W Mass Measurements from the Tevatron

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The CDF collaboration has analysed 2.2 fb^{-1} of Run II electron and muon data for a new precise determination of the mass of the W boson; the result obtained is $m_W = 80.387 \pm 0.019$ MeV/c^2. The DØ collaboration has analysed 4.3 fb^{-1} of Run II electron data for a new precise determination of the mass of the W boson; when combined with a previous DØ collaboration measurement using 1 fb^{-1}, the result obtained is $m_W = 80375 \pm 23$ MeV/c^2. The new world average value for the W mass including both these new results is $m_W = 80385 \pm 15$ MeV/c^2 and the new (95 %CL) indirect Higgs constraint from this updated value of m_W is $m_H < 152$ MeV/c^2.

1 Introduction

The three principle motivations for measuring the W mass are: as a test of the Standard Model; as an indirect constraint on the mass of the Higgs boson; and if the Higgs boson is discovered, as a probe for indication of new physics through the comparison of direct and indirect Higgs mass measurement. The number of W events available for analysis at the two Tevatron experiments is about two orders of magnitude greater than for the final measurements of the W mass at any of the four LEP II experiments; thus allowing for greater statistical precision in Tevatron W mass analyses than those from LEP II. Though precision measurements at the Tevatron are impeded by the 'messy' collision environment, by combined bespoke detector simulation with careful study the Tevatron experiments can produce W mass analyses with competitive systematic uncertainties.

2 Technique

The DØ analysis uses the decay channel $W \to e\nu$ for its W mass measurement; the CDF analysis also uses this channel and considers the channel $W \to \mu\nu$. The hadronic decay channels of the W produce events that are too 'messy' to accurately determine the W mass from and events in the τ leptonic decay channel are difficult to reconstruct. Tight cuts are used to give high purity samples of W decays and to ensure only events falling into well instrumented regions of the detector are used.

Because of the missing energy of the neutrino it is not possible to fully reconstruct W decay events in three dimensions. Instead the W mass (m_W) is determined by fitting Monte-Carlo templates to data. The main distribution fitted is the transverse mass distribution:

$$m_T = \sqrt{2 p_T^{\ell} p_T^{\nu} \left(1 - \cos(\Delta\phi^{\ell\nu})\right)} \qquad (1)$$

where p_T^ℓ is the transverse momentum (energy) of the muon (electron), p_T^ν is the transverse momentum of the neutrino reconstructed from the missing transverse energy and $\Delta\phi^{\ell\nu}$ is the angle between $\vec{p}_T^{\,\ell}$ and $\vec{p}_T^{\,\nu}$. The CDF analysis momentum is measured in the CDF MWPC gaseous tracker (the COT) and energy is measured in the various calorimeters; the silicon tracker is not used in this the CDF analysis. In the DØ analysis energy is measured in the calorimeter. Simulated background distributions are added to the Monte-Carlo templates. The p_T^ℓ distribution is also fitted; the final m_W is obtained by combining the results of these fits correctly accounting for statistical correlations. (The CDF analysis also determines m_W by fitting the p_T^ν distribution and adds this to the combination too.)

For both analyses samples of W decay events are simulated using the event generator RESBOS. NLO QCD correction are calculated by tuning the parameters of RESBOS for the non-perturbative region by fitting the Z invariant mass in $Z \to \ell^+\ell^-$ data. Both analyses calculate NLO QED corrections using PHOTOS. CDF have studied QED effects extensively in HORACE and then validated PHOTOS against HORACE; DØ have validated PHOTOS against WGRAD/ZGRAD.

CDF uses momentum measurements from the tracker both directly in the muon channel and indirectly in the electron channel. Thus it is necessary to calibrate the momentum scale; the level of accuracy required for W mass measurement being greater than that provided by collaboration wide calibrations. The procedure for calibrating the momentum scale in the CDF analysis begins with a precise alignment of the COT using cosmic ray data. Fits of J/ψ mass distribution of $J/\psi \to \mu^+\mu^-$ in bins of $< 1/p_T >$ are used to tuning the thickness of ionising material modelled in the inner detector. The overall momentum scale is set using a combined fits to the J/ψ, Υ and Z mass distributions in $J/\psi \to \mu^+\mu^-$, $\Upsilon \to \mu^+\mu^-$ and $Z \to \mu^+\mu^-$ events. As a cross check the momentum scale fitted using just the J/ψ and Υ mass distribution is compared to that fitted using just the Z mass distribution; these two measurement are consistent to within the statistical uncertainty on the fits.

Both analyses use energy measurements from their detectors electromagnetic calorimeter to measured the energy of electrons. DØ fits the calorimeter energy scale using the boson invariant mass distribution from $Z \to e^+e^-$. CDF fits the calorimeter scale separately using two different techniques. The first is boson invariant mass distribution from $Z \to e^+e^-$ events. The second is the E/p (energy over momentum) distribution from $W \to e\nu$ events; this transfers the precise momentum calibration to calorimeter energy measurements. The two techniques produced results that are consistent to within the statistical uncertainty of the fits; the two results are combined to produced an overall calorimeter energy scale.

The p_T of the neutrino is reconstructed from the measured p_T of the lepton and the measured hadronic recoil using the relation $p_T = -(\vec{p}_T^{\,\ell} + \vec{u}_T)$, where u_T is the hadronic recoil, the vector sum of all energy measured in the calorimeters (both electromagnetic and hadronic) not associated with the lepton. The recoil is modelled in these analyses Monte-Carlo simulations using parameterisations of minimum bias data and fully leptonic Z decay data.

3 Results

The new CDF result [1] analyses 2.2 fb^{-1} of data in both the electron and muon channels. The final combined result for both channels (fitting all of m_T, p_T^ℓ and p_T^ν in each) is:

$$m_W = 80387 \pm 19 \text{ MeV/c}^2. \tag{2}$$

The m_T distribution fit for m_W is given in figure 1.

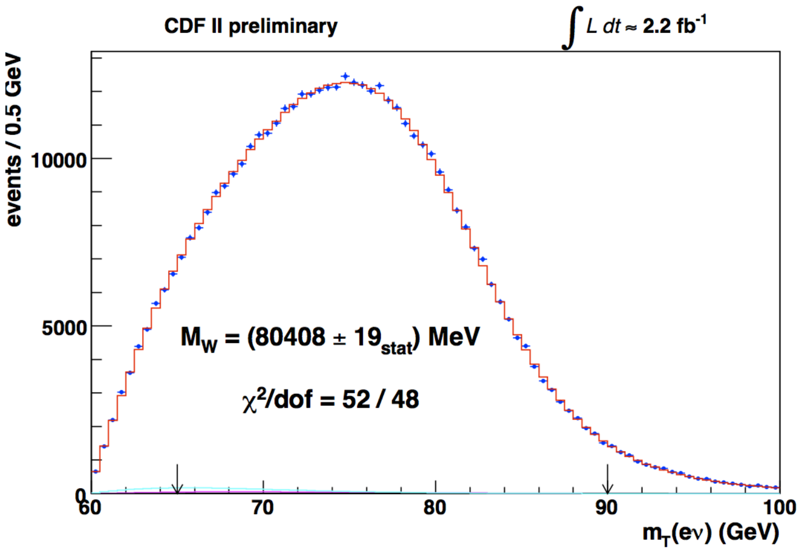

Figure 1: Comparison of best fit template m_T distribution (red histogram) to data (blue points) for $W \to e\nu$ events from the new CDF W mass analysis.

The new DØ result [2] analyses 4.3 fb^{-1} of data in the electron channel. The final result (fitting both m_T, p_T^ℓ) is:

$$m_W = 80367 \pm 26 \text{ MeV/c}^2. \tag{3}$$

The m_T distribution fit for m_W is given in figure 2. This can be combined with a previous independent DØ measurement using 1 fb^{-1} to give:

$$m_W = 80375 \pm 23 \text{ MeV/c}^2. \tag{4}$$

The uncertainties on both the DØ and CDF analyses are given in table 1. Combining these results with the old world average ($m_W = 80.399 \pm 0.023$) give a new world average of:

$$m_W = 80385 \pm 15 \text{ MeV/c}^2. \tag{5}$$

The new (95 %CL) indirect Higgs constraint from combining this updated value of m_W with the current world average top quark mass is $m_H < 152$ MeV/c^2.

References

[1] T. Aaltonen *et al.* [CDF Collaboration], Phys. Rev. Lett. **108** (2012) 151803.

[2] V. M. Abazov *et al.* [D0 Collaboration], Phys. Rev. Lett. **108** (2012) 151804.

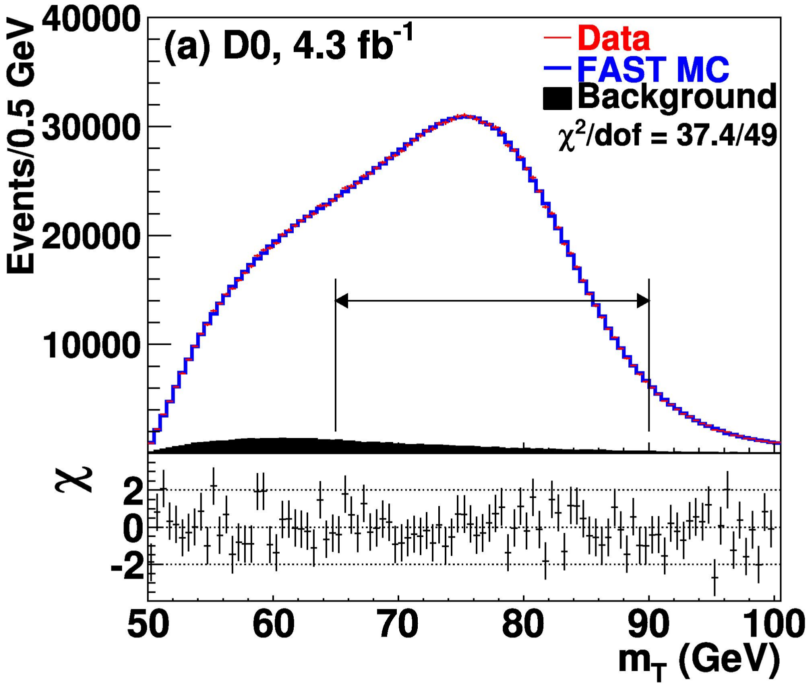

Figure 2: Comparison of best fit template m_T distribution (red histogram) to data (blue points) for $W \to e\nu$ events from the new DØ W mass analysis.

Uncertainty Source	CDF Uncertainty (MeV/c^2)	DØ Uncertainty (MeV/c^2)
Energy (and Momentum) Scale Calibration and Resolution	7	17
Recoil Model	6	5
Efficiencies	-	2
Backgrounds	3	2
Experimental Sub Total	**10**	**18**
PDFs	10	11
QED	4	7
Boson p_T	5	2
Production Sub Total	12	13
Total Systematics	15	22
W **Sample Statistics**	12	13
Overall Total	19	26

Table 1: Systematic and Statistical Uncertainties on the new Tevatron W mass analyses.