Brookhaven National Laboratory

BNL-104694-2014-TECH

AGS/AD/Tech Note No. 276;BNL-104694-2014-IR

COMMENTS ON THE AGS CHROMATICITY

E. Auerbach

February 1987

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

DISCLAIMER

Accelerator Division
Alternating Gradient Synchrotron Department
BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, New York 11973

Accelerator Division

AGS/AD/Tech. Note No. 276

COMMENTS ON THE AGS CHROMATICITY

E. Auerbach, E. Bleser, R. Thern

February 25, 1987

I. Introduction

In an accelerator at a given value of the magnetic field, changing the mean radius of the orbit will change the momentum of the beam and the tune of the beam. It is customary to define the natural chromaticity of the accelerator as the fractional change in the tune of the machine divided by the fractional change in momentum that occurs for a change in mean radius. The chromaticity is normally designated by the Greek letter Xi. Thus, we have:

$$Xi = (dQ/Q)/(dP/P)$$

[Chromaticity is also often defined as Xi = dQ/(dP/P), but in this note we shall avoid that definition.]

In an accelerator without long straight sections, the chromaticity is very close to being -1. This can be observed by running various designs through an accelerator design program, but finding the reason for it is a little harder. Some authors simply assert it, while others leave it as an exercise for the student. S-Y. Lee has published a more detailed calculation [Lee and Tepikian, IEEE Trans. Nucl. Sci. NS-32, 2225 (1985)] and gets the result

$$Xi = -[\tan(mu/2)]/(mu/2) \qquad (1)$$

where mu is the phase advance per cell. In the AGS mu is 0.91 radians so we have:

$$Xi = -1.07$$

and since (mu/2) is less than 1, we can write:

$$Xi = -[1 + (1/3)*(mu/2)**2]$$

The important point here is that for a simple accelerator such as the AGS, Xi is always very close to -1.

However, this is never observed directly since in a real accelerator there is always some sextupole present. The sextupole splits the natural chromaticity, shifting the horizontal chromaticity in one direction and the vertical chromaticity a nearly equal amount in the opposite direction. Thus, it is the average of the measured horizontal and vertical chromaticities that should be very close to -1.

II. Measurements

In AGS Studies Report 182, Ahrens, et al. report their measurements of the tune and chromaticity of the AGS. Figure 1 is a plot of their data. The mean value of the horizontal and vertical chromaticities is about -1.4, which cannot be. The data must be wrong.

In AGS Studies Report 202, it is reported that the scale factor in the pick-up electrode system is off by 20%. Recalculating Ahrens data using this correction factor gives the results of Table I and Fig. 2. The mean measured Xi and that calculated from Eq. (1) are now in very good agreement.

III. Magnetic Measurements

Detailed field maps have been made of sample AGS magnets (to be published, Thern). In general, they display three characteristics:

i) At low field, significant magnetization effects of opposite sign for open and closed magnets;
ii) At intermediate fields, very low sextupole in the body of the magnet but significant effects in the end fields;
iii) At high fields, strong saturation sextupole.

The precise interpretation of the data and its use in a modeling program, such as MAD, is very subtle and worthy of much study. For our purposes Figs. 3 and 4 show the integrated quadrupole and sextupole strengths for long and short, open and closed magnets, where the integration has been carried out along the curved path of the nominal central orbit. These figures use the usual terminology: A is a long open magnet; B is a short open magnet; C is a long closed magnet; and the plus sign indicates the magnet is open to the outside, a minus sign that it is open to the inside.

IV. MAD Results

Using the magnet data from above, MAD calculates the chromaticities shown in Fig. 5. These results are pretty good. The overall behavior of the chromaticity at intermediate and high field is clearly explained by the measured magnetic fields. The absolute agreement is good, although better precision in calculation or measurement should be achievable. Below about 7 GeV/c the measured and calculated chromaticities plainly diverge. The shape of this divergence suggests the presence of a large sextupole field which does not vary with the magnet current. The field measurements of Section III were all dc measurements and eddy current effects were not taken into account. However, the sextupole required to produce the observed effects is very large compared to the measured eddy currents (M.H. Blewett, 10/3/58) and is very large compared to all the known low field sextupole terms. Therefore, we have at present no easy explanation for this difference between the measurements and the calculations.

V. Conclusion

The AGS is a very simple machine and at intermediate and high fields the chromaticity and the tune behave just as we would expect from the measured magnetic fields. At low fields we do not have all the answers yet.

TABLE I

Data from AGS Studies Report 182

P	Q(h)	Q(v)	Xi(h)	Xi(v)	(Xi(h)+Xi(v))/2
3	8.72	8.75	-1.30	-1.50	-1.40
6	8.72	8.76	-1.75	-0.70	-1.23
9	8.70	8.76	-2.15	-0.45	-1.30
12	8.71	8.76	-2.20	-0.45	-1.33
15	8.71	8.76	-2.20	-0.40	-1.30
18	8.70	8.76	-2.70	-0.25	-1.48
21	8.69	8.75	-3.00	0.10	-1.45
22.5	8.69	8.75	-2.95	0.10	-1.43
24	8.67	8.74	-3.55	0.30	-1.63
25.5	8.68	8.73	-3.35	0.55	-1.40
27	8.65	8.72	-3.75	0.90	-1.43
28.8	8.66	8.69	-4.18	1.41	-1.39

Data corrected by factor of 0.829947

P	Q(h)	Q(v)	Xi(h)	Xi(v)	(Xi(h)+Xi(v))/2
3	8.72	8.75	-1.08	-1.24	-1.16
6	8.72	8.76	-1.45	-0.58	-1.02
9	8.70	8.76	-1.78	-0.37	-1.08
12	8.71	8.76	-1.83	-0.37	-1.10
15	8.71	8.76	-1.83	-0.33	-1.08
18	8.70	8.76	-2.24	-0.21	-1.22
21	8.69	8.75	-2.49	0.08	-1.20
22.5	8.69	8.75	-2.45	0.08	-1.18
24	8.67	8.74	-2.95	0.25	-1.35
25.5	8.68	8.73	-2.78	0.46	-1.16
27	8.65	8.72	-3.11	0.75	-1.18
28.8	8.66	8.69	-3.47	1.17	-1.15

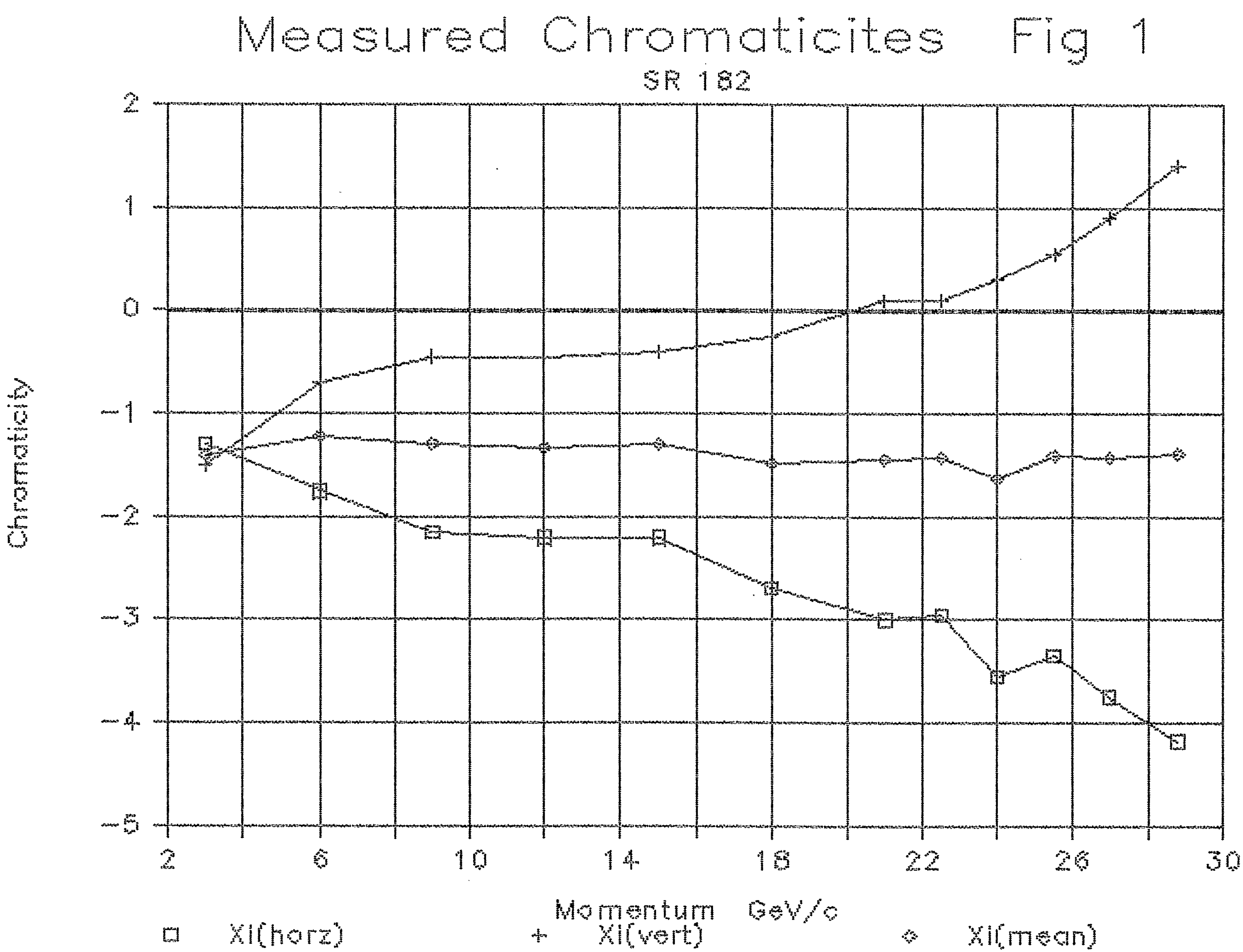
Measured Chromaticites Fig 1
SR 182
Chromaticity
2
1
0
−1
−2
−3
−4
−5
2
6
10
14
18
22
26
30
Momentum GeV/c
Xi(horz)
Xi(vert)
Xi(mean)

Figure 1.

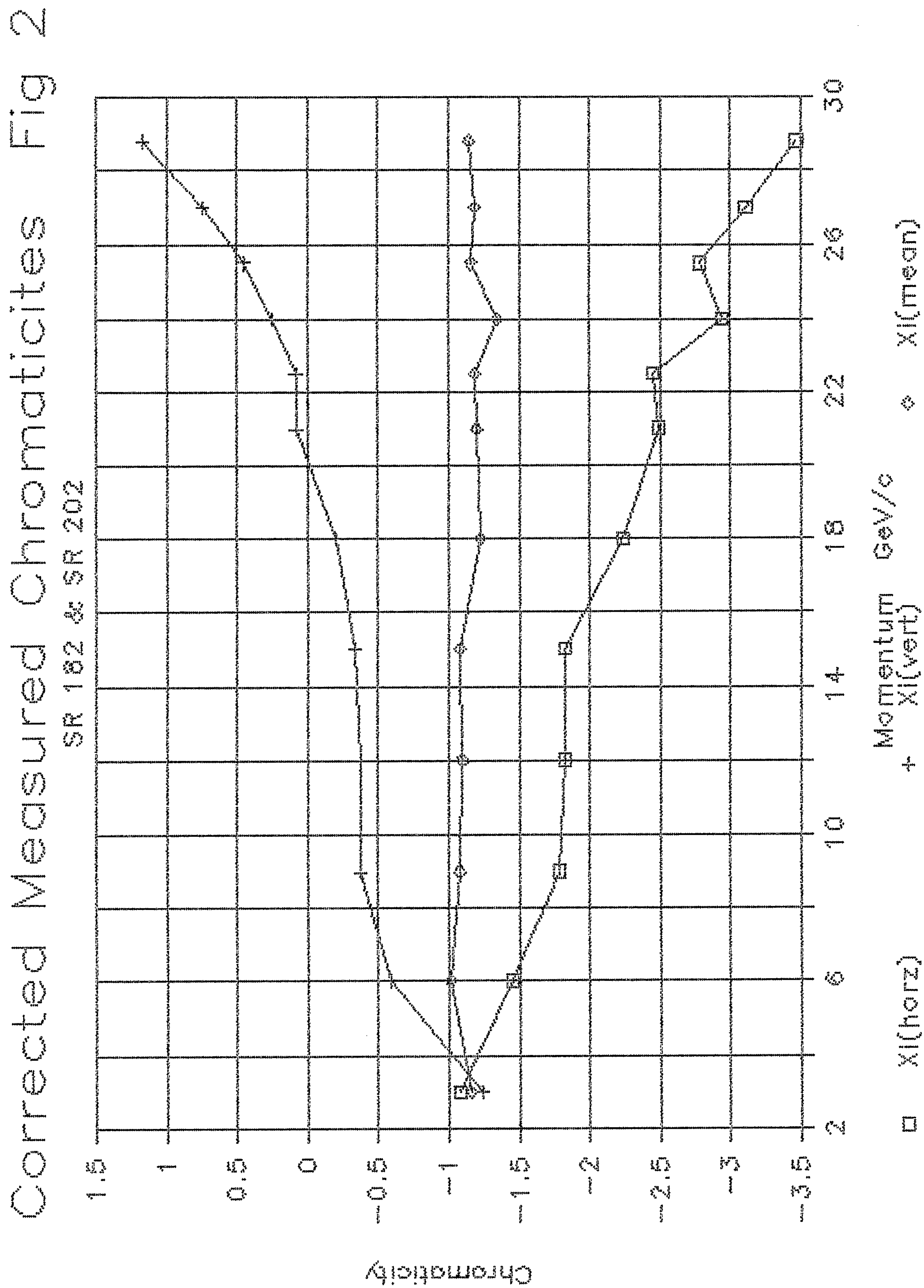
Corrected Measured Chromaticites Fig 2
SR 182 & SR 202
Chromaticity
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
2
6
10
14
18
22
26
30
Momentum GeV/c
□ Xi(horz)
+ Xi(vert)
◇ Xi(mean)

Figure 2.

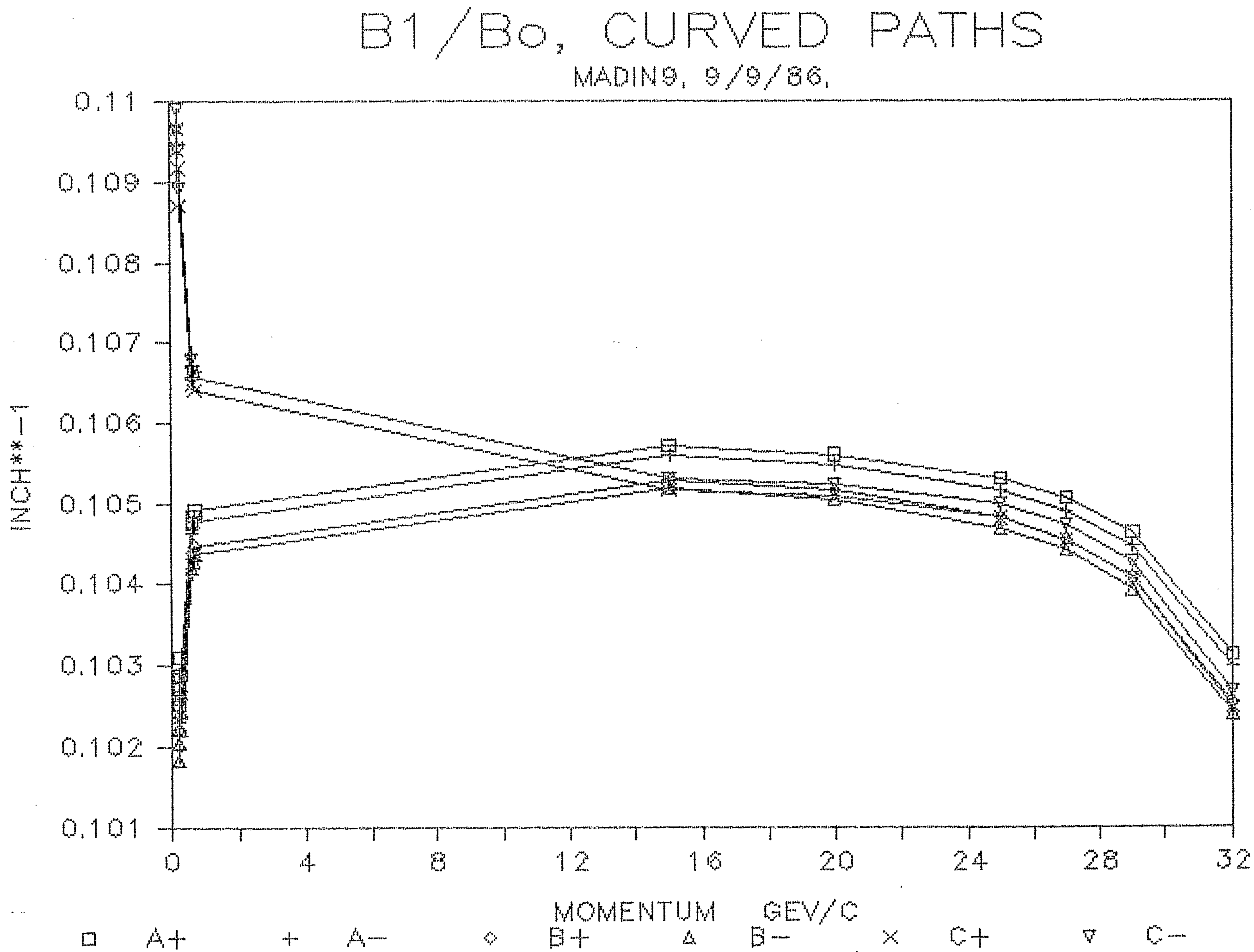
B1 / Bo, CURVED PATHS
MADIN9, 9/9/86,
INCH**-1
0.11
0.109
0.108
0.107
0.106
0.105
0.104
0.103
0.102
0.101
0
4
8
12
16
20
24
28
32
MOMENTUM GEV/C
□ A+
+ A-
◇ B+
△ B-
× C+
▽ C-

Figure 3.

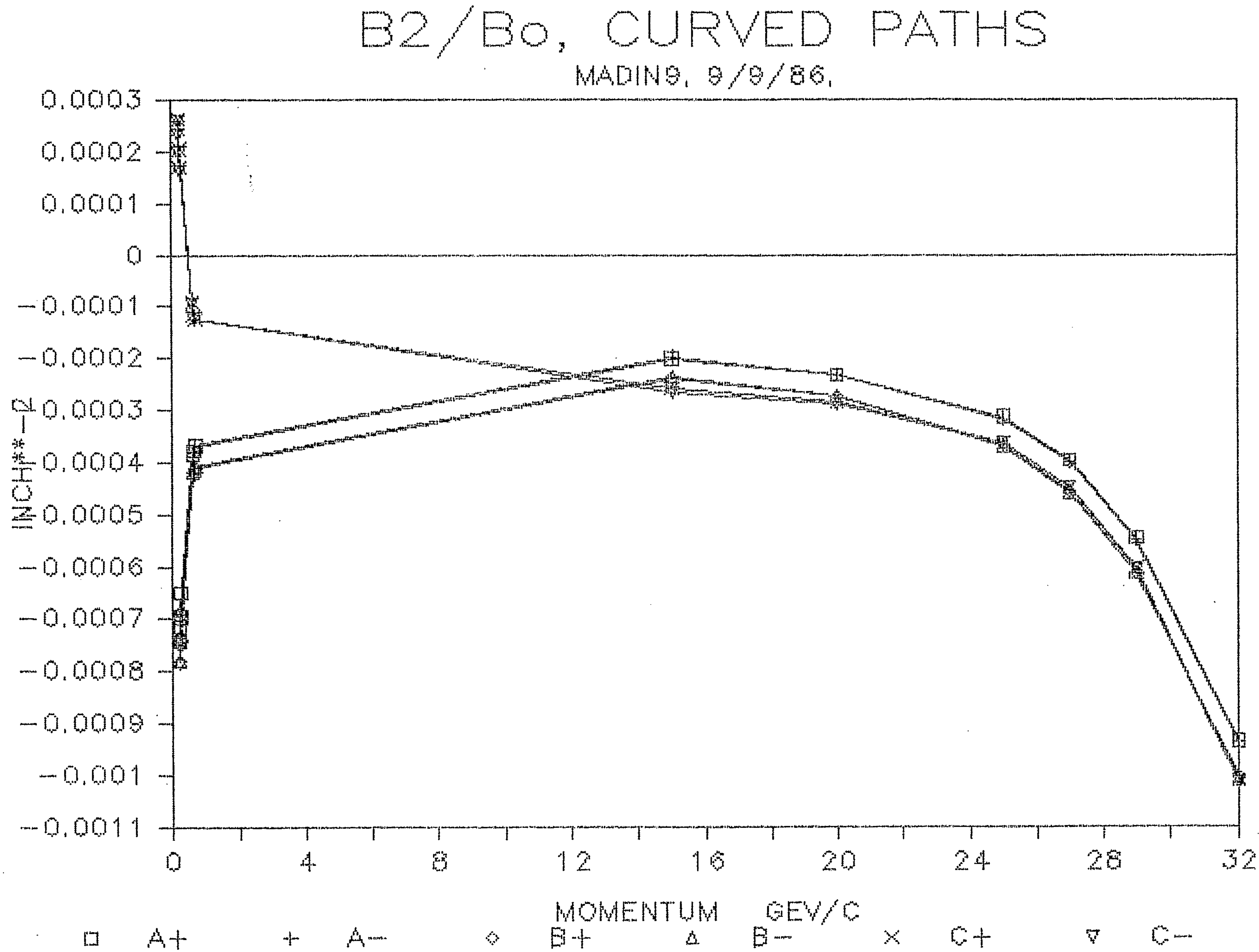
B2/Bo, CURVED PATHS
MADIN9, 9/9/86,
0.0003
0.0002
0.0001
0
-0.0001
-0.0002
-0.0003
-0.0004
-0.0005
-0.0006
-0.0007
-0.0008
-0.0009
-0.001
-0.0011
INCH**-2
0
4
8
12
16
20
24
28
32
MOMENTUM GEV/C
A+
A-
B+
B-
C+
C-

Figure 4.

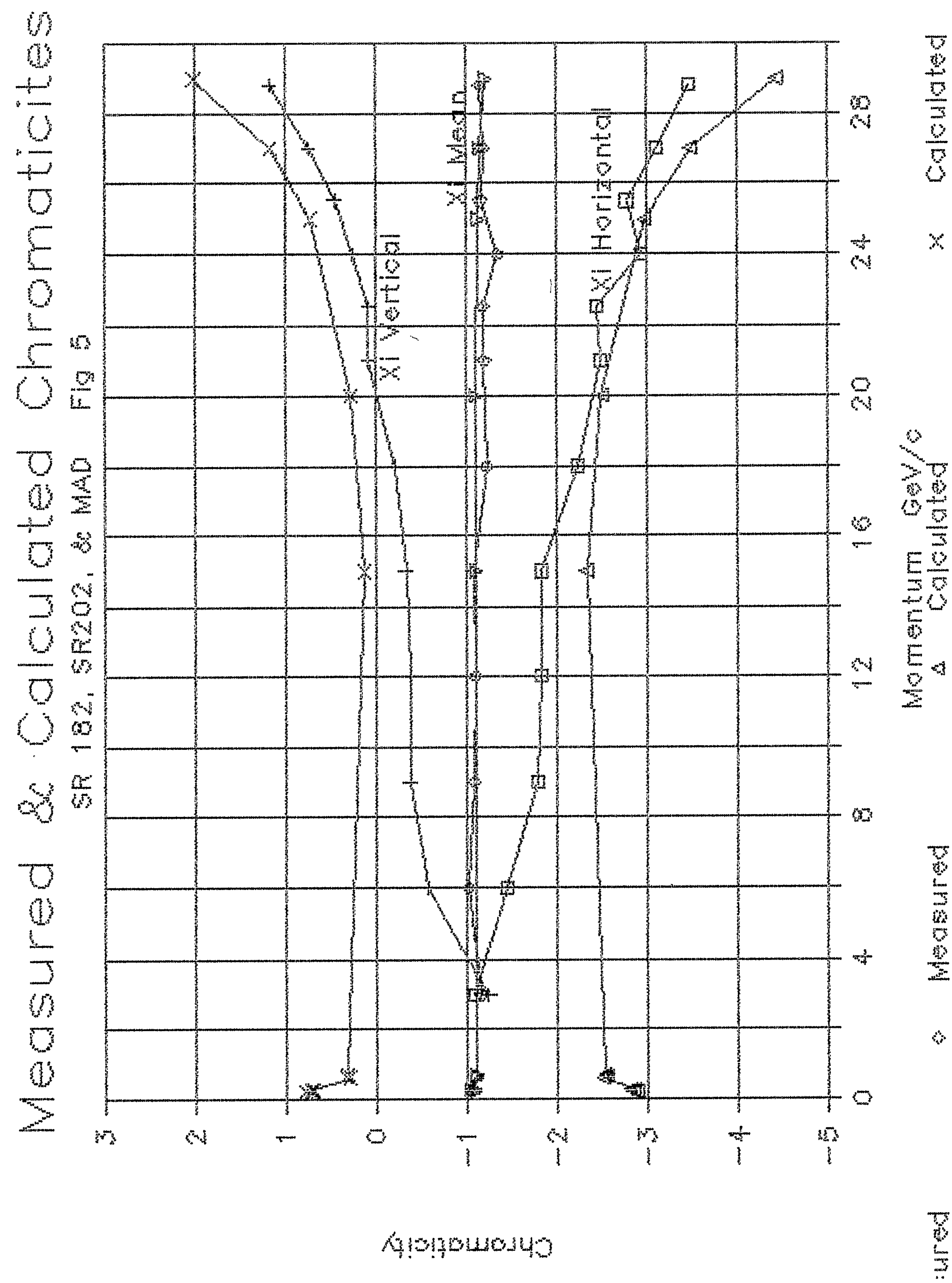
Measured & Calculated Chromaticites
SR 182, SR202, & MAD Fig 5
Xi Vertical
Xi Mean
Xi Horizontal
Chromaticity
Momentum GeV/c
◇ Measured
△ Calculated
× Calculated

Figure 5.