# WW PRODUCTION AT LEP2

R. PARAMATTI
*Univ. of Rome "La Sapienza" and INFN Rome*
*P.ze Aldo Moro 2, 00185 Rome, Italy*
*E-mail: riccardo.paramatti@roma1.infn.it*

In this article LEP combined results on W-pair cross section and W decay branching ratios are presented. The results are based on the whole data sample collected by LEP experiments up to a center of mass energy of 209 GeV; the LEP combinations from single experiment results are performed taking into account correlations beetwen experiments and beetwen different energies. The most recent results are still preliminary.

## 1 Introduction

Since 1996 the center of mass energy of the LEP (Large Electron Positron collider) at CERN was increased above the W-pair production threshold. The four LEP experiments ALEPH, DELPHI, L3 and OPAL collected more than 700 $\mathrm{pb}^{-1}$ per experiment in the energy range $\sqrt{s} = 161-209$ GeV.
In the Standard Model there are three lowest-order diagrams (CC03 diagrams [1]) contributing to W-pair production: the neutrino exchange diagram (the $t$-channel) and the $\gamma$ and $Z$ exchange diagrams with triple gauge boson vertex $\gamma WW$ and $ZWW$ (the $s$-channel). The Standard Model foresees also a fourth diagram, the Higgs exchange diagram, which is completely negligible because of the low value of $m_e$.

## 2 Decay channels

The W boson can decay hadronically into a quark-antiquark pair (top quark production is kinematically forbidden) or into a lepton-antilepton pair (for example $W^- \to l^-\overline{\nu}_l$ with $l = e, \mu, \tau$). Therefore W-pair events present three decay channels given in Table 1 together with the Standard Model Branching Ratios.

The hadronic events are characterized by the presence of many tracks, 4 or more hadronic jets, no missing energy. The selection of $W^+W^- \to q\overline{q}q\overline{q}$ events is performed in two steps; experiments use a cut-based preselection followed by a neural network application or a likelihood selection procedure to reject the major background coming from $e^+e^- \to q\overline{q}$ events with multigluon radiation.

Table 1. $W^+W^-$ Decay Channels and SM Branching Ratios.

| Decay Channel | Branching Ratio | Standard Model BR Expectation |
|---|---|---|
| $W^+W^- \to q\overline{q}q\overline{q}$ | $BR(W \to q\overline{q}) \times BR(W \to q\overline{q})$ | 45.55% |
| $W^+W^- \to q\overline{q}l\nu$ | $2 \times BR(W \to q\overline{q}) \times BR(W \to l\nu)$ | 43.88% |
| $W^+W^- \to l\nu l\nu$ | $BR(W \to l\nu) \times BR(W \to l\nu)$ | 10.57% |

The signature of semileptonic events ($W^+W^- \to q\overline{q}l\nu$) is given by 2 hadronic jets, missing energy due to the presence of one or more neutrinos and either one isolated lepton in case of $q\overline{q}e\nu_e$, $q\overline{q}\mu\nu_\mu$ and $q\overline{q}\tau\nu_\tau$ events when the $\tau$ decays leptonically, or one low multiplicity jet when $\tau$ decays hadronically. The background comes mainly from $e^+e^- \to q\overline{q}$ events and from four-fermion final states containing two quarks and two leptons of the same flavour.
Events in which both W decay leptonically are characterized by a large missing energy and a large missing transverse momentum, two energetic and acoplanar leptons of opposite charge. If one or two $\tau$ decay hadronically, the event will present one or two low multiplicity hadronic jets instead of isolated leptons. The relevant backgrounds are due to Bhabha scattering, $e^+e^- \to Z(\gamma) \to l^+l^-$ events and two-photon collisions events.

## 3 Cross section measurements

The selection's results in different signal channels are used in a maximum likelihood fit assuming that the number of selected events follows a Poissonian distribution. The number of expected events in each channel is derived taking into account the selection correlations and the expected background events.
The fit is performed by determining the total $e^+e^- \to W^+W^-$ cross section and the W Branching Ratios.
The four LEP experiments results at different center of mass energies are combined in a global fit using the Best Linear Unbiased Estimate technique (BLUE [2]). The systematic errors due to the uncertainties on jet fragmentation and final state interaction models are considered fully correlated between experiments and between different center of mass energies; the theoretical errors on the SM background cross sections and the luminosity uncertainties are assumed to be correlated between energies; other sources of systematic (Montecarlo statistics, detector simulation, selection procedures) are considered not correlated.
The full covariance matrix is built with inter-experiment and inter-energy correlations to take into account all these effects.

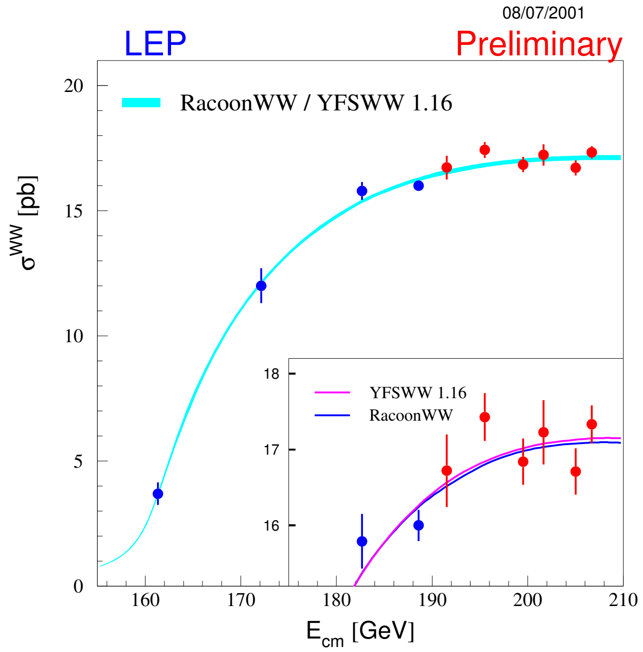


Figure 1. $e^+e^- \rightarrow W^+W^-$ cross section measurements; the LEP combined results (dots) are shown with the Standard Model expectation (line); the zoom of the region above 180 GeV is reported in the box.

The $\chi^2/d.o.f.$ of this global fit is 27.42/24.

The LEP experimental points are shown in Figure 1 compared with the theoretical calculations from YFSWW [3] and RACOONWW [4] Montecarlo generators; the two codes agree at level of 0.5% in the LEP2 energy range. Both include $\mathcal{O}(\alpha)$ electroweak radiative corrections in the so called Double Pole Approximation [5].

The measurements above 190 GeV are still preliminary.

The agreement, averaged over different center of mass energies, between LEP WW cross section measurements and theoretical expectations can be expressed quantitatively by the combination of their ratio:

$$\mathcal{R}_{WW} = \frac{\sigma_{WW}^{meas}}{\sigma_{WW}^{theo}} \tag{1}$$

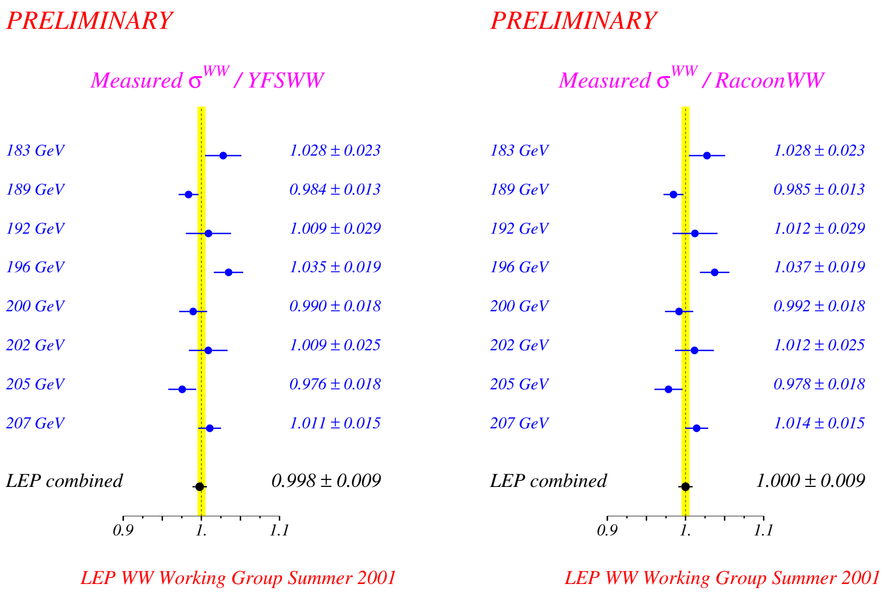


Figure 2. Ratios of LEP combined $e^+e^- \rightarrow W^+W^-$ cross section measurements to the expectations according to YFSWW and RACOONWW Montecarlo; the vertical bands represent theoretical errors on the two cross section predictions (0.5%).

The values of $\mathcal{R}_{WW}$ relative to YFSWW and RACOONWW are shown in Figure 2. The average result of the four experiments at different energies and the global average over the whole energy range are given for both Montecarlo models.

## 4 Branching Ratio measurements

The lepton universality in W boson decays can be tested by measuring the W Branching Ratios. Assuming unitarity ($BR_{W\rightarrow e\nu} + BR_{W\rightarrow \mu\nu} + BR_{W\rightarrow \tau\nu} + BR_{W\rightarrow q\overline{q}} = 1$) the results from individual experiments coming from the combination of the full data sets are shown in Figure 3; the ratios of leptonic Branching Ratios are:

$$BR_{W\rightarrow \mu\nu}/BR_{W\rightarrow e\nu} = 1.000 \pm 0.0021$$

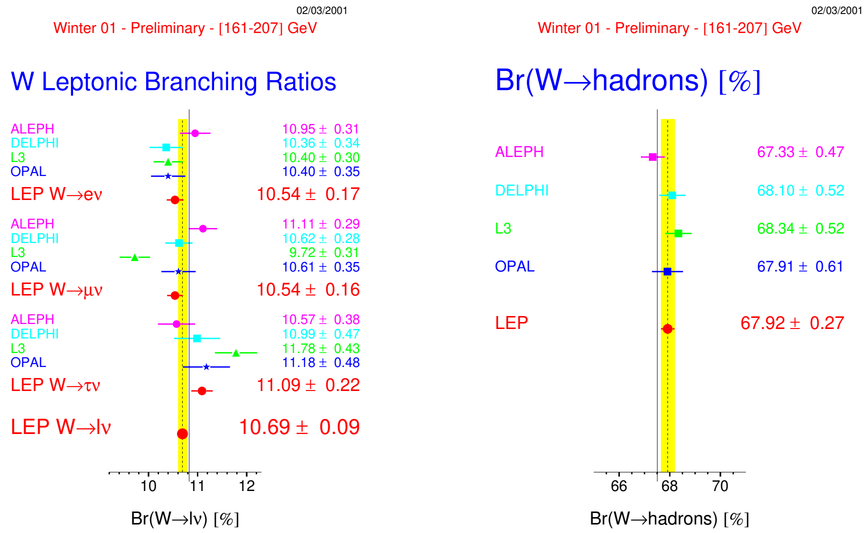


Figure 3. Hadronic and leptonic Branching Ratio measurements from individual experiments and LEP combination.

$$BR_{W\to\tau\nu}/BR_{W\to e\nu} = 1.052 \pm 0.0029 \qquad (2)$$
$$BR_{W\to\tau\nu}/BR_{W\to\mu\nu} = 1.052 \pm 0.0028$$

Assuming lepton universality the LEP fit gives:

$$BR_{W\to l\nu} = 10.69\% \pm 0.06\%(stat.) \pm 0.07\%(syst.)$$
$$BR_{W\to q\overline{q}} = 67.92\% \pm 0.17\%(stat.) \pm 0.21\%(syst.) \qquad (3)$$

These preliminary results are in agreement with the Standard Model predictions ($BR_{W\to l\nu} = 10.83\%$ and $BR_{W\to q\overline{q}} = 67.51\%$).

Within the Standard Model the W branching ratios depend on the elements of the Cabibbo-Kobayashi-Maskawa matrix not involving the top quark.

$$\frac{BR_{W\to q\overline{q}}}{1 - BR_{W\to q\overline{q}}} = \left(1 + \frac{\alpha_s(M_W^2)}{\pi}\right) \cdot \sum_{i\neq t} |V_{ij}|^2 \qquad (4)$$

Assuming $\alpha_s(M_W^2) = 0.121 \pm 0.002$ [6], the measurement of W hadronic branching ratio gives:

$$\sum_{i \neq t} |V_{ij}|^2 = 2.039 \pm 0.025 \tag{5}$$

This result can be interpreted as a measurement of $|V_{cs}|$, the least well determined of these CKM matrix elements:

$$|V_{cs}| = 0.996 \pm 0.013 \tag{6}$$

## 5 Conclusions

More than 40000 $e^+e^- \rightarrow W^+W^-$ events were collected by the four LEP experiments in 1996-2000.
The $e^+e^- \rightarrow W^+W^-$ cross section measurements are in perfect agreement with the Standard Model expectation confirming the existence of the triple gauge boson vertex $\gamma WW$ and $ZWW$. In particular the combined value over the whole energy range of the ratio between measured and predicted (RACOONWW) WW cross section is $\mathcal{R}_{WW} = 1.000 \pm 0.009$.
Also the Branching Ratios of W are in agreement with the Standard Model predictions and the comparison of the leptonic BRs allows to test the lepton universality in W boson decays at level of 3%.
Some of the results and LEP combinations presented here are still preliminary; LEP Collaborations will publish final results in the next months.

## References


1. W. Beenakker and F.A. Berends *PHYSICS AT LEP2 - WW Cross-Sections and Distributions* - Vol. 1, ed. G. Altarelli, T. Sjöstrand and F. Zwirner, CERN 96-01, (1996)
2. L. Lyons, D. Gibaut and P. Clifford, *Nucl. Instrum. Methods* A **270**, 110 (1988)
3. S. Jadach *et al.*, *YFSWW3 version 1.14*, *Phys. Rev.* D **54**, 5434 (1996), *Phys. Lett.* B **417**, 326 (1998), *Phys. Rev.* D **61**, 113010 (2000)
4. A. Denner *et al.*, *RACOONWW*, *Phys. Lett.* B **475**, 127 (2000)
5. M.W. Grünewald, G. Passarino *et al.*, *Reports of the Working Groups on Precision Calculations for LEP2 Physics*, ed. S. Jadach, G. Passarino and R. Pittau, CERN 2000-009
6. Particle Data Group, *Review of Particle Physics*, The European Physical Journal C **Vol. 15 N. 1-4**, 23 (2000)