WW and ZZ production in e^+e^- interactions at LEP2

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The pair production of W and Z bosons at centre-of-mass energy from 161 GeV to 196 GeV is measured using the ALEPH detector at LEP. WW cross sections are given for different topologies of W decays into leptons and hadrons. ZZ cross sections are also given including all possible ZZ final states.

1. INTRODUCTION

After six years of running at energies around the Z^0 resonance, LEP has reached high energy range : in 1996 WW production threshold was reached and one year after ZZ production threshold. The integrated luminosities collected by ALEPH are reported in Table 1 together with the number of expected WW events.

Table 1
Luminosities and number of WW events expected during different periods of data taking (for $\sqrt{s}$=200 GeV only a part of the data is considered).

Running period	$\sqrt{s}$	$\int \mathcal{L}$ dt	Events
Jun-aug 96	161 GeV	11 pb^{-1}	$\sim$ 40
Oct-nov 96	172 GeV	11 pb^{-1}	$\sim$ 135
Jul-nov 97	183 GeV	57 pb^{-1}	$\sim$ 890
May-nov 98	189 GeV	175 pb^{-1}	$\sim$ 2800
May-jun 99	192 GeV	29 pb^{-1}	$\sim$ 480
Jun-jul 99	196 GeV	80 pb^{-1}	$\sim$1400
Aug 99	200 GeV	$>$ 20 pb^{-1}	$>$ 340

2. WW PRODUCTION

WW events are produced at e^+e^- colliders through 3 doubly resonant tree-level diagrams called CC03 (Charged Current 03 diagrams) involving the γZ s-channel exchange and the neutrino t-channel exchange (Fig. 1). The t-diagram is dominant whatever the centre-of-mass energy is. With increasing $\sqrt{s}$ s-diagrams also contribute (γ exchange not significantly) and the interferences between s and t channels. Each W is expected to decay into a fermion-antifermion pair : the branching ratio for a W into a lepton-neutrino pair is about 11% and into a quark-antiquark pair (ud or cs) about 32.5%. As the two W's are going into 2 $f\bar{f}$ pairs, the events are conventionally classified in three classes : the fully hadronic decays representing 45% of the cases, the semileptonic decays where a W goes into a $q\bar{q}$ pair and the other into a lepton-neutrino pair, and the fully leptonic decays. Each CC03 diagram leads to an experimentally accessible four fermions final state (4f). However, many other non-resonant Standard Model diagrams contribute to the same 4f final states, interfering with the CC03 diagrams. The number of extra diagrams depends on the studied final state. The contribution of these diagrams can be very large, however their effect reduces to at most a few percent by requiring that all four fermions be within the detector acceptance and well separated from each other. Therefore the selection procedures are optimized for the CC03 process and results are presented as CC03 cross-sections. The effect of the other diagrams is corrected by comparing MonteCarlo simulations including only CC03 processes to the full set of 4f diagrams.

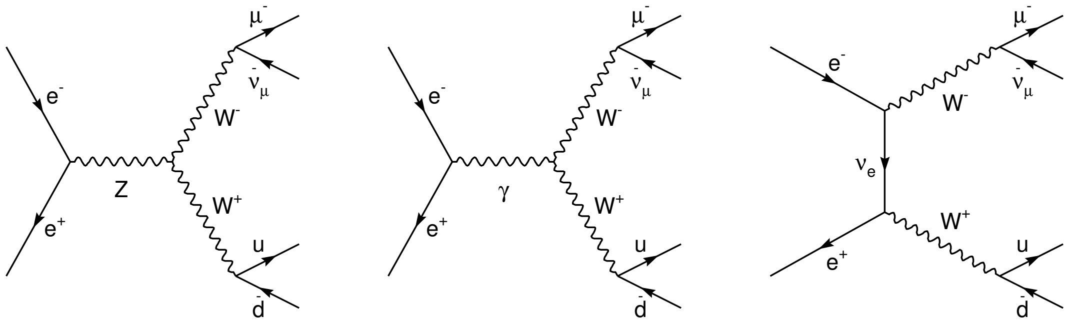

Figure 1. CC03 diagrams for the production of W-pair events in the case of $WW \to qq\mu\nu$.

3. WW SELECTIONS

It has been already pointed out that the W-pair decays are divided in three classes. The selection guidelines for each of the classes are shortly described below :

3.1. $WW \to qqqq$

The events are clustered into four jets, have no missing energy or momentum and are characterised by a large multiplicity of charged and neutral objects. The largely dominant background comes from non-radiative $q\bar{q}$ events with hard QCD gluon emission and multi-jet spherical topologies. After a simple preselection of hadronic non-radiative events with a 4-jets topology, several variables are built to discriminate signal from backgrounds. They are related to global event topologies, as the thrust, the sphericity and the missing energy, and to jet properties as the electromagnetic energy in each jet, the number of tracks in the jets, and also to WW kinematics, as the angle between the jets. Since individual variables do not provide a good discrimination, different multivariables methods, as Neural Networks, have been employed to combine the information from each distribution and separate optimally signal events from background.

3.2. Semileptonic decays

These events are characterised by 2 hadronic jets, an energetic isolated lepton, electron or muon, or a tau jet, and missing energy. In the event selection a large multiplicity of charged and calorimetric hadronic objects is required together with missing momentum out of the beam axis direction. Then an energetic identified isolated electron or muon is searched for or a narrow tau jet. Main backgrounds are $q\bar{q}$ events with energetic leptons from heavy flavour decays, and $e^+e^- \to ZZ^*, Zee$ processes.

3.3. $WW \to \ell\nu\ell\nu$

The events are characterised by two acoplanar energetic leptons and large missing energy carried away by the corresponding neutrinos. A low multiplicity of charged tracks is required in the selection as well as a large missing transverse momentum and acoplanarity in the transverse plane to the beam axis. Further cuts are applied to reduce $\gamma\gamma \to \ell^+\ell^-$ and $ZZ \to \nu\nu, \ell\ell$.

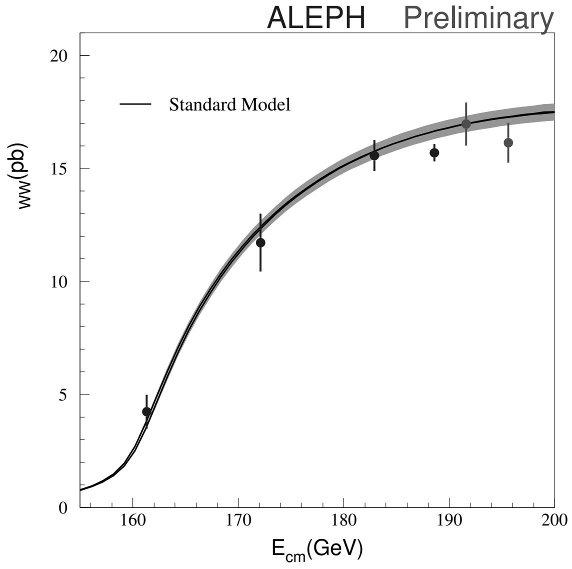

Figure 2. Measurement of the W-pair production cross-section at different centre-of-mass energies, compared to the Standard Model prediction from GENTLE [1].

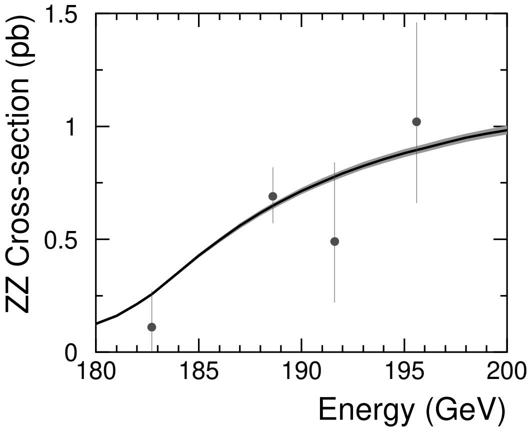

Figure 3. The measured expected NC02 cross-sections compared to the Standard Model prediction. The shaded area represents the theoretical uncertainty on the calculations.

4. WW CROSS-SECTIONS

The cross-sections of all decay channels are determined simultaneously using maximum likelihood fit with Poisson statistics. The total WW cross-sections are extracted assuming Standard Model W branching ratios in the fit. The results [2] are summarised in Table 2 and are also displayed on Figure 2 .

Table 2
Summary of WW cross-sections measurements. The first error is statistical and the second comes from systematic uncertainties. For 192 GeV and for 196 GeV the results are still preliminary and the systematic errors have not yet been evaluated.

$\sqrt{s}$	$\sigma(\ell\nu\ell\nu)$	$\sigma(\ell\nu qq)$	$\sigma(qqqq)$	$\sigma(WW)$ (pb)
161 GeV	$0.68 \pm 0.34 \pm 0.03$	$1.85 \pm 0.51 \pm 0.06$	$1.93 \pm 0.66 \pm 0.19$	$1.80 \pm 0.50 \pm 0.19$
172 GeV	$1.22 \pm 0.46 \pm 0.07$	$4.73 \pm 0.76 \pm 0.16$	$5.76 \pm 0.88 \pm 0.21$	$11.71 \pm 1.23 \pm 0.28$
183 GeV	$1.38 \pm 0.20 \pm 0.04$	$6.81 \pm 0.40 \pm 0.14$	$7.35 \pm 0.42 \pm 0.25$	$15.57 \pm 0.62 \pm 0.29$
189 GeV	$1.77 \pm 0.13 \pm 0.02$	$7.11 \pm 0.23 \pm 0.11$	$6.83 \pm 0.23 \pm 0.13$	$15.69 \pm 0.34 \pm 0.17$
192 GeV	1.54 ± 0.31	7.10 ± 0.59	8.30 ± 0.62	$16.96.30 \pm 0.93$
196 GeV	1.89 ± 0.35	7.68 ± 0.63	6.66 ± 0.59	Z 16.13 ± 0.87

5. ZZ PRODUCTION

For two years, the center-of-mass at LEP is above the ZZ threshold. The observation of pair-produced resonant Z bosons has become possible. The measurement of ZZ cross-section is important because, it allows to check consistency with the Standard model, it constitutes the major background in the searches for Higgs bosons and particularly the Standard Model Higgs boson at masses near the mass of the Z, and it could be a probe for new physics. Various extensions of the Standard Model allow ZZZ and $ZZ\gamma$ couplings which can modify the total production cross-section significantly. ZZ events at e^+e^- colliders proceed via the two NC02 diagrams which involve the t-channel exchange of an electron. Unlike the W-pair production, there are no s-channel diagrams contributing to in $e^+e^- \to ZZ$ since three neutral vector boson couplings do not exist in the Standard Model. Like WW events, other Standard Model diagrams have the same final states and interfere (NC08 diagrams).

All visible Z final states have been studied and they are divided in four classes :

- The four jets topology where both Z decay into a quark-antiquark pair. This final state has the largest branching fraction, 54%, but also the largest background. The events are characterised by four distinct jets and the total reconstructed energy has to be near the centre-of-mass energy.
- The $q\bar{q}\nu\bar{\nu}$ final state which represents about 30% of the ZZ events, is characterised by missing mass and visible mass consistent with the Z mass.
- The leptonic final states with one Z decaying into a pair of electrons or muons and the other Z decays into anything except neutrinos. Although the branching fraction is small, it benefits greatly from the high lepton identification efficiency and excellent mass resolution.
- The last case where one of the Z decays into electron or muon and the other into neutrinos.

The selections for these final states are similar to Higgs bosons searches, but an additional constraint on the dijet masses is set. Both cut-based and Neural Networks selections exist. The analyses are combined with maximum likelihood in order to extract the total NC02 cross-section. The results [3] are shown on Figure 3.

6. CONCLUSIONS

All the measured cross-sections are in good agreement with the Standard Model predictions.

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