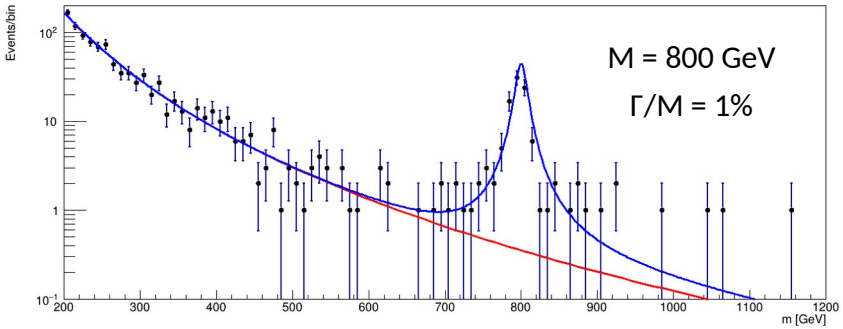
Summary of *LHC EFT Working Group* activities

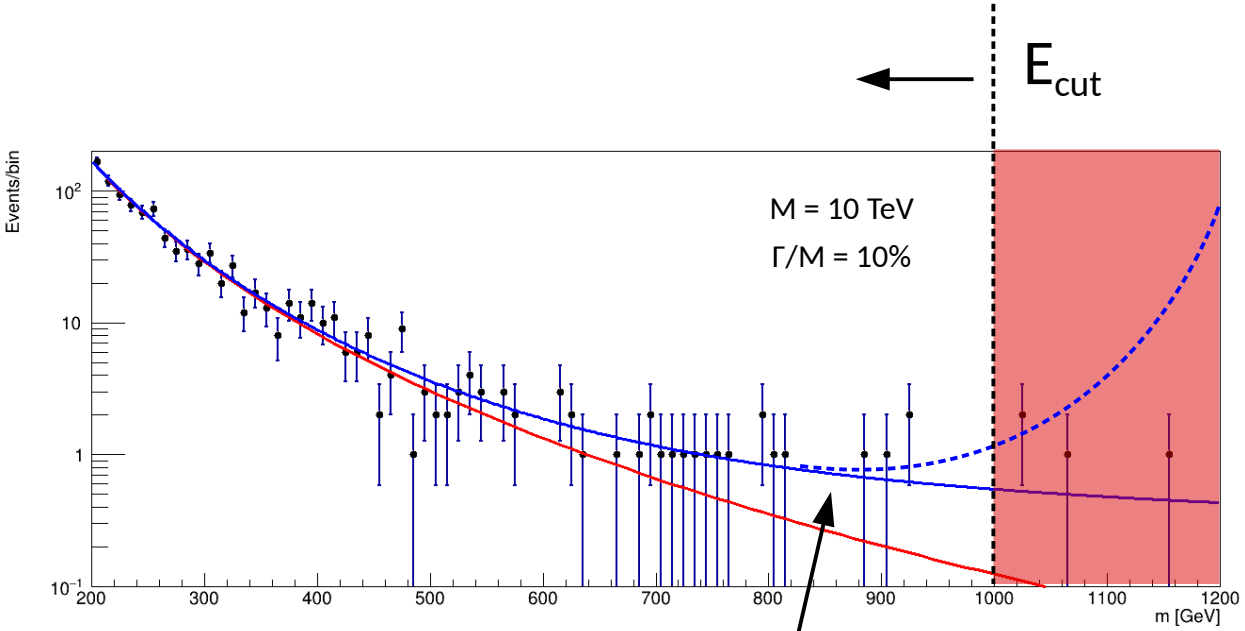
Nicolas Berger (LAPP Annecy) on behalf of many people

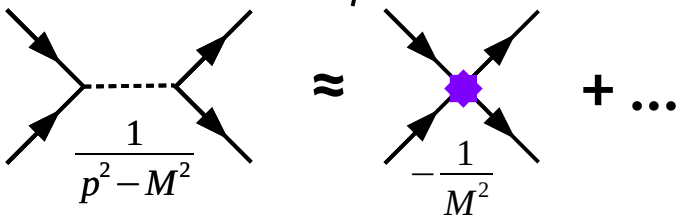
EFTs at LHC

LHC measurements allow indirect BSM searches, complementary to direct bump-hunts.

→ Will play an increasingly important role in Run 3 and Run 4







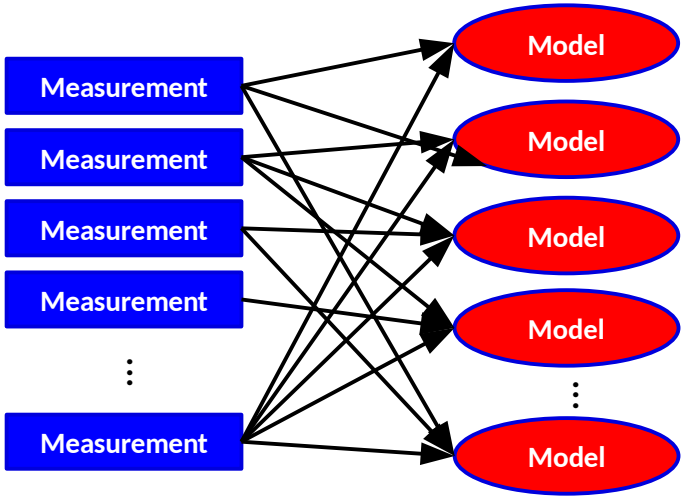
EFTs at LHC

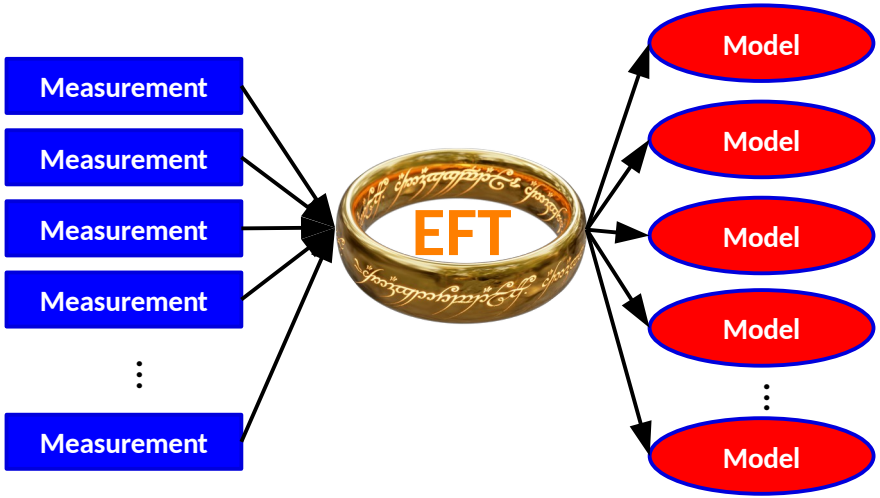
LHC measurements allow indirect BSM searches, complementary to direct bump-hunts.

→ Will play an increasingly important role in Run 3 and Run 4

EFTs offer an intermediate step between the measurement and the NP model

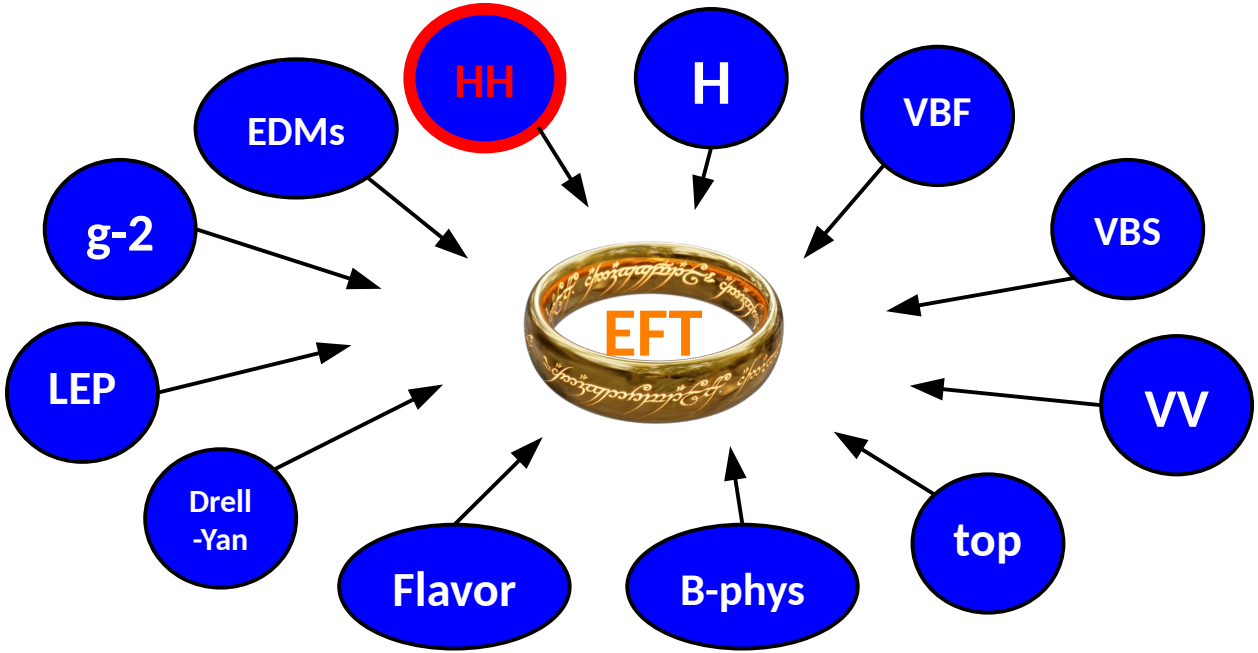
→ Allows to decouple the measurements and the interpretation





EFTs at LHC

General EFTs (e.g. SMEFT) have **many free parameters**, but describe **many processes**



⇒ Use **combinations of many measurements** to constraint EFTs.

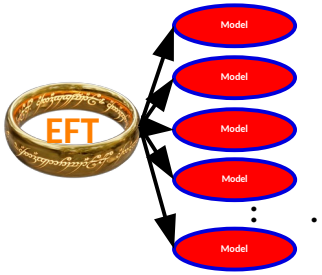
→ **Theory**: define standard EFT frameworks

→ **Experiment**: define standard practices for measurements and reporting results.

The LHC EFT WG

Goal: provide guidance for LHC EFT measurements (details here)

- EFT framework, theory uncertainties, higher-order effects
- Tool configuration/usage, MC simulation of EFT effects
- Global fits
- Constraints on UV models from EFT



Organization:

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

Current conveners:

ATLAS:

Nicolas Berger (Higgs WG contact)

Nuno Castro (Top WG contact)

Kristin Lohwasser (EW WG contact)

Pierre Savard

CMS:

Andrew Gilbert (EW WG contact)

Andrei Gritsan

Abideh Jafari (Top WG contact)

Giovanni Petrucciani (Higgs WG contact)

LHCb:

Patrick Owen

Theory:

Ilaria Brivio

Sally Dawson

Jorge De Blas (Higgs WG contact)

Celine Degrande (EW WG contact)

Gauthier Durieux

Admir Greljo

Eleni Vryonidou (Top WG contact)

Area 1: Theory formalism

Coordinators
Gauthier Durieux
Ilaria Brivio
Giovanni Petrucciani

Main topics (see TWiki for details**):**

- Bases, notations, inputs

Avoid large corrections to W,Z propagators

→ **Input scheme**: $\{\alpha, G_\mu, m_Z\}$, $\{G_\mu, m_Z, m_W\}$ or $\{\alpha, m_Z, m_W\}$?

Used at LEP | Most used by tools | Avoids leptonic corrections to G_μ.

Public note out, providing **a recommendation for $\{G_\mu, m_Z, m_W\}$.**

- **Assumptions** (flavor structures, symmetries) → See also **Area 6**
- **Constraints** (unitarity, positivity…)

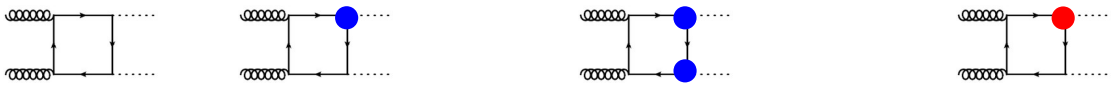
Mainly focused on SMEFT (for now), but other EFTs (e.g. HEFT) in principle also in scope.

Area 1: Theory formalism

Coordinators
Gauthier Durieux
Ilaria Brivio
Giovanni Petrucciani

Main topics (see TWiki for details):

- **EFT order, validity, uncertainties:**



$$\sigma \sim |\mathcal{M}|^2 = \left| \mathcal{M}_{\rm SM} + \sum_i \frac{C_i^{(6)}}{\Lambda^2} \mathcal{M}_i^{(6)} + \sum_{ij} \frac{C_i^{(6)} C_j^{(6)}}{\Lambda^4} \mathcal{M}_{ij}^{(6)} + \sum_k \frac{C_k^{(8)}}{\Lambda^4} \mathcal{M}_k^{(8)} + \ldots \right|^2$$

$$= \mathcal{A}_{\rm SM} + \sum_i \frac{C_i^{(6)}}{\Lambda^2} \mathcal{A}_i^{(6)} + \sum_{ij} \frac{C_i^{(6)} C_j^{(6)}}{\Lambda^4} \mathcal{B}_{ij}^{(6)} + \sum_k \frac{C_k^{(8)}}{\Lambda^4} \mathcal{A}_k^{(8)} + \ldots$$

Mainly focused on SMEFT (for now), but other EFTs (e.g. HEFT) in principle also in scope.

→ **SMEFT order**: **d=6 baseline**, but:

- **d=8 terms** enter at **same $1/\Lambda^4$ order** as **$(d=6)^2$**
- (Partial) d=8 already available in some cases (e.g. VBS, DY, geoSMEFT).
- Also need to account for higher orders in QCD, EW.

Area 1: EFT Truncation/validity/uncertainties

Activities:

- Topical meetings in January and June 2021
- Public note released in January + new contribution under review (comments here)
- Presentation at the LHC EFT general meeting on May 23rd.

Ongoing discussions:

- **Validity**: when can we trust the EFT expansion ? (e.g. SMEFT at d=6, or 8)

  → Typically require measurement energy scale $E < E_{cut}$, but process-dependent

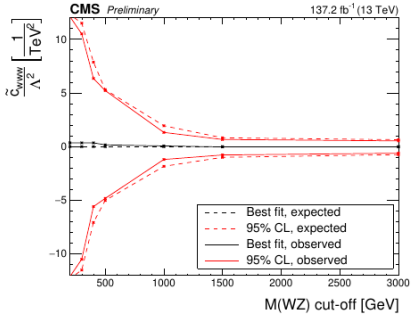
  → Which E variable for which processes ?..
- Uncertainties to consider

→ Benchmarking exercise planned to test out different possibilities (with Area 4).

Proposals

"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.**

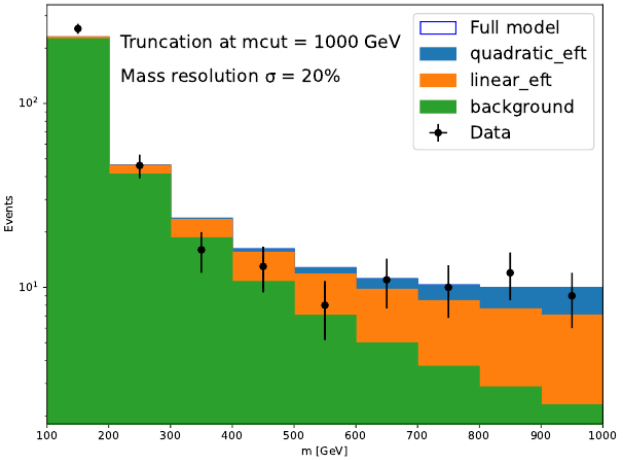
  → Experimentally easier, equivalent to clipping data for well-measured E observables but questionable in other cases (is the clipped model a consistent description of the data ?)

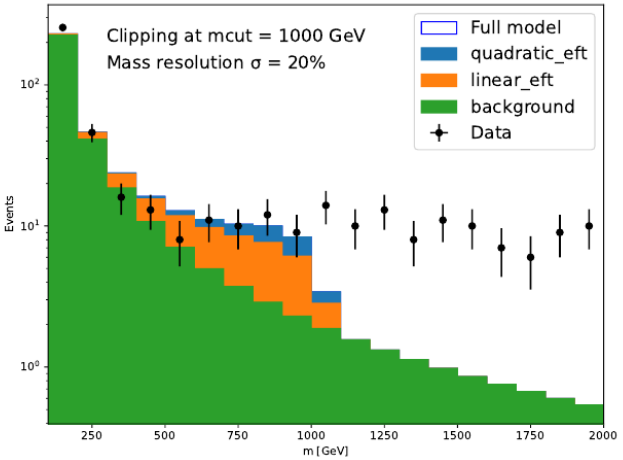
"C"

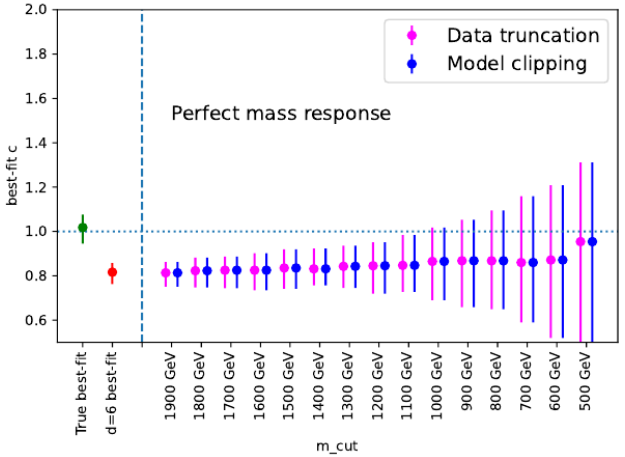
- **Add uncertainties**: closest to usual treatment of theory unknowns in LHC measurements, but need proper determinations of magnitudes (use size of $(d=6)^2$ terms as proxy ?) and correlation scheme (decorrelate across observables and c_i ?)

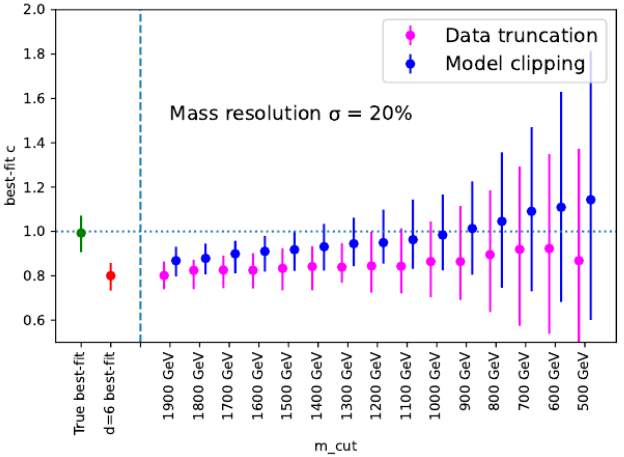
Clipping schemes

From this contribution









Area 2: Predictions and Tools

Coordinators :
Celine Degrande
Pierre Savard
Nadjieh Jafari

Goals: (see TWiki for details)

- Keep track of the various tools used to provide EFT predictions

  → Organize cross-validation

- **Provides recipes and recommendations on usage.**

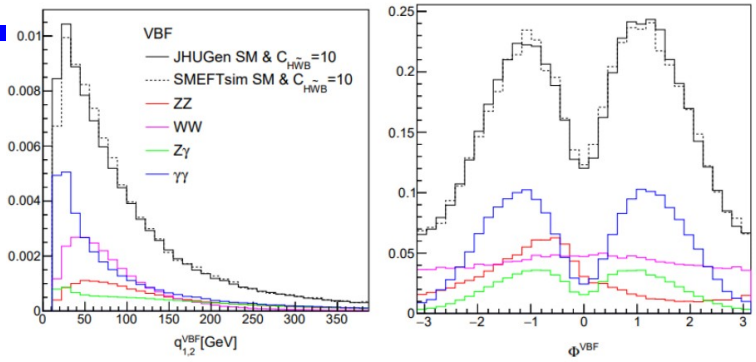
  → Both central value + uncertainties

  → Ensure settings are consistent across different processes/tools to allow global combinations.

- **Specific topics**:

  → PDF, αs, showering effects

  → Treatment of unstable particles



Recent efforts (Topical meeting in January)

- Comparison of predictions from various tools JHUGen vs. SMEFTsim (sign conventions, etc.), SMEFT@NLO vs SMEFTsim.
- Modeling extra-jet effects on EFT in tt+X
- Framework for MC/MC comparisons. Participation by many tools, some comparisons already performed (e.g. dim6top/SMEFTsim/SMEFT@NLO)

Area 3: Experimental measurements and observables

Coordinators :
Nuno Castro
Andrei Gritsan
Eleni Vryonidou

Goals (see TWiki for details) : Study experimental methods and observables, and optimize for EFT sensitivity

- **Strategy**: “straight-to-EFT” vs. “two-step” (measurement + EFT interpretation) techniques
- **Observables** : diff. XS, fiducial XS, STXS, optimal observables, amplitudes, ML discriminants, …
- **Associated uncertainties**: detector effects, unfolding, EFT in backgrounds…

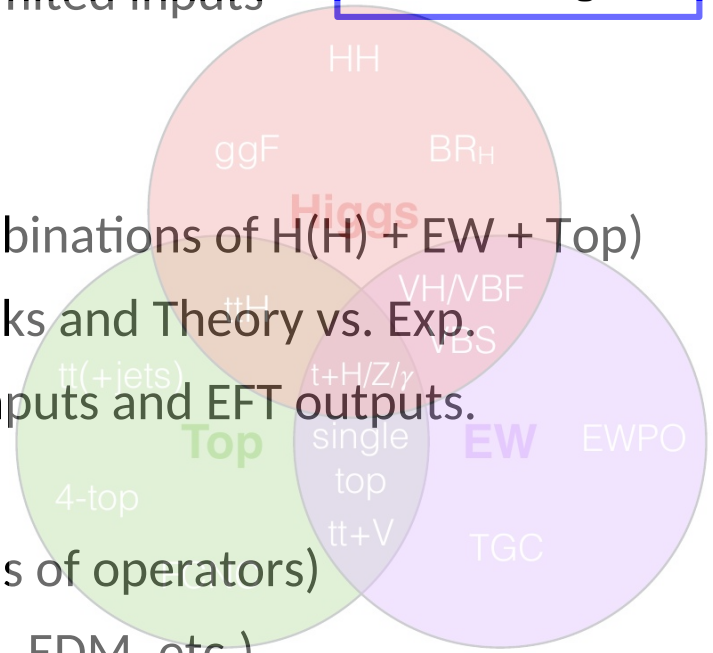
Public Note on these topics currently in preparation:

Contents

Area 4: Fits and related systematics

Coordinators :
Jorge de Blas
Andrew Gilbert
Nicolas Berger

Global fits: "Theory" fits using publicly available information vs.
"Experimental" fits using full likelihood but more limited inputs



Goals (see TWiki for details): provide guidance for EFT fits:

- **Experimental combinations** (starting with ATLAS/CMS combinations of H(H) + EW + Top)
- **Benchmarks for "theory" fits** → compare theory frameworks and Theory vs. Exp.
- **Input/output formats**: how to make public experimental inputs and EFT outputs.
- **Implementation of systematics** (theory + exp) in EFT fits
- **Treatment of "flat" directions** (unconstrained combinations of operators)
- **Inclusion of non-LHC constraints** (LEP, Tevatron, flavor, g-2, EDM, etc.)

Main effort: CMS/ATLAS/… "Exercise" to establish a working EFT example

→ See also this study of EFT effects in WW and VBS-WW performed within Area 2.

Fitting exercise

See talk from Rahul Subramanian for details

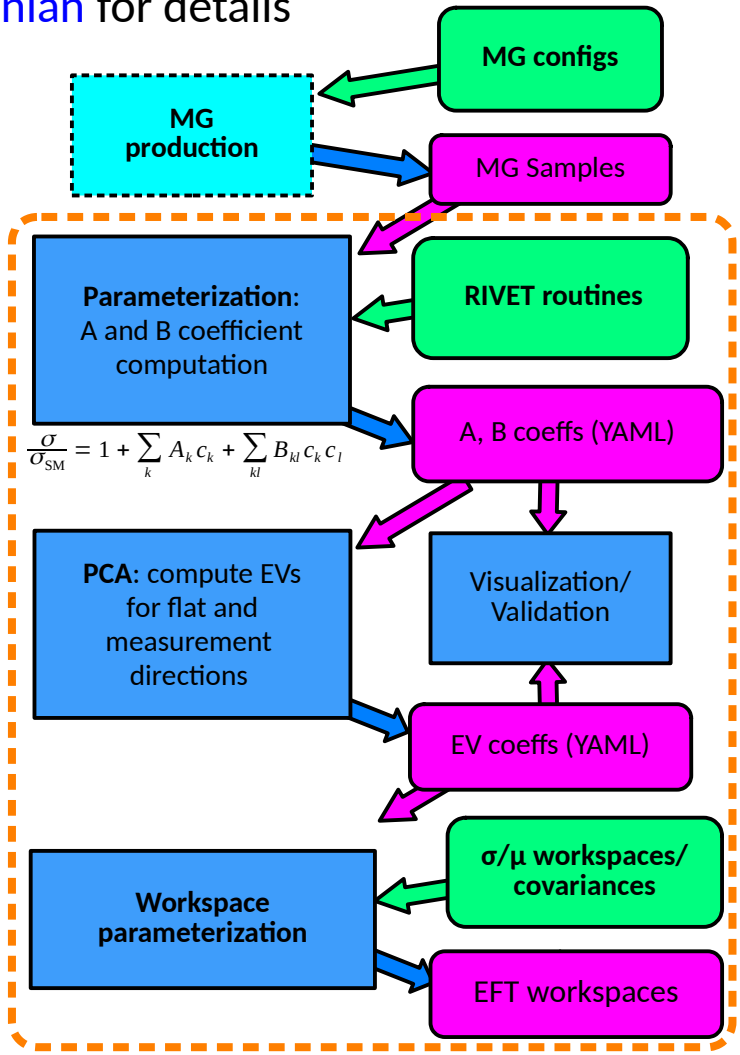
Full SMEFT analysis using **public inputs** and **public tools.**

Current inputs:

- **Higgs**: **CMS**: H→γγ, **ATLAS**: H→γγ + H→ZZ*→4l + H→bb
- **EW**: **ATLAS** WW, WZ, Zjj, **CMS** Wγ, **LEP-I** precision obs.
- **Top**: **CMS** single-top.

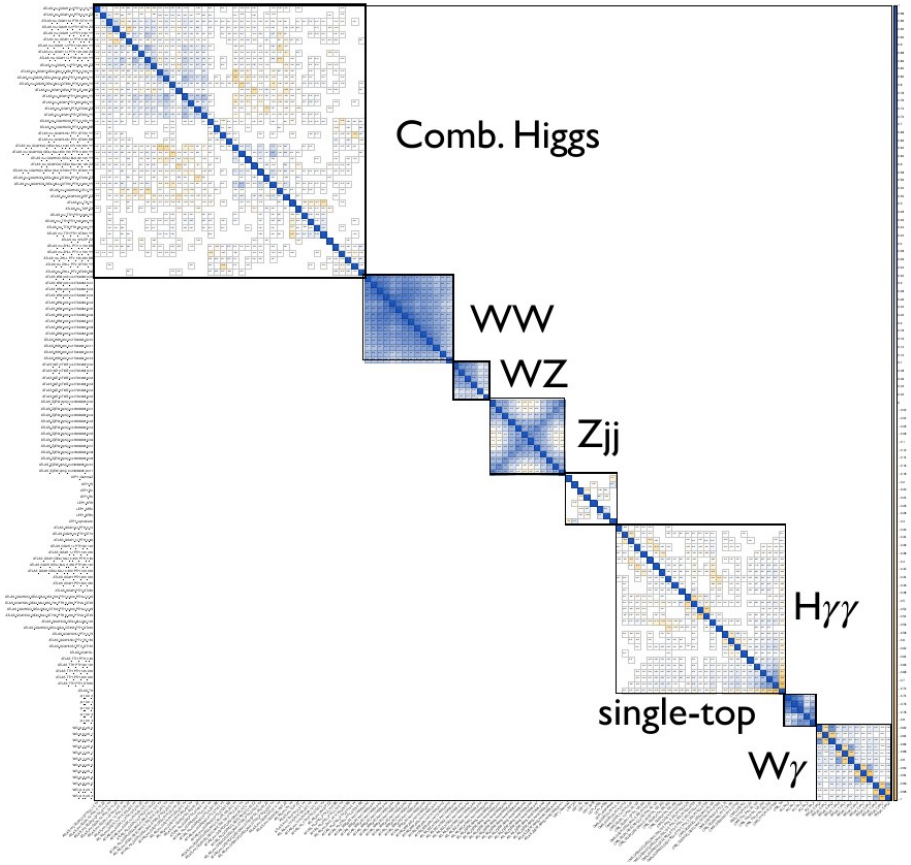
Analysis overview:

- For now use public covariance matrices (Gaussian PDFs).
- (Re)compute EFT effects from public RIVET routines.
- Basis for future exp/theory combinations
- **Future**: more inputs, or serve as test-bench for some procedures (e.g. truncation/clipping schemes)

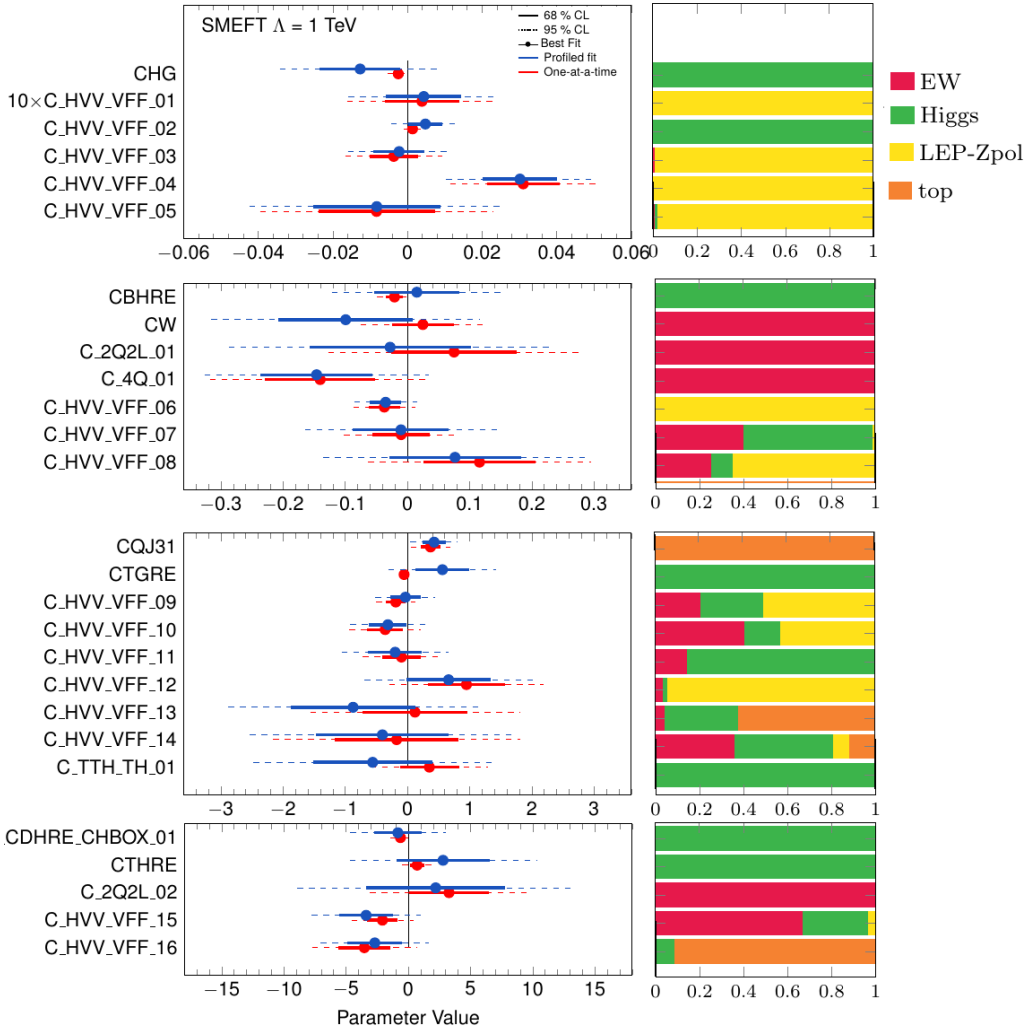


Fitting exercise: first combination

See talk from Rahul Subramanian for details



Full input covariance matrix



SMEFT Eigenvector results

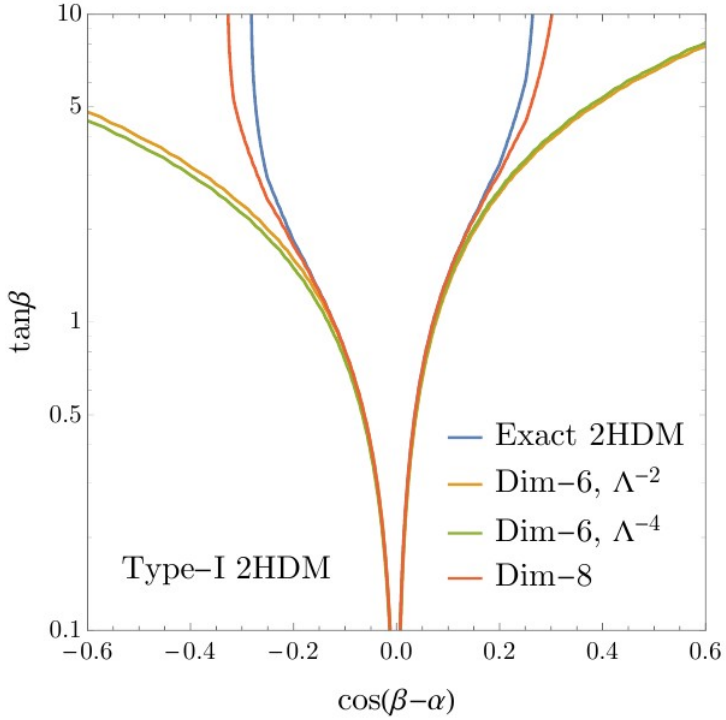
Area 5: Benchmark Scenarios from UV Models

Coordinators:
Sally Dawson
Kristin Lohwasser
Admir Greljo

Goals (see TWiki for details) :

- Matching to specific models, BSM-driven subsets of operators
- Benchmarks beyond SMEFT, incl. non-linear EFT
- Comparison of EFT constraints vs. direct BSM searches

A concrete example on SMEFT description of 2DHM from Dawson et al. (2205.01561) :



Note in preparation on matching SMEFT to UV models beyond the tree-level:

→ Some analytical matchings exist for specific models:

Type-I seesaw, Heavy Vector Triplets, S1+ S3 LQ models

⇒ Describe matching code, provide comparison framework

Area 6: Flavor assumptions

Coordinators:
Admir Greljo
Patrick Owen

Goals (see TWiki for details) :

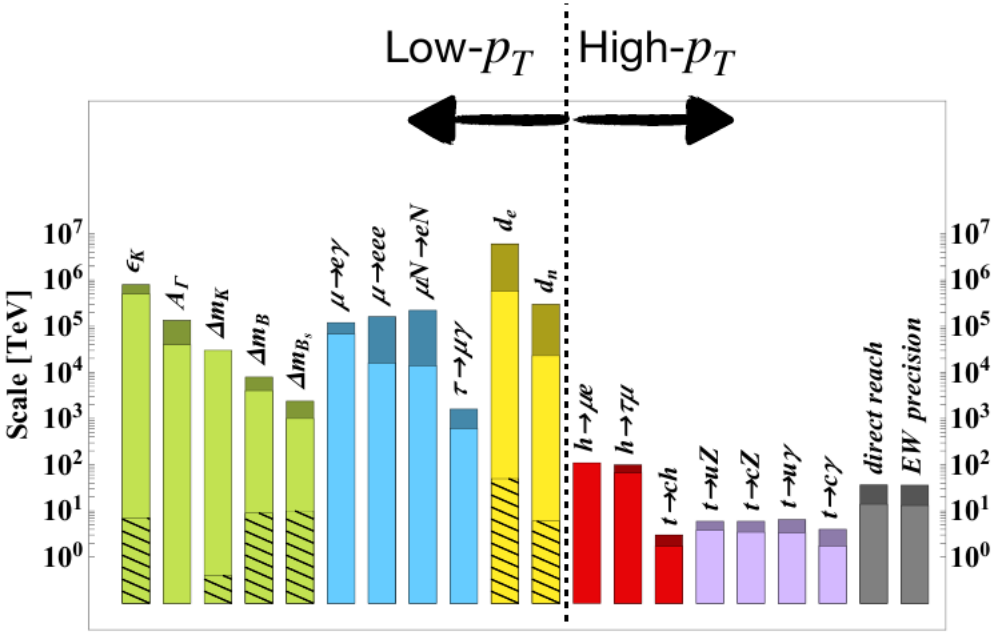
- Define relevant flavor scenarios for EFT interpretations

  → SMEFT at d=6 has 2499 operators in most general case!

- Account for interplay with other experiments (flavor, EDM, g-2, ...)

→ Some Wilson coefficients can already be constrained beyond LHC sensitivity

⇒ Making full use of LHC data (e.g. top measurements) requires at least partial separation of 3rd generation fermions.



Physics Briefing Book, 1910.11775

From A. Greljo

Area 6: Flavor assumptions

Topical meeting on flavor in January with a lot of feedback.

Presentation at the general meeting on May 23rd.

Note on flavor assumptions in preparation

- Builds on a previous document for top EFT measurements
- Possible scenarios:

  → $U(2)^2_{q,u} \times U(3)^3_{d,l,e}$: single out top,

  everything else symmetric.

  → Separate 3rd-gen quarks: $U(2)^3_{q,u,d} \times U(3)^2_{l,e}$

  → Separate e/μ/τ : $U(1)^6_{l,e}$

  → …

Contents

Some possible scenarios for EFT flavor

From A. Greljo

SMEFT $\mathcal{O}(1)$ terms (dim-6, $\Delta B = 0$)		Lepton sector							
		MFV_L	$\mathrm{U}(3)_V$	$\mathrm{U}(2)^2 \times \mathrm{U}(1)$	$\mathrm{U}(2)^2$	$\mathrm{U}(2)_V$	$\mathrm{U}(1)^6$	$\mathrm{U}(1)^3$	No symm.
Quark sector	MFV_Q	47	54	65	71	80	87	111	339
	$\mathrm{U}(2)^2 \times \mathrm{U}(3)_d$	82	93	105	115	128	132	168	450
	$\mathrm{U}(2)^3 \times \mathrm{U}(1)_{b_R}$	96	107	121	128	144	150	186	480
	$\mathrm{U}(2)^3$	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.

Conclusions

- LHC EFT WG (already!) almost 2 years old, activities ongoing on several fronts
- **Notes** (public or in preparation):
  - **EFT Input scheme**
  - **Truncation/validity/uncertainties** (+ **additional contribution**)
  - **Matching to UV models beyond tree level** (in preparation)
  - **Flavor scheme** (in preparation)
- Ongoing activity on the public interpretation/fitting exercise

- Moving towards long-term goal of full-fledged global EFT fits.

- **pp→HH** bring crucial inputs to SMEFT (O_H) and perspectives on other EFTs (HEFT)

  ⇒ Involvement in LHC EFT activities is very welcome!