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Indirect Determination of the W Boson Width Based on Inclusive W- and Z-Boson Cross Sections at Tevatron and LHC

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The W boson decay width, Γ_W, is predicted within the Standard Model with an uncertainty of 0.1%. New heavy particles that naturally appear in many scenarios beyond the Standard Model, could imply additional higher order corrections to the W boson propagator and therefore alter the W boson width. A precise determination of Γ_W allows therefore for a stringent test of the Standard Model. In this work we discuss and derive Γ_W from published cross section ratios of the inclusive W and Z boson production at Tevatron and LHC. These values are compared with the direct measurements of Γ_W and also with the predicted value of the global electroweak fit.

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1. Introduction

The precise knowledge of the W boson properties, such as its mass m_W and its decay width Γ_W, allow for testing the standard model (SM) of particle physics. Models beyond the SM could alter the relation between m_W and m_H, since new particles can appear in virtual loops. Similarly, the W boson width could be altered by these new loop contributions. The total width of the W boson can be either measured directly by kinematic fits on the measured decay lepton spectra, such as the transverse momentum of the charged lepton decay p_T or the high-mass tail of the transverse mass m_T. A combination of these direct results leads to $\Gamma_W = 2085 \pm 42$ MeV, which is currently dominating the world average [1].

One possibility to confront the direct measurements of the W boson width with an independent determination is based on the cross section ratio measurement of the W and Z boson production in hadron collisions, i.e.

$$R = \frac{\sigma(pp' \to W^\pm + X) \cdot BR(W^\pm \to l^\pm \nu)}{\sigma(pp' \to Z^0 + X) \cdot BR(Z \to l^+ l^-)} = \frac{\sigma_W}{\sigma_Z} \cdot \frac{\Gamma_{W\to l\nu}}{\Gamma_W} \cdot \frac{\Gamma_Z}{\Gamma_{Z\to ll}} \tag{1.1}$$

where $BR(V \to ll') = \Gamma_{V\to ll'}/\Gamma_V$ denotes the leptonic branching ratio of the vector boson ($V = W, Z$) decays. The total cross section ratio σ_W/σ_Z is known theoretically to high precision. The ratio $\sigma_{Z\to ll}/\sigma_Z = 0.033658(23)$ was precisely measured by the LEP experiments [2] and therefore a leptonic branching ratio of the W boson, i.e. $BR(W^\pm \to l^\pm \nu) = \frac{\Gamma_{W\to l\nu}}{\Gamma_W}$ can be inferred once R is measured. The advantage of the measurement of the cross section ratio R lies in the fact that many experimental systematic uncertainties on the individual cross section measurements, such as the uncertainty of the integrated luminosity, are highly correlated and therefore cancel in the ratio. The leptonic decay width of the W boson in the SM is $\Gamma(W \to l\nu) = 226.6 \pm 0.2$ MeV. Using this value, the total width of the W boson can be extracted by a measurement of the leptonic branching ratio. In the following we review the existing indirect measurements, derive an indirect Γ_W value from the published cross section ratio of the ATLAS experiment [3] and outline a combination strategy.

2. Indirect Γ_W Measurements

The indirect approach for the W boson width determination via the measurement of cross section ratios was already chosen by several experiments, in particular CDF [4], D0 [5] and CMS [6] in the past. Their results are summarized in Table 1 and reach a similar precision as the current world average. The predictions of the inclusive cross section ratios and associated uncertainties, shown in Table 1, are based on next-to-next-to leading order calculations in the strong-coupling constant and have been provided by the experiments. It should be noted, that the differences in these ratios are due to different mass range definitions of the Z boson, as well as due to different sets of underlying parton distribution functions (PDFs). The uncertainties, quoted by the D0 and CDF collaborations, are significantly smaller compared to the uncertainties at the LHC, since the PDF uncertainties are expected to be smaller in proton-antiproton collisions than in proton-proton collisions. However, the estimation of electroweak (EW) effects, scale uncertainties and uncertainties in the modeling of initial state radiation (ISR) seems to be underestimated in the CDF and D0 analyses.

The ATLAS collaboration published a cross section ratio, but did not perform the extraction of Γ_W. We predict the cross section ratio for ATLAS as $\sigma_W/\sigma_Z = 3.39 \pm 0.06$, using the FEWZ generator [7] and the MMHT2014NNLO PDF set [8]. The given uncertainty includes a preliminary estimation of scale, ISR and EW uncertainties. This results in a value of $\Gamma_W = 2100 \pm 50\,\text{MeV}$.

Experiment	Production Process	R^{lep}_{Incl} (published)	R^{incl}_{Pred} NNLO Pred.	Γ_W [MeV]
D0 [5]	$p\bar{p}$, $\sqrt{s}$= 1.8 TeV	10.43±0.27	3.29 ± 0.03	2130 ± 32 (stat.) ± 40 (sys.) ± 20 (mod.) 2130 ± 60
CDF [4]	$p\bar{p}$, $\sqrt{s}$= 1.96 TeV	10.84 ±0.20	3.33 ± 0.02	2092 ± 31 (stat.) ± 29 (sys.) ± 18 (mod.) 2092 ± 42
ATLAS [3]	pp, $\sqrt{s}$= 7 TeV	10.89 ±0.18	3.39 ± 0.06	2100 ± 17 (stat.) ± 23 (sys.) ± 40 (mod.) 2100 ± 50
CMS [9]	pp, $\sqrt{s}$= 8 TeV	10.54 ±0.19	3.34 ± 0.08	2144 ± 15 (stat.) ± 17 (sys.) ± 53 (mod.) 2144 ± 62

Table 1: Summary of measured cross section ratios in the leptonic decay channels at Tevatron and LHC, their production process and the corresponding center of mass energy. In addition, the indirect determined values for Γ_W are given. The predicted values of $R = \sigma_W/\sigma_Z$ are provided by the experiments and differ due to the Z boson invariant mass selected. The value of the ATLAS Collaboration, as well as the breakdown of the statistical (stat), systematic (sys) and model uncertainties (mod) on Γ_W have been derived by the authors, while the other values are given by the experiments themselves.

3. Combination Strategy

While the statistical and experimental systematic uncertainties are uncorrelated between the measurements of Table 1, large correlations between the model uncertainties are expected. A summary of the relevant systematic and model uncertainties can be found in [10]. These correlations have to be precisely estimated for a combination. In addition, the predicted values of $\sigma_W\sigma_Z$ have to be recalculated in a common framework. Therefore the combination strategy aims at measured cross section ratios within the fiducial volumes of the experiments $R_{fid} = \sigma_W^{fid}/\sigma_Z^{fid}$, which are published for ATLAS and CMS and can be rederived for D0 and CDF. The values of $R_{fid} = \sigma_W^{fid}/\sigma_Z^{fid}$ are nearly not affected by any model uncertainties, i.e. have only associated uncorrelated uncertainties, and hence can built the basis for a combination procedure. The extrapolation from the fiducial measurement to the inclusive value of R, and the subsequent extraction of Γ_W, can be performed coherently. Following this procedure, a preliminary study indicates a combined value of $\Gamma_W = 2119\,\text{MeV}$ with an expected uncertainty of $\approx 35\,\text{MeV}$. A detailed study is currently under preparation [11].

4. Comparison and Conclusion

As mentioned in Section 2, the total width of the W boson is potentially sensitive to physics beyond the SM. However, it should be noted that loop corrections due to contributions of new physics to the W boson width would alter the total width in a similar way as the leptonic decay width. As a consequence, the predicted branching ratio $\Gamma_{W\to l\nu}/\Gamma_W$ is rather insensitive to new physics effects. The consistency of the SM can therefore only be tested by confronting the indirect

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measurement of Γ_W with the value from direct measurements, as those would be affected by new physics effects. A comparison of the indirect determined Γ_W values and the current world average, which is based on the direct measurements, is shown in Figure 1. A very good consistency can be seen, i.e. exhibiting no signs of new physics.

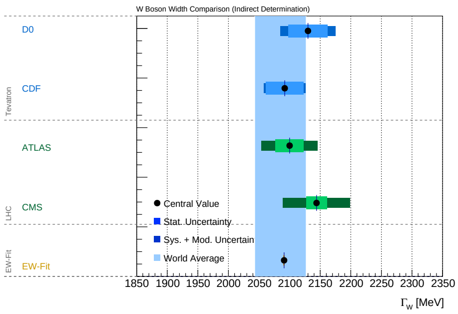

Figure 1: Comparison of the Tevatron and LHC results of various indirect determined values for Γ_W measurements. The current world average and expectations of the PDG global fit are also shown.

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