W MASS MEASUREMENTS USING FULLY HADRONIC EVENTS AT LEP2

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Since 1996 each LEP experiment recorded data corresponding to an integrated luminosity around $460-500\,\mathrm{pb}^{-1}$ at centre-of-mass energies between 161 GeV and 202 GeV. The experimental methods to measure the mass of the W boson in the fully hadronic channel are discussed and the preliminary combined value of the four LEP experiments is presented: $\mathrm{M_W(qqqq)} = 80.432 \pm 0.073$ GeV. The LEP combined result for the mass of the W boson, obtained from all channels and all data recorded at centre-of-mass energies above the W-pair threshold, is $\mathrm{M_W} = 80.427 \pm 0.046$ GeV. The width of the W boson is measured to be $\Gamma_\mathrm{W} = 2.12 \pm 0.11$ GeV.

1 Introduction

The study of the properties of the W boson is one of the main physics goals of the LEP2 program. The mass of the W boson is indirectly measured exploiting its relation with the Z boson mass and couplings within the Standard Model, precisely measured at LEP1 and SLC. The direct measurement of the W boson mass by the LEP and TEVATRON[1] experiments and the comparison with its indirect determination from fits to electroweak data is therefore an important consistency check of the Standard Model.

The mass of the W boson was first directly measured at LEP at the energy threshold for W-pair production[2], exploiting the sensitivity of the $\mathrm{W^+W^-}$ cross-section on $\mathrm{M_W}$ at this centre-of-mass energy of 161 GeV. At higher energies from 172 GeV up to 202 GeV, $\mathrm{M_W}$ is measured by direct reconstruction of the W decay products. In 46% of the time, both W bosons decay hadronically. The experimental methods of the direct reconstruction of $\mathrm{M_W}$ in the fully hadronic channel, $\mathrm{W^+W^-} \to \mathrm{qqqq}$, are discussed in this paper. The analysis exploiting the semileptonic and fully leptonic channel are presented elsewhere[4]. The combination of the preliminary results for the fully hadronic channel is presented, including data collected in 1999 at centre-of-mass energies between 192 GeV and 202 GeV [3]. Combining all data and mass information from all decay channels, preliminary results for the mass, $\mathrm{M_W}$, and width, Γ_W, of the W boson are reported.

2 Experimental methods

2.1 Event Selection

Fully hadronic $\mathrm{W^+W^-} \to \mathrm{qqqq}$ decays are selected as high multiplicity hadronic events with no missing energy. In order to separate the signal from the dominating QCD background, $\mathrm{e^+e^-} \to \mathrm{Z}/\gamma \to 4\,\mathrm{jets}$, the LEP experiments apply multivariate analyses. The signal efficiencies ranges between 83% and 89%, and comparing with the remaining background, the signal is selected with purities up to 85%. Details of the selection are described elsewhere in these proceedings[5].

2.2 Invariant masses and kinematic fits

Using jet cluster algorithms, the selected events are forced into four jets. The raw invariant masses of the W bosons, calculated from the observed decay products, are improved imposing kinematic constraints as energy and momentum conservation, $\sum(\mathrm{E},\vec{p}) = (\sqrt{s}, 0)$ (4C), and the requirement of equal masses of pairs of jets (1C). Since the jet angles are experimentally better determined than their energies, the kinematic fit mainly improves the en-

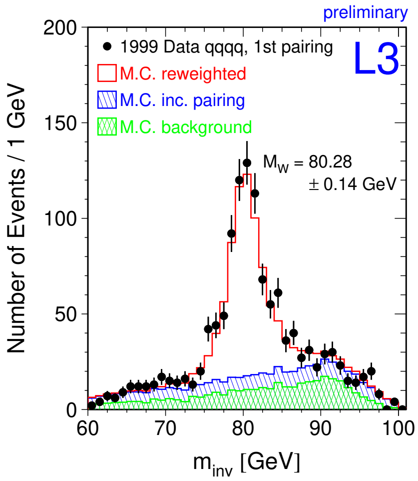

Figure 1. Reconstructed invariant mass distribution of the first pairing of selected fully hadronic W^+W^- events after applying a 5C kinematic fit.

ergy resolution. The L3 and OPAL collaborations apply a 5C fit yielding an average mass $\langle M \rangle$ for each event, whereas the ALEPH and DELPHI collaborations impose only the four energy and momentum constraints, taking into account afterwards both masses M_1 and M_2. The ALEPH collaboration rescales the masses with respect to the ratio of the LEP beam energy to the sum of measured jet energies: $M'_i = M_i \cdot E_{\mathrm{beam}}/(E_1 + E_2)$.

2.3 Jet-Pairing

Forcing the hadronic event into four jets, three combinations of associating the jets to the two W bosons have to be taken into account. Only the correct pairing contains information on the mass of the W boson, whereas the other two incorrect pairings result in a combinatorial background. The L3 and OPAL collaborations arrange the jet pairings in descending order with respect to the 5C fit probabilities, $P_1 > P_2 > P_3$. Since the second highest probability fit still contains significant mass information, the first and second pairing satisfying cuts on P_1 and P_2 are used to determine the W boson mass. Figure 1 shows the mass information contained in the first pairing of $W^+W^- \to qqqq$ events obtained by L3 after applying a 5C kinematic fit. The ALEPH collaboration applies a dedicated algorithm to decide on the best pairing: Ordering the jet pairings with respect to the corresponding matrix element $|\mathcal{M}|^2$ for W^+W^- production, the first or second pairing satisfying cuts as regards a window around the W boson mass and the sum of di-jet angles is chosen. The OPAL and DELPHI collaborations also include 5-jet configurations if they are more likely than the 4-jet hypothesis. OPAL selects the preferred permutation among ten possible pairing combinations, whereas the DELPHI analysis to determine M_W takes into account all possible jet pairings. In general, the correct combination is assigned in typically up to 90% of cases by the different approaches.

2.4 Methods to determine M_W

Various methods are applied and cross-checked by the LEP experiments to determine M_W. The ALEPH, L3 and OPAL collaborations apply likelihood fits comparing the measured and expected mass spectra. The Monte Carlo events are reweighted calculating the ratio of the matrix elements for various values of M_W with respect to the generated mass: $\omega_i = |\mathcal{M}_i(M_W^{\mathrm{fit}})|^2/|\mathcal{M}_i(M_W^{\mathrm{gen}})|^2$. Biases in the reconstructed mass spectra, e.g. due to detector resolution and event selection, are included in the Monte Carlo distributions. ALEPH determines the mass from a 2-dimensional fit to the two rescaled masses from the 4C kinematic fit, whereas L3 and OPAL perform a 1-dimensional fit of the average mass distribution from the 5C fit. Additionally, OPAL fits an asymmetric Breit-Wigner-Function to the average mass spectrum to determine M_W. This method needs to be calibrated using several Monte Carlo samples and ,unlike in the reweighting method, the fitted mass has to be corrected for biases. DELPHI uses a convolution method to determine the mass, taking into account all possible pairings of the 4-jet and 5-jet configurations. The fitted masses M_1 and M_2 and their uncertainties are interpreted as 2-dimensional probability density functions. They are convoluted with a 2-dimensional Breit-Wigner-Function $BW(M_1, M_2, M_W)$, yielding an event likelihood $\mathcal{L}(M_W)$. Experimental biases and effects due to initial state radiation have to be corrected afterwards. A comparable approach is also applied by the OPAL collaboration.

3 Results

The preliminary results for the W boson mass using the fully hadronic channel (Fig. 2) include all data used for direct reconstruction ($\sqrt{s}$ = 172 GeV – 202 GeV). While the statistical uncertainties of the individual experiments are comparable, the systematic uncertainties show large differences, reflected by the differences of the total errors given in Figure 2. For final state interactions (FSI) such as Bose-Einstein Correlations[6] and Colour Reconnection[7], which affect only the fully hadronic W^+W^- decay channel, the experiments quote different estimates for their effect on the measured value M_W. Common tests using Monte Carlo events with and without Colour Reconnection yield that all experiments show equal sensitivity to this FSI. Assuming also an equal sensitivity to Bose-Einstein Correlations, a common uncertainty for both FSI is used in the combination of the four LEP results. A typical breakdown of the contributions to the systematic uncertainty of M_W using only fully hadronic events is given in table 1. The LEP combination is a simultaneous fit to all individual results from the experiments for each channel and year, accounting for a correct treatment of correlated errors. As an experimental test of a possible mass shift due to FSI, the difference between the values for M_W from the hadronic and semileptonic decay channels, $\Delta M_W = M_W(qqqq) - M_W(qq\ell\nu)$, is determined. Setting the systematic uncertainty due to FSI to zero, the LEP combined value is found to be $\Delta M_W = 5 \pm 51$ MeV. Thus no experimental indication of a mass shift due to Colour Reconnection and Bose-Einstein Correlations is found. Some of the systematic uncertainties like the LEP beam energy uncertainty, the

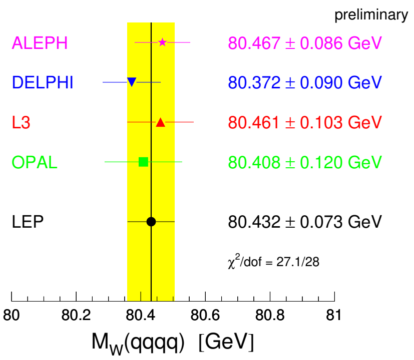

Figure 2. Preliminary results for M_W from direct mass reconstruction using fully hadronic events.

QED radiation effects (ISR/FSR) and particularly the mass shift evaluated using different hadronization models are correlated between the fully hadronic and semileptonic final state. Consequently, they contribute significantly to the total systematic uncertainty of the combined mass value from all channels. Combining all measurements of M_W from the direct reconstruction using all W^+W^- decay channels with the threshold measurement at 161 GeV yields the preliminary LEP result $M_W = 80.427 \pm 0.046$ GeV. Figure 3 compares the results from the individual LEP experiments and their combined value, respecting correlations between the different channels and experiments. The large uncertainty due to FSI reduces the weight of the fully hadronic channel to 27% when combined with the semileptonic and fully leptonic channel. It should be noted that if there were no systematic uncertainties, the statistical precision of the measurement would be

Table 1. Typical breakdown of the contributions to the systematic uncertainty on M_W using only fully hadronic events.

Source	ΔM_W[MeV]
ISR/FSR	10
Hadronization	23
Detector systematics	7
LEP beam energy	17
Colour Reconnection	50
Bose-Einstein Correlations	25
Other	5
Total Systematic	64
Statistical	34

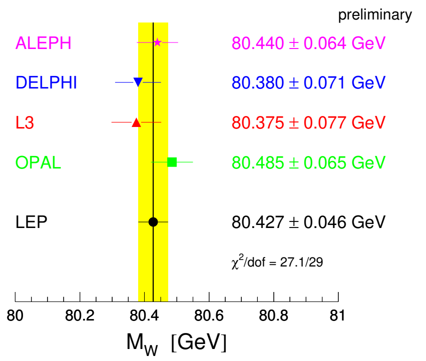

Figure 3. Preliminary results for M_W, combining all W^+W^- decay channels and the measurements using direct reconstruction as well as the threshold measurement at $\sqrt{s} = 161$ GeV.

25 MeV, to be compared to the actual value of 30 MeV. The systematic uncertainty of the combined M_W value is dominated by the uncertainty describing the hadronization, correlated between the fully hadronic and semileptonic final state. The method of direct reconstruction is also used to determine the width of the W boson, Γ_W. The LEP combination is based on a similar procedure as described for the mass value. Taking into account the correlated systematic uncertainties, a value of $\Gamma_W = 2.12 \pm 0.11$ GeV is obtained. This result is in good agreement with the direct determination of the W boson width $\Gamma_W = 2.05 \pm 0.13$ GeV performed by the CDF collaboration[8].

4 Conclusions

Preliminary measurements for the mass and width of the W boson, including data recorded by the LEP experiments in 1999, are reported. Using the direct reconstruction method in the fully hadronic channel, the mass is found to be $M_W(qqqq) = 80.432 \pm 0.073$ GeV. No experimental indication of a mass shift due to FSI is found comparing with the result for M_W from the semileptonic channel only. The LEP combined measurement of the mass and width of the W boson are $M_W = 80.427 \pm 0.046$ GeV and $\Gamma_W = 2.12 \pm 0.11$ GeV. An additional luminosity of 200 pb^{-1} per experiment is expected for the year 2000 run. Thus the uncertainty on the W boson mass could be reduced to $\Delta M_W = 30 - 40$ MeV.

Acknowledgements

It is a pleasure to thank all collaborators of the LEP electroweak and W working group who provided much of the information presented here as well as Arno Straessner and Martin Grünewald for valuable discussions. This work has been supported by the German Bundesministerium für Bildung und Forschung.

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