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W Mass and Properties

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Abstract. Precise measurements of the mass and width of the W boson are sensitive to radiative corrections and can be used to place limits on new physics beyond the Standard Model and validate the consistency of the model. In particular, the W boson mass constrains the mass of the, as yet unobserved, Higgs boson and the width can be used to place limits on the existence of new particles that couple to the W. Results are presented from $p\bar{p}$ collisions recorded by the CDF and DØ experiments at the Fermilab Tevatron collider, operating at a centre of mass energy of 1.96 TeV. The uncertainty on the W mass is determined to be 76 MeV by CDF and the width, by DØ, to be 2011 ± 90 (stat.) ± 107 (syst.) MeV.

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1 Introduction

The world's largest sample of W bosons is presently being analysed by the CDF and DØ collaborations. The results presented here are based on an integrated luminosity of $\sim 200\text{pb}^{-1}$, accumulated in 2002-2003; which is a factor of two larger than used in the previously published results [1]. Results on the W production cross section, angular distribution and couplings to other gauge bosons have been presented at this conference [2]. In this talk results on the W boson mass and width will be presented. The results are important in verifying the consistency of the Standard Model, placing limits on new physics, and in determining the mass of the Higgs boson.

2 CDF W Mass Measurement

At tree level, the mass of the W boson is determined by the mass of the Z boson (which has been very precisely measured at LEP [3]) and the electromagnetic and weak coupling constants. Beyond tree level, it is subject to radiative corrections which depend on the masses of all the particles the W can couple to. The largest contribution comes from the top quark and there is a weak dependence on the mass of the Higgs boson. Precision measurements of the W boson mass, in conjunction with a top quark mass measurement [4], can therefore be used to constrain the mass of the Higgs boson and other more exotic particles e.g. those predicted by super-symmetric (SUSY) models. This is shown in figure 1, which shows the predicted variation of the W and top masses for three choices of the Higgs mass and the region favoured by the minimal SUSY extension to the Standard Model (MSSM) with a light Higgs boson. In general scenarios with a light Higgs and SUSY particles tend to raise the mass of the W boson.

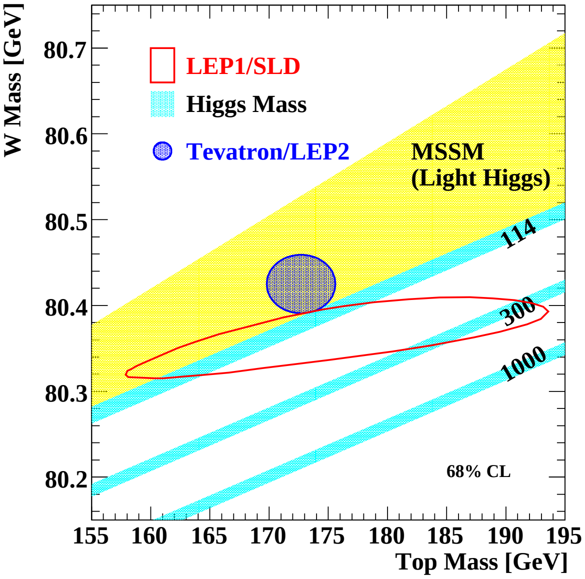

Fig. 1. The predicted W boson and top quark mass in the Standard Model for three Higgs masses (114 - the lower limit from LEP direct searches, 300 and 1000 GeV) and in the MSSM extension to the Standard Model. The present constraint from the Tevatron top and W mass and LEP2 W mass measurements are shown. The indirect constraint from precision electroweak measurements at LEP1 and SLD is also shown.

At hadron colliders the W mass is measured in the electron and muon decay channels since these channels can be identified with high efficiency and with little background contamination. However, with these decay modes there is an accompanying neutrino whose momentum can only be inferred through momentum conservation in the transverse plane. As such the mass of the W boson has to be determined from a measurement of the mass using transverse momentum components only. It is not possible to have a simple functional form, in terms of the true W mass, for this transverse mass owing to the effects of the varying parton-parton centre of mass energy, and the detector acceptance and resolution. Templates of the transverse mass distribution after a full simulation of the physics and the detector are therefore generated at various W mass values and the W mass is ultimately obtained from a likelihood comparison of the data with these templates. Events are generated using the NLO QCD generator RESBOS [5] and the effect of photon radiation from the decay charged leptons is taken from the WGRAD [6] calculation. This calculation only simulates the emission of a single photon and the uncertainty in the W mass arising from not including further emissions has been estimated to be 15 (20) MeV in the electron (muon) channel respectively. Owing to the similarity in the production mechanism between W and Z bosons, it is possible to predict the W transverse momentum distribution from a measurement of the Z transverse momentum distribution using the decay leptons. The uncertainty in the W transverse momentum, due to the finite statistics of the calibrating Z sample, results in a 15 MeV uncertainty in the W mass. The uncertainty in the angular distribution of the W bosons, arising from uncertainties in the parton distribution functions (PDFs) is determined using the CTEQ6 [7] and MRST [8] PDFs and is determined to be 15 MeV.

A key aspect of the measurement of the W mass is the determination of the momentum and energy scale of the charged leptons from the tracking detectors and the calorimeter. For the muons, the momentum scale is set using measurements of the J/ψ and Upsilon masses. For the electrons, the energy scale is set by requiring the energy scale to match the momentum scale (already set from the J/ψ). Both these determinations require a very detailed simulation of the photon radiation in the passive material, both in terms of simulating all possible physics processes but also in the composition and location of the material. The scale uncertainties are determined to be 70 and 25 MeV for the electron and muon channels respectively. The resolution of the energy and momentum measurements are taken from a fit to the width of the Z invariant mass distributions and the finite Z statistics result in a 15 MeV W mass uncertainty from this source for both channels.

In order to determine the neutrino momentum, through momentum conservation in the transverse plane, it is necessary to have a simulation of the underlying event, concurrent minimum bias event and the initial state QCD radiation. These components cannot be accurately modelled using a standard Monte Carlo event generator and are instead parameterised by fitting a model to real minimum bias and Z events; whose characteristics with regard the underlying event and QCD radiation are expected to be very similar to W events. Uncertainties in this model arise from the finite statistics of the Z sample and from biases induced by the differing selection criteria and acceptance of the Z and W events e.g. Z events are selected with both leptons in the central detector region, whereas in W events there can be no such constraint on the direction of the neutrino. These uncertainties contribute a 50 MeV uncertainty in the W mass in both channels. The two largest sources of background : W to τ decays with subsequent τ decay to $e\nu\nu$ or $\mu\nu\nu$ and Z events where the second charged lepton escapes detection can be accurately simulated and the level of background (typically $\sim$ 5%) can be reliably estimated from the simulation. Backgrounds from QCD processes, cosmic rays and decay in flight Kaons cannot be accurately simulated and estimates of the transverse mass distributions from these sources are taken from the data by relaxing the selection cuts to provide background rich samples. Uncertainties in the level and shape of the background distributions contribute $\sim$ 20 MeV to the W mass uncertainty. The complete list of systematic uncertainties for the CDF W mass analysis are shown in table 1. The total combined error, after taking into account correlations between the two channels, is 76 MeV. This is better than the previously published CDF W mass which had an uncertainty of 79 MeV. This systematic error analysis is a preliminary one and it expected to be reduced before publication. The transverse mass distributions of the electron sample used to determine the W mass is shown in figure 2.

Table 1. Systematic and statistical uncertainties (in MeV) for the CDF W mass analysis

Error Source	$W \rightarrow e\nu$	$W \rightarrow \mu\nu$
Statistics	45	50
Production model & decay	30	30
Charged lepton scale & resolution	70	30
Backgrounds	20	20
Recoil scale & resolution	50	50
Total	105	95

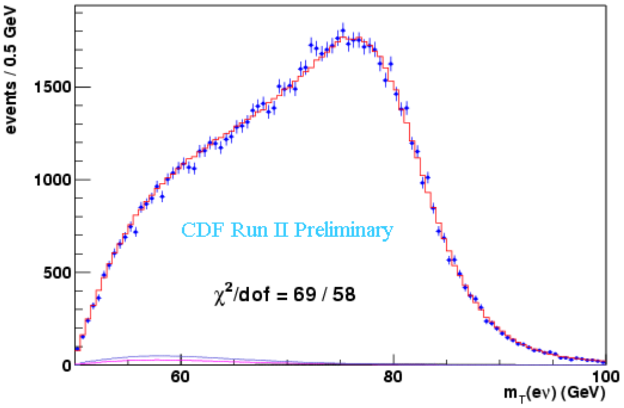

Fig. 2. The transverse mass distributions of the $W \rightarrow e\nu$ sample used to extract the W mass.

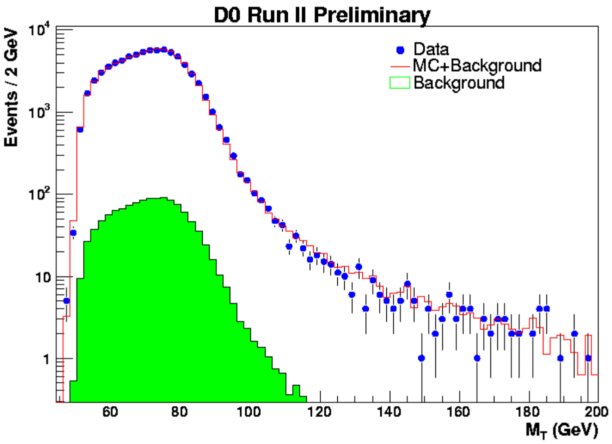

Fig. 3. The transverse mass distributions of the W → $e\nu$ sample used to extract the W width by DØ.

3 W Width measurement

As seen in figure 2 the W transverse mass distribution has a sharp edge close to the value of the W mass. However owing to the finite width of the W boson, it is also possible for events to be measured with transverse mass values higher than the mass of the W boson. From a likelihood fit to the transverse mass distribution in the $100 < m_T < 200$ GeV, it is therefore possible to determine the W width. However events in the high transverse mass region can also arise due to the finite resolution of the detector and so a detailed understanding and modelling of resolution effects is a vital component of this analysis and indeed dominates the systematic uncertainty for the measurement. Using 177 pb^{-1} of data, and 625 W → $e\nu$ events in the high transverse mass region, DØ have determined the W width to be 2011 ± 93 (stat.) ± 107 (syst.) MeV; which agrees well with the Standard Model prediction of 2099 ± 3 MeV [9]. The transverse mass distribution of the W → $e\nu$ events used by DØ to determine the W width are shown in figure 3.

4 Future measurements

The analyses presented here have been based on an integrated luminosity of $\sim$ 200 pb^{-1}. At the time of this conference the Tevatron had passed the 1 fb^{-1} milestone and the next set of W width and mass measurements are expected to be based on datasets of 1-2 fb^{-1}. In these analyses the limiting factor in precision will be systematic and not statistical. The systematic uncertainties arising from PDFs and QED radiative corrections are likely to the limiting source of error in these analyses. At present these two sources contribute $\sim$ 25 MeV to the W mass uncertainty and this is common to the two experiments. Further developments in parton fitting (additional d/u data from HERA and a more sophisticated error analysis) and the provision of a fast generator that incorporates both NLO QED (i.e $\mathcal{O}(\alpha^2)$) *and* NLO QCD are likely to be needed if this 25 MeV uncertainty is to be reduced. The expectations are that with a 2 fb^{-1} dataset the Tevatron experiments will produce a W mass with a combined uncertainty of 20-30 MeV and a width uncertainty of 35 MeV. These uncertainties will surpass those from LEP2; furthermore each experiment will have more precise measurements than any single LEP experiment.

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