Measurements of Fermion Pair Production at LEPII with the L3 detector

Sandra Muijs
NIKHEF,1009 DB Amsterdam, The Netherlands

A review of L3 measurements on fermion-pair cross sections and lepton-pair forward-backward asymmetries at centre-of-mass energies between 130 and 189 GeV is presented. No deviations from the Standard Model are observed, and the data are used to constrain the allowed regions for new physics phenomena. Limits on contact interactions, exchange of R-parity violating sneutrino's or an additional heavy gauge boson Z' are given. All 189 GeV data are preliminary.

I. INTRODUCTION

Since 1995 LEP has been operated at centre-of-mass energies well above the Z-resonance. Because of the successfull running of LEP in 1998 the total integrated luminosity of LEPII has been doubled. The collected integrated luminosities per centre-of-mass energy are listed in Table I.

TABLE I. Integrated lunimosities per centre-of-mass energy. In the last column the statistical error on the hadronic cross section for the total sample (including events with hard initial state radiation) and high energy sample are listed.

year	$\sqrt{s}$ [GeV]	$\mathcal{L}$ [pb^{-1}]	$q\overline{q}$ stat. err [%]
1995,1997	130	~ 6	2.3/5.2
1995,1997	136	~ 6	2.6/6.0
1996	161	~ 10	2.7/5.9
1996	172	~ 10	3.2/7.1
1997	183	~ 55	1.4/3.3
1998	189	~ 175	0.9/2.0

II. MEASUREMENTS OF CROSS SECTIONS AND ASYMMETRIES

At LEPII two event classes are distinguished in the analyses of fermion pair production. The events with an effective centre-of-mass energy $\sqrt{s'} > .85\sqrt{s}$ form the genuine high energy sample. This sample is most sensitive to the presence of new physics channels. The second sample, the inclusive sample, is defined by $\sqrt{s'} > .1\sqrt{s}$ and contains also the events with hard initial Bremsstrahlung. Most of these highly energetic photons are emitted at very small angles with the electron-positron beam and escape therefore undetected in the beampipe. In those cases $\sqrt{s'}$ is determined from a kinematic fit to the event for hadrons, and for the leptons it is derived from the polar angles. In Figure 1 the distribution of $\sqrt{s'}$ for hadrons at $\sqrt{s} = 189$ GeV is shown. On the left the events with a hard initial state photon ('radiative returns to the Z') can be seen.

The measured cross sections of all fermion pairs are compared to the Standard Model (SM) p redictions in Figures 2 and 3. The bhabha scattering cross section is only shown for the high energy sample because due t o the dominant presence of the s-channel the difference between the two samples is very sm all. In Figure 4 the forward-backward asymmetries for lepton pairs are shown toge ther with the SM predictions. No statistically significant deviations from the Standard Model are observed.

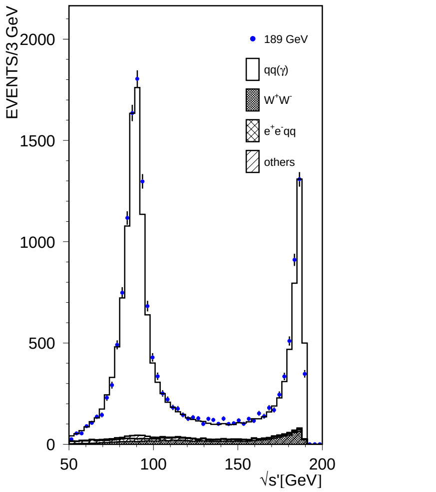

FIG. 1. The effective centre-of-mass energy $\sqrt{s'}$ for hadrons.

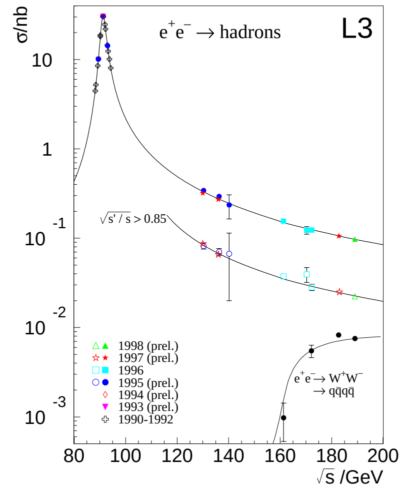

FIG. 2. Cross sections for hadrons.

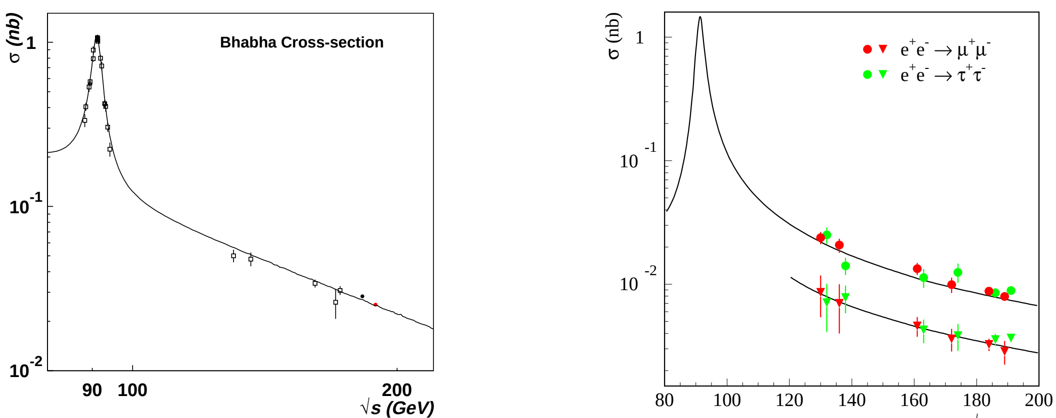

FIG. 3. Cross sections for lepton pairs. The lines represent the Standard Model predictions.

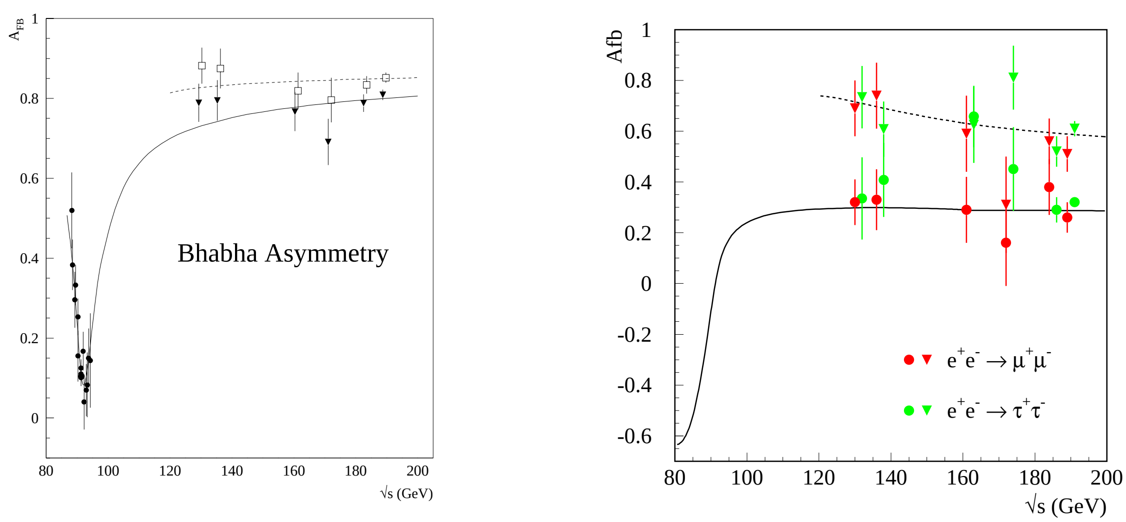

FIG. 4. Asymmetries for bhabha's and muon- and tau-pairs. The SM predictions for the total sample (solid line) and for the high energy sample (dotted line) are also shown.

III. SEARCHES FOR NEW PHENOMENA

A. Contact Interactions

The framework of contact interactions offers a general description of new physics phenomena. At energies far below the energy scale Λ of the new interaction, the exchange of virtual new particles can be described by an effective Lagrangian [1]:

$$\mathcal{L} = \frac{1}{1+\delta_{ef}} \frac{g^2}{\Lambda_{ij}^2} \sum \eta_{ij} (\overline{e_i} \gamma^\mu e_i)(\overline{f_j} \gamma_\mu f_j) \tag{1}$$

By convention, the coupling g is $\sqrt{4\pi}$, and the helicity amplitudes $|\eta_{ij}|$ are taken to be ≤ 1.
The occurrence of a new interaction leads to deviations in the differential cross sections for fermion pair production:

$$\frac{d\sigma}{d\Omega} = SM(s,t) + \frac{g^2}{\Lambda^2} C_{Interference} + \frac{g^4}{\Lambda^4} C_{NewPhysics} \tag{2}$$

Strong effects, like resonances, can be observed directly through the $C_{NewPhysics}$ term. Otherwise, new physics phenomena can still contribute via the $C_{Interference}$ term.
No deviations from the Standard Model are observed, and therefore the measured fermion pair cross sections and asymmetries can be used to put constrains on the energy scale Λ. The results from a fit to the measurements are listed in Figure 5 for various scenario's. The 95 % CL vary from 3 to 10 TeV for final states with two leptons and from 2.5 to 6.5 TeV for hadronic final states.

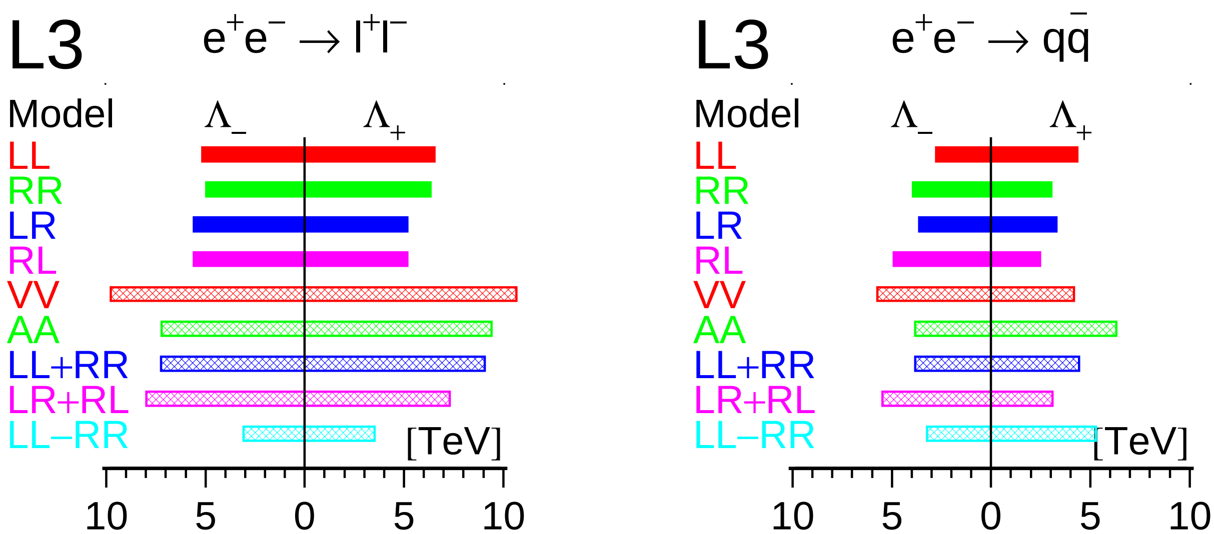

FIG. 5. 95% CL on contact interactions for leptonic (l^+l^-) and hadronic ($q\overline{q}$) final states.

B. R-Parity Violating Susy

A more specific strategy to look for new physics phenomena is the search for parity violating SuperSymmetry (SUSY). Already in the minimal supersymmetric standard model (MSSM) lepton number (L) violating terms can be found [2]:

$$W_{\not R} = \lambda_{ijk} L_L^i L_L^j \overline{E}_R^k + \lambda'_{ijk} L_L^i Q_L^j \overline{D}_R^k \tag{3}$$

where L_L stands for left handed doublets of leptons, E_R for right-handed singlets of charged leptons, and Q_L and D_R for left-handed doublets of quarks and right-handed singlets of down-type quarks respectively. The couplings λ and λ' are only non-zero if $i < j$, where i and j denote generations. This leads to 9 (21) independent λ's (λ''s).
In case of very heavy sparticles, these interactions can best be understood in the framework of contact interactions, as described in the previous section. However, if the sparticles have masses in the range of the LEPII energies, their formation can be observed as sharp resonances. In Figure 6 the expected change due to resonant τ-sneutrino exchange in the cross section and forward-backward asymmetry of muon pairs is shown [3].

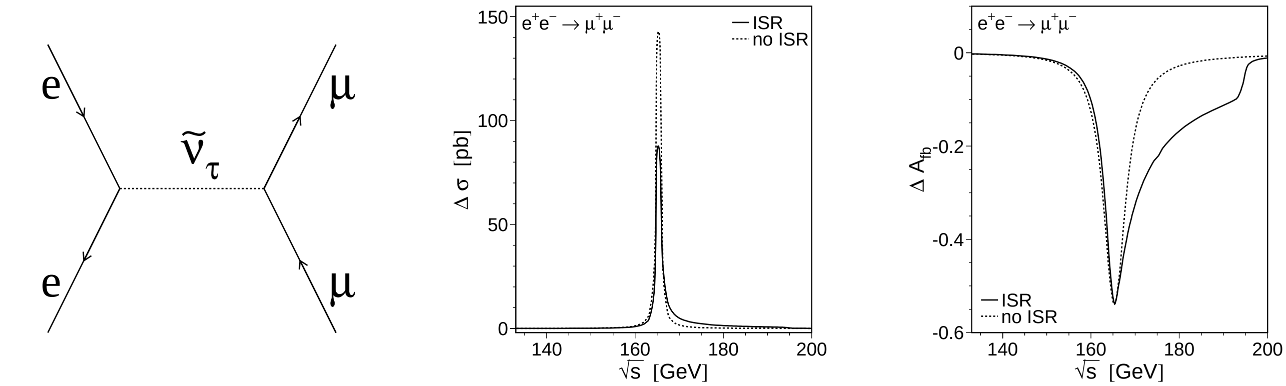

FIG. 6. The changes in the cross section and forward-backward asymmetry of muon-pairs due to the presence of a nearby τ-sneutrino resonance.

No deviations from the Standard Model are observed, and therefore limits on the sneutrino masses and couplings can be derived. In Figure 7 the lower limits on the tau- or muonsneutrino couplings as a function of their masses are shown. The shaded area represents the region that has been excluded by the L3 measurements. The solid line comes from precision measurements on decay ratio's by other experiments.

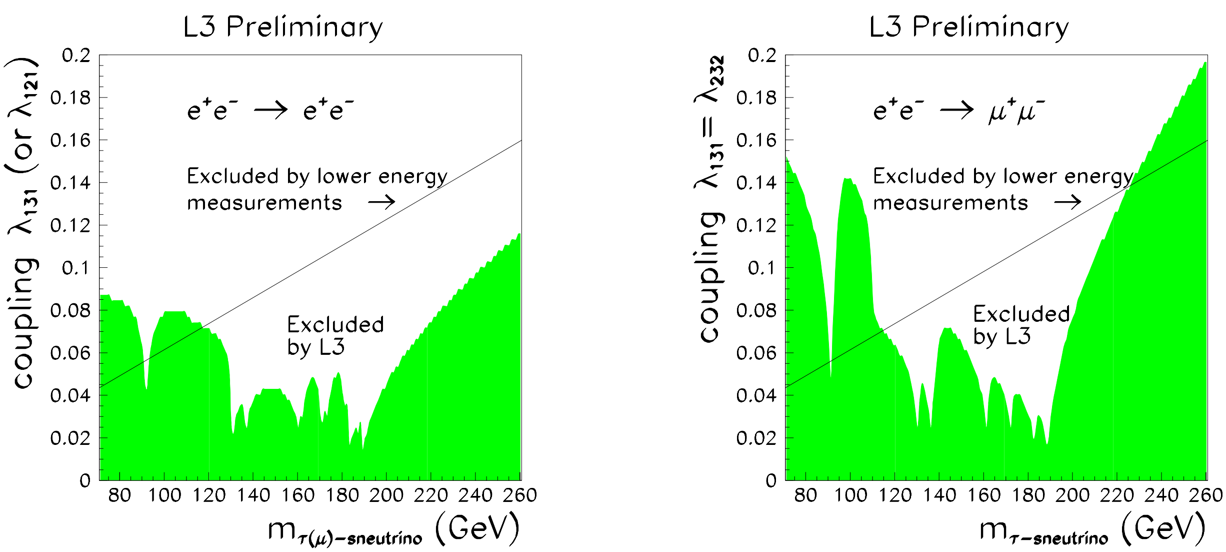

FIG. 7. 95% CL for the couplings λ_{131} (or λ_{121}) and λ_{232} as a function of the τ- (or μ-) sneutrino mass.

C. Additional Heavy Vector Boson

Another scheme for new physics is the extension of the Standard Model with an additional massive boson, the Z':

$$\mathcal{L} = eA_\mu J^\mu_\gamma + gZ^0_\mu J^\mu_{Z_0} + g' Z^{0\prime}_\mu J^\mu_{Z^{0\prime}} \tag{4}$$

The Z' is characterized by it's mass $M_{Z'}$ and the angle θ_M for the mixing between the Z and Z' mass-eigenstates. $J^\mu_{Z^{0\prime}}$ and the coupling g' depend on the choice of the model (Left-Right, E6, etc. [4]).
The precision measurements of the Z-parameters on the Z-pole have resulted in strict limits on the mixing angle θ_M. Above the Z-resonance contributions from the Z' propagator could become significant. From the measurements of high energy cross sections and forward-backward asymmetries lower limits on the mass of the Z' can be obtained. In Figure 8 these limits are shown for the χ, Ψ, η and LR models.

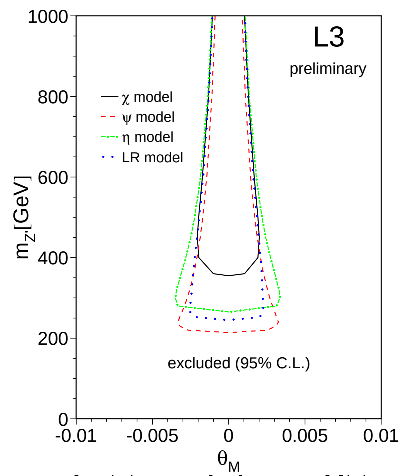

FIG. 8. 95% CL on the mass and mixing angle for an additional heavy vector boson, Z'.

In this Figure the data of 189 GeV are not included in the fit. Including them would raise the lower limit by about 20%, which could result in a Z' mass of at least $\sim$ 290 for the Ψ-model to 450 GeV for the χ-model.

IV. CONCLUSION

Cross sections and asymmetries of fermion pairs at energies up to 189 GeV have been measured. No deviations from the Standard Model are observed.
Inproved limits on contact interactions, resonant sneutrino exchange and an additional heavy vector boson Z$'$ are derived. No indications for new phenomena are found.

[1] E.J.Eichten, K.D.Lane, M.E. Peskin Phys. Rev. Lett. B **50** 811-814 (1983).
[2] J.Kalinowski, R.Rückl, H.Spiesberger, P.M.Zerwas, Physics Letters B **406** 314-320 (1997).
[3] L3 Collab., Physics Letters B **412** 189-200 (1997).
[4] L.S. Durkin, P. Langacker, Phys. Lett. B **166** 436 (1986).