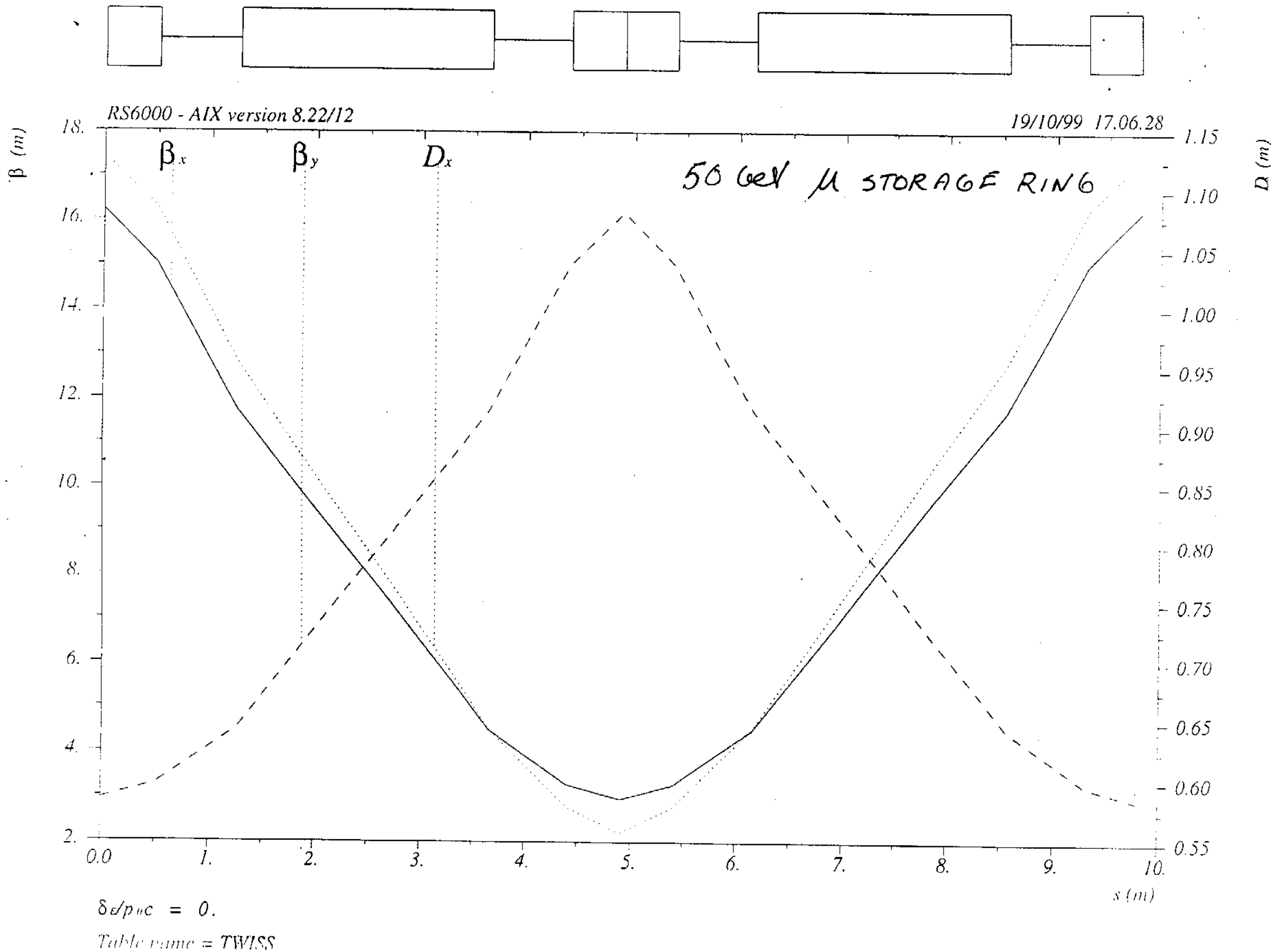
STATUS OF MUON COLLIDER AND NEUTRINO FACTORY STORAGE RING LATTICES

C. Johnstone

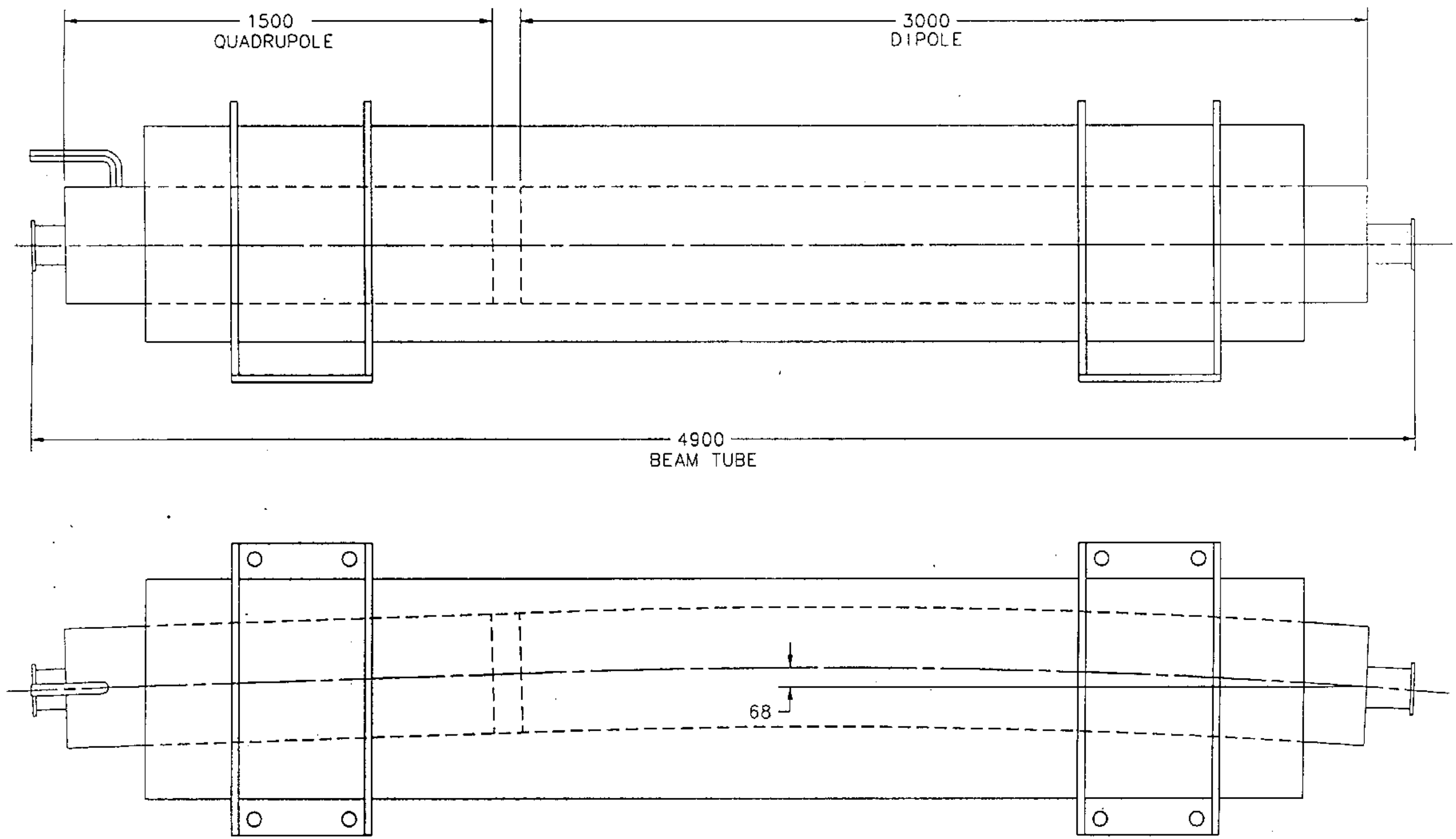
UCLA

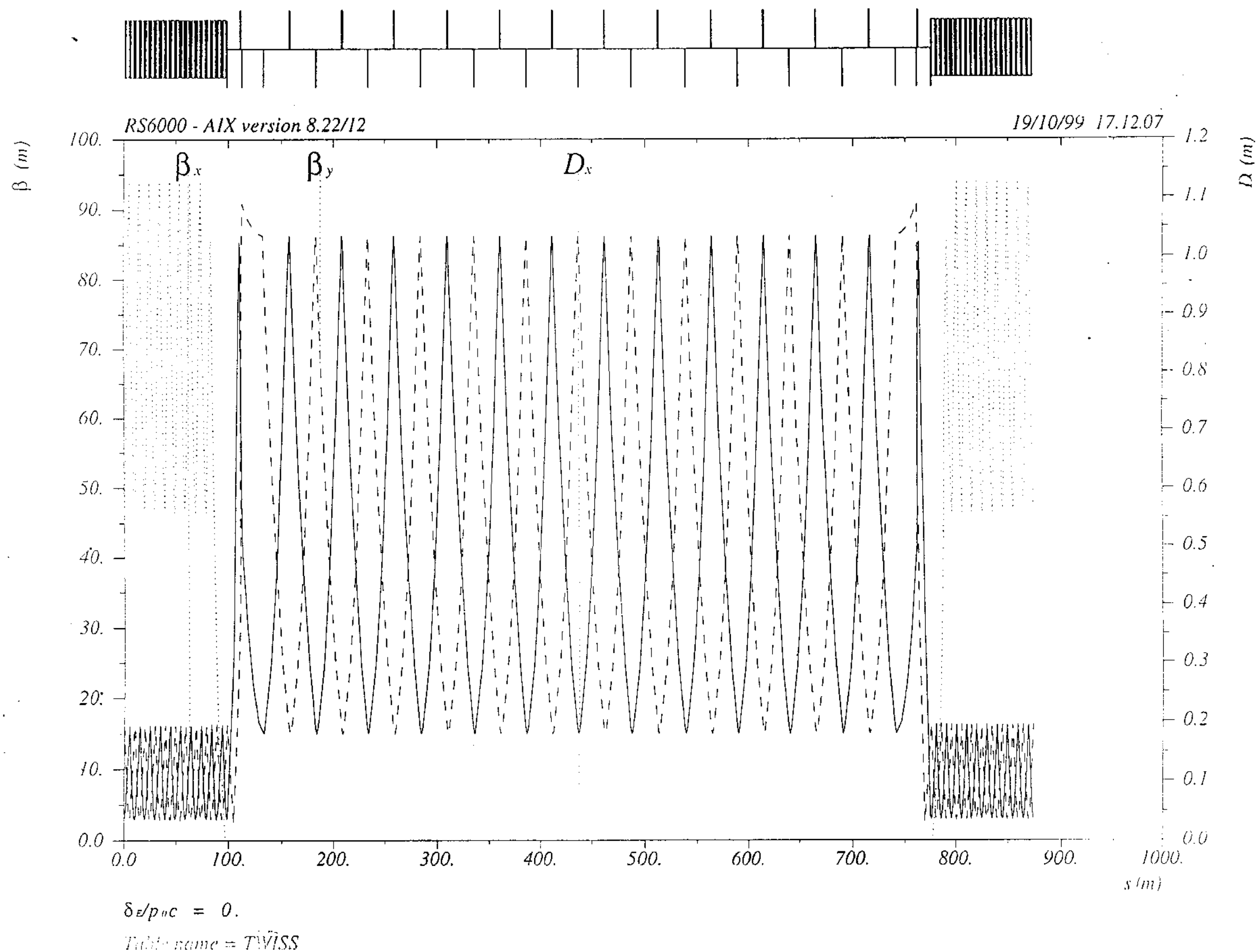


RS6000 - AIX version 8.22/12
19/10/99 17.06.28
50 GeV μ STORAGE RING
βx
βy
Dx
β (m)
D (m)
s (m)
18.
16.
14.
12.
10.
8.
6.
4.
2.
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.0
1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
δE/p0c = 0.
Table name = TWISS

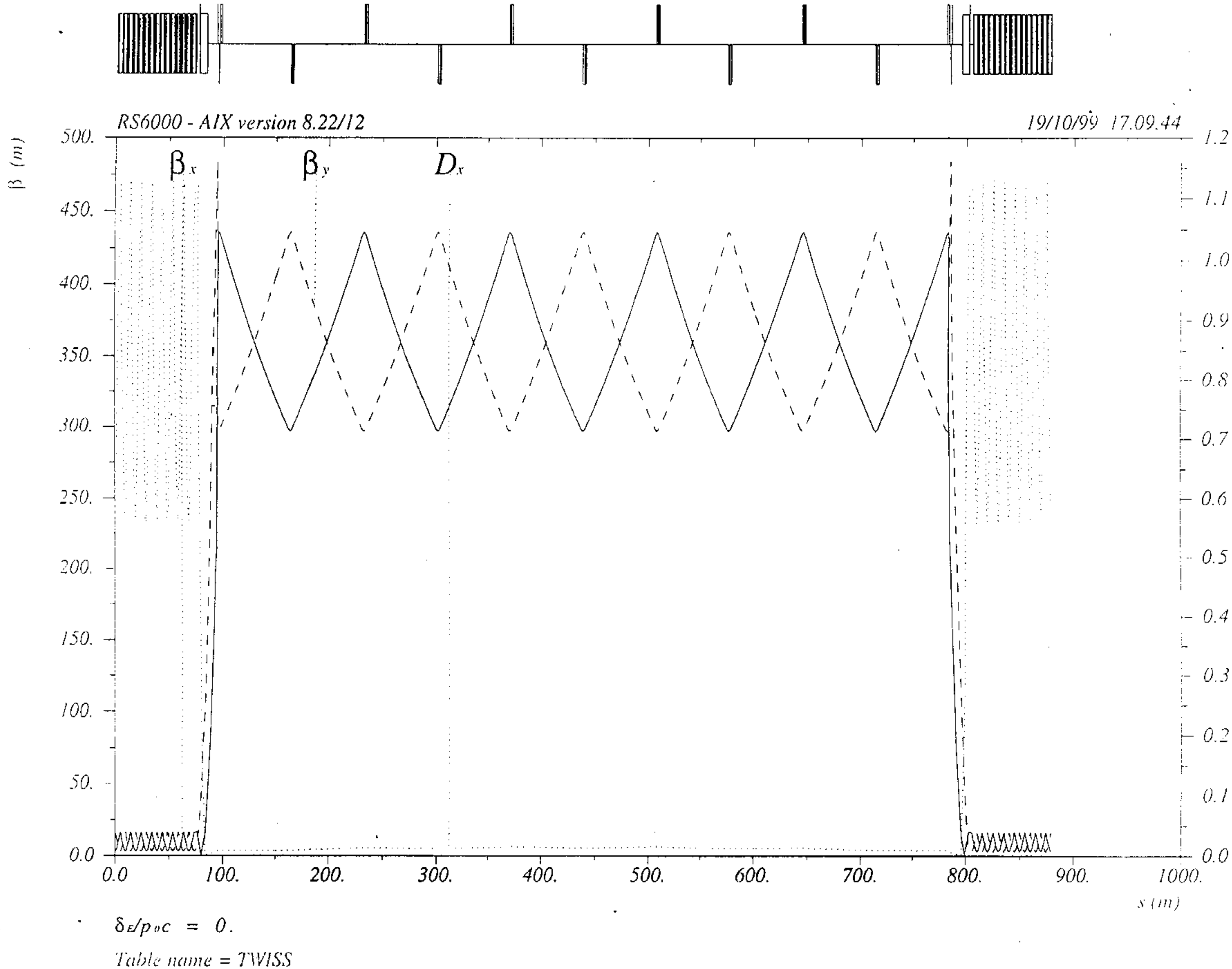
ARC MODULE

CRYOSTAT PLAN AND ELEVATION VIEW





50 GeV μ STORAGE RING: ~~PRODUCTION~~ INJECTION STRAIGHT



50 GeV μ STORAGE RING: PRODUCTION STRAIGHT

Large Acceptance 50-GeV Muon Storage Ring for Neutrino Production: Lattice Design, CJ2.0 *

[illegible], † FNAL, Batavia, IL 60510

Table 1: Muon Storage Ring Design Parameters and Constraints

Storage Ring Geometry		racetrack
Storage Ring Energy	GeV	50
Vertical Descent Limit	m	≈183
Declination Angle	deg	≈13
Cross-sectional profile	m	813
ϵ_{rms} (normalized)	mm-rad	3.2π
dp/p (rms)	%	1
maximum poletip field	T	6.0
arc cell phase advance	deg	90

Table 2: Parameters of the large-momentum acceptance arc cells for a 50-GeV muon storage ring

General: tungsten shield thickness	cm	1.0
beam-stay clear	cm	1.0
intermagnet spacing	m	0.75
Dipoles:		
dipole length	m	2.4
dipole bend	rad	0.0859
dipole field	T	6.0
beam size (6σ, max), WxH	cm	8.0x5.3
dipole full aperture**, WxH	cm	12x9.3
sagitta	cm	2.67
Quadrupoles:		
quadrupole length	m	1
arc quadrupole strength	m^{-2}	.31
arc quadrupole poletip field	T	3.6
beam size (6σ), WxH		
F quad	cm	9.2x2.6
D quad	cm	4.2x6.2
arc quadrupole bore**	cm	14
Sextupoles (overlay on quad field)		
horiz. sextupole strength	m^{-2}	0.64
vert. sextupole strength	m^{-2}	1.26
horiz. sextupole poletip field	T	.52
vert. sextupole poletip field	T	1.03
Arc FODO cell parameters:		
cell length	m	9.8
cell phase advance	deg	90
β_{max}	m	16.2
$D_x(max)$	m	1.3
total number arc cells		31

**aperture = beam size + liner thickness + beam-stay-clear

Table 3: Parameters of the high-beta cells for neutrino production in a 50-GeV muon storage ring

drift length	m	65.8
quadrupole length	m	3
quadrupole strength	m^{-2}	0.0019
quadrupole poletip field	T	0.05
quadrupole bore	cm	33
total cell length	m	137.6
cell phase advance	deg	≈ 22
β_{max}	m	436.0
rms divergence	mr	0.20
number of high-beta cells		5

Table 4: Parameters of cells in return straight of 50-GeV muon storage ring

cell length	m	50.78
quadrupole length	m	1
quadrupole strength	m^{-2}	0.056
quadrupole poletip field	T	0.84
quadrupole bore	cm	18
cell phase advance	deg	90
β_{max}	m	86.3
rms divergence	mr	0.73
number of cells		12

Table 5: Storage Ring Parameters at 50-GeV

Circumference	m	1752.8
Neutrino decay fraction		39.2%
Production region:		
matching and dispersion suppression	m	44.1
High-β FODO straight	m	688
$\beta_{xmax}/\beta_{ymax}$	m	435/484
$\nu_x/\nu y$		13.63/13.31
natural chromaticity		-23.9/-23.9

* Work supported by the U.S. Department of Energy under contract No. DE-AC02-76HO3000

† email: cjj@fnal.gov

50-GEV NEUTRINO FACTORY STORAGE RING

1. Complete ring with large ideal transverse and momentum acceptances (rms: $\varepsilon_N = 3.2\pi$ mm-rad, dp/p of 1%). Assumed acceptance is 3σ each.

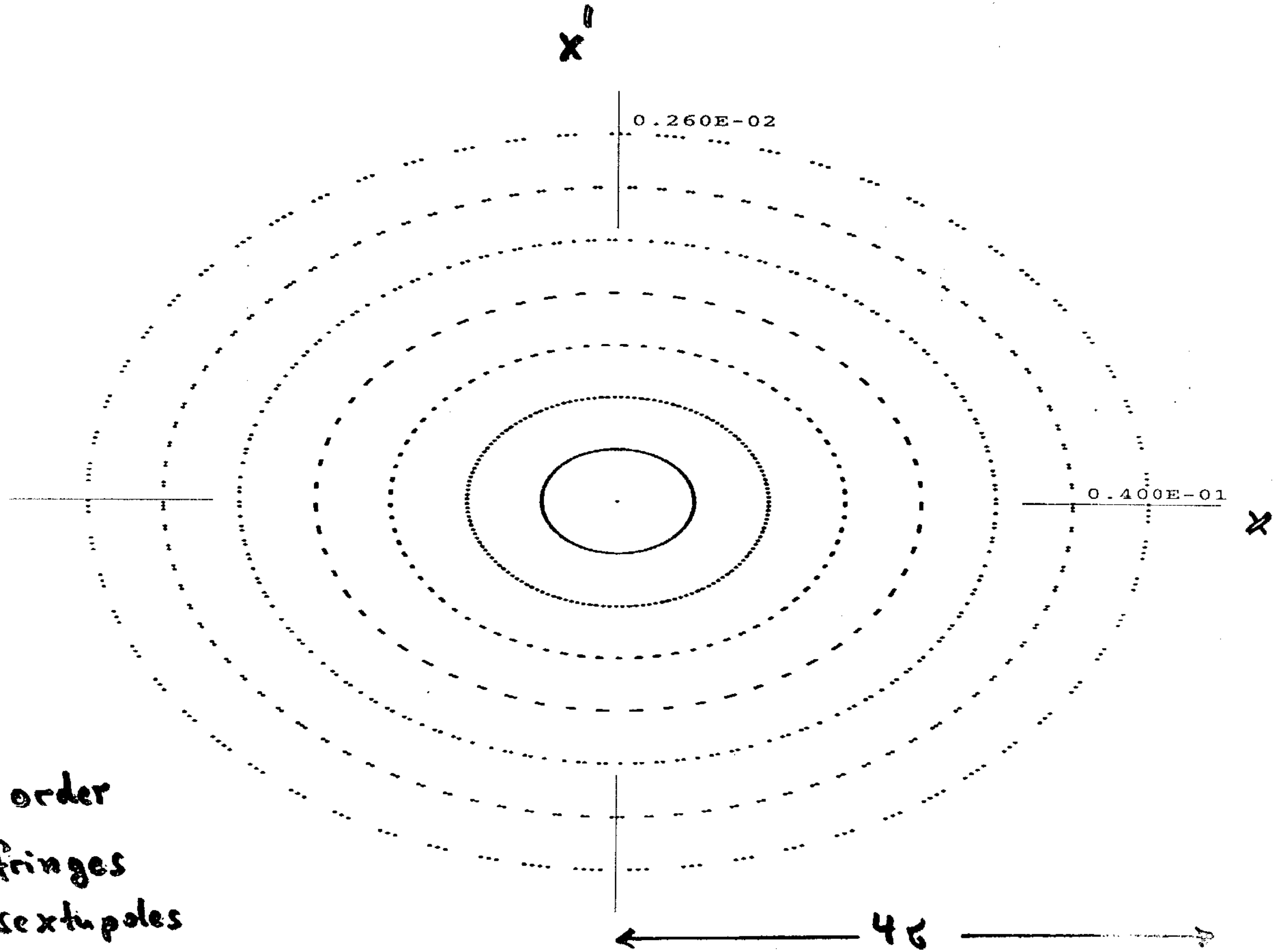
2. Completed:
   superconducting arcs with 6T dipoles
   long baseline production straight (.2 mr divergence)
   brute force downward injection into this straight, E. Keil
   return straight for surface detector

3. Extraction, shielding and collimation remain

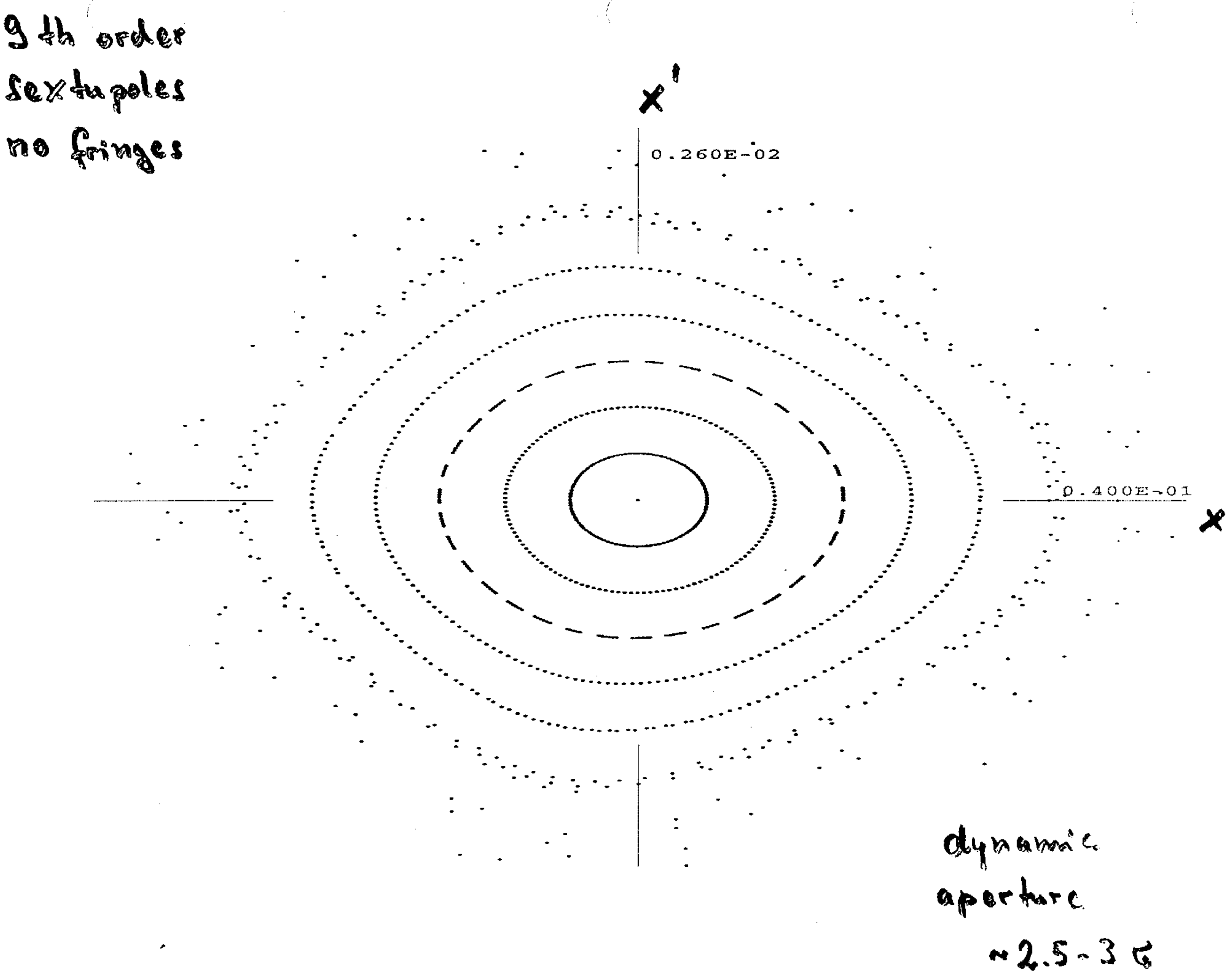
4. Tracking and endfield studies show large kinematical tuneshifts with amplitude with serious impact on dynamic aperture and polarization.

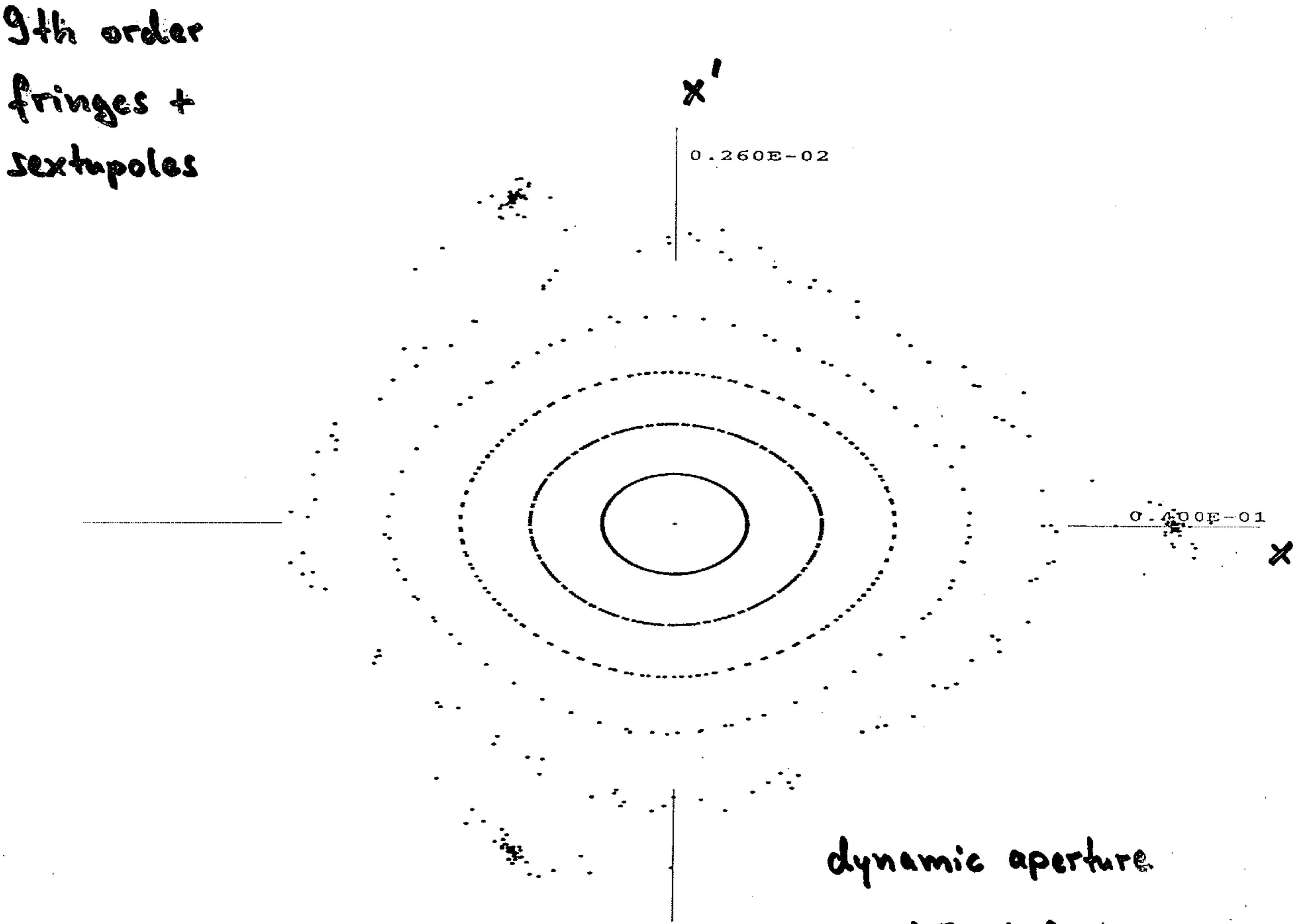
>The contributing terms need to be individually studied by tracking. Most likely high-order correctors (octupoles) will need to be placed in the return straight implying 90-degree cells.

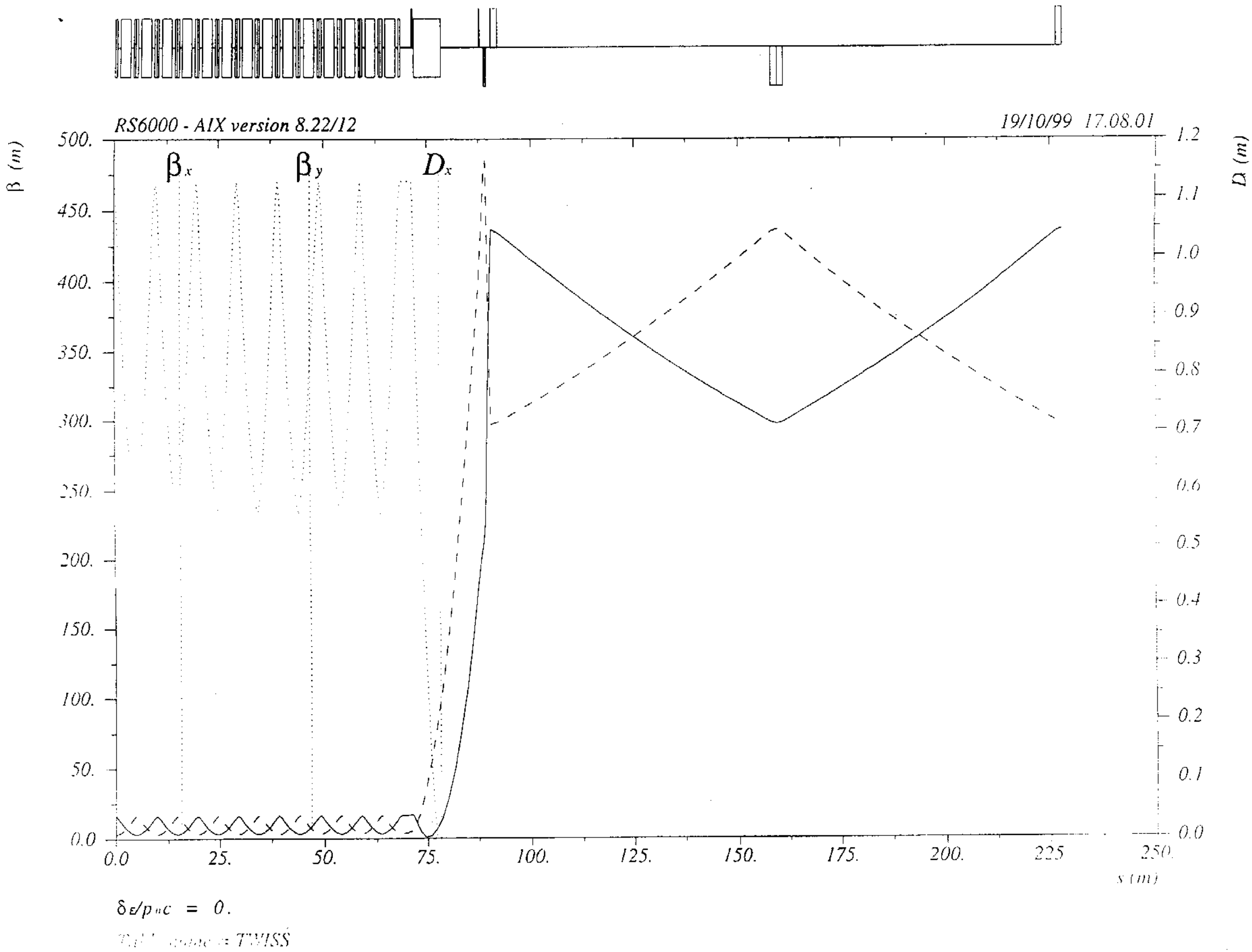
5. If dynamic aperture and polarization can be preserved in transverse phase space using h.o. corrections, rf will still be required to preserve polarization over the large energy spread.



9th order
no fringes
no sextupoles
kinematic terms only

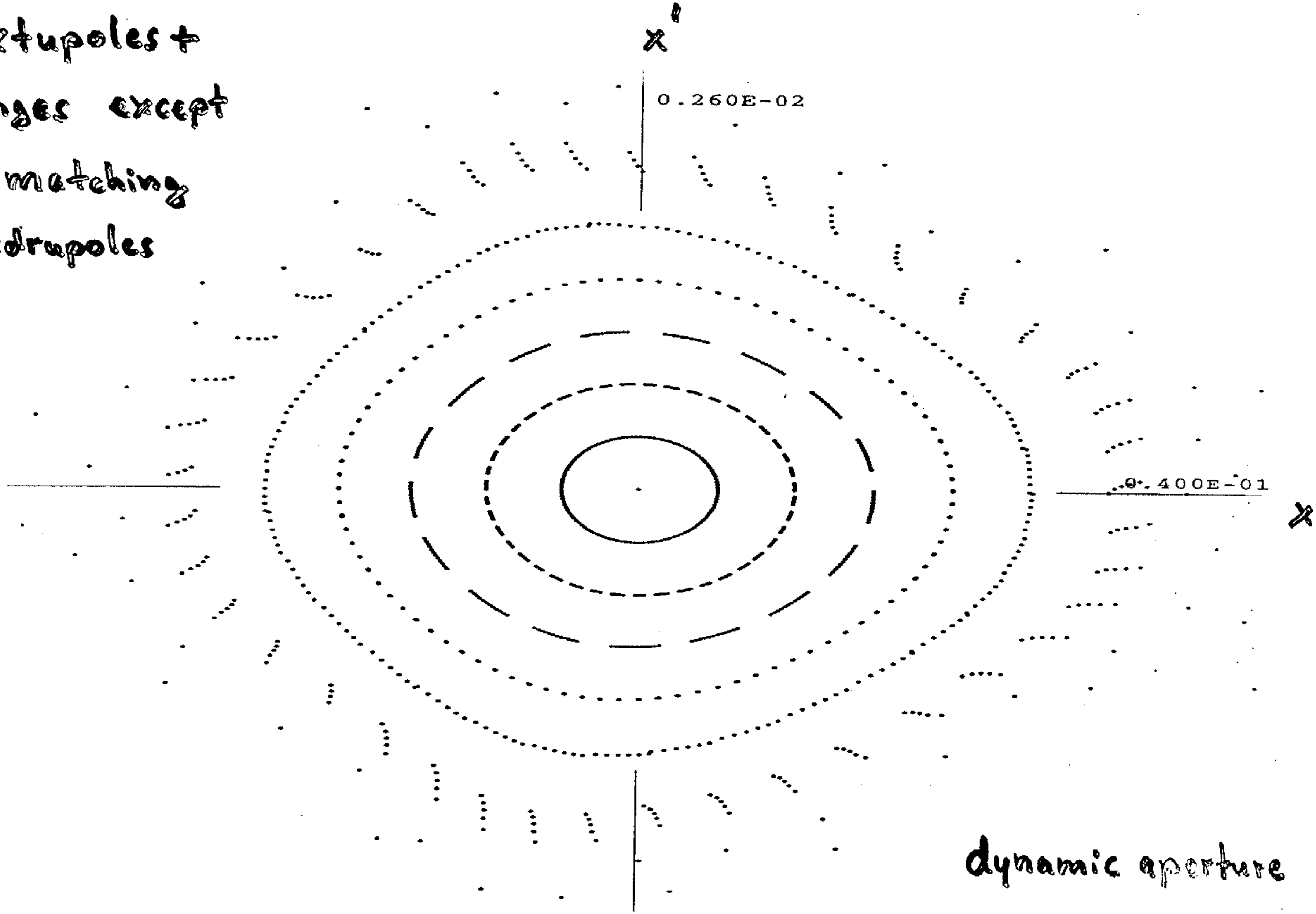

9 th order
sextupoles
no fringes
x'
0.260E-02
0.400E-01
x
dynamic
aperture
~2.5-3 σ


9th order
fringes +
sextupoles
x'
0.260E-02
0.400E-01
x
dynamic aperture
1.5 - 2.0 σ



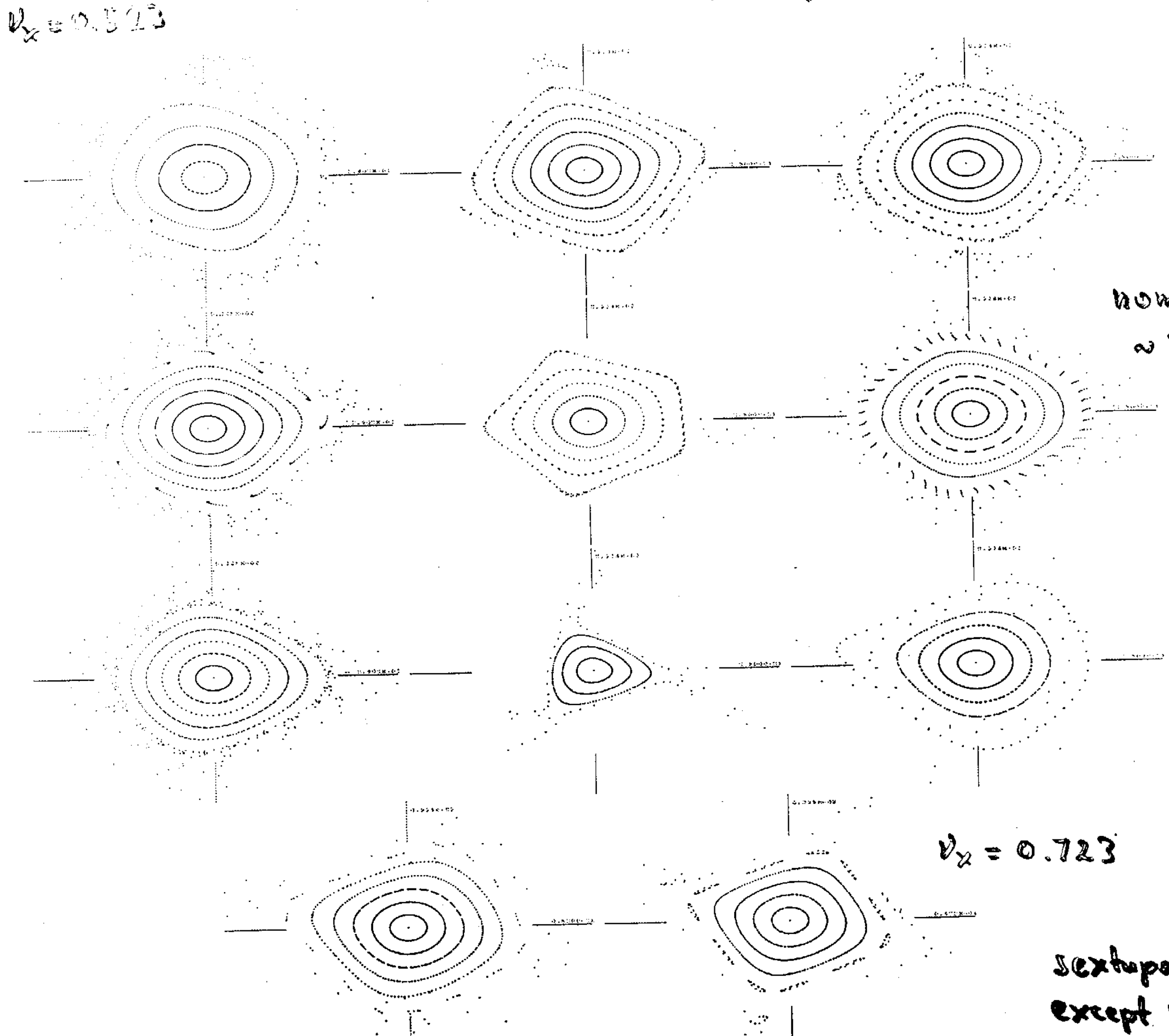
50-GeV μ STORAGE RING: MATCHING

9 th order
sextupoles +
fringes except
in matching
quadrupoles



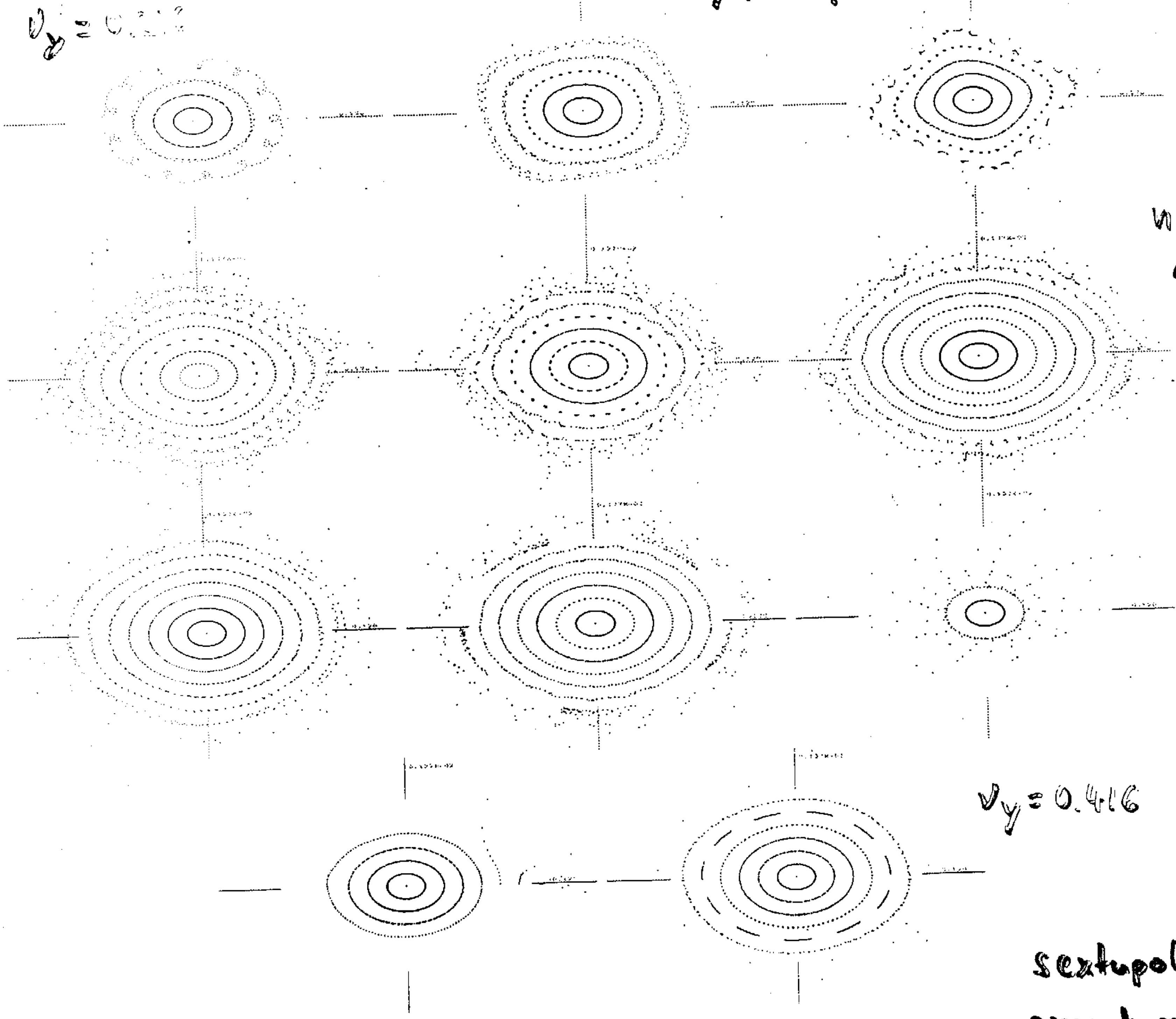
dynamic aperture
2.5-3.0 σ

tune scan in x, steps 0.02



sextupoles + fringe
except 1 [illegible]ching ...

tune scan in y, steps 0.02



sextupoles + fringes
except matching qu.

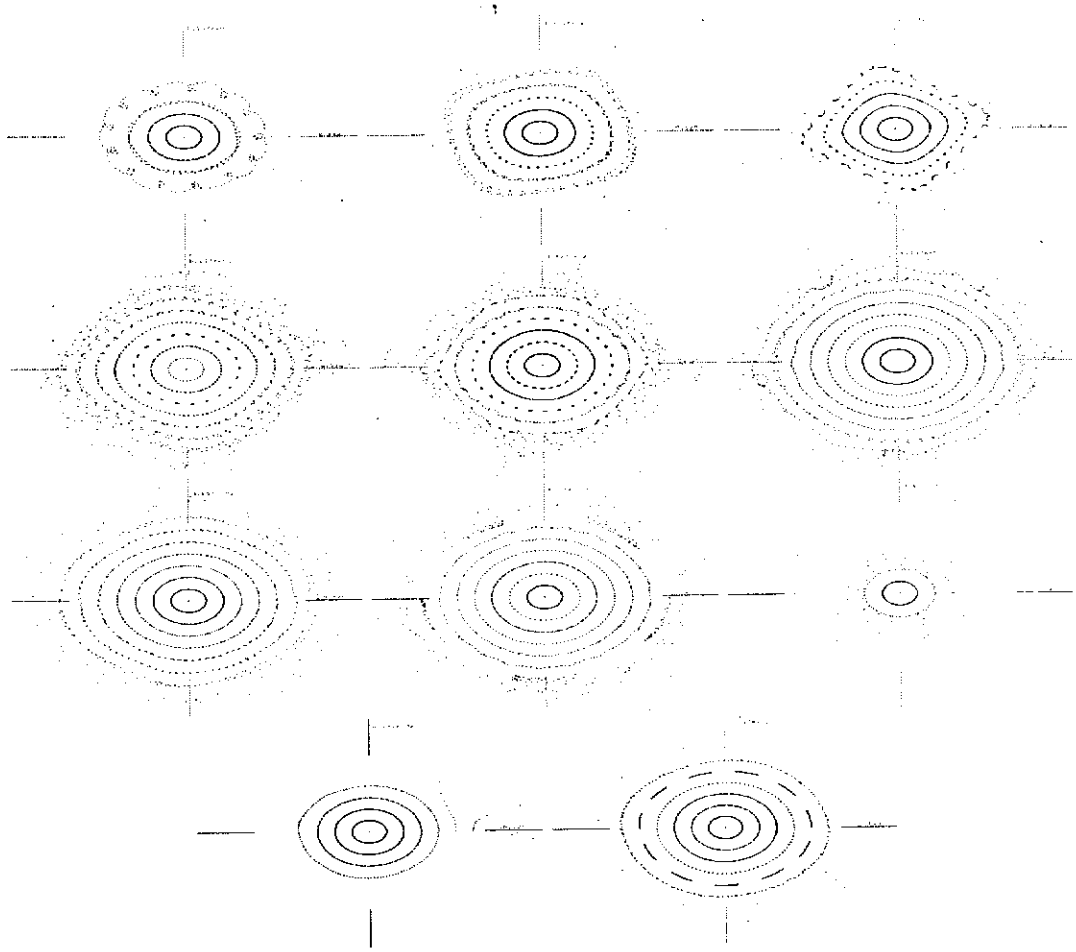


Figure 17: Vertical phase space with 9th order map an including sextupoles and fringe fields (except those in matchign quadrupoles) for several values of the vertical tune, varying from 0.216 (top left) to 0.416 (bottom right) in steps of 0.02. Each plot extends over $\pm 5\ \sigma$.

Mu SR Kicker System

The Muon Storage Ring has need of an injection kicker system that will deflect the incoming beam on orbit. The main parameters for the system are:

Type	-	Horizontal
Clear Gap	-	308 mm(w) by 246 mm(h)
Integral BL	-	0.6 Tesla•Meters
Field Flattop	-	2.0 µsec
Field Fall	-	4.0 µsec
Field Variation	-	10%
Rep Rate	-	15 Hz

The proposed system has two engineer defined limits that will be treated as design criteria. Our experience has suggested that the maximum system voltage should be limited to 50k volts and the maximum switch tube current should be limited to 5k amps. These two requirements imply the system impedance of 5 ohms.

The above constraints are such that the peak field will be:

$$B_{\max} = \frac{\mu_0 \times I_{\max}}{h} \qquad B_{\max} = 0.0255 Tesla$$

And the total length of the magnet system will be:

$$Length = \frac{\int Bl}{B_{\max}} \qquad Length = 23.5\ Meters$$

On a per meter basis the inductance, capacitance and the field drift time of the magnet is:

$$L = \mu_0 \times 1 \times \frac{w}{h} \qquad L = 1.573 \mu H / meter$$

$$C = \frac{L}{Z_o^{\,2}} \qquad C = 62.93 nF / meter$$

$$drift = \sqrt{L \times C} \qquad drift = 0.315 \mu\sec/ meter$$

From the above numbers, we are tempted to install two 12 meter magnet strings each driven by a pulser. We will take a conservative approach at this point and assume that the kicker system will be made up from four 6 meter magnet strings each driven by a pulser.

Figure 1 is included as a proposal for the cross section of the magnet. The mechanical design for the support structure and vacuum vessel is non-existent and will need to be addressed for the next level design. The actual magnet length and number of pulsers will need to be nailed down at that time.

The PFN that will be used to drive each magnet will have:

$$Z_0 = 5.0\Omega \qquad Length = 2.25\mu\sec$$

A ***SPICE*** simulation of both the PFN and magnet has been completed and the normalized magnet input/output voltage and normalized integral of field is included for reference. Figure 2 is a simplified schematic of the kicker system that was modeled in ***SPICE***.

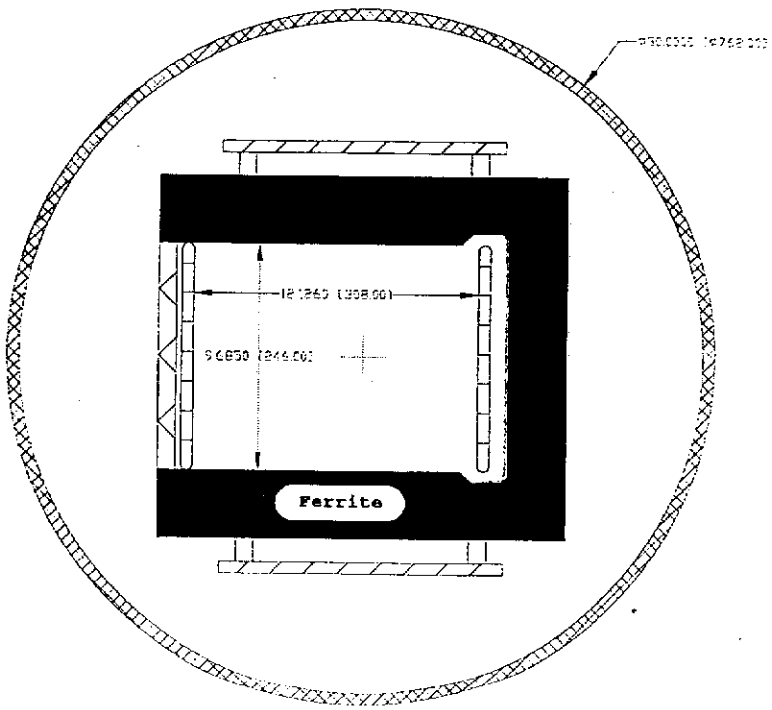


Figure 1 - Proposed Magnet Cross Section

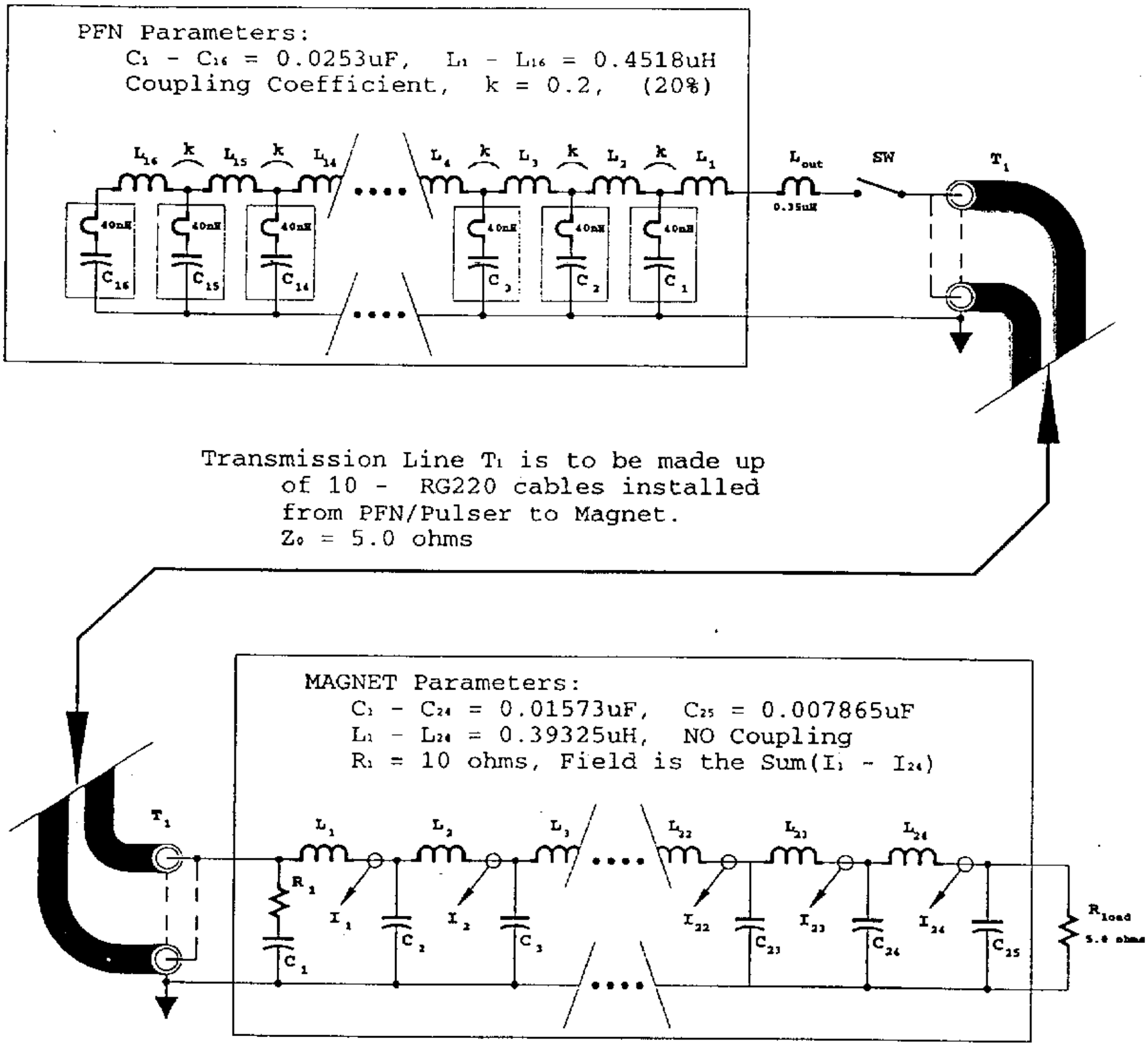
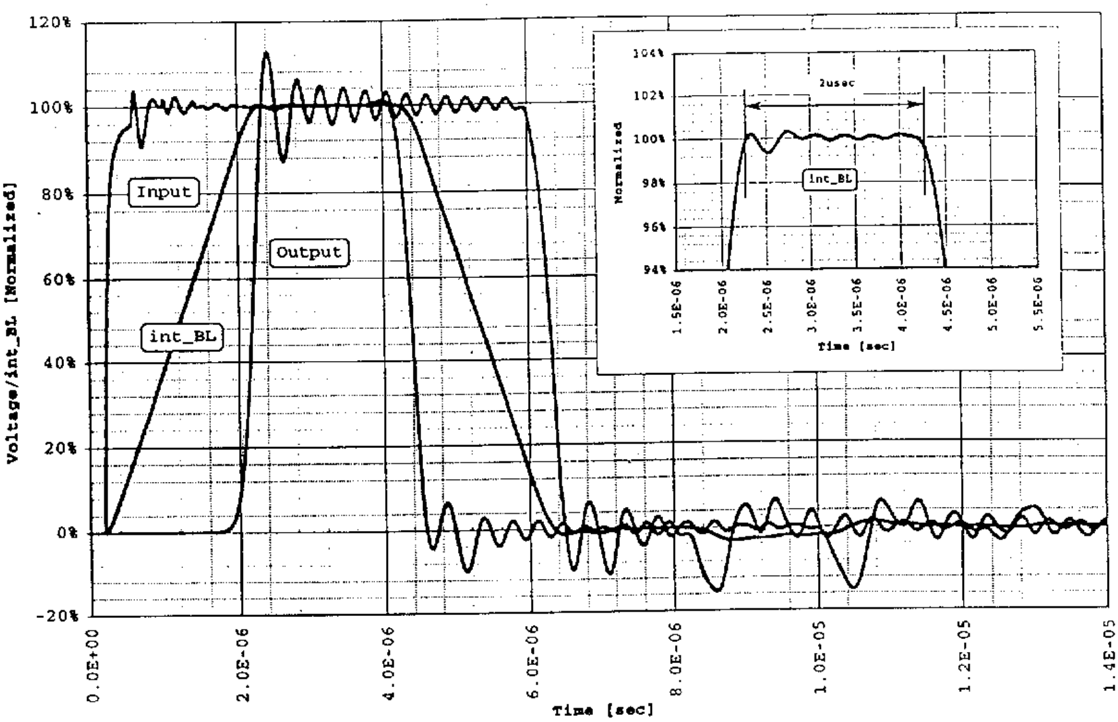


Figure 2 - Simplified Diagram of Mu SR Kicker System (used for ***SPICE*** Simulation)

Spice Simulation of Mu SR Kicker System
PFN, 16 Cell (20% Coupling), Zo = 5.0 ohms,
Magnet, 24 Cell (NO Coupling) Zo = 5.0 ohms,
6 Meters, (RELTOL = 0.00001)



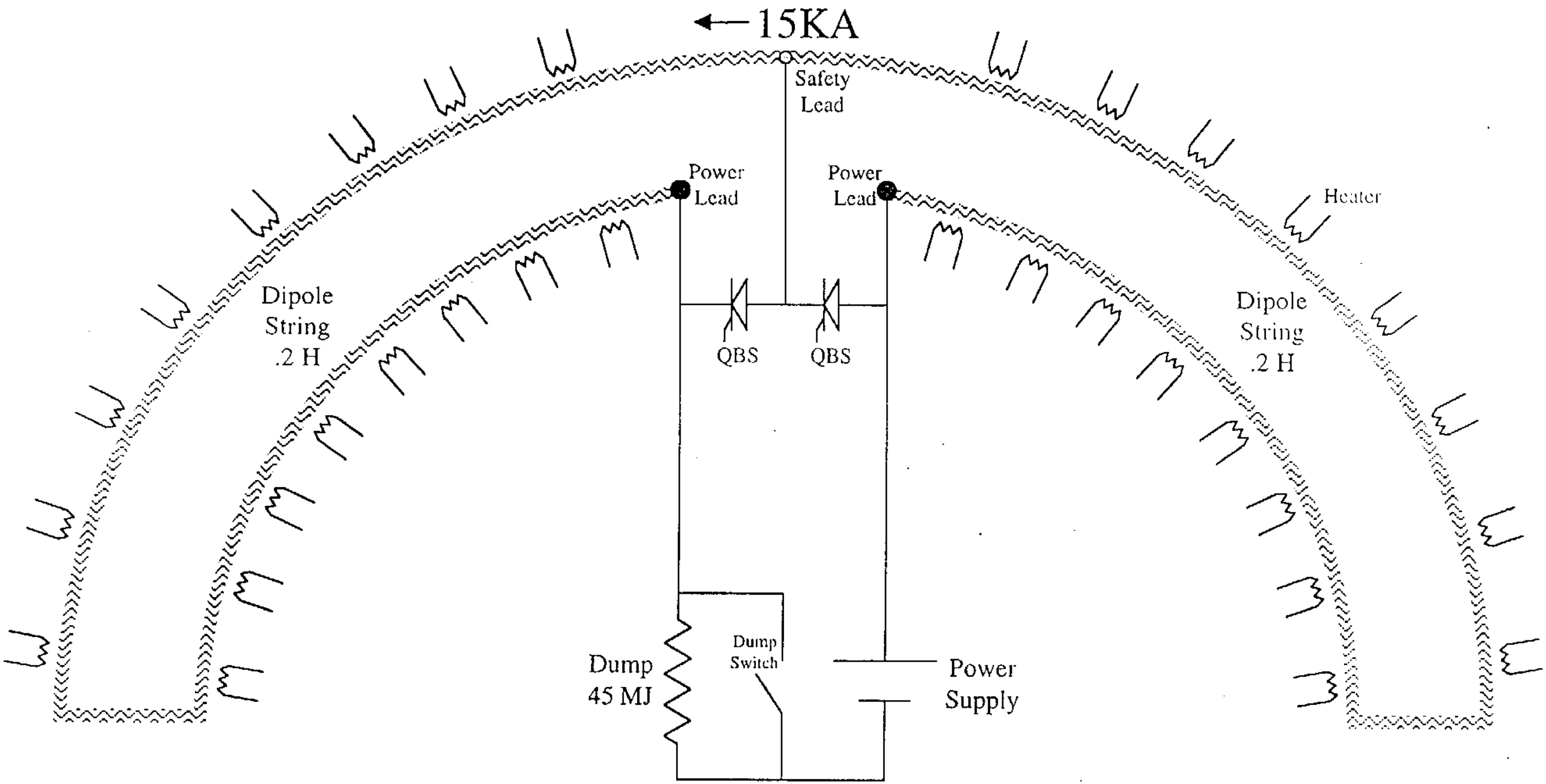
The cost of the system at this point will need to have a large contingence that can be refined at the next stage of design with the input of mechanical support personnel.

The magnets are larger and longer than the MI 52 extraction kickers built in '93 - '95. These magnets cost about \$90k per meter. An initial quote (for budget purpose) from our ferrite vendor put the ferrite at a little over twice the cost of the MI 52 ferrite. Therefore with inflation and the larger size I am putting the cost of the magnet at \$200K per meter.

The pulsers should be similar to MI 52 pulser with the exception of rep rate. Since the MI 52 pulser cost \$400k in the same '93 - '95 time frame, I am putting the cost of each pulser at \$500K.

Therefore 24 meters of magnet and 4 pulsers puts the cost of the system at about \$6.8M.

MμSR Dipole Quench Protection



MμSR Quench Detection & Protection

The MμSR will consist of 6 separately excited superconducting magnet strings. Each of the two arcs will have a dipole, and two quad circuits. The dipole circuits will store much more energy (45 MJ each) than the quad circuits, but quench protection will be implemented in the same manner for each. One embedded Quench Protection Monitor (QPM) will be needed in the "Power Supply Room" at each arc.

Quench Detection

One voltage tap from each magnet will need to be connected with a coax to the QPM. VFC or $\Delta\Sigma$ technology can be used for data acquisition.

Quench Protection

Each magnet will need an embedded heater connected to a capacitive discharge Heater Firing Unit located in the PS room. Also located in the PS room, will be the dump, dump switch, and two Quench Bypass Switches (QBS), as shown in the diagram. Only one safety lead is needed in the center of each arc.