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TWO-FERMION PRODUCTION AT LEP2, MEASUREMENTS AND INTERPRETATIONS.

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The study of the two-fermion production at LEP2, based on the data collected at a centre-of-mass energy ranging from $\sim$ 130 GeV to $\sim$ 209 GeV for a total integrated luminosity of about 700 pb^{-1} per experiment, is reported. The preliminary combinations produced by the LEP ElectroWeak Working Group on the basis of the results obtained by the four LEP experiments (ALEPH, DELPHI, L3 and OPAL) are shown. A brief summary of the two-photon production is also given. The result interpretations in terms of S-matrix formalism and of Physics beyond the Standard Model are presented.

1 Introduction

The two-fermion final state at LEP2 is a good tool for high precision Standard Model Tests and for search for new physics. In particular, the measured quantities as the total and differential cross-sections and the forward-backward asymmetries can be compared with the SM predictions and can be used to check the γZ interference. Furthermore, virtual effects mainly due to the interference can extend the sensitivity to new physics well above the kinematical limit.

In the Standard Model, the fermion-pair production is due, at tree level, to s-channel annihilation of the $\mathrm{e^+e^-}$ into a photon or a $\mathrm{Z^0}$ with the additional dominant t-channel contribution for the electron final state. At LEP2 the photon exchange has a large importance while at LEP1 the $\mathrm{Z^0}$ production dominates being two orders of magnitude larger. In addition, at LEP2, the photon Initial State Radiation is important and it induces the so-called *radiative return to* $\mathrm{Z^0}$ which doubles the total cross sections (except for the electron final state) but it reduces the $\mathrm{e^+e^-}$ annihilation energy $\sqrt{s'}$ with respect to the total centre-of-mass energy $\sqrt{s}$. To study the high kinematical region of LEP2 (i.e. by selecting the events with $\sqrt{s'}/\sqrt{s} > 85\%$) only a fraction of the total number of produced events can be used. On the other hand, all the final states have quite clear signatures and the productions are much larger than expected backgrounds making the fermion-pair study an ideal sector for high precision tests.

2 Data analysis

The data collected from year 1995 to 2000 at a centre-of-mass energy ranging from $\sim$ 130 GeV to $\sim$ 209 GeV correspond to a total integrated luminosity of about 700 pb^{-1} per experiment.

The four LEP experiments (ALEPH, DELPHI, L3 and OPAL) selected the e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$ and $q\bar{q}$ final states with selection criteria similar to those used at LEP1. The selection efficiency was about 90% for all the channels but the τ one which had an efficiency of about 50%. The residual backgrounds were very small for the e^+ e^- and $\mu^+\mu^-$ channels (about 1% and $2 \div 3$% respectively) while for the τ final state it could be more than 10%, depending on the experiment. The hadronic final state had a large contamination due to the WW production which could be reduced to less than 10% by means of dedicated analyses.

The measured physical observables were the total and the differential cross sections (the latter not for the $q\bar{q}$ channel), the forward-backward asymmetry A_{fb} for the leptonic and $b\bar{b}/c\bar{c}$ final states and the ratios $R_{b,c} = \sigma_{b\bar{b},c\bar{c}}/\sigma_{q\bar{q}}$.

The $non-radiative$ events were selected with additional cuts ($\sqrt{s'}/\sqrt{s} > 0.85 \div 0.90$ or acollinearity $< 20°$) depending on the considered final state. To determine the centre-of-mass energy after the initial state radiation $\sqrt{s'}$ the information from jet/lepton directions and momenta and the possible photon detection were considered and the results were cross-checked with the Z^0 peak.

The heavy flavour final states were selected on the basis of lifetime variables, mass of secondary vertex, track rapidity and jet/vertex charge. Dedicated Neural Network analyses were performed by Aleph and Opal for the charm final state selection.

3 Results

The results obtained by the single experiments are still incomplete and in part preliminary. As a consequence all the combinations performed by the LEP ElectroWeak Working Group [1] taking into account the different correlations have to be considerd as preliminary.

The measured total cross sections for $\mu^+\mu^-$, $\tau^+\tau^-$ and $q\bar{q}$ and the forward-backward asymmetries for $\mu^+\mu^-$ and $\tau^+\tau^-$ final states including the comparisons with the Standard Model predictions are shown in Fig. 1. Agreement with SM expectations was found at all the energies. No deviations from the predictions were present in the leptonic differential cross section, as it can be seen in Fig. 2 for the e^+e^- final state, nor in the $R_{b,c}$ ratios and in the b,c forward-backward asymmetries.

The photon-pair production was also in agreement with QED expectations both in the total and in the differential cross-sections.

4 Interpretations

The measurements of the observables listed above, have been interpreted in several scenarios.

The fermion-pair cross-sections and asymmetries were fitted according to the S-matrix formalism, a semi model-independent approach [2] where the γZ interference is not fixed to the SM prediction. At LEP-1 the S-matrix fit gave a large correlation between the Z mass and the interference term j^{tot}_{had} which was reduced using the LEP1+LEP2 data as it can be seen in Fig. 3.

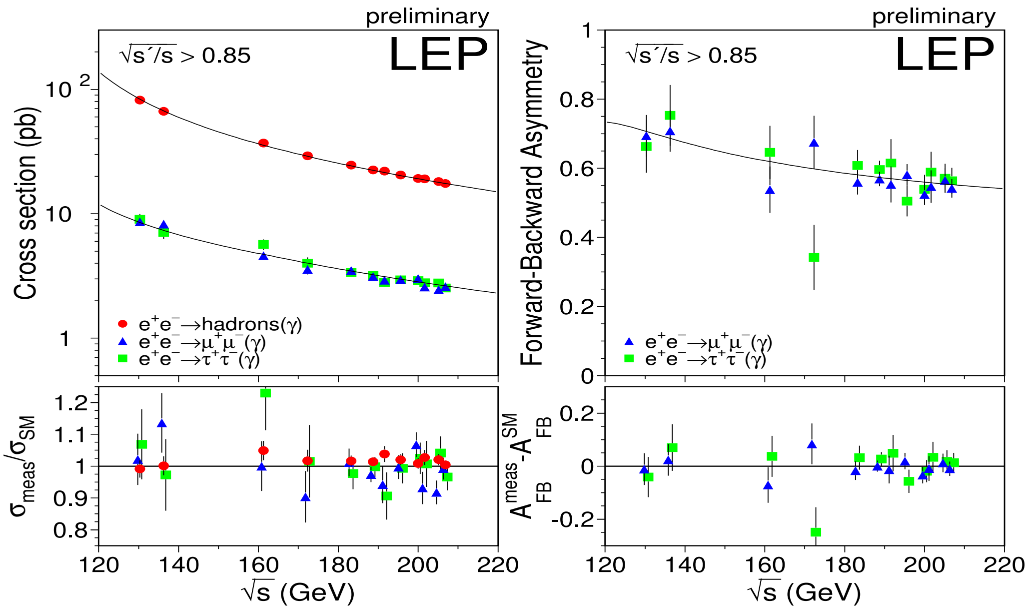

Figure 1. The combined LEP [1] cross-sections (top left) and forward-backward asymmetries (top right) compared with Standard Model predictions (bottom).

Contact interactions between fermions give a general description of low energy behaviour of new physics at high scale. Following [3] contact interactions are parameterised as an effective Lagrangian $\mathcal{L}_{eff}$:

$$\mathcal{L}_{eff} = \frac{g^2}{(1+\delta)\Lambda^2} \sum_{i,j=L,R} \eta_{ij}\overline{e}_i\gamma_\mu e_i \overline{f}_j \gamma^\mu f_j, \tag{1}$$

where $g^2/4\pi$ is taken to be 1 by convention, $\delta = 1(0)$ for $f = e (f \neq e)$, $\eta_{ij} = \pm 1$ or 0 and Λ is the scale of the contact interactions. A set of different models with constructive or destructive interference with the SM can be defined from $\mathcal{L}_{eff}$ depending on the assumed helicity couplings. The average measurements of cross-sections for $\mu^+\mu^-$, $\tau^+\tau^-$ and $q\bar{q}$ final states and of forward-backward asymmetries for $\mu^+\mu^-$ and $\tau^+\tau^-$ were used to search for those interactions. For fitting purpose the parameter $\epsilon = 1/\Lambda^2$ was defined and its value was compatible with zero, corresponding to no contact interactions, at the two standard deviations level for each model. The values of ϵ were converted into 95Λ [1].

Several models predicting the existence of additional gauge bosons Z′ exist and three different scenarios, namely E$_6$ [4], Left-Right [5] and Sequential SM [6] were investigated. The E$_6$ model is based on a symmetry breaking of the E_6 GUT where two gauge groups $U(1)_\chi$ and $U(1)_\psi$ are introduced and the mixing angle Θ_6 of the χ and ψ fields to form the Z′ is a free parameter. Usual choices of Θ_6 are $\Theta_6 = 0, \pi/2, -\arctan\sqrt{5/3}$ (χ, ψ and η model). Since no evidence of Z′ was

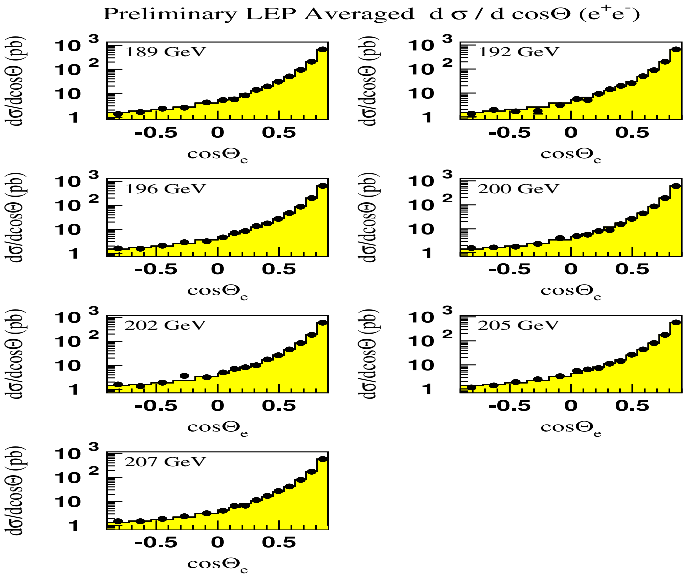

Figure 2. The combined LEP [1] e^+e^- differential cross-sections. The dots are the measured values and the histogram represents the SM prediction.

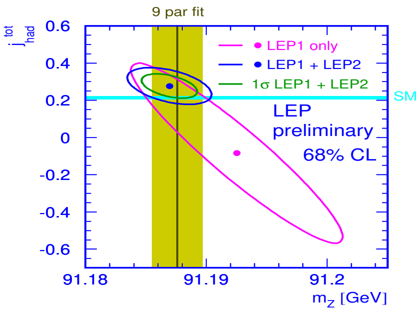

Figure 3. Error contours (at 39% and 68% CL) for m_Z and j^{tot}_{had} for the LEP1+LEP2 data combination compared with the LEP1 results

found, lower limits on the Z′ mass were obtained with the hypothesis of no ZZ′ mixing as suggested by LEP1 data. The results are shown in table 1.

Model	χ	ψ	η	LR	SSM
Limit(GeV/c^2)	673	481	434	804	1787

Table 1. 95% Confidence Level lower limits on the Z′ mass for the χ, ψ, η, L-R and SSM models.

Lepton-quark transitions could be mediated by LeptoQuarks (LQ). At LEP

LQ exchange can modify the hadronic cross-section and asymmetries [7]. No LQ evidence was found and consequently upper limits on the LQ's coupling as function of its mass were set. The detailed results can all be found in Ref. [1].

Fermion and photon-pair differential cross sections are sensitive to effects of graviton exchange in large extra dimensions as foreseen by low scale quantum gravity [8]. The most sensitive channel is the e^+e^- final state. Deviations from SM expectations can be expressed in terms of a parameter ϵ_G which is related to the quantum gravity scale M_G as $\epsilon_G = \lambda/M_G^4$. The coefficient λ is expected to be of $\mathcal{O}(1)$ but cannot be calculated explicitly. Results were given for $\lambda = \pm 1$ in order to cope with both positive and negative interference. Only the e^+ e^- and the $\gamma\gamma$ final state are considered at the present in Ref. [1]. For both cases the value of ϵ_G was compatible with 0. Therefore the following limits at the 95% C.L were obtained: $M_G > 1020(1009)$ GeV for $\lambda = 1(-1)$, and $M_G > 933(1010)$ GeV for $\lambda = 1(-1)$ for the electron and photon final states, respectively.

5 Conclusions

Fermion (and photon) pair production were studied at LEP in the whole energy range from Z^0 to $\sim$ 209 GeV. Agreement with Standard Model was present in the results of the single experiments and in the combined results. S-matrix fit gave results with a precision similar to the SM fits and with a parameter correlation much reduced with respect to the LEP1 analyses. Limits on several models of physics beyond Standard Model were set : Contact Interactions, exchange of Z' bosons, Leptoquarks, Quantum Gravity, etc.. The results of the single experiments are still incomplete and in part preliminary and consequently all the combined results have to be considered as preliminary.

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