THE W MASS MEASUREMENT AT LEP

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The LEP2 program has allowed for high precision measurements of the W-boson mass. Last update of the LEP combined measurement was given at the winter-conferences of 2003. The progress of the measurement during the last year and prospects for the final update are presented.

1 Introduction

Measurements performed at LEP1 have provided accurate knowledge of the parameters of the Z boson, which turned out to be in perfect agreement with the Standard Model (SM) predictions. Goal of the LEP2 program was to further challenge the theory by detailed studies of the other key parameter, the W boson. Precision measurements of the W properties, and in particular its mass, can provide stringent tests of the SM, information for the last -predicted but missing-particle, the Higgs boson and potentially signs of new physics.

Together the four LEP experiments have collected $\approx 40K$ WW events, allowing indeed high precision measurements of the W mass. The last LEP update of the measurement, presented in winter 2003 [1] was

$$Mw = 80.412 \pm 0.029(stat.) \pm 0.031(systematic)$$

This result is still preliminary; no experiment has finalised their analysis. For the past two years the collaborations have been concentrating on the better understanding and reduction of the systematic errors. Highlights of this work are presented here.

2 The WW Events

At LEP2, and at lowest order, W pairs are produced by two types of diagrams; the t-channel, neutrino exchange diagram and the s-type γ, Z annihilations. Subsequently, each W decays either hadronically ($q\bar{q}$) or leptonically ($l\nu, l = e, \mu, \tau$) yielding three distinct final states, the hadronic ($W^+, W^- \rightarrow q\bar{q}q\bar{q}$), semileptonic ($W^+, W^- \rightarrow q\bar{q}l\nu$) and fully-leptonic ($l\nu, l\nu$) events with production fractions 46%, 44% and 10% respectively.

Hadronic events are characterised by four jets and very little missing energy. The hadronic selection is the most demanding, as the main background process (($e^+e^- \rightarrow Z/\gamma \rightarrow q\bar{q}$) has the highest cross-section of $\approx$ 110pb. Multivariable selection procedures are hence employed yielding purities of $\approx$ 85% for $\approx$ 80% efficiency. The presence of two hadronic systems make possible final state interactions between particles originating from different W's. As the theoretical knowledge of such effects is currently incomplete measurements from the hadronic channel suffer from FSI systematic errors. On the other hand the analysis of those events, with almost no missing energy, can take full advantage of the knowledge of the centre-of-mass-energy of the interaction, minimizing systematic uncertainties from the absolute detector energy calibration.

The semileptonic events are selected by requiring one energetic and isolated lepton, two hadronic jets and missing energy and momentum. High purities are achieved, of the order of 90% while retaining high efficiencies $\approx$ 70%.

The fully leptonic events do not contribute significantly to the to the mass measurements due to the two missing neutrinos and the low statistics.

3 The W Mass Measurement

The measurement of M_w is based on the direct reconstruction of the invariant mass of the W decay particles. Hence the statistical power of the analysis depends mostly on the good energy and mommentum resolution of those reconstructed jets and leptons. In the hadronic channel also crucial is the correct association of jets to pairs of di-jets.

To improve the reconstructed energy and direction resolutions the analyses take advantage of the precise knoweledge of the total energy and mommentum of the interactions. These constrains, imposed via a kinematic fit not only improve greatly the resolutions but moreover, make the absolute energy calibration of the detectors less important, yielding small systematic uncertainties related to the detectors.

To extract M_w, the invariant mass distribution has to be related to the underlying W mass. This is not straightforward as the parent Breit-Wigner distribution is convoluted with many effects like initial state radiation, hadronisation and the detector responce/resolution. Hence the analyses rely heavily on Monte Carlo to simulate such effects and relate the reconstructed mass distributions to M_w. Consequetivelly, any discrepancies on the simulation of those effects can lead to systematic errors on the measurement.

4 Systematic Uncertainties

4.1 Theoretical Uncertainties

Theoretical uncertainties on initial state radiation coming from incomplete simulation of the $e^+e^- \rightarrow W^+W^+ + n\gamma$ process are small and yield $\approx$ 10MeV error on M_w. On the contrary, hadronisation effects, involving soft QCD, carry larger uncertainties In the absence of a theoretical description phenomenological models are employed to simulate this non-perturbative process. Different such models (e.g[2],[3]), are able to reproduce the global properties of e^+e^-events equally well, but predict different mass distributions and $\approx$ 20 MeV uncertainties on M_w.

During the last years a lot of effort has been invested for the better understanding of this error. The strategy consisted of tree main steps: First the identification of those fragmentation properties that mostly infuence the measurement (eg momentum spectrum, jet mass). For this, models with the same W mass but different fragmentation were exploited. Second step was the improvement of the simulation of exactly those most relevant properties, for example by better tunning of the model parameters. The goal of the final analysis is that the fragmentation error will be asseced based on any remaining discrepancies in the simulation of those fragmenetation properties.

QCD uncertainties special to the hadronic channel

Finite state interactions (FSI) can take place among particles originating from different W's and could biass the measurement from the hadronic channel. However, the difference between the individual measurements from the hadronic and semileptonic events, $\Delta Mw(q\bar{q}q\bar{q} - q\bar{q}l\bar{v}) = +22 \pm 43$, shows no evidence of large FSI effects.

Nevertheless two such effects are considered important, Color Reconection (CR) and Bose-Einstein (BE). Again, in the absence of a theoretical description phenomenological models are employed, and in general they predict significant effects for M_w.

The collaborations have concentrated in two areas. First dedicated analyses have been developed to search for FSI effects and/or constrain these models. Second, new, less sensitive to FSI effects, M_w analyses have been developed.

The most sensitive so far, dedicated analysis to look for CR is the *particle flow* analysis. This compares the particle density between two jets from the same W (inter-W region) to the particle density between two jets from different W (intra-W region). Preliminary LEP combined results[4,1] are able to exclude only extreme CR scenarios. Hence, currently the systematic error assigned to M_w is the maximum of the effects predicted by models that cant be excluded. This is 90 MeV (coming from the Jetset-SK1 model[5]) with a κ parameter of 2.13) and implies that the hadronic channel contributes very little to the M_w measurement. In fact, its weight in the global combination is only 0.10.

Alternative mass analysis are motivated by the fact that colour reconnection should primarily affect particles bettwen jets from different W's and also of low mommentum. Hence the jet clustering algorithms are modified to exclude particles either at large angles from the jet axis -in an iterative approach- (*cone* algorithm) or of low mommentum (*pcut* algorithm).With such algorithms the effects on CR on M_w are greatly reduced with the expence of some statistical power loss. As an example figure 1 shows the CR shift on M_w predicted by the Jetset-SK1 as a function of a CR strength parameter κ for different *cone* and *pcut* jet algorithms, measured by DELPHI[6]. Similar trends are observed for all available CR models, which inspires confidence that such analyses are less CR-sensitive independent of the exact model.

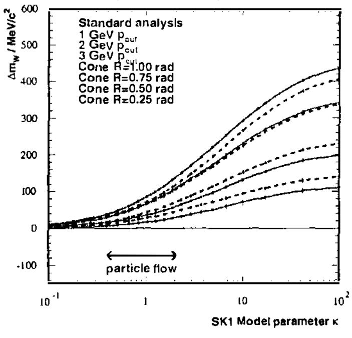

Figure 1: Delphi results for the CR error on M_w, for the SK1 model and as a function of the strength parameter κ for different type of jet algorithms. The region of κ favoured by the *particle flow* analusis is indicated.)

If all four experiments use for their final measurement such alternative jet algorithms th total error of the hadronic channel can be reduced from ≈ 110 MeV to ≈ 60 MeV and its weigh in the combination will increase to ≈ 0.30. Moreover, such alternative analyses can be used t further constrain CR models. Any difference of a M_w measurement with a standard analysi and, for example, a *cone* analysis is itself an indication of the precence of CR effects. Preliminar results indicate that such analysis can be as sensitive, or even more for some CR scenarios, tha the *particle flow* method.

Another type of final state interaction effect that could introduce biasses in the measuremen in the hadronic channel is Bose-Einstein (BE) correlations. The existence of such correlations i well established, however they could affect the M_w measurement only if affected pions fron jets from different W's. So far only one phenomenological model of such interactions has beer tested by the LEP experiments, LUBOEI[7] and it predicts a significant effect on M_w, of 35MeV. This is the current estimate of the BE error on M_w. However, preliminary results of the LEP combined measurement of BE disfavour effects between W's and hence this error is likely to b reduced.

4.2 Detector Simulation and LEP Energy

The final important systematic effects arise from the detector simulation uncertainties. Such effects are reduced signficantly due to the knoweledge of the center-of-mass energy and the corresponding kinematic constrain, especially for the tottaly-constrained hadronic channel. Nevertheless, the high precision required for the measuremt necessitated extensive studies of the detector simulation. LEPI Z data have been used for further fine tuning, calibrations and cross-checks.

On the oter hand, the LEP energy value used for the kinematic constrains has a measurement error which translates directly on a systematic effect on M_w of ≈ 17 MeV which is 100% correlated between all measurements (different channels, experiments).

5 Conclusions

The past year the four LEP collaborations have concentrated in the better understanding and reduction of the dominant systematic errors, especially for the the hadronic channel. Hence, the W mass measurement from LEP

$$Mw = 80.412 \pm 0.029(stat.) \pm 0.031(systematic).$$

has not been updated since winter 2003.

The aims for the final measurement, expected this summer, are better understanding and evaluation of the fragmentation and detector errors plus new, less CR dependent analyses for the hadronic channel.

References

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