FERMION PAIR PRODUCTION AT LEPII AND LIMITS ON NEW PHYSICS PROCESSES

A.J.M. MUIJS
NIKHEF,
P.O. Box 41882, 1009 DB Amsterdam, The Netherlands
E-mail: muijs@cern.ch

The measurements of production cross sections for fermion pairs are presented. For lepton pairs also the differential cross sections and the forward-backward asymmetries are shown. No statistically significant deviations from the Standard Model predictions are observed, and hence limits have been placed on new physics processes. All results are still preliminary.

1 Introduction to the LEPII program

From 1995 till the end of 2000 the four LEP experiments have been taken data above the Z-resonance. In total, integrated luminosities of more than 700 pb^{-1} have been collected per experiment at center-of-mass energies ranging from $\sqrt{s} = 130$ GeV to $\sqrt{s} = 208.8$ GeV.

The measurements of fermion pair production at these energies differs from those at the Z-peak, because of the significantly smaller cross sections. The rise of new background channels such as WW-production and ZZ-production and the large radiative corrections due to the nearby presence of the Z-resonance further complicate the measurements. On the other hand, the relatively small cross sections are more sensitive to additional contributions from new physics processes and hence the possibility to observe new physics phenomena indirectly increases.

2 Reconstruction of the effective center-of-mass energy.

At LEPII energies a large fraction of the events will have a hard initial state photon, leading to a so-called radiative return to the Z. The effective center-of-mass energies, i.e. the energy after initial state radiation, is an important variable in both the selection procedures and in the signal definition.

In only 10 % of the events the ISR photon can be detected, in all other cases it escapes into the beam pipe. For those events the energy of the missing photon(s) and the effective center-of-mass energy can be reconstructed from the polar angles of the outgoing fermions by imposing four-momentum conservation, under the assumption that a single photon escaped parallel to the beam pipe:

$$E_\gamma = \sqrt{s} \cdot \frac{|\sin\theta_1 + \theta_2|}{\sin\theta_1 + \sin\theta_2 + |\sin\theta_1 + \theta_2|} \tag{1}$$

$$s' = s - 2\sqrt{s}E_\gamma + E_\gamma^2 - \mathbf{P}_\gamma^\mathbf{2} \tag{2}$$

The effective center-of-mass energy is used to define to samples:

$\sqrt{s'} > 60$ GeV - hadrons *inclusive sample*
$\sqrt{s'} > 75$ GeV - muon and tau leptons
$\sqrt{s'} > 0.85\sqrt{s}$ *non-radiative sample*

For the Bhabha channel the variable $\sqrt{s'}$ is not a convenient choice due to the t-channel contributions to this process. Therefore the acolinearity ζ is chosen to distinguish between radiative ($\zeta < 120°$) and high-energy ($\zeta < 25°$) events.

3 Measurements

The cross sections for fermion pair production have been measured at 13 different center-of-mass energies for both the inclusive and the non-radiative samples. For the lepton channels also the differential cross section and forward-backward asymmetries have been measured. Figure 1 shows selection plots for hadrons and muon pairs. The Monte Carlo simulations describe the data very well.

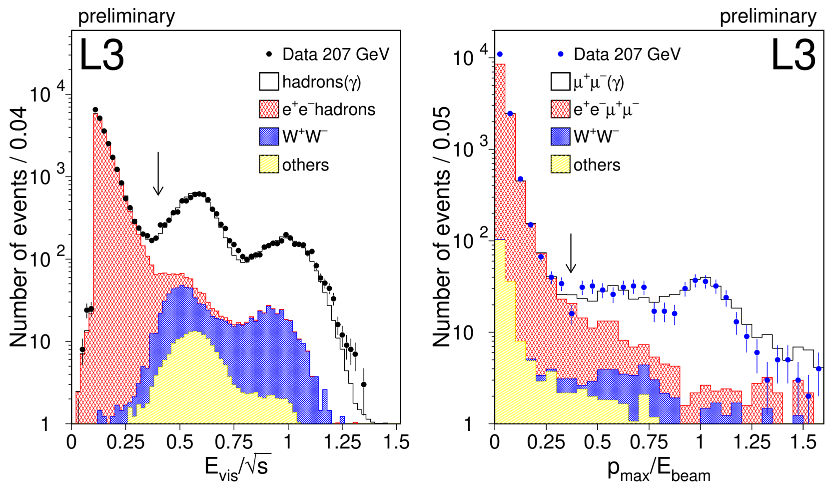

Figure 1. Selection plots for hadrons and muons. The area to the left of the arrow is rejected in order to reduce two-photon background.

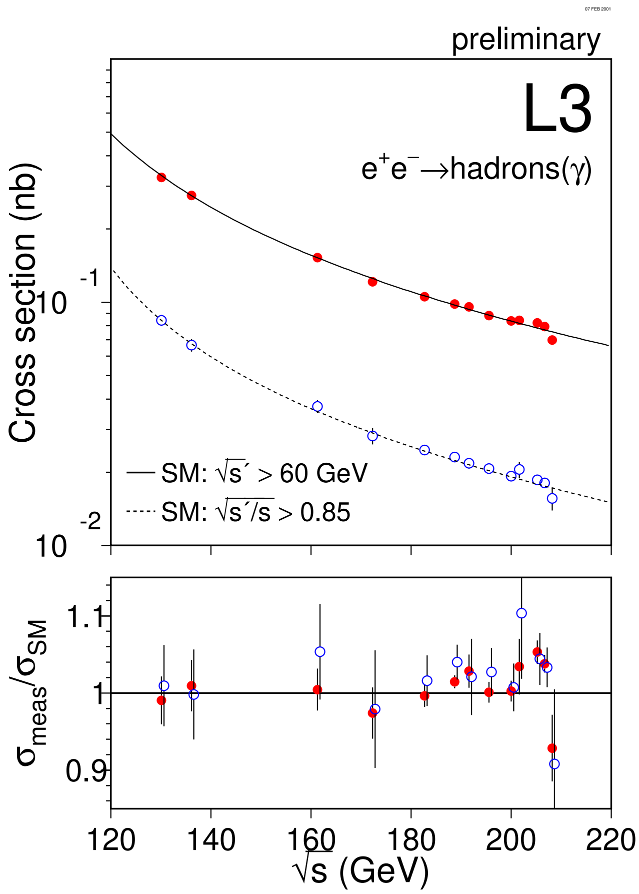

Figure 2. The hadronic cross section measurements above the Z-peak. The lower plot shows a direct comparison with the Standard Model prediction.

The results of the measurements of the cross section for the process $e^+e^- \to q\bar{q}$ are shown in figure 2. The lower plot shows the excellent agreement between the measurements and the Standard Model predictions calculated with the ZFITTER program [1].

In Figure 3 the results are shown for the cross section and asymmetry measurements for the leptonic channels. The processes $e^+e^- \to \mu^+\mu^-$ and $e^+e^- \to \tau^+\tau^-$ are combined. Again a good agreement is observed between the measurements and the Standard Model predictions.

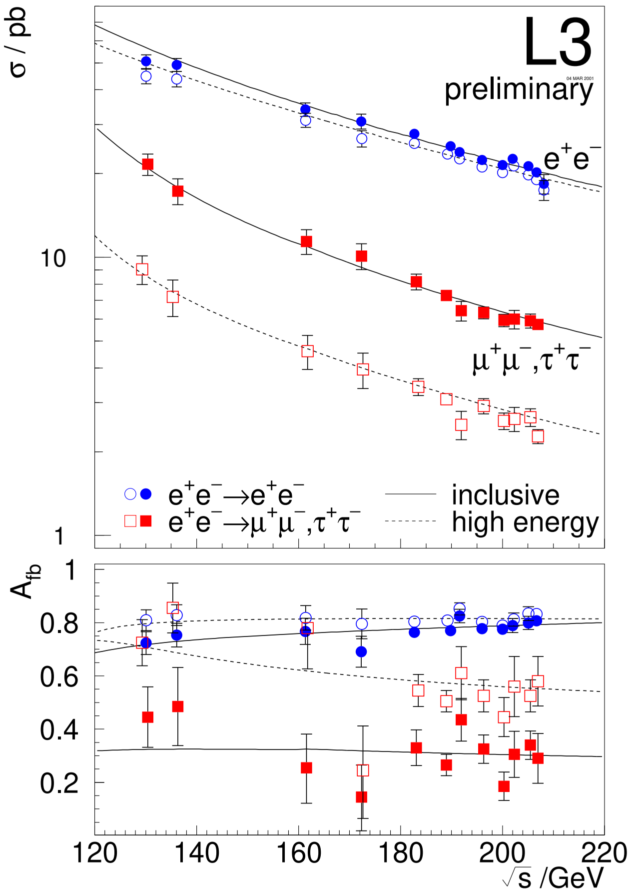

Figure 3. The cross section and asymmetry measurements for the leptonic channels. The results for muon and tau pairs have been combined.

4 Interpretation

Since no statistically significant deviations from the Standard Model have been observed, the immediate presence of non-standard physics processes can be excluded. Sensitivity to new physics processes has been investigated and limits have been placed on the parameters of their models [2,3]. A few of these models will be discussed in this section.

4.1 Contact Interactions

The most general approach to search for the presence of new physics phenomena is to assume an additional contribution from a contact interaction term. The parameters in this model are the energy scale Λ, the coupling g, which is fixed to 4π by convention, and the helicity amplitudes η_{ij}, which are taken to be 0 or ±1. The strongest limits can be obtained by using the leptonic differential cross sections, where the lower limits on Λ range from 9 to 25 TeV.

4.2 Quantum Gravity

Another model that has received a lot of attention in the last years predicts effects mediated by gravitons travelling in extra dimensions [5]. Through interactions with Standard Model particles, which are confined to the normal 3+1 dimensions, these gravitons can alter the differential cross sections for fermion pair production [6,7]. The fundamental scale of gravity in N dimensions, $\mathrm{M_S}$, is related to the Planck scale n the 4-dimensional world:

$$\mathrm{M}^2_{\mathrm{Pl}} \approx \mathrm{R}^{\delta}\mathrm{M}_{\mathrm{S}}^{\delta+2} \tag{3}$$

where $\delta = \mathrm{N}-4$ is the number of extra dimensions and R the size of the extra dimensions.

The interference between the Standard Model and the new physics terms gives contributions of the order $\lambda/\mathrm{M}_{\mathrm{S}}^4$. The largest effect is expected to occur in the Bhabha channel, due to additional t-channel contributions. By fixing the coupling to ±1, lower limits on $\mathrm{M_S}$ of 1.2 TeV are derived for both positive and negative interference.

4.3 Fermion Sizes

If fermions would have a finite size, the differential cross section would again slightly be changed [8]. This correction can be modelled with form factors, and assuming the simplest case of a Dirac form factor, one obtains:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}q^2} = \left(\frac{\mathrm{d}\sigma}{\mathrm{d}q^2}\right)_{\mathrm{SM}} F^2_{\mathrm{e}}(q^2)F^2_{\mathrm{f}}(q^2) \tag{4}$$

$$F(q^2) = 1 + \frac{1}{6}q^2\mathrm{R}^2 \tag{5}$$

The upper limits on the size R of the fermions derived from our measurements is $3.0 \cdot 10^{-19}$m for quarks and $2.2 \cdot 10^{-19}$m for leptons.

5 conclusions

The cross sections for fermion pair production have been measured at 13 different center-of-mass energy points above the Z-resonance. For the lepton channels the differential cross sections and the forward-backward asymmetries have been measured as well. No significant deviations from the Standard Model have been observed.

The excellent agreement of the Standard Model with the data excludes the presence of new physics processes. Limits have been placed on several models predicting new phenomena:

- The lower limit for the energy scale for contact interactions ranges (depending on the helicities) from 9 to 25 TeV under the assumption of lepton universality.
- The lower limit for the fundamental scale for gravity in a higher dimensional world is 1.2 TeV, derived from the differential cross sections of Bhabha scattering.
- If fermions have a finite size, then they are very small indeed: quarks are smaller than $3.0 \cdot 10^{-19}$m and leptons smaller than $2.2 \cdot 10^{-19}$m.

References

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