DØ Note #2920

W Mass Analysis - Run 1A
Study of Bias in CD and CAL positions in W and Z events

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1 Introduction

In the W and Z mass determination, we use the center of gravity (cog) of the CDC track from the DTRK bank (termed CD hit) and the hit in the calorimeter as determined from the energy deposition in EM layer 3 (termed CAL hit) to define the electron angles. In the W data sample, the event vertex is determined by projecting a line drawn from the CD hit and CAL hit to the z-axis. In the Z data sample, a constrained fit is used with the 2 CD hits and 2 CAL hits to determine the vertex and angles.

The data samples are obtained from DSTs processed using RECO 11.19 in which the calorimeter hit position is corrected using CM3POS (see DØ note 2419). The calorimeter hit position is corrected further in the W and Z data samples by using the correction in CM3POS_PV$'$ which has the fit to the 7th order polynomial. The CAL hit correction uses the vertex (determined from the intersection of the electron with the z axis) and therefore the correction and vertex are iterated until they are stable.

There is a bias between the z position of the electron hit calculated using the tracking system and the calorimeter. There were several studies done to determine a correction for the bias in the z position of the CD hit. These analyses did not use the calorimeter information. The correction needed to remove the bias was determined from the muon chamber alignment [1] to be

$$z^t_{CD}(\mathrm{cm}) = 0.987 \times \mathrm{z}^{\mathrm{m}}_{\mathrm{CD}} + .0986,$$

where the superscripts t and m will refer to the true and measured quantities, respectively. However this analysis constrained the electron to point to the RECO z vertex, which itself may be biased. An analysis of cosmic ray data [2] was used to determine the correction to the CD hit without using the RECO vertex. Using this data, it was found that the bias is removed when a scale of 0.988 is applied to the CD hit:

$$z^t_{CD}(\mathrm{cm}) = 0.988 \times \mathrm{z}^{\mathrm{m}}_{\mathrm{CD}}.$$

There are two final data samples each for the W and Z events, both using the corrections and definitions listed above. The first set has the CD hit unscaled and the second set has the measured z position of the CD hit scaled by 0.988. The CAL hit position is slightly different in the two sets of data because of the iterations used in applying the CM3POS_PV′ correction. The first set was used in the analyses described below to determine, using a number of different assumptions, to remove the bias in the data. The standard W and Z event selection is used and also the requirement that the number of vertices equals 1 is placed on the events (unless otherwise specified) [3].

Below we describe a series of studies done to examine and determine corrections for the bias between the CD and CAL position measurements. The change in the W and Z masses due to the corrections are discussed.

2 Using W data to determine correction to biases

To determine the CD and calorimeter scales, we calculate several quantities which should be equal to zero on average. If these quantities do not average to zero, the bias is addressed by using different models and assumptions about it's origin. The scaling needed to remove the bias is then determined for each assumption.

We calculate the quantity S which is defined as the difference of the electron position in the z direction of the CAL hit and the electron position determined by a line drawn using the CD hit and tracking angle extrapolated to EM layer 3

$$S = z^m_{CD} + R_2 \tan\theta^m_{CD} - z^m_{CAL}. \tag{1}$$

Here R_2 is the radial distance from the average position of the measured CD hit z^m_{CD} to the average position of the CAL hit z^m_{CAL} (about 30cm) and the measured polar angle, θ^m_{CD}, is determined relative to the vertical axis. The quantity S is plotted versus the CAL or CD hit z positions. Figure 1 shows S versus z^m_{CD} as a scatter plot. Figure 2 shows S versus

z^m_{CD} as profile plots with z^m_{CD} from $\pm$80cm and $\pm$60cm respectively. Figure 3 shows S versus z^m_{CAL} with z^m_{CAL} from $\pm$80cm and $\pm$120cm respectively. At the larger ranges of z, there may be acceptance biases due to only tracks in the CC being considered. This is because the interaction point is not at $z = 0$, and only tracks originating from certain vertex z positions are accepted.

Another quantity we can examine is the difference between the RECO z-vertex and the electron z-vertex using the CAL and CD hits projected to the z-axis:

$$S^* = z_v^{el} - z_v^{\mathrm{RECO}}. \quad (2)$$

The value of S^* versus z^m_{CAL} is shown in the two parts of figure 4, where z^m_{CAL} is from $\pm$80cm and $\pm$120cm respectively. Figure 4b does not have the requirement that the number of RECO vertices in the event is one.

Table 1 lists the parameters of the fits of the above quantities shown in figures 2 - 4. Below we discuss the results obtained from studying the behavior of the quantities S and S^* using different models for scaling the various quantities.

2.1 CD hit scaling

In this case we assume that the cog of the CDC track observes a scaling law, but not the track angle or calorimeter hit position, i.e.

$$z^m_{CD} = \alpha z^t_{CD} + b$$

$$\tan\theta^m_{CD} = \tan\theta^t_{CD}$$

$$z^m_{CAL} = z^t_{CAL}.$$

Then

$$S = \alpha z^t_{CD} + b + R_2 tan\theta^t_{CD} - z^t_{CAL}$$

	fitting range	slope	intercept(cm)	χ^2/dof
Fig 2a: S vs z_{CD}	$\pm$80cm	.01306 $\pm$ .00067	-.03615 $\pm$ .028	20.9/8
Fig 2b: S vs z_{CD}	$\pm$60cm	.01018 $\pm$ .00094	-.03286 $\pm$ .031	2.42/8
Fig 3a: S vs z_{CAL}	$\pm$80cm	.007245 $\pm$ .00072	-.06057 $\pm$ .032	4.49/8
Fig 3b: S vs z_{CAL}	$\pm$120cm	.008187 $\pm$ .00047	-.08122 $\pm$ .028	9.64/8
Fig 4a: S^* vs z_{CAL}	$\pm$80cm	.01803 $\pm$ .0012	-.2700 $\pm$ .051	6.68/8
Fig 4b: S^* vs z_{CAL}	$\pm$120cm	.02467 $\pm$ .00095	-.2435 $\pm$ .059	46.8/38

Table 1: Parameters of fits of line to S and S^* versus z position of hit

$$S = (\alpha - 1)z^t_{CD} + z^t_{CD} + b + R_2 tan\theta^t_{CD} - z^t_{CAL}$$

and

$$\langle S \rangle = (\alpha - 1)z^t_{CD} + b$$

since the rest of the terms average to zero. We can rewrite this as

$$\langle S \rangle = \frac{(\alpha - 1)}{\alpha} z^m_{CD} + \frac{b}{\alpha}. \tag{3}$$

We use the slopes and intercepts of the fits from the two fitting ranges of figure 2 to determine the values of α and b and obtain $\alpha = 1.0132 \pm .00069$; $b = -.0366 \pm .028$ and $\alpha = 1.0103 \pm .00096$; $b = -.0332 \pm .031$ for $z_{CD} =$ ± 80, ± 60cm respectively. Now $z^t_{CD} = (1/\alpha)z^m_{CD} - b/\alpha$ and therefore we obtain

$$z^t_{CD} = 0.987 z^m_{CD} + 0.0361 \; (|z^m_{cd}| < 60\text{cm})$$

and

$$z^t_{CD} = 0.990 z^m_{CD} + 0.0323 \ (|z^m_{cd}| < 80\text{cm})$$

for the two fitting ranges. The errors on α and b, ignoring correlations, are determined from

$$\delta\alpha = \alpha^2 \delta x$$

$$\delta b = \alpha \delta y$$

where $\delta x, \delta y$ are the errors on the slope and intercept obtained from the fit.

If instead we want to write this in terms of z_{CAL} then we use

$$z^t_{CAL} = z^t_{CD} + R_2 tan\theta^t_{CD}$$

and

$$z^t_{CAL} = z^t_v + (z^t_{CAL} - z^t_{CD})\frac{R}{R_2}$$

where R is the radial distance to the calorimeter hit (about 90 cm) and z^t_v is the true z vertex. Then we get

$$\langle S \rangle = (\alpha - 1)\left(1 - \frac{R_2}{R}\right) z^m_{CAL} + (\alpha - 1)\left(\frac{R_2}{R}\right) z^t_v + b \qquad (4)$$

since $z^t_{CAL} = z^m_{CAL}$.

Since z^t_v extends ± 30cm, z_{cal} may depend on its value and therefore this method may be biased. Using this method, we cannot solve for the intercept b. However using the value of α calculated from this method and $b = -0.0332$cm obtained from the previous analysis, one can solve for z^t_v. Using the slopes and intercepts from the fits to figure 3 and solving for α we obtain $\alpha = 1.0109 \pm .0011$ and $1.0123 \pm .0007$ for the two fitting ranges. This gives a scaling of $z^t_{CD} \propto 0.989 z^m_{CD}$ and $z^t_{CD} \propto 0.988 z^m_{CD}$ and a vertex $z^t_v = -7.5$ or -11.7cm for the two fitting ranges, respectively. The value obtained from 3a which is the better fit (since the χ^2 of the fit is smaller), is in very good agreement with the average RECO z vertex, which is -8.0 cm. If we assume that $z_v^t = -8$cm and then solve for b, we obtain $b = -.0315 \pm .032$ and $-.0484 \pm .028$ for the two fitting ranges. Therefore

$$z_{CD}^t = 0.989 z_{CD}^m + 0.0315 \; (|z_{cal}^m| < 80\text{cm})$$

and

$$z_{CD}^t = 0.988 z_{CD}^m + 0.0478 \; (|z_{cal}^m| < 120\text{cm})$$

for the two fitting ranges. The errors on α and b are determined from

$$\delta\alpha = \frac{1}{(1 - \frac{R_2}{R})}\delta x$$

$$\delta b = \delta y$$

where $\delta x, \delta y$ are the errors on the slope and intercept obtained from the fit.

2.2 CD and CAL hit scaling

In this case we assume that both the CD and CAL hits scale but not the track angle, i.e.

$$\begin{aligned} z_{CD}^m &= \alpha z_{CD}^t + b \\ \tan\theta_{CD}^m &= \tan\theta_{CD}^t \\ z_{CAL}^m &= \beta z_{CAL}^t + b', \end{aligned}$$

then

$$\langle S \rangle = \left[(\alpha - 1) + \frac{(\beta - 1)(\frac{R}{R_2})}{(1 - \frac{R}{R_2})}\right] z_{CD}^t - \frac{(\beta - 1)}{(1 - \frac{R}{R_2})} z_v^t + (b - b')$$

and

$$\langle S \rangle = \left(\frac{1}{\alpha}\right)\left[(\alpha - 1) + \frac{(\beta - 1)(\frac{R}{R_2})}{(1 - \frac{R}{R_2})}\right] z_{CD}^m - \left(\frac{b}{\alpha}\right)\left[(\alpha - 1) + \frac{(\beta - 1)(\frac{R}{R_2})}{(1 - \frac{R}{R_2})}\right] - \frac{(\beta - 1)}{(1 - \frac{R}{R_2})} z_v^t + (b - b'). \tag{5}$$

Taking $1/\alpha$ to be 0.988, which is the value obtained from the cosmic ray study, and using the value $b = -.0332$cm obtained previously and the average RECO vertex $z_v^t = -8$cm, we can solve for the CAL scale and offset using the results of the fits from figure 2. Using these values, we then get $\beta = .9992 \pm .00044$; $b' = .0066 \pm .028$ and $\beta = 1.001 \pm .00063$; $b' = -.0007 \pm .031$ for the two fitting ranges. Thus we obtain

$$z_{CAL}^t = 1.001 z_{CAL}^m - .0066 \ (|z_{cd}^m| < 80\text{cm})$$

and

$$z_{CAL}^t = 0.999 z_{CAL}^m + .0007 \ (|z_{cd}^m| < 60\text{cm}).$$

The errors on β and b' are determined from

$$\delta\beta = \frac{\alpha(1 - \frac{R}{R_2})}{\frac{R}{R_2}} \delta x$$

$$\delta b' = -\delta y$$

where $\delta x, \delta y$ are the errors on the slope and intercept obtained from the fit. The errors on α and b have been ignored.

If we instead write S in terms of z_{CAL} then

$$\langle S \rangle = \left[(\alpha - 1)(1 - \frac{R_2}{R}) - (\beta - 1) \right] z_{CAL}^t + \frac{R_2}{R}(\alpha - 1) z_v^t + (b - b')$$

and

$$\langle S \rangle = \left[\frac{(\alpha - 1)}{\beta}(1 - \frac{R_2}{R}) - \frac{(\beta - 1)}{\beta} \right] z_{CAL}^m - \left(\frac{b'}{\beta} \right) \left[(\alpha - 1)(1 - \frac{R_2}{R}) - (\beta - 1) \right] + \frac{R_2}{R}(\alpha - 1) z_v^t + (b - b'). \tag{6}$$

As before we use $1/\alpha = 0.988$, $z_v^t = -8$cm and $b = -.0332$cm and the results of of the fits from figure 3 to obtain $\beta = 1.0007 \pm .00072$; $b' = -.0046 \pm .032$ and $\beta = 0.9998 \pm .00047$; $b' =$

$-.0046 \pm .028$ for the two fitting ranges. Thus we obtain

$$z^t_{CAL} = 0.9993 z^m_{CAL} + .0046 \ (|z^m_{cal}| < 80\text{cm})$$

and

$$z^t_{CAL} = 1.0002 z^m_{CAL} + .0046 \ (|z^m_{cal}| < 120\text{cm}).$$

The errors on β and b' are determined from

$$\delta\beta = \frac{\beta^2}{1 + (\alpha - 1)(1 - \frac{R_2}{R})}\delta x$$

$$\delta b' = \frac{\beta}{\frac{R_2}{R}(\alpha - 1) - \alpha}\delta y$$

where $\delta x, \delta y$ are the errors on the slope and intercept obtained from the fit and the errors on α and b have been ignored. Using the independent measurement of the CD scale from the cosmic ray analysis, which was obtained without any calorimeter information, we find the calorimeter exhibits no scaling behavior. That is, within errors there is no offset and the measured position equals the true position.

2.3 CD hit and angle scaling

We assume that both the CD hit and angle scale but not the CAL hit, i.e.

$$z^m_{CD} = \alpha z^t_{CD} + b$$

$$\tan\theta^m_{CD} = \alpha \tan\theta^t_{CD}$$

$$z^m_{CAL} = z^t_{CAL}$$

$$S = \alpha z^t_{CD} + b + R_2 \alpha \tan\theta^t_{CD} - z^t_{CAL}.$$

Therefore on average

$$\langle S\rangle = (\alpha - 1)z^t_{CAL} + b$$

and

$$\langle S\rangle = (\alpha - 1)z^m_{CAL} + b. \tag{7}$$

We use the results of the fits from figure 3 and and determine $\alpha = 1.007245 \pm .00072;\ b = -.06057 \pm .032$ and $\alpha = 1.008187 \pm .00047;\ b = -.08122 \pm .028$ and therefore

$$z^t_{CD} = 0.993 z^m_{CD} + .061\ (|z^m_{cal}| < 80\text{cm})$$

and

$$z^t_{CD} = 0.992 z^m_{CD} + .082\ (|z^m_{cal}| < 120\text{cm}).$$

If we write S in terms of z_{CD} then we use

$$z^t_{CAL} = z^t_v + (z^t_{CAL} - z^t_{CD})(R/R_2)$$

and write

$$\langle S\rangle = \frac{-\frac{R}{R_2}(\alpha - 1)}{(1 - \frac{R}{R_2})} z^t_{CD} + \frac{(\alpha - 1)}{(1 - \frac{R}{R_2})} z^t_v + b$$

and

$$\langle S\rangle = \frac{-R(\alpha - 1)}{\alpha R_2(1 - \frac{R}{R_2})} z^m_{CD} + \frac{bR(\alpha - 1)}{\alpha R_2(1 - \frac{R}{R_2})} + \frac{(\alpha - 1)}{(1 - \frac{R}{R_2})} z^t_v + b. \tag{8}$$

Using the results of the fits from figure 2 and $z^t_v = -8$cm we obtain $\alpha = 1.0088 \pm .00045;\ b = -.097 \pm .032$ and $\alpha = 1.0068 \pm .00064;\ b = -.1095 \pm .028$ for the two fitting ranges and therefore

$$z^t_{CD} = 0.991 z^m_{CD} + .096\ (|z^m_{cd}| < 80\text{cm})$$

and

$$z^t_{CD} = 0.993 z^m_{CD} + .109\ (|z^m_{cd}| < 60\text{cm}).$$

The errors on α and b are determined from

$$\delta\alpha = \frac{\alpha^2(1-\frac{R}{R_2})}{\frac{R}{R_2}}\delta x$$

$$\delta b = \frac{\alpha(1-\frac{R}{R_2})}{\alpha-\frac{R}{R_2}}\delta y$$

where $\delta x, \delta y$ are the errors on the slope and intercept obtained from the fit.

2.4 CD hit and angle and CAL hit scaling

Now if we assume that both the CD and CAL hits need to be scaled along with the CD angle, i.e.

$$z^m_{CD} = \alpha z^t_{CD} + b$$

$$tan\theta^m_{CD} = \alpha tan\theta^t_{CD}$$

$$z^m_{CAL} = \beta z^t_{CAL} + b',$$

then

$$\langle S\rangle = (\alpha-\beta)z^t_{CAL} + (b-b')$$

and

$$\langle S\rangle = \frac{(\alpha-\beta)}{\beta}z^m_{CAL} + b - \frac{b'\alpha}{\beta} \tag{9}$$

We use the results of the fits from figure 3 and the values of $\alpha = 1.0068$ and $b = .006$cm from the CD hit and angle scaling study above and obtain $\beta = .9996 \pm .00071$; $b' = .066 \pm .032$ and $\beta = .9986 \pm .00047$; $b' = .086 \pm .028$ for the two fitting ranges and therefore

$$z^t_{CAL} = 1.0004 z^m_{CAL} - .066 \ (|z^m_{cal}| < 80\text{cm})$$

and

$$z^t_{CAL} = 1.0014 z^m_{CAL} - .086 \ (|z^m_{cal}| < 120\text{cm}).$$

The errors on β and b' are determined from

$$\delta\beta = \frac{\beta^2}{\alpha}\delta x$$

$$\delta b' = \frac{\beta}{\alpha}\delta y$$

where $\delta x, \delta y$ are the errors on the slope and intercept obtained from the fit.

If we rewrite this in terms of z_{CD} then

$$\langle S\rangle = \frac{-(\alpha-\beta)(\frac{R}{R_2})}{(1-\frac{R}{R_2})} z^t_{CD} + \frac{(\alpha-\beta)}{(1-\frac{R}{R_2})} z^t_v + (b-b')$$

$$\langle S\rangle = \frac{-(\alpha-\beta)(\frac{R}{R_2})}{\alpha(1-\frac{R}{R_2})} z^m_{CD} + \frac{bR(\alpha-\beta)}{\alpha R_2(1-\frac{R}{R_2})} + \frac{(\alpha-\beta)}{(1-\frac{R}{R_2})} z^t_v + (b-b') \tag{10}$$

We use the results of the fits from figure 2 and the values of $\alpha = 1.0068$ and $b = .006$ from the CD hit and angle scaling study above and set $z^t_v = -8\mathrm{cm}$ and obtain $\beta = .998 \pm .00045$; $b' = .076 \pm .028$ and $\beta = 1.000 \pm .00063$; $b' = .066 \pm .031$ for the two fitting ranges and therefore

$$z^t_{CAL} = 1.002 z^m_{CAL} - .076 \ (|z^m_{cd}| < 80\mathrm{cm})$$

and

$$z^t_{CAL} = 1.000 z^m_{CAL} - .066 \ (|z^m_{cd}| < 60\mathrm{cm}).$$

The errors on β and b' are determined from

$$\delta\beta = \frac{\alpha(1-\frac{R}{R_2})}{\frac{R}{R_2}}\delta x$$

$$\delta b' = \delta y$$

where $\delta x, \delta y$ are the errors on the slope and intercept obtained from the fit.

2.5 CD hit scaling - vertex difference

We assume that

$$z^m_{CD} = \alpha z^t_{CD} + b$$
$$z^m_{CAL} = z^t_{CAL}$$
$$z^{\mathrm{RECO}}_v = \alpha z^t_v + b.$$

Then

$$S^* = z^m_{CAL} - \frac{R}{R_2}(z^m_{CAL} - z^m_{CD}) - z^{\mathrm{RECO}}_v.$$

We use

$$z^t_{CD} = \frac{R_2}{R} z^t_v + \frac{R_1}{R} z^t_{CAL},$$

where R_1 is the radial distance from the z-axis to the CD hit position (about 60 cm), and $R = R_1 + R_2$ and obtain

$$\langle S^* \rangle = (1-\alpha)(1 - \frac{R}{R_2}) z^m_{CAL} - (1 - \frac{R}{R_2}) b. \tag{11}$$

This method is not as good as the previous ones because of the assumption that the RECO vertex scales with the true vertex, which may not be completely accurate because of the complicated algorithms involved in determining the vertex. However, we use it as another check. We use the results of the fits from figure 4 and obtain $\alpha = 1.0090 \pm .0006$; $b = -.135 \pm .025$ and $\alpha = 1.0123 \pm .00048$; $b = -.122 \pm .029$ for the two fitting ranges and therefore

$$z^t_{CD} = 0.991 z^m_{CD} + .134 \ (|z^m_{cal}| < 80\text{cm})$$

and

$$z^t_{CD} = 0.988 z^m_{CD} + .120 \ (|z^m_{cal}| < 120\text{cm}).$$

The errors on α and b are determined from

$$\delta\alpha = \frac{-1}{(1 - \frac{R}{R_2})}\delta x$$

x-axis variable plotted	limits	CD hit scaled to determine CD hit scale	offset	CD hit and angle scaled to determine CD hit scale	offset	CD hit and vertex scaled to determine CD hit scale	offset
z_{CD}	±80cm	0.987±.0007	.036±.028	0.991±.0005	.096±.032		
z_{CD}	±60cm	0.990±.0009	.032±.031	0.993±.0006	.109±.028		
z_{CAL}	±80cm	0.989±.001	.031±.032	0.993±.0007	.061 ±.032	0.991±.0006	.134 ±.025
z_{CAL}	±120cm	0.988±.0007	.048±.028	0.992±.0007	.082 ±.028	0.988±.0005	.120 ±.029

Table 2: Results of studies to determine CD scale and offset.

$$\delta b = \frac{-1}{(1 - \frac{R}{R_2})}\delta y$$

where $\delta x, \delta y$ are the errors on the slope and intercept obtained from the fit.

2.6 Summary of Results of W Studies

Table 2 lists a summary of the results obtained from the above studies to determine the scale factor and offset needed to correct the CD hit or CD hit and angle. The first two columns of numbers in this table are obtained from the plots of the quantity S and the last column is obtained from the plots of S^*. Table 3 lists a summary of the results obtained from the above studies to determine the scale factor and offset needed to correct the CAL hit, where the CD hit scale and offset was taken from previous studies. The two columns of numbers in this table are obtained from the results of the plots of the quantity S.

2.7 Application of Results

A factor of 0.988 for the CD hit scale was obtained from the cosmic ray analysis and this scale is used to correct the z_{CD} in the final data sample for the W and Z mass analysis. We apply this scale to the CD hit in the data to determine the effect on the quantity S. Figure 5 shows the quantity S when the CD hit is scaled by 0.988 versus z_{CD} and versus z_{CAL} with

x-axis variable plotted	limits	CD and CAL hit scaled to determine CAL hit: scale	offset	CD hit and angle and CAL hit scaled to determine CAL hit: scale	offset
z_{CD}	±80cm	1.001±.0005	-.007±.028	1.002±.0005	-.076±.028
z_{CD}	±60cm	.999 ±.0005	.001 ±.031	1.000±.0006	-.066±.031
z_{CAL}	±80cm	.9993±.0005	.0046±.032	1.000±.0007	-.066±.032
z_{CAL}	±120cm	1.0002±.0005	.0046±.028	1.001±.0005	-.086±.028

Table 3: Results of studies to obtain CAL scale and offset assuming previously measured values for CD scale.

and without the 1 vertex requirement. The values of S are now closer to zero than when unscaled and except for the points at large z (which are near the edge of acceptance), the scaled data follows a line. The first plot in the figure is fit to a line from $z_{CD} = \pm 60$cm as in the unscaled data (Fig. 2b). The slope and intercept of the line fit to the scaled data are $-0.0018, -0.032$cm, respectively, which is an improvement of approximately a factor of 5 in the slope compared to the unscaled data and a slight improvement in the intercept. However the χ^2 of the fit is 2.54/8 which is slightly worse than the fit to the unscaled data.

We determine the effect on the quantity S when applying the corrections determined in the analysis presented here in which only the CD hit was scaled. The fits to the values of S versus z_{CD} from ±60cm and z_{CAL} from ±80cm have the smallest χ^2 values and gave scale factors between 0.989 and 0.990 with an offset of ≈ 0.032cm. Figure 6 shows the quantity S when the CD hit is scaled by 0.990 and with an offset of 0.032cm versus z_{CD} and versus z_{CAL} with and without the 1 vertex requirement. The value of S is now closer to zero as a function of z than when using a scale factor of 0.988 as shown in Fig. 5. The first plot in the figure is fit to a line from $z_{CD} = \pm 60$cm. The slope and intercept of the line are $0.00020, -0.00044$cm, respectively, and the fit has $\chi^2 = 2.52/8$. These results improve on the slope and intercepts obtained when scaling the data by 0.988 (Fig. 5) by a factor of 70 in the slope and a factor of 9 for the intercept.

Fig #	CD hit scale,offset	CAL hit scale,offset	CD angle scale	intercept(cm)	slope	χ^2/dof
5a	0.988,0.0	1.0,0.0	1.0	-0.032	-0.0018	2.54/8
6a	0.990,0.032	1.0,0.0	1.0	-0.00044	0.00020	2.52/8
7a	0.993,0.06	1.0,0.0	0.993	0.0025	0.00022	2.43/8
8a	0.988,0.032	0.999,0.0005	1.0	0.0027	-0.00038	2.54/8

Table 4: Parameters of fits of line to S versus z position of unscaled CD hit

Now we examine what happens to the data when both the CD hit and angle are scaled using the factors determined from the data. Figure 7 shows the quantity S versus z_{CD} and versus z_{CAL} when the CD hit is scaled by 0.993 with an offset of 0.06cm and the CD angle is scaled by 0.993. The first plot in the figure is fit to a line from $z_{CD} = \pm 60$cm. The slope (0.00022) is consistent and the intercept (0.0025) is a factor of 5 times larger than when just the hit is scaled (Fig. 6). The $\chi^2 = 2.43/8$, which is slightly better.

The last application is to examine what happens to the data when the CD and CAL hit are scaled by the amount obtained from the above studies. Figure 8 shows the quantity S versus z_{CD} when the CD hit is scaled by 0.988 with an offset of 0.032cm and the CAL hit is scaled by 0.999 with an offset of 0.0005cm. The first plot in the figure is fit to a line from $z_{CD} = \pm 60$cm. The slope (-0.00038) and intercept (0.0027) are larger than when just the CD hit is scaled (Fig. 6) but the intercept is consistent with that obtained when the CD hit and angle are scaled. The $\chi^2 = 2.54/8$, which is consistent with the other scalings applied. The CAL hit scale is 1.0 when both the CD hit and angle are scaled, which is the same scaling as shown in Fig. 7, so this configuration has already effectively been shown.

The summary of these results is listed in Table 4. From these studies and results, we conclude that biases in the data are most effectively removed by correcting the z position of the CD hit by

$$z_{CD} \rightarrow 0.990 \times z_{CD} + 0.032.$$

The CAL hit scaling obtained is consistent with 1.0.

CD hit scale	ΔM_W (MeV/c^2) $M_T(W)$	$P_T(e)$	$P_T(\nu)$	ΔM_Z (MeV/c^2) M_Z
0.988	-472	-494	-501	-177
0.990	-396	-411	-417	-151
0.992	-305	-329	-326	-124
0.994	-221	-255	-247	-97
0.996	-145	-179	-167	-57
0.998	-74	-103	-66	-29
1.00	-	-	-	-
slope	39.58	40.08	42.24	15.02
intercept	41.31	40.76	38.27	72.14

Table 5: Difference in mass for the fits to the W and Z spectra as a function of the CD hit scale compared to the masses obtained with a scale factor of 1.0. The slope and intercept of a line fit to the distribution of ΔM versus CD hit scale for each spectrum is also listed.

3 Effect of CD hit scale on W and Z mass

The W and Z masses depend on the scale factor and offset used to correct the bias in the CD hit. In the final data sample, a scale factor of 0.988 (which was obtained from the cosmic ray analysis) is used to correct for the bias in the CD hit. To determine the sensitivity of the the W and Z mass to the CD hit scale, the data were processed with a range of scale factors. These results are shown in Table 5 for fits of the three W spectra and the Z invariant mass spectrum. The parameters of a fit to a line for each spectrum are also listed and the results are that the W mass increases by 39.6 MeV/c^2 per increase of 0.001 in CD scale (for the $M_T(W)$ spectrum) and the Z mass increases by 15.0 MeV/c^2 per increase of 0.001 in CD scale.

To determine how an offset in the CD hit affects the mass, we scale and add an offset to the CD hit from the unscaled data and recalculate the mass using the $M_T(W)$ spectrum for the W. These results are shown in Table 6 and in figure 9. These values may not be exactly the same as if the data was scaled when processed because the iterations (as discussed in the introduction) are not applied to the scaled values used here. The change in mass of the W is -473 MeV/c^2 when the CD scale changes from 1.0 to 0.988, which is an increase of 39.4 MeV/c^2 per increase of 0.001 in CD scale. The average change in the mass of the W with an offset in the CD z hit position of 0.4 cm is 10 MeV/c^2, which is an increase of 2.5 MeV/c^2 per increase of 0.1 cm in the CD offset. Using an offset of ≈ 0.03 cm which was obtained from the studies presented above, the resulting change in the W mass is < 1 MeV/c^2.

4 Conclusions

The bias that exists between the z position of the electron in the tracking system and calorimeter has been examined using the run 1A W and Z event samples. The measured calorimeter position was determined to be consistent with the true calorimeter position. We determine that the bias in the data can be removed when correcting the CD hit by

$$z^t_{CD}(\mathrm{cm}) \rightarrow (0.990 \pm 0.001) z^m_{CD} + (0.032 \pm 0.032).$$

The data were also examined to determine if there is a bias in the CD angle as well as the z hit coordinate and the results of the above analyses do not rule this out. However the bias in the data corrected for both the hit and angle does not improve when scaling the angle as well as the hit.

For the final W and Z data samples used in the W mass analysis, the data have a scale of 0.988 applied to the z coordinate of the CD hit position. This causes the measured W and Z masses to decrease by 472 MeV/c^2 and 177 MeV/c^2, respectively, compared to the unscaled data. If the data were instead scaled by 0.990, which is the value determined in the analyses presented here, the W and Z masses would instead decrease by 396 MeV/c^2 and 151 MeV/c^2, respectively. Since the ratio of the W to Z mass is used for the final result, we determine the sensitivity of the final W mass value by taking the difference in sensitivities, that is the mass increases by $39.6 - 15.0 = 24.6$ MeV/c^2 per increase of 0.001 in the CD scale.

CD scale	CD offset	ΔW mass (MeV/c^2) (scaled - unscaled value)
1.0	0.0	-
1.0	-0.1	7
1.0	0.1	14
1.0	0.2	26
0.998	0.0	-63
0.998	-0.1	-64
0.998	0.1	-70
0.998	0.2	-51
0.996	0.0	-140
0.996	-0.1	-149
0.996	0.1	-139
0.996	0.2	-137
0.994	0.0	-218
0.994	-0.1	-225
0.994	0.1	-220
0.994	0.2	-216
0.992	0.0	-303
0.992	-0.1	-305
0.992	0.1	-306
0.992	0.2	-299
0.990	0.0	-391
0.990	-0.1	-392
0.990	0.1	-384
0.990	0.2	-383
0.988	0.0	-473
0.988	-0.1	-468
0.988	0.1	-469
0.988	0.2	-463

Table 6: Change in W mass when rescaling and adding an offset to the CD hit as compared to the unscaled data.

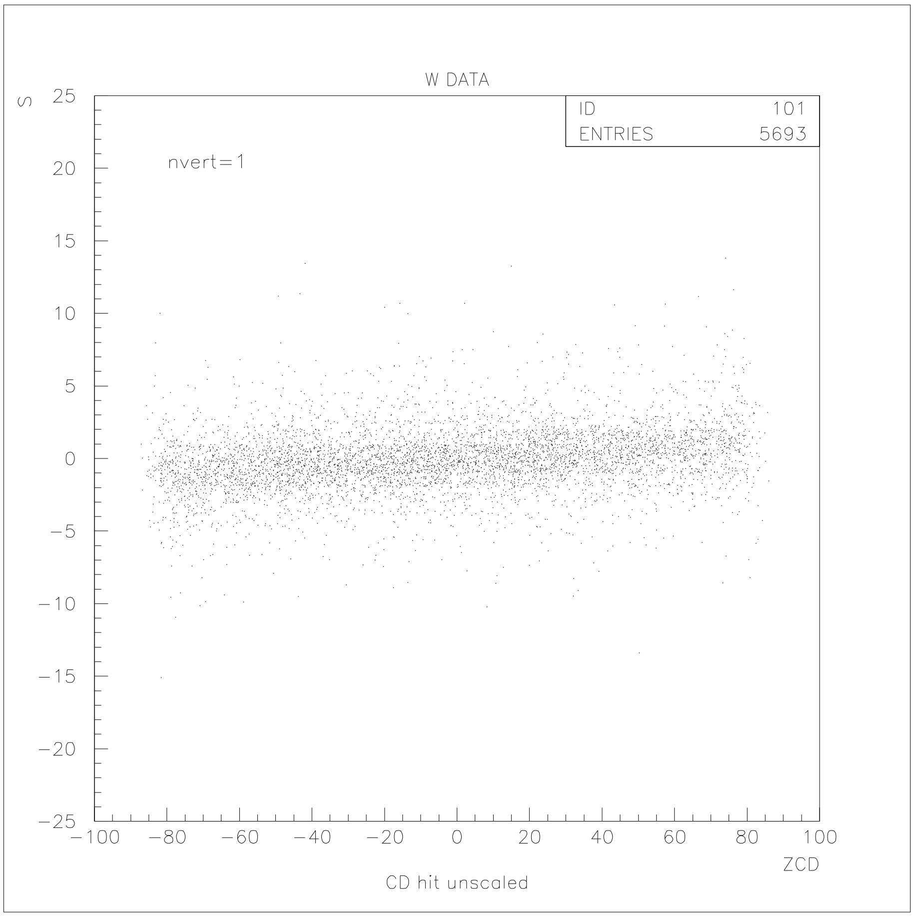

Figure 1: Difference (S) in z values of CAL hit and projection to EM3 of line defined by CD hit and tracking angle vs z_{CD} for W events with only 1 vertex.

References

[1] Johari,Smart,Taketani,Yasuda, "Muon Chamber Alignment", DØ note #2279 (1994).

[2] Graf and Yasuda.

[3] M. Demarteau, J. Sculli, K. Streets, Run 1A W mass analysis paper.

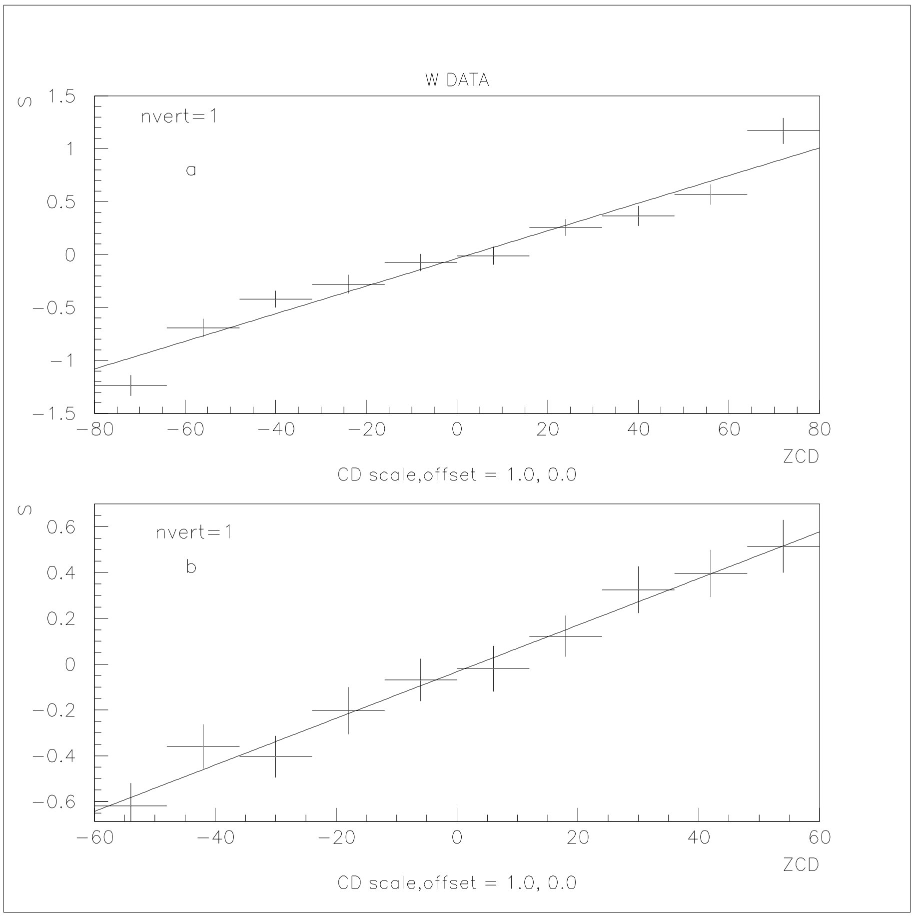

Figure 2: Difference (S) in z values of CAL hit and projection to EM3 of line defined by CD hit and tracking angle vs z_{CD} for W events with only 1 vertex for $z^m_{CD} = \pm 80$cm in a and $z^m_{CD} = \pm 60$cm in b.

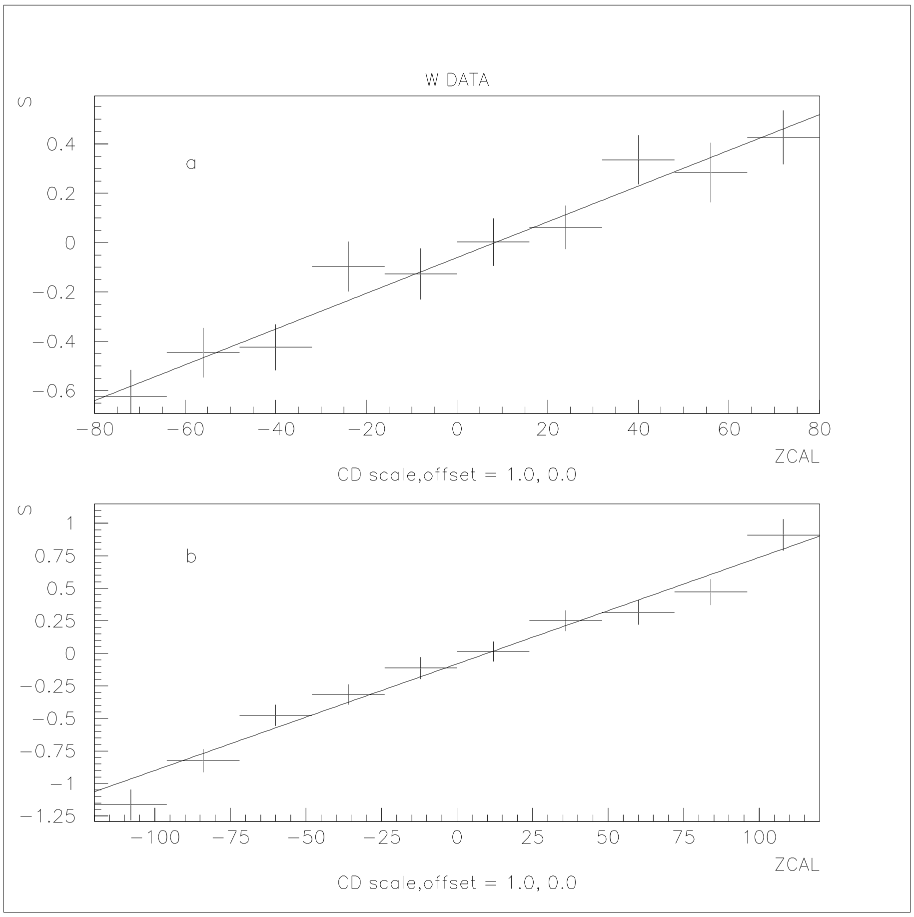

Figure 3: Difference (S) in z values of CAL hit and projection to EM3 of line defined by CD hit and tracking angle vs z_{CAL} for W events with only 1 vertex for $z^m_{CAL} = \pm 80$ in a and $z^m_{CAL} = \pm 120$ in b.

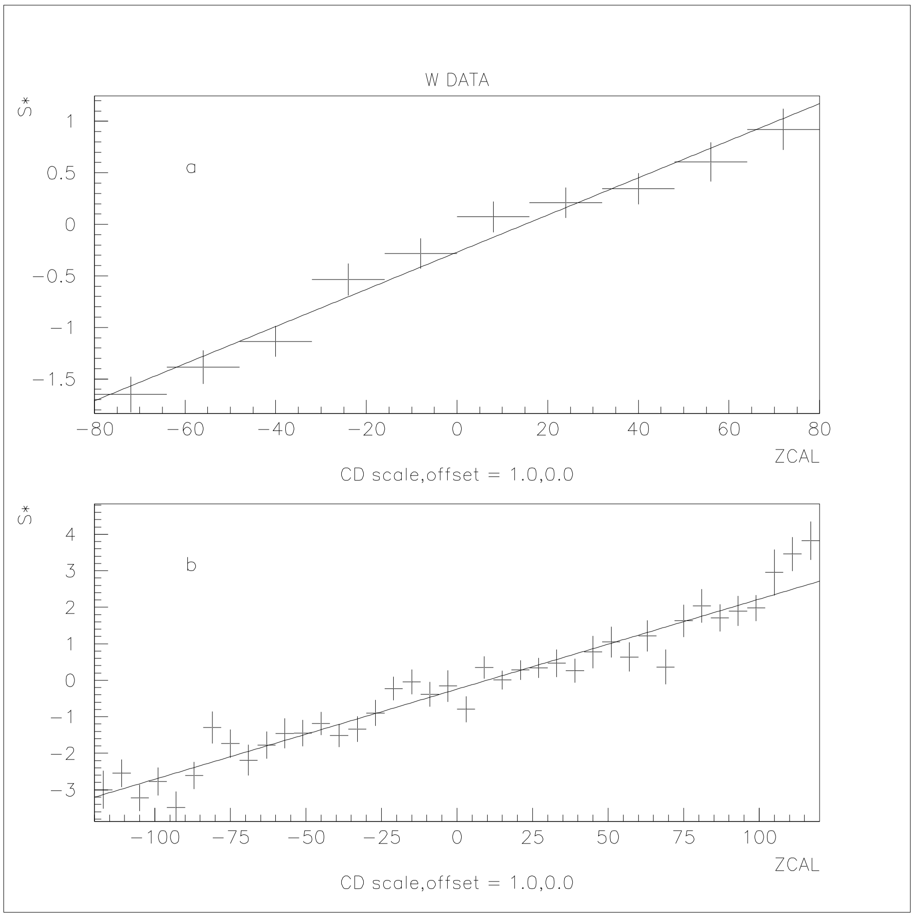

Figure 4: Difference (S^*) in z-vertex obtained using CD and CAL hits and RECO z-vertex vs z_{CAL} for W events with only 1 vertex and $z^m_{CAL} = \pm 80$cm in a and for all W events and $z^m_{CAL} = \pm 120$cm in b

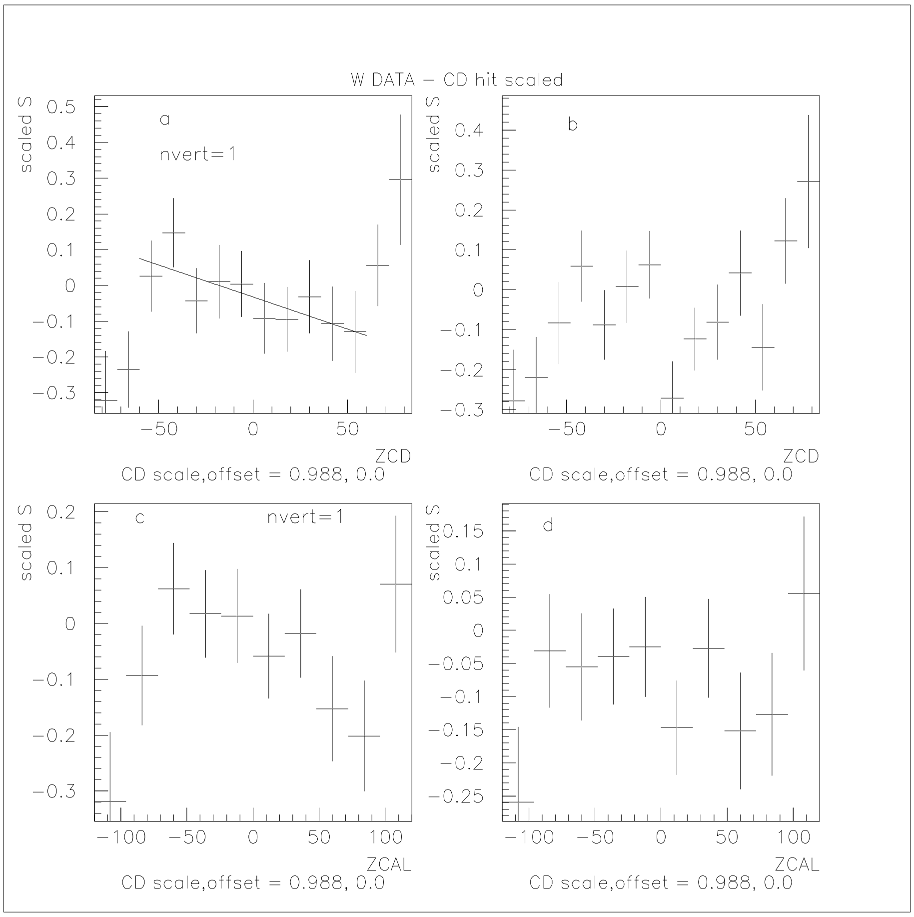

Figure 5: Difference (S) in z values of CAL hit and projection to EM3 of line defined by CD hit (scaled by 0.988) and tracking angle vs z_{CD} and vs z_{CAL} for W events with and without the 1 vertex requirement. The fit to the line in a is over the central 10 points.

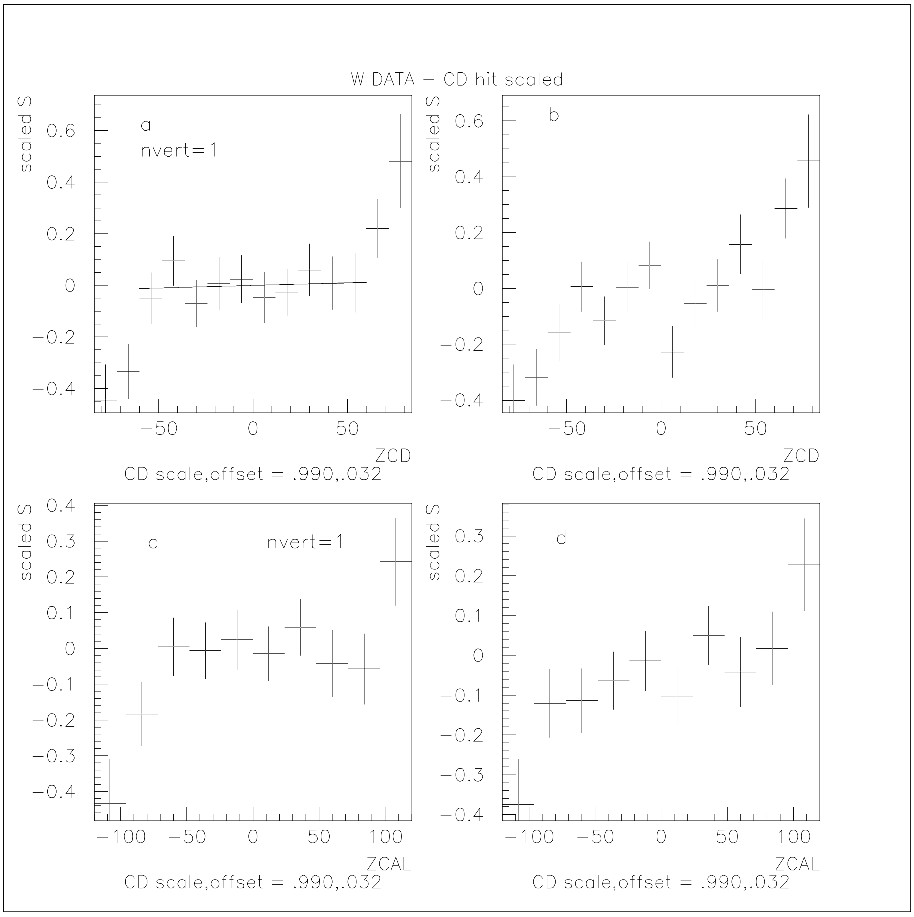

Figure 6: Difference (S) in z values of CAL hit and projection to EM3 of line defined by CD hit (scaled by 0.990 and with an offset of 0.032 cm applied) and tracking angle vs z_{CD} and vs z_{CAL} for W events with and without the 1 vertex requirement. The fit to the line in a is over the central 10 points.

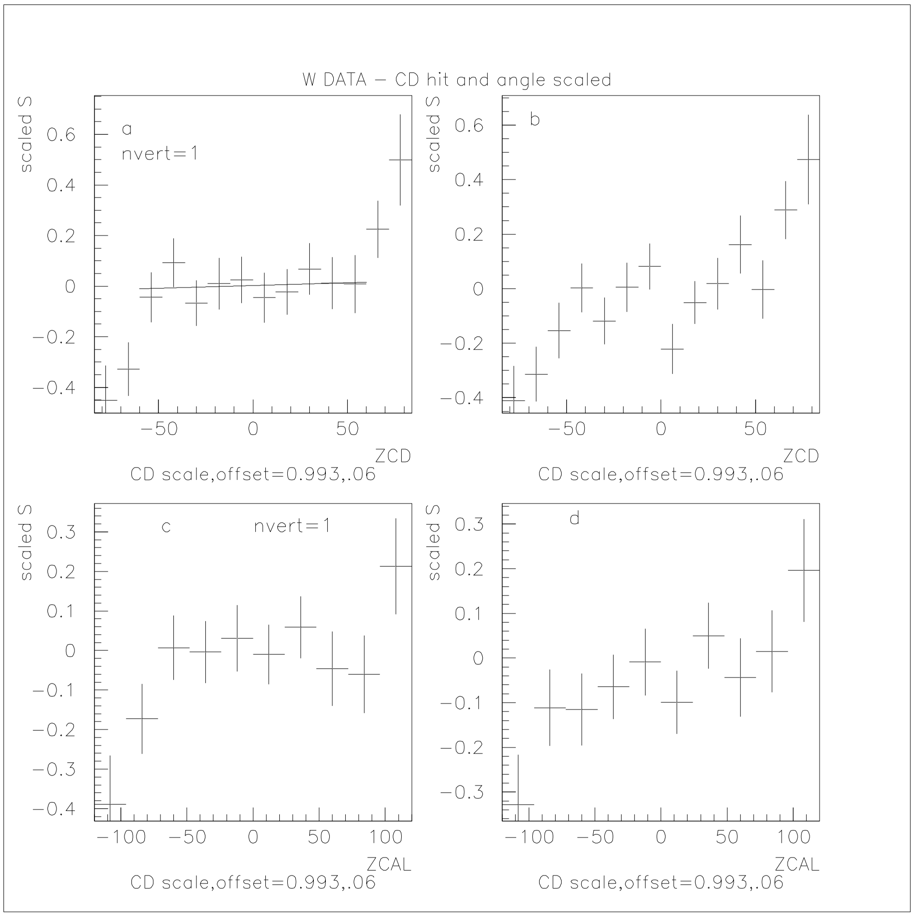

Figure 7: Difference (S) in z values of CAL hit and projection to EM3 of line defined by CD hit (scaled by 0.993 and with an offset of 0.06 cm applied) and tracking angle (scaled by 0.993) vs z_{CD} and vs z_{CAL} for W events with and without the 1 vertex requirement. The fit to the line in a is over the central 10 points.

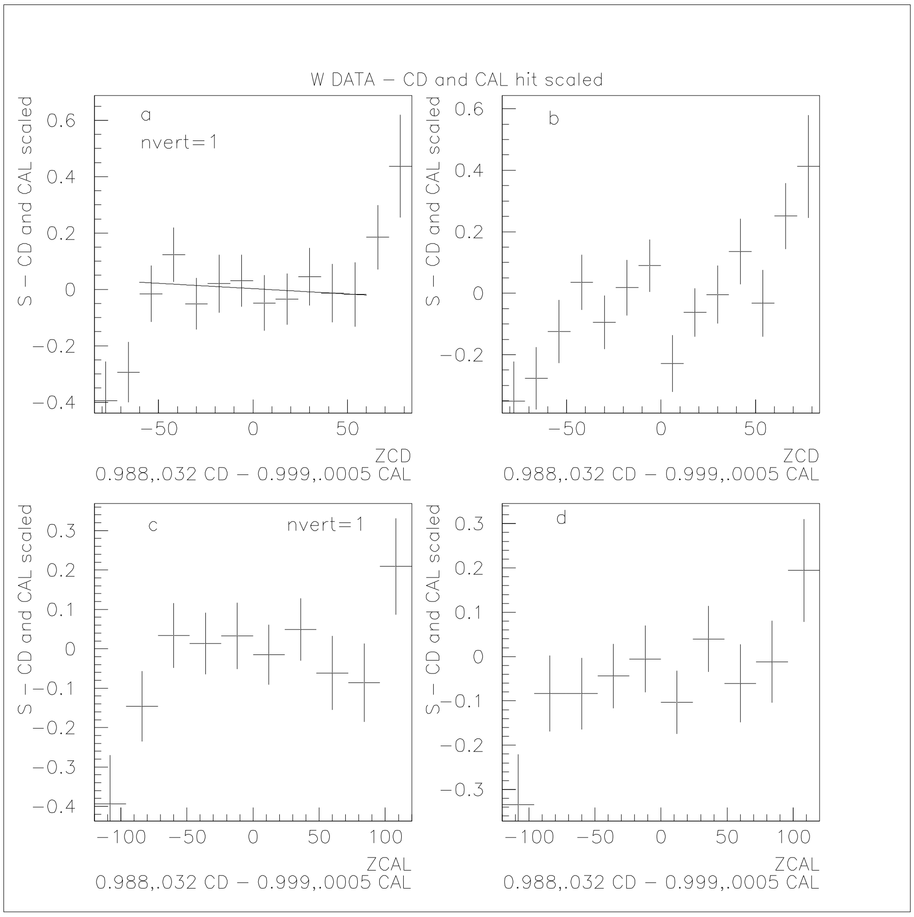

Figure 8: Difference (S) in z values of CAL hit (scaled by 0.999 with offset .0005 cm) and projection to EM3 of line defined by CD hit (scaled by 0.988 and with an offset of 0.032 cm applied) and tracking angle vs z_{CD} and vs z_{CAL} for W events with and without the 1 vertex requirement. The fit to the line in a is over the central 10 points.

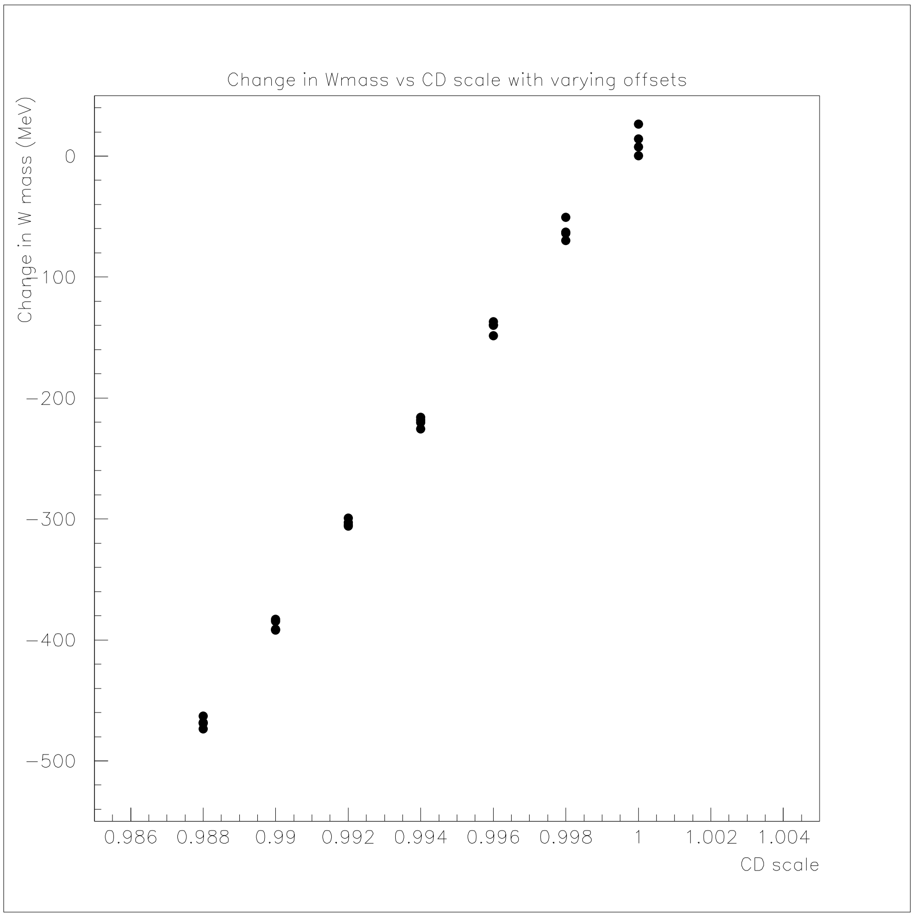

Figure 9: Δ W mass versus the multiplicative scale factor applied to the z position of the CD hit in the unscaled data. For each value of the scale factor, there are 4 different offsets also applied to the CD hit and the masses obtained are shown as separate points for these 4 offsets.