Dimension-six electroweak top-loop corrections in Higgs production and decay

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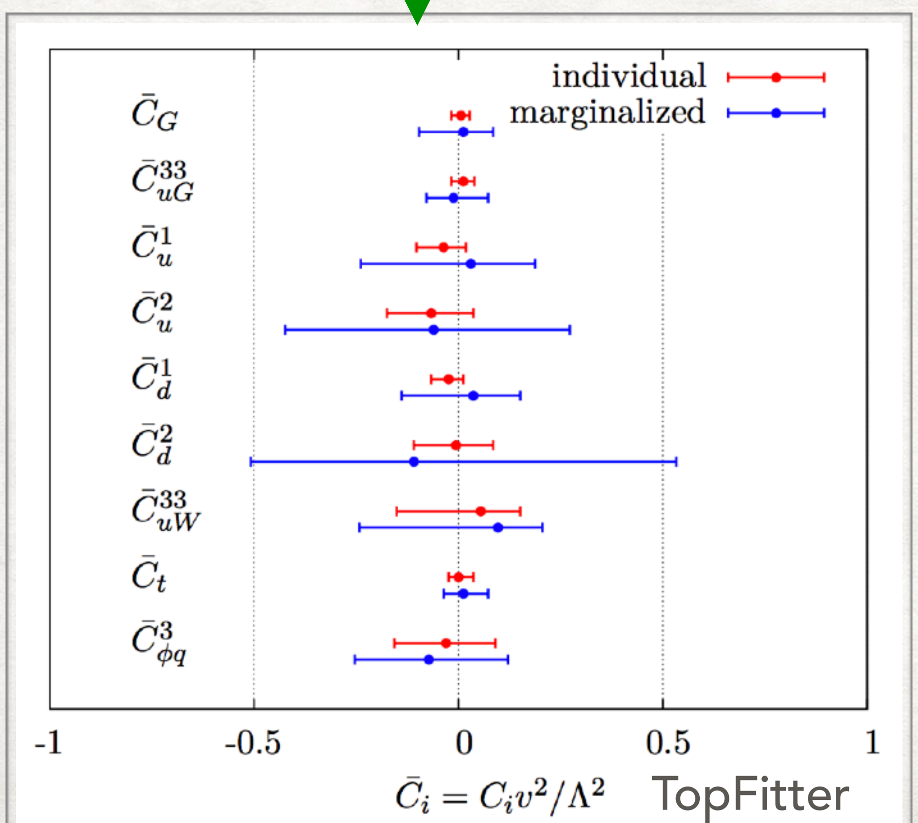
In collaboration with Eleni Vryonidou, 1804.xxxxx

SMEFT

Top

4-fermion operators		Non 4-fermion operators	
O_{qq}^1	$(\bar q\gamma_\mu q)(\bar q\gamma^\mu q)$	$O_{\phi q}^3$	$i(\phi^\dagger\tau^I D_\mu\phi)(\bar q\gamma^\mu\tau^I q)$
O_{qq}^3	$(\bar q\gamma_\mu\tau^I q)(\bar q\gamma^\mu\tau^I q)$	O_{tW}	$(\bar q\sigma^{\mu\nu}\tau^I t)\tilde\phi W_{\mu\nu}^I$
O_{uu}	$(\bar u\gamma_\mu u)(\bar u\gamma^\mu u)$	O_{tG}	$(\bar q\sigma^{\mu\nu}\lambda^A t)\tilde\phi G_{\mu\nu}^A$
O_{qu}^8	$(\bar q\gamma_\mu T^A q)(\bar u\gamma^\mu T^A u)$	O_G	$f_{ABC}\, G_\mu^{A\nu} G_\nu^{B\lambda} G_\lambda^{C\mu}$
O_{qd}^8	$(\bar q\gamma_\mu T^A q)(\bar d\gamma^\mu T^A d)$	$O_{\tilde G}$	$f_{ABC}\, \tilde G_\mu^{A\nu} G_\nu^{B\lambda} G_\lambda^{C\mu}$
O_{ud}^8	$(\bar u\gamma_\mu T^A u)(\bar d\gamma^\mu T^A d)$	$O_{\phi G}$	$(\phi^\dagger\phi) G_{\mu\nu}^A G^{A\mu\nu}$
		$O_{\phi\tilde G}$	$(\phi^\dagger\phi)\tilde G_{\mu\nu}^A G^{A\mu\nu}$



Higgs+TGC

$$\mathcal{O}_{WW} = \phi^\dagger \hat W_{\mu\nu}\hat W^{\mu\nu}\phi$$

$$\mathcal{O}_B = (D_\mu\phi)^\dagger \hat B^{\mu\nu}(D_\nu\phi)$$

$$\mathcal{O}_{u\phi,33} = (\phi^\dagger\phi)(\bar Q_3\tilde\phi u_{R,3})$$

$$\mathcal{O}_{GG} = \phi^\dagger\phi\, G_{\mu\nu}^a G^{a\mu\nu}$$

$$\mathcal{O}_W = (D_\mu\phi)^\dagger \hat W^{\mu\nu}(D_\nu\phi)$$

$$\mathcal{O}_{e\phi,33} = (\phi^\dagger\phi)(\bar L_3\phi e_{R,3})$$

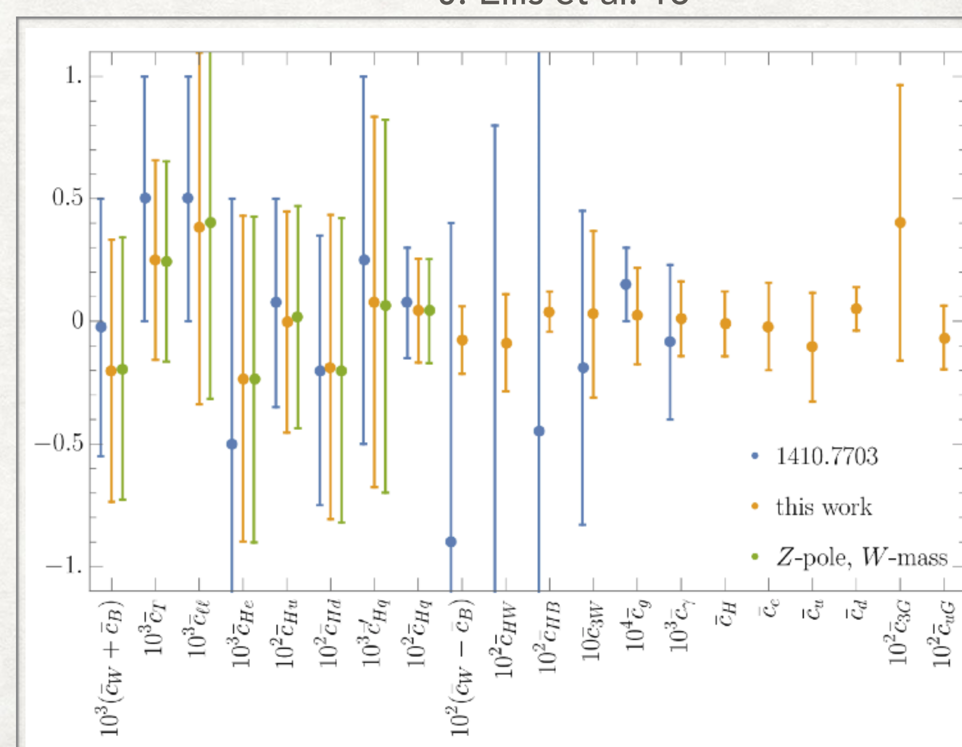
$$\mathcal{O}_{WWW} = \mathrm{Tr}\left(\hat W_{\mu\nu}\hat W^{\nu\rho}\hat W_\rho^\mu\right)$$

$$\mathcal{O}_{BB} = \phi^\dagger\hat B_{\mu\nu}\hat B^{\mu\nu}\phi$$

$$\mathcal{O}_{\phi,2} = \frac{1}{2}\partial^\mu(\phi^\dagger\phi)\,\partial_\mu(\phi^\dagger\phi)$$

$$\mathcal{O}_{d\phi,33} = (\phi^\dagger\phi)(\bar Q_3\phi d_{R,3})$$

J. Ellis et al. 18



SMEFT

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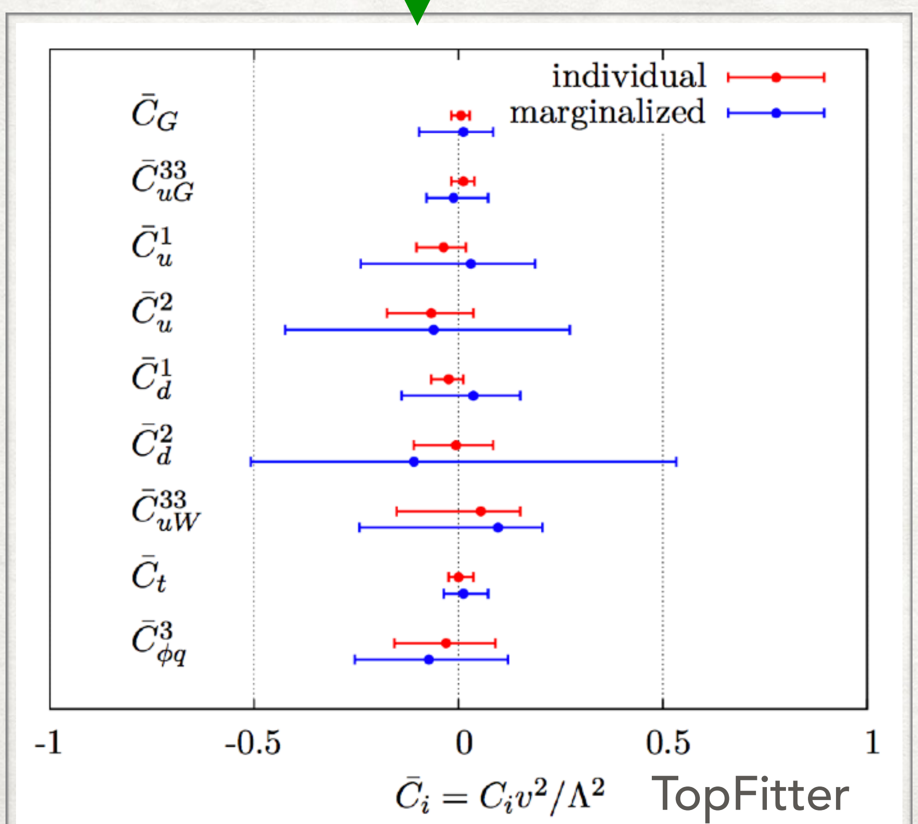

?

Higgs+TGC

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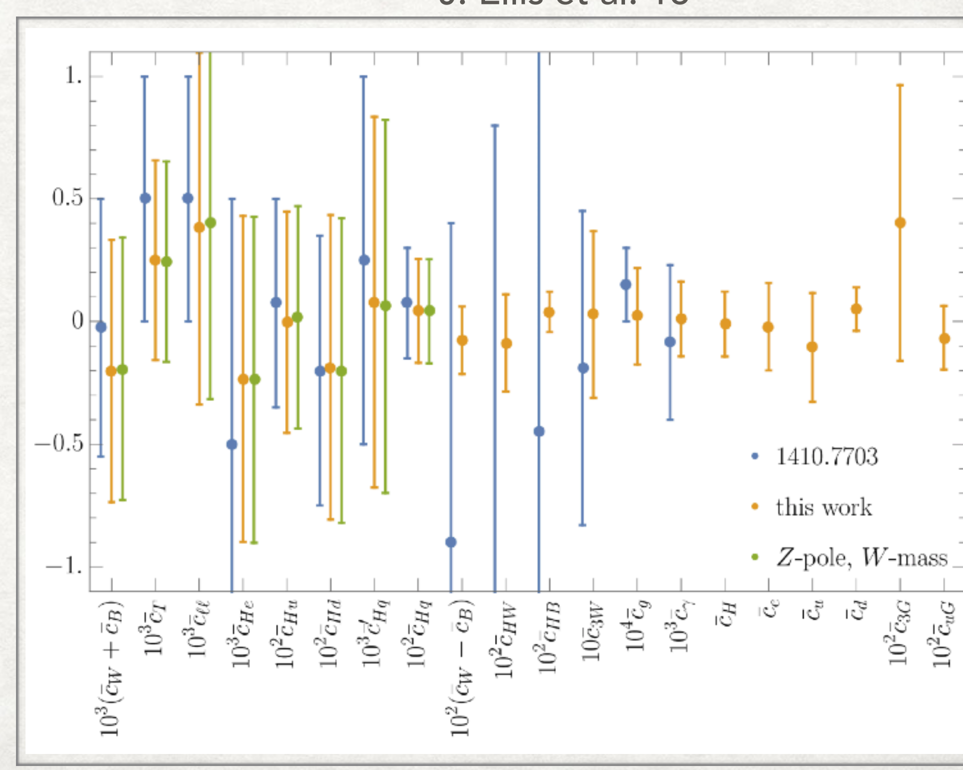
J. Ellis et al. 18



SMEFT @ 1-LOOP

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O^8_{ud}	$(\bar{u}\gamma_\mu T^A u)(\bar{d}\gamma^\mu T^A d)$	$O_{\phi G}$	$(\phi^\dagger\phi)G^A_{\mu\nu}G^{A\mu\nu}$
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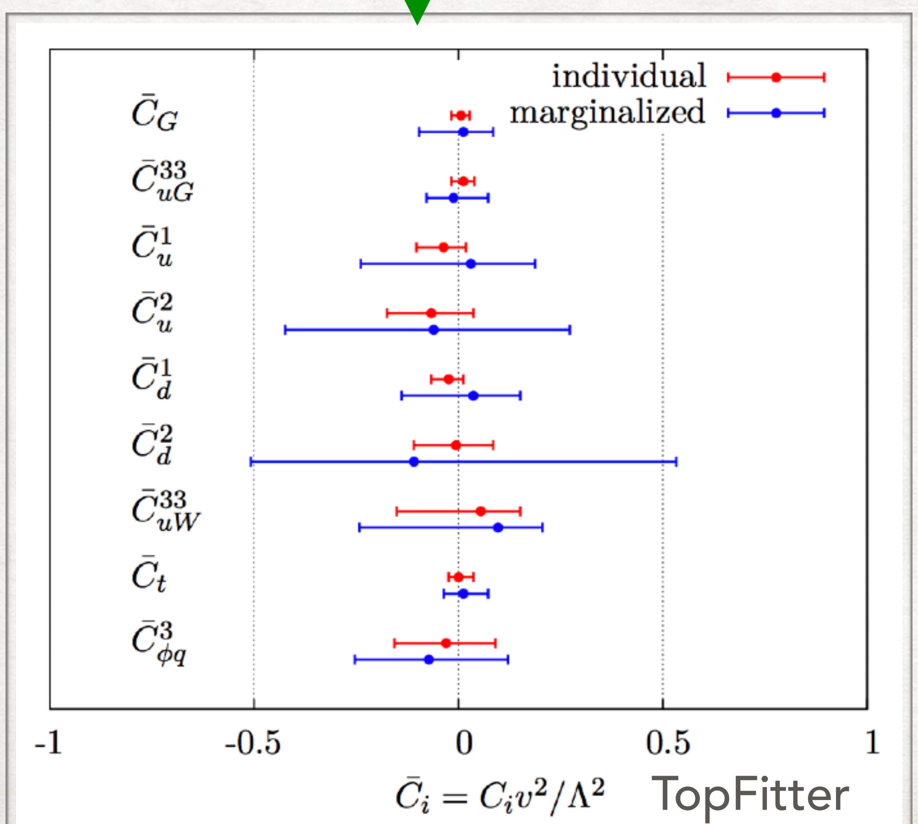
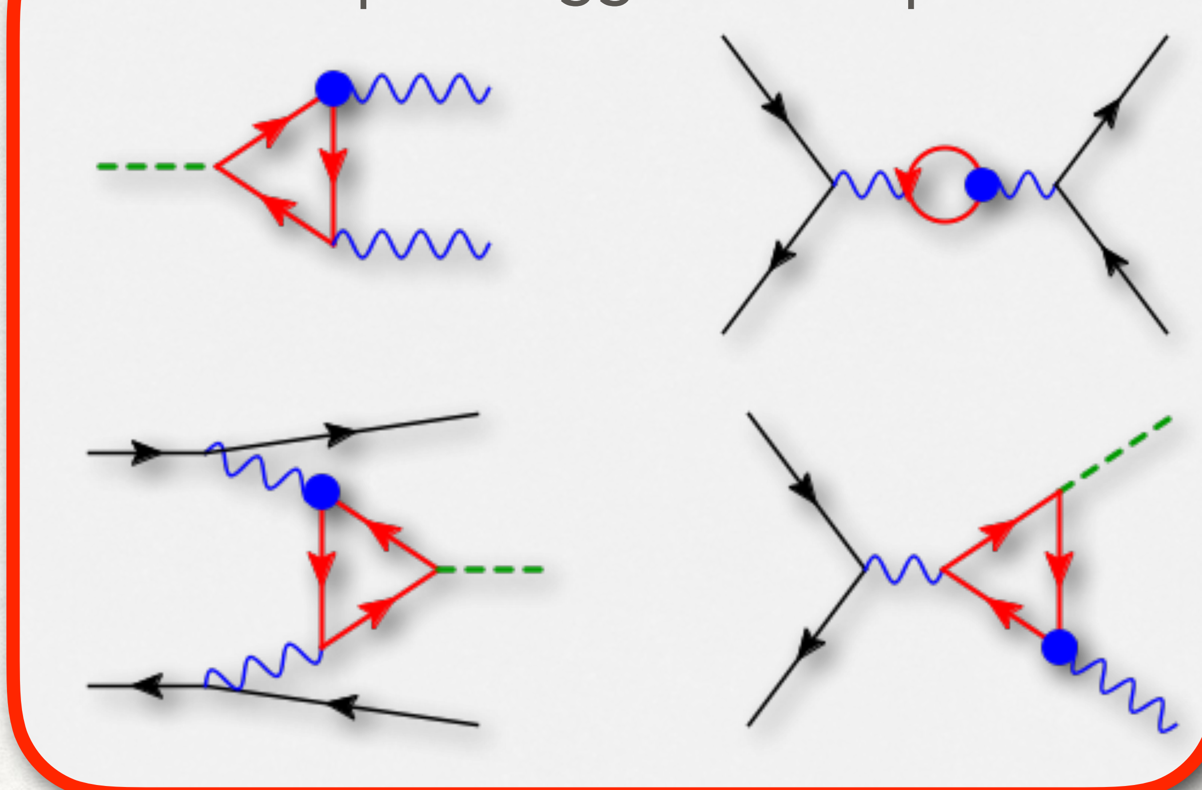
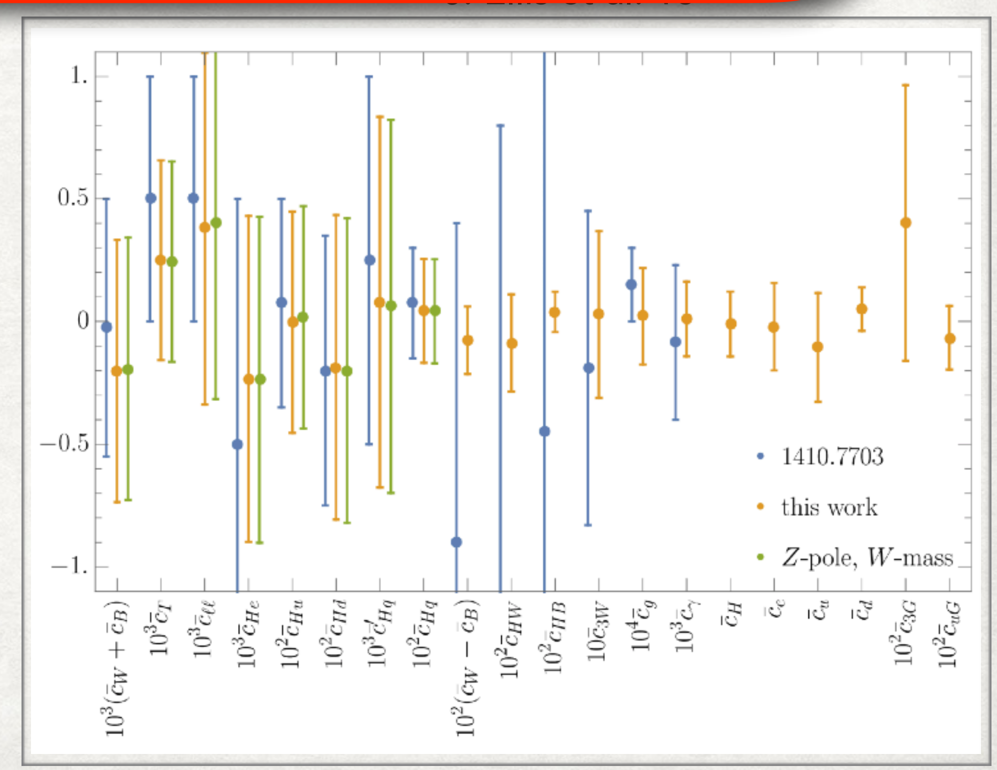


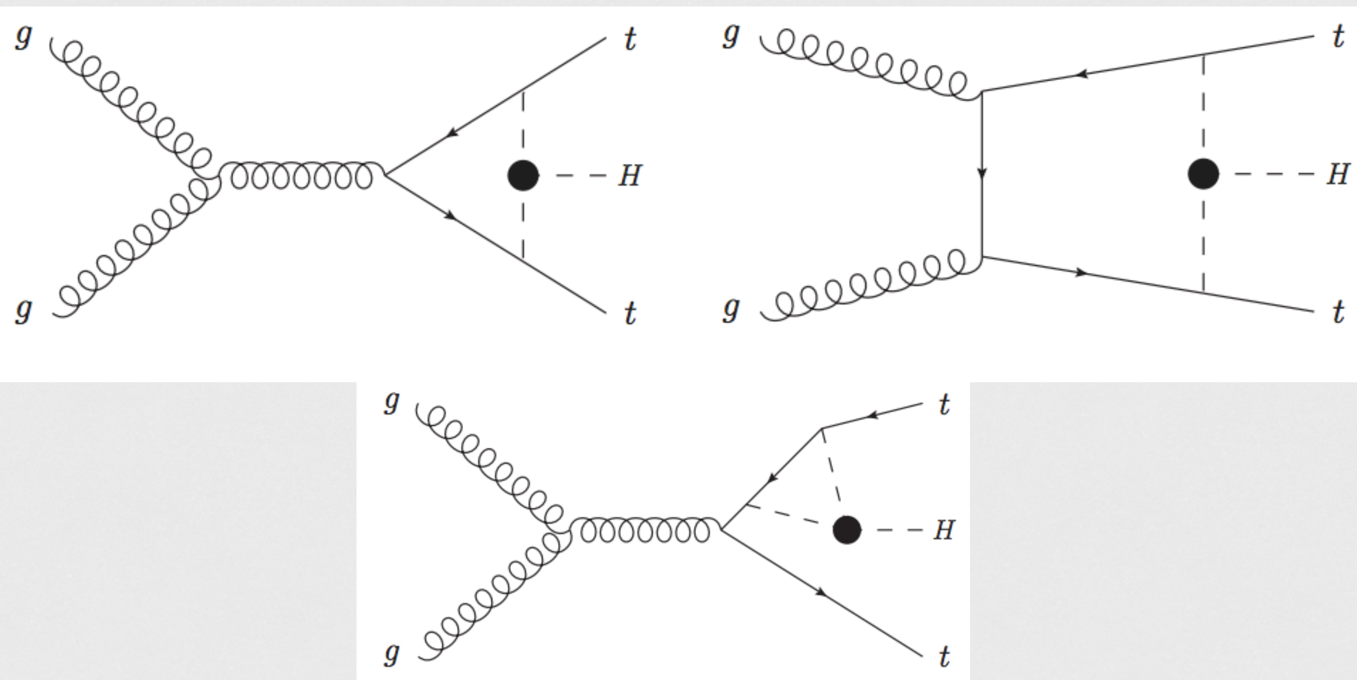
Top → Higgs at 1-loop

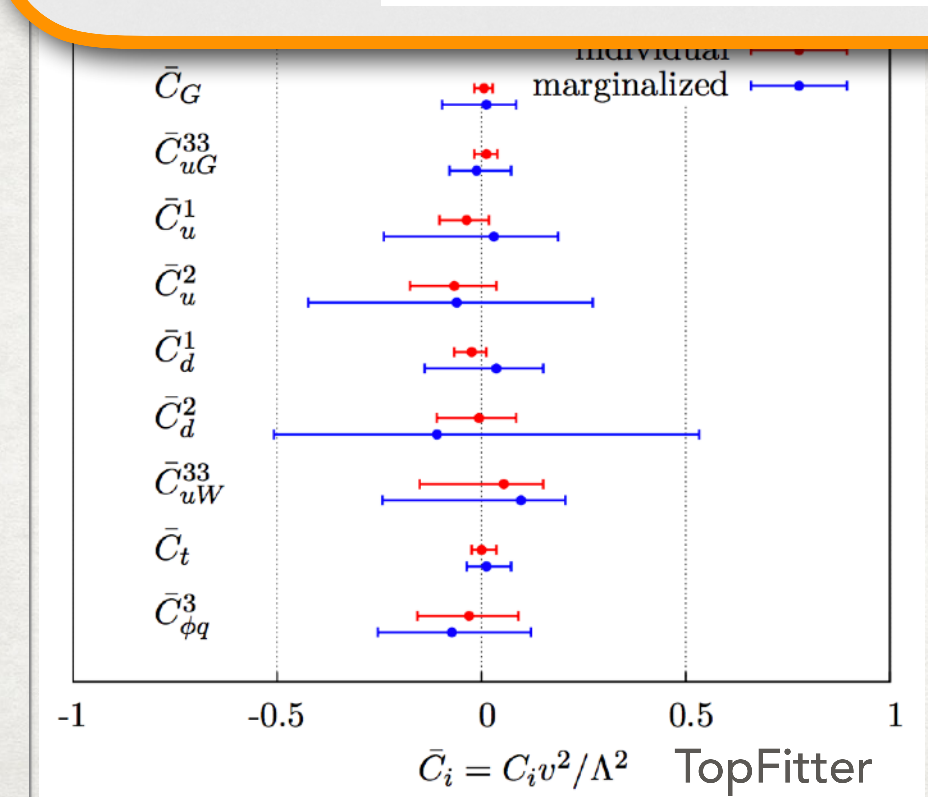




SMEFT @ 1-LOOP

Degrassi, Giardino, Maltoni, Pagani 16





Higgs+TGC

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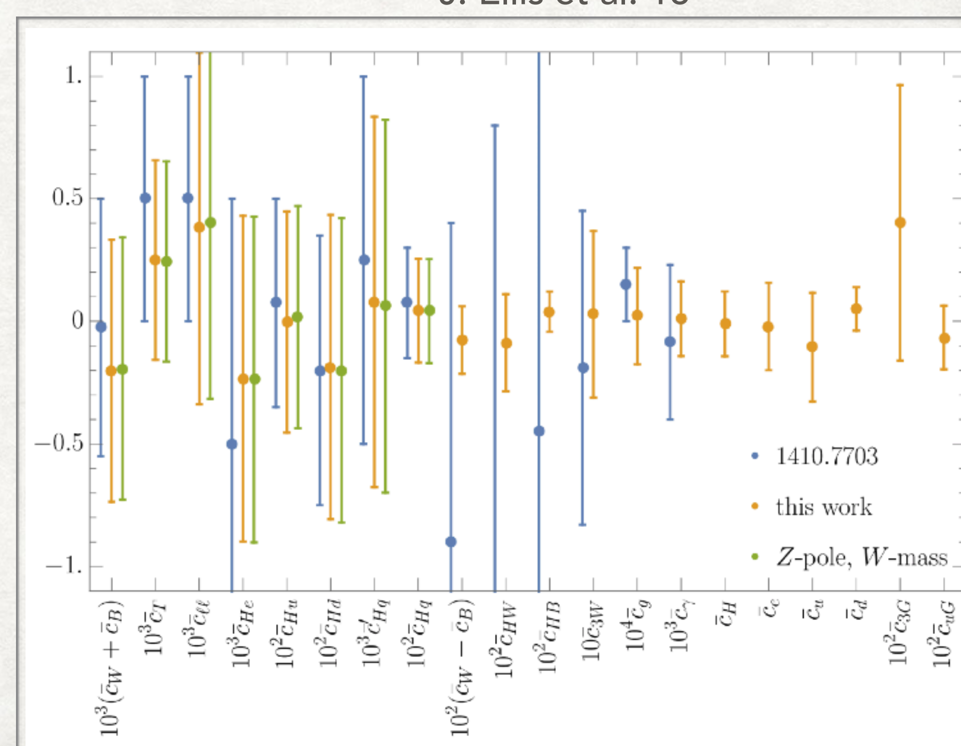
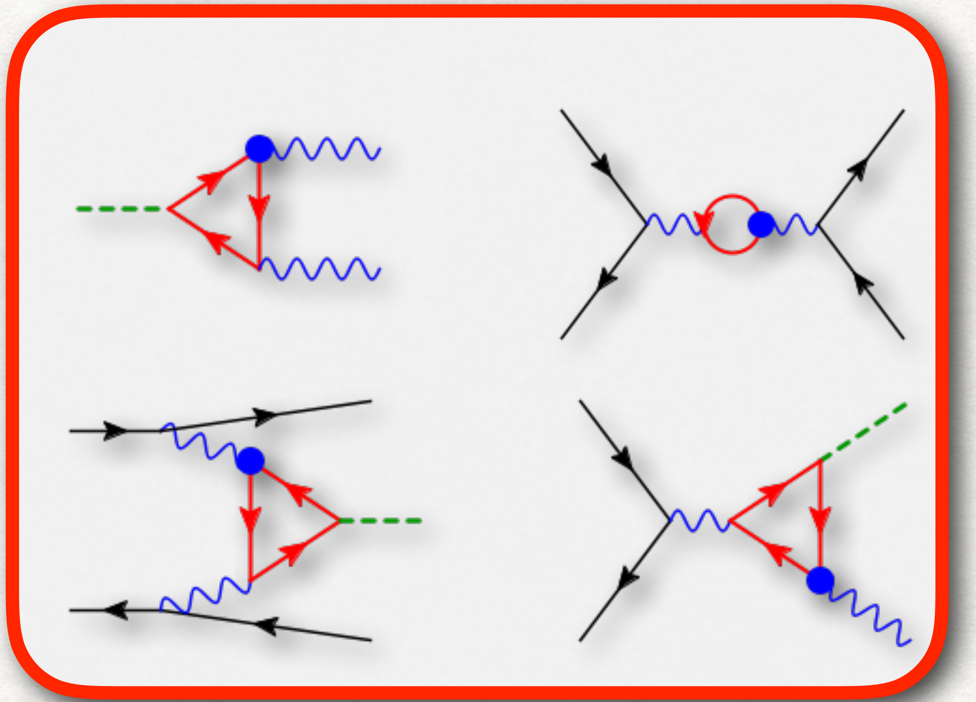
J. Ellis et al. 18



How large are these?



We study dim-6 **EW** top-loop effects in Higgs processes, including

- VBF, ZH, WH at LHC
- ZH, WWF, ZZF at e^+e^-
- H decay to γγ, γZ, Zll, Wlν, bb, ττ, μμ
- ggH is known

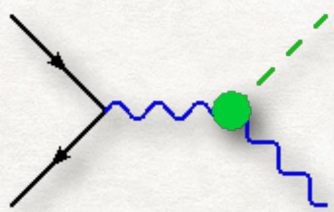
OUTLINE

- Motivation
- Implementation
- Results
- Physics impacts
- Conclusion

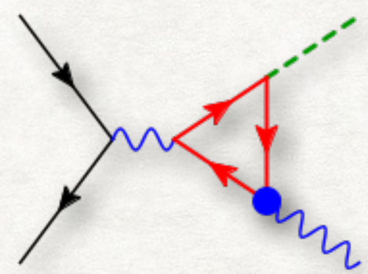
MOTIVATION

MOTIVATION (1)

- Physics:
  - To correctly interpret Higgs signal strength measurements…
    Are we measuring



or



?

  - When does this start to matter, Run-2? HL/HE? Future LC?
  - NLO EW in SMEFT may not be small:

$$\mathcal{O}(\alpha_{EW}/\pi \cdot C_t/C_H) \quad \text{instead of} \quad \mathcal{O}(\alpha_{EW}/\pi)$$

    given that in general ***C_t is less constrained than C_H***.
  - ***TH uncertainties*** due to unknown C_t cannot be avoided, in a global view.

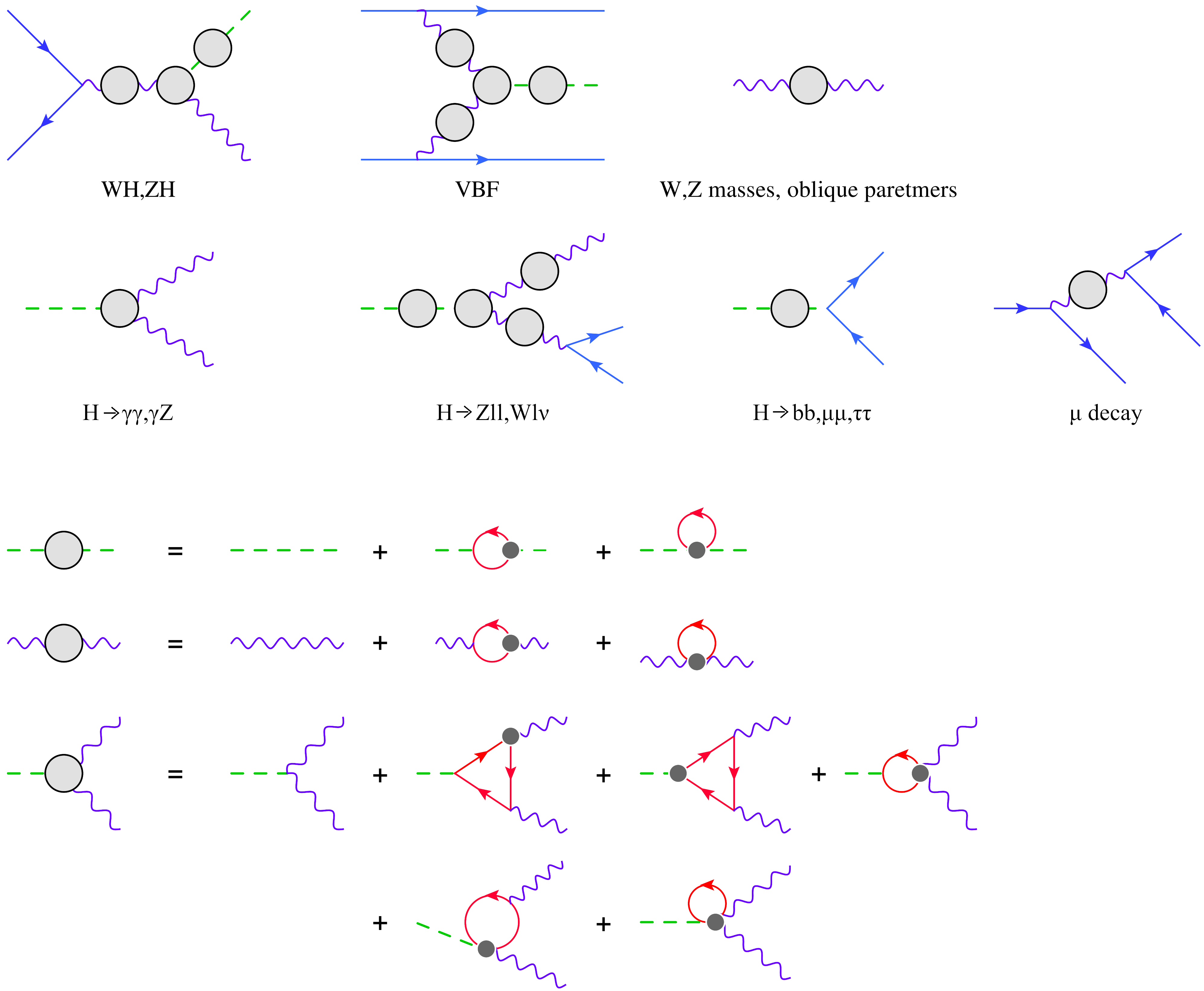
MOTIVATION (2)

- Techical:
  - Along the effort of ***automating SMEFT @ NLO with MG5***, see Ken's talk for progress in NLO QCD.
    - Existing implementation, see e.g.

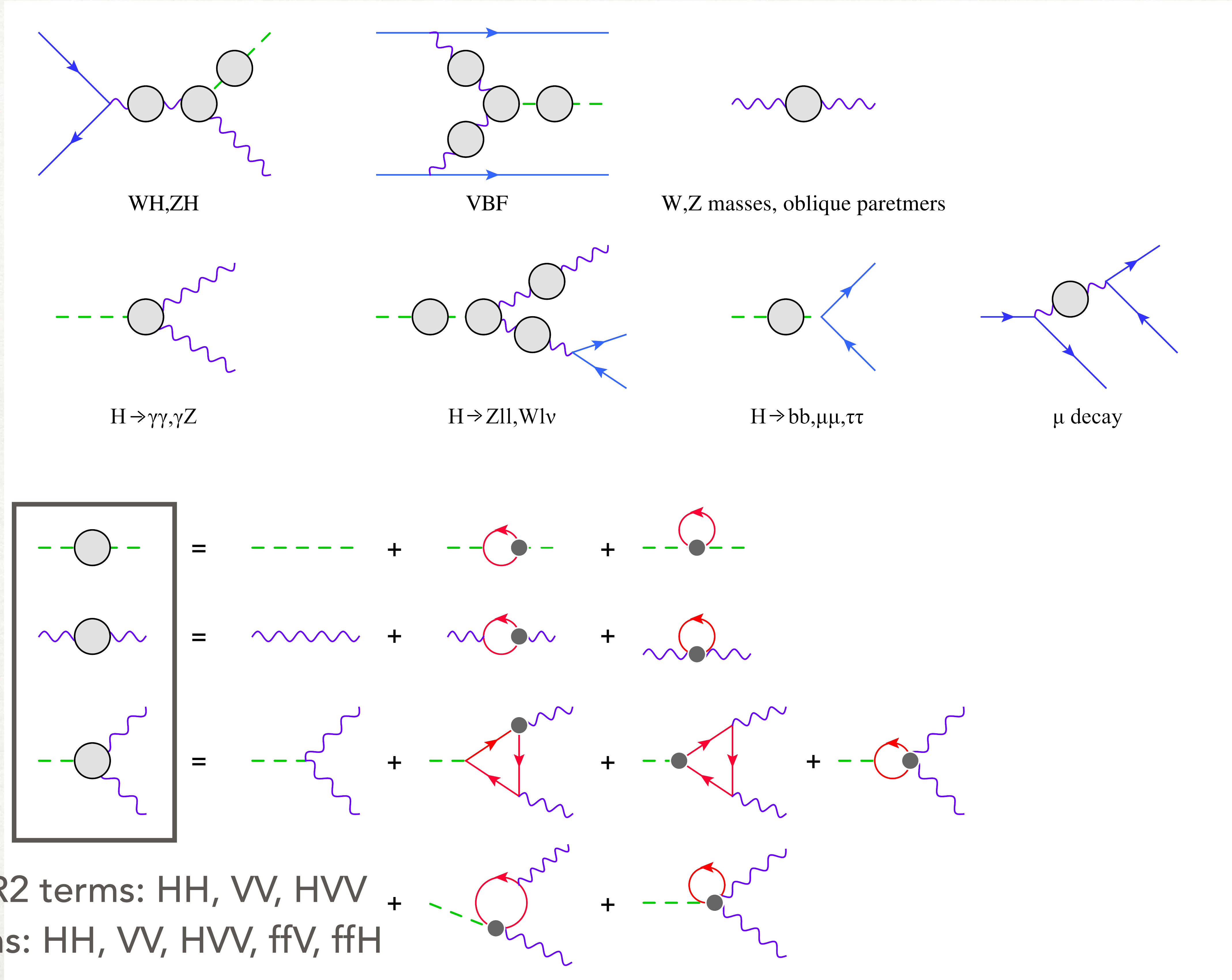
      Degrande, Maltoni, Wang, **CZ** 15, D. B. Franzosi, **CZ** 15, **CZ** 16
      Bylund, Maltoni, Tsinikos, Vryonidou, **CZ** 16
      Degrande, Fuks, Mawatari, Mimasu, Sanz 17
  - A first step towards automatic NLO EW.
    - Some NLO EW computations for Higgs, e.g.

      C. Hartmann, M. Trott 15, Ghezzi, Gomez-Ambrosio, Passarino, Uccirati 15
      S. Dawson, P. P. Giardino 18, Gauld, Pecjak, Scott 16
      …
  - **A suitable problem for automation…**

BECAUSE...


WH,ZH
VBF
W,Z masses, oblique paretmers
H→γγ,γZ
H→Zll,Wlν
H→bb,μμ,ττ
μ decay
=
+
+
=
+
+
=
+
+
+
+
+

BECAUSE...



Need R2 terms: HH, VV, HVV

UV terms: HH, VV, HVV, ffV, ffH

IMPLEMENTATION

IMPLEMENTATION (0)

- Our goal is to include operators that enter either ttV, tbW, or ttH:

$$
\begin{aligned}
O_{t\varphi} &= \bar{Q} t \tilde{\varphi}\, (\varphi^\dagger \varphi), & O^{(1)}_{\varphi Q} &= (\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{Q}\gamma^\mu Q), \\
O^{(3)}_{\varphi Q} &= (\varphi^\dagger i\overleftrightarrow{D}^I_\mu \varphi)(\bar{Q}\gamma^\mu \tau^I Q), & O_{\varphi t} &= (\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{t}\gamma^\mu t), \\
O_{\varphi tb} &= (\tilde{\varphi}^\dagger i D_\mu \varphi)(\bar{t}\gamma^\mu b), & O_{tW} &= (\bar{Q}_i \sigma^{\mu\nu} \tau^I t)\, \tilde{\varphi} W^I_{\mu\nu}, \\
O_{tB} &= (\bar{Q}\sigma^{\mu\nu} t)\, \tilde{\varphi} B_{\mu\nu}, & &
\end{aligned}
$$

and we define

$$
O^{(+)}_{\varphi Q} \equiv \frac{1}{2}\left(O^{(1)}_{\varphi Q} + O^{(3)}_{\varphi Q}\right) \qquad O^{(-)}_{\varphi Q} \equiv \frac{1}{2}\left(O^{(1)}_{\varphi Q} - O^{(3)}_{\varphi Q}\right),
$$

bbZ

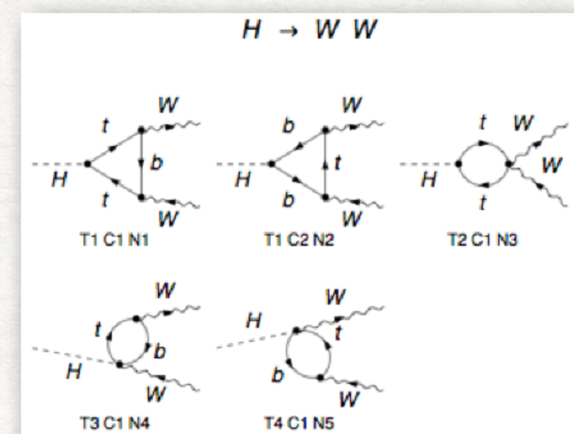
ttZ

IMPLEMENTATION (1)

- MadGraph5.26x, with reweighting functionality (Olivier Mattelaer 16)
  - Generate events at tree level in SM
  - then for each event recompute a new weight with EW loops (at dim-6).

- For loops, need R2. Compute with FeynArts->FeynCalc
  - Gamma5: KKS scheme (Korner, Kreimer, Schilcher 92)
    - always anticommute
    - no cyclic relation
    - trace starts with a reading point

Example: HWW



$$\frac{1}{64\,\pi^2\,\mathrm{Lambda}^2\,\mathrm{sw}^2\,\mathrm{vev}}$$
$$i\,\mathrm{EL}\,\mathrm{IPL}(\{\})\Big(\bar{g}^{\mu_1\mu_2}\Big(-2\,\mathrm{vev}\,\overline{p_3}^2\Big(\mathrm{EL}\,\mathrm{vev}\,(\mathrm{cHQM}-\mathrm{cHQP})+4\sqrt{2}\,\mathrm{ctW}\,\mathrm{MT}\,\mathrm{sw}\Big)-2\,\mathrm{cHQM}\,\mathrm{EL}\,\mathrm{vev}^2\,\overline{p_4}^2+2\,\mathrm{cHQP}\,\mathrm{EL}\,\mathrm{vev}^2\,\overline{p_4}^2-8\sqrt{2}\,\mathrm{ctW}\,\mathrm{MT}\,\mathrm{sw}\,\mathrm{vev}\,\overline{p_4}^2-$$
$$32\sqrt{2}\,\mathrm{ctW}\,\mathrm{MT}\,\mathrm{sw}\,\mathrm{vev}\,(\overline{p_3}\cdot\overline{p_4})+12\,\mathrm{cHQM}\,\mathrm{EL}\,\mathrm{MB}^2\,\mathrm{vev}^2+6\sqrt{2}\,\mathrm{cHQM}\,\mathrm{EL}\,\mathrm{MB}\,\mathrm{vev}^3\,\mathrm{yb}+12\,\mathrm{cHQM}\,\mathrm{EL}\,\mathrm{MT}^2\,\mathrm{vev}^2+12\,\mathrm{cHQM}\,\mathrm{EL}\,\mathrm{MT}\,\mathrm{MT}\,\mathrm{vev}^2-$$
$$12\,\mathrm{cHQP}\,\mathrm{EL}\,\mathrm{MB}^2\,\mathrm{vev}^2-6\sqrt{2}\,\mathrm{cHQP}\,\mathrm{EL}\,\mathrm{MB}\,\mathrm{vev}^3\,\mathrm{yb}-12\,\mathrm{cHQP}\,\mathrm{EL}\,\mathrm{MT}^2\,\mathrm{vev}^2-12\,\mathrm{cHQP}\,\mathrm{EL}\,\mathrm{MT}\,\mathrm{MT}\,\mathrm{vev}^2+6\,\mathrm{cHtb}\,\mathrm{EL}\,\mathrm{MB}\,\mathrm{MT}\,\mathrm{vev}^2+3\sqrt{2}\,\mathrm{cHtb}\,\mathrm{EL}\,\mathrm{MT}$$
$$\mathrm{vev}^3\,\mathrm{yb}+6\sqrt{2}\,\mathrm{ctH}\,\mathrm{EL}\,\mathrm{MT}\,\mathrm{vev}^3-6\sqrt{2}\,\mathrm{EL}\,\mathrm{Lambda}^2\,\mathrm{MB}\,\mathrm{vev}\,\mathrm{yb}-12\,\mathrm{EL}\,\mathrm{Lambda}^2\,\mathrm{MT}\,\mathrm{MT}\Big)+8\sqrt{2}\,\mathrm{ctW}\,\mathrm{MT}\,\mathrm{sw}\,\mathrm{vev}\,(\overline{p_3}^{\mu_1}\,\overline{p_3}^{\mu_2}+\overline{p_4}^{\mu_1}\,(4\,\overline{p_3}^{\mu_2}+\overline{p_4}^{\mu_2}))\Big)$$

IMPLEMENTATION (2)

- Dim-6 renormalization
  - Counter term operators

$$
\begin{aligned}
&O_{\varphi WB} = \varphi^\dagger \tau^I \varphi W^I_{\mu\nu} B^{\mu\nu}, && O_{\varphi W} = \varphi^\dagger \varphi W^I_{\mu\nu} W^{I\mu\nu}, \\
&O_{\varphi B} = \varphi^\dagger \varphi B_{\mu\nu} B^{\mu\nu}, && O_{\varphi\Box} = \left(\varphi^\dagger\varphi\right) \Box \left(\varphi^\dagger\varphi\right), \\
&O_{\varphi D} = \left(\varphi^\dagger D^\mu \varphi\right)^* \left(\varphi^\dagger D_\mu \varphi\right), && O_W = i D^\mu \varphi^\dagger \tau^I D^\nu \varphi W^I_{\mu\nu}, \\
&O_B = i D^\mu \varphi^\dagger D^\nu \varphi B_{\mu\nu}, && O_{b\varphi} = (\varphi^\dagger\varphi)\bar{Q} b \varphi, \\
&O_{\mu\varphi} = (\varphi^\dagger\varphi)\bar{l}_2 e_2 \varphi, && O_{\tau\varphi} = (\varphi^\dagger\varphi)\bar{l}_3 e_3 \varphi.
\end{aligned}
$$

  - Starting with Warsaw basis but replace

$$
\begin{aligned}
&O^{(3)}_{\varphi q} + O^{(3)}_{\varphi l}, \\
&\frac{1}{6} O^{(1)}_{\varphi q} - \frac{1}{2} O^{(1)}_{\varphi l} + \frac{2}{3} O_{\varphi u} - \frac{1}{3} O_{\varphi d} - O_{\varphi e},
\end{aligned}
$$

    by O_W, O_B which are *blind directions* in EWPO.

C. Grojean, W. Skiba, J. Terning 06
I. Brivio, M. Trott 17

  - CTs are independent of basis.
  - S and T parameters can be identified as $C_{\phi WB}$ and $C_{\phi D}$

IMPLEMENTATION (3)

- Mixing

	$O_i = O_{\varphi t}$	$O_{\varphi Q}^{+}$	$O_{\varphi Q}^{-}$	$O_{\varphi tb}$	O_{tW}	O_{tB}	$O_{t\varphi}$
$O_j = O_{\varphi WB}$	$\frac{1}{3s_W c_W}$	$\frac{1}{3s_W c_W}$	$-\frac{1}{6s_W c_W}$	0	$-\frac{5y_t}{2ec_W}$	$-\frac{3y_t}{2es_W}$	0
$O_{\varphi D}$	$-6\frac{y_t^2}{e^2}$	$3\frac{y_t^2-y_b^2}{e^2}$	$3\frac{y_t^2-y_b^2}{e^2}$	$-6\frac{y_t y_b}{e^2}$	0	0	0
$O_{\varphi\Box}$	$-\frac{3}{2}\frac{y_t^2}{e^2}$	$-\frac{3y_t^2+6y_b^2}{2e^2}$	$\frac{6y_t^2+3y_b^2}{2e^2}$	$3\frac{y_t y_b}{e^2}$	0	0	0
$O_{\varphi W}$	0	$\frac{1}{4s_W^2}$	$-\frac{1}{4s_W^2}$	0	$\frac{3y_t}{2es_W}$	0	0
$O_{\varphi B}$	$\frac{1}{3c_W^2}$	$\frac{1}{12c_W^2}$	$\frac{1}{12c_W^2}$	0	0	$\frac{5y_t}{2ec_W}$	0
O_W	0	$\frac{1}{es_W}$	$-\frac{1}{es_W}$	0	0	0	0
O_B	$\frac{4}{3ec_W}$	$\frac{1}{3ec_W}$	$\frac{1}{3ec_W}$	0	0	0	0
$O_{b\varphi}$	0	$-\frac{y_b}{2c_W^2} + y_b\frac{8\lambda-3y_t^2-5y_b^2}{4e^2}$	$y_b\frac{-4\lambda+3y_t^2+7y_b^2}{4e^2}$	$\frac{3y_t}{4s_W^2} - y_t\frac{2\lambda+y_t^2-6y_b^2}{2e^2}$	$\frac{y_t y_b}{2es_W}$	0	$\frac{3y_t y_b}{4e^2}$
$O_{\mu\varphi}$	0	$-\frac{3y_\mu(y_t^2+y_b^2)}{2e^2}$	$\frac{3y_\mu(y_t^2+y_b^2)}{2e^2}$	$\frac{3y_t y_b y_\mu}{e^2}$	0	0	$\frac{3y_t y_\mu}{2e^2}$
$O_{\tau\varphi}$	0	$-\frac{3y_\tau(y_t^2+y_b^2)}{2e^2}$	$\frac{3y_\tau(y_t^2+y_b^2)}{2e^2}$	$\frac{3y_t y_b y_\tau}{e^2}$	0	0	$\frac{3y_t y_\tau}{2e^2}$

Consistent with [Alonso, Jenkins, Manohar, Trott]

- MSbar renomalization for all C's except $C_{\Phi WB}$ and $C_{\Phi D}$, where S and T are used as renormalization conditions.
  - So that we can easily set S=T=0 to be consistent with EWPO

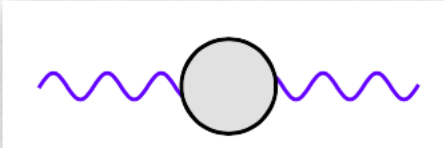
IMPLEMENTATION (4)

- SM renormalization

$$
\begin{aligned}
e_0 &= (1+\delta Z_e)e,\\
M_{W,0}^2 &= M_W^2 + \delta M_W^2\\
M_{Z,0}^2 &= M_Z^2 + \delta M_Z^2\\
M_{H,0}^2 &= M_H^2 + \delta M_H^2.
\end{aligned}
$$

$$
\begin{aligned}
W_0^\pm &= \left(1+\frac{1}{2}\delta Z_W\right)W^\pm\\
Z_0 &= \left(1+\frac{1}{2}\delta Z_{ZZ}\right)Z + \frac{1}{2}\delta Z_{ZA}A\\
A_0 &= \frac{1}{2}\delta Z_{AZ}Z + \left(1+\frac{1}{2}\delta Z_{AA}\right)A\\
H_0 &= \left(1+\frac{1}{2}\delta Z_H\right)H.
\end{aligned}
$$

$$
\begin{aligned}
\delta M_W^{2(6)} &= \Re\bar{\Sigma}_{WW}^{(6)}(M_W^2), & \delta M_Z^{2(6)} &= \Re\bar{\Sigma}_{ZZ}^{(6)}(M_Z^2),\\
\delta M_H^{2(6)} &= \Re\bar{\Sigma}_{HH}^{(6)}(M_H^2), & \delta Z_W^{(6)} &= -\Re\left.\frac{\partial\bar{\Sigma}_{WW}^{(6)}(k^2)}{\partial k^2}\right|_{k^2=M_W^2},\\
\delta Z_{ZZ}^{(6)} &= -\Re\left.\frac{\partial\bar{\Sigma}_{ZZ}^{(6)}(k^2)}{\partial k^2}\right|_{k^2=M_Z^2}, & \delta Z_{AA}^{(6)} &= -\left.\frac{\partial\bar{\Sigma}_{AA}^{(6)}(k^2)}{,}\partial k^2\right|_{k^2=0}\\
\delta Z_{AZ}^{(6)} &= -2\Re\frac{\bar{\Sigma}_{AZ}^{(6)}(M_Z^2)}{M_Z^2}, & \delta Z_{ZA}^{(6)} &= 2\frac{\bar{\Sigma}_{AZ}^{(6)}(0)}{M_Z^2},\\
\delta Z_H^{(6)} &= -\Re\left.\frac{\partial\bar{\Sigma}_{HH}^{(6)}(k^2)}{\partial k^2}\right|_{k^2=M_H^2}, & \delta Z_e^{(6)} &= \frac{1}{2}\left.\frac{\partial\bar{\Sigma}_{AA}^{(6)}(k^2)}{\partial k^2}\right|_{k^2=0} - \frac{s_W}{c_W}\frac{\bar{\Sigma}_{AZ}^{(6)}(0)}{M_Z^2}.
\end{aligned}
$$



Switch to MW, MZ, GF scheme (for convenient reweighting):

$$
\Delta_r^{(6)} = \left.\frac{\partial\bar{\Sigma}_{AA}^{(6)}(k^2)}{\partial k^2}\right|_{k^2=0} - \frac{c_W^2}{s_W^2}\left(\frac{\bar{\Sigma}_{ZZ}^{(6)}(M_Z^2)}{M_Z^2} - \frac{\bar{\Sigma}_{WW}^{(6)}(M_W^2)}{M_W^2}\right) + \frac{\bar{\Sigma}_{WW}^{(6)}(0) - \bar{\Sigma}_{WW}^{(6)}(M_W^2)}{M_W^2}.
$$

RESULTS
(PRELIMINARY)

RESULT (0)

- A UFO model, with which we can compute dim-6 top loop corrections in many processes, thanks to automation
  - Higgs production at LHC: WH, ZH, VBF
  - Higgs production at LC: ZH, WWF, ZZF
  - Higgs decay: γγ, γZ, WW*->Wlν, ZZ*->Zll, bb, ττ, μμ
  - EWPO: S T U
  - Many others: W-/Z-pole, widths, ee→ff, Drell-Yan at LHC…
- All results are with scale dependence…

$$\sigma = C_H(\mu_{EFT})\sigma_{\rm tree} + C_t \frac{\alpha_{EW}}{\pi}\left(\log\frac{Q^2}{\mu_{EFT}^2}\sigma_{\rm log} + \sigma_{\rm fin}\right)$$

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$$\sigma = C_H(\mu_{EFT})\sigma_{\mathrm{tree}} + C_t\frac{\alpha_{EW}}{\pi}\left(\log\frac{Q^2}{\mu_{EFT}^2}\sigma_{\log} + \sigma_{\mathrm{fin}}\right)$$

"Top-down": μ_{EFT} = 1 TeV
"Bottom-up": μ_{EFT} = 125 GeV

RESULT (1): LHC

13 TeV, $C/\Lambda^2 = 1\ \mathrm{TeV}^{-2}$

channel	$\mu_{\rm EFT}$ [GeV]	$O_{\varphi W}$	$O_{\varphi B}$	$O_{\varphi t}$	$O^{+}_{\varphi Q}$	$O^{-}_{\varphi Q}$	$O_{\varphi tb}$	O_{tW}	O_{tB}	$O_{t\varphi}$
$pp \to ZH$	125	73.7	8.17	-0.30	0.21	0.21	-0.0034	1.00	-0.064	-0.017
$pp \to ZH$	1000			0.57	0.11	-0.66	-0.055	-2.75	-0.44	-0.017
$pp \to WH$	125	88.6		-0.15	-0.041	0.19	-0.000050	0.43	0	-0.21
$pp \to WH$	1000			0.79	-0.27	-0.52	-0.051	-4.08	0	-0.21
$pp \to Hjj$	125	-4.52	-0.035	-0.26	-0.24	0.51	0.0065	0.044	-0.0050	0.029
$pp \to Hjj$	1000			0.68	0.94	-1.61	-0.045	0.29	-0.0031	0.029

This means the 0.94% deviation in signal strength

RESULT (2): LEPTON COLLIDER

channel	μ_{EFT} [GeV]	$O_{\varphi t}$	$O_{\varphi Q}^{+}$	$O_{\varphi Q}^{-}$	$O_{\varphi tb}$	O_{tW}	O_{tB}	$O_{t\varphi}$
$e^+e^- \to ZH$	125	-0.40	-0.21	0.22	-0.00063	1.82	-0.25	0.0053
$e^+e^- \to ZH$	1000	0.78	-0.10	-0.71	-0.052	-2.71	0.62	0.0053
$e^+e^- \to H\nu\nu$	125	-0.15	-0.26	0.41	0.0076	-0.083	0	-0.0138
$e^+e^- \to H\nu\nu$	1000	0.79	0.76	-1.55	-0.044	0.127	0	-0.0138
$e^+e^- \to He^+e^-$	125	-0.51	-0.27	0.56	0.00050	0.68	0.65	0.084
$e^+e^- \to He^+e^-$	1000	0.28	0.77	-1.50	-0.051	0.78	-0.57	0.084

250 GeV $(e^+,e^-) = (+0.3,-0.8)$

channel	μ_{EFT} [GeV]	$O_{\varphi t}$	$O_{\varphi Q}^{+}$	$O_{\varphi Q}^{-}$	$O_{\varphi tb}$	O_{tW}	O_{tB}	$O_{t\varphi}$
$e^+e^- \to ZH$	125	-0.44	0.36	0.55	-0.0085	-0.62	0.17	0.055
$e^+e^- \to ZH$	1000	0.0031	1.14	-1.42	-0.060	-1.35	-2.35	0.055
$e^+e^- \to H\nu\nu$	125	-0.15	-0.26	0.41	0.0076	-0.0083	0	-0.0138
$e^+e^- \to H\nu\nu$	1000	0.79	0.76	-1.55	-0.044	0.0127	0	-0.0138
$e^+e^- \to He^+e^-$	125	-0.62	0.127	0.66	-0.0086	0.43	1.69	0.048
$e^+e^- \to He^+e^-$	1000	0.29	0.92	-1.08	-0.060	-0.60	-1.11	0.048

250 GeV $(e^+,e^-) = (-0.3,+0.8)$

PHYSICS IMPACT

PHYSICS IMPACT 1: AT LHC

- Let's use current constraints on the top operators

Alioli, Cirigliano, Dekens, de Vries, Mereghetti 17
Maltoni, Vryonidou, Zhang 16
The TopFitter 16

  - Current constraints:
    (reconstruct the 95% allowed region in parameter space, neglecting correlation)

Operator	Top Fitter	RHCC tree	$\sigma_{t\bar{t}H}$ [33]
$C_{\varphi tb}$		[-5.28,5.28]	
$C^{(3)}_{\varphi Q}$	[-2.59,1.50]		
$C^{(1)}_{\varphi Q}$	[-3.10,3.10]		
$C_{\varphi t}$	[-9.78,8.18]		
C_{tW}	[-2.49,2.49]		
C_{tB}	[-7.09,4.68]		
$C_{t\varphi}$			[-6.5,1.3]

  - Possible deviations in Higgs channels at **LHC**:

	$\gamma\gamma$	γZ	bb	WW*	ZZ*	$\tau\tau$	$\mu\mu$
gg	(-100%,1980%)	(-88%,200%)	(-40%,48%)	(-40%,47%)	(-40%,46%)	(-40%,48%)	(-40%,48%)
VBF	(-100%,1880%)	(-88%,170%)	(-6.1%,5.3%)	(-6.8%,6.7%)	(-8.8%,9.2%)	(-6.2%,5.9%)	(-6.2%,5.9%)
WH	(-100%,1880%)	(-88%,170%)	(-5.5%,4.2%)	(-6.1%,5.6%)	(-7.8%,7.9%)	(-5.8%,5.1%)	(-5.8%,5.1%)
ZH	(-100%,1880%)	(-87%,170%)	(-6.5%,5.9%)	(-7.1%,7.1%)	(-9.4%,9.9%)	(-6.8%,6.7%)	(-6.8%,6.7%)

This means potentially ~9% deviation ZH, H->ZZ*

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The TopFitter 16

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PHYSICS IMPACT 2: AT LEPTON COLLIDERS

- Let's use current constraints on the top operators
  - Current constraints:
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Alioli, Cirigliano, Dekens, de Vries, Mereghetti 17
Maltoni, Vryonidou, Zhang 16
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C_{tW}	[-2.49,2.49]		
C_{tB}	[-7.09,4.68]		
$C_{t\varphi}$			[-6.5,1.3]

- Possible deviations in Higgs channels at **LC:**

Even a LC below 350 GeV can probe top couplings

	$\gamma\gamma$	γZ	bb	WW*	ZZ*	$\tau\tau$	$\mu\mu$
ZH(+30%,-80%)	(-100%,1900%)	(-87%,160%)	(-7.5%,7.5%)	(-8.3%,8.6%)	(-11%,11%)	(-8%,8.3%)	(-8%,8.3%)
ZH(-30%,+80%)	(-100%,1870%)	(-88%,180%)	(-7.6%,7.1%)	(-8.1%,7.9%)	(-10%,11%)	(-7.6%,7.3%)	(-7.6%,7.3%)
WWF(+30%,-80%)	(-100%,1880%)	(-88%,170%)	(-5.7%,4.7%)	(-6.5%,6.2%)	(-8.1%,8.3%)	(-5.9%,5.3%)	(-5.9%,5.3%)
WWF(-30%,+80%)	(-100%,1880%)	(-88%,170%)	(-5.7%,4.7%)	(-6.5%,6.2%)	(-8.1%,8.3%)	(-5.9%,5.3%)	(-5.9%,5.3%)
ZZF(+30%,-80%)	(-100%,1810%)	(-88%,170%)	(-9.9%,8.2%)	(-10%,9.2%)	(-12%,12%)	(-10%,8.6%)	(-10%,8.6%)
ZZF(-30%,+80%)	(-100%,1690%)	(-88%,190%)	(-15%,12%)	(-15%,13%)	(-17%,16%)	(-15%,13%)	(-15%,13%)

250 GeV, all operators allowed

PHYSICS IMPACT 2: AT LEPTON COLLIDERS

- Let's use current constraints on the top operators
  - Current constraints:
    (reconstruct the 95% allowed region in parameter space, neglecting correlation)

Alioli, Cirigliano, Dekens, de Vries, Mereghetti 17
Maltoni, Vryonidou, Zhang 16
The TopFitter 16

Operator	Top Fitter	RHCC tree	$\sigma_{t\bar{t}H}$ [33]
$C_{\varphi tb}$		[-5.28,5.28]	
$C_{\varphi Q}^{(3)}$	[-2.59,1.50]		
$C_{\varphi Q}^{(1)}$	[-3.10,3.10]		
$C_{\varphi t}$	[-9.78,8.18]		
C_{tW}	[-2.49,2.49]		
C_{tB}	[-7.09,4.68]		
$C_{t\varphi}$			[-6.5,1.3]

If fixed with 350 run

  - Possible deviations in Higgs channels at **LC**:

	$\gamma\gamma$	γZ	bb	WW*	ZZ*	$\tau\tau$	$\mu\mu$
ZH(+30%,-80%)	(-17%,18%)	(-6.7%,6.4%)	(-3.4%,2.7%)	(-3.9%,3.3%)	(-4.4%,3.8%)	(-3%,2.4%)	(-3%,2.4%)
ZH(-30%,+80%)	(-17%,19%)	(-7.3%,7.1%)	(-4%,3.4%)	(-4.5%,4%)	(-5%,4.4%)	(-3.6%,3%)	(-3.6%,3%)
WWF(+30%,-80%)	(-17%,18%)	(-7.3%,7%)	(-3.9%,3.3%)	(-4.5%,3.9%)	(-4.9%,4.4%)	(-3.6%,2.9%)	(-3.6%,2.9%)
WWF(-30%,+80%)	(-17%,18%)	(-7.3%,7%)	(-3.9%,3.3%)	(-4.5%,3.9%)	(-4.9%,4.4%)	(-3.6%,2.9%)	(-3.6%,2.9%)
ZZF(+30%,-80%)	(-17%,19%)	(-7.7%,7.4%)	(-4.3%,3.7%)	(-4.9%,4.3%)	(-5.3%,4.8%)	(-4%,3.4%)	(-4%,3.4%)
ZZF(-30%,+80%)	(-17%,19%)	(-7.6%,7.4%)	(-4.3%,3.7%)	(-4.8%,4.3%)	(-5.2%,4.7%)	(-3.9%,3.3%)	(-3.9%,3.3%)

350 GeV, only $O_{t\phi}$ (the Yukawa) allowed

PHYSICS IMPACT 3: PROBING TOP COUPLINGS AT HL-LHC

- To estimate HL-LHC "sensitivities" to top-quark operators, we perform a "global fit" using HL projected Higgs measurements.
  - Other **Higgs operators are fixed to 0**.
  - **Set S=T=0**, which means $C_{\phi WB}$ and $C_{\phi D}$=0 in our scheme.
  - Projections follow [Maltoni, Pagani, Shivaji, Zhao 17]
    - Add bb ATL-PHYS-PUB-2014-011
    - and γZ ATL-PHYS-PUB-2014-006

Category		ggF	VBF	WH	ZH	$t\bar{t}H$	Backgrounds	sys.
ZZ^*	ggF-like	3380	274	77	53	25	2110	283
	VBF-like	41	54	0.7	0.4	1.0	4.2	7.4
	WH-like	22	6.6	25	4.4	8.8	1.3	4.9
	ZH-like	0.0	0.0	0.01	4.4	1.3	0.06	0.41
	$t\bar{t}H$-like	3.1	0.6	0.6	1.1	30	1.6	3.2
$\gamma\gamma$	ggF-like	7.51×10^4	5.66×10^3	0	0	0	4.06×10^6	2.5×10^3
	VBF-like	63.9	149	0	0	0	802	6.5
	WH-like	15.9	9.08	163	2.27	15.9	995	7.4
	ZH-like	0	0	0	23.0	3.13	22.8	0.85
	$t\bar{t}H$-like, 1ℓ	6.75	0	11.3	4.5	200	428	6.9
	$t\bar{t}H$-like, 2ℓ	0	0	0	0.38	18.5	48.3	0.98
WW^*	ggF-like, 0j	40850	990	0	0	0	366450	9.5×10^3
	ggF-like, 1j	20050	2325	0	0	0	259610	1.1×10^4
	VBF-like	90	500	0	0	0	1825	1.6×10^2
$\tau^+\tau^-$	VBF-like, lept.	0	147	0	0	0	190	10
	VBF-like, semi-lept.	0	297	0	0	0	1610	21
$\mu^+\mu^-$	ggF-like	1.51×10^4	1.25×10^3	450	270	180	5.64×10^6	630
	$t\bar{t}H$-like	0	0	0	0	33	22	1.7

PHYSICS IMPACT 3: PROBING TOP COUPLINGS AT HL-LHC

- Individual “limits”:

Operator	$C_{\varphi t}$	$C_{\varphi Q}^{(+)}$	$C_{\varphi Q}^{(-)}$	$C_{\varphi tb}$	C_{tW}	C_{tB}	$C_{t\varphi}$
$\mu_{EFT} = 125$ GeV	2.5	1.3	3.2	9.5	0.2	0.07	0.9
$\mu_{EFT} = 1000$ GeV	1.3	0.5	4.3	1.3	0.6	0.08	0.9
Current	9.0	5.1	5.1	5.3	2.5	5.9	3.9

- Chi square eigenvalues:

$$\begin{pmatrix} -0.0251 & 0.0454 & 0.0189 & 0.00501 & -0.429 & -0.901 & -0.0414 \\ 0.0244 & 0.00927 & -0.0187 & -0.0579 & -0.0441 & -0.0257 & 0.997 \\ 0.0722 & -0.43 & -0.147 & 0.0117 & 0.79 & -0.404 & 0.0247 \\ 0.366 & -0.711 & -0.368 & -0.187 & -0.411 & 0.143 & -0.0346 \\ 0.33 & 0.492 & -0.462 & -0.642 & 0.133 & -0.0585 & -0.0542 \\ -0.518 & -0.257 & 0.367 & -0.728 & -0.00803 & 0.00986 & -0.0205 \\ 0.695 & -0.00499 & 0.703 & -0.139 & 0.0516 & -0.0297 & -0.0103 \end{pmatrix}$$

$$\times \frac{1\mathrm{TeV}^2}{\Lambda^2} \begin{pmatrix} C_{\varphi t} \\ C_{\varphi Q} \\ C_{\varphi Q} \\ C_{\varphi tb} \\ C_{tW} \\ C_{tB} \\ C_{t\varphi} \end{pmatrix} = \pm \begin{pmatrix} 0.0326 \\ 0.577 \\ 0.984 \\ 5.21 \\ 7.73 \\ 30.5 \\ 83.9 \end{pmatrix}$$

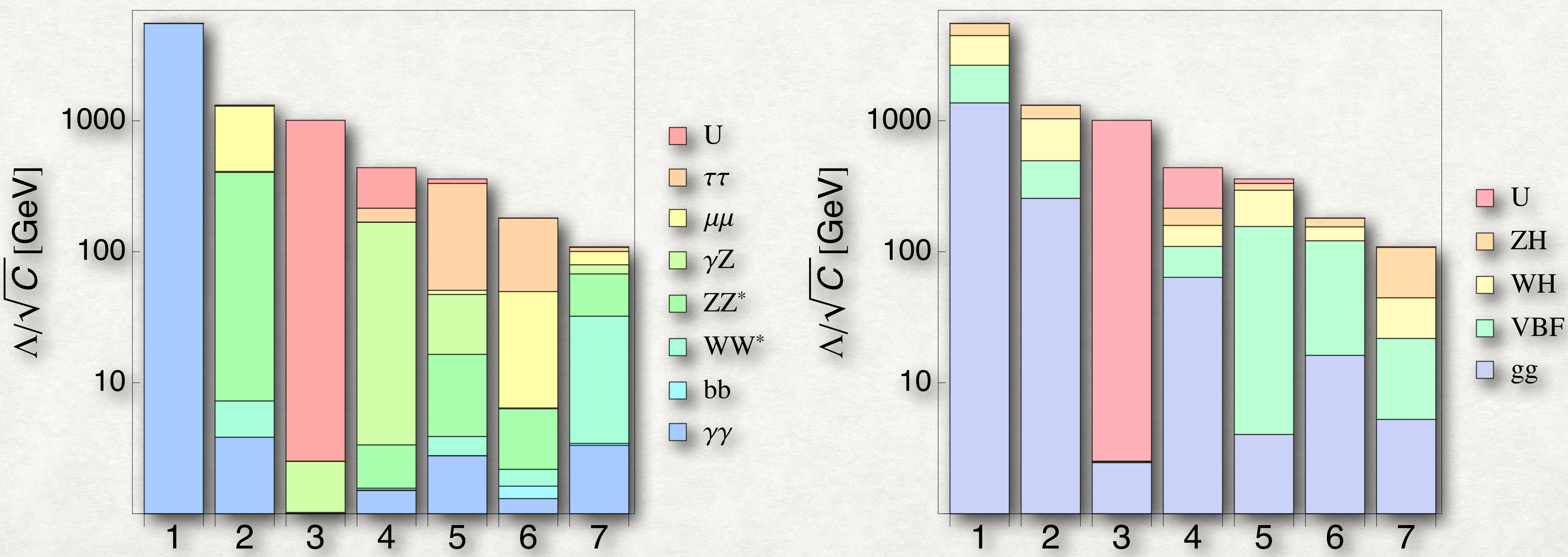
Loop-induced

NLO EW

PHYSICS IMPACT 3: PROBING TOP COUPLINGS AT HL-LHC

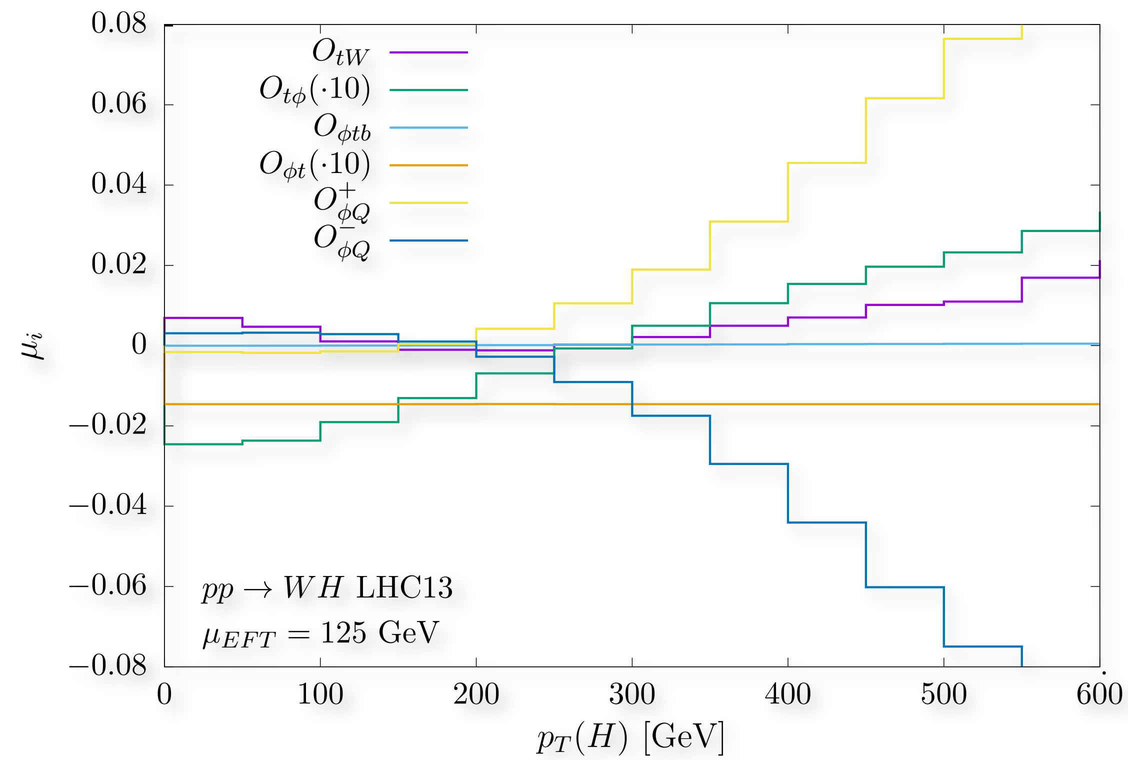
SENSITIVITY DECOMPOSITION

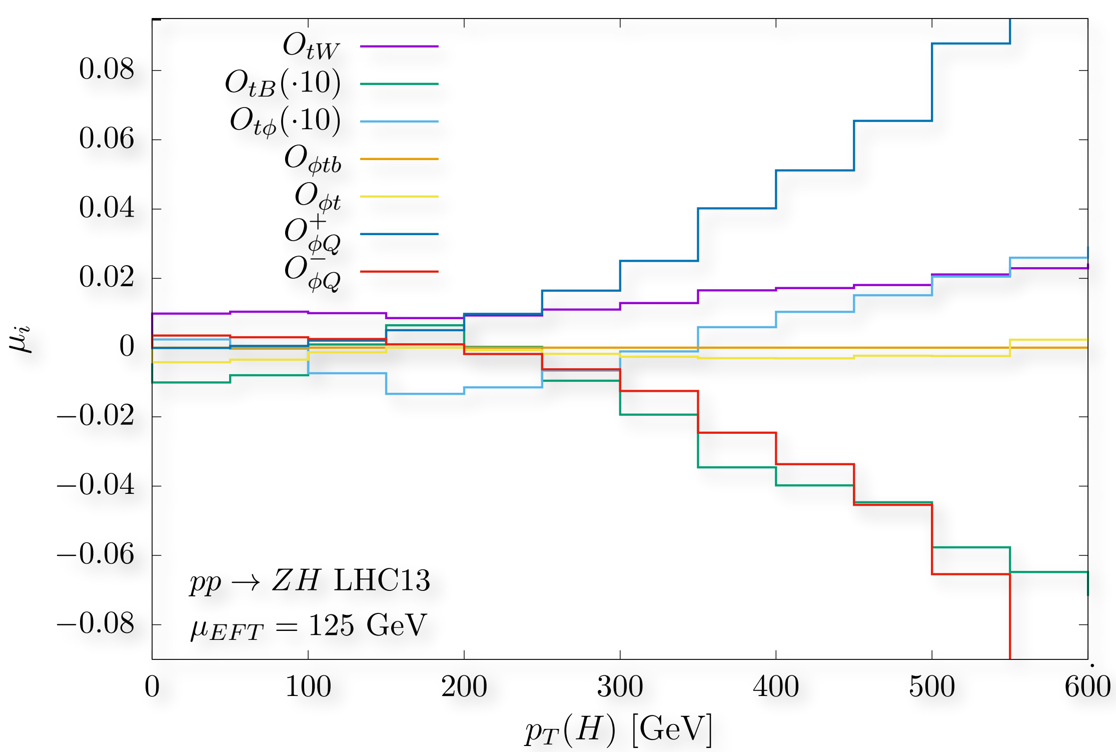
Eigenstates	Coefficients	Channels
$1st$	$C_{tB}(81\%)$	$gg \to H \to \gamma\gamma$ (84%)
$2nd$	$C_{t\varphi}(99\%)$	$gg \to H \to WW^*, ZZ^*, \mu\mu$ (74%)
$3rd$	$C_{tW}(62\%), C_{\varphi Q}^{(+)}(18\%)$	U (87%)
$4th$	$C_{\varphi Q}^{(+)}(50\%), C_{tW}(17\%)$	$gg \to H \to \gamma Z$ (64%)
$5th$	$C_{\varphi tb}(41\%), C_{\varphi Q}^{(+)}(24\%), C_{\varphi Q}^{(-)}(21\%)$	$VBF \to ZZ^*, \tau\tau, \gamma\gamma$ (56%) $gg \to H \to \gamma Z$ (18%)
$6th$	$C_{\varphi tb}(53\%), C_{\varphi t}(27\%), C_{\varphi Q}^{(-)}(13\%)$	$gg \to H \to \mu\mu, ZZ*$ (48%) $VBF \to \tau\tau, ZZ^*$ (36%)
$7th$	$C_{\varphi Q}^{(-)}(49\%), C_{\varphi t}(48\%)$	$ggF, VBF \to WW^*(48\%)$ $WH, ZH \to \gamma\gamma(21\%)$

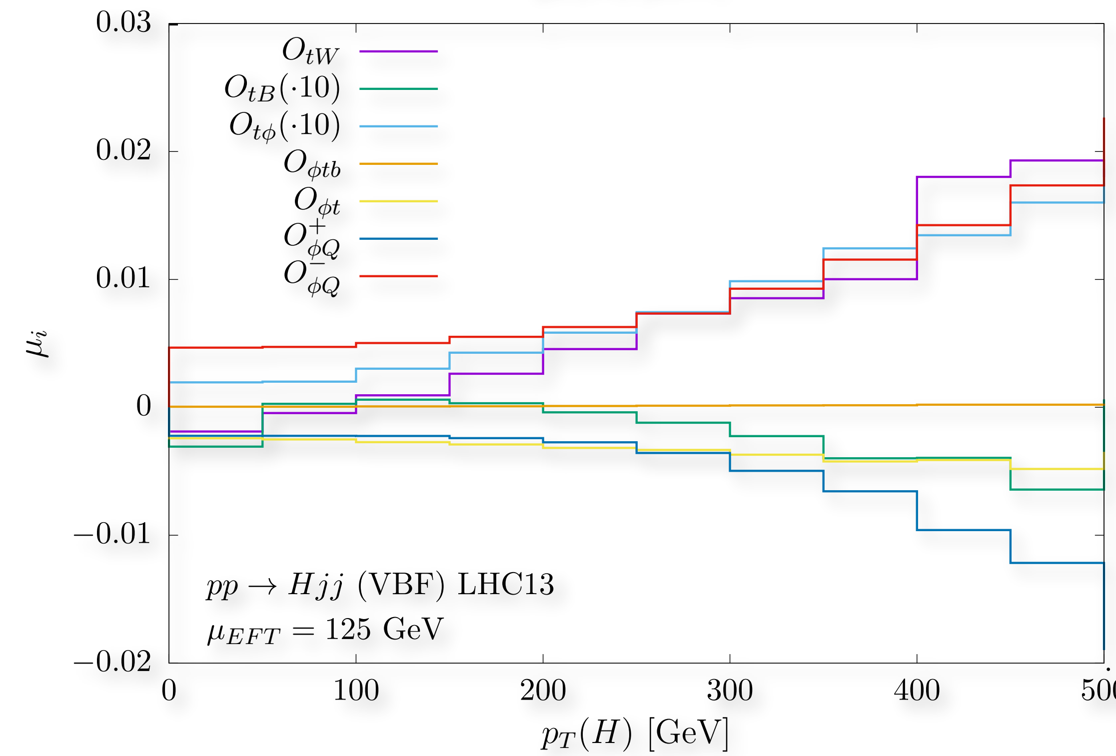


PHYSICS IMPACT 4: DIFFERENTIAL DISTRIBUTIONS

DIFFERENTIAL CROSS SECTION:
LARGER DEVIATIONS AT TAIL







PHYSICS IMPACT 4: DIFFERENTIAL DISTRIBUTIONS

- Improve the fit with differential distributions… [Maltoni, Pagani, Shivaji, Zhao 17]

Bin [GeV]	Channel	r value	$O_{\varphi t}$	$O^{+}_{\varphi Q}$	$O^{-}_{\varphi Q}$	$O_{\varphi tb}$	O_{tW}	O_{tB}	$O_{t\varphi}$
0-50	VBF	0.22	-0.24	-0.22	0.47	0.0051	-0.19	-0.031	0.02
	WH	0.35	-0.15	-0.16	0.31	-0.0022	0.69	0.	-0.25
	ZH	0.34	-0.42	-0.0086	0.35	-0.0034	0.98	-0.1	0.024
50-100	VBF	0.37	-0.25	-0.22	0.47	0.0055	-0.045	0.0028	0.02
	WH	0.38	-0.15	-0.18	0.32	-0.0025	0.47	0.	-0.24
	ZH	0.38	-0.35	0.049	0.3	-0.0034	1.	-0.08	-0.003
100-150	VBF	0.23	-0.27	-0.22	0.5	0.0067	0.094	0.006	0.03
	WH	0.16	-0.15	-0.14	0.29	0.00061	0.11	0.	-0.19
	ZH	0.17	-0.13	0.2	0.25	-0.0034	0.99	0.0088	-0.074
150-200	VBF	0.1	-0.29	-0.24	0.55	0.0085	0.26	0.0032	0.043
	WH	0.062	-0.15	0.043	0.1	0.0067	-0.1	0.	-0.13
	ZH	0.066	-0.0019	0.5	0.094	-0.0034	0.85	0.064	-0.13
200-250	VBF	0.043	-0.32	-0.27	0.63	0.01	0.46	-0.0039	0.058
	WH	0.026	-0.15	0.42	-0.27	0.013	-0.12	0.	-0.069
	ZH	0.027	-0.075	0.97	-0.19	-0.0034	0.93	0.002	-0.11
250-300	VBF	0.018	-0.33	-0.36	0.73	0.013	0.73	-0.012	0.074
	WH	0.012	-0.15	1.1	-0.91	0.02	0.022	0.	-0.0069
	ZH	0.012	-0.18	1.6	-0.63	-0.0034	1.1	-0.096	-0.066
300-350	VBF	0.0087	-0.37	-0.5	0.93	0.015	0.85	-0.022	0.099
	WH	0.0063	-0.15	1.9	-1.7	0.026	0.22	0.	0.05
	ZH	0.0056	-0.26	2.5	-1.3	-0.0034	1.3	-0.19	-0.011
350-400	VBF	0.0038	-0.42	-0.66	1.2	0.016	1.	-0.04	0.12
	WH	0.0034	-0.15	3.1	-2.9	0.031	0.49	0.	0.11
	ZH	0.0033	-0.31	4.	-2.5	-0.0034	1.7	-0.35	0.059
400-450	VBF	0.002	-0.41	-0.96	1.4	0.02	1.8	-0.04	0.13
	WH	0.002	-0.15	4.6	-4.4	0.036	0.7	0.	0.15
	ZH	0.0017	-0.31	5.1	-3.4	-0.0034	1.7	-0.4	0.1
450-500	VBF	0.00098	-0.48	-1.2	1.7	0.021	1.9	-0.064	0.16
	WH	0.0014	-0.15	6.2	-6.	0.04	1.	0.	0.2
	ZH	0.0011	-0.24	6.5	-4.5	-0.0035	1.8	-0.45	0.15
500+	VBF	0.0014	-0.58	-2.5	3.	0.026	3.	-0.1	0.21
	WH	0.0024	-0.15	14.	-14.	0.051	1.9	0.	0.32
	ZH	0.0021	0.35	15.	-12.	-0.0035	2.4	-0.71	0.29

PHYSICS IMPACT 4: DIFFERENTIAL DISTRIBUTIONS

- Improve the fit with differential distributions… [Maltoni, Pagani, Shivaji, Zhao 17]

Bin [GeV]	Channel	r value	$O_{\varphi t}$	$O^{+}_{\varphi Q}$	$O^{-}_{\varphi Q}$	$O_{\varphi tb}$	O_{tW}	O_{tB}	$O_{t\varphi}$
0-50	VBF	0.22	-0.24	-0.22	0.47	0.0051	-0.19	-0.031	0.02
	WH	0.35	-0.15	-0.16	0.31	[illegible]	[illegible]	[illegible]	[illegible]
	ZH	0.34	-0.42	-0.0086	0.35	[illegible]	[illegible]	[illegible]	[illegible]
50-100	VBF	0.37	-0.25	-0.22	0.47	[illegible]	[illegible]	[illegible]	[illegible]
	WH	0.38	-0.15	-0.18	0.32	[illegible]	[illegible]	[illegible]	[illegible]
	ZH	0.38	-0.35	0.049	0.3	[illegible]	[illegible]	[illegible]	[illegible]
100-150	VBF	0.23	-0.27	-0.22	0.5	[illegible]	[illegible]	[illegible]	[illegible]
	WH	0.16	-0.15	-0.14	0.29	[illegible]	[illegible]	[illegible]	[illegible]
	ZH	0.17	-0.13	0.2	0.25	[illegible]	[illegible]	[illegible]	[illegible]
150-200	VBF	0.1	-0.29	-0.24	0.55	[illegible]	[illegible]	[illegible]	[illegible]
	WH	0.062	-0.15	0.043	0.1	[illegible]	[illegible]	[illegible]	[illegible]
	ZH	0.066	-0.0019	0.5	0.094	[illegible]	[illegible]	[illegible]	[illegible]
200-250	VBF	0.043	-0.32	-0.27	0.63	[illegible]	[illegible]	[illegible]	[illegible]
	WH	0.026	-0.15	0.42	-0.27	[illegible]	[illegible]	[illegible]	[illegible]
	ZH	0.027	-0.075	0.97	-0.19	[illegible]	[illegible]	[illegible]	[illegible]
250-300	VBF	0.018	-0.33	-0.36	0.73	[illegible]	[illegible]	[illegible]	[illegible]
	WH	0.012	-0.15	1.1	-0.91	[illegible]	[illegible]	[illegible]	[illegible]
	ZH	0.012	-0.18	1.6	-0.63	[illegible]	[illegible]	[illegible]	[illegible]
300-350	VBF	0.0087	-0.37	-0.5	0.93	[illegible]	[illegible]	[illegible]	[illegible]
	WH	0.0063	-0.15	1.9	-1.7	[illegible]	[illegible]	[illegible]	[illegible]
	ZH	0.0056	-0.26	2.5	-1.3	[illegible]	[illegible]	[illegible]	[illegible]
350-400	VBF	0.0038	-0.42	-0.66	1.2	[illegible]	[illegible]	[illegible]	[illegible]
	WH	0.0034	-0.15	3.1	-2.9	[illegible]	[illegible]	[illegible]	[illegible]
	ZH	0.0033	-0.31	4.	-2.5	-0.0034	1.7	-0.35	0.059
400-450	VBF	0.002	-0.41	-0.96	1.4	0.02	1.8	-0.04	0.13
	WH	0.002	-0.15	4.6	-4.4	0.036	0.7	0.	0.15
	ZH	0.0017	-0.31	5.1	-3.4	-0.0034	1.7	-0.4	0.1
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	ZH	0.0011	-0.24	6.5	-4.5	-0.0035	1.8	-0.45	0.15
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	WH	0.0024	-0.15	14.	-14.	0.051	1.9	0.	0.32
	ZH	0.0021	0.35	15.	-12.	-0.0035	2.4	-0.71	0.29

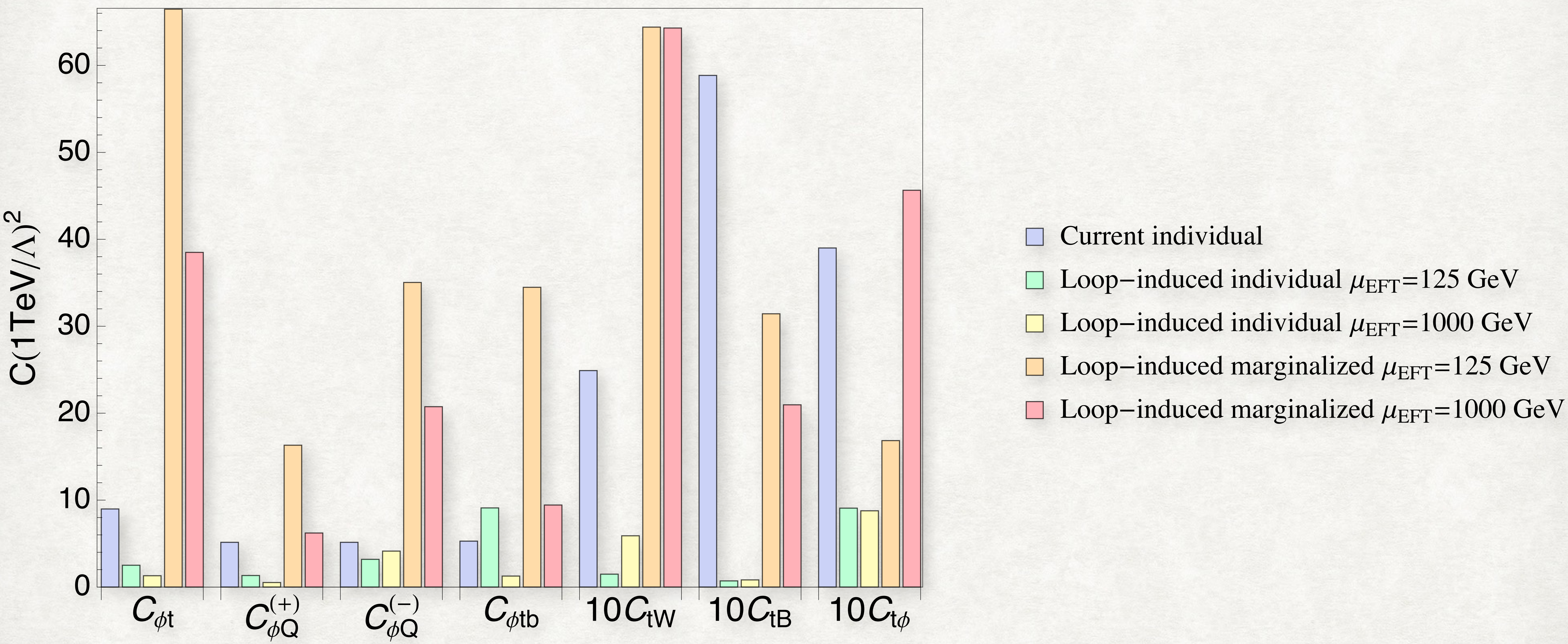
$$\begin{pmatrix} -0.0251 & 0.0454 & 0.0189 & 0.00501 & -0.429 & -0.901 & -0.0411 \\ 0.0261 & 0.0105 & -0.0208 & -0.0598 & -0.0465 & -0.0242 & 0.996 \\ 0.0731 & -0.438 & -0.147 & 0.0128 & 0.786 & -0.403 & 0.0273 \\ 0.386 & -0.676 & -0.387 & -0.24 & -0.407 & 0.141 & -0.0411 \\ -0.268 & -0.554 & 0.552 & 0.534 & -0.157 & 0.0666 & 0.0507 \\ -0.0101 & 0.123 & -0.636 & 0.759 & -0.0519 & 0.0207 & 0.0294 \\ 0.879 & 0.166 & 0.345 & 0.278 & 0.0539 & -0.033 & 0.00077 \end{pmatrix} \times \frac{1\mathrm{TeV}^2}{\Lambda^2} \begin{pmatrix} C_{\varphi t} \\ C_{\varphi Q} \\ C_{\varphi Q} \\ C_{\varphi tb} \\ C_{tW} \\ C_{tB} \\ C_{t\varphi} \end{pmatrix}$$

$$= \pm \begin{pmatrix} 0.0325 \\ 0.569 \\ 0.965 \\ 4.97 \\ 6.28 \\ \boxed{17.8} \\ \boxed{38.5} \end{pmatrix}, \text{ compared with } \begin{pmatrix} 0.0326 \\ 0.577 \\ 0.984 \\ 5.21 \\ 7.73 \\ \boxed{30.5} \\ \boxed{83.9} \end{pmatrix} \text{ from inclusive measurements.} \quad (5.7$$

GDP improved by a factor of ~0.8

PHYSICS IMPACT 4: DIFFERENTIAL DISTRIBUTIONS

Comparison of sensitivity, current direct limits with HL-LHC



CONCLUSION

CONCLUSION

- We compute NLO EW corrections from dim-6 top operators to major Higgs processes:
  - LHC: VBF, WH, ZH
  - LC: ZH, VBF
  - Decay: $\gamma\gamma$, γZ, WW^*, ZZ^*, bb, $\tau\tau$, $\mu\mu$
  - and in principle many other non-Higgs processes
- Implemented in MG5_aMC@NLO: a first step towards automated SMEFT@NLO in EW
- Using these results we find **Higgs measurements are sensitive to top operators**
  - Loop-induced processes (in SM) affected by O(1)-O(10), while others by ***~10%*** due to NLO EW corrections. Will matter at HL-LHC and LC.
- We derive projected “constraints” on top operator coefficients using loop effects. They could range from ***O(0.01) to O(10)***, if Λ=1TeV.

CONCLUSION

- Treating the dim-6 top-quark sector and the Higgs/EW sector separately will not continue to be a good approximation. A global approach with loop effects is desirable.

- Our implementation provides an automatic and realistic simulation tool for this purpose.

BACKUPS

H DECAY

channel	μ_{EFT} [GeV]	$O_{\varphi W}$	$O_{\varphi B}$	$O_{\varphi t}$	$O^{+}_{\varphi Q}$	$O^{-}_{\varphi Q}$	$O_{\varphi tb}$	O_{tW}	O_{tB}	$O_{t\varphi}$
$H \to bb$	125	0	0	-0.15	-0.06	0.24	-1.13	-0.28	0	-0.18
$H \to bb$	1000			0.79	0.54	-1.25	-8.16	0.34	0	0.29
$H \to \mu\mu, \tau\tau$	125	0	0	-0.15	0.001	0.15	0	0	0	-0.27
$H \to \mu\mu, \tau\tau$	1000			0.79	0.002	-0.79	0	0	0	0.68
$H \to \gamma\gamma$	125	-1378	-4806	-3.37	5.86	2.64	0	-56.4	-117.9	3.45
$H \to \gamma\gamma$	1000			6.95	16.2	-2.52	0	14.0	101.3	3.45
$H \to Z\gamma$	125	-1437	1437	0.512	2.20	2.74	0	-39.5	14.0	0.723
$H \to Z\gamma$	1000			4.35	6.04	0.830	0	33.9	-51.6	0.723
$H \to Zll$	125	2.79	-8.67	-0.541	-0.098	0.556	-0.004	0.188	-0.062	0.082
$H \to Zll$	1000			0.334	0.738	-1.253	-0.055	0.048	0.333	0.082
$H \to Wl\nu$	125	-9.00		-0.146	-0.235	0.382	0.004	-0.134	0.	-0.033
$H \to Wl\nu$	1000			0.794	0.627	-1.421	-0.047	0.326	0.	-0.033

LOOP/TREE DISCRIMINATION

- We have set Higgs operators to ZERO. What if we have not? i.e. in a real global fit, how do we discriminate tree-level contributions from OH and loop-level contributions from Ot?
    - RG correction is not useful here: observable-independent.
    - Finite correction is the key. This is why we think mu_{EFT}=125 GeV better reflects the "sensitivity" of a real fit.
    - Consider O_{tB} that mixes into $O_{\phi B}$. Suppose we want to distinguish the two only using Higgs processes (γγ, γZ, WW*, ZZ*, all 10%)

$$C_{\varphi B} + 0.021 C_{tB} = \pm 0.0022\ (\Lambda/1\mathrm{TeV})^2\ ,$$
$$C_{tB} - 0.021 C_{\varphi B} = \boxed{\pm 6.7}\ (\Lambda/1\mathrm{TeV})^2\ ,$$

With finite corrections

$$C_{\varphi B} - 0.045 C_{tB} = \pm 0.0022\ (\Lambda/1\mathrm{TeV})^2\ ,$$
$$C_{tB} + 0.045 C_{\varphi B} = \boxed{\pm \infty}\ (\Lambda/1\mathrm{TeV})^2\ ,$$

With RG logs only

LOOP/TREE DISCRIMINATION

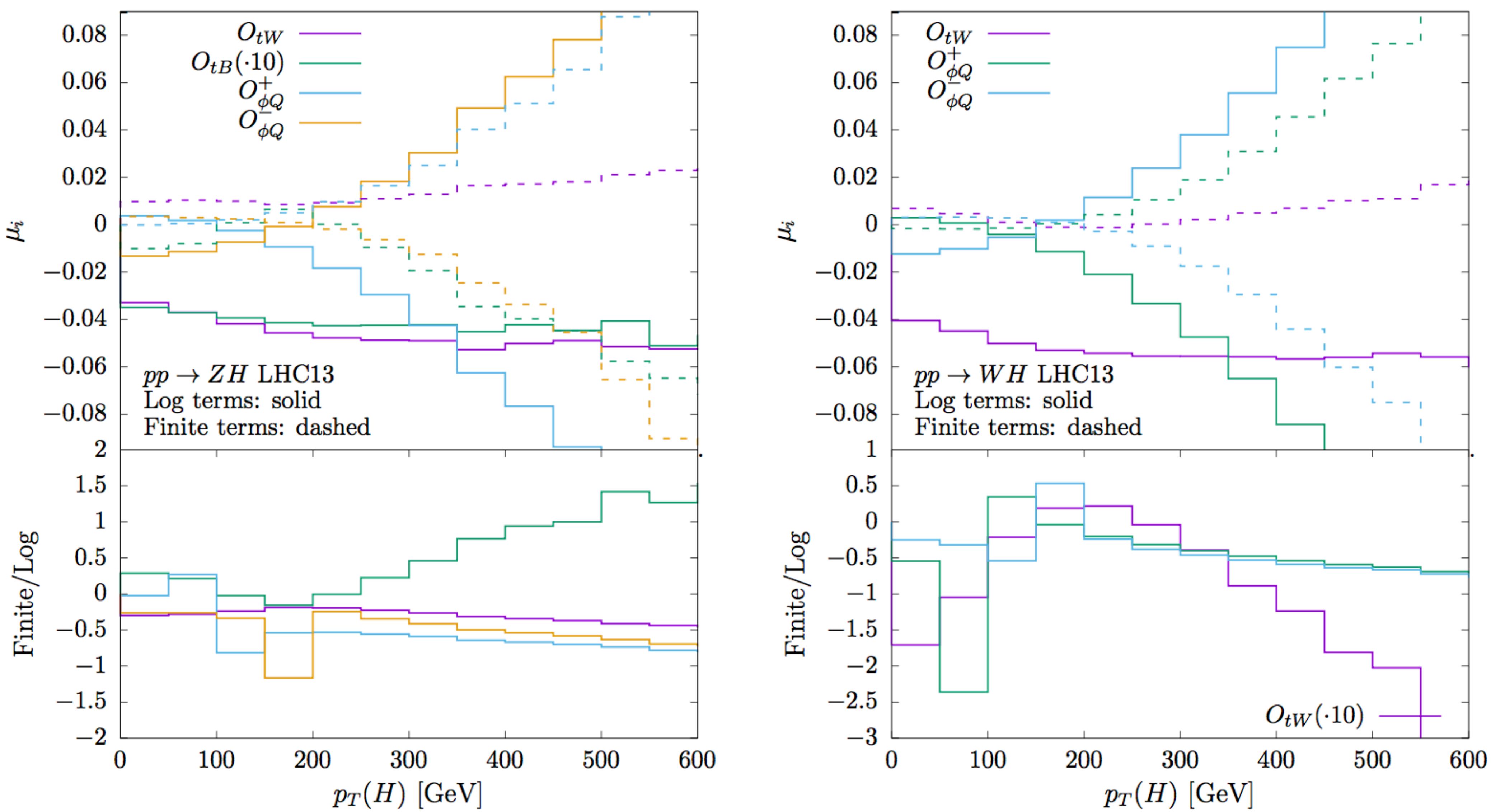


Figure 9. Comparison of logarithmic and finite terms in the Higgs transverse momentum distribution in ZH and WH production for the different operators. The lower panels show the ratio of the finite over the logarithmic terms.

DISTRIBUTIONS ARE CRUCIAL