54. Mass and Width of the W Boson

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Precision determination of the W mass is of great importance in testing the internal consistency of the Standard Model. From the time of its discovery in 1983, the W boson has been studied and its mass determined in $p\bar{p}$ and e^+e^- interactions; it is currently studied in pp interactions at the LHC. The mass and width definition used here corresponds to a Breit-Wigner with mass-dependent width.

Production of on-shell W bosons at hadron colliders is tagged by the high p_{T} charged lepton from its leptonic decay modes. Owing to the unknown parton-parton effective energy and missing energy in the longitudinal direction, the hadron collider experiments reconstruct the transverse mass of the W boson, and derive the W mass from comparing the transverse mass distribution with Monte Carlo predictions as a function of the mass m_W. The transverse momentum of the charged lepton itself and the transverse missing energy (arising from the neutrino in W decay) are also sensitive to the W mass and used in its determination. These analyses use the electron and muon decay modes of the W boson.

At the e^+e^- collider LEP, a precise knowledge of the beam energy enables one to determine the $e^+e^- \to W^+W^-$ cross section as a function of center of mass energy, as well as to reconstruct the W mass precisely from its decay products, even if one of them decays leptonically. Close to the W^+W^- production threshold ($\sqrt{s} = 161\,\mathrm{GeV}$), the dependence of the W-pair production cross section on m_W is large, and this was used to determine m_W. At higher centre-of-mass energies (172 to 209 GeV) this dependence is much weaker, thus W bosons were directly reconstructed and the mass determined as the invariant mass of the decay products, improving the resolution with a kinematic fit.

To compute the LEP average W mass, each experiment provided its measured W mass for the $q\bar{q}q\bar{q}$ and $q\bar{q}\ell\nu,\ \ell = e, \mu, \tau$ channels at each center-of-mass energy, along with a detailed decomposition of uncertainty contributions: statistical, uncorrelated, partially correlated and fully correlated systematics [1]. This yielded a combined LEP average W mass of $m_W = 80.376 \pm 0.033\,\mathrm{GeV}$. Errors on m_W due to uncertainties in the LEP beam energy (9 MeV), and possible effect of color reconnection (CR) and Bose-Einstein correlations (BEC) between quarks from different W bosons (8 MeV) are included. Similarly the combined LEP average of the W boson total width is determined to be $\Gamma_W = 2.195 \pm 0.083\,\mathrm{GeV}$ [1].

In the past a similar procedure was followed for the measurements at hadron colliders. The two Tevatron experiments CDF [2] and D0 [3] identified common systematic errors: uncertainties due to the parton distribution functions (PDF), radiative corrections, and choice of mass (width) in the width (mass) measurements were treated as correlated and the resultant mass [4] and width [5] of the W were determined. The W boson total width obtained is $\Gamma_W = 2.046 \pm 0.049\,\mathrm{GeV}$. Similarly the mass results from the two LHC experiments, ATLAS [6] and LHCb [7] were combined to obtain an LHC average mass of the W, and an overall hadron collider average of the W mass was obtained as well [8].

The results on mass and width published by the experiments are shown in Figures 54.1 and 54.2, respectively. Until 2022, all measurements were in good agreement with each other and with the world average [8]. In April 2022 the CDF collaboration published a result $m_W = 80.4335 \pm 0.0094\,\mathrm{GeV}$ [10], based upon their full Run-II dataset of $8.8\,\mathrm{fb}^{-1}$. The result is of higher precision than the 2022 world average, but the two results disagree significantly.[1]

[1] The 2022 CDF result includes the $2.2\,\mathrm{fb}^{-1}$ of data used for the previous CDF Run-II result of $80.387 \pm 0.019\,\mathrm{GeV}$

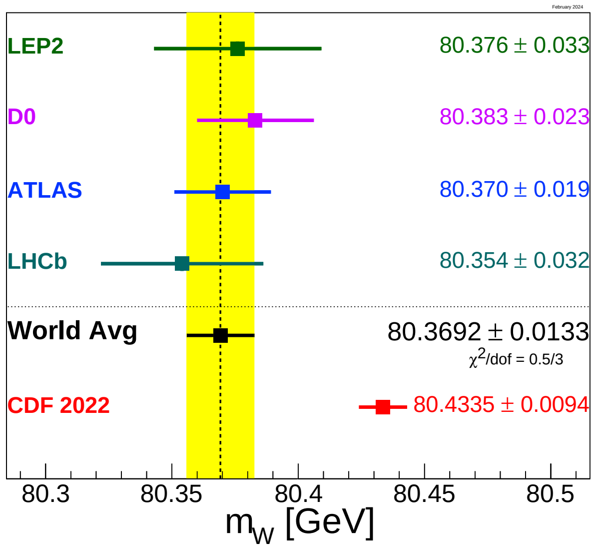

Figure 54.1: Measurements of the W-boson mass by the LEP, Tevatron and LHC experiments. The CDF 2022 result is not used in the world average. In March 2024, after the cut-off of results for this review, the ATLAS Collaboration has submitted for publication a refined analysis of their data used in [6] and obtained a more precise mass value of 80.3665 ± 0.0159 GeV [9].

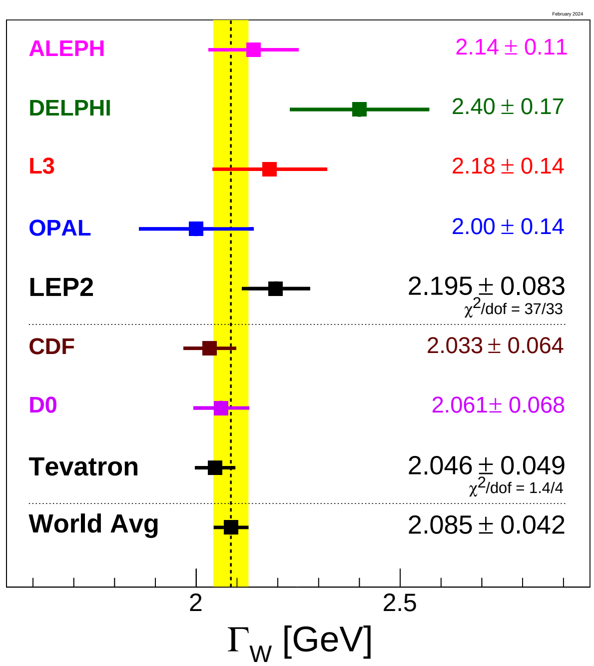

Figure 54.2: Measurements of the W-boson width by the LEP and Tevatron experiments. In March 2024, after the cut-off of results for this review, the ATLAS Collaboration has submitted for publication a refined analysis of their data used in [6] and obtained a width value of 2.202 ± 0.047 GeV [9].

[2]. Incorporating the improved understanding of PDFs and track reconstruction, the central value of the 2.2 fb^{-1} result is increased by 13.5 MeV to 80,400.5 MeV [10].

The LHC-TeV W-mass Working Group, including W-mass experts from all hadron collider experiments, CDF, D0, ATLAS, CMS, LHCb, has been working to understand better the nature of this disagreement and suggest a way forward to obtain a world average value of the W mass. Corrections, uncertainties and their correlations have been evaluated to a greater detail and used in the combination: the central values are corrected to a common theory description and PDF, and the uncertainties, especially due to PDFs, have been re-evaluated to account for correlations properly. The group reports [11] that a combination of all W-mass measurements has a probability of compatibility of 0.5% only, and is therefore disfavoured. A 91% probability of compatibility is obtained when the CDF-II measurement is removed. The corresponding value of the W boson mass is $m_W = 80369.2 \pm 13.3\,\text{MeV}$, which we quote as the World Average. More details are given in [11].

The Standard Model prediction from an electroweak fit, including Z-pole data and the measured masses of the top quark and of the Higgs boson but excluding results on m_W and Γ_W, implies a W-boson mass of $m_W = 80.353 \pm 0.006\,\text{GeV}$ and a W-boson width of $\Gamma_W = 2.089 \pm 0.001\,\text{GeV}$; see Section 10, Electroweak Model and Constraints on New Physics, J.Erler and A.Freitas, 2024, this review. Note that the electroweak fit of Section 10 to all measurements uses slightly different measurements of the W boson mass and width as explained there.

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