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Limits on anomalous neutral current triple gauge boson couplings

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ABSTRACT: The coupling of three neutral gauge bosons have been measured at LEP2with the ALEPH, DELPHI, L3 and OPAL detectors. Limits the anomalous couplings h_i^V and f_i^V with i = 1..5 and $V = \gamma$,Z have been derived for the combined data set of all four detectors. No signs of existence of anomalous neutral triple gauge couplings have been found. For the first time off-shell couplings have been studied with the DELPHI detector.

1. Introduction

There are two classes of Lorentz invariant structures associated with neutral TGC vertices which preserve $U(1)_{em}$ and Bose symmetry, as described in [1, 2].
The first class refers to anomalous Z$\gamma\gamma^*$ and ZγZ* couplings which are accessible at LEP in the process $e^+e^- \to Z\gamma$. The parametrisation contains eight couplings: h_i^V with $i = 1, ..., 4$ and $V = \gamma$,Z. The superscript γ refers to Z$\gamma\gamma^*$ couplings and superscript Z refers to ZγZ* couplings. The photon and the Z boson in the final state are considered as on-shell particles, while the third boson at the vertex is off shell. The couplings h_1^V and h_2^V are CP-odd while h_3^V and h_4^V are CP-even.

The second class refers to anomalous ZZγ^* and ZZZ* couplings which are accessible at LEP2 in the process $e^+e^- \to ZZ$. This anomalous vertex is parametrised in terms of four couplings: f_i^V with $i = 4, 5$ and $V = \gamma$,Z. The superscript γ refers to ZZγ^* couplings and the superscript Z refers to ZZZ* couplings, respectively. Both Z bosons in the final state are assumed to be on-shell, while the third boson at the triple vertex is off-shell. The couplings f_4^V are CP-odd whereas f_5^V are CP-even.

Note that the h_i^V and f_i^V couplings are independent of each other. They are assumed to be real and they vanish at tree level in the Standard Model.

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2. Measurements

All experiments have measured the h and f-couplings for all or part of the data set. The h-coupling analyses of ALEPH, DELPHI and L3 use the data collected at LEP2 up to centre-of-mass energies of 209 GeV. The OPAL measurements so far use the data at 189 GeV. The results of the f-couplings are now obtained from the whole data set above the ZZ-production threshold by all of the experiments. The experiments already pre-combine different processes and final states for each of the couplings. The analyses use measurements of the total cross sections of Zγ and ZZ production and the differential distributions, while L3 uses the Optimal Observables technique to extract the couplings. The individual references should be consulted for details of the analyses of the h_i^V couplings [3, 4, 5, 6] and the f_i^V couplings [3, 4, 7, 8].

3. Results

Results from the four LEP experiments on the various electroweak gauge boson couplings, and their combination are presented. The results quoted for each individual experiment are calculated using the method described in [9]. Thus they may differ slightly from those reported in the individual references.

3.1 Neutral Triple Gauge Boson Couplings in Zγ Production

The individual analyses and results of the experiments for the h-couplings are described in [3, 4, 5, 6].

Single-Parameter Analyses

The results for each experiment are shown in Table 1, where the errors include both statistical and systematic uncertainties. The results of the combination are given in Table 2. The sensitivity of the L3 analysis [5] is the highest amongst the LEP experiments. This is partially due to the use of a larger phase space region, which increases the statistics by about a factor two, and partially due to added information from using an Optimal Observable technique.

Two-Parameter Analyses

The LEP average values are given in Table 3. Only ALEPH, DELPHI and L3 are used for the combination.

3.2 Neutral Triple Gauge Boson Couplings in ZZ Production

The individual analyses and results of the experiments for the f-couplings are described in [3, 4, 7, 8].

Single-Parameter Analyses

The results for each experiment are shown in Table 4, where the errors include both statistical and systematic uncertainties. The results of the combination are given in Table 5.

Two-Parameter Analyses

The LEP average values are given in Table 6.

3.3 Off-shell Triple Gauge Boson Couplings

An analysis of off-shell neutral gauge boson coupling parameters from four fermion final states was presented by DELPHI. It uses the $\mu^+\mu^- q\bar{q}$ four fermion final state from ZZ and $Z\gamma^*$ production to derive limits on anomalous coupling parameters $l_i^{V^*V^*V^*}$ with $i = 1..3$ and $V = \gamma, Z$. No significant deviation from the Standard Model value was found and limits were set [4].

Conclusions

No significant deviation from the Standard Model prediction is seen for any of the electroweak gauge boson couplings studied.

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Parameter	ALEPH	DELPHI	L3	OPAL
h_1^γ	$[-0.14, \quad +0.14]$	$[-0.15, \quad +0.15]$	$[-0.06, \quad +0.06]$	$[-0.13, \quad +0.13]$
h_2^γ	$[-0.07, \quad +0.07]$	$[-0.09, \quad +0.09]$	$[-0.053, \quad +0.024]$	$[-0.089, \quad +0.089]$
h_3^γ	$[-0.069, \quad +0.037]$	$[-0.047, \quad +0.047]$	$[-0.062, \quad -0.014]$	$[-0.16, \quad +0.00]$
h_4^γ	$[-0.020, \quad +0.045]$	$[-0.032, \quad +0.030]$	$[-0.004, \quad +0.045]$	$[+0.01, \quad +0.13]$
h_1^Z	$[-0.23, \quad +0.23]$	$[-0.24, \quad +0.25]$	$[-0.17, \quad +0.16]$	$[-0.22, \quad +0.22]$
h_2^Z	$[-0.12, \quad +0.12]$	$[-0.14, \quad +0.14]$	$[-0.10, \quad +0.09]$	$[-0.15, \quad +0.15]$
h_3^Z	$[-0.28, \quad +0.19]$	$[-0.32, \quad +0.18]$	$[-0.23, \quad +0.11]$	$[-0.29, \quad +0.14]$
h_4^Z	$[-0.10, \quad +0.15]$	$[-0.12, \quad +0.18]$	$[-0.08, \quad +0.16]$	$[-0.09, \quad +0.19]$

Table 1: The 95% C.L. intervals ($\Delta \log \mathcal{L} = 1.92$) measured by the ALEPH, DELPHI, L3 and OPAL. In each case the parameter listed is varied while the remaining ones are fixed to their Standard Model values. Both statistical and systematic uncertainties are included.

Parameter	95% C.L.
h_1^γ	$[-0.056, \quad +0.055]$
h_2^γ	$[-0.045, \quad +0.025]$
h_3^γ	$[-0.049, \quad -0.008]$
h_4^γ	$[-0.002, \quad +0.034]$
h_1^Z	$[-0.13, \quad +0.13]$
h_2^Z	$[-0.078, \quad +0.071]$
h_3^Z	$[-0.20, \quad +0.07]$
h_4^Z	$[-0.05, \quad +0.12]$

Table 2: The 95% C.L. intervals ($\Delta \log \mathcal{L} = 1.92$) obtained combining the results from the four experiments. In each case the parameter listed is varied while the remaining ones are fixed to their Standard Model values. Both statistical and systematic uncertainties are included.

Parameter	95% C.L.	Correlations	
h_1^γ	$[-0.16, \quad +0.05]$	1.00	+0.79
h_2^γ	$[-0.11, \quad +0.02]$	+0.79	1.00
h_3^γ	$[-0.08, \quad +0.14]$	1.00	+0.97
h_4^γ	$[-0.04, \quad +0.11]$	+0.97	1.00
h_1^Z	$[-0.35, \quad +0.28]$	1.00	+0.77
h_2^Z	$[-0.21, \quad +0.17]$	+0.77	1.00
h_3^Z	$[-0.37, \quad +0.29]$	1.00	+0.76
h_4^Z	$[-0.19, \quad +0.21]$	+0.76	1.00

Table 3: The 95% C.L. intervals ($\Delta \log \mathcal{L} = 1.92$) obtained combining the results from ALEPH, DELPHI and L3. In each case the two parameters listed are varied while the remaining ones are fixed to their Standard Model values. Both statistical and systematic uncertainties are included. Since the shape of the log-likelihood is not parabolic, there is some ambiguity in the definition of the correlation coefficients and the values quoted here are approximate.

Parameter	ALEPH	DELPHI	L3	OPAL
f_4^γ	$[-0.26, \quad +0.26]$	$[-0.26, \quad +0.28]$	$[-0.24, \quad +0.26]$	$[-0.36, \quad +0.36]$
f_4^Z	$[-0.44, \quad +0.43]$	$[-0.49, \quad +0.42]$	$[-0.43, \quad +0.41]$	$[-0.55, \quad +0.64]$
f_5^γ	$[-0.54, \quad +0.56]$	$[-0.48, \quad +0.61]$	$[-0.48, \quad +0.56]$	$[-0.82, \quad +0.72]$
f_5^Z	$[-0.73, \quad +0.83]$	$[-0.42, \quad +0.69]$	$[-0.46, \quad +1.2]$	$[-0.96, \quad +0.31]$

Table 4: The 95% C.L. intervals ($\Delta \log \mathcal{L} = 1.92$) measured by ALEPH, DELPHI, L3 and OPAL. In each case the parameter listed is varied while the remaining ones are fixed to their Standard Model values. Both statistical and systematic uncertainties are included.

Parameter	95% C.L.
f_4^γ	$[-0.17, \quad +0.19]$
f_4^Z	$[-0.31, \quad +0.28]$
f_5^γ	$[-0.36, \quad +0.40]$
f_5^Z	$[-0.36, \quad +0.39]$

Table 5: The 95% C.L. intervals ($\Delta \log \mathcal{L} = 1.92$) obtained combining the results from all four experiments. In each case the parameter listed is varied while the remaining ones are fixed to their Standard Model values. Both statistical and systematic uncertainties are included.

Parameter	95% C.L.	Correlations	
f_4^γ	$[-0.17, \quad +0.19]$	1.00	+0.10
f_4^Z	$[-0.30, \quad +0.28]$	+0.10	1.00
f_5^γ	$[-0.34, \quad +0.38]$	1.00	−0.18
f_5^Z	$[-0.36, \quad +0.38]$	−0.18	1.00

Table 6: The 95% C.L. intervals ($\Delta \log \mathcal{L} = 1.92$) obtained combining the results from all four experiments. In each case the two parameters listed are varied while the remaining ones are fixed to their Standard Model values. Both statistical and systematic uncertainties are included. Since the shape of the log-likelihood is not parabolic, there is some ambiguity in the definition of the correlation coefficients and the values quoted here are approximate.