Study of W boson properties at LEP

A. Tonazzo[a] *

[a]CERN, EP Division, CH-1211 Geneva 23, Switzerland

The precision study of W boson properties is one of the most important goals of the LEP2 physics programme. A review of the (preliminary) results obtained by the four LEP experiments with the data collected at centre-of-mass energies up to 189 GeV is presented.

1. INTRODUCTION

The LEP e^+e^- collider at CERN has been operated at centre-of-mass energies above the W-pair production threshold since 1996, when the so-called LEP2 phase started. The energy was gradually raised to reach 189 GeV in 1998. A total integrated luminosity of about 240 pb^{-1}, corresponding to nearly 4000 WW events, has been collected by each of the four LEP experiments. LEP2 data taking is currently going on at 200 GeV, and will continue in the year 2000.

WW production gives origin to a four-fermion final state: $qqqq$ (B.R.=45.9%), characterised by a four-jet topology, $qql\nu$ (43.7%), with one energetic lepton isolated from the hadronic system and missing energy due to the undetected neutrino, and $l\nu l\nu$ (10.4%), with two acoplanar leptons and missing energy. Detailed descriptions of the characteristics of the $e^+e^- \to W^+W^-$ process and of the selection of WW events, which is common to all the analyses described below, can be found in the quoted references.

2. W DECAY BRANCHING RATIOS

The decay branching ratios of the W boson are extracted from the same information that is used for the cross-section determination. The method is described in [1], and no detail will be given here.

The results of the individual experiments [2–5] are in good agreement. The combined LEP measurements of the W decay branching ratios into leptons are reported in table 1. These values are consistent with the hypothesis of lepton universality in charged current weak interactions. If this is assumed to hold, the decay ratio of the W into hadrons can be extracted.

*On behalf of the DELPHI Collaboration

Table 1
W decay branching ratios.

$BR(W \to e\bar{\nu}_e)$	$10.61 \pm 0.25\%$
$BR(W \to \mu\bar{\nu}_\mu)$	$10.65 \pm 0.24\%$
$BR(W \to \tau\bar{\nu}_\tau)$	$10.82 \pm 0.32\%$
$BR(W \to q\bar{q}')$	$67.96 \pm 0.41\%$

3. MEASUREMENTS OF $|V_{cs}|$

The W hadronic branching ratio is related to the CKM matrix elements by

$$\frac{BR(W \to q\bar{q}')}{1 - BR(W \to q\bar{q}')} = 1 + \frac{\alpha_s(m_W^2)}{\pi} \cdot \sum |V_{ij}|^2 \ ; \tag{1}$$

knowing the world average values of α_s and of the other CKM elements [6], the LEP measurement of $BR(W \to q\bar{q}')$ can be interpreted as a determination of $|V_{cs}|$ which does not assume unitarity of the CKM matrix, reported in table 2. This is currently the most precise measurement of this parameter.

An independent direct measurement of $|V_{cs}|$ can be derived from the rate of W decays containing a c quark, $R_c(W)$, which can be expressed as a function of the CKM elements involved in W decays.

In the Standard Model, the predicted value of $R_c(W)$ is 0.5, thus its measurement is a test of CKM unitarity.

If CKM unitarity is not assumed, the result on $R_c(W)$ can be interpreted as a direct measurement of $|V_{cs}|$, using the precise knowledge of the other matrix elements.

The experimental analyses [7–10] use charm-tagging algorithms based on the fact that charm is the heaviest quark produced in W decays, since top production is kinematically forbidden and $W \to b$ decays are strongly Cabibbo-suppressed. DELPHI measures $BR(W \to cs)$ using also s-tag based on identification of kaons in jets by means of the RICH detector.

The results are reported in table 2.

Table 2
Measurements of $R_c(W)$ and of $|V_{cs}|$.

	$R_c(W)$	$\lvert V_{cs}\rvert$
$D \to Kl\nu$ [6]		1.04 ± 0.16
ALEPH	$0.51 \pm 0.05 \pm 0.03$	$1.00 \pm 0.11 \pm 0.07$
DELPHI	$0.42 \pm 0.13 \pm 0.06$	$0.87 \pm 0.24 \pm 0.11$
L3	$0.50 \pm 0.11 \pm 0.04$	$0.98 \pm 0.22 \pm 0.08$
OPAL	$0.47 \pm 0.04 \pm 0.06$	$0.91 \pm 0.07 \pm 0.11$
LEP from $BR(W \to q\bar{q}')$		0.997 ± 0.020

4. TRILINEAR GAUGE BOSON COUPLINGS (TGCs)

Couplings among gauge bosons are a distinctive feature of non-abelian theories, such as the Standard Model. A direct measurement of the WWV ($V = Z, \gamma$) vertices allows for a test of the predicted form of the interaction. The observation of deviations from the Standard Model could be a hint for new physics.

In the most general Lorenz-invariant lagrangian, 7 independent parameters describe each of the two vertices. Assuming C, P and CP conservation, gauge invariance and $SU(2)\times U(1)$ constraints, the number of free parameters is reduced to 3, indicated as κ_γ, g_Z^1 and λ_γ. These are directly related to the electric dipole and magnetic quadrupole moments of the W boson [11]. Deviations from the SM values are quoted:

$$\Delta\kappa_\gamma = \kappa_\gamma - 1 \;\; ; \;\; \Delta g_Z^1 = g_Z^1 - 1 \;\; ; \;\; \lambda_\gamma \tag{2}$$

At LEP2, WWV vertices can be explored directly in several processes, where they contribute at tree level: W-pair production, single-W ($e^+e^- \to We\nu_e$) and single photon ($e^+e^- \to \nu\bar{\nu}\gamma$) events.

Anomalous contributions to the WWV vertices would alter both the total production rate and the relative weight of different W helicity amplitudes. Sensitive observables are the total cross-sections for the above mentioned processes, and the differential distributions of W production and decay angles (in $e^+e^- \to W^+W^-$ only).

The kinematical variables used for TGC analyses in WW events are the polar angle of W^- production in the lab frame (Θ_W) and the polar and azimuthal angles of the W^+ and W^- decay products in the rest system of the respective parent boson (θ^*, ϕ^*). An example of how anomalous couplings would alter the W polar angle distribution in $qql\nu$ events is shown in figure 1.

Not all these variables can be measured in general: the accessible information depends on the WW decay channel.

Furthermore, the loss of information introduced by detector effects must be taken into account. Constrained fits based on four-momentum conservation are used to improve the resolution on the observables.

Several statistical techniques are used to determine TGCs. Maximum likelihood fits require the choice of a subset of the kinematical variables, due to the limited statistics available. With the method of Optimal Observables [12], based on the quadratic dependence of any differential cross-section on any of the couplings, the five kinematical variables are reduced to two, retaining maximal information on the TGCs; one clear advantage is that detector effects are much easier to include.

Combining the data from all the LEP experiments [13–16], and allowing for one free parameter at a time, with the other ones fixed to their SM values, the results reported in tabe 3 are obtained.

No evidence is seen for deviations from the null values expected in the Standard Model.

TGC measurements will specially profit from the future LEP2 data both because of the larger statistics (the systematic error is negligible with respect to the statistical one), and because the sensitivity increases at higher energy. The ultimate precision will be a factor two better than the current one.

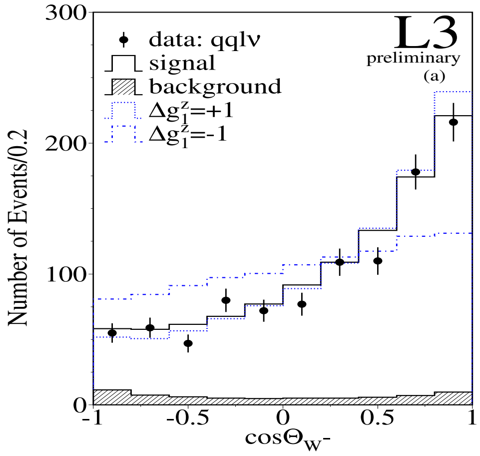

Figure 1. Distribution of the W^- production polar angle in the lab for different TGC values. The real data are shown with error bars.

Table 3
Combined LEP results on TGCs.

$\Delta\kappa_\gamma$	0.04 ± 0.08
Δg_1^Z	-0.01 ± 0.03
λ_γ	-0.04 ± 0.04

REFERENCES

1. F.Badaud, these proceedings.
2. ALEPH Note 99-064 CONF 99-038 (1999); ALEPH Collaboration, R.Barate et al., Physics Letters B 453 (1999) 107
3. DELPHI Note 99-61 CONF 248 (1999); DELPHI Collaboration, P.Abreu et al., Phys. Lett. B456 (1999) 310
4. L3 Note 2376 (1999); L3 Collaboration, M.Acciarri et al., Phys. Lett. B 436 (1998) 437-452
5. OPAL Physics Note PN378 (1999)
6. Particle Data Group, Eur. Phys. J. C3 (1998)
7. ALEPH Note 99-062 CONF 99-037 (1999)
8. DELPHI Collaboration, P.Abreu et al., Phys. Lett. B439 (1998) 209
9. L3 Note 2232 (1998)
10. OPAL Physics Note PN402 (1999)
11. G.Gounaris, J.L.Kneur and D.Zeppenfeld, in *Physics at LEP2*, eds. G.Altarelli, T.Sjöstrand and F.Zwirner, CERN 96-01 Vol.1, 525 (1996)
12. M.Diehl and O.Nachtmann, Z. Phys. C62 (1994) 397
13. ALEPH Note 99-019 99-014 (1999); ALEPH Note 99-072 CONF 99-046 (1999); ALEPH Note 99-021 CONF 99-016 (1999); ALEPH Collaboration, R.Barate et al., Physics Letters B 445 (1998) 239; ALEPH Collaboration, R.Barate et al., Physics Letters B 422 (1998) 369
14. DELPHI Note 99-63 CONF 250 (1999); DELPHI Collaboration, P.Abreu et al., CERN-EP/99-62
15. L3 Note 2378 (1999); L3 Collaboration, M.Acciarri et al., Phys. Lett. B 436 (1998) 417-427
16. OPAL Physics Note PN375 (1999); OPAL Collaboration, G.Abbiendi et al., Eur. Phys. J. C8 (1999) 191-215