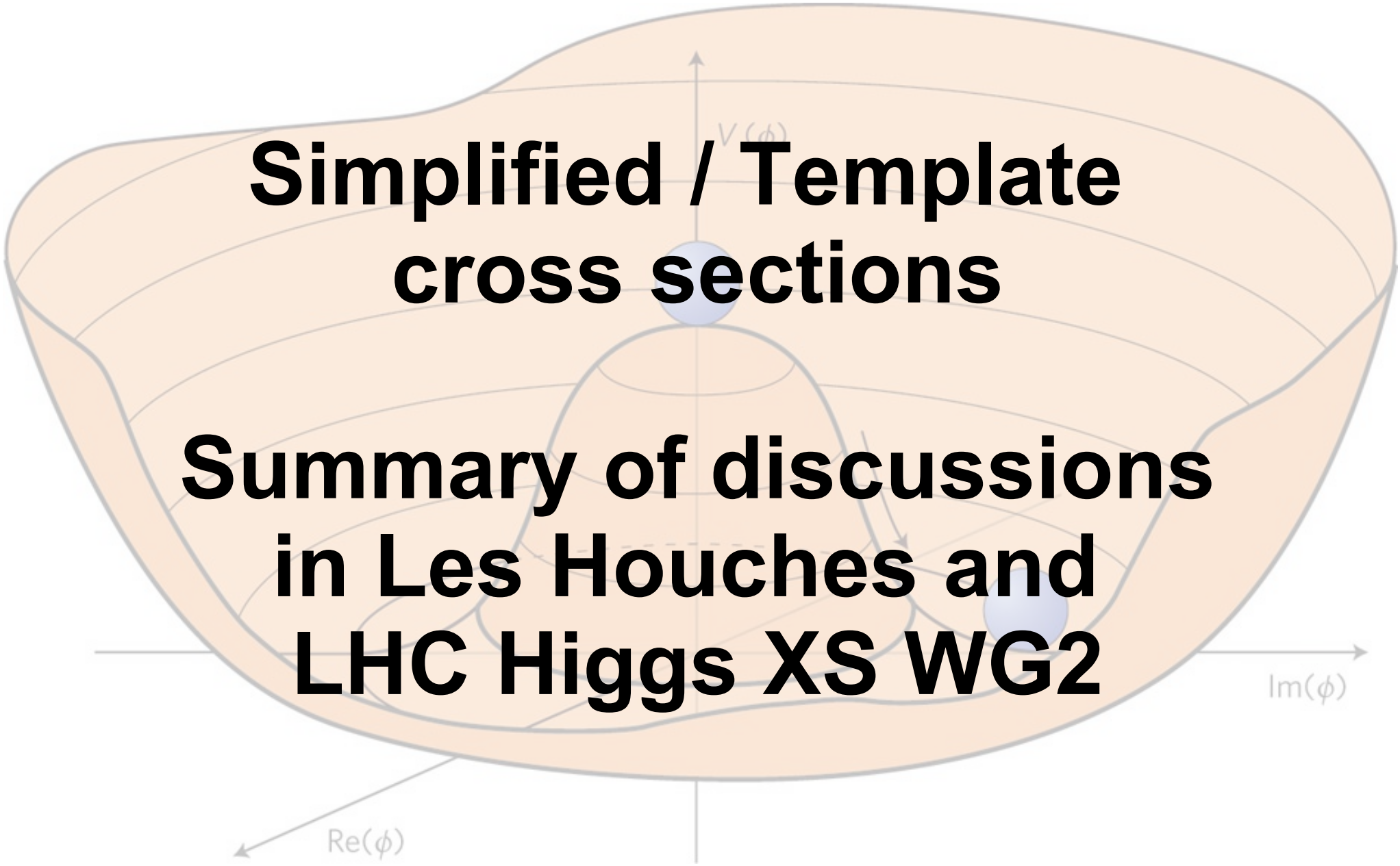



# Simplified / Template cross sections

# Summary of discussions in Les Houches and LHC Higgs XS WG2

**Michael Duehrssen**

**Higgs plenary, 10th September 2015**

# (Selected) lessons learned from run 1

- The run 1 Higgs analysis for the 125 GeV Higgs started as searches
- After discovery, experiments adapted these analysis into first measurements of properties

**Some legacy of the Higgs searches left in the analysis:**

- Most analysis report a signal strength $\mu$, calculated relative to the SM theory prediction at some point in time. These SM theory prediction are deeply embedded in the analysis
- Also the Higgs boson signal theory uncertainties at that point in time are an intrinsic part of the analysis
  → Better calculations cannot easily be compared to these measurements (e.g. N3LO gg→H, ...)
- Reporting well chosen observed cross sections could remove (a large part of) that theory dependence

# (Selected) lessons learned from run 1

- The run 1 Higgs analysis for the 125 GeV Higgs started as searches
- After discovery, experiments adapted these analysis into first measurements of properties

Some legacy of the Higgs searches left in the analysis:

- Analysis assume properties of a SM Higgs boson: "... the Higgs boson production and decay kinematics are assumed to be compatible with those expected for a SM Higgs boson ..."
- If its not a SM Higgs, we close our eyes to a part of the information that could tell us

- Using a more general signal model than SM (e.g. EFT, Pos, ...) could be one option
- "Measuring" the largest expected BSM deviation could be another option

# (Selected) lessons learned from run 1

- The run 1 Higgs analysis for the 125 GeV Higgs started as searches
- After discovery, experiments adapted these analysis into first measurements of properties

Some run 1 analysis already changed the approach:

- Fiducial and differential cross section measurements in $H\to\gamma\gamma$, $H\to ZZ$ and $H\to WW$
  → almost model independent measurements
- Cross section results in coupling combination papers
  → removes theory dependence on inclusive xsec
- Angular analysis of $H\to ZZ$ and $H\to WW$ decays
  → explicitly analyze SM kinematics in Higgs decays

# (Selected) advantages of run 1

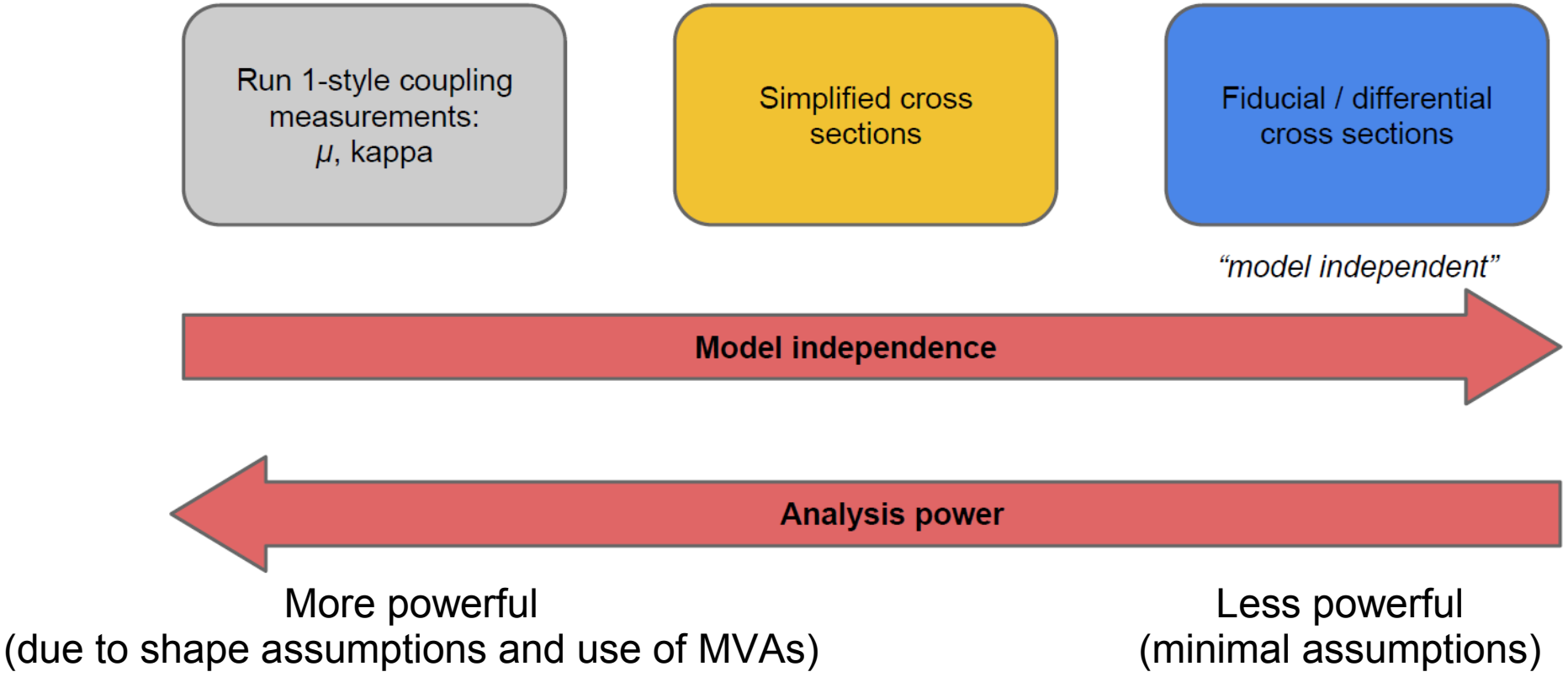
- The run 1 Higgs analysis for the 125 GeV Higgs started as searches
- After discovery, experiments adapted these analysis into first measurements of properties

**Run 1 analysis were not blind to BSM Higgs effects:**

- Independent fit of signal strength for all Higgs boson production and decay modes:
  $gg \to H$, VBF, VH, ttH, $H \to \gamma\gamma$, $H \to WW$, $H \to ZZ$, $H \to \tau\tau$, $H \to bb$
- Knowledge of signal kinematics in each production and decay mode allowed to
  - use categories and MVAs to discriminate between production modes themselves and backgrounds
  - search for deviations from the SM in production and decay rates

# What to do for run 2?

- **Fiducial and differential measurements?**
  - **Not easy and might not be possible for all channels**
  - **Usually can't use most powerful techniques (MVAs)**
- **EFT, PO analysis**
  - **Very complex**
  - **EFT also has model assumptions**
- **Would be good to find a doable compromise...**



# Compromise: Simplified/Template cross sections

**Guiding example: gg→H**

- **Run 1:**
  - **Ignore all aspects of Higgs decays for now**
  - **Measure μ(ggH) → could be "simply" transformed to σ(ggH)**
  - **Assume jet bin cross sections (and uncertainties) as given by best SM calculations in early 2014:**
    **σ(1jet)/σ(incl.), σ(2jet)/σ(1jet), … , σ(high $p_T$)/σ(incl.), ...**

# Compromise: Simplified/Template cross sections

**Guiding example: gg→H**

- **Run 1:**
  - **Measure μ(ggH)**
- **Proposal:**
  - **Measure σ(ggH,0jet), σ(ggH,1jet), σ(ggH,2jet), ...**
  - **Eventually also σ(ggH,1jet high pT), σ(ggH,2jet high pT), ...**
  - **Provide correlations between these measurements!**
    **→ if a theory model is injected that connects all σ(ggH,XXX) measurements, run 1 sensitivity should be recovered**
  - **Include only SM theory uncertainties for the acceptance difference between analysis selections and the cross sections σ(ggH,XXX)**
  - **Sufficiently fine granular to accommodate all current gg→H uncertainty models**
  - **Directly sensitive to BSM physics entering at high pT**

# General definition: Simplified/Template cross sections

Consider current $\mu$ fits:

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

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

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

- $\sigma_i^{\text{meas}}$ are the measured analysis categories/selections
- Fit for $\sigma_{ggH}$, $\sigma_{\text{VBF}}$
  - 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

# General definition: Simplified/Template cross sections

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

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

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

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

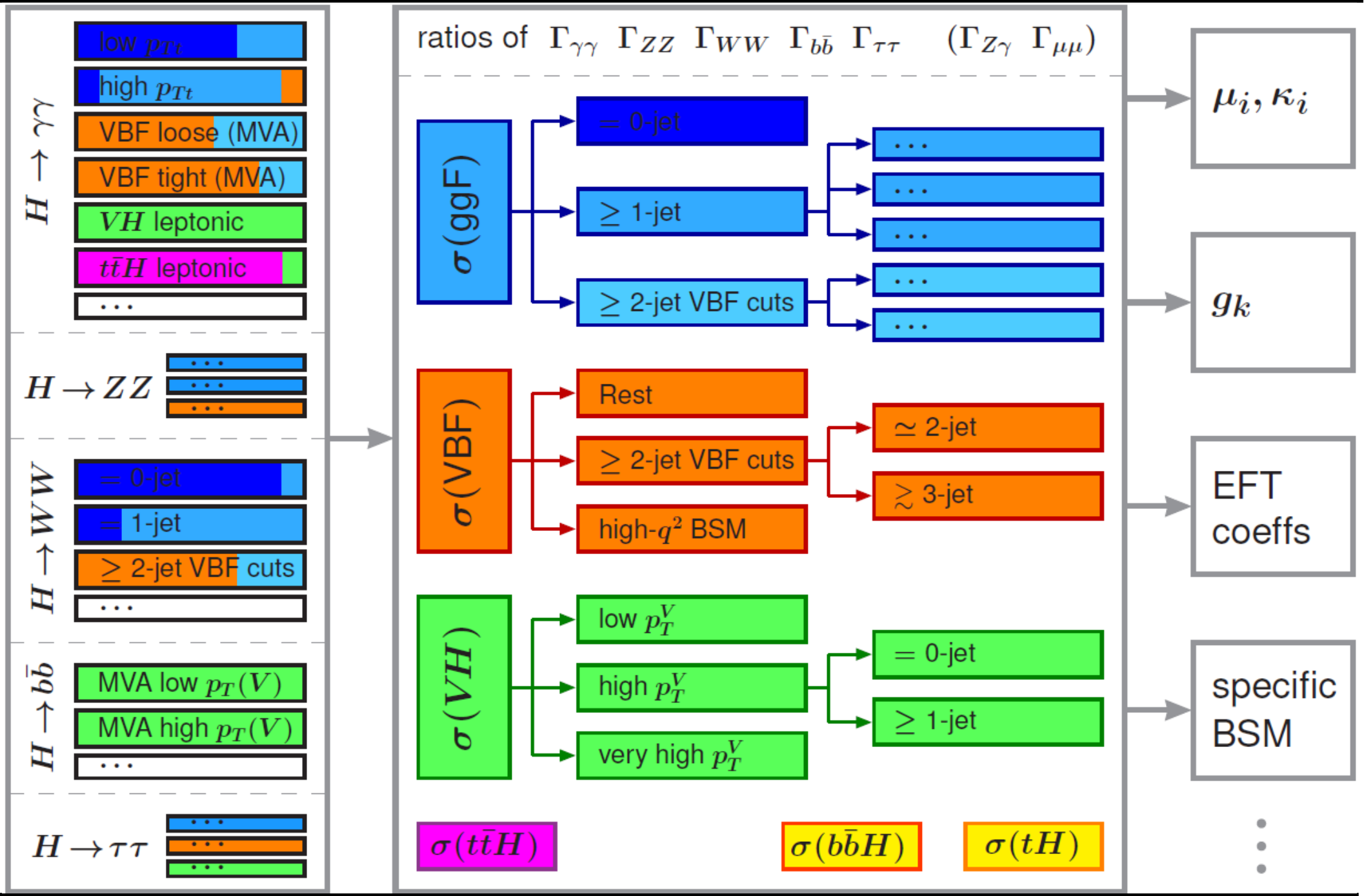
**Bins a, b, c, … can be different for different production modes! This is NOT a fiducial volume!**

- $\sigma_i^{\text{meas}}$ are still the measured analysis categories/selections
- Separately fit for cross sections in each bin $\sigma_{ggH}^{a}$, $\sigma_{ggH}^{b}$, $\sigma_{\text{VBF}}^{c}$, ...
- $A_{ij}^{ggH}$, $A_{ij}^{\text{VBF}}$ 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)

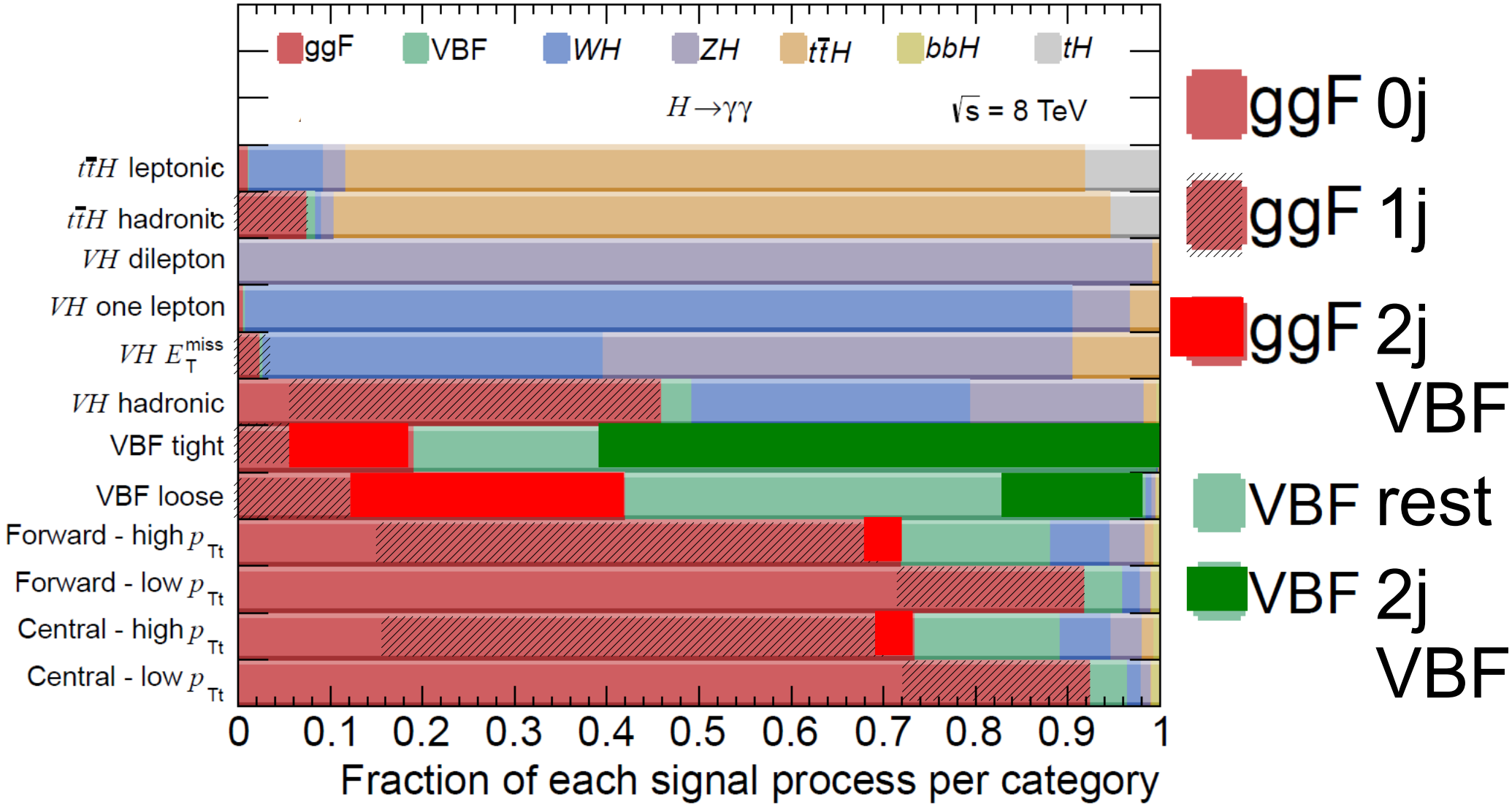
# One advantage not mentioned so far...

- The simplified/template cross sections are a direct evolution of the current μ-style analysis
- No changes to experimental analysis code needed (can of course always improve)
- No change to MC production needed
  → just need to split MC samples by applying the generator cuts that define the theory bins
- Need to add more parameters of interest
  → already done in run 1, exp. know how to do that

# 1st proposal for all production modes

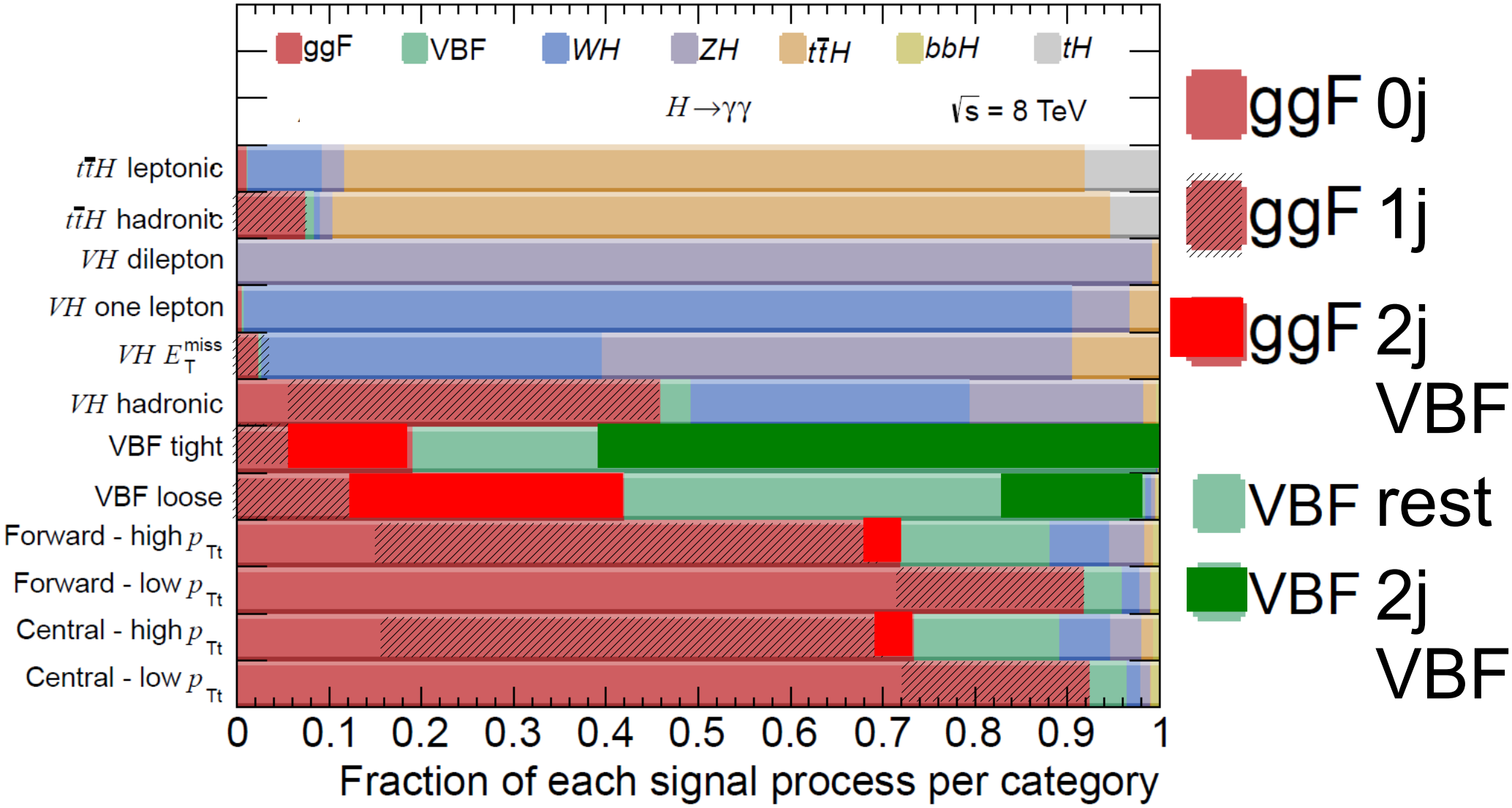


# Sketch of how this might look in H→γγ




- **Discussion of how to define bins ongoing in LHC XS WG**
  → **we should provide feedback!**
  **better split of VBF bins? Directly introduce 1j high pT?**

# What would experiments report?



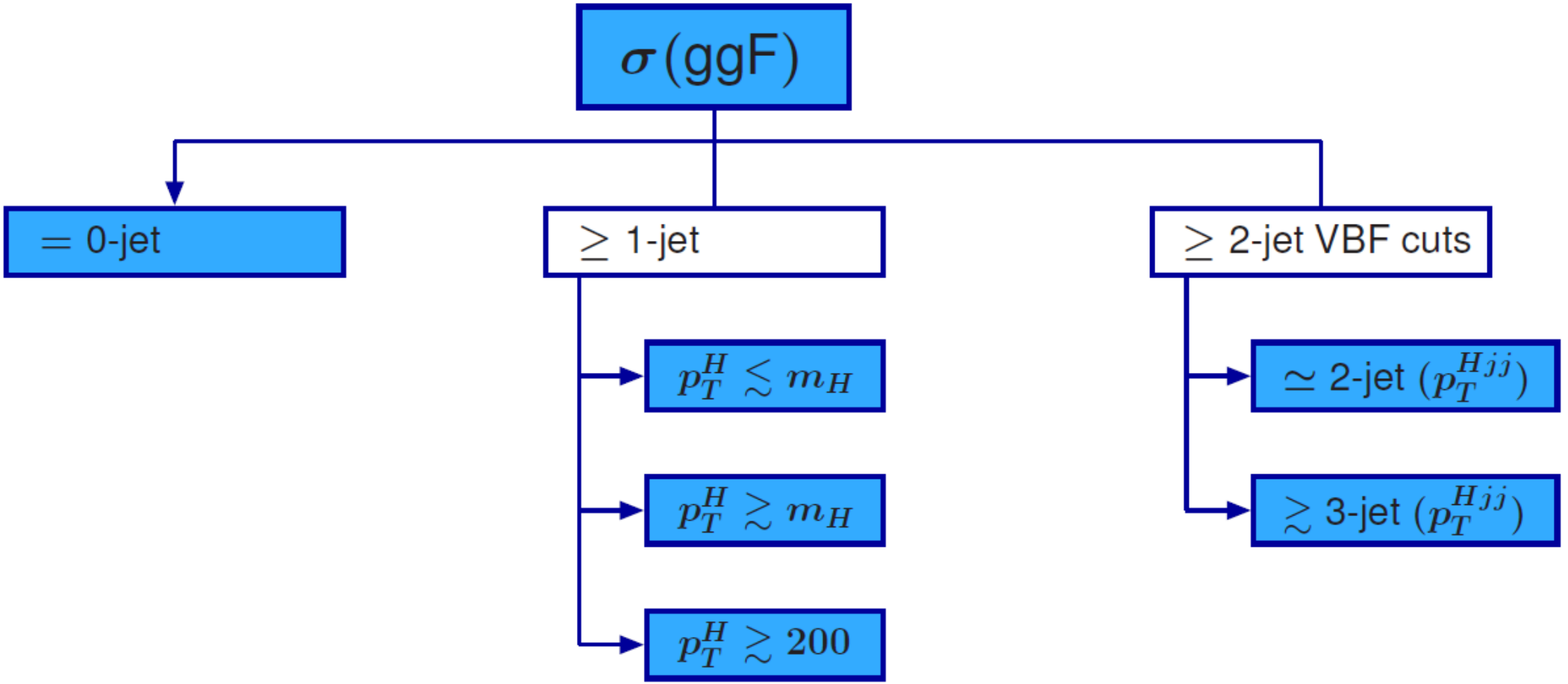

- **Experimentally there might not be much power to distinguish some parameters. Example: 2j VBF selection of ggF and VBF**
- **Example result: 0.5*σ(VBF 2j) + 0.05*σ(ggF 2j) = 1.1pb ± 0.4pb**

# 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)

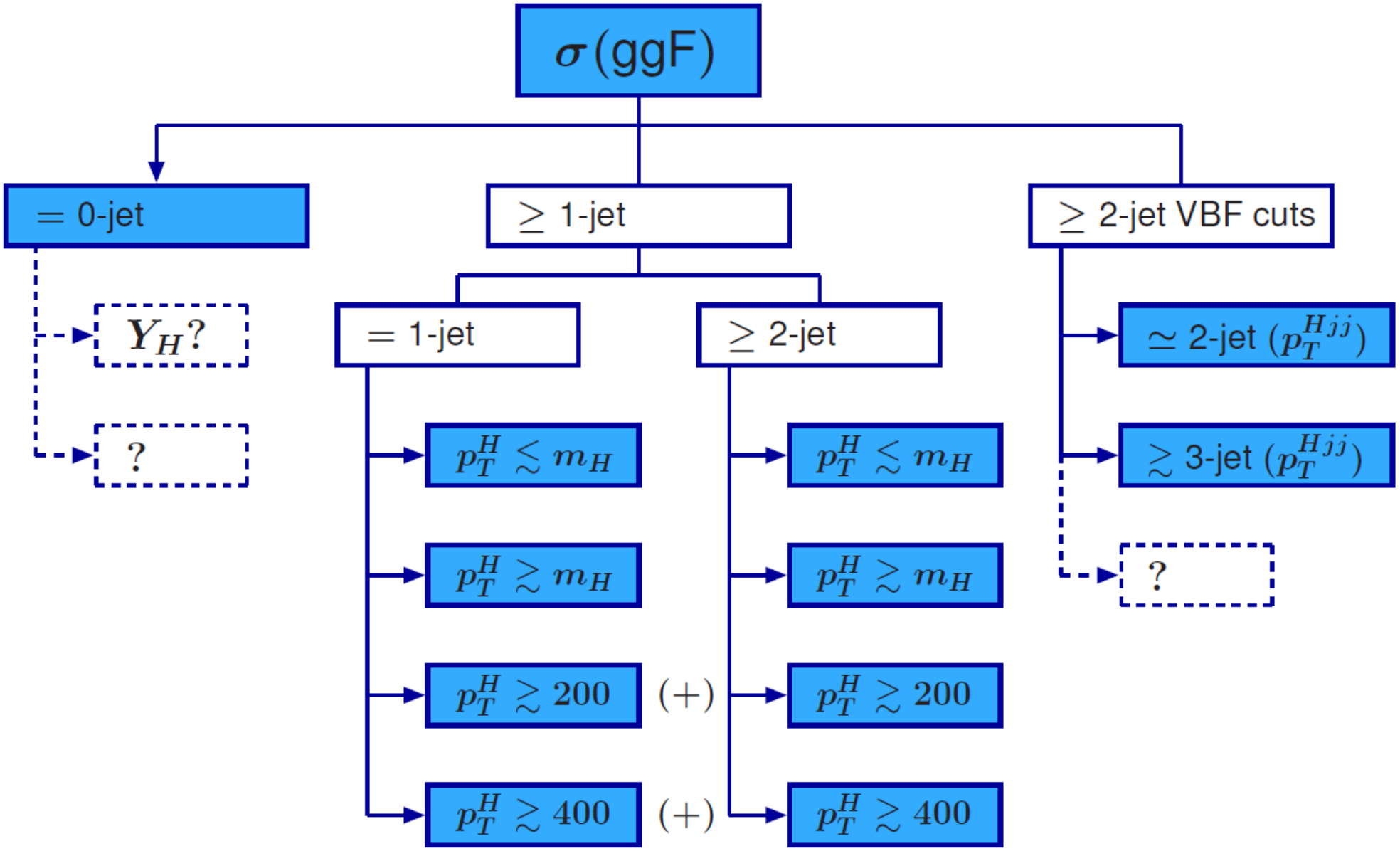
# Details...

## $gg \to H$: Small.



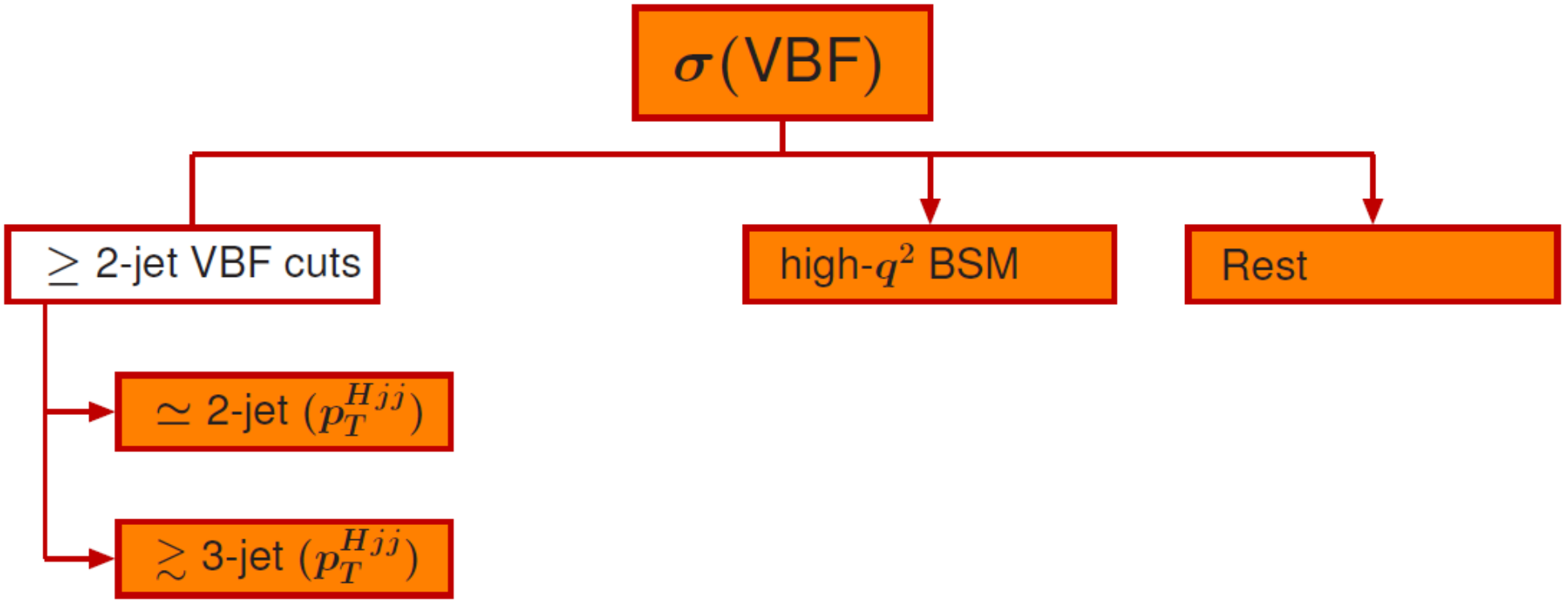
# Details...

## $gg \to H$: Medium-Term.



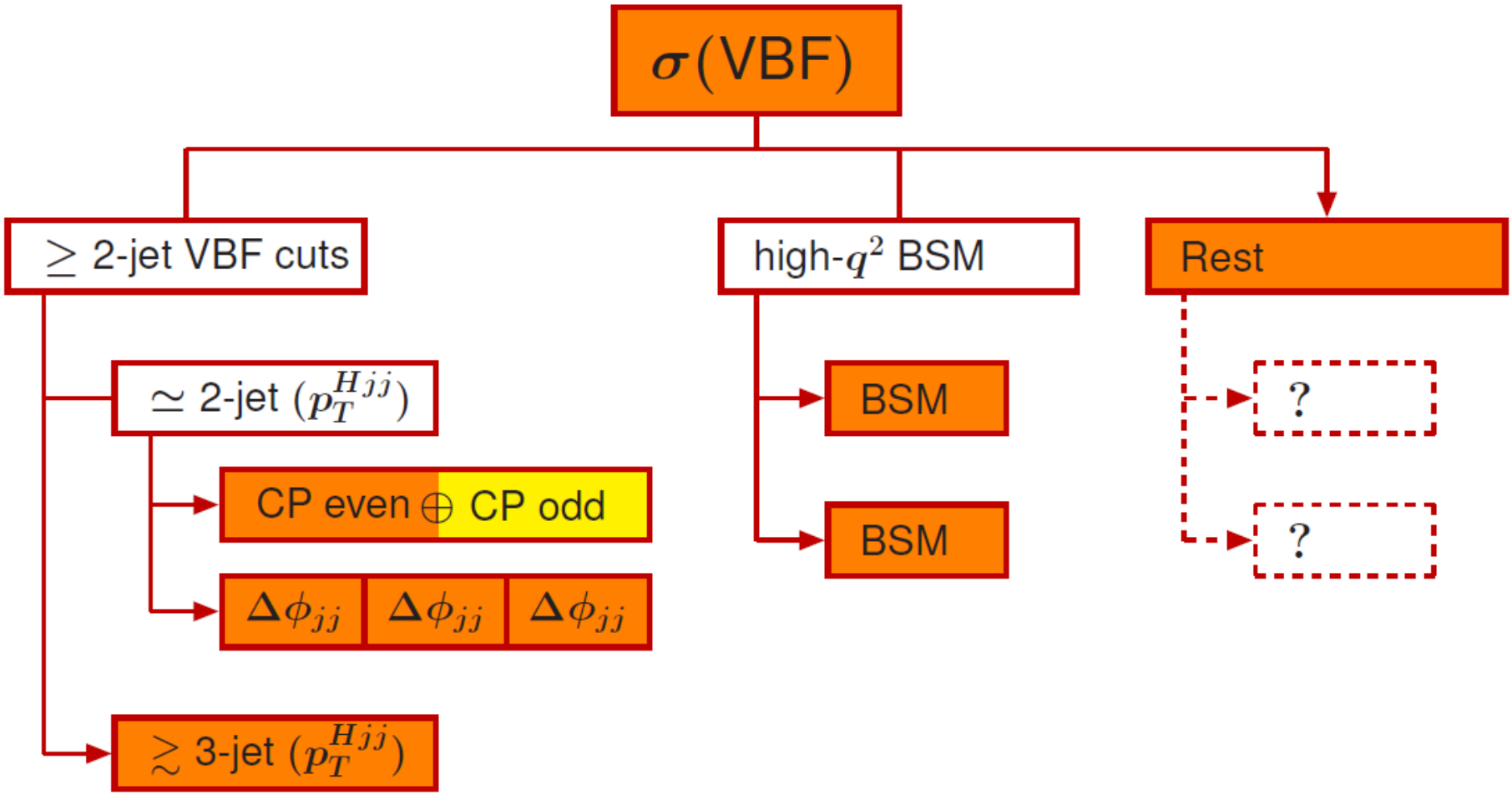
# Details...

## VBF: Small.



# Details...

## VBF: Medium-Term.

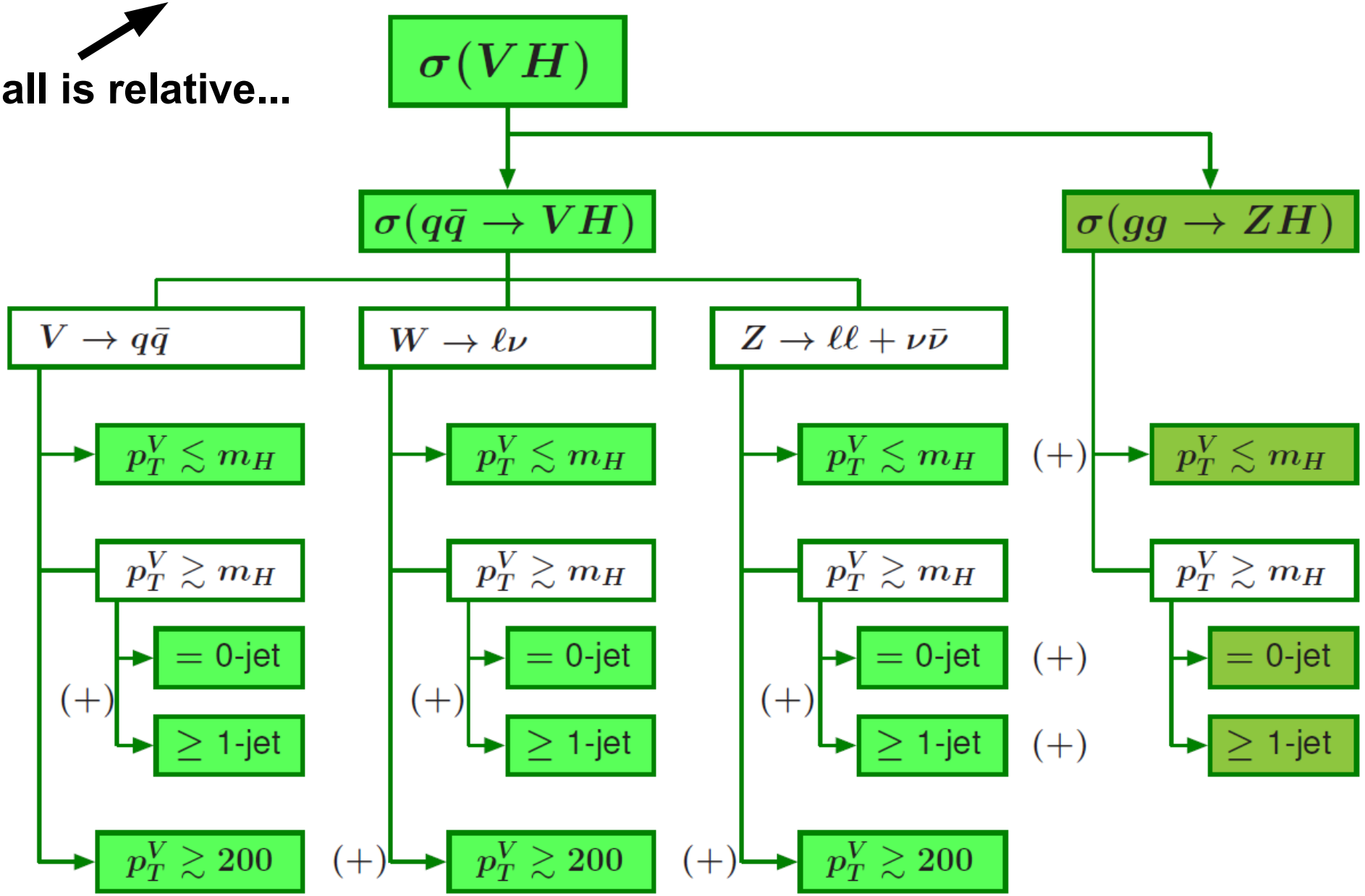



- Instead or in addition to binning in $\Delta\phi_{jj}$ can use continuous parameter to allow for a CP-odd admixture

# Details...

## VH: Small.

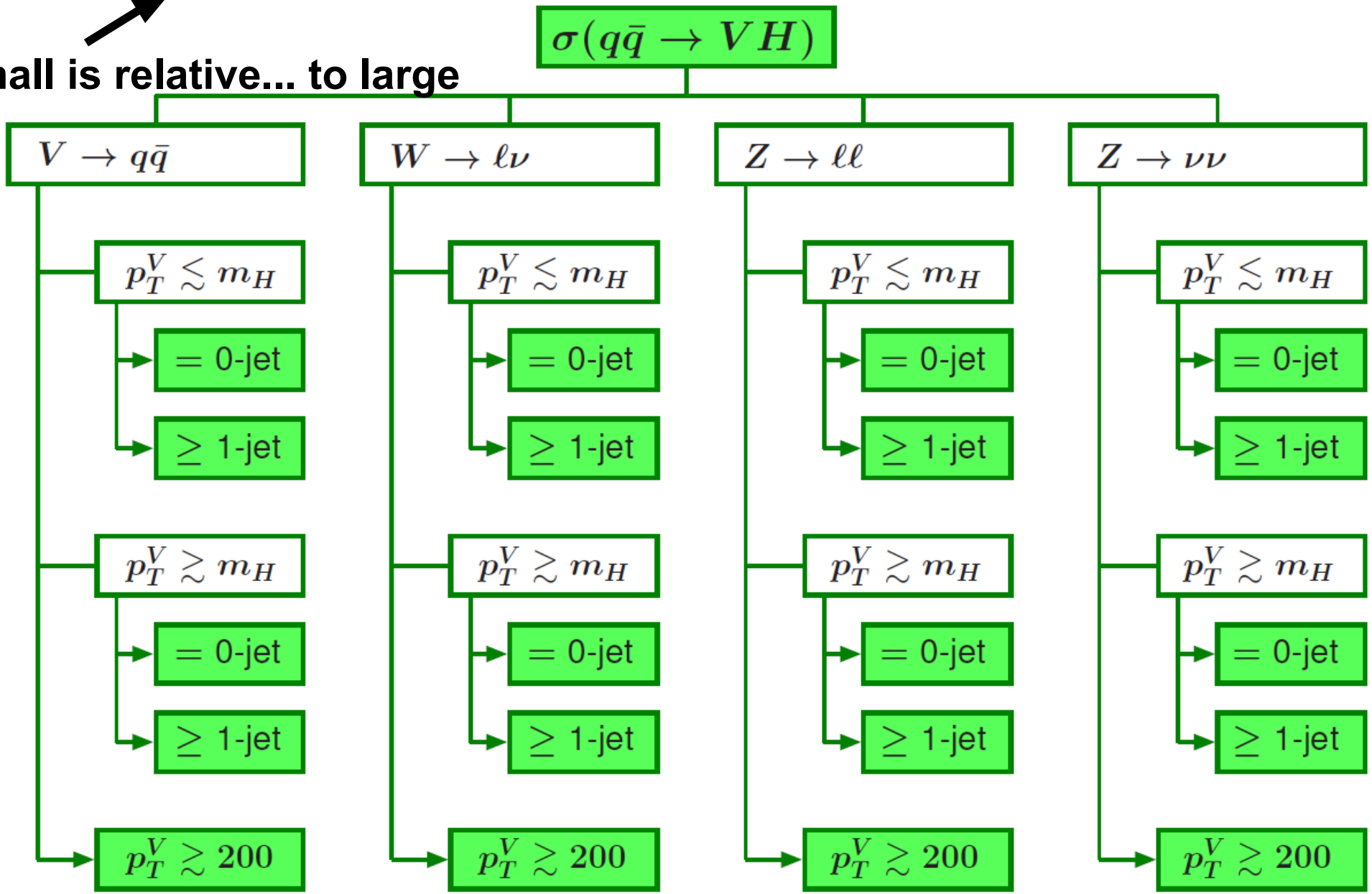
**Small is relative...**



# Details...

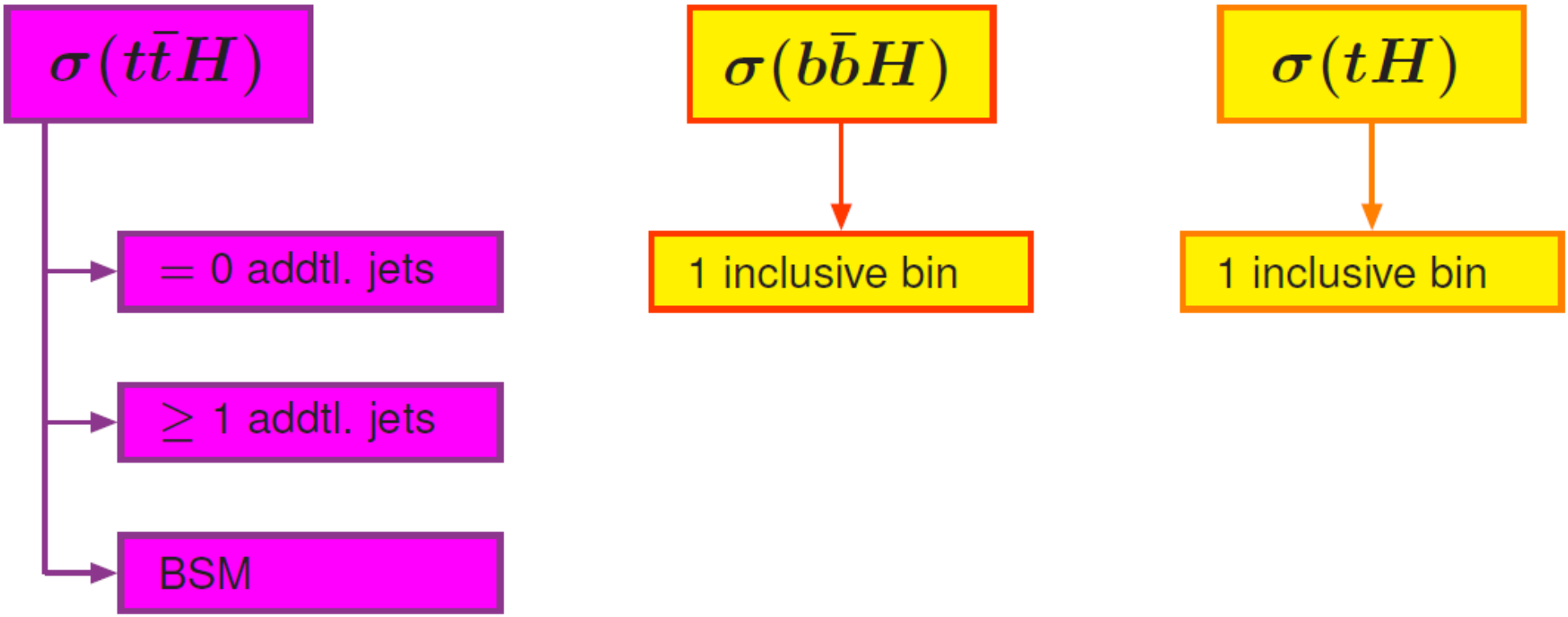
**$q\bar{q} \to VH$: Medium-Term** (similarly for $gg \to ZH$).

**Small is relative... to large**



# Details...

## Other Production Channels: Medium-Term.



# … and more details

- Need to define all cuts very well!
  - Which jet algorithm, pT, eta range, …?
  - Which (truth) particles are clustered in jets?
    → ideally, should exclude Higgs decay particles
  - What is a lepton? How to treat radiation?
  - What is ggH, VBF, VH?
- The theory bins are a convention
  - In principle no need to have the same convention between channels and experiments
  - However, would simplify all our lives a lot if the same convention is used!
- Treating decays the same way is likely unfeasible:
  - too many bins
  - Better use decay pseudo-observables

# Summary

- Simplified/Template cross sections are a proposal to replace our current μ measurements
  - Should make results more model independent
  - Should not compromise the analysis power

- This is still a proposal
  - Feedback to the LHC Higgs XS WG2 welcome
  - Especially concerning changes to bin definitions

- Simplified/Template cross sections should not replace fiducial/differential measurements
  - It is a compromise to get many advantages of fiducial measurements to those channels, where a fiducial measurement is not easy