A Introduction To SMEFT

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Contents:

1) EFT Introduction
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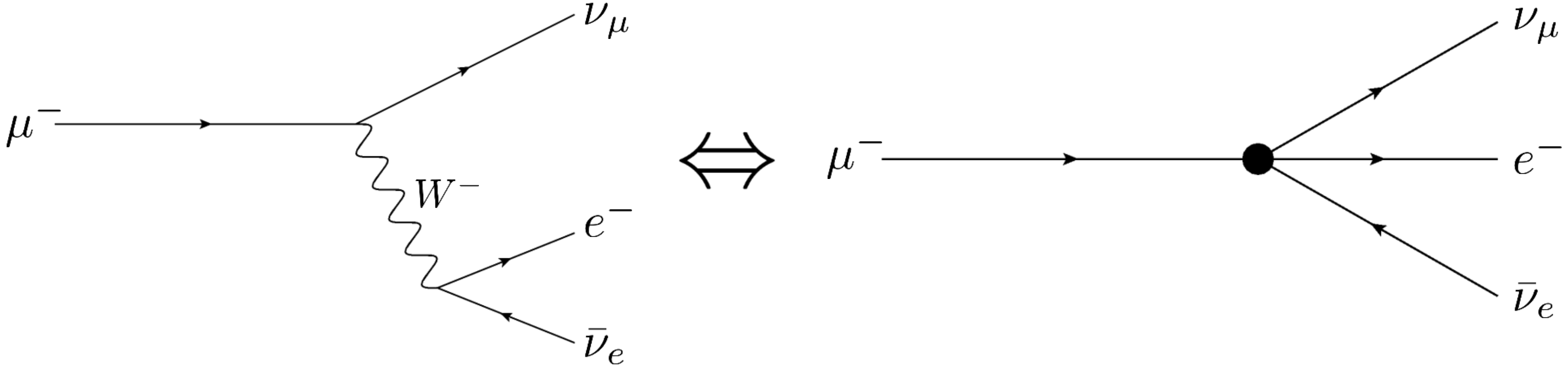
3) NLO SMEFT Calculations

EFTs In a Nutshell [1]

- Applicable in any theory with large scale separation
- Often assumption that "heavy" particle mediates an interaction which is approximated to be point-like
- Create vertices not seen in the SM, with **Wilson Coefficients** behaving as effective couplings
- Calculations can be performed with a precision up to the ~ ratio of the two scales

EXAMPLE: Fermi Weak Theory



$$\mathcal{L}_W = \frac{g}{2\sqrt{2}}\left(J^\mu W_\mu^+ + J^{\mu\dagger} W_\mu^-\right) \quad \Leftrightarrow \quad \mathcal{L}_W^{\text{eff.}}(x) = -\frac{G_F}{\sqrt{2}}\left[J^{\mu\dagger}(x) J_\mu(x)\right] + \mathcal{O}\left(\frac{p^2}{M_W^4}\right)$$

EFFECTIVE FIELD THEORY

Top-Down Vs Bottom-Up

Top-Down

- Start with full UV-complete theory
- Integrate out heavy fields (limit on possible vertices)
- Generate mathematically simpler theory
- Wilson coefficients defined by variables of full theory

$$G_F = \frac{\sqrt{2}g^2}{8M_W^2}$$

Suppressed by "heavy" scale

Bottom-Up

- Build basis of operators without making any connection to a UV complete theory
- Wilson coefficients entirely unspecified

STANDARD MODEL EFFECTIVE FIELD THEORY (SMEFT)

What Is SMEFT? [2]

SMEFT is a “bottom up” effective field theory that describes SM interactions with new physics under certain assumptions

1) Assume that new physics is above some high energy scale
2) Assume that new physics Lorentz and gauge invariance

$\Rightarrow$ Build every possible operator at each order in mass dimension from the existing Standard Model fields

$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_{\forall i, n \geq 5} \frac{C_i \mathcal{O}_i^{(n)}}{\Lambda^{n-4}}$$

Higher (mass) dimension operators suppressed by NP scale

Pro: We make no connection to any UV-complete model

Con: LARGE number of Wilson coefficients!

STANDARD MODEL EFFECTIVE FIELD THEORY (SMEFT)

- 59 gauge invariant operators for unspecified flavour (non baryon number violating)
- 2499 total operators (non baryon number violating)

WARSAW BASIS [3]:

$1: X^3$	
Q_G	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$
$Q_{\widetilde{G}}$	$f^{ABC} \widetilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$
Q_W	$\epsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$
$Q_{\widetilde{W}}$	$\epsilon^{IJK} \widetilde{W}_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$

$2: H^6$	
Q_H	$(H^\dagger H)^3$

$3: H^4 D^2$	
$Q_{H\Box}$	$(H^\dagger H)\Box(H^\dagger H)$
Q_{HD}	$\left(H^\dagger D_\mu H\right)^* \left(H^\dagger D_\mu H\right)$

$4: X^2 H^2$	
Q_{HG}	$H^\dagger H\, G_{\mu\nu}^A G^{A\mu\nu}$
$Q_{H\widetilde{G}}$	$H^\dagger H\, \widetilde{G}_{\mu\nu}^A G^{A\mu\nu}$
Q_{HW}	$H^\dagger H\, W_{\mu\nu}^I W^{I\mu\nu}$
$Q_{H\widetilde{W}}$	$H^\dagger H\, \widetilde{W}_{\mu\nu}^I W^{I\mu\nu}$
Q_{HB}	$H^\dagger H\, B_{\mu\nu} B^{\mu\nu}$
$Q_{H\widetilde{B}}$	$H^\dagger H\, \widetilde{B}_{\mu\nu} B^{\mu\nu}$
Q_{HWB}	$H^\dagger \tau^I H\, W_{\mu\nu}^I B^{\mu\nu}$
$Q_{H\widetilde{W}B}$	$H^\dagger \tau^I H\, \widetilde{W}_{\mu\nu}^I B^{\mu\nu}$

$5: \psi^2 H^3 + \text{h.c.}$	
Q_{eH}	$(H^\dagger H)(\bar{l}_p e_r H)$
Q_{uH}	$(H^\dagger H)(\bar{q}_p u_r \widetilde{H})$
Q_{dH}	$(H^\dagger H)(\bar{q}_p d_r H)$

$6: \psi^2 X H + \text{h.c.}$	
Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\tau^I H W_{\mu\nu}^I$
Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r) H B_{\mu\nu}$
Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r)\widetilde{H}\, G_{\mu\nu}^A$
Q_{uW}	$(\bar{q}_p \sigma^{\mu\nu} u_r)\tau^I \widetilde{H}\, W_{\mu\nu}^I$
Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r)\widetilde{H}\, B_{\mu\nu}$
Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) H\, G_{\mu\nu}^A$
Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r)\tau^I H\, W_{\mu\nu}^I$
Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r) H\, B_{\mu\nu}$

$7: \psi^2 H^2 D$	
$Q_{Hl}^{(1)}$	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{l}_p \gamma^\mu l_r)$
$Q_{Hl}^{(3)}$	$(H^\dagger i \overleftrightarrow{D}_\mu^I H)(\bar{l}_p \tau^I \gamma^\mu l_r)$
Q_{He}	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{e}_p \gamma^\mu e_r)$
$Q_{Hq}^{(1)}$	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{q}_p \gamma^\mu q_r)$
$Q_{Hq}^{(3)}$	$(H^\dagger i \overleftrightarrow{D}_\mu^I H)(\bar{q}_p \tau^I \gamma^\mu q_r)$
Q_{Hu}	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{u}_p \gamma^\mu u_r)$
Q_{Hd}	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{d}_p \gamma^\mu d_r)$
Q_{Hud} + h.c.	$i(\widetilde{H}^\dagger D_\mu H)(\bar{u}_p \gamma^\mu d_r)$

$8: (\bar{L}L)(\bar{L}L)$	
Q_{ll}	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$
$Q_{qq}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$
$Q_{qq}^{(3)}$	$(\bar{q}_p \gamma_\mu \tau^I q_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$
$Q_{lq}^{(1)}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_t)$
$Q_{lq}^{(3)}$	$(\bar{l}_p \gamma_\mu \tau^I l_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$

$8: (\bar{R}R)(\bar{R}R)$	
Q_{ee}	$(\bar{e}_p \gamma_\mu e_r)(\bar{e}_s \gamma^\mu e_t)$
Q_{uu}	$(\bar{u}_p \gamma_\mu u_r)(\bar{u}_s \gamma^\mu u_t)$
Q_{dd}	$(\bar{d}_p \gamma_\mu d_r)(\bar{d}_s \gamma^\mu d_t)$
Q_{eu}	$(\bar{e}_p \gamma_\mu e_r)(\bar{u}_s \gamma^\mu u_t)$
Q_{ed}	$(\bar{e}_p \gamma_\mu e_r)(\bar{d}_s \gamma^\mu d_t)$
$Q_{ud}^{(1)}$	$(\bar{u}_p \gamma_\mu u_r)(\bar{d}_s \gamma^\mu d_t)$
$Q_{ud}^{(8)}$	$(\bar{u}_p \gamma_\mu T^A u_r)(\bar{d}_s \gamma^\mu T^A d_t)$

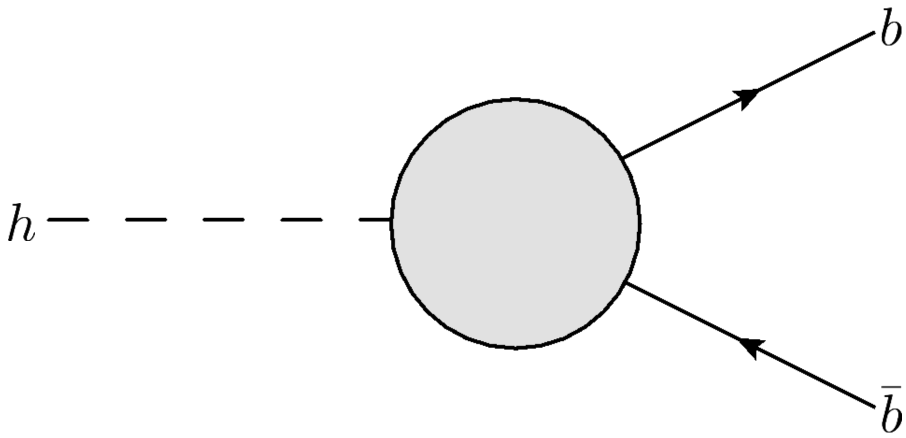
$8: (\bar{L}L)(\bar{R}R)$	
Q_{le}	$(\bar{l}_p \gamma_\mu l_r)(\bar{e}_s \gamma^\mu e_t)$
Q_{lu}	$(\bar{l}_p \gamma_\mu l_r)(\bar{u}_s \gamma^\mu u_t)$
Q_{ld}	$(\bar{l}_p \gamma_\mu l_r)(\bar{d}_s \gamma^\mu d_t)$
Q_{qe}	$(\bar{q}_p \gamma_\mu q_r)(\bar{e}_s \gamma^\mu e_t)$
$Q_{qu}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{u}_s \gamma^\mu u_t)$
$Q_{qu}^{(8)}$	$(\bar{q}_p \gamma_\mu T^A q_r)(\bar{u}_s \gamma^\mu T^A u_t)$
$Q_{qd}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{d}_s \gamma^\mu d_t)$
$Q_{qd}^{(8)}$	$(\bar{q}_p \gamma_\mu T^A q_r)(\bar{d}_s \gamma^\mu T^A d_t)$

$8: (\bar{L}R)(\bar{R}L) + \text{h.c.}$	
Q_{ledq}	$(\bar{l}_p^j e_r)(\bar{d}_s q_{tj})$

$8: (\bar{L}R)(\bar{L}R) + \text{h.c.}$	
$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r)\epsilon_{jk}(\bar{q}_s^k d_t)$
$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r)\epsilon_{jk}(\bar{q}_s^k T^A d_t)$
$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r)\epsilon_{jk}(\bar{q}_s^k u_t)$
$Q_{lequ}^{(3)}$	$(\bar{l}_p^j \sigma_{\mu\nu} e_r)\epsilon_{jk}(\bar{q}_s^k \sigma^{\mu\nu} u_t)$

SMEFT AT NLO

Current Work: Calculate $h \to b\bar{b}$ decay rate to one loop order with the Standard Model Effective Field Theory (SMEFT) framework (non-QCD)



We consider only dimension 6 operators

- Dimension 5 operators generate neutrino masses. Given current neutrino mass bounds, this requires that the new physics scale is incredibly large
- Dimension 7 operators comparatively suppressed by another factor of the new physics scale

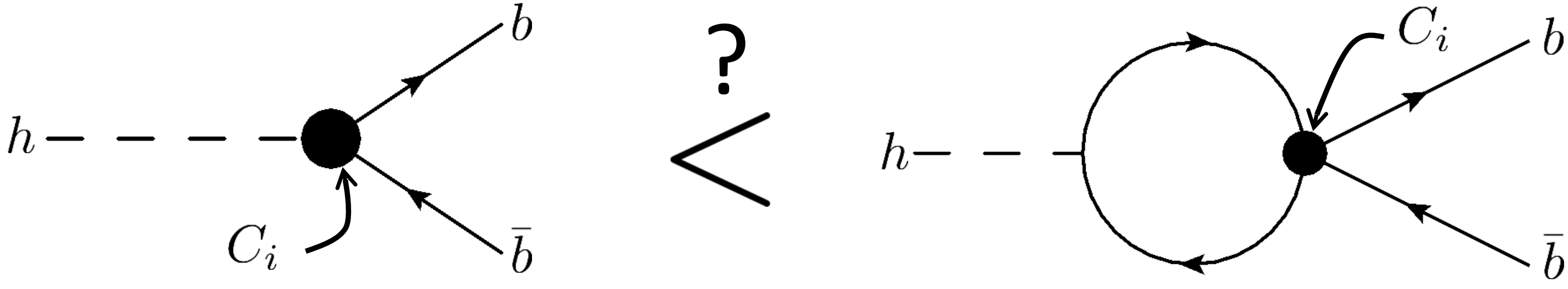
WHY?

Can fit these Wilson coefficients to search for new physics [2]

- Need one observable for every unconstrained Wilson coefficient
- Perform global fit of parameter space to constrain experimental values of Wilson coefficients
- Deviation of Wilson coefficients away from 0 is an indication of new physics in the corresponding effective interaction vertex
- Can match to specific NP theories for a consistency check of non-vanishing coefficients

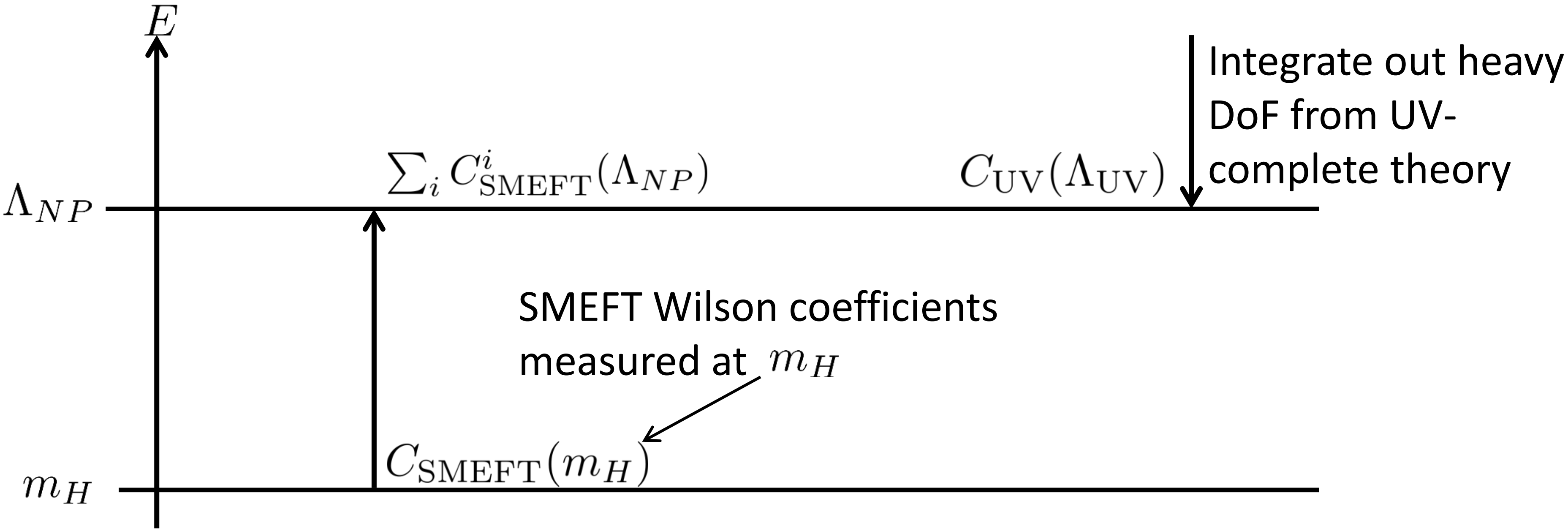
WHY ONE LOOP?

- The unknown size of the Wilson coefficients means that operators that do not contribute at tree-level could actually be providing larger contributions to observables than those that do contribute at tree-level
- Anomalous dimension matrix mixes Wilson coefficients [4]



Making connection with UV-complete models

- When sufficient Wilson coefficients have been fitted, need to connect to UV complete models
- Integrate out heavy states of UV-Complete theory
- Run resulting Wilson coefficients of BSM theory and SMEFT theory to same scale
- Can compare consistency of (non) vanishing Wilson coefficients and general self-consistency
- Allow us to reject or support UV-complete theories



APPROXIMATIONS

- The technical difficulties in performing calculations in the SMEFT means various approximations are often made
- Previous work have the approximations such as vanishing gauge couplings [2,5]
- Two approximations made here:
  1) Minimal flavour violation (MFV)
  2) Only consider 3rd generation fermions

1) The SMEFT contains a myriad of (suppressed) flavour violating effects beyond those seen in the SM. The main focus here is NLO rather than questions of flavour.
2) Given the constraints of (1), any non-3rd generation fermions are suppressed by their smaller Yukawa coupling

ON THE SHOULDERS OF GIANTS

- Work builds on previous work [2]
- 4 Fermion operators already accounted for
- Equivalent computation in QCD already performed [6]
- Calculation previously performed in vanishing gauge coupling limit

The combination of our work with the aforementioned QCD corrections gives a full treatment of the SMEFT NLO decay rate

THANK YOU!

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