Effective Field Theories at one loop

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Based on:

arXiv:1704.04504 (to appear in EPJC)
In collaboration with: Alejandro Celis, Avelino Vicente, Javier Virto

JHEP 1609 (2016) 156 [arXiv:1607.02142]
In collaboration with: Jorge Portolés and Pedro Ruíz-Femenía

Motivation: Effective Field Theories

- EFTs offer a **model independent approach**: Physics above a given scale mapped into Wilson coefficients of higher dimensional operators

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

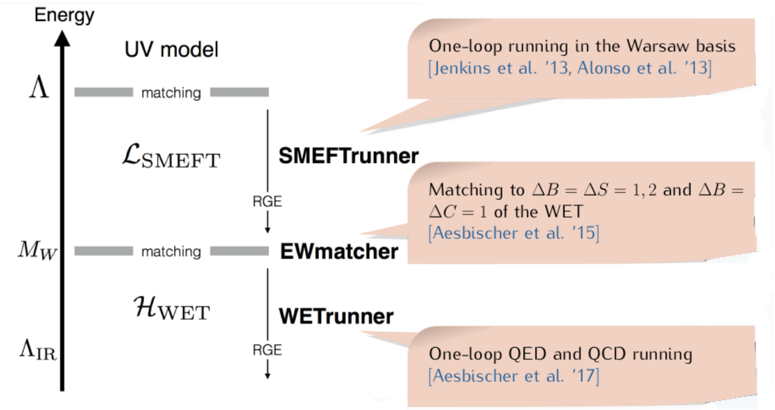
- LHC + EWPD data can be used to do global fits of the Wilson coefficients of the SMEFT
  $\longrightarrow$ Any UV model should satisfy the resulting bounds

- EFTs at one-loop ?
  - Some contributions to the EFT are only generated at one-loop. Moreover, with the increasing precision in some observables, one-loop corrections can be important
  - Ongoing efforts to extend the EFT analyses to NLO
    See for instance CERN Yellow Report 4
  - Loop corrections to the EFT also important in Flavor Physics
    e.g. Feruglio, Paradisi, Pattori, 1705.00929; Pruna, Signer, 1408.3565

DsixTools: The SMEFT toolkit

Celis, JF, Vicente, Virto, 1704.04504

A **Mathematica** package for the handling of the $d = 6$ SMEFT

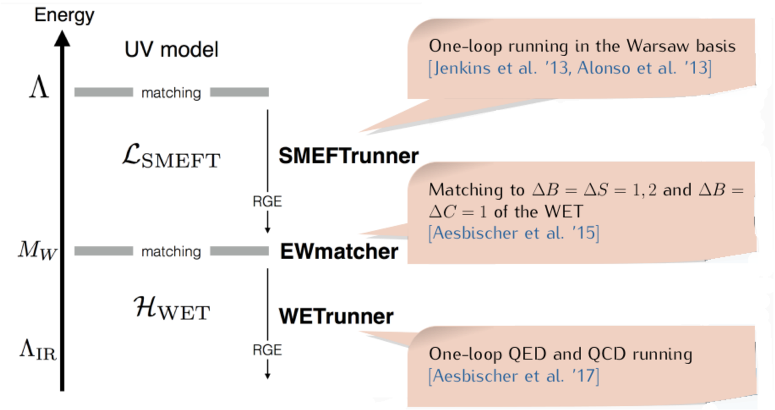


- **Modular structure** $\Longrightarrow$ Each module can be used independently
- DsixTools is expected to be extended with more modules

DsixTools: The SMEFT toolkit

Celis, JF, Vicente, Virto, 1704.04504

A **Mathematica** package for the handling of the $d = 6$ SMEFT

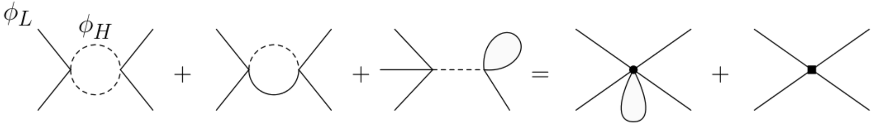


- A (simple) systematic framework to match any UV theory to its EFT is highly desirable!

Conventional matching vs functional approach

Two general approaches for the construction of the EFT:

- **Matching** the diagrammatic computation of Green Functions with light particles in the external legs in the UV theory and in the EFT



- **Integrate out the heavy fields**, and extract the local contributions relevant for the Wilson coefficients

$$e^{iS} = \mathcal{N} \int \mathcal{D}\phi_L \, \mathcal{D}\phi_H \, \exp\left[i \int dx \, \mathcal{L}(\phi_L, \phi_H) \right]$$

Functional integration techniques are **more powerful** than the matching procedure when one aims to determine the **full EFT**

One-loop effective action

Expand the UV Lagrangian around the classical fields

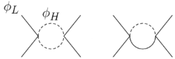
$$\mathcal{L} = \mathcal{L}^{\text{tree}}(\hat{\eta}) + \underbrace{\left(\eta^\dagger \frac{\delta \mathcal{L}}{\delta \eta^*} + \frac{\delta \mathcal{L}}{\delta \eta}\eta\right)_{\eta=\hat{\eta}}}_{=0 \quad (\text{EOM})} + \frac{1}{2}\eta^\dagger \underbrace{\frac{\delta \mathcal{L}}{\delta \eta^* \delta \eta}}_{\equiv O}\eta + \mathcal{O}(\eta^3)$$

fluctuation operator

From the fluctuation operator we get the one-loop effective action

$$e^{iS^{1\text{loop}}} = \mathcal{N}\int \mathcal{D}\eta \, \exp\left[i\int dx \, \frac{1}{2}\eta^\dagger \, O \, \eta\right] \qquad \eta \equiv \begin{pmatrix} \eta_H \\ \eta_L \end{pmatrix}$$

Generic form of the fluctuation operator:



$$O = \begin{pmatrix} \Delta_H & X_{LH}^\dagger \\ X_{LH} & \Delta_L \end{pmatrix}$$

Δ_H, Δ_L: heavy and light loops

X_{HL}: heavy-light loops

Our aim: compute the one-loop heavy particle effects and extract their contributions to the Wilson coefficients of the EFT

Two important simplifications

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- The effect of the heavy-light loops can be shifted to the heavy part

$$\eta \to P\,\eta \qquad O = \begin{pmatrix} \Delta_H & X_{LH}^\dagger \\ X_{LH} & \Delta_L \end{pmatrix} \longrightarrow P^\dagger O P = \begin{pmatrix} \widetilde{\Delta}_H & 0 \\ 0 & \Delta_L \end{pmatrix}$$

- Loops with heavy fields receive contributions from the **soft** ($p \sim m_L$) and the **hard** ($p \sim m_H$) momentum regions but **only the hard region contributes to the EFT**
  - The method of **expansion by regions** allows to separate each region by Taylor expanding the loop integrand over the parameters that are small there, and integrating over the full domain. Beneke, Smirnov '98

$$S_H = \underbrace{S_H^{\text{hard}}}_{p\,\sim\, m_H \,\gg\, m_L} + \underbrace{S_H^{\text{soft}}}_{p\,\sim\, m_L \,\ll\, m_H}$$

Pure short distance!

Heavy propagator expanded in p/m_H
(same as loops with tree EFT vertices)

Long story short

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We developed a functional method for the one-loop matching that clarifies the treatment of heavy-light loops and provides important simplifications

$$\int d^dx \, \mathcal{L}_{\text{EFT}}^{\text{1loop}} = S_H^{\text{hard}}$$

- A shift in the field allows to easily isolate the heavy-field contributions
- **Compute only the hard part**, the rest cancel in the matching (also true for diagrammatic matching!)

$$S_H^{\text{soft}} + S_L - S_{\text{EFT}}^{\text{tree}} = 0$$

- S_H^{hard} can be easily computed using functional techniques. Mostly algebraic problem... but a large amount of algebra is involved
- **Automation** becomes essential for any realistic model


Work in progress

A Mathematica package for the matching and RGE evolution from the new physics scale to the scale of low energy observables

Manual: arXiv:1704.04504
Website: https://dsixtools.github.io/

New features are coming soon
Comments (including critical ones!), questions and suggestions are welcome!

Thanks!