Measurement of the Mass of the W Boson in the $W^+W^- \to q\bar{q}'\ell\bar{\nu}$ Channel with the OPAL Detector at LEP

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The precise determination of the mass of the W boson is a central topic of the LEP2 program of the Large Electron Positron Collider (LEP) at CERN. Together with the measurement of the properties of the Z^0 boson from the LEP1 period [1], it offers the opportunity to probe and test the electroweak sector of the Standard Model of Elementary Particle Physics with unprecedented precision. Furthermore, these measurements can be used in conjunction with the measurement of the mass of the top quark at Fermilab to derive constraints on the mass of the Higgs boson, an up to now unobserved scalar particle, which could explain the appearance of massive weak gauge bosons in the scope of the Standard Model.

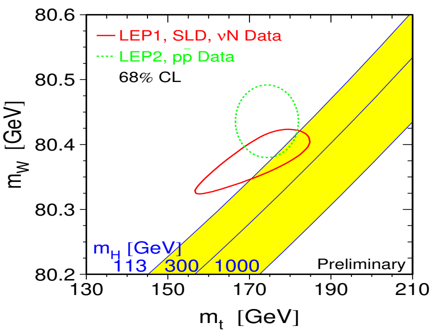

Fig. 1: Comparison of the Standard Model predictions of the top quark and W boson masses with indirect (LEP1, SLD, νN) and direct measurements (LEP2, $p\bar{p}$) [2]. The shaded area shows the prediction for a range of the Higgs mass (the lower bound on m_H is the current limit derived from direct searches).

Our group participates in the maintenance, the data taking and the analysis of the data of the OPAL experiment at LEP. A major effort is devoted to the study of W bosons which are produced in pairs at the LEP accelerator at center-of-mass energies of $\sqrt{s} \geq 161$ GeV.

This article describes the determination of the mass of the W boson in the semileptonic decay channel, $W^+W^- \to q\bar{q}'\ell\bar{\nu}$. This channel proves to be the most important one as it has high statistics (approx. 44% of all decays) and a low background from other processes. The fully hadronic decay channel [3], $W^+W^- \to q\bar{q}'q\bar{q}'$, while comparable in statistic power, suffers from increased background and from systematic uncertainties introduced by Final State Interactions (FSI), as e.g. Bose-Einstein Correlations or the Color-Reconnection Effect [4,5]. Currently there is no reliable measurement to estimate the effects of these FSI on the reconstructed W mass and large conservative errors have to be assigned. The fully leptonic channel [6], $W^+W^- \to \ell\bar{\nu}\bar{\ell}'\nu'$, suffers from low statistics (10% of the decays) and therefore does not contribute significantly to the final W mass result but offers an important, independent cross-check of the results of the other channels.

The analysis approach we use to determine the mass of the W boson, the Convolution method [7], is based on an Unbinned Maximum Likelihood fit of a theoretical distribution to the data sample. For each event, an event probability density, which corresponds to the—in general—asymmetric error of the measurement, is convolved with a semi-analytical physics function which represents the best estimate of the expected mass distribution of the W boson pairs to yield the event likelihood. The total likelihood function is given by the product of the event likelihoods and is maximized with respect to the mass M_W of the W boson.

The event reconstruction of the $W^+W^- \to q\bar{q}'\ell\bar{\nu}$ candidates identifies the lepton and forces the hadronic part into two jets, in conformance with the hypothesis of a semileptonic W-pair decay. The event probability density is then calculated by applying a kinematic fit to the measured lepton and jet momenta. It implements energy-momentum conservation and an equal mass constraint ($m_{W^+} = m_{W^-}$) and forces the W boson mass to specific values to obtain the probability that a W pair of such a mean mass produced the event.

The physics function is based on the superposition of relativistic Breit-Wigner functions and takes—on a statistical level—the effects of Initial State Radiation (the emission of a photon just before the e^+e^- collision, which changes the available center-of-mass energy) on the mass reconstruction into account.

So far the data collected with the OPAL detector at center-of-mass energies of $\sqrt{s} = 183$ GeV and $\sqrt{s} = 189$ GeV have been analyzed [7]. The systematic uncertainties of the measurement were studied in detail, the LEP beam energy uncertainty and the modeling of the hadronization of the primary quarks give the largest contributions. We obtain a value of

$$M_W = 80.394 \pm 0.090_{\text{stat.}} \pm 0.033_{\text{syst.}}$$

for the mass of the W boson, in agreement with the Standard Model expectation and other measurements.

Additional data recorded in 1999 at center-of-mass energies of $\sqrt{s} = 192$ GeV to $\sqrt{s} = 202$ GeV are currently analyzed.

A possible improvement of the Convolution method is also under study: The equal mass constraint in the kinematic fit will be dropped and a 2-dimensional calculation of the physics function and the event probability densities will allow the full consideration of the two W boson subsystems in each event in the most natural way.

References

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