Highlights of Emittance Exchange talks from Riverside

R.C. Fernow
BNL

MC Friday Meeting
6 February 2004

Outline

1. Linear precoolers

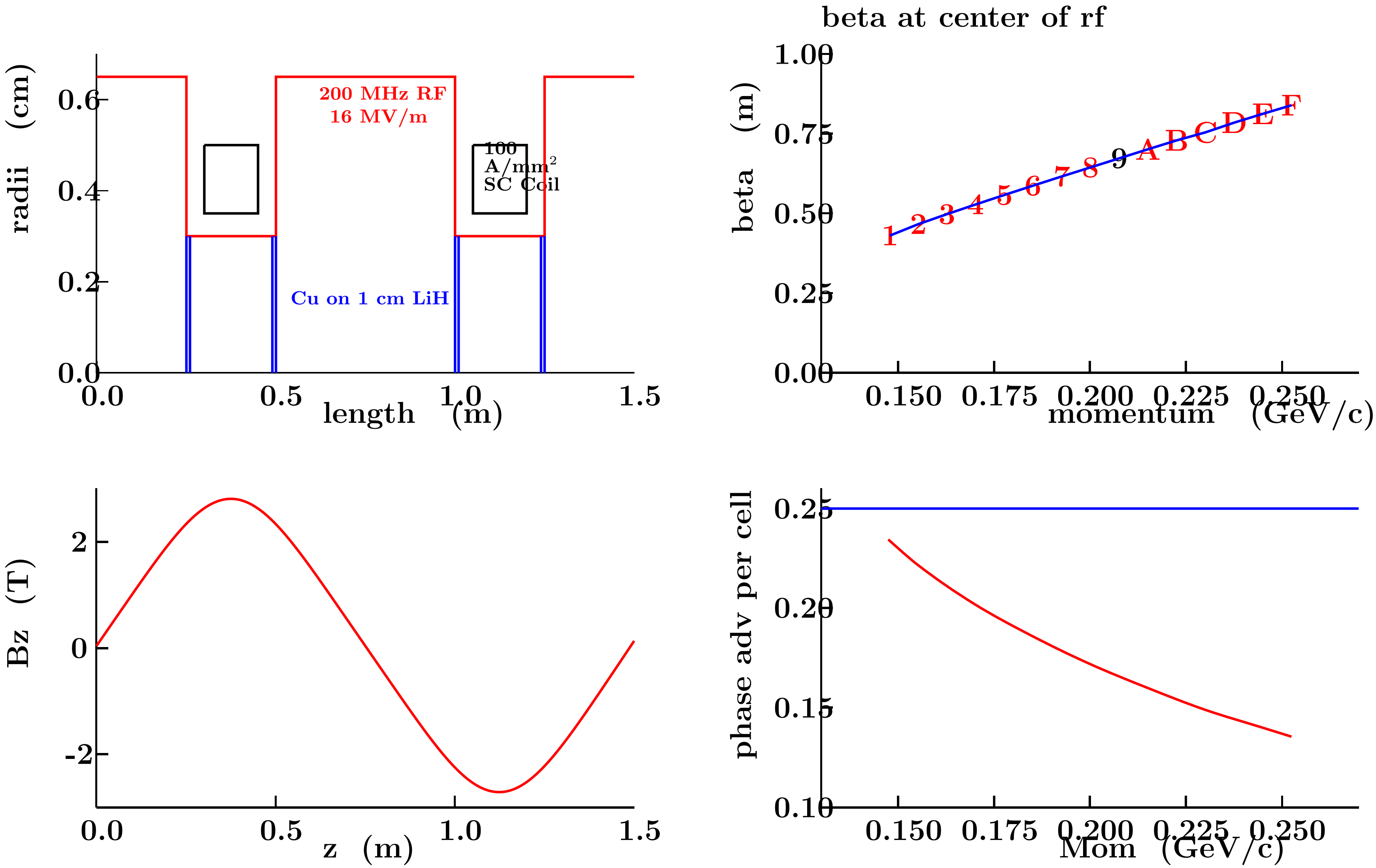
R. Palmer	LiH channel with bends
R. Fernow	helical channels

2. Ring coolers

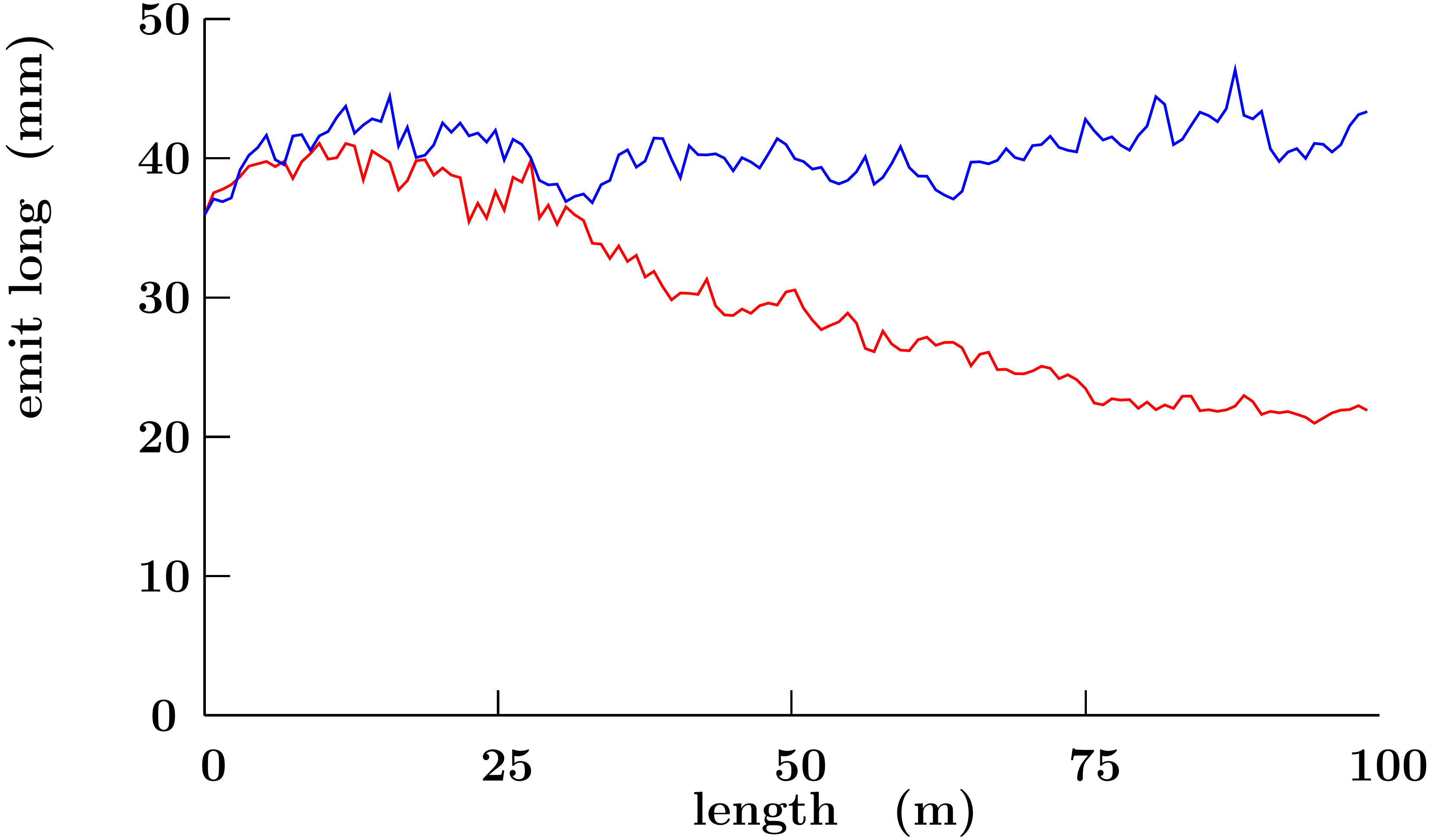
A. Garren	dipole ring - designs
H. Kirk	dipole ring – hard edge
S. Kahn	dipole ring with realistic fields
R. Godang	RFOFO ring with Geant
A. Klier	RFOFO ring with Geant

3. Final cooling

Y. Fukui	Li lens ring cooler



200 MHz RF
16 MV/m
100
A/mm²
SC Coil
Cu on 1 cm LiH
radii (cm)
length (m)
0.0
0.2
0.4
0.6
0.5
1.0
1.5
beta at center of rf
beta (m)
momentum (GeV/c)
1.00
0.75
0.50
0.25
0.00
0.150
0.175
0.200
0.225
0.250
1 2 3 4 5 6 7 8 9 A B C D E F
Bz (T)
z (m)
2
0
-2
phase adv per cell
Mom (GeV/c)
0.25
0.20
0.15
0.10



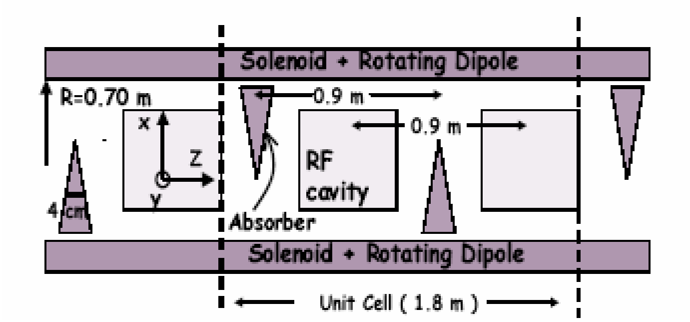
Longitudinal Cooling is observed

Summary

	linear		curved	
initial				
trans (pi mm)	10.4		10.4	
long (pi mm)	34.0		34.0	
6 D (pi mm)^3	13.5 k		13.5 k	
50 m				
trans (pi mm)	9.2	(1/2.1)	12.7	(1/1.5)
long (pi mm)	39.9	(1/.9)	30.5	(1/1.2)
6 D (pi mm)^3	3.39 k	(1/4.0)	4.9 k	(1/2.7)
100 m				
trans (pi mm)	5.9	(1/3.3)	10.1	(1/1.9)
long (pi mm)	43.4	(1/.8)	21.9	(1/1.6)
6 D (pi mm)^3	1.52 k	(1/8.9)	2.3 k	(1/5.9)

Balbekov helical cooling channel

72 m long, 40 x 1.8 m cells
$B_S = 5$ T, $b_0 = 0.3$ T
201 MHz, 14 MV/m, 30^o phase
14.7^o LiH wedge absorbers
dipole field tapered on/off over 8 cells
simulations described in MC146 and MC193



Input beam parameters

- $\sigma_X = \sigma_Y = 3.25$ cm
- $\sigma_Z = 10$ cm
- $\sigma_{PX} = \sigma_{PY} = 48.7$ MeV/c
- $\sigma_{PZ} = 18$ MeV/c
- L_Z for 5 T solenoid
- momentum – transverse amplitude

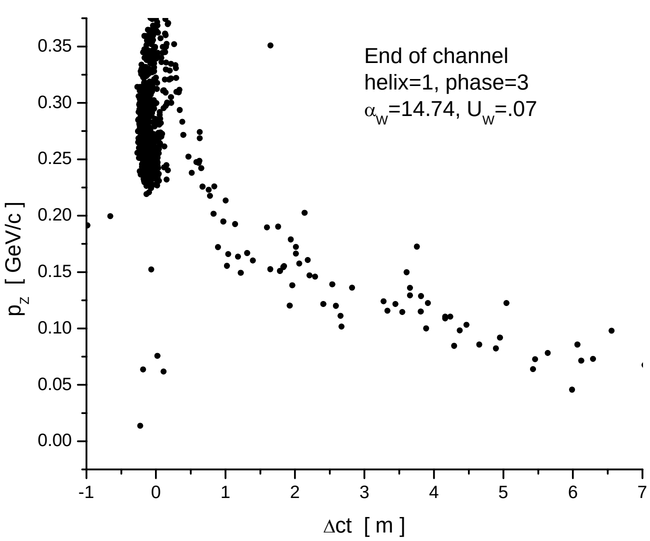
ICOOL cooling performance with Gaussian beam

include stochastics
$\alpha_W = 14.74^o$, optimized U_W
100< p< 320 MeV/c cut in ECALC9
initial emittances

ε_{TN} = 11.0 mm
ε_{LN} = 28 mm

helix model	phase model	U_W [cm]	ε_{TN} [mm]	ε_{LN} [mm]	Tr [%]
1	3	7	8.0	17	48
	4	6	7.8	20	54
2 (D)	3	7	7.8	22	65

• channel performs very poorly !!!
• sheet field has better transmission



• clear problems keeping beam bunched

ICOOL cooling performance

include stochastics
initial emittances

ε_{TN} = 11.0 mm

ε_{LN} = 28 mm

helix	phase	P [atm]	ε_{TN} [mm]	ε_{LN} [mm]	Tr [%]
1	3	140	4.9	26	50
	4	160	5.1	27	50
2 (D)	3	160	5.2	25	56
2 (D+Q)	3	160	5.5	30	45

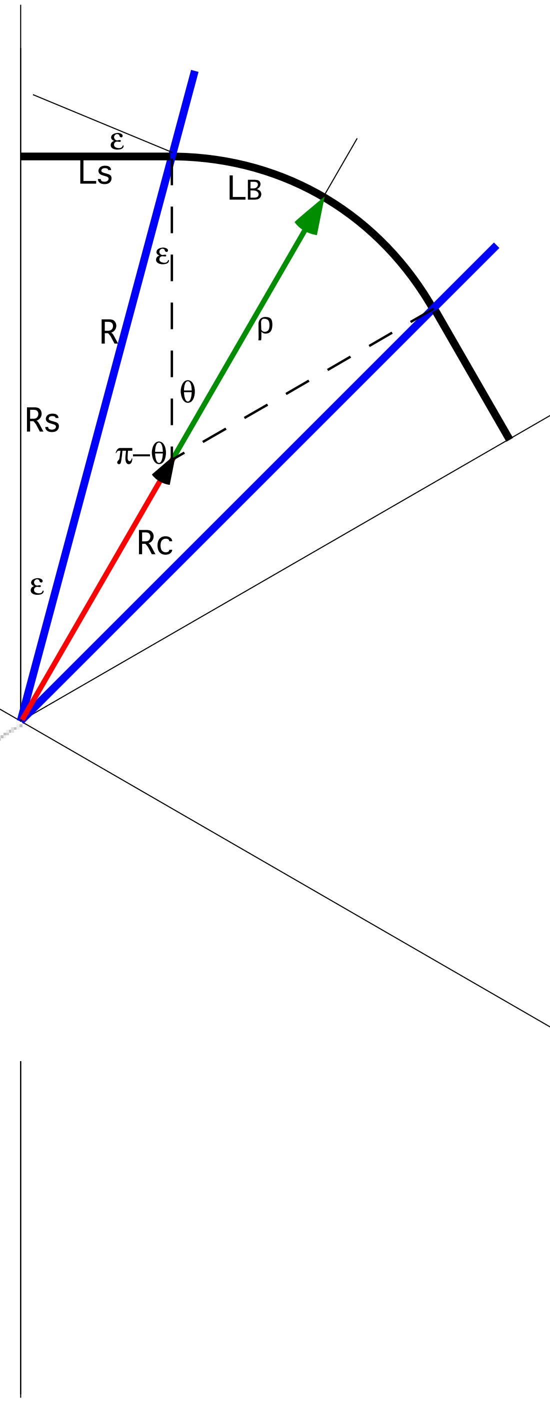
• slightly better performance than channel with LiH wedges
• no evidence for longitudinal cooling
• adding quad term to sheet model makes it worse

6 DIPOLE RING

$\lambda = \rho \,/\, Rc = 1$

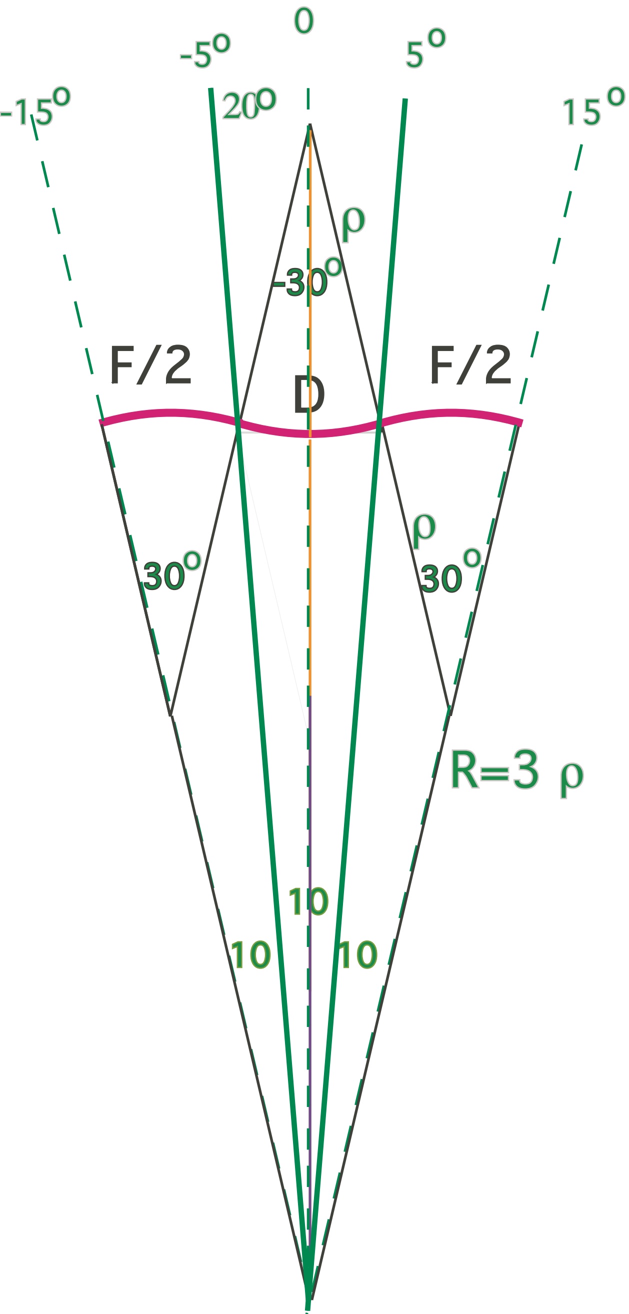
Parameters of 6-Sector Rings

rho=Rc, theta=30deg, eps=15deg



Momentum, GeV/c	0.25
Magnetic field, T	2.62
Magnet half length LB	0.167
Gap half length LS	0.159
Rho	0.318
Rc	0.318
Cell length	0.637
Circumference	3.82
RS	0.594
R	0.615
Bx, max	0.719
By, max	0.645
D, max	0.637

12 Cell Ring without Drifts
Layout of 1 Cell



$k = nd = -nf = 2.7$

$B/B0 = (R/R0)^{k} = (\rho/\rho o)^{-n}$

$P/P0 = (R/R0)^{k+1}$

$(R/R0) = (P/P0)^{1/k+1}$

$D = dR/d(p/po) = R/(k+1) = .2581\text{m}$

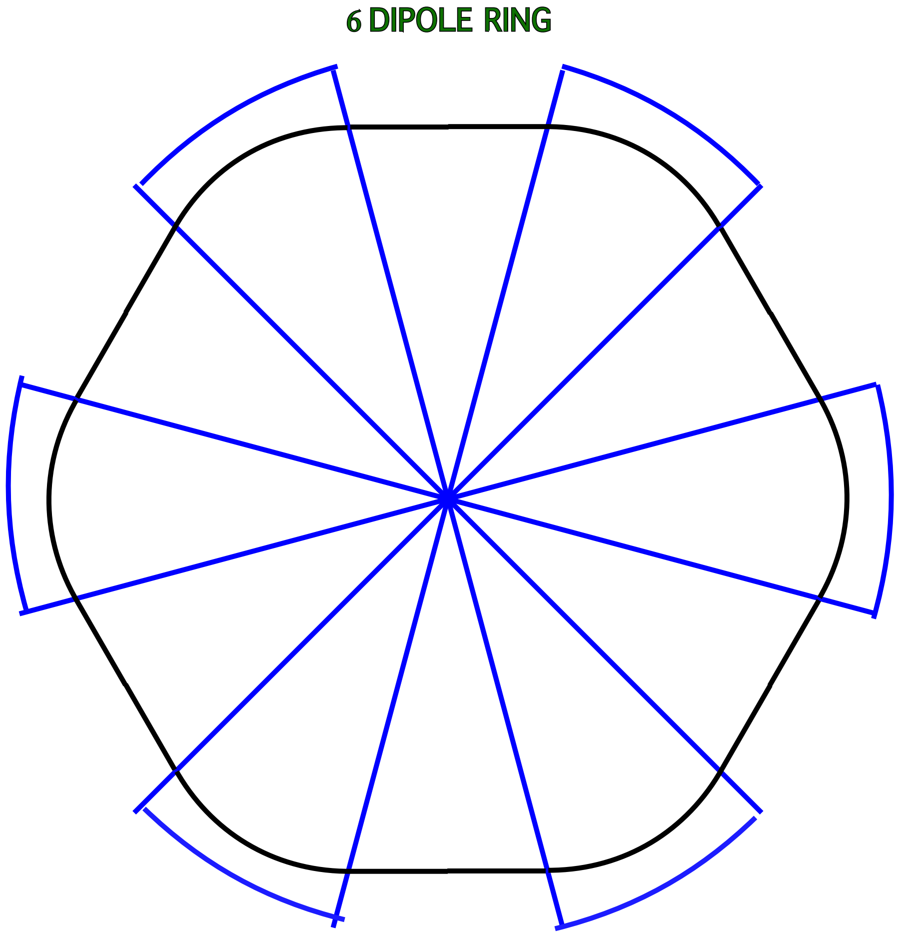
Lf = .3333m ; Ld = .1667m

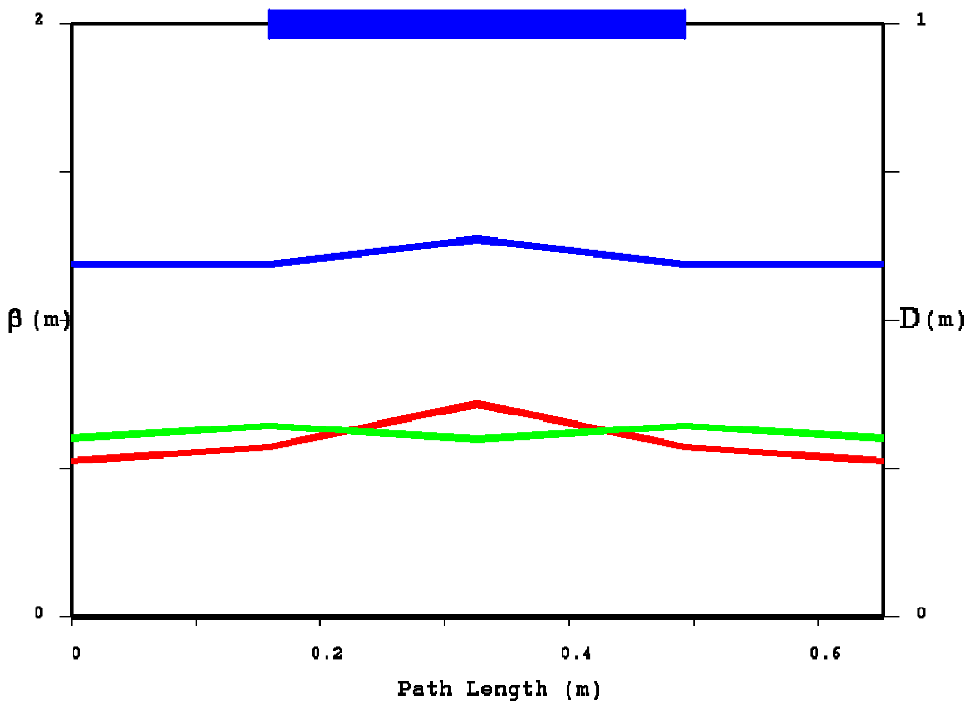
Lcell = 0.5m ; Circumference = 6m

ρ0 = .3183m ; R0 = .9549m ; B0 = 2.620T

pc = 0.25 GeV ; B ρ = 0.8339 m

Gas Filled Dipole Wedge Rings





Key parameters at r = 60 cm

β_x = 53 to 72 cm ; β_y = 60 to 64 cm

Dispersion = 60 to 64 cm

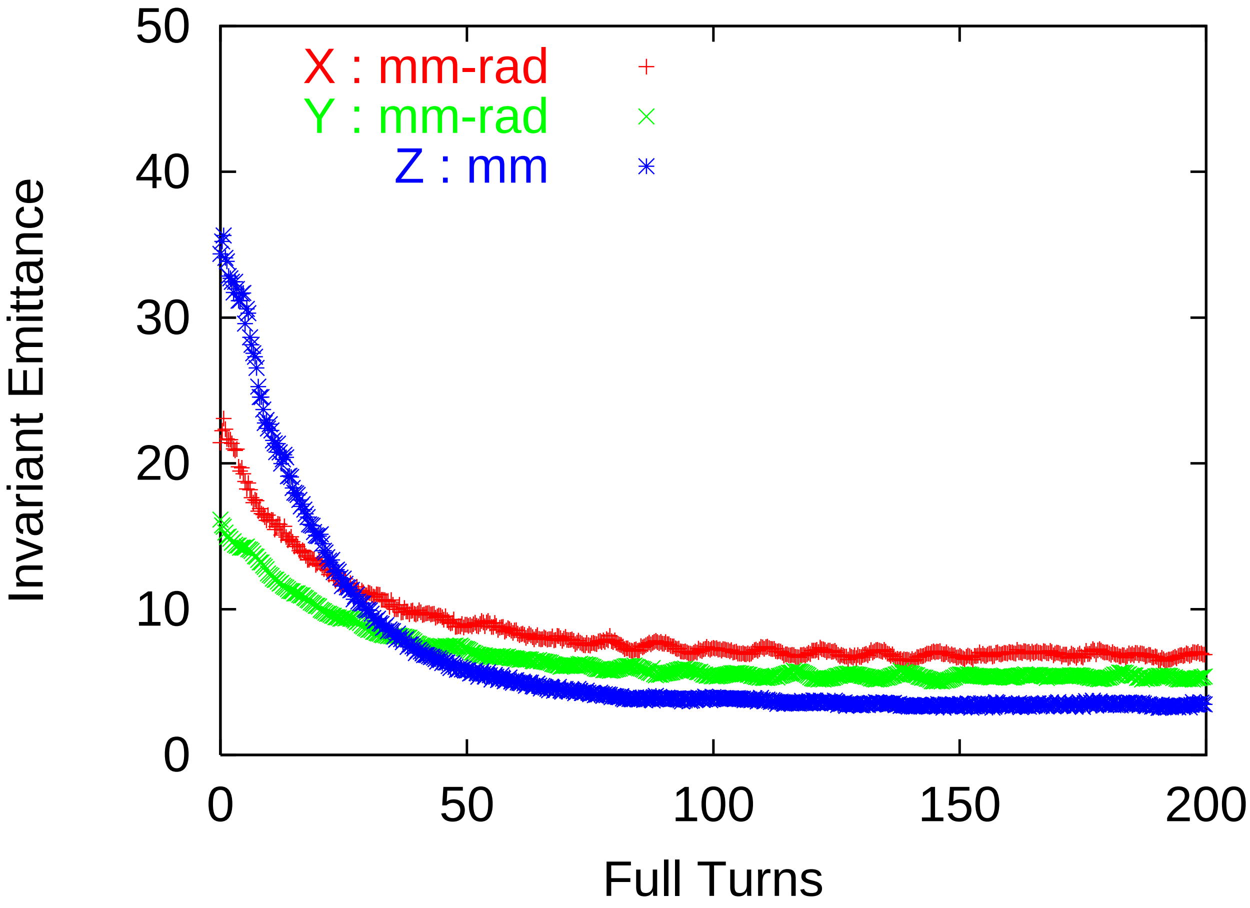
Circumference = 3.91 m

BROOKHAVEN NATIONAL LABORATORY

Harold G. Kirk

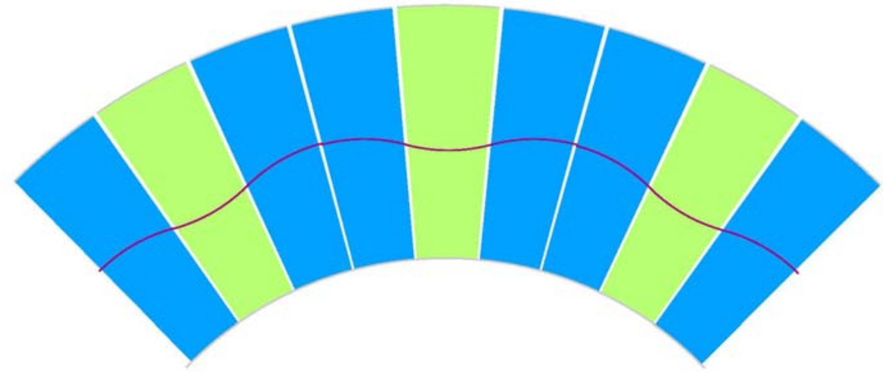
Introduce Skew Quadrupoles

- Bracket dipoles with thin (3cm) skew quadroles
- Skew quadrupoles real estate at 9% circumference
- Test various gradients.
- X/Y Coupling achieved



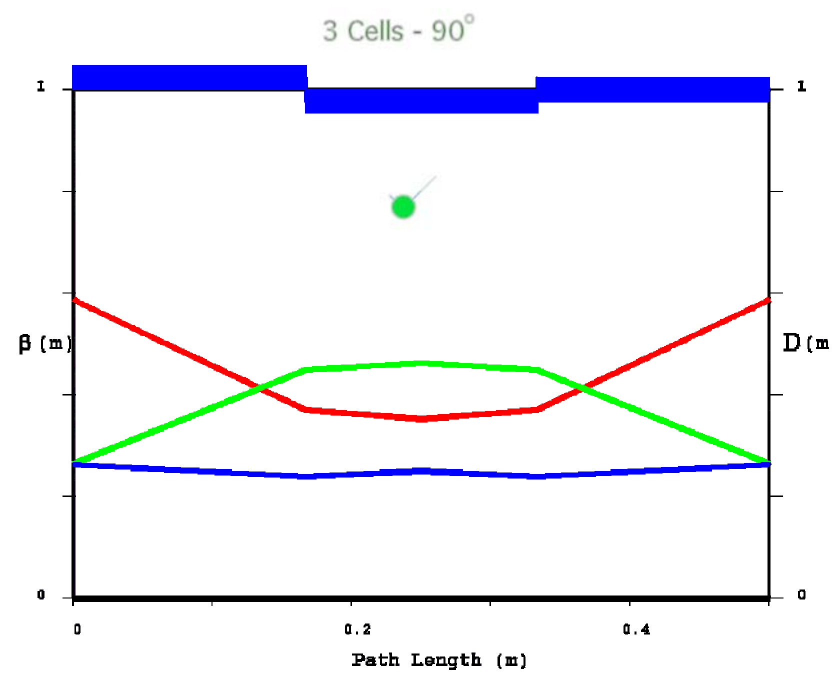
An FFAG-like Lattice

Lattice consists of alternating Horz. Defocusing and Horz. Focusing with $L_{HD} = ½ L_{HF}$. No drift cells between dipole elements.



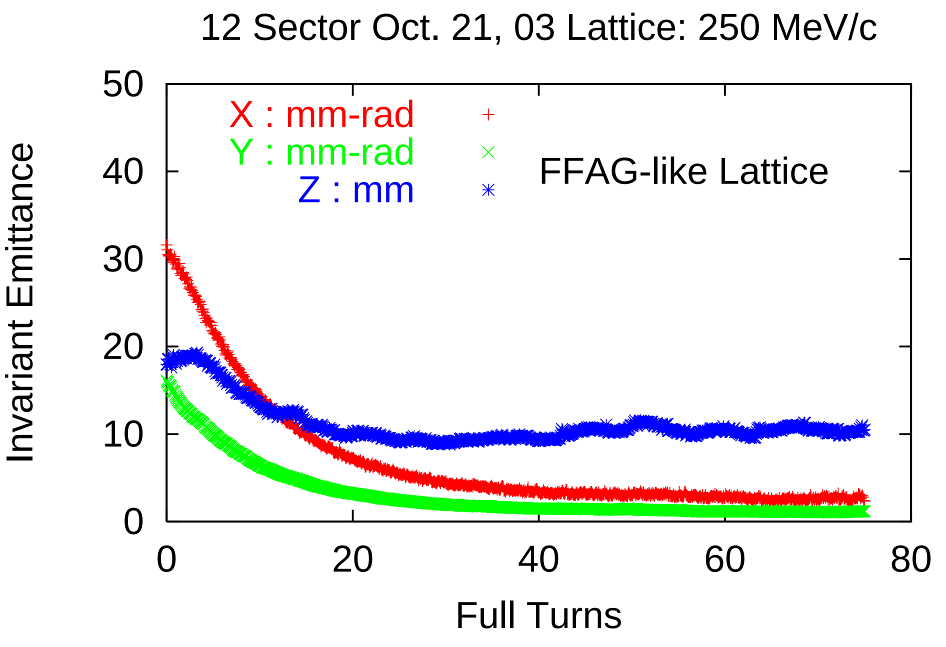
Parameters

12 cells
Bend angles 30° and –15°
Circumference = 6m
B_o = 2.6T and P_o = 250 MeV/c
Dispersion = 25 cm

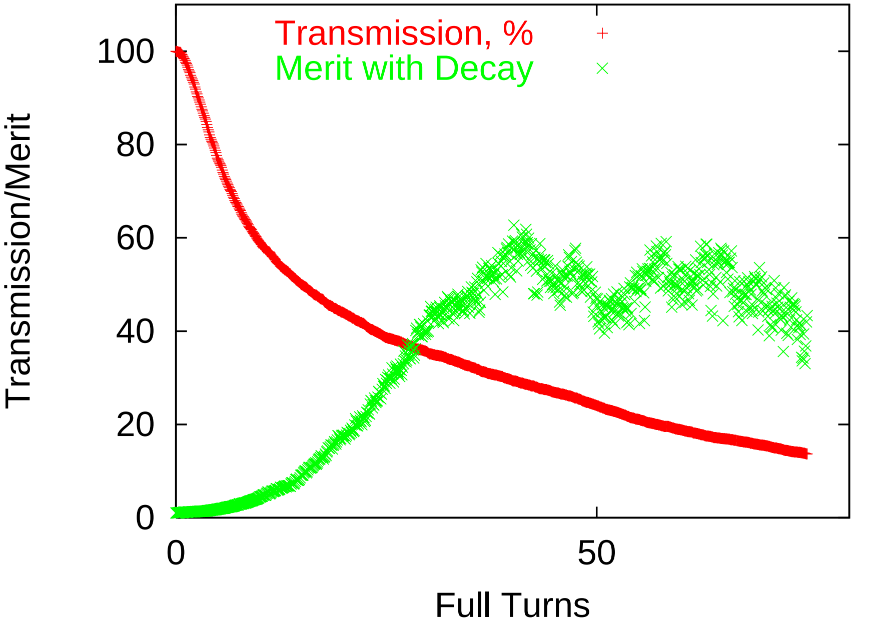


Harold G. Kirk

FFAG Lattice Performance



RF at 25 MV/m over
60% of circumference



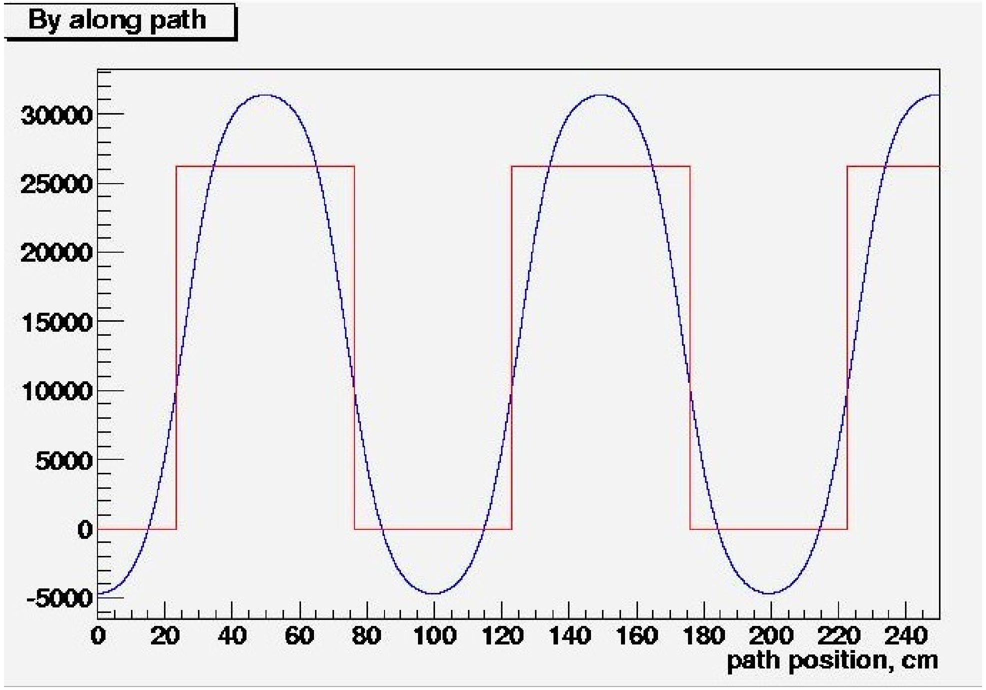
Horizontal Emittance Reduction Factor 10
Vertical Emittance Reduction Factor 11
Longitudinal Emittance Reduction Factor 2

A Demonstration Scenario

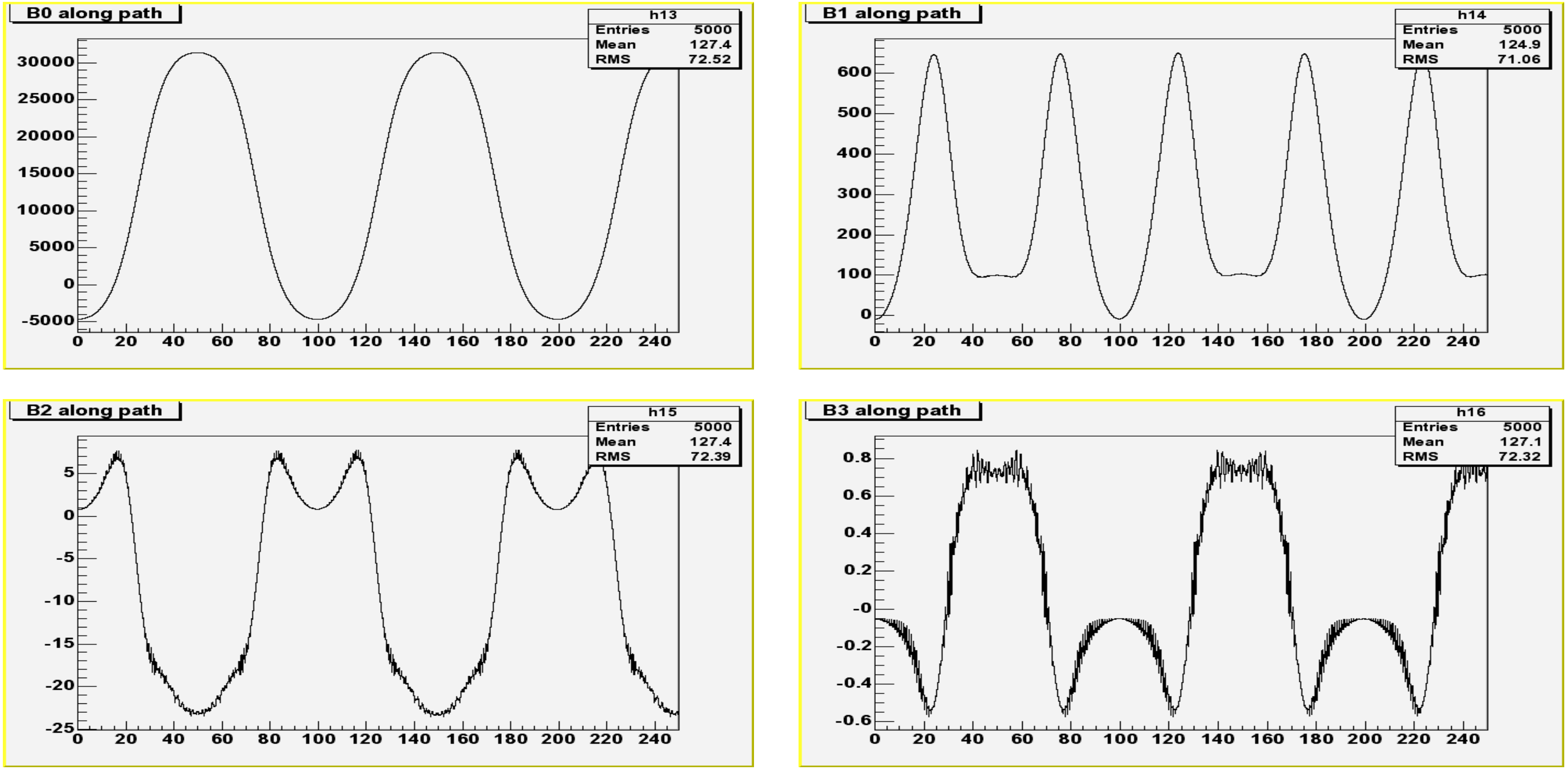
- Merit factor of ~ 10 is sufficient
- Muon decay ignored
- Rf frequency at 800 MHz
- Beam aperature at ±7 cm
- Gas density at 10 atmos at 77^{o} K
- DC dipole field at 1.5T
- Pulsed dipole field ~ 3T

Field Along the Reference Path

- Figure shows B_y along the 250 MeV/c reference path.
  - The blue curve indicates the field from the Tosca field map.
  - The red curve is the hard edge field.
- Note the –0.5 T field in the gap mid-way between the magnets.

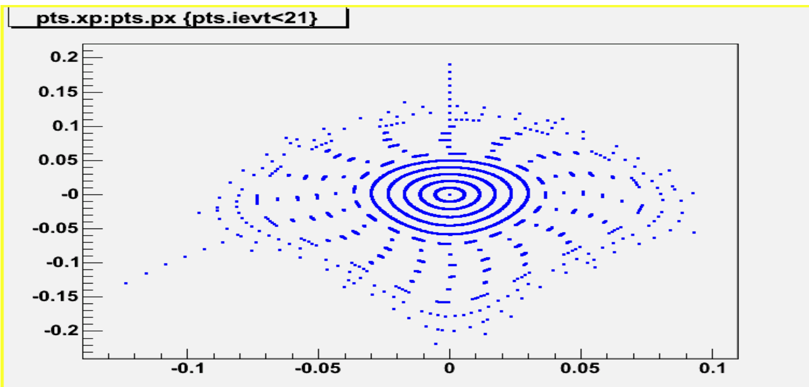


b_n along the path

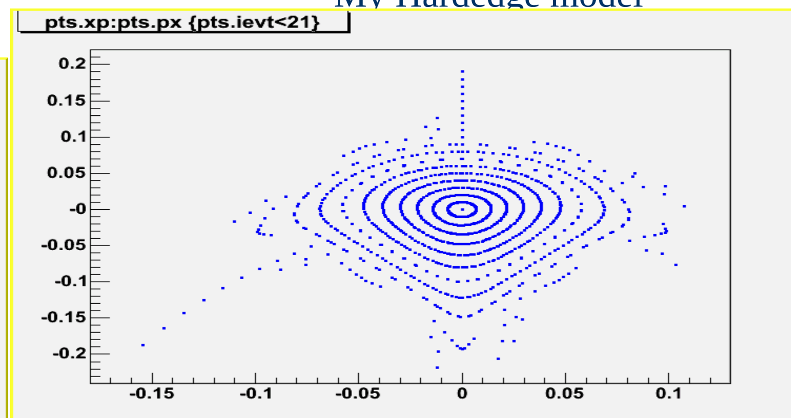


Horizontal Dynamic Aperture (x vs. p_x)

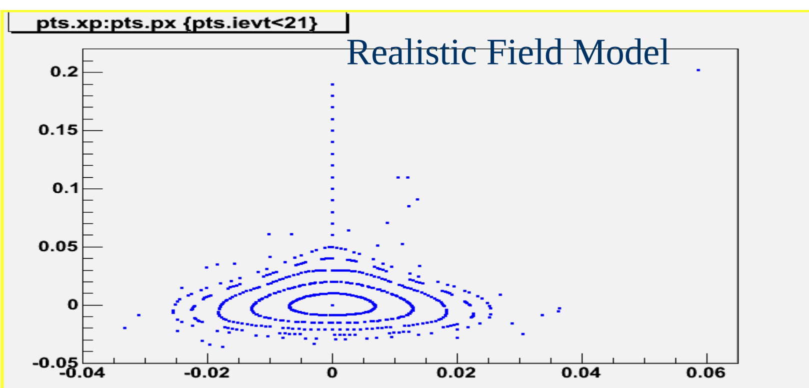
Kirk's Hardedge model



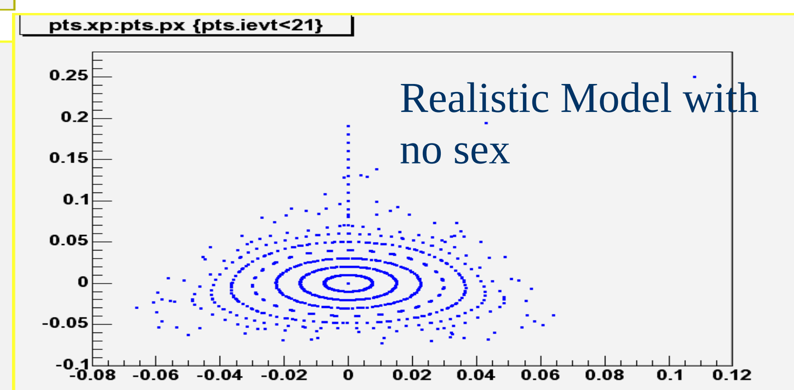
My Hardedge model



Realistic Field Model

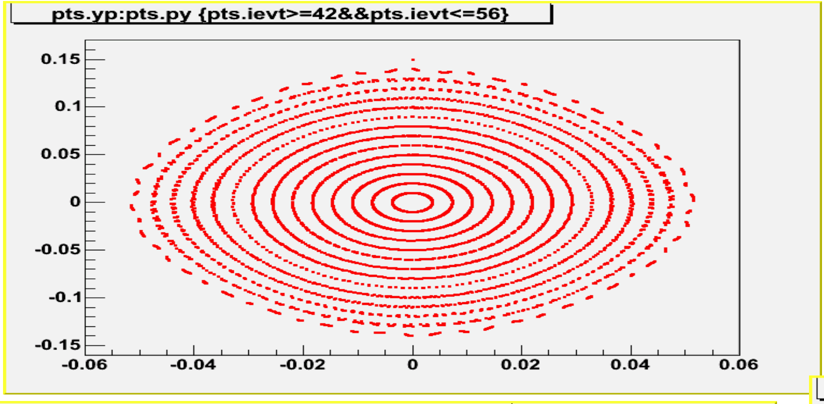


Realistic Model with no sex

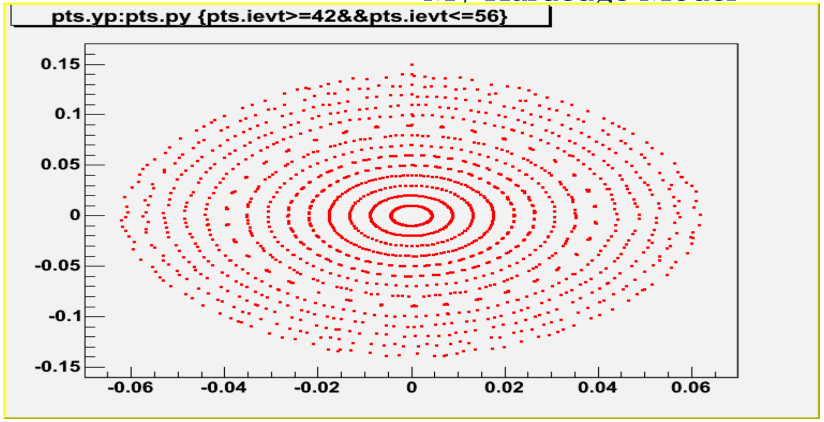


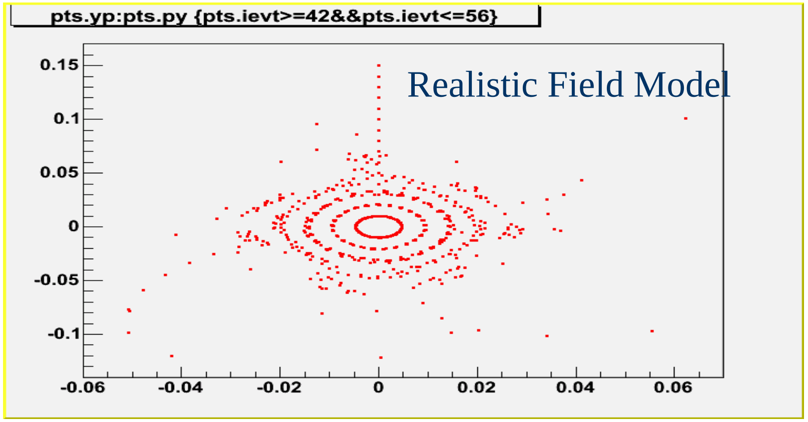
Vertical Dynamic Aperture (y vs. p_y)

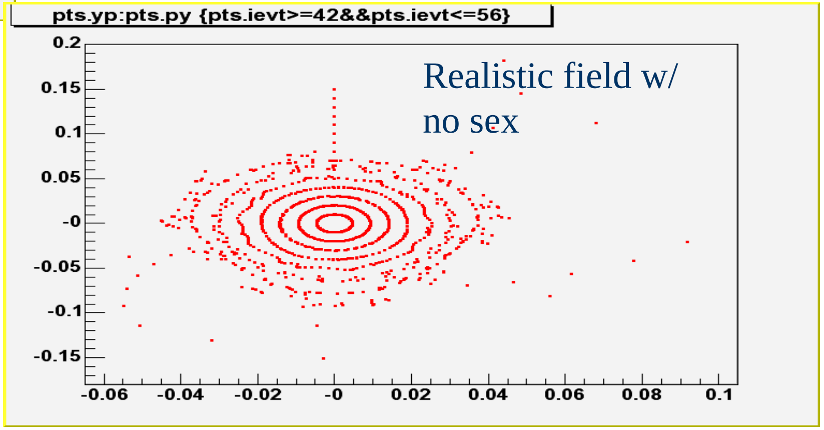
Kirk's Hardedge Model



My Hardedge Model







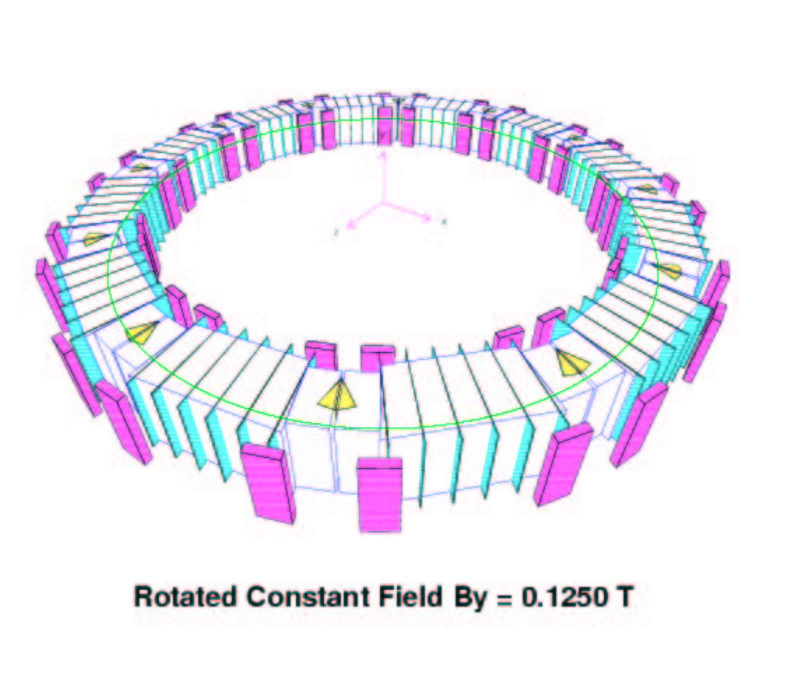
Storage Ring Parameters

- The table below shows the Twiss Parameters as seen in ICOOL for both the *realistic* and *hardedge* models. These were calculated in a manner similar to those shown before
- Both ICOOL models look reasonably comparable to the original SYNCH and TOSCA models.
  - This is extremely encouraging and says that the realistic fields do not significantly alter the lattice!

Parameter	A. Garren Synch	Tosca	Icool Realistic	Icool Hardedge	Icool with No Sex
μ_x	99.8784°	98.38°	105.496°	103.626°	106.313
β_x	37.854 cm	32.3099 cm	34.293 cm	38.8635 cm	33.6023 cm
α_x	0	-0.00124	-0.000461	-0.000576	-0.00593
μ_y	92.628°	100.62°	100.619°	94.9662°	100.865
β_y	56.891 cm	53.9188 cm	54.086 cm	56.9616 cm	53.844 cm
α_y	0	0.0009894	0.000652	-0.000001	0.00597

GEANT Simulation

Geometry and Material



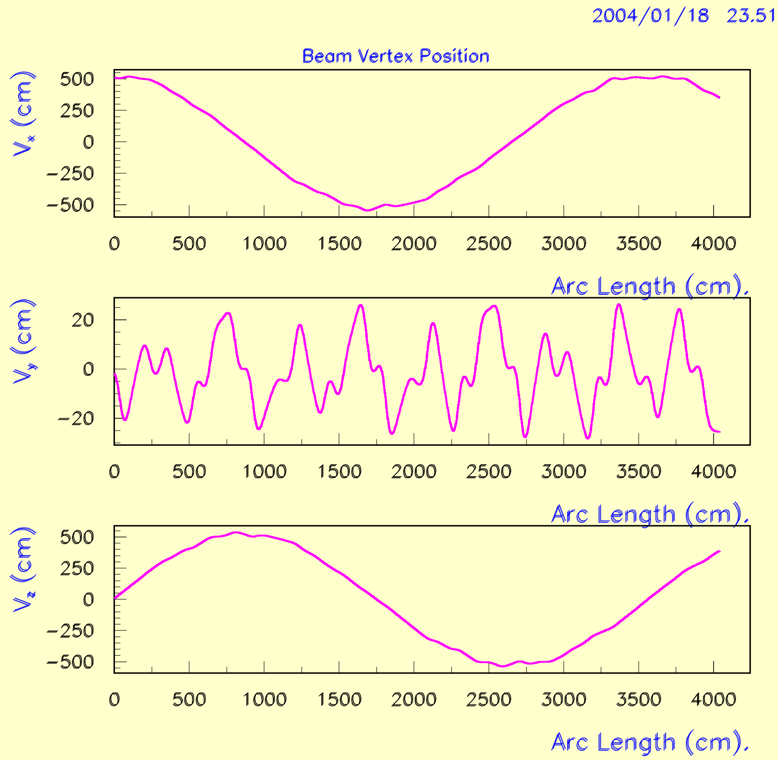
- RFOFO geometry and material in GEANT are identical as in ICOOL
  - Overall dipole B is 0.125 Tesla
  - Alternating Solenoids B is $\pm$ 3.0 Tesla
- **RFOFO's circumference is $\sim$ 33 m**

GRID Magnetic Fields

- We determine the particle closed orbit using constant magnetic fields (shown)
- We generate 1cm x 1cm x 1cm GRID fields map with tilt angle of 53 mrad (S. Bracker, MUCOOL-271)
- Satisfy fundamental Maxwell's equations $\Longrightarrow \nabla \cdot B = 0$ and $\nabla \times B = 0$
- **We use FINT interpolation routine with result of 10^{-4} Tesla differences compared to the real fields**
- $\Longrightarrow$ It is a very good resolution!
- We apply the GRID fields into GEANT with satisfying the geometry boundary condition

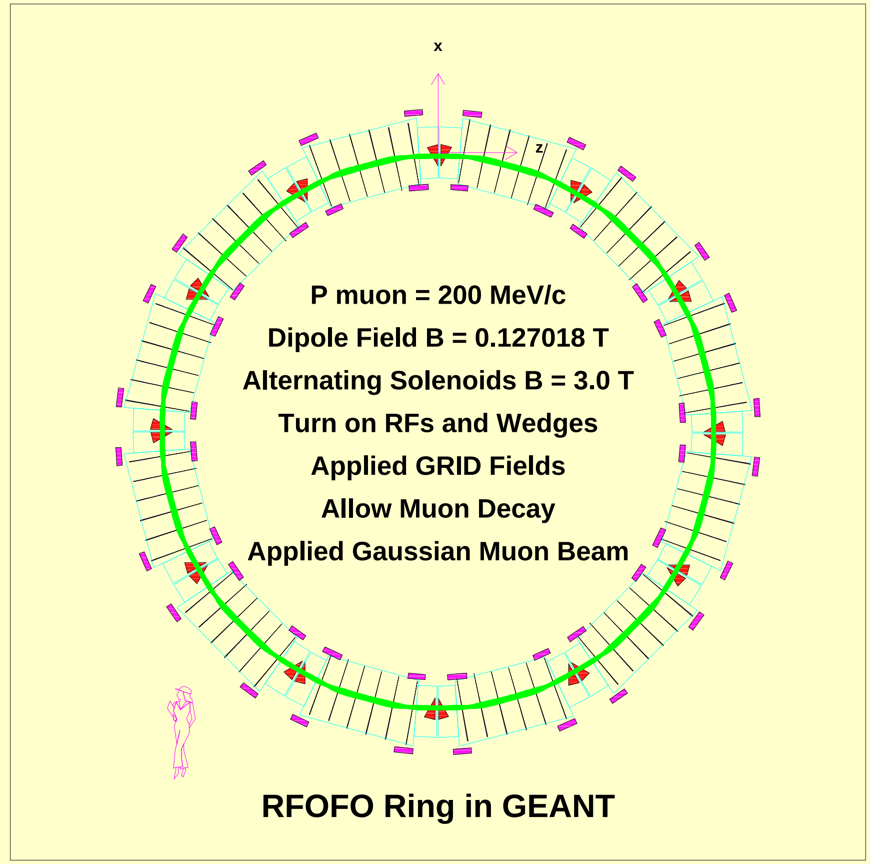
Vertex μ-Beam

μ-Beam Vertex Position



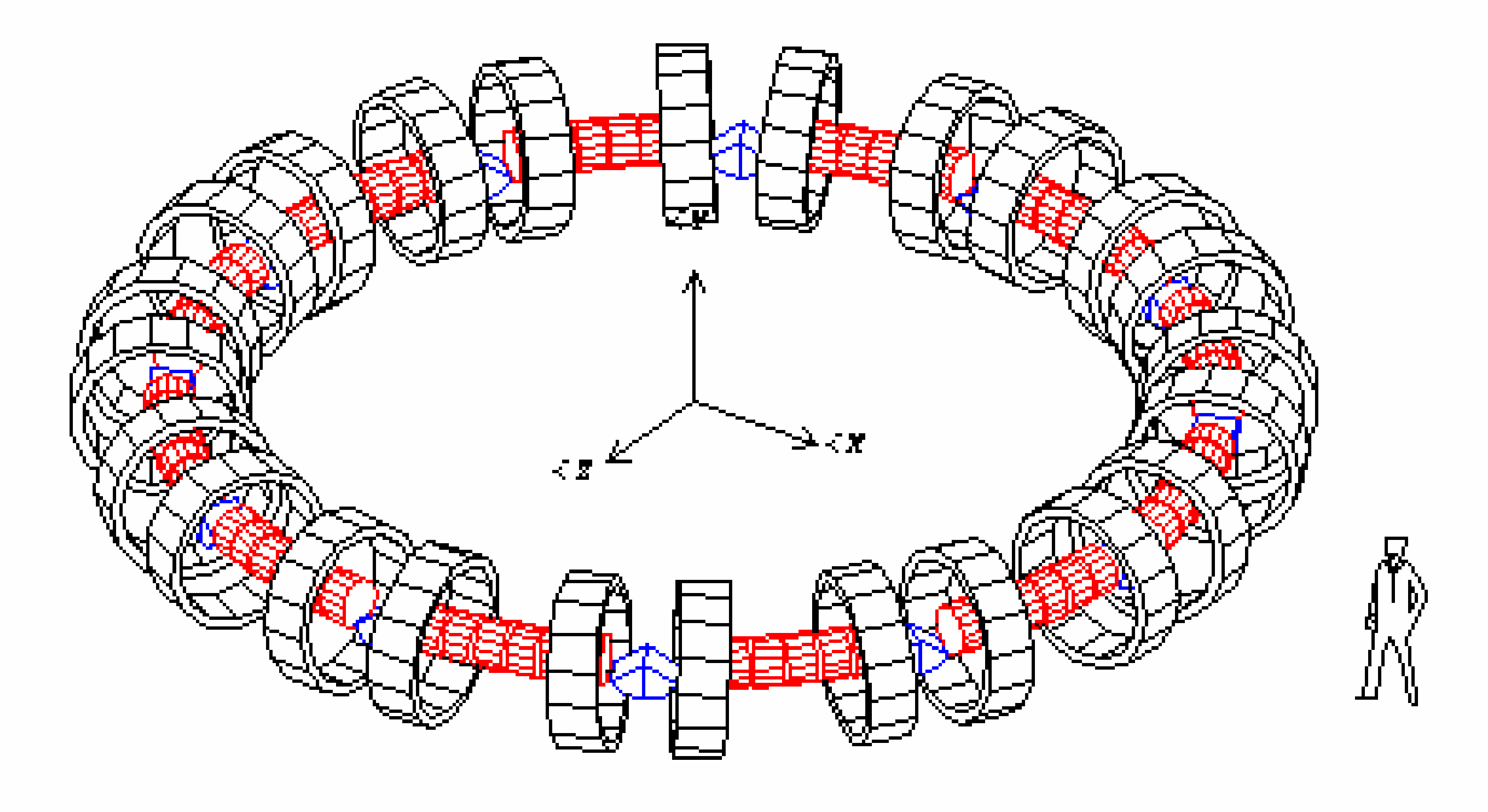
- μ-beam vertexes in x,y and z direction

μ-Beam in RFOFO Ring



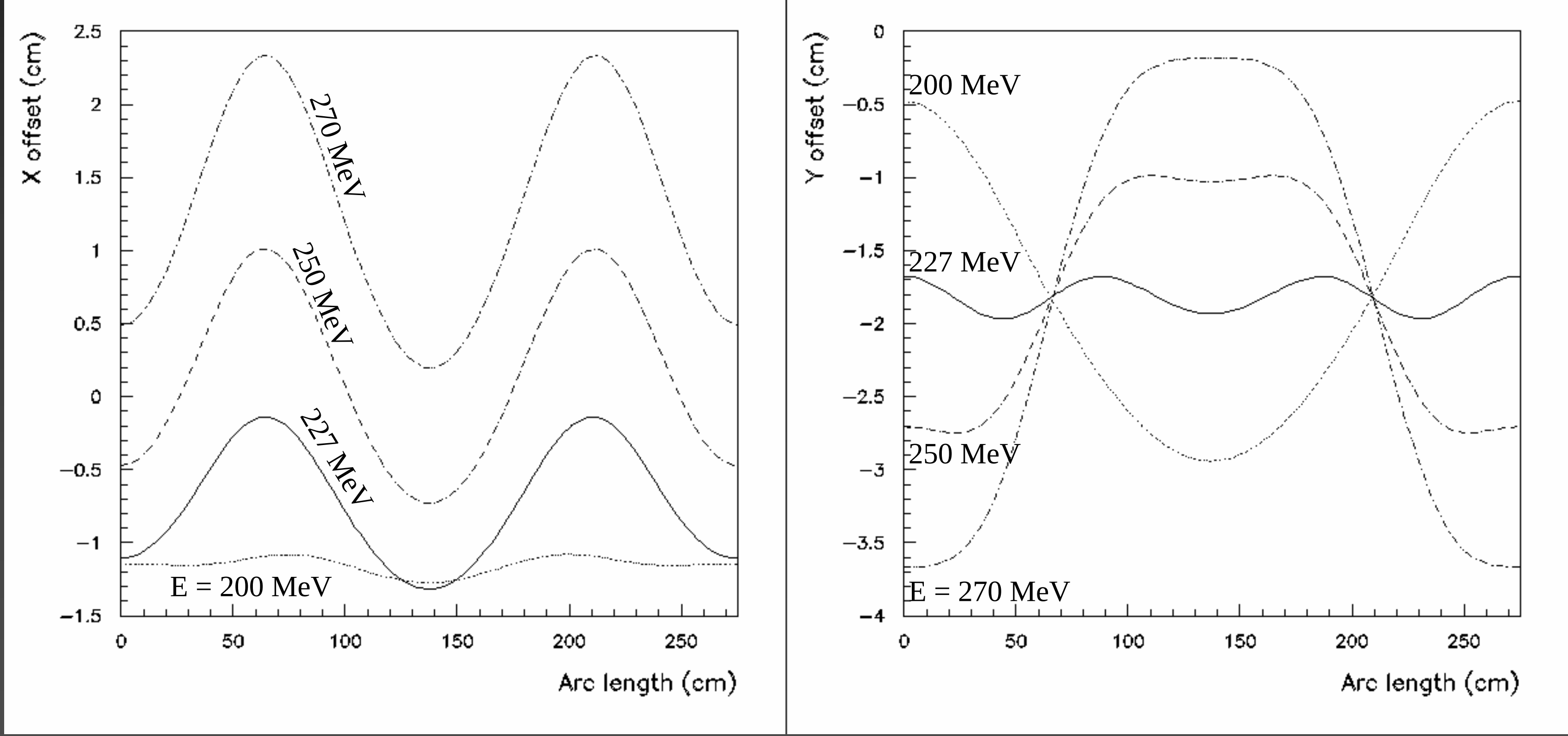
- μ-beam is circulating in the RFOFO Ring with the RF, wedges and B fields on!

3-D view of the RFOFO ring

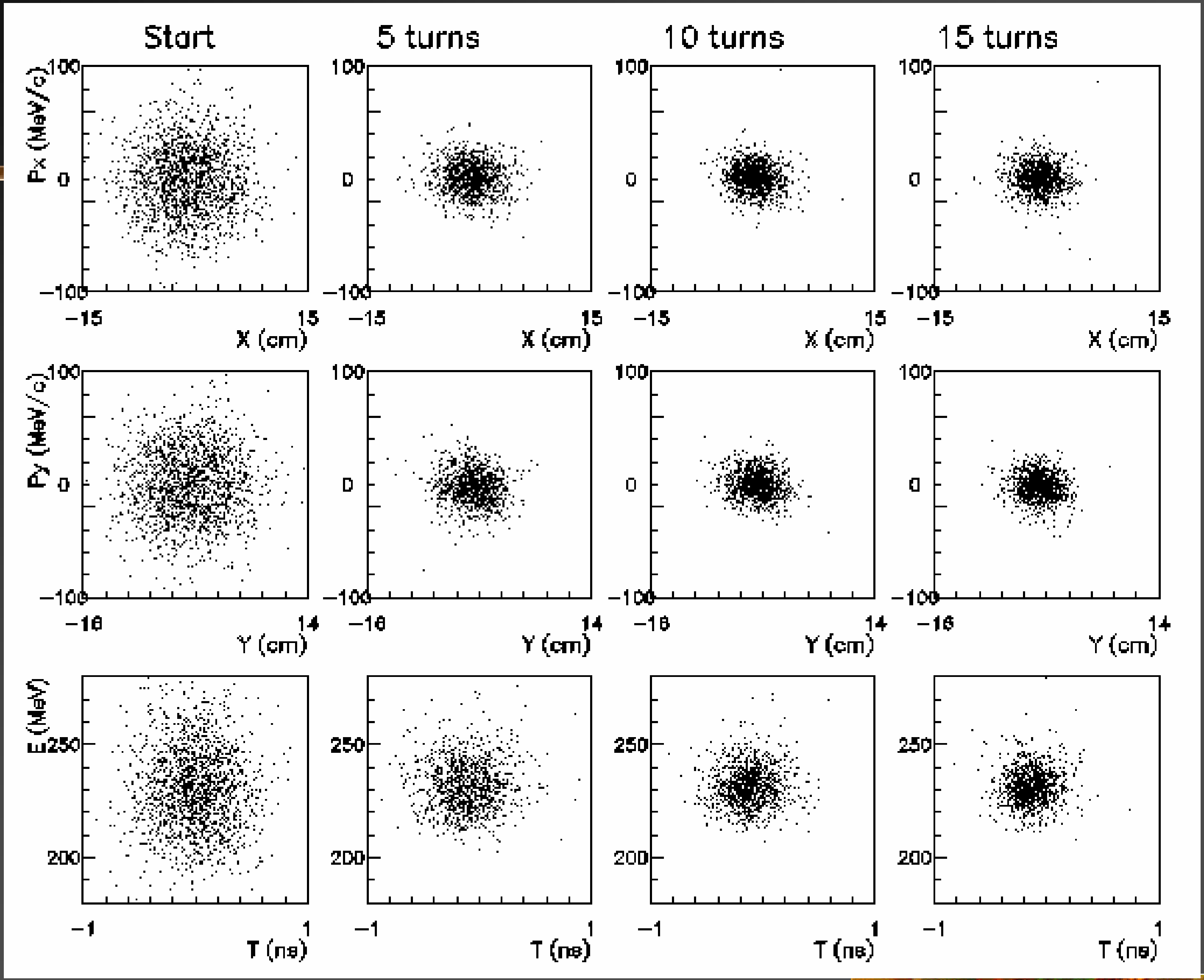


Closed orbits in a single cell

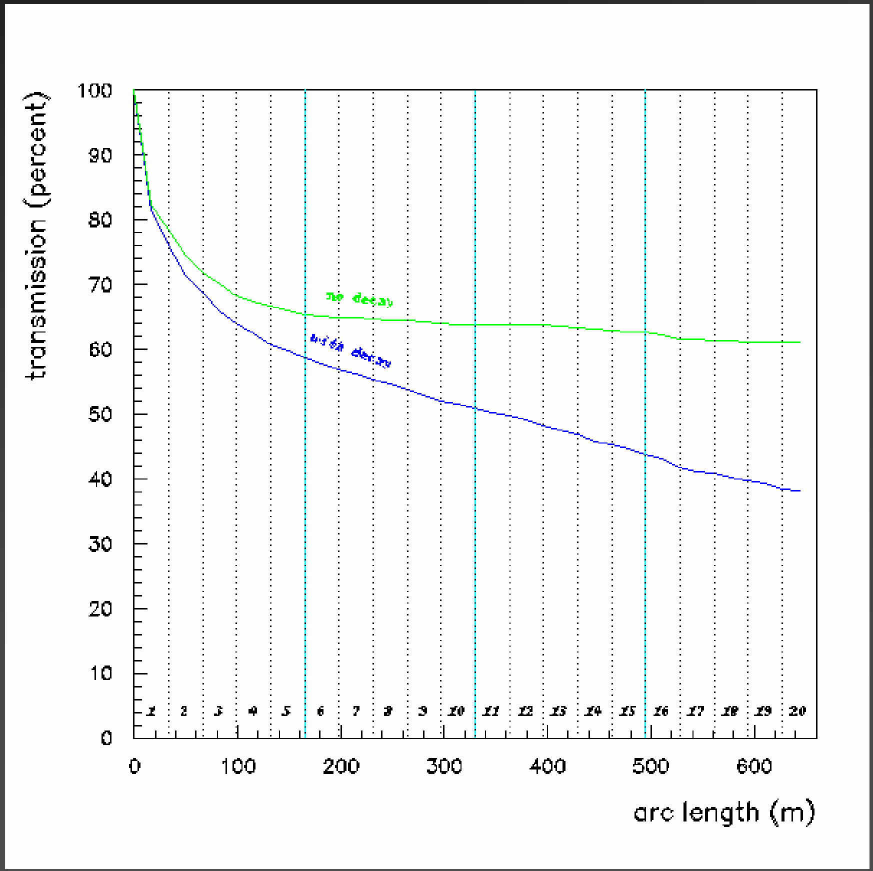
Solid line – the reference orbit

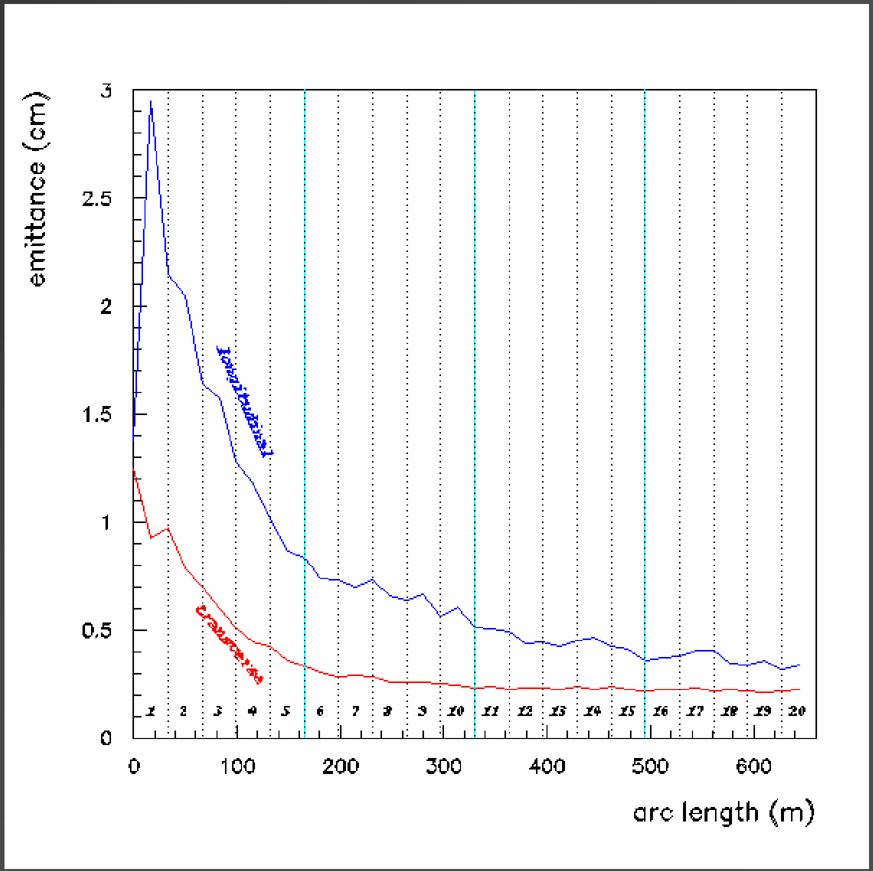


The beam in 15 turns (no muon decay)

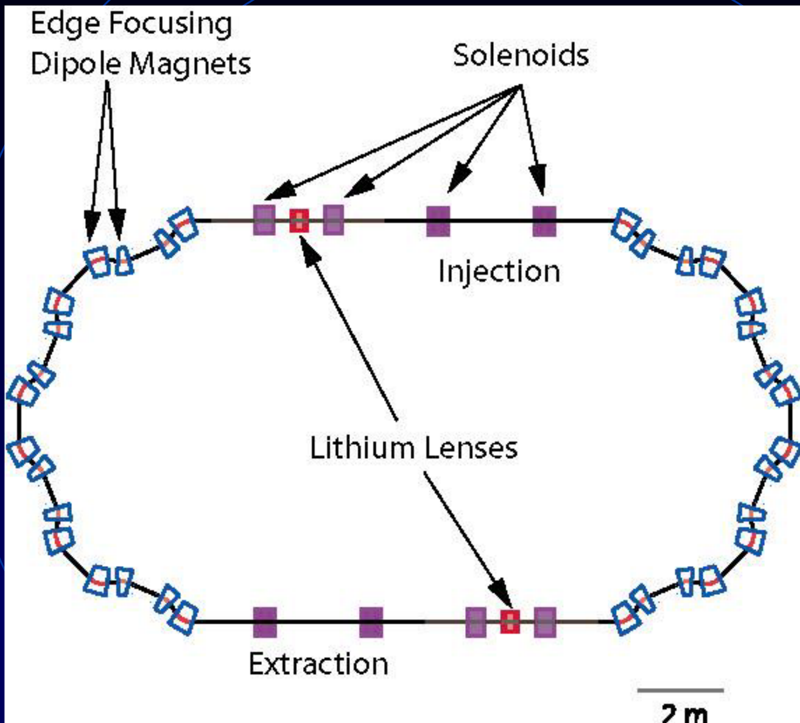


Cooling performance: transmission, 2-D emittances

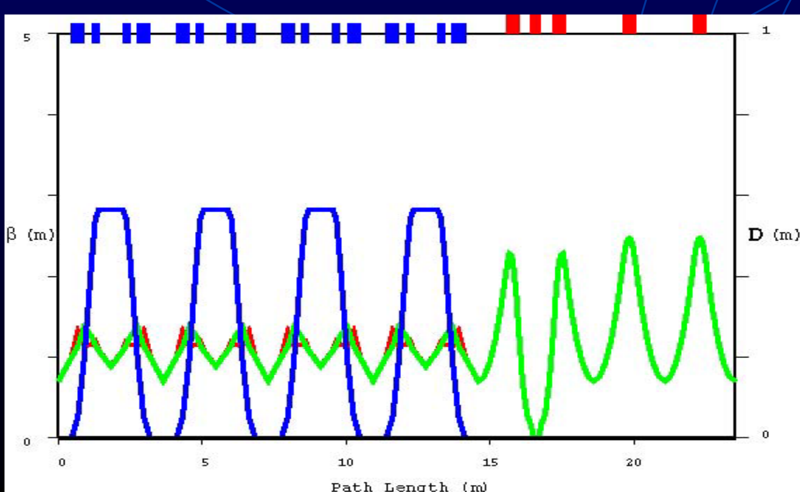




Lithium Lens Ring Cooler

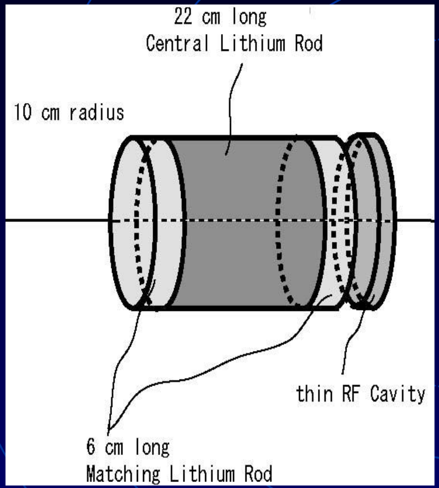


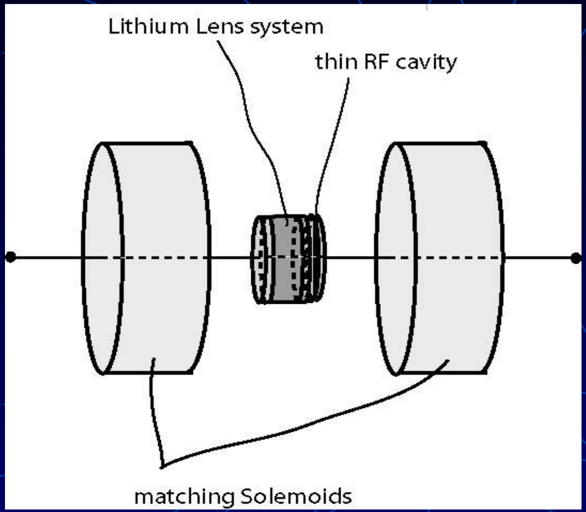
Al Garren

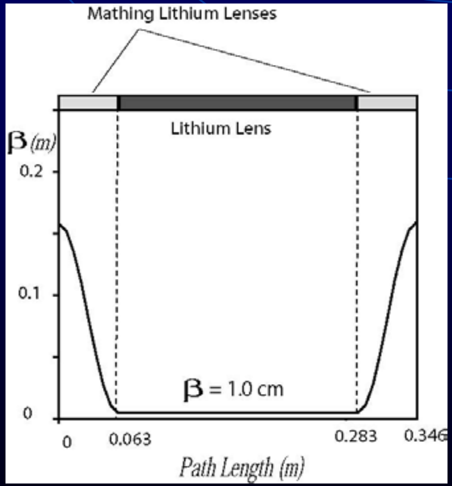


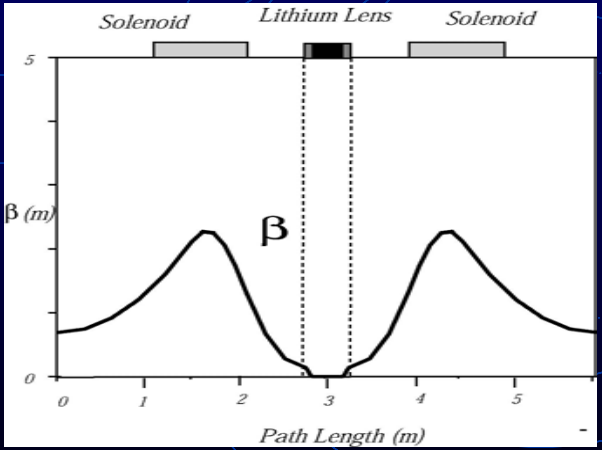
muon momentum	250 MeV/c
Circumference	42.1 m
straight section length	5.9 m (x 2)
Structure of half cell	2 dipoles with edges
number of bending cells	8
bend cell length	3.6 m
length of Lithium lens	34.5 cm (x 2)
Lowest/highest β in Li	1.0 cm /16 cm
dE/dx	35 MeV/turn (x 2)
dipole bend angles	44.2, -21.7 degree
dipole edge angles	30/-3, -11/-11 degree
dipole magnetic field	6.5, -3.2 tesla
Cell tunes bend cell	0.72/0.70
Cell tunes straight cell	4.0

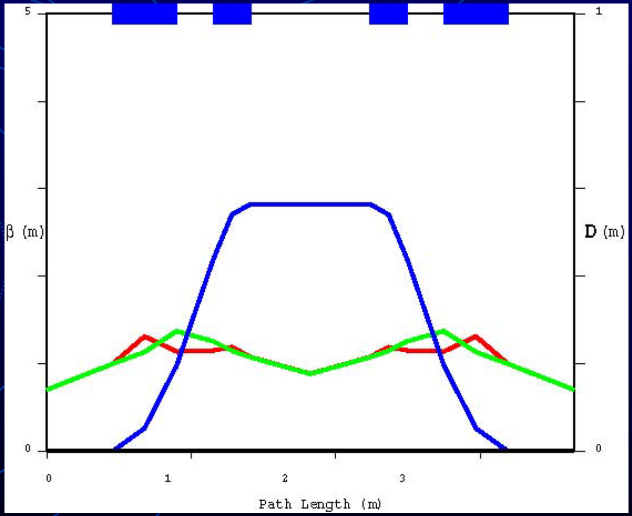
Lithium Lens Ring Cooler











Li lens Ring Cooler with matrix solenoid, matrix pole face rotation