6th General Meeting of the LHC EFT Working Group

Wednesday 15 November 2023 - Friday 17 November 2023

CERN

Book of Abstracts

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One Loop Effective Action up to Dimension Eight: integrating out heavy scalars and fermions

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I will discuss the computation of effective action after integrating out heavy scalars and fermions respectively up to dimension eight. The result is very universal. The generic expressions for the effective operators up to dimension eight are computed for the first time and applicable for any UV model. At this current situation when we are looking more precise calculation beyond dimension six, these will be very useful and effective.

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Leading directions in SMEFT

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Standard Model Effective Field Theory (SMEFT) provides a robust approach to explore short-distance new physics effects in a model-independent way. One of the inherent shortcomings of SMEFT is the number of independent parameters, which need to be taken into account to perform the SMEFT analysis in full generality. In this presentation, some of the well-motivated options to reduce the number of independent parameters by means of flavor symmetries are explored, providing a very useful organizing principle. Moreover, this approach is then also applied to the new spin-0, 1/2, and 1 fields, which integrate out to the dimension-6 SMEFT operators at tree level. The full classification of these mediators under the $U(3)^5$ flavor symmetry is performed. Additionally, once integrated out, the vast majority of flavor-symmetric interactions predict a single SMEFT operator with a definite sign, and these operators are referred to as leading SMEFT directions. Utilizing the available SMEFT fits, bounds for various mediators entering the leading directions can be estimated.

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Area 4: A practical framework of EFT fits with published likelihoods (20'+5')

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Recently there has been rapid increase in the number of full statistical models (or "likelihoods") published by the experiments. Most are based on the HistFactory (pyhf) format and published in HEPData. This allows theorists and others to reproduce and combine measurements with the same gold standard as the internal experimental results. However, these are mainly from SUSY and exotics searches and working with EFTs is more complicated because quantum interference effects lead to changes in the signal template (via the dependence of the differential cross-sections and phase-space dependent selection efficiency on the EFT parameters). In this talk I will propose a simple, lightweight framework that would extend current likelihood publishing to overcome these

challenges and enable 'exact' EFT fits (i.e. with the same level of detail as the internal experimental fits and combinations).

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Area 4: Introducing the FAIROS-HEP Research Coordination Network (5'+5')

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The US National Science Foundation has funded a 3-year "Research Coordination Network" called FAIROS-HEP. FAIROS-HEP aims to foster the adoption of practices and cyberinfrastructure to enable reuse and reinterpretation of high energy physics (HEP) datasets. The network has funds to support international workshops and to contribute directly to cyberinfrastructure components such as INSPIRE, HEPData, etc. A specific aim of FAIROS-HEP is to aid in developing a framework for EFT global fits as conceptualized by the community through meetings such as the LHC EFT WG. The purpose of this talk is just to announce the project and the availability of funds for participants to attend dedicated workshops and targeted contributions to cyberinfrastructure components.

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Computing optimal observables from the Matrix Element Method with Conditional Normalizing Flows

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This work presents a novel strategy to enhance and expedite the computation of the Matrix Element Method (MEM), a powerful technique for calculating the probability of an event generated by a given theory, using generative machine learning architectures. Despite the theoretical knowledge contained in the MEM, its practical application is hindered by the need for many approximations to compute high-dimensional integrals, particularly for complex final states with jets. However, the MEM computation is desirable to obtain powerful optimal observables for EFT measurements.

Our approach employs a combination of Transformers and Normalizing Flows. The Transformer network analyzes the complete event description at the reconstruction level, extracting a latent information vector. This vector conditions a Normalizing Flow model, which learns the conditional probability at the parton level directly. The model is trained to generate plausible parton sets compatible with the observed objects, which are then used for MEM integration through importance sampling.

This strategy is scalable and can handle events with multiple jet multiplicities and additional radiation at the parton level. We will discuss the results of the initial implementation of this architecture for a complex final state, specifically the ttH(bb) semileptonic channel

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Closing in on New Physics via the Flavor, Collider, and Electroweak Triad

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Any new physics (NP) lying at the TeV scale must pass stringent flavor as well as collider bounds. Since the top Yukawa gives the largest quantum correction to the Higgs mass, one well-motivated expectation is TeV-scale NP dominantly coupled to the third family. This setup delivers U(2) flavor symmetries that allow one to start explaining flavor at the TeV scale, while simultaneously improving compatibility with the aforementioned bounds.

In all such models that also seek to address the hierarchy problem or the flavor puzzle, there are unavoidably new particles with sizable couplings to the Higgs. Integrating out these heavy particles generates contributions to SMEFT operators that modify EW precision observables, which are precisely measured on the Z- and W-poles. We therefore have a triad of bounds that all models of this type must pass: flavor, direct collider searches, and EW precision tests.

The SMEFT in the U(2)ˆ5 symmetric limit contains only 124 independent operators. This makes an exhaustive phenomenological study tractable, where one can place bounds on all of these operators from each prong of the triad. I will show that while flavor bounds depend on how U(2) is broken, the U(2) symmetric limit is sufficient for EW and collider parts of the triad, which most strongly constrain the flavor conserving parts of the operators. Additionally, important effects come from resummed RGE, in particular from operators with third-family quarks running strongly into Higgs operators constrained on the Z-pole. Finally, I present projections showing how the FCC-ee Z-pole run will indirectly probe a plethora of operators via their unavoidable RG mixing into Higgs operators.

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SmeftFR v3 - a tool for creating and handling vertices in SMEFT to the 1/Λˆ4 order

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SmeftFR v3 [Comput.Phys.Commun. 294 (2024) 108943, 2302.01353, https://www.fuw.edu.pl/smeft/] enables derivation of Feynman rules for interaction vertices from the dimension-5, dimension-6, and (so far) all bosonic dimension-8 SMEFT operators. Obtained Feynman rules allow for consistent numerical or symbolic calculations in SMEFT (e.g., in Madgraph or in FeynArts) to the 1/Λˆ4 order in the EFT expansion, including dimension-6 squared and dimension-8 terms, which is a novelty in the literature. In my talk, I will discuss some of the most important new features of SmeftFR v3, such as choosing among and using one of the predetermined input schemes, including one for the CKM matrix. I will also describe examples of its usage and some possible applications.

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Roadmap towards future combinations and Effective Field Theory interpretations of top+X processes

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The ATLAS Collaboration produced a roadmap detailing the challenges of combining top+X measurements to produce coherent probes of the Standard Model predictions and Effective Field Theory (EFT) interpretations. Different approaches for combinations and EFT parameter extractions are outlined, and prerequisites on the harmonisation of physics objects and phase-space regions are described. A plan for the top quark sector is prepared with steps of increasing complexity and potential, for the interpretation of future measurements.

https://cds.cern.ch/record/2872789

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Quantum Computing and Quantum information in estimating EFTs from measurements.

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In the quest for new physics at the LHC, Effective Field Theory (EFT) provides a robust framework for interpreting data. While classical machine learning is an excellent tool for isolating the effects of individual Wilson Coefficients in experimental data, it is limited in its ability to capture the underlying quantum correlations that these coefficients parametrize. This research proposes the use of aspects of Quantum Computing techniques, specifically Hamiltonian Learning and Quantum State Tomography into EFT measurements at the LHC.

In quantum chemistry, Hamiltonian Learning provides a way to directly learn the Hamiltonian from data, without the need for approximations like mean-field theories or perturbative methods. It can capture strongly correlated quantum phenomena that classical methods often approximate or simplify. Aspects of this Hamiltonian picture have been demonstrated to be beneficial for estimating the value of up to 8 Wilson coefficients including their quadratic contributions from data \[1\]. In quantum state tomography, a coupling of an arbitrary Hilbert operators coupling to the spin components of a multipartite final state can be completely characterised in given measurement basis by the density matrix \[2\] opening the door to learn such characterisations not through fitting differential distributions but directly using machine learning \[3\].

These techniques promise to provide a more direct and comprehensive understanding of the quantum phenomena parametrized by Wilson Coefficients, thereby enhancing the precision of EFT measurements. By integrating Quantum Computing into the EFT analysis pipeline, we aim to leverage the quantum native nature of the way these tools describe elementary processes to unlock new avenues for beyond-the-Standard-Model discoveries, offering a complementary approach to classical machine learning methods.

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Public repository for limits on SMEFT Wilson coefficients

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Here, we will propose a github repository for collecting and displaying the best limits on SMEFT Wilson coefficients. We will explain the bound submission and automated display process for new contributors and the minimal coding steps included for that. We will elaborate on how we keep it open-source and involve minimal (or null) human maintenance. Also, We will discuss the template in which bounds-related information needs to be submitted. We will give a brief demo on the submission and retrieval of the present limits from the repository – https://smeftbounds.github.io/. We will also invite suggestions on the future utilities that should be included in the repository.

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Developments in SMEFT phenomenology (20'+10')

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Formal developments in EFTs (20'+10')

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Progress in the SMEFT-UV connection (20'+10')

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SMEFT in the EWK and TOP sectors in CMS (20'+10')

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SMEFT in the EWK sector in ATLAS (10'+5')

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EFT in flavor and B-physics in ATLAS, CMS and LHCb (20'+10')

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Machine Learning opportunities for EFT analyses

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Computing optimal observables from the Matrix Element Method with Conditional Normalizing Flows

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Public repository for limits on SMEFT Wilson coefficients

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Roadmap towards future combinations and Effective Field Theory interpretations of top+X processes

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Area 2: Update on EFT prediction note

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Area 2: Update on common format & toolchain for SMEFT parameterisations (STXS)

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Higher-order corrections in SMEFT (20'+5')

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Positivity constraints (20'+5')

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SMEFT vs HEFT: multi-Higgs phenomenology (15'+5')

Authors: Alexandre Salas-Bernárdez[1]; Javier Martínez Martín[2]; Juan José Sanz-Cillero[2]; Rafael Delgado López[3]; Raquel Gomez Ambrosio[4]

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This article studies the production of multiple Higgs bosons from longitudinal vector boson scattering in the context of effective field theories.
The equivalence theorem is employed for a clearer understanding of the $WW \to n \times h$ dynamics.
In this approximation, the Higgs dynamics is determined at lowest order in the general Higgs Effective Theory (HEFT) by the flare function $\mathcal{F}$, which provides the WWh^n effective vertices.
We find that the amplitudes can be written in a very compact way for the production of two, three and four Higgs bosons.
However, when mapped to the Standard Model Effective Theory (SMEFT), we find a strong suppression in the production of multi-Higgs states.
Non-SMEFT scenarios that allow the flare-function to deviate from the correlations required by

SMEFT can avoid this feature and have cross sections orders of magnitude larger.
We provide some phenomenological comparisons between HEFT and SMEFT cross sections and exclusion plots for models assuming the SMEFT scenario. For the computation of these cross sections we provide various specific codes which we have made publicly available to the community.

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Geometry of EFTs (15'+5')

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Lagrangian terms of an effective field theory (EFT) are commonly organized as an expansion in terms of the EFT power counting. Field space geometry reorganizes these terms in a more efficient way, allowing the direct generalization of some known results to a resummed tower of operators containing higher-order terms, such as the renormalization group equations at one- and two-loop order, some scattering amplitudes, decay widths and electroweak precision observables.This geometric approach also gives a basis independent formulation which can be interpreted with different EFT power counting parameters, helping us select the most appropriate EFT (with faster convergence) for phenomenology studies, such as the Standard Model EFT vs the Higgs EFT.
The purpose of this proposal to the LHC EFT working group is twofold:
1) Fully generalize the formalism to arbitrary EFTs by including derivative terms and particles of higher-spin (fermions and vectors). Ideas to deal with the former include Lagrange spaces and jet bundle geometry, while the latter is straightforward and requires an extension of the field space to supermanifolds.
2) Facilitate the adoption of these techniques in phenomenology studies, allowing to deal with more compact expressions in terms of the geometrical objects, which makes the calculations with higher-dimensional operators trivial.

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Summary of Area 5 activities and new directions

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Matching 2HDM onto Effective Field Theories in ATLAS (15' + 5')

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Matching database + new framework for matching repository (20' + 5')

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One Loop Effective Action up to Dimension Eight: integrating out heavy scalars and fermions (15' + 5')

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I will discuss the computation of effective action after integrating out heavy scalars and fermions respectively up to dimension eight. The result is very universal. The generic expressions for the effective operators up to dimension eight are computed for the first time and applicable for any UV model. At this current situation when we are looking more precise calculation beyond dimension six, these will be very useful and effective.

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Area 4: Update on EFTWG fitting exercise (10'+5')

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Area 4: Report on LHC reinterpretation forum workshop (10'+5')

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Closing in on New Physics via the Flavor, Collider, and Electroweak Triad (15+5)

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Effective couplings in $B^0 \to K^{*0}\mu^+\mu^-$ (15+5)

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Workshop summary: Heavy flavour aspects in EFT - SL decays (10+5)

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Leading directions in SMEFT (15+5)

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EFT in flavor and B-physics in ATLAS, CMS and LHCb (20'+10')

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SMEFT in the TOP sector in ATLAS (10'+5')

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