PROCEEDINGS OF SCIENCE

(Anomalous) Gauge boson couplings

Evelyne Delmeire[∗†]

Université de Genève, Switzerland

E-mail: Evelyne.Delmeire@cern.ch

During the LEP2 period the e^+e^- collider increased its center-of-mass energy from 161 GeV up to 209 GeV. A total integrated luminosity of approximately 700 pb^{-1} was recorded per experiment. Massive W bosons are dominantly produced in pairs via e^+e^- interactions and gauge couplings involving the charged gauge bosons W^+ and W^-, and the neutral gauge bosons γ and Z, are studied by the LEP experiments. The LEP measurement of the coupling of the W boson to the neutral gauge bosons, $g_1^Z = 0.984^{+.022}_{-.019}$, $\kappa_\gamma = 0.973^{+.044}_{-.045}$, and $\lambda_\gamma = -0.028^{+.020}_{-.021}$, are in agreement with the Standard Model expectation $g_1^Z = 1$, $\kappa_\gamma = 1$, and $\lambda_\gamma = 0$. Couplings between tree and four neutral gauge bosons are forbidden by the Standard Model. No evidence has been found for couplings of three neutral gauge bosons, parametrized by $f_{4,5}^{Z,\gamma}$ and $h_{1,2,3,4}^{Z,\gamma}$. Limits are derived on couplings of four gauge bosons, parametrized by $a_0^{Z,W}/\Lambda^2$, a_n^W/Λ^2 and $a_c^{Z,W}/\Lambda^2$ where Λ represents the energy scale for new physics. A lower limit on the techni-ρ mass of 600 GeV/c^2 is set at 95% confidence level by the ALEPH experiment.

International Europhysics Conference on High Energy Physics
July 21st - 27th 2005
Lisboa, Portugal

∗Speaker.
†On behalf of the LEP Collaborations

PoS(HEP2005)302

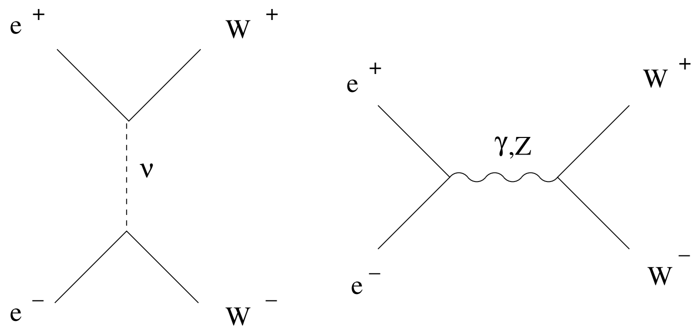

Figure 1: *The CCO3 Feynman diagrams for W-pair production.* Left : *t-channel ν-exchange*, Right : *s-channel γ/Z-exchange*

At LEP2, the four LEP experiments ALEPH, DELPHI, L3 and OPAL [1] recorded approximately 700 pb^{-1} of total integrated luminosity in the center-of-mass energy range from 161 GeV up to 209 GeV. Massive W bosons are dominantly produced in pairs via e^+e^- interactions and gauge couplings involving the charged gauge bosons W^+ and W^-, and the neutral gauge bosons γ and Z, are studied by the LEP experiments.

The non-Abelian $SU(2)_L \otimes U(1)_Y$ gauge structure of the Standard Model [2] introduces interactions, at tree level, between three or four charged and neutral gauge bosons, called triple and quartic gauge couplings. At LEP, the charged Triple Gauge Couplings (TGC) WWZ and WWγ are directly observed. The Quartic Gauge Couplings (QGC) WWWW and WWZZ are not accessible at LEP as the center-of-mass energy is not sufficient, while WWZγ and WW$\gamma\gamma$ are statistically negligible. Neutral triple and quartic gauge couplings between neutral gauge bosons are forbidden by the Standard Model. A coupling is called anomalous if it deviates from its value predicted by the Standard Model or if a new physics process introduces a new vertex at tree level or in the loop corrections that already exist in the Standard Model. The deviations of possible new physcis like supersymmetry, technicolor, composite W bosons, etc, are estimated of the same order of the already existing Standard Model radiative corrections i.e. 10^{-3}, depending on the coupling parameter.

1. Charged Triple Gauge Couplings

The Standard Model predicts the contribution of three charged current Feynman diagrams, referred to as CC03, and presented in Figure 1. The t-channel ν-exchange diagram (Left), is dominant at the WW threshold. The s-channel γ and Z-exchange diagrams (Right) contain the triple gauge boson vertex ZWW or γWW. Figure 2 shows the LEP measurement of the W-pair production cross section as function of the center-of-mass energy $\sqrt{s}$. The good agreement between the LEP data and the Standard Model prediction as calculated by the YFSWW [3] and the RACOONWW [4] Monte Carlo's, gives a direct confirmation of the existence of the γWW and the ZWW vertices, predicted by the Standard Model. Also the theoretical prediction for the total W pair production cross section under different hypotheses is shown. The dotted line shows the contribution to the W-pair production cross section of the t-channel ν-exchange process only. The t-channel ν-exchange dominates around the WW threshold, but grows rapidly with increasing energy and could eventually

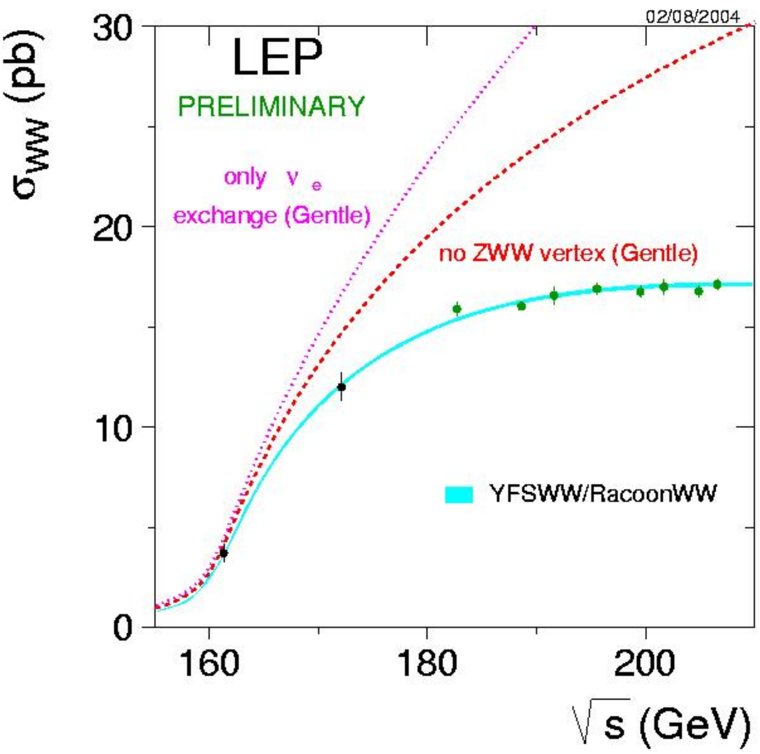

Figure 2: *The LEP measurement of the total W pair production cross section as function of the center-of-mass energy $\sqrt{s}$.*

violate unitarity at large energy scale. According to the Standard Model the t-channel growth is compensated by the contribution of the s-channel γ/Z-exchange with such a coefficient that the cross section decreases with increasing center-of-mass energy. The dashed line represents the behaviour in absence of the ZWW vertex. In this case there would be unitarity violation too. Therefore, the γWW vertex alone is not sufficient to make the cross section finite, but the destructive interference of all three diagrams is needed to describe the LEP data.

The most general Lorentz invariant Lagrangian involving WWV ($V = \gamma, Z$) vertices can be parametrized by 14 parameters [5]

$$i\,\mathscr{L}^{WWV}/\,g_{WWV} = g_1^V V^\mu (W^-_{\mu\nu} W^{+\nu} - W^+_{\mu\nu} W^{-\nu}) + \kappa_V W^+_\mu W^-_\nu V^{\mu\nu} \tag{1.1}$$

$$+ \frac{\lambda_V}{M_W^2} V^{\mu\nu} W^{+\rho}_\nu W^-_{\rho\mu} + i g_5^V \varepsilon_{\mu\nu\rho\sigma} [(\partial^\rho W^{-\mu}) W^{+\nu} - W^{-\mu} (\partial^\rho W^{+\nu})] V^\sigma$$

$$+ i g_4^V W^-_\mu W^+_\nu (\partial^\mu V^\nu - \partial^\nu V^\mu) - \frac{\tilde{\kappa}_V}{2} W^-_\mu W^+_\nu \varepsilon^{\mu\nu\rho\sigma} V_{\rho\sigma} - \frac{\tilde{\lambda}_V}{2M_V^2} W^-_{\rho\mu} W^{+\mu}_\nu \varepsilon^{\nu\rho\alpha\beta} V_{\alpha\beta}$$

where g_1^V, κ_V, λ_V and g_5^V are CP-conserving couplings while g_4^V, $\tilde{\kappa}_V$ and $\tilde{\lambda}_V$ are CP-violating. Assuming CP-conservation and electromagnetic gauge invariance of the Lagrangian, five parameters are left : g_1^Z, κ_Z, κ_γ, λ_Z and λ_γ. The custodial $SU(2)$ symmetry of the Lagrangian imposes the constraints

$$\kappa_Z = g_1^Z - (\kappa_\gamma - 1)\tan^2\theta_W \qquad\qquad \lambda_\gamma = \lambda_Z \tag{1.2}$$

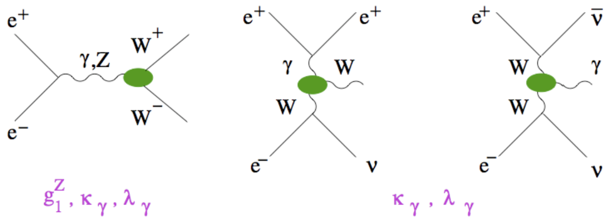

Figure 3: *The processes sensitive to ZWW and γWW triple gauge couplings :* W*-pair, single* W *and single photon production.*

where θ_W is the weak mixing angle. Three free parameters are left : g_1^Z, κ_γ and λ_γ. They are related to the magnetic dipole and electric quadrupole moment of the W. The Standard Model predicts their values to be $g_1^Z = \kappa_\gamma = 1$ and $\lambda_\gamma = 0$ at tree level.

The triple gauge couplings are studied in W-pair production, sensitive to all three parameters, and single W and single photon production which are sensitive to κ_γ and λ_γ only. The corresponding Feynman diagrams are presented in Figure 3. In general W-pair production is the most sensitive process, except for the parameter κ_γ, where single W poduction has the maximum sensitivity. The single W and single γ process are included in the TGC analysis by some LEP experiments.

A deviation from a coupling value predicted by the Standard Model would modify the total cross section, the shape of the W production angle θ_W, the polar angle $\theta_f^\star$ and azimuthal angle, $\phi_f^\star$ of the W-decay fermion in the corresponding W restframe. These angles are presented in Figure 4 together with the distribution of the W production angle as measured by the ALEPH experiment in fully hadronic W-pair events. The expected distribution in presence of an anomalous coupling $\lambda_\gamma = \pm 0.2$ is also indicated.

The couplings are extracted by a maximum likelihood fit to the angular distributions (DELPHI, L3) or by a χ^2-fit to Optimal Observables distributions (ALEPH, OPAL). The results from each LEP experiment are then combined using a log-likelihood method [6]. A one-parameter fit [1] is performed for the PDG 2005 including published results from ALEPH, L3 and OPAL and is presented in Figure 5.

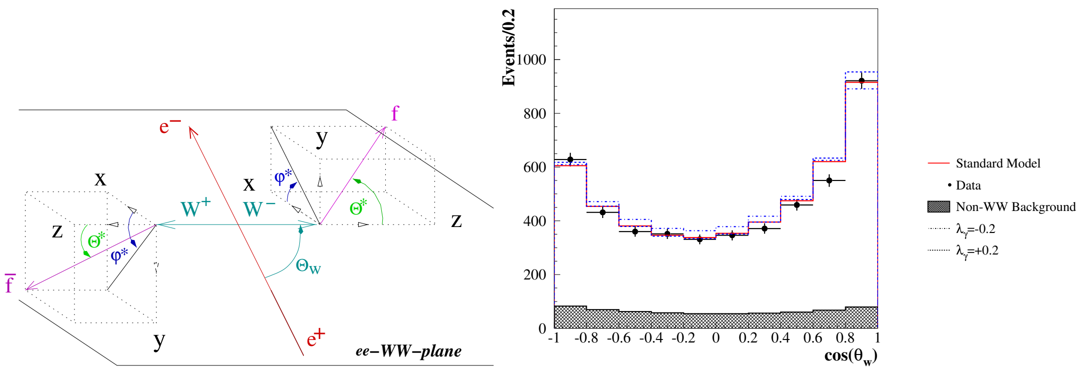

Figure 4: Left : *The definition of the angles used in the coupling extraction.* Right : *The* W *boson production angle measured by the ALEPH experiment in fully hadronic* W*-pair events.*

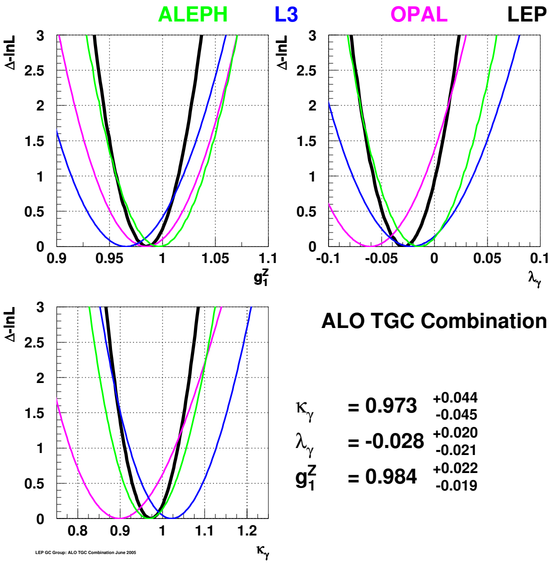

Figure 5: *The -log$\mathscr{L}$ curves of the one-parameter fit for the PDG 2005 including published results from ALEPH, L3 and OPAL. Each coupling parameter is varied individually fixing the other two parameters to their Standard Model expectation.*

Source	g_1^Z	λ_γ	κ_γ
$\mathscr{O}(\alpha)$ corrections	0.010	0.010	0.020
Hadronisation	0.004	0.002	0.004
Bose-Einstein correlation	0.005	0.004	0.009
Colour Reconnection	0.005	0.004	0.010
σ_{WW} prediction	0.003	0.005	0.014
$\sigma_{single\ W}$ prediction			0.011

Table 1: *The sources of experiment correlated systematic uncertainties in the LEP combination and their effect on the combined fit results.*

The fit results

$$g_1^Z = 0.984^{+.022}_{-.019} \qquad \kappa_\gamma = 0.973^{+.044}_{-.045} \qquad \lambda_\gamma = -0.028^{+.020}_{-.021} \; .$$

are in agreement with the Standard Model prediction. A final LEP combination is forseen once the DELPHI TGC results published. The quoted errors include both statistical and systematic uncertainties. The uncertainty is dominated by the statistical component. The largest contribution to the systematic uncertainty comes from the $\mathscr{O}(\alpha)$ radiative corrections. The experiment correlated systematic uncertainties in the combined fit results are presented in Table 1.

The ALEPH experiment also performs unconstrained fits assuming no relation between the 28 TGC parameters. No deviation from the Standard Model prediction is observed [7].

The L3 experiment uses the TGC measurement to study spacial extention of the W boson, approximated by an ellipsoid with longitudinal radius a and transverse radius b. The size and radius would be related to the TGC by $R_W \equiv (a+b)/2 = (\kappa_\gamma + \lambda_\gamma - 1)/m_W$ [8] and $\Delta_W \equiv (a^2-b^2)/2 = (5/4)(\kappa_\gamma - \lambda_\gamma - 1)/m_W^2$ [9] where m_W is the W-boson mass. There is no evidence that the W boson would be an extended object [10]

$$R_W = (0.3 \pm 1.9) \times 10^{-19}\mathrm{m}$$
$$\Delta_W = (0.89 \pm 0.83) \times 10^{-36}\mathrm{m}^2$$

1.1 Measurement of the W boson Spin Density Matrix

The Spin Density Matrix (SDM) method [11, 12] is used to set direct limits on CP-violating couplings, absent in the Standard Model.

Considering the helicity, the W-pair production process is written as

$$\mathrm{e}^+(\lambda')\,\mathrm{e}^-(\lambda) \rightarrow \mathrm{W}^+(\tau_2)\,\mathrm{W}^-(\tau_1)\,, \tag{1.3}$$

where λ, λ' are the helicity of the electron (positron). In the high energy limit, where we can neglect the electron mass, the helicity of the positron is opposite to the electron's helicity: $\lambda' = -\lambda$. The helicities of the W^- and the W^+, denoted by τ_1 and τ_2 respectively, take the value $\tau = \pm 1$ for transversely polarised W bosons and the value $\tau = 0$ for W bosons with a longitudinal polarisation.

The two-particle joint SDM elements are then defined as [13]

$$\rho_{\tau_1\tau_1'\tau_2\tau_2'}(s, cos\theta_\mathrm{W}) \equiv \frac{\sum_\lambda F^\lambda_{\tau_1\tau_2}\,(F^\lambda_{\tau_1'\tau_2'})^\star}{\sum_{\lambda,\tau_1,\tau_2}|F^\lambda_{\tau_1\tau_2}|^2}\,, \tag{1.4}$$

where s is the center-of-mass energy and $F^\lambda_{\tau_1\tau_2}$ is the helicity amplitude for the production of a W-pair with helicities τ_1 and τ_2. The single W SDM elements are obtained by summation over all possible helicities of one of the W's, by convention the W^+,

$$\rho^{\mathrm{W}^-}_{\tau_1\tau_1'}(s, cos\theta_{\mathrm{W}^-}) \equiv \sum_{\tau_2} \rho_{\tau_1\tau_1'\tau_2\tau_2}(s, cos\theta_{\mathrm{W}^-})\,. \tag{1.5}$$

The SDM elements are constrained by Hermiticity $\rho^{\mathrm{W}^-}_{\tau\tau'} = (\rho^{\mathrm{W}^-}_{\tau'\tau})^\star$ and are normalised to unity $\sum_\tau \rho^{\mathrm{W}^-}_{\tau\tau} = 1$. The diagonal elements of the SDM are real and express the probability to produce a W^- with a transverse polarisation (ρ_{++} and ρ_{--}) or with a longitudinal polarisation (ρ_{00}). The off-diagonal elements measure the interference between different W helicity amplitudes. They differ from zero if the W boson is be produced in a linear superposition of helicity states, predicted by the Standard Model, but would be zero for a W boson produced in a definite helicity state. The off-diagonal elements are complex and provide a test of CP violation.

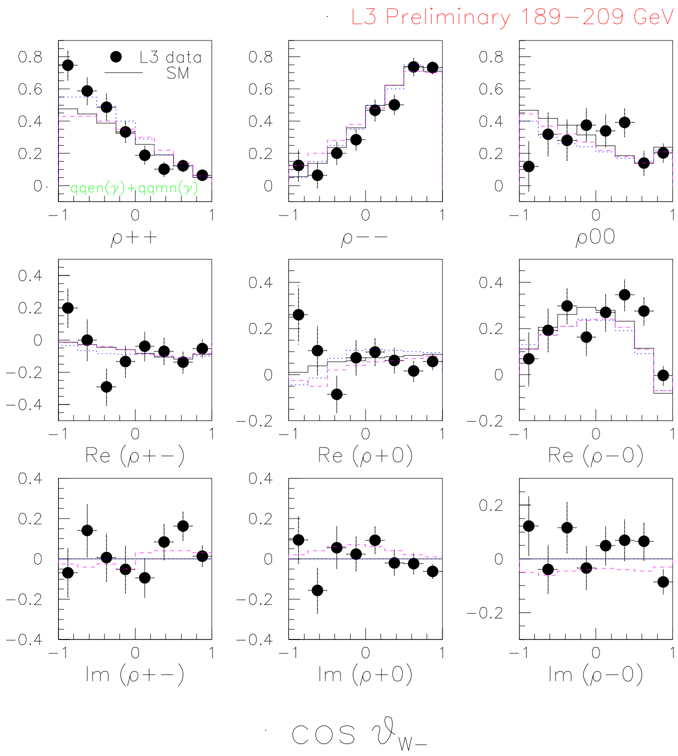

Figure 6: *The nine single SDM elements, $\rho^{W^-}_{\tau\tau'}$, as a function of* $\cos\theta_{W^-}$. *The errors bars include statistical and systematic uncertainty.*

The SDM elements are calculated in bins of $\cos\theta_{W^-}$ using a projection operator method assuming a V-A decay of the W boson into fermions

$$\rho^{W^-}_{\tau\tau'}(k) = \frac{1}{N_k}\sum_{i=1}^{N_k}\Lambda^{W^-}_{\tau\tau'}(\theta^\star_f,\phi^\star_f)_i \ , \tag{1.6}$$

where N_k is the number of events in the k-th bin and where the projection operator $\Lambda^{W^-}_{\tau\tau'}$ is applied event by event. The reconstructed SDM elements need to be corrected for detector acceptance, resolution effects and background contamination for a direct comparison with the theoretical expectation.

The single W SDM elements measured with the L3 combined $q\bar{q}e\nu$ and the $q\bar{q}\mu\nu$ data selected at the center-of-mass energies $\sqrt{s} = 189-209$ GeV are presented in Figure 6 [14]. The measurements for the leptonically decaying W^+ and W^- are combined assuming CPT-invariance. Agreement is found with the Standard Model prediction represented by the solid line. The expected distributions in presence of an anomalous CP-conserving coupling $\kappa_\gamma = +1.5$ (blue dotted line) and the CP-violating coupling $\tilde{\lambda}_Z = -0.5$ (pink dashed line) are also shown.

Parameter	DELPHI 189-208 GeV	OPAL 189 GeV
g_4^Z	-0.30 ± 0.17	$+0.01^{+.32}_{-.33}$
$\tilde{\lambda}_Z$	-0.08 ± 0.07	$-0.18^{+.24}_{-.16}$
$\tilde{\kappa}_Z$	$-0.03^{+.06}_{-.05}$	$-0.20^{+.10}_{-.07}$

Table 2: *The one-parameter fit results on the CP-violating TGC g_4^Z, $\tilde{\lambda}_Z$ and $\tilde{\kappa}_Z$. The error combine the statistical and the systematic uncertainty except for DELPHI where only the statistical component is included.*

Parameter	ALEPH	DELPHI	L3	OPAL
h_1^γ	[-.14 ; +.14]	[-.14 ; +.14]	[-.06 ; +.06]	[-.13 ; +.13]
h_2^γ	[-.07 ; +.07]	[-.09 ; +.09]	[-.053 ; +.024]	[-.089 ; +.089]
h_3^γ	[-.069 ; +.037]	[-.049 ; +.044]	[-.062 ; +.014]	[-.16 ; +.00]
h_4^γ	[-.020 ; +.045]	[-.032 ; +.030]	[-.004 ; .+045]	[-.01 ; +.13]
h_1^Z	[-.23 ; +.23]	[-.23 ; +.23]	[-.17 ; +.16]	[-.22 ; +.22]
h_2^Z	[-.12 ; +.12]	[-.14 ; +.14]	[-.10 ; +.09]	[-.15 ; +.15]
h_3^Z	[-.28 ; +.19]	[-.30 ; +.16]	[-.23 ; +.11]	[-.29 ; +.14]
h_4^Z	[-.10 ; +.15]	[-.12 ; +.18]	[-.08 ; +.16]	[-.09 ; +.19]
f_4^γ	[-.26 ; +.26]	[-.23 ; +.25]	[-.28 ; +.28]	[-.32 ; +.33]
f_5^γ	[-.54 ; +.56]	[-.52 ; +.48]	[-.39 ; +.47]	[-.71 ; +.59]
f_4^Z	[-.44 ; +.43]	[-.40 ; +.42]	[-.48 ; +.46]	[-.45 ; +.58]
f_5^Z	[-.73 ; +.83]	[-.62 ; +.38]	[-.35 ; +1.03]	[-.94 ; +.25]

Table 3: *The 95% confidence level one-dimensional limits set by the LEP experiments on the neutral triple gauge couplings.*

The imaginary parts of the off-diagonal elements are not sensitive to CP-conserving couplings and only contribute in presence of tree level CP-violation. This makes the SDM method particularly suitable to measure CP-violating couplings which are extracted by a χ^2-fit to the nine SDM-element distributions. The results of the DELPHI [15] and OPAL [16] experiment using semi-leptonic W-pair events are presented in Table 2. No deviation from the Standard Model prediction is observed.

2. Neutral Triple Gauge Couplings

Neutral triple gauge couplings do not exist in the Standard Model. The most general Lorentz invariant Lagrangian [5, 17] for the VVZ ($V = \gamma, Z$) vertex is described by 12 parameters. The couplings h_1^V, h_2^V, h_3^V and h_4^V are studied at LEP in the $e^+e^- \rightarrow Z\gamma$ production, while f_4^V and f_5^V are accessible in $e^+e^- \rightarrow ZZ$ production. Electromagnetic gauge invariance and Bose symmetry for final states with identical bosons are imposed. The couplings are determined from the angular distributions of the decay products and the total cross section. The one-dimensional limits at 95% confidence level are [1, 25] summarized in Table 3. Both statistical and systematic uncertainties are included. No evidence for anomalous h- and f- couplings has been found.

Parameter (GeV^{-2})	ALEPH	DELPHI	L3	OPAL
a_0^W/Λ^2	[-.060 ; +.055]	[-.020 ; +.020]	[-.015 ; +.015]	[-.020 ; +.020]
a_c^W/Λ^2	[-.099 ; +.093]	[-.063 ; +.032]	[-.048 ; +.026]	[-.052 ; +.037]
a_n^W/Λ^2		[-.180 ; +.140]	[-.140 ; +.130]	[-.160 ; +.150]
a_0^Z/Λ^2	[-.012 ; +.019]		[-.014 ; +.027]	[-.007 ; +.023]
a_c^Z/Λ^2	[-.041 ; +.044]		[-.037 ; +.054]	[-.029 ; +.029]

Table 4: *The 95% confidence level one-dimensional limits set by the LEP experiments on the quartic gauge couplings.*

3. Neutral and Charged Quartic Gauge Couplings

The contribution of the Standard Model quartic gauge couplings is below the LEP sensitivity and therefore, anomalous quartic gauge couplings resulting from new physics beyond the LEP energy are searched for. Deviations are introduced into the Lagrangian [18, 19] as effective couplings at a new physics scale Λ.

Starting from electromagnetic gauge invariance and custodial $SU(2)$ symmetry, the most general Lorentz invariant Lagrangian has 5 parameters. The charged quartic gauge couplings a_0^W/Λ^2, a_n^W/Λ^2 and a_c^W/Λ^2 are studied at LEP in the $e^+e^- \to W^+W^-\gamma$ reaction, while a_0^W/Λ^2 and a_c^W/Λ^2 are also accessible in the $e^+e^- \to \nu\bar{\nu}\gamma\gamma$ process. The neutral quartic gauge couplings a_0^Z/Λ^2 and a_c^Z/Λ^2, forbidden by the Standard Model, are searched for in the $e^+e^- \to Z\gamma\gamma \to \nu\bar{\nu}\gamma\gamma$, $q\bar{q}\gamma\gamma$ process. Quartic gauge couplings are mainly determined from the photon energy spectrum and the total cross section.

The one-dimensional limits at 95% confidence level on the charged and neutral quartic gauge couplings set by ALEPH [20], DELPHI [21], L3 [22, 23] and OPAL [24] are summarized in Table 4. Both statistical and systematic uncertainties are included. No evidence for anomalous quartic gauge couplings has been found.

4. Techni-ρ Resonance

The existence of a techni-ρ resonance in $W_L^+W_L^-$ production, in analogy with the ρ-resonance formation in the $e^+e^- \to \pi^+\pi^-$ reaction, is probed by the ALEPH experiment through the study of the complex technipion form factor F_T [26]

$$F_T = \frac{M_\rho^2 - i\Gamma_\rho M_\rho}{M_\rho^2 - s - i\Gamma_\rho M_\rho} \tag{4.1}$$

where M_ρ and Γ_ρ are the mass and the width of the techni-ρ respectively. No deviation from the Standard Model prediction is observed.

The 95% confidence level intervals on the techni-ρ formfactor are

$$0.868 < Re(F_T) < 1.061$$
$$-0.332 < Im(F_T) < 0.044$$

which leads to the 95% confidence level limit $M_\rho < 600$ GeV/c^2, assuming the techni-ρ width to be smaller than its mass [7].

Acknowledgments

I wish to express my gratitude to my collegues from LEP and convenors of the LEP gauge coupling working groups for their support and discussions.

References

[1] The LEP Collaborations ALEPH, DELPHI, L3, OPAL and the LEP TGC Working Group, LEPEWWG/TGC/2003-01(2003), LEPEWWG/TGC/2005-01(2005), http://lepewwg.web.cern.ch/LEPEWWG/lepww/tgc.

[2] S.L.Glashow, Nucl. Phys. **22** (1961) 579 ;
S.Weinberg, Phys. Rev. Lett. **19** (1967) 1264 ;
A.Salam, in *Elementary Particle Theory*, ed. N. Svartholm, Stockholm, Almquist and Wiksell (1968), 367.

[3] S.Jadach *et al.*, *Precision Predictions for (Un)Stable W^+W^- Pair Production At and Beyond LEP2 Energies*, Phys. Rev. **D 65** (2002) 093010.

[4] A.Denner *et al.*, *Electroweak Radiative Corrections to $e^+e^- \to W^+W^- \to$ 4 fermions in Double Pole Approximation : the RACOONWW Approach*, Nucl. Phys. **B 587** (2000) 67.

[5] K.Hagiwara, R.D.Peccei, D.Zeppenfeld and K.Hikasa, Nucl. Phys. **B 282** (1987) 253.

[6] J.Alcaraz, L3 Note 2718 (2001).

[7] ALEPH Collaboration, Phys. Lett.**B 614** (2005) 7.

[8] S.J.Brodsky and S.D.Drell, Phys.Rev. **D 22** (1980) 2236.

[9] H.Frauenfelder and E.M.Henley, *"Subatomic physics"*, Englewood Cliffs, New Jersey (1974).

[10] L3 Collaboration, *"Measurement of Triple-Gauge-Boson Couplings of the W boson at LEP"*, Phys. Lett. **B 586** (2004) 151.

[11] G.Gournaris, D.Schildknecht and F.M.Renard, Phys. Lett. **B 263** (1991) 291.

[12] G.Gournaris, J.Layssac, G.Moultaka and F.M.Renard, Int. J. Mod. Phys. **A 8** (1993) 3285.

[13] M.Bilenky, J.L. Knuer, F.M. Renard and D. Schildknecht, Nucl. Phys. **B 409** (1993) 22 ;
B 419 (1994) 240.

[14] L3 Collaboration, L3 Note 2831, submitted to HEP-EPS2005 (Lisbon).

[15] DELPHI Collaboration, DELPHI 2004-018 CONF 693 (2004), submitted to ICHEP2004 (Beijing).

[16] OPAL Collaboration, G.Abbiendi *et al.* Eur. Phys. J. **C 19** (2001) 1-14.

[17] G.J.Gounaris *et al.* Phys. Rev. **D 61** 075020 (2000).

[18] G.Bélanger and F.Boudjema, Phys. Lett. **B 288** (1992) 210.

[19] W.J.Stirling and Ghadir Abu Leil, J. Phys. **G 21** (1995) 517.

[20] ALEPH Collaboration, "Anomalous Quartic Gauge Couplings in e^+e^- Interactions from 183-209 GeV", submitted to HEP-EPS2003 (Aachen) and ICHEP2004 (Beijing).

[21] DELPHI Collaboration, Eur. Phys. J. **C 31** (2003) 139-147.

[22] L3 Collaboration, Phys. Lett. **B 527/1-2** (2002) 29-38.

[23] L3 Collaboration, Phys. Lett. **B 540/1-2** (2002) 43-51.

[24] OPAL Collaboration, Phys. Rev. **D 70** (2004) 032005.

[25] DELPHI Collaboration, 2005-006 CONF 726 (2005), submitted to HEP-EPS2005 (Lisbon) and LP2005 (Uppsala).

[26] T.L.Barklow *et al.*, *"Strong coupling electroweak symmetry breaking"* in Proceedings of DPF/DPB *"Summer Study on New Directions for High Energy Physics (Snowmass 1996)"*, Snowmass, Colorado, eConf **C960625** (1996) STC118.