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^γ 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, $h_i^V(s) = h_{i\circ}^V/(1 + s/\Lambda^2)^n$, where Λ 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 Λ, sometimes ∞.

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^γ 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 Λ 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).