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PRELIMINARY

Measurement of Triple Gauge-Boson Couplings at 192-202 GeV

The ALEPH Collaboration

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Abstract

The triple gauge-boson couplings Δg_1^Z, $\Delta\kappa_\gamma$, and λ_γ, have been studied using W pair production final states. The events were selected from the data collected in 1999 with the ALEPH detector at centre-of-mass energies between 192 GeV and 202 GeV, corresponding to an integrated luminosity of 236.96 pb^{-1}. The triple gauge-boson couplings have been measured using an optimal observable analysis of kinematic information and total cross-section information from W^+W^- events. The measurements are combined with ALEPH results from W^+W^- production and single-γ production at 183 and 189 GeV and single-W results at energies up to 202 GeV.

(*Contributed Paper for ICHEP2000*)

1 Introduction

The existence of the trilinear gauge boson couplings (TGC) is a direct consequence of the $SU(2)_L \times U(1)_Y$ gauge theory. Therefore the measurement of the TGC's represents a fundamental test probing the non-Abelian nature of the electroweak Standard Model. In e^+e^- collisions at high energies, the trilinear γW^+W^- and ZW^+W^- couplings can be studied with direct W-pair production ($e^+e^- \to W^+W^-$), single-W production ($e^+e^- \to We\nu$) or with photon production ($e^+e^- \to \nu\overline{\nu}\gamma(\gamma)$). The results presented in this paper are derived from the analysis of W pair production using data recorded with the ALEPH detector at centre-of-mass energies between 192 GeV and 202 GeV.

The most general Lorentz invariant parametrisation of the γW^+W^- and ZW^+W^- vertices can be described by 14 independent couplings [1], 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 [2], where their Standard Model values are equal to $g_1^Z = \kappa_Z = \kappa_\gamma = 1$ and $\lambda_Z = \lambda_\gamma = 0$. Precision measurements on the Z^0 resonance at LEP also provide bounds on the couplings [3]. Requiring local $SU(2)_L \times U(1)_Y$ gauge invariance, which limits the size of loop corrections to observables relevant at LEP1, introduces the constraints:

$$\Delta\kappa_Z = -\Delta\kappa_\gamma \tan^2\theta_w + \Delta g_1^Z$$

$$\lambda_Z = \lambda_\gamma$$

and reduces the 5 couplings to the three parameters Δg_1^Z, $\Delta\kappa_\gamma$, and λ_γ. The Δ denotes the deviations of the respective quantity from its non-zero SM value, and θ_w is the weak mixing angle. In this analysis the three couplings Δg_1^Z, $\Delta\kappa_\gamma$ and λ_γ are measured individually assuming the two other couplings to be fixed at zero, their Standard Model value. Two- and three-parameter fits, where two or all three couplings are allowed to vary, are also presented.

2 Determination of the TGCs

An optimal observable analysis employing first and second order observables of the W pair production $\ell\nu q\bar{q}$ and $q\bar{q}q\bar{q}$ final states, is used to measure the TGC's at 192-202 GeV. The optimal observable method project the sensitive kinematic information onto one dimensional distributions [4]. For the channels $e\nu q\bar{q}$ and $\mu\nu q\bar{q}$, a generalised maximum likelihood analysis have also been performed to provide one-parameter limits on the three CP-conserving TGCs and on the real and imaginary parts of the C- and P-violating TGCs. For both analyses, additional information is included from the measured total cross-section.

A detailed description of the optimal observable analysis of W pair production final states and of the generalised maximum likelihood analysis of $e\nu q\bar{q}$ and $\mu\nu q\bar{q}$, along with a description of the ALEPH detector, Monte Carlo event generators, and event selection can be found in [5]. The reconstruction of $\tau\nu q\bar{q}$ events have been slightly changed with respect to the reconstruction used earlier [5].

The new $\tau\nu q\bar{q}$ reconstruction minimises the mixing between the τ decay products and the jets from the hadronic decaying W by a detailed study of the τ decay topology. The final kinematic reconstruction of the $\tau\nu q\bar{q}$ events is done by a 1-constraint kinematic fit. In the kinematic fit the direction of the τ is approximated by its visible decay products and the τ energy and the neutrino momentum is determined assuming equal mass with the

$\sqrt{s}$ (GeV)	192		196		200		202	
Channel	N_{exp}	N_{data}	N_{exp}	N_{data}	N_{exp}	N_{data}	N_{exp}	N_{data}
$e\nu q\bar{q}$	49.6 (1.3)	52	136.0 (3.6)	131	141.5 (3.2)	140	67.1 (1.6)	71
$\mu\nu q\bar{q}$	51.5 (0.5)	57	141.8 (1.6)	128	150.3 (1.7)	157	71.2 (0.8)	68
$\tau\nu q\bar{q}$	47.9 (13.7)	40	127.3 (37.9)	138	131.8 (42.8)	130	61.2 (20.6)	66
$q\bar{q}q\bar{q}$	219.4 (30.9)	234	618.6 (85.6)	566	661.8 (89.4)	613	322.5 (45.4)	273

Table 1: *The number of events after selection for data and Monte Carlo simulation in all W pair production final state channels for the four centre-of-mass energies. The number of Monte Carlo events is normalised to the respective integrated luminosity of the data. The expected background contribution from non-*W^+W^- *events are given in brackets.*

di-jet system from the hadronic decaying W. For single prong τ decays the charge of the τ is directly accessible, but in the case of three-prong τ decays ambiguities arise due to mis-assigned particles from the jets to the τ. For three-prong τ decays the charge of the τ is therefore determined from the sign of the jet charge built from the τ decay products. The charge mis-assignment in $\tau\nu q\bar{q}$ events is 20% .

The expected number of events for signal and background processes at the different centre-of-mass energies is summarised in Table 1 for each W pair production channel.

The distributions of the five angles describing W pair production and decay, constituting the measured variables of the maximum likelihood analysis: The angle θ_W between the W^- and initial e^- in the W^+W^- rest frame, the polar and azimuthal angles of the lepton, θ_l^* and ϕ_l^*, in the rest frame of its parent W, and the the polar and azimuthal angles of a quark jet, θ_{jet}^* and ϕ_{jet}^*, in the rest frame of its parent W, are shown in Fig. 1 for $e\nu q\bar{q}$ and $\mu\nu q\bar{q}$ events. As no quark flavour tagging is performed the quark and anti-quark directions are averaged. The distributions of the W^- production angle, θ_W, for $\tau\nu q\bar{q}$ and $q\bar{q}q\bar{q}$ final states are shown in Fig. 2. For the fully hadronic final states each event enters with two solutions weighted according to the charge difference between the two di-jet systems as described in [5]. For comparison the expected distributions from fully simulated Monte Carlo events for the Standard Model and $\lambda_\gamma = \pm 0.5$ are also shown.

The systematic errors that were calculated for 189 GeV [5] are used for 192-202 GeV, with the exception of the Monte Carlo statistical error which is updated for each of the centre-of mass energies for which significant luminosity was accumulated (192, 196, 200, and 202 GeV).

3 Results

3.1 Results for 192-202 GeV

The final results for the couplings Δg_1^Z, $\Delta\kappa_\gamma$ and λ_γ, measured individually assuming the two other couplings to be fixed at zero, using W pair production events at 192-202 GeV are given in Table 2 for the optimal observable analysis. The corresponding negative log-likelihood functions, in the following denoted $\log L$, including the systematic uncertainties, are shown in Fig. 3. For comparison, the results for the generalised maximum likelihood analysis of $e\nu q\bar{q}$ and $\mu\nu q\bar{q}$ events are given in Table 3. The results for the generalised maximum likelihood analysis of $e\nu q\bar{q}$ and $\mu\nu q\bar{q}$ events for the real and imaginary parts of the C- and P- violating

192-202 GeV	Δg_1^Z	$\Delta\kappa_\gamma$	λ_γ
$e\nu q\bar{q}$	$0.09^{+0.09}_{-0.09}{}^{+0.02}_{-0.02}$	$0.02^{+0.36}_{-0.18}{}^{+0.07}_{-0.05}$	$0.09^{+0.10}_{-0.09}{}^{+0.02}_{-0.02}$
$\mu\nu q\bar{q}$	$-0.12^{+0.07}_{-0.07}{}^{+0.02}_{-0.02}$	$-0.35^{+0.19}_{-0.16}{}^{+0.04}_{-0.05}$	$-0.10^{+0.07}_{-0.07}{}^{+0.02}_{-0.02}$
$\tau\nu q\bar{q}$	$0.01^{+0.11}_{-0.10}{}^{+0.02}_{-0.02}$	$-0.04^{+0.44}_{-0.26}{}^{+0.06}_{-0.10}$	$-0.09^{+0.10}_{-0.09}{}^{+0.02}_{-0.02}$
$\ell\nu q\bar{q}$	$-0.02^{+0.05}_{-0.05}{}^{+0.02}_{-0.02}$	$-0.15^{+0.14}_{-0.12}{}^{+0.03}_{-0.03}$	$-0.04^{+0.05}_{-0.05}{}^{+0.01}_{-0.01}$
$q\bar{q}q\bar{q}$	$0.09^{+0.07}_{-0.07}{}^{+0.09}_{-0.07}$	$0.36^{+0.20}_{-0.17}{}^{+0.10}_{-0.09}$	$-0.01^{+0.07}_{-0.06}{}^{+0.04}_{-0.03}$
all	$-0.00^{+0.04}_{-0.04}{}^{+0.02}_{-0.02}$	$0.06^{+0.13}_{-0.11}{}^{+0.12}_{-0.08}$	$-0.01^{+0.04}_{-0.04}{}^{+0.03}_{-0.02}$

Table 2: *Fit results for the optimal observable analysis for the couplings Δg_1^Z, $\Delta\kappa_\gamma$ and λ_γ at 192-202 GeV using W pair production events. Each coupling has been determined setting the two other couplings to their Standard Model value. The first error is the 68% statistical error, the second is one the systematic error.*

couplings are summarised in Table 4.

192-202 GeV	Δg_1^Z	$\Delta\kappa_\gamma$	λ_γ
$e\nu q\bar{q}$	$0.06^{+0.10}_{-0.10}{}^{+0.01}_{-0.01}$	$-0.06^{+0.27}_{-0.20}{}^{+0.08}_{-0.08}$	$-0.01^{+0.09}_{-0.08}{}^{+0.02}_{-0.02}$
$\mu\nu q\bar{q}$	$-0.11^{+0.07}_{-0.07}{}^{+0.01}_{-0.01}$	$-0.11^{+0.20}_{-0.17}{}^{+0.08}_{-0.08}$	$-0.08^{+0.07}_{-0.07}{}^{+0.02}_{-0.02}$

Table 3: *Fit results for the generalised maximum likelihood analysis for the couplings Δg_1^Z, $\Delta\kappa_\gamma$ and λ_γ at 192-202 GeV from semileptonic $e\nu q\bar{q}$ and $\mu\nu q\bar{q}$ events. Each coupling has been determined setting the two other couplings to their Standard Model value. The first error is the 68% statistical error, the second is one the systematic error.*

	fit result	95% confidence limits
$Re(\tilde{\kappa}_\gamma)$	$0.121^{+0.219}_{-0.299}{}^{+0.084}_{-0.084}$	[-0.420, 0.524]
$Re(\tilde{\lambda}_\gamma)$	$0.112^{+0.159}_{-0.223}{}^{+0.066}_{-0.066}$	[-0.303, 0.409]
$Re(\tilde{\kappa}_Z)$	$0.058^{+0.140}_{-0.156}{}^{+0.031}_{-0.031}$	[-0.241, 0.319]
$Re(\tilde{\lambda}_Z)$	$0.047^{+0.106}_{-0.117}{}^{+0.027}_{-0.027}$	[-0.179, 0.245]
$Re(g_4^\gamma)$	$0.143^{+0.306}_{-0.315}{}^{+0.054}_{-0.054}$	[-0.478, 0.735]
$Re(g_5^\gamma)$	$0.420^{+0.397}_{-0.403}{}^{+0.093}_{-0.093}$	[-0.395, 1.212]
$Re(g_4^Z)$	$0.123^{+0.212}_{-0.217}{}^{+0.041}_{-0.041}$	[-0.307, 0.534]
$Re(g_5^Z)$	$0.252^{+0.247}_{-0.248}{}^{+0.074}_{-0.074}$	[-0.255, 0.759]
$Im(\tilde{\kappa}_\gamma)$	$-0.050^{+0.122}_{-0.120}{}^{+0.033}_{-0.033}$	[-0.292, 0.199]
$Im(\tilde{\lambda}_\gamma)$	$0.051^{+0.091}_{-0.093}{}^{+0.024}_{-0.024}$	[-0.138, 0.234]
$Im(\tilde{\kappa}_Z)$	$-0.051^{+0.080}_{-0.080}{}^{+0.018}_{-0.018}$	[-0.212, 0.110]
$Im(\tilde{\lambda}_Z)$	$0.050^{+0.062}_{-0.063}{}^{+0.013}_{-0.013}$	[-0.075, 0.174]
$Im(g_4^\gamma)$	$0.463^{+0.236}_{-0.241}{}^{+0.067}_{-0.067}$	[-0.030, 0.938]
$Im(g_5^\gamma)$	$-0.096^{+0.471}_{-0.463}{}^{+0.102}_{-0.102}$	[-1.008, 0.845]
$Im(g_4^Z)$	$0.219^{+0.175}_{-0.180}{}^{+0.039}_{-0.039}$	[-0.145, 0.566]
$Im(g_5^Z)$	$-0.068^{+0.286}_{-0.284}{}^{+0.045}_{-0.045}$	[-0.630, 0.501]

Table 4: *Fit results for the real and imaginary parts of C- and P- violating couplings at 192-202 GeV using semileptonic $e\nu q\bar{q}$ and $\mu\nu q\bar{q}$ events. Each coupling has been determined setting all other couplings to their Standard Model value. The first error is the 68% statistical error, the second is one the systematic error.*

To study the full correlation between the parameters, a three-parameter fit, where all three couplings are allowed to vary, have been performed in the optimal observable analysis. The results, errors [1], and the correlation matrix, computed from a variation from

[1] These errors correspond to 68% C.L. for each parameter integrating over all possible values of the other

coupling	fit result	Correlation		
Δg_1^Z	$0.009^{+0.116}_{-0.161}$	1.0	-0.51	-0.59
$\Delta\kappa_\gamma$	$0.128^{+0.551}_{-0.258}$	-0.51	1.0	-0.10
λ_γ	$-0.064^{+0.127}_{-0.088}$	-0.59	-0.10	1.0

Table 5: *Result and correlation from the three-parameter fit in the optimal observable analysis for Δg_1^Z, $\Delta\kappa_\gamma$ and λ_γ at 192-202 GeV using W pair production events. The local correlation matrix is estimated at the minimum.*

the minimum of the $\log L$ functions, are summarised in Table 5 including the systematic uncertainties.

3.2 Combined results for 172-202 GeV

The TGC measurements from the optimal observable analysis of W pair production events at 192-202 GeV have been combined with ALEPH results from W^+W^- production at 172-189 GeV [6, 5], single-W production at 183-202 GeV [7, 5, 8], and single-γ production at 183 and 189 GeV [9, 5]. The combined results for Δg_1^Z, $\Delta\kappa_\gamma$ and λ_γ are listed in Table 6. In Fig. 4 the corresponding $\log L$ curves are shown.

Coupling	Fit result	95% confidence limits
Δg_1^Z	$0.015^{+0.038}_{-0.037}$	[-0.063 , 0.090]
$\Delta\kappa_\gamma$	$0.055^{+0.094}_{-0.088}$	[-0.113 , 0.244]
λ_γ	$-0.004^{+0.039}_{-0.038}$	[-0.083 , 0.066]

Table 6: *Combined fit results for the couplings Δg_1^Z, $\Delta\kappa_\gamma$ and λ_γ from W pair production at 172-202 GeV, single-γ, and single-W production. Each coupling has been determined setting the two other couplings to their Standard Model value. The error quoted is the 68% error obtained by integration of the likelihood function including systematics. The corresponding 95% confidence intervals are listed in the last column.*

Two- and three-parameter fits, where two or all three couplings are allowed to vary, have been performed. The results including their errors and correlation matrix, as obtained from a variation from the minimum of the $\log L$ functions, are summarised in Table 7 including the systematic uncertainties. The correlation matrix of the three-parameter fit has been evaluated at the local minimum. As can be seen in fig. 5, correlations vary substantially depending on the exact value of the minimum. The 2-dimensional shadow of the 95% confidence regions of the three-parameter fit, which have been estimated assuming parabolic behaviour, are shown in fig. 5 a)-c) as the shaded areas. The 95% confidence limits of the respective 2-parameter fits of the three pairs of couplings (Δg_1^Z, $\Delta\kappa_\gamma$), (Δg_1^Z, λ_γ) and ($\Delta\kappa_\gamma$,

two. The integrated probability that all three parameters are within these limits is 20%.

coupling	fit result	Correlation		
Δg_1^Z	$0.016^{+0.086}_{-0.089}$	1.0	-0.20	-0.61
$\Delta\kappa_\gamma$	$0.045^{+0.169}_{-0.147}$	-0.20	1.0	-0.14
λ_γ	$-0.029^{+0.084}_{-0.085}$	-0.61	-0.14	1.0

Table 7: *Result and correlation from a three-parameter fit for Δg_1^Z, $\Delta\kappa_\gamma$ and λ_γ from W pair production at 172-202 GeV, single-γ, and single-W production. The correlation matrix is estimated at the minimum.*

λ_γ) are shown as full lines. For the 2-parameter fits the limits have been determined by integration of the likelihood functions, to accommodate cases with non-parabolic behaviour. The systematic uncertainties are included in the limits shown.

The results for the generalised maximum likelihood analysis of $e\nu q\bar{q}$ and $\mu\nu q\bar{q}$ events for the real and imaginary parts of the C- and P- violating couplings have been combined with ALEPH results from a generalised maximum analysis on $e\nu q\bar{q}$ and $\mu\nu q\bar{q}$ events at 183-189 GeV [5]. The combined results are summarised in Table 8.

4 Summary

The triple gauge boson couplings have been measured using an optimal observable analysis on W pair production final states at 192-202 GeV, corresponding to an integrated luminosity of 236.96 pb^{-1}. The measurements for Δg_1^Z, $\Delta\kappa_\gamma$ and λ_γ have been combined with previous ALEPH results from W pair production at 172-189 GeV, single-W production at 183-202 GeV, to give

$$\begin{aligned}
\Delta g_1^Z &= 0.015^{+0.038}_{-0.037} \\
\Delta\kappa_\gamma &= 0.055^{+0.094}_{-0.088} \\
\lambda_\gamma &= -0.004^{+0.039}_{-0.038},
\end{aligned}$$

where the error is the 68% statistical and systematical error. Each coupling is determined fixing the other couplings to their Standard Model value. The corresponding 95% confidence level limits are

$$\begin{aligned}
-0.063 < &\ \Delta g_1^Z < 0.090 \\
-0.113 < &\ \Delta\kappa_\gamma < 0.244 \\
-0.083 < &\ \lambda_\gamma < 0.066,
\end{aligned}$$

coupling	fit result	95% confidence limits
$Re(\tilde{\kappa}_\gamma)$	$-0.112^{+0.169}_{-0.153}$	[-0.394, 0.218]
$Re(\tilde{\lambda}_\gamma)$	$0.145^{+0.113}_{-0.129}$	[-0.117, 0.353]
$Re(\tilde{\kappa}_Z)$	$-0.034^{+0.096}_{-0.094}$	[-0.213, 0.151]
$Re(\tilde{\lambda}_Z)$	$0.062^{+0.072}_{-0.076}$	[-0.088, 0.198]
$Re(g_4^\gamma)$	$0.106^{+0.234}_{-0.238}$	[-0.358, 0.557]
$Re(g_5^\gamma)$	$0.243^{+0.326}_{-0.328}$	[-0.401, 0.879]
$Re(g_4^Z)$	$0.095^{+0.159}_{-0.161}$	[-0.220, 0.402]
$Re(g_5^Z)$	$0.126^{+0.207}_{-0.206}$	[-0.277, 0.532]
$Im(\tilde{\kappa}_\gamma)$	$0.029^{+0.090}_{-0.089}$	[-0.146, 0.205]
$Im(\tilde{\lambda}_\gamma)$	$-0.013^{+0.070}_{-0.070}$	[-0.150, 0.123]
$Im(\tilde{\kappa}_Z)$	$-0.011^{+0.059}_{-0.059}$	[-0.126, 0.105]
$Im(\tilde{\lambda}_Z)$	$0.014^{+0.047}_{-0.047}$	[-0.077, 0.105]
$Im(g_4^\gamma)$	$0.425^{+0.194}_{-0.197}$	[0.037, 0.803]
$Im(g_5^\gamma)$	$-0.061^{+0.372}_{-0.369}$	[-0.777, 0.668]
$Im(g_4^Z)$	$0.240^{+0.135}_{-0.137}$	[-0.031, 0.503]
$Im(g_5^Z)$	$-0.015^{+0.226}_{-0.225}$	[-0.454, 0.428]

Table 8: *Combined results for the real and imaginary parts of C- and P- violating couplings from $e\nu q\bar{q}$ and $\mu\nu q\bar{q}$ events at 183-202 GeV. Each coupling has been determined setting all other couplings to their Standard Model value. The error quoted is the 68% error obtained by integration of the likelihood functions including systematic uncertainties. The corresponding 95% confidence intervals are listed in the last column.*

in good agreement with the Standard Model expectation. Multi-parameter fits, where two or all three couplings are allowed to vary show also good agreement with the Standard Model.

The measurements for the real and imaginary parts of the C- and P- violating couplings at 192-202 GeV have been combined with previous ALEPH results at 183 and 189 GeV to give the results summarised in Table 8.

5 Acknowledgements

It is a pleasure to congratulate our colleagues from the CERN accelerator divisions for the highly successful operation of LEP at high energies. We are indebted to the engineers and technicians in all our institutions for the contributions to the excellent performance of ALEPH. Those of us from non-member countries thank CERN for its hospitality.

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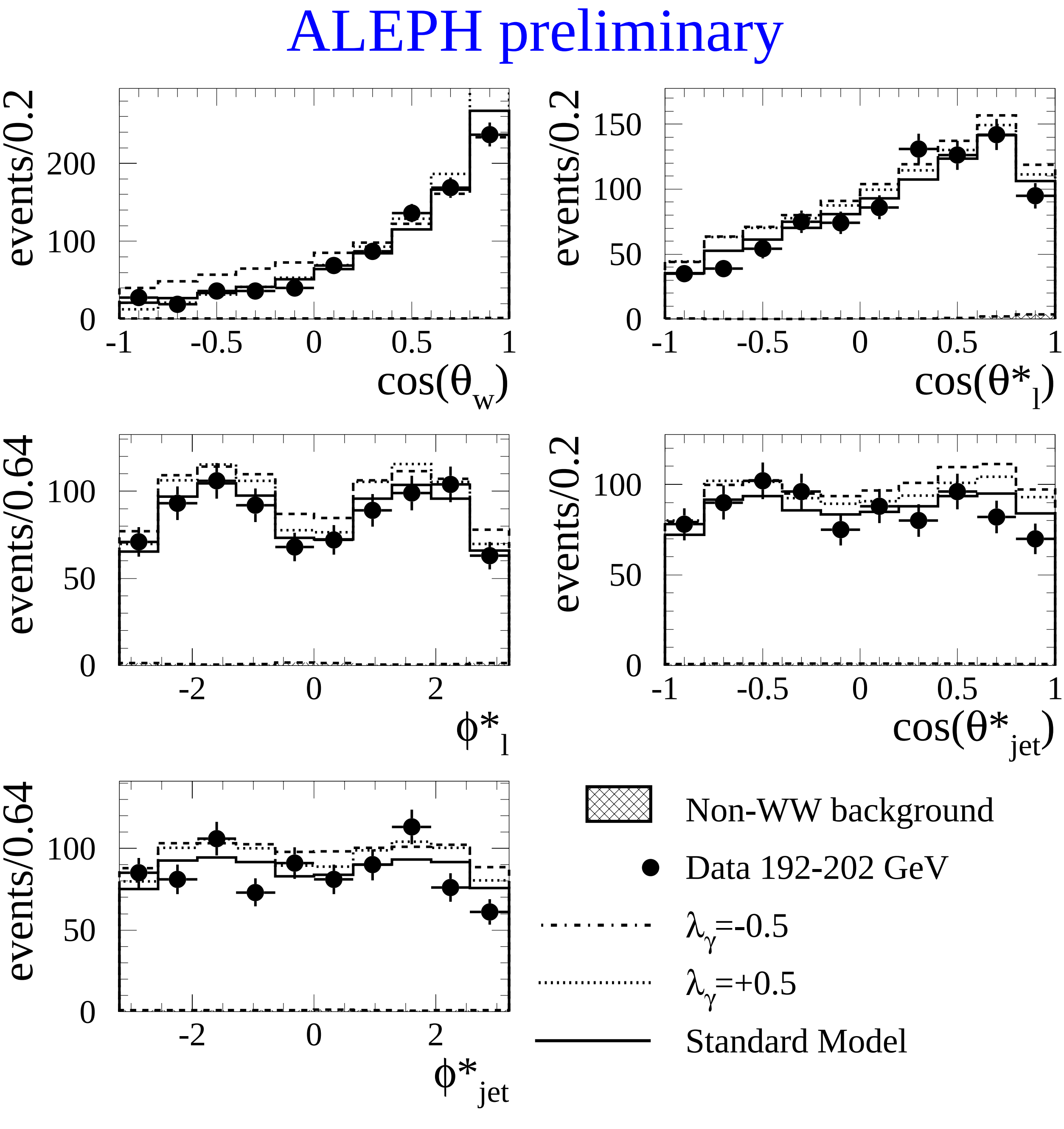

Figure 1: *The distributions of the kinematic quantities* $\cos\theta_W$, $\cos\theta^*_l$, ϕ^*_l, $\cos\theta^*_{\rm jet}$ *and* $\phi^*_{\rm jet}$ *from the combined sample of the* $e\nu q\bar{q}$ *and* $\mu\nu q\bar{q}$ *channels at 192-202 GeV. The data is represented by solid dots, while the solid and dashed histograms show distributions for Standard Model and non-standard values of* $\lambda_\gamma = \pm 0.5$*, respectively. For the hadronic decay angles, each of the two ambiguous solutions enters with a weight of 0.5.*

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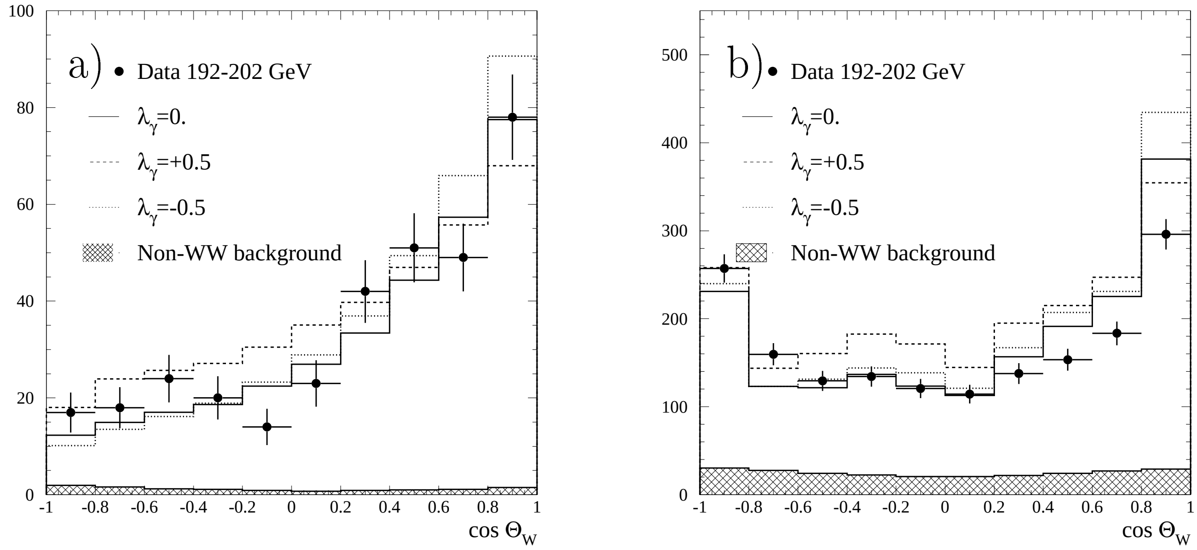

Figure 2: *Distributions of the cosine of the* W^- *production angle ,* $\cos\theta$*, at 192-202 GeV for a)* $\tau\nu q\bar{q}$ *and b)* $q\bar{q}q\bar{q}$ *events. The data is represented by solid dots, while the solid and dashed histograms show distributions for Standard Model and non-standard values of the TGCs, respectively. The shaded area represents the non-WW background. For* $q\bar{q}q\bar{q}$ *events, each event enters with two solutions for* $\cos\theta$ *in the distribution with the weights* P_+ *and* $1 - P_+$*, respectively, where* P_+ *is the probability for a di-jet pair to be a* W^+*.*

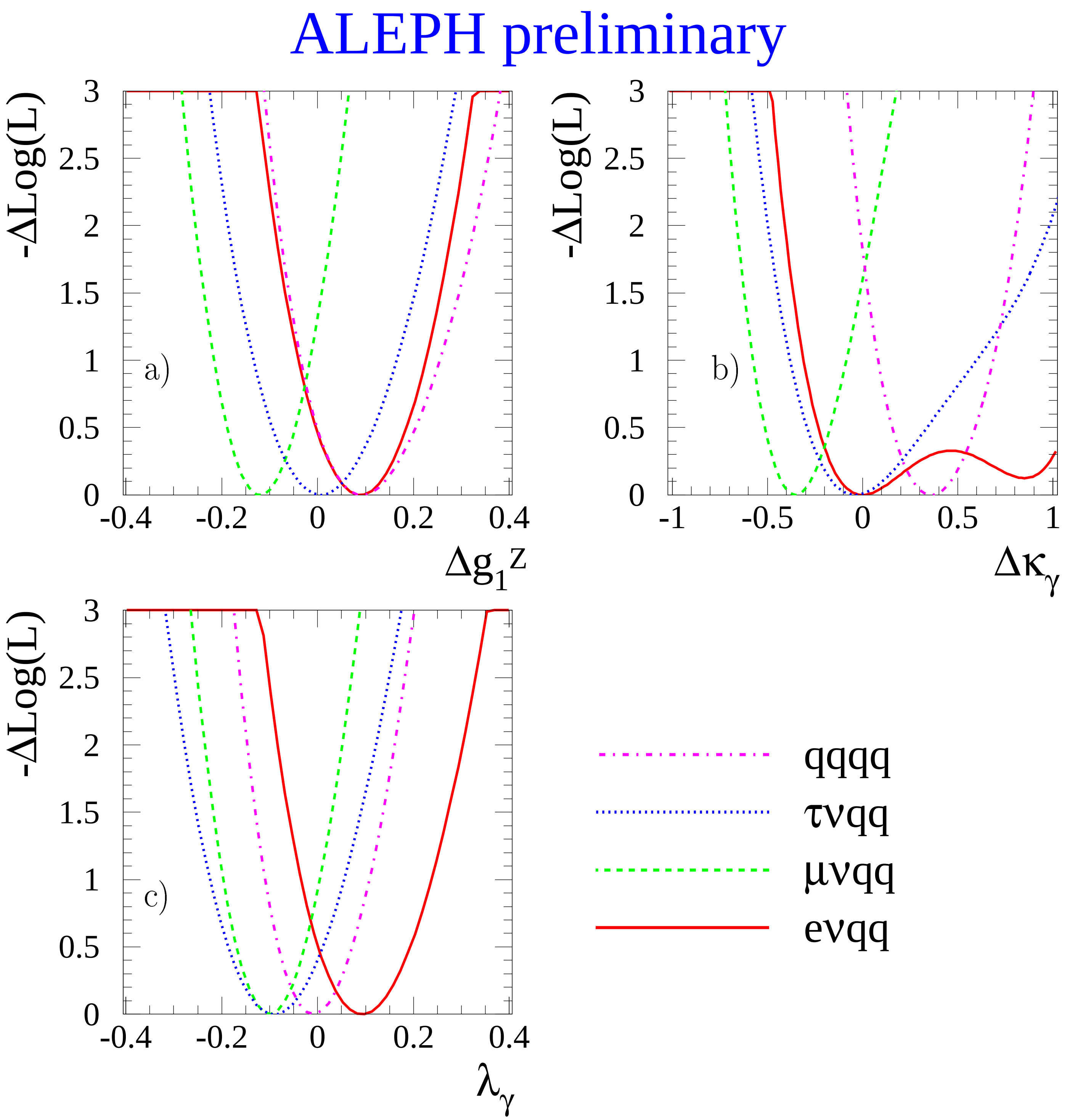

Figure 3: *The $-\Delta \log L$ curves at 192-202 GeV for the individual fits in the $e\nu q\bar{q}$ (full), $\mu\nu q\bar{q}$(dashed), $\tau\nu q\bar{q}$(dotted) and $q\bar{q}q\bar{q}$ (dashed-dotted) channels for the three couplings a) Δg_1^Z, b) $\Delta\kappa_\gamma$ and c) λ_γ. The systematic uncertainties are included. The combined result for all channels is shown as the solid curve.*

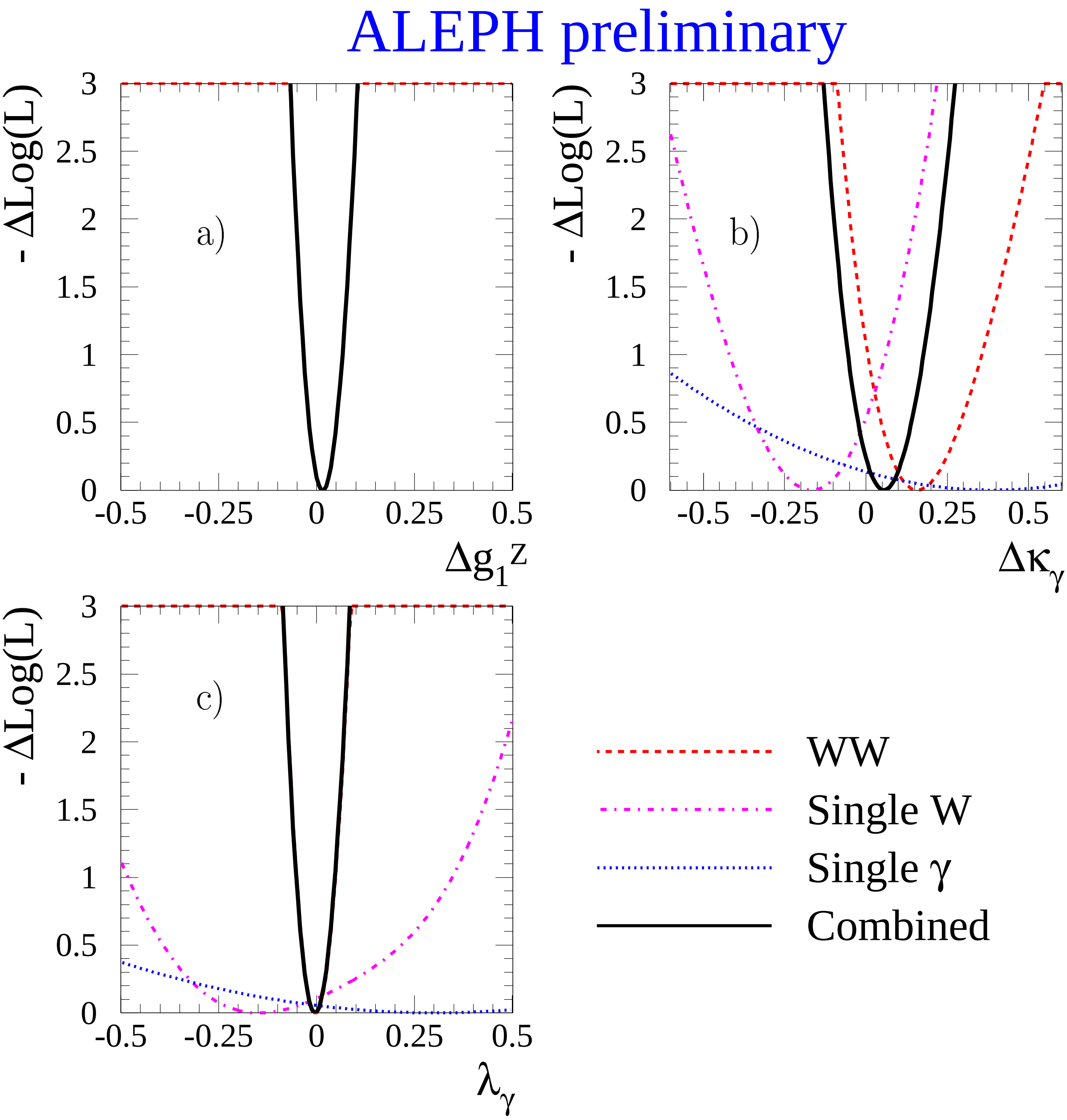

Figure 4: *The* $-\Delta \log L$ *curves for the combined fits using information from* W^+W^- *production (dashed) at 172-202 GeV, single-W production (dashed-dotted) at 183-202 GeV, and single-*γ *production (dotted) at 183-189 GeV for the three couplings a)* Δg_1^Z*, b)* $\Delta\kappa_\gamma$ *and c)* λ_γ*. The systematic uncertainties are included. The solid curve corresponds to the combination result.*

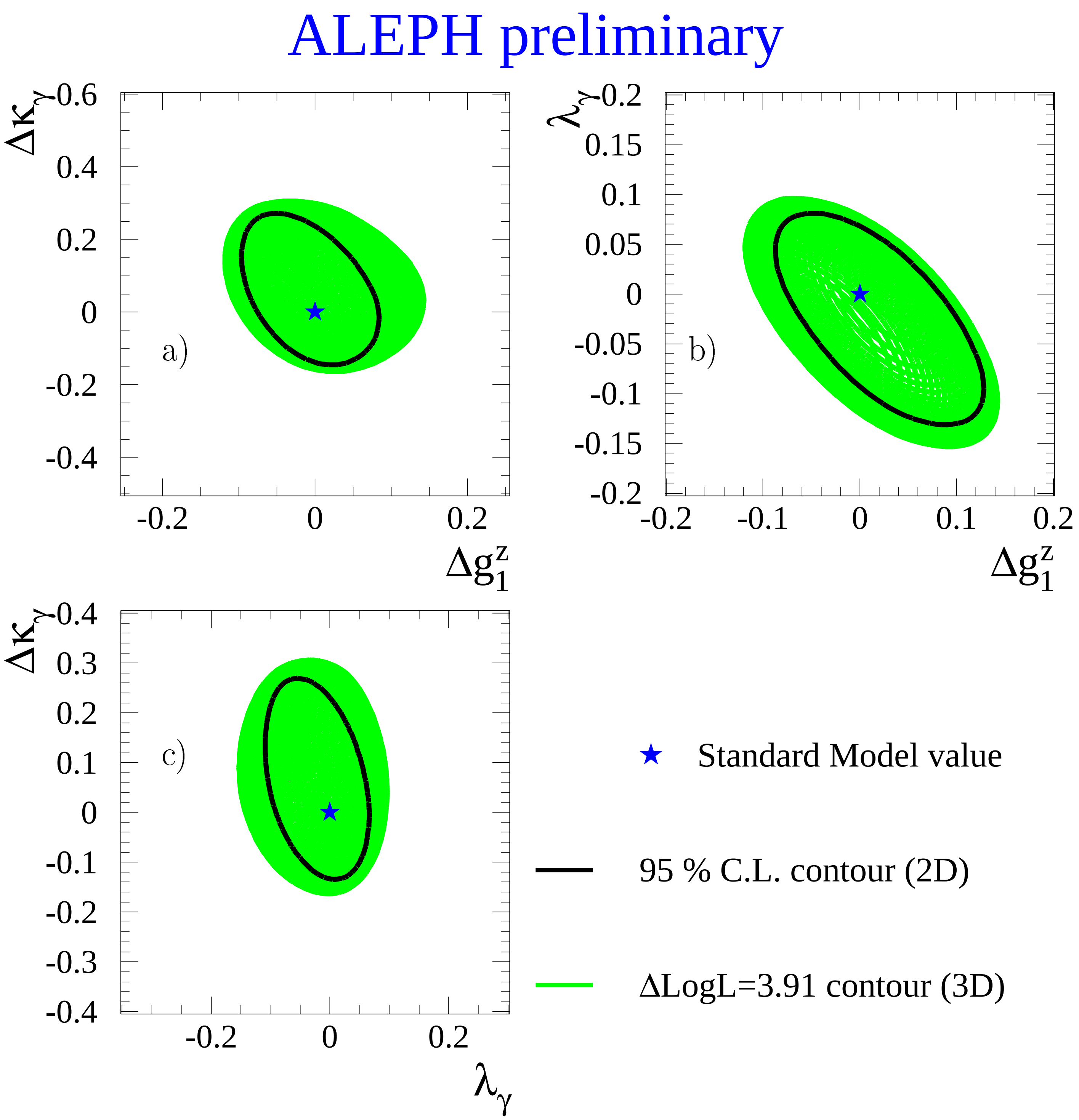

Figure 5: *Multi-parameter fits using the combined data. The two-dimensional 95% confidence level contours for the three pairs of couplings, a) (Δg_1^Z, $\Delta\kappa_\gamma$), b) (Δg_1^Z, λ_γ) and c) ($\Delta\kappa_\gamma$, λ_γ). The solid lines show the 95% confidence level contours of the two-parameter fit. The shaded area represents the 'shadow' of the 95% confidence level volume, representing the integration of the confidence over the corresponding third coupling. The Standard Model point is represented by a star.*