Large Acceptance Fixed-Field Accelerators

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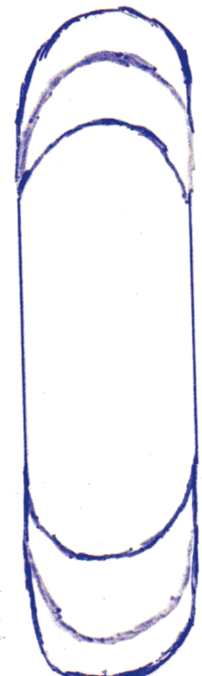
1ST RECIRCULATING LINAC



--Two 200-m Linacs

--Passive beam spreader

--Multiple arcs

CONSTRAINTS:

Previous:

ε_{rms} (normalized) = 3200 π mm-mrad

Central Momentum (GeV)	dp/p (3σ)	Momentum Spread (GeV)
2	12%	1.760-2.240
4	7.9%	3.685-4.315
6	6.5%	5.610-6.590
8	5.8%	7.535-8.465
10	5.4%	9.460-10.54

Present:

1100 π mm-mrad

Central Momentum (GeV)	dp/p (3σ)	Momentum Spread (GeV)
3		injection*
4	5.1%	3.795-4.205
6	4.2%	5.747-6.253
8	3.8%	7.698-8.302
10	3.5%	9.650-10.350
11		extraction*

*hopefully kickers will inject/extract 3/11 GeV and will not traverse the beam spreader

Definitions:

Accelerators which use fixed-field magnets rather than ramped-field magnets have been traditionally called FFAG Accelerators (Fixed Field Alternating Gradient).

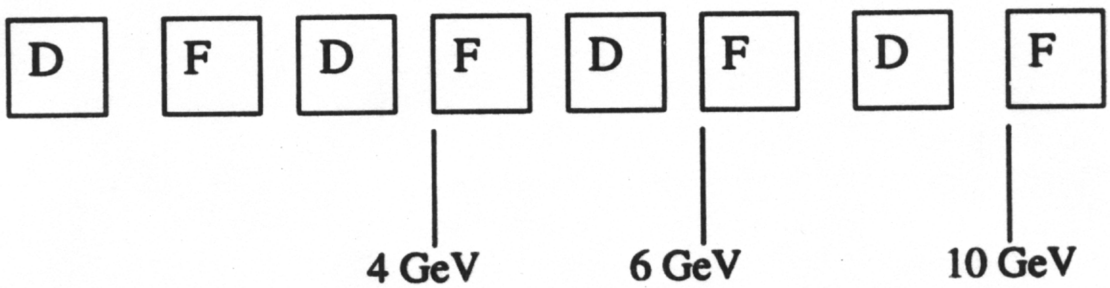
The large momentum spreads, and, to a lesser extent, the large beam sizes, coming out of cooling require FFAG-based optical structures.

⇨ Cannot copy existing machine lattices

BEAM SPREADER

The beam spreader is so difficult and constraining it dictates the entire lattice of the RLA.

1. To minimize (ha-ha) apertures in the spreader, a single energy is split off at a time into its separate channel:



2. The "unseparated" channel must contain the remaining spread in momenta: 6-10 GeV, then 8-10 GeV. The large momentum spreads in each channel result in large apertures in order to contain the remaining combined channels as the distance required to accomplish the split is achieved.

3. The large apertures and required focussing gradients conspire to drive the some of the beam spreader magnets superconducting.

3. The separate channels are defined to be when the highest energy in the channel to be split is .4 m from the lowest energy in the next channel. To achieve this separation, given the table of momentum spreads, results in magnet lengths 1.5-2 m for the above spreader. To keep the beta functions in the arc matched to the spreader, the arc combined function magnets are the same length and gradient as the spreader. (Gradients in separated spreader channels are varied slightly to achieve symmetry points at the start of the arc.)

Fixed-Field Accelerator Design

Two types of lattice structures currently prevail in FFAG design work:

Traditional Scaling FFAG: Combined-function short FODO cell with edge focussing or B fields which scale with momentum.

Triplet-based scaling FFAG: A scaling module based on a triplet quadrupole structure (developed for the KEK POP machine). It's advantage over the previous structure is the inclusion of a straight in each cell which can be used for rf, for example.

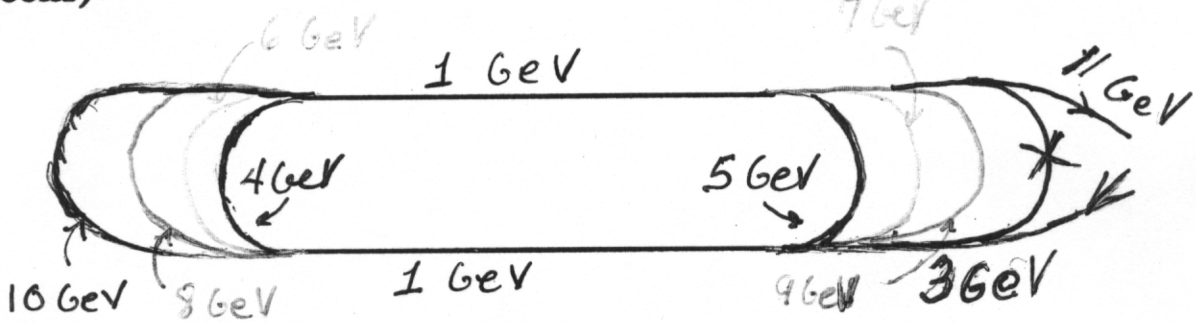
Specific to Muon Acceleration

Nonscaling FFAG: For muon acceleration where acceleration is rapid and there are only a few turns in the accelerator, you do not have to avoid resonances and lattice parameters do not have to scale as a function of momentum. One has the freedom to chose parameters which are optimal for muon acceleration, such as minimizing the circumference and maintaining a large transverse dynamic aperture.

Note: Current large acceptance rings (dp/p of ±4%) with many acceleration turns consist of short FODO cells with sextupole and octupole correction. (This makes them approximately scaling.)

THE MULTIPLE ARCS

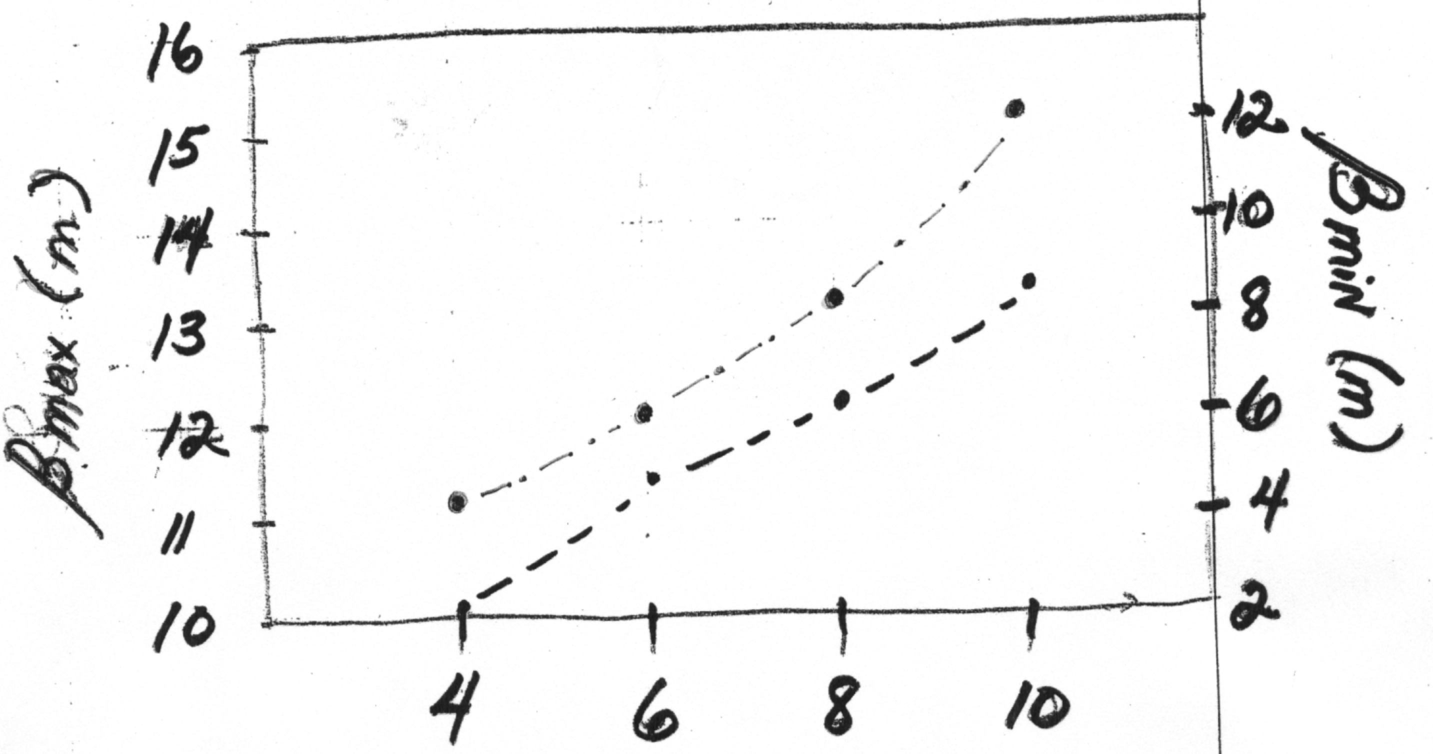
1. To generate an integer spread across the separate channels with no matching, requires the gradient to go as 1/p and the arc energies to follow a sequence: 4, 6, 8 with 2 GeV/turn for 90 degree phase advance @4 GeV and 24 cells. Then the injection energy must be 3 GeV, for 2 GeV would be unstable. The last arc at 10 GeV has to be gently tuned to an integer (over 20 cells)*



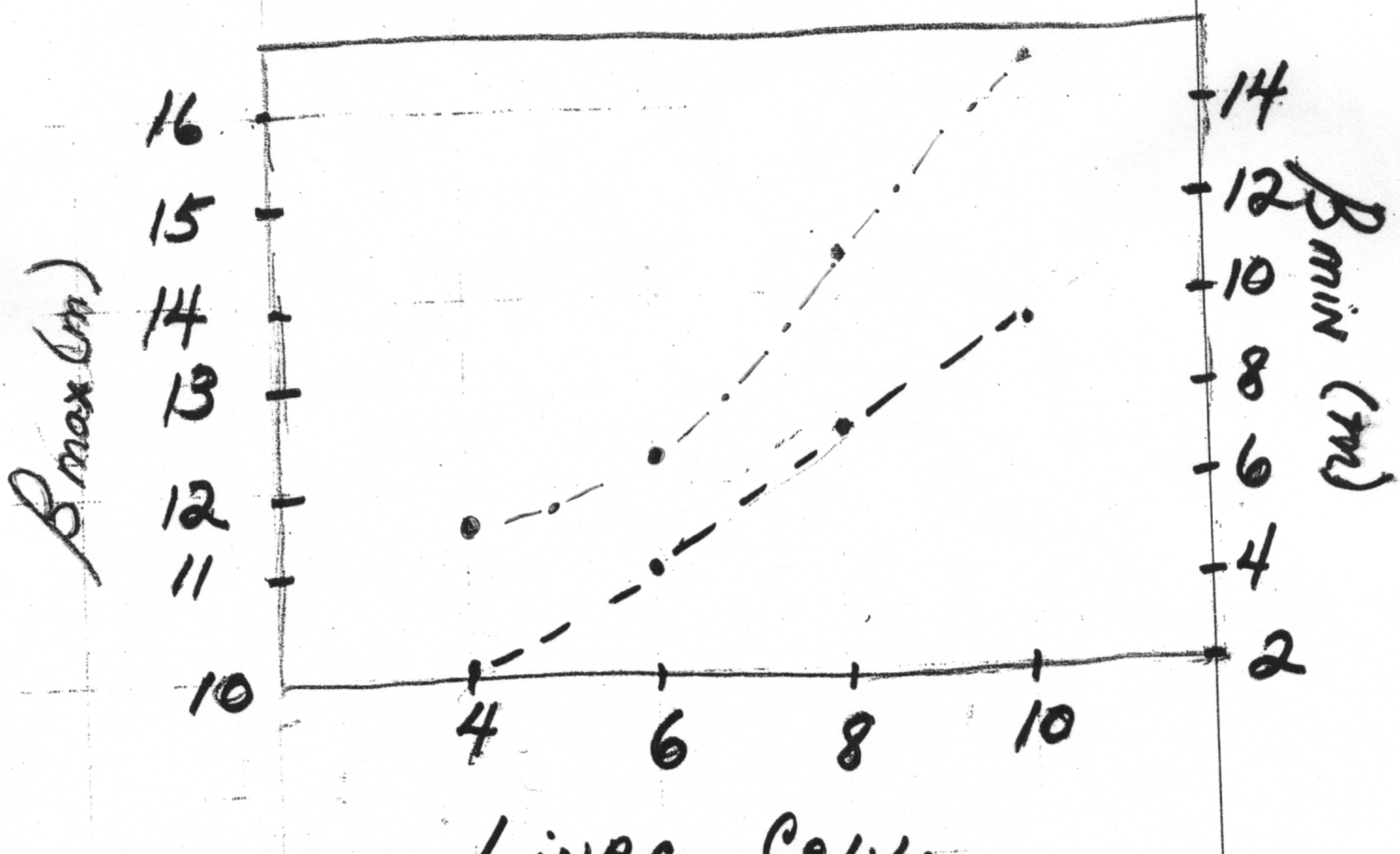
*The 5,7,9 arc also has to be slightly adjusted in overall gradient.

2. In order to keep the arcs from ending up in the buffalo pasture, they are nested with equal arc lengths. This is particularly important for superconducting arcs where interleaving would require incredible spacings per arc.

2. The beam spreader sets up an unavoidable, but periodic dispersion wave throughout the arc. Sextupoles are introduced once the channels are separate to flatten the momentum compaction over the momentum spread.

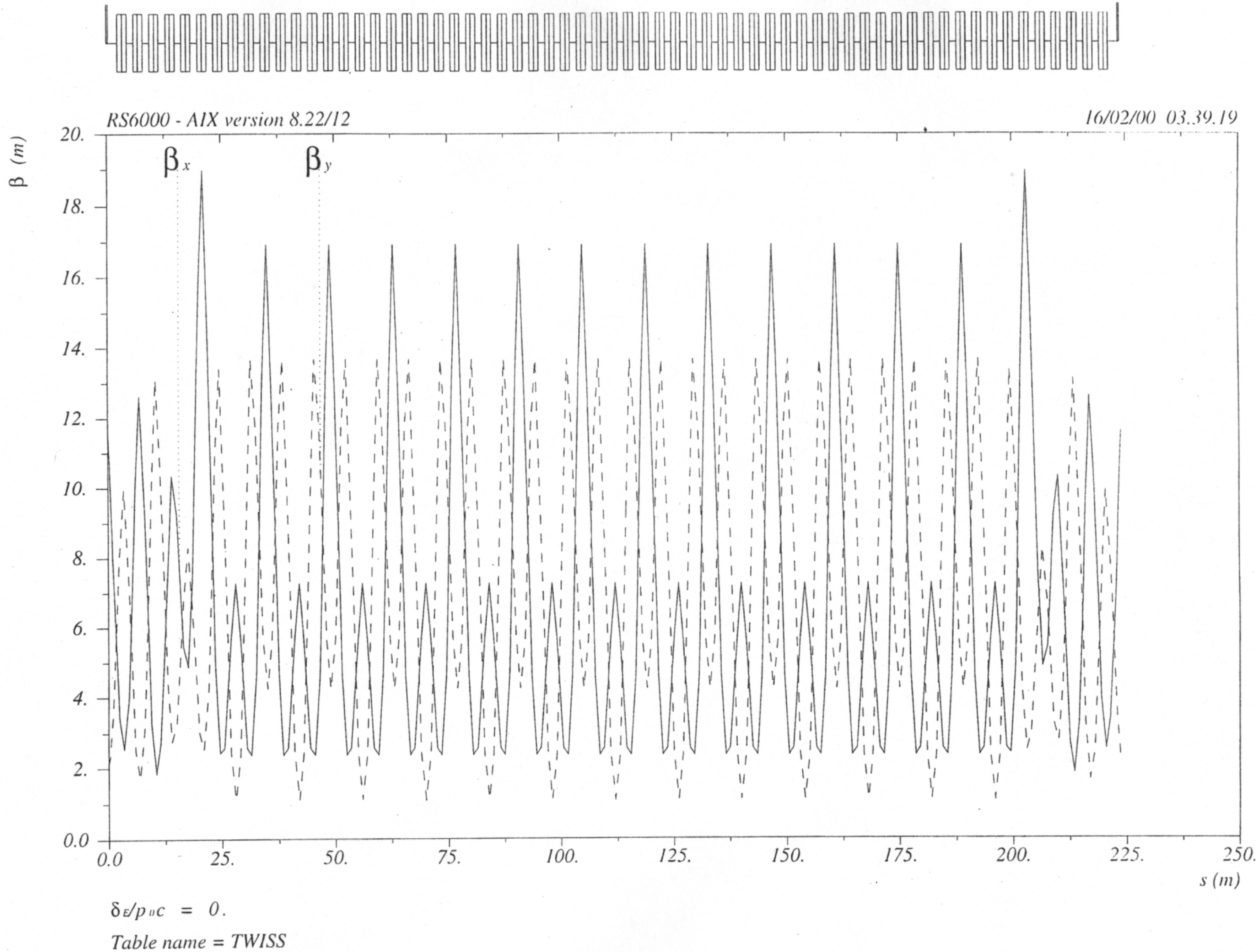


Arc Cell



Linac Cell

Cell → ∅ chromaticity correction is not needed.

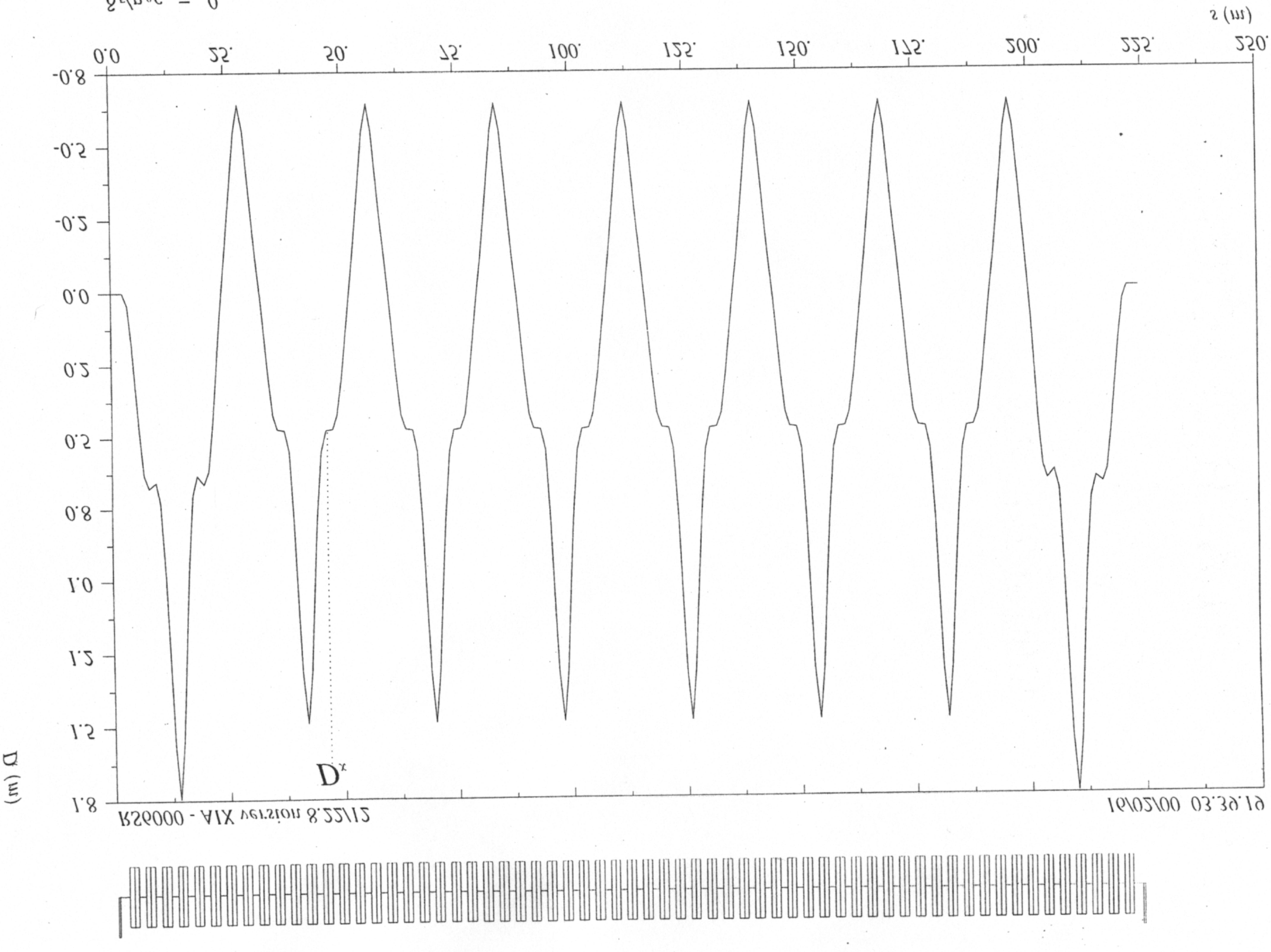


4 GeV ARC : β functions

11 Cell Arc: Dispersion Wave

Table name = TWISS

δE/p0c = 0.



"FIXED" DESIGN ASPECTS:

1). "Unbroken" periodic structure

2). Horizontal layout of beam spreader and arcs

3). 90° phase advance in arc cells to support sextupoles with minimal impact on transverse dynamic aperture

PHILOSOPHICAL DIFFERENCES
TRIPLET VS. FODO

I. **Arc Cell Structure:**

Triplet—Separated Function Magnets
FODO—Combined Function Magnets

II. **Spreader**

Triplet—Simple dipole until separation is achieved
FODO—Integrated into periodic structure

III. **Dispersion Suppression/matching linac ⇨ arc**

Triplet—Sextupole family for D, D' matching

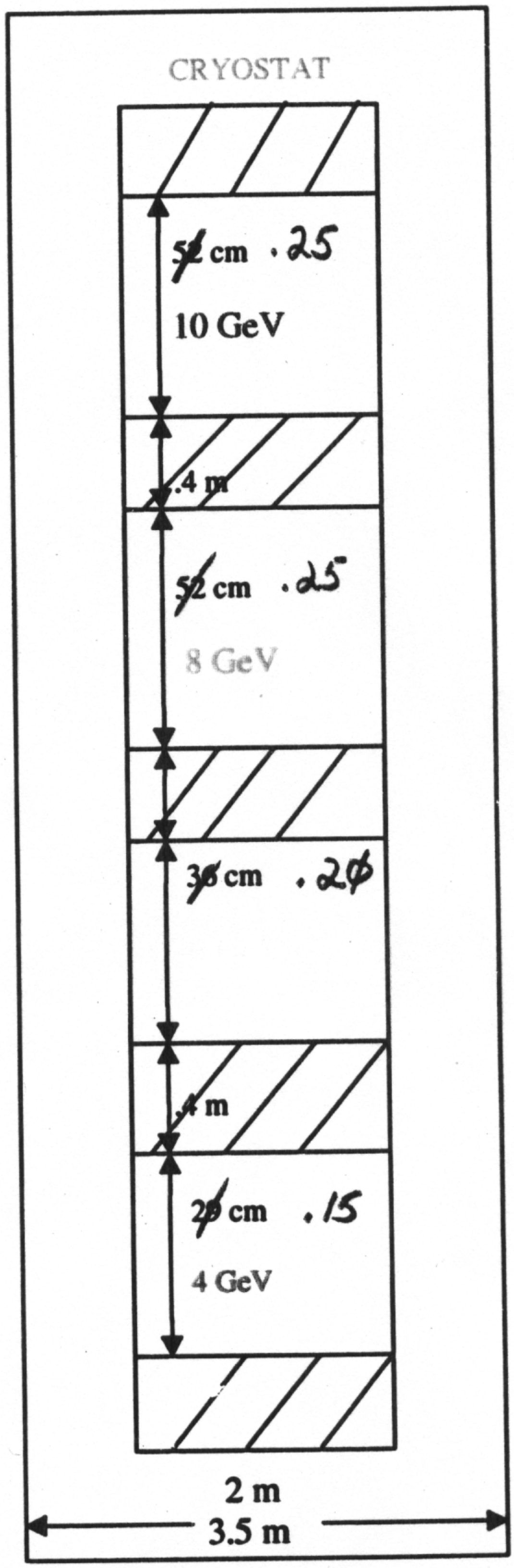
FODO—Integer phase advance/symmetry pt for D, D' matching

IV. **M56/ Momentum Compaction Control:**

Triplet—Bend/cell for central value of M56, second sextupole family for M56 derivative

FODO—Move dipole component from "F" to "D" combined-function for central value of M56, single family of arc sextupoles for M56 derivative

ARC MAGNETS



Vertical Aperture: 13 cm

B = .3T *p/4 *

B' = 3.6 T/m

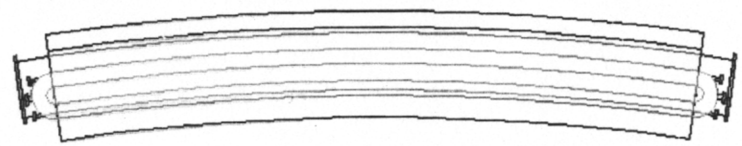
* chosen to achieve $\alpha = .002$ for/@ arclength of 225 m

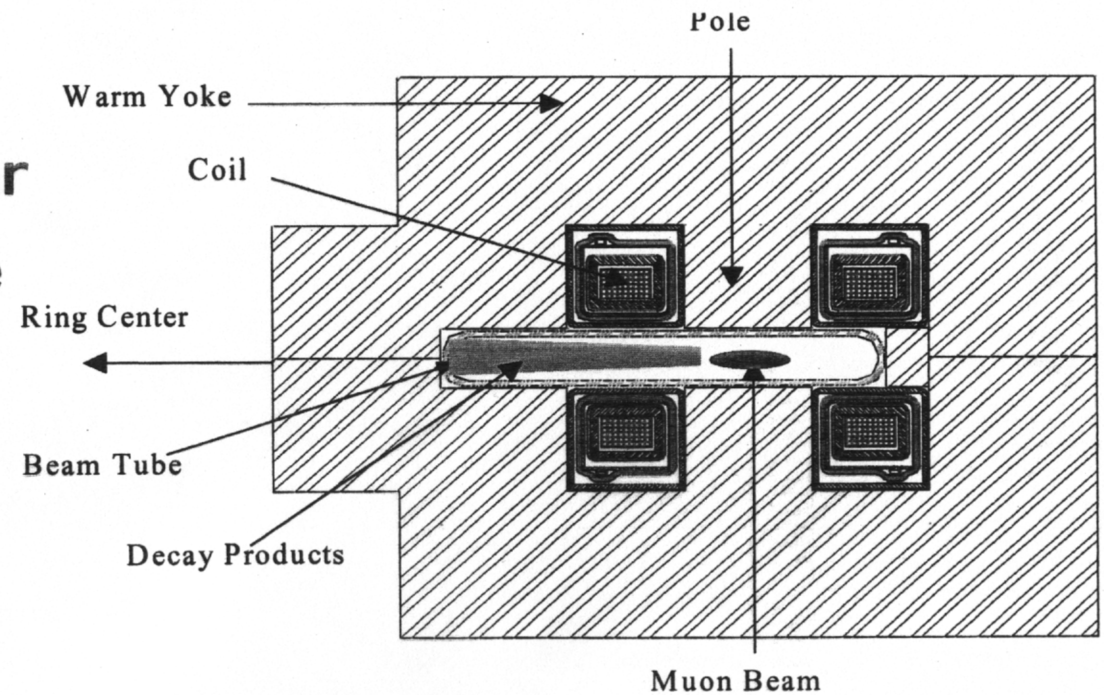
TOTAL ARC LENGTH: 450 m

Basic Design Principles

Basic Design Principles from Mike Harrison:

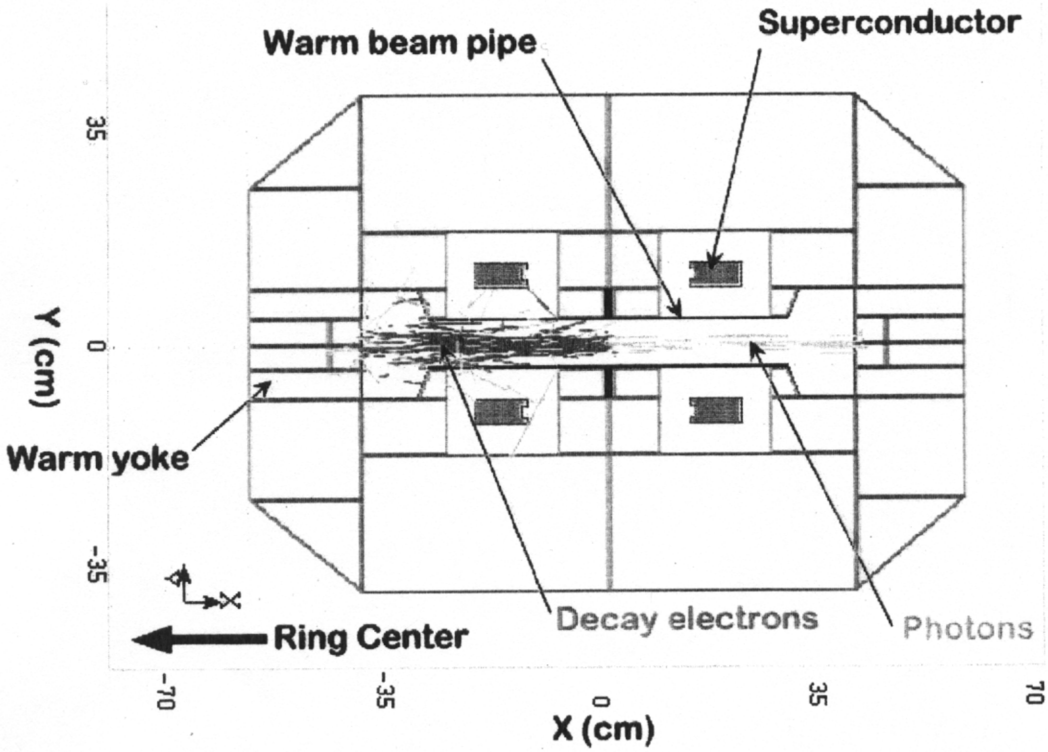
- Nb-Ti Racetrack coils
- Design Field: ~5 T
- **Decay products clear SC coils at midplane**
- Warm iron
- Compact cryostat
- Low cost

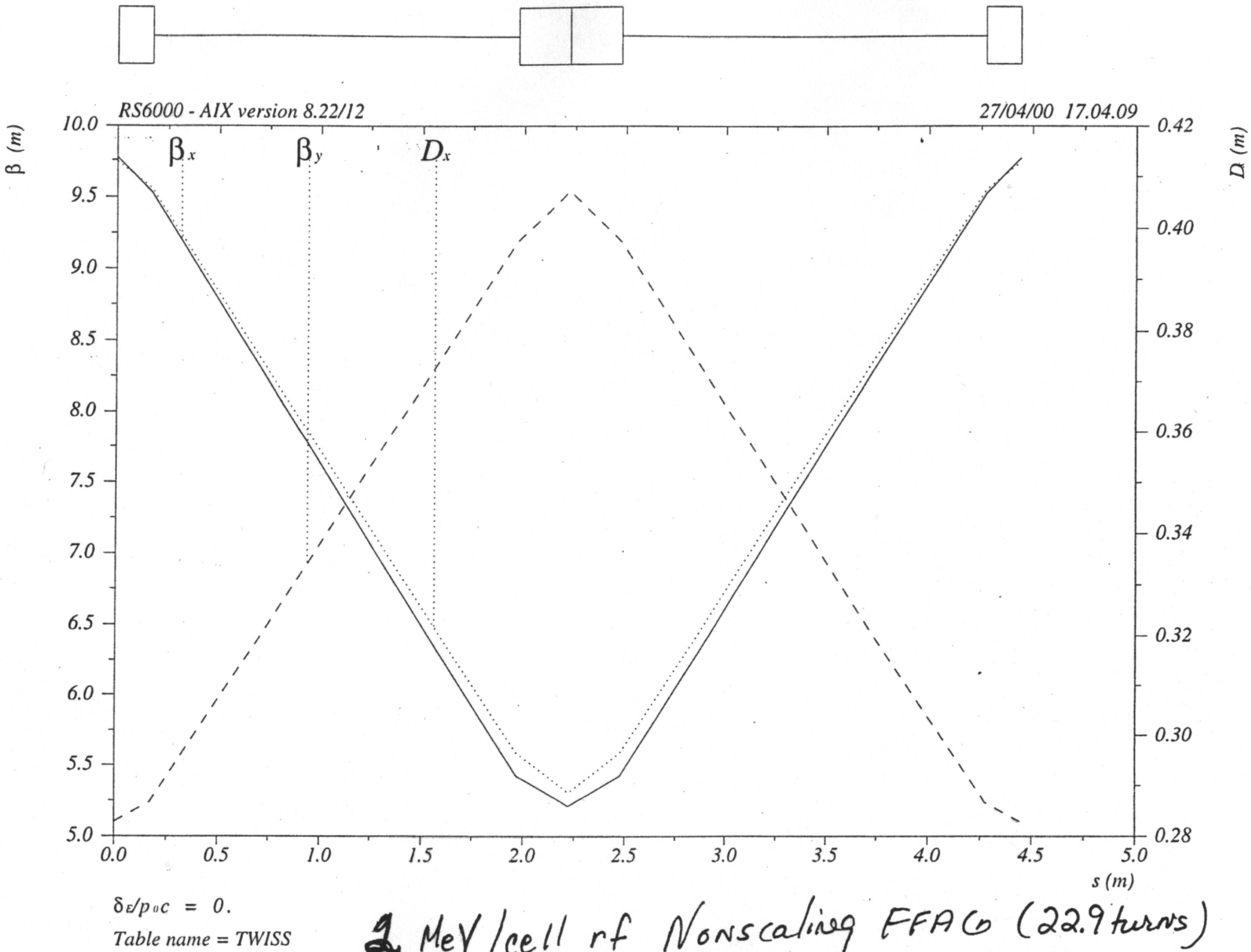




BROOKHAVEN NATIONAL LABORATORY
Superconducting Magnet Division

What does the dipole magnet cross section look like for the toy model study?





2 MeV/cell rf Nonscaling FFAG (22.9 turns)

CENTRAL [redacted] (9 GeV) LATTICE FUNCTIONS

NONSCALING FFAG LATTICE FOR MUON ACCELERATION

Central Momentum: 9 GeV

Focussing quadrupole

kf (@ 9 GeV): .89 m-2
"F" aperture (HxV): ±15 **x** ±4.5 cm
"F" poletip field: 4 T

Defocussing combined-function magnet

kf (@ 9GeV): .59 m-2
Bd (dipole component): 2.13 T
"D" aperture (HxV): ±10 **x** ±6 cm
"D" poletip field: 3.91 T

Ring Parameters and Comparison with 1st RLA*

rf/ cell	"F" length	"D" length	cell length	Bend/ cell	# cells	^ C	# turns	Total Path	Comp Factor
MeV/ cell	(m)	(m)	(m)	(mr)		(m)		(km)	
2	.169	.253	4.44	36.0	175	778	22.9	17.8	4.4
3	.141	.212	5.31	30.2	209	1107	12.8	14.1	3.5

*1st RLA has ~4 km total pathlength for 4 turns