# Anomalous $ZZ\gamma$, $Z\gamma\gamma$, and $ZZV$ Couplings

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In on-shell $Z\gamma$ production, deviations from the Standard Model for the $Z\gamma\gamma^*$ and $Z\gamma Z^*$ couplings may be described in terms of eight parameters, $h_i^V$ ($i = 1, 4$; $V = \gamma, Z$) [1]. The parameters $h_i^\gamma$ describe the $Z\gamma\gamma^*$ couplings and the parameters $h_i^Z$ the $Z\gamma Z^*$ couplings. In this formalism $h_1^V$ and $h_2^V$ lead to $CP$-violating and $h_3^V$ and $h_4^V$ to $CP$-conserving effects. All these anomalous contributions to the cross section increase rapidly with center-of-mass energy. In order to ensure unitarity, these parameters are usually described by a form-factor representation, $h_i^V(s) = h_{io}^V/(1 + s/\Lambda^2)^n$, where $\Lambda$ is the energy scale for the manifestation of a new phenomenon and $n$ is a sufficiently large power. By convention one uses $n = 3$ for $h_{1,3}^V$ and $n = 4$ for $h_{2,4}^V$. Usually limits on $h_i^V$'s are put assuming some value of $\Lambda$, sometimes $\infty$.

In on-shell $ZZ$ production, deviations from the Standard Model for the $ZZ\gamma^*$ and $ZZZ^*$ couplings may be described by means of four anomalous couplings $f_i^V$ ($i = 4, 5$; $V = \gamma, Z$) [2]. As above, the parameters $f_i^\gamma$ describe the $ZZ\gamma^*$ couplings and the parameters $f_i^Z$ the $ZZZ^*$ couplings. The anomalous couplings $f_5^V$ lead to violation of $C$ and $P$ symmetries while $f_4^V$ introduces $CP$ violation. Also here, formfactors depending on a scale $\Lambda$ are used.

All these couplings $h_i^V$ and $f_i^V$ are zero at tree level in the Standard Model; they are measured in $e^+e^-$, $p\bar{p}$ and $pp$ collisions at LEP, Tevatron and LHC.

**References:**

1.  U. Baur and E.L. Berger, Phys. Rev. **D47**, 4889 (1993).
2.  K. Hagiwara *et al.*, Nucl. Phys. **B282**, 253 (1987).

P.A. Zyla *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. **2020**, 083C01 (2020) and 2021 update

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