

Simplified Template Cross Sections for VH

Frank Tackmann

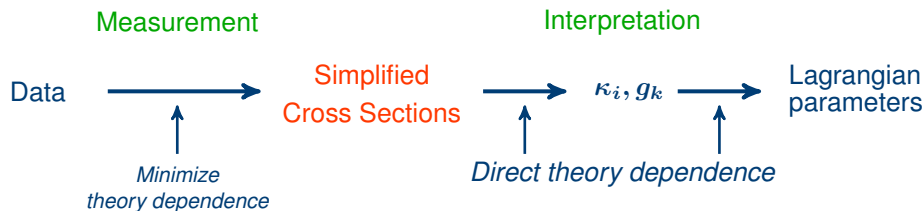
Deutsches Elektronen-Synchrotron

WG1 VH subgroup meeting
June 29, 2017

Reporting on recent discussions at Les Houches
and in fid/STXS subgroup



Separating Measurement from Interpretation.



Goals

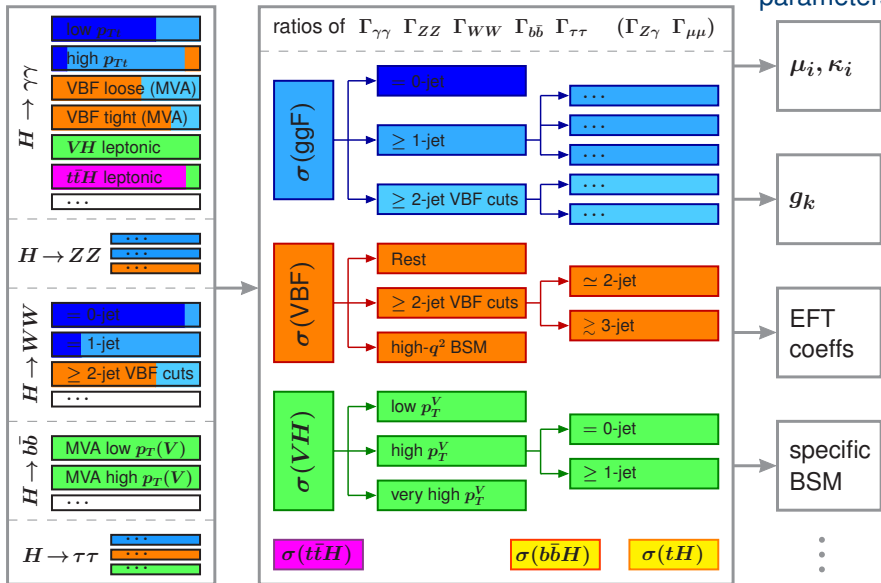
- Minimize dependence on theory systematics in measurements
 - ▶ Clearer and systematically improvable treatment at interpretation level (acceptance corrections, extrapolations to total xsec, ...)
- Minimize model dependence in measurements
 - ▶ Decouples measurements from discussions about specific models (SM, linear/nonlinear EFT, BSM models, ...)
- Measurements stay long-term useful
- Allows easy (re)interpretation with different theory inputs/assumptions
 - ▶ Improved theory predictions/uncertainties
 - ▶ μ_i, κ_i , anomalous couplings, EFT coefficients, specific BSM scenarios

Simplified Template Cross Section Framework.

Analysis categories

Simplified Template Cross Sections

Lagrangian parameters



Defining Features.

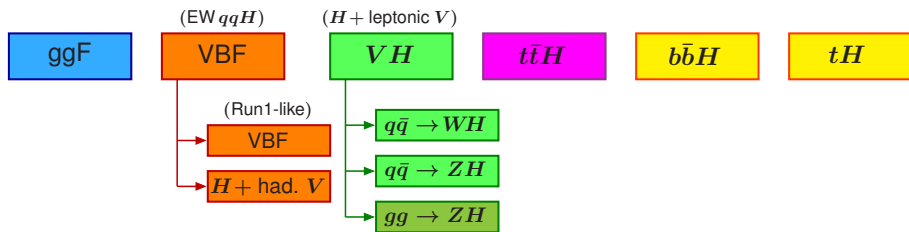
- Measure cross sections but separated into production modes
 - ▶ Allows different efficiencies/acceptances for different production modes without incurring dependence on SM production mode mix
 - ▶ SM processes act as kinematic templates
 - ▶ Future: Can add more kinematic templates (e.g. CP-odd Higgs)
- Non-Higgs backgrounds are subtracted
 - ▶ Future: Can add templates for BSM sensitive backgrounds (e.g. $pp \rightarrow WW$)
- Inclusive over the Higgs decays
 - ▶ Can perform a global combination of channels
- “Simplified” bin definitions abstracted from the actual measurement categories
 - ▶ Allow some acceptance corrections,
 - ▶ Analyses can use optimized selections at reconstruction level, MVAs ...
 - ▶ Avoid extrapolations that are unnecessary or nontrivial (i.e. theory sensitive)

⇒ Maximize sensitivity while reducing theory dependence

Define different “stages” for each production mode

- Each analysis implements the binning according to the appropriate stage
- Evolution of different production modes can take place independently
- Bin definitions can evolve with statistics
 - ▶ Individual analyses can quote sum of bins while sensitivity is still limited
 - ▶ In BSM “overflow” bins even limits are very interesting
 - ▶ Can split into more fine-grained bins as required and allowed by statistics (previous determinations remain useful)
- Stage 0: closest correspondence to Run1
- Stage 1
 - ▶ All “minimally hoped-for” splits
 - ▶ Intermediate steps to get there indicated by “(+)” for possible bin merging
 - ▶ Early measurements will show if adjustments are needed (will not make any changes unless serious problems arise)
- Stage 2: to be defined (after gaining more real-life experience)

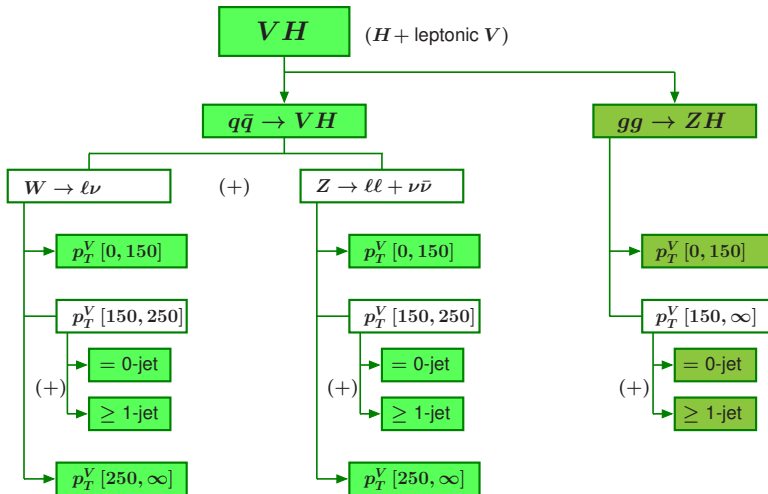
Stage 0.



Template processes are defined for a stable Higgs but decayed V

- “VH” is defined as $pp \rightarrow V(\rightarrow \text{leptons})H$, split into
 - ▶ $q\bar{q} \rightarrow W(\rightarrow \ell\nu)H$
 - ▶ $q\bar{q} \rightarrow Z(\rightarrow \ell\bar{\ell}, \nu\bar{\nu})H$
 - ▶ $gg \rightarrow Z(\rightarrow \ell\bar{\ell}, \nu\bar{\nu})H$
- $q\bar{q} \rightarrow V(\rightarrow qq)H$ is part of “VBF” (EW qqH production)
 - ▶ Targeted via dedicated “VBF” bin with $V(\rightarrow jj)H$ topology cuts
- $gg \rightarrow Z(\rightarrow q\bar{q})H$ is part of “ggF”
 - ▶ Effectively considered a (real-emission) EW correction to ggF
 - ▶ Currently no experimental sensitivity, swamped by ggF+2jets
 - ▶ In the future could split out of ggF bin with $V(\rightarrow jj)H$ topology cuts

VH – Stage 1.



- Binning in p_T^V aligned with $H \rightarrow b\bar{b}$ (which is main contributor)

Theory Uncertainties.

Two aspects to theory uncertainties

- Residual theoretical uncertainties related to “unfolding” experimental event categories to STXS bins
- Uncertainties in interpretation of STXS bins, i.e. in SM (or beyond) cross section predictions for each bin
 - ▶ Also enter as “residual” uncertainties in measurement whenever bins with different sensitivities are merged

Implementation of uncertainties (in measurement or interpretation)

- Requires uncertainties per bin and their correlations
 - ▶ Particularly important when binning cut itself introduces a source of uncertainty that affects each bin but cancels in their sum
 - ▶ Experimental implementation in terms of $\pm 100\%$ correlated or uncorrelated nuisance parameters
- Need to identify and distinguish different sources of uncertainties and evaluate also their correlations between kinematic bins
 - ▶ Use generic parametrization of uncertainties in kinematic bins as discussed in YR4 Section 1.4.2a

Uncertainties With Multiple Bin Boundaries.

- Each bin can have multiple boundaries, and each boundary can be shared by different bins
- Consider given bin boundary when all additional subdivisions are removed and parametrize in terms of independent yield and migration uncertainties
- Consider binning cut “a/b” with $\sigma_{ab} = \sigma_a + \sigma_b$ and associated $\Delta_{a/b}$ (anticorrelated between σ_a and σ_b)
 - ▶ Allow for additional subbins such that $\sigma_a = \sum_i \sigma_a^i$ and $\sigma_b = \sum_j \sigma_b^j$
 - ▶ Consider binning uncertainty as fully correlated among subbins and implement with a single nuisance parameter

$$\theta_{a/b} : \Delta_{a/b} \times \{\{x_a^i\}, -\{x_b^j\}\} \quad \text{with} \quad \sum_i x_a^i = \sum_j x_b^j = 1$$

where x_a^i and x_b^j specify how $\Delta_{a/b}$ gets distributed among the subbins

- Consider each binning cut/bin boundary as potential uncertainty source
 - ▶ Migration uncertainty between σ_a and σ_b , and yield uncertainty inside each
 - ▶ Limiting case: Global yield uncertainty for total xsec

Parametrization of VH Uncertainties: Sources.

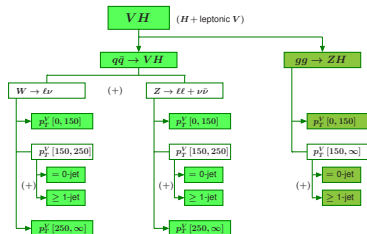
QCD uncertainties

- $\Delta_\mu, \Delta_{150}, \Delta_{250}$
 - ▶ Option 1: overall yield uncertainty plus two p_T^V binning (shape) uncertainties
 - ▶ Option 2: one uncorrelated uncertainty for each p_T^V bin
- $\Delta_{0/1}$: jet bin migration uncertainty
- Same nuisance parameter for W and Z (i.e. 100% correlated)

EW uncertainties

- Δ_{Sud} : EW Sudakov effects (correlated between W and Z)
- $\Delta_W, \Delta_Z, \Delta_\gamma$
 - ▶ Separate uncertainties for non-Sudakov contributions

- Separate sources (uncorrelated uncertainties) for $q\bar{q} \rightarrow VH$ and $gg \rightarrow ZH$
 - ▶ Study which sources for $gg \rightarrow ZH$ should be correlated with $gg \rightarrow H$
- Some of this also impact “VBF” bins through its hadronic VH contribution



Parametrization of VH Uncertainties.

Bin	QCD uncertainties (Option 1)				EW uncertainties			
	Δ_μ	Δ_{150}	Δ_{250}	$\Delta_{0/1}$	Δ_{Sud}	Δ_W	Δ_Z	Δ_γ
$W [0,150]$	x_1	$-c$	0		y_1	*		*
$W [150,250]$	x_2	$+c$	$+d$		y_2	*		*
$=0j [150,250]$	$x_2 z$	$+cz$	$+dz$	$+1$	\dots	*		*
$\geq 1j [150,250]$	$x_2(1-z)$	$+c(1-z)$	$+d(1-z)$	-1	\dots	*		*
$W [250,\infty]$	x_3	0	$-d$		y_3	*		*
$Z [0,150]$	x_1	$-c$	0		y_1		*	
$Z [150,250]$	x_2	$+c$	$+d$		y_2		*	
$=0j [150,250]$	$x_2 z$	$+cz$	$+dz$	$+1$	\dots		*	
$\geq 1j [150,250]$	$x_2(1-z)$	$+c(1-z)$	$+d(1-z)$	-1	\dots		*	
$Z [250,\infty]$	x_3	0	$-d$		y_3		*	

+ Analogous uncorrelated sources for $gg \rightarrow ZH$

We need a consistent/common/coherent treatment of theory uncertainties across kinematic regions and across production modes

- Same approach also followed for ggF bins (already agreed upon) and for VBF bins (to be discussed)
- This is a first “not-so-minimal” proposal, which we think should work
- We appreciate your feedback, in particular
 - ▶ Any objections? Anything missing?
 - ▶ Is this sufficiently general for the EW corrections?
- We (STXS) would like to agree with you (VH) on one parametrization
 - ▶ One goal is for us to be able to easily switch between different predictions
 - ▶ We will then at some point ask you for the numbers to fill the table
- We have a STXS subgroup meeting on July 6, 2pm ([Indico link](#)) where we will further discuss this (for both VH and VBF)
 - ▶ Please join if you're interested

Backup Slides

Fiducial vs. Simplified Template Cross Sections.

Fiducial: Optimized for maximal theory independence

- Minimize acceptance corrections
- Simple (rectangular) signal cuts
- “Exact” fiducial volume
- Fiducial in Higgs decay
- Targeted object definitions

Agnostic to production modes

(Single-)differential distributions
(overlapping events)

Only $H \rightarrow \gamma\gamma, ZZ, (WW)$
(by default no combination of channels)

Simplified: Maximize sensitivity while reducing theory dependence

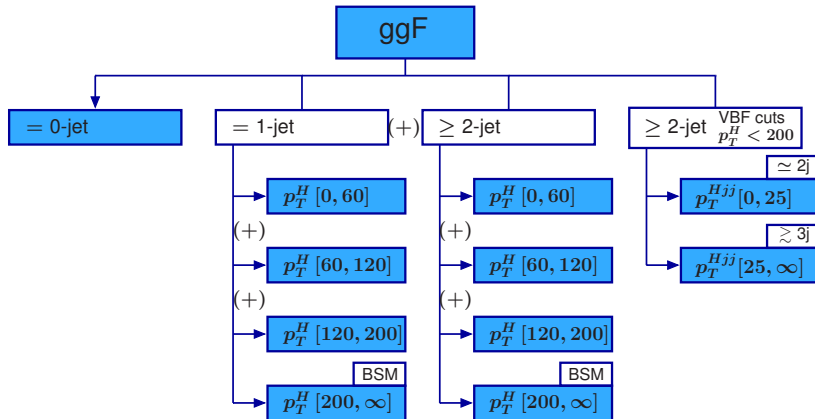
- Allow larger acceptance corrections
- Allow event categories, MVAs, ...
- Abstracted/simplified fiducial volumes
- Inclusive in Higgs decay
- Common idealized object definitions

Xsec split by production mode

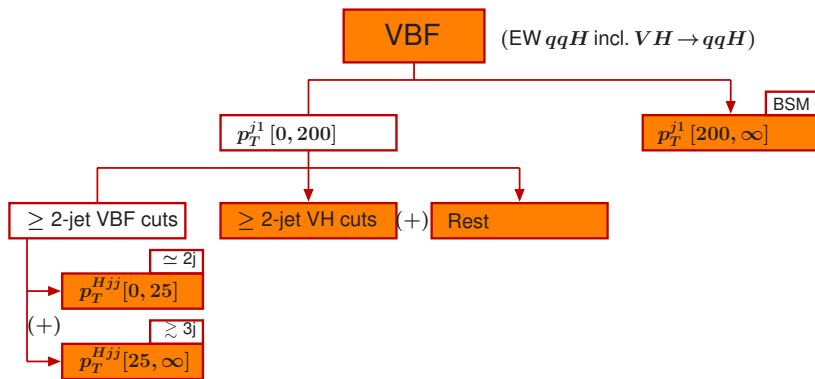
Xsec split into mutually exclusive regions of phase space

Explicitly designed for combination of all decay channels

Gluon Fusion – Stage 1.

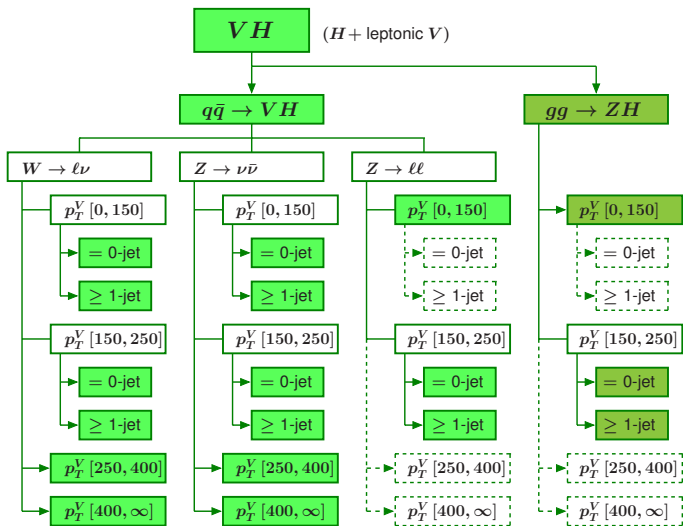


- Jet bins motivated by experimental analyses
- High p_T^H bins target boosted categories ($\tau\tau$) and BSM overflow
- VBF-like cuts to constrain ggF contribution in VBF categories



- VBF defined as electroweak $qq'H$ production
 - ▶ including usual VBF process and VH with hadronic V decays
- First split by p_T^{j1}
 - ▶ VBF topology cuts: $m_{jj} > 400 \text{ GeV}$ and $\Delta\eta_{jj} > 2.8$ (no other cuts)
 - ▶ $V(\rightarrow jj)H$ topology cuts: $60 \text{ GeV} < m_{jj} < 120 \text{ GeV}$
 - ▶ Rest: Everything not passing above (including events with < 2 jets)

VH – Stage 2.



Possible options for stage 2

- Separate Z decays, further split high p_T^V