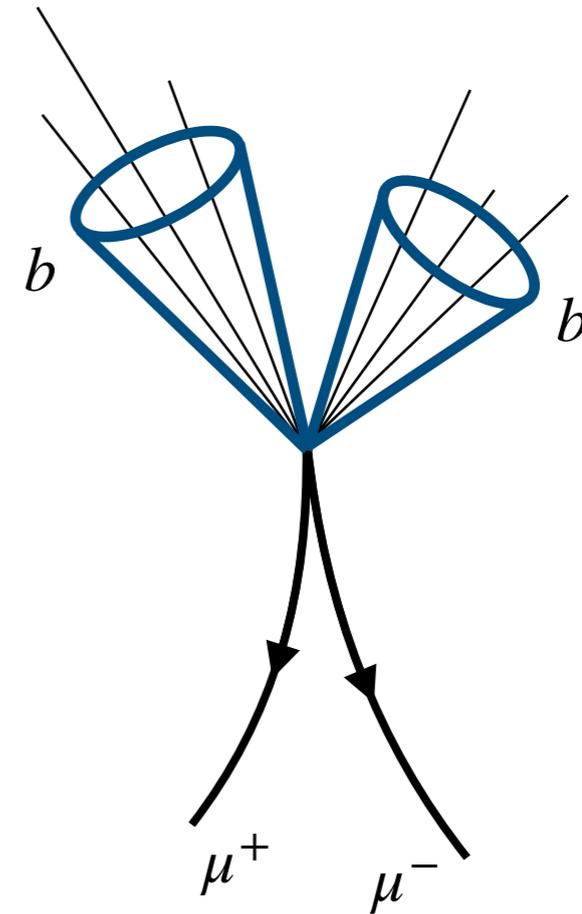
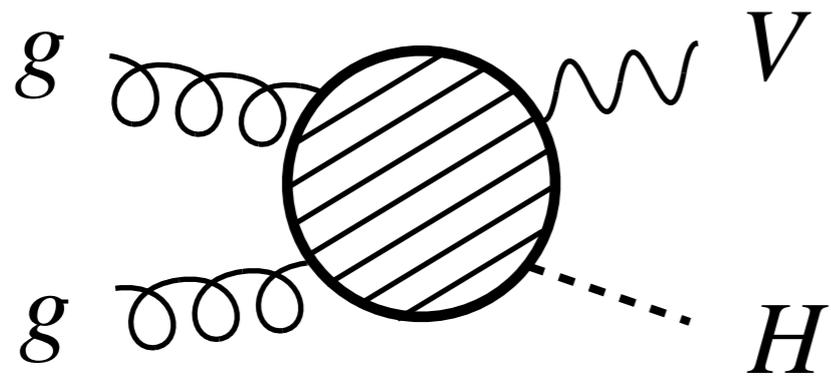


VH: theory and experiment



17th Workshop of the
LHC Higgs Cross Section Working Group

9-11 November 2020

Philipp Windischhofer (University of Oxford)
for the ATLAS Collaboration and $VH \subset WG1 \subset HXSWG$



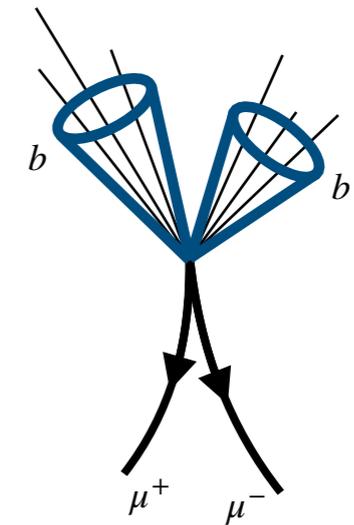
Overview

Recent experimental results from CMS and ATLAS

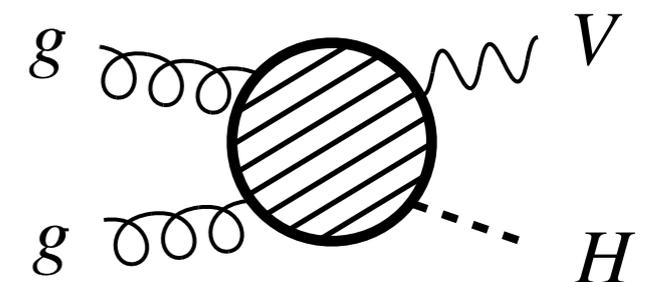
VH(bb) resolved

VH(bb) boosted

Uncertainties (*and how to improve*)



Experiment

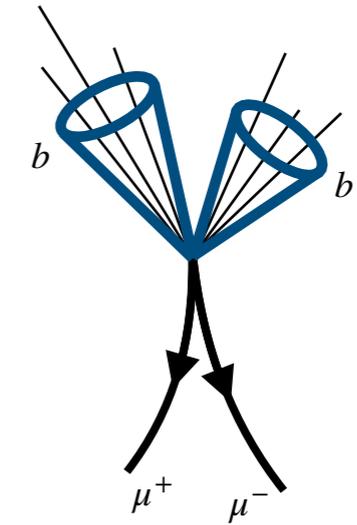


Theory

Recent experimental results from CMS and ATLAS

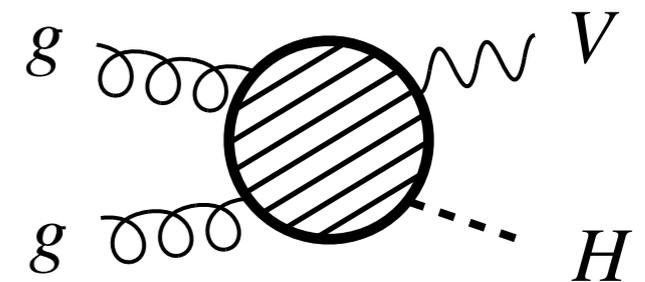
VH(bb) resolved

VH(bb) boosted



Experiment

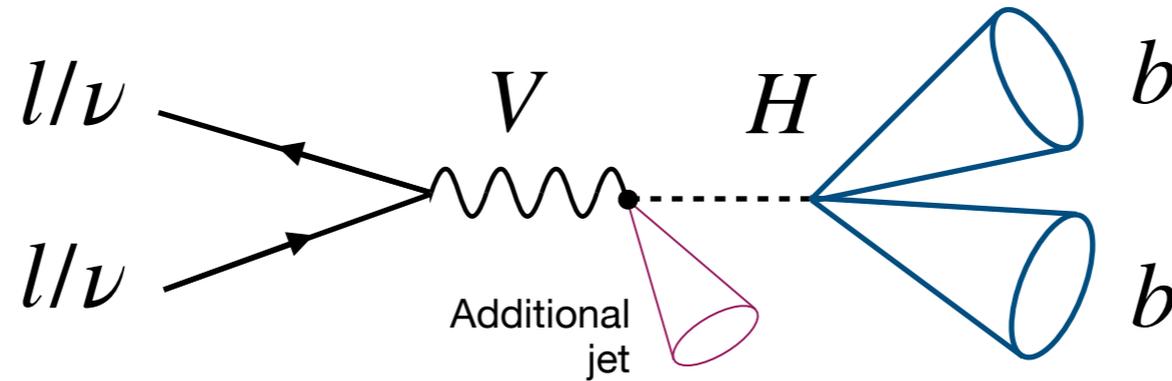
Uncertainties *(and how to improve)*



Theory

VH(bb) “resolved”

VH(bb) drives experimental sensitivity



Leptonic V decay

0-lep. $Z(\nu\nu)H$ 1-lep. $W(l\nu)H$ 2-lep. $Z(ll)H$

(p_T^V is convenient variable: proxy for p_T^H)

Higgs decay “resolved” in two isolated $R=0.4$ jets for

$$p_T^H \lesssim \frac{m_H}{R} \approx 300 \text{ GeV}$$

(limited signal acceptance in highly boosted regime)

Analyses binned in p_T^V , # leptons, # additional jets

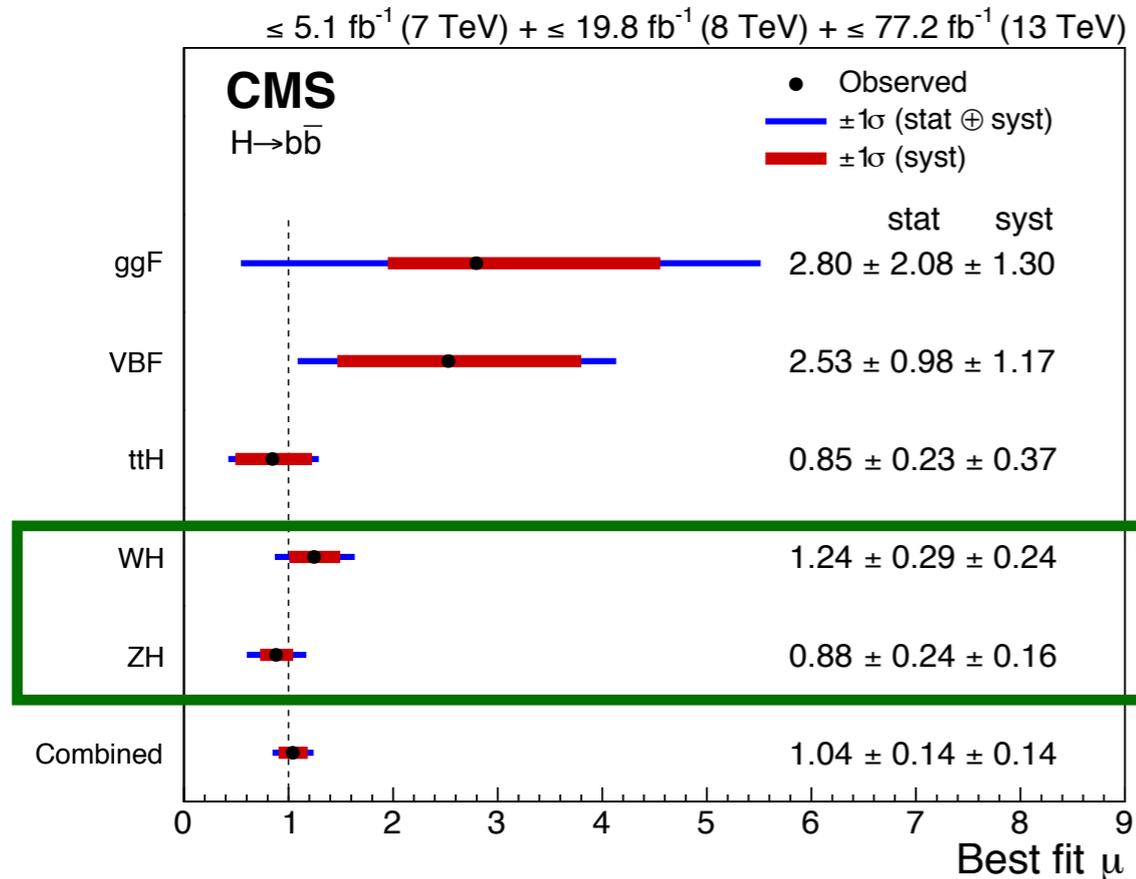
Key analysis ingredients

Challenging backgrounds $\begin{cases} \rightarrow \text{b-tagging, b-jet energy corrections} \\ \rightarrow \text{robust background model} \end{cases}$

VH(bb) “resolved”: inclusive results

CMS (2018), partial Run 2 + Run 1

arXiv: [\[1808.08242\]](https://arxiv.org/abs/1808.08242)

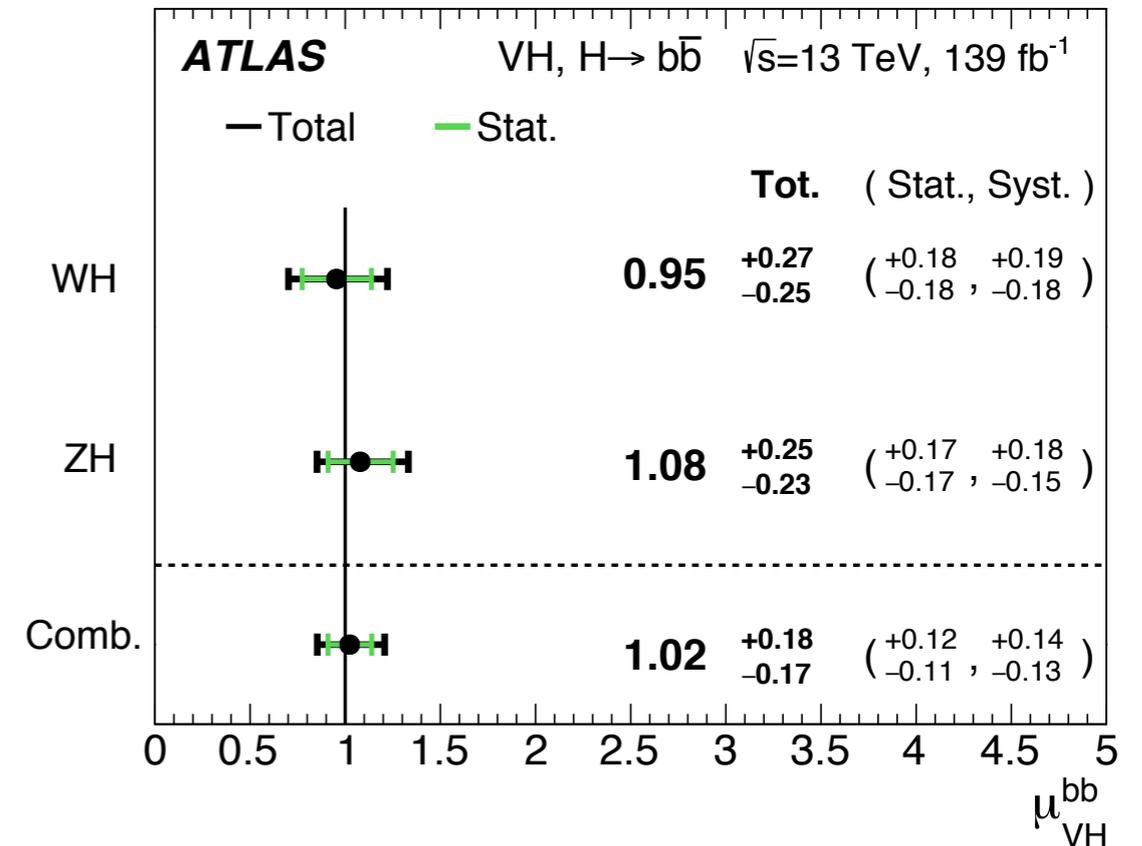


Strong evidence:

$VH @ 4.8 \sigma$ obs. (4.9 σ exp.)

ATLAS (2020), full Run 2

arXiv: [\[2007.02873\]](https://arxiv.org/abs/2007.02873)



Observation of $ZH @ 5.3 \sigma$

Strong evidence for $WH @ 4.0 \sigma$
(observed @ 6.3 σ in decay [combination](#))

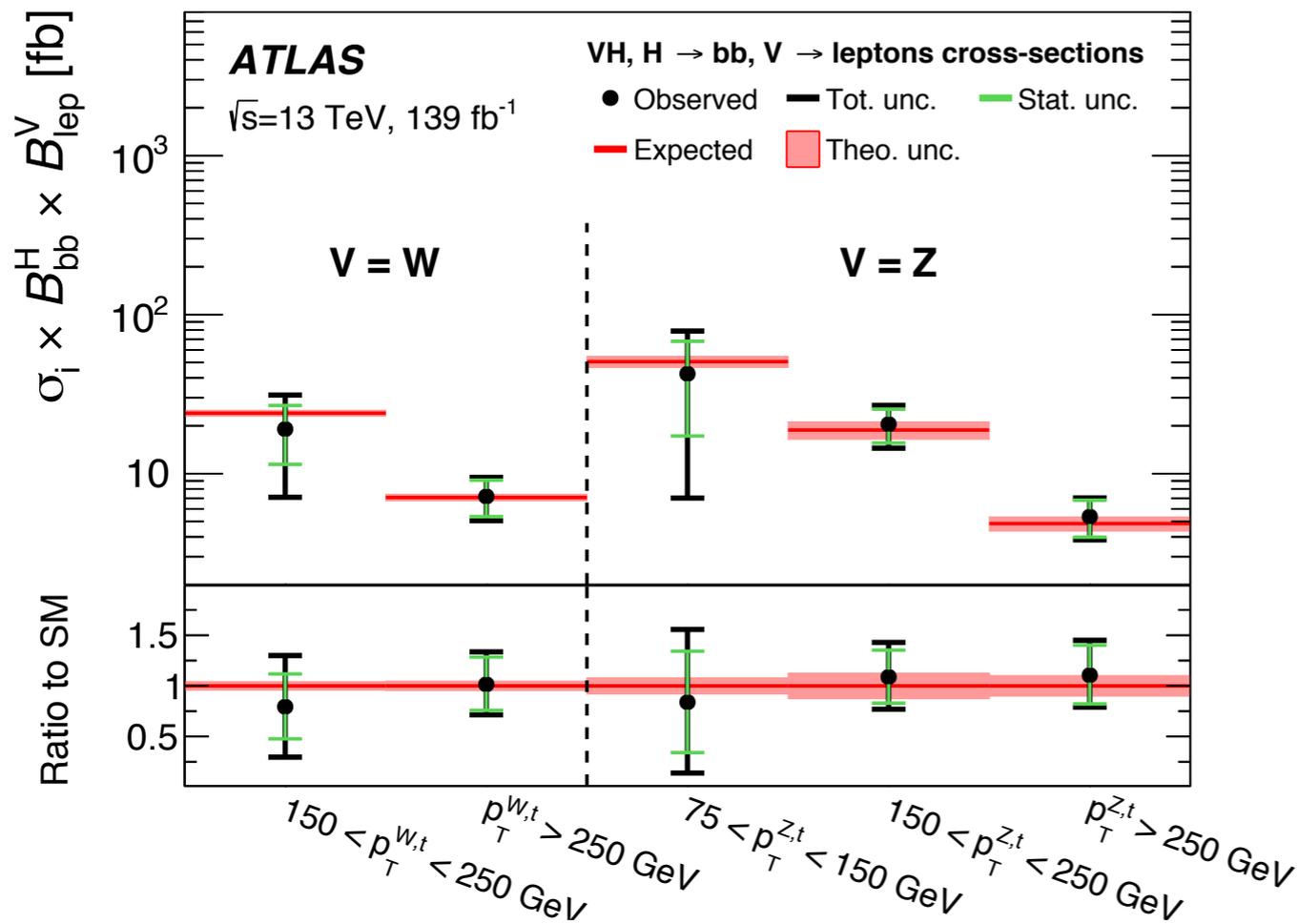
$VH @ 6.7 \sigma$ obs. (6.7 σ exp.)

VH sig. strength measured to better than 20%, good agreement with SM

VH(bb) “resolved”: STXS

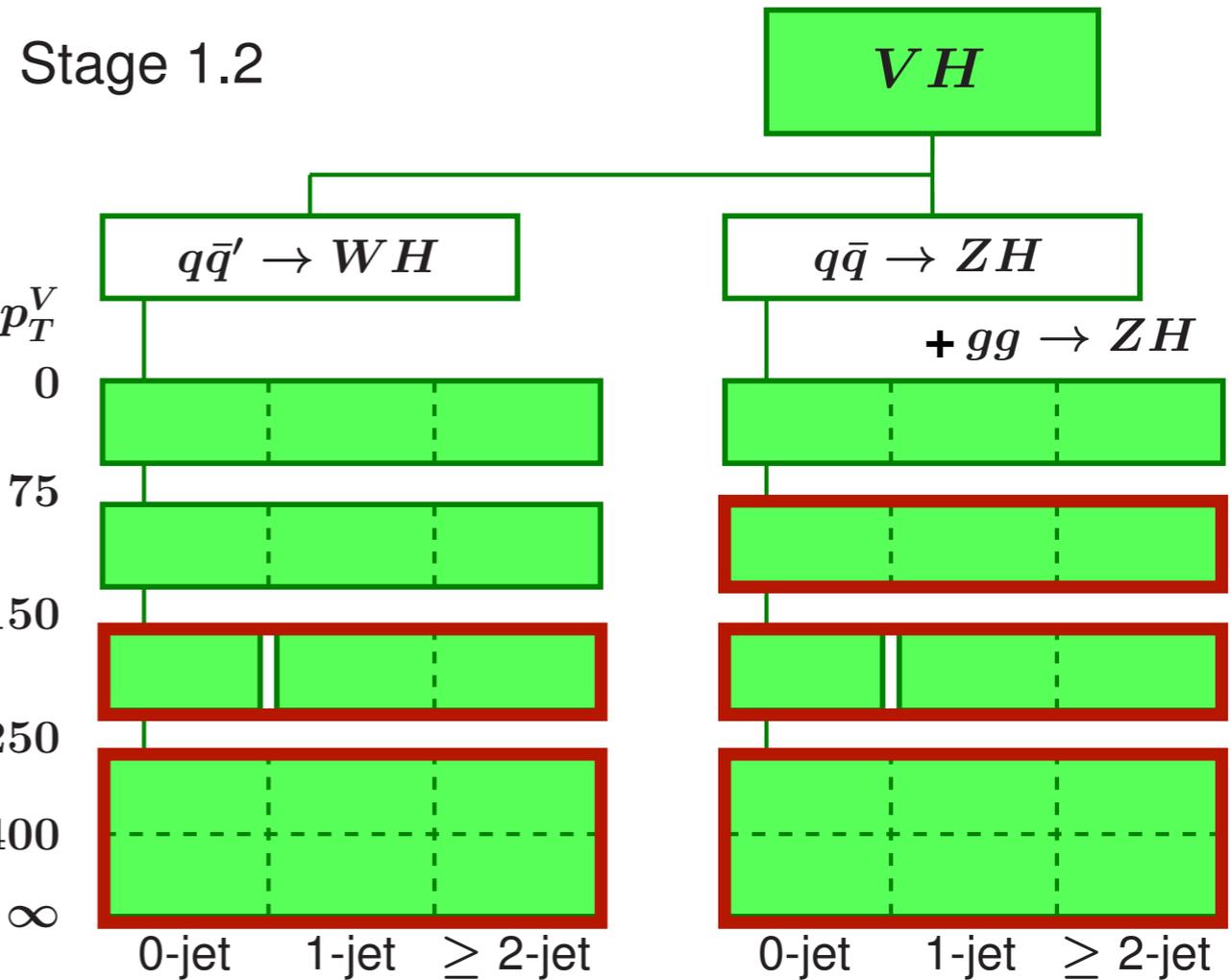
Measurement of Stage 1.2 STXS

Inclusive $\mu \longrightarrow$ **STXS** \longrightarrow Unfolded differential cross sections



[2007.02873]

Precision reaches $\mathcal{O}(30 - 40\%)$!

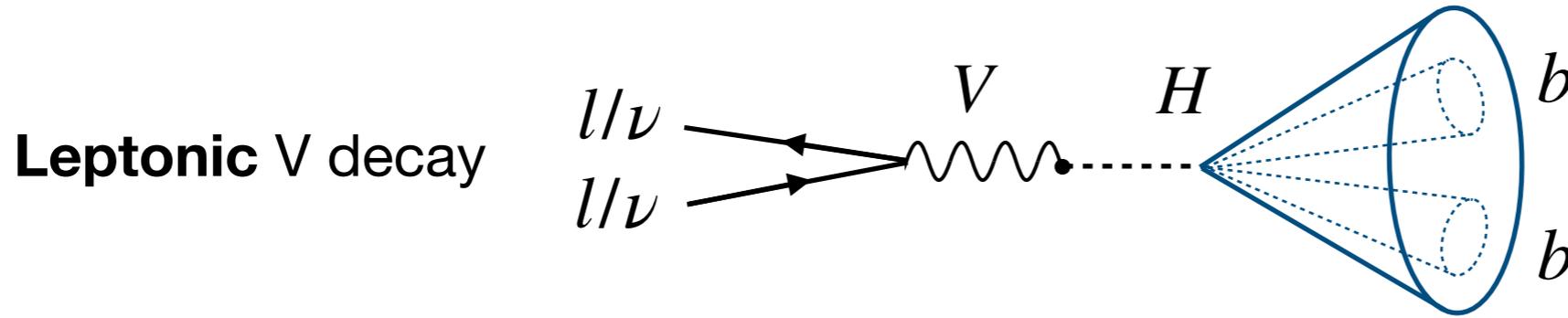


Exp. categories closely follow STXS
 \longrightarrow *Reduced model dependence*

VH(bb) “boosted”

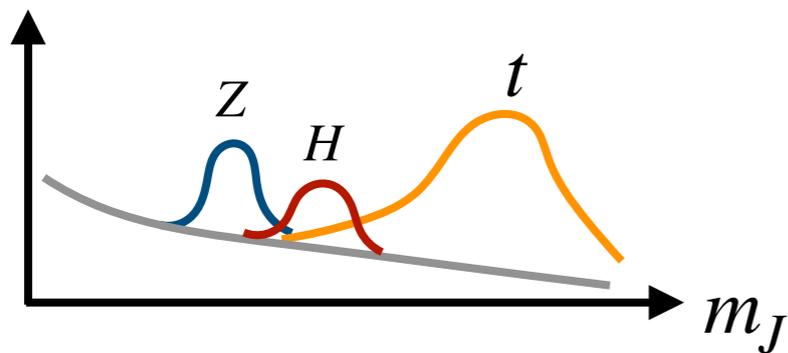
Moving towards higher pTV: boosted VH(bb)

arXiv:
[2008.02508]

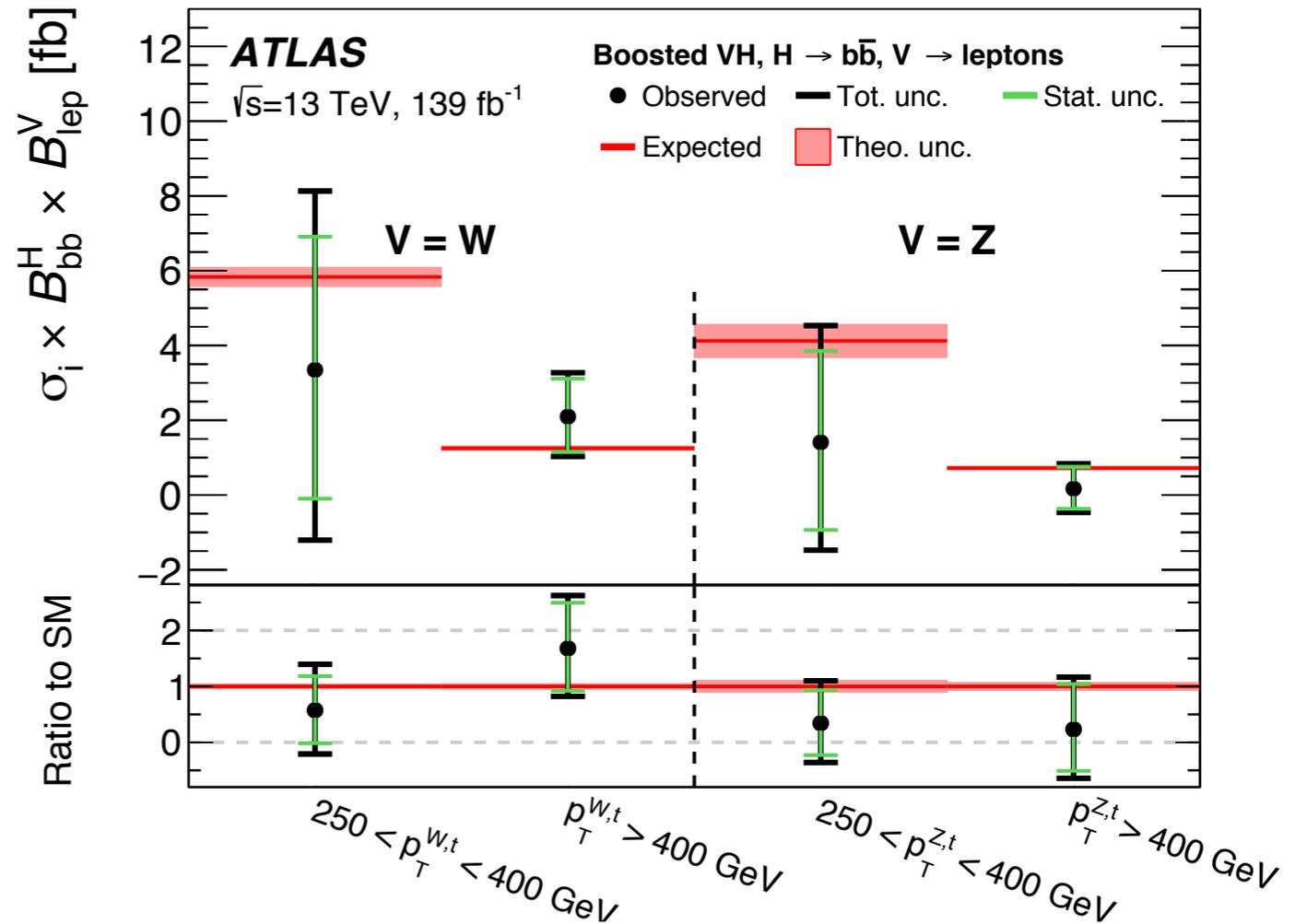
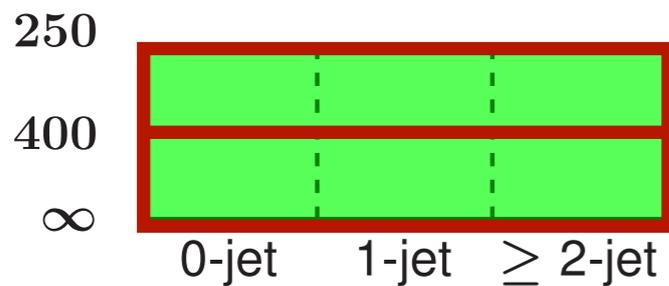


H decay “**boosted**”
into R=1.0 jet
Substructure: variable-R
b-tagged jets

Fit large-R jet mass



Finer granularity for $p_T^V > 250$ GeV



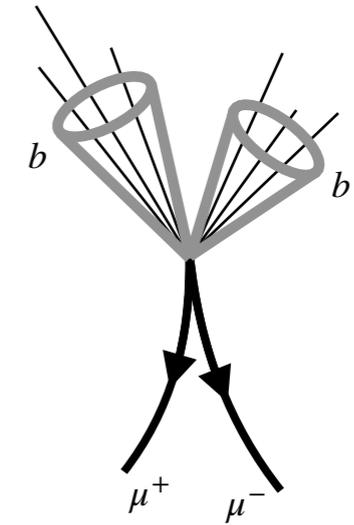
Event selection overlaps with VH(bb) “resolved”!

Overview

Recent experimental results from CMS and ATLAS

VH(bb) resolved

VH(bb) boosted



Experiment

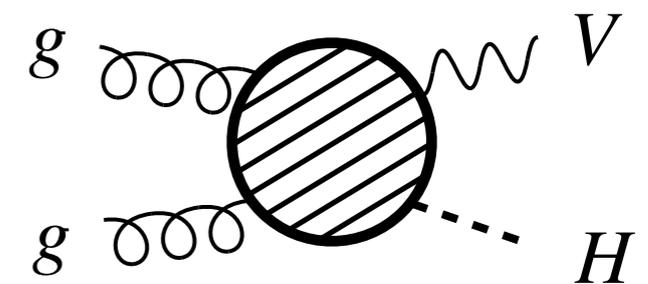
Uncertainties (*and how to improve*)

Theory signal uncertainties

STXS uncertainty scheme

Main components: $ggZH$, $qqZH$, Hbb

Backgrounds (*diboson, $t\bar{t}$, V +jets*)



Theory

Uncertainties: the big picture

Uncertainties from 2020 ATLAS STXS measurement

[2007.02873]

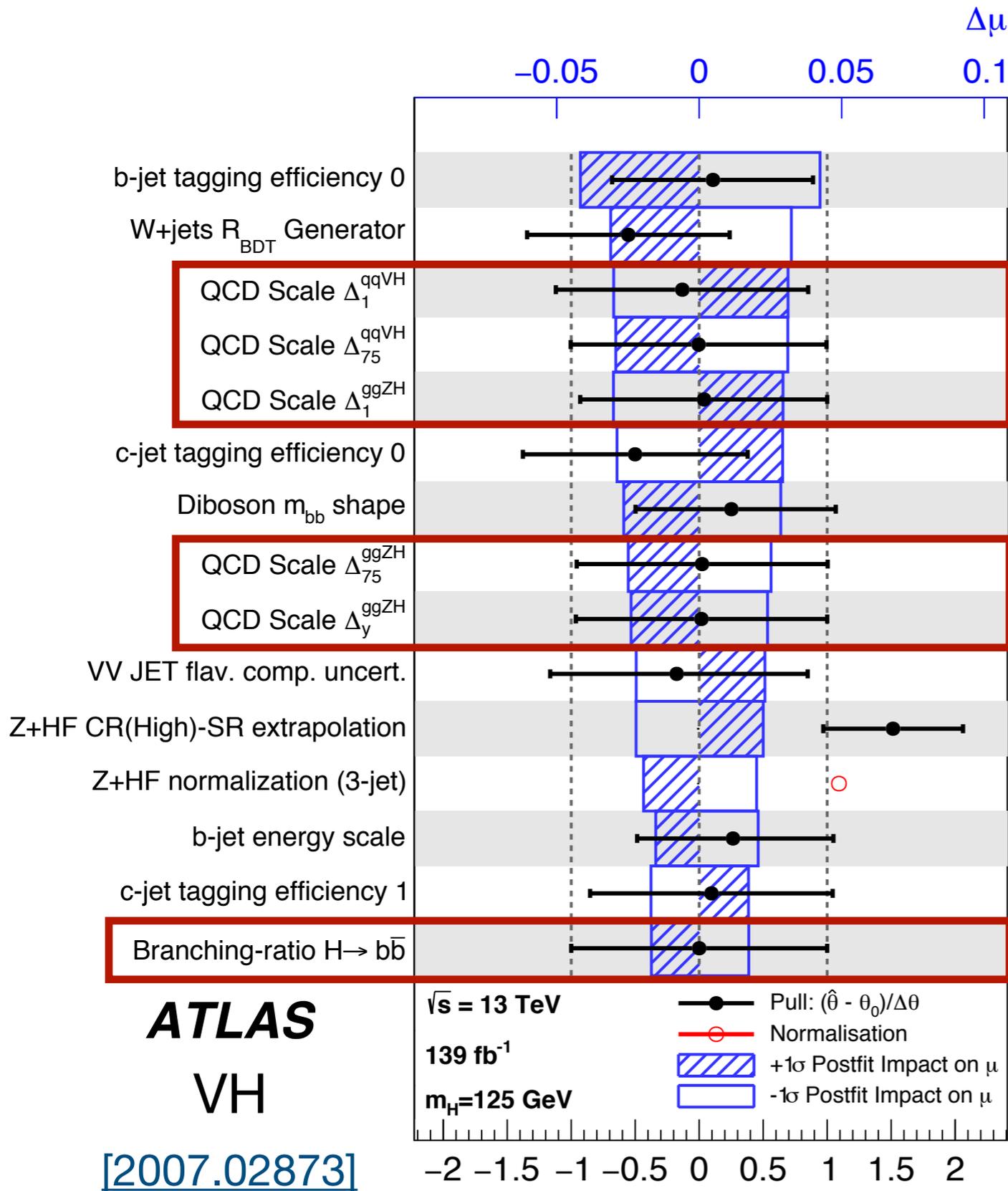
Process	STXS region $p_T^{V, \tau}$ interval	SM prediction		Result		Stat. unc.		Syst. unc. [fb]					
		[fb]		[fb]		[fb]		Th. sig.	Th. bkg.	Exp.			
$W(\ell\nu)H$	150–250 GeV	24.0	± 1.1	19.0	± 12.1	± 7.7	± 0.9	± 5.5	± 6.0				
$W(\ell\nu)H$	> 250 GeV	7.1	± 0.3	7.2	± 2.2	± 1.9	± 0.4	± 0.8	± 0.7				
$Z(\ell\ell/\nu\nu)H$	75–150 GeV	50.6	± 4.1	42.5	± 35.9	± 25.3	± 5.6	± 17.2	± 19.7				
$Z(\ell\ell/\nu\nu)H$	150–250 GeV	18.8	± 2.4	20.5	± 6.2	± 5.0	± 2.3	± 2.4	± 2.3				
$Z(\ell\ell/\nu\nu)H$	> 250 GeV	4.9	± 0.5	5.4	± 1.7	± 1.5	± 0.5	± 0.5	± 0.3				

With present dataset, theory uncertainties currently smaller than stat. uncertainty ...

... but are comparable to total experimental systematics

In the following: look at signal & background in more detail, highlight ways to improve

Theory signal uncertainties



Theory signal uncertainties

... are important!

QCD scale uncertainties on qqVH and ggZH

(overall impact factored out for STXS measurement)

Hbb decay

How can we improve?

Reminder: QCD scale uncertainties and STXS

Goal: factor out uncertainties on overall measured cross-sections

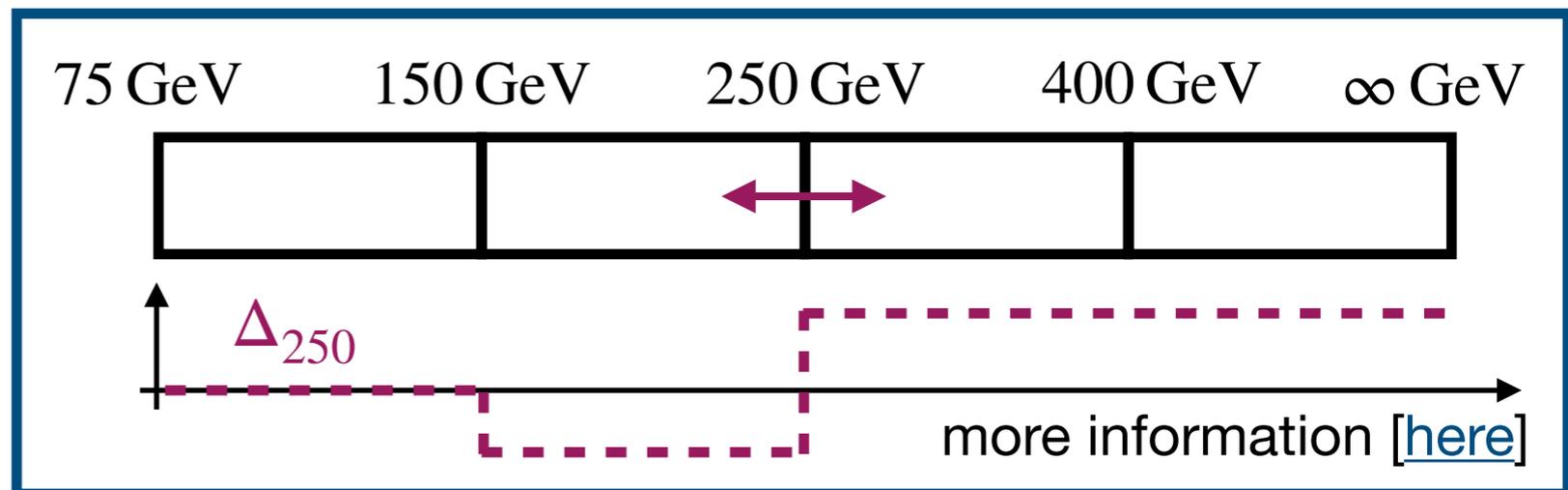
(applies to QCD scale & PDF uncertainties; PS / UE uncertainties remain folded into measurement result)

1) Parametrisation (on fine binning):

QCD scale uncertainty = overall \oplus migrations across bin boundaries (p_T^V & $nJet$)

Production mode	$\Delta_y^{<VH>}$
WH	$\pm 0.7\%$
$q\bar{q} \rightarrow ZH$	$\pm 0.6\%$
$gg \rightarrow ZH$	$\pm 25\%$

from [YR4]



2) Removal of total uncertainty on each unfolded STXS bin:

Cross-section uncertainties turn into residual shape uncertainties
within coarser STXS bins

Great success of discussions within WG1!

(ongoing work in WG1 / WG2 to study and provide more precise prescription [[link](#)])

Reminder: QCD scale uncertainties and STXS

Goal: factor out uncertainties on overall measured cross-sections

(applies to QCD scale & PDF uncertainties; PS / UE uncertainties remain folded into measurement result)

1) Parametrisation (on fine binning):

QCD scale uncertainty = overall \oplus migrations across bin boundaries (p_T^V & $nJet$)

Product
WH
$q\bar{q} \rightarrow Zl$
$gg \rightarrow Zl$
f

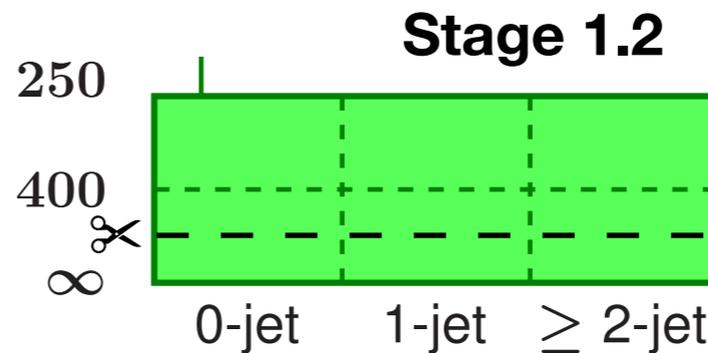
Note to the future:

Current experimental precision on $p_T^V > 400$ GeV bin is $\mathcal{O}(50\%)$

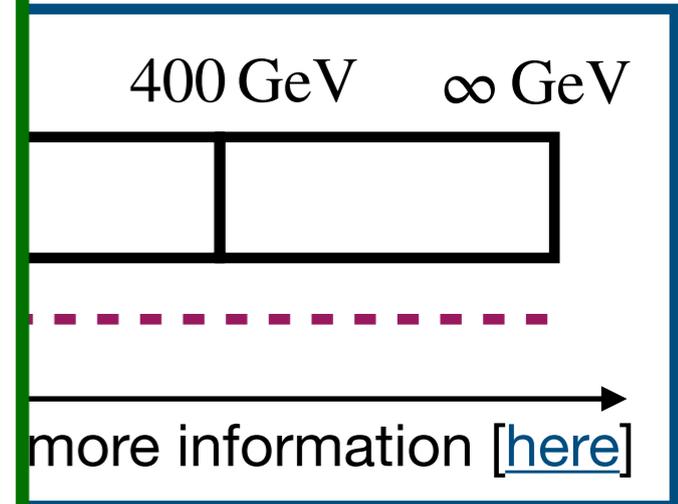
Current uncertainty model is still sufficient ...

... but how to extend **Stage 1.2?**

(additional split?)



within coarser STXS bins



uncertainties

2) Removal

Great success of discussions within WG1!

(ongoing work in WG1 / WG2 to study and provide more precise prescription [\[link\]](#))

Signal modelling: ggZH

[2007.02873]

	Signal
Cross-section (scale)	0.7% (qq), <u>25% (gg)</u>
$H \rightarrow b\bar{b}$ branching fraction	1.7%
Scale variations in STXS bins	3.0%–3.9% ($qq \rightarrow WH$), 6.7%–12% ($qq \rightarrow ZH$), <u>37%–100% ($gg \rightarrow ZH$)</u>
PS/UE variations in STXS bins	1%–5% for $qq \rightarrow VH$, <u>5%–20% for $gg \rightarrow ZH$</u>
PDF+ α_S variations in STXS bins	1.8%–2.2% ($qq \rightarrow WH$), 1.4%–1.7% ($qq \rightarrow ZH$), 2.9%–3.3% ($gg \rightarrow ZH$)
m_{bb} from scale variations	M+S ($qq \rightarrow VH$, $gg \rightarrow ZH$)
m_{bb} from PS/UE variations	M+S
m_{bb} from PDF+ α_S variations	M+S
p_T^V from NLO EW correction	M+S

ATLAS and CMS use ggZH@LO(QCD) from POWHEG

[inclusive calculation: NLO + NLL (QCD)]

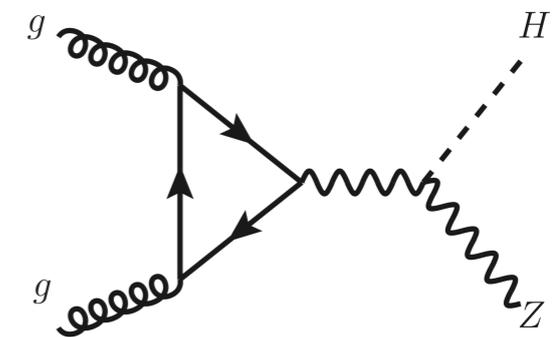
→ Large scale uncertainties

ggZH accounts only for ~10% of inclusive ZH cross section

Uncertainties still very important!

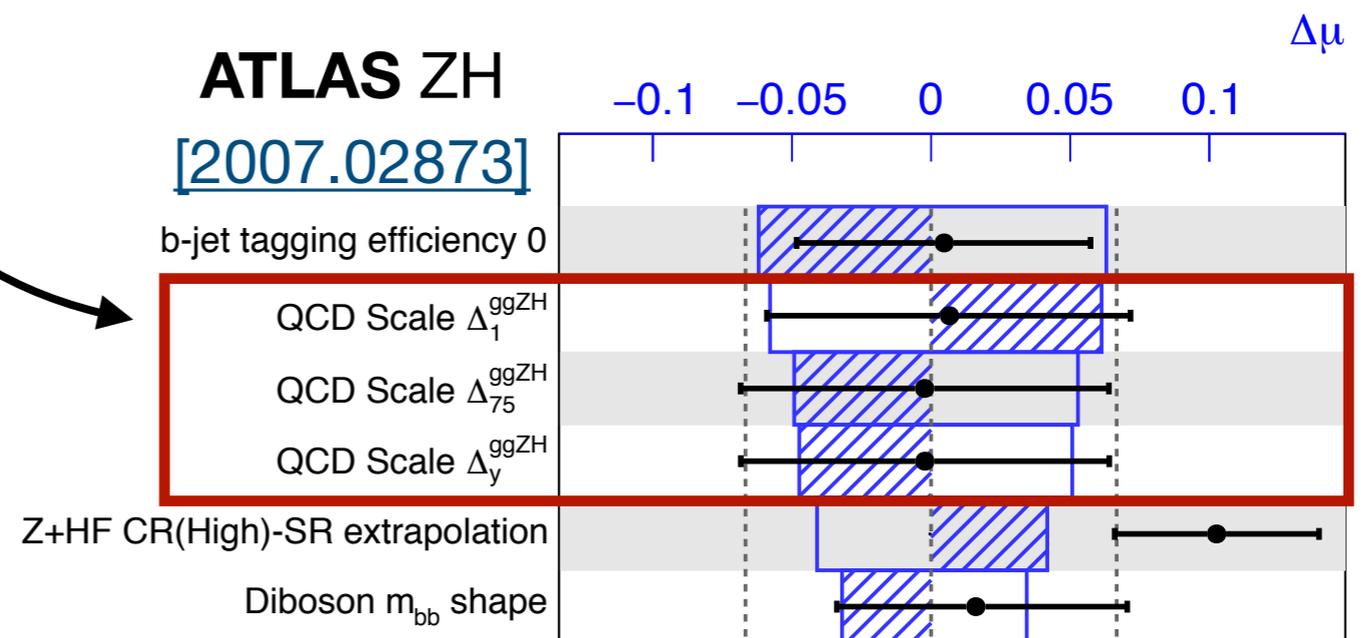
No full NLO calculation available for the foreseeable future (?)

How to improve?



ATLAS ZH

[2007.02873]

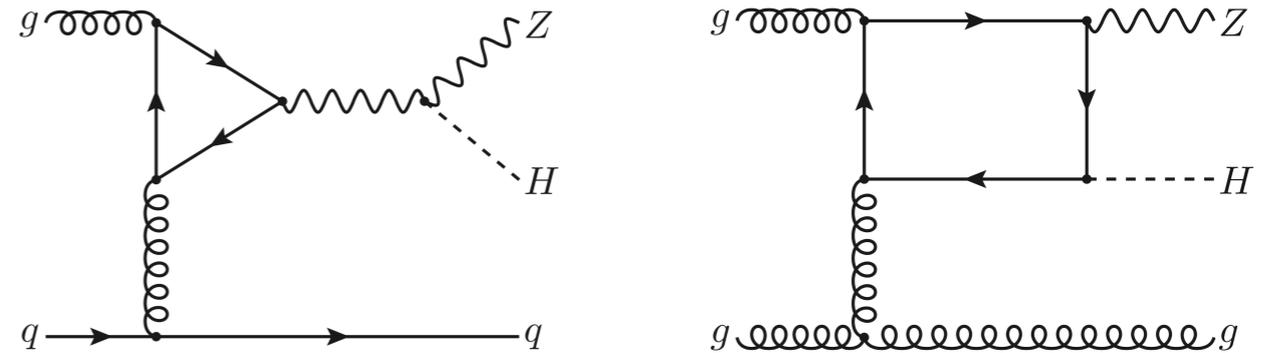


Signal modelling: ggZH

For now: add 2 → 3 process

$$gg \rightarrow Z(l^+l^-)H + 0,1j$$

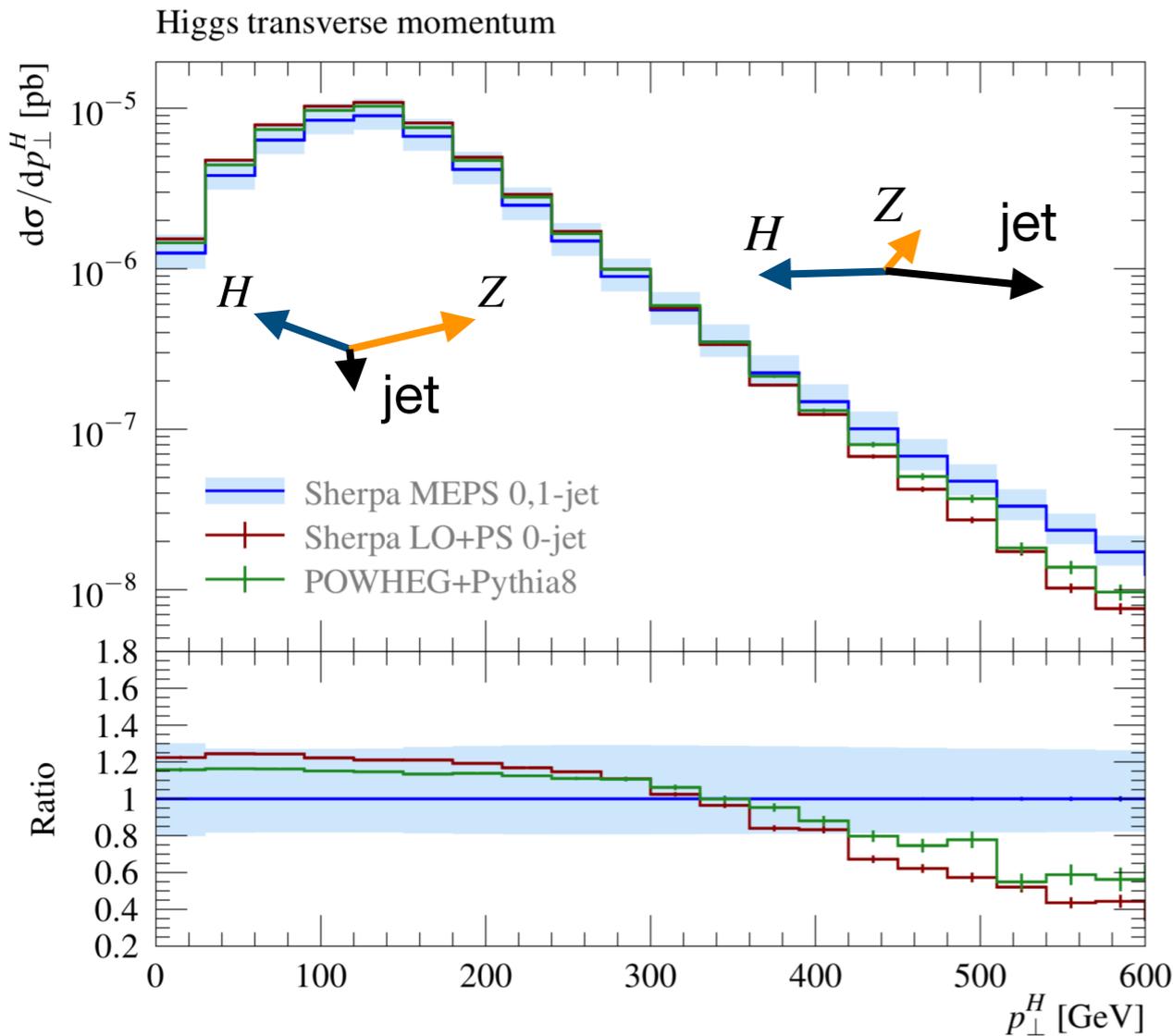
(available in Sherpa and aMC@NLO)



Sherpa setup studied in Les Houches project

Proceedings: [\[2003.01700\]](#)

E. Bothmann, M. Calvetti, P. Francavilla,
C. Pandini, E. Re, S. L. Villani



← p_T^H spectrum gets **harder**, p_T^Z spectrum **softer**

Scale uncertainties increase w.r.t. 2→2:

Cross-section [pb]	POWHEG+PYTHIA	SHERPA MEPS 0,1j
total cross-section (before cuts)	0.001883(1) ^{+25%} _{-19%}	0.001640(1) ^{+39%} _{-26%}
fiducial cross-section (after cuts)	0.001575(3)	0.001384(1)

What does enlarged uncertainty mean for current estimations / usage in LHC experiments?

Studies with Sherpa setup and comparison to aMC@NLO ongoing in ATLAS

Many thanks to Enrico and Simon Luca for invaluable help!

Signal modelling: qqZH

[2007.02873]

	Signal
Cross-section (scale)	0.7% (qq), 25% (gg)
$H \rightarrow b\bar{b}$ branching fraction	1.7%
Scale variations in STXS bins	<u>3.0%–3.9% (qq → WH), 6.7%–12% (qq → ZH), 37%–100% (gg → ZH)</u>
PS/UE variations in STXS bins	<u>1%–5% for qq → VH, 5%–20% for gg → ZH</u>
PDF+ α_S variations in STXS bins	1.8%–2.2% (qq → WH), 1.4%–1.7% (qq → ZH), 2.9%–3.3% (gg → ZH)
m_{bb} from scale variations	M+S (qq → VH, gg → ZH)
m_{bb} from PS/UE variations	M+S
m_{bb} from PDF+ α_S variations	M+S
p_T^V from NLO EW correction	M+S

dominated by P8 / H7 differences

ATLAS and CMS use qqZH@MiNLO(QCD) from POWHEG

[inclusive calculation: NNLO(QCD) + NLO (EW)]

p_T^V reweighting for EW corrections @ NLO

(computed by HAWK: old WG1 prescription, only available up to 500 GeV)

qqVH now available from POWHEG @ NLO QCD + EW

No need for dedicated reweighting anymore

[1706.03522]

F. Granata et al.

ZH @ NNLOPS

Reweight events from POWHEG-BOX-RES to MCFM

[1804.08141]

W. Astill et al.

WH+jet @ NNLO

Starting to include also b-quark mass effects for WH @ NNLO!

[2009.14209]

R. Gauld et al.

Signal modelling: Hbb decay

[2007.02873]

	Signal
Cross-section (scale)	0.7% (qq), 25% (gg)
$H \rightarrow b\bar{b}$ branching fraction	1.7%
Scale variations in STXS bins	3.0%–3.9% ($qq \rightarrow WH$), 6.7%–12% ($qq \rightarrow ZH$), 37%–100% ($gg \rightarrow ZH$)
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PDF+ α_S variations in STXS bins	1.8%–2.2% ($qq \rightarrow WH$), 1.4%–1.7% ($qq \rightarrow ZH$), 2.9%–3.3% ($gg \rightarrow ZH$)
m_{bb} from scale variations	M+S ($qq \rightarrow VH$, $gg \rightarrow ZH$)
m_{bb} from PS/UE variations	M+S
m_{bb} from PDF+ α_S variations	M+S
p_T^V from NLO EW correction	M+S

ATLAS and CMS use Pythia 8 to handle Hbb decay

Hbb decay now known at N3LO

Starting to include effects from finite b-quark mass at NNLO

[1904.08960]

R. Mondini et al.

[1804.08141]

W. Astill et al.

[2003.08321]

A. Behring et al.

Improved m_{bb} modelling

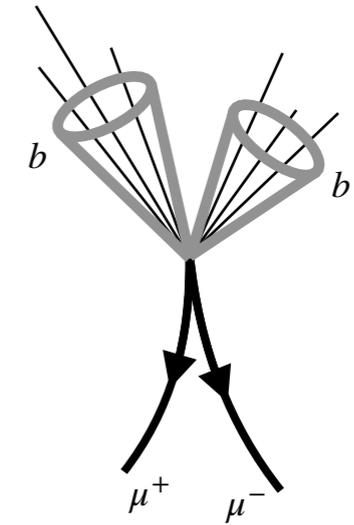
Importance for jet substructure in boosted regime?

Overview

Recent experimental results from CMS and ATLAS

VH(bb) resolved

VH(bb) boosted



Experiment

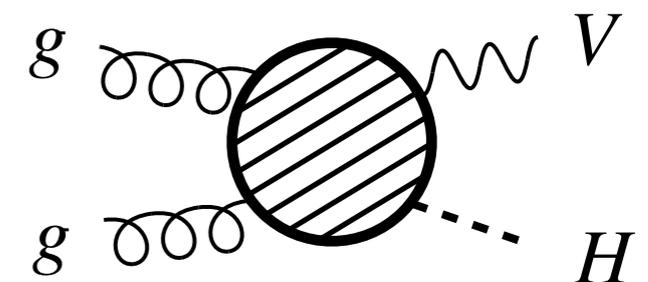
Uncertainties (*and how to improve*)

Theory signal uncertainties

STXS uncertainty scheme

Main components: $ggZH$, $qqZH$, Hbb

Backgrounds (*diboson, $t\bar{t}$, V +jets*)



Theory

Background modelling: uncertainties

VH(bb) faces a number of backgrounds of similar magnitudes ...

... in a highly specific region of event phase-space

[\[2007.02873\]](#)

Source of uncertainty	VH	σ_μ WH	ZH
Total	0.177	0.260	0.240
Statistical	0.115	0.182	0.171
Systematic	0.134	0.186	0.168
Statistical uncertainties			
Data statistical	0.108	0.171	0.157
$t\bar{t} e\mu$ control region	0.014	0.003	0.026
Floating normalisations	0.034	0.061	0.045
Theoretical and modelling uncertainties			
Signal	0.052	0.048	0.072
$Z + \text{jets}$	0.032	0.013	0.059
$W + \text{jets}$	0.040	0.079	0.009
$t\bar{t}$	0.021	0.046	0.029
Single top quark	0.019	0.048	0.015
Diboson	0.033	0.033	0.039
Multi-jet	0.005	0.017	0.005

Background modelling: diboson

VH(bb) faces a number of backgrounds of similar magnitudes ...

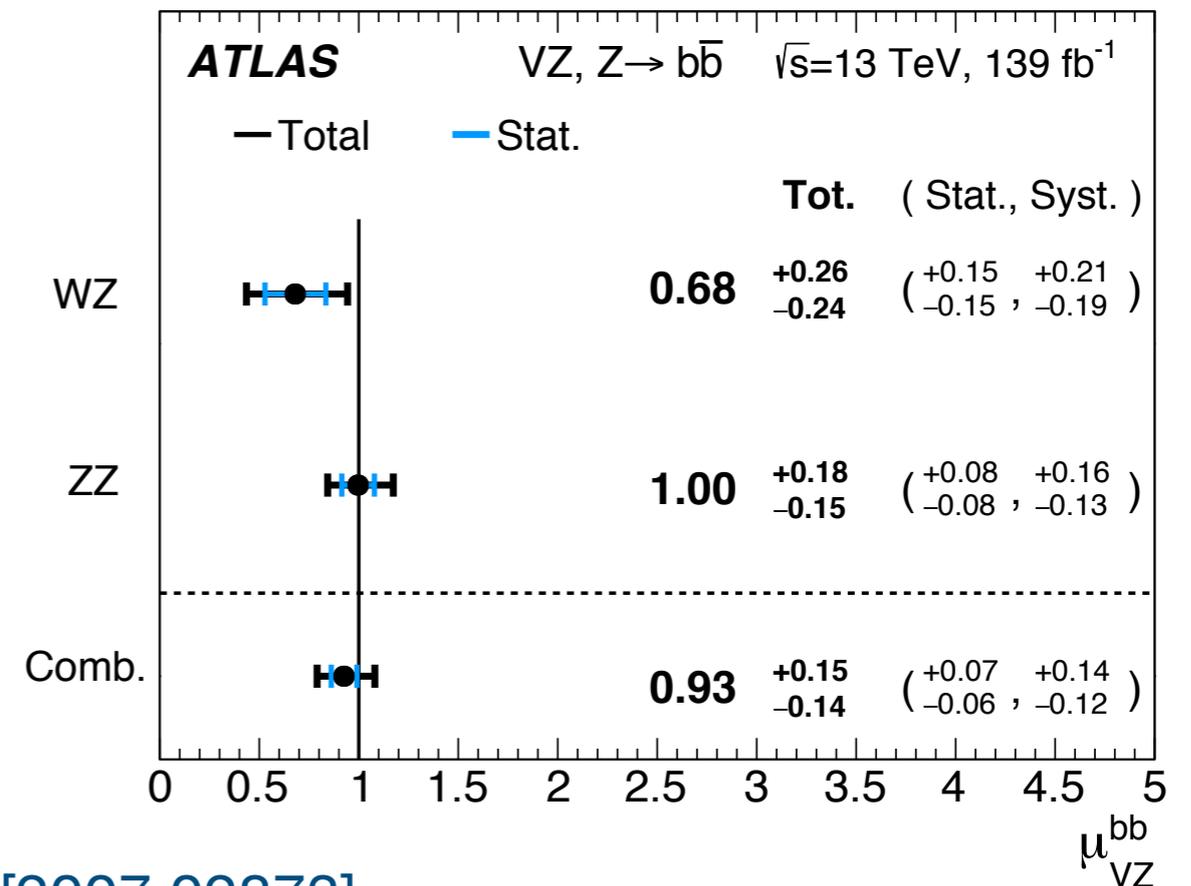
... in a highly specific region of event phase-space

[2007.02873]

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Single top quark	0.019	0.048	0.015
Diboson	0.033	0.033	0.039
Multi-jet	0.005	0.017	0.005

Diboson

Good modelling, dedicated WZ / ZZ cross-check analysis, no concerning features seen



[2007.02873]

Background modelling: ttbar

VH(bb) faces a number of backgrounds of similar magnitudes ...

... in a highly specific region of event phase-space

[2007.02873]

Source of uncertainty	σ_μ		
	VH	WH	ZH
Total	0.177	0.260	0.240
Statistical	0.115	0.182	0.171
Systematic	0.134	0.186	0.168
Statistical uncertainties			
Data statistical	0.108	0.171	0.157
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Single top quark	0.019	0.048	0.015
Diboson	0.033	0.033	0.039
Multi-jet	0.005	0.017	0.005

ttbar / single top

Some 0+1-lep. regions not covered by standard ttbar measurements
(leptons or jets 'lost')

No concerning features in MC modelling

Use of data-driven techniques in 2-lep. channel (less modelling impact)

Background modelling: V+jets

VH(bb) faces a number of backgrounds of similar magnitudes ...

... in a highly specific region of event phase-space

[\[2007.02873\]](#)

Source of uncertainty	σ_μ		
	VH	WH	ZH
Total	0.177	0.260	0.240
Statistical	0.115	0.182	0.171
Systematic	0.134	0.186	0.168
Statistical uncertainties			
Data statistical	0.108	0.171	0.157
$t\bar{t} e\mu$ control region	0.014	0.003	0.026
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Theoretical and modelling uncertainties			
Signal	0.052	0.048	0.072
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tt	0.021	0.046	0.029
Single top quark	0.019	0.048	0.015
Diboson	0.033	0.033	0.039
Multi-jet	0.005	0.017	0.005

V + heavy flavour

Model quite different between CMS / ATLAS

Normalisation in data significantly different from MC

Let's have a closer look ...

V+hf models in CMS & ATLAS

CMS

ATLAS

Generator setup	<i>MadGraph</i> V+0,1,2,3,4J@LO	<i>Sherpa</i> V+0,1,2J@NLO +3,4J@LO
+ reweighting	EW corrections (p_T^V) NLO / LO (ΔR_{bb})	

Fit model	CRs in 1-lep. [2-lep] channel from m_{bb} sidebands (multiple p_T^V / m_{bb} bins depending on channel)	CRs in 1-lep. [2-lep.] channel at low [and high] ΔR_{bb} for W+hf [Z+hf] (for separate jet multiplicities, p_T^V bins)
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Normalisation factors

[\[1808.08242\]](#)

Process	Z($\nu\nu$)H	W($\ell\nu$)H	Z($\ell\ell$)H low- p_T	Z($\ell\ell$)H high- p_T
W + udscg	1.04 ± 0.07	1.04 ± 0.07	-	-
W + b	2.09 ± 0.16	2.09 ± 0.16	-	-
W + $b\bar{b}$	1.74 ± 0.21	1.74 ± 0.21	-	-
Z + udscg	0.95 ± 0.09	-	0.89 ± 0.06	0.81 ± 0.05
Z + b	1.02 ± 0.17	-	0.94 ± 0.12	1.17 ± 0.10
Z + $b\bar{b}$	1.20 ± 0.11	-	0.81 ± 0.07	0.88 ± 0.08
tt	0.99 ± 0.07	0.93 ± 0.07	0.89 ± 0.07	0.91 ± 0.07

[\[2007.02873\]](#)

Process and Category	Normalisation factor
$t\bar{t}$ 2-jet	0.98 ± 0.09
$t\bar{t}$ 3-jet	0.93 ± 0.06
W + HF 2-jet	1.06 ± 0.11
W + HF 3-jet	1.15 ± 0.09
Z + HF 2-jet, $75 < p_T^V < 150$ GeV	1.28 ± 0.08
Z + HF 3-jet, $75 < p_T^V < 150$ GeV	1.17 ± 0.05
Z + HF 2-jet, $150 \text{ GeV} < p_T^V$	1.16 ± 0.07
Z + HF 3-jet, $150 \text{ GeV} < p_T^V$	1.09 ± 0.04

Exercise ongoing within HXSWG to compare & study V+hf models:
common phase-space defined, objects harmonised; study progressing

Summary

VH(bb) process under intense experimental scrutiny
(recent publication of full-Run 2 results by ATLAS)

Current / next generation of VH(bb) analyses benefit from dialogue with theory community to pin down key uncertainties

Improvements in VH modelling — we as experimentalists should do our homework and validate / test new calculations in our analyses

To address: which (combinations of) tools are important for the analyses?



QCD scale uncertainties
Quo vadis ggZH?

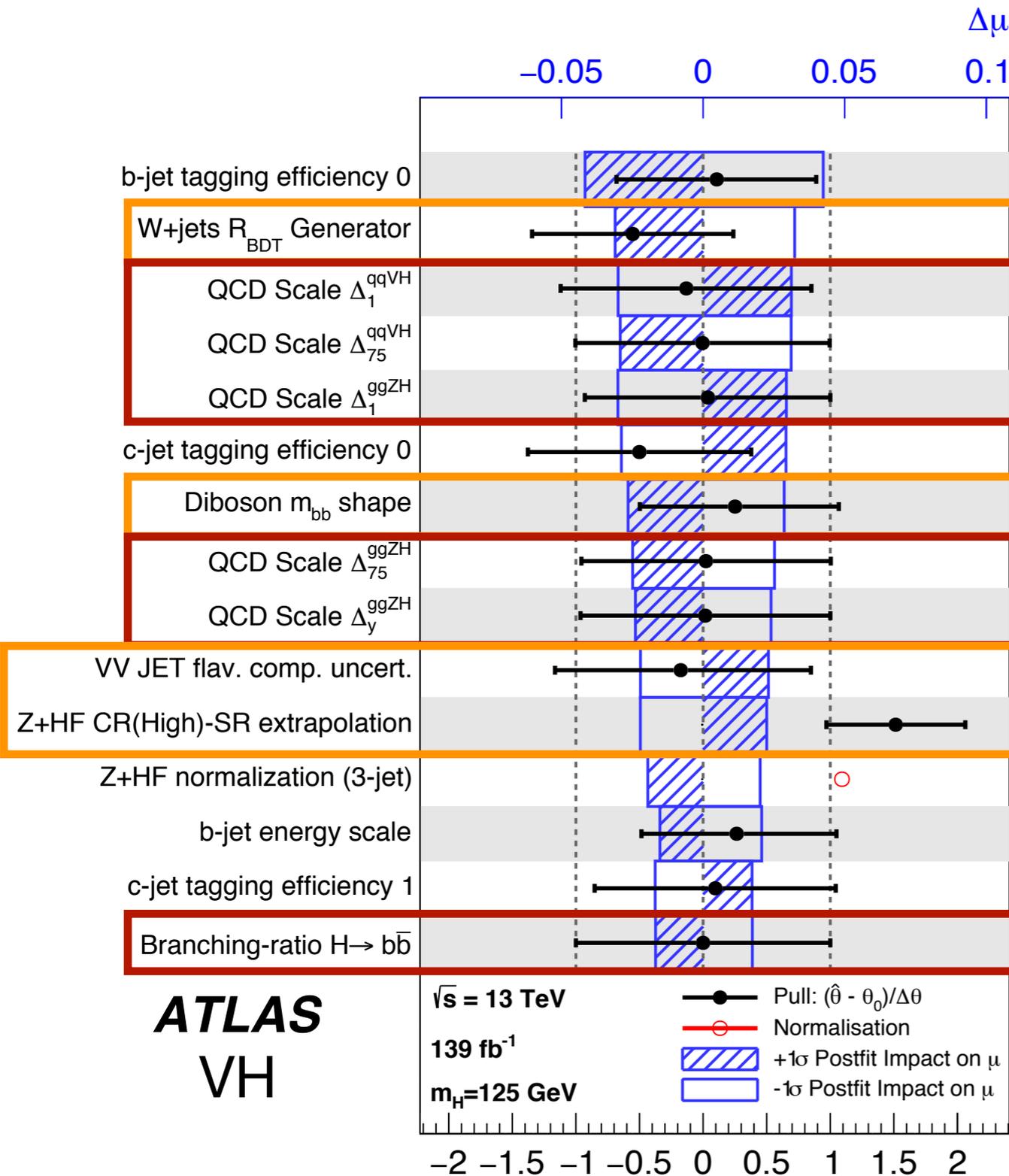


Higgs decay: N3LO vs parton shower
Importance for jet substructure?

Backup

Theory uncertainties

Theory uncertainties are more important than ever!



Impact of uncertainties on VH signal strength ($VHbb$ resolved)

Theory background

(mainly $W+hf$, $Z+hf$, diboson)

Much progress in controlling bkg. uncertainties “in situ”:
dedicated CRs ↔ profile likelihood fit

Theory signal

(mainly scale variations, $ggZH$)

Data have no constraining power:
full uncertainty propagated to result!

Need advances from theory in order to improve!

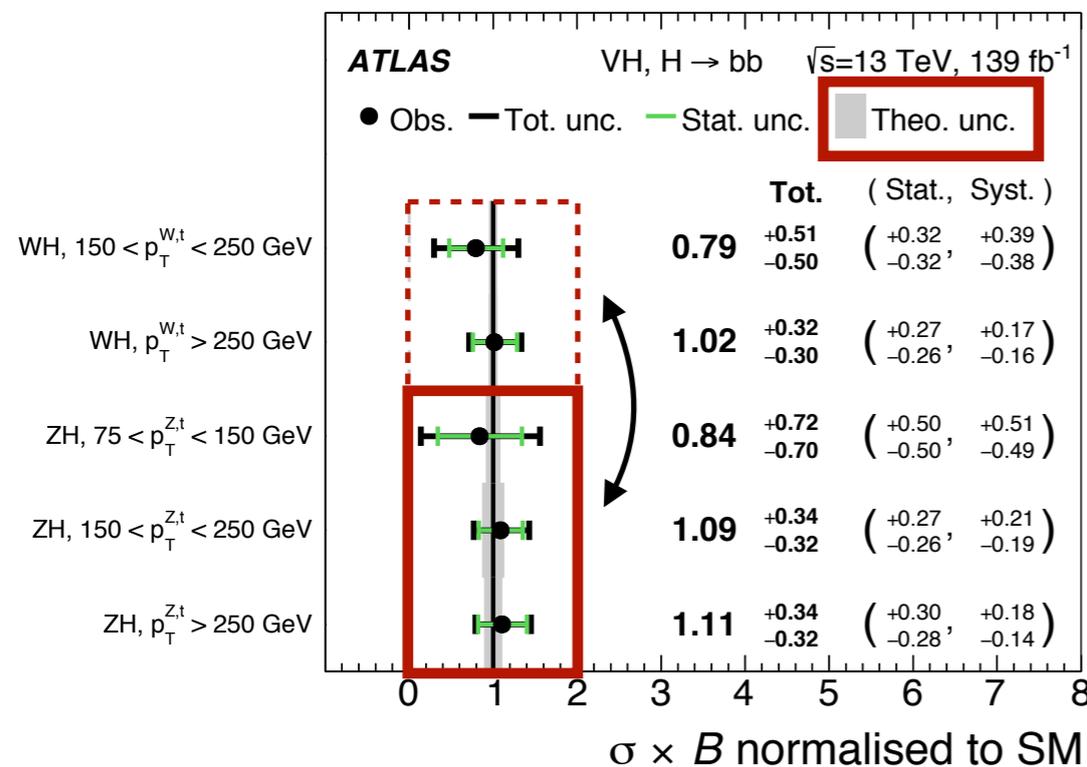
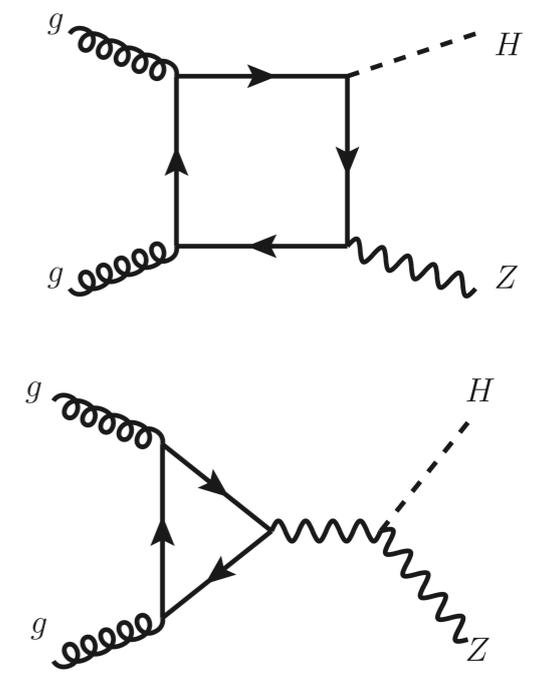
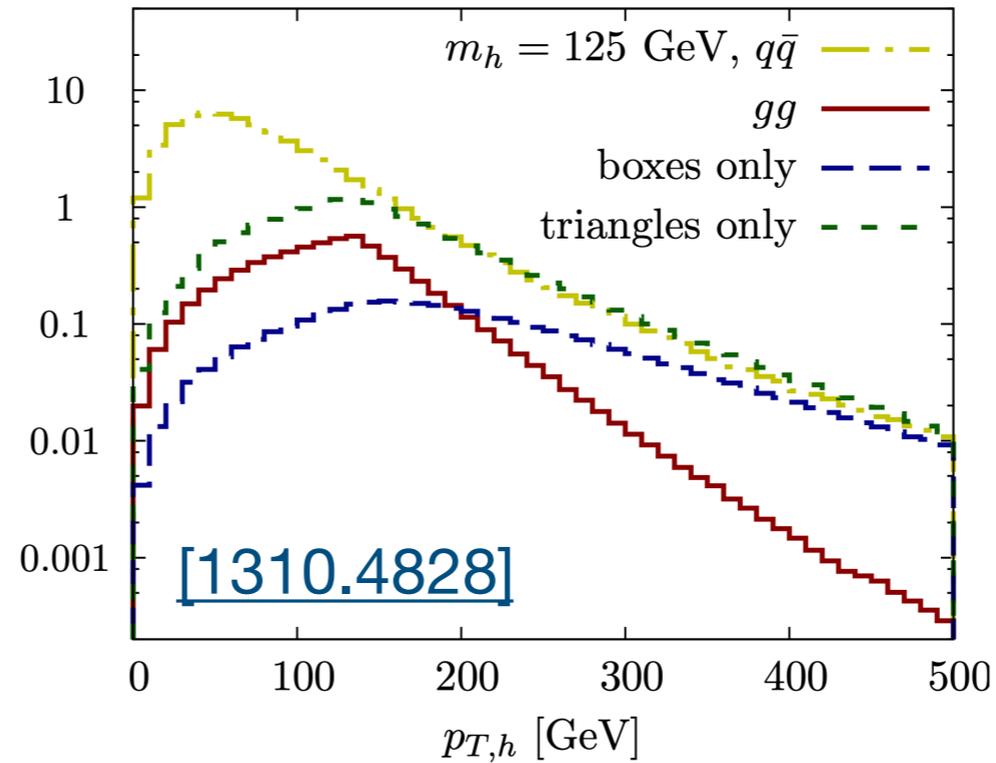
Signal modelling: ggZH

ATLAS and CMS use ggZH@LO(QCD) from POWHEG

ggZH subleading compared to DY ...
(even more so at high $p_{T,h}$)



$d\sigma/dp_{T,h}$ [fb/10 GeV]



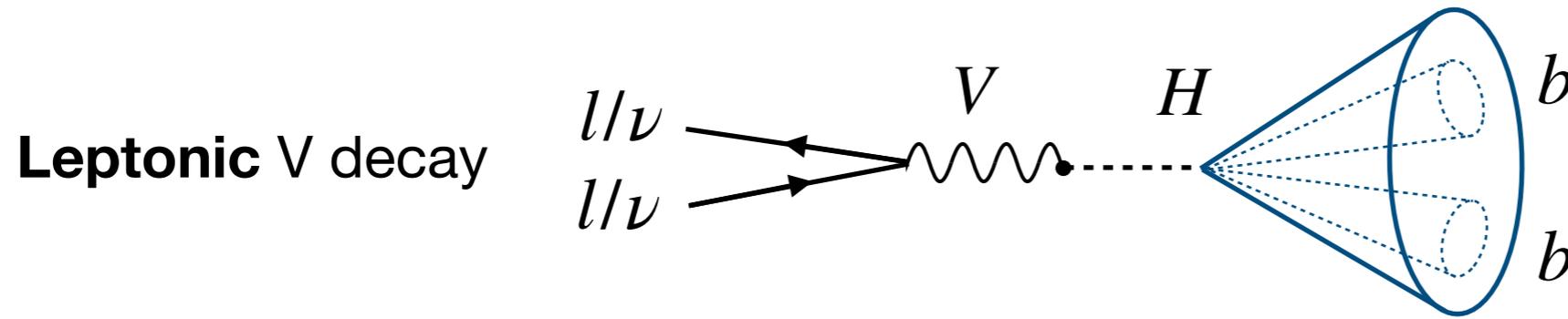
... but large (~25%) scale uncertainties contribute significantly to overall uncertainty on ZH cross section!

No full NLO calculation available for the foreseeable future (?)

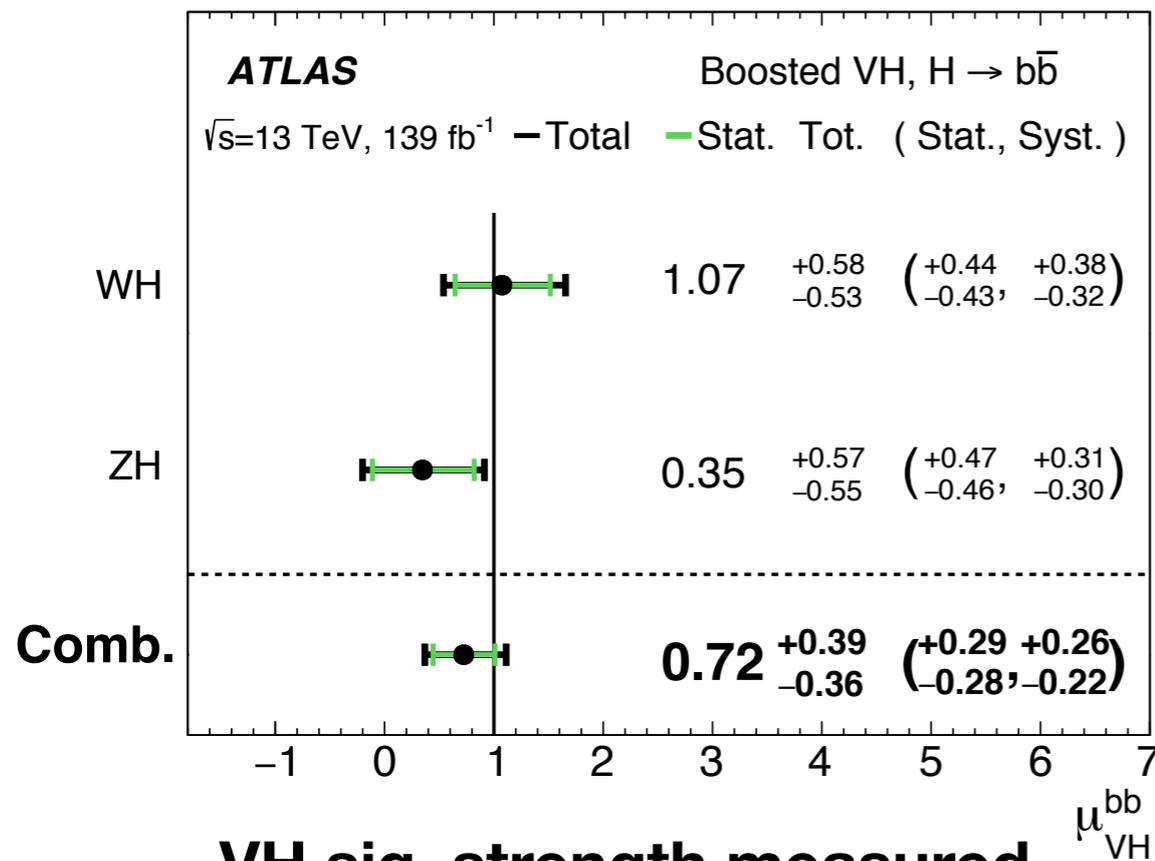
Recent experimental results

Moving towards higher pTV: boosted VH(bb)

arXiv:
[2008.02508]



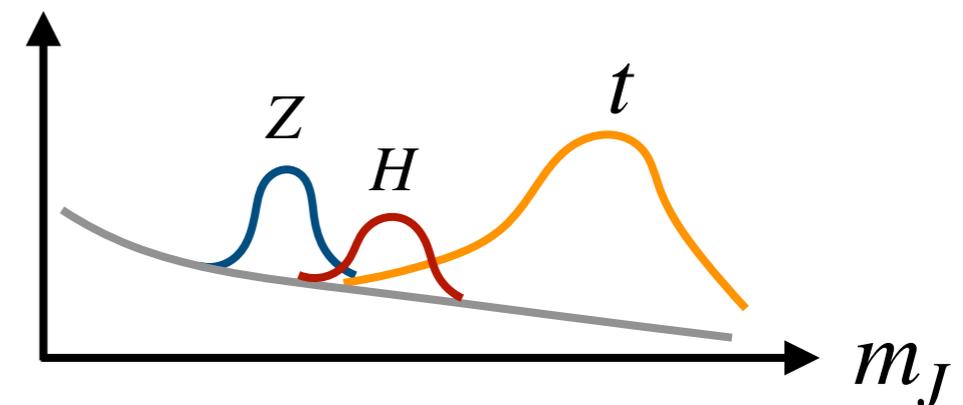
H decay “**boosted**”
into R=1.0 jet
Substructure: variable-R
b-tagged jets



VH sig. strength measured
with ~40% precision
(2.1 σ obs.)

Provide finer granularity
for pTV ≥ 250 GeV

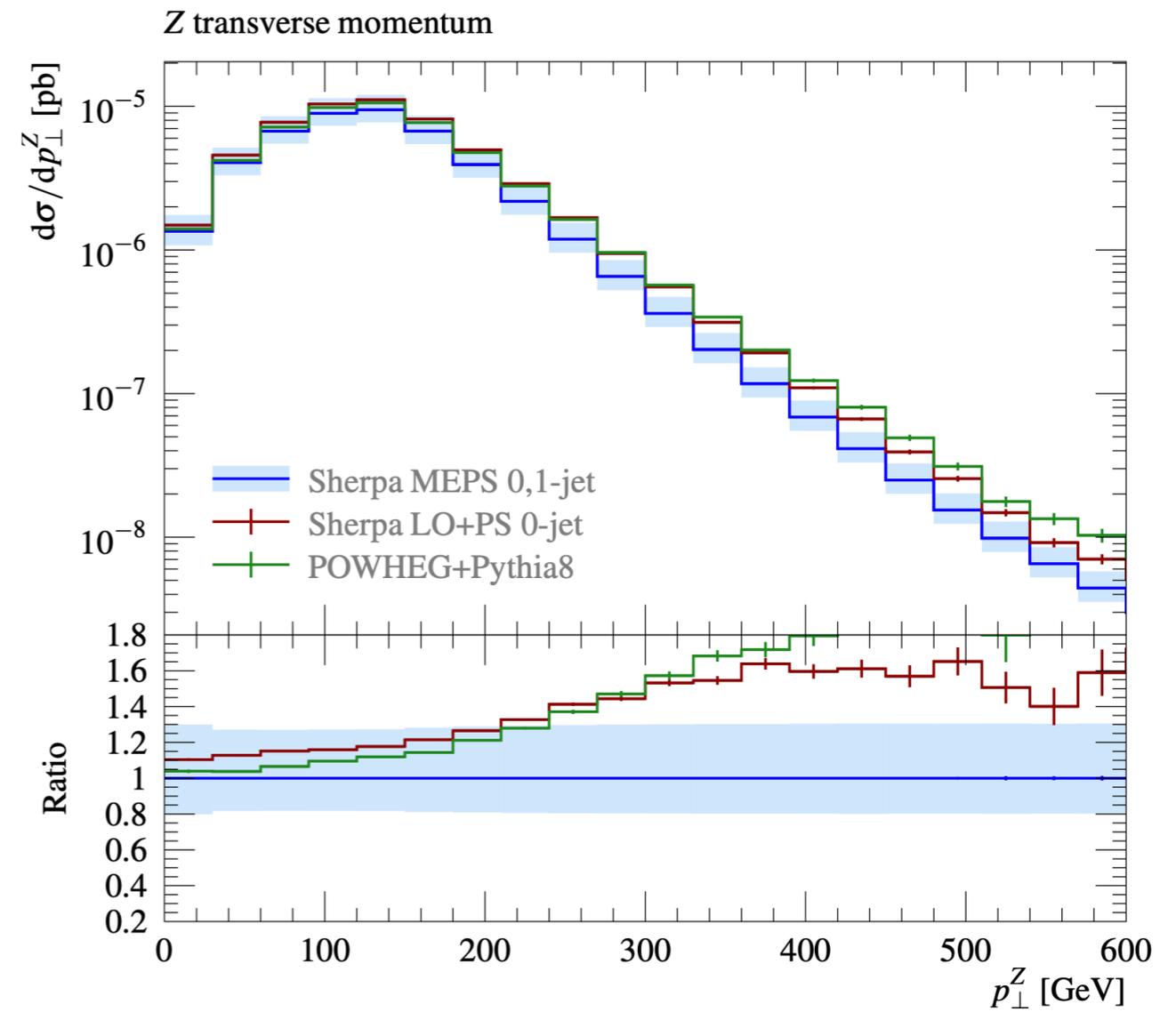
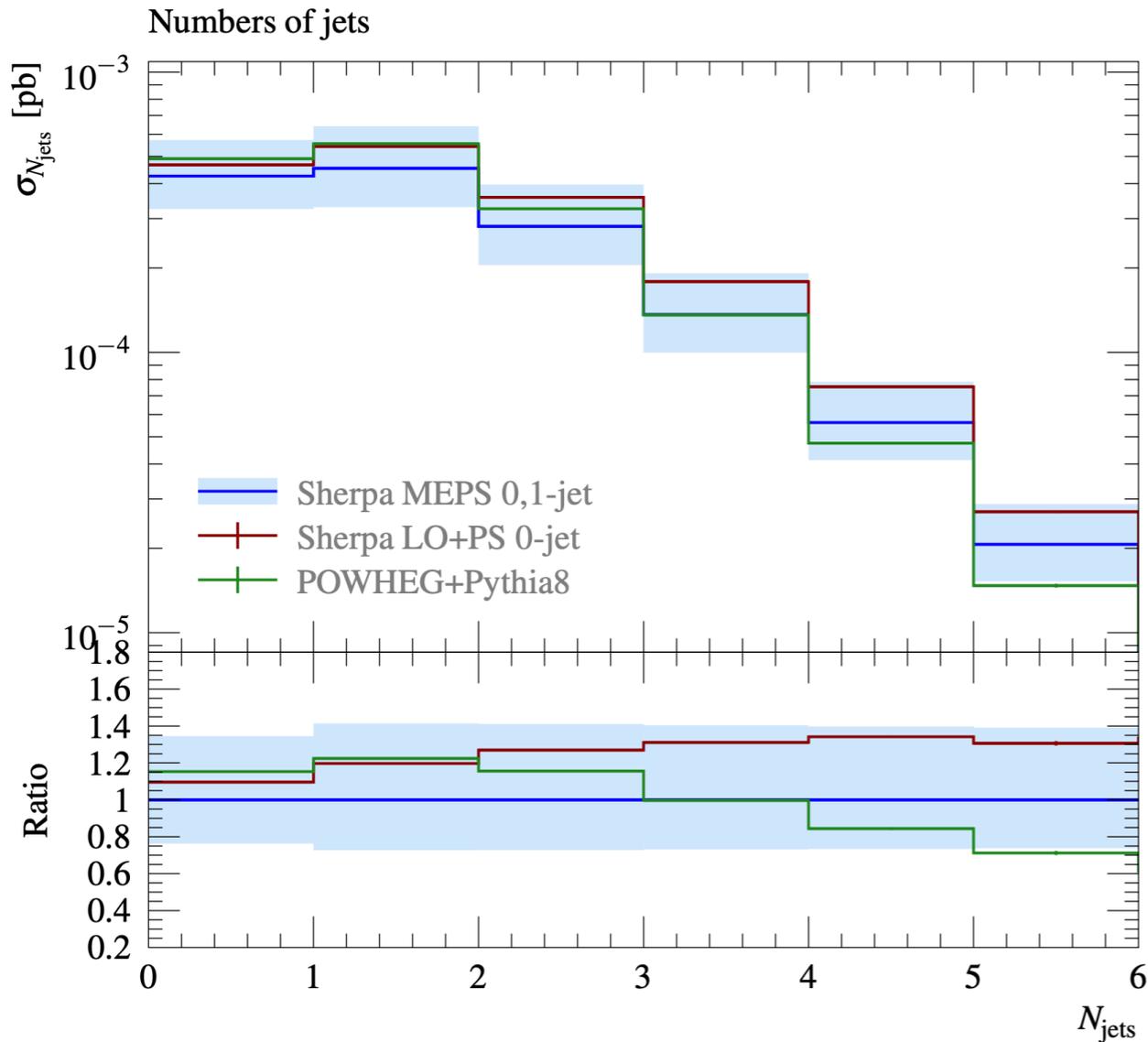
Fit large-R jet mass



Event selection overlaps
with VH(bb) “resolved”!

Sherpa ggZH+0,1J

Proceedings: [\[2003.01700\]](#)



0J only

0+1J merged

Cross-section [pb]	POWHEG+PYTHIA	SHERPA MEPS 0,1j
total cross-section (before cuts)	0.001883(1) ^{+25%} _{-19%}	0.001640(1) ^{+39%} _{-26%}
fiducial cross-section (after cuts)	0.001575(3)	0.001384(1)

A word about the boosted regime ...

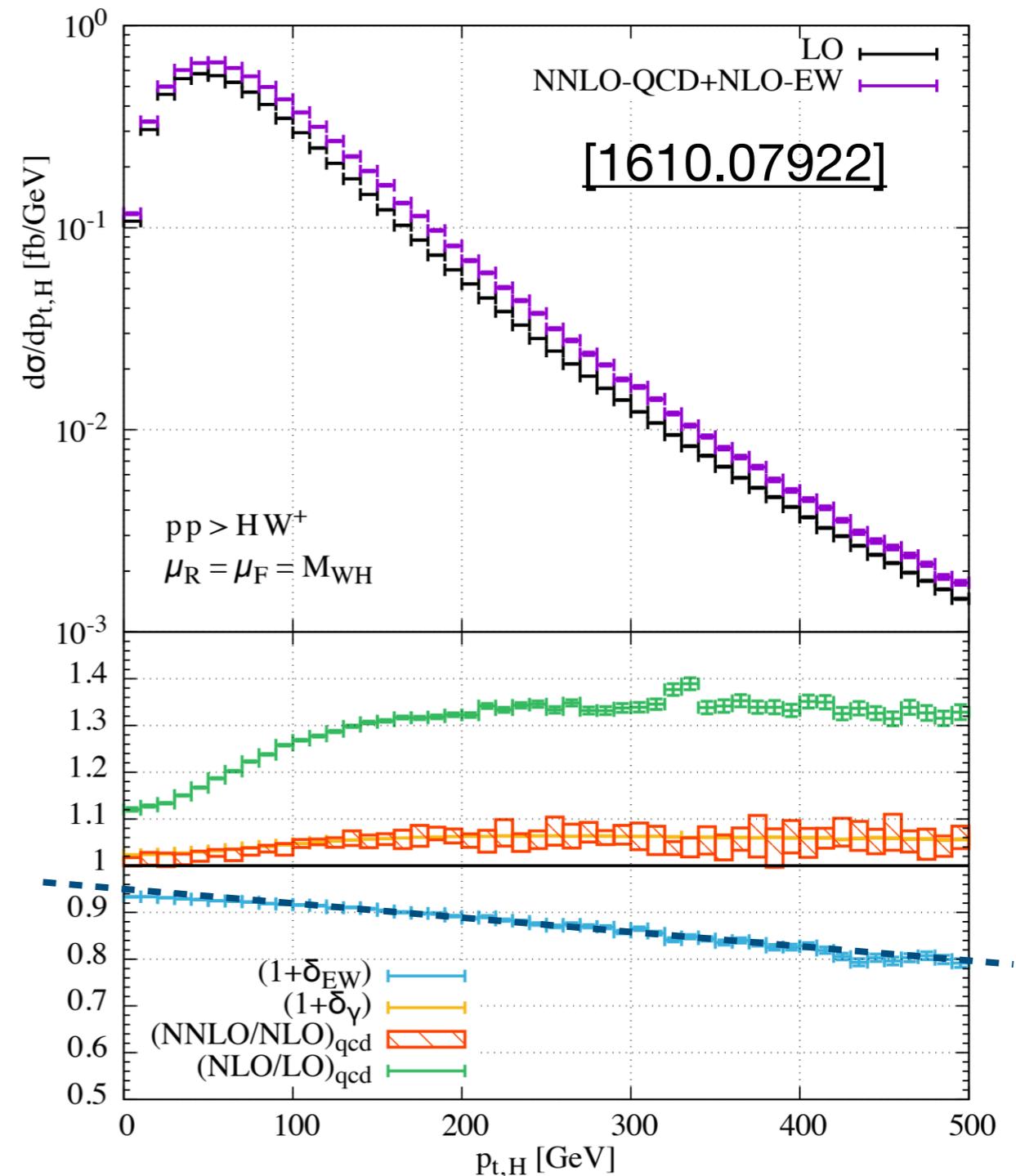
... and some takeaway points from the **ATLAS VH(bb) boosted analysis**

**NLO EW corrections from HAWK
available only up to 500 GeV**

*(In ATLAS: take last available value,
flat extrapolation)*

**No problems at current
level of precision**

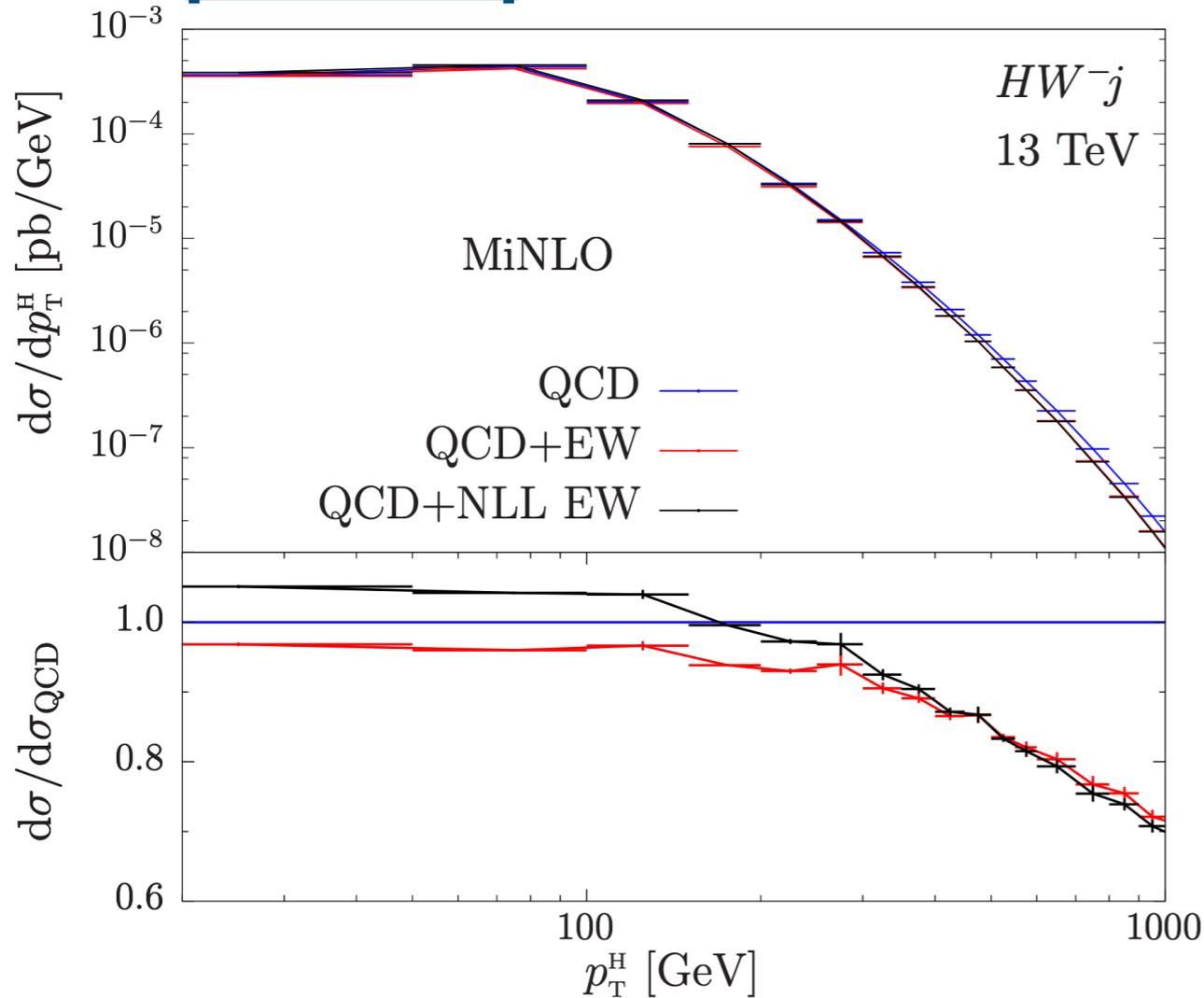
Might need to revisit if / when
additional STXS splits at higher
pTV are introduced



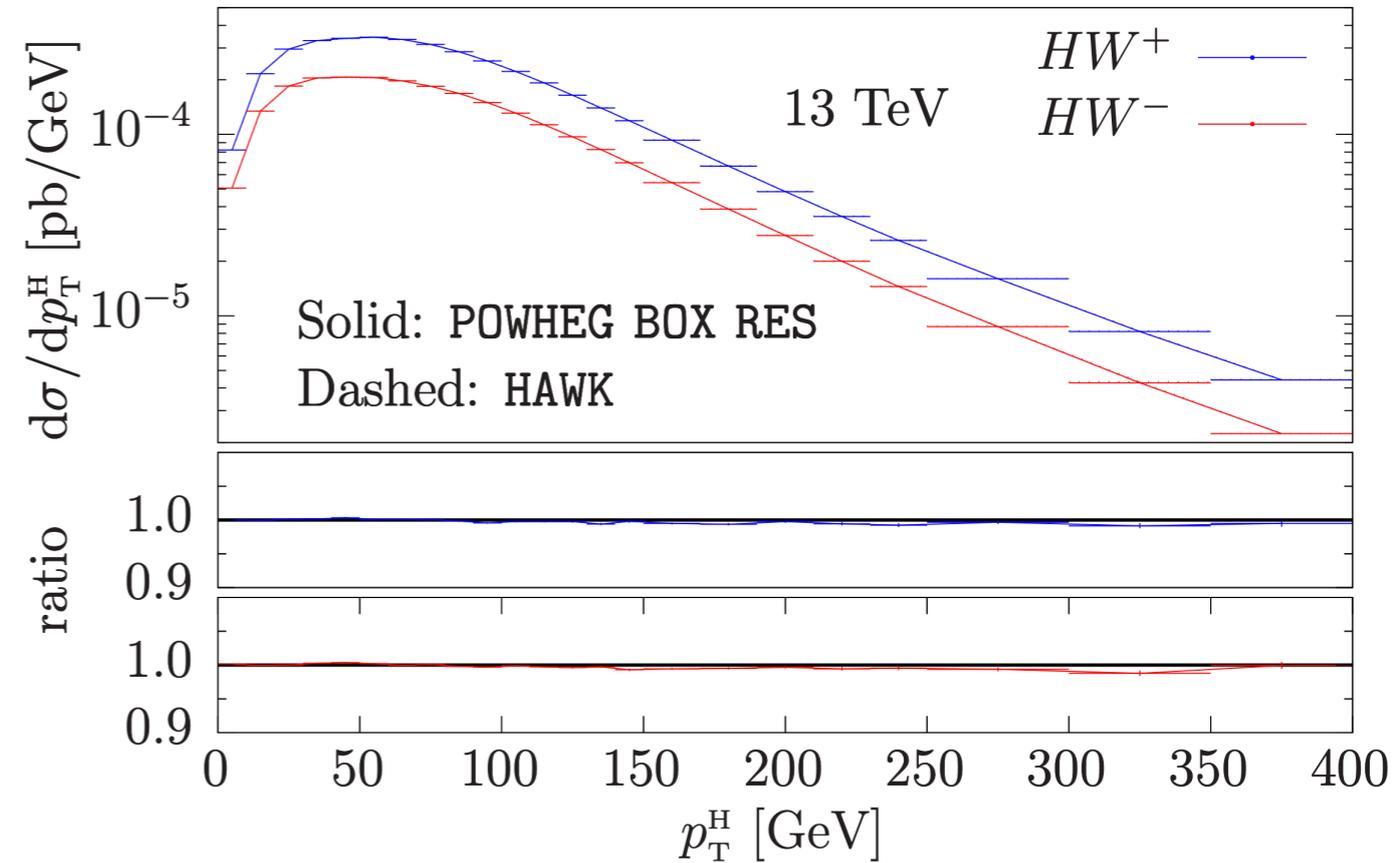
NLO EW corrections from Powheg

VH @ NLO (QCD + EW)

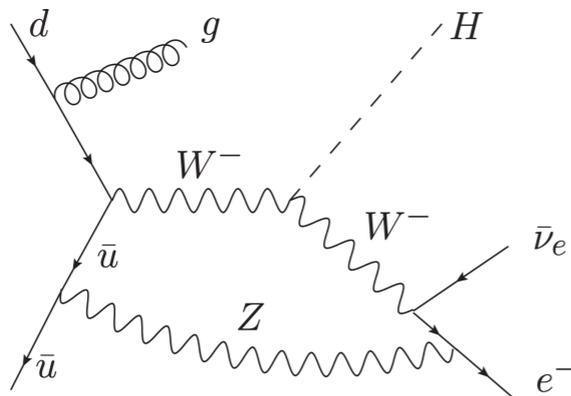
[1706.03522]



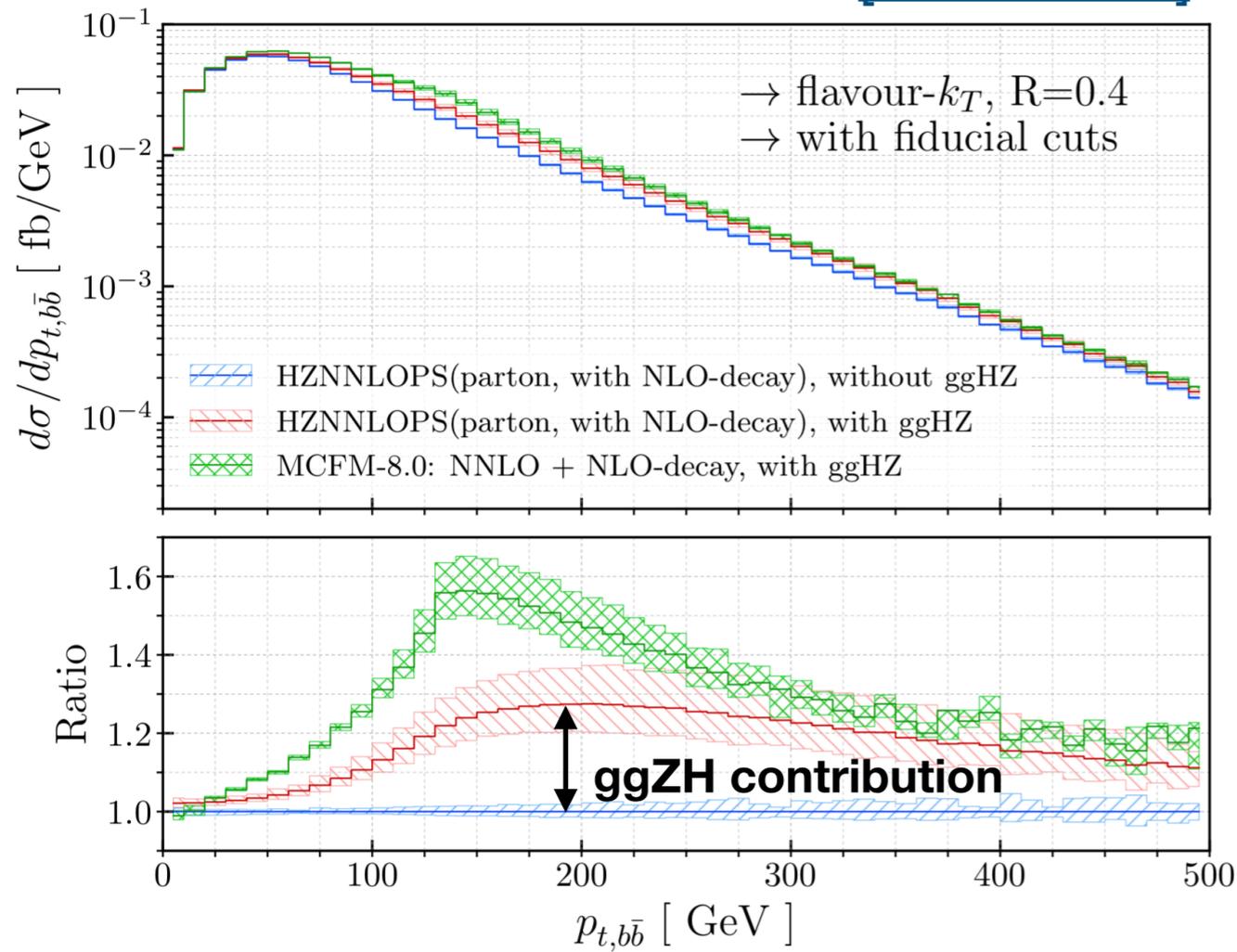
[1706.03522]



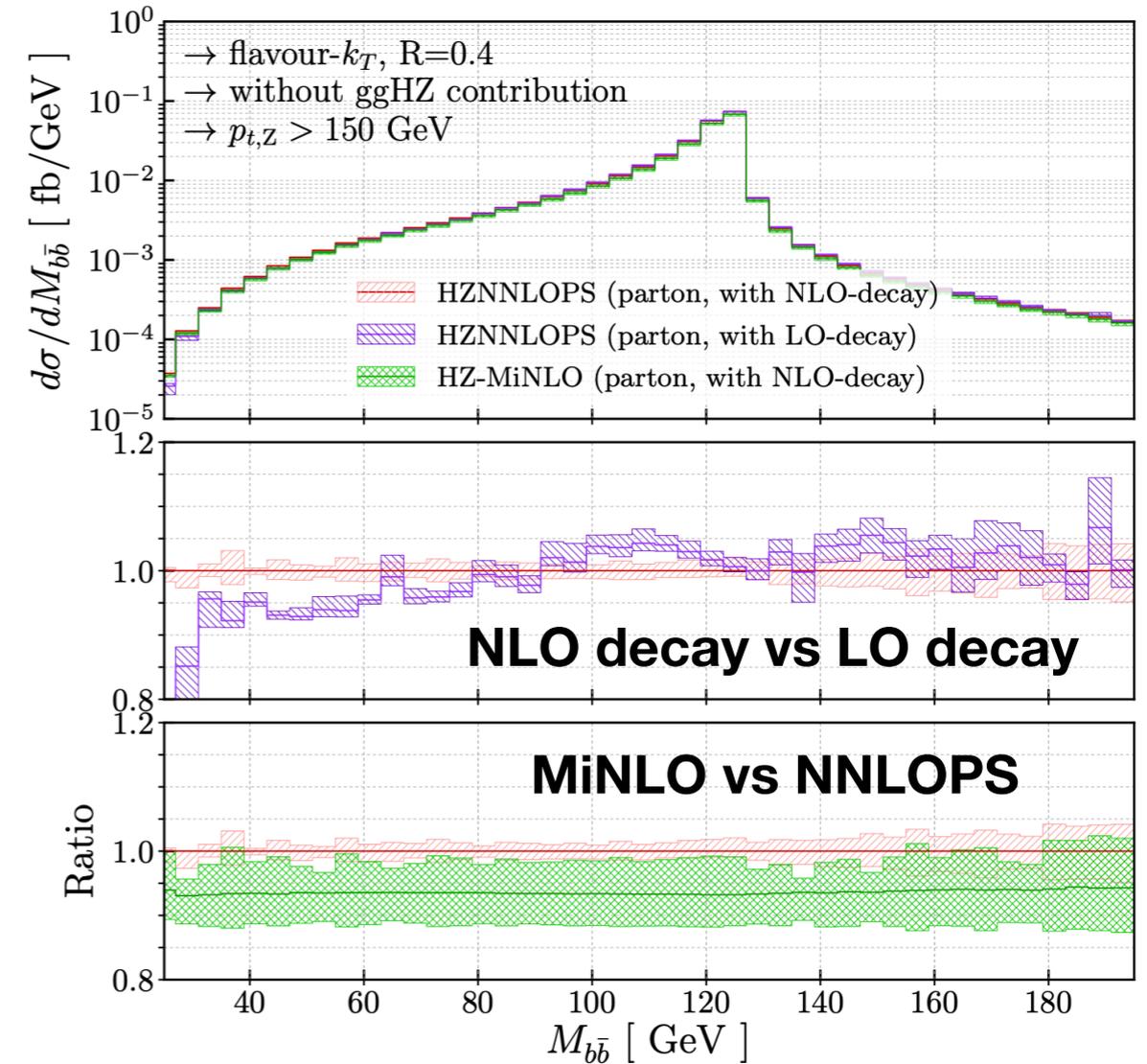
Validated against HAWK
(used in present WG1 prescription)



[1804.08141]



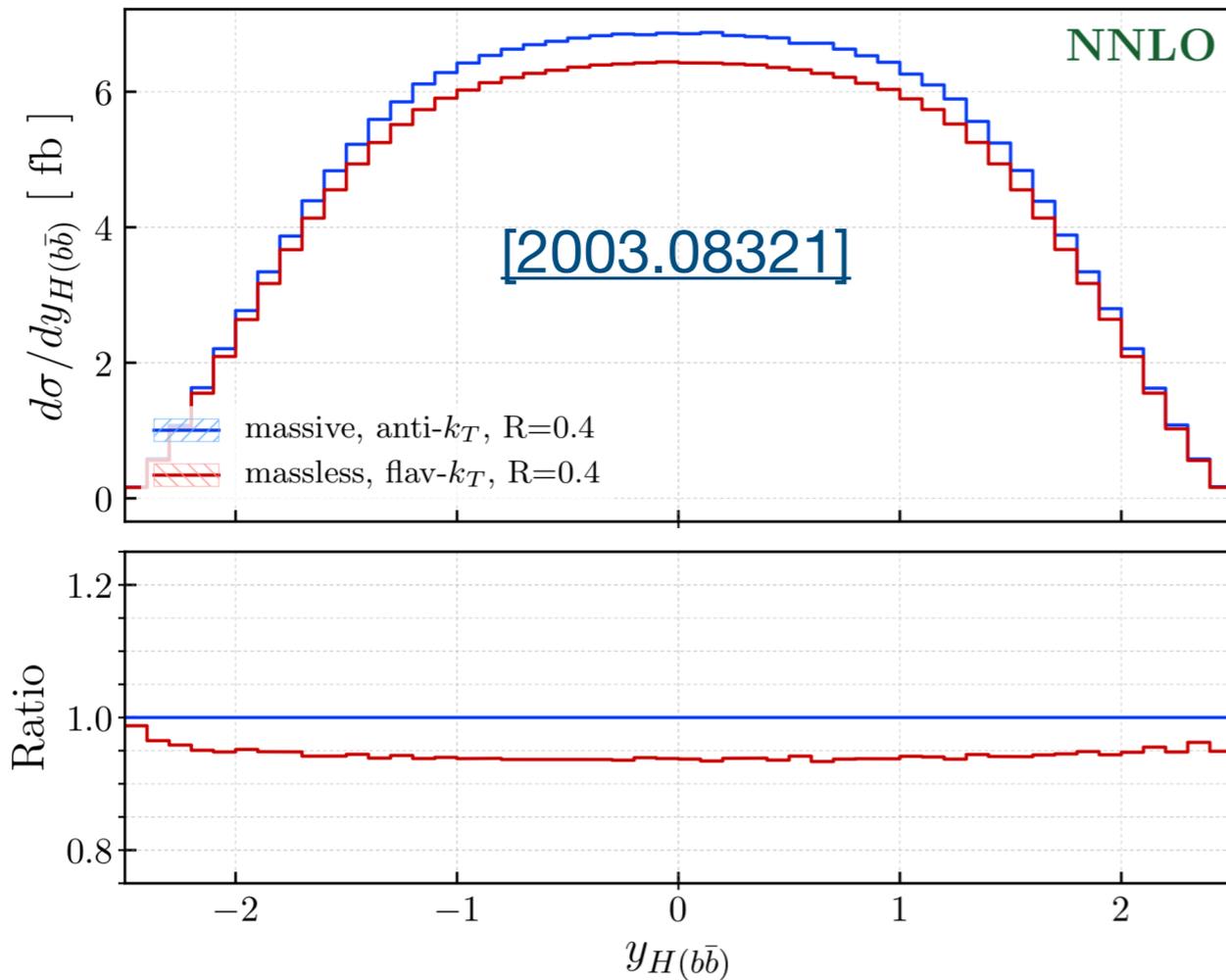
[1804.08141]



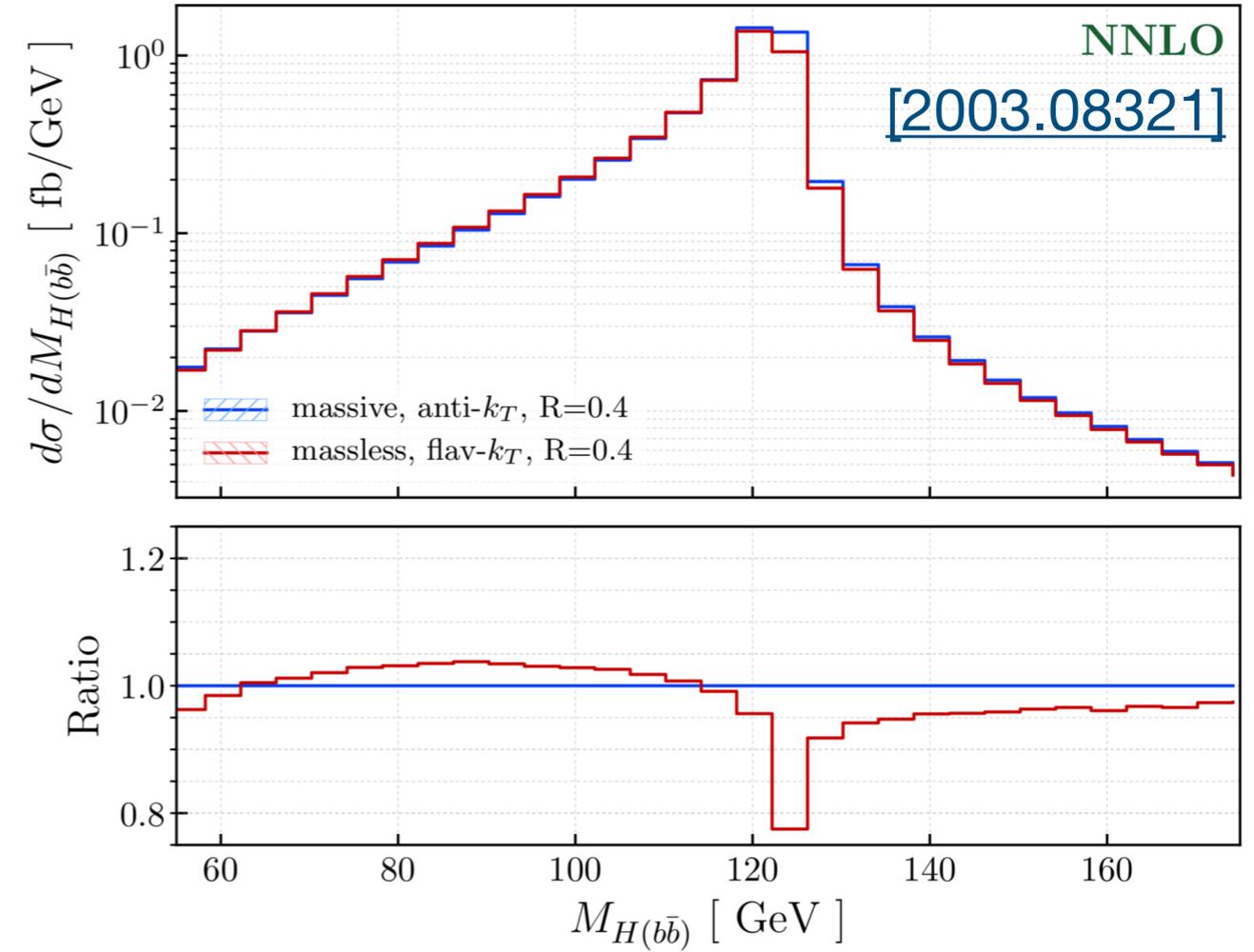
Bottom quark mass effects

WH(bb) production @ NNLO(QCD)

With b-quark mass effects

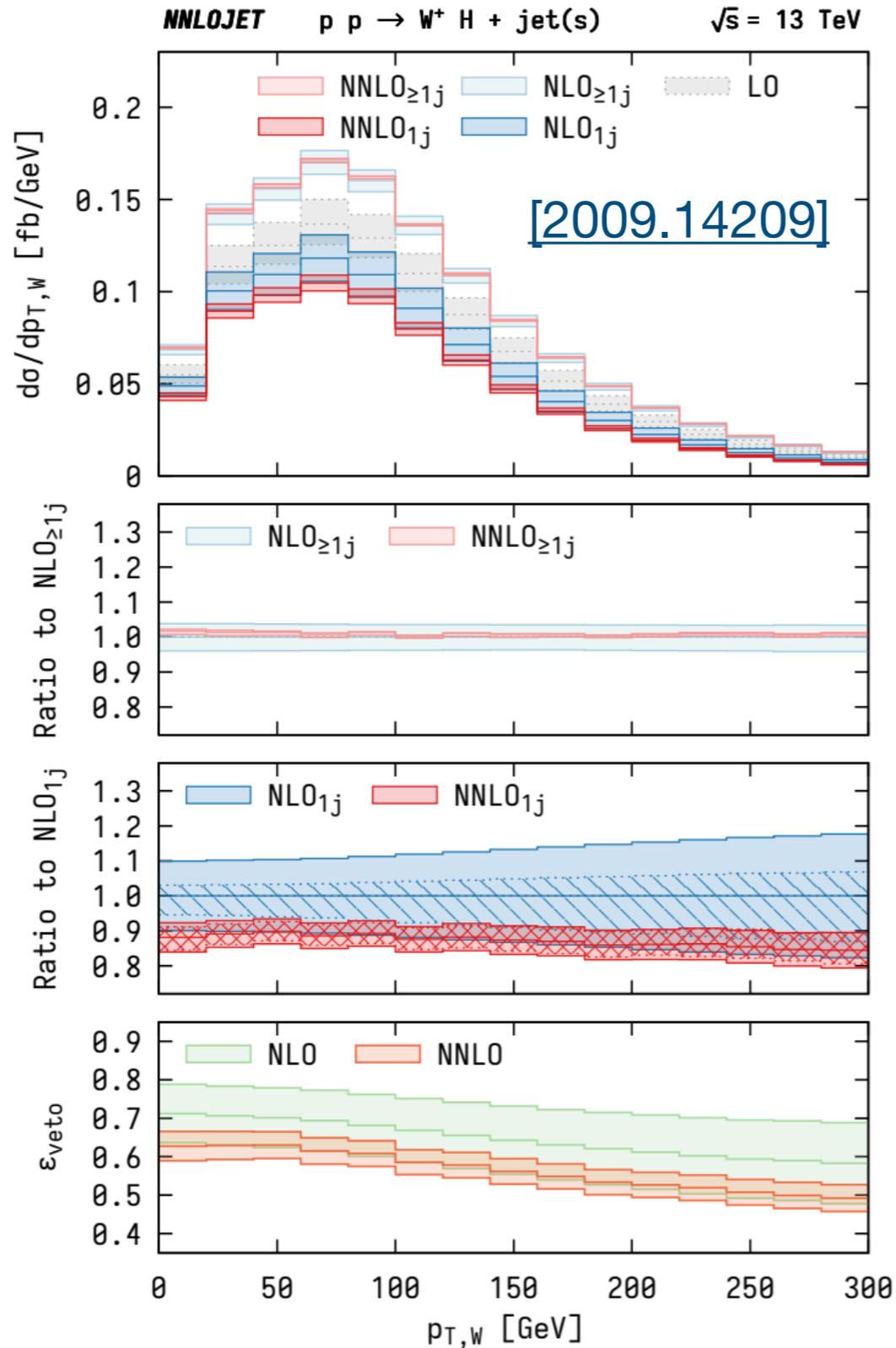


Higgs rapidity spectrum



Mbb spectrum
(improved modelling!)

WH + jet @ NNLO



← **NNLO / NLO for inclusive jet bins**
(k-factor ~ 1, but uncertainties reduced significantly!)

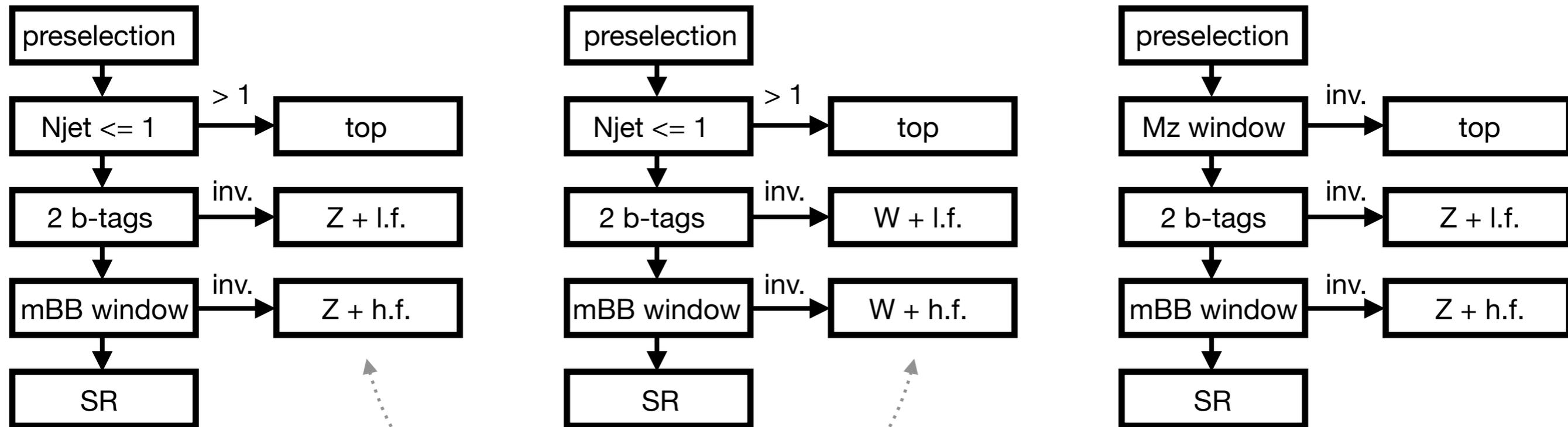
← **NNLO / NLO for exclusive jet bins**
*(corrections $O(-10\%)$,
 Stewart-Tackmann prescription in action!)*

Background control regions: CMS

0-lep.

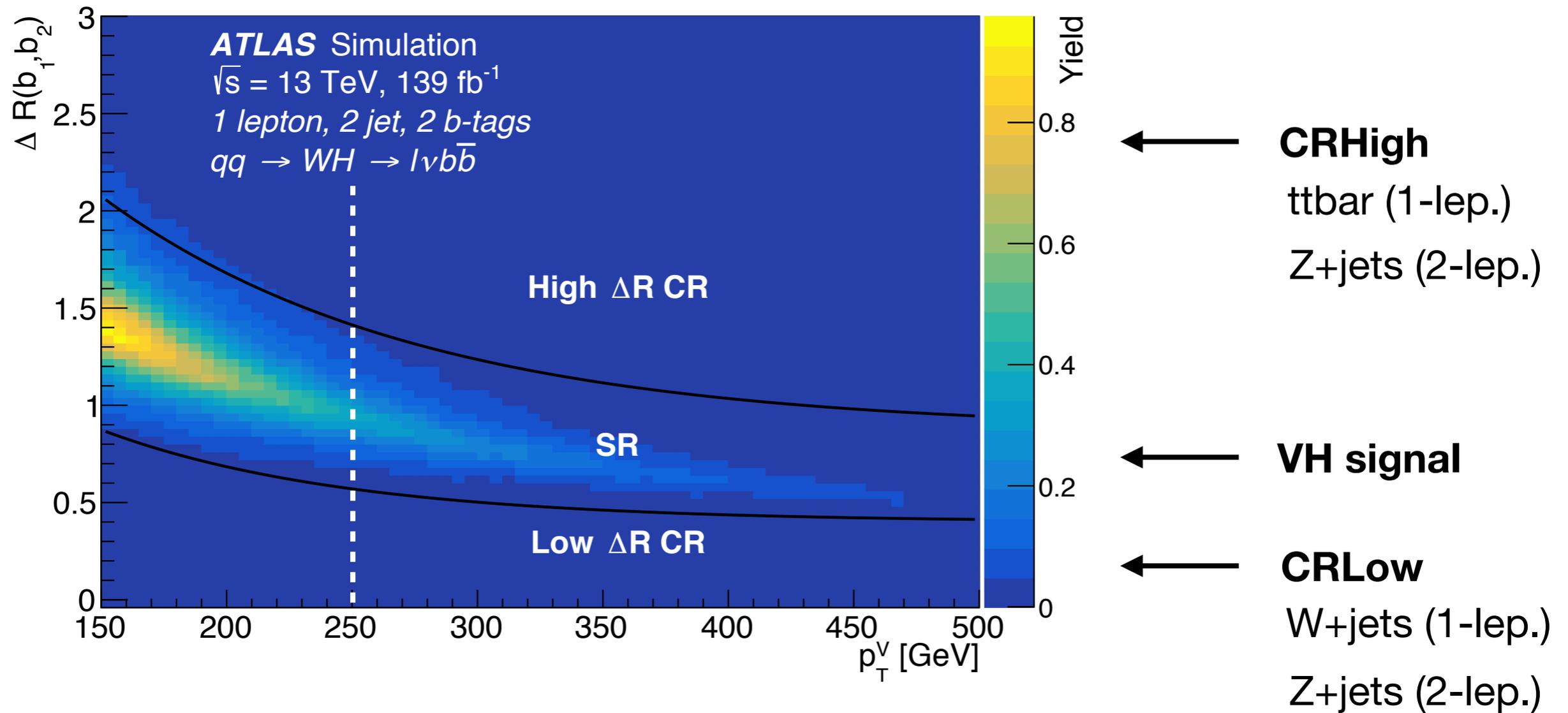
1-lep.

2-lep.



Fit distribution of dedicated DNN

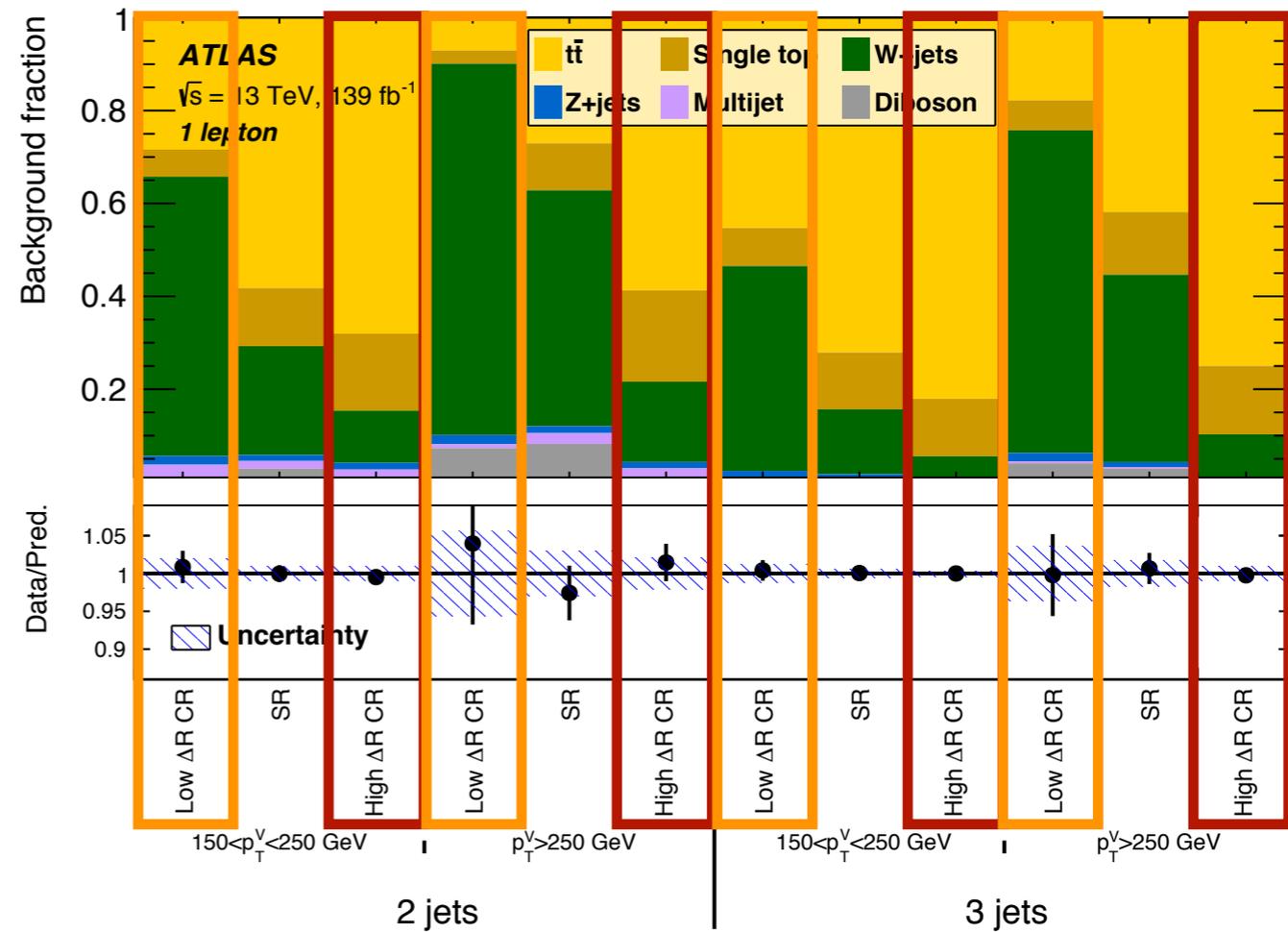
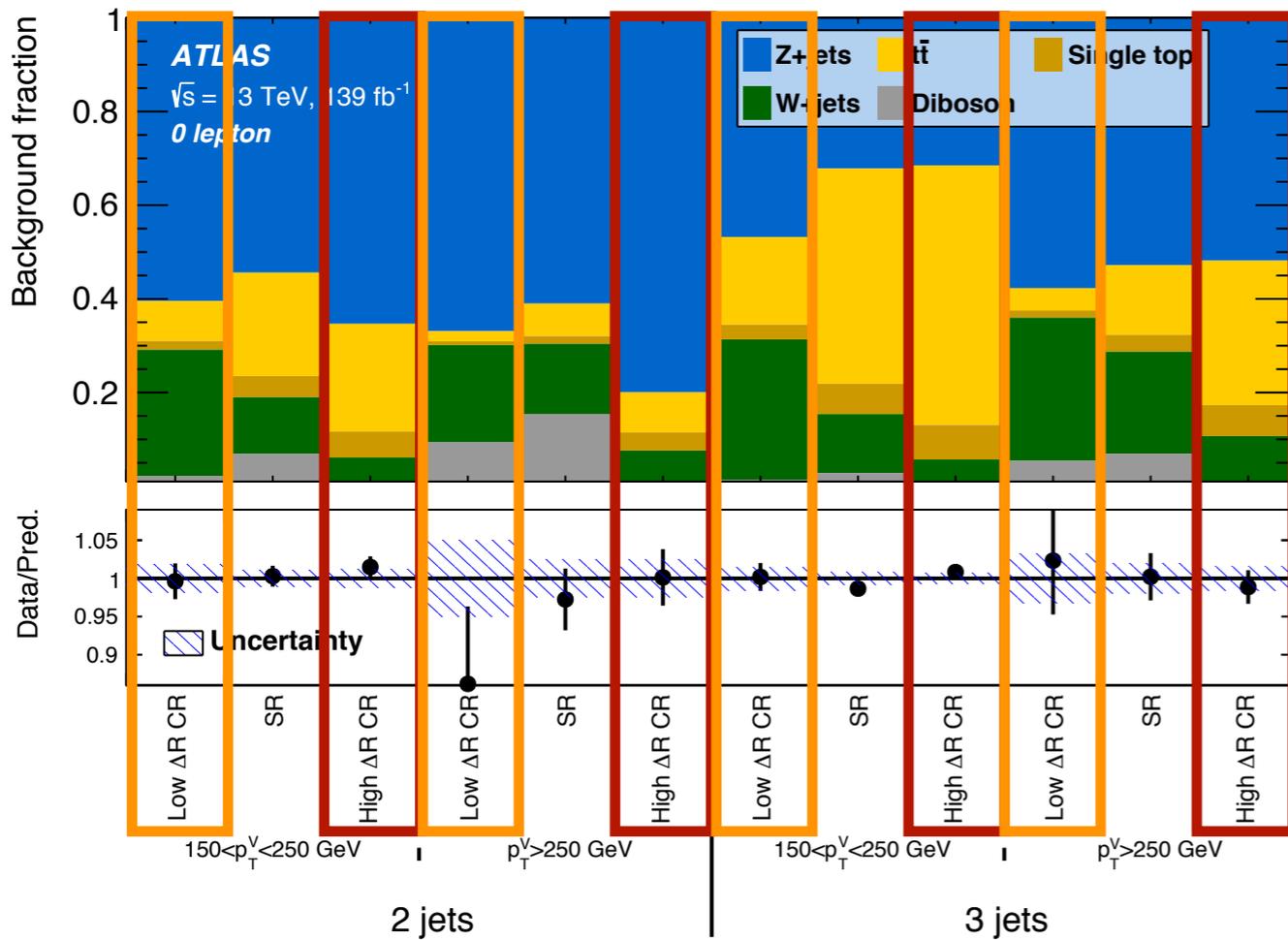
Background control regions: ATLAS



Background control regions: ATLAS

0-lep.

1-lep.



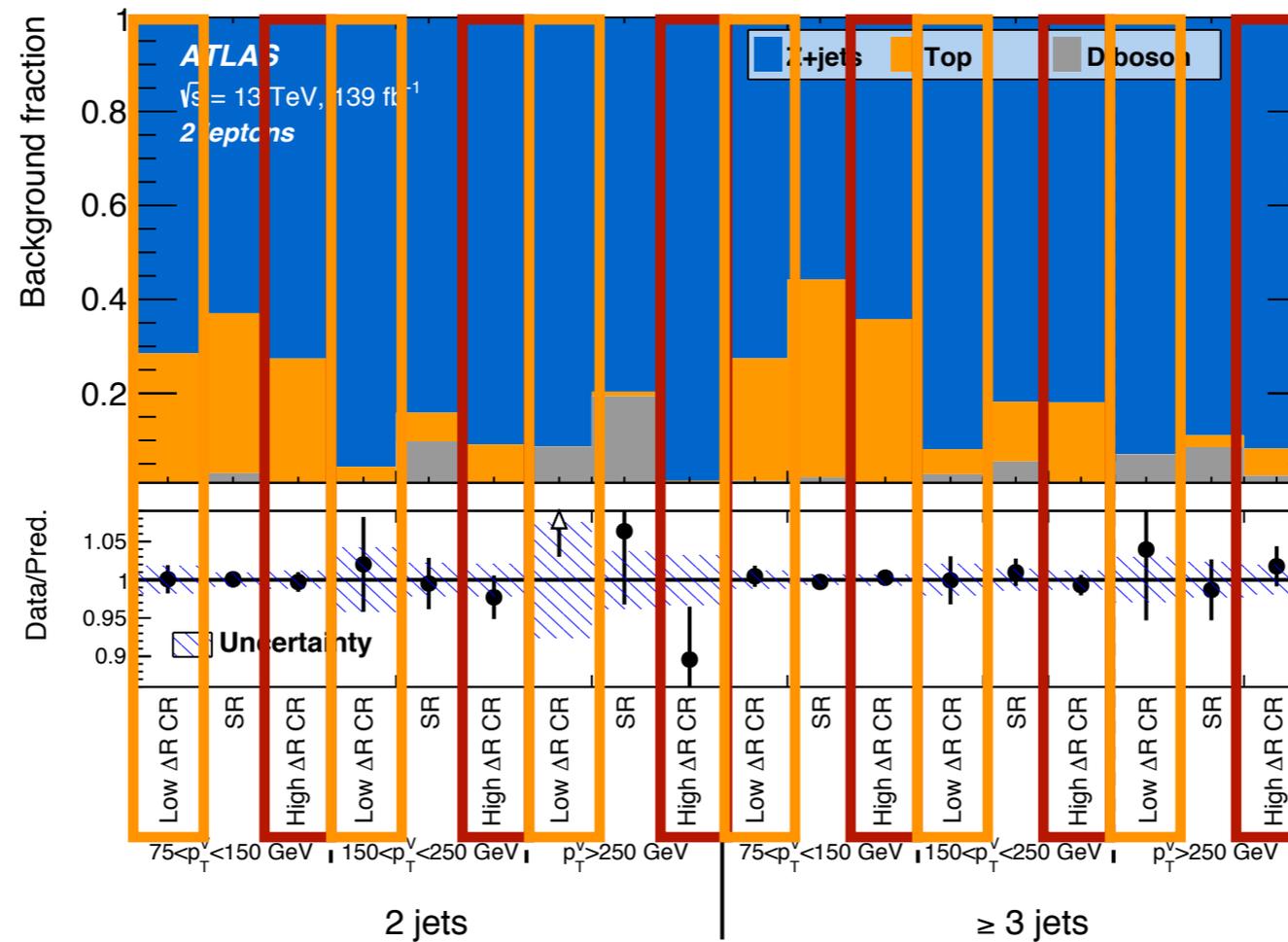
In fit: only total yields used from CRs, no distributions

CRHigh

CRLow

Background control regions: ATLAS

2-lep.



In fit: only total yields used from CRs, no distributions

CRHigh

CRLow

V+hf models in CMS & ATLAS

CMS

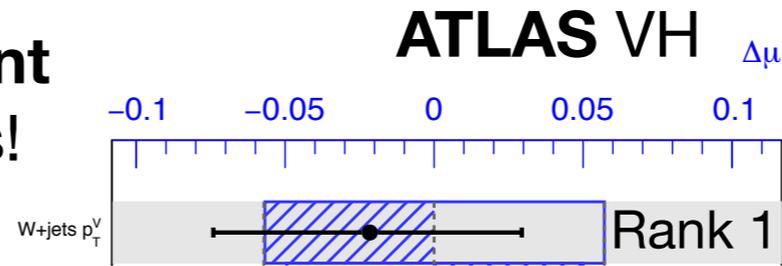
ATLAS

MadGraph

Sherpa

W+hf pTV shape was **most important uncertainty** in 2018 ATLAS analysis!

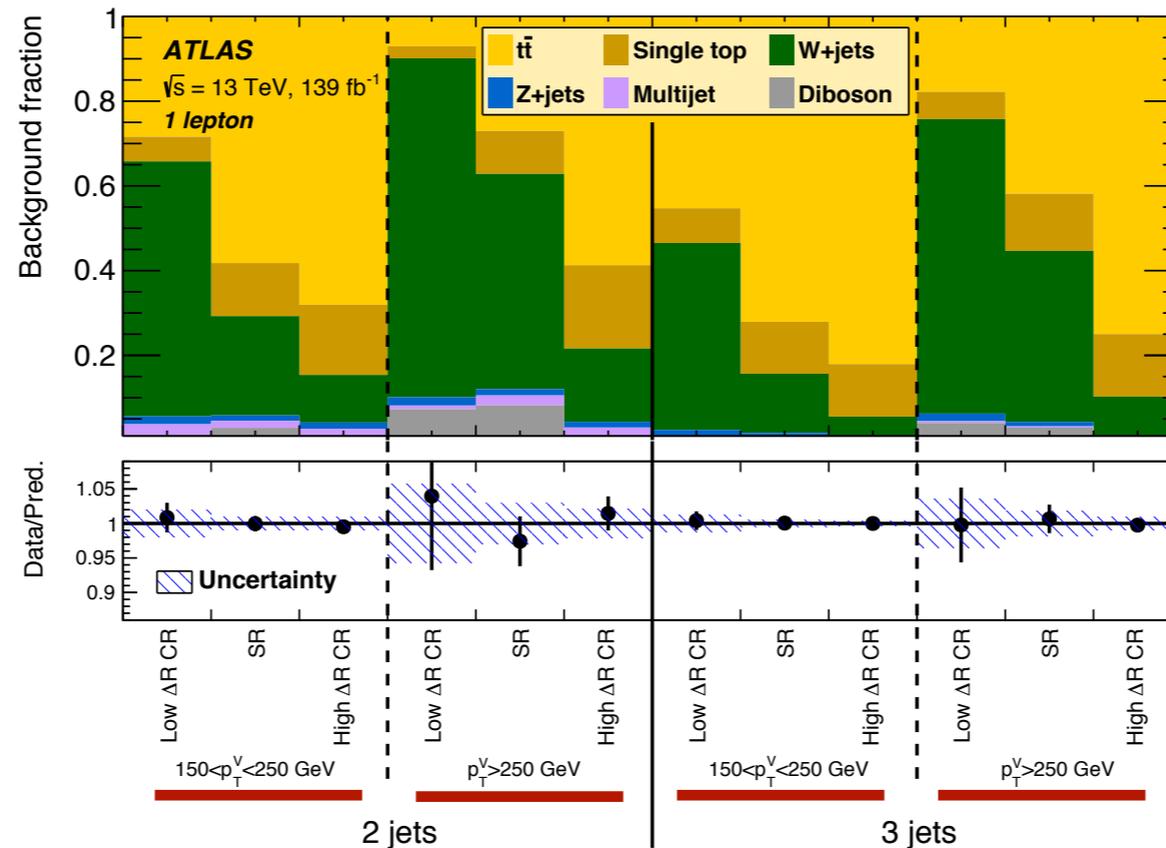
[\[1808.08238\]](#)



2J@NLO +3,4J@LO

2020 analysis:
pTV shape controlled from data, impact reduced considerably (*W+hf control regions binned in pTV*)

[\[2007.02873\]](#)



1L [2L] channel at [h] dRbb for W+hf [Z+hf] jet multiplicities, *pTV bins*

[\[2007.02873\]](#)

Category	Normalisation factor
	0.98 ± 0.09
	0.93 ± 0.06
	1.06 ± 0.11
	1.15 ± 0.09
$p_T^V < 150 \text{ GeV}$	1.28 ± 0.08
$p_T^V < 150 \text{ GeV}$	1.17 ± 0.05
$150 \text{ GeV} < p_T^V$	1.16 ± 0.07
$150 \text{ GeV} < p_T^V$	1.09 ± 0.04

Exercise ongoing within HXSWG to compare & study V+hf models: common phase-space defined, objects harmonised; study progressing

STXS: Parametrisation of scale uncertainties

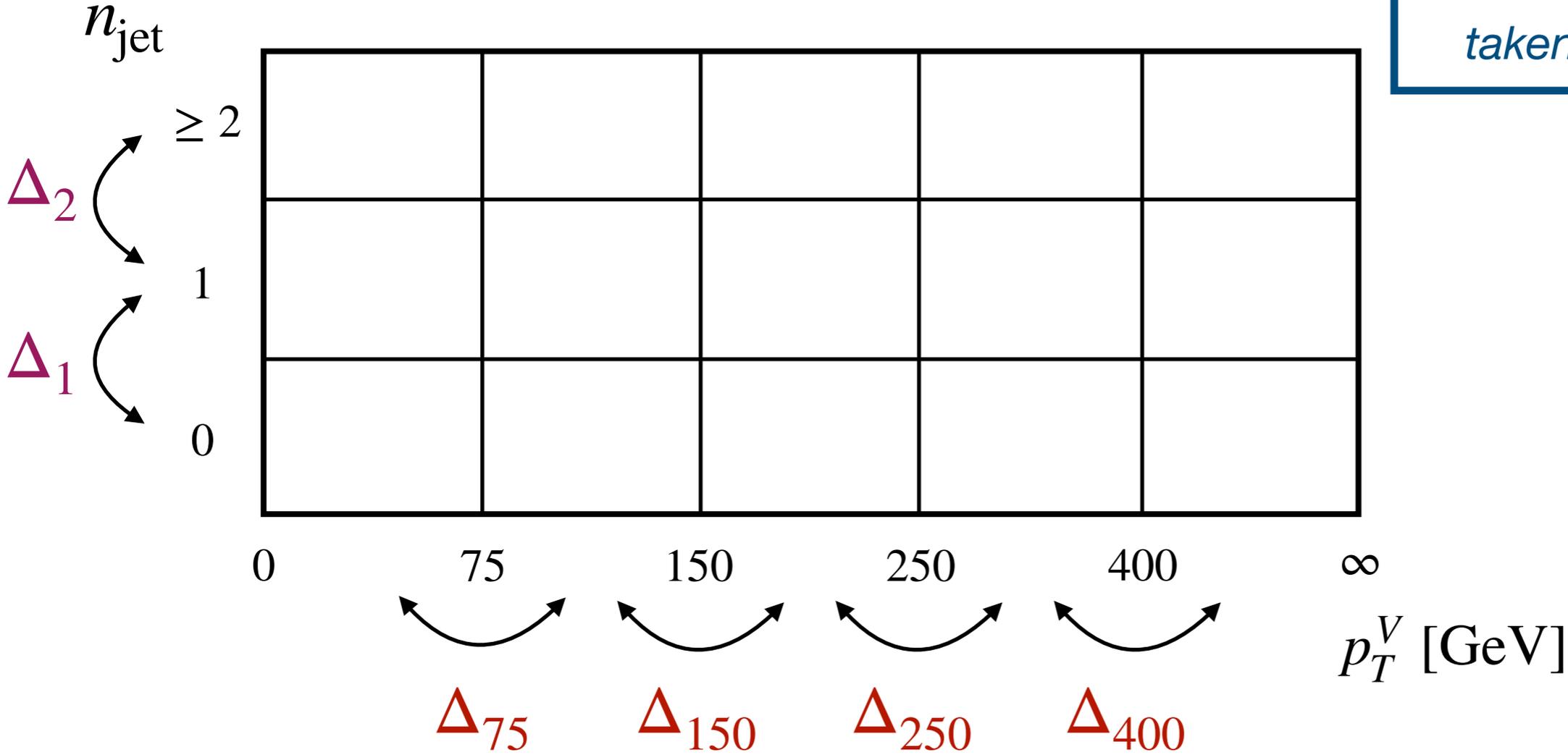
migrations across bin boundaries + inclusive XS uncertainty



In total 2 (nJet: Δ_2, Δ_1) + 4 (pTV: $\Delta_{75}, \Delta_{150}, \Delta_{250}, \Delta_{400}$) + 1 (incl.) = 7 independent parameters per signal process

Production mode	$\Delta_y^{<VH>}$
WH	$\pm 0.7\%$
$q\bar{q} \rightarrow ZH$	$\pm 0.6\%$
$gg \rightarrow ZH$	$\pm 25\%$

taken from HXSWG



More information: [\[ATL-PHYS-PUB-2018-035\]](#)

STXS: Parametrisation of scale uncertainties

migrations across bin boundaries + inclusive XS uncertainty



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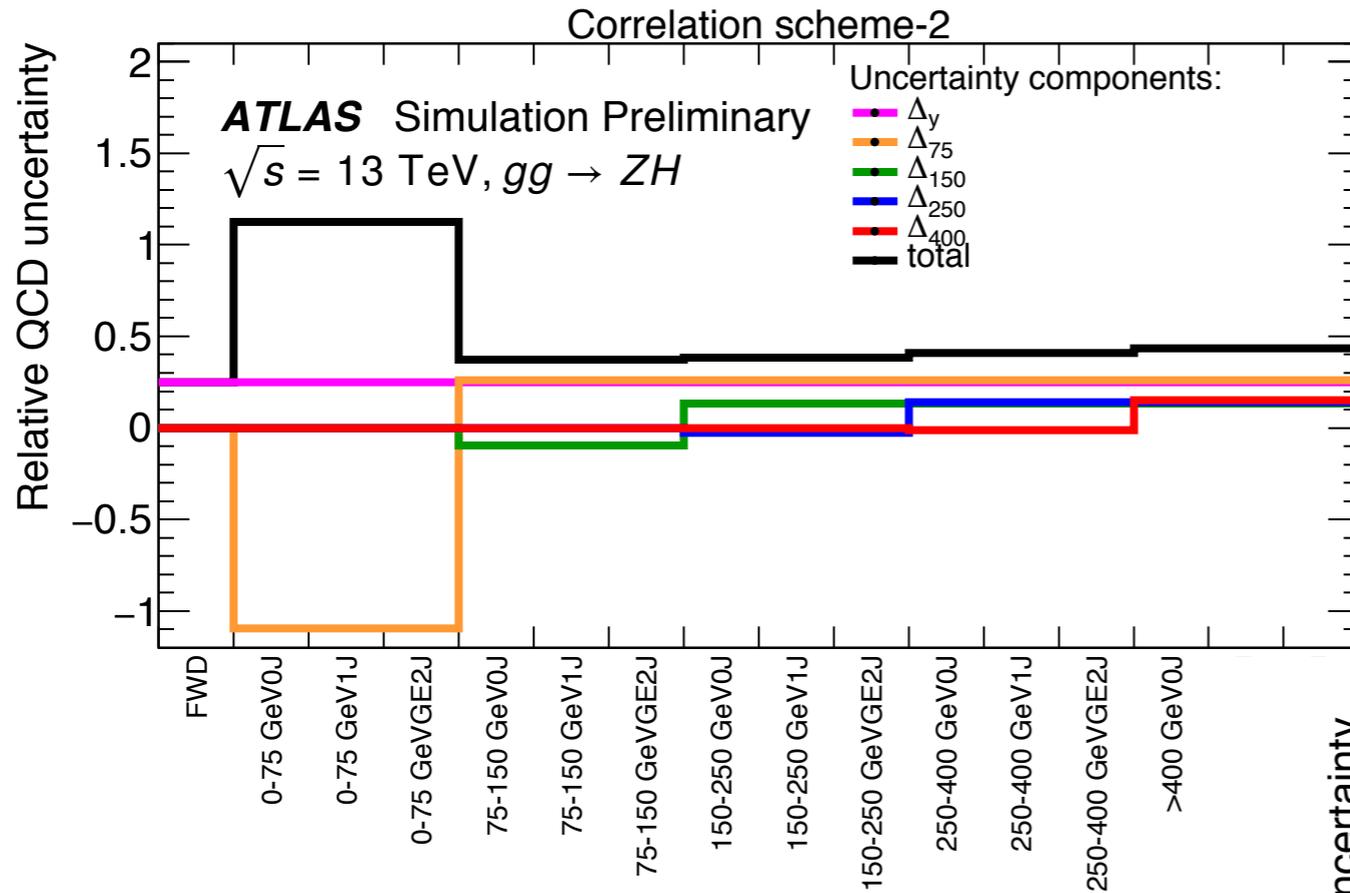
taken from HXSWG

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, ∞ [$+\Delta_{75}/\sigma_{[75,\infty[}$	$+\Delta_{150}/\sigma_{[150,\infty[}$	$+\Delta_{250}/\sigma_{[250,\infty[}$	$+\Delta_{400}/\sigma_{[400,\infty[}$

More information: [\[ATL-PHYS-PUB-2018-035\]](#)

STXS: Parametrisation of scale uncertainties

Example for $ggZH$ (see more plots in backup)

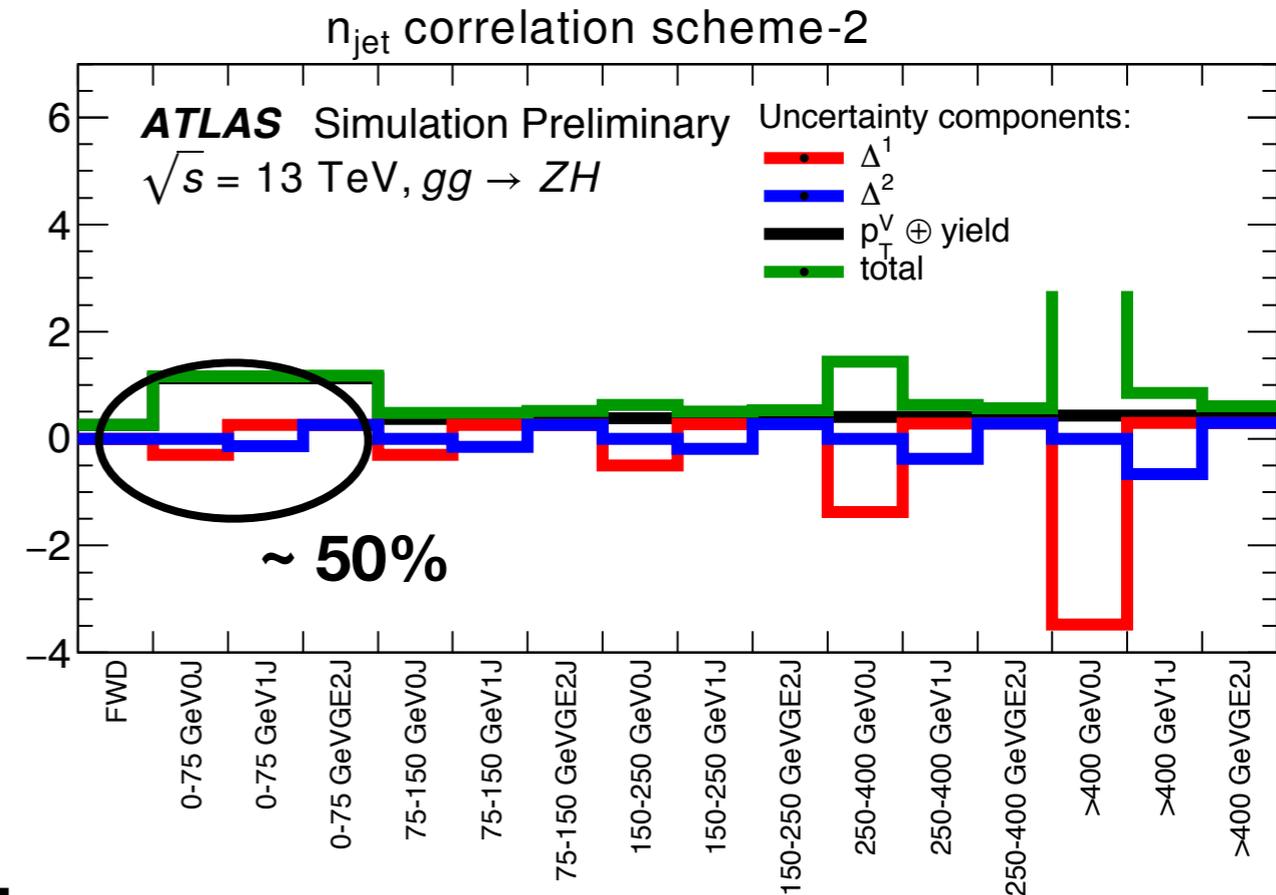


pTV migration (correlated in nJet)

nJet migration (correlated across pTV)

(use ICHEP uncertainties - same signal prediction)

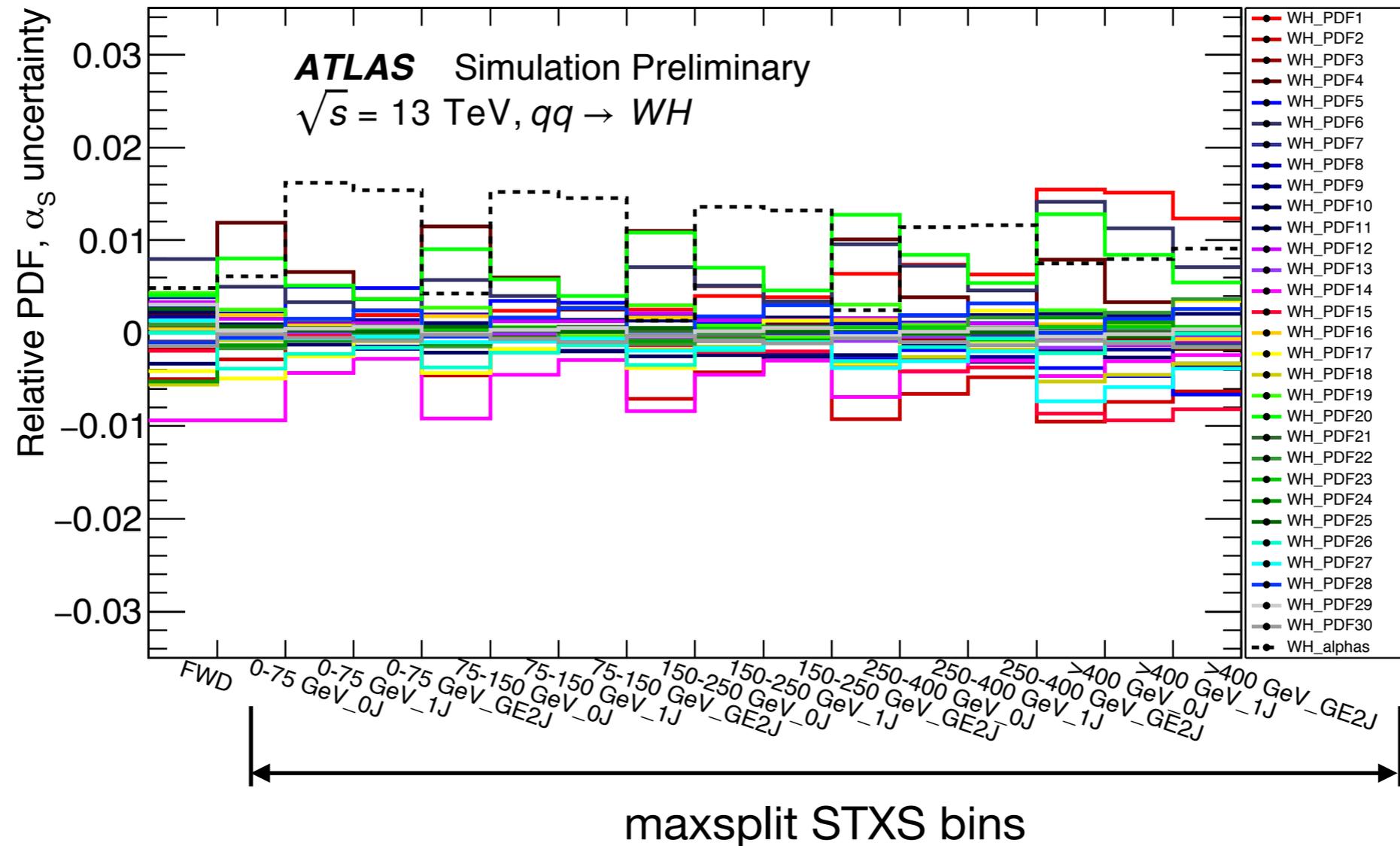
Relative QCD uncertainty



More information: [\[ATL-PHYS-PUB-2018-035\]](#)

STXS: Parametrisation of PDF uncertainties

Follow PDF4LHC prescription: 30 Hessian PDF variations + α_s
(all variations kept independent and fully correlated across STXS bins,
use ICHEP uncertainties - same signal prediction)

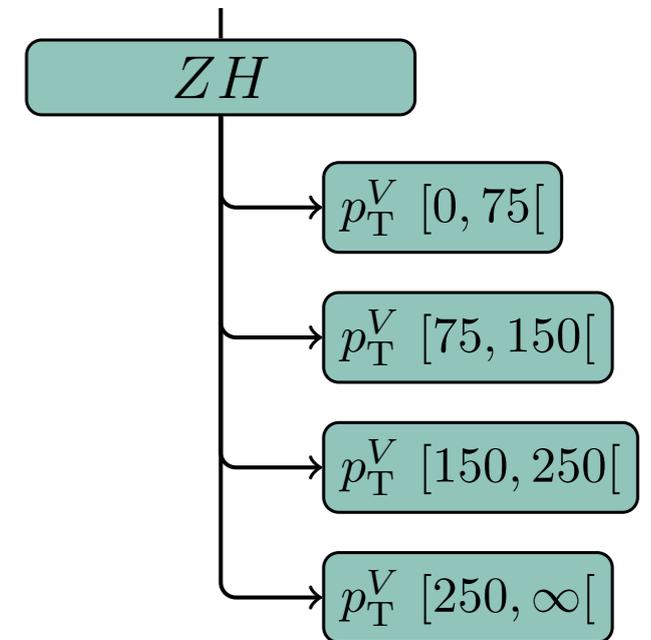
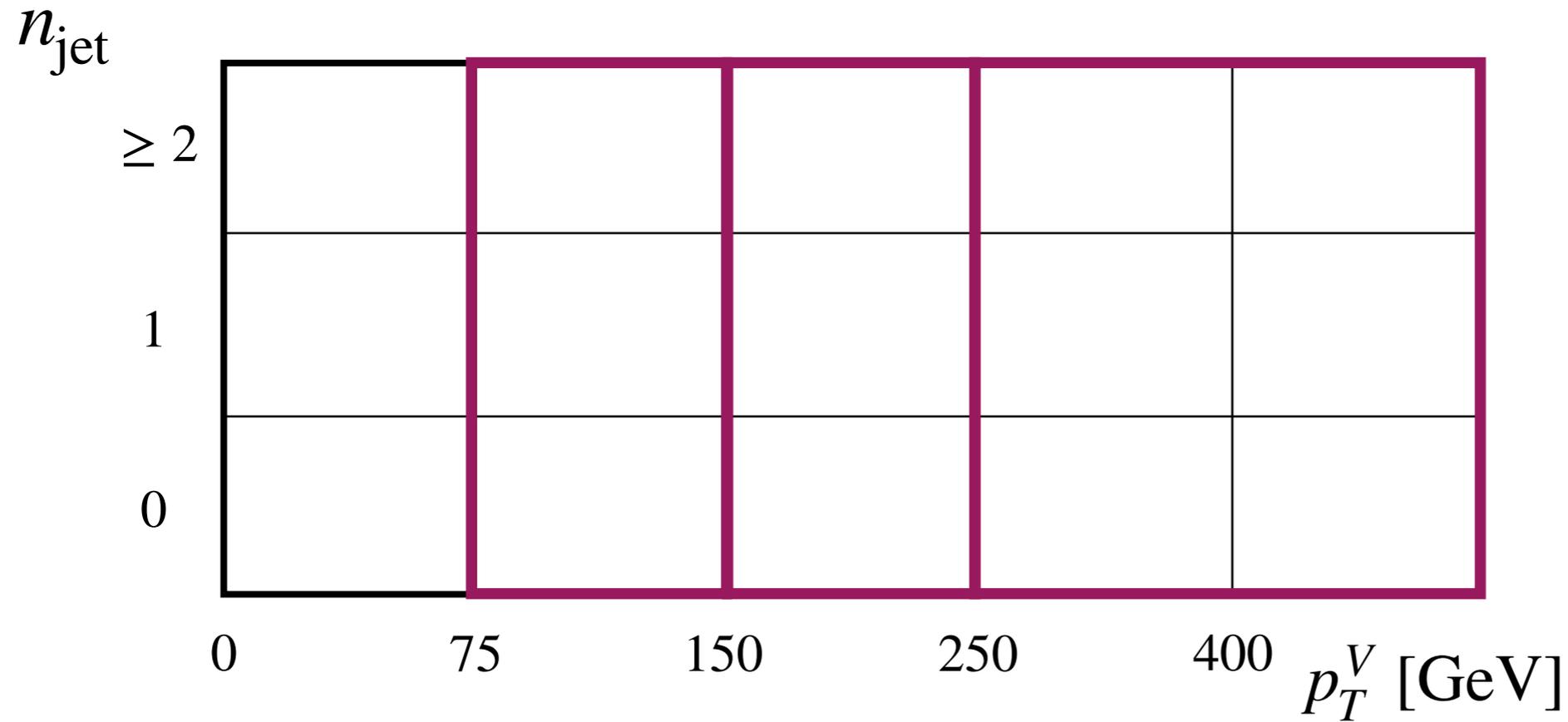


Total impact on STXS bins: 1-3% for WH and qqZH, 2-5% for ggZH

More information: [\[ATL-PHYS-PUB-2018-035\]](#)

STXS: reduction to Stage 1.2 binning

 ... measured Stage 1.2 STXS bins



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

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

Compute impact on overall cross section in Stage 1.2 bin ...

... and redefine variation to remove it