EFT Wilson Coefficent Conversions

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1 Conversions in `dim6top`

1.1 $\mathrm{C_{tB}}$ to $\mathrm{C_{tZ}}$ conversion

Basis transformation of the Wilson coefficient $\mathrm{C_{tB}}$ to $\mathrm{C_{tZ}}$ using the Weinberg angle θ_W and $\sin\theta_W \approx 0.471$

$$C_{\mathrm{tZ}} = \mathrm{Re}\left(-\sin\theta_W C_{\mathrm{tB}} + \cos\theta_W C_{\mathrm{tW}}\right), \tag{1}$$

where only one Wilson coefficient at a time is used, thus for the conversion of $\mathrm{C_{tB}}$ to $\mathrm{C_{tZ}}$, the coefficent $\mathrm{C_{tW}}$ is set to 0.

$$C_{\mathrm{tZ}} = \mathrm{Re}\left(-\sin\theta_W\, C_{\mathrm{tB}}\right) \approx -0.471\, C_{\mathrm{tB}} \tag{2}$$

$\mathrm{C_{tB}}$ limits translate to $\mathrm{C_{tZ}}$ limits with a factor of ≈ -0.471

1.2 $\mathrm{C_{\phi Q}}$ conversion

In the `FeynRules` model `dim6top`, a linear combination of Wilson coefficients is used to parametrize the Z boson coupling. The coefficent `cpQM` is given as

$$C_{\phi Q}^{-} = C_{\phi q}^{1(33)} - C_{\phi q}^{3(33)}, \tag{3}$$

where additionally `cpQ3` is defined as $C_{\phi q}^{3(33)}$. If `cpQM` is the only Wilson coefficient set to non-zero, its definition reduces to

$$C_{\phi Q}^{-} = C_{\phi q}^{1(33)} \tag{4}$$

which removes effects of `cpQM` on the tWb vertex, but adds effects on the bbZ coupling. This can be seen in the operator definitions of the processes

$$O_{\phi q}^{1(ij)} = (\phi^\dagger i\overleftrightarrow{D}_\mu \phi)(\bar{q}_i\gamma^\mu q_j) \tag{5}$$
$$O_{\phi q}^{3(ij)} = (\phi^\dagger i\overleftrightarrow{D}_\mu^I \phi)(\bar{q}_i\gamma^\mu \tau^I q_j) \tag{6}$$

where τ^I are the Pauli matrices and thus, $O_{\phi q}^{3(ij)}$ introduces anomalous couplings to the W boson.

2 Conversion of ATLAS Wilson coefficients

ATLAS presented ttZ limits on EFT in the talk of Ref. [2]. However different definitions of the operators $\mathcal{O}$ are used in ATLAS [3] compared to CMS [4], leading to a scale factor for the Wilson coefficients.

2.1 $\mathbf{C_{tB}}$ conversion: ATLAS vs. CMS

To convert the definitions, the Lagrangians have to be equal.

$$C_{\mathrm{tB}}^{\mathrm{ATLAS}}\,\mathcal{O}_{\mathrm{tB}}^{\mathrm{ATLAS}} \overset{!}{=} C_{\mathrm{tB}}^{\mathrm{CMS}}\,\mathcal{O}_{\mathrm{tB}}^{\mathrm{CMS}} \tag{7}$$

$$\mathcal{O}_{\mathrm{tB}}^{\mathrm{CMS}} = \left(\bar{Q}\sigma^{\mu\nu}t\right)\tilde{\phi}B_{\mu\nu} \tag{8}$$

$$\mathcal{O}_{\mathrm{tB}}^{\mathrm{ATLAS}} = y_t\,g_Y\,\left(\bar{Q}\sigma^{\mu\nu}t\right)\tilde{\phi}B_{\mu\nu} = y_t\,g_Y\,\mathcal{O}_{\mathrm{tB}}^{\mathrm{CMS}}. \tag{9}$$

Using Eq. 7 and Eq. 9 leads to

$$C_{\mathrm{tB}}^{\mathrm{CMS}} = y_t\,g_Y C_{\mathrm{tB}}^{\mathrm{ATLAS}} \tag{10}$$

where $y_t = \frac{\sqrt{2}m_t}{v}$. Using the definitions from Ref. [3]

$$\begin{aligned}
m_t &= 173.3\text{ GeV}\\
\alpha_{\mathrm{EW}} &= \frac{1}{127.9}\\
v &= 246\text{ GeV}\\
\tan\theta_W &= \frac{g_1}{g_2} = 0.535\\
\alpha &= \frac{1}{4\pi}\frac{(g_1g_2)^2}{g_1^2+g_2^2} = \frac{g_1^2}{4\pi(1+\tan^2\theta_W)} = \frac{g_1^2\cos^2\theta_W}{4\pi} = \frac{1}{127.9}\\
g' = g_1 = g_Y &= \sqrt{4\pi\alpha(1+\tan^2\theta_W)} = \frac{\sqrt{4\pi\alpha}}{\cos\theta_W} \approx 0.34\\
g = g_2 = g_w &= \frac{g_1}{\tan\theta_W} \approx 0.636\\
y_t &= \frac{\sqrt{2}m_t}{v} \approx 0.996
\end{aligned}$$

leads to a conversion factor for C_{tB} from ATLAS to CMS of

$$C_{\mathrm{tB}}^{\mathrm{CMS}} = y_t\,g_Y C_{\mathrm{tB}}^{\mathrm{ATLAS}} \approx 0.34\,C_{\mathrm{tB}}^{\mathrm{ATLAS}} \tag{11}$$

The ATLAS $\mathbf{C_{tB}}$ limits translates to limits used in CMS with a factor of ≈ 0.34

2.1.1 Total conversion from $\mathbf{C_{tB}^{ATLAS}}$ to $\mathbf{C_{tZ}^{CMS}}$ limits

To convert from $\mathrm{C_{tB}^{ATLAS}}$ to $\mathrm{C_{tZ}^{CMS}}$, an additional conversion factor for $\mathrm{C_{tB}}$ to $\mathrm{C_{tZ}}$ from Sec. 1.1 has to be applied.

$$C_{\mathrm{tZ}}^{\mathrm{CMS}} = -\sin\theta_W\,y_t\,g_Y C_{\mathrm{tB}}^{\mathrm{ATLAS}} \approx -0.16\,C_{\mathrm{tB}}^{\mathrm{ATLAS}} \tag{12}$$

The ATLAS $\mathbf{C_{tB}}$ limits translates to CMS $\mathbf{C_{tZ}}$ limits with a factor of ≈ -0.16

2.1.2 Conversion of ATLAS ttZ $\mathbf{C_{tB}^{ATLAS}}$ limits

The presented ttZ ATLAS $\mathrm{C_{tB}^{ATLAS}}$ limits of Ref. [2] convert to CMS $\mathrm{C_{tZ}^{CMS}}$ limits as

$$C_{\mathrm{tZ}}^{\mathrm{ATLAS}\rightarrow\,\mathrm{CMS}}(36.1\ \mathrm{fb}^{-1}, 95\%, \text{x-sec only}) : [-2.40, +2.40] \tag{13}$$

2.2 $\mathbf{C_{tW}}$ conversion: ATLAS vs. CMS

To convert the definitions, the Lagrangians have to be equal.

$$C_{\mathrm{tW}}^{\mathrm{ATLAS}}\,\mathcal{O}_{\mathrm{tW}}^{\mathrm{ATLAS}} \stackrel{!}{=} C_{\mathrm{tW}}^{\mathrm{CMS}}\,\mathcal{O}_{\mathrm{tW}}^{\mathrm{CMS}} \tag{14}$$

$$\mathcal{O}_{\mathrm{tW}}^{\mathrm{CMS}} = (\bar{q}_i\sigma^{\mu\nu}\tau^I u_j)\tilde{\phi}W_{\mu\nu}^I \tag{15}$$

$$\mathcal{O}_{\mathrm{tW}}^{\mathrm{ATLAS}} = y_t\, g_w\, (\bar{q}_i\sigma^{\mu\nu}\tau^I u_j)\tilde{\phi}W_{\mu\nu}^I = y_t\, g_w\, \mathcal{O}_{\mathrm{tW}}^{\mathrm{CMS}} \tag{16}$$

Using Eq. 14 and Eq. 16 leads to

$$C_{\mathrm{tW}}^{\mathrm{CMS}} = y_t\, g_w C_{\mathrm{tW}}^{\mathrm{ATLAS}} \approx 0.633\, C_{\mathrm{tW}}^{\mathrm{ATLAS}} \tag{17}$$

where $y_t = \frac{\sqrt{2}m_t}{v} \approx 0.996$ and $g_w \approx 0.636$ (see Sec. 2.1).

The ATLAS $\mathbf{C_{tW}}$ limits translates to limits used in CMS with a factor of ≈ 0.633

2.3 $\mathbf{C_{\phi t}}$ and $\mathbf{C_{\phi Q}}$ conversion: ATLAS vs. CMS

To convert the definitions, the Lagrangians have to be equal.

$$C_{\phi\mathrm{t}}^{\mathrm{ATLAS}}\,\mathcal{O}_{\phi\mathrm{t}}^{\mathrm{ATLAS}} \stackrel{!}{=} C_{\phi\mathrm{t}}^{\mathrm{CMS}}\,\mathcal{O}_{\phi\mathrm{t}}^{\mathrm{CMS}} \tag{18}$$

$$\mathcal{O}_{\phi\mathrm{t}}^{\mathrm{CMS}} = (\phi^\dagger i\overleftrightarrow{D_\mu}\phi)(\bar{t}\gamma^\mu t) \tag{19}$$

$$\mathcal{O}_{\phi\mathrm{t}}^{\mathrm{ATLAS}} = \frac{1}{2}y_t^2\,(\phi^\dagger i\overleftrightarrow{D_\mu}\phi)(\bar{t}\gamma^\mu t) = \frac{1}{2}y_t^2\,\mathcal{O}_{\phi\mathrm{t}}^{\mathrm{CMS}} \tag{20}$$

However, the factor $\frac{1}{2}$ cancels, as the definition of ATLAS [3] includes the hermitian conjugate state in the Lagrangian, where the CMS definitions [4] uses the fact that these operators are hermitian. Thus, using Eq. 18 and Eq. 20 leads to

$$C_{\phi\mathrm{t}}^{\mathrm{CMS}} = y_t^2\, C_{\phi\mathrm{t}}^{\mathrm{ATLAS}} \approx 0.992\, C_{\phi\mathrm{t}}^{\mathrm{ATLAS}} \tag{21}$$

where $y_t = \frac{\sqrt{2}m_t}{v} \approx 0.996$ (see Sec. 2.1). The same pre-factor is applied to $\mathrm{C_{\phi Q}^{(1)}}$ and $\mathrm{C_{\phi Q}^{(3)}}$, thus $\mathrm{C_{\phi Q}}$.

The ATLAS $\mathbf{C_{\phi t}}$, $\mathbf{C_{\phi Q}^{(1)}}$, $\mathbf{C_{\phi Q}^{(3)}}$ and $\mathbf{C_{\phi Q}}$ limits translate to limits used in CMS with a factor of 0.992.

3 Conversion of HEL UFO Wilson coefficients

Comparison of the Wilson coefficients using couplings of Lagrangians from the `couplings.py` files in the `FeynRules` directories for the `dim6top-` and `HEL-UFO` models. Here, only an example of one coupling for one Lagrangian is used to show the conversion factor, where the Lagrangians are labeled similar to the definitions in the `couplings.py` file (GC #).

3.1 $\mathbf{C_{tB}}$ to $\mathbf{C_{tZ}}$ conversion

$$g(\mathcal{L}_{\mathrm{dim6}}, \mathrm{GC\ 664}) = \frac{C_{\mathrm{tZ}}}{\Lambda^2\sqrt{2}} \tag{22}$$

$$g(\mathcal{L}_{\mathrm{HEL}}, \mathrm{GC\ 2191}) = \frac{\sqrt{4\pi\alpha_{\mathrm{EW}}}\, y_t}{M_W^2\sqrt{2}} \left(C_{\mathrm{uB}}\frac{\sin\theta_W}{\cos\theta_W} - C_{\mathrm{uW}}\frac{\cos\theta_W}{\sin\theta_W} \right) \tag{23}$$

$$g(\mathcal{L}_{\mathrm{dim6}}) \stackrel{!}{=} g(\mathcal{L}_{\mathrm{HEL}}) \tag{24}$$

but only one Wilson coefficient at a time is used, thus $\mathrm{C_{uW}} = 0$, leading to a direct comparison of C_{tZ} and C_{uB} (see Sec. 1.1):

$$\frac{C_{\mathrm{tZ}}}{\Lambda^2} = -C_{\mathrm{uB}}\frac{\sqrt{4\pi\alpha_{\mathrm{EW}}}\, y_t}{M_W^2}\frac{\sin\theta_W}{\cos\theta_W} \tag{25}$$

A second example is the comparison of the Lagrangians $g(\mathcal{L}_{\mathrm{dim6}}, \mathrm{GC\ 948})$ and $g(\mathcal{L}_{\mathrm{HEL}}, \mathrm{GC\ 2187})$, leading to the same results. Even though it may look reasonable to compare the Lagrangian in switched order (DIM6: GC 664 $\leftrightarrow$ HEL: GC 2187, DIM6: GC 948 $\leftrightarrow$ HEL: GC 2187), the results are then not consistant.

3.1.1 Comparison of Limits in Top 17-005

In Ref. [1], a factor k is applied to the presented limits, where k is taken from Ref. [5].

$$k = \frac{\sqrt{4\pi\alpha_{\mathrm{EW}}}\, y_t}{2\, M_W^2\, \cos\theta_W} \tag{26}$$

$$\bar{C}_{\mathrm{uB}} = C_{\mathrm{uB}}\, k = C_{\mathrm{uB}}\, \frac{\sqrt{4\pi\alpha_{\mathrm{EW}}}\, y_t}{2\, M_W^2\, \cos\theta_W} \tag{27}$$

To compare the limits to current efforts using the `dim6top` model, the conversion factor is thus

$$\rightarrow \frac{C_{\mathrm{tZ}}}{\Lambda^2} = -2\, \sin\theta_W\, \bar{C}_{\mathrm{uB}} = -0.96\, \bar{C}_{\mathrm{uB}} \tag{28}$$

The HEL UFO $\mathbf{\bar{C}_{uB}}$ limits in Ref. [1] translate to limits of $\mathbf{C_{tZ}}$ with a factor of -0.96

3.1.2 Conversion of Top 17-005 $\mathbf{\bar{C}_{uB}}$ limits

Thus, the presented ttZ $\bar{\mathrm{C}}_{\mathrm{uB}}$ limits of Ref. [1] convert to `dim6top` limits as

$$\mathrm{C}_{\mathrm{tZ}}^{\mathrm{Top\ 17\text{-}005}\rightarrow\ \mathrm{dim6top}}(36.1\ \mathrm{fb}^{-1}, 95\%, \mathrm{x\text{-}sec\ only}) : [-2.02, +2.02] \tag{29}$$

3.2 $\mathbf{C_{Hu}}$ to $\mathbf{C_{\phi t}}$ conversion

$$g(\mathcal{L}_{\text{dim6}}, \text{GC 1112}) = -i\frac{C_{\phi\text{t}}\,\cos\theta_W\,\sqrt{4\,\alpha_{\text{EW}}\pi}\,v}{\Lambda^2\,\sin\theta_W} - i\frac{C_{\phi\text{t}}\,\sqrt{4\,\alpha_{\text{EW}}\pi}\,\sin\theta_W\,v}{\cos\theta_W\,\Lambda^2} \tag{30}$$

$$g(\mathcal{L}_{\text{HEL}}, \text{GC 1136}) = -i\frac{C_{\text{Hu}}\,\cos\theta_W\,\sqrt{4\,\alpha_{\text{EW}}\pi}}{\sin\theta_W\,v} - i\frac{C_{\text{Hu}}\,\sqrt{4\,\alpha_{\text{EW}}\pi}\,\sin\theta_W}{\cos\theta_W\,v} \tag{31}$$

$$g(\mathcal{L}_{\text{dim6}}) \stackrel{!}{=} g(\mathcal{L}_{\text{HEL}}) \tag{32}$$

$$\rightarrow \frac{C_{\phi\text{t}}}{\Lambda^2} = \frac{C_{\text{Hu}}}{v^2} \tag{33}$$

3.2.1 Comparison of Limits in Top 17-005

In Ref. [1], a factor k is applied to the presented limits, where k is taken from Ref. [5].

$$k = \frac{1}{2\,v^2} \tag{34}$$

$$\bar{C}_{\text{Hu}} = C_{\text{Hu}}\,k = \frac{C_{\text{Hu}}}{2\,v^2} \tag{35}$$

To compare the limits to current efforts using the `dim6top` model, the conversion factor is thus

$$\rightarrow \frac{C_{\phi\text{t}}}{\Lambda^2} = 2\,\bar{C}_{\text{Hu}} \tag{36}$$

The HEL UFO $\mathbf{\bar{C}_{Hu}}$ limits in Ref. [1] translate to limits of $\mathbf{C_{\phi t}}$ with a factor of 2.0

3.2.2 Conversion of Top 17-005 $\mathbf{\bar{C}_{Hu}}$ limits

Thus, the presented ttZ $\bar{\text{C}}_{\text{Hu}}$ limits of Ref. [1] convert to `dim6top` limits as

$$\text{C}_{\phi\text{t}}^{\text{Top 17-005}\rightarrow\text{ dim6top}}(36.1\text{ fb}^{-1}, 95\%, \text{x-sec only}):\ [-20.2, +4.0] \tag{37}$$

References

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