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A Preliminary Combination of LEP-II results for the reaction $e^+e^- \rightarrow \gamma\gamma(\gamma)$ and interpretations.

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Abstract

This note presents a combination of published and preliminary results on the $e^+e^- \rightarrow \gamma\gamma(\gamma)$ reaction for the four LEP collaborations which were presented at the Siena conference in October 2001. Averages in terms of deviations from QED on the total cross-section and the parameters obtained from differential cross-section fits are given. No deviations from the QED expectations have been found.

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1 Introduction

The reaction $e^+e^- \to \gamma\gamma(\gamma)$ provides a clean test of QED at LEP energies and is well suited to detect the presence of non-standard physics. The differential QED cross-section at the Born level is given by:

$$\left(\frac{d\sigma}{d\Omega}\right)_{\rm Born} = \frac{\alpha^2}{s}\frac{1+\cos^2\theta}{\beta_{\rm e}^{-2}-\cos^2\theta} \ . \qquad (1)$$

Since the two final state particles are identical the polar angle θ is defined such that $\cos\theta > 0$. Various models with deviations from this cross-section will be discussed in section 4. Results on the $\geq$2-photon final state using the high energy data collected by the four LEP collaborations are reported by the individual experiments [1]. Here the results of the LEP working group dedicated to the combination of the $e^+e^- \to \gamma\gamma(\gamma)$ measurements are reported. Results are given for the averaged total cross-section and for global fits to the differential cross-sections.

2 Event Selection

The channel is very clean and the event selection, similar in all the experiments, is based on the presence of at least two energy clusters on the electromagnetic calorimeters. A minimum energy is required with typical values $E_1+E_2 > 0.3 \div 0.6\sqrt{s}$ where E_1 and E_2 are the energies of the two most energetic photons. In order to remove e^+e^- events, charged tracks are in general not allowed except when they can be associated to a photon conversion in one hemisphere.

The polar angle is defined in order to minimise effects due to initial state radiation as

$$\cos\theta = \left|\sin(\frac{\theta_1-\theta_2}{2})\right| \Big/ \sin(\frac{\theta_1+\theta_2}{2}) \ ,$$

where θ_1 and θ_2 are the polar angles of the two most energetic photons. The polar angle acceptance changes among experiments being in the range $\cos\theta < 0.96 \div 0.90$.

With these criteria, the selection efficiencies are in the range $68 \div 95\%$ and the residual background (from e^+e^- events and from $e^+e^- \to \tau^+\tau^-$ with $\tau^\pm \to e^\pm\nu\bar{\nu}$) is very small $(0.1 \div 1\%)$. The detailed descriptions of the event selection performed by the four collaborations can be found in [1].

3 Total cross-section

The total cross-sections are combined using a χ^2 average. Given the different angular acceptances, only the ratio of the measured cross-section relative to the QED expectation $r = \sigma_{\rm meas}/\sigma_{\rm QED}$ is averaged. Figure 1 shows the measured ratios $r_{i,k}$ of the experiments i at energies k with their statistical and systematic errors $(\epsilon_{i,k}^{stat}, \epsilon_{i,k}^{sys})$ added in quadrature. No error on the theory is included in the experimental errors.

For all measurements a covariance matrix C is constructed via:

$$C_{i,k}^{j,l} = \epsilon_{i,k}^{stat}\cdot\epsilon_{j,l}^{stat}\delta_{ij}\delta_{kl} + \epsilon_{i,k}^{sys}\cdot\epsilon_{j,l}^{sys}\delta_{ij} \ , \qquad (2)$$

where $\delta_{ij} = 1$ for $i = j$ and 0 otherwise. The χ^2 is calculated via:

$$\chi^2 = \Delta^{\rm T} C^{-1} \Delta \ , \qquad (3)$$

where Δ is the vector of residuals between the measurement and the expected ratio. Three different averages are performed:

1. per energy $k = 1, \ldots, 7$: $\Delta_{i,k} = r_{i,k} - x_k$
2. per experiment $i = 1, \ldots, 4$: $\Delta_{i,k} = r_{i,k} - y_i$
3. global value: $\Delta_{i,k} = r_{i,k} - z$

The seven fit parameters per energy x_k are shown in Figure 1 as LEP combined cross-sections. They are correlated between each other with correlation coefficients of $10 - 20\%$. The four fit-parameters per experiment y_i are uncorrelated between each other, the results are given in Table 1 together with the one fit-parameter of the global value, z.

No significant deviations from the QED expectations have been found. The global ratio is below unity by 1.5σ not accounting for the error on the radiative corrections which is of the same size as the experimental error.

Experiment	cross-section ratio
ALEPH	0.963±0.025
DELPHI	0.974±0.032
L3	0.982±0.021
OPAL	1.000±0.021
global	0.982±0.012

Table 1: Cross-section ratios $r = \sigma_{\mathrm{meas}}/\sigma_{\mathrm{QED}}$ for the four LEP experiments averaged over all energies and the global average over all experiments and energies. The error includes the statistical and experimental systematic error but no error from theory.

4 Global fit to the differential cross-sections

The global fit is based on angular distributions at energies between 183 and 207 GeV from the individual experiments. As an example angular distributions from each experiment are shown in Figure 2. Combined differential cross-sections are not available yet, since they need a common binning of the histograms. All the experiments but ALEPH have given preliminary results including the whole year 2000 data-taking as shown in Table 2. The systematic errors arise from Luminosity evaluation (including theory uncertainty on cross-section computation),

	data used		sys. error [%]		$\lvert\cos\theta\rvert$
	published	preliminary	experimental	theory	
ALEPH		189 – 202	2	1	0.95
DELPHI	189 – 202	206	2.5	1	0.90
L3	183 – 189	192 – 207	2.1	1	0.96
OPAL	183 – 189	192 – 207	1.1	1	0.90

Table 2: The considered data-taking period, the systematic errors, the assumed error on the theory and the polar angle acceptance for the LEP experiments.

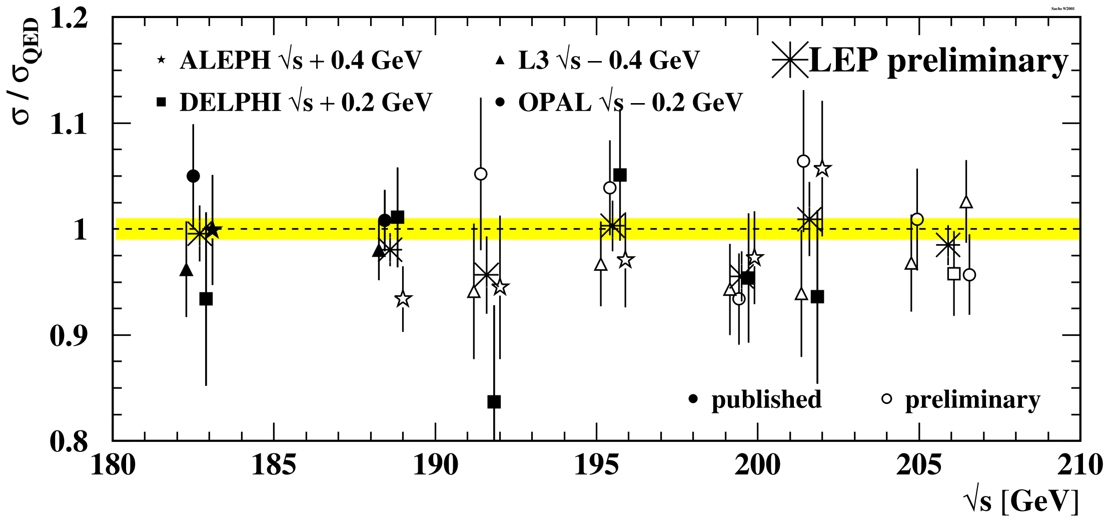

Figure 1: Cross-section ratios $r = \sigma_{\mathrm{meas}}/\sigma_{\mathrm{QED}}$ at different energies. The measurements of the single experiments are displaced by ± 200 or 400 MeV from the actual energy for clarity. Filled symbols indicate published results, open symbols stand for preliminary numbers. The average over the experiments at each energy is shown as a star. Measurements between 203 and 209 GeV are averaged to one energy point. The theoretical error is not included in the experimental errors but is represented as a yellow band.

from selection efficiency and background evaluations and from radiative corrections. The last contribution, since the available $\mathrm{e^+e^-} \to \gamma\gamma(\gamma)$ cross-section calculation is based on $\mathcal{O}(\alpha^3)$ code, is assumed to be of the order of 1% and it is correlated among energies and experiments.

Various model predictions are fitted to these angular distributions taking into account the experimental systematic error correlated between energies for each experiment and the error on the theory. A binned log likelihood fit is performed with one free parameter for the model and five fit parameters used to keep the normalisation free within the systematic errors of the theory and the four experiments.

The following models are considered, which lead partially to the same type of deviation. Hence some parameters can be transfered into each other.

Cut-off parameter $\Lambda_\pm$ [2, 3]:

$$\left(\frac{d\sigma}{d\Omega}\right)_{\Lambda_\pm} = \left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{Born}} \pm \frac{\alpha^2 s}{2\Lambda_\pm^4}(1+\cos^2\theta) \tag{4}$$

Effective Lagrangian theory [4] describing anomalous $\mathrm{e^+e^-}\gamma$ couplings in dimension 6 ($\Lambda_6^4 = \frac{2}{\alpha}\Lambda_\pm^4$) or contact interactions for dimensions 7 and 8 ($\Lambda_7 = \Lambda'$; $\Lambda_8^4 = m_{\mathrm{e}}\Lambda_7^3$):

$$\left(\frac{d\sigma}{d\Omega}\right)_{\Lambda'} = \left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{Born}} + \frac{s^2}{32\pi}\frac{1}{\Lambda'^6} \tag{5}$$

Low scale gravity in extra dimensions [5], where M_s is related to the string scale and expected to be of order $\mathcal{O}(\mathrm{TeV})$:

$$\left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{M_s}} = \left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{Born}} - \frac{\alpha s}{2\pi}\,\frac{\lambda}{M_s^4}\,(1+\cos^2\theta) + \frac{s^3}{16\pi^2}\,\frac{\lambda^2}{M_s^8}\,(1-\cos^4\theta)\,,\ \lambda = \pm 1 \tag{6}$$

Excited electrons [6] with mass M_{e^*} and chiral magnetic coupling described by the Lagrangian

$$\mathcal{L} = \frac{1}{2\Lambda}\bar{\ell}^* \sigma^{\mu\nu} \left[g f \frac{\tau}{2} W_{\mu\nu} + g' f' \frac{Y}{2} B_{\mu\nu} \right] \ell_L + \text{h.c.} \; . \tag{7}$$

For the two photon final state this leads to the following cross-section:

$$\left(\frac{d\sigma}{d\Omega}\right)_{e^*} = \left(\frac{d\sigma}{d\Omega}\right)_{\text{Born}} + \frac{\alpha^2}{4} \frac{f_\gamma^4}{\Lambda^4} M_{e^*}^2 \left[\frac{p^4}{(p^2 - M_{e^*}^2)^2} + \frac{q^4}{(q^2 - M_{e^*}^2)^2} + \frac{\frac{1}{2} s^2 \sin^2\theta}{(p^2 - M_{e^*}^2)(q^2 - M_{e^*}^2)} \right] , \tag{8}$$

with $f_\gamma = -\frac{1}{2}(f + f')$, $p^2 = -\frac{s}{2}(1 - \cos\theta)$ and $q^2 = -\frac{s}{2}(1 + \cos\theta)$ and $\Lambda = M_{e^*}$.

5 Fit Results

Where possible the fit parameters are chosen such that the likelihood function is approximately Gaussian. The preliminary results of the fits to the differential cross-sections are given in Table 3. No significant deviations with respect to the QED expectations have been found (all the parameters are compatible with zero) and therefore 95% confidence level limits are obtained by renormalising the probability distribution of the fit parameter to the physically allowed region. For limits on f_γ/Λ a scan over M_{e^*} is performed and presented in Figure 3. Only for M_{e^*} the cross-section function is non-linear in the fit-parameter. The obtained log likelihood difference ΔLogL is shown in Figure 4 and the limit is determined at ΔLogL = 1.92.

Fit parameter	Fit result	95% CL Limit [GeV]
$\Lambda_\pm^{-4}$	$\left(4.6\,^{+27.0}_{-26.5}\right) \cdot 10^{-12}$ GeV^{-4}	$\Lambda_+ > 365$ $\Lambda_- > 379$
Λ_7^{-6}	$\left(0.18\,^{+1.95}_{-1.92}\right) \cdot 10^{-18}$ GeV^{-6}	$\Lambda_7 > 794$
derived from Λ_+ derived from Λ_7		$\Lambda_6 > 1484$ $\Lambda_8 > 22.5$
λ/M_s^4	$\left(-0.106\,^{+0.609}_{-0.615}\right) \cdot 10^{-12}$ GeV^{-4}	$\lambda = +1$: $M_s > 972$ $\lambda = -1$: $M_s > 940$
$f_\gamma^4(M_{e^*} = 200\text{GeV})$	$0.036\,^{+0.414}_{-0.400}$	$f_\gamma/\Lambda < 4.1$ TeV^{-1}

Table 3: The preliminary combined fit parameters and the 95% Confidence Level limits for the four LEP experiments.

6 Conclusion

The LEP collaborations have studied the $e^+e^- \rightarrow \gamma\gamma(\gamma)$ channel up to the highest available centre-of-mass energies. The total cross-section results are combined in terms of ratio w.r.t. QED expectations. No deviations have been found. The differential cross-sections are fitted following different parametrisations from models predicting deviations from QED. No evidence for deviations have been found and therefore combined 95% confidence level limits are given.

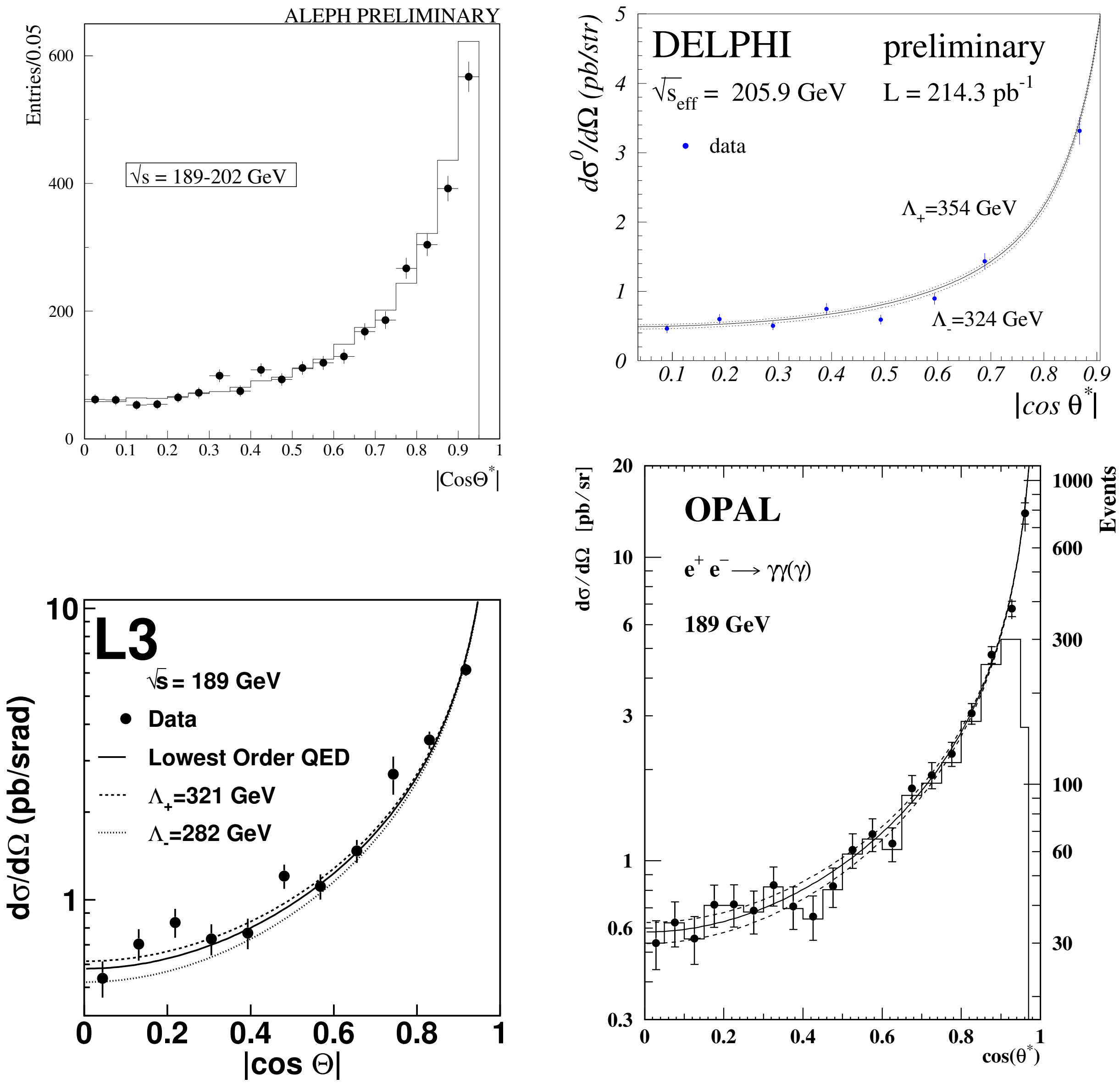

Figure 2: Examples for angular distributions of the four LEP experiments. Points are the data and the curves are the QED prediction (solid) and the individual fit results for $\Lambda_\pm$ (dashed). ALEPH shows the uncorrected number of observed events, the expectation is presented as histogram. For OPAL the histogram represents the number of observed events, before efficiency and radiative corrections are applied.

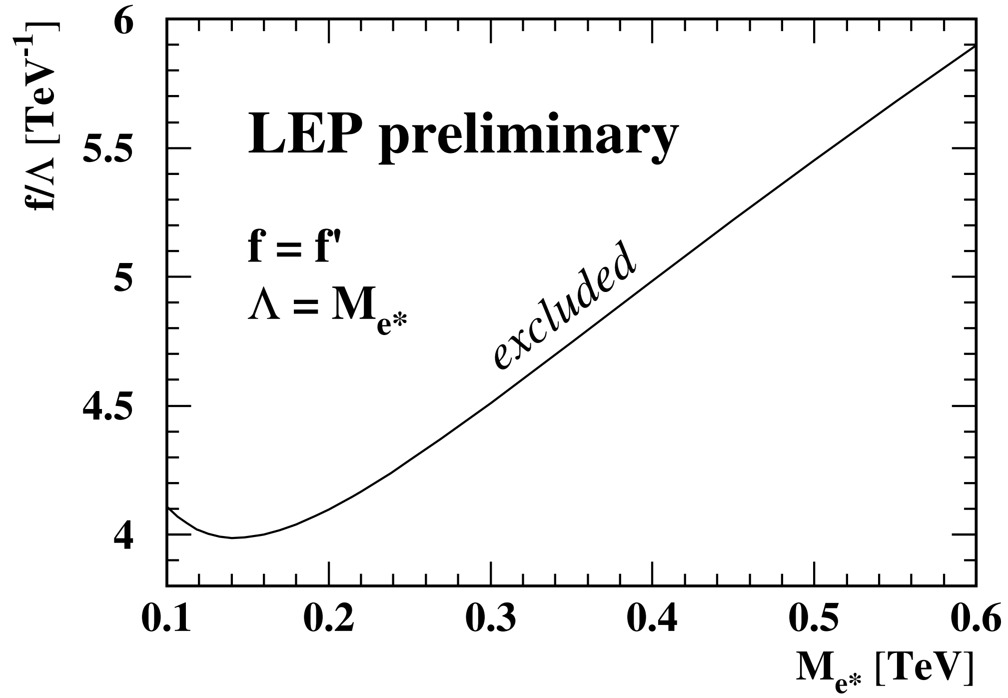

Figure 3: 95% CL limits on f_γ/Λ depending on M_{e^*}. In the case of $f = f'$ it follows that $f_\gamma = f$. It is assumed that $\Lambda = M_{\mathrm{e}^*}$.

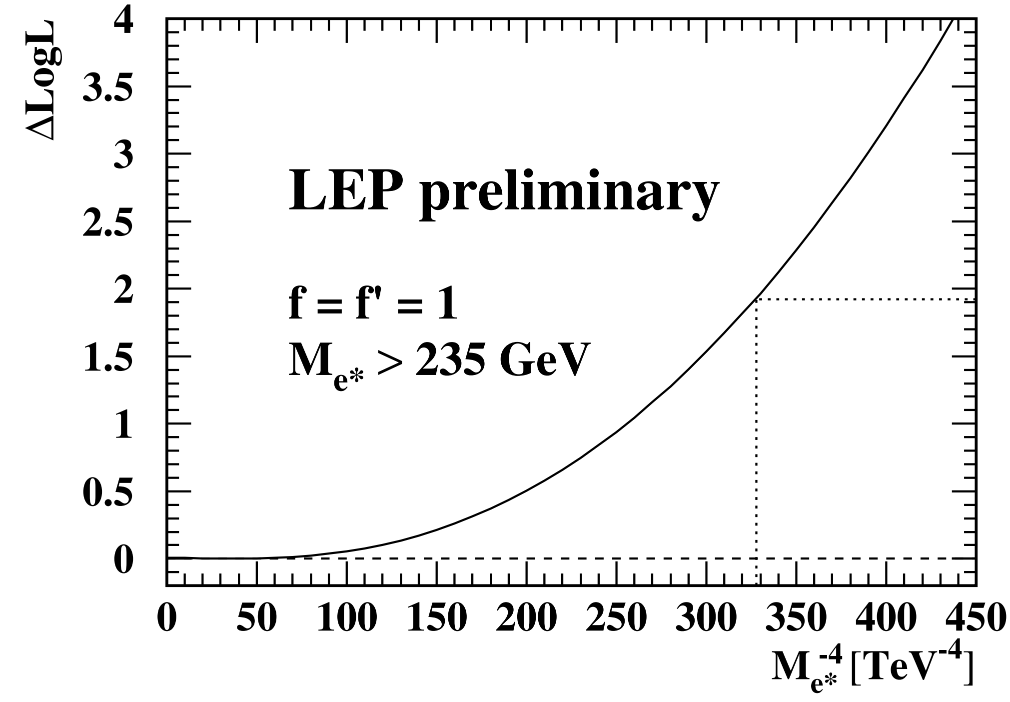

Figure 4: Log likelihood difference $\Delta\mathrm{LogL} = -\ln\mathcal{L} + \ln\mathcal{L}_{\max}$ as a function of $M_{\mathrm{e}^*}^{-4}$. The coupling is fixed at $f = f' = 1$. The value corresponding to $\Delta\mathrm{LogL} = 1.92$ is $M_{\mathrm{e}^*} = 235$ GeV.

References

[1] ALEPH Collab., ALEPH 2000-008 CONF 2000-005 and ref. therein;
DELPHI Collab., DELPHI 2001-093 CONF 521 and ref. therein;
L3 Collab., L3 Note 2650 and ref. therein;
OPAL Collab. OPAL PN469.

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