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Polarized Protons--1986 and Recommendations for Future Operation

L. A. Ahrens,

July 1986

Collider Accelerator Department

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No. 255

Polarized Protons--1986 and Recommendations for Future Operation

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July 1, 1986

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Polarized Protons - 1986

and

Recommendations for Future Operation

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Other Participants: H. Brown, E. Courant, H. Foelsche, C. Gardner, D. Lowenstein, D. Mohl, R. Ruth, S. Tepikian, W. van Asselt

I. Cost and Effort for Upgrades

		Hardware	Effort
A.			
1.	Upgrade of a fast quad P.S. from 5A to 15A	$ 14,000	Outside
2.	Reduce failures due to fuse, diodes, and use of marginal tubes	100,000	6 mm tech.
3.	200 MeV polarimeter	----	1 mm phys.
4.	Pick-up electrodes	Available	AGS studies
5.	Gauss clock stabilization		Studies
6.	Faster polarimeter		U. of M.
7.	Control work		
	a. Fast quads	6,000	6 m days tech. 1 mm prog.
	b. Pulsed dipoles		11 m days prog.
B.			
1.	2 additional fast quads & modulators	200,000	3 m yrs. tech.

II. Results of Mini-Workshop on 1986 Commissioning

The recently held workshop reviewing the activities of the last polarized proton run led to the following recommendations for further progress and delineated some areas for further study. Section A deals with hardware/software improvements, which would increase the reliability and accuracy of the tuning process and result directly in a more cost effective operation. Section B investigates the question of bringing the number of fast quads and modulators up to the design value of 12. Section C considers some of the physics questions raised by the commissioning run.

A. Hardware/Software Improvements

1. Fast Quads

a. Fuse failure and the use of a marginal tube caused most of the down time. Some testing and evaluation needs to be done. However, it is apparent now that about $100K in hardware is needed for the 10 modulators to correct these faults. A 1/2 manyear of technician effort would be required to make the necessary changes.

b. We should upgrade one of the unused 5A supplies to 15A so that we have one spare available. This would cost about $14K to an out-of-house supplier.

c. We did not quickly know (within a few AGS cycles) if a quad pulse had failed--computer fault scanning too slow--any improvement?

d. Digitization of the fast quad current analog signal, which requires the computer control of the MUX, to do software analysis of the quality of the match of high and low voltage supplies.

2. Dipoles

a. Check that we get two good analog current signals/superperiod to MCR.

b. Error reporting--trigger report if either the difference between request and obtained current exceeds some threshold, or if the percentage error exceeds some threshold.

c. Harmonic readback--use magnet current readbacks and Fourier analysis to determine amount of magnetic harmonic actually present in harmonic being tuned. Must be fast (a few AGS cycles).

3. 200 MeV Polarimeter

The 200 MeV polarimeter has no responsible owner. This device needs to be adopted by some AGS group. It misbehaved last run (unequal rates) which apparently resulted from a steering problem, but the problem went unfixed until near the end of the run. (documentation? cookbook?).

4. Pick-Up Electrodes

Because of the low intensity, the beam radius was controlled by a single, low-noise PUE instead of the usual pair. This results in unwanted radial shifts if the harmonics in the equilibrium orbit are varied (which is what happens if the tune is violently shifted--which we do regularly at the intrinsic resonances). Radius changes require compensating Gauss Clock timing changes to keep momentum fixed at resonances (a 1 mm shift is equivalent to a 20 Gauss count change at 20 GeV/c). To simplify tuning, we need two PUE's, spaced by approximately 180° of betatron phase. This is easily obtained if we can use "conversion" PUE's; these PUE's are noisier than the one used for PP radial control in the past. If the intensity is $> 10^{10}$, conversion PUE's can probably be used.

5. Gauss Clock

The accuracy desired of the Gauss clock is easily estimated, the presently obtained accuracy and a procedure to improve it are not so clear. Intrinsic resonance plateau widths obtained are as narrow as 100 Gauss clock counts, and one would like the freedom to shrink these further (smaller tune jumps) since this may reduce emittance growth. Then, the Gauss clock must be stable to a count number small compared with 100, say $\pm$ 10. At 20 GeV/c $\simeq$ 40,000 GCC, this means an accuracy of 2.5 in 10^4.

There was some evidence during the 1986 run of polarization loss associated wth a change in Gauss clock calibration. Efforts at measuring the Gauss clock time stability are an on-going project; the present results show a spread at least 5 times worse than that needed (namely, ± 50 counts at 20 GeV/c).

6. Faster Polarimetry

Can anything be done to speed up the acquisition of polarization data? Conern was expressed that there are sufficient numbers of "bad" polarization shots to make data containing only a few spin reversals unreliable. Clearly, if a way could be found, there is substantial running time or money to be gained here. The subject is being looked at by T. Roser of Michigan who feels that a software fix can eliminate "bad" points and allow a higher data rate.

7. Estimates for Control Upgrades

a. Pulsed Dipoles

1. Provide absolute and percentage errors for watch-dogging readbacks: 1 man-day.

2. Stand-alone Fourier analysis program for setpoints, readbacks, and readbacks with commanded polarity: 5 man-days.

3. Fourier analysis readback for Agast display, including rapid update on command changes: 5 man-days.

Total pulsed dipoles: 11 man-days.

b. Pulsed Quadrupoles

1. Cleanup alarm situation, i.e., provide for consolidation of alarms into fewer displayed lines; this is also required by violation in FSTUN of the maximum alarm number per program (64): 4 man-days.

2. More rapid alarm response and alarm testing/verification: 2 man-days.

3. Analysis of HV vs. LV setpoints

   i. hardware to acquire signals in function digitizer

      -- RELWAY II control of multiplexer, including IEEE-488 translators for A10, E10, H10, and RELWAY II station for E10: $6,000 + 5 man-days (tech.).
      (Assumption: PDP-10 control via Apollo of RELWAY II devices is previously implemented and combox/station installations already made in A10 and H10.)

      -- Cabling to function digitizer: 1 man-day (tech.).

   ii. Program to acquire all signals via function digitizer and output on Versatek: 15 man-days.

   iii. Studies to learn to analyze acquired signals: 8(?) hours machine time, without beam.

<u>Total pulsed quadrupoles</u>: 21 man-days programmer, 6 man-days technician, $6,000.

B. 12 Fast Quads

1. Reliability. Having 12 would reduce the strain caused by using 10 and allow the appropriate supply to be used at its design value. (We are essentially using the +20% engineering tolerance.)

2. Emittance. Courant stresses that 12 mods improves the emittance by a factor of 2. We know that improving emittance has led to better extraction efficiency (by as much as a factor of 5) and probably higher polarization. This could be very cost effective since AGS running time is very expensive. We will make a more definitive estimate of cost effectiveness as soon as we obtain some more results from our ongoing study effort to measure emittance growth.

3. Higher Energy. This is of secondary importance at this time, but may be of future interest at RHIC. 12 mods would make the extension much easier, although it is possible by re-arrangement of the modulators and operating full out that we could jump the next resonance and get to 26 GeV.

4. Cost Estimate. Considering that the houses and electrical services and cabling to the ring exists, we think the following estimate is reasonable:

a.	Frames & shop work	\$ 60K
b.	Air conditioning	15K
c.	Parts for 2 mods	100K
d.	Misc. & contingency	25K
		\$200K
e.	Rebuild 2 quads + any necessary rework on present quads & marginal vacuum chambers	1 manyear
f.	Build & test 2 mods	2 manyears

We would probably need 3 experienced technicians for one year with minimal supervision.

C. Physics Questions

1. The beat resonances, imperfection corrections. The 1986 run includes a wealth of data showing the effect of applying a number of possible magnetic harmonics in order to correct particular resonances. The Terwilliger model and/ or the Courant-Ruth matrix = M_{ij} where $\varepsilon_i = \sum M_{ij} C_j$, ε_i = strength of resonance i (usual $= \frac{Pol_{out}}{Pol_{in}} = 2e^{-\frac{\pi\varepsilon^2}{2\alpha}} - 1)$ C_j = magnetic correction applied at harmonic j (which matrix is promised) should make many predictions which can be tested using the 1986 data. The upshot may be a way to estimate corrections needed at higher harmonics, and certainly a rationale for choosing which magnetic harmonic to use to correct a given resonance.

2. The 1986 run required less correction at most harmonics than the 1984 run, but required significantly more correction at $G\gamma = 12$. The vertical alignment prior to the run may have increased the amount of 12 (superperiod symmetry) although the mechanism is not understood. The amount of 12th might make $G\gamma = 48$ uncorrectable (beats). Survey techniques are being improved.

3. The separation of $G\gamma = 27$ and $G\gamma = 36 - \nu$ by pushing the tune down to essentially 8.5 decreased the polarization loss in this region but a loss remains. The tune cannot go lower, perhaps retuning $G\gamma = 27$ (9) might have gained the rest but it is not clear. It is also speculated that having 12 fast quads would help.

4. Some "odd" phenomena remain--not yet with any explanation.

   a. Precursors at $0 + \nu$ and $36 - \nu$???

   b. The "widths" at $G\gamma = 24$ do not show the predicted difference between sin and cosine expected (and seen at 12 and 36).

   c. The $0 + \nu$ slow quad shift was toward 8.5, so the fast quad shifted the tune through 8.5. Why was this the best strategy--why was it possible?

5. The strengths of the intrinsics will be compared with prediction. We still have no good agreement between theory and experiment, and people are working on this.

III. Data Base Resulting from 1986 Operation

A. Graphs of polarization calibration.

1. Analyzing power in PP ealstic scattering at t = - 0.3 as determined after measurements at 13.3 GeV/c.

2. Effective analyzing power of p-nylon scattering at t = - 0.15 as calibrated from above.

3. Polarization of the AGS beam as a function of energy. Major loss at $G\gamma = 36 - \nu$ and $G\gamma = 27$ (interference).

4. Measurement of asymmetry as a function of energy, showing abrupt loss of polarization (internal polarimeter).

B. Gauss clock calibration.

5. Graph shows spread in GCC as a function of day-to-day scans. $\Diamond$ Symbol represents the GCC extracted from the P↑ intrinsic resonance corrections.

C. Tune space and slow quad operation.

6. Measurements of stopbands in tune space. It is possible to cross the $\nu_v = 8.5$ band to 8.4 or less with minimal beam loss.

7. Tune space operating points for the slow and fast quads at the indicated resonances. These led to minimum emittance growth during the acceleration cycle. Slow quad settings are given.

D. Imperfection resonance strengths and corrections.

8. Definitions of parameters.

9. Listing of strengths and corrections.

NOTE: α_n, β_n are given in counts where 127 counts = 10 amps.

E. Intrinsic resonance corrections.

10. Polarization and quadrupole settings. An attempt was made to correct 12-ν, but there was no evidence of polarization loss. 24-ν was turned off because of problems with pulsing the fast quads at transition, although there might be a 1 or 2% loss of polarization.

F. Comparisons of "beat conditions" and model for imperfection resonances. Implications for the future.

11. Listing of "beat" corrections and comparison with model by K.M. Terwilliger. The errors on widths and experimental ratio from error analysis by F.Z. Khiari.

12. Graph of experiment vs. model. Note that for corrections from $G\gamma = 41$ on, 36+ appears to be the best with 60- doing well from $G\gamma = 46$ on.

13. Errors on resonance widths.

G. Vertical alignment, summer 1985.

14. Magnet elevations 8/27/85 before adjustment.

15. After adjustment 10/2/85.

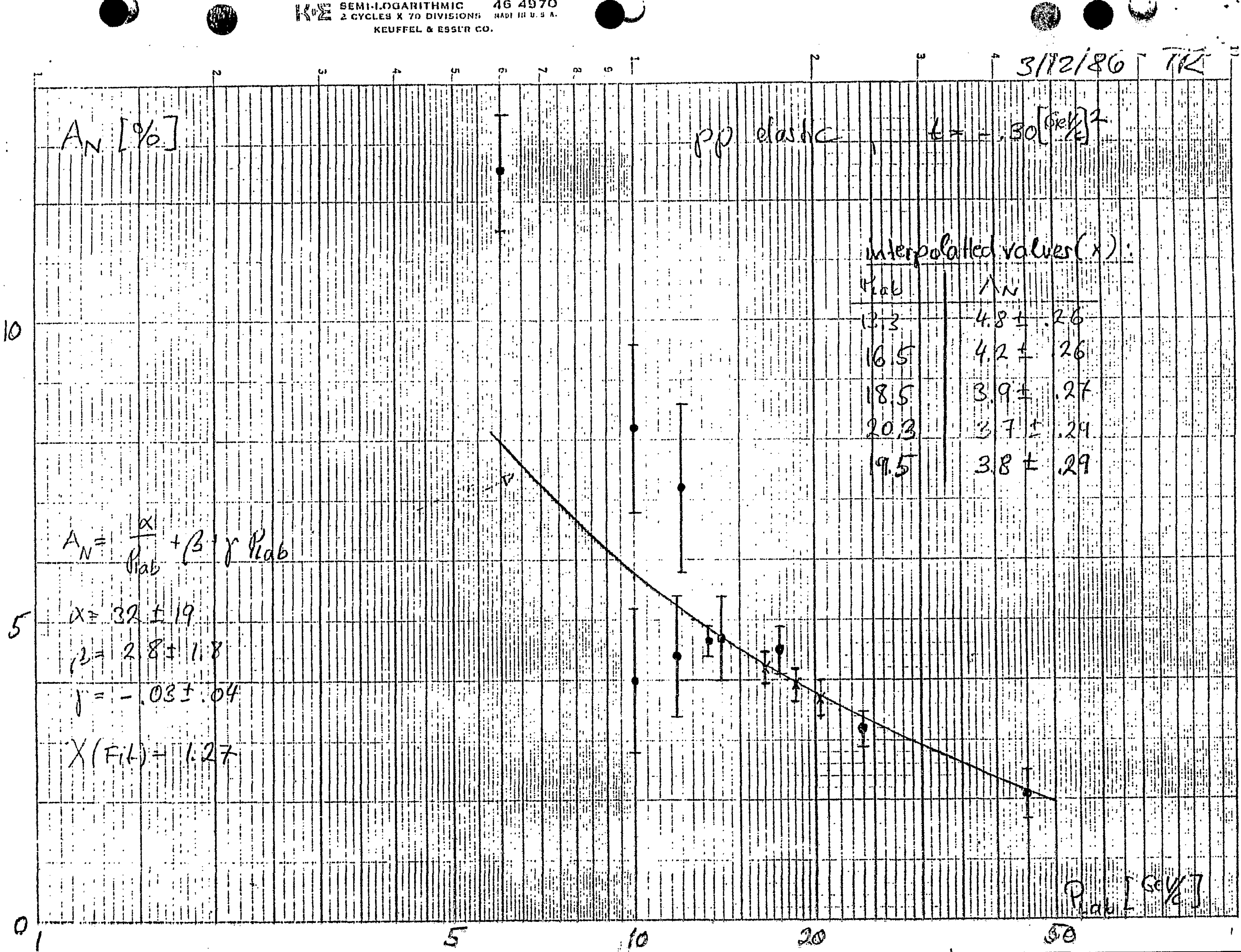
16. Expanded scale 10/2/85.

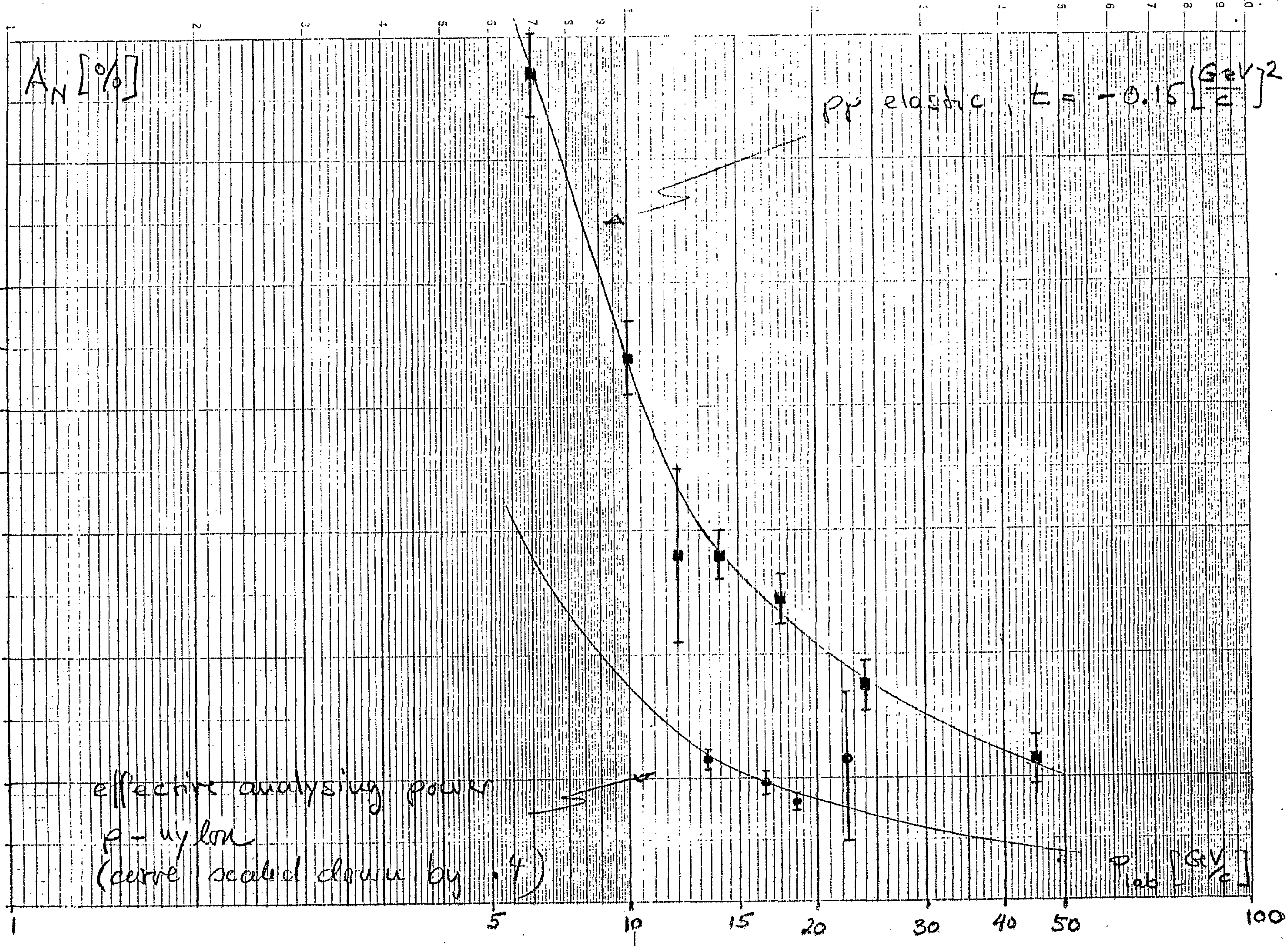
H. Some "odd" phenomena.

17. $G\gamma = 36 - \nu$ showing as yet unexplained "precursor".

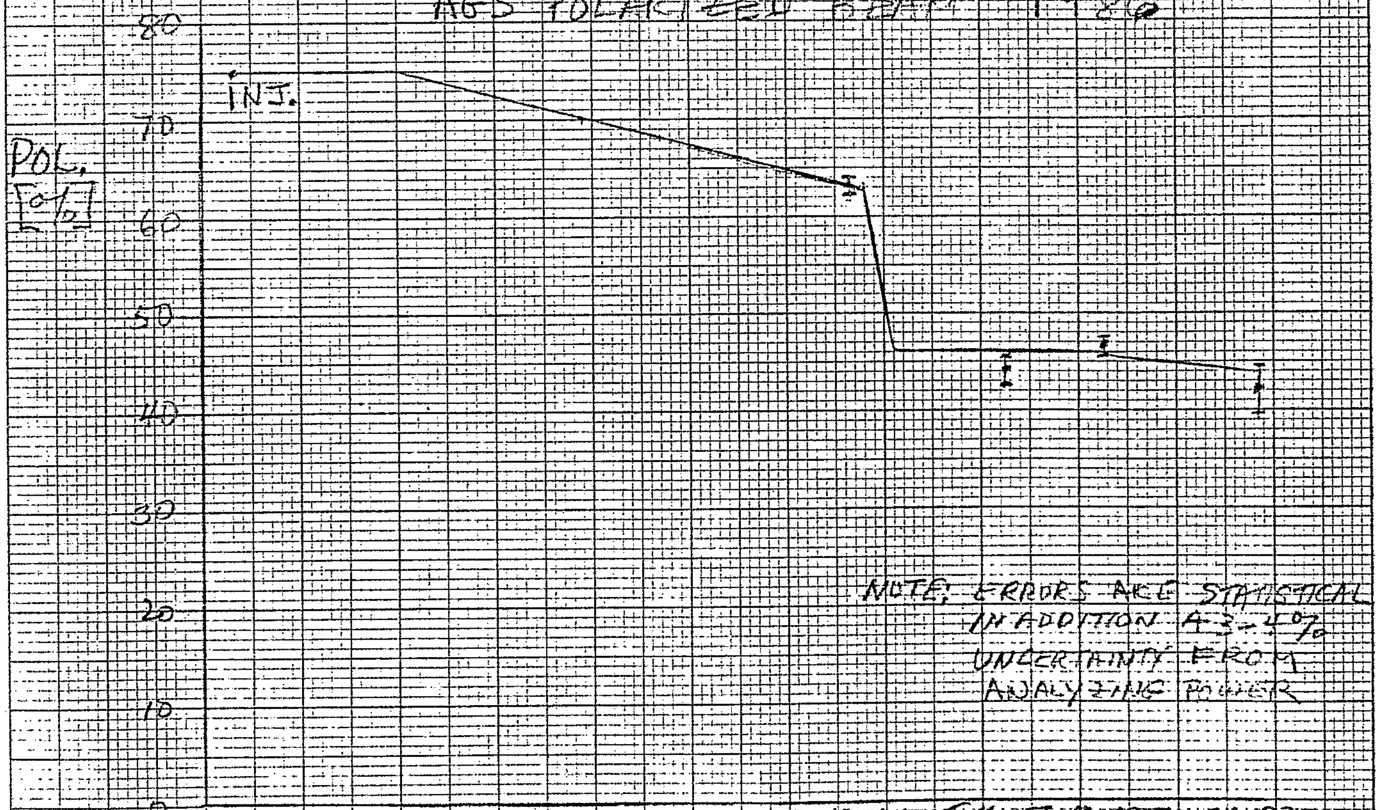
18. The following table shows the difference between $G\gamma = 12$, $G\gamma = 36$, and $G\gamma = 24$ with regard to ratio of Cosine to Sine correction. One expects $Cn/Sn \approx 2$ because of the location of missing dipoles in the lattice.

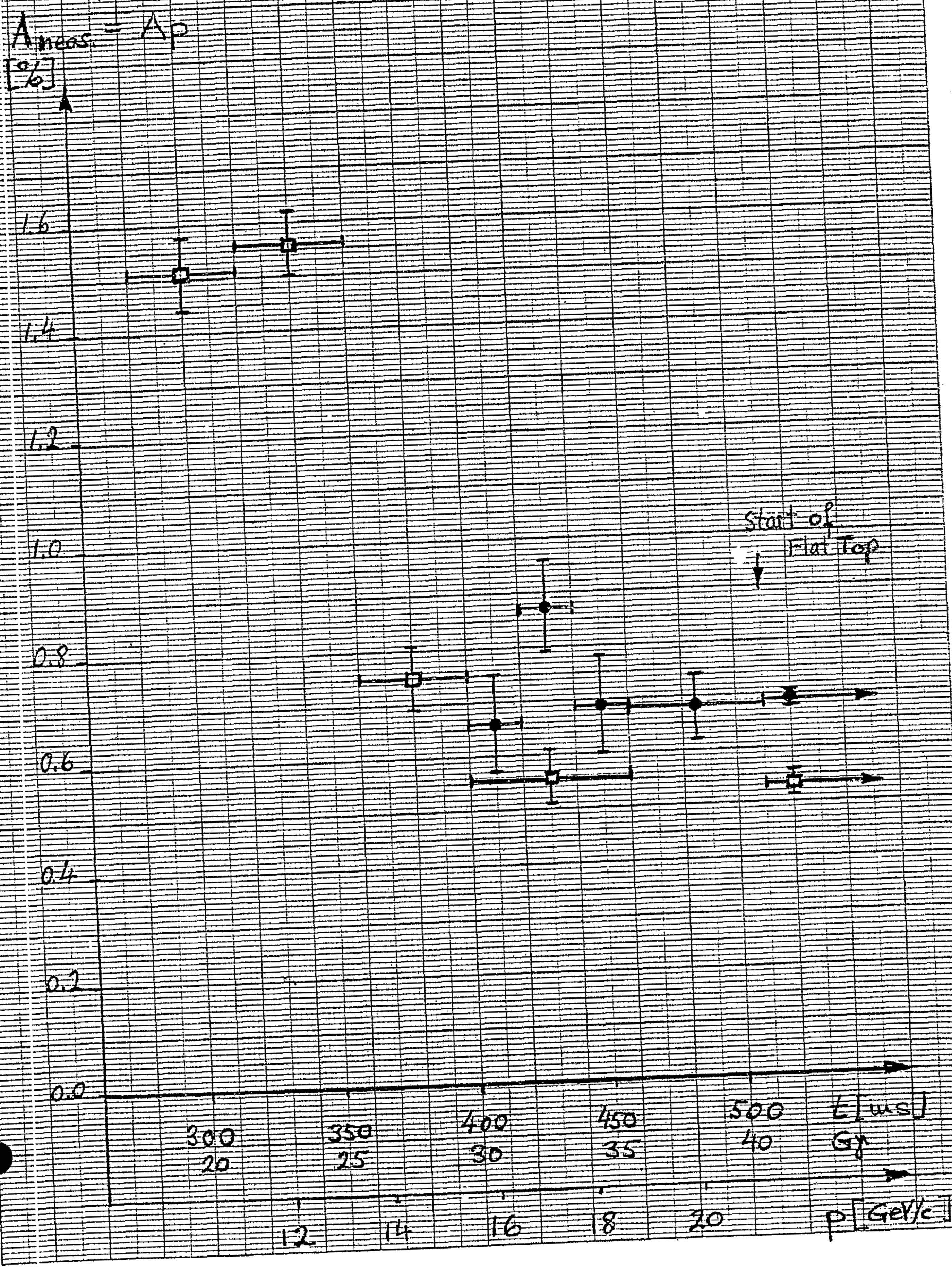
	$G\gamma = 12$	$G\gamma = 24$	$G\gamma = 36$
Cn	73	86	1.46
Sn	41	105	80
R	1.78	.82	1.83


K+E SEMI-LOGARITHMIC 2 CYCLES X 70 DIVISIONS 46 4970 MADE IN U.S.A.
KEUFFEL & ESSER CO.
3/12/86 TK
A_N [%]
pp elastic , t = -.30 [GeV/c]^2
interpolated values (x):
P_lab | A_N
13.3 | 4.8 ± .26
16.5 | 4.2 ± .26
18.5 | 3.9 ± .27
20.3 | 3.7 ± .29
19.5 | 3.8 ± .29
A_N = α/P_lab + β + γ P_lab
α = 32 ± 19
β = 2.8 ± 1.8
γ = -.03 ± .04
χ (Fit) = 1.27
10
5
0
1
5
10
20
50
P_lab [GeV/c]


A_N [%]
pp elastic, t = -0.15 [GeV/c]^2
effective analysing power
p - nylon
(curve scaled down by .4)
P_lab [GeV/c]
1
5
10
15
20
30
40
50
100

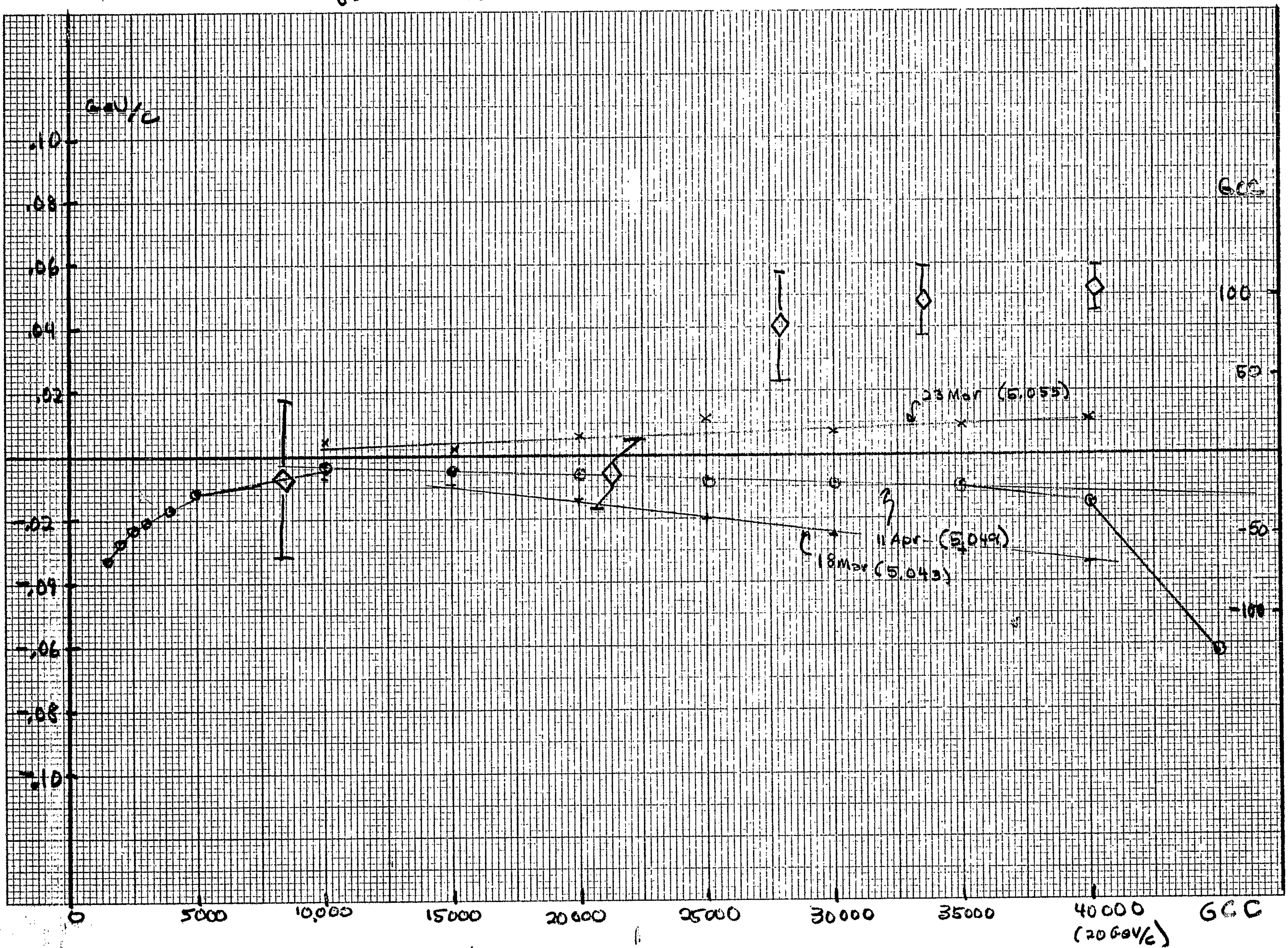
AGS POLARIZED BEAM 1986





A meas. − Ap
[%]
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Start of
Flat Top
300
20
350
25
400
30
450
35
500
40
t [ms]
G γ
12
14
16
18
20
p [GeV/c]

$P(freq, R) - P_{cal}(GC)$ $R_0 = 12845.7$ cm



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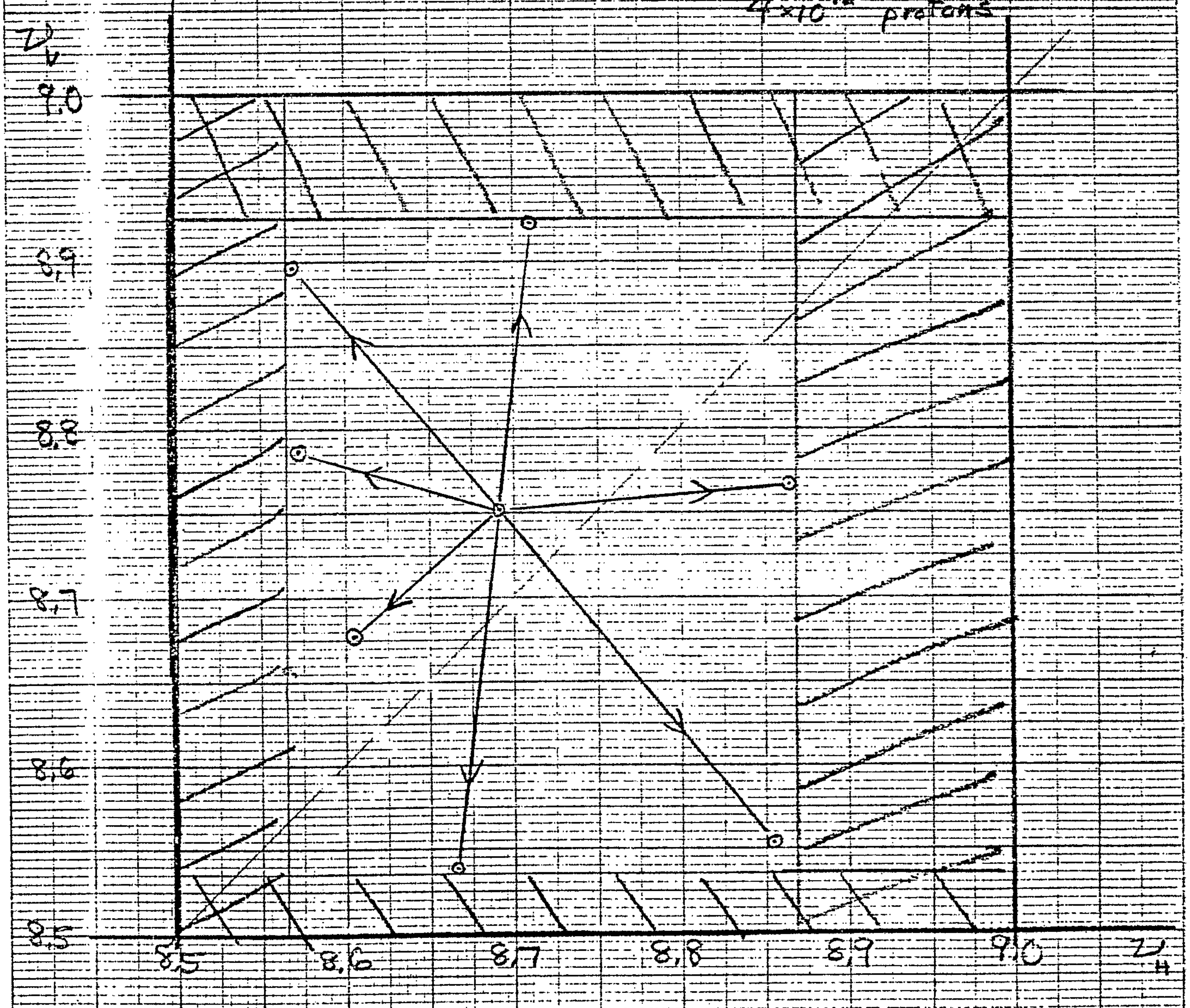
Available Tune space at 14 GeV/c

4×10^{12} protons



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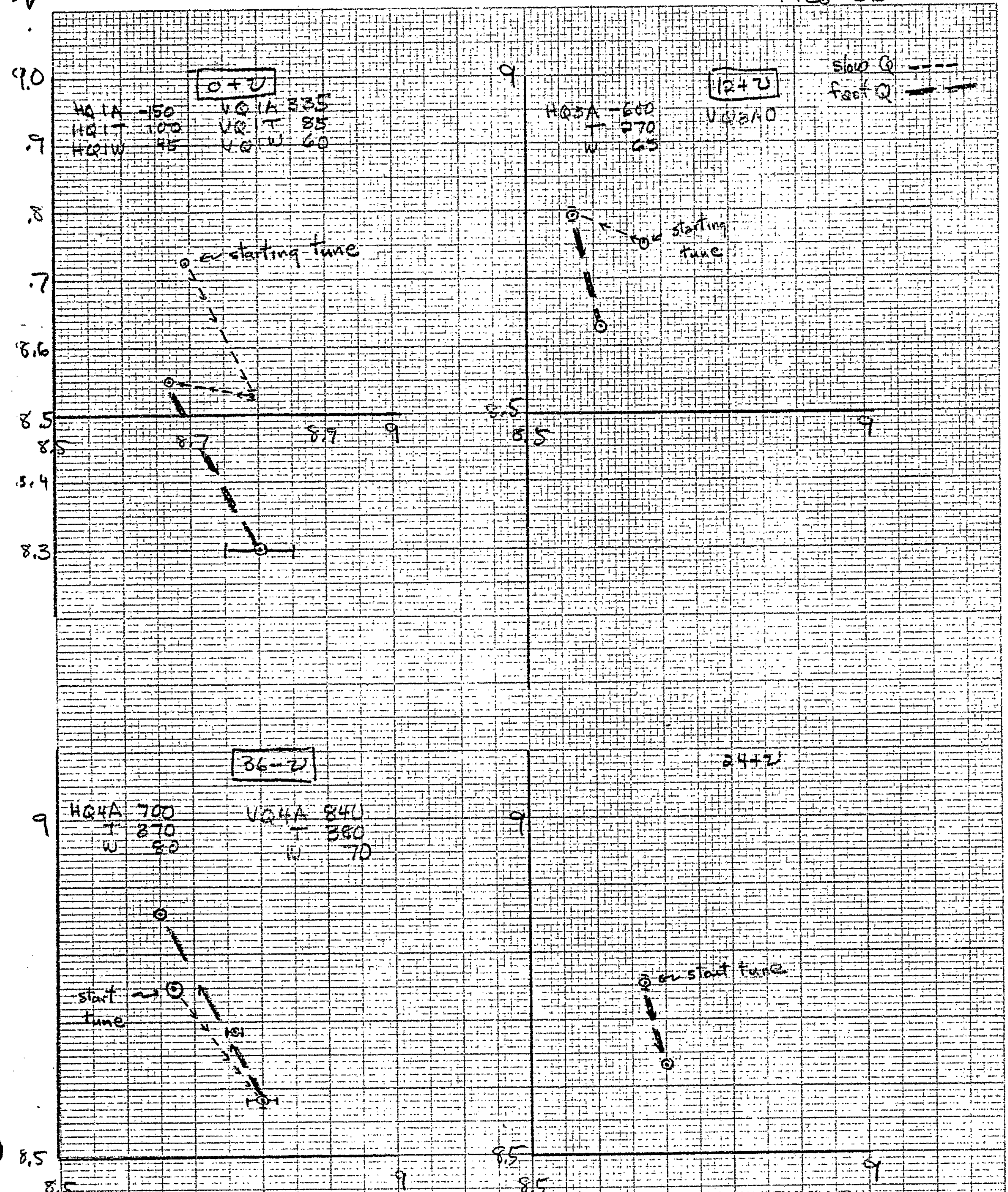


Motion in Tune space at intrinsic resonances

Correction Amplitudes and Strengths for the Imperfection Resonances

$$G\,\gamma_n = n$$

$$Correction = \alpha_n Sin(n\theta) + \beta_n Cos(n\theta) = \rho_n Sin(n\theta + \phi_n)$$

θ = 0 is defined as the start of the AGS "A" superperiod.

$$P(\alpha_n, \beta_n)$$

$$\rho_n = Correction\ \ Amplitude = \sqrt{(\alpha_n^2 + \beta_n^2)}$$

$$\phi_n = Arctan(\beta_n / \alpha_n)$$

$$FWHM[Sin(n\theta)] = S_n\ \ , FWHM[Cos(n\theta)] = C_n$$

$$P(\alpha_n \pm \tfrac{S_n}{2}, \beta_n \pm \tfrac{C_n}{2}) = \tfrac{P_{max}}{2}$$

$$\sigma_n = Correction\ \ Strength = \sqrt{(\tfrac{1}{S_n^2} + \tfrac{1}{C_n^2})}$$

$$F_n \equiv (\int B.dl)_{max} = Correction\ \ Amplitude \times \tfrac{10}{127} \times \tfrac{1}{2} \times \tfrac{100}{1.6}\ \ \text{G.INC}$$

Correction Amplitudes and Strengths for the Imperfection Resonances

n	α_n	β_n	ρ_n	F_n	S_n	C_n	$10^3\sigma_n$	ϕ_n
7	5	0	5		53	59	26	0
8	−8	−5	9		17	15	92	32
9	−4	−11	12	25	10	11	135	70
10	−2	−2	3		38	38	37	45
11	−10	−2	10		46	46	31	11.3
12	40	−9	41	101	41	73	28	−12.7
13	−10	5	11		68	65	21	−26.6
14	5	−13	14		73	78	19	−59
15	0	−15	15		92	79	17	−90
16	−5	−10	11		85	90	16	63.4
17	−10	−5	11		88	79	17	26.6
18	5	20	21		122	89	14	76
19	10	−10	14		83	85	17	−45
20	−2	33	33		122	102	13	−86
21	−10	−10	14		144	120		45
22	−10	−5	11		105	81	16	26.6
23	25	15	29		120	99	13	31
24	−5	40	40	98	105	86	15	−82.9
25	20	12	23		120	109	12	31
26	−5	−10	11		125	92	14	63.4
27	0	0	0		100	62	19	
9	−17	−32	36		20	23	66	62
28	0	0	0		90	90	16	
8	−25	−25	34		38	38	37	45
29	5	−3	6		100	100	14	−31
30	5	0	5		100	100	14	0
31	−5	0	5		100	120	13	0
32	20	0	20		128	140	11	0
33	0	−30	30		174	127	10	−90
34	−12	−40	42		104	92	15	73.3
35	20	−60	63	155	120	120	12	−71.6
36	−40	−60	78	192	80	146	14	56.3
37	−20	−35	40		110	104	13	60.3
38	60	45	75		96	110	14	36.9
39	100	−50	112	276	120	120	12	−26.5
40	30	20	36		92	84	16	33.7

Intrinsic Resonances

$G\gamma$	P_i	P_f	P_f/P_i	Predictions Courant-Ruth
12-ν	--	--	100%	100%
0+ν	17%	-10%	-59% Spin Flip	-100% Flip
24-ν	--	--	100%	97%
12+ν	45%	~ 3%	~ 7%	-36% Flip
36-ν	-40%	+24%	-60% Spin Flip	-99% Flip
24+ν	+37%	+33%	89%	93%
48-ν	+30%	+21%	70%	84%

The predictions are not too unreasonable when we consider that they are made for those particles which have maximum betatron amplitude and not for a normal distribution.

Quadrupole Values Used

$G\gamma$	HV Volts	LV Volts	$\Delta\nu$	GCC	FWHM GCC
0+ν	3200	450	0.24	8340	230
12+ν	4716	800	0.17	21130	150
36-ν	11943	1986	0.28	27960	250
24+ν	6357	1468	0.14	33500	250
48-ν	7172	1492	0.11	40180	150

"Beat" Corrections and Simple Model Predictions

		Beat	Sin FWHM	Cos FWHM	$\sigma n = \sqrt{1/Sn^2+1/Cn^2}$	Beat σn/Fund. σn	
$G\gamma$	θ		S_n	C_n	10^3 σn	R	R_M
20	20		122	102	12.8	.94 ± .08	1.18
	8	12+	120	116	12.0		
21	21		114	120	12.1	3.2 ± .08	3.4
	9	12+	36	38	38.3		
22	22		105	81	15.6		
	10	12+					
24	24		105	86	15.0	.47 ± .12	.53
	12	36–	200	200	7.1		
		12+					
25	25		120	109	12.4	.89 ± .09	.81
	11	36–	116	146	11.0		
26	26		116	100	13.2	1.3 ± .10	1.6
	10	36–	78	86	17.3		
27	27		88	56	21.2	3.2 ± .04	8.3
	9	36–	19	23	68.3		
				(for ν_z = 8.50 produced by slow quads.			R_M = 4.0)
28	28		90	90	15.7	2.4 ± .16	2.9
	8	36–	38	38	37		
29	29		100	100	14	1.8 ± .22	1.4
	7	36–	50	64	25.4		
32	32		128	140	11	.64 ± .27	.22
	8	24+	200	200?	7		
33	33		174	127	10	.70	.58
	9	24+	200	200?	7		
36	36		80	146	14.3	.98 ± .33	.65
	24	60–	90	120	13.9		
		12+					
37	37		110	100	13.5	.59 ± .07	.72
	23	60–	200	160	8.0		
38	38		96	110	13.8	.57 ± .14	.78
	22	60–	180	180	7.9		
40	40		92	84	16.1	.65 ± .50	1.01
	20	60–	136	136	10.4		
41	41		86	86	16.4	1.2 ± .08	1.2
	19	60–	70	80	19.0		

"Beat" Corrections and Simple Model Predictions

1984 Measurements

		Beat	Sin FWHM	Cos FWHM	$\sigma n = \sqrt{1/Sn^2+1/Cn^2}$	Beat σn/Fund. σn	
$G\gamma$	θ		S_n	C_n	$10^3\ \sigma n$	R	R_M
26	26		110	138	11.6	1.7	1.6
	10	36−	70	72	19.9		
27	27		130	64	17.4	7.5	8.3
	9	36−	12	10	130.0		
28	28		120	54	20.3	2.3	2.9
	8	36−	26	36	47.0		
29	29		100	70	17.4	1.7	1.4
	7	36−	48	50	28.9		
30	30		85	80	17.2	.38	1.10
	6	36−	200	240	6.5		
31	31		(160)	160	8.8		
	5	36−	160	160	8.8	1.0	.53
	7	24+	120	130	11.3	1.3	.09

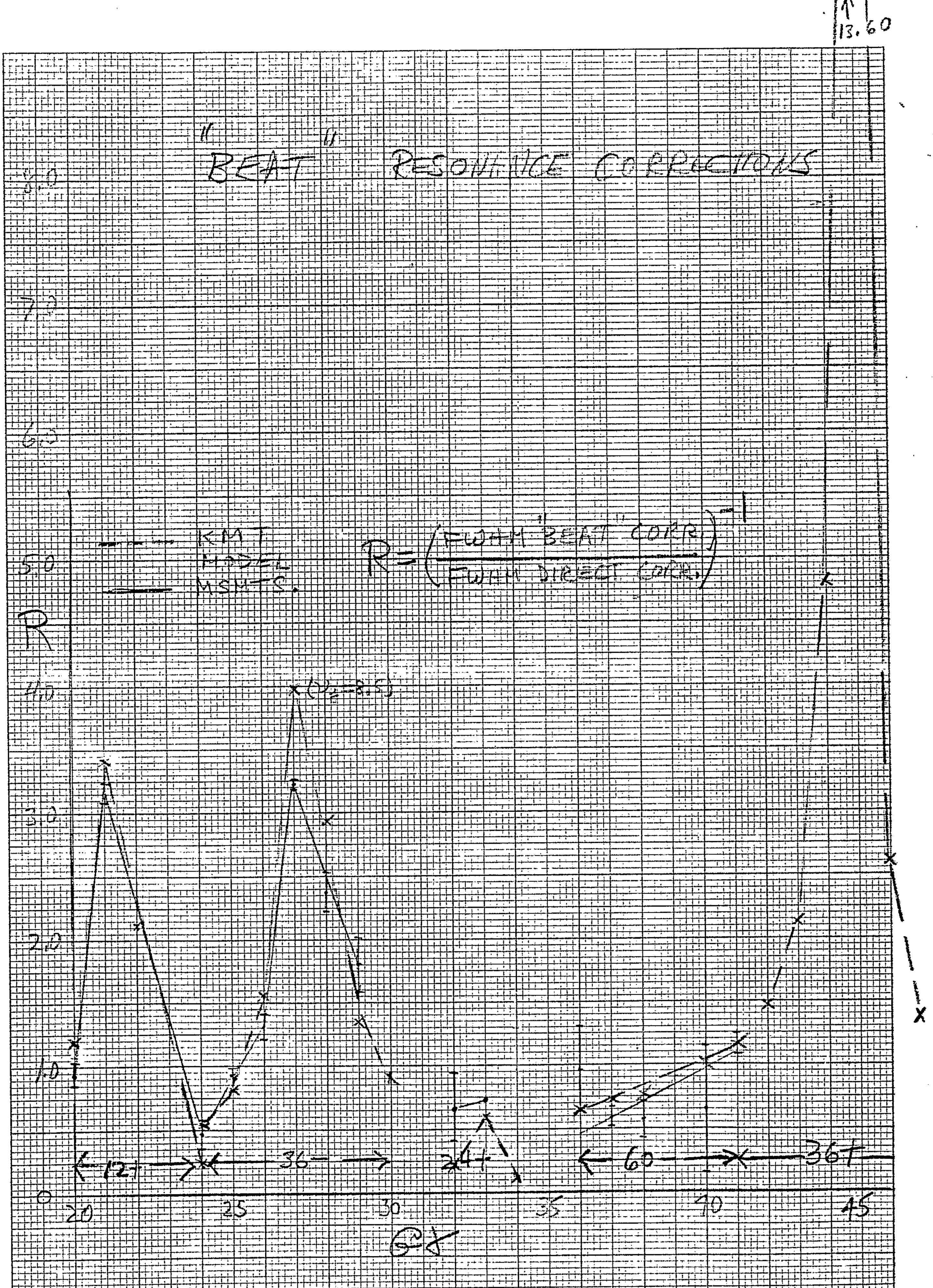
$$\text{Model } R_M = \frac{[1 - (\frac{\nu_z}{k})^2]}{[(\frac{k'}{\nu_z})^2 - 1]\ [1/\alpha]}$$

12+	α = .24
36−	.535
24+	.036
48−	.049
36+	.82
60−	4.48

α = beat amplification factor

Nominal ν_z = 8.75

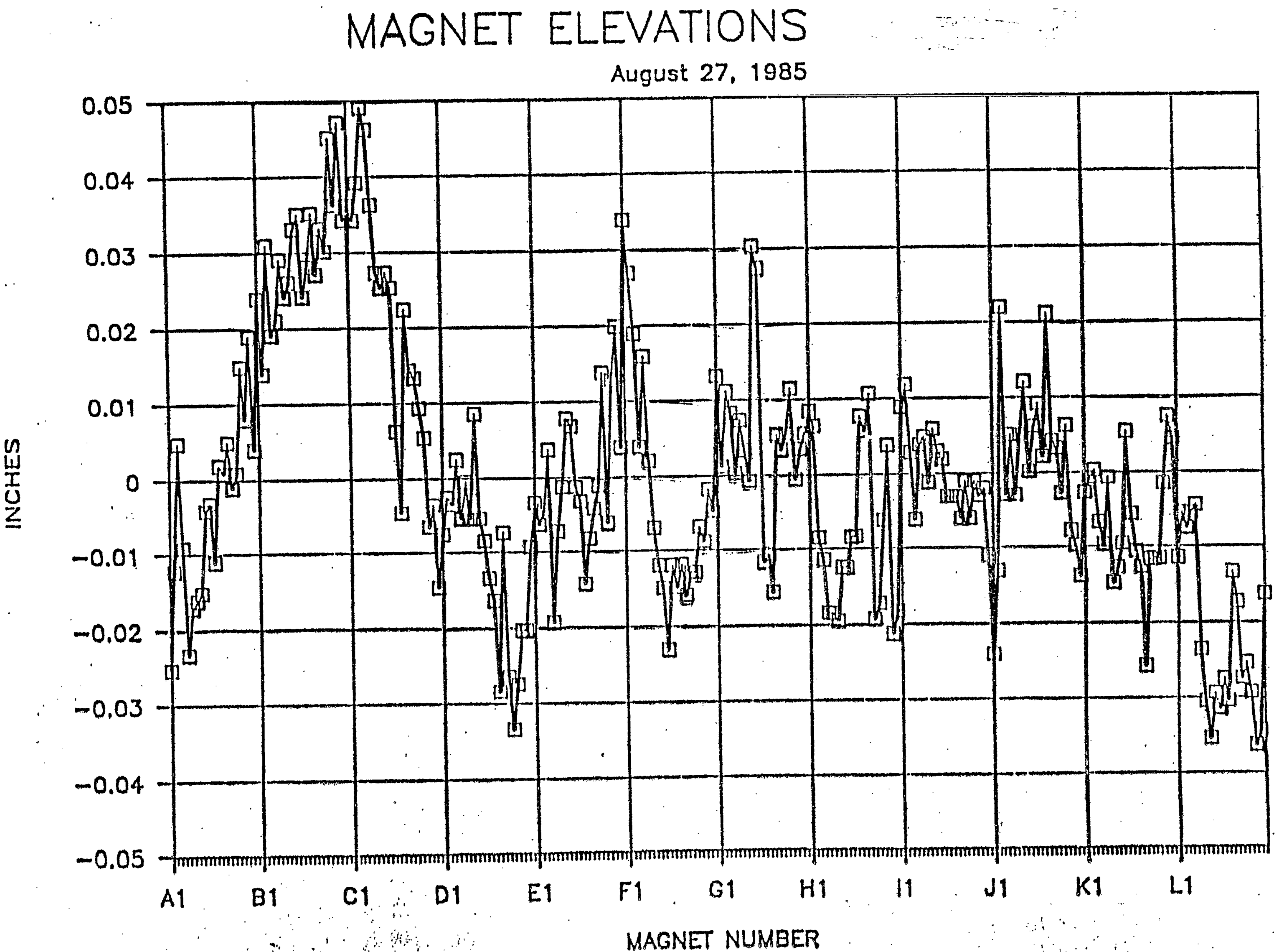
"BEAT" RESONANCE CORRECTIONS



Sn = FWHM (sin), Cn = FWHM (cos)

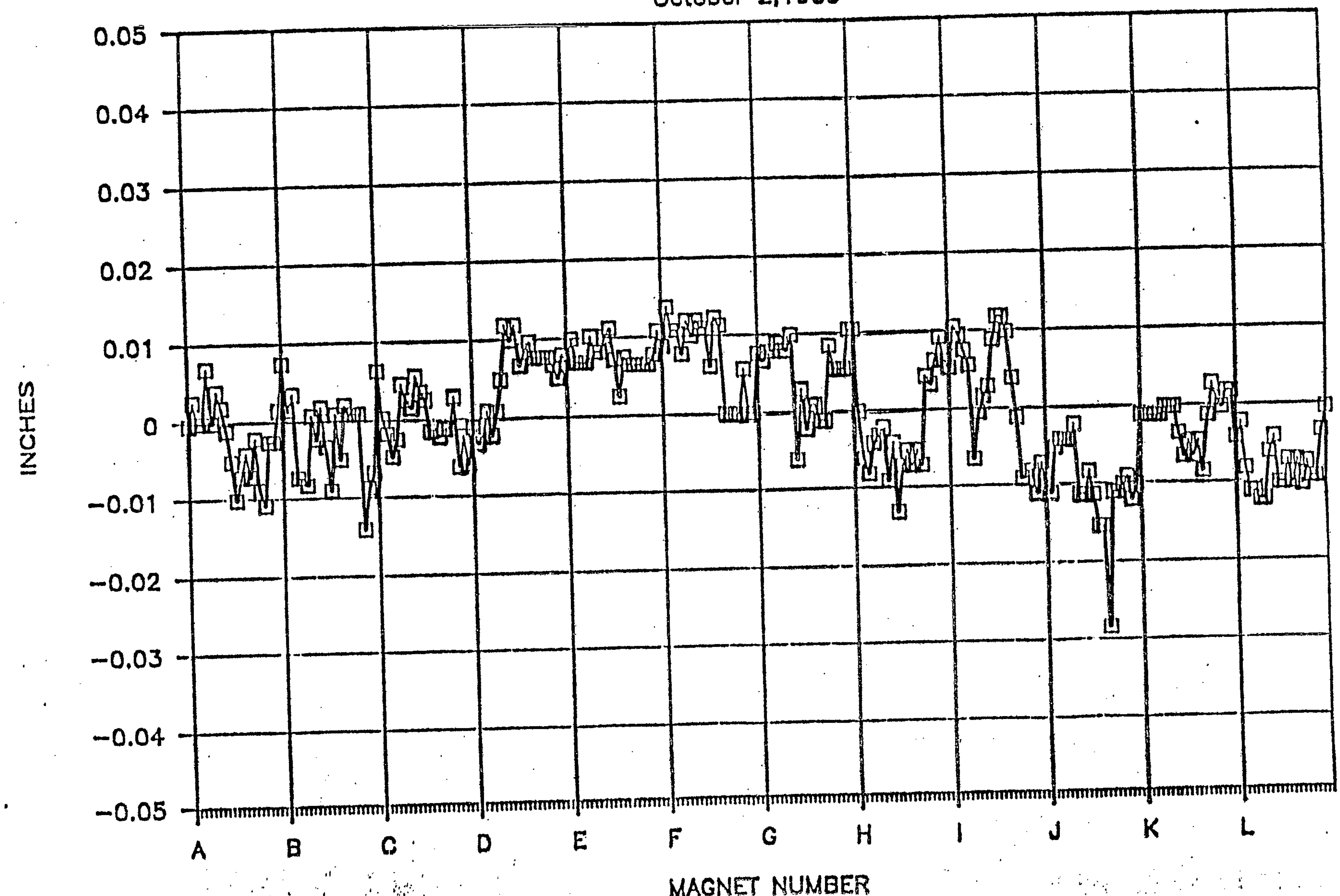
Gγ	ΔSn	ΔCn
7	3.01	1.42
8	.36	.45
9	.25	.10
10	4.76	2.08
11	1.79	.67
12	1.79	1.60
13	1.84	2.42
14	3.16	1.50
15	4.06	3.43
16	1.38	2.67
17	5.16	2.16
18	8.13	1.77
19	6.03	7.62
20	5.21	8.00
21	3.47	5.30
22	5.12	3.03
23	2.41	3.95
24	3.25	5.64
25	5.04	5.79
26	8.36	5.13
27	6.82	4.29
28	12.83	12.86
29	5.58	10.39
30	5.80	9.26
31	4.57	6.64
32	5.62	9.36
33	18.82	14.45
34	7.26	5.22
35	3.33	4.72
36	7.26	7.64
37	3.65	3.14
38	4.42	7.54
29	5.26 (?)	5.26
40	51.46	36.06
41	3.85	3.52

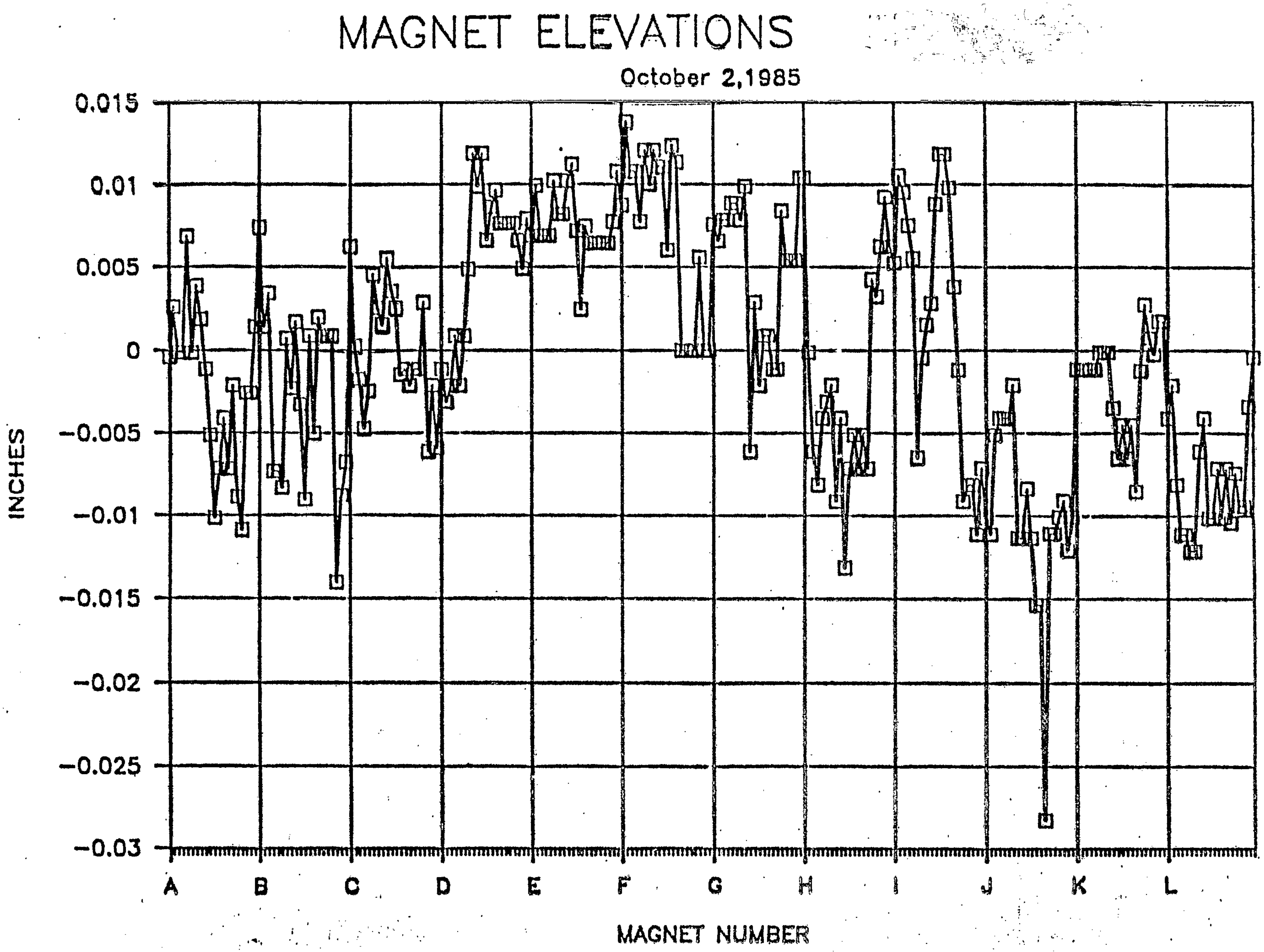
Gγ	ΔSn	ΔCn
20/8	7.72	8.54
21/9	1.02	3.70
24/12	15.24	27.59
25/11	8.89	9.47
26/10	5.66	8.06
27/9	.44	.64
27/15	4.64	11.0
28/8	3.69	2.41
28/16	7.28	23.59
29/7	11.80	8.13
32/8	63.87	43.76
36/24	32.53	27.01
37/23	12.54	8.94
38/22	26.17	16.12
40/20	19.60	8.30
41/19	4.47	5.26


MAGNET ELEVATIONS
August 27, 1985
INCHES
0.05
0.04
0.03
0.02
0.01
0
−0.01
−0.02
−0.03
−0.04
−0.05
A1
B1
C1
D1
E1
F1
G1
H1
I1
J1
K1
L1
MAGNET NUMBER

MAGNET ELEVATIONS

October 2,1985




MAGNET ELEVATIONS
October 2,1985
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
−0.025
−0.03
INCHES
A
B
C
D
E
F
G
H
I
J
K
L
MAGNET NUMBER

7 JAN 1986
AOK FZK HALB
1300

$6\gamma = 36 - \nu$