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Isolated photons and constraints on anomalous WWγ couplings at LEP2

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Abstract

A study of single and multiphoton events has been performed for the data sample obtained with the ALEPH detector at 161 and 172 GeV in 1996. The anomalous coupling parameters are measured, leading to the values:

$$\Delta\kappa_\gamma = -0.5^{-2.8}_{+3.3}(\mathrm{stat})^{-0.45}_{+0.35}(\mathrm{syst})$$
$$\lambda_\gamma = 0. \pm 5.8(\mathrm{stat})^{-0.45}_{+0.35}(\mathrm{syst})$$

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1 Introduction

The study of the reaction $e^+e^- \to \gamma(\gamma)$ + X(X: undetectable particles) at LEP2 energies covers a wide range of physics topics :

- An inclusive measurement of neutral events with at least two energetic photons is a test, at these energies, of the purely QED process $e^+e^- \to \gamma\gamma(\gamma)$ [1], and of the pointlike structure of the electron.

- One may search for pairs of neutral SUSY particles such as neutralinos (followed by their decay into a gravitino and a photon).

- When a final state leads to the $\nu\overline{\nu}\gamma(\gamma)$ channel, it comprises the radiative return to the Z^0 with one or several photons (the Z^0 decaying into $\nu\overline{\nu}$), the W exchange in the t-channel and the W W γ process. At these energies, the weak corrections may become significant above the W pair production threshold.

  In this channel it is possible to measure the so-called "anomalous coupling parameters", which would lead to deviations from Standard Model (SM) predictions in the $\nu\overline{\nu}\gamma(\gamma)$ final state. The WWγ anomalous coupling is described by only two parameters, $\Delta\kappa_\gamma$ and λ_γ, as $\Delta g_1^\gamma = 0$ for real photons. At LEP2 the trilinear gauge couplings can also be measured in the W pair production channel. In the latter case, the W$^+$W$^-$ channel receives contributions from six WWγ and WWZ couplings [1], leading inevitably to model-dependant descriptions where the six couplings are interrelated (e.g. the model with $\alpha_W, \alpha_{W\phi}, \alpha_{B\phi}$ [1]).

In this paper we describe the measurement of the anomalous coupling parameters $\Delta\kappa_\gamma$ and λ_γ from the $e^+e^- \to \nu\overline{\nu}\gamma(\gamma)$ channel, using data taken at 161 and 172 GeV. The theoretical framework of this study follows the one presented in [2] and [3], in which the matrix elements of the standard and non-standard couplings are calculated using the helicity formalism. The prospects of this measurement lie in combination with the results from the W pair channel and the single W channel.

2 Event samples and selection

2.1 Data and Monte Carlo event samples

The data have been collected with the ALEPH detector at LEP in 1996, at a centre of mass energy of 161 and 172 GeV. The ALEPH detector and its performance are described in detail elsewhere [4].

The simulation uses a modified version of the KORALZ program [5], which comprises SM expectations (electroweak corrections) as well as QED radiative corrections, and the contributions of anomalous coupling amplitudes with exact matrix element calculations [6]. For each event, this program produces six weights which may be used to recalculate any variable as a function of $(\Delta\kappa_\gamma, \lambda_\gamma)$. Therefore only one simulation is necessary for a given energy.

2.2 Selections and cuts

Only events with no charged tracks and at least 1 photon with an energy $\mathrm{E}_\gamma > 0.1\sqrt{\mathrm{s}}$ GeV are considered. At most 1 hit is required in the muon chambers, to eliminate beam-related background events; the timing of the energy deposition in the electromagnetic calorimeter is checked to be consistent with the beam crossing time.

A photon candidate is then identified as a localised energy deposition in the electromagnetic calorimeter with a profile consistent with that of an electromagnetic shower. The additional selections are based on the results of the energy flow algorithm (Eflow) which estimates the total energy deposited in the detector as described in [7]. All events containing an energy contribution within a cone of 12° with respect to the beam axis are rejected, which removes radiative Bhabha events. Furthermore, to minimize the remaining background, the resulting total energy flow is required to satisfy the condition:

$$10 \text{ GeV} < \text{Eflow} < 80 \text{ GeV}$$

and to come mostly from photon candidates:

$$|\mathrm{E_{flow}} - \textstyle\sum_\mathrm{i} \mathrm{E}^\mathrm{i}_\gamma| < 2.5 \text{ GeV},$$

where the sum runs over all photon candidates.

The photon energy E_γ is estimated from the electromagnetic energy deposition (summed with the hadronic energy when the photon points to a crack region). At least one photon candidate is required to fulfil the following conditions:

$$E_\gamma > 0.1\sqrt{s}$$
$$\theta_\gamma > 20^\circ$$
$$x_T = p_T^\gamma / E_{beam} > 0.15$$

In addition, for the multiphoton candidates, the energy of the second photon is required to be greater than 2 GeV, and the overall missing momentum $p_{T_{miss}}$ is required to fulfil the condition:$p_{T_{miss}} > 10\mathrm{GeV/c}$.

Table 1 shows the data and Monte Carlo event samples used in this analysis.

Table 1: Data and Monte Carlo samples

Energy (GeV)	Luminosity (pb^{-1})	Data N Events	Monte Carlo N Events
161	11.0	37	4×10^4
172	10.7	31	8×10^4
Total	21.7	68	12×10^4

2.3 Kinematic regions used in this study

Two kinematical variables of the photon are used: the scaled energy x_E ($x_E = E_\gamma / E_{beam}$) and the scaled transverse momentum x_t. The domains of these variables vary with the centre of mass energy. Two regions of interest are used, below and above the Z^0 peak for which the sensitivity to anomalous couplings is very poor:

region (1) where

$$x_E < 0.585 \text{ (161 GeV)}$$
$$x_E < 0.625 \text{ (172 GeV)}$$

corresponding to the photon energy:

$$E_\gamma < E_\gamma(Z^0) + 3\Gamma_Z$$

and region (2) where

$$x_E > 0.685 \text{ (161 GeV)}$$
$$x_E > 0.725 \text{ (172 GeV)}$$

corresponding to:

$$E_\gamma > E_\gamma(Z^0) + 0.5 \text{ GeV}$$

where $E_\gamma(Z^0)$ is the expected photon energy in case of one photon radiative return.

Figure 1 shows the distribution of the scaled energy for data, compared to the Standard Model predictions. A good compatibility is observed. In the following analysis, the two kinematic regions were treated separately and the results merged at the level of the likelihood functions.

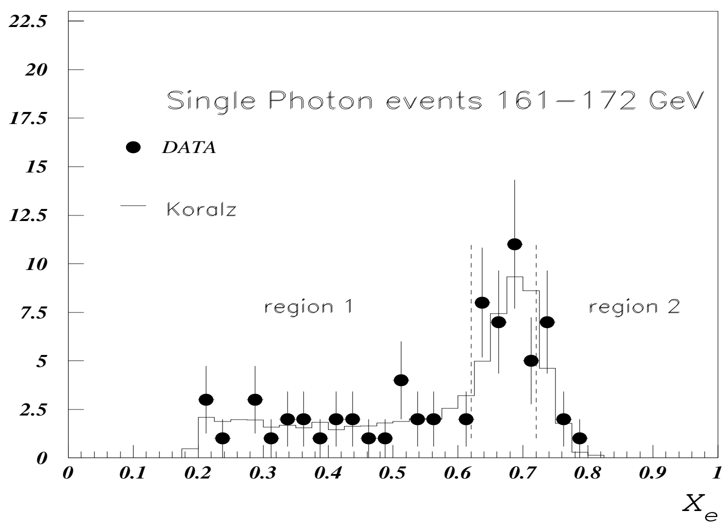

Figure 1: Distribution of the scaled energy x_E of single photons, for data and Monte Carlo

2.4 Background contributions

The possible contributions to the $e^+e^- \to \gamma(\gamma) + \mathrm{X}$ channel, other than $\mathrm{X} = \nu\overline{\nu}$, may come from radiative Bhabhas, QED multiphotons or SUSY particles. The angular and energy cuts eliminate the first two contributions. The SUSY particles have not yet been observed, however they may interfere in the anomalous coupling interpretation of the deviations from the Standard Model.

The irreducible background in region 1 comes from the multiphoton Z^0 return.

The KORALZ simulation of higher order effects gives about +100% correction for the cross-section in region 1, and about −30% correction in region 2.

A theoretical estimate of the error on these correction factors is of the order of $10 - 15\%$. However, only comparisons with complete calculations from the exact matrix elements (not present in KORALZ) for the 2 and 3 hard bremsstrahlung photons will allow a satisfactory estimation of this uncertainty. A discussion of the uncertainty due to the implementation of the matrix elements with anomalous couplings for the multiphoton events will be presented in a future publication.

3 Likelihood fit

The limits for anomalous coupling parameters have been derived from the generalised likelihood expression:

$$\mathrm{L} = \frac{(\mathrm{N_{th}})^{\mathrm{N_{obs}}}\, \mathrm{e}^{-\mathrm{N_{th}}}}{\mathrm{N_{obs}}!} \prod_{\mathrm{i=1}}^{\mathrm{Nobs}} \mathrm{P_i}$$

$\mathrm{P_i}$ is the probability for each event obtained from the kinematical distributions.

This likelihood formula contains two parts: the first one concerning the number of observed events, the second one being related to differential distributions for each kinematic region. This leads to an expression containing four terms:

$$\log(\mathrm{L}) = \log\left(\frac{(\mathrm{N_{th}})^{\mathrm{N_{obs}^{(1)}}}\, \mathrm{e}^{-\mathrm{N_{th}}}}{\mathrm{N_{obs}^{(1)}}!}\right) + \log\left(\frac{(\mathrm{N_{th}})^{\mathrm{N_{obs}^{(2)}}}\, \mathrm{e}^{-\mathrm{N_{th}}}}{\mathrm{N_{obs}^{(2)}}!}\right) + \sum \log(\mathrm{P_i^1}) + \sum \log(\mathrm{P_i^2})$$

where $\mathrm{N_{th}}$ is the expected number of events in each region, including background. The acceptance convoluted with the experimental resolution leads to correction factors of 0.75 for the first kinematic region and 1.4 for the second.

The treatment of the two kinematic regions differs in the following points:

- Region 1 (low energy photons) : the contribution from higher order radiative corrections is described as a constant term obtained by the Monte Carlo simulation; this procedure results in a relatively low uncertainty on these corrections. The scaled p_t variable, x_t, is found to be the most discriminant single variable for the $\Delta\kappa_\gamma, \lambda_\gamma$ measurement in this region, and is used as a kinematical variable in the unbinned likelihood fit.

- Region 2 (high energy photons) : the higher order radiative corrections decrease the number of expected events by 30 %. In this region, the scaled energy x_E is found to be the most discriminant single variable and is used in the fit.

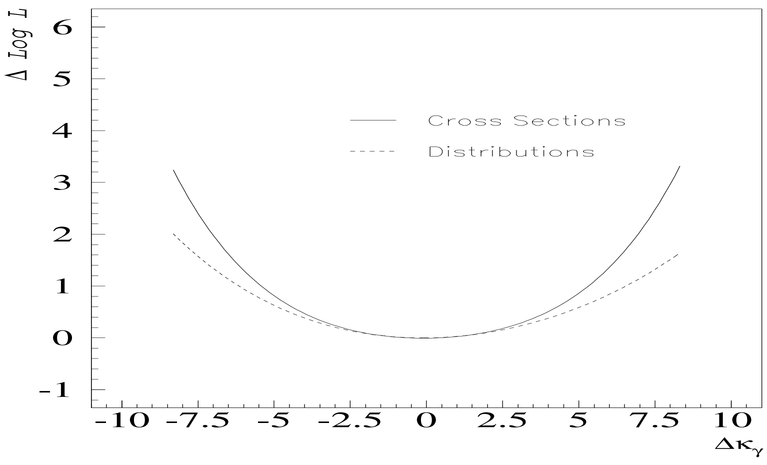

Figure 2: Likelihood curves for the fit of $\Delta\kappa_\gamma$ at $\lambda_\gamma = 0$

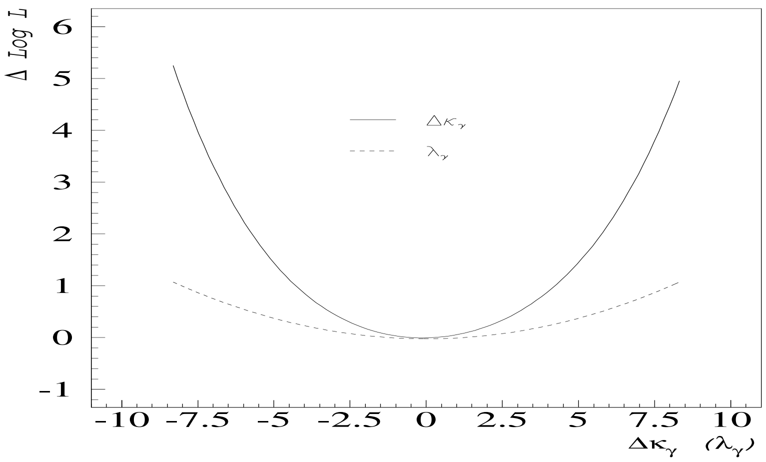

Figure 3: Likelihood curves for the fit of λ_γ at $\Delta\kappa_\gamma = 0$ and $\Delta\kappa_\gamma$ at $\lambda_\gamma = 0$.

The cross-sections and distribution shapes vary differently in the two regions. As this variation is monotonous and linear for $\Delta\kappa_\gamma(\lambda_\gamma) > 0$ and $\Delta\kappa_\gamma(\lambda_\gamma) < 0$ for the low energy photons, only one solution is expected for the $\Delta\kappa_\gamma$ fit. For the high energy photons, the dependences are quadratic and one or two solutions are expected, the case of one solution corresponds to $\Delta\kappa_\gamma = 0$ or $\lambda_\gamma = 0$. The likelihood fit yields consistent results for both kinematic regions.

4 Results

Figure 2 shows the -Δlog(L) curves corresponding to the fit of $\Delta\kappa_\gamma$ at $\lambda_\gamma = 0$, the cross-section and distribution terms being separated. At present energies, the cross-section term gives the dominant contribution but at higher centre of mass energies the two terms are expected to contribute equally.

Figure 3 shows the -Δlog(L) functions for $\Delta\kappa_\gamma$ fitted at $\lambda_\gamma = 0$, and for λ_γ fitted at $\Delta\kappa_\gamma = 0$.

The results are:

$$\Delta\kappa_\gamma = -0.5^{-2.8}_{+3.3}(\text{stat}) \text{ (assuming } \lambda_\gamma = 0)$$
$$\lambda_\gamma = 0. \pm 5.8\text{stat (assuming } \Delta\kappa_\gamma = 0).$$

The analysis of $\lambda_\gamma(\Delta\kappa_\gamma)$ has been repeated for various values of $\Delta\kappa_\gamma(\lambda_\gamma)$. The results show almost no correlation between the two parameters. Figure 4 displays the 1- and $2-\sigma$ contours in the $(\Delta\kappa_\gamma, \lambda_\gamma)$ plane.

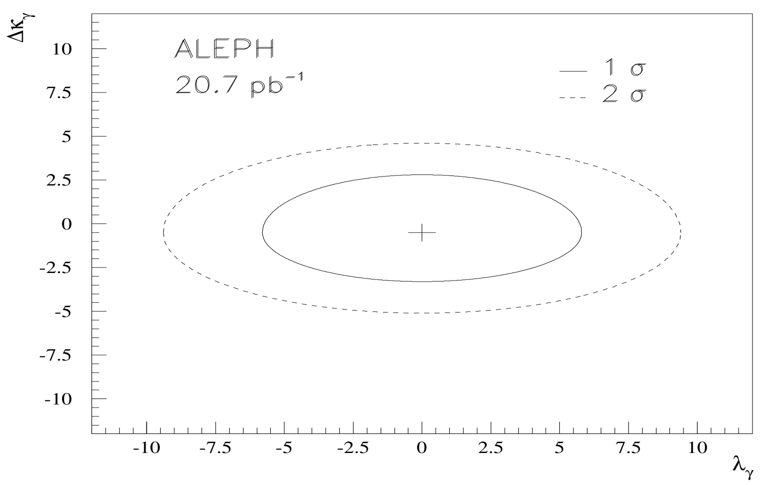

Figure 4: $\Delta\kappa_\gamma, \lambda_\gamma$ contours

5 Systematic uncertainties

A total number of 42 simulated Monte Carlo samples have been used to study possible statistical biases due to the very limited data sample. The size of the Monte Carlo samples has been optimized to minimize the inhomogeneity of the weights in the sample: 4 times the data for region 1 and 12 times for region 2. This procedure allows to cross-check the linearity of the measured parameters as a function of the true ones as well as the validity of the errors given by the likelihood fit. Both linearity and error estimations were found to be reliable.

The contributions to the systematic uncertainty on the determination of $\Delta\kappa_\gamma$ and λ_γ are summarised in Table 2.

Table 2: Contributions to the systematic uncertainty

Uncertainty	Error
Photon energy calibration $\pm 1\%$	± 0.25
QED Background	- 0.25
Higher Order corrections $\pm 15\%$	± 0.2
Fit procedure	- 0.2
Total	- 0.45 + 0.35

The total systematic uncertainty is much lower than the statistical one and the present study does not contain all possible contributions. In particular the effects of photon conversions in the inner part of the ALEPH detector have not yet been studied.

The main contribution to the systematic error in the present study comes from the energy calibration of high energy photons. Here, the redundancy of the photon energy measurement on the pads and on the wires of the electromagnetic calorimeter [4] plays a crucial role. The other contributions will substantially decrease when the luminosity of the data sample increases. The photon energy calibration will be checked with a large QED photon sample.

6 Conclusions

The anomalous coupling parameters $\Delta\kappa_\gamma$ and λ_γ have been measured from single photon production at 161 and 172 GeV. The results from the fit to the cross-sections and to the p_t and energy distributions of the photons (for $\Delta\kappa_\gamma$) are:

$$\Delta\kappa_\gamma = -0.5^{-2.8}_{+3.3}(\text{stat})^{-0.45}_{+0.35}(\text{syst}) \text{ (assuming } \lambda_\gamma = 0)$$
$$\lambda_\gamma = 0. \pm 5.8(\text{stat})^{-0.45}_{+0.35}(\text{syst}) \text{ (assuming } \Delta\kappa_\gamma = 0).$$

The uncertainty is largely dominated by the limited statistics of the data sample.

The future developments will concentrate on a full two-parameter fit to the double differential cross-section $d^2\sigma/d\theta_\gamma dE_\gamma$.

7 Acknowledgements

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