The SMEFT and its precision future

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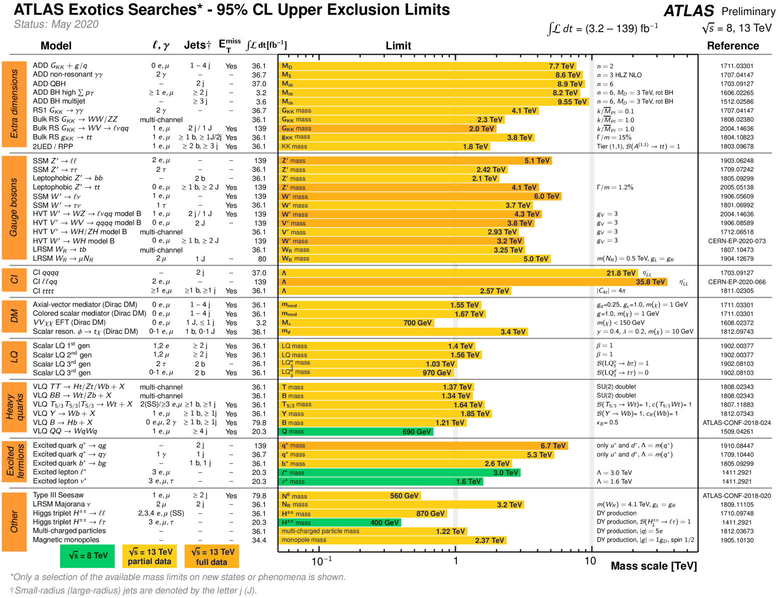
ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: May 2020

ATLAS Preliminary

$\int\mathcal{L}\,dt$ = (3.2 – 139) fb^{-1} $\sqrt{s}$ = 8, 13 TeV



	Model	ℓ,γ	Jets†	E_T^{miss}	$\int\mathcal{L}\,dt$[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 $\gamma\gamma$	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 $\sum p_T$	≥ 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 $G_{KK}\to\gamma\gamma$	2 γ	–	–	36.7	G_{KK} mass 4.1 TeV	$k/\overline{M}_{Pl}=0.1$	1707.04147
	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,μ	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,μ	≥ 1 b, ≥ 1J/2j	Yes	36.1	g_{KK} mass 3.8 TeV	$\Gamma/m=15\%$	1804.10823
	2UED / RPP	1 e,μ	≥ 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,μ	–	–	139	Z' mass 5.1 TeV		1903.06248
	SSM $Z'\to\tau\tau$	2 τ	–	–	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,μ	≥ 1 b, ≥ 2 J	Yes	139	Z' mass 4.1 TeV	$\Gamma/m=1.2\%$	2005.05138
	SSM $W'\to\ell\nu$	1 e,μ	–	Yes	139	W' mass 6.0 TeV		1906.05609
	SSM $W'\to\tau\nu$	1 τ	–	Yes	36.1	W' mass 3.7 TeV		1801.06992
	HVT $W'\to WZ\to\ell\nu qq$ model B	1 e,μ	2 j / 1 J	Yes	139	W' mass 4.3 TeV	$g_V=3$	2004.14636
	HVT $V'\to WV\to qqqq$ model B	0 e,μ	2 J	–	139	V' mass 3.8 TeV	$g_V=3$	1906.08589
	HVT $V'\to WH/ZH$ model B	multi-channel			36.1	V' mass 2.93 TeV	$g_V=3$	1712.06518
	HVT $W'\to WH$ model B	0 e,μ	≥ 1 b, ≥ 2 J		139	W' mass 3.2 TeV	$g_V=3$	CERN-EP-2020-073
	LRSM $W_R\to tb$	multi-channel			36.1	W_R mass 3.25 TeV		1807.10473
	LRSM $W_R\to\mu N_R$	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 $\ell\ell qq$	2 e,μ	–	–	139	Λ 35.8 TeV	η_{LL}^{-}	CERN-EP-2020-066
	CI $tttt$	$\geq$1 e,μ	$\geq$1 b, $\geq$1 j	Yes	36.1	Λ 2.57 TeV	$\lvert C_{4t}\rvert=4\pi$	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, $m(\chi)=1$ 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, $m(\chi)=1$ GeV	1711.03301
	$VV\chi\chi$ EFT (Dirac DM)	0 e,μ	1 J, ≤ 1 j	Yes	3.2	M_* 700 GeV	$m(\chi)<150$ GeV	1608.02372
	Scalar reson. $\phi\to t\chi$ (Dirac DM)	0-1 e,μ	1 b, 0-1 J	Yes	36.1	m_ϕ 3.4 TeV	$y=0.4$, $\lambda=0.2$, $m(\chi)=10$ GeV	1812.09743
LQ	Scalar LQ 1st gen	1,2 e	≥ 2 j	Yes	36.1	LQ mass 1.4 TeV	$\beta=1$	1902.00377
	Scalar LQ 2nd gen	1,2 μ	≥ 2 j	Yes	36.1	LQ mass 1.56 TeV	$\beta=1$	1902.00377
	Scalar LQ 3rd gen	2 τ	2 b	–	36.1	LQ_3^u mass 1.03 TeV	$\mathcal{B}(LQ_3^u\to b\tau)=1$	1902.08103
	Scalar LQ 3rd gen	0-1 e,μ	2 b	Yes	36.1	LQ_3^d mass 970 GeV	$\mathcal{B}(LQ_3^d\to t\tau)=0$	1902.08103
Heavy quarks	VLQ $TT\to Ht/Zt/Wb+X$	multi-channel			36.1	T mass 1.37 TeV	SU(2) doublet	1808.02343
	VLQ $BB\to Wt/Zb+X$	multi-channel			36.1	B mass 1.34 TeV	SU(2) doublet	1808.02343
	VLQ $T_{5/3}T_{5/3}\lvert T_{5/3}\to Wt+X$	2(SS)/$\geq$3 e,μ	$\geq$1 b, $\geq$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 $Y\to Wb+X$	1 e,μ	≥ 1 b, ≥ 1j	Yes	36.1	Y mass 1.85 TeV	$\mathcal{B}(Y\to Wb)$= 1, $c_R(Wb)$= 1	1812.07343
	VLQ $B\to Hb+X$	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 $QQ\to WqWq$	1 e,μ	≥ 4 j	Yes	20.3	Q mass 690 GeV		1509.04261
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 γ	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,μ	–	–	20.3	ℓ^* mass 3.0 TeV	$\Lambda=3.0$ TeV	1411.2921
	Excited lepton ν^*	3 e,μ,τ	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda=1.6$ TeV	1411.2921
Other	Type III Seesaw	1 e,μ	≥ 2 j	Yes	79.8	N^0 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 $H^{\pm\pm}\to\ell\ell$	2,3,4 e,μ (SS)	–	–	36.1	$H^{\pm\pm}$ mass 870 GeV	DY production	1710.09748
	Higgs triplet $H^{\pm\pm}\to\ell\tau$	3 e,μ,τ	–	–	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

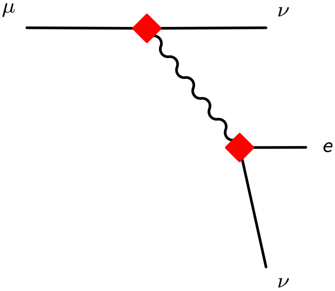
🟩 $\sqrt{s}$ = 8 TeV
🟨 $\sqrt{s}$ = 13 TeV partial data
🟧 $\sqrt{s}$ = 13 TeV full data

*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).

What's an EFT?

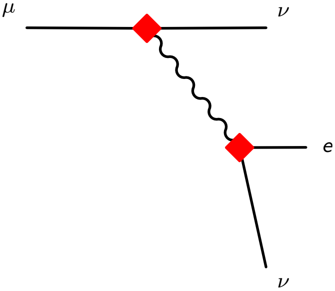
In the SM



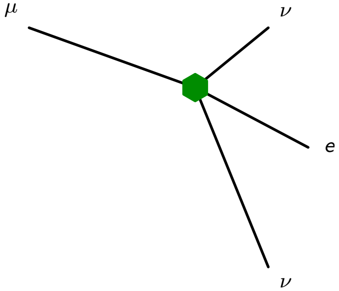
$$\mathcal{M} \sim \frac{g_{\rm W}^2}{2} \frac{(\bar{\nu}_\mu \gamma^\mu P_L \mu)(\bar{e}\gamma^\mu P_L \nu_e)}{k^2 - M_W^2}$$

What's an EFT?

In the SM



In the Fermi theory



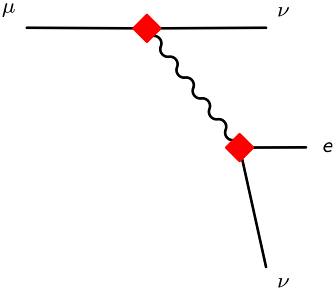
$$\mathcal{M} \sim \frac{g_{\mathrm{W}}^2}{2}\,\frac{(\bar{\nu}_\mu\gamma^\mu P_L\mu)(\bar{e}\gamma^\mu P_L\nu_e)}{k^2-M_W^2}$$

$$\frac{1}{M_W^2}(\bar{\psi}\gamma^\mu P_L\psi)^2$$

$$\mathcal{M} \sim -\frac{g_{\mathrm{W}}^2}{2M_W^2}(\bar{\nu}_\mu\gamma^\mu P_L\mu)(\bar{e}\gamma^\mu P_L\nu_e)+\cdots$$

What's an EFT?

In the SM



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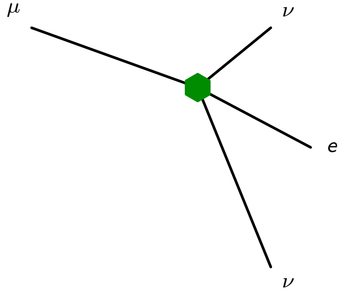


$$\mathcal{M} \sim \frac{g_{\mathrm{W}}^2}{2}\frac{(\bar{\nu}_\mu\gamma^\mu P_L\mu)(\bar{e}\gamma^\mu P_L\nu_e)}{k^2 - M_W^2}$$

$\frac{1}{M_W^2}(\bar{\psi}\gamma^\mu P_L\psi)^2$

$\frac{1}{M_W^4}\partial^2(\bar{\psi}\gamma^\mu P_L\psi)^2$

$$\mathcal{M} \sim -\frac{g_{\mathrm{W}}^2}{2M_W^2}(\bar{\nu}_\mu\gamma^\mu P_L\mu)(\bar{e}\gamma^\mu P_L\nu_e) - \frac{g_{\mathrm{W}}^2 k^2}{2M_W^4}(\bar{\nu}_\mu\gamma^\mu P_L\mu)(\bar{e}\gamma^\mu P_L\nu_e) + \cdots$$

SMEFT: Effective Vertices (taking $H \to v + h$)

T3: $Q_{H\Box} = (H^\dagger H)\Box(H^\dagger H)$ 🔴 🟥

T3: $Q_{HD} = (H^\dagger D^\mu H)^*(H^\dagger D^\mu H)$ 🔴 🟥 ♦

T4: $Q_{HV} = (H^\dagger H)V^{\mu\nu}V_{\mu\nu}$ 🟩

T4: $Q_{HWB} = (H^\dagger \tau^I H)W^I_{\mu\nu}B^{\mu\nu}$ ♦ 🟩

T5: $Q_{\psi H} = (H^\dagger H)(\bar{\Psi} H \psi)$ 🔴

T7: $Q^{(3)}_{HL} = (H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{L}\gamma^\mu L)$ ♦ 🟥 ⬟

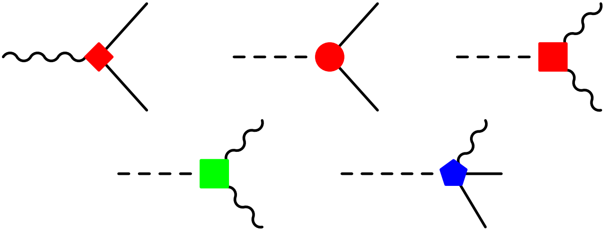
T7: $Q^{(1,3)}_{H\Psi} = (H^\dagger \overleftrightarrow{D}_\mu H)(\bar{\Psi}\gamma^\mu \Psi)$ ♦ ⬟

T7: $Q_{H\psi} = (H^\dagger \overleftrightarrow{D}_\mu H)(\bar{\psi}\gamma^\mu \psi)$ ♦ ⬟

T8: $Q_{LL} = (\bar{L}\gamma^\mu L)(\bar{L}\gamma^\mu L)$ ♦ 🟥

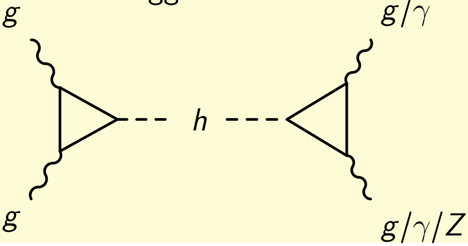
♦ 🔴 🟥 SM–like

🟩 ⬟ Non-SM-like kinematic structure

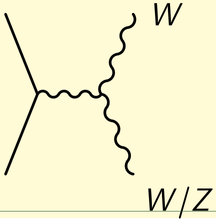


Global fits of the SMEFT

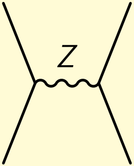
Higgs Sector



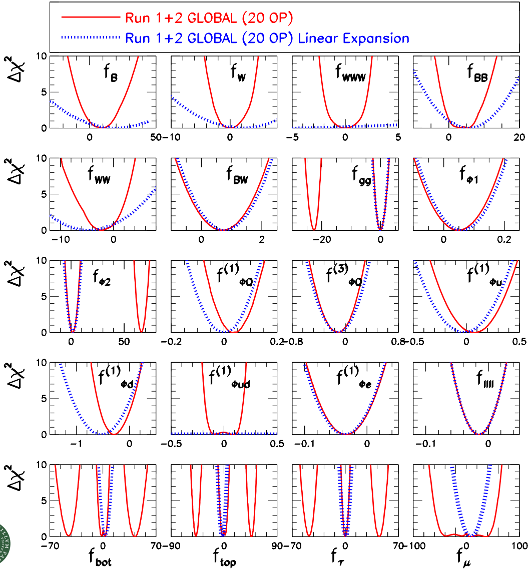
Triple Gauge Sector



Electroweak Precision Data



An example global fit



Almeida et al. 1812.01009

- ☺ Dbl insertions of c_i in red, single in blue
- ☺ Blind direction broken by TGC+EWPD
- ☹ Many cases where constraints lost
- ☹ Current status:
  testing how well we can measure 0

Long term goals for the SMEFT

1. Do these global fits
2. Improve theory predictions, understand theory errors
3. Measure a deviation
   → correlations between operators reveal nature of NP
   → scale at which unitarity is violated gives scale of NP
   (i.e. as π scattering predicts $\rho \sim 1$ GeV)

Extremely important for FCC-ee as a precision machine

Still important for FCC-hh for physics on a (SM) pole

SMEFT Loops (short version)

Many different groups doing loops in the SMEFT
Some of the calculations done include:

- $H\gamma\gamma$ (see e.g. 1507.03568)
- EWPD (arXiv:1909.02000)
- $pp \to WW, WZ, HZ, HW$ (QCD only, see e.g. arXiv:2003.07862)

Automated QCD loops in Madgraph w/ SMEFT@NLO (2008.11743)

Background field method for analytic loops (e.g. TC arXiv:2010.15852)

Loops give us a hold on theory errors!

tt production at one loop in SMEFT@NLO

SM: $744^{+12\%}_{-12\%}$pb

$(\bar{\psi}\psi)^2$	$\mathcal{O}(\frac{1}{\Lambda^2}=\frac{1}{\mathrm{TeV}^2})$ tree	loop	$\mathcal{O}(\frac{1}{\Lambda^4}=\frac{1}{\mathrm{TeV}^4})$ tree	loop
$(\bar{t}_R\gamma^\mu u_R)(\bar{u}_R\gamma_\mu t_R)$	$.67^{+1\%}_{-1\%}$pb	$.41^{+13\%}_{-17\%}$pb	$4.66^{+6\%}_{-5\%}$pb	$5.92^{+6\%}_{-5\%}$pb
$(\bar{t}_R\gamma^\mu d_R)(\bar{d}_R\gamma_\mu t_R)$	$-.21^{+1\%}_{-1\%}$pb	$-.306^{+30\%}_{-22\%}$pb	$2.62^{+6\%}_{-5\%}$pb	$3.46^{+5\%}_{-5\%}$pb
$(\bar{Q}_3\gamma^\mu q_i)(\bar{q}_i\gamma_\mu Q_3)$	$1.92^{+0\%}_{-1\%}$pb	$1.05^{+17\%}_{-22\%}$pb	$7.25^{+6\%}_{-5\%}$pb	$9.32^{+5\%}_{-5\%}$pb

1. Tree level result for $\frac{1}{\Lambda^2}$ ⇒ error in SM which is consistent w SMEFT

tt production at one loop in SMEFT@NLO

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$(\bar{\psi}\psi)^2$	$\mathcal{O}(\frac{1}{\Lambda^2}=\frac{1}{\mathrm{TeV}^2})$		$\mathcal{O}(\frac{1}{\Lambda^4}=\frac{1}{\mathrm{TeV}^4})$	
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① Tree level result for $\frac{1}{\Lambda^2}$ ⇒ error in SM which is consistent w SMEFT

② Loop result for $\frac{1}{\Lambda^2}$ ⇒ error in tree $\frac{1}{\Lambda^2}$, $\mathcal{O}(60-146\%)$

tt production at one loop in SMEFT@NLO

SM: $744^{+12\%}_{-12\%}$pb

	$\mathcal{O}(\frac{1}{\Lambda^2} = \frac{1}{\mathrm{TeV}^2})$		$\mathcal{O}(\frac{1}{\Lambda^4} = \frac{1}{\mathrm{TeV}^4})$	
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1. Tree level result for $\frac{1}{\Lambda^2}$ ⇒ error in SM which is consistent w SMEFT
2. Loop result for $\frac{1}{\Lambda^2}$ ⇒ error in tree $\frac{1}{\Lambda^2}$, $\mathcal{O}(60 - 146\%)$
3. Tree level result for $\frac{1}{\Lambda^4}$ ⇒ error in tree $\mathcal{O}(300 - 1200\%)$???
   $|\mathcal{M}|^2 \equiv |\mathcal{M}_{\mathrm{SM}} + \frac{1}{\Lambda^2}\mathcal{M}_6|^2$

NLO SMEFT

The consistent squared amplitude to $\mathcal{O}\left(\frac{1}{\Lambda^4}\right)$:

$$|\mathcal{M}|^2 = |\mathcal{M}_{\rm SM}|^2 + \frac{2}{\Lambda^2}{\rm Re}[\mathcal{M}_{\rm SM}\mathcal{M}_6] + \frac{1}{\Lambda^4}\left(|\mathcal{M}_6|^2 + 2{\rm Re}[\mathcal{M}_{6^2}\mathcal{M}_{\rm SM} + \mathcal{M}_8\mathcal{M}_{\rm SM}]\right)$$

NLO SMEFT

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So SMEFT@NLO is missing $\mathcal{M}_{6^2}\mathcal{M}_{\rm SM}$ and $\mathcal{M}_8\mathcal{M}_{\rm SM}$ terms...

① $\mathcal{M}_{6^2}$ requires $\mathcal{M}_8$ for consistency (renormalizability)

② $\mathcal{M}_8$ seems intractible – sooo many parameters, $\mathcal{O}(40k)$

NLO SMEFT

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So SMEFT@NLO is missing $\mathcal{M}_{6^2}\mathcal{M}_{\rm SM}$ and $\mathcal{M}_8\mathcal{M}_{\rm SM}$ terms...

1. $\mathcal{M}_{6^2}$ requires $\mathcal{M}_8$ for consistency (renormalizability)
2. $\mathcal{M}_8$ seems intractible – sooo many parameters, $\mathcal{O}(40k)$

without a consistent calculation to $\frac{1}{\Lambda^4}$ we lack understanding of theory errors...
we need a new methodology to tackle this problem

A taste of geoSMEFT

Consider operators shifting $Z\bar{\psi}\psi$:

$$\sum_{n=0} \frac{c^{(6+2n)}}{\Lambda^{2n+2}} (H^\dagger H)^n (H^\dagger i \overleftrightarrow{D}^\mu H)(\bar{\psi}\gamma_\mu \psi)$$

A taste of geoSMEFT

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$$\sum_{n=0} \frac{c^{(6+2n)}}{\Lambda^{2n+2}}(H^\dagger H)^n(H^\dagger i\overleftrightarrow{D}^\mu H)(\bar{\psi}\gamma_\mu\psi)$$

Define a field space connection

$$L_{J,A}^{pr} = \frac{\delta^2\mathcal{L}}{\delta(D^\mu\phi)^J\delta(\bar{\psi}_p\gamma_\mu\sigma_A\psi_r)}\bigg|_{\text{fields}\to 0} = -(\phi\gamma_4)\delta_{A4}\sum_{n=0}^{\infty}\frac{c_{H\psi,pr}^{1,(6+2n)}}{\Lambda^{2n}}(H^\dagger H)^n + 4\text{ more}$$

A taste of geoSMEFT

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Get an all orders result:

$$\mathcal{M}^\mu_{Z\bar{\psi}\psi} = \gamma^\mu \frac{\bar{g}_Z}{2}\left[(2s^2_{\theta_Z}Q_\psi - \sigma_3)\delta_{pr} + \bar{v}_T\langle L^{\psi,pr}_{3,4}\rangle + \sigma_3\bar{v}_T\langle L^{\psi pr}_{3,3}\rangle\right]$$

Go calculate EWPD to all orders (or truncate at $\frac{1}{\Lambda^4}$, TC et al. 2102.02819)

Errors from EWPD to $\frac{1}{\Lambda^4}$

- Perform a χ^2 to EWPD
- include SM two loop results
- include SMEFT results up to $\frac{1}{\Lambda^4}$ including D8 operators
- randomly sample relevant WCs

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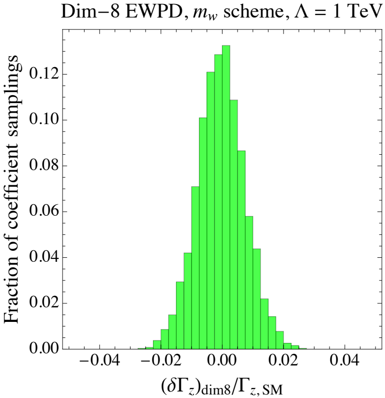

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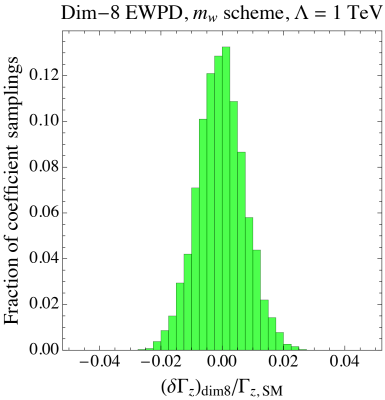
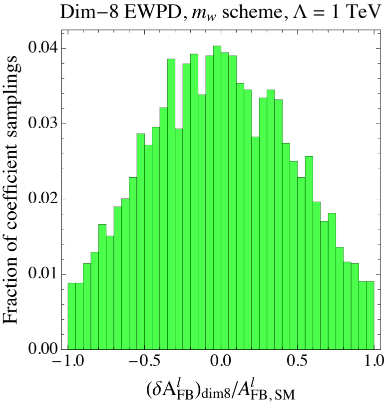
- include SMEFT results up to $\frac{1}{\Lambda^4}$ including D8 operators
- randomly sample relevant WCs

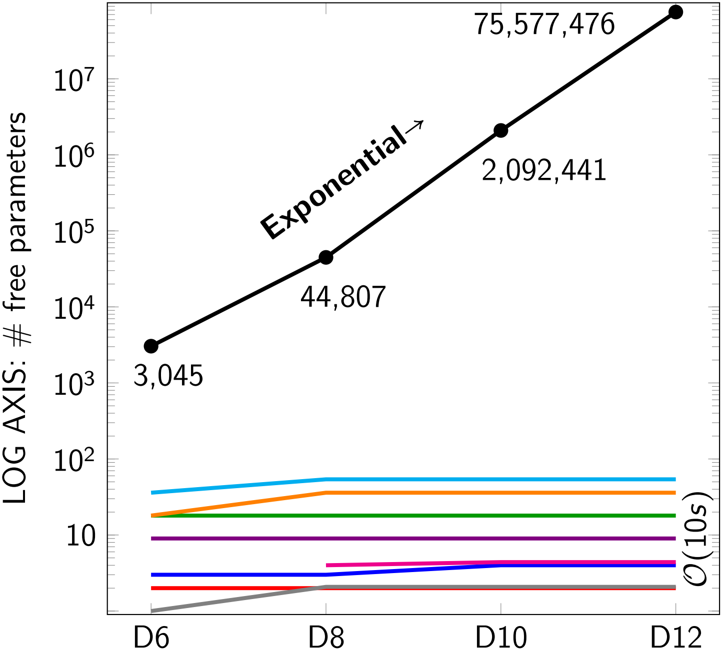




2- and 3-pt functions known in geoSMEFT

		Mass Dimension				
	Operator form:	6	8	10	12	
🟥	$h_{IJ}(D_\mu \phi)^I (D^\mu \phi)^J$	2	2	2	2	masses
🟦	$g_{AB} W^A_{\mu\nu} W^{B,\mu\nu}$	3	4	4	4	couplings, mix. angles
🟪	$k_{IJA}(D^\mu \phi)^I (D^\nu \phi)^J W^A_{\mu\nu}$	0	3	4	4	TGC, HVV
⬛	$f_{ABC} W^A_{\mu\nu} W^{B,\nu\rho} W^{C,\mu}_{\rho}$	1	2	2	2	QGC, TGC
🟩	$Y^{\psi}_{pr} \bar{\Psi}_L \psi_R + h.c.$	$2N_f^2$	$2N_f^2$	$2N_f^2$	$2N_f^2$	Yukawa
🟦	$d^{\psi,pr}_A \bar{\Psi}_L \sigma_{\mu\nu} \psi_R W^{\mu\nu}_A + h.c.$	$4N_f^2$	$6N_f^2$	$6N_f^2$	$6N_f^2$	dipoles
🟪	$L^{\psi_R}_{pr,J,A}(D^\mu \phi)^J (\bar{\psi}_{p,R} \gamma_\mu \sigma_A \psi_{r,R})$	N_f^2	N_f^2	N_f^2	N_f^2	$V\bar{\psi}\psi$
🟧	$L^{\Psi_L}_{pr,J,A}(D^\mu \phi)^J (\bar{\Psi}_{p,L} \gamma_\mu \sigma_A \Psi_{r,L})$	$2N_f^2$	$4N_f^2$	$4N_f^2$	$4N_f^2$	$V\bar{\psi}\psi$

The number of new free parameters saturates at some point!


LOG AXIS: # free parameters
10^7
10^6
10^5
10^4
10^3
10^2
10
75,577,476
2,092,441
44,807
3,045
Exponential→
$\mathcal{O}(10s)$
D6
D8
D10
D12

Summarizing geoSMEFT

- geoSMEFT rewrite the SMEFT in a curved field space
- number of degrees of freedom saturates for *n*–point fxn
- all orders results in SMEFT power counting
- better understanding of error in SMEFT interpretation
- Further development ⇒ merger loops $+\ \frac{1}{\Lambda^4}$

Precision SMEFT for HL-LHC and FCC

SMEFT is the natural choice for the precision frontier:

- quantifies heavy new physics we can't produce
- systematically improvable (loops + $\frac{1}{\Lambda^{2n}}$ expansion)
- indirect evidence → information about properties of NP

What's happening for the precision SMEFT:

- loop expansion
- geoSMEFT → $\frac{1}{\Lambda^4}$ contributions
- further development will allow for merger of the two

Current efforts in SMEFT should help support and inform design of FCC

FCC-ee will give precision SMEFT results that will help identify NP

FCC-hh can give precision SMEFT result on poles (where $E \ll \Lambda$)

FCC-hh can give access to part of SMEFT not seen at HL-LHC
(e.g. vertices w two Higgs)

The SMEFT at dimension-six

D6 operators from SM field content ⇒ SMEFT @ D6

The SMEFT at dimension-six

D6 operators from SM field content ⇒ SMEFT @ D6

Type I: X^3		Type II, III: $H^6,\ H^4D^2$		Type V: $\Psi^2H^3+\mathrm{h.c.}$	
Q_G	$f^{ABC}G_\mu^{A\nu}G_\nu^{B\rho}G_\rho^{C\mu}$	Q_H	$(H^\dagger H)^3$	Q_{eH}	$(H^\dagger H)(\bar{L}eH)$
$Q_{\tilde{G}}$	$f^{ABC}\tilde{G}_\mu^{A\nu}G_\nu^{B\rho}G_\rho^{C\mu}$	$Q_{H\Box}$	$(H^\dagger H)\Box(H^\dagger H)$	Q_{uH}	$(H^\dagger H)(\bar{Q}u\tilde{H})$
Q_W	$\epsilon^{IJK}W_\mu^{I\nu}W_\nu^{J\rho}W_\rho^{K\mu}$	Q_{HD}	$(H^\dagger D^\mu H)^*(H^\dagger D^\mu H)$	Q_{dH}	$(H^\dagger H)(\bar{Q}dH)$
$Q_{\tilde{W}}$	$\epsilon^{IJK}\tilde{W}_\mu^{I\nu}W_\nu^{J\rho}W_\rho^{K\mu}$				

Type IV: $X^2\Phi^2$		Type VI: Ψ^2H^3		Type VII: Ψ^2H^2D	
Q_{HG}	$(H^\dagger H)G_{\mu\nu}^AG^{A\mu\nu}$	Q_{eW}	$(\bar{L}\sigma^{\mu\nu}e)\tau^IHW_{\mu\nu}^I$	$Q_{HL}^{(1)}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{L}\gamma^\mu L)$
$Q_{H\tilde{G}}$	$(H^\dagger H)\tilde{G}_{\mu\nu}^AG^{A\mu\nu}$	Q_{eW}	$(\bar{L}\sigma^{\mu\nu}e)\tau^IHB_{\mu\nu}$	$Q_{HL}^{(3)}$	$(H^\dagger i\overleftrightarrow{D}_\mu^I H)(\bar{L}\tau^I\gamma^\mu L)$
Q_{HW}	$(H^\dagger H)W_{\mu\nu}^IW^{I\mu\nu}$	Q_{uG}	$(\bar{Q}\sigma^{\mu\nu}T^Au)\tilde{H}G_{\mu\nu}^A$	Q_{He}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{e}\gamma^\mu e)$
$Q_{H\tilde{W}}$	$(H^\dagger H)\tilde{W}_{\mu\nu}^IW^{I\mu\nu}$	Q_{uW}	$(\bar{Q}\sigma^{\mu\nu}u)\tau^I\tilde{H}W_{\mu\nu}^I$	$Q_{HQ}^{(1)}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{q}\gamma^\mu q)$
Q_{HB}	$(H^\dagger H)B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{Q}\sigma^{\mu\nu}u)\tilde{H}B_{\mu\nu}$	$Q_{HQ}^{(3)}$	$(H^\dagger i\overleftrightarrow{D}_\mu^I H)(\bar{q}\tau^I\gamma^\mu q)$
$Q_{H\tilde{B}}$	$(H^\dagger H)\tilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{Q}\sigma^{\mu\nu}T^Ad)HG_{\mu\nu}^A$	Q_{Hu}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{u}\gamma^\mu u)$
Q_{HWB}	$(H^\dagger\tau^IH)W_{\mu\nu}^IB^{\mu\nu}$	Q_{dW}	$(\bar{Q}\sigma^{\mu\nu}d)\tau^IHW_{\mu\nu}^I$	Q_{Hd}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{d}\gamma^\mu d)$
$Q_{H\tilde{W}B}$	$(H^\dagger\tau^IH)\tilde{W}_{\mu\nu}^IB^{\mu\nu}$	Q_{dB}	$(\bar{Q}\sigma^{\mu\nu}d)\tilde{H}B_{\mu\nu}$	Q_{Hud}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{u}\gamma^\mu d)$

$$\begin{aligned}\text{Type VIII: } & 5\times(\bar{L}L)(\bar{L}L)+7\times(\bar{R}R)(\bar{R}R)+8\times(\bar{L}L)(\bar{R}R)\\ & +(\bar{L}R)(\bar{R}L)+4[(\bar{L}R)(\bar{L}R)+\mathrm{h.c.}]=25(\bar{\Psi}\Psi)(\bar{\Psi}\Psi)\end{aligned}$$