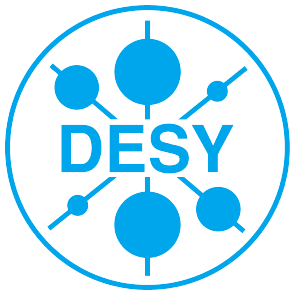
Simplified Cross Section Framework

Frank Tackmann

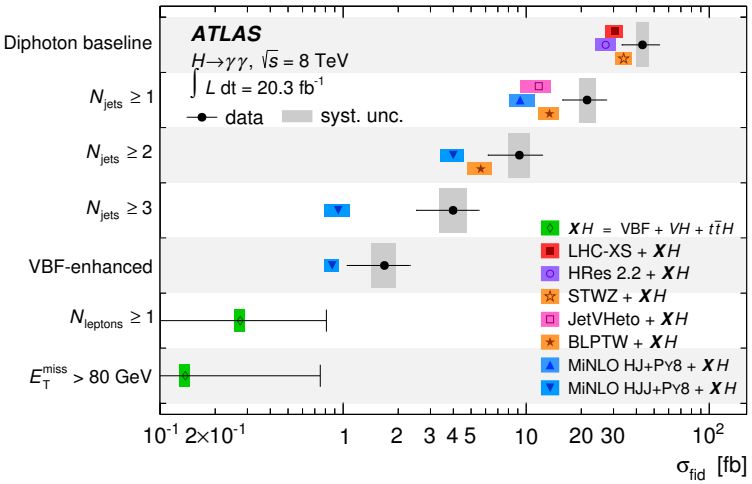
Deutsches Elektronen-Synchrotron

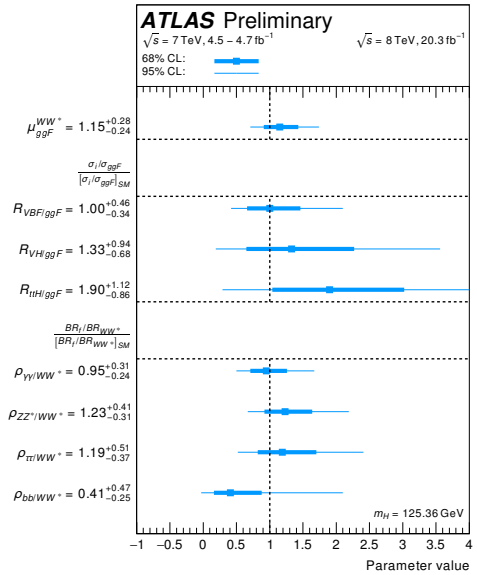
Higgs XS WG fiducial kick-off
June 24, 2015

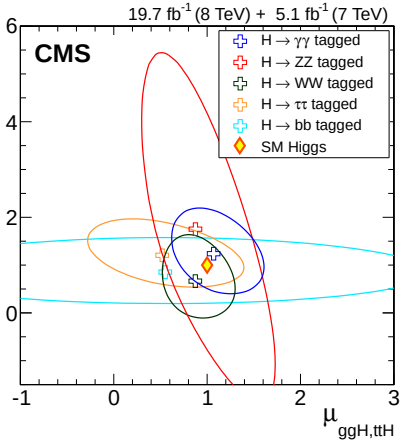
From Les Houches discussions with
Josh Bendavid, Andre David, Marco Delmastro,
Michael Duehrssen, Paolo Francavilla,
Sabine Kraml, Michael Rauch, Kerstin Tackmann,
...



Measurement vs. Interpretation.







Measurement

Interpretation

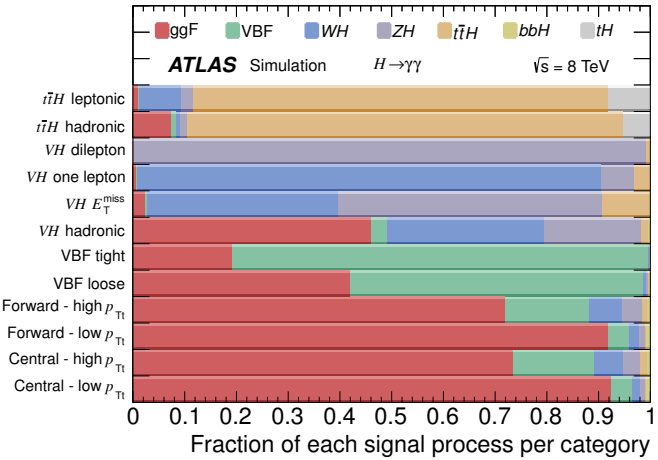
theory-independent

theory-dependent

where “Theory dependence” includes 2 aspects

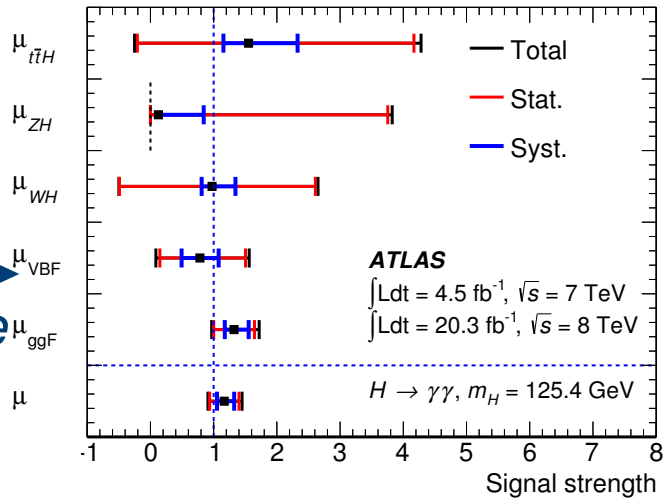
- Dependence on underlying physics model:
  - Assume/test a specific model (Lagrangian)
  - Dependence on kinematic distributions
- Dependence on theory systematics/uncertainties
  - In theory predictions that are needed to extrapolate to total cross sections
  - Perturbative and parametric (PDFs, α_s,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

Pros and Cons of μ Fits.



Raw measurements

Direct theory dependence



Interpretation

Pros

- Maximum possible 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

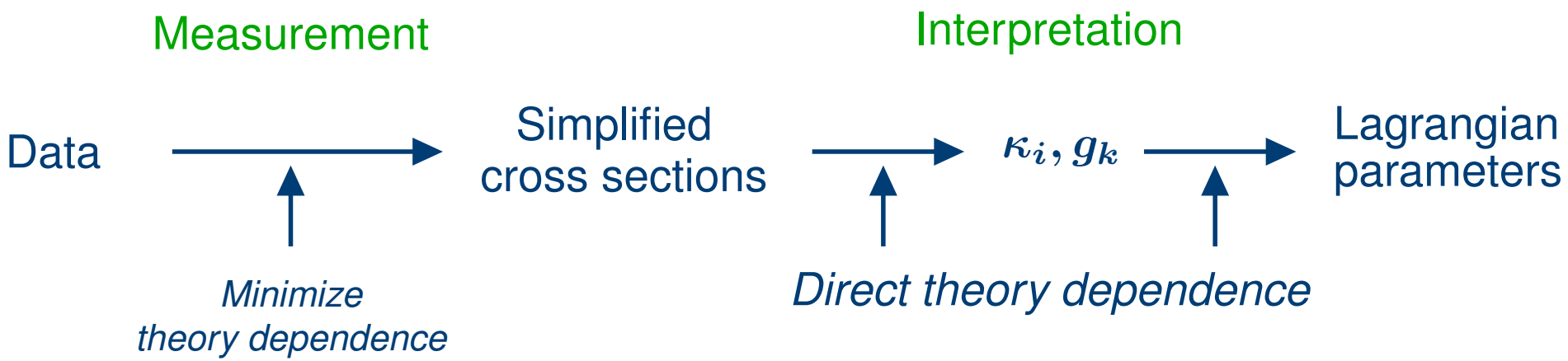
- Allows maximally theory-independent measurements
- Results remain long-term useful

$\Rightarrow$ The ultimate goal ...

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.

Current μ fits:

$$\sigma_1^{\text{meas}} = A_1^{ggH} \times \underbrace{\mu_{ggH} \times \sigma_{ggH}^{\text{SM}}}_{\sigma_{ggH}} + A_1^{\text{VBF}} \times \underbrace{\mu_{\text{VBF}} \times \sigma_{\text{VBF}}^{\text{SM}}}_{\sigma_{\text{VBF}}}$$

$$\sigma_2^{\text{meas}} = A_2^{ggH} \times \underbrace{\mu_{ggH} \times \sigma_{ggH}^{\text{SM}}}_{\sigma_{ggH}} + A_2^{\text{VBF}} \times \underbrace{\mu_{\text{VBF}} \times \sigma_{\text{VBF}}^{\text{SM}}}_{\sigma_{\text{VBF}}}$$

- 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 $\rightarrow$ theory-dependent
  - Split each production cross section into several kinematic bins/slices a, b, ...

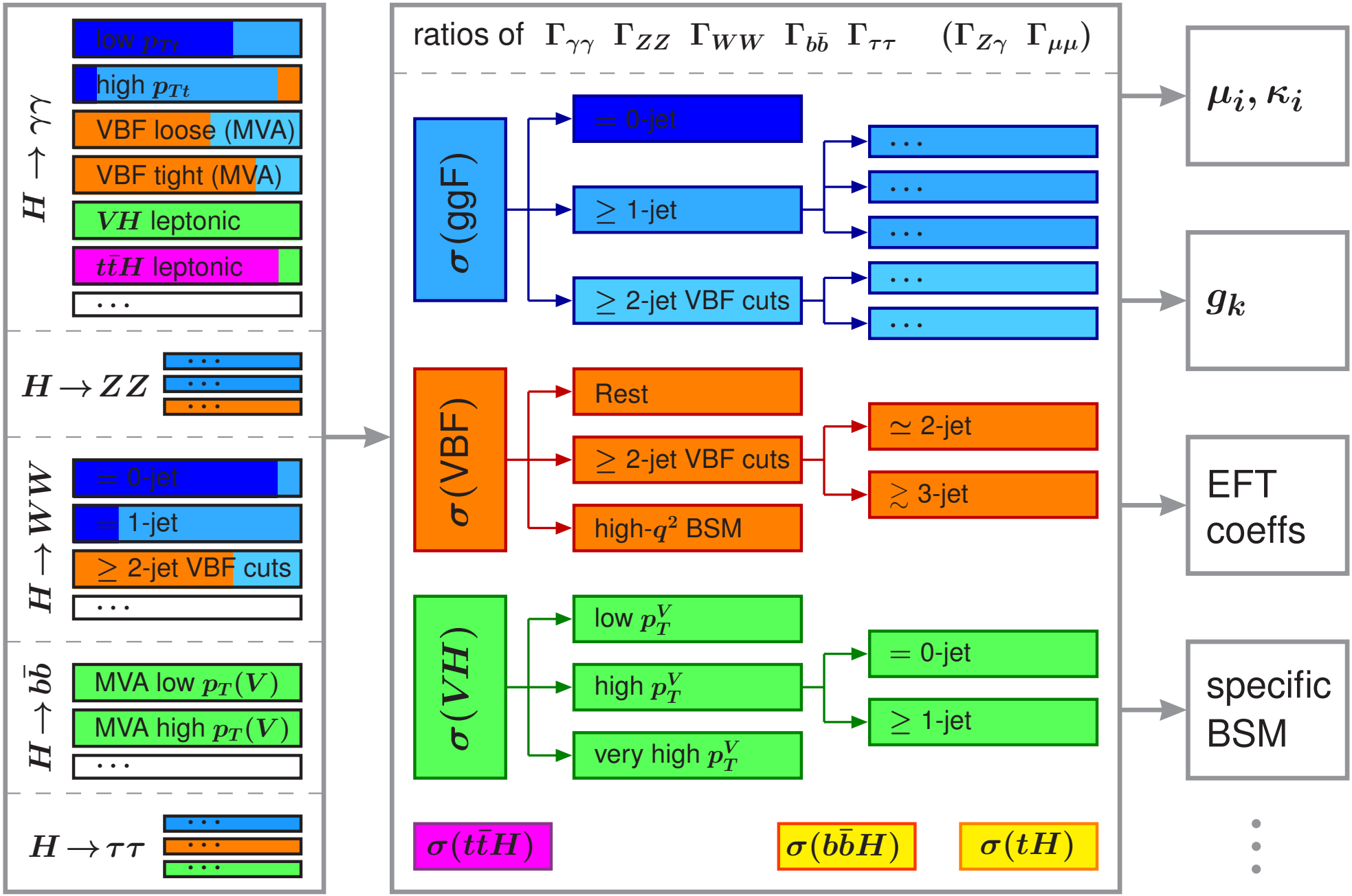
$$\sigma_1^{\text{meas}} = A_1^{ggH\,a} \times \sigma_{ggH\,a} + A_1^{ggH\,b} \times \sigma_{ggH\,b} + A_2^{\text{VBF c}} \sigma_{\text{VBF c}} + \cdots$$

$$\sigma_2^{\text{meas}} = \ldots$$

  - A_i^j only depend on SM kinematics *inside* a given bin
  - If this becomes a problem, split the bin

$\Rightarrow$ SM processes act as kinematic templates

Simplified Cross Section Framework.



Trying to Get the Best of Both Worlds.

Difference compared to current μ fits

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

Difference compared to fully-fiducial cross sections

- Non-Higgs backgrounds are subtracted
- Inclusive over the Higgs decays
  - Can perform a global combination of channels
- "Simplified" bin definitions *per production mode* 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.

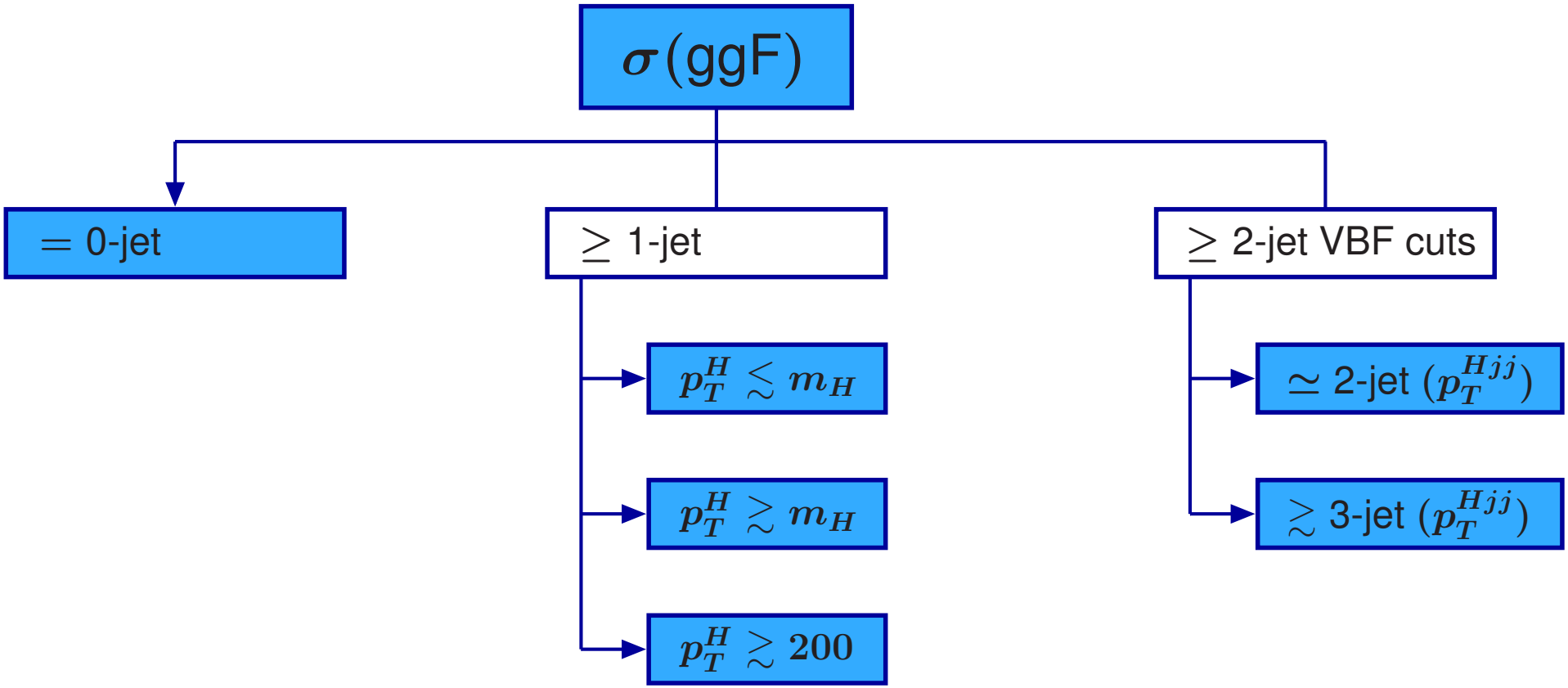
- Bins should be reasonably well constrained (except BSM “overflow” bins)
- Identify phase-space regions that are most important to separate out from the theory side
  - Where are largest theory systematics (e.g. ggF 0jet bin)
  - BSM sensitivity/interpretation
- Try to minimize residual theory dependence
  - 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)
- Definition of bins can evolve
  - Can split into more fine-grained bins as required and allowed by statistics (previous determinations remain useful)

Bin Definitions.

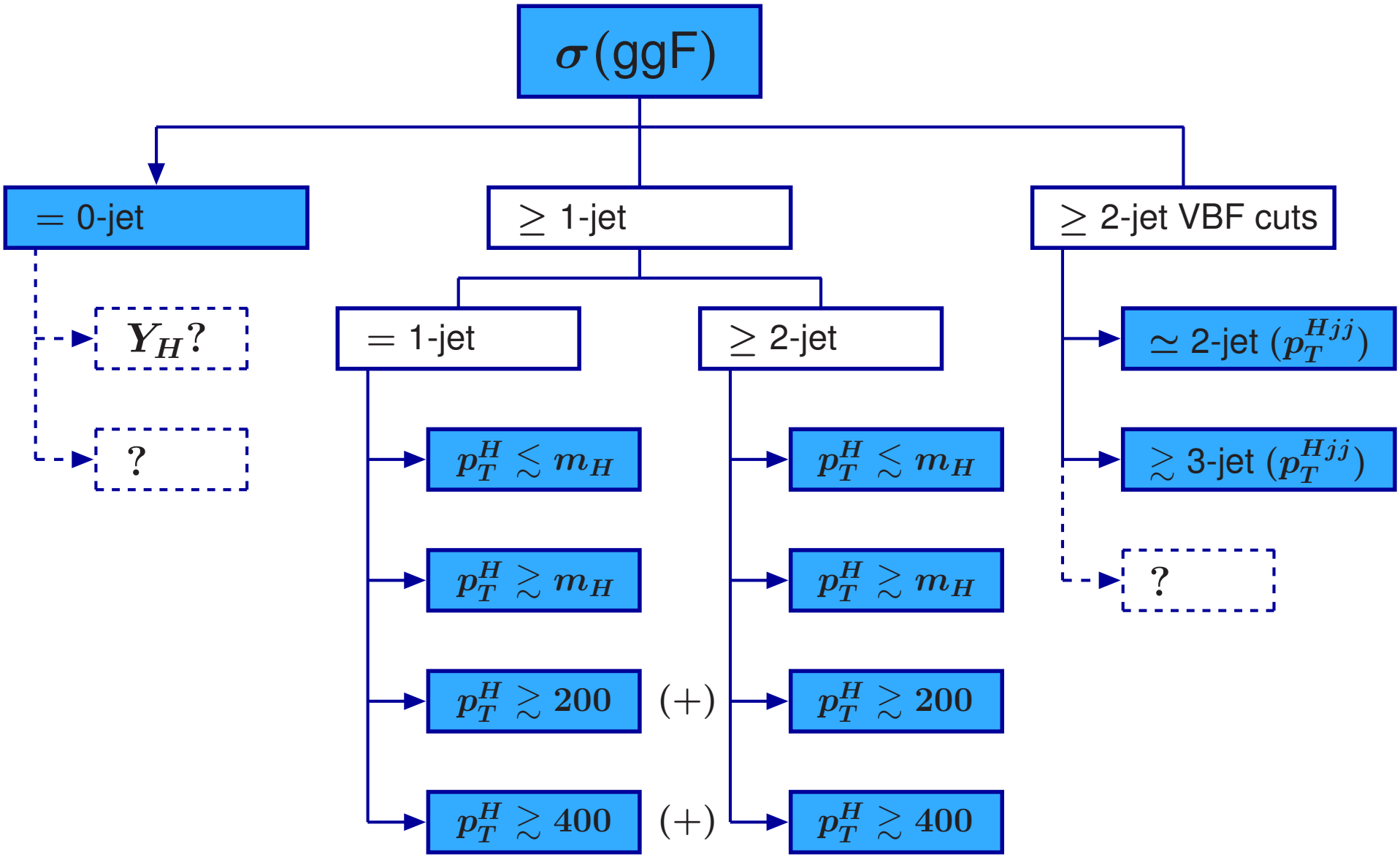
In the following: Concrete proposal which came out of Les Houches

- 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 by definition mutually exclusive and sum up to parent bin

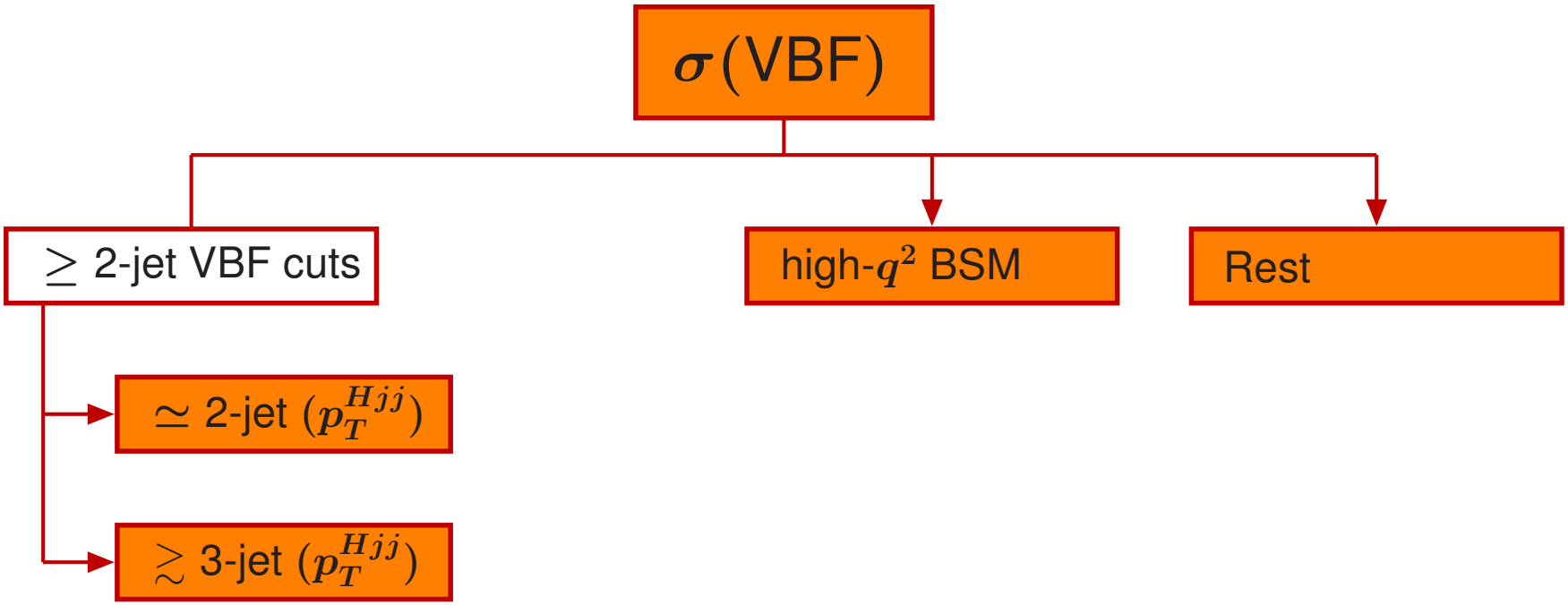
$gg \to H$: Small.


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})

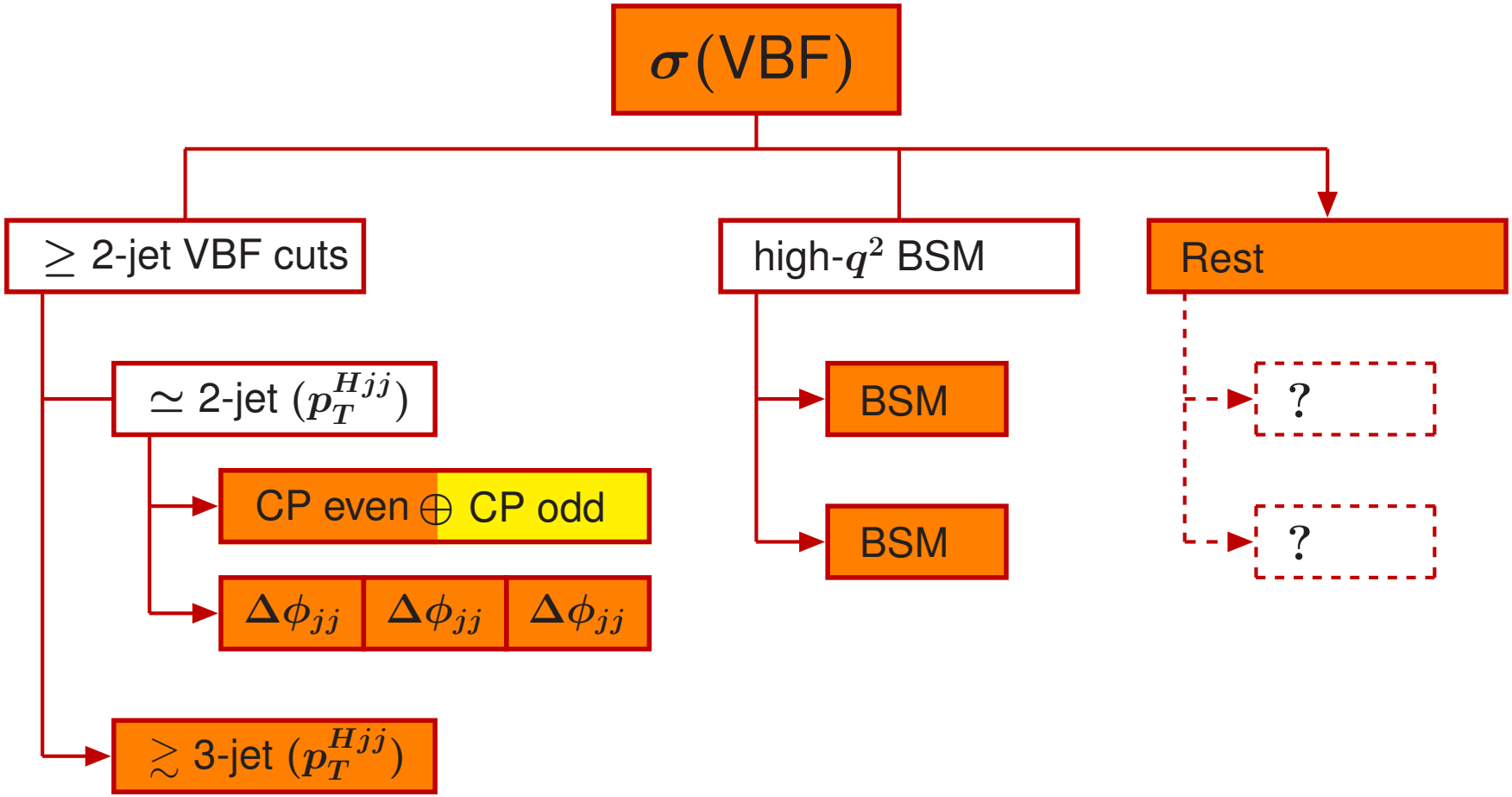
$gg \to H$: Medium-Term.



VBF: Small.

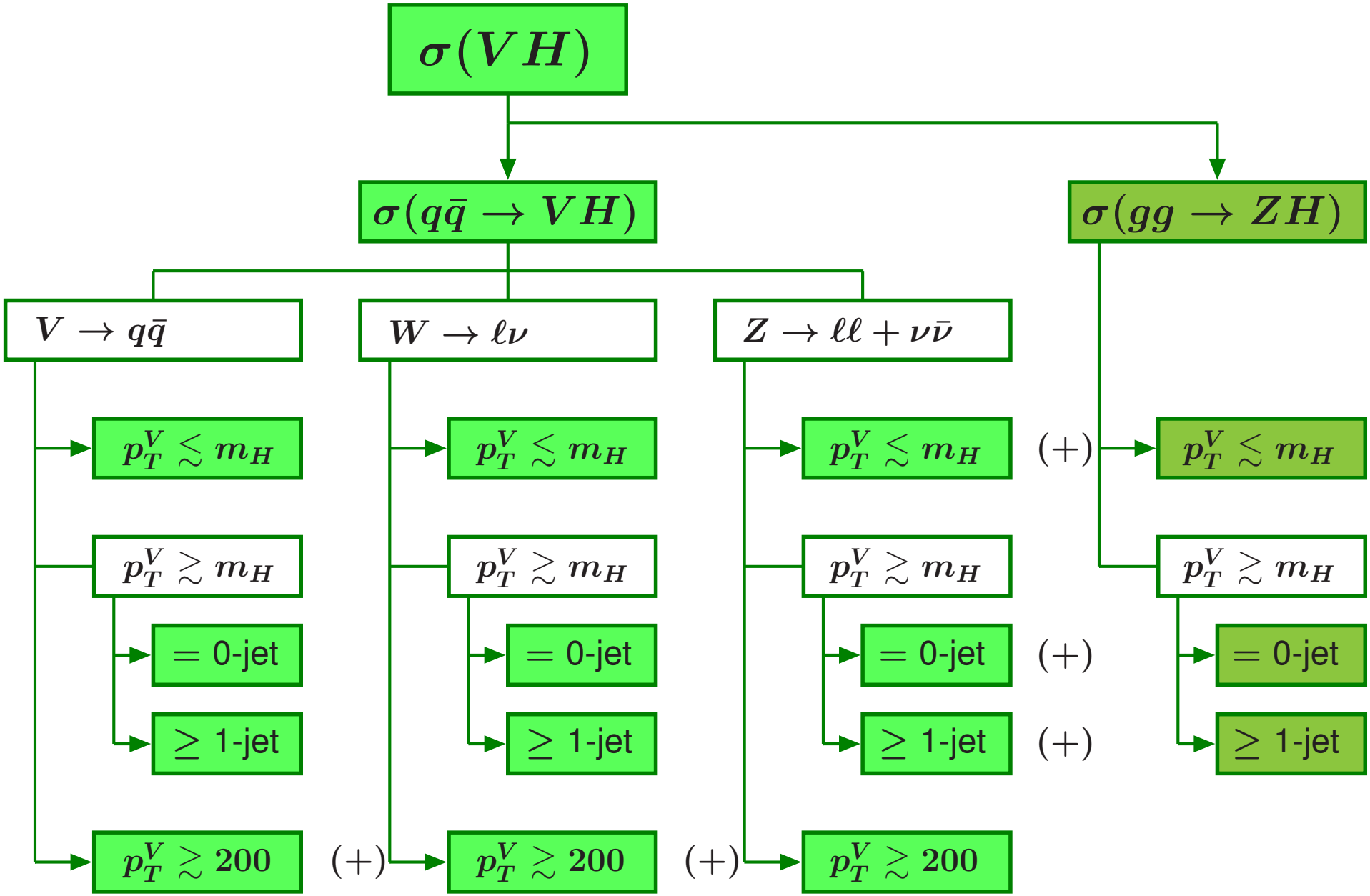

σ(VBF)
$\geq$ 2-jet VBF cuts
high-q^2 BSM
Rest
$\simeq$ 2-jet (p_T^{Hjj})
$\gtrsim$ 3-jet (p_T^{Hjj})

VBF: Medium-Term.

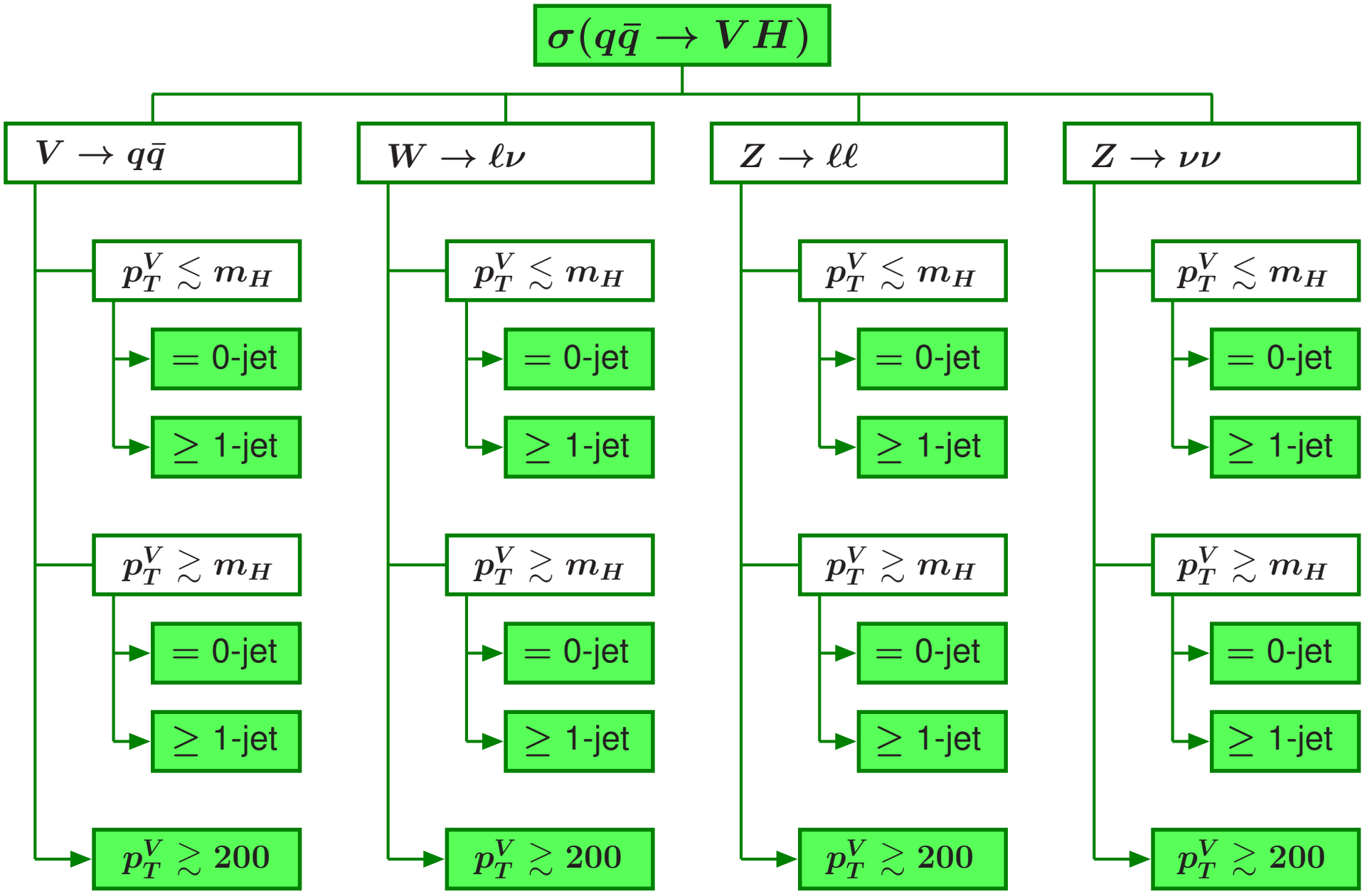


- Instead or in addition to binning in $\Delta\phi_{jj}$ can use continuous parameter to allow for a CP-odd admixture

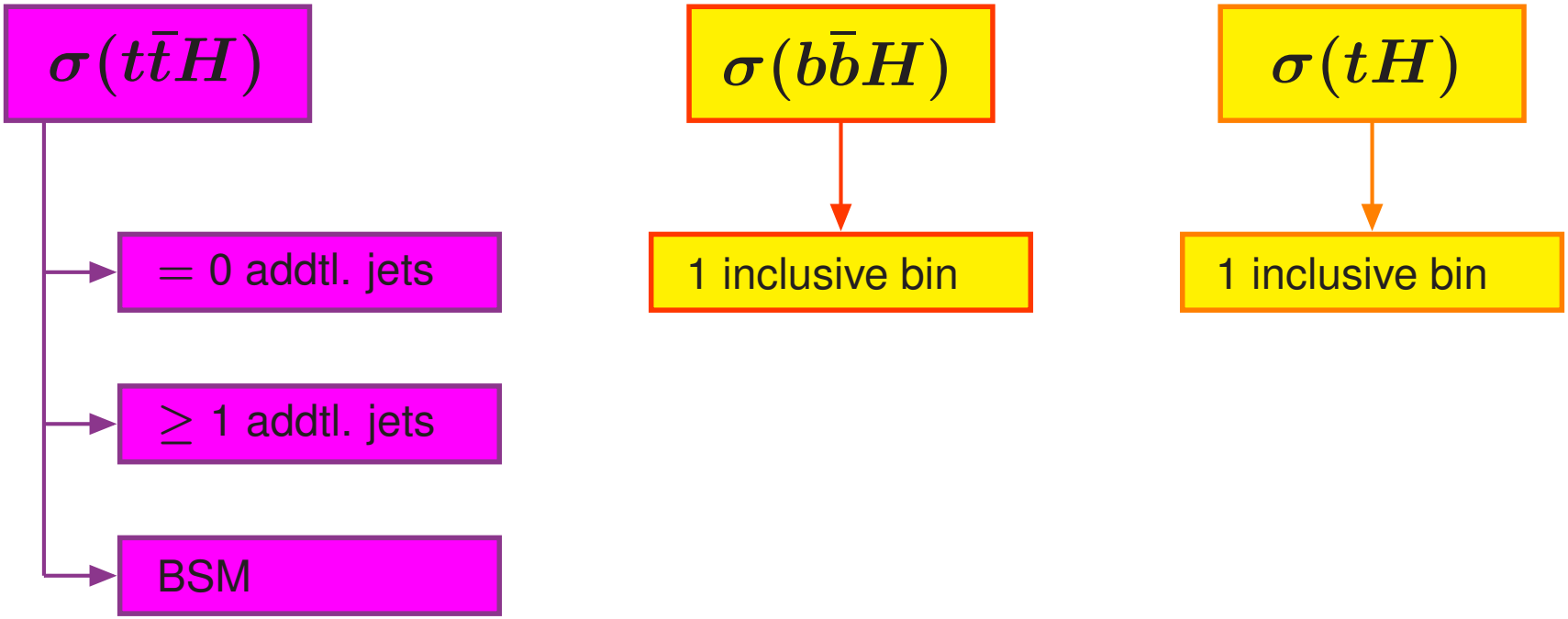
VH: Small.


$\sigma(VH)$
$\sigma(q\bar{q} \to VH)$
$\sigma(gg \to ZH)$
$V \to q\bar{q}$
$W \to \ell\nu$
$Z \to \ell\ell + \nu\bar{\nu}$
$p_T^V \lesssim m_H$
$p_T^V \gtrsim m_H$
$= 0$-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
- Input from BSM community important

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 ($\rightarrow$ see Gino's talk)

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")
  - Experimental: 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 still do μ fits with these as input layer (just like any other interpretations like EFT
- Experiments would publish results for combined and/or channel-specific simplified cross sections
  - ... including full covariance (or if insufficient full likelihood)

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)

Next Steps

- Dedicated WG2 meeting 1st week of July (see your inbox for a doodle)
- Planning to have a joint writeup for YR4 and Les Houches proceedings