$Q\bar{Q}$, $L\bar{L}$, WW, and ZZ Cross Sections at LEP

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Standard Model cross section results from the four experiments at the LEP electron-positron collider are summarised. Many preliminary results from the data-taking run during 1998 at a centre-of-mass energy of 189 GeV are presented, as are finalised results from data taken in previous years.

1 Introduction

The electron-positron collider LEP, at CERN in Geneva, ran at a centre-of-mass collision energy of 189 GeV during 1998. The integrated luminosity collected by the four experiments ALEPH, DELPHI, L3, and OPAL, amounted to roughly 176 pb^{-1} each. This was 30% more than the original expectations and corresponds to over three times the 55 pb^{-1} recorded at 183 GeV in 1998. We present here the results from the four experiments of cross section measurements for the Standard Model (SM) processes $e^+e^- \rightarrow q\bar{q}$, l^+l^-, WW, and ZZ. For the WW measurements, combined results from the four LEP experiments are also provided.

These cross section measurements are important in themselves as tests of the SM, and from them measurements of SM parameters can be obtained, as can limits on possible models of new physics beyond the SM. In addition, the study of these processes is also important in terms of the understanding of background processes for many new particle searches.

2 Fermion Pair Production

Fermion pair production at high centre-of-mass energies is studied in order to look for deviations from the SM and to put limits on possible new physics models. To this end, the experiments measure production cross sections and forward-backward asymmetries for a subsample of events with a high value of the

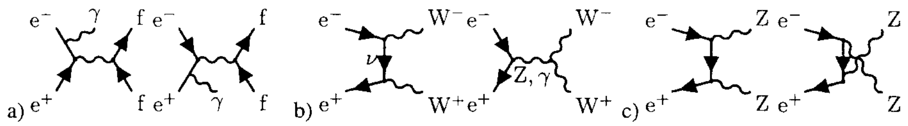

Figure 1: Some Feynman diagrams for processes discussed here. a) fermion-pair production (showing initial state radiation), b) 'CC03' W pair, and c) 'NC02' Z pair production

quantity $\sqrt{s'}$, the effective centre-of-mass of fermion pair production, excluding any energy carried away by initial state radiation as is schematically shown by the Feynman diagrams in Fig. 1a.

Fig. 2 shows such results from ALEPH. The results from the other experiments show similarly excellent agreement with the SM calculations.

The collaborations use these results, and those from LEP I data taken at the Z peak, to obtain fits on SM parameters, and limits on new physics such as the existence of additional gauge bosons, R-parity violating Supersymmetry, and leptoquarks, and also express these limits in terms of new physics energy scales in contact interaction fits, and S-matrix framework fits[1,2,3,4].

3 WW Production

The study of W boson pair production is one of the main physics goals of the LEP high energy run. The nature of the total cross section dependence on the centre of mass energy is sensitive to the specific form of the couplings of the gauge bosons. In the SM, cancellations occur among the contributing Feynman diagrams (t-channel neutrino exchange, and s-channel γ/Z exchange) that allow the theory to be renormalisable and consistent with unitarity.

Each W boson can decay into a quark pair '$q\bar{q}$' or a charged lepton and a neutrino '$l\nu$'. This results in three types of signature for Wpair production/decay events. 45% of WW events are of the '$q\bar{q}q\bar{q}$' form, with four hadronic jets and no missing energy. The main sources of background are $q\bar{q}$ events with QCD gluon radiation, and hadronic ZZ events. 44% are '$q\bar{q}l\nu$' events, with two hadronic jets, a hard charged lepton and some missing energy. Most of the background is from semileptonic heavy flavour decays with hard leptons in $q\bar{q}$ events, and semileptonic ZZ events. The final 11% of WW events are of the '$l\nu l\nu$' form, with two hard acoplanar leptons and large missing energy. Leptonic two-photon interaction processes and $l^+l^-\nu\bar{\nu}$ events from ZZ production are the main background sources. The signatures are subdivided further according to the flavour of the charged leptons.

The cross section results shown here are the 'CC03' values, which correspond to the cross section of four fermion production events that can be attributed to the three contributing double-resonant charged current Feynman diagrams of Fig.1b. These quantities are stable and are better suited for comparison among experiments and with theory than are the actually observed cross sections[5]. Combined results for the four LEP experiments are shown in Figs. 4 and 3[8,9,10,11,12]. The finalised LEP WW cross section at 183 GeV is 15.83±0.36 pb. The W decay branching ratios have also been obtained from the distribution of events among the various categories and have been found to be consistent with lepton universality, with a LEP combined result of 10.64±0.13 for the branching ratio into each type of lepton using data from 161–189 GeV.

The WW cross section just above the production threshold of 161 GeV was used to measure the mass of the W boson; the cross sections at higher energies are not sensitive to the mass but limits on anomalous couplings are derived by the experiments[6]. The cross section measurement also provides a limit on the invisible decay width of the W boson[7].

As can be seen from Fig. 4, the LEP combined error for the cross section at 189 GeV is smaller than the SM theoretical error. A 2% uncertainty is assigned to the cross sections calculated using the semi-analytical program GENTLE[17]. This corresponds to the uncertainty in the contributions from radiative corrections. The reduction of this error is one of the main goals of the recently formed LEP Monte Carlo groups.

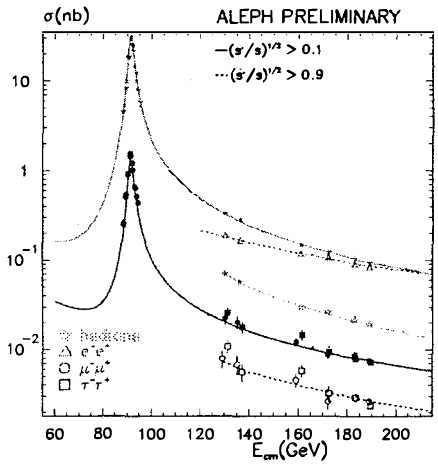

Figure 2: ALEPH results for fermion pair production at LEP for energies up to 189 GeV.

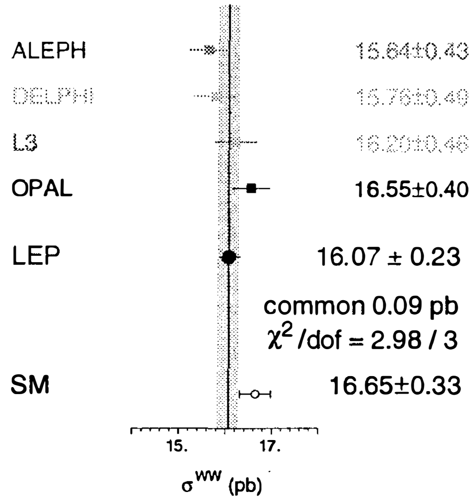

Figure 4: LEP combined results for WW cross sections at 189 GeV. The common error is largely due to uncertainties in the QCD background.The SM value is calculated using GENTLE and is assigned a 2% uncertainty.

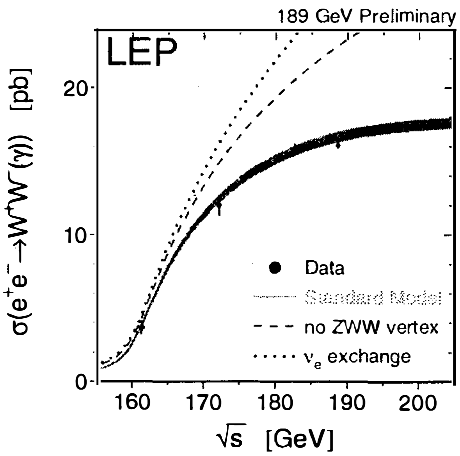

Figure 3: LEP combined W pair production cross sections for centre-of-mass energies of 161, 172, 183, and 189 GeV running. The solid band shows the Standard Model prediction while the other curves represent predictions according to alternative models with different gauge boson interactions.

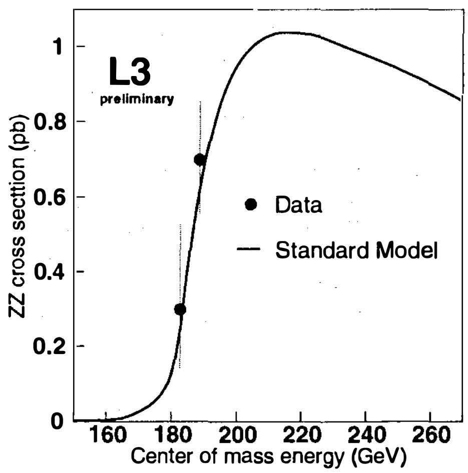

Figure 5: ZZ production cross sections and SM predictions at 183 and 189 GeV from L3

4 ZZ Production

Since 1997, LEP has been running at energies above the threshold for Z boson pair production, which occurs through the two 'NC02' diagrams (Fig.1c), involving t-channel electron exchange. There are multiple event signatures as with WW production, but as Z bosons decay into pairs of quarks, charged leptons, or neutrinos, there are a larger number of variations, namely, $q\bar{q}q\bar{q}$, $q\bar{q}l^+l^-$, $q\bar{q}\nu\bar{\nu}$, $l^+l^-l^+l^-$, $l^+l^-\nu\bar{\nu}$, and $\nu\bar{\nu}\nu\bar{\nu}$. There processes are significant as background processes for new particle searches at LEP II such as Higgs and Supersymmetry searches.

Results for the 'NC02' Z pair production cross sections at 189 GeVfrom the four experiments are summarised in Table 1 [13,14,15,16].

Table 1: Preliminary 'NC02' cross sections results at 189 GeVcentre-of-mass energy. The OPAL results are from July 1998.

	σ_{NC02}[pb] (189 GeV)
ALEPH	$0.63 \pm 0.12 \pm 0.05$
DELPHI	0.58 ± 0.17
L3	$0.71^{+0.16}_{-0.15}$
OPAL	$0.24^{+0.28}_{-0.21}{}^{+0.05}_{-0.04}$
SM	$0.60 - 0.63$

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