SLAC TN-68-16
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The Distortionless 40" SLAC Hydrogen Bubble Chamber

I. Introduction:

We have studied the possible systematic distortion in the 40" SLAC bubble chamber and the geometrical reconstruction process. Systematic distortions may be caused by various sources: Flow of the chamber liquid; remaining errors in the optical parameters (see below); errors in the measuring process and in the geometrical reconstruction. No attempt was made to entangle the contributions of each source, but rather the combined effect was measured.

The distortions were determined from a charged particle beam passing through the chamber. The chamber was operated without magnetic field. As a result, no systematic displacements were found in either y or z directions. (See drawing.) The upper limits are 50 μ and 250 μ respectively. From a fit of the curvature a maximum detectable momentum of $P_{MDM} = (1600 {+2400 \atop -600})$ GeV was found for a track length of L = 100 cm and assuming a magnetic field of 26 kG.

II. Method:

Charged particles when passing through the chamber undergo multiple scattering and therefore even in the absence of a magnetic field or distortions, these particle tracks may be curved. However, by averaging over many tracks, the deviations from a straight line due to multiple scattering cancel. The remaining deviations must be due to distortions.

(a) Beam: The charged particle beam was produced by 10 GeV electrons striking 4 radiation lengths of tungsten. The beam passed through a total of 60 rℓ tungsten and 35 rℓ of lead (see Figure 2). Hereby the photon and electron components of the beam were filtered out. The beam cross section $\Delta y\ \Delta z$ was roughly 70 x 25 cm^2 at the position of the chamber. The flux was approximately 0.2-0.5 particles per frame.

(b) Chamber: The bubble chamber was operated at 1.6 expansion/sec. The flash delay was 2.5 msec. The bubble density was 14 bubbles/cm.

(c) Measurements: 370 tracks have been measured with no visible kink and no δ ray with length > 6 cm. The measurements were done on NRI machines. For these machines the rms error for measuring points of minimum ionizing tracks is 7 μ on film corresponding to ~ 130 μ in space. Each track was measured in three views with 8 points per view equally spaced along the track. Four fiducials were measured per view.

(d) Geometrical reconstruction: The tracks were reconstructed in space by TVGP. The optical parameters used by TVGP were determined from a measurement of the space - and film positions of fiducials. (See G. Wolf TN 68-3.) Thereby, a 12-parameter polynomial was determined for each view to account for lens distortions and the fact that two glasses with different refractive indices have been averaged over. The reconstructed xyz coordinates of each track point were punched on cards. In a separate program these coordinates for each track were fitted to straight lines in the xy and xz planes:

$$y = a + bx$$

$$z = c + dx$$

Let x^i_m, y^i_m, z^i_m be the measured coordinates and x^i_c, y^i_c, z^i_c the fitted coordinates:

$$y^i_c = a + bx^i_m$$

$$z^i_c = c + dx^i_m$$

Then the deviations dy, dz were determined for each track point i:

$$d^i_y(x^i_m, y^i_m) = y^i_c - y^i_m$$

$$d_z^i\,(x^i_m, z^i_m) = z^i_c - z^i_m$$

(Note: dy, dz can be both positive and negative.) The chamber was subdivided into xy and zy grids with cells of 5 x 2 cm^2 and 5 x 1 cm^2 respectively. For each cell the average deviations $Dy^{\alpha,\beta}$ and $D_z^{\alpha,\gamma}$ were calculated, where the cell indices are defined as follows:

$$\alpha = \left\{\frac{x + 50}{5}\right\} \qquad \beta = \left\{\frac{y + 50}{2}\right\} \qquad \gamma = \{z + 56\}$$

$\{t\}$ means integral part of t.

$$D_y^{\alpha,\beta} = \frac{1}{N^{\alpha\beta}_y} \sum_{k=1}^{N_y^{\alpha\beta}} d_y(x^k_m\, ,\, y^k_m)$$

where the sum is to be taken over all tracks and points k with coordinates x^k_m, y^k_m being in the cell α, β:

$$\alpha \leq \frac{x^k_m + 50}{5} < (\alpha + 1) \quad ; \quad \beta \leq \frac{y^k_m + 50}{2} < \beta + 1$$

Obviously the error $\Delta D^{\alpha\beta}$ of $D^{\alpha\beta}_y$ is given by

$$\Delta D^{\alpha\beta}_y = \sqrt{\frac{<(d^{\alpha\beta}_y)^2> - (< d^{\alpha\beta}_y >)^2}{N^{\alpha\beta}_y \, (N^{\alpha\beta}_y - 1)}}$$

where

$$<(d^{\alpha\beta}_y)^2> = \frac{1}{N^{\alpha\beta}_y} \sum_{k=1}^{N^{\alpha\beta}_y} d^2_y \, (x^k_m, y^k_m)$$

Analogous expressions hold for $D^{\alpha\gamma}_z$, $\Delta D^{\alpha\gamma}_z$.

III. Results:

(a) Displacements: In Figs 3 and 4 the average deviations in the y and z directions are plotted as a function of the xy and xz coordinates of the cells. Only cells containing 5 or more points were plotted. There is no evidence for systematic distortions in either y or z direction. Upper limits for the displacements in y and z direction are 50 μ and 250 μ respectively.

(b) Check of the geometrical reconstruction: In order to check the geometrical reconstruction (i.e. chamber constants and geometry program) one can compare the reconstructed y (and z) coordinates of the same track point as measured in different views. Let (x_k, y_k, z_k) be the coordinates as reconstructed from the measurement in view k and

$$y_{k\ell} = y_k - y_\ell$$

$$z_{k\ell} = z_k - z_\ell$$

From the measurements of the straight tracks (which were approximately parallel to x axis) the following mean values were obtained:

$$\bar{y}_{12} = -(30 \pm 36)\ \mu \qquad \bar{y}_{13} = -(10 \pm 6)\ \mu \qquad \bar{y}_{23} = (25 \pm 30)\ \mu$$

$$\bar{z}_{12} = -(50 \pm 100)\mu \qquad \bar{z}_{13} = (100 \pm 140)\mu \qquad \bar{z}_{23} = (0 \pm 70)\ \mu$$

The reconstructed points as measured in different views agree within the errors.

(c) <u>Maximum detectable momentum (P_{MDM})</u>. A parabola fit was made to the xy and xz coordinates of the points of each track and the curvatures k_y, k_z in the xy and xz planes were determined. Figs 5 and 6 show the distributions of k_y versus y and k_z versus z and their projections onto the k axes. The mean values are:

$$\bar{k}_y = (-\ 0.5 \pm 0.3) \times 10^{-5}\ \text{cm}^{-1}.$$

$$\bar{k}_z = (0 \pm 0.6) \times 10^{-5}\ \text{cm}^{-1}.$$

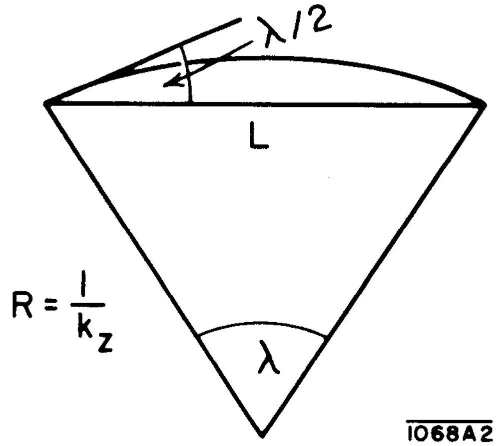
The value for $\bar{k}_y$ leads to a maximum detectable momentum of

$$P_{MDM} = (1600 \begin{matrix} + 2400 \\ - 600 \end{matrix}) \text{ GeV/c}$$

assuming a magnetic field of 26 kG. The systematic error in the momentum measurement for a track of momentum P and tracklength L is connected with P_{MDM} via

$$\frac{\Delta P}{P}\text{sys} = \frac{P}{P_{MDM}} \left(\frac{L_{MAX}}{L}\right)^2 \quad \text{where } L_{MAX} = 100 \text{ cm in our case.}$$

A nonzero value of $\bar{k}_z$ would lead to a systematic error in the measurement of the dip angle λ:



$\Delta\lambda^{sys} < L * \bar{k}_z$ where L is the track length. The measured value of $\bar{k}$ leads to

$$\Delta\lambda^{sys} \simeq (0 \pm 0.6) \text{ mrad.}$$

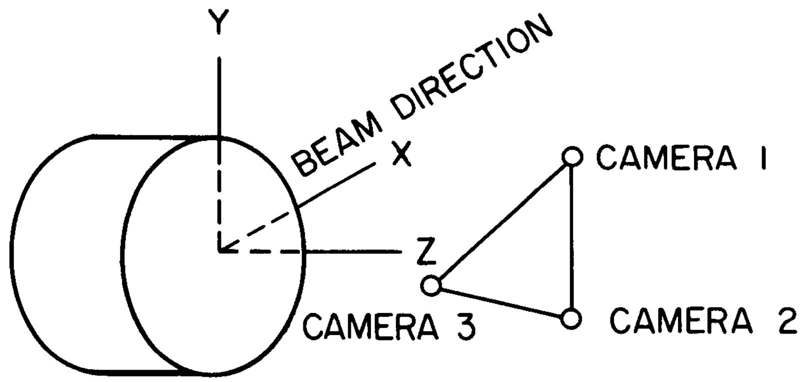

Y
BEAM DIRECTION
X
Z
CAMERA 1
CAMERA 2
CAMERA 3

Fig. 1

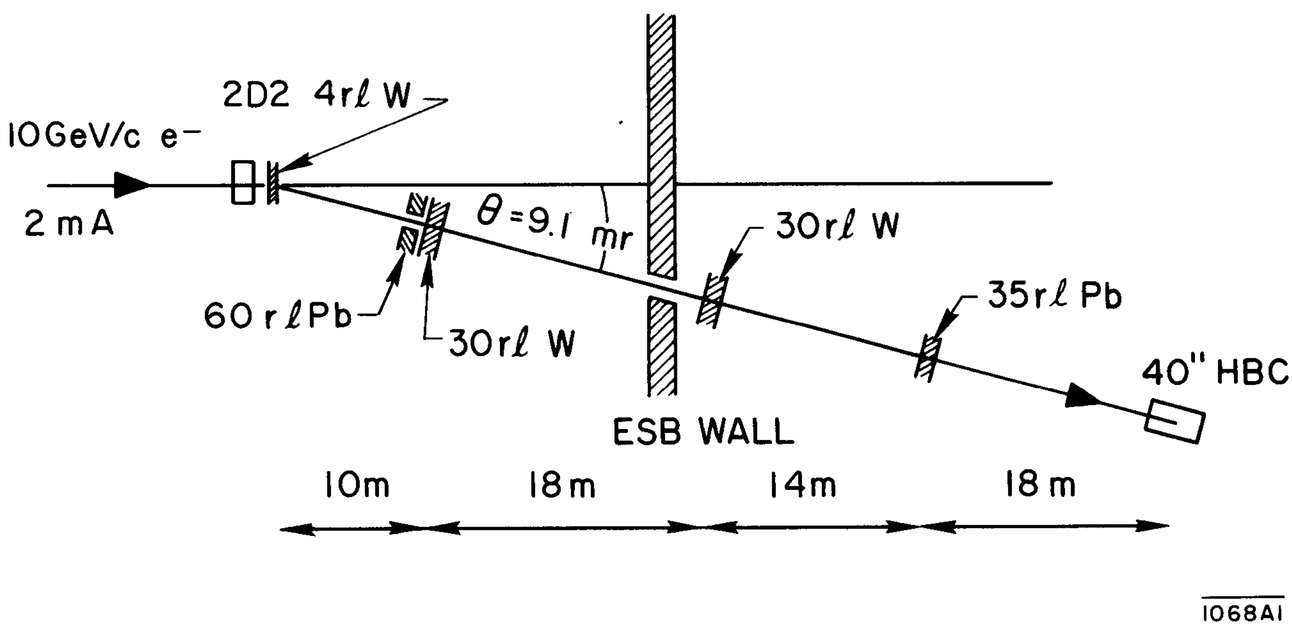
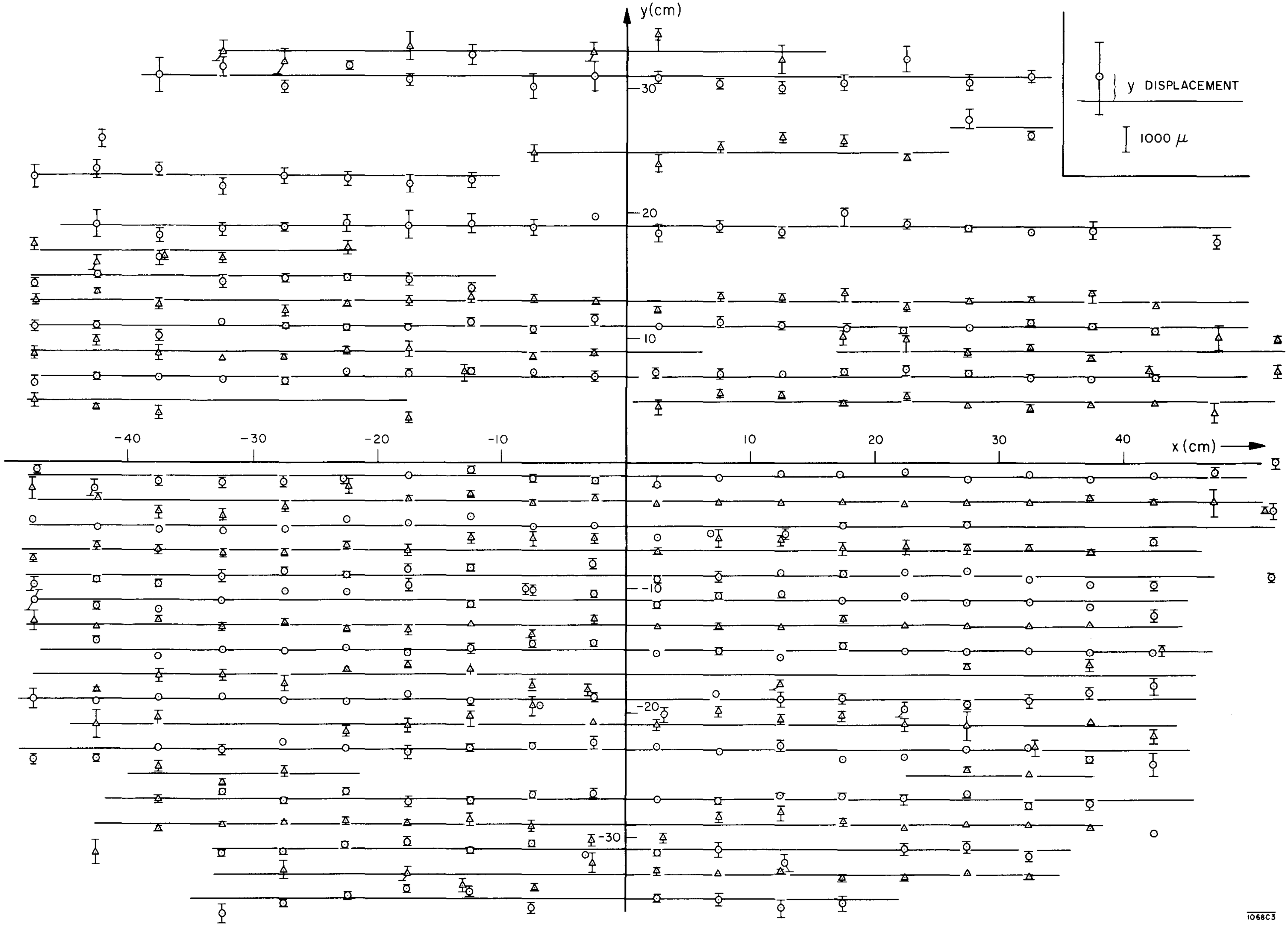
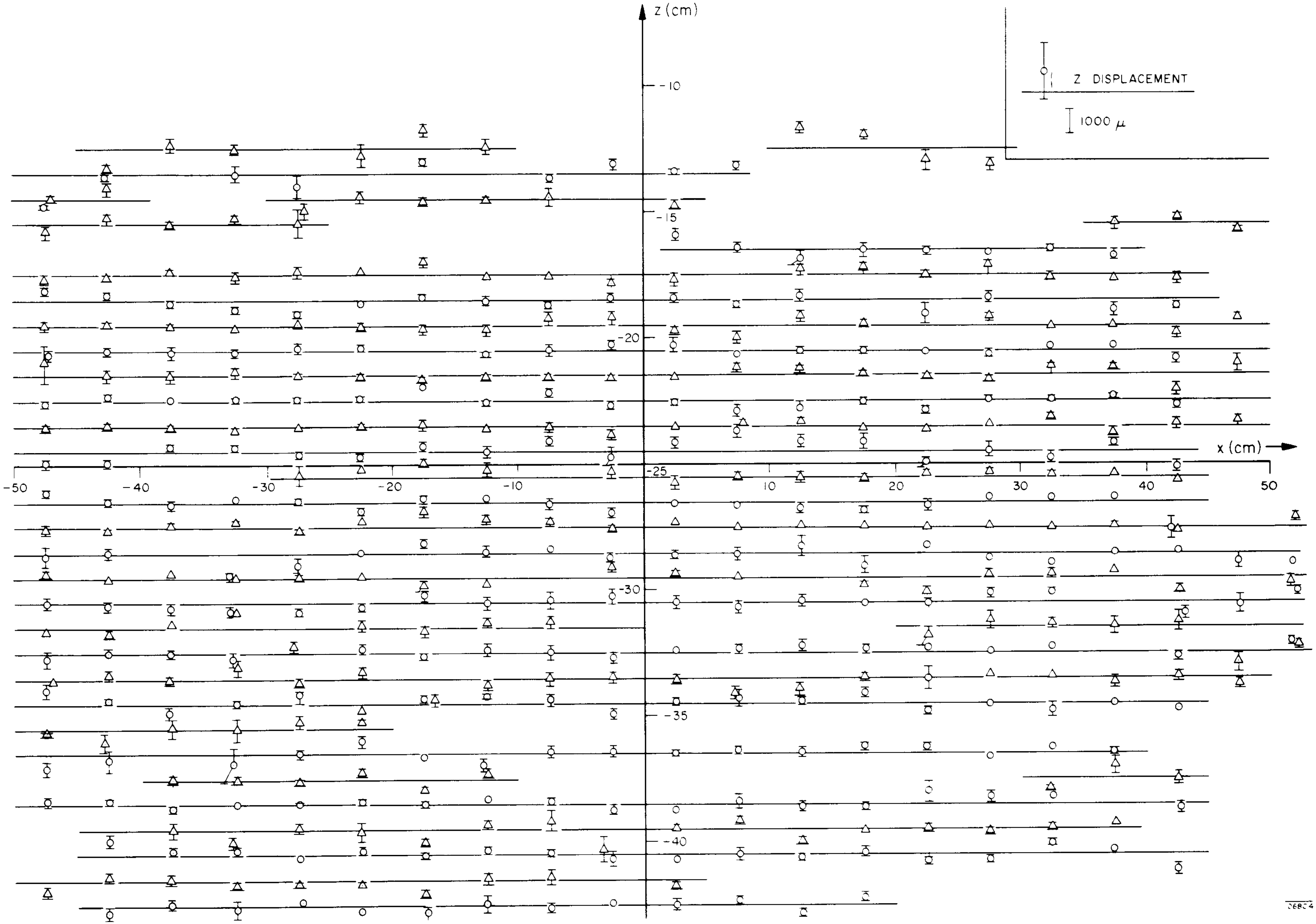

10GeV/c e−
2 mA
2D2 4rℓ W
θ=9.1 mr
60 rℓPb
30rℓ W
30rℓ W
35rℓ Pb
40" HBC
ESB WALL
10m
18m
14m
18 m
1068A1

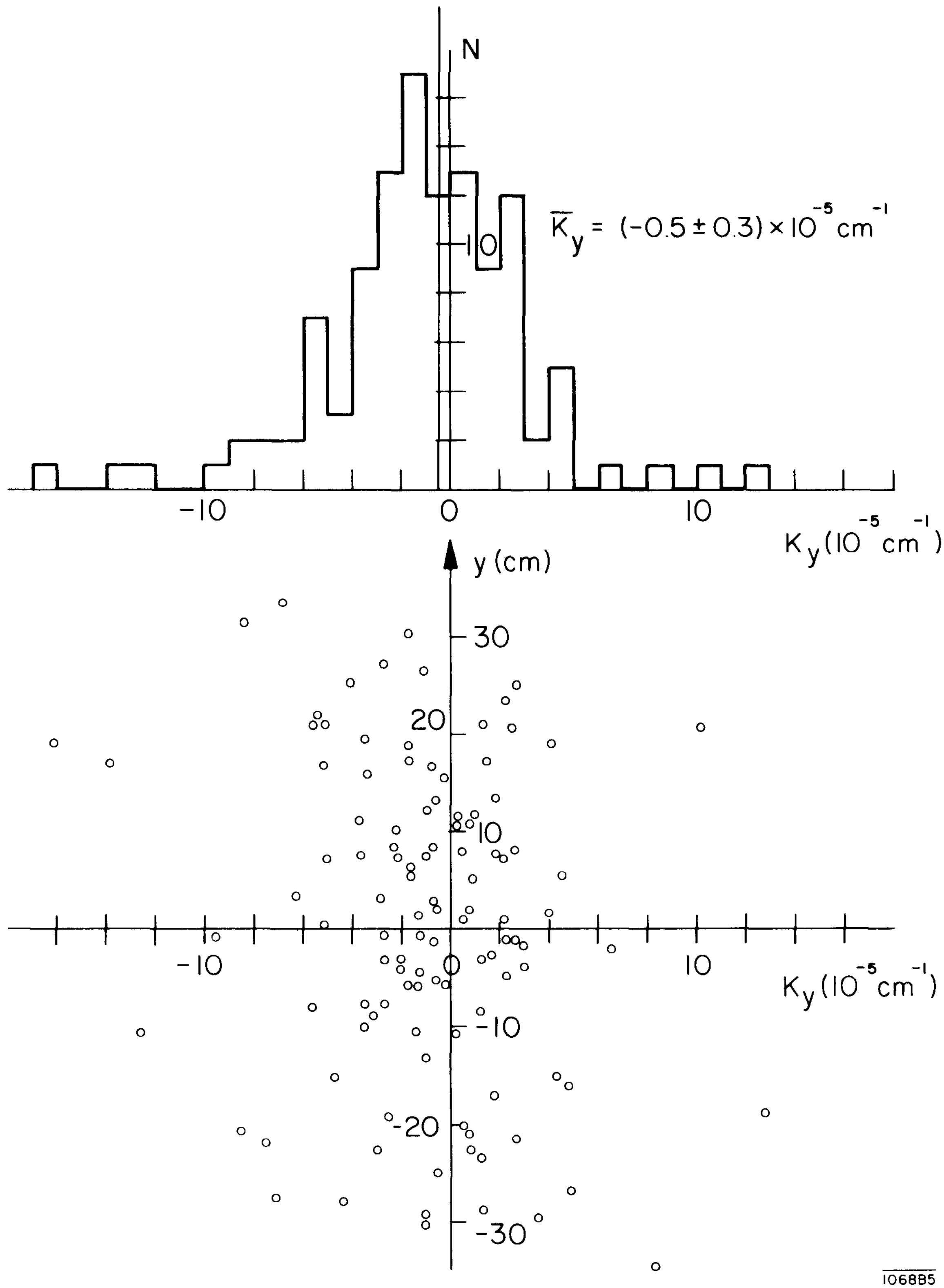
Fig. 2

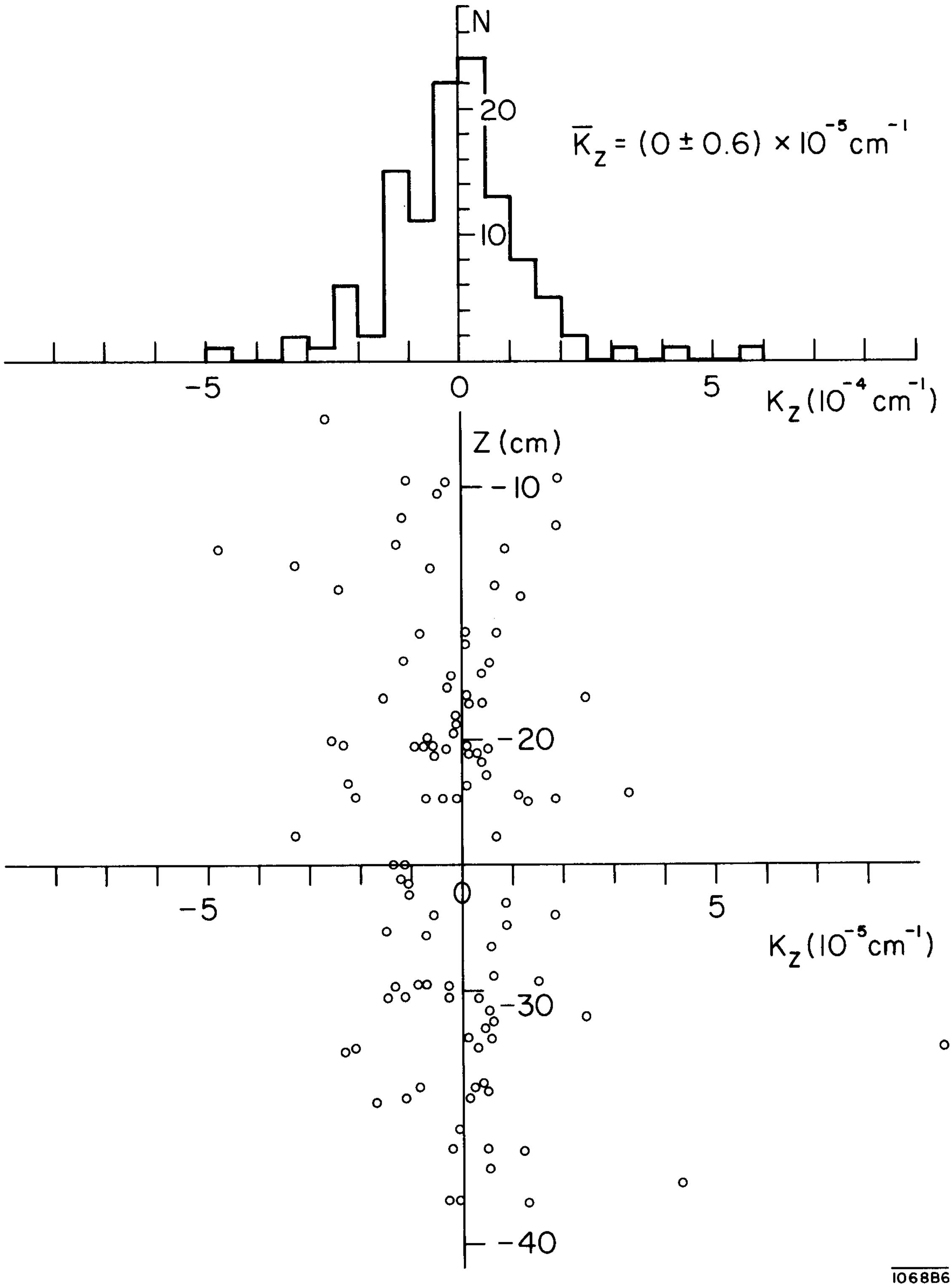


y(cm)
y DISPLACEMENT
1000 μ
30
20
10
-10
-20
-30
-40
-30
-20
-10
10
20
30
40
x (cm)
1068C3



z (cm)
Z DISPLACEMENT
1000 μ
-10
-15
-20
-25
-30
-35
-40
x (cm)
-50
-40
-30
-20
-10
10
20
30
40
50


N
10
$\overline{K}_y = (-0.5 \pm 0.3) \times 10^{-5}\ cm^{-1}$
-10
0
10
$K_y (10^{-5}\ cm^{-1})$
y (cm)
30
20
10
0
-10
-20
-30
-10
10
$K_y (10^{-5}\ cm^{-1})$
1068B5


N
20
10
$\overline{K}_z = (0 \pm 0.6) \times 10^{-5}\,cm^{-1}$
-5
0
5
$K_z\,(10^{-4}\,cm^{-1})$
Z (cm)
-10
-20
-30
-40
-5
0
5
$K_z\,(10^{-5}\,cm^{-1})$
106886