Recent results for dimension-eight SMEFT

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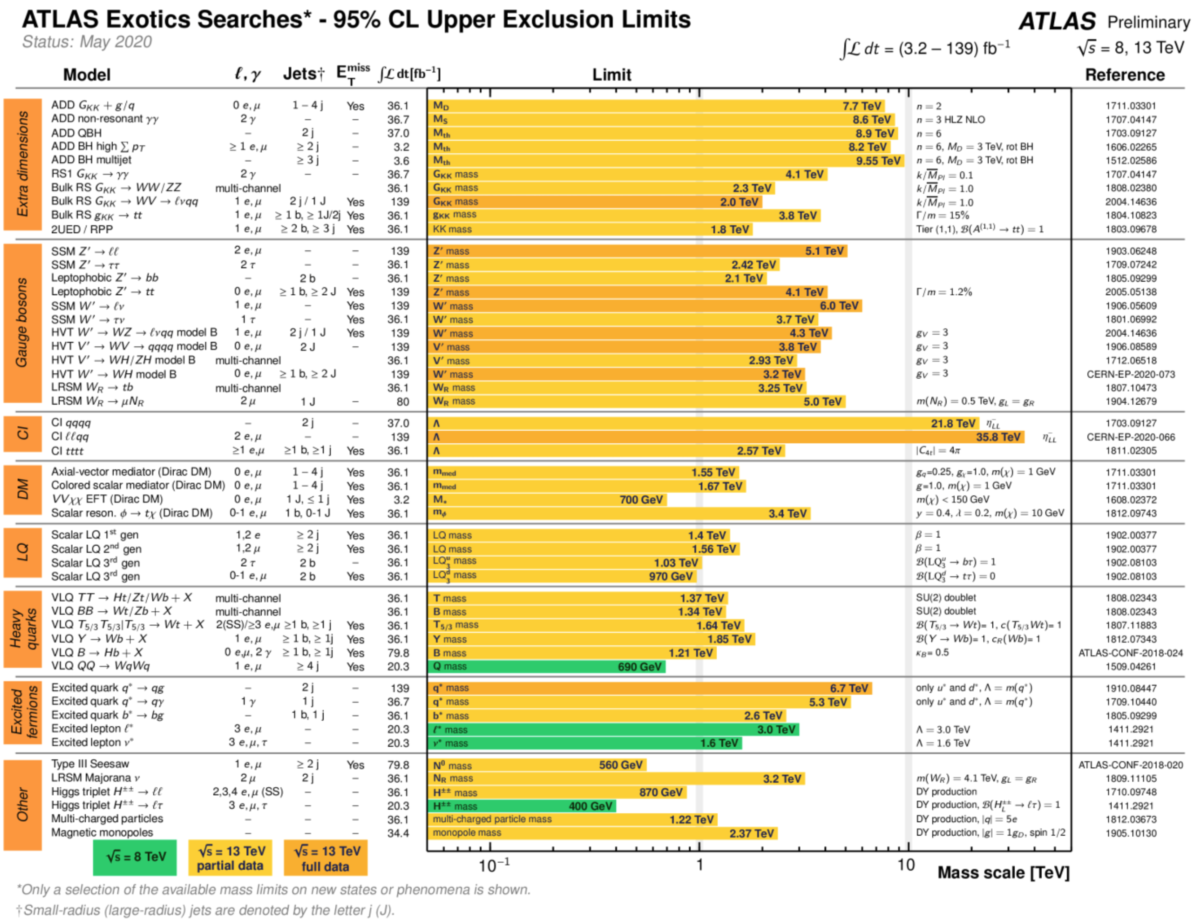

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits
Status: May 2020
ATLAS Preliminary
∫L dt = (3.2 – 139) fb⁻¹
√s = 8, 13 TeV
Model
ℓ, γ
Jets†
E_T^miss
∫L dt[fb⁻¹]
Limit
Reference
Extra dimensions
ADD G_KK + g/q 0 e, μ 1 – 4 j Yes 36.1 M_D 7.7 TeV n = 2 1711.03301
ADD non-resonant γγ 2 γ – – 36.7 M_S 8.6 TeV n = 3 HLZ NLO 1707.04147
ADD QBH – 2 j – 37.0 M_th 8.9 TeV n = 6 1703.09127
ADD BH high Σ p_T ≥ 1 e, μ ≥ 2 j – 3.2 M_th 8.2 TeV n = 6, M_D = 3 TeV, rot BH 1606.02265
ADD BH multijet – ≥ 3 j – 3.6 M_th 9.55 TeV n = 6, M_D = 3 TeV, rot BH 1512.02586
RS1 G_KK → γγ 2 γ – – 36.7 G_KK mass 4.1 TeV k/M̄_Pl = 0.1 1707.04147
Bulk RS G_KK → WW/ZZ multi-channel 36.1 G_KK mass 2.3 TeV k/M̄_Pl = 1.0 1808.02380
Bulk RS G_KK → WV → ℓνqq 1 e, μ 2 j / 1 J Yes 139 G_KK mass 2.0 TeV k/M̄_Pl = 1.0 2004.14636
Bulk RS g_KK → tt 1 e, μ ≥ 1 b, ≥ 1J/2j Yes 36.1 g_KK mass 3.8 TeV Γ/m = 15% 1804.10823
2UED / RPP 1 e, μ ≥ 2 b, ≥ 3 j Yes 36.1 KK mass 1.8 TeV Tier (1,1), B(A^(1,1) → tt) = 1 1803.09678
Gauge bosons
SSM Z′ → ℓℓ 2 e, μ – – 139 Z′ mass 5.1 TeV 1903.06248
SSM Z′ → ττ 2 τ – – 36.1 Z′ mass 2.42 TeV 1709.07242
Leptophobic Z′ → bb – 2 b – 36.1 Z′ mass 2.1 TeV 1805.09299
Leptophobic Z′ → tt 0 e, μ ≥ 1 b, ≥ 2 J Yes 139 Z′ mass 4.1 TeV Γ/m = 1.2% 2005.05138
SSM W′ → ℓν 1 e, μ – Yes 139 W′ mass 6.0 TeV 1906.05609
SSM W′ → τν 1 τ – Yes 36.1 W′ mass 3.7 TeV 1801.06992
HVT W′ → WZ → ℓνqq model B 1 e, μ 2 j / 1 J Yes 139 W′ mass 4.3 TeV g_V = 3 2004.14636
HVT V′ → WV → qqqq model B 0 e, μ 2 J – 139 V′ mass 3.8 TeV g_V = 3 1906.08589
HVT V′ → WH/ZH model B multi-channel 36.1 V′ mass 2.93 TeV g_V = 3 1712.06518
HVT W′ → WH model B 0 e, μ ≥ 1 b, ≥ 2 J 139 W′ mass 3.2 TeV g_V = 3 CERN-EP-2020-073
LRSM W_R → tb multi-channel 36.1 W_R mass 3.25 TeV 1807.10473
LRSM W_R → μN_R 2 μ 1 J – 80 W_R mass 5.0 TeV m(N_R) = 0.5 TeV, g_L = g_R 1904.12679
CI
CI qqqq – 2 j – 37.0 Λ 21.8 TeV η⁻_LL 1703.09127
CI ℓℓqq 2 e, μ – – 139 Λ 35.8 TeV η⁻_LL CERN-EP-2020-066
CI tttt ≥1 e, μ ≥1 b, ≥1 j Yes 36.1 Λ 2.57 TeV |C_4t| = 4π 1811.02305
DM
Axial-vector mediator (Dirac DM) 0 e, μ 1 – 4 j Yes 36.1 m_med 1.55 TeV g_q=0.25, g_χ=1.0, m(χ) = 1 GeV 1711.03301
Colored scalar mediator (Dirac DM) 0 e, μ 1 – 4 j Yes 36.1 m_med 1.67 TeV g=1.0, m(χ) = 1 GeV 1711.03301
VVχχ EFT (Dirac DM) 0 e, μ 1 J, ≤ 1 j Yes 3.2 M_* 700 GeV m(χ) < 150 GeV 1608.02372
Scalar reson. ϕ → tχ (Dirac DM) 0-1 e, μ 1 b, 0-1 J Yes 36.1 m_ϕ 3.4 TeV y = 0.4, λ = 0.2, m(χ) = 10 GeV 1812.09743
LQ
Scalar LQ 1st gen 1,2 e ≥ 2 j Yes 36.1 LQ mass 1.4 TeV β = 1 1902.00377
Scalar LQ 2nd gen 1,2 μ ≥ 2 j Yes 36.1 LQ mass 1.56 TeV β = 1 1902.00377
Scalar LQ 3rd gen 2 τ 2 b – 36.1 LQ₃ᵘ mass 1.03 TeV B(LQ₃ᵘ → bτ) = 1 1902.08103
Scalar LQ 3rd gen 0-1 e, μ 2 b Yes 36.1 LQ₃ᵈ mass 970 GeV B(LQ₃ᵈ → tτ) = 0 1902.08103
Heavy quarks
VLQ TT → Ht/Zt/Wb + X multi-channel 36.1 T mass 1.37 TeV SU(2) doublet 1808.02343
VLQ BB → Wt/Zb + X multi-channel 36.1 B mass 1.34 TeV SU(2) doublet 1808.02343
VLQ T_5/3 T_5/3 | T_5/3 → Wt + X 2(SS)/≥3 e, μ ≥1 b, ≥1 j Yes 36.1 T_5/3 mass 1.64 TeV B(T_5/3 → Wt)= 1, c(T_5/3 Wt)= 1 1807.11883
VLQ Y → Wb + X 1 e, μ ≥ 1 b, ≥ 1j Yes 36.1 Y mass 1.85 TeV B(Y → Wb)= 1, c_R(Wb)= 1 1812.07343
VLQ B → Hb + X 0 e, μ, 2 γ ≥ 1 b, ≥ 1j Yes 79.8 B mass 1.21 TeV κ_B= 0.5 ATLAS-CONF-2018-024
VLQ QQ → WqWq 1 e, μ ≥ 4 j Yes 20.3 Q mass 690 GeV 1509.04261
Excited fermions
Excited quark q* → qg – 2 j – 139 q* mass 6.7 TeV only u* and d*, Λ = m(q*) 1910.08447
Excited quark q* → qγ 1 γ 1 j – 36.7 q* mass 5.3 TeV only u* and d*, Λ = m(q*) 1709.10440
Excited quark b* → bg – 1 b, 1 j – 36.1 b* mass 2.6 TeV 1805.09299
Excited lepton ℓ* 3 e, μ – – 20.3 ℓ* mass 3.0 TeV Λ = 3.0 TeV 1411.2921
Excited lepton ν* 3 e, μ, τ – – 20.3 ν* mass 1.6 TeV Λ = 1.6 TeV 1411.2921
Other
Type III Seesaw 1 e, μ ≥ 2 j Yes 79.8 N⁰ mass 560 GeV ATLAS-CONF-2018-020
LRSM Majorana ν 2 μ 2 j – 36.1 N_R mass 3.2 TeV m(W_R) = 4.1 TeV, g_L = g_R 1809.11105
Higgs triplet H^±± → ℓℓ 2,3,4 e, μ (SS) – – 36.1 H^±± mass 870 GeV DY production 1710.09748
Higgs triplet H^±± → ℓτ 3 e, μ, τ – – 20.3 H^±± mass 400 GeV DY production, B(H_L^±± → ℓτ) = 1 1411.2921
Multi-charged particles – – – 36.1 multi-charged particle mass 1.22 TeV DY production, |q| = 5e 1812.03673
Magnetic monopoles – – – 34.4 monopole mass 2.37 TeV DY production, |g| = 1g_D, spin 1/2 1905.10130
√s = 8 TeV
√s = 13 TeV partial data
√s = 13 TeV full data
10⁻¹
1
10
Mass scale [TeV]
*Only a selection of the available mass limits on new states or phenomena is shown.
†Small-radius (large-radius) jets are denoted by the letter j (J).

$$\mathcal{L}_d = c_i \mathcal{O}_i$$
$$[\mathcal{O}_i] = d$$

The SMEFT

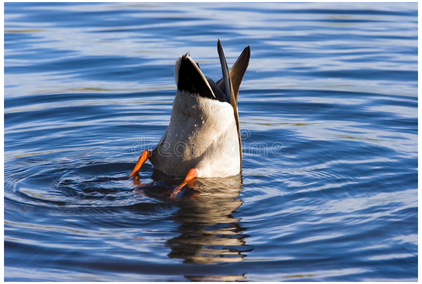
$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \frac{\mathcal{L}_6}{\Lambda^2} + \frac{\mathcal{L}_8}{\Lambda^4} + \mathcal{O}(1/\Lambda^6)$$

$\Lambda \gg p$

UV physics

↑

p **EFT**
Accessible scale

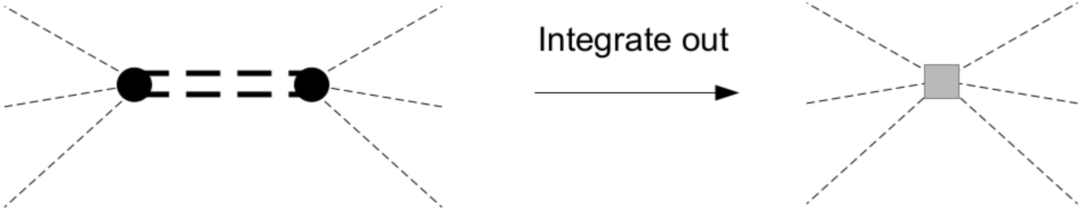


Bottom up: Write observables in terms of Wilson coeff; Global fits, etc with *<u>no mention of the UV</u>*

Top down: Calculate coefficients from a UV, *<u>translate EFT bounds into UV constaints</u>*

When does dimension-eight matter?

- Some observables are not captured by dimension-six operators:
  - Purely quartic anomalous gauge couplings;
  - Triple neutral gauge couplings;
  - Light-by-light scattering;
- Interpreting data in terms of models might necessitate dimension-eight corrections



Chala, Krause, Nardini 2018
Durieux, McCullough, Salvioni 2022

- No custodial breaking at tree and one-loop dim-6, but at one-loop dim-8

When does dimension-eight matter?

- Some observables are not captured by dimension-six operators:
  - Purely quartic anomalous gauge couplings;
  - Triple neutral gauge couplings;
  - Light-by-light scattering;
- Interpreting data in terms of models might necessitate dimension-eight corrections
- Theoretical considerations: positivity bounds, tree-loop mixing,...

Development at dimension-eight

- Physical and Green's basis developed

  Murphy 2005.00059
  Li, Ren, Shu, Xiao, Yu, Zheng 2005.00008
  Chala, Carmona, GG, 2112.12724

- RGEs computed

  Chala, GG, Ramos, Santiago 2106.05291
  Huber, De Angelis 2108.03669
  Bakshi, Chala, Diaz-Carmona, GG 2205.03301
  Helset, Jenkins, Manohar; 2212.03253
  Assi, Helset, Manohar, Pagès, Shen 2307.03187
  Boughezal, Huang, Petriello 2408.15378
  Bakshi, Chala, Diaz-Carmona, Ren, Vilches 2409.15408

- Observables

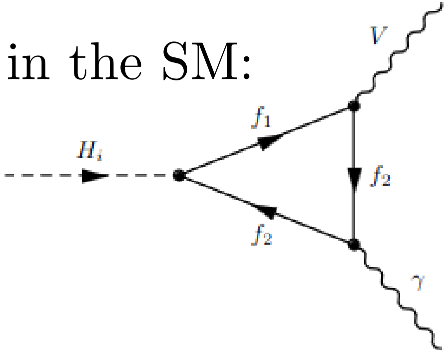
  Kim, Martin, 2203.11976
  Ellis, He, Xiao 2206.11676
  Degrande, Li 2303.10493
  Corbett, Desai, Eboli, Gonzalez-Garcia, Martines, Reimitz 2304.03305

- Matching of models:

  Carmona, Lazopoulos, Olgoso, Santiago 2112.10787
  Fuentes-Martín, König, Pagès, Thomsen, Wilsch 2212.04510
  Dawson, Forslund, Schnubel 2404.01375
  Adhikary, Biswas, Chakrabortty, Englert, Spannowsky 2501.12160

Higgs decays in the SMEFT

Loop in the SM:



- Warsaw basis:

$$C_{h\gamma\gamma} = e^2 \left(\frac{C_{\phi W}}{g_2^2} + \frac{C_{\phi B}}{g_1^2} - \frac{C_{\phi WB}}{g_1 g_2} \right)$$

$$\mathcal{O}_{\phi XX'} = (\phi^\dagger \phi) X_{\mu\nu} X^{\mu\nu}$$

- Every dim-6 operator with a field-strength tensor is **necessarily generated at loop-level.**
  - *As it should, Higgs diphoton decay is loop-level in the SMEFT*

Higgs decays in the SMEFT

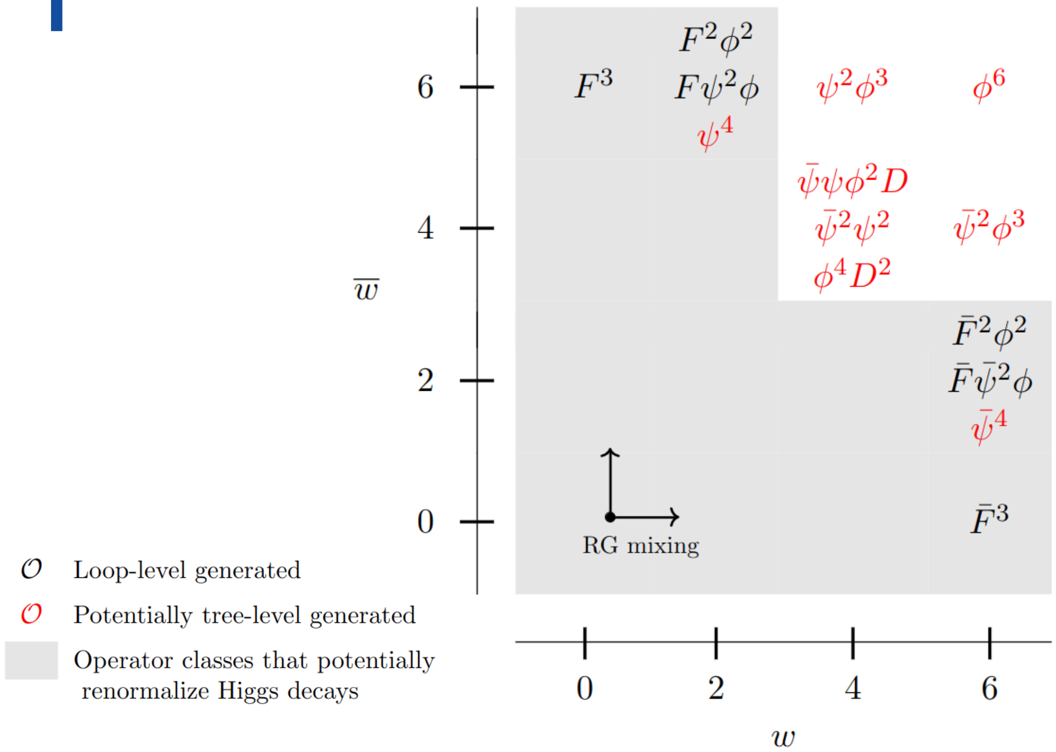
$$\mathcal{L}_{\mathrm{SMEFT}} \supset C_{h\gamma\gamma} \frac{v}{\Lambda^2} h F_{\mu\nu} F^{\mu\nu}$$

$$C_{h\gamma\gamma}(m) = C_{h\gamma\gamma}(\Lambda) + \frac{\gamma_i C_i}{16\pi^2} \log\left(\frac{m}{\Lambda}\right)$$

- If **tree-level operator mixes into loop**, RGE is of the same order (with a log-enhancement)
- Does not happen in Higgs decays at dimension-six SMEFT

Grojean, Jenkins, Manohar and Trott, 1711.10391
Elias-Miro, Espinosa, Masso and Pomarol 1302.5661
Alonso, Jenkins, Manohar and Trott 1308.2627, 1310.4838, 1312.2014

RG mixing structure of EFTs

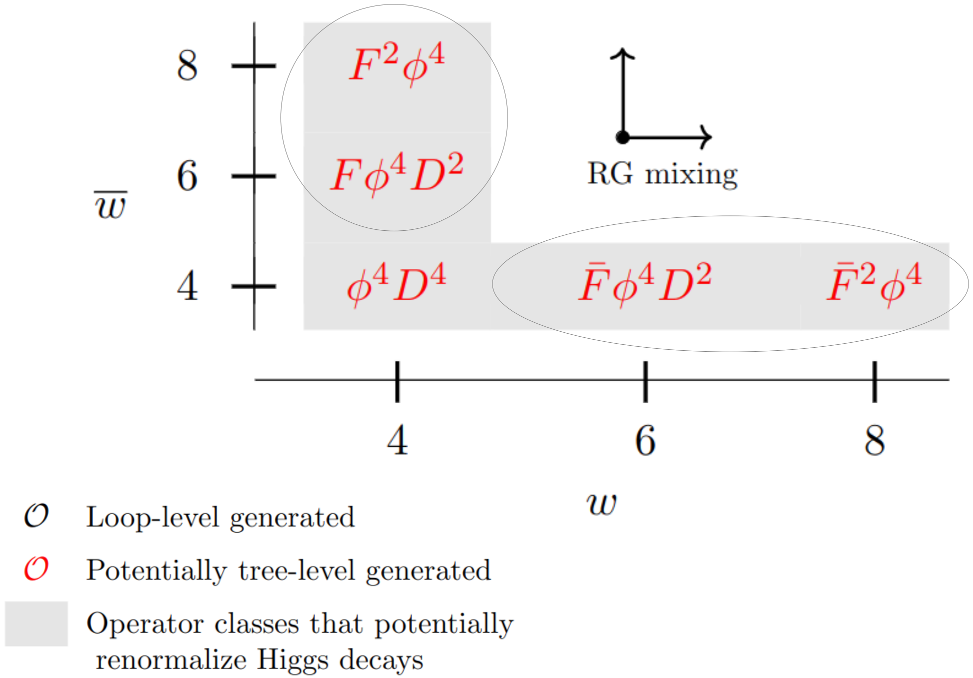


- RGE structure almost aligns with perturbative generation
- Explained by non-renormalization theorem:

$$\gamma_{ij} = 0 \quad \text{if} \quad \omega(\mathcal{O}_i) < \omega(\mathcal{O}_j)$$
$$\text{or} \quad \overline{\omega}(\mathcal{O}_i) < \overline{\omega}(\mathcal{O}_j)$$

Cheung and Shen 1505.01844

RG mixing structure of EFTs – dim eight



$$\mathcal{O}_{F^2\phi^4} = (\phi^\dagger\phi)^2 F_{\mu\nu}F^{\mu\nu}$$

$$\mathcal{O}_{F\phi^4D^2} = (\phi^\dagger\phi)(D_\mu\phi^\dagger D_\nu\phi)F_{\mu\nu}$$

$$\mathcal{O}_{\phi^4D^4} = (D_\mu\phi^\dagger D_\nu\phi)(D^\nu\phi^\dagger D^\mu\phi)$$

- Richer structure at dimension-eight
  - Theorem allows for more **trees mixing into loops**

Craig, Jiang, Li and Sutherland, 2001.00017
Murphy, 2005.00059

Matching at tree-level

Consider all (scalar) extensions coupling to two Higgs:

		$S \sim (1,1,0)$	$\Xi \sim (1,3,0)$	$\Xi_1 \sim (1,3,1)$
$\phi^4 D^4$	$\mathcal{O}^{(1)}_{\phi^4}$		4	
	$\mathcal{O}^{(2)}_{\phi^4}$			8
	$\mathcal{O}^{(3)}_{\phi^4}$	2	-2	
$X\phi^4 D^2$	$g\mathcal{O}^{(1)}_{W\phi^4 D^2}$			
	$g'\mathcal{O}^{(1)}_{B\phi^4 D^2}$			
$X^2\phi^4$	$g^2\mathcal{O}^{(1)}_{\phi^4 W^2}$		0	
	$g^2\mathcal{O}^{(3)}_{\phi^4 W^2}$			
	$g'g\mathcal{O}^{(1)}_{\phi^4 WB}$			
	$g'^2\mathcal{O}^{(1)}_{\phi^4 B^2}$			

$$\mathscr{L}_\Xi = \frac{1}{2}D_\mu\Xi^a D^\mu\Xi^a - \frac{1}{2}M^2\Xi^a\Xi^a - \kappa_\Xi\Xi^a\phi^\dagger\sigma^a\phi$$

- Results presented in dim 8 Green's basis

Chala, Carmona and G. G., 2112.12724

- **Scalar extensions do not generate** the operator classes responsible for the Higgs decays

Corbett, Helset, Martin and Trott 2102.02819
Chala and Santiago 2110.01624
Banerjee, Chakrabortty, Englert, Rahaman and Spannowsky 2210.14761
Ellis, Mimasu and Zampedri, 2304.06663

Matching at tree-level

Criado and Perez-Victoria, 1811.09413
Hays, Helset, Martin and Trott 2007.00565
Chala, Carmona and G. G., 2112.12724
Dawson, Forslund, Schnubel, 2404.01375

Consider all (vector) extensions coupling to two Higgs:

		$\mathcal{B}^\mu \sim (1,1,0)$	$\mathcal{B}_1^\mu \sim (1,1,1)$	$\mathcal{W}^\mu \sim (1,3,0)$	$\mathcal{W}_1^\mu \sim (1,3,1)$
$\phi^4 D^4$	$\mathcal{O}_{\phi^4}^{(1)}$	-2	2	$\frac{1}{2}$	
	$\mathcal{O}_{\phi^4}^{(2)}$	2		$\frac{1}{2}$	
	$\mathcal{O}_{\phi^4}^{(3)}$		-2	-1	
$X\phi^4 D^2$	$g\mathcal{O}_{W\phi^4 D^2}^{(1)}$	2	2	$-\frac{1}{2}(1+2k_{\mathcal{W}})$	
	$g'\mathcal{O}_{B\phi^4 D^2}^{(1)}$	-2	$-2k_{\mathcal{B}_1}$	$\frac{3}{2}$	
$X^2\phi^4$	$g^2\mathcal{O}_{\phi^4 W^2}^{(1)}$	$\frac{1}{4}$	$\frac{1}{4}$	$-\frac{1}{16}(1+2k_{\mathcal{W}})$	$\frac{1}{32}(k_{\mathcal{W}_1,2}-1)$
	$g^2\mathcal{O}_{\phi^4 W^2}^{(3)}$				$\frac{1}{32}(k_{\mathcal{W}_1,2}-1)$
	$g'g\mathcal{O}_{\phi^4 WB}^{(1)}$		$\frac{1}{4}(1-k_{\mathcal{B}_1})$	$\frac{1}{8}(1-k_{\mathcal{W}})$	$\frac{1}{16}(k_{\mathcal{W}_1,1}+k_{\mathcal{W}_1,2}-2)$
	$g'^2\mathcal{O}_{\phi^4 B^2}^{(1)}$	$-\frac{1}{4}$	$-\frac{1}{4}k_{\mathcal{B}_1}$	$\frac{3}{16}$	$\frac{1}{16}(k_{\mathcal{W}_1,1}-1)$

Matching at tree-level

Consider all (vector) extensions coupling to two Higgs:

$$\mathscr{L}_{\mathcal{B}_1} \supset -i\, g'\, k_{\mathcal{B}_1}\, \mathcal{B}_1^{\dagger\mu} \mathcal{B}_1^{\nu} B_{\mu\nu}\,,$$

$$\mathscr{L}_{\mathcal{W}} \supset -\frac{1}{2}\, g\, k_{\mathcal{W}}\, \epsilon^{abc} \mathcal{W}^{\mu a} \mathcal{W}^{\nu a} W^{c}_{\mu\nu}\,,$$

$$\mathscr{L}_{\mathcal{W}_1} \supset -i\, g'\, k_{\mathcal{W}_{1},1}\, \mathcal{W}_{1\mu}^{\dagger a} \mathcal{W}_{1\nu}^{a} B^{\mu\nu} - g\, k_{\mathcal{W}_{1},2}\, \epsilon^{abc} \mathcal{W}_{1\mu}^{\dagger a} \mathcal{W}_{1\nu}^{b} W^{\mu\nu c}$$

- **Tree-level perturbative unitarity** in the UV entails $k_{\mathcal{X}} = 1$

Ferrara, Porrati and Telegdi (1992)
Henning, Lu and Murayama, 1412.1837
Feuillat, Lucio and Pestieau hep-ph/0010145
Djukanovic, Schindler, Gegelia and Scherer hep-ph/0505180
Barbieri, Isidori, Pattori and Senia 1512.01560
Biggio, Bordone, Di Luzio and Ridolfi 1607.07621

When this is imposed, generation of Higgs decays vanishes at tree-level

Renormalization group equations

Using dimension-eight RGEs

Chala, G. G., Ramos and Santiago, 2106.05291
Huber and De Angelis, 2108.03669
Das Bakshi, Chala, Carmona and G. G., 2205.03301

$$
\begin{aligned}
16\pi^2\mu\frac{\mathrm{d}}{\mathrm{d}\mu}\left(\frac{\mathcal{A}\left[h\gamma\gamma\right]}{v^3/\Lambda^4}\right) = -3e^2g'^2&\left(\frac{C^{(1)}_{\phi^4W^2}}{g^2}+\frac{C^{(3)}_{\phi^4W^2}}{g^2}-\frac{C^{(1)}_{\phi^4WB}}{g'g}+\frac{C^{(1)}_{\phi^4B^2}}{g'^2}\right)\\
+e^2g^2&\bigg(-9\frac{C^{(1)}_{\phi^4W^2}}{g^2}+3\frac{C^{(3)}_{\phi^4W^2}}{g^2}+3\frac{C^{(1)}_{\phi^4WB}}{g'g}\\
&\quad-9\frac{C^{(1)}_{\phi^4B^2}}{g'^2}+\frac{3}{2}\frac{C^{(1)}_{W\phi^4D^2}}{g}+\frac{3}{2}\frac{C^{(1)}_{B\phi^4D^2}}{g'}\bigg)\\
+e^2\lambda&\bigg(36\frac{C^{(1)}_{\phi^4W^2}}{g^2}+28\frac{C^{(3)}_{\phi^4W^2}}{g^2}-32\frac{C^{(1)}_{\phi^4WB}}{g'g}\\
&\quad+36\frac{C^{(1)}_{\phi^4B^2}}{g'^2}-\frac{C^{(1)}_{W\phi^4D^2}}{g}-\frac{C^{(1)}_{B\phi^4D^2}}{g'}\bigg)\,,
\end{aligned}
$$

- Triggered by operators in potentially tree-level generated classes
  - But are these **linear combinations actually generated**?

Renormalization group equations

$$16\pi^2\mu\frac{\mathrm{d}}{\mathrm{d}\mu}\left(\frac{\mathcal{A}[h\gamma\gamma]}{v^3/\Lambda^4}\right) = e^2\begin{cases} g_{\mathcal{B}_1}^2(\lambda - \frac{3}{2}g^2)(k_{\mathcal{B}_1} - 1), & \mathcal{B}_1 \sim (1,1,1) \\ \frac{1}{2}g_{\mathcal{W}}^2(\lambda - \frac{3}{2}g^2)(k_{\mathcal{W}} - 1), & \mathcal{W} \sim (1,3,0) \\ \frac{1}{4}g_{\mathcal{W}_1}^2(\lambda - \frac{3}{2}g^2)(k_{\mathcal{W}_{1,1}} - 1), & \mathcal{W}_1 \sim (1,3,1) \end{cases}$$

No trees mixing into loops for

$h \to \gamma\gamma$ **for** $k_{\mathcal{X}} = 1$

Renormalization group equations

$$16\pi^2\mu\frac{\mathrm{d}}{\mathrm{d}\mu}\left(\frac{\mathcal{A}\left[h\gamma Z\right]}{v^3/\Lambda^4}\right) = g'g^3\begin{cases} \frac{3}{2}\frac{\kappa_\Xi^2}{M^2}, & \Xi\sim(1,3,0),\\ -3\frac{|\kappa_{\Xi_1}|^2}{M^2}, & \Xi_1\sim(1,3,1),\\ \frac{9}{4}g_{\mathcal{B}_1}^2, & \mathcal{B}_1\sim(1,1,1),\ k_{\mathcal{B}_1}=1,\\ -\frac{9}{8}g_{\mathcal{W}}^2, & \mathcal{W}\sim(1,3,0),\ k_{\mathcal{W}}=1 \end{cases}$$

Trees mix into operators responsible for $h\to\gamma Z$ at dimension-eight

A new basis

	Scalar extensions			Vector extensions			
	S $(1,1,0)$	Ξ $(1,3,0)$	Ξ_1 $(1,3,1)$	$\mathcal{B}^\mu$ $(1,1,0)$	$\mathcal{B}_1^\mu$ $(1,1,1)$	$\mathcal{W}^\mu$ $(1,3,0)$	$\mathcal{W}_1^\mu$ $(1,3,1)$
$\mathcal{O}_{\phi^4}^{(1)}$		4		-2	2	$1/2$	
$\mathcal{O}_{\phi^4}^{(2)}$			8	2		$1/2$	
$\mathcal{O}_{\phi^4}^{(3)}$	2	-2			-2	-1	
$C_{h\gamma\gamma}$	0						
$C_{h\gamma Z}$							
C_3							
C_4							
C_5							
C_{TLO}				$\frac{1}{4}$	$\frac{1}{4}$	$-3/16$	

$$\frac{\mathcal{A}\left[h\gamma\gamma\right]^{(8)}}{v^3/\Lambda^4} = 2e^2 C_{h\gamma\gamma}\,,$$

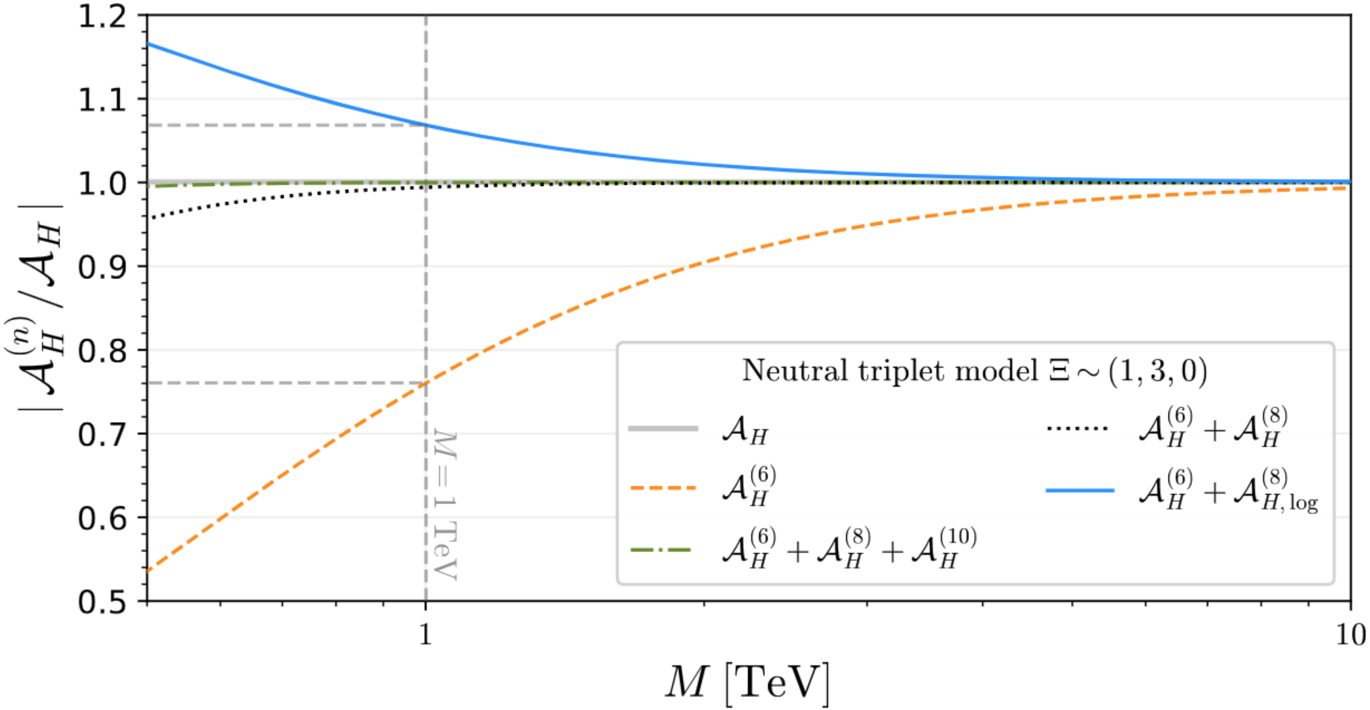
$$\frac{\mathcal{A}\left[h\gamma Z\right]^{(8)}}{v^3/\Lambda^4} = 2e^2\,\frac{g^2-g'^2}{g'g}\,C_{h\gamma\gamma} + 2g'g\,C_{h\gamma Z}$$

Only one direction is tree-level generated

A full model

$$\mathscr{L}_\Xi = \frac{1}{2} D_\mu \Xi^a D^\mu \Xi^a - \frac{1}{2} M^2 \Xi^a \Xi^a - \kappa_\Xi \Xi^a \phi^\dagger \sigma^a \phi$$

- Compared with full results in **Hue, Arbuzov, Hong, Nguyen, Si and Long, 1712.05234** **Degrande, Hartling and Logan, 1708.08753**



Decay width

- Pheno estimate:
  - Use numerical results from

    Dawson and Giardino, 1801.01136
    Dedes, Suxho and Trifyllis, 1903.12046
    Hays, Helset, Martin and Trott, 2007.00565

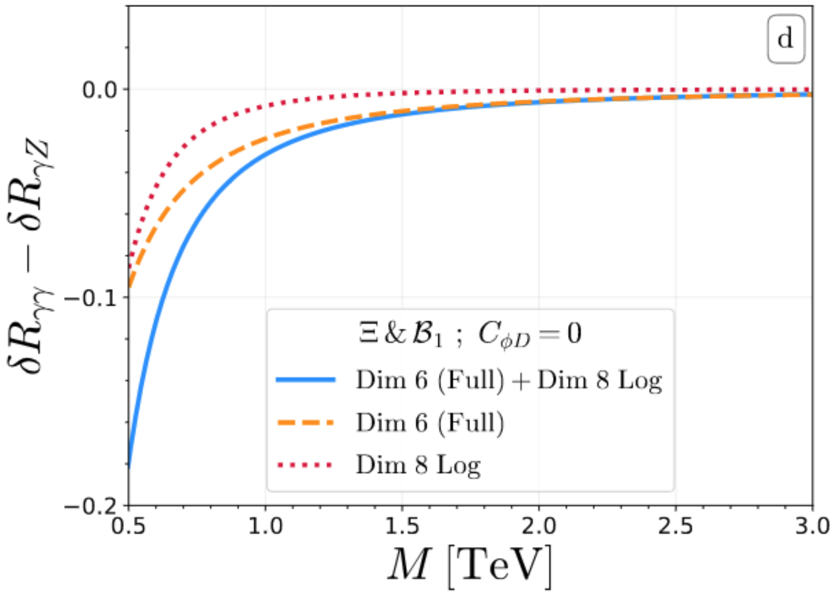
  - Include: dimension-six one-loop effects + dimension-eight RGE effects
  - Not including: one-loop dimension-eight (non-RGE) terms
- Can the logarithm of dimension-eight important?
- The decay $h \to \gamma Z$ is dominated by indirect effects at dimension-six

Influence for the decay width – custodial symmetry?

$$\frac{1+\delta\mathcal{R}_{\gamma\gamma}}{1+\delta\mathcal{R}_{\gamma Z}} = 1+\delta\mathcal{R}_{\gamma\gamma}-\delta\mathcal{R}_{\gamma Z}+O(\delta\mathcal{R}^2)$$
$$= 1-\left(\frac{1\ \text{TeV}}{\Lambda}\right)^2\left(0.12C_{\phi D}-0.02C_{u\phi,33}+0.049\bar{C}_{\phi B}-0.002\bar{C}_{\phi W}-0.024\bar{C}_{\phi WB}\right)$$
$$+0.0007\left(\frac{1\ \text{TeV}}{\Lambda}\right)^4\left(6C_{\text{TLO}}+\frac{3}{8}C^{(1)}_{\phi^4}-\frac{3}{8}C^{(2)}_{\phi^4}\right)\log\left(\frac{m_h}{\Lambda}\right)+O(\delta\mathcal{R}^2)\,, \qquad (5.7)$$

- Most indirect contributions cancelled. However the leading numerical term comes from custodial-symmetry breaking
  - In scalar scenarios **logarithm and custodial-symmetry are correlated**! Need vectors to break correlation

Influence at the observable level – custodial symmetry?



- Adding a heavy vector allows for the cancellation of tree-level $C_{\phi D}$, while mantaining a non-zero dimension-eight RGE.
- Matching with results from dictionaries

  de Blas, Criado, Perez-Victoria and Santiago, 1711.10391
  G. G., Olgoso and Santiago, 2303.16965
- Dimension-eight RGE corresponds to **25% of the full result**

Conclusions

- Immense development of dimension-eight SMEFT
  - Basis construction, observable parameterization, renormalization group structure, etc.
- Certain scalings and/or kinematics are only captured by dimension-eight
- Trees renormalizing higgs decays arises at dimension-eight whereas it was absent at dimension-six – new qualitative behaviour at higher-order
- Relevance to these observations dependent on the model

Thanks

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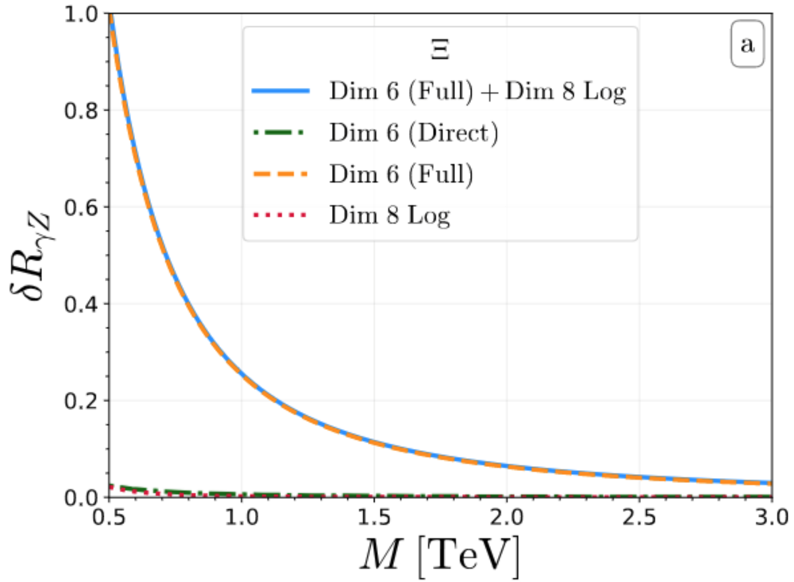
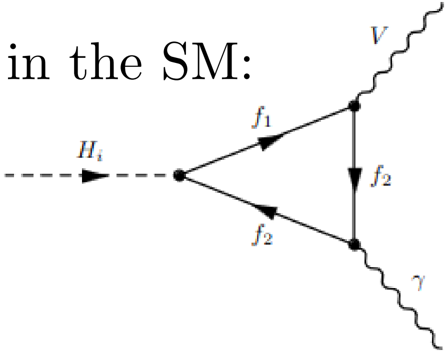
Influence for the decay width



- Indirect contributions at dimension-six completely dominate
- One could imagine more complicated models or ...

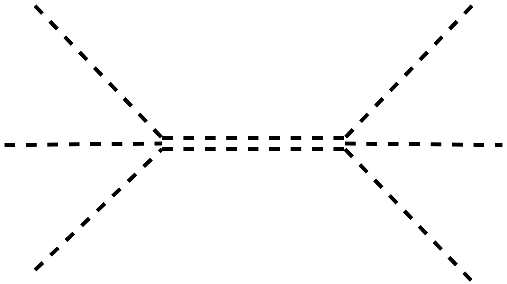
Higgs decays in the SMEFT

Loop in the SM:



$$\mathcal{L}_{\text{SMEFT}} \supset C_{h\gamma\gamma}\frac{v}{\Lambda^2}hF_{\mu\nu}F^{\mu\nu}$$

- For basis of operators with non-vanishing leading terms (non-zero amplitudes for the lowest field content):



$+$ Considering that UV respects SM gauge symmetries – gauge bosons couple diagonally:

- An operator must have at least 4 Higgses or fermions for it to be potentially tree-level generated