Review of Top WG Conventions

Area 1 meeting: EFT formalism

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LHCtopWG EFT Efforts

- Much already said by Eleni in first meeting of LHC EFT group in October
  - https://indico.cern.ch/event/943996/contributions/4041512/attachments/2125690/3578832/Vryonidou_EFTWG.pdf
- LHCtopWG has been considering EFT interpretations for a number of years (first papers in 2008-9)
  - Main highlight is https://arxiv.org/abs/1802.07237 our 'top EFT white paper'
  - Wonderful example of collaboration across theorists with input from experimentalists!
- Main points from that document
  - Warsaw basis
  - 3 different flavour assumptions
    - 'Default': Minimal flavour violation in the quark sector (less and more restrictive are considered as alternatives): U(2)q × U(2)u × U(2)d
  - FCNC is treated separately
  - Identify the **linear combination**s of Warsaw-basis operators that appear in interferences with SM amplitudes and in interactions with physical fields after electroweak symmetry breaking (notation and normalisation agreed upon)
- Main limitations
  - "Our discussion exclusively concerns processes involving at least a top quark"
  - For now: tree-level description only
    - NLO work ongoing

89 citations to date

Interpreting top-quark LHC measurements
in the standard-model effective field theory

J. A. Aguilar Saavedra,[1] C. Degrande,[2] G. Durieux,[3]
F. Maltoni,[4] E. Vryonidou,[2] C. Zhang[5] (editors),
D. Barducci,[6] I. Brivio,[7] V. Cirigliano,[8] W. Dekens,[8,9] J. de Vries,[10] C. Englert,[11]
M. Fabbrichesi,[12] C. Grojean,[3,13] U. Haisch,[2,14] Y. Jiang,[7] J. Kamenik,[15,16]
M. Mangano,[2] D. Marzocca,[12] E. Mereghetti,[8] K. Mimasu,[4] L. Moore,[4] G. Perez,[17]
T. Plehn,[18] F. Riva,[2] M. Russell,[18] J. Santiago,[19] M. Schulze,[13] Y. Soreq,[20]
A. Tonero,[21] M. Trott,[7] S. Westhoff,[18] C. White,[22] A. Wulzer,[2,23,24] J. Zupan.[25]

LHCtopWG EFT Efforts: # degrees of freedom

- "We recommend to determine systematically the dependence of each observable of interest on the listed degrees of freedom"
- Non FCNC: 56 CP conserving + 17 CPV

The $U(2)_q \times U(2)_u \times U(2)_d$ flavour symmetry assumption is used by default in this note where not otherwise specified. The following numbers of degrees of freedom are produced for the operators of each category of field content:

four heavy quarks	$11 + 2$ CPV
two light and two heavy quarks	14
two heavy quarks and bosons	$9 + 6$ CPV
two heavy quarks and two leptons	$(8 + 3\text{ CPV}) \times 3$ lepton flavours

- FCNC: 61 CP even (excl light q flavour factor), total of 316 if include flavour factor and CPV parameters

In total, the counting of FCNC degrees of freedom is as follows:

one-light-one-heavy	$(15 + 15\,\text{CPV}) \times 2$
one-light-one-heavy-two-leptons	$(9 + 9\,\text{CPV}) \times 2 \times 3$
one-light-three-heavy	$(23 + 23\,\text{CPV}) \times 2$
three-light-one-heavy	$(14 + 14\,\text{CPV}) \times 2$

What EFT conventions/bases/notations/assumptions have been used or have been considered?

- **This one is easy for the LHC top community!!!!**
- Basis: Warsaw
  - Don’t believe anyone is using anything else within the top group
- Notations
  - LHCtopWG has an agreement on the notation of the operators
    - After lots of discussions, not saying it was straight-forward but everyone compromised and agreed a common set was better than multiple!!!
- Assumptions
  - FCNC treated separately (don’t think anyone is revisiting this?)
  - ‘Intermediate’ level of complexity: $U(2)_q \times U(2)_u \times U(2)_d$ as default
  - Alternatives
    - Less restrictive: $U(2)_{q+u+d}$: +10 CP-conserving + 10 CPV parameters (don’t believe anyone has used that)
    - More restricture: ‘top-philic’: only 19+6CPV operators (don’t believe anyone has used that)
- Implementation: dim6top
  - Most analyses (with EFT interpretations) now using the dim6top implementation (UFO)
  - Incl some global fits e.g. 1901.05965 & 1910.03606

Lessons learned

- Having all these (years of) discussions in an open forum of the LHCtopWG meant
    - Input from experimentalists as the theorists were coming up with their agreement
- Built a consensus before the analyses had the power (sensitivity and manpower) to make EFT interpretations
    - We benefited from the EFT interpretation approach being new to us (no kappa framework for us to get rid of)
- Doesn't mean there weren't heated discussions and lots of iterations
    - But that in the end we have a way forwards
- Now is the time to do this for an 'LHC-wide' effort
    - Need to carefully think about balancing the need for innovation with the need for stability
        - How to 'future proof' our interpretations? Or should we?
- In our case the main issue doesn't come from 'what' but 'how'
    - Clearly testing every variable ever measured by ATLAS & CMS against >50 parameter isn't realistic!
- There were some grand ideas of 'top down' and 'bottom up' dictionaries and recipes
    - But actually too complicated to implement in practice
    - Result: onus is on the analysis teams to figure out what parameters they should look at

Lessons learned (cont)

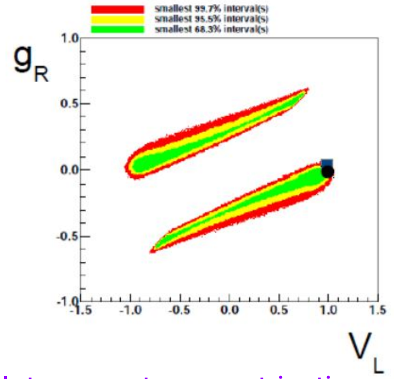
- Good lesson learnt when thinking of operators affecting the Wb vertex
  - If we don't use suitable (and enough) observables, we can't constraint them all
    - There are degenerate directions
  - Concrete example
    - W helicity is not sensitive to particular combinations of them nor to the imaginary part
    - Only including single top observables can we break the degeneracy

- For a global fit, the choice of observables is critical
  - Otherwise we will only be able to constrain some combinations of operators
  - How do we figure out the minimum set of measurements that breaks any degeneracy? Or is it OK to have insensitive directions for now
  - e.g. quote results as linear combinations of operators (c.f. Higgs) and create our own ‘non-degenerate’ directions?

W-helicity:

At the time parametrisation:

$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\,\gamma^{\mu}\left(V_L P_L + V_R P_R\right) t\, W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\,\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}\left(g_L P_L + g_R P_R\right) t\, W_{\mu}^{-} + \text{H.c.}\,.$$



Into current parametrisation:

$$\delta V_L = C_{\phi q}^{(3,33)*}\frac{v^2}{\Lambda^2}, \qquad \delta g_L = \sqrt{2}C_{dW}^{33*}\frac{v^2}{\Lambda^2},$$

$$\delta V_R = \frac{1}{2}C_{\phi\phi}^{33}\frac{v^2}{\Lambda^2}, \qquad \delta g_R = \sqrt{2}C_{uW}^{33}\frac{v^2}{\Lambda^2}.$$

Still degenerate direction

Looking to the future?

- dim6top
  - Perfect for including only top measurements!
- SMEFTSim
  - At the time of the note, this was an option, guess still an option but not heard of anyone using it
  - Not clear to me if there are advantages over dim6top?
- SMEFT@NLO
  - Potentially the future if we want to move to more global combinations (between physics groups)
  - Can be run with LO only and should be similar to dim6top (right?)
  - How much of a community push should there be to unify here? Should this be done before we get in too deep?
    - Should this group be leading this effort?
- Are there advantages of maintaining different frameworks?
- Do we need to go beyond LO? Interference and/or quadratic terms?
  - How to include them into a ‘global’ approach?
  - **For top physics:** we need to make sure that we don't use a oversimplified approach
    - Else risk losing sensitivity to some important phenomena (e.g. FCNC)

Towards Global Combinations (my personal view)

- dim6top works well for top specific operators
- But what if we want to include Higgs or EW measurements?
    - Higgs+EW seems reasonable as they can live with a 2 flavour scheme
    - How to include top?
        - assuming e.g ttH only comes from top operators is naive so making the assumption that q=t and using a light flavour basis is too simplistic (c.f. ATL-PHYS-PUB-2019-042)

$ttH + tH$	$0.133 \cdot c_G + 0.1182 \cdot c_{Hbox} - 0.0296 \cdot c_{HDD} + 0.532 \cdot c_{HG} + 0.0120 \cdot c_{HW} - 0.1152 \cdot \lvert c_{uH}\rvert - 0.790 \cdot \lvert c_{uG}\rvert - 0.0111 \cdot \lvert c_{uW}\rvert - 0.0017 \cdot \lvert c_{uB}\rvert - 0.1320 \cdot c_{Hl3} + 0.0146 \cdot c_{Hq3} + 0.0660 \cdot c_{ll1} + 0.0218 \cdot c_{qq1} + 0.1601 c_{qq11} + 0.0263 \cdot c_{qq3} + 0.388 c_{qq31} + 0.0114 \cdot c_{uu} + 0.1681 \cdot c_{uu1} - 0.0018 \cdot c_{ud1} + 0.0265 \cdot c_{ud8} + 0.007 \cdot c_{qu1} + 0.1087 \cdot c_{qu8} - 0.0011 \cdot c_{qd1} + 0.0266 \cdot c_{qd8}$

- Right now we don't have a parameter set we could use for a top-Higgs combination really [I'd love to be corrected if I am just not aware of it]
- Can we learn something from the top effort when moving towards a 'global' set of parameters
    - Where global would still be 'LHC non-B-physics' for now

Towards Global Combinations (my personal view)

- Knowing what parameters (or sets of parameters) to consider is a big sticking point for analysers *[beyond the scope of this area 1 but still important when determining the minimum set of operators needed]*
  - Cannot ask each analysis to determine their sensitivity to 50+ operators
  - Should we have common particle level samples everyone could use?
    - 1 parameter at a time is easy
    - How to decide which parameter combinations to also include?
  - What do we do with acceptance corrections?
    - Particle vs reco level combination etc etc...

Backup

Requests for this talk

- What EFT conventions/bases/notations/assumptions have been used or have been considered
- Activities of the LHC Top WG on EFT
  - current agreement as model for this group?
    - Review some of the underlying principles, which could hopefully guide us for next step
- Status of discussions to move towards SMEFT ?
- Lessons learned from dealing with different sets of parameters
  - For instance whether any issues were met with a certain choice or another, or any practical aspect you believe should be kept into account when defining the formalism
- ATLAS/CMS differences?
  - in the flavour conserving or FCNC sectors, spin-correlation studies may also have be using parametrisations
- Comments on
  - Selecting a common set of EW input parameters
  - Streamlining translations between conventions
  - Handling and understanding flat directions
- Any personal thoughts you and your colleagues may have on EFT in the top sector would also be welcome