Higgs Effective Theory to its limits

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based on work together with
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Outline

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Portraying a BSM Higgs sector

- **Modified Higgs couplings** $\boxed{g_{xxH} = g^{\mathsf{SM}}_{xxH}(1+\Delta_x)}$
- **New fields** $\boxed{\Psi}$

Portraying a BSM Higgs sector

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- UV–complete model:

$$\mathcal{L}_{\mathsf{UV}} = \mathcal{L}_{\mathsf{SM}}(g,\phi) + \mathcal{L}_{\mathsf{BSM}}(g^*,\Psi) + \mathcal{L}_{\Phi-\mathsf{SM}}(\lambda,\phi,\Psi)$$

- Maximize theory input:
  - Complete mass & coupling dependences
  - Parameter correlations & sum rules
- Model–specific computational effort

Overly broad model landscape

Portraying a BSM Higgs sector

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♠ New fields Ψ

♠ UV–complete model:

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♣ Maximize theory input:

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♣ Model–specific computational effort

Overly broad model landscape

♠ Effective Field Theory:

$$\mathcal{L}_{\mathsf{eff}} = \mathcal{L}_{\mathsf{SM}} + \sum_{d=5}^{\infty}\sum_{a_d}\frac{C^{(d)}_{a_d}}{\Lambda^{d-4}}\,\mathcal{O}^{(d)}_{a_d}$$

♣ Minimize theory input

- Model–independence
- Universal computational effort
- Beyond Form Factors:
  - Linkable to couplings & scales
  - Quantum effects may be included — Freitas & al. [in progress]
  - Coupling fits may be extended off-shell — Corbett & al. [1505.05516]

EFT challenges - the role of scales

BSM Higgs program at the LHC **challenges** the EFT approach

- RELEVANCE versus VALIDITY: *a crucial tradeoff!*
  - EFT accurate if $E_{\textbf{phys}} < \Lambda$
  - EFT relevant if $\Delta_{xxH}(\Lambda) \sim \mathcal{O}(10)\%$ LHC accuracy

$$\left| \frac{\sigma \times \textbf{BR}}{(\sigma \times \textbf{BR})_{\textbf{SM}}} - 1 \right| = \frac{g^2 m_H^2}{\Lambda^2} \gtrsim 0.1$$

$\Rightarrow$ $\boxed{\Lambda < \sqrt{10}\, g\, m_H \simeq 280 \text{ GeV}}$, if $g^2 < 1/2$

$\Rightarrow$ $\boxed{\Lambda \lesssim \sqrt{10}\, g\, m_H \simeq 5 \text{ TeV}}$, if $g \lesssim 4\pi$

LHC poorly sensitive to large UV scales in weakly–coupled theories

- MULTIPLE SCALES
  - Hadron collisions involve a **broad** $\sqrt{\hat{S}}$ range
  - Searches rely on additional scales $E \gg m_H$:
    - Acceptance & selection, • boosted kinematics

EFT challenges - new physics issues

BSM Higgs program at the LHC **challenges** the EFT approach

$$\boxed{\mathcal{O} \propto \frac{g^2 v^2}{\Lambda^2}}, \qquad \boxed{\mathcal{O} \propto \frac{g^2 \partial^2}{\Lambda^2}}$$

- ♠ Strong couplings — ♣ Inaccurate truncation — ♣ Competing orders
- ♠ Multiple scales — ♣ Mass splittings — ♣ Ambiguous matching scale
- ♠ Light scales — ♣ Resonances
- ♠ Off-shell regimes — ♣ Incomplete kinematics — ♣ Distorted shapes

Outline

Higgs EFTs versus UV–complete models

*"Given the future experimental resolution, **full calculations** in a **UV complete model** do not offer considerable advantage in accuracy over the **effective theory**"*

Higgs EFTs versus UV–complete models

UV-complete model | QFT framework | Effective Field Theory

*"Given the future experimental resolution, **full calculations** in a **UV complete model** do not offer considerable advantage in accuracy over the **effective theory**"* ?

Key questions

- Is there a scale hierarchy $\Lambda \gg v$ for typical models testable at the LHC ?
- How accurately does the linear, d6 EFT reproduce full model predictions for trademark extended Higgs sectors?
- **Where** and **why** may **discrepancies** arise? May the EFT description fail elsewhere than expected ?
- May full model versus EFT departures be quantitatively relevant for BSM Higgs analyses?

EFT versus full model departures

INTEGRATING OUT

missing resonances

- **On–shell**
  - S–channel resonances
  - Loop thresholds
- **Off–shell**
  - Unitarity breakdown
  - Distorted tails

EFT versus full model departures

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EXPANDING

higher orders

- Competing orders
- Accidental cancellations
- $|\mathcal{O}^{\mathbf{d6}}|^2$ VS $\mathcal{O}^{\mathbf{d4}} \times \mathcal{O}^{\mathbf{d8}}$
- Correlations

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MATCHING

ambiguous choices

- Matching scale
- Default VS v-improved
- Renormalization scheme

Outline

Model setup

- Scalar singlet: Higgs mixing Heavy resonance: H^0

$$V(\phi, S) = \mu_1^2\,(\phi^\dagger\,\phi) + \lambda_1\,|\phi^\dagger\phi|^2 + \mu_2^2\,S^2 + \lambda_2\,S^4 + \lambda_3\,|\phi^\dagger\,\phi|S^2\ ,$$

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- Two–Higgs Doublet Model: Heavy resonances: $H, A, H^\pm$ flexible Yukawas

$$V(\phi_1, \phi_2) = m_{11}^2\,\phi_1^\dagger\phi_1 + m_{22}^2\,\phi_2^\dagger\phi_2 + \frac{\lambda_1}{2}\,(\phi_1^\dagger\phi_1)^2 + \frac{\lambda_2}{2}\,(\phi_2^\dagger\phi_2)^2 + \lambda_3\,(\phi_1^\dagger\phi_1)\,(\phi_2^\dagger\phi_2) + \lambda_4\,|\phi_1^\dagger\,\phi_2|^2 + \left[-m_{12}^2\,\phi_1^\dagger\phi_2 + \frac{\lambda_5}{2}\,(\phi_1^\dagger\phi_2)^2 + \text{h.c.}\right]\ .$$

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- Vector triplet: Weak boson mixing | Heavy resonances: $\xi^0, \xi^\pm$

$$\mathcal{L} \supset -\frac{1}{4}\,V_{\mu\nu}^a\,V^{\mu\nu\,a} + \frac{M_V^2}{2}\,V_\mu^a\,V^{\mu\,a} + i\,\tfrac{g_V}{2}\,c_H\,V_\mu^a\,\left[\phi^\dagger\sigma^a\,\overleftrightarrow{D}^\mu\,\phi\right] + \frac{g_w^2}{2g_V}\,V_\mu^a\,\sum_f c_F\,\overline{F}_L\,\gamma^\mu\,\sigma^a\,F_L + g_V^2\,c_{VVHH}\,V_\mu^a\,V^{\mu a}\,\phi^\dagger\,\phi$$

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- Scalar top partners: NLO corrections VS Loop–induced operators

$$\mathcal{L} \supset (D_\mu\,\tilde{Q})^\dagger\,(D^\mu\tilde{Q}) + (D_\mu\,\tilde{t}_R)^*\,(D^\mu\,\tilde{t}_R) - \tilde{Q}^\dagger\,M^2\,\tilde{Q} - M^2\,\tilde{t}_R^*\,\tilde{t}_R - \kappa_{LL}\,(\phi\cdot\tilde{Q})^\dagger\,(\phi\cdot\tilde{Q}) - \kappa_{RR}\,(\tilde{t}_R^*\tilde{t}_R)\,(\phi^\dagger\,\phi) - \left[\kappa_{LR}\,M\,\tilde{t}_R^*\,(\phi\cdot\tilde{Q}) + \text{h.c.}\right]$$

Higgs EFT

- SM fields & $SU(3)_C \times SU(2)_L \times U(1)_Y$ invariance
- Linearly realized EWSB
- SILH basis @ dimension–six   Giudice, Grojean, Pomarol, Ratazzi ['07]
- HEFT MadGraph model   Alloul, Sanz, Fuks ['13]   *(with in–house modifications)*

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$$
\begin{aligned}
\mathcal{L}_{\textsf{EFT}} =& \mathcal{L}_{\textsf{SM}} + \frac{\bar{c}_H}{2v^2}\,\partial^\mu(\phi^\dagger\,\phi)\,\partial_\mu(\phi^\dagger\,\phi) + \frac{\bar{c}_T}{2v^2}\,(\phi^\dagger\,\overleftrightarrow{D}^\mu\,\phi)\,(\phi^\dagger\,\overleftrightarrow{D}_\mu\,\phi) - \frac{\bar{c}_6\,\lambda}{v^2}(\phi^\dagger\,\phi)^3 \\
&+ \frac{ig\bar{c}_W}{2m_W^2}\,(\phi^\dagger\,\sigma^k\overleftrightarrow{D}^\mu\phi)\,D^\nu\,W^k{}_{\mu\nu} + \frac{ig'\bar{c}_B}{2m_W^2}\,(\phi^\dagger\,\overleftrightarrow{D}^\mu\,\phi)\,\partial^\nu\,B_{\mu\nu} \\
&+ \frac{ig\,\bar{c}_{HW}}{m_W^2}\,(D^\mu\,\phi^\dagger)\,\sigma^k\,(D^\nu\,\phi)\,W^k_{\mu\nu} + \frac{ig'\,\bar{c}_{HB}}{m_W^2}(D^\mu\phi^\dagger)\,(D^\nu\,\phi)\,B_{\mu\nu} \\
&+ \frac{g'^2\,\bar{c}_\gamma}{m_W^2}\,(\phi^\dagger\,\phi)\,B_{\mu\nu}\,B^{\mu\nu} + \frac{g_s^2\,\bar{c}_g}{m_W^2}\,(\phi^\dagger\,\phi)\,G^A_{\mu\nu}\,G^{\mu\nu\,A} \\
&- \left[\frac{\bar{c}_u}{v^2}\,y_u\,(\phi^\dagger\,\phi)(\phi^\dagger\cdot\overline{Q}_L)\,u_R + \frac{\bar{c}_d}{v^2}\,y_d\,(\phi^\dagger\,\phi)(\phi\,\overline{Q}_L)\,d_R + \frac{\bar{c}_\ell}{v^2}\,y_\ell\,(\phi^\dagger\,\phi)(\phi\,\overline{L}_L)\,\ell_R + \text{h.c.}\right].
\end{aligned}
$$

Tree-level matching

UV complete model:

$$\int d^4x\ \mathcal{L}_{\mathsf{UV}}[\phi,\Psi] = \int d^4x\ \left\{ \mathcal{L}_{\mathsf{SM}}[\phi] + (\Psi^\dagger F[\phi] + \text{h.c.}) + \Psi^\dagger (P^2 - M^2 - U[\phi])\Psi + \mathcal{O}(\Psi^3) \right\}$$

Effective action:

$$e^{iS_{\mathsf{eff}}[\phi]} = \int [D\Psi] e^{iS[\phi,\Psi]} = \int [D\eta] e^{i\left(S[\phi,\Psi_c] + \frac{1}{2}\ \frac{\delta^2 S}{\delta\Psi^2}\Big|_{\Psi=\Psi_c} \eta^2 + \mathcal{O}(\eta^3)\right)}$$

$$\approx e^{iS[\phi,\Psi_c]} \left[\det\left(-\frac{\delta^2 S}{\delta \Psi^2}\Big|_{\Psi=\Psi_c}\right)\right]^{-\frac{1}{2}} \approx e^{iS[\phi,\Psi_c] - \frac{1}{2}\mathsf{Tr}\ \mathsf{ln}\left(-\frac{\delta^2 S}{\delta\Psi^2}\Big|_{\Psi=\Psi_c}\right)}\ .$$

$$\boxed{\frac{\delta S}{\delta \Psi}\Big|_{\Psi=\Psi_c} = 0} \quad \Rightarrow \quad \boxed{\mathcal{L}^{\mathsf{eff}}_{\mathsf{tree}}[\phi] = \sum_{n=0}^{\infty} F[\phi]^\dagger M^{-2}[(P^2 - U)M^{-2}]^n F[\phi] + \mathcal{O}(\Phi_c^3)}$$

Tree-level matching

Sample case: vector triplet

♣ Full model Lagrangian:

$$\mathcal{L}_{\text{eff}} \supset \frac{M_V^2}{2} V^{\mu,a}\, V_\mu^a + V_\mu^a \left[g_V\, c_H\, J_H^{\mu,a} + \frac{g_w^2}{2 g_V} c_F\, \sum_F\, J_F^{\mu,a} + \tilde{c}_{WV}\, \frac{g_w}{g_V} J_\mu^{W\,a} \right] + \mathcal{O}(V^3)$$

♣ Classical field equations:

$$V^{\mu,a} = -\frac{1}{M_V^2} \left[\tilde{c}_{WV}\, \frac{g_w}{g_V} J_W^{\mu,a} + g_V\, c_H\, J_H^{\mu,a} + \frac{g_w^2}{2 g_V} c_F\, \sum_F\, J_F^{\mu,a} \right] + \mathcal{O}(p_V^2/m_V^4) + \mathcal{O}(V^2)$$

♣ Effective Lagrangian

$$\mathcal{L}_{\text{eff}} \supset -\frac{(g_V^2 c_H + g_w^2 \tilde{c}_{WV})^2}{2\, g_V^2\, M_V^2} J_H^{\mu,a}\, J_\mu^{H\,a} - \frac{g_w^2\, (c_F + \tilde{c}_{WV})\, (g_V^2 c_H + g_w^2 \tilde{c}_{WV})}{2\, g_V^2\, M_V^2} J_H^{\mu,a}\, J_\mu^{F\,a} + \text{4ferm.}$$

♣ Light field currents

$$J_\mu^{\mathbf{H},\,\mathbf{a}} = \frac{i}{2} \left[\Phi^\dagger\, \sigma^a\, \overleftrightarrow{D}_\mu\, \Phi \right]$$

$$J_\mu^{\mathbf{F},\,\mathbf{a}} = \overline{F}_L \gamma_\mu\, \sigma^a\, F_L$$

♣ Wilson coefficients

$$\bar{c}_{\mathbf{H}} = \frac{3\, g_w^2\, v^2}{4\, m_V^2} \left[c_H^2\, \frac{g_V^2}{g_w^2} - 2 c_F\, \tilde{c}_{WV}\, \frac{g^2}{g_V^2} - 2\, c_F\, c_H\, - \tilde{c}_{WV}^2\, \frac{g^2}{g_V^2} \right]$$

One-loop matching

Effective action:

$$\exp\, iS_{\text{eff}}[\phi] \approx \exp\left\{ iS[\phi,\Psi_c] - \boxed{\frac{1}{2}\text{Tr}\ \ln\left(- \left.\frac{\delta^2 S}{\delta \Psi^2}\right|_{\Psi=\Psi_c}\right)} \right\}.$$

Effective Lagrangian

$$\boxed{\mathcal{L}_{\text{eff}}^{\text{one-loop}} = i\, c_s \int \frac{d^4 q}{(2\pi)^4}\, \text{Tr}\ \log\left[-(P_\mu - q_\mu)^2 + M^2 + U(x)\right]}$$

Covariant Derivative Expansion [Henning, Lu, Murayama '14] [Drozd, Ellis, Quevillon, You '15]

$$\begin{aligned}\mathcal{L}_{\text{eff}}^{\text{1-loop}} \supset \frac{c_s}{(4\pi)^2\, M^2}\, \text{Tr} \Big\{ & -\frac{1}{12} U\, G'_{\mu\nu}\, G'^{\mu\nu} + \frac{1}{24\, M^2} U^2\, G'_{\mu\nu} G'^{\mu\nu} + \frac{1}{240\, M^2}\left[U, G'_{\mu\nu}\right]\left[U, G'^{\mu\nu}\right] \\ & - \frac{1}{120\, M^2}\left[(P_\mu U), (P_\nu U)\right] G'^{\mu\nu} - \frac{1}{12 M^4}(P_\mu U)^2 \\ & - \frac{1}{20\, M^6} U^2\, (P_\mu U)^2 - \frac{1}{30\, M^6}(U\, P_\mu U)^2 \Big\}\end{aligned}$$

$\Rightarrow$ **Notes of caution !** : [arXiv:1602.00126]

One-loop matching

Sample case: scalar partners

♣ Full model Lagrangian:

$$\mathcal{L} \supset (D_\mu\, \tilde{Q}^\dagger\, (D^\mu \tilde{Q}) + (D_\mu\, \tilde{t}_R)^*\, (D^\mu\, \tilde{t}_R) - \underbrace{\tilde{Q}^\dagger\, M^2_{\tilde{Q}}\, \tilde{Q}\, - M_R^2\, \tilde{t}_R^*\, \tilde{t}_R}_{\mathcal{L}_{\text{mass}}}$$

$$- \underbrace{\kappa_{LL}\, (\Phi \cdot \tilde{Q})^\dagger\, (\Phi \cdot \tilde{Q}) - \kappa_{RR}\, (\tilde{t}_R^* \tilde{t}_R)\, (\Phi^\dagger\, \Phi)}_{\mathcal{L}_{\text{Yukawa}}} - \underbrace{\left[\kappa_{LR} \tilde{t}_R^*\, (\Phi \cdot \tilde{Q}) + \text{h.c.}\right]}_{\mathcal{L}_{\text{mixing}}}$$

♣ $U(x)$ matrix

$$\boxed{U(x) = \begin{pmatrix} \kappa_{LL}\, \tilde{\Phi}\, \tilde{\Phi}^\dagger + M^2_{\tilde{Q}}\, \mathbb{I}_{2\to 2} & \kappa_{LR}\, \tilde{\Phi} \\ \kappa_{LR}\, \tilde{\Phi}^\dagger & \kappa_{RR}\, (\Phi^\dagger \Phi)\, + M_R^2 \end{pmatrix}}$$

♣ Effective Lagrangian

$$\mathcal{L}_{\text{eff}} \supset \frac{i g_w}{4\, (4\pi)^2\, M^2} \left[\kappa_{LL} - \frac{3\, \kappa_{LR}^2}{10\, M^2}\right] \left(\phi^\dagger\, \sigma^k\, \overleftrightarrow{D}^\mu\, \phi\right)\, (D^\nu\, W^k_{\mu\nu}) +$$

$$\frac{1}{8\, (4\pi)^2\, M^2} \left[\kappa_{LL}^2 - \frac{\kappa_{LL}\, \kappa_{LR}^2}{2\, M^2} + \frac{\kappa_{LR}^4}{10\, M^4}\right] (\phi^\dagger\, \overleftrightarrow{D}^\mu\, \phi)\, (\phi^\dagger\, \overleftrightarrow{D}_\mu\, \phi)$$

Truncation prescriptions: default VS v-improved

♠ Multiple $M_{\mathbf{heavy}}$'s

♠ v-induced scales

$\Lambda \pm gv \Rightarrow$ mass splittings

Λ choice and/or truncation not always univoque $\Leftrightarrow$ Matching might be ambiguous

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♠ DEFAULT MATCHING: ♠ Matching scale $\Lambda = M_{\text{heavy}}$ ♠ $\mathcal{O}(\Lambda^{-2})$ truncation

$\Rightarrow$ Limitation: Sizable couplings to Higgs sector

- $\boxed{M_{\text{phys}} \sim M_{\text{heavy}} \pm gv}$ $\Rightarrow$ spoilt scale separation & sizable mass splittings
- Large $d > 6$ contributions $\boxed{\mathcal{O}^d \propto \mathcal{O}^6\,(\Phi^\dagger\Phi)^{d-6}}$

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- Large $d > 6$ contributions $\boxed{\mathcal{O}^d \propto \mathcal{O}^6\,(\Phi^\dagger \Phi)^{d-6}}$

♠ **v-IMPROVED MATCHING:** absorb $\mathcal{O}\left(\frac{v}{\Lambda}\right)^{d-6}$ terms into $\mathcal{L}_{\mathrm{eff}}^{d=6}$.

- Matching scale $\Lambda = M_{\mathrm{phys}}$
- Wilson coefficients written in terms of mass-eigenstate/broken phase quantities

$$\mathcal{O}_H^{\mathrm{singlet}} : \boxed{\frac{\lambda_3^2}{2\lambda_2}\frac{v^2}{\Lambda^2}[\partial_\mu(\Phi^\dagger\,\Phi)\,\partial^2\mu(\Phi^\dagger\,\Phi)]} \quad \text{VS} \quad \boxed{\frac{2(1-\cos\alpha)\,v^2}{m_H^2}[\partial_\mu(\Phi^\dagger\,\Phi)\,\partial^2\mu(\Phi^\dagger\,\Phi)]}$$

Simulation setup

Channels

- **Gluon fusion:** $pp \to h \to 4l$ $pp \to h \to \gamma\gamma$
- **WBF:** $ud \to h\,ud \to W^+W^-\,ud \to (\ell^+\nu)\,(\ell^-\bar{\nu})\,ud$
- **VH:** $qq \to W^\pm h, Zh$
- **Higgs pair:** $gg \to hh$

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Toolbox:

MadGraph5 Hdecay hh@2HDM HiggsBounds HiggsSignals

2HDMC FeynRules HEFT model Alloul, Sanz, Fuks ['13]

Tricks:

- in–house $ggH, \gamma\gamma H$ for loop–induced amplitudes
- FeynArts/FormCalc/LoopTools + event reweighting for NLO corrections

$\sim 100000\ pp$ **events @13 TeV per benchmark point**

Outline

Cataloguing departures

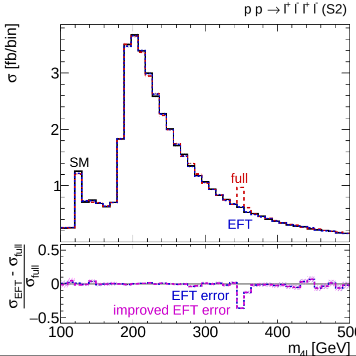
♠ CATEGORY I: | *Integrating out* | Resonances: On–shell

♣ S–channel resonance

♣ On–shell peak $\sqrt{S} = M^2$

Singlet | $m_H = 350$ GeV

$pp(gg) \to h \to 4l$

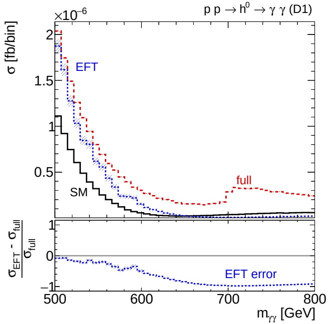


♣ Loop threshold

♣ On–shell kink $q^2 = 4M^2$

2HDM | $m_{H^\pm} = 350$ GeV

$pp(gg) \to h \to \gamma\gamma$

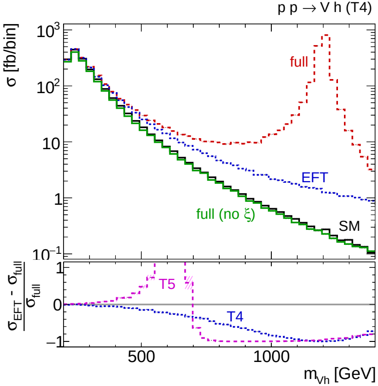


Cataloguing departures

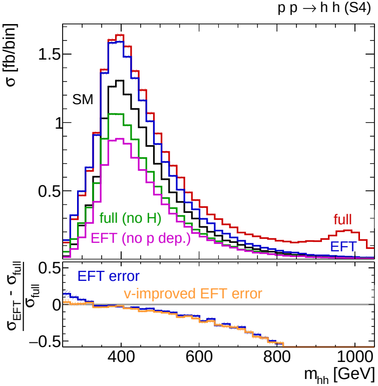
♠ CATEGORY I: *Integrating out* Resonances: off–shell

♣ Incomplete p^2 dependence from the virtual heavy–field exchange
♣ **Modified bulk shapes** (yet far from threshold)

Vector Triplet $M_{\mathbf{VH}}$



Singlet M_{hh} in Higgs pair



Cataloguing departures

♠ CATEGORY II: *Truncating and matching* **Innaccurate truncation**

♣ **Default VS v-improved matching** Singlet

$\Lambda = \sqrt{2\lambda_2}\, v_s$ VS $\Lambda = m_H$ $\bar{c}_H \sim \left(\frac{\lambda_3}{2\lambda_2} \frac{v}{v_s} \right)^2$ VS $\bar{c}_H \sim 2(1-\cos\alpha)$

♣ **Effects on couplings & rates** $g_{xxH} = g^{SM}_{xxH}(1+\Delta_x)$

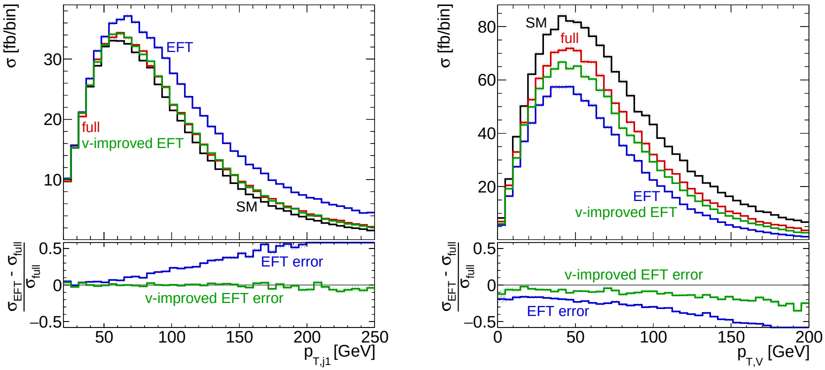
singlet			EFT (default)				EFT (v-improved)		
m_H	$\sin\alpha$	$\Delta_x^{\text{singlet}}$	Λ	$\bar{c}_H$	Δ_x^{EFT}	$\frac{\sigma_{\text{EFT}}}{\sigma_{\text{full}}}\Big\vert_{\text{ggF}}$	$\bar{c}_H$	Δ_x^{EFT}	$\frac{\sigma_{\text{EFT}}}{\sigma_{\text{full}}}\Big\vert_{\text{ggF}}$
500	0.2	−0.020	491	0.036	−0.018	1.006	0.040	−0.020	1.001
350	0.3	−0.046	336	0.073	−0.037	1.019	0.092	−0.046	1.000
200	0.4	−0.083	190	0.061	−0.031	1.119	0.167	−0.083	1.000
1000	0.4	−0.083	918	0.183	−0.092	0.982	0.167	−0.092	0.999
500	0.6	−0.200	407	0.461	−0.231	0.925	0.400	−0.200	0.999

Cataloguing departures

♠ CATEGORY II: *Truncating and matching* **Innaccurate truncation**

♣ **Default VS v-improved matching** ⇒ **,Effects on kinematics**

Vector Triplet | Tagging jets in WBF | Vector triplet | Z p_T



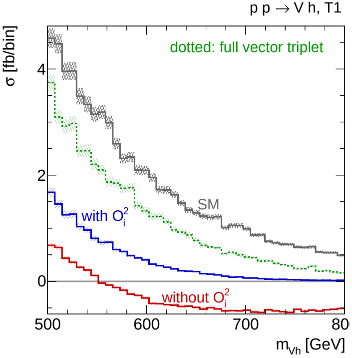
Cataloguing departures

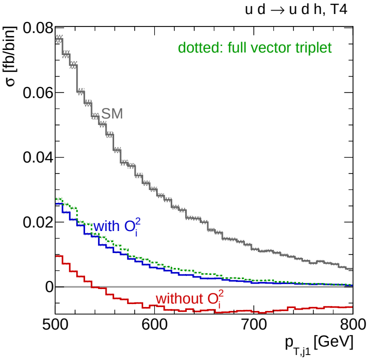
♠ CATEGORY II: | *Truncating and matching* | Competing orders

♣ **Suppressed** $M^{\mathbf{d4}}_{\mathsf{SM}}$

♣ $|M^{\mathbf{d6}}|^2$ **terms in** $|M^{\mathbf{d4}}_{\mathsf{SM}} + M^{\mathbf{d6}}|^2$ **may dominate – while** $M^{\mathbf{d4}}_{\mathsf{SM}} \times M^{\mathbf{d8}} \ll |M^{d6}|^2$

Vector triplet | $pp(gg) \to VH$ | 2HDM | Tagging jets in WBF





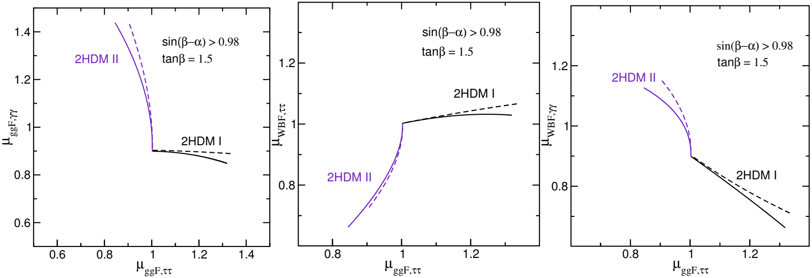
[Biekötter, Brehmer, Krämer, Plehn, in preparation]

Cataloguing departures

♠ CATEGORY II: *Truncating and matching* Correlations

♣ **Departing trajectories in the signal strength plane** Cranmer, Kreiss, DLV, Plehn ['14]

2HDM



⇒ Implications for EFT theory uncertainties

Outline

Birds-eye summary

EFT VS full model departures

A (more or less) complete catalogue

Model	Process	EFT failure		
		resonance	kinematics	matching
singlet	on-shell $h \to 4\ell$, WBF, Vh, ...			$\times$
	off-shell WBF, ...		$(\times)$	$\times$
	hh	$\times$	$\times$	$\times$
2HDM	on-shell $h \to 4\ell$, WBF, Vh, ...			$\times$
	off-shell $h \to \gamma\gamma$, ...		$(\times)$	$\times$
	hh	$\times$	$\times$	$\times$
top partner	WBF, Vh			$\times$
vector triplet	WBF		$(\times)$	$\times$
	Vh	$\times$	$(\times)$	$\times$

Take–home ideas

♠ **Robustness** of Higgs EFT–based predictions is **challenged** at the LHC

• Multiple scales • Validity VS Relevance

♠ $\mathcal{L}^{\mathbf{d6}}_{\mathbf{HEFT}}$ satisfactory for weakly coupled new physics within LHC reach (of limited interest though).

♠ EFT fails when expected:

- ♣ Missing light resonances & incomplete kinematic structures
- ♣ Competing higher orders
- ♣ Ambiguous matching & truncation

- ***Due to*** ♭ strong couplings ♭ light scales ♭ VEV–induced scales
- ***Visible as:***
  - ♣ Innaccurate coupling shifts, total rates & correlations
  - ♣ On–shell peaks and loop thresholds
  - ♣ Distorted shapes (bulk, tail)

♠ **HEFT versus full model agreement** can be **improved**:

♭ v-improved matching & ♭ non–linear EFT [González-Fraile, Freitas, DLV, Plehn, in progress]