



Northwestern
University

Status report from the LHC EFT WG

A. Gilbert on behalf of the LHC EFT WG conveners
LHC EW WG General Meeting | 16 November 2022

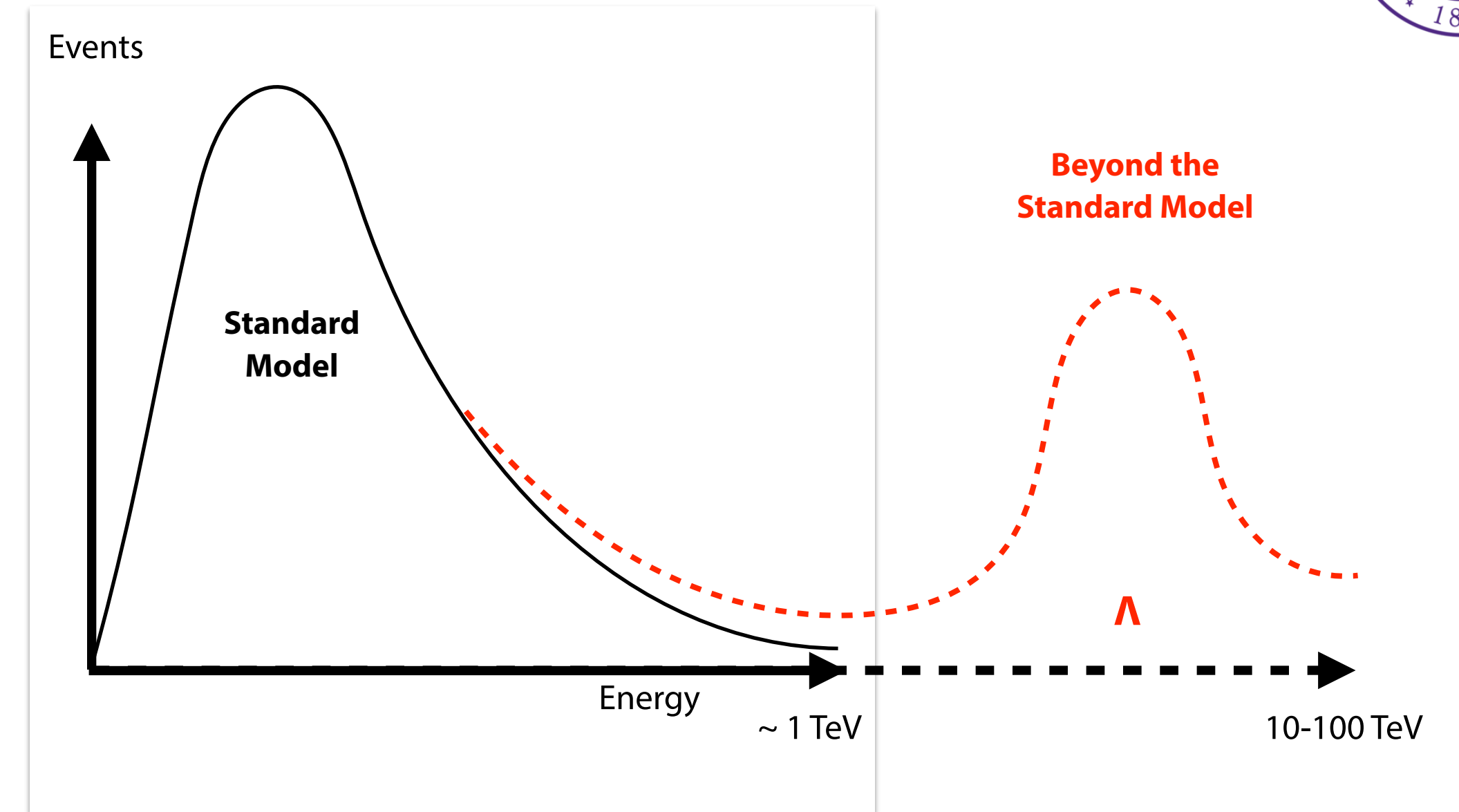


The LHC EFT WG

- Goal: Advise and develop recommendations for EFT measurements at the LHC
 - **General information:** [\[link\]](#), [\[Twiki\]](#), **Contact:** lhc-eftwg-admin@cern.ch
- Organisation:
 - Area 1: EFT formalism
 - Area 2: Predictions and tools
 - Area 3: Experimental measurements and observables
 - Area 4: Fits and related systematics
 - Area 5: Benchmark scenarios from UV models
 - Area 6: Interplay/connection with flavour
- Conveners:
 - **ATLAS:** Nicolas Berger, Sandra Kortner, Jacob Kempster, Kristin Lohwasser
 - **CMS:** Matteo Presilla, Nadjieh Jafari, Robert Schoefbeck, Nicholas Wardle
 - **LHCb:** Patrick Owen
 - **Theory:** Ilaria Brivio, Anke Biekötter, Shankha Banerjee, Gauthier Durieux, Admir Greljo, Ken Mimasu

The SM EFT approach

- Strong motivation for new physics at the TeV scale
 - Energy scale of new physics (Λ) may be beyond our direct reach
- Construct an effective field theory starting from the known SM fields and symmetries
 - No specific high-energy (UV complete) theory required
 - Provides a renormalisable quantum field theory
 - Universal - can connect to other experiments
- Expand in powers of $(1/\Lambda)$:



$$L_{\text{EFT}} = L_{\text{SM}} + \sum_i \frac{C_i^{(5)}}{\Lambda} \mathcal{O}_i^{(5)} + \sum_i \frac{C_i^{(6)}}{\Lambda^2} \mathcal{O}_i^{(6)} + \sum_i \frac{C_i^{(7)}}{\Lambda^3} \mathcal{O}_i^{(7)} + \sum_i \frac{C_i^{(8)}}{\Lambda^4} \mathcal{O}_i^{(8)} + \dots$$

~~Lepton-number violating~~ Violates B-L

\mathcal{O}_i : operators = interaction terms at a given expansion order

C_i : operators = Wilson coefficients, free parameters

- First relevant order at dimension 6
- Dimension 8 also important for certain processes

Area 1: EFT formalism

- Goal: establish the key parameters of the EFT formalism: what **operators**, what **bases**, what **perturbation orders**, how to **combine operators** of different dimensions, which **flavour** and **symmetry** assumptions

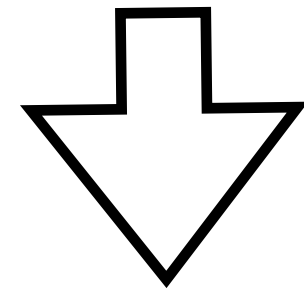
arXiv:2111.12515

- Scheme dependence: $\{\alpha, G_\mu, m_Z\}$, $\{G_\mu, m_Z, m_W\}$ or $\{\alpha, m_Z, m_W\}$?
 - Used at LEP** (points to α, G_μ, m_Z)
 - Used in many tools** (points to G_μ, m_Z, m_W)
 - Avoid leptonic corrections to G_μ** (points to α)
 - Avoid large W/Z propagator corrections** (points to m_Z, m_W)

- Public note released, recommending the $\{G_\mu, m_Z, m_W\}$ scheme:

- EFT expansion:

$$L_{\text{EFT}} = L_{\text{SM}} + \sum_i \frac{C_i^{(6)}}{\Lambda^2} \mathcal{O}_i^{(6)} + \sum_i \frac{C_i^{(8)}}{\Lambda^4} \mathcal{O}_i^{(8)} + \dots$$



$$\sigma \propto A_{\text{SM}} + \sum_i \frac{C_i^{(6)}}{\Lambda^2} A_i^{(6)} + \sum_{i,j} \frac{C_i^{(6)} C_j^{(6)}}{\Lambda^4} A_{ij}^{(6)} + \sum_k \frac{C_k^{(8)}}{\Lambda^4} A_k^{(8)} + \dots$$

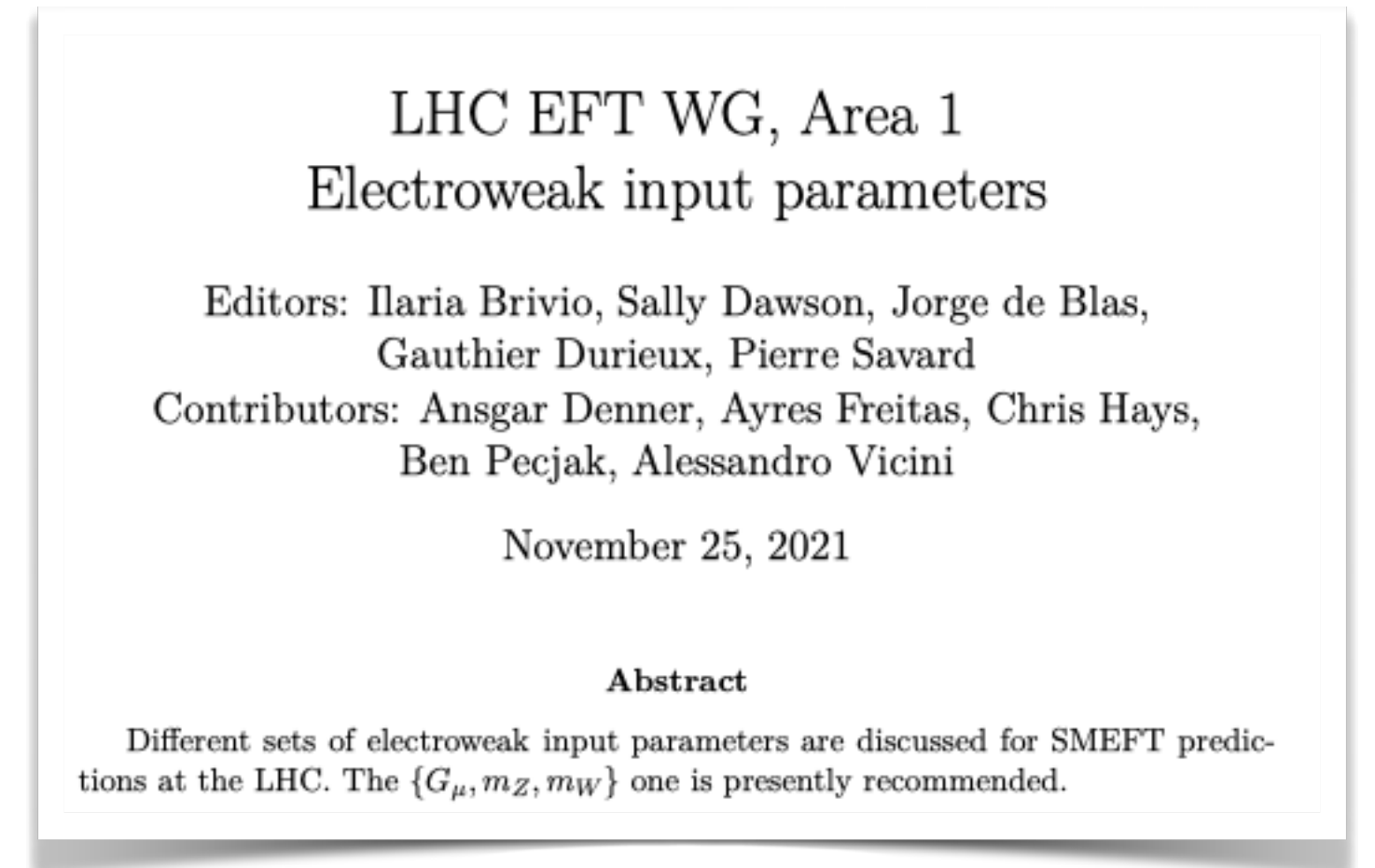
Leading dim-6 interference term with the SM

Quadratic "pure BSM" dim-6

SM - dim-8 interference

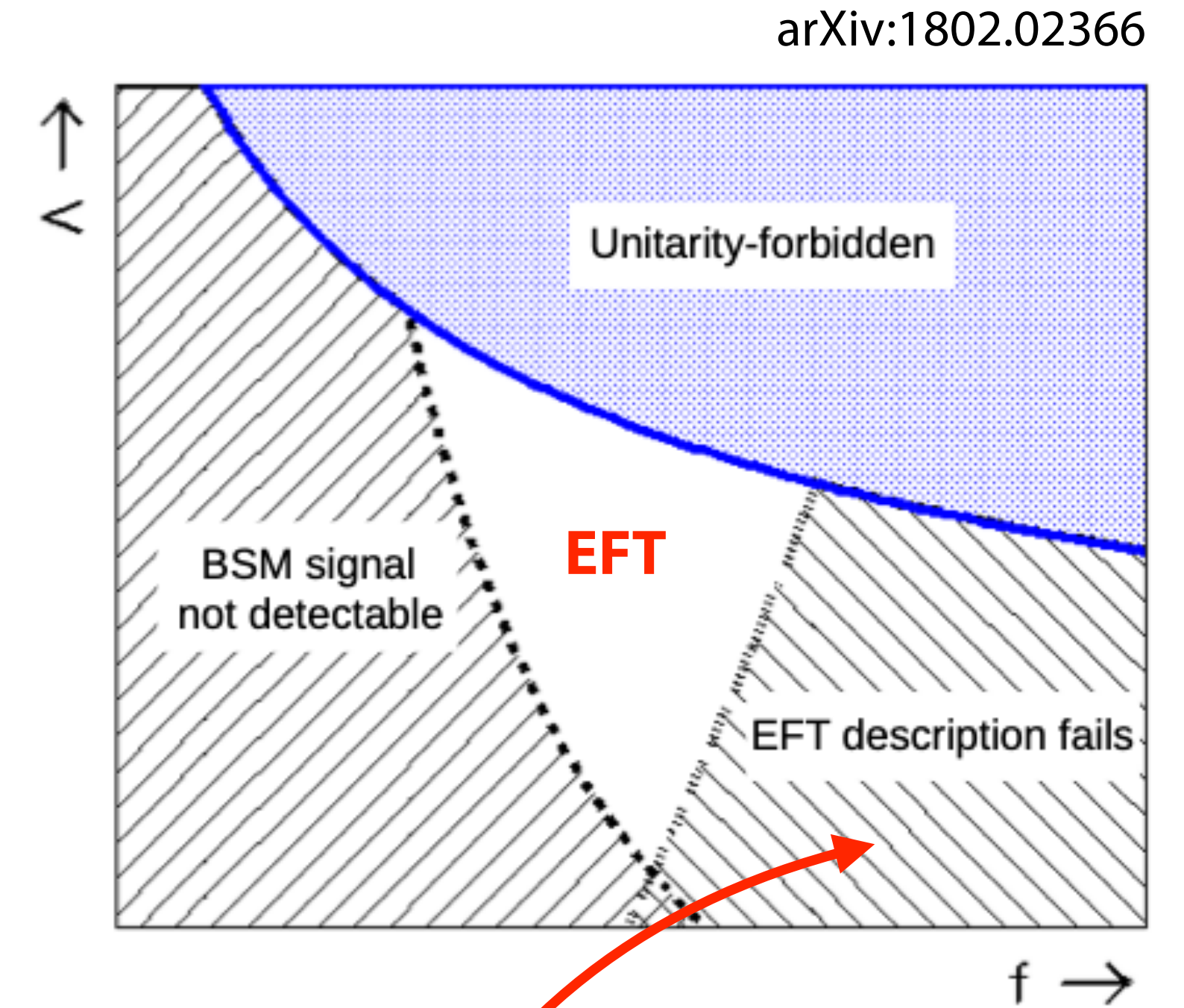
Baseline assumption: dim6, however:

- SM-dim8 interference also at $1/\Lambda^4$
- Dim8 calculated for subset of processes
- $(\text{dim6})^2$ may be large compared with SM-dim6 interference



Area 1: EFT validity

- Want to know if our EFT prediction for $\sigma(c_i^{(6)}, c_k^{(8)}, \dots)$ is valid - i.e. does it describe the true model underlying the data?
 - Depends on the concrete NP model, but hope generically valid for $E < \Lambda$
- Which terms to keep in the EFT expansion?
 - Ideally: $1/\Lambda^4$ terms small compared to $1/\Lambda^2$, and dim8 small compared to dim6
 - Known not to be the case (e.g. WV cross sections has large dim6², VBS w/ large dim8)
 - **Consensus:** by default include **dim6 linear+quadratic**, linear-only for comparison
- Up to which energy scale is the EFT valid? Considerations:
 - How to define it - which quantity? \Rightarrow Process (and EFT operator) dependent
 - Violation of unitarity (depends on c_i and Λ)
 - What to do if experimental measurement includes regions where the EFT is known to be invalid?
- Incorporate theoretical uncertainties in the SMEFT?
 - Different options, e.g. geoSMEFT
 - May also need to account for higher orders in QCD & EW



$$f_i^{(6)} = \frac{C_i^{(6)}}{\Lambda^2}, \quad f_i^{(8)} = \frac{C_i^{(8)}}{\Lambda^4}, \dots$$

Λ too low: dim6-only assumption not valid

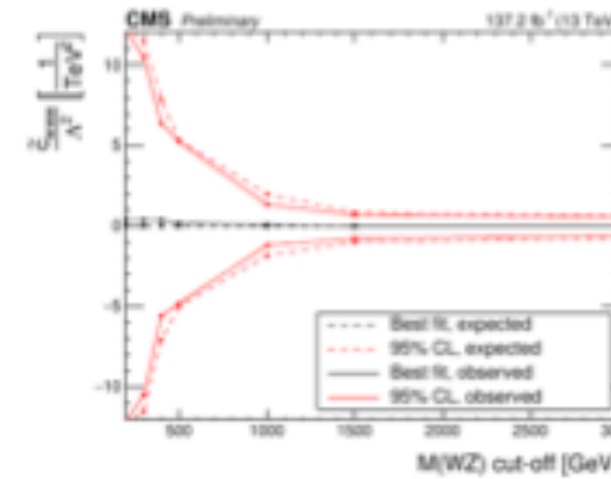
Area 1: Proposals

- Several options for dealing with the case that EFT model is not valid in some parts of the phase space
- Based on topical meetings in January and June 2021 - public note first released in January and **updated today with additional proposal**

N. Berger

“A & B”

- Include **d=6 linear ($1/\Lambda^2$) + quadratic ($1/\Lambda^4$) terms**, linear-only model for comparison only.
- Apply **clipping on data**: most natural for theory, but more difficult for analyses (need to repeat the analysis for several cutoffs)
- Provide exp. results as a function of E_{cut} , use best E_{cut} for each UV model.



“D”

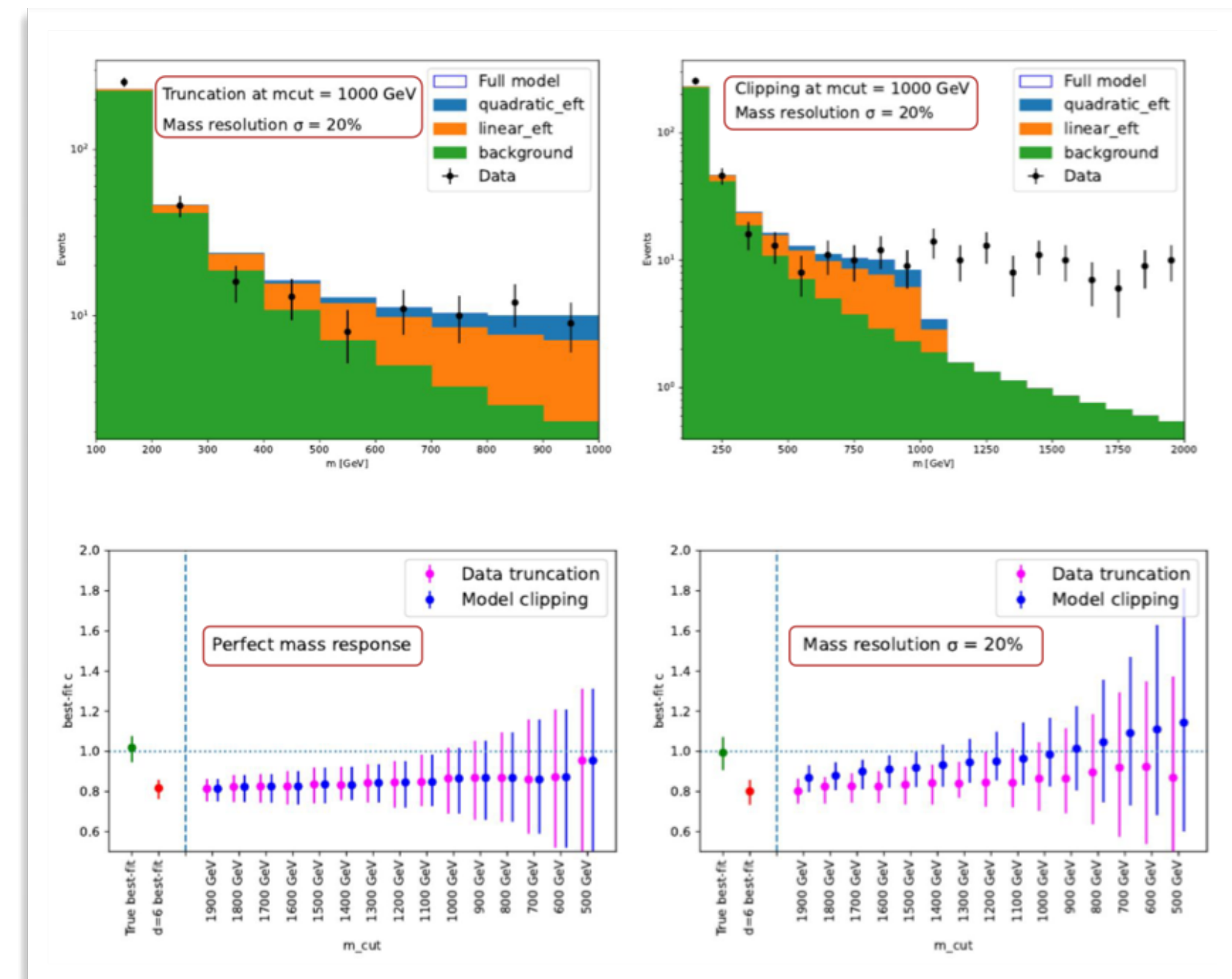
- Same as above, but apply **clipping on the EFT prediction**.
→ Experimentally easier, equivalent to clipping data for well-measured E observables but questionable in other cases (is the clipped model a consistent description of the data ?)

“C”

- **Add uncertainties**: closest to usual treatment of theory unknowns in LHC measurements, but need proper determinations of magnitudes (use size of $(d=6)^2$ terms as proxy ?) and correlation scheme (decorrelate across observables and c_i ?)

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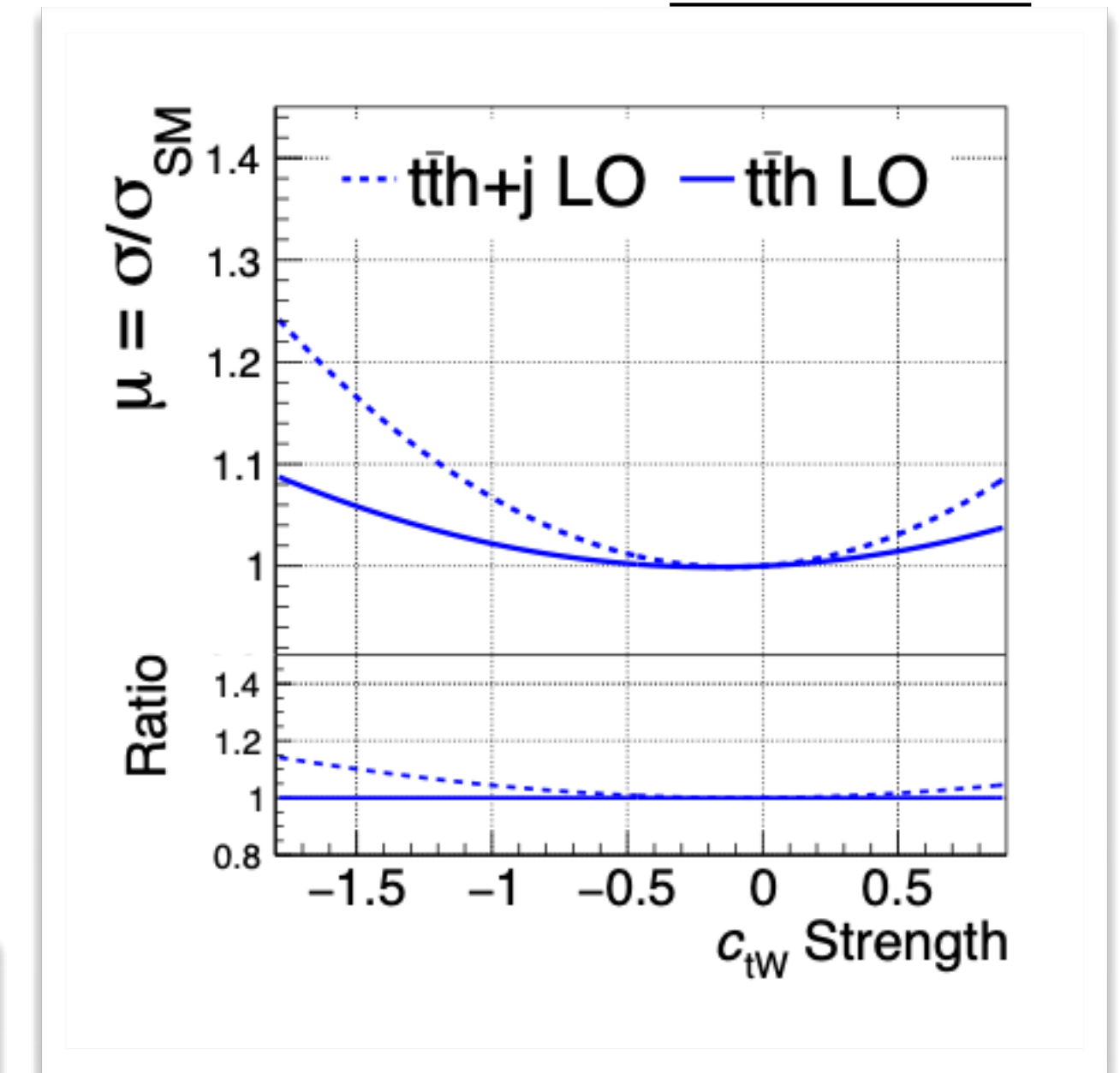
Toy studies of different approaches:



[\[link\]](#)

Area 2: Predictions & tools

- Goals: (twiki)
 - Track the various tools that are used to provide EFT predictions
 - Organise cross-validation
 - E.g. this year compared predictions of JHUGen vs SMEFTsim, SMEFT@NLO vs SMEFTsim
 - Provide recipes and recommendations on usage
- Topical meeting in January this year, topics including:
 - Effect of additional jets in $t\bar{t}+X$ EFT modelling - can lead to sizeable corrections
 - Framework for MC/MC comparisons
 - LHE level study of dim6 sensitivity in VBS (and global fit with WW)



Tag, generator, model, processes, parameter point

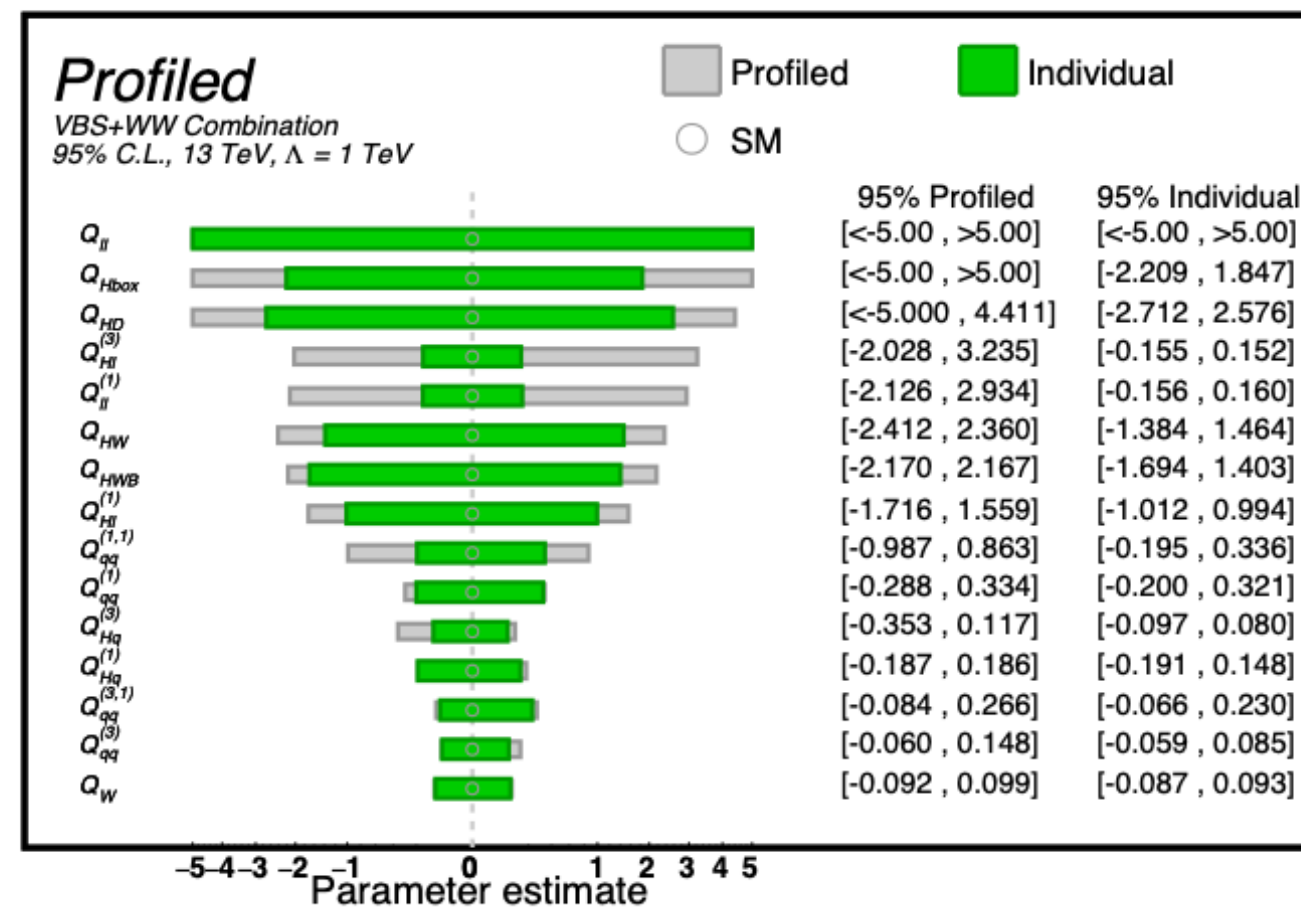
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      <weight_generator>MadGraph5_aMC@NLO_v2.6.5</weight_generator>
      <weight_model-version>dim6top_LO_UFO v1.0 Sat 8 Dec 2018 14:17:45</weight_model_version>
    </weight_card>
  </weightgroup>
</initrwgt>
```

Human-readable tables

		interference			square		
1.20 $gg \rightarrow t\bar{t}$		mod1	mod2	1 - mod2/mod1	mod1	mod2	1 - mod2/mod1
ctG	0.1391	0.1391	0	0	0.08771	0.08771	0
ctGI	$9.152 \cdot 10^{-19}$	$-4.544 \cdot 10^{-8}$	$4.966 \cdot 10^{10}$	0	0.08173	0.08173	0
sm	0	0	0	0	0.4418	0.4418	0

Phase-space point, squared matrix elements

```
<event>
4
  2 +5.7925728e-01 9.11180000e+01 0.00000000e+00 1.18400000e-01
  21 -1 0 0 0 0 +0.00e+00 +0.00e+00 +5.00e+02 5.00e+02 0.00e+00 0.00e+00 9.00e+00
  22 -1 0 0 0 0 +0.00e+00 +0.00e+00 -5.00e+02 5.00e+02 0.00e+00 0.00e+00 9.00e+00
  -6 1 1 2 0 0 +1.66e+02 -3.90e+02 +2.01e+02 5.00e+02 1.72e+02 0.00e+00 9.00e+00
  6 1 1 2 0 0 -1.66e+02 +3.90e+02 -2.01e+02 5.00e+02 1.72e+02 0.00e+00 9.00e+00
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```



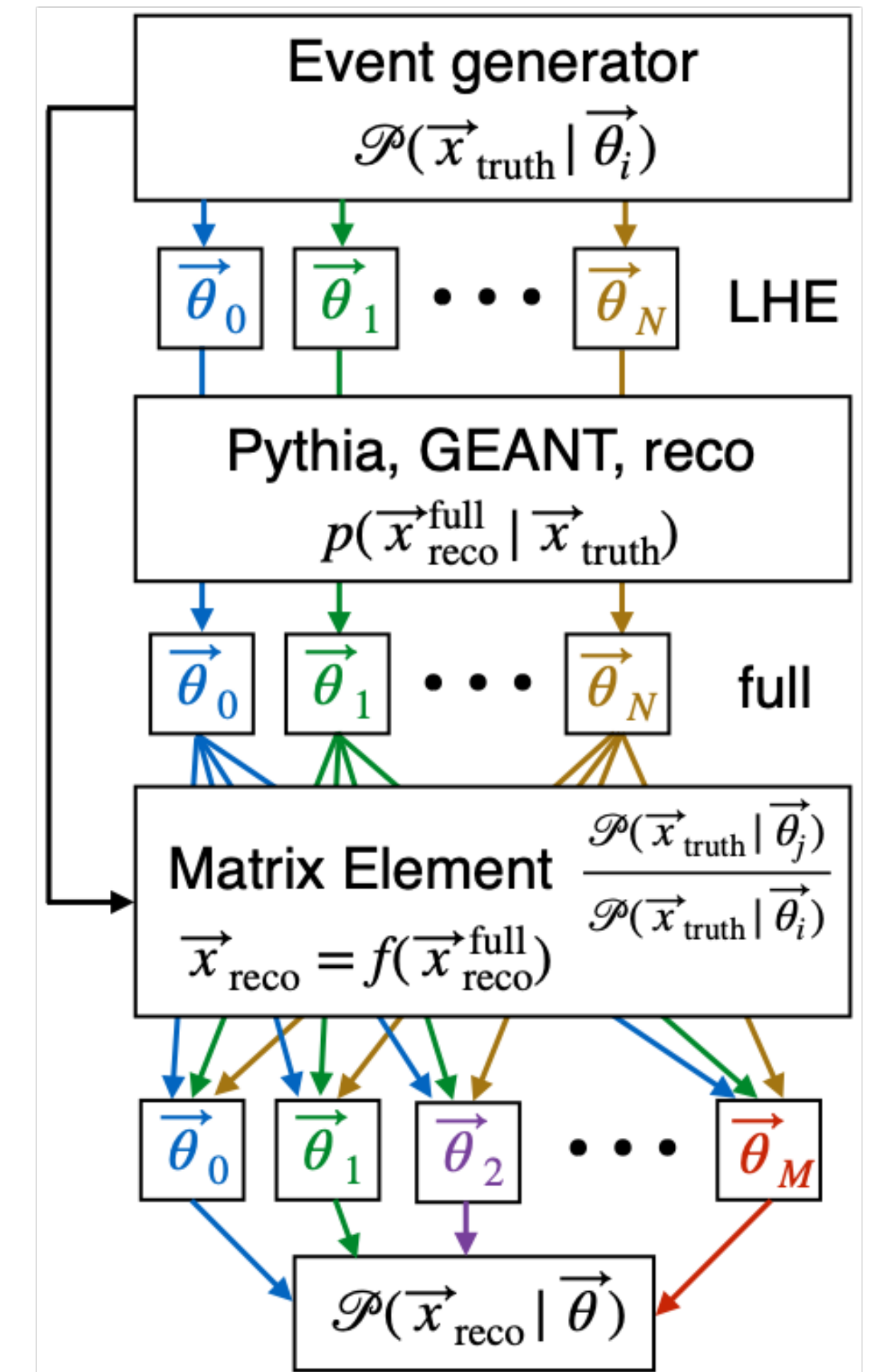
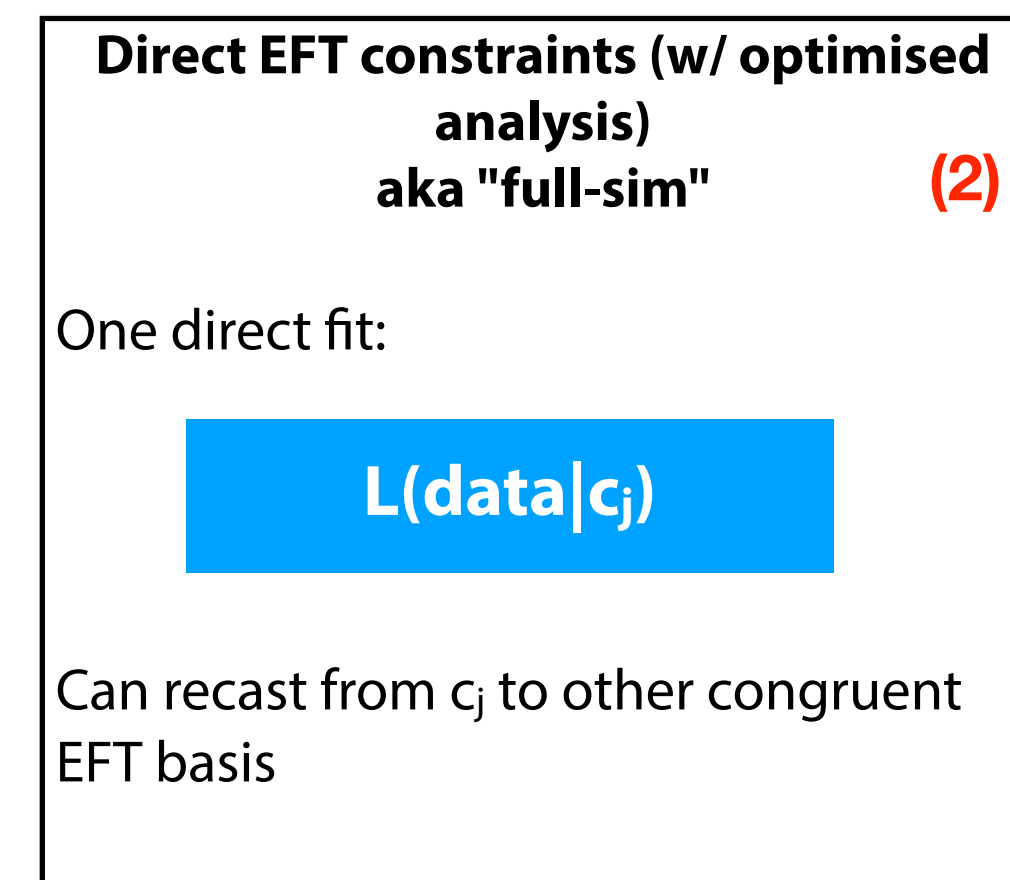
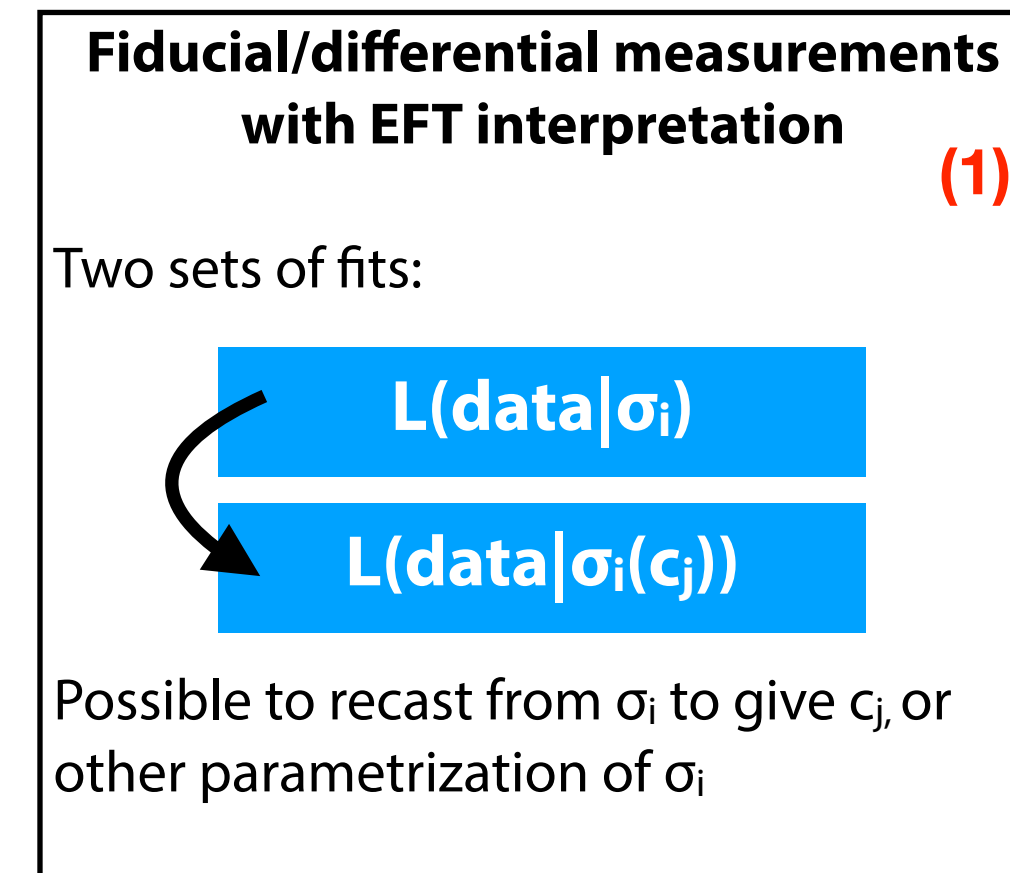
Proposal for comparison between different tools

(comparison of dim6top/SMEFTsim/SMEFT@NLO already studied)

G. Durieux

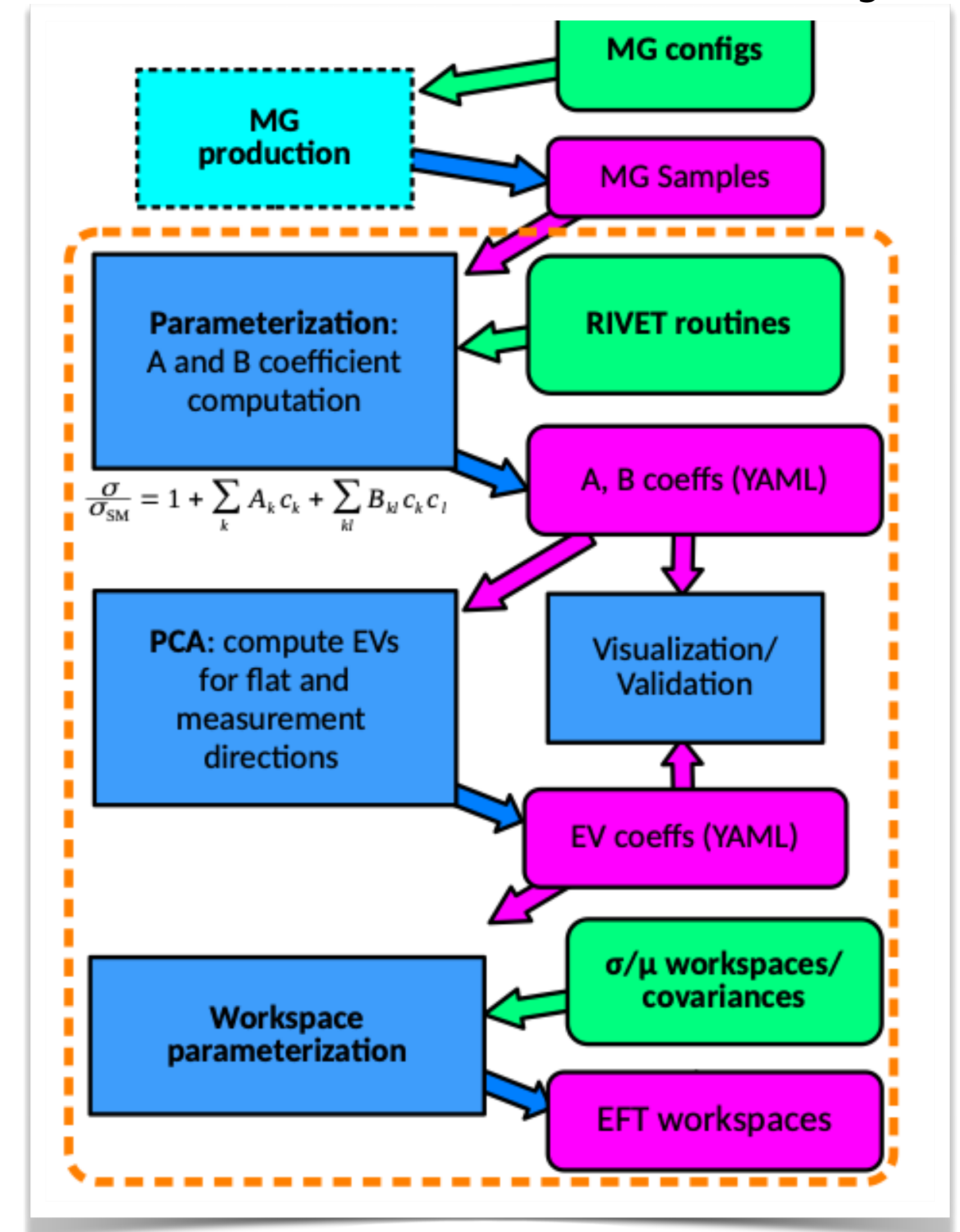
Area 3: Experimental measurements & observables

- Goals ([twiki](#)):
 - Study **experimental approaches** for EFT inference, **choice of observables** and **optimisation for sensitivity**
- Strategies:
 - **Two-step approach** (reinterpretation of diff./fid. measurements)
 - ▶ Easier to recast / incorporate in external global fits
 - ▶ Less sensitive, typically only 1-2 observables
 - **Direct approach**
 - ▶ Use of optimal / multi-variate observables for best sensitivity
 - ▶ Reinterpretation more difficult
- Observables:
 - Differential / fiducial XS
 - Higgs simplified template cross sections
 - Optimal observables: ME ratios, ML discriminators, etc.
- Associated uncertainties:
 - Detector / acceptance effects, unfolding, EFT in backgrounds
- Note released today!



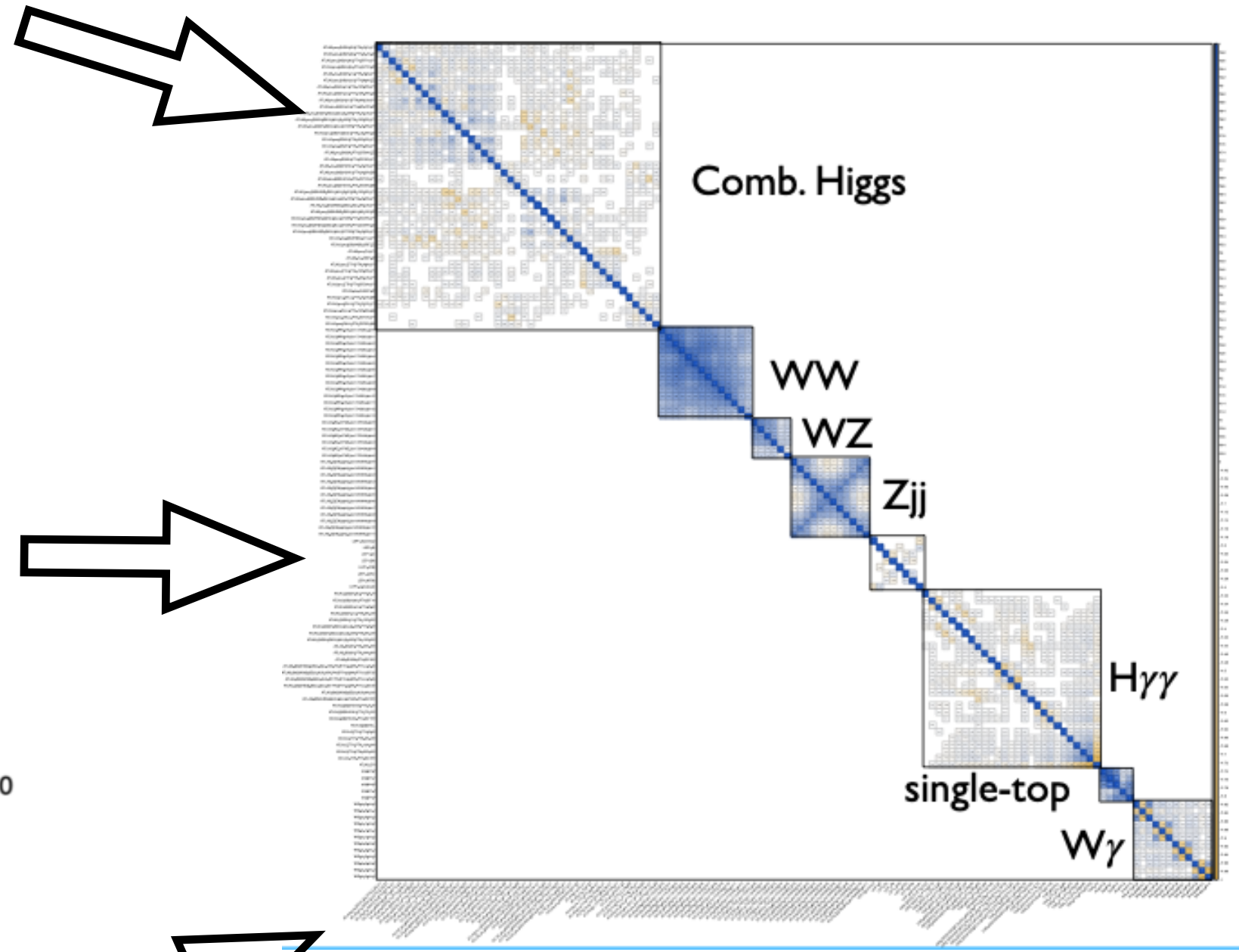
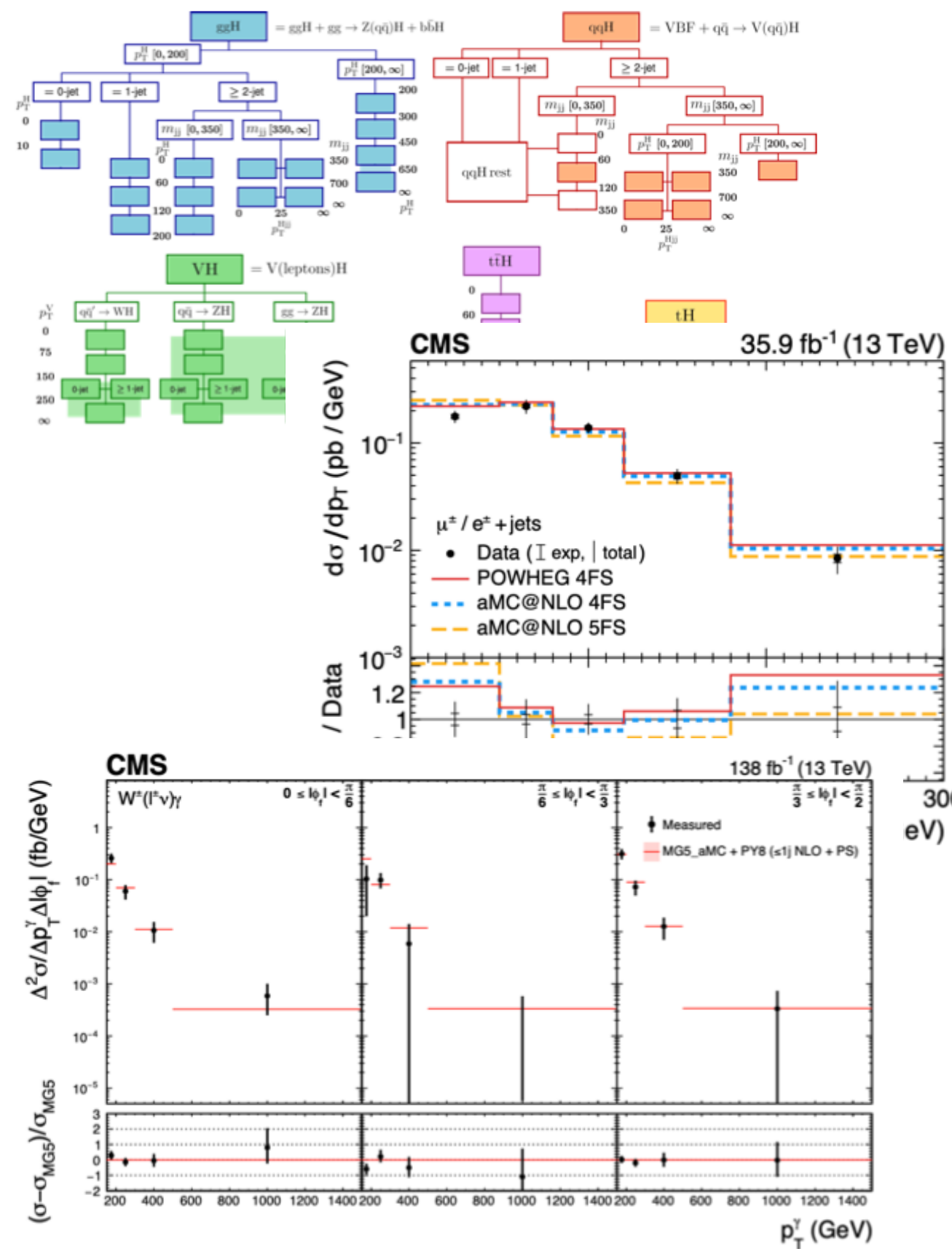
Area 4: Fits and related systematics

- **Long term goal:** combined likelihood fit of Higgs, top & EW measurements to give strongest constraints on the widest possible set of EFT operators
- Goal is to provide guidance for:
 - Experimental combinations
 - Benchmarks for "theory" fits (typically use public information only)
 - Input/output formats, the level of information the experiments should provide
 - Implementation of common experimental + theoretical uncertainties in combination
 - Inclusion of non-LHC constraints (EWPO, flavour, g-2,...)
- Know from experience that these large-scale combinations take a long time
 - Pragmatic approach: started a fitting exercise, with a simplified χ^2 fit, based on public information
 - Previous meetings: [June 22] [Feb 22]
 - Twiki to document conventions

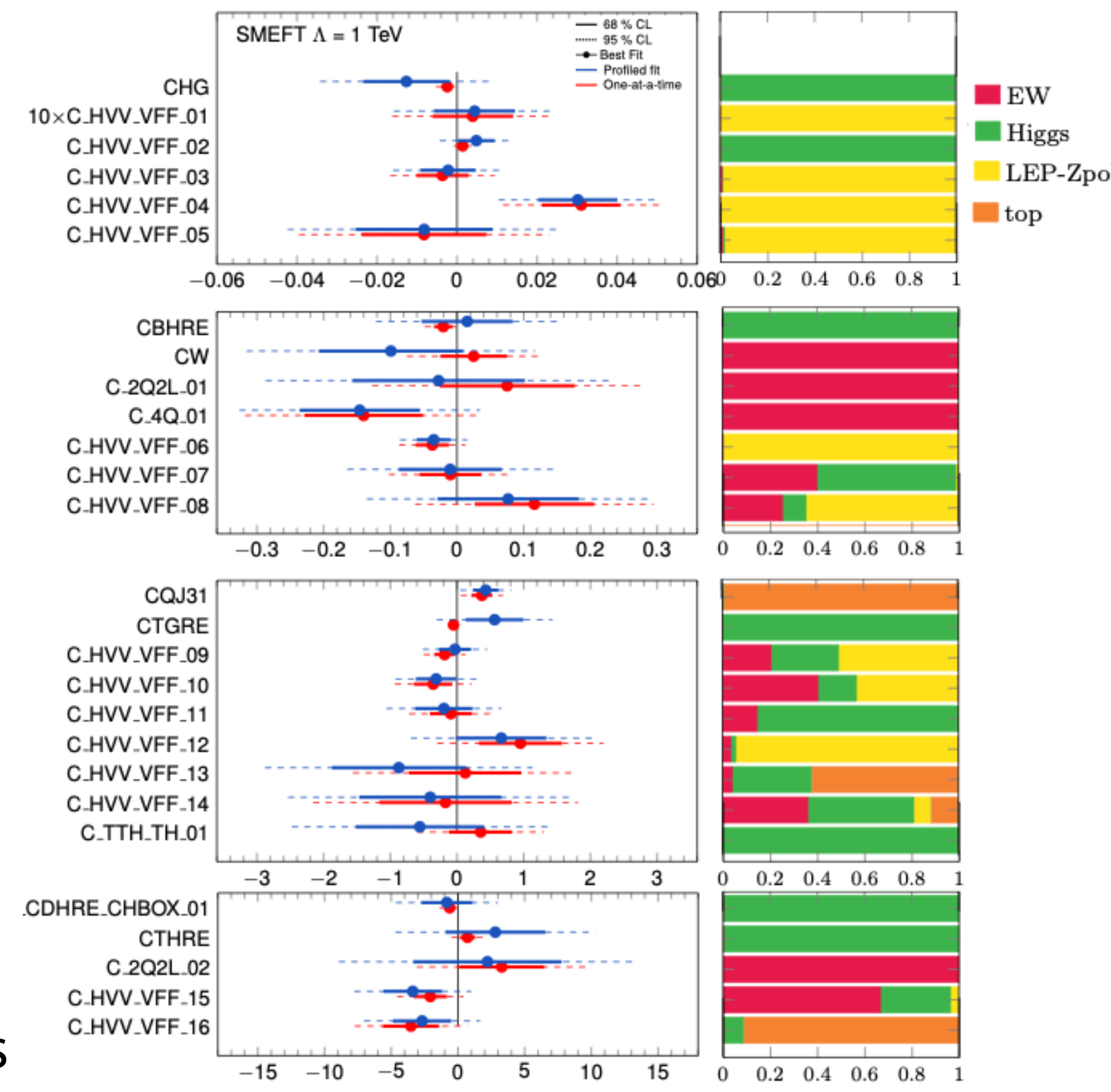


Area 4: Fitting exercise

- Current inputs:
 - **Higgs** (CMS $H \rightarrow \gamma\gamma$, ATLAS $H \rightarrow \gamma\gamma, 4l, bb$); **EW** (ATLAS $WW, WZ Zjj$, CMS $W\gamma$, LEP EWPO); **top** (CMS single top)
 - Use public covariance matrices, neglect inter-analysis uncertainty correlations
 - **Future plans:** add more channels, use as benchmark for flavour choice, truncation/validity studies

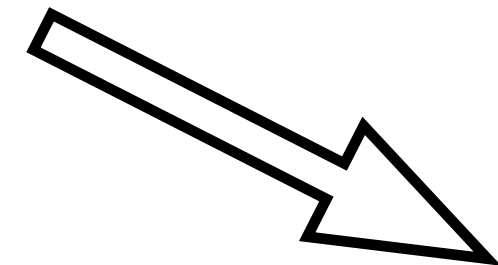
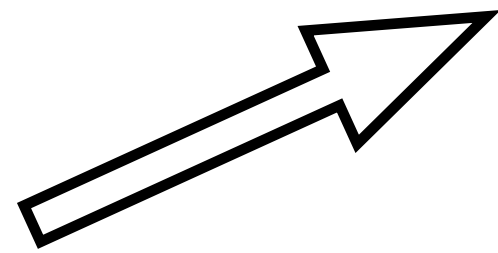


Basis rotation to remove flat directions



Area 5: benchmark scenarios from UV models

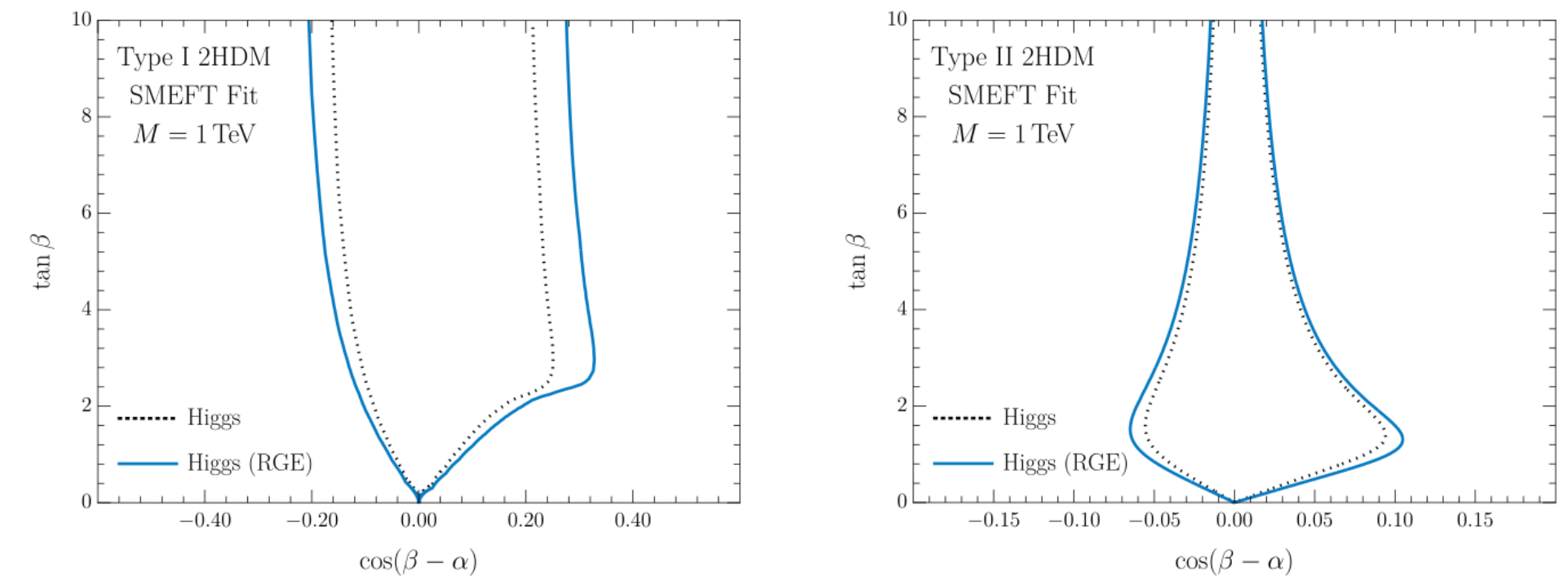
- Goals ([twiki](#)):
 - Study matching to specific models
 - Identify BSM-driven subsets of operators
 - Benchmarks beyond SMEFT, incl. non-linear EFT
- Two topical meetings: [[Feb 21](#)] [[March 22](#)]
 - Comparison of EFT constraints vs. direct BSM searches beyond EFT
- Note in development:
 - Review of (automated) codes: STrEAM, SuperTracer, Matchmakereft, CoDEx, Matchete, MatchingTools, ...
 - Provide comparison framework
 - Define relevant benchmark models, e.g. SMEFT ↔ MSSM



Two Higgs Doublet Models *S. Homiller*

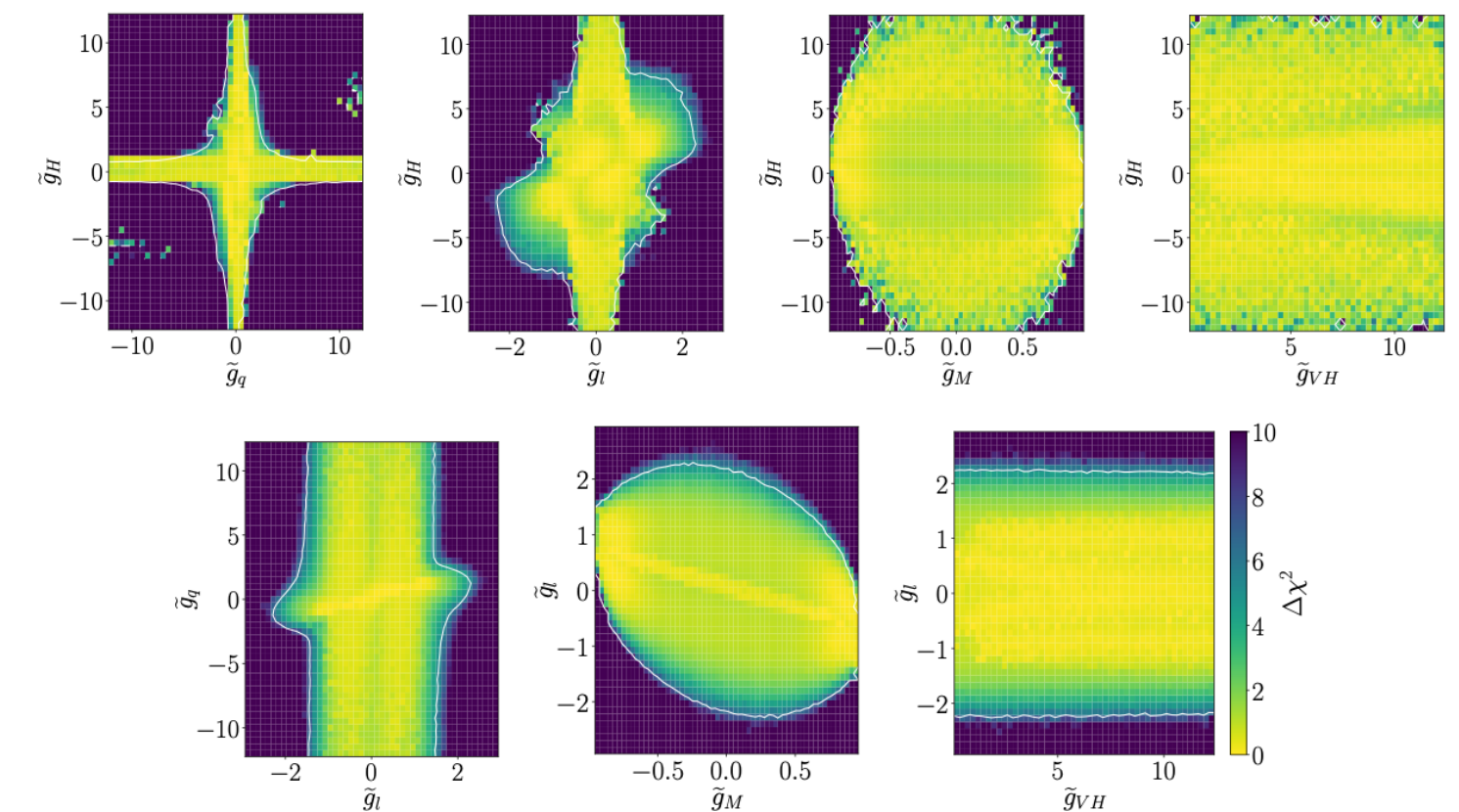
Generates $C_H, C_{bH}, C_{tH}, C_{\tau H}$ at the matching scale

Note that these are SMEFT Fits — not 2HDM fits!



Heavy vector triplet model

E. Geoffray



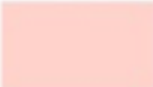


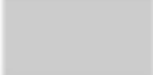
We get constraints for $m_V = \frac{\tilde{m}_V}{\sqrt{1-g_M^2}} = 8\text{TeV}$, where direct resonance searches don't exist. And we fit in the full 5 parameter model space.

Area 6: flavour assumptions

- Goals (twiki):
 - Define relevant flavour scenarios for EFT interpretations (not possible to constrain all 2499 SMEFT dim6 operators simultaneously)
 - Depends on the scope of the combination, e.g. EW+Higgs+top \Rightarrow requires some separation of 3rd gen. fermions
 - Understand interplay with other experiments (flavour, EDM, $g-2$, ...) - some coefficients stronger constrained elsewhere
- Note on flavour assumptions in preparation

From [A. Grejfo](#)

SMEFT $\mathcal{O}(1)$ terms (dim-6, $\Delta B = 0$)		Lepton sector							
		MFV _L	U(3) _V	U(2) ² × U(1)	U(2) ²	U(2) _V	U(1) ⁶	U(1) ³	No symm.
Quark sector	MFV _Q	47	54	65	71	80	87	111	339
	U(2) ² × U(3) _d	82	93	105	115	128	132	168	450
	U(2) ³ × U(1) _{b_R}	96	107	121	128	144	150	186	480
	U(2) ³	110	123	135	147	162	164	206	512
	No symm.	1273	1334	1347	1407	1470	1425	1611	2499

-  MFV with all breakings neglected apart from y_t . Radiatively stable (approximate symmetry of $\dim[\mathcal{O}] = 4$)
-  Third-family specific. Discriminates t and b from light jets, and τ from μ/e (experimentally possible). Motivated by the charged-current B anomalies.
-  Allows for LFUV between e and μ which is experimentally accessible. Neutral-current B anomalies.
-  Work out which linear combinations actually contribute to the Top/Higgs/EW.



Summary

- LHC EFT working group aims to cover all the main aspects of EFT interpretation
 - Develop recommendations that will ultimately facilitate full-scale global EFT fits

- Public notes already released:
 - Electroweak input parameters
 - Truncation, validity & uncertainties
 - Experimental Measurements and Observables

- In preparation:
 - Matching to UV models beyond tree level
 - Flavour schemes

- Work on the prototype fitting exercise ongoing \Rightarrow start to focus on studying proposals from other areas

- Excellent time to get involved!