FOUR-FERMION FINAL STATES IN e^+e^- COLLISIONS AT LEP2

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Abstract

The measurements of four-fermion production rates performed at LEP2 in e^+e^- collisions at centre-of-mass energies ranging from 161 to 209 GeV are presented. The focus is put on processes that involve the production and decay of W or Z electroweak bosons. Results on W decay rates and couplings are also discussed.

1 Introduction

Between 1995 and 2000, the LEP collider at CERN delivered e^+e^- collisions above the Z peak, at centre-of-mass energies up to 209 GeV, corresponding to an integrated luminosity of about 700 $pb^{-1}$for each of the four experiments. Within the Standard Model (SM) of electroweak interactions, the most interesting new processes in this energy range are those leading to four-fermion final states, arising from single or pair productions W or Z bosons. For each process the average ratio ($\mathcal{R}$) between the measured cross sections and the SM expectations are determined, in order to illustrate their level of agreement.

2 Single-W and single-Z productions

For the single-boson production ($e^+e^- \rightarrow We\nu, Zee$), a subset of Feynman diagrams leading to identical four-fermion final states, defines the signal to be measured. The signal is further defined with additional kinematic cuts on the outgoing four-fermion phase-space configuration [1]. The selections yield efficiencies of 40 to 60% with purities of 70 to 50%, depending on the decay channel. The measured cross

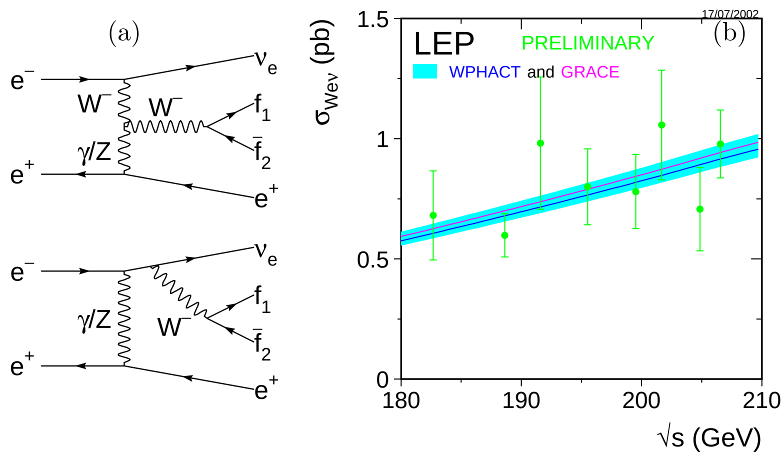

Figure 1: Electroweak t-channel diagrams (a) and combined LEP cross section measurements at $\sqrt{s}$=183-209 GeV (b), for the $e^+e^- \to We\nu$ process.

sections for single-W [1] production (Fig. 1b), and for single-Z [2] productions are in good agreement with the SM predictions, as calculated by the `grace` program [3], within the accuracy of the measurements, of 8% and 9% respectively. The resulting cross section ratios are $\mathcal{R}_{\mathrm{We}\nu} = 0.949 \pm 0.078$ and $\mathcal{R}_{\mathrm{Zee}} = 0.928 \pm 0.088$. The single-W cross section measurement also allows the WWγ trilinear gauge-boson coupling to be constrained with an accuracy of 15% [1].

3 Z-pair and Zγ^* productions

The Z-pair production measurements are defined as the contribution of the `NC02` diagrams (Fig.2a) to the detected four-fermion final states. Selection efficiencies of 50 to 80% are achieved with purities of 80 to 50%, depending on the decay channel. The measured Z-pair cross sections, (Fig.2b), are in agreement with the theoretical predictions of `yfszz` [4], within the measurements accuracy of 5.5%. The resulting cross section ratio is $\mathcal{R}_{\mathrm{ZZ}} = 0.962 \pm 0.055$. Rates for Z$\gamma^*$ four-fermion processes are also measured to be in agreement with the SM predictions [5].

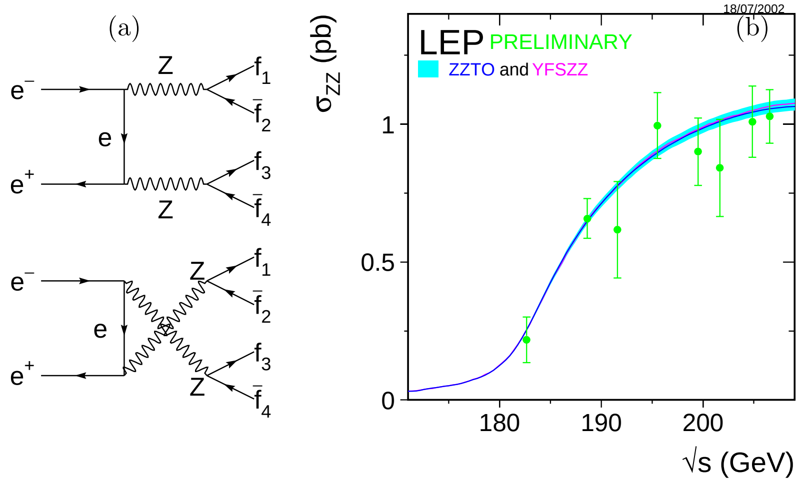

Figure 2: Electroweak NC02 diagrams (a) and combined LEP cross section measurements at $\sqrt{s}$=183-209 GeV (b), for the $e^+e^- \to ZZ$ process.

4 W-pair productions

The LEP W-pair production is defined as the contribution of the CC03 diagrams (Fig.3a) to the detected four-fermion final states. Selection efficiencies vary from 60 to 90% with purities of 90 to 80%, depending on the decay channel. The W-pair cross section experimental determinations at $\sqrt{s}$=161-209 GeV (Fig.3b), are in agreement with the theoretical predictions of `yfsww` [6] and `racoonww` [7] to an overall precision of 1.1%. This precision allowed the first clear proof of the existence of WWγ and WWZ couplings to be obtained, as visible in Fig. 3b, and to test the effects of O(α) electroweak radiative corrections to the CC03 diagrams. The resulting cross section ratio is $\mathcal{R}_{\rm WW} = 0.997 \pm 0.011$.

The measurement of the W-pair cross section at the production threshold, is sensitive to the W mass value, and allowed the determination of $m_{\rm W} = 80.40^{+0.22}_{-0.21}$ GeV/c^2 to be achieved, independently from the subsequent direct mass determinations performed at LEP2.

5 W decay rates and couplings

The sample of W decays collected at LEP (about 10^4 WW events per experiment), allowed for the first time the hadronic and leptonic W decay branching ratios to be determined directly. The combined value BR(W→hadrons)=67.92±0.27% is in agreement with the SM

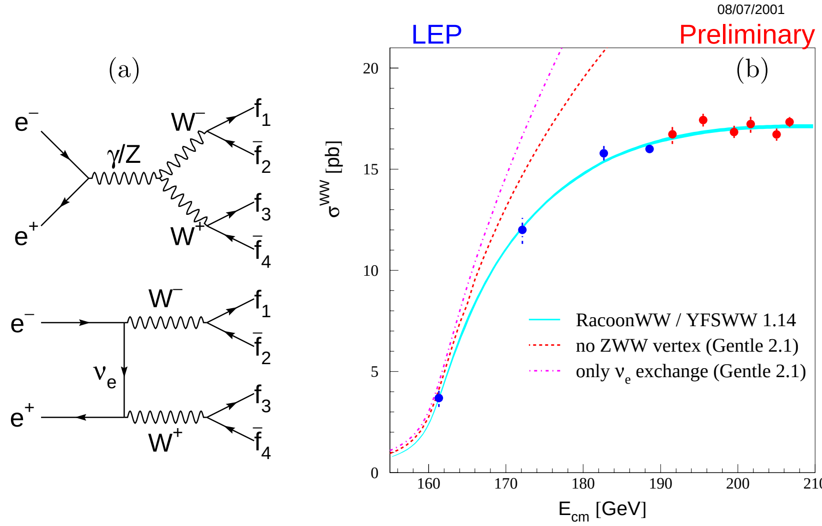

Figure 3: Electroweak `CC03` diagrams (a) and LEP combined cross section measurements at $\sqrt{s}$=161-209 GeV (b), for the $e^+e^- \rightarrow W^+W^-$ process. The experimental points clearly prove the existence of both the WWγ and WWZ SU(2)$\otimes$U(1) gauge-boson self-couplings.

expectations, and tests the universality of lepton and quark charged weak couplings at the 0.7% level, $g_q/g_\ell = 1.010 \pm 0.007$. The W hadronic branching ratio measurement is also used to constrain the CKM quark-mixing matrix, its unitarity in the first two families, and to extract the best current constraint on the $V_{\rm cs}$ amplitude, $|V_{\rm cs}| = 0.996 \pm 0.013$. Finally, the agreement of the measurement of the three leptonic W branching ratios translates to a test of the universality of the charged weak couplings of the three lepton species at the 1% level, yielding $g_\mu/g_{\rm e} = 1.000 \pm 0.010$, $g_\tau/g_{\rm e} = 1.026 \pm 0.014$ and $g_\tau/g_\mu = 1.026 \pm 0.014$.

6 Conclusions

The measurement of four-fermion production rates at LEP has been a nice and exciting work. It has provided different and crucial new results on the structure of gauge boson couplings, the W mass, the lepton and quark universality of charged weak interactions, and quark mixing.

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