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Measurement of charged triple gauge-boson couplings(cTGC) at LEP2

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The measurement of charged triple gauge-boson couplings (WWZ and WWγ vertices) at LEP2 is presented, in this note, based on the whole data collected between 1997 and 2000. It corresponds to $\simeq$700 pb^{-1} per experiment with energies ranging from 183 to 209 GeV. These couplings are measured through W-pair and single W events and are compared to the Standard Model expectation. Deviations would indicate new physics at higher energies than for direct searches. This note will show that these measurements achieve a precision of a few percent and are limited by systematics.

1. Introduction

Due to the non-abelian nature of $SU(2)_L \times U(1)_Y$, WWV (V=Z or γ) vertices exist at tree level. In the Standard Model, the effective coupling is affected by vertex corrections including known particles ($\simeq 10^{-3}$[1]). It can also have contributions from new particles existing at higher scale than LEP2 threshold. Deviations from the Standard Model expectations would indicate new physics at higher scale. For the Minimal SuperSymetric Model, it was estimated to be of the order of 10^{-3}[1].

The most general Lagrangian being Lorentz invariant for the WWV interaction is described in these papers[1],[2],[3],[4]. It contains seven terms:

- (g_1^V, κ_V and λ_V) conserve C and P
- g_5^V violates C and P but conserves CP
- (g_4^V, $\tilde{\kappa}_V$ and $\tilde{\lambda}_V$) violate CP

For ICHEP2002, the only new measurement of individual coupling provided by LEP experiments comes from OPAL on g_5^Z[5]. Because there is no new LEP combined result on individual parameters, no number is presented in this note.

Taking into account usual constraints (C and P conservation, U(1)$_{em}$ gauge symmetry) and LEP1 indirect measurements, the base line analysis[1] at LEP2 measures 3 parameters (Δg_1^Z , $\Delta\kappa_\gamma$, λ_γ) which are the most likely to deviate from the Standard Model. They are equal to zero at the Standard Model. The $SU(2)_L \times U(1)_Y$ gauge symmetry implies the following constraint:

$$\Delta\kappa_Z = \Delta g_1^Z + \Delta\kappa_\gamma \tan^2\theta_w; \lambda_Z = \lambda_\gamma$$

Results are computed for the following configurations :

- three measurements of a single parameter (implying that the two others are fixed at their Standard Model value)
- simultaneous measurement of the three parameters

These couplings are evaluated through the single W and W-pair productions. A new result is presented by OPAL using single-γ channel[6]. It is not used for the final LEP combination because of its low sensitivity for cTGC compared to the two other channels with equivalent luminosity.

2. WW analysis

W pair production is sensitive to Δg_1^Z, $\Delta\kappa_\gamma$ and λ_γ through the s-channel contrary to the t-channel. Since the s-channel contribution increases with energy, the sensitivity to cTGC improves also with energy.

The selection of WW events is the same as for the cross section[7] but restricted to well reconstructed events[8]. Anomalous couplings affect quadratically the differential cross-section as summarized in the following equation.

$$d\sigma(\Omega,\alpha) = S^0(\Omega) + \Sigma_i \alpha_i . S_i^1(\Omega) + \Sigma_{ij} \alpha_i . \alpha_j . S_{ij}^2(\Omega) \quad (1)$$

with $\alpha_i = g_1^z$, κ_γ and λ_γ and Ω describes phase space. This effect is looked for through the total WW cross section and the kinematical distributions of events. Cross section are extracted from adjustment of the expected cross-section which is a function of couplings to the observed one. The kinematic information is described by 5 angles ($\cos\theta_W$,$\cos\theta^*$ and ϕ^* of the fermion in both Ws). To have the most precise measurement of one/many couplings from the five angles, an unbinned maximum likelihood is performed by ALEPH (analytical Particle Density Function convoluted with a detector resolution function), DELPHI and L3 (PDF mapped from simulated events). A second solution is the Optimal Observable[9] method where the five kinematic variables are projected onto 1 or 2 parameters per TGC coupling. OPAL and ALEPH fits the $\mathcal{O}_i^1$ and $\mathcal{O}_{ij}^2$ averages.

The main sensitive channel is the semileptonic one because the lepton tags the W charge and the jet pair gives the W direction. In the fully hadronic channel, the mispairing of jets to reconstruct Ws (80% efficiency) and the mischarge assignment of Ws (80 % efficiency) decrease the sensitivity. The fully leptonic channel is handicapped by its low branching ratio compared to the two other ones. The figure 1 gives the relative sensitivity for λ_γ for each channel.

3. Single W analysis

The single W channel was defined by the LEP TGC Working Group to deal with the many t-channel diagram contributions. It is asked that:

- the electron is undetected ($|\cos\theta| > 0.95$)
- in case of $W \rightarrow l\nu$ the lepton is within the detector acceptance and with an energy greater than 20 GeV
- in case of $W \rightarrow q\bar{q'}$, the invariant mass should be greater than 45 GeV

The selection for the hadronic and leptonic decays of the W is identical to the cross section one [10].

This channel is sensitive to couplings mainly through the cross-section measurement. The

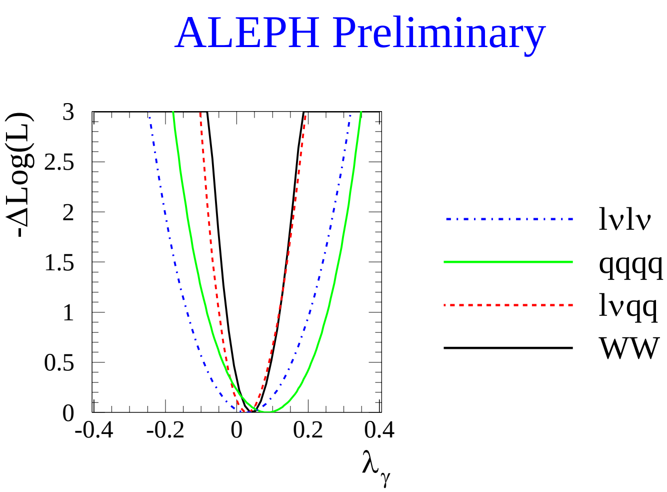

Figure 1. Loglikelihood distributions for fully hadronic, semileptonic, fully leptonic channels to λ_γ and the combined one (WW)

kinematic information improves slightly the measurement [11] and is given by:

- Pt_W,$|\cos\theta_{jet1} - \cos\theta_{jet2}|$, NN output for W→2 jets
- E_l,$\cos\ \theta_l$ for W→lν

4. Systematics

The main systematic affecting the single-W channel is the theoretical uncertainty on the total cross section (± 5%). It is smaller than the statistical uncertainty since one measures experimentally the cross section with a precision of 8%.

For the TGC measurement using W-pair events, there are five systematics:

- the fragmentation model of jets (comparison JETSET/HERWIG),
- the empirical models on final state interaction (Bose-Einstein and Color Reconnection effect) affecting the fully hadronic channel
- the theoretical uncertainty on the total W

pair cross-section (±0.5%) after $\mathcal{O}(\alpha)$ correction

- the theoretical uncertainty on the $\mathcal{O}(\alpha)$ correction to the angle distributions after $\mathcal{O}(\alpha)$ correction

Although there is an estimation of the last systematics[12][13], the LEP-TGC Working Group decided to be conservative and quotes as systematics the full effect. The numerical values of the systematics are listed in table 1.

Table 1
List of systematics for cTGC

Systematics	Δg_1^Z	λ_γ	$\Delta\kappa_\gamma$
σ (Weν)	-	-	0.011
Fragmentation	0.004	0.002	0.004
Color-Reconnection	0.005	0.004	0.010
Bose-Einstein	0.005	0.004	0.009
σ (W^+W^-)	0.003	0.005	0.014
Full $\mathcal{O}(\alpha)$ corr. on angular distribution	0.015	0.015	0.039

The $\mathcal{O}(\alpha)$ uncertainty on the angular distribution of $\cos\theta_W$ is the main contributor to systematics.

5. Global results

For the W-pair analysis, the presented results[14] include all LEP2 data up to 209 GeV (≃700 pb^{-1} per experiment). Most of the experiments analyzed the single W channel up to 202 GeV. For the LEP combination, the likelihood (statistical+uncorrelated systematics) are provided by each experiment for the W pair and single W channels. Due to the non gaussian behavior of the curves especially in multidimensional fits, a special minimization method[15] has been performed to improve the treatment of correlated systematics which are not small compared to the statistical errors. The results are presented for 1D or 3D fit in figures 2 and 3. In the 3D fit, ALEPH data are not included.

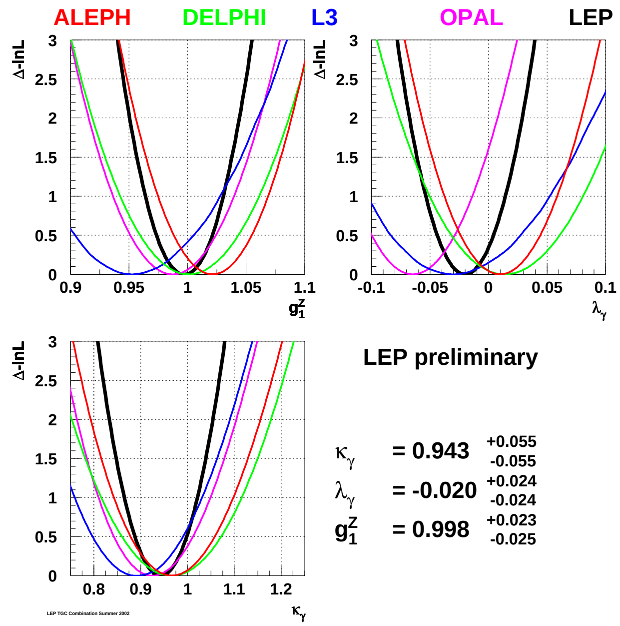

Figure 2. Results for 1 parameter fit for the 4 LEP experiments and the combined one

Conclusion

For the baseline analysis, supposing that only one parameter deviates from Standard Model, the limits at 95% confidence level, are:

$$0.951 < g_1^Z < 1.043$$

$$0.835 < \kappa_\gamma < 1.052$$

$$-0.067 < \lambda_\gamma < +0.028$$

Since almost all LEP2 data have been analyzed (only single W has not been analyzed at all energies), no major improvement on the statistical error is foreseen at LEP2. But, the measurement is still limited by the full $O(\alpha)$ correction systematics. Experiments are cross checking the results based on YFSWW/RACOONWW comparisons to reduce it. In the mean time, experiments are finalizing their results. The LEP2 data analysis for charged triple gauge-boson couplings rejects models changing the effective coupling by more than a few percent.

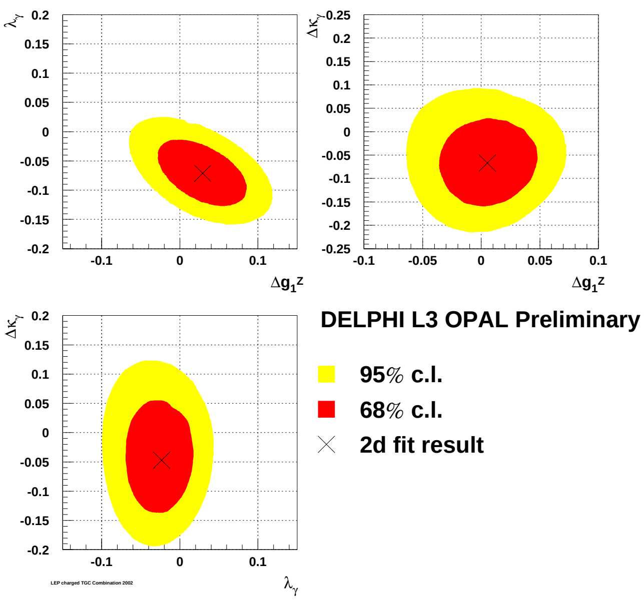

Figure 3. Result for 3 parameter fit. Figures are plotted with the third parameter fixed at the smallest χ^2. ALEPH results are not included

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