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Effects of Shower Spreading on $Z^0 \rightarrow JJ$ Mass Resolution

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1 Introduction:

This study concerns the effects of hadronic shower spreading and lateral calorimeter segmentation on the jet-jet mass resolution, for high Pt (Pt>500 GeV) hadronic Z^0 decays. In a previous study (1), we examined the effects of lateral calorimeter segmentation on detection and measurement of high Pt $Z^0 \rightarrow$ jet jet, for an ideal calorimeter with no lateral shower spreading. Other recent studies have also examined the dependence of Z^0 mass resolution on calorimeter segmentation, using more realistic models of shower spreading (2,3). The studies reported so far have assumed a common calorimeter segmentation for the EM and HAD compartments, and have concluded that (.05X.05) segmentation is a desirable optimization point, given the basic limitations imposed by calorimeter energy resolution, shower size, underlying event, etc. In the present study, we consider the case that HAD is segmented more coarsely, specifically (.1X.1) instead of (.05X.05), and we assume that the EM segmentation is fixed at (.05X.05), as driven by electron identification requirements. This "hybrid segmentation" would represent a significant cost saving for SDC. We might expect that the effects of coarser HAD segmentation on the jet-jet mass resolution would be minimal for two reasons. First, roughly half the jet energy is deposited in the EM compartment anyway, and benefits from the (.05X.05) EM cell size. Second, the lateral hadron shower size increases with depth, so that the shower spreading is larger on average in the HAD calorimeter alone, than it is in $EM + HAD$ combined. Thus we might expect coarser segmentation to be less important deeper in the calorimeter.

2 Event Generation

For this study we used ISAJET (V.6.36) $Z^0 \rightarrow$ jet jet events, with no underlying event particles, and with Pt(Z^0)>500 GeV/c. We make the following cuts:

1. N>5 ..... stable particles in the Z^0 decay, to avoid dilepton decay modes.
2. Pt(Z) >400..where Pt excludes neutrino contributions.
3. M(Z) >85 ...to avoid the tail of events with large neutrino energy losses.

4. η(Z)<1.5

These cuts pass 36% of the Z's generated, but still include events with significant energy loss due to neutrinos or muons (muons are assumed to deposit 2.7 GeV in $EM + HAD$.) Individually, the fraction of Z^0 events passing each cut is (1) 74%, (2) 66%, (3) 59%, and (4) 36%, where the percentages are cumulative and the cuts are applied in succession.

We compute the Z^0 mass by summing over calorimeter cells, with no Et cut on either EM or HAD. The dependence of the mass resolution on the "cluster radius" is described in ref. (1); the resolution bottoms out with a cut on η or ϕ of order 0.8 with respect to the Z direction. The contributions of calorimeter cells to the Z mass varies roughly as ER^2, where E is the cell energy and R the distance between the cell and the Z direction in $\eta - \phi$ space, so that the mass resolution is strongly influenced by low Et cells far from the Z direction vector. For this simulation, we make no cut on cluster radius, since we are primarily interested in the comparison between (.1X.1) and (.05X.05) calorimeter segmentation.

3 Calorimeter Simulation

We include the effect of the B-field on charged hadrons and leptons, so that charged particles with Pt<0.57 GeV/c do not register in the calorimeter, and charged particles above 0.57 GeV/c are spread out in the R-ϕ plane due to magnetic bending. To simulate longitudinal and transverse hadron shower response, we combine calorimeter response functions measured in ZEUS (4) and CDF(5). The ZEUS results give a lateral profile, integrated in depth and projected in a single view, characterized by

$$dE/dz = A_1 exp(-z/b_1) + A_2 exp(-z/b_2), \text{with}$$

$$A_1 b_1/(A_1 b_1 + A_2 b_2) = 0.5, \text{and}$$

$$b_1 = 1.96cm, b_2 = 11.3cm.$$

We estimate the relative densities of the ZEUS, CDF, and SDC detectors, measured in absorption length per cm, to be

$$ZEUS/CDF = \frac{.0554\lambda(abs)/cm}{.0396\lambda(abs)/cm} = 1.40$$

$$SDC/CDF = \frac{.0457\lambda(abs)/cm}{.0396\lambda(abs)/cm} = 1.15,$$

and assume that the "b" parameters are to be scaled according to these density ratios. From CDF data, using a single exponential fit to the shower profile in the HAD calorimeter, we obtain the following variation of shower size with $\frac{EM}{EM+HAD}$ fraction

$$b = 5cm + 10cm\frac{EM}{EM + HAD}$$

We assume that the fractional dependence on $\frac{EM}{EM+HAD}$ is the same for all three calorimeters, CDF, SDC, and ZEUS, since EM represents roughly the same number of absorption lengths in each case. Integrated in depth (eg, summing $EM + HAD$), the appropriate shower size in CDF would be b=5 cm; however, early showering hadrons (with $\frac{EM}{EM+HAD}$=1) would exhibit a much broader profile in the HAD compartment, given by b=15 cm. Thus, we describe the SDC HAD and $EM + HAD$ responses according to the following algorithms:

- $EM + HAD$ (total energy)

  Use ZEUS profile, scaled by SDC/ZEUS density for b_1 and b_2, eg., $b_1 \rightarrow$2.39 cm, $b_2 \rightarrow$13.8 cm)

- HAD only

  1. Start with ZEUS profile, scaled by SDC/ZEUS density, as in $EM + HAD$.
  2. elect $\frac{EM}{EM+HAD}$ from CDF distribution.
  3. Define "b" in the range 5<b<15 cm from $b = 5 + 10\frac{EM}{EM+HAD}$
  4. Increase the b_1, b_2 parameters further by the factor b/5cm, obtained in (3).

This is not a unique prescription, but gives the correct scaling of shower size with EM fraction (variation of the A_1 and A_2 parameters with $\frac{EM}{EM+HAD}$would provide an alternate ansatz.) The dependence on EM fraction is of course just the variation of hadron shower size with depth. To translate the projected shower profile, measured in the ZEUS and CDF experiments, into a radial profile, we use the ansatz

$$dE/dR = R[exp(-4/3R/b_1)/{b_1}^2 + gexp(-4/3R/b_2)/{b_2}^2],$$

$$g = A_2b_2/(A_1b_1 + A_2b_2)$$

Here "g" is the energy fraction in the "broad component", and 4/3 is the numerical factor that gives optimal translation between projected and radial profile (as determined by numerical computation.)

To get a better feeling for the relation between SDC cell size and the lateral shower spreading, we compute the average fraction of a hadronic shower contained in a 1X1, 3X3, 5X5... cell cluster, where we take a single cell to be approximately .05X.05, or 10.3 cm by 12.0 cm in Rϕ $\times$ Z, at an effective radius of 210 cm. For the integrated shower in $EM + HAD$, we get the containment fractions:

Cluster Size	Tower Center	Face average
1X1	62%	49 $\pm$ 10%
3X3	85%	85%
5X5	93%	92%
7X7	97%	96%

For the shower energy deposited in HAD alone, we get the following containment fractions, averaged over the $\frac{EM}{EM+HAD}$ distribution:

Cluster Size	Tower Center	Face average
1X1	46±14%	35±12%
3X3	75± 7%	75± 8%
5X5	86± 7%	86± 7%
7X7	91± 6%	91± 6%

For those entries that have a significant spread, we include the rms spread as an error. The containment fraction is higher for the case that the hadron is at tower center, as opposed to the case that the hadron is averaged over η and ϕ in the tower, ("face-averaged") but this difference is negligible for the larger cluster sizes. We note that a single (.05X.05) cell in EM+HAD combined contains 62% of the total shower energy, whereas the same cell in HAD contains on average only 46% of the hadronic calorimeter deposition; this is a reflection of the larger shower size in HAD, which is given by the dependence of "b" on EM/EM+HAD.

4 Results for Z→jet jet mass resolution.

We measure the distribution in the difference, M(jet-jet) - M(Z), where M(Z) is the invariant mass of all particles in the Z decay, excluding neutrinos, and M(J-J) is the reconstructed invariant mass of all calorimeter cells after simulation. We summarize the mean and variance of this mass difference in table 1, where we consider the following cases:

B-off B field off

B-on B field on

Res.-off perfect energy resolution, so that E(HAD)= particle energy.

Res.-on assume 50%/ $\sqrt{E}$ stochastic term for the sum of EM+HAD for hadrons only (assume perfect resolution on electrons and photons.)

Sim-off Lateral shower spreading turned off for hadrons

Sim-on Lateral shower spreading turned on for hadrons (not for electrons or photons.)

Table 1.

B	Res.	Sim.	HAD=.05X.05	HAD=.1X.1
off	off	off	-2.04/2.67	-1.29/3.68
on	off	off	+4.54/4.03	+5.20/4.92
on	on	off	+4.60/4.86	+5.26/5.53
on	off	on	+7.93/3.94	+8.85/4.21
on	on	on	+8.02/4.68	+8.97/4.95

The entries give the mean/ rms on the Z mass difference. The first row gives the resolution for perfect calorimeter response with no B-field losses, and for this case the Z-mass rms worsens from 2.7 to 3.7 GeV in going from .05 to .10 HAD segmentation. These numbers are close to those reported in ref.(1) (2.6 and 4.6 GeV rms respectively for combined $EM + HAD$ cell sizes of .05 and .10.). The stochastic term ("Res. on") adds 2-3 % in quadrature to the resolution, as would be expected for 500 GeV/c Z's with 50%/ $\sqrt{E}$ resolution. The lateral shower spreading ("Sim. on") does not degrade the resolution, but actually improves it slightly; it also shifts the Z mass systematically by around 3 GeV. Finally, for the last row (Sim on and Res. on), we see that the .1X.1 HAD segmentation worsens the overall Z mass resolution by a factor of 1.06. This is consistent with previous studies (2), which obtain a factor 1.12 increase in resolution with with a change .03X.03 → .1X.1 in cell size, for *combined* $EM + HAD$ cells.

Figures (1) and (2) show the distributions in mass difference for various cases listed in Table 1.

5 Conclusions:

We conclude that the Z→jet jet mass resolution is worsened by a factor of around 1.06, in going from (.05X.05) to (.1X.1) HAD segmentation, taking into account the lateral and longitudinal correlations in hadronic shower development, the B-field smearing effects, and the intrinsic calorimeter energy resolution. Other contributions to the Z^0 mass resolution, such as underlying event and pileup, are model dependent, but should effect the resolution by a common factor in each case (assuming that these effects are distributed randomly in η-ϕ space relative to the Z^0 direction.) The shower spreading itself does not make the resolution worse in either case, and actually improves the resolution for the .1X.1 cell size. The shower spreading does shift the effective Z^0 mass by about +3 GeV, which may be compared with the +6 GeV shift caused by the B-field.

References

1. A. B. Wicklund, "Z^0→Hadrons in SDC", SDC-91-00081.

2. A.Para et al.,"Jet energy resolution of SDC detector", SDC-90-00149.

3. R. Blair et al, "SDC hadronic mass resolutions in Z and Z' decays", SDC-90-00150.

4. R. Barreiro et al., Nucl.Instrum. Meth. A292 (1990)259.

5. F.Ukegawa and B. Wicklund, CDF Note 1469 (1991).

Figure Captions

1. Mass difference (1a) .1X.1, B off; (1b).05X.05, B off; (1c) .1X.1, B on; (1d).05X.05, B on.

2. Mass difference, (1a) .1X.1, Simulation on, Resolution off; (1b) .05X.05, Sim. on, Res. off; (1c) .1X.1, Sim. on, Res on; (1d) .05X.05, Sim. on, Res. on.

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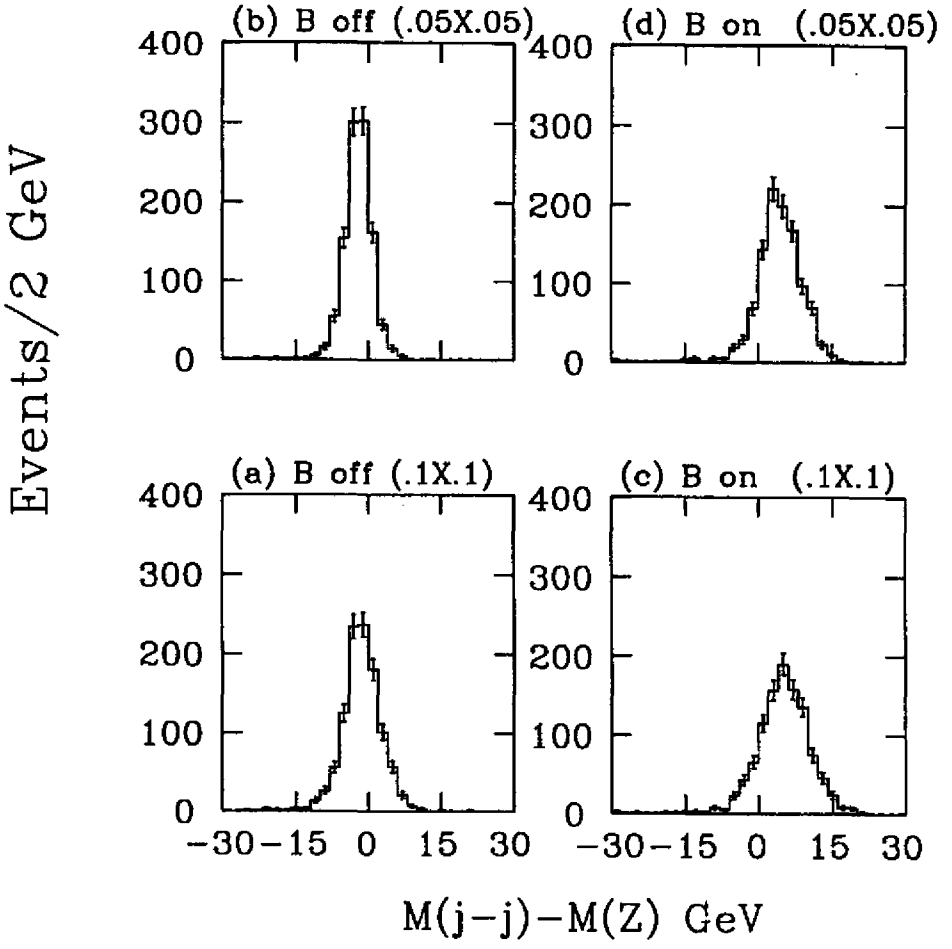
(b) B off (.05X.05)
(d) B on (.05X.05)
(a) B off (.1X.1)
(c) B on (.1X.1)
Events/2 GeV
400
300
200
100
0
−30 −15 0 15 30
M(j−j)−M(Z) GeV

Figure 1

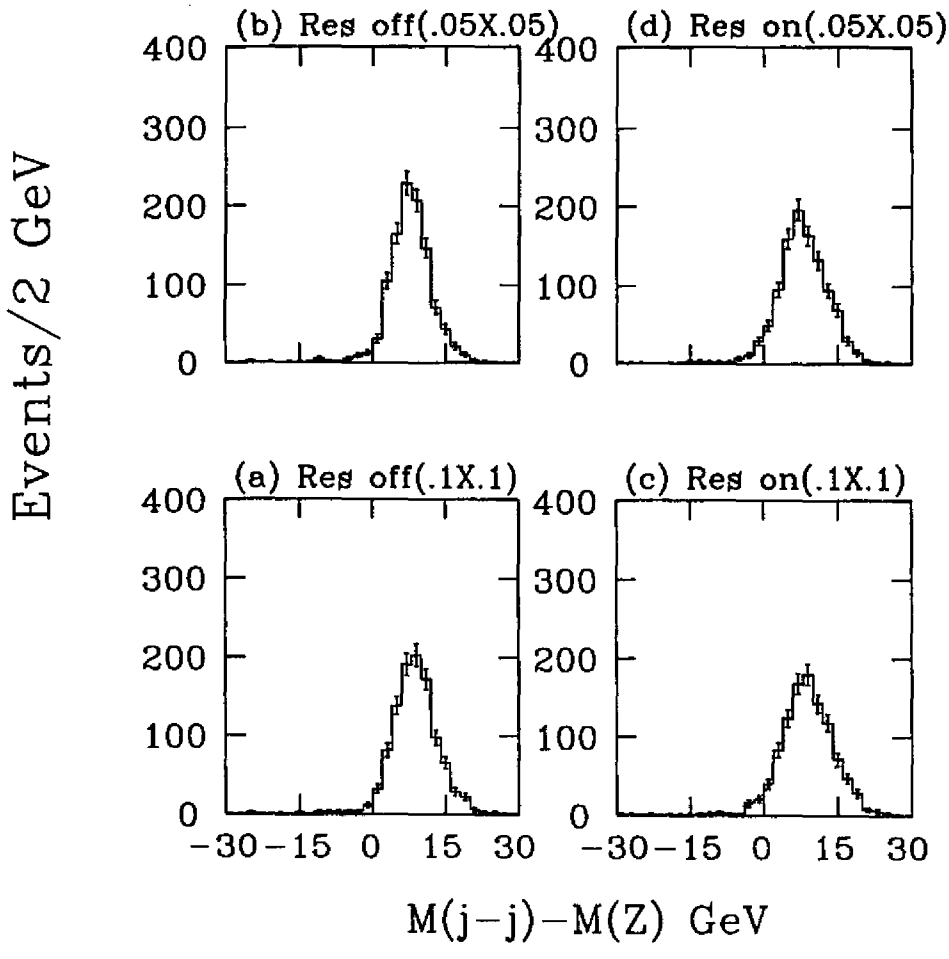
(b) Res off(.05X.05)
(d) Res on(.05X.05)
(a) Res off(.1X.1)
(c) Res on(.1X.1)
Events/2 GeV
400
300
200
100
0
-30 -15 0 15 30
M(j-j)-M(Z) GeV

Figure 2