# HXSWG1 - VH
# Towards STXS

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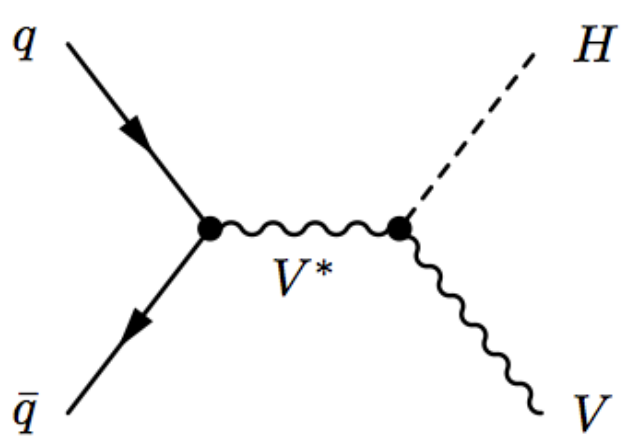
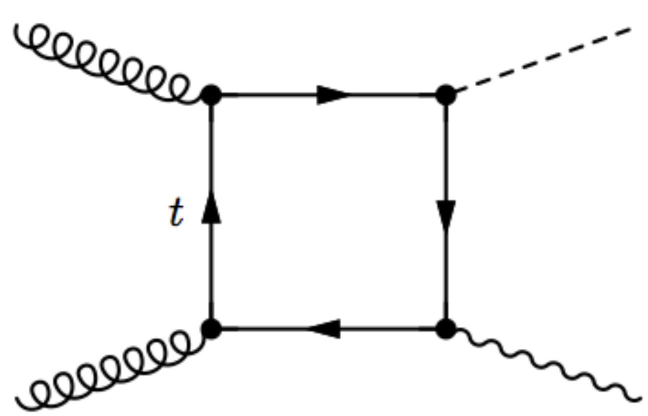
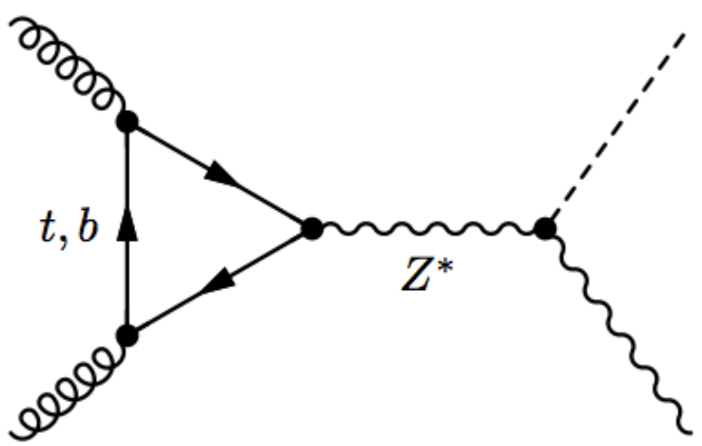



**Welcome Chris, joining Luca as CMS convener!**

# VH WG1 subgroup activities

**VH twiki:** https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWGVH

**Mailing lists**

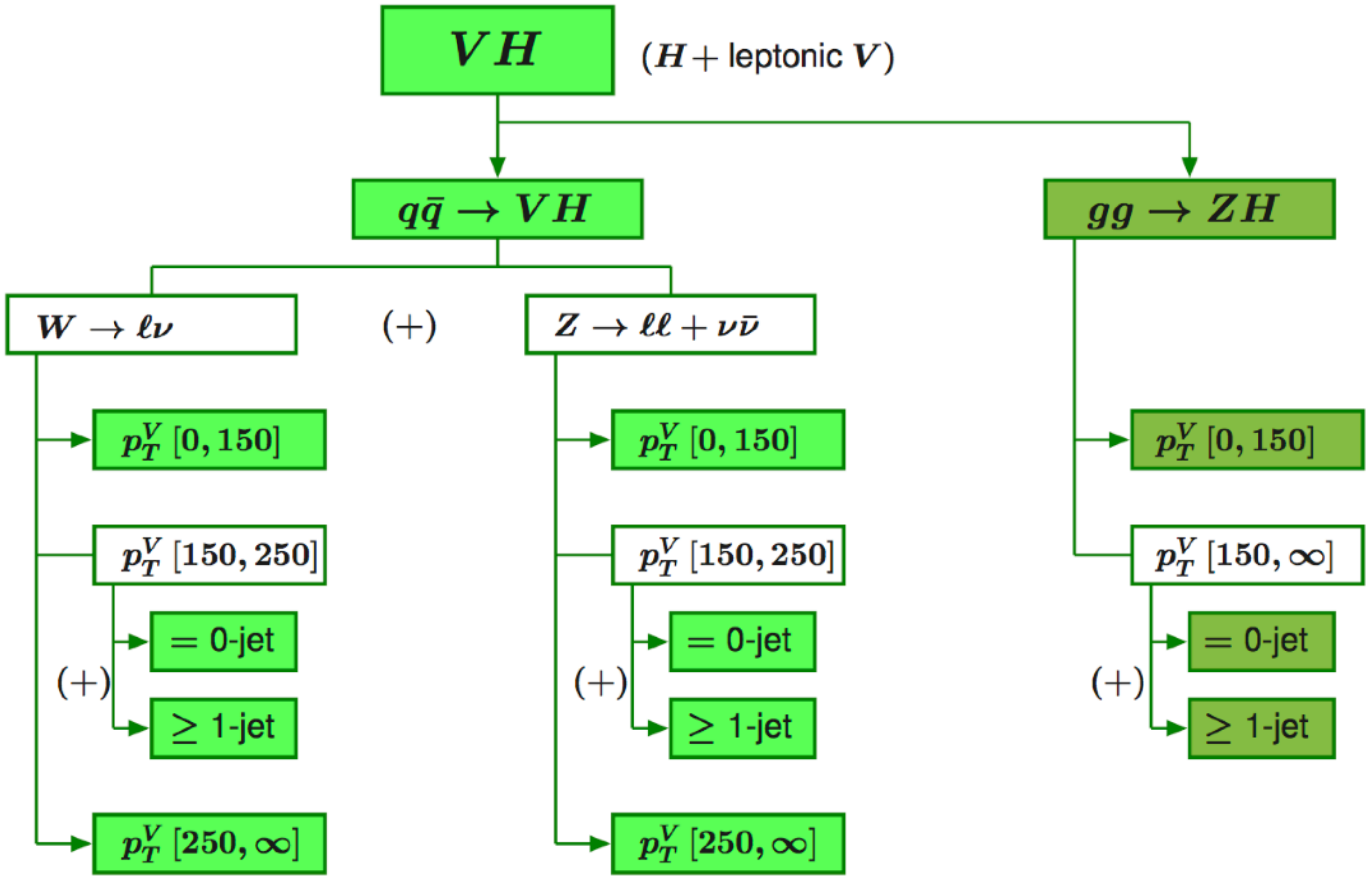
- lhc-higgs-xsbr@cern.ch
  [general WG1 thread - for discussions / meeting advertisement]
- lhc-higgs-vh-convener@cern.ch
  [conveners mailing list for direct communication]
- lhc-higgs-xsbr-vhvbf@cern.ch is obsolete and **not used anymore**!

**Indico page for VH WG1 meetings:** https://indico.cern.ch/category/5847/

| | | | |
|---|---|---|---|
| VH | VH XS prediction and uncertainties in STXS framework | Software tool providing central value and uncertainties + recommendations | ~mid-summer 2018 |
| VH | HL/HE-LHC 27TeV VH cross-section | VH cross-section and uncertainties calculation at 27TeV | few months / summer 2018 |
| VH | V+hf modeling for VH(bb) | [public note] MC comparison across several V+hf MC tools targeting VH(bb) phase space, guidelines for theory uncertainties on V+hf predictions | autumn 2018 |
| VH | ggZH merged predictions | [potentially public note] Comparison between showered ggZH 0+1jet merged LO MC prediction, and ggZH LO prediction | ~mid-summer 2018 |

# STXS for VH - short intro

- Stage-1 bin split mostly based on VH(bb) analysis categories / variables




- "VH" bins include leptonic VH (H undecayed)
- qq → V(qq)H as part of "VBF" bins
- gg → Z(qq)H as part of "ggF"

- Feedback on the bin split is still welcome, not set in stone!

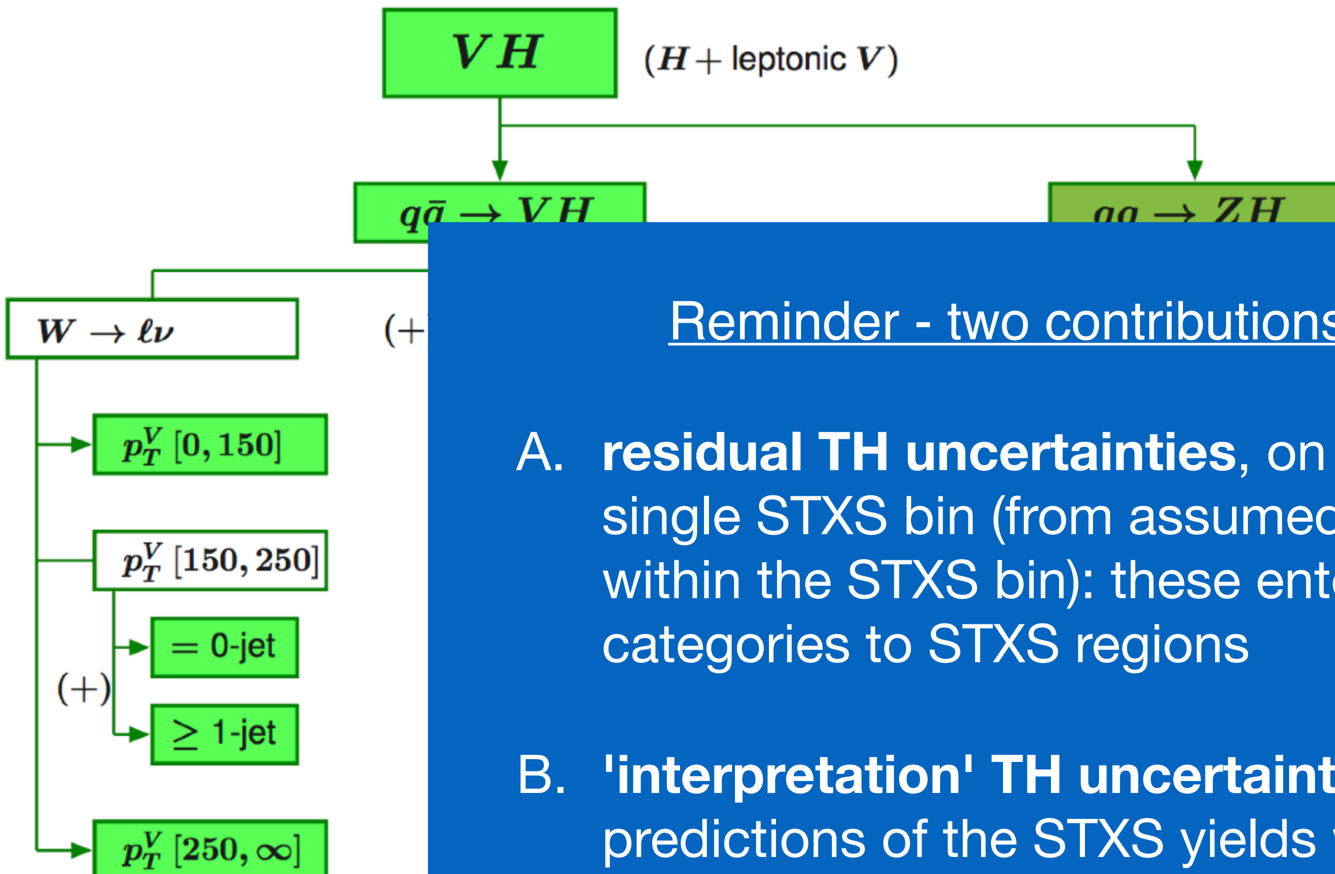
STXS ≠ fiducial XS (and complementary)
[fid/diff XS minimize theory dependence and acceptance corrections, decayed Higgs, ... ]

- optimized for analysis sensitivity (e.g. in this case driven by VH(bb) categorization)
- reducing dominant theory dependence in the measurement (by moving it to the interpretation stage)
- reduced residual theory uncertainties within the measurement of each bin (if residual th. uncertainties become large in the exp. acceptance for a bin, the bin the be further split in sub-categories)

*(reference from LesHouches2017)*

# STXS for VH - short intro

- Stage-1 bin split mostly based on VH(bb) analysis categories / variables




- “VH” bins include leptonic VH (H undecayed)
- qq → V(qq)H as part of “VBF” bins
  Z(qq)H ... f “ggF”

plit is still
one!

omplementary)
dependence and
cayed Higgs, ... ]

Reminder - two contributions from theory uncertainties

A. **residual TH uncertainties**, on the measurement of each single STXS bin (from assumed SM prediction of H kinematic within the STXS bin): these enter in the unfolding of exp. categories to STXS regions

B. **'interpretation' TH uncertainties**, on the SM or BSM predictions of the STXS yields which enter in any subsequent interpretations

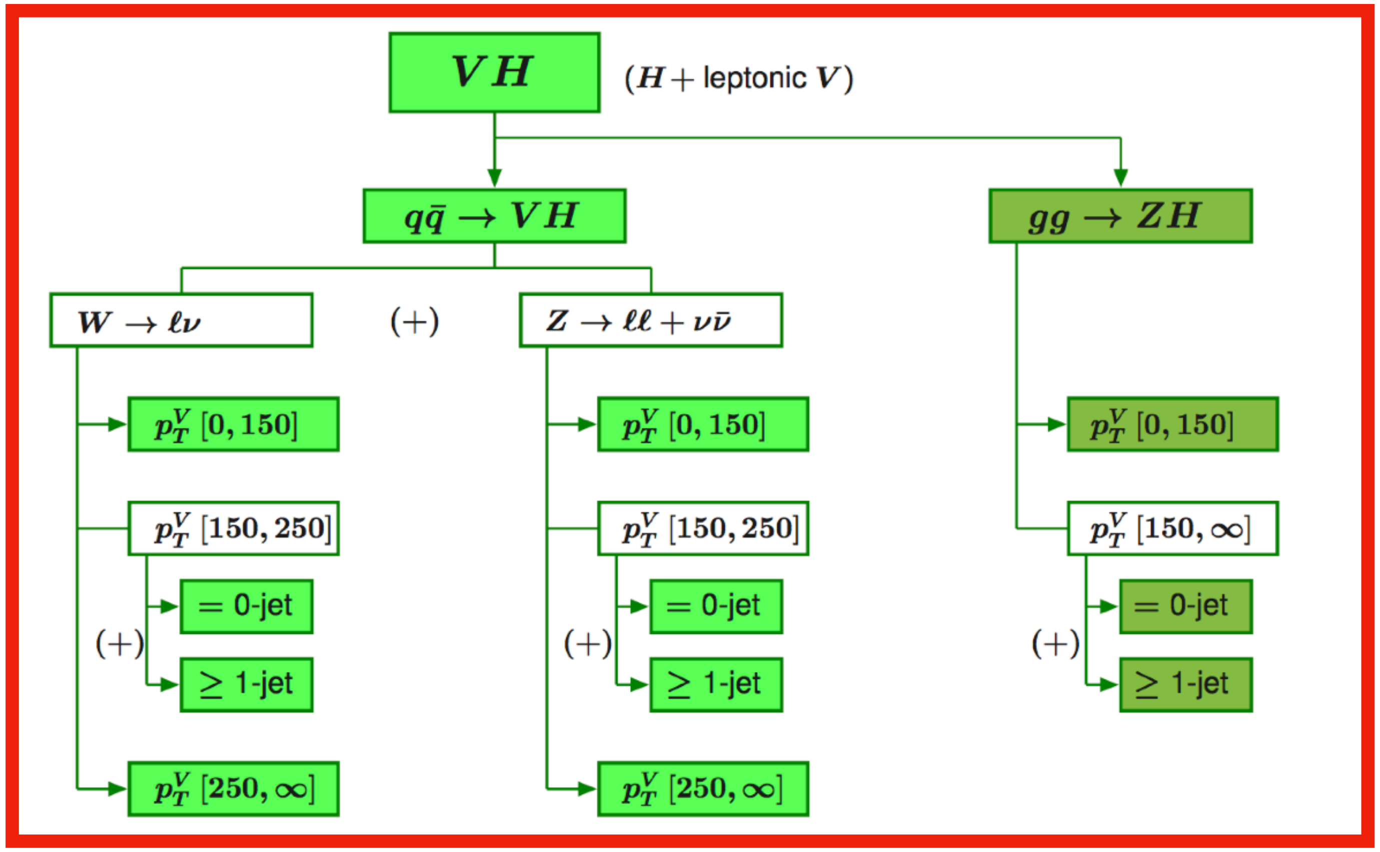
STXS scheme goal is to move the dominant TH unc. from A to B

**First step: addressing B**

- optimized for ... tion)
- reducing dom
  (by moving it
- reduced resid
  (if residual th. uncertainties become large in the exp. acceptance for a bin, the bin the be further split in sub-categories)

*(reference from LesHouches2017)*

# STXS for VH - bin split



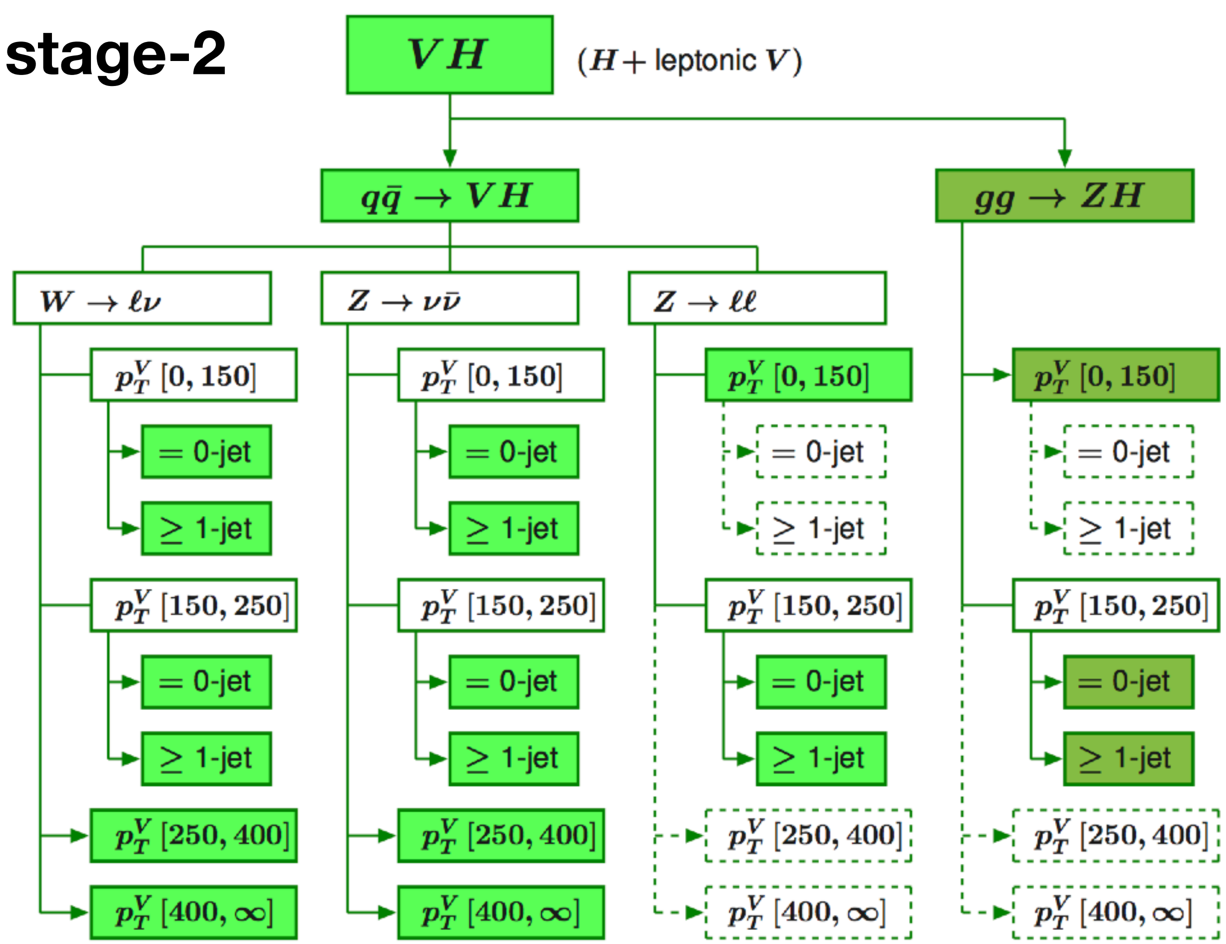

stage-1

Feedback on the bin split is still welcome, not set in stone!

- experimental analyses adopted a finer pTV split at below 150GeV: [75,150]+[150, ∞]
- split in exclusive jet-bins already in use across the whole pTV range, not only [150,250]GeV
- jet-bin definition: exclusive or inclusive bins for higher jet multiplicities?
- high-pT (above 250GeV) intended as BSM-sensitive bins:
  could an mVH categorization be interesting?

  (e.g. BSM effects in ggZH)

stage-2



# STXS for VH - uncertainty scheme

**General parametrization of TH uncertainties for the interpretation step**

Ideally: ATLAS & CMS publish the measured STXS in each bin → TH prediction compared to the measurement with uncertainties coming directly from the table below

**stage-1**

| | QCD uncertainties | | | | EW uncertainties | | |
|---|---|---|---|---|---|---|---|
| $q\bar{q}' \to W$ | $\Delta^{\mathrm{y}}_{\mathrm{WH}}$ | $\Delta^{\mathrm{WH}}_{150}$ | $\Delta^{\mathrm{WH}}_{250}$ | $\Delta^{\mathrm{WH}}_{0/1}$ | $\Delta^{\mathrm{WH}}_{\mathrm{Sud}}$ | $\Delta^{\mathrm{WH}}_{\mathrm{hard}}$ | |
| $p_T^V$ [0,150] | $x_1$ | $-1$ | $-y$ | | $x_1$ | $\cdots$ | |
| $p_T^V$ [150,250] | $x_2$ | $+1-y$ | $-(1-y)$ | $0$ | $x_2$ | $\cdots$ | |
| $=$ 0-jet | $x_2 z$ | $+(1-y)z$ | $-(1-y)z$ | $+1$ | $\cdots$ | $\cdots$ | |
| $\geq$ 1-jet | $x_2(1-z)$ | $+(1-y)(1-z)$ | $-(1-y)(1-z)$ | $-1$ | $\cdots$ | $\cdots$ | |
| $p_T^V$ [250,$\infty$] | $x_3$ | $y$ | $+1$ | | $x_3$ | $\cdots$ | |
| $q\bar{q} \to Z$ | $\Delta^{\mathrm{y}}_{\mathrm{ZH}}$ | $\Delta^{\mathrm{ZH}}_{150}$ | $\Delta^{\mathrm{ZH}}_{250}$ | $\Delta^{\mathrm{ZH}}_{0/1}$ | $\Delta^{\mathrm{ZH}}_{\mathrm{Sud}}$ | | $\Delta^{\mathrm{ZH}}_{\mathrm{hard}}$ |
| $p_T^V$ [0,150] | $x_1$ | $-1$ | $-y$ | | $x_1$ | | $\cdots$ |
| $p_T^V$ [150,250] | $x_2$ | $+1-y$ | $-(1-y)$ | $0$ | $x_2$ | | $\cdots$ |
| $=$ 0-jet | $x_2 z$ | $+(1-y)z$ | $-(1-y)z$ | $+1$ | $\cdots$ | | $\cdots$ |
| $\geq$ 1-jet | $x_2(1-z)$ | $+(1-y)(1-z)$ | $-(1-y)(1-z)$ | $-1$ | $\cdots$ | | $\cdots$ |
| $p_T^V$ [250,$\infty$] | $x_3$ | $y$ | $+1$ | | $x_3$ | | $\cdots$ |

# STXS for VH - uncertainty scheme

## One word on the implementation of the uncertainty scheme:

Single bin-boundary a/b splitting the phase space in 2:

The a/b cut itself is a new source of uncertainty, which is not present on $\sigma_{ab}$
(e.g. jet-binning)

**General parametrization of the uncertainty matrix** = fully correlated + fully anti-correlated components

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

- 2 independent nuisance parameter for each of the 3 observables $\{\sigma_{ab}, \sigma_a, \sigma_b\}$

*fully correlated* $\theta^{\mathrm{y}} : \quad \{\Delta_{ab}^{\mathrm{y}}, \Delta_a^{\mathrm{y}}, \Delta_b^{\mathrm{y}}\}$ **1st NP** - overall yield uncertainty of a common source

*fully anti-correlated* $\theta_{a/b} : \quad \{0, \Delta_{a/b}, -\Delta_{a/b}\}$ **2nd NP** - migration uncertainty introduced by the a/b cut which **fully cancels out** in the a+b sum

This parametrization is useful also for theorists that want to identify and estimate each component of the uncertainty -- well known case of uncertainties in fixed-order or resummed calculation for jet-binning.

**Note**: example of single a/b boundary extendable to multiple regions / multiple boundaries

**(reference in Section 6 from LH17)**

# STXS for VH - uncertainty scheme

**Simple example**: pTV split only
[0,150] + [150, 250] + [250, ∞]

$$\sigma_{tot} = \sigma_{[0,150]} + \sigma_{[150,250]} + \sigma_{[250,\infty]}$$
$$= \sigma_{[0,150]} + \sigma_{[150,\infty]}$$

$$\sigma_{[150,\infty]} = \sigma_{[150,250]} + \sigma_{[250,\infty]}$$

| $q\bar{q}' \to W$ | $\Delta^{\mathrm{y}}_{\mathrm{WH}}$ | $\Delta^{\mathrm{WH}}_{150}$ | $\Delta^{\mathrm{WH}}_{250}$ |
|---|---|---|---|
| $p_T^V$ [0,150] | $x_1$ | $-1$ | $-y$ |
| $p_T^V$ [150,250] | $x_2$ | $+1-y$ | $-(1-y)$ |
| [redacted] | | | |
| $p_T^V$ [250,∞] | $x_3$ | $y$ | $+1$ |

**5 observables**: $\{\sigma_{tot}, \sigma_{[0,150]}, \sigma_{[150,\infty]}, \sigma_{[150,250]}, \sigma_{[250,\infty]}\}$

$\theta^{\mathrm{y}}$ : $\{\Delta^{\mathrm{y}}_{ab}, \Delta^{\mathrm{y}}_{a}, \Delta^{\mathrm{y}}_{b}\}$ 1NP → $\theta^{\mathrm{y}}$ : $\{\Delta^{\mathrm{y}}_{\mathrm{WH}}; \Delta^{\mathrm{y}}_{[0,150]}; \Delta^{\mathrm{y}}_{[150,\infty]}; \Delta^{\mathrm{y}}_{[150,250]}; \Delta^{\mathrm{y}}_{[250,\infty]}\}$

$$\Delta^{\mathrm{y}}_{\mathrm{WH}} = \Delta^{\mathrm{y}}_{[0,150]} + \Delta^{\mathrm{y}}_{[150,\infty]}$$
$$\Delta^{\mathrm{y}}_{[150,\infty]} = \Delta^{\mathrm{y}}_{[150,250]} + \Delta^{\mathrm{y}}_{[250,\infty]}$$

**$x_i$ parameters in the table derived from the distribution of the overall yield uncertainty:**

$$x_1 = \Delta^{\mathrm{y}}_{[0,150]} / \Delta^{\mathrm{y}}_{\mathrm{WH}}$$
$$x_2 = \Delta^{\mathrm{y}}_{[150,250]} / \Delta^{\mathrm{y}}_{\mathrm{WH}}$$
$$x_3 = \Delta^{\mathrm{y}}_{[250,\infty]} / \Delta^{\mathrm{y}}_{\mathrm{WH}}$$

# STXS for VH - uncertainty scheme

**Simple example**: pTV split only
[0,150] + [150, 250] + [250, ∞]

$$\sigma_{tot} = \sigma_{[0,150]} + \sigma_{[150,250]} + \sigma_{[250,\infty]}$$
$$= \sigma_{[0,150]} + \sigma_{[150,\infty]}$$

$$\sigma_{[150,\infty]} = \sigma_{[150,250]} + \sigma_{[250,\infty]}$$

| $q\bar{q}' \to W$ | $\Delta^{y}_{WH}$ | $\Delta^{WH}_{150}$ | $\Delta^{WH}_{250}$ |
|---|---|---|---|
| $p_T^V$ [0,150] | $x_1$ | $-1$ | $-y$ |
| $p_T^V$ [150,250] | $x_2$ | $+1-y$ | $-(1-y)$ |
| [redacted] | | | |
| $p_T^V$ [250,∞] | $x_3$ | $y$ | $+1$ |

**5 observables**: $\{\sigma_{tot}, \sigma_{[0,150]}, \sigma_{[150,\infty]}, \sigma_{[150,250]}, \sigma_{[250,\infty]}\}$

$\theta_{a/b}$ : $\{0,\ \Delta_{a/b}, -\Delta_{a/b}\}$

2NP → $\theta_{0/150}$ : $\Delta_{150}$ x {0; 1; -1; -(1-$y_1$); -$y_1$}

$\theta_{150/250}$ : $\Delta_{250}$ x {0; $y_2$; -$y_2$; (1-$y_2$); -1}

(A priori the $y_i$ parameters don't have the same values)

Uncertainties on the cross-section bins:

unc.($\sigma_{[0,150]}$) = $x_1 \cdot \Delta^{y}_{WH}$ - $\Delta_{150}$ - $y_2 \cdot \Delta_{250}$
unc.($\sigma_{[150,250]}$) = $x_2 \cdot \Delta^{y}_{WH}$ + $(1-y_1) \cdot \Delta_{150}$ - $(1-y_2) \cdot \Delta_{250}$
unc.($\sigma_{[250,\infty]}$) = $x_3 \cdot \Delta^{y}_{WH}$ + $y_1 \cdot \Delta_{150}$ + $\Delta_{250}$

- $\Delta_{150}$ is the unc. induced by the cut at 150GeV, fully anticorrelated {+1;-1} across the boundary, and distributed by $y_1$ over the [150,∞] region
- $\Delta_{250}$ is the unc. induced by the cut at 250GeV, fully anticorrelated {+1;-1} across the boundary, and distributed by $y_2$ over the [150,250] region

# STXS for VH - uncertainty scheme

Ideally we want to provide a tool that implements this scheme with the state-of-the-art estimate of central values and uncertainties for/across each STXS bin.

the main item provided by this tool is the **parametrization scheme**
the tool itself has to be flexible enough to potentially accommodate a new/different TH prediction with its own uncertainty estimate

## First step - test the implementation with the available predictions

- start with MC samples used in experimental analyses: PowhegMiNLO [readily available]
- consider scale variations as first step - uncertainties from pTV and n-jet cuts
- start to build the uncertainty matrix from this first (simpler) example to spot potential issues and prepare the framework for more advanced TH predictions/estimates

deriving the {x, y, z} and $\Delta$ parameters from slide 6

# STXS for VH - uncertainty scheme

Example from Dag's talk for ggF -- full table of uncertainties for ggF categories

Cross sections and absolute uncertainties in pb

| STXS | sig | stat | mu | res | mig01 | mig12 | D60 | D120 | D200 | Tot |
|---|---|---|---|---|---|---|---|---|---|---|
| Incl | 48.52 +/- | 0.00 | 2.25 | 1.06 | 0.02 | -0.01 | -0.00 | 0.00 | 0.08 | 2.49 |
| FWDH | 4.27 +/- | 0.01 | 0.19 | 0.08 | -0.02 | -0.02 | -0.02 | -0.01 | 0.00 | 0.21 |
| VBF1 | 0.27 +/- | 0.00 | 0.02 | 0.02 | 0.01 | 0.04 | 0.00 | 0.00 | 0.00 | 0.05 |
| VBF2 | 0.36 +/- | 0.00 | 0.03 | 0.03 | 0.01 | 0.06 | 0.01 | 0.01 | 0.00 | 0.07 |
| 0J | 27.25 +/- | 0.03 | 1.03 | 0.03 | -1.12 | 0.00 | 0.00 | 0.00 | 0.00 | 1.52 |
| 1J_0-60 | 6.49 +/- | 0.01 | 0.35 | 0.30 | 0.52 | -0.45 | -0.79 | -0.08 | 0.00 | 1.14 |
| 1J_60 | 4.50 +/- | 0.01 | 0.24 | 0.21 | 0.36 | -0.31 | 0.52 | -0.06 | 0.00 | 0.78 |
| 1J_120 | 0.74 +/- | 0.00 | 0.04 | 0.03 | 0.06 | -0.05 | 0.09 | 0.08 | 0.00 | 0.15 |
| 1J_200 | 0.15 +/- | 0.00 | 0.01 | 0.01 | 0.01 | -0.01 | 0.00 | 0.00 | 0.02 | 0.03 |
| 2J_0-60 | 1.22 +/- | 0.01 | 0.10 | 0.10 | 0.05 | 0.20 | -0.15 | -0.02 | 0.00 | 0.29 |
| 2J_60 | 1.86 +/- | 0.01 | 0.15 | 0.15 | 0.07 | 0.30 | 0.22 | -0.02 | 0.00 | 0.43 |
| 2J_120 | 0.99 +/- | 0.00 | 0.08 | 0.08 | 0.04 | 0.16 | 0.11 | 0.10 | 0.00 | 0.25 |
| 2J_200 | 0.42 +/- | 0.00 | 0.03 | 0.03 | 0.02 | 0.07 | 0.00 | 0.00 | 0.06 | 0.10 |
| =0J | 30.12 +/- | 0.03 | 1.14 | 0.03 | -1.24 | 0.00 | 0.00 | 0.00 | 0.00 | 1.68 |
| =1J | 12.92 +/- | 0.02 | 0.69 | 0.59 | 1.04 | -0.90 | -0.21 | -0.07 | 0.02 | 1.66 |
| >=2J | 5.47 +/- | 0.01 | 0.43 | 0.43 | 0.22 | 0.88 | 0.21 | 0.07 | 0.06 | 1.12 |
| >=1J 60-200 | 9.09 +/- | 0.01 | 0.57 | 0.53 | 0.59 | 0.17 | 1.05 | 0.11 | 0.00 | 1.45 |
| >=1J 120-200 | 1.96 +/- | 0.01 | 0.13 | 0.13 | 0.11 | 0.14 | 0.23 | 0.21 | 0.00 | 0.40 |
| >=1J >200 | 0.58 +/- | 0.00 | 0.04 | 0.04 | 0.03 | 0.06 | 0.00 | 0.00 | 0.08 | 0.12 |
| >=1J >60 | 9.68 +/- | 0.01 | 0.61 | 0.57 | 0.62 | 0.22 | 1.05 | 0.11 | 0.08 | 1.51 |
| >=1J >120 | 2.54 +/- | 0.01 | 0.18 | 0.17 | 0.14 | 0.20 | 0.23 | 0.21 | 0.08 | 0.47 |
| >=1 | 18.40 +/- | 0.02 | 1.12 | 1.02 | 1.26 | -0.01 | -0.00 | 0.00 | 0.08 | 1.97 |

# STXS for VH - uncertainty scheme

Example from Dag's talk for ggF -- full table of uncertainties for ggF categories

Fractional impact of each uncertainty source

| STXS | sig +/- stat | mu | res | mig01 | mig12 | D60 | D120 | D200 |
|---|---|---|---|---|---|---|---|---|
| Total abs uncertainty | | 2.25 | 1.04 | 1.25 | 0.88 | 1.05 | 0.21 | 0.08 |
| Incl | 48.52 +/- 0.00 | 1.00 | 1.01 | 0.02 | -0.01 | -0.00 | 0.00 | 1.00 |
| FWDH | 4.27 +/- 0.01 | 0.08 | 0.07 | -0.02 | -0.02 | -0.02 | -0.04 | 0.02 |
| VBF1 | 0.27 +/- 0.00 | 0.01 | 0.02 | 0.01 | 0.05 | 0.00 | 0.01 | 0.00 |
| VBF2 | 0.36 +/- 0.00 | 0.01 | 0.03 | 0.01 | 0.07 | 0.01 | 0.03 | 0.00 |
| 0J | 27.25 +/- 0.03 | 0.46 | 0.03 | -0.90 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1J_0-60 | 6.49 +/- 0.01 | 0.15 | 0.29 | 0.42 | -0.51 | -0.74 | -0.41 | 0.00 |
| 1J_60 | 4.50 +/- 0.01 | 0.11 | 0.20 | 0.29 | -0.35 | 0.49 | -0.28 | 0.00 |
| 1J_120 | 0.74 +/- 0.00 | 0.02 | 0.03 | 0.05 | -0.06 | 0.08 | 0.38 | 0.00 |
| 1J_200 | 0.15 +/- 0.00 | 0.00 | 0.01 | 0.01 | -0.01 | 0.00 | 0.00 | 0.26 |
| 2J_0-60 | 1.22 +/- 0.01 | 0.04 | 0.09 | 0.04 | 0.22 | -0.14 | -0.08 | 0.00 |
| 2J_60 | 1.86 +/- 0.01 | 0.07 | 0.14 | 0.06 | 0.34 | 0.20 | -0.12 | 0.00 |
| 2J_120 | 0.99 +/- 0.00 | 0.03 | 0.07 | 0.03 | 0.18 | 0.11 | 0.50 | 0.00 |
| 2J_200 | 0.42 +/- 0.00 | 0.01 | 0.03 | 0.01 | 0.08 | 0.00 | 0.00 | 0.72 |
| =0J | 30.12 +/- 0.03 | 0.50 | 0.03 | -0.99 | 0.00 | 0.00 | 0.00 | 0.00 |
| =1J | 12.92 +/- 0.02 | 0.31 | 0.57 | 0.83 | -1.02 | -0.20 | -0.36 | 0.26 |
| >=2J | 5.47 +/- 0.01 | 0.19 | 0.41 | 0.17 | 1.00 | 0.20 | 0.36 | 0.74 |
| >=1J 60-200 | 9.09 +/- 0.01 | 0.25 | 0.51 | 0.47 | 0.19 | 1.00 | 0.55 | 0.00 |
| >=1J 120-200 | 1.96 +/- 0.01 | 0.06 | 0.12 | 0.09 | 0.16 | 0.22 | 1.00 | 0.00 |
| >=1J >200 | 0.58 +/- 0.00 | 0.02 | 0.04 | 0.02 | 0.07 | 0.00 | 0.00 | 1.00 |
| >=1J >60 | 9.68 +/- 0.01 | 0.27 | 0.55 | 0.50 | 0.26 | 1.00 | 0.55 | 1.00 |
| >=1J >120 | 2.54 +/- 0.01 | 0.08 | 0.16 | 0.11 | 0.22 | 0.22 | 1.00 | 1.00 |
| >=1 | 18.40 +/- 0.02 | 0.50 | 0.98 | 1.01 | -0.01 | -0.00 | 0.00 | 1.00 |

Sum across the column gives back 1, and the absolute uncertainty on the single category is obtained from each single x-value:

0J - 2.25*0.46 = 1.03

# STXS for VH - uncertainty sources and estimates

## Second step - uncertainty estimate

For the QCD uncertainties, we identify the following sources/nuisance parameters:

- $\boldsymbol{\theta^{\mathbf{y}}_{\mathbf{VH}}}$, $\boldsymbol{\theta^{\mathbf{y}}_{gg\to ZH}}$: The overall yield uncertainty for the underlying VH production process.
- $\boldsymbol{\theta^{\mathbf{VH}}_{\mathbf{150}}}$, $\boldsymbol{\theta^{gg\to ZH}_{\mathbf{150}}}$: The migration uncertainty related to the $p_T^V = 150\,\mathrm{GeV}$ bin boundary.
- $\boldsymbol{\theta^{\mathbf{VH}}_{\mathbf{250}}}$: The migration uncertainty related to the $p_T^V = 250\,\mathrm{GeV}$ bin boundary.
- $\boldsymbol{\theta^{\mathbf{VH}}_{\mathbf{0/1}}}$, $\boldsymbol{\theta^{gg\to ZH}_{\mathbf{0/1}}}$: The migration uncertainty related to the 0/1-jet bin boundary.

fixed-order predictions?

sensitive to resummation effects: resummed calculations or parton-shower MCs

Uncertainty from the modeling of parton-shower effects not included right now, but usually one of the dominant in the Higgs signal model

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For the EW uncertainties, we identify the following sources/nuisance parameters:

- $\boldsymbol{\theta^{\mathbf{VH}}_{\mathbf{Sud}}}$: The uncertainty related to EW Sudakov effects.
- $\boldsymbol{\theta^{\mathbf{WH}}_{\mathbf{hard}}}$, $\boldsymbol{\theta^{\mathbf{ZH}}_{\mathbf{hard}}}$: The uncertainty related to hard EW (non-Sudakov) effects.

How do we want to estimate EW uncertainties?

The theoretical uncertainties of integrated cross sections originating from unknown higher-order EW effects can be estimated by

$$\Delta_{\mathrm{EW}} = \max\{0.5\%, \delta^2_{\mathrm{EW}}, \Delta_\gamma\}. \qquad \text{(I.5.18)}$$

This estimate is based on the maximum of the generic size $\sim 0.5\%$ of the neglected NNLO EW effects, taking into account a possible systematic enhancement $\sim \delta^2_{\mathrm{EW}}$, and the potentially large relative uncertainty $\Delta_\gamma = \Delta\sigma_\gamma/\sigma$ of the photon-induced contribution $\sigma_\gamma$, whose absolute uncertainty $\Delta\sigma_\gamma$ can be read from the tables.

# STXS for VH - uncertainty sources and estimates

## Second step - uncertainty estimate

For the QCD uncertainties, we identify the following sources/nuisance parameters:

- $\theta^{\mathrm{y}}_{\mathrm{VH}}$, $\theta^{\mathrm{y}}_{gg\to ZH}$: The overall yield uncertainty for the underlying VH production process.
- $\theta^{\mathrm{VH}}_{150}$, $\theta^{gg\to ZH}_{150}$: The migration uncertainty related to the $p_T^V = 150\,\mathrm{GeV}$ bin boundary.
- $\theta^{\mathrm{VH}}_{250}$: The migration uncertainty related to the $p_T^V = 250\,\mathrm{GeV}$ bin boundary.
- $\theta^{\mathrm{VH}}_{0/1}$, $\theta^{gg\to ZH}_{0/1}$: The migration uncertainty related to the 0/1-jet bin boundary.

fixed-order predictions?

sensitive to resummation effects: ...lations or ...ICs

Uncertainty from ... now, but usu...

For the EW uncerta...

- $\theta^{\mathrm{VH}}_{\mathrm{Sud}}$: The unc...
- $\theta^{\mathrm{WH}}_{\mathrm{hard}}$, $\theta^{\mathrm{ZH}}_{\mathrm{hard}}$: ...

...ant to estimate ...rtainties?

Correlation of uncertainties with other Higgs production modes
not discussed here and now, but we'll need to address it

E.g.
EW-uncertainty VH-VBF correlation
QCD-uncertainty ggZH-ggH correlation
?

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This estimate is based on the maximum of the generic size $\sim 0.5\%$ of the neglected NNLO EW effects, taking into account a possible systematic enhancement $\sim \delta^2_{\mathrm{EW}}$, and the potentially large relative uncertainty $\Delta_\gamma = \Delta\sigma_\gamma/\sigma$ of the photon-induced contribution $\sigma_\gamma$, whose absolute uncertainty $\Delta\sigma_\gamma$ can be read from the tables.

# STXS for VH - on the experimental side ...

Implementation of the uncertainty scheme first intended to provide a parametrization for the interpretation of STXS results
Not 'meant' to address residual TH uncertainties within the STXS bins

**however**

When bins are merged in a measurement (e.g. not enough sensitivity), we are re-introducing the dependence on the XS(bin1)/XS(bin2) SM prediction with its uncertainty

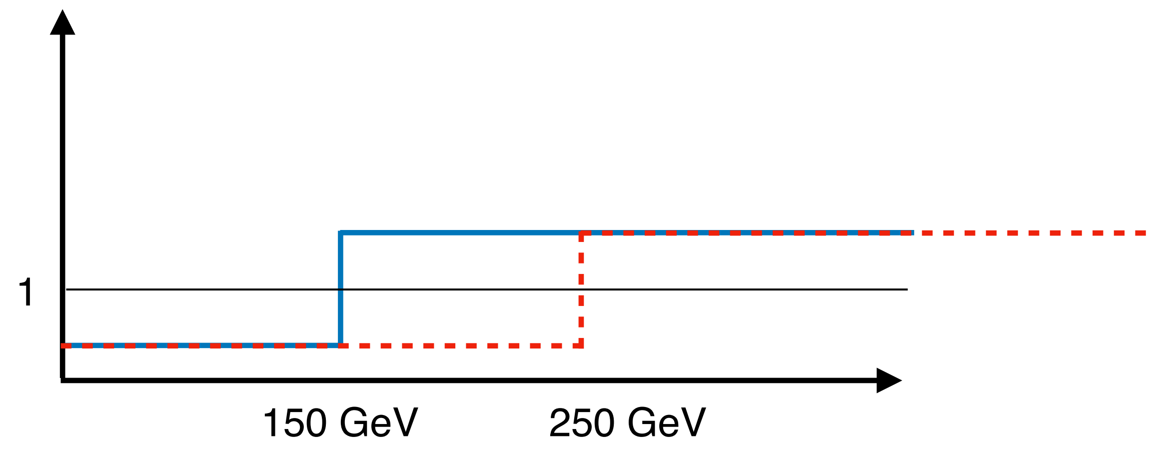
→ *Consistent treatment of uncertainty on the measurement and the interpretation sides is important*

Uncertainty on variables whose shape information is critical in the experimental analyses should be encoded as a continuous shape variation, to facilitate a consistent treatment within the measured bins and across the boundaries

**pTV shape is the critical candidate for VH**
(shape information control the bin-bin migration and enters in the MVA discriminant)

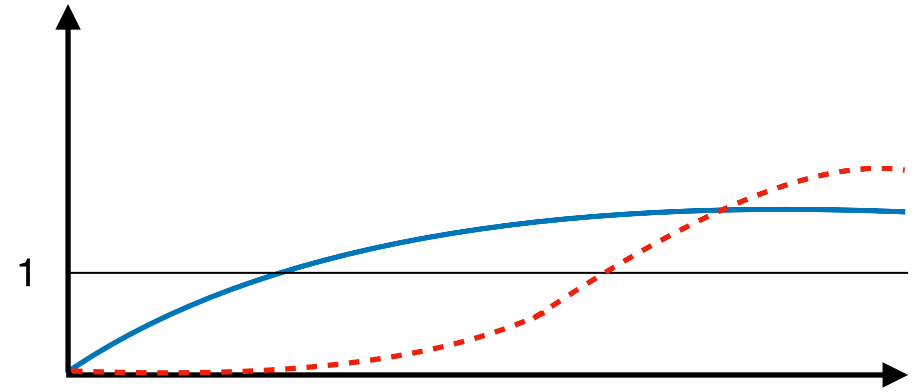
# STXS for VH - on the experimental side ... shapes

- $\theta_{0/150}$ and $\theta_{150/250}$ act effectively like 2 'shape-variations' with inflection point at 150 and 250 GeV and no residual shape in the bins




- $\theta_{0/150}$ and $\theta_{150/250}$ are uncorrelated: these **two** parameters are not intended to encode the shape variations from QCD scale variations across the pTV range (which is probably not clearly defined), but rather the uncertainty induced by the **two** cuts on pTV

- What do we usually intend with 'pTV shape variation' in the experimental analyses?

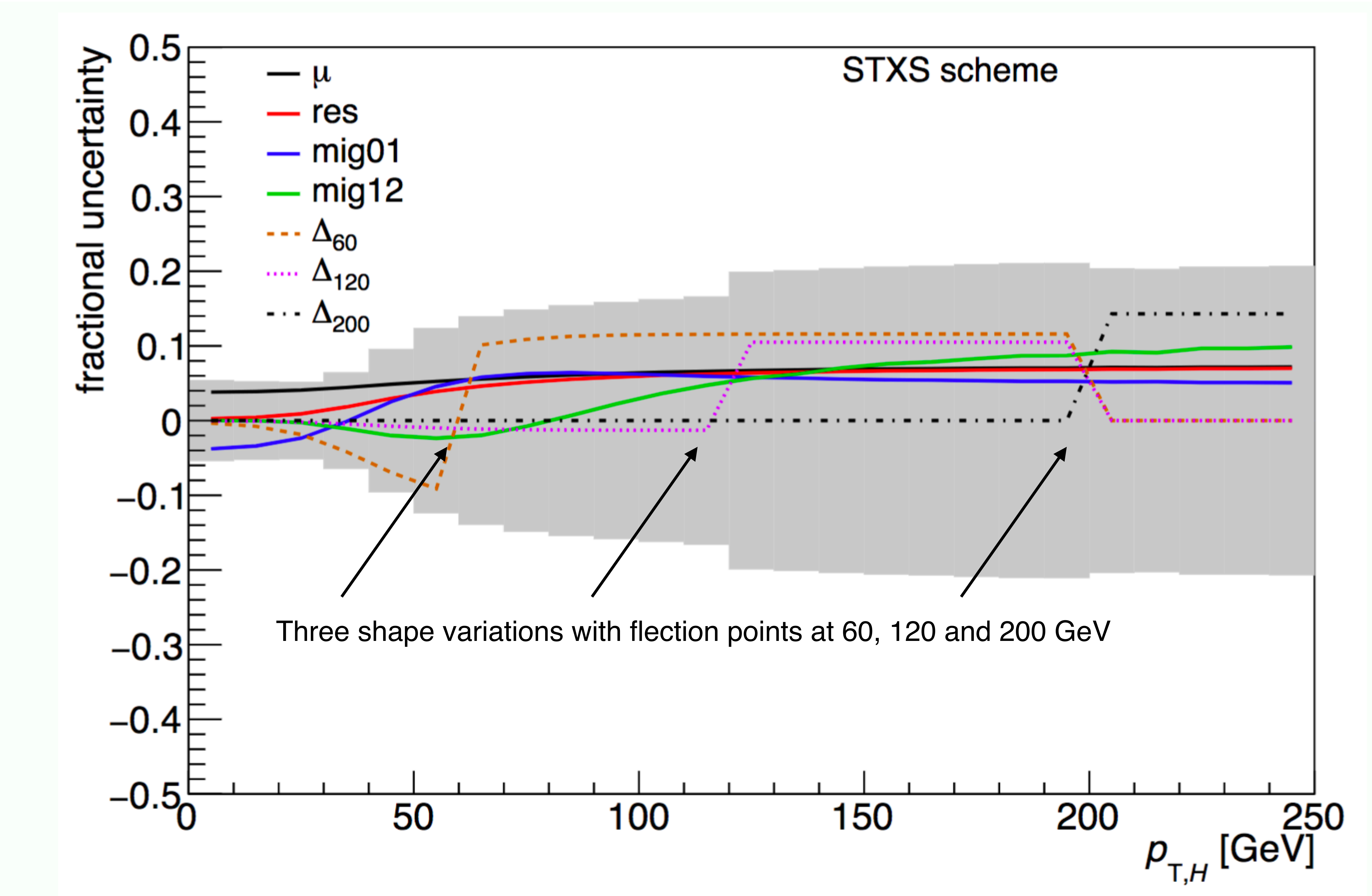



Each of the θ parameter would correspond to a separate shape systematic with different inflection points

- one example of this kind of implementation comes directly from ggH:

# STXS for VH - on the experimental side ...

Shape uncertainties: example from ggH

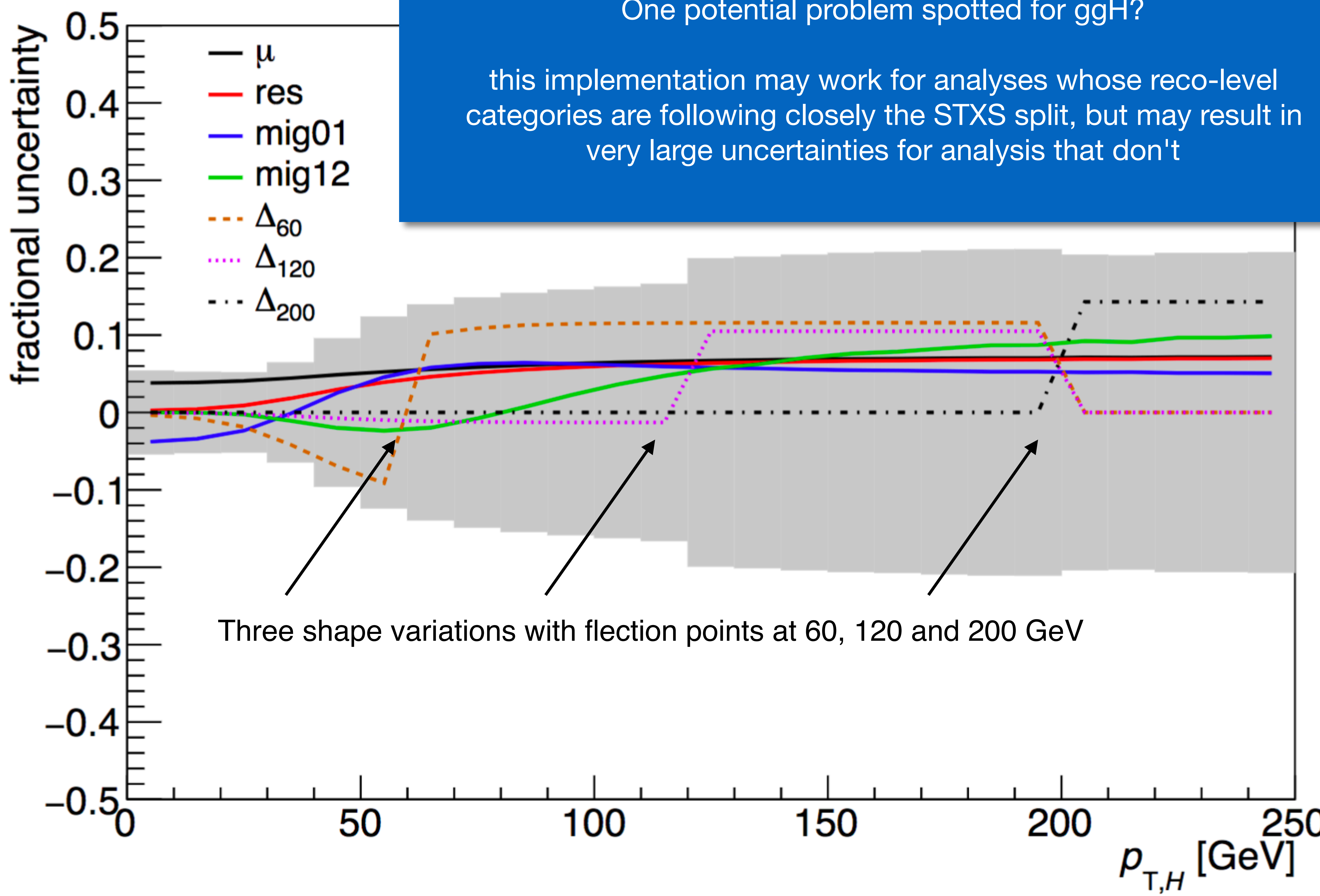


# STXS for VH - on the experimental side ...

Shape uncertainties: example from ggH

One potential problem spotted for ggH?

this implementation may work for analyses whose reco-level categories are following closely the STXS split, but may result in very large uncertainties for analysis that don't



# Conclusions and operative steps

- First step towards STXS: start by available MC samples with QCD scale variations included and work to derive a first 'draft' of the uncertainty table

  this is a first quick step, but can already reveal possible issues to address [help/manpower from exp. groups? potentially not trivial to make plots/numbers public with a quick turnaround, but we should work around this]

- start discussing which tools we want to use for the estimate of all uncertainties:
  - fixed order prediction consistent with YR4? (vh@nnlo)
  - resummed calculation / parton-shower MC?
  - EW uncertainties: how to divide between Sudakow and non-Sudakow effects, how to estimate the uncertainty?
    (can the new POWHEG-BOX-V2 implementation with NLO EW included be helpful?)
  - parton-shower effects ???

- implementation of uncertainties on variables whose shape information is used in the analyses has to be treated with care -- discussion

# BACK-UP

# STXS for VH - uncertainty scheme

Example from Dag's talk for ggF -- full table of uncertainties for ggF categories

- Using ATLAS MC (Powheg NNLOPS) normalized to N3LO @mH = 125.09 GeV

Cross sections and fractional uncertainties

| STXS | sig | stat | mu | res | mig01 | mig12 | pTH | qm_b | qm_top | Tot |
|---|---|---|---|---|---|---|---|---|---|---|
| Incl | 48.52 | +/- 0.00 | +4.6% | +2.2% | +0.0% | -0.0% | -0.1% | -0.2% | +0.0% | +5.1% |
| FWDH | 4.27 | +/- 0.01 | +4.4% | +1.8% | -0.5% | -0.4% | -0.5% | -0.6% | -1.5% | +5.1% |
| VBF1 | 0.27 | +/- 0.00 | +7.9% | +7.9% | +3.9% | +16.2% | -2.5% | -2.4% | +0.1% | +20.3% |
| VBF2 | 0.36 | +/- 0.00 | +7.9% | +7.9% | +3.9% | +16.2% | -0.9% | -1.1% | +0.2% | +20.1% |
| 0J | 27.25 | +/- 0.03 | +3.8% | +0.1% | -4.1% | +0.0% | +0.0% | -0.2% | +0.0% | +5.6% |
| 1J_0-60 | 6.49 | +/- 0.01 | +5.3% | +4.6% | +8.1% | -6.9% | -4.5% | -4.0% | +0.0% | +14.1% |
| 1J_60 | 4.50 | +/- 0.01 | +5.3% | +4.6% | +8.1% | -6.9% | +3.0% | +4.9% | +0.0% | +14.0% |
| 1J_120 | 0.74 | +/- 0.00 | +5.3% | +4.6% | +8.1% | -6.9% | +14.0% | +5.0% | +0.5% | +19.6% |
| 1J_200 | 0.15 | +/- 0.00 | +5.3% | +4.6% | +8.1% | -6.9% | +16.0% | +5.0% | +10.5% | +23.5% |
| 2J_0-60 | 1.22 | +/- 0.01 | +7.9% | +7.9% | +3.9% | +16.2% | -7.4% | -7.2% | +0.0% | +22.5% |
| 2J_60 | 1.86 | +/- 0.01 | +7.9% | +7.9% | +3.9% | +16.2% | -1.0% | -0.1% | +0.0% | +20.0% |
| 2J_120 | 0.99 | +/- 0.00 | +7.9% | +7.9% | +3.9% | +16.2% | +6.8% | +5.0% | +0.6% | +21.7% |
| 2J_200 | 0.42 | +/- 0.00 | +7.9% | +7.9% | +3.9% | +16.2% | +15.5% | +5.0% | +11.8% | +28.3% |
| =0J | 30.12 | +/- 0.03 | +3.8% | +0.1% | -4.1% | +0.0% | +0.0% | -0.2% | -0.2% | +5.6% |
| =1J | 12.92 | +/- 0.02 | +5.3% | +4.6% | +8.1% | -6.9% | -0.3% | +0.0% | +0.2% | +12.7% |
| >=2J | 5.47 | +/- 0.01 | +7.9% | +7.9% | +3.9% | +16.1% | +0.1% | -0.7% | +1.1% | +20.0% |
| >=1J 60-200 | 9.09 | +/- 0.01 | +6.3% | +5.8% | +6.5% | +1.8% | +3.4% | +3.7% | +0.2% | +12.0% |
| >=1J 120-200 | 1.96 | +/- 0.01 | +6.9% | +6.6% | +5.6% | +7.0% | +9.6% | +5.0% | +0.6% | +17.0% |
| >=1J >200 | 0.58 | +/- 0.00 | +7.2% | +7.0% | +5.0% | +10.1% | +15.6% | +5.0% | +11.4% | +25.0% |
| >=1J >60 | 9.68 | +/- 0.01 | +6.3% | +5.9% | +6.4% | +2.3% | +4.2% | +3.8% | +0.8% | +12.4% |
| >=1J >120 | 2.54 | +/- 0.01 | +6.9% | +6.7% | +5.4% | +7.7% | +11.0% | +5.0% | +3.1% | +18.4% |
| >=1 | 18.40 | +/- 0.02 | +6.1% | +5.6% | +6.8% | -0.1% | -0.2% | -0.2% | +0.5% | +10.7% |

The 11 ggF STXS bins

# Notes

[from here]

## Multiple bin boundaries: example.

- 3 mutually exclusive jet bins: $\{\sigma_0, \sigma_1, \sigma_{\geq 2}\}$
- Identify 2 boundaries: $\sigma_{\geq 0} = \sigma_0 + \sigma_{\geq 1}$ and $\sigma_{\geq 1} = \sigma_1 + \sigma_{\geq 2}$
- Nuisance parameters for five observables $\{\sigma_{\geq 0}, \sigma_0, \sigma_{\geq 1}, \sigma_1, \sigma_{\geq 2}\}$

$$\kappa^{\mathrm{y}} : \quad \{\Delta^{\mathrm{y}}_{\geq 0},\ \Delta^{\mathrm{y}}_{0},\ \Delta^{\mathrm{y}}_{\geq 1},\ \Delta^{\mathrm{y}}_{1},\ \Delta^{\mathrm{y}}_{\geq 2}\} \quad \text{with}$$

$$\Delta^{\mathrm{y}}_{\geq 0} = \Delta^{\mathrm{y}}_{0} + \Delta^{\mathrm{y}}_{\geq 1}\,, \qquad \Delta^{\mathrm{y}}_{\geq 1} = \Delta^{\mathrm{y}}_{1} + \Delta^{\mathrm{y}}_{\geq 2}$$

$$\kappa^{0/1}_{\mathrm{cut}} : \quad \Delta^{0/1}_{\mathrm{cut}} \times \{0,\ 1,\ -1,\ -(1 - x_1),\ -x_1\}$$

$$\kappa^{1/2}_{\mathrm{cut}} : \quad \Delta^{1/2}_{\mathrm{cut}} \times \{0,\ x_2,\ -x_2,\ 1 - x_2,\ -1\}$$

  - ★ $x_1$ determines how $\Delta^{0/1}_{\mathrm{cut}}$ is split between $\sigma_1$ and $\sigma_{\geq 2}$
  - ★ $x_2$ determines how $\Delta^{1/2}_{\mathrm{cut}}$ is split between $\sigma_0$ and $\sigma_1$

- Independent of particular theory framework, and maintains interpretation in terms of underlying physical sources
  - ★ Allows to judge correlations between different observables
  - ★ Associate each source with one nuisance parameter

# Notes

**from here**

$$\sigma_{\geq 0} = \sigma_0(p_T^{\text{cut}}) + \sigma_{\geq 1}(p_T^{\text{cut}})$$

$$C(\{\sigma_0, \sigma_{\geq 1}\}) = \begin{pmatrix} (\Delta_0^{\text{y}})^2 & \Delta_0^{\text{y}}\,\Delta_{\geq 1}^{\text{y}} \\ \Delta_0^{\text{y}}\,\Delta_{\geq 1}^{\text{y}} & (\Delta_{\geq 1}^{\text{y}})^2 \end{pmatrix} + \begin{pmatrix} \Delta_{\text{cut}}^2 & -\Delta_{\text{cut}}^2 \\ -\Delta_{\text{cut}}^2 & \Delta_{\text{cut}}^2 \end{pmatrix}$$

$$\kappa^{\text{y}} : \quad \{\Delta_{\geq 0}^{\text{y}},\, \Delta_0^{\text{y}},\, \Delta_{\geq 1}^{\text{y}}\} \qquad\qquad \kappa_{\text{cut}} : \quad \{0,\, \Delta_{\text{cut}},\, -\Delta_{\text{cut}}\}\,,$$

FO-ST

$$\Delta_0^{\text{y}} = \Delta_{\geq 0}^{\text{y}} = \Delta_{\geq 0}^{\text{FO}}\,, \quad \Delta_{\geq 1}^{\text{y}} = 0\,, \qquad\qquad \Delta_{\text{cut}} = \Delta_{\geq 1}^{\text{FO}}$$

- Migration uncertainty is approximated by perturbative uncertainty of $\sigma_{\geq 1}(p_T^{\text{cut}})$, motivated by structure of perturbative series
- Perturbative uncertainties in $\sigma_{\geq 0}$ and $\sigma_{\geq 1}$ treated as independent sources

# Notes

XStot = XS(0,150) + XS(150,250) + XS(250,inf)

{XStot; XS(0,150); XS(150,inf); XS(150,250); XS(250,inf)} --> 5 observables

Example:

f(0,150) = XS(0,150) / XStot = 0.8
f(150,250) = XS(150,250) / XStot = 0.13
f(250,inf) = XS(250,inf) / XStot = 0.07
XStot = 1.0

Percentage uncertainty bin-by-bin (relative to the bin itself)
ΔY(0,150) [%] = 5% (5% of 0.8 --> 0.04)
ΔY(150,250) [%] = 10% (10% of 0.13 --> 0.013)
ΔY(250,inf) [%] = 15% (15% of 0.07 --> 0.0105)

ΔYtot [%] = 6.35% (6.35% of 1.0 --> 0.0635)
ΔY(150,inf) [%] = 11.75% (11.75% of 0.2 --> 0.0235)

# VH Signal Model @ 13TeV

| $m_H$ = 125 GeV at $\sqrt{s}$ = 13TeV | | | | |
|---|---|---|---|---|
| Process | Cross section × BR [fb] | Acceptance [%] | | |
| | | 0-lepton | 1-lepton | 2-lepton |
| $q\bar{q} \to (Z \to \ell\ell)(H \to b\bar{b})$ | 29.9 | < 0.1 | < 0.1 | 7.0 |
| $gg \to (Z \to \ell\ell)(H \to b\bar{b})$ | 4.8 | < 0.1 | < 0.1 | 15.7 |
| $q\bar{q} \to (W \to \ell\nu)(H \to b\bar{b})$ | 269.0 | 0.2 | 1.0 | – |
| $q\bar{q} \to (Z \to \nu\nu)(H \to b\bar{b})$ | 89.1 | 1.9 | – | – |
| $gg \to (Z \to \nu\nu)(H \to b\bar{b})$ | 14.3 | 3.5 | – | – |

Table 8: Summary of the systematic uncertainties in the signal modelling. "PS/UE" indicates parton shower / underlying event. An "S" symbol is used when only a shape uncertainty is assessed.

| Signal | |
|---|---|
| Cross-section (scale) | 0.7% ($qq$), 27% ($gg$) |
| Cross-section (PDF) | 1.9% ($qq \to WH$), 1.6% ($qq \to ZH$), 5% ($gg$) |
| Branching ratio | 1.7 % |
| Acceptance from scale variations (var.) | 2.5% – 8.8% (Stewart-Tackmann jet binning method) |
| Acceptance from PS/UE var. for 2 or more jets | 10.0% – 13.9% (depending on lepton channel) |
| Acceptance from PS/UE var. for 3 jets | 12.9%–13.4% (depending on lepton channel) |
| Acceptance from PDF+$\alpha_s$ var. | 0.5%–1.3% |
| $m_{bb}$, $p_T^V$, from scale var. | S |
| $m_{bb}$, $p_T^V$, from PS/UE var. | S |
| $m_{bb}$, $p_T^V$, from PDF+$\alpha_s$ var. | S |
| $p_T^V$ from NLO EW correction | S |

# Talking points with VH(bb) CMS analysis

## CMS

| | Source | Type | Individual contribution to the $\mu$ uncertainty (%) | Effect of removal to the $\mu$ uncertainty (%) |
|---|---|---|---|---|
| 1 | Scale factors ($t\bar{t}$, V+jets) | norm. | 9.4 | 3.5 |
| 2 | Size of simulated samples | shape | 8.1 | 3.1 |
| 3 | Simulated samples' modeling | shape | 4.1 | 2.9 |
| | b tagging efficiency | shape | 7.9 | 1.8 |
| | Jet energy scale | shape | 4.2 | 1.8 |
| 5 | Signal cross sections | norm. | 5.3 | 1.1 |
| | Cross section uncertainties (single-top, VV) | norm. | 4.7 | 1.1 |
| 4 | Jet energy resolution | shape | 5.6 | 0.9 |
| | b tagging mistag rate | shape | 4.6 | 0.9 |
| | Integrated luminosity | norm. | 2.2 | 0.9 |
| | Unclustered energy | shape | 1.3 | 0.2 |
| | Lepton efficiency and trigger | norm. | 1.9 | 0.1 |

**CMS** $1.19^{+0.21}_{-0.20}(stat)^{+0.34}_{-0.32}(syst)$

**ATLAS** $1.20^{+0.24}_{-0.23}(stat)^{+0.34}_{-0.28}(syst)$

## ATLAS

| | Source of uncertainty | | $\sigma_\mu$ |
|---|---|---|---|
| | Total | | 0.39 |
| | Statistical | | 0.24 |
| | Systematic | | 0.31 |
| | **Experimental uncertainties** | | |
| | Jets | | 0.03 |
| | $E_T^{miss}$ | | 0.03 |
| | Leptons | | 0.01 |
| 4 | $b$-tagging | $b$-jets | 0.09 |
| | | $c$-jets | 0.04 |
| | | light jets | 0.04 |
| | | extrapolation | 0.01 |
| | Pile-up | | 0.01 |
| | Luminosity | | 0.04 |
| | **Theoretical and modelling uncertainties** | | |
| 1 | Signal | | 0.17 |
| | Floating normalisations | | 0.07 |
| 3 | $Z$ + jets | | 0.07 |
| 3 | $W$ + jets | | 0.07 |
| 3 | $t\bar{t}$ | | 0.07 |
| 3 | Single top quark | | 0.08 |
| | Diboson | | 0.02 |
| | Multijet | | 0.02 |
| 2 | MC statistical | | 0.13 |

Signal-uncertainties: as part of the effort on STXS, can we harmonise their treatment? (interesting towards combination)

**Smoking gun: parton-shower uncertainties**

Backgrounds: as part of the V+hf modeling studies, better definition of systematic handles from theoretical modeling of these processes

(Participation from the VH(bb) experts is critical here)

# CMS Stage-0 STXS

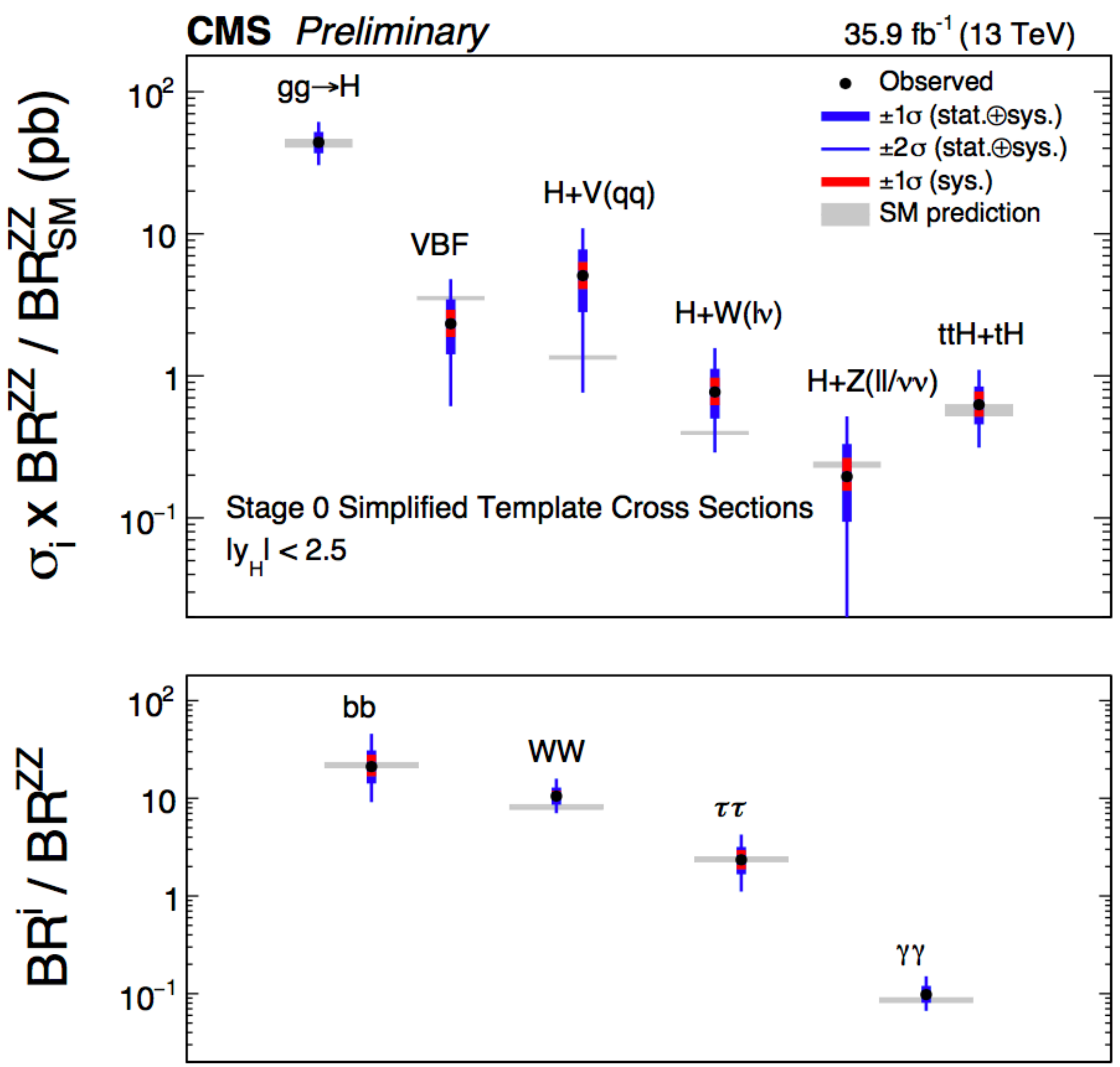



Figure 8: Summary of the stage 0 model, ratios of cross sections and branching ratios. The points indicate the best-fit values while the error bars show the $\pm1\sigma$ and $\pm2\sigma$ uncertainties. Also shown are the $\pm1\sigma$ uncertainties on the measurements considering only the contributions from the systematic uncertainties. Also shown are the uncertainties on the SM predictions.

# Simplified Template Cross Sections - VH

**STXS: separating measurements from interpretations**

- maximize measurements sensitivity
- minimize theory dependence (models&systematics)

- combine **all decay channels**
- measure **XS instead of signal strengths**
- measure XS separately for **production modes**
- measure XS in **simplified fiducial volumes**
- allow for advanced analysis techniques (**MVAs**)

**Exclusive phase space regions ("bins") defined to**

- maximize experimental sensitivity
- minimize dependence on theory uncertainties directly folded into the measurements
- provide sensitivity to BSM scenarios

$$\sigma^{meas} = A^{ggH} \times \mu_{ggH} \times \sigma_{ggH}^{SM} + A^{VBF} \times \mu_{VBF} \times \sigma_{VBF}^{SM}$$
$$= A^{ggH} \times \sigma_{ggH} + A^{VBF} \times \sigma_{VBF}$$

$A^{ggH}$, $A^{VBF}$ Signal acceptance theory dependent

↓

$$\sigma^{meas} = A_a^{ggH} \times \sigma^a{}_{ggH}^{SM} + A_b^{ggH} \times \sigma^b{}_{ggH}^{SM} + A_c^{VBF} \times \sigma^c{}_{VBF}^{SM}$$

a,b,c = "bins" of STXS

$A_i^{ggH}$, $A_i^{VBF}$ Signal acceptance dependent on SM signal kinematic only within the given bin "i" [reduce theory dependence]

# gg→ZH (loop-induced) MC modeling