An EFT Compendium for Discoveries

Joydeep Chakrabortty
IIT Kanpur, India

Higgs and Effective Field Theory - HEFT 2021

15 April 2021

Talk is based on:

1. **EFT Diagrammatica: UV Roots of the CP-conserving SMEFT**
   Supratim Das Bakshi, Joydeep Chakrabortty, Suraj Prakash, Michael Spannowsky, Shakeel Ur Rahaman.
   arXiv:2103.11593 [hep-ph].

2. **Classifying Standard Model Extensions Effectively with Precision Observables**
   Supratim Das Bakshi, Joydeep Chakrabortty, Michael Spannowsky
   arXiv:2012.03839 [hep-ph]. Phys.Rev. D103 (2021) no.5, 056019.

3. **CoDEx: Wilson coefficient calculator connecting SMEFT to UV theory**
   Supratim Das Bakshi, Joydeep Chakrabortty, Sunando Kumar Patra
   arXiv:1808.04403 [hep-ph]. Eur.Phys.J. C79 (2019) no.1, 21.

4. **A Step Toward Model Comparison: Connecting Electroweak-Scale Observables to BSM through EFT and Bayesian Statistics**
   Anisha, Supratim Das Bakshi, Joydeep Chakrabortty, Sunando Kumar Patra
   arXiv:2010.04088 [hep-ph].

5. **Effective Operator Bases for Beyond Standard Model Scenarios: An EFT compendium for discoveries**
   Upalaparna Banerjee, Joydeep Chakrabortty, Suraj Prakash, Shakeel Ur Rahaman, Michael Spannowsky.
   arXiv:2008.11512 [hep-ph]. JHEP 2101 (2021) 028.

Points to note...

- Bottom-Up vs Top-Down
- BSMs as Effective Theories
- Observables (set of operators) as “Response Screen”
- Classifications of BSMs
- Future directions: Relying on the presence of new particle(s)
- Operator driven BSM construction: Reverse engineering

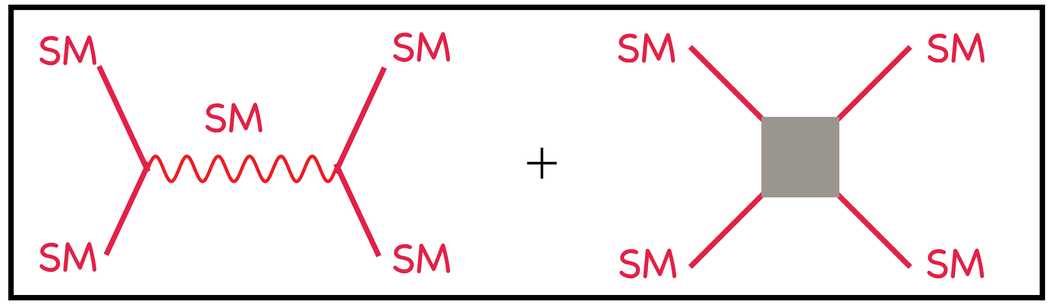
Bottom-Up approach: *SMEFT*

★ **Knowledge of exact nature of new physics is not required**

✤ **Wilson coefficients are free parameters: *origin-less***

$$\mathcal{L}_{\rm SM} + \sum_{j=5,\ldots} \sum_{i} \frac{C_i^{(j)}}{\Lambda^{j-4}} Q_i^{(j)}$$

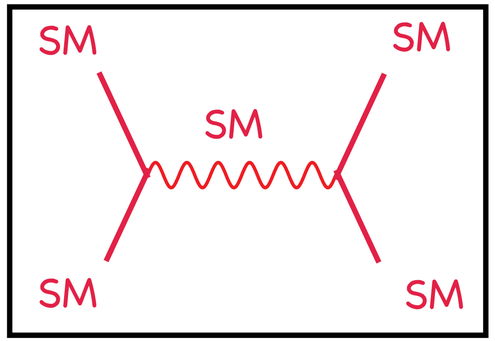
Effective operators



Effective operators

SMEFT

$\mathcal{L}_{\rm SM}$

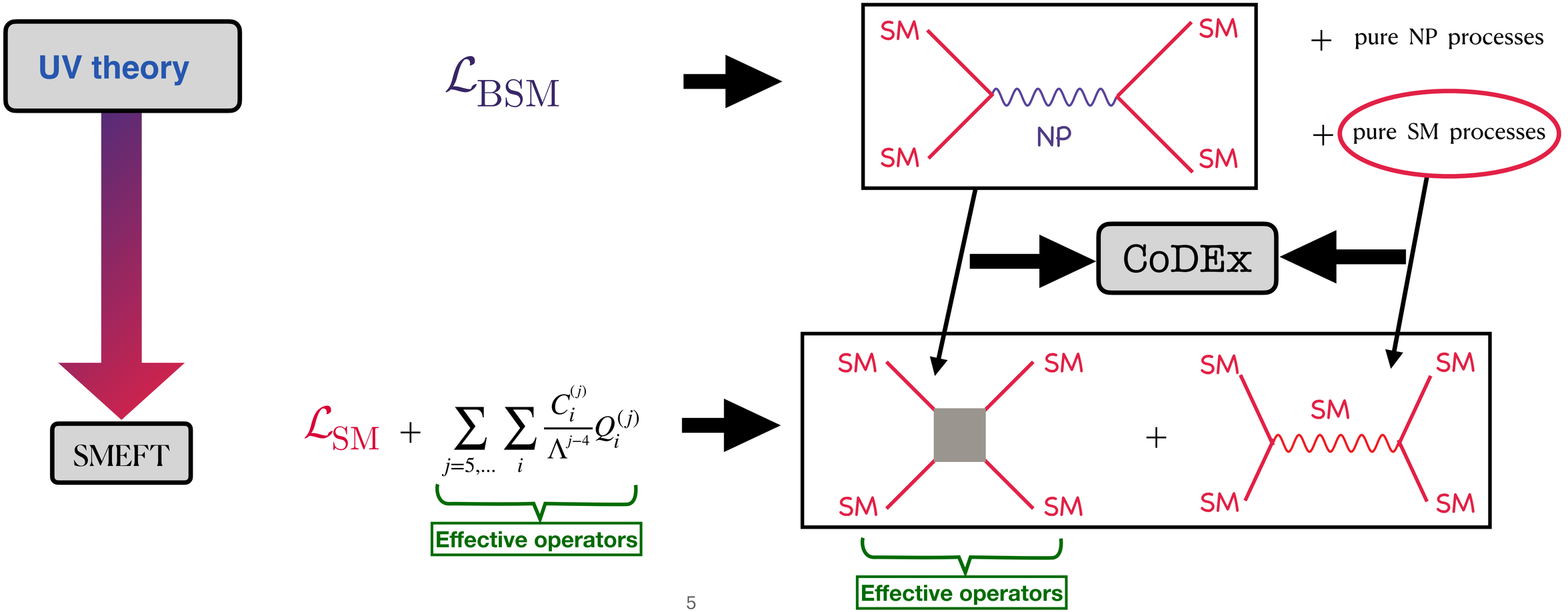


Low Energy Theory

Top-Down approach: *SMEFT*

★ **The Wilson coefficients known in terms of BSM parameters**

✤ **The UV complete Lagrangian must be known**



CoDEx : Wilson coefficient calculator

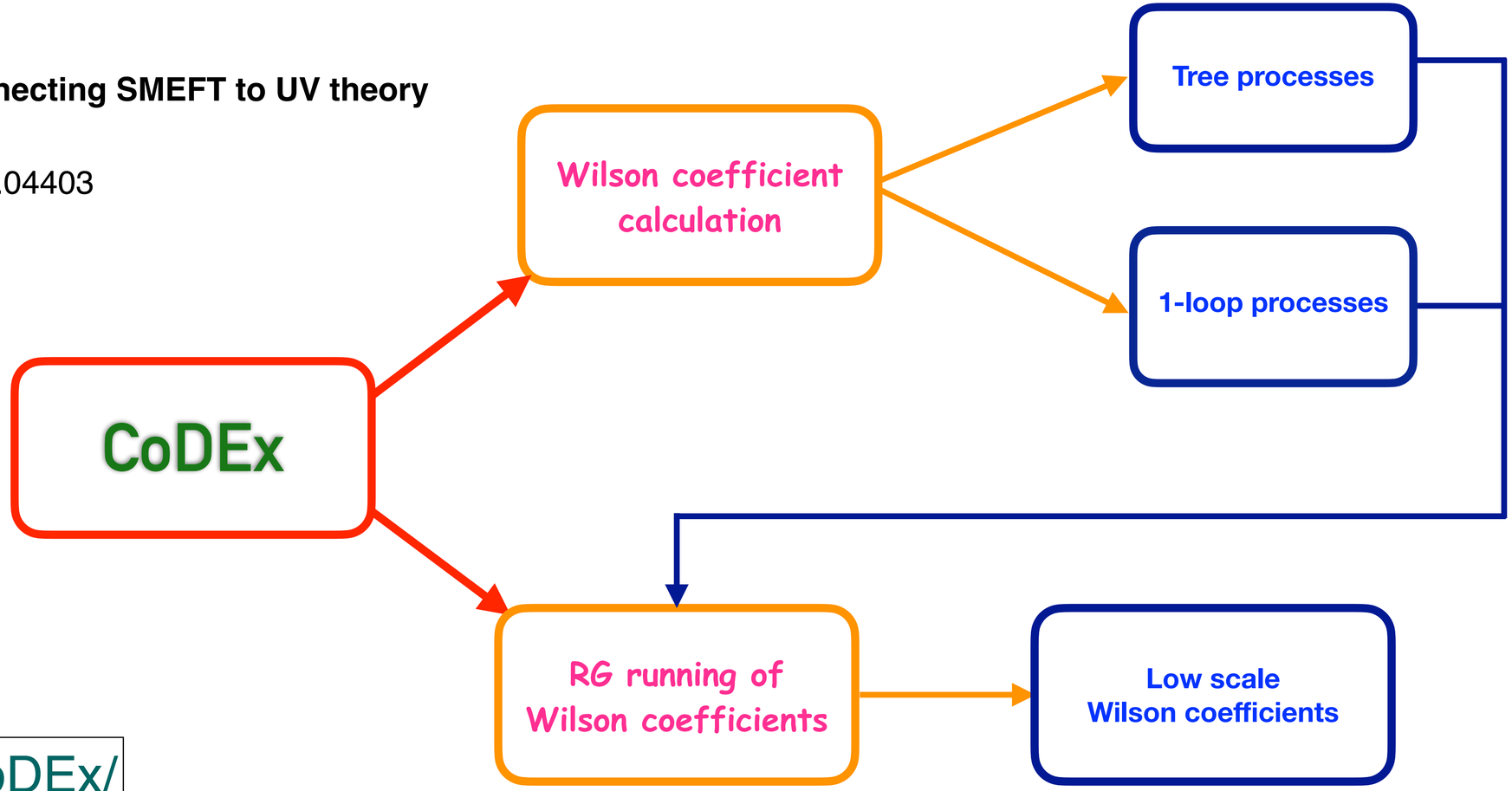
Complete 1-loop Wilson coefficients within seconds !

Manually matching BSMs to SMEFT is involved.

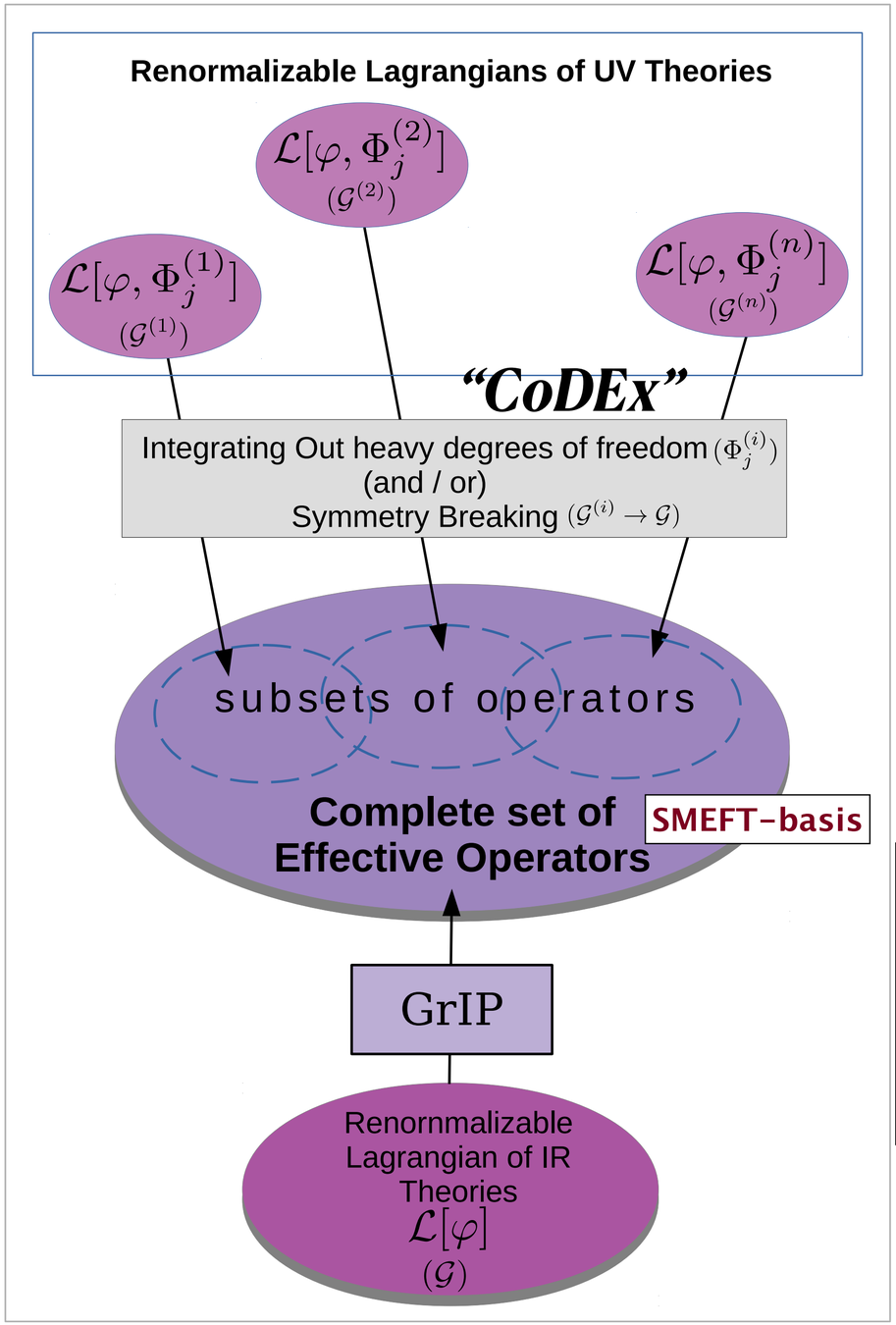
Package for automization is much needed.

CoDEx: Wilson coefficient calculator connecting SMEFT to UV theory

Supratim Das Bakshi, JC, S K Patra
Eur.Phys.J.C 79 (2019) 1, 21 • e-Print: 1808.04403



https://effexteam.github.io/CoDEx/



CoDEx: Wilson coefficient calculator connecting SMEFT to UV theory

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Eur.Phys.J.C 79 (2019) 1, 21 ; e-Print: 1808.04403 [hep-ph]

Available at: https://effexteam.github.io/CoDEx/

With "***CoDEx***" and "***GrIP***" in arsenal one can use effective field theory to connect **UV** and **IR** theories very easily and of course automatically.

Characters and Group Invariant Polynomials of (Super)fields: Road to "Lagrangian"

Upalaparna Banerjee, Joydeep Chakrabortty, Suraj Prakash, Shakeel Ur Rahaman

Eur.Phys.J.C 80 (2020) 10, 938; e-print: 2004.12830[hep-ph]

Available at: https://teamgrip.github.io/GrIP/

Observable-Operator correspondance

EWPO-LO : $\{Q_{HD}, Q_{HWB}, Q_{Hq}^{(1)}, Q_{Hq}^{(3)}, Q_{Hl}^{(1)}, Q_{Hl}^{(3)}, Q_{He}, Q_{Hu}, Q_{Hd}, Q_{ll}\}$

EWPO-NLO-I : $\{Q_{HB}, Q_{HW}, Q_{H\Box}\}$

Higgs Signal Strength (HSS) : EWPO-LO + EWPO-NLO-I + $\{Q_H, Q_{uH}, Q_{dH}, Q_{eH}, Q_G, Q_{HG}\}$

EWPO-NLO-II : $\{Q_{ed}, Q_{ee}, Q_{eu}, Q_{lu}, Q_{ld}, Q_{le}, Q_{lq}^{(1)}, Q_{lq}^{(3)}, Q_{qe}, Q_{uB}, Q_{uW}, Q_W, Q_{qd}^{(1)}, Q_{qq}^{(1)}, Q_{qq}^{(3)}, Q_{qu}^{(1)}, Q_{ud}^{(1)}, Q_{uu}, Q_{dd}\}$

Additional Operators (AdOps) : $\{Q_{ud}^{(8)}, Q_{qd}^{(8)}, Q_{qu}^{(8)}, Q_{quqd}^{(1)}, Q_{lequ}^{(1)}, Q_{quqd}^{(8)}, Q_{ledq}\}$

B,L volating Operators (BLV) : $\{Q_{qqq}, Q_{duu}, Q_{qqu}, Q_{duq}\}$

S Dawson, P P Giardino

arXiv:1909.02000

B Grzadkowski, M Iskrzynski, M Misiak, J Rosiek

arXiv:1008.4884

J Ellis, C Murphy, V Sanz, T You

arXiv:1803.03252

BSM Classifications

SM
+
Heavy Scalars

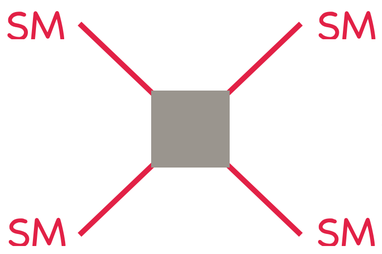
BSMs	$\mathcal{S}$	$\mathcal{S}_2$	Δ	$\mathcal{H}_2$	Δ_1	Σ
$\mathcal{G}_{3,2,1}$	1,1,0	1,1,2	1,3,0	1,2,-1/2	1,3,1	1,4,1/2

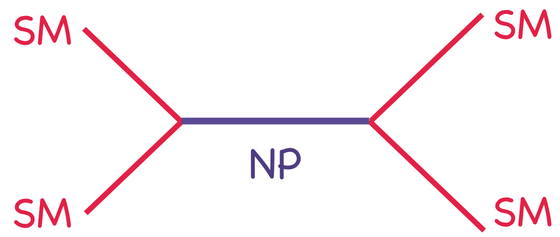
Color-singlets

BSMs	φ_1	φ_2	Θ_1	Θ_2	Ω	χ_1	χ_2	χ_3	χ_4
$\mathcal{G}_{3,2,1}$	3,1,-1/3	3,1,-4/3	3,2,1/6	3,2,7/6	3,3,-1/3	6,3,1/3	6,1,4/3	6,1,-2/3	6,1,1/3

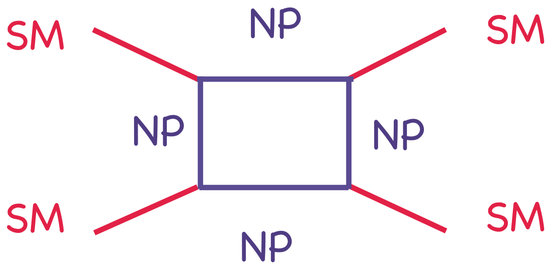
Colored

Unfurling the Effective Vertex

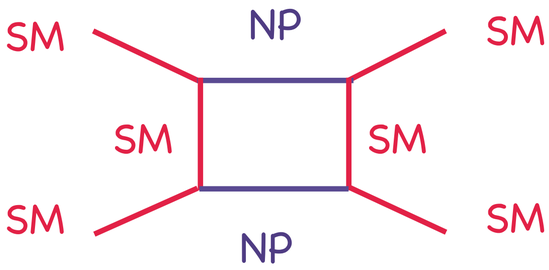




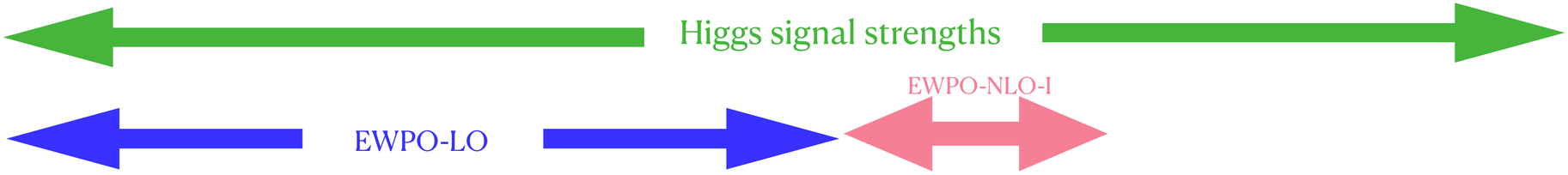
T — Tree-level effective operators



HH — Only heavy field propagator in the loop



HL — Both heavy and light field propagators in the loop



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Heavy BSM fields	$\mathcal{G}_{3,2,1}$	Q_{HD}	Q_{ll}	Q_{Hu}	Q_{Hd}	Q_{He}	$Q_{Hq}^{(1)}$	$Q_{Hl}^{(1)}$	$Q_{Hl}^{(3)}$	$Q_{Hq}^{(3)}$	Q_{HWB}	$Q_{H\Box}$	Q_{HB}	Q_{HW}	Q_{H}	Q_{G}	Q_{HG}	Q_{eH}	Q_{uH}	Q_{dH}
$\mathcal{S}$	(1,1,0)	HL	✗	✗	✗	✗	✗	✗	✗	✗	HL	T	HL	HL	T	✗	✗	HL	HL	HL
$\mathcal{S}_2$	(1,1,2)	HH	HH	HH	HH	HH	HH	HH	✗	✗	✗	HH	HH	✗	HH	✗	✗	✗	✗	✗
Δ	(1,3,0)	T	HH	✗	✗	✗	✗	✗	HH	HH	HL	T	HL	HH	T	✗	✗	T	T	T
$\mathcal{H}_2$	$(1,2,-\frac{1}{2})$	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	T	✗	✗	T	T	T
Δ_1	(1,3,1)	T	T	HH	HH	HH	HH	HH	HH	HH	HH	T	HH	HH	T	✗	✗	T	T	T
Σ	$(1,4,\frac{1}{2})$	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	✗	✗	HH	HH	HH
φ_1	$(3,1,-\frac{1}{3})$	HH	HH	HH	HH	HH	HH	HH	✗	✗	✗	HH	HH	✗	HH	HH	HH	✗	✗	✗
φ_2	$(3,1,-\frac{4}{3})$	HH	HH	HH	HH	HH	HH	HH	✗	✗	✗	HH	HH	✗	HH	HH	HH	✗	✗	✗
Θ_1	$(3,2,\frac{1}{6})$	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH
Θ_2	$(3,2,\frac{7}{6})$	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH
Ω	$(3,3,\text{-}\frac{1}{3})$	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH
χ_1	$(6,3,\frac{1}{3})$	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH
χ_2	$(6,1,\frac{4}{3})$	HH	HH	HH	HH	HH	HH	HH	✗	✗	✗	HH	HH	✗	HH	HH	HH	✗	✗	✗
χ_3	$(6,1,\text{-}\frac{2}{3})$	HH	HH	HH	HH	HH	HH	HH	✗	✗	✗	HH	HH	✗	HH	HH	HH	✗	✗	✗
χ_4	$(6,1,\frac{1}{3})$	HH	HH	HH	HH	HH	HH	HH	✗	✗	✗	HH	HH	✗	HH	HH	HH	✗	✗	✗

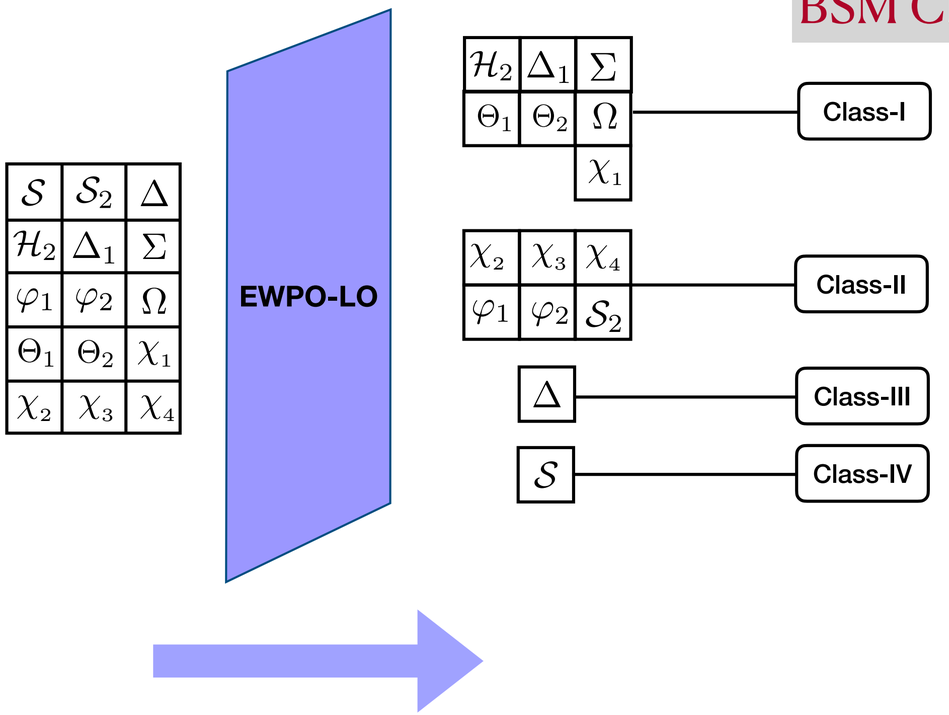
EWPO-NLO-II

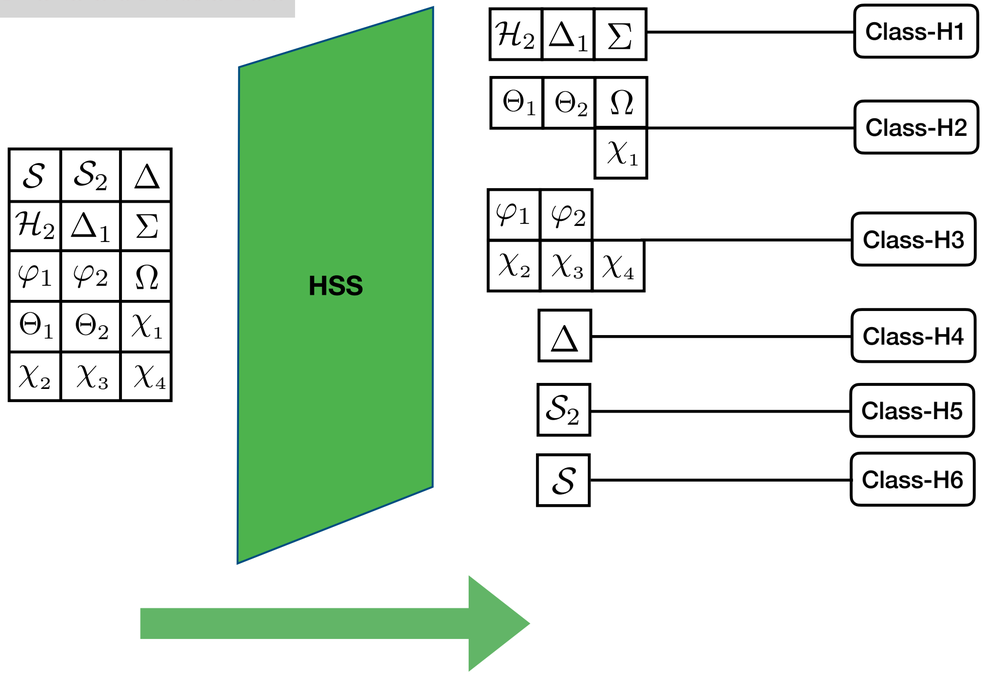
AdOps

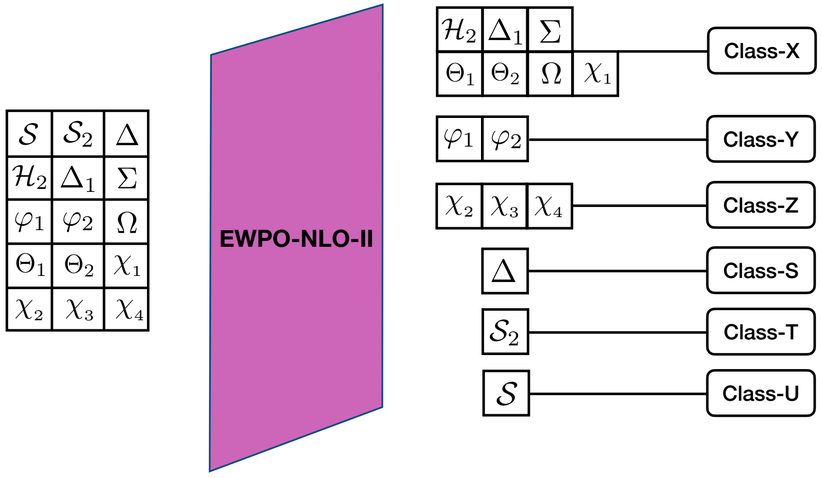
BLV

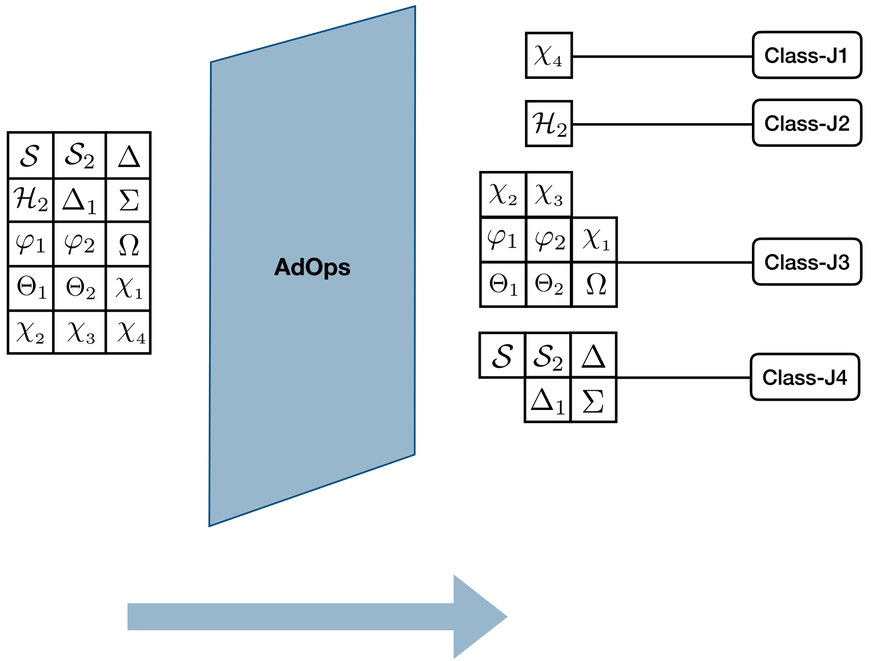
	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
Heavy BSM fields	$Q_{qq}^{(1)}$	$Q_{qq}^{(3)}$	Q_{uu}	Q_{dd}	$Q_{ud}^{(1)}$	$Q_{lq}^{(1)}$	Q_{ee}	Q_{eu}	Q_{ed}	Q_{le}	Q_{lu}	Q_{ld}	Q_{qe}	$Q_{qu}^{(1)}$	$Q_{qd}^{(1)}$	$Q_{lq}^{(3)}$	Q_W	$Q_{ud}^{(8)}$	$Q_{qd}^{(8)}$	$Q_{qu}^{(8)}$	$Q_{quqd}^{(1)}$	$Q_{lequ}^{(1)}$	$Q_{quqd}^{(8)}$	Q_{ledq}	Q_{qqq}	Q_{duu}	Q_{qqu}	Q_{duq}
$\mathcal{S}$	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
$\mathcal{S}_2$	HH	✗	HH	HH	HH	HH	T	HH	HH	HH	HH	HH	HH	HH	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Δ	✗	HH	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	HH	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
$\mathcal{H}_2$	HH	HH	HH	HH	HH	HH	HH	HH	HH	T	HH	HH	HH	T	T	HH	HH	✗	✗	✗	T	T	✗	T	✗	✗	✗	✗
Δ_1	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Σ	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
φ_1	HH	HH	HH	HH	HH	HH	HH	T	HH	HH	HH	HH	HH	HH	HH	T	✗	HH	HH	HH	✗	✗	✗	✗	T	T	T	T
φ_2	HH	HH	HH	HH	HH	HH	HH	HH	T	HH	HH	HH	HH	HH	HH	HH	✗	HH	HH	HH	✗	✗	✗	✗	✗	T	✗	✗
Θ_1	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	T	HH	HH	HH	HH	HH	HH	HH	HH	✗	✗	✗	✗	✗	✗	✗	✗
Θ_2	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	T	HH	T	HH	HH	HH	HH	HH	HH	HH	✗	✗	✗	✗	✗	✗	✗	✗
Ω	HH	HH	HH	HH	HH	T	HH	HH	HH	HH	HH	HH	HH	HH	HH	T	HH	HH	HH	HH	✗	✗	✗	✗	T	✗	✗	✗
χ_1	T	T	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	✗	✗	✗	✗	✗	✗	✗	✗
χ_2	HH	HH	T	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	✗	✗	HH	HH	HH	✗	✗	✗	✗	✗	✗	✗	✗
χ_3	HH	HH	HH	T	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	✗	✗	HH	HH	HH	✗	✗	✗	✗	✗	✗	✗	✗
χ_4	T	T	HH	HH	T	HH	HH	HH	HH	HH	HH	HH	HH	HH	HH	✗	✗	T	HH	HH	T	✗	T	✗	✗	✗	✗	✗

BSM Classification based on Observables









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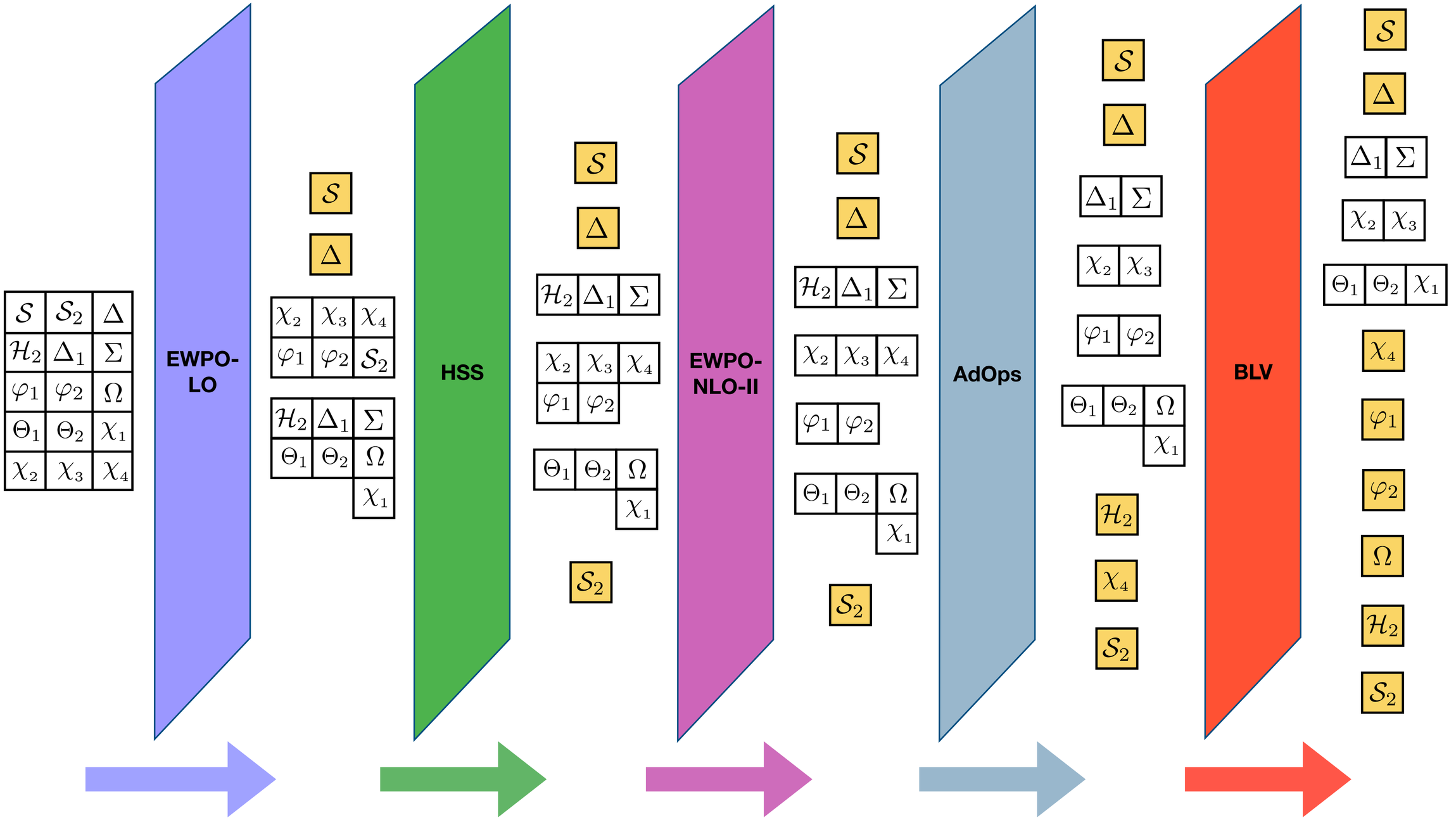
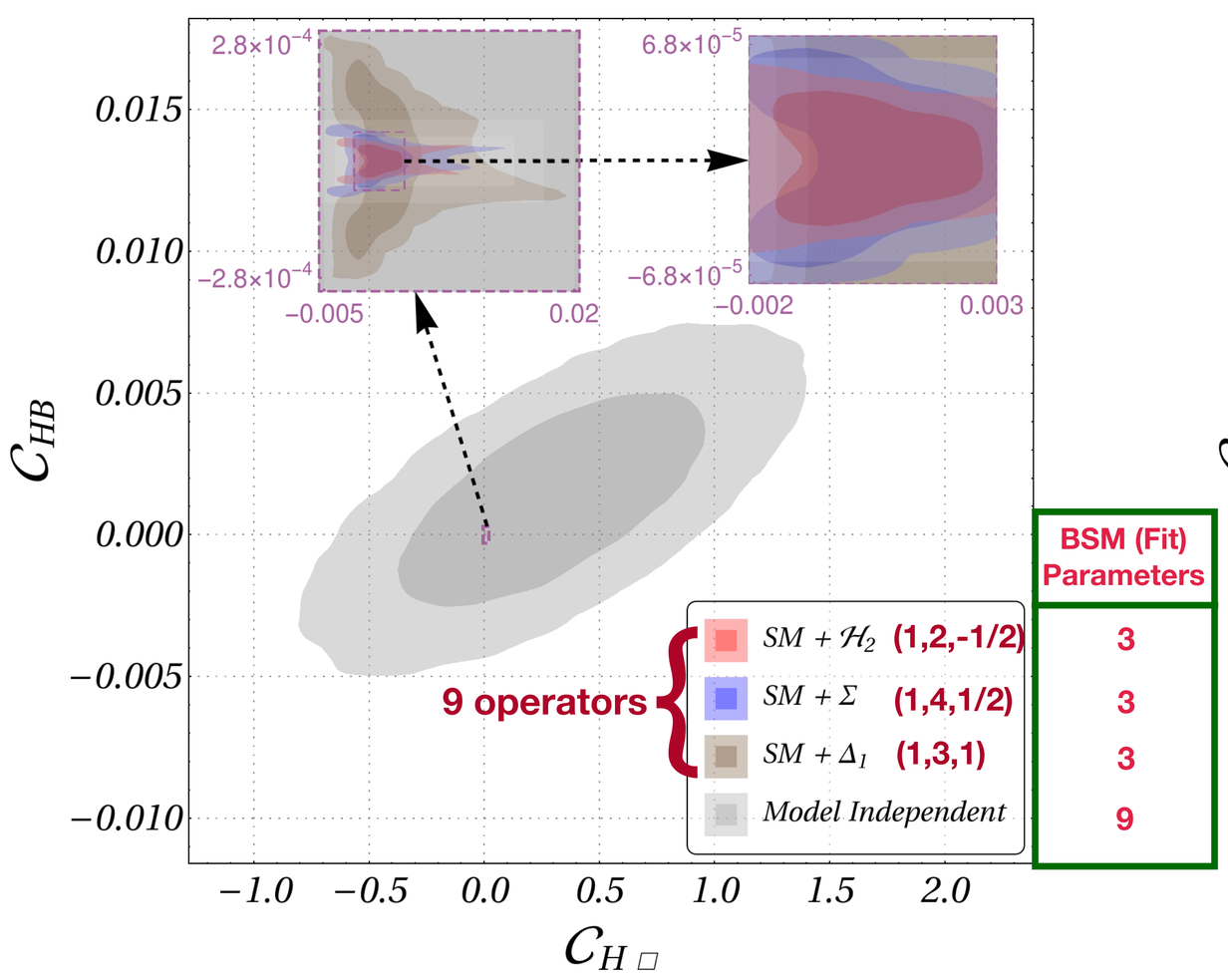


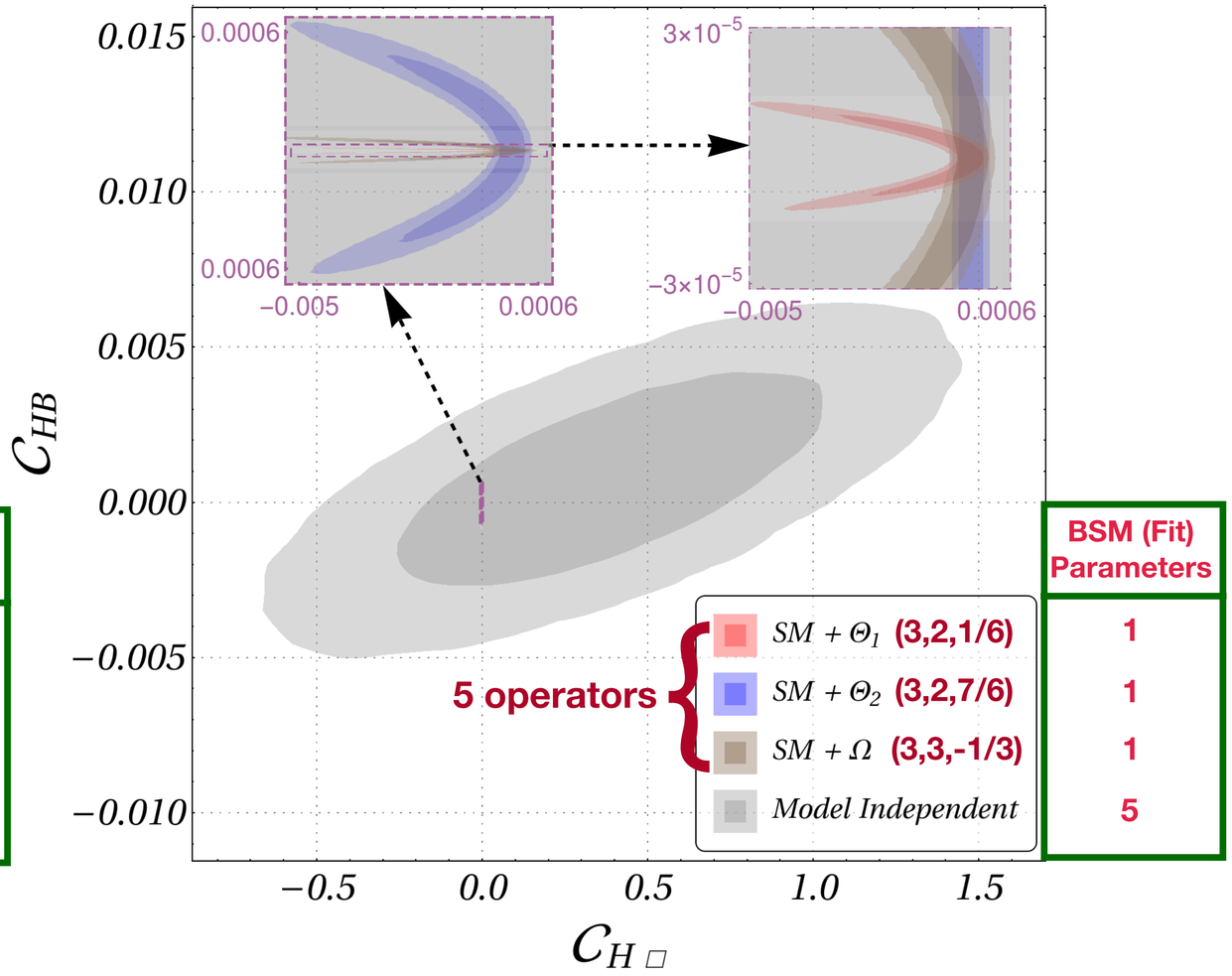
Tag match: {BSM$_i$} vs Bottom-Up

Anisha, S D Bakshi, JC, S K Patra

arXiv:2010.04088



BSM (Fit) Parameters
3
3
3
9



BSM (Fit) Parameters
1
1
1
5

❖ New particle and BSMEFT

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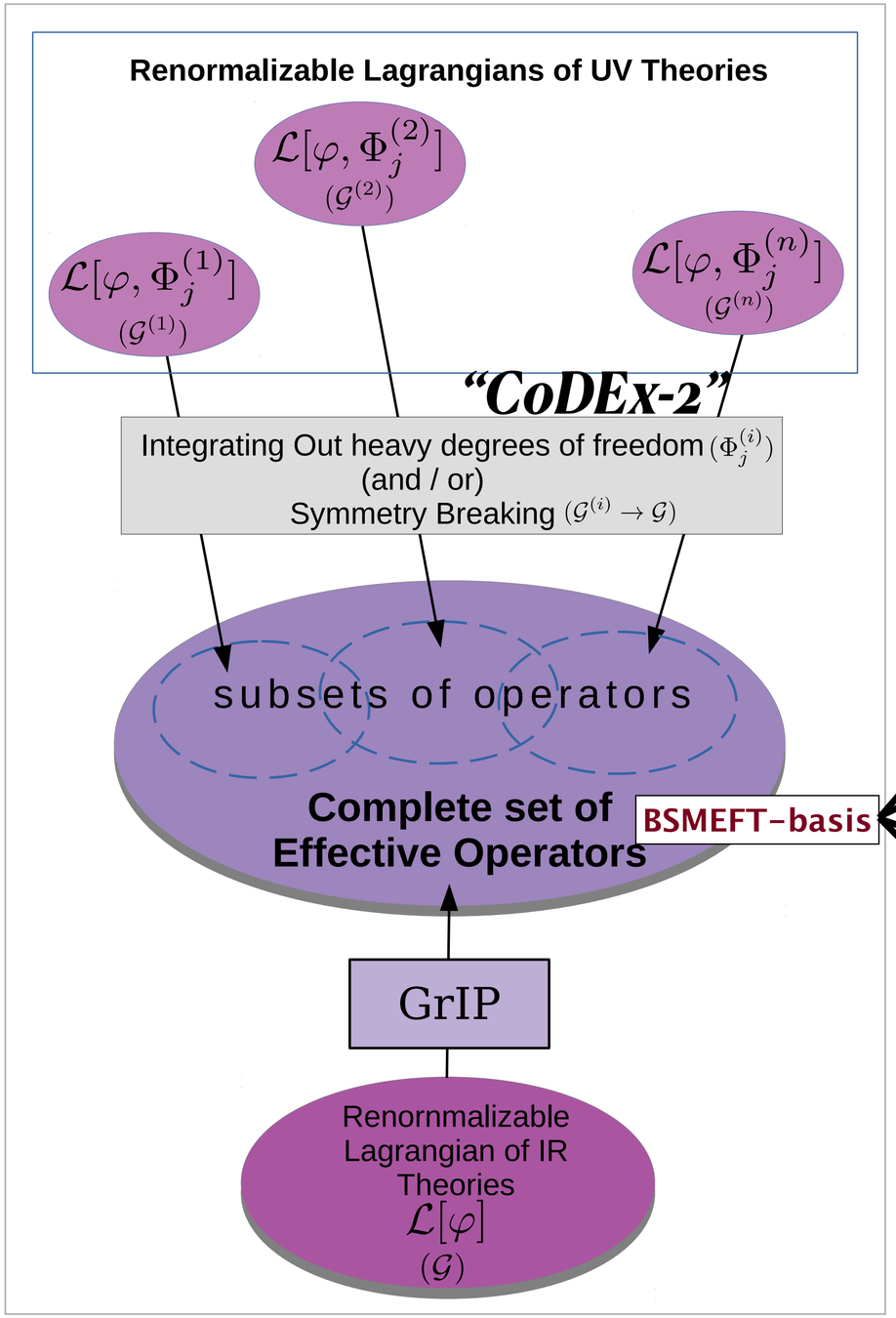


★ **SM extended by multiple heavy fields**

★ **Integrate-out heavy field according to spectrum hierarchy: CoDEx**

★ **BSMEFT for desired symmetry and particle content: GrIP**

SM + $\mathcal{S}_1$ (1,1,1)

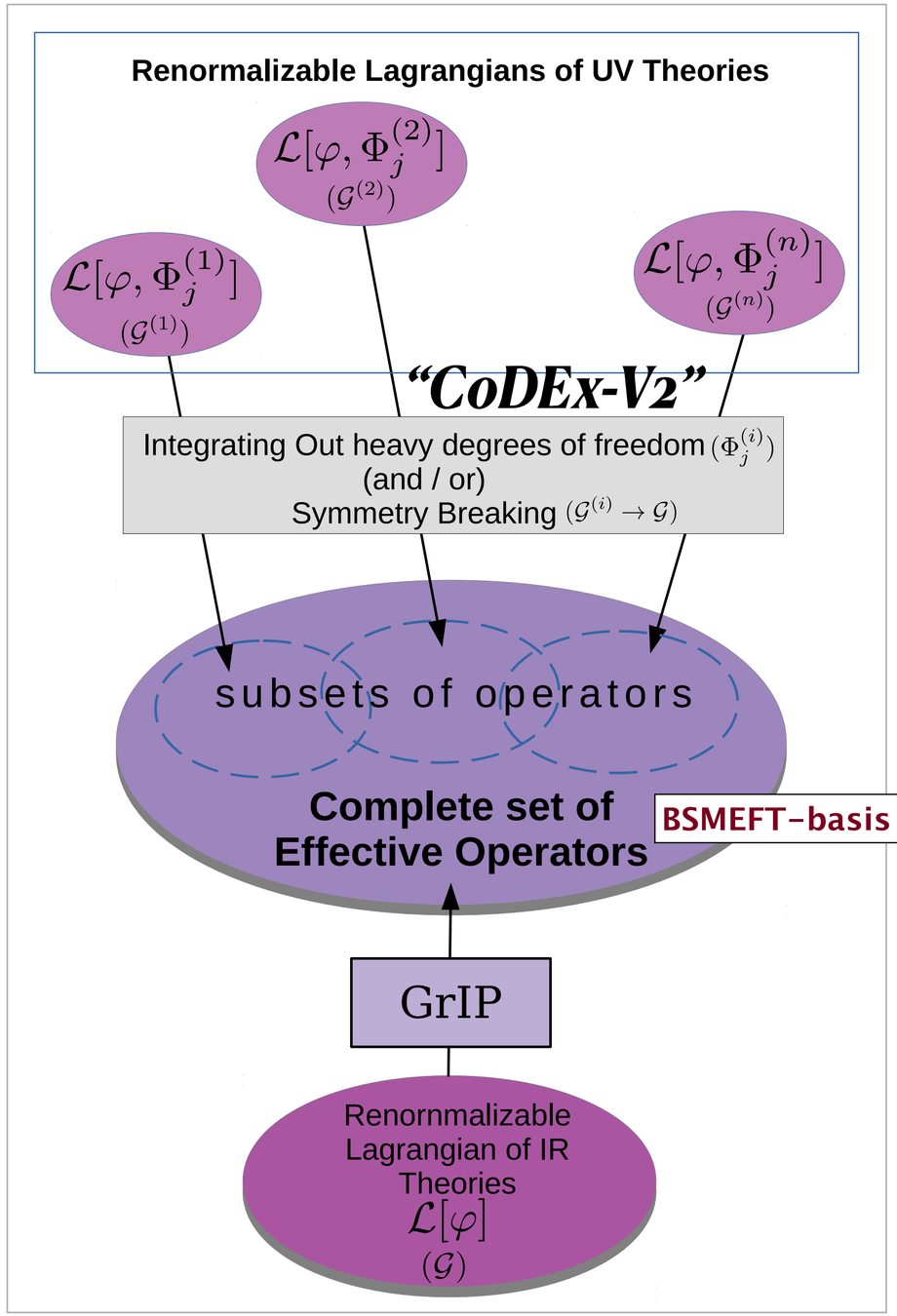
SM + $\mathcal{S}_2$ (1,1,2)

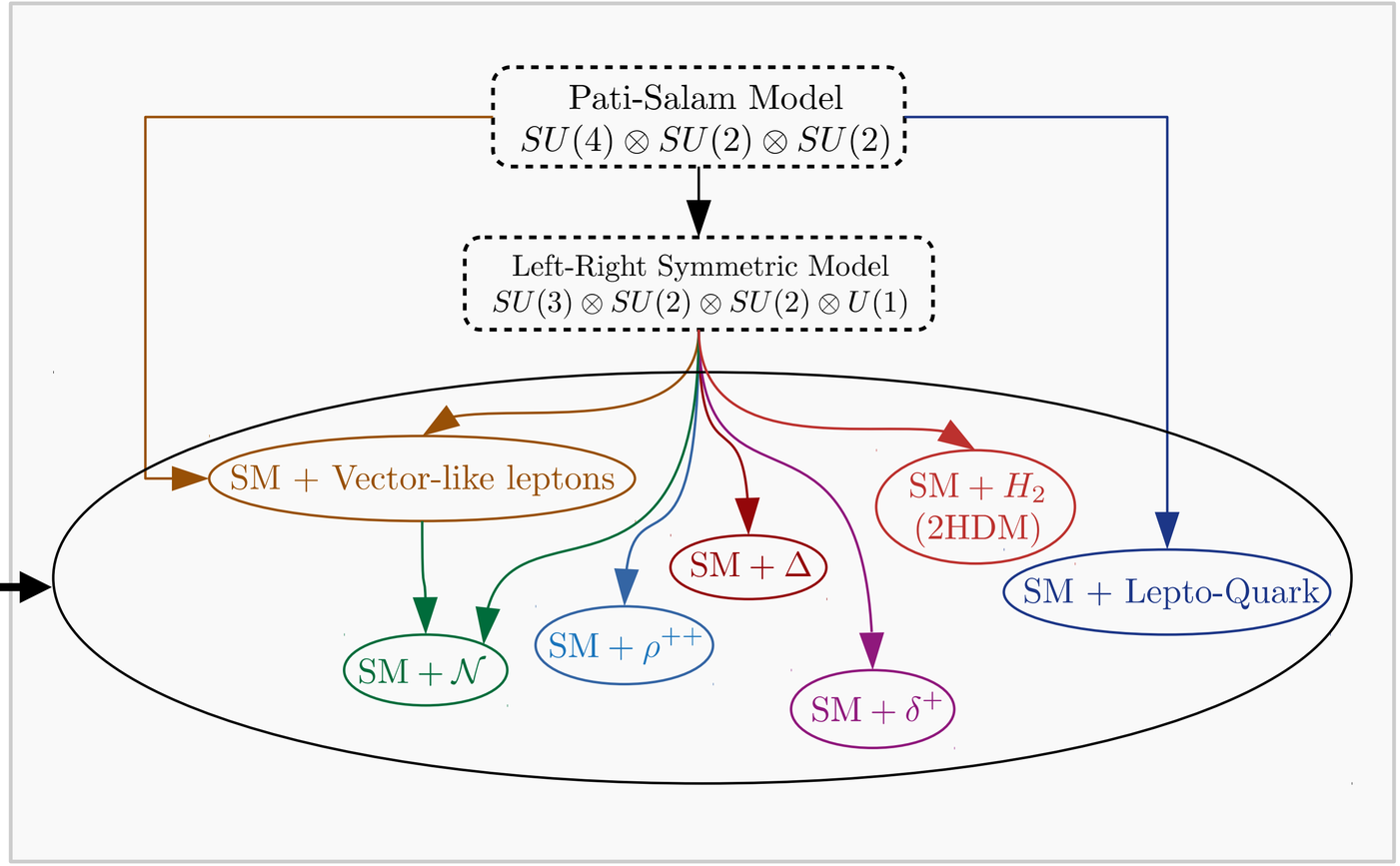
SM + $\mathcal{H}_2$ (1,2,-1/2)

SM + Δ (1,3,0)

U Banerjee, JC, S Prakash, S U Rahaman, M Spannowsky

JHEP 01 (2021) 028, arXiv:2008.11512





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U Banerjee, JC, S Prakash, S U Rahaman, M Spannowsky

❖ Operator driven Heavy Fields

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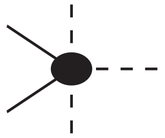
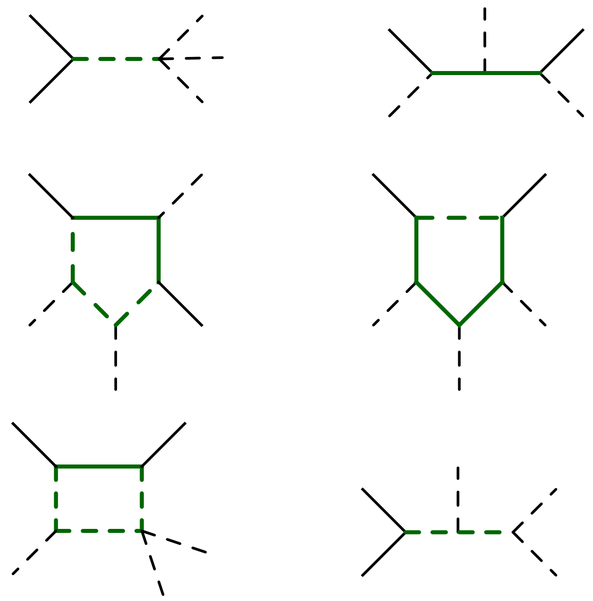
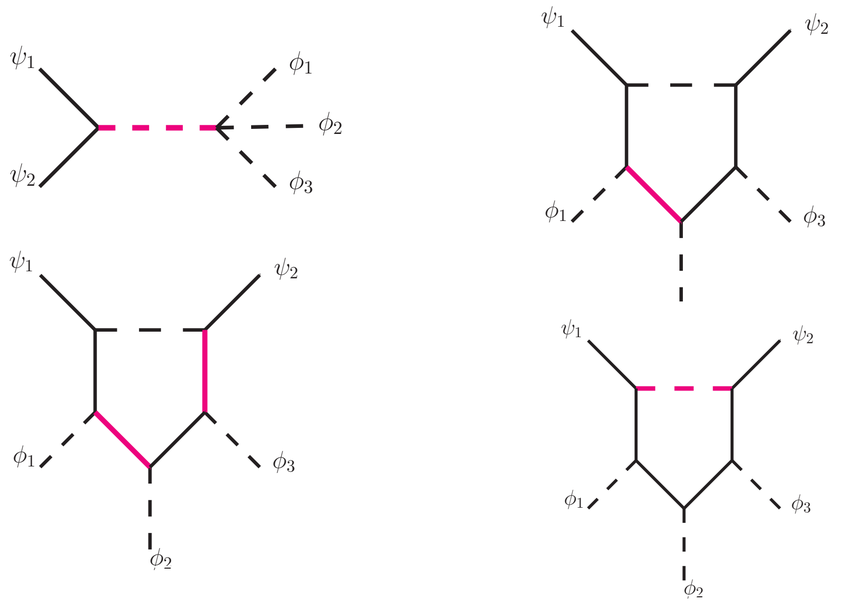
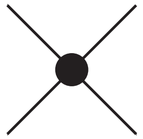
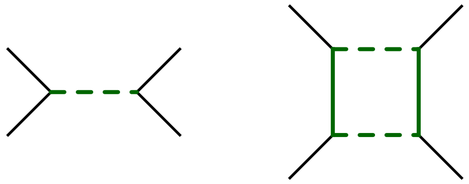
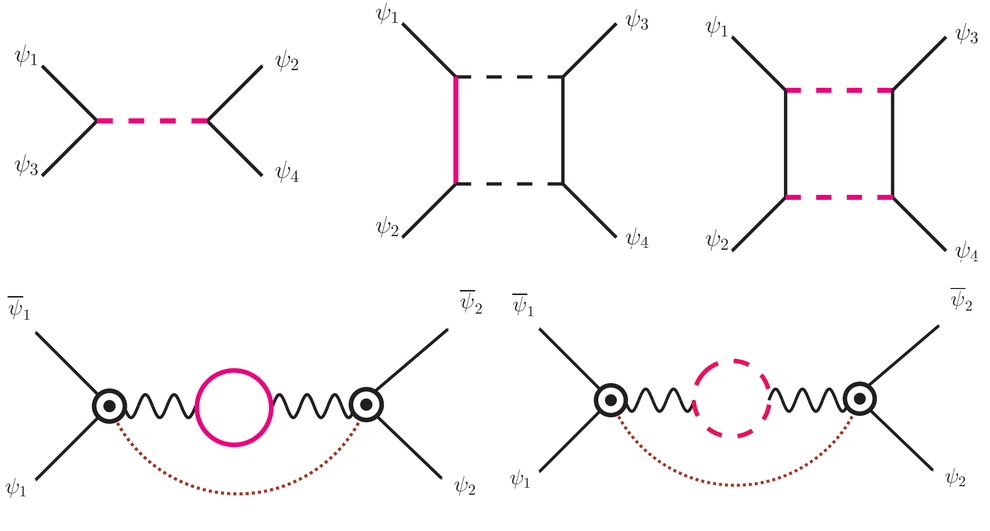
Supratim Das Bakshi, Joydeep Chakrabortty, Suraj Prakash, Michael Spannowsky, Shakeel Ur Rahaman.
arXiv:2103.11593 [hep-ph].

Effective Operator	Lorentz invariant structures	Single heavy field extensions of the SM	Operators & Heavy fields representations $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$
$\psi^2\phi^3$ 			Q_{eH} $\left[1,2,\frac{1}{2}\right]_{\Phi}$ $[1,1,0]_{\Psi}$ Q_{uH} $\left[3,1,-\frac{1}{3}\right]_{\Phi}\left[3,3,-\frac{1}{3}\right]_{\Psi}$ Q_{dH} $\left[6,1,\frac{1}{3}\right]_{\Phi}$ $\left[3,2,\frac{7}{6}\right]_{\Psi}$
ψ^4 			$Q_{qu}^{(1)}$ $\left[3,1,-\frac{1}{3}\right]_{\Phi}$ $\left[3,2,\frac{7}{6}\right]_{\Psi}$ Q_{le} $\left[3,2,\frac{7}{6}\right]_{\Phi}$ $\left[1,2,\frac{1}{2}\right]_{\Psi}$ Q_{ee} $[\{1,R_C\},\{1,R_L\},Y]_{\Phi,\Psi}$

❖ Take home messages

Aim: To pin down correct nature of UV theory

Complementarity of Bottom-Up and Top-Down approaches are important

Observables as sets of Effective Operators: Adjudging BSMs

Identification of Heavy Fields for individual SMEFT Operators: guide for model building

How to extend our existing knowledge if a new particle is discovered: BSMEFT