2-Loop SMEFT RGEs

Anders Eller Thomsen

Based on [arXiv:2601.19974]
with *L. Born* and *J. Fuentes-Martín*

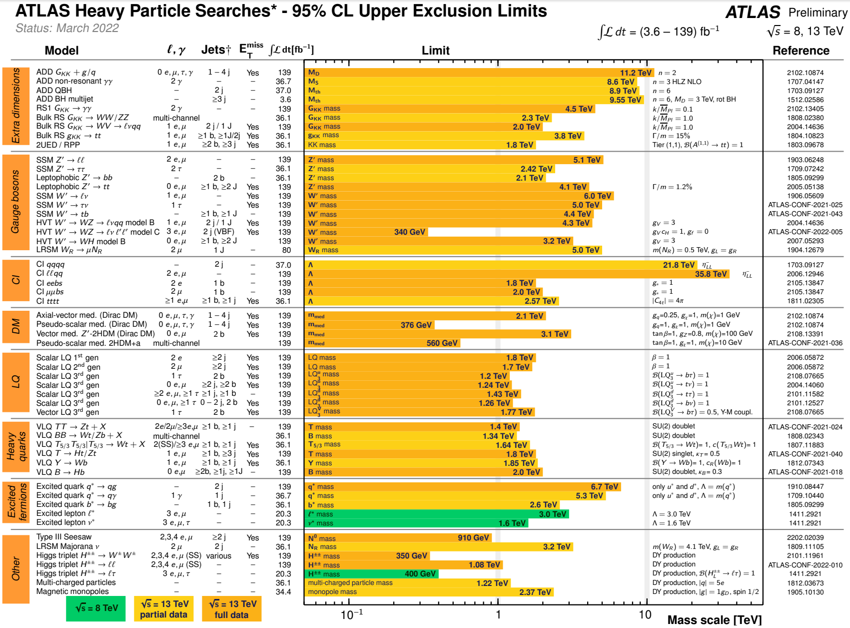
Les Rencontres de Physique de la Vallée d'Aoste
La Thuile, 6 March 2026

UNIVERSITÄT
BERN

AEC
ALBERT EINSTEIN CENTER
FOR FUNDAMENTAL PHYSICS

Swiss National
Science Foundation

Direct searches for new physics

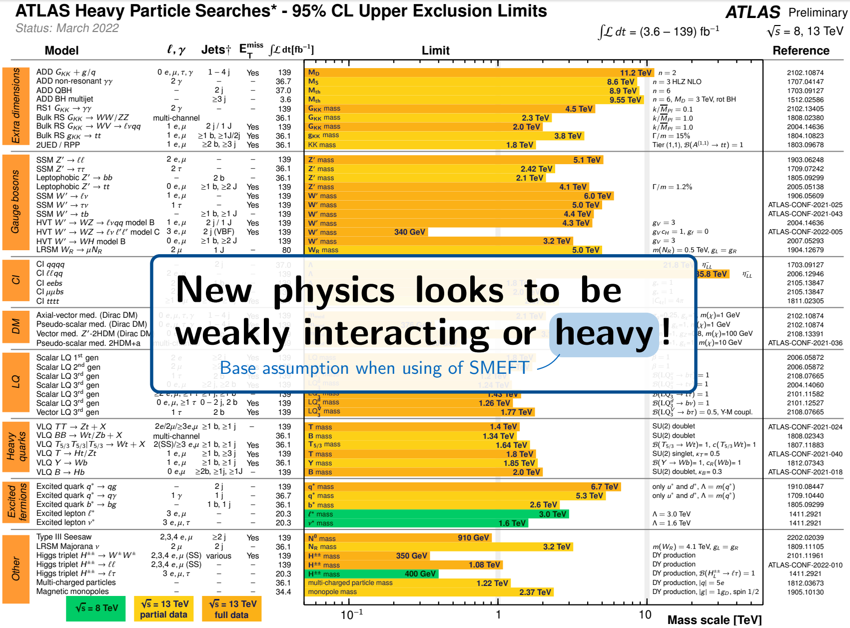


ATLAS Heavy Particle Searches* - 95% CL Upper Exclusion Limits

Status: March 2022

	Model	ℓ,γ	Jets†	E_T^{miss}	$\int\mathcal{L}\,dt[\text{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK}+g/q$	$0\ e,\mu,\tau,\gamma$	1 – 4 j	Yes	139	M_D 11.2 TeV	$n=2$	2102.10874
	ADD non-resonant $\gamma\gamma$	$2\ \gamma$	–	–	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 multijet	–	≥3 j	–	3.6	M_{th} 9.55 TeV	$n=6$, $M_D=3$ TeV, rot BH	1512.02586
	RS1 $G_{KK}\to\gamma\gamma$	$2\ \gamma$	–	–	139	G_{KK} mass 4.5 TeV	$k/\overline{M}_{Pl}=0.1$	2102.13405
	Bulk RS $G_{KK}\to WW/ZZ$	multi-channel			36.1	G_{KK} mass 2.3 TeV	$k/\overline{M}_{Pl}=1.0$	1808.02380
	Bulk RS $G_{KK}\to WV\to\ell\nu qq$	$1\ e,\mu$	2 j / 1 J	Yes	139	G_{KK} mass 2.0 TeV	$k/\overline{M}_{Pl}=1.0$	2004.14636
	Bulk RS $g_{KK}\to tt$	$1\ e,\mu$	≥1 b, ≥1J/2j	Yes	36.1	g_{KK} mass 3.8 TeV	$\Gamma/m=15\%$	1804.10823
	2UED / RPP	$1\ e,\mu$	≥2 b, ≥3 j	Yes	36.1	KK mass 1.8 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)}\to tt)=1$	1803.09678
Gauge bosons	SSM $Z'\to\ell\ell$	$2\ e,\mu$	–	–	139	Z' mass 5.1 TeV		1903.06248
	SSM $Z'\to\tau\tau$	$2\ \tau$	–	–	36.1	Z' mass 2.42 TeV		1709.07242
	Leptophobic $Z'\to bb$	–	2 b	–	36.1	Z' mass 2.1 TeV		1805.09299
	Leptophobic $Z'\to tt$	$0\ e,\mu$	≥1 b, ≥2 J	Yes	139	Z' mass 4.1 TeV	$\Gamma/m=1.2\%$	2005.05138
	SSM $W'\to\ell\nu$	$1\ e,\mu$	–	Yes	139	W' mass 6.0 TeV		1906.05609
	SSM $W'\to\tau\nu$	$1\ \tau$	–	Yes	139	W' mass 5.0 TeV		ATLAS-CONF-2021-025
	SSM $W'\to tb$	–	≥1 b, ≥1 J	–	139	W' mass 4.4 TeV		ATLAS-CONF-2021-043
	HVT $W'\to WZ\to\ell\nu qq$ model B	$1\ e,\mu$	2 j / 1 J	Yes	139	W' mass 4.3 TeV	$g_V=3$	2004.14636
	HVT $W'\to WZ\to\ell\nu\,\ell'\ell'$ model C	$3\ e,\mu$	2 j (VBF)	Yes	139	W' mass 340 GeV	$g_V c_H=1$, $g_f=0$	ATLAS-CONF-2022-005
	HVT $W'\to WH$ model B	$0\ e,\mu$	≥1 b, ≥2 J		139	W' mass 3.2 TeV	$g_V=3$	2007.05293
	LRSM $W_R\to\mu N_R$	$2\ \mu$	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 $\ell\ell qq$	$2\ e,\mu$	–	–	139	Λ 35.8 TeV	η_{LL}^-	2006.12946
	CI $eebs$	$2\ e$	1 b	–	139	Λ 1.8 TeV	$g_*=1$	2105.13847
	CI $\mu\mu bs$	$2\ \mu$	1 b	–	139	Λ 2.0 TeV	$g_*=1$	2105.13847
	CI $tttt$	≥1 e,μ	≥1 b, ≥1 j	Yes	36.1	Λ 2.57 TeV	$\lvert C_{4t}\rvert=4\pi$	1811.02305
DM	Axial-vector med. (Dirac DM)	$0\ e,\mu,\tau,\gamma$	1 – 4 j	Yes	139	m_{med} 2.1 TeV	g_q=0.25, g_χ=1, $m(\chi)$=1 GeV	2102.10874
	Pseudo-scalar med. (Dirac DM)	$0\ e,\mu,\tau,\gamma$	1 – 4 j	Yes	139	m_{med} 376 GeV	g_q=1, g_χ=1, $m(\chi)$=1 GeV	2102.10874
	Vector med. Z'-2HDM (Dirac DM)	$0\ e,\mu$	2 b	Yes	139	m_{med} 3.1 TeV	$\tan\beta$=1, g_Z=0.8, $m(\chi)$=100 GeV	2108.13391
	Pseudo-scalar med. 2HDM+a	multi-channel			139	m_{med} 560 GeV	$\tan\beta$=1, g_χ=1, $m(\chi)$=10 GeV	ATLAS-CONF-2021-036
LQ	Scalar LQ 1st gen	$2\ e$	≥2 j	Yes	139	LQ mass 1.8 TeV	$\beta=1$	2006.05872
	Scalar LQ 2nd gen	$2\ \mu$	≥2 j	Yes	139	LQ mass 1.7 TeV	$\beta=1$	2006.05872
	Scalar LQ 3rd gen	$1\ \tau$	2 b	Yes	139	LQ_3^u mass 1.2 TeV	$\mathcal{B}(\text{LQ}_3^u\to b\tau)=1$	2108.07665
	Scalar LQ 3rd gen	$0\ e,\mu$	≥2 j, ≥2 b	Yes	139	LQ_3^u mass 1.24 TeV	$\mathcal{B}(\text{LQ}_3^u\to t\nu)=1$	2004.14060
	Scalar LQ 3rd gen	≥2 e,μ, ≥1 τ	≥1 j, ≥1 b	–	139	LQ_3^d mass 1.43 TeV	$\mathcal{B}(\text{LQ}_3^d\to t\tau)=1$	2101.11582
	Scalar LQ 3rd gen	$0\ e,\mu$, ≥1 τ	0 – 2 j, 2 b	Yes	139	LQ_3^d mass 1.26 TeV	$\mathcal{B}(\text{LQ}_3^d\to b\nu)=1$	2101.12527
	Vector LQ 3rd gen	$1\ \tau$	2 b	Yes	139	LQ_3^V mass 1.77 TeV	$\mathcal{B}(\text{LQ}_3^V\to b\tau)=0.5$, Y-M coupl.	2108.07665
Heavy quarks	VLQ $TT\to Zt+X$	2e/2μ/≥3e,μ	≥1 b, ≥1 j	–	139	T mass 1.4 TeV	SU(2) doublet	ATLAS-CONF-2021-024
	VLQ $BB\to Wt/Zb+X$	multi-channel			36.1	B mass 1.34 TeV	SU(2) doublet	1808.02343
	VLQ $T_{5/3}T_{5/3}\vert T_{5/3}\to Wt+X$	2(SS)/≥3 e,μ	≥1 b, ≥1 j	Yes	36.1	$T_{5/3}$ mass 1.64 TeV	$\mathcal{B}(T_{5/3}\to Wt)$= 1, $c(T_{5/3}Wt)$= 1	1807.11883
	VLQ $T\to Ht/Zt$	$1\ e,\mu$	≥1 b, ≥3 j	Yes	139	T mass 1.8 TeV	SU(2) singlet, κ_T= 0.5	ATLAS-CONF-2021-040
	VLQ $Y\to Wb$	$1\ e,\mu$	≥1 b, ≥1 j	Yes	36.1	Y mass 1.85 TeV	$\mathcal{B}(Y\to Wb)$= 1, $c_R(Wb)$= 1	1812.07343
	VLQ $B\to Hb$	$0\ e,\mu$	≥2b, ≥1j, ≥1J	–	139	B mass 2.0 TeV	SU(2) doublet, κ_B= 0.3	ATLAS-CONF-2021-018
Excited fermions	Excited quark $q^*\to qg$	–	2 j	–	139	q^* mass 6.7 TeV	only u^* and d^*, $\Lambda=m(q^*)$	1910.08447
	Excited quark $q^*\to q\gamma$	$1\ \gamma$	1 j	–	36.7	q^* mass 5.3 TeV	only u^* and d^*, $\Lambda=m(q^*)$	1709.10440
	Excited quark $b^*\to bg$	–	1 b, 1 j	–	36.1	b^* mass 2.6 TeV		1805.09299
	Excited lepton ℓ^*	$3\ e,\mu$	–	–	20.3	ℓ^* mass 3.0 TeV	$\Lambda=3.0$ TeV	1411.2921
	Excited lepton ν^*	$3\ e,\mu,\tau$	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda=1.6$ TeV	1411.2921
Other	Type III Seesaw	2,3,4 e,μ	≥2 j	Yes	139	N^0 mass 910 GeV		2202.02039
	LRSM Majorana ν	$2\ \mu$	2 j	–	36.1	N_R mass 3.2 TeV	$m(W_R)=4.1$ TeV, $g_L=g_R$	1809.11105
	Higgs triplet $H^{\pm\pm}\to W^\pm W^\pm$	2,3,4 e,μ (SS)	various	Yes	139	$H^{\pm\pm}$ mass 350 GeV	DY production	2101.11961
	Higgs triplet $H^{\pm\pm}\to\ell\ell$	2,3,4 e,μ (SS)	–	–	139	$H^{\pm\pm}$ mass 1.08 TeV	DY production	ATLAS-CONF-2022-010
	Higgs triplet $H^{\pm\pm}\to\ell\tau$	$3\ e,\mu,\tau$	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, $\mathcal{B}(H_L^{\pm\pm}\to\ell\tau)=1$	1411.2921
	Multi-charged particles	–	–	–	36.1	multi-charged particle mass 1.22 TeV	DY production, $\lvert q\rvert=5e$	1812.03673
	Magnetic monopoles	–	–	–	34.4	monopole mass 2.37 TeV	DY production, $\lvert g\rvert=1g_D$, spin 1/2	1905.10130

Direct searches for new physics

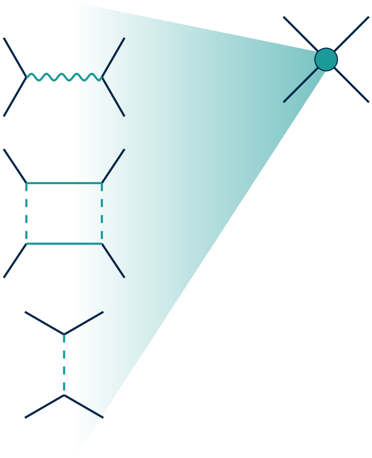


New physics looks to be weakly interacting or heavy!

Base assumption when using of SMEFT

SM effective field theory

High-energy BSM physics manifests as contact interactions in the SMEFT

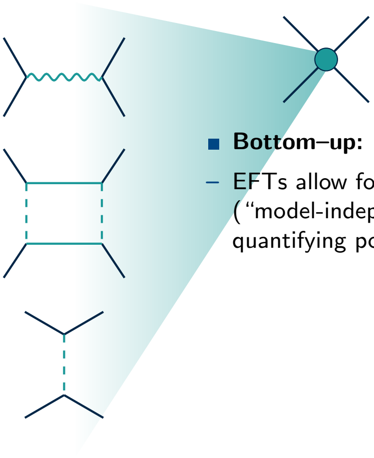


UV Physics

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_{d=5} \sum_{k} \frac{C_{d,k}}{\Lambda^{d-4}} \mathcal{O}_{d,k}$$

SM effective field theory

High-energy BSM physics manifests as contact interactions in the SMEFT



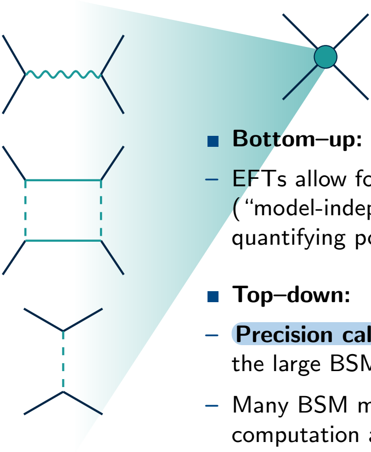
$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_{d=5} \sum_{k} \frac{C_{d,k}}{\Lambda^{d-4}} \mathcal{O}_{d,k}$$

UV Physics

- **Bottom–up:**
  - EFTs allow for a **model-comprehensive** ("model-independent") analysis of deviations from the SM, quantifying possible deviations as an expansion in E/Λ

SM effective field theory

High-energy BSM physics manifests as contact interactions in the SMEFT



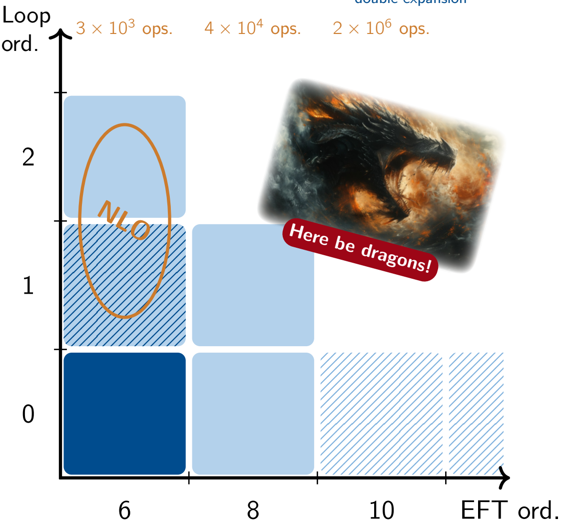
UV Physics

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_{d=5} \sum_{k} \frac{C_{d,k}}{\Lambda^{d-4}} \mathcal{O}_{d,k}$$

- **Bottom–up:**
  - EFTs allow for a **model-comprehensive** ("model-independent") analysis of deviations from the SM, quantifying possible deviations as an expansion in E/Λ
- **Top–down:**
  - **Precision calculations** necessitates the use of EFTs to separate the large BSM energy scales
  - Many BSM models results in the same EFT, ensuring that computation are **reusable**: you only need to compute once in the EFT

SMEFT as a double expansion

$$\mathcal{L}_{\mathsf{SMEFT}}(\phi) = \mathcal{L}_{\mathsf{SM}}(\phi) + \sum_{d=5}^{\infty}\sum_{\ell=0}^{\infty}\sum_{k} \underbrace{\frac{C^{(\ell)}_{d,k}}{(16\pi^2)^{\ell}\,\Lambda^{d-4}}}_{\text{double expansion}} \mathcal{O}^{(\ell)}_{d,k}(\phi)$$



The importance of RG running

The dimension-six operators change with the renormalization scale:

$$\frac{\mathrm{d}C_i}{\mathrm{d}\ln\mu} = \gamma_{ij} C_j$$

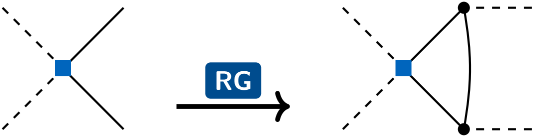
γ_{ij} is non-diagonal (operator mixing): **leading effects, not only precision**

The importance of RG running

The dimension-six operators change with the renormalization scale:

$$\frac{\mathrm{d}C_i}{\mathrm{d}\ln\mu} = \gamma_{ij} C_j$$

γ_{ij} is non-diagonal (operator mixing): **leading effects, not only precision**



Hard to access at LHC

See talk by Dominik Babal, $ttWj$ search

C_{Hu}^{33}

$Z/W/h$ couplings to t_{R}

Constrained by LEP

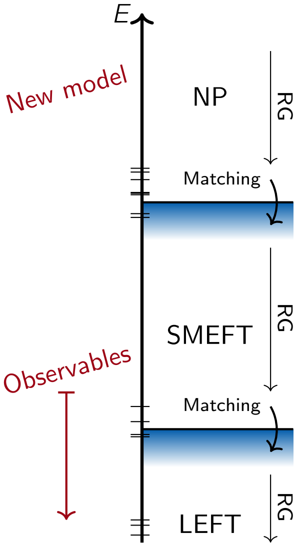
$C_{HD}^{(\times)}$

EWPO: $\Delta m_W, A_b^{\mathrm{FB}}, \ldots$

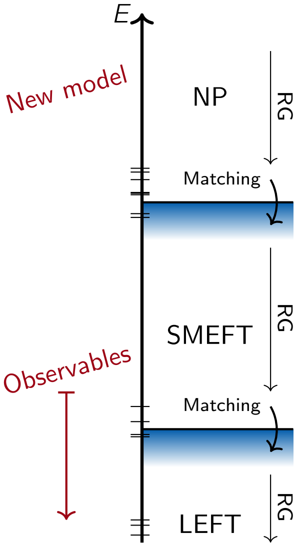
$$|C_{Hu}^{33}| < \frac{1}{(3\,\mathrm{TeV})^2}$$

Allwicher *et al.* [2311.00020]

EFT workflow



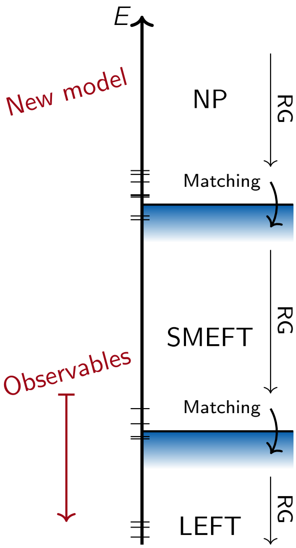
EFT workflow



Current status:

- Automated RG flow @ 1-loop
- Automated UV matching @ 1-loop
- Automated SMEFT likelihoods
- Calculation of observables @ 1-loop order
- Calculation of LEFT β-functions @ 2-loop order
- **New**: calculation of SMEFT β-functions @ 2-loop order

EFT workflow



E

New model

NP

RG

Matching

SMEFT

RG

Observables

Matching

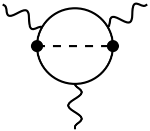
LEFT

RG

Why we should go beyond one-loop order:

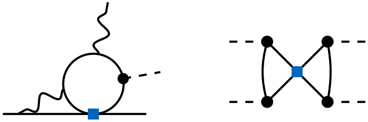
- Restoration of scheme invariance
- New effects at 2-loop order

$\mathcal{O}_{WW\widetilde{W}} \subseteq$



Das Bakshi *et al.* [2103.15861]

- Surprisingly large 2-loop effects



Ardu, Davidson [2103.07212]; Allwicher *et al.* [2302.11584]

- We (might) learn something new about QFT

Functional master formula

An application of functional methods at multi-loop order

Born, Fuentes-Martín, Kvedaraitė, Moreno-Sánchez, Palavrić, **AET** [2311.13630], [2412.12270], [2412.12270]

$$\delta\widehat{S}^{(2)} = \frac{1}{8}\boldsymbol{K}\bar{\boldsymbol{R}}^{*}\boldsymbol{T}\Big[\widehat{\mathcal{V}}^{(0)}_{IJKL}\,\widehat{\mathcal{Q}}^{-1}_{IJ}\,\widehat{\mathcal{Q}}^{-1}_{KL}\Big] - \frac{1}{12}\boldsymbol{K}\bar{\boldsymbol{R}}^{*}\boldsymbol{T}\Big[\widehat{\mathcal{V}}^{(0)}_{IJK}\,\widehat{\mathcal{Q}}^{-1}_{IL}\,\widehat{\mathcal{Q}}^{-1}_{JM}\,\widehat{\mathcal{Q}}^{-1}_{KN}\,\widehat{\mathcal{V}}^{(0)}_{LMN}\Big]$$

Functional master formula

An application of functional methods at multi-loop order

Born, Fuentes-Martín, Kvedaraitė, Moreno-Sánchez, Palavrić, **AET** [2311.13630], [2412.12270], [2412.12270]

$$\delta\widehat{S}^{(2)} = \frac{1}{8}\boldsymbol{K}\bar{\boldsymbol{R}}^{*}\boldsymbol{T}\Big[\widehat{\mathcal{V}}^{(0)}_{IJKL}\,\widehat{\mathcal{Q}}^{-1}_{IJ}\,\widehat{\mathcal{Q}}^{-1}_{KL}\Big] - \frac{1}{12}\boldsymbol{K}\bar{\boldsymbol{R}}^{*}\boldsymbol{T}\Big[\widehat{\mathcal{V}}^{(0)}_{IJK}\,\widehat{\mathcal{Q}}^{-1}_{IL}\,\widehat{\mathcal{Q}}^{-1}_{JM}\,\widehat{\mathcal{Q}}^{-1}_{KN}\,\widehat{\mathcal{V}}^{(0)}_{LMN}\Big]$$

Master recipe:

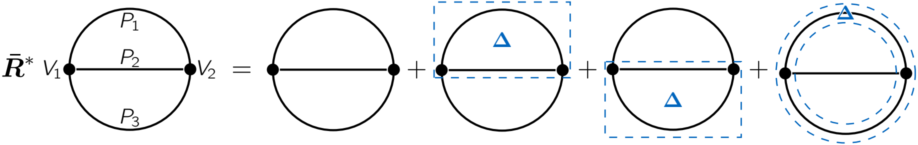
i) Construct gauge-invariant graphs w/ full background field dependence

ii) Expand in the hard loop-momentum region

iii) Subtract subdivergences w/ a local version of $\boldsymbol{R}^{*}$-operation

Herzog, Ruijl [1703.03776]

iv) Evaluate tadpole loop diagrams



γ_5-ambiguities and the limits of NDR

NDR assumptions: $(d = 4 - 2\epsilon)$

$$\{\gamma_\mu, \gamma_\nu\} = 2g_{\mu\nu}, \qquad \{\gamma_\mu, \gamma_5\} = 0, \qquad \gamma_5^2 = \mathbb{1},$$

$$\mathrm{Tr}\big[\gamma_\mu\gamma_\nu\gamma_\rho\gamma_\sigma\gamma_5\big] \xrightarrow[\epsilon\to 0]{} -4i\varepsilon_{\mu\nu\rho\sigma}.$$

Reading point ambiguity/loss of cyclicity (for γ_5-odd traces):

$$\begin{aligned} \mathrm{Tr}\big[\gamma_\alpha\gamma_\mu\gamma_\nu\gamma_\rho\gamma_\sigma\gamma^\alpha\gamma_5\big] &= 4(4+2\epsilon)i\varepsilon_{\mu\nu\rho\sigma} \\ -\mathrm{Tr}\big[\gamma^\alpha\gamma_\alpha\gamma_\mu\gamma_\nu\gamma_\rho\gamma_\sigma\gamma_5\big] &= 4(4-2\epsilon)i\varepsilon_{\mu\nu\rho\sigma} \end{aligned}$$

↯

γ_5-ambiguities and the limits of NDR

NDR assumptions: $(d = 4 - 2\epsilon)$

$$\{\gamma_\mu, \gamma_\nu\} = 2g_{\mu\nu}, \qquad \{\gamma_\mu, \gamma_5\} = 0, \qquad \gamma_5^2 = \mathbb{1},$$

$$\mathrm{Tr}\big[\gamma_\mu\gamma_\nu\gamma_\rho\gamma_\sigma\gamma_5\big] \xrightarrow[\epsilon\to 0]{} -4i\varepsilon_{\mu\nu\rho\sigma}.$$

Reading point ambiguity/loss of cyclicity (for γ_5-odd traces):

$$\mathrm{Tr}\big[\gamma_\alpha\gamma_\mu\gamma_\nu\gamma_\rho\gamma_\sigma\gamma^\alpha\gamma_5\big] = 4(4+2\epsilon)i\varepsilon_{\mu\nu\rho\sigma}$$

$$-\,\mathrm{Tr}\big[\gamma^\alpha\gamma_\alpha\gamma_\mu\gamma_\nu\gamma_\rho\gamma_\sigma\gamma_5\big] = 4(4-2\epsilon)i\varepsilon_{\mu\nu\rho\sigma}$$

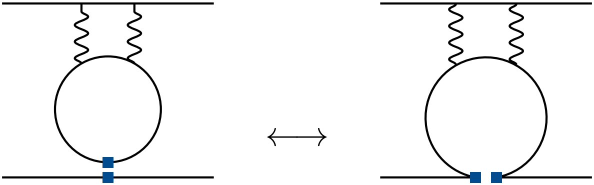
↯

Operator class	Problematic diagrams	Affected β-functions
Reading point at the dimension-six vertex		
Scalar ψ^4	—	—
Vector ψ^4	—	—
$\psi^2 H^2 D$	—	—
$\psi^2 H^3$	1	CP-odd $X^2 H^2$
$\psi^2 X H$	11	$\psi^2 X H$, CP-odd $X^2 H^2$, and CP-odd X^3
Averaging over vertex reading points		
Scalar ψ^4	1	CP-odd $X^2 H^2$
$\psi^2 X H$	1	$\psi^2 X H$
$H^2 X^2$	1	$\psi^2 H^3$
X^3 and $H^4 D^2$	—	—
Weinberg operator	—	—

Example: how some ambiguities can resolved

The reading-point for almost all four-fermion operators can be **verified through Fierzing** to another operator basis

Strategy devised for the LEFT: Buras *et al.* [hep-ph/9211304]; Aebischer *et al.* [2501.08384]

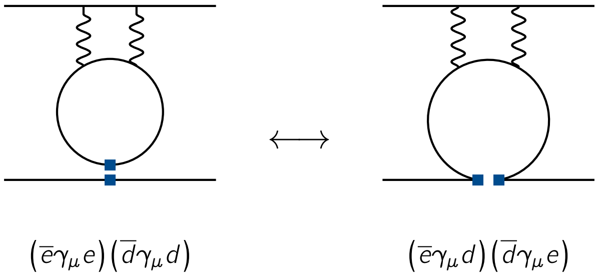


$\left(\overline{e}\gamma_\mu e\right)\left(\overline{d}\gamma_\mu d\right)$ $\quad$ $\left(\overline{e}\gamma_\mu d\right)\left(\overline{d}\gamma_\mu e\right)$

Example: how some ambiguities can resolved

The reading-point for almost all four-fermion operators can be **verified through Fierzing** to another operator basis

Strategy devised for the LEFT: Buras *et al.* [hep-ph/9211304]; Aebischer *et al.* [2501.08384]



Fierzing tensor-current operators involves an ambiguous evanescent contribution causing the trick to fail: **we abandon the Warsaw basis**

The “Mainz” basis

$(\bar{L}L)(\bar{R}R)$	
$O_{\ell e}^{prst}$	$(\bar{\ell}^p\,\gamma_\mu\,\ell^r)(\bar{e}^s\,\gamma^\mu\,e^t)$
$O_{\ell u}^{prst}$	$(\bar{\ell}^p\,\gamma_\mu\,\ell^r)(\bar{u}^s\,\gamma^\mu\,u^t)$
$O_{\ell d}^{prst}$	$(\bar{\ell}^p\,\gamma_\mu\,\ell^r)(\bar{d}^s\,\gamma^\mu\,d^t)$
O_{qe}^{prst}	$(\bar{q}^p\,\gamma_\mu\,q^r)(\bar{e}^s\,\gamma^\mu\,e^t)$
$O_{qu}^{(\parallel)\,prst}$	$(\bar{q}^p\,\gamma_\mu\,q^r)(\bar{u}^s\,\gamma^\mu\,u^t)$
$O_{qu}^{(\times)\,prst}$	$(\bar{q}_a^p\,\gamma_\mu\,q^{br})(\bar{u}_b^s\,\gamma^\mu\,u^{at})$
$O_{qd}^{(\parallel)\,prst}$	$(\bar{q}^p\,\gamma_\mu\,q^r)(\bar{d}^s\,\gamma^\mu\,d^t)$
$O_{qd}^{(\times)\,prst}$	$(\bar{q}_a^p\,\gamma_\mu\,q^{br})(\bar{d}_b^s\,\gamma^\mu\,d^{at})$

$(\bar{R}R)(\bar{R}R)$	
O_{ee}^{prst}	$(\bar{e}^p\,\gamma_\mu\,e^r)(\bar{e}^s\,\gamma^\mu\,e^t)$
O_{uu}^{prst}	$(\bar{u}^p\,\gamma_\mu\,u^r)(\bar{u}^s\,\gamma^\mu\,u^t)$
O_{dd}^{prst}	$(\bar{d}^p\,\gamma_\mu\,d^r)(\bar{d}^s\,\gamma^\mu\,d^t)$
O_{eu}^{prst}	$(\bar{e}^p\,\gamma_\mu\,e^r)(\bar{u}^s\,\gamma^\mu\,u^t)$
O_{ed}^{prst}	$(\bar{e}^p\,\gamma_\mu\,e^r)(\bar{d}^s\,\gamma^\mu\,d^t)$
$O_{ud}^{(\parallel)\,prst}$	$(\bar{u}^p\,\gamma_\mu\,u^r)(\bar{d}^s\,\gamma^\mu\,d^t)$
$O_{ud}^{(\times)\,prst}$	$(\bar{u}_a^p\,\gamma_\mu\,u^{br})(\bar{d}_b^s\,\gamma^\mu\,d^{at})$

$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$	
$O_{\ell edq}^{prst}$	$(\bar{\ell}_j^p\,e^r)(\bar{d}^s\,q_j^t)$
$O_{quqd}^{(\parallel)\,prst}$	$(\bar{q}_i^p\,u^r)\varepsilon^{ij}(\bar{q}_j^s\,d^t)$
$O_{quqd}^{(\times)\,prst}$	$(\bar{q}_{ai}^p\,u^{br})\varepsilon^{ij}(\bar{q}_{bj}^s\,d^{at})$
$O_{\ell equ}^{prst}$	$(\bar{\ell}_i^p\,e^r)\varepsilon^{ij}(\bar{q}_j^s\,u^t)$
$O_{\ell uqe}^{prst}$	$(\bar{\ell}_i^p\,u^r)\varepsilon^{ij}(\bar{q}_j^s\,e^t)$

$(\bar{L}L)(\bar{L}L)$	
$O_{\ell\ell}^{prst}$	$(\bar{\ell}^p\,\gamma_\mu\,\ell^r)(\bar{\ell}^s\,\gamma^\mu\,\ell^t)$
$O_{qq}^{(\parallel)\,prst}$	$(\bar{q}^p\,\gamma_\mu\,q^r)(\bar{q}^s\,\gamma^\mu\,q^t)$
$O_{qq}^{(\times)\,prst}$	$(\bar{q}_i^p\,\gamma_\mu\,q^{jr})(\bar{q}_j^s\,\gamma^\mu\,q^{it})$
$O_{\ell q}^{(\parallel)\,prst}$	$(\bar{\ell}^p\,\gamma_\mu\,\ell^r)(\bar{q}^s\,\gamma^\mu\,q^t)$
$O_{\ell q}^{(\times)\,prst}$	$(\bar{\ell}_i^p\,\gamma_\mu\,\ell^{jr})(\bar{q}_j^s\,\gamma^\mu\,q^{it})$

See also `https://github.com/NewSMEFTBasis/basis-proposal` and discussions in the LHC EFT Working Group

The “Mainz” basis

$(\bar{L}L)(\bar{R}R)$	
$O_{\ell e}^{prst}$	$(\bar{\ell}^p\,\gamma_\mu\,\ell^r)(\bar{e}^s\,\gamma^\mu\,e^t)$
$O_{\ell u}^{prst}$	$(\bar{\ell}^p\,\gamma_\mu\,\ell^r)(\bar{u}^s\,\gamma^\mu\,u^t)$
$O_{\ell d}^{prst}$	$(\bar{\ell}^p\,\gamma_\mu\,\ell^r)(\bar{d}^s\,\gamma^\mu\,d^t)$
O_{qe}^{prst}	$(\bar{q}^p\,\gamma_\mu\,q^r)(\bar{e}^s\,\gamma^\mu\,e^t)$
$O_{qu}^{(\parallel)\,prst}$	$(\bar{q}^p\,\gamma_\mu\,q^r)(\bar{u}^s\,\gamma^\mu\,u^t)$
$O_{qu}^{(\times)\,prst}$	$(\bar{q}_a^p\,\gamma_\mu\,q^{br})(\bar{u}_b^s\,\gamma^\mu\,u^{at})$
$O_{qd}^{(\parallel)\,prst}$	$(\bar{q}^p\,\gamma_\mu\,q^r)(\bar{d}^s\,\gamma^\mu\,d^t)$
$O_{qd}^{(\times)\,prst}$	$(\bar{q}_a^p\,\gamma_\mu\,q^{br})(\bar{d}_b^s\,\gamma^\mu\,d^{at})$

$(\bar{R}R)(\bar{R}R)$	
O_{ee}^{prst}	$(\bar{e}^p\,\gamma_\mu\,e^r)(\bar{e}^s\,\gamma^\mu\,e^t)$
O_{uu}^{prst}	$(\bar{u}^p\,\gamma_\mu\,u^r)(\bar{u}^s\,\gamma^\mu\,u^t)$
O_{dd}^{prst}	$(\bar{d}^p\,\gamma_\mu\,d^r)(\bar{d}^s\,\gamma^\mu\,d^t)$
O_{eu}^{prst}	$(\bar{e}^p\,\gamma_\mu\,e^r)(\bar{u}^s\,\gamma^\mu\,u^t)$
O_{ed}^{prst}	$(\bar{e}^p\,\gamma_\mu\,e^r)(\bar{d}^s\,\gamma^\mu\,d^t)$
$O_{ud}^{(\parallel)\,prst}$	$(\bar{u}^p\,\gamma_\mu\,u^r)(\bar{d}^s\,\gamma^\mu\,d^t)$
$O_{ud}^{(\times)\,prst}$	$(\bar{u}_a^p\,\gamma_\mu\,u^{br})(\bar{d}_b^s\,\gamma^\mu\,d^{at})$

Avoiding uncontrolled γ_5 traces from tensor currents:

$$Q_{\ell equ}^{(3)} = (\bar{\ell}_i\sigma_{\mu\nu}e)\varepsilon^{ij}(\bar{q}_j\sigma^{\mu\nu}u) \qquad \longrightarrow \qquad O_{\ell uqe} = (\bar{\ell}_i u)\varepsilon^{ij}(\bar{q}_j e)$$

$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$	
$O_{\ell edq}^{prst}$	$(\bar{\ell}_j^p\,e^r)(\bar{d}^s\,q_j^t)$
$O_{quqd}^{(\parallel)\,prst}$	$(\bar{q}_i^p\,u^r)\varepsilon^{ij}(\bar{q}_j^s\,d^t)$
$O_{quqd}^{(\times)\,prst}$	$(\bar{q}_{ai}^p\,u^{br})\varepsilon^{ij}(\bar{q}_{bj}^s\,d^{at})$
$O_{\ell equ}^{prst}$	$(\bar{\ell}_i^p\,e^r)\varepsilon^{ij}(\bar{q}_j^s\,u^t)$
$O_{\ell uqe}^{prst}$	$(\bar{\ell}_i^p\,u^r)\varepsilon^{ij}(\bar{q}_j^s\,e^t)$

$(\bar{L}L)(\bar{L}L)$	
$O_{\ell\ell}^{prst}$	$(\bar{\ell}^p\,\gamma_\mu\,\ell^r)(\bar{\ell}^s\,\gamma^\mu\,\ell^t)$
$O_{qq}^{(\parallel)\,prst}$	$(\bar{q}^p\,\gamma_\mu\,q^r)(\bar{q}^s\,\gamma^\mu\,q^t)$
$O_{qq}^{(\times)\,prst}$	$(\bar{q}_i^p\,\gamma_\mu\,q^{jr})(\bar{q}_j^s\,\gamma^\mu\,q^{it})$
$O_{\ell q}^{(\parallel)\,prst}$	$(\bar{\ell}^p\,\gamma_\mu\,\ell^r)(\bar{q}^s\,\gamma^\mu\,q^t)$
$O_{\ell q}^{(\times)\,prst}$	$(\bar{\ell}_i^p\,\gamma_\mu\,\ell^{jr})(\bar{q}_j^s\,\gamma^\mu\,q^{it})$

See also `https://github.com/NewSMEFTBasis/basis-proposal` and discussions in the LHC EFT Working Group

The “Mainz” basis

$(\bar{L}L)(\bar{R}R)$	
$O_{\ell e}^{prst}$	$(\bar{\ell}^p\,\gamma_\mu\,\ell^r)(\bar{e}^s\,\gamma^\mu\,e^t)$
$O_{\ell u}^{prst}$	$(\bar{\ell}^p\,\gamma_\mu\,\ell^r)(\bar{u}^s\,\gamma^\mu\,u^t)$
$O_{\ell d}^{prst}$	$(\bar{\ell}^p\,\gamma_\mu\,\ell^r)(\bar{d}^s\,\gamma^\mu\,d^t)$
O_{qe}^{prst}	$(\bar{q}^p\,\gamma_\mu\,q^r)(\bar{e}^s\,\gamma^\mu\,e^t)$
$O_{qu}^{(\parallel)\,prst}$	$(\bar{q}^p\,\gamma_\mu\,q^r)(\bar{u}^s\,\gamma^\mu\,u^t)$
$O_{qu}^{(\times)\,prst}$	$(\bar{q}_a^p\,\gamma_\mu\,q^{br})(\bar{u}_b^s\,\gamma^\mu\,u^{at})$
$O_{qd}^{(\parallel)\,prst}$	$(\bar{q}^p\,\gamma_\mu\,q^r)(\bar{d}^s\,\gamma^\mu\,d^t)$
$O_{qd}^{(\times)\,prst}$	$(\bar{q}_a^p\,\gamma_\mu\,q^{br})(\bar{d}_b^s\,\gamma^\mu\,d^{at})$

$(\bar{R}R)(\bar{R}R)$	
O_{ee}^{prst}	$(\bar{e}^p\,\gamma_\mu\,e^r)(\bar{e}^s\,\gamma^\mu\,e^t)$
O_{uu}^{prst}	$(\bar{u}^p\,\gamma_\mu\,u^r)(\bar{u}^s\,\gamma^\mu\,u^t)$
O_{dd}^{prst}	$(\bar{d}^p\,\gamma_\mu\,d^r)(\bar{d}^s\,\gamma^\mu\,d^t)$
O_{eu}^{prst}	$(\bar{e}^p\,\gamma_\mu\,e^r)(\bar{u}^s\,\gamma^\mu\,u^t)$
O_{ed}^{prst}	$(\bar{e}^p\,\gamma_\mu\,e^r)(\bar{d}^s\,\gamma^\mu\,d^t)$
$O_{ud}^{(\parallel)\,prst}$	$(\bar{u}^p\,\gamma_\mu\,u^r)(\bar{d}^s\,\gamma^\mu\,d^t)$
$O_{ud}^{(\times)\,prst}$	$(\bar{u}_a^p\,\gamma_\mu\,u^{br})(\bar{d}_b^s\,\gamma^\mu\,d^{at})$

$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$	
$O_{\ell edq}^{prst}$	$(\bar{\ell}_j^p\,e^r)(\bar{d}^s\,q_j^t)$
$O_{quqd}^{(\parallel)\,prst}$	$(\bar{q}_i^p\,u^r)\varepsilon^{ij}(\bar{q}_j^s\,d^t)$
$O_{quqd}^{(\times)\,prst}$	$(\bar{q}_{ai}^p\,u^{br})\varepsilon^{ij}(\bar{q}_{bj}^s\,d^{at})$
$O_{\ell equ}^{prst}$	$(\bar{\ell}_i^p\,e^r)\varepsilon^{ij}(\bar{q}_j^s\,u^t)$
$O_{\ell uqe}^{prst}$	$(\bar{\ell}_i^p\,u^r)\varepsilon^{ij}(\bar{q}_j^s\,e^t)$

$(\bar{L}L)(\bar{L}L)$	
$O_{\ell\ell}^{prst}$	$(\bar{\ell}^p\,\gamma_\mu\,\ell^r)(\bar{\ell}^s\,\gamma^\mu\,\ell^t)$
$O_{qq}^{(\parallel)\,prst}$	$(\bar{q}^p\,\gamma_\mu\,q^r)(\bar{q}^s\,\gamma^\mu\,q^t)$
$O_{qq}^{(\times)\,prst}$	$(\bar{q}_i^p\,\gamma_\mu\,q^{jr})(\bar{q}_j^s\,\gamma^\mu\,q^{it})$
$O_{\ell q}^{(\parallel)\,prst}$	$(\bar{\ell}^p\,\gamma_\mu\,\ell^r)(\bar{q}^s\,\gamma^\mu\,q^t)$
$O_{\ell q}^{(\times)\,prst}$	$(\bar{\ell}_i^p\,\gamma_\mu\,\ell^{jr})(\bar{q}_j^s\,\gamma^\mu\,q^{it})$

See also `https://github.com/NewSMEFTBasis/basis-proposal` and discussions in the LHC EFT Working Group

The “Mainz” basis

$(\bar{L}L)(\bar{R}R)$	
$O_{\ell e}^{prst}$	$(\bar{\ell}^p\,\gamma_\mu\,\ell^r)\,(\bar{e}^s\,\gamma^\mu\,e^t)$
$O_{\ell u}^{prst}$	$(\bar{\ell}^p\,\gamma_\mu\,\ell^r)\,(\bar{u}^s\,\gamma^\mu\,u^t)$
$O_{\ell d}^{prst}$	$(\bar{\ell}^p\,\gamma_\mu\,\ell^r)\,(\bar{d}^s\,\gamma^\mu\,d^t)$
O_{qe}^{prst}	$(\bar{q}^p\,\gamma_\mu\,q^r)\,(\bar{e}^s\,\gamma^\mu\,e^t)$
$O_{qu}^{(\parallel)\,prst}$	$(\bar{q}^p\,\gamma_\mu\,q^r)\,(\bar{u}^s\,\gamma^\mu\,u^t)$
$O_{qu}^{(\times)\,prst}$	$(\bar{q}^p_a\,\gamma_\mu\,q^{br})\,(\bar{u}^s_b\,\gamma^\mu\,u^{at})$
$O_{qd}^{(\parallel)\,prst}$	$(\bar{q}^p\,\gamma_\mu\,q^r)\,(\bar{d}^s\,\gamma^\mu\,d^t)$
$O_{qd}^{(\times)\,prst}$	$(\bar{q}^p_a\,\gamma_\mu\,q^{br})\,(\bar{d}^s_b\,\gamma^\mu\,d^{at})$

$(\bar{R}R)(\bar{R}R)$	
O_{ee}^{prst}	$(\bar{e}^p\,\gamma_\mu\,e^r)\,(\bar{e}^s\,\gamma^\mu\,e^t)$
O_{uu}^{prst}	$(\bar{u}^p\,\gamma_\mu\,u^r)\,(\bar{u}^s\,\gamma^\mu\,u^t)$
O_{dd}^{prst}	$(\bar{d}^p\,\gamma_\mu\,d^r)\,(\bar{d}^s\,\gamma^\mu\,d^t)$
O_{eu}^{prst}	$(\bar{e}^p\,\gamma_\mu\,e^r)\,(\bar{u}^s\,\gamma^\mu\,u^t)$
O_{ed}^{prst}	$(\bar{e}^p\,\gamma_\mu\,e^r)\,(\bar{d}^s\,\gamma^\mu\,d^t)$
$O_{ud}^{(\parallel)\,prst}$	$(\bar{u}^p\,\gamma_\mu\,u^r)\,(\bar{d}^s\,\gamma^\mu\,d^t)$
$O_{ud}^{(\times)\,prst}$	$(\bar{u}^p_a\,\gamma_\mu\,u^{br})\,(\bar{d}^s_b\,\gamma^\mu\,d^{at})$

Simplify group algebra:

$$(t^A)^i{}_j(t^A)^k{}_\ell = \tfrac{1}{2}\delta^i{}_\ell\delta^k{}_j - \tfrac{1}{2N}\delta^i{}_j\delta^k{}_\ell$$

$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$	
$O_{\ell edq}^{prst}$	$(\bar{\ell}^p_j\,e^r)\,(\bar{d}^s\,q^t_j)$
$O_{quqd}^{(\parallel)\,prst}$	$(\bar{q}^p_i\,u^r)\varepsilon^{ij}(\bar{q}^s_j\,d^t)$
$O_{quqd}^{(\times)\,prst}$	$(\bar{q}^p_{ai}\,u^{br})\varepsilon^{ij}(\bar{q}^s_{bj}\,d^{at})$
$O_{\ell equ}^{prst}$	$(\bar{\ell}^p_i\,e^r)\varepsilon^{ij}(\bar{q}^s_j\,u^t)$
$O_{\ell uqe}^{prst}$	$(\bar{\ell}^p_i\,u^r)\varepsilon^{ij}(\bar{q}^s_j\,e^t)$

$(\bar{L}L)(\bar{L}L)$	
$O_{\ell\ell}^{prst}$	$(\bar{\ell}^p\,\gamma_\mu\,\ell^r)\,(\bar{\ell}^s\,\gamma^\mu\,\ell^t)$
$O_{qq}^{(\parallel)\,prst}$	$(\bar{q}^p\,\gamma_\mu\,q^r)\,(\bar{q}^s\,\gamma^\mu\,q^t)$
$O_{qq}^{(\times)\,prst}$	$(\bar{q}^p_i\,\gamma_\mu\,q^{jr})\,(\bar{q}^s_j\,\gamma^\mu\,q^{it})$
$O_{\ell q}^{(\parallel)\,prst}$	$(\bar{\ell}^p\,\gamma_\mu\,\ell^r)\,(\bar{q}^s\,\gamma^\mu\,q^t)$
$O_{\ell q}^{(\times)\,prst}$	$(\bar{\ell}^p_i\,\gamma_\mu\,\ell^{jr})\,(\bar{q}^s_j\,\gamma^\mu\,q^{it})$

See also `https://github.com/NewSMEFTBasis/basis-proposal` and discussions in the LHC EFT Working Group

The “Mainz” basis

X^3	
O_W	$g_L^3 f^{IJK} W_\mu^{I\,\nu} W_\nu^{J\,\rho} W_\rho^{K\,\mu}$
O_G	$g_s^3 f^{ABC} G_\mu^{A\,\nu} G_\nu^{B\,\rho} G_\rho^{C\,\mu}$
$O_{\widetilde{W}}$	$g_L^3 f^{IJK} \widetilde{W}_\mu^{I\,\nu} W_\nu^{J\,\rho} W_\rho^{K\,\mu}$
$O_{\widetilde{G}}$	$g_s^3 f^{ABC} \widetilde{G}_\mu^{A\,\nu} G_\nu^{B\,\rho} G_\rho^{C\,\mu}$

$H^4 D^2$ and H^6	
O_H	$(H^\dagger H)^3$
$O_{HD}^{(\Vert)}$	$(H^\dagger H)(D_\mu H^\dagger D^\mu H)$
$O_{HD}^{(\times)}$	$H_i^* H^j D_\mu H_j^* D^\mu H^i$

$\psi^2 H^3$	
O_{eH}^{pr}	$(H^\dagger H)(\bar{\ell}^p e^r H)$
O_{uH}^{pr}	$(H^\dagger H)(\bar{q}^p u^r \widetilde{H})$
O_{dH}^{pr}	$(H^\dagger H)(\bar{q}^p d^r H)$

$X^2 H^2$	
O_{HG}	$g_s^2 (H^\dagger H) G^{A\,\mu\nu} G^A_{\mu\nu}$
$O_{H\widetilde{G}}$	$g_s^2 (H^\dagger H) G^{A\,\mu\nu} \widetilde{G}^A_{\mu\nu}$
O_{HW}	$g_L^2 (H^\dagger H) W^{I\,\mu\nu} W^I_{\mu\nu}$
$O_{H\widetilde{W}}$	$g_L^2 (H^\dagger H) W^{I\,\mu\nu} \widetilde{W}^I_{\mu\nu}$
O_{HB}	$g_Y^2 (H^\dagger H) B^{\mu\nu} B_{\mu\nu}$
$O_{H\widetilde{B}}$	$g_Y^2 (H^\dagger H) B^{\mu\nu} \widetilde{B}_{\mu\nu}$
O_{HWB}	$g_Y g_L (H^\dagger t^I H) B^{\mu\nu} W^I_{\mu\nu}$
$O_{H\widetilde{W}B}$	$g_Y g_L (H^\dagger t^I H) B^{\mu\nu} \widetilde{W}^I_{\mu\nu}$

$\psi^2 X H$	
O_{eW}^{pr}	$g_L (\bar{\ell}^p \sigma^{\mu\nu} e^r t^I H) W^I_{\mu\nu}$
O_{eB}^{pr}	$g_Y (\bar{\ell}^p \sigma^{\mu\nu} e^r H) B_{\mu\nu}$
O_{uG}^{pr}	$g_s (\bar{q}^p \sigma^{\mu\nu} T^A u^r \widetilde{H}) G^A_{\mu\nu}$
O_{uW}^{pr}	$g_L (\bar{q}^p \sigma^{\mu\nu} u^r t^I \widetilde{H}) W^I_{\mu\nu}$
O_{uB}^{pr}	$g_Y (\bar{q}^p \sigma^{\mu\nu} u^r \widetilde{H}) B_{\mu\nu}$
O_{dG}^{pr}	$g_s (\bar{q}^p \sigma^{\mu\nu} T^A d^r H) G^A_{\mu\nu}$
O_{dW}^{pr}	$g_L (\bar{q}^p \sigma^{\mu\nu} d^r t^I H) W^I_{\mu\nu}$
O_{dB}^{pr}	$g_Y (\bar{q}^p \sigma^{\mu\nu} d^r H) B_{\mu\nu}$

$\psi^2 H^2 D$	
$O_{H\ell}^{(\Vert)\,pr}$	$i(H^\dagger \overleftrightarrow{D}_\mu H)(\bar{\ell}^p \gamma^\mu \ell^r)$
$O_{H\ell}^{(\times)\,pr}$	$i(H_i^* \overleftrightarrow{D}_\mu H^j)(\bar{\ell}_j^p \gamma^\mu \ell^{ir})$
O_{He}^{pr}	$i(H^\dagger \overleftrightarrow{D}_\mu H)(\bar{e}^p \gamma^\mu e^r)$
$O_{Hq}^{(\Vert)\,pr}$	$i(H^\dagger \overleftrightarrow{D}_\mu H)(\bar{q}^p \gamma^\mu q^r)$
$O_{Hq}^{(\times)\,pr}$	$i(H_i^* \overleftrightarrow{D}_\mu H^j)(\bar{q}_j^p \gamma^\mu q^{ir})$
O_{Hu}^{pr}	$i(H^\dagger \overleftrightarrow{D}_\mu H)(\bar{u}^p \gamma^\mu u^r)$
O_{Hd}^{pr}	$i(H^\dagger \overleftrightarrow{D}_\mu H)(\bar{d}^p \gamma^\mu d^r)$
O_{Hud}^{pr}	$i(\widetilde{H}^\dagger D_\mu H)(\bar{u}^p \gamma^\mu d^r)$

See also `https://github.com/NewSMEFTBasis/basis-proposal` and discussions in the LHC EFT Working Group

The "Mainz" basis

X^3	
O_W	$g_L^3 f^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$
O_G	$g_s^3 f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$
$O_{\widetilde{W}}$	$g_L^3 f^{IJK} \widetilde{W}_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$
$O_{\widetilde{G}}$	$g_s^3 f^{ABC} \widetilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$

H^4D^2 and H^6	
O_H	$(H^\dagger H)^3$
$O_{HD}^{(\parallel)}$	$(H^\dagger H)(D_\mu H^\dagger D^\mu H)$
$O_{HD}^{(\times)}$	$H_i^* H^j D_\mu H_j^* D^\mu H^i$

$\psi^2 H^3$	
O_{eH}^{pr}	$(H^\dagger H)(\bar{\ell}^p e^r H)$
O_{uH}^{pr}	$(H^\dagger H)(\bar{q}^p u^r \widetilde{H})$
O_{dH}^{pr}	$(H^\dagger H)(\bar{q}^p d^r H)$

X^2H^2	
O_{HG}	$g_s^2 (H^\dagger H) G^{A\mu\nu} G^A_{\mu\nu}$
$O_{H\widetilde{G}}$	$g_s^2 (H^\dagger H) G^{A\mu\nu} \widetilde{G}^A_{\mu\nu}$
O_{HW}	$g_L^2 (H^\dagger H) W^{I\mu\nu} W^I_{\mu\nu}$
$O_{H\widetilde{W}}$	$g_L^2 (H^\dagger H) W^{I\mu\nu} \widetilde{W}^I_{\mu\nu}$
O_{HB}	$g_Y^2 (H^\dagger H) B^{\mu\nu} B_{\mu\nu}$
$O_{H\widetilde{B}}$	$g_Y^2 (H^\dagger H) B^{\mu\nu} \widetilde{B}_{\mu\nu}$
O_{HWB}	$g_Y g_L (H^\dagger t^I H) B^{\mu\nu} W^I_{\mu\nu}$
$O_{H\widetilde{W}B}$	$g_Y g_L (H^\dagger t^I H) B^{\mu\nu} \widetilde{W}^I_{\mu\nu}$

$\psi^2 XH$	
O_{eW}^{pr}	$g_L (\bar{\ell}^p \sigma^{\mu\nu} e^r t^I H) W^I_{\mu\nu}$
O_{eB}^{pr}	$g_Y (\bar{\ell}^p \sigma^{\mu\nu} e^r H) B_{\mu\nu}$
O_{uG}^{pr}	$g_s (\bar{q}^p \sigma^{\mu\nu} T^A u^r \widetilde{H}) G^A_{\mu\nu}$
O_{uW}^{pr}	$g_L (\bar{q}^p \sigma^{\mu\nu} u^r t^I \widetilde{H}) W^I_{\mu\nu}$
O_{uB}^{pr}	$g_Y (\bar{q}^p \sigma^{\mu\nu} u^r \widetilde{H}) B_{\mu\nu}$
O_{dG}^{pr}	$g_s (\bar{q}^p \sigma^{\mu\nu} T^A d^r H) G^A_{\mu\nu}$
O_{dW}^{pr}	$g_L (\bar{q}^p \sigma^{\mu\nu} d^r t^I H) W^I_{\mu\nu}$
O_{dB}^{pr}	$g_Y (\bar{q}^p \sigma^{\mu\nu} d^r H) B_{\mu\nu}$

$\psi^2 H^2 D$	
$O_{H\ell}^{(\parallel)\,pr}$	$i(H^\dagger \overleftrightarrow{D}_\mu H)(\bar{\ell}^p \gamma^\mu \ell^r)$
$O_{H\ell}^{(\times)\,pr}$	$i(H_i^* \overleftrightarrow{D}_\mu H^j)(\bar{\ell}_j^p \gamma^\mu \ell^{ir})$
O_{He}^{pr}	$i(H^\dagger \overleftrightarrow{D}_\mu H)(\bar{e}^p \gamma^\mu e^r)$
$O_{Hq}^{(\parallel)\,pr}$	$i(H^\dagger \overleftrightarrow{D}_\mu H)(\bar{q}^p \gamma^\mu q^r)$
$O_{Hq}^{(\times)\,pr}$	$i(H_i^* \overleftrightarrow{D}_\mu H^j)(\bar{q}_j^p \gamma^\mu q^{ir})$
O_{Hu}^{pr}	$i(H^\dagger \overleftrightarrow{D}_\mu H)(\bar{u}^p \gamma^\mu u^r)$
O_{Hd}^{pr}	$i(H^\dagger \overleftrightarrow{D}_\mu H)(\bar{d}^p \gamma^\mu d^r)$
O_{Hud}^{pr}	$i(\widetilde{H}^\dagger D_\mu H)(\bar{u}^p \gamma^\mu d^r)$

Remove derivatives acting on multiple fields

$$Q_{\Box H} = (H^\dagger H)\Box(H^\dagger H) \quad\longrightarrow\quad O_{HD}^{(\parallel)} = (H^\dagger H)(D_\mu H^\dagger D^\mu H)$$

See also https://github.com/NewSMEFTBasis/basis-proposal and discussions in the LHC EFT Working Group

The “Mainz” basis

X^3	
O_W	$g_L^3 f^{IJK}\, W_\mu^{I\,\nu}\, W_\nu^{J\,\rho}\, W_\rho^{K\,\mu}$
O_G	$g_s^3 f^{ABC}\, G_\mu^{A\,\nu}\, G_\nu^{B\,\rho}\, G_\rho^{C\,\mu}$
$O_{\widetilde{W}}$	$g_L^3 f^{IJK}\, \widetilde{W}_\mu^{I\,\nu}\, W_\nu^{J\,\rho}\, W_\rho^{K\,\mu}$
$O_{\widetilde{G}}$	$g_s^3 f^{ABC}\, \widetilde{G}_\mu^{A\,\nu}\, G_\nu^{B\,\rho}\, G_\rho^{C\,\mu}$

H^4D^2 and H^6	
O_H	$(H^\dagger H)^3$
$O_{HD}^{(\parallel)}$	$(H^\dagger H)(D_\mu H^\dagger D^\mu H)$
$O_{HD}^{(\times)}$	$H_i^* H^j\, D_\mu H_j^* D^\mu H^i$

$\psi^2 H^3$	
O_{eH}^{pr}	$(H^\dagger H)(\bar{\ell}^p e^r H)$
O_{uH}^{pr}	$(H^\dagger H)(\bar{q}^p u^r \widetilde{H})$
O_{dH}^{pr}	$(H^\dagger H)(\bar{q}^p d^r H)$

$X^2 H^2$	
O_{HG}	$g_s^2 (H^\dagger H)\, G^{A\,\mu\nu}\, G_{\mu\nu}^A$
$O_{H\widetilde{G}}$	$g_s^2 (H^\dagger H)\, G^{A\,\mu\nu}\, \widetilde{G}_{\mu\nu}^A$
O_{HW}	$g_L^2 (H^\dagger H)\, W^{I\,\mu\nu}\, W_{\mu\nu}^I$
$O_{H\widetilde{W}}$	$g_L^2 (H^\dagger H)\, W^{I\,\mu\nu}\, \widetilde{W}_{\mu\nu}^I$
O_{HB}	$g_Y^2 (H^\dagger H)\, B^{\mu\nu}\, B_{\mu\nu}$
$O_{H\widetilde{B}}$	$g_Y^2 (H^\dagger H)\, B^{\mu\nu}\, \widetilde{B}_{\mu\nu}$
O_{HWB}	$g_Y g_L (H^\dagger t^I H) B^{\mu\nu}\, W_{\mu\nu}^I$
$O_{H\widetilde{W}B}$	$g_Y g_L (H^\dagger t^I H) B^{\mu\nu}\, \widetilde{W}_{\mu\nu}^I$

$\psi^2 X H$	
O_{eW}^{pr}	$g_L (\bar{\ell}^p \sigma^{\mu\nu} e^r t^I H) W_{\mu\nu}^I$
O_{eB}^{pr}	$g_Y (\bar{\ell}^p\, \sigma^{\mu\nu} e^r H) B_{\mu\nu}$
O_{uG}^{pr}	$g_s (\bar{q}^p\, \sigma^{\mu\nu}\, T^A\, u^r \widetilde{H}) G_{\mu\nu}^A$
O_{uW}^{pr}	$g_L (\bar{q}^p\, \sigma^{\mu\nu} u^r t^I \widetilde{H}) W_{\mu\nu}^I$
O_{uB}^{pr}	$g_Y (\bar{q}^p\, \sigma^{\mu\nu}\, u^r \widetilde{H}) B_{\mu\nu}$
O_{dG}^{pr}	$g_s (\bar{q}^p\, \sigma^{\mu\nu}\, T^A d^r H) G_{\mu\nu}^A$
O_{dW}^{pr}	$g_L (\bar{q}^p\, \sigma^{\mu\nu}\, d^r t^I H) W_{\mu\nu}^I$
O_{dB}^{pr}	$g_Y (\bar{q}^p\, \sigma^{\mu\nu}\, d^r H) B_{\mu\nu}$

$\psi^2 H^2 D$	
$O_{H\ell}^{(\parallel)\,pr}$	$i(H^\dagger \overleftrightarrow{D}_\mu H)(\bar{\ell}^p \gamma^\mu\, \ell^r)$
$O_{H\ell}^{(\times)\,pr}$	$i(H_i^* \overleftrightarrow{D}_\mu H^j)(\bar{\ell}_j^p\, \gamma^\mu\, \ell^{ir})$
O_{He}^{pr}	$i(H^\dagger \overleftrightarrow{D}_\mu H)(\bar{e}^p\, \gamma^\mu\, e^r)$
$O_{Hq}^{(\parallel)\,pr}$	$i(H^\dagger \overleftrightarrow{D}_\mu H)(\bar{q}^p\, \gamma^\mu\, q^r)$
$O_{Hq}^{(\times)\,pr}$	$i(H_i^* \overleftrightarrow{D}_\mu H^j)(\bar{q}_j^p\, \gamma^\mu\, q^{ir})$
O_{Hu}^{pr}	$i(H^\dagger \overleftrightarrow{D}_\mu H)(\bar{u}^p\, \gamma^\mu\, u^r)$
O_{Hd}^{pr}	$i(H^\dagger \overleftrightarrow{D}_\mu H)(\bar{d}^p\, \gamma^\mu\, d^r)$
O_{Hud}^{pr}	$i(\widetilde{H}^\dagger D_\mu H)(\bar{u}^p\, \gamma^\mu\, d^r)$

See also `https://github.com/NewSMEFTBasis/basis-proposal` and discussions in the LHC EFT Working Group

The "Mainz" basis

X^3	
O_W	$g_L^3 f^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$
O_G	$g_s^3 f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$
$O_{\widetilde{W}}$	$g_L^3 f^{IJK} \widetilde{W}_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$
$O_{\widetilde{G}}$	$g_s^3 f^{ABC} \widetilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$

H^4D^2 and H^6	
O_H	$(H^\dagger H)^3$
$O_{HD}^{(\parallel)}$	$(H^\dagger H)(D_\mu H^\dagger D^\mu H)$
$O_{HD}^{(\times)}$	$H_i^* H^j D_\mu H_j^* D^\mu H^i$

$\psi^2 H^3$	
O_{eH}^{pr}	$(H^\dagger H)(\bar{\ell}^p e^r H)$
O_{uH}^{pr}	$(H^\dagger H)(\bar{q}^p u^r \widetilde{H})$
O_{dH}^{pr}	$(H^\dagger H)(\bar{q}^p d^r H)$

X^2H^2	
O_{HG}	$g_s^2 (H^\dagger H) G^{A\mu\nu} G_{\mu\nu}^A$
$O_{H\widetilde{G}}$	$g_s^2 (H^\dagger H) G^{A\mu\nu} \widetilde{G}_{\mu\nu}^A$
O_{HW}	$g_L^2 (H^\dagger H) W^{I\mu\nu} W_{\mu\nu}^I$
$O_{H\widetilde{W}}$	$g_L^2 (H^\dagger H) W^{I\mu\nu} \widetilde{W}_{\mu\nu}^I$
O_{HB}	$g_Y^2 (H^\dagger H) B^{\mu\nu} B_{\mu\nu}$
$O_{H\widetilde{B}}$	$g_Y^2 (H^\dagger H) B^{\mu\nu} \widetilde{B}_{\mu\nu}$
O_{HWB}	$g_Y g_L (H^\dagger t^I H) B^{\mu\nu} W_{\mu\nu}^I$
$O_{H\widetilde{W}B}$	$g_Y g_L (H^\dagger t^I H) B^{\mu\nu} \widetilde{W}_{\mu\nu}^I$

$\psi^2 XH$	
O_{eW}^{pr}	$g_L (\bar{\ell}^p \sigma^{\mu\nu} e^r t^I H) W_{\mu\nu}^I$
O_{eB}^{pr}	$g_Y (\bar{\ell}^p \sigma^{\mu\nu} e^r H) B_{\mu\nu}$
O_{uG}^{pr}	$g_s (\bar{q}^p \sigma^{\mu\nu} T^A u^r \widetilde{H}) G_{\mu\nu}^A$
O_{uW}^{pr}	$g_L (\bar{q}^p \sigma^{\mu\nu} u^r t^I \widetilde{H}) W_{\mu\nu}^I$
O_{uB}^{pr}	$g_Y (\bar{q}^p \sigma^{\mu\nu} u^r \widetilde{H}) B_{\mu\nu}$
O_{dG}^{pr}	$g_s (\bar{q}^p \sigma^{\mu\nu} T^A d^r H) G_{\mu\nu}^A$
O_{dW}^{pr}	$g_L (\bar{q}^p \sigma^{\mu\nu} d^r t^I H) W_{\mu\nu}^I$
O_{dB}^{pr}	$g_Y (\bar{q}^p \sigma^{\mu\nu} d^r H) B_{\mu\nu}$

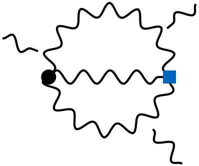
$\psi^2 H^2 D$	
$O_{H\ell}^{(\parallel)pr}$	$i(H^\dagger \overleftrightarrow{D}_\mu H)(\bar{\ell}^p \gamma^\mu \ell^r)$
$O_{H\ell}^{(\times)pr}$	$i(H_i^* \overleftrightarrow{D}_\mu H^j)(\bar{\ell}_j^p \gamma^\mu \ell^{ir})$
O_{He}^{pr}	$i(H^\dagger \overleftrightarrow{D}_\mu H)(\bar{e}^p \gamma^\mu e^r)$
$O_{Hq}^{(\parallel)pr}$	$i(H^\dagger \overleftrightarrow{D}_\mu H)(\bar{q}^p \gamma^\mu q^r)$
$O_{Hq}^{(\times)pr}$	$i(H_i^* \overleftrightarrow{D}_\mu H^j)(\bar{q}_j^p \gamma^\mu q^{ir})$
O_{Hu}^{pr}	$i(H^\dagger \overleftrightarrow{D}_\mu H)(\bar{u}^p \gamma^\mu u^r)$
O_{Hd}^{pr}	$i(H^\dagger \overleftrightarrow{D}_\mu H)(\bar{d}^p \gamma^\mu d^r)$
O_{Hud}^{pr}	$i(\widetilde{H}^\dagger D_\mu H)(\bar{u}^p \gamma^\mu d^r)$

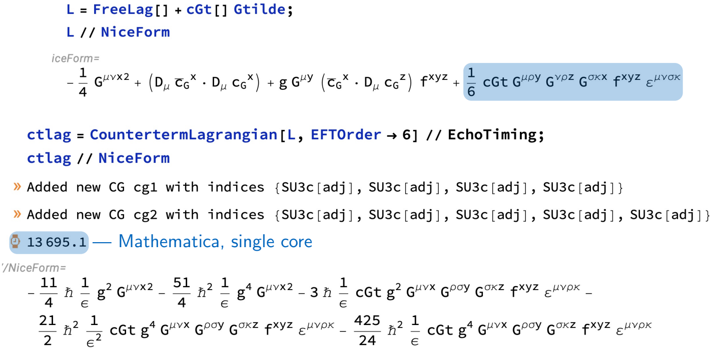
Canonical gauge coupling normalization:

$$X_{\mu\nu} \longrightarrow g_X X_{\mu\nu}$$

See also `https://github.com/NewSMEFTBasis/basis-proposal` and discussions in the LHC EFT Working Group

Private version of MATCHETE





```
L = FreeLag[] + cGt[] Gtilde;
L // NiceForm
```

iceForm=

$$-\frac{1}{4}\,G^{\mu\nu x\,2}+\left(D_\mu\,\bar{c}_G{}^{x}\cdot D_\mu\,c_G{}^{x}\right)+g\,G^{\mu y}\left(\bar{c}_G{}^{x}\cdot D_\mu\,c_G{}^{z}\right)f^{xyz}+\frac{1}{6}\,\mathrm{cGt}\,G^{\mu\rho y}\,G^{\nu\rho z}\,G^{\sigma\kappa x}\,f^{xyz}\,\varepsilon^{\mu\nu\sigma\kappa}$$

```
ctlag = CountertermLagrangian[L, EFTOrder → 6] // EchoTiming;
ctlag // NiceForm
```

```
» Added new CG cg1 with indices {SU3c[adj], SU3c[adj], SU3c[adj], SU3c[adj]}
» Added new CG cg2 with indices {SU3c[adj], SU3c[adj], SU3c[adj], SU3c[adj], SU3c[adj]}
```

13 695.1 — Mathematica, single core

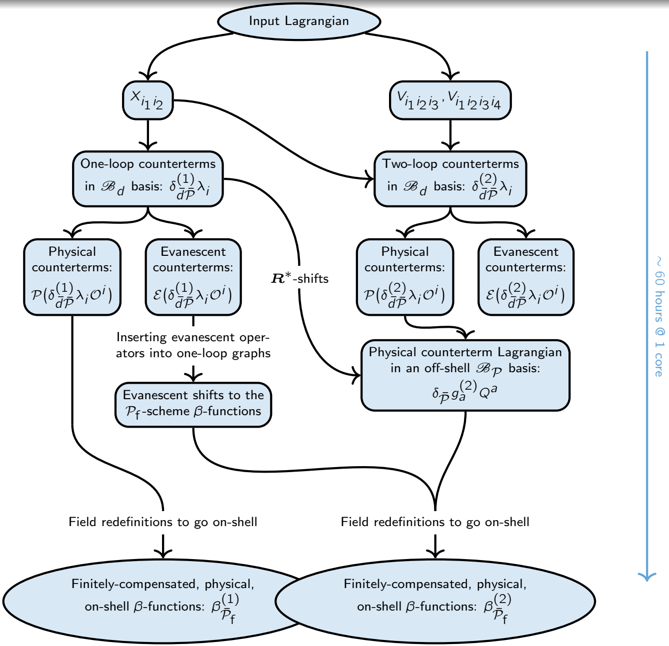
'/NiceForm=

$$-\frac{11}{4}\,\hbar\,\frac{1}{\epsilon}\,g^2\,G^{\mu\nu x\,2}-\frac{51}{4}\,\hbar^2\,\frac{1}{\epsilon}\,g^4\,G^{\mu\nu x\,2}-3\,\hbar\,\frac{1}{\epsilon}\,\mathrm{cGt}\,g^2\,G^{\mu\nu x}\,G^{\rho\sigma y}\,G^{\sigma\kappa z}\,f^{xyz}\,\varepsilon^{\mu\nu\rho\kappa}-$$
$$\frac{21}{2}\,\hbar^2\,\frac{1}{\epsilon^2}\,\mathrm{cGt}\,g^4\,G^{\mu\nu x}\,G^{\rho\sigma y}\,G^{\sigma\kappa z}\,f^{xyz}\,\varepsilon^{\mu\nu\rho\kappa}-\frac{425}{24}\,\hbar^2\,\frac{1}{\epsilon}\,\mathrm{cGt}\,g^4\,G^{\mu\nu x}\,G^{\rho\sigma y}\,G^{\sigma\kappa z}\,f^{xyz}\,\varepsilon^{\mu\nu\rho\kappa}$$

Born, Fuentes-Martín, Kvedaraitė, **AET** [2410.07320]

Result agrees with de Vries *et al.* [1907.04923]

Computation



Input Lagrangian

$X_{i_1 i_2}$

$V_{i_1 i_2 i_3}, V_{i_1 i_2 i_3 i_4}$

One-loop counterterms in $\mathscr{B}_d$ basis: $\delta^{(1)}_{\bar{d}\bar{\mathcal{P}}}\lambda_i$

Two-loop counterterms in $\mathscr{B}_d$ basis: $\delta^{(2)}_{\bar{d}\bar{\mathcal{P}}}\lambda_i$

Physical counterterms: $\mathcal{P}(\delta^{(1)}_{\bar{d}\bar{\mathcal{P}}}\lambda_i\mathcal{O}^i)$

Evanescent counterterms: $\mathcal{E}(\delta^{(1)}_{\bar{d}\bar{\mathcal{P}}}\lambda_i\mathcal{O}^i)$

$\boldsymbol{R}^*$-shifts

Physical counterterms: $\mathcal{P}(\delta^{(2)}_{\bar{d}\bar{\mathcal{P}}}\lambda_i\mathcal{O}^i)$

Evanescent counterterms: $\mathcal{E}(\delta^{(2)}_{\bar{d}\bar{\mathcal{P}}}\lambda_i\mathcal{O}^i)$

Inserting evanescent operators into one-loop graphs

Evanescent shifts to the $\mathcal{P}_\mathrm{f}$-scheme β-functions

Physical counterterm Lagrangian in an off-shell $\mathscr{B}_\mathcal{P}$ basis: $\delta_{\bar{\mathcal{P}}} g_a^{(2)} Q^a$

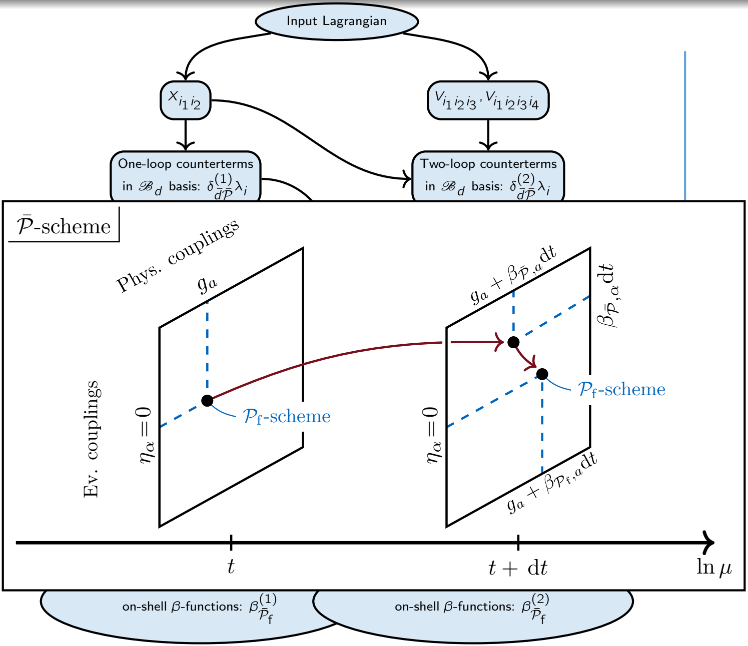
Field redefinitions to go on-shell

Field redefinitions to go on-shell

Finitely-compensated, physical, on-shell β-functions: $\beta^{(1)}_{\bar{\mathcal{P}}_\mathrm{f}}$

Finitely-compensated, physical, on-shell β-functions: $\beta^{(2)}_{\bar{\mathcal{P}}_\mathrm{f}}$

Computation



Input Lagrangian

$X_{i_1 i_2}$

$V_{i_1 i_2 i_3}, V_{i_1 i_2 i_3 i_4}$

One-loop counterterms in $\mathscr{B}_d$ basis: $\delta^{(1)}_{d\bar{\mathcal{P}}}\lambda_i$

Two-loop counterterms in $\mathscr{B}_d$ basis: $\delta^{(2)}_{d\bar{\mathcal{P}}}\lambda_i$

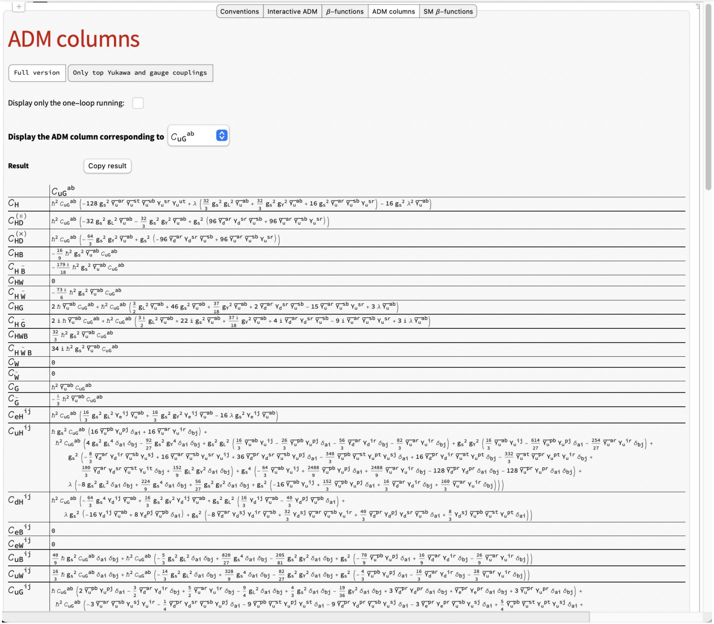
on-shell β-functions: $\beta^{(1)}_{\bar{\mathcal{P}}_\mathrm{f}}$

on-shell β-functions: $\beta^{(2)}_{\bar{\mathcal{P}}_\mathrm{f}}$

Results: `pdf`

$$
\begin{aligned}
\beta^{(2)}_{C^{pr}_{dB}} = {} & \bigg\{\frac{1}{72}g_Y^2 Y_d^{pr} + \frac{1}{8}\big(Y_d Y_d^\dagger Y_d\big)^{pr} + \frac{1}{4}g_L^2 Y_d^{pr} - \frac{1}{3}\big(Y_u Y_u^\dagger Y_d\big)^{pr}\bigg\} C_{HD}^{(\|)} + \bigg\{\frac{1}{3}\big(Y_u Y_u^\dagger Y_d\big)^{pr} - \frac{5}{144}g_Y^2 Y_d^{pr} - \frac{1}{8}\big(Y_d Y_d^\dagger Y_d\big)^{pr} - \frac{3}{16}g_L^2 Y_d^{pr}\bigg\} C_{HD}^{(\times)} \\
& + \bigg\{\frac{29}{108}g_Y^4 Y_d^{pr} + \frac{1}{2}\lambda g_Y^2 Y_d^{pr} + g_Y^2\Big(\frac{1}{12}\big(Y_u Y_u^\dagger Y_d\big)^{pr} + \frac{1}{6}\mathrm{T}_2 Y_d^{pr} + \frac{1}{4}\big(Y_d Y_d^\dagger Y_d\big)^{pr}\Big) + \frac{8}{3}g_Y^2 g_s^2 Y_d^{pr} - \frac{1}{8}g_Y^2 g_L^2 Y_d^{pr}\bigg\} C_{HB} + \bigg\{\frac{i}{8}g_Y^2 g_L^2 Y_d^{pr} \\
& + g_Y^2\Big(\frac{19i}{12}\big(Y_u Y_u^\dagger Y_d\big)^{pr} - \frac{i}{6}\mathrm{T}_2 Y_d^{pr} - \frac{i}{4}\big(Y_d Y_d^\dagger Y_d\big)^{pr}\Big) - \frac{29i}{108}g_Y^4 Y_d^{pr} - \frac{i}{2}\lambda g_Y^2 Y_d^{pr} - \frac{8i}{3}g_Y^2 g_s^2 Y_d^{pr}\bigg\} C_{H\widetilde{B}} + \frac{1}{8}g_L^4 C_{HW} Y_d^{pr} - \frac{i}{8}g_L^4 C_{H\widetilde{W}} Y_d^{pr} \\
& + \frac{4}{3}g_s^4 C_{HG} Y_d^{pr} - \frac{4i}{3}g_s^4 C_{H\widetilde{G}} Y_d^{pr} + \bigg\{\frac{9}{32}g_Y^2 g_L^2 Y_d^{pr} + \frac{425}{96}g_L^4 Y_d^{pr} - \frac{3}{8}\lambda g_L^2 Y_d^{pr} - g_L^2\Big(\frac{3}{8}\mathrm{T}_2 Y_d^{pr} + \frac{9}{16}\big(Y_d Y_d^\dagger Y_d\big)^{pr} + \frac{15}{16}\big(Y_u Y_u^\dagger Y_d\big)^{pr}\Big) \\
& - 6 g_s^2 g_L^2 Y_d^{pr}\bigg\} C_{HWB} + \bigg\{\frac{3i}{8}\lambda g_L^2 Y_d^{pr} + g_L^2\Big(\frac{3i}{16}\big(Y_u Y_u^\dagger Y_d\big)^{pr} + \frac{3i}{8}\mathrm{T}_2 Y_d^{pr} + \frac{9i}{16}\big(Y_d Y_d^\dagger Y_d\big)^{pr}\Big) + 6i g_s^2 g_L^2 Y_d^{pr} - \frac{9i}{32}g_Y^2 g_L^2 Y_d^{pr} \\
& - \frac{425i}{96}g_L^4 Y_d^{pr}\bigg\} C_{H\widetilde{W}B} - \frac{21}{4}g_L^6 C_W Y_d^{pr} + \frac{35i}{12}g_L^6 C_{\widetilde{W}} Y_d^{pr} + 2 g_s^6 C_G Y_d^{pr} - \frac{26i}{9}g_s^6 C_{\widetilde{G}} Y_d^{pr} + \bigg\{\frac{3}{8}\delta^{pa}\delta^{rb} g_L^2 - \frac{1}{8}\delta^{pa}\delta^{rb} g_Y^2 - \frac{1}{8}\delta^{pa}\big(Y_d^\dagger Y_d\big)^{br} \\
& - \frac{1}{8}\delta^{rb}\big(Y_d Y_d^\dagger\big)^{pa}\bigg\} C_{dH}^{ab} + \bigg\{\frac{5}{4}g_Y^2 Y_e^{*\,ab} Y_d^{pr} + \frac{9}{4}g_L^2 Y_e^{*\,ab} Y_d^{pr}\bigg\} C_{eB}^{ab} - \frac{9}{4}g_L^2 Y_e^{*\,ab} C_{eW}^{ab} Y_d^{pr} + \bigg\{\frac{1}{2}\mathrm{T}_2\delta^{pa}\big(Y_u^\dagger Y_d\big)^{br} + g_L^2\Big(\frac{9}{4}Y_u^{*\,ab} Y_d^{pr} - \frac{39}{8}\delta^{pa}\big(Y_u^\dagger Y_d\big)^{br}\Big) \\
& + g_Y^2\Big(\frac{5}{12}Y_u^{*\,ab} Y_d^{pr} - \frac{11}{24}\delta^{pa}\big(Y_u^\dagger Y_d\big)^{br}\Big) + \frac{5}{2}\big(Y_u^\dagger Y_d\big)^{br}\big(Y_u Y_u^\dagger\big)^{pa} + \frac{5}{2}\delta^{pa}\big(Y_u^\dagger Y_u Y_u^\dagger Y_d\big)^{br} - \frac{1}{2}\big(Y_u^\dagger Y_d\big)^{br}\big(Y_d Y_d^\dagger\big)^{pa} - \delta^{pa}\big(Y_u^\dagger Y_d Y_d^\dagger Y_d\big)^{br}\bigg\} C_{uB}^{ab} \\
& + C_{uB}^{*\,ab}\bigg\{\frac{1}{2}Y_u^{pb}\big(Y_u Y_u^\dagger Y_d\big)^{ar} + \mathrm{T}_2 Y_d^{ar} Y_u^{pb} + g_Y^2\Big(\frac{5}{12}Y_d^{pr} Y_u^{ab} - \frac{2}{9}Y_d^{ar} Y_u^{pb}\Big) + \frac{5}{2}Y_d^{ar}\big(Y_u Y_u^\dagger Y_u\big)^{pb} - Y_u^{pb}\big(Y_d Y_d^\dagger Y_d\big)^{ar} - 2Y_d^{ar}\big(Y_d Y_d^\dagger Y_u\big)^{pb} - \frac{9}{4}g_L^2 Y_d^{ar} Y_u^{pb} \\
& - 8 g_s^2 Y_d^{ar} Y_u^{pb}\bigg\} - \frac{5}{8}\delta^{pa} g_L^2 C_{uW}^{ab}\big(Y_u^\dagger Y_d\big)^{br} + g_L^2 C_{uW}^{*\,ab}\bigg\{\frac{15}{8}Y_d^{pr} Y_u^{ab} - \frac{1}{8}Y_d^{ar} Y_u^{pb}\bigg\} + \frac{8}{3}\delta^{pa} g_s^2 C_{uG}^{ab}\big(Y_u^\dagger Y_d\big)^{br} + \frac{44}{9}g_s^2 C_{uG}^{*\,ab} Y_d^{ar} Y_u^{pb} \\
& + \bigg\{g_L^2\Big(\frac{9}{16}\delta^{rb}\big(Y_u Y_u^\dagger\big)^{pa} + \frac{15}{8}\mathrm{T}_2\delta^{pa}\delta^{rb} + \frac{27}{4}Y_d^{*\,ab} Y_d^{pr} + 9\delta^{pa}\big(Y_d^\dagger Y_d\big)^{br} + \frac{237}{16}\delta^{rb}\big(Y_d Y_d^\dagger\big)^{pa}\Big) + g_Y^2\Big(\frac{5}{12}Y_d^{*\,ab} Y_d^{pr} + \frac{601}{144}\delta^{rb}\big(Y_d Y_d^\dagger\big)^{pa} \\
& + \frac{349}{72}\delta^{pa}\big(Y_d^\dagger Y_d\big)^{br} + \frac{39}{8}\delta^{pa}\delta^{rb}\,\mathrm{Tr}\Big[Y_e^\dagger Y_e\Big] - \frac{3}{8}\delta^{pa}\delta^{rb}\,\mathrm{Tr}\Big[Y_d^\dagger Y_d\Big] - \frac{101}{144}\delta^{rb}\big(Y_u Y_u^\dagger\big)^{pa} - \frac{29}{8}\delta^{pa}\delta^{rb}\,\mathrm{Tr}\Big[Y_u^\dagger Y_u\Big]\Big) + g_s^2\Big(20\delta^{pa}\delta^{rb}\,\mathrm{Tr}\Big[Y_d^\dagger Y_d\Big] \\
& + 20\delta^{pa}\delta^{rb}\,\mathrm{Tr}\Big[Y_u^\dagger Y_u\Big] - \frac{16}{3}\delta^{rb}\big(Y_d Y_d^\dagger\big)^{pa} - \frac{16}{3}\delta^{rb}\big(Y_u Y_u^\dagger\big)^{pa} - \frac{32}{3}\delta^{pa}\big(Y_d^\dagger Y_d\big)^{br}\Big) + \frac{5}{4}\mathrm{T}_2\delta^{rb}\big(Y_u Y_u^\dagger\big)^{pa} + \frac{5}{4}\delta^{pa}\big(Y_d^\dagger Y_d Y_d^\dagger Y_d\big)^{br} + \frac{5}{4}\delta^{rb}\big(Y_d Y_d^\dagger Y_d Y_d^\dagger\big)^{pa} \\
& + \frac{3}{2}\delta^{pa}\delta^{rb}\lambda^2 + \frac{3}{2}\delta^{pa}\delta^{rb}\,\mathrm{Tr}\Big[Y_d^\dagger Y_d Y_u^\dagger Y_u\Big] + \frac{103}{48}\delta^{pa}\delta^{rb} g_Y^2 g_L^2 + \frac{11}{4}\delta^{rb}\big(Y_u Y_u^\dagger Y_u Y_u^\dagger\big)^{pa} + \frac{172}{3}\delta^{pa}\delta^{rb} g_s^4 - \frac{1}{4}\delta^{pa}\big(Y_d^\dagger Y_u Y_u^\dagger Y_d\big)^{br} \\
& - \frac{1}{2}\delta^{rb}\big(Y_d Y_d^\dagger Y_u Y_u^\dagger\big)^{pa} - \lambda\Big(\frac{3}{2}\delta^{pa}\delta^{rb} g_Y^2 + 6\delta^{pa}\big(Y_d^\dagger Y_d\big)^{br} + 6\delta^{rb}\big(Y_d Y_d^\dagger\big)^{pa}\Big) - \delta^{rb}\big(Y_u Y_u^\dagger Y_d Y_d^\dagger\big)^{pa} - \frac{31}{27}\delta^{pa}\delta^{rb} g_Y^2 g_s^2 - \frac{1577}{1296}\delta^{pa}\delta^{rb} g_Y^4
\end{aligned}
$$

Results: interactive notebook



ADM columns

Display only the one–loop running: ☐

Display the ADM column corresponding to $C_{uG}{}^{ab}$

Result Copy result

	$C_{uG}{}^{ab}$
C_H	$\hbar^2 C_{uG}{}^{ab} \left(-128\, g_s{}^2\, \overline{Y}_u{}^{ar}\, \overline{Y}_u{}^{st}\, \overline{Y}_u{}^{ub}\, Y_u{}^{sr}\, Y_u{}^{ut} + \lambda \left(\frac{32}{3} g_s{}^2 g_L{}^2 \overline{Y}_u{}^{ab} + \frac{32}{3} g_s{}^2 g_Y{}^2 \overline{Y}_u{}^{ab} + 16\, g_s{}^2\, \overline{Y}_u{}^{ar}\, \overline{Y}_u{}^{sb}\, Y_u{}^{sr}\right) - 16\, g_s{}^2 \lambda^2\, \overline{Y}_u{}^{ab}\right)$
$C_{HD}^{(\parallel)}$	$\hbar^2 C_{uG}{}^{ab} \left(-32\, g_s{}^2 g_L{}^2 \overline{Y}_u{}^{ab} - \frac{32}{3} g_s{}^2 g_Y{}^2 \overline{Y}_u{}^{ab} + g_s{}^2 \left(96\, \overline{Y}_d{}^{ar}\, Y_d{}^{sr}\, \overline{Y}_u{}^{sb} + 96\, \overline{Y}_u{}^{ar}\, \overline{Y}_u{}^{sb}\, Y_u{}^{sr}\right)\right)$
$C_{HD}^{(\times)}$	$\hbar^2 C_{uG}{}^{ab} \left(-\frac{64}{3} g_s{}^2 g_Y{}^2 \overline{Y}_u{}^{ab} + g_s{}^2 \left(-96\, \overline{Y}_d{}^{ar}\, Y_d{}^{sr}\, \overline{Y}_u{}^{sb} + 96\, \overline{Y}_u{}^{ar}\, \overline{Y}_u{}^{sb}\, Y_u{}^{sr}\right)\right)$
C_{HB}	$-\frac{16}{9} \hbar^2 g_s{}^2 \overline{Y}_u{}^{ab} C_{uG}{}^{ab}$
$C_{H\tilde{B}}$	$-\frac{179\, i}{18} \hbar^2 g_s{}^2 \overline{Y}_u{}^{ab} C_{uG}{}^{ab}$
C_{HW}	0
$C_{H\tilde{W}}$	$-\frac{73\, i}{6} \hbar^2 g_s{}^2 \overline{Y}_u{}^{ab} C_{uG}{}^{ab}$
C_{HG}	$2\, \hbar\, \overline{Y}_u{}^{ab} C_{uG}{}^{ab} + \hbar^2 C_{uG}{}^{ab} \left(\frac{3}{2} g_L{}^2 \overline{Y}_u{}^{ab} + 46\, g_s{}^2 \overline{Y}_u{}^{ab} + \frac{37}{18} g_Y{}^2 \overline{Y}_u{}^{ab} + 2\, \overline{Y}_d{}^{ar}\, Y_d{}^{sr}\, \overline{Y}_u{}^{sb} - 15\, \overline{Y}_u{}^{ar}\, \overline{Y}_u{}^{sb}\, Y_u{}^{sr} + 3\, \lambda\, \overline{Y}_u{}^{ab}\right)$
$C_{H\tilde{G}}$	$2\, i\, \hbar\, \overline{Y}_u{}^{ab} C_{uG}{}^{ab} + \hbar^2 C_{uG}{}^{ab} \left(\frac{3\, i}{2} g_L{}^2 \overline{Y}_u{}^{ab} + 22\, i\, g_s{}^2 \overline{Y}_u{}^{ab} + \frac{37\, i}{18} g_Y{}^2 \overline{Y}_u{}^{ab} + 4\, i\, \overline{Y}_d{}^{ar}\, Y_d{}^{sr}\, \overline{Y}_u{}^{sb} - 9\, i\, \overline{Y}_u{}^{ar}\, \overline{Y}_u{}^{sb}\, Y_u{}^{sr} + 3\, i\, \lambda\, \overline{Y}_u{}^{ab}\right)$
C_{HWB}	$\frac{32}{3} \hbar^2 g_s{}^2 \overline{Y}_u{}^{ab} C_{uG}{}^{ab}$
$C_{H\tilde{W}B}$	$34\, i\, \hbar^2 g_s{}^2 \overline{Y}_u{}^{ab} C_{uG}{}^{ab}$
C_W	0
$C_{\tilde{W}}$	0
C_G	$\hbar^2 \overline{Y}_u{}^{ab} C_{uG}{}^{ab}$
$C_{\tilde{G}}$	$-\frac{i}{3} \hbar^2 \overline{Y}_u{}^{ab} C_{uG}{}^{ab}$
$C_{eH}{}^{ij}$	$\hbar^2 C_{uG}{}^{ab} \left(\frac{16}{3} g_s{}^2 g_L{}^2 Y_e{}^{ij} \overline{Y}_u{}^{ab} + \frac{16}{3} g_s{}^2 g_Y{}^2 Y_e{}^{ij} \overline{Y}_u{}^{ab} - 16\, \lambda\, g_s{}^2 Y_e{}^{ij} \overline{Y}_u{}^{ab}\right)$
$C_{uH}{}^{ij}$	$\hbar\, g_s{}^2 C_{uG}{}^{ab} \left(16\, \overline{Y}_u{}^{pb} Y_u{}^{pj} \delta_{ai} + 16\, \overline{Y}_u{}^{ar} Y_u{}^{ir} \delta_{bj}\right) +$ $\hbar^2 C_{uG}{}^{ab} \left(4\, g_s{}^2 g_L{}^4 \delta_{ai} \delta_{bj} - \frac{92}{27} g_s{}^2 g_Y{}^4 \delta_{ai} \delta_{bj} + g_s{}^2 g_L{}^2 \left(\frac{16}{3} \overline{Y}_u{}^{ab} Y_u{}^{ij} - \frac{26}{3} \overline{Y}_u{}^{pb} Y_u{}^{pj} \delta_{ai} - \frac{56}{3} \overline{Y}_d{}^{ar} Y_d{}^{ir} \delta_{bj} - \frac{82}{3} \overline{Y}_u{}^{ar} Y_u{}^{ir} \delta_{bj}\right) + g_s{}^2 g_Y{}^2 \left(\frac{16}{3} \overline{Y}_u{}^{ab} Y_u{}^{ij} - \frac{614}{27} \overline{Y}_u{}^{pb} Y_u{}^{pj} \delta_{ai} - \frac{254}{27} \overline{Y}_u{}^{ar} Y_u{}^{ir} \delta_{bj}\right) +\right.$ $g_s{}^2 \left(-\frac{8}{3} \overline{Y}_d{}^{ar} Y_d{}^{ir} \overline{Y}_u{}^{sb} Y_u{}^{sj} + 16\, \overline{Y}_u{}^{ar} \overline{Y}_u{}^{sb} Y_u{}^{sr} Y_u{}^{ij} + 36\, \overline{Y}_d{}^{pr} Y_d{}^{sr} \overline{Y}_u{}^{sb} Y_u{}^{pj} \delta_{ai} - \frac{340}{3} \overline{Y}_u{}^{pb} \overline{Y}_u{}^{st} Y_u{}^{pt} Y_u{}^{sj} \delta_{ai} + 16\, \overline{Y}_d{}^{pr} Y_d{}^{ir} \overline{Y}_u{}^{at} Y_u{}^{pt} \delta_{bj} - \frac{332}{3} \overline{Y}_u{}^{at} \overline{Y}_u{}^{pr} Y_u{}^{pt} Y_u{}^{ir} \delta_{bj} +\right.$ $\left.\frac{100}{3} \overline{Y}_d{}^{ar} Y_d{}^{sr} \overline{Y}_u{}^{st} Y_u{}^{it} \delta_{bj} + \frac{152}{9} g_L{}^2 g_Y{}^2 \delta_{ai} \delta_{bj}\right) + g_s{}^4 \left(-\frac{64}{3} \overline{Y}_u{}^{ab} Y_u{}^{ij} + \frac{2488}{9} \overline{Y}_u{}^{pb} Y_u{}^{pj} \delta_{ai} + \frac{2488}{9} \overline{Y}_u{}^{ar} Y_u{}^{ir} \delta_{bj} - 128\, \overline{Y}_d{}^{pr} Y_d{}^{pr} \delta_{ai} \delta_{bj} - 128\, \overline{Y}_u{}^{pr} Y_u{}^{pr} \delta_{ai} \delta_{bj}\right) +$ $\left.\lambda \left(-8\, g_s{}^2 g_L{}^2 \delta_{ai} \delta_{bj} + \frac{224}{9} g_s{}^4 \delta_{ai} \delta_{bj} + \frac{56}{27} g_s{}^2 g_Y{}^2 \delta_{ai} \delta_{bj} + g_s{}^2 \left(-16\, \overline{Y}_u{}^{ab} Y_u{}^{ij} + \frac{152}{3} \overline{Y}_u{}^{pb} Y_u{}^{pj} \delta_{ai} + \frac{16}{3} \overline{Y}_d{}^{ar} Y_d{}^{ir} \delta_{bj} + \frac{160}{3} \overline{Y}_u{}^{ar} Y_u{}^{ir} \delta_{bj}\right)\right)\right)$
$C_{dH}{}^{ij}$	$\hbar^2 C_{uG}{}^{ab} \left(-\frac{64}{3} g_s{}^4 Y_d{}^{ij} \overline{Y}_u{}^{ab} + \frac{16}{3} g_s{}^2 g_Y{}^2 Y_d{}^{ij} \overline{Y}_u{}^{ab} + g_s{}^2 g_L{}^2 \left(\frac{16}{3} Y_d{}^{ij} \overline{Y}_u{}^{ab} - \frac{40}{3} Y_d{}^{pj} \overline{Y}_u{}^{pb} \delta_{ai}\right) +\right.$ $\left.\lambda\, g_s{}^2 \left(-16\, Y_d{}^{ij} \overline{Y}_u{}^{ab} + 8\, Y_d{}^{pj} \overline{Y}_u{}^{pb} \delta_{ai}\right) + g_s{}^2 \left(-8\, \overline{Y}_d{}^{ar} Y_d{}^{sj} Y_d{}^{ir} \overline{Y}_u{}^{sb} + \frac{32}{3} Y_d{}^{sj} \overline{Y}_u{}^{ar} \overline{Y}_u{}^{sb} Y_u{}^{ir} + \frac{40}{3} \overline{Y}_d{}^{pr} Y_d{}^{pj} Y_d{}^{sr} \overline{Y}_u{}^{sb} \delta_{ai} + \frac{8}{3} Y_d{}^{sj} \overline{Y}_u{}^{pb} \overline{Y}_u{}^{st} Y_u{}^{pt} \delta_{ai}\right)\right)$
$C_{eB}{}^{ij}$	0
$C_{eW}{}^{ij}$	0
$C_{uB}{}^{ij}$	$\frac{40}{9} \hbar\, g_s{}^2 C_{uG}{}^{ab} \delta_{ai} \delta_{bj} + \hbar^2 C_{uG}{}^{ab} \left(-\frac{5}{3} g_s{}^2 g_L{}^2 \delta_{ai} \delta_{bj} + \frac{820}{27} g_s{}^4 \delta_{ai} \delta_{bj} - \frac{205}{81} g_s{}^2 g_Y{}^2 \delta_{ai} \delta_{bj} + g_s{}^2 \left(-\frac{70}{9} \overline{Y}_u{}^{pb} Y_u{}^{pj} \delta_{ai} + \frac{16}{9} \overline{Y}_d{}^{ar} Y_d{}^{ir} \delta_{bj} - \frac{26}{9} \overline{Y}_u{}^{ar} Y_u{}^{ir} \delta_{bj}\right)\right)$
$C_{uW}{}^{ij}$	$\frac{16}{3} \hbar\, g_s{}^2 C_{uG}{}^{ab} \delta_{ai} \delta_{bj} + \hbar^2 C_{uG}{}^{ab} \left(-\frac{14}{3} g_s{}^2 g_L{}^2 \delta_{ai} \delta_{bj} + \frac{328}{9} g_s{}^4 \delta_{ai} \delta_{bj} - \frac{82}{27} g_s{}^2 g_Y{}^2 \delta_{ai} \delta_{bj} + g_s{}^2 \left(-\frac{4}{3} \overline{Y}_u{}^{pb} Y_u{}^{pj} \delta_{ai} - \frac{16}{3} \overline{Y}_d{}^{ar} Y_d{}^{ir} \delta_{bj} - \frac{28}{3} \overline{Y}_u{}^{ar} Y_u{}^{ir} \delta_{bj}\right)\right)$
$C_{uG}{}^{ij}$	$\hbar\, C_{uG}{}^{ab} \left(2\, \overline{Y}_u{}^{pb} Y_u{}^{pj} \delta_{ai} - \frac{3}{2} \overline{Y}_d{}^{ar} Y_d{}^{ir} \delta_{bj} + \frac{5}{2} \overline{Y}_u{}^{ar} Y_u{}^{ir} \delta_{bj} - \frac{9}{4} g_L{}^2 \delta_{ai} \delta_{bj} + \frac{4}{3} g_s{}^2 \delta_{ai} \delta_{bj} - \frac{19}{36} g_Y{}^2 \delta_{ai} \delta_{bj} + 3\, \overline{Y}_d{}^{pr} Y_d{}^{pr} \delta_{ai} \delta_{bj} + \overline{Y}_e{}^{pr} Y_e{}^{pr} \delta_{ai} \delta_{bj} + 3\, \overline{Y}_u{}^{pr} Y_u{}^{pr} \delta_{ai} \delta_{bj}\right) +$ $\hbar^2 C_{uG}{}^{ab} \left(-3\, \overline{Y}_u{}^{ar} \overline{Y}_u{}^{sb} Y_u{}^{sj} Y_u{}^{ir} - \frac{1}{4} \overline{Y}_d{}^{pr} Y_d{}^{sr} \overline{Y}_u{}^{sb} Y_u{}^{pj} \delta_{ai} - 9\, \overline{Y}_u{}^{pb} \overline{Y}_u{}^{st} Y_u{}^{pj} Y_u{}^{st} \delta_{ai} - 9\, \overline{Y}_d{}^{pr} Y_d{}^{pr} \overline{Y}_u{}^{sb} Y_u{}^{sj} \delta_{ai} - 3\, \overline{Y}_e{}^{pr} Y_e{}^{pr} \overline{Y}_u{}^{sb} Y_u{}^{sj} \delta_{ai} + \frac{5}{4} \overline{Y}_u{}^{pb} \overline{Y}_u{}^{st} Y_u{}^{pt} Y_u{}^{sj} \delta_{ai} +\right.$

Summary and outlook

- The 2-loop SMEFT RGEs are needed for consistent NLO phenomenology
- B-violating sector results by Banik *et al.* [2510.08682]
- Results can be adapted to the Warsaw basis at the price of an extra ambiguity
- Remaining ambiguities (such as they are) would have to be resolved in the BMHV scheme: we hope to integrate the code with a BMHV-scheme implementation
  w/ Adrian Moreno-Sánchez

Summary and outlook

- The 2-loop SMEFT RGEs are needed for consistent NLO phenomenology
- B-violating sector results by Banik *et al.* [2510.08682]
- Results can be adapted to the Warsaw basis at the price of an extra ambiguity
- Remaining ambiguities (such as they are) would have to be resolved in the BMHV scheme: we hope to integrate the code with a BMHV-scheme implementation
  w/ Adrian Moreno-Sánchez

Thank you!