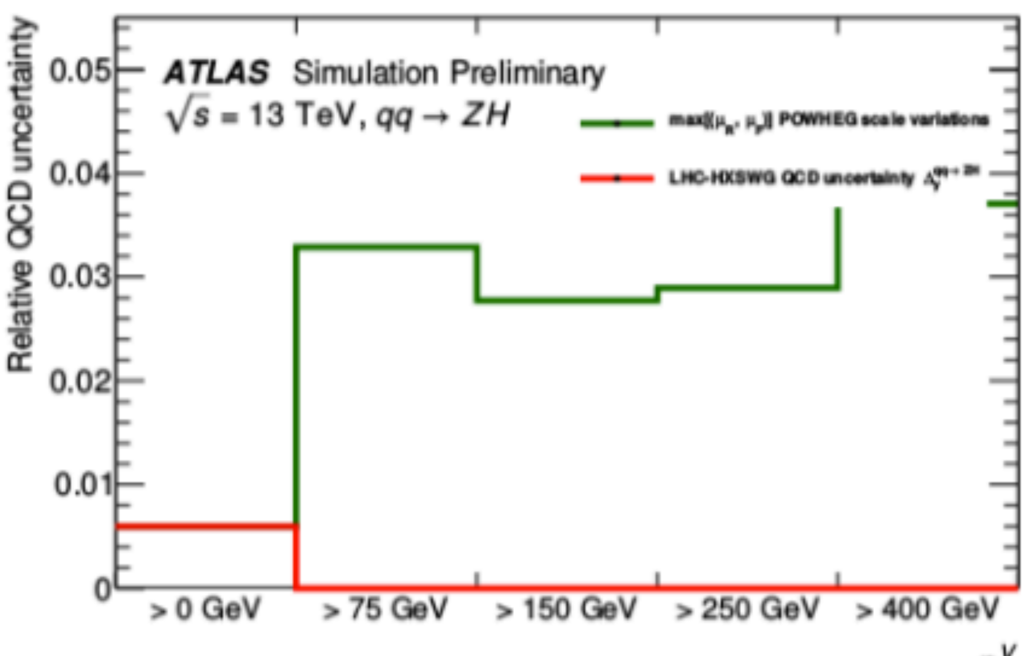


Preliminary checks with public MC

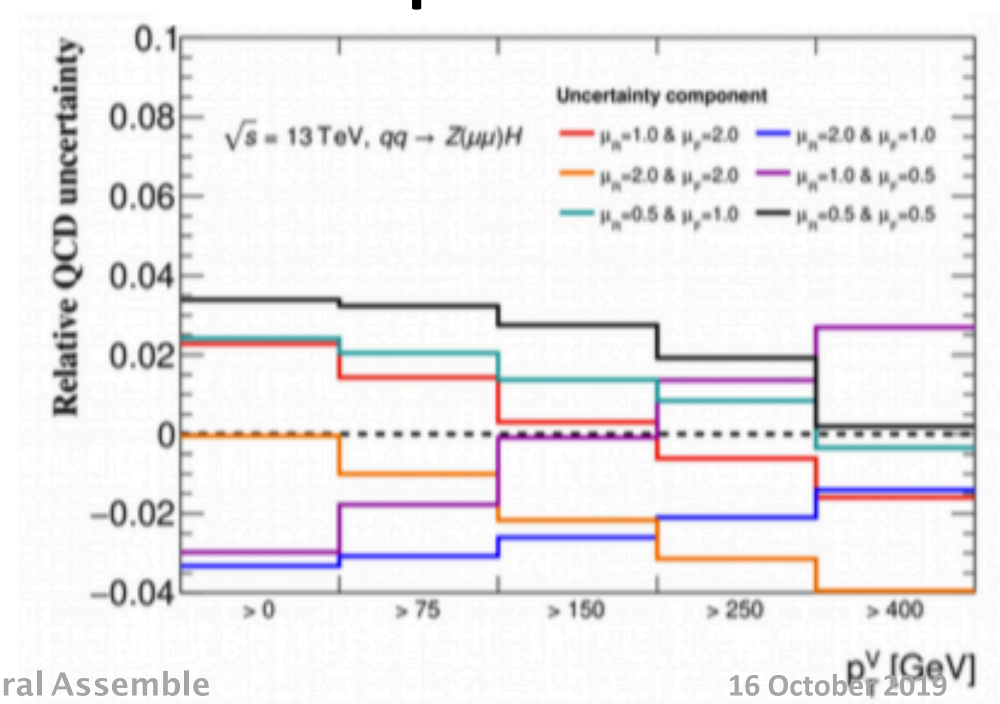
- Not every plot has perfect agreement, but the scales are the right size and this was really a very quick test with very promising validations!

Comparing scale variation in inclusive pTV bins

ATLAS Public Results



Preliminary results with public MC



Plans for official tools

- Objective
  - Toolkit both for theorists (to test new theories) and experimentalists (to understand assess variations)
  - Input theory prediction
  - Output nominal cross sections with systematic variation in STXS bin
- Process
  - Shower LHE with HEPMC product
  - Compute STXS bin with Rivet
  - VH program to compute variations
- Expected versatility
  - One default showering, a few pre-configured options, configuration option for experts
- As similar tools exist (e.g. for VBF) we would consider integration.

Looking forward

- Consider the impact of multijet ggZH0+1jet MC on QCD uncertainties across STXS bins (e.g. Njet bins)
  - See Carlo's VH talk from this morning
- Add higher order prediction in QCD (e.g. NNLOPS MC or NNLO code)
- EW uncertainties
- Consider VH binning for analyses targeting other Higgs' decays (beyond VHbb)
  - Looking toward Run 3, are there experimental modes with emerging sensitivity?
  - Add CP sensitive bins in VH? E.g. $d\phi(l,l)$
  - Low Higgs PT spectrum for self-coupling sensitivity in VH (e.g. $H\gamma\gamma$)

Backup

MC Settings

- NNPDF31 NNLO (306000)
- Higgs
  - mass 125, width = 0.00407
- Z
  - mass 91.1876, width = 2.4952
- Top
  - mass 172.5

ATLAS STXS Systematic Breakdown

Measurement region ($\|y_H\| < 2.5$, $H \to b\bar{b}$)	SM prediction [fb]	Result [fb]	Stat. unc. [fb]	Syst. unc. [fb] Th. sig.	Th. bkg.	Exp.
5-POI scheme						
$W \to \ell\nu$; $150 < p_T^V < 250$ GeV	24.0 ± 1.1	20 ± 25	± 17	± 2	± 13	± 9
$W \to \ell\nu$; $p_T^V > 250$ GeV	7.1 ± 0.3	8.8 ± 5.2	± 4.4	± 0.5	± 2.5	± 0.9
$Z \to \ell\ell, \nu\nu$; $75 < p_T^V < 150$ GeV	50.6 ± 4.1	81 ± 45	± 35	± 10	± 21	± 19
$Z \to \ell\ell, \nu\nu$; $150 < p_T^V < 250$ GeV	18.8 ± 2.4	14 ± 13	± 11	± 1	± 6	± 3
$Z \to \ell\ell, \nu\nu$; $p_T^V > 250$ GeV	4.9 ± 0.5	8.5 ± 4.0	± 3.7	± 0.8	± 1.2	± 0.6
3-POI scheme						
$W \to \ell\nu$; $p_T^V > 150$ GeV	31.1 ± 1.4	35 ± 14	± 9	± 2	± 9	± 4
$Z \to \ell\ell, \nu\nu$; $75 < p_T^V < 150$ GeV	50.6 ± 4.1	81 ± 45	± 35	± 10	± 21	± 19
$Z \to \ell\ell, \nu\nu$; $p_T^V > 150$ GeV	23.7 ± 3.0	28.4 ± 8.1	± 6.4	± 2.4	± 3.6	± 2.3