A 50-GeV Storage Ring at FNAL

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How do you begin?

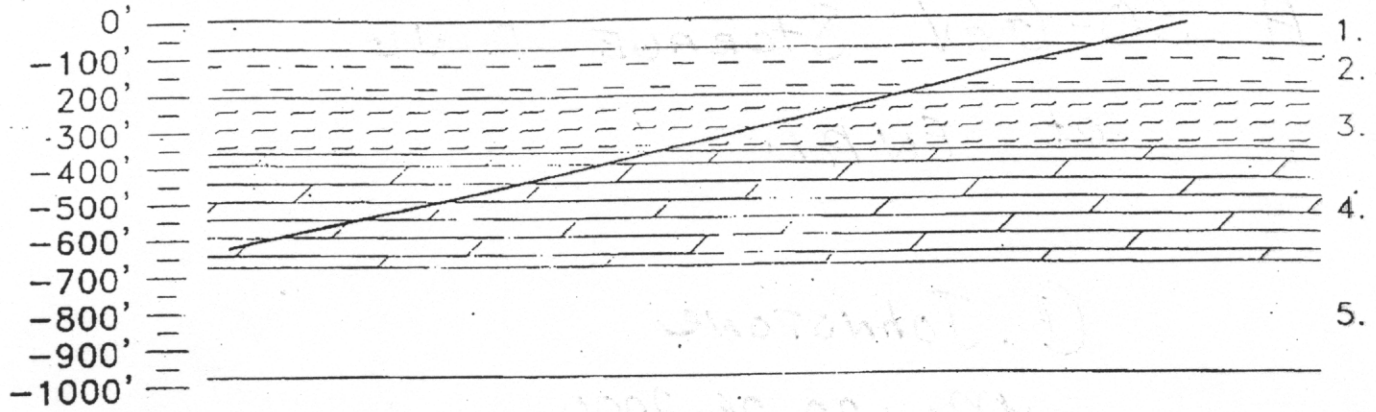
Givens:

- Aiming through the earth to a far detector implies a specific angle of declination for the downward neutrino production straight.

  ⟹ tilt the entire ring, including arcs, to maximize neutrino beam intensity (no additional out-of-plane bends)

- The circumference of the ring and, therefore, the lengths of the neutrino production straights are limited by the declination angle and the amount of vertical drop allowed under the site.

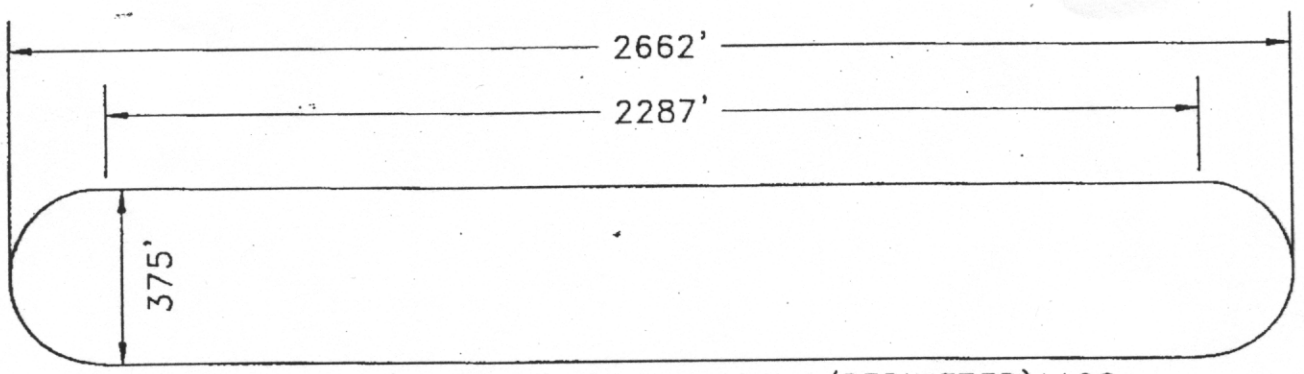
  ⟹ the underlying geology of the site ultimately sets the limits on the neutrino production efficiency for a given arc design.



GEOLOGY DETAIL

1"=100'-0"

1. GLACIAL TILL – AQUIFER
2. SILURIAN GROUP – AQUIFER (PRIMARILY DOLOMITE)
3. MAQUOKETA GROUP – AQUIFER (PRIMARILY SHALE)
4. GALENA / PLATTEVILLE GROUP – AQUATARD (PRIMARILY DOLOMITE)
5. ANCEL GROUP – AQUIFER (PRIMARILY SANDSTONE)



39.8% = (ONE STRAIGHT SECTION/PERIMETER)*100

CJ 2.0 LATTICE PLAN

N.T.S.

ORIENTATION:

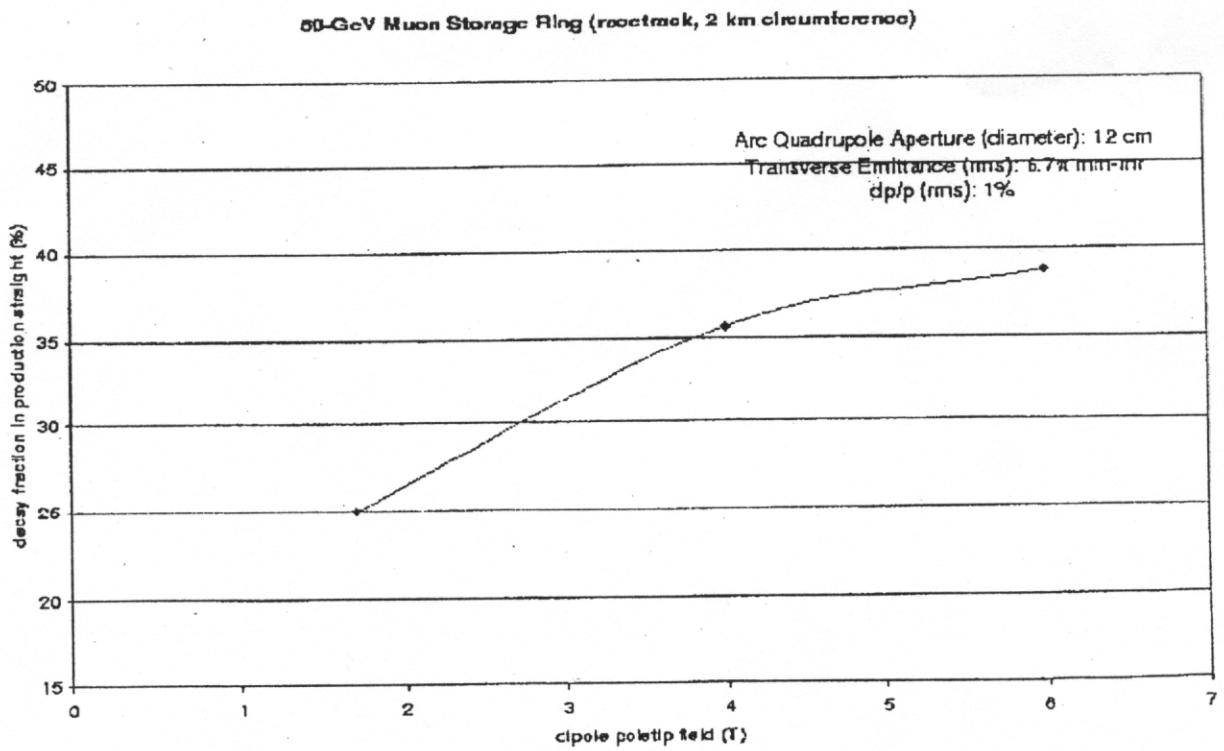
NAME	AZIMUTH (DEG-MIN-SEC)	VERT. ANGLE (DEG-MIN-SEC)
PALO ALTO CA.	271-20'-42.27"	-13-09'-26.99"

MuSR
CTE 9-NOV-99

Optimization of the Storage Ring

- Rule: The cheapest way to produce muons decaying in the straight section is to make the straight sections as long as possible compared to the circumference.

- Efficiency = straight section / circumference
- = Length of straight / (2 π ρ + 2 x Length of straight)

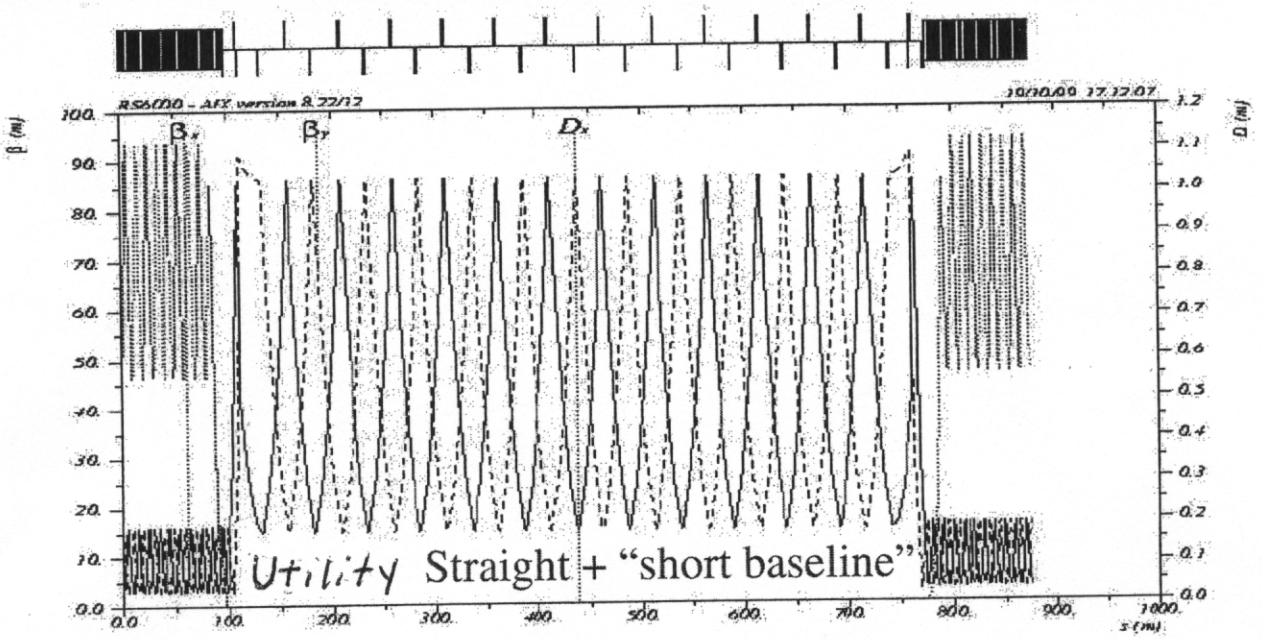


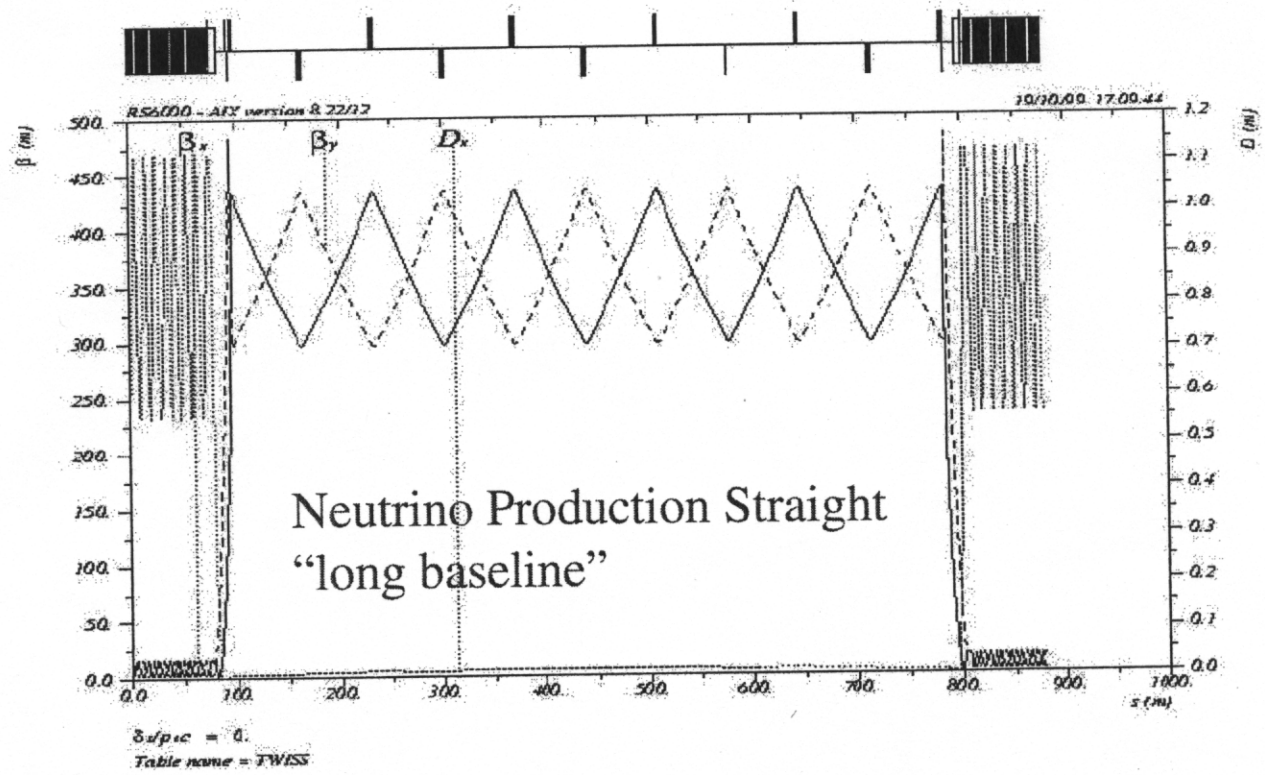
B (Tesla)

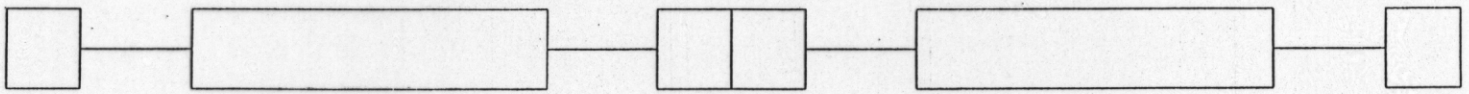
Table 1: Muon Storage Ring Design Parameters and Constraints

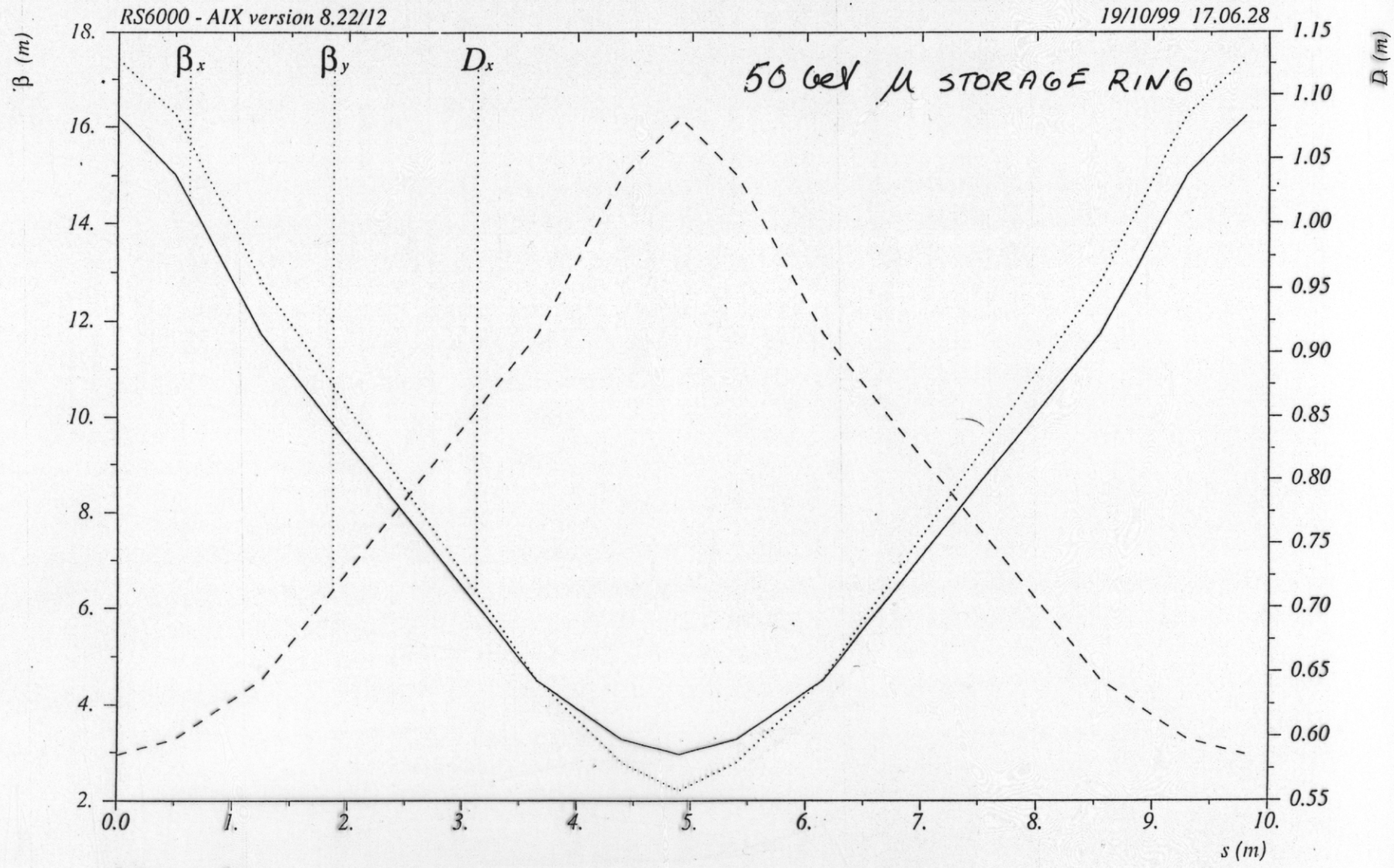
Storage Ring Geometry		racetrack
Storage Ring Energy	GeV	50
Vertical Descent Limit	m	$\approx$183
Declination Angle	deg	$\approx$13
Cross-sectional profile	m	813
ϵ_{rms} (normalized)	mm-rad	3.2π
dp/p (rms)	%	1
maximum poletip field	T	6.0
arc cell phase advance	deg	90

The Storage Ring







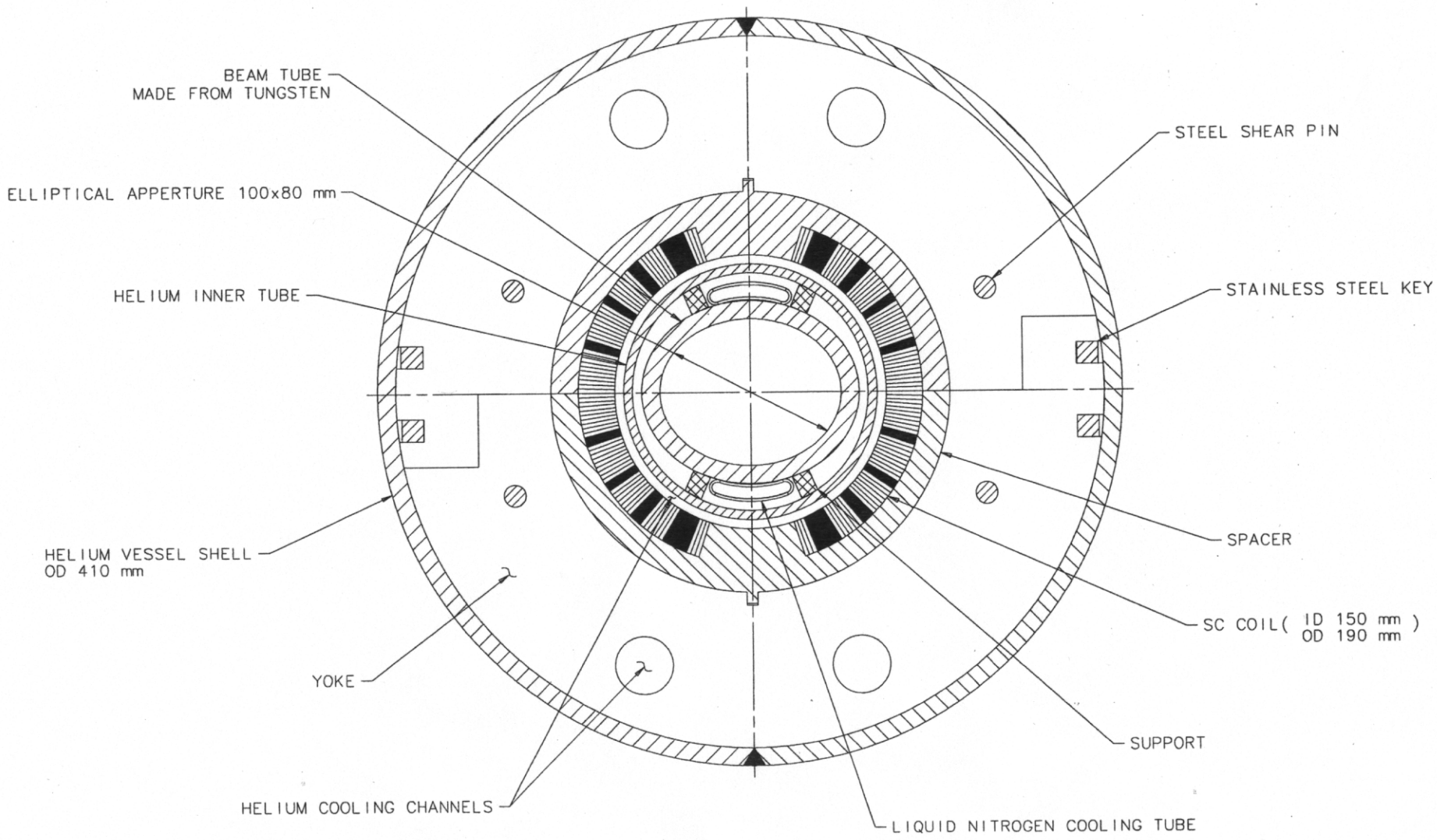


$\delta_E/p_0c = 0.$

Table name = TWISS

ARC MODULE

MuSR DIPOLE CROSS SECTION



SC Quadrupole and Sextupole Magnet Parameters for MuSR

Quadrupole Parameters:	
Operating Field	3.6 T
Magnetic Length	1.0 m
Operating Current	10 kA
Operating Temperature	4.5 K
Beam Aperture	120 mm
Tungsten Beam Tube Thickness	10 mm
Operating Temperature of Beam Tube	77 K
Quadrupole Coil:	
One Layer Cos(Phi) Type Design	
Coil Inner Diameter	160 mm
Sextupole Coil:	
One Layer Cos(Phi) Type Design	
Coil Inner Diameter	220 mm
Horizontal Sextupole Poletip Field	0.52 T
Vertical Sextupole Poletip Field	1.03 T
Magnetic Length	1.0 m
Structure:	
Design Concept	Collared coil assembly of the quadrupole is installed inside aperture of sextupole with common iron yoke.
Common Cold Mass Diameter	410 mm
Length of Cold Mass	1.5 m
Weight of Cold Mass	1.5 t

Arc Half Cell of the MuSR

Design Concept:	
Common cold mass vessel for the arc half cell which will contain dipole, quadrupole and sextupole magnets.	
Common vacuum vessel for the cryostat.	
Two suspension posts and anchor in the middle of quadrupole.	
Structure Parameters:	
Cold Mass Diameter	410 mm
Total Length of Cold Mass	4.6 m
Beam Tube Length	4.9 m
Total Weight of the Common Cold Mass	4.5 t
Outer Diameter of Cryostat	800 mm
Suspension Post Dimension (HxW)	900 x 800 mm
Total Weight of the Half Cell Assembly	5.5 t
Cryo-loads:	
Static heat leaks:	
to He level, at 4.5 K	5 W/cryostat
to N2 level, at 77 K	30 W/cryostat
Dynamic heat losses: (Included beam losses)	
to He level, at 4.5 K	7 W/cryostat
to N2 level, at 77 K	70 W/cryostat

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

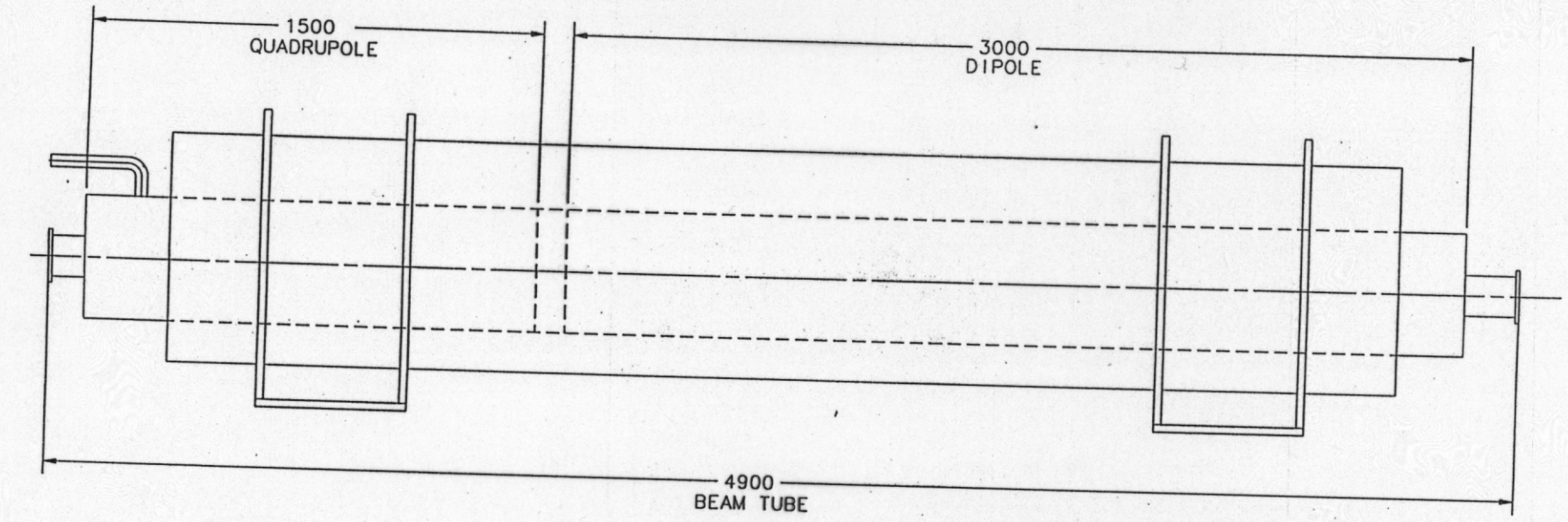
General: tungsten shield thickness	cm	1.0
beam-stay clear	cm	1.0
intermagnet spacing	m	0.75
Dipoles:		
dipole length	m	2.4
dipole bend	rad	0.0859
dipole field	T	6.0
beam size (6σ, max), WxH	cm	8.0x5.3
dipole full aperture**, WxH	cm	12x9.3
sagitta	cm	2.67
Quadrupoles:		
quadrupole length	m	1
arc quadrupole 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

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

† email: cjj@fnal.gov

CRYOSTAT PLAN AND ELEVATION VIEW



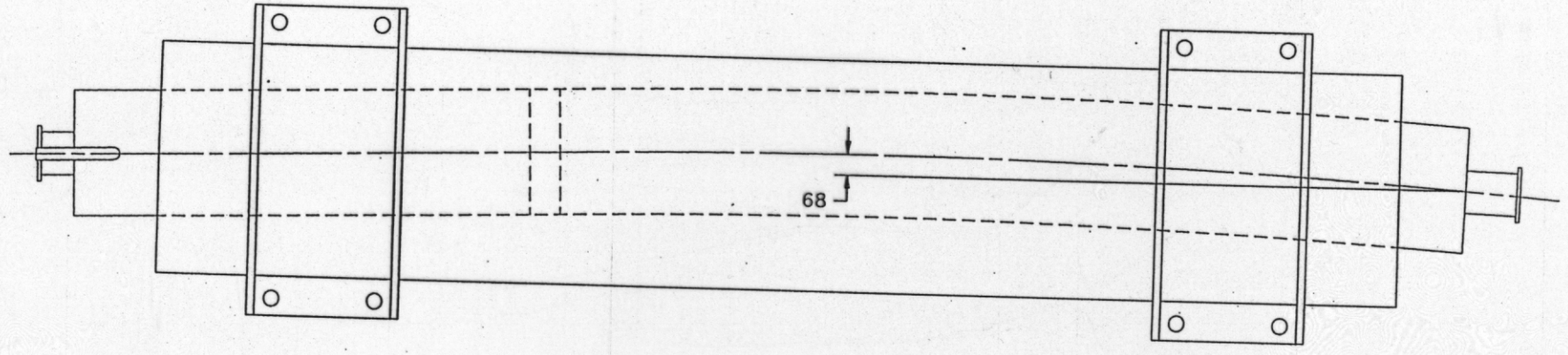


Table 4: Parameters of cells in return straight of 50-GeV muon storage ring

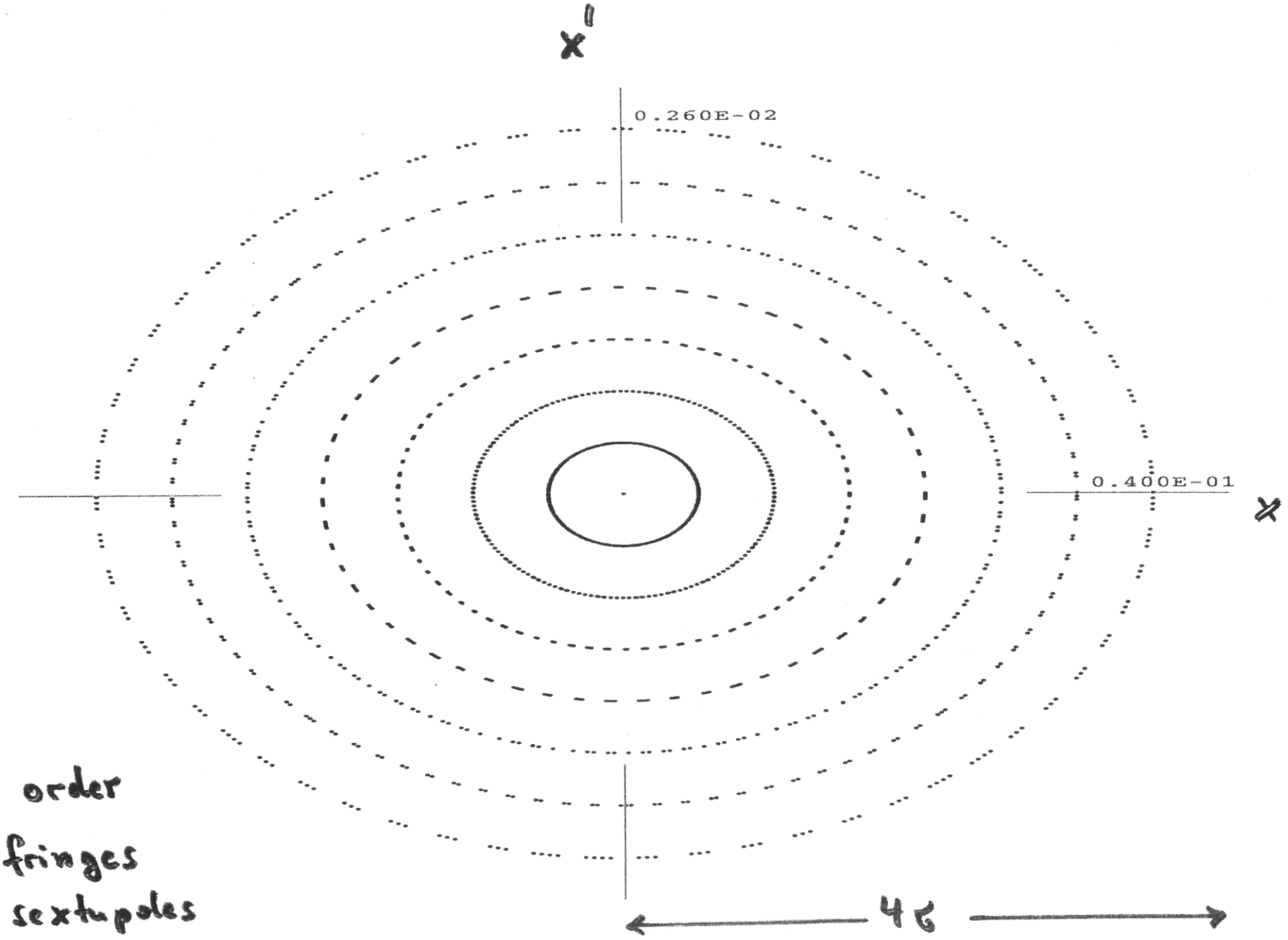
cell length	m	50.78
quadrupole length	m	1
quadrupole strength	m^{-2}	0.056
quadrupole poletip field	T	0.84
quadrupole bore	cm	18
cell phase advance	deg	90
β_{max}	m	86.3
rms divergence	mr	0.73
number of cells		12

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

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



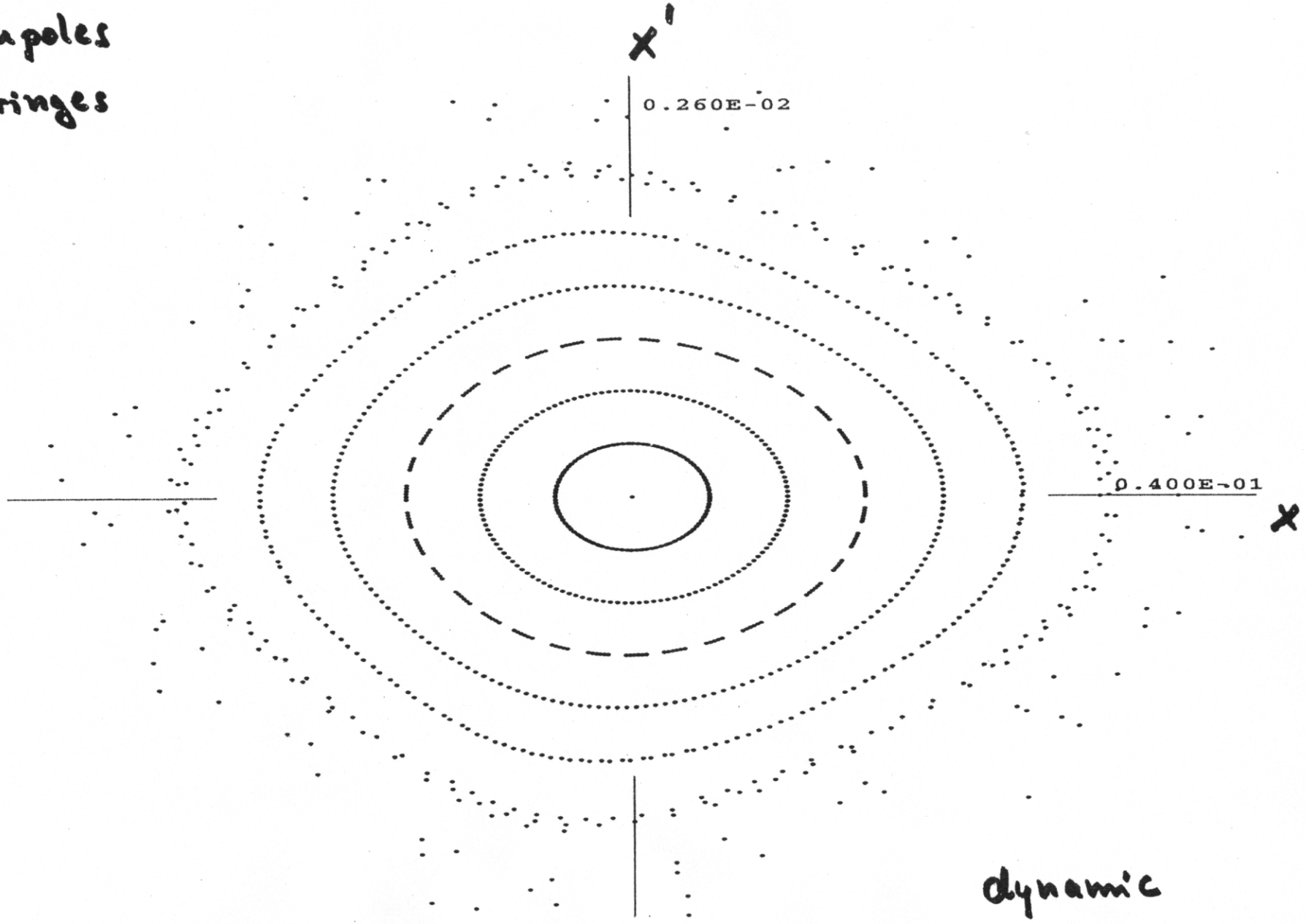
9th order

no fringes

no sextupoles

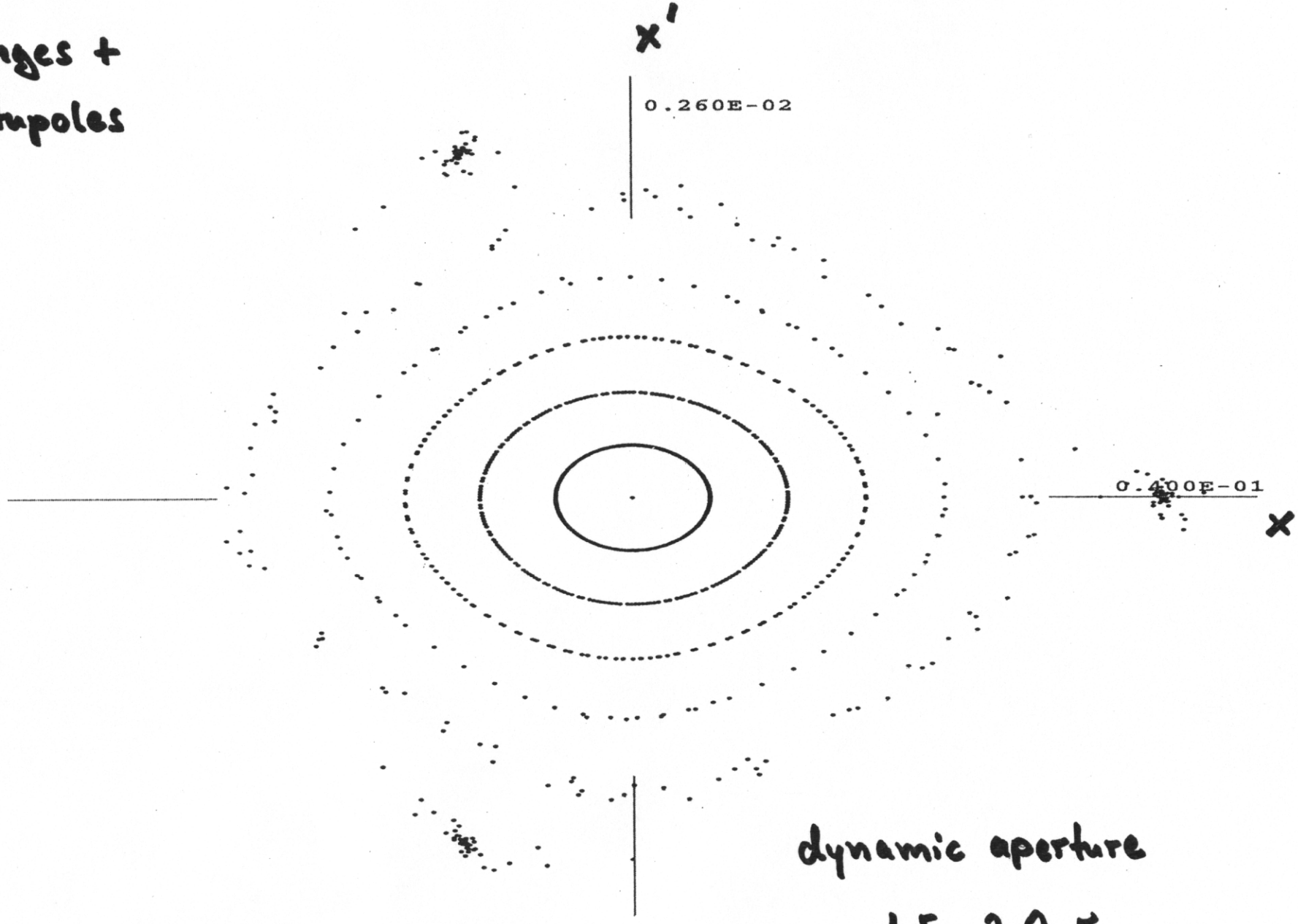
kinematic terms only

3th order
sextupoles
no fringes



dynamic
aperture
~2.5-3 σ

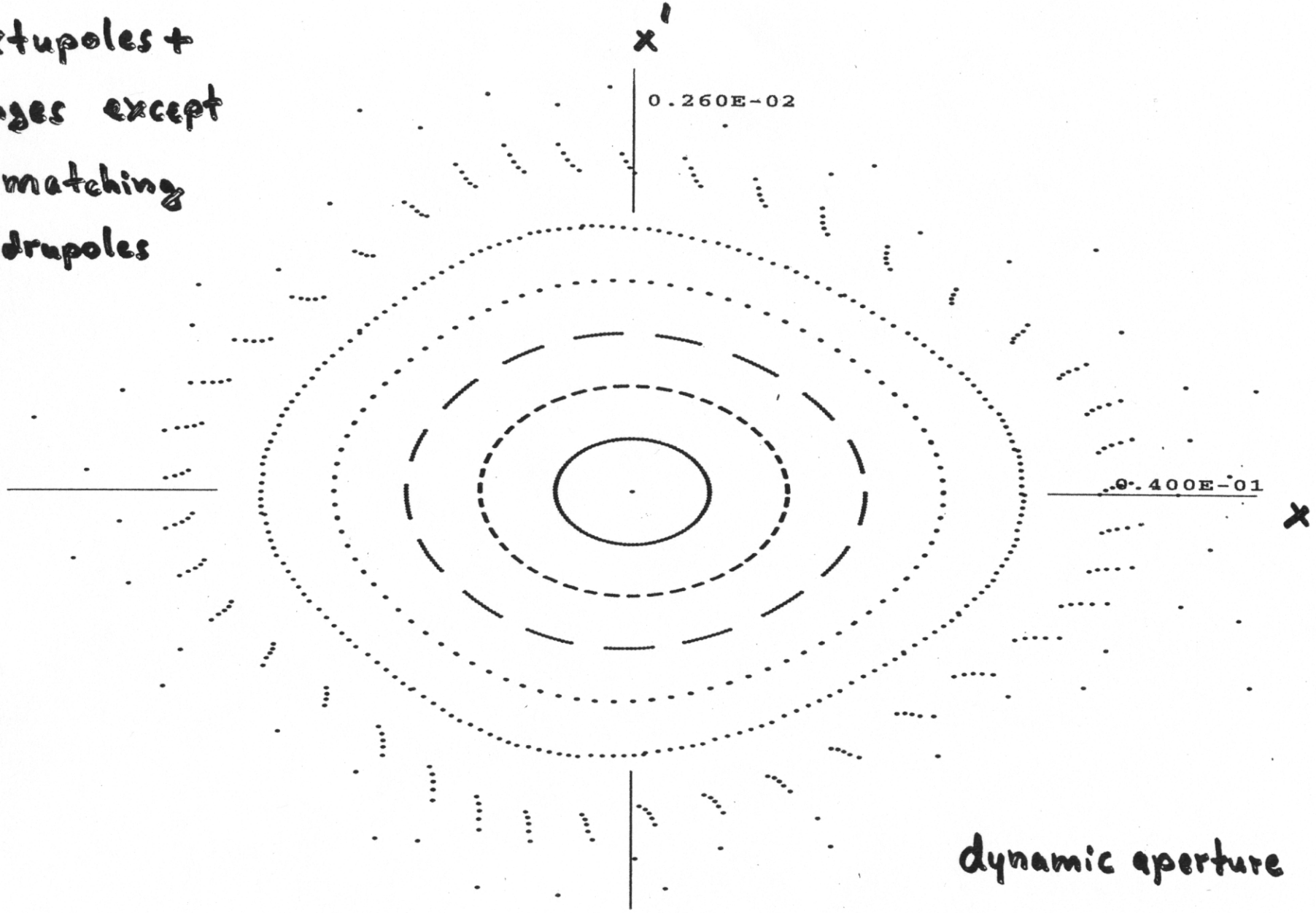
9th order
fringes +
sextupoles



dynamic aperture

1.5 - 2.0 σ

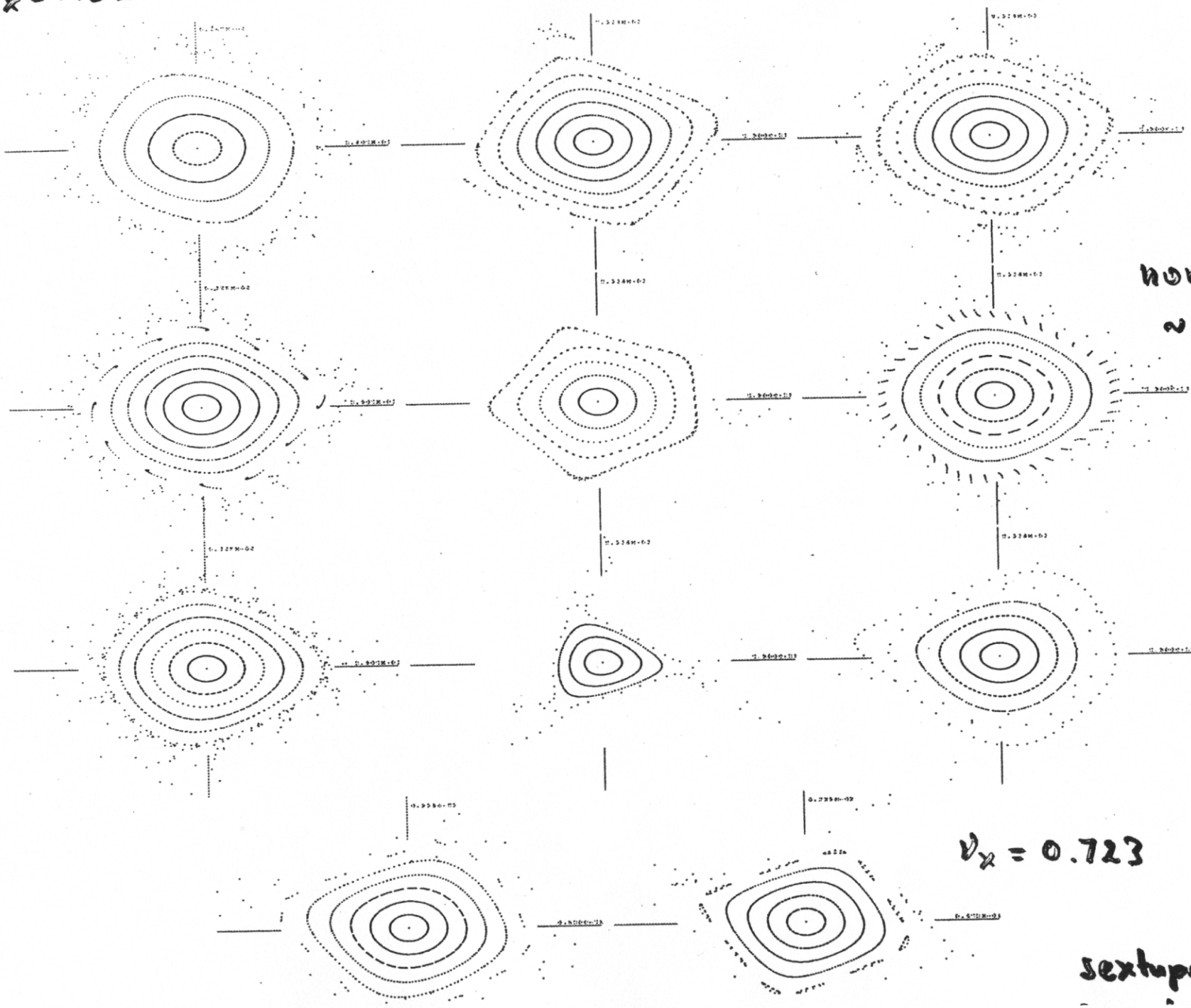
th order
xtupoles +
nges except
matching
edrupoles



dynamic aperture
2.5-3.0 σ

tune scan in x, steps 0.02

$\nu_x = 0.523$



nominal

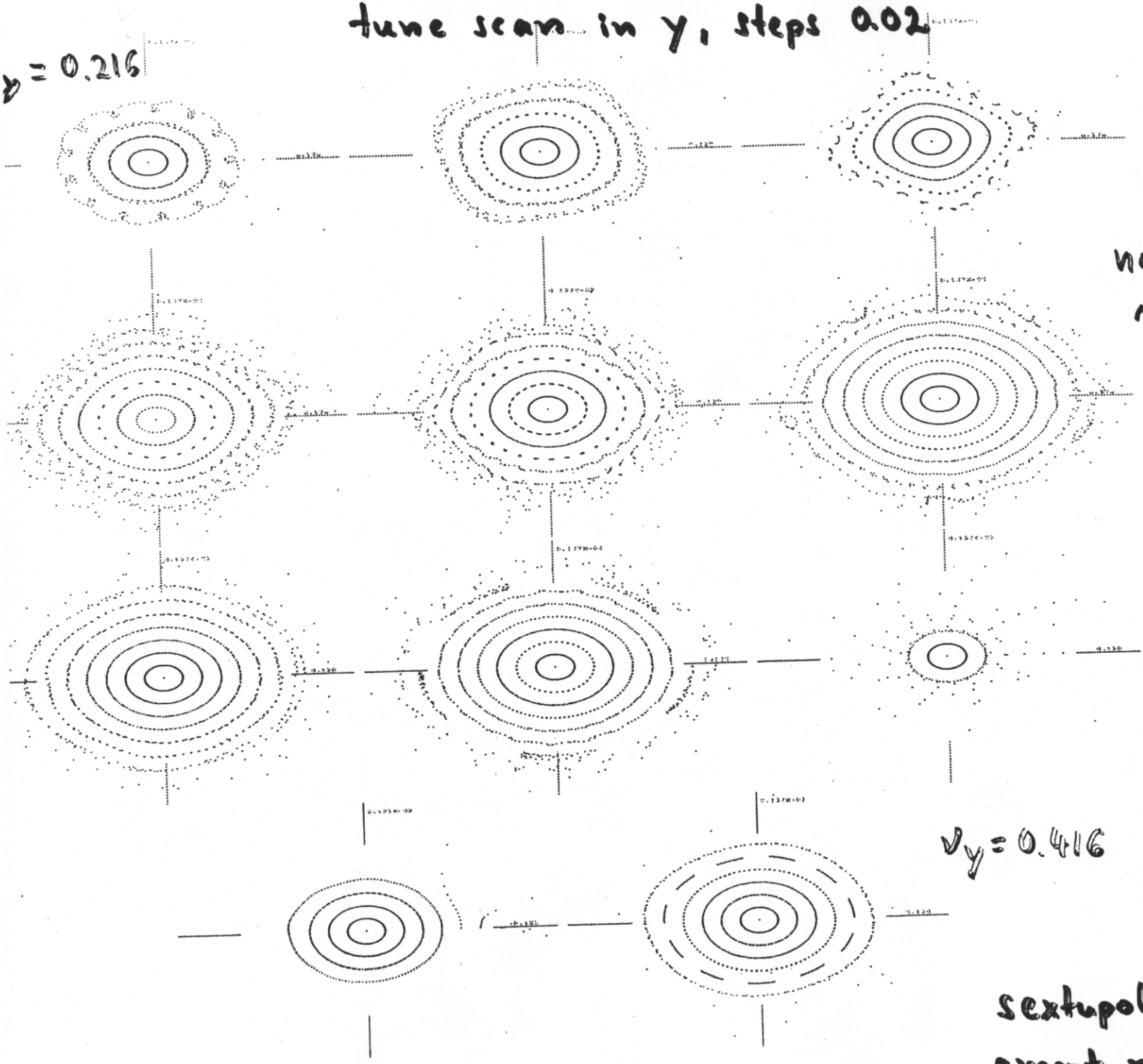
$\sim 3\sigma$

$\nu_x = 0.723$

sextupoles + fringe

tune scan in y, steps 0.02

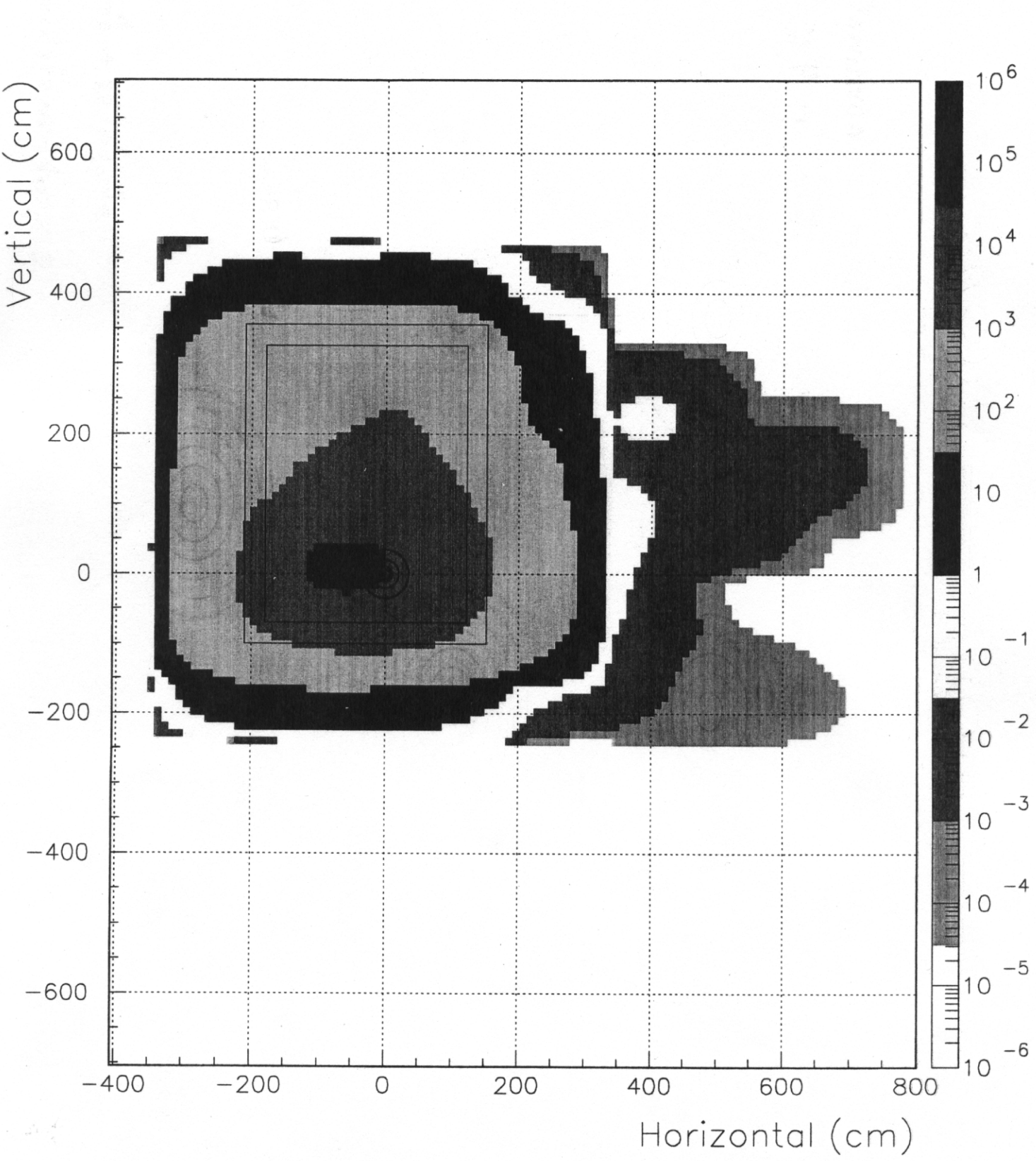
$\nu_y = 0.216$



nominal
~ 4 σ

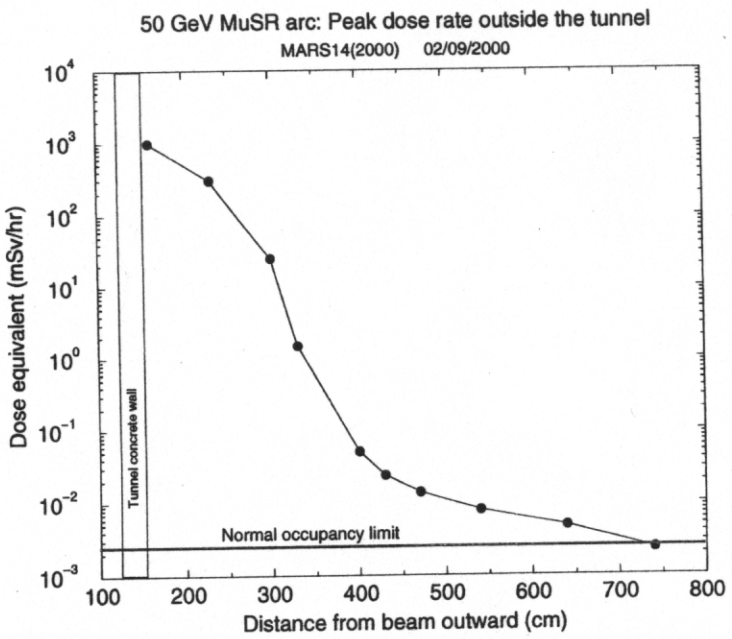
$\nu_y = 0.416$

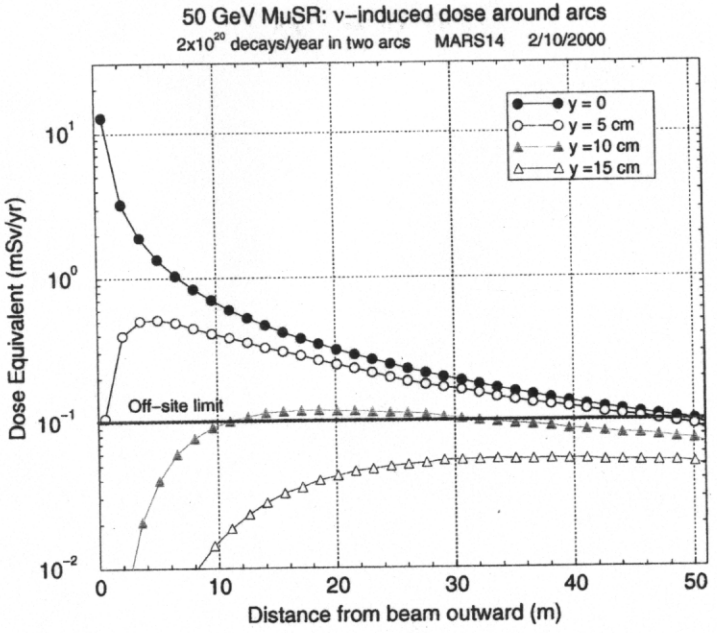
sextupoles + fringes
except matching sn.



50 GeV MuSR arc tunnel. Dose rate (mSv/hr)

DOSE OUTWARD FROM ARC TUNNEL





Dose distribution radially outward from the arc tunnel enclosure: conventional in mSv/hr (left) and neutrino-induced in mSv/yr (right).