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# Measurement of the W boson mass and width in $e^+e^-$ collisions at LEP

**F. Cossutti**
CERN, CH-1211 Geneva 23, Switzerland

**Abstract**

A review of the present status of the W boson mass and width measurements at LEP is presented. The analysis of the data collected in 1998 by the 4 LEP collaborations, corresponding to about 700 $\mathrm{pb}^{-1}$, allows to reach an experimental uncertainty on the W boson mass measured at LEPII approaching the precision of the indirect results from the high precision electroweak measurements at LEPI.

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# 1 Introduction

The measurement of the $\mathrm{W}$ boson mass $m_{\mathrm{W}}$ constitutes a fundamental test of the Standard Model of the electroweak interactions. The comparison of the direct $m_{\mathrm{W}}$ measurement with the indirect evaluation from the other electroweak precision measurements allows a stringent consistency check of the Standard Model and plays a key role in constraining the Higgs boson mass and the possible presence of new physics.

# 2 W mass measurement at LEPII

At LEPII the $\mathrm{W}$ pair production in $e^+e^-$ collision is exploited to perform this measurement. Two different methods have been used depending on the centre of mass energy of the collision.

## 2.1 Measurement at the WW production threshold

At the $\mathrm{WW}$ production kinematical threshold ($\sqrt{s} \simeq 161\,$GeV/c$^2$) the cross section of this process is highly sensitive to $m_{\mathrm{W}}$. Exploiting the $\mathrm{WW}$ cross section measurement performed on the statistics collected at this energy by the LEP collaborations in 1996 ($\simeq 42\,\mathrm{pb}^{-1}$) [1] the following result is obtained:

$$m_{\mathrm{W}} = 80.400 \pm 0.221 \quad \text{GeV/c}^2$$

where the error is completely dominated by the limited experimental statistics.

This method cannot be used at higher energies because the sensitivity of the cross section to $m_{\mathrm{W}}$ drops rapidly becoming almost negligible.

## 2.2 Measurement using direct reconstruction of WW decay products

The LEP collaborations have collected and analysed data at 3 centre of mass energies beyond the threshold one, $\simeq 40\,\mathrm{pb}^{-1}$ at 172 GeV/c$^2$, $\simeq 220\,\mathrm{pb}^{-1}$ at 183 GeV/c$^2$ and $\simeq 690\,\mathrm{pb}^{-1}$ at 189 GeV/c$^2$ (see [3, 5, 6, 7] and references therein).

At these energies the method used for the $\mathrm{W}$ mass measurement is the direct reconstruction of the $\mathrm{W}$ invariant mass spectrum from the final state measured particles. According to the way the $\mathrm{W}$s decay into fermions (a quark pair or a charged lepton - neutrino pair) 3 final state channels can be distinguished (in parenthesis the Standard Model branching ratios are given): fully hadronic ($qqqq$, 45.9%), semileptonic ($ql\nu$, 43.7%) and fully leptonic ($l\nu\, l\nu$, 10.4%). Due to the loss of kinematical information in the fully leptonic channel because of the 2 unmeasured neutrinos, only the first 2 channels can be used in this approach.

Experimentally the final states are made by either 4 hadronic jets ($qqqq$) or by 2 hadronic jets and an energetic charged lepton ($qql\nu$). The reconstruction of the event is improved using a kinematic constrained fit imposing the global energy and momentum conservation $\sum_i E_i = \sqrt{s}$ and $\sum_i \vec{p}_i = \vec{0}$ (in the semileptonic events the neutrino momentum is assumed to be equal to the missing momentum).

In the fully hadronic channel the 4 jets can be combined in 3 different way to build the $\mathrm{W}$ invariant masses. ALEPH, L3 and OPAL solve the ambiguity choosing the best pairing according to given quality criteria, while DELPHI uses a more elaborate technique (ideogram) where the information from all the pairings is combined in a global event by event probability and convoluted with the theoretical $m_{\rm W}$ distribution.

The further constraint that the 2 reconstructed invariant masses are equal is always applied in the semileptonic channel; OPAL and L3 use it also on $qqqq$ events, while ALEPH rescales the reconstructed masses to the beam energy. In the DELPHI ideogram technique the full information from all possible mass value combinations is exploited to build the event by event probability.

$m_{\rm W}$ is finally extracted from a likelihood fit: ALEPH, L3 and OPAL fit the data directly with the simulation prediction for the invariant mass as a function of $m_{\rm W}$, while DELPHI uses event by event likelihoods exploiting approximated analytical parametrisations of the reconstructed distributions and correcting the result with a calibration curve evaluated on the simulated data.

In the results presented here there is no DELPHI result on the $qq\tau\nu$ semileptonic channel yet. ALEPH has presented a measurement on the $l\nu\ l\nu$ final state performed at 183 GeV/c$^2$ fitting simultaneously the leptons energy and the missing energy spectra, which are sensitive to the $\rm W$ mass. Also semileptonic events not entering the former analyses have been treated in a similar way. The error quoted is 2.5 times bigger than the result on the standard semileptonic analyses [4].

## 2.3 Error sources on the $m_{\rm W}$ direct reconstruction measurement

The main uncorrelated systematic error sources are the detector resolution effects on the jets and leptons reconstruction, that spoil the quality of the information brought by the reconstructed final state.

Several uncertainties correlated among the 4 LEP experiments have to be taken into account: the errors arising from the data-simulation residual discrepancies due to the models of the hadronisation of quarks; the LEP energy measurement error and the uncertainty on the theoretical description of the ISR (both effects imply a shift of the effective centre of mass energy of the event which has to be corrected).

A category of error sources specific to the $qqqq$ final state is that due to the final state interaction effects that produce interferences between the final state systems coming from the 2 $\rm W$s: the colour reconnection between the quark pairs from different $\rm W$s (that are not fragmenting independently) and the Bose-Einstein correlations among identical bosons in the final state coming from different $\rm W$s.

The present error quoted for these effects is about 50 MeV/c$^2$, coming from preliminary studies on phenomenological models. The present results of LEP on the difference between the masses measured in the $qqqq$ and in the $ql\nu + l\nu\ l\nu$ channels, which is sensitive to final state interaction effects, is [2]:

$$m_{\rm W}^{qqqq} - m_{\rm W}^{qql\nu + l\nu\ l\nu} \;=\; 152 \pm 74 \quad \text{MeV/c}^2.$$

## 2.4 Results on $m_{\rm W}$ from the direct reconstruction method

The preliminary combined results of the 4 LEP collaborations on $m_{\rm W}$ from the direct reconstruction method are shown in table 1 [2]. The $non - qqqq$ channel corresponds to the combination of the semileptonic analyses and the $l\nu\ l\nu$ analysis of ALEPH.

The preliminary combined LEP result from the direct reconstruction approach on all the

Table 1: Preliminary combined LEP results on $m_{\rm W}$ from the direct reconstruction method.

| Channel | $m_{\rm W}$ | Stat. | Syst. | FSI | LEP energy |
|---|---|---|---|---|---|
| $qqqq$ | 80.429 | 0.049 | 0.043 | 0.058 | 0.017 |
| $non-qqqq$ | 80.313 | 0.052 | 0.032 | – | 0.017 |

channels is:

$$m_{\rm W} \;=\; 80.347 \pm 0.057 \quad \text{GeV/c}^2$$

# 3 Measurement of the W boson width

The DELPHI, L3 and OPAL collaborations have presented preliminary results on the measurement of the $\rm W$ boson width $\Gamma_{\rm W}$. The technique used to extract it from the data is the same used for the mass: due to the small correlation between the measured values of the 2 observables, the fits can be performed either simultaneously (L3 and OPAL) or separately (DELPHI).

The main error sources are the detector resolution and the final state interaction effects. The summary of the present LEP results is presented in the table 2.

Table 2: Preliminary LEP results for the $\rm W$ boson width $\Gamma_{\rm W}$. In the first column the centre of mass energies corresponding to the data sets analysed are shown.

| Experiment | $\Gamma_{\rm W}$ | Stat. | Syst. |
|---|---|---|---|
| DELPHI (183) | 2.48 | 0.40 | 0.10 |
| L3 (172+183+189) | 2.12 | 0.25 | – |
| OPAL (172+183) | 1.84 | 0.32 | 0.20 |

# 4 Conclusions

The preliminary LEP result on the $m_{\rm W}$ measurement combining the cross section method at the $\rm WW$ threshold with the direct reconstruction method at higher energies is shown in the figure 1, together with all the other direct (from $p\bar{p}$ colliders) and indirect measurements of $m_{\rm W}$. The combined error from the direct measurements is approaching the uncertainty from the indirect ones. In figure 2 the measured values of $m_{\rm W}$ and of the top quark mass $m_t$ are compared with the expected ones from the global electroweak fits and with the Standard Model predictions as a function of the Higgs boson mass $m_H$.

No evidence for a breakdown of the Standard Model can be observed. Also the direct $m_{\rm W}$ measurement favours a low Higgs boson mass.

# References


[1] OPAL COll., L3 Coll., DELPHI Coll., ALEPH Coll., LEP Electroweak Working Group, SLD Heavy Flavour Group, CERN-PPE 97-154 (1997).

[2] LEP Electroweak Working Group, LEPEWWG/WW/99-01 (1999).

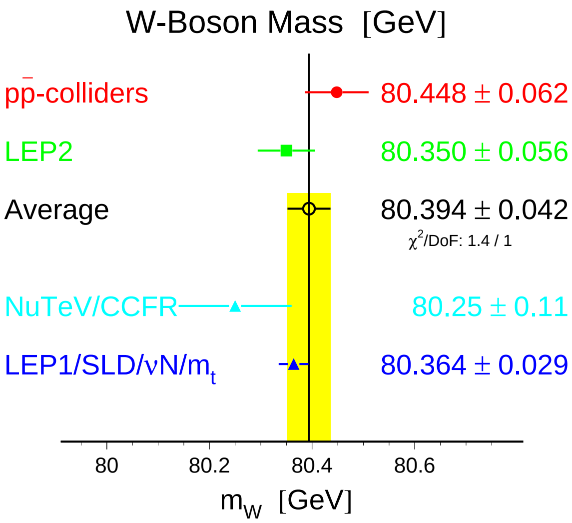


Figure 1: Global summary of the $m_{\mathrm{W}}$ direct and indirect measurements.

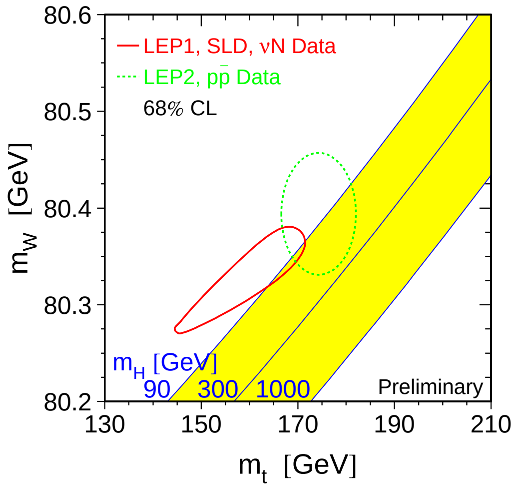


Figure 2: $m_{\mathrm{W}}$ vs $m_t$ from electroweak fits (solid), direct measurements (dotted) and the Standard Model prediction (band).

[3] ALEPH Coll., ALEPH 99-017 CONF 99-012 (1999).

[4] ALEPH Coll., ALEPH 99-015 CONF 99-010 (1999).

[5] DELPHI Coll., DELPHI 99-51 CONF 244 (1999).

[6] L3 Coll., L3 Note 2377 (1999).

[7] OPAL Coll., Physics Note PN385 (1999).