ANOMALOUS W/Z QUARTIC COUPLINGS (QGCS)

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The Standard Model quartic couplings, $W W W W$, $W W Z Z$, $W W Z \gamma$, $W W \gamma \gamma$, and $Z Z \gamma \gamma$, lead to negligible effects at LEP energies, while they are important at a TeV Linear Collider. Outside the Standard Model framework, possible quartic couplings, $a_0$, $a_c$, $a_n$, are expressed in terms of the following dimension-6 operators [1,2];

\[
L_0^6 = -\frac{e^2}{16\Lambda^2} a_0 F_{\mu\nu} F_{\mu\nu} W^\alpha \cdot \bar{W}_\alpha \\
L_6^c = -\frac{e^2}{16\Lambda^2} a_c F_{\mu\alpha} F_{\mu\beta} \bar{W}_\beta \cdot \bar{W}_\alpha \\
L_6^n = -i \frac{e^2}{16\Lambda^2} a_n \epsilon_{ijk} W^{(i)}_{\mu\alpha} W^{(j)}_{\nu\beta} W^{(k)}_{\alpha} F_{\mu\nu} \\
\tilde{L}_0^6 = -\frac{e^2}{16\Lambda^2} \tilde{a}_0 F_{\mu\nu} \tilde{F}_{\mu\nu} W^\alpha \cdot \bar{W}_\alpha \\
\tilde{L}_6^n = -i \frac{e^2}{16\Lambda^2} \tilde{a}_n \epsilon_{ijk} W^{(i)}_{\mu\alpha} W^{(j)}_{\nu\beta} W^{(k)}_{\alpha} \tilde{F}_{\mu\nu}
\]

where $F, W$ are photon and $W$ fields, $L_0^6$ and $L_6^c$ conserve $C, P$ separately ($\tilde{L}_6^0$ conserves only $C$) and generate anomalous $W^+W^-\gamma\gamma$ and $ZZ\gamma\gamma$ couplings, $L_6^n$ violates $CP$ ($\tilde{L}_6^n$ violates both $C$ and $P$) and generates an anomalous $W^+W^-Z\gamma$ coupling, and $\Lambda$ is an energy scale for new physics. For the $ZZ\gamma\gamma$ coupling the $CP$-violating term represented by $L_0^6$ does not contribute. These couplings are assumed to be real and to vanish at tree level in the Standard Model.

Within the same framework as above, a more recent description of the quartic couplings [3] treats the anomalous parts of the $WW\gamma\gamma$ and $ZZ\gamma\gamma$ couplings separately, leading to two sets parameterized as $a_0^V/\Lambda^2$ and $a_c^V/\Lambda^2$, where $V = W$ or $Z$.

At LEP the processes studied in search of these quartic couplings are $e^+e^- \rightarrow WW\gamma$, $e^+e^- \rightarrow \gamma\gamma\nu\bar{\nu}$, and $e^+e^- \rightarrow Z\gamma\gamma$ and limits are set on the quantities $a_0^W/\Lambda^2, a_c^W/\Lambda^2, a_n/\Lambda^2$.

The characteristics of the first process depend on all the three couplings whereas those of the latter two depend only on the two $CP$-conserving couplings. The sensitive measured variables are the cross sections for these processes as well as the energy and angular distributions of the photon and recoil mass to the photon pair. At hadron colliders, tri-boson production $VV\gamma$ as
well as di-boson scattering $\gamma\gamma \rightarrow VV$ is analysed to set limits on anomalous QGCs.

**References**


   J.W. Stirling and A. Werthenbach, Phys. Lett. **B466**, 369 (1999);
   A. Denner et al., Eur. Phys. J. **C20**, 201 (2001);