Simplified Cross Section Framework

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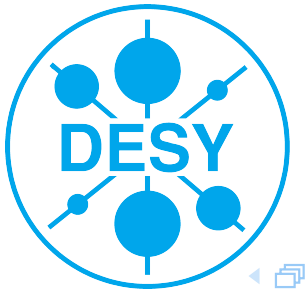
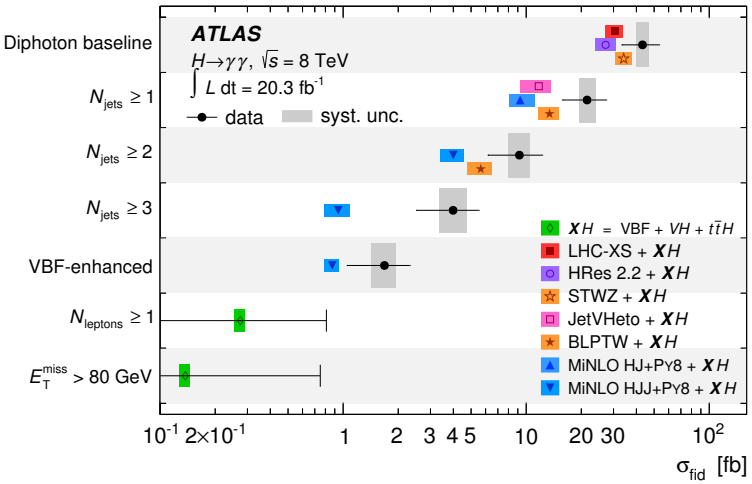
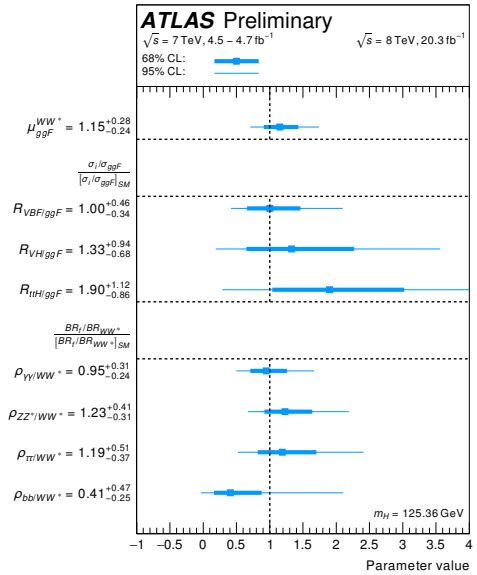
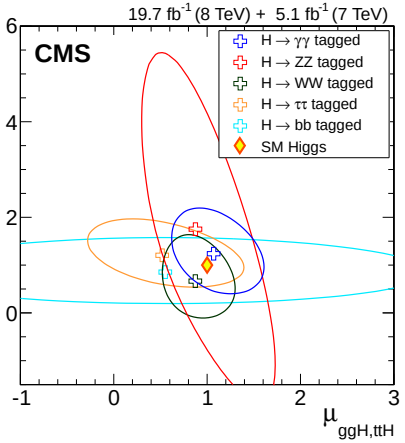
Les Houches + WG2 discussions



Measurement vs. Interpretation.







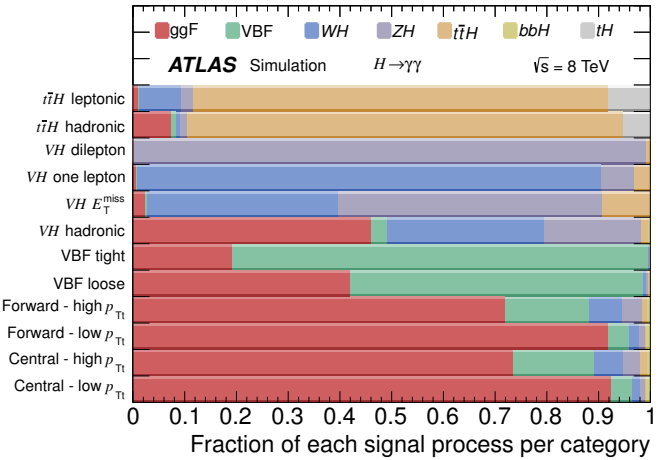
Measurement — Interpretation

theory-independent — *theory-dependent*

“Theory dependence” includes 2 aspects

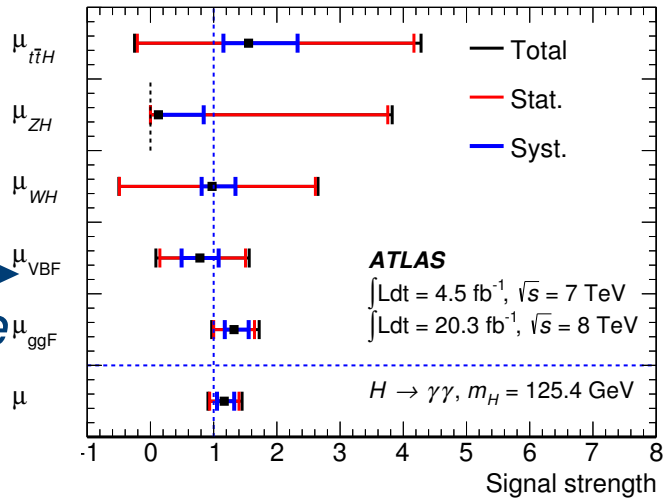
- Dependence on underlying physics model:
  - Assume/test a specific model (Lagrangian)
  - Dependence on kinematic distributions
- Dependence on theory systematics/uncertainties
  - In theory predictions that are needed to extrapolate to total cross sections
  - Perturbative and parametric (PDFs, α_s, ...)

μ Fits.



Raw measurements

Direct theory dependence



Interpretation

Pros

- Maximum possible experimental sensitivity
- Allows use of advanced techniques like MVAs
- Can benefit from kinematic correlations among production modes across channels in combination

Cons

- Theory predictions and *uncertainties* maximally entangled in results
- Any nontrivial theory changes require new results from experiments

Fiducial and Differential Cross Sections.

Pros

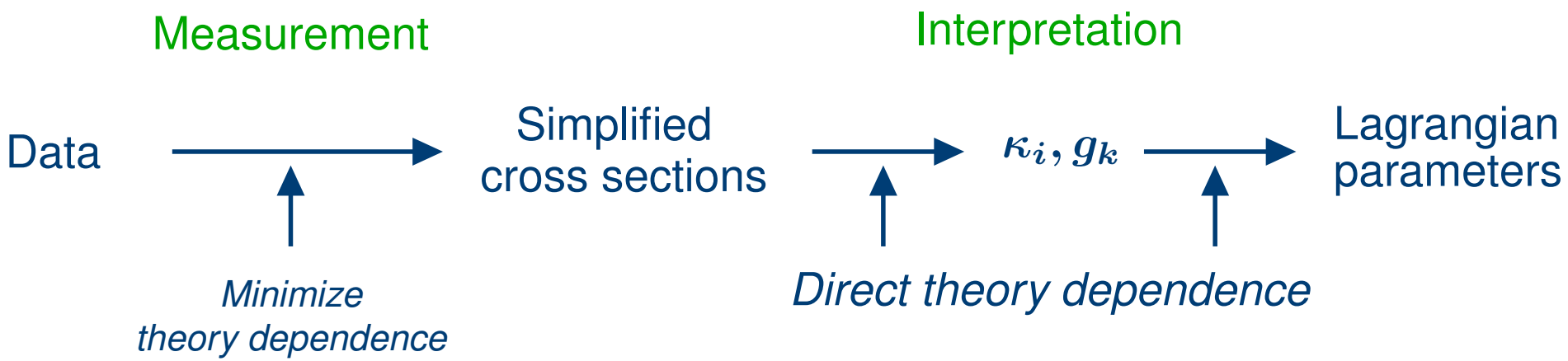
- Allows maximally theory-independent measurements
- Experimental results remain long-term useful

$\Rightarrow$ ... which are the ultimate goals if you like

Cons: Inevitably loose some sensitivity

- (Currently) only possible for cleanest channels: $H \to \gamma\gamma, ZZ$
- Requires signal definitions such that experimental efficiencies are (close to) production-mode independent
  - E.g. $H \to \gamma\gamma$ isolation included in signal definition, since isolation efficiency very different for $t\bar{t}H$
  - Cannot use MVAs for signal selection
  - Sometimes simply not possible
- Projection onto several 1D spectra looses information compared to fully-differential level

Split In the Middle.



Ultimate Goals: Interface to split "Measurement" from "Interpretations"

- Minimize theory systematics in measurements
  - Clearer and systematically improvable treatment at interpretation level
- Measurements stay long-term useful
- Decouples measurements from discussions about specific models
- Allows for interpretation with different model assumptions/BSM scenarios
  - μ_i, κ_i, effective couplings, EFT coefficients, specific models

Definition of Simplified Cross Sections.

Consider current μ fits:

$$\begin{aligned}
\sigma_1^{\text{meas}} &= A_1^{ggH} \times \underbrace{\mu_{ggH} \times \sigma_{ggH}^{\text{SM}}}_{\sigma_{ggH}} + A_1^{\text{VBF}} \times \underbrace{\mu_{\text{VBF}} \times \sigma_{\text{VBF}}^{\text{SM}}}_{\sigma_{\text{VBF}}} \\
&= A_1^{ggH} \times \sigma_{ggH} + A_1^{\text{VBF}} \times \sigma_{\text{VBF}} \\
\sigma_2^{\text{meas}} &= A_2^{ggH} \times \underbrace{\mu_{ggH} \times \sigma_{ggH}^{\text{SM}}}_{\sigma_{ggH}} + A_2^{\text{VBF}} \times \underbrace{\mu_{\text{VBF}} \times \sigma_{\text{VBF}}^{\text{SM}}}_{\sigma_{\text{VBF}}} \\
&= A_2^{ggH} \times \sigma_{ggH} + A_2^{\text{VBF}} \times \sigma_{\text{VBF}} \\
\sigma_3^{\text{meas}} &= \cdots
\end{aligned}$$

- σ_i^{meas} are the measured analysis categories/selections
- Fit for σ_{ggH}, σ_{VBF}
  - In the SM: Correspond to total ggH and VBF production cross sections
- A_i^{ggH}, A_i^{VBF} are acceptances for SM processes
  - theory-dependent inputs

Definition of Simplified Cross Sections.

Split each production mode into several kinematic bins a, b, c, ...

$$\sigma_1^{\text{meas}} = A_{1a}^{ggH} \times \sigma_{ggH}^{a} + A_{1b}^{ggH} \times \sigma_{ggH}^{b} + A_{1c}^{\text{VBF}} \sigma_{\text{VBF c}}^{c} + \cdots$$

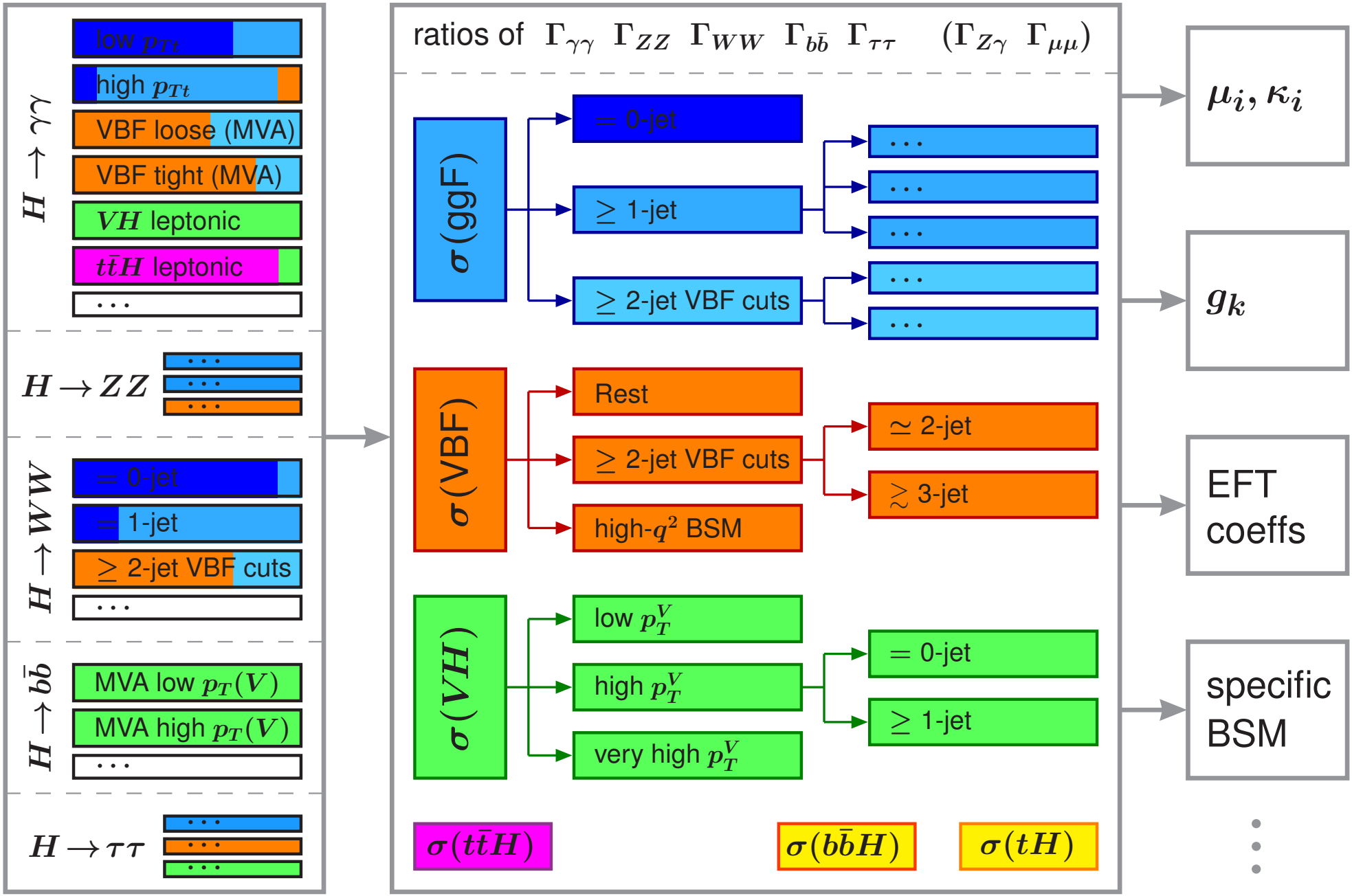
$$\sigma_2^{\text{meas}} = A_{2a}^{ggH} \times \sigma_{ggH}^{a} + A_{2b}^{ggH} \times \sigma_{ggH}^{b} + A_{2c}^{\text{VBF}} \sigma_{\text{VBF c}}^{c} + \cdots$$

$$\sigma_3^{\text{meas}} = \cdots$$

- σ_i^{meas} are still the measured analysis categories/selections
- Separately fit for cross sections in each bin σ_{ggH}^{a}, σ_{ggH}^{b}, σ_{VBF}^{c}, ...
- A_{ij}^{ggH}, A_{ij}^{VBF} only depend on SM kinematics *inside* a given bin
  - If this becomes a problem, split the bin
  - SM processes act as kinematic templates (SM acts as “simplified model”)
  - If necessary, can add more kinematic templates (e.g. CP-odd Higgs)

$\Rightarrow$ Direct extension of existing framework that can be implemented by experiments straightforwardly on top of existing MC samples

Simplified Cross Section Framework.



Trying to Get the Best of Both Worlds.

More differential/fine-grained compared to current μ fits

- Further split production modes into kinematic bins
- Fit for cross sections instead of μ_i

Simplified compared to full-fledged fiducial cross sections

- Non-Higgs backgrounds are subtracted
- Inclusive over the Higgs decays
  - Can perform global combination of channels
- Bin definitions are *per production mode* and simplified/abstracted from the actual measurement categories
  - Analyses can use optimized selections at reconstruction/analysis level
  - Can still use MVAs
  - Different production modes can have different efficiencies/acceptances *without* incurring dependence on SM production mode mix

$\Rightarrow$ Maximize sensitivity while reducing theory dependence

Basic Design Principles.

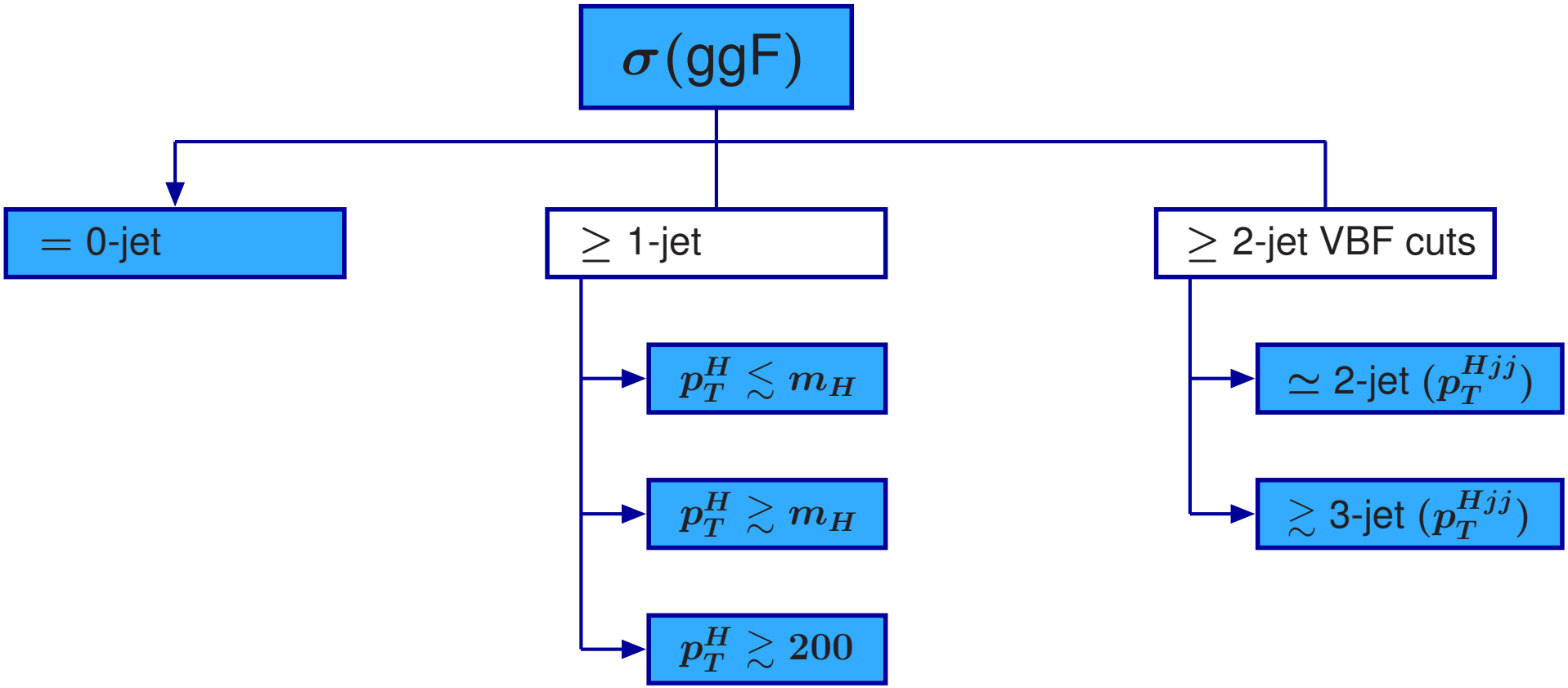
- Identify phase-space regions that are most important to separate out from the theory side
  - Where are largest theory systematics (e.g. ggF 0jet bin)
  - BSM sensitivity/interpretation
- Try to minimize residual theory dependence
  - Try to align cuts with experimental categories to reduce extrapolations (e.g. reason to use p_T^V instead of $m(VH)$)
  - Still have to keep MVAs in check to avoid uncontrolled theory systematics
- Some of the observables might also be
  - Asymmetries
  - Continuous parameters for kinematic deviations (e.g. CP odd admixture)
- 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)

Current Proposal for Bin Definitions.

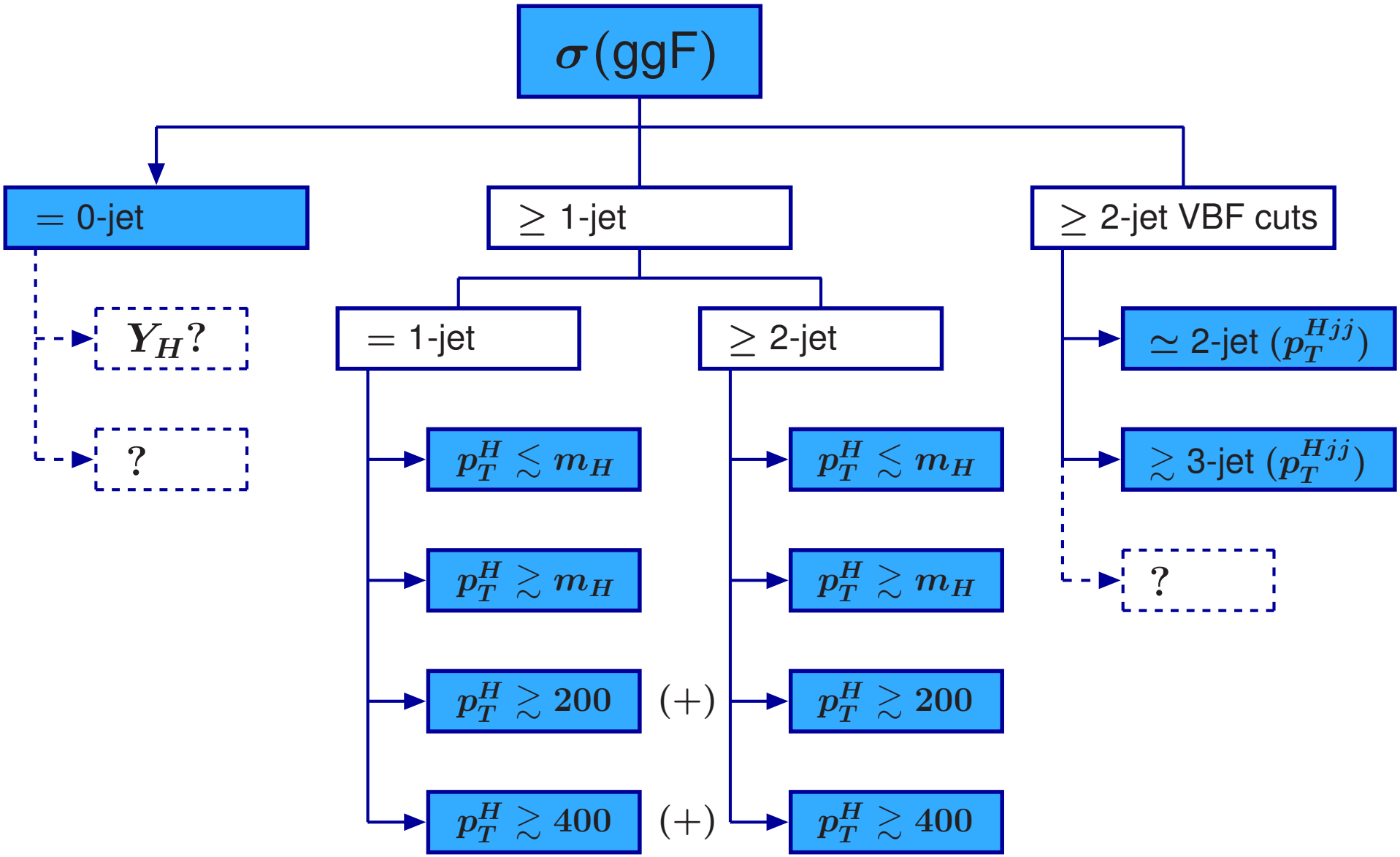
Outcome of Les Houches and follow-up discussions

- Tries to balance minimal requirements for theory uncertainties and BSM sensitivity with experimental feasibility
- Define two scenarios
  - “Small” : $\sim$ current statistics
  - “Medium”: medium-term, somewhere between now and 300/fb
- Specific details are not fixed
  - Feedback and ideas are very welcome
- Bins on each branch are defined to be mutually exclusive and to sum up to parent bin

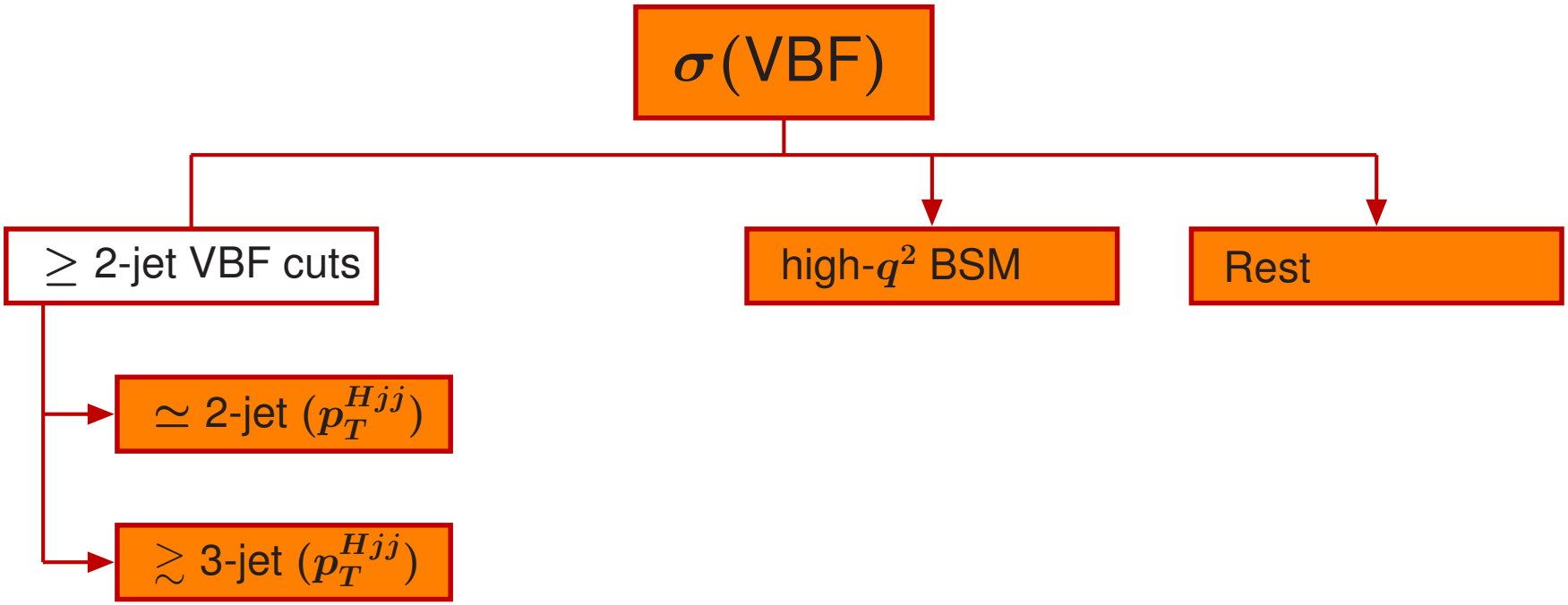
$gg \to H$: Small.


σ(ggF)
$= 0$-jet
≥ 1-jet
$\geq$ 2-jet VBF cuts
$p_T^H \lesssim m_H$
$p_T^H \gtrsim m_H$
$p_T^H \gtrsim 200$
$\simeq$ 2-jet (p_T^{Hjj})
$\gtrsim$ 3-jet (p_T^{Hjj})

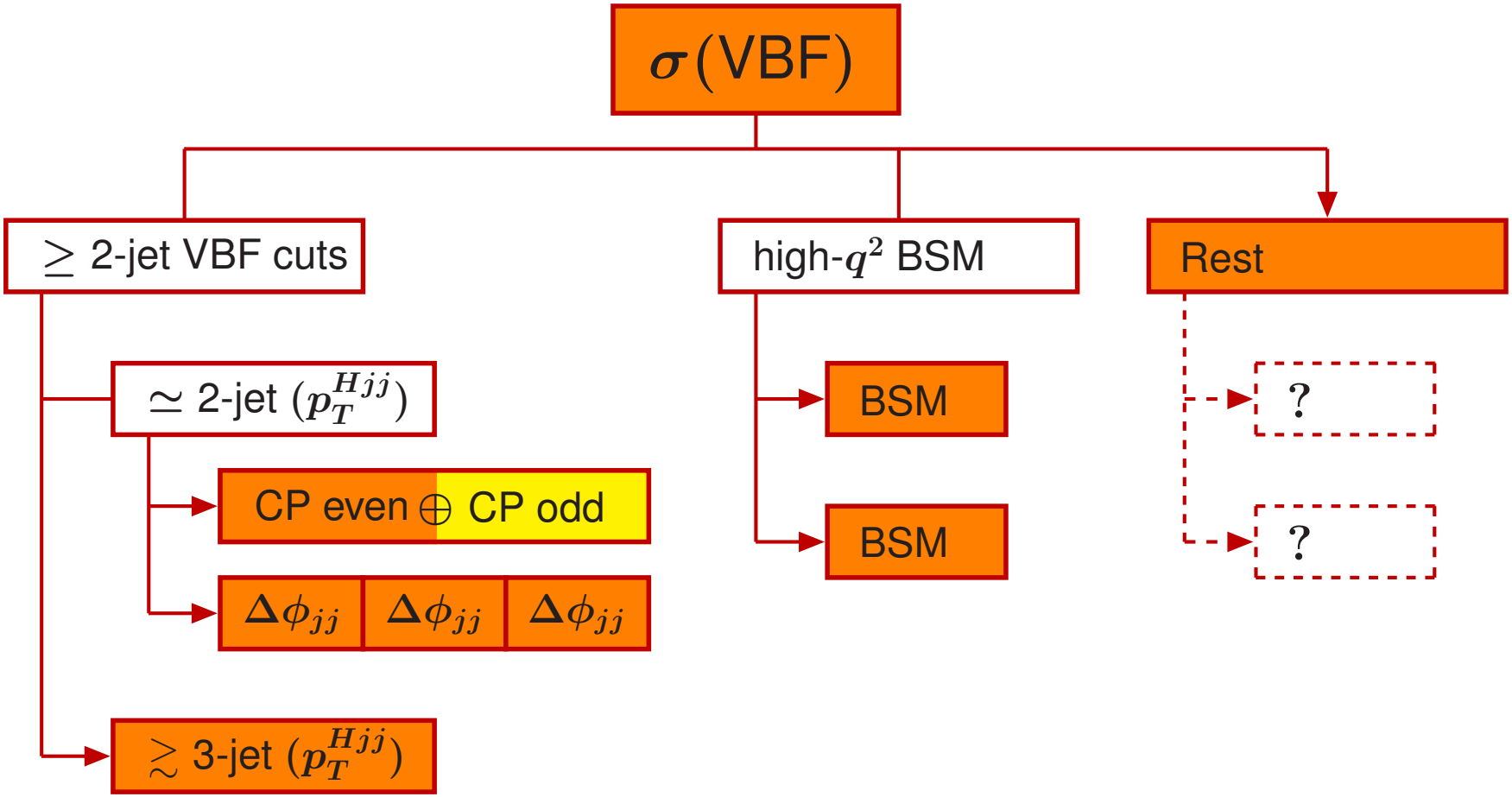
$gg \to H$: Medium-Term.



VBF: Small.

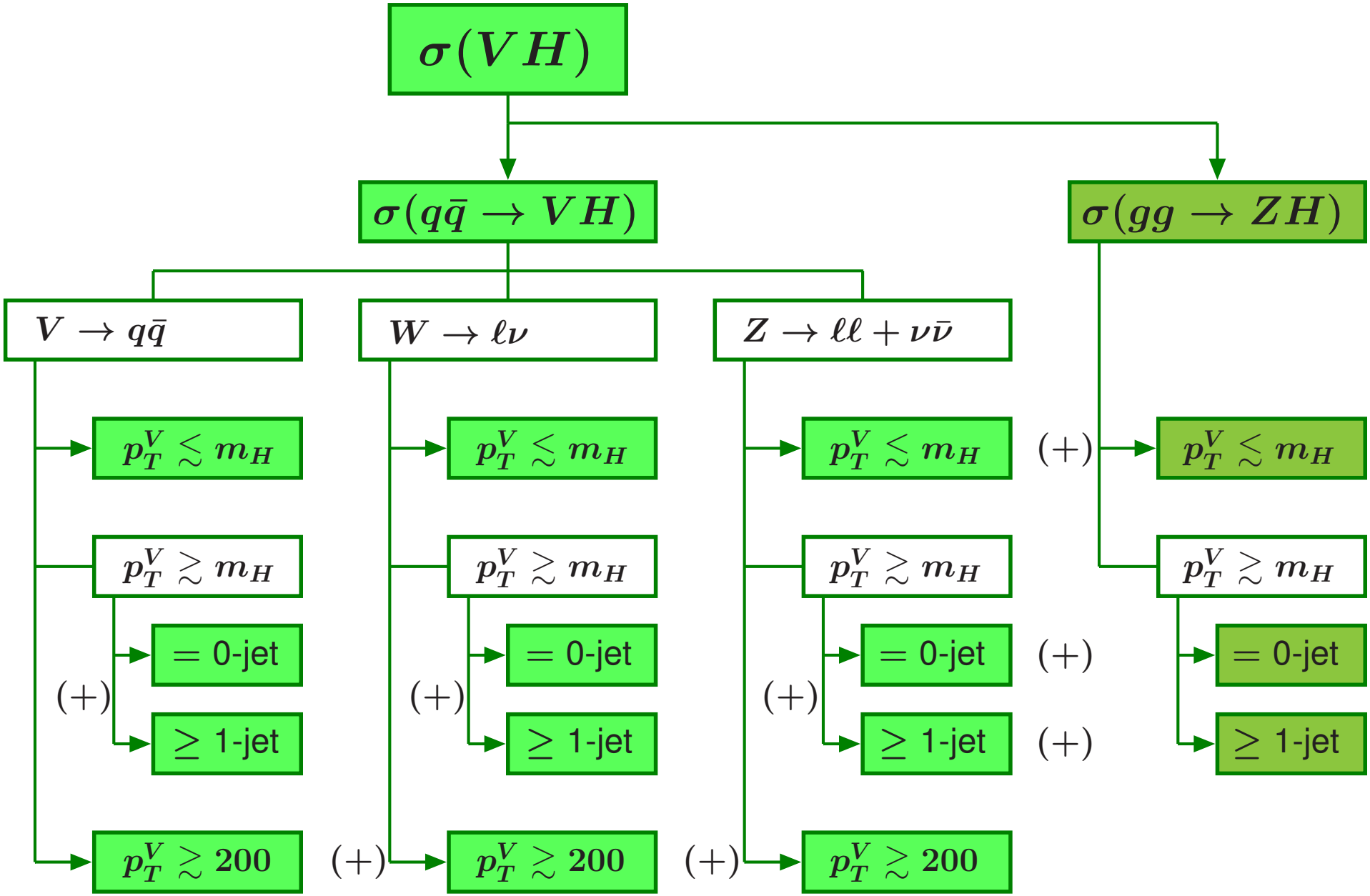

σ(VBF)
$\geq$ 2-jet VBF cuts
high-q^2 BSM
Rest
$\simeq$ 2-jet (p_T^{Hjj})
$\gtrsim$ 3-jet (p_T^{Hjj})

VBF: Medium-Term.

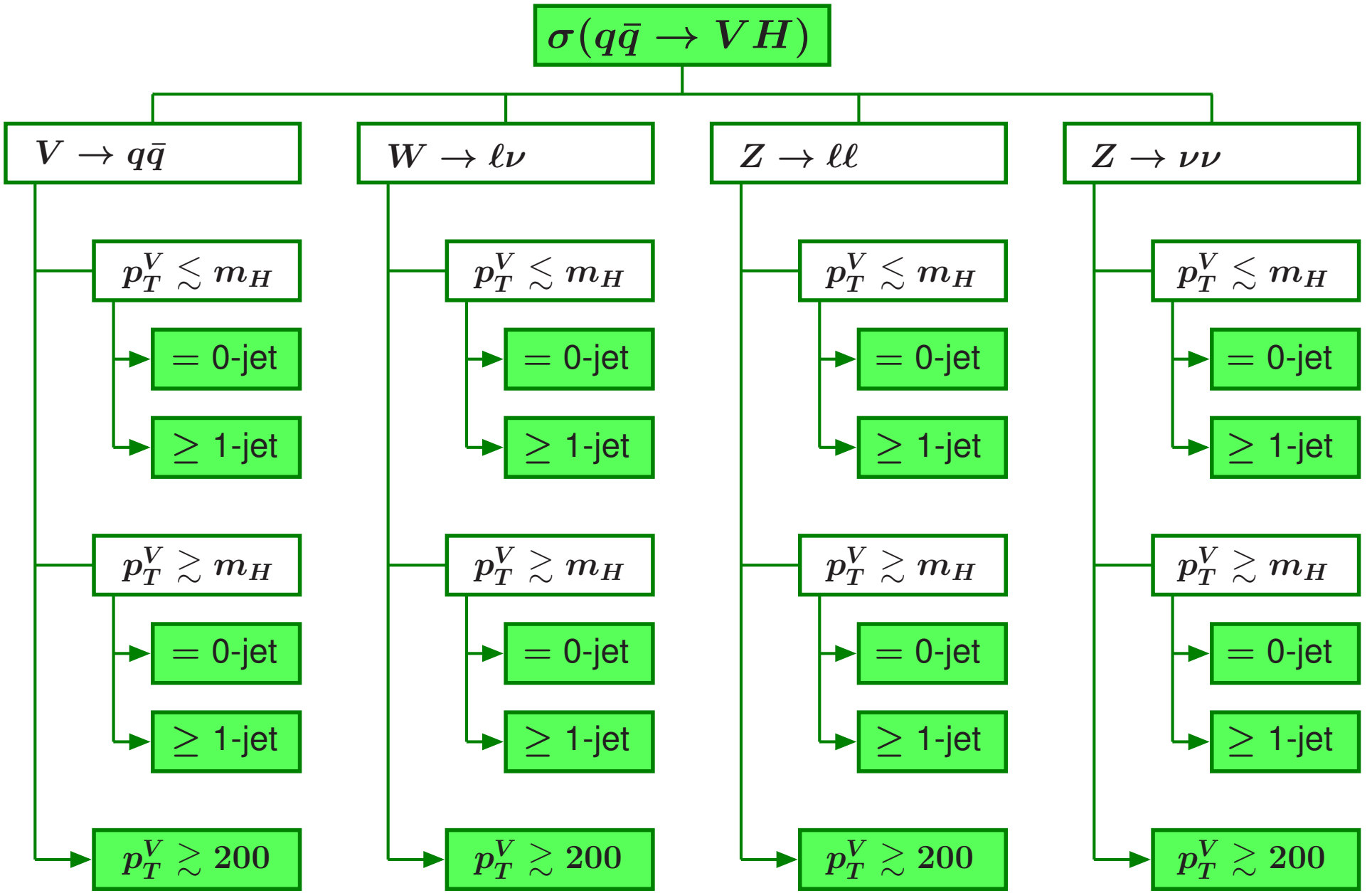


- Instead or in addition to binning in $\Delta\phi_{jj}$ can use continuous parameter to allow for a CP-odd admixture

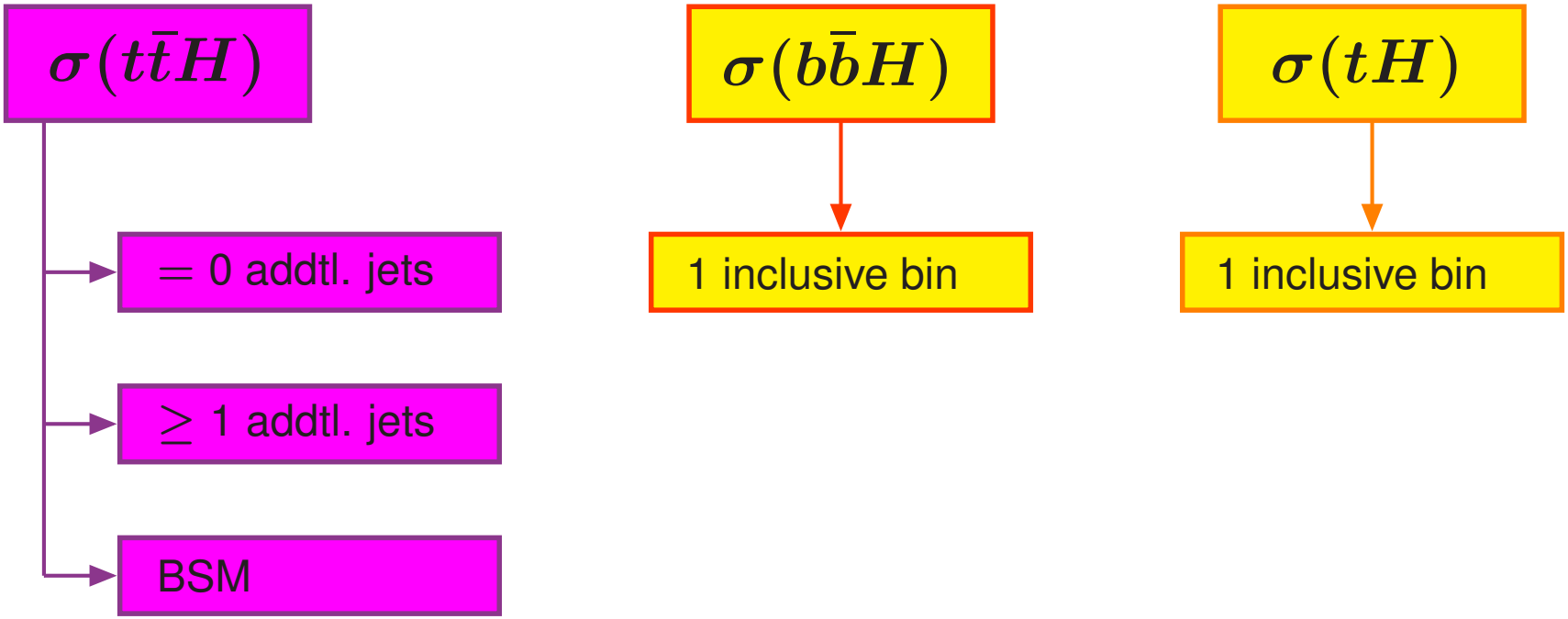
VH: Small.


$\sigma(VH)$
$\sigma(q\bar{q} \to VH)$
$\sigma(gg \to ZH)$
$V \to q\bar{q}$
$W \to \ell\nu$
$Z \to \ell\ell + \nu\bar{\nu}$
$p_T^V \lesssim m_H$
$p_T^V \gtrsim m_H$
$= 0$-jet
≥ 1-jet
$p_T^V \gtrsim 200$
(+)

$q\bar{q} \to VH$: Medium-Term (similarly for $gg \to ZH$).



Other Production Channels: Medium-Term.



- With enough statistics can start adding other production channels

Open Issues.

Finalize bin definitions

- Identify where kinematic bins and where continuous parameters or deformations are better suited
- Explicitly define BSM bins $\rightarrow$ Input/feedback very welcome

Treatment of decays

- Currently use (ratios of) partial widths $\Gamma_{\gamma\gamma}$, Γ_{ZZ}, Γ_{WW}, $\Gamma_{b\bar{b}}$, $\Gamma_{\tau\tau}$, ...
- Can extend these with decay POs

Precise definition of $\sigma(ggF)$, $\sigma(VBF)$, $\sigma(VH)$, ...

- Basic idea: Want SM process to act as kinematic template
  (treat SM itself like a "simplified model")
  - Experimentally: Use corresponding SM MC samples
  - Theoretically: Need to be well-defined such that theorists know precisely what to calculate (at least in the SM limit)
- How to best quantify residual dependence on SM distribution inside each bin

Summary.

The Proposal

- is that this will be the evolution of combined μ measurements
  - ... can do μ fits or any other interpretations like EFT with these as input layer
- Experiments would publish results for combined and/or channel-specific simplified cross sections
  - ... including full covariance (or if insufficient full likelihood)
- Planning to have joint write-up for YR4 and Les Houches proceedings
  - ... maximizing synergy and avoiding duplicate efforts

This *does not*

- replace full-fledged fiducial cross section measurements
  - ... but converges toward them in high statistics limit
- exclude optimized analyses for specific purposes
  (e.g. spin or CP measurements, dedicated BSM searches)