

# Extraction of Triple Gauge Couplings (TGCs)

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Fourteen independent couplings, seven each for  $ZWW$  and  $\gamma WW$ , completely describe the  $VWW$  vertices within the most general framework of the electroweak Standard Model (SM) consistent with Lorentz invariance and U(1) gauge invariance. Of each of the seven TGCs, three conserve  $C$  and  $P$  individually, three violate  $CP$ , and one violates  $C$  and  $P$  individually while conserving  $CP$ . Assumption of  $C$  and  $P$  conservation and electromagnetic gauge invariance reduces the number of independent  $VWW$  couplings to five: one common set [1,2] is  $(\kappa_\gamma, \kappa_Z, \lambda_\gamma, \lambda_Z, g_1^Z)$ , where  $\kappa_\gamma = \kappa_Z = g_1^Z = 1$  and  $\lambda_\gamma = \lambda_Z = 0$  in the Standard Model at tree level. The parameters  $\kappa_Z$  and  $\lambda_Z$  are related to the other three due to constraints of gauge invariance as follows:  $\kappa_Z = g_1^Z - (\kappa_\gamma - 1) \tan^2 \theta_W$  and  $\lambda_Z = \lambda_\gamma$ , where  $\theta_W$  is the weak mixing angle. The  $W$  magnetic dipole moment,  $\mu_W$ , and the  $W$  electric quadrupole moment,  $q_W$ , are expressed as  $\mu_W = e (1 + \kappa_\gamma + \lambda_\gamma)/2M_W$  and  $q_W = -e (\kappa_\gamma - \lambda_\gamma)/M_W^2$ .

Precision measurements of suitable observables at LEP1 has already led to an exploration of much of the TGC parameter space. At LEP2, the  $VWW$  coupling arises in  $W$ -pair production via  $s$ -channel exchange, or in single  $W$  production via the radiation of a virtual photon off the incident  $e^+$  or  $e^-$ . At the Tevatron and the LHC, hard-photon bremsstrahlung off a produced  $W$  or  $Z$  signals the presence of a triple-gauge vertex. In order to extract the value of one TGC, the others are generally kept fixed to their SM values. While most analyses use the above gauge constraints in the extraction of TGCs, one analysis of  $W$ -pair events also determines the real and imaginary parts of all 14 couplings using unconstrained single-parameter fits [3]. The results are consistent. Some experiments have determined limits on the couplings under various non-LEP scenarios and assuming different values of the form factor  $\Lambda$ , where the coupling parameters are scaled by  $1/(1 + s/\Lambda^2)^2$ . For practical reasons it is not possible to quote all such determinations in the listings. For that the individual papers may be consulted. Recently, EFT-inspired sets of couplings [4,5], such as  $c_{WWW}/\Lambda^2, c_W/\Lambda^2, c_B/\Lambda^2$  which are linearly related to the couplings discussed above, are also determined by the LHC experiments.

## References:

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