Standard Model EFT: the on-shell way

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With S. De Angelis

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Motivation

The Standard Model is awesome but there are many open questions:

- How to accommodate gravity in it?
- What about dark matter?
- How to explain matter-antimatter asymmetry in the universe?
- What about the hierarchy problem?
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Where to look for **new Beyond SM physics**?

Higgs precision measurements

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Parametrizing deviations from the SM with EFTs

EFTs parametrize physical effects in a model-independent way

EFT Lagrangian

$$\mathcal{L} = \mathcal{L}_{SM}^{(4)} + \sum_{d>4} \frac{1}{\Lambda^{d-4}} \sum_i C_i^{(d)} \mathcal{O}_i^{(d)}$$

- Λ is an energy scale, $\Lambda \gg M_Z$
- $\mathcal{O}_i^{(d)}$ are operators of mass-dimension d
- $C_i^{(d)}$ are Wilson coefficients

Example: $d = 6 \quad \rightarrow \quad \mathcal{O}_{F^3} = f^{abc} F^{a\,\mu}{}_{\nu} F^{b\,\nu}{}_{\rho} F^{c\,\rho}{}_{\mu}$

Operator basis

Key ingredient:

Use the most general possible basis of operators of the form:

$$\mathcal{O}_i^{(d)} \sim \underbrace{L_i(\{F,\psi,\phi,D\})}_{\text{Lorentz invariant}} \times \underbrace{G_i(\{f^{abc},(\tau^a)^i_j,\dots\})}_{\text{Gauge group invaraint}}$$

Tasks:

1. list them all for a given dimension.
2. remove redundancies, *i.e.* equivalence up to
   - total derivatives (IBP)
   - equations of motion (EOM)

d	5	6	7	8
#	2	84	30	993

[Henning,Lu,Melia,Murayama;. . .]

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Testing models

[Henning,Lu,Murayama;...]

E

Λ

M_Z

UV model

$\mathcal{L}^{UV} = \sum_i b_i f_i(\{\Phi\})$

integrate out

some heavy d.o.f.

EFT

$\mathcal{L}^{EFT}(\{C_i^{(d)}(b)\})$

RG flow

$C_i^{(d)}(M_Z) \leftrightarrow C_j^{(d)}(\Lambda)$

compare

to data

Requires anomalous dimension matrix

$$C_i(M_Z) = C_i(\Lambda) - (4\pi)^{-2}\dot{C}_i \log\left(\Lambda/M_Z\right)\,, \qquad \dot{C}_i = \gamma_{ij} C_j$$

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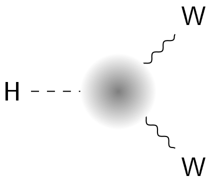
M_Z — 

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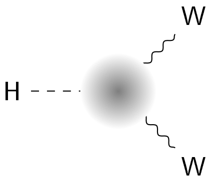

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What we are after

[Alonso,Jenkins,Manohar,Trott;Henning,Lu,Melia,Murayama;Li,Ren,Xiao,Yu,Zheng;...]

What has already been explored

	$d=6$	$d=7$	$d=8$	$d=9$	$d=10$
$\mathcal{O}$ basis	✓	✓	✓	✓	
γ_{ij}	@ 2-loop	✓	✓		

[Bern,Parra-MArtinez,Sawyer;...]

Our goal

1. $d=8$
2. SU(N) gauge group
3. compute γ_{ij} @ 1-loop

N.B. Is $d=8$ relevant compared to $d=6$? [Hays,Martin,Sanz,Setford]

Very much process dependent, but it is worth computing.

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Building the operator basis

[Ma,Shu,Xiao; Aoude,Machado; Falkowski; Durieux,Machado]

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$$\mathcal{O}_i^{(d)} \sim \underbrace{L_i(\{F,\psi,\phi,D\})}_{\text{Lorentz invariant}} \times \underbrace{G_i(\{f^{abc},(\tau^a)^i_j,\ldots\})}_{\text{Gauge group invaraint}}$$

on-shell

$$\underbrace{\mathcal{F}_i(\{\lambda,\tilde{\lambda}\})}_{\text{form factor}} \sim f_i(\{\lambda,\tilde{\lambda}\}) \; g_i(f^{abc},\ldots)$$

The $f_i(\{\lambda,\tilde{\lambda}\})$ correspond to tree-level contact terms and are completely characterized by mass-dimension and helicity weight. Advantages:

1. easy to build
2. equation of motion redundancy absent
3. IBP redundancy becomes momentum conservation (with caveat...)

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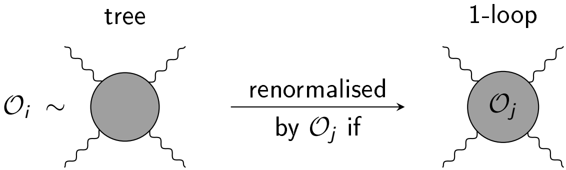
Anomalous dimensions and unitarity

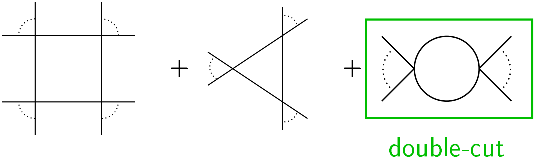
[Huang et al;Arkani-Hamed et al]

When does $\mathcal{O}_j$ renormalise $\mathcal{O}_i$?



One is interested in the UV divergent part of this matrix element:

$$\mathcal{O}_i^{(d)}\Big|_{\text{1-loop}} =$$



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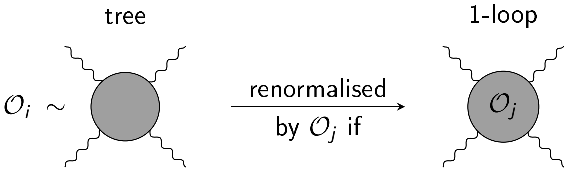

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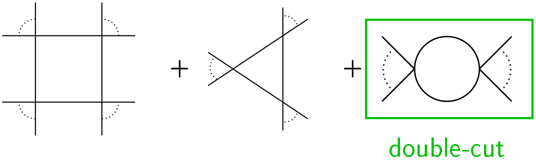

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Direct extraction of anomalous dimensions from cuts:

Non-perturbative results

RG equation:
$$D\mathcal{F}_i = \left(\Delta\gamma_{ij} + \delta_{ij}\beta\frac{\partial}{\partial g}\right)\mathcal{F}_j, \quad D = -\mu\frac{\partial}{\partial\mu}$$

$$\left(e^{-i\pi D} - 1\right)\mathcal{F}_i^* = i\mathcal{M}\mathcal{F}_i^*, \qquad S = 1 + i\mathcal{M}$$

Expanding order by order and comparing: [Caron-Huot,Wilhelm]

$$\left[\Delta\gamma_{ij}^{(1)} + \delta_{ij}\beta^{(1)}\partial\right]\mathcal{F}_i^{(0)} = -\frac{1}{\pi}\left(\mathcal{M}\mathcal{F}_i\right)^{(1)}$$

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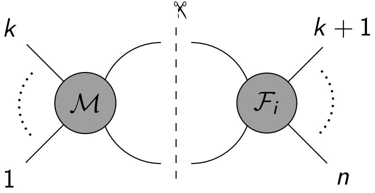

Take-home message

- SMEFT is a good playground for testing possible new physics
- key ingredients are a complete operator basis and the anomalous dimension matrix
- on-shell methods greatly facilitate the computations of these ingredients
- there is still much to explore ($d \geq 7$, HEFT model,...)