NEUTRAL CURRENT FOUR-FERMION PRODUCTION IN THE DELPHI EXPERIMENT* **

Mariusz Witek

H. Niewodniczański Institute of Nuclear Physics
Kawiory 26a, 30-055 Kraków, Poland

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The results for the production of the four-fermions via neutral electroweak currents are presented. The experimental data coming from the DELPHI experiment at the LEP2 at CMS energy from 130 GeV to 189 GeV are compared to the Monte Carlo predictions.

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1. Introduction

The four-fermion production via neutral currents is an example of the higher order processes in the Standard Model (SM). A good knowledge of such processes is crucial for several reasons. First it enables the subtle test of the SM and observation of possible departures from its predictions. In particular the limit for the anomalous triple gauge boson coupling ZZZ has not yet been set. Secondly they significantly contribute to the background in the searches for new particles at LEP2. The event signatures are often similar to those of SUSY particles production. Four main classes of diagrams involving neutral gauge bosons exchange are shown in Fig. 1. The actual contributions from the different classes depend strongly on the collision energy and the final state produced. In particular bremsstrahlung and multiperipheral diagrams lead to at least one e^+e^- pair in the final state with electrons predominantly going close to the beam direction. Moreover the overall cross-section for $e^+e^-f\bar{f}$ at any LEP2 energy is large as compared to the conversion and the annihilation processes. In order to balance the contributions from the different classes a cut on the direction of the outgoing $e^+(e^-)$ with respect to the $e^+(e^-)$ beam was imposed. The minimum angle of 20° has been chosen to study the overall four-fermion production.

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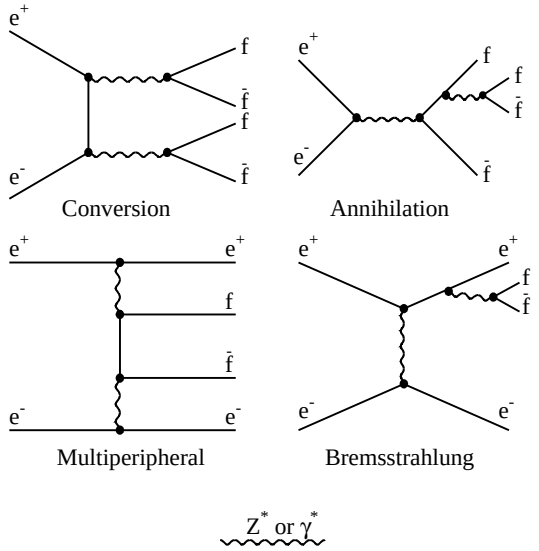

Fig. 1. The four groups of diagrams for the four-fermion neutral current production.

In the case of ZZ on-shell production the final states are distributed according to the well known branching fractions of the Z boson [1]. For $e^+e^-f\bar{f}$ channels the problem of electrons going close to the beam direction is not present. Only two diagrams are allowed by the SM at the tree level (Fig. 2). The triple gauge boson vertices ZZZ or γZZ are forbidden. Their existence would modify the value of the total cross-section and the angular distributions of the final products. Any deviation would suggest the presence of the phenomena beyond SM.

In 1997 LEP2 reached the threshold for the ZZ bosons production. This enabled to study these processes for the first time in the experiment. The energy was further increased to about 189 GeV in 1998 and the large samples were recorded by the LEP experiments.

2. The Standard Model prediction for the cross-section

The cross-sections were calculated using two programs KORALW [2] and EXCALIBUR [3]. Both generators gave consistent results within the statistical error. Table I contains the values of the cross-section for the overall and ZZ on-shell production at the different CMS energies. The second column gives the integrated luminosity collected by the DELPHI experiment.

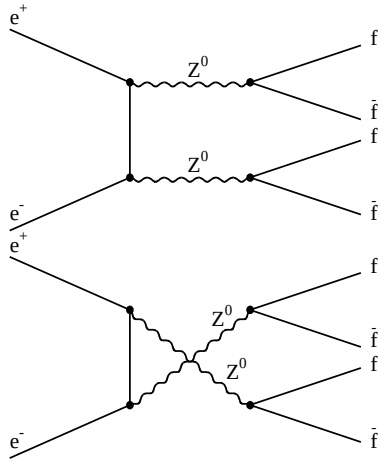

Fig. 2. Two lowest order diagrams leading to ZZ on-shell production.

TABLE I

The cross-sections at different LEP2 energies calculated using the KORALW and EXCALIBUR programs. For the overall $\sigma(f_1\bar{f}_1 f_2\bar{f}_2)$ the angle between the directions of the outgoing $e^+(e^-)$ and the $e^+(e^-)$ beam had to be greater than 20°.

$\sqrt{s}$ (GeV)	Int. Lumi. (pb^{-1})	$\sigma(f_1\bar{f}_1 f_2\bar{f}_2)$ [pb]	$\sigma(ZZ)$ [pb]
130-136	11.8	2.41	-
161.0	9.9	1.60	-
172.0	10.0	1.41	0.04
182.7	54.0	1.40	0.25
188.7	158.0	1.48	0.64

On the basis of integrated luminosities and values of cross-section we expect that about 350 events were produced in total and 100 of them were ZZ events (without taking into account the detector acceptance and the selection efficiency). The main background comes from the two-fermion production and from the four-fermion production mediated by the charged currents. The ratios of the cross-sections $\sigma_{ZZ} : \sigma_{W^+W^-} : \sigma_{f\bar{f}}$ follows $1 : 25 : 215$ at the energy of 189 GeV. Therefore for some specific channels the background is quite high.

3. Selection strategy and results

Out of the six possible topologies shown in Fig. 3, the undetectable four-neutrino channel was not considered in this analysis. For the remaining channels the analysis is going on. Here the preliminary results for the selected final states are presented: *(i)* the overall production of $l^+l^-l^+l^-$ and $l^+l^-q\bar{q}$ and *(ii)* the ZZ on-shell production for $l^+l^-l^+l^-$, $l^+l^-q\bar{q}$, $q\bar{q}\nu\bar{\nu}$ and $q\bar{q}q\bar{q}$ at the highest energy of 189 GeV.

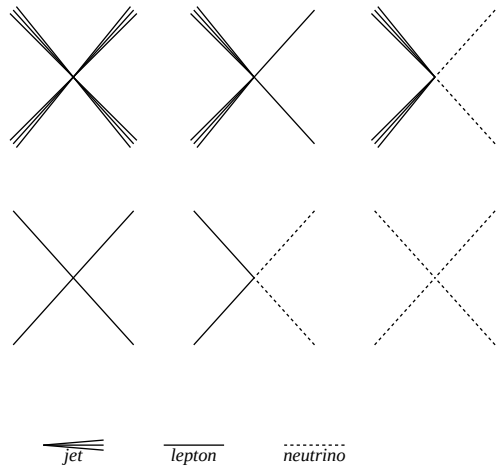

Fig. 3. Six possible topologies of the ZZ final states.

3.1. Overall four-fermion production for $l^+l^-l^+l^-$ and $l^+l^-q\bar{q}$

The four charged lepton final states were searched for among the low multiplicity events. The tracks were required to pass through the barrel part of the DELPHI detector [4] (polar angle between 20° and 160°) to reduce the contribution from the bremsstrahlung and multiperipheral processes and to ensure good quality of the track reconstruction. Since the $e^+e^-\tau^+\tau^-$ and $\mu^+\mu^-\tau^+\tau^-$ events often contain two hadrons from the τ decay, only two tracks were demanded to be identified as leptons (loose criteria). The cuts on the global event parameters like total charged energy or visible invariant mass have been applied based on the Monte Carlo study. The events with two close tracks compatible with coming from the γ conversion in the detector material were rejected.

The analysis of the $l^+l^-q\bar{q}$ covered $e^+e^-q\bar{q}$ and $\mu^+\mu^-q\bar{q}$ final states. High multiplicity events with at least two lepton candidates of the same flavour, opposite charge and invariant mass exceeding 2 GeV/c^2 were selected. All tracks excluding leptons were then clustered into jets (JADE algorithm with $y_{min} = 0.01$). After the kinematic 4C fit two discriminating variables were used to optimize the signal to background ratio: p_t of the lepton with respect to the nearest jet and χ^2/NDF of the kinematic fit.

The results for both channels are collected in Table II. In the wide CMS energy range 65 events were selected. This agrees well with the Monte Carlo prediction of 54.2 events (49.2 from signal and 5.0 from background).

TABLE II

Number of selected and predicted events for the overall production of $l^+l^-l^+l^-$ and $l^+l^-q\bar{q}$ channels.

$\sqrt{s}$ (GeV)	channel	observed events	predicted signal	background events
161-189	$l^+l^-q\bar{q}$	46	33.4	4.0
130-189	$l^+l^-l^+l^-$	19	15.8	1.0
130-189	Total	65	49.2	5.0

3.2. ZZ on-shell production

The results for ZZ on-shell production have been obtained for the four channels.

In the case of four charged leptons the branching fraction $ZZ \to l^+l^-l^+l^-$ is around 1 % and only one event is expected in the 189 GeV sample. Owing to the characteristic topology of the ZZ on-shell kinematics it was possible to increase the selection efficiency. The main differences with respect to the selection described in previous section are the following. Only two good quality tracks of opposite charge had to be found in the barrel. Their invariant mass and recoil mass should be close to the Z mass. The second pair of tracks which was supposed to come from the second Z was demanded to be separated by at least 90° from each other. No particle identification was applied. The selected $ZZ \to e^+e^-\mu^+\mu^-$ event with $\mu^+\mu^-$ invariant mass of 92.9 GeV/c^2 and the recoil mass of 92.3 GeV/c^2 is shown in Fig. 4.

In the case of $l^+l^-q\bar{q}$ final state the ZZ on-shell candidates were selected from the sample obtained for the overall production at 189 GeV (Sec. 3.1) requiring invariant masses of l^+l^- and jet-jet systems to be close to the Z mass.

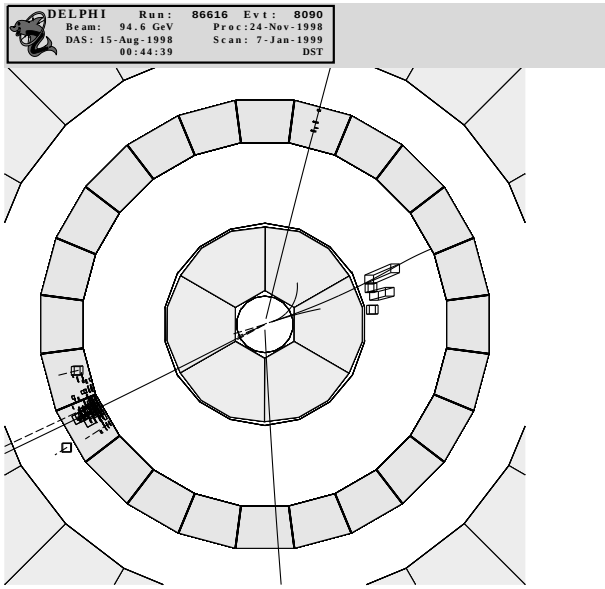

Fig. 4. The $ZZ \to e^+e^-\mu^+\mu^-$ candidate.

The search in the four jet events has been restricted to the $q\bar{q}b\bar{b}$ channel. The b-quark jets were identified using the b-tagging procedure based on the analysis of the impact parameter of the tracks. This restriction was necessary to suppress the combinatorial background coming from more than order of magnitude stronger sources like QCD $q\bar{q}gg$ or W^+W^- production. For the preselected events a kinematic fit was performed and the sophisticated discriminant analysis was applied to obtain good signal to background ratio. The analysis is very similar to that of the Higgs search (Higgs mass being close to the Z mass).

The $q\bar{q}\nu\bar{\nu}$ candidates were selected from the events with large missing momentum and high multiplicity. The signature of this decay mode is a pair of acoplanar jets with visible and recoil masses compatible with the Z mass. The invariant mass of the $q\bar{q}$ system was reconstructed using the visible masses and then rescaled. The condition for the energy and momentum conservation was applied constraining the invariant mass of the recoil system to the Z mass. The selection was based on the nonlinear discriminant analysis (IDA) [5]. Several event variables were used to construct a second order polynomial to maximize the separation between signal and background. To compromise the efficiency and purity a discrimination level was chosen to obtain the signal to background ratio around 3.

The numbers of selected and predicted events for considered channels are shown in Table III. The result is also illustrated in Fig. 5. The distri-

bution shows the sum of two invariant masses for all ZZ candidates. The points with errors represent the data while the histogram shows MC prediction (light grey for signal and black for background). 23 observed events are consistent with the 26.6 expected ones (22.1 signal and 4.5 background events).

TABLE III

The numbers of selected and predicted events for the ZZ on-shell production.

channel	observed events	predicted signal	predicted background	efficiency %
$q\bar{q}b\bar{b}$	6	3.7	1.1	22
$q\bar{q}\nu\bar{\nu}$	8	9.8	2.5	35
$l^+l^-q\bar{q}$	8	7.6	0.8	68
$l^+l^-l^+l^-$	1	1.03	0.06	80
Total	23	22.1	4.5	-

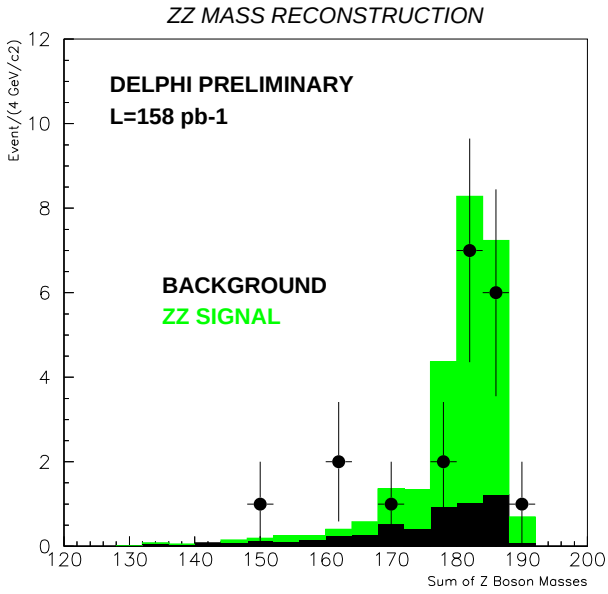

Fig. 5. The distribution of the sum of two Z boson masses for selected candidates.

4. Summary

The preliminary results for the overall four-fermion production via neutral currents and for double resonant ZZ production have been extracted from the DELPHI data in the energy range 130 GeV–189 GeV. The numbers of selected events agree well with the Standard Model prediction. For the overall four-fermion production 65 events events have been selected in two channels $l^+l^-l^+l^-$ and $l^+l^-q\bar{q}$ to be compared to 54.2 events predicted (49.2 signal and 5.0 background events). The analysis of the ZZ on-shell production at the energy of 189 GeV for $l^+l^-l^+l^-$, $l^+l^-q\bar{q}$, $q\bar{q}\nu\bar{\nu}$ and $q\bar{q}q\bar{q}$ final states showed also the consistency with the SM prediction. There are 23 ZZ candidates in the data compared to the 26.6 predicted events (22.1 signal and 4.5 background events). No sign of the physics beyond the SM has been found. The analysis is being continued. The future aim is to determine the ZZ on-shell cross-section at the energy of 189 GeV.

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