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Constraints on Anomalous Quartic Gauge boson Couplings from photon pair events from 189 to 209 GeV

ALEPH Collaboration
PRELIMINARY

Abstract

The analysis of acoplanar photon pair events with missing energy and transverse momentum measured in the ALEPH detector at centre-of-mass energies between 189 and 209 GeV, leads to constraints on anomalous quartic gauge couplings in the reaction $\mathrm{e}^+\mathrm{e}^- \to \nu\bar{\nu}\gamma\gamma$.

From 1-parameter fits, and using only the cross-section variation in the low missing mass region, the following 95 % CL constraints are obtained on the anomalous parameters a_0/Λ^2 and a_c/Λ^2:

$$-0.029\ \mathrm{GeV}^{-2} < a_0/\Lambda^2 < 0.026\ \mathrm{GeV}^{-2}$$

$$-0.080\ \mathrm{GeV}^{-2} < a_c/\Lambda^2 < 0.075\ \mathrm{GeV}^{-2}$$

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1 Introduction

Quartic gauge couplings (QGCs) between the electroweak vector bosons are predicted by the Standard Model (SM), as a consequence of the SU(2) × U(1) non-Abelian gauge structure. The SM prediction for the QGC cross-section at LEP2 energies is very small, of the order of 1 femtobarn [1]; however it is possible that new physics at large unprobed scales may give low energy effects, leading to "anomalous" QGCs in the SM Lagrangian.

In addition to Triple Gauge Couplings (TGCs) which are well constrained to zero, the QGCs provide a new window to Electroweak Symmetry breaking, in particular in the Higgs sector. When TGCs are constrained to zero, the QGCs may deviate from SM values.

This note gives limits on the possible contributions of QGCs to the reaction $e^+e^- \rightarrow \nu\overline{\nu}\gamma\gamma(\gamma)$ at LEP2 energies. This channel probs the QGC vertex shown in the diagram of Figure 1.

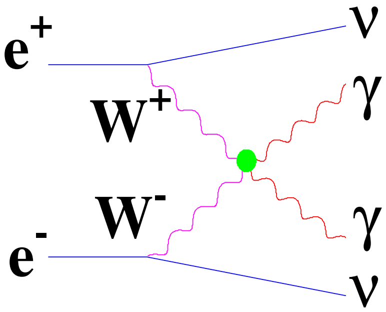

Figure 1: W fusion diagram giving quartic gauge couplings considered in the present analysis.

Anomalous "genuine" QGC contributions are described by two additional dimension six terms in the Lagrangian [1]:

$$
\begin{aligned}
L_6^0 &= -\frac{e^2}{16}\,\frac{a_0}{\Lambda^2}\,F^{\mu\nu}F_{\mu\nu}\,\overrightarrow{W^{\alpha}}\cdot\overrightarrow{W_{\alpha}} \\
L_6^c &= -\frac{e^2}{16}\,\frac{a_c}{\Lambda^2}\,F^{\mu\alpha}F_{\mu\beta}\,\overrightarrow{W^{\beta}}\cdot\overrightarrow{W_{\alpha}}
\end{aligned}
$$

where $F_{\mu\nu}$ is the field strength tensor of the photon and $\overrightarrow{W_\mu}$ is the weak boson field:

$$
\overrightarrow{W_\mu} = \begin{pmatrix} \frac{1}{\sqrt{2}}(W_\mu^+ + W_\mu^-) \\ \frac{i}{\sqrt{2}}(W_\mu^+ - W_\mu^-) \\ Z_\mu/cos\theta_W \end{pmatrix}
$$

The parameters a_0 and a_c describe respectively the neutral and charged strength of the QGCs, and Λ represents the scale of the new physics responsible for the anomalous contributions; this scale is unknown and conventionnally set to M_W in previous publications. In the Standard Model one has $a_0 = a_c = 0$.

2 Event samples and selection

2.1 Data sample:

The data have been collected with the ALEPH detector at LEP in 1998, 1999 and 2000. The ALEPH detector and its performance are described in detail elsewhere [4].

In 1998 data were collected at a nominal centre-of-mass energy of 188.6 GeV, the integrated luminosity being 177.1 pb^{-1}. In 1999 data were collected at centre-of-mass energies of 191.6, 195.5, 199.5 and 201.6 GeV, the integrated luminosity being 241.6 pb^{-1}. In 2000, data were collected at various centre-of-mass energies between 200 and 209 GeV, the integrated luminosity being 222.3 pb^{-1}. This gives a total data sample of 641.1 pb^{-1}.

2.2 Monte Carlo simulation:

A generator - hereafter called EENUNUGGANO [1] - is used to simulate the QGC signal for the reaction $\text{e}^+\text{e}^- \to \nu\bar{\nu}\gamma\gamma$. This generator computes the SM quartic coupling contributions, as well as possible "anomalous" effects beyond the SM. However it contains only the subset of SM diagrams leading to the $\nu\bar{\nu}\gamma\gamma$ final state via WW fusion processes. In particular the radiative return production of Z^0 bosons is not included here. Therefore the cross-section calculation from EENUNUGGANO is meaningful only for $\nu\bar{\nu}$ invariant mass significantly away from the Z^0 resonance.

The simulation of the SM background has been done with the KORALZ program [2], which comprises SM expectations (electroweak corrections) as well as QED radiative corrections, for the reaction $\text{e}^+\text{e}^- \to \nu\bar{\nu}\gamma\gamma(\gamma)$

Using EENUNUGGANO for the QGC signal and KORALZ for the SM background may give some approximations: possible double counting of some SM diagrams and neglected interference effects. These approximations should be negligible if the search for a QGC signal is restricted to the region where the contribution from the SM is expected to be very small.

The QED background coming from the reaction $\text{e}^+\text{e}^- \to \gamma\gamma\gamma(\gamma)$ is simulated using the GGGB Monte-Carlo program [3].

2.3 Selection of events with two acoplanar high transverse momentum photons

Photon candidates in the ALEPH detector are defined as described in Ref [4].

Only events with no reconstructed charged particle tracks and total photon energy $\sum E_\gamma < \sqrt{s}$ are considered. At most 1 hit is required in the muon chambers, to eliminate beam-related and cosmic ray muons. Events with at least 0.5 GeV detected below 14° from the beam axis are rejected.

In the following sections, one considers only events with two and only two photon candidates which both fulfil all the conditions: $E_\gamma/\sqrt{s} > 0.05$, $|\cos\theta_\gamma| < 0.95$ and $p_{T\gamma}/E_{beam} > 0.05$. The energy deposition in the electromagnetic calorimeter is required to be outside the calorimeter cracks and to have a timing consistent with the beam crossing time.

Only events with a photon acoplanarity above ±5° are kept. This condition removes almost all candidates from the QED reaction $e^+e^- \to \gamma\gamma\gamma(\gamma)$.

Efficiencies are obtained from a full simulation of the detector and a reconstruction of the events generated by KORALZ. The reconstruction efficiency of a two-photon event which fulfils the above cuts is $70.0 \pm 2.0\%$. 22 events are found in the data, whereas 21.1 are expected from SM contributions.

Figure 2 shows the distribution of the photon energy, of $|\cos\theta_\gamma|$ and of the missing mass for data, compared to the SM predictions from KORALZ.

Finally, a cut is applied on the missing mass: $M_{miss} < 0.35\sqrt{s}$, which keeps events in a kinematical region where the generator EENUNUGGANO gives sizeable cross-sections. The number of data event after this cut is zero, the number of expected events from the SM being 0.2 and the contribution from QED processes being 0.01 events.

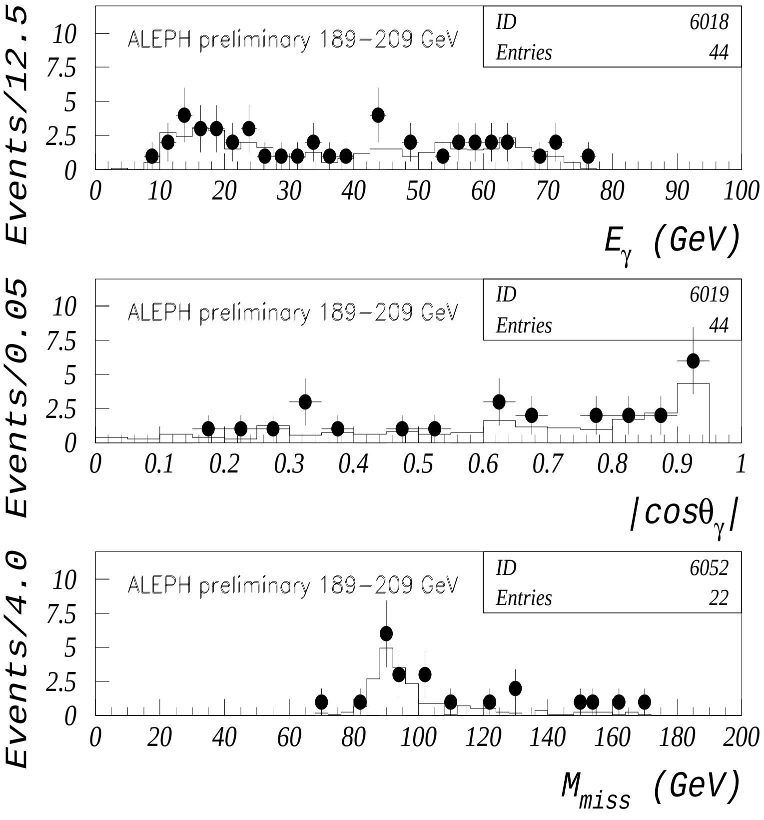

Figure 2: Distribution of the photon energy E_γ, of $|\cos\theta_\gamma|$ and of the missing mass for the 16 events with two photons selected as described in the text (black dots). The histograms show the SM Monte Carlo predictions.

2.4 Cross sections:

The data is divided in four samples:

- data taken at 188.6 and 191.6 GeV, with a resulting average energy $E_1 = 189.02$ GeV and a luminosity of 206.1 pb^{-1};

- data taken in year 1999 at 195.5, 199.5 and 201.6 Gev, with a resulting average energy $E_2 = 198.38$ GeV and a luminosity of 212.6 pb^{-1}.

- data taken in year 2000 between 199.8 and 206 GeV , with a resulting average energy $E_3 = 204.86$ GeV and a luminosity of 84.1 pb^{-1}.

- data taken in year 2000 above 206 GeV , with a resulting average energy $E_4 = 206.53$ GeV and a luminosity of 138.3 pb^{-1}.

As the Monte-Carlo program EENUNUGGANO doesn't include High Order (HO) radiative corrections, their effect is estimated from KORALZ as being equivalent to a shift in the center-of-mass energy. This leads to the following effective energies for the four data samples: $E_{eff}^{MC}(\mathrm{GeV}) = 187.0,\ 195.9,\ 201.7,\ 203.4$. The effect of radiative corrections is to decrease the expected cross-section and therefore to lower the sensitivity.

QGC and SM background cross sections are computed using respectively the Monte-Carlo programs EENUNUGGANO and KORALZ at the four above effective energies.

3 Results

3.1 Likelihood fit

Cross-section variations only have been used in the fit for a_0/Λ^2 and a_c/Λ^2.

Figure 3 shows the -Δlog(L) curve corresponding to the fit of a_0/Λ^2 with a_c set to 0., and Figure 4 the -Δlog(L) curve for the fit of a_c/Λ^2 with a_0 set to 0.

The following 95 % confidence level limits are obtained (with systematic errors included):

$$-0.029\ \mathrm{GeV}^{-2} < a_0/\Lambda^2 < 0.026\ \mathrm{GeV}^{-2}$$
$$-0.080\ \mathrm{GeV}^{-2} < a_c/\Lambda^2 < 0.075\ \mathrm{GeV}^{-2}$$

Figure 5 shows the 68% and 95% confidence level contours in the ($a_0/\Lambda^2, a_c/\Lambda^2$) plane from a two-parameter fit. The 95 % C.L. limits obtained from the 2-parameter fit give the following constraints :

$$-0.050\ \mathrm{GeV}^{-2} < a_0/\Lambda^2 < 0.048\ \mathrm{GeV}^{-2}$$
$$-0.100\ \mathrm{GeV}^{-2} < a_c/\Lambda^2 < 0.100\ \mathrm{GeV}^{-2}$$

These constraints are compatible with the ones obtained by the OPAL collaboration [5] for the same reaction, and by the L3 and OPAL collaborations [6] in the reaction $\mathrm{e}^+\mathrm{e}^- \rightarrow \mathrm{Z}\gamma\gamma$ with $\mathrm{Z} \rightarrow \mathrm{q}\overline{\mathrm{q}}$.

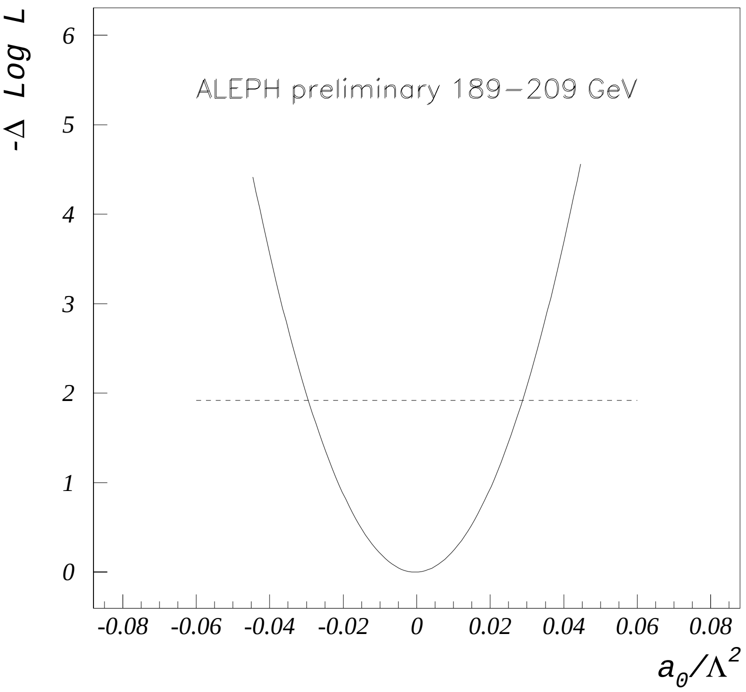

Figure 3: Likelihood curve for the fit of the QGC parameter a_0/Λ^2, the other QGC parameter a_c being set to 0. The dashed line at 1.92 allows to determine the 95 % confidence level.

3.2 Systematic uncertainties

The contributions to the systematic uncertainty on the determination of a_0/Λ^2 and a_c/Λ^2 are summarised in Table 1.

Table 1: Contributions to the systematic uncertainty on 95 % C.L. limits in one-parameter fits.

Source of systematics	Error (%)
Higher Order corrections	5.0
Acceptance	1.0
Luminosity	1.0
Energy scale	negligible
Background	negligible
Total	7.0

The total systematic uncertainty is much lower than the statistical one and contains presently only the contributions relative to the cross-section determination.

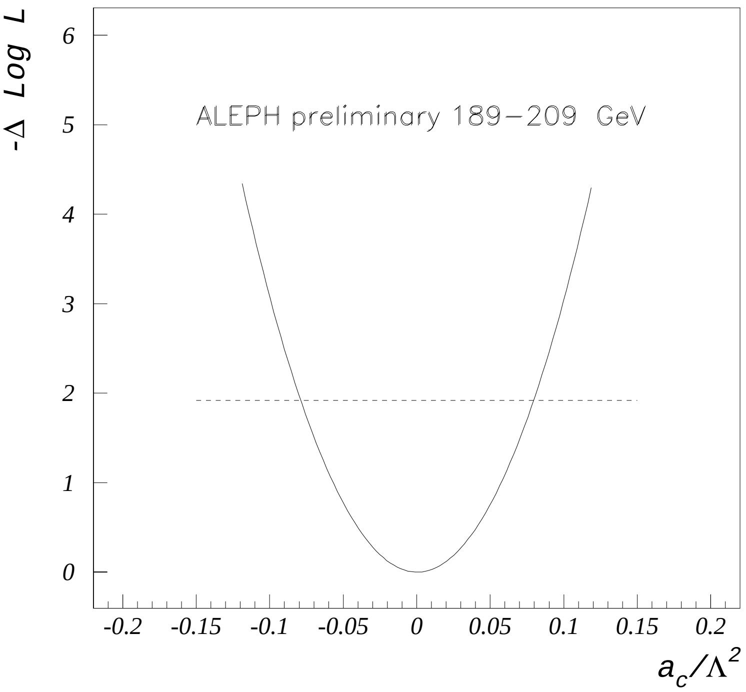

Figure 4: Likelihood curve for the fit of the QGC parameter a_c/Λ^2, the other QGC parameter a_0 being set to 0.

The main contribution to the systematic error comes from the determination of the radiative correction effects (lowering of the centre-of-mass energy, as described in Sec. 3). The error quoted in Table 1 has been obtained by doubling this energy shift.

The error on the acceptance comes from the extrapolation from the KORALZ SM Monte-Carlo events into the region where the QGC events are expected, after the cut on the missing mass $M_{miss} < 0.35\sqrt{s}$. The acceptance is found to be stable within 1 % when this cut is varied.

The error on the luminosity is estimated to be 0.5 %, giving a contribution of 1% to the systematic uncertainty.

Using the GGGB Monte-Carlo [3], the contribution to the background from QED events with 3 or 4 photons has been found to be < 0.01 events.

In the future, the sensitivity of the determination of the QGC parameters a_0 and a_c can be improved if the QGC generator is integrated inside a full Monte Carlo generator containing HO effects. This will allow to use the differential cross-sections (e.g. $d\sigma/dE_\gamma$) in the whole phase space and taking into account the interference terms which have been ignored in the present analysis.

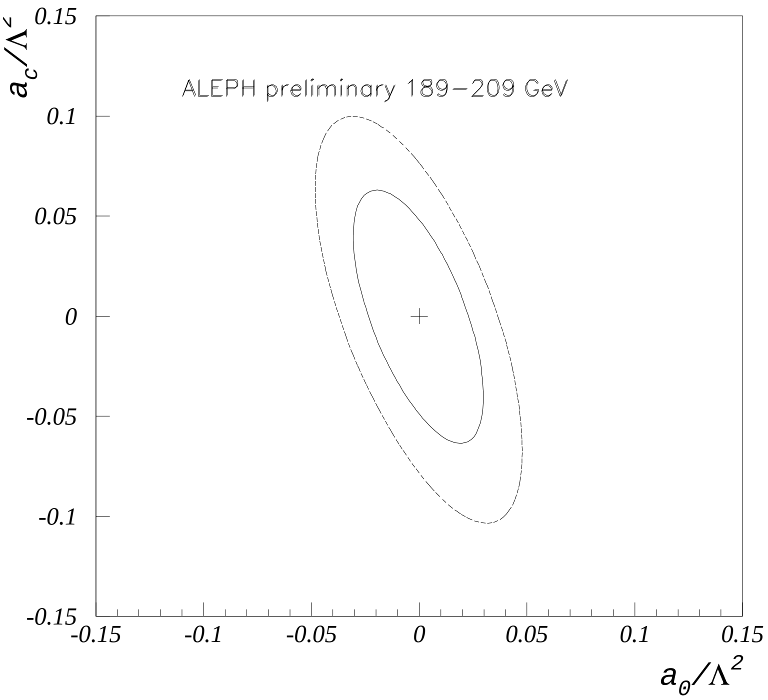

Figure 5: Two-dimensional contours for the QGC parameters a_0/Λ^2 and a_c/Λ^2. Full line: 68 % C.L. contour. Dashed line: 95 % C.L. contour. As only variations of the cross-section are considered, a strong correlation is observed between the two parameters.

4 Conclusions

The 95 % C.L. limits on a_0/Λ^2 and a_c/Λ^2 determined in a kinematical region where the contribution of the SM processes is very low are :

$$-0.029 \text{ GeV}^{-2} < a_0/\Lambda^2 < 0.026 \text{ GeV}^{-2} \text{ with } \mathrm{a_c} = 0,$$
$$-0.080 \text{ GeV}^{-2} < a_c/\Lambda^2 < 0.075 \text{ GeV}^{-2} \text{ with } \mathrm{a_0} = 0.$$

These values are obtained from the variation of the cross-section with a_0 and a_c on a data sample taken between 189 and 209 GeV in the ALEPH detector, corresponding to an integrated luminosity of 641pb^{-1}.

5 Acknowledgements

We thank and congratulate our colleagues in the CERN accelerator divisions for the successful operation of LEP2. We are indebted to the engineers and technicians in all our institutions for their contribution to the excellent performance of ALEPH. Those of us from non-member countries thank CERN for its hospitality and support.

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