Accelerator Physics Issues

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Sept 17-19, 1996

Main Injector DOE Review

Accelerator Physics Issues

- Lattice Results from Previous Reviews
- Recent Results
    - **Magnet Data analysis**
    - **Dipoles and Quadrupole Placement**
    - **Lattice Calculations**
- Comments on Impedance Issues
- Conclusions

Introduction

All the Lattice calculations performed for Main Injector have been done using thin element tracking code TEAPOT (Talman et al.)

These calculations includes:-

- Strength variations in the dipoles and quadrupoles.
- Measured higher order multipoles.
- Misalignment of the magnetic elements and BPM.
- $\Delta p/p$
- RF

The tune of the Main Injector is adjusted to 26.425, 25.415.

The chromaticity is (-5,-5) below transition and small positive above.

Using these calculations and harmonics correctors in the Ring, we have developed a correction scheme.

Table 2.3-1 Magnetic errors used in the 8.9 GeV simulation.

	Multipole Order	Normal $\langle b_n \rangle$	Normal σ_{b_n}	Skew $\langle a_n \rangle$	Skew σ_{a_n}
Dipole	dipole	1.10	15.30	-	-
	quadrupole	0.06	0.80	-	-
	sextupole	-0.40	0.18	0.00	0.12
	8	0.04	0.06	0.03	0.03
	10	0.33	0.05	0.00	0.05
	12	-0.01	0.05	-0.03	0.04
	14	-0.03	0.05	0.00	0.05
Recycled Main Ring Quadrupoles (New Style)	quadrupole	-	24.00	-	-
	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 MI Quadrupoles	quadrupole	-	24.00	-	-
	sextupole	-0.51	2.73	1.08	1.85
	8	3.41	1.02	-2.05	2.38
	10	0.03	1.12	-0.75	0.47
	12	-1.49	0.63	0.43	0.70
	14	0.21	0.64	-	0.44
	16	1.41	0.64	-	-
	18	-0.19	0.12	-0.07	0.16
	20	-0.77	0.06	-0.12	0.07

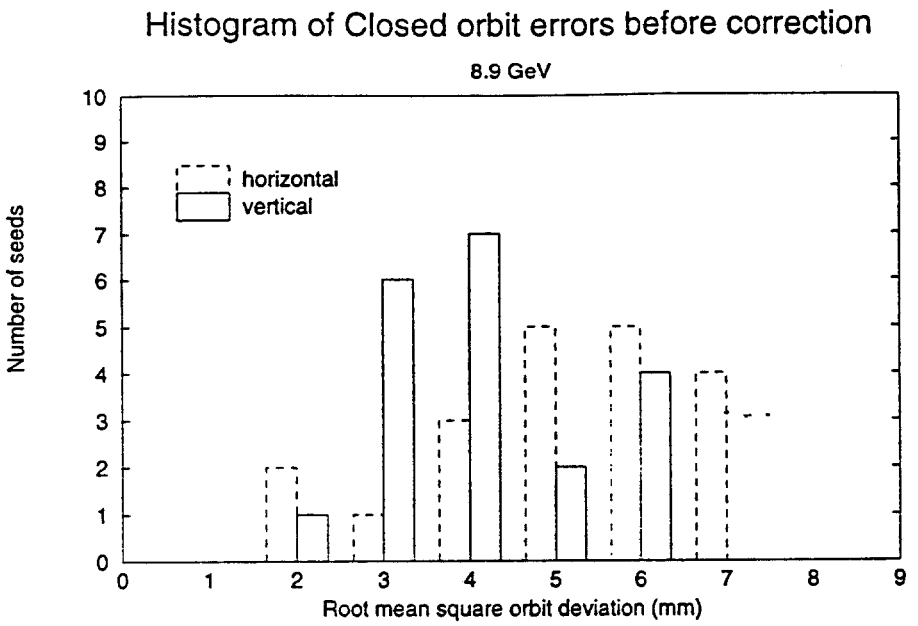


Figure 2.3-2(a). Histogram of Closed Orbit Errors Before Correction at 8.9 GeV

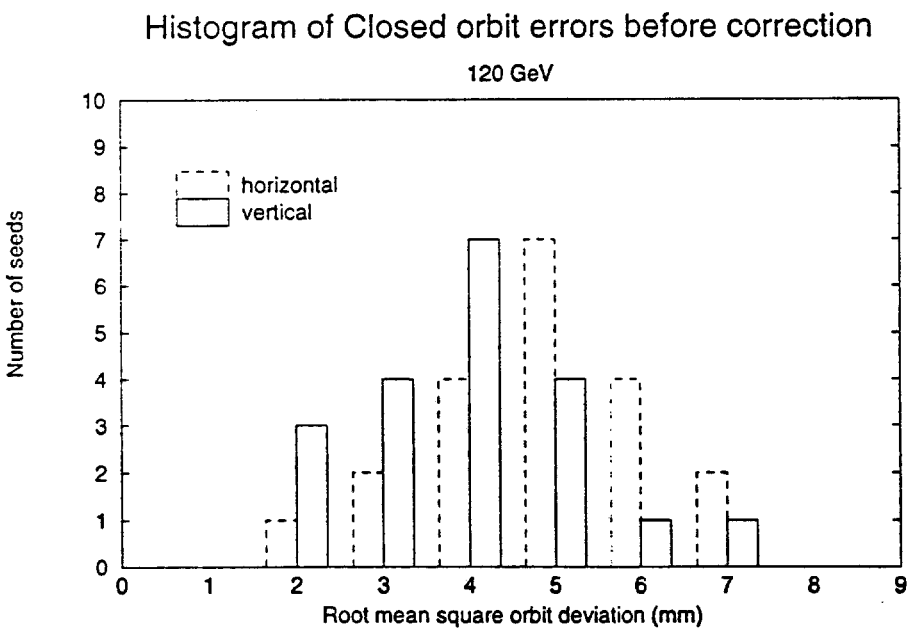


Figure 2.3-2(b). Histogram of Closed Orbit Errors Before Correction at 120 GeV

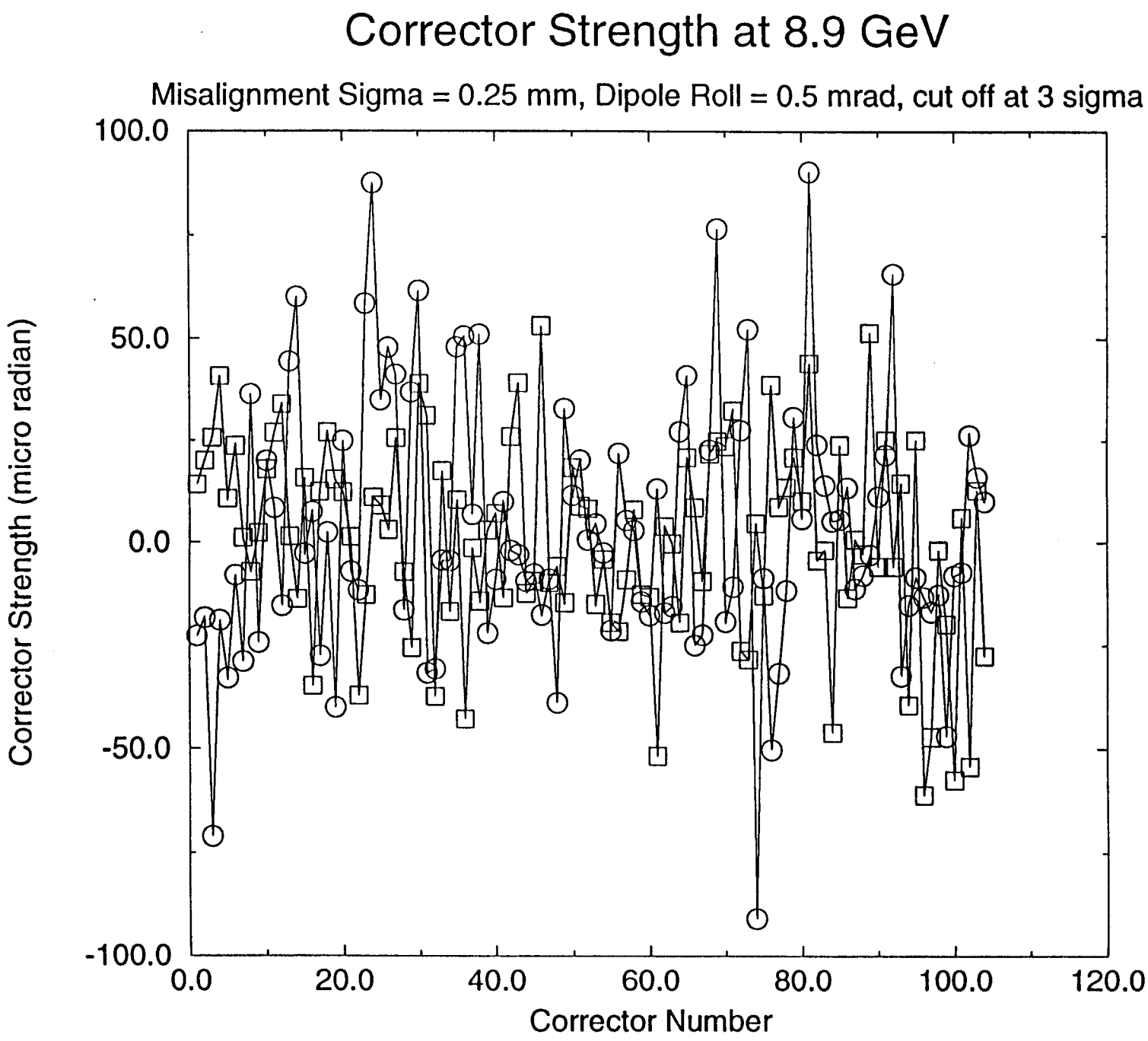


Figure 2.3-3 Corrector Strength at 8.9 GeV

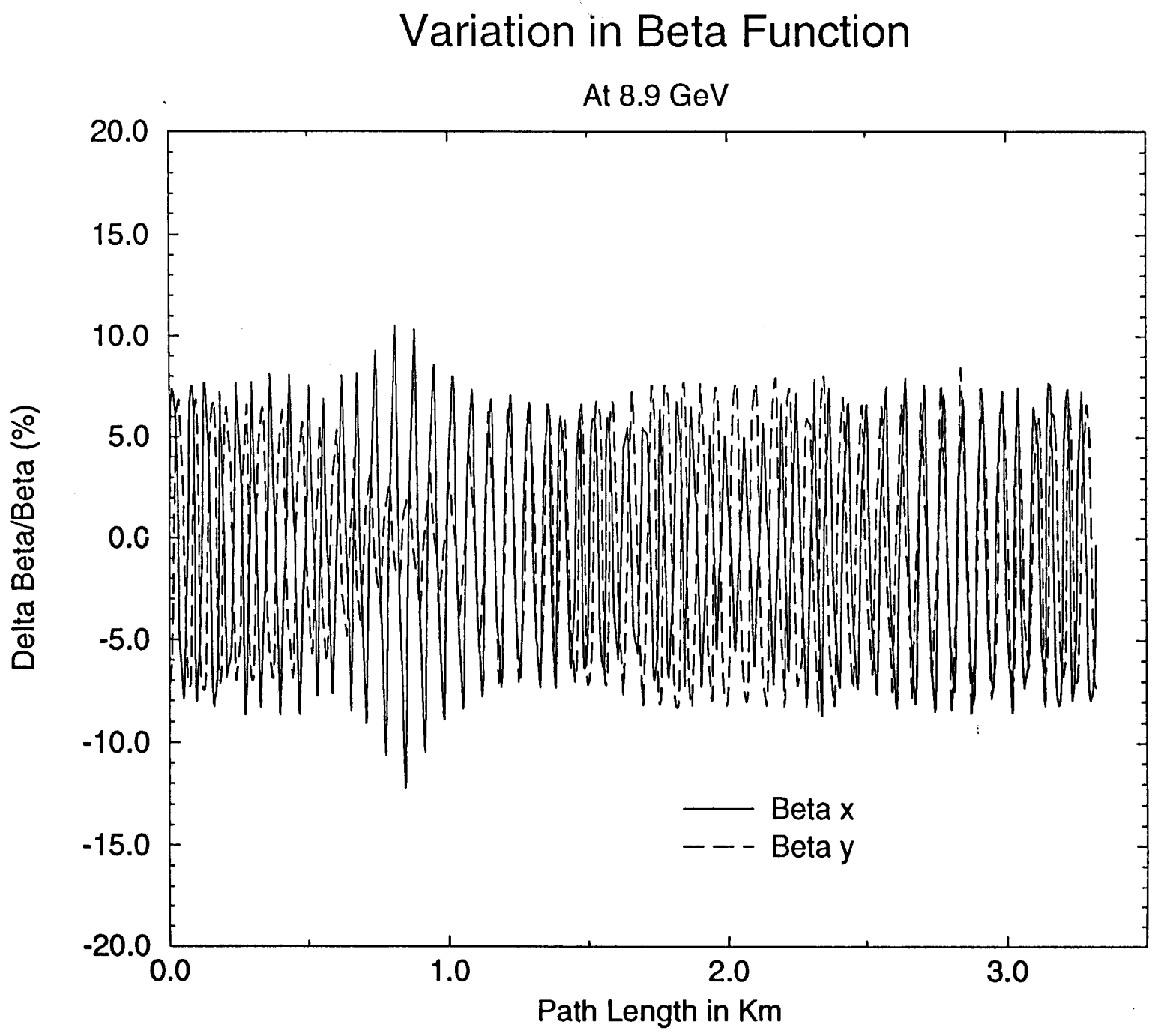


Figure 2.3-4. Typical Variation in Beta Function

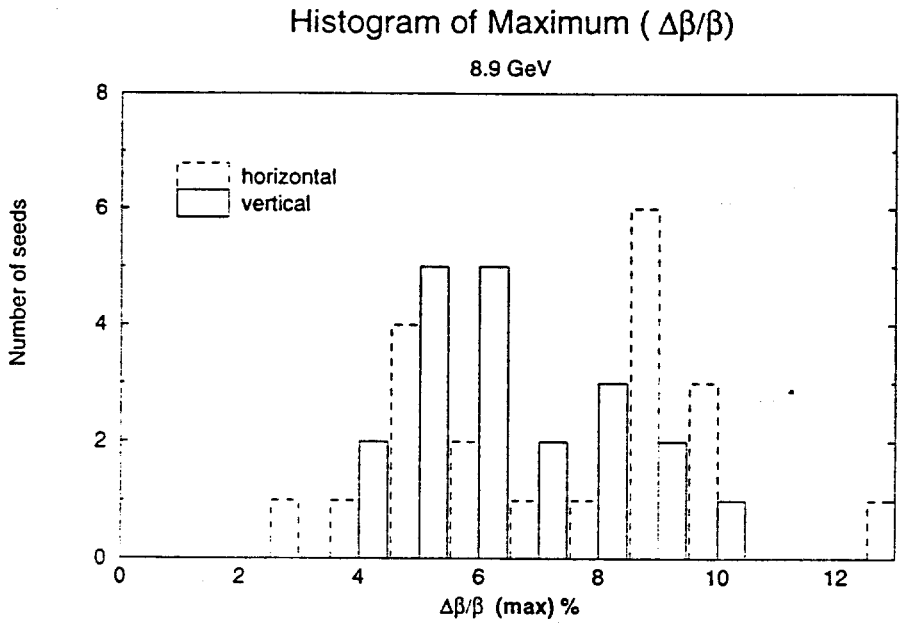


Figure 2.3-5(a). Histogram of (Δß/ß) Errors at 8.9 GeV

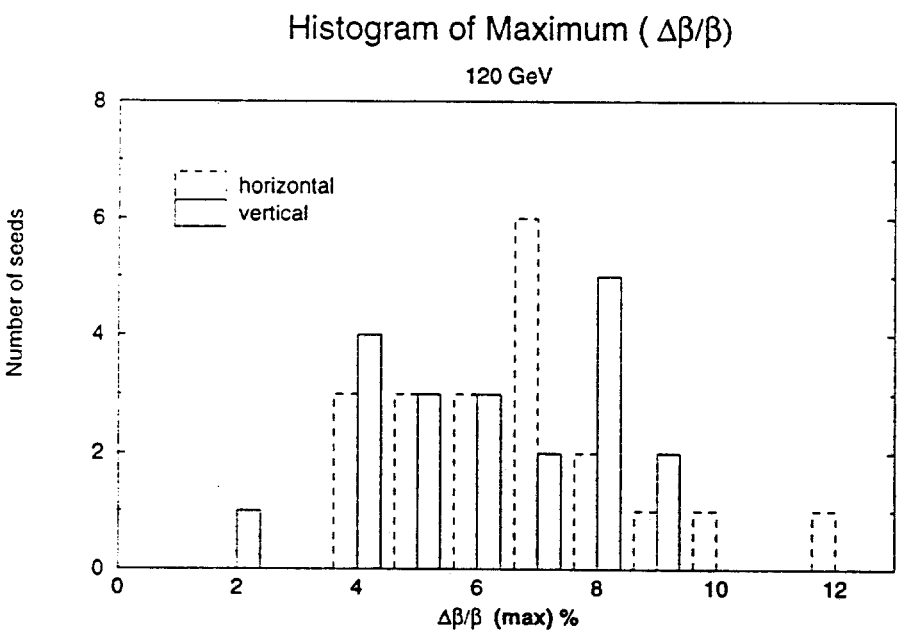


Figure 2.3-5(b). Histogram of (Δß/ß) Errors at 120 GeV

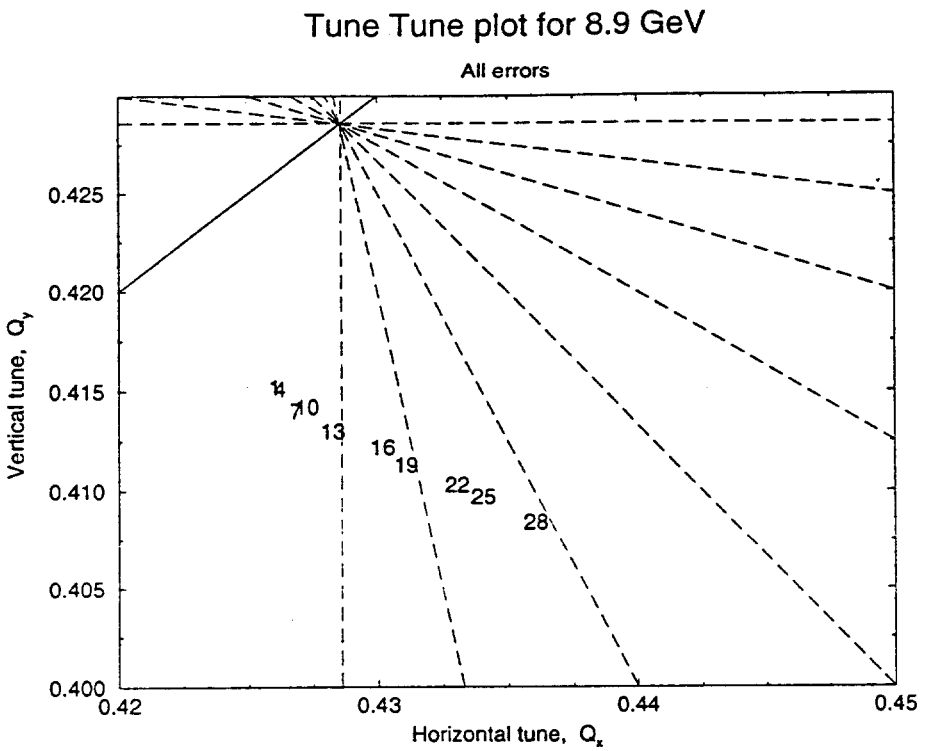


Figure 2.3-10(a). Tune-Tune Plot at 8.9 GeV

Numbers 1 to 28 are Initial Amplitude of the Launched Particle.

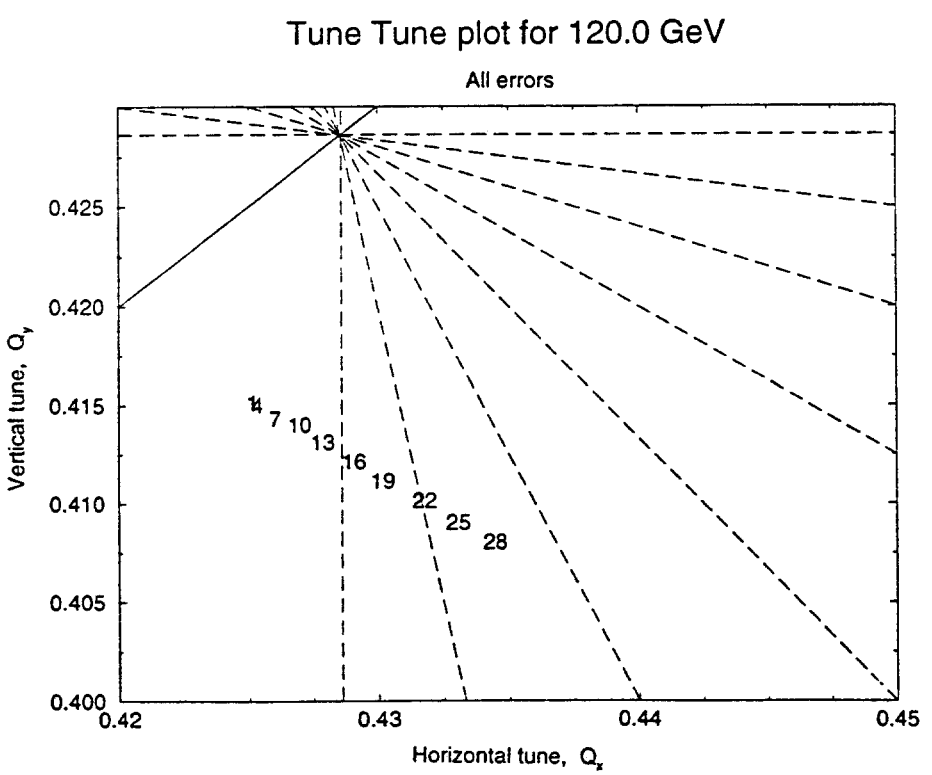


Figure 2.3-10(b). Tune-Tune Plot at 120 GeV

Numbers 1 to 28 are Initial Amplitude of the Launched Particle.

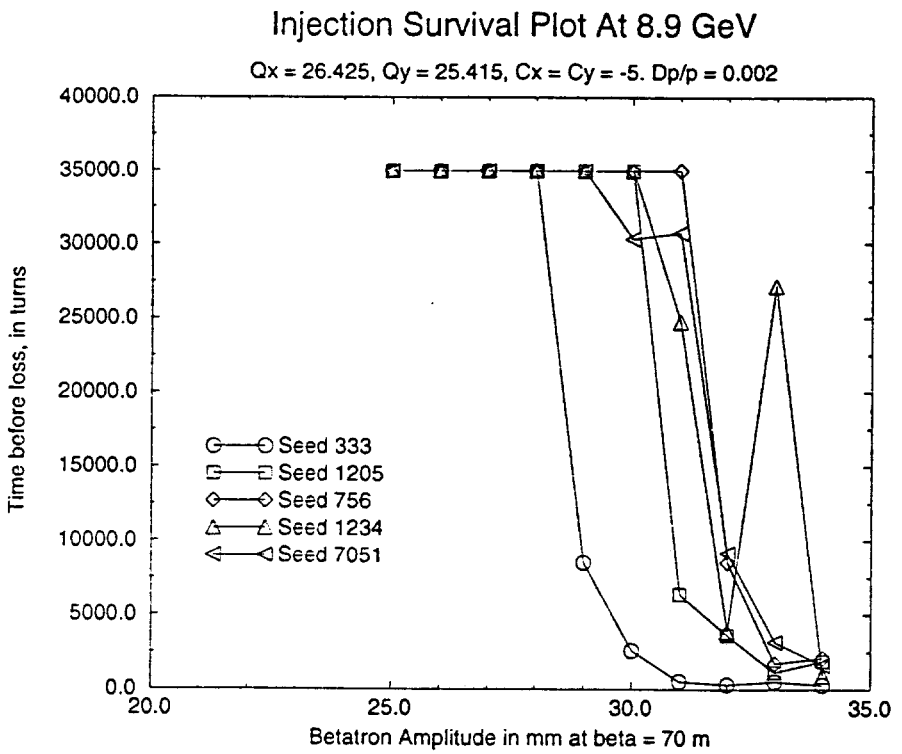


Figure 2.3-6(a). Survival Plot for Five Seeds at 8.9 GeV

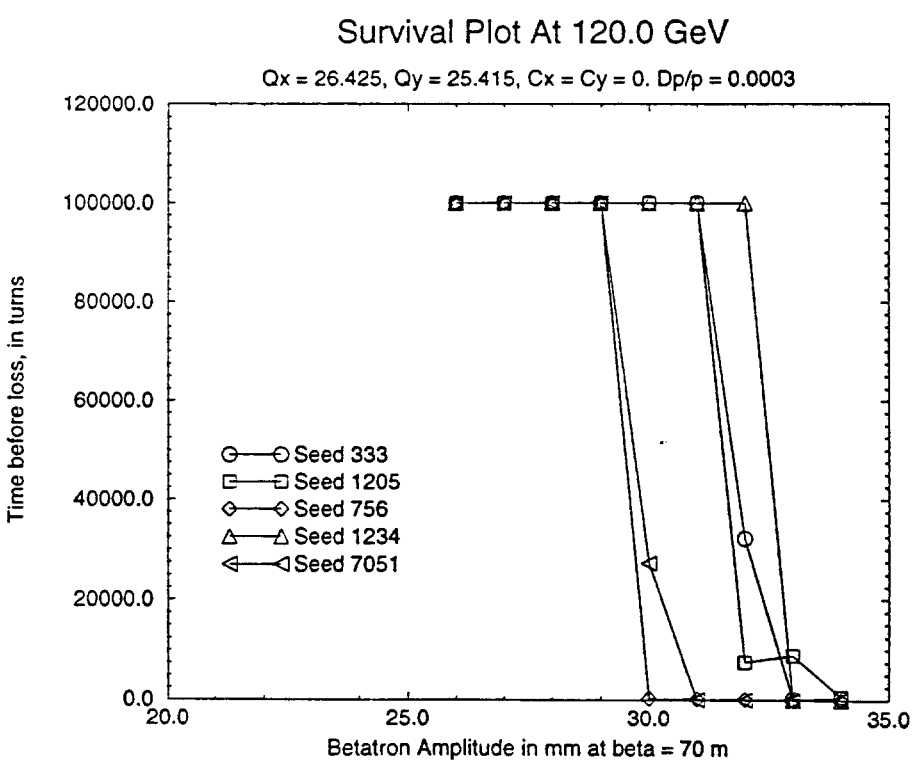


Figure 2.3-6(b). Survival Plot for Five Seeds at 120 GeV

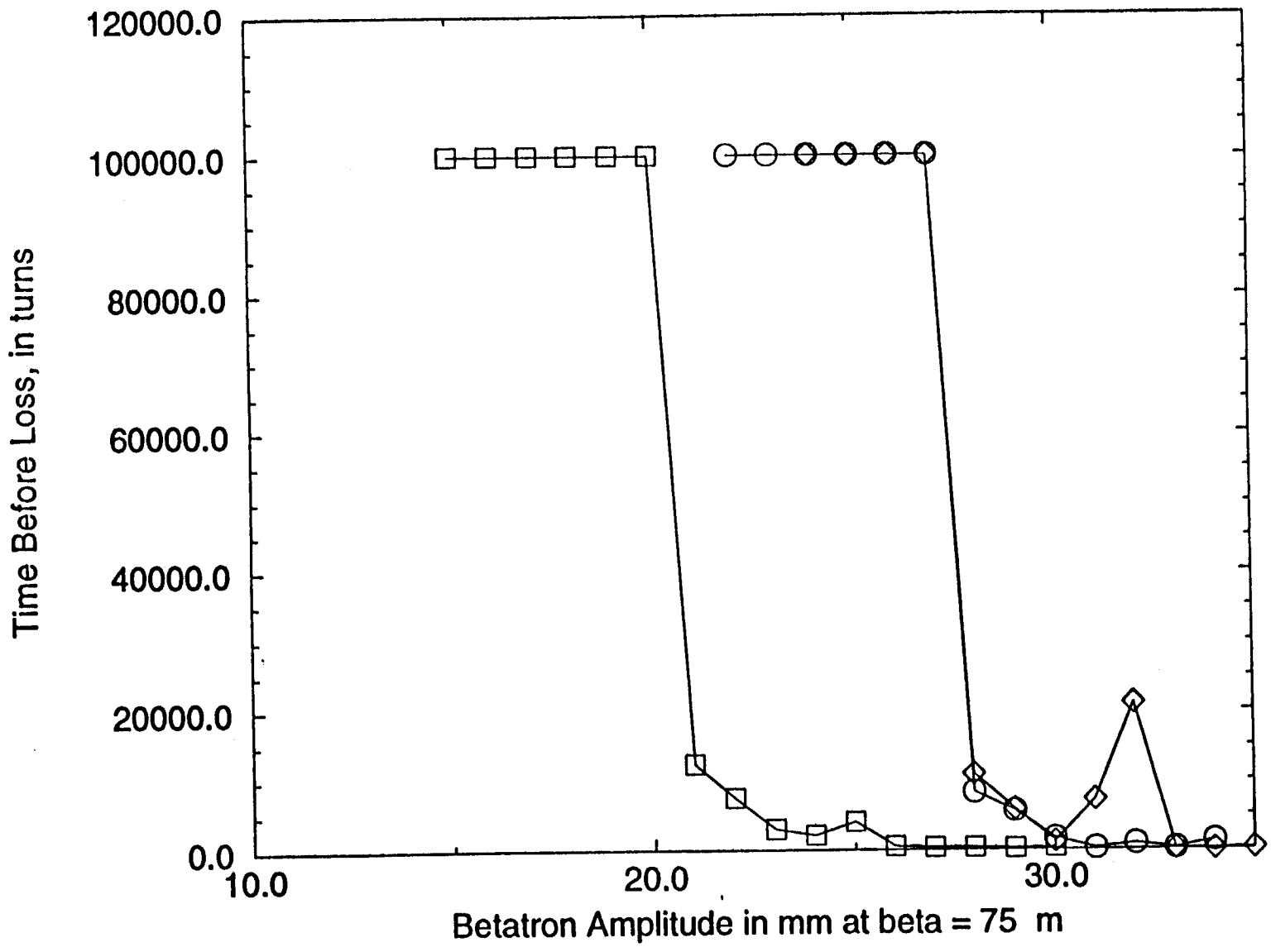


Figure 2.3-13. Survival Plot at 120 GeV and ν = .485 Before and After Correction

Magnet Data Analysis

Dipole Strength Analysis

- The FMI Dipole Strength has changed during the production of the dipoles, due to change in steel properties.

- Dipoles magnets have been divided into following groups according to their strength.

  - R&D Magnets : - After machining

    3 IDA and IDB (+12 Units)

    3 IDC and IDD. (+30 Units)

  - Pre Run 4 Steel :-

    25 IDA (-35 Units)

    19 IDB (-35 –> -10 Units)

  - Run 12 Steel:- (60 % Run 12 Steel)

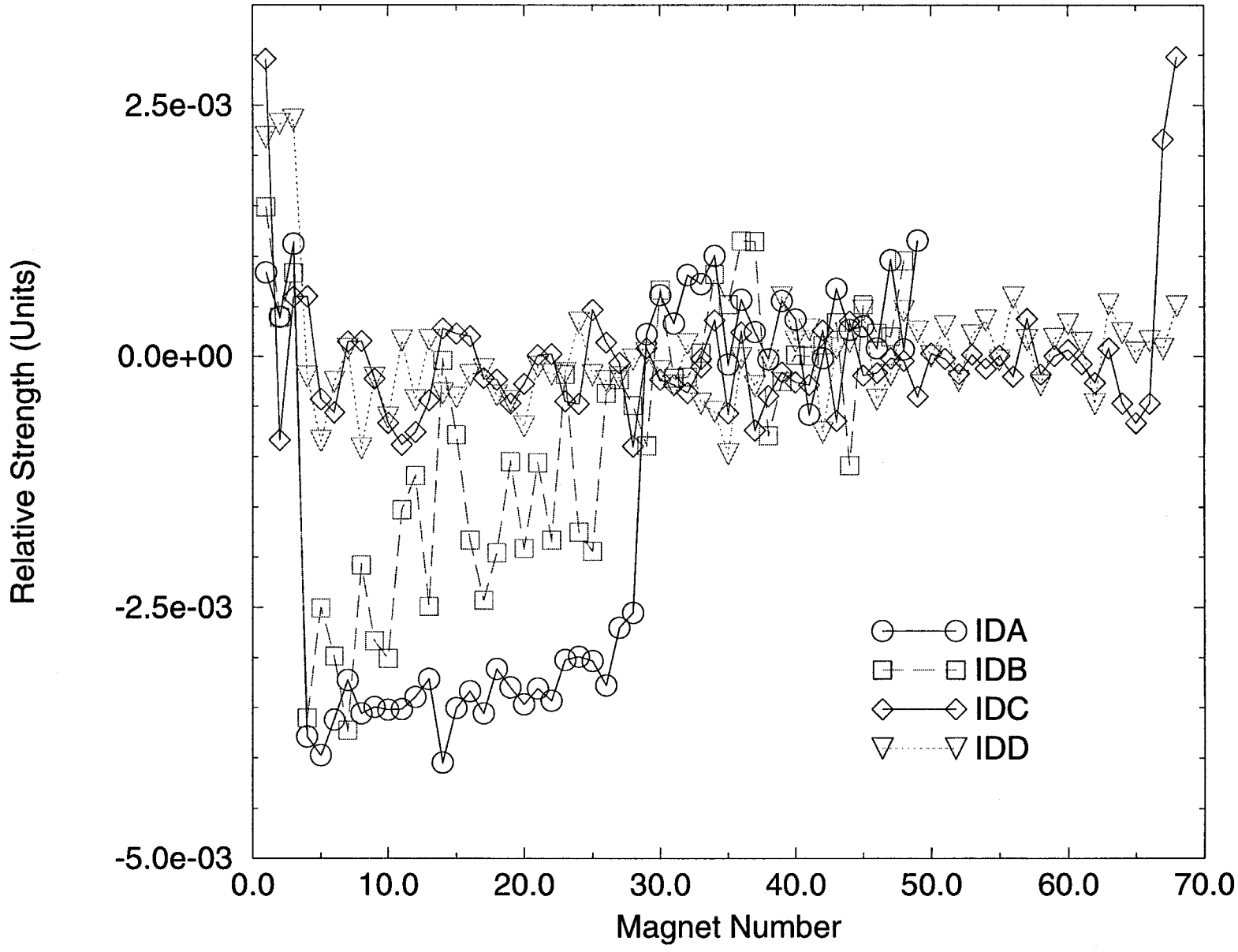
    1 IDA (+12 Units)

    6 IDB (+12 Units)

  - Rest Nominal Magnets (~170 Magnets)

Relative Strength of Main Injector Dipoles

7000 Amps



Dipole Multipoles at Injection

Multipole	Mean (in Units)	sigma (in Units)
b1	-0.3	0.6
b2	-0.7	0.2
b3	0.03	0.1
b4	0.2	0.1
b5	-0.02	0.1
b6	0.2	0.2
b7	0.3	0.4
b8	0.7	0.5
a1	-0.6	0.4
a2	-0.06	0.3
a3	-0.4	0.1
a4	0.0	0.2
a5	-0.6	0.2
a6	-0.04	0.3
a7	-0.6	0.2
a8	0.0	0.4

Magnet Data Analysis ...

Quadrupole Data Analysis

We have Build 35 IQC(100") and 52 IQD(116") new quadrupole magnets. These magnets will be placed in the Dispersion suppresser region.

• Sigma of the strength variation is 7 units at injection and 5 units at 120 GeV.

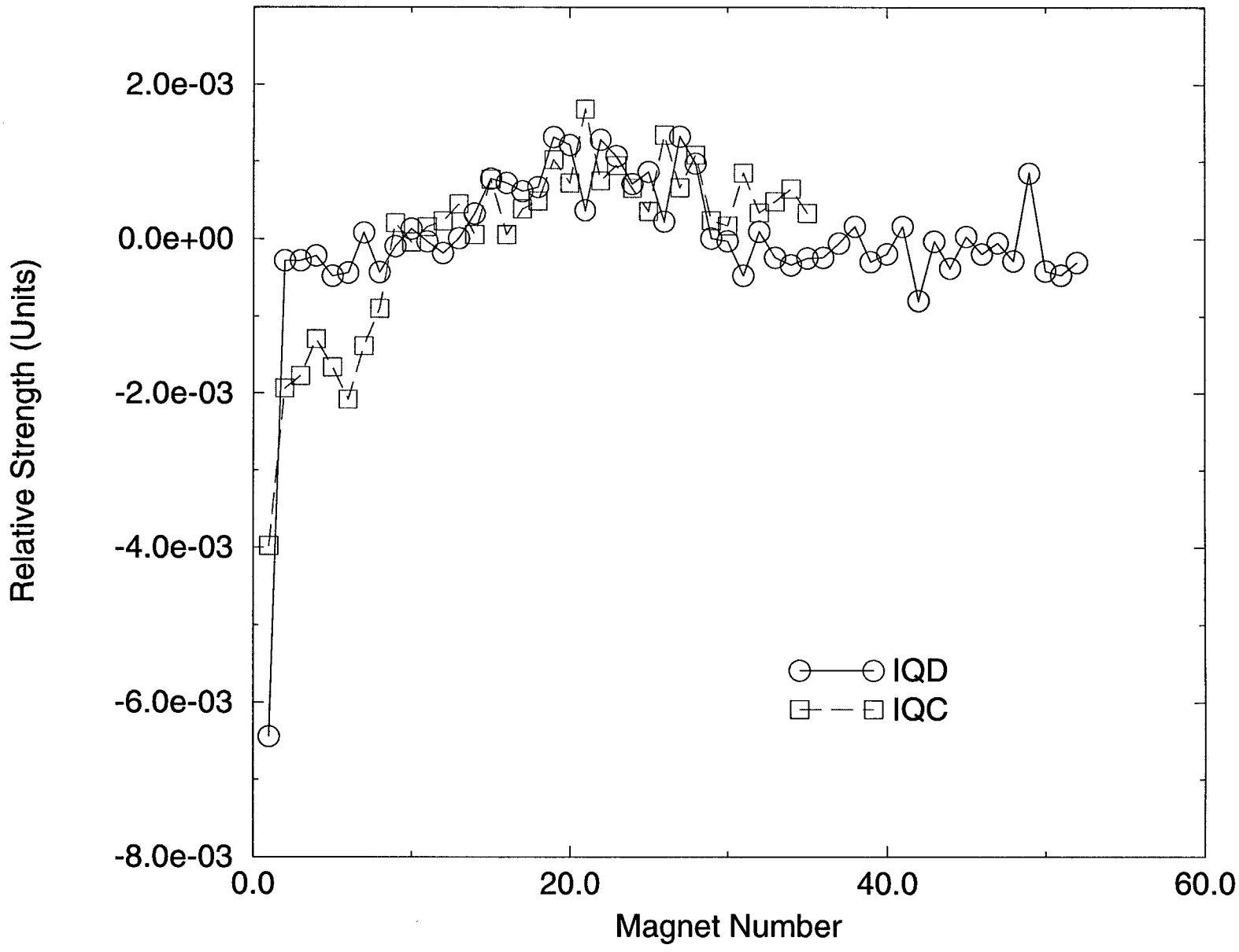
• Systematic strength difference between IQC and IQD is 17 units. (25 Units was allowed, see MI Note 110, ``Study of the long and short quadrupole strength match'' , C. S. Mishra)

• Normal octupole component in these quadrupoles are about 5 Units.

• Main Injector will also use 128 quadrupoles recycled from Main Ring. We have good measurements of a handful of these magnets.

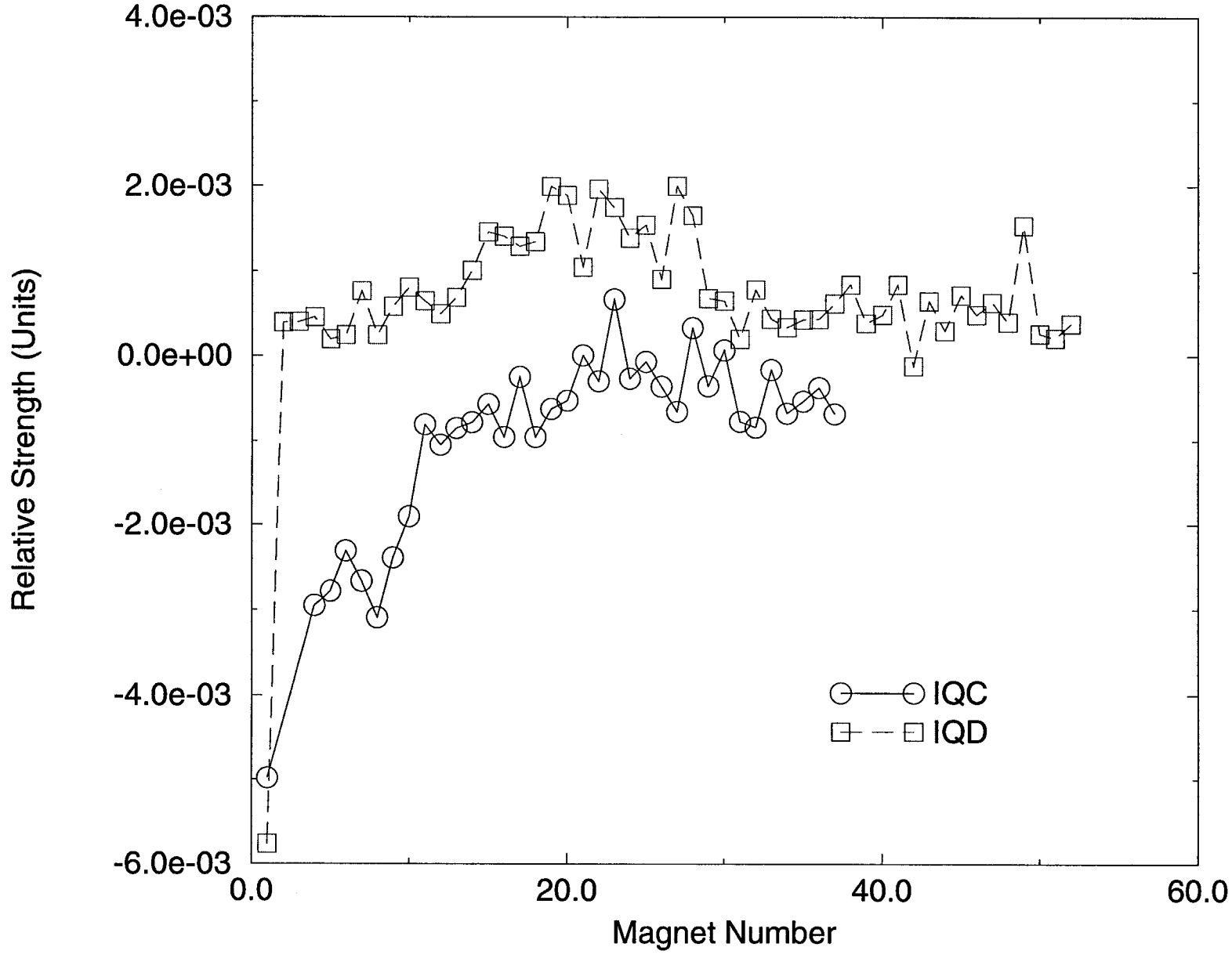
Main Injector New Quadrupole Strength

2900 Amps (wrt its own mean)

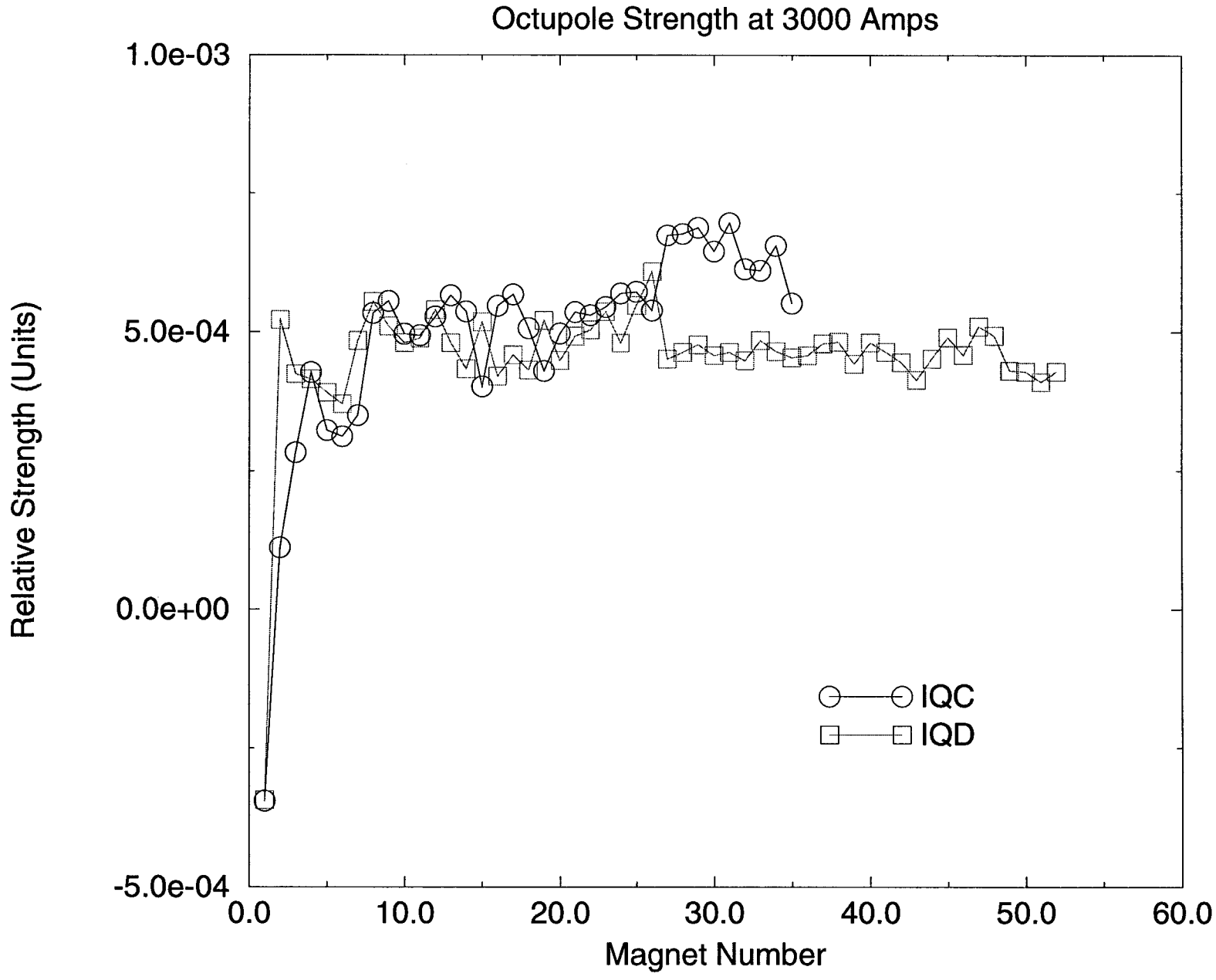


Main Injector New Quadrupole Strength

At 2900 Amps (wrt all new quadrupoles)



Main Injector New Quadrupole



Quadrupole Multipole at Injection

Multipole	Mean (in Units)	Sigma
b0	-1.1	5.4
b2	0.0	1.3
b3	6.2	1.0
b4	0.05	0.5
b5	-1.7	0.3
b6	0.2	0.6
b7	1.4	0.6
b8	-0.1	0.1
b9	-0.8	0.1
a2	0.5	1.4
a3	-1.95	1.4
a4	-0.4	0.3
a5	0.5	0.4
a6	-0.6	0.4
a8	-0.05	0.1
a9	-0.05	0.1

Dipole Magnet Placement

Placement of the Dipole magnets in the FMI ring has been determined by shuffling on the dipole strength.

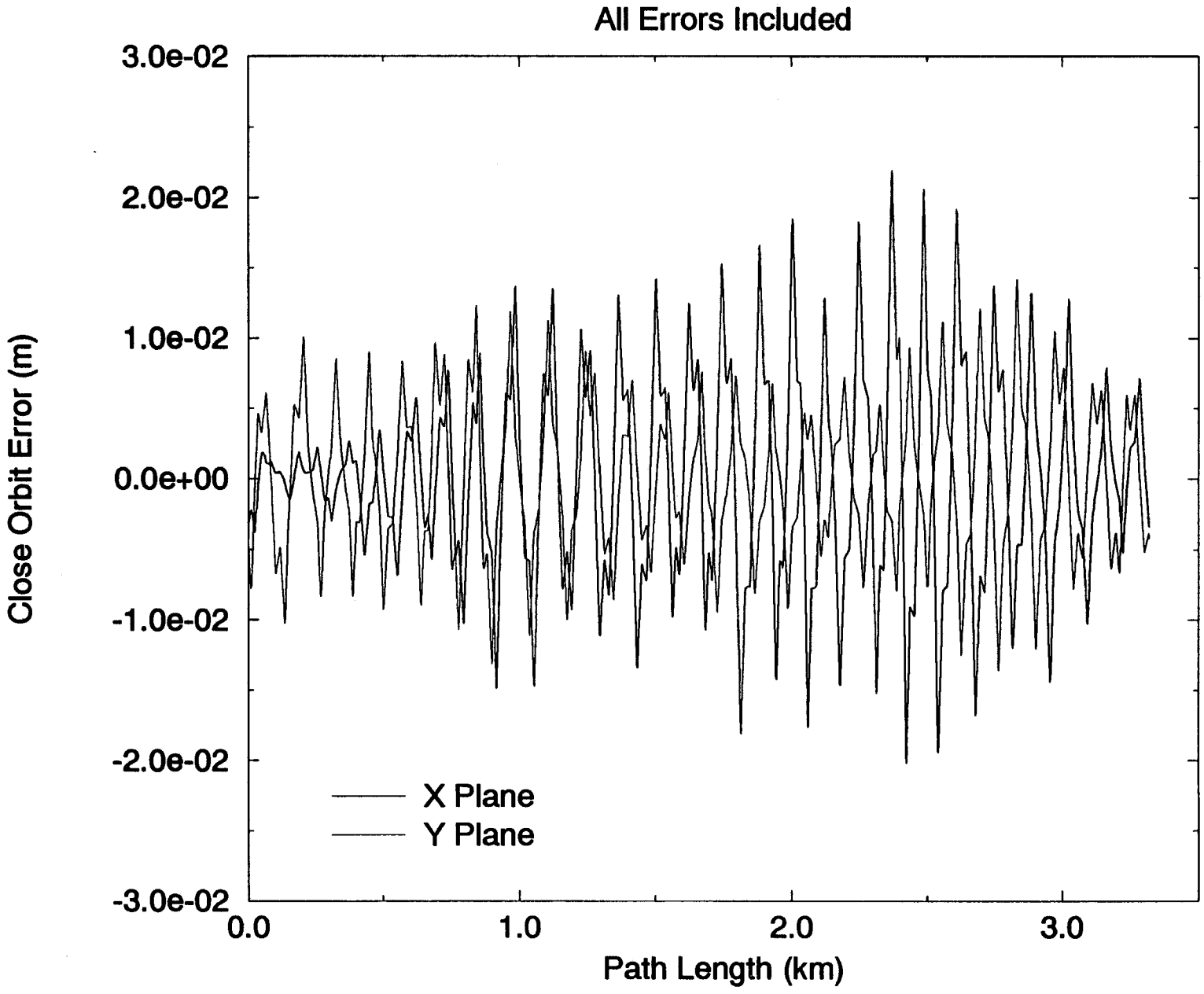
Criteria of the dipole placement:-

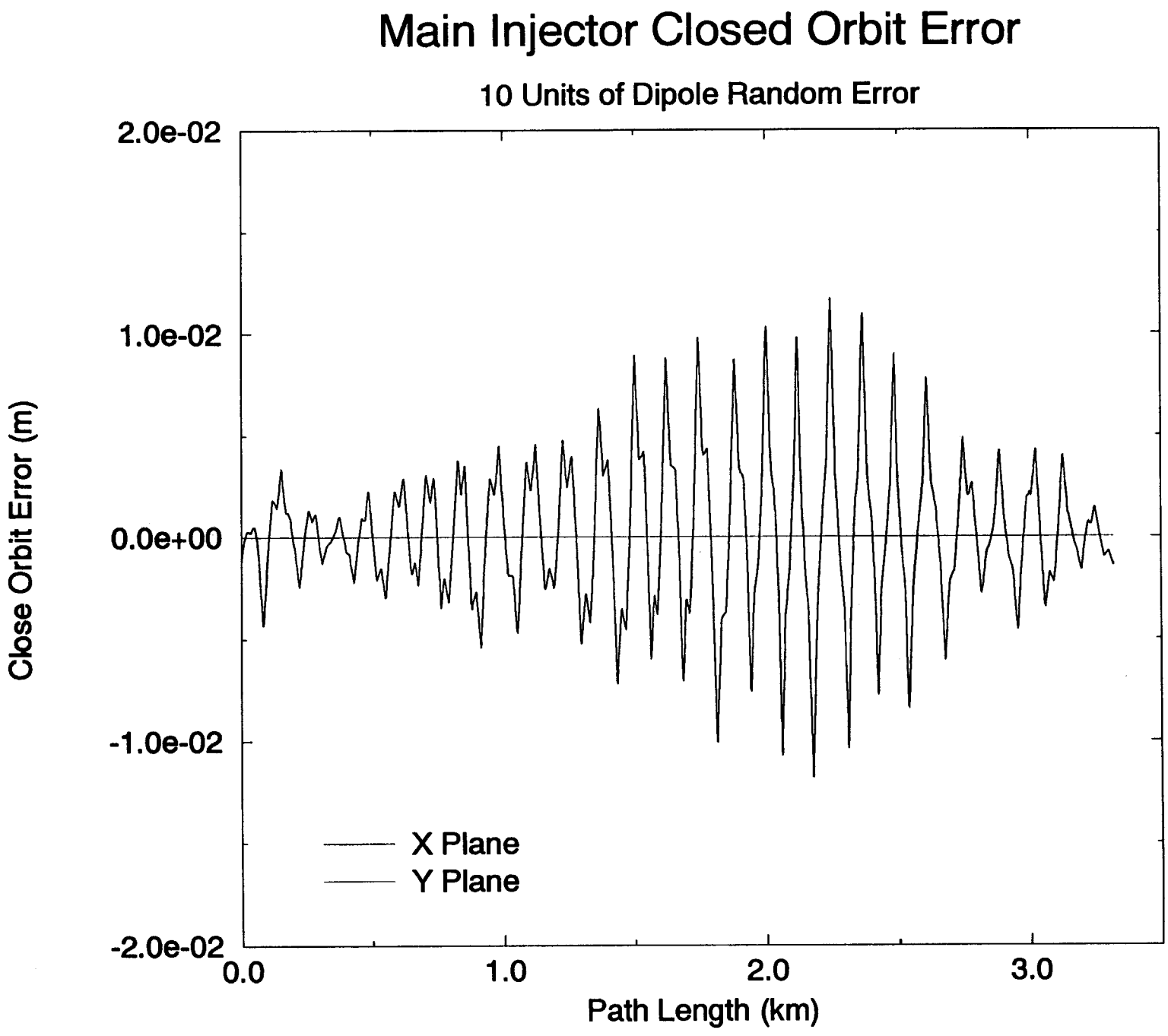
- No sizable closed orbit error in the injection and extraction section.
- The dipole selection should not introduce a closed orbit error larger than due to misalignment error.

We had designed the dipole correctors to correct closed orbit error due to 10 units of random dipole strength error.

After the assignment of 210 dipoles, which includes varieties of dipole strength, we have achieved relatively smaller closed orbit error.

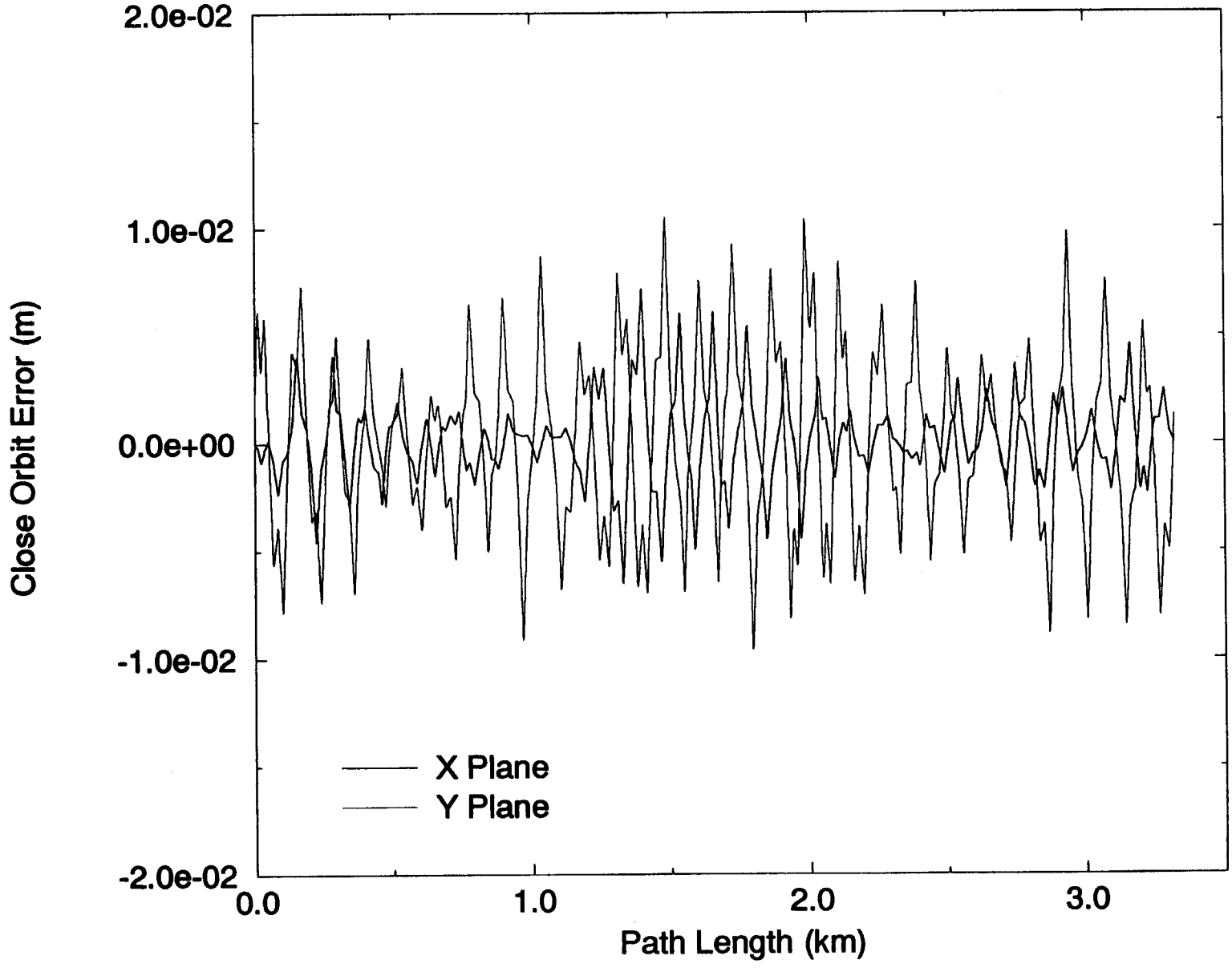
Main Injector Closed Orbit Error




Main Injector Closed Orbit Error
10 Units of Dipole Random Error
2.0e-02
1.0e-02
0.0e+00
-1.0e-02
-2.0e-02
Close Orbit Error (m)
0.0
1.0
2.0
3.0
Path Length (km)
X Plane
Y Plane

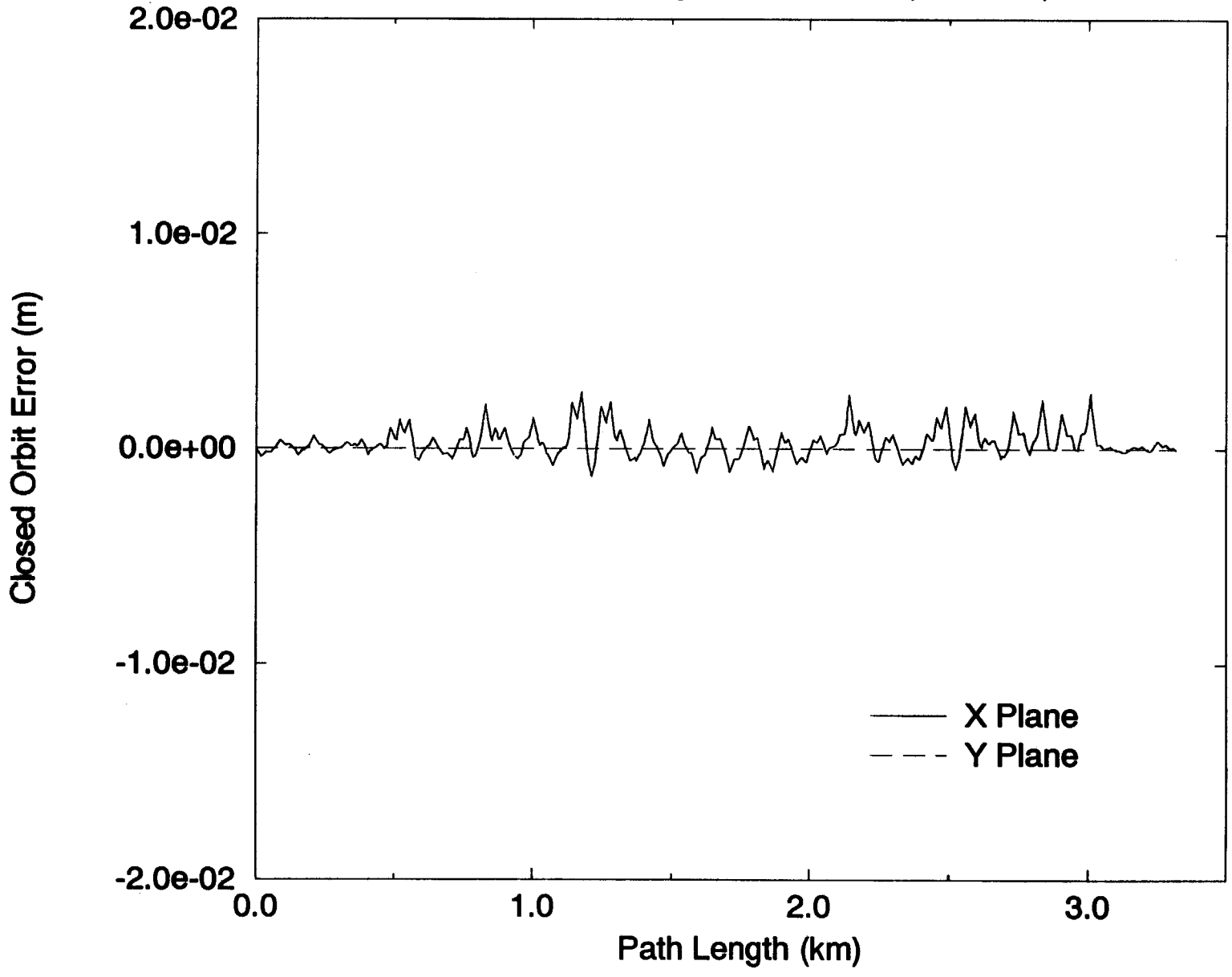
Main Injector Closed Orbit Error

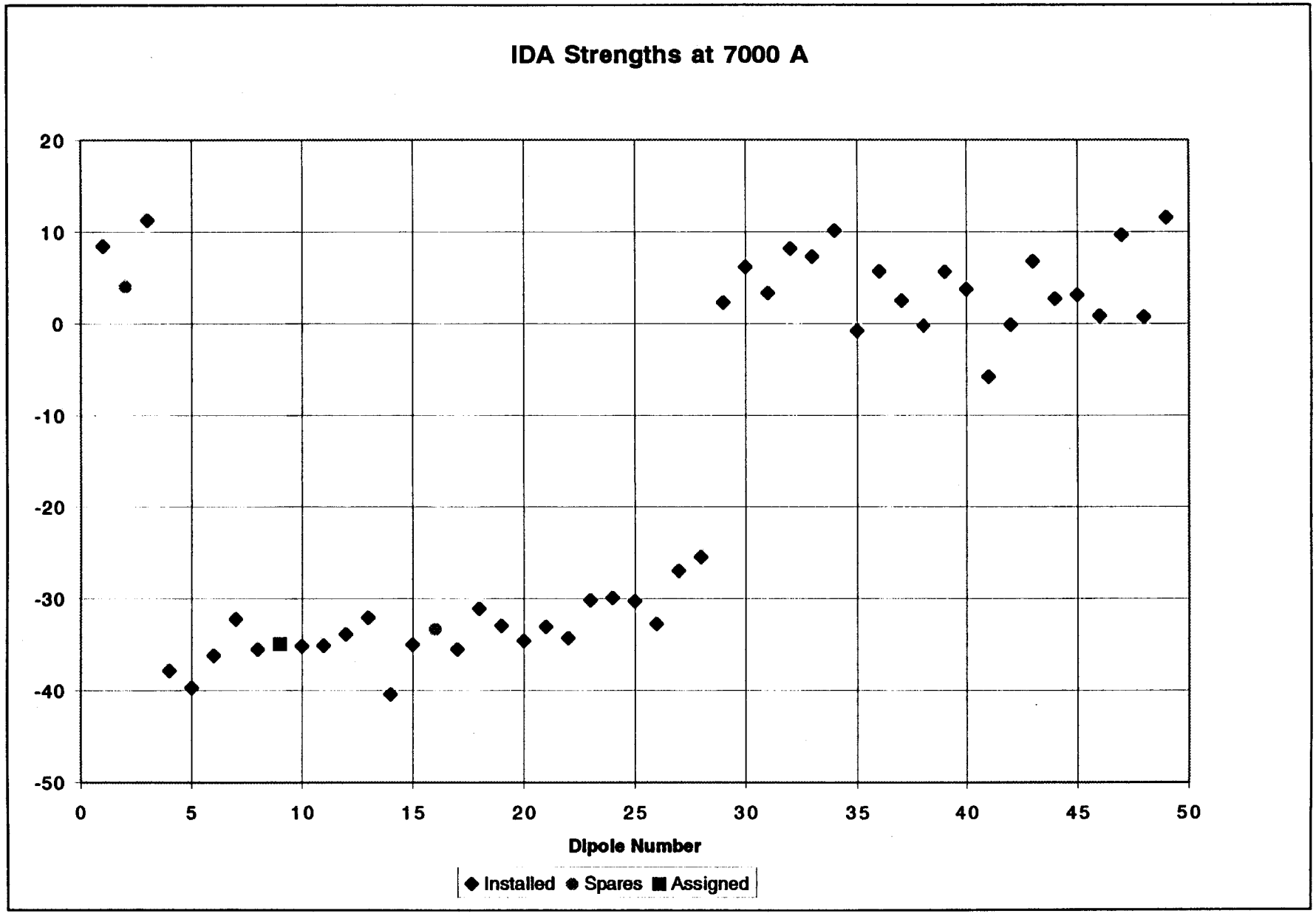
All Magnetic Element Misalignment Errors Included

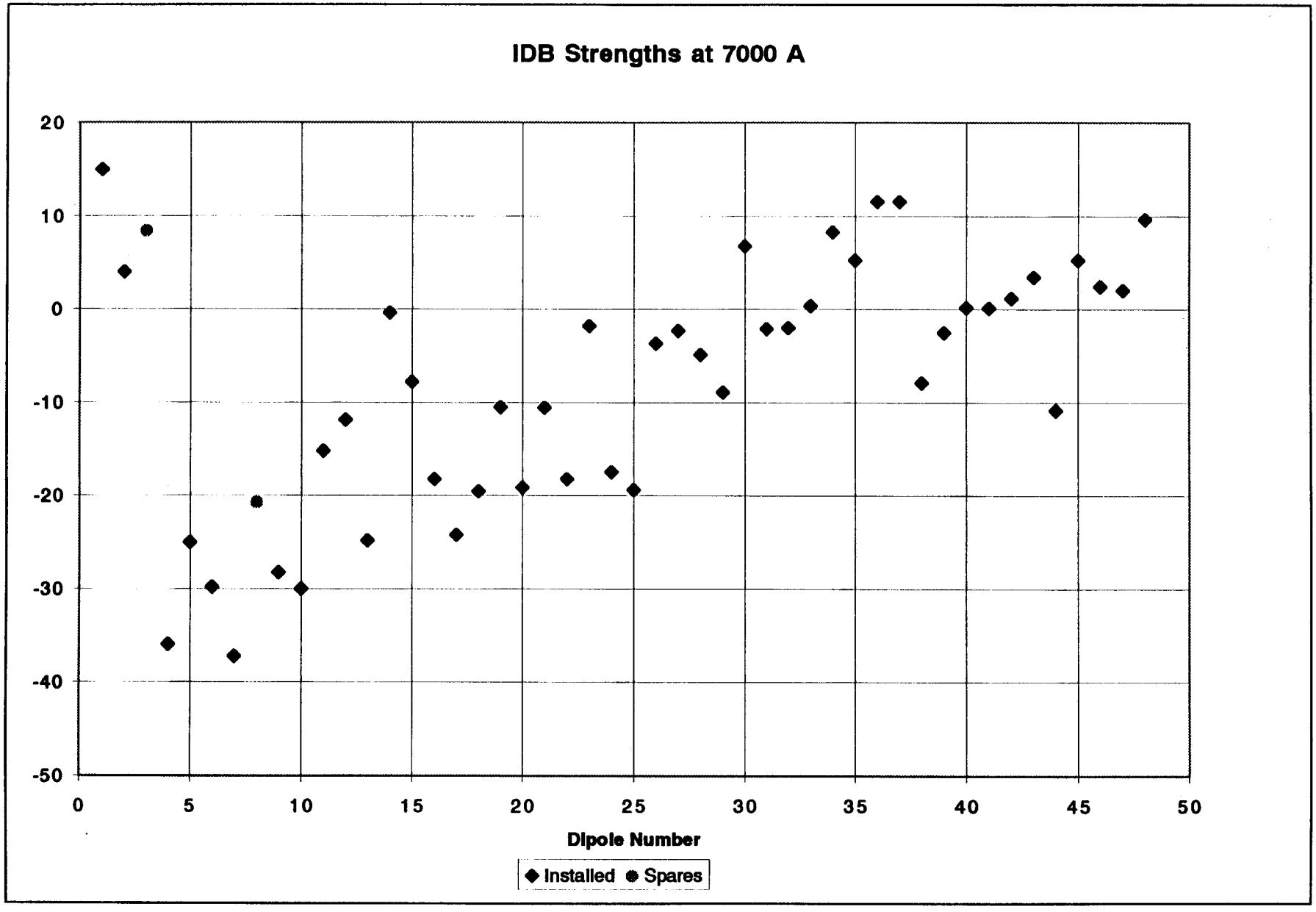


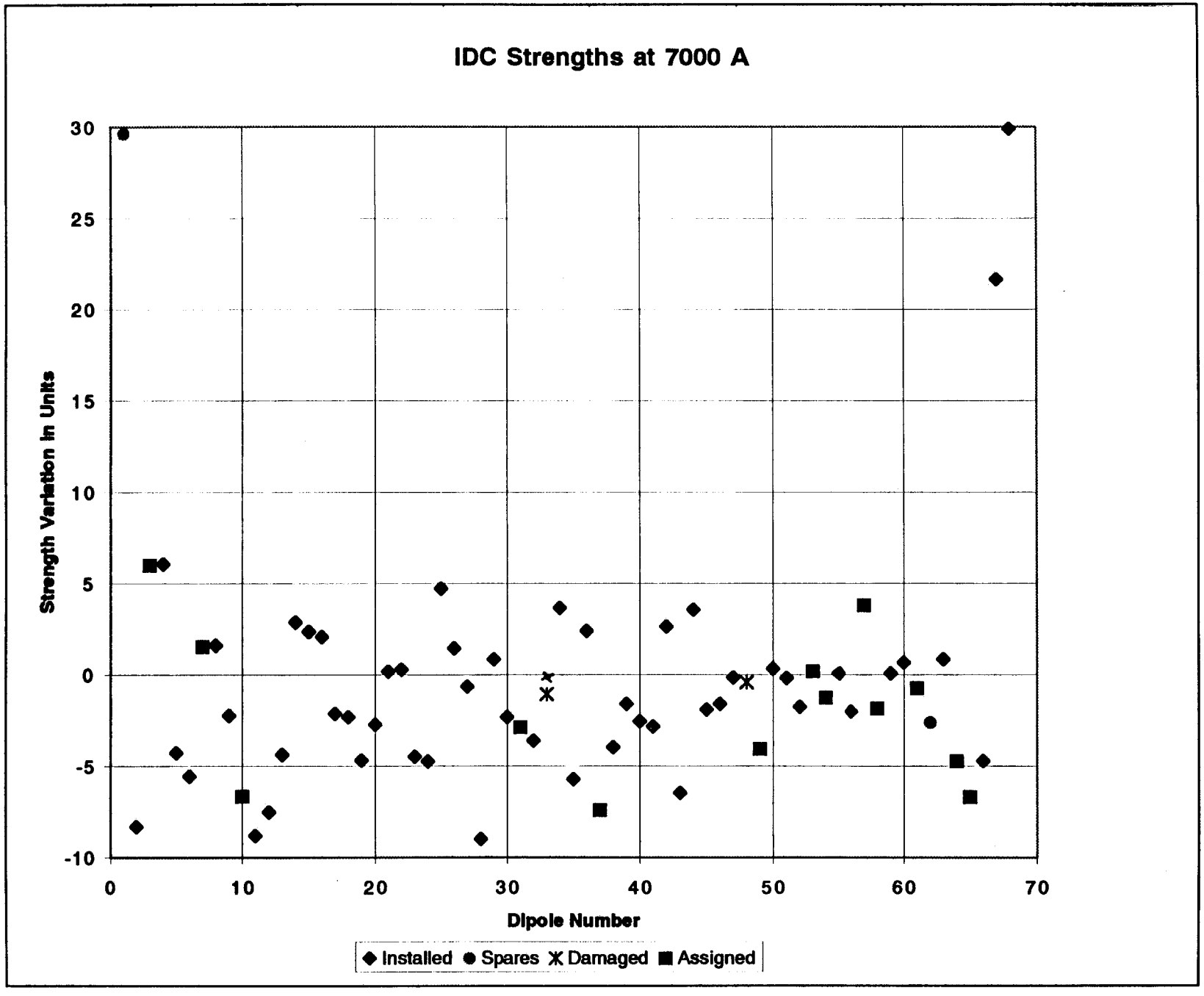
Main Injector Closed Orbit Error

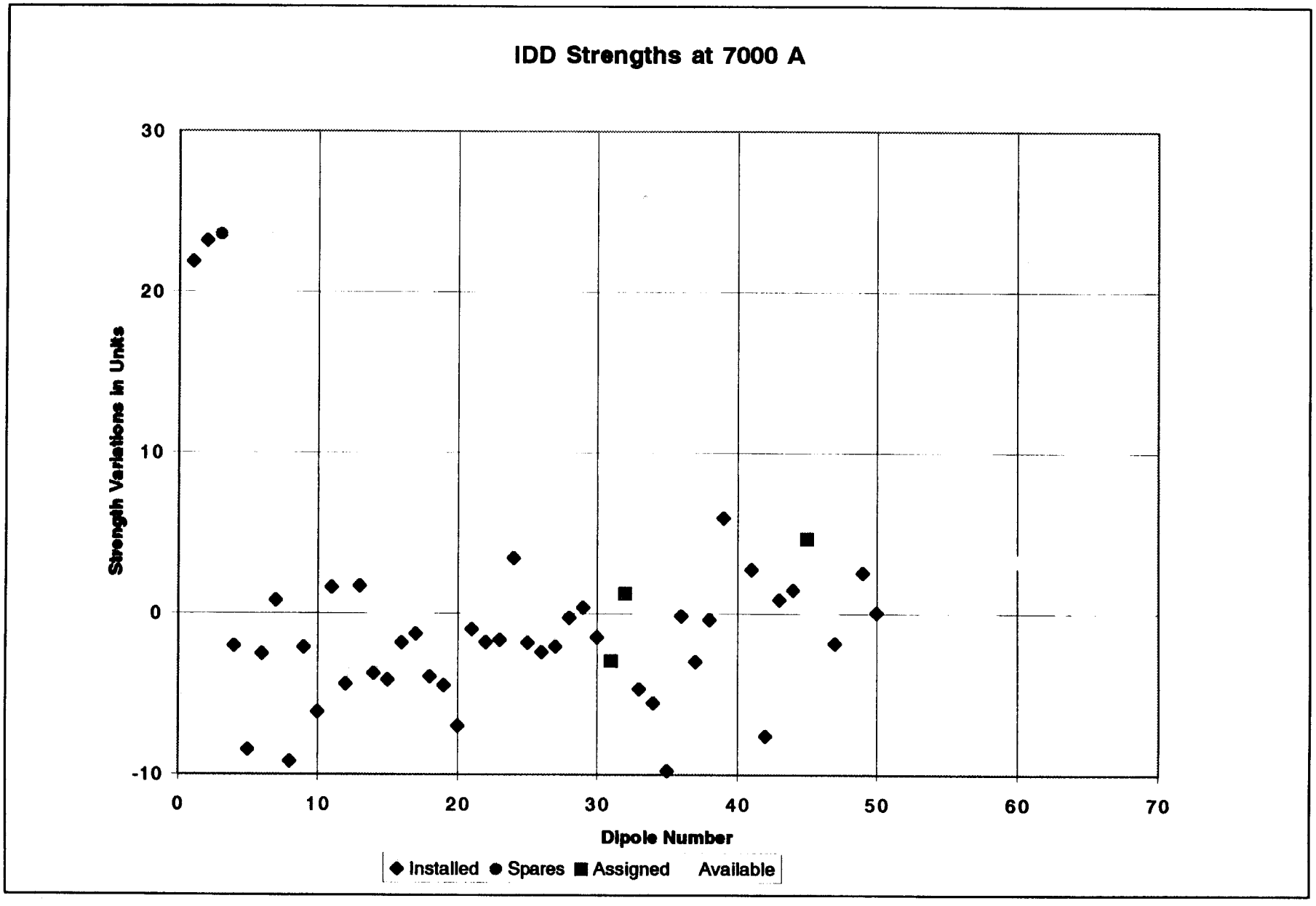
210 Dipoles Assigned in the FMI (120 GeV)




IDA Strengths at 7000 A
20
10
0
-10
-20
-30
-40
-50
0
5
10
15
20
25
30
35
40
45
50
Dipole Number
Installed
Spares
Assigned


IDB Strengths at 7000 A
20
10
0
-10
-20
-30
-40
-50
0
5
10
15
20
25
30
35
40
45
50
Dipole Number
Installed
Spares


IDC Strengths at 7000 A
Strength Variation in Units
30
25
20
15
10
5
0
-5
-10
0
10
20
30
40
50
60
70
Dipole Number
Installed
Spares
Damaged
Assigned

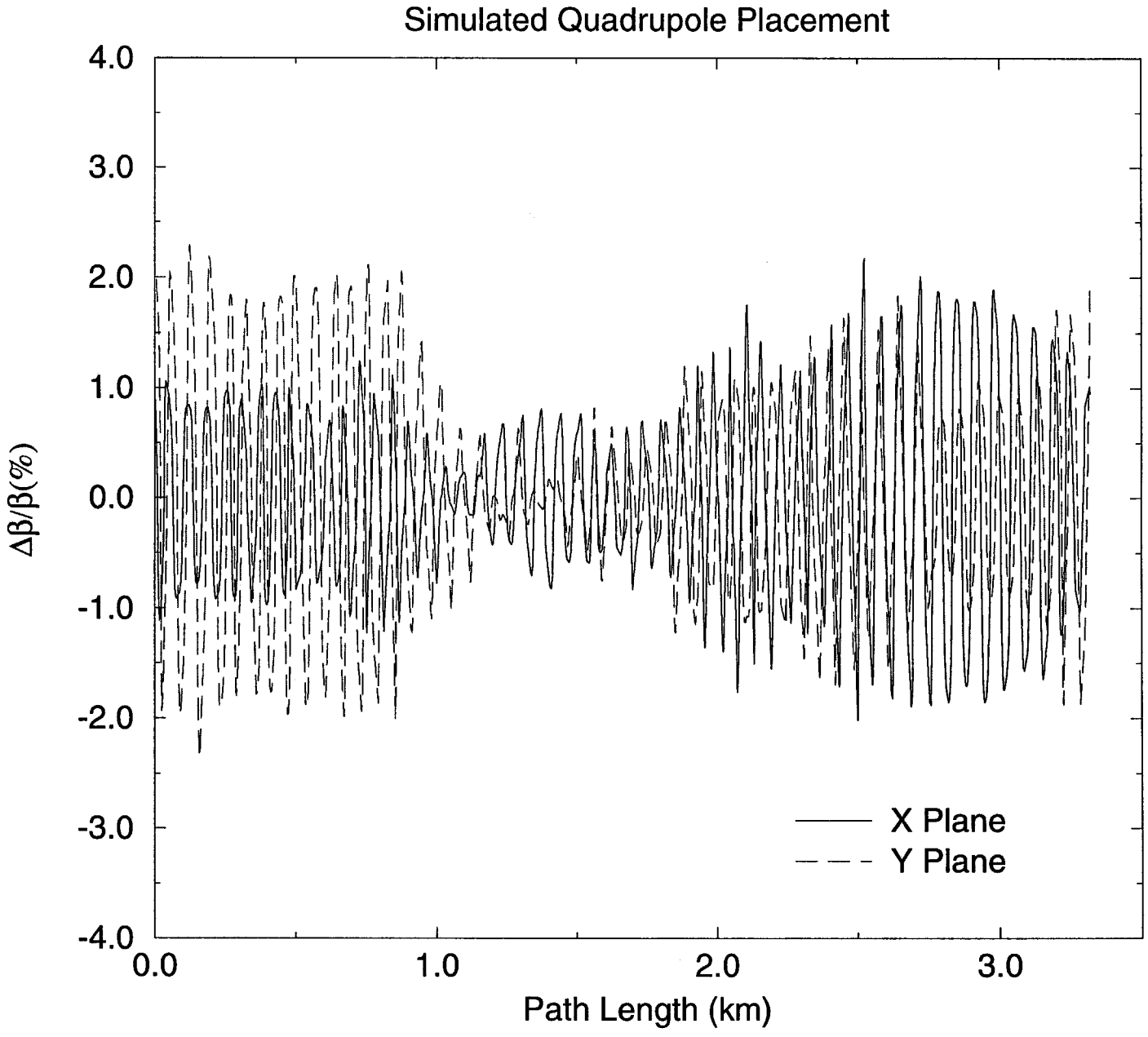

IDD Strengths at 7000 A
Strength Variations in Units
30
20
10
0
-10
0
10
20
30
40
50
60
70
Dipole Number
Installed
Spares
Assigned
Available

Quadrupole Placement

- The Placement of the New Main Injector Quadrupole has been determined by the strength of the magnet.
- The octupole component of the quadrupole is correlated with its strength and no special sorting on the octupole component is performed.
- In the design of FMI we had developed a quadrupole placement scheme using a Monte Carlo Technique. Which was performed to keep $\Delta\beta/\beta$ small.
- We have assigned New quadrupoles in FMI using the above scheme and have kept the beta function variations to about 2%.

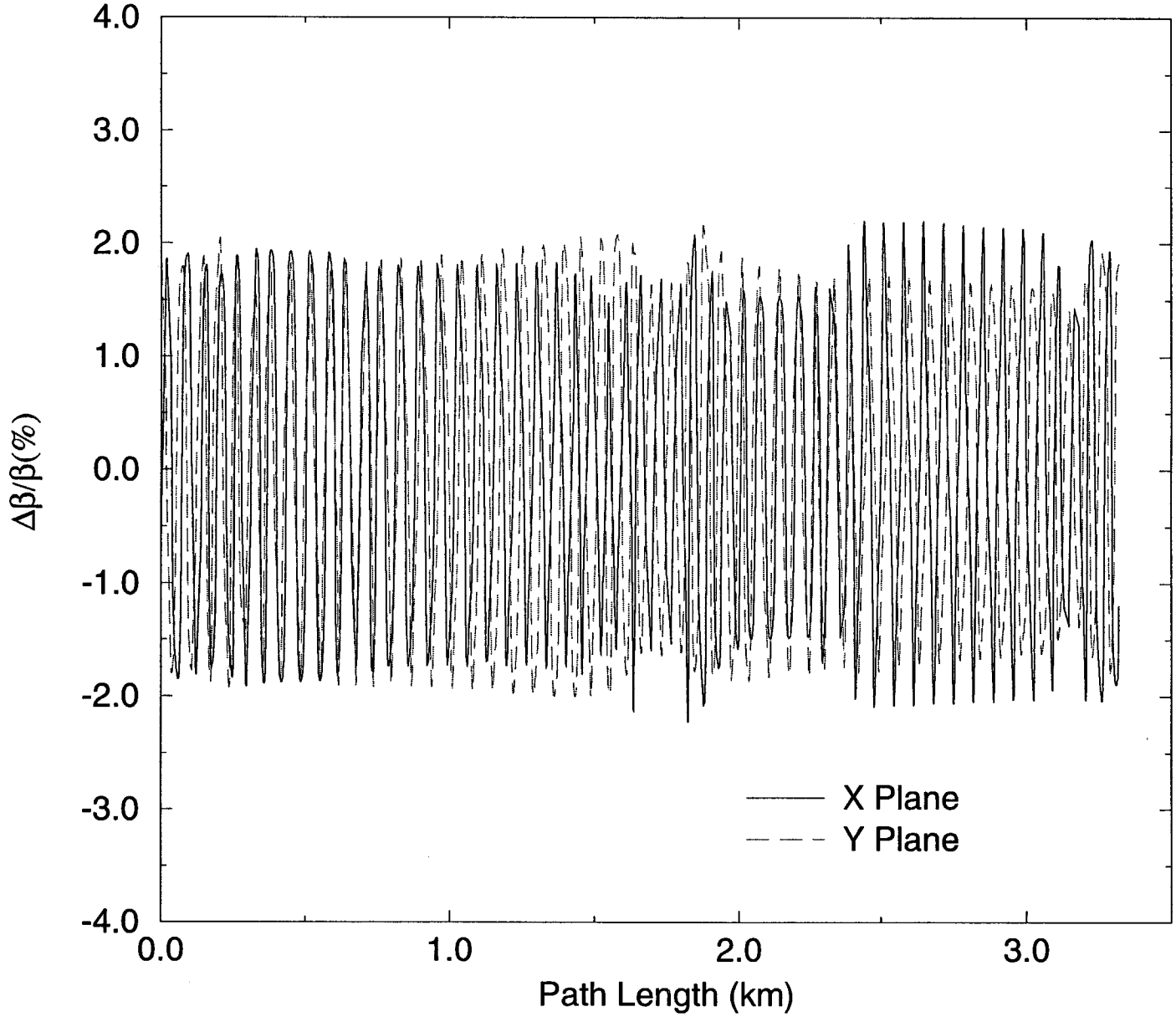
In the placement of both the dipoles and quadrupoles we have paid close attention to spares and how a magnet will be replaced in case of failure.

Main Injector Beta Function Error



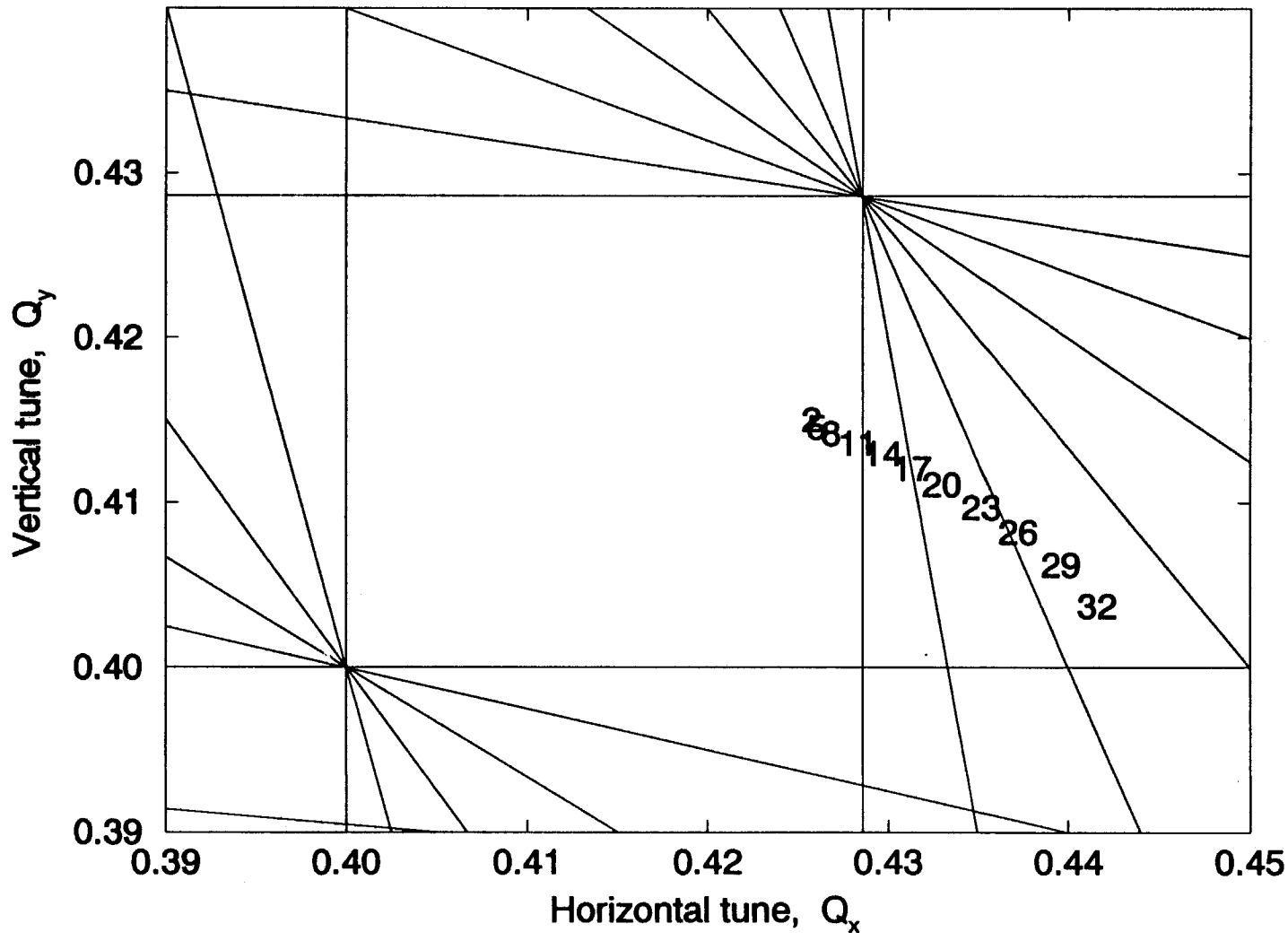
Main Injector Beta Function Error

After Placement of all long Quadrupoles



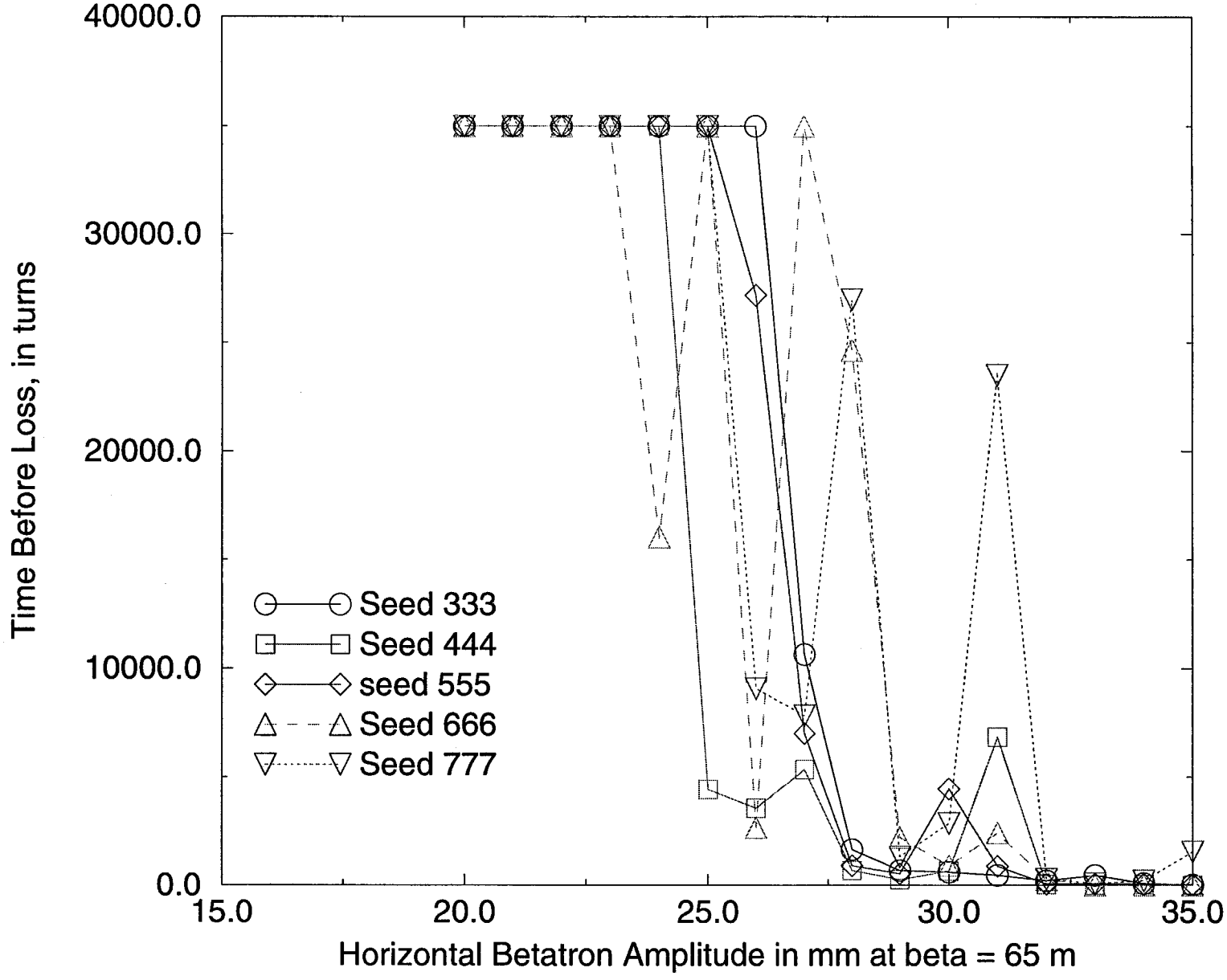
Tune Tune plot for 8.9 GeV

All errors



Injection Survival Plot at 8.9 GeV

Qx=26.425, Qy=25.415, Cx=Cy=-5, Δp/p=0.2%, Y=0.4X



Comments on Impedance Issues

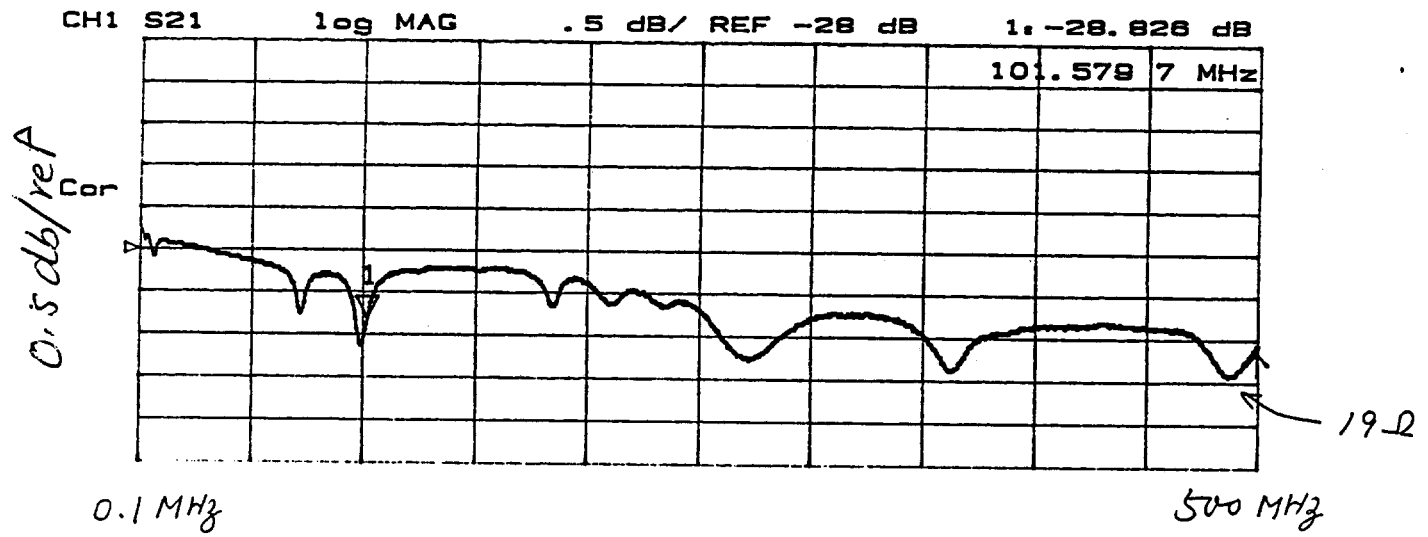
FMI is a designed to be a low impedance machine in order to achieve high beam intensity.

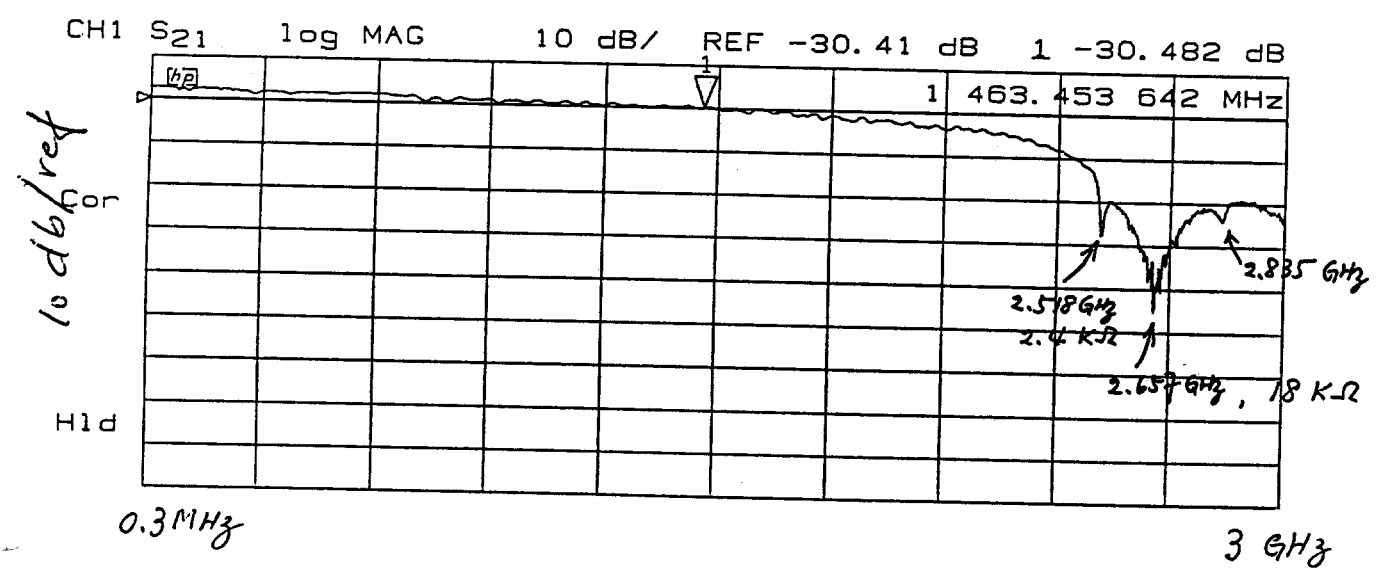
- Impedance & Instability Threshold Estimates in the Main Injector I, Martens and Ng, MI Note 103.
- Beam Instabilities in Main Injector, W. Chou, F3TAC.

	Component	Number	Impedance $\lvert Z(z)/n \rvert$ (Ohm)	Z(y) (MOhm/m)
1.	rf cavities (HOM)		0.09	0.023
	Main cavities (53 MHz)	18		
	Coalescing (2.5 MHz)	5		
	Coalescing (5 MHz)	1		
	2nd harmonic (106 MHz)	1		
2.	Transitions (tapered)		0.012	0.01
	rf section	10		
	inj section	2		
3.	Bellows (shielded)	552	0.37	0.67
4.	Flange gaps (shielded)	552	-	-
5.	Weldments/gaps	2208	0.001	0.005
6.	Gate valves (shielded)	34	0.04	0.05
7.	Pump ports (screened)	577	0.1	0.07
8.	Beam position monitors	208	0.18	0.3
9.	Kickers		0.3	0.6
	p inj (l = 2.27 m)	3		
	p- inj/p ext (l = 2.24m)	2		
	p- ext (l = 2.2m)	2		
	Abort (l = 2.2m)	2		
10.	Lambertson laminations		0.1	0.3
11.	Lambertson joints		0.3	0.1
	Lambertson-quad	12		
	Lambertson-Lambertson	6		
	Lambertson-dipole tube	10		
12.	Resistive wall		0.11	0.092
	TOTAL		1.6	2.2

Impedance ....

The impedance of an abort kicker has been measured. It is made of ferrite that houses a 2.2 m-long ceramic tube in center. In the Range from 100 kHz to 500 MHz |Z/n| is less than 0.01 ohm, which is well within the budget.





Conclusions

- Dipoles and Quadrupole Magnet data has been analyzed.
- The dipole assignment and placement in the ring is well underway. 210 assigned and 185 installed.
- The dipole strength variation is <u>not</u> a serious problem. We will not need any special or stronger horizontal corrector to correct the closed orbit error.
- All the new long quadrupoles have been assigned for placement in the ring.
- The dynamical aperture of the FMI is large.
- More measurements of the impedance will be carried out when other Kickers and Lambertson magnets will be available.