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The triple gauge-boson couplings involving the W are determined using data samples collected with the ALEPH detector at mean centre-of-mass energies between 183 GeV and 208 GeV, corresponding to an integrated luminosity of 683.6 pb^{-1}. The triple gauge-boson couplings, Δg_1^Z, $\Delta\kappa_\gamma$ and λ_γ are measured using an optimal observable analysis of W-pair event topology. Results from single-W and single-γ production are included. The three couplings are measured individually assuming the two other couplings to be fixed at zero (Standard Model value). In addition, we use W-pair events to set limits on the C- and P-violating couplings g_4^V, g_5^V, $\tilde{\kappa}_V$, and $\tilde{\lambda}_V$, where V denotes either γ or Z. No deviations from the Standard Model expectations are observed.

1 Introduction

Triple Gauge-Boson Couplings can be separated in two main categories: vertices which involves only neutral bosons Z or γ and vertices with charged bosons W. The former $VZ\gamma$ and VZZ ($V = Z^*/\gamma^*$) are not present in the standard model at tree level. They are searched at LEP2 in the production of ZZ pairs and in $Z\gamma$ events [1] and won't be treated in the following note. The latter VW^+W^- can be found in three different physics processes at LEP2: WW pair production, single W production and single γ production. The VW^+W^- vertices are a direct consequence of the $SU(2)_L \times U(1)_Y$ gauge theory and are present in the standard model at Born level. Their study represents a fundamental test of the non-Abelian nature of the Standard Model. The most general Lorentz invariant parametrisation of the γW^+W^- and ZW^+W^- vertices can be described by 14 independent complex couplings [2,3], 7 for each vertex: g_1^V, g_4^V, g_5^V, κ_V, λ_V, $\tilde{\kappa}_V$ and $\tilde{\lambda}_V$, where V denotes either γ or Z. Assuming electromagnetic gauge invariance, C- and P-conservation, the set of 14 couplings can be reduced to 5 parameters: g_1^Z, κ_γ, κ_Z, λ_γ and λ_Z, with Standard Model values $g_1^Z = \kappa_Z = \kappa_\gamma = 1$ and $\lambda_Z = \lambda_\gamma = 0$. Finally, local $SU(2)_L \times U(1)_Y$ gauge invariance introduces the constraints:

$$\Delta\kappa_Z = -\Delta\kappa_\gamma tan^2\theta_W + \Delta g_1^Z, \tag{1}$$

$$\lambda_Z = \lambda_\gamma, \tag{2}$$

where Δ denotes the deviation of the respective quantity from its non-zero Standard Model value, and θ_W is the weak mixing angle. Hence, only three parameters remain: Δg_1^Z, $\Delta\kappa_\gamma$, and λ_γ [3]. This paper presents preliminary results on the three couplings Δg_1^Z, $\Delta\kappa_\gamma$, and λ_γ using all ALEPH data, but also updates the results from single-parameter fits to the unconstrained real and imaginary parts of the 8 C- or P-violating couplings [4].

2 The ALEPH Detector

A detailed description of the ALEPH detector may be found in [5,6]. The central part of the ALEPH detector is dedicated to the reconstruction of the trajectories of charged particles. Following a charged particle from the interaction point outwards, the trajectory is measured by a two-layer silicon strip vertex detector (VDET), a cylindrical drift chamber (ITC) and a large time projection chamber (TPC). They are immersed in a 1.5 T axial field and combined, they measure charged tracks with a momentum resolution of $\delta p_T/p_T = 6\times10^{-4} p_T \oplus 0.005$. Photons and electrons are identified in the electromagnetic calorimeter (ECAL), situated between the TPC and the coil. It yields a relative energy resolution of $0.18/\sqrt{E} \oplus 0.009$. The iron return yoke is equipped of 23 layers of streamer tubes and forms the hadron calorimeter (HCAL). Combined with ECAL it provides a relative energy resolution of charged and neutral hadrons of $0.85/\sqrt{E}$. Muons are distinguished from hadrons by their distinct pattern in HCAL and by the muon chambers outside the HCAL.

3 Event selection and kinematic reconstruction

The selection of W^+W^- candidates is highly dependent of the event topology. Selected events are exclusively classified with the following order of priority: $e\nu q\bar{q}$, $\mu\nu q\bar{q}$, $\tau\nu q\bar{q}$, $q\bar{q}q\bar{q}$, and $l\nu l\nu$ according to the way each W is decaying [7].

3.1 $W^+W^- \to e\nu q\bar{q}$ *and* $W^+W^- \to \mu\nu q\bar{q}$ *events*

Semileptonic events are selected such that they contain a high energy lepton candidate and two jets. The selection of the lepton is using track isolation. The DURHAM-PE clustering algorithm is then applied to all objects that are not used to construct the lepton four-momentum, and these are forced in two jets. After this preselection, the probability for the event being signal is determined using a Neural Networks based on the momentum of the lepton, the total missing transverse momentum and the lepton isolation. To improve the resolution on the reconstructed four-momenta of the W decay products, the events are subjected to a kinematic fit. Typical efficiency of semileptonic channels is roughly 80% for a purity of 95%.

3.2 $W^+W^- \to \tau\nu q\bar{q}$ *events*

Selection of semileptonic events with a τ is slightly different from the previous case, since τ lepton can decay into hadrons. In that case, an iterative method is applied to search for the most isolated jet amongst the jets resulting from a low y_{cut} value of 0.75 GeV/c^2 with the JADE algorithm. To improve the resolution of the angular observables a kinematic fit is performed where the direction of the τ is approximated by its visible decay products. Efficiency of $\tau\nu q\bar{q}$ selection is about 54% and purity is roughly 76%.

3.3 $W^+W^- \to q\bar{q}q\bar{q}$ *events*

Fully hadronic events are identified by having four separated jets contained in the detector. To extract the hadronic W^+W^- signal with high purity ($\simeq$ 85%) and efficiency ($\simeq$ 80%), the selection is based on the output of a neural network based on 14 variables [7]. Moreover, for the hadronic W^+W^- events the reconstruction of the relevant information is more complicated since there is no clean signature of the W^- direction nor any information of the particle flavors in either W systems. In this case the four jets can be paired in three different ways. To select the best pairing with a purity of 75%, a 6-constraint kinematic fit is applied to all three possible pairings. To assign a jet pair to the W^+ or W^-, a jet charge algorithm is used. The jet charge is obtained from the pseudorapidity-weighted charge for the particles forming a jet.

3.4 $W^+W^- \to l\nu l\nu$ *events*

The efficient of the selection of purely leptonic events is low 27%, but with a high purity 97%. Selection is based on missing transverse momentum, missing mass and kinematic properties of the lepton candidates. For purely leptonic W^+W^- events the momenta of the two neutrinos are unknown. However in the absence of Initial State Radiation and neglecting the W width, the constraint that the two $l\nu$ systems should have the W mass in combination with the usual four-momentum conservation allows a reconstruction of the neutrino momenta.

4 Determination of the TGCs

4.1 Coupling extraction

All the information on the couplings is contained in a five angles distribution and the electric charge of the fermions [3]. Since triple gauge-boson couplings contribute only linearly to the amplitude of the considered processes, the differential cross section can be expanded in these couplings g_i as a second order polynomial

$$\frac{d\sigma}{d\Omega} = S_0(\Omega) + \sum_i S_{1,i}(\Omega) g_i + \sum_{ij} S_{2,ij}(\Omega) g_i g_j . \qquad (3)$$

Couplings estimators are then extracted with an optimal observable method [8]. The general idea of optimal observables is to extract the couplings g_i by measuring the mean values $\overline{OO}$ of distributions of suitably defined observables OO. In addition to the total number of selected events, the two optimal observables builded are

$$OO_{1,i}(\Omega) = \frac{S_{1,i}(\Omega)}{S_0(\Omega)} \; and \; OO_{2,ij}(\Omega) = \frac{S_{2,ij}(\Omega)}{S_0(\Omega)} . \qquad (4)$$

With only Gaussian distributed variables, likelihood function is then equivalent to a least square method. In particular, including systematic errors is easy.

4.2 Systematic uncertainties

A complete list of all the systematics errors computed can be found in [4]. The main sources are coming from uncertainties on the Monte Carlo model used to generate the W^+W^- signal. They were estimated as the effect of higher order correction for these results, but a reduction of the error size is forseen for the final results [9]. The other main systematic uncertainties are due to fragmentation or final state interactions not perfectly modeled, i.e. Color Reconnection and Bose-Einstein effects.

5 Results and conclusion

The triple gauge-boson couplings have been measured using W-pair events at all LEP2 energies. Combining with the ALEPH measurement from single-W production and single-γ production, the three couplings Δg_1^Z, $\Delta\kappa_\gamma$ and λ_γ have been measured individually. The results are

$$\Delta g_1^Z = 0.015^{+0.035}_{-0.032}$$

$$\Delta\kappa_\gamma = -0.020^{+0.078}_{-0.072}$$
$$\lambda_\gamma = -0.001^{+0.034}_{-0.031},$$

where the error includes systematic uncertainties. The corresponding 95% confidence level limits,

$$-0.048 < \Delta g_1^Z < 0.080$$
$$-0.164 < \Delta\kappa_\gamma < 0.132$$
$$-0.059 < \lambda_\gamma < 0.065,$$

are in good agreement with the Standard Model expectation.

In addition, W-pair events were used to set limits on the C- or P-violating couplings g_4^V, g_5^V, $\tilde{\kappa}_V$ and $\tilde{\lambda}_V$, where V denotes either γ or Z. Results are shown on Table 1.

Table 1. Combined results for the real and imaginary parts of the C- or P- violating couplings from W-pair production at 183-208 GeV. Each coupling is determined setting all other couplings to their Standard Model value. The error includes systematic uncertainties. The corresponding 95% confidence intervals are listed in the last column.

Coupling	Fit result	95% confidence limits
$Re(\tilde{\kappa}_\gamma)$	$-0.027^{+0.114}_{-0.111}$	[-0.236, 0.191]
$Re(\tilde{\lambda}_\gamma)$	$0.001^{+0.090}_{-0.090}$	[-0.170, 0.173]
$Re(\tilde{\kappa}_Z)$	$-0.006^{+0.060}_{-0.060}$	[-0.123, 0.111]
$Re(\tilde{\lambda}_Z)$	$-0.004^{+0.048}_{-0.048}$	[-0.096, 0.089]
$Re(g_4^\gamma)$	$0.116^{+0.156}_{-0.158}$	[-0.193, 0.418]
$Re(g_5^\gamma)$	$-0.186^{+0.188}_{-0.189}$	[-0.557, 0.181]
$Re(g_4^Z)$	$0.103^{+0.119}_{-0.120}$	[-0.134, 0.334]
$Re(g_5^Z)$	$-0.130^{+0.138}_{-0.138}$	[-0.400, 0.141]
$Im(\tilde{\kappa}_\gamma)$	$-0.022^{+0.057}_{-0.057}$	[-0.134, 0.090]
$Im(\tilde{\lambda}_\gamma)$	$0.037^{+0.045}_{-0.046}$	[-0.053, 0.125]
$Im(\tilde{\kappa}_Z)$	$-0.045^{+0.037}_{-0.037}$	[-0.116, 0.027]
$Im(\tilde{\lambda}_Z)$	$0.043^{+0.029}_{-0.029}$	[-0.015, 0.100]
$Im(g_4^\gamma)$	$0.286^{+0.130}_{-0.132}$	[0.027, 0.539]
$Im(g_5^\gamma)$	$-0.180^{+0.219}_{-0.216}$	[-0.600, 0.251]
$Im(g_4^Z)$	$0.167^{+0.082}_{-0.082}$	[0.005, 0.326]
$Im(g_5^Z)$	$-0.089^{+0.142}_{-0.142}$	[-0.366, 0.190]

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