Measurement of the W boson mass at LEP

J. D'Hondt

Vrije Universiteit Brussel (VUB)
Inter-University Institute for High Energies (IIHE)
Pleinlaan 2, B-1040 Brussels, Belgium
e-mail : jdhondt@hep.iihe.ac.be

Abstract

The mass of the W boson has been measured by all LEP experiment by the method of direct reconstruction in the WW decay channels where at least one W boson decays hadronically. This precision measurement is influenced by many systematic uncertainties which were extensively studied. One example is the possible effect of Colour Reconnection between the decay products from different W bosons in fully hadronic WW final states. These proceedings overview the preliminary results concerning the W mass measurement and the ongoing measurements of the Colour Reconnection effect.

Proceedings of a talk given at the Lake Louise Winter Institute (2003)

1 Achievements of LEP towards WW events

The LEP accelerator provided between 1996 and 2000 e^+e^- collisions above the threshold for W^+W^- production, in the centre-of-mass energy range between threshold $\sqrt{s} \simeq 161$ GeV and $\sqrt{s} \simeq 208$ GeV. These events have a branching ratio of about 45% to decay into a fully hadronic final state ($q\bar{q}'\bar{Q}Q'$) and about 45% to decay semi-leptonically ($q\bar{q}'l\bar{l}_1$). The $q\bar{q}'\bar{Q}Q'$ events could be selected with an efficiency of about 90% and a purity of about 70-80% depending on the experiment. For the $q\bar{q}'l\bar{l}_1$ channel these numbers are similar depending on the lepton flavour. In total about 40000 W^+W^- events were selected from the full LEP2 data.

2 Applied analysis methods

The clear environment within LEP collisions allows a full kinematic reconstruction of the invariant mass on an event-by-event basis. The W mass from both W bosons can be determined directly from the measured kinematics of the observed final state particles usually clustered in jets. A fit algorithm aims to improve the energy resolution of these jets by forcing energy and momentum conservation between the well known initial state and the poorly measured final state.

In the fully hadronic channel the main challenges are to select the correct jet pairing into two W bosons and the treatment of the hard gluon radiation in the perturbative parton shower of the event. The semi-leptonic channel suffers from a decreased W mass resolution due to the neutrino, there the energy resolution is the limiting factor.

Two different methods are applied to extract the W mass from the selected data sample. The most widely used is the technique based on Monte Carlo reweighting, where one reweights observable distributions to different W mass values which can each be fitted to the data distributions. Another method involves a convolution technique of the theoretical predicted Breit-Wigner function with the experimental response function to obtain an event-by-event likelihood. The W width extraction methods are similar to those used for the W mass.

3 Systematic uncertainties

The most significant systematic uncertainties are those which are correlated between the experiments : the knowledge of the LEP beam energy, the fragmentation process and the implementation of the electroweak radiative corrections. In the spirit of common LEP Workshops the influence of the fragmentation process has been thoroughly investigated. Not only the difference in W mass between different fragmentation models, JETSET, ARIADNE and HERWIG, was studied, but also possible effects arising from cross-talk phenomena like Colour Reconnection and Bose-Einstein Correlations between decay products of different W bosons.

Table 1 summarizes all systematic uncertainties. Detector systematics include uncertainties in the jet and lepton energy scales and resolution. The 'Other' category refers to uncertainties, all of which are uncorrelated between experiments, arising from simulation statistics, background estimation, four-fermion treatment, fitting method and event selection. The current uncertainty assigned due to Bose-Einstein Correlations of 35 MeV/c²

Table 1: Uncertainty decomposition for the combined LEP W mass results.

Source	Systematic Uncertainty on m_W (MeV/c ²)		
	q $\bar{q}$ 'l $\bar{l}$ '	q $\bar{q}$ ' $\bar{Q}Q'$	Combined
ISR/FSR	8	8	8
Hadronisation	19	18	18
Detector Systematics	12	8	11
LEP Beam Energy	17	17	17
Colour Reconnection	-	90	9
Bose-Einstein Correlations	-	35	3
Other	4	5	4
Total Systematic	29	101	30
Statistical	33	36	30
Total	44	107	42
Statistical in absence of Systematics	32	29	22

is considered as a conservative estimate. Studies of this effect within W^+W^- events [2] prefer smaller shifts on the W mass.

4 Measurement of Colour Reconnection

The dominating systematic uncertainty in the fully hadronic channel arises from the possible effect of Colour Reconnection. Several phenomenological models do exist to emulate the effect in W^+W^- events.

According to the Lund string model it is assumed that Colour Reconnection happens in the non-perturbative phase-space and acts on low momentum particles and on particles in the angular region between the jets. It is shown that the effect on the W mass could be reduced by neglecting the information content of the event in these regions [1].

The effect has also been estimated by measuring the average particle flow ratio R_N between the regions between jets from the same W boson and jets from different W bosons. A small amount of Colour Reconnection is preferred of 50 % according to the SK1 model [2], see Figure 2, and corresponding with a 68 % CL for the model parameter κ of [0.39,2.13]. The maximum effect observed at the 1σ level was used to estimate the systematic uncertainty on the W mass. The centre-of-mass energy dependence of the effect was taken into account, see Figure 1. The four experiments have observed a weak sensitivity to the ARIADNE and HERWIG models of Colour Reconnection with the particle flow analysis, as indicated in Figure 2. These fragmentation models without their implementation of Colour Reconnection differ from the measured data value of r by respectively 3.1 and 3.7 standard deviations.

An alternative method to measure the Colour Reconnection effect in W^+W^- events was proposed and performed in [3]. The method infers information about the models which is to a good approximation uncorrelated with that obtained with the particle flow ratio observable. Therefore all LEP experiments are strongly advised to perform a similar

Figure 1: Preliminary particle flow results $r = R_N^{data}/R_{Nno} - CR$ using all data, combined to test the limiting case of the SK1 model in which all events are colour reconnected, the ARIADNE model and the HERWIG model. The predicted values of the particle flow ratio, $r = R_N^{CR}/R_{Nno} - CR$, are indicated separately for the analysis of each experiment by the dashed lines.

analysis, in order that results can be combined. Only when the combined information will become available one will be able to reduce the effect on the W mass.

5 Preliminary results

The results from the individual LEP experiments are in good agreement as can be observed in Figure 3 and yield a combined value of :

$$m_W = 80.412 \pm 0.029(stat) \pm 0.031(syst) \text{ GeV}/c^2$$

with a probability for being self-consistent of 70 %. In this combination the weight of the fully hadronic channel is only about 10 %, while those events contain in principle the larger amount of information on the W mass. This is due to the large possible effect of Colour Reconnection. The largest part of the systematic uncertainty in the combined W mass value comes from hadronisation uncertainties which are conservatively treated as correlated between the two channels, between experiments and between years. In the absence of systematic uncertainties the precision on the W mass would be 21 MeV/c². In addition to this result the difference between the W mass estimated with the $q\bar{q}'\bar{Q}Q'$ and $q\bar{q}'l\bar{\nu}_l$ events was estimated as a cross-check:

$$\Delta m_W(q\bar{q}'\bar{Q}Q' - q\bar{q}'l\bar{\nu}_l) = +22 \pm 43 \text{ MeV}/c^2.$$

A significant non-zero value for this measurement could indicate that the Colour Reconnection and/or Bose-Einstein Correlation effects are biasing the value of m_W determined in the fully hadronic channel. When estimating the uncertainty on $\Delta m_W(q\bar{q}'\bar{Q}Q' - q\bar{q}'l\bar{\nu}_l)$ the uncertainties arising from Colour Reconnection and Bose-Einstein Correlations are set to zero. For the W width a value of :

$$\Gamma_W = 2.150 \pm 0.068(stat) \pm 0.060(syst) \text{ GeV}/c^2$$

was found, with a probability of 71 % to be self-consistent.

Figure 2: The energy dependent value of the W mass uncertainty due to SK1 ($\kappa=2.13$) Colour Reconnection as used in the LEP combination.

In Figure 4 the combined LEP results are compared with results from the Tevatron Run I and from indirect measurement of the W boson characteristics. In general a good agreement was found, except with the recent measurement from the NuTeV experiment.

References

- [1] J. D'Hondt, *Possible reduction of the total uncertainty on the m_W measurement at LEP2*, Proceedings of the XXXVIIth Rencontres de Moriond 2002.
- [2] The LEP and SLD Collaborations, *A combination of preliminary electroweak Measurements and Constraints on the Standard Model*, CERN-EP 2002-091 and hep-ex/0212036.
- [3] J. D'Hondt and N.J. Kjaer, *Measurement of Colour Reconnection model parameters using m_W analyses*, paper submitted to the ICHEP Conference 2002 (Amsterdam).

Figure 3: Combined W boson mass and width measurements from LEP2 experiments.

Figure 4: Combined W boson mass and width measurements from different measurements. On the top part of the plot the direct measurements are combined, while in the bottom part they are compared with the indirect measurements.