W MASS MEASUREMENTS USING SEMILEPTONIC AND FULLY LEPTONIC EVENTS AT LEPII

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All 4 LEP experiments have preliminary results for the W-mass which include the 1999 data [1,2,3]. The preliminary combined result from semileptonic and fully leptonic events is $\mathrm{M_W} = 80.427 \pm 0.051$ GeV. Combining this results with the measurement from fully hadronic events and the threshold measurement at $\sqrt{\mathrm{s}} = 161$ GeV one obtains a preliminary result of $\mathrm{M_W} = 80.427 \pm 0.046$ GeV.

1 Introduction

At the end of the 1999 data taking period each LEP experiment had collected more then 7000 W-pairs at center-of-mass energies from 161 to 202 GeV. (The integrated luminosity per experiment above the W-pair threshold was in the range of 460 - 500 pb^{-1}). 44 % of the W pairs decay semileptonically and 10 % decay fully leptonically. Both channels are free from the problems which arises from the fact that both W's decay into hadrons in the fully hadronic channel. Therefore there are no systematic uncertainties due to final state interactions between the decay products of the two W. There are also no problems to associate which jets and which particles originate from which W except for the hadronic τ decays when the τ decays close to one of the jets from the hadronic W decay.

2 M_W from semileptonic W decays

2.1 Event selection

The event selection is based on the event topology of two jets and one lepton. In the case of electrons and muons the lepton is identified by a loose lepton identification and isolation cuts. Taus are identified as isolated low multiplicity jets. The selections have both a high purity and a high efficiency. The cross contamination from e and μ in $q\bar{q}\tau\nu$ events does not pose a problem since in this channel the mass information is extracted from the hadronic system which is not influenced by the misidentification of an e or μ as a τ (see also figure 3). On the contrary, it is better to use $q\bar{q}e\nu$ and $q\bar{q}\mu\nu$ which fail the lepton identification as $q\bar{q}\tau\nu$ events than not to use them at all.

2.2 Kinematic fit

For each event the momentum of the partons can be determined from the measured jet and lepton momenta and their errors in a kinematic fit. The 4 constraints from energy and momentum conservation are always used in these fits. A possible 5th constraint is the assumption that both W bosons have the same mass which is equivalent to the assumption that the energies of the $q\bar{q}$ and of the $l\nu$ pair are equal to the beam energy (beam energy constraint). Due to the finite width of the W-mass this constraint does not exactly reflect the momentum of partons; however if one is interested in the average W-mass in an event it improves the resolution.

For the electron and muon channel there are 3 unknowns (the neutrino momentum). This allows both, a fit with two constraints using the beam constraint, from which on gets one mass M^{BC} and it's error σ^{BC}, and a fit with one remaining constraint, which gives both the mass and error of the hadronically decaying W ($M^{q\bar{q}}$, $\sigma^{q\bar{q}}$) and of the leptoni-

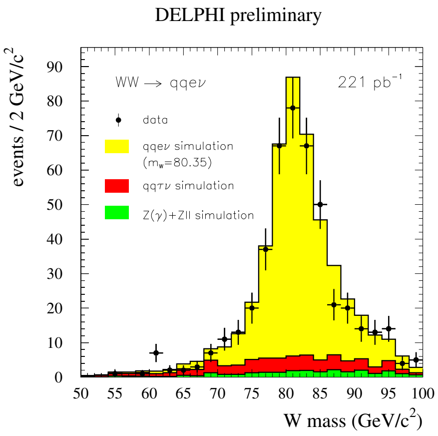

Figure 1. M^{BC} from $q\bar{q}e\nu$ events

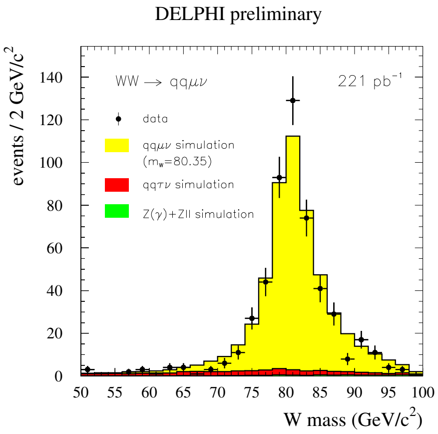

Figure 2. M^{BC} from $q\bar{q}\mu\nu$ events

cally decaying W ($M^{l\nu}$, $\sigma^{l\nu}$).

In the tau channel only the τ direction can be determined. Due to the neutrino(s), in the τ decays the energy of the τ cannot be determined. Because of this extra unknown one can only determine the mass and its error of the hadronic decaying W using the beam constraint (M^{BC},σ^{BC}). Figures 1 to 3 show as an example M^{BC} the mass from the beam constraint fits for electrons, muons and taus from DELPHI. One can see that in the $q\bar{q}\tau\nu$ channel the contamination from $q\bar{q}e\nu$ and $q\bar{q}\mu\nu$ events has the same shape (mass information) as the signal.

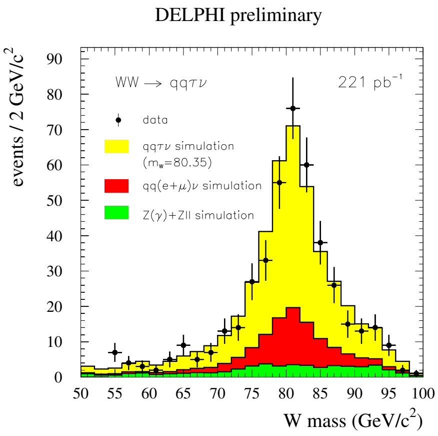

Figure 3. M^{BC} from $q\bar{q}\tau\nu$ events

2.3 Mass extraction

There are different approaches to extract the value of $\mathrm{M_W}$ from the event masses and errors. One approach is to compare the distribution in data with that predicted from Monte Carlo for different values of $\mathrm{M_W}$ and Γ_W. Since it is not feasible to produce Monte Carlo events for every considered value of $\mathrm{M_W}$ a reweighting technique is used to produce the Monte Carlo predictions for arbitrary values of $\mathrm{M_W}$ and Γ_W. Each event (with W boson masses M_W^1 and M_W^2) is weighted with the ratio of the probabilty that such a mass combination of M_W^1 and M_W^2 is produced for the desired values of $\mathrm{M_W}$ and Γ_W by the probability that M_W^1 and M_W^2 are produced for the values of $\mathrm{M_W}$ and Γ_W used to generate the original Monte Carlo sample. The W-mass is then determined by finding the value of $\mathrm{M_W}$ for which the Monte Carlo and Data distributions agree best. The value of Γ_W is fixed by the standard model prediction as a function of $\mathrm{M_W}$. ALEPH used for electrons and muons a 3-dimensional distribution in M^{BC}, σ^{BC} and $M^{q\bar{q}}$. For taus they used a 2-dimensional distribution in M^{BC}, σ^{BC}. L3 and OPAL used 1-dimensional distributions in M^{BC}. In OPAL the analysis was done separately in 4 bins of σ^{BC}.

A 1-dimensional convolution fit was used by DELPHI and OPAL to extract the W-mass. For each event, M^{BC} and σ^{BC} can be used to estimate the likelihood as a function of $\mathrm{M_W}$, that such an event is produced, by the convolution of a physics function (e.g. a Breit Wigner function with $\mathrm{M_W}$ and Γ_W) and a resolution function (e.g. a gaussian with width σ^{BC}). The W-mass is then determined by maximizing the overall likelihood, the product of the event likelihoods. The main effect from initial state radiation can be included in the proper definition of the physics function. But potential biases due to details of the fragmentation, detector resolution, backgrounds and event selection can only be taken into account by a calibration curve which is obtained by performing the full analysis with Monte Carlo samples produced at different values of $\mathrm{M_W}$.

2.4 Systematic uncertainties

As we have seen in Sec. 2.3 the mass extraction relies on the comparison of data with Monte Carlo prediction, either direct as in the case of the reweighting approach or indirect via the calibration curve in the convolution fit. Thus the primary systematic uncertainties are due to the uncertainties in the Monte Carlo simulation.

- Detector simulation: Each year also data at the Z^0 resonance are taken. This is used to measure the energy scale and the energy and angular resolution for jets and leptons.
- Hadronisation: The systematic error is determined from the comparison of different Monte Carlo generators (PYTHIA, HERWIG, ARIADNE) and different Monte Carlo tunes. This is cross-checked by analyzing Z^0 calibration data emulating a W in $\mathrm{W^+W^-}$ after a suitable Lorentz boost (DELPHI) and by propagating the difference between data and Monte Carlo in fragmentation related observables as weights through the mass analysis and thus estimating the effect of the difference in $\mathrm{M_W}$ (ALEPH).
- Beam Energy: Detailed studies of the uncertainty in the beam energy are made by the LEP energy working group.
- Initial and final state radiation: The difference between the ISR treatment in KORALW and EXCALIBUR or between different orders in KORALW are used to estimate the ISR uncertainties.
  The full $\mathcal{O}(\alpha)$ effects are not included yet. Calculations using double-pole approximations indicate possible mass shifts of about 10 MeV, but full simulations were not available at the time of the analysis.

Table 1. Typical values for systematic errors

Source	Error
Detector Systematic	11 MeV
Hadronisation	26 MeV
LEP Beam Energy	17 MeV
ISR/FSR	8 MeV
Other	5 MeV
Total Systematic	35 MeV
Statistical	38 MeV
Total	51 MeV

Table 1 shows typical errors for the systematic errors discussed above. In the combination of the 4 LEP experiments the correlation between the different experiments and the different center-of-mass energies have been properly taken into account.

3 Fully leptonic W deacys

In 10 % of all W pairs both W's decay leptonically. Because of the two undetected neutrinos in these events, one has 6 unknowns and only 5 possible constraints. Thus one cannot reconstruct the event completely in a kinematic fit. Instead one can look at quantities which are sensitive to the W-mass. One such quantity is the lepton energy. It's spectrum is given by:

$$E_\ell = \frac{\sqrt{s}}{4} + \cos\theta_\ell^* \sqrt{\frac{s}{16} - \frac{M_W^2}{4}}$$

Where θ_ℓ^* is the angle between the W and its decay products in the W restframe and s is the center-of-mass energy. Another quantity can be calculated when one reconstructs the event under the assumption that the neutrinos are in the same plane as the charged leptons. If the assumption is nearly true, one reconstructs the right mass, otherwise one gets a larger mass. This procedure yields a distribution (called pseudo-mass) with an edge which depends on $\mathrm{M_W}$. The following results were obtained:

ALEPH (E_ℓ, 189 GeV data):

$\mathrm{M_W^{l\nu l\nu}} = 81.81 \pm 0.67(\mathrm{stat.}) \pm 0.20(\mathrm{syst.})$ GeV.

OPAL preliminary

(E_ℓ, pseudo-mass, 183-202 GeV):

$\mathrm{M_W^{l\nu l\nu}} = 80.27\ ^{+0.51}_{-1.62}(\mathrm{stat.})\ \pm 0.14(\mathrm{syst.})$ GeV.

The curvature of the Likelihood curve at $\mathrm{M_W} = 80.5$ GeV corresponds to a parabolic error of ~ 0.5 GeV.

4 Results

Figure 4 shows the results of the four LEP experiments in the semileptonic channel. Figure 5 compares the direct and indirect measurements of M_W. The LEP2 result is the combination of all decay modes and of the threshold measurement at 161 GeV.

5 Conclusions

The direct measurements of $\mathrm{M_W}$ have reached the same precision as the indirect prediction from electroweak fits. The measurement starts to be dominated by systematic uncertainties. We still expect an improvement of the LEP2 $\mathrm{M_W}$ measurement with this year's (2000) data and with refined analysis.

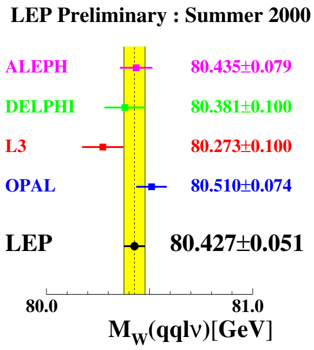

Figure 4. Preliminary results from semileptonic W^+W^- decays, for ALEPH and OPAL the fully leptonic channel is included.

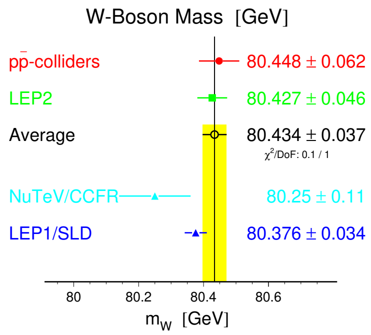

Figure 5. Comparison of different $\mathrm{M_W}$ determinations.

Acknowledgments

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