Simplified Cross Section Framework for Higgs Measurements

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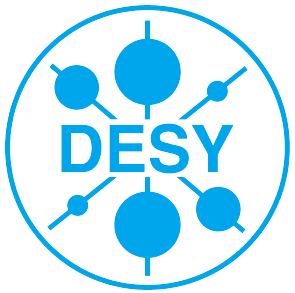
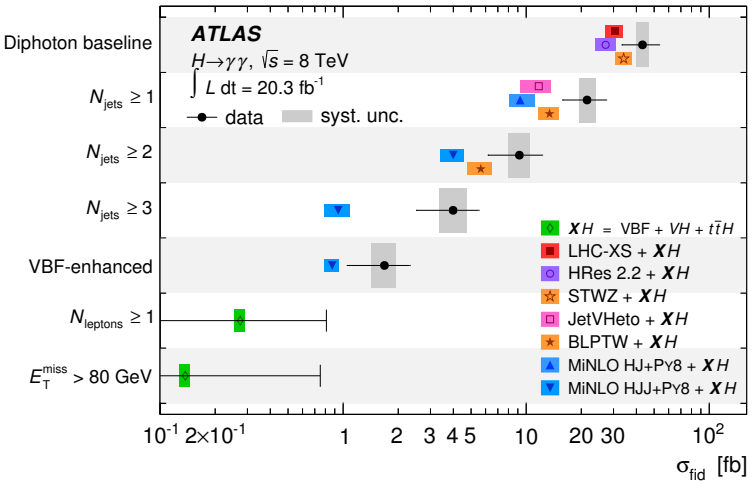
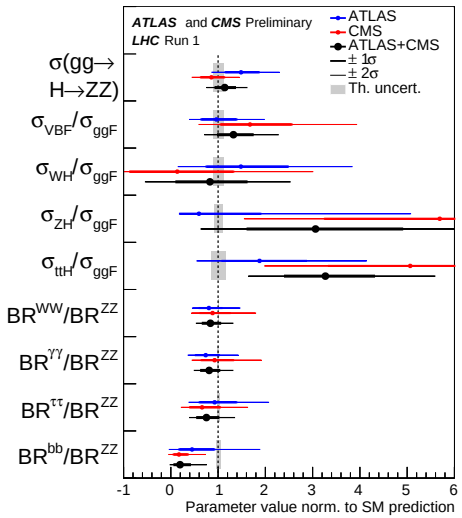
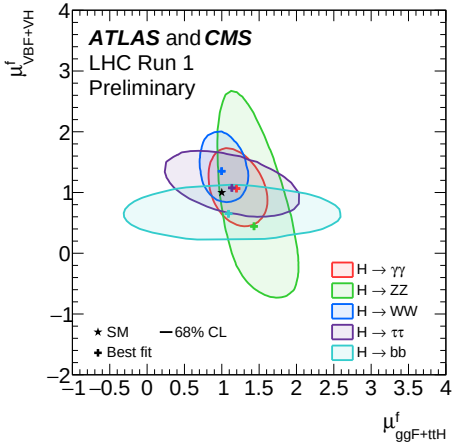


Measurement vs. Interpretation.







Measurement

Interpretation

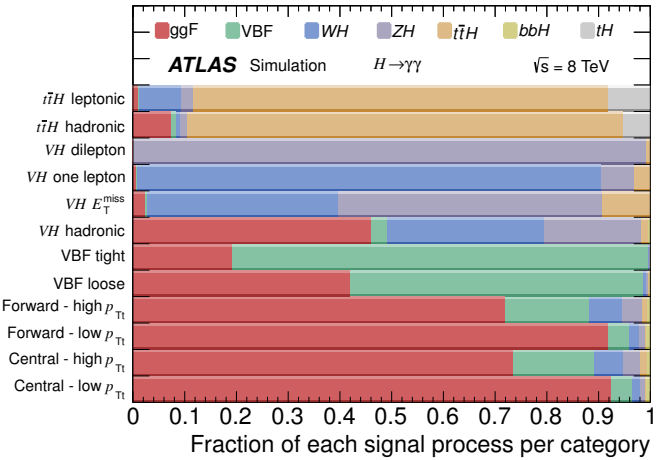
theory-independent

theory-dependent

where “Theory dependence” includes 2 aspects

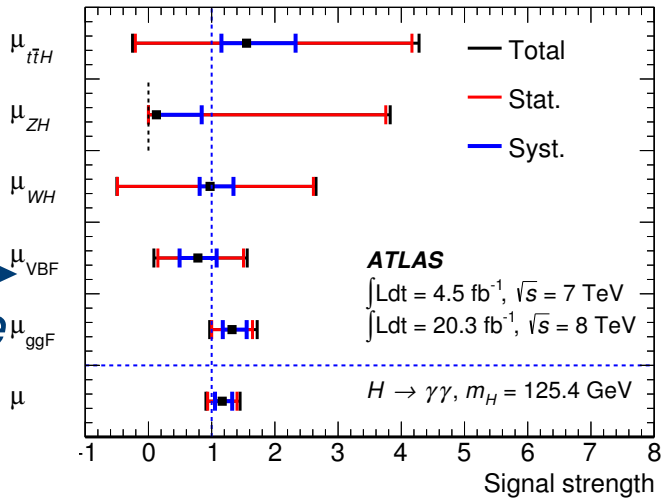
- Dependence on underlying physics model:
  - Assume/test a specific Lagrangian (linear/nonlinear EFT, specific model)
  - Dependence on kinematic distributions
- Dependence on theory systematics/uncertainties
  - In theory predictions that are needed to extrapolate to total cross sections
  - Perturbative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

Direct Coupling Fits.



Raw measurements

Direct theory dependence



Interpretation

Pros

- Maximum possible sensitivity
- Allows use of advanced selection techniques (MVAs, black magic, ...)
- 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 Cross Sections.

Pros

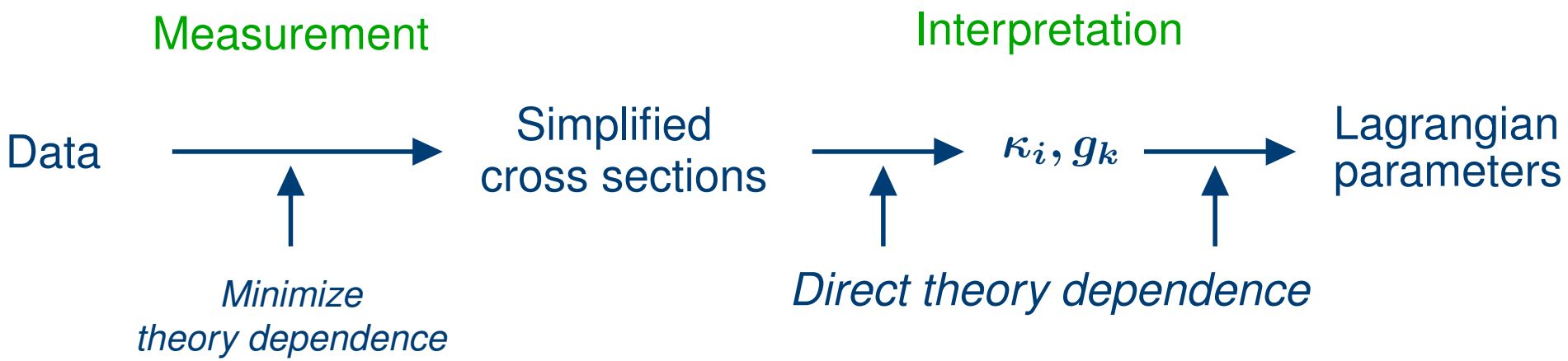
- Allows maximally theory-independent measurements
- Results remain long-term useful

$\Rightarrow$ The ultimate goal, but ...

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, anomalous couplings, EFT coefficients, specific models

Definition of Simplified Template Cross Sections.

Consider schematic μ fits:

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

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

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

- σ_i^{meas} are the measured analysis categories/selections
- A_i^{ggH}, A_i^{VBF} are acceptances for SM processes
  - theory-dependent

Definition of Simplified Template Cross Sections.

Consider schematic μ fits:

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

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

Definition of Simplified Template Cross Sections.

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

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

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

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

- Separately fit bin cross sections 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, can be implemented by experiments straightforwardly on top of existing MC samples

Trying to Get the Best of Both Worlds.

Difference compared to direct μ fits

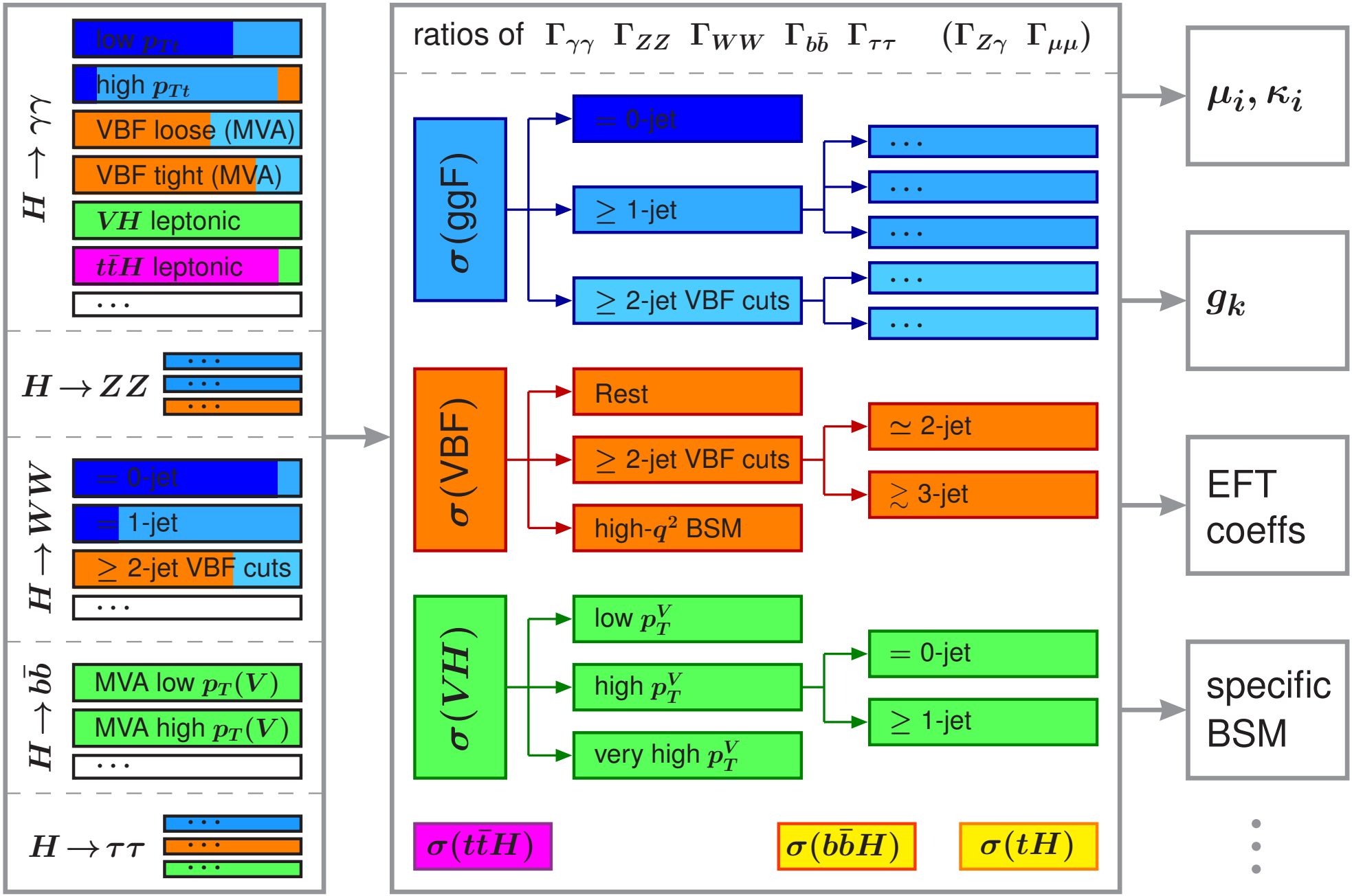
- Further split production modes into kinematic bins
- Fit for cross sections instead of μ_i

Difference compared to full-fledged 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

Simplified Template Cross Section Framework.



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)
  - Where does BSM change kinematics (e.g. high p_T bins)
- 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)

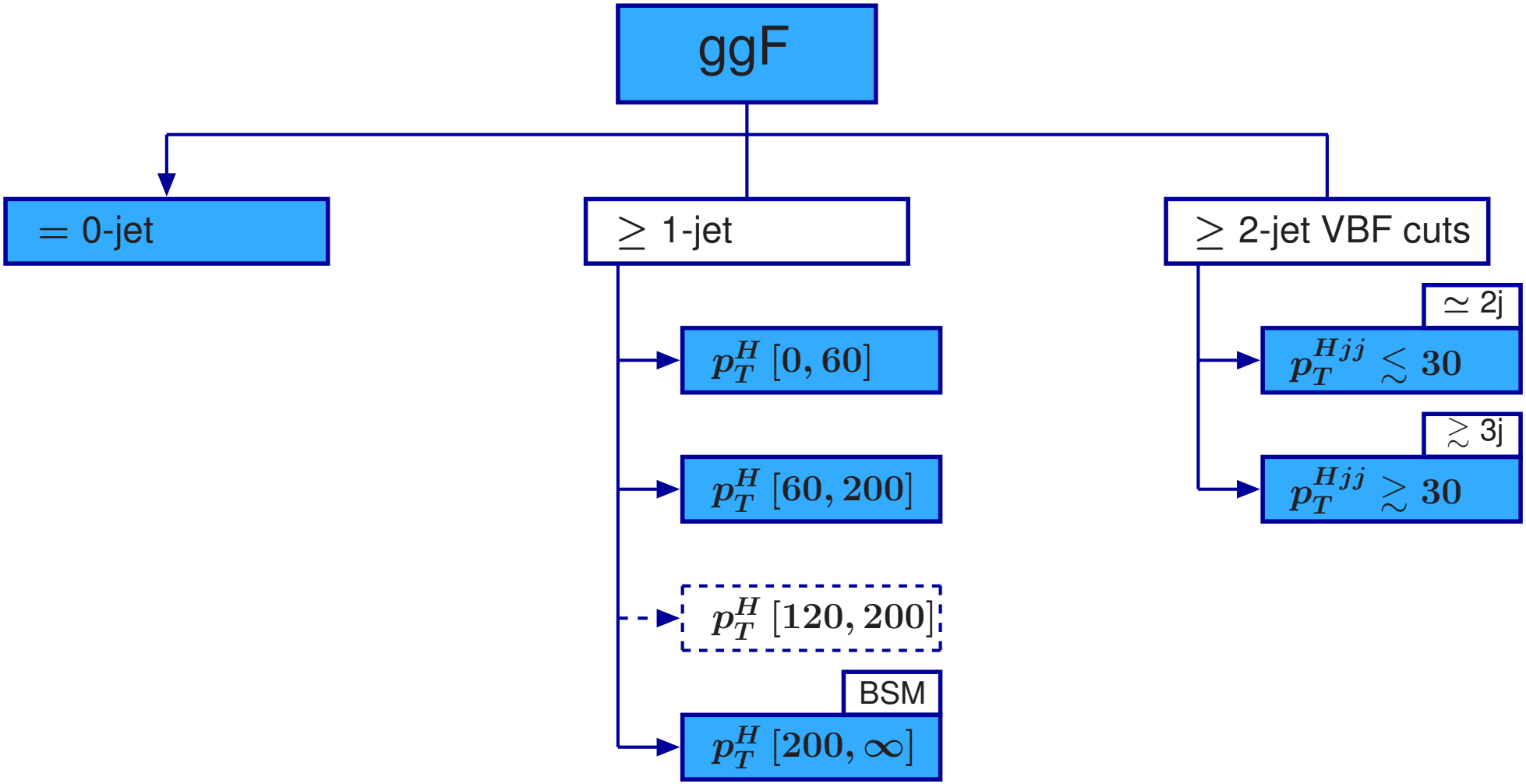
Bin Definitions.

In the following: Current proposal (still under discussion)

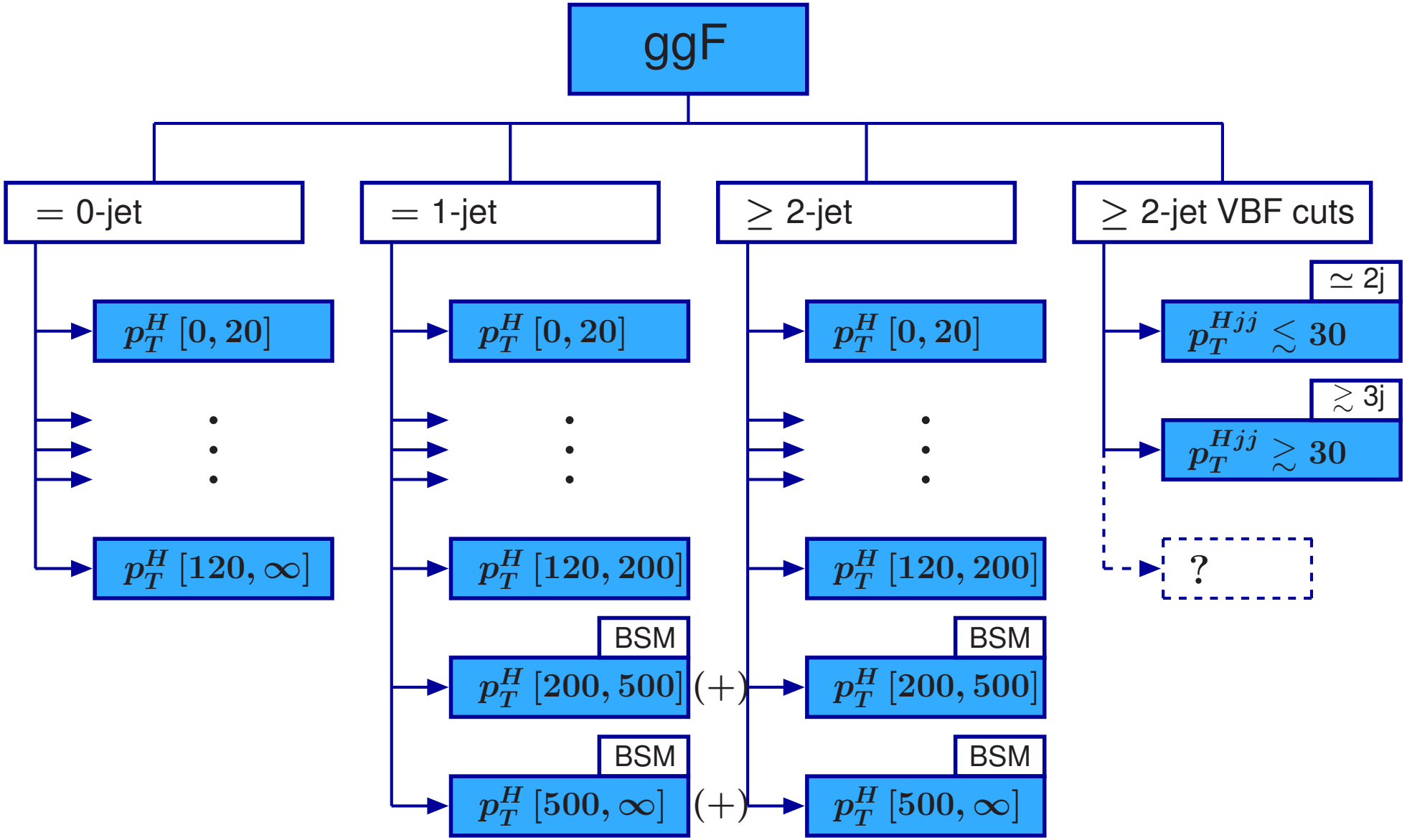
- Tries to balance minimal requirements for theory uncertainties and BSM sensitivity with experimental feasibility
- Define two scenarios
  - "Small" : target 2016 data/analyses
  - "Evolved": medium-term, somewhere between now and 300/fb
- Bins on each branch are always defined to be mutually exclusive and to sum up to parent bin
- "$(+)$" means bins are already separated in the implementation but could be combined in the fit at first

$\Rightarrow$ Hoping to finalize soon, feedback and ideas are still very welcome

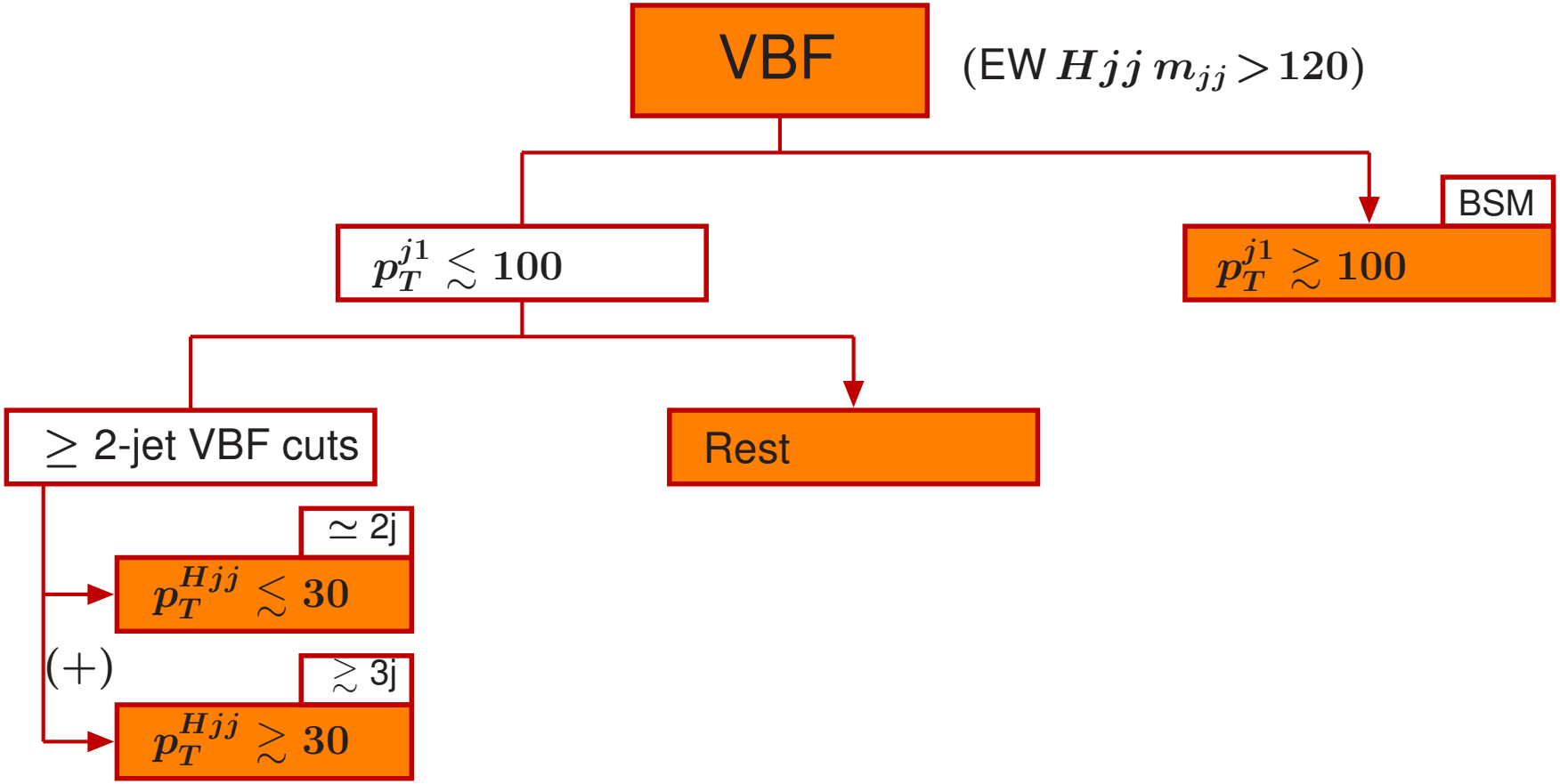
$gg \to H$: Small.


ggF
$= 0$-jet
≥ 1-jet
≥ 2-jet VBF cuts
$p_T^H\ [0, 60]$
$p_T^H\ [60, 200]$
$p_T^H\ [120, 200]$
BSM
$p_T^H\ [200, \infty]$
$\simeq$ 2j
$p_T^{Hjj} \lesssim 30$
$\gtrsim$ 3j
$p_T^{Hjj} \gtrsim 30$

$gg \to H$: Evolved.

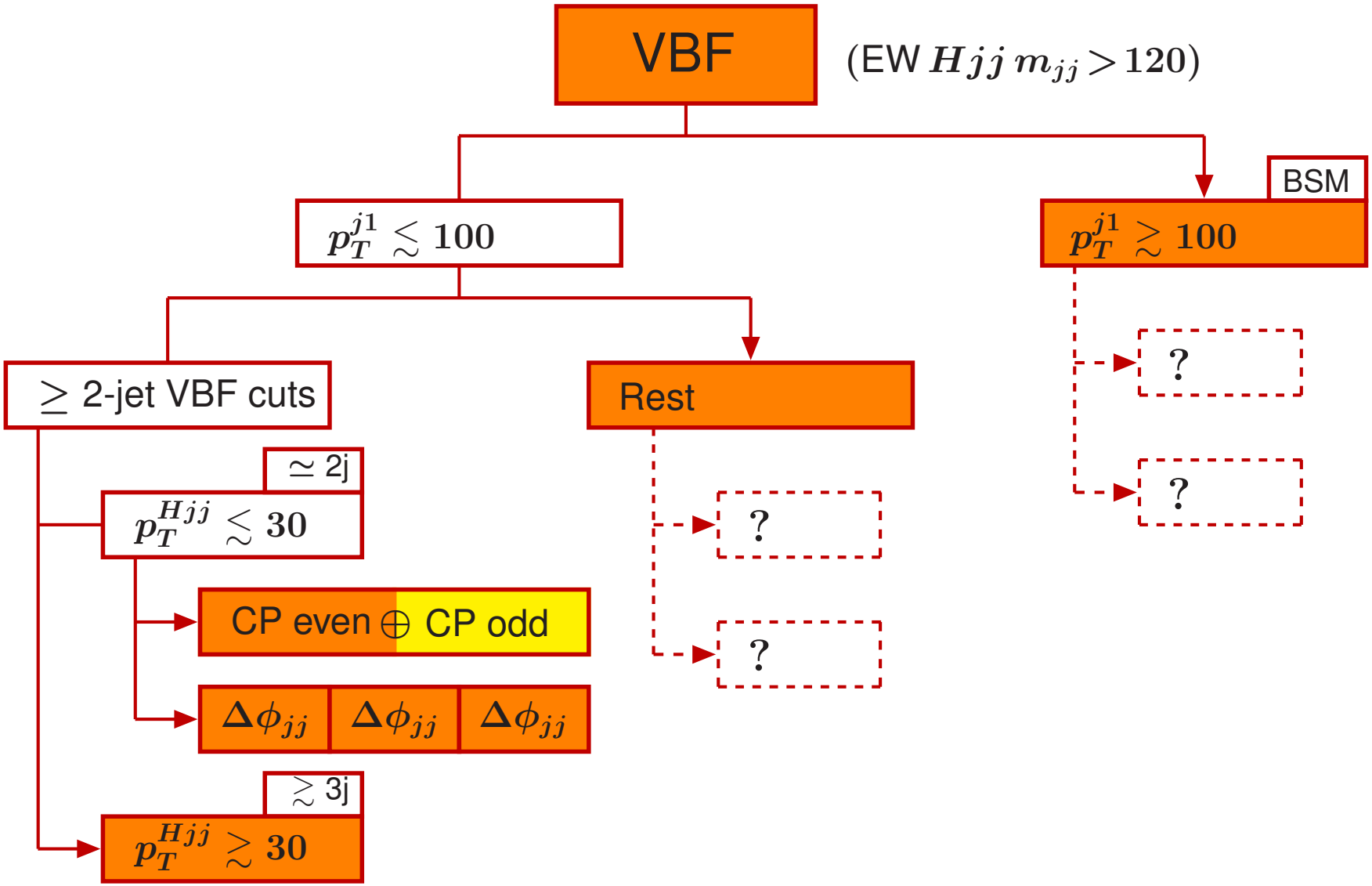


VBF: Small.



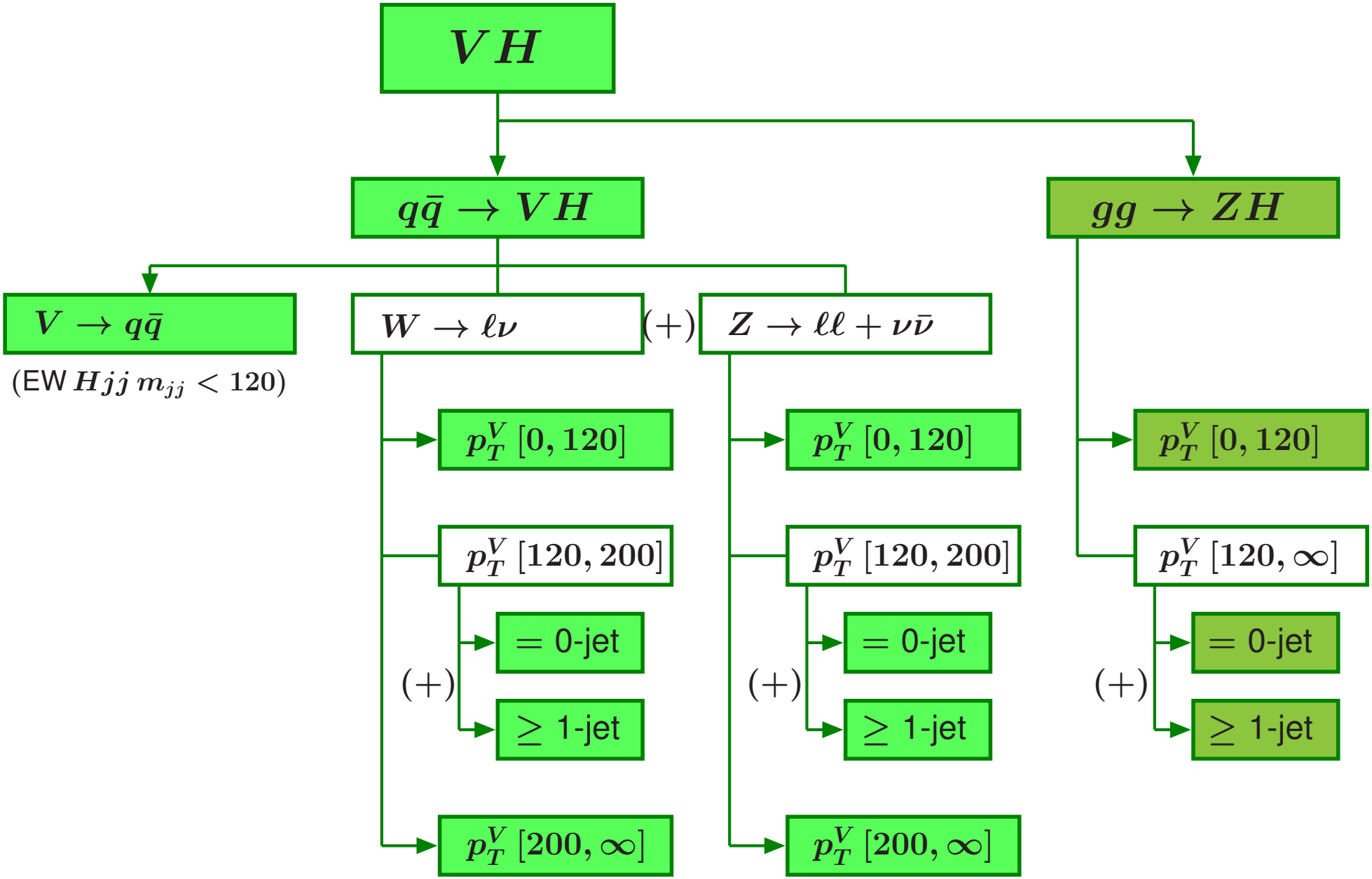
- nominal VBF cuts are to be decided
  - something like $m_{jj} > 400$ and $\Delta\eta_{jj} > 2.8$

VBF: Evolved.

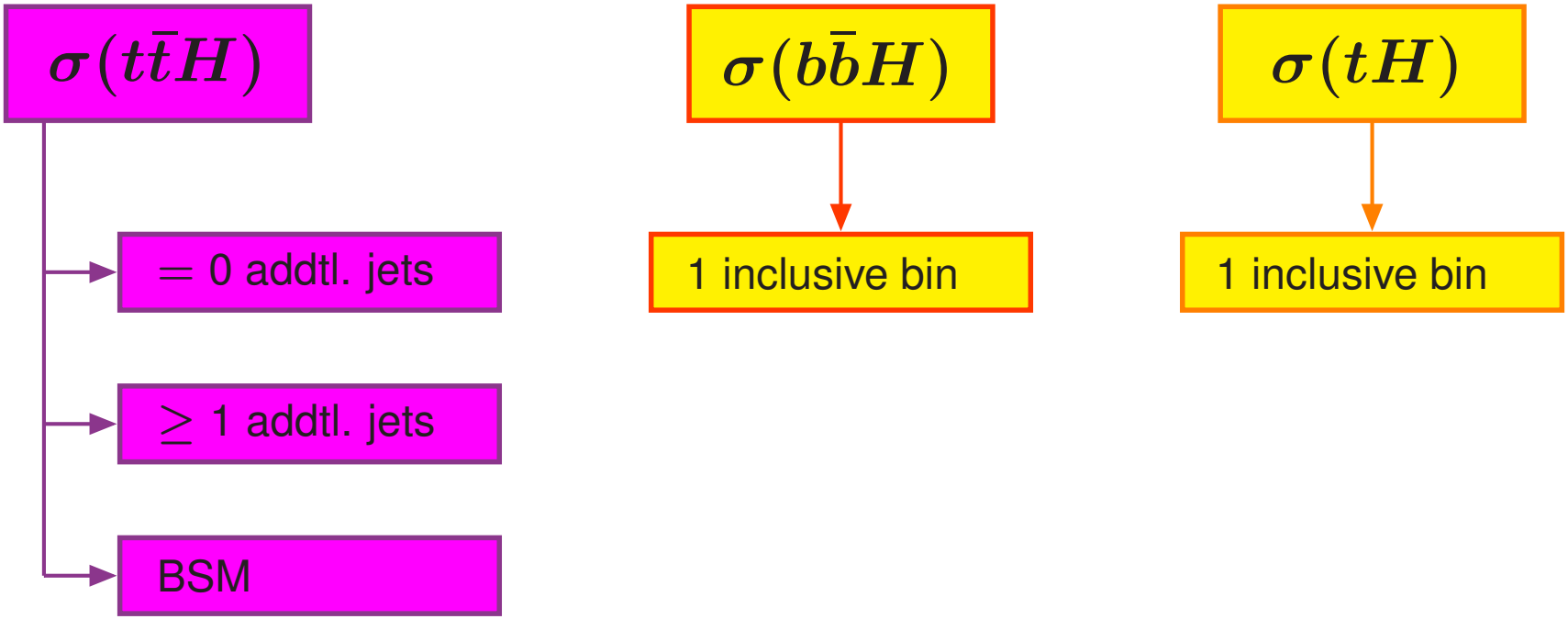


- Instead or in addition to binning in $\Delta\phi_{jj}$ can use continuous parameter to allow for a CP-odd admixture

VH: Small.


VH
$q\bar{q} \to VH$
$gg \to ZH$
$V \to q\bar{q}$
(EW Hjj $m_{jj} < 120$)
$W \to \ell\nu$
(+)
$Z \to \ell\ell + \nu\bar{\nu}$
$p_T^V\,[0, 120]$
$p_T^V\,[120, 200]$
$p_T^V\,[200, \infty]$
$p_T^V\,[0, 120]$
$p_T^V\,[120, 200]$
$p_T^V\,[200, \infty]$
$p_T^V\,[0, 120]$
$p_T^V\,[120, \infty]$
(+)
= 0-jet
≥ 1-jet
(+)
= 0-jet
≥ 1-jet
(+)
= 0-jet
≥ 1-jet

Other Production Channels: Evolved.



- With enough statistics can start adding other production channels

Decays and Backgrounds.

Treatment of decays

- Unfold to on-shell fully-inclusive Higgs (considering cut on $|Y_H| \lesssim 2.5$)
- Fit ratios of partial widths $\Gamma_{\gamma\gamma}$, Γ_{ZZ}, Γ_{WW}, $\Gamma_{b\bar{b}}$, $\Gamma_{\tau\tau}$, ...
- Future: Can be extended with decay POs

Treatment of backgrounds

- non-Higgs backgrounds are assumed SM and subtracted on the experimental side
- Future: Backgrounds that can receive BSM contributions (e.g. $pp \to WW$) can be added as another template and treated like the signal

Summary.

The Proposal

- is that this will be the lowest layer of how experiments publish results for individual channels, combination of channels, and ATLAS+CMS combination
  - Do κ fits (or any other interpretations) with these as input layer
  - Publication includes 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, off-shell studies, dedicated BSM searches, etc.)

YOUR input is very important

- Test if/how your favourite BSM model, EFT, etc. maps into these bins
- Tell us if there are large (kinematic) model dependences *inside* a bin
  - ... and what a useful split would be