Summary of LHC EFT Working Group activities

Ken Mimasu, on behalf of the LHCEFTWG conveners
King's College London

(Re)interpretation of the LHC results for new physics

31st August 2023

Special thanks to Ilaria Brivio & Nicholas Wardle for their (un)knowing input!

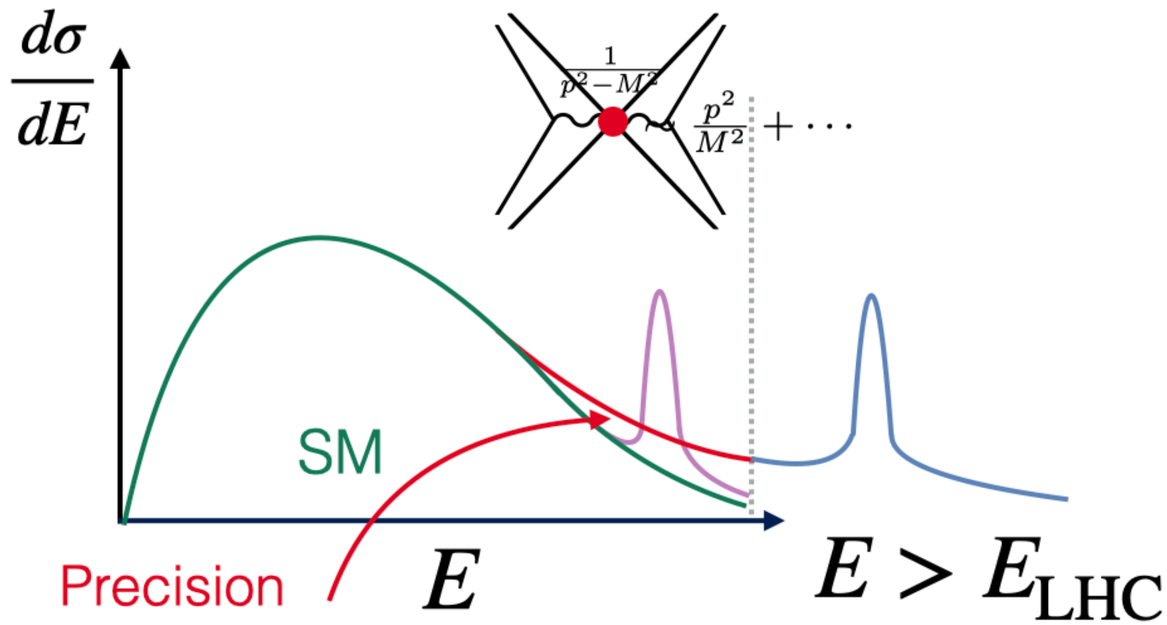
Energy & precision

Paradigm shift at the energy frontier for BSM searches

Direct (bumps)

Indirect (tails)

⇒ New physics is heavy



measurements

Heavy new physics
Precision measurements
High energy

→ **Effective Field Theory (EFT)**

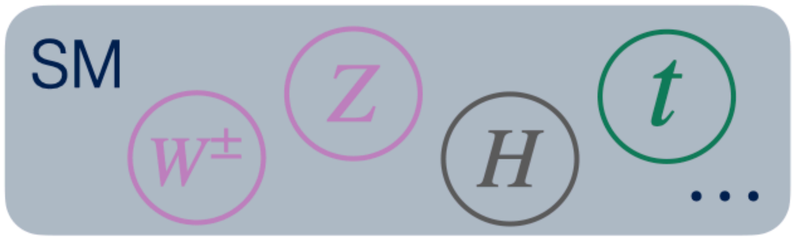
$$\mathcal{A}^n_{\mathrm{BSM}}(E,M) \sim E^{4-n}\left(a_0 + a_1\frac{E}{M} + a_2\frac{E^2}{M^2} + \cdots\right), \quad E \ll M$$

SMEFT: SM v2.0

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \sum_{i,D} \frac{c_i^{(D)} \mathcal{O}_i^{(D)}}{\Lambda^{D-4}}$$

BSM particle masses M ⇔ *Generic new physics scale* Λ

Taylor expansion of $\mathscr{A}_{BSM}$ ⇔ *Tower of operators* $\mathcal{O}_i^{(D)}$

$\mathcal{O}_i^{(D)} \supset$ 

Low energy (SM) fields & symmetries

Model parameters $\left\{g^i_{\rm BSM}, M_k\right\}$ ⇔ *Wilson coefficients* $\frac{c_j^{(D)}}{\Lambda^{D-4}}\left(g^i_{\rm BSM}, M_k\right)$

measure g_i *: new physics model parameters*

"Matching"

measure c_i *: coupling strengths of new BSM interactions*

SMEFT

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \sum_{i,D} \frac{c_i^{(D)} \mathcal{O}_i^{(D)}}{\Lambda^{D-4}}$$

Model independent

- Few underlying assumptions

Heavy new physics: $\Lambda > E_{exp}$
SM field content & symmetries

Systematically improvable

- Double expansion

higher dimensions $\frac{E}{\Lambda}$ & $\{g_S, g_W, g'\}$ *quantum corrections*

Global

- Model independence: **we don't know** what operators new physics will generate
- Patterns & correlations among observables & operators are key
- Ultimate goal: **complete SMEFT likelihood** confronted with HEP dataset

LEP data, Higgs, multiboson, top, flavor physics,…

$\mathscr{L}(c_i) \Rightarrow$ **indirectly constrain many UV models**

SMEFT interpretation

Maximising sensitivity means improving…

$$\Delta o_n = o_n^{\mathrm{EXP}} - o_n^{\mathrm{SM}} = \sum_i a_{n,i}^{(6)}(\mu)\,\frac{c_{n,i}^{(6)}(\mu)}{\Lambda^2} + O\left(\frac{1}{\Lambda^3}\right)$$

Global nature

As many observables as possible

Identify patterns & correlations in fits

Exploit energy-growth

Sensitivity

Experiment:
Best measurements & understanding of uncertainties and correlations

Theory:
Best available SM predictions for observables

Interpretation

Accurate knowledge of the size & correlations among a_i

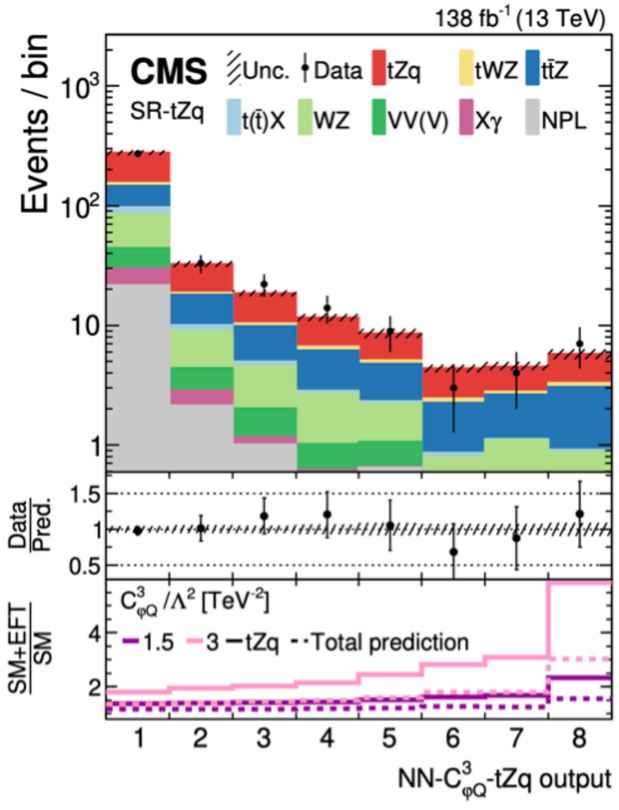
Determining c_i requires most precise available SMEFT predictions

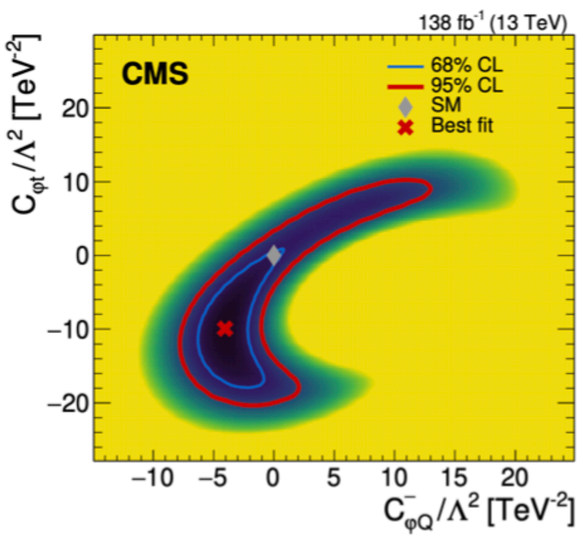
Collider probes of SMEFT

Dedicated searches

- SRs optimised to discriminate between SM and SMEFT

$$|\mathscr{A}_{\text{SMEFT}}|^2 = |\mathscr{A}_{\text{SM}}|^2 + \mathscr{A}^*_{\text{SM}}\mathscr{A}^{(6)}_i \frac{C^{(6)}_i}{\Lambda^2} + \cdots$$

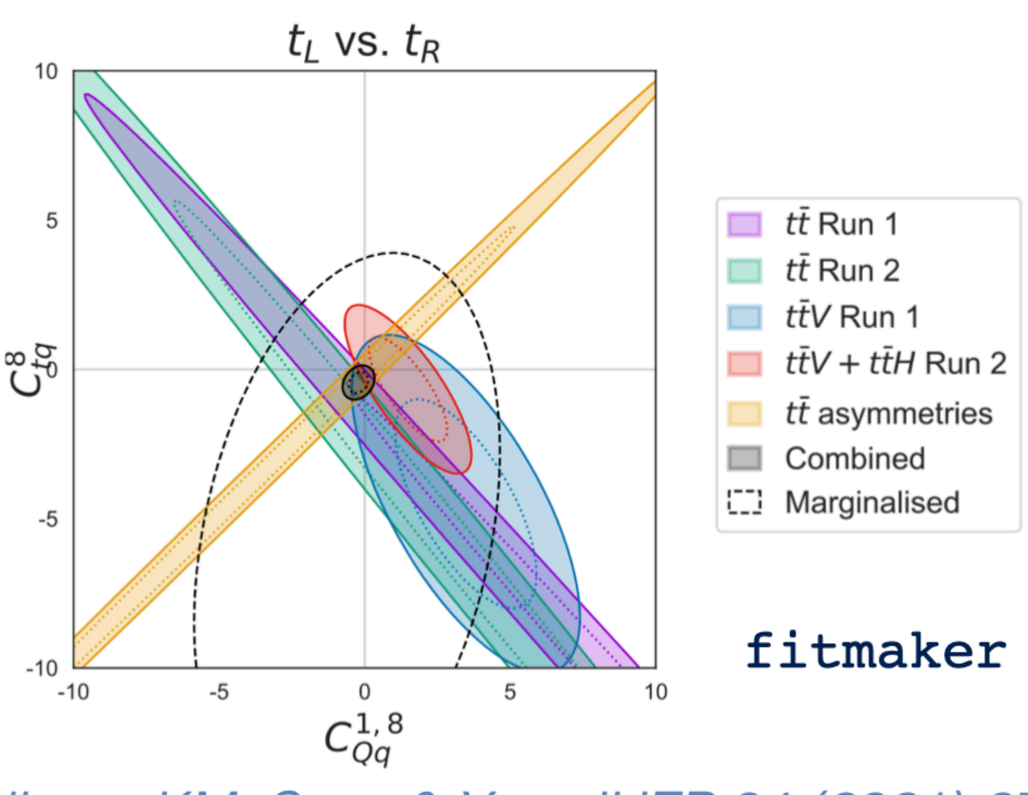




[CMS; JHEP 12 (2021) 083]

(Re)interpretation

- Re-use existing measurements
- Differential cross sections, signal strengths, asymmetries,…
- Combine into global analysis



`fitmaker`

[Ellis, Madigan, KM, Sanz & You; JHEP 04 (2021) 279]

Collider probes of SMEFT

Dedicated searches

- SRs optimised to discriminate between SM and SMEFT

$$|\mathscr{A}_{\text{SMEFT}}|^2 = |\mathscr{A}_{\text{SM}}|^2 + \mathscr{A}^*_{\text{SM}}\mathscr{A}^{(6)}_i \frac{C_i^{(6)}}{\Lambda^2} + \cdots$$

(Re)interpretation

- Re-use existing measurements
- Differential cross sections, signal strengths, asymmetries,…
- Combine into global analysis

Pros & Cons

- ✓ ‘Optimal’ ⇒ best sensitivity
- X Restricted to specific SMEFT effects considered
- X Not easy to reinterpret
- ✓ ‘Easy’ to interpret ⇒ repeat for new parameter sets, better theoretical predictions …
- ✓ More global ⇒ applicable to a wider range of UV completions
- X Not optimal

The LHC EFT WG: 2020-

Webpage: *lpcc.web.cern.ch/lhc-eft-wg*

TWiki: *twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCEFT*

Meetings: *indico.cern.ch/category/12671/* Contact: *lhc-eftwg-admin@cern.ch*

Sign up: *simba3.web.cern.ch/simba3/SelfSubscription.aspx?groupName=lhc-eftwg*

Mandate

The LHC effective field theory working group (LHC EFT WG) gathers members of the LHC experiments and the theory community to provide a framework for the interpretation of LHC data in the context of effective field theories (EFTs)…

Conveners

ATLAS
Sarah Heim (Higgs)
Jacob Kempster (Top)
Sandra Kortner
Kristin Lohwasser (EW)

CMS
Nadjieh Jafari
Matteo Presilla (EW)
Robert Schöfbeck (Top)
Nicholas Wardle (Higgs)

LHCb
Greg Cisarek
Christoph - Langenbrusch

Theory
Shankha Banerjee (EW)
Anke Biekötter (Higgs)
Ilaria Brivio
Gauthier Durieux
Admir Greljo
Ken Mimasu (Top)

Contacts with the RIF

Informal meeting between WG conveners & Sabine in Feb.

- Many LHC EFT interpretations cannot always be directly reused
- Encourage reusability of experimental SMEFT results
- EFT fitting groups can benefit from the expertise & experience of RIF
- Synergies & possible joint activities between EFTWG & RIF

Why we are here today!

- EFT day @ RIF is a first ‘joint meeting’ between EFTWG & RIF
- If it is well received, we can continue the exchange
- RIF contacts: Nicholas Wardle and Ken Mimasu

WG structure

Googledoc summarising targets & activities of each area

Area 1: EFT formalism

- Ilaria Brivio, Gauthier Durieux, Matteo Presilla

Area 2: Predictions and tools

- Ilaria Brivio, Sarah Heim, Robert Schöfbeck, Ken Mimasu

Area 3: Experimental measurements and observables

- Shankha Banerjee, Anke Biekötter, Nadjieh Jafari, Jacob Kempster, Kristin Lohwasser

Area 4: Fits and related systematics

- Anke Biekötter, Jacob Kempster, Kristin Lohwasser, Ken Mimasu, Nicholas Wardle

Area 5: Benchmark scenarios from UV models

- Shankha Banerjee, Admir Greljo, Sandra Kortner

Area 6: Interplay with (heavy) flavour

- Greg Cisarek, Gauthier Durieux, Admir Greljo, Christoph Langenbrusch

Area 1: formalism *TWiki*

Aim: Establish key parameters of the formalism

- Operator basis, perturbation orders, symmetry assumptions (flavor, CP,…)
- How to combine operators of different dimension
- EFT validity, other theoretical constraints
- Practical considerations relating to experimental analyses

2 WG notes released

- *'Electroweak input parameters'* *[CERN-LHCEFTWG-2021-001]*
- *'Truncation, validity & uncertainties'* *[CERN-LHCEFTWG-2021-002]*
- 'Benchmarks for flavour assumptions' in progress with areas 3 & 6

Recent meeting on positivity constraints (link)

- What are they and how can we use them alongside exp. results

Area 2: predictions & tools

TWiki

Aim: how to simulate EFT and generate events

- Guidance/recommendations on use and limitations of MC models
- Higher order/loop calculations
- Benchmarking & validation of techniques for generation predictions (reweighting, morphing, …)
- Identify theory systematics
- Publication of predictions, shared event samples,…

Ongoing activities, notes in preparation

- *'EFT predictions'* benchmarking exercise
- *'Publishing SMEFT parametrisations for HEP measurements'*

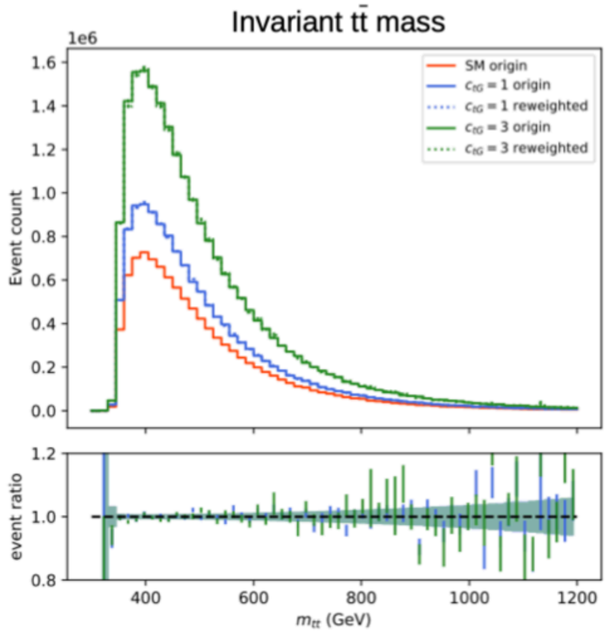
Area 2 activities

EFT predictions (*googledoc*)

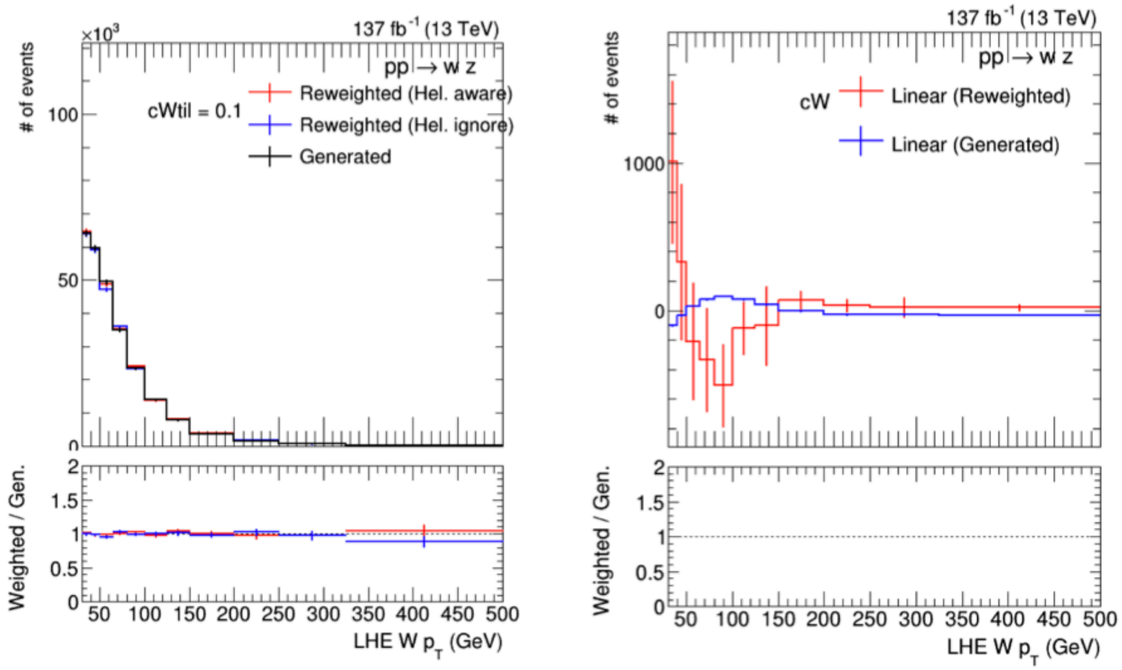
Contacts: R. Schöfbeck, M. Presilla, C. Knight

- Establish best practises using benchmarks for simulated EFT predictions
- 3 meetings: *6th April (kick-off)*, 24th May, 28th June
- Next meeting: *21st September*
- Validation/closure tests on reweighting and sample-based (morphing) techniques
- Ongoing studies on VH, tt, ttZ, multi-boson

A. Grohsjean & L. Jeppe



S. Chatterjee



Area 2 activities

$$\sigma_{\text{SMEFT}} \propto |\mathcal{A}_{\text{SM}}|^2 + \sum_i \mathcal{A}^*_{\text{SM}} \mathcal{A}^{(6)}_i \frac{C^{(6)}_i}{\Lambda^2} + \sum_{i,j} \mathcal{A}^{(6)*}_i \mathcal{A}^{(6)}_j \frac{C^{(6)}_i C^{(6)}_j}{\Lambda^4}$$

Publishing SMEFT parametrisation: collab w/ LHCHWG2

Contact: K. Mimasu

- Validate complex calculations & avoid duplication of efforts
- Use case: Higgs STXS - a 'standardised' set of observables
- ATLAS & CMS colleagues who worked on generating STXS parametrisation + developers of **`SMEFTsim`** & **`SMEFTatNLO`**
- Common data format for SMEFT parametrisation of HEP measurements
- Public codebase for generating the numbers using ***EFT2Obs***
- Extendable to any observable

ex: `H_gluglu.json`


```
{
 "metadata": {
  "coefficients": [   "chgtil",   "chg"  ],
  "observable_shape": "(1,)",
  "observable_names": [   "gluglu"  ],
  "flavor_scheme": "topU3l",
  "inputs": {
   "Lambda": 1000,
   "MW": 91.1876,
   "GF": 1.16638e-05,
   ...
```

```
 "data": {
  "central": {
   "a_chgtil": [    -5.1261021119540705e-06   ],
   "a_chg": [    39.34896452737338   ],
   "b_chgtil_chgtil": [    387.08519581710067   ],
   "b_chgtil_chg": [    5.1261021119540705e-06   ],
   "b_chg_chg": [    387.08519581710067   ]
  },
  "u_MC": {
   "a_chgtil": [    0.0   ],
   "a_chg": [    0.0036136598569541825   ],
   "b_chgtil_chgtil": [    0.0   ],
   "b_chgtil_chg": [    0.0   ],
   "b_chg_chg": [    0.0   ]
  }
 }
```

Area 3: measurements

TWiki

Aim: study experimental approaches for EFT inference

- How observables relate to operators
- Differential vs. dedicated
- Identification of optimal observables/ML based
- Quantify detector/acceptance effects & impact of EFT in backgrounds
- Optimise presentation of experimental results

[CERN-LHCEFTWG-2022-001]

Recent note: *'Experimental measurements & observables'*

- Summary of relations between operators & measurements used in global SMEFT analyses
- Contributions from various fitting groups

$$I_{ij}(\boldsymbol{c}) = -\mathrm{E}\left[\frac{\partial^2 \ln f\left(\boldsymbol{\sigma}_{\mathrm{exp}}|\boldsymbol{c}\right)}{\partial c_i \partial c_j}\right]$$

Planned activity: ML in EFT analyses

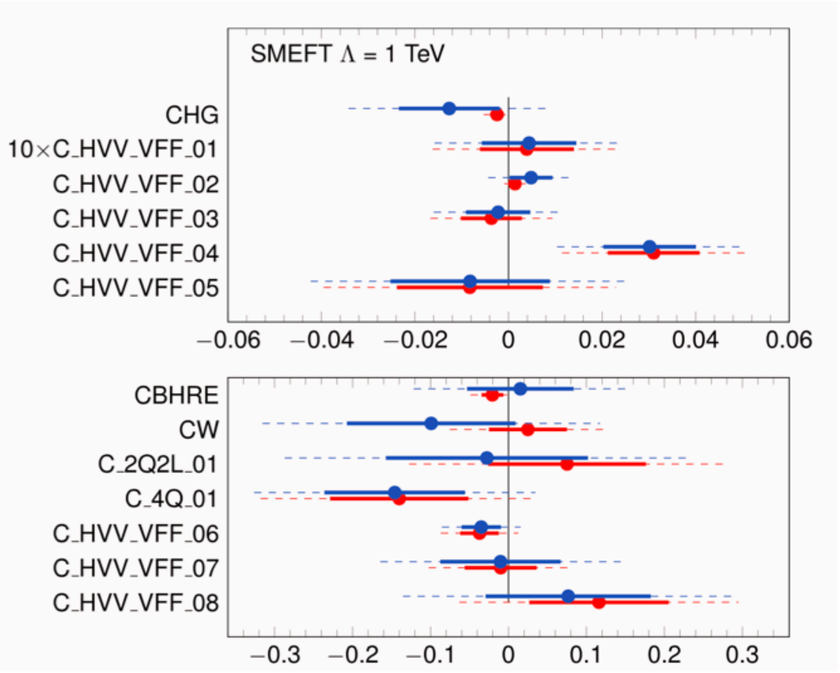
- How to construct them & how to reinterpret existing analyses

Area 4: fits

TWiki

Aim: discuss issues that concern global fits

- Combining ATLAS, CMS, LHCb data
- Benchmarks for theory fits
- Incorporating external data (LEP, flavor physics,…)
- Determining future projections



Ongoing: CMS+ATLAS fitting exercise

- 'Playground' SMEFT fit combining Top/Higgs/EW data from both experiments
- Harmonise workspaces/conventions
- Iron out differences & identify potential pitfalls
- Using public data, public combination code *ATLAS*/*CMS* repos

Area 5: UV benchmarks TWiki

Aim: study matching to specific models *see next talk by Shankha!*

- Identify BSM-driven subsets of operators
- Well-motivated benchmarks/patterns that come from classes of UV completions
- Benchmarks beyond SMEFT e.g. nonlinear EW symmetry breaking → HEFT
- Compare EFT constraints to direct searches

[CERN-LHCEFTWG-2022-002]

Note: *'Precision matching of microscopic physics to SMEFT'*

- Review of existing tools for 1-loop matching to SMEFT
- Supplementary codes for basis conversion & RG running

ModelMatch: Github repo to archive matching results

Area 6: flavour

TWiki

Aim: study interplay between high energy and flavour physics

- Most SMEFT operators are flavourful!
- How to input LHCb, other flavour data into global fits
- How does LHCb handle SMEFT analyses?
- Connecting SMEFT to the weak (low energy) EFT

1 ⇒ 3 generations
59 ⇒ 2499 operators

b-anomalies ⇔ *high-mass Drell-Yan*

CKM unitarity ⇔ *CDF* m_W *anomaly*

Recent meeting: Heavy flavour aspects in EFT fits

https://indico.cern.ch/event/1274528/

Possible future activities

some topics brought up at past meetings: *[I. Brivio, HEFT 2023]*

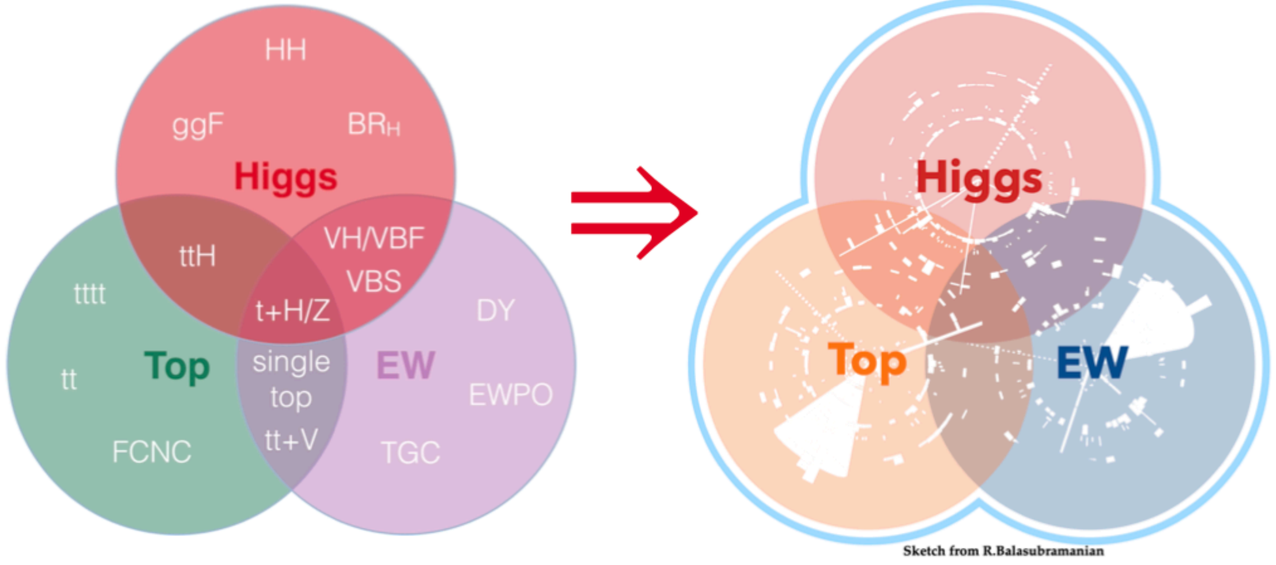
- Studies for H + HH combinations (→ Higgs WG)
- **Validation** procedure for NLO event generators
- Database of **conversions** between tools and notations
- Preparation of **shared samples** for some measurements
- Adding **EFT weights to HEPdata** for reco-level observables
- Start a **full-likelihood combination** in parallel to fitting exercise
- Database of **1-loop matching** results for UV benchmark models
- Matching of **MSSM** in decoupling limit
- ...

new suggestions are always welcome!

participation to the activities is open to anyone!

Conclusions

We are in the precision era of EFTs, where details start to matter!



K. Mimasu 2017

R. Balasubramanian ~ 202X

- Precision calculations have an impact: NLO/loops
- Sophisticated statistical inference - beyond Gaussians etc.
- Treatment of theory uncertainties
- Optimising experimental data presentation for SMEFT interpretations
- Shared theory predictions/MC samples
- Your ideas…

The start of a beautiful friendship?

Hope for ongoing exchange & collaboration with the RIF