Report from the LHC EFT WG

LHC EWWG general meeting (15-17.2.2022)

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On behalf of many people

LHC EFT WG: A global view on general SM extension

- Goal: provide guidance for the interpretation of LHC data in the context of effective field theories (EFTs).

- General information:
  - https://lpcc.web.cern.ch/lhc-eft-wg
  - https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCEFT

- First open meeting: 19 Oct - 20 Oct 2020
  - https://indico.cern.ch/event/943996/

- **Next general meeting: ~May 23 2022**
  (→ there were more meetings inbetween!)

- **Areas of interest:**
  → Basics / EFT formalism
  → Predictions and tools
  → Experimental measurements and observables
  → Fits and related systematics
  → Benchmark scenarios from UV models
  → 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:
    Abideh Jarafi (Top WG contact)
    Andrew Gilbert (EW WG contact)
    Andrei Gritsan
    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)
- Reach all conveners through lhc-eftwg-admin at cern.ch

Area 1: Basics / Formalism

- **EFT formalism and implementation**
  → *establish common conventions on possible SMEFT bases/normalization/input schemes*
  (e.g. currently little overlap between Top and diboson and Higgs → everything used consistently?)
  e.g. translation dim6 ←→aTGC in MG5 vs. seminal paper with different sign
  (flipped limits in WW results between ATLAS and CMS)

  → Assumptions on symmetries (CP, flavour)

  → Definition of scenarios (for fit with limited data / benchmark)

  → Truncations, dim8 contributions, **validity**

  → Theory constraints (unitarity, positivity) and how to use in fit

- **General review of formalism and conventions**
  → of different groups (incl. LHC Top, LHC Higgs WG)
  → Translation between Wilson coefficients and result reporting (Rosetta, WCxf)
  https://indico.cern.ch/event/971722/

- **Identified validity and EWK input parameter recommendations as first working goals**

Area 1: EWK Input parameter scheme

- **Recommendations presented in LHC EFT note: https://arxiv.org/abs/2111.12515**

- **Common set of electroweak parameters for SMEFT predictions for LHC observables eases comparisons and combinations**
  → Implementation of different schemes in tools desirable for comparing different choices

- **Considerations:**
  → Input parameters are precisely measured (impact negligible in SMEFT fit)
  → Experimental measurement of input parameters is independent of SMEFT effects
  → Choice does not introduce dependence of the fit on other unrelated operators (i.e. those that are not included in the fit) [or at least minimizes this effect]

- **Choices reviewed:**
  → (1) $\{\alpha, G\mu, m_Z\}$
  → (2) $\{G\mu, m_Z, m_W\}$ → favoured as it reduced dependence on propagators, but needs to care when combining LHC and LEP results (which use (1) – however no large numerical impact is expected)
  → (3) $\{\alpha, m_Z, m_W\}$

Area 1: Validity

- **What is "validity"?**

  → An estimate of how valid or correct the used EFT parametrization is

  → Answers the question on how reliable the EFT constrain is when translated to a concrete model (→ see quote)

A Quote from a Model Builder

- "Whatever bound you get from your EFT, I can always write down a model that passes the test against data and violates the bound you claim to have." – Bhaskar Dutta

Slide by William Shepherd

- **Breakdown of validity (at large scale)**

$$\sigma = \sigma_{\text{SM}} + \sum_i \frac{c_i}{\Lambda^2}\sigma_i^{\text{dim-6-interf}} + \sum_{ij} \frac{c_i c_j}{\Lambda^4}\sigma_{ij}^{(\text{dim-6})^2} + \sum_k \frac{c_k}{\Lambda^4}\sigma_k^{\text{dim-8-interf}} + \ldots$$

- Most general description of violation of validity: EFT expansion does not describe the model underlying the actual data (anymore)
  → Does the dim-6 terms match the underlying new physics (and for which NP scenarios?)
  (1) general consideration: growth with energy cannot go on forever
  (2) Dim-6 terms are not necessarily smaller than Dim-8 (and quadratic Dim-6) terms, especially at large energy scales (→ truncation after linear Dim-6 is incorrect, example: WW)
  (3) Correspondence between UV model and EFT breaks down above certain energy threshold

- **Interpretation of EFT fits can be misleading (overconstraints, wrongly excluded models...)**

Area 1: Validity

- **Possible solutions / Proposals discussed**

  → Proposals are presented in LHC EFT note: https://arxiv.org/abs/2201.04974v1

  → based on dedicated meeting January 19, 2021 (https://indico.cern.ch/event/980681/)
  → follow-up in general meeting on May 3, 2021 (https://indico.cern.ch/event/1016713/)
  → Comment collection: https://docs.google.com/document/d/13gLoLsELfBaifcTwhSXkcj6z152uz-xlB_WDx2HirFo/edit
  → Feedback from the collaborations June 28, 2021 (https://indico.cern.ch/event/1048848/)

- **Proposal C**

  → using quadratic dim-6 as proxies for missing dim-8 terms (of same order) *where needed* (dim-8 functional form unknown)
  → employing a power-counting rule to estimate dim-8 contributions from quadratic dim-6 (general on power counting: https://arxiv.org/abs/1601.07551 → which are dominant term depending on which aspect of the theory is more relevant)
  → Use as uncertainties quadratic dim-6 and dim-8 terms
  → Directly use in experimental analysis

Pro: best "mapping" → correspondence between 'error' and dim-6-quad / dim-8 model
Contra: Difficult to apply a posteriori (and concrete implementation not quite known)
Difficult to find consist choice of variables and cuts across different processes

Area 1: Validity

- **Proposals A and B**

→ provide full information on phase space and EFT constraints
→ quadratic terms included as default (comparison to linear fit only)
→ Clipping: providing experimental results as functions of the maximal energy probed ***in data****
→ Clipped constraints (even after combination) allows to identify concrete models for the included energy range

Pro: Relatively easy to implement and well-defined
Contra: Collaborations preferred cut on MC (as on data is more work-intensive, see later)

*The proponents A and B however judge that comparing data in a given phase-space region (without energy cut) with predictions in a different one (with energy cut) is inconsistent. **Further studies could clarify whether the two approaches are practically equivalent in cases of interest.**

- **Further studies and considerations (Proposal (A and B)a)**

→ Using data truncation problematic for cases where energy scale not directly observable (neutrinos, ….): always available in the MC truth
→ Toy studies on data truncation vs. model clipping show that show that resolution effects between truth and reco level clipping could be mild
→ **ongoing study (circulated with convenor group)**
– possibly feeds into ATLAS/CMS fit (testing clipping/truncation on actual data)

Area 2: Predictions and Tools

- **Review of tools available:**
  → https://indico.cern.ch/event/971724/

  - SMEFTSim
  - SMEFT@NLO
  - Madgraph5_aMC@NLO
  - EFT in JHUGen
  - EFT in SHERPA
  - EFT in VBFNLO
  - EFT in Powheg-Box

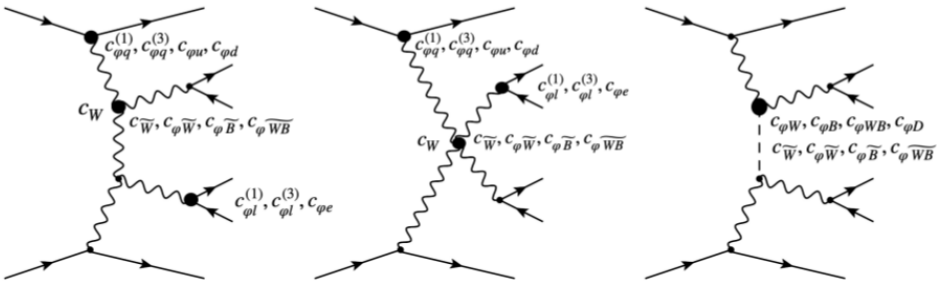
- What is provided by the tools and what is needed / wished for by the experiments?

- Most recent project (started 2022):

  → **Proposal to validate the implementations**
  https://indico.cern.ch/event/1096488/contributions/4659864/attachments/2381609/4069411/durieux-lhceftwg-eftvalidation-2022-01-31.pdf

Area 3: Experimental Measurements and Observables

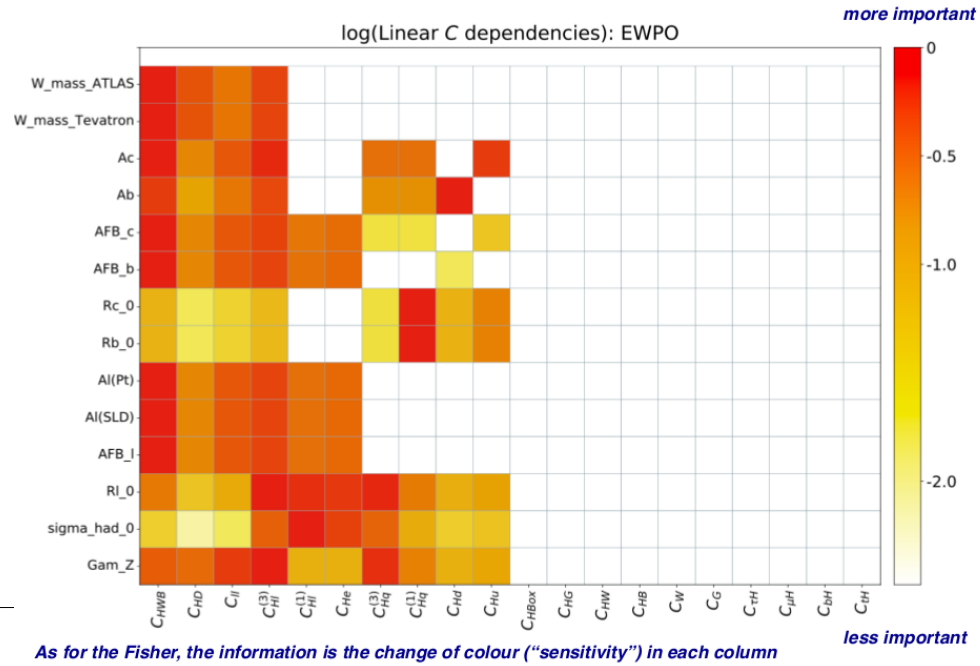
- **Study observables, channel, process sensitivities and complementarities**



To determine which operators affect a process is trivial
→ How important a process is in the global (EFT fit) picture is far from obvious!

- Impact is intrinsically interlinked with choice of observable / selection / measurement

- Ongoing investigations might hopefully provide guidance to develop experimental program further (in a more targeted way)



As for the Fisher, the information is the change of colour ("sensitivity") in each column
comparison between ``columns" unphysical

Slide by Juan Rojo

Area 4: Fits and Related Systematics

- **Generally two "camps" here:**

  - **Fitting groups – using unfolded experimental results from outside the collaboration**
    Overview of available codes here;
    → https://indico.cern.ch/event/971727/
    Enhance comparability:
    → common conventions and (conversion) tools
    → common standards for systematics (see: Area 1)
    → Improve experimental information available (a wishlist: https://indico.cern.ch/event/1007581/contributions/4228635/attachments/2194426/3709763/Presentation_ExpResults_TH_Interp.pdf)

  - **Experimental combination between ATLAS and CMS (Feb 22, 2021)**
    → Kick-off: https://indico.cern.ch/event/1007581/
  - Use our combination project to get feedback and advice from the WG but also to help focus the WG discussions on something concrete and help those discussions converge, in some cases break the symmetry

  - Scope:
    - Cross-experimental (ATLAS+CMS)
    - Cross-topical (i.e. including top, Higgs and EWK measurements)

Area 4: Fits and Related Systematics

- **Experimental combination between ATLAS and CMS**

  - Examples:
    → **ATLAS/CMS Higgs combination (Run-1) – JHEP 08 (2016) 045**
    Maximized sensitivity of LHC in extraction of Higgs properties

    → **Cross-topical/signature:**
    https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2021-022/
    (Combined EFT analysis of WW, WZ, ZZ, VBF Z processes)
    https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2021-010
    (Combined EFT interpretation of H to WW and WW processes)

    → Generally: Global fits are being prepared **within** the collaborations

  - Current status:
    → regular meetings, discussions slowly converging on general setup

→ https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCEFTExpCombinationConventions

Interim Conventions for a first EFT Combination between LHC experiments

- Interim Conventions for a first EFT Combination between LHC experiments
  - Fundamentals
    - Basis & Flavour Structure
      - Full list of operators TODO
    - Input scheme
  - Computing predictions
    - Reference predictions for different processes
      - Higgs Cross Sections and STXS
      - Higgs decays
      - Top differential cross sections TODO
      - Top decays TODO
      - Gauge boson differential cross sections TODO
    - Implementation of EFT uncertainties TODO
    - Implementation of EFT validity constraints TODO
  - Inclusion of external constraints (e.g. LEP) TODO
  - Non-EFT issues that are anyway relevant for an EFT combination
    - Correlation of theoretical uncertainties on SM predictions from missing higher orders etc TODO
    - Correlation of uncertainties from PDF, alphaS, m(top), ... TODO
    - Correlation of experimental uncertainties (mainly LHC luminosity inputs) TODO
    - Statistical procedures
    - Technical aspects TODO

⚠ Recently proposed ATLAS evolutions are in red text below and still need to be singed off by CMS.

We will use only dimension-6 operators, in the Warsaw basis.
The default input scheme will be (GF, mZ, mW),

Area 5: Benchmark Scenarios from UV Models

- **Review of (automated) codes**
  → https://indico.cern.ch/event/971736/

- STrEAMlining EFT Matching
- SuperTracer
- Matchmakereft
- CoDEx

- Two main possible projects identified so far:

- **1) Define relevant benchmark models**
  → i) serve as a playground for validation of different tools for the automated matching and
  → ii) are phenomenologically relevant.

- **2) Interplay SMEFT and MSSM**
  → Develop a small set of benchmark points for comparison between MSSM and SMEFT studies

Area 6: Flavour

- **Kick-off with general discussion on flavour and EFT on April 12, 2021**
  → https://indico.cern.ch/event/1011800/

  The big questions of the group:

  → Most of the 2499 dim-6 operators in SMEFT are flavourful. Heavy flavor input is important for a global fit: **How to introduce flavour to the currently flavour-blind EFT models?**

  → **What is the LHCb input to the global SMEFT fits?** How does LHCb handle EFT analysis?

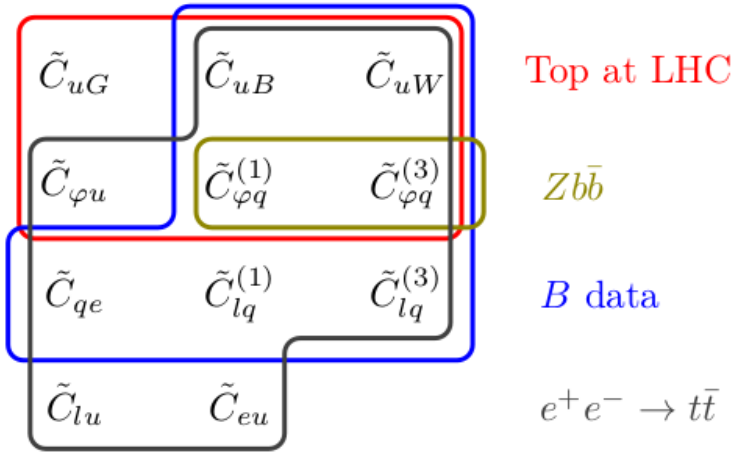
Impact on EW/Higgs/top through

– indirect constraints (via RGE and CKM)

– direct constraints (new flavoured physics) difficult to detect / address if flavour not included in EFT models

→ **So what are useful flavoured EFT benchmark models / assumptions?**

→



Area 6: Flavour assumptions - Benchmarks

- **Benchmark proposal discussed on January 25, 2022**
  → https://indico.cern.ch/event/1096487/

- **Goals:**
  → consistent flavour assumptions

  → for EW+Higgs+top experimental fits
  (not a full flavour model applicable to any observable)

  → near-future [O(50) d.o.f.] and run-3 perspective

- **Lively discussion:**
  → 9 discussion contributions on the suggestion

- **Ongoing review of inputs**
  → idea to test in ATLAS/CMS fit exercise as well

Starting-point proposal

more restrictive — Top-philic (extending the 'universal' scenario)

- new physics couples dominantly to bosons+tops
  - e.g. realized in composite Higgs scenarios
- $\mathcal{O}(30)$ CP-even + $\mathcal{O}(10)$ CP-odd d.o.f.
- not radiatively stable

baseline — $SU(2)^2_{u,q} \times SU(3)^3_{d,l,e}$

- basically MFV with all breakings neglected apart from y_t
- $\mathcal{O}(100)$ d.o.f. [$\mathcal{O}(180)$ for $SU(2)^3_{q,u,d} \times SU(3)^2_{l,e}$]
- reasonable approx. for dim$\leq$4 too
  - radiatively stable then
  - massless b (5F scheme), no $h \to b\bar{b}$ or $\mu^+\mu^-$

less restrictive — LFU-violating

- separating e, μ, τ (e.g. $U(1)^3_e \times U(1)^3_l$, $[U(1)_{l+e}]^3$, $U(2)^5$, etc.)
- not needed, a priori, given the limited interplay with B anomalies (only in high-mass Drell-Yan)
- $\mathcal{O}(15)$ Warsaw operators with leptons

Gauthier Durieux – Flavour assumptions – 25 January 2022

Conclusion

- LHC EFT working group has established working areas and started to converge on a number of topics

  → Recommendations on electroweak input scheme (final)

  → Target: Recommendations on validity error estimates / truncation (with additional open investigations)

- Number of projects started

  → First steps towards ATLAS/CMS combined global EFT fit

  - playground for validity scheme investigations
  - playground for flavour assumptions

  → Survey on operators and observables

  → Benchmarks for UV Models and SM EFT flavour models

Backup slides.