陕西師範大學
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有效场论视角下的新物理：从紫外(UV)模型到QCD强子谱

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“粲强子衰变和标准模型的精确检验” 2025 年夏季年会

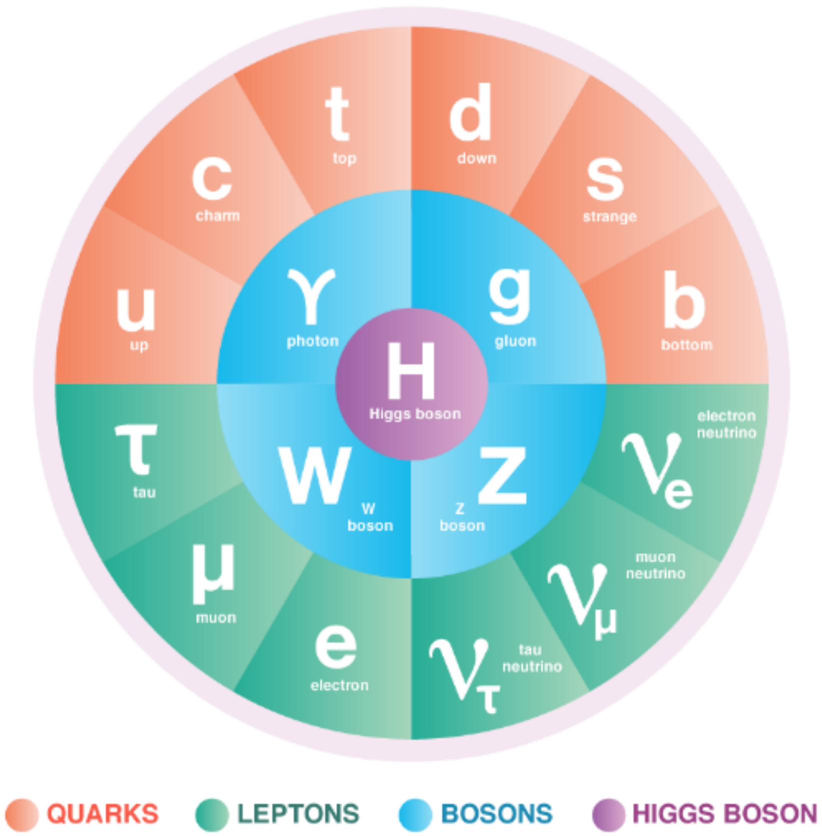
贵阳, 8月13日, 2025.

提纲

- 简介
- 标准模型有效场论(SMEFT)和希格斯有效场论(HEFT)
- 低能有效场论(Low-energy EFT, LEFT)
- 总结

标准模型

粒子(～场)



对称性

- 庞加莱对称性:洛伦兹协变性+平移不变性

  粒子被分为庞加莱群的不同表示：

  - 标量粒子（如希格斯玻色子）对应自旋0表示。
  - 费米子（如电子、夸克）对应自旋1/2表示。
  - 光子（自旋1）对应规范场的表示。

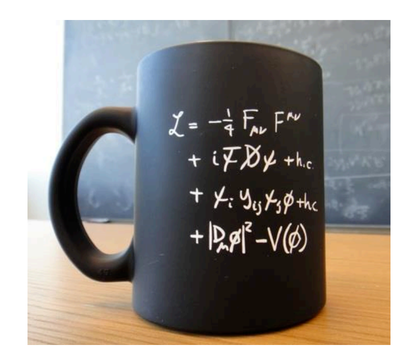
- 内部对称性

$$SU(3)_c \times SU(2)_L \times U(1)_Y$$

- 动力学和相互作用: 构建Lagrangian量，写出满足对称性的所有可重整项。

E.g.
$$H=\frac{1}{\sqrt{2}}\begin{pmatrix} G^+ \\ v+h+iG^0 \end{pmatrix}, \quad \mathscr{L}_{\rm SM} \supset \frac{1}{2} D_\mu H^\dagger D^\mu H + \frac{m^2}{2} H^\dagger H$$

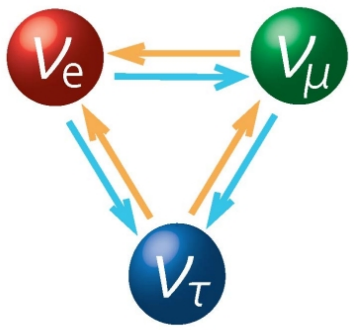
$H \to UH, H^\dagger \to H^\dagger U^\dagger : H^\dagger H \to H^\dagger H$ (对称性下不变)

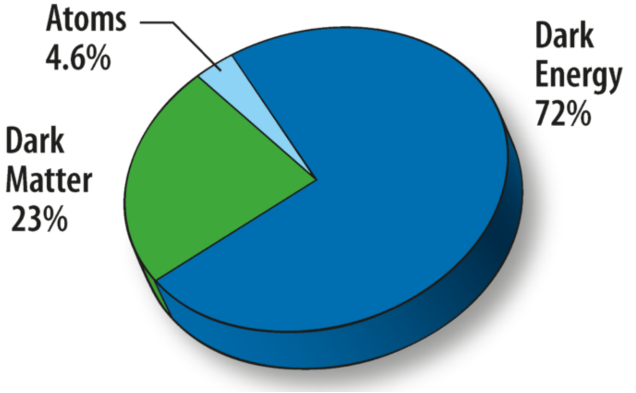


标准模型是不完备的

Experimental evidence

- Neutrino mass
- Dark matter, Dark energy
- Matter-antimatter asymmetry
- Gravity





新物理模型：新粒子+新对称性

$SU(3)_c \times SU(2)_L \times U(1)_Y$

对称性类型	例子	应用 /动机
额外规范对称性	$U(1)', U(1)_{B-L}$	Z′, 中微子
离散对称性	$\mathbb{Z}_2$	暗物质稳定
味对称性	$U(3)^5, S_4, A_4$	轻子、夸克质量和混合矩阵
全局G	$SO(5) \rightarrow SO(4)$	复合希格斯粒子
超对称	SUSY	等级问题、暗物质
大统一模型(GUT)	SU(5),SO(10)	规范耦合常数的统一

新物理模型有多少种?

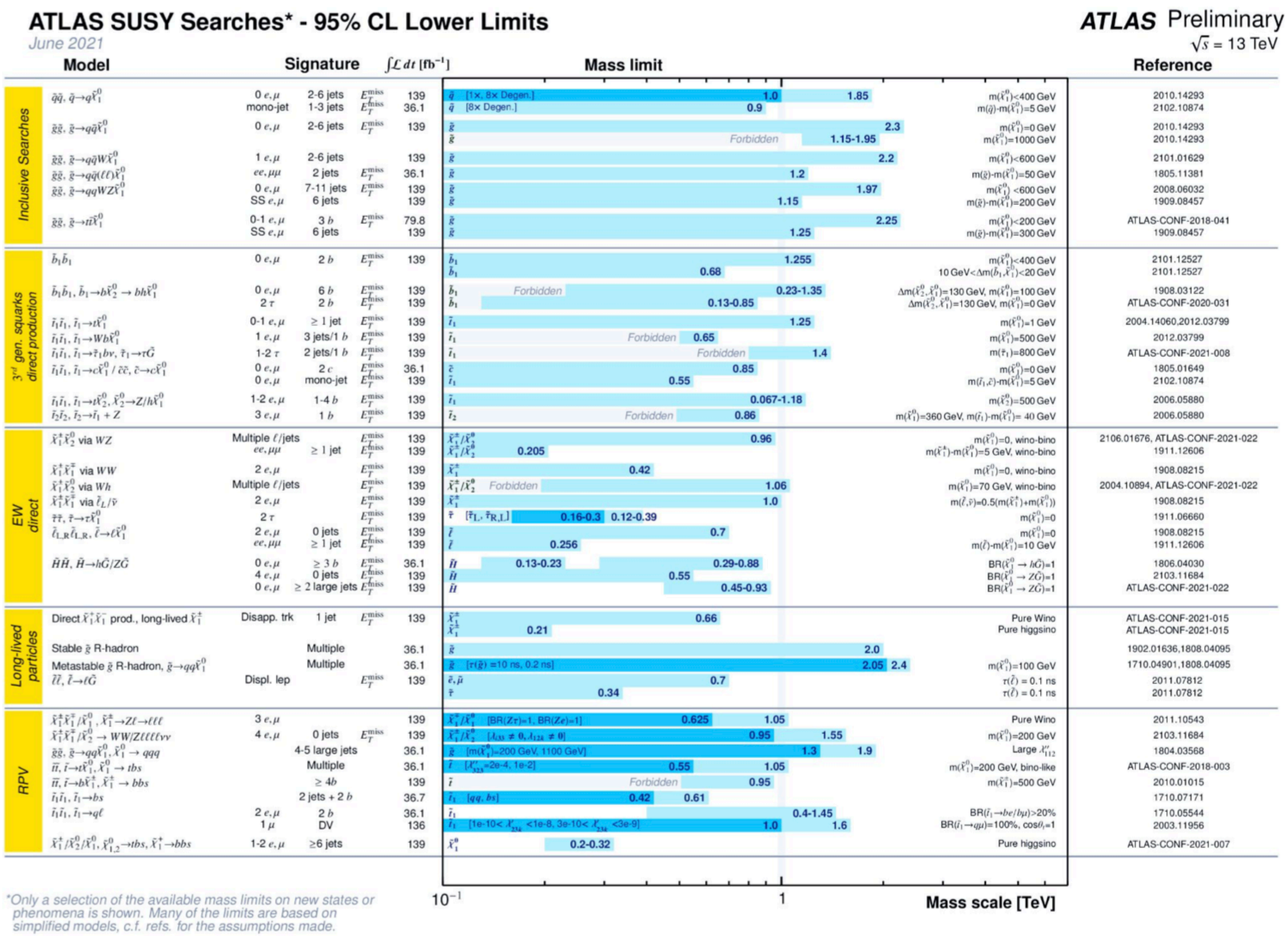
理论框架	主流模型总数	模型变化范围说明
大统一理论(GUT)	15-30+种	5种主群 × 3-6种典型破缺路径
超对称(SUSY)	20-50+种	6种主形式 × 不同破缺参数/UV完成方式
复合希格斯	10-20+种	4种陪集类型 × 不同嵌入/共振态结构
跷跷板机制	10-15+种	6种基础类型 × 味结构/能标组合

基础类型 55 ∼ 115 种。

另加 暗物质模型，规范扩展模型，其它创新模型(leptogenesis,ALP)等，保守估计～500种。

LHC实验结果

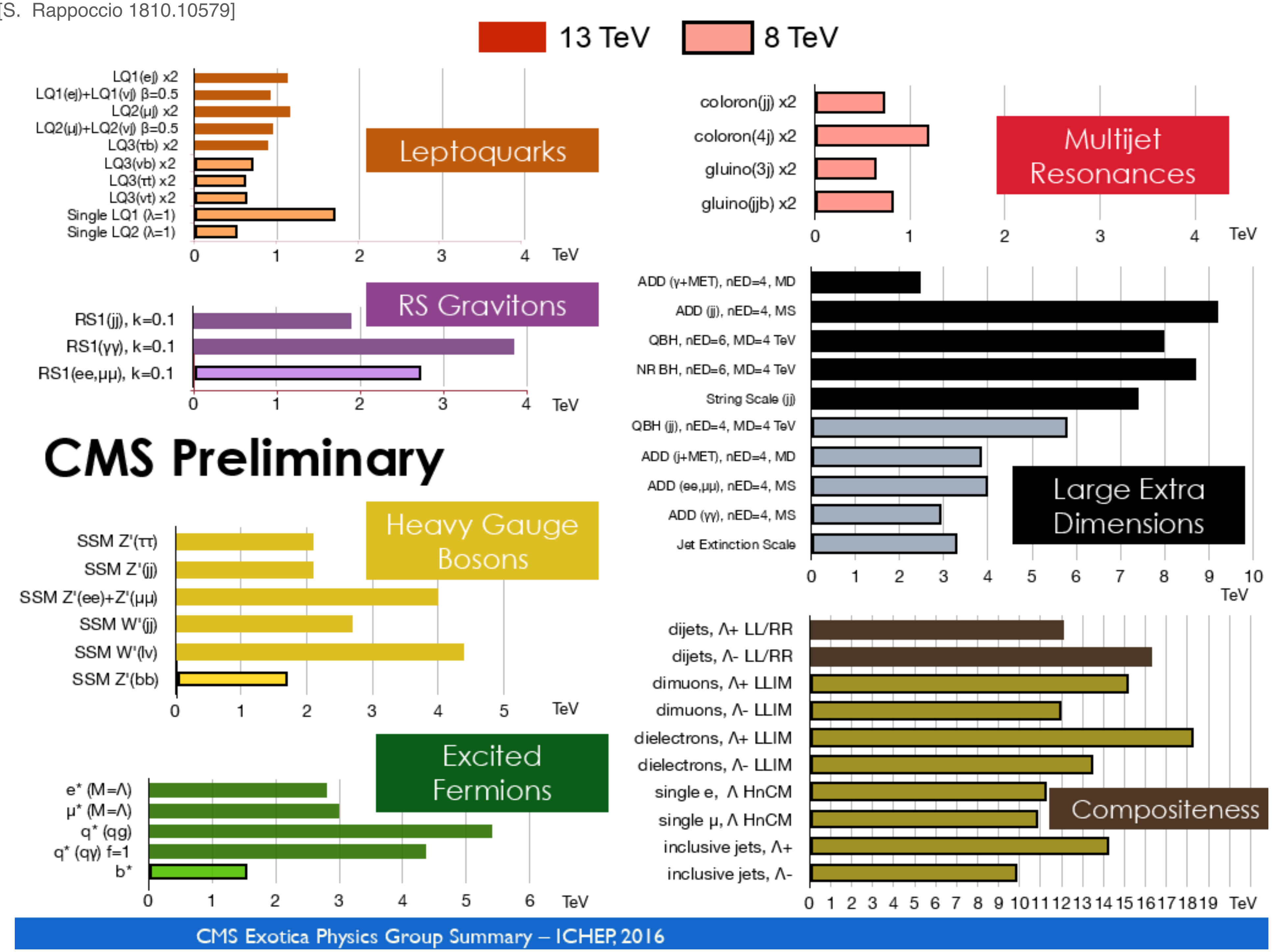
Supersymmetry Public Results



没有找到超对称粒子，对其质量做了上限 Mass > 1TeV

LHC实验结果

[S. Rappoccio 1810.10579]



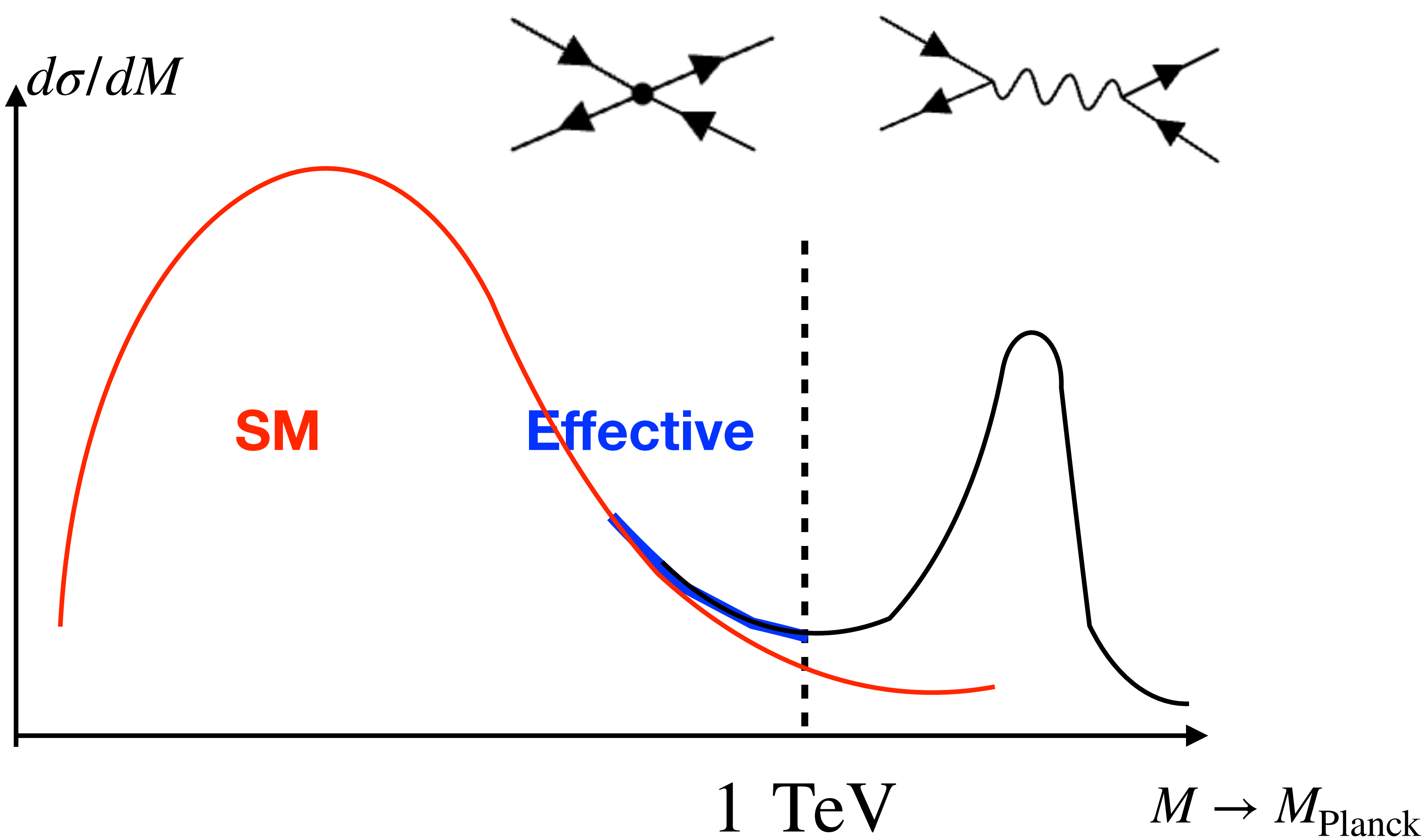
没有找到新物理模型预言的粒子，对其质量做了上限 Mass > 1TeV

有效场论

经验:

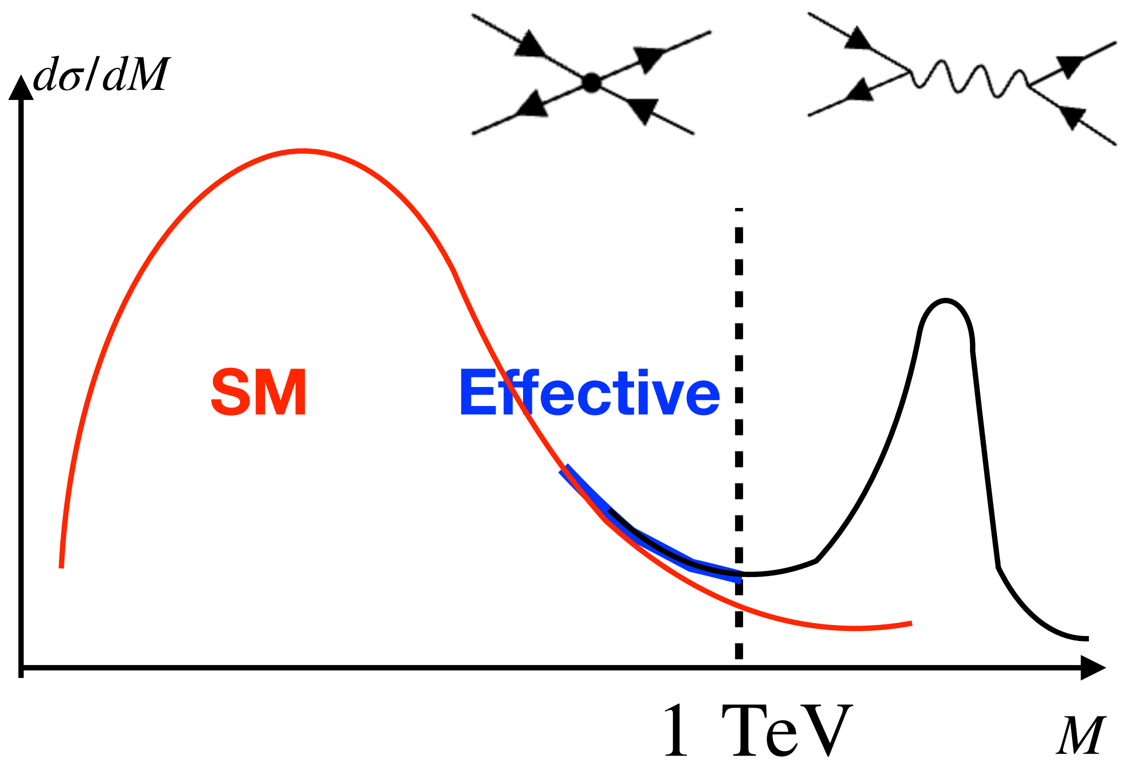
1. New particles are heavy.
2. Top-down (from high energy to low energy) is good, currently down-top (from low energy to high energy) is better?

Model-dependent Vs. Data-driven

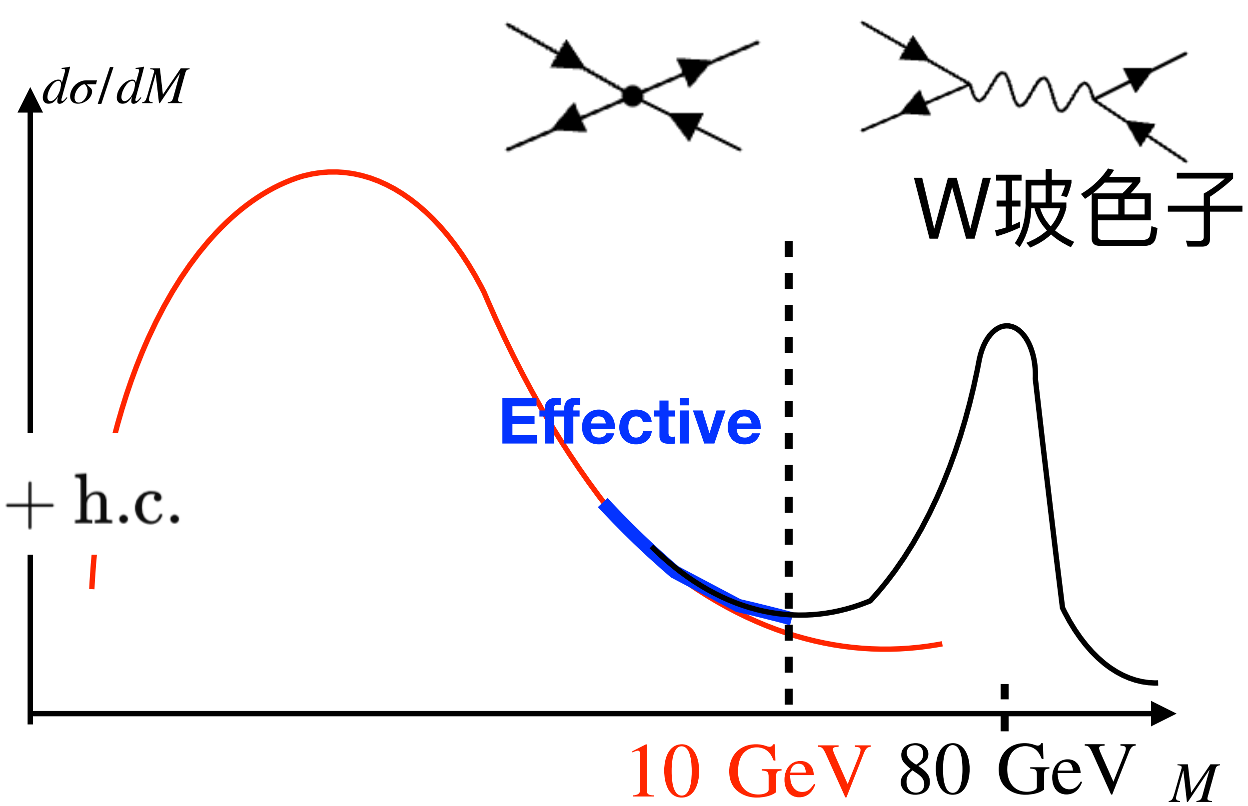


有效场论

2025年



1934年



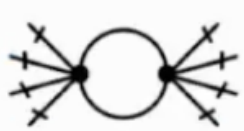
$$\mathcal{L}_F = -G_F(\bar{p}\gamma^{\mu}n)(\bar{e}\gamma_{\mu}\nu_e) + \text{h.c.}$$

用于β衰变

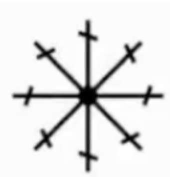
现代有效场论

- 构建完备基。
- 有效场论包含高维算符，在有限精度上它是可以重整的。

$$\mathscr{L}_{\text{EFT}} \supset \mathscr{L}_{\text{SM}} + \frac{C_H}{\Lambda^2}(H^\dagger H)^3 + \cdots$$



$$\sim \frac{1}{M^4}\int \frac{d^4k}{(2\pi)^4}\frac{1}{k^4} \sim \frac{1}{16\pi^2 M^4}\ln\Lambda.$$

\+ 

dim-6 SMEFT

$\mathcal{L}_6^{(1)} - X^3$		$\mathcal{L}_6^{(6)} - \psi^2 XH$		$\mathcal{L}_6^{(8b)} - (\bar{R}R)(\bar{R}R)$	
Q_G	$f^{abc}G_\mu^{a\nu}G_\nu^{b\rho}G_\rho^{c\mu}$	Q_{eW}	$(\bar{l}_p\sigma^{\mu\nu}e_r)\sigma^i HW_{\mu\nu}^i$	Q_{ee}	$(\bar{e}_p\gamma_\mu e_r)(\bar{e}_s\gamma^\mu e_t)$
$Q_{\widetilde{G}}$	$f^{abc}\widetilde{G}_\mu^{a\nu}G_\nu^{b\rho}G_\rho^{c\mu}$	Q_{eB}	$(\bar{l}_p\sigma^{\mu\nu}e_r)HB_{\mu\nu}$	Q_{uu}	$(\bar{u}_p\gamma_\mu u_r)(\bar{u}_s\gamma^\mu u_t)$
Q_W	$\varepsilon^{ijk}W_\mu^{i\nu}W_\nu^{j\rho}W_\rho^{k\mu}$	Q_{uG}	$(\bar{q}_p\sigma^{\mu\nu}T^a u_r)\widetilde{H}\,G_{\mu\nu}^a$	Q_{dd}	$(\bar{d}_p\gamma_\mu d_r)(\bar{d}_s\gamma^\mu d_t)$
$Q_{\widetilde{W}}$	$\varepsilon^{ijk}\widetilde{W}_\mu^{i\nu}W_\nu^{j\rho}W_\rho^{k\mu}$	Q_{uW}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\sigma^i\widetilde{H}\,W_{\mu\nu}^i$	Q_{eu}	$(\bar{e}_p\gamma_\mu e_r)(\bar{u}_s\gamma^\mu u_t)$
$\mathcal{L}_6^{(2)} - H^6$		Q_{uB}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\widetilde{H}\,B_{\mu\nu}$	Q_{ed}	$(\bar{e}_p\gamma_\mu e_r)(\bar{d}_s\gamma^\mu d_t)$
Q_H	$(H^\dagger H)^3$	Q_{dG}	$(\bar{q}_p\sigma^{\mu\nu}T^a d_r)H\,G_{\mu\nu}^a$	$Q_{ud}^{(1)}$	$(\bar{u}_p\gamma_\mu u_r)(\bar{d}_s\gamma^\mu d_t)$
$\mathcal{L}_6^{(3)} - H^4D^2$		Q_{dW}	$(\bar{q}_p\sigma^{\mu\nu}d_r)\sigma^i H\,W_{\mu\nu}^i$	$Q_{ud}^{(8)}$	$(\bar{u}_p\gamma_\mu T^a u_r)(\bar{d}_s\gamma^\mu T^a d_t)$
$Q_{H\Box}$	$(H^\dagger H)\Box(H^\dagger H)$	Q_{dB}	$(\bar{q}_p\sigma^{\mu\nu}d_r)H\,B_{\mu\nu}$		
Q_{HD}	$(D^\mu H^\dagger H)\,(H^\dagger D_\mu H)$				
$\mathcal{L}_6^{(4)} - X^2H^2$		$\mathcal{L}_6^{(7)} - \psi^2 H^2 D$		$\mathcal{L}_6^{(8c)} - (\bar{L}L)(\bar{R}R)$	
Q_{HG}	$H^\dagger H\,G_{\mu\nu}^a G^{a\mu\nu}$	$Q_{Hl}^{(1)}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{l}_p\gamma^\mu l_r)$	Q_{le}	$(\bar{l}_p\gamma_\mu l_r)(\bar{e}_s\gamma^\mu e_t)$
$Q_{H\widetilde{G}}$	$H^\dagger H\,\widetilde{G}_{\mu\nu}^a G^{a\mu\nu}$	$Q_{Hl}^{(3)}$	$(H^\dagger i\overleftrightarrow{D}_\mu^i H)(\bar{l}_p\sigma^i\gamma^\mu l_r)$	Q_{lu}	$(\bar{l}_p\gamma_\mu l_r)(\bar{u}_s\gamma^\mu u_t)$
Q_{HW}	$H^\dagger H\,W_{\mu\nu}^i W^{I\mu\nu}$	Q_{He}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{e}_p\gamma^\mu e_r)$	Q_{ld}	$(\bar{l}_p\gamma_\mu l_r)(\bar{d}_s\gamma^\mu d_t)$
$Q_{H\widetilde{W}}$	$H^\dagger H\,\widetilde{W}_{\mu\nu}^i W^{i\mu\nu}$	$Q_{Hq}^{(1)}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{q}_p\gamma^\mu q_r)$	Q_{qe}	$(\bar{q}_p\gamma_\mu q_r)(\bar{e}_s\gamma^\mu e_t)$
Q_{HB}	$H^\dagger H\,B_{\mu\nu}B^{\mu\nu}$	$Q_{Hq}^{(3)}$	$(H^\dagger i\overleftrightarrow{D}_\mu^i H)(\bar{q}_p\sigma^i\gamma^\mu q_r)$	$Q_{qu}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{u}_s\gamma^\mu u_t)$
$Q_{H\widetilde{B}}$	$H^\dagger H\,\widetilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{Hu}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{u}_p\gamma^\mu u_r)$	$Q_{qu}^{(8)}$	$(\bar{q}_p\gamma_\mu T^a q_r)(\bar{u}_s\gamma^\mu T^a u_t)$
Q_{HWB}	$H^\dagger\sigma^i H\,W_{\mu\nu}^i B^{\mu\nu}$	Q_{Hd}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{d}_p\gamma^\mu d_r)$	$Q_{qd}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{d}_s\gamma^\mu d_t)$
$Q_{H\widetilde{W}B}$	$H^\dagger\sigma^i H\,\widetilde{W}_{\mu\nu}^i B^{\mu\nu}$	Q_{Hud} + h.c.	$i(\widetilde{H}^\dagger D_\mu H)(\bar{u}_p\gamma^\mu d_r)$	$Q_{qd}^{(8)}$	$(\bar{q}_p\gamma_\mu T^a q_r)(\bar{d}_s\gamma^\mu T^a d_t)$
$\mathcal{L}_6^{(5)} - \psi^2 H^3$		$\mathcal{L}_6^{(8a)} - (\bar{L}L)(\bar{L}L)$		$\mathcal{L}_6^{(8d)} - (\bar{L}R)(\bar{R}L),\,(\bar{L}R)(\bar{L}R)$	
Q_{eH}	$(H^\dagger H)(\bar{l}_p e_r H)$	Q_{ll}	$(\bar{l}_p\gamma_\mu l_r)(\bar{l}_s\gamma^\mu l_t)$	Q_{ledq}	$(\bar{l}_p^j e_r)(\bar{d}_s q_{tj})$
Q_{uH}	$(H^\dagger H)(\bar{q}_p u_r\widetilde{H})$	$Q_{qq}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{q}_s\gamma^\mu q_t)$	$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r)\varepsilon_{jk}(\bar{q}_s^k d_t)$
Q_{dH}	$(H^\dagger H)(\bar{q}_p d_r H)$	$Q_{qq}^{(3)}$	$(\bar{q}_p\gamma_\mu\sigma^i q_r)(\bar{q}_s\gamma^\mu\sigma^i q_t)$	$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^a u_r)\varepsilon_{jk}(\bar{q}_s^k T^a d_t)$
		$Q_{lq}^{(1)}$	$(\bar{l}_p\gamma_\mu l_r)(\bar{q}_s\gamma^\mu q_t)$	$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r)\varepsilon_{jk}(\bar{q}_s^k u_t)$
		$Q_{lq}^{(3)}$	$(\bar{l}_p\gamma_\mu\sigma^i l_r)(\bar{q}_s\gamma^\mu\sigma^i q_t)$	$Q_{lequ}^{(3)}$	$(\bar{l}_p^j\sigma_{\mu\nu}e_r)\varepsilon_{jk}(\bar{q}_s^k\sigma^{\mu\nu}u_t)$

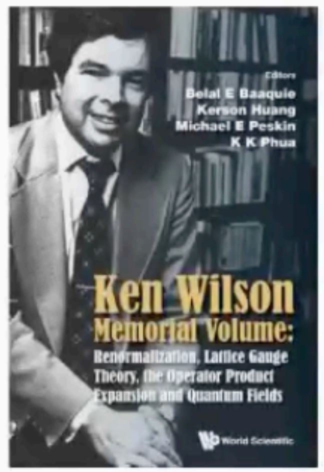
2012.11343, I. Brivio

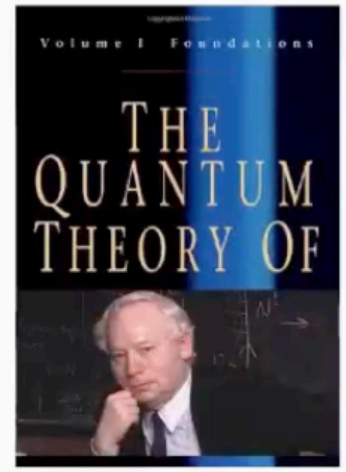
6点振幅的圈图需要8点振幅来抵消，依此类推，会有无穷项, 即不可重整。

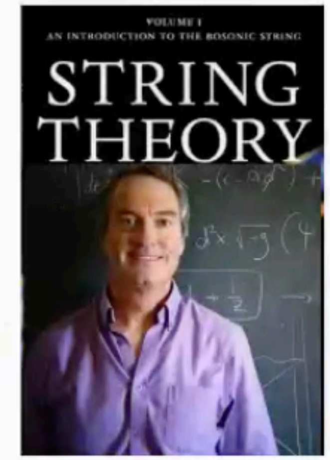
但是，对于精度做截断, e.g. $\mathscr{O}(1/M^2)$，则无需抵消。因此“可重整”。

场论和有效场论的发展历程

from J.H. Yu's slide







1949~1970	1970	1979	1984
QFT should be Renormalizable	Wilsonian EFT	Folk theorem	EFT should be Renormalizable

Renormalization and Effective Lagrangians

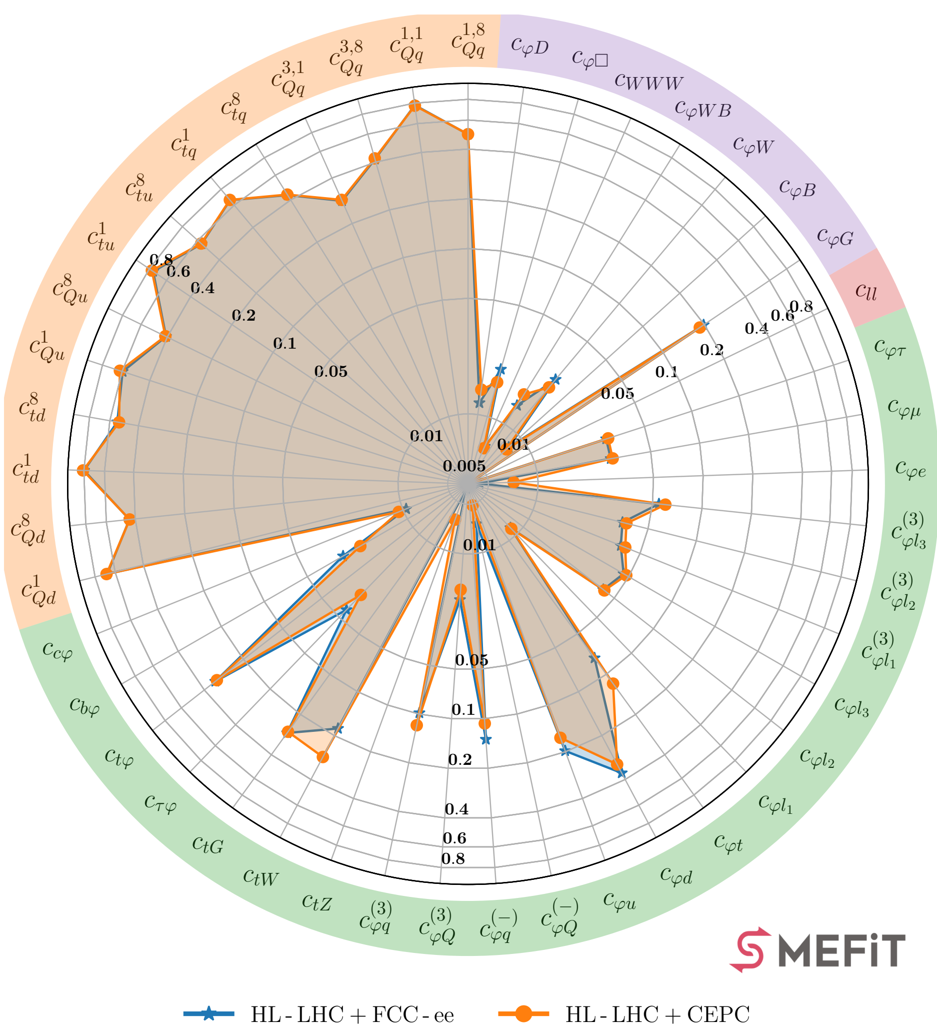
J. Polchinski, *Nucl. Phys. B* **231**, 269 (1984)

"What bothered me was that the proofs that renormalization works seemed extremely combinatoric and technical, but the results in the end came down to dimensional analysis. What I realized was that things would become nearly trivial if, instead of describing the path integral order by order in perturbation theory, as nearly always done, we described it scale-by-scale in energy. As soon as I thought those words, I knew I could prove them...It took just three weeks for me to work out the proof and write it up."

SMEFT/HEFT

EFT: 3 要素

UV: Ultra-Violet, 紫外，高能标



From Jaco ter Hoeve, ICHEP 2024

1. Construct a complete basis.

   [H. Sun, M.-L. Xiao, and J.-H. Yu, 2206.07722]

2. Data analysis: simulation and fitting. Global fitting.

3. Matching: relate the Wilson coefficients to the masses and couplings of UV models. EFT-UV匹配词典.

Complete Basis

$(\tilde{n}=1, n=3)$

$W e_{\mathbb{C}} L H^\dagger D^2$ $\qquad \#1=3, \#2=\#3=2, \#4=1.$

1	1	1	2
2	3	3	4

$\epsilon_{\alpha_1\alpha_3}\epsilon_{\alpha_1\alpha_3}\epsilon_{\alpha_2\alpha_4}\epsilon^{\dot\alpha_3\dot\alpha_4}$

$F_{\rm L1}^{\alpha\beta}\psi_2^{\gamma}\,(D\psi_3)_{\alpha\beta\dot\alpha}\,(D\phi_4)_{\gamma}{}^{\dot\alpha}$

1	1	1	3
2	2	3	4

$\epsilon_{\alpha_1\alpha_2}\epsilon_{\alpha_1\alpha_3}\epsilon_{\alpha_3\alpha_4}\epsilon^{\dot\alpha_3\dot\alpha_4}$

$F_{\rm L1}^{\alpha\beta}\psi_{2\alpha}\,(D\psi_3)_{\beta}{}^{\gamma}{}_{\dot\alpha}\,(D\phi_4)_{\gamma}{}^{\dot\alpha}$

$B W H H^\dagger D^2$ $\qquad \#1=3, \#2=3, \#3=1, \#4=1$

1	1	1	3
2	2	2	4

$\epsilon_{\dot\alpha_3\dot\alpha_4}\epsilon^{\alpha_1\alpha_2}\epsilon^{\alpha_1\alpha_2}\epsilon^{\alpha_3\alpha_4}$

$B_L{}^{\alpha\beta}W_{L\alpha\beta}\,(DH^\dagger)^{\gamma}{}_{\dot\alpha}\,(DH)_{\gamma}{}^{\dot\alpha}$

2

1	1	1	2
2	2	3	4

$\epsilon_{\dot\alpha_3\dot\alpha_4}\epsilon^{\alpha_1\alpha_2}\epsilon^{\alpha_1\alpha_3}\epsilon^{\alpha_2\alpha_4}$

$B_L{}^{\alpha\beta}W_{L\alpha}{}^{\gamma}\,(DH^\dagger)_{\beta\dot\alpha}\,(DH)_{\gamma}{}^{\dot\alpha}$

Young tensor method (No need EoM&IBP)

Traditional method

$B W H H^\dagger D^2$

[Hays, Martin, Sanz, Setford, 2018]

$(D^2H^\dagger)HB_{L\mu\nu}W_L^{\mu\nu}$, $(D^\mu D_\nu H^\dagger)HB_{L\mu\rho}W_L^{\nu\rho}$, $(D_\nu D^\mu H^\dagger)HB_{L\mu\rho}W_L^{\nu\rho}$, $(D_\mu H^\dagger)(D^\mu H)B_{L\nu\rho}W_L^{\nu\rho}$,
$(D_\mu H^\dagger)(D^\nu H)B_{L\nu\rho}W_L^{\mu\rho}$, $(D^\nu H^\dagger)(D_\mu H)B_{L\nu\rho}W_L^{\mu\rho}$, $(D_\mu H^\dagger)H(D^\mu B_{L\nu\rho})W_L^{\nu\rho}$, $(D_\mu H^\dagger)H(D^\nu B_{L\nu\rho})W_L^{\mu\rho}$,
$(D^\nu H^\dagger)H(D_\mu B_{L\nu\rho})W_L^{\mu\rho}$, $(D_\mu H^\dagger)HB_{L\nu\rho}(D^\mu W_L^{\nu\rho})$, $(D_\mu H^\dagger)HB_{L\nu\rho}(D^\nu W_L^{\mu\rho})$, $(D^\nu H^\dagger)HB_{L\nu\rho}(D_\mu W_L^{\mu\rho})$,
$H^\dagger(D^2H)B_{L\mu\nu}W_L^{\mu\nu}$, $H^\dagger(D^\mu D_\nu H)B_{L\mu\rho}W_L^{\nu\rho}$, $H^\dagger(D_\nu D^\mu H)B_{L\mu\rho}W_L^{\nu\rho}$, $H^\dagger(D^\mu H)(D_\mu B_{L\nu\rho})W_L^{\nu\rho}$,
$H^\dagger(D^\nu H)(D_\mu B_{L\nu\rho})W_L^{\mu\rho}$, $H^\dagger(D_\mu H)(D^\nu B_{L\nu\rho})W_L^{\mu\rho}$, $H^\dagger(D^\mu H)B_{L\nu\rho}(D_\mu W_L^{\nu\rho})$, $H^\dagger(D^\nu H)B_{L\nu\rho}(D_\mu W_L^{\mu\rho})$,
$H^\dagger(D_\mu H)B_{L\nu\rho}(D^\nu W_L^{\mu\rho})$, $H^\dagger H(D^2B_{L\mu\nu})W_L^{\mu\nu}$, $H^\dagger H(D^\mu D_\nu B_{L\mu\rho})W_L^{\nu\rho}$, $H^\dagger H(D_\nu D^\mu B_{L\mu\rho})W_L^{\nu\rho}$,
$H^\dagger H(D^\mu B_{L\nu\rho})(D_\mu W_L^{\nu\rho})$, $H^\dagger H(D^\nu B_{L\nu\rho})(D_\mu W_L^{\mu\rho})$, $H^\dagger H(D_\mu B_{L\nu\rho})(D^\nu W_L^{\mu\rho})$, $H^\dagger HB_{L\mu\nu}(D^2W_L^{\mu\nu})$,
$H^\dagger HB_{L\mu\rho}(D^\mu D_\nu W_L^{\nu\rho})$, $H^\dagger HB_{L\mu\rho}(D_\nu D^\mu W_L^{\nu\rho})$. (14)

30

EOM

$$(DH^\dagger)_{\alpha\dot\alpha}(DH)_{\beta\dot\beta}B_{L\{\gamma\delta\}}W_{L\{\xi\eta\}}\;\epsilon^{\dot\alpha\dot\beta}\epsilon^{\alpha\beta}\epsilon^{\gamma\xi}\epsilon^{\delta\eta}$$
$$(DH^\dagger)_{\alpha\dot\alpha}(DH)_{\beta\dot\beta}B_{L\{\gamma\delta\}}W_{L\{\xi\eta\}}\;\tfrac{1}{2}\epsilon^{\dot\alpha\dot\beta}\epsilon^{\delta\xi}(\epsilon^{\alpha\gamma}\epsilon^{\beta\eta}+\epsilon^{\beta\gamma}\epsilon^{\alpha\eta})$$
$$(DH^\dagger)_{\alpha\dot\alpha}\,H\,(DB_L)_{\{\beta\gamma\delta\},\dot\beta}W_{L\{\xi\eta\}}\;\epsilon^{\dot\alpha\dot\beta}\epsilon^{\alpha\beta}\epsilon^{\gamma\xi}\epsilon^{\delta\eta}$$
$$(DH^\dagger)_{\alpha\dot\alpha}\,H\,B_{L\{\xi\eta\}}(DW_L)_{\{\beta\gamma\delta\},\dot\beta}\;\epsilon^{\dot\alpha\dot\beta}\epsilon^{\alpha\beta}\epsilon^{\gamma\xi}\epsilon^{\delta\eta}$$
$$H^\dagger\,(DH)_{\alpha\dot\alpha}\,(DB_L)_{\{\beta\gamma\delta\},\dot\beta}W_{L\{\xi\eta\}}\;\epsilon^{\dot\alpha\dot\beta}\epsilon^{\alpha\beta}\epsilon^{\gamma\xi}\epsilon^{\delta\eta}$$
$$H^\dagger\,(DH)_{\alpha\dot\alpha}\,B_{L\{\xi\eta\}}(DW_L)_{\{\beta\gamma\delta\},\dot\beta}\;\epsilon^{\dot\alpha\dot\beta}\epsilon^{\alpha\beta}\epsilon^{\gamma\xi}\epsilon^{\delta\eta}$$
$$H^\dagger H\,(DB_L)_{\{\alpha\beta\gamma\},\dot\alpha}(DW_L)_{\{\xi\eta\delta\},\dot\beta}\;\epsilon^{\dot\alpha\dot\beta}\epsilon^{\alpha\xi}\epsilon^{\beta\eta}\epsilon^{\gamma\delta}$$

7

IBP

$$B_L{}^{\alpha\beta}W_{L\alpha\beta}\,(DH^\dagger)^{\gamma}{}_{\dot\alpha}\,(DH)_{\gamma}{}^{\dot\alpha}$$
$$B_L{}^{\alpha\beta}W_{L\alpha}{}^{\gamma}\,(DH^\dagger)_{\beta\dot\alpha}\,(DH)_{\gamma}{}^{\dot\alpha}$$

2

From J.H. Yu's slide

Complete Basis

SMEFT

Warsaw basis

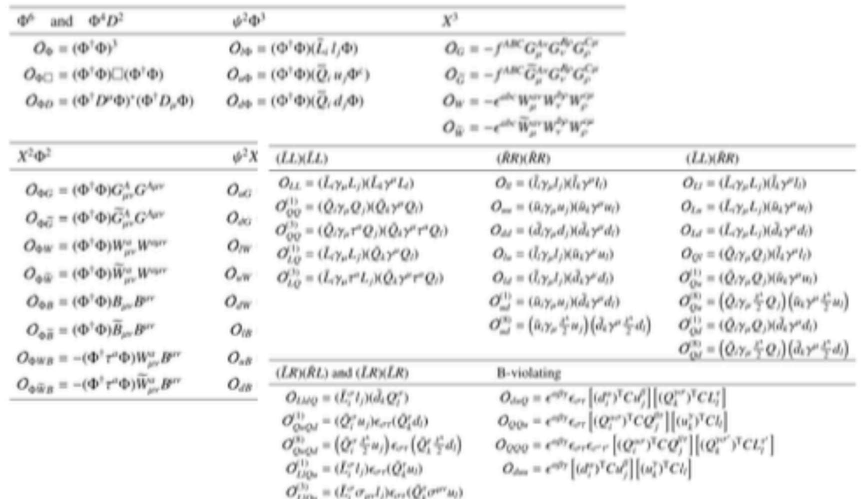
Dimension-5

$$\epsilon_{ij}\epsilon_{mn}(L^i C L^m)H^j H^n$$

[Weinberg, 1979]

2

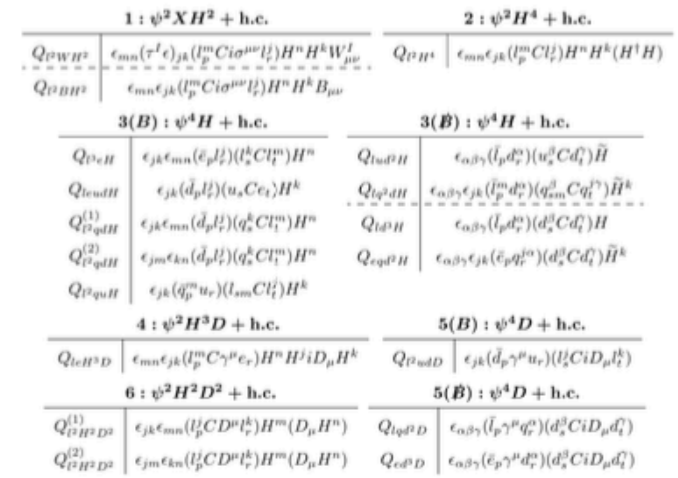
Dimension-6



[Buchmuller, Wyler, 1986] [Grzadkowski, Iskrzynski, Misiak, Rosiek, 2010]

84

Dimension-7



[Lehman, 2014]

30

Dimension-8

[Li, Ren, Shu, Xiao, **Yu**, Zheng, **2020**]

[Murphy, 2020]

993

N	$(n,\tilde{n})$	Subclasses	$\mathcal{N}_{\rm type}$	$\mathcal{N}_{\rm term}$	$\mathcal{N}_{\rm operator}$	Equations
4	(4,0)	$F_{\rm L}^4 + h.c.$	14	26	26	(4.19)
	(3,1)	$F_{\rm L}^2\psi\psi^\dagger D + h.c.$	22	22	$22n_f^2$	(4.51)
		$\psi^4 D^2 + h.c.$	$4\underline{+4}$	$18\underline{+14}$	$12n_f^4\underline{+n_f^3(5n_f-1)}$	(4.75, 4.78, 4.80)
		$F_{\rm L}\psi^2\phi D^2 + h.c.$	16	32	$32n_f^2$	(4.44)
		$F_{\rm L}^2\phi^2 D^2 + h.c.$	8	12	12	(4.14)
	(2,2)	$F_{\rm L}^2 F_{\rm R}^2$	14	17	17	(4.19)
		$F_{\rm L}F_{\rm R}\psi\psi^\dagger D$	27	35	$35n_f^2$	(4.50, 4.51)
		$\psi^2\psi^{\dagger 2}D^2$	$17\underline{+4}$	$54\underline{+8}$	$\frac{1}{2}n_f^2(75n_f^2+11)\underline{+6n_f^4}$	(4.74, 4.79-4.81)
		$F_{\rm R}\psi^2\phi D^2 + h.c.$	16	16	$16n_f^2$	(4.44)
		$F_{\rm L}F_{\rm R}\phi^2 D^2$	5	6	6	(4.14)
		$\psi\psi^\dagger\phi^2 D^3$	7	16	$16n_f^2$	(4.31, 4.32)
		$\phi^4 D^4$	1	3	3	(4.8)
5	(3,0)	$F_{\rm L}\psi^4 + h.c.$	$12\underline{+10}$	$66\underline{+54}$	$42n_f^4\underline{+2n_f^3(9n_f+1)}$	(4.86, 4.88, 4.89, 4.91)
		$F_{\rm L}^2\psi^2\phi + h.c.$	32	60	$60n_f^2$	(4.47, 4.48)
		$F_{\rm L}^3\phi^2 + h.c.$	6	6	6	(4.16)
	(2,1)	$F_{\rm L}\psi^2\psi^{\dagger 2} + h.c.$	$84\underline{+24}$	$172\underline{+32}$	$2n_f^2(59n_f^2-2)\underline{+24n_f^4}$	(4.84-4.85), (4.88-4.92)
		$F_{\rm R}^2\psi^2\phi + h.c.$	32	36	$36n_f^2$	(4.47, 4.48)
		$\psi^3\psi^\dagger\phi D + h.c.$	$32\underline{+14}$	$180\underline{+56}$	$n_f^3(135n_f-1)\underline{+n_f^3(29n_f+3)}$	(4.66, 4.69-4.72)
		$F_{\rm L}\psi\psi^\dagger\phi^2 D + h.c.$	38	92	$92n_f^2$	(4.39, 4.40)
		$\psi^2\phi^3 D^2 + h.c.$	6	36	$36n_f^2$	(4.28)
		$F_{\rm L}\phi^4 D^2 + h.c.$	4	6	6	(4.10)
6	(2,0)	$\psi^4\phi^2 + h.c.$	$12\underline{+4}$	$48\underline{+18}$	$5(5n_f^4+n_f^2)\underline{+\frac{2}{3}(8n_f^4+n_f^2)}$	(4.55, 4.59, 4.62, 4.64)
		$F_{\rm L}\psi^2\phi^3 + h.c.$	16	22	$22n_f^2$	(4.36)
		$F_{\rm L}^2\phi^4 + h.c.$	8	10	10	(4.12)

Dimension-9

[Li, Ren, Xiao, **Yu**, Zheng, **2020**]

[Liao, Ma, 2020]

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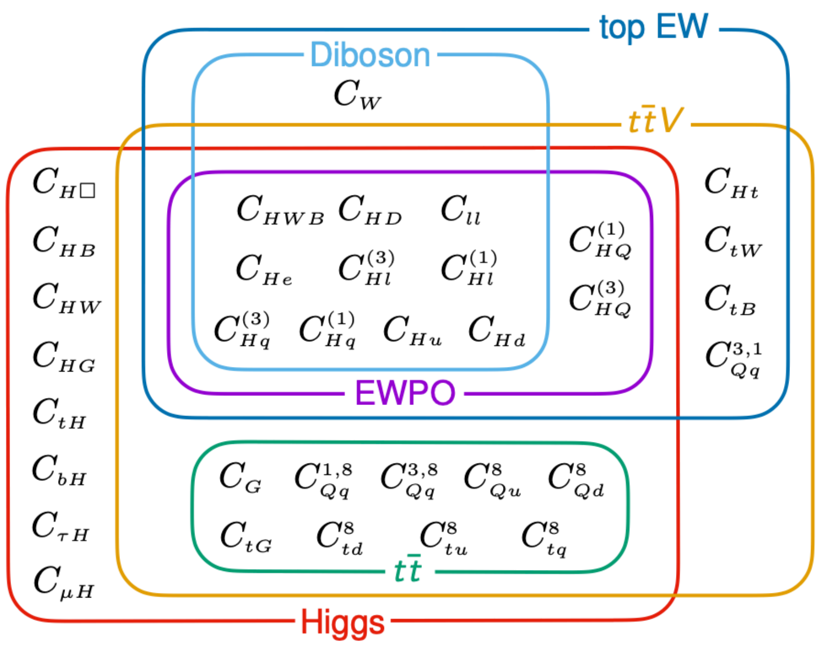
N	$(n,\tilde{n})$	Classes	$\mathcal{N}_{\rm type}$	$\mathcal{N}_{\rm term}$	$\mathcal{N}_{\rm operator}$	Equations
4	(3,2)	$\psi^3\psi^\dagger D^3 + h.c.$	$0+4+2+0$	10	$\frac{2}{3}n_f^2(7n_f^2-1)$	(5.50)(5.51)
		$\psi^2\phi^2 D^4 + h.c.$	$0+0+2+0$	6	$3n_f(n_f+1)$	(5.21)
5	(3,1)	$F_{\rm L}\psi^3\psi^\dagger D + h.c.$	$0+10+6+0$	72	$32n_f^4$	(5.59)(5.60)
		$\psi^4\phi D^2 + h.c.$	$0+4+4+0$	100	$40n_f^4$	(5.45-5.48)
		$F_{\rm L}\psi^2\phi^2 D^2 + h.c.$	$0+0+4+0$	34	$17n_f^2-n_f$	(5.28)(5.29)
	(2,2)	$F_{\rm R}\psi^3\psi^\dagger D + h.c.$	$0+10+6+0$	54	$4n_f^3(6n_f+1)$	(5.59)(5.60)
		$\psi^2\psi^{\dagger 2}\phi D^2$	$0+4+4+0$	84	$n_f^3(49n_f+1)$	(5.45-5.48)
		$F_{\rm R}\psi^2\phi^2 D^2 + h.c.$	$0+0+4+0$	20	$2n_f(5n_f-1)$	(5.28)(5.29)
		$\psi\psi^\dagger\phi^3 D^3$	$0+0+2+0$	6	$6n_f^2$	(5.19)
6	(3,0)	$\psi^6 + h.c.$	$2+4+6+0$	116	$\frac{1}{24}n_f^2(415n_f^4+53n_f^3+59n_f^2+139n_f+6)$	(5.63-5.70)
		$F_{\rm L}\psi^4\phi + h.c.$	$0+12+10+0$	102	$2n_f^3(21n_f+1)$	(5.54-5.56)
		$F_{\rm L}^2\psi^2\phi^2 + h.c.$	$0+0+8+0$	20	$2n_f(5n_f+2)$	(5.32)
	(2,1)	$\psi^4\psi^{\dagger 2} + h.c.$	$4+26+20+4$	244	$\frac{1}{6}n_f^3(382n_f^3-9n_f^2+2n_f+21)$	(5.63-5.69)
		$F_{\rm L}\psi^2\psi^{\dagger 2}\phi + h.c.$	$0+24+24+0$	92	$52n_f^4$	(5.54-5.56)
		$F_{\rm L}^2\psi^{\dagger 2}\phi^2 + h.c.$	$0+0+8+0$	12	$2n_f(3n_f+2)$	(5.32)
		$\psi^3\psi^\dagger\phi^2 D + h.c.$	$0+12+18+0$	186	$\frac{2}{3}n_f^2(146n_f^2+1)$	(5.39-5.42)
		$F_{\rm L}\psi\psi^\dagger\phi^3 D + h.c.$	$0+0+8+0$	12	$12n_f^2$	(5.25)
		$\psi^2\phi^4 D^2 + h.c.$	$0+0+4+0$	24	$2n_f(6n_f+1)$	(5.17)
7	(2,0)	$\psi^4\phi^3 + h.c.$	$0+6+6+0$	32	$\frac{4}{3}n_f^2(10n_f^2-1)$	(5.35-5.37)
		$F_{\rm L}\psi^2\phi^4 + h.c.$	$0+0+4+0$	8	$2n_f(2n_f-1)$	(5.23)

From J.H. Yu's slide

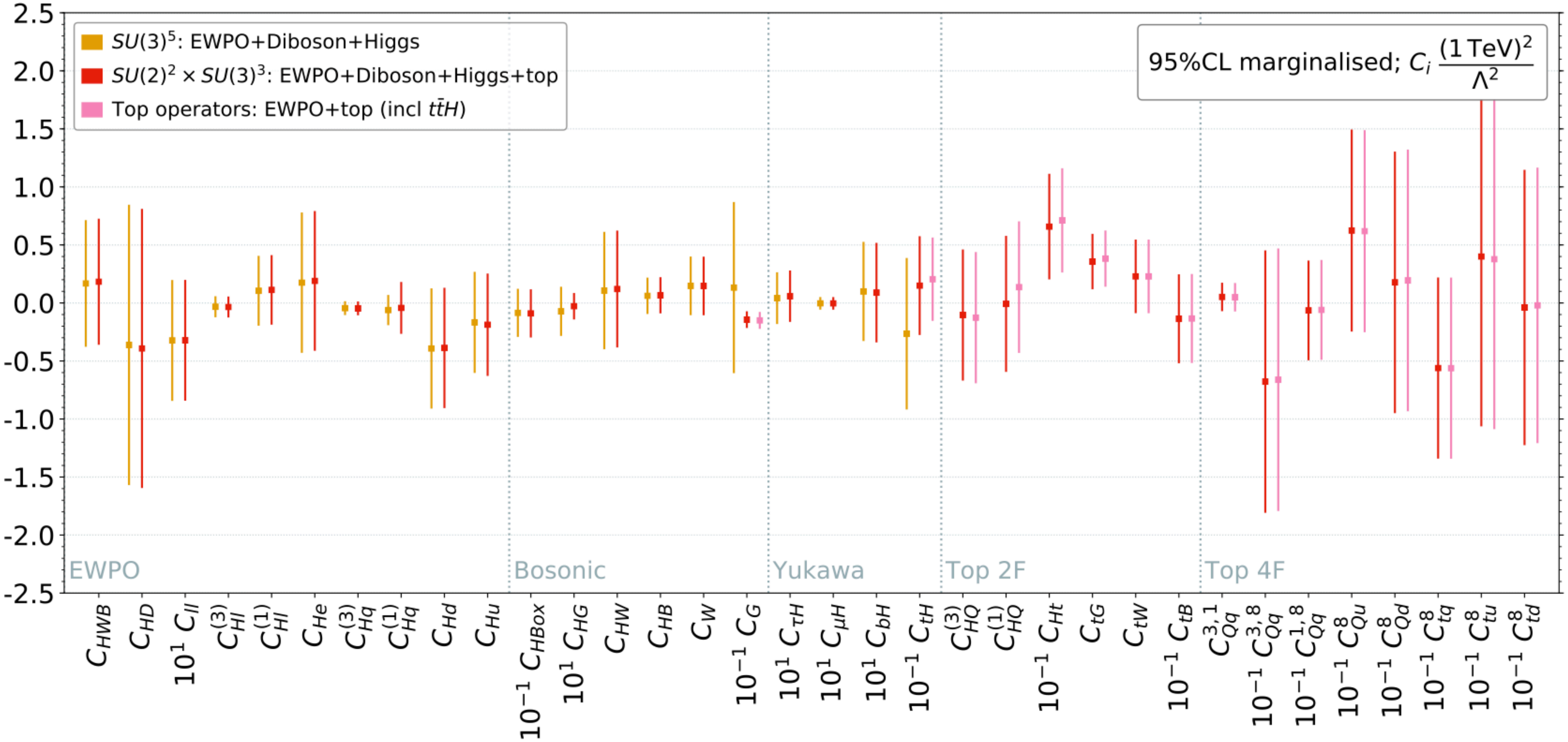
Global Fitting



$$\chi^2(C_i) = (\vec{y} - \vec{\mu}(C_i))^T \mathbf{V}^{-1} (\vec{y} - \vec{\mu}(C_i))$$

2012.02779, John Ellis,Maeve Madigan,Ken Mimasu,Veronica Sanz and Tevong You

FitMaker



Global Fitting

Theory

(N)NLO QCD + NLO EW SM XS

NLO-QCD, linear and quadratic, EFT (**SMEFT@NLO**)

PDFs, avoid redundancy (no top)

Data

Higgs data (inclusive, diff, STXS)

Top quark data

Diboson production (LEP + LHC)

SMEFiT

Output

Validation statistical toolbox: **Fisher information, PCA, closure tests**

Posterior probabilities in EFT parameter space, **CL intervals**

Methodology

Two independent fitting methods: **MCfit** and **Nested Sampling**

Modular structure: easy to add new theory predictions and data

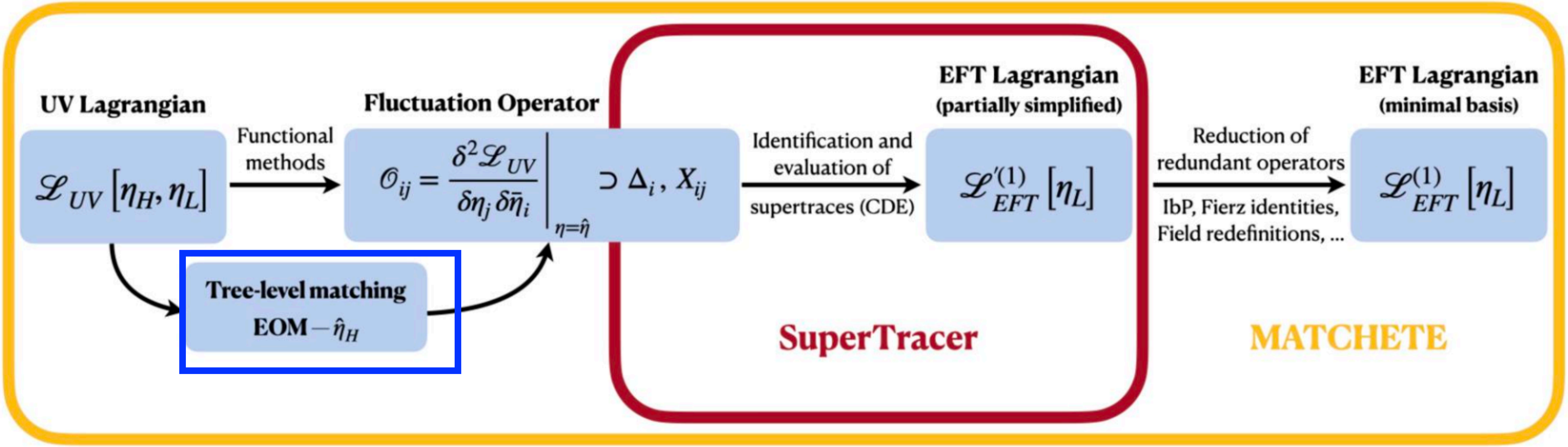
From Luca Mantani's Slide, HEFT2021

A Monte Carlo global analysis of the Standard Model Effective Field Theory: the top quark sector, N. P. Hartland, F. Maltoni, E. R. Nocera, J. Rojo, E. Slade, E. Vryonidou, C. Zhang

SMEFiT: a flexible toolbox for global interpretations of particle physics data with effective field theories, T. Giani, G. Magni and J. Rojo,

Matching

SMEFT matching procedure (Covariant Derivative Expansion)



UV-EFT Matching Dictionary

匹配词典

Name	$\mathcal{S}$	$\mathcal{S}_1$	$\mathcal{S}_2$	φ	Ξ	Ξ_1	Θ_1	Θ_3
Irrep	$(1,1)_0$	$(1,1)_1$	$(1,1)_2$	$(1,2)_{\frac{1}{2}}$	$(1,3)_0$	$(1,3)_1$	$(1,4)_{\frac{1}{2}}$	$(1,4)_{\frac{3}{2}}$

Name	ω_1	ω_2	ω_4	Π_1	Π_7	ζ
Irrep	$(3,1)_{-\frac{1}{3}}$	$(3,1)_{\frac{2}{3}}$	$(3,1)_{-\frac{4}{3}}$	$(3,2)_{\frac{1}{6}}$	$(3,2)_{\frac{7}{6}}$	$(3,3)_{-\frac{1}{3}}$

Name	Ω_1	Ω_2	Ω_4	Υ	Φ
Irrep	$(6,1)_{\frac{1}{3}}$	$(6,1)_{-\frac{2}{3}}$	$(6,1)_{\frac{4}{3}}$	$(6,3)_{\frac{1}{3}}$	$(8,2)_{\frac{1}{2}}$

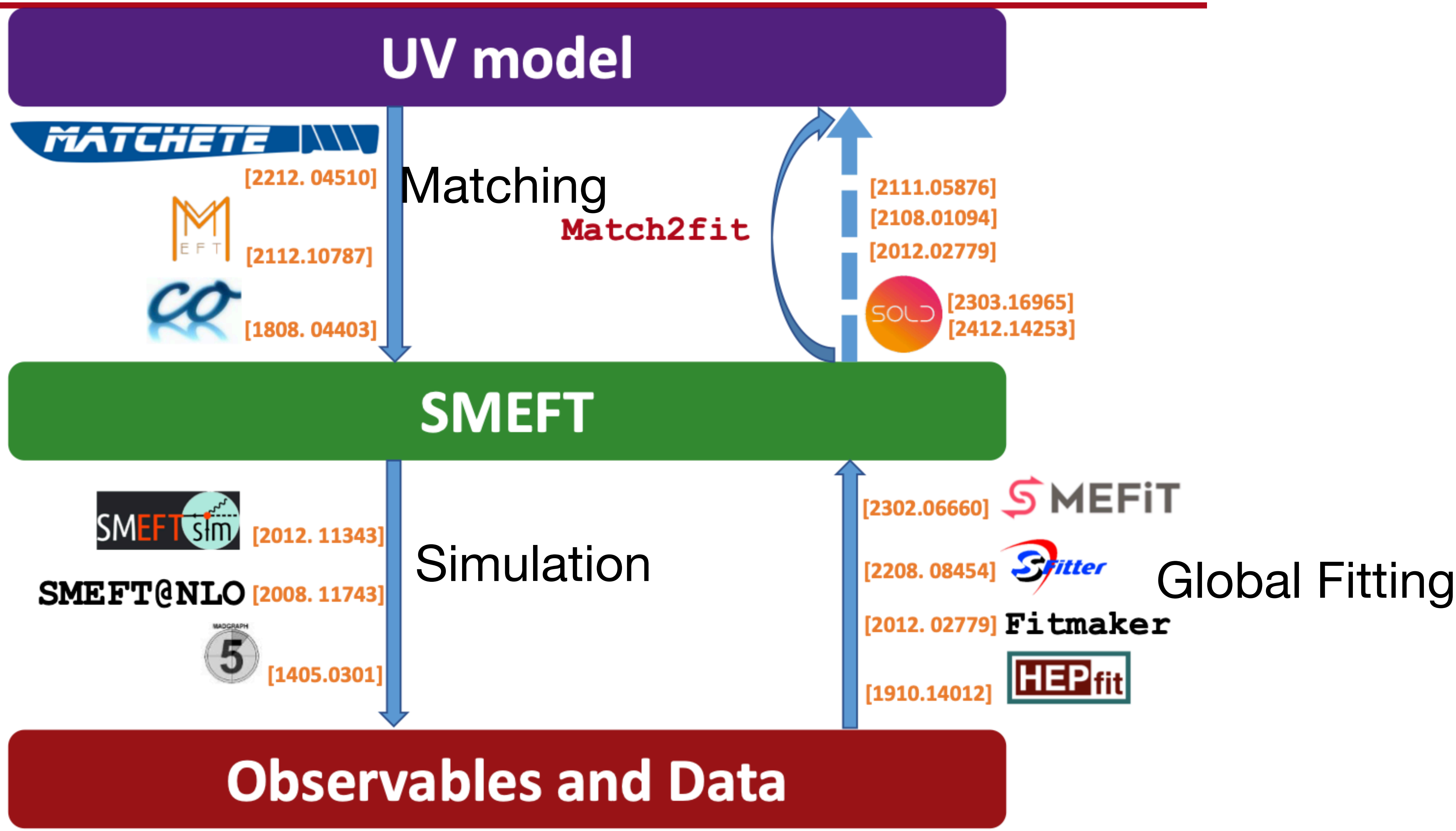
Table 1. New scalar bosons contributing to the dimension-six SMEFT at tree level.

1711.10391 J. de Blas, J. C. Criado, M. Pérez-Victoria and J. Santiago

1. 从实验得到的EFT coefficients 寻找可能的新物理存活空间。

2. 从UV模型匹配到EFT coefficients的模式指导实验。

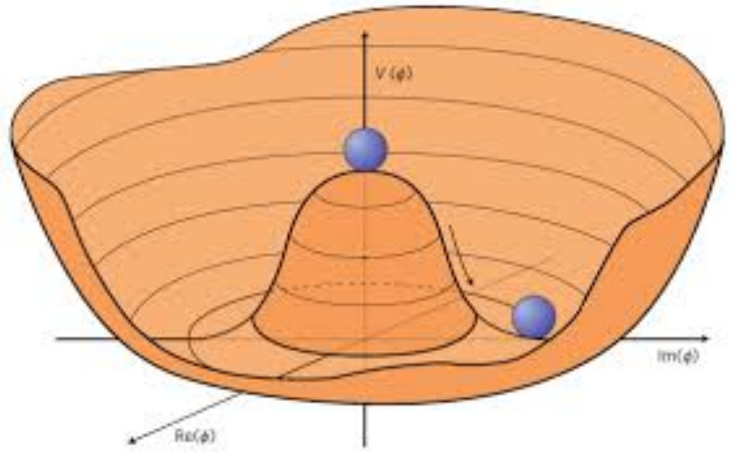
Automation of SMEFT



From Alejo N. Rossia's Silde, SMEFT-Tools,2025

自发对称性破缺机制

标准模型

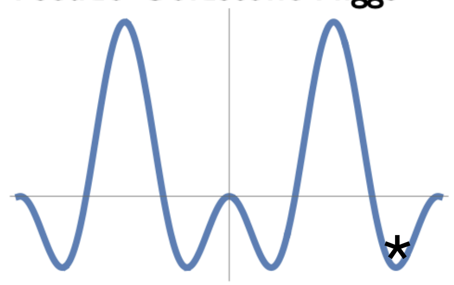


Landau-Ginzburg Higgs

$$V(\phi) = -m^2\phi^\dagger\phi + \lambda(\phi^\dagger\phi)^2$$

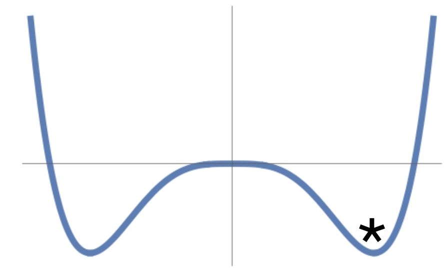
新物理模型

Pseudo-Goldstone Higgs



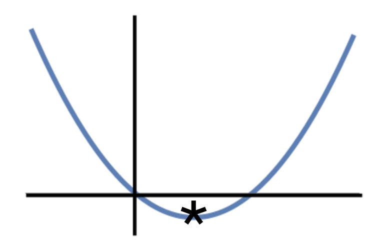
$$V(\phi) = -a\sin^2(\phi/f) + b\sin^4(\phi/f)$$

Coleman Weinberg Higgs



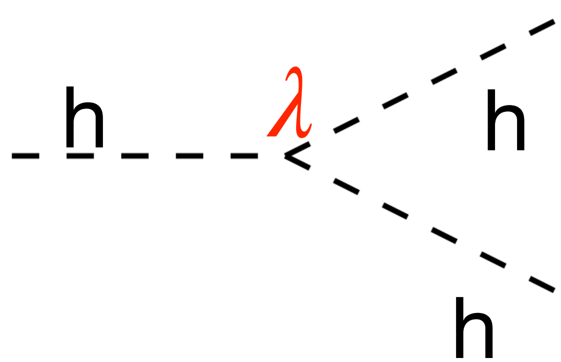
$$V(\phi) = \lambda(\phi^\dagger\phi)^2 + \epsilon(\phi^\dagger\phi)^2\log\frac{\phi^\dagger\phi}{\mu^2}$$

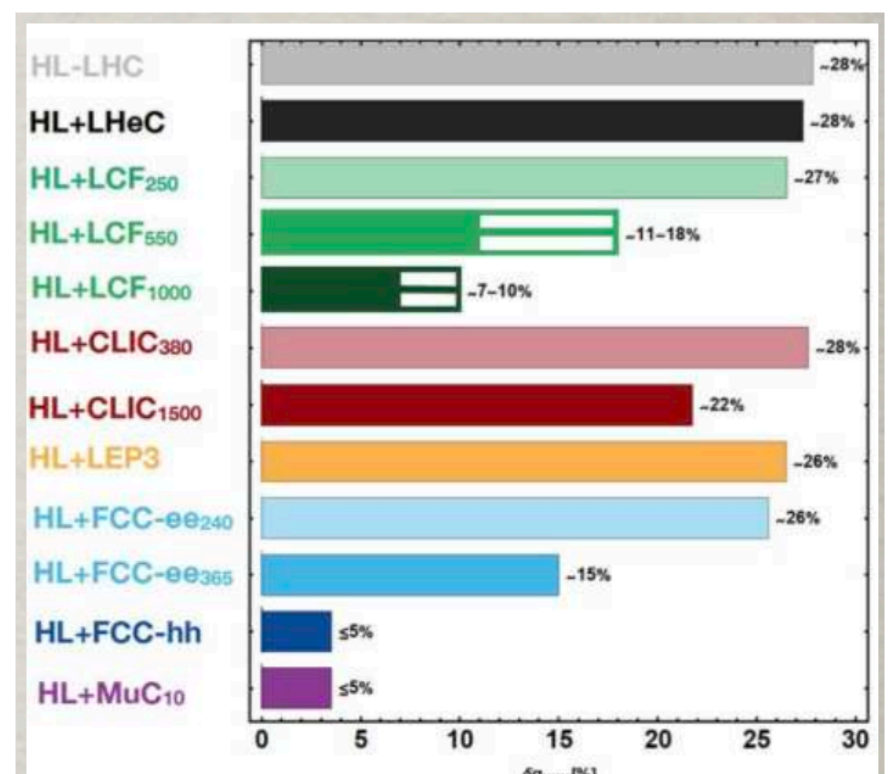
Tadpole-induced Higgs



$$V(\phi) = -\mu^3\sqrt{\phi^\dagger\phi} + m^2\phi^\dagger\phi$$

$$v(h) = 1/2m_h^2h^2 + \lambda v_{\rm EW}h^3 + 1/4\lambda h^4 + \ldots$$





from Tao Han's Slide @ NOPP2025

EFTs at electroweak scale: SMEFT and HEFT

- SMEFT, linear realization of the Higgs and Goldstones, canonical dimension

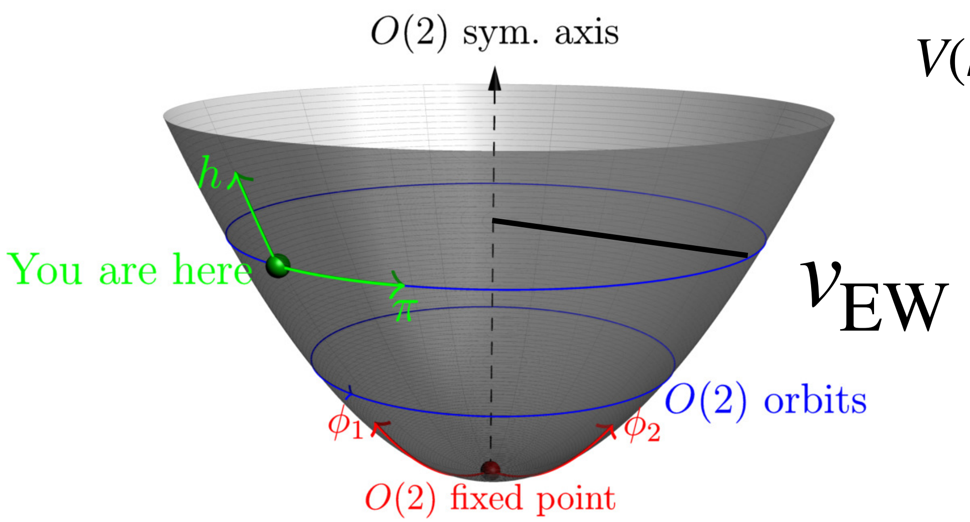
$$H = \frac{1}{\sqrt{2}}\begin{pmatrix} G^+ \\ v + h + iG^0 \end{pmatrix}, \quad \mathscr{L}_{\text{SMEFT}} \supset \frac{1}{2} D_\mu H^\dagger D^\mu H + \frac{m^2}{2} H^\dagger H - \lambda (H^\dagger H)^2 + \frac{C_H}{\Lambda^2}(H^\dagger H)^3 + \cdots$$

- HEFT, nonlinear realization, chiral dimension

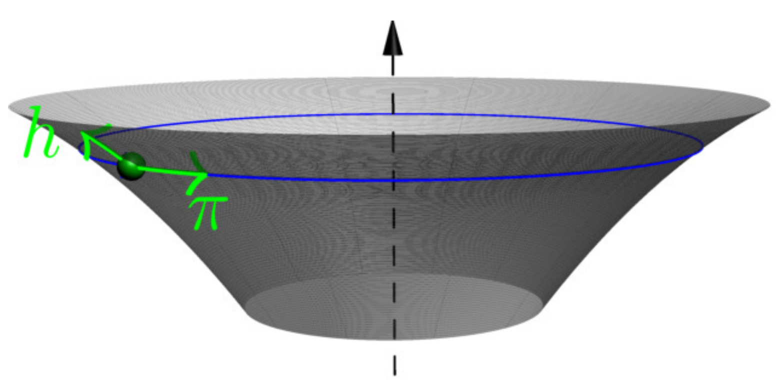
$$h,\, U \equiv \exp\left(\frac{i\pi_i \sigma_i}{v_{\text{EW}}}\right), \quad \mathscr{L}^{\text{LO}}_{\text{HEFT}} \supset \frac{1}{2} D_\mu h D^\mu h - V(h) + \frac{v_{\text{EW}}^2}{4} F(h) \text{Tr}(D_\mu U^\dagger D^\mu U) + \cdots$$

$$V(h) = \frac{1}{2} m_h^2 h^2 \left[1 + (1 + \Delta\kappa_3)\frac{h}{v_{\text{EW}}} + \cdots\right], \quad F(h) = 1 + 2(1 + \Delta a)\frac{h}{v_{\text{EW}}} + \cdots$$

[H. Sun, M.-L. Xiao, and J.-H. Yu, 2206.07722]

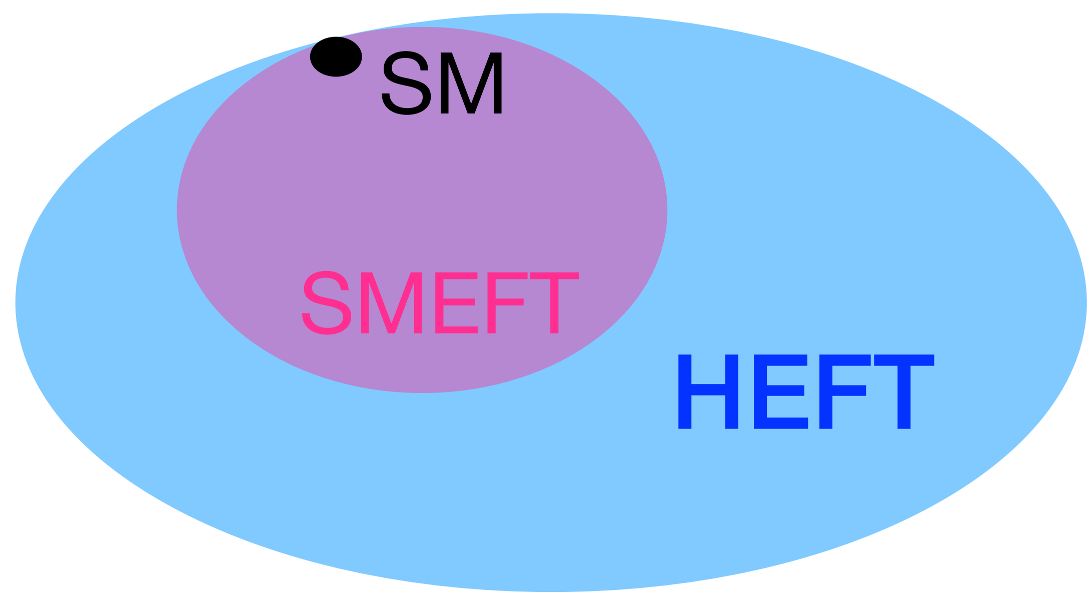


SMEFT/HEFT



only HEFT

from N. Craig, HEFT2021



HEFT encompasses SMEFT.

R. Alonso, E. Jenkins, A. Manohar [1511.00724,1605.03602]

Matching a same model both to SMEFT and HEFT

- SM with a singlet extension.

  [G. Buchala et al, 1608.03564.

- 2HDM (i.e. SM+ another Higgs doublet).

  [G. Buchala et al, 2312.13885], [S. Dawson et al, 2205.01561, 2311.16897],[F. Arco et al, 2307.15693]

- The Real Triplet Model (i.e. SM + a triplet Higgs).

  [Huayang Song, XW, 2412.00355(*JHEP* 06 (2025) 021), 2503.00707(*JHEP* 06 (2025) 249)]

Linear form

$$\mathrm{H} = \begin{pmatrix} G^+ \\ \frac{1}{\sqrt{2}}\left(v_\mathrm{H} + h + iG^0\right) \end{pmatrix}, \qquad \Sigma = \frac{1}{2}\Sigma_i\sigma_i = \frac{1}{2}\begin{pmatrix} v_\Sigma + \Sigma^0 & \sqrt{2}\Sigma^+ \\ \sqrt{2}\Sigma^- & -v_\Sigma - \Sigma^0 \end{pmatrix}, i = 1, 2, 3,$$

$$\mathscr{L}_{\mathrm{RHTE}}(\mathrm{H}, \Sigma) \supset D_\mu \mathrm{H}^\dagger D^\mu \mathrm{H} + \langle D_\mu \Sigma^\dagger D^\mu \Sigma \rangle - V(H, \Sigma),$$

$$V(\mathrm{H}, \Sigma) = Y_1^2 \mathrm{H}^\dagger \mathrm{H} + Z_1(\mathrm{H}^\dagger \mathrm{H})^2 + Y_2^2 \langle \Sigma^\dagger \Sigma \rangle + Z_2 \langle \Sigma^\dagger \Sigma \rangle^2 + Z_3 \mathrm{H}^\dagger \mathrm{H} \langle \Sigma^\dagger \Sigma \rangle + 2Y_3 \mathrm{H}^\dagger \Sigma \mathrm{H}$$

$Z_i s$ are dimensionless, $Y_i s$ are dimensional

$< \ldots >$ denotes trace

Matching Real Triplet Model to SMEFT

$$\mathscr{L}_{\rm RHTE}({\rm H},\Sigma) \supset D_\mu {\rm H}^\dagger D^\mu {\rm H} + \langle D_\mu \Sigma^\dagger D^\mu \Sigma \rangle - V,$$

$$V = \frac{1}{2}\vec{\Sigma}^T(-D_\mu D^\mu - M^2 - Z_3\,{\rm H}^\dagger {\rm H})\vec{\Sigma} + Y_3 \vec{\Sigma}\cdot {\rm H}^\dagger \vec{\sigma} {\rm H} - \frac{1}{4} Z_2 (\vec{\Sigma}\cdot\vec{\Sigma})^2$$

EoM of Σ:

$$(-D_\mu D^\mu - M^2 - Z_3\,{\rm H}^\dagger {\rm H})\vec{\Sigma}_c = -\,Y_3 {\rm H}^\dagger \vec{\sigma} {\rm H} + Z_2(\vec{\Sigma}_c\cdot\vec{\Sigma}_c)\vec{\Sigma}_c$$

$$\vec{\Sigma}_c = -\frac{1}{-D_\mu D^\mu - M^2 - Z_3\,{\rm H}^+{\rm H}} Y_3 {\rm H}^+ \vec{\sigma} {\rm H} + \frac{1}{-D_\mu D^\mu - M^2 - Z_3\,{\rm H}^+{\rm H}} Z_2(\vec{\Sigma}_c\cdot\vec{\Sigma}_c)\vec{\Sigma}_c$$

Expansion with $1/M^2$ (Assume $M^2 \gg v_{\rm EW}^2$)

$$\mathscr{L}_{\rm SMEFT} = \frac{1}{2M^2} Y_3^2 {\rm H}^\dagger \vec{\sigma} H \cdot {\rm H}^\dagger \vec{\sigma} {\rm H} + \frac{1}{2}({\rm H}^\dagger \vec{\sigma} H)^T \frac{1}{M^2}(-D_\mu D^\mu - Z_3 H^\dagger H)\frac{1}{M^2}{\rm H}^\dagger \vec{\sigma} H + \cdots$$

T. Corbett, A. Helset, A. Martin, M. Trott, [2102.02819]
J. Ellis, K. Mimasu, F. Zamperdri, [2304.06663]

Matching Real Triplet Model to HEFT

$$\mathrm{H} = \begin{pmatrix} G^+ \\ \frac{1}{\sqrt{2}}\left(v_\mathrm{H} + h + iG^0\right) \end{pmatrix}, \qquad \Sigma = \frac{1}{2}\Sigma_i\sigma_i = \frac{1}{2}\begin{pmatrix} v_\Sigma + \Sigma^0 & \sqrt{2}\Sigma^+ \\ \sqrt{2}\Sigma^- & -v_\Sigma - \Sigma^0 \end{pmatrix}, i = 1, 2, 3,$$

$$\begin{pmatrix} G^+_\mathrm{EW} \\ H^+ \end{pmatrix} = \begin{pmatrix} \cos\delta & -\sin\delta \\ \sin\delta & \cos\delta \end{pmatrix}\begin{pmatrix} G^+ \\ \Sigma^+ \end{pmatrix} \qquad \begin{pmatrix} h \\ K \end{pmatrix} = \begin{pmatrix} \cos\gamma & -\sin\gamma \\ \sin\gamma & \cos\gamma \end{pmatrix}\begin{pmatrix} h^0 \\ \Sigma^0 \end{pmatrix}$$

$$\tan\delta = 2v_\Sigma / v_\mathrm{H}.$$

- Integrate not Σ as a whole, but the K and $H^\pm$ particles.
- $G^\pm_\mathrm{EW}, G^0_\mathrm{EW}$ should be written into a U matrix.

$$h, U \equiv \exp\left(\frac{i\pi_i\sigma_i}{v_\mathrm{EW}}\right), \qquad \mathscr{L}^\mathrm{LO}_\mathrm{HEFT} \supset \frac{1}{2}D_\mu h D^\mu h - V(h) + \frac{v^2_\mathrm{EW}}{4}F(h)\mathrm{Tr}(D_\mu U^\dagger D^\mu U) + \cdots$$

A non-linear framework

Huayang Song, XW, 2412.00355(*JHEP* 06 (2025) 021)

$$\mathrm{H} = U\frac{1}{\sqrt{2}}\begin{pmatrix}\chi^{\pm}\\ v_{\mathrm{H}} + h^0 + i\chi^0\end{pmatrix}, U \equiv \exp\left(\frac{i\pi_i\sigma_i}{v_{EW}}\right)$$

$$\Sigma = U\Phi U^{\dagger},\ \Phi = \frac{1}{2}\phi_i\sigma_i = \frac{1}{2}\begin{pmatrix} v_{\Sigma} + \phi^0 & \sqrt{2}\phi^+ \\ \sqrt{2}\phi^- & -v_{\Sigma} - \phi^0\end{pmatrix}$$

$$\chi^{\pm} = 2\frac{v_{\Sigma}}{v_{\mathrm{H}}}\phi^{\pm}, \chi^0 = 0$$

$$\mathcal{L} = (D_\mu H)^\dagger (D^\mu H) + \langle D_\mu \Sigma^\dagger D^\mu \Sigma\rangle - V,$$

$$V = Y_1^2 H^\dagger H + Z_1(H^\dagger H)^2 + Y_2^2\langle\Sigma^\dagger\Sigma\rangle + Z_2\langle\Sigma^\dagger\Sigma\rangle^2 + Z_3 H^\dagger H\langle\Sigma^\dagger\Sigma\rangle + 2Y_3 H^\dagger \Sigma H,$$

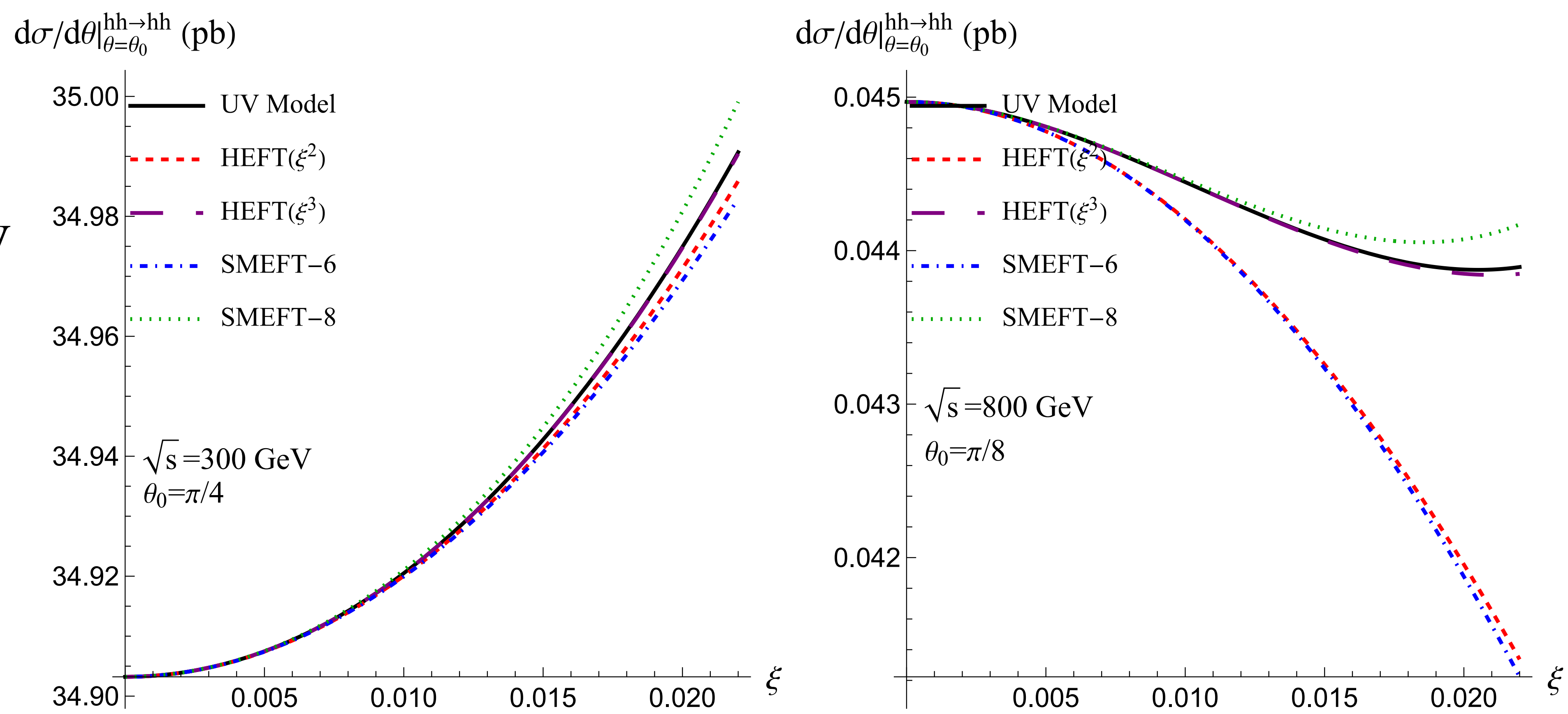
- 三个重粒子与U矩阵完全分离，并且是线性相互作用。积掉重粒子得到HEFT形式变得简单，并易于编程。
- 用张量符号描写$SU(2)$多重态，适用于一般多重态扩展的UV模型。

$$\mathrm{H}_i = U_i^j \mathfrak{h}_j,\quad \mathfrak{h} = \begin{pmatrix}\chi^+ \\ \frac{1}{\sqrt{2}}\left(v_{\mathrm{H}} + h^0 + i\chi^0\right)\end{pmatrix}$$

$$\Phi_{ijklm\cdots} = U_{i_1}^i U_{j_1}^j U_{k_1}^k U_{l_1}^l U_{k_1}^k U_{m_1}^m \cdots \phi_{i_1 j_1 k_1 l_1 m_1 \cdots}$$

SMEFT Vs. HEFT

$Y_2 > 2\text{TeV}$



HEFT converges faster, which is same as in $WW \to hh, ZZ \to hh$ process

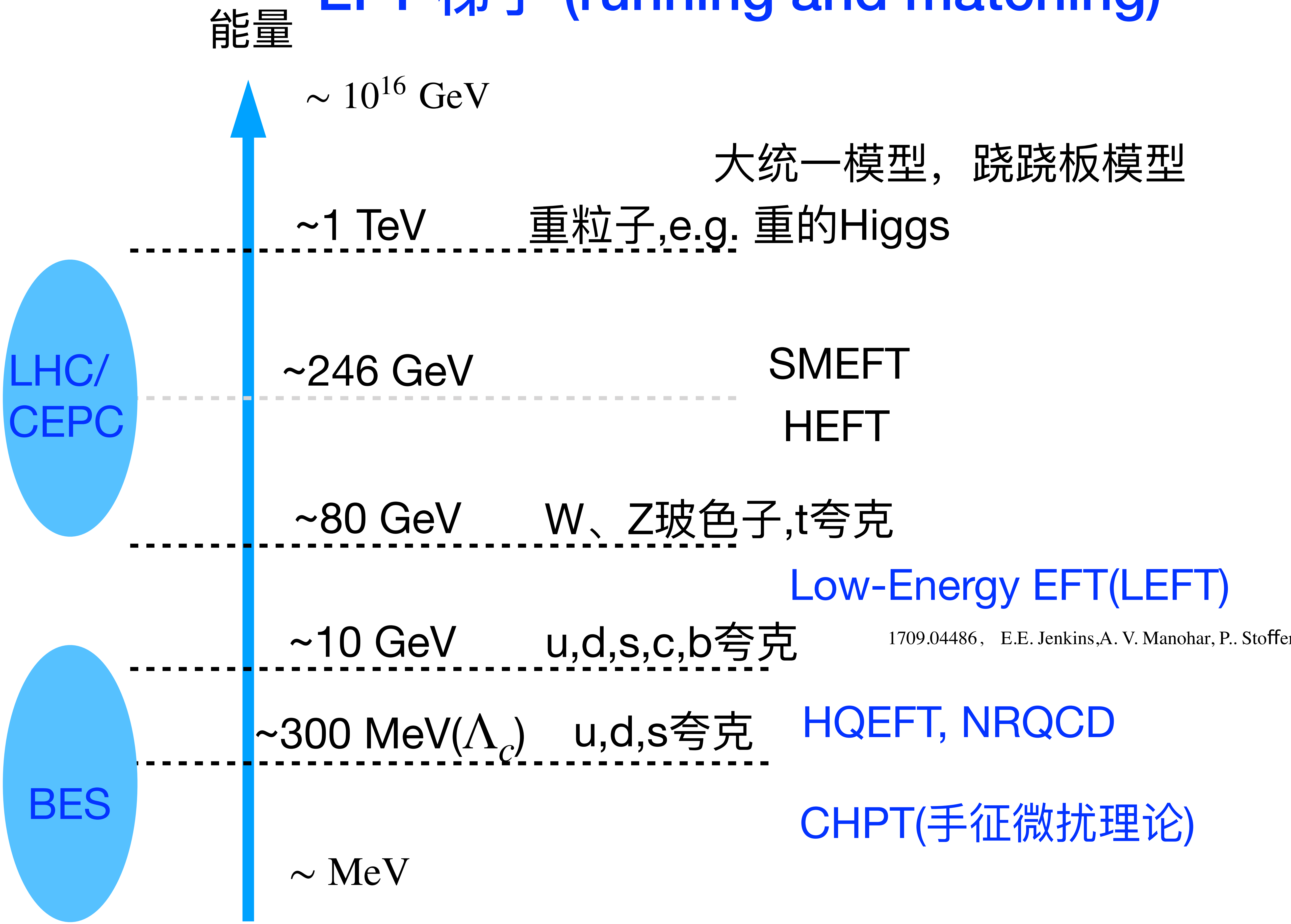
Similar results also from 2504.02580,
Yi Liao, Xiao-Dong Ma, Yoshiki Uchida

HEFT 研究的挑战

- HEFT 有多种，不同的Power counting 对应不同的HEFT。
- 退耦的HEFT与SMEFT描述UV模型的参数空间基本一致，非退耦的HEFT与SMEFT可能会有不同。
- HEFT与UV模型1圈的匹配。

EFT-Hadron spectroscopy

EFT 梯子 (running and matching)



LEFT (QCD × QED)

1. 轻子味破坏（LFV）过程，　　　　夸克(除了t), 胶子，轻子，光子

例如$\tau \to \mu\gamma, \mu \to e\gamma, \tau \to 3\mu, \mu \to 3e$

$\tau \to \mu\gamma$

LEFT $\mathcal{O}_{\text{dipole}} = \frac{e}{m_\tau} \left(\bar{\mu}\sigma^{\mu\nu} P_{L/R}\tau\right) F_{\mu\nu} + \text{h.c.}$

SMEFT $\mathcal{O}_{eB}^{\mu\tau} = \left(\bar{L}_\mu \sigma^{\mu\nu} \tau_R\right) H B_{\mu\nu}, \quad \mathcal{O}_{eW}^{\mu\tau} = \left(\bar{L}_\mu \sigma^{\mu\nu} \tau_R\right) \sigma^I H W_{\mu\nu}^I$

- $\tau \to \mu\gamma$ 过程，$\mu \to e\gamma$ 过程，muon g-2(loop), 电子的电偶极矩
- LHC上 $pp \to \ell\ell\gamma$过程

τ 衰变中寻找新物理

过程	LEFT 算符	SMEFT 算符	新物理敏感性
$\tau \to \mu\gamma$	dipole	$\mathcal{O}_{eB}, \mathcal{O}_{eW}$	LFV, leptoquark, SUSY
$\tau \to 3\mu$	$(\ell\ell\ell\ell)$	$\mathcal{O}_{L\ell}, \mathcal{O}_{\ell e}, \mathcal{O}_{ee}$	Z', scalar mediator
$\tau \to \mu\pi^0,\ \mu\rho$	$(\ell\ell qq)$	$\mathcal{O}_{lq}^{(1)},\ \mathcal{O}_{lq}^{(3)}$	LFV,Z',SUSY
$\tau \to \mu\nu\nu$	$(\ell\nu\ell\nu)$	$\mathcal{O}_{Hl}^{(1)}, \mathcal{O}_{Hl}^{(3)}$	LUV,W',SUSY
$\tau \to K\nu, K\pi^0\nu$	$\ell\ell sd$	$\mathcal{O}_{\ell d}, \mathcal{O}_{ledq}$	Z', 2HDM

粲介子衰变中的新物理

过程	LEFT 算符	NP 敏感性
$D^0 \to \mu^+\mu^-$	$(\ell\ell qq)$	Z', leptoquark
$D \to \pi\mu\mu$	$(\ell\ell qq)$, dipole	FCNC, SUSY
$c \to u\gamma(\text{e.g. } D \to \pi\gamma)$	dipole	SUSY, vector-like quark
D^0–$\overline{D^0}$ 混合	$(qqqq)$	$\Delta C = 2$ NP 算符

2410.00115，Hector Gisbert, Gudrun Hiller and Dominik Suelmann

Summary

- EFT 3要素：完整基，全局拟合，匹配词典。SMEFT的自动化工具构建已初步完成。

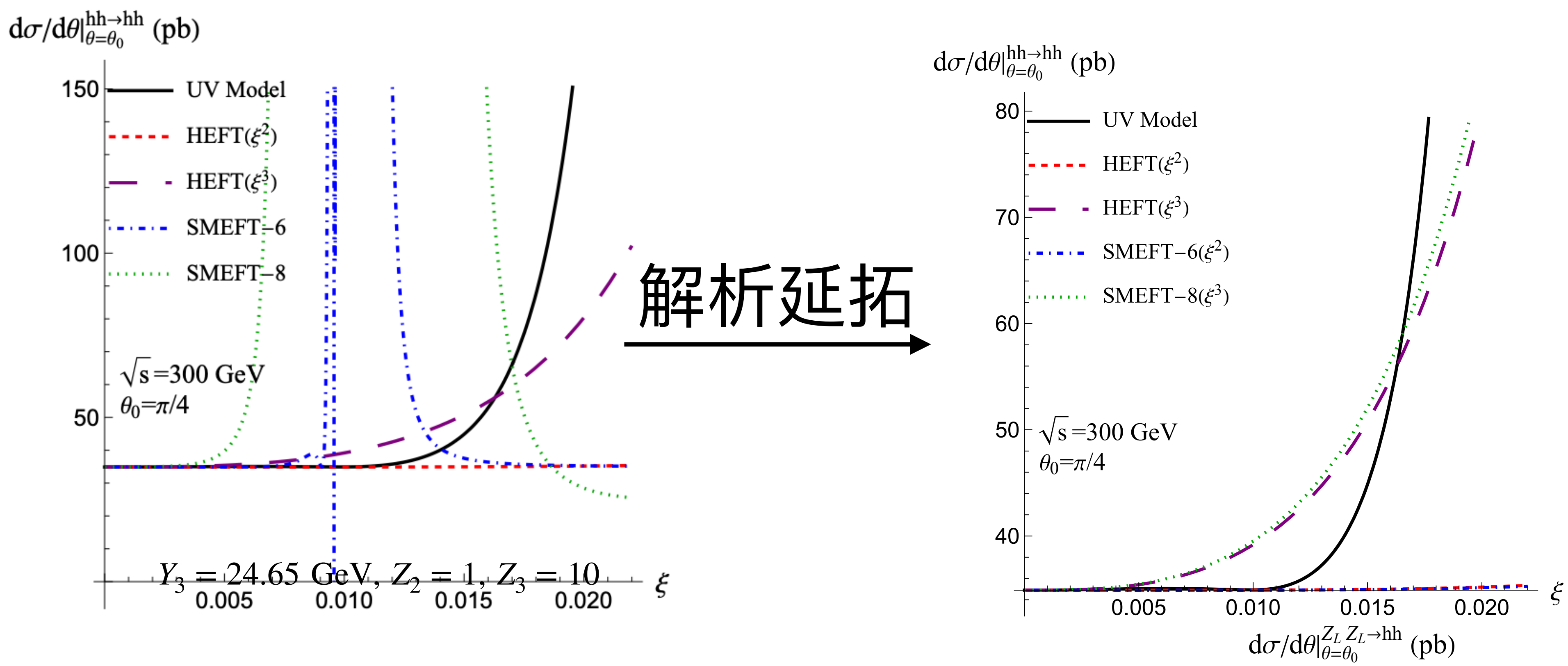
- HEFT包含SMEFT，描述更多真空自发对称性破缺机制. 我和合作者构建了UV模型的非线性框架，适用于一般标量场扩展模型与HEFT的匹配。

- SMEFT可以跑动到LEFT. LEFT应用于GeV能区探索新物理，并与TeV能区实验开展联合研究。

Thank you for your attention!

Backups

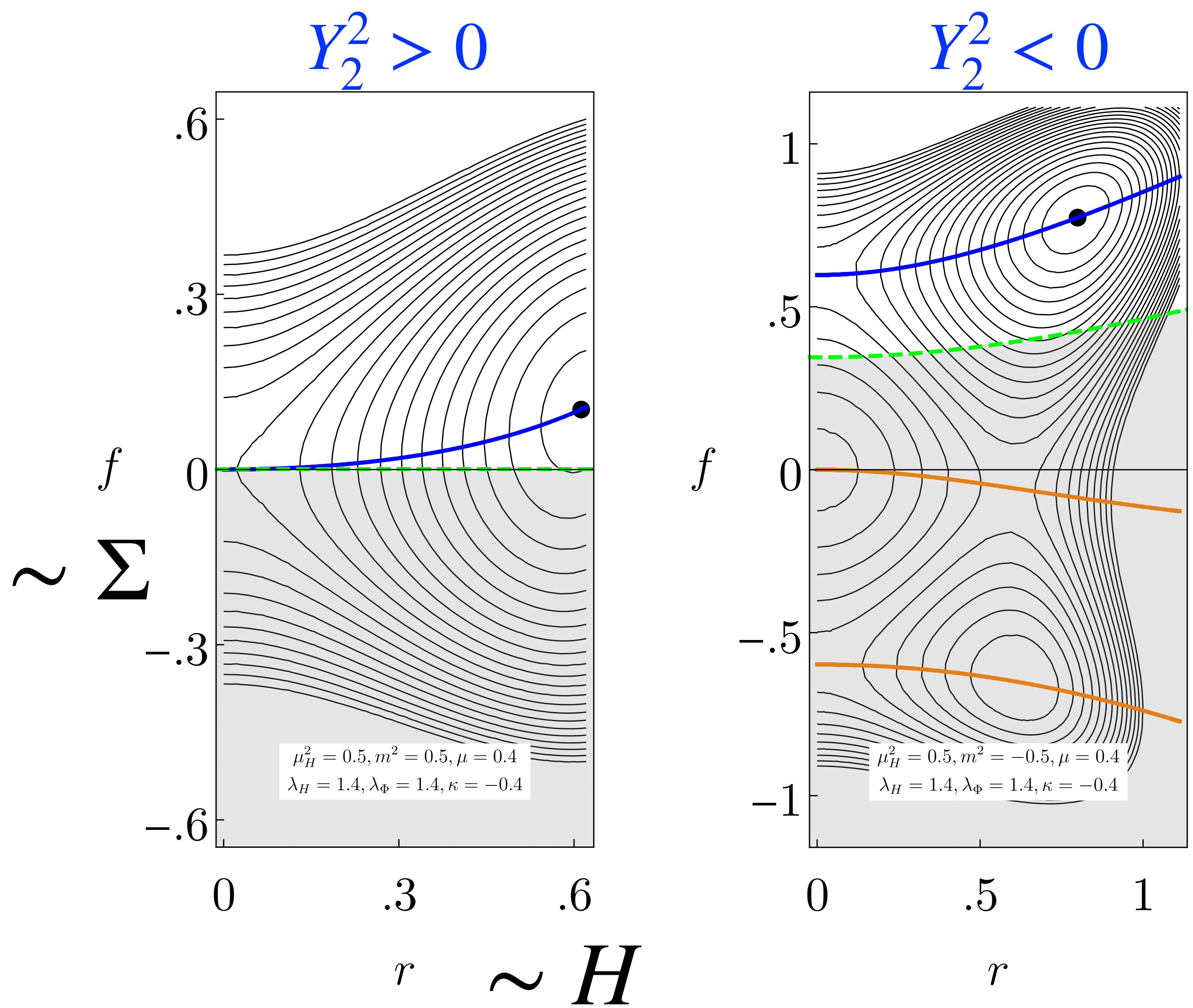
SMEFT Vs. HEFT



对于退耦合的HEFT，SMEFT适用的参数空间与其一致。

非退耦的HEFT才能探索到模型其它的参数空间

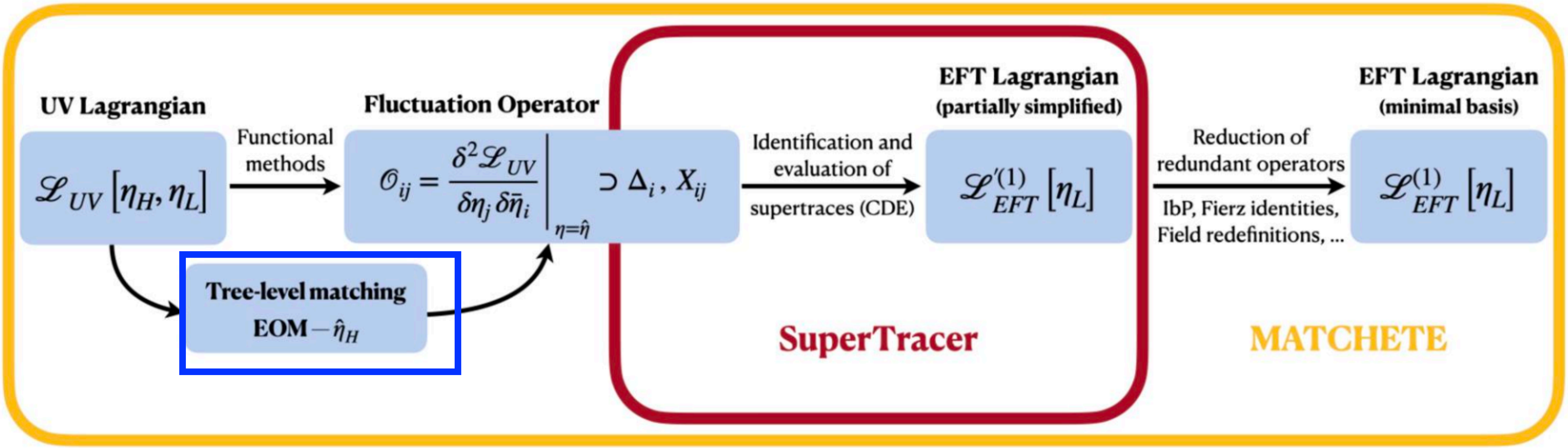
While $Y_2^2 < 0$ (A Geometrical View)



T. Cohen, Nathaniel Craig, Xiaochuan Lu, Dave Sutherland 2008.08597

$Y_2^2 \leq 0$ represents there exists another source of spontaneously symmetry breaking, which cause the breakdown of SMEFT. Only HEFT works.

SMEFT matching procedure (Covariant Derivative Expansion)



How to use the Standard Model effective field theory, Brian Henning, Xiaochuan Lu, and Hitoshi Murayama, 1412.1837

The Universal One-Loop Effective Action, Aleksandra Drozd, John Ellis, J´er´emi Quevillon and Tevong You, 1512.03003

STrEAMlining EFT Matching, Timothy Cohen,[1] Xiaochuan Lu,[1] and Zhengkang Zhang, 2012.07851

From the EFT to the UV: the complete SMEFT one-loop dictionary

Guilherme Guedes, Pablo Olgoso, 2412.14253

Linear Standard Model extensions in the SMEFT at one loop and Tera-Z,

John Gargalionis, Jérémie Quevillon, Pham Ngoc Hoa Vuong, Tevong You, 2412.01759

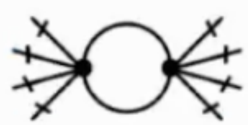
Effective field theory

A linear form under canonical dimension.

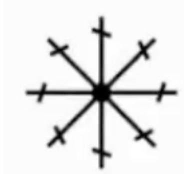
$$\mathscr{L}_{\mathrm{EFT}} = \mathscr{O}(\Lambda^0) + \frac{E}{\Lambda}\mathscr{O}_1 + \left(\frac{E}{\Lambda}\right)^2 \mathscr{O}_2 + \ldots$$

- At each order in E/Λ, all terms consistent with the symmetries are included.
- Renormalizable order by order, higher order become less relevant.

$$\frac{C_H}{\Lambda^2}(H^\dagger H)^3$$



$$\sim \frac{1}{M^4}\int \frac{d^4k}{(2\pi)^4}\frac{1}{k^4} \sim \frac{1}{16\pi^2 M^4}\ln\Lambda.$$



A non-linear form under chiral dimension. E.g. ChPT.

$$SU(N_f)_L \times SU(N_f)_R \longrightarrow SU(N_f)_V$$

$$U(x) = \exp\left(\frac{i\phi(x)}{F}\right), \quad \phi = \sum_a \pi^a \lambda^a$$

$\mathrm{Tr}[\partial_\mu U^\dagger \partial^\mu U]$ 树图 $\left[\mathrm{Tr}(\partial_\mu U^\dagger \partial^\mu U)\right]^2$ 1-loop图

$$\mathcal{L}_{\mathrm{ChPT}} = \mathcal{L}_2 + \mathcal{L}_4 + \mathcal{L}_6 + \cdots$$