WW **and** ZZ **production at LEP**

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Abstract: An overview about actual studies in the reaction ee $\rightarrow$ WW or ZZ at LEP is presented. In the case of ee $\rightarrow$ WW a cross section of 16.91 ± 0.32 pb and 17.53 ± 0.32 pb for a center of mass energy of 200 GeV and 202 GeV respectively was obtained. With these precise values and the result of the previous runs at lower energies first deviations from the tree level cross sections was observed and agreement with newer Monte Carlos which account for first order terms was found. A direct analysis of the helicity states in this process is also presented. In agreement with standard modell a fraction of 0.259 ± 0.035 of longitudanally polarized W was found. With this measurement the identification of longitudanal polarized W states with the goldstone bosons of the spontanous symmetry breaking with the higgs mechanism is so far confirmed. Also in the case of ee $\rightarrow$ ZZ good agreement with the standard model is found. For the parameters of the triple gauge couplings errors on the measurement between 2% and 5% seem to be achievable. First measurement of quartic gauge couplings are performed.

1. WW production and W branching ratios

One of the main scientific goals of the LEPII program are measurements of the triple gauge vertices ee $\rightarrow \gamma/Z \rightarrow$ WW. This reaction has a huge background with neutrino exchange in the t-channel. The actual cross section measurements for different center of mass energies are shown in table 1. Also figure 1 summarizes these measurements and shows that a clear observation of triple gauge reactions has been made. The precision is now sufficient to distinguish between tree level and higher orders. The χ^2/dof of the data compared to the tree level Monte Carlo Gentle is 11.6/6 while for Racoon, which accounts for first order terms, we find 5.6/6.

The branching ratios of the decaying W bosons into hadrons or into leptons was also measured. In agreement with standard model predictions a value of 67.85 ± 0.33% for hadronic and 10.71 ± 0.10% for leptonic decays was found. The values for the individual leptonic channels are 10.63 ± 0.20%, 10.56 ± 0.19% and 11.02 ± 0.26 for the electron, muon and tau channel respectively. From the branching ratio BR(W $\rightarrow$ hadrons) the element $|V_{cs}|$ of the CKM matrix can be extracted to be 0.993 ± 0.016.

$\sqrt{s}$ [GeV]	Gentle [pb]	Racoon [pb]	Data [pb]
183	15.71	15.37	15.83±0.36
189	16.65	16.24	16.05±0.22
192	16.96	16.52	16.80±0.50
196	17.26	16.79	17.39±0.35
200	17.46	16.97	16.91±0.32
202	17.53	17.03	17.11±0.46

Table 1: Cross section for different center of mass energies compared with the Gentle and Racoon MC predictions.

A more detailed description can be found in [1] which contains also updates until this summer.

2. Helicity states of the W boson

One of the new measurement performed at LEP is the direct measurement of the helicity states of

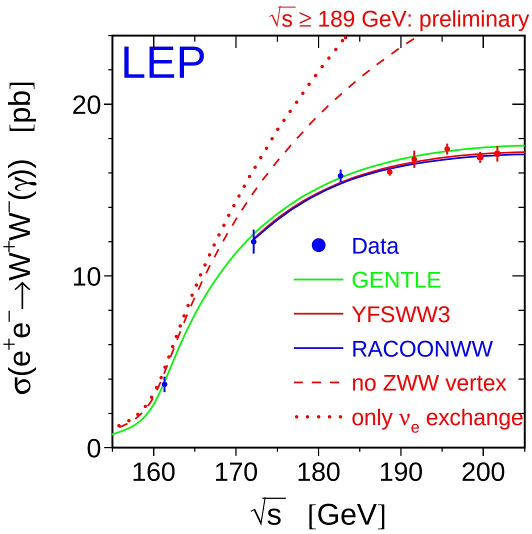

Figure 1: Comparison of cross section measurements with tree level Monte Carlo(Gentle) and Monte Carlo accounting for first order terms. Expected behavior without s-channel reaction or where only γ is exchanged is also shown.

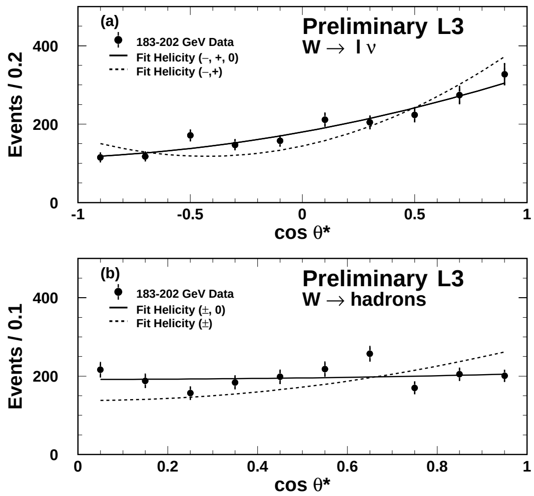

Figure 2: Corrected $\cos\Theta^*$ distributions for (a) leptonic W decays and (b) for hadronic W decays at $\sqrt{s} = 183 - 202$ GeV. The fit results for the different W helicity hypotheses are also shown.

the W boson [2]. Here especially the longitudinal polarized W boson is important, because in the standard model the longitudinal states of the gauge bosons are Goldstone bosons of the symmetry breaking, thus directly connected to the Higgs sector of the theory. So if we measure deviations of this fraction from the standard model we falsify this model. A detailed discussion of the expected cross sections and fractions can be found in paper [3], where also differential fractions are given with respect to $\cos\Theta$ of the produced W.

The direct measurement is performed as follows. W pairs are selected where at least one W decays leptonicly. The lepton determines the charges of the W's. Then the decay angle $\cos\Theta^\star$ of the lepton is calculated. For the hadronic side, which is represented by all particles in the event except the lepton, the particles are boosted back to the W rest frame and the thrust axis is determined. This axis is used to calculate $\cos\Theta^\star$ of the hadronic system. Since the sign of the thrust axis respectively the charge of the quarks are unknown, only the absolute value of $\cos\Theta^\star$ can be used in the hadronic decay. In the leptonic case the fractions $f(-), f(+), f(0)$ for helicity $-1, +1, 0$ respectively follow a simple distribution,

$$\frac{1}{N}\frac{dn}{d\cos\Theta^*} = f(-)\cdot 3/8(1+cos\Theta^*)^2 + f(+)\cdot 3/8(1-cos\Theta^*)^2 + f(0)\cdot 3/4\sin^2\Theta^*.$$

In the hadronic case we have for the fractions $f(\pm), f(0)$ for helicity $\pm 1, 0$ respectively the distribution

$$\frac{1}{N}\frac{dn}{d|\cos\Theta^*|} = f(\pm)\times 3/4(1+cos^2\Theta^*) + f(0)\times 3/2\sin^2\Theta^*.$$

Then fractions are determined by a fit as seen in figure 2. For the longitudinally polarized W a fraction of 0.259 ± 0.035 is obtained compared with 0.248 in the Monte Carlo. As figure 3 shows, it is possible to differentiate the result further by determining the fractions in bins of the production angle $\cos\Theta$. These measurements are in agreement with the standard model predictions.

3. ZZ production

The results presented here for ee → ZZ are based

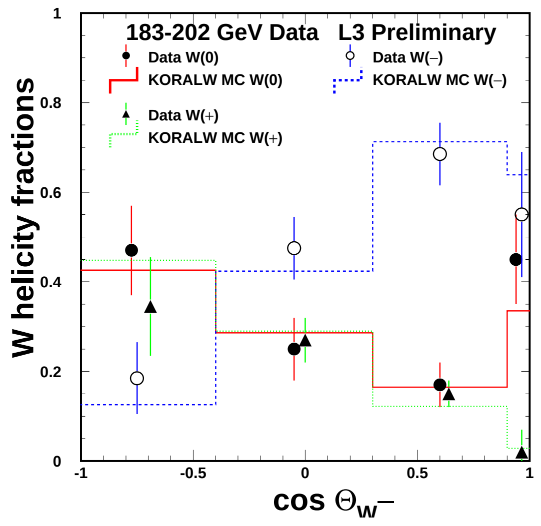

Figure 3: Helicity fractions in dependency of the production angle.

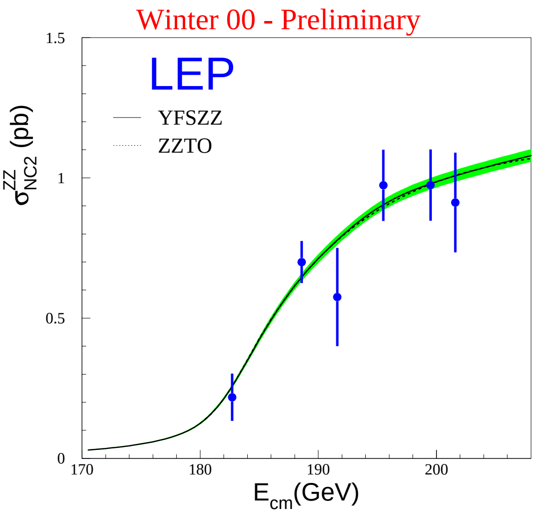

Figure 4: Comparison of cross section measurements with Monte Carlo(ZZTO)

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$\sqrt{s}$ [GeV]	ZZTO [pb]	Data [pb]
183	0.25±0.01	0.22±0.08
189	0.65±0.01	0.70±0.08
192	0.78±0.02	0.57±0.17
196	0.90±0.02	0.96±0.13
200	0.99±0.02	0.97±0.13
202	1.02±0.02	0.91±0.18

Table 2: Cross section for different center of mass energies compared with the ZZTO predictions.

on a dataset of 1.8 fb^{-1} above the production threshold. They also refer only to tree level processes the so called NC02 diagrams for four neutral-current four-fermion production, where an electron is exchanged in the t-channel. The cross sections obtained can be seen in table 2 and figure 4. Also here no deviation from the standard model is observed, the agreement is in the order of 6% with the standard model predictions, where the error is mainly statistically.

4. Triple gauge couplings

The definition of the parameters used in charged triple gauge boson coupling analysis are described in [4]. If we assuming electromagnetic gauge invariance and CP invariance we find six triple gauge parameters. A common set is $\kappa_\gamma, \kappa_Z, g_1^Z$, $\lambda_\gamma, \lambda_Z, g_5^Z$ where in the standard model $\kappa_\gamma = \kappa_Z = g_1^Z = 1$ and the others are 0. One derives also relations like $\Delta\kappa_Z = \kappa_Z - 1 = \Delta g_1^Z - \Delta\kappa_\gamma \tan^2\Theta_W$ which reduces the number of independent variables further. The set which is left over is $\Delta\kappa_\gamma, \Delta g_1^Z, \lambda_\gamma$ which is determined to be $0.021^{+0.063}_{-0.059}, -0.024\pm0.024, -0.016\pm0.026$ respectively. Results including most recent data can be found in [5].

In the case of neutral triple gauge boson couplings or anomalous couplings one measures f_4 and f_5 which represents CP-odd and CP-even states respectively. As seen in figure 5 the statistically uncertainties are large. But despite the big error range one can conclude that no deviations form the standard is observed.

Aleph, Opal and L3 [5] have also performed studies of quartic couplings. In the case of neutral quartic gauge couplings an additional photon is radiated from the vertex. This would lead to deviations in the final state photon spectrum of these events, which is not observed.

5. Conclusion

In the processes ee $\to$ WW or ZZ for the cross section and detailed coupling studies good agreement with the standard model is found. In case

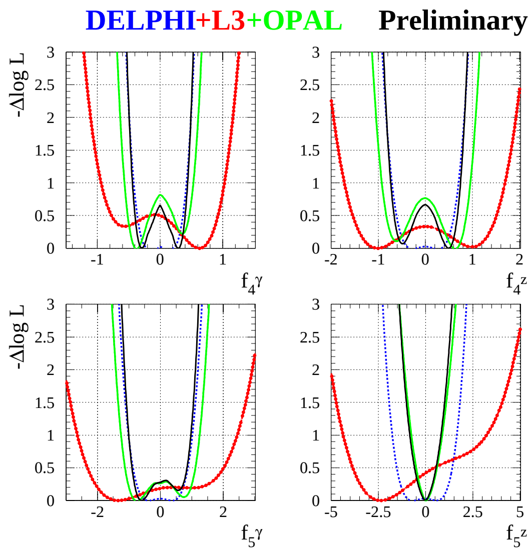

Figure 5: Log likelihood for the anomoulus coupling parameters, performed by different LEP experiments. One sees the big error range and that the results are all compatible with 0.

of ee $\rightarrow$ WW precision is already sufficient to see deviations from the tree level and higher order Monte Carlo is needed. For the errors in the charged triple gauge couplings a value of 2% for $\Delta\kappa_\gamma$ and Δg_1^Z and to 5% for λ_γ is achievable.

References

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