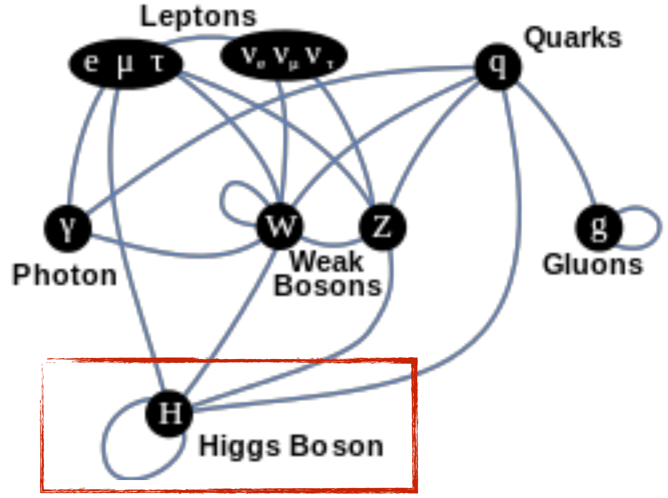
LHC Higgs X-section WG2

CERN 10.12.2018



- BSM Benchmarks -

Mingshui Chen, Marco Delmastro, Chris Hays, Predrag Milenovic, David Marzocca, Francesco Riva

Higgs and EW Physics

Precision SM Measurements in Higgs physics...why?

1) Indirect searches of BSM
2) Test of how well we know the SM

Established framework: EFT*

$$\mathcal{L}^{EFT} = \mathcal{L}^{SM} + \sum_i c_i \frac{\mathcal{O}}{M^2} + \cdots$$

for 2), we want this as general as possible
(for a nice parametrisation in this case, see last YR, 1610.07922)

* Anomalous couplings lower SM cutoff and are an EFT

...as general as possible, model independent.

- Difficult in practice
- Inefficient (e.g. nearly flat direction $\lambda_Z \approx -\delta g_{1.Z}$) 1411.0669

  affects V_T (λ_Z), affects V_L ($\delta g_{1.Z}$)
- Restricting assumptions appear in most analyses (e.g. flavour universality)
- More is learnt about the SM when it's tested against specific BSM hypotheses

BSM Benchmarks

Document that summarizes classes of BSM scenarios and matches to EFT

- Useful for experiments to motivate more sharply specific searches
- Useful for theorists to interpret exp. results in EFT language
- Leads to educated choices of subsets of operators

BSM Benchmarks

Largest effects: at tree level, when NP Φ couples to SM as,

$$\Phi \mathcal{O}_{SM}$$

1) Composite Higgs models Vecchi

2) Generic Minimal SM extension deBlas, Criado, Perez-Victoria,Santiago

3) Extended scalar sectors Dawson, Murphy

4) Strongly interacting vectors Liu, Wang

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Symmetry can lead to first interactions with NP

$$\Phi^2 \mathcal{O}_{SM}$$

5) New Physics at loop level Henning

HXSWG Document

All contributions have arrived

Introduction missing

Document will provide a dictionary between class of models and class of processes

1) Composite Higgs

Luca Vecchi

Guiding table: operators <-> processes

(Universal Theories)

Operators (SILH) — Main effects in (low-energy) Higgs physics — Main effects in (high-energy) 2->2 physics

Operator name	Operator definition	Main On-shell (Higgs)	Dominant Off-shell
$\mathcal{O}_H$	$\frac{1}{2}\,\partial_\mu(H^\dagger H)\partial^\mu(H^\dagger H)$	$h\to\psi\bar\psi, VV^*$ at $\lesssim O(10\%)$	$V_LV_L\to V_LV_L, hh$
$\mathcal{O}_T$	$\frac{1}{2}\,(H^\dagger \overleftrightarrow{D}_\mu H)(H^\dagger \overleftrightarrow{D}^\mu H)$	$h\to ZZ^*$ at $\lesssim O(0.1\%)$	$V_LV_L\to V_LV_L, hh$
$\mathcal{O}_6$	$\lambda_h(H^\dagger H)^3$	None	$h\to hh$
$\mathcal{O}_\psi$	$y_\psi\ \overline{\psi}_L H\psi_R(H^\dagger H)$	$h\to\psi\bar\psi$ at $\lesssim O(10\%)$	$V_LV_L\to t\bar t$
$\mathcal{O}_W$	$\frac{i}{2}\ g(H^\dagger\sigma^i \overleftrightarrow{D}_\mu H)(D_\nu W^{\mu\nu})^i$	$h\to VV^*, V^*\to hV$ at $\lesssim O(0.1\%)$	$q\bar q\to V_LV_L$
$\mathcal{O}_B$	$\frac{i}{2}\ g'(H^\dagger \overleftrightarrow{D}_\mu H)(\partial_\nu B^{\mu\nu})$	$h\to VV^*$ at $\lesssim O(0.1\%)$	$q\bar q\to V_LV_L$
$\mathcal{O}_{HW}$	$ig(D^\mu H)^\dagger\sigma^i(D^\nu H)W^i_{\mu\nu}$	$h\to\gamma Z$ at $\lesssim O(10\%)$	$q\bar q\to V_LV_L$
$\mathcal{O}_{HB}$	$ig'(D^\mu H)^\dagger(D^\nu H)B_{\mu\nu}$	$h\to\gamma Z$ at $\lesssim O(10\%)$	$q\bar q\to V_LV_L$
$\mathcal{O}_g$	$g_s^2 H^\dagger H G^a_{\mu\nu}G^{a\mu\nu}$	$h\to gg$ at $\lesssim O(10\%)$	$pp\to V_LV_L, hh$
$\mathcal{O}_\gamma$	$g'^2 H^\dagger H B_{\mu\nu}B^{\mu\nu}$	$h\to\gamma\gamma,\gamma Z, ZZ$ at $\lesssim O(10\%)$	$V_LV_L\to\gamma\gamma,\gamma Z, ZZ$
$\mathcal{O}_{2G}$	$-\frac{1}{2}g_s^2(D^\mu G_{\mu\nu})^a(D_\rho G^{\rho\nu})^a$	None	$pp\to jj$
$\mathcal{O}_{2W}$	$-\frac{1}{2}g^2(D^\mu W_{\mu\nu})^i(D_\rho W^{\rho\nu})^i$	None	$q\bar q\to\psi\bar\psi, VV$
$\mathcal{O}_{2B}$	$-\frac{1}{2}g'^2(\partial^\mu B_{\mu\nu})(\partial_\rho B^{\rho\nu})$	None	$q\bar q\to\psi\bar\psi, VV$
$\mathcal{O}_{3G}$	$g_s^3 f_{abc}G^{a\nu}_\mu G^{b\rho}_\nu G^{c\mu}_\rho$	None	$pp\to jj$
$\mathcal{O}_{3W}$	$g^3\epsilon_{ijk}W^{i\nu}_\mu W^{j\rho}_\nu W^{k\mu}_\rho$	None	$q\bar q\to VV$

Subleading

1) Composite Higgs

Luca Vecchi

New (perhaps large) coupling

Composite Higgs:

$$\delta\mathcal{L}_{\rm NDA} = \frac{m_*^4}{g_*^2}\hat{\mathcal{L}}\left(\frac{g_* H}{m_*}, \epsilon_\psi \frac{g_*\psi}{m_*^{3/2}}, \frac{D_\mu}{m_*}\right),$$

Symmetries

New mass

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Luca Vecchi

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Composite Higgs:

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Symmetries　　New mass

Assumptions <-> EFT:

Naive Power Counting (→ Generic CH)　　Only BSM Scalar (→ Light $j=0$)　　Only BSM Vector (→ Light $j=1$)　　No EW-BSM interaction (→ Only Higgs)

Coefficient	Generic CH	Light $j=0$	Light $j=1$	Only Higgs	$SU(2)$ custodial	NGB-Higgs
$c_{H,\psi}$	g_*^2	g_*^2	g_*^2	g_*^2	g_*^2	g_*^2
c_T	g_*^2	g_*^2	g_*^2	g_*^2	$g_*^2\times\frac{g'^2}{16\pi^2}$	g_*^2
c_6	$\frac{g_*^4}{\lambda_h}$	$\frac{g_*^4}{\lambda_h}$	$\frac{g_*^4}{\lambda_h}$	$\frac{g_*^4}{\lambda_h}$	$\frac{g_*^4}{\lambda_h}$	$\frac{g_*^4}{\lambda_h}\times\left(\frac{g_{\not{g}}^2}{g_*^2} \text{ or } \frac{g_{\not{g}}^2}{16\pi^2}\right)$
$c_{W,B}$	1	$\frac{g_*^2}{16\pi^2}$	1	$\frac{g_*^2}{16\pi^2}$	1	1
$c_{HW,HB}$	1	$\frac{g_*^2}{16\pi^2}$	$\frac{g_*^2}{16\pi^2}$	$\frac{g_*^2}{16\pi^2}$	1	1
$c_{g,\gamma}$	1	$\frac{g_*^2}{16\pi^2}$	$\frac{g_*^2}{16\pi^2}$	$\frac{g_*^2}{16\pi^2}$	1	$\frac{g_{\not{g}}^2}{16\pi^2}$
$c_{2G,2W,2B}$	$\frac{1}{g_*^2}$	$\frac{1}{g_*^2}\times\frac{g_*^2}{16\pi^2}$	$\frac{1}{g_*^2}$	$\frac{1}{g_*^2}\times\frac{g_*^2}{16\pi^2}$	$\frac{1}{g_*^2}$	$\frac{1}{g_*^2}$
$c_{3G,3W}$	$\frac{1}{g_*^2}$	$\frac{1}{g_*^2}\times\frac{g_*^2}{16\pi^2}$	$\frac{1}{g_*^2}\times\frac{g_*^2}{16\pi^2}$	$\frac{1}{g_*^2}\times\frac{g_*^2}{16\pi^2}$	$\frac{1}{g_*^2}$	$\frac{1}{g_*^2}$

2) Generic Minimal SM extensions

deBlas, Criado, Perez-Victoria, Santiago
(summarising 1711.10391)

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Simple extension with just one resonance:

Fields that can couple (renormalizably) to SM

SM quantum numbers of the resonance

Scalars	$\mathcal{S}$	φ	Ξ	Ξ_1	Θ_1	Θ_3
	$(1,1)_0$	$(1,2)_{1/2}$	$(1,3)_0$	$(1,3)_1$	$(1,4)_{1/2}$	$(1,4)_{3/2}$

Fermions							
	N	E	Δ_1	Δ_3	Σ	Σ_1	
	$(1,1)_0$	$(1,1)_{-1}$	$(1,2)_{-1/2}$	$(1,2)_{-3/2}$	$(1,3)_0$	$(1,3)_{-1}$	
	U	D	Q_1	Q_5	Q_7	T_1	T_2
	$(3,1)_{2/3}$	$(3,1)_{-1/3}$	$(3,2)_{1/6}$	$(3,2)_{-5/6}$	$(3,2)_{7/6}$	$(3,3)_{-1/3}$	$(3,3)_{2/3}$

Vectors	$\mathcal{B}$	$\mathcal{B}_1$	$\mathcal{W}$	$\mathcal{W}_1$
	$(1,1)_0$	$(1,1)_1$	$(1,3)_0$	$(1,3)_1$

2) Generic Minimal SM extensions

deBlas, Criado, Perez-Victoria, Santiago
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Generated operator(s), Warsaw basis

Affect EWPT

Name	Operator	Fields that generate it
$\star\, \mathcal{O}_{\phi}$	$\lvert\phi\rvert^6$	$\mathcal{S},\ \varphi,\ \Xi,\ \Xi_1,\ \Theta_1,\ \Theta_3,\ \mathcal{B}_1,\ \mathcal{W}$
$\star\, \mathcal{O}_{\phi\Box}$	$\lvert\phi\rvert^2\Box\lvert\phi\rvert^2$	$\mathcal{S},\ \Xi,\ \Xi_1,\ \mathcal{B},\ \mathcal{B}_1,\ \mathcal{W},\ \mathcal{W}_1$
$\mathcal{O}_{\phi D}$	$\lvert\phi^\dagger D_\mu \phi\rvert^2$	$\Xi,\ \Xi_1,\ \mathcal{B},\ \mathcal{B}_1,\ \mathcal{W},\ \mathcal{W}_1$
$\bullet\, \mathcal{O}_{e\phi}$	$\lvert\phi\rvert^2 \bar{l}_L \phi e_R$	$\mathcal{S},\ \varphi,\ \Xi,\ \Xi_1,\ E,\ \Delta_1,\ \Delta_3,\ \Sigma,\ \Sigma_1,\ \mathcal{B},\ \mathcal{B}_1,\ \mathcal{W},\ \mathcal{W}_1$
$\bullet\, \mathcal{O}_{d\phi}$	$\lvert\phi\rvert^2 \bar{q}_L \phi d_R$	$\mathcal{S},\ \varphi,\ \Xi,\ \Xi_1,\ D,\ Q_1,\ Q_5,\ T_1,\ T_2,\ \mathcal{B},\ \mathcal{B}_1,\ \mathcal{W},\ \mathcal{W}_1$
$\star\, \mathcal{O}_{u\phi}$	$\lvert\phi\rvert^2 \bar{q}_L \tilde{\phi} u_R$	$\mathcal{S},\ \varphi,\ \Xi,\ \Xi_1,\ U,\ Q_1,\ Q_7,\ T_1,\ T_2\ \mathcal{B},\ \mathcal{B}_1,\ \mathcal{W},\ \mathcal{W}_1$
$\mathcal{O}_{\phi l}^{(1)}$	$(\bar{l}_L\gamma^\mu l_L)(\phi^\dagger i \overleftrightarrow{D}_\mu \phi)$	$N,\ E,\ \Sigma,\ \Sigma_1,\ \mathcal{B}$
$\mathcal{O}_{\phi l}^{(3)}$	$(\bar{l}_L\gamma^\mu \sigma^a l_L)(\phi^\dagger i \overleftrightarrow{D}^a_\mu \phi)$	$N,\ E,\ \Sigma,\ \Sigma_1,\ \mathcal{W}$
$\mathcal{O}_{\phi q}^{(1)}$	$(\bar{q}_L\gamma^\mu q_L)(\phi^\dagger i \overleftrightarrow{D}_\mu \phi)$	$U,\ D,\ T_1,\ T_2,\ \mathcal{B}$
$\mathcal{O}_{\phi q}^{(3)}$	$(\bar{q}_L\gamma^\mu \sigma^a q_L)(\phi^\dagger i \overleftrightarrow{D}^a_\mu \phi)$	$U,\ D,\ T_1,\ T_2,\ \mathcal{W}$
$\mathcal{O}_{\phi e}$	$(\bar{e}_R\gamma^\mu e_R)(\phi^\dagger i \overleftrightarrow{D}_\mu \phi)$	$\Delta_1,\ \Delta_3,\ \mathcal{B}$
$\mathcal{O}_{\phi u}$	$(\bar{u}_R\gamma^\mu u_R)(\phi^\dagger i \overleftrightarrow{D}_\mu \phi)$	$Q_1,\ Q_7,\ \mathcal{B}$
$\mathcal{O}_{\phi d}$	$(\bar{d}_R\gamma^\mu d_R)(\phi^\dagger i \overleftrightarrow{D}_\mu \phi)$	$Q_1,\ Q_5,\ \mathcal{B}$
$\mathcal{O}_{\phi ud}$	$(\bar{u}_R\gamma^\mu d_R)(\phi^\dagger i D_\mu \tilde{\phi})$	$Q_1,\ \mathcal{B}_1$

2) Generic Minimal SM extensions

deBlas, Criado, Perez-Victoria, Santiago
(summarising 1711.10391)

Many models contribute to EW precision data:

→ assume custodial symmetry (Rather than neglecting operators)

Quark bidoublet: $Q_1 \sim (3,2)_{1/6}$ **and** $Q_7 \sim (3,2)_{7/6}$

$(C_{u\phi})_{33}$
$\frac{\lvert\lambda\rvert^2}{M^2}$

Neutral vector triplet: $\mathcal{W} \sim (1,3)_0$

C_ϕ	$C_{\phi\Box}$	$(C_{\psi\phi})_{ij}$	$(C^{(3)}_{\phi\psi})_{ij}$
$-\frac{\lambda_\phi (g^\phi)^2}{M^2}$	$-\frac{3(g^\phi)^2}{8M^2}$	$-\frac{y^{\psi *}_{ji}(g^\phi)^2}{4M^2}$	$-\frac{(g^\psi)_{ij}(g^\phi)}{4M^2}$

Pair of vector singlets: $\mathcal{B} \sim (1,1)_0$ **and** $\mathcal{B}_1 \sim (1,1)_1$

C_ϕ	$C_{\phi\Box}$	$(C_{\psi\phi})_{ij}$
$-\frac{4\lambda_\phi (g^\phi)^2}{M^2}$	$-\frac{3(g^\phi)^2}{2M^2}$	$-\frac{y^{\psi *}_{ji}(g^\phi)^2}{M^2}$

3) More details on Extended Scalar Sectors

Dawson, Murphy
(summarising 1704.07851)

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Dawson, Murphy
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Scalar models parametrised through physical $\alpha,\ \beta$

mixing

$$\begin{pmatrix} h \\ \mathcal{H} \end{pmatrix} = \begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} h' \\ \varphi \end{pmatrix}$$

ratio of vevs

$$\tan\beta_s = v_h / v_\phi.$$

$\mathrm{Re}(\phi^0) = v_\phi + \varphi.$

Model	$\mathbf{c_H}$	$\mathbf{c_6}\lambda_{\mathbf{SM}}$	$\mathbf{c_T}$	$\mathbf{c_t}$	$\mathbf{c_b} = \mathbf{c}_\tau$
Real Singlet: explicit $\not{Z}_2$	$\tan^2\alpha$	$\tan^2\alpha\left(\lambda_\alpha - \frac{m_2}{v}\tan\alpha\right)$	0	0	0
Real Singlet: spontaneous $\not{Z}_2$	$\tan^2\alpha$	0	0	0	0
2HDM: Type I	0	$-\cos^2(\beta-\alpha)\frac{\Lambda^2}{v^2}$	0	$-\cos(\beta-\alpha)\cot(\beta)$	$-\cos(\beta-\alpha)\cot(\beta)$
2HDM: Type II	0	$-\cos^2(\beta-\alpha)\frac{\Lambda^2}{v^2}$	0	$-\cos(\beta-\alpha)\cot(\beta)$	$\cos(\beta-\alpha)\tan(\beta)$
Real Triplet	$-2c_T$	$c_T\lambda_\alpha$	✓	c_T	c_T
Complex Triplet	c_T	$-c_T\left(\lambda_{\alpha 1} - \frac{\lambda_{\alpha 2}}{2}\right)$	✓	$-c_T$	$-c_T$
Quartet: $Y = \frac{1}{2}$	0	$-2c_T\frac{\Lambda^2}{v^2}$	✓	0	0
Quartet: $Y = \frac{3}{2}$	0	$\frac{2}{3}c_T\frac{\Lambda^2}{v^2}$	✓	0	0

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Real Singlet: explicit $\not{Z}_2$	$\tan^2\alpha$	$\tan^2\alpha\left(\lambda_\alpha - \frac{m_2}{v}\tan\alpha\right)$	0	0	0
Real Singlet: spontaneous $\not{Z}_2$	$\tan^2\alpha$	0	0	0	0
2HDM: Type I	0	$-\cos^2(\beta-\alpha)\frac{\Lambda^2}{v^2}$	0	$-\cos(\beta-\alpha)\cot(\beta)$	$-\cos(\beta-\alpha)\cot(\beta)$
2HDM: Type II	0	$-\cos^2(\beta-\alpha)\frac{\Lambda^2}{v^2}$	0	$-\cos(\beta-\alpha)\cot(\beta)$	$\cos(\beta-\alpha)\tan(\beta)$
Real Triplet	$-2c_T$	$c_T\lambda_\alpha$	✓	c_T	c_T
Complex Triplet	c_T	$-c_T\left(\lambda_{\alpha 1} - \frac{\lambda_{\alpha 2}}{2}\right)$	✓	$-c_T$	$-c_T$
Quartet: $Y = \frac{1}{2}$	0	$-2c_T\frac{\Lambda^2}{v^2}$	✓	0	0
Quartet: $Y = \frac{3}{2}$	0	$\frac{2}{3}c_T\frac{\Lambda^2}{v^2}$	✓	0	0

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Constraints from T-parameter

Model	ρ	3σ **upper limit on** β
Singlet	1	none
2HDM	1	none
Real Triplet	$\sec^2\beta$	0.030
Complex Triplet	$2\,(3-\cos 2\beta)^{-1}$	0.014
Quartet: $Y=\frac{1}{2}$	$7\,(4+3\cos 2\beta)^{-1}$	0.033
Quartet: $Y=\frac{3}{2}$	$(2-\cos 2\beta)^{-1}$	0.010

4) Strongly interacting vectors

Da Liu, Lian-Tao Wang

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Da Liu, Lian-Tao Wang

Models where transverse polarisations are strongly coupled (Remedios),

$$\mathcal{O}_{3W} = \frac{1}{3!} g \epsilon_{abc} W_\mu^{a\nu} W_{\nu\rho}^b W^{c\rho\mu}$$

Model	$\mathcal{O}_{2V}$	$\mathcal{O}_{3V}$	$\mathcal{O}_{HW}$	$\mathcal{O}_{HB}$	$\mathcal{O}_V$	$\mathcal{O}_{VV}$	$\mathcal{O}_H$	$\mathcal{O}_{y_\psi}$
Remedios	1	g_*						
Remedios+MCHM	1	g_*	g	g'	g_V	g_V^2	g_*^2	$y_\psi g_*^2$
Remedios+$ISO(4)$	1	g_*	g_*	g'	g_V	g_V^2	λ_h	$y_\psi \lambda_h$

4) Strongly interacting vectors

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Model	$\mathcal{O}_{2V}$	$\mathcal{O}_{3V}$	$\mathcal{O}_{HW}$	$\mathcal{O}_{HB}$	$\mathcal{O}_{V}$	$\mathcal{O}_{VV}$	$\mathcal{O}_{H}$	$\mathcal{O}_{y_\psi}$
Remedios	1	g_*						
Remedios+MCHM	1	g_*	g	g'	g_V	g_V^2	g_*^2	$y_\psi g_*^2$
Remedios+*ISO*(4)	1	g_*	g_*	g'	g_V	g_V^2	λ_h	$y_\psi \lambda_h$

..& Higgs strongly coupled

4) Strongly interacting vectors

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Model	$\mathcal{O}_{2V}$	$\mathcal{O}_{3V}$	$\mathcal{O}_{HW}$	$\mathcal{O}_{HB}$	$\mathcal{O}_{V}$	$\mathcal{O}_{VV}$	$\mathcal{O}_{H}$	$\mathcal{O}_{y_\psi}$
Remedios	1	g_*						
Remedios+MCHM	1	g_*	g	g'	g_V	g_V^2	g_*^2	$y_\psi g_*^2$
Remedios+$ISO(4)$	1	g_*	g_*	g'	g_V	g_V^2	λ_h	$y_\psi \lambda_h$

..& Higgs strongly coupled

Large effects in $V_L V_L$

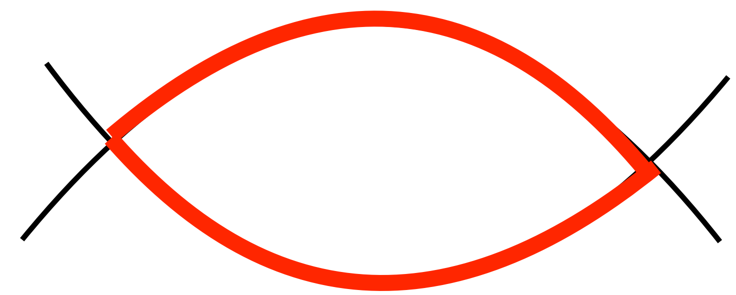
Large effects in $V_T V_T$

→ Important to motivate TGC or VH analysis

5) Loop effects Henning

A Z_2 accidental symmetry could lead to BSM-SM interactions:

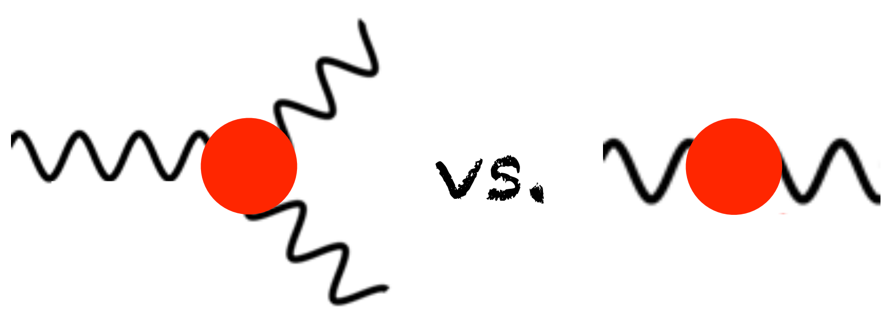
$$\Phi^2 \mathcal{O}_{SM} \quad \longrightarrow$$



- First effects at loop level - calculable in weakly coupled UV

- Some operators can only arise at loop level if UV = weakly coupled particles of spin<=1 Arzt,Einhorn

Patterns:



$$\frac{c_{3W}}{c_{2W}} \sim spin(\Phi)$$

5) Loop effects

Explicit Examples: Light scalar stops $\Phi = (\tilde{Q}_3, \tilde{t}_R)^T$

$$\mathcal{L} = \Phi^\dagger \left(-D^2 - m^2 - U\right) \Phi,$$

$$c_{GG} = \frac{h_t^2}{(4\pi)^2}\frac{1}{12}\left[\left(1+\frac{1}{12}\frac{g'^2 c_{2\beta}}{h_t^2}\right) - \frac{1}{2}\frac{X_t^2}{m_{\tilde{t}}^2}\right]$$

$$c_{WW} = \frac{h_t^2}{(4\pi)^2}\frac{1}{16}\left[\left(1-\frac{1}{6}\frac{g'^2 c_{2\beta}}{h_t^2}\right) - \frac{2}{5}\frac{X_t^2}{m_{\tilde{t}}^2}\right]$$

$$c_{BB} = \frac{h_t^2}{(4\pi)^2}\frac{17}{144}\left[\left(1+\frac{31}{102}\frac{g'^2 c_{2\beta}}{h_t^2}\right) - \frac{38}{85}\frac{X_t^2}{m_{\tilde{t}}^2}\right]$$

$$c_{WB} = -\frac{h_t^2}{(4\pi)^2}\frac{1}{24}\left[\left(1+\frac{1}{2}\frac{g^2 c_{2\beta}}{h_t^2}\right) - \frac{4}{5}\frac{X_t^2}{m_{\tilde{t}}^2}\right]$$

$$c_W = \frac{h_t^2}{(4\pi)^2}\frac{1}{40}\frac{X_t^2}{m_{\tilde{t}}^2}$$

$$c_B = \frac{h_t^2}{(4\pi)^2}\frac{1}{40}\frac{X_t^2}{m_{\tilde{t}}^2}$$

$$c_{3G} = \frac{g_s^2}{(4\pi)^2}\frac{1}{20}$$

$$c_{3W} = \frac{g^2}{(4\pi)^2}\frac{1}{20}$$

$$c_{2G} = \frac{g_s^2}{(4\pi)^2}\frac{1}{20}$$

$$c_{2W} = \frac{g^2}{(4\pi)^2}\frac{1}{20}$$

$$c_{2B} = \frac{g'^2}{(4\pi)^2}\frac{1}{20}$$

$$c_H = \frac{h_t^4}{(4\pi)^2}\frac{3}{4}\left[\left(1+\frac{1}{3}\frac{g'^2 c_{2\beta}}{h_t^2}+\frac{1}{12}\frac{g'^4 c_{2\beta}^2}{h_t^4}\right) - \frac{7}{6}\frac{X_t^2}{m_{\tilde{t}}^2}\left(1+\frac{1}{14}\frac{(g^2+2g'^2)c_{2\beta}}{h_t^2}\right)+\frac{7}{30}\frac{X_t^4}{m_{\tilde{t}}^2}\right]$$

$$c_T = \frac{h_t^4}{(4\pi)^2}\frac{1}{4}\left[\left(1+\frac{1}{2}\frac{g^2 c_{2\beta}}{h_t^2}\right)^2 - \frac{1}{2}\frac{X_t^2}{m_{\tilde{t}}^2}\left(1+\frac{1}{2}\frac{g^2 c_{2\beta}}{h_t^2}\right)+\frac{1}{10}\frac{X_t^4}{m_{\tilde{t}}^4}\right]$$

$$c_R = \frac{h_t^4}{(4\pi)^2}\frac{1}{2}\left[\left(1+\frac{1}{2}\frac{g^2 c_{2\beta}}{h_t^2}\right)^2 - \frac{3}{2}\frac{X_t^2}{m_{\tilde{t}}^2}\left(1+\frac{1}{12}\frac{(3g^2+g'^2)c_{2\beta}}{h_t^2}\right)+\frac{3}{10}\frac{X_t^4}{m_{\tilde{t}}^4}\right]$$

$$c_D = \frac{h_t^2}{(4\pi)^2}\frac{1}{20}\frac{X_t^2}{m_{\tilde{t}}^2}$$

$$c_6 = -\frac{h_t^6}{(4\pi)^2}\frac{1}{2}\left\{\begin{array}{l}\left[1+\frac{1}{12}\frac{(3g^2-g'^2)c_{2\beta}}{h_t^2}\right]^3+\left[-\frac{1}{12}\frac{(3g^2+g'^2)c_{2\beta}}{h_t^2}\right]^3+\left(1+\frac{1}{3}\frac{g'^2 c_{2\beta}}{h_t^2}\right)^3 \\ -\frac{X_t^2}{m_{\tilde{t}}^2}\left[2\left(1+\frac{1}{12}\frac{(3g^2-g'^2)c_{2\beta}}{h_t^2}\right)\left(1+\frac{1}{8}\frac{(g^2+g'^2)c_{2\beta}}{h_t^2}\right)+\left(1+\frac{1}{3}\frac{g'^2 c_{2\beta}}{h_t^2}\right)^2\right] \\ +\frac{X_t^4}{m_{\tilde{t}}^4}\left[1+\frac{1}{8}\frac{(g^2+g'^2)c_{2\beta}}{h_t^2}\right]-\frac{X_t^6}{m_{\tilde{t}}^6}\frac{1}{10}\end{array}\right\}$$

Useful for loop-level operators

Conclusions

EFT important for BSM searches and as generic SM test

Generic analysis difficult

→ Important to provide list of EFT BSM models with well-defined hypotheses (Benchmarks)

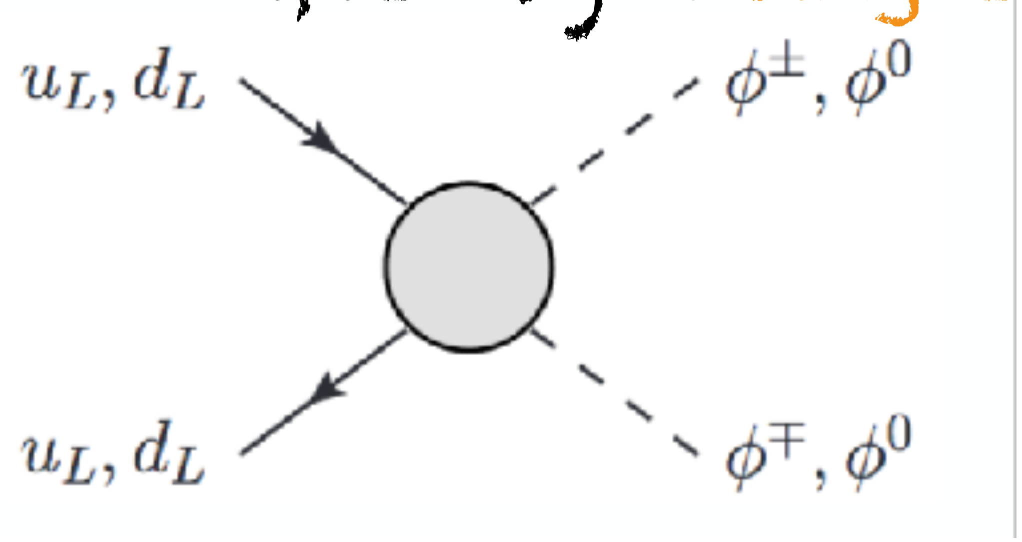
→ Document ready early 2019

...more benchmarks...

Conclusions

- Identify processes where EFT particularly simple or where dedicated analysis particularly advantageous

Ex: VH at high-E modified by a single dim-6 effect



Ex: WZ – angular information improves analysis