MEASUREMENTS OF QUARTIC GAUGE BOSON COUPLINGS AT LEP

S. SPAGNOLO

Rutherford Appleton Laboratory, Chilton, Didcot, Oxon, OX11 0QX, UK

E-mail: Stefania.Spagnolo@cern.ch

At the LEP 2 center-of-mass energies quartic gauge boson couplings (QGCs) involving at least one photon can be studied in final states with two W bosons and one photon, two acoplanar photons and two photons and a Z boson. Preliminary determinations of event rates and of distributions of kinematic variables, which are in good agreement with the Standard Model predictions, have been used to constrain the strength of anomalous contributions to quartic couplings of the gauge bosons.

1 Introduction

The study of QGCs has been initiated very recently at LEP 2[1]. Four quartic gauge boson vertices are predicted in the Standard Model (SM) with fixed couplings, $W^+W^-W^+W^-$, $W^+W^-Z^0Z^0$, $W^+W^-Z^0\gamma$ and $W^+W^-\gamma\gamma$, but their contributions to processes studied at LEP 2 is negligible. On the other hand, anomalous contributions to effective QGCs arising from physics beyond the SM could lead to measurable effects.

This report will describe the constraints on anomalous neutral and charged QGCs, obtained from the study of the production of the final states $W^+W^-\gamma$, $Z^0\gamma\gamma$ and two photons with missing energy ($\not{E}_T$). The diagrams in figure 1 show the processes involving quartic gauge vertices which are regarded as signal in the following discussion. Table 1 summarises the data sets used in QGC analyses.

The formalism of anomalous QGCs involving at least one photon[2,3] has recently received new contributions[4,5]. After neglecting operators leading to triple gauge couplings[a], two Lorentz structures, corresponding to C and P conserving operators of dimension 6 are required to describe the anomalous vertex $WW\gamma\gamma$, which contributes to the $WW\gamma$ and $\gamma\gamma+\not{E}_T$ final states. Therefore, two parameters a_0 and a_c, normalised to the square of the energy scale Λ of the underlying new physics, are introduced. Similarly, in the neutral sector two couplings a_0' and a_c' parametrise the anomalous $ZZ\gamma\gamma$ vertex which contributes to $q\bar{q}\gamma\gamma$ production through the third diagram in fig. 1. Originally explicit custodial SU(2) symmetry was imposed to the effective Lagrangian with the relations $a_0' = a_0$ and $a_c' = a_c$, although the four parameters are, in general, independent.

[a] Already strongly constrained by TGC studies.

		$\sqrt{s}$ /GeV	$\mathcal{L}$ /pb^{-1}
$WW\gamma$	L3	189	180
	OPAL	189	180
$\gamma\gamma+\not{E}_T$	ALEPH	189-202	430
	L3	183-202	450
	OPAL	189	180
$Z\gamma\gamma$	L3	130-202	500
	OPAL	130-208	580

Table 1. Data samples used for the QGCs analyses.

2 Measurements at LEP 2

$WW\gamma$ production at LEP 2 proceeds mainly via initial state radiation (ISR) in W pair events. Further contributions come from final state radiation (FSR) and radiation of the photon off a W boson (WR). The signature of anomalous QGCs is an excess of high energy photons in W pair events. Therefore, the event selection is based on a search for an isolated photon in four-fermion events consistent with two hadronic W decays or one hadronic and one leptonic W decay. While the background from FSR and WR can be

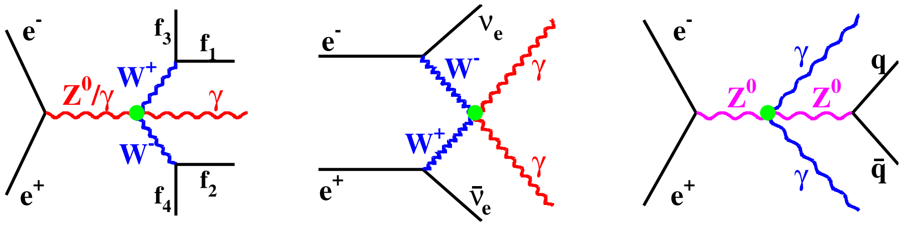

Figure 1. The processes involving quartic gauge boson couplings at LEP2.

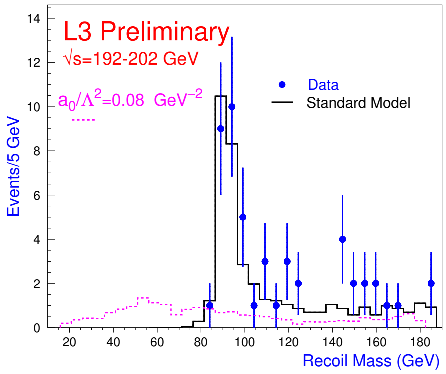

Figure 2. Distribution of the mass recoiling against the two acoplanar photons observed by L3 in the analysis of the $\gamma\gamma+\not{E}_T$ channel.

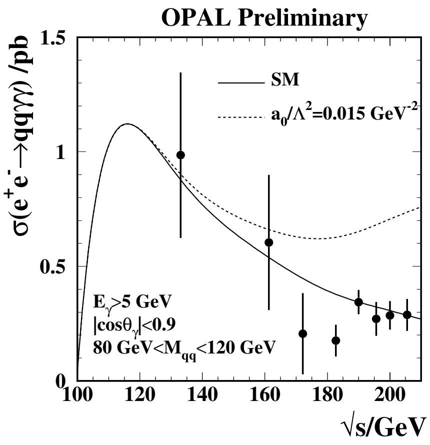

Figure 3. Cross section for $q\bar{q}\gamma\gamma$ production as a function of the center-of-mass energy.

reduced by requiring the invariant mass of the two pairs of fermions to match M_W, ISR is an irreducible background to $WW\gamma$ production via a quartic gauge vertex. L3 and OPAL have measured the cross section within similar signal definitions based on kinematic cuts on the photon energy, E_γ, and polar angle, θ_γ, on the separation between the photon and the fermions from the W decays and, in the case of OPAL, on the invariant mass of fermion pairs. The measurements, based on 42 and 17 events selected, respectively, by L3 and OPAL, are in agreement with the SM predictions, within the statistical uncertainty. The constraints on a_0 and a_c[1,6], listed in table 2, have been derived from the comparison of the event rate and of the shape of the distributions of E_γ (L3) and of E_γ and $\cos\theta_\gamma$ (OPAL) with the predictions of the EEWWG[4] Monte Carlo (MC)[b].

In general, the theoretical predictions for the processes relevant for QGC measurements at LEP 2 are affected by uncertainties related to the consistent treatment of all the contributing diagrams and of the interference between them, which are taken into account, as systematic uncertainties, in the experimental results on anomalous QGCs.

The W fusion diagram, shown in fig. 1, competes with the large SM background from doubly-radiative return to the Z^0 in the final

[b] $WW\gamma$ production can be achieved also via the quartic vertex $W^+W^-Z^0\gamma$. Recently a set of Lorentz structures, C and P conserving, associated to it has been introduced[5] but previously only a CP violating coupling a_n was considered[3]. The combined L3 and OPAL constraint on this parameter is $-0.45\ \mathrm{GeV}^{-2} < a_n/\Lambda^2 < 0.41\ \mathrm{GeV}^{-2}$ at 95% C.L..

state with two acoplanar photons. The signal from anomalous QGCs in the $WW\gamma\gamma$ vertex can be isolated from the dominant background by restricting the signal acceptance to values of the invariant mass, recoiling against the two-photon system, lower than, typically, 70-80 GeV where the SM predicts a negligible cross-section (fig. 2). Since, no events are observed in the signal region[1,6,7] by ALEPH, L3 and OPAL, the bounds on a_0 and a_c reported in table 2 are derived using the predictions from the ENUNUGANO calculation[4].

Finally, the anomalous $ZZ\gamma\gamma$ vertex might enhance the rate of events with two jets and two photons, which arise in the SM mainly from doubly-radiative return to the Z^0. The cross section for $q\bar{q}\gamma\gamma$ has been measured at several center of mass energies (fig. 3) by L3 and OPAL within signal definitions based on cuts on the photon energies and polar angles and on the di-jet invariant mass, which is required to be close to M_Z. In addition to the event rate, the shape of the distributions of variables like the energy of the second most energetic photon, E_{γ_2}, and the polar angle, θ_f, of the most forward photon are sensitive to QGCs. The predictions for the contributions of anomalous QGCs, obtained with the EEZGG[4] MC, are fit to the measured cross sections and distributions (E_{γ_2} is used by L3 and OPAL and $\cos\theta_f$ by OPAL only) and the bounds on the value of a'_0 and a'_c summarised in table 2 are derived[8,9].

95% C.L. bounds on anomalous QGCs			
Charged vertex $W^+W^-\gamma\gamma$			
		a_0/Λ^2	a_c/Λ^2
$WW\gamma$	L	[-0.045, 0.045]	[-0.08,0.13]
	O	[-0.070, 0.070]	[-0.13,0.19]
$\gamma\gamma$	A	[-0.045,0.042]	[-0.115,0.115]
$+\not{E}_T$	L	[-0.041,0.040]	[-0.12,0.12]
	O	[-0.086,0.085]	[-0.23,0.23]
	All	[-0.037,0.036]	[-0.077,0.095]
Neutral vertex $Z^0Z^0\gamma\gamma$			
		$(a'_0/\Lambda^2)\cdot 10^2$	$(a'_c/\Lambda^2)\cdot 10^2$
$Z\gamma\gamma$	L	[-0.6,0.6]	[-0.6,1.0]
	O	[-0.6,0.8]	[-0.8,1.2]
	All	[-0.48,0.56]	[-0.52,0.99]

Table 2. Preliminary constraints on anomalous QGCs from Aleph (A), L3 (L) and Opal (O). The preliminary combined results (All) are supplied by the LEP TGC working group. Units are GeV^{-2}.

3 Conclusions

Preliminary results on anomalous QGCs from LEP 2 data have been presented. Since the effect of anomalous QGCs increases with the center-of-mass energy, the present constraints are weak compared to the foreseen sensitivity of future colliders, but the full potential of the LEP 2 data is not yet fully exploited and future improvements of the combined LEP results can be expected.

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