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A Combination of Preliminary Measurements of Triple Gauge Boson Coupling Parameters Measured by the LEP and DØ Experiments

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Abstract

This note presents a combination of published and preliminary measurements of triple gauge boson coupling parameters from the four LEP experiments and the DØ experiment. In the present combination a new parametrization is used in term of the couplings g_1^z, κ_γ, λ_γ, differing from that used in the combination prepared for the winter conferences.

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The Collaborations each take responsibility for the preliminary data of their own experiment.

1 Introduction

During its operation in 1997, LEP2 reached a centre-of-mass energy of 183 GeV at which a total integrated luminosity of approximately 55 pb^{-1} was recorded per experiment. Each experiment selected about 1000 $\mathrm{W}^+\mathrm{W}^-$ pairs. The $\mathrm{W}^+\mathrm{W}^-$ production process involves the triple gauge boson vertices between the $\mathrm{W}^+\mathrm{W}^-$ and the Z or photon. Single W ($\mathrm{e}\nu\mathrm{W}$) and single gamma ($\nu\bar{\nu}\gamma$) productions at LEP are sensitive to the $\mathrm{WW}\gamma$ vertex. The measurement of these triple gauge boson couplings (TGCs) and the search for possible anomalous values is one of the principal physics goals at LEP2.

The triple gauge boson coupling measurements from DØ are based on the analysis of di-boson production events, i.e. $W\gamma$ production with subsequent decay $W \to \ell\nu$, the process $p\bar{p} \to W^+W^-$ (or $W^{\pm}Z$) $+X \to \ell\nu jj + X$, and the process $p\bar{p} \to W^+W^- + X \to \ell\nu\ell'\nu' + X$. Approximately 100 pb^{-1} of data was collected.

The four LEP experiments and DØ have recently combined [1] preliminary (at $\sqrt{s} = 183$ GeV for LEP) and published (at $\sqrt{s} = 161$ and 172 GeV for LEP) measurements of TGCs parameters. In this note we present the results of a combination of updated analyses based on the 1997 data from the four LEP experiments [2–5] and DØ [6,7] and expressed in a new parametrization.

2 Anomalous coupling parameters

The parametrization of anomalous TGCs is described in references [8–13]. The most general Lorentz invariant Lagrangian which describes the triple gauge boson interaction has fourteen independent terms, seven describing the $\mathrm{WW}\gamma$ vertex and seven describing the WWZ vertex. Assuming electromagnetic gauge invariance and C and P conservation the number of parameters reduces to five. One common set is $\{g_1^{\mathrm{z}}, \kappa_{\mathrm{z}}, \kappa_\gamma, \lambda_{\mathrm{z}}, \lambda_\gamma\}$ where $g_1^{\mathrm{z}} = \kappa_{\mathrm{z}} = \kappa_\gamma = 1$ and $\lambda_{\mathrm{z}} = \lambda_\gamma = 0$ in the Standard Model.

The set of parameters proposed in [13] and used up to now were:

$$\alpha_{W\phi} \equiv \Delta g_1^{\mathrm{z}} \cos^2\theta_{\mathrm{W}} \tag{1}$$

$$\alpha_W \equiv \lambda_\gamma \tag{2}$$

$$\alpha_{B\phi} \equiv \Delta\kappa_\gamma - \Delta g_1^{\mathrm{z}} \cos^2\theta_{\mathrm{W}} \tag{3}$$

with the constraints:

$$\Delta\kappa_{\mathrm{z}} = -\Delta\kappa_\gamma \tan^2\theta_W + \Delta g_1^{\mathrm{z}} \tag{4}$$

$$\lambda_{\mathrm{z}} = \lambda_\gamma \tag{5}$$

where Δ indicates the deviation of the respective quantity from its Standard Model value (and therefore are all zero in this context), and θ_W is the weak mixing angle. Each of the α parameters has the value zero in the Standard Model. These couplings neither generate anomalous Higgs couplings nor affect the gauge-boson propagators at tree level, thus are not constrained by LEP-I results.

Recently, after the combination of available results for the Moriond conference, [1], the LEP and the DØ collaborations agreed to express their results directly through the parameters Δg_1^{z}, $\Delta\kappa_\gamma$, λ_γ, retaining the same underlying physics by imposition of the constraints (4) and (5).

3 Input measurements

The results presented use measurements of all three parameters Δg_1^z, $\Delta\kappa_\gamma$and λ_γ, by DELPHI, L3 and OPAL, and of $\Delta\kappa_\gamma$ and λ_γ by ALEPH and DØ . In each case, the individual references should be consulted for details. ALEPH reports no results on W pair production at 183 GeV.

In this note updated analyses of the 1997 data are reported using different channels, typically the semileptonic, fully hadronic and fully leptonic W decays [2–5]. Anomalous TGCs can affect both the total production cross-section and the shape of the differential cross-section as a function of the W^- production angle. The relative contributions of each helicity state of the W bosons are also changed, which in turn affects the distributions of their decay products. The analyses presented by each experiment make use of different combinations of each of these quantities; the reader should consult the references for details. In general, however, all analyses use at least the expected variations of the total production cross-section and the W^- production angle. In this note, results from $e\nu W$ and $\nu\bar{\nu}\gamma$ productions have been included. Single W production has a particular sensitivity to κ_γ, thus provides the complementary information to those of W pair production.

In the DØ analyses, the TGCs are modified by dipole form factors with a scale Λ (*e.g.* $\lambda_\gamma(\hat{s}) = \lambda_\gamma/(1+\hat{s}/\Lambda^2)^2$, where $\hat{s}$ is the square of the invariant mass of the $W\gamma$,WW or WZ system). DØ uses $\Lambda = 2.0$ TeV, which corresponds to a 1.7% correction to the TGCs in the LEP case with no form factor. Since this is a negligible effect, the correction has not been perfomed for the combination. The limits from DØ are obtained by performing a simultaneous fit to the data samples of three gauge boson pair final states: $W\gamma$ production with the W decaying to $e\nu$ and $\mu\nu$, W pair production with both of the W's decaying to $e\nu$ or $\mu\nu$, and WW or WZ production with one W decaying to $e\nu$ and the other W or the Z decaying to two jets.

4 Combination of measurements

The method followed is the same as already used in the previous combinations [1, 14]. Each of the experiments has provided the full negative log likelihood curve, $\log\mathcal{L}$, as a function of each of the measured TGC parameters. The $\log\mathcal{L}$ curves from each experiment include both statistical and systematic effects. It is necessary to use the $\log\mathcal{L}$ curves directly for the combination as they are not parabolic, and it is therefore not possible to combine the results correctly by taking simple weighted averages of one standard deviation measurements.

In principle there are some common systematic effects which should be included in a correlated way. These include the uncertainties of the LEP beam energy and the W mass, and some effects estimated by varying Monte Carlo generators. However, in the combination this correlation is neglected, as it has a negligible effect. The main contributions to the uncorrelated systematic errors come from the background to the selected W^+W^- sample, detector resolutions, fitting methods and from limited Monte Carlo statistics. Their importance varies for each experiment and the individual experiment publications should be consulted for details.

4.1 Single parameter fits

The single parameter fits are performed putting the values of all the parameters to their Standard Model values, except the one to be measured.

The results from each experiment are shown in table 1, where the errors include both statistical and systematic effects.

Parameter	ALEPH [2]	DELPHI [3]	L3 [4]	OPAL [5]	DØ [6]
Δg_1^z		$0.04^{+0.14}_{-0.14}$	$-0.03^{+0.18}_{-0.16}$	$-0.02^{+0.12}_{-0.11}$	
$\Delta\kappa_\gamma$	$-0.02^{+0.28}_{-0.33}$	$0.34^{+0.26}_{-0.28}$	$0.16^{+0.40}_{-0.35}$	$0.19^{+0.47}_{-0.37}$	$-0.08^{+0.34}_{-0.34}$
λ_γ	$0.05^{+0.50}_{-0.51}$	$-0.07^{+0.19}_{-0.16}$	$0.01^{+0.19}_{-0.17}$	$-0.08^{+0.13}_{-0.12}$	$0.00^{+0.10}_{-0.10}$

Table 1: The measured central values and one standard deviation errors obtained by the four LEP experiments and DØ for the TGC parameters mentioned in section 2. The listed parameter is varied while the remaining two are fixed to the SM. Both statistical and systematic errors are included.

The individual $\log\mathcal{L}$ curves for each parameter are added together. The results are shown in figures 1 to 4 for the 4 LEP experiments and DØ (where each is plotted relative to its minimum value).

The one standard deviation limits (S.D.) are obtained directly from the curves by taking the values of each TGC parameter where $\Delta\log\mathcal{L} = +0.5$ from the minimum, as already done in the previous combinations [1, 14]. The 95% confidence level (C.L.) limit is given by the values of each TGC parameter where $\Delta\log\mathcal{L} = +1.92$. The results obtained are given in table 2. The value of each TGC parameter given in the table is consistent with the expectation of the Standard Model.

Parameter	68% C.L.	95% C.L. interval
Δg_1^z	$0.00^{+0.08}_{-0.08}$	$[-0.15,\ \ 0.16]$
$\Delta\kappa_\gamma$	$0.13^{+0.14}_{-0.14}$	$[-0.14,\ \ 0.48]$
λ_γ	$-0.03^{+0.07}_{-0.07}$	$[-0.22,\ \ 0.13]$

Table 2: The combined 68% C.L. errors and 95% confidence intervals obtained after combination of the results from the four LEP experiments and DØ . The TGC parameters are those listed in section 2 - only the one parameter listed is varied while the other two are fixed to their SM value. Both statistical and systematic errors are included.

4.2 Two-parameter fits

The results of fits to data in which two parameters were allowed to vary are shown in table 3 for each of the four LEP experiments.

The combinations of the two-dimensional likelihood curves result into the 68% C.L. and 95% C.L. contours shown in figures 5 to 7. The 68% C.L. contours are obtained by requiring $\Delta\log\mathcal{L} = +1.15$, while for the 95% C.L. contours a value $\Delta\log\mathcal{L} = +3.0$ is required.

The combined results are given in table 4.

Parameter	ALEPH [2]	DELPHI [3]	L3 [4]	OPAL [5]
Δg_1^z $\Delta\kappa_\gamma$		$0.06^{+0.21}_{-0.18}$ $0.31^{+0.50}_{-0.39}$	$-0.06^{+0.20}_{-0.16}$ $0.33^{+0.62}_{-0.52}$	$0.01^{+0.15}_{-0.17}$ $0.00^{+0.60}_{-0.30}$
Δg_1^z λ_γ		$0.17^{+0.16}_{-0.18}$ $-0.23^{+0.22}_{-0.19}$	$-0.06^{+0.23}_{-0.21}$ $0.04^{+0.24}_{-0.23}$	$-0.15^{+0.34}_{-0.20}$ $0.23^{+0.26}_{-0.43}$
$\Delta\kappa_\gamma$ λ_γ	$0.05^{+1.2}_{-1.1}$ $-0.05^{+1.6}_{-1.5}$	$0.27^{+0.39}_{-0.36}$ $-0.10^{+0.36}_{-0.31}$	$0.35^{+0.64}_{-0.53}$ $-0.04^{+0.21}_{-0.19}$	$-0.01^{+0.46}_{-0.34}$ $0.03^{+0.22}_{-0.18}$

Table 3: The measured central values and one standard deviation errors obtained by the four LEP experiments for the TGC parameters mentioned in section 2. The listed parameters are varied while the remaining one is fixed to its SM value. Both statistical and systematic errors are included.

No deviation from the Standard Model predictions is seen for all the couplings determined here. It is of interest to note that these data allow the Kaluza-Klein theory [15], in which κ_γ= -2, to be excluded completely [16].

Parameter	68% C.L.	95% C.L.	Correlation
Δg_1^z $\Delta\kappa_\gamma$	$0.00^{+0.12}_{-0.11}$ $0.28^{+0.33}_{-0.27}$	$[-0.19,\ 0.22]$ $[-0.19,\ 0.89]$	-0.54
Δg_1^z λ_γ	$0.05^{+0.13}_{-0.13}$ $-0.07^{+0.16}_{-0.15}$	$[-0.21,\ 0.29]$ $[-0.34,\ 0.26]$	-0.79
$\Delta\kappa_\gamma$ λ_γ	$0.09^{+0.17}_{-0.15}$ $0.02^{+0.13}_{-0.12}$	$[-0.19,\ 0.44]$ $[-0.22,\ 0.27]$	-0.50

Table 4: The combined 68% C.L. errors and 95% confidence intervals obtained after combination of the results from the four LEP experiments. Since the contour plots are not elliptic, there is some ambiguity in the definition of the corrrelation coefficients and their values quoted here are only approximate estimates.

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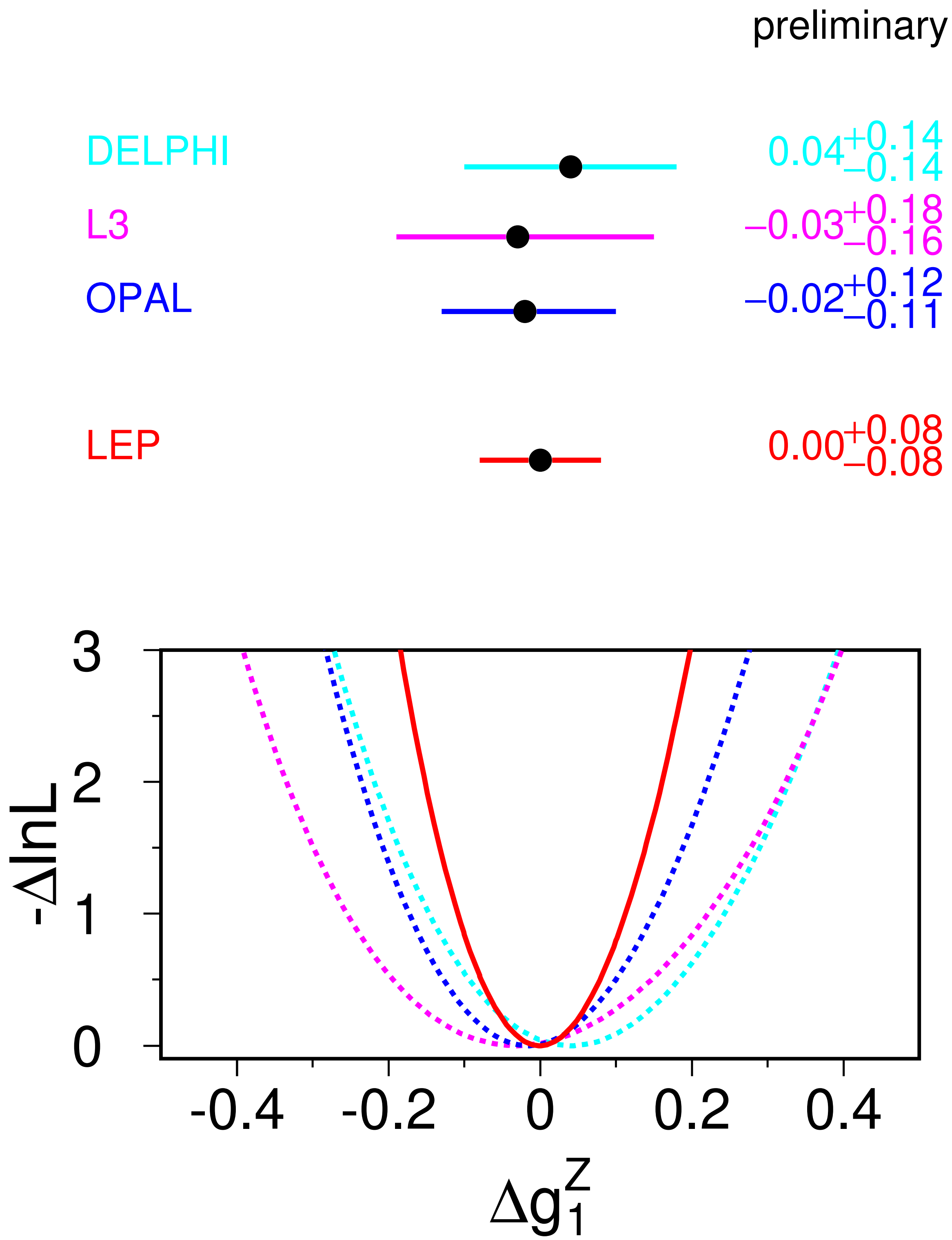

Figure 1: The LEP combined $\log \mathcal{L}$ curve as a function of the parameter Δg_1^z. This is obtained from the combination of the curves from the individual LEP experiments which are shown as dotted lines. The minimum value has been subtracted in all cases. The measurements and 1 standard deviation errors are also listed. For the assignment of each curve to an experiment, the reader should consult the version in color on http://www.cern.ch/LEPEWWG/tgc.

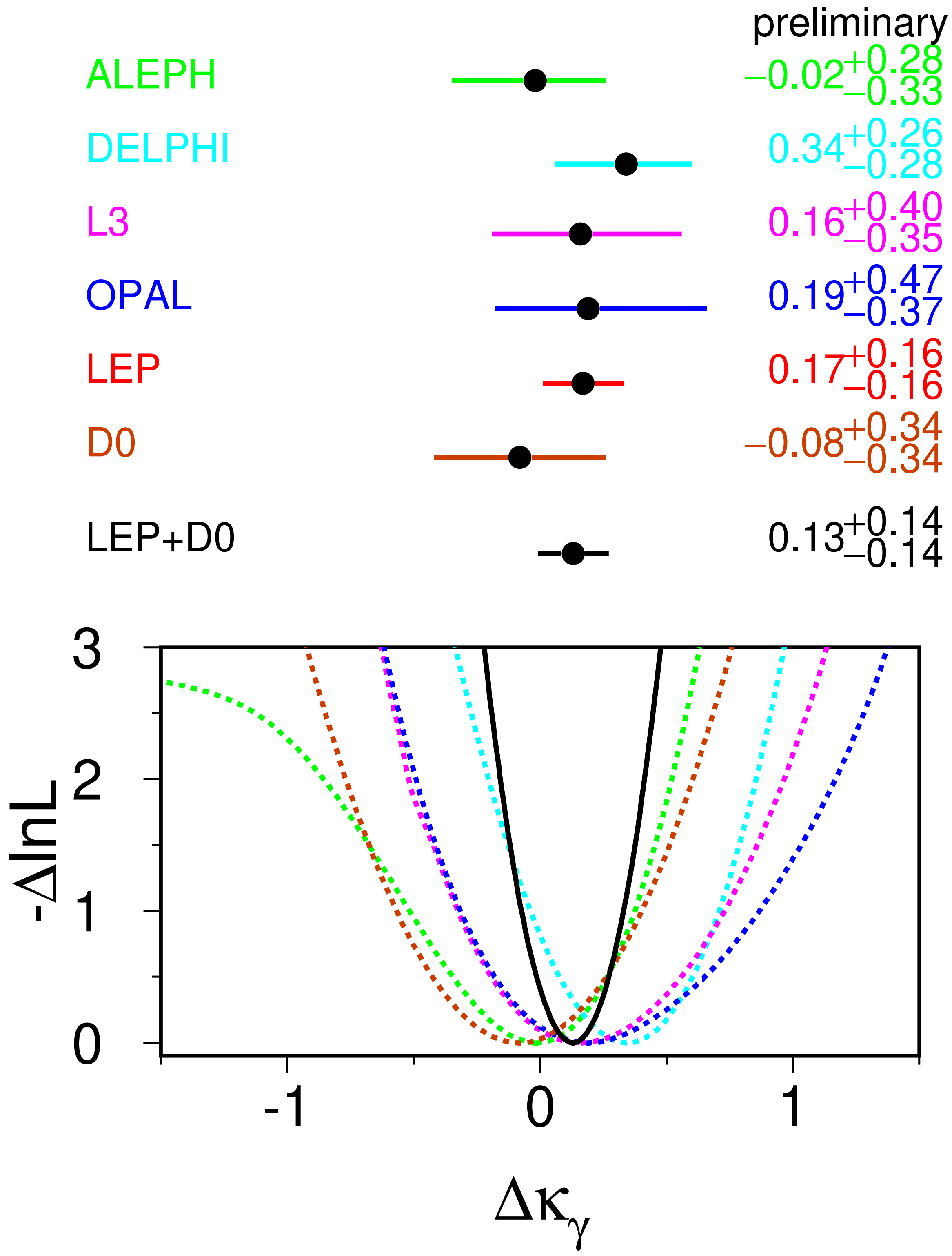

Figure 2: The LEP and DØ results for $\Delta\kappa_\gamma$ (for details see caption to figure 1)

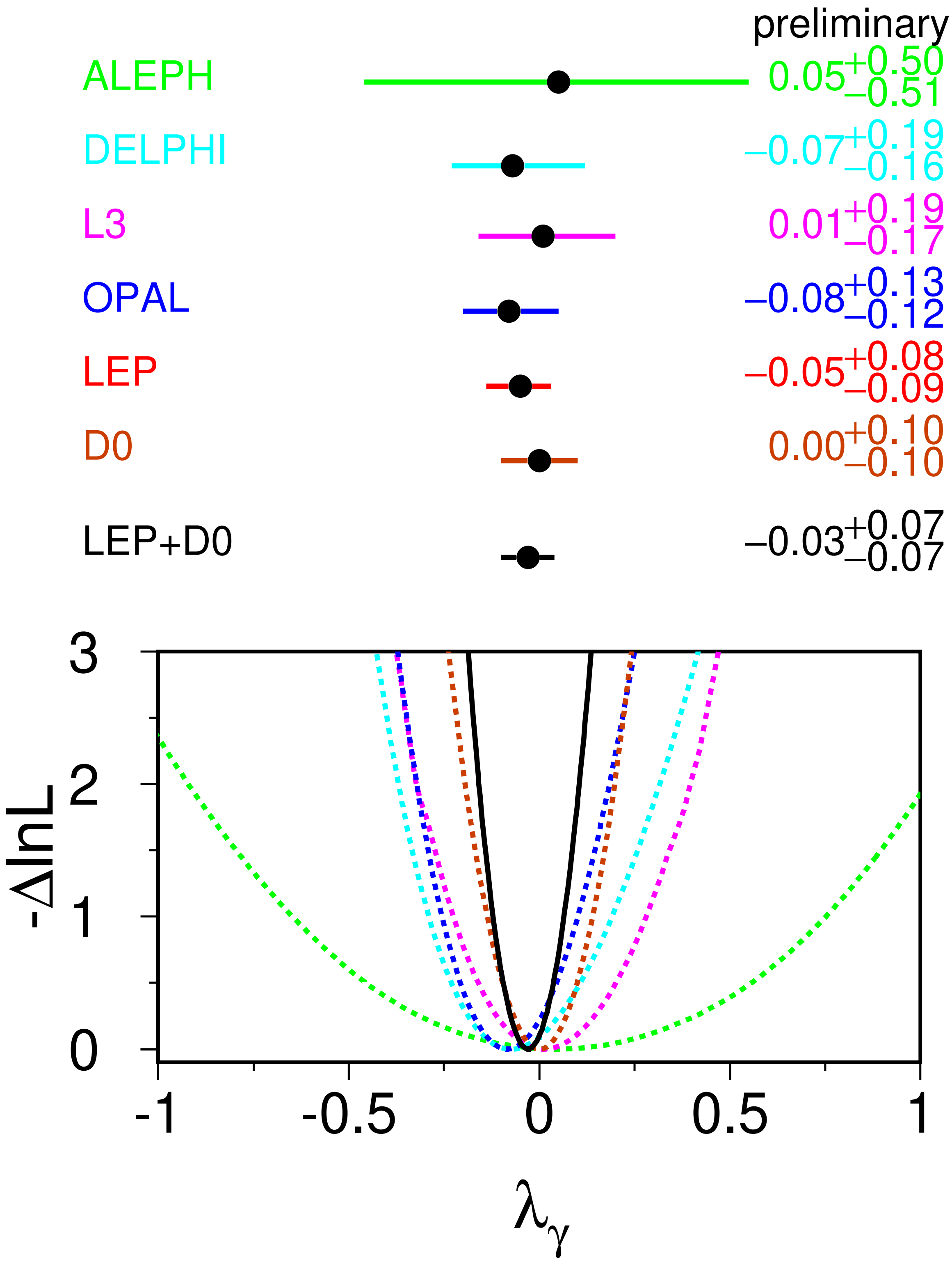

Figure 3: The LEP and DØ results for λ_γ (for details see caption to figure 1)

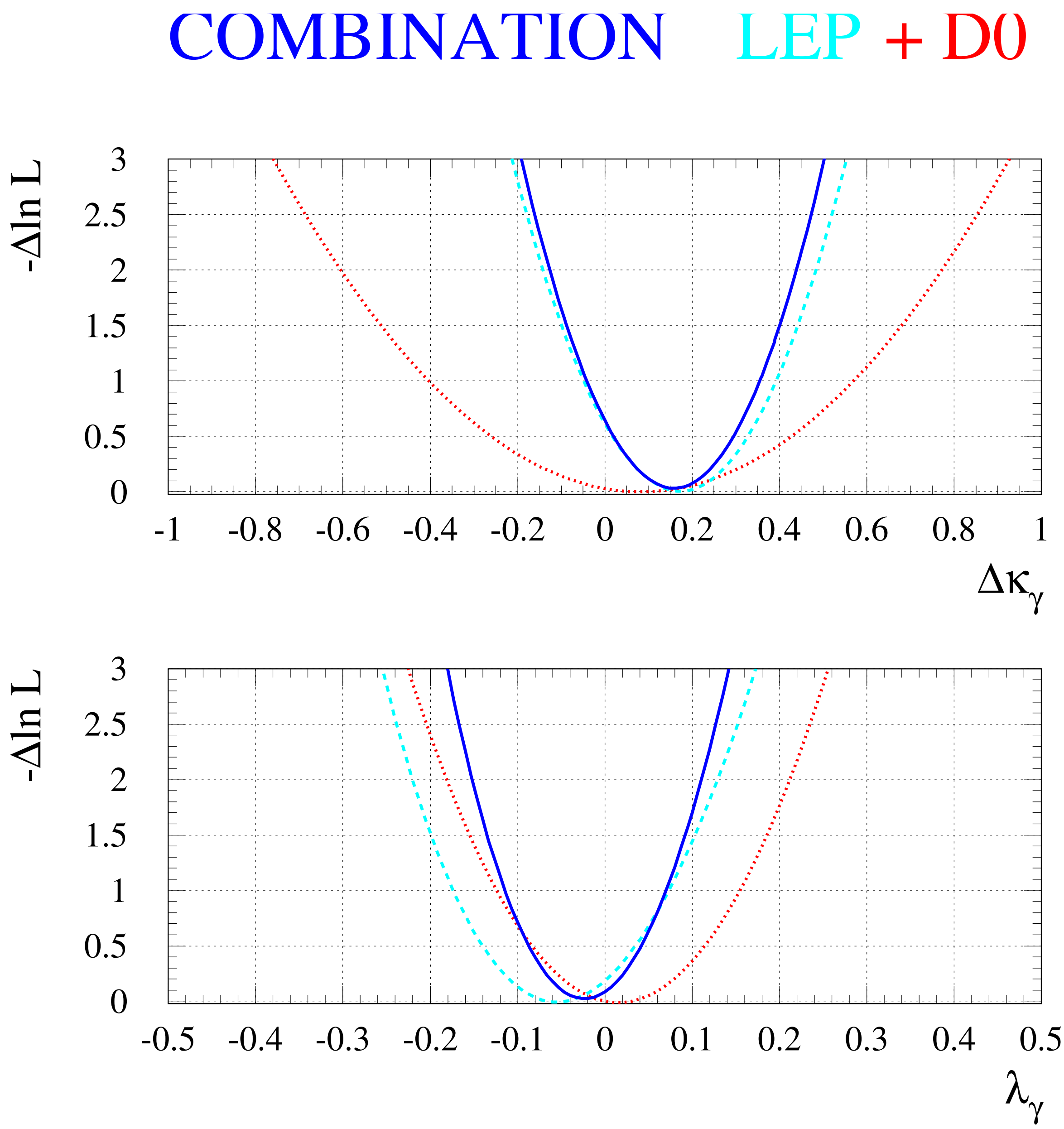

Figure 4: Results (continuous line) for the two couplings combining LEP (dashed line) and DØ (dotted line) results.

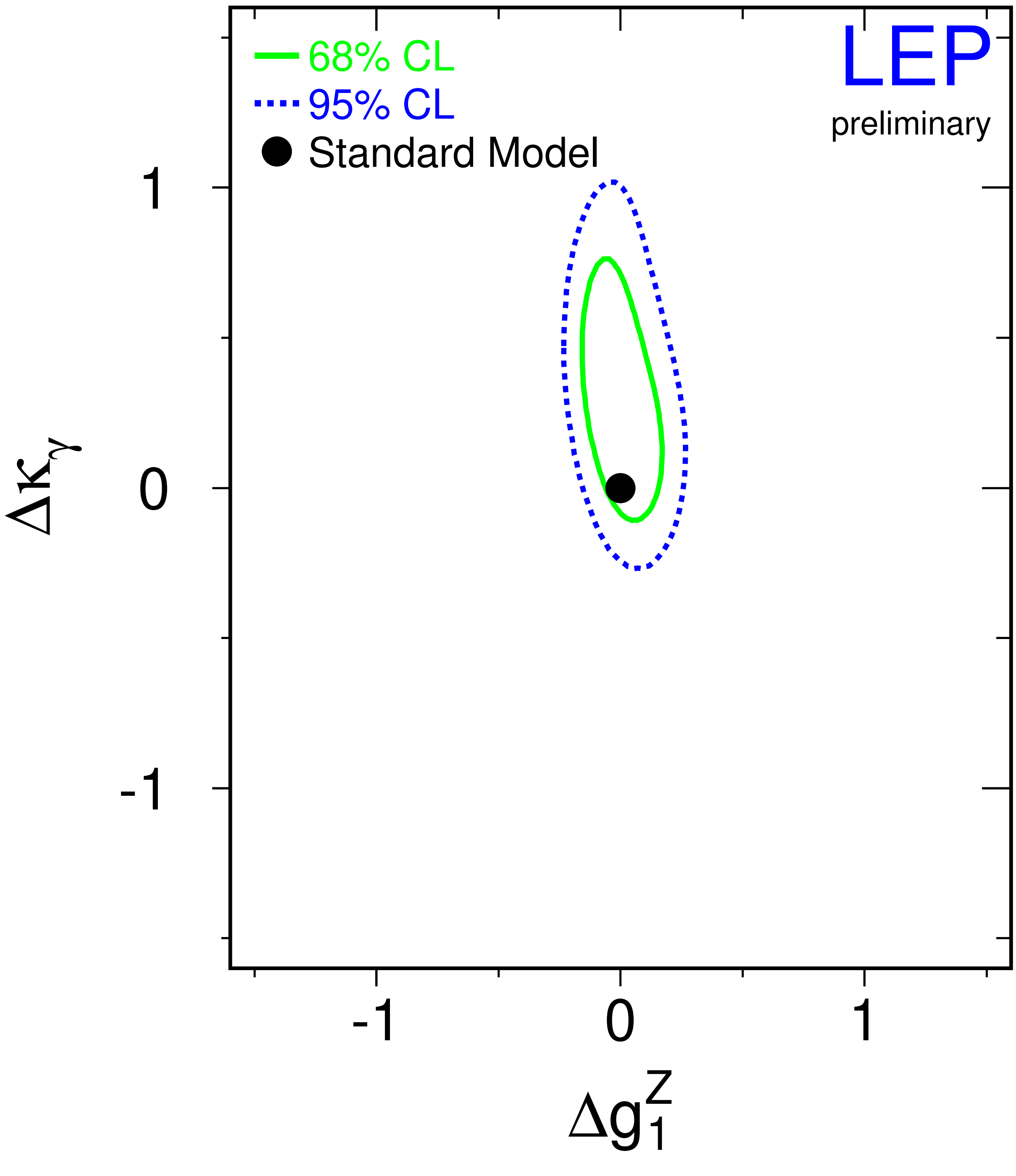

Figure 5: The contour curves for 68% C.L. ($\Delta \log \mathcal{L} = 1.15$) and 95% C.L. ($\Delta \log \mathcal{L} = 3.0$) in the parameter space Δg_1^z-$\Delta\kappa_\gamma$, obtained from the sum of the curves from the individual LEP experiments.

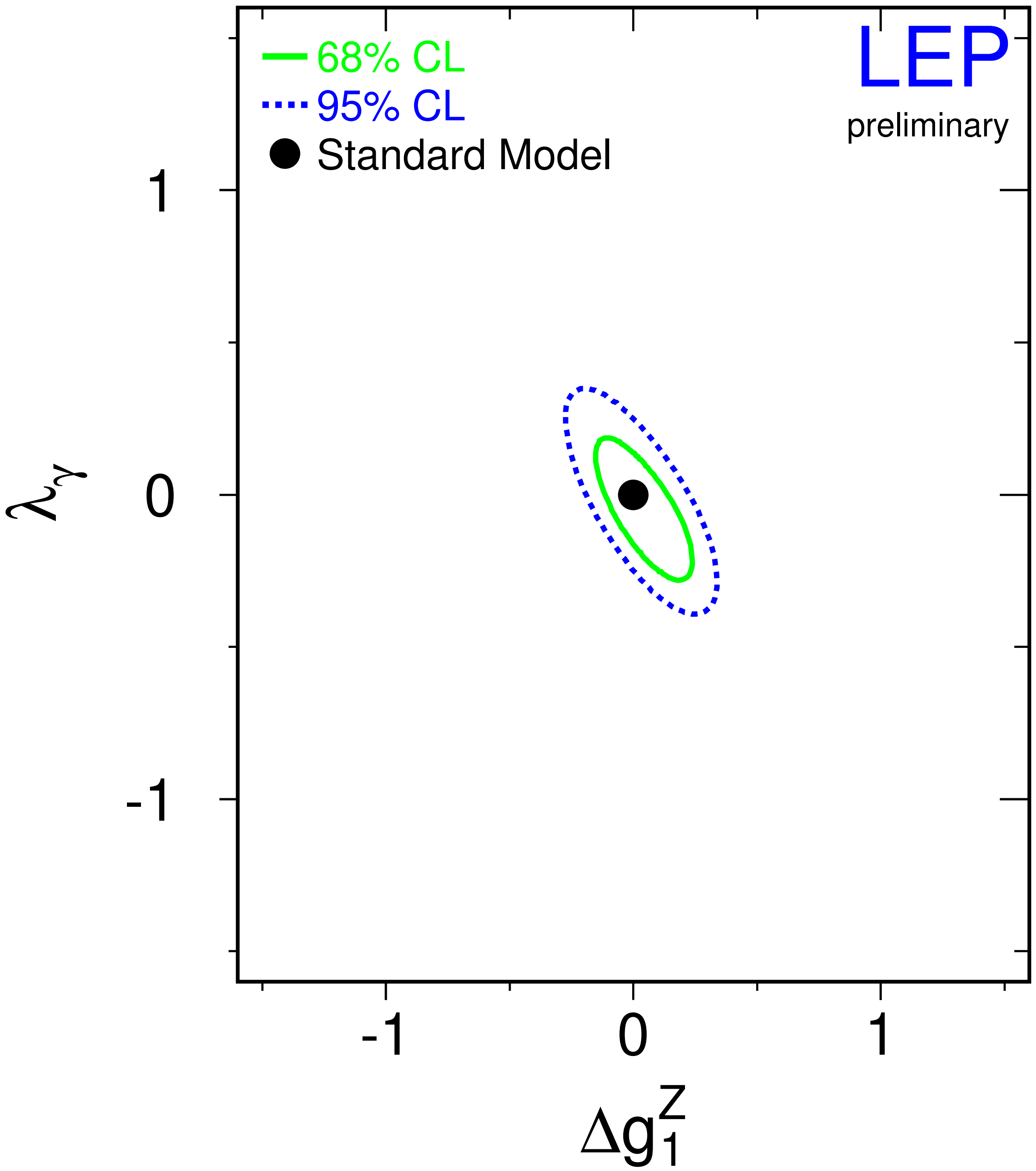

Figure 6: The contour curves for 68% C.L. ($\Delta \log \mathcal{L} = 1.15$) and 95% C.L. ($\Delta \log \mathcal{L} = 3.0$) in the parameter space Δg_1^z-λ_γ, obtained from the sum of the curves from the individual LEP experiments.

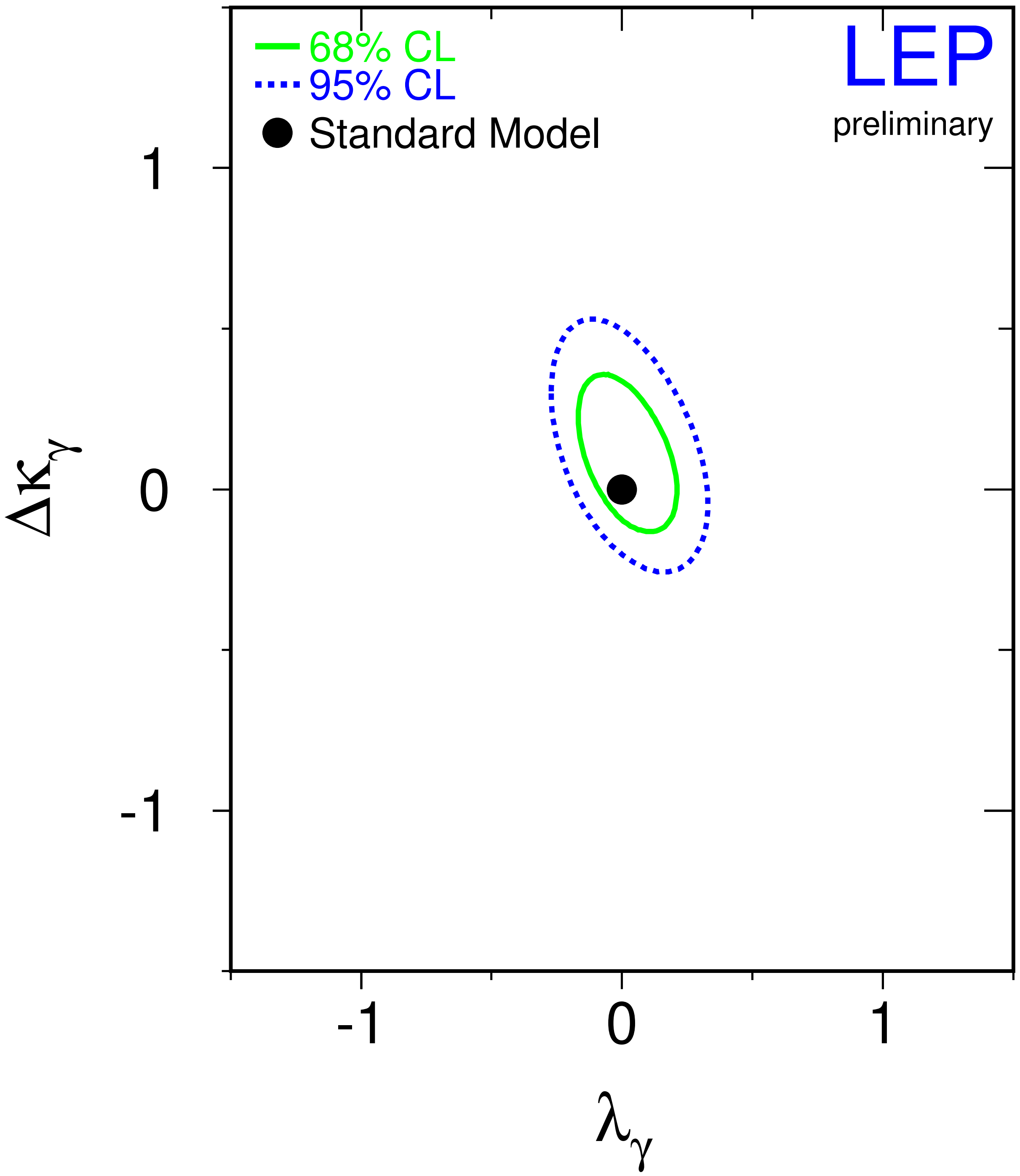

Figure 7: The contour curves for 68% C.L. ($\Delta \log \mathcal{L} = 1.15$) and 95% C.L. ($\Delta \log \mathcal{L} = 3.0$) in the parameter space $\Delta\kappa_\gamma$-λ_γ, obtained from the sum of the curves from the individual LEP experiments.