What i do(t): Last year and half, (re)focused on h,H

Michael Trott, CERN Theory Retreat

Fit pheno:	*Content (for ref):*
Espinosa, Muhlleitner, Grojean, Trott arXiv:1202.3697	*Basic EFT fits & limits*
Espinosa, Muhlleitner, Grojean, Trott arXiv: 1205.6790	*Invisible width, PDF developments*
Espinosa, Muhlleitner, Grojean, Trott arXiv:1207.1717	*"Tension", ICHEP data (updates)*
Espinosa, Grojean, Sanz, Trott arXiv:1207.7355	*NSUSY*

RGE/Minimal Coupling bro-ha-ha:	
Grojean , Jenkins, Manohar,Trott, arXiv:1301.1717	*Higgs RGE, initial study*
Jenkins, Manohar,Trott, arXiv:1305.0017	*EFT's are not Minimal coupled!*
Jenkins, Manohar,Trott arXiv:1308.2627, 1309.0819, 1310.4838	*RGE systematically being sorted out*
Distributions for the EFTs, rare decays:	
Isidori, Manohar,Trott arXiv:1305.0017	*EFT analysis h -> V F*
Isidori, Trott arXiv:1307.4051	*EFT analysis F-> h V*

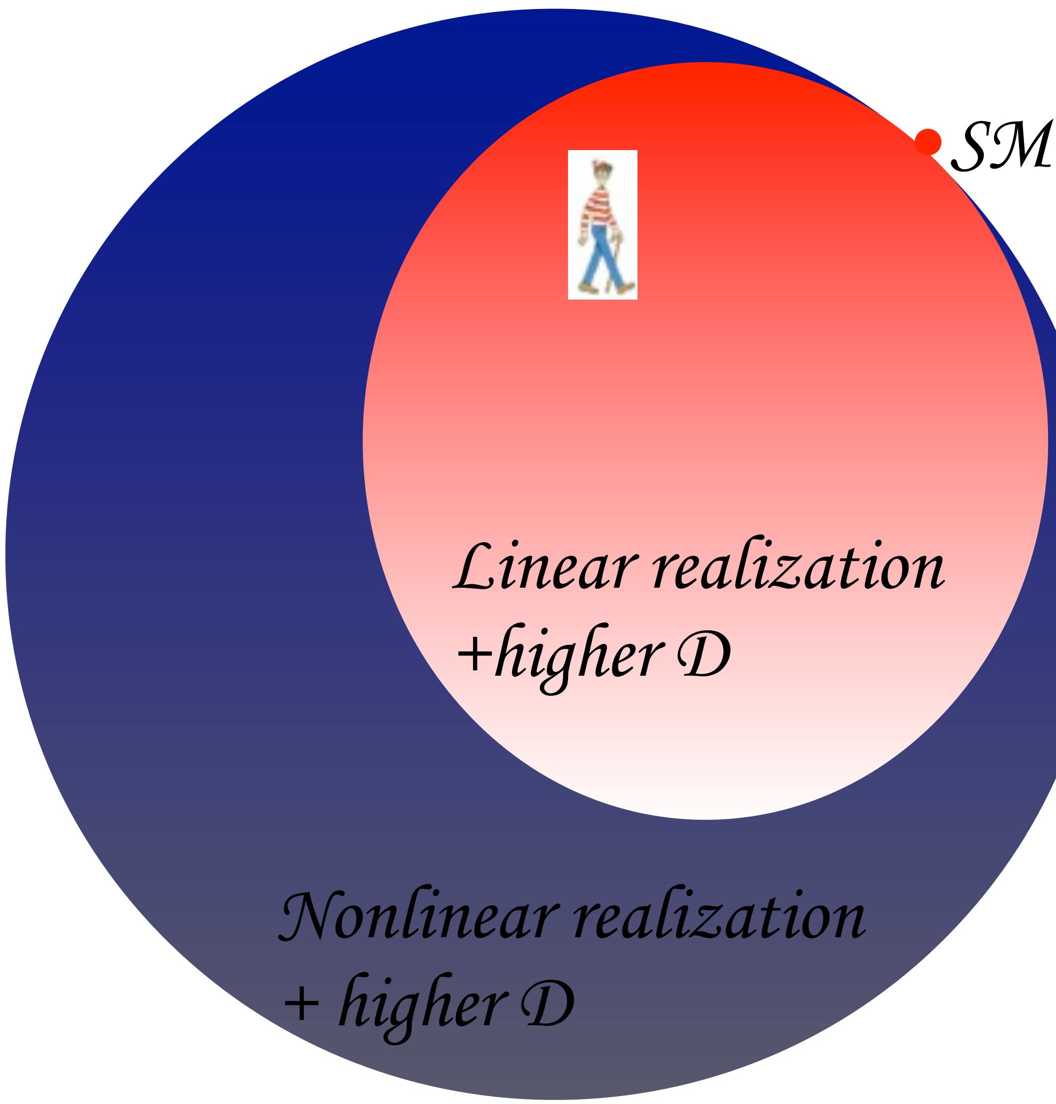
Although currently interested in h,H...

Broad interests:

- Phd on flavour physics, relevant precise SM calculation in inclusive B decays and pheno
- Have been known to think about QCD and SCET
- Interested (and developed) higgs EFTs
- Interested in EFTs in cosmology (found a higgs inflation cut off)
- MFV and flavour symmetric field content, top quark forward backward asymmetry, relevant precise SM calculation (EW sudakovs)
- Neutrino EFTs

unprecedented MT flow!
limit cycle?

Current interests, 1: is it h or H?



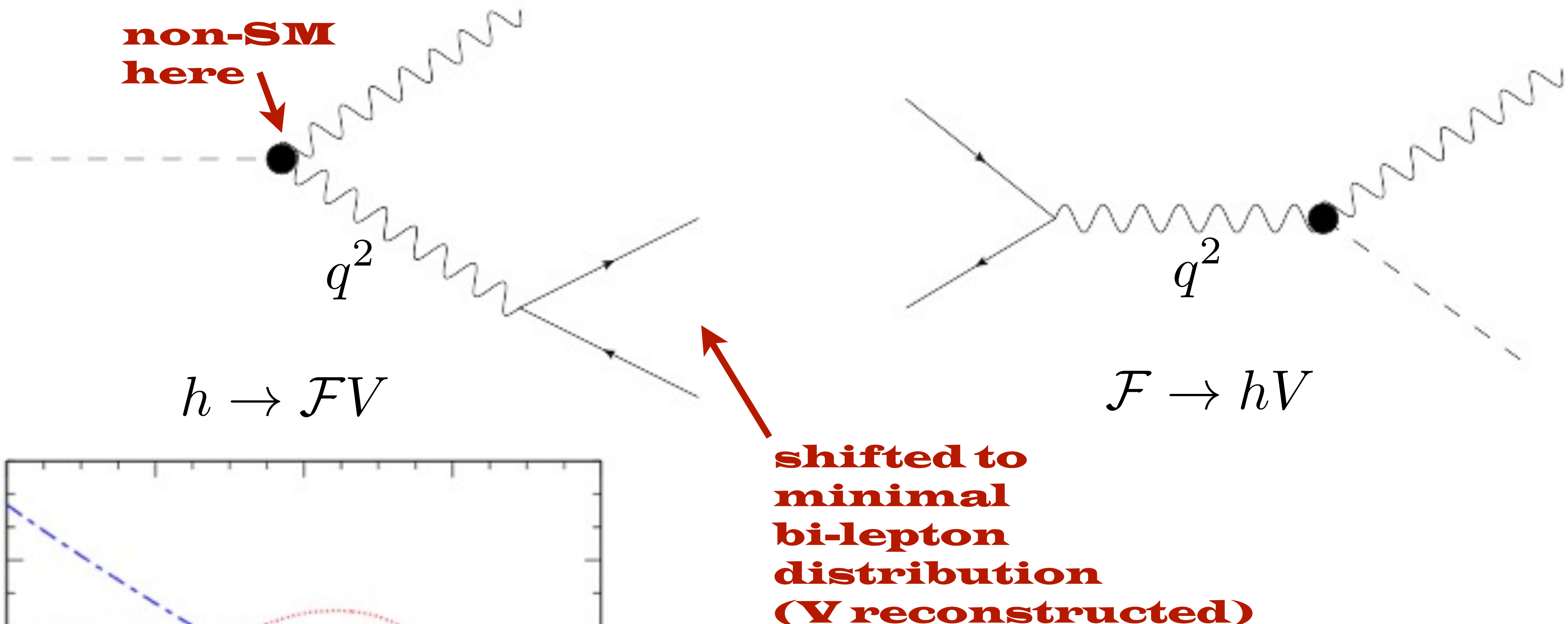
We want to know IF the scalar, the Higgs-Like Boson, the BEEH, whatever ....is embedded in a non-SM derivative expansion, and if so, which one.

We need to test, and distinguish the EFT's to sub-leading order.

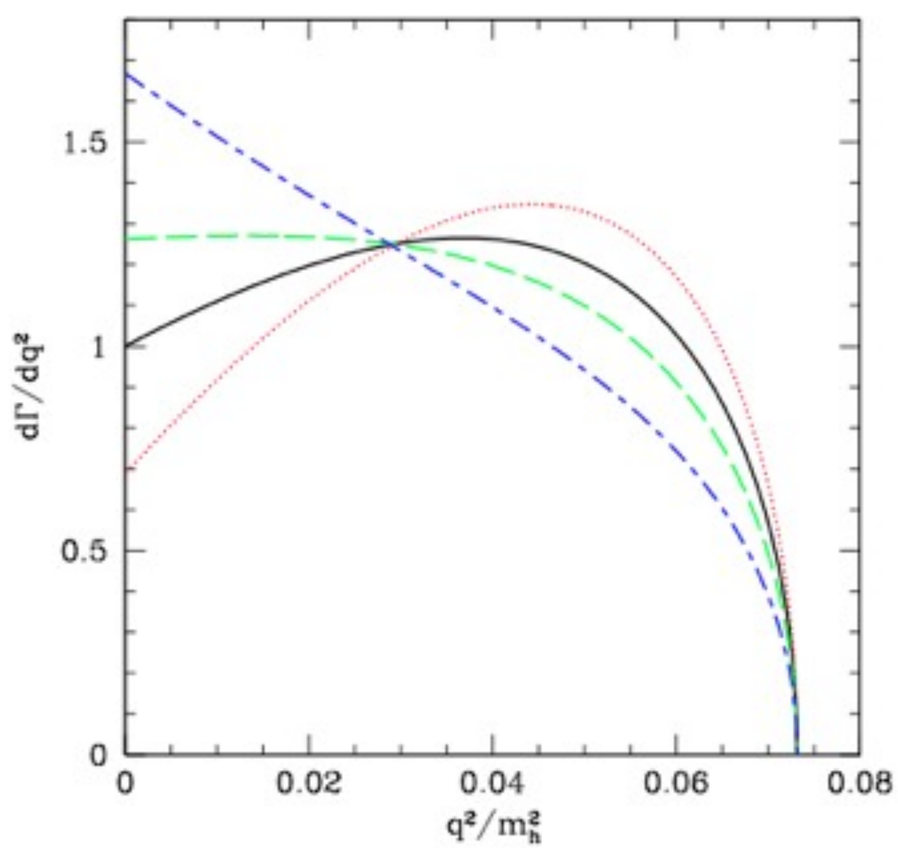
These two extensions of the SM are NOT the same EFT ---at any finite precision.

Testing the derivative expansion

Consider the following processes with non-SM interactions involving the "h":

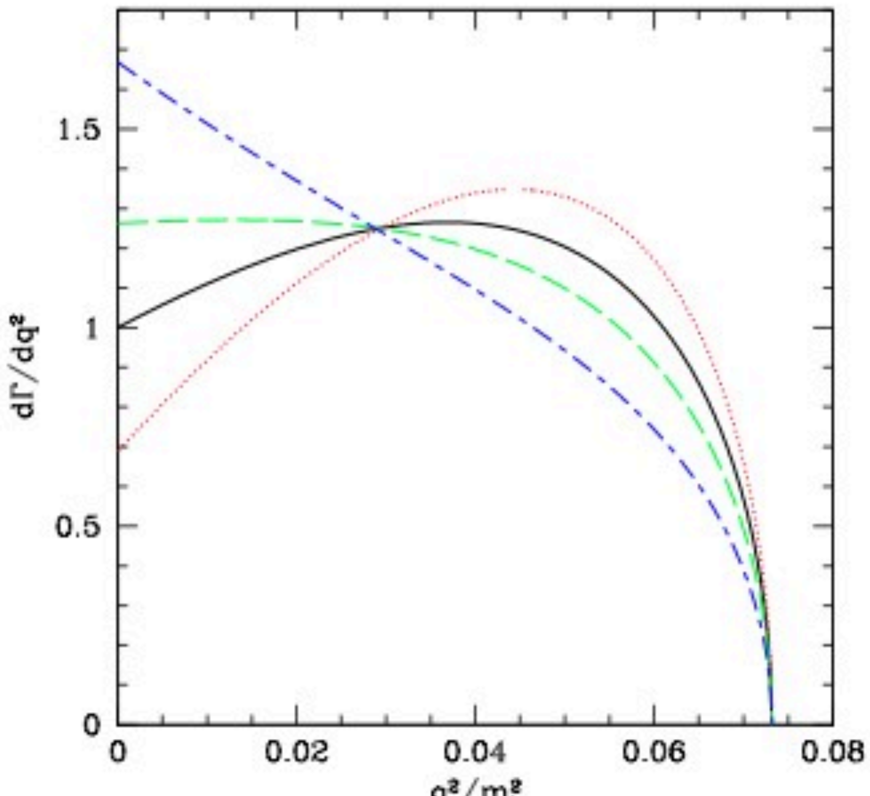


$h \to \mathcal{F}V$ $\mathcal{F} \to hV$

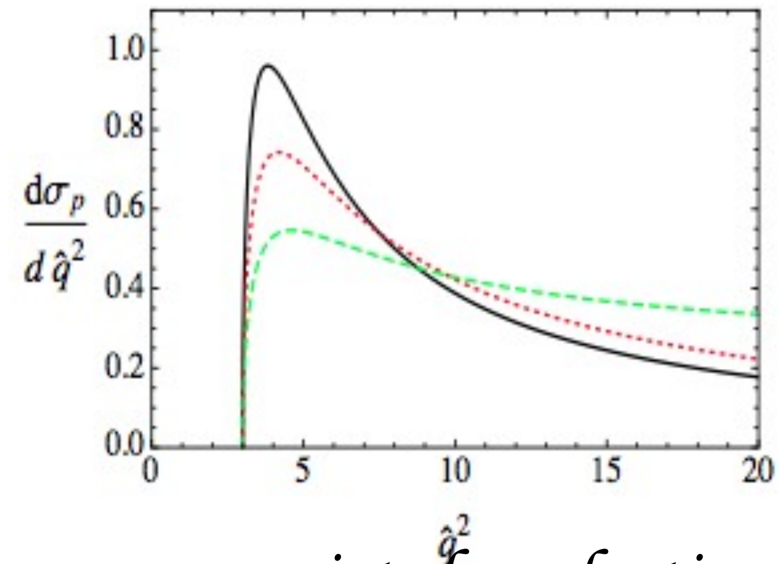


Total signal strength the same,
shape variations possible in q^2 spec.

Testing the derivative expansion



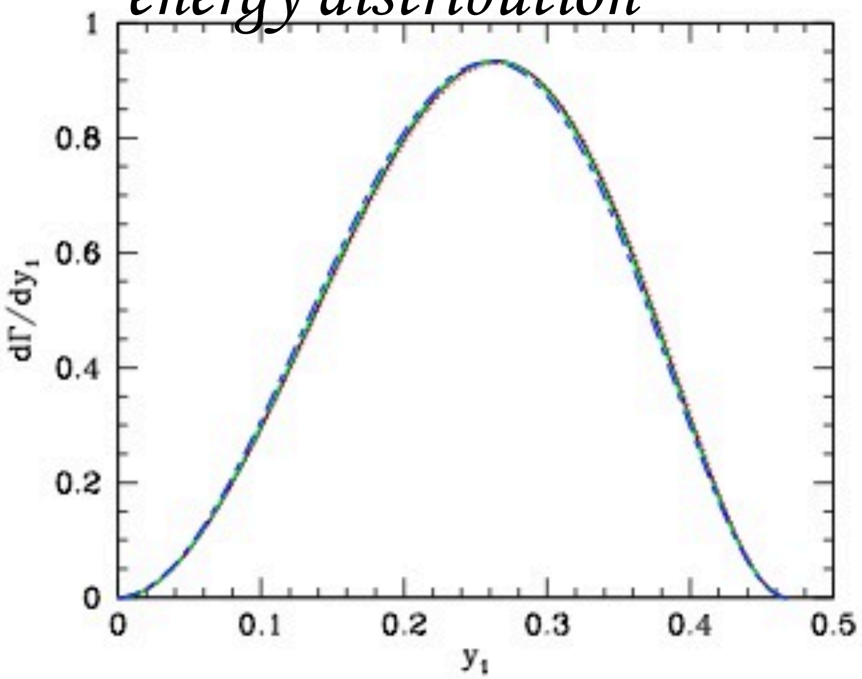
If this deviates more than expected in linear realization, nonlinear smoking gun

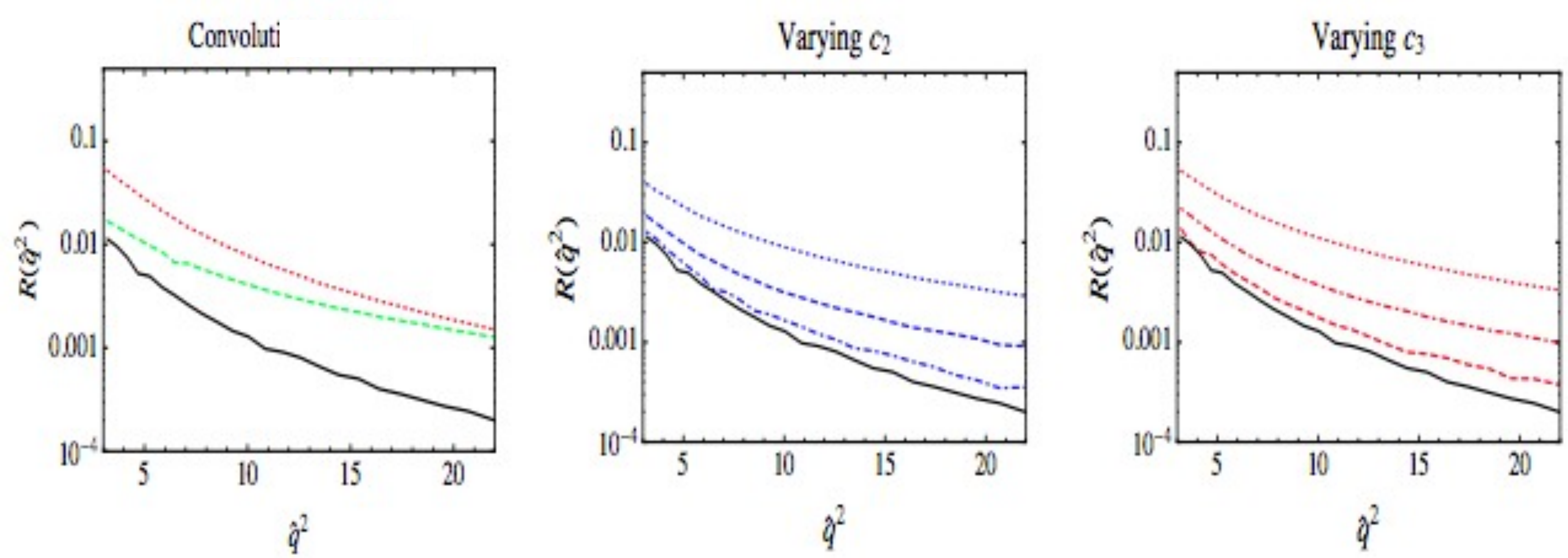


associated production

q^2 bi-lepton and lepton energy distribution

PDF's suck (sorry juan) in associated production





2: Moving towards a precision understanding of the (linear) SM EFT

1) Using EFT allow(s,ed) you to make pretty plots.

2) Violently changes the UV divergence structure of the theory!

- this may seem like a trivial modification of Higgs phenomenology, some new interactions, some re-scalings of SM expectations.

Effective Theory:

$$\mathcal{L}_{SM} + \sum_i \frac{c_i}{\Lambda^2}\mathcal{O}_i + \sum_i c.t.$$

Renormalize it!

MUST reproduce the IR of the full theory!

Run the ops.

As we don't see other NP effects at low scales

Matching

Full Theory:

$$\mathcal{L}_{SM} + \mathcal{L}_{please\, exist} + \sum_i c.t.$$

Renormalize it!

There were subtle warnings not to do this:

Interesting fact, Latexit will not even display a 59x59 dim matrix. Here is a 45x45 one:

$$\begin{pmatrix} \mathcal{O}_1 \\ \mathcal{O}_2 \\ \mathcal{O}_3 \\ \mathcal{O}_4 \\ \mathcal{O}_5 \\ \mathcal{O}_6 \\ \mathcal{O}_7 \\ \mathcal{O}_8 \\ \mathcal{O}_9 \\ \mathcal{O}_{10} \\ \mathcal{O}_{11} \\ \mathcal{O}_{12} \\ \mathcal{O}_{13} \\ \mathcal{O}_{14} \\ \mathcal{O}_{15} \\ \mathcal{O}_{16} \\ \mathcal{O}_{17} \\ \mathcal{O}_{18} \\ \mathcal{O}_{19} \\ \mathcal{O}_{20} \\ \mathcal{O}_{21} \\ \mathcal{O}_{22} \\ \mathcal{O}_{23} \\ \mathcal{O}_{24} \\ \mathcal{O}_{25} \\ \mathcal{O}_{26} \\ \mathcal{O}_{27} \\ \mathcal{O}_{28} \\ \mathcal{O}_{30} \\ \mathcal{O}_{31} \\ \mathcal{O}_{32} \\ \mathcal{O}_{33} \\ \mathcal{O}_{34} \\ \mathcal{O}_{35} \\ \mathcal{O}_{36} \\ \mathcal{O}_{37} \\ \mathcal{O}_{38} \\ \mathcal{O}_{39} \\ \mathcal{O}_{40} \\ \mathcal{O}_{41} \\ \mathcal{O}_{42} \\ \mathcal{O}_{43} \\ \mathcal{O}_{44} \\ \mathcal{O}_{45} \end{pmatrix} = \begin{pmatrix}
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Took a couple months of work..

With further thought, it does not really make sense to think of just RGE improving a sector like the higgs sector. We need the whole RGE evolution.

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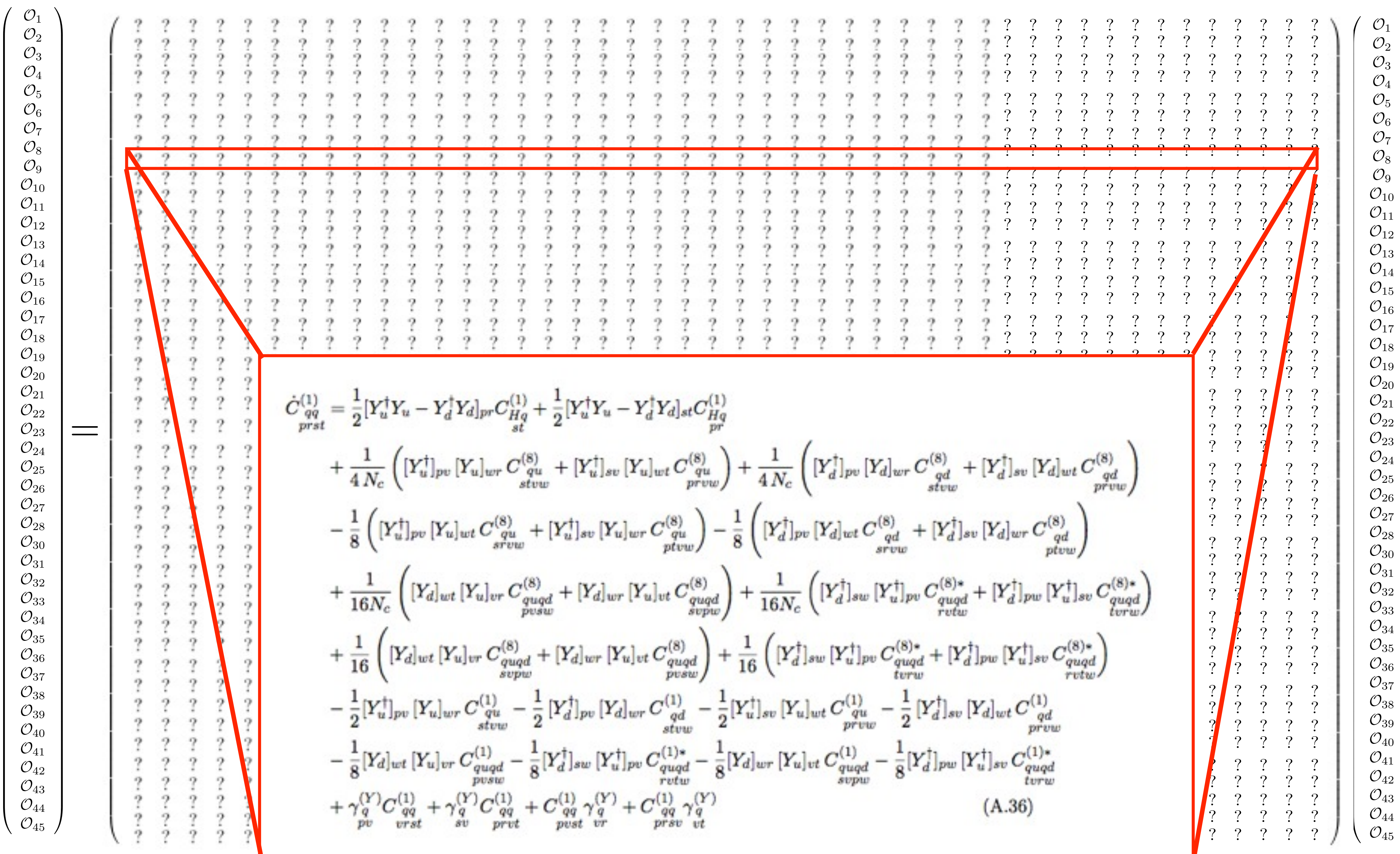
Almost DONE!

Example

Not the whole row, just a subset of terms (yukawas)



$$
\begin{aligned}
\dot{C}^{(1)}_{\substack{qq\\prst}} &= \frac{1}{2}[Y_u^\dagger Y_u - Y_d^\dagger Y_d]_{pr} C^{(1)}_{\substack{Hq\\st}} + \frac{1}{2}[Y_u^\dagger Y_u - Y_d^\dagger Y_d]_{st} C^{(1)}_{\substack{Hq\\pr}} \\
&+ \frac{1}{4N_c}\left([Y_u^\dagger]_{pv}\,[Y_u]_{wr}\,C^{(8)}_{\substack{qu\\stvw}} + [Y_u^\dagger]_{sv}\,[Y_u]_{wt}\,C^{(8)}_{\substack{qu\\prvw}}\right) + \frac{1}{4N_c}\left([Y_d^\dagger]_{pv}\,[Y_d]_{wr}\,C^{(8)}_{\substack{qd\\stvw}} + [Y_d^\dagger]_{sv}\,[Y_d]_{wt}\,C^{(8)}_{\substack{qd\\prvw}}\right) \\
&- \frac{1}{8}\left([Y_u^\dagger]_{pv}\,[Y_u]_{wt}\,C^{(8)}_{\substack{qu\\srvw}} + [Y_u^\dagger]_{sv}\,[Y_u]_{wr}\,C^{(8)}_{\substack{qu\\ptvw}}\right) - \frac{1}{8}\left([Y_d^\dagger]_{pv}\,[Y_d]_{wt}\,C^{(8)}_{\substack{qd\\srvw}} + [Y_d^\dagger]_{sv}\,[Y_d]_{wr}\,C^{(8)}_{\substack{qd\\ptvw}}\right) \\
&+ \frac{1}{16N_c}\left([Y_d]_{wt}\,[Y_u]_{vr}\,C^{(8)}_{\substack{quqd\\pvsw}} + [Y_d]_{wr}\,[Y_u]_{vt}\,C^{(8)}_{\substack{quqd\\svpw}}\right) + \frac{1}{16N_c}\left([Y_d^\dagger]_{sw}\,[Y_u^\dagger]_{pv}\,C^{(8)*}_{\substack{quqd\\rvtw}} + [Y_d^\dagger]_{pw}\,[Y_u^\dagger]_{sv}\,C^{(8)*}_{\substack{quqd\\tvrw}}\right) \\
&+ \frac{1}{16}\left([Y_d]_{wt}\,[Y_u]_{vr}\,C^{(8)}_{\substack{quqd\\svpw}} + [Y_d]_{wr}\,[Y_u]_{vt}\,C^{(8)}_{\substack{quqd\\pvsw}}\right) + \frac{1}{16}\left([Y_d^\dagger]_{sw}\,[Y_u^\dagger]_{pv}\,C^{(8)*}_{\substack{quqd\\tvrw}} + [Y_d^\dagger]_{pw}\,[Y_u^\dagger]_{sv}\,C^{(8)*}_{\substack{quqd\\rvtw}}\right) \\
&- \frac{1}{2}[Y_u^\dagger]_{pv}\,[Y_u]_{wr}\,C^{(1)}_{\substack{qu\\stvw}} - \frac{1}{2}[Y_d^\dagger]_{pv}\,[Y_d]_{wr}\,C^{(1)}_{\substack{qd\\stvw}} - \frac{1}{2}[Y_u^\dagger]_{sv}\,[Y_u]_{wt}\,C^{(1)}_{\substack{qu\\prvw}} - \frac{1}{2}[Y_d^\dagger]_{sv}\,[Y_d]_{wt}\,C^{(1)}_{\substack{qd\\prvw}} \\
&- \frac{1}{8}[Y_d]_{wt}\,[Y_u]_{vr}\,C^{(1)}_{\substack{quqd\\pvsw}} - \frac{1}{8}[Y_d^\dagger]_{sw}\,[Y_u^\dagger]_{pv}\,C^{(1)*}_{\substack{quqd\\rvtw}} - \frac{1}{8}[Y_d]_{wr}\,[Y_u]_{vt}\,C^{(1)}_{\substack{quqd\\svpw}} - \frac{1}{8}[Y_d^\dagger]_{pw}\,[Y_u^\dagger]_{sv}\,C^{(1)*}_{\substack{quqd\\tvrw}} \\
&+ \gamma^{(Y)}_{\substack{q\\pv}} C^{(1)}_{\substack{qq\\vrst}} + \gamma^{(Y)}_{\substack{q\\sv}} C^{(1)}_{\substack{qq\\prvt}} + C^{(1)}_{\substack{qq\\pvst}} \gamma^{(Y)}_{\substack{q\\vr}} + C^{(1)}_{\substack{qq\\prsv}} \gamma^{(Y)}_{\substack{q\\vt}} \qquad \text{(A.36)}
\end{aligned}
$$

Some nice field theory here

The EOM have been used EXTENSIVELY in reducing the basis to 59 operators. Our intuition does not accommodate that, but it is a fact.

Here is one way this non-intuitive physics shows up.

An operator O_1 *can mix with an operator* O_2 *when NO 1PI diagram exists that corresponds to the mixing.*

You renormalize and obtain a divergence, for example

$$E_{H\Box} = [H^\dagger H][H^\dagger (D^2 H) + (D^2 H^\dagger) H]$$

This operator form is not retained in the basis, so remove it:

$$\mathcal{L}_{\rm SM} + \frac{c}{\Lambda^2} E_{H\Box} \to \mathcal{L}_{\rm SM} + \frac{c}{\Lambda^2} \widetilde{E}_{H\Box} + \mathcal{O}\left(\frac{1}{\Lambda^4}\right) \qquad \textit{via field redefinition} \qquad H \to H + \frac{c}{\Lambda^2}(H^\dagger H) H$$

$$\widetilde{E}_{H\Box} = 2\lambda v^2 (H^\dagger H)^2 - 4\lambda Q_H - \left([Y_u^\dagger]_{rs}\, Q_{\substack{uH \\ rs}} + [Y_d^\dagger]_{rs}\, Q_{\substack{dH \\ rs}} + [Y_e^\dagger]_{rs}\, Q_{\substack{eH \\ rs}} + \text{h.c.} \right)$$

RGE improved SM EFT

Structure:

		g^3X^3	H^6	H^4D^2	$g^2X^2H^2$	$y\psi^2H^3$	$gy\psi^2XH$	ψ^2H^2D	ψ^4
		1	2	3	4	5	6	7	8
g^3X^3	1	g^2	0	0	1	0	0	0	0
H^6	2	$g^6\lambda$	λ, g^2, y^2	$g^4, g^2\lambda, \lambda^2$	$g^6, g^4\lambda$	$\lambda y^2, y^4$	0	$\lambda y^2, y^4$	0
H^4D^2	3	g^6	0	g^2, λ, y^2	g^4	y^2	g^2y^2	g^2, y^2	0
$g^2X^2H^2$	4	g^4	0	1	g^2, λ, y^2	0	y^2	1	0
$y\psi^2H^3$	5	g^6	0	g^2, λ, y^2	g^4	g^2, λ, y^2	$g^2\lambda, g^4, g^2y^2$	g^2, λ, y^2	λ, y^2
$gy\psi^2XH$	6	g^4	0	0	g^2	1	g^2, y^2	1	1
ψ^2H^2D	7	g^6	0	g^2, y^2	g^4	y^2	g^2y^2	g^2, λ, y^2	y^2
ψ^4	8	g^6	0	0	0	0	g^2y^2	g^2, y^2	g^2, y^2

Entries follow the rule: $\left(\frac{g^2}{16\pi^2}\right)^{n_g}\left(\frac{y^2}{16\pi^2}\right)^{n_y}\left(\frac{\lambda}{16\pi^2}\right)^{n_\lambda}, \qquad N = n_g + n_y + n_\lambda$

Where: $N = L + w - \sum_k w_k \equiv L + \Delta.$ *nice general equation*

The ω *is the power of f^2 in the operator normalization.*

RGE improved SM EFT

What has been calculated in the last few months: **Jenkins, Manohar, Trott arXiv:1308.2627**

$$\mu \frac{d}{d\,\mu} C_{d\leq 4} \propto m_h^2 \sum_{i=1..59} C^i_{d=6}$$

Complete result for the higher d ops.

Computed the complete dependence of the 59x59 matrix on $\lambda,\ \lambda^2, \lambda\, y^2$

(about 50 diagrams or so (x 59 ops), not so bad) **Jenkins, Manohar, Trott arXiv:1308.2627**

Computed the complete dependence of the 59x59 matrix on y^2, y^4

(about 100 diagrams or so (x 59 ops) , pretty darn bad) **Jenkins, Manohar, Trott arXiv: 1310.4838**

The complete gauge dependence of the 59x59 matrix ...

(> 100 diagrams, (x 59 ops) very very bad)

Soon..