

## On Measurement of SSC Magnet Multipole Moments With a Discrete Set of NMR Probes

Donald H. Stork, UCLA, December 12, 1986

The nmr method may provide an alternate means of determining the SSC dipole magnetic field and multipole moment coefficients on the production line. Gil Clark has suggested simultaneous pulsed nmr field measurements with a set of small nmr coils arranged on a circle whose axis is the beam pipe axis. We report here on a preliminary investigation of the factors that are important in obtaining an accurate field representation.

Given the field expansion of the Conceptual Design Report

$$B_x + iB_y = B_0 \sum_{n=0}^{\infty} (b_n + ia_n)(x + iy)^n$$

the coefficients  $a_n$  and  $b_n$  can be determined from the field measurements of a set of  $N$  nmr coils equally spaced on a circle of radius  $r$  by

$$a_n = -\frac{2}{r^n} \frac{\sum_{i=1}^N B(x_i, y_i) \sin[n(\frac{2\pi i}{N})]}{\sum_{i=1}^N B(x_i, y_i)}$$

$$b_n = +\frac{2}{r^n} \frac{\sum_{i=1}^N B(x_i, y_i) \cos[n(\frac{2\pi i}{N})]}{\sum_{i=1}^N B(x_i, y_i)}$$

where the central field is known *a priori* to lie along the positive  $y$  direction. In the limit of large  $N$ , exact measurements give an exact result for the field pattern within the circle.

Effects which limit the quality of the result include (1) individual coil field measurement resolution, (2) limited number  $N$  of nmr coils, (3) uncertainty in individual coil position  $x_i, y_i$ , (4) uncertainty in longitudinal position, (5) displacement error in positioning the nmr probe, and (6) uncertainty in azimuthal nmr probe orientation. A preliminary examination of some of these effects has been done with an SSC magnet modeling and measurement simulation.

(1) From the expressions for the evaluation of  $a_n$  and  $b_n$  one finds that the error contributed by random field measurement errors is given by

$$\delta a_n = \delta b_n = \frac{2}{r^n} \sqrt{\frac{1}{2N}} \frac{\delta B}{B}$$

With typical nmr field measurement errors this would appear not to be a problem.

(2) It may be expected that valid results would obtain for  $n < N/2$ . A simulated magnet was prepared by assigning the Conceptual Design Report systematic coefficients and then selecting deviations according to gaussian distributions with

the Report's random coefficient values. Exact field measurements were taken with  $N = 24$  coils on a 1 cm radius circle. The resulting measured coefficients are plotted as circles in the Figure and can be compared to the histogrammed actual coefficients for this particular simulated magnet. No discrepancy is seen except for the  $n = 14$  "aliasing" effect. Further investigation of the effect of anomolous high  $n$  coefficients is required for a detailed understanding of this issue.

(3) A set of probes was simulated with 100 micron random coil displacements. The measurement distribution of the coefficients for the above magnet are characterized by an rms deviation which is plotted as the flag about each point in the Figure. The typical rms value is 0.08 compared to the desired resolution of 0.05. This suggests that relative coil location is critical and bears further study.

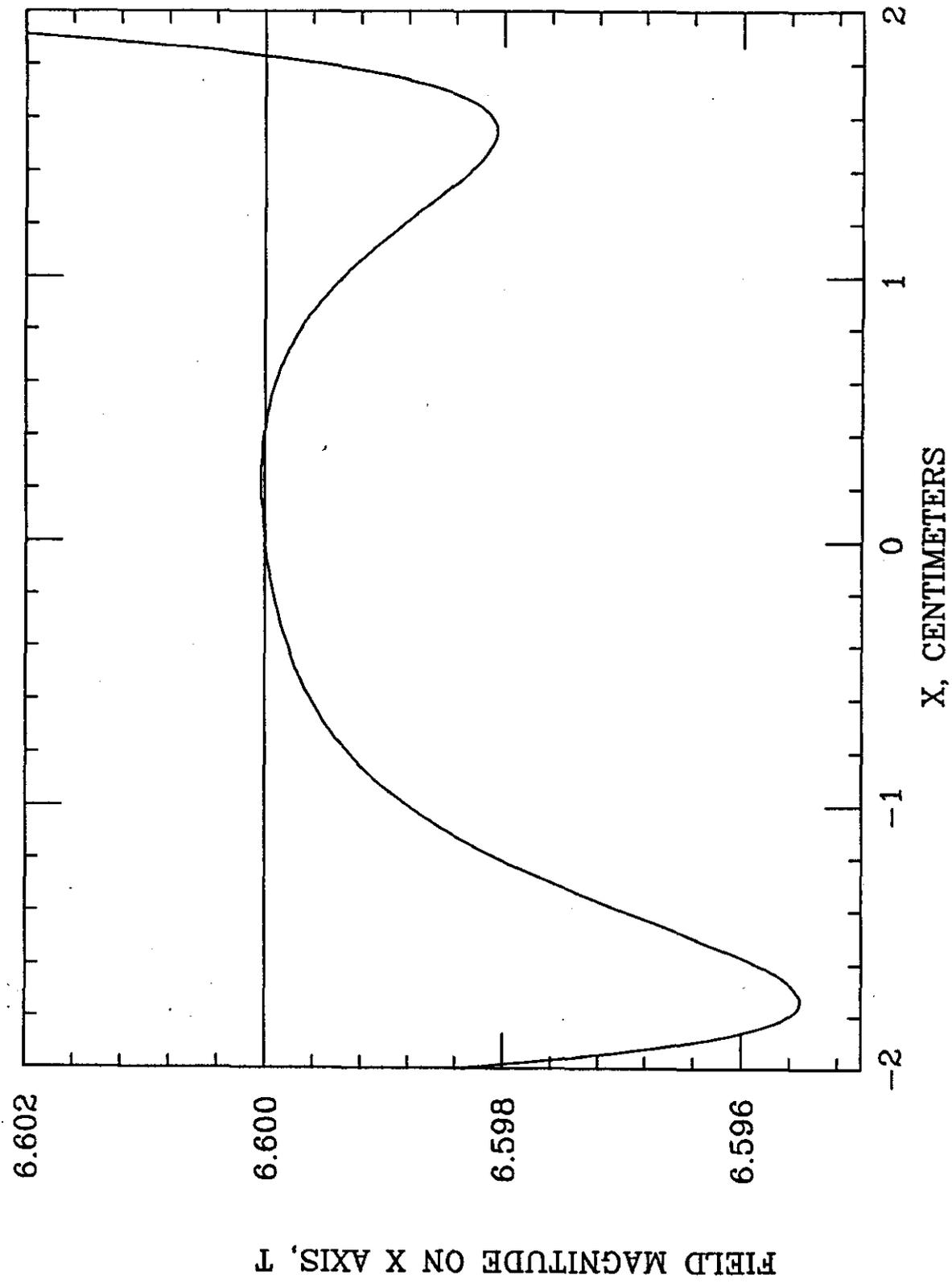
(4) A study of longitudinal coil placement has not yet been done.

(5) A displacement of the nmr probe gives a set of coefficients that represent the same field pattern displaced by a corresponding ammount. The field pattern itself is not changed. A transverse displacement of the nmr probe by 1 mm relative to the above simulated magnet produces a shifts in  $b_1$ ,  $b_3$ ,  $a_2$ , and  $a_4$  of between 0.15 and 0.20. Further study of this effect and its significance is necessary.

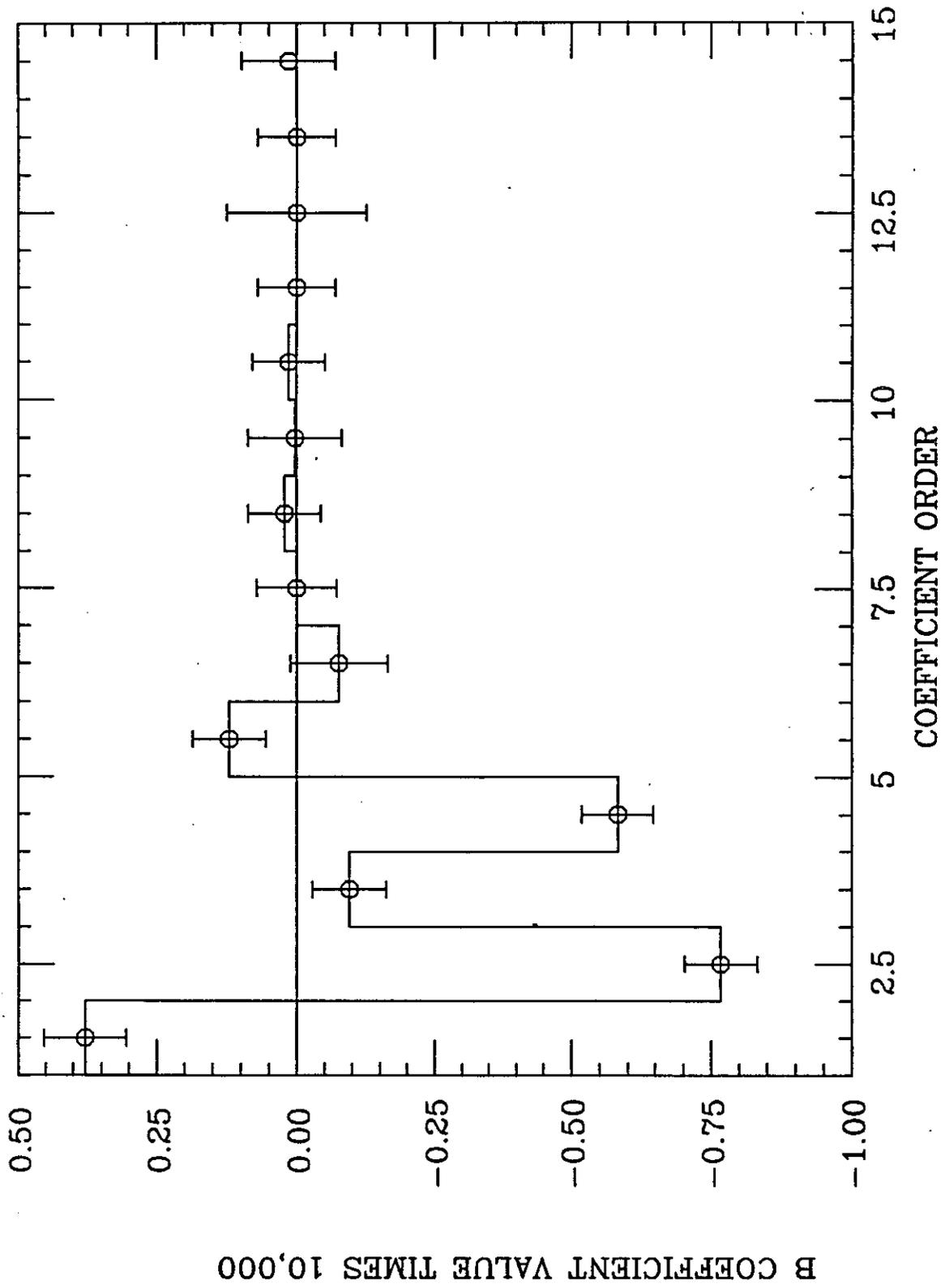
(6) Rotation of the probe relative the central field direction (or *vice versa*) corresponds to a phase shift that mixes the  $a$  and  $b$  coefficients for given order  $n$ . The effect becomes increasingly serious for increasing  $n$ . For the particular simulated magnet studied above, plausible ratation errors cause little difficulty. Limits on rotation error should be determined by realistic requirements on the higher order coefficients.

**Conclusions:** No insurmountable difficulty has been uncovered in this preliminary study of precision requirements for the discrete nmr probe method of field moment measurements. A 24-coil probe may not have the coverage or redundancy that is desired and a 32-coil or higher number coil probe should be considered. The most critical consideration appears to be the relative transverse location of each coil in the probe. If this study is born out, a location precision of significantly better than 100 microns would seem to be required.

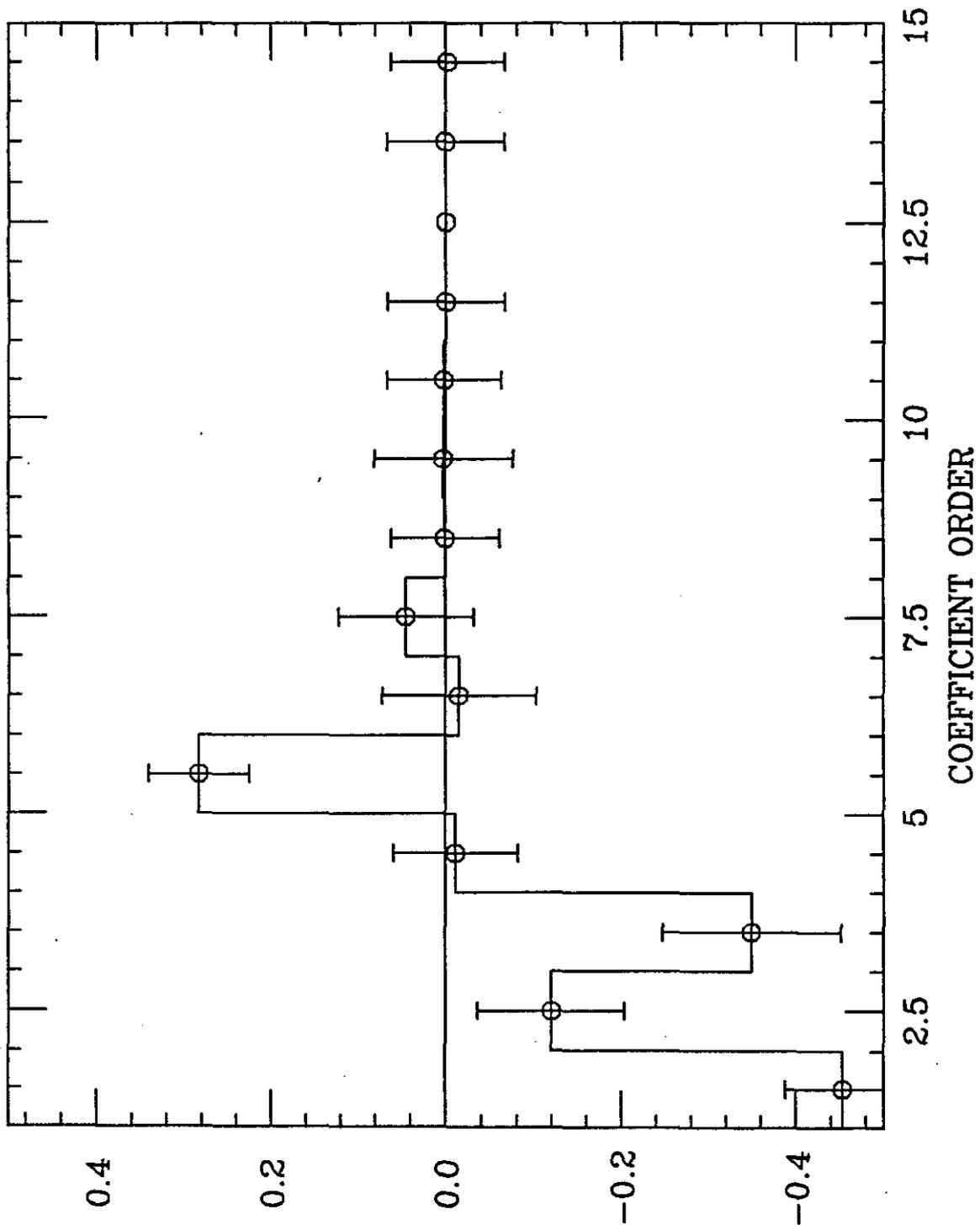
# SIMULATED MAGNET #1



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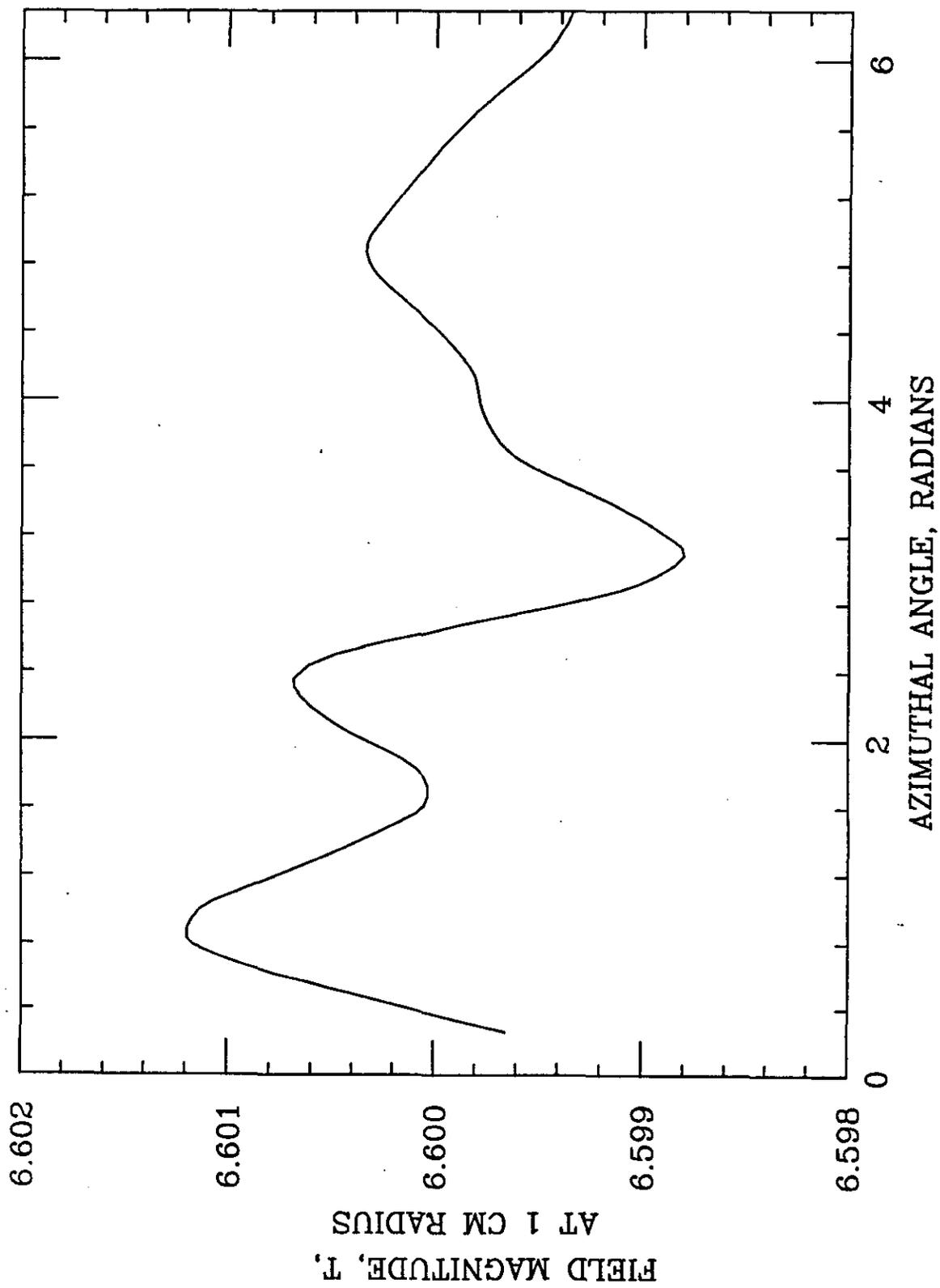


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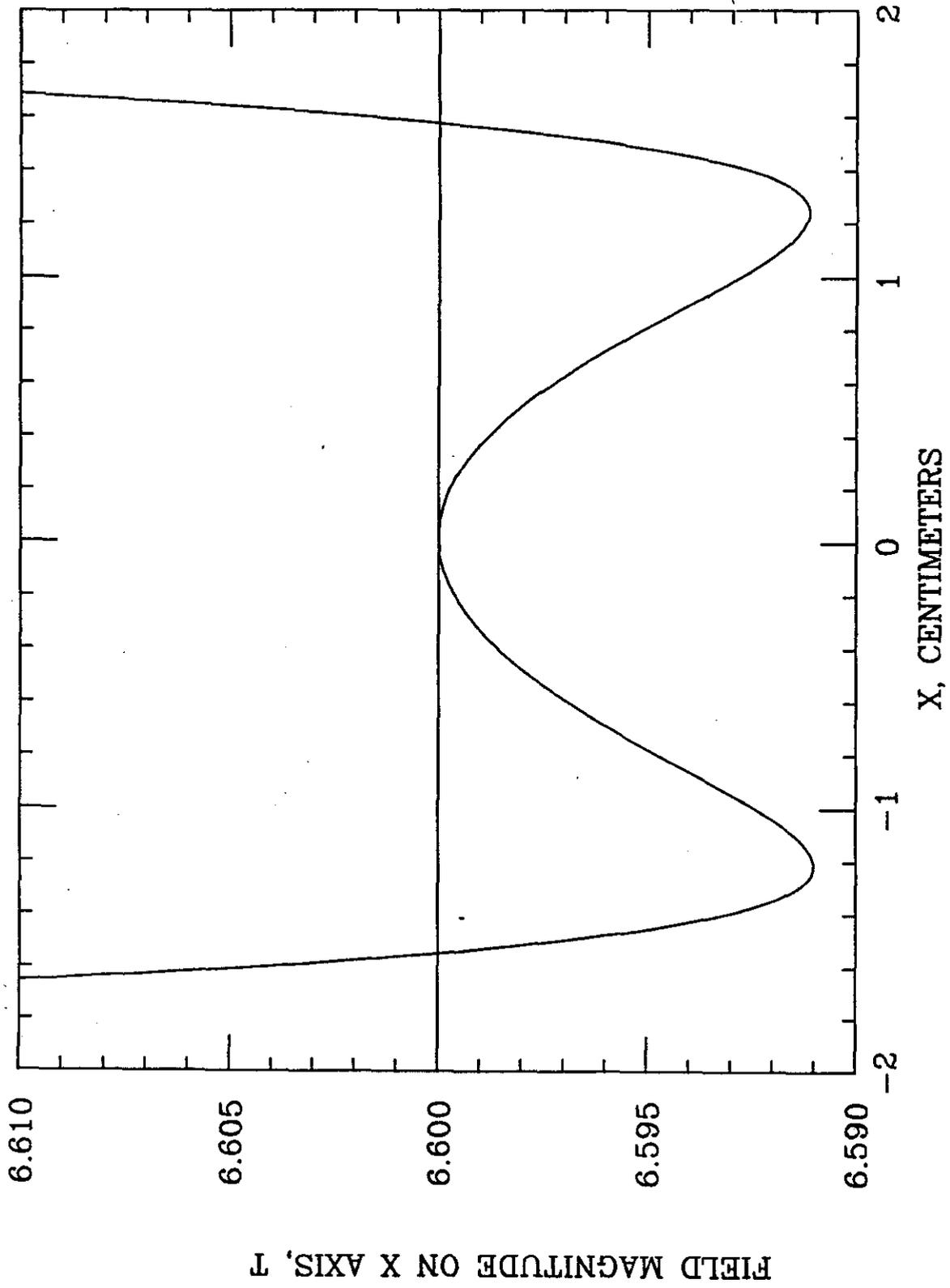


A COEFFICIENT VALUE TIMES 10,000

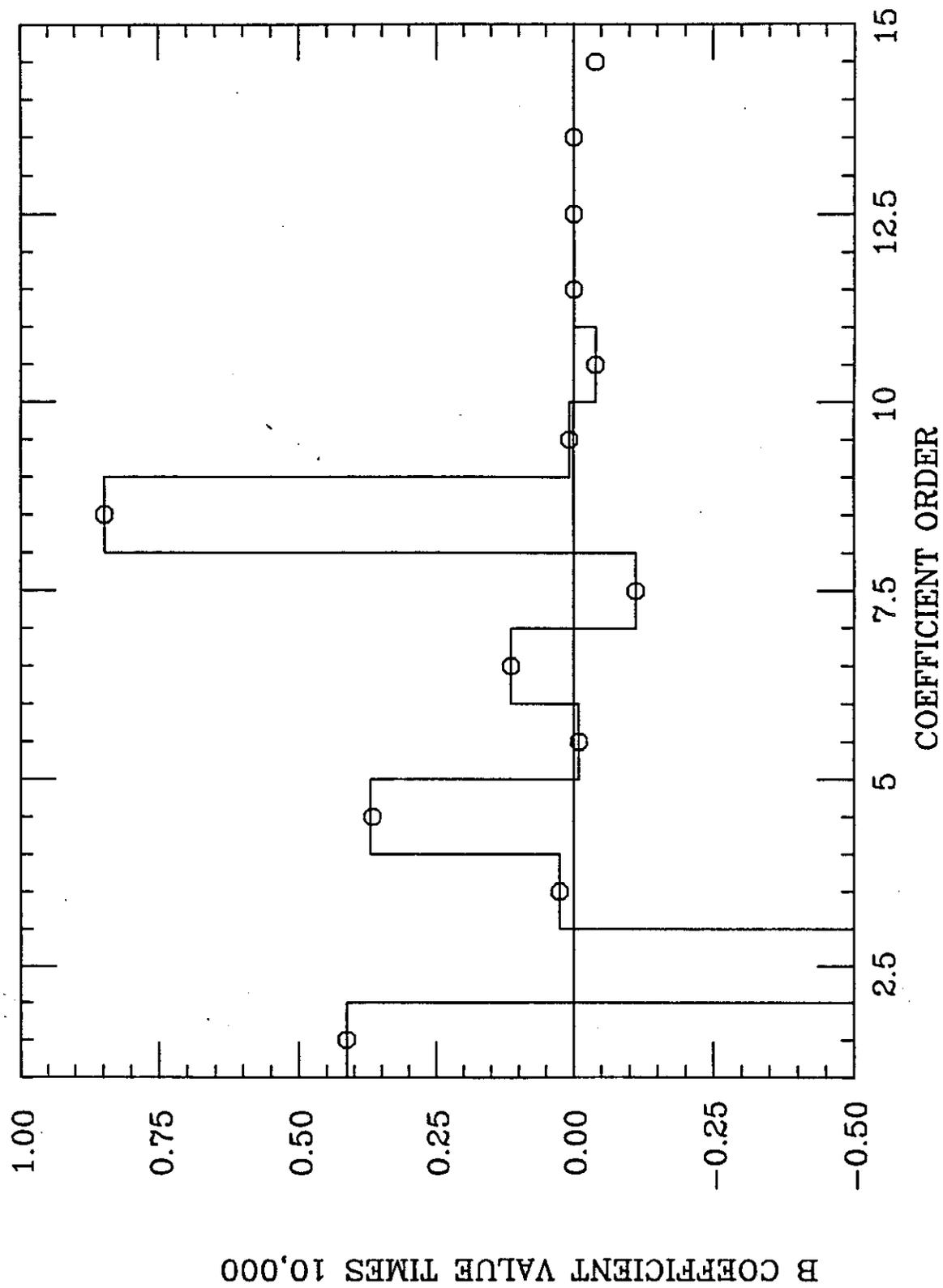
# SIMULATED MAGNET #1



MAGNET D00001

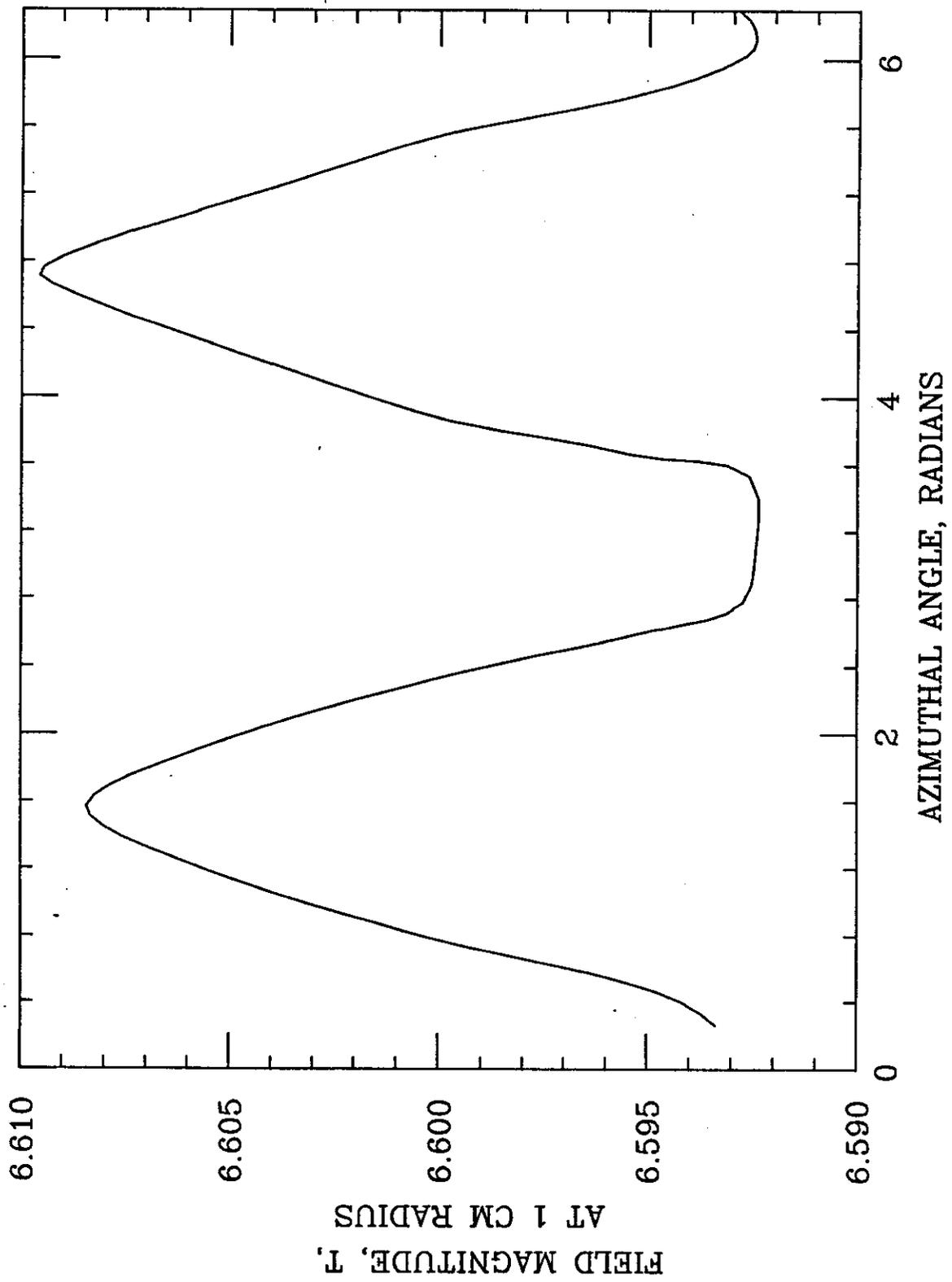


# MAGNET D00001

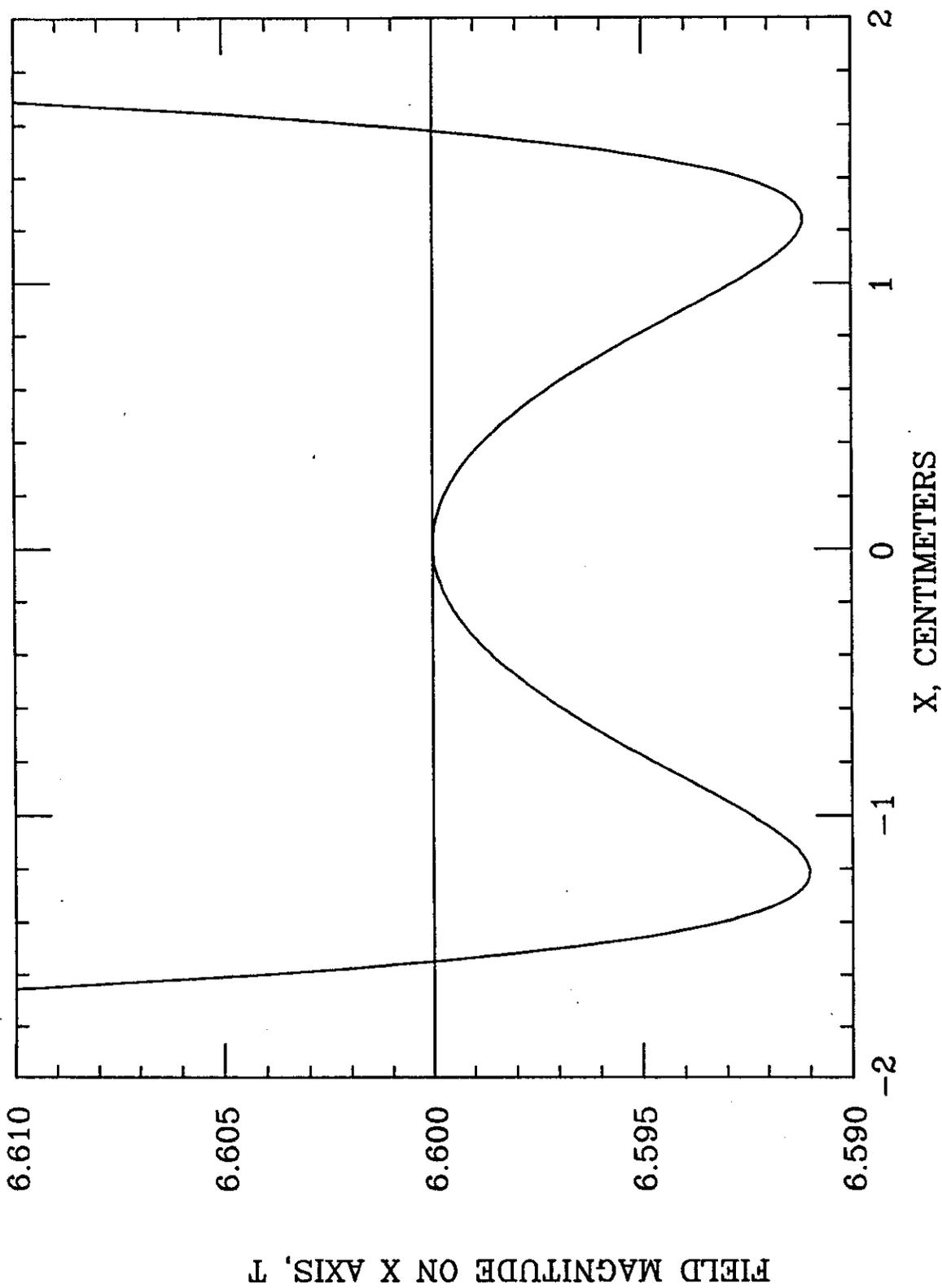




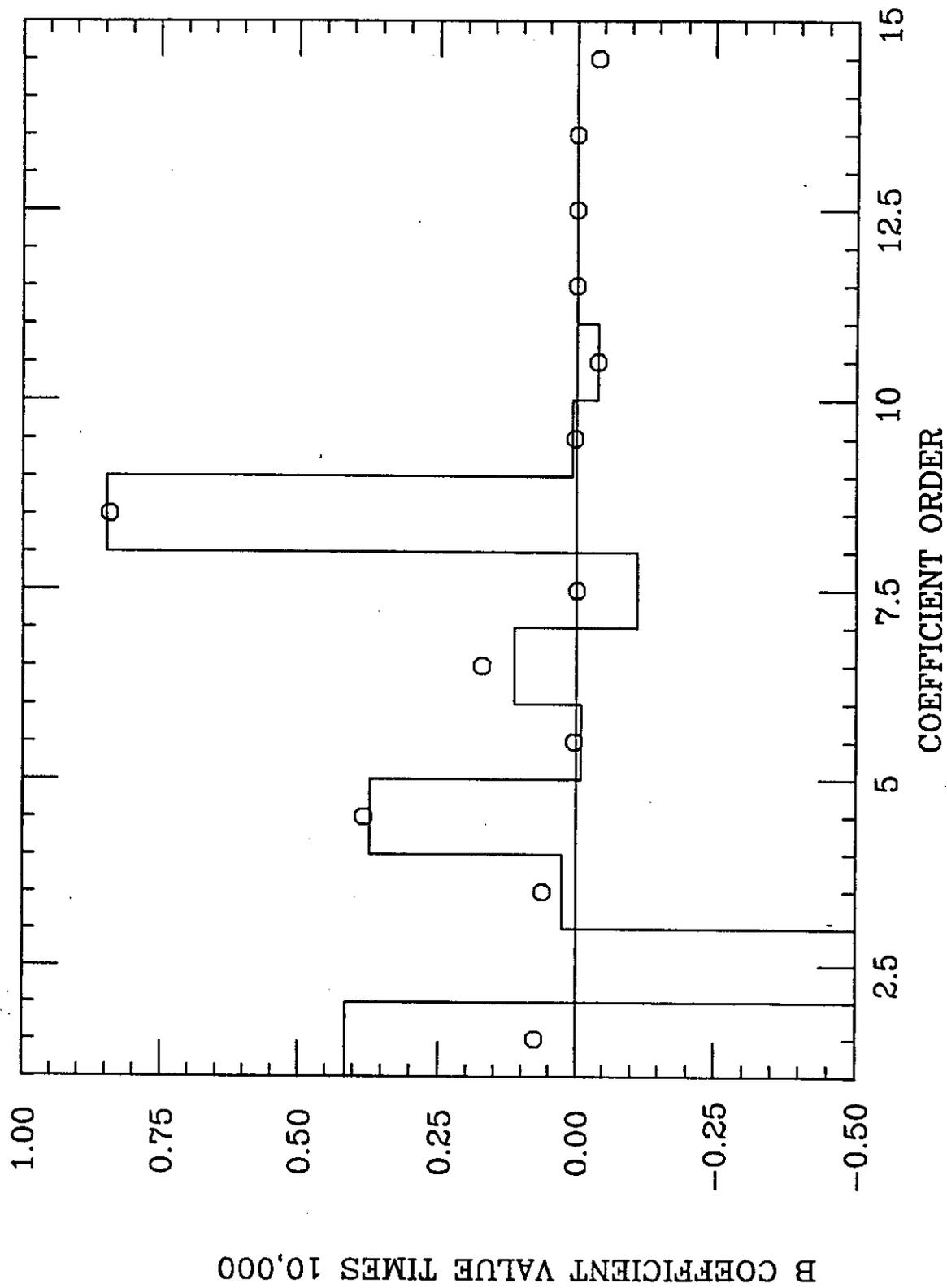
# MAGNET D00001



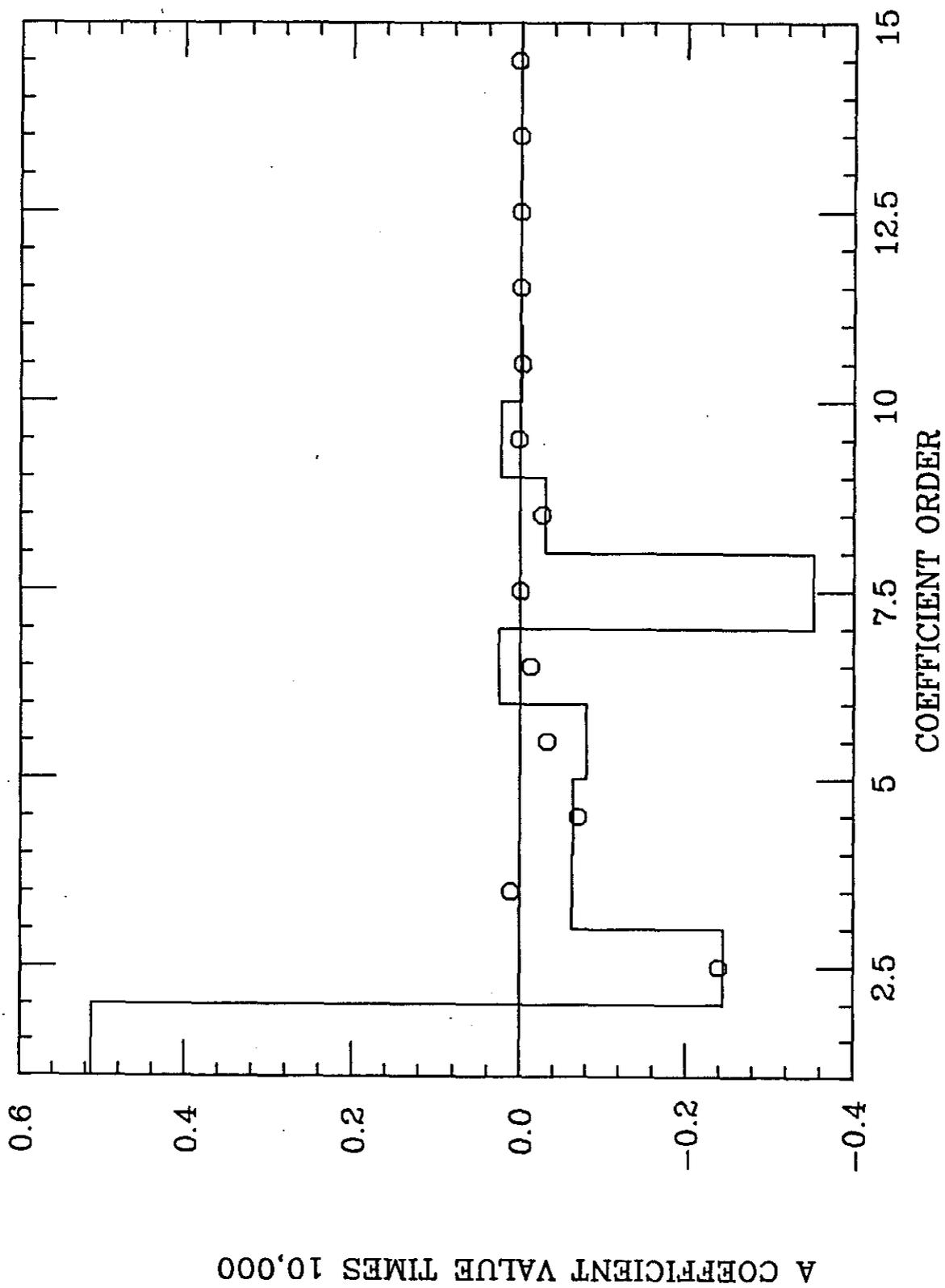
# MAGNET D00001, "SHIFTED"



# MAGNET D00001, "SHIFTED"



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