2 fermion and 2 photon production at e^+e^- colliders

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High energy e^+e^- collisions have provided a large amount of information and contributed considerably to our understanding of particle physics. Fermion pair and photon pair production have been extensively studied at LEP2, covering the large range of centre of mass energy from 130 to 208 GeV. In this paper, the available combined measurements of the four LEP experiments are given for these two processes. At the end, and with these results, limits upon a subset of possible extensions of the SM are derived.

1. INTRODUCTION

Difermion and diphoton subgroups of the LEP Electroweak Working Group were formed in order to combine the measurements of the fermion and photon pair production. With the combination of the four LEP experiments (ALEPH, DELPHI, L3 and OPAL) the statistical error of the combined measurements is reduced by a factor of two.

2. FERMION PAIR PRODUCTION

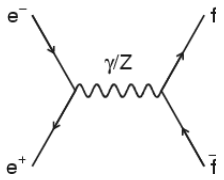

Figure 1. Lowest order diagrams for $e^+e^- \to f\bar{f}$

The e^+e^- annihilation into a fermion pair $e^+e^- \to f\bar{f}$ with f being a μ, τ or quark proceeds in lowest order via photon and Z exchange as sketched in Fig 1.

2.1. Event selection and measurements

For these s-channel processes, events at high effective centre of mass energies $\sqrt{s'}$ are selected by requiring $\sqrt{s'} > 0.85\sqrt{s}$.

The selection criteria for hadronic events use the multiplicity of tracks and electromagnetic calorimeter clusters, the total electromagnetic energy and the energy balance along the beam direction. Muon pair events are required to have two tracks identified as muons and for $\tau^+\tau^-$ events two low multiplicity jets. The detailed descriptions of the event selection performed by each collaboration can be found in [1].

The averages between all four LEP experiments were made using a technique equivalent to a χ^2 minimization. The combined results for the total cross sections and forward-backward asymmetries[1] at the full range of LEP2 energies are shown in Figures 2, 3 and 4 for hadronic, muon and tau pair final states. The measurements of the ratios[1] R_b and R_c are displayed in Figure 5.

2.2. Searches for new phenomena

Comparison of the measured cross sections, forward-backward asymmetries and angular distributions with SM predictions allows to place limits upon many possible extension of the SM.

In the contact term formalism [2], in which Λ represents the scale of new physics, several different models are possible, which differ on the helicities of the fermionic currents involved.

Another scheme for new physics is the extension of SM with an additional boson, the Z′ [3],

[1] A_{FB} is defined as $\frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$ and R_q as $\frac{\sigma_{q\bar{q}}}{\sigma_{had}}$

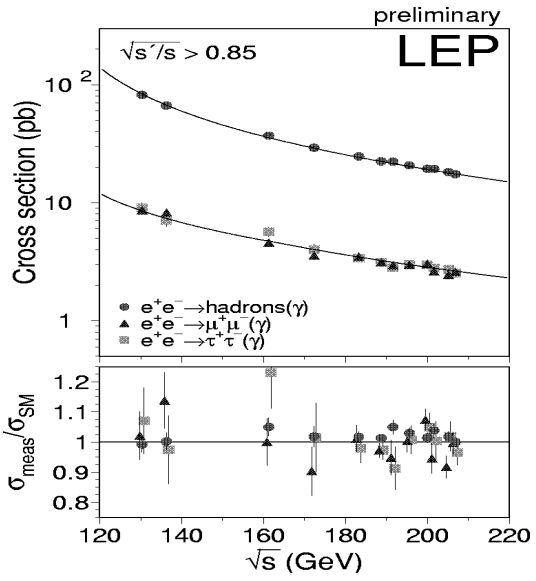

Figure 2. Preliminary combined LEP results on the total cross section for $q\bar{q}$, $\mu^+\mu^-$ and $\tau^+\tau^-$ final states as a function of centre of energy

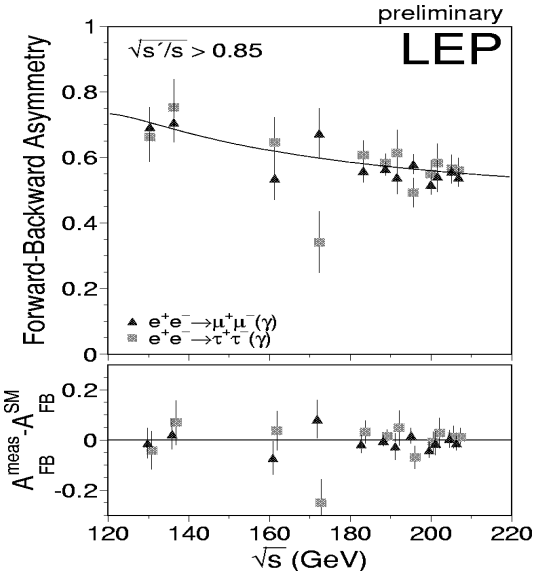

Figure 3. Preliminary combined LEP results on the forward-backward asymmetries for $\mu^+\mu^-$ and $\tau^+\tau^-$ final states as a function of centre of energy

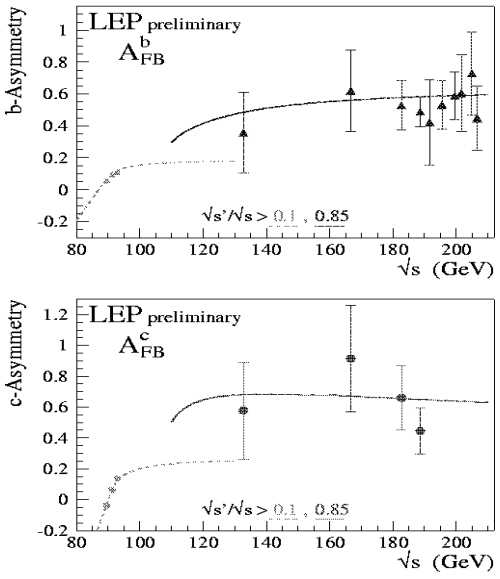

Figure 4. Preliminary combined LEP results on forward-backward asymmetries of $A_{FB}^{b\bar{b}}$ and $A_{FB}^{c\bar{c}}$

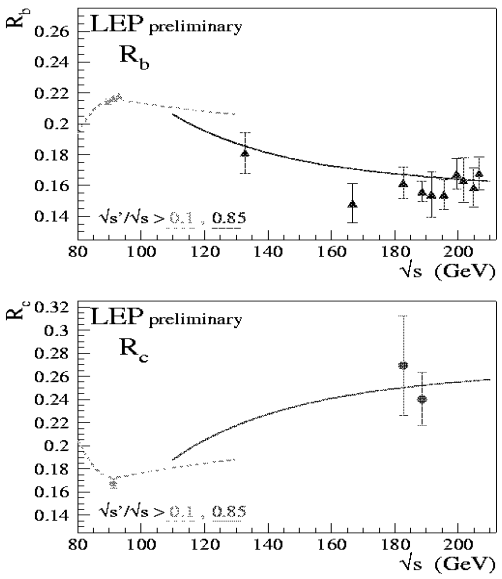

Figure 5. Preliminary combined LEP results on R_b and R_c

characterized by its mass and the angle for the mixing between the Z and the Z′. Different models exist for different choice of the couplings.

The last set of model considered is the existence of leptoquarks (LQ) [4], coloured spin 0 or spin 1 particles carrying both baryon and lepton quantum numbers.

The lower limits obtained at 95% of confidence level for the three extensions of the SM are collected in Table 1.

Table 1
Combined 95% Confidence Level limits

Model	95% CL Limit (TeV)	
Contact interactions[2]	$\Lambda >$	$8.5 - 26.2$
	$\Lambda >$	$1.3 - 14.6$
Z′	$M_{Z'} >$	$0.4 - 1.9$
Leptoquarks	M >	$0.2 - 1.1$

3. PHOTON PAIR PRODUCION

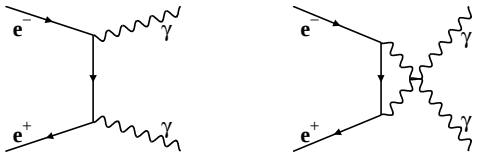

Figure 6. Lowest order diagrams for $e^+e^- \rightarrow \gamma\gamma$

The photon pair production reaction provides a very clean QED test. It proceeds in lowest order α^2 via single electron exchange (Figure 6). Higher order contributions can be described by QED, the first order weak corrections are completely negligible at LEP2 energies.

The differential cross section has the following simple form:

$$\left(\frac{d\sigma}{d\Omega}\right)_0 = \frac{\alpha^2}{s}\frac{1+\cos^2\theta}{1-\cos^2\theta} \qquad (1)$$

[2]The first line is the result for contact interaction between leptons and the second one the result for contact interaction between electron and b and c quarks.

where θ is the polar angle between the electron and photon.

3.1. Event selection and measurements

Events are selected by requiring at least two photons in the fiducial volume, identified as energy clusters on the electromagnetic calorimeters without associated tracks.

The analyses for each experiment are described in Reference [5] and the angular distributions are shown in Figure 7.

Due to the different angular acceptances in the LEP experiments, only the ratio of the measured cross section relative to the QED expectation is averaged. Table 2 shows the results of the single experiments and of the LEP χ^2 average for the measured ratio with their statistical and systematic error added in quadrature.

Table 2
Ratios $r = \sigma_{meas}/\sigma_{QED}$ for the four LEP experiments averaged over all energies and the global average over all experiments and energies

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

3.2. Limits on deviations from QED

Possible deviations from QED were considered in the context of several models.

In the case of effective interaction with non-standard $e^+e^-\gamma$ couplings or with $e^+e^-\gamma\gamma$ contact terms, a cutt-off parameter Λ [7] or $\Lambda_\pm$ [8,9] is introduced to describe the scale of the interaction.

In the low scale gravity model [10], there can be effects due to the exchange of virtual gravitons. This model introduce an effective scale M_S.

The 95% confidence level lower limits on each model parameter were derived combining the four

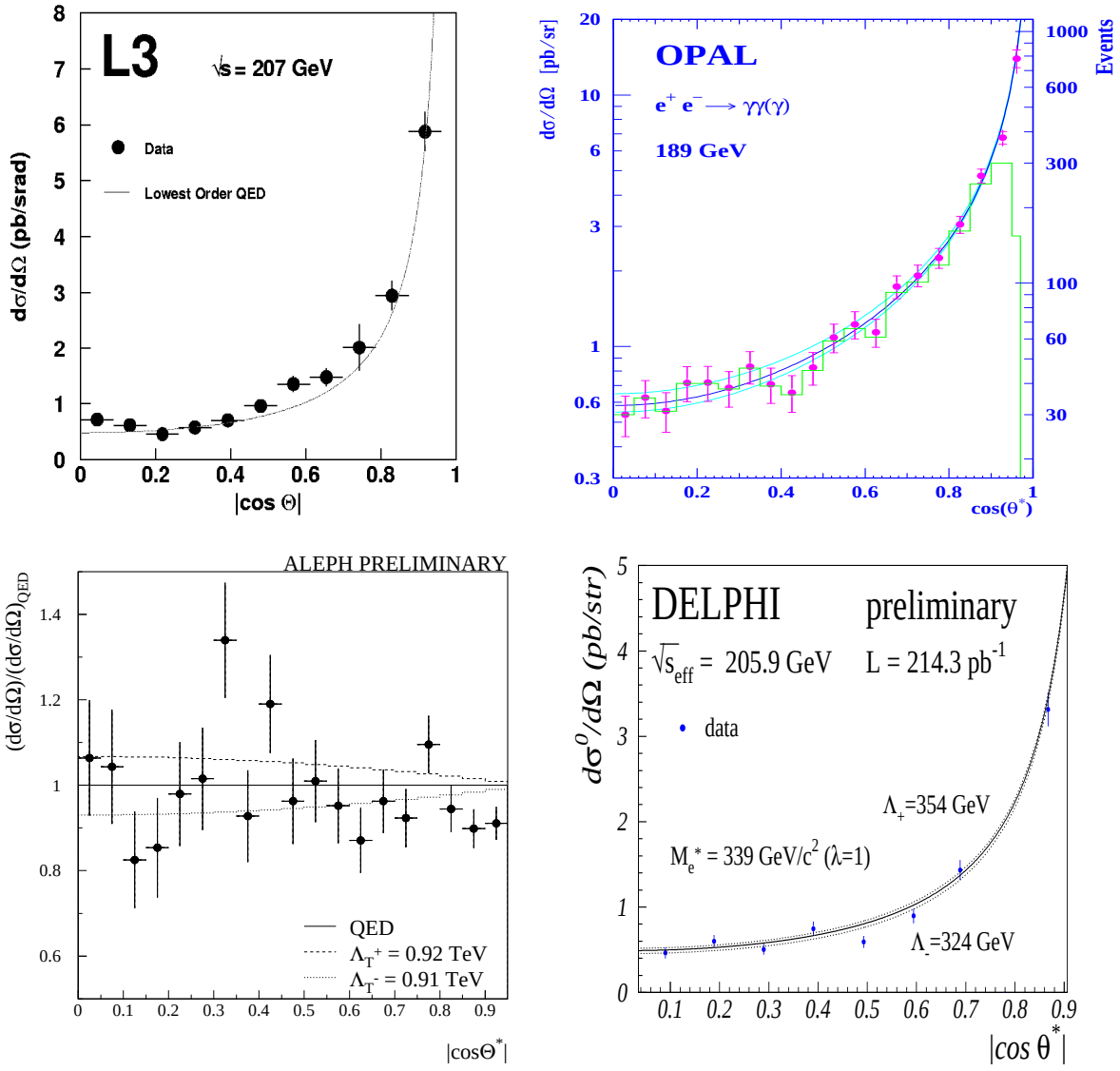

Figure 7. Angular distributions of the four LEP experiments for the process $e^+e^- \to \gamma\gamma$

experiments results. They are displayed in Table 3.

Table 3
Combined 95% Confidence Levels limits

Model	95% CL Limit (GeV)
Contact interactions	$\Lambda_+ > 365$
	$\Lambda_- > 379$
	$\Lambda_6 > 1484$
Anomalous couplings	$\Lambda_7 > 794$
Virtual graviton	$\lambda = +1$: $M_S > 972$
	$\lambda = -1$: $M_S > 940$

4. CONCLUSIONS

The LEP combinations for the measurements of the fermion and photon pairs show no significant deviations from the SM predictions, which allows to present limits at 95% of confidence level on several new physics proposals.

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