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Measurement of the invisible W width

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Abstract: The results of the W pair production cross section measurements at the LEP II experiments are used to obtain a measurement of the invisible decay width of the W boson. Such an invisible decay width, resulting from W decay channels that have event signatures that are not consistent with any Standard Model decay, would lower the observed cross section compared to that of the Standard Model. From the LEP combined result from the 183 GeV data gathered in 1997, we obtain an upper limit of 45 MeV at 95% CL.

Keywords: Standard Model, Beyond Standard Model, Weak Decays, LEP HERA and SLC Physics.

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Contents

1. Introduction

We present a measurement of the invisible decay width [1, 2] of the W boson using the W-pair production cross sections measurements carried out at the LEP II experiments. Beyond the assumption that W bosons couple to the known quarks and leptons as predicted by the Standard Model, the invisible width measurement is independent of the nature of the deviation from the Standard Model which causes the invisible decays, which are defined as decays of the W boson into states that are not covered by the standard event selections used for the cross sections measurements. One example of such a decay is [1]

$$\begin{array}{l} W^{+} \rightarrow \chi^{+}\chi^{0} \\ \qquad\quad \hookrightarrow \; l^{+} + \chi^{0}, \end{array} \tag{1.1}$$

in Supersymmetric [3] models, where the neutralino and chargino can be nearly degenerate in mass, leading to a decay signature with just one very low energy lepton.

We note that the existence of an invisible decay width lowers the W-pair production cross section, as opposed to many other models incorporating deviations from the Standard Model, such as models with anomalous Triple Gauge Boson Couplings [4], which cause the cross section to increase.

The method described here is complementary to direct searches for events with single visible W bosons, and can be used to distinguish between the New Physics models that can cause events with signatures similar to that of W-pair production with one W decaying invisibly.

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2. Theory

The W boson total decay width can be written as follows:

$$\Gamma_{W(\text{total})} = \Gamma_{W(\text{visible})} + \Gamma_{W(\text{invisible})}, \tag{2.1}$$

where $\Gamma_{W(\text{visible})}$ stands for the decay width into modes that are visible in analyses designed to observe W-pair production events, and $\Gamma_{W(\text{invisible})}$ is the decay width into other modes. In the Standard Model, $\Gamma_{W(\text{visible})} = \Gamma_{W(\text{SM})}$, and $\Gamma_{W(\text{invisible})} = 0$. Here, we assume that published measurements of the W boson decay width using W events at p$\bar{\text{p}}$ colliders [5] describe the visible decays well, and set

$$\Gamma_{W(\text{visible})} = 2.07 \pm 0.06. \tag{2.2}$$

We find that the relatively large error on this quantity has very little effect on our final results.

The visible W-pair cross section is calculated by convoluting the Breit-Wigner distributions of the two W bosons with a width-independent expression for the cross section [6, 7]:

$$\sigma^{\text{CC03}}_{\text{visible}}(s) = \int_0^{(\sqrt{s}-\sqrt{s_+})^2} \rho_W(s_+) \int_0^{s} \rho_W(s_-)\, \sigma_0^{\text{CC03}}(s; s_+, s_-)\, ds_-\, ds_+, \tag{2.3}$$

where σ^{CC03} is the cross section contribution from the three double-resonant W-pair production tree level diagrams. All the cross section calculations and measurements in this paper refer to this quantity. The Breit-Wigner distributions can be written

$$\begin{aligned} \rho_{W\,\text{visible}}(s_\pm) &= \sum_{i\in\text{visible}} \frac{1}{\pi} \frac{m_{\text{W}}\Gamma_{W\to i}}{|s_\pm - m_{\text{W}}^2 + i m_{\text{W}}\Gamma_{W(\text{total})}|^2} \\ &= \frac{1}{\pi} \frac{m_{\text{W}}\Gamma_{W(\text{visible})}}{|s_\pm - m_{\text{W}}^2 + i m_{\text{W}}\Gamma_{W(\text{total})}|^2}. \end{aligned} \tag{2.4}$$

Here one notes that the total decay width, $\Gamma_{W(\text{total})}$, appears in the denominator of eq. (2.4), whereas in the numerator of eq. (2.3), only the sum of the partial cross sections for the visible decay modes, $\Gamma_{W(\text{visible})}$, appears. One can therefore vary $\Gamma_{W(\text{total})}$ in eqs. (2.4) and (2.3), while keeping $\Gamma_{W(\text{visible})}$ within its measurement error, in order to obtain a relation between the measured cross section and the invisible decay width of the W boson.

3. Calculations

The semi-analytic program GENTLE [8] was modified to allow the calculation of the dependency of the W pair production cross sections on $\Gamma_{W(\text{visible})}$ and $\Gamma_{W(\text{invisible})}$, when

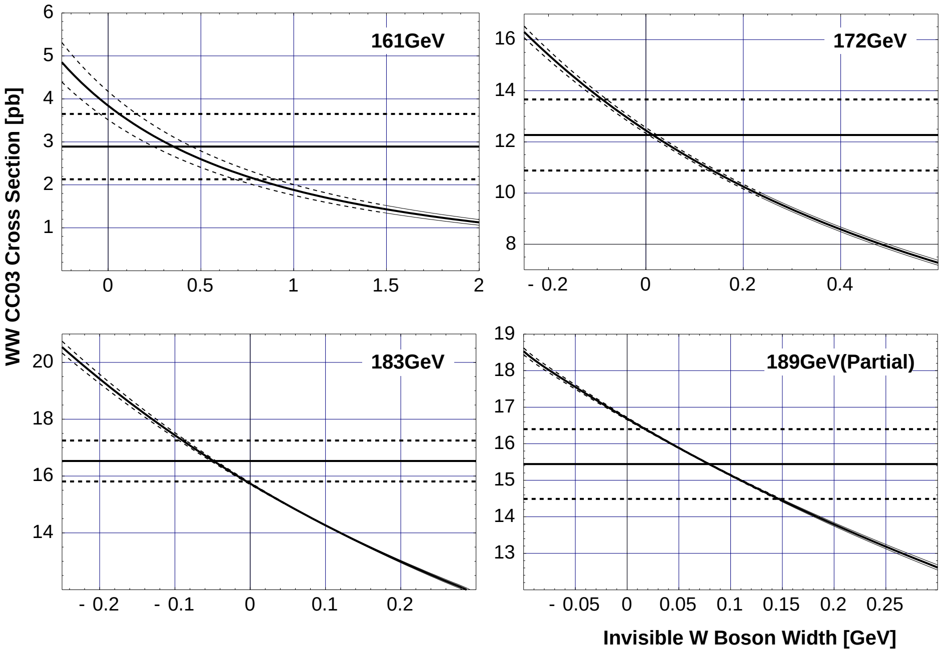

Figure 1: The calculated dependency of the CC03 W pair production cross sections on the invisible W boson width, for four different values of the LEP centre-of-mass energy. The broken lines on either side of the thick curve represent the errors due to the uncertainty of the input W boson mass and SM width. The horizontal lines show the cross section values and their errors, as measured by the L3 experiment.

these quantities were varied as independent parameters. The GENTLE parameters were set to reflect typical settings used by the LEP experiements for their calculations.

Figure 1 shows the dependence of the CC03 cross sections on the invisible W boson width. The solid curves are the central values of the cross sections, and the broken curves represent the 1-sigma error on these values due to the uncertainties in the input parameter values. The measured cross sections and their errors, from the LEP experiment L3, are shown as horizontal lines. Uncertainties in both the SM W width and m_W contribute strongly to the errors at $\sqrt{s} = 161$ and 172 GeV, while at the higher energies both contributions are almost negligible.

The dependence of the cross section and errors from the uncertainties on the input parameters, were fully calculated for a wide range of $\Gamma_{W(\mathrm{invisible})}$ values.

The values of the input parameters used for the calculations are listed in table 1.

Quantity	Value Used	Comments
m_W	80.33±0.15 [GeV]	PDG 1996 Fit
$\Gamma_{W(\mathrm{SM})}$	2.07±0.06 [GeV]	PDG 1997 Average
m_Z	91.187±0.007 [GeV]	PDG 1997 Fit
Γ_Z	2.490±0.007 [GeV]	PDG 1997 Fit

Table 1: Input values[5] for the calculations used to obtain the $\Gamma_{W(\mathrm{invisible})}$ measurements.

4. Measurement results

The calculations described in the previous section can be combined with measured values of the CC03 cross section from the LEP experiments to obtain a measurement of the W boson invisible width. Table 2 lists the input cross section values and the resulting invisible width measurements.

Since the probability distributions for $\Gamma_{W(\text{invisible})}$ are consistent with the true values being 0 or greater, these can be used to obtain upper limits on this quantity, as summarised in table 3.

At lower LEP II energies (161 and 172GeV), the lower intergrated luminosities collected result in sensitivities $\frac{\partial \Gamma_{W(\text{inv})}}{\partial \sigma_{WW}} \sqrt{\frac{\sigma_{WW}}{\sqrt{\mathcal{L}_{\text{int}}}}}$ that are 2 to 5 times worse than for the 183GeV results, and together with the higher sensitivity to the input parameter errors, this greatly diminishes the significance of results from these lower energies.

$\sqrt{s}$ [GeV]	W-pair Cross Section [pb]	$\mathcal{L}_{\text{int}}$ [pb^{-1}]	$\Gamma_{W(\text{invisible})}$ [GeV]
183	16.53 ± 0.72 (L3)	55.47	-0.050 ± 0.043
183	15.89 ± 0.40 (LEP Combined)	$\sim$220	-0.010 ± 0.025
189	15.24 ± 0.57 (LEP Combined)	$\sim$144	0.093 ± 0.040

Table 2: Results of this analysis for various W-pair production cross section values [9, 10].

$\sqrt{s}$ [GeV]	Measurement	$\Gamma_{W(\text{invisible})}$ Upper Limits[GeV] 90% CL	95% CL
183	L3	0.054	0.068
183	LEP Combined	0.037	0.045
189	LEP Combined	0.147	0.163

Table 3: Upper limits on the invisible W width obtained from results in previous table.

5. Conclusions

We have described the measurement of the W boson invisible width, based on some simple assumptions. The results are largely model-independent, and can be used to exclude possible models for New Physics [1, 11].

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