DELPHI Collaboration

DELPHI 99-168 TALK 9
05 November, 1999

W mass from fully leptonic and mixed decays at LEP

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Abstract

This article describes the determination of the W boson mass through the mixed hadronic-leptonic and fully leptonic channels at LEP. The results are preliminary and refer to the data collected up to 1998. The combined LEP W mass value for (mixed)-leptonic events is m_W = (80.310±0.060) GeV/c^2. This value, combined with the result from the hadronic channel [1], gives m_W = (80.339±0.055) GeV/c^2.

Presented at the International Europhysics Conference on High Energy Physics 99, Tampere, Finland.

1 Introduction

Before LEP2 and Tevatron [2] the mass of the W boson was one of the fundamental parameters of the Standard Model (SM) determined with poorest experimental precision from direct observations. At LEP1 a precise estimate of the W mass was possible only indirectly, through a fit to all measured electroweak parameters.

In the present status of electroweak measurements, with the top quark mass determined at the percent level [3] and with no evidence of a Higgs signal, a precise measure of m_W is of utmost importance as electroweak radiative corrections introduce a dependence of the Higgs mass upon m_t and m_W: therefore from the experimental determination of these two masses one can get predictions on m_H. Moreover, a precise determination of m_W can also lead to a stringent test of the SM or, alternatively, signal the presence of new physics.

Since 1996 LEP is the only machine which produces W bosons from leptonic annihilations, providing a unique opportunity to study them in all possible decay channels. The performance of the machine, summarised in table 1, has been improving through the years reaching, from 1998, the high luminosity regime.

year	1996	1996	1997	1998
$\sqrt{s}$ (GeV)	161	172	183	189
$\int \mathcal{L} dt$ (pb^{-1}/exp.)	~ 10	~ 10	~ 60	~ 180

Table 1: Integrated luminosity collected per experiment at LEP2.

2 W mass from mixed decay channels

2.1 Event reconstruction

The SM branching ratio for a W boson pair to decay in hadrons and leptons is .437. The mixed hadronic-leptonic (or semileptonic) topology is characterised by hadronic activity and the presence of an isolated and energetic lepton in the event. This gives a very clean signature and allows a strong reduction of the two-fermion background, with typical purities exceeding 90%, with efficiencies ranging from 50% ($q\bar{q}\tau\nu$) to 90% ($q\bar{q}\mu\nu$). However, from the point of view of the W mass extraction, topologies with at least one lepton from the W decays retain less information than fully hadronic ones because of the missing neutrino(s). In addition, detector and fragmentation effects contribute to broaden the invariant mass distribution.

To improve the W mass resolution all LEP experiments use the consolidated kinematic constrained fitting technique [4]: the measured four momenta are rescaled in such a way as to fulfill energy and momentum conservation. To further improve the resolution, the constraint of the equality of hadronic and leptonic masses is imposed. Three (four in case of $q\bar{q}\tau\nu$ events) of the five constraints are used to determine the neutrino (and τ) momentum(a) and neutrino direction so that a 2C(1C) constrained fit is actually applied. For each event one mass value can therefore be extracted. Figure 1 shows some of the mass spectra obtained at $\sqrt{s} = 189$ GeV, compared with reference Montecarlo distributions. The constrained fitting technique gives, however, an approximated description of the true

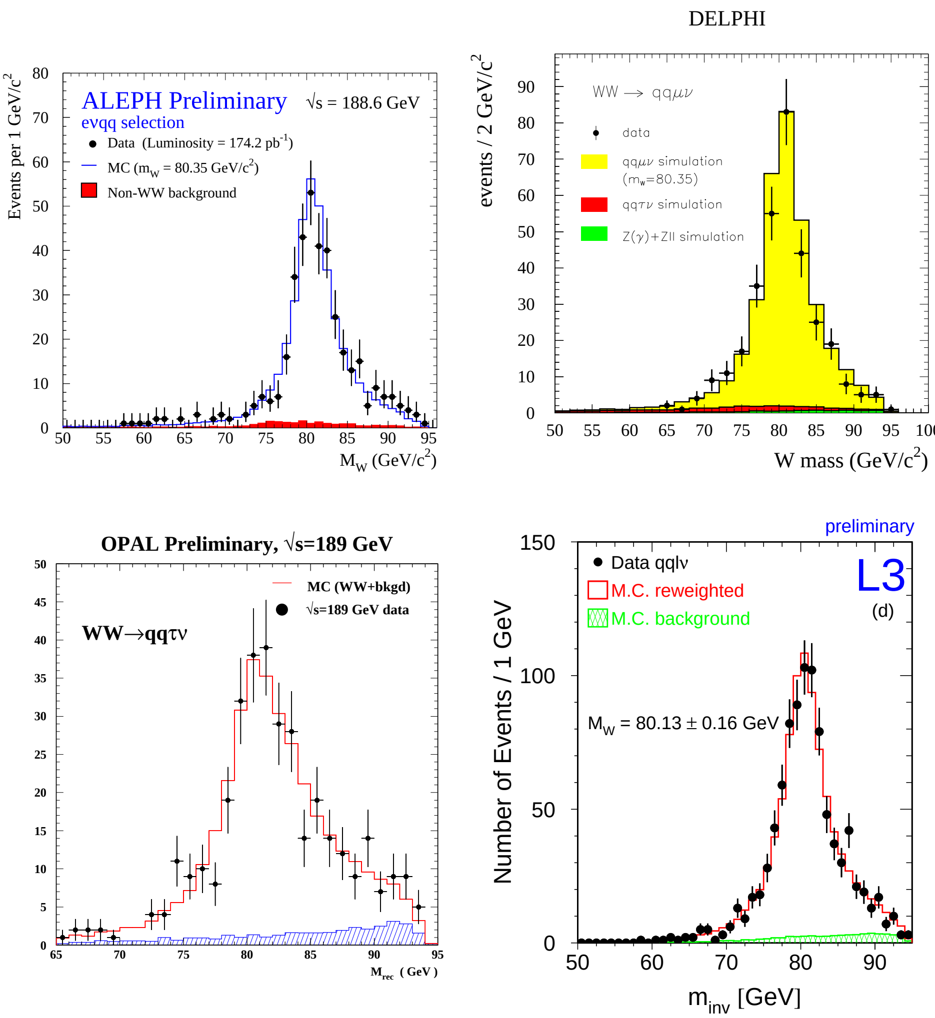

Figure 1: Semileptonic invariant mass spectra from a 2C(1C) constrained fit obtained at 189 GeV. Data (dots) are compared with simulation expectations.

kinematics because it completely neglects the width of the bosons. Furthermore, ISR effects are ignored resulting in a shift of invariant masses. These effects are accounted for in the calibration of the analyses.

2.2 Reweighting techniques

Both the direct extraction of m_W from the mass spectra and the calibration of the fitting method are based on the so-called reweighting technique. This is used whenever different Montecarlo reference distributions are needed at several values of a generator parameter Ψ. It is implemented by generating a high statistics, fully simulated sample at a certain value Ψ_0 and then reweighting each event p_j^μ of the distribution according to the ratio of the squared four-fermion matrix elements w_j:

$$w_j = |\mathcal{M}_{4f}(p_j^\mu;\Psi)|^2/|\mathcal{M}_{4f}(p_j^\mu;\Psi_0)|^2$$

In this way it is possible to obtain several W mass Montecarlo distributions which can be used for fit purposes. The limitation of the method is that the equivalent statistics of the new sample becomes smaller going away from the reference value Ψ_0, the loss of statistical power being controlled by the dependence of $\mathcal{M}_{4f}$ on Ψ.

2.3 W mass and width determination

The method generally used to determine m_W from the semileptonic mass spectra is a binned likelihood fit. The approach followed by ALEPH, L3 and OPAL is to perform a fit to the data of reweighted Montecarlo distributions: the advantage of doing this is that ISR, detector and constrained fitting effects are automatically taken into account in the fit. DELPHI performs instead an analytical likelihood fit to take into account event-by-event errors and calibrates the method a posteriori making use of Montecarlo samples reweighted at different values of m_W. The preliminary results that combine all the direct measurements up to 189 GeV are:

A	$(80.343 \pm 0.089_{\text{stat}} \pm 0.041_{\text{syst}})$ GeV/c^2
D	$(80.239 \pm 0.129_{\text{stat}} \pm 0.056_{\text{syst}})$ GeV/c^2
L	$(80.224 \pm 0.117_{\text{stat}} \pm 0.068_{\text{syst}})$ GeV/c^2
O	$(80.361 \pm 0.091_{\text{stat}} \pm 0.053_{\text{syst}})$ GeV/c^2

The ALEPH measurement includes the result from the fully leptonic channel as well.
In the likelihood fits both m_W and Γ_W can be left independent and the correlation coefficient is measured to be about 10%. The most recent measurements of Γ_W are:

D	$(2.89 \pm 0.76 \pm 0.07)$ GeV	$q\bar{q}l\nu$	183 GeV
	$(2.48 \pm 0.40 \pm 0.10)$ GeV	all	183 GeV
L	$(2.14 \pm 0.34 \pm 0.20)$ GeV	$q\bar{q}l\nu$	189 GeV
	$(2.16 \pm 0.21 \pm 0.19)$ GeV	all	189 GeV
O	$(1.84 \pm 0.32 \pm 0.20)$ GeV	all	183 GeV

where the first error is statistical and the second one systematic.

3 W mass from fully leptonic channels

The SM branching ratio for both Ws to decay leptonically is .104. A fully leptonic event is characterised by low multiplicity with two acollinear and acoplanar leptons; the selection efficiency is 70% with a purity of about 90%. $l\nu l\nu$ events contain no direct information on invariant masses, but the dependence of the lepton energy on the W mass can still be exploited to determine m_W. ALEPH's pioneer approach consists of a fit to the data of reweighted Montecarlo distributions of the maximum and minimum lepton energy in the event and the missing momentum. The results obtained from the fit are then combined taking into account the correlation between these variables, estimated by the simulation. The preliminary result by ALEPH, using the data at $\sqrt{s} = 183$ GeV, is:

$$m_W = (80.291 \pm 0.526_{\text{stat}} \pm 0.090_{\text{syst}})\ \text{GeV/c}^2$$

4 Systematics

Many sources contribute to give a systematic effect on m_W and Γ_W, the most important ones being related with the jet systems and the detector calibrations. The errors are summarized in table 4.

source	$m_W(q\bar{q}l\nu)$	$m_W(l\nu l\nu)$	Γ_W
	correlated errors		
Fragmentation	30	-	50
I.S.R.	15	5	25
Det. calibration	25	90	100
LEP energy	17	10	12
Fitting methods	15	-	25
	uncorrelated errors		
MC statistics	15	50	80
Background	5	5	80
Lepton id.	-	10	-
Total	46	105	160

Table 2: Maximal systematic effects (in Mev) at 189 GeV. The errors are divided into correlated and uncorrelated between the channels.

Most of the present systematic errors are still dominated by the limited Montecarlo statistics. It is therefore possible to envisage their reduction in the long run and, at least for the (semi)-leptonic channels, to expect that they will not represent the dominant part of the error on m_W.

5 Combination of results

The combination of LEP2 preliminary results on the W mass in the (semi)-leptonic channels from direct measurements yields:

$$m_W = (80.310 \pm 0.051_{\text{stat}} \pm 0.032_{\text{syst}})\ \text{GeV/c}^2$$

The combination of this result with the hadronic one [1] and with the indirect measurements at threshold energy gives:

$$m_W = (80.339 \pm 0.055_{\text{exp}})\ \text{GeV/c}^2$$

where the error accounts for systematics and statistics. The combinations have been done taking into account systematics correlated between channels but not between experiments (detector calibration related), systematics correlated between channel and experiments (Fragmentation and ISR) as well as a correlation between years (LEP energy).

The preliminary average value of Γ_W is:

$$m_W = (2.13 \pm 0.19_{\text{exp}})\ \text{GeV/c}^2$$

where the error includes systematic and statistic uncertainties.

Figure 2 shows the impact of the present measurement of m_W and m_t on the predictions on the Higgs mass. The direct measurements from LEP2 and hadron colliders are superimposed to the indirect fit curve. The agreement confirms the validity of the SM and contributes to set a stringent limit on the possible m_H values.

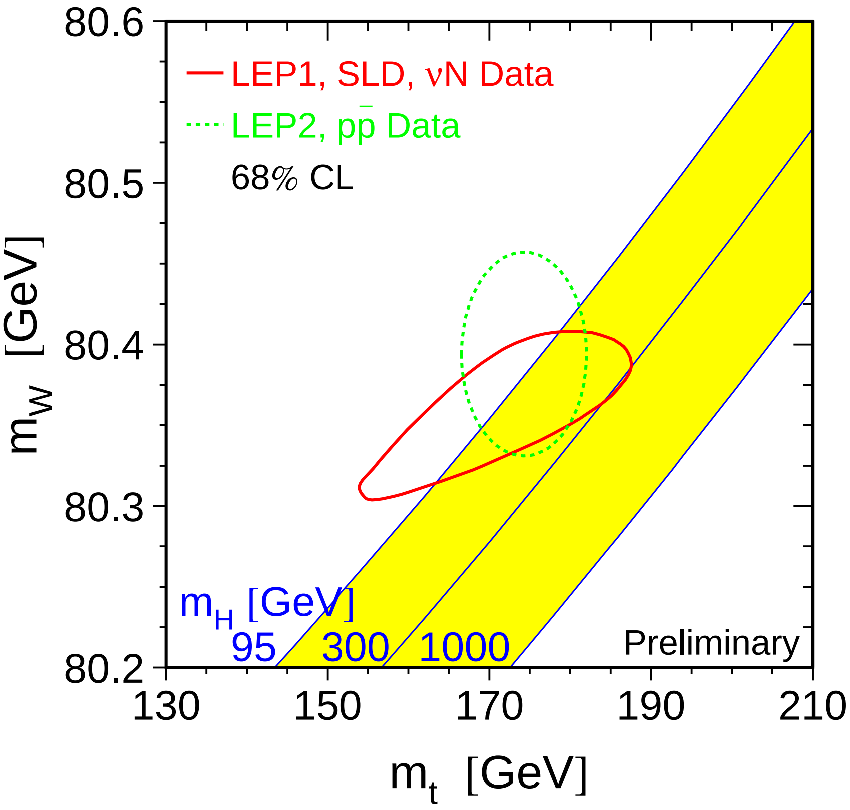

Figure 2: Predictions on the Higgs mass from the combined W mass result.

6 Conclusions and outlook

Thanks to the excellent performance of LEP, W physics measurements have entered the high precision regime. The preliminary combination of LEP2 W mass measurements up to 189 GeV gives m_W = (80.339±0.055) GeV/c^2. This result is, at present, the most precise determination of the W mass and is in agreement with the indirect measurements.

With two more years of high luminosity runs the goal of reaching an error on the W mass of 30 MeV is realistic. This is an important result which goes beyond the expectations at the start of LEP2 [4]. Such precision will reduce by almost a factor two the present world error on m_W, strongly bounding the allowed values of the Higgs mass within the SM. Even in absence of a direct Higgs signal, LEP2 will therefore play a major role in constraining the Standard Model.

References

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[2] W. Carithers, Proceedings of HEP99

[3] P. Koehn, Proceedings of HEP99

[4] Physics at LEP2, **141**, Ed. G. Altarelli, T. Sjöstrand and F. Zwirner