Signal uncertainties in STXS stage 1 for VH(bb)

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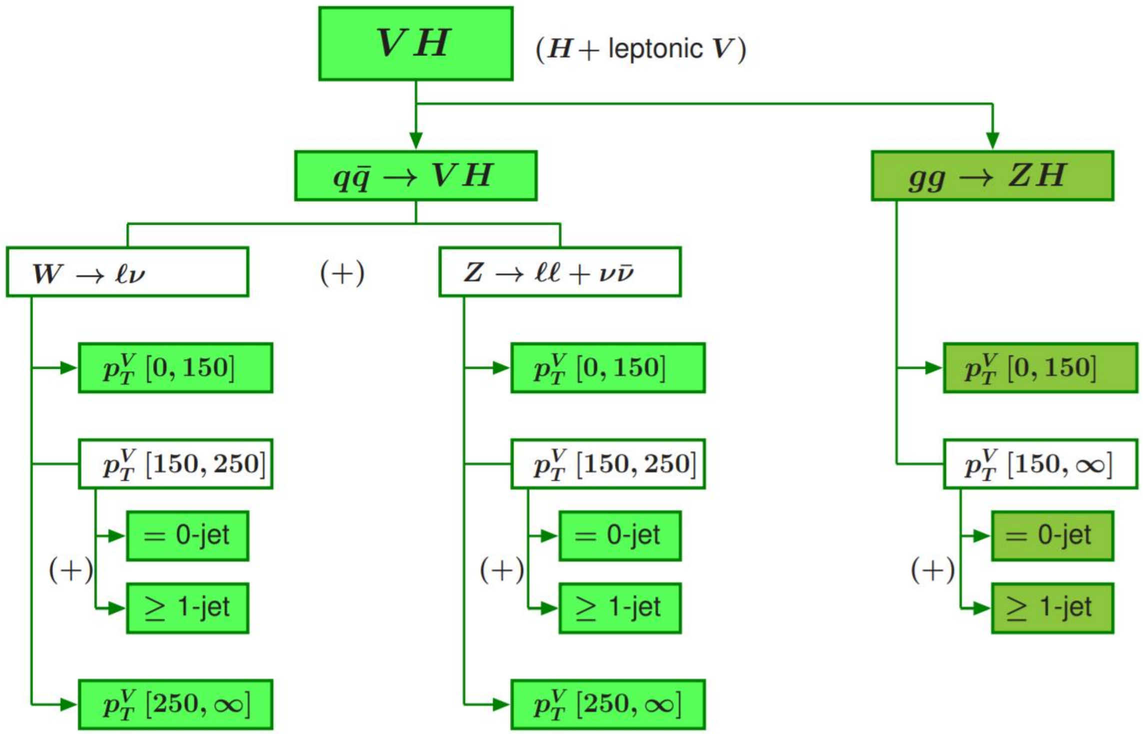
ATLAS EXPERIMENT

Introduction: STXS binning

- Stage 1: truth binning based on VH(bb) analysis categories
  - Reduce impact of theory on the measurement (no acceptance, …)



Split production mode:
→ qq/gg initiated
→ different calculations

Split with variables used for analysis categorization:
→ W/Z, $p_T(V)$, N(jets) not from Higgs

Original plan: **[LHC report 4 (click me)]**

Introduction: STXS binning

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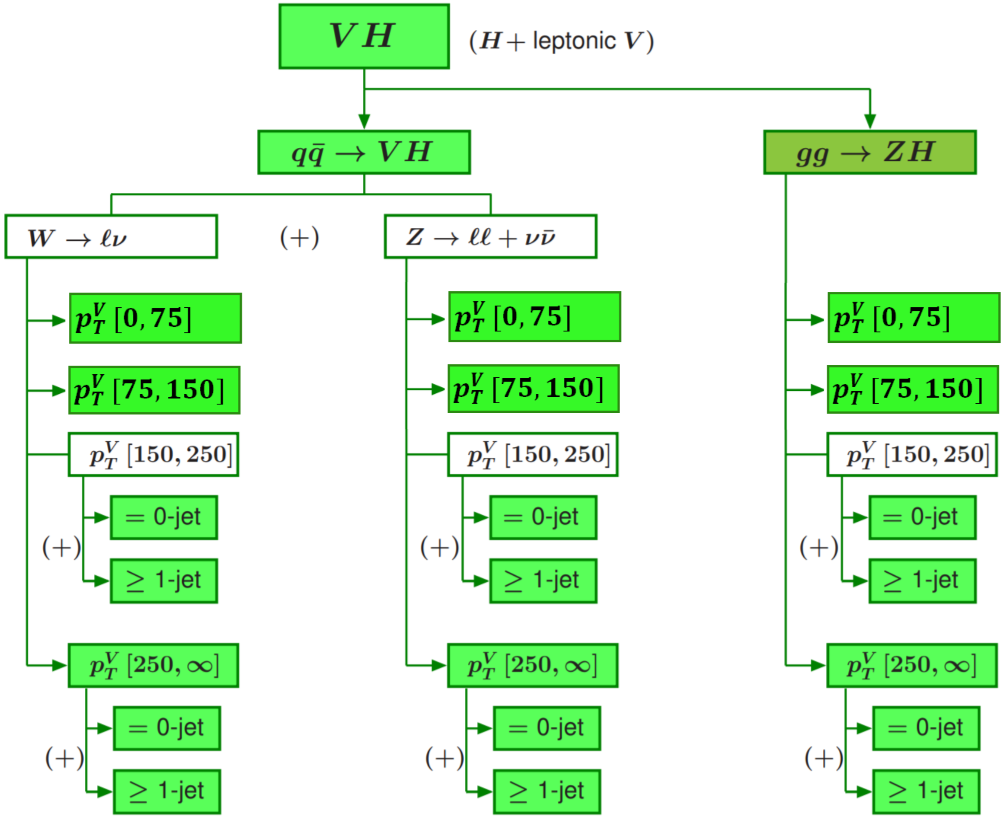


Analysis already use finer categorization

Implement stage 1+:

→ Get closer to analysis bins

→ Left figure with split Z to ll/vv

Consider a finer "stage 1++":

→ Towards stage 2:

Split at $p_T(V)$ = 400 GeV

→ For analysis unc. estimation:

More N(add jet) bins (≥2)

N(add jet) also for low $p_T(V)$?

Goal: derive uncertainties for stage 1++ and merge where needed

3 signal uncertainty sets to discuss:

-> Scale
-> PDF
-> PS / UE

Scale Variations: The Big Guys

- Problematic: how to deal with bin migration/correlation
- 2 bins (a and b) case: the generic parametrization

Uncertainty matrix = correlated + anti-correlated components

$$C(\{\sigma_a, \sigma_b\}) = \begin{pmatrix} (\Delta_a^y)^2 & \Delta_a^y \Delta_b^y \\ \Delta_a^y \Delta_b^y & (\Delta_b^y)^2 \end{pmatrix} + \begin{pmatrix} \Delta_{a/b}^2 & -\Delta_{a/b}^2 \\ -\Delta_{a/b}^2 & \Delta_{a/b}^2 \end{pmatrix}$$

1 bin case

XSec = σ_{ab}
Unc Δ_{ab}^{y}

2 bin case: a + b = 1 (event fractions)

XSec = σ_a
Unc $\Delta_a^y + \Delta_{a/b}$

XSec = σ_b
Unc $\Delta_b^y - \Delta_{a/b}$

Overall unc:
Impact of Δ_{ab}^{y}
in the two bins

Migration unc
induced by a/b
cut

LHC report 4 (click me) for more details

Scale Variations: The Big Guys

- Parametrization in the VH(bb) stage 1 case
  - Showing WH here, in stage 1 same table for ZH (from [Les Houches 2017, click me]())

	QCD uncertainties			
$q\bar{q}' \to W$	Δ^{y}_{WH}	$\Delta^{\mathrm{WH}}_{150}$	$\Delta^{\mathrm{WH}}_{250}$	$\Delta^{\mathrm{WH}}_{0/1}$
p_T^V [0,150]	x_1	-1	$-y$	
p_T^V [150,250]	x_2	$+1-y$	$-(1-y)$	0
$=$ 0-jet	$x_2 z$	$+(1-y)z$	$-(1-y)z$	$+1$
$\geq$ 1-jet	$x_2(1-z)$	$+(1-y)(1-z)$	$-(1-y)(1-z)$	-1
p_T^V [250,∞]	x_3	y	$+1$	

$$unc_{[0,150]} = x_1\,\Delta^{y}_{WH} - \Delta^{WH}_{150} - y_2\,\Delta^{WH}_{250}$$

$$unc_{[150,250]} = x_2\,\Delta^{y}_{WH} + (1-y_1)\Delta^{WH}_{150} - y_2\,\Delta^{WH}_{250}$$

$$unc_{[250,\infty]} = x_3\,\Delta^{y}_{WH} + y_1\,\Delta^{WH}_{150} + \Delta^{WH}_{250}$$

- How to compute all parameters ?

Original proposal: $x_{[250,\infty]} = \Delta^{y}_{[250,\infty]}/\Delta^{y}$

$\Delta^{y}_{250} \sim \Delta^{y}_{[250,\infty]}$

- Over-enhancement issue:

$$unc_{[250,\infty]} = (\Delta^{y}_{250}/\Delta^{y})\,\Delta^{y} + y_1\,\Delta_{150} + \Delta_{250}$$

Can new scheme solve this ?

Parameter Calculation Proposal

- Calculating the $x_i/y/z$:

	Δ	Δ_{75}	Δ_{150}	Δ_{250}	Δ_{150J}	Δ_{250J}
0-75	$y_{[0,75]}/y_{Total}$	-1	$-y_{[0,75]}/y_{[0,150]}$	$-y_{[0,75]}/y_{[0,250]}$		
75-150	$y_{[75,150]}/y_{Total}$	$y_{[75,150]}/y_{[75,\infty]}$	$-y_{[75,150]}/y_{[0,150]}$	$-y_{[75,150]}/y_{[0,250]}$		
150-250 0J	$y_{[150,250]+0J}/y_{Total}$	$y_{[150,250]+0J}/y_{[75,\infty]}$	$y_{[150,250]+0J}/y_{[150,\infty]}$	$-y_{[150,250]+0J}/y_{[0,250]}$	-1	
150-250 1J+	$y_{[150,250]+1J+}/y_{Total}$	$y_{[150,250]+1J+}/y_{[75,\infty]}$	$y_{[150,250]+1J+}/y_{[150,\infty]}$	$-y_{[150,250]+1J+}/y_{[0,250]}$	1	
250+ 0J	$y_{[250,\infty]+0J}/y_{Total}$	$y_{[250,\infty]+0J}/y_{[75,\infty]}$	$y_{[250,\infty]+0J}/y_{[150,\infty]}$	$y_{[250,\infty]+0J}/y_{[250,\infty]}$		-1
250+ 1J+	$y_{[250,\infty]+1J+}/y_{Total}$	$y_{[250,\infty]+1J+}/y_{[75,\infty]}$	$y_{[250,\infty]+1J+}/y_{[150,\infty]}$	$y_{[250,\infty]+1J+}/y_{[250,\infty]}$		1
Sum to	1	0	0	0	0	0

Replace:
"relative unc fraction"
$$x_{[250,\infty]} = \Delta^{y}_{[250,\infty]}/\Delta^{y}$$
"yields fractions (bin acceptance)"
$$x_{[250,\infty]} = y_{[250,\infty]}/y_{[0,\infty]}$$

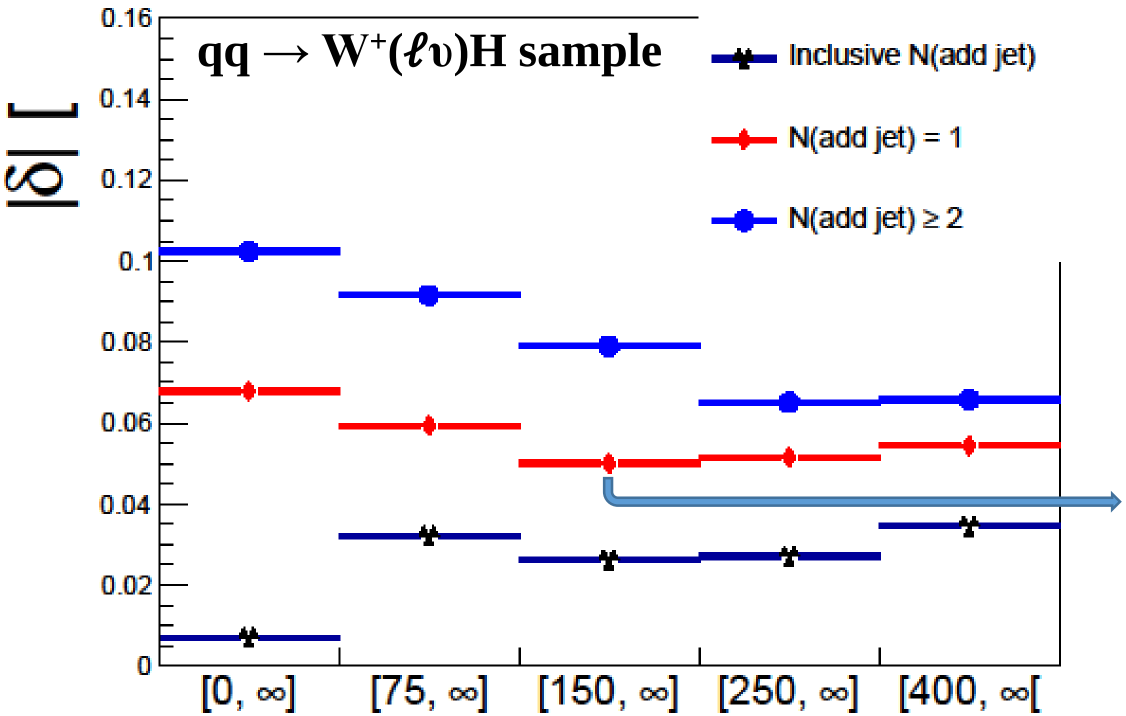
In the [250, ∞[(without considering N(jet) split)
$$unc_{[250,\infty]} = \Delta * \frac{y_{[250,\infty[}}{y_{[0,\infty[}} + \Delta_{75}\frac{y_{[250,\infty[}}{y_{[75,\infty[}} + \Delta_{150}\frac{y_{[250,\infty[}}{y_{[150,\infty[}} + \Delta_{250}$$

Estimations of Δs

- Available ingredients:

→ Overall relative unc. δ from NNLO QCD cross-section in YR4

→ Relative uncertainties $\delta_{[a,b]}$ on $y_{[a,b]}$ from Powheg+MINLO with non-diagonal scale variation by a factor of 2

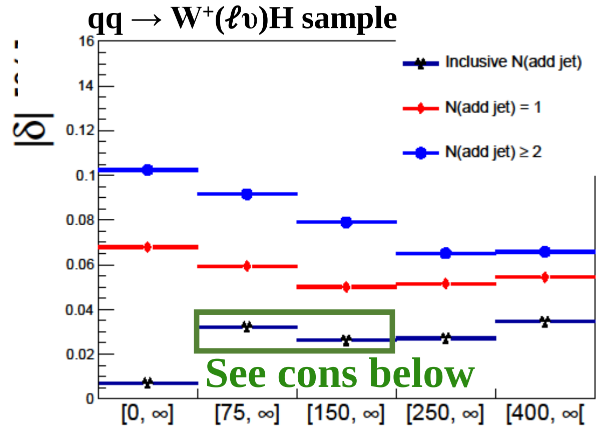


Read as:

For $p_T(V) > 150$ GeV (bin 3) and N(add jets) = 1 (red points)

Rel unc: $\delta_{[250,\infty[\,\cup\,[1jet]} = 5.01\%$

Estimations of Δs



- Available ingredients:

→ Overall relative unc. δ from YR4

→ Relative uncertainties $\delta_{[a,b]}$ on $y_{[a,b]}$ from Powheg+MINLO

- Proposal for Δs:

→ In our same example:

$$y_{[250,\infty[} * \delta_{[250,\infty[} = \Delta * \frac{y_{[250,\infty[}}{y_{[0,\infty[}} + \Delta_{75}\frac{y_{[250,\infty[}}{y_{[75,\infty[}} + \Delta_{150}\frac{y_{[250,\infty[}}{y_{[150,\infty[}} + \Delta_{250}$$

→ When solving the equations (with approximations):

$$\begin{aligned}
\Delta &= y_{tot}\cdot\delta \\
\Delta_{75} &= y_{[75,\infty[}\cdot(\delta_{[75,\infty[} \ominus \delta) \\
\Delta_{150} &= y_{[150,\infty[}\cdot(\delta_{[150,\infty[} \ominus \delta_{[75,\infty[}) \\
\Delta_{250} &= y_{[250,\infty[}\cdot\left(\delta_{[250,\infty[} \ominus \delta_{[150,\infty[}\right) \\
\Delta_{150J} &= y_{[150,\infty[\,\cup\,[\geq 1 jet]} \\
&\quad\cdot\left(\delta_{[150,\infty[\,\cup\,[\geq 1 jet]} \ominus \delta_{[150,\infty[}\right) \\
\Delta_{250J} &= y_{[250,\infty[\,\cup\,[\geq 1 jet]} \\
&\quad\cdot\left(\delta_{[250,\infty[\,\cup\,[\geq 1 jet]} \ominus \delta_{[250,\infty[}\right)
\end{aligned}$$

Pro

Quadrature subtraction naturally remove some double-counting

Cons

Ill defined if relative uncertainty reduce with $p_T(V)$ or N(add jet)

Δ_{150} for us

Estimations of Δs

- Frank's proposal: if ill defined use 0.5*relative variation
  - Applied also to sub-sequent Δ's
  - Also consider applying it only to ill defined Δ's
  - Which error propagation is the more correct ?

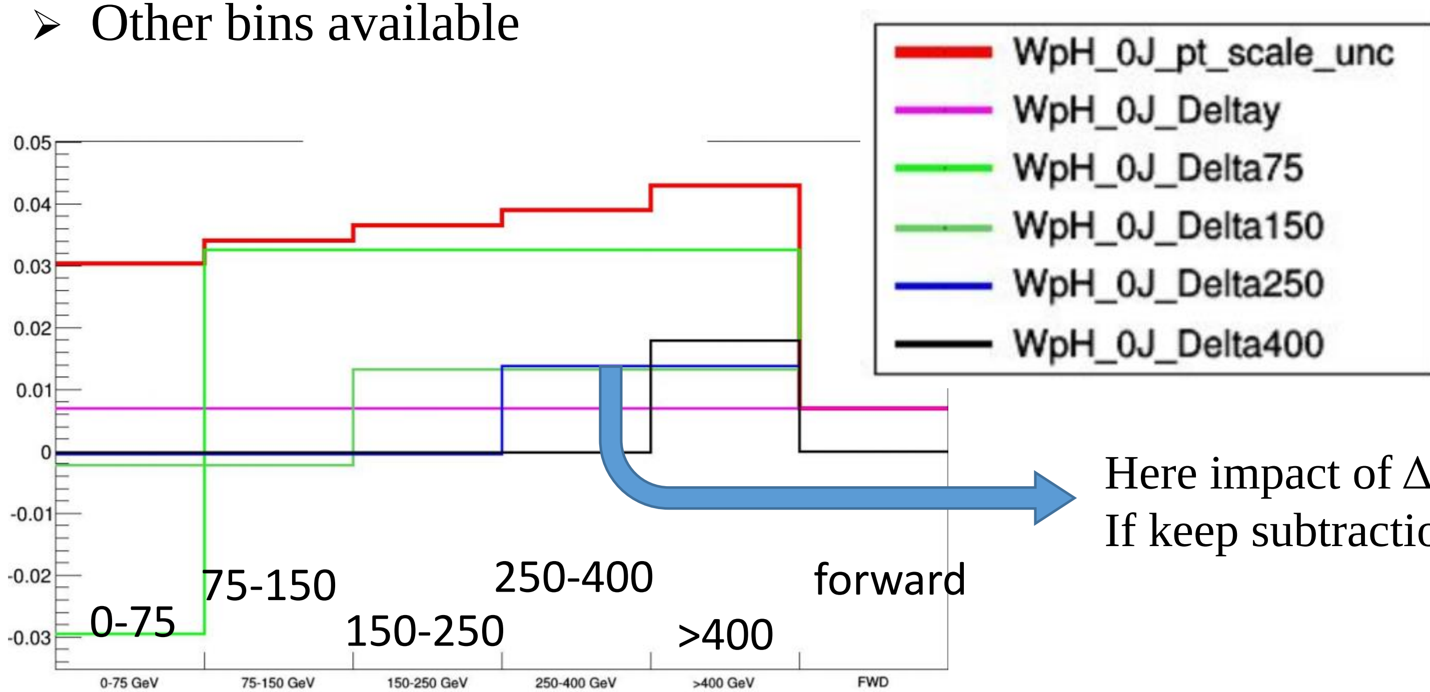
$$\Delta = y_{tot} \cdot \delta$$
$$\Delta_{75} = y_{[75,\infty[} \cdot (\delta_{[75,\infty[} \ominus \delta)$$
$$\Delta_{150} = y_{[150,\infty[} \cdot (\delta_{[150,\infty[} \ominus \delta_{[75,\infty[})$$
$$\Delta_{250} = y_{[250,\infty[} \cdot \left(\delta_{[250,\infty[} \ominus \delta_{[150,\infty[}\right)$$
$$\Delta_{150J} = y_{[150,\infty[\,\cup\,[\geq 1 jet]} \cdot \left(\delta_{[150,\infty[\cup\,[\geq 1 jet]} \ominus \delta_{[150,\infty[}\right)$$
$$\Delta_{250J} = y_{[250,\infty[\,\cup\,[\geq 1 jet]} \cdot \left(\delta_{[250,\infty[\cup\,[\geq 1 jet]} \ominus \delta_{[250,\infty[}\right)$$

$\Rightarrow$

$$\boxed{\begin{aligned}
\Delta &= y_{tot} \cdot \delta \\
\Delta_{75} &= y_{[75,\infty[} \cdot (\delta_{[75,\infty[} \ominus \delta) \\
\Delta_{150} &= y_{[150,\infty[} \cdot (0.5) \cdot \delta_{[150,\infty[} \\
\Delta_{250} &= y_{[250,\infty[} \cdot (0.5) \cdot \delta_{[250,\infty[} \\
\Delta_{150J} &= y_{[150,\infty[\,\cup\,[\geq 1 jet]} \cdot \left(\delta_{[150,\infty[\cup\,[\geq 1 jet]} \ominus \delta_{[150,\infty[}\right) \\
\Delta_{250J} &= y_{[250,\infty[\,\cup\,[\geq 1 jet]} \cdot \left(\delta_{[250,\infty[\cup\,[\geq 1 jet]} \ominus \delta_{[250,\infty[}\right)
\end{aligned}}$$

Result for the Δs

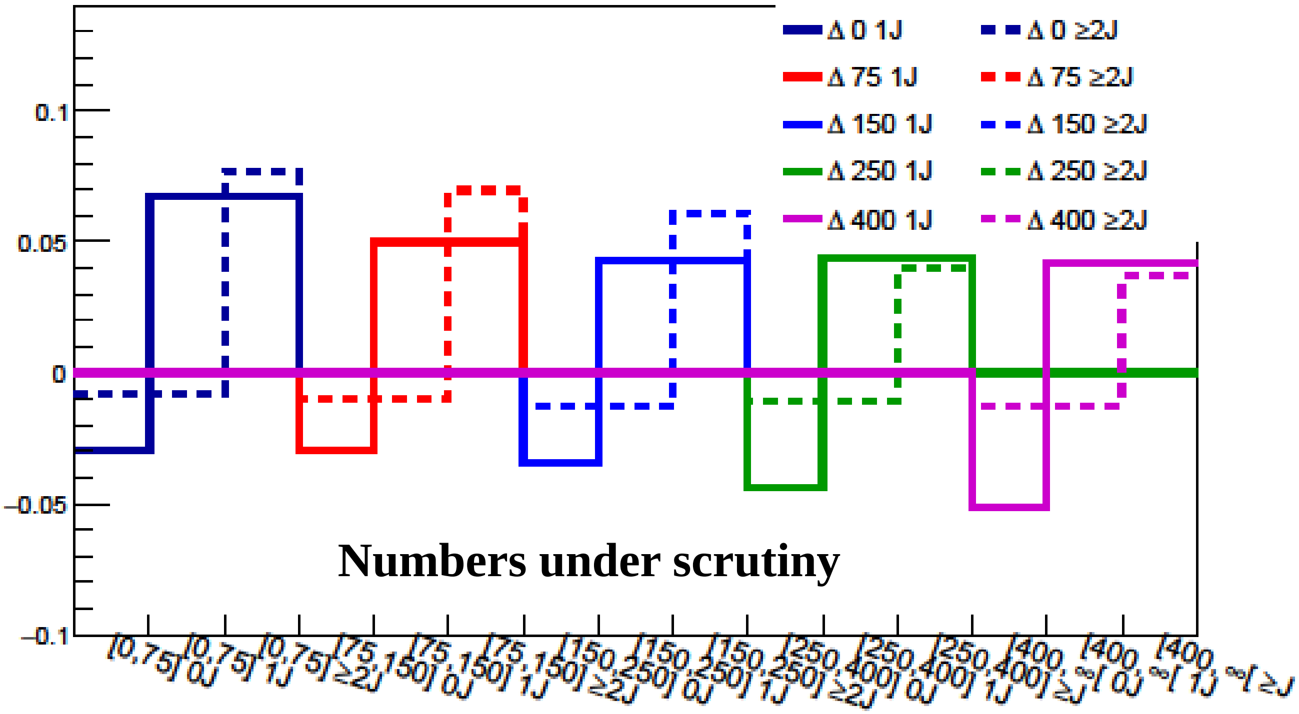
- Frank's proposal: if ill defined use 0.5*relative variation
  - Applied also to sub-sequent Δ's
- Impact of Δ's in the stage1++ bins:
  - Showing here no add jet bin for qq $\rightarrow W^{+}(\ell\nu)H$
  - Other bins available



Here impact of Δ_{250} is ~1.3%
If keep subtraction def ~0.7%

Result for the Δs

- Frank's proposal: if ill defined use 0.5*relative variation
  - Applied also to sub-sequent Δ's
- Impact of Δ's in the stage1++ bins:
  - Showing here no add jet bin for $qq \rightarrow W^+(\ell\upsilon)H$
  - Other bins available



2 signal uncertainty sets left to discuss:

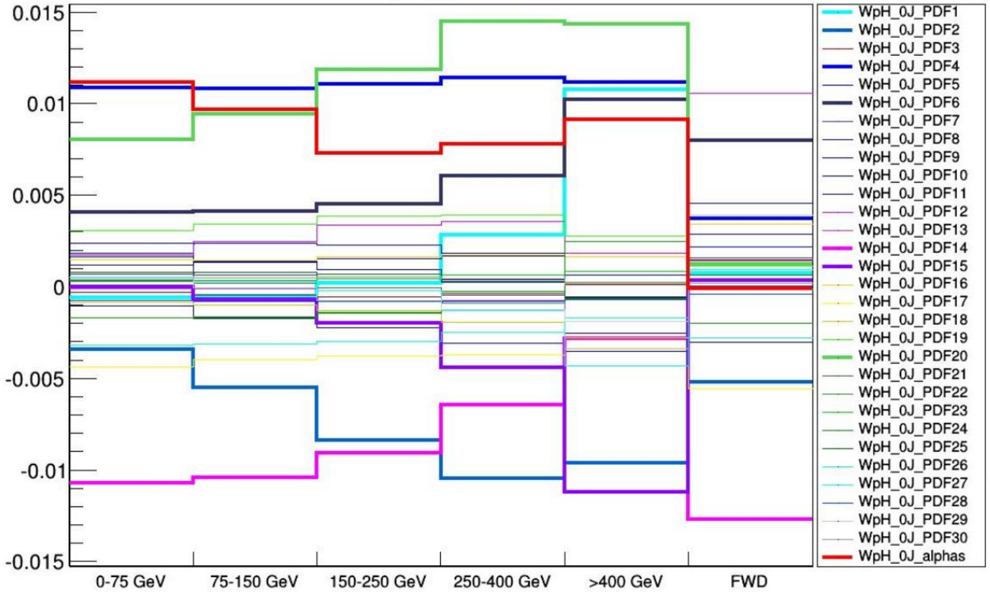
~~-> Scale~~

-> PDF

-> PS / UE

PDF uncertainties

- Want to use the relative PDF variation in each stage1++ bin:
  - Use PDF4LHC_nlo_30_pdfas (click me) set
  - Compute variation w.r.t first weight
  - Use yields per in each bin: $var[i] = \frac{y\_pdf[i] - y\_pdf[0]}{y\_pdf[0]} \; \forall\, i \in [1,30]$
- α_S uncertainty as average of up/down relative uncertainties on yields.



Only few variations > 0.5%

→ Can merge small variations

→ Maximum impact 1.5%

1 signal uncertainty set left to discuss:

~~-> Scale~~

~~-> PDF~~

-> PS / UE

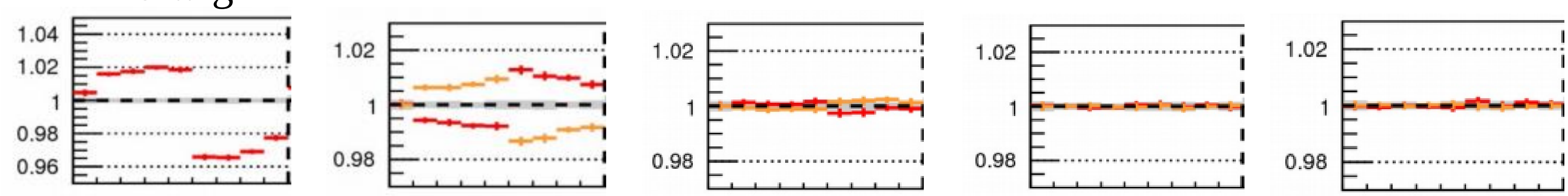
Parton Shower / UE uncertainties

- Important source of uncertainty for EPS:
  - Acceptance uncertainty
- Estimated comparing different samples across STXS bins:
  - Powheg+Pythia8 (nom), Powheg+Herwig7, MPI up/down, Ren up/down, Var1 and Var2 up/down (primordial-kT and ISR-cutoff variations).

qq → W(ℓυ)H sample

Relative variation over Powheg+Pythia8:

Herwig7 Ren MPI Var1 Var2



Binning: [foward] – [N(add jets)=0]x([0, 75] [75, 150] [150, 250] [250, ∞])

– [N(add jets)≥1]x([0, 75] [75, 150] [150, 250] [250, ∞])

Now talking of only 2-4% effects

→ Main effect on N(jets)

Note: expect bigger impact from shape/acceptance

Conclusion

Conclusion

- First implementation of the stage 1++ scale uncertainties ~ready to go:
  - Calculation based on inclusive bin acceptances (y's) and their associated relative uncertainties (δ's)
  - Still some tunable items: "δ-subtraction" and "δ*0.5"
  - Final uncertainties Δ's showing ~1 to 4% effects
- PDFs/alpha_S based on standard approach:
  - Relative uncertainties on yields following recommendations
  - Unc < 1.5% with $p_T(V)$ and N(jet) trends.
- PS/UE uncertainties:
  - Sample differences across the STXS bins
  - ~2/4% with N(jet slope)
  - Still stage 1+ (don't expect new conclusions with 1++)

Thank you for your attention