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Improved DØ W Boson Mass Determination

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Abstract

We present a measurement of the W boson mass in proton-antiproton collisions at $\sqrt{s} = 1.8$ TeV based on a data sample of 82 pb^{-1} integrated luminosity collected by the DØ detector at the Fermilab Tevatron. We utilize $e\nu$ events in which the electron shower is close to the phi edge of one of the 32 modules in the DØ central calorimeter. The electromagnetic calorimenter response and resolution in this region differs from that in the rest of the module and electrons in this region were not previously utilized. We determine the calorimeter response and resolution in this region using $Z \to ee$ events. We extract the W boson mass by fitting to the transverse mass and to the electron and neutrino transverse momentum distributions. The result is combined with previous DØ results to obtain an improved measurement of the W boson mass: $m_W = 80.483 \pm 0.084$ GeV.

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I. INTRODUCTION

Measurements of the W boson mass are of fundamental interest since they help constrain the Standard Model and the Higgs boson mass [1]. Recent measurements of the W boson mass have been made by DØ [2] and CDF [3] at the Tevatron and by the LEP experiments [4]. Previous measurements by DØ have relied on $W \to e\nu$ events in which the electron was detected in the central calorimeter or the forward calorimeters. The central calorimeter is divided azimuthally into 32 modules [5]. Electrons incident close to the azimuthal module boundaries were found to have a reduced response and degraded energy resolution. These "edge" electrons were excluded from our W and Z boson data samples in previous measurements. In this paper, we report a new measurement of the W boson mass using these edge electrons. We rely on $Z \to ee$ events in which at least one electron is detected in the edge region to calibrate the response of the calorimeter. $Z \to ee$ events in which only one electron is incident at a central calorimeter module boundary are also used to additionally constrain the elecromagnetic calorimeter enegry scale for non-edge electrons, thereby improving our previous measurements based on non-edge electrons.

II. EVENT SELECTION AND DETECTOR CALIBRATION

Direct measurement of the W boson mass m_W at DØ is performed using $W \to e\nu$ events from $p\bar{p}$ collisions at a center-of-mass energy of 1.8 TeV. A detailed description of the method used to measure m_W is given in Ref. [2]. Events are selected by requiring the presence of an isolated electron with high transverse momentum (p_T) and large missing transverse energy ($\not{E}_T$). The W boson mass is extracted by fitting Monte Carlo templates to the observed kinematic distributions. Maximum likelihood fits are made to the transverse mass $m_T = \sqrt{2p_T^e p_T^\nu(1 - \cos\phi_{e\nu})}$, electron transverse momentum p_T^e, and neutrino transverse momentum p_T^ν. Here, $\phi_{e\nu}$ is the azimuthal angle between the electron and neutrino. The three W boson mass measurements are combined taking into account correlations to obtain the final result. A Monte Carlo simulation is used to provide the expected lineshapes of the distributions as a function of m_W. The Monte Carlo contains all resolution effects and backgrounds as determined from data.

The W boson sample for this measurement is selected requiring $\not{E}_T > 25$ GeV and a high-quality isolated electron in the central calorimeter (CC) with $p_T^e > 25$ GeV and $\Delta\phi < 0.1 \times 2\pi/32 = 0.02$ radians, where $\Delta\phi$ is the angle between the electron direction and the closest CC module boundary. The electron direction is calculated from the center-of-gravity of the track in the central drift chamber and the event vertex position. Electrons satisfying these criteria are referred to as "$\widetilde{\mathrm{C}}$ electrons", while non-edge electrons which have $\Delta\phi > 0.02$ radians are called "C electrons". The number of candidate edge-electron W events selected by applying the above criteria was 3 853. For comparison, our previous central calorimeter measurement using the 1994-95 data set was based on 28 323 candidates.

We also select $Z \to ee$ candidates requiring two isolated electrons with $p_T^e > 25$ GeV with dielectron invariant mass 60 GeV $< m_{ee} <$ 120 GeV. Events are required to have one electron in the edge region. The second electron may also be in the edge region ($\widetilde{\mathrm{C}}$-$\widetilde{\mathrm{C}}$ events), or it may be in the non-edege region ($\widetilde{\mathrm{C}}$-C events), or in one of the end calorimeters ($\widetilde{\mathrm{C}}$-E events). The numbers of Z candidates selected are 470 $\tilde{\mathrm{C}}$-C events, 47 $\tilde{\mathrm{C}}$-$\tilde{\mathrm{C}}$events, and 154 $\tilde{\mathrm{C}}$-E events. Backgrounds to the edge electron W and Z samples are determined using the same methods used in our previous analyses.

The calorimeter response to edge electrons is illustrated in Fig. 1, which compares the reconstructed dielectron invariant mass distributions of $\tilde{\mathrm{C}}$-C and C-C events. Above the Z peak, the distributions are consistent with one another, but at low m_{ee} there is an excess of events in the edge sample indicating that a fraction of the edge electrons have a lower electromagnetic response in the calorimeter. The difference between the distributions is well

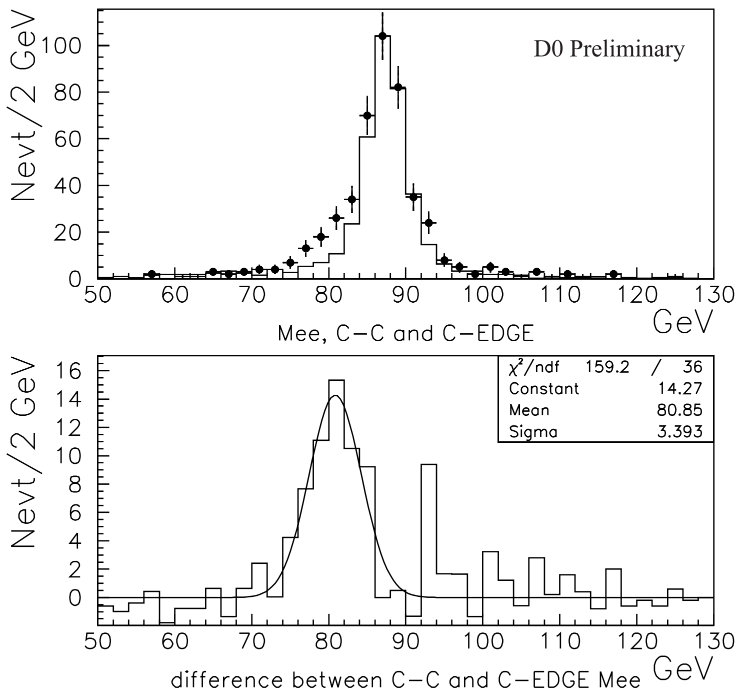

FIG. 1. (a) Dielectron mass distribution for the edge sample (points with error bars) and the non-edge sample (solid line). (b) Difference between the two distributions in (a) fitted with a single Gaussian function.

described by a single Gaussian function. This suggests that the electromagnetic calorimeter response for edge-electrons can be described by the sum of two Gaussians, one with the same mean and width as for non-edge electrons and the second with a reduced response and degraded energy resolution. This is consistent with expectations, since the high voltage electrodes are set back near the module edge, thus reducing the electric field in that region and giving lower response. There is no evidence for increased energy deposit in the backing hadron calorimeter module that would occur if particles were passing within a crack between EM modules. We assume that a fraction f_{edge} of the edge electrons has a reduced response and degraded energy resolution, while the remaining edge electrons have the same response and energy resolution as non-edge electrons. Thus, for the fraction f_{edge} of edge electrons, the calorimeter response is parameterized by

$$E^{\mathrm{meas}} = \alpha_{\mathrm{edge}} E_e^{\mathrm{true}} + \delta$$

The offset δ was found to be consistent with the offset previously used in the parameterization of non-edge electrons, while the scale $\alpha_{\rm edge}$ must be separately determined for the edge electrons. The energy resolution is parameterized by:

$$\left(\frac{\sigma_E}{E}\right)^2 = (c_{\rm edge})^2 + \left(\frac{s}{\sqrt{E}}\right)^2 + \left(\frac{n}{E}\right)^2$$

where the sampling term s and noise term n are the same as for non-edge electrons. The parameters $f_{\rm edge}$, $\alpha_{\rm edge}$, and $c_{\rm edge}$ are determined by fitting the invariant mass distribution of $\tilde{\rm C}$-C events to two Gaussians, assuming a Z boson mass equal to the measured LEP value. This fit gives

$$\begin{aligned} f_{\rm edge} &= 0.346 \pm 0.076 \\ \alpha_{\rm edge} &= 0.912 \pm 0.018 \\ c_{\rm edge} &= 0.101^{+0.028}_{-0.018}. \end{aligned}$$

Figure 2 shows a fit to the dielectron invariant mass distribution using the sum of two Gaussians, one with the edge parameters determined above and the other with the parameters for non-edge electrons previously determined from C-C events. The parameterization gives a good description of the observed data.

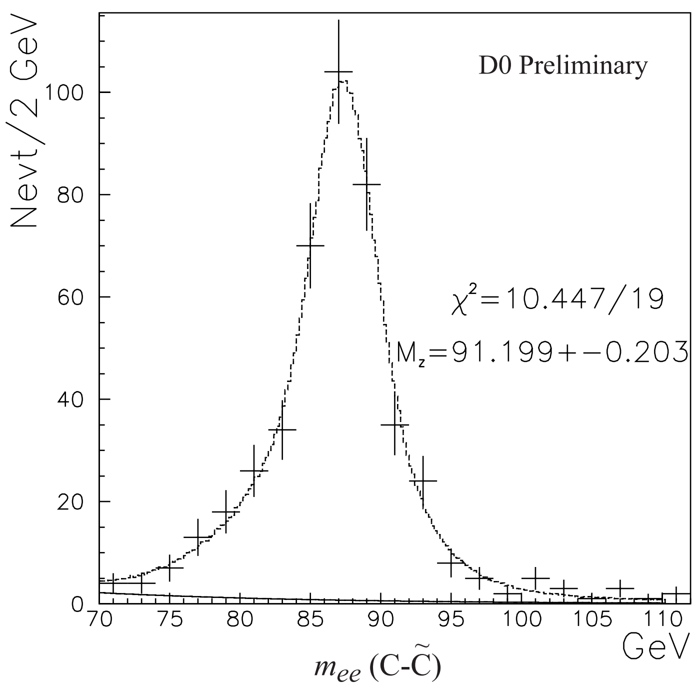

FIG. 2. Dielectron mass distribution for $\tilde{\rm C}$-C events. The dashed histogram shows the maximum likelihood fit and the solid curve is the background contribution.

III. RESULTS

The results of the fits to the transverse mass and electron and neutrino transverse momentum distributions are shown in Fig. 3. The results are:

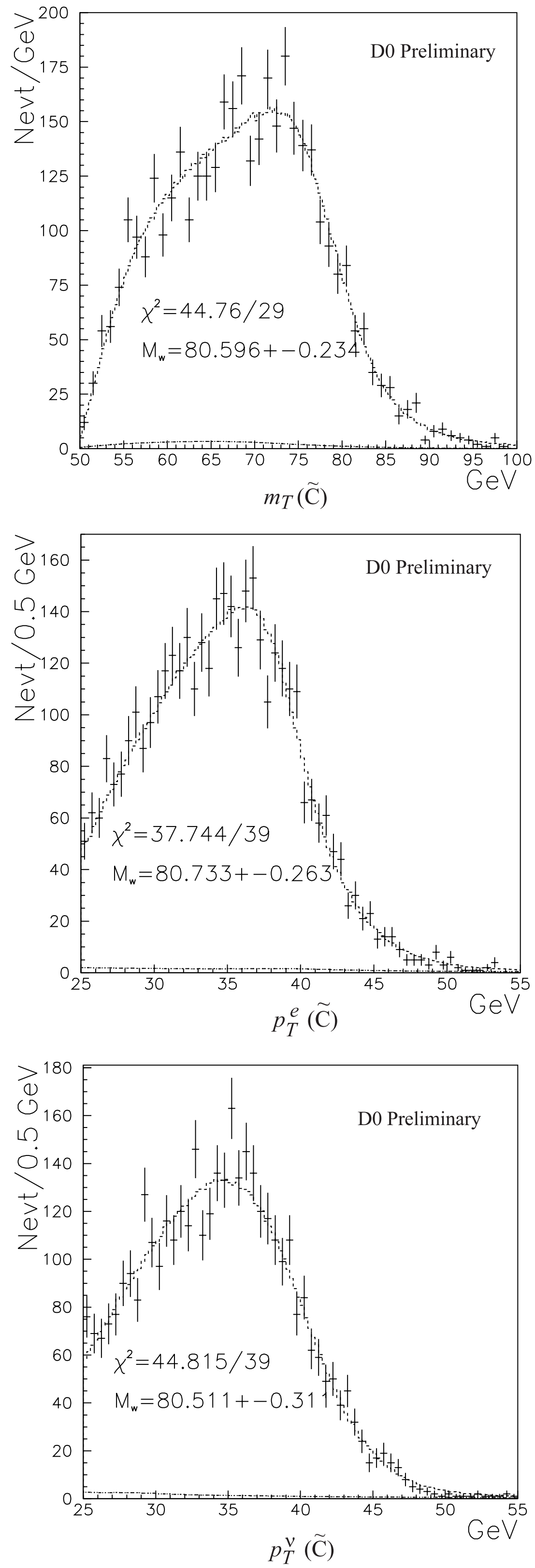

FIG. 3. Distributions of m_T, p_T^e, and p_T^ν from the edge electron W data. The superimposed dashed histograms show the maximum likelihood fits and the solid curves show the estimated backgrounds.

$$m_W = 80.596 \pm 0.234 \text{ (stat) GeV}, \quad \chi^2 = 45/29 \quad (m_T \text{ fit})$$
$$m_W = 80.733 \pm 0.263 \text{ (stat) GeV}, \quad \chi^2 = 38/39 \quad (p_T^e \text{ fit})$$
$$m_W = 80.511 \pm 0.311 \text{ (stat) GeV}, \quad \chi^2 = 45/39 \quad (p_T^\nu \text{ fit})$$

The errors are statistical only. The systematic errors are listed in Table I. Combining these measurements taking into account systematic errors and their correlations gives the final result for the edge electron W mass:

$$m_W = 80.574 \pm 0.405 \text{ GeV}$$

Source	m_T Fit	p_T^e Fit	p_T^ν Fit
W Statistics	234	263	311
Edge EM scale (α_{edge})	265	309	346
CC EM scale (α_{cc})	128	131	113
CC EM offset (δ_{cc})	142	139	145
Calorimeter uniformity	10	10	10
Electron angle calibration	38	40	52
Backgrounds	10	20	20
CC EM resolution (c_{cc})	15	18	2
Edge EM resolution (c_{edge})	268	344	404
Fraction of events (f_{edge})	8	14	22
Recoil response	20	16	46
Recoil resolution	25	10	90
Electron removal	15	15	20
Selection bias	2	9	20
Parton luminosity	9	11	9
Radiative corrections	4	8	0
PDF	0	64	9
$p_T(W)$	10	50	25
W-boson width	10	10	10

TABLE I. W mass uncertainties (in MeV) in the edge electron measurements. The uncertainties due to the edge electron parameters f_{edge}, α_{edge}, and c_{edge} are explained in the text, while details of the other sources of uncertainty are given in Ref. [2].

The $\tilde{\text{C}}$-C $Z \to ee$ data sample provides a means to additionally constrain the central calorimeter scale α_{CC} and resolution constant term c_{CC} for non-edge electrons. Fitting to the observed m_{ee} distribution yields $\alpha_{CC} = 0.9552 \pm 0.0023$. The $\tilde{\text{C}}$-E events can also be used to fit for α_{CC} and α_{EC} yielding $\alpha_{CC} = 0.9559 \pm 0.0107$ and $\alpha_{EC} = 0.9539 \pm 0.0085$. These values are consistent with the results obtained in our earlier analyses of non-edge and EC events and can be combined with them taking into account the correlations to improve the energy scale uncertainty, and hence the uncertainty on the W boson mass measurement.

IV. COMBINED W MASS RESULTS

To obtain the final result for the W boson mass, we combine the following measurements:

(i) The Run 1a W mass measurement from a fit to m_T

(ii) The three Run 1b central calorimeter measurements from fits to m_T, p_T^e, and p_T^ν

(iii) The three Run 1b end calorimeter measurements from fits to m_T, p_T^e, and p_T^ν

(iv) The three edge electron measurements from fits to m_T, p_T^e, and p_T^ν

The measurements in (ii) and (iii) include the improvement due to the additional constraints on the EM calorimeter energy scale from edge events as discussed above.

The final combined result is

$$m_W = 80.483 \pm 0.084 \text{ GeV}$$

This represents an improved error of 7 MeV over our previously published result (80.482 ± 0.091 GeV [2]). A major part of the improved uncertainty is due to the use of the $\tilde{\mathrm{C}}$-C events to constrain the EM calorimeter energy scale for non-edge electrons.

V. CONCLUSION

We have improved the uncertainty in the DØ measurement of the W boson mass, using $W \to e\nu$ and $Z \to ee$ events in which electrons are detected in the edge region at the boundary between modules of the central calorimeter. The new result is $m_W = 80.483 \pm 0.084$ GeV.

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