MAIN INJECTOR
CORRECTORS WORKSHOP

Friday May 8 1992

Fermilab

ONE DAY MAIN INJECTOR CORRECTORS WORKSHOP

Friday May 8, Music Room, Fermilab Users Center, 8:30-17:00

AGENDA

08:15 - 08:30		**Coffee and rolls**
08:30 - 08:40	Francois Ostiguy	ORGANIZATION
08:40 - 09:00	Steve Holmes	INTRODUCTION (To be confirmed)
09:00 - 09:30	Rod Gerig	SCC MEB CORRECTORS
09:30 - 10:00	Al Russell	MAIN INJECTOR LATTICE REAL ESTATE
10:00 - 10:30	G. Krafczyk / S. Hayes	CORRECTOR POWER SUPPLIES SPECS
10:30 - 10:45		**Coffee**
10:45 - 11:15	Shekhar Mishra	CORRECTION DIPOLES
11:15 - 11:45	Dave Johnson	BEAMLINE CORRECTORS & DIAGNOSTICS
11:45 - 12:15	Jian Ping Shan	γ_t-JUMP QUADRUPOLES
12:15 - 13:00		**Buffet Luncheon**
~~13:00 - 13:30~~	Alex Bogacz	CHROMATIC SEXTUPOLES
13:30 - 14:00	John Johnstone	SLOW EXTRACTION ELEMENTS
14:00 - 14:30	Phil Martin	INJECTION AND EXTRACTION ELEMENTS
14:30 - 15:00		**Coffee and Soft Drinks**
15:00 - 15:30	Peter Bagley	SKEW QUADRUPOLES
16:00 - 17:00		DISCUSSIONS

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OBJECTIVES

- To determine what the state of work in progress is by getting individuals make presentations.
- To identify who is responsible for finalizing plans for each correction element.
- To stimulate debate on the proposed topics.
- To promote an early consensus on the parameters to be used for 120 GeV tracking.
- To include all necessary correction elements in database MI-18.

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TIME AND LOCATION

In order to avoid being distracted by the usual daily nonsense, the meeting will be held in the Music Room of the Fermilab Users Center. A luncheon will be served. Coffee and rolls will be available at 8:00. Presentations will start at 8:30.

PRESENTATIONS

Speakers should limit themselves to a 30 minute presentation (including a 5 min question period) focusing on the following points:

(1) What kind of element will go where

(2) What is the strength of the elements

(3) What is the physical length of elements

(4) **How decisions about (1) (2) and (3) are being made.**

VIEWGRAPHS

Legible paper copies of all viewgraphs should be submitted to Marge Harvey BEFORE 16:00, THURSDAY MAY 7. These copies will be assembled and distributed to all participants. They will also be archived in the form of an internal AP note.

ONE DAY MAIN INJECTOR CORRECTORS WORKSHOP

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The number of participants is limited to approximately 20 (the limit has already been exceeded). The following people have either been "drafted" or have expressed interest in participating. Please let us know if you **DO NOT** expect to participate or if you know of someone whose name should be added to the list.

François Ostiguy AD/AP X2231 ostiguy@calvin.fnal.gov
Al Russell AD/MI X4829 russell@calvin.fnal.gov

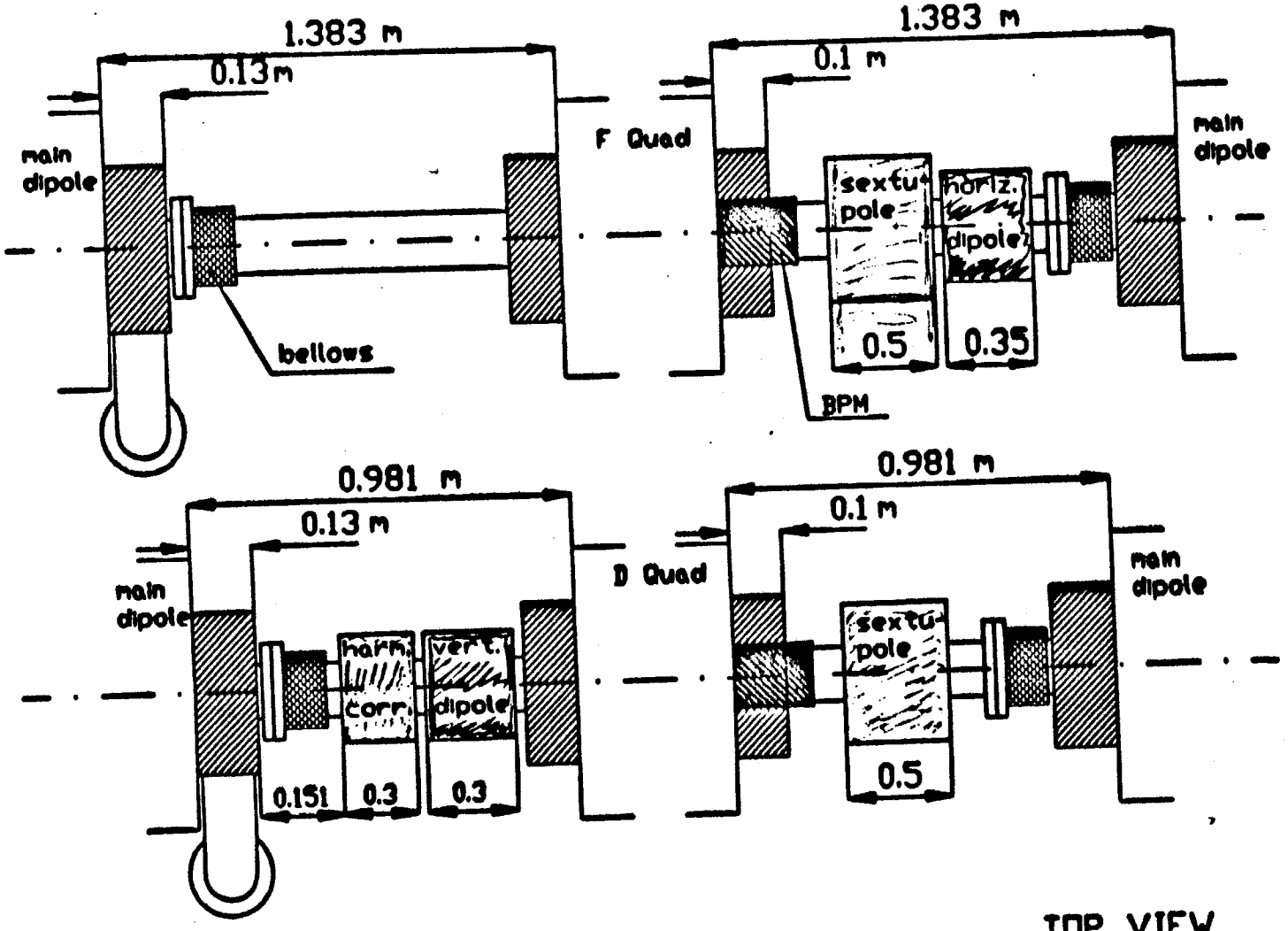
PARTICIPANTS

Peter Bagley	Gerald Jackson
Chandra Bhat	John Johnstone
Alex Bogacz	David Johnson
Bruce Brown	Henry Glass
Glenn Goderre	Fritz Lang
David Harding	Philip Martin
Fady Harfoush	Shekhar Mishra
Steve Hays	François Ostiguy
Stephen Holmes	Stephen Peggs
James Holt	Stan Pruss
George Krafczyk	Allison Russell
	Jian Ping Shan

EXTERNAL GUESTS

Rod Gerig (SSCL)
SY Lee (UI / BNL)

ROD GERIG



Mini-straight layout sketch

Rod Gerig

TORRANCE, CA 90503

MEB CROMATICITY SEXTUPOLE CORRECTION MAGNET

Integrated sextupole field strength (BL at r=1 m)	57.5	T/m
Sextupole field strength (B at r= 1 m)	143.75	T
Effective length (L_{eff})	0.4	m
Current max. (I_{max})	567	A
Current eff. (I_{rms})	363	A
Current density max. (j_{max})	5.38	A/mm**2
Current density eff. (j_{rms})	3.44	A/mm**2
Number of turns per pole (N)	7	
Resistance (R)	0.0081	Ohm
Inductance (L)	0.0014	H
Voltage drop on R ($V_{r\,max}$)	4.59	V
Voltage drop on L ($V_{L\,max}$)	2.8	V
Power consumption max. (P_{max})	2.61	kW
Power consumption ave. (P_{ave})	1.07	kW
Overall width (W_{oa})	44	cm
Overall height (H_{oa})	44	cm
Overall length (L_{oa})	50	cm
Weight (G cu+fe)	286	kg

Table 2.4-VI
Chromaticity Sextupole Correction Magnet

Field Strength	57.5(T/m²)m
Aperture Radius	50 x 100 mm with 25 mm corner round
Magnet Length	~.4 m
Physical Length	< .5 m
Current, Max	~800
Voltage to Ground, Max	1000 V
Resistance, Max	6 mΩ
dI/dt, Max	2000 A/sec
Inductance, Max	1.5 mH
Cooling	LCW or Air

Specified values in MEB 3B

Table 2.4-IX
Magnet Uniformity

Attribute	Corrector Dipoles	All Others
Unit to unit strength variation	$< 1\times10^{-2}$	$< 1\times10^{-3}$
Field Purity - within ±25 mm of centerline	$< 1\times10^{-3}$	$< 1\times10^{-3}$
- over aperture	$< 1\times10^{-2}$	$< 1\times10^{-2}$

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

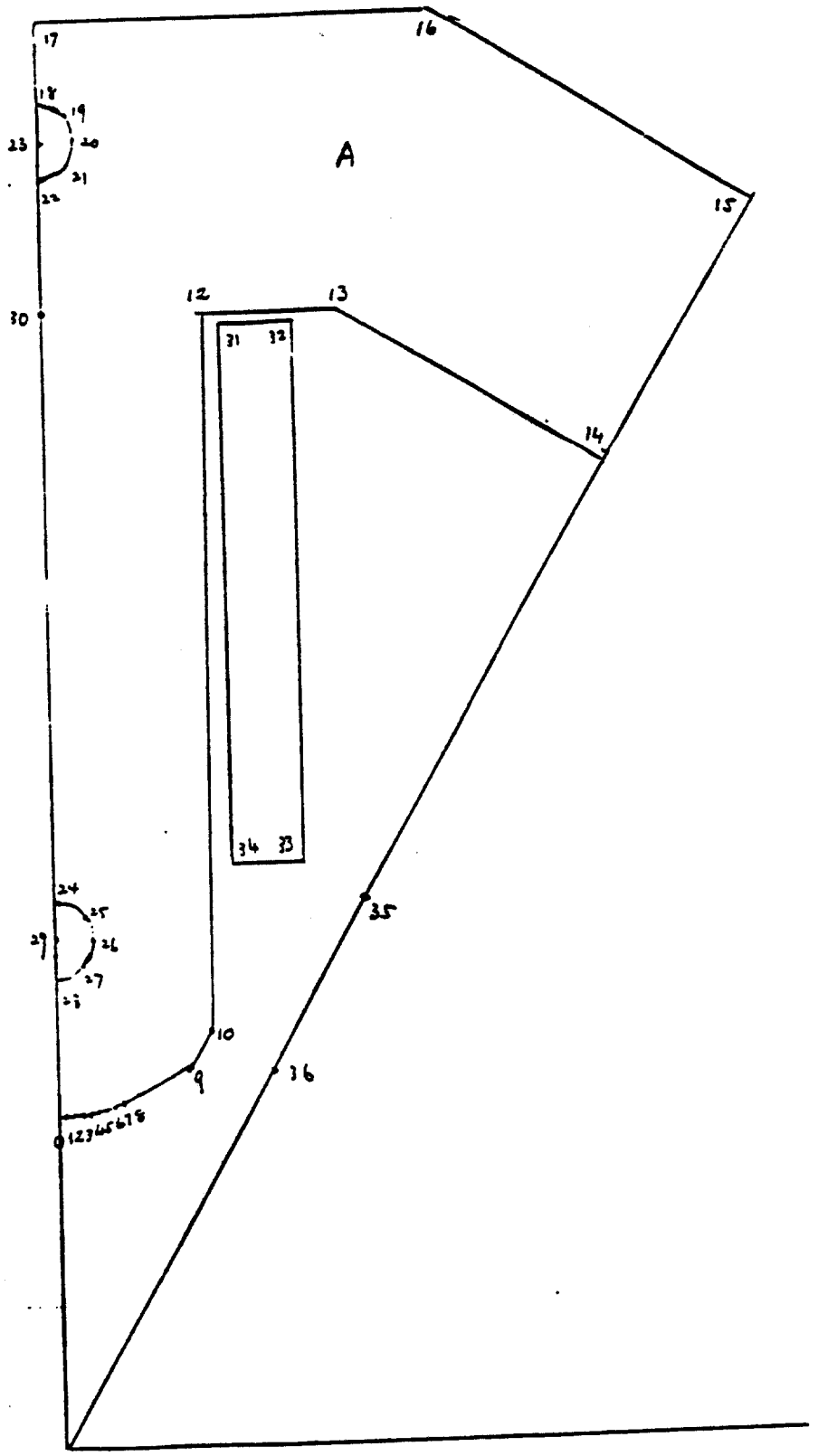


Fig 5

Conductor

12.6 x 10 mm x mm

ϕ 5 mm

r = 1 mm

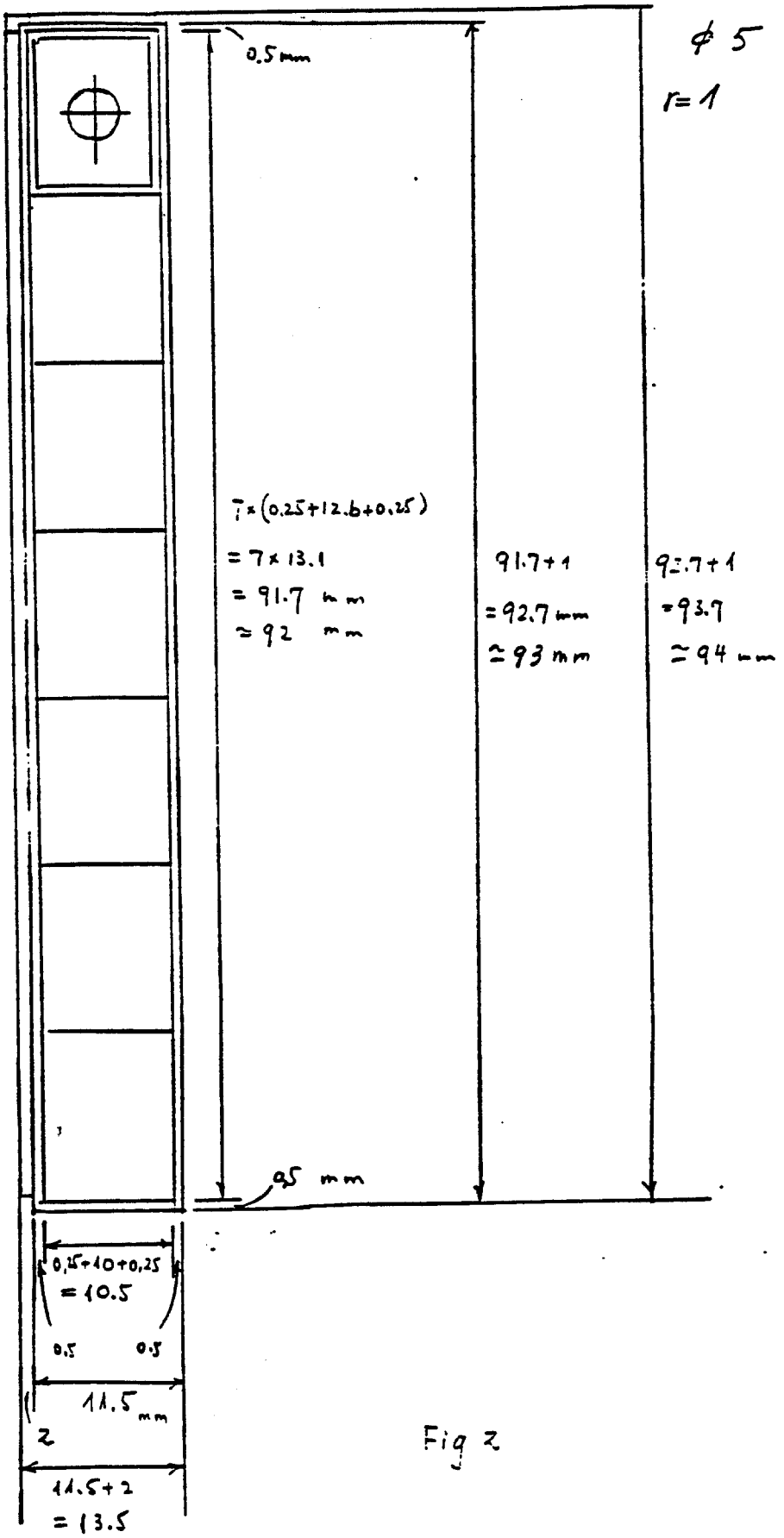
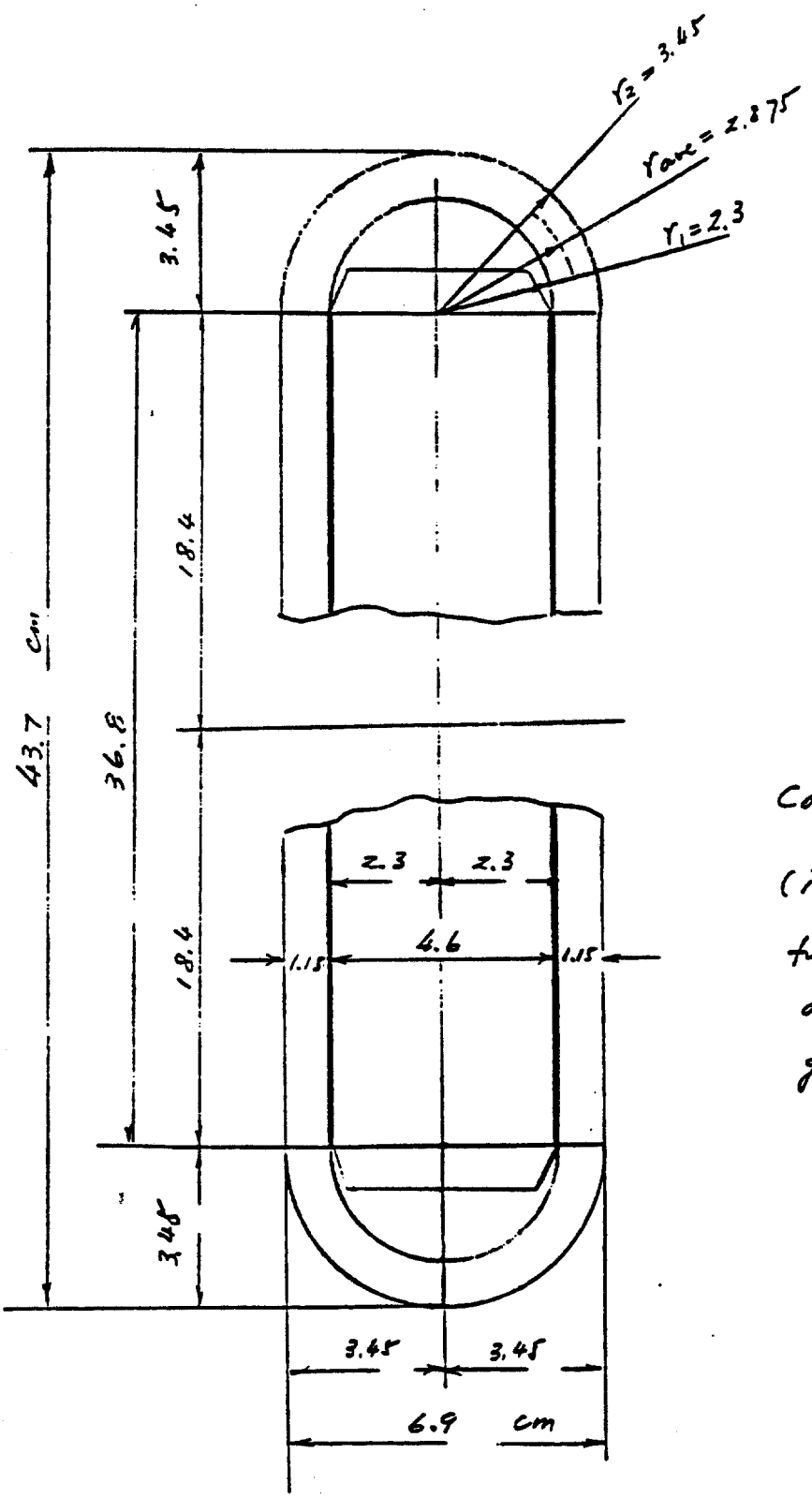


Fig 2

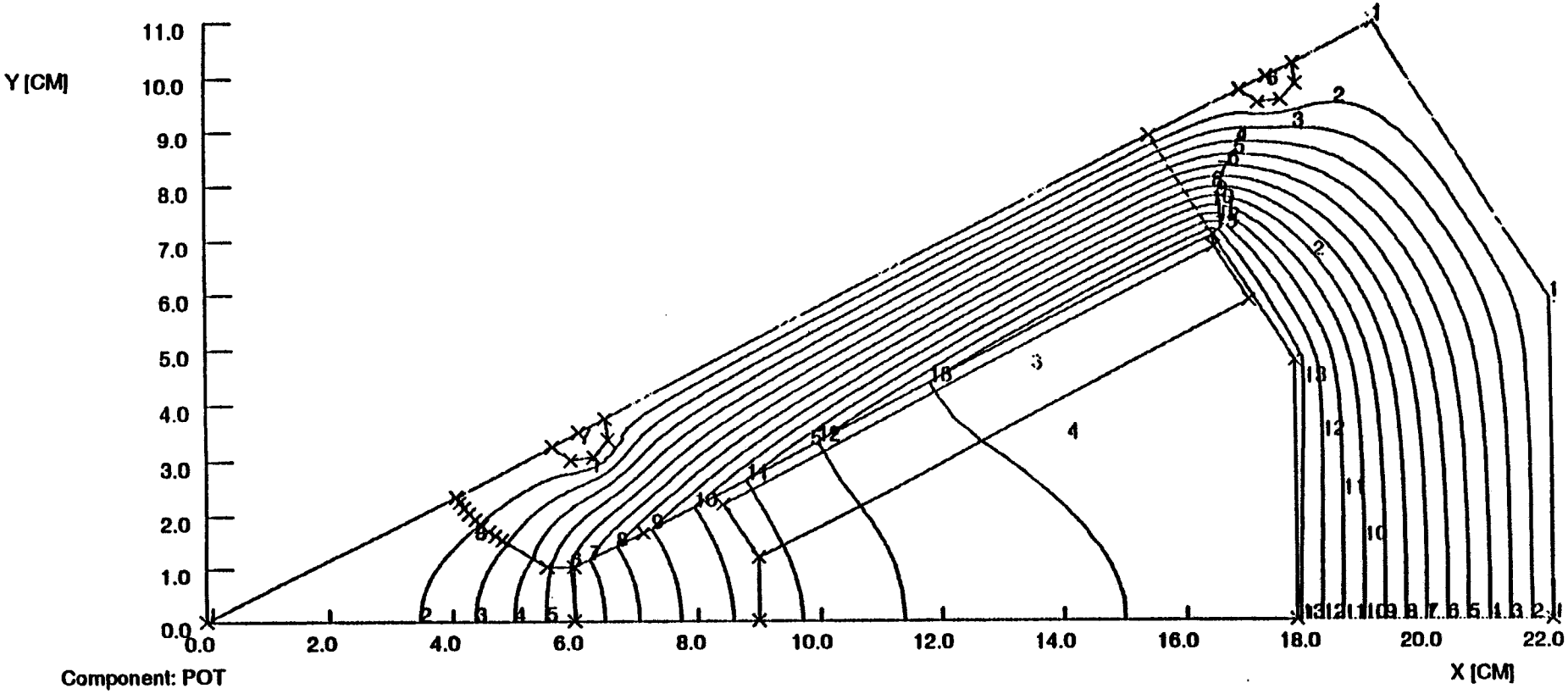
Unit: cm



Coil dimension (including turn insulation and ground insulation)

Fig 4

CS2.STRES
31/Mar/92 14:17:19 Page 6 : RECO



Component: POT
Minimum: 0.0, Maximum: 0.024, Interval: 0.002

Fig 6

ELEM=QUAD SYMM=XY SOLN=AT SCALE=1.0 FIEL=MAGN
Static Solution Mesh 1739 Elements 8 Regions

VF/PE2D.8

CS2.STRES
1/Apr/92 13:55:40 Page 2 : LINE 0 0 6 0 NP=60 COMP=-BY

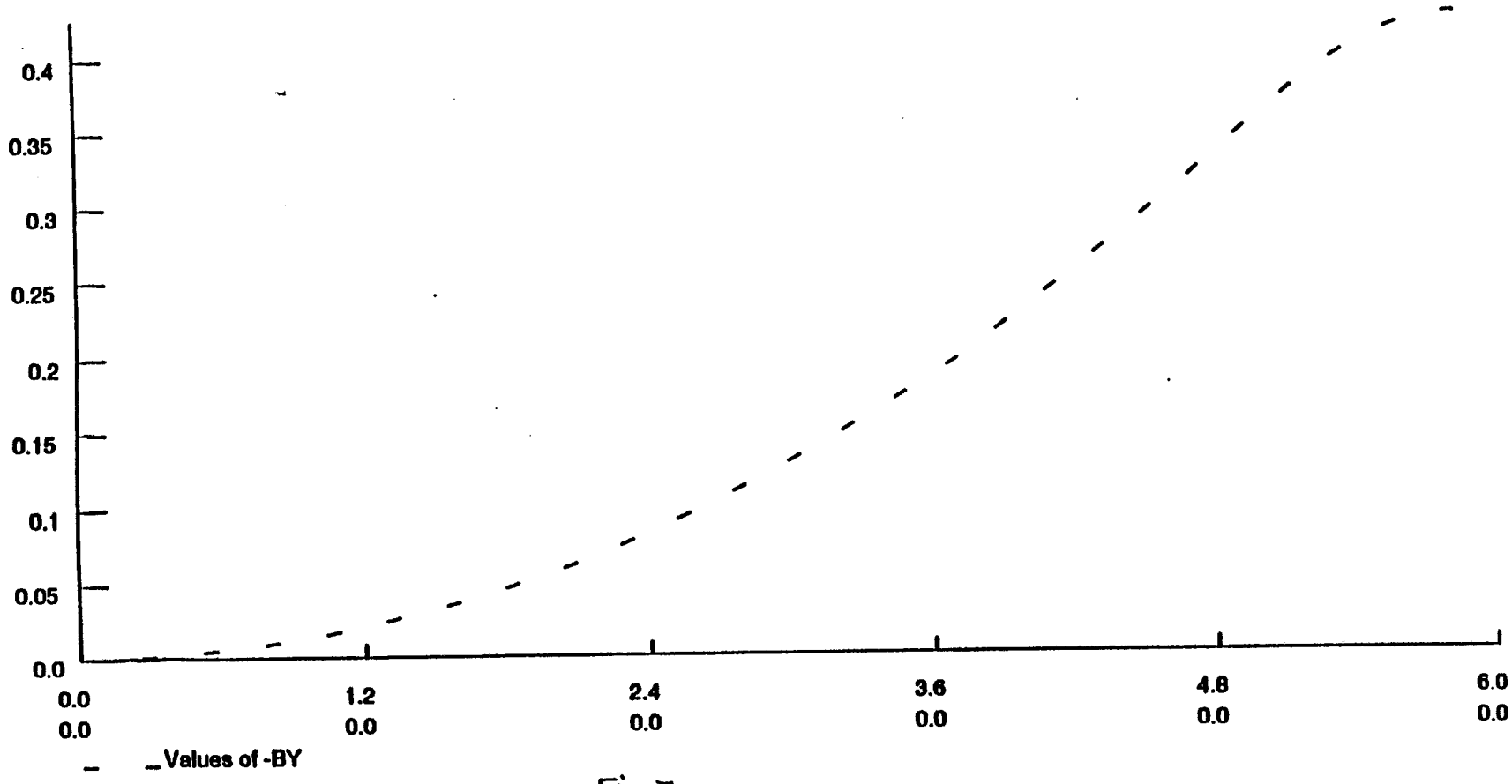


Fig 7

VF/PE2D.8

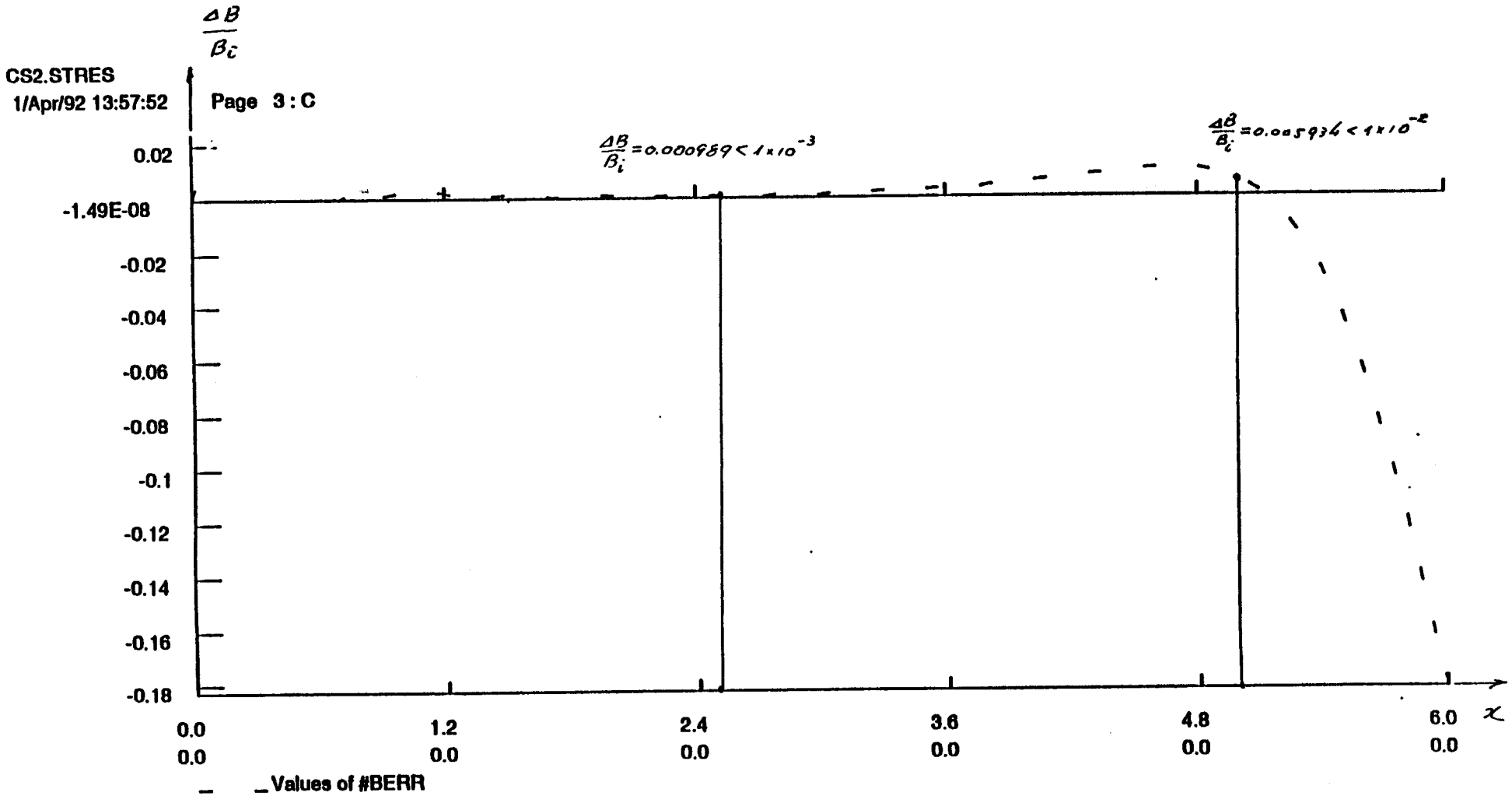
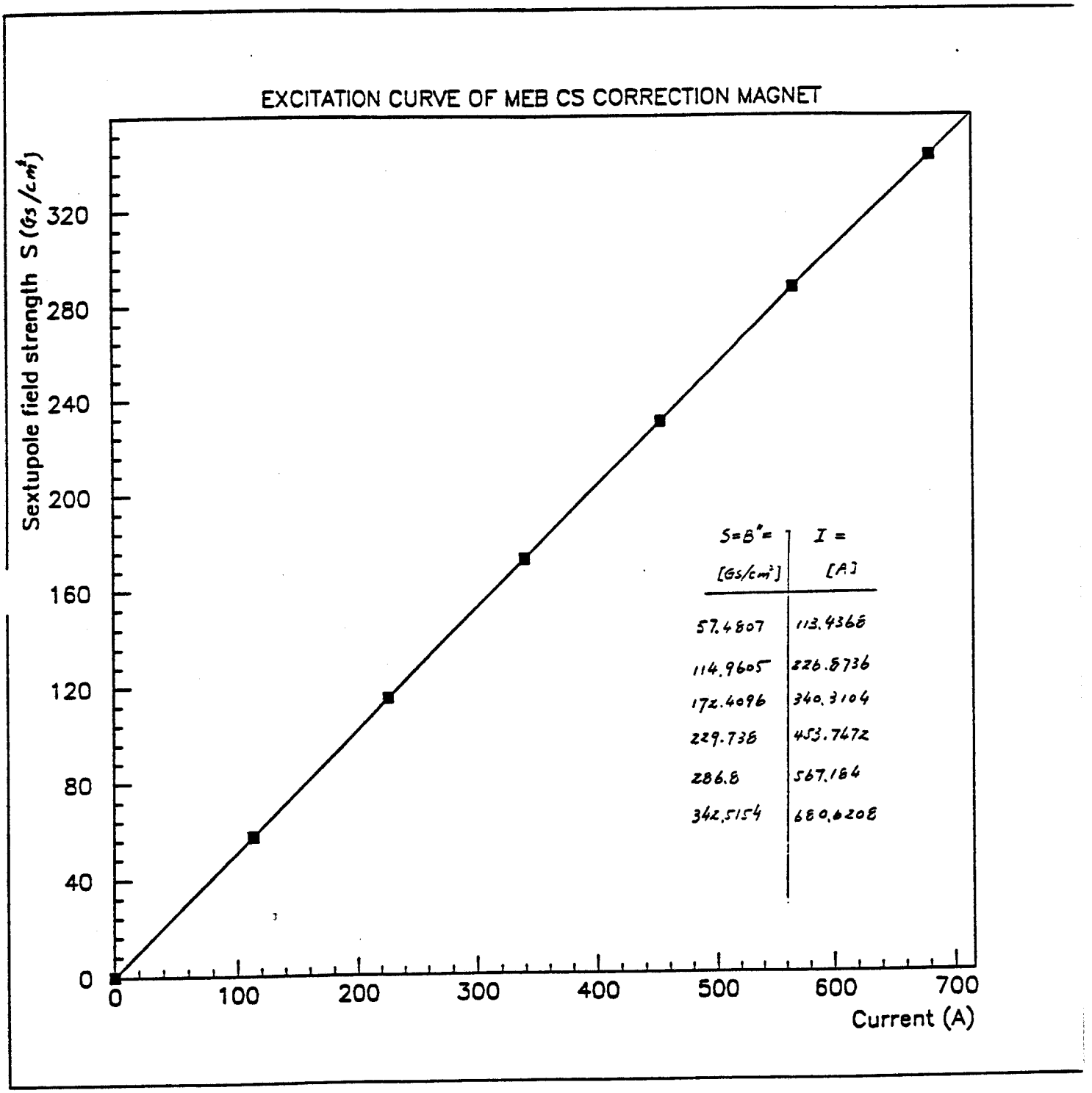


Fig 8

VF/PE2D.8

Fig 9


EXCITATION CURVE OF MEB CS CORRECTION MAGNET
Sextupole field strength S (Gs/cm²)
0
40
80
120
160
200
240
280
320
0
100
200
300
400
500
600
700
Current (A)
S=B''= [Gs/cm²]
I = [A]
57.4807 113.4368
114.9605 226.8736
172.4096 340.3104
229.738 453.7472
286.8 567.184
342.5154 680.6208

CS2.TOSCAB
7/Apr/92 12:13:58 Page 5 : SIZE=40 XE=1 1 3 SHAD=ELEM HIDD=Y

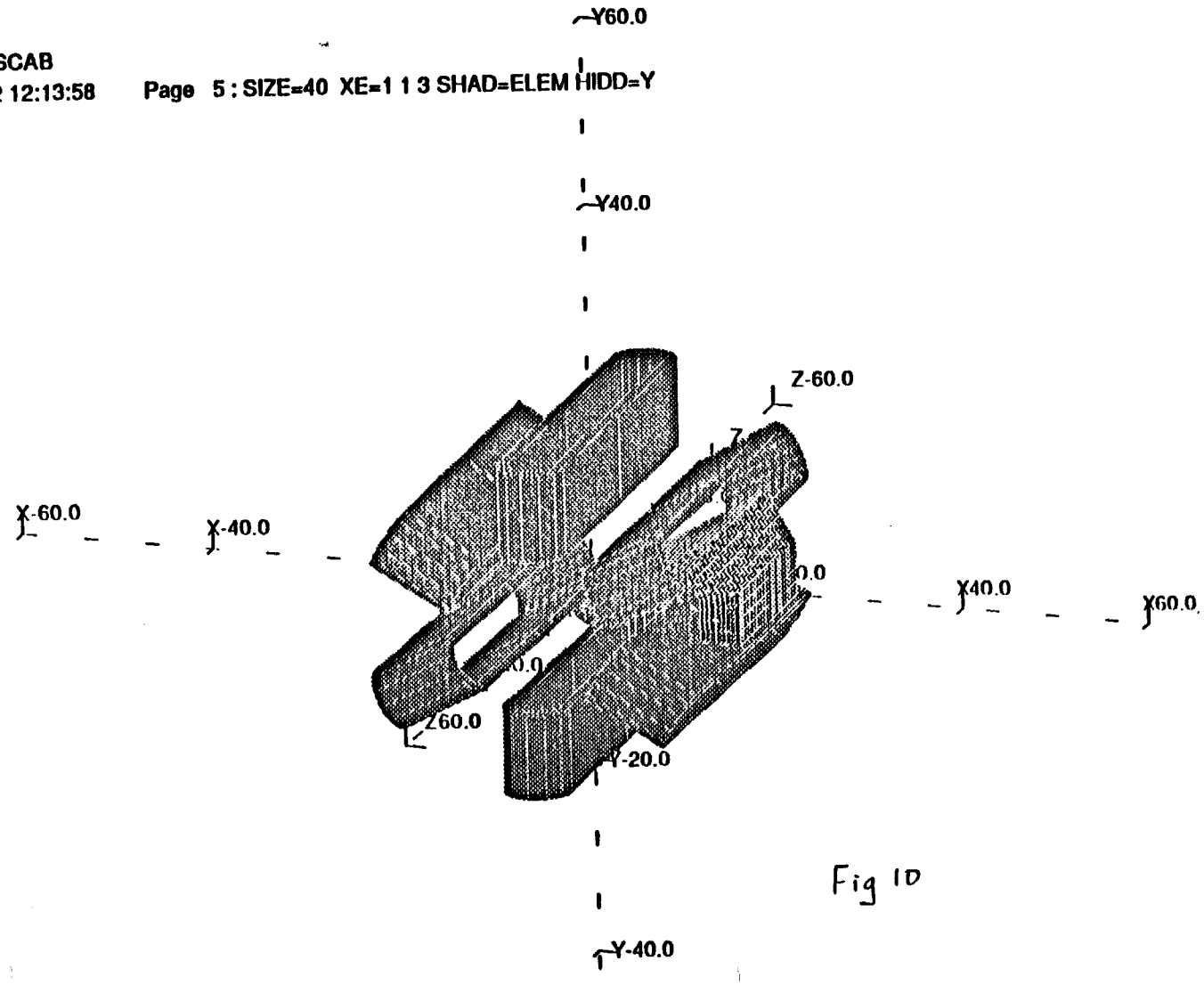


Fig 1D

VF/OPERA.2

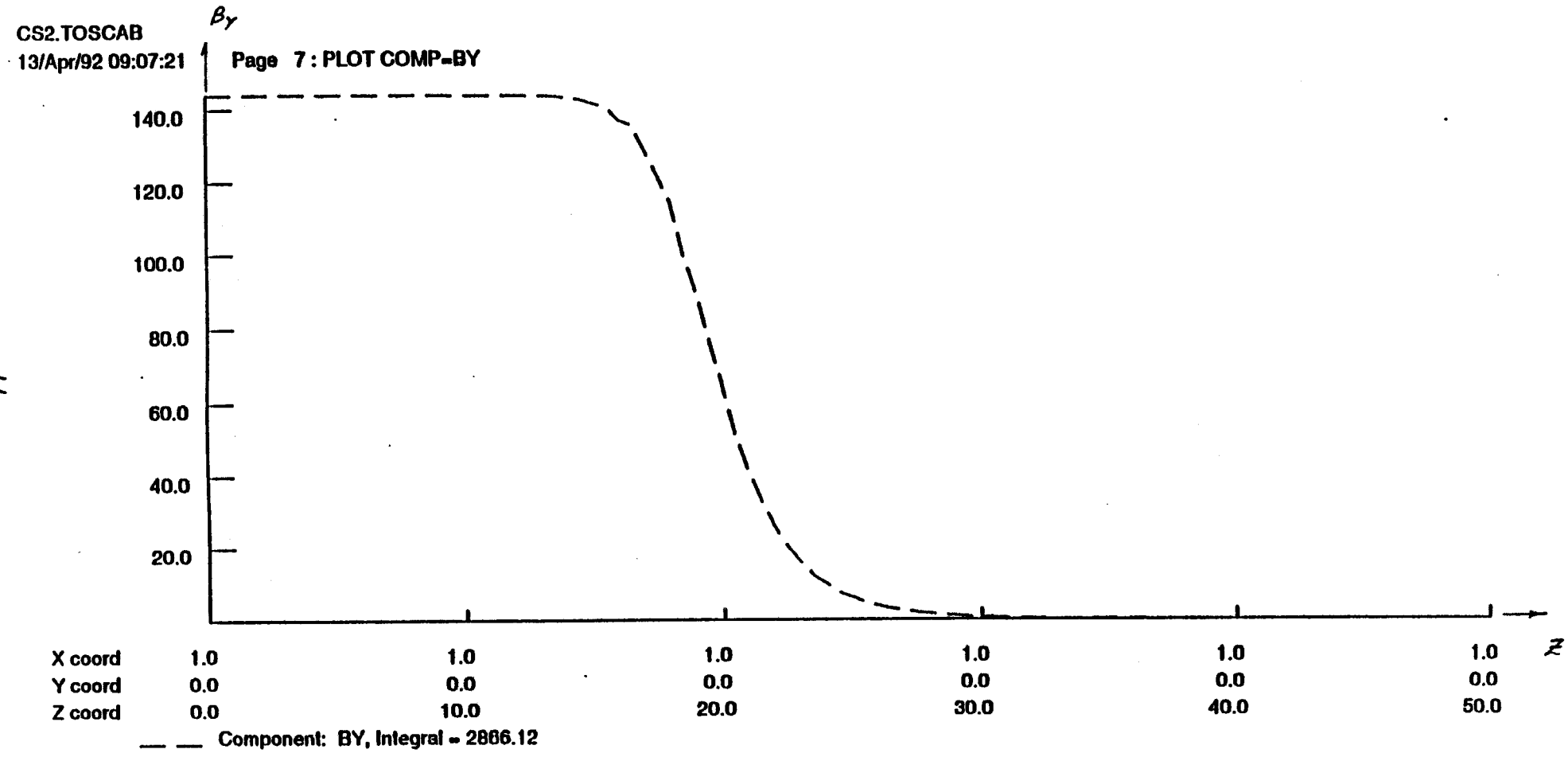


Fig 11

VF/OPERA.2

MEB HORIZONTAL DIPOLE CORRECTION MAGNET

Dipole field strength (B_0)	1360	Gs
Effective length (L_{eff})	25	cm
Current max. (I_{max})	9.09	A
Current eff. (I_{eff})	5.82	A
Current density max. (j_{max})	0.92	A/mm**2
Current density eff. (j_{eff})	0.59	A/mm**2
Number of turns (N)	640	
Resistance (R)	1.186	Ohm
Inductance (L)	0.495	H
Voltage drop on R ($V_{R\,max}$)	10.78	V
Voltage drop on L ($V_{L\,max}$)	49.5	V
Power consumption max. (P_{max})	0.098	kW
Power consumption ave. (P_{ave})	0.04	kW
Overall width (W_{OA})	32.5	cm
Overall height (H_{OA})	40	cm
Overall length (L_{OA})	35	cm
Weight (G cu+fe)	177	kg

Table 2.4-II
Horizontal Dipole Correction Magnet

Field Strength	0.034 T-m
Aperture Radius	50 x 100 mm with 25 mm corner round
Magnet Length	~.25 m
Physical Length	< .35 m
Current, Max	10A
Power Supply Voltage, Max	80V
Resistance, Max	2Ω
dI/dt, Max	100A/sec
Inductance, Max	400 mH
Cooling	Air

Specified values in MEB 3B

Table 2.4-IX
Magnet Uniformity

Attribute	Corrector Dipoles	All Others
Unit to unit strength variation	$< 1\times10^{-2}$	$< 1\times10^{-3}$
Field Purity - within ±25 mm of centerline	$< 1\times10^{-3}$	$< 1\times10^{-3}$
- over aperture	$< 1\times10^{-2}$	$< 1\times10^{-2}$

AMPAD 22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS

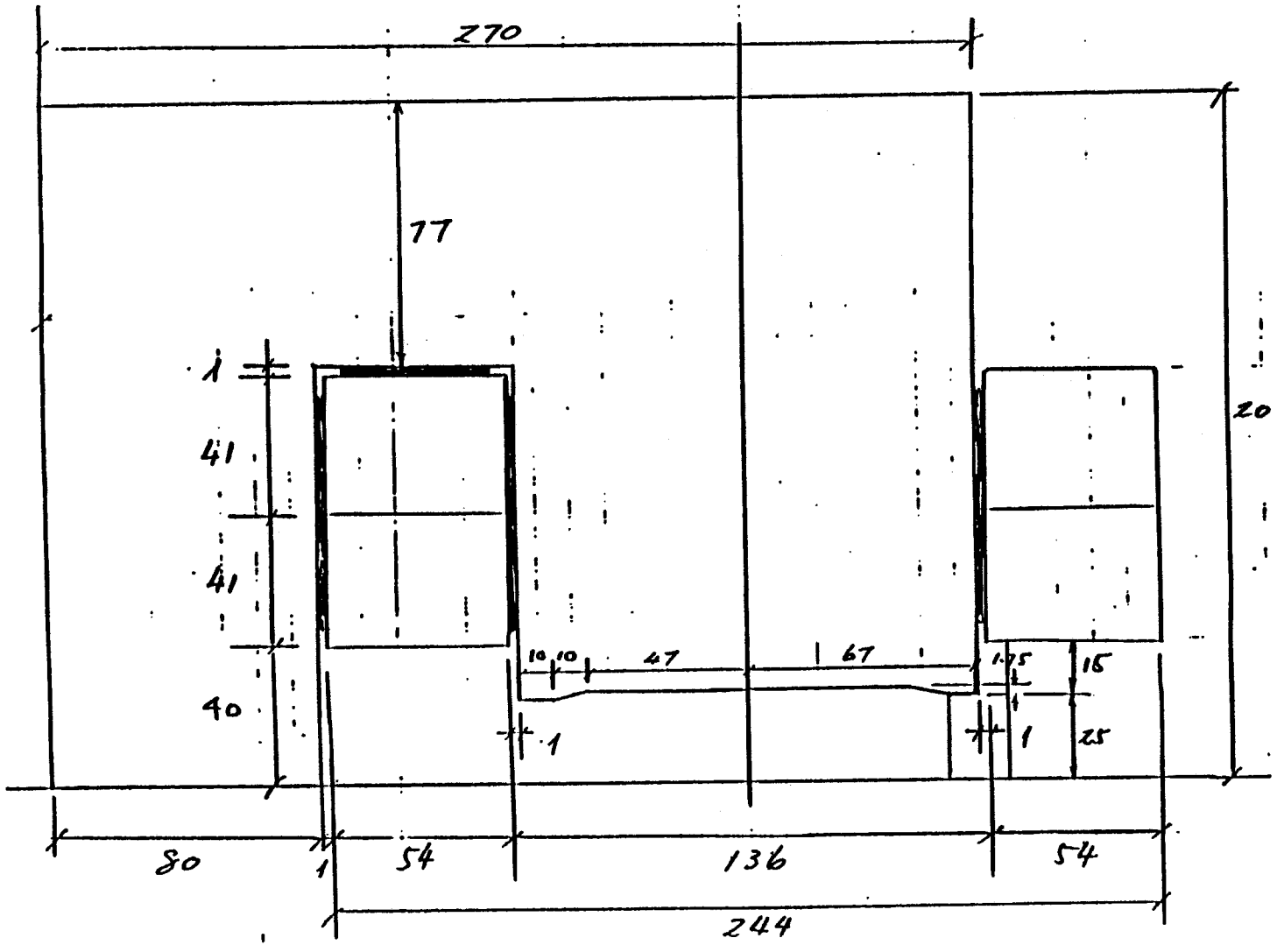
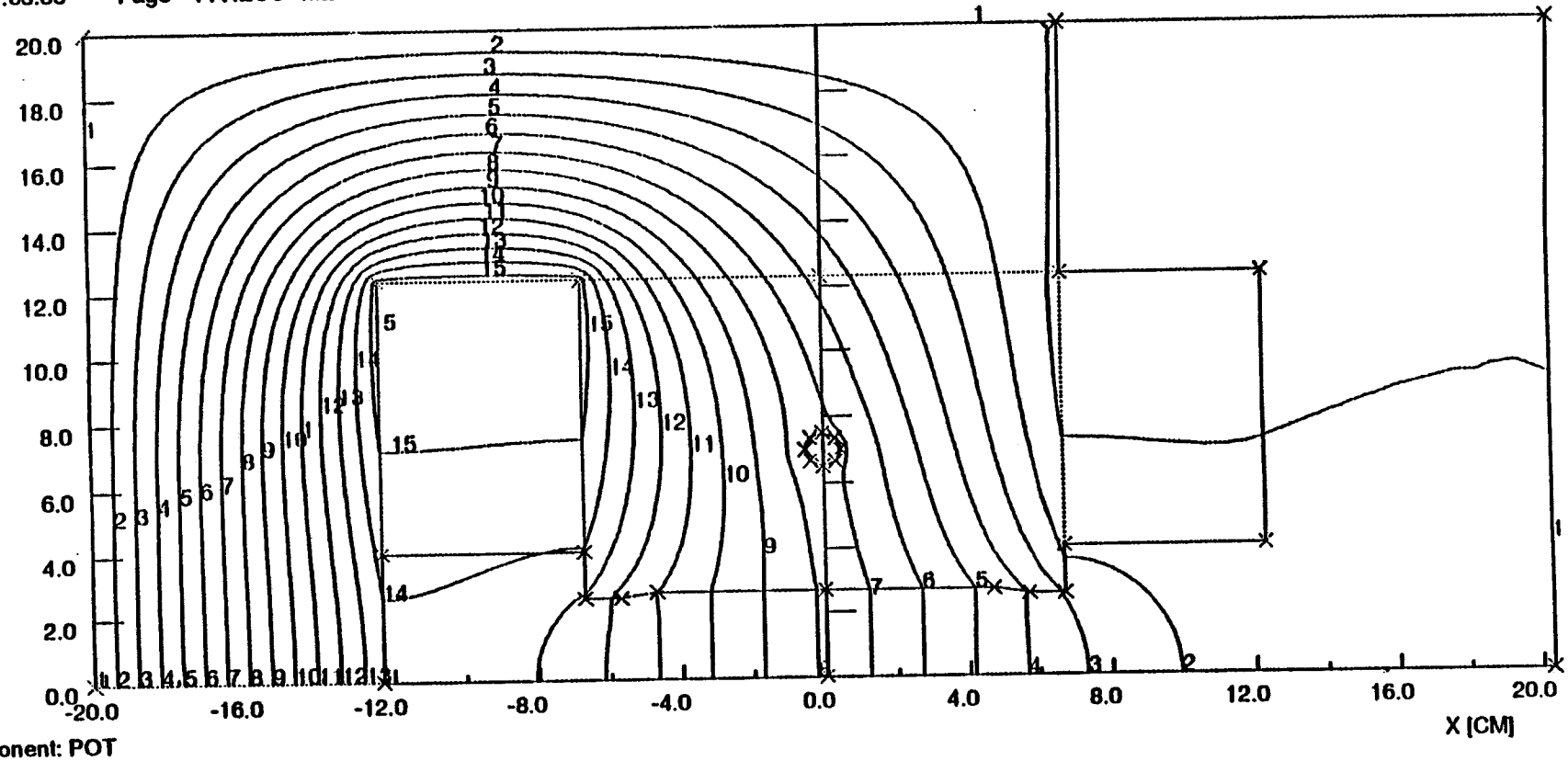


Fig 1

HD.STRES
18/Mar/92 11:08:36 Page 4 : RECO -ME



Component: POT
Minimum: 0.0, Maximum: 0.028, Interval: 0.002

Fig 5

ELEM=QUAD SYMM=XY SOLN=AT SCALE=1.0 FIEL=MAGN
Static Solution Mesh 4125 Elements 7 Regions

VF/PE2D.8

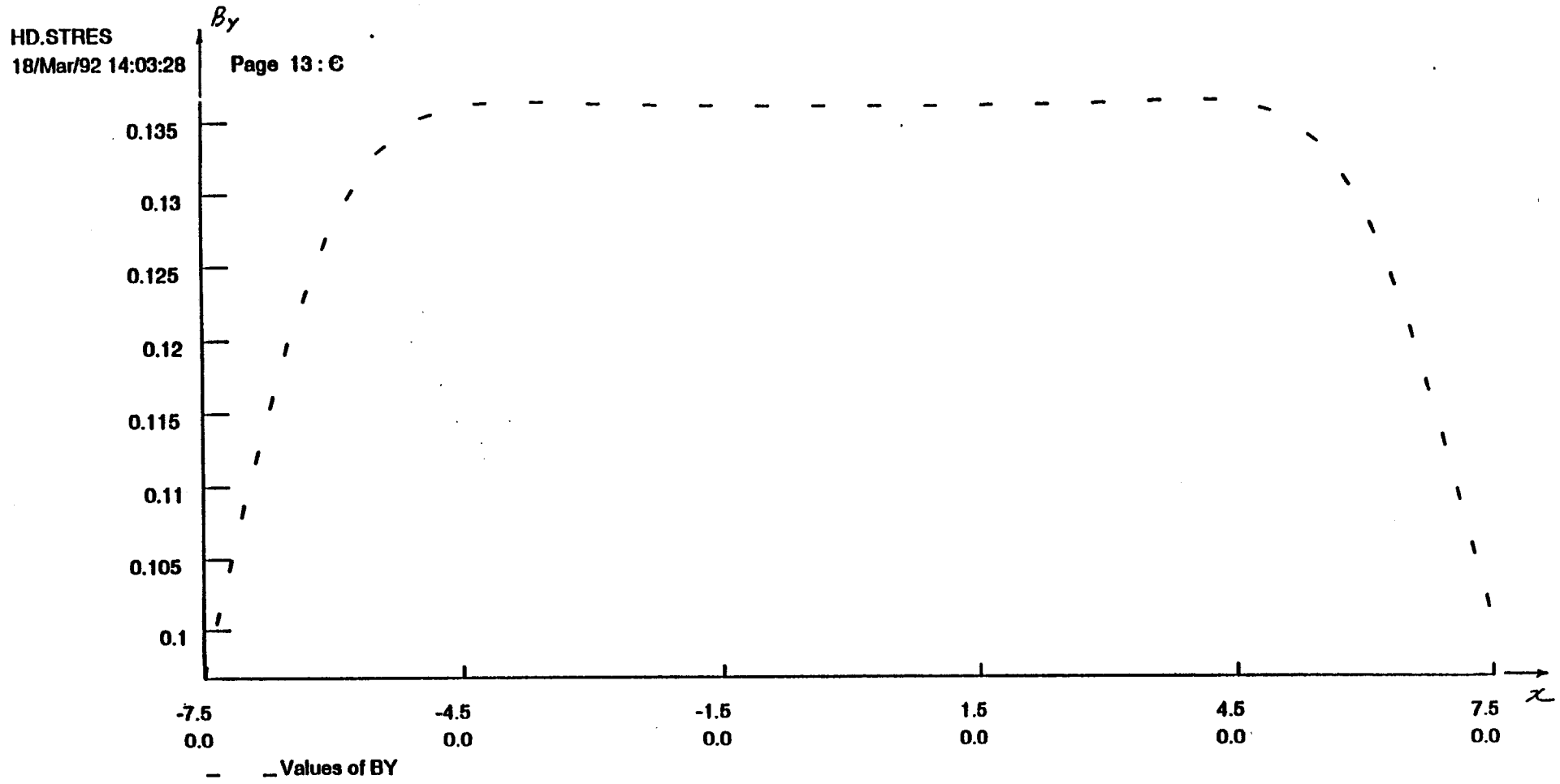


Fig 6

VF/PE2D.8

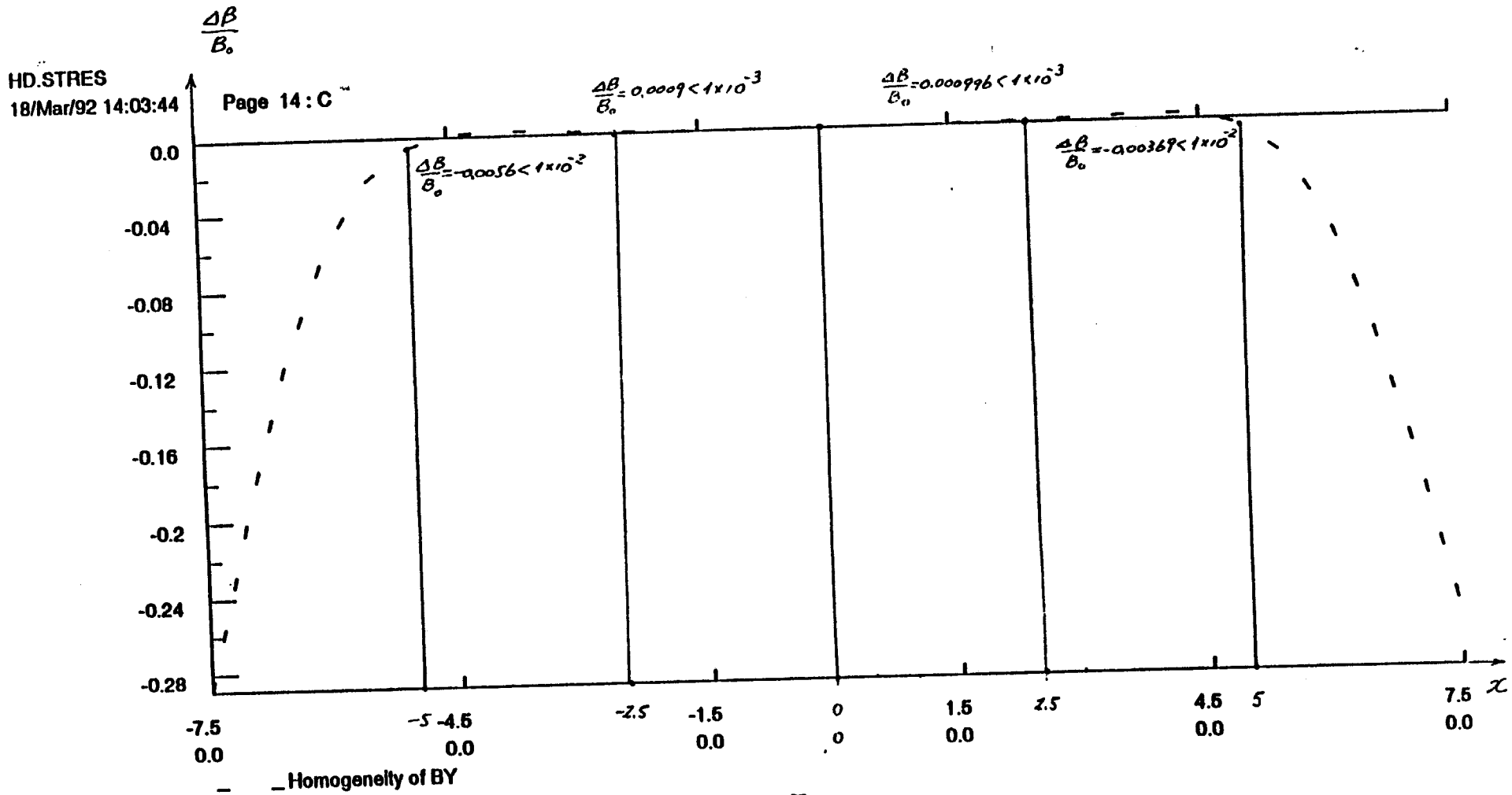
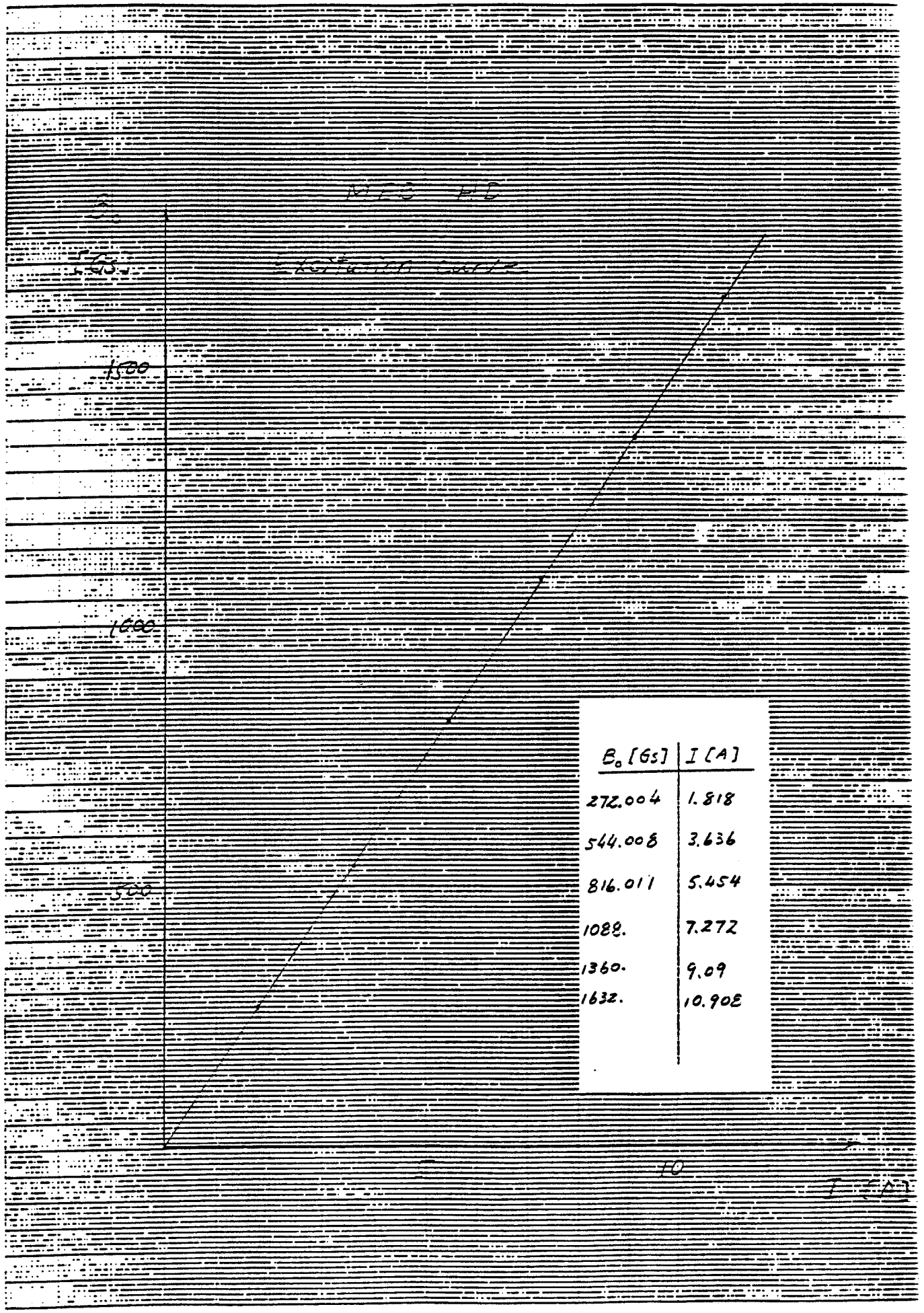


Fig 7

VF/PE2D.8



B_0 [Gs]	I [A]
272.004	1.818
544.008	3.636
816.011	5.454
1088.	7.272
1360.	9.09
1632.	10.908

Fig. 8

AL RUSSELL

Main Injector Correctors
Real Estate Allocation

A. D. Russell
May 8, 1992

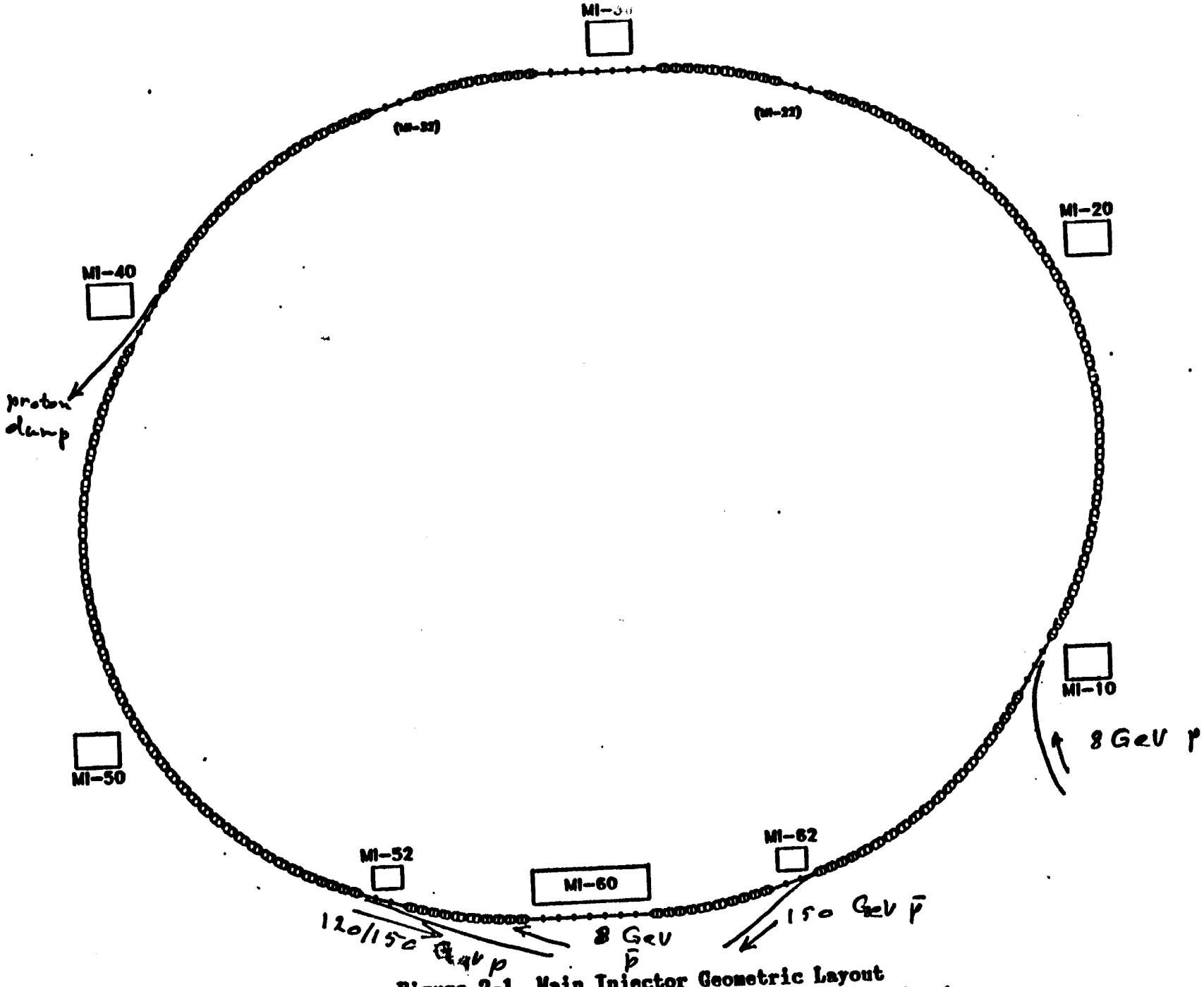
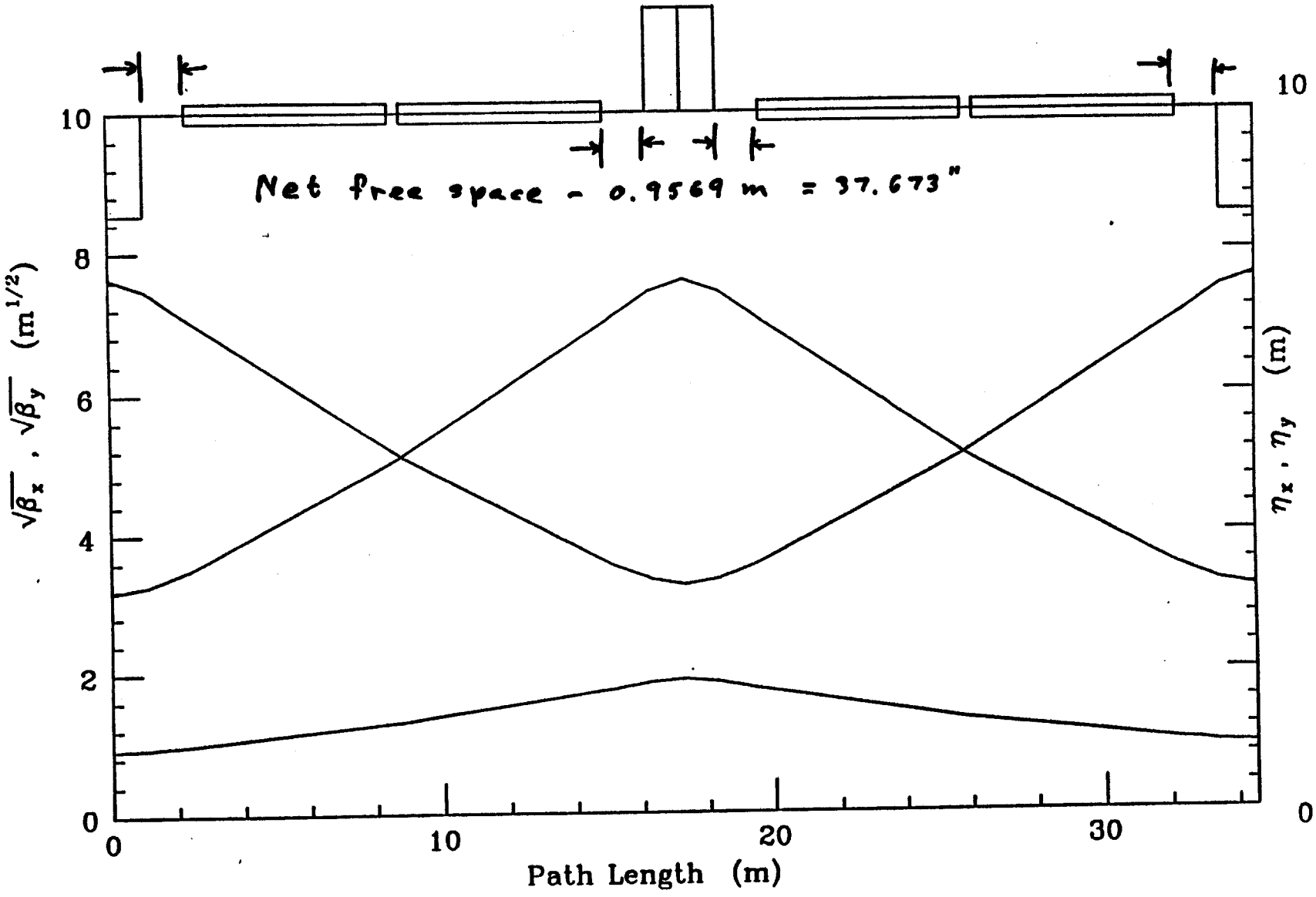
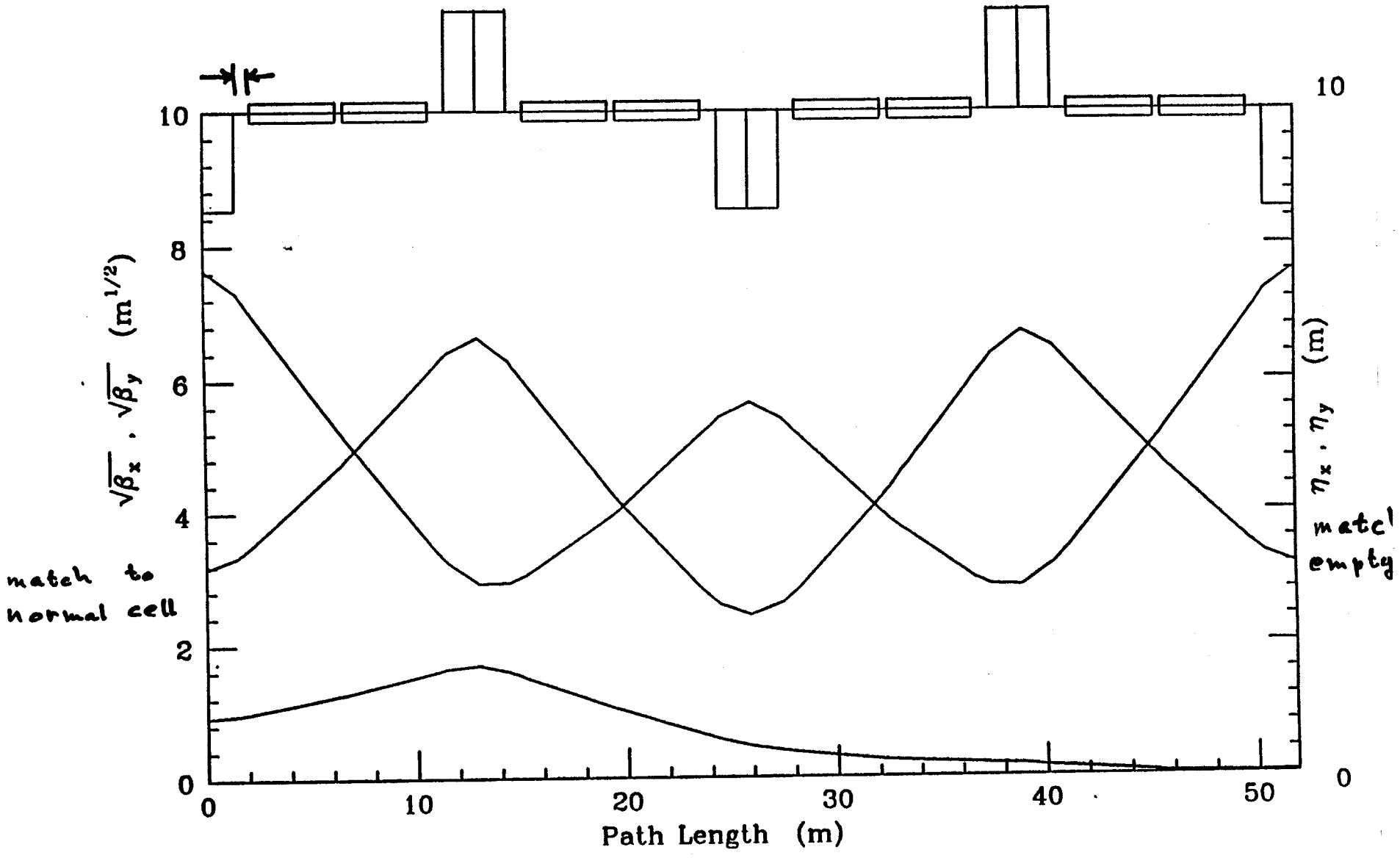


Figure 2-1. Main Injector Geometric Layout Showing Locations of Service Buildings and Straight Sections



Mon May 4 11:19:51 1992

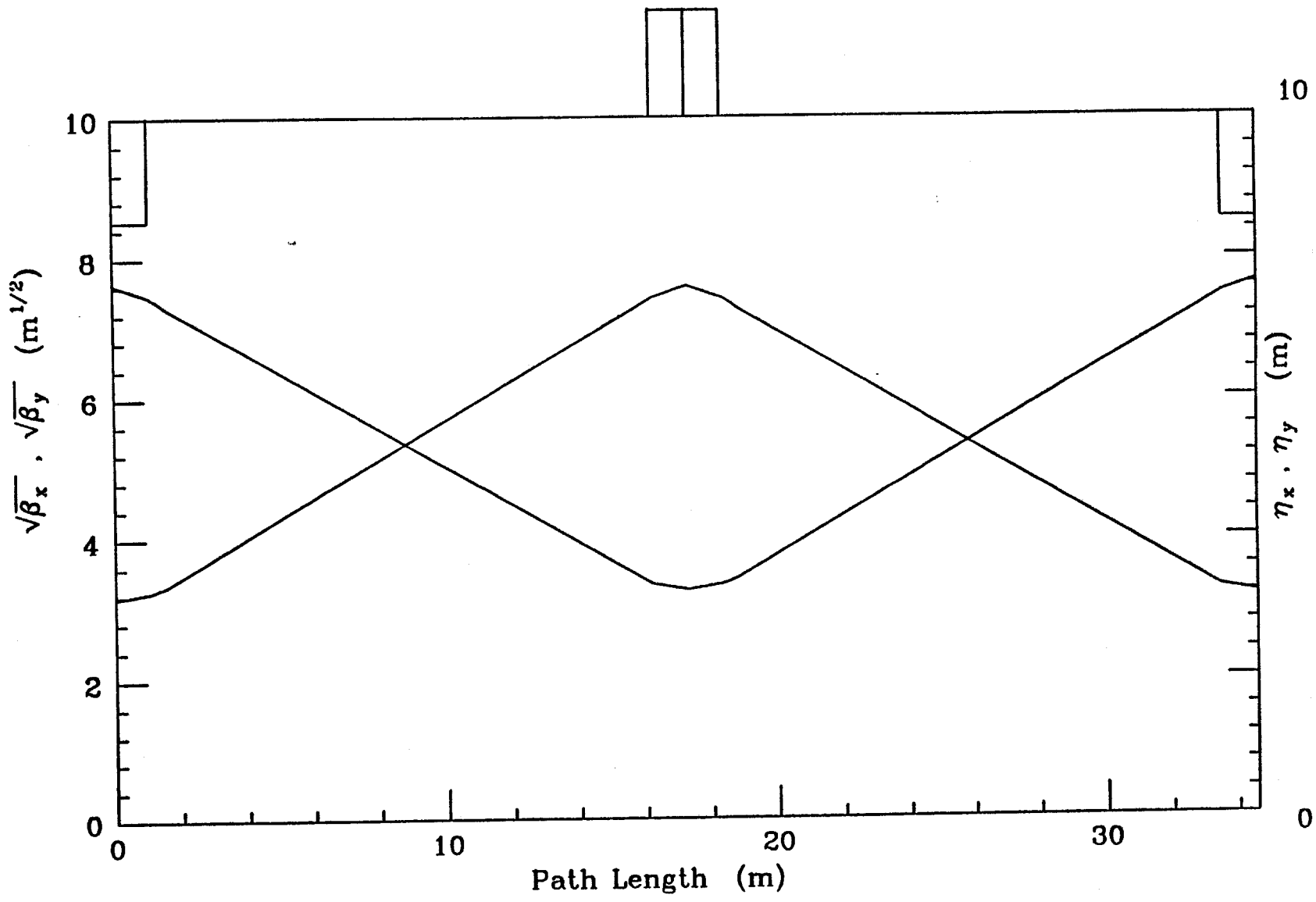
CELLD



2 D.S. cells
Net free space: 0.4182 m
16.464"

Mon May 4 11:20:19 1992

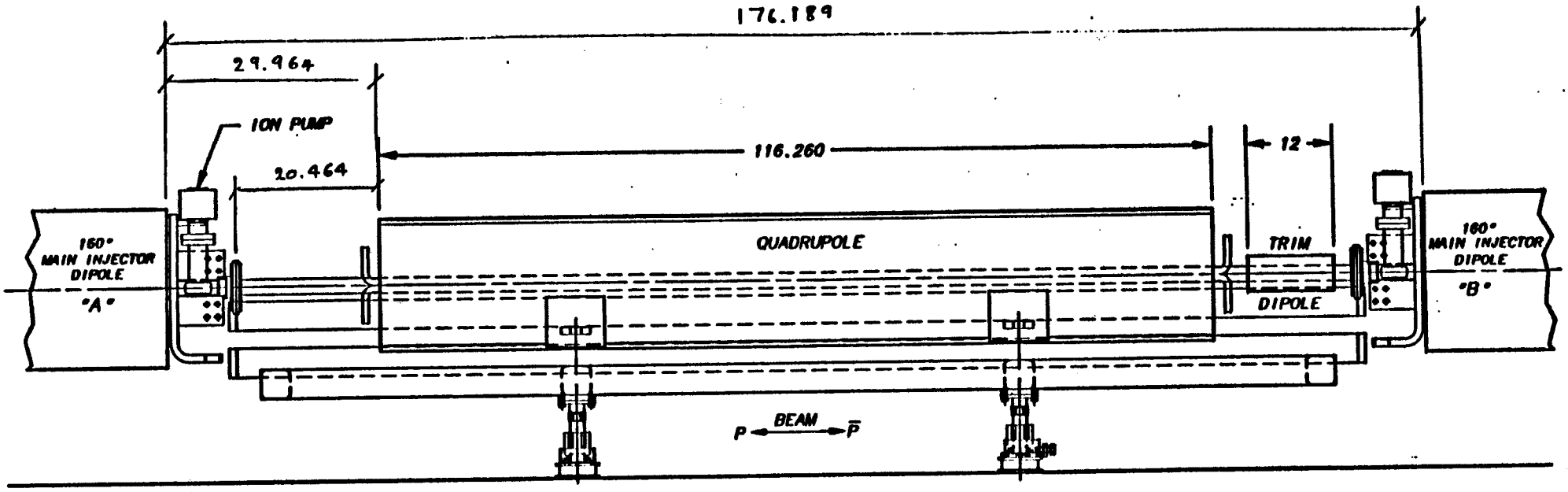
DSD



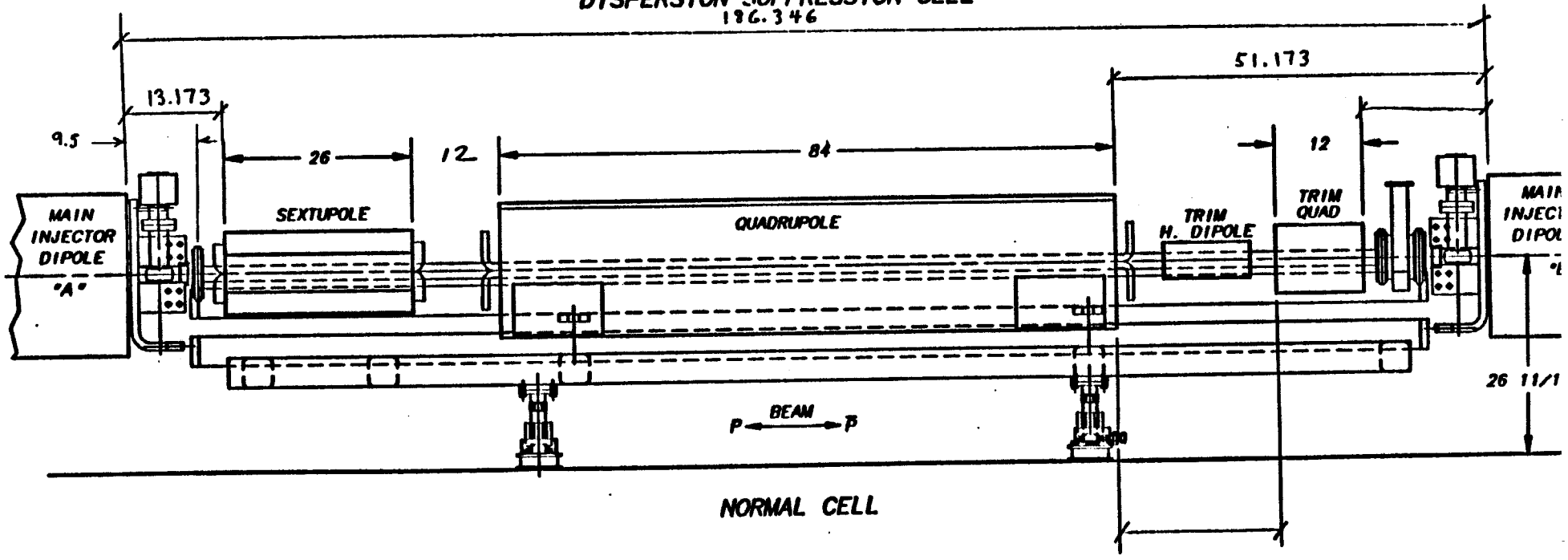
Mon May 4 11:20:43 1992

MTCELLD

5



DISPERSION SUPPRESSION CELL



NORMAL CELL

QUADRUPOLE DRIFT-LENGTH CALCULATIONS			
NORMAL CELL			Inch Equiv.
Cell (arc) length	17.288639	m	680.655
Dipole magnetic length	6.096000	m	240.000
Number dipoles	301.333333		
Dipole half-angle	10.425639	mr	
Dipole radius	292.361468	m	11510.294
Dipole (arc) length	6.096110	m	240.004
Dipole-dipole drift	0.359410	m	14.150
Lattice drift space	4.737008	m	186.496
Dipole steel excess length	0.003810	m	0.150
Steel-to-steel space	4.733198	m	186.346
Dipole beam pipe extension	0.241300	m	9.500
Quad slot length	4.250598	m	167.346
Quad length	2.133600	m	84.000
Total free space	2.116998	m	83.346
Half free space (=quad steel to flange)	1.058499	m	41.673
Quad coil+beampipe flange	0.101600	m	4.000
Net free space (each side)	0.956899	m	37.673
DISPERSION SUPPRESSOR CELL			
Ratio of cell lengths	0.750000		
Ratio of dipole lengths	0.666667		
Cell (arc) length	12.966479	m	510.491
Dipole length	4.064000	m	160.000
Dipole half-angle	6.950426	mr	
Dipole radius	292.358525	m	11510.178
Dipole (arc) length	4.064033	m	160.001
Dipole-dipole drift	0.359410	m	14.150
Lattice drift space	4.479004	m	176.339
Dipole steel excess length	0.003810	m	0.150
Steel-to-steel space	4.475194	m	176.189
Dipole beam pipe extension	0.241300	m	9.500
Quad slot length	3.992594	m	157.189
Quad length	2.953000	m	116.260
Total free space	1.039594	m	40.929
Half free space (=quad steel to flange)	0.519797	m	20.464
Quad coil+beampipe flange	0.101600	m	4.000
Net free space (each side)	0.418197	m	16.464

NORMAL CELL/DISPERSION SUPPRESSOR INTERFACE			
Sum of cell lengths	30.255118	m	1191.146
Dipole lengths + dipole drifts & ends	21.525516	m	847.461
Sum of .5*Quad drifts	4.121596	m	162.268
Lattice drift space	4.608006	m	181.418
Dipole steel excess length	0.003810	m	0.150
Steel-to-steel space	4.604196	m	181.268
Dipole beam pipe extension	0.241300	m	9.500
Quad slot length	4.121596	m	162.268
Quad length	2.543300	m	100.130
Total free space	1.578296	m	62.138
Normal cell side free space (steel/flange)	1.058499	m	41.673
D.S. cell side free space (steel/flange)	0.519797	m	20.464
Quad coils and flanges	0.203200	m	8.000
Net free space	1.375096	m	54.138
Normal cell side net free space	0.956899	m	37.673
D.S. cell side net free space	0.418197	m	16.464

Correction element lengths

element	steel length	coil extension	total length	source
dipole (MR, horiz)	8	1.625	11.25	exists
dipole (MR, vert)	6	2.6875	11.375	exists
dipole (MI)	12	1.5	13	new
quad (MR)	10	2	14	exists
quad (MI, proposed)			12	new
sextupole	32	1	34	new
sextupole (MR)	6	2	10	exists
octupole	6	1	10	exists

QUADRUPOLE DEVICE LIST

MI-10				MI-20				MI-30			
Quad Number	Quad Length	BPM	Devices US/DS	Quad Number	Quad Length	BPM	Devices US/DS	Quad Number	Quad Length	BPM	Devices US/DS
624	116	H	HD/	114	84	H	O,O,HD/CSF	220	100	H	HD/BV
625	116	V	VD/	115	84	V	O,VD/CSD	221	84	V	VD/
626	100	H	HD/CSF	116	84	H	O,O,HD/CSF	222	84	H	HD/
627	84	V	VD/CSD	117	84	V	VD/CSD	223	100	V	BV,VD/
628	84	H	QD,HD/CSF	118	84	H	HD/CSF	224	116	H	HD/
629	84	V	VD/CSD	119	84	V	VD/CSD	225	116	V	VD/
630	84	H	QF,HD/CSF	120	84	H	HD/CSF	226	116	H	HD/
631	84	V	BV,VD/CSD	121	84	V	BV,VD/CSD	227	100	V	VD/CSD
632	84	H	QD,HD/CSF	122	84	H	HD/CSF	228	84	H	HD/CSF
633	84	V	VD/CSD	123	84	V	VD/CSD	229	100	V	VD/
634	84	H	QF,HD/CSF	124	84	H	HD/CSF	230	116	H	HD/
635	84	V	VD/CSD	125	84	V	VD/CSD	231	116	V	VD/
636	84	H	O,O,HD/CSF	126	84	H	HD/CSF	232	116	H	HD/
637	84	V	O,VD/CSD	127	84	V	VD/CSD	301	100	V	VD/BV
638	100	H	O,O,HD/	128	84	H	HD/CSF	302	84	H	HD/
639	116	V	VD/	129	84	V	VD/CSD	303	84	V	VD/
640	116	H	HD/	130	84	H	HD/CSF	304	84	H	O,O,HD/
641	116	V	VD/	201	84	V	BV,VD/CSD	305	84	V	O,VD/
100	100	H	HD/BV	202	84	H	HD/CSF	306	84	H	O,O,HD/
101	84R	H,V	LAM,VD/	203	84	V	VD/CSD	307	84	V	VD/
102	84	H,V	HD/	204	84	H	HD/CSF	308	84	H	HD/
103	84	H,V	K,VD/FW,MW	205	84	V	VD/CSD	309	100	V	BV,VD/
104	100	H,V	FW,MW,BV,HD/	206	84	H	QD,HD/CSF	310	116	H	HD/
105	116	V	VD/	207	84	V	VD/CSD	311	116	V	VD/
106	116	H	HD/	208	84	H	QF,HD/CSF	312	116	H	HD/
107	116	V	VD/	209	84	V	VD/CSD	313	100	V	VD/CSD
108	100	H	HD/CSF	210	84	H	QD,HD/CSF	314	84	H	HD/CSF
109	84	V	VD/CSD	211	84	V	BV,VD/CSD	315	100	V	VD/
110	84	H	HD/CSF	212	84	H	QF,HD/CSF	316	116	H	HD/
111	84	V	VD/CSD	213	84	V	VD/CSD	317	116	V	VD/
112	84	H	HD/CSF	214	84	H	O,O,HD/CSF	318	116	H	HD/
113	84	V	BV,VD/CSD	215	84	V	O,VD/CSD	319	100	V	VD/BV
				216	100	H	O,O,HD/	320	84	H	HD/
				217	116	V	VD/	321	84	V	VD/
				218	116	H	HD/	322	100	H	BV,HD/
				219	116	V	VD/	323	116	V	VD/

HD/= HORIZONTAL DIPOLE CORRECTOR
VD/= VERTICAL DIPOLE CORRECTOR
CSF=CHROMATICITY SEXTUPOLE (FOCUSSING)
CSD=CHROMATICITY SEXTUPOLE (DEFOCUSSING)
QF=QUADRUPOLE CORRECTOR (FOCUSSING)
QD=QUADRUPOLE CORRECTOR (DEFOCUSSING)
SF=RESONANCE-CORRECTING SEXTUPOLE (FOCUSSING)
SD=RESONANCE-CORRECTING SEXTUPOLE (DEFOCUSSING)
SQ=SKEW QUADRUPOLE CORRECTOR
SS=SKEW SEXTUPOLE CORRECTOR
O=OCTUPOLE
XXX = STRAIGHT SECTION QUADS

FW=FLYING WIRE
BV=BEAM VALVE
MW=MULTIWIRE
K=KICKER
LAM=LAMBERTSON, lam=possible future lambertson
ES=ELECTROSTATIC SEPTUM, es=possible future e.s.
DV=DAMPER (VERTICAL)
DH=DAMPER (HORIZONTAL)

QUADRUPOLE DEVICE LIST

MI-40				MI-50				MI-60			
Quad Number	Quad Length	BPM	Devices US/DS	Quad Number	Quad Length	BPM	Devices US/DS	Quad Number	Quad Length	BPM	Devices US/DS
324	116	H	HD/	414	84	H	O,O,HD/CSF	520	100	H,V	HD/BV,K,ES
325	116	V	VD/	415	84	V	O,VD/CSD	521	84	H,V	VD/
326	100	H	HD/CSF	416	84	H	O,O,HD/CSF	522	84	H,V	LAM,HD/LAM
327	84	V	VD/CSD	417	84	V	VD/CSD	523	100	H,V	BV,VD/
328	84	H	QF,HD/CSF	418	84	H	HD/CSF	524	116	H	HD/
329	84	V	VD/CSD	419	84	V	VD/CSD	525	116	V	VD/
330	84	H	QD,HD/CSF	420	84	H	HD/CSF	526	116	H	HD/
331	84	V	BV,VD/CSD	421	84	V	BV,VD/CSD	527	100	V	VD/CSD
332	84	H	QF,HD/CSF	422	84	H	HD/CSF	528	84	H	HD/CSF
333	84	V	VD/CSD	423	84	V	VD/CSD	529	100	V	VD/
334	84	H	QD,HD/CSF	424	84	H	HD/CSF	530	116	H	HD/
335	84	V	VD/CSD	425	84	V	VD/CSD	531	116	V	VD/
336	84	H	O,O,HD/CSF	426	84	H	HD/CSF	532	116	H	HD/
337	84	V	O,VD/CSD	427	84	V	VD/CSD	601	100	V	VD/BV
338	100	H	O,O,HD/	428	84	H	HD/CSF	602	84	H	es,HD/
339	116	V	VD/	429	84	V	VD/CSD	603	84	V	VD/
340	116	H	HD/	430	84	H	HD/CSF	604	84	H	O,O,HD/
341	116	V	VD/	501	84	V	BV,VD/CSD	605	84	V	O,VD/
400	100	H,V	HD/BV,K	502	84	H	HD/CSF	606	84	H,V	O,O,HD/
401	84	H,V	VD/	503	84	V	VD/CSD	607	84	H,V	VD/
402	84	H,V	LAM,HD/LAM	504	84	H	HD/CSF	608	84	H,V	lam,HD/lam
403	84	H,V	VD/	505	84	V	VD/CSD	609	100	H,V	BV,VD/
404	100	H	BV,HD/	506	84	H	QF,HD/CSF	610	116	H	HD/
405	116	V	VD/	507	84	V	VD/CSD	611	116	V	VD/
406	116	H	HD/	508	84	H	QD,HD/CSF	612	116	H	HD/
407	116	V	VD/	509	84	V	VD/CSD	613	100	V	VD/CSD
408	100	H	HD/CSF	510	84	H	QF,HD/CSF	614	84	H	HD/CSF
409	84	V	VD/CSD	511	84	V	BV,VD/CSD	615	100	V	VD/
410	84	H	HD/CSF	512	84	H	QD,HD/CSF	616	116	H	HD/
411	84	V	VD/CSD	513	84	V	VD/CSD	617	116	V	VD/
412	84	H	HD/CSF	514	84	H	O,O,HD/CSF	618	116	H	HD/
413	84	V	BV,VD/CSD	515	84	V	O,VD/CSD	619	100	H,V	VD/BV
				516	100	H	O,O,HD/	620	84	H,V	LAM,HD/LAM
				517	116	V	VD/	621	84	H,V	VD/
				518	116	H	HD/	622	100	H,V	K,BV,HD/
				519	116	V	VD/	623	116	V	VD/

NOTES:

EACH BUILDING STARTS WITH AN F-QUAD

EACH BUILDING SERVICES 32 OR 36 QUAD LOCATIONS

BUILDINGS MI-10, MI-20, MI-30, MI-40, AND MI-50 EACH SERVICE 36 BPM CHANNELS

FLYING WIRES ONLY IN MI-10 STRAIGHT SECTION; NONE REQUIRED AT HIGH DISPERSION POINT

	MI-10				MI-20				MI-30		
Quad Number	Quad Length	BPM	Devices US/DS	Quad Number	Quad Length	BPM	Devices US/DS	Quad Number	Quad Length	BPM	Devices US/DS
113	84	V	BV,VD/CSD	121	84	V	BV,VD/CSD	222	84	H	HD/
631	84	V	BV,VD/CSD	201	84	V	BV,VD/CSD	302	84	H	HD/
102	84	H,V	HD/	211	84	V	BV,VD/CSD	308	84	H	HD/
110	84	H	HD/CSF	118	84	H	HD/CSF	320	84	H	HD/
112	84	H	HD/CSF	120	84	H	HD/CSF	228	84	H	HD/CSF
103	84	H,V	K,VD/FW,MW	122	84	H	HD/CSF	314	84	H	HD/CSF
636	84	H	O,O,HD/CSF	124	84	H	HD/CSF	304	84	H	O,O,HD/
637	84	V	O,VD/CSD	126	84	H	HD/CSF	306	84	H	O,O,HD/
628	84	H	QD,HD/CSF	128	84	H	HD/CSF	305	84	V	O,VD/
632	84	H	QD,HD/CSF	130	84	H	HD/CSF	221	84	V	VD/
630	84	H	QF,HD/CSF	202	84	H	HD/CSF	303	84	V	VD/
634	84	H	QF,HD/CSF	204	84	H	HD/CSF	307	84	V	VD/
109	84	V	VD/CSD	114	84	H	O,O,HD/CSF	321	84	V	VD/
111	84	V	VD/CSD	116	84	H	O,O,HD/CSF	322	100	H	BV,HD/
627	84	V	VD/CSD	214	84	H	O,O,HD/CSF	223	100	V	BV,VD/
629	84	V	VD/CSD	115	84	V	O,VD/CSD	309	100	V	BV,VD/
633	84	V	VD/CSD	215	84	V	O,VD/CSD	220	100	H	HD/BV
635	84	V	VD/CSD	206	84	H	QD,HD/CSF	229	100	V	VD/
104	100	H,V	FW,MW,BV,HD/	210	84	H	QD,HD/CSF	315	100	V	VD/
100	100	H	HD/BV	208	84	H	QF,HD/CSF	301	100	V	VD/BV
108	100	H	HD/CSF	212	84	H	QF,HD/CSF	319	100	V	VD/BV
626	100	H	HD/CSF	117	84	V	VD/CSD	227	100	V	VD/CSD
638	100	H	O,O,HD/	119	84	V	VD/CSD	313	100	V	VD/CSD
106	116	H	HD/	123	84	V	VD/CSD	224	116	H	HD/
624	116	H	HD/	125	84	V	VD/CSD	226	116	H	HD/
640	116	H	HD/	127	84	V	VD/CSD	230	116	H	HD/
105	116	V	VD/	129	84	V	VD/CSD	232	116	H	HD/
107	116	V	VD/	203	84	V	VD/CSD	310	116	H	HD/
625	116	V	VD/	205	84	V	VD/CSD	312	116	H	HD/
639	116	V	VD/	207	84	V	VD/CSD	316	116	H	HD/
641	116	V	VD/	209	84	V	VD/CSD	318	116	H	HD/
101	84R	H,V	LAM,VD/	213	84	V	VD/CSD	225	116	V	VD/
				216	100	H	O,O,HD/	231	116	V	VD/
				218	116	H	HD/	311	116	V	VD/
				217	116	V	VD/	317	116	V	VD/
				219	116	V	VD/	323	116	V	VD/

HD/= HORIZONTAL DIPOLE CORRECTOR
VD/= VERTICAL DIPOLE CORRECTOR
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CSD=CHROMATICITY SEXTUPOLE (DEFOCUSSING)
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BV=BEAM VALVE
MW=MULTIWIRE
K=KICKER
LAM=LAMBERTSON, lam=possible future lambertson
ES=ELECTROSTATIC SEPTUM, es=possible future e.s.
DV=DAMPER (VERTICAL)
DH=DAMPER (HORIZONTAL)

Sorted QUADRUPOLE DEVICE LIST

MI-40				MI-50				MI-60			
Quad Number	Quad Length	BPM	Devices US/DS	Quad Number	Quad Length	BPM	Devices US/DS	Quad Number	Quad Length	BPM	Devices US/DS
331	84	V	BV,VD/CSD	421	84	V	BV,VD/CSD	602	84	H	es,HD/
413	84	V	BV,VD/CSD	501	84	V	BV,VD/CSD	528	84	H	HD/CSF
410	84	H	HD/CSF	511	84	V	BV,VD/CSD	614	84	H	HD/CSF
412	84	H	HD/CSF	418	84	H	HD/CSF	522	84	H,V	LAM,HD/LAM
402	84	H,V	LAM,HD/LAM	420	84	H	HD/CSF	608	84	H,V	lam,HD/lam
336	84	H	O,O,HD/CSF	422	84	H	HD/CSF	620	84	H,V	LAM,HD/LAM
337	84	V	O,VD/CSD	424	84	H	HD/CSF	604	84	H	O,O,HD/
330	84	H	QD,HD/CSF	426	84	H	HD/CSF	606	84	H,V	O,O,HD/
334	84	H	QD,HD/CSF	428	84	H	HD/CSF	605	84	V	O,VD/
328	84	H	QF,HD/CSF	430	84	H	HD/CSF	521	84	H,V	VD/
332	84	H	QF,HD/CSF	502	84	H	HD/CSF	603	84	V	VD/
401	84	H,V	VD/	504	84	H	HD/CSF	607	84	H,V	VD/
403	84	H,V	VD/	414	84	H	O,O,HD/CSF	621	84	H,V	VD/
327	84	V	VD/CSD	416	84	H	O,O,HD/CSF	523	100	H,V	BV,VD/
329	84	V	VD/CSD	514	84	H	O,O,HD/CSF	609	100	H,V	BV,VD/
333	84	V	VD/CSD	415	84	V	O,VD/CSD	520	100	H,V	HD/BV,K,ES
335	84	V	VD/CSD	515	84	V	O,VD/CSD	622	100	H,V	K,BV,HD/
409	84	V	VD/CSD	508	84	H	QD,HD/CSF	529	100	V	VD/
411	84	V	VD/CSD	512	84	H	QD,HD/CSF	615	100	V	VD/
404	100	H	BV,HD/	506	84	H	QF,HD/CSF	601	100	V	VD/BV
400	100	H,V	HD/BV,K	510	84	H	QF,HD/CSF	619	100	H,V	VD/BV
326	100	H	HD/CSF	417	84	V	VD/CSD	527	100	V	VD/CSD
408	100	H	HD/CSF	419	84	V	VD/CSD	613	100	V	VD/CSD
338	100	H	O,O,HD/	423	84	V	VD/CSD	524	116	H	HD/
324	116	H	HD/	425	84	V	VD/CSD	526	116	H	HD/
340	116	H	HD/	427	84	V	VD/CSD	530	116	H	HD/
406	116	H	HD/	429	84	V	VD/CSD	532	116	H	HD/
325	116	V	VD/	503	84	V	VD/CSD	610	116	H	HD/
339	116	V	VD/	505	84	V	VD/CSD	612	116	H	HD/
341	116	V	VD/	507	84	V	VD/CSD	616	116	H	HD/
405	116	V	VD/	509	84	V	VD/CSD	618	116	H	HD/
407	116	V	VD/	513	84	V	VD/CSD	525	116	V	VD/
				516	100	H	O,O,HD/	531	116	V	VD/
				518	116	H	HD/	611	116	V	VD/
				517	116	V	VD/	617	116	V	VD/
				519	116	V	VD/	623	116	V	VD/

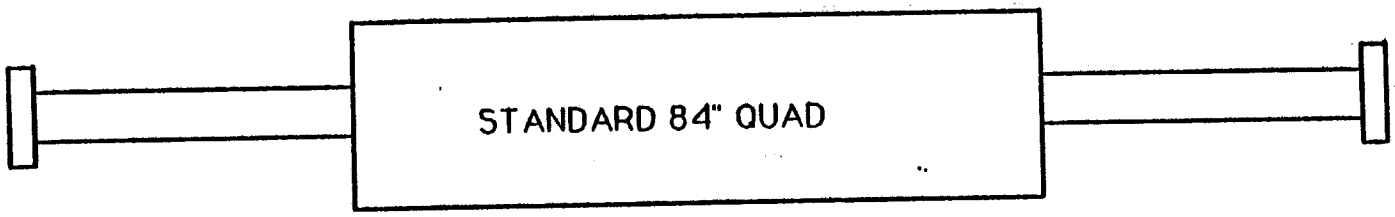
NOTES:

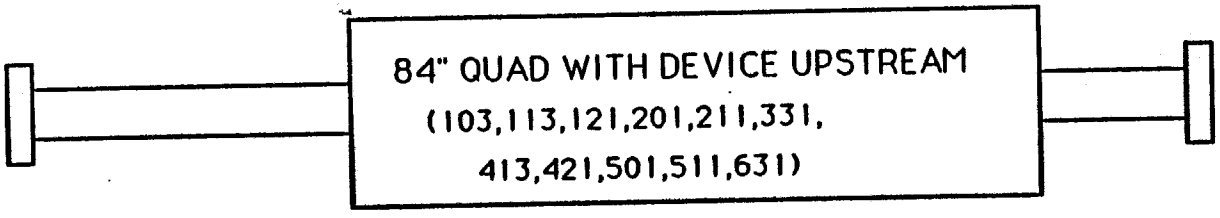
EACH BUILDING STARTS WITH AN F-QUAD

EACH BUILDING SERVICES 32 OR 36 QUAD LOCATIONS

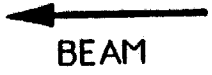
BUILDINGS MI-10, MI-20, MI-30, MI-40, AND MI-50 EACH SERVICE 36 BPM CHANNELS

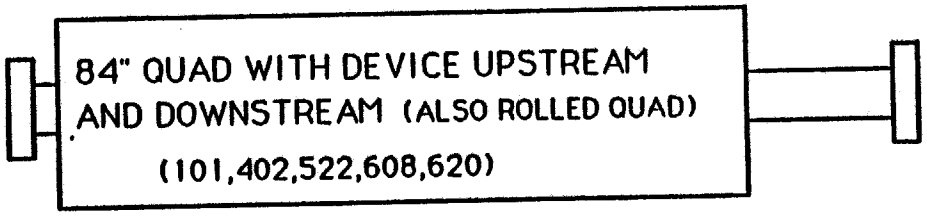
FLYING WIRES ONLY IN MI-10 STRAIGHT SECTION; NONE REQUIRED AT HIGH DISPERSION POINT



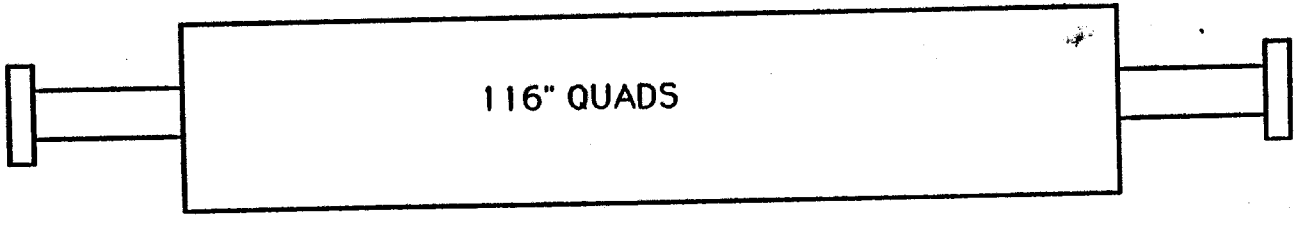


Var. 1

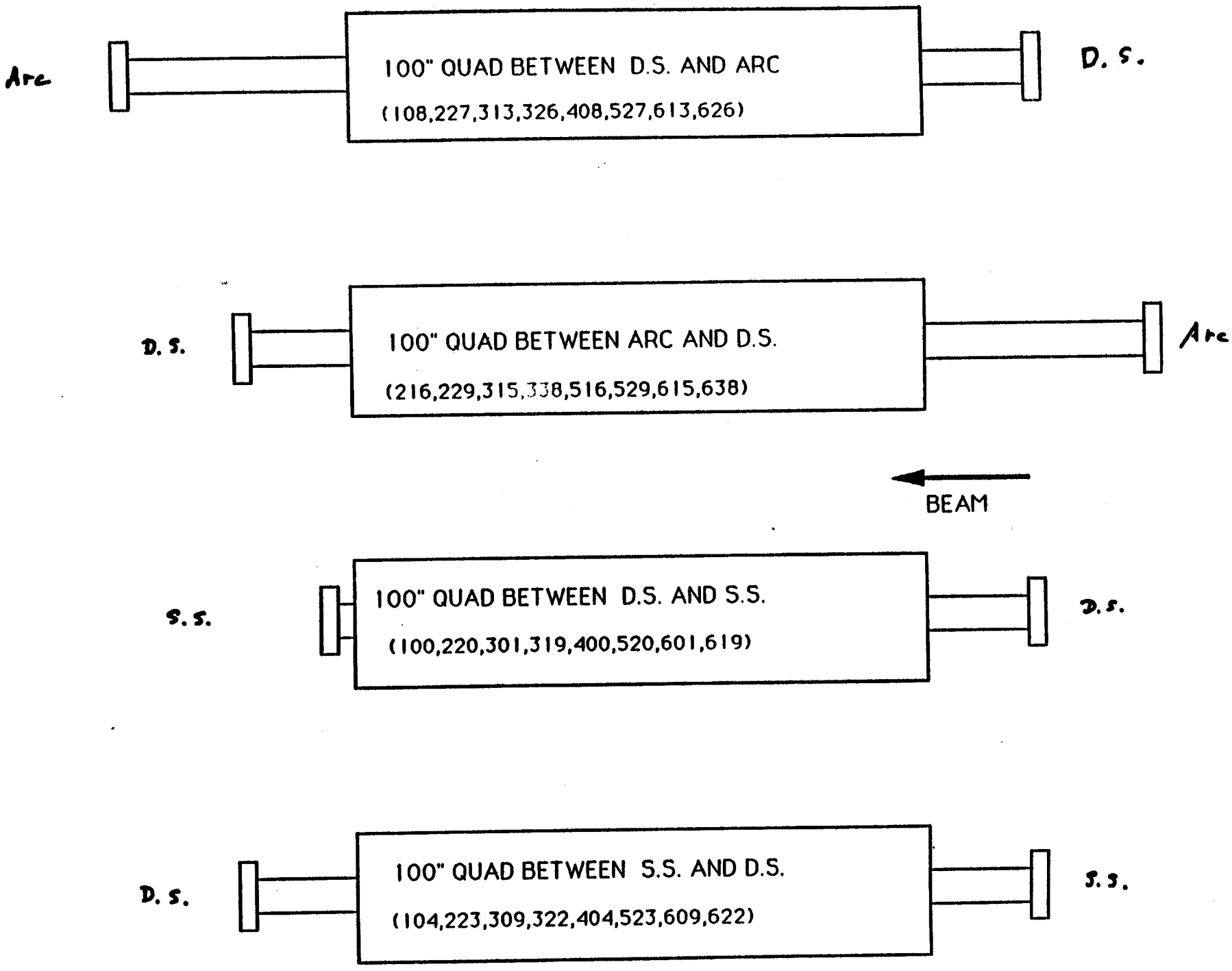




Var. 2



all


Arc
100" QUAD BETWEEN D.S. AND ARC
(108,227,313,326,408,527,613,626)
D. S.
D. S.
100" QUAD BETWEEN ARC AND D.S.
(216,229,315,338,516,529,615,638)
Arc
BEAM
S. S.
100" QUAD BETWEEN D.S. AND S.S.
(100,220,301,319,400,520,601,619)
D. S.
D. S.
100" QUAD BETWEEN S.S. AND D.S.
(104,223,309,322,404,523,609,622)
S. S.

84" quads		
Regular quads	HD or VD	CSF or CSD

84" quad variant 1		
Q103	K VD	CSD
Q113	BV VD	CSD
Q121	BV VD	CSD
Q201	BV VD	CSD
Q211	BV VD	CSD
Q331	BV VD	CSD
Q413	BV VD	CSD
Q421	BV VD	CSD
Q501	BV VD	CSD
Q511	BV VD	CSD
Q631	BV VD	CSD

84" quad variant 2		
Q101 (ROLLED)	LAM	VD
Q402	LAM HD	LAM
Q522	LAM HD	LAM
Q608	lam HD	lam
Q620	LAM HD	LAM

100" quads (DS to ARC)		
Q108	HD	CSF
Q227	VD	CSD
Q313	HD	CSF
Q326	VD	CSD
Q408	HD	CSF
Q527	VD	CSD
Q613	HD	CSF
Q626	VD	CSD

100" quads (ARC to DS)		
Q216	O O HD	-
Q229	VD	-
Q315	VD	-
Q338	O O HD	-
Q516	O O HD	-
Q529	VD	-
Q615	VD	-
Q638	O O HD	-

100" quads (DS TO SS)		
Q100	HD	BV
Q220	HD	BV
Q301	VD	BV
Q319	VD	BV
Q400	HD	BV K
Q520	HD	BV K ES
Q601	VD	BV
Q619	VD	BV

100" quads (SS to DS)		
Q104	FW MW BV HD	-
Q223	BV VD	-
Q309	BV VD	-
Q323	VD	-
Q404	BV HD	-
Q523	BV VD	-
Q609	BV VD	-
Q622	K BV HD	-

	116" QUADS	
all	HD or VD	-

SHEKHAR MISHRA

Study of the Main Injector Performance at 8.9 GeV and 120 GeV

C. S. Mishra and F. Harfoush

TEAPOT

1) Input parameters

   Multipole Errors

   Change in effective length of dipole

   Parameters at 8.9 and 120 GeV

2) Closed orbit errors and Corrector strength

3) octupole strength of Main Ring Quads

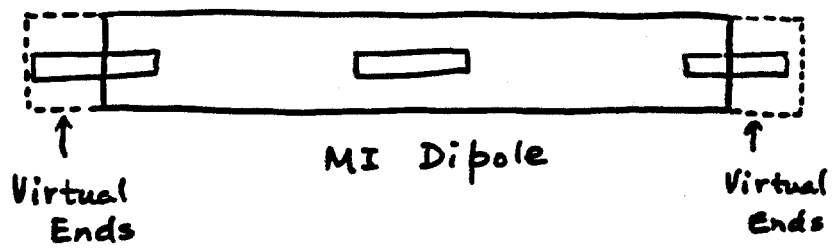
4) End sextupole strength of MI dipoles

5) β function

6) Further Work

Input Parameters

Described in detail in MI 66



Flat coil 80", 16'4", 24'

Harmonic 80"

NMR and Hall Probes

- @ 120 GeV

$$L_{ref\ Long\ Dipole} = L_{magnetic\ long\ D} = 6.096\,m$$

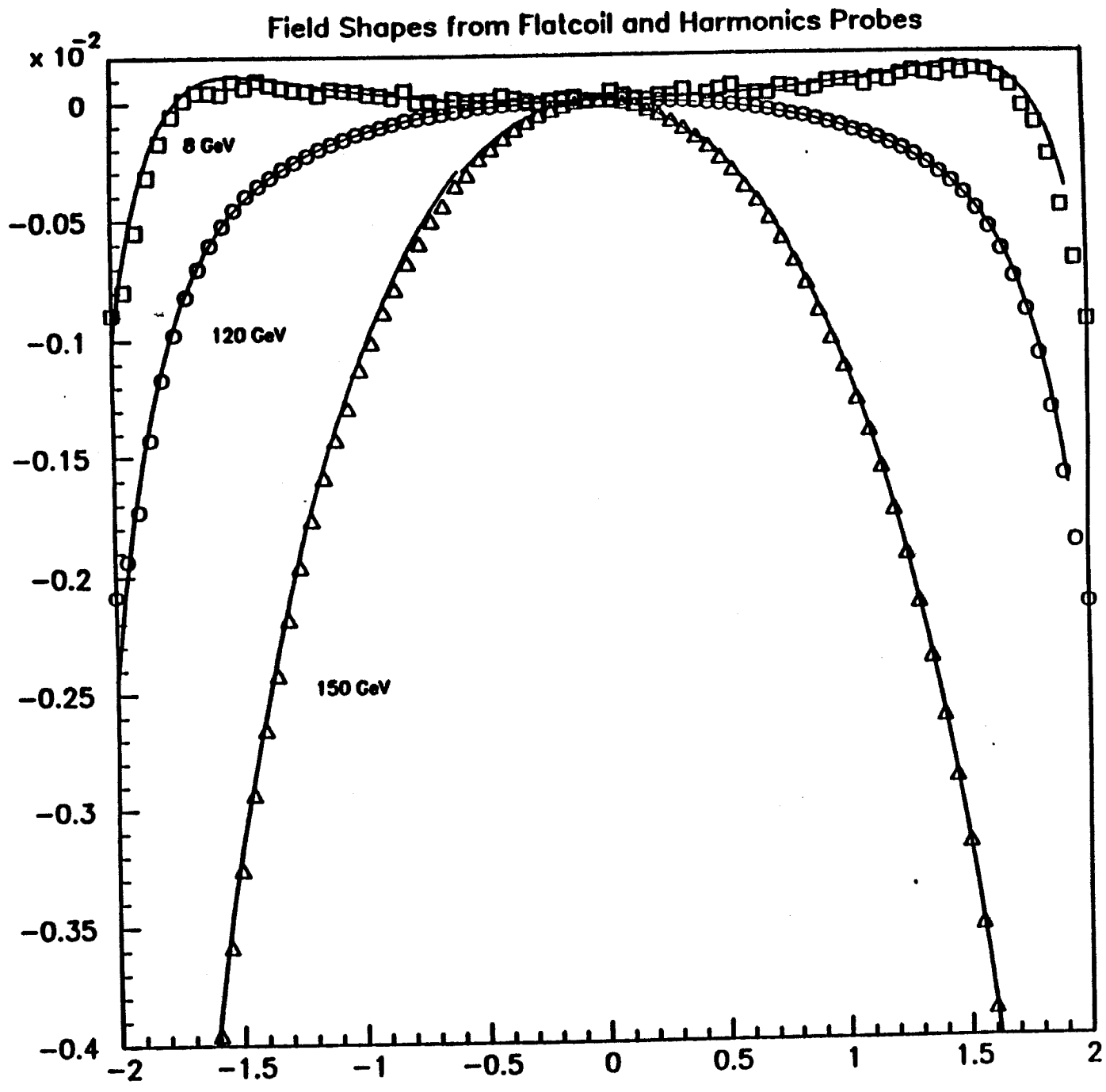
$$L_{ref\ short\ Dipole} = L_{magnetic\ short\ D} = 4.064\,m$$

- other Energies

$$L_{magnetic} \neq L_{ref}$$

$$\theta_L = \left(1 + \epsilon + \frac{\Delta L}{L_{ref}}\right)\theta_{0L}$$

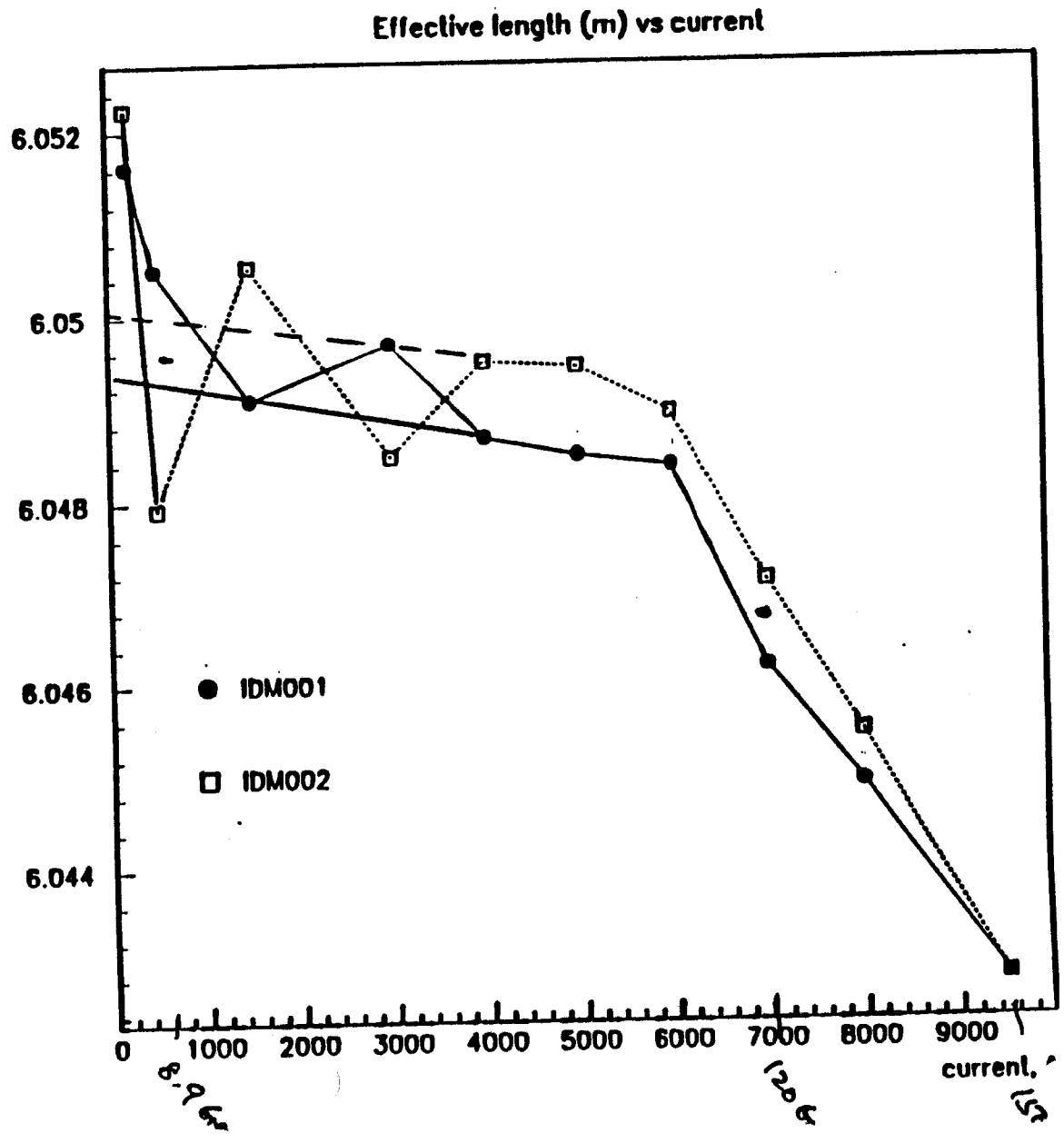
$$\theta_S = \left(\frac{2}{3} + \frac{2}{3}\epsilon + \frac{\Delta L}{L_{ref}}\right)\theta_{0S}$$



H. Glass

Figure 2-8. Magnetic Measurements at various Energies

Energy	ΔL (m)
8.9 GeV	−0.0025
21 GeV	−0.003
120 GeV	0
150 GeV	0.004



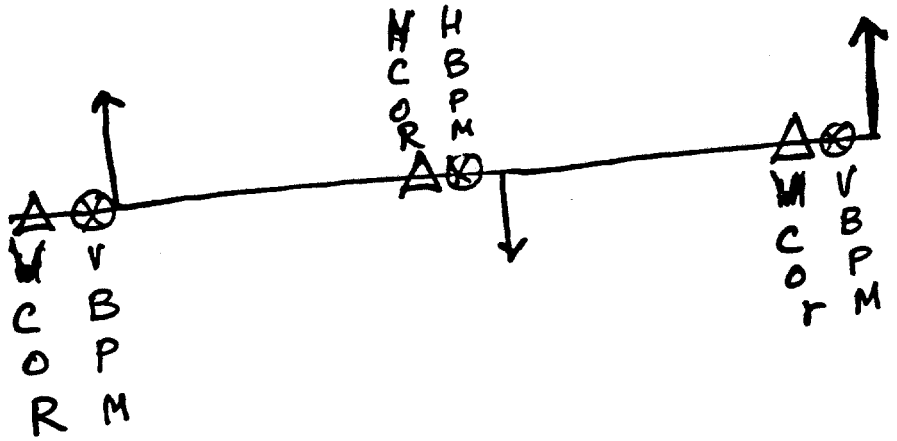
H. Glass

Magnetic errors used in the 8.9 GeV simulation

	Multipole order	Normal $< b_n >$	σb_n	Skew $< a_n >$	σa_n
Dipole Body	dipole	-4.68	10.0	-	-
	quadrupole	-0.13	0.45	-	-
	sextupole	0.43	0.61	-0.04	0.22
	8	0.09	0.13	0.00	0.41
	10	0.18	0.32	0.03	0.15
	12	-0.03	0.10	0.00	0.19
	14	-0.01	0.23	-0.05	0.08
Dipole end BUS	Dipole	2.05	-	0.0	-
	quadrupole	0.03	-	-	-
Divided by eight	sextupole	0.92	-	0.03	-
	8	-0.02	-	0.02	-
	10	-0.09	-	0.04	-
	12	0.04	-	-0.03	-
	14	-0.07	-	0.00	-
Dipole end NO BUS	Dipole	2.05	-	0.0	-
	quadrupole	0.03	-	-	-
	sextupole	0.99	-	-0.07	-
ivided by eight	8	-0.08	-	-0.02	-
	10	-0.11	-	-0.05	-
	12	-0.06	-	0.03	-
	14	-0.09	-	0.00	-
Recycled new Main Ring quadrupole	quadrupole	-	24.0	-	-
	sextupole	0.50	2.73	0.12	1.85
	8	5.85	1.02	-1.16	2.38
	10	-0.10	1.12	0.42	0.47
	12	-1.82	0.63	0.40	0.70
	14	0.21	0.64	-0.55	0.44
	16	1.41	0.64	-	-
	18	-0.03	0.12	0.14	0.16
	20	-0.80	0.06	0.02	0.07
Newly Built Main Injector quads	quadrupole	-	24.0	-	-
	sextupole	-	2.73	-	-
	8	-0.39	1.02	-	-
	10	-	1.12	-	-
	12	-1.39	0.63	-	-
	14	-	0.64	-	-
	16	1.29	0.64	-	-
	18	-	0.12	-	-
	20	-0.73	0.06	-	-

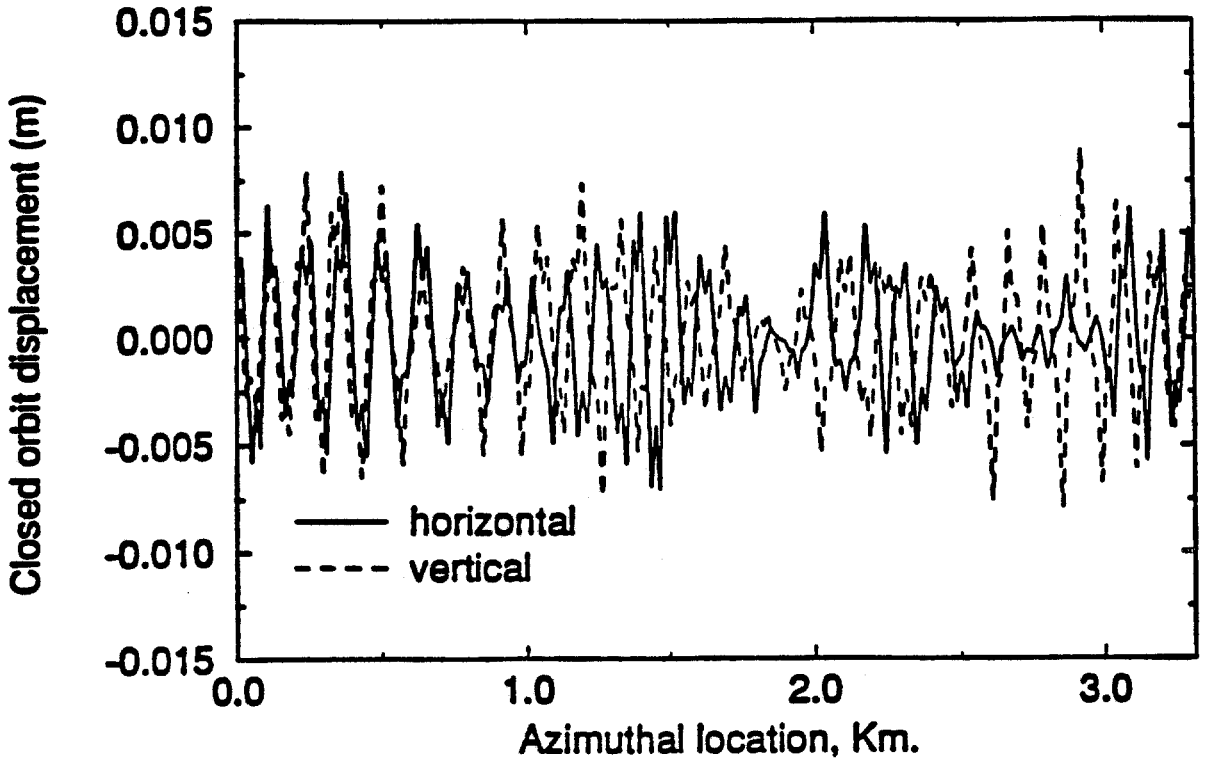
Magnetic errors used in the 120 GeV simulation

	Multipole order	Normal $< b_n >$	Normal σb_n	Skew $< a_n >$	Skew σa_n
Dipole Body	dipole	0.00	10.0	-	-
	quadrupole	-0.30	0.21	-	-
	sextupole	-1.16	0.49	-0.03	0.17
	8	0.02	0.06	-0.02	0.29
	10	-0.09	0.25	-0.04	0.07
	12	-0.04	0.06	-0.01	0.21
	14	-0.08	0.25	-0.05	0.08
Dipole end BUS	Dipole	0.0	-	0.0	-
	quadrupole	0.08	-	-	-
Divided by eight	sextupole	1.00	-	0.05	-
	8	0.01	-	0.02	-
	10	-0.11	-	0.05	-
	12	0.06	-	-0.03	-
	14	-0.06	-	0.01	-
Dipole end NO BUS	Dipole	0.0	-	0.0	-
	quadrupole	0.08	-	-	-
	sextupole	1.03	-	-0.10	-
Divided by eight	8	-0.09	-	-0.03	-
	10	-0.12	-	-0.03	-
	12	-0.06	-	0.03	-
	14	-0.08	-	0.02	-
Recycled new Main Ring quadrupole	quadrupole	-	24.0	-	-
	sextupole	1.69	2.29	-0.47	3.14
	8	5.29	1.29	0.68	0.43
	10	-0.72	0.90	0.41	0.34
	12	-1.71	0.16	-0.31	0.14
	14	-0.25	0.92	-0.02	1.11
	16	1.37	0.92	-	-
	18	-0.22	0.92	0.06	0.25
	20	-0.82	0.33	-0.05	0.08
Newly Built Main Injector quads	quadrupole	-	24.0	-	-
	sextupole	-	2.29	-	-
	8	-0.10	1.29	-	-
	10	-	0.90	-	-
	12	-1.41	0.16	-	-
	14	-	0.92	-	-
	16	1.32	0.92	-	-
	18	-	0.92	-	-
	20	-0.74	0.33	-	-



1 Corrector
1 BPF

Per plane in 1 cell



Tune $Q_x = 26.425$ .409

$Q_y = 25.415$ .407

RF on

Chromoticity -5, -5 at 8.9 GeV

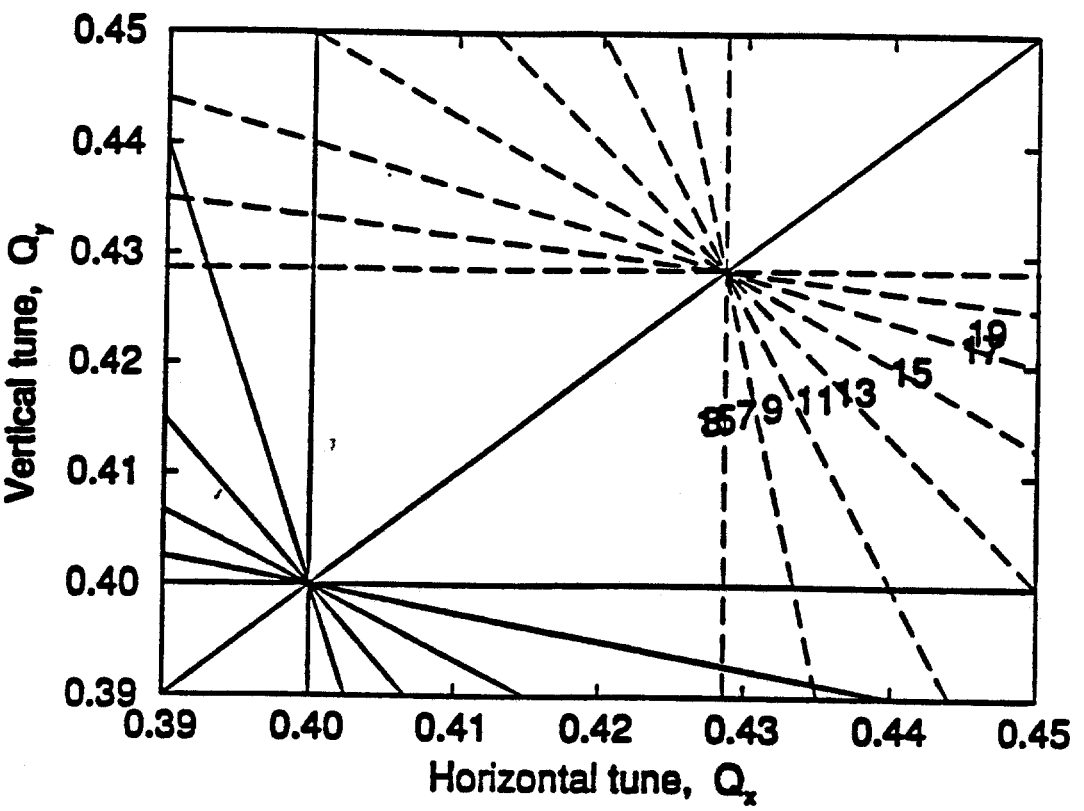
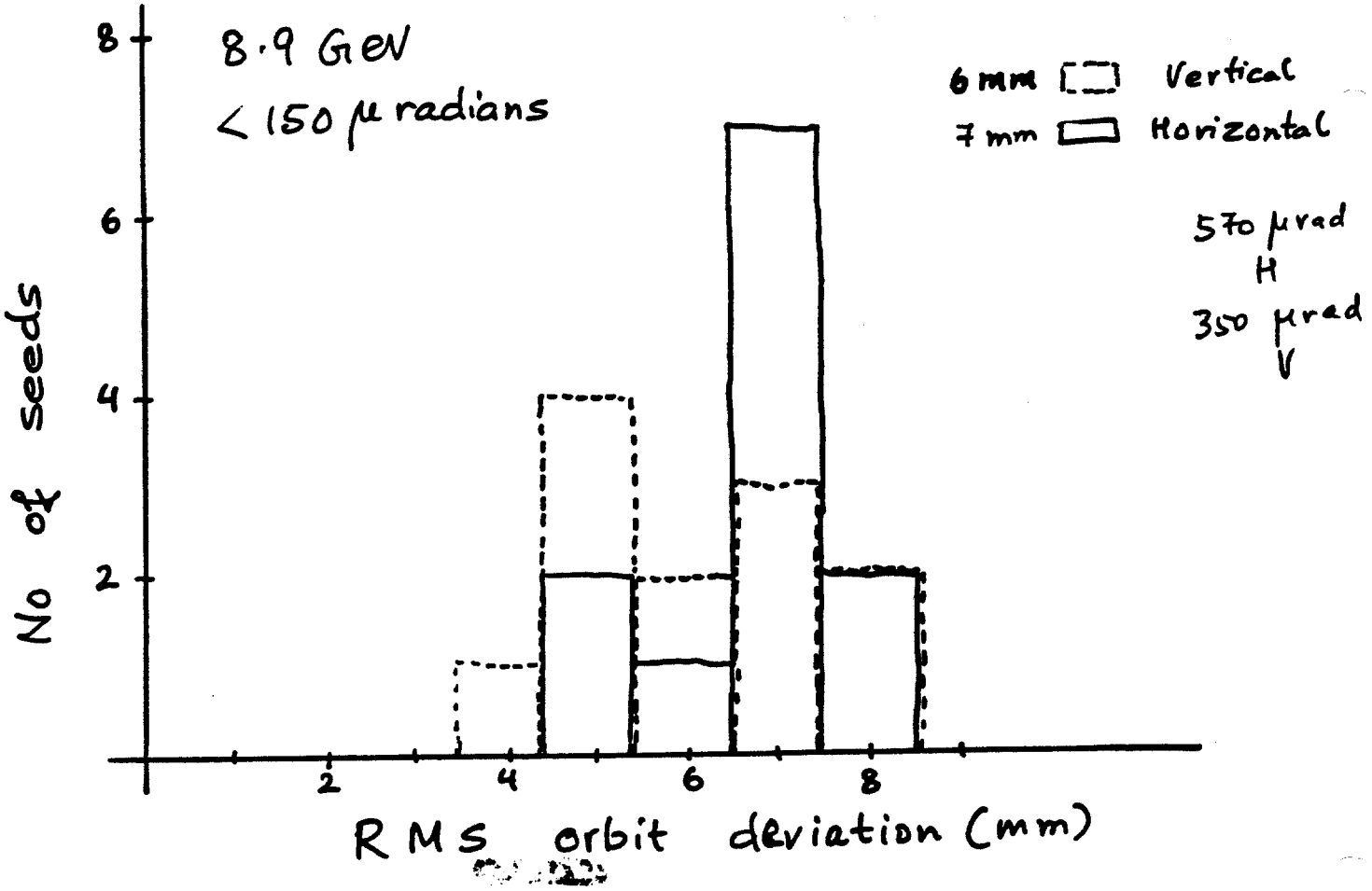
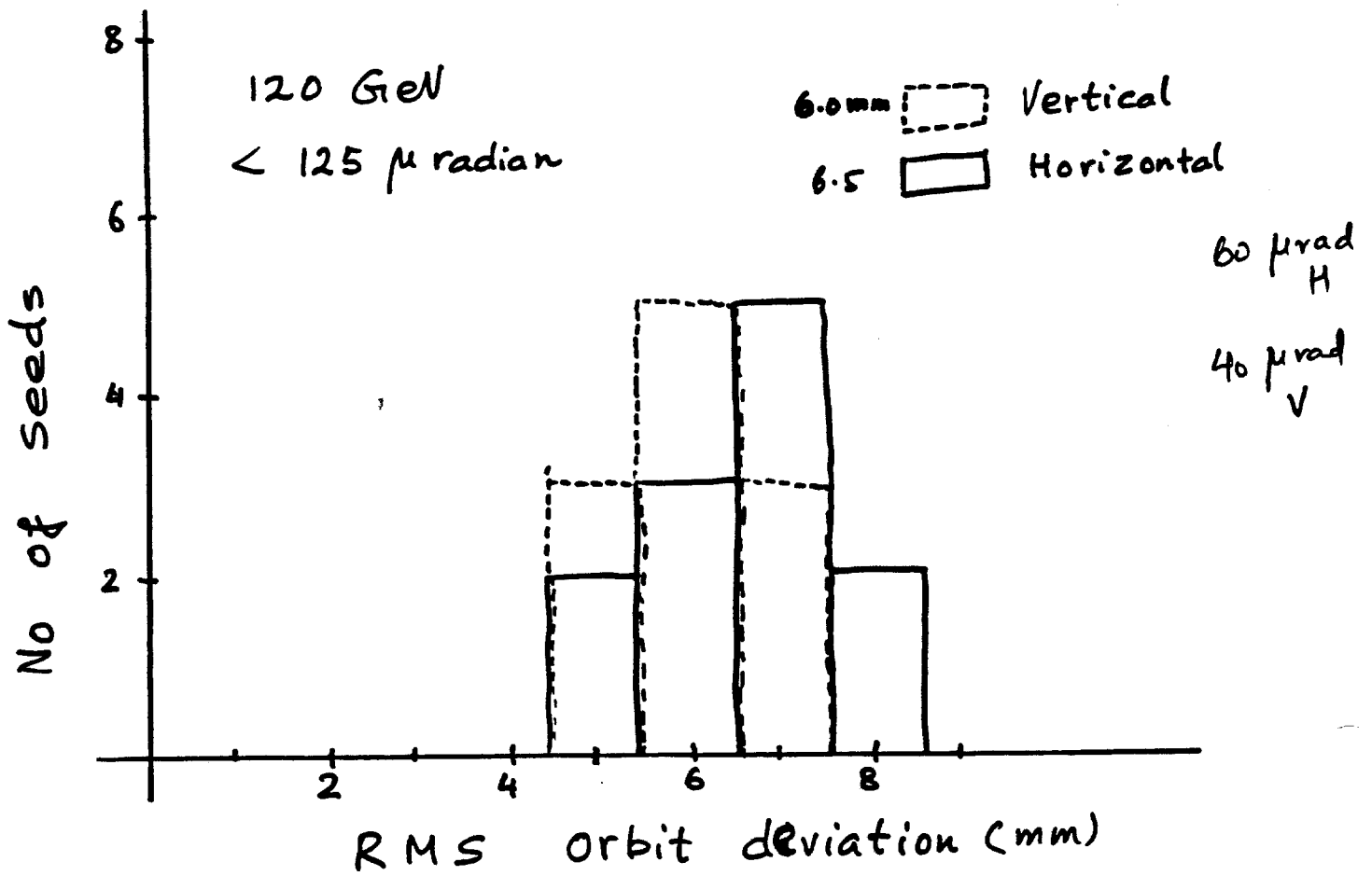


Figure 3.1.2-5 Tune versus amplitude in millimeters

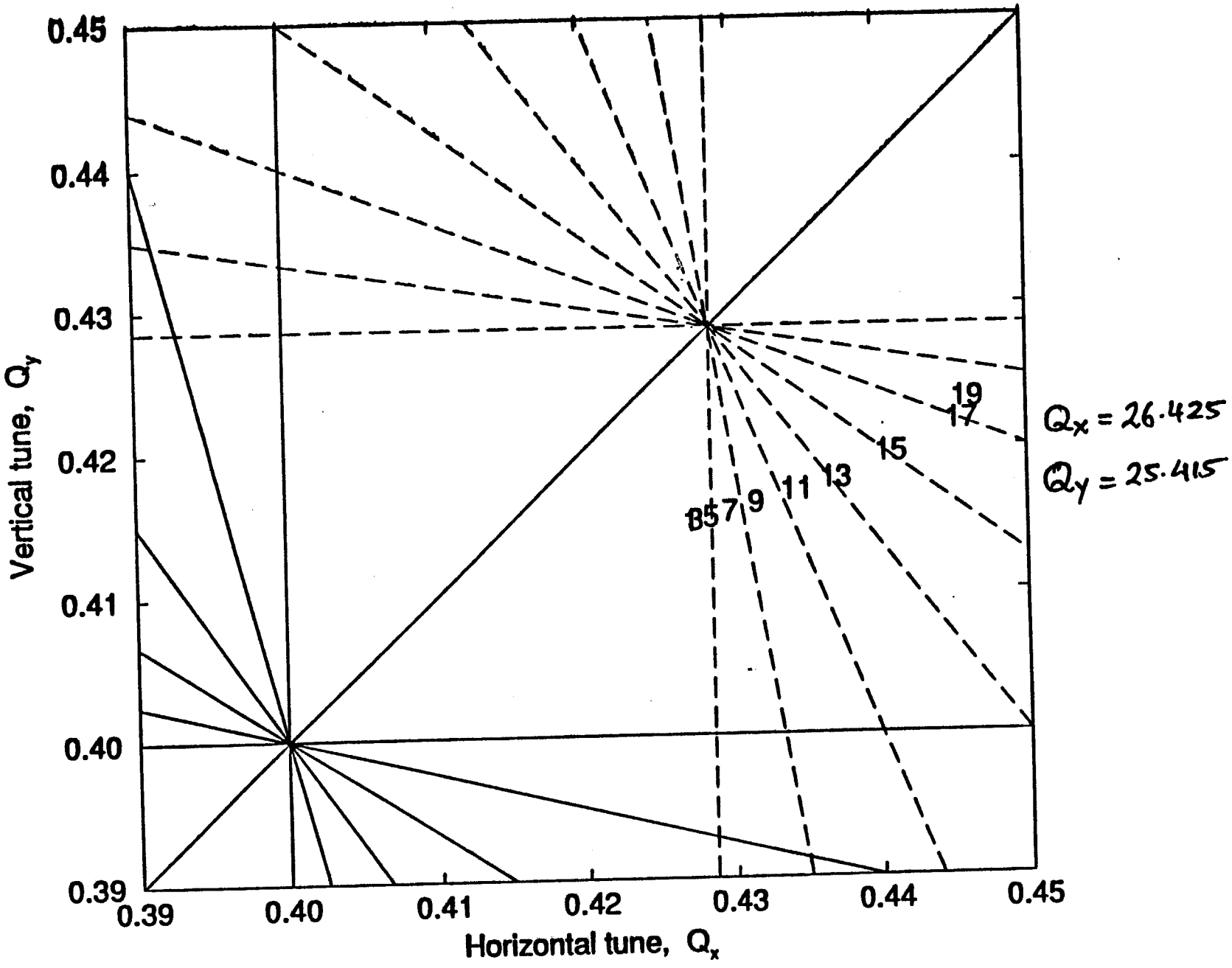
CLOSED ORBIT ERRORS

		8.9 GeV (mm)	120 GeV (mm)
1) All errors	$\sigma(H)$	5.3	6.8
	$\sigma(V)$	5.3	5.6
2) All systematic errors (Includes AL)	$\sigma(H)$	3.5	0
	$\sigma(V)$	0.1	0
3) Dipole Random		5.3	5.6
		0	0
4) Quad Random		0	0
		0	0
5) Displacement and Rotational Error		4.1	4.9
		4.6	4.6
6) Change of effective length		3.2	4.2
		Small	Small

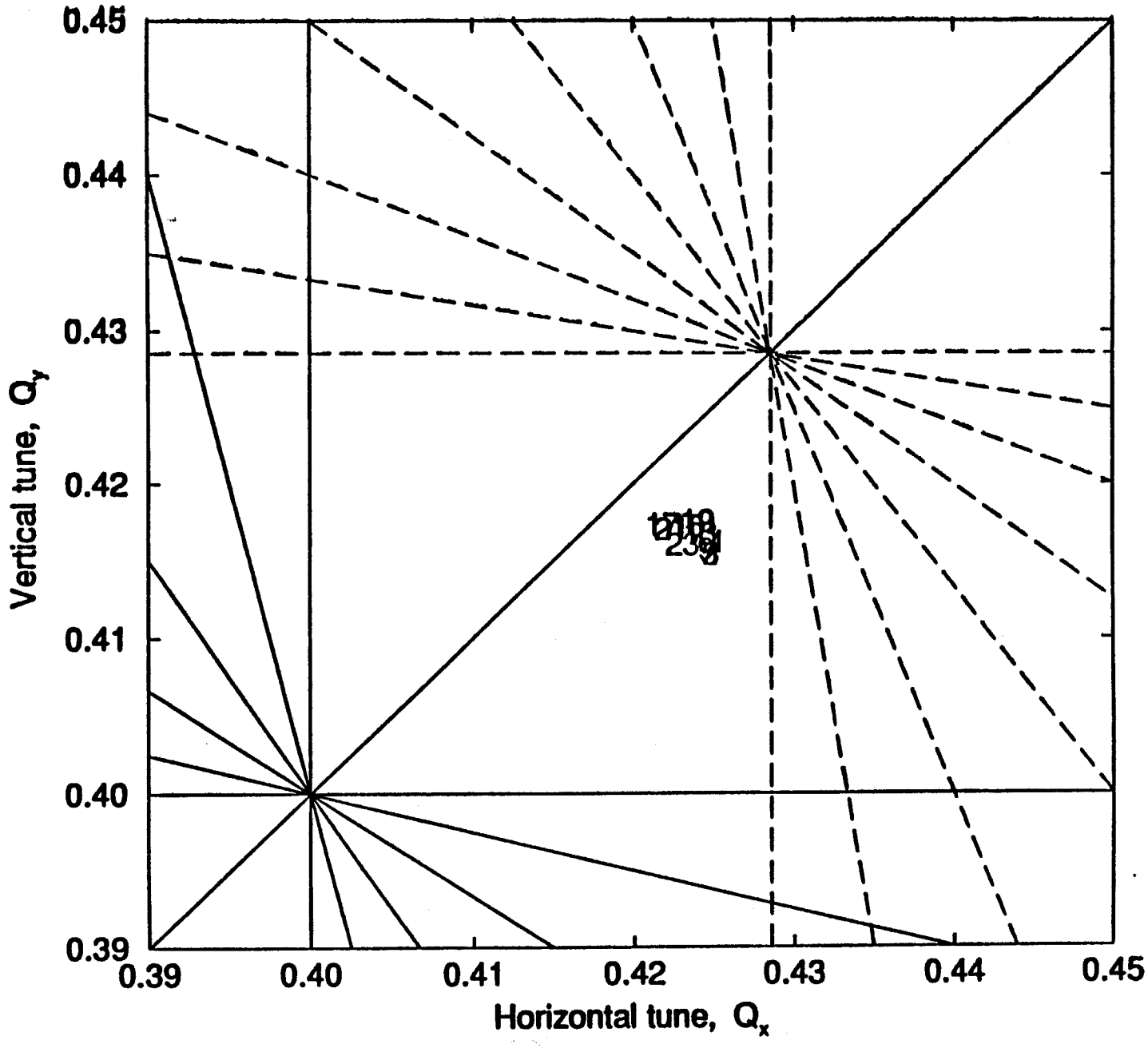

8.9 GeV
< 150 μ radians
6 mm Vertical
7 mm Horizontal
570 μrad H
350 μrad V
No of seeds
RMS orbit deviation (mm)


120 GeV
< 125 μ radian
6.0mm Vertical
6.5 Horizontal
60 μrad H
40 μrad V
No of seeds
RMS orbit deviation (mm)

With Quad Octupole

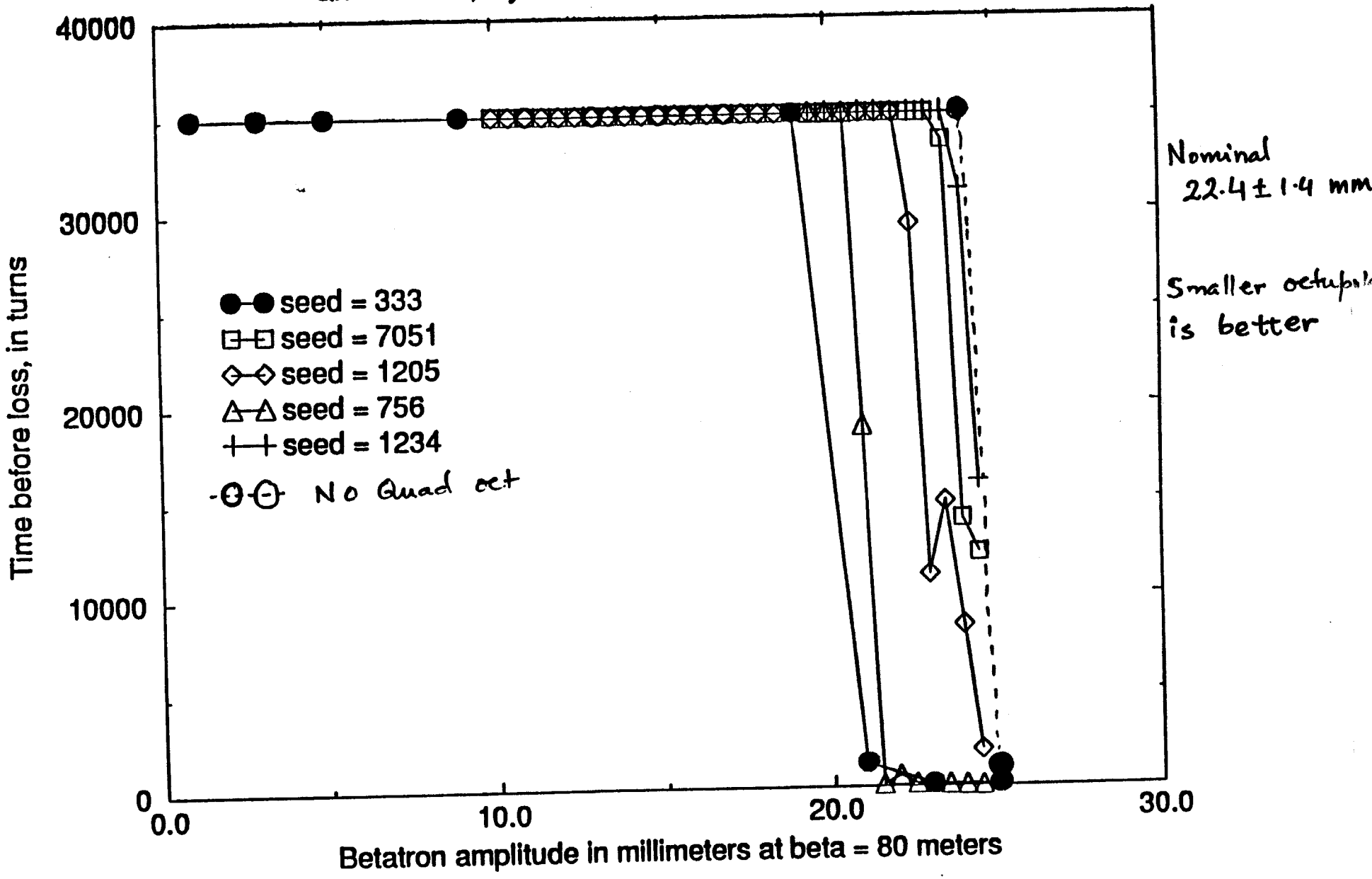


With No Quad Octupole + $\frac{1}{2}$ MI Dipole ends Sextupole



Injection survival plot

Qx = 26.425, Qy = 25.415, Cx = Cy = -5, Dp/p = 0.002



End Sextupole strength

Adjust the Chromoticity to (-5, -5) at 8.9 GeV

Nominal Strength

14.05 kg/m² - m ⟶ - 8.51 kg/m² - m

-26.25 - 52.12

½ Nominal strength

1.78

- 38.3

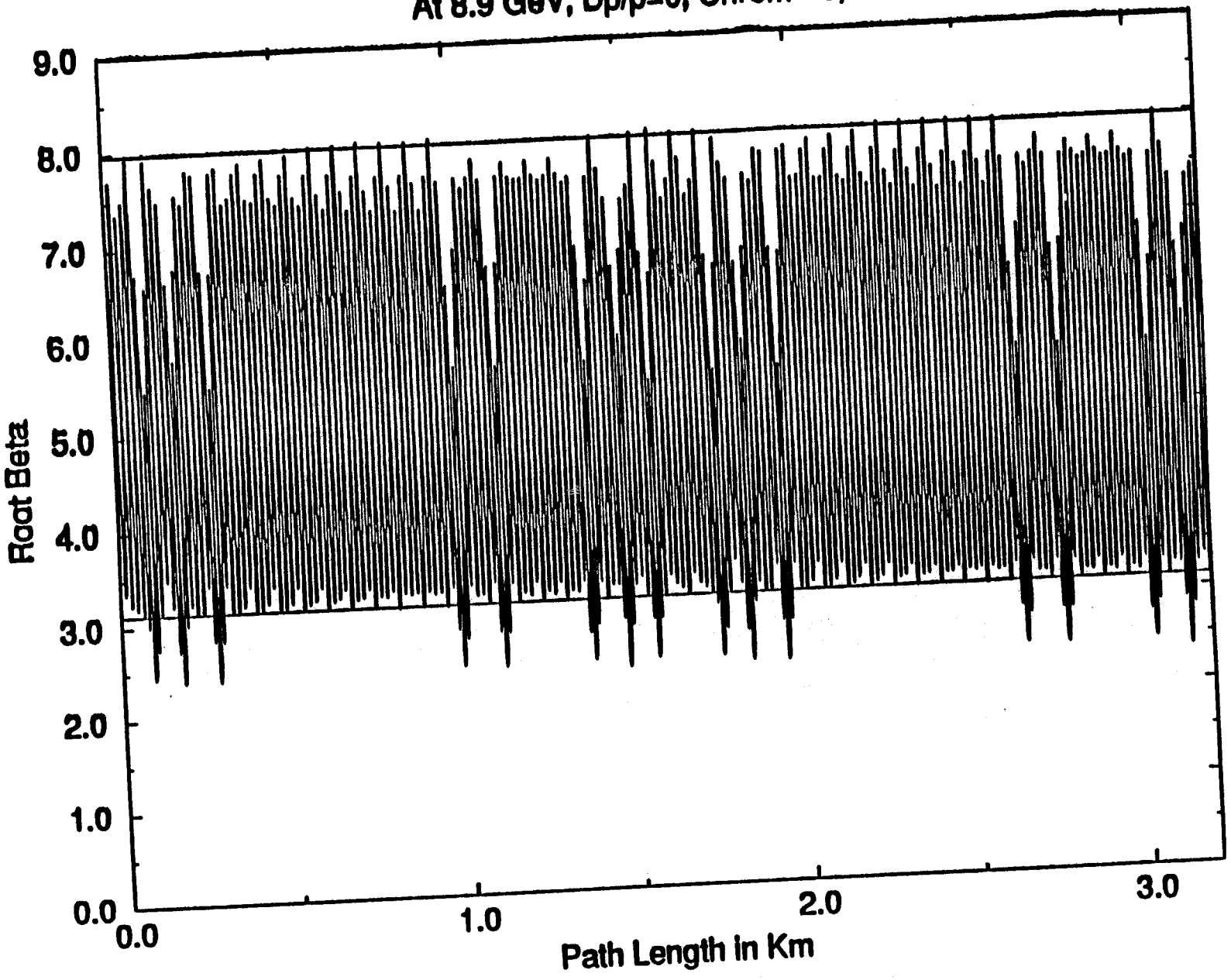
1/10 Nominal Strength

9.94

- 27.11

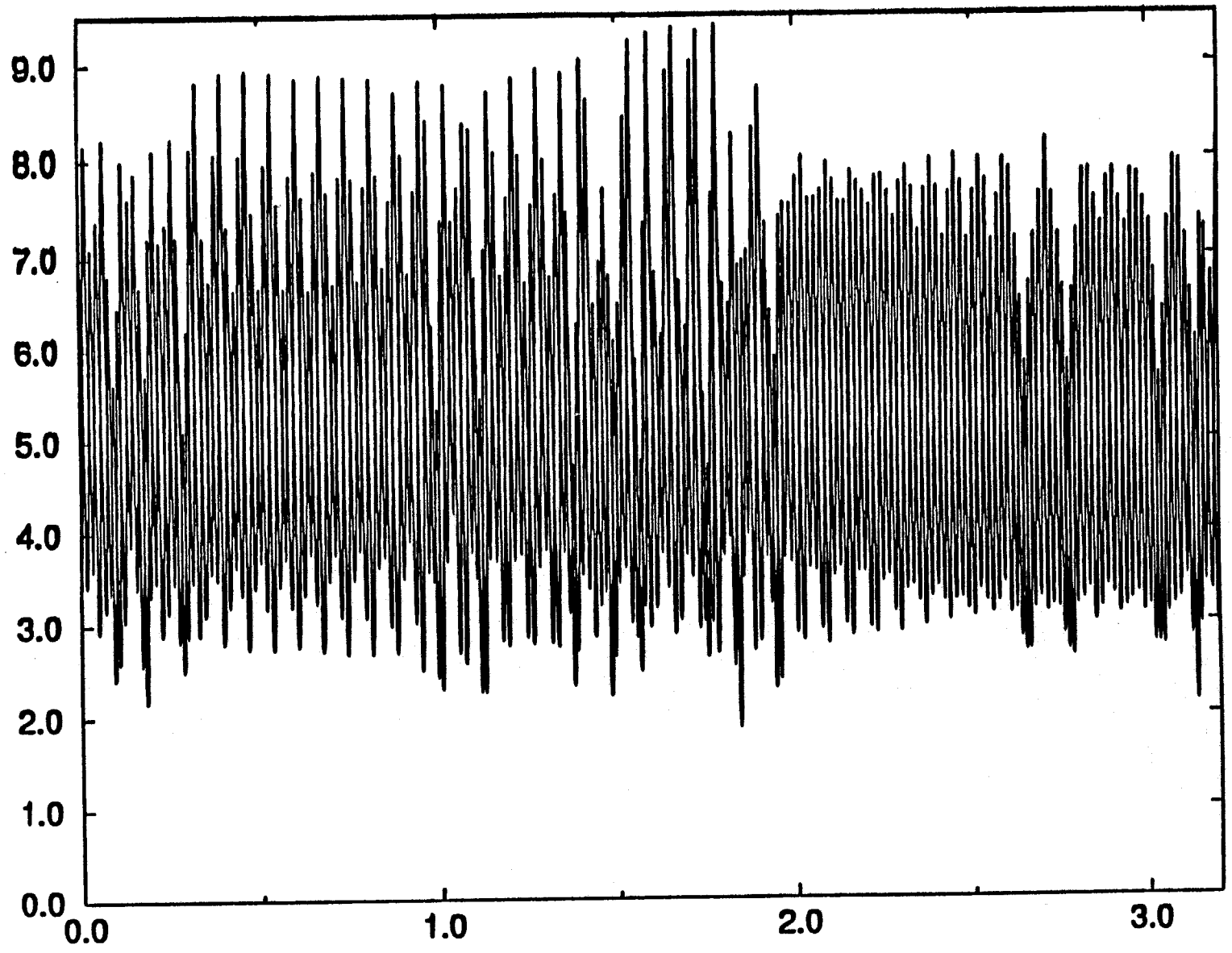
No Errors Beta Functions

At 8.9 GeV, Dp/p=0, Chrom=-5,-5



All Errors Beta Functions

Seed=7051



Further Work

1) Include octupole Corrector in the tracking

2) Study dynamical aperture

   @ 8.9 GeV

   @ 120 GeV

3) Slow Extraction ??

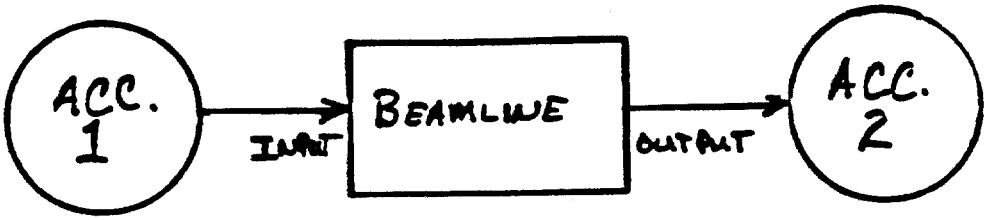
DAVE JOHNSON

4/8/9.

GOAL OF TRANSPORT LINES

(INITIAL THOUGHTS ON BEAMLINE CORRECTORS AND DIAGNOSTICS)

D. Johnson



SUCH THAT

① $\text{INTENSITY}_{OUT} = \text{INTENSITY}_{IN}$

② $\text{EMITTANCE}_{OUT} = \text{EMITTANCE}_{IN}$

IN REALITY ONE TRYS TO MINIMIZE LOSSES AND EMITTANCE GROWTH DUE TO MIS MATCHES BETWEEN THE BEAMLINE AND ACCELERATOR 2.

(i.e) $\Delta\epsilon_{TOTAL} = \Delta\epsilon_{\substack{\text{position}\\\text{error}}} + \Delta\epsilon_{\substack{\text{dispersion}\\\text{error}}} + \Delta\epsilon_{\substack{\text{Amplitude}\\\text{function}\\\text{error}}}$

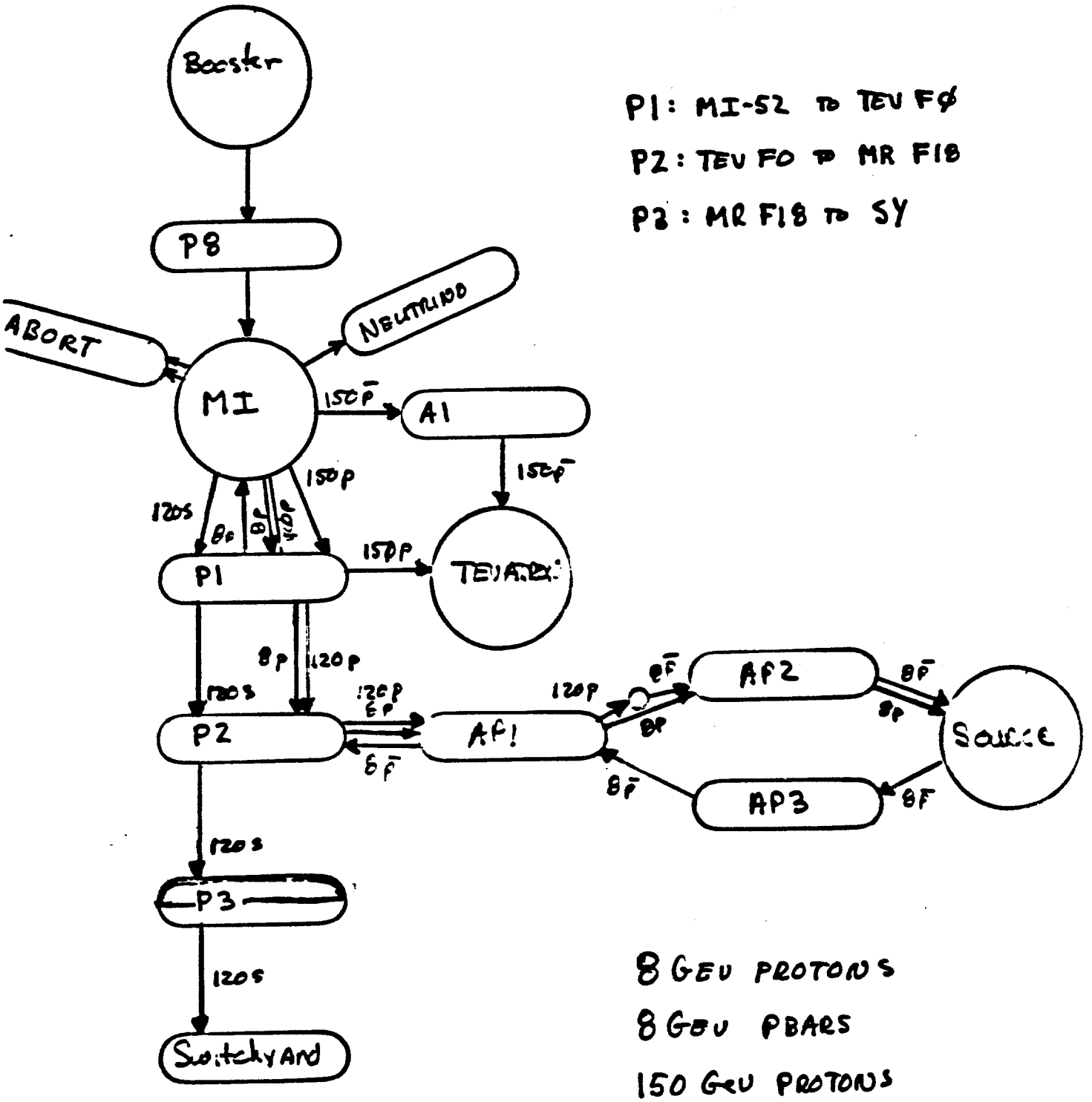
FOR THE MI TO TEVATRON, I BELIEVE WE ARE TRYING TO REACH 5% OR KEEP

$\Delta\epsilon = 1\pi$ FOR 20π beams.

IN ORDER TO ACCOMPLISH THESE GOALS THE TRANSPORT LINE NEEDS TO HAVE <u>DIPOLE CORRECTORS</u> (IGNORING ANY OTHER HIGHER ORDER CORRECTORS) AND THE APPROPRIATE <u>DIAGNOSTICS</u> TO MEASURE BEAM PARAMETERS AND DETERMINE THE EXTENT OF ANY MIS MATCHES - IF ANY.

4/8/92

BEAMLINES WE ARE TALKING ABOUT:



P1: MI-52 TO TEV FØ

P2: TEV FO TO MR F18

P3: MR F18 TO SY

8 GEV PROTONS

8 GEV PBARS

150 GEV PROTONS

150 GEV PBARS

120 GEV PROTONS

120 GEV SLOW

TO ASSURE CONDITION 1 IS MET WE NEED THE ABILITY TO MEASURE BEAM POSITION, INTENSITY, AND LOSSES.

Beam Position Monitors - will serve to give position and intensity information

CURRENT PLANS ARE TO UTILIZE SURPLUS BPM'S (AND ELECTRONICS) FROM MR.

EACH QUAD IN THE BEAMLINES WILL HAVE ITS VERY OWN BPM. TOTAL NUMBERS CAN BE ESTIMATED BY LOOKING AT CURRENT QUAD COUNTS (D. HARDING)

P8 GEV	51 +
P1	14 +
P2	8 +
P3	32 +
A1	14 +
ABORT	2 +
	121 quads + A FEW MORE

THERE WILL NEED TO BE A FEW SY TYPE FOR THE SLOW SPILL—THE NUMBER AND LOCATION ARE NOT YET DETERMINED BUT WILL BE PROBABLY LIMITED TO THE LINE P3 AND (P1?)

Beam Loss Monitors -

will be located at each quad and transfer point and be recycled from MR.

NOTE: IF THESE ARE USED IN THE MI WE WILL PROBABLY WANT/NEED TO BUILD A FEW MORE

NOTE: ON SOME BEAMLINES (LIKE P3) WE MAY WANT TO REDUCE THE NUMBER OF BLM'S FROM THE 1 PER QUAD NUMBER.

TO ASSURE CONDITION 2 IS MET REQUIRES THE ABILITY TO MEASURE BEAM PROFILES AT STRATEGIC LOCATIONS ALONG THE BEAMLINE AND ACCELERATOR 2.

- POTENTIAL CHOICES FOR MEASURING PROFILES INCLUDE:

  MULTIWIRES: 12 exist IN 8GeV line
  8 exist IN MR
  some may be broken & no spares

  SEM's: as used in $\bar{p}$: no SPARES
  currently exist

  good sensivity range w/ VARIABLE WIRE SPACINGS.

  SWICS: as USED IN SY
  no SPARES so ALL NEW?

- IT WOULD BE NICE IF WE COULD USE THE SAME TYPE OF PROFILE MONITORS IN ALL THE BEAMLINES LISTED IN THE 2nd TRANSPARIENCY.

- NUMBERS REQUIRED FOR EACH BEAMLINE (LATER)

- WHERE SHOULD PROFILE MONITORS BE PLACED? AND IS THERE ROOM?

- HOW DO YOU DECIDE WHERE THEY GO?

- THERE ARE 2 PRIMARY USAGES FOR THE PROFILE MONITORS, NAMELY EMITTANCE MEASUREMENT AND AMPLITUDE FUNCTION MEASUREMENT.

CURRENTLY, WE HAVE MULTIWIRES IN 8 GeV LINE WHICH ARE USED ROUTINELY FOR MEASUREING/MONITORING ϵ and $\delta p/p$ FROM BOOSTER AND MEASURING DILUTION DUE TO AMPLITUDE FUNCTION MISMATCHES BETWEEN THE 8 GeV LINE AND MAIN RING.

EMITTANCE MEASUREMENT:

$$\sigma_{calc}(i) = \frac{\beta_i \epsilon_N}{6\pi(\gamma\beta)} + \eta_i^2\left(\frac{\sigma_p}{p}\right)^2$$

$$\chi^2 = \sum_{i=1}^{n}\left(\sigma_{meas}(i)^2 - \sigma_{calc}(i)^2\right)^2$$

for non-zero η $i \geq 2$ [minimize χ^2 FITTING FOR ϵ_N & $\frac{\sigma_p}{p}$]

AMPLITUDE FUNCTION MISMATCH ($\Delta\epsilon_{\text{Amplitude function}}$)

- PROVIDE A QUANTATIVE MEASURE OF MISMATCH BETWEEN BEAM & BEAMLINE AT A REFERENCE LATTICE POSITION.

- THIS INVOLVES MEASURING PROFILES (σ_{wire}'s) AT SOME NUMBER OF LOCATIONS IN THE BEAMLINE AND RING AND CALCULATING THE LATTICE FUNCTIONS AT A COMMON REF POINT. THEN THE DILUTION FACTOR

$$D = \frac{\epsilon}{\epsilon_0} = \frac{1}{2}\left(\beta_1\gamma_2 + \beta_2\gamma_1 - 2\alpha_1\alpha_2\right)$$

where 1 is ~~beam~~ ref point lattice functions calculated by propigating beamline MEASUREMENTS AND 2 by RING σ_w MEASUREMENTS.

DIAGNOSTICS 4/8/9. (6

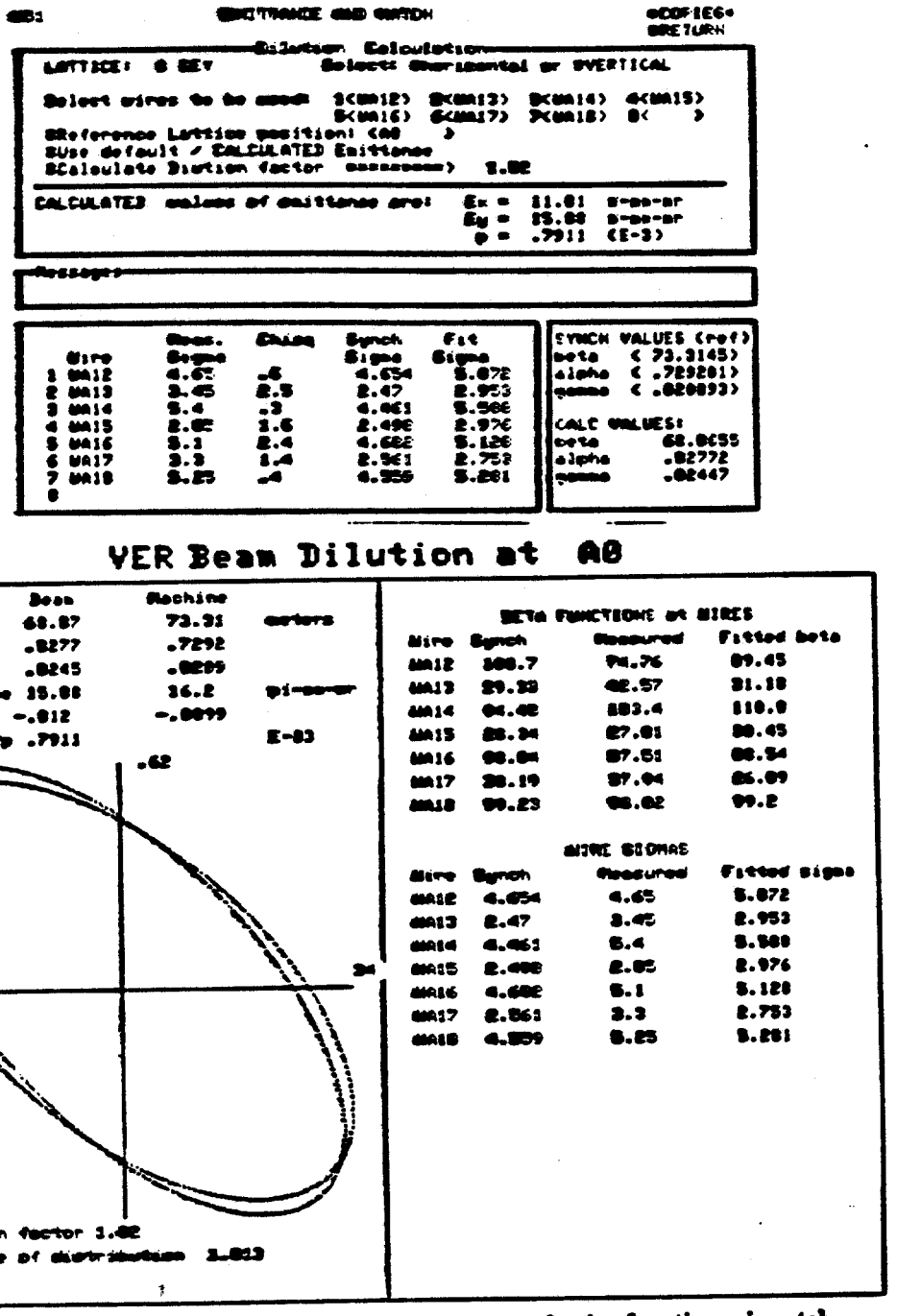
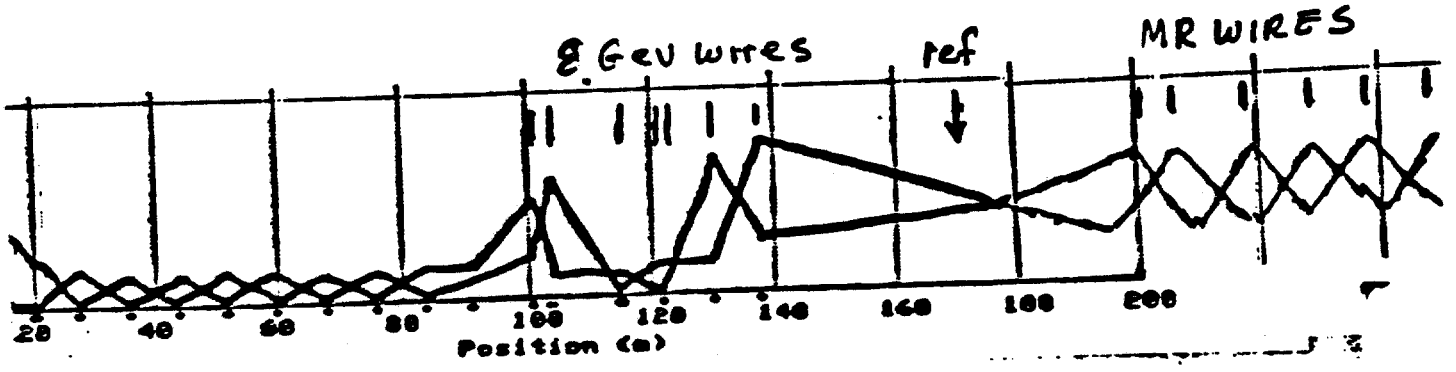


Figure 6: Results of dilution calculation due to a lattice function mismatch between the 8 Gev line and Main Ring. The reference location for computing the match is taken to be A0.



- WHERE SHOULD THE EMITTANCE BE MEASURED
  - 8 GeV PROTON LINE (PB)
  - P1 LINE (FOR 150 GeV, 120 GeV p's & 8 GeV $\bar{p}$'s)
  - A1 LINE FOR 150 GeV $\bar{p}$'s

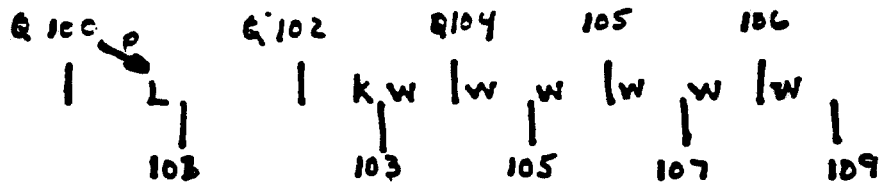
FOR HOR EMITTANCE AND $\frac{\sigma_p}{p}$ MEASUREMENT TWO WIRES ARE NEEDED AT LARGE β WITH $\frac{\sigma_p}{p} = 0$ at one and large at the other.

ONLY A SINGLE VER WIRE IS NEEDED

(THESE WIRES COULD POTENTIALLY BE PLACED TO BE USED IN CONJUNCTION WITH DILUTION MEASUREMENTS)

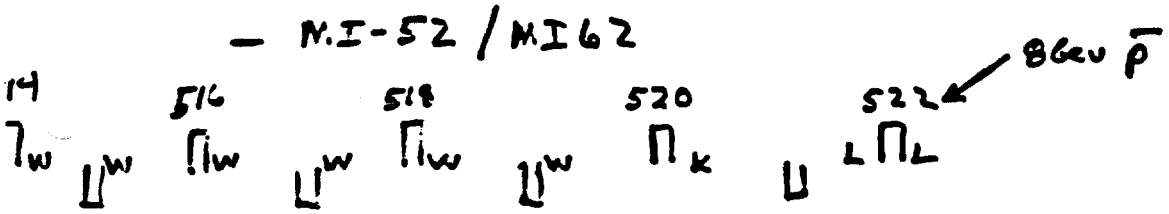
- THIS GIVES US A TOTAL OF 9 WIRES FOR THE 3 LINES (IF THEY ARE TO BE DEDICATED FUNCTION MONITORS. 9

- WHERE WOULD WIRES USED FOR MATCHING BE POSITIONED?
  - 8 GeV LINE — IS THERE ROOM IN MI?



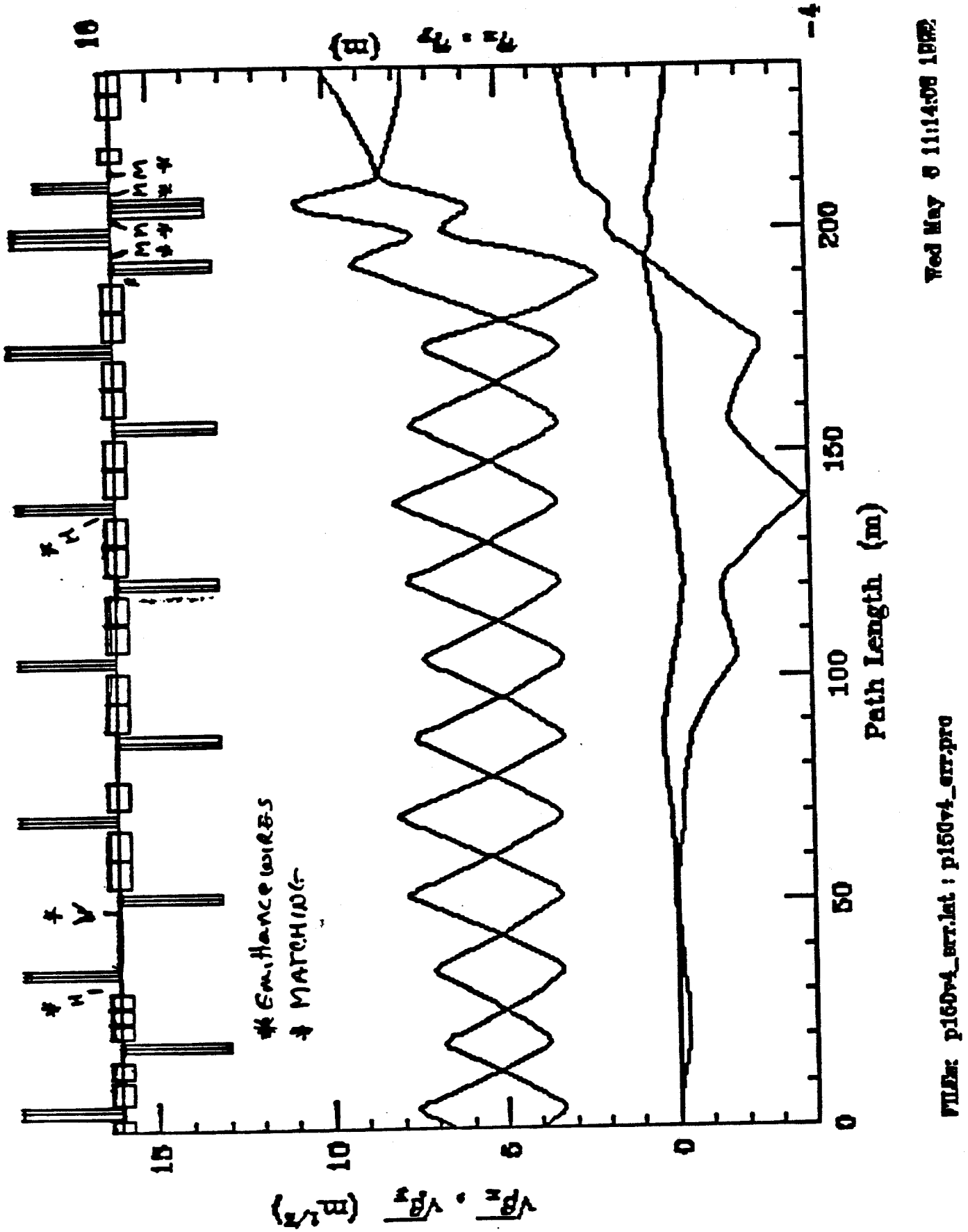
12

- 150 LINE A1/P1 (SEE NEXT SLIDE) 8
- P3 (120 GeV $\bar{p}$ prod) 3 WIRES LOCATED AT F15, F16, F17 3
- M.I-52 / MI62



12

TOTAL PROFILE MONITORS ≈ 44 (LARGE) 44


Path Length (m)
$\sqrt{\beta_x} \cdot \sqrt{\beta_y}$ (m$^{1/2}$)
$\eta_x \cdot \eta_y$ (m)
* Emittance wires
* MATCHING
Wed May 6 11:14:08 1992
FILE: p160v4_arr.lat : p160v4_arr.pro

DIPOLE CORRECTORS (TRIMS) ARE NEEDED TO:

① CORRECT FOR INSTALLATION MISALIGNMENTS

② CONTROL POSITION/ANGLE THROUGH POTENTIALLY TIGHT APERTURES
i.e. LAMBERTSONS

③ CONTROL POSITION/ANGLE AT INJECTION KICKER LOCATIONS

④ CENTRAL TRAJECTORY CONTROL

① TO DETERMINE CORRECTOR STRENGTHS REQUIRED TO COMPENSATE FOR MISALIGNMENTS THE MISALIGNMENTS WILL BE INCLUDED IN LATTICE FILES (MAD, TRANSPORT) AND CORRECTOR STRENGTHS DETERMINED

THE MAGNITUDE OF MISALIGNMENT ERRORS ASSUMED ARE:

INCLUDE SAME TOLERANCES FOR BOTH DIPOLES AND QUADS:

DX = DY = .25 mm

DS = 1/4" (currently have used 1/16")

ΔROLL = .5mr

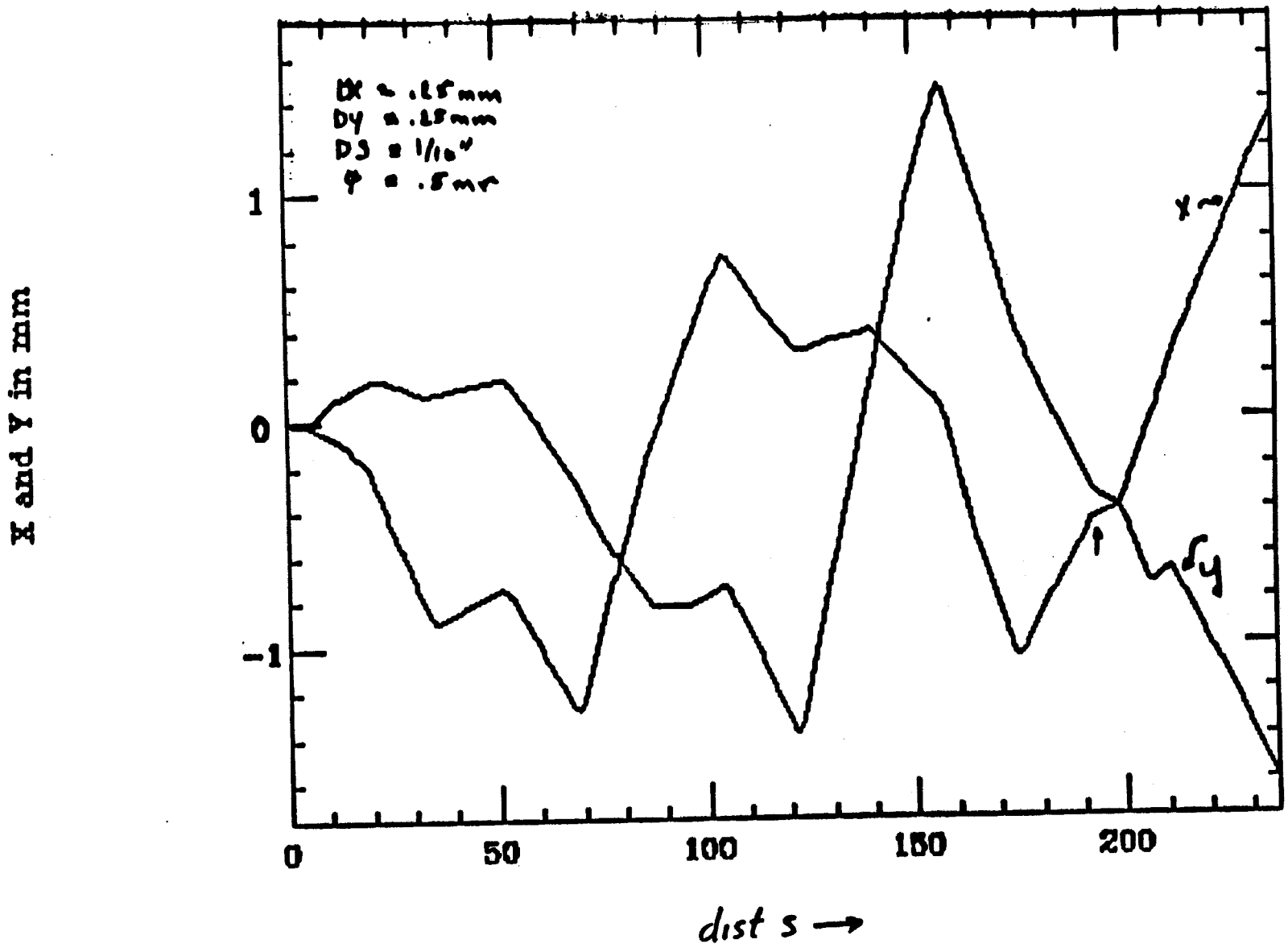
Δ PITCH = .1mr (not included yet)

INITIAL TEST OF THESE ERRORS ON THE P1 (MI-52 TO F0) LINE SHOWS LESS THAN 2mm errors IN CENTRAL TRAJECTORY.

② The potentially TIGHT APERTURES ARE

- INJECTION (MI) LAMBERTSON LOCATED UPSTREAM OF Q102
- P150 EXTRACTION LAMBERTSONS LOCATED ON EITHER SIDE OF Q522 (ALSO FOR $\bar{P}$ INJ)
- A150 EXTRACTION LAMBERTSONS LOCATED ON EITHER SIDE OF Q620

P160 ORBIT ERROR FOR MISALIGNMENTS



- TEV INJECTION LAMBERTSONS

- SWITCHING B3 MAGNET (FOR AF! or SLOW) LOCATED DOWNSTREAM OF F17 QUAD.

- SWITCHING B3 (ROLLED) USED FOR THE SWITCHYARD CONNECTION.

REQUIRED STRENGTHS FOR THESE FUNCTIONS HAVE NOT YET BEEN DETERMINED BUT IT IS EXPECTED TO BE NO MORE THAN 5 mm.

(3) TO MINIMIZE THE DILUTION DUE TO POSITION/ANGLE ERRORS AT INJECTION KICKERS.

$$\frac{\Delta \epsilon}{\pi} = 3(\gamma\beta)\,\frac{\Delta X_{eq}^2}{\beta}$$

where $\Delta X_{eq}^2 = \Delta X^2 + (B\Delta X' + \alpha \Delta X)^2$

For 8 GeV this is ~10 time less sensitive then for 150 GeV.

- TYPICAL LATTICE FUNCTIONS AT INJ. KICKERS

	β	α	ΔX_{eq}^2 ($1\pi\Delta\epsilon$)
MR AØ	~ 85	.2	3.03
MI Q103 (P)	~ 50	-2.	1.75
MI Q520 (P̄)	~ 60	-2.	2.12
TEV F17	~ 90	1.7	0.186
TEV E49	~ 90	.1	0.186

(4) CENTRAL TRAJECTORY CONTROL

THE MAXIMUM EXCURSIONS FOR 8/150 GEV LINES HAVE NOT BEEN DETERMINED. HOWEVER, EXPECTED REQUIREMENTS THROUGHOUT THE BEAMLINE SHOULD BE ON THE ORDER OF A FEW MM.

THIS TOPIC NEEDS MORE DISCUSSION.

POTENTIAL CORRECTOR (TRIM) STRENGTHS

- USE EXISTING MR CORRECTORS
- IN ADDITION TRIMS ON NEW LAMBERTS AND CMAGNETS AND EXISTING B3's.

MR CORRECTOR STRENGTHS

TYPE	G-m/a	$\theta[mr]_{8.9}$	$\theta[mr]_{150}$
NORMAL H	34.5	.118	.007
SHIMMED H	25.9	.089	.005
Double H	58.6	.20	.012
V	20.2	.067	.004

The MAXIMUM CURRENT IS 12 A (RAMPED)
7A (rms)

FOR SHIMMED H CORR AT 10 Amps & β_{ij} of 60m

ΔX_{max} (8GeV) = 53 mm
Δy_{max} (8GeV) = 40 mm

ΔX_{max} (150) = 3 mm
Δy_{max} (150) = 2.4 mm

CORRECTORS

- TRIM STRENGTHS AND POWER SUPPLY REQUIREMENTS FOR LAMBERTSONS AND C-MAGNETS HAVE NOT YET BEEN DETERMINED.

- MAXIMUM FIELD ON EACH IS ON ORDER OF 12KG. WITH A 1% TRIM CAPABILITY THIS WOULD GIVE US A .12 KG FIELD. (THIS WOULD BE ABOUT FACTOR 4 OVER THE SHIMMED H CORRECTOR).
- THESE REQUIREMENTS WILL BE DRIVEN BY DESIRED TUNING RANGE FOR POSITION/ANGLE AT INJECTION KICKERS.
- THE B3 TRIM IS ABOUT 1% FULL FIELD OR ~~ABOUT~~ .13 KG

LOCATIONS OF CORRECTORS IN BEAMLINES

- IN GENERAL EACH QUAD WILL HAVE ITS VERY OWN CORRECTOR.
- DETAILED LOCATION (OPTIMIZED) FOR CONTROL OF POSITION/ANGLE AT KICKERS SHOULD BE ORTHOGONAL BUT THIS IS NOT AN ABSOLUTE REQUIREMENT

  (SEE COMMENTS ON ALGORITHMS LATER)
- MR CORRECTORS REQUIRE ~ 14" SPACE
- 150 GeV LINE AVALIABLE SPACE AT QUADS

$A_{TYPICAL} = 46''$ $A_{MIN} = 33''$

- 8GeV LINE AVAILABLE SPACE (

Software 4/29

This discussion would not be complete without bringing up software requirements.

We will be trying to commission a new accelerator and 5 new beamlines.

So, we should have the software to permit easy (and automatic?) control of devices and diagnostics built around a compact set of algorithms.

WRT beamlines and injection
- auto steering and trajectory correction
- injection closure
- emittance measurements
- dilution measurements

Currently, there are many application programs which peform these functions:

200 MeV steering
200 MeV emittance
8 GeV steering
8 GeV emittance / dilution
8 GeV MR closure
150 GeV TEV injection closure
$\bar{p}$ closure program

And new software is being developed for 400 MeV transport line and 200-400 MeV transition piece in the linac.

- It is not too early to start thinking about requirements and algorithms for MI beamlines.

SUMMARY

1. INITIAL THOUGHTS ON CORRECTOR TYPES INDICATE THAT MR CORRECTORS CAN BE UTILIZED FOR ALL BEAMLINES AND NO OTHER CORRECTORS TYPES SHOULD BE NEEDED.

2. THERE APPEARS TO BE SUFFICIENT SPACE FOR CORRECTORS WITH DETAILED LOCATIONS TO BE DETERMINED

3. TRIM REQUIREMENTS FOR C-MAG/LAMB NEED TO BE DETERMINED.

4. INITIAL/POTENTIAL LOCATIONS FOR PROFILE MONITORS HAVE BEEN LOOKED BUT MORE DETAILED WORK IS NEEDED.

JIAN PING SHAN

γ_t - Jump in the Main Injector *

J. Shan

May 8, 92

Outline

- Purpose
- γ_t - Jump Scheme
- Implementation in Main Injector

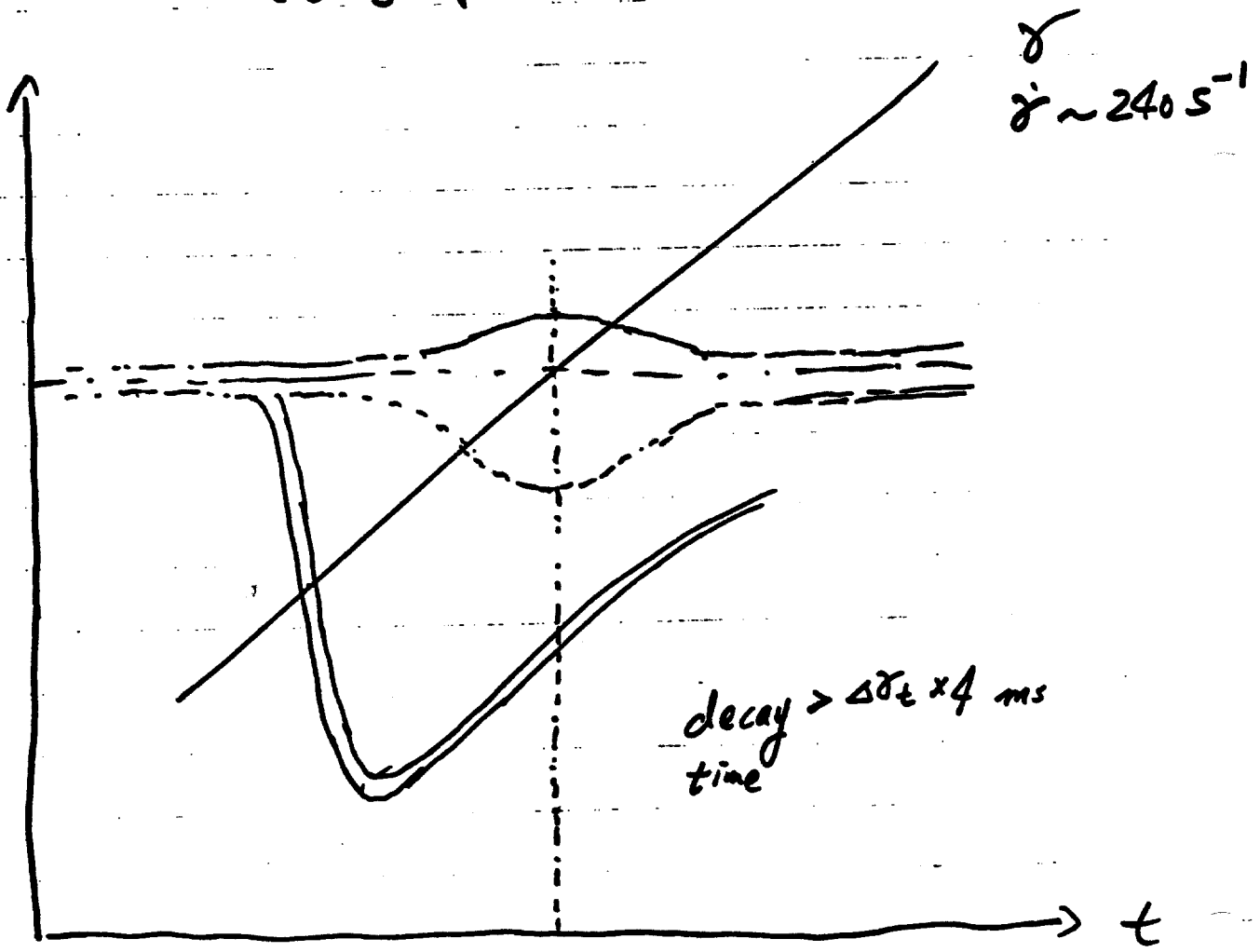
* for Main Injector Corrector Workshop

Purpose

Transition Problem (longitudinal emittance dilutio
possibly beam loss) due to

- Johnsen effect
- Space Space Mismatch
- Microwave Instability ...

CAN BE SOLVED BY
γ_t - JUMP SCHEME



γ_t - Jump Scheme

Regular FODO lattice $\gamma_t \sim Q$ tune

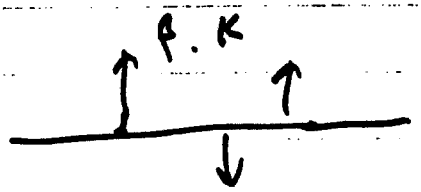
Here we want to pulse some quads such that

$$\Delta\gamma_t \; : \; 1 \sim 2$$

but $\Delta Q = 0$

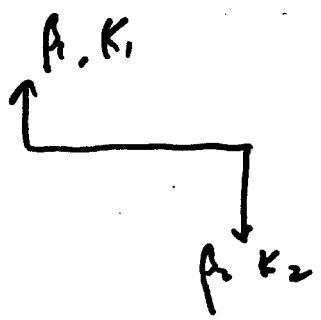
Also D_{max} (dispersion), $\beta_{x\,max}$, $\beta_{y\,max}$ } not too big!

Golden Rule:



$$\Delta Q = \frac{1}{4\pi}\sum \beta_i K_i$$

(First order)



If $\boxed{\begin{cases} \beta_1 K_1 + \beta_2 K_2 = 0 \\ \sin\Delta\mu = 0 \Rightarrow \Delta\mu = n\pi \end{cases}}$

THEN

$\Delta Q = 0$

β @ pulsed quads unchanged

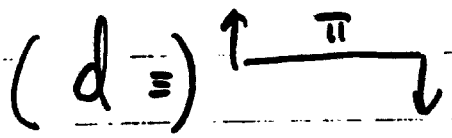
$n <$ even: ~~not~~ $\Delta\gamma_t$ not sensitive

$n <$ odd: good for $\Delta\gamma_t$

$n - 1$

π - Doublet

CHANGE OF DISPERSION IS LINEAR TO PERTURBATION



$$\vec{D}^* = (1+M)\vec{D}$$

$$M_{ij} = -K_j\, m_{ij}$$

"closed orbit distortion" function:

$$m_{ij} = \frac{\sqrt{\beta_i \beta_j}}{2\sin\pi Q}\sin(\pi Q - |\mu_i - \mu_j|)$$

$$\boxed{C_0\,\Delta(\gamma_t^{-2}) = -\sum K_i D_i^2 + \sum_{i,j} K_i K_j m_{ij} D_i D_j}$$

$\Delta\gamma_t \propto \Delta(\gamma_t^{-2})$ linear + quadra.

π Doublet ⑨

Normalized Dispersion $\frac{D}{\sqrt{\beta_x}} = \text{const}$

Linear Term $\sum K_i D_i^2 \sim \sum K_i \beta_i = 0$

BAD NEWS!

$\therefore$

$$\Delta(\gamma_t^{-2}) = \frac{1}{2 C_0 \sin \pi Q} \sum_{i,j} D_i^2 \beta_j K_i K_j \cos(\pi Q - |\mu_i - \mu_j|)$$

Further more if $D_i = D_j = D$, $\beta_i = \beta_j = \beta$

$\Rightarrow |K_i| = |K_j|$

$$\boxed{\Delta(\gamma_t^{-2}) = \frac{D^2 \beta K^2}{2 C_0 \sin \pi Q} \sum_{i,j} S_{ij} \cos(\pi Q - |\Delta\mu_{ij}|) \propto D^2 \beta_x K^2}$$

$S_{ij} = \pm 1$

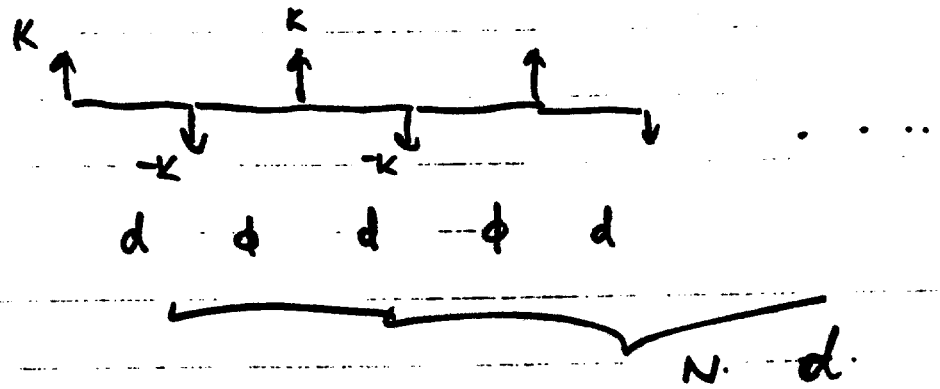
Pulsed quads located (near) @ F quads where D, β_x are max.

It seems $\Delta\gamma_t^{-2} \propto K^2$ Unipolar

Is Bipolar possible?

A Chain of π Doublets

N: number of doublets



Hope $\quad s_{ij} \cos(\pi Q - |\Delta\mu_{ij}|)$ same sign

$\phi = \pi$ good choice

every term identical $\cos \pi Q$

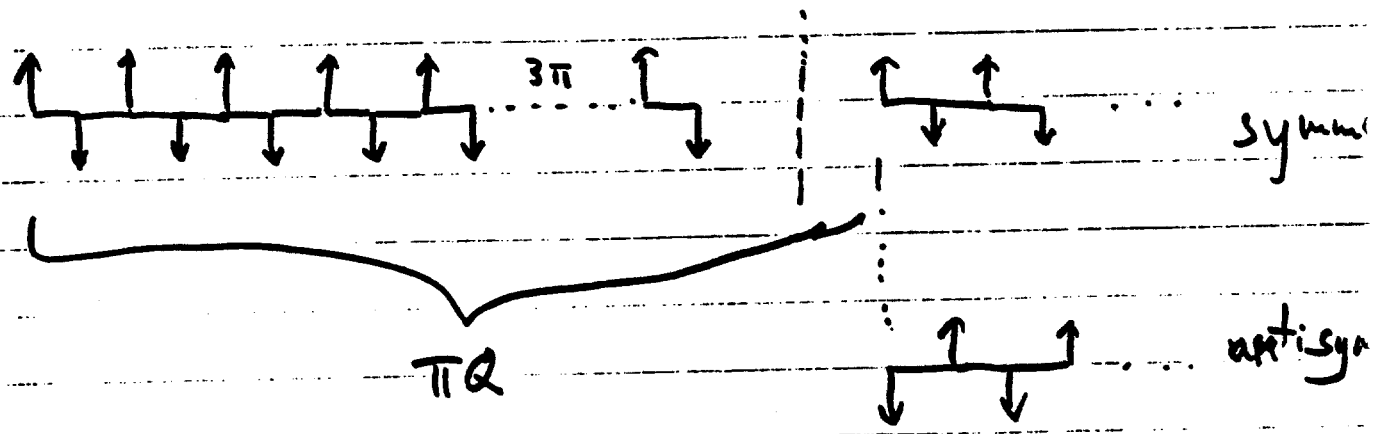
$$(2N)^2 \cos \pi Q = 4N^2 \cos \pi Q$$

MI Lattice

has a superperiod of 2

with $2 \times (19 + 6)$ normal cells

(90° Phase Advan



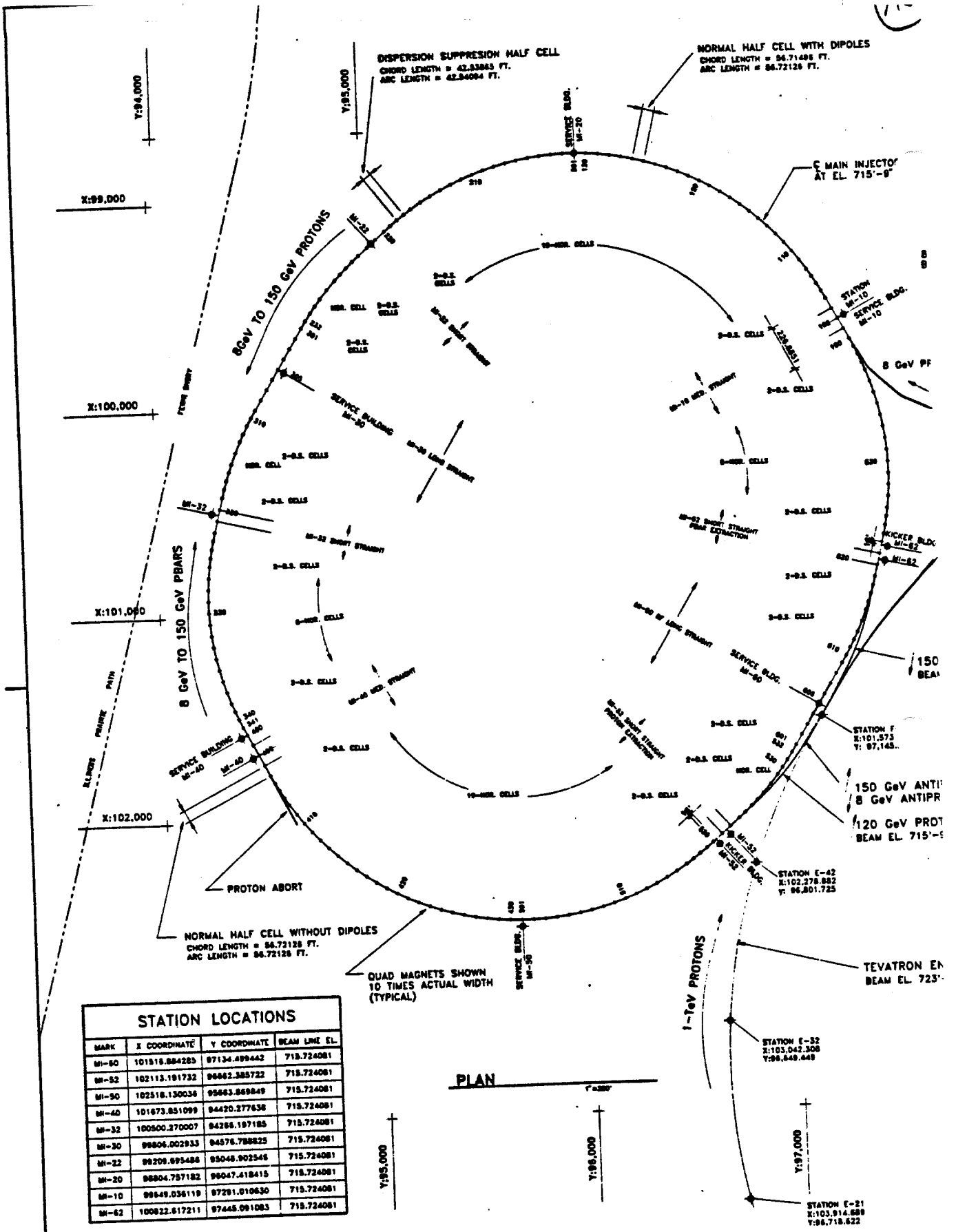
Self term $2 \times 4N^2 \cos \pi Q$

Cross term $\pm 2 \times 4N^2 \cos 0$

+ : symmetric

− : antisymmetric

$$\Delta\left(\gamma_t^{-2}\right) = \frac{D^2 \beta K^2 \cdot 4N^2}{C_0 \sin \pi Q} \left(\cos \pi Q \pm 1 \right)$$



STATION LOCATIONS

MARK	X COORDINATE	Y COORDINATE	BEAM LINE EL.
MI-60	101318.884285	97134.499442	715.724081
MI-52	102113.191732	96862.385722	715.724081
MI-50	102518.130036	95663.869849	715.724081
MI-40	101673.851099	94420.277638	715.724081
MI-32	100500.270007	94266.197185	715.724081
MI-30	99806.002933	94576.788825	715.724081
MI-22	99209.695486	95048.902545	715.724081
MI-20	98804.757182	96047.418415	715.724081
MI-10	99649.036119	97291.010630	715.724081
MI-62	100822.617211	97445.091083	715.724081

MAIN INJECTOR

REV	DATE	DESCRIPTION
		REVISIONS

CDR-10

~~Symmetric~~

$$\Delta(\gamma_t^{-2}) = \frac{4D^2\beta K^2 N^2}{C_0} \begin{cases} ctg\,\frac{\pi}{2}Q & \text{symmetric (S)} \\ -tg\,\frac{\pi}{2}Q & \text{antisymmetr (A)} \end{cases}$$

MI: $Q = 26.4$ $\quad \frac{\pi}{2}Q = 13.2\pi$

$$\begin{cases} tg\,13.2\pi = tg\,1.2\pi = tg\,0.2\pi = 0.73 > 0 \\ ctg\,13.2\pi = \frac{1}{tg\,13.2\pi} = 1.38 \end{cases}$$

Unipolar: Symmetric is favored for MI

MI: $D = 1.7\,m$, $\beta = 50\,m$, $N = 6$, $C_0 = 3300$

$$\Delta(\gamma_t^{-2}) = \frac{4 \times 1.7^2 \times 50 \times 6^2 \times K^2}{3300} \times 1.38 \sim 6.5\,K^2 \times 1.3$$

If $\Delta\gamma_t$ small

$$\Delta(\gamma_t^{-2}) \approx \frac{-2\Delta\gamma_t}{\gamma_t^3} = 6.5\,K^2 \times 1.38$$

$$\Delta\gamma_t = -3.2 \times 21.6^3\,K^2 \times 1.38 = -3.3 \times 10^4\,K^2 \times 1.38$$

$K = 6 \times 10^{-3}\,m$ $\quad \Delta\gamma_t = -1.63 \xrightarrow[\text{higher order}]{} \frac{-1.63}{0.85} \sim -2.0$

		γ_t	$\Delta\gamma_t$	$\beta_{x\,max}$	$\beta_{y\,max}$	D_{max}
	Nominal	21.59		59.8	63.2	1.98
7.5%	(S, 5)	20.18	−1.41	63.7	64.0	7.08
	(A, 5)	22.21	+0.62	86.2	67.7	5.76
	(S, 5)*	20.42	−1.17	59.8	65.3	6.54
	(A, 5)*	22.10	+0.51	60.8	65.7	5.45
	(S, 6)	19.61	−1.98	64.5	63.9	7.91
	(A, 6)	22.34	+0.75	86.8	66.7	6.43
5%	(S, 6)	20.62	−0.97	60.7	62.7	5.94
10%	(S, 6)	18.45	−3.14	71.5	64.4	9.80
		22.25	+0.66	134.3	68.6	2.38
		20.86	−0.73	141.3	69.0	2.68

*: end magnet strength → one half

S: Symmetric

A: antisymmetric

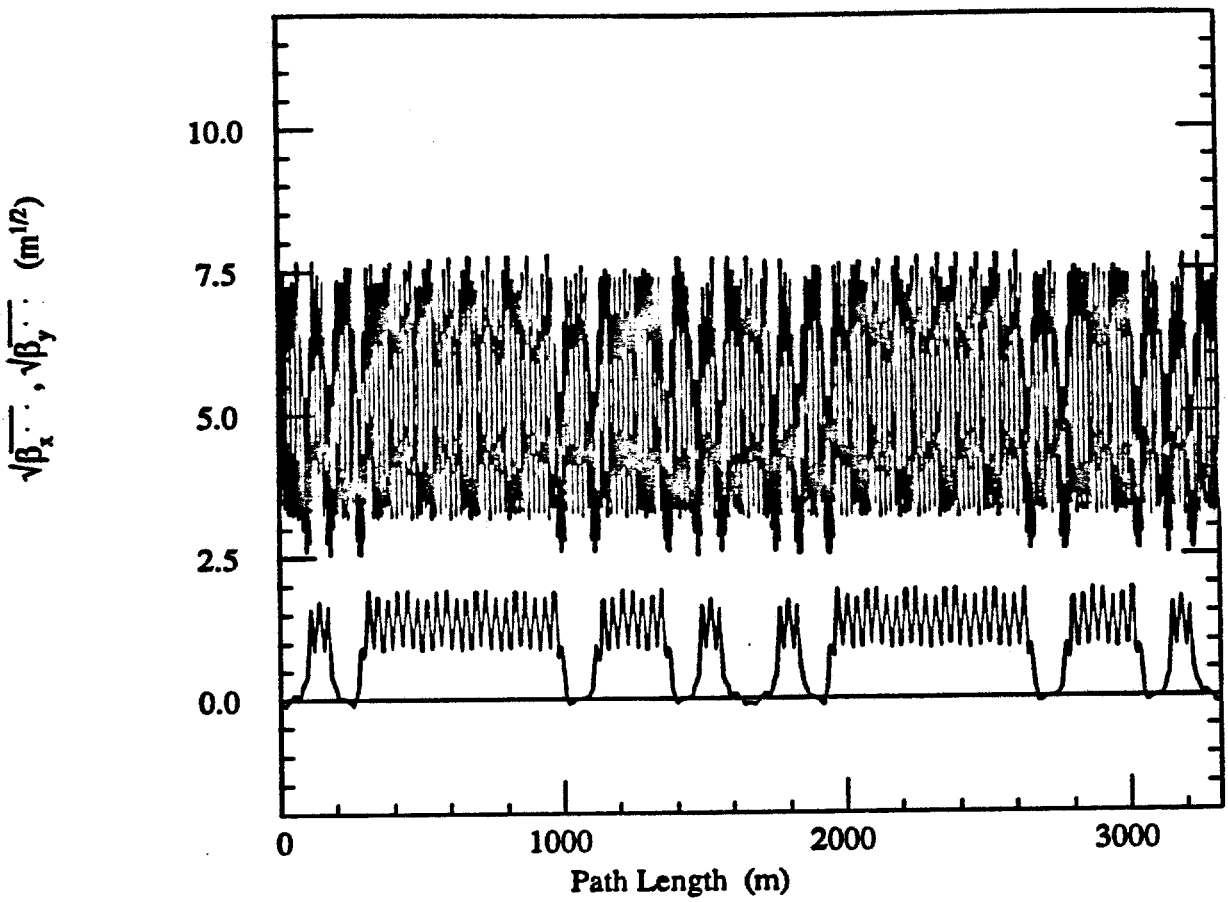
5, 6: number of doublets in half ring

Magnet and Power Supply

$\Delta\gamma_t = -2.0 \Rightarrow \oint K_1 \, dl = 6\times10^{-3}\ m^{-}$

Effective Length L	(m)	0.20	0.15
Gradient K_1	(m^{-2})	0.03	0.04
$B' = B\rho \cdot K_1 = \frac{\gamma_t}{3} K_1$	(Tesla/m)	2	8/3
Radius R	(m)	0.05	0.05
$NI = \frac{B' R^2}{2\mu_0}$	(A)	2500	3300

		adiabaticity
		> 0.4 ms (40t.
Rise Time	as short as possible	< 1 ms
Decay Time	$> 4 \cdot \Delta\gamma_t$ (ms)	



Thu May 7 21:5..43

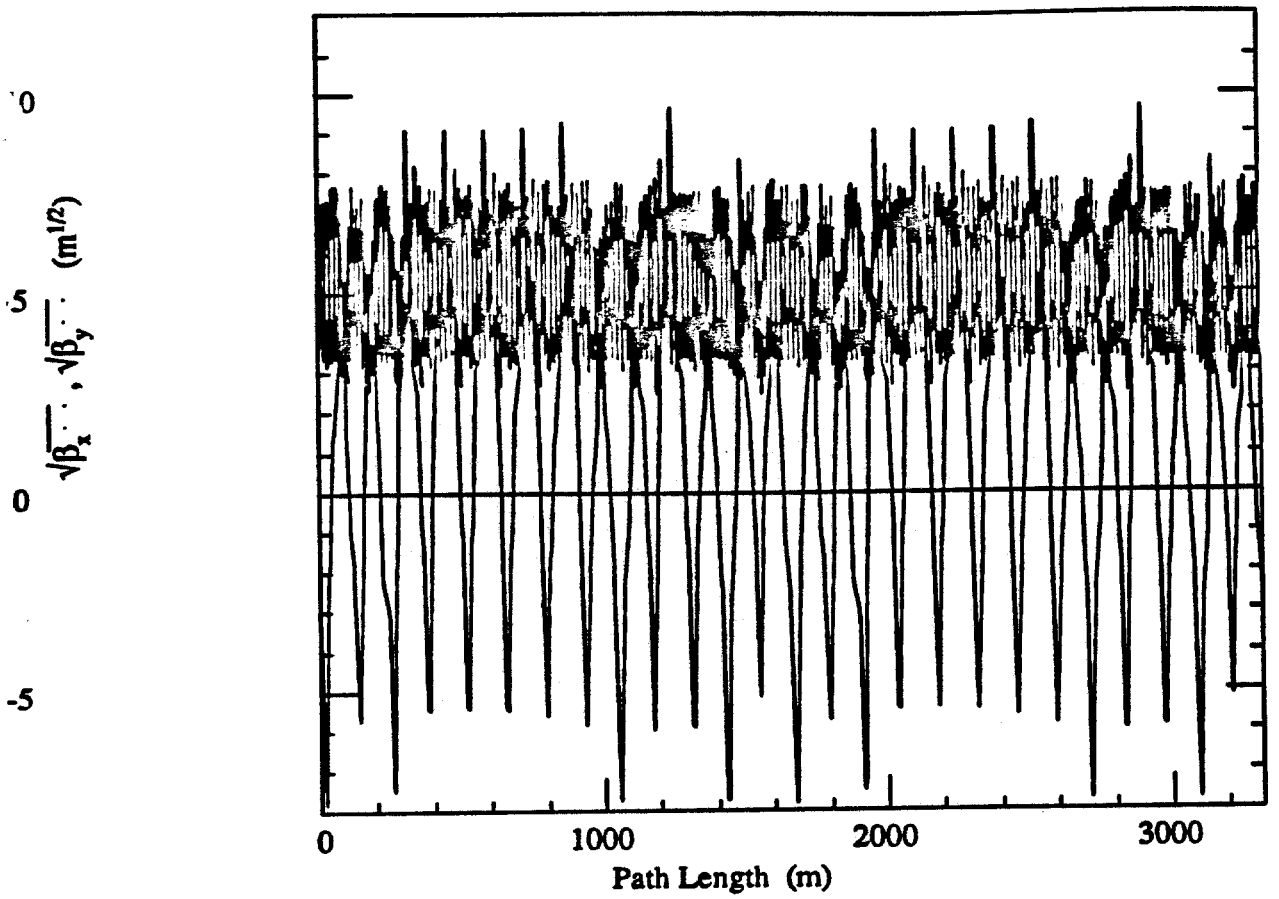
Reference Lattice MI-17

$Q_x = 26.41$, $Q_y = 25.91$

$\gamma_t = 21.59$, $D_{max} = 1.98$ m

$\beta_{x\,max} = 59.8$ m $\beta_{y\,max} = 63.2$ m

CASE 6



Thu May 7 21:01:52

24 quads (each) with 10% of normal quad strength

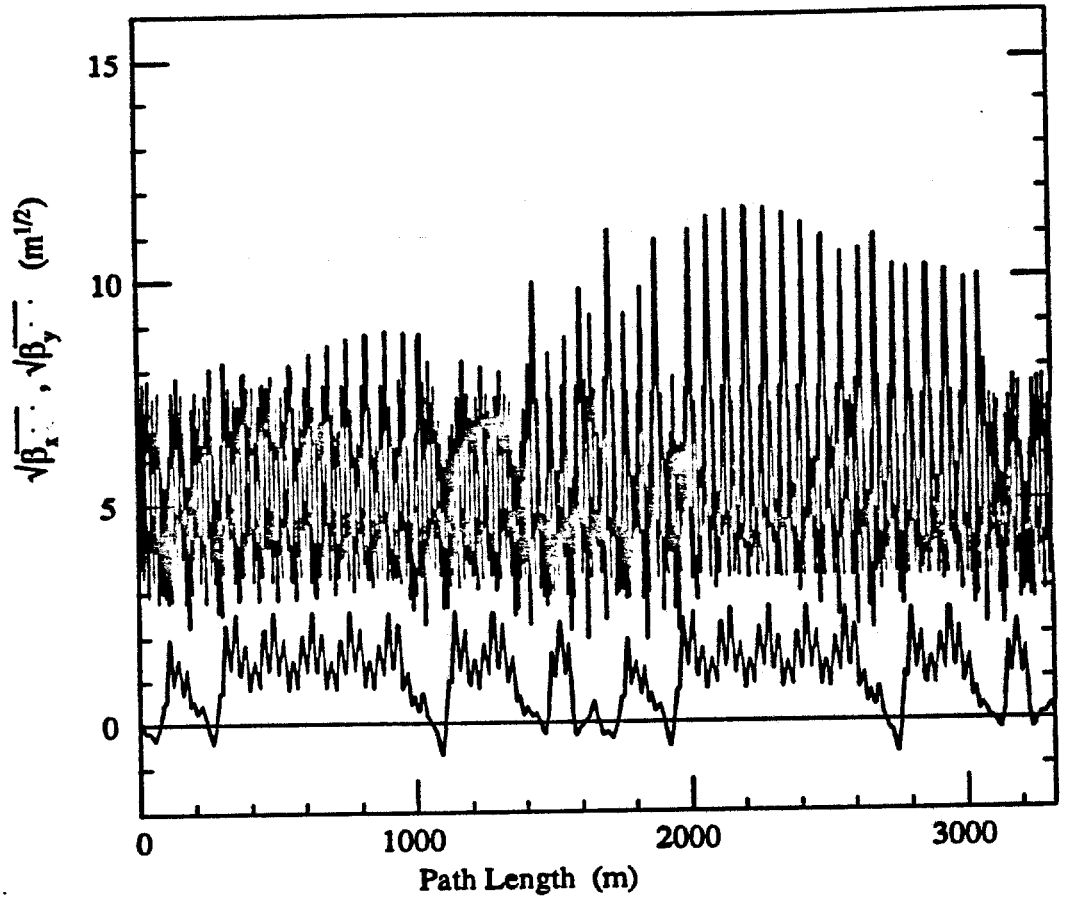
$\Delta\gamma_t = -3.14$

$\beta_{x\,max} = 71.5$ m

$\beta_{y\,max} = 64.4$ m

$D_{max} = 9.80$ m

CASE (10)



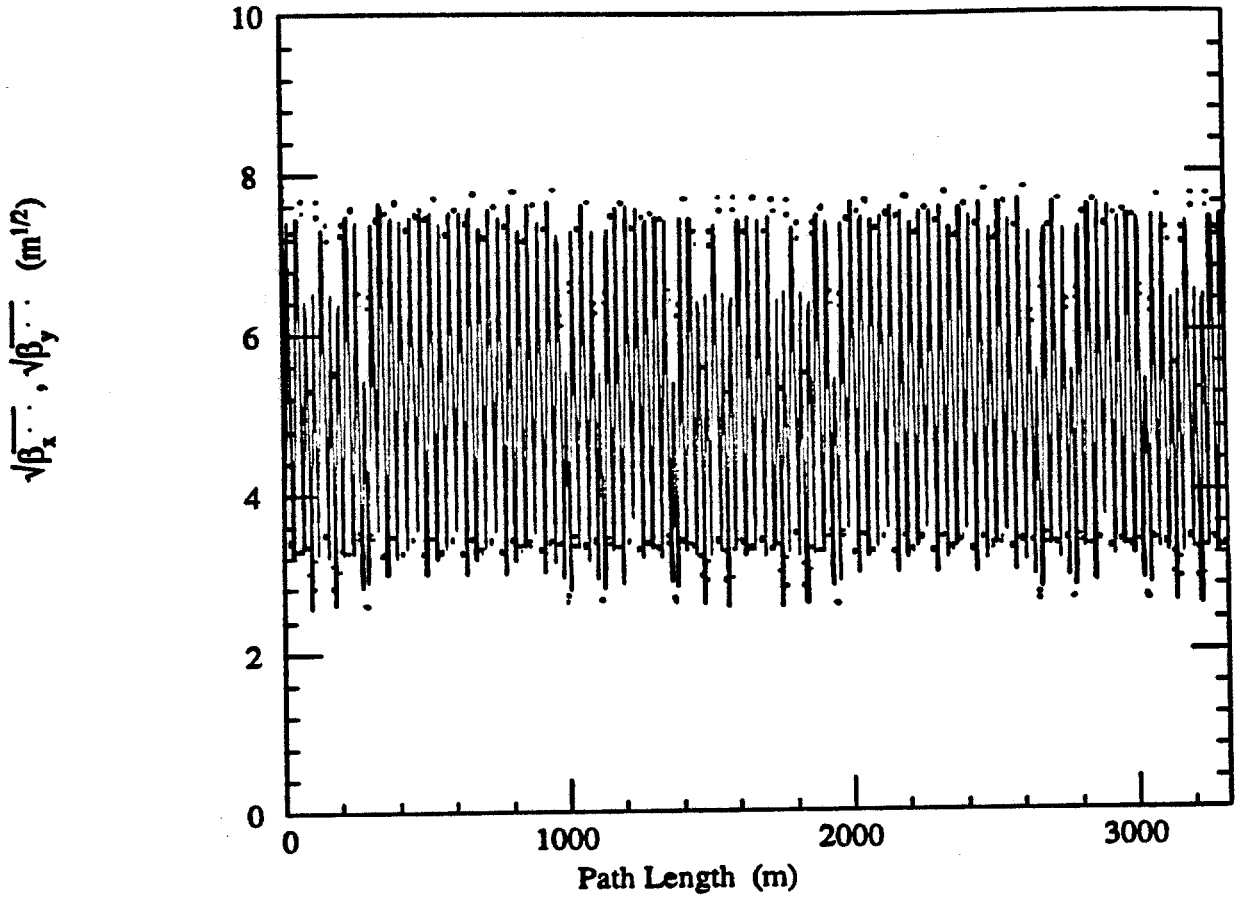
Mon May 4 17: 3

Matched γ_t jump

$\gamma_t = 20.86$ $\quad \Delta\gamma_t = -0.73$ $\quad \beta_{x\,max} = 141.3\,m$ $\quad \beta_{y\,max} = 69.0\,m$

$D_{max} = 2.68\,m$

CASE ①



Thu May 7 16:26:21

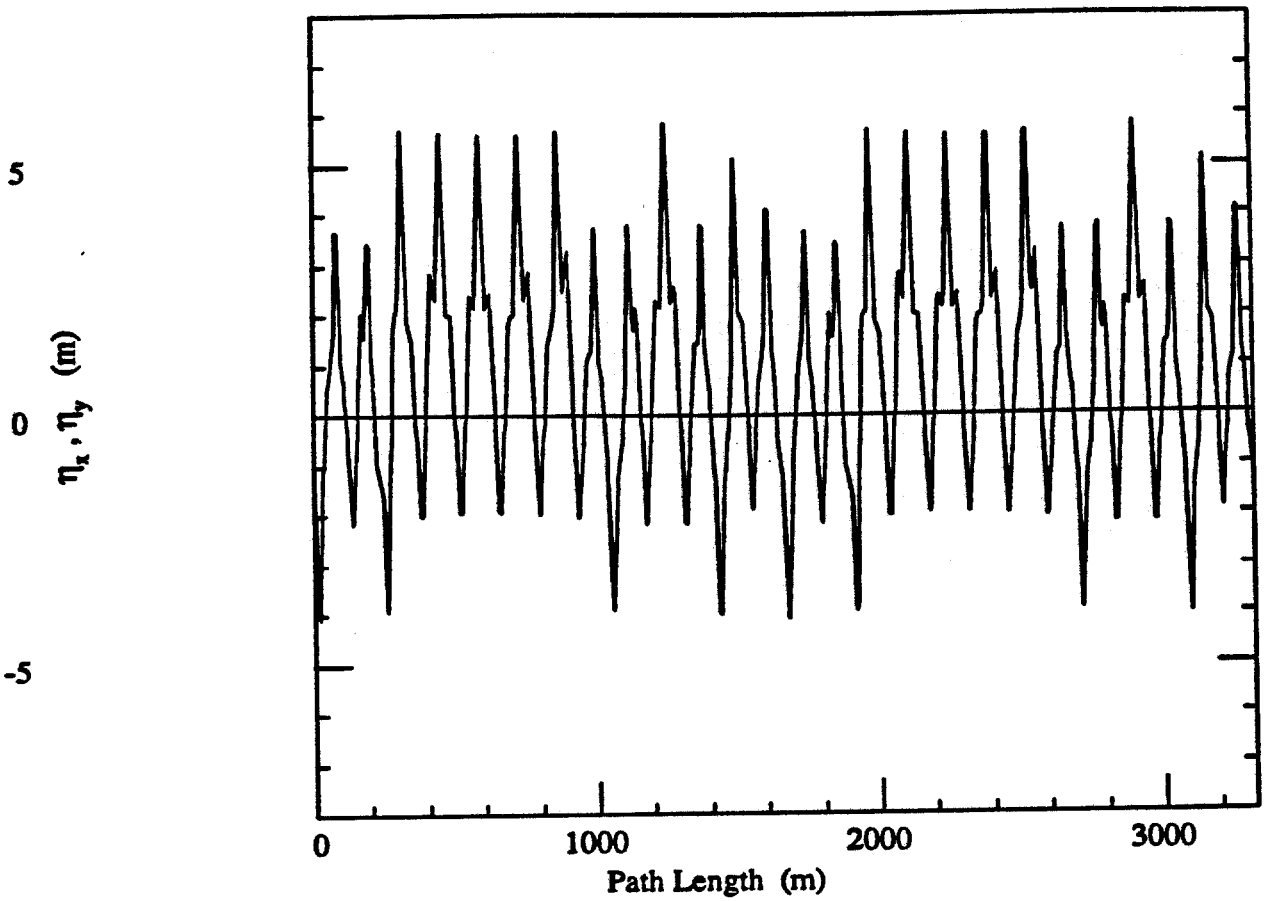
24 pulsed quad. (5% of normal quad strength)

$\Delta\gamma_t = -0.97$

$\beta_{x_{max}} = 60.7$

$\beta_{y_{max}} = 63.7$

CASE (7)



Thu May 7 16:26:

$\Delta\gamma_t = -0.97$

$D_{max} = 5.94$ m

References.

Booster

L. Teng (1970) FN-207

CPS

W. Hardt (1974) Int. Conf on HEA, Stanford

Booster

W. Merz et. al. (1987)

MI

S. Holmes (1989)

S. Peggs & A. Rosacz & F. Hartfouch (1990) Comparison of γ_t schemes for

General:

Risselada (1990) "Design of Quadrupole Schemes to Modify GAMMA TRANSITION"

Conclusion:

- 24 pulsed quads. (12F + 12D) with single Power Supply are ~~possible~~ able to change γ_t

  $\Delta\gamma_t$ $-1 \sim -3$

  D_{max} 6.9m ~ 9.8m

  SIMPLE
  EFFECTIVE

- Bipolar is possible but not necessary.

- To have better understanding, propose to have detail study in the Booster.

ALEX BOGACZ

5/8/19

Chromatic Sextupoles

Alex Bogacz

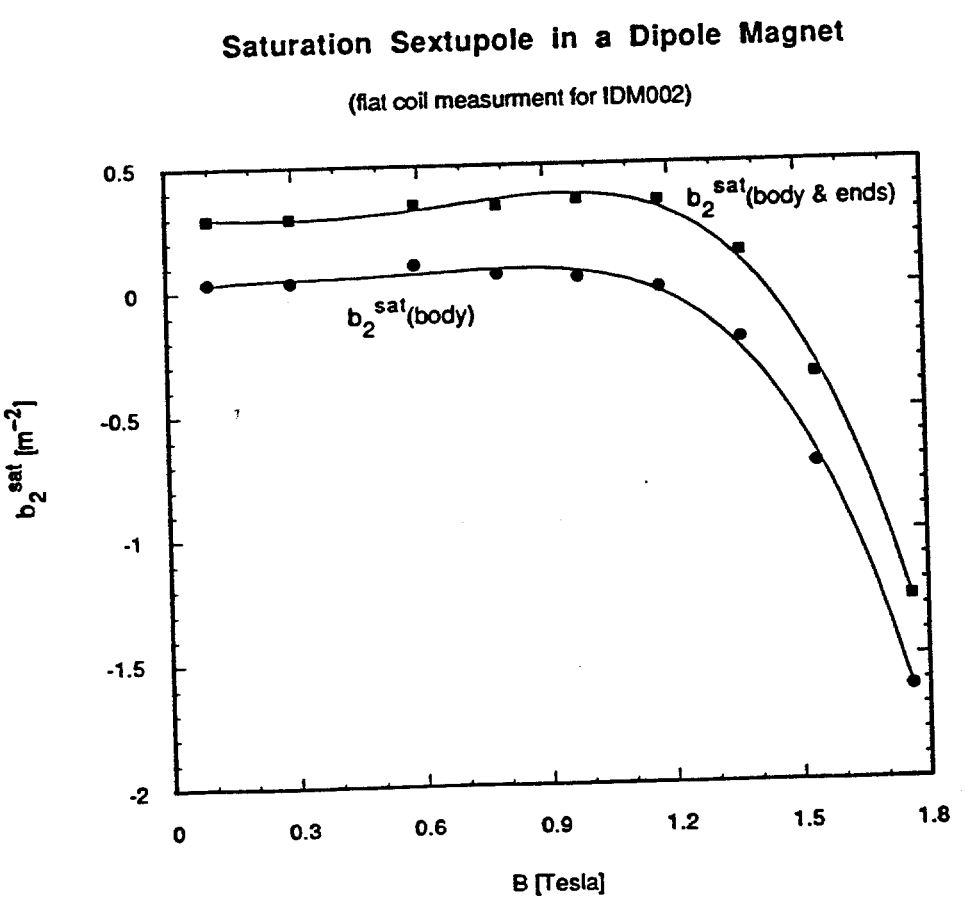
- Saturation sextupole in a MI dipole (body + ends)
- Saturation and Eddy sextupoles (150 GeV and 120 GeV ramps)
- Correcting sextupole strength
- Extreme sextupole magnet characteristics
- Shorter sextupoles?

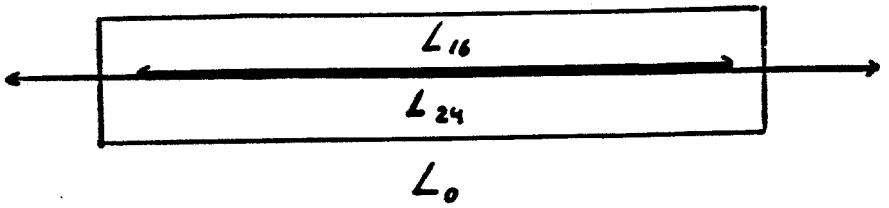
$$B = B_0 b_2 r^2 \qquad [b_2] = m^{-2}$$

$$\langle b_2 \rangle_L = \frac{1}{L} \int_0^L b_2 \, dl$$

(H. Glass)

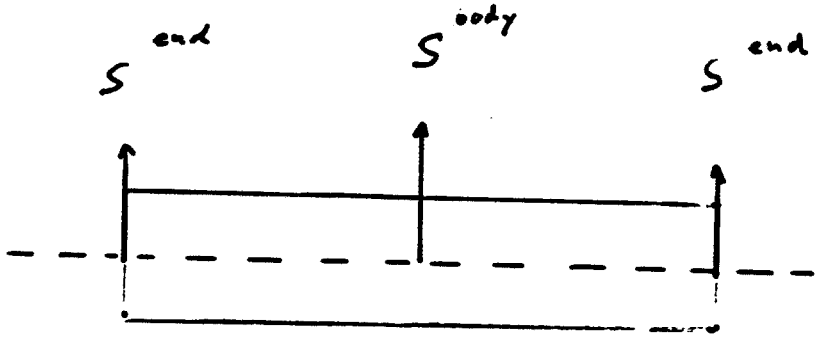
I [Amps]	B [Tesla]	b_3 (body)	b_3 (body+ends)	b_2 (body) $\langle b_2 \rangle_{16}$	b_2 (body+ends) $\langle b_2 \rangle_{24}$
5.000000e+02	9.955370e-02	2.200000e-05	1.890000e-04	3.410007e-02	2.929506e-01
1.500000e+03	2.965548e-01	2.200000e-05	1.890000e-04	3.410007e-02	2.929506e-01
3.000000e+03	5.917796e-01	6.499999e-05	2.210000e-04	1.007502e-01	3.425507e-01
4.000000e+03	7.877406e-01	3.600000e-05	2.170000e-04	5.580011e-02	3.363507e-01
5.000000e+03	9.831362e-01	2.700000e-05	2.310000e-04	4.185009e-02	3.580507e-01
6.000000e+03	1.177572e+00	-3.000000e-06	2.240000e-04	-4.650009e-03	3.472007e-01
7.000000e+03	1.368532e+00	-1.380000e-04	8.899999e-05	-2.139004e-01	1.379503e-01
8.000000e+03	1.542802e+00	-4.660000e-04	-2.320000e-04	-7.223014e-01	-3.596007e-01
9.500000e+03	1.762195e+00	-1.050000e-03	-8.160000e-04	-1.627503e+00	-1.264803e+00





sat
$$\begin{cases} b_2^{body} = \dfrac{L_{16}}{L_0} \langle b_2 \rangle_{16} \\[2ex] b_2^{end} = \dfrac{1}{2} \left\{ \dfrac{L_{24}}{L_0} \langle b_2 \rangle_{24} - \dfrac{L_{16}}{L_0} \langle b_2 \rangle_{16} \right\} \end{cases}$$

$$b_2^{eddy} = 5.16 \times 10^{-2} \times \frac{\dot{B}}{B} \quad [m^{-2}]$$



$$\Delta x^1 = -S x^2$$

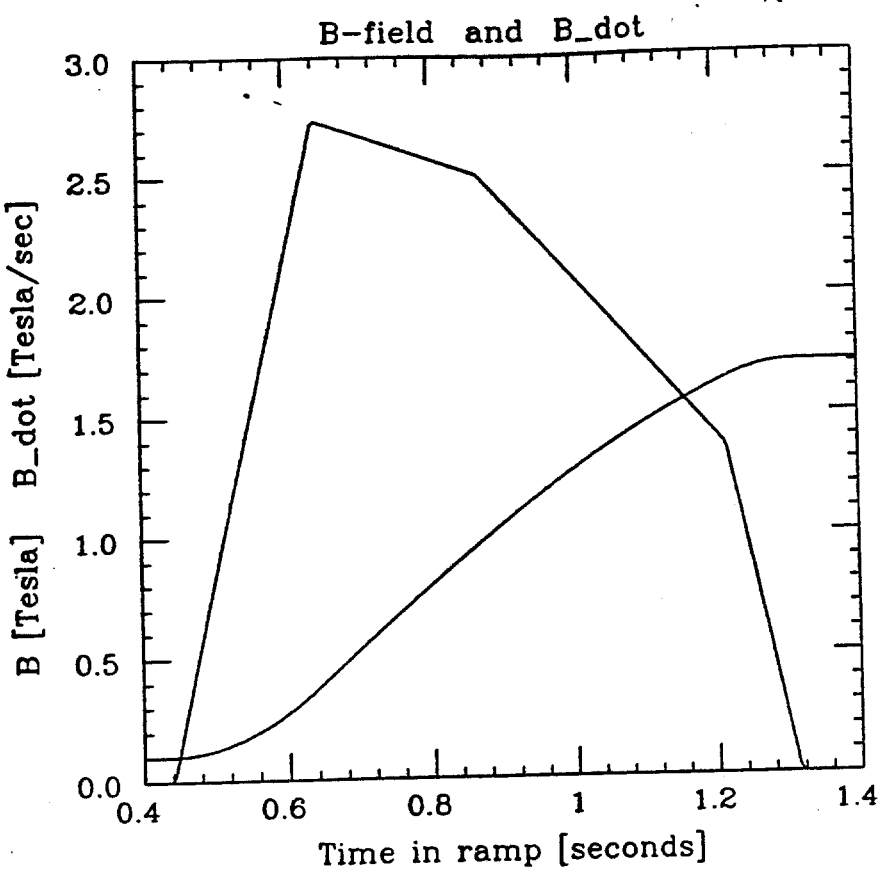
$$S = \langle g_2 \rangle_{L_0} \Theta_{dip} \quad , \quad \Theta_{dip} = \frac{L_0}{\rho}$$

$$S^{body} = \left(b_2^{body} + \frac{1}{3} b_2^{eddy} \right) \Theta_{dip}$$

$$S^{end} = \left(b_2^{end} + \frac{1}{3} b_2^{eddy} \right) \Theta_{dip}$$

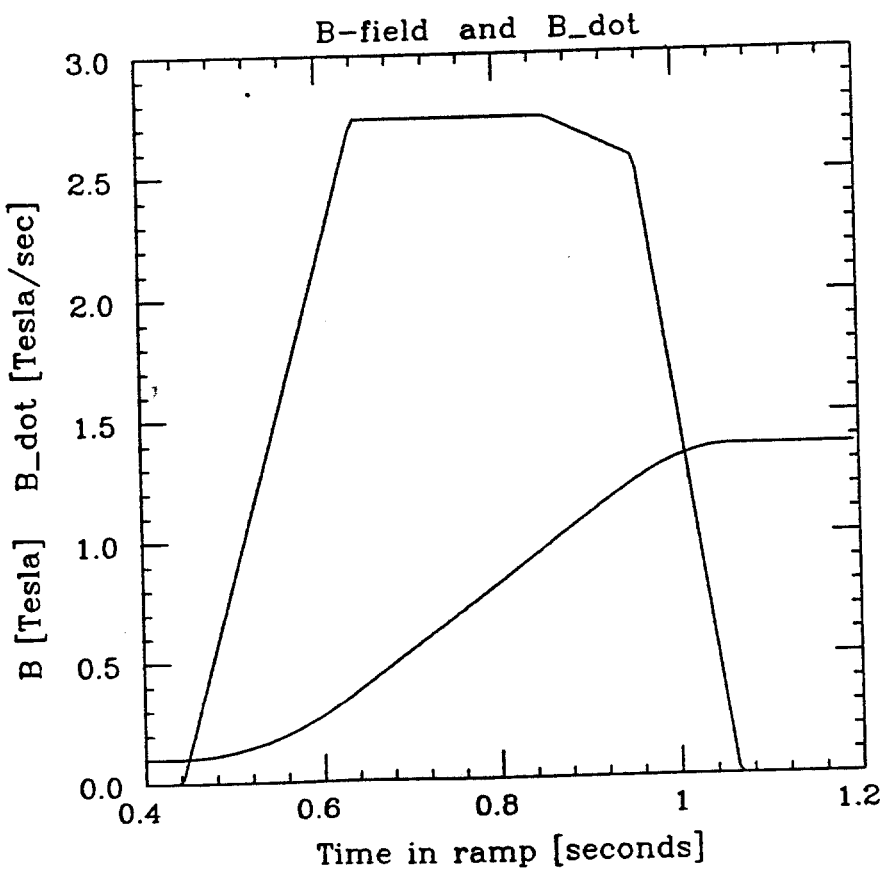
150 GeV

ramp



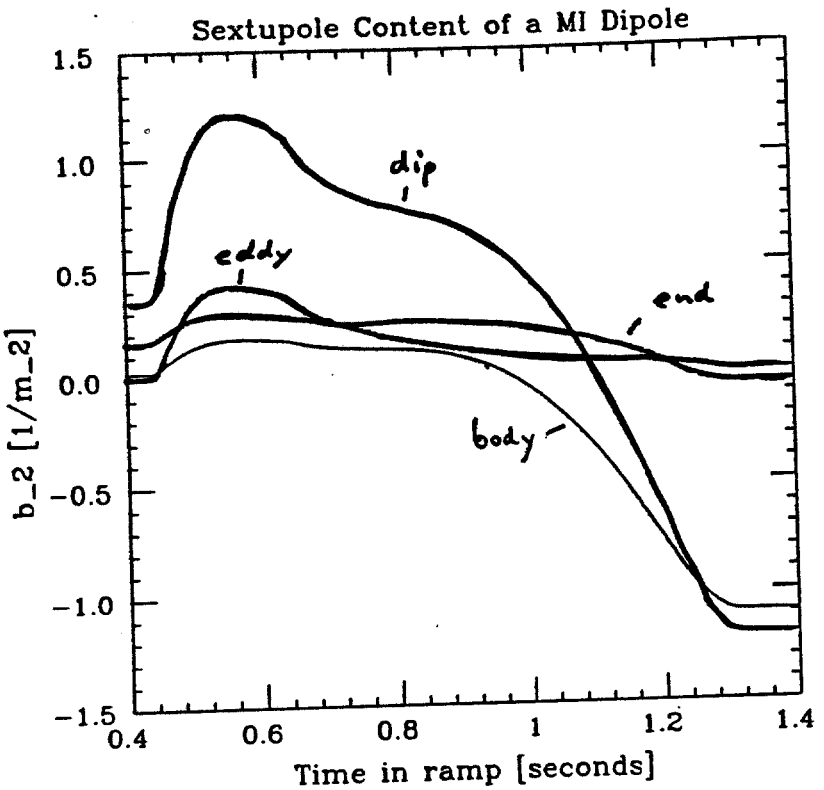
120 GeV

ramp



150 GeV

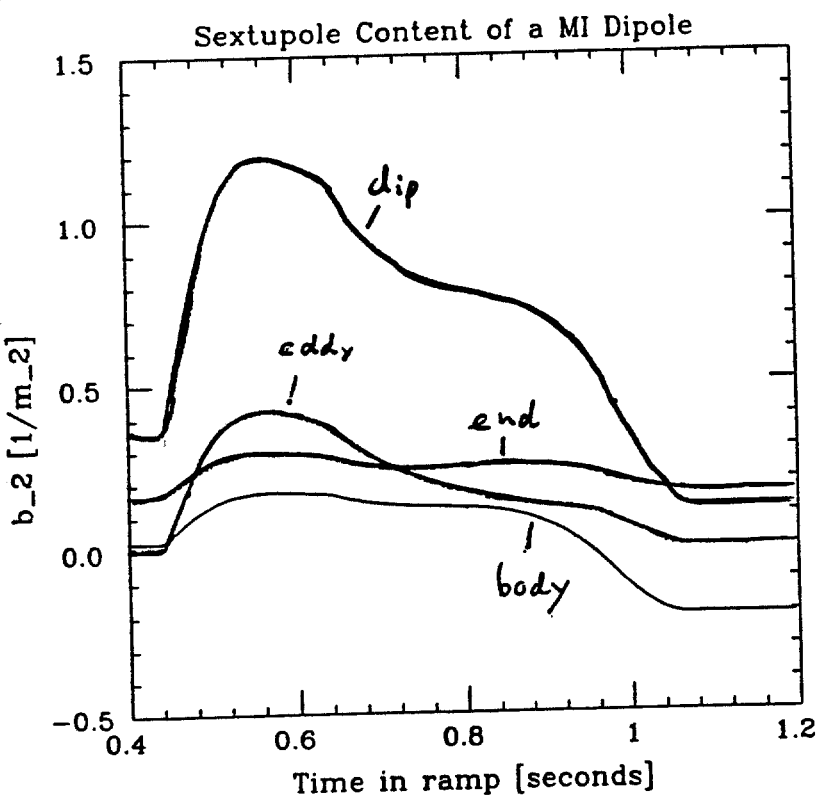
ramp



$$b_2^{dip} = b_2^{eddy} + b_2^{body} + 2\, b_2^{end}$$

120 GeV

ramp



$$\underline{\chi} = \underline{\chi}^{o} + \mathbf{M}\begin{pmatrix} S_f \\ S_d \end{pmatrix} + S_{b\&e}\,\underline{b} \qquad\qquad \underline{\chi} = \underline{\chi}^{o} + \mathbf{M}\begin{pmatrix} S_f \\ S_d \end{pmatrix} + \mathbf{S}\begin{pmatrix} S_b \\ S_e \end{pmatrix}$$

$$\underline{g} = (B\rho)\begin{pmatrix} S_f \\ S_d \end{pmatrix} \qquad B\rho = \frac{p}{c}$$

$$\boxed{\underline{g} = (B\rho)\,\mathbf{M}^{-1}\left[\underline{\chi} - \left(\underline{\chi}^{o} + \mathbf{S}\begin{pmatrix} S_b \\ S_e \end{pmatrix}\right)\right]},$$

$$\mathbf{M} = \begin{pmatrix} 8.28 & 0.901 \\ -1.82 & -4.43 \end{pmatrix} \times 10^{2},$$

(MAD)

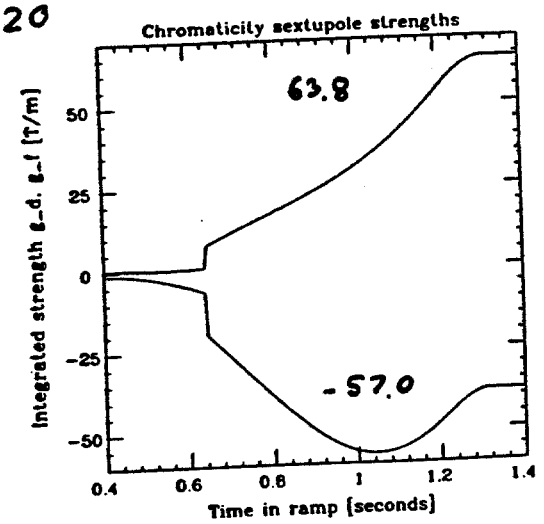
$$\mathbf{S} = \begin{pmatrix} 1.49 & 3.50 \\ -1.39 & -3.00 \end{pmatrix} \times 10^{3},$$

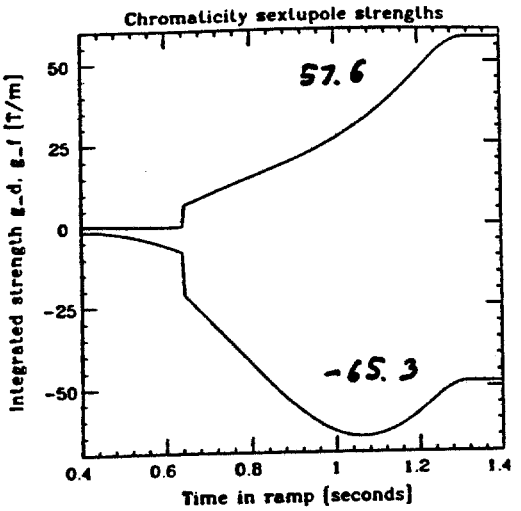
120 GeV ramp

"body"

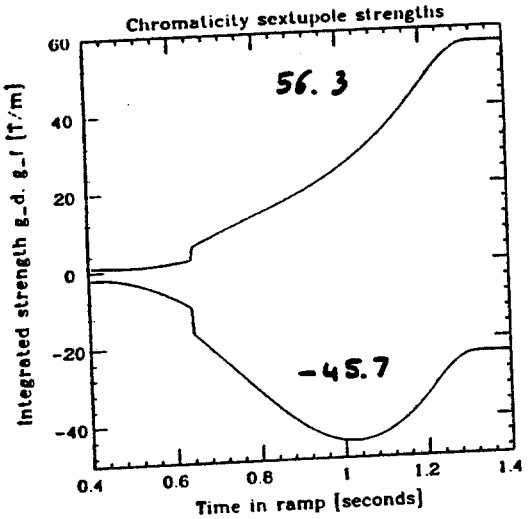
"body & ends"

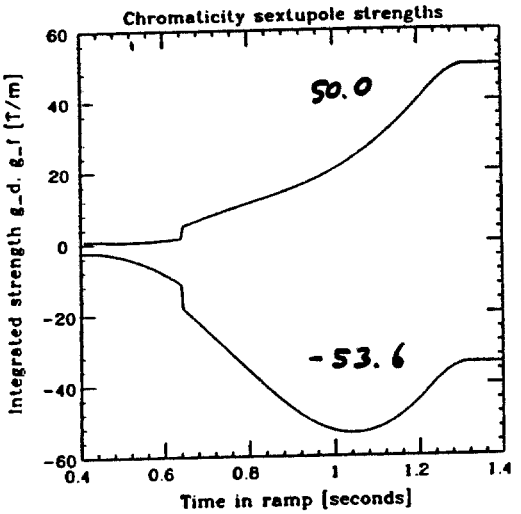
$x = \mp 20$



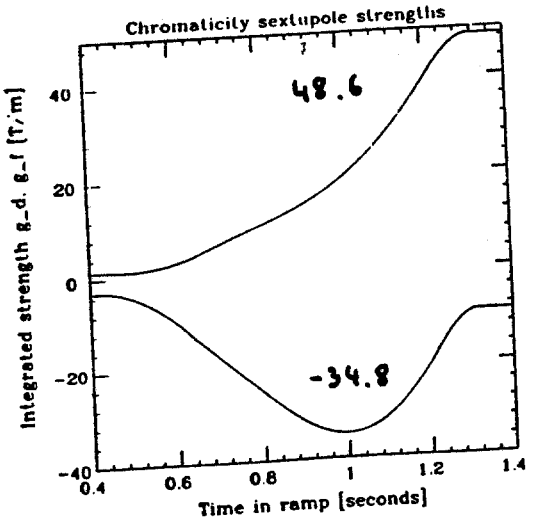


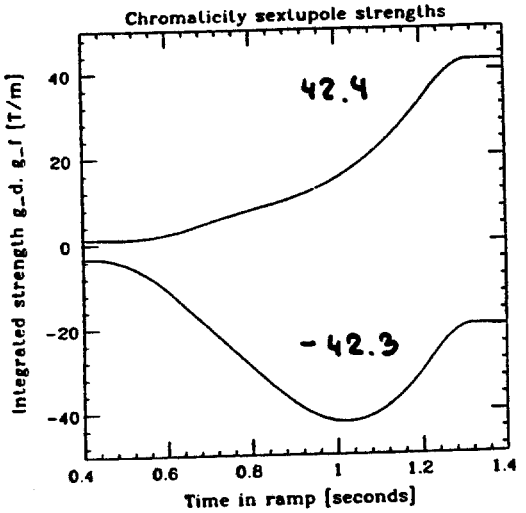
$x = \mp 10$





$x = 0$

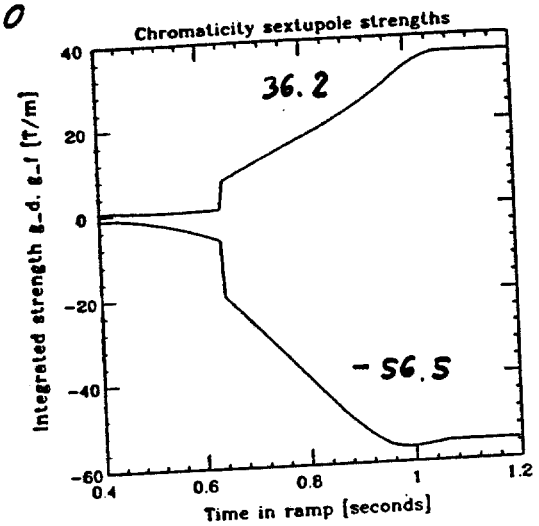


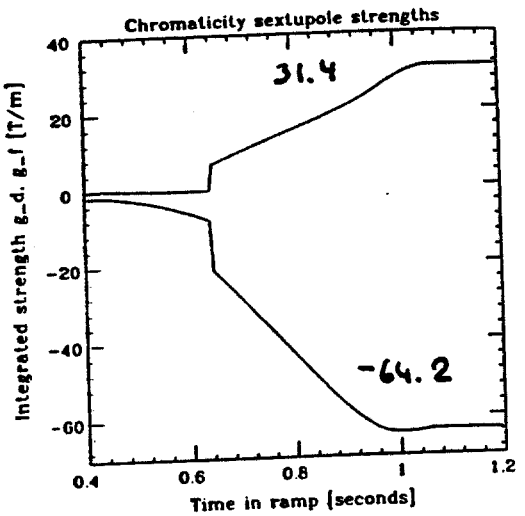


120 GeV ramp

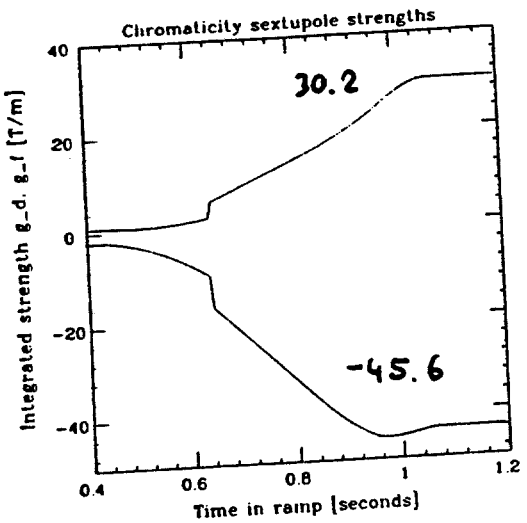
"body" "body & ends"

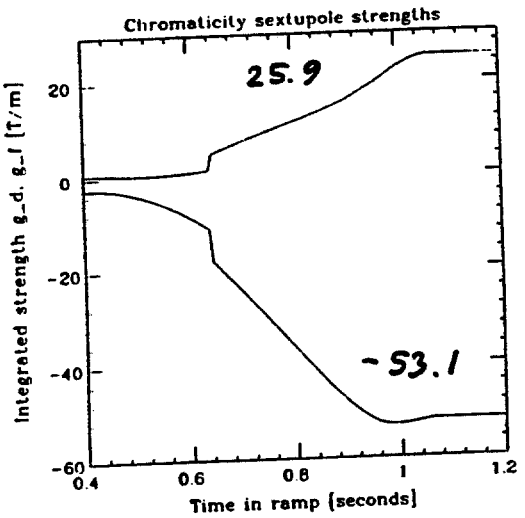
$x = \mp 20$



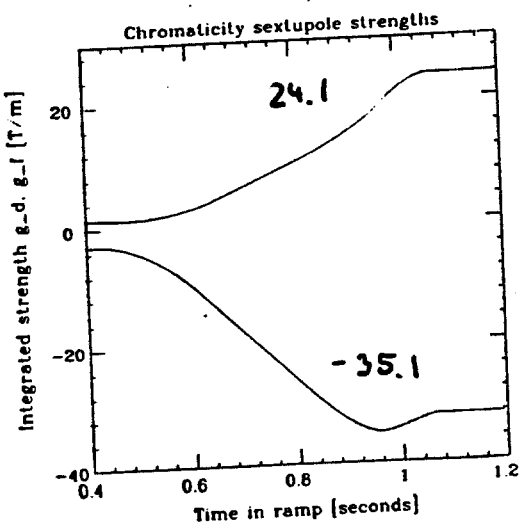


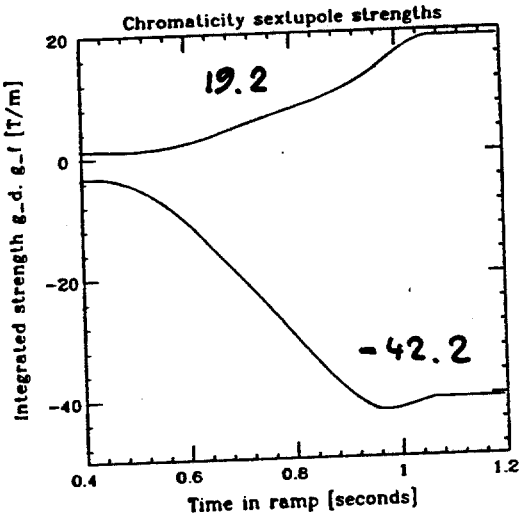
$x = \mp 10$





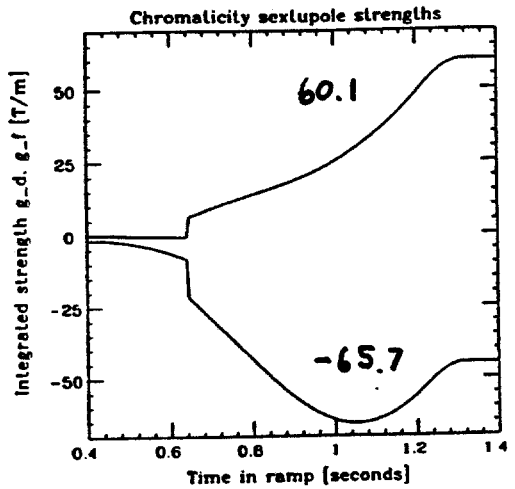
$x = 0$



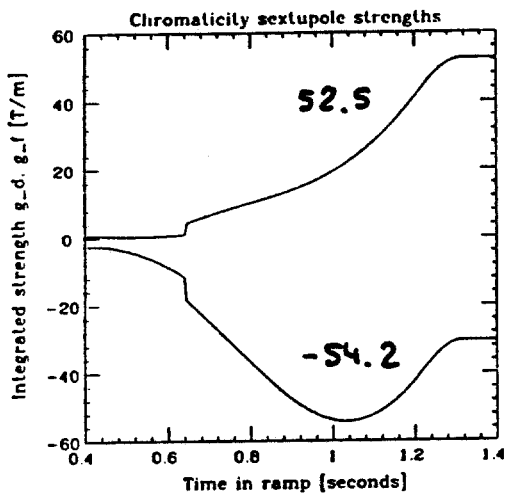


150 GeV ramp

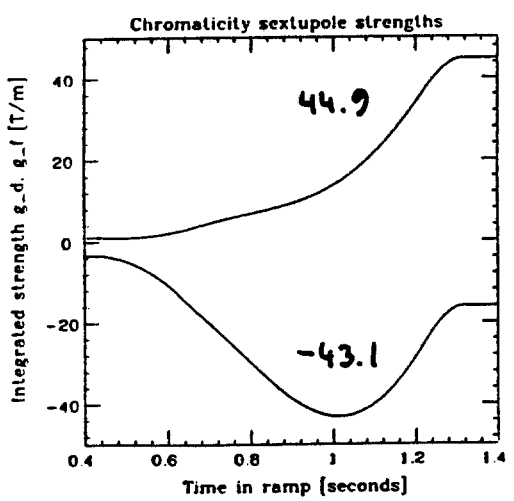
$x = \mp 20$



$x = \mp 10$

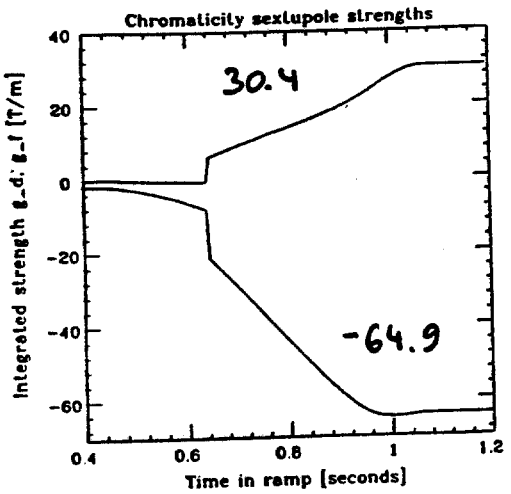


$x = 0$

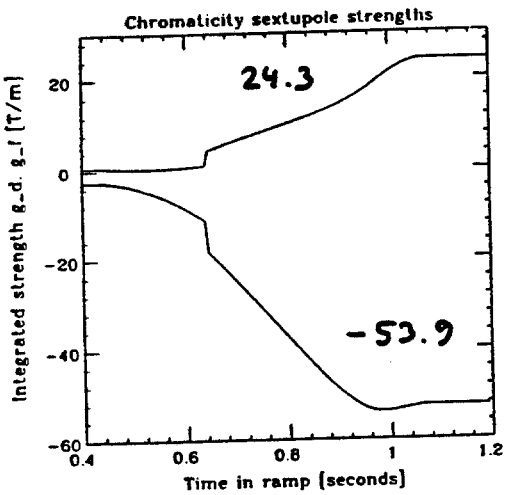


120 GeV ramp

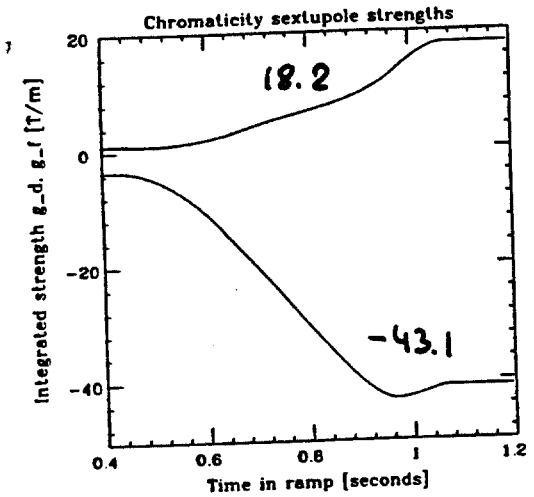
$x = \mp 20$



$x = \mp 10$



$x = 0$



Shorter Sextupole? (24" → 20")

$g \simeq 65$ Tesla / m

$L = 20 \cdot 2.54 \times 10^{-2}$ m

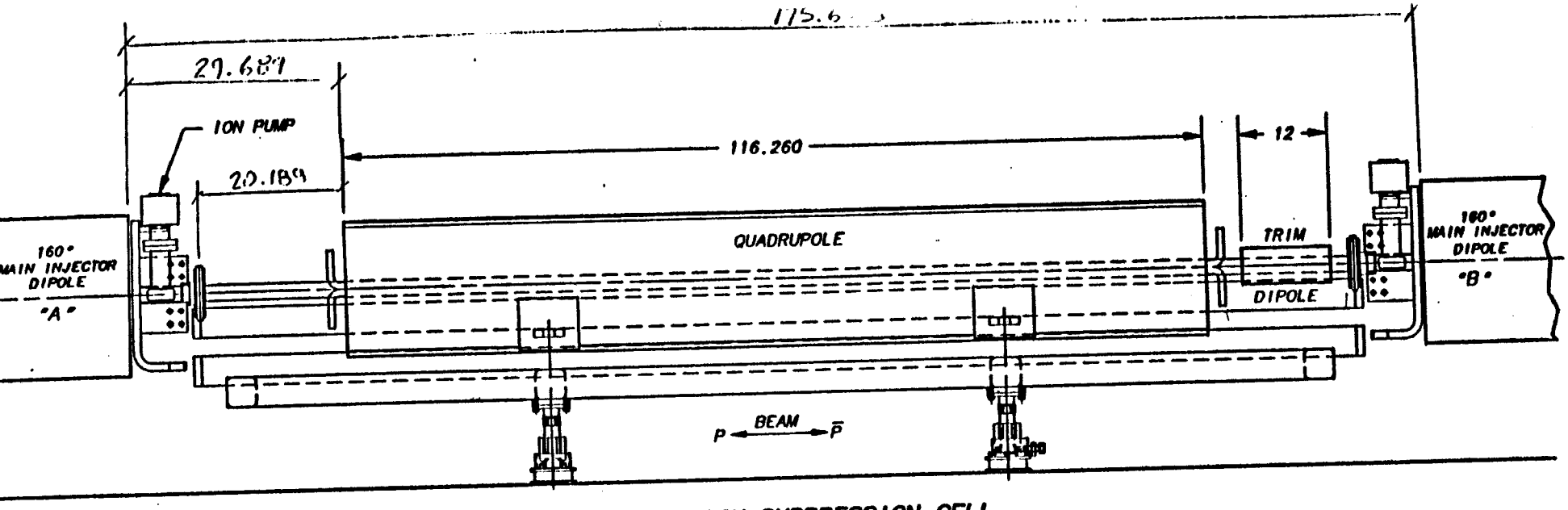
→ B-field at the tip ($r_1 = 8 \times 10^{-2}$ m)

$$B_{tip} = \frac{65}{20 \times 2.54 \times 10^{-2}} (8 \times 10^{-2})^2 = 0.82 \text{ Tesla}$$

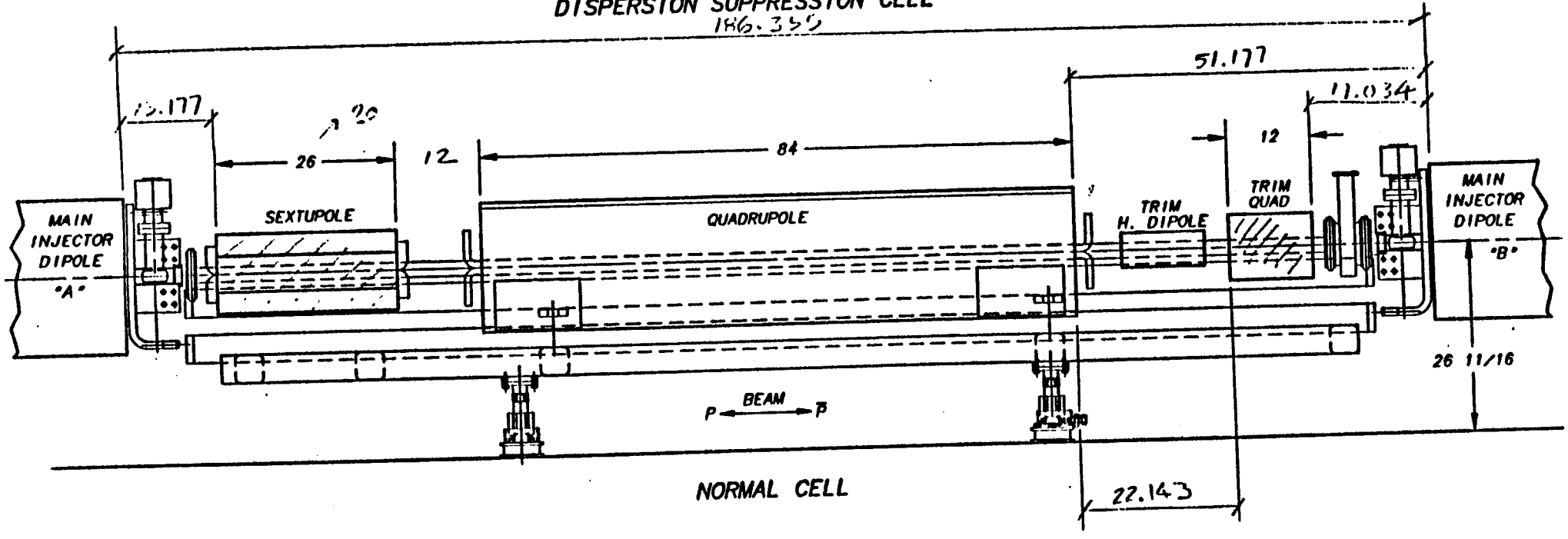
→ sextupole current

$$I = \frac{1}{3} \frac{r_0^3}{4\pi \times 10^{-7}} \frac{g}{L} \quad , \quad r_0 = 2.9 \times 10^{-2} \text{ m}$$

$$I = \frac{(2.9)^3 \times 10^{-6} \cdot 65}{12\pi \times 10^{-7} \cdot 20 \times 2.54 \times 10^{-2}} = 917 \text{ Amps}$$



DISPERSION SUPPRESSION CELL



NORMAL CELL

Sext., slow spill (Oct. + Quads), γ_t-jump Quads

JOHN JOHNSTONE

SLOW EXTRACTION HARMONIC ELEMENTS

J. A. JOHNSTONE

- APPROPRIATE ELEMENTS FOR EXCITATION & CONTROL OF ½ - INTEGER RESONANCE ARE QUADRUPOLES + OCTUPOLES.

- <u>QUADRUPOLES:</u>

  THE RELEVANT (53rd) HARMONIC IS PROVIDED BY 2 ORTHOGONAL FAMILIES OF 8 QUADRUPOLES EACH.

  QUADS MOVE TUNE THROUGH THE ½ INTEGER
  + ALLOW CONTROL OF PHASE SPACE ORIENTATION AT EXTRACTION SEPTUM
  + CANCEL INTRINSIC ½ INTEGER STOP-BAND OF THE MACHINE.

- <u>OCTUPOLES:</u>

  ONE FAMILY OF 32 OCTUPOLES PRODUCES A (NON-LINEAR) 0th HARMONIC COMPONENT.

  OCTUPOLES PRODUCE AN AMPLITUDE-DEPENDENT TUNE SHIFT
  + CANCEL THE (LARGE) OCTUPOLE COMPONENT OF THE RECYCLED MR QUADS AT INJECTION.

NUMBERS & KINDS OF HARMONIC ELEMENTS

- HARMONIC ELEMENTS TO BE CANNIBALIZED FROM M.R.
- QUADRUPOLES

  - 14" M.R. TRIM QUAD : $B_1 L = 0.255 \frac{kG \cdot m}{m \cdot Amp} \cdot I$

  - RAISING TUNE FROM 0.485 → 0.5 USING N QUADS @ 120 GeV REQUIRES:

$$N(B'L) = \frac{4\pi}{\beta}(.015)B_0\rho \sim 14.5 \frac{kG \cdot m}{m}$$

⇒ 8 QUADS ARE REQUIRED RUNNING AT ~ 7 Amps.

- OCTUPOLES

  - 8" M.R. OCTUPOLE : $B_3 L = 27.9 \frac{kG \cdot m}{m^3 Amp} \cdot I$

  - AT INJECTION THE OCTUPOLE COMPONENT OF THE MR. QUADS (84") IS:

$$B_3 L = 24.3 \ kG \cdot m / m^3$$

TO CANCEL THE CONTRIBUTION FROM 64 QUADS WITH n OCTUPOLES:

$$nI \sim 56 \text{ Amps.}$$

⇒ MINIMUM 16 OCTUPOLES OPERATING AT ~ 4 Amps

(AT 120 GeV THESE NUMBERS BECOME 64 OCTUPOLES RUNNING AT 10 Amps)

OVERVIEW OF RESONANT EXTRACTION

- NEAR THE ½ - INTEGER:

$$K = \left(\frac{53}{2} - \nu\right) R^2 - \left[g_0 + g_2 \cos(2\varphi - 2\chi_2) \right] R^2$$
$$- \left[3\lambda_0 + 4\lambda_2 \cos(2\varphi - 2\psi_2) + \lambda_4 \cos(4\varphi - 4\psi_4) \right] R^4$$

IS AN APPROXIMATE CONSTANT OF THE MOTION.

- $\beta R^2 = x^2 + (\beta x' + \alpha x)^2$: $\varphi = \frac{53}{2}\theta + \tan^{-1}\left(\frac{\beta x' + \alpha x}{x}\right)$

$\theta = 0 \rightarrow 2\pi$ IN 1 TURN

- <u>QUADRUPOLE TERMS:</u>

- $g_0 = \frac{1}{2\pi} \oint ds \, \frac{B'\beta}{2B\rho}$ — 0th HARMONIC

- $g_2 = (g_s^2 + g_c^2)^{1/2}$ — 53rd HARMONIC

$$g_s \sim \frac{1}{2\pi} \oint ds \, \frac{B'\beta}{2B\rho} \cdot \sin(53\theta)$$

$$g_c \sim \frac{1}{2\pi} \oint ds \, \frac{B'\beta}{2B\rho} \cdot \cos(53\theta)$$

$$\chi = \frac{1}{2} \tan^{-1}(g_s / g_c)$$

- OCTUPOLE TERMS:

- $\lambda_0 = \frac{1}{2\pi} \oint ds \frac{B'''}{96 B\rho} \beta^2$ — 0th HARMONIC

- $\lambda_2 = (\lambda_{2s}^2 + \lambda_{2c}^2)^2$ — 53rd HARMONIC

$$\lambda_{2s} \sim \frac{1}{2\pi} \oint ds \frac{B'''}{96 B\rho} \beta^2 \sin(53\theta)$$

$$\lambda_{2c} \sim \frac{1}{2\pi} \oint ds \frac{B'''}{96 B\rho} \beta^2 \cos(53\theta)$$

$\psi_2 = \frac{1}{2} \tan^{-1}\left(\lambda_{2s} / \lambda_{2c} \right)$ — 106th HARMONIC

- $\lambda_4 = (\lambda_{4s}^2 + \lambda_{4c}^2)^{1/2}$

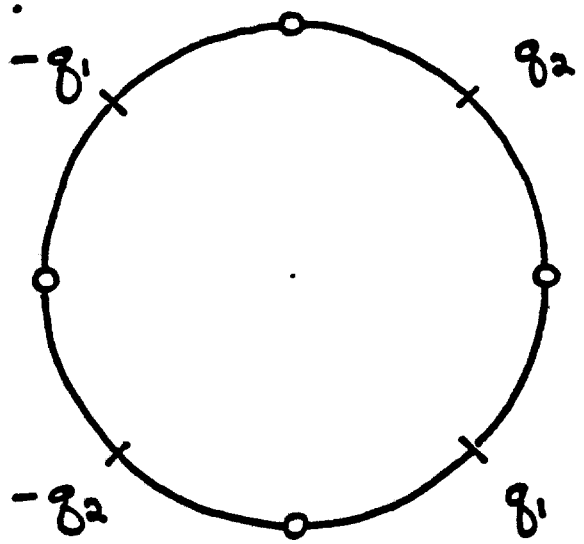
$$\lambda_{4s} \sim \frac{1}{2\pi} \oint ds \frac{B'''}{96 B\rho} \beta^2 \sin(106\theta)$$

$$\lambda_{4c} \sim \frac{1}{2\pi} \oint ds \frac{B'''}{96 B\rho} \beta^2 \cos(106\theta)$$

$$\psi_4 = \frac{1}{4} \tan^{-1}\left(\lambda_{4s} / \lambda_{4c} \right)$$

POSITIONING OF THE HARMONIC ELEMENTS

- ONLY 53rd HARMONIC QUADRUPOLE CONTRIBUTION IS RETAINED BY SEPARATING OPPOSITE POLARITY QUADS BY 90°. (TOTAL # = 2n)
- ONLY 0th HARMONIC OCTUPOLE TERM IS RETAINED BY SPACING SUCCESSIVE ELEMENTS 45° APART. (TOTAL # = 4m)
- SCHEMATICALLY:



- VECTOR SUMS:

q_0 ↑ ↓ = 0

q_2 ↑ ↑ = 2

λ_0 ↑↑↑↑ = 4

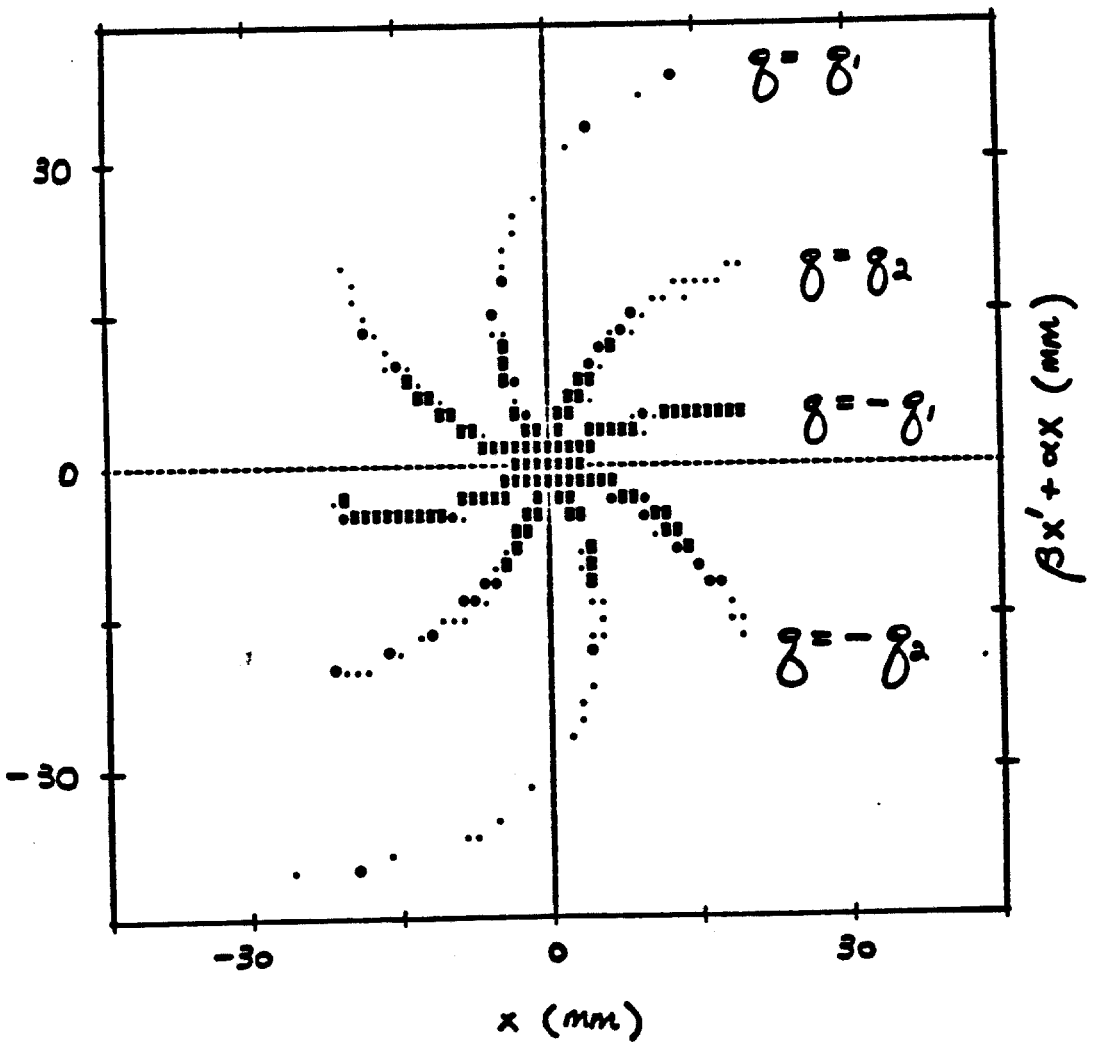
λ_2 ↑ → ↓ ← = 0

λ_4 ↑↓↑↓ = 0

- 2 FAMILIES OF QUADS g_1, g_2 (SEPARATED BY 45°) PROVIDE CONTROL OF PHASE-SPACE ORIENTATION.
- THE ANGLE BETWEEN THE P.S. DISTRIBUTION AND X-AXIS IS:

$$\chi \sim \frac{1}{2}\tan^{-1}\left\{\frac{g_1\sin(2\psi) + g_2\cos(2\psi)}{g_1\cos(2\psi) - g_2\sin(2\psi)}\right\}$$

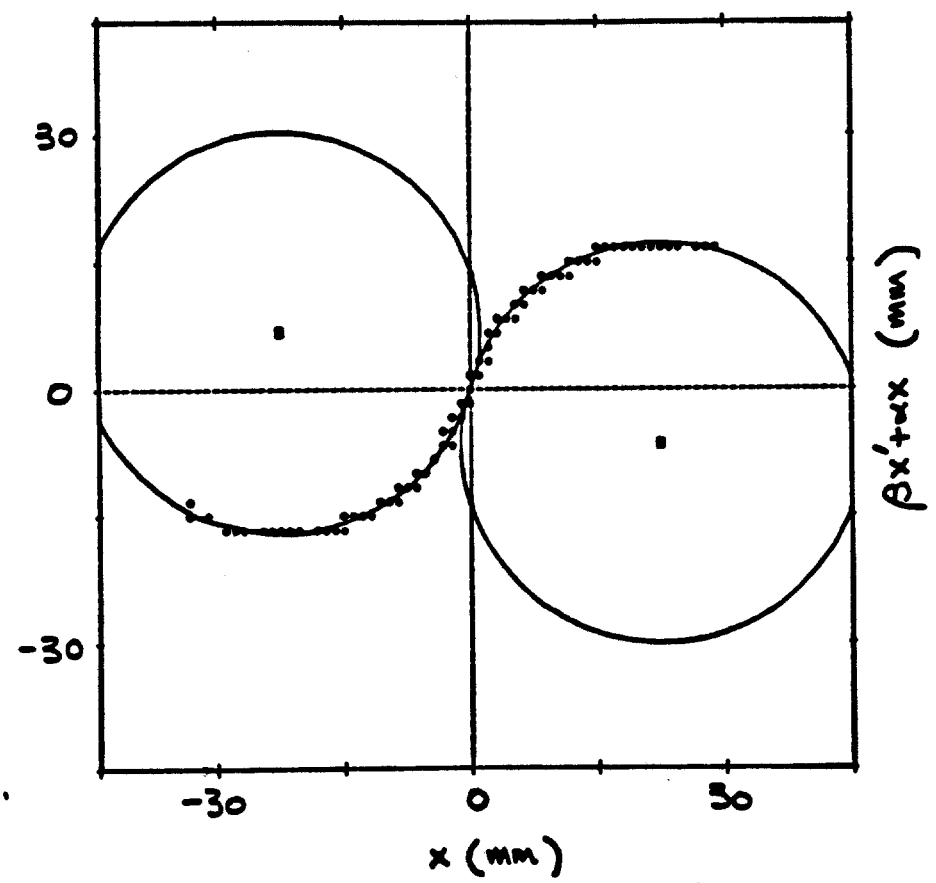
ψ = PHASE ADVANCE FROM POINT OF INTEREST TO g_1.



- WITH ONLY THE g_2 AND λ_0 TERMS, IT CAN BE SHOWN THAT THE SEPARATRICES ARE DESCRIBED BY CIRCLES:

$$\left[(\hat{x}-\sin\chi)^2+(\hat{x}'+\cos\chi)^2-\Delta\right]\left[(\hat{x}+\sin\chi)^2+(\hat{x}'-\cos\chi)^2-\Delta\right]=0$$

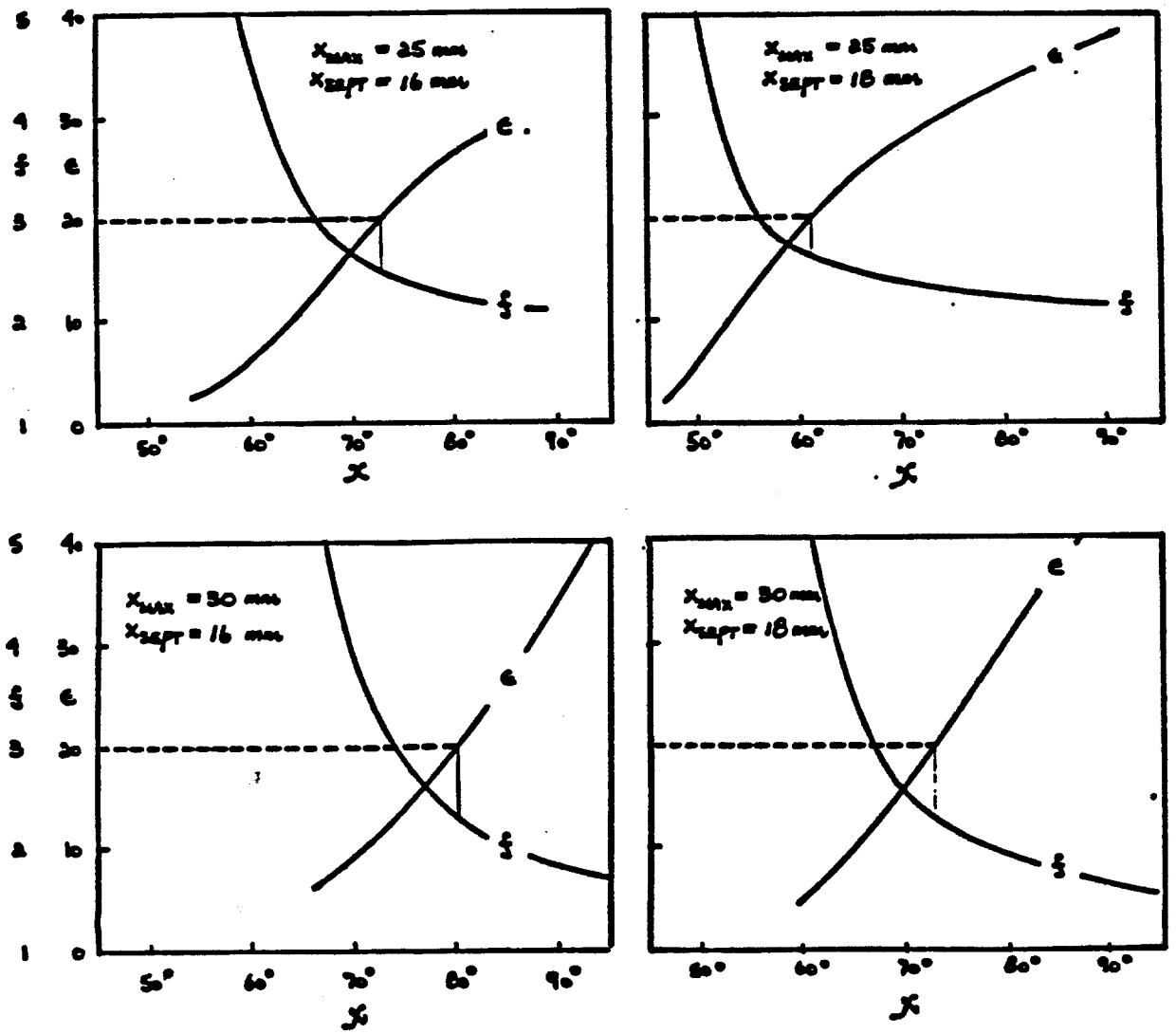
$$\hat{x} = \left(\frac{6\lambda}{\beta g}\right)^{1/2} x \quad ; \quad \hat{x}' = \left(\frac{6\lambda}{\beta g}\right)^{1/2}\left[\beta x' + \alpha x\right]$$



(PHASE-SPACE TRAJECTORY OF PARTICLES FROM TRACKING (DOTS) COMPARED TO ANALYTIC PREDICTION (CIRCLES) AT THE SEPTUM.)

$\lambda = 245\ m^{-1}$ $\quad g = 0.0150$ $\quad \chi = 74^\circ$

- STEP-SIZE, ORIENTATION AT THE SEPTUM CAN BE DETERMINED ANALYTICALLY IN TERMS OF SEPTUM OFF-SET, QUAD POSITION κ, & OCTUPOLE STRENGTH λ. FROM THIS IS DETERMINED:
  - EMITTANCE OF EXTRACTED BEAM
  - MAXIMUM SIZE OF CIRCULATING BEAM
  - EXTRACTION INEFFICIENCY



ϵ = EMITTANCE OF EXTRACTED BEAM (UNITS π mm·mr)
f = % OF PARTICLES LOST ON SEPTUM WIRE
x_{MAX} = MAXIMUM SIZE OF CIRCULATING BEAM (FIXED)
20π mm·mr CIRCULATING BEAM.

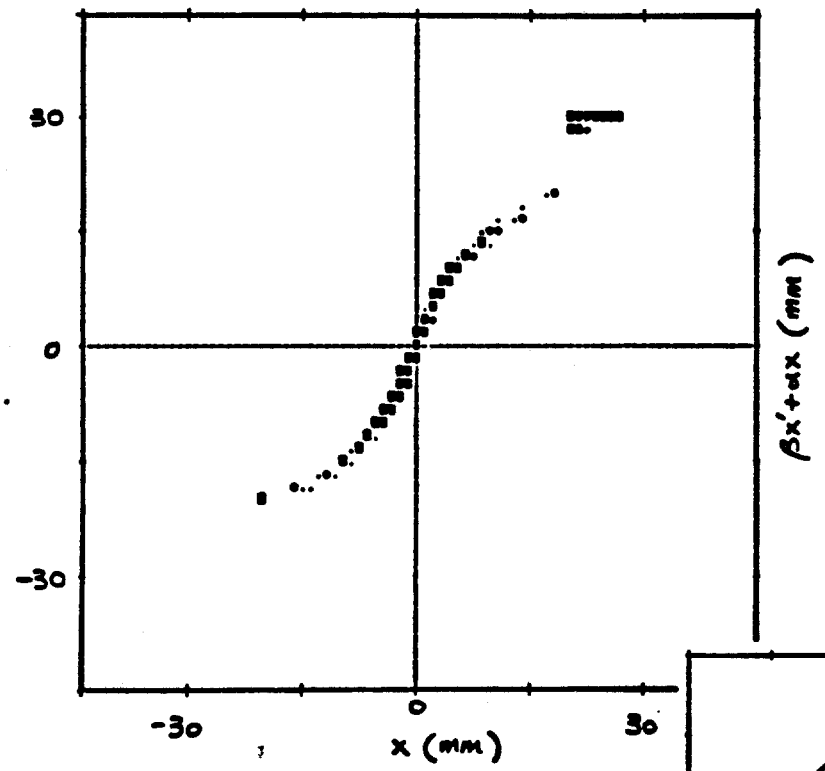
- THERE IS NO PERFECT SOLUTION
- A GOOD COMPROMISE IS :

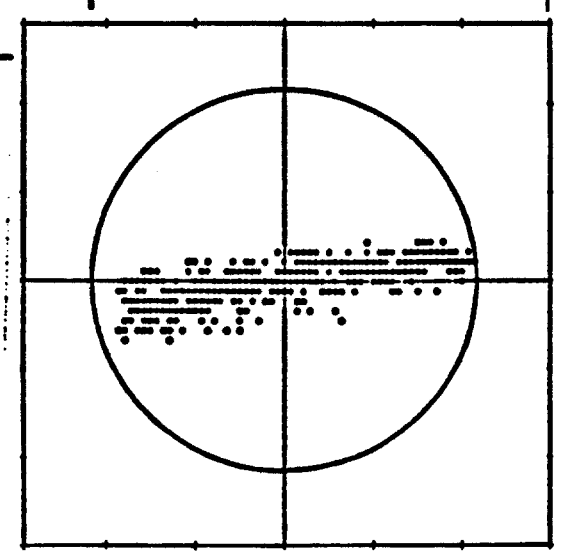
$$\lambda \sim 230\ m^{-1} \qquad \chi \sim 75^\circ$$

GIVING $\epsilon_{EXTRACTED} \sim 20\pi$ mm·mr

FOR $\epsilon_{CIRCULATING} \simeq 30\pi$ mm·mr

AND EXTRACTION INEFFICIENCY $f \sim 2\frac{1}{2}\%$.





PHASE-SPACE AT SEPTUM
& BLOW-UP OF EXTRACTED
PHASE-SPACE

NUMBER & STRENGTH OF OCTUPOLES

- AT 120 GeV THE M.R. QUADS HAVE AN OCTUPOLE COMPONENT:

$$\frac{B_3 L}{B_0 \rho} = 0.075 \ m^{-3}$$

- WITH 64 F QUADS IN THE RING THE CONTRIBUTION TO λ_0 IS:

$$\lambda_{MR} \sim \frac{1}{2\pi} \cdot 64 \cdot (.075) \frac{\beta^2}{16}$$

$$\sim 130 \ m^{-1}$$

- FOR N 8" OCTUPOLES TO MAKE UP THE REMAINING 100 m^{-1}:

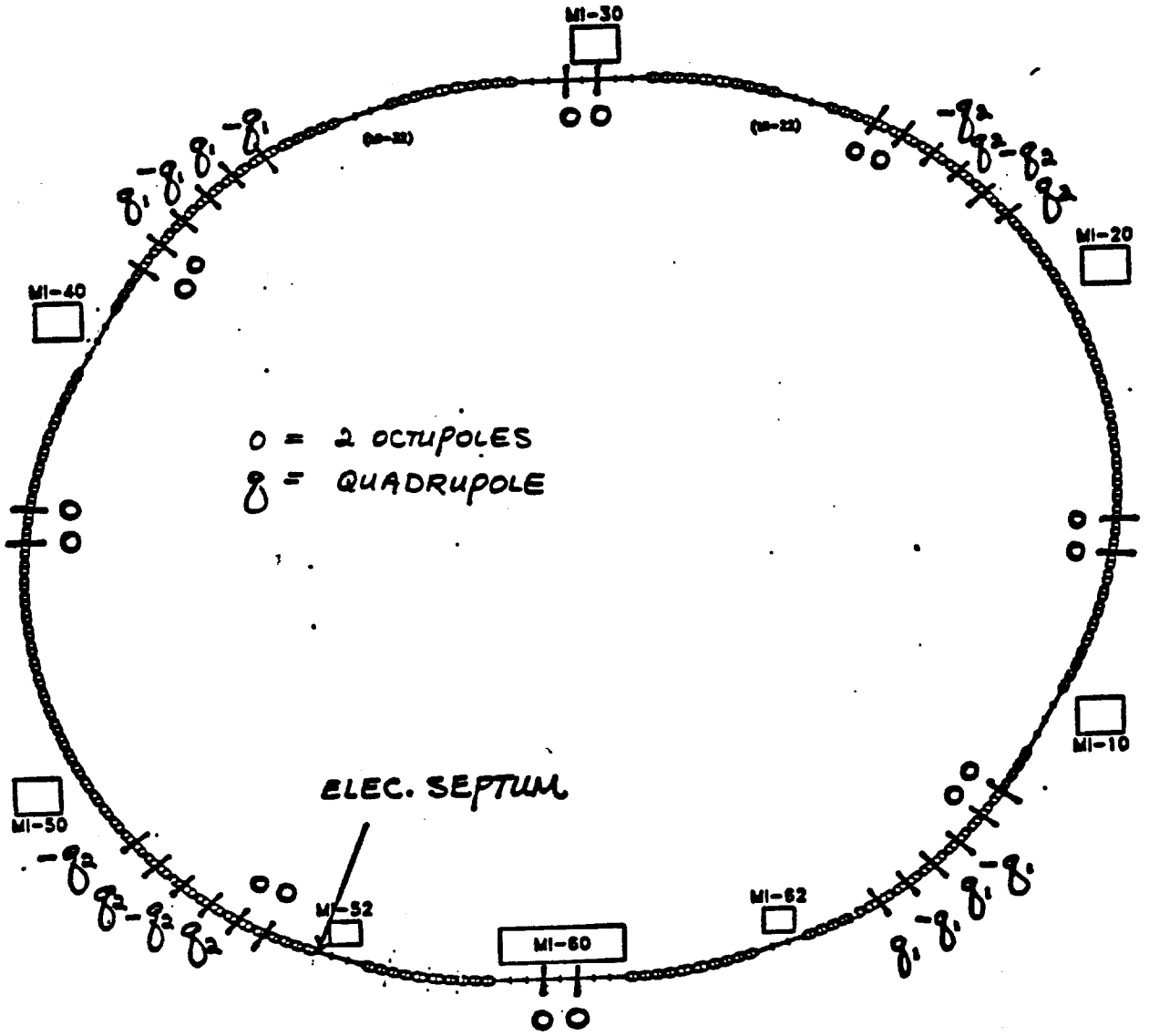
$$NI = \frac{32\pi}{\beta^2} (100) \left(\frac{B_0 \rho}{B_3 L} \right)$$

$$\sim 530 \text{ Amps}$$

$\Rightarrow$ 32 8" OCTUPOLES OPERATING @ ~ 16½ AMPS

DISTRIBUTION OF QUADRUPOLES & OCTUPOLES IN THE MAIN INJECTOR

- 0th HARMONIC OCTUPOLES ARE DISTRIBUTED UNIFORMLY AROUND THE RING.
- THE q_2 FAMILY OF 53rd HARMONIC QUADS ARE SITUATED TO PROVIDE THE DESIRED PHASE SPACE ORIENTATION AT THE SEPTUM.
- THE ORTHOGONAL q_1 FAMILY IS AVAILABLE FOR CANCELLING THE INTRINSIC ½ · INTEGER STOP-BAND OF THE MACHINE.



SUMMARY

- ALL HARMONIC ELEMENTS ARE TO BE RECYCLED FROM MAIN RING.
- A TOTAL OF 16 MR. 14" TRIM QUADS
  8 OF THESE RUN AT ~7 A. DURING EXTRACTION
- LOCATION OF THE QUADS IS FIXED BY PHASE-SPACE REQUIREMENTS AT THE SEPTUM
- 32 M.R. 8" OCTUPOLES RUN AT ~16 A. DURING EXTRACTION.
- OCTUPOLES ARE LOCATED SO AS TO CANCEL ALL BUT THE 0th HARMONIC.

PHIL MARTIN

Fermilab
Main Injector Department

May 8, 1992

MAIN INJECTOR CORRECTION ELEMENT WORKSHOP

INJECTION AND EXTRACTION ELEMENTS

P. MARTIN

INJECTION:

HORIZONTALLY-BENDING LAMBERTSON MAGNET
(IMMEDIATELY UPSTREAM OF Q101)
BRINGS INJECTED BEAM ONTO HORIZONTAL CLOSED ORBIT
VERTICAL KICKER (IMMEDIATELY UPSTREAM OF Q103)
PLACES BEAM ONTO VERTICAL CLOSED ORBIT

OTHER ASPECTS:
Q101 MUST BE ROLLED 90° TO PROVIDE CLEARANCE FOR INJECTED BEAM
CIRCULATING BEAM MUST BE DISPLACED DOWN ABOUT 5 mm AT 8 GEV TO AVOID LAMBERTSON SEPTUM--NORMAL CORRECTION ELEMENTS CAN PROVIDE THIS DISPLACEMENT

SUMMARY: NO SPECIAL CORRECTION ELEMENTS REQUIRED

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EXTRACTION:

THREE LOCATIONS TO DISCUSS:
PROTON EXTRACTION AT MI-52
ANTIPROTON EXTRACTION AT MI-62
PROTON ABORT AT MI-40

FOLLOWING DISCUSSION APPLIES TO ALL THREE IN GENERAL, BUT IS SPECIFIC TO THE ABORT, WHICH IS MOST COMPLICATED
EXTRACTION INITIATED BY KICKER (FOR SINGLE-TURN) OR ELECTROSTATIC SEPTUM (FOR RESONANT EXTRACTION)
MI-52: BOTH SINGLE-TURN AND RESONANT; MI-62: SINGLE-TURN
MI-40: SINGLE-TURN AND POSSIBLY RESONANT ALSO (ν TO IMB)
COMMENT: ANOTHER EXTRACTION AT MI-60 IS ALSO UNDER CONSIDERATION FOR ν DIRECTED TOWARDS SOUDAN II (NORTHERN MINNESOTA)
ABORT KICKER (AND POSSIBLY, ELECTROSTATIC SEPTUM) LOCATED AT Q400
EXTRACTED BEAM IS DEFLECTED BY VERTICALLY-BENDING LAMBERTSON AND C-MAGNETS BOTH UPSTREAM AND DOWNSTREAM OF Q402. THIS IS REQUIRED BY RELATIVELY SHORT FREE SPACE BETWEEN QUADS (15 m) AND LARGE REQUIRED DEFLECTION (24 mrad)

ORBIT CONTROL AT KICKERS: NO SPECIAL REQUIREMENTS

ORBIT CONTROL AT LAMBERTSONS:

8 GEV BEAM: 24 mm INSIDE

120/150 GEV BEAM: NOT MORE THAN 4 mm OUTSIDE

BOTH OF THESE REQUIREMENTS CAN BE HANDLED BY THE HORIZONTAL CORRECTION DIPOLES BEING DESIGNED.

SUMMARY: NO SPECIAL CORRECTION ELEMENTS REQUIRED

CONTROL OF EXTRACTED BEAM TRAJECTORY

NOT REALLY PART OF CORRECTION ELEMENTS FOR THE MI, BUT WORTH MENTIONING THE PROBLEMS HERE

1. MUST BE ABLE TO ABORT BEAM AT ANY ENERGY
(ALSO, EXTRACT PROTONS AT MI-52 AT 8, 120 OR 150 GEV)
WANT BEND-CENTER OF LAMBERTSON AND C-MAGNETS TO REMAIN CONSTANT, BUT NOT HAVE 8 GEV BEAM TOO FAR OFF-CENTER IN THE QUADRUPOLE
SOLUTION: TRIM WINDINGS IN LAMBERTSON AND C-MAGNETS WHICH CAN CHANGE LOW-ENERGY B-FIELD BY 50-100% (i.e. 3-6% OF FULL-FIELD)

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2. THE QUAD WILL "REFOCUS" THE EXTRACTED BEAM TOWARDS X=0. POSSIBLE SOLUTIONS ARE

(i) TO "ROLL" THE FIRST LAMBERTSON, AND POSSIBLY SPLIT THE SECOND LAMBERTSON INTO TWO, THE FIRST ONE ALSO BEING ROLLED

(ii) "COCK" THE LAMBERTSONS SO THAT THE SEPTUM FOLLOWS THE EXTRACTED BEAM TRAJECTORY. THIS EFFECTIVELY MAKES THE SEPTUM LOOK THICKER TO THE CIRCULATING BEAM (BY AT LEAST A FACTOR OF TWO)

(iii) MAKE THE LAMBERTSON FIELD-REGION APERTURE LARGER; THEN THE EXTRACTED BEAM CAN BE KICKED HARDER AND YET HAVE ROOM TO BE REFOCUSED.

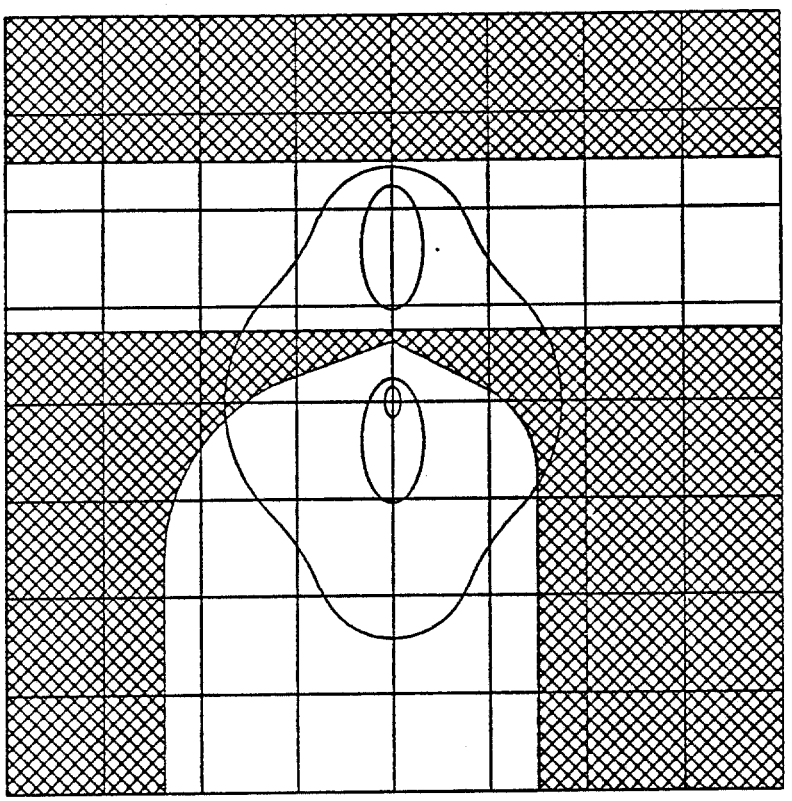


Figure 3-4. Profiles at the Injection Lambertson and Quadrupole

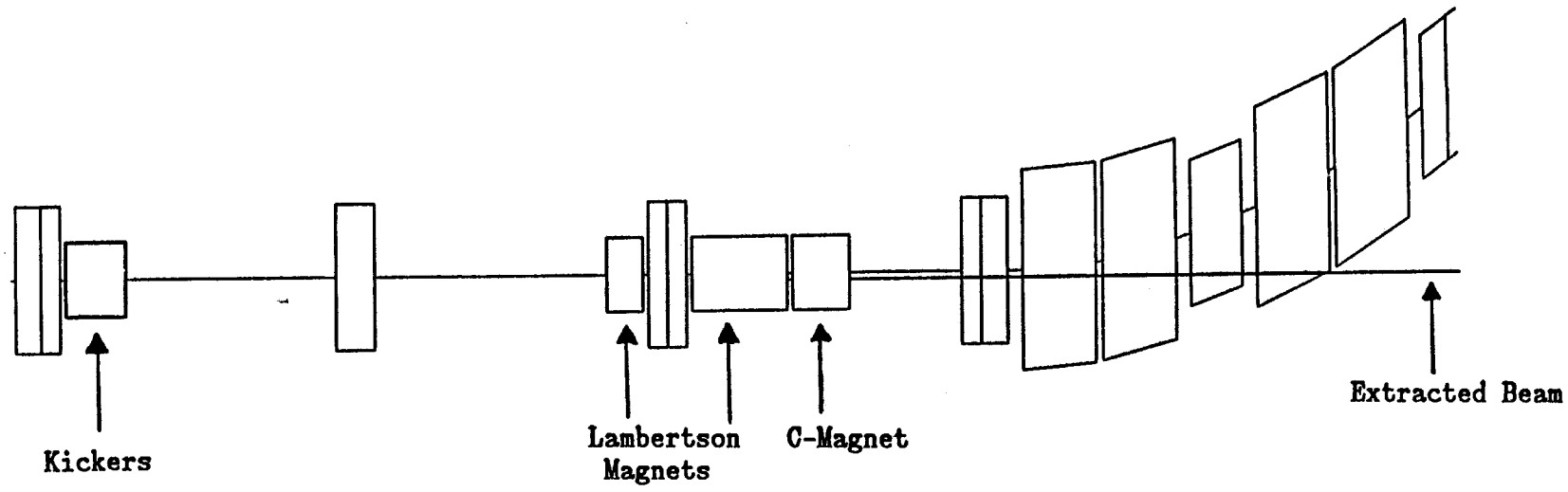


Figure 2-4. Detail (Plan View) of MI-52
used for 8 GeV Antiproton Injection and 120/150 GeV Proton Extraction

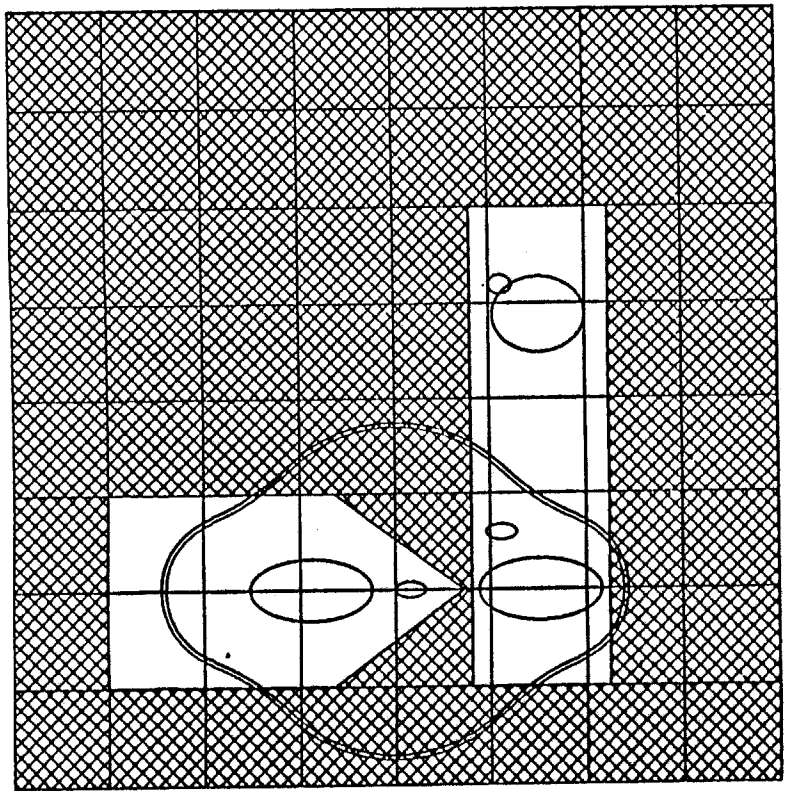


Figure 3-6a.
Profiles at the Extraction Lambertson
and the Adjacent Quadrupole

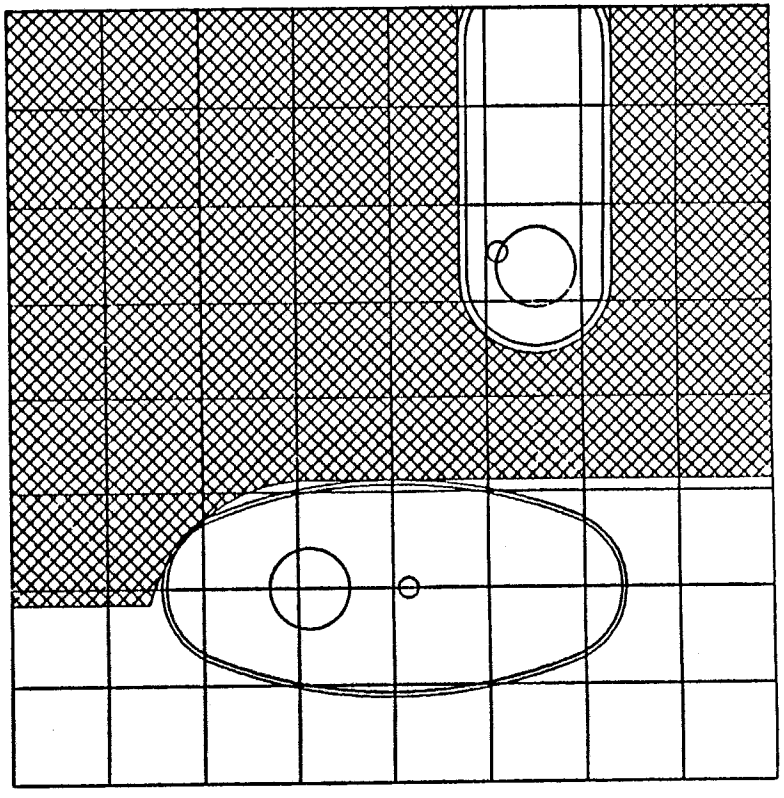
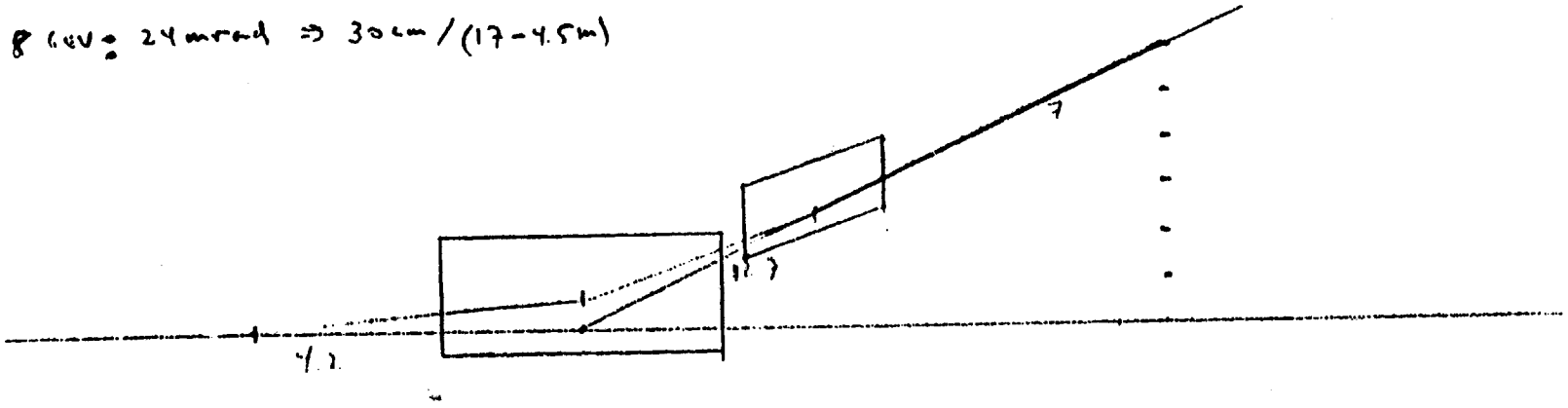
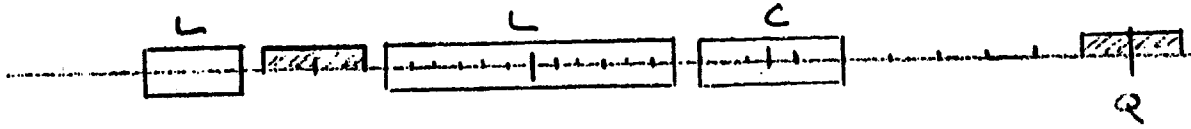


Figure 3-6b.
Profiles at the Entrance to the C-magnet

8 GeV: 24 mrad ⇒ 30 cm / (17 − 4.5 m)





150 GeV:

4.24 mrad × 19.5 m = 8.3 cm
+ 12.72 mrad × 12.5 m = 15.9 cm
+ 7.04 mrad × 7.5 m = 5.6 cm

29.8 cm

FERMILAB ENGINEERING NOTE

SUBJECT

SECTION | PROJECT | SERIAL-CATEGORY | PAGE 8

NAME | DATE | REVISION DATE

PETER BAGLEY

5/8/9.

Main Injector Corrector Workshop
Skew Quads

$$T = \begin{pmatrix} M & m \\ n & N \end{pmatrix} = V \quad U \quad V^{-1}$$

$$= \begin{pmatrix} \gamma I & C \\ -C^{+} & \gamma I \end{pmatrix} \begin{pmatrix} A & 0 \\ 0 & B \end{pmatrix} \begin{pmatrix} \gamma I & -C \\ C^{+} & \gamma I \end{pmatrix}$$

$$\gamma^2 + \det C = 1 \qquad I = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

$$A = \begin{pmatrix} \cos 2\pi\nu_A + \alpha_A \sin 2\pi\nu_A & \beta_A \sin 2\pi\nu_A \\ -\gamma_A \sin 2\pi\nu_A & \cos 2\pi\nu_A - \alpha_A \sin 2\pi\nu_A \end{pmatrix}$$

$$\bar{C} = G_A C G_B^{-1} \qquad G_A = \frac{1}{\sqrt{\beta_A}} \begin{pmatrix} 1 & 0 \\ \alpha_A & \beta_A \end{pmatrix}$$

$$\bar{C} = \frac{-\bar{H}}{2[\cos 2\pi\nu_A - \cos 2\pi\nu_B]}$$

$$H = m + n^{+} \qquad \bar{H} = G_A H G_B^{-1}$$

$$\underbrace{Tr^2(A-B)}_{4[\cos 2\pi\nu_A - \cos 2\pi\nu_B]^2} = Tr^2(M-N) + 4 \det \bar{H}$$

Near coupling resonance $Tr^2(M-N) = 0$

$$\nu_A = \nu + \frac{\Delta\nu}{2}$$

$$\nu_B = \nu - \frac{\Delta\nu}{2}$$

$$\boxed{\Delta\nu = \frac{\sqrt{\det \bar{H}}}{2\pi |\sin 2\pi\nu|}}$$

$$\bar{H} = \bar{H}_+ \sin \pi(2\nu_A + 2\nu_B) + \bar{H}_- J \sin \pi(2\nu_A - 2\nu_B)$$

$$\det \bar{H} = (\det \bar{H}_+) \sin^2 \pi(2\nu_A + 2\nu_B) - (\det \bar{H}_-) \sin^2 \pi(2\nu_A - 2\nu_B)$$

$$J = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \qquad R(\varphi) = \begin{pmatrix} \cos\varphi & \sin\varphi \\ -\sin\varphi & \cos\varphi \end{pmatrix} \qquad q = \frac{\sqrt{\beta_A \beta_B}}{f_s}$$

$$\bar{H}_\pm = R[-\pi(2\nu_A \mp 2\nu_B)] \sum_{k=SQ} q_k R(\varphi_{A,pk} \mp \varphi_{B,pk})$$

$$\det(a_1 R(\varphi_1) + a_2 R(\varphi_2)) = a_1^2 + a_2^2 + 2a_1 a_2 \cos(\varphi_1 - \varphi_2)$$

Sum over many random couplers

$\rightarrow$ Random walk in 2-dimensions

$\rightarrow (\bar{H}_\pm)_{rms} = \sqrt{N}\, q_{rms}\, R(\varphi)$ $\quad \varphi$ is random

$\rightarrow \det(\bar{H}_\pm)_{rms} = N q_{rms}^2$

Near coupling resonance

$$(\det \bar{H})_{rms} \approx \det(\bar{H}_+)_{rms} \sin^2 2\pi\nu = N q_{rms}^2 (\sin^2 2\pi\nu)$$

$$\boxed{\Delta 2\nu_{min} = \frac{\sqrt{\det \bar{H}}}{2\pi |\sin 2\pi\nu|} = \frac{\sqrt{N}\, q_{rms}}{2\pi}}$$

$\Delta 2\nu_{min}$ is determined by $\det(\bar{H}_+)_{rms}$

$\bar{H}_+$ propagates like $\varphi_A - \varphi_B$

Quads

About 208 quads

Typical strengths of $.09 \frac{1}{m} = K\ell$

$\theta_{rms} \approx 1$ mrad

$$\sqrt{N}\, q_{rms} = \sqrt{N}\sqrt{\beta_A \beta_B}/f_s = \sqrt{N}\sqrt{\beta_A \beta_B}(K\ell)(2\theta_{rms})$$

$$= \sqrt{208}\sqrt{(60m)(10m)}(.09\tfrac{1}{m})(2)(.001\,rad)$$

$$= .064 = \sqrt{\beta_A \beta_B}(K\ell)(.029)$$

Sextupoles

About 108 sextupoles

$$\frac{\Delta x'}{x^2} = .485 \times 10^{-2} \frac{1}{m^2}$$

$$= -.915 \times 10^{-2} \frac{1}{m^2}$$

$y_{rms} = 3$ mm

$$\sqrt{N}\, q_{rms} = \sqrt{N}\sqrt{\beta_A \beta_B}/f_s = \sqrt{N}\sqrt{\beta_A \beta_B}\left(\frac{\Delta x'}{x^2}\right) y_{rms}$$

$$= \sqrt{108}\sqrt{(60m)(10m)}\sqrt{(.485)^2 + (-.915)^2} \times 10^{-2} \frac{1}{m^2}(3\,mm)$$

$$= .0079 = \sqrt{\beta_A \beta_B}(K\ell)(.0036)$$

Global Coupling

$$\Delta 2\nu_{min} = \frac{\sqrt{\det(\bar{H}_+)}}{2\pi} = \frac{\sqrt{N}\, q_{rms}}{2\pi}$$

determined by $\bar{H}_+$ which propagates like

$$\varphi_A - \varphi_B$$

Since $2\nu_A - 2\nu_B \approx 1$, we want 2 skew quads separated by $\approx \frac{1}{4}$ the ring.

$$\frac{1}{f_{skew}} \approx (3)(.029)(.09\tfrac{1}{m}) = .008\,\tfrac{1}{m}$$

Local Coupling

If the global coupling has been corrected, remainder is mostly $\bar{H}_-$, which propagates like $\varphi_A + \varphi_B$ (expect $\bar{C} \approx .036$)

Phase advance per cell is $\approx \frac{\pi}{4}$

So $\varphi_A + \varphi_B$ advances by $\approx \frac{\pi}{4}$ in <u>half cell</u>

<u>Local</u> Coupling so want <u>Local</u> Compensation

Satisfied if we can "close the bump"

2 skew quads separated by half cell.

$$\frac{1}{f_{skew}} \approx .008\,\tfrac{1}{m}$$

Vertical Dispersion

Treat this like a vertical closed orbit where the vertical kicks are $\Delta y' = \frac{\eta_{horiz}}{f_{skew}}$

$$y_{co} = \frac{(\Delta y')\sqrt{\beta_{source}\,\beta_{obs}}}{2\sin \pi\nu} \cos(\varphi_{obs} - \varphi_{source} - \pi\nu)$$

$$\Downarrow$$

$$|\eta_{v,peak}| \approx \left(\frac{1}{f_{skew}}\right)_{rms} \frac{\eta_{horiz}\sqrt{\beta_{v,source}\,\beta_{v,obs}}}{2\sin \pi\nu}$$

if η_{horiz} is large $\Rightarrow \beta_v$ is small

$1.\,m < \eta_{horiz} < 2m$ in the arcs

$$|\eta_{v,peak}| \approx \left(.0026\tfrac{1}{m}\right) \frac{(2m)\sqrt{(10m)(60m)}}{2\sin \pi(.42)}$$

$$\approx 7.\ cm$$

Shouldn't be a problem.

What skew quads do we have from the MR?

From TM1412 Magnetic Measurements of the Correction and Adjustment Magnets of the MR
D. Trbojevic July 1986

18 SQ's in MR

$$\frac{a_2 * L_{eff}}{I(A)} = 7.506 \times 10^{-3} \frac{T}{A} \qquad (0-15A)$$

$$\text{max strength} \approx (15A)\left(7.5 \times 10^{-3} \frac{T}{A}\right)\left(\frac{3 \times 10^8}{150 \times 10^9} \frac{s \cdot C}{kg \cdot m}\right)$$

$$= 2.3 \times 10^{-4} \frac{1}{m}$$

physical length $\approx 8\frac{1}{2}$ inches

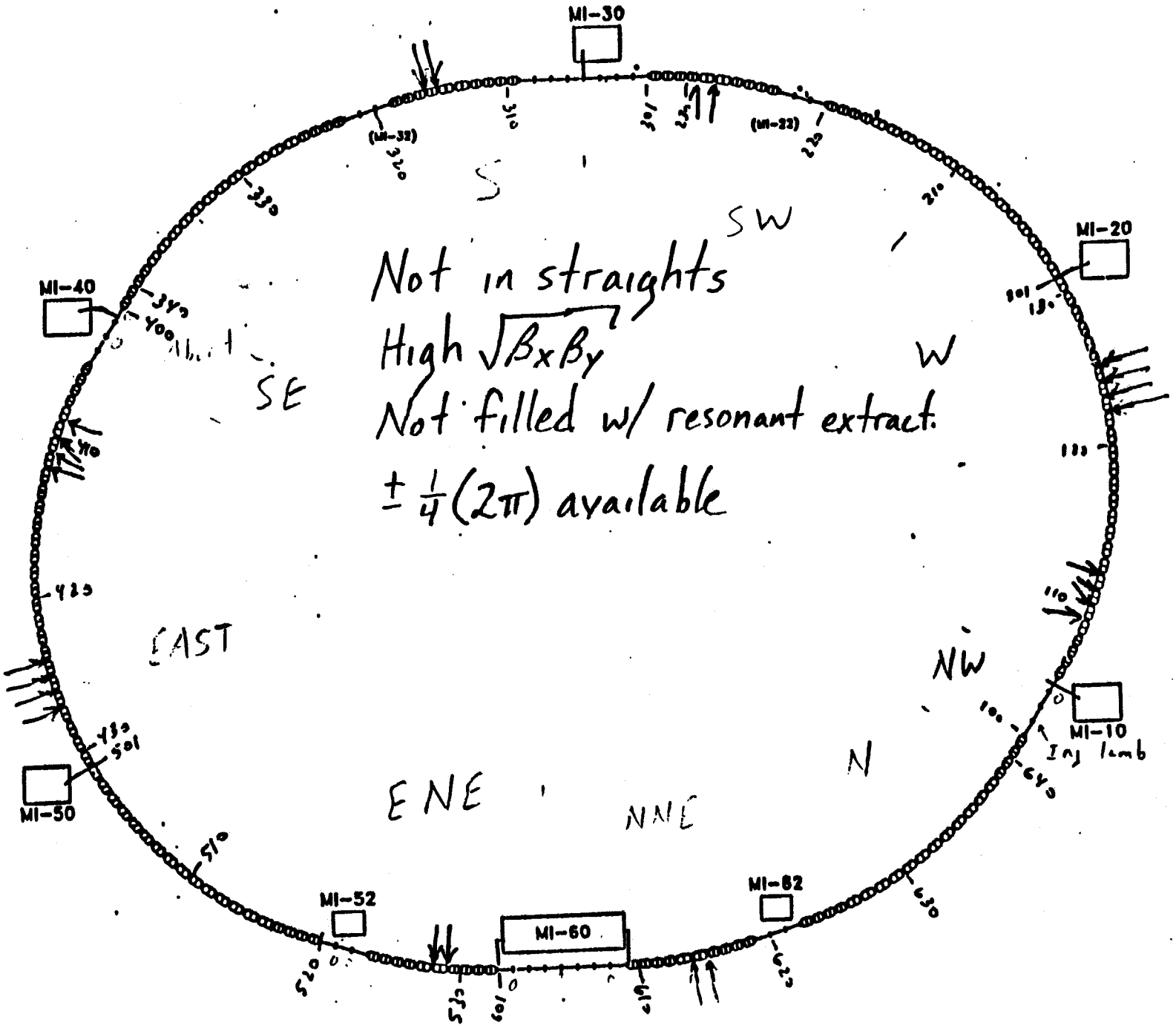
desired SQ strengths $\approx .008 \frac{1}{m}$ per SQ

$$\boxed{\frac{.008 \frac{1}{m}}{.00023 \frac{1}{m}} \approx \underline{\underline{35}}}$$

Ways out

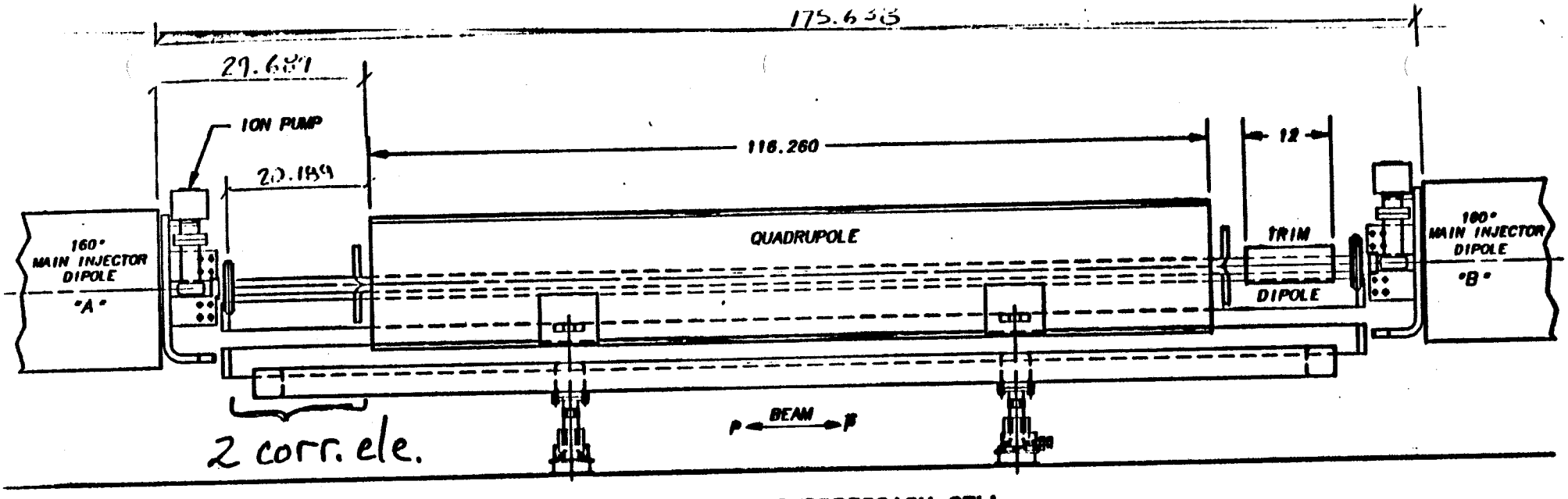
1) Tighten roll angle tolerance on quads
   1 mrad rms $\Rightarrow$ 0.3 mrad rms
2) Build new stronger skew quads
   about 3.5 * stronger but still at 15A
   should not be difficult
3) Rotatable Quads ??

$1 - \cos 2\theta \approx -.4e-3$ for $\sin 2\theta \approx \frac{1}{35}$

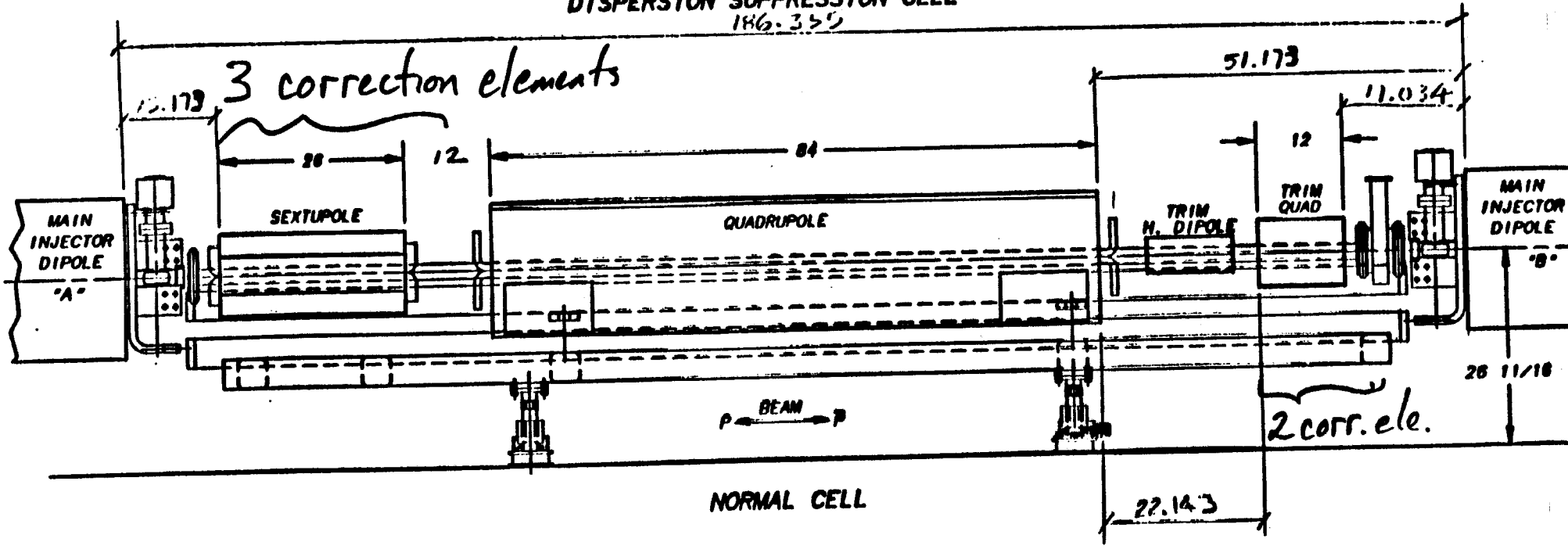


Not in straights
High $\sqrt{\beta_x \beta_y}$
Not filled w/ resonant extract.
$\pm \frac{1}{4}(2\pi)$ available

MI-17



DISPERSION SUPPRESSION CELL



NORMAL CELL

ACTION ITEMS

To: slh@fnal.fnal.gov, dej@calvin.fnal.gov, harding@fnal.fnal.gov, shan@calvin.fnal.gov, peggs@calvin.fnal.gov, ppb@calvin.fnal.gov, dejan@calvin.fnal.gov, bcbrown@fnal.fnal.gov, holmes@adcalc.fnal.gov, pmartin@fnal.fnal.gov
Subject: MI Correctors Workshop: ACTION ITEMS

MI CORRECTORS WORKSHOP ACTION ITEMS

The following is a list of the points that we all agreed needed to be addressed. What I am looking for is a 1 or 2 page note which may be handwritten. If possible (actually even if it is impossible), I would like to get your contribution BEFORE MAY 29. I would prefer May 22, but I suspect that some people will want to take a few days off around Memorial Day.

Francois

==========

(0) Description and Specs of existing Power Supplies
[In writing !]
======> STEVE HAYS <=========

(1) Should we worry about alignement errors in beamlines ?
======> DAVE JOHNSON <=======

(2) Hysteresis effects in beamline magnets: do we care ?
Should they be measured ? Past experience ?
======> DAVE HARDING <=======

(3) Comparison of existing Booster gamma_t quadrupoles with requirements for MI. Can we recycle an existing design to build MI quadrupoles ?
======> JIAN PING SHAN<======

(4) 30% random variation in Beta. How does that affect slow extraction ? What kind of RMS variation in the quad strength can we tolerate ? To what extent can the situation be improved by sorting the quads ?
======> STEVE PEGGS <=========

(5) What can be said about the existing ~25 unit rms variation in quadrupole strength ... How can it be explained ?
Is reality REALLY that bad ? Can some statement be made about which part of the rms variation represents measurement error ?
Suppose we decide that we want a better measurement of the quad strength (say within 5 units of integrated strength) what does that imply ?
======> BRUCE BROWN<========

(6) How well can quad roll be determined ? How would that be done ?
======> PETER BAGLEY<=======

(7) Do we need other harmonic correctors ?
=======> DEJAN TRBOJEVIC<======

(8) Pros and cons: smaller number of longer sextupoles ?
large number of shorter sextupoles ?
========> ALEX BOGACZ<==========

(9) Is there any problem with a 3rd order resonance from chromatic sextupoles in the MI ?
=======> DEJAN TRBOJEVIC<======

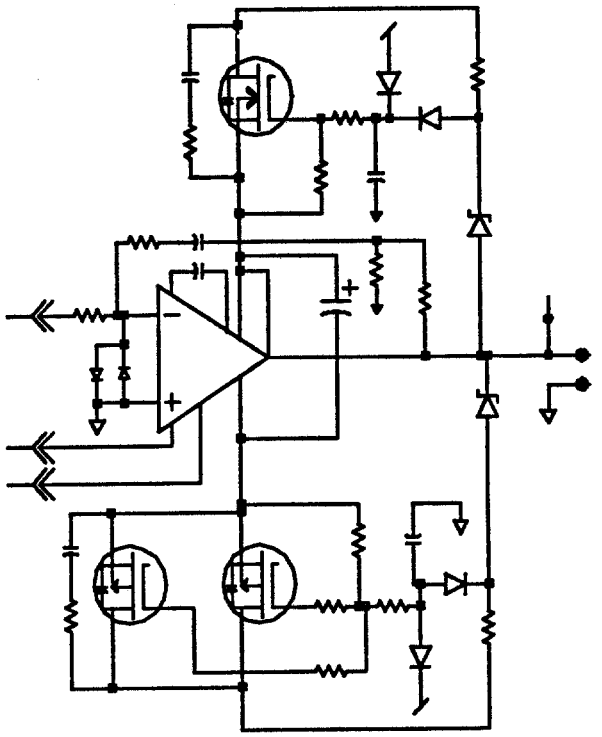
End of returned message

STEVE HAYS

Steven Hays
5-15-92

MAIN INJECTOR CORRECTION ELEMENT POWER SUPPLIES
(Reused Main Ring Correction Element Supplies)

SMALL CORRECTORS



The Main Ring Correction Element Magnet Power Supply system consist of two 5K watt bulk power supplies and a power op-amp for each magnet. Figure 1 shows the output stage for each channel. These channels are grouped 6 per chassis with two chassis grouped with a pair of bulk power supplies. The 6th channel can be configured for twice the output voltage if needed for larger magnets. What this means is that the channels are to be moved in groups of 12 but can be broken up into groups of 6 if we buy more bulk supplies at ≈$8K/pair. The channels are water cooled so installation will require a location with 95° F water.

The choice of linear power amplifiers for these supplies was driven by the reuse of the existing cable in the Main Ring and the shared tunnel space with the collider. The noise transmitted from long unshielded cables connected to switcher power supplies was believed to be a possible problem, limiting life times in the collider. The relocation of the main injector out of the collider tunnel will allow the use of switcher power supplies. Any new channels that must be added to the main injector correction system should have switcher supplies installed.

NEW SEXTUPOLE LOOPS

The main Sextupole correction systems in the cost estimate are 150 volt 480 amp power supplies. They are four quadrant switcher supplies and will have a bandwith of 4K Hz and 100ppm pulse to pulse regulation. The supplies cost is ≈ $90K each installed. If the correction loops can be first or first and fourth quadrant only the cost of this system will go down to ≈ $40K each.

Steven Hays
5-15-92

Specifications

Correction Element:

Power Supplies

Output Voltage Standard Channel	± 80 Volts
Output Voltage Dual (super Dipoles)	± 160 Volts
Output Current all channels	± 12A peak
Average RMS over one minute	6A RMS
Ramping limits	
Current to peak value	50 A/sec
Bandwidth for all except Super Dipole	1K Hz
Super Dipole	800 Hz
Total Bulk Power Supply Current	80 or 100 amps

The channels are grouped in sets of 12 per bulk supply. The total current draw must be less than the above number in any one direction.

Magnet Loads

Super Dipole (18 magnets installed)	800 mH
Horizontal and Vertical Dipole	300 mH
Tev 1 trim Dipole	300 mH
Quadrupole	80 mH
Sextupole	100 mH
Skew Sextupole	35 mH

Load resistance is set to 6 ohms for all standard channels to control the power in the amplifiers and 12 ohms for the dual channels.

DAVE JOHNSON

DO WE NEED TO WORRY ABOUT MAGNET ALIGNMENT IN BEAMLINES : A FOLLOW UP REPORT FOR THE MAIN INJECTOR CORRECTION ELEMENT WORKSHOP IN MAY '92.

DAVE JOHNSON JUNE 12, 1992

> It is assumed that there will be a corrector and BPM at every quad location in all transport lines.

> The critical aperture for the MI-52 TO FØ beamline is the vertical aperture through the rolled B2's. This will limit the available aperture to approx. ±4mm for a 40 π beam (8.9 GeV/c pbars).

> The following errors were introduced into the lattice as a random gaussian distribution.

TABLE 1

ERROR			1σ VALUES
H quad misalignment	–	DX	.25mm
V quad misalignment	–	DX	.25mm
B2 roll error	–	DPSI	.5mr
CMAGNET roll error	–	DPSI	.5mr
random B2 field error	–	ΔB/B	25 units (25×10^{-4})

These errors are consistant with those used for tracking in the MI.

> Twenty seeds were used to obtain a distribution of orbit distortions. Figure 1 shows the central trajectory (uncorrected) from the 20 seeds.

> Seed 1357 was chosen for correction at both injection and 150 GeV levels. Five cases were investigated as summarized in Table 2.

TABLE 2

CASE	E	Position Constraints (mm) BPM's 2-14	Position Constraints (mm) Inj BPM's	Corrector Constraints (μr) θ_H (max)	Corrector Constraints (μr) θ_V (max)
1	8	0.0	0.0	±1000	±1000
2	150	0.0	0.0	±117	±40
3	150	±5	0.0	±117	±40
4*	8	0.0	0.0	±1380	±477
5*	150	±10	0.0	±117	±40

* The alignment errors listed in Table 1 were increased by a factor of 4 for these two runs.

> The results of the fit for cases 1 and 2 are shown in Figure 2. These show the before and after trajectory and corrector strengths (rms and max). If the double strength horizontal correctors are used, they should be able to compensate for errors in Table 1. In all runs with 150 GeV corrector limits there were at least 1 corrector maxed out at 40 μr [10 Amps in a standard V corrector].

> Table 3 summarizes the results of the five cases.

Table 3

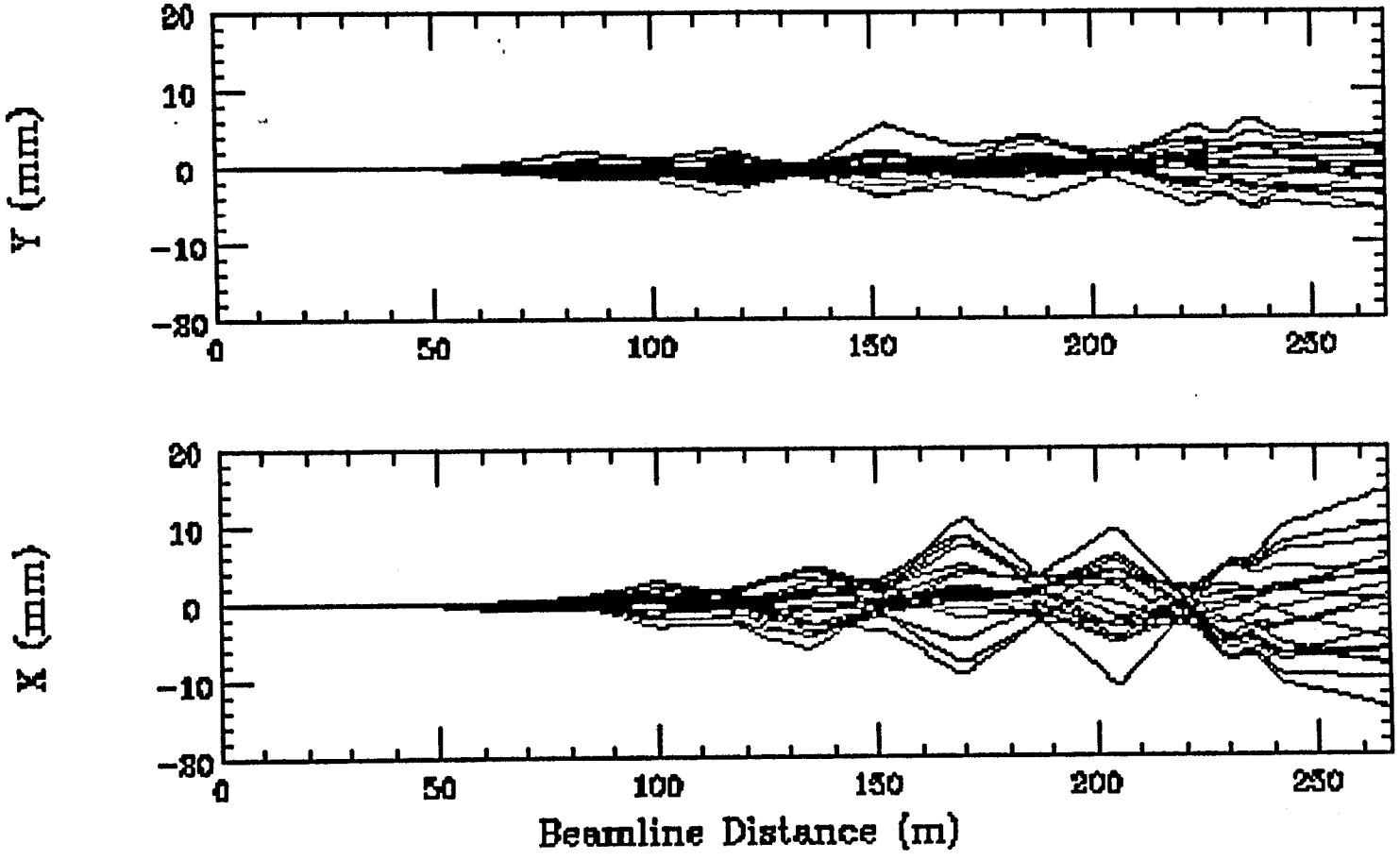
CASE	E	θ_H (rms) [μr]	θ_H (max)	θ_V (rms)	θ_V (max)
1	8	62	99	41	78
2	150	62	97	29	40
3	150	66	92	24	39
4 *	8	113	166	150	272
5 *	150	114	117	40	40

> RESULTS / SUMMARY (further details in upcomming MI-NOTE)

1. With correctors at each quad there is no trouble correcting the errors in Table 1 or correcting X4 the errors at 8 GeV. (# 1 & 4)
2. In runs 2 and 3 the vertical orbit at 150 GeV was corrected but at least 1 vertical corrector was maxed out. The horizontal correctors were well within their range but at least 1 of the correctors was at greater than 80% max current.
3. When the correctors were constrained to 150 GeV levels with X4 errors neither orbit was completely corrected with all (almost) correctors at their maximum value.
4. IF ALIGNMENT ERRORS EXCEED THOSE LISTED IN TABLE I STRONGER CORRECTORS ARE NEEDED IN BOTH PLANES (~~PRIMARILY~~ FOR 150 GeV - 8 GeV OK).

5. IF ALIENMENT ERRORS ARE WITHIN THOSE LISTED IN TABLE 1 THEN ONE HORIZONTAL DIPOLE (DOUBLE STRENGTH) AND ONE REGULAR VERTICAL DIPOLE AT QF and QD LOCATIONS ARE SUFFICIENT TO CORRECT 8 GeV TRAJECTORIES BUT NOT 150 G TRAJECTORIES. ADDING A FEW EXTRA H and V DIPOLES TO RUN IN SERIES WITH THE STANDARD CORRECTORS WOULD WORK.

Errors: σ(DX,DY) = 0.25 mm , σ(roll) = 0.5 mr , ΔB/B = 25E−4
Central Trajectory Before Correction: 20 seeds

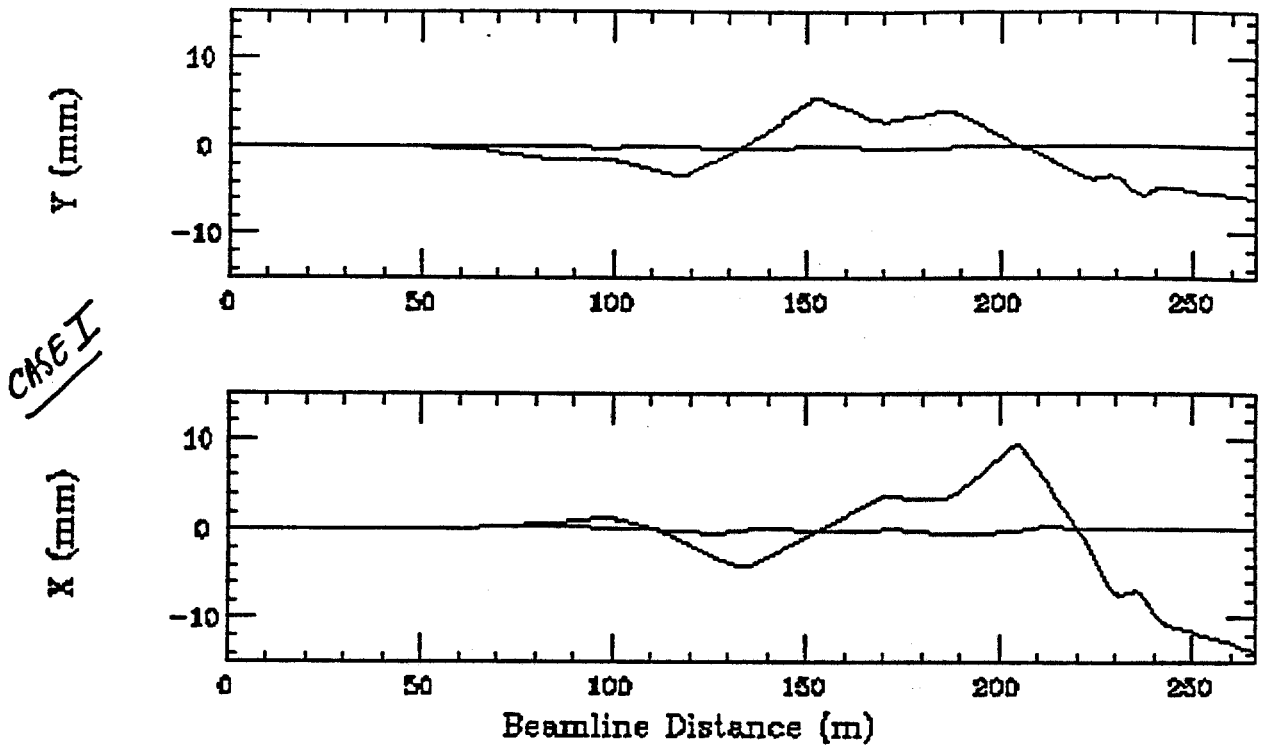


File: ealign_1g10.out

Wed Jun 10 15:19:09 1992

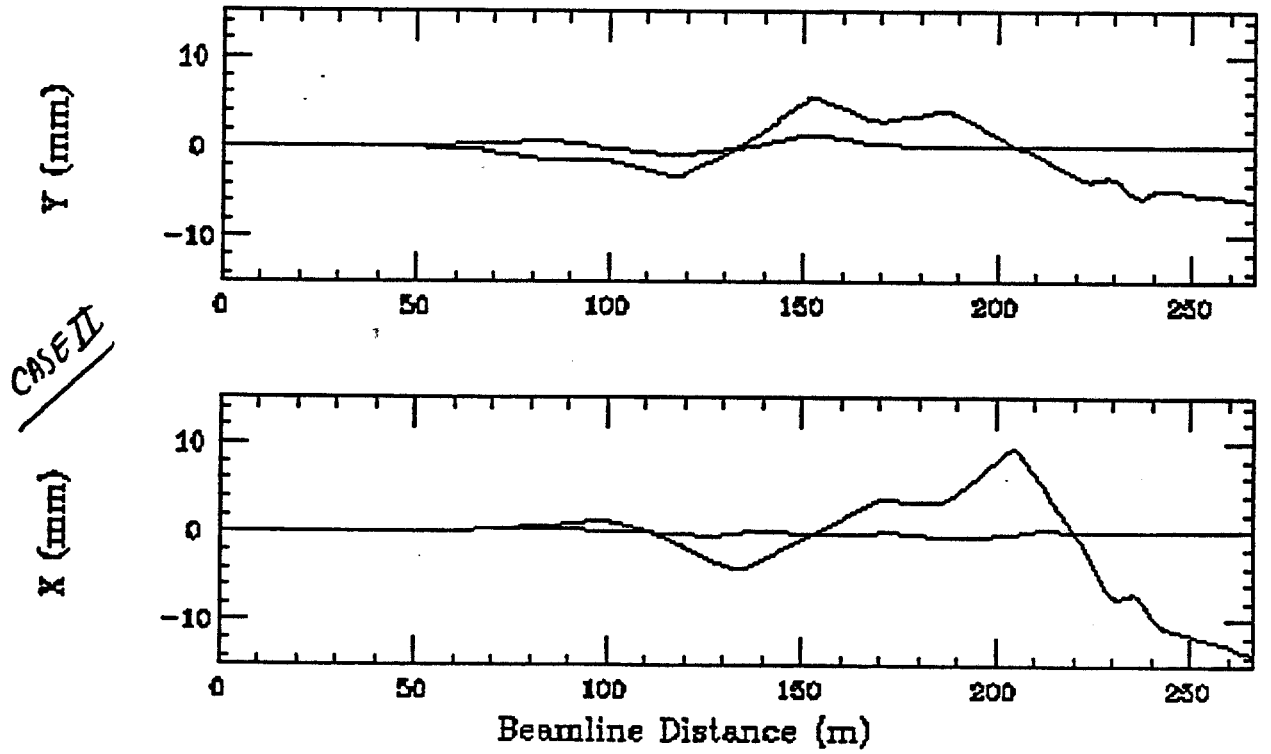
FIGURE 1.

Errors: σ(DX,DY) = 0.25 mm , σ(roll) = 0.5 mr , $\Delta B/B$ = 25E−4
Central Trajectory Before and After Correction: seed 1357
θ_X(rms) = 62 μr θ_X(max) = 99 μr θ_Y(rms) = 41 μr θ_Y(max) = 78 μr



File: ealign_1g10_corr.out Thu Jun 11 08:07:01 1992

Errors: σ(DX,DY) = 0.25 mm , σ(roll) = 0.5 mr , $\Delta B/B$ = 25E−4
Central Trajectory Before and After Correction: seed 1357
θ_X(rms) = 62 μr θ_X(max) = 97 μr θ_Y(rms) = 29 μr θ_Y(max) = 40 μr



File: ealign_1g13_corr.out Thu Jun 11 13:37:39 1992

FIGURE 2.

DAVE HARDING

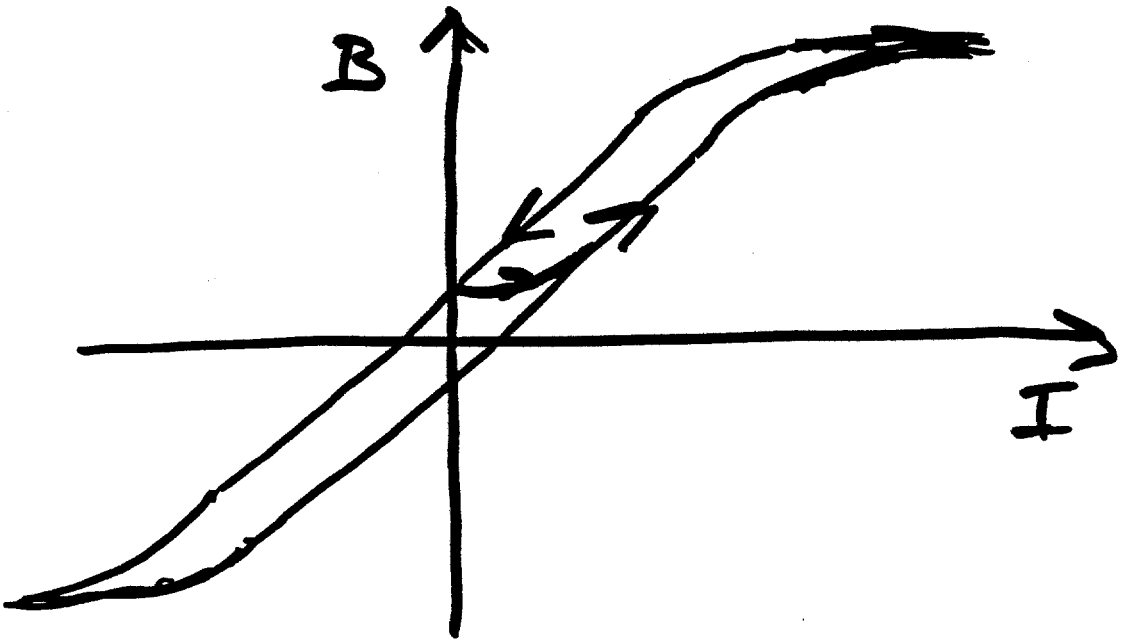
Hysteresis Effects in Beamline Magnets

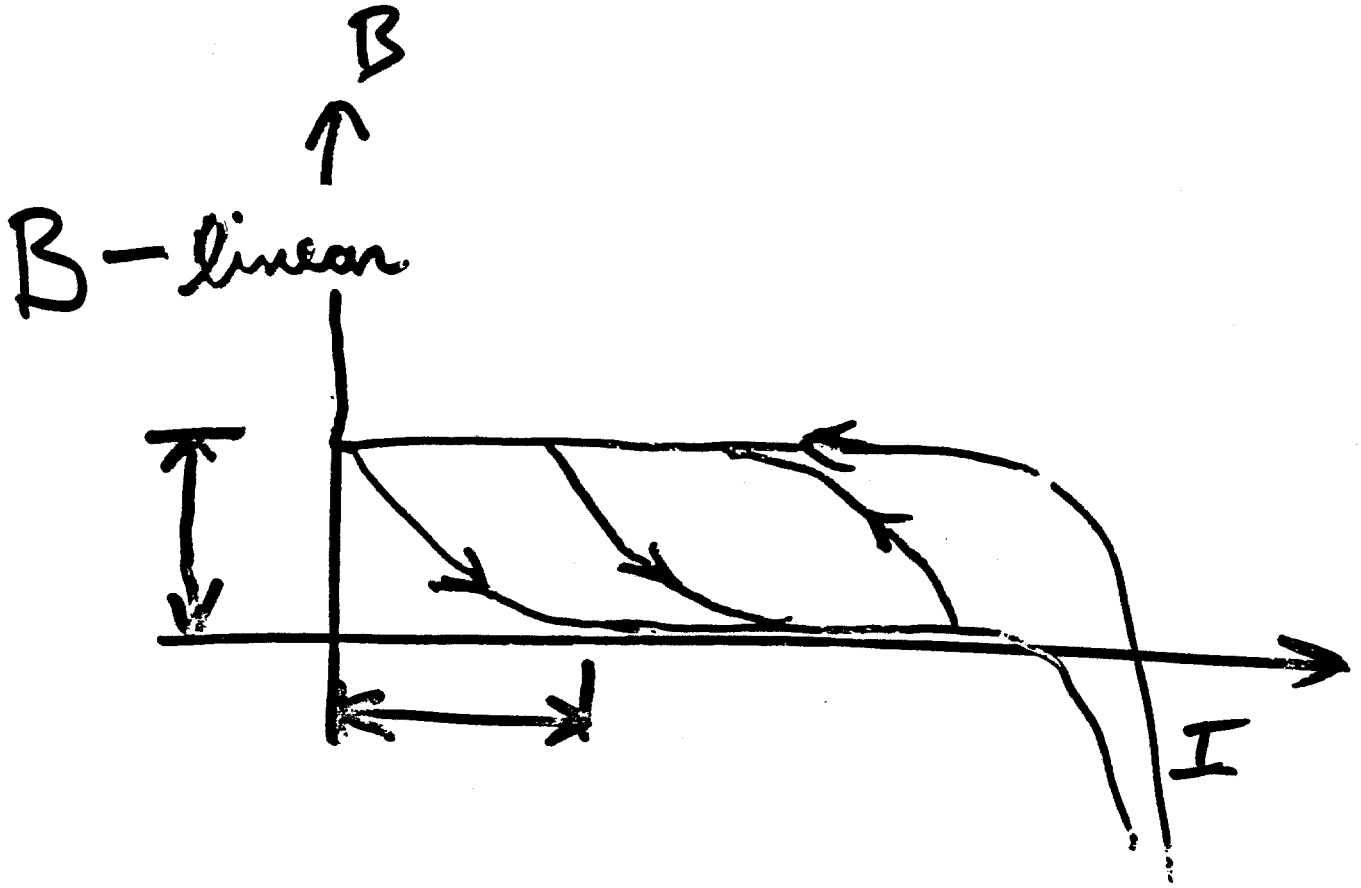
David Harding
22 May 1992

Based on Accelerator Experiment #127
Charles Schmidt (1985)
<u>and</u>
Conversations with
Bruce Brown

See also Pub. notes 430, 431
by Al Wehman (1985)

Hysteresis





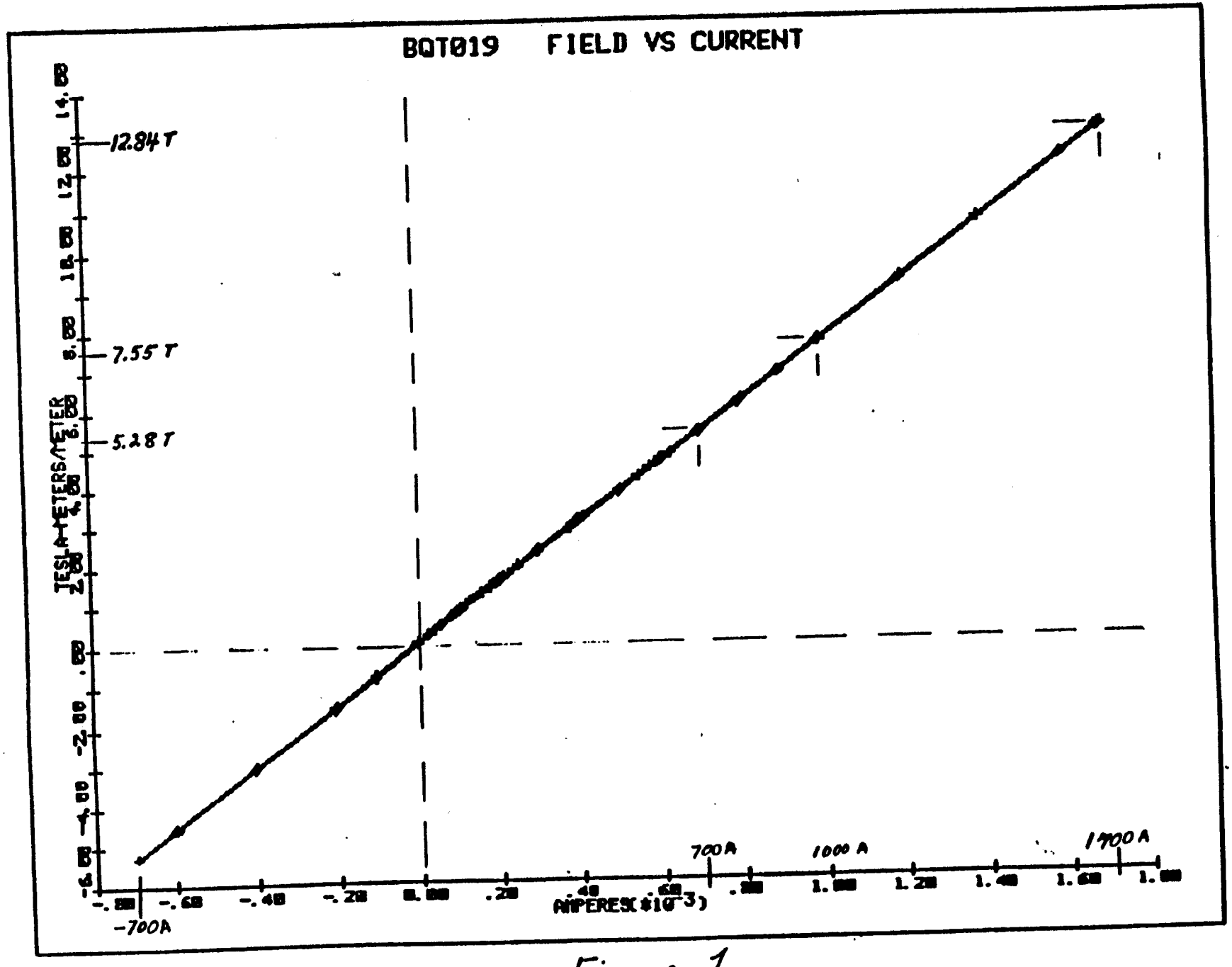

BQT019 FIELD VS CURRENT
TESLA-METERS/METER
AMPERES(*10^-3)
12.84 T
7.55 T
5.28 T
-700A
700A
1000 A
1700 A

Figure 1

After ramping to maximum (preceded by ramps for 300, 500, 700)

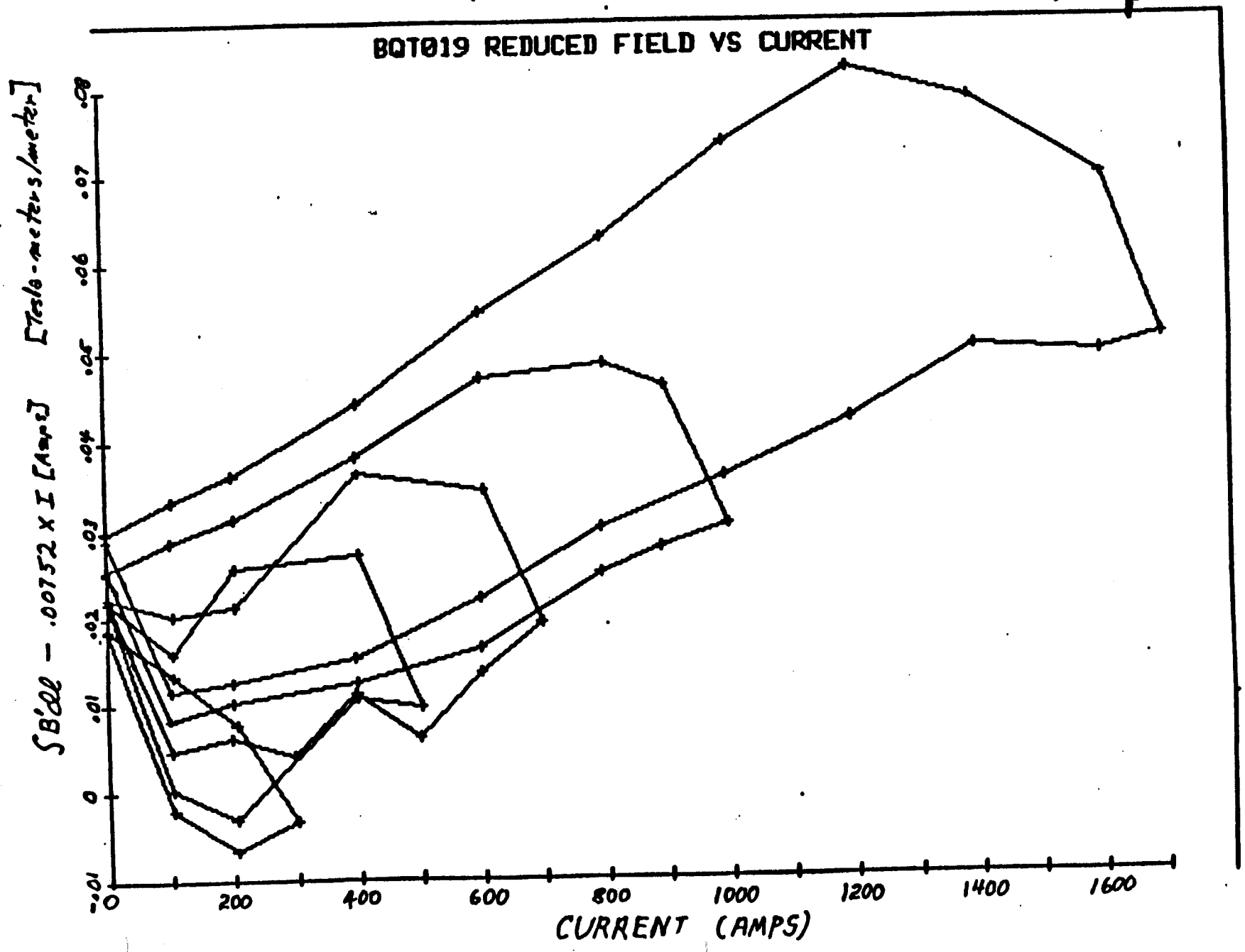


Figure 8

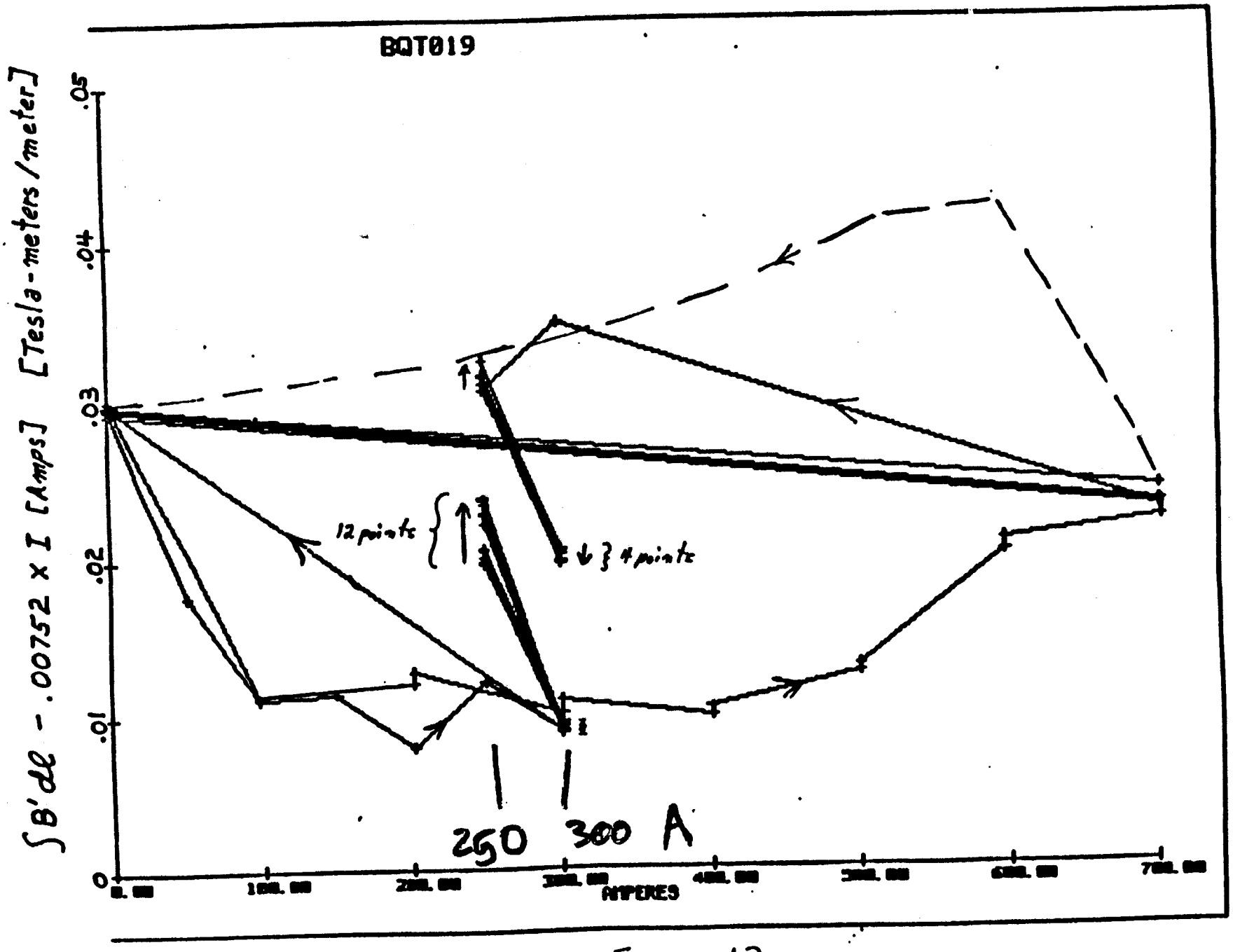

BQT019
∫B' dl - .00752 x I [Amps] [Tesla-meters/meter]
.05
.04
.03
.02
.01
0
0.00
100.00
200.00
300.00
400.00
500.00
600.00
700.00
AMPERES
12 points
4 points
250
300
A

Figure 12

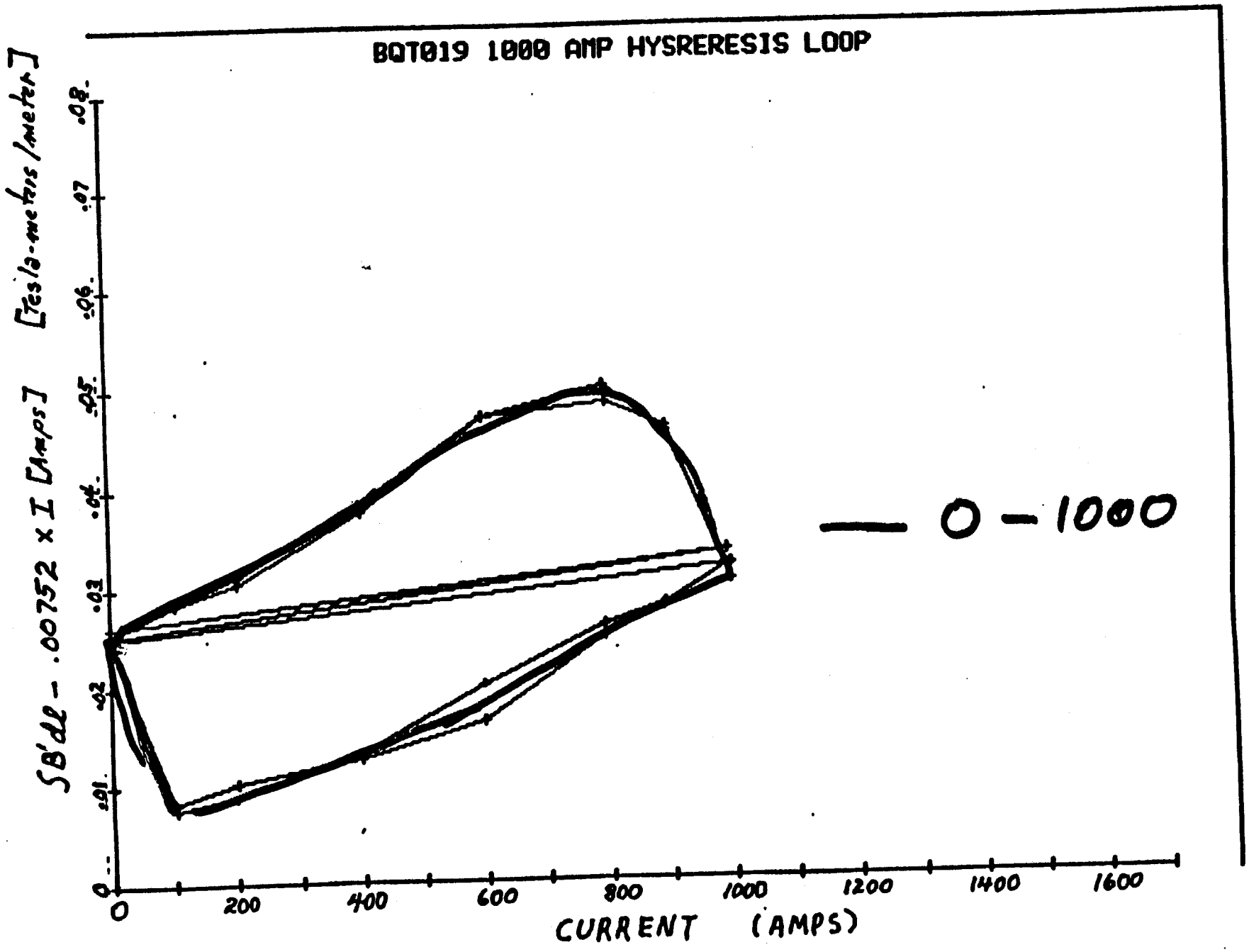

BQT019 1000 AMP HYSRERESIS LOOP
∫B'dl - .00752 x I [Amps] [Tesla-meters/meter]
0
.01
.02
.03
.04
.05
.06
.07
.08
0
200
400
600
800
1000
1200
1400
1600
CURRENT (AMPS)
— 0 - 1000

Figure 13

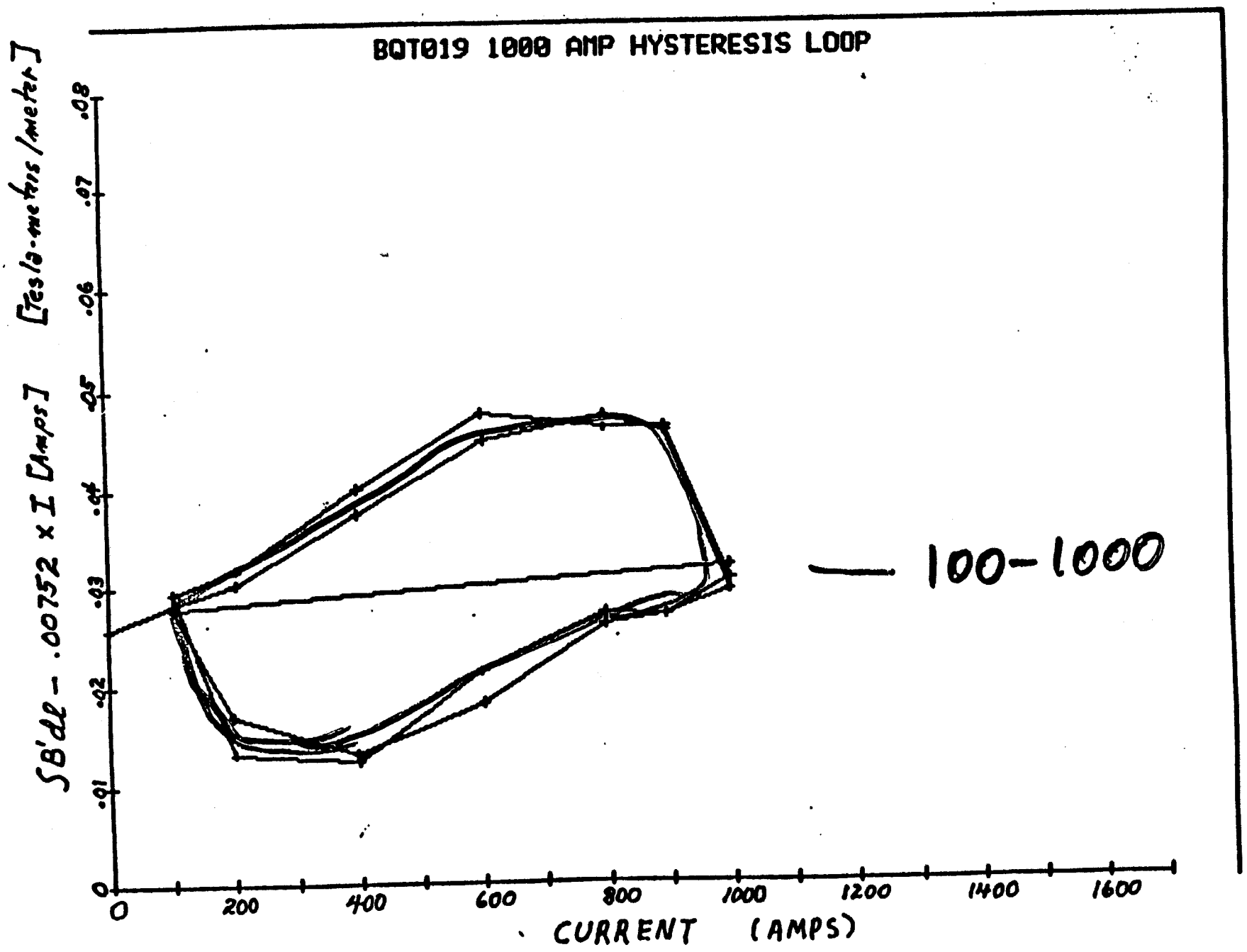

BQT019 1000 AMP HYSTERESIS LOOP
∫B'dl - .00752 x I [Amps] [Tesla-meters/meter]
0
.01
.02
.03
.04
.05
.06
.07
.08
0
200
400
600
800
1000
1200
1400
1600
CURRENT (AMPS)
100-1000

Figure 14

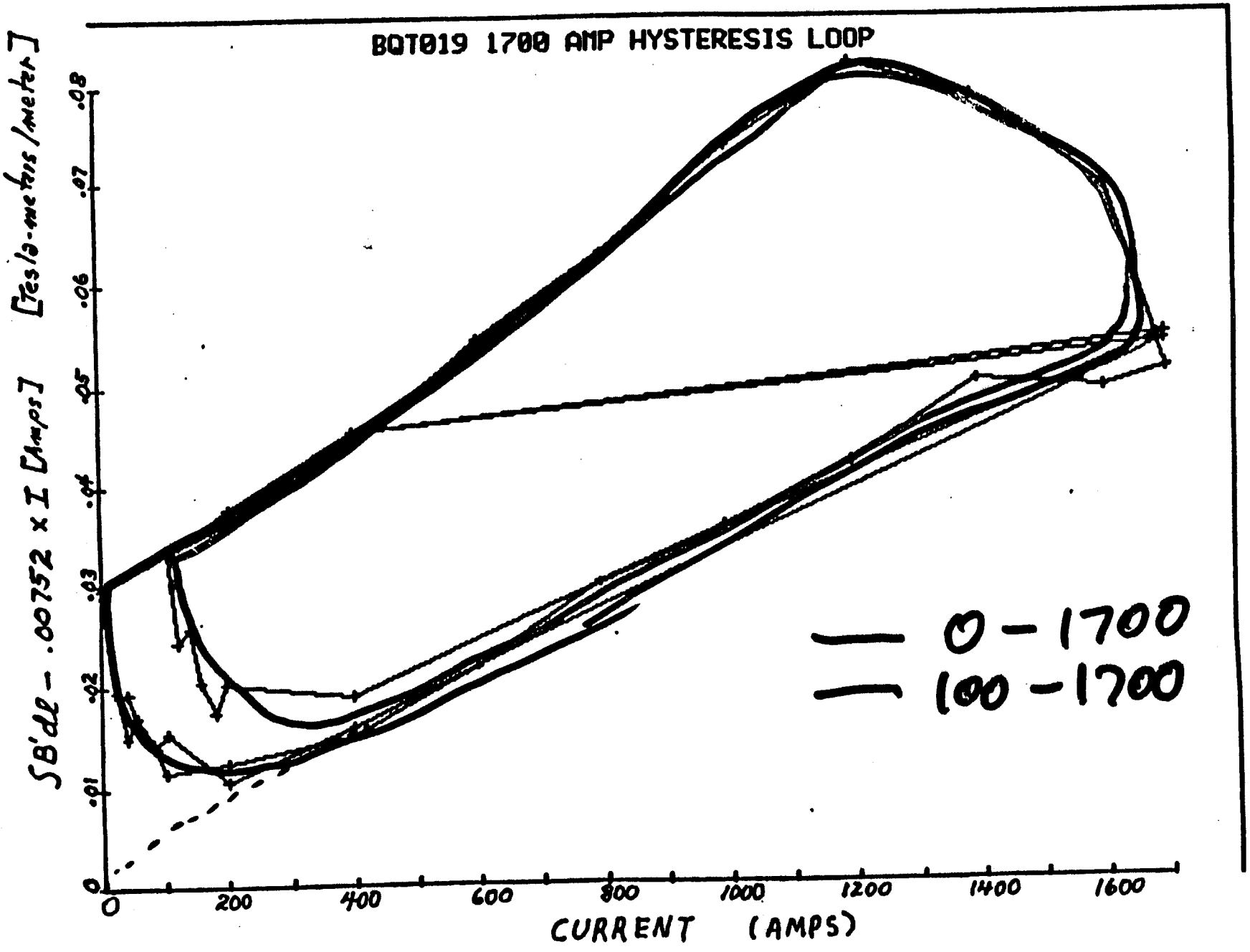

BQT019 1700 AMP HYSTERESIS LOOP
∫B'dl - .00752 x I [Amps] [Tesla-meters/meter]
0
.01
.02
.03
.04
.05
.06
.07
.08
0
200
400
600
800
1000
1200
1400
1600
CURRENT (AMPS)
0 - 1700
100 - 1700

Figure 15

Implications

This is an operational issue.

Take a typical quad:

p	G	I
150 GeV/c	200	3500 A
120	160	2800 A
8.9	11.9	208 A

@ 200 A $\quad \dfrac{\Delta G}{G} = \dfrac{.02}{200 \times .00752}$

$= 1.3\%$

If we care about gradient changes of order 1.3% in beam lines OR <u>ring</u>, then we must pay attention to history to achieve the desired gradient.

JIAN PING SHAN

Comparison of γ_t Jump Magnet

	Booster	MI $\Delta\gamma_t=-1.2$	MI $\Delta\gamma_t=-3$
Magnetic length (in)	9.7	8	
Physical length (in)	10	8.5	
Physical Aperture (in)	6.0	4.0	
Gradient (G/in)	480	400	670
current (A)	2000	2000	3300
rise time (ms)	0.1	0.4	
decay time (ms)	2.5	4	12
Numer of Magnets	12	24	
F/D	15/17	1	

Remarks:

The length ~~of~~ and strength of pulsed quads ~~pr~~ in the current Booster and proposed MI is ~~roughly~~ in the same order.

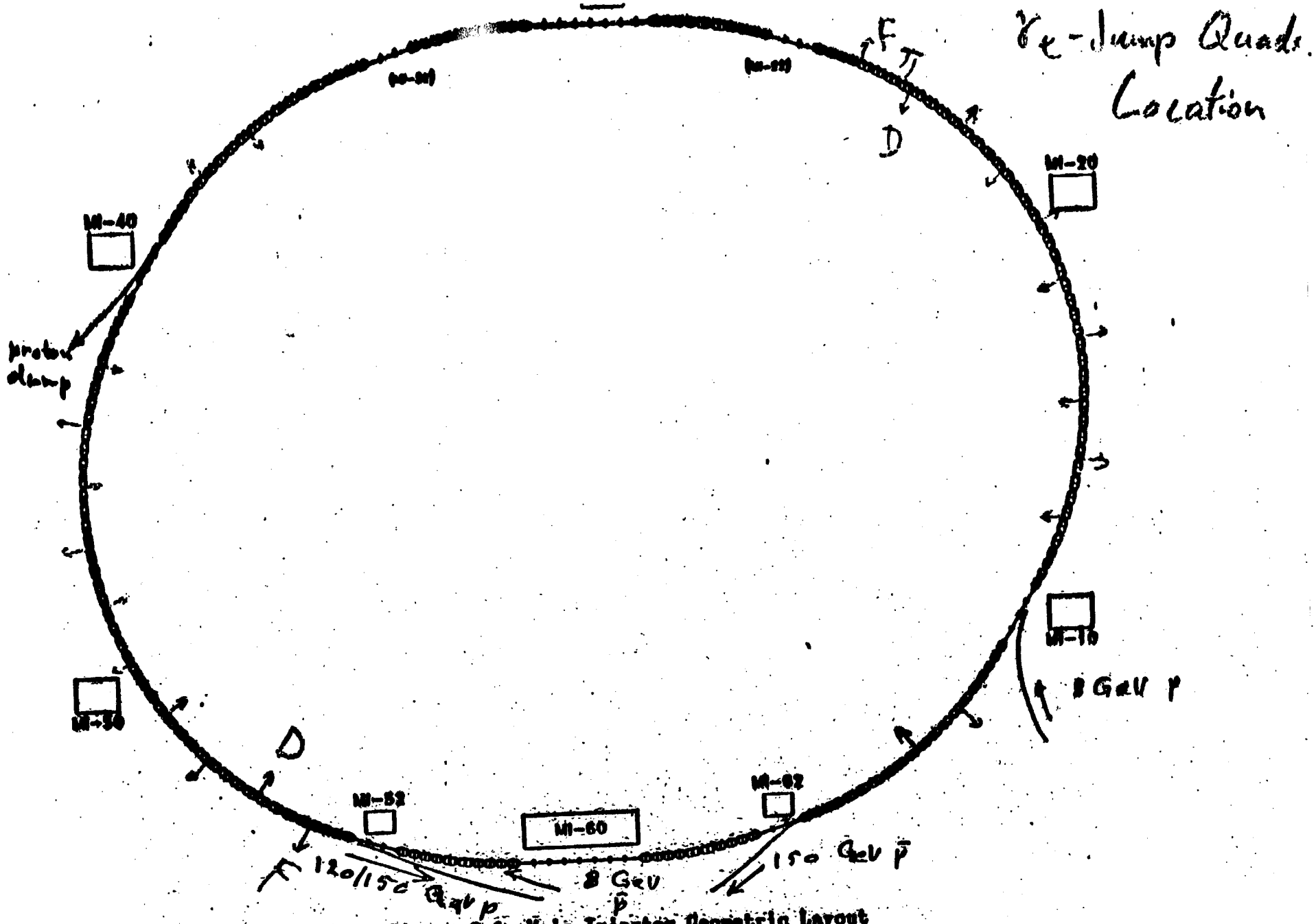
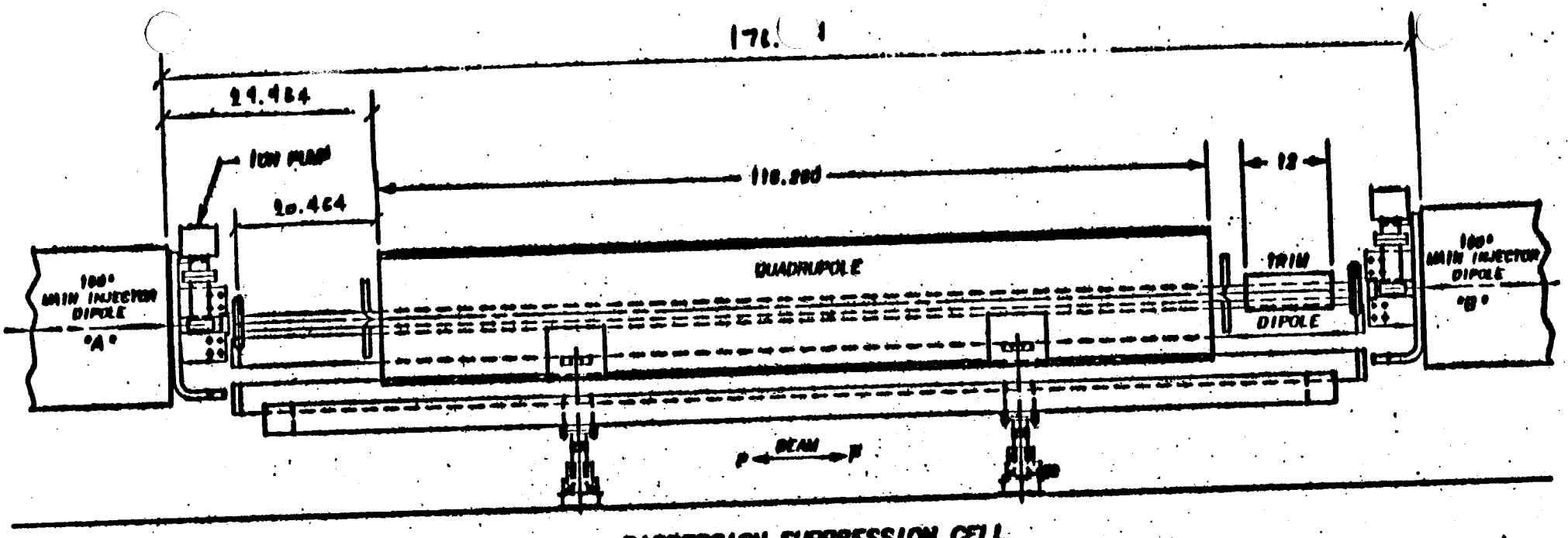
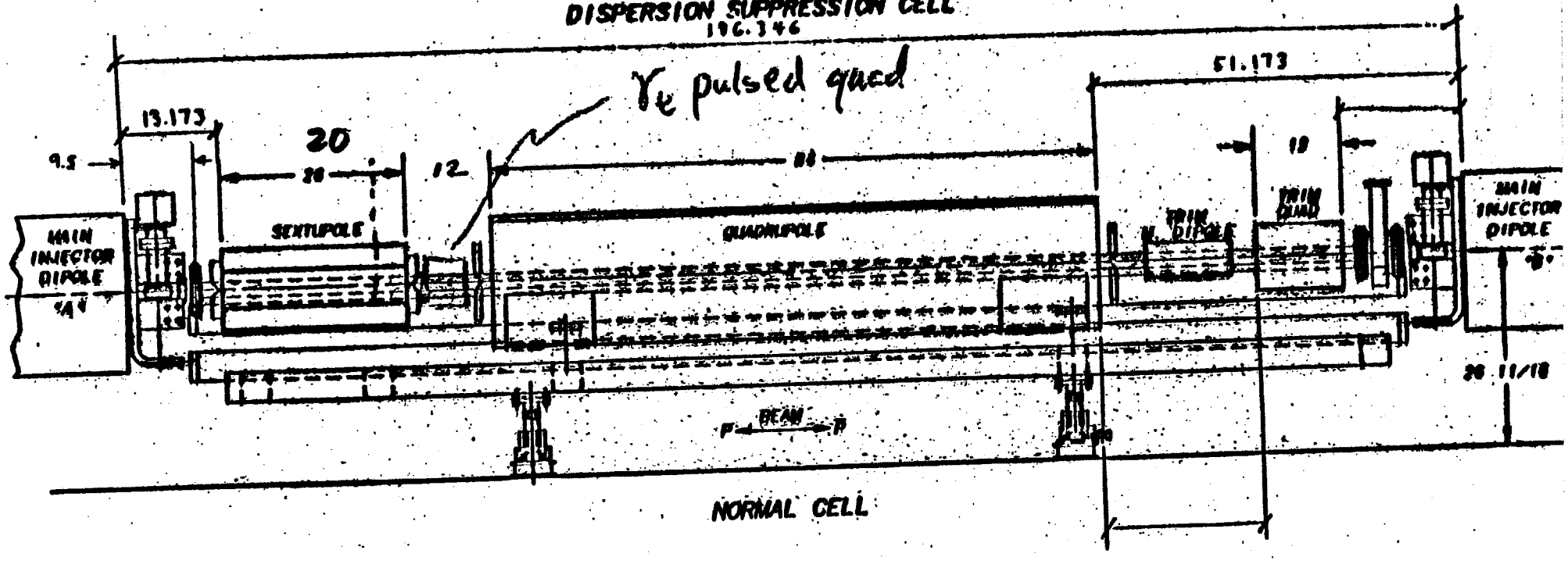


Figure 2-1. Main Injector Geometric Layout
Showing Locations of Service Buildings and Straight Sections



DISPERSION SUPPRESSION CELL



NORMAL CELL

Path Length (m)
0
1000
2000
3000
$\sqrt{\beta_x}$ $\sqrt{\beta_y}$ ($m^{1/2}$)
0
1
2
3
4
η_x η_y (m)
0
1
2
3
4

21

ボーム ビ ー ス

Path Length (m)
0
1000
2000
3000
$\sqrt{\beta_x}$, $\sqrt{\beta_y}$ (m$^{1/2}$)
η_x, η_y (m)

ベータ関数

BRUCE BROWN

MR Quad Preliminary Strength Variation Results

Bruce C. Brown

2 June 1992

The measurements of MR Quads at MTF since 1986 has been carried out with an emphasis on field quality studies. We have utilized a rotating coil harmonic system which provides a strength measurement as well. The usual measurements utilize a 2.75" diameter Morgan Coil probe which is 92" long. An anlaysis of the harmonic field shape with some measurement details is available in B. C. Brown et. al., "Harmonic Analysis of Fermilab Main Ring Quadrupoles" Conference Record of the 1991 IEEE Particle Accelerator Conference, San Francisco, May 6-9, 1991, p. 2128 or FERMILAB-Conf-91/128. Attached is the first analysis of the strength measurement results from that system. It has been carried out using measurements at 1575 A where the field is controlled by the iron shape with neither the remanent field nor the saturation effects from iron quality will affect the results substantially.

The measurements are analyzed using the data from the QUADSET database with some reference to additional information on the measurements from the MRQHARM database. These databases are VAX Indexed RMS files which can be examined using DATATRIEVE. They are stored on the Accelerator Division VAXCluster (ALMOND). From these data we find that the stored information includes the following unwanted data:

- Measurements with a different probe. Use only Probe 21
- Measurements with Stand C/Station A7
  - (Use only Stand A/Station A3 or A7) These Stand C measurements were taken with different current measurement systems which analysis suggests have not been properly cross calibrated with the Stand A Transductor.
- Measurements in which the probe was extended only through half of the body of the magnet.

The measurements are then separated into measurements of OLD STYLE 84" quads, NEW STYLE 84" quads, and NEW STYLE 54" quads. Results for each group are reported separately.

Here are some statistical results from these measurements:

BQB341 Remeasurements

Max	1.2200e-02T/A
Min	1.2153e-02T/A
Range/Avg	3.8161e-03
Sigma/Avg	1.7305e-03
Count	4

BQB Measurement Stats
("New-Style" Quads Only)

Max	1.2323e-02T/A
Min	1.2171e-02T/A
Average	1.2253e-02T/A
Range/Avg	1.2371e-02
Sigma/Avg	3.0398e-03
Count	22

BQB Measurement Stats
("Old-Style" Quads Only)

Max	1.2212e-02T/A
Min	1.2153e-02T/A
Average	1.2176e-02T/A
Range/Avg	4.8550e-03
Sigma/Avg	2.6214e-03
Count	3

BQA Measurement Stats
("New-Style" Quads Only)

Max	7.6920e-03T/A
Min	7.5171e-03T/A
Average	7.5551e-03T/A
Range/Avg	2.3156e-02
Sigma/Avg	5.6249e-03
Count	16

In an attempt to discover measurement errors and possible correlations within the data, we examined the strength as a function of both serial number and of the octapole strength (b4 in this notation). One check is to consider the strength change created by the geometry change associated with the change of "OLD STYLE" quads into quad in which the top half core was machined to remove 0.010 inches (sigma of 0.001 inch) of steel. We compare this change as observed and as calculated using PE2D (by Francois Ostiguy).

Calculation of Gradient Change w/ inifinte mu.

G standard geometry	9.4242e+00	(ignor units....)
G 2 x .005" added	9.3825e+00	(ignor units....)
G 2 x .050" added	9.0171e+00	(ignor units....)
Frac Change per 10 mils	4.4301e-03	
Frac Change per 10 mils	4.3197e-03	

We note that this is about one half of
-2 sin 45 dy/r -9.4281e-03
which is the result for a symmetric change of pole location

The measured result based on 3 "OLD STYLE" quads and 16 "NEW STYLE" quad is
Frac Change per 10 mils -6.277E-03
but the variation is such that this result is only a bit more than one sigma from the expected result.

The printed version of this note will include plots of strength vs octapole and strength vs serial number for both the 84" and 54" magnets with the vertial scale appropriately adjusted. The variation with production serial number is not conclusive with the present set of data but it is suggestive that there may be the large variations as suggested by the width of this distribution.

Conclusions: We can examine the 84" quads for their strength variation. If we assume that the measurement errors which create the variations during repeat measurements of BQB341 are representative of the measurement errors for the whole sample of BQB quadrupoles measured with Stand A then we may wish to subtract (in quadrature) that sigma. This results in the following measurement of the strength distribution of BQB "NEW STYLE" quads.

Correct Width for remeasurement error
BQB Sig/Avg 2.4992e-03

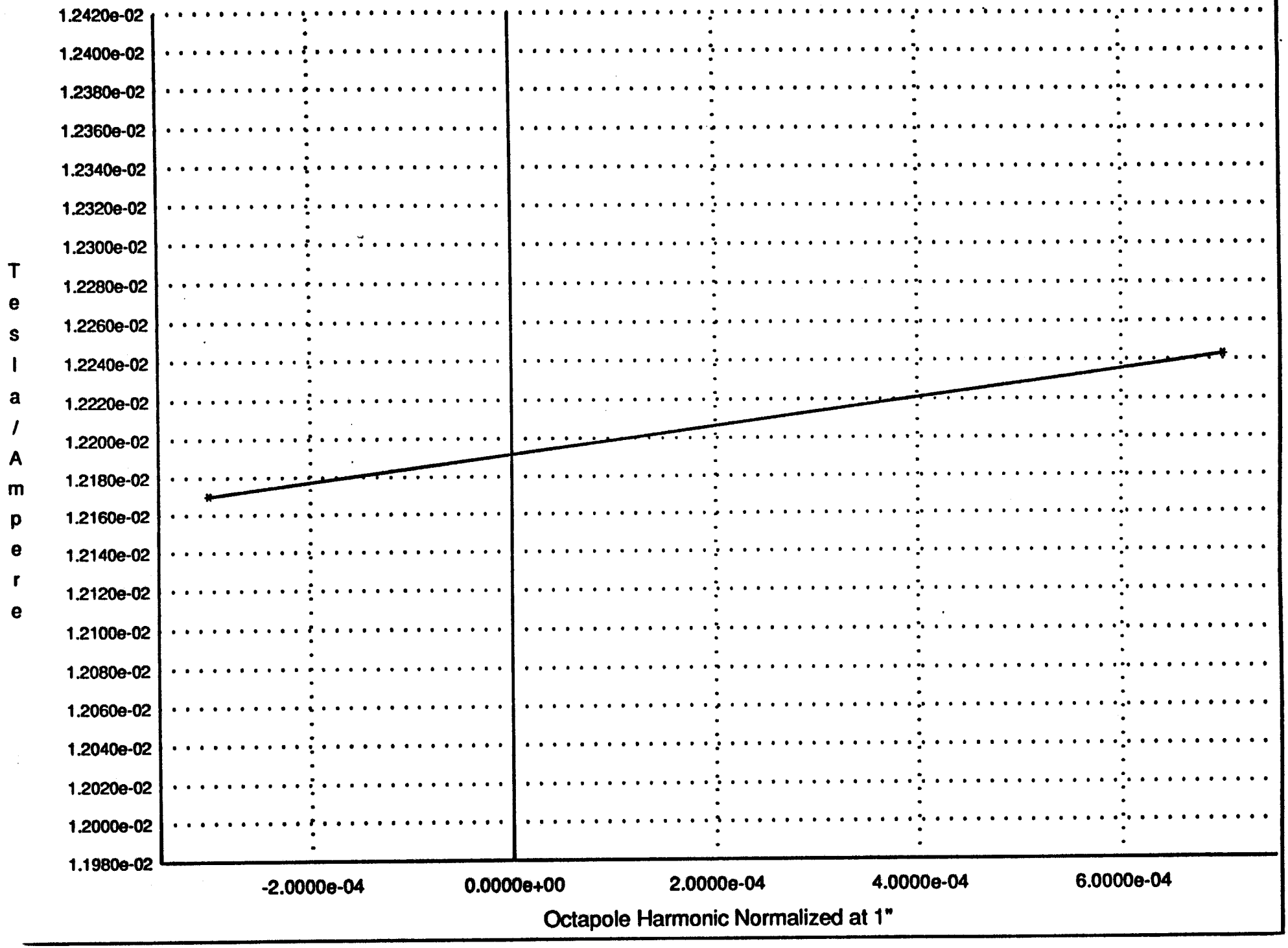
We note that the width of the b4 distribution may be interpreted as being due, possibly, to the
variation in the machining operation which remove the 0.010" from the pole tip. The sigma of that distribution is 1 unit. Since 7.4 units corresponds to 10 mils, we might assign a sigma of 1.35 mils. Since 10 mils is calculated to cause 44E-04 change in the strength (relative) then 1.35 mils would cause 6E-04 fractional strength change. This suggests that the variation in machining of the cores is not responsible for the strength variation of the MR Quads.

The ability to measure strength in quadrupole magnets requires substantially more effort to achieve the same accuracy as in dipole magnets. No attempt has been made at this point to understand the 17E-4 sigma in the measurements reported here. If better measurements are required, plans and hardware will be required.

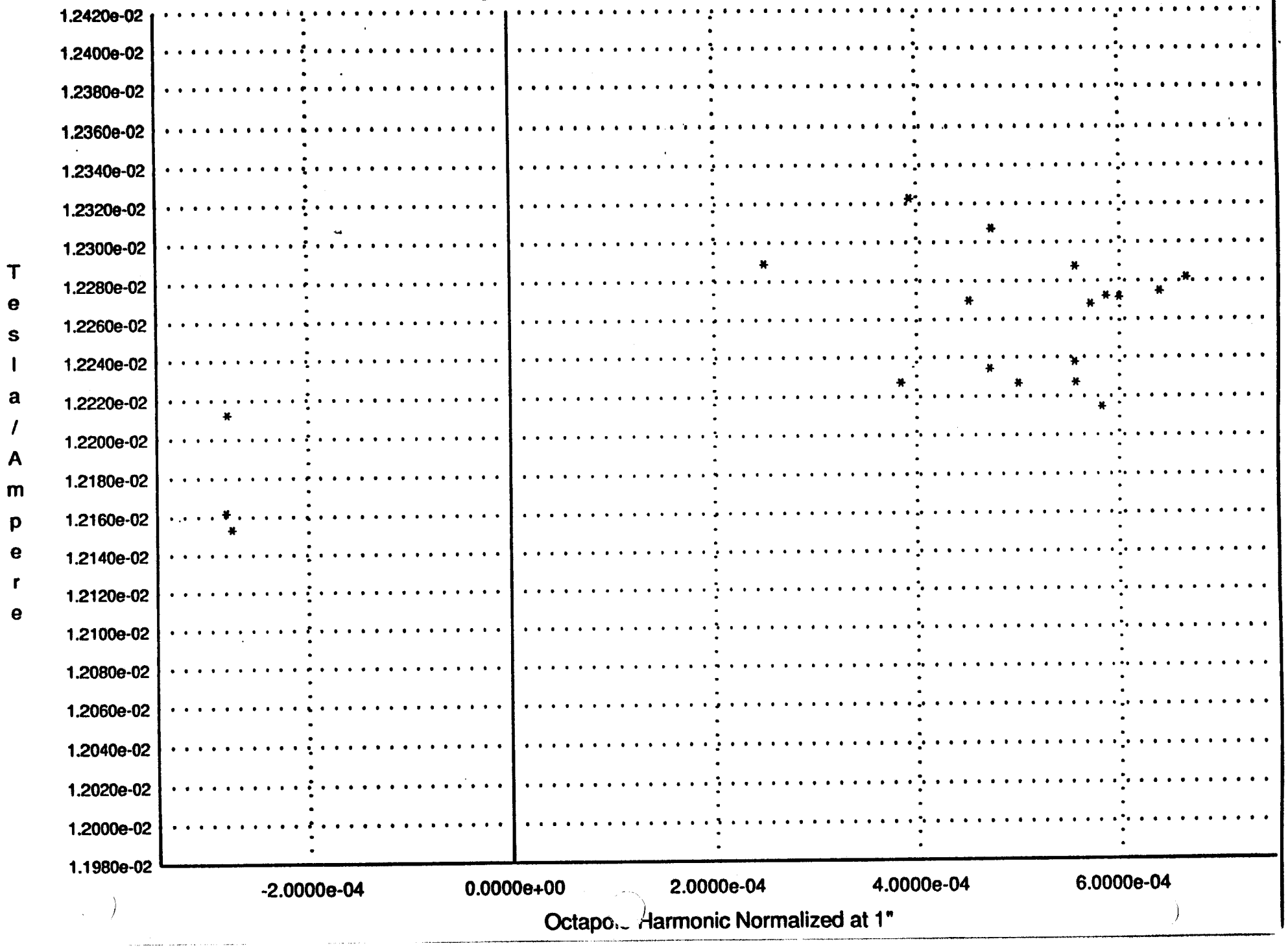
Results used are attached:

MAGNET_ID	SN	RDATE_2	REF_AMPLTD_2	REF_CURRENT_2	B4	Ampltd/Cur
BQA017	017	09-APR-1986	1.1948e+01	1.5736e+03	5.9737e-04	7.5926e-03
BQA019	019	31-MAR-1987	1.1893e+01	1.5763e+03	4.0901e-04	7.5450e-03
BQA030	030	25-MAR-1986	1.1933e+01	1.5843e+03	6.6097e-04	7.5321e-03
BQA033	033	06-MAY-1986	1.1877e+01	1.5769e+03	5.1131e-04	7.5317e-03
BQA049	049	07-MAY-1986	1.1881e+01	1.5733e+03	5.6122e-04	7.5520e-03
BQA050	050	07-MAY-1986	1.2061e+01	1.5680e+03	4.6047e-04	7.6920e-03
BQA053	053	01-MAY-1987	1.1919e+01	1.5766e+03	4.8829e-04	7.5598e-03
BQA056	056	10-APR-1987	1.1865e+01	1.5752e+03	5.3399e-04	7.5322e-03
BQA060	060	06-APR-1987	1.1847e+01	1.5760e+03	2.8402e-04	7.5171e-03
BQA084	084	08-MAY-1986	1.1882e+01	1.5720e+03	5.9281e-04	7.5588e-03
BQA096	096	07-MAY-1986	1.1890e+01	1.5771e+03	5.4712e-04	7.5390e-03
BQA097	097	11-APR-1986	1.1951e+01	1.5739e+03	2.5694e-04	7.5933e-03
BQA098	098	20-MAR-1986	1.1939e+01	1.5847e+03	3.9631e-04	7.5338e-03
BQA100	100	19-MAR-1986	1.1956e+01	1.5848e+03	7.0589e-04	7.5441e-03
BQA102	102	09-JUN-1987	1.1891e+01	1.5778e+03	1.5308e-03	7.5365e-03
BQA103	103	08-JUN-1987	1.1866e+01	1.5776e+03	1.0499e-03	7.5218e-03
BQB019	019	31-MAR-1986	1.9265e+01	1.5840e+03	-2.8191e-04	1.2162e-02
BQB024	024	26-MAR-1986	1.9256e+01	1.5844e+03	-2.7617e-04	1.2153e-02
BQB031	031	14-MAY-1986	1.9211e+01	1.5731e+03	-2.8024e-04	1.2212e-02
BQB082	082	01-APR-1986	1.9401e+01	1.5853e+03	5.5512e-04	1.2238e-02
BQB109	109	15-MAY-1986	1.9305e+01	1.5732e+03	5.9949e-04	1.2272e-02
BQB135	135	14-MAY-1986	1.9308e+01	1.5730e+03	6.3957e-04	1.2274e-02
BQB136	136	13-MAY-1986	1.9293e+01	1.5726e+03	5.7125e-04	1.2268e-02
BQB162	162	02-APR-1986	1.9345e+01	1.5742e+03	2.5035e-04	1.2289e-02
BQB196	196	08-APR-1986	1.9336e+01	1.5736e+03	5.5551e-04	1.2288e-02
BQB207	207	13-MAY-1986	1.9306e+01	1.5732e+03	5.8659e-04	1.2272e-02
BQB210	210	09-MAY-1986	1.9329e+01	1.5738e+03	6.6572e-04	1.2282e-02
BQB234	234	05-AUG-1991	1.9251e+01	1.5745e+03	4.9911e-04	1.2227e-02
BQB241	241	22-MAR-1986	1.9376e+01	1.5846e+03	3.8434e-04	1.2227e-02
BQB242	242	04-MAY-1987	1.9296e+01	1.5772e+03	4.7116e-04	1.2234e-02
BQB283	283	28-MAR-1986	1.9349e+01	1.5840e+03	5.8244e-04	1.2215e-02
BQB314	314	07-APR-1986	1.9384e+01	1.5730e+03	3.9329e-04	1.2323e-02
BQB332	332	12-MAY-1986	1.9289e+01	1.5721e+03	4.5092e-04	1.2269e-02
BQB333	333	04-APR-1986	1.9376e+01	1.5744e+03	4.7265e-04	1.2307e-02
BQB340	340	29-APR-1987	1.9281e+01	1.5769e+03	5.5651e-04	1.2227e-02
BQB341	341	16-AUG-1991	1.9141e+01	1.5727e+03	4.1404e-04	1.2171e-02
BQB341	341	02-JUL-1991	1.9112e+01	1.5726e+03	4.1989e-04	1.2153e-02
BQB341	341	16-APR-1987	1.9238e+01	1.5769e+03	4.0399e-04	1.2200e-02
BQB341	341	11-DEC-1991	1.9198e+01	1.5746e+03	4.1597e-04	1.2192e-02
BQB343	343	30-JUL-1991	1.9217e+01	1.5728e+03	1.0462e-03	1.2218e-02
BQB343	343	02-JUN-1987	1.9265e+01	1.5772e+03	1.0569e-03	1.2215e-02
BQB346	346	17-FEB-1992	1.9246e+01	1.5740e+03	1.3654e-03	1.2227e-02
BQB347	347	24-JUL-1991	1.9223e+01	1.5723e+03	2.3611e-03	1.2226e-02

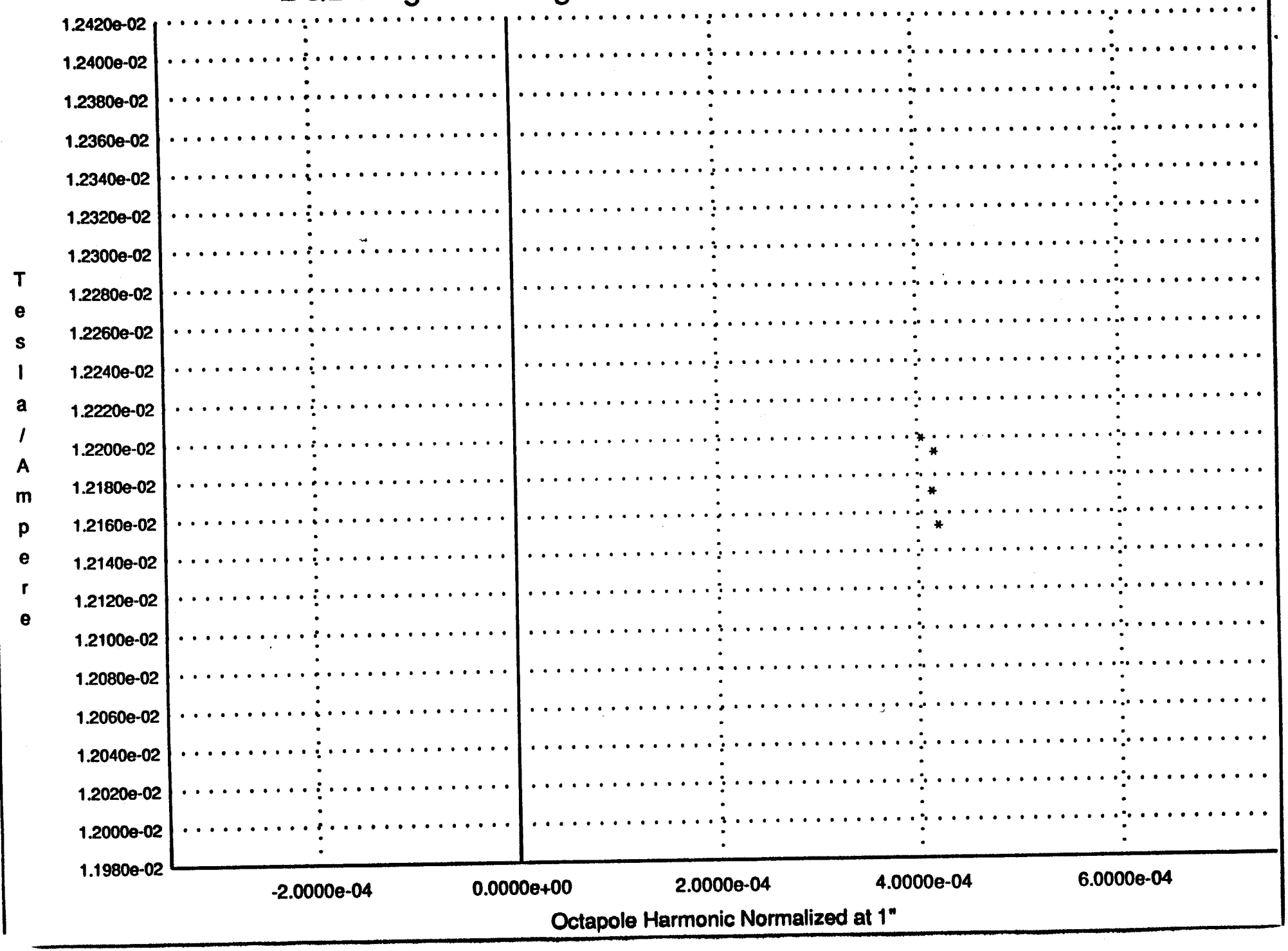
Predicted magnet Strength vs b4 Harmonic



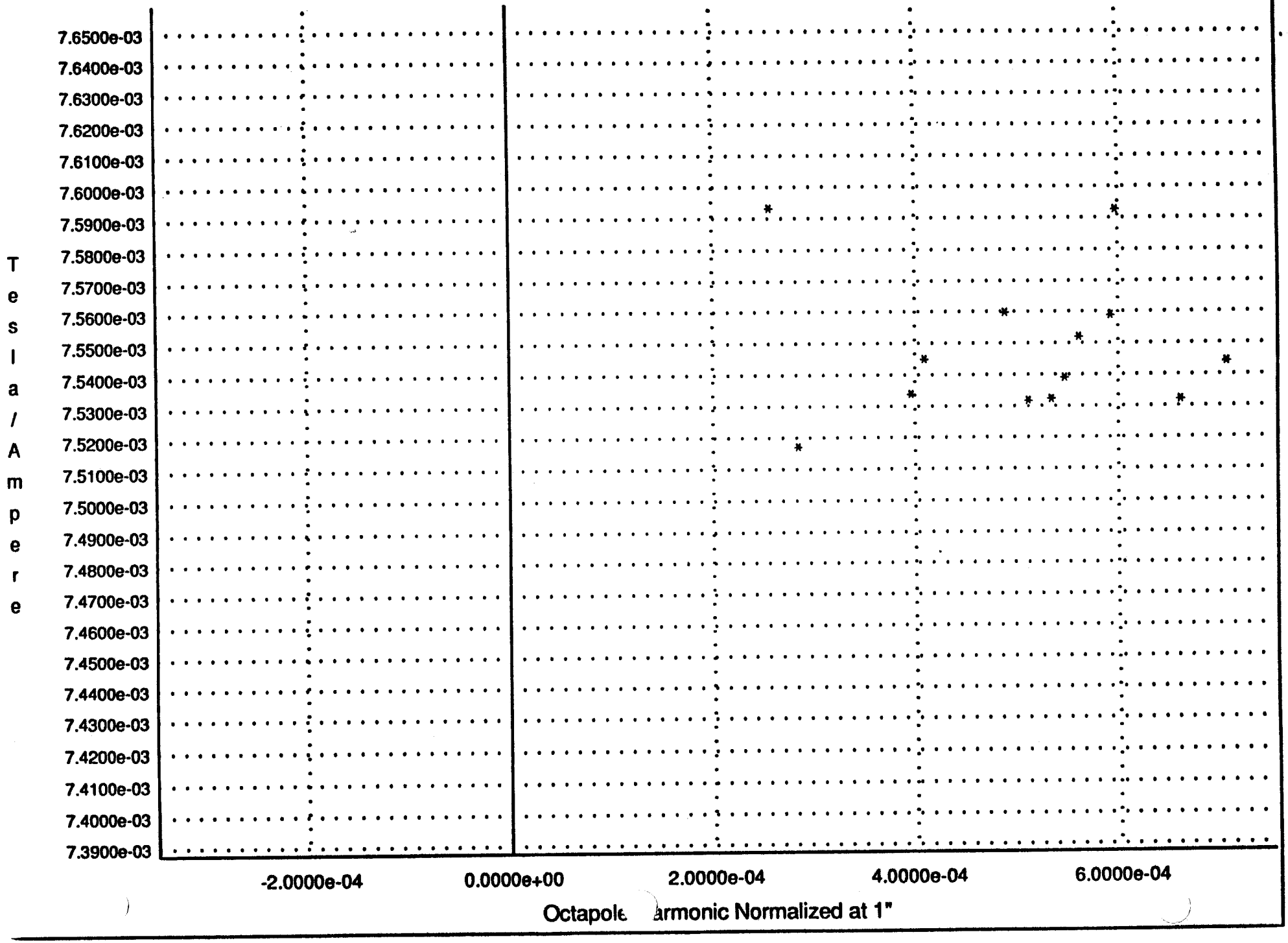
BQB magnet Strength vs b4 Harmonic

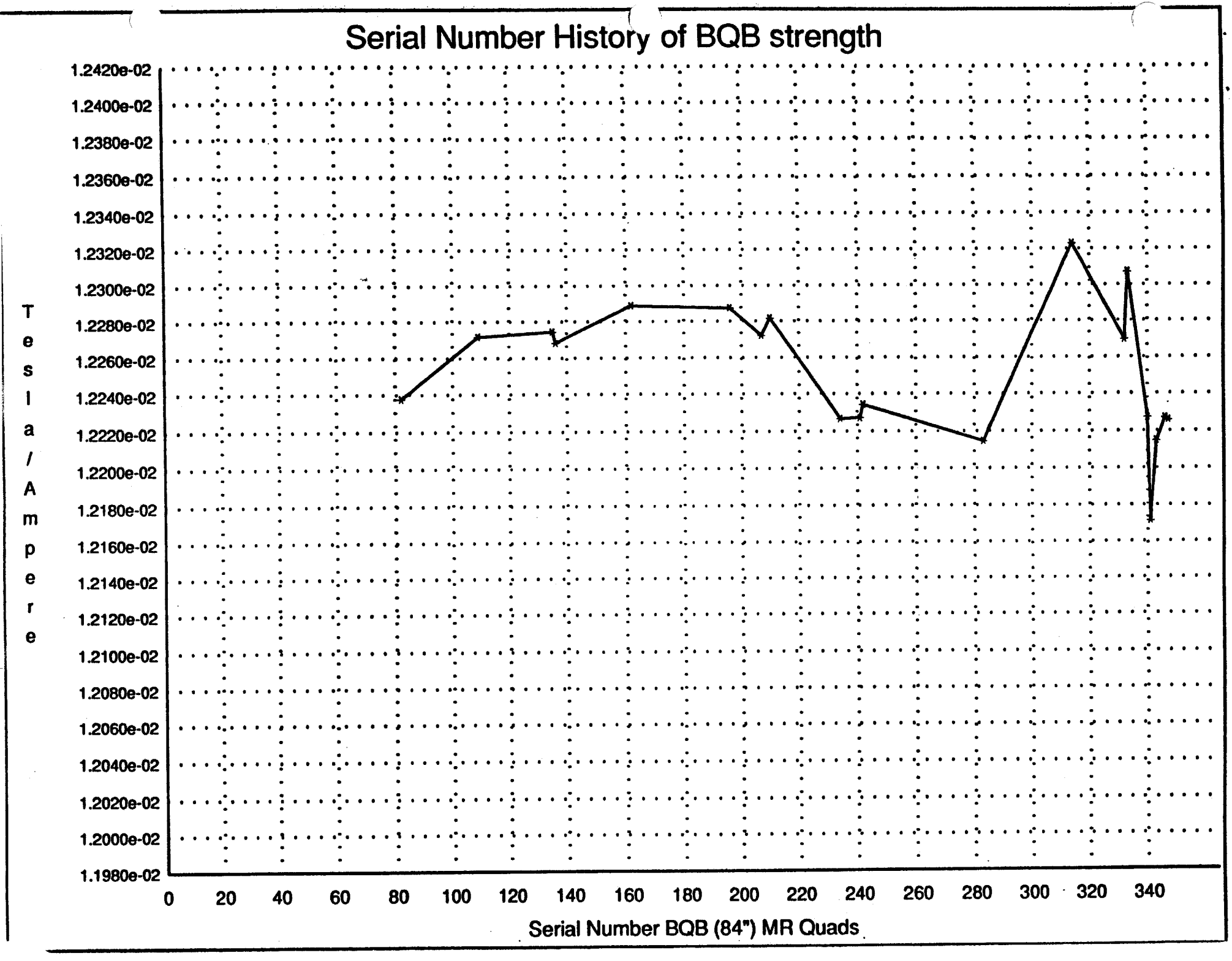


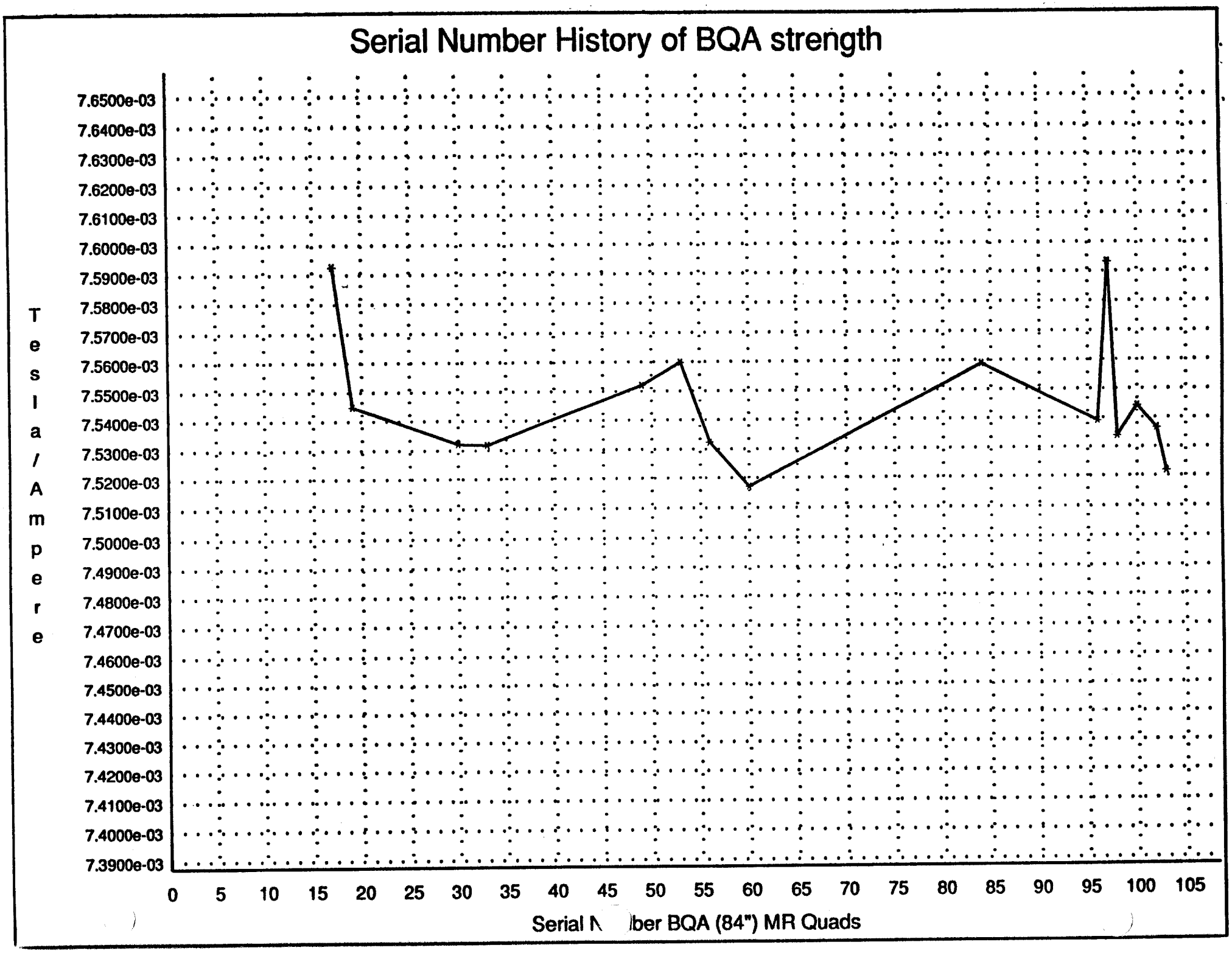
BQB magnet Strength vs b4 Harmonic - BQB341



BQA strength vs b4




Serial Number History of BQB strength
Tesla/Ampere
1.2420e-02
1.2400e-02
1.2380e-02
1.2360e-02
1.2340e-02
1.2320e-02
1.2300e-02
1.2280e-02
1.2260e-02
1.2240e-02
1.2220e-02
1.2200e-02
1.2180e-02
1.2160e-02
1.2140e-02
1.2120e-02
1.2100e-02
1.2080e-02
1.2060e-02
1.2040e-02
1.2020e-02
1.2000e-02
1.1980e-02
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
Serial Number BQB (84") MR Quads


Serial Number History of BQA strength
Tesla/Ampere
7.6500e-03
7.6400e-03
7.6300e-03
7.6200e-03
7.6100e-03
7.6000e-03
7.5900e-03
7.5800e-03
7.5700e-03
7.5600e-03
7.5500e-03
7.5400e-03
7.5300e-03
7.5200e-03
7.5100e-03
7.5000e-03
7.4900e-03
7.4800e-03
7.4700e-03
7.4600e-03
7.4500e-03
7.4400e-03
7.4300e-03
7.4200e-03
7.4100e-03
7.4000e-03
7.3900e-03
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105
Serial N ber BQA (84") MR Quads

PETER BAGLEY

208 Quads $kl \approx .09 \frac{1}{m}$ $\theta_{rms} = \frac{1}{2}$ mrad

$$\sqrt{N}\, q_{rms} = \sqrt{208}\sqrt{\beta_A \beta_B}\,(.09\tfrac{1}{m})(2)(.0005\text{ rad})$$
$$= (.0013\tfrac{1}{m})\sqrt{\beta_A\beta_B} = (.0144)(kl)\sqrt{\beta_A\beta_B}$$

$$\frac{1}{f_{skew}} = \underbrace{(2)}_{\text{unlucky phases}}(.0144)(.09\tfrac{1}{m}) = .0026\tfrac{1}{m} \;/SQ$$

---

screw with 50 turns/inch $\Rightarrow$ 20 mils/turn

10" baseline $\Rightarrow$ 2 mrad/turn

0.5 mrad/($\frac{1}{4}$ turn)

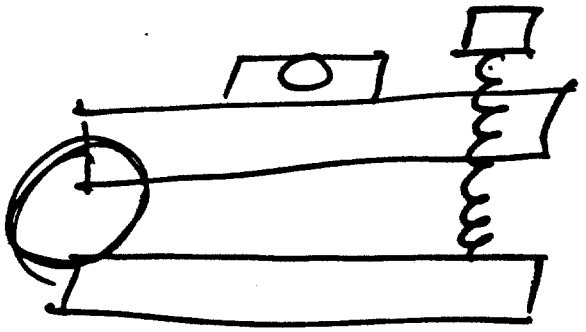
$\approx$ 18 MR Skew quads

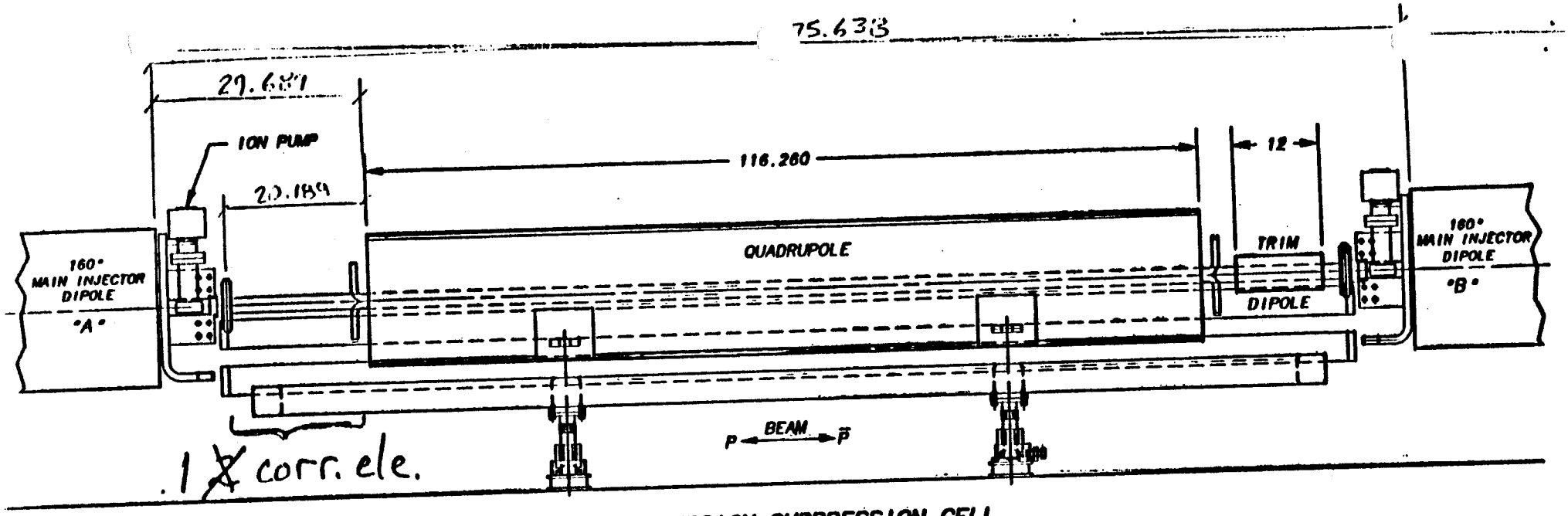
$.00023 \frac{1}{m}$ length $\approx 8\frac{1}{2}$"

$\approx$ 32 Electron Cooling Ring Quads

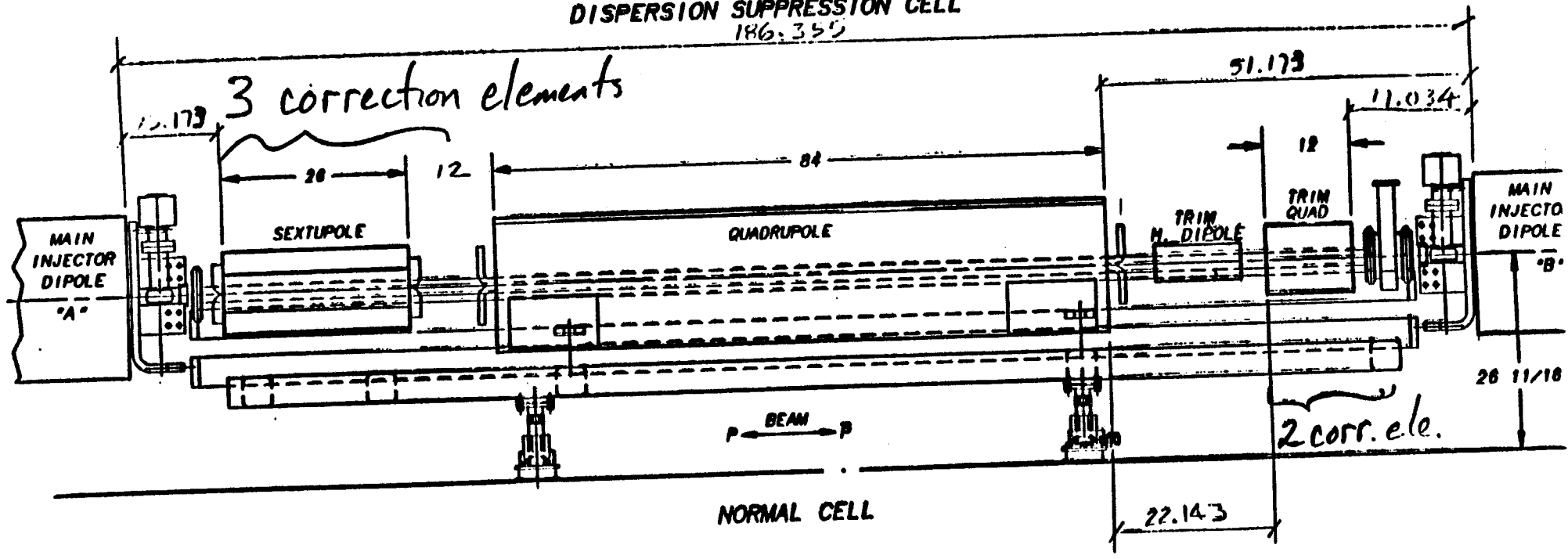
$.0024 \frac{1}{m}$ length $\approx$ 24"

can only be put in straight sections.



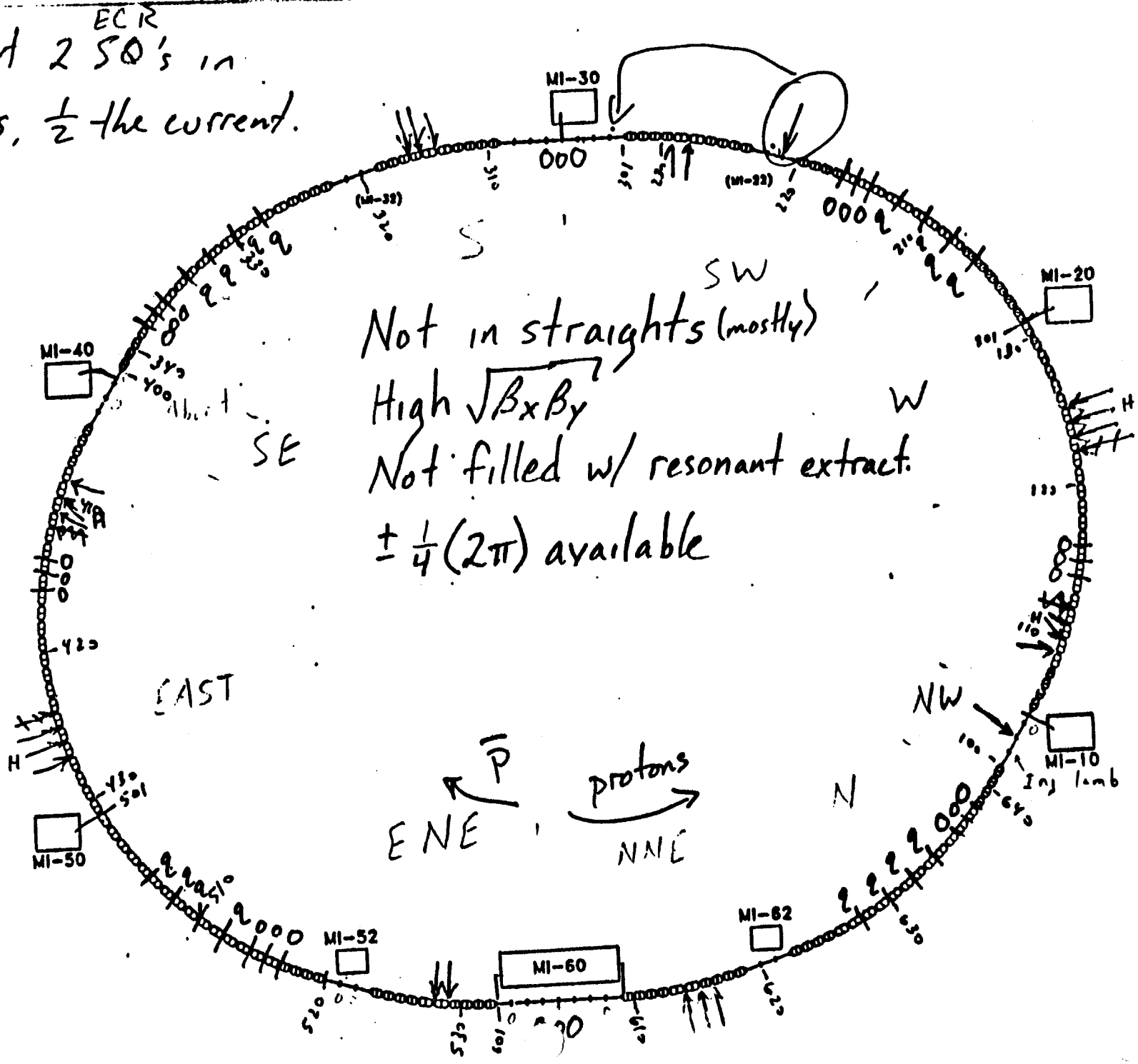


DISPERSION SUPPRESSION CELL



NORMAL CELL

Maybe put 2 SQ's in straights, $\frac{1}{2}$ the current.



MI.17

STEVE PEGGS

Sorting Main Injector quadrupoles to reduce beta errors

Steve Peggs, June 5 '92

The perturbation of the beta function at a general azimuthal location s due to a set of discrete gradient errors is given by

$$\frac{\Delta\beta(s)}{\beta(s)} = \frac{1}{2\sin(2\pi Q)} \sum_i \Delta_i(kL)\, \beta_i \cos(2[\,|\phi(s) - \phi_i| - \pi Q]) \qquad 1$$

where Q is the betatron tune, ϕ is the betatron phase, and $\Delta_i(kL)$ is the integrated gradient error at the i'th quadrupole. Recycled Main Ring quadrupoles are sometimes said to have a root mean square gradient error of $\sigma = 2.4 \times 10^{-3}$, the value that has been used in simulations and in tracking. The actual value may be larger, and will only be reliably known after all the quadrupoles have been re measured during transference to the Main Injector. Assuming that this value is correct, this note tries to answer two questions

1) what is the root mean square beta error if the quadrupoles are randomly transferred?
2) how can the quadrupoles be sorted? how much can sorting help?

The unsorted RMS beta error is estimated by representing the Main Injector as N = 104 FODO cells of approximately 90 degrees phase advance per cell, with a nominal horizontal and vertical tune of 26.424 and 25.425, respectively. Ignoring the effect of defocusing quadrupoles (β_i at defocusing quads is about six times smaller than at focusing quads), then

$$\left(\frac{\Delta\beta}{\beta}\right)_{RMS} = \frac{\sigma N^{1/2}}{2\sqrt{2}\sin(2\pi Q)} \frac{\beta_F}{f} \qquad 2$$

where f is the focal length of the N focusing quadrupoles, with beta functions of β_F. Putting all this together, after noting that $\beta_F/f = 4.82$ for 90 degree FODO cells, gives

$$\left(\frac{\Delta\beta}{\beta}\right)_{RMS} \approx \frac{0.0024 \times 104^{1/2} \times 4.82}{2\sqrt{2} \times 0.454} = 0.092 \qquad 3$$

That is, it is reasonable to expect RMS beta errors of about 9.2 %, corresponding to a beta wave with a typical amplitude of $\sqrt{2} \times 9.2$ %, or about 13 %. Since the phase and amplitude of the

wave varies as it progresses around the Main Injector, the peak beta error at the worst location in the accelerator is expected to be much larger than 13 %. The attached figure shows that beta errors found by a TEAPOT simulation, with a complete spectrum of magnetic errors turned on, are consistent with these estimates. That is, random quadrupole gradient errors are expected to be the dominant source of beta errors in the Main Injector.

Quadrupoles may be sorted to reduce the optical perturbations caused by the random gradient errors by placing pairs of strong or weak quadrupoles exactly one FODO cell apart. The beta waves created by a pair of identical errors cancel (to first order) if the phase advance per cell is exactly 90 degree phase advance cells, because of the factor of 2 on the right hand side of equation 1 in the phase advance factor. In practice, however, the phase advance is not exactly 90 degrees, and the errors cannot be perfectly matched. Suppose that two nearly equal errors, $\Delta_1(kL)$ and $\Delta_2(kL)$, are placed at neighboring focusing quadrupoles in a Main Injector cell. Outside the cell, the magnitude of their net effect is as if due to a single error $\Delta_0(kL)$, given by

$$\Delta_0 \approx \sqrt{([\Delta_1 + \Delta_2]\,\Delta\phi)^2 + (\Delta_1 - \Delta_2)^2} \qquad 4$$

where $\Delta\phi$ is the difference of the phase advance from $\pi/2$ radians. An estimate of the suppression that this gives is made by approximating

$$\Delta_1 - \Delta_2 \approx \frac{\Delta_1 + \Delta_2}{2N} \qquad 5$$

so that the typical effective suppression factor becomes

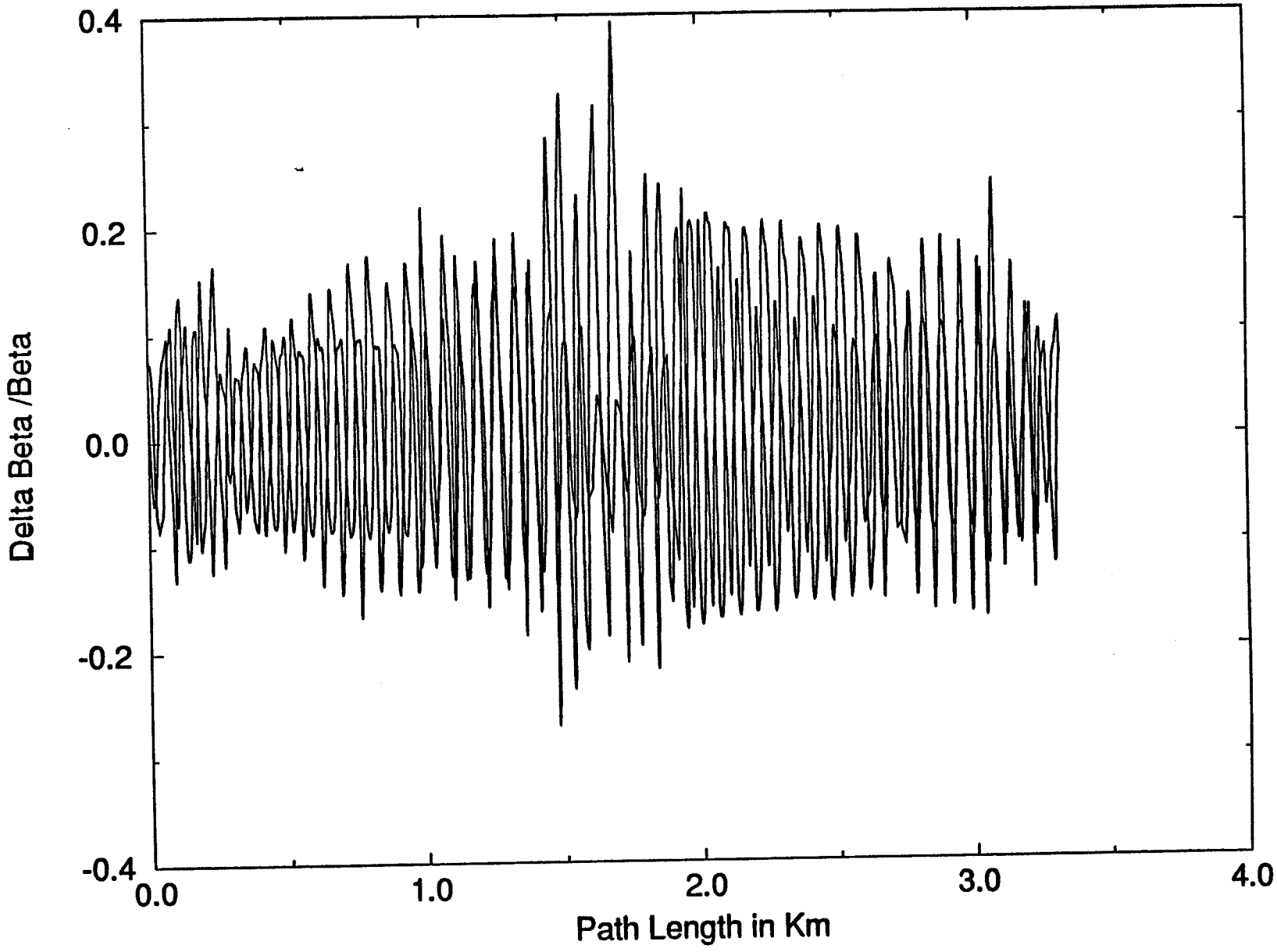
$$\frac{\Delta_0}{\frac{1}{2}[\Delta_1 + \Delta_2]} \approx \sqrt{4\,\Delta\phi^2 + \frac{1}{N^2}} \qquad 6$$

The average horizontal and vertical phase advance per Main Injector cell is 91.5 and 88.0 degrees, respectively. Thus, the first term under the square root in equation 6 dominates in both planes, with approximate suppression factors of 0.05 in the horizontal plane and 0.07 in the vertical. This is a pessimistic estimate, since there are now only 52 errors to randomly distribute, not 104, and since there are even smarter ways to sort the quadrupoles.

Note, finally, that even though the beta function errors cancel in a perfect situation, the betatron phase errors add. Large local accumulations of phase advance can be avoided by randomly distributing pairs of quadrupoles.

Variation in Beta Function

At 8.9 GeV , Dp/p=0, Chrom=-5,-5, Seed=333



DEJAN TRBOJEVIC

Dejan T.

M1_17

$SXD = -1.901315 \times 10^{-1}$

$SXF = 1.020831 \times 10^{-1}$

$\varepsilon_x = 40\pi \times 10^{-6}$ 91

42

1

$\Delta\nu_x = \nu_x + (-223.2164)\,\varepsilon_x - 74.73\,\varepsilon_y$

2.2

$\Delta\nu_y = \nu_y \quad -74.73\,\varepsilon_x \quad -427.45\,\varepsilon_y$

$\underline{\nu_x}$ $\underline{2\nu_y \pm \nu_x}$ $\underline{3\nu_x}$

Distortion function ~~IV~~

1984

ALEX BOGACZ

Shorter Sextupoles

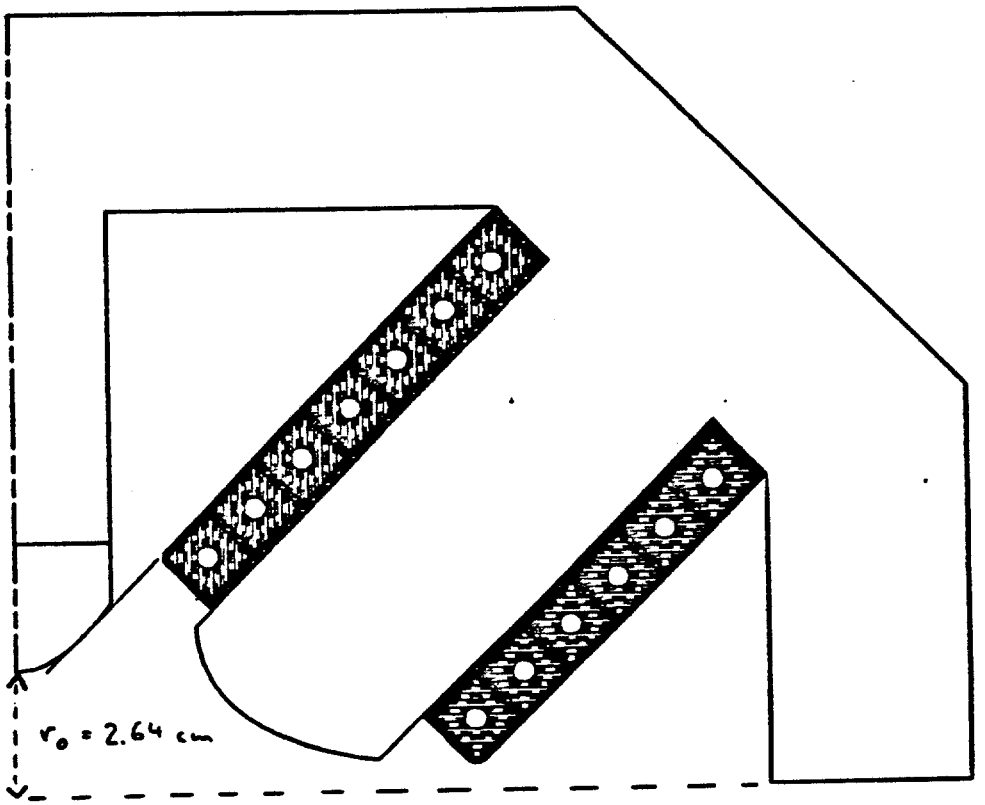
6/5/92

Alex Bogacz

- new sextupole magnet geometry
- new dipole end - sextupole content of a dipole magnet
- chromaticity ramp - linear across transition
- requisite current, resistive and inductive voltage ramps for (f, d) families of correcting sextupole:

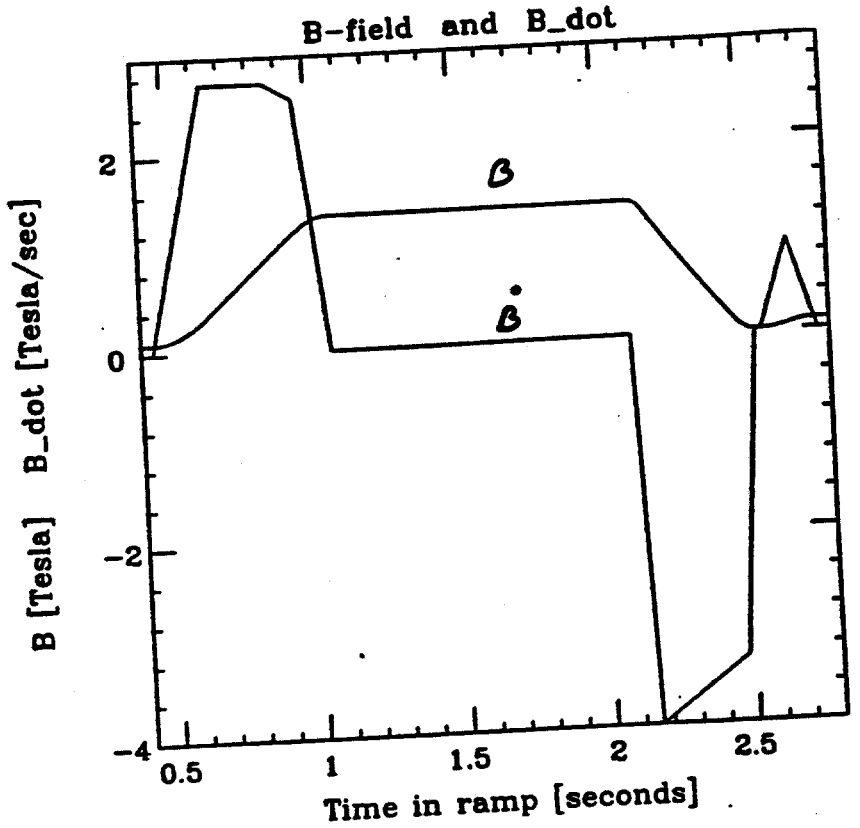
Correctors - Integration into the Lattice

from D. Harding

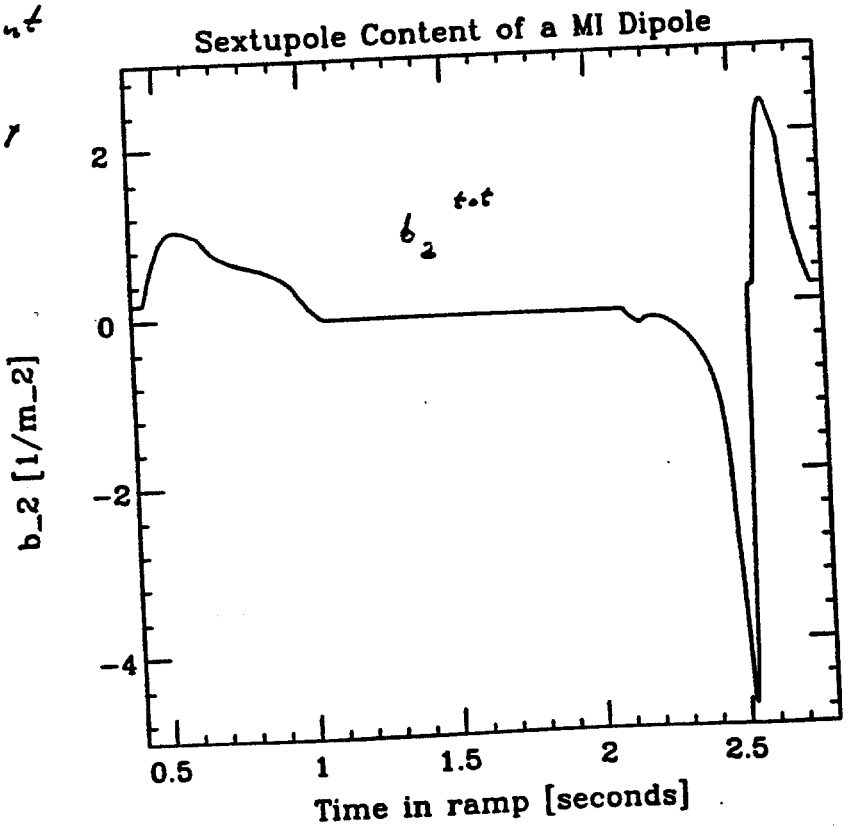


$$I \sim r_0^3 \qquad (B = \text{const})$$

120 GeV ramp



eddy + remanent + saturation (body & ends)

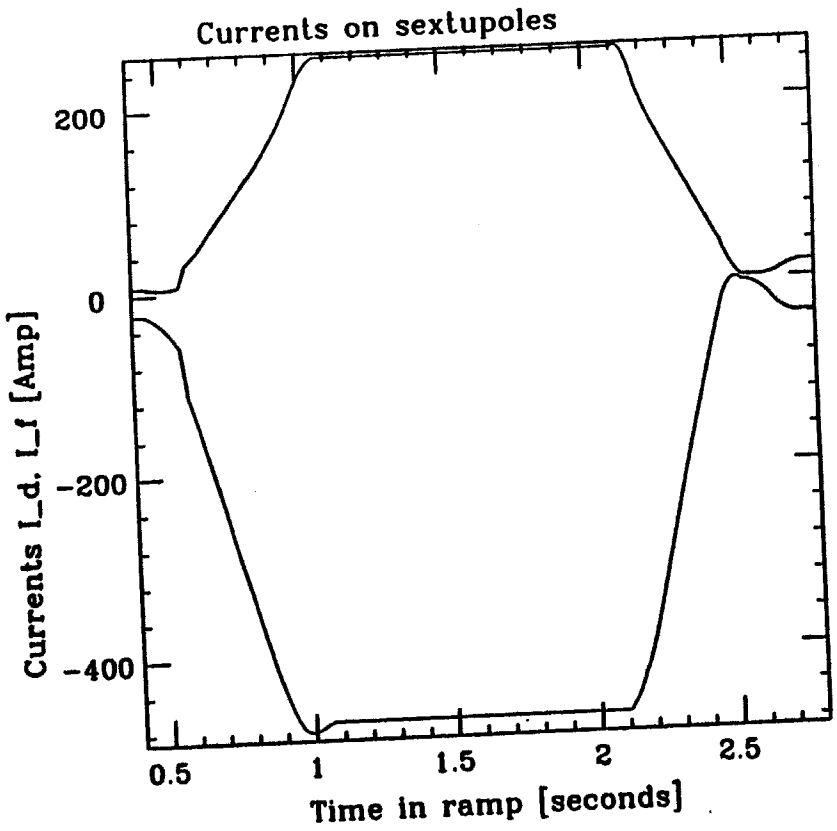


$$I = \frac{1}{3} \frac{r_0^3}{\mu_0} \frac{g}{L}$$

$r_0 = 2.64$ cm

$L = 20$ in

$\mu_0 = 4\pi \times 10^{-7}$ Henry/m



$I^f_{rms} = 175$ Amp

$I^f_{max} = 257$ Amp

$\bar{I}^f = 137$ Amp

$\sigma_{I^f} = 110$ Amp

$I^d_{rms} = 337$ Amp

$I^d_{max} = -481$ Amp

$\bar{I}^d = -270$ Amp

$\sigma_{I^d} = 202$ Amp

<u>transition</u> :

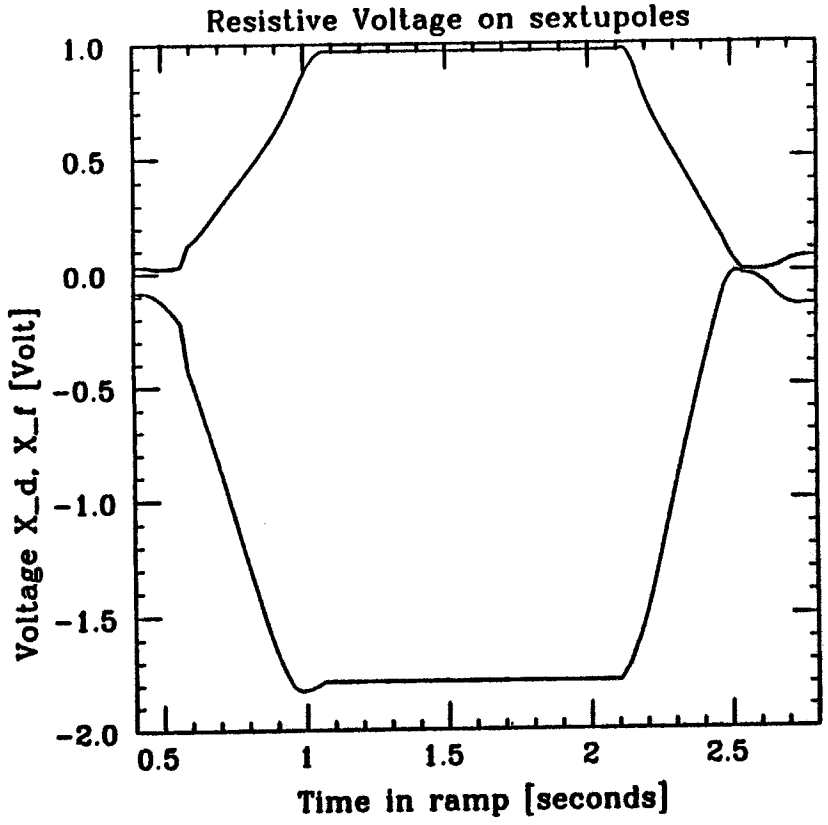
$\gamma_t = 21.6$

α : -10 , 10 units

over $\Delta t_{tr} = 25 \times 10^{-3}$ sec

$R = 3.8 \cdot 10^{-3}$ Ohm (sextupole resistivity)

$X = R I$

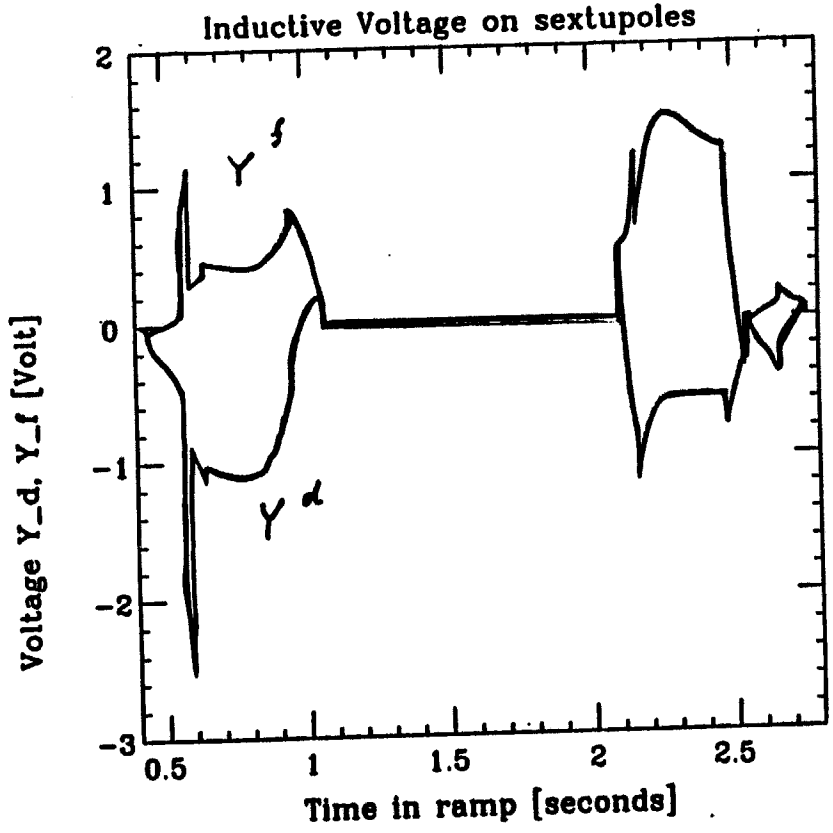


$X^f_{max} = 0.978$ Volt

$X^d_{max} = -1.83$ Volt

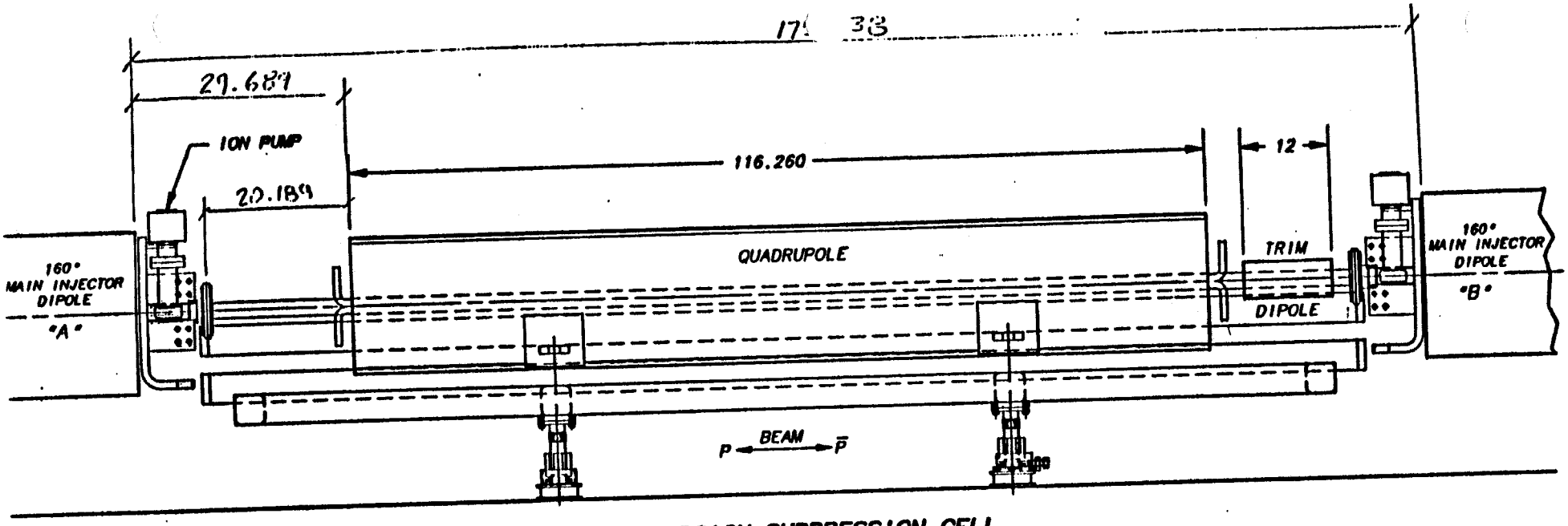
$L = 1 \cdot 10^{-3}$ Henry (sextupole inductance)

$$Y = L \frac{dI}{dt}$$

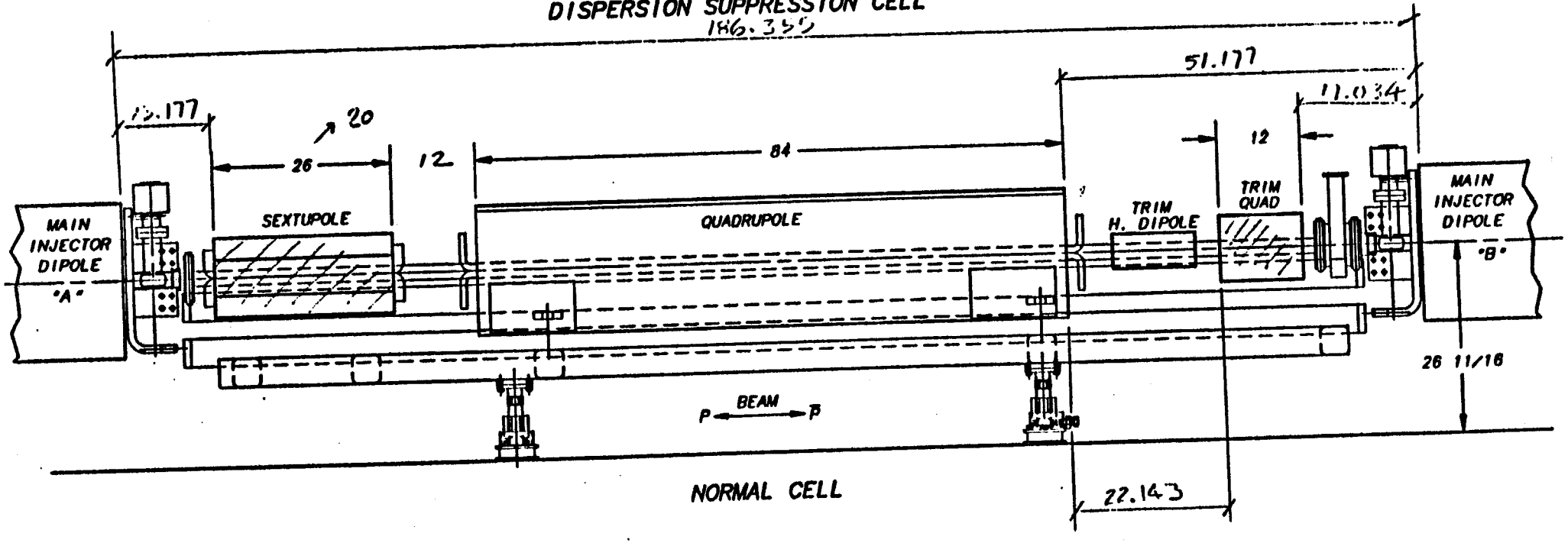


$Y^f_{max} = -1.18$ Volt

$Y^d_{max} = -2.53$ Volt



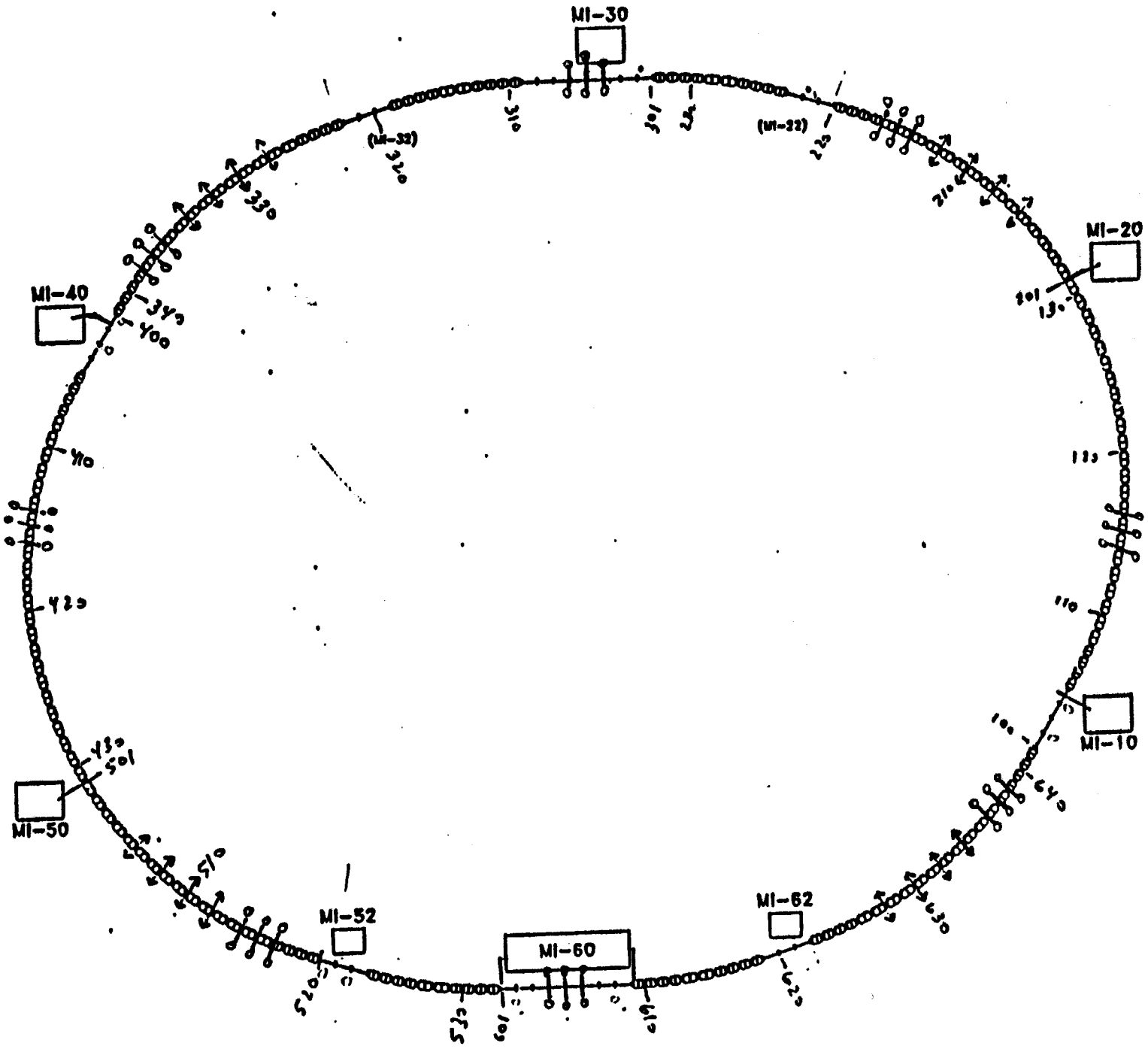
DISPERSION SUPPRESSION CELL



NORMAL CELL

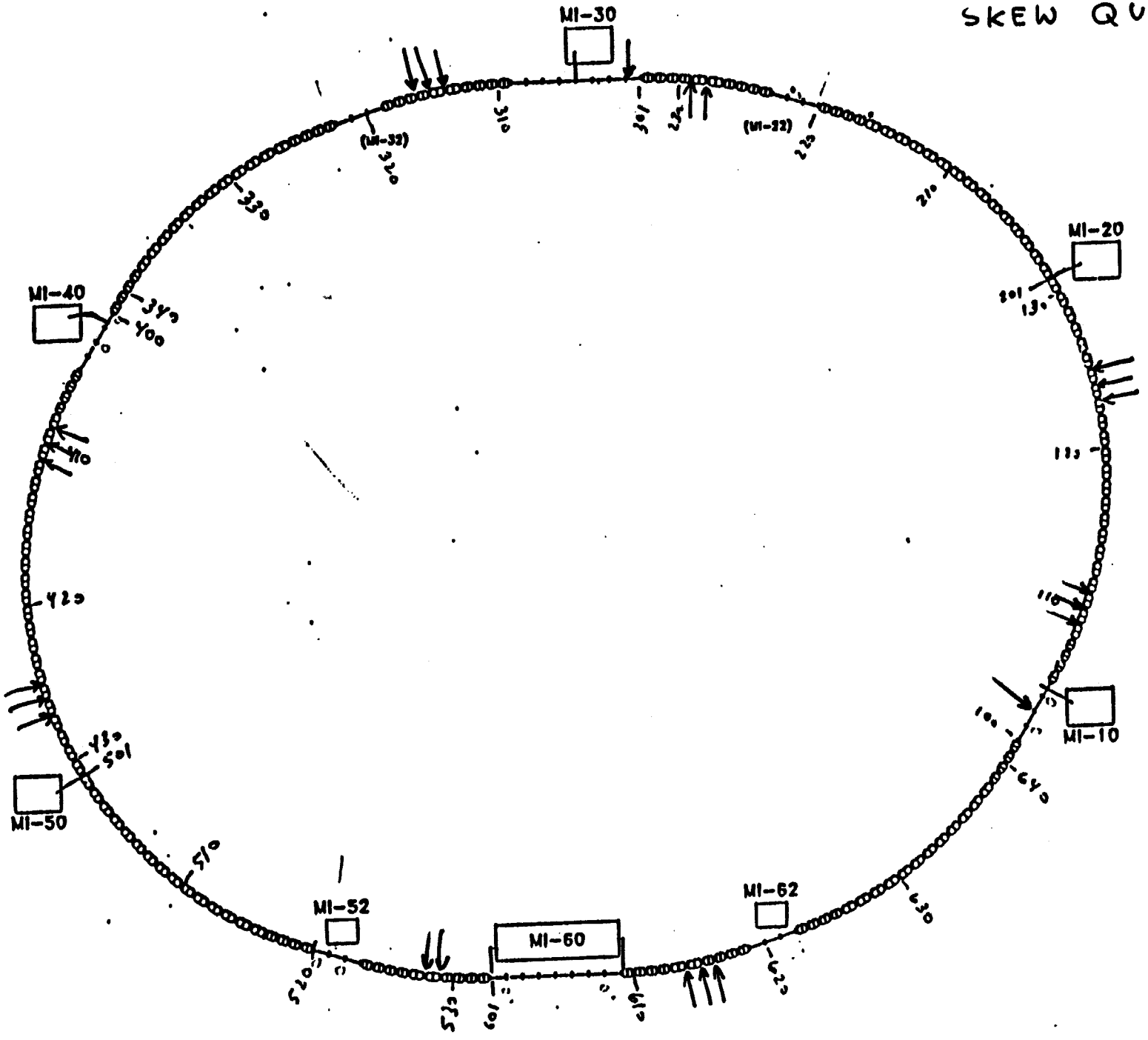
Sext., slow spill (oct. + Quads), β-jump Quads

SLOW EXTRACTION

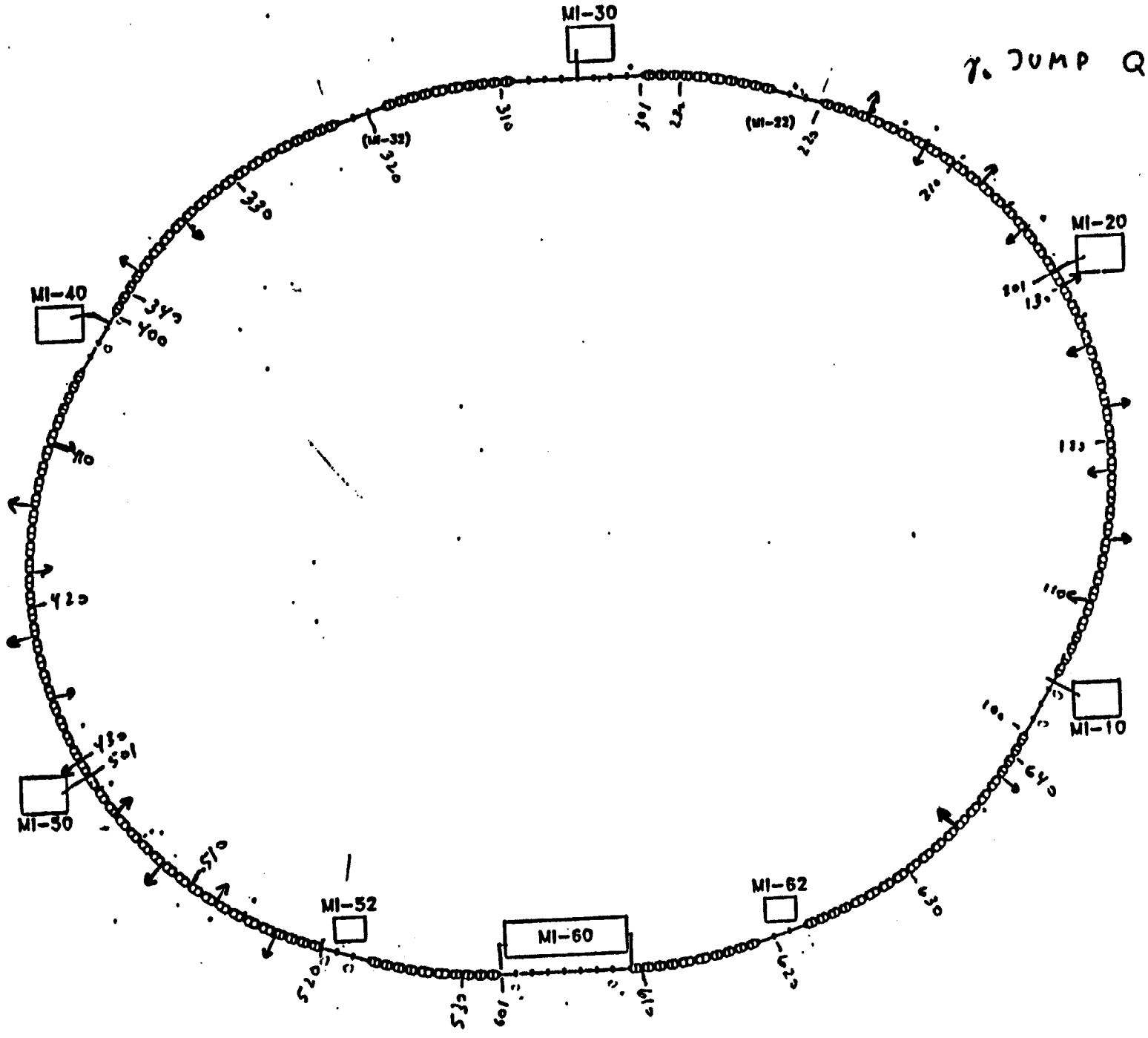


MI.17

SKEW QUADS



MI.17



γ. JUMP QUADS

MI.17

KING-YUEN NG

Minimize Third-Integer Nonlinearity to Increase Aperture

K.Y. NG

- Natural Chromaticities
- Correction Sextupoles
- Nonlinearity is introduced
- Dynamical Aperture is reduced due to tune dependence on amplitude
- To increase dynamical aperture
  1. add another set of harmonic sextupoles or octapoles
  2. to reduce the nonlinearity of the correction sextupoles
     - Careful design of lattice
     - Careful positioning of sextupoles

Tune shift dependence on amplitude:

$$\begin{cases} \Delta\nu_x = a\,\epsilon_x/\pi + b\,\epsilon_y/\pi\ , \\ \Delta\nu_y = b\,\epsilon_x/\pi + c\,\epsilon_y/\pi\ , \end{cases}$$

$$a = -\frac{1}{8\pi}\sum_k (B_3 S + 3B_1 S)_k\ ,$$

$$b = -\frac{1}{4\pi}\sum_k (B_+\bar{S} + B_-\bar{S} - 2B_1\bar{S})_k\ ,$$

$$c = -\frac{1}{8\pi}\sum_k (B_+\bar{S} - B_-\bar{S} + 4\bar{B}\bar{S})_k\ .$$

Here $S_k, \bar{S}_k$ are the reduced sextupole strengths,

$$S_k = \left(\frac{B''\ell}{B\rho}\beta_x^{3/2}\right)_k \qquad \text{and} \qquad \bar{S}_k = \left(\frac{B''\ell}{B\rho}\beta_x^{1/2}\beta_y\right)_k\ ,$$

Definition of distortion functions

$$B_{1k} = \frac{1}{16 \sin \pi\nu_x} \sum_{k'} S_{k'} \cos(|\psi_{xk'} - \psi_{xk}| - \pi\nu_x) ,$$

$$B_{3k} = \frac{1}{16 \sin 3\pi\nu_x} \sum_{k'} S_{k'} \cos(3|\psi_{xk'} - 3\psi_{xk}| - 3\pi\nu_{x,}) ,$$

$$\bar{B}_k = \frac{1}{16 \sin \pi\nu_x} \sum_{k'} \bar{S}_{k'} \cos(|\psi_{xk'} - \psi_{xk}| - \pi\nu_x) ,$$

$$B_{\pm k} = \frac{1}{16 \sin \pi\nu_\pm} \sum_{k'} \bar{S}_{k'} \cos[2|\psi_{yk'} - \psi_{yk}| \pm |\psi_{xk'} - \psi_{xk}| - \pi\nu_\pm] ,$$

where $\nu_\pm = 2\nu_y \pm \nu_x$.

Another definition

1. $\begin{pmatrix} B_1 \\ A_1 \end{pmatrix}$ rotates by ψ_x $\qquad A_1 = B_1'$

in the absence of sextupoles

2. Crossing a "thin" sextupole of strength s_k

B_1 is continuous

A_1 jumps by $\frac{s_k}{B}$

3. Closure around the ring

To reduce detuning

1. Detuning $\propto S_k^2$ or $\bar{S}_k^2$

   $\therefore$ reduce sextupole strength

   e.g. break one sextupole up into 2

   there may be more terms in summation

   but can arrange cancellation.

2. Minimize distortion functions by

   arranging sextupoles wisely

To make distortion fcns vanish we need

$$\sum_{k'} S_{k'} e^{i\psi_{xk'}} = 0 ,$$

$$\sum_{k'} S_{k'} e^{i3\psi_{xk'}} = 0 ,$$

$$\sum_{k'} \bar{S}_{k'} e^{i\psi_{xk'}} = 0 ,$$

$$\sum_{k'} \bar{S}_{k'} e^{i\psi_{\pm k'}} = 0 ,$$

where $\psi_{\pm} = 2\psi_y \pm \psi_x$

For conventional FODO lattice

choose phase advance per cell $\psi_x = \psi_y = 60°$

cancel in every 6 cells

$\psi_x = \psi_y = 90°$ cancel every 4 cells

If we take 90° cell & there are 13 cells in a row

- place sextupoles only in 12 consecutive cells but not the 13th.
- Do not put sextupoles in straight sections
- If there is a low-β for collision, low-β triplets contribute mostly to chromaticity
  ∴ sextupoles must be placed near them for efficient correction.
  Nonlinearity will be hard to cancel

Unconventional lattice

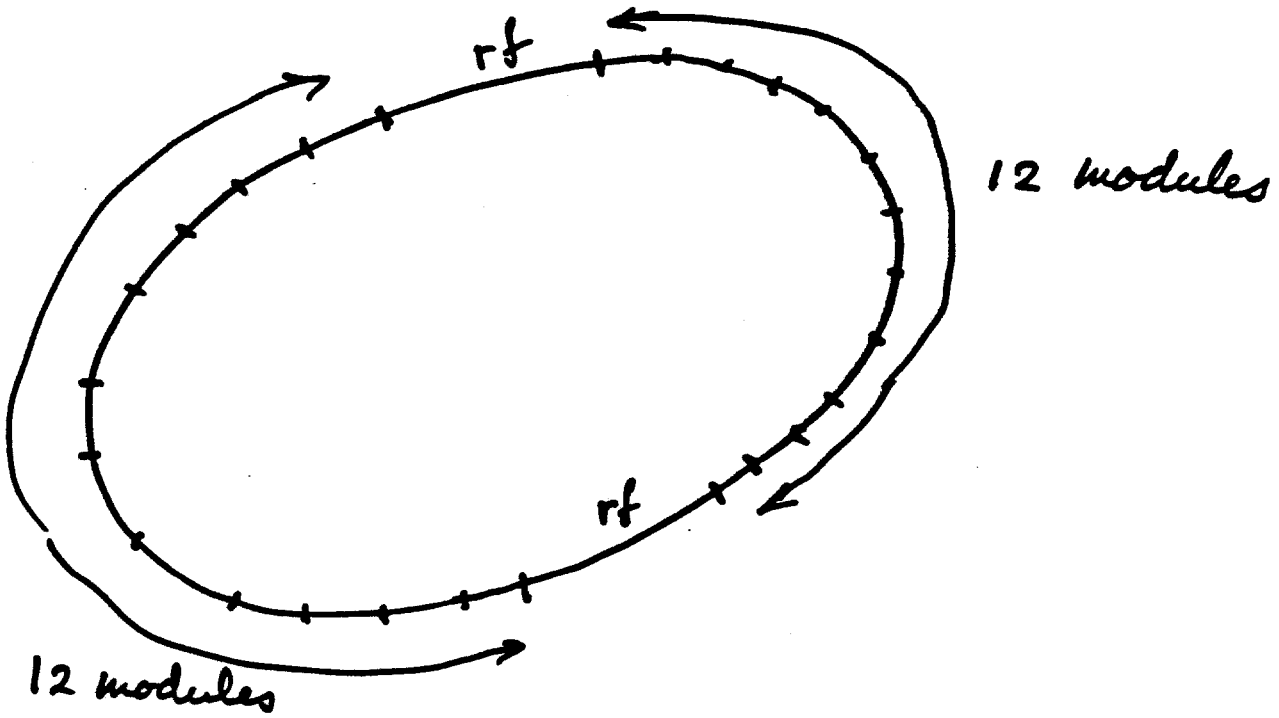
- small ring: hard to cancel nonlinearity
  usually need harmonic sextupoles
  or octapole to cancel tuneshift

- large ring: can design modules (supercells)
  make them all alike

  Then the distortion fcns can be
  made to cancel as before

<u>Example</u>

Imaginary-γ_t lattice for Main Injector

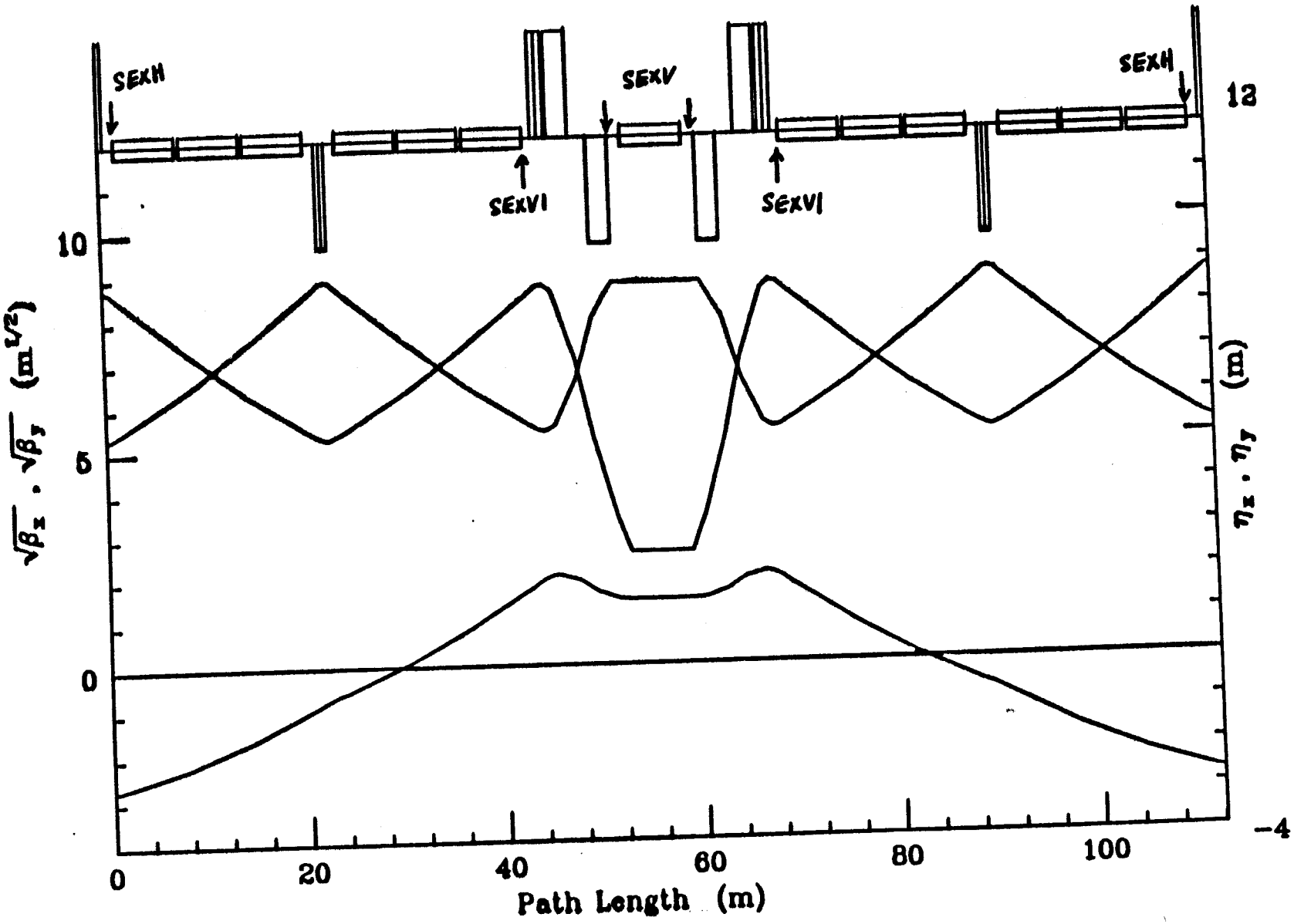


3 types of modules

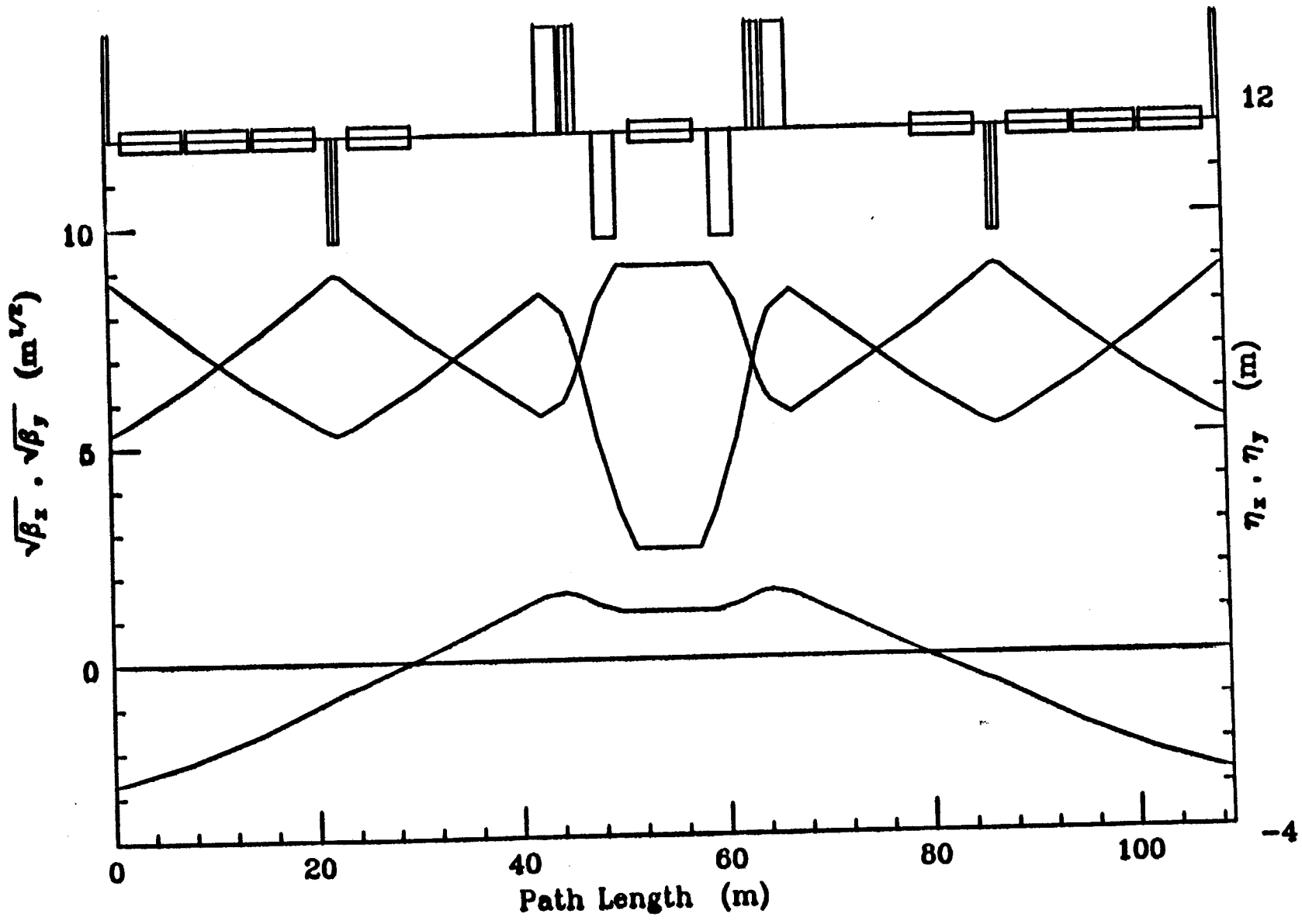
Basic:	6	contains 7 dipoles each
Extract 1:	3	4 dipoles removed
Extract 2:	3	6 dipoles removes

- Try to design these modules so that they have nearly the same twiss-parameters
- Phase advance / module $\psi_x \sim 0.75$

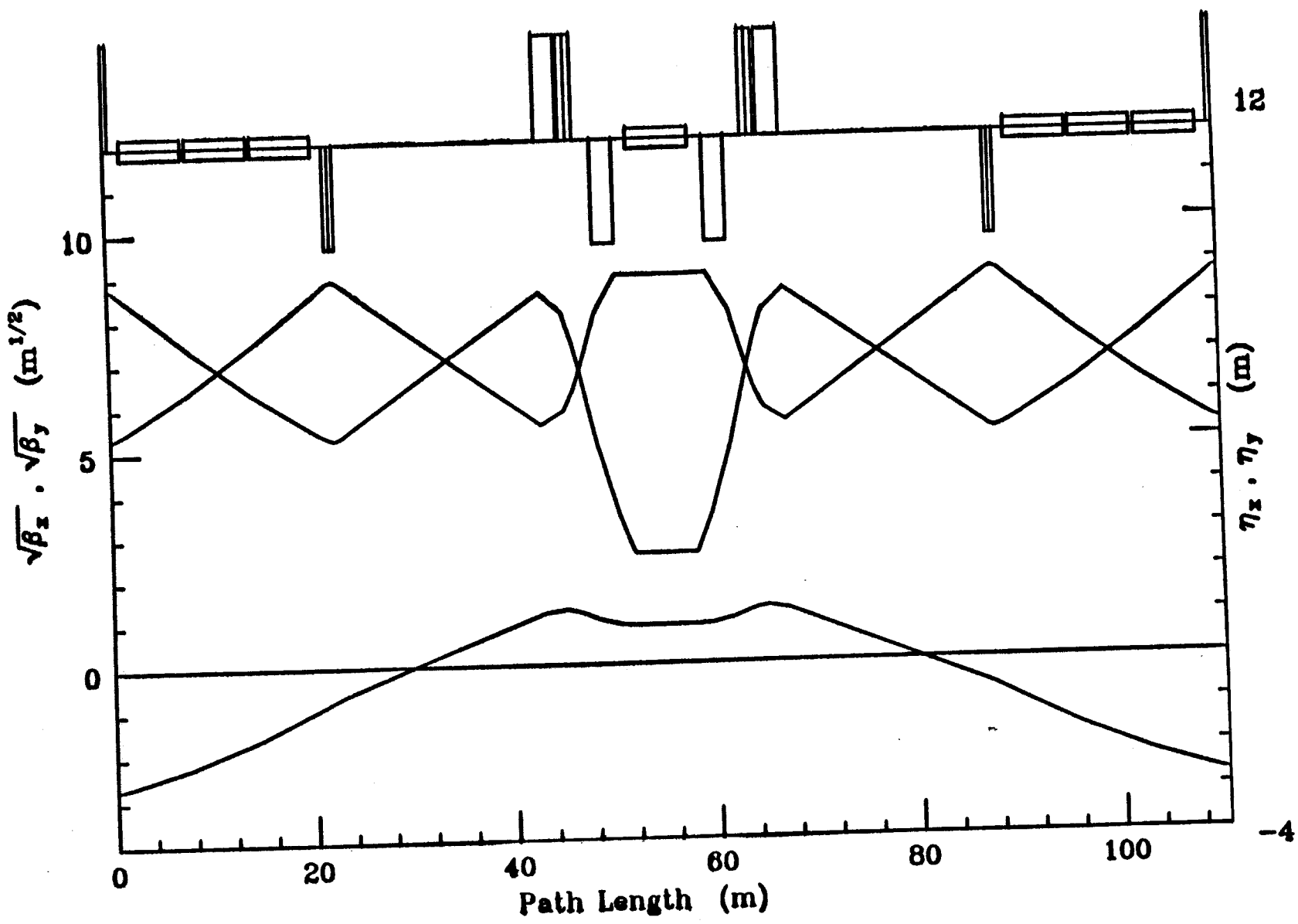
so that cancellation in every 4



Tue Apr 14 16:51:49 1992



Tue Apr 14 17:00:10 1992



Tue Apr 14 17:02:01 1992

	$\Delta\psi_x$	$2\Delta\psi_y$
BASIC	0.7524	0.7603
EXTR1	0.7391	0.7662
EXTR2	0.7450	0.7334

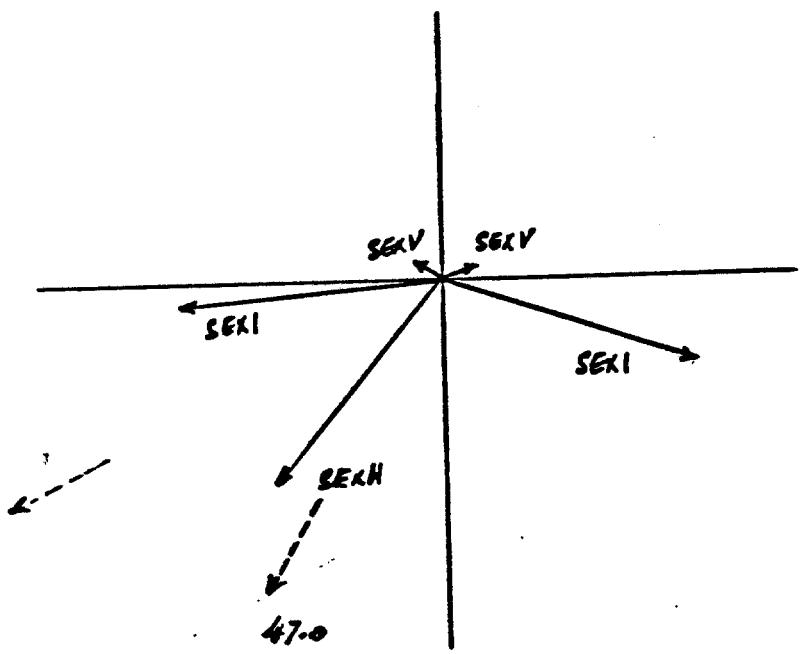
[EXTR1, EXTR2, 5(BASIC), EXTR2, EXTR1, BASIC, EXTR2, EXTR1].

Because of this special arrangement, B_1, B_3, $\bar{B}$, and B_+ rotate with amplitudes of only 0.4, 2.6, 0.4, 2.2 $m^{-1/2}$, respectively outside these 12 modules. Inside these 12 modules, they are determined roughly by the contributions of 4 modules only. There, their amplitudes are, respectively, 6.2, 17.9, 2.3, and 2.2 $m^{-1/2}$. Among these, B_3 appears to be much bigger than the others. This is due mostly to the fact that the contributions of the five sextupoles (1 SEXH, 2 SEX1's, 2 SEXV's) within a module add more constructively for B_3 than for the others.

	ϕ_x	S_x	
SEXH	2.3591	-35.07	129.3°
SEXI	2.5132	35.07	184.8°
SEXV	2.5523	-4.00	198.8°
SEXV	2.9114	-4.00	328.1°
SEXI	2.9505	35.07	342.2°

$$-\frac{1}{\sin \pi \nu_x} = \frac{1}{\sin \pi \times 21.4197} = -1.03$$

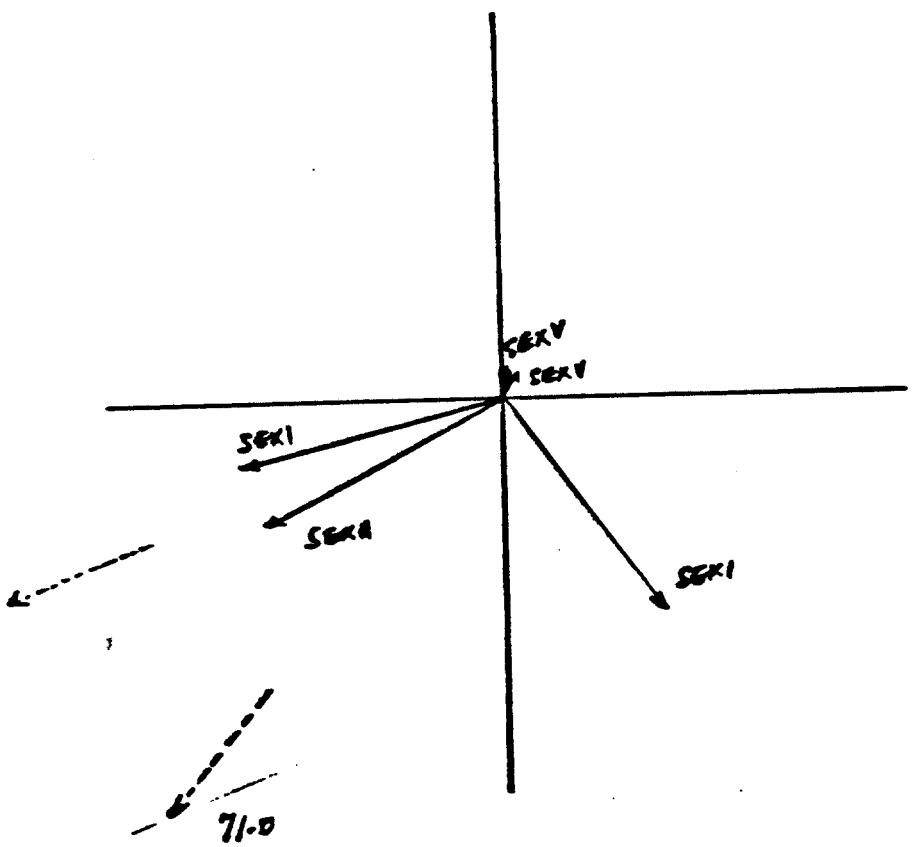
B_1



	$3\phi_x$		S_n
SEXII	7.0773	27.8°	−35.07
SEXI	7.8396	194.3°	35.07
SEXV	7.6569	236.5°	−4.00
SEXV	8.7342	264.3°	−4.00
SEXI	8.8915	306.44	35.07

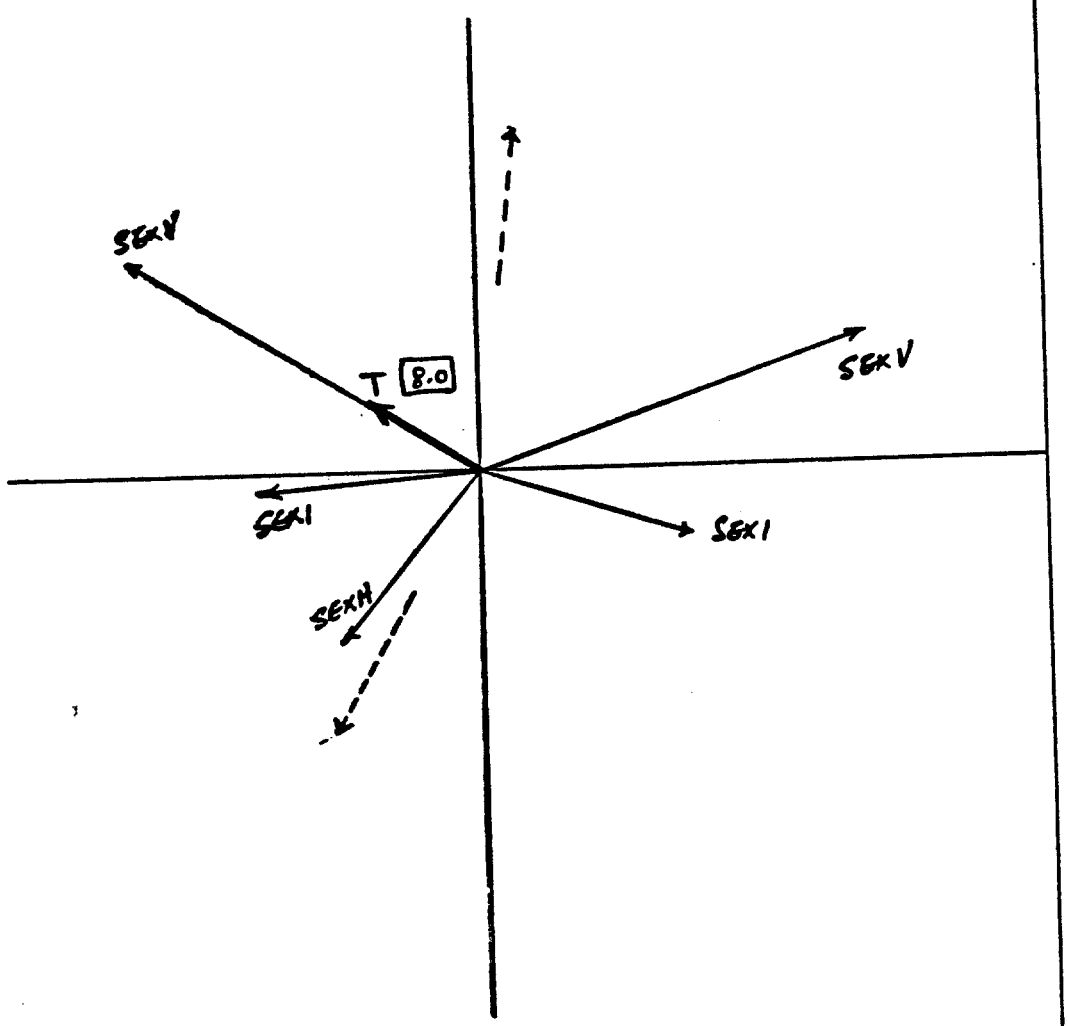
$$\frac{1}{\sin \pi 3\nu_x} = \frac{1}{\sin \pi\, 64.259} = 1.375$$

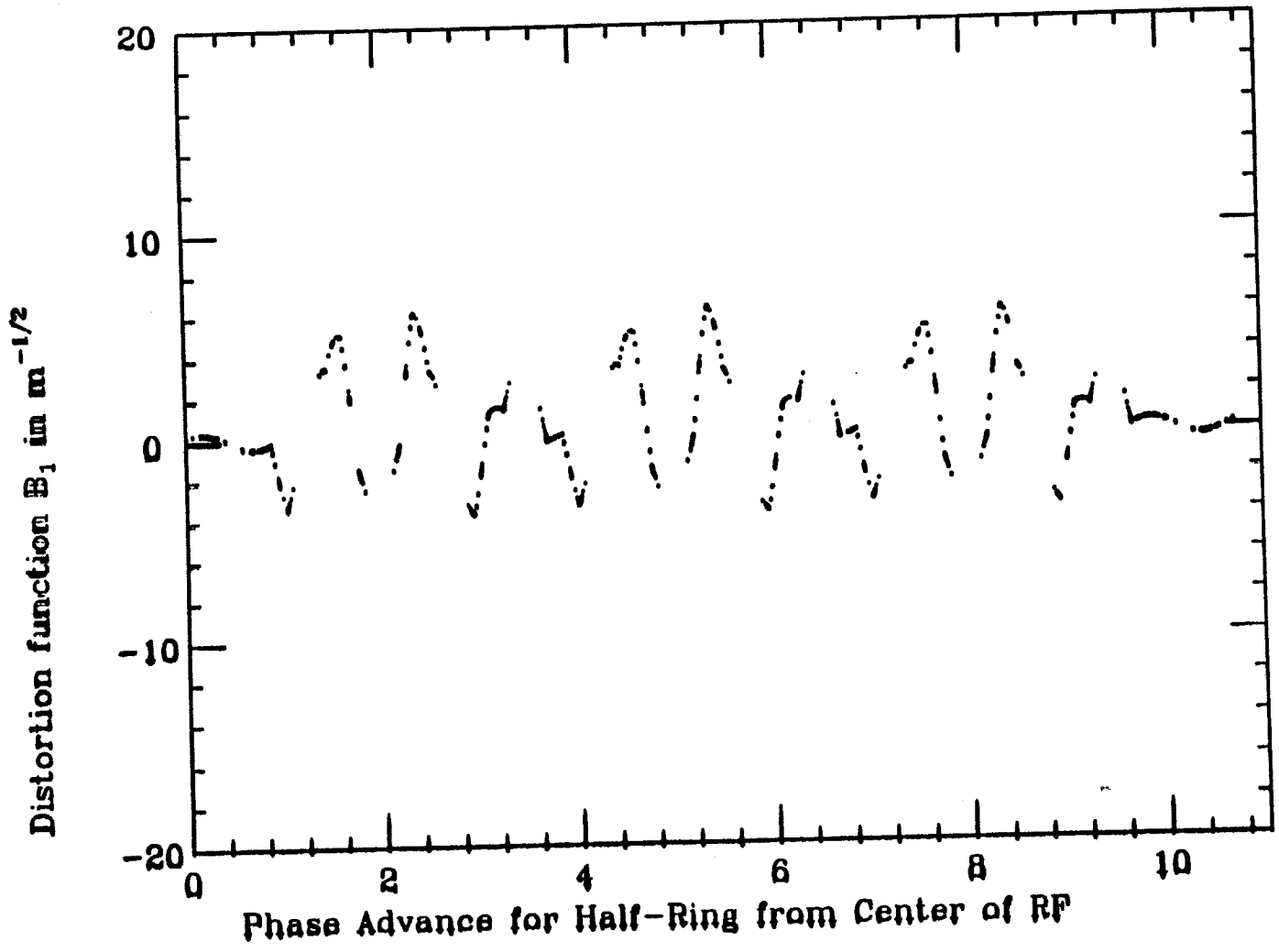
B_3



	ϕ_x		$\bar{S}$
SEXH	2.3891	129.3°	−14.56
SEX I	2.5132	184.8°	14.56
SEXV	2.8523	198.8°	−27.00
SEXV	2.9114	328.1°	−27.00
SEX I	2.9505	342.2°	14.56

$\bar{B}$




20
10
0
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-20
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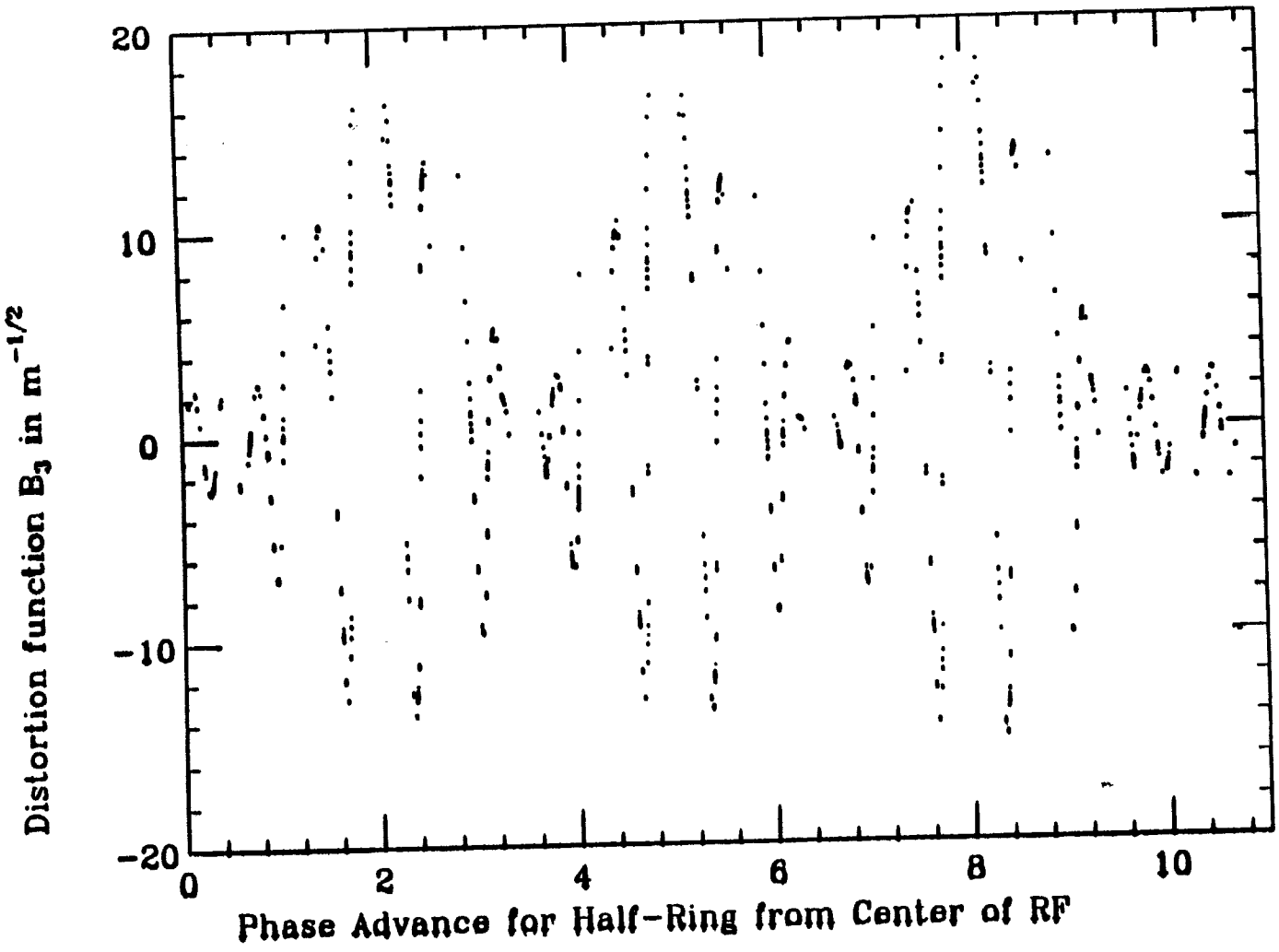
2
4
6
8
10
Distortion function B_1 in $m^{-1/2}$
Phase Advance for Half-Ring from Center of RF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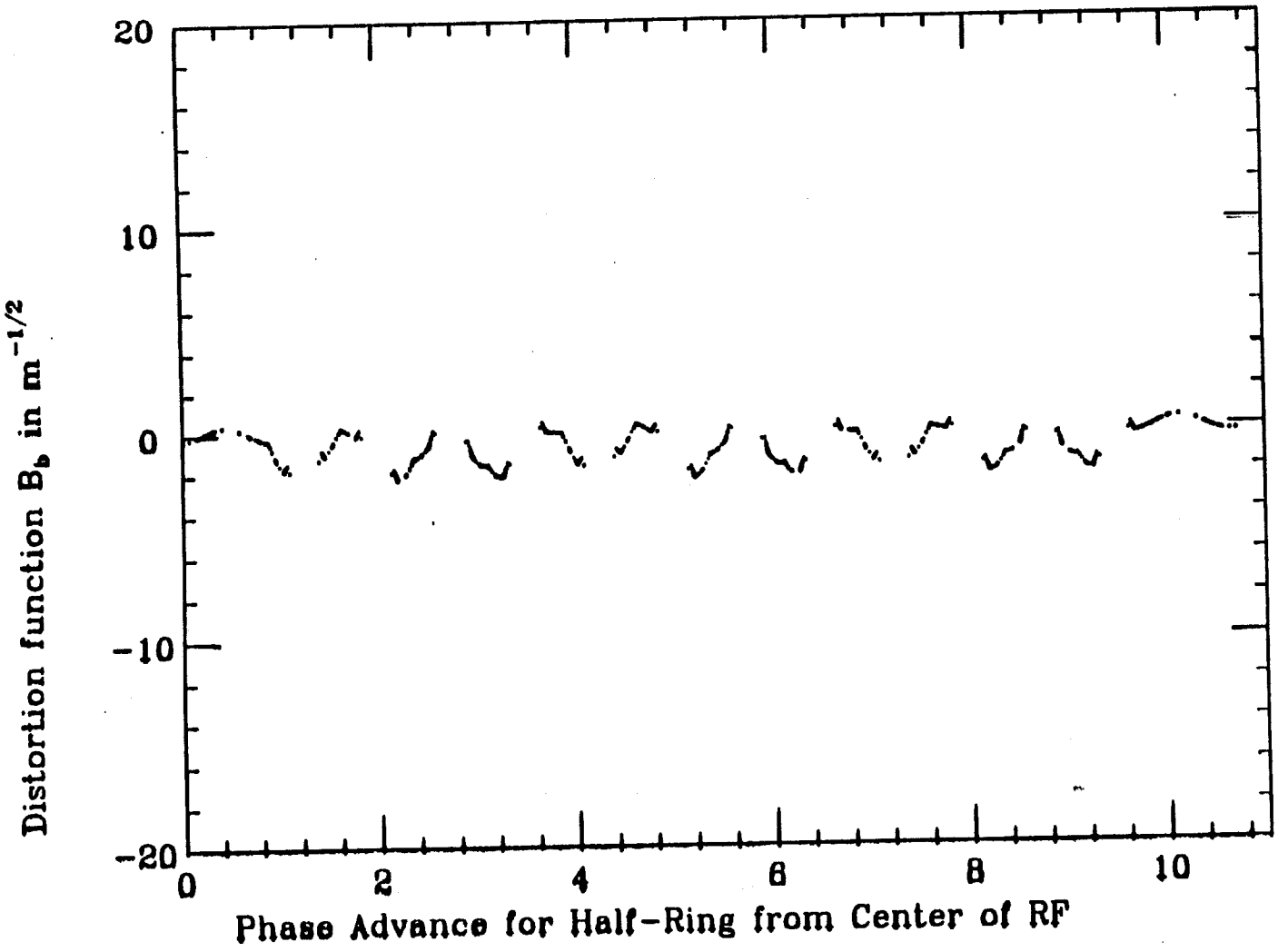
Distortion function B_3 in $m^{-1/2}$
Phase Advance for Half-Ring from Center of RF


20
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-10
-20
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2
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6
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10
Distortion function B_b in $m^{-1/2}$
Phase Advance for Half-Ring from Center of RF

$\boxed{B_3}$ larger than B_1 & $\bar{B}$

3 reasons

1. closer to resonance $\frac{1}{\sin 3\pi\nu_x}$ is bigger

2. the 5 sextupoles add up more constructively inside a module

3. for B_1 & $\bar{B}$

   phase advance for 12 modules = 8.9667

   ∴ cancellation not exact

   for B_3 phase ad. for 12 modules = 3×8.966

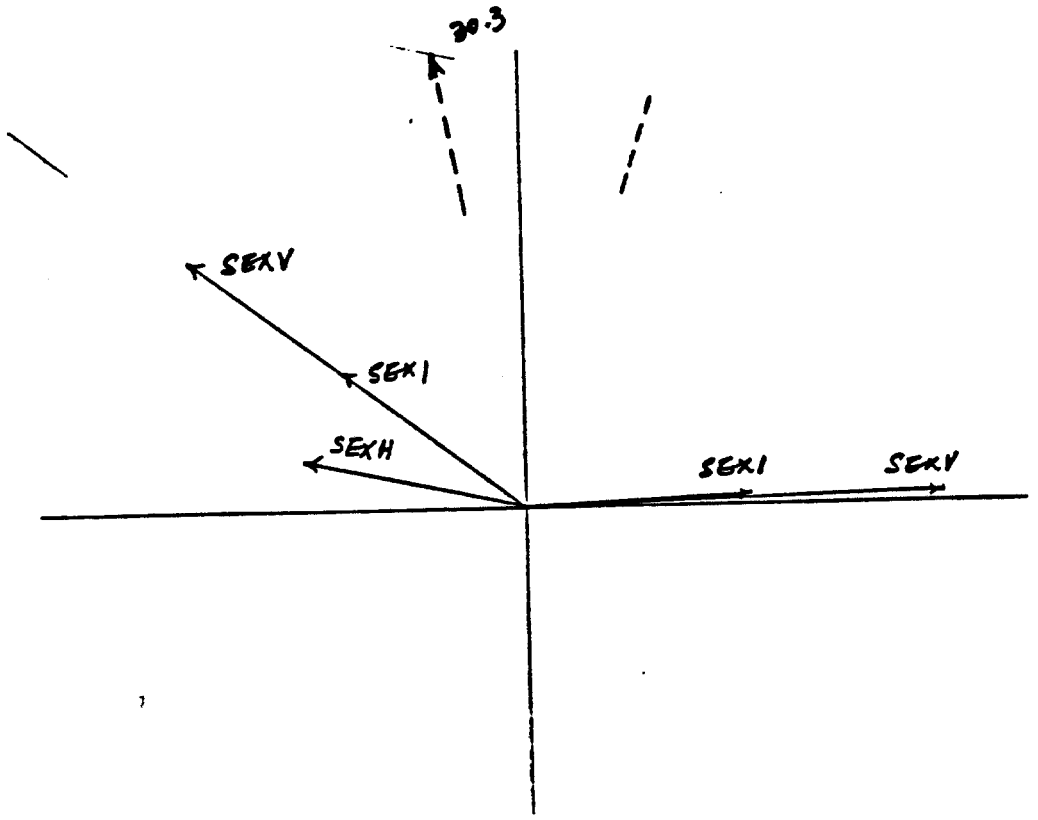
   $= 26.9001$

   ∴ cancellation is worse than B_1, $\bar{B}$

	ϕ_x	ϕ_y	$\phi_+ = 2\phi_y + \phi_x$		$\bar{s}$
SEXH	2.3691	1.3037	4.9465	347.9°	-14.56
SEX1	2.6732	1.4421	5.3974	143.1°	14.56
SEXV	2.6523	1.4757	5.5037	181.3°	-27.00
SEXV	2.9114	1.4940	5.8994	323.8°	-27.00
SEX1	2.9505	1.5275	6.0085	2.0°	14.56

$\nu_+ = 2 \times 11.19046 + 21.41970 = 43.8006 \qquad \frac{1}{\sin \pi \nu_+} = 1.706$

B_+



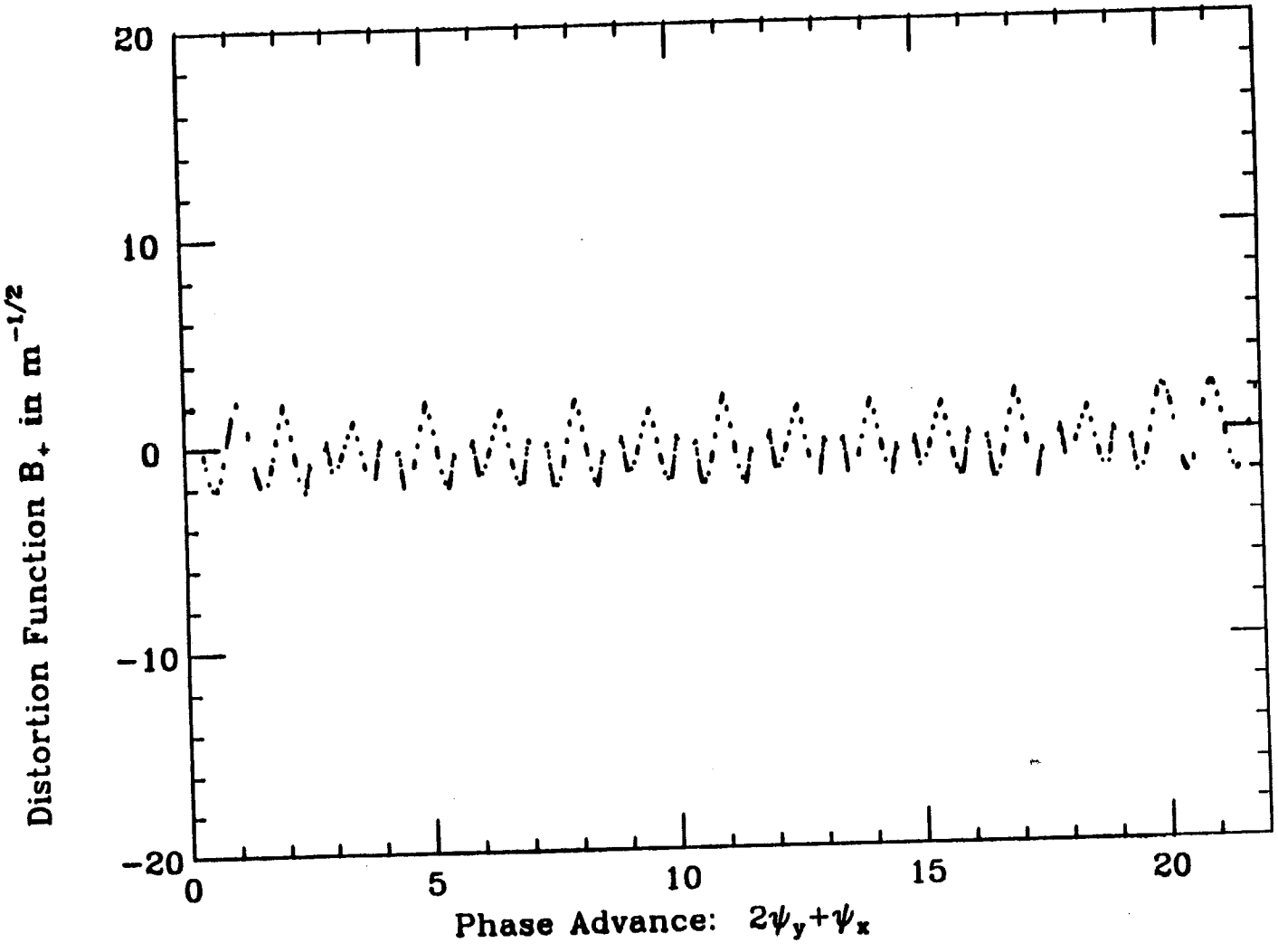
$\boxed{B_+}$

$$\psi_+ = 2\psi_y + \psi_x$$

For the 12 modules, average phase advance per module $\Delta\psi_+ = 1.5023$

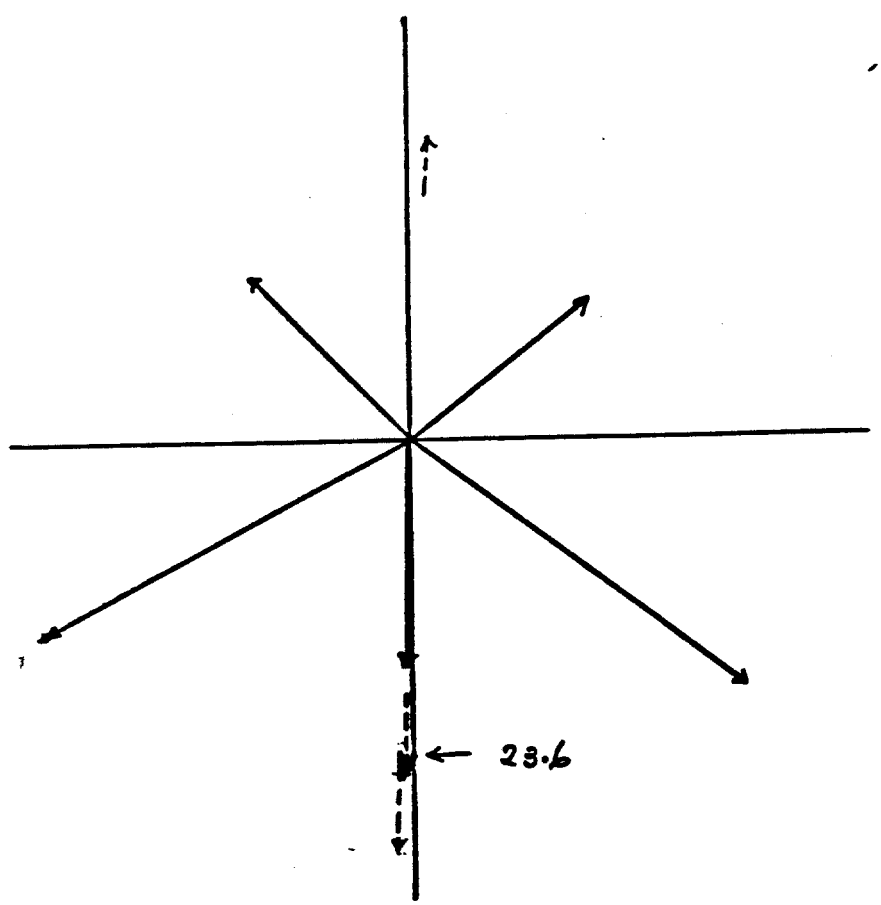
$\therefore$ there is cancellation for every 2 adjacent modules.

Highest contribution comes from 2 modules only instead of 4 in B_1, B_3, $\bar{B}$


20
10
0
−10
−20
0
5
10
15
20
Distortion Function B_+ in $m^{-1/2}$
Phase Advance: $2\psi_y+\psi_x$

	ϕ_x	ϕ_y	$\phi_- = 2\phi_y - \phi_x$		$\bar{s}$
SEXH	2.3691	1.3037	0.2463	89.4°	−14.56
SEXI	2.5132	1.4421	0.3710	133.6°	14.56
SEXV	2.5423	1.4757	0.3991	143.7	−27.00
SEXV	2.9114	1.4940	0.0766	27.6	−27.00
SEXI	2.9505	1.5278	0.1045	37.6°	14.56

B_



The distortion function B_- rotates with a tune of

$$\nu_- = 2\nu_y - \nu_x = 0.9612\,,$$

which is extremely slow.

- Therefore, cancellation between adjacent modules will not be possible.

- No cancellation among the five sextupoles within a module.

- However, due to:

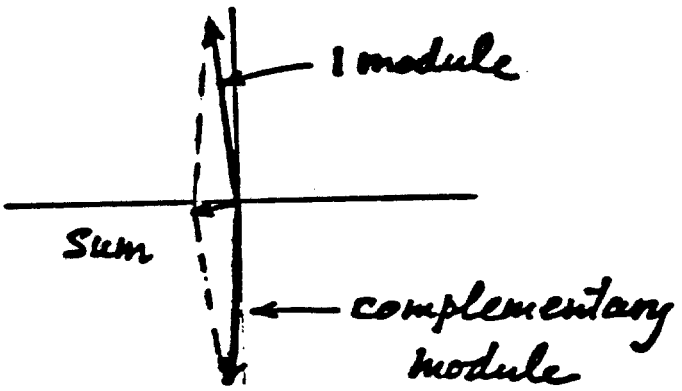
  (1)near integral value of ν_- ,

  (2)two-fold symmetry of the ring,

  each sextupole in the first 12 modules is nearly canceled by a complementary sextupole in the other 12 modules.

Each module contributes a vector of length $\sim 24\ \mathrm{m}^{-1/2}$

together with its complementary module on the other side of the ring,



angle $\pi\nu_-$

$$\sqrt{2+2\cos\pi\nu_-} = 2\cos\frac{\pi\nu_-}{2}$$

contributes a vector of length

$$\sim 24 \times 2\cos\frac{\pi\nu_-}{2} \simeq 2.9\ \mathrm{m}^{-1/2}\,.$$

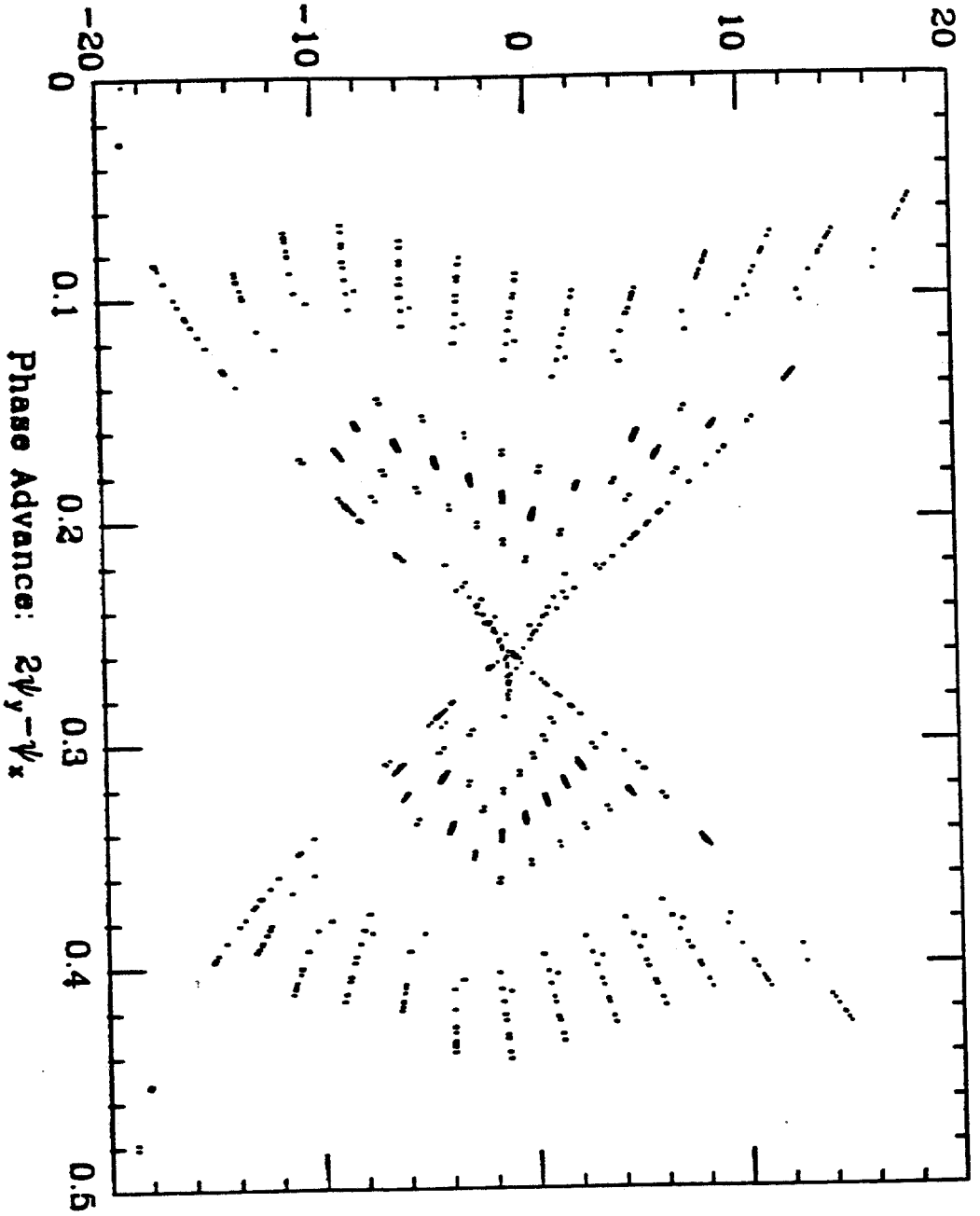
Each of the 12 adjacent modules has nearly the same phase advance ψ_-. Therefore, $|B_-|$ may reach the maximum value of

$$|B_-|_{\max} \simeq 12 \times \frac{24 \times 2\cos\frac{\pi\nu_-}{2}}{16\sin\pi\nu_-} = \frac{18}{\sin\frac{\pi\nu_-}{2}} \simeq 18\ \mathrm{m}^{-1/2}\,,$$

which agrees very well with computation.

Insensitive to how close the difference resonance is.

Distortion Function B_- in $m^{-1/2}$



From MAD and SYNCH,

$$\nu_x = 21.42005 - 97.1\epsilon_x/\pi - 42.5\epsilon_y/\pi \ ,$$

$$\nu_y = 11.18993 - 42.5\epsilon_x/\pi + 2.20\epsilon_y/\pi \ .$$

The detunings here are actually smaller than those of the existing FODO-lattice of the Fermilab Main Injector by 50%. As a result, harmonic sextupoles are not required. In our previous design of the same imaginary-γ_t lattice, these special precautions had not been taken, and the detuning turned out to be

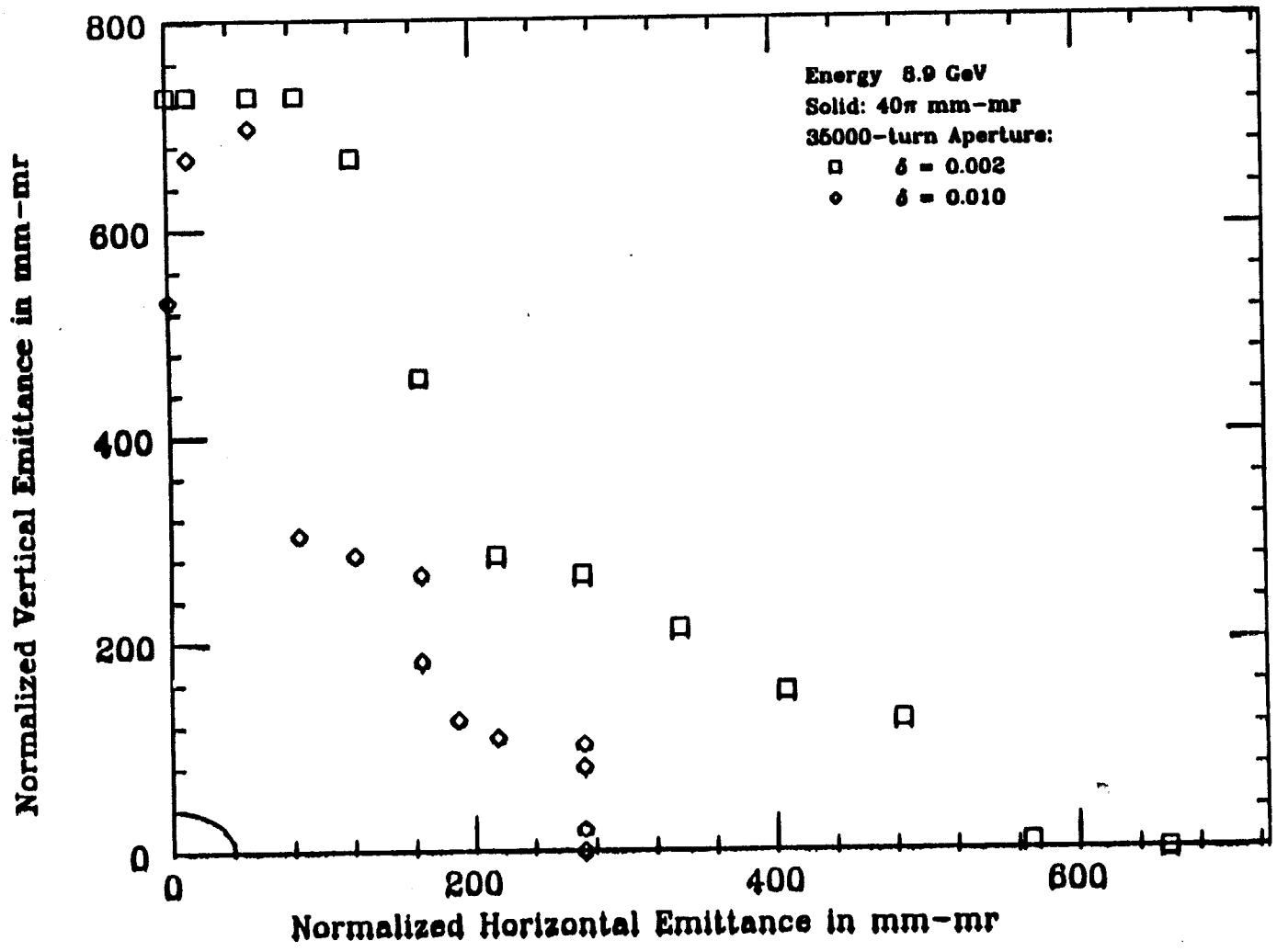
$$\frac{\partial \nu_x}{\partial(\epsilon_x/\pi)} = 4.82 \times 10^2 \ \mathrm{m}^{-1} \ ,$$

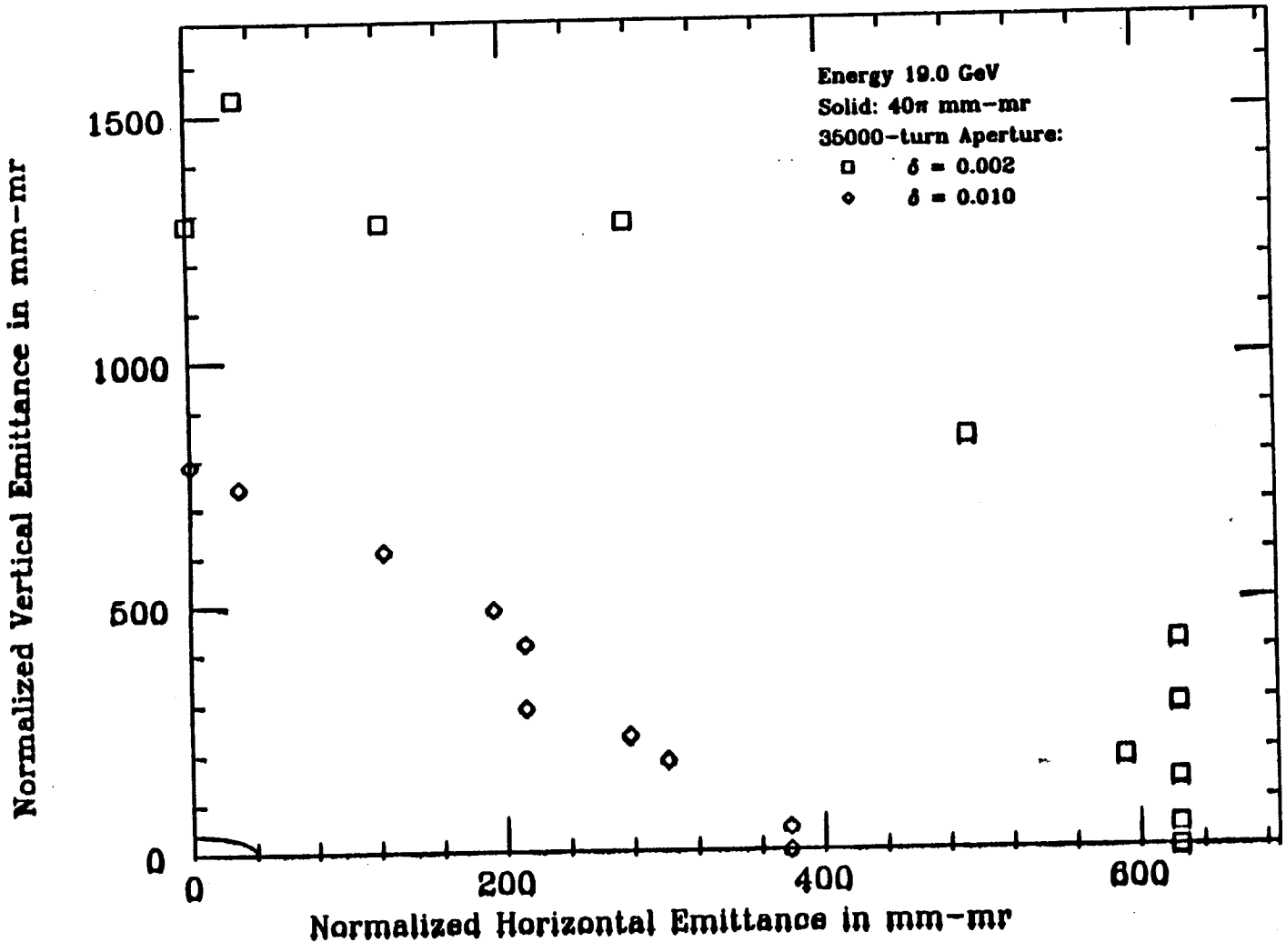
$$\frac{\partial \nu_x}{\partial(\epsilon_y/\pi)} = -1.56 \times 10^4 \ \mathrm{m}^{-1} \ ,$$

$$\frac{\partial \nu_y}{\partial(\epsilon_y/\pi)} = -7.49 \times 10^3 \ \mathrm{m}^{-1} \ ,$$

which are very large. In order to maintain a reasonably large aperture, a family of harmonic sextupoles were installed in the previous lattice to lower the nonlinearity. The three detunings then reduced

to 4.43×10^2, -2.81×10^2, and 1.33×10^3 m^{-1}, which are still very much larger than the detunings of the present design.


Energy 8.9 GeV
Solid: 40π mm-mr
35000-turn Aperture:
δ = 0.002
δ = 0.010
800
600
400
200
0
0
200
400
600
Normalized Vertical Emittance in mm-mr
Normalized Horizontal Emittance in mm-mr


Energy 19.0 GeV
Solid: 40π mm−mr
35000−turn Aperture:
δ = 0.002
δ = 0.010
1500
1000
500
0
0
200
400
600
Normalized Vertical Emittance in mm−mr
Normalized Horizontal Emittance in mm−mr