WW CROSS SECTIONS AND W BRANCHING RATIOS

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Data at collision energies up to 208 GeV collected by LEP experiments have been analysed to extract the W pair production cross section. Combining all LEP2 centre-of-mass energies has allowed the determination of the W decay branching ratios into leptons and hadrons and to derive the value of the CKM matrix element $|V_{cs}|$. An update of direct $|V_{cs}|$ measurements is also presented.

1 Introduction

Since 1997, LEP has increased its centre-of-mass energy from 161 to 208 GeV in 2000. An integrated luminosity of 450 pb^{-1}has been recorded at different energies as summarised in Table 1. In 2000, LEP has been running at centre-of-mass energies between 200 GeV and 208 GeV. Data have been averaged in 2 sets with mean centre-of-mass energies of 204.9 and 206.7 GeV. Results presented here use an integrated luminosity for each set respectively of 60 and 30 pb^{-1}.
In this paper, the determination of the WW production cross section is reviewed and the W branching ratio into leptons and hadrons is extracted.
Most of the results quoted in this paper are the combined values of the four experiments. They are preliminary unless specified otherwise. These results are compared with new theoretical predictions recently available through the work of the LEP2 Monte-Carlo workshop[1] .

2 Event Selections

At LEP, Ws are pair-produced and can decay leptonically or hadronically, giving three possible final states. The selections are based on the ones developed by the four experiments at 189 GeV [2], scaled by the centre-of-mass energy.
The fully leptonic channels WW $\rightarrow l\nu l\nu$ (11 % of the decays) are characterized by 2 acoplanar leptons and missing momentum. The selections are in general cut based analyses and give typical efficiencies of 60-80 % for a low background level of $\approx$ 150 fb.
The semileptonic channels account for 44 % of final states and are characterised by 2 hadronic jets and an isolated lepton. Selections are based on a well identified and isolated lepton (e, μ or τ jet) and missing momentum. To improve upon cut based selections, the experiments use multivariate techniques based on probability or likelihood. Very high purity ($\approx$ 90 %) are achieved in those analyses.
The fully hadronic channel has four hadronic jets, no missing energy with a decay fraction of 46 %. However, analyses have also to fight against a huge QCD background ($e^+e^- \rightarrow q\bar{q}\gamma(gg)$). To enhance background rejection, all experiments use sophisticated analyses based on neural network techniques or likelihood analyses. The efficiencies are around 85 % with a typical background of 1-2 pb.

3 Results and interpretation

3.1 Method

The WW cross section in each channel is extracted from a maximum likelihood fit using the number of observed events, a cross-efficiency matrix between channels, the luminosity and the expected number of background events. The signal WW events are produced only via the so-called CC03

Table 1. LEP recorded energies and luminosity

YEAR	1996		1997	1998	1999				2000	
$\sqrt{s}$ (GeV)	161	172	183	189	192	196	200	202	205	207
lumi.(pb^{-1})	10	10	55	180	30	80	80	40	60	30

diagrams[2]. The interference with other 4 fermions final states is corrected in the cross section measurement. Combining all channels in one fit allows the extraction of the total WW production cross section and of the leptonic and hadronic W branching fractions.

3.2 WW cross sections

The 4 experiments have given preliminary results at all energies[3,4]. The combined results of the LEP experiments for the total WW production cross section at the various centre-of-mass energies are shown in figure 1, included two new points at 205 and 207 GeV. The experimental points are compared with new calculations using the Double Pole Approximation (DPA)[5], `RACOONWW`[6] and `YFSWW 1.14`[7]. These new codes have been shown to agree at a level better than 0.4 %[1]. The gray band of figure 1 represents the theoretical uncertainty, which decreases with the centre-of-mass energy from 0.7 % at 170 GeV to 0.4 % at 210 GeV. Since the DPA calculation can only be used away from the production threshold, the `GENTLE` model [8], tuned to reproduce DPA predictions, is used below 170 GeV for a complete comparison with the experimental results. The measured cross sections are in good agreement with the actual predictions.

3.3 W Branching ratios

Using the data on the full range of centre-of-mass energies, a fit to extract the W branching ratios can be performed with and without the assumption of lepton universality.

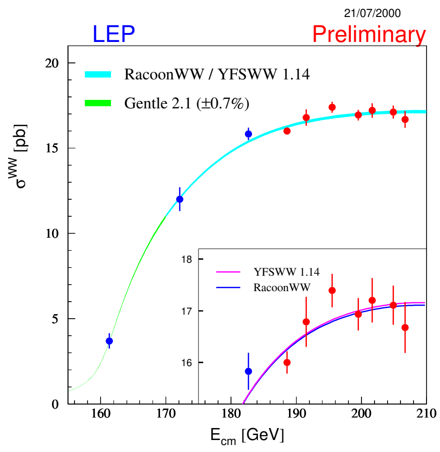

Figure 1. WW cross section results of the LEP combined data compared to the predictions of `RacoonWW`, `YFSWW` and `GENTLE`.

ALEPH and OPAL have used all data from 161 to 207 GeV whereas DELPHI and L3 have only used data up to 202 GeV. The results from each experiment are given in Table 2 together with the LEP combined value. Assuming lepton universality, the leptonic and hadronic branching ratios are:

$$B(\mathrm{W} \to l\nu) = 10.74 \pm 0.10\%$$
$$B(\mathrm{W} \to \mathrm{qq}) = 67.78 \pm 0.32\%$$

Results agree well within the SM expectations. The quoted errors include systematic uncertainty derived from the error calculated at 189 GeV. The correlated errors between the different channels of each experiment are taken into account in the averaging procedure together with the QCD component which is assumed to be fully correlated among experiments.

Table 2. W branching ratios results in % using all data from 161 GeV to 208 GeV for ALEPH and OPAL and up to 202 GeV for DELPHI and L3.

Exp	e ν	$\mu\nu$	$\tau\nu$	qq
A	11.19 ± 0.34	11.05 ± 0.32	10.53 ± 0.42	67.22 ± 0.53
D	10.33 ± 0.45	10.68 ± 0.34	11.28 ± 0.56	67.81 ± 0.61
L	10.22 ± 0.36	9.87 ± 0.38	11.64 ± 0.51	68.47 ± 0.59
O	10.52 ± 0.37	10.56 ± 0.35	11.15 ± 0.49	67.84 ± 0.62
LEP	10.62 ± 0.20	10.60 ± 0.18	11.07 ± 0.25	67.78 ± 0.32

3.4 $|V_{cs}|$ from $B(\mathrm{W} \to \mathrm{qq})$

Within the Standard Model, the hadronic branching ratio can be related to the CKM matrix element $|V_{cs}|$ using

$$\frac{\mathrm{B(W \to qq)}}{1 - \mathrm{B(W \to qq)}} = (\sum_{i,j} |V_{\mathrm{ij}}|^2)(1 + \alpha_s(m^2_{\mathrm{W}})/\pi).$$

without need for a CKM unitarity constraint. Using the world average value of α_s and the experimental values of CKM matrix elements involving light quarks [9], the above result is then interpreted as

$$|V_{\mathrm{cs}}| = 0.989 \ \pm 0.016$$

which is the best existing measurement.

3.5 $|V_{cs}|$ from R_c

A direct measurement of $|V_{cs}|$ can be made by measuring the charm content of hadronic W decays.

$$R_c^W = \frac{\Gamma(\mathrm{W} \to cX)}{\Gamma \mathrm{W} \to \mathrm{qq})} = \frac{|V_{\mathrm{cd}}|^2 + |V_{\mathrm{cs}}|^2 + |V_{\mathrm{cb}}|^2}{\sum_{i,j=u,d,s} |V_{\mathrm{cij}}|^2}$$

OPAL has used data up to 189 GeV[10] to provide a new measurement of: $R_c^W = 0.48 \pm 0.042 \pm 0.032$ leading to the direct estimation:

$$|V_{\mathrm{cs}}| = 0.93 \ \pm 0.08 \pm 0.06$$

Combining this result to previous published values from ALEPH, DELPHI and L3 at lower energies gives an average direct LEP mesurement of

$$|V_{\mathrm{cs}}| = 0.95 \ \pm 0.08$$

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