Anomalous HVV couplings in HAWK

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This short note summarizes the implementation of Anomalous HVV couplings in HAWK 2.0: A Monte Carlo program for Higgs production in vector-boson fusion and Higgs strahlung at hadron colliders [1–4].

General remarks

- HAWK 2.0 supports anomalous HVV couplings based on the parametrization of Ref. [6] supplemented by a rescaling of the SM couplings
- Predictions with anomalous couplings are provided with NLO QCD corrections.
- EW corrections have to be treated additively, i.e. no EW corrections to anomalous couplings are provided.

The following description is taken from Ref. [5] and can also be found in the README of HAWK 2.0.

3.3.9. Anomalous HVV couplings

HAWK supports predictions with anomalous HVV couplings for $V = \mathrm{W,Z}$. Our implementation of anomalous couplings follows the (modified) parameterization of Ref. [6]. In addition the Standard Model HVV coupling can be rescaled via `rsm`. In this parameterization, the different (anomalous) couplings are related to the parameters `d`, `db`, `dt`, and `dtb` via

$$
\begin{aligned}
&\texttt{a1hww} &&= \texttt{rsm}\, M_\mathrm{W}/s_\mathrm{W} &&= \text{SM HWW coupling},\\
&\texttt{a2hww} &&= 2\,\texttt{d}\,/(s_\mathrm{W}M_\mathrm{W}) &&= 2\, g^{(2)}_{\mathrm{HWW}},\\
&\texttt{a3hww} &&= 2\,\texttt{dt}/(s_\mathrm{W}M_\mathrm{W}) &&= 2\, \tilde{g}^{(2)}_{\mathrm{HWW}},\\
&\texttt{a1haa} &&= 0 &&= \mathrm{H}\gamma\gamma \text{ like HZZ in SM},\\
&\texttt{a2haa} &&= 4\,(\texttt{d}\, s_\mathrm{W}^2 + \texttt{db}\, c_\mathrm{W}^2)/(2s_\mathrm{W}M_\mathrm{W}) &&= 4\, g_{\mathrm{H}\gamma\gamma},\\
&\texttt{a3haa} &&= 4\,(\texttt{dt}\, s_\mathrm{W}^2 + \texttt{dtb}\, c_\mathrm{W}^2)/(2s_\mathrm{W}M_\mathrm{W}) &&= 4\, \tilde{g}_{\mathrm{H}\gamma\gamma},\\
&\texttt{a1haz} &&= 0 &&= \mathrm{HZ}\gamma \text{ like HZZ in SM},\\
&\texttt{a2haz} &&= -2c_\mathrm{W}(\texttt{d} - \texttt{db})/M_\mathrm{W} &&= 2g^{(2)}_{\mathrm{HZ}\gamma},\\
&\texttt{a3haz} &&= -2c_\mathrm{W}(\texttt{dt} - \texttt{dtb})/M_\mathrm{W} &&= 2\tilde{g}^{(2)}_{\mathrm{HZ}\gamma},\\
&\texttt{a1hzz} &&= \texttt{rsm}\, M_\mathrm{W}/(s_\mathrm{W}c_\mathrm{W}^2) &&= \text{SM HZZ coupling},\\
&\texttt{a2hzz} &&= 4(\texttt{d}\, c_\mathrm{W}^2 + \texttt{db}\, s_\mathrm{W}^2)/(2s_\mathrm{W}M_\mathrm{W}) &&= 4\, g^{(2)}_{\mathrm{HZZ}},\\
&\texttt{a3hzz} &&= 4(\texttt{dt}\, c_\mathrm{W}^2 + \texttt{dtb}\, s_\mathrm{W}^2)/(2s_\mathrm{W}M_\mathrm{W}) &&= 4\, \tilde{g}_{\mathrm{HZZ}},
\end{aligned}
$$

where the notation for the coupling constants corresponds to the Feynman rule

$$\mathrm{i}\,\texttt{a1hvv}\,g_{\mu\nu} + \mathrm{i}\,\texttt{a2hvv}\,(-k_1\cdot k_2 g_{\mu\nu} + k_{1\nu}k_{2\mu}) + \mathrm{i}\,\texttt{a3hvv}\,\epsilon_{\rho\sigma\mu\nu}k_1^\rho k_2^\sigma$$

for $\mathrm{H}V_1(k_{1\mu})V_2(k_{2\nu})$ and the $g_{\mathrm{H}VV}$'s correspond to the notation in Ref. [6]. Note the sign changes in `a2haz` and `a3haz` due to our conventions of SM couplings which follow Refs. [7, 8]. Cosine and sine of the electroweak mixing angle are defined as $c_\mathrm{W} = M_\mathrm{W}/M_\mathrm{Z}$ and $s_\mathrm{W} = \sqrt{1-c_\mathrm{W}^2}$, respectively. The input for the anomalous couplings is governed by the following switch:

`shvv` : integer that enables/disables anomalous $\mathrm{H}VV$ couplings.

- `shvv=0` : anomalous $\mathrm{H}VV$ couplings disabled (default),
- `shvv=1` : anomalous $\mathrm{H}VV$ couplings enabled, input for parameters `d`, `db`, `dt`, `dtb` expected,
- `shvv=2` : anomalous $\mathrm{H}VV$ couplings enabled, direct input for `a1hww`, ..., `a3hzz` expected.

According to `shvv`, one either specifies `d`, `db`, etc. or `a1hww`, `a2hww`, etc. as double-precision numbers. By default, all anomalous couplings are set to zero. One can also specify `rsm` which by default is set to one.

The anomalous couplings to the neutral gauge bosons are switched off for small momentum transfer with a form factor $|s_1||s_2|/(m_0^2+|s_1|)/(m_0^2+|s_2|)$ to avoid IR singularities from anomalous couplings, where s_1 and s_2 are the virtualities of the two intermediate W and Z bosons and $m_0 = 1\,\mathrm{GeV}$ is used.

To control the scale dependence of the anomalous couplings, there is the option to use a form factor:

`lambdahvv=-2d0` : double-precision number that sets the mass scale in the form factor for anomalous couplings in GeV.

- `lambdahvv` > 0 : form factor= `lambdahvv`^{4}/(`lambdahvv`^{2}+$|s_1|$)/(`lambdahvv`^{2}+$|s_2|$),
- `lambdahvv` < 0 : form factor=1 (formal limit `lambdahvv` $\to\infty$).

References

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