Anomalous Higgs Couplings at $e\,\gamma$ Collider

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Introduction

We examine the resolving power of an $e\,\gamma$ collider in context of WWH vertices.

The coupling of Higgs to gauge bosons may be directly related to EWSB.
In Standard Model:

$$g^{SM}_{WWH} = e\ \cot\theta_W\ M_Z$$
$$g^{SM}_{ZZH} = 2\,e\,\frac{M_Z}{\sin 2\theta_W}$$

arising from the Higgs kinetic term.
If we accept the SM to be an effective low energy description of some other theory, higher dimensional terms are alloweed.

$$\mathcal{L}_{eff} = \sum_n \frac{f_n}{\Lambda^2}\mathcal{O}_n$$

where $f_n's$ are dimensionless "amomalaous couplings", and $\mathcal{O}_n$ are dimension-6 operators constructed from vector bosons and/or Higgs boson fields.

Introduction

Demanding Lorentz invariance and gauge invariance, the most general coupling structure may be expressed as

$$\Gamma_{\mu\nu} = g_V \left[a_V g_{\mu\nu} + \frac{b_V}{m_V^2}(k_{1\mu}k_{2\nu} - g_{\mu\nu} k_1 \cdot k_2) + \iota \, \frac{\tilde{b}_V}{m_V^2} \epsilon_{\mu\nu\alpha\beta} k_1^\alpha k_2^\beta \right]$$

where k_i are the momenta of two W's or Z's. In general, each of these couplings can be complex. In the context of SM, at the tree level,

$$a_W^{SM} = a_Z^{SM} = 1 \text{ and } b_W = \tilde{b}_W = 0$$

Sudhanshu,Rohini, Ritesh and Debajyoti [hep-ph/0509070]

Cross-section

The process

$$e^- \gamma \longrightarrow \nu_e W^- H$$

followed by the decays
$H \longrightarrow b\,\bar{b}$ with branching fraction ~ 0.9
and
$W \longrightarrow q\,\bar{q}$ with branching fraction ~ 0.68

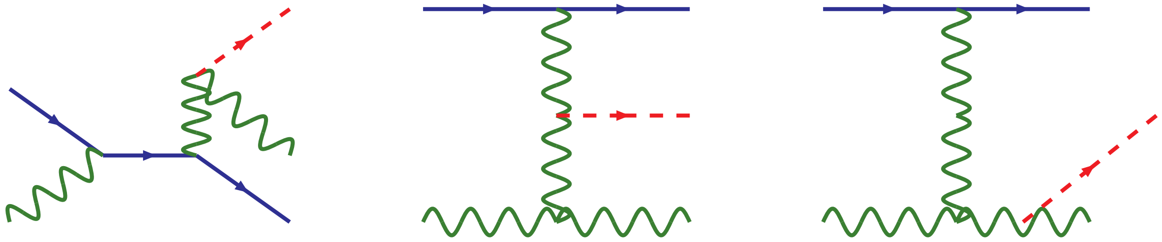


Figure 1: Feynman Diagrams for $e^-\gamma \to \nu_e W^- h$

Cross-section

- $$m_H = 120 \text{ GeV}$$
- $$\sqrt{s}_{e\,e} = 1 \text{ TeV}$$
- We assume that
$$a_W = 1 + \Delta a_W$$
- We restrict to uunpolarised beams

Retaining only the contributions upto the lowest non-trivial order, arising from terms linear in the additional couplings, the cross-section may be written as

$$\sigma = (1 + 2\,\Delta a_W)\sigma_0 + \mathcal{R}(b_V)\sigma_1 + \mathcal{I}(b_V)\sigma_2 + \mathcal{R}(\tilde{b}_V)\sigma_3 + \mathcal{I}(\tilde{b}_V)\sigma_4$$

Kinematical Cuts

To ensure detectability of the final products, we require that,

$$\begin{aligned} -3.0 \leq \eta_j &\leq 3.0 && \text{for rapidity of each jet} \\ p_T &\leq 10\ \text{GeV} && \text{for each jet} \\ \Delta R_{j_1 j_2} &\geq 0.7 && \text{for each pair of jets} \end{aligned}$$

where $(\Delta R_{j_1 j_2})^2 \equiv (\Delta\phi)^2 + (\Delta\eta)^2$

$$p_T^{\text{miss}} \geq 20\ \text{GeV}$$

.

Apart from the cross-section, the kinematical distributions are different for different couplings.

Couplings Δa_W, $\mathcal{R}(b_W)$ and $\mathcal{I}(\tilde{b}_W)$

For Higgs boson of mass 120 GeV and $\sqrt{s_{e\,e}} = 1$ TeV, the rates in femtobarns with unpolarised beams are:

$$\sigma = 29.3(1 + 2\,\Delta a_W) - 101.6\,\mathcal{R}(b_W) + 4.92\,\mathcal{I}(\tilde{b}_W)$$

cut	cross-section σ in femto barns
$\mathcal{C}_1$: $p_T(H) \geq 100$ GeV	$11.92\,(1 + 2\,\Delta a_W) - 43.4\,\mathcal{R}(b_W) - 0.31\,\mathcal{I}(\tilde{b}_W)$
$\mathcal{C}_2$: $p_T(W) \geq 100$ GeV and $\mid \sin\phi_{HW} \mid \leq 0.4$	$4.27\,(1 + 2\,\Delta a_W) - 27.5\,\mathcal{R}(b_W) + 0.59\,\mathcal{I}(\tilde{b}_W)$
$\mathcal{C}_3$: $p_T(W) \leq 100$ GeV and $p_T^{\text{miss}} \leq 100$ GeV	$18.6\,(1 + 2\,\Delta a_W) - 41.2\,\mathcal{R}(b_W) + 0.41\,\mathcal{I}(\tilde{b}_W)$
$\mathcal{C}_4$: $p_T(H) \leq 100$ GeV	$17.33\,(1 + 2\,\Delta a_W) - 58.2\,\mathcal{R}(b_W) + 5.21\,\mathcal{I}(\tilde{b}_W)$
$\mathcal{C}_5$: $p_T(W) \geq 100$ GeV and $\mid \sin\phi_{HW} \mid \geq 0.4$	$2.15\,(1 + 2\,\Delta a_W) - 20.1\,\mathcal{R}(b_W) + 3.24\,\mathcal{I}(\tilde{b}_W)$
$\mathcal{C}_6$: $p_T(W) \geq 100$ GeV and $p_T(\text{miss}) \geq 100$ GeV	$1.265\,(1 + 2\,\Delta a_W) - 13.85\,\mathcal{R}(b_W) + 2.40\,\mathcal{I}(\tilde{b}_W)$

Couplings Δa_W, $\mathcal{R}(b_W)$ and $\mathcal{I}(\tilde{b}_W)$

Strong correlations between Δa_W and $\mathcal{R}(b_W)$ Neglecting contribution of $\mathcal{I}(\tilde{b}_W)$, after each of the cut $\mathcal{C}_i$,$(i = 1,\ 2,\ 3)$, the rate depends on a combination of Δa_W and $\mathcal{R}(b_W)$

$$\sigma(\mathcal{C}_i) = \sigma_{SM}(1 + \eta_i)$$

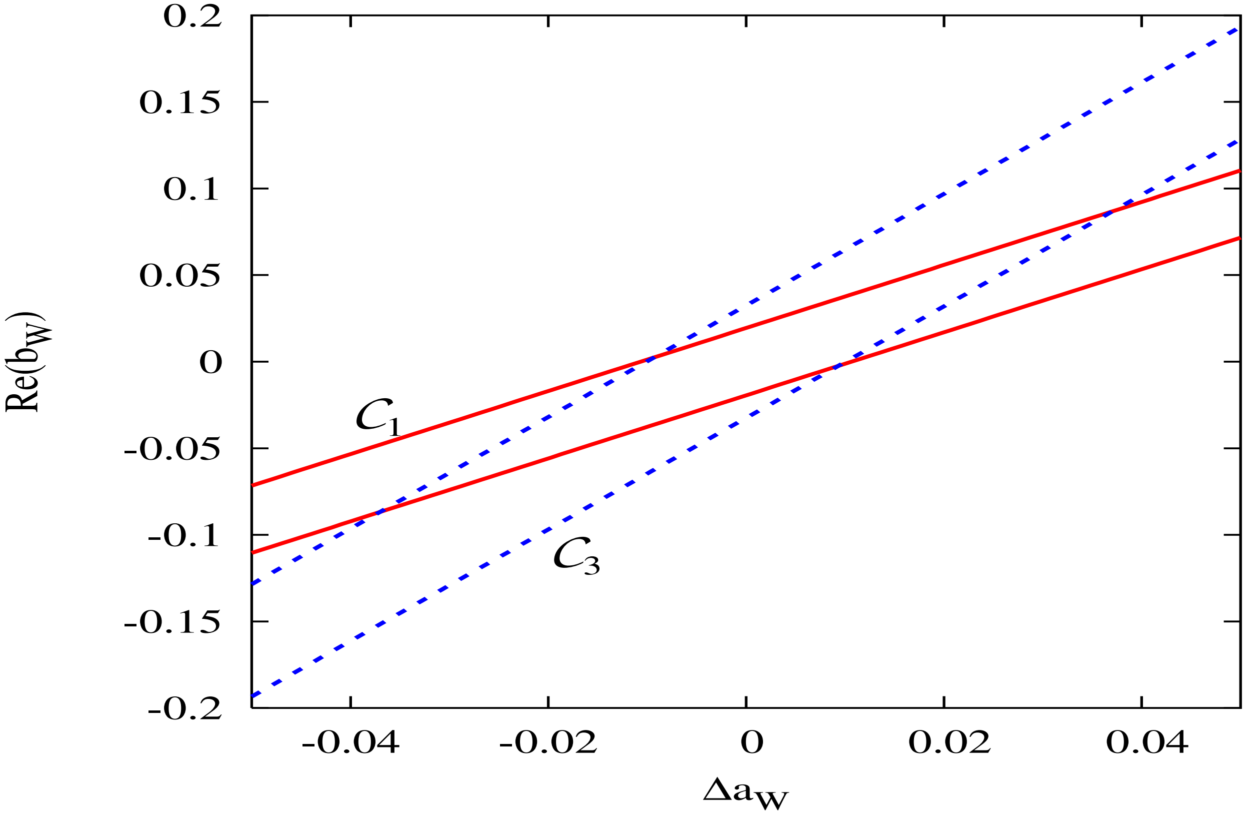
Thus, for an integrated luminosity of $500\ \mathrm{fb}^{-1}$, the lack of deviation from the SM expectation values would (at $3\,\sigma$ level) give limits on η_i as

$$\begin{aligned}
\eta_1 &= |\,2\,\Delta a_W - 3.64\,\mathcal{R}(b_W)\,| \le\ 0.039 \\
\eta_2 &= |\,2\,\Delta a_W - 6.44\,\mathcal{R}(b_W)\,| \le\ 0.064 \\
\eta_3 &= |\,2\,\Delta a_W - 2.22\,\mathcal{R}(b_W)\,| \le\ 0.031
\end{aligned}$$

Individual Limits on the couplings are

Coupling		$\mathcal{C}_1$	$\mathcal{C}_2$	$\mathcal{C}_3$
$\mid\Delta a_W\mid$	$\le$	0.020	0.032	0.015
$\mid\mathcal{R}(b_W)\mid$	$\le$	0.011	0.010	0.014

Couplings Δa_W, $\mathcal{R}(b_W)$ and $\mathcal{I}(\tilde{b}_W)$

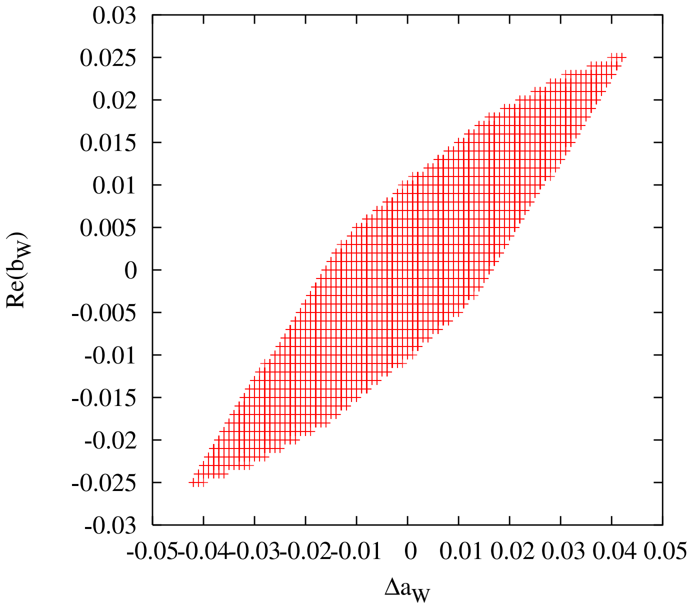


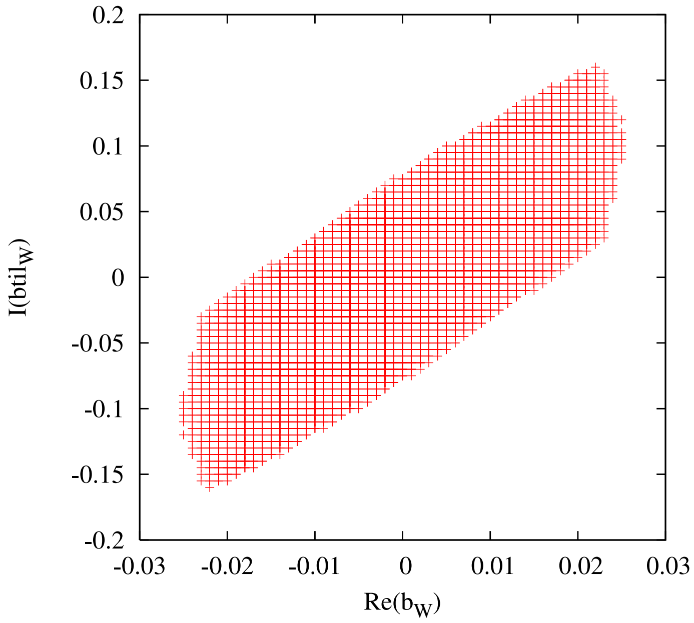
Couplings Δa_W, $\mathcal{R}(b_W)$ and $\mathcal{I}(\tilde{b}_W)$

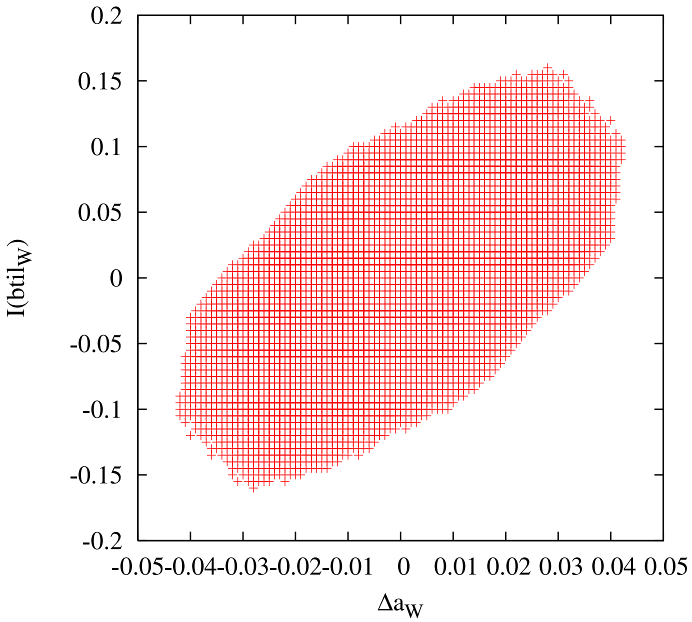
From the cuts $\mathcal{C}_4$, $\mathcal{C}_5$ and $\mathcal{C}_6$

$$
\begin{aligned}
|\ 12.74\,\Delta a_W - 58.2\,\mathcal{R}(b_W) + 5.21\,\mathcal{I}(\tilde{b}_W)\,| &\leq 0.33 \\
|\,6.3\,\Delta a_W - 20.1\,\mathcal{R}(b_W) + 3.24\,\mathcal{I}(\tilde{b}_W)\,| &\leq 0.20 \\
|\,2.54\,\Delta a_W - 13.85\,\mathcal{R}(b_W) + 2.4\,\mathcal{I}(\tilde{b}_W)\,| &\leq 0.15
\end{aligned}
$$

Couplings Δa_W, $\mathcal{R}(b_W)$ and $\mathcal{I}(\tilde{b}_W)$







Couplings $\mathcal{I}(b_W)$ and $\mathcal{R}(\tilde{b}_W)$

To get contribution from these couplings, we restrict the W-bosons to be in the upper hemisphere $i.e.$ $\sin\phi_{HW} \geq 0$. This partial cross-section is

$$\begin{aligned}\sigma(\sin\phi_{HW} \geq 0) &= 14.7\,(1 + 2\,\Delta a_W) - 50.79\,\mathcal{R}(b_W) + 2.48\,\mathcal{I}(\tilde{b}_W) + 7.26\,\mathcal{I}(b_W) \\ &+ 26.58\,\mathcal{R}(\tilde{b}_W)\end{aligned}$$

To get limits on the imaginary couplings, we construct the asymmetry

$$\begin{aligned}\mathcal{A}1 &= \frac{\sigma_{\sin\phi_{HW}\geq 0} - \sigma_{\sin\phi_{HW}\leq 0}}{\sigma_{\sin\phi_{HW}\geq 0} + \sigma_{\sin\phi_{HW}\leq 0}} \\ &= \frac{2\,\left[7.26\,\mathcal{I}(b_W) + 26.6\,\mathcal{R}(\tilde{b}_W)\right]}{2\,\left[14.75\,(1 + 2\,\Delta a_W) - 50.79\,\mathcal{R}(b_W) + 2.48\,\mathcal{I}(\tilde{b}_W)\right]}\end{aligned}$$

With a further cut $\cos\theta_H \leq 0$, we get

Couplings $\mathcal{I}(b_W)$ and $\mathcal{R}(\tilde{b}_W)$

$$\begin{aligned}\mathcal{A}2 &= \mathcal{A}1(\cos\theta_H \leq 0) \\ &= \frac{2\left[0.79\,\mathcal{I}(b_W) + 7.35\,\mathcal{R}(\tilde{b}_W)\right]}{2\left[3.36\,(1+2\,\Delta a_W) - 14.27\,\mathcal{R}(b_W) + 0.21\,\mathcal{I}(\tilde{b}_W)\right]}\end{aligned}$$

Keeping only one of the couplings to be non-zero we obtain the following limits on them using $\mathcal{A}2$:

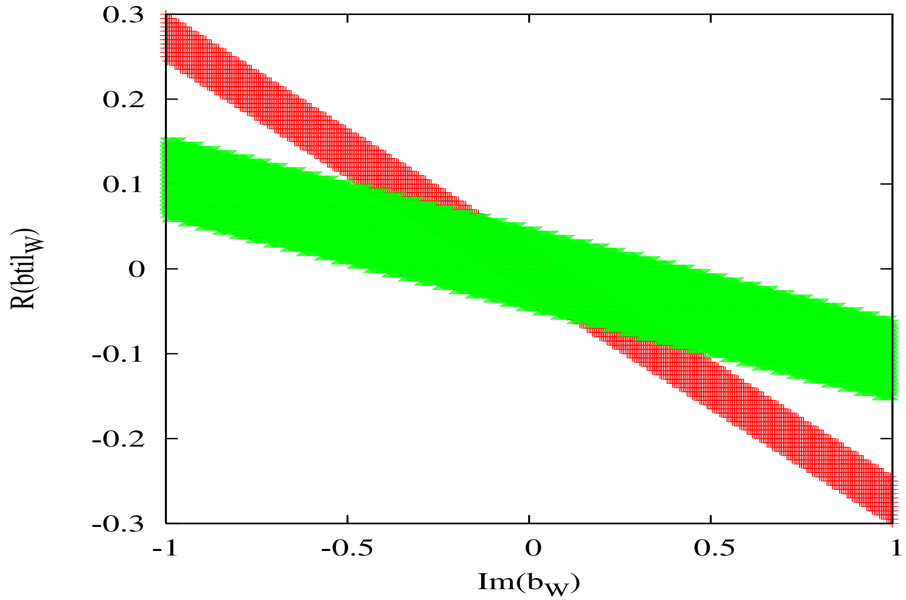
$$\begin{aligned}|\,\mathcal{I}(b_W)\,| &\leq 0.032 \\ |\,\mathcal{R}(\tilde{b}_W)\,| &\leq 0.019\end{aligned}$$

where the fluctuation in the measurement of asymmetry is taken to be

$$(\delta\mathcal{A})^2 = \frac{1-\mathcal{A}_{SM}^2}{\sigma_{SM}\,\mathcal{L}}$$

at $3\,\sigma$ level.

Couplings $\mathcal{I}(b_W)$ and $\mathcal{R}(\tilde{b}_W)$



Summary

- Contributions proportional to Δa_W and $\mathcal{R}(b_W)$ are intertwineved and hence can't be separated.

- Similar is the case with couplings $\mathcal{I}(b_W)$ and $\mathcal{R}(\tilde{b}_W)$.

- Limits obtained on couplings $\mathcal{I}(b_W)$ and $\mathcal{R}(\tilde{b}_W)$ are weak.

- If it were possible to use the CP-conjugate process with $e^+\gamma$ initial state, then it would be possible to construct observables that would isolate the CP-odd couplings and can be used to probe them. The work is under the progress.

- Using polarised photons can improve the limits and that work is under progess.