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ZZ CROSS SECTION MEASUREMENTS

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Results on the cross section measurement of Z boson pair–production at LEP[1,2] are presented. The more general case of neutral–current four–fermion production and the particular case of ZZ events enriched in b quarks are also discussed. All the results agree with the Standard Model predictions.

1 Introduction

LEP was successfully operated in the years from 1997 through 2000 at centre–of–mass ($\sqrt{s}$) energies from 183 GeV up to 208 GeV. This allowed each of its four experiments to collect more than $540\,\mathrm{pb}^{-1}$ of data above the Z boson pair–production threshold, as summarised in Table 1.

This process tests the Standard Model of electroweak interactions in the neutral–current sector and is sensitive to New Physics scenarios such as couplings between neutral gauge bosons[4] or extra space dimensions[5].

The results presented here refer to a particular subset of all the possible diagrams for neutral–current four–fermion production, denoted as NC02 and depicted in Figure 1. The Figure also shows the ZZ production cross section as calculated with the YFSZZ and ZZTO programs[3]. These diagrams define the Z pair production signal, also defined by some experiments with a wider part of the full four–fermion phase space compatible with Z pair–production.

The related topics of general neutral–current four–fermion production and b quark content in Z–pair events are also investigated, and discussed in the following.

Detailed accounts of the data sets, analysis techniques and results of each experiment can be found elsewhere[1,2]. All the results at $\sqrt{s} = 183$ and 189 GeV are published while the others are preliminary.

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2 Data analysis

The four experiments devised analysis strategies that rely on the identification of the signatures of the pair–production of two particles with equal masses, compatible with Z bosons.

Multivariate techniques are used for the largest statistic fully hadronic final state (49% of the Z pair decays), where a large background is expected from the QCD and W pair–production processes. Event shape variables are used to reject the first, focusing on the signal four–jet topology, also common to hadronic decays of W pairs. This background can be discriminated thanks to the different boson mass that reflects into the topology of the decay products. Moreover, W decays lack b quarks, present in 39% of the fully hadronic decays of the Z pairs. The use of the b tag techniques developed for the Higgs search hence increases the signal purity.

The final state with a Z decaying into hadrons and the other into neutrinos is the second most populated (28%) and is investigated with hadronic events with large missing energy. The hermeticity of the detectors allows to reconstruct the four–momentum of the Z decaying into neutrinos. The main backgrounds are the production of a Z in association with an undetected high energy and low polar angle initial state radiation photon, semileptonic decay of W pairs with the charged lepton escaping detection or the more general case of a W decaying into

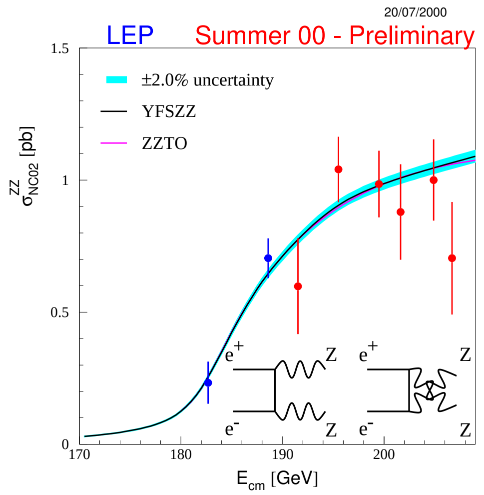

Figure 1. Measured and predicted cross sections for the Z boson pair–production process via the two diagrams shown in the lower right corner.

Table 1. LEP $\sqrt{s}$ and sum of the integrated luminosities ($\mathcal{L}$) collected by the four experiments together with the measured ($\sigma^{\mathrm{ZZ\ Exp}}_{\mathrm{NC02}}$) and expected ($\sigma^{\mathrm{ZZ\ Th}}_{\mathrm{NC02}}$) ZZ cross sections. Data collected in the year 2000 are grouped into the two last energy bins. The first uncertainty is statistical, the second systematic.

$\sqrt{s}$ GeV	$\mathcal{L}$ pb^{-1}	$\sigma^{\mathrm{ZZ\ Exp}}_{\mathrm{NC02}}$ pb	$\sigma^{\mathrm{ZZ\ Th}}_{\mathrm{NC02}}$ pb
182.7	221	$0.23 \pm 0.08 \pm 0.02$	0.25
188.7	686	$0.70 \pm 0.07 \pm 0.03$	0.65
191.5	114	$0.60 \pm 0.18 \pm 0.04$	0.77
195.6	310	$1.04 \pm 0.12 \pm 0.04$	0.90
199.6	326	$0.98 \pm 0.12 \pm 0.04$	0.98
201.7	152	$0.88 \pm 0.18 \pm 0.04$	1.01
205.0	241	$1.00 \pm 0.15 \pm 0.05$	1.04
206.8	123	$0.70 \pm 0.21 \pm 0.05$	1.06

hadrons produced together with a non resonant system of a low polar angle electron and a neutrino. Sequential cuts or multivariate techniques that enforce the signal topology of an undetected Z suppress these backgrounds.

High signal purity is achieved in the lower statistic (14%) final state with hadrons and charged leptons, which benefits of the high resolution measurements of the lepton momenta. Kinematic fits in the hypothesis of an equal mass of the lepton–lepton and hadron systems are performed, requiring then this mass to be compatible with the Z mass. Topological variables such as the angles of the leptons and the hadronic jets are also used.

The final states with two charged leptons and two neutrinos (4%) and four charged leptons (1%) are penalised by low statistics, even though identified with good purity thanks to the high lepton resolutions. The background from lepton pair–production and four–fermion processes is mainly rejected by requiring the lepton invariant and recoil masses to be compatible with the Z mass.

The undetectable final state with four neutrinos accounts only for 4% of the Z–pair decays.

3 Results

The four experiments measured the Z pair-production cross section at all the $\sqrt{s}$ above threshold[1,2]. Combined results are presented in Table 1 and Figure 1. This average takes into account sources of common and correlated systematic uncertainties, mainly due to uncertainties on the background cross sections and modelling, as well as uncorrelated ones, dominated by Monte Carlo statistics and detector related effects, in particular for the b tag procedure.

All the measurements agree with the Standard Model predictions. The ratio between the measured and predicted cross sections is formed at each $\sqrt{s}$, and its average over all the $\sqrt{s}$ yields 0.99 ± 0.06, what reveals an overall agreement within the combined accuracy of 6%, mainly statistical.

4 Four–fermion production

The DELPHI Collaboration extends its Z pair–production analysis to the case of a Z boson produced in association with a pair of fermions from a virtual photon. Final states with two quarks and either a muon– or a neutrino–pair are analysed. In the latter case the mass of the hadronic system must be below 60 GeV. The cross sections over the full data sample are respectively expected to be $0.19 - 0.25$ pb and $0.13 - 0.16$ pb, decreasing with $\sqrt{s}$. The measured cross sections read:

$$\sigma^{183\,\mathrm{GeV}-208\,\mathrm{GeV}}_{\mathrm{e^+e^-\to Z\gamma^\star\to\mu^+\mu^-q\bar{q}}} = 0.22 \pm 0.05 \pm 0.02\,\mathrm{pb}$$

$$\sigma^{183\,\mathrm{GeV}-208\,\mathrm{GeV}}_{\mathrm{e^+e^-\to Z\gamma^\star\to\nu\bar{\nu}q\bar{q}}} = 0.19 \pm 0.06 \pm 0.02\,\mathrm{pb}\,,$$

where the first uncertainty is statistical and the second systematic.

5 B quark content

The experimental investigation of Z–pair final states containing b quarks validates the capability of the LEP experiments to detect the production and decay of the Higgs boson.

These two process have a similar topology, as the Higgs boson production would preferentially manifests as a pair of b quarks from the decay of a heavy object that recoils against a Z. The expected cross sections are also similar, as illustrated in Figure 2. The Figure also shows the results of the measurement by the L3 Collaboration, in agreement with the Standard Model predictions. In this measurement Z decays into hadrons, neutrinos and charged leptons are considered in association with the b quark pair.

The OPAL Collaboration measures the branching ratio of the Z into b quarks in the selected Z–pair events, als finding agreement with the value measured at LEP at the Z resonance.

In conclusion, if such rare processes with these topologies can be observed, a Higgs boson light enough to be produced at LEP will not escape detection.

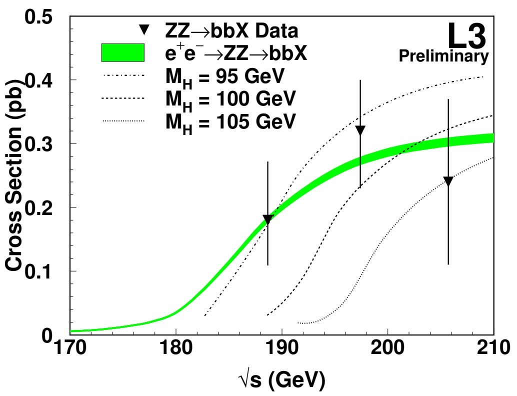

Figure 2. Measured and predicted cross sections for neutral–current four–fermion events compatible with Z pairs with at least a b quark pair. Data are presented for the average $\sqrt{s}$ of the years 1998, 1999 and 2000. The computed cross section for the production of the Standard Model Higgs boson is also presented for different mass hypotheses.

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[a] Notation for contributed papers to this conference