Electroweak input schemes in SMEFT

Anke Biekötter - KIT

Karlsruher Institut für Technologie

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Outline

- Electroweak input parameters and their influence on one-loop calculations in the SMEFT
  - Size of NLO corrections
- Resuming scheme-dependent NLO corrections

Based on 2305.03763, 2312.08446 and WIP with Benjamin Pecjak, Darren Scott and Tommy Smith

Input schemes

- Lagrangian written in terms of $\{g_1,\, g_w,\, v\}$
- Choice of input parameters

$$\{g_1,\, g_w,\, v\} \rightarrow \{\text{input 1, input 2, input 3}\}$$

- Typical choices

M_W	$80.433(9)$	GeV
M_Z	$91.1876(21)$	GeV
G_F	$1.1663797(6)\ \times 10^{-5}$	GeV^2
$\alpha(M_Z)$	$0.007127(2)$	

Why does the choice of input scheme matter?

In the SM:

- Precision of input parameters
- Convergence of the perturbative series

In the SMEFT:

- Number of Wilson coefficients appearing
  (at LO and at higher orders)
- Practicality (parameters appearing in propagators)
- **Convergence in term of the Wilson coefficients**

Teaser: perturbative convergence for leptonic W decay

$$\Gamma^{(4,0)}_{W\tau\nu} + \Gamma^{(6,0)}_{W\tau\nu} = \frac{M_W}{12\pi}\frac{M_W^2}{v_T^2}\left(1 + 2v_T^2 C^{(3)}_{\substack{Hl\\33}}\right)$$

Different schemes

$W \to \tau\nu_\tau$	SM	C_{HD}	C_{HWB}	$C^{(3)}_{\substack{Hl\\jj}}$	$C^{(3)}_{\substack{Hl\\33}}$	$C_{\substack{ll\\1221}}$
α	-4.2%	-1.7%	-3.0%	—	2.2%	—
α_μ	-0.3%	—	—	2.5%	2.2%	-0.2%
LEP	2.0%	8.1%	3.2%	5.1%	4.6%	2.5%

Corrections to the LO Wilson coefficients at NLO

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Corrections to the LO Wilson coefficients at NLO

Are there patterns and can they be understood?

Meet the schemes

- **The α_μ scheme -** $\{G_F,\, M_W,\, M_Z\}$
  - M_W and M_Z are renormalised on-shell
  - G_F is renormalised through muon decay
  - Sometimes called "M_W scheme" in the SMEFT
- **The α scheme -** $\{\alpha,\, M_W,\, M_Z\}$
  - M_W and M_Z are renormalised on-shell
  - α is renormalised on-shell or in $\overline{\mathrm{MS}}$-lite scheme

[Cullen, Pecjak, Scott (1904.06358)]

- **The LEP scheme -** $\{\alpha,\, G_F,\, M_Z\}$
  - Inputs renormalised as above
  - Sometimes called "α scheme" in the SMEFT

- Wilson coefficients renormalised in $\overline{\mathrm{MS}}$ scheme

The α_μ vs α schemes

α_μ scheme

- Inputs $\{G_F,\, M_W,\, M_Z\}$
- G_F or v_μ is renormalised by requiring that Fermi decay is exact to all orders

$$\frac{1}{v_{T,0}^2} = \frac{1}{v_\mu^2}\left[1 - v_\mu^2 \Delta v^{(6,0,\mu)} - \frac{1}{v_\mu^2}\Delta v_\mu^{(4,1,\mu)} - \Delta v_\mu^{(6,1,\mu)}\right]$$

Tree-level	One-loop	One-loop
SMEFT	SM	SMEFT

The α_μ vs α schemes

α_μ scheme

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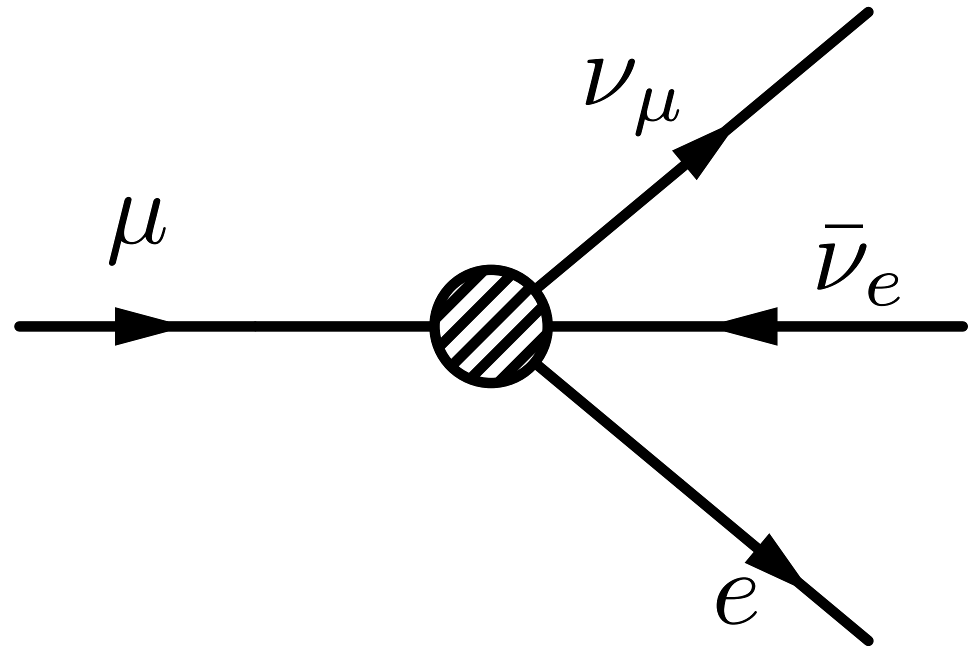
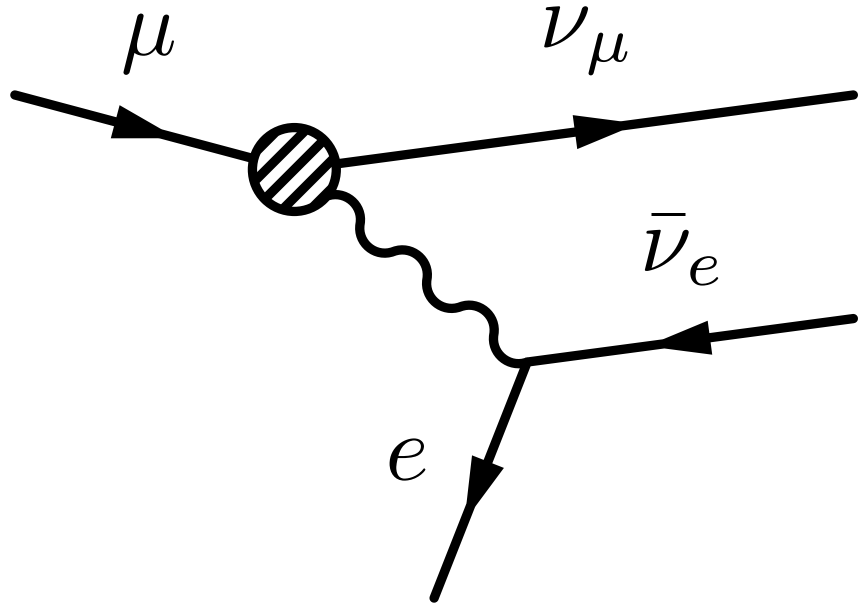




$$\Delta v^{(6,0,\mu)} = C_{\substack{Hl\\11}}^{(3)} + C_{\substack{Hl\\22}}^{(3)} - C_{\substack{ll\\1221}}$$

The α_μ vs α schemes

α_μ scheme

- Inputs $\{G_F,\, M_W,\, M_Z\}$
- G_F or v_μ is renormalised by requiring that Fermi decay is exact to all orders

$$\frac{1}{v_{T,0}^2} = \frac{1}{v_\mu^2}\left[1 - v_\mu^2 \Delta v^{(6,0,\mu)} - \frac{1}{v_\mu^2}\Delta v_\mu^{(4,1,\mu)} - \Delta v_\mu^{(6,1,\mu)}\right]$$

Tree-level	One-loop	One-loop
SMEFT	SM	SMEFT

α scheme

- Inputs $\{\alpha,\, M_W,\, M_Z\}$
- Differs from the α_μ scheme through the way we renormalise the vev
- v_α is a derived parameter

$$v_\alpha = \frac{2 M_W s_W}{\sqrt{4\pi\alpha}}$$

$$\frac{\delta v_\alpha}{v_\alpha} \equiv \frac{\delta M_W}{M_W} + \frac{\delta s_W}{s_W} - \frac{\delta e}{e}$$

$$\frac{v_\alpha^2}{v_\mu^2} \equiv 1 + \Delta r$$

The LEP scheme

- Inputs $\{\alpha,\, G_F,\, M_Z\}$
- $\hat{M}_W$ is a derived parameter

$$\hat{M}_W^2 = \frac{M_Z^2}{2}\left(1+\sqrt{1-\frac{4\pi\alpha v_\mu^2}{M_Z^2}}\right)$$

$$M_W^2 = \hat{M}_W^2\left[1-\frac{\hat{s}_w^2}{\hat{c}_{2w}}\Delta r - \frac{\hat{c}_w^2\,\hat{s}_w^4}{\hat{c}_{2w}^3}\Delta r^2\right]+\mathcal{O}\left(\Delta r^3\right)$$

$$\frac{v_\alpha^2}{v_\mu^2} \equiv 1+\Delta r$$

NLO corrections

- Process dependent pieces and scheme dependent pieces
- Counterterms contain tadpoles and divergences

Physical processes

- Tadpole and divergence free
- Look at decay rates
  - $W \to l\nu_l$
  - $Z \to l^+l^-$
  - $H \to b\bar{b}$

[Dawson, Giardino (1909.02000), (2201.09887)]

$$\Gamma^{(4,0)}_{W\tau\nu} = \frac{M_W}{12\pi}\frac{M_W^2}{v_T^2}$$

[Cullen, Pecjak, Scott (1512.02508)]

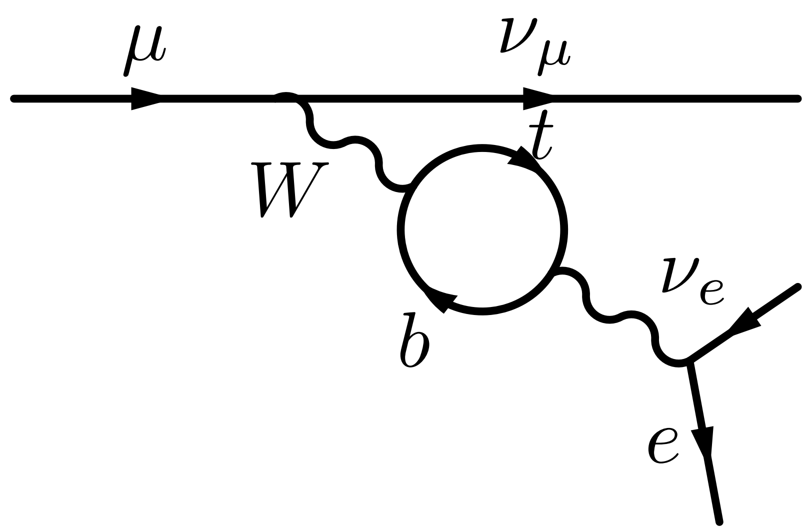
Corrections for W decay - SM

$$\Gamma^{(4,0)}_{W\tau\nu} + \Gamma^{(6,0)}_{W\tau\nu} = \frac{M_W}{12\pi}\frac{M_W^2}{v_T^2}\left(1 + 2v_T^2 C^{(3)}_{\substack{Hl\\33}}\right)$$

$$\frac{M^2_{W,0}}{v^2_{T,0}} z_W\Big|_{m_t\to\infty} \equiv \frac{M_W^2}{v_\sigma^2}\left[1 + v_\sigma^2 K_W^{(6,0,\sigma)} + \frac{1}{v_\sigma^2}K_W^{(4,1,\sigma)} + K_W^{(6,1,\sigma)}\right]$$

Tadpole and divergence free

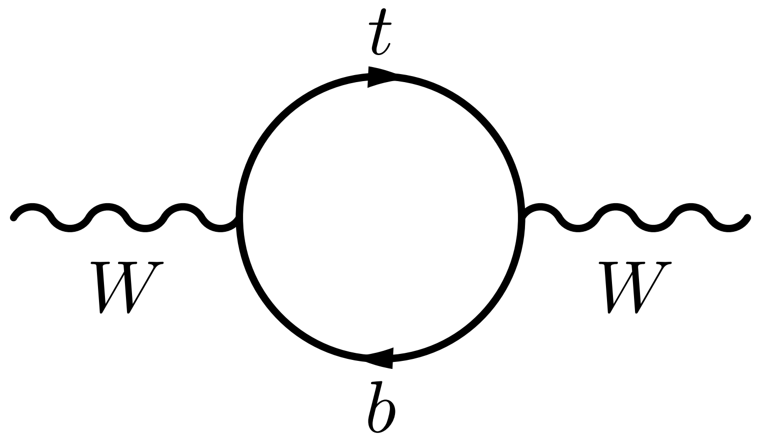
$$K_W^{(4,1,\sigma)} = -\Delta v^{(4,1,\sigma)}_{\sigma,t} + 2\Delta M^{(4,1)}_{W,t}$$



$$K_W^{(4,1,\alpha)} = \Delta r_t^{(4,1)} \approx -3.4\%$$

$$K_W^{(4,1,\mu)} = 0$$

$$\hat{K}_W^{(4,1,\mu)} = -\frac{s_w^2}{c_{2w}}\Delta r_t^{(4,1)} \approx 1.5\%$$



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$$\frac{M_{W,0}^2}{v_{T,0}^2} z_W \Big|_{m_t\to\infty} \equiv \frac{M_W^2}{v_\sigma^2}\left[1 + v_\sigma^2 K_W^{(6,0,\sigma)} + \frac{1}{v_\sigma^2} K_W^{(4,1,\sigma)} + K_W^{(6,1,\sigma)}\right]$$

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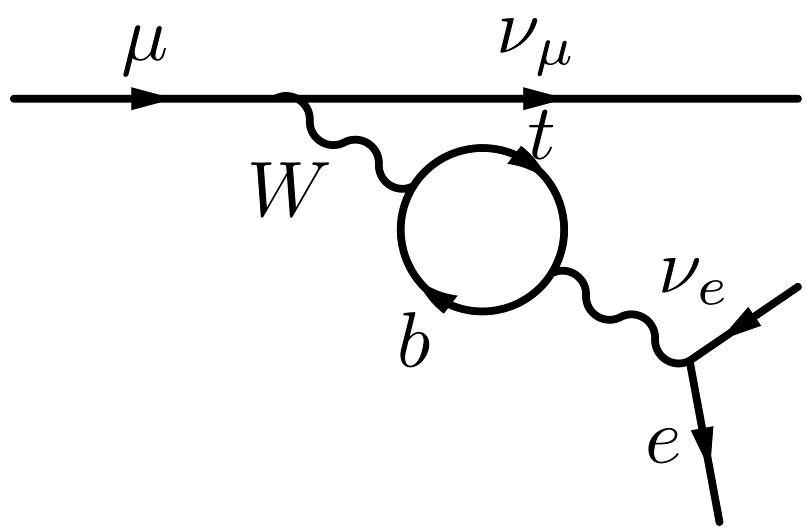

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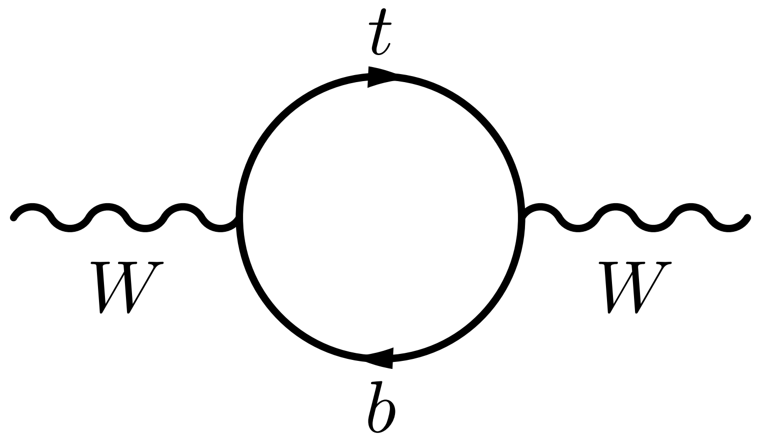

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Corrections for W decay - SMEFT

$W \to \tau\nu_\tau$	SM	C_{HD}	C_{HWB}	$C^{(3)}_{\substack{Hl \\ jj}}$	$C^{(3)}_{\substack{Hl \\ 33}}$	$C_{\substack{ll \\ 1221}}$
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α_μ	-0.3%	—	—	2.5%	2.2%	-0.2%
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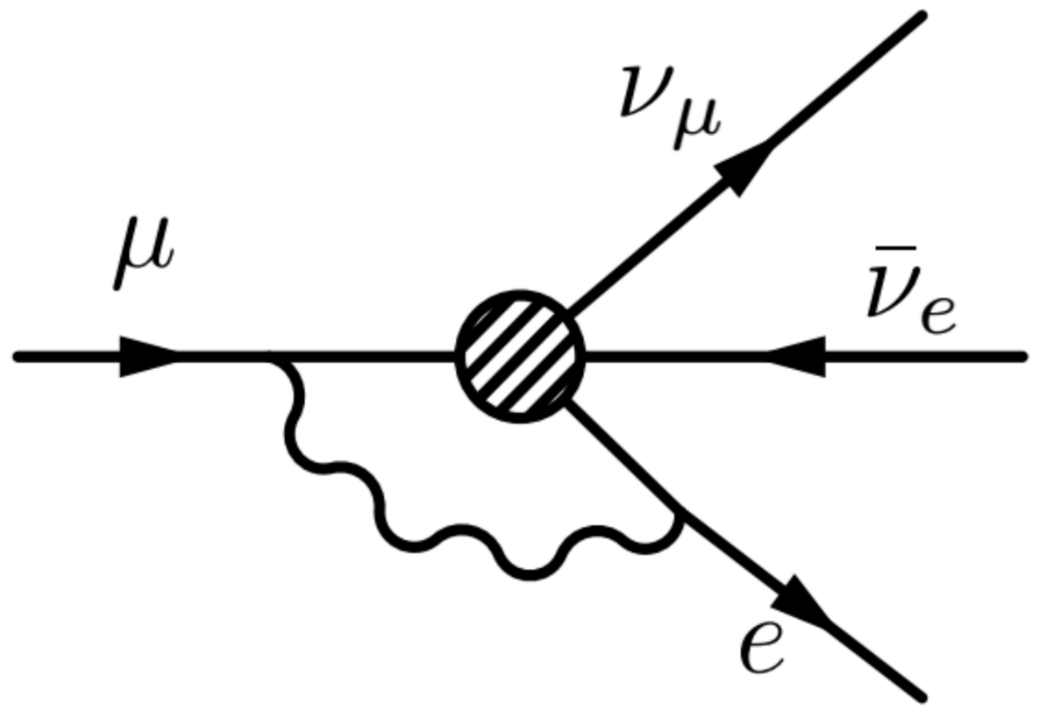
No large MT contribution



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No vT dependence

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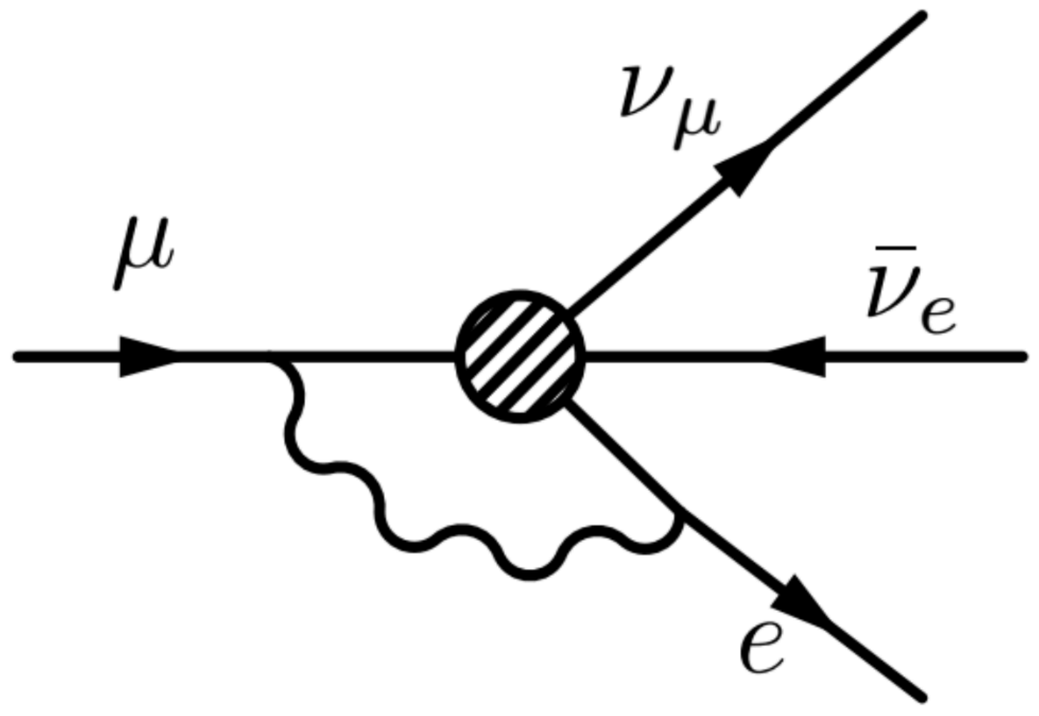

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Similar MW dependence

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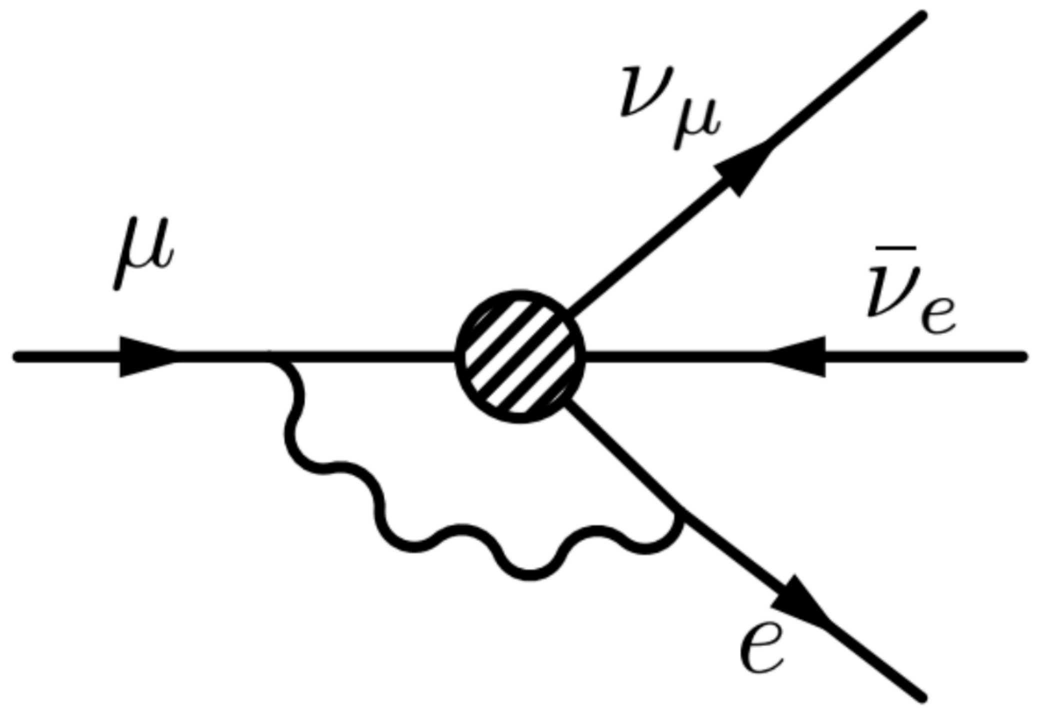

Corrections for H decay - SMEFT

$j = 1,\, 2$

$h \to b\bar{b}$		SM	$C_{H\Box}$	C_{HD}	$C_{\underset{33}{dH}}$	C_{HWB}	$C^{(3)}_{\underset{jj}{Hl}}$	$C_{\underset{1221}{ll}}$
α	NLO QCD	20.3%	20.3%	20.3%	20.3%	20.3%	-	-
	NLO EW	-5.2 %	2.1%	-11.0%	4.2%	-6.7%	-	-
	NLO correction	15.1%	22.4%	9.3%	24.5%	13.6%	-	-
α_μ	NLO QCD	20.3%	20.3%	20.3%	20.3%	-	20.3%	20.3%
	NLO EW	-0.8 %	2.1%	2.0%	1.9%	-	0.9%	-0.8%
	NLO correction	19.5%	22.4%	22.3%	22.2%	-	21.2%	19.5%
LEP	NLO QCD	20.3%	20.3%	20.3%	20.3%	-	20.3%	20.3%
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$$\Gamma^{(4,0)}_{hb\bar{b}} + \Gamma^{(6,0)}_{hb\bar{b}} = \frac{3m_b^2 M_H}{8\pi v_T^2}\left[1 + v_T^2\left(2C_{H\Box} - \frac{1}{2}C_{HD} - \sqrt{2}\frac{v_T}{m_b}C_{\underset{33}{dH}}\right)\right]$$

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Corrections for H decay - SMEFT

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MW dependence subdominant

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Corrections for H decay - SMEFT

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H decay α scheme - SMEFT

$$\left.\Gamma^{s}_{hb\bar{b}}\right|_{m_t\to\infty} = \frac{3m_b^2 M_H}{8\pi v_\sigma^2}\left[1 + v_\sigma^2\left(K_H^{(6,0)} + K_W^{(6,0,\sigma)}\right) + \frac{1}{v_\sigma^2}\left(K_H^{(4,1)} + K_W^{(4,1,\sigma)}\right) + K_H^{(6,1)} + \Delta K_H^{(6,1,\sigma)}\right]$$

H decay α scheme - SMEFT

Scheme independent

$$\Gamma^{s}_{hb\bar{b}}\Big|_{m_t\to\infty} = \frac{3m_b^2 M_H}{8\pi v_\sigma^2}\left[1 + v_\sigma^2\left(\boxed{K_H^{(6,0)}} + \boxed{K_W^{(6,0,\sigma)}}\right) + \frac{1}{v_\sigma^2}\left(\boxed{K_H^{(4,1)}} + \boxed{K_W^{(4,1,\sigma)}}\right) + \boxed{K_H^{(6,1)}} + \boxed{\Delta K_H^{(6,1,\sigma)}}\right]$$

Scheme dependent

H decay α scheme - SMEFT

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$$+ K_H^{(6,1)} + \Delta K_H^{(6,1,\sigma)}\Big]$$

Scheme dependent

$$\Delta K_H^{(6,1,\sigma)} = K_W^{(6,1,\sigma)} + 2K_H^{(4,1)}K_W^{(6,0,\sigma)} + \frac{1}{\sqrt{2}}\frac{v_\sigma}{m_b}K_W^{(4,1,\sigma)}C_{\substack{dH\\33}}$$

H decay α scheme - SMEFT

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Scheme dependent

$$\Delta K_H^{(6,1,\sigma)} = K_W^{(6,1,\sigma)} + 2K_H^{(4,1)}K_W^{(6,0,\sigma)} + \frac{1}{\sqrt{2}}\frac{v_\sigma}{m_b}K_W^{(4,1,\sigma)}C_{\substack{dH\\33}}$$

$$\frac{1}{v_\alpha^2}\left(K_H^{(6,1)} + \Delta K_H^{(6,1,\alpha)}\right) = \Bigg\{ - C_{HD}(1.6 + 9.7) + (0.0 - 17)C_{HWB} - (3.7 + 6.8)C^{(3)}_{\substack{Hq\\33}} + (0.0 - 8.8)(C_{\substack{Hu\\33}} - C^{(1)}_{\substack{Hq\\33}}) + (0.0 - 3.1)C_{\substack{uB\\33}} + (-4.6 + 0.42)C_{\substack{uW\\33}} - \frac{\sqrt{2}v_\alpha}{m_b}(1.8 + 1.7)\,C_{\substack{dH\\33}}\Bigg\} \times 10^{-2} + \dots$$

Scheme dependent corrections larger in most cases

H decay α scheme - SMEFT

Scheme independent

$$\Gamma^s_{hb\bar{b}}\Big|_{m_t\to\infty} = \frac{3m_b^2 M_H}{8\pi v_\sigma^2}\Big[1 + v_\sigma^2\left(K_H^{(6,0)} + K_W^{(6,0,\sigma)}\right) + \frac{1}{v_\sigma^2}\left(K_H^{(4,1)} + K_W^{(4,1,\sigma)}\right) + K_H^{(6,1)} + \Delta K_H^{(6,1,\sigma)}\Big]$$

Scheme dependent

$$\Delta K_H^{(6,1,\sigma)} = K_W^{(6,1,\sigma)} + 2K_H^{(4,1)} K_W^{(6,0,\sigma)} + \frac{1}{\sqrt{2}}\frac{v_\sigma}{m_b} K_W^{(4,1,\sigma)} C_{\underset{33}{dH}}$$

$\frac{1}{v_\alpha^2}$

$-($ … $2)C_{\underset{33}{uW}}$

$-$ …

SMEFT corrections come from several sources but some are common to all processes.

Scheme dependent corrections larger in most cases

Why should I care? Resummation!

- Knowing where the NLO corrections come from allows us to include these in the LO results already

$$\frac{1}{v_{T,0}^2}\Big|_{m_t\to\infty} = \frac{1}{v_\alpha^2}\left[1+\frac{1}{v_{T,0}^2}\Delta r_t^{(4,1)}\right] = \frac{1}{v_\alpha^2}\left[1+\frac{1}{v_\alpha^2}\Delta r_t^{(4,1)} + \frac{1}{v_\alpha^2 v_{T,0}^2}\left(\Delta r_t^{(4,1)}\right)^2 + \dots\right]$$
$$= \frac{1}{v_\alpha^2}\left[1-\frac{1}{v_\alpha^2}\Delta r_t^{(4,1)}\right]^{-1} \equiv \frac{1}{\tilde{v}_\alpha^2}$$

- Formulate as replacements for SMEFT

$$\frac{1}{v_T^2} \to \frac{1}{v_\sigma^2}\left[1 + v_\sigma^2 K_W^{(6,0,\sigma)} + \frac{K_W^{(4,1,\sigma)}}{v_\sigma^2} + K_W^{(6,1,\sigma)}\right],$$
$$s_w^2 \to s_w^2\left(1-\frac{1}{v_\sigma^2}\Delta r_t^{(4,1)} + \Delta v_\sigma^{(6,0,\sigma)}\Delta r_t^{(4,1)} - 2C_{\substack{Hq\\33}}^{(3)}\Delta r_t^{(4,1)}\right),$$
$$c_w^2 \to c_w^2\left(1-\frac{1}{v_\sigma^2}\Delta \rho_t^{(4,1)} + \Delta v_\sigma^{(6,0,\sigma)}\Delta \rho_t^{(4,1)} - 2C_{\substack{Hq\\33}}^{(3)}\Delta \rho_t^{(4,1)}\right)$$

Z decay - resummation

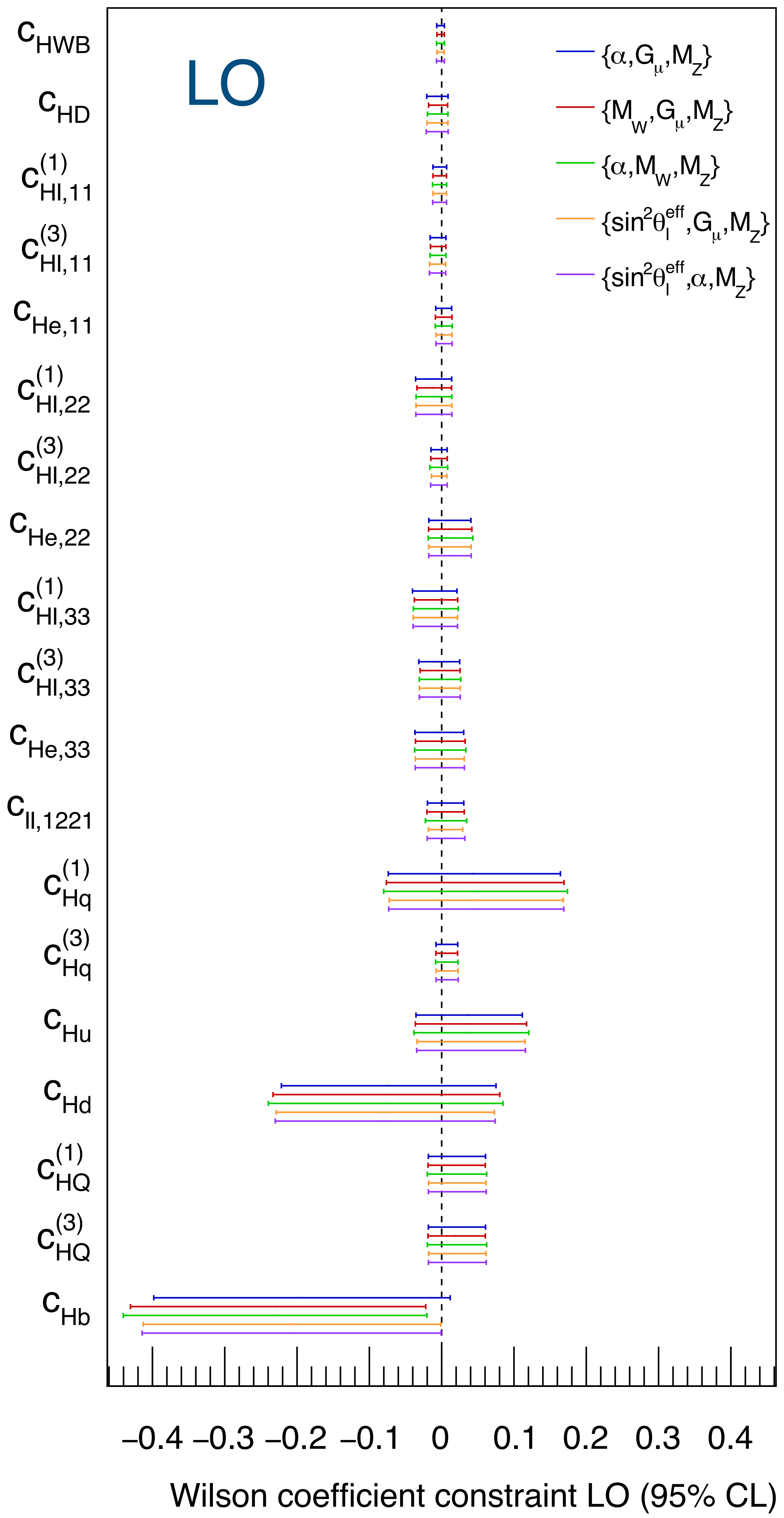
$Z \to \tau\tau$	$C^{(3)}_{\substack{Hl\\jj}}$	$C^{(3)}_{\substack{lq\\jj33}}$	$C_{\substack{ll\\1221}}$	$C^{(3)}_{\substack{Hq\\33}}$	C_{HD}	C_{HWB}	$C_{\substack{He\\33}}$
NLO	$-1.029^{+0.001}_{-0.000}$	$0.015^{+0.000}_{-0.001}$	$1.006^{+0.000}_{-0.000}$	$0.006^{+0.000}_{-0.002}$	$-0.289^{+0.009}_{-0.007}$	$0.258^{+0.003}_{-0.008}$	$-1.897^{+0.006}_{-0.002}$
NLO_t	$-1.021^{+0.001}_{-0.000}$	$0.015^{+0.004}_{-0.005}$	$1.006^{+0.002}_{-0.002}$	$0.006^{+0.000}_{-0.002}$	$-0.266^{+0.006}_{-0.005}$	$0.272^{+0.002}_{-0.002}$	$-1.864^{+0.005}_{-0.001}$
LO	$-1.000^{+0.015}_{-0.015}$	$0.000^{+0.026}_{-0.026}$	$1.000^{+0.004}_{-0.004}$	$0.000^{+0.001}_{-0.001}$	$-0.169^{+0.011}_{-0.011}$	$0.355^{+0.012}_{-0.012}$	$-1.764^{+0.046}_{-0.046}$
LO_K	$-1.021^{+0.012}_{-0.010}$	$0.015^{+0.000}_{-0.001}$	$1.006^{+0.004}_{-0.004}$	$0.006^{+0.001}_{-0.000}$	$-0.260^{+0.017}_{-0.017}$	$0.267^{+0.009}_{-0.009}$	$-1.838^{+0.048}_{-0.048}$

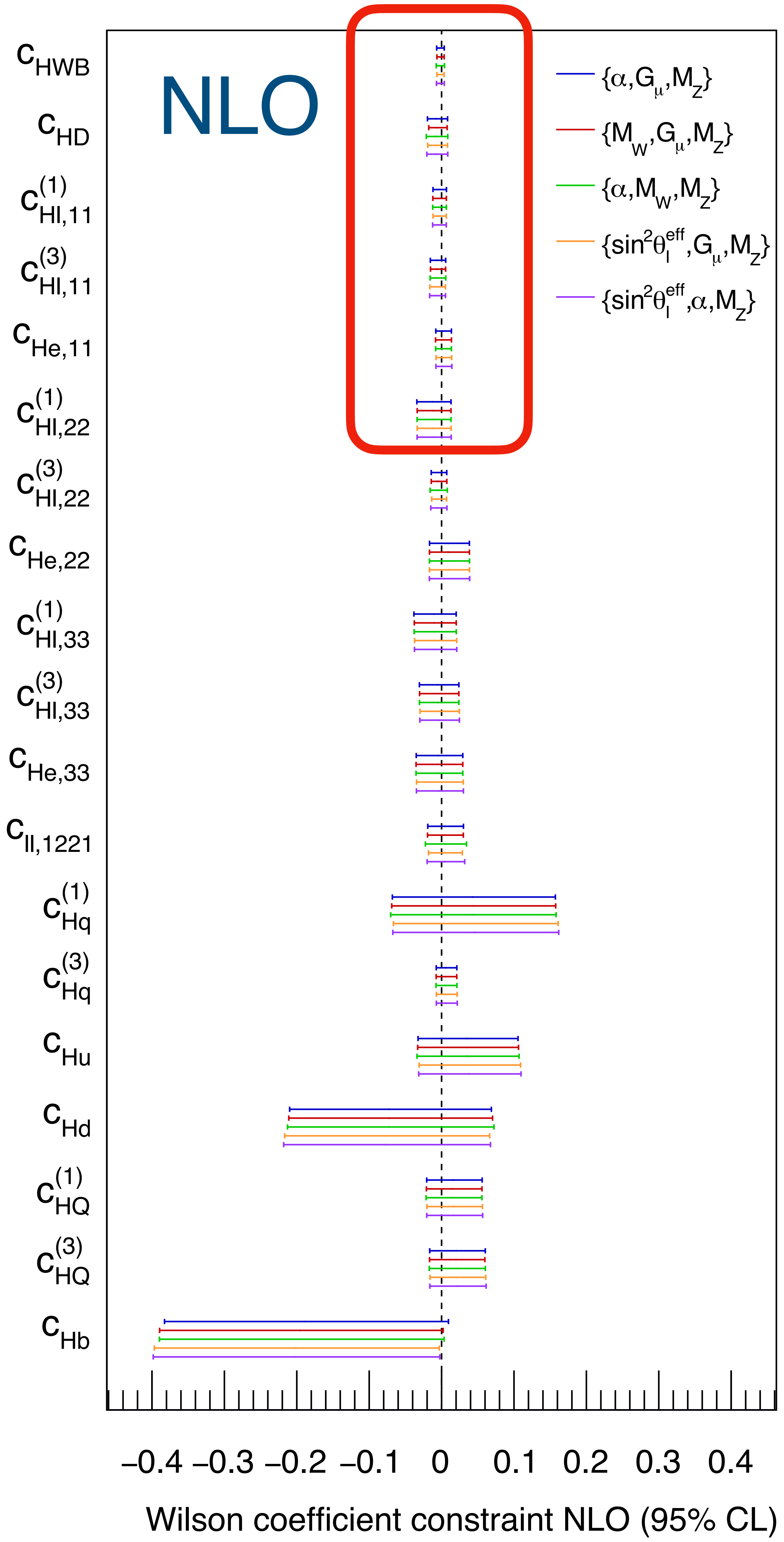
Same large corrections in e+ e- -> Zh

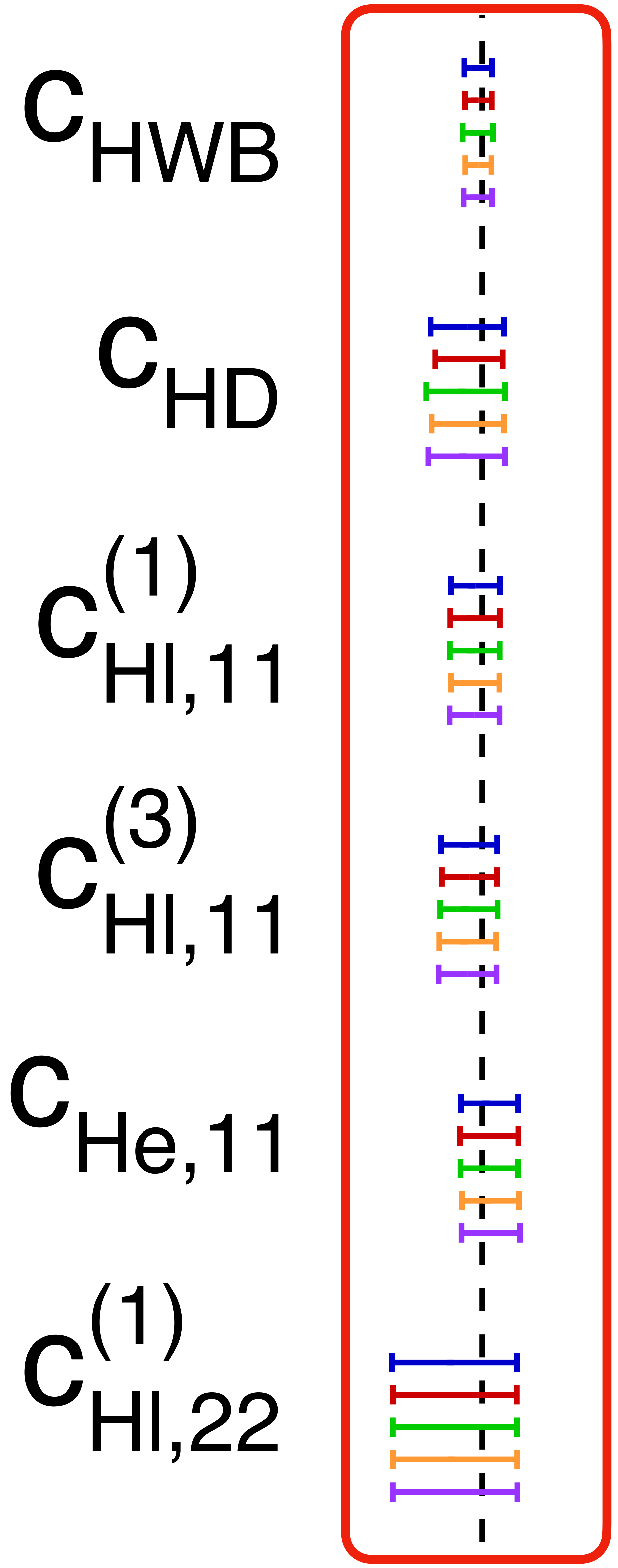
[Asteriadis, Dawson, Giardino, Szafron (2406.03557,2409.11466)]

Electroweak precision observables in different schemes

[Mildner (2412.07651)]







Conclusions

EW input schemes for the SMEFT

- Corrections can be understood in the large-MT limit
- Possible to resum (some) corrections

- EWPO@NLO: analytic results to be published soon

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Thank you for your attention!

Discussion - changing the basis

$$\mathcal{O} = (\phi^\dagger \phi)|D_\mu \phi|^2$$

- Enters MW and MZ shift, thereby enters GF
- Partial cancellations of shifts