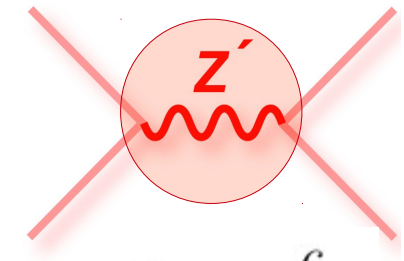
Using SMEFT and other EFTs to quantify sensitivity to new physics

The University Of Sheffield.

Kristin Lohwasser
University of Sheffield

Effective Field theory: A motivation*

$$\frac{1}{p^2 - M_{Z'}^2} = \frac{1}{-M_{Z'}^2}\left[1 + \frac{p^2}{M_{Z'}^2} + \left(\frac{p^2}{M_{Z'}^2}\right)^2 + \dots\right]$$



$$c' = -\frac{c}{M_{Z'}^2}$$

- **Effective Lagrangian as extension of SM Lagrangian**
  - → Taylor expansion of local operators of "light" degrees of freedom
  - → removes explicit description of "heavy" / high energy physics (suppressed by orders of energy scale Λ >> E_{CM})

$$\mathcal{L}^{(\dim)} = \frac{1}{\Lambda}\sum_k C_k^{(\dim)} Q_k^{(\dim)}$$

Number of Operator | Wilson Coefficient | Operator

→ easier calculation of low energy physics by "skipping" complicated terms without large effects on final state

→ systematic measure of SM deviations that can be linked to possible new physics phenomena (→ https://arxiv.org/abs/1711.10391, https://arxiv.org/abs/2009.01249)

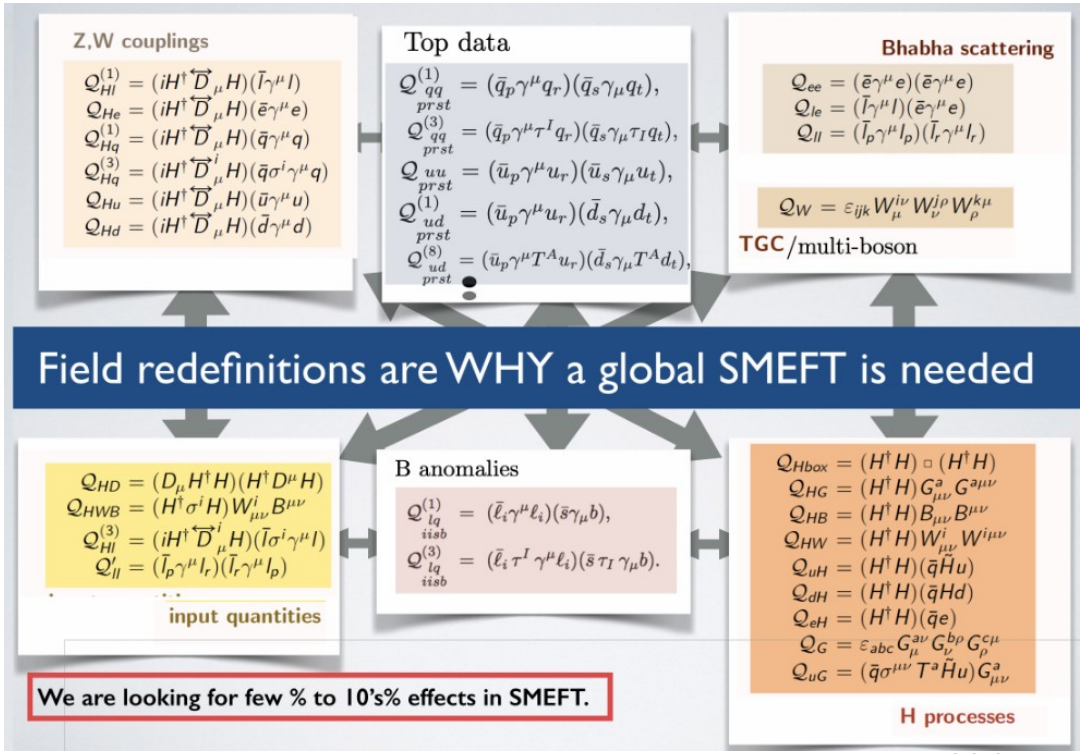
$$\mathscr{L}_{EFT} = \mathscr{L}_{SM}^{(4)} + \frac{1}{\Lambda}\sum_k C_k^{(5)} Q_k^{(5)} + \frac{1}{\Lambda^2}\sum_k C_k^{(6)} Q_k^{(6)} + \mathscr{O}\left(\frac{1}{\Lambda^3}\right)$$

- SM up to dim-4
- dim-5: neutrino masses but lepton flavour violating
- dim-6: most studied at the LHC
- dim-8: not complete, studied for VBS processes

*as the first speaker I take the liberty to give a general intro, but am not a theorist!

Dimension-6 effective field theory: SMEFT

- Dim-6: 2499 parameters reduced to 81 ($U(3)^5$ flavour symm.)
  - → Warsaw basis: orthogonal, complete, renormalisable
  - → https://arxiv.org/abs/1008.4884, https://arxiv.org/abs/1709.06492, https://arxiv.org/abs/2005.05366



Brivio/Trott

- Dim-8: complete basis available since recently
  - → https://arxiv.org/abs/2005.00059
  - → https://arxiv.org/abs/2005.00008

  relevant for VBS+tribosons (and available in MG5)
  - → https://arxiv.org/abs/1604.03555

- Not entirely trivial interplay:

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

So what is being done at the LHC?

- official CERN/LHC groups

LHC EFT WG https://lpcc.web.cern.ch/lhc-eft-wg **(new!)**

LHC top WG
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCTopWG

LHC Higgs XS WG
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWG

LHC EW (MB) WG
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCEW

CMS

ATLAS

- Other

European strategy

Snowmass **(here/now!)**

VBScan
EU/ERC-sponsored network

https://vbscanaction.web.cern.ch/

. . . potential others

LHC EFT WG

LHC EFT WG https://lpcc.web.cern.ch/lhc-eft-wg (new!)

- New groups (after first discussion last year)
- First open meeting: 19 Oct - 20 Oct
  - https://indico.cern.ch/event/943996/
  - Summary of:
    - experimental (ATLAS+CMS) + theory efforts
    - EFT summary of Higgs/Top/EW
    - 2nd day: discussion on EFT WG targets and goals
  - Working group discussion then

- General plan has been discussed amongst the convenors with different topics
  → Basics / EFT formalism
  → Predictions and tools
  → Experimental measurements and observables
  → Fits and related systematics
  → Benchmark scenarios from UV models
  Discussed in the following in a bit more details

- **General split with other LHC groups → more global fits**

- **Conveners:**
  - ATLAS:
    Nicolas Berger (Higgs WG contact)
    Nuno Castro (Top WG contact)
    Kristin Lohwasser (EW WG contact)
    Pierre Savard
  - CMS:
    Florencia Canelli (Top WG contact)
    Pietro Govoni (EW WG contact)
    Andrei Gritsan
    Giovanni Petrucciani (Higgs WG contact)
  - 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

LHC EFT WG: Topics (shortened)

LHC EFT WG https://lpcc.web.cern.ch/lhc-eft-wg (new!)

- **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

- **Predictions and tools**
  - → *Guidance: what is available, how to use → reweighting techniques?*
  - → Deliverables: Cross-validation at tree and loop levels, **common MC generator/settings (exp)**
  - → Specific theory developments: treatment of unstable particles, EFT in PDFs, α_s, ...

LHC EFT WG: Topics

LHC EFT WG https://lpcc.web.cern.ch/lhc-eft-wg (new!)

- **Experimental measurements and observables**
  - → *Study observable, channel, process sensitivities and complementarities*
    Differential distributions, optimal observables, including machine learning, and dedicated EFT measurements ...
    What observables are most sensitive to new physics? Exploit energy growing effects, non-interferences, and other TH knowledge
  - → Analysis strategies & experimental outputs
    legacy measurements and their possible reinterpretation

- **Fits and related systematics**
  - → *Experimental EFT fits: ATLAS+CMS+... combination of H+EW+Top*
  - → Inputs and outputs, fitting procedures and tools (focus on practical considerations!)
  - → Comparison to, and inclusion of, non-LHC constraints (LEP, Tevatron, flavor, g-2, EDM, etc.)
  - → Future projections

- **Benchmark scenarios from UV models**
  - → Matching to specific models, BSM-driven subsets of operators, benchmarks beyond SMEFT,
  - → Comparison of EFT constraints vs. direct BSM searches beyond EFT

Topical LHC groups

LHC top WG
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCTopWG

- EFT subgroup
- Official recommendations: https://arxiv.org/abs/1802.07237
- A variety of global fits on the market

LHC Higgs WG
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWG

- Technically there are 2 groups:
  Higgs (XS) WG
  Higgs Combination
- EFT subgroup
- Various EFT publication (different frameworks)
- Next general meeting in November: https://indico.cern.ch/event/922192/

LHC EW (MB) WG
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCEW

- Multiboson Subgroup of general EW group
- Traditionally working with (higgsless) anomalous couplings
  → transition to SMEFT in Run-2
- Work on YR ongoing
- Meeting in 2 days: https://indico.cern.ch/event/941711/

Topical LHC groups

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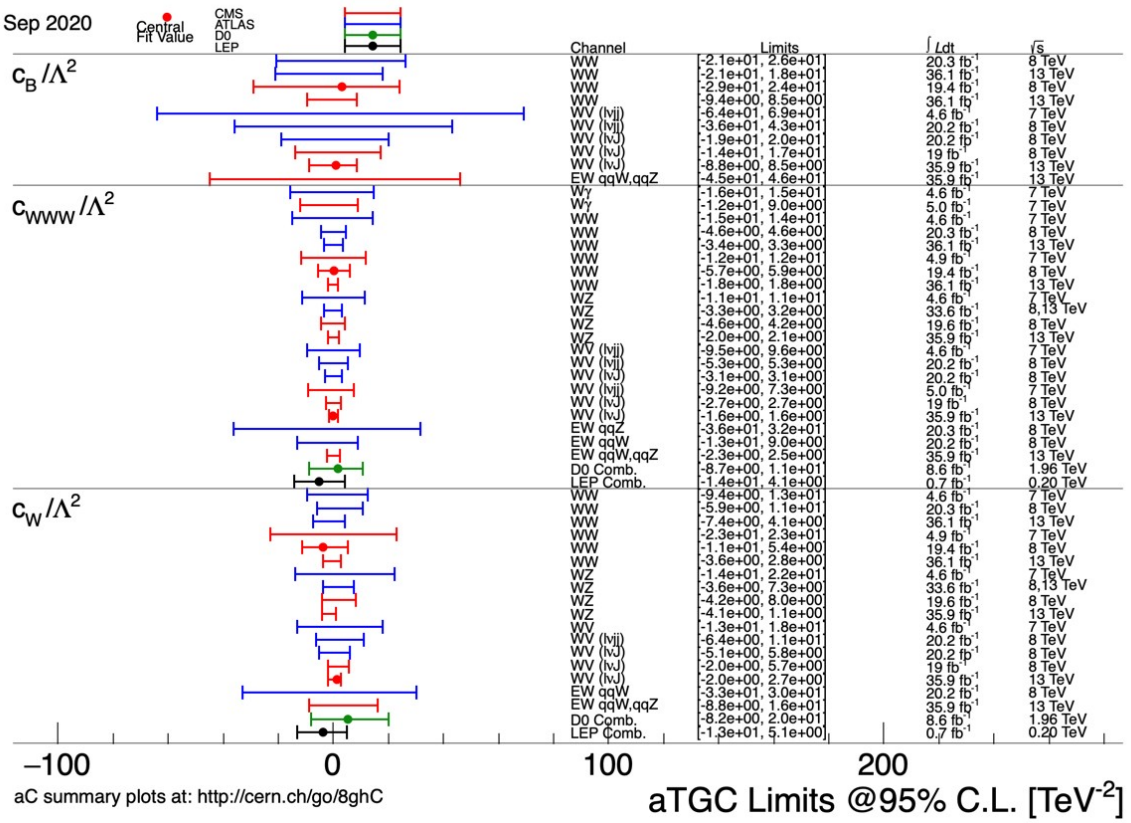

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMPaTGC

Work within the experiments

CMS

ATLAS

- Global EFT efforts ongoing in both collaborations (but as far as I know no public results yet)

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

- ATLAS:
  https://twiki.cern.ch/twiki/bin/view/AtlasPublic/WebHome#PhysicsGroups
  (Select → more → EFT interpretations)

Papers and publications of ATLAS physics and performance results (40 shown of 967 total)
(Full list of ATLAS papers, List/RSS from CDS)

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Short Title	Group	Journal Reference	Date	√s (TeV)	L	Links
EW Zjj differential cross sections	STDM	Submitted to EPJC	27-JUN-20	13	139 fb^{-1}	Documents | 2006.15458 | Inspire Internal
H(125)->4l STXS and couplings	HIGG	Accepted by EPJC	07-APR-20	13	139 fb^{-1}	Documents | 2004.03447 | Inspire HepData | Internal
Search for FCNC tqgamma in single top	TOPQ	Phys. Lett. B 800 (2019) 135082	22-AUG-19	13	80 fb^{-1}	Documents | 1908.08461 | Inspire HepData | Internal
ZZ production with two neutrinos in the final state at 13 TeV	STDM	JHEP 10 (2019) 127	17-MAY-19	13	36 fb^{-1}	Documents | 1905.07163 | Inspire Internal
WZ boson pair production at 13 TeV	STDM	Eur. Phys. J. C 79 (2019) 535	15-FEB-19	13	36.1 fb^{-1}	Documents | 1902.05759 | Inspire HepData | Internal
Measurement of ttV in multilepton final states using 36.5fb-1 at 13 TeV	TOPQ	Phys. Rev. D 99 (2019) 072009	11-JAN-19	13	36 fb^{-1}	Documents | 1901.03584 | Inspire HepData | Internal
Search for flavor-changing neutral current t to Hq with H->b-bbar and tautau at 13 TeV	TOPQ	JHEP 05 (2019) 123	30-DEC-18	13	36 fb^{-1}	Documents | 1812.11568 | Inspire Internal
Search for FCNC tqH with H->WW at 13 TeV	TOPQ	Phys. Rev. D 98 (2018) 032002	09-MAY-18	13	36 fb^{-1}	Documents | 1805.03483 | Inspire Internal

- CMS: http://cms-results.web.cern.ch/cms-results/public-results/publications/Run2/index.html

Closest to snowmass: European strategy

European strategy

- Discussions in prior EF04 group meetings: https://indico.fnal.gov/category/1138/
- e.g. Jorge de Blas https://indico.fnal.gov/event/43963/contributions/190544/attachments/131694/161343/EWphys_Snowmass_21_deBlas.pdf

	Higgs	aTGC	EWPO	Top EW
FCC-ee	Yes (μ, σ_{ZH}) (Complete with HL-LHC)	Yes (aTGC dom.)	Yes	Yes (365 GeV, Ztt)
ILC	Yes (μ, σ_{ZH}) (Complete with HL-LHC)	Yes (HE limit)	Yes (Rad. Return, Giga-Z)	Yes (500 GeV, Ztt)
CEPC	Yes (μ, σ_{ZH}) (Complete with HL-LHC)	Yes (aTGC dom)	Yes	No
CLIC	Yes (μ, σ_{ZH})	Yes (Full EFT parameterization)	Yes (Rad. Return, Giga-Z)	Yes
HE-LHC	Extrapolated from HL-LHC	N/A → LEP2	LEP/SLD + HL-LHC (M_W, $\sin^2\theta_w$)	-
FCC-hh	Yes (μ, BR_i/BR_j) Used in combination with FCCee/eh	From FCC-ee	From FCC-ee	-
LHeC	Yes (μ)	N/A → LEP2	LEP/SLD + HL-LHC (M_W, $\sin^2\theta_w$)	-
FCC-eh	Yes (μ) Used in combination with FCCee/hh	From FCC-ee	From FCC-ee + Zuu, Zdd	-

Summary

- The European Strategy Update 2020 EW/Higgs studies provided a solid first step towards comparing the capabilities (and complementarities) of the different future collider projects in the Energy frontier in a realistic way.
- These studies were nevertheless limited in their nature by the official inputs available from the different FC groups, as well as by the TH assumptions needed for a coherent comparison of the different machines.
- These limitations provide a stepping stone for more complete studies to be done within the Snowmass 2021 process:
  - ✓ In this talk I reviewed a few points for improvement wrt. ESU2020, from the point of view of EW physics.
  - ✓ Much more can be done! (See also talk by C. Grojean at EF01 kickoff meeting for extended list covering also Higgs topics.)
- Clean separation between frontiers (EW, Higgs, Top, …), while useful, is not completely possible from the point of view of assessing the sensitivity to general BSM effects. Interaction between them is needed to obtain a global picture of the capabilities of future colliders!

Other groups: VBScan

VBScan
EU/ERC-sponsored network

https://vbscanaction.web.cern.ch/

- ERC-funded network (mainly travel costs and conferences) co-organisation of MBI planned https://vbscanaction.web.cern.ch/
- https://vbscanaction.web.cern.ch/publications.html
- Focus on VBS signatures: measurements, theory, interpretation, extrapolation
- Next general meeting in January/Febuary (tbc)

Conclusion

- Discussed (larger/official) groups around EFT interpretations and measurements
- LHC EFT group just founded → general goals and interests briefly outlined (as relationship with other LHC (sub)groups
- More detailed discussion planned for the first open meetings
- Upcoming meeting of LHC EW group and Higgs XS groups
- Lessons from Snowmass