FFAG and Weak Focusing Muon Gas-Filled 6-D Cooling Rings

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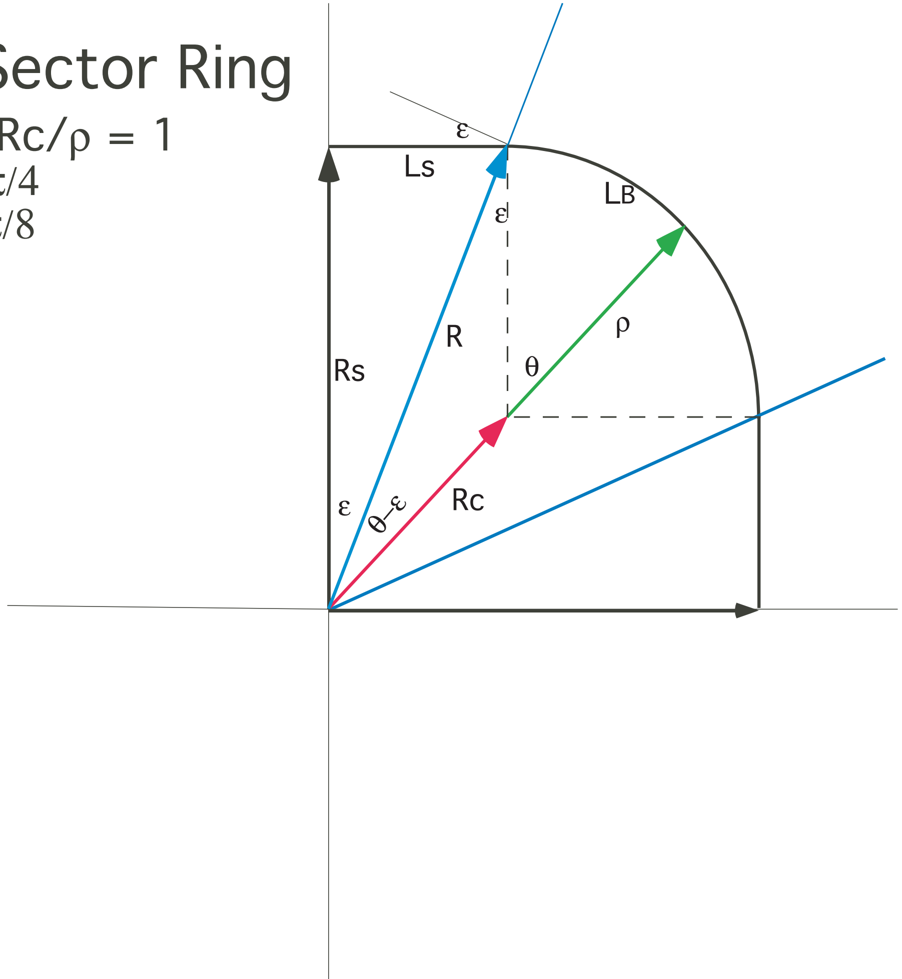
The Weak-focusing Rings

4–Sector Ring

$\lambda = Rc/\rho = 1$

$\theta = \pi/4$

$\varepsilon = \pi/8$



Lattices examined:

4 sector ring, $\lambda = 1$

4 sector ring, $\lambda = 3/4$

6 sector ring, $\lambda = 1$

CELL OF 4–CELL RING

$\lambda = \rho / Rc$

$\sigma = (1+\lambda^2+2\lambda\cos\theta)^{1/2}$

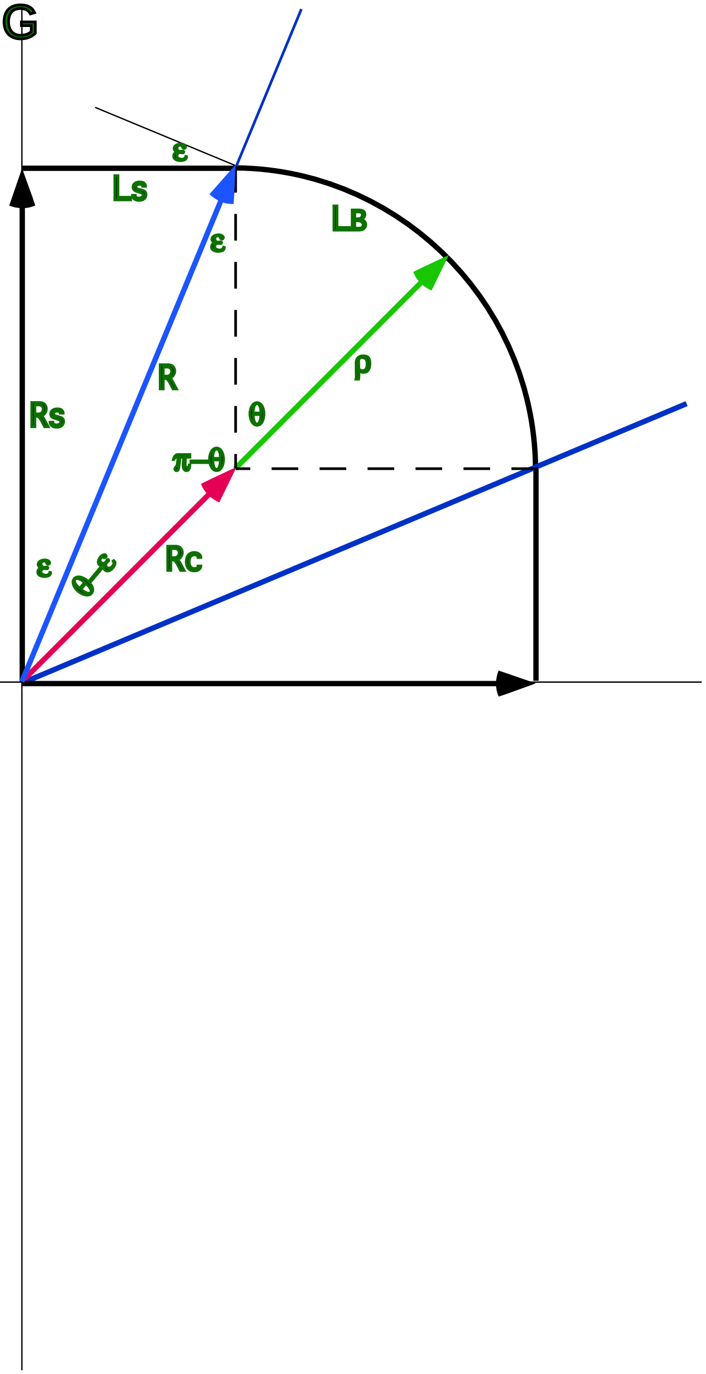
$R = Rc\ \ \sigma$

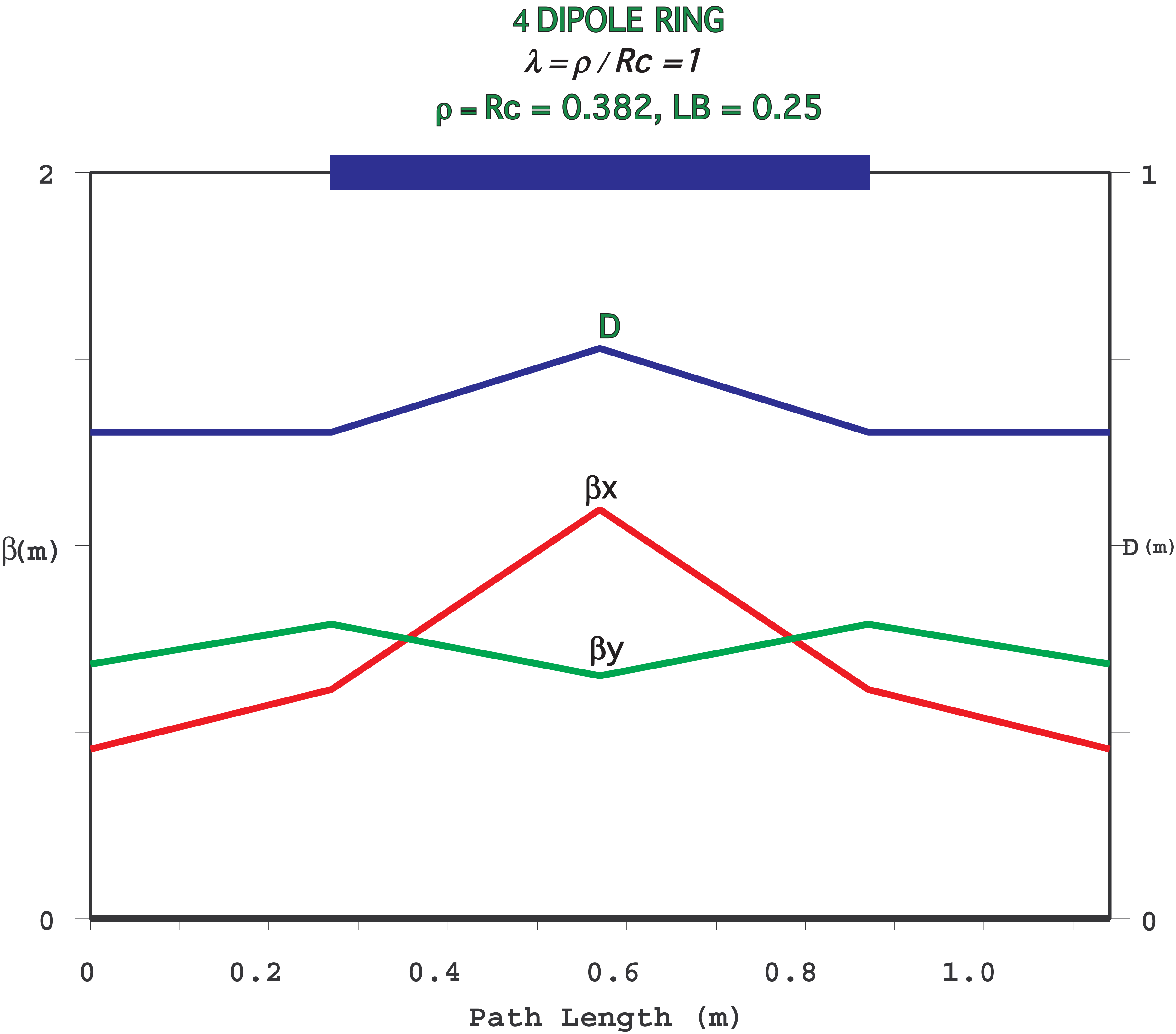
$\varepsilon\ =\ \sin^{-1}(\sin\theta / \sigma)$

$Rs = R \cos \varepsilon$

$Ls = R \sin \varepsilon$

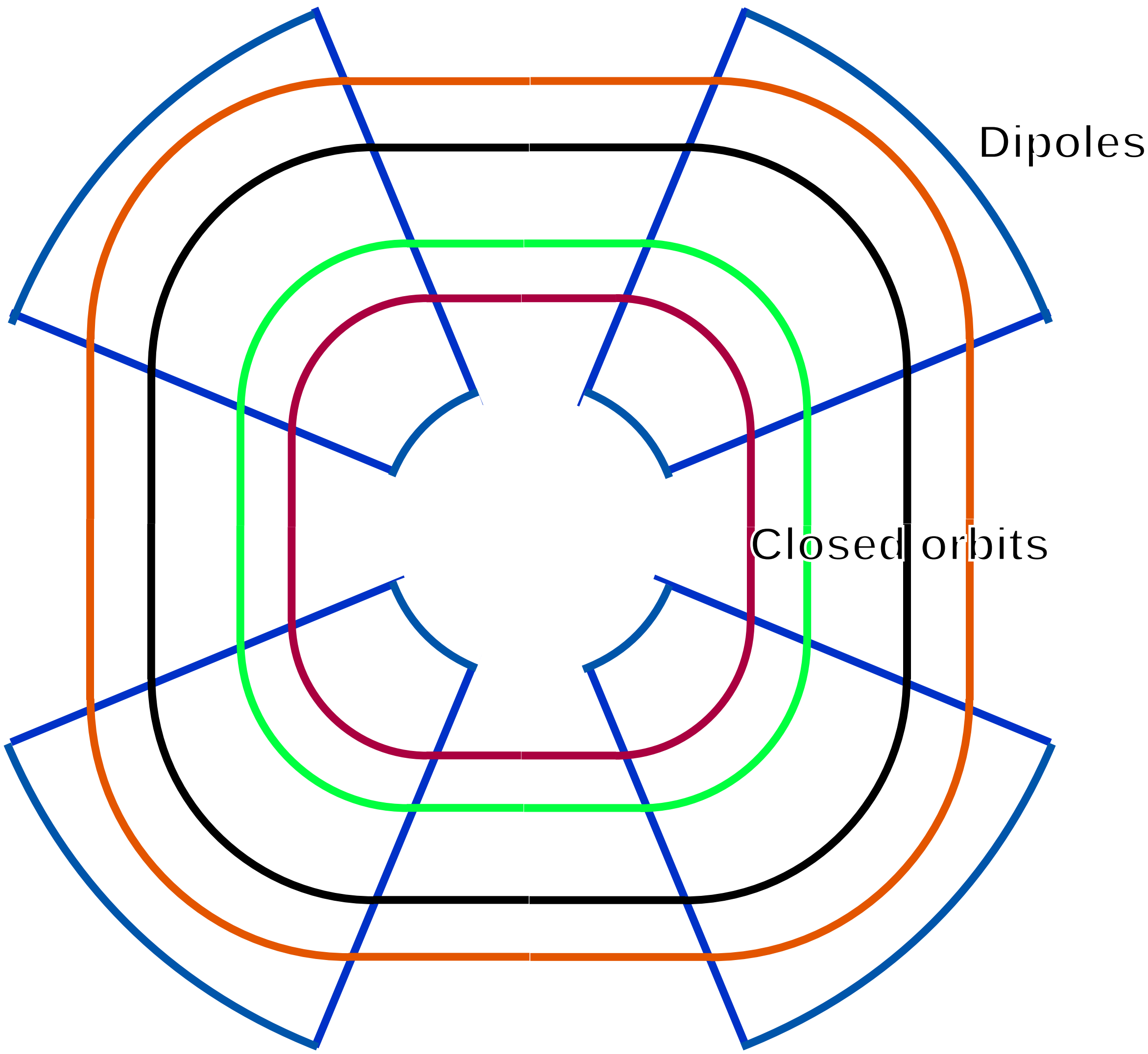
$LB = \rho\ \theta$



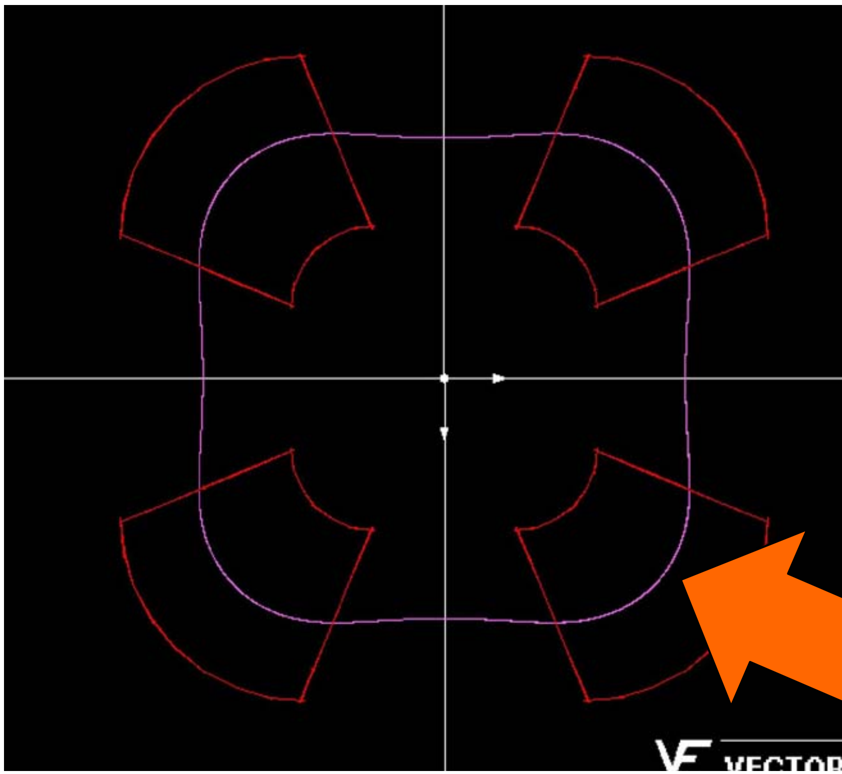


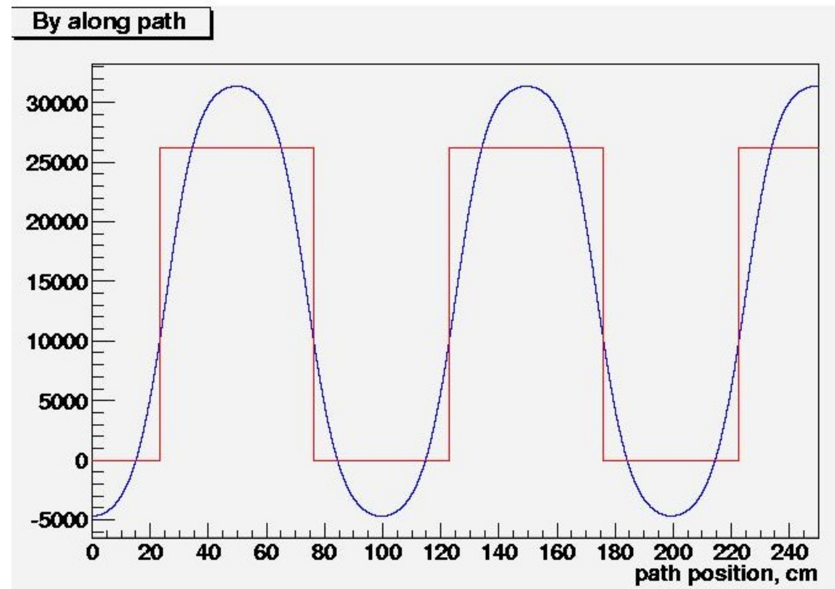
4 DIPOLE RING
λ = ρ / Rc = 1
ρ = Rc = 0.382, LB = 0.25
D
βx
βy
β(m)
D (m)
2
0
1
0
0
0.2
0.4
0.6
0.8
1.0
Path Length (m)

4-DIPOLE WEAK-FOCUSING RING
$\lambda = \rho / Rc = 1$

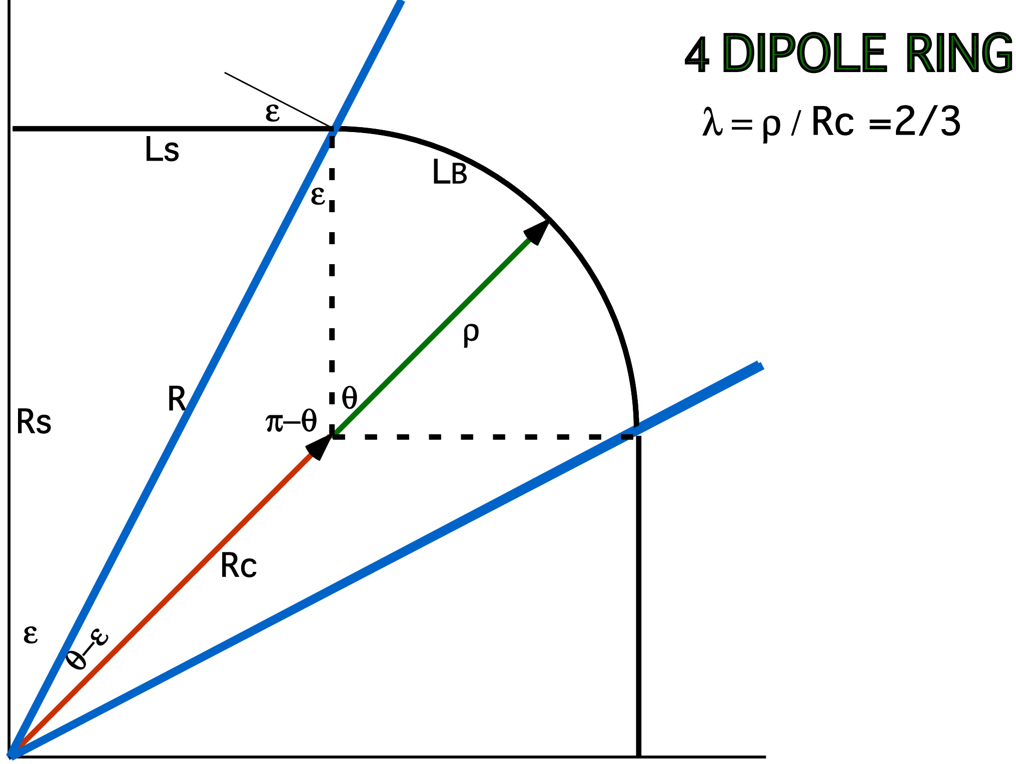


Tosca Results – Steve Kahn

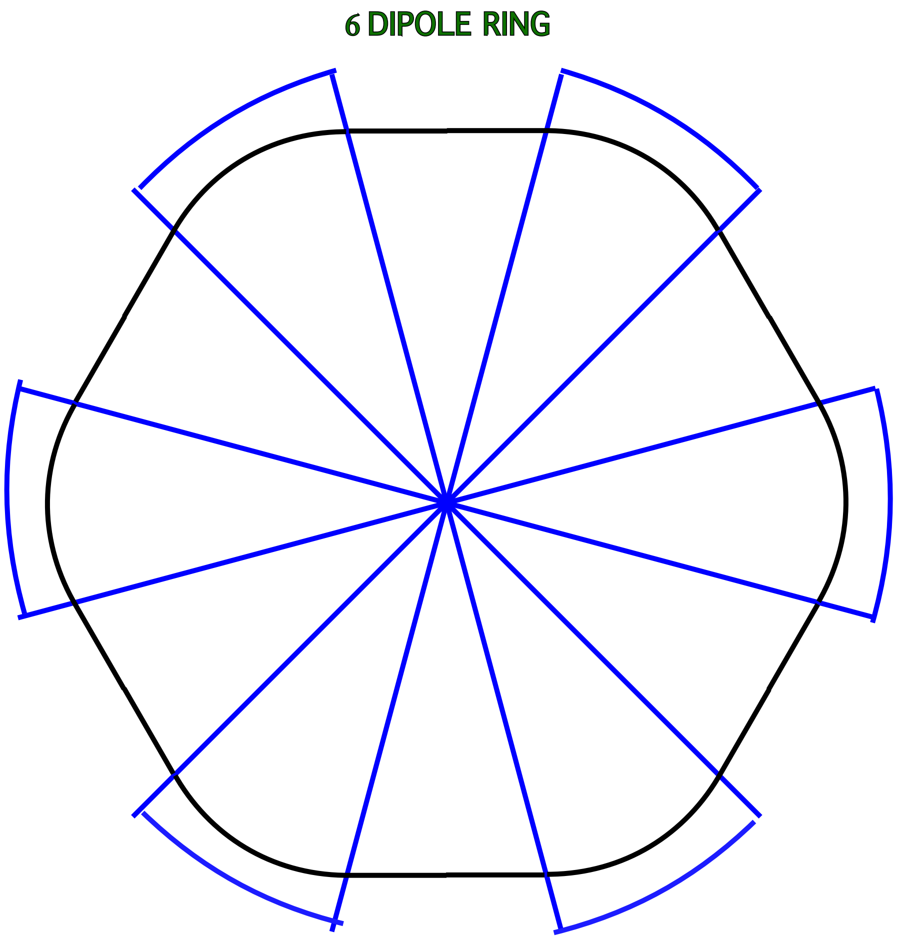


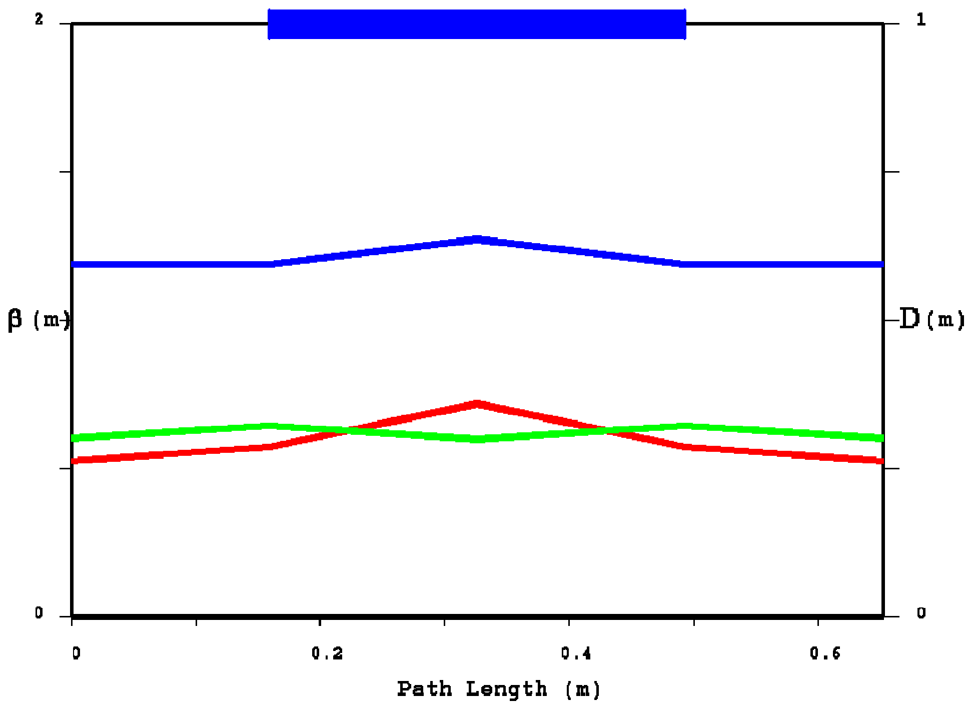


Closed orbit for
250 MeV/c muons
at r = 55.03cm


4 DIPOLE RING
λ = ρ / Rc =2/3
ε
Ls
LB
ε
ρ
R
θ
Rs
π−θ
Rc
ε
θ−ε

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

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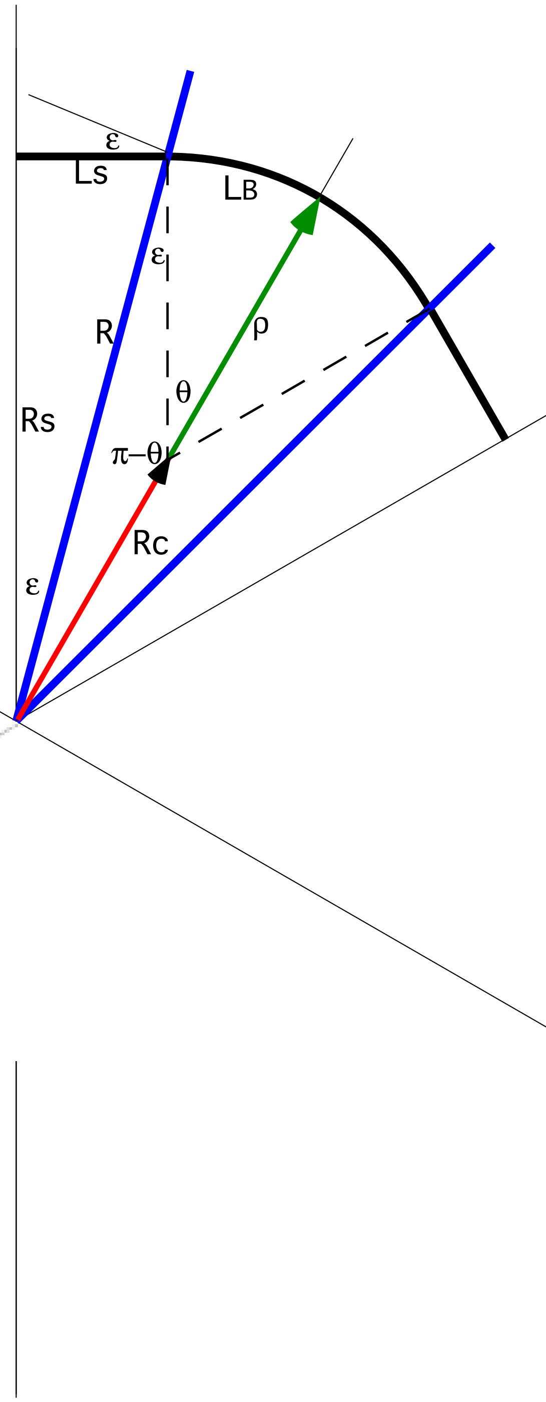
6 DIPOLE RING

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

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

Global Parameters Used

Gas Density 100 atmospheres except where noted

Vertical Aperture +/- 15 cm

Horizontal Aperture +/- 25 cm

Gas filled RF cavities

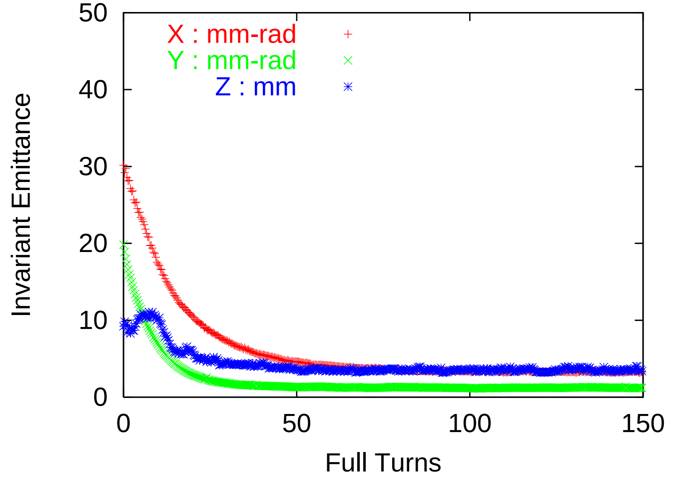
RF frequency 201.25 MHz

Hard edge magnetic fields

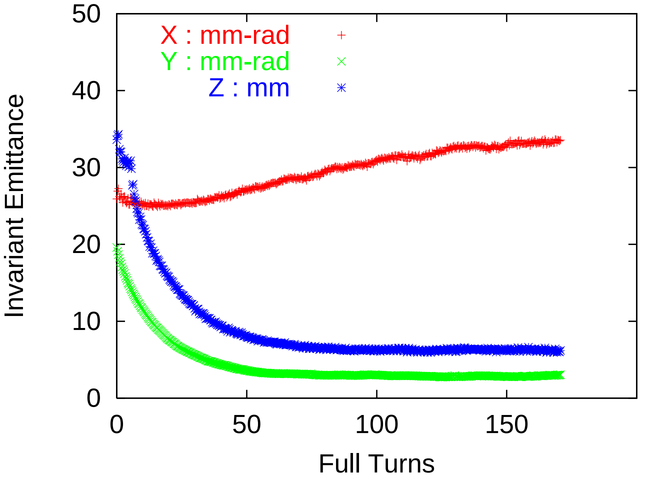
Except where noted ICOOL V2.66

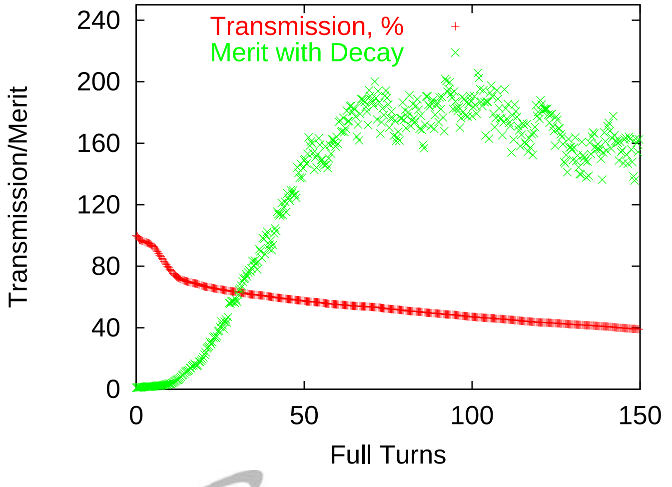
Recalculation with ICOOL V2.66

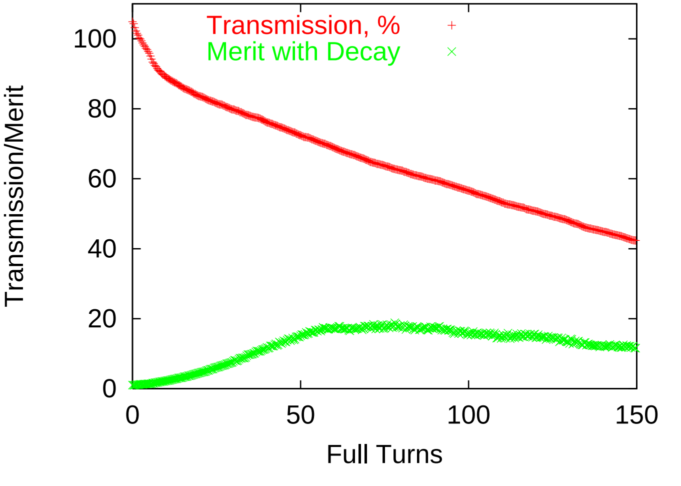
ICOOL V2.59



ICOOL V.266







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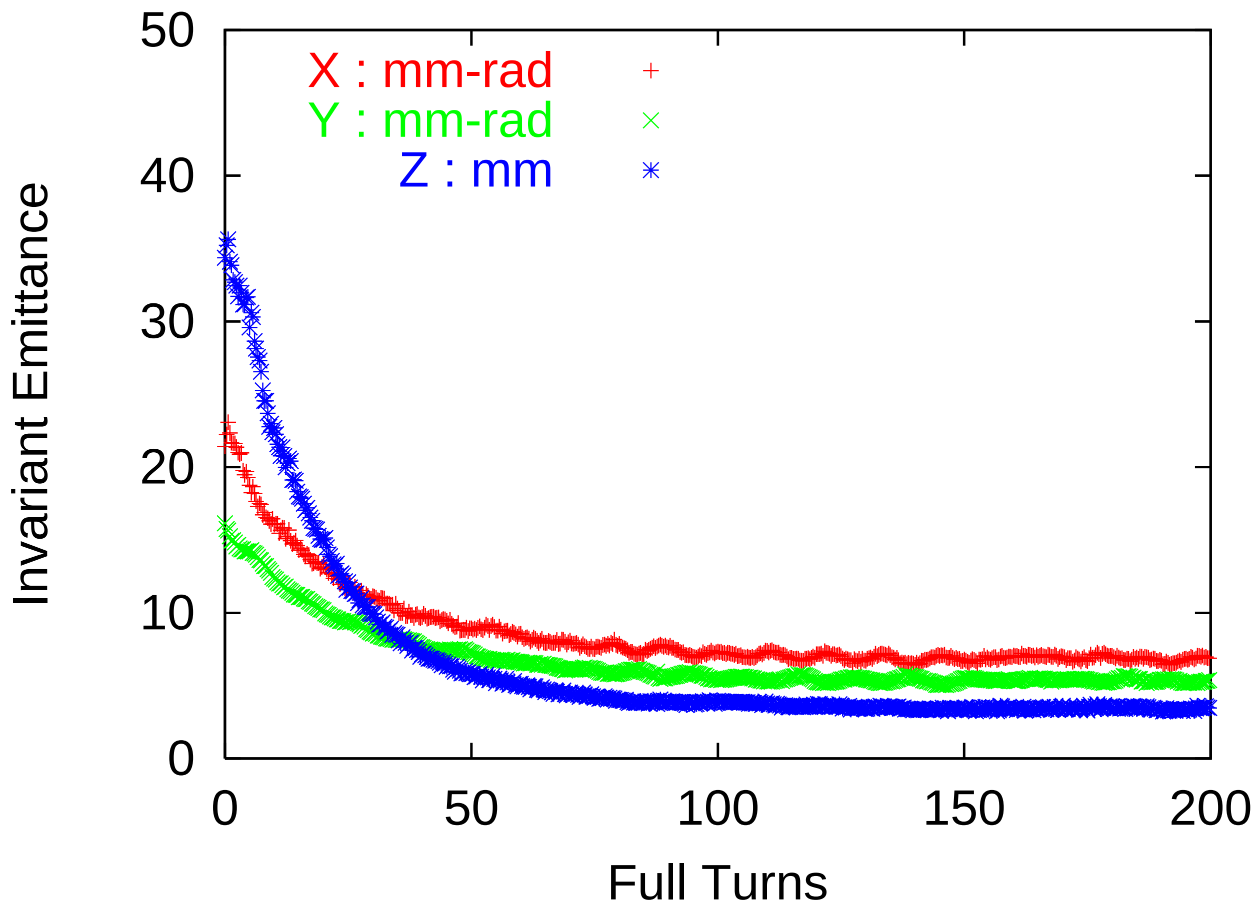
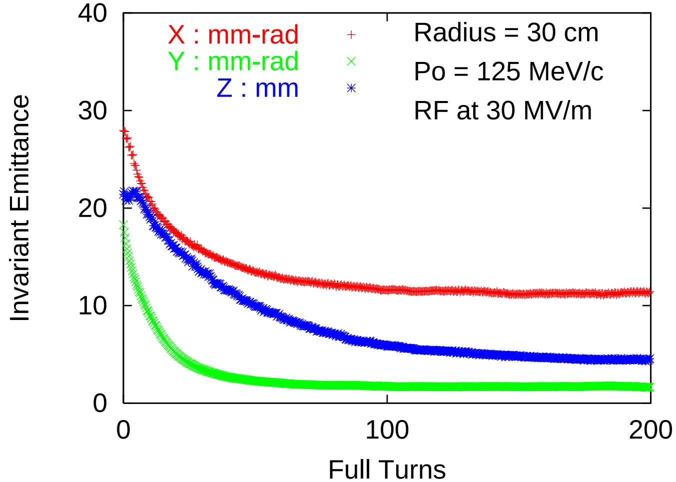
Introduce Skew Quadrupoles

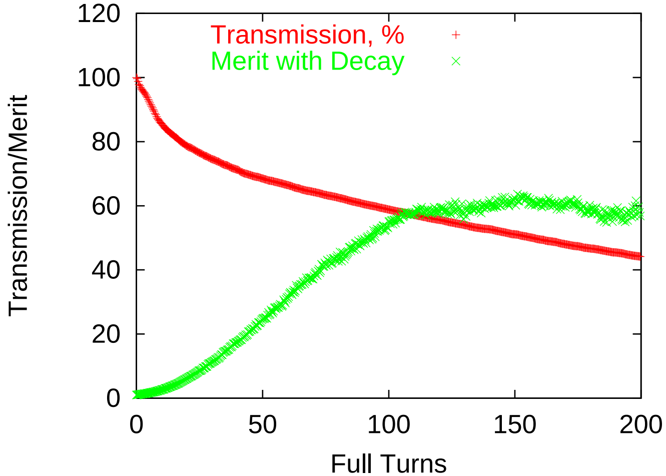
- Bracket dipoles with thin (3cm) skew quadroles
- Skew quadrupoles real estate at 9% circumference
- Test various gradients.
- X/Y Coupling achieved



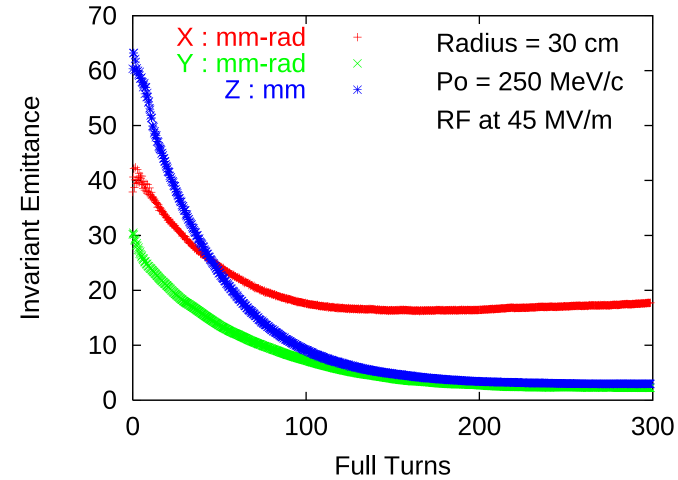
Reduced Radius Performance

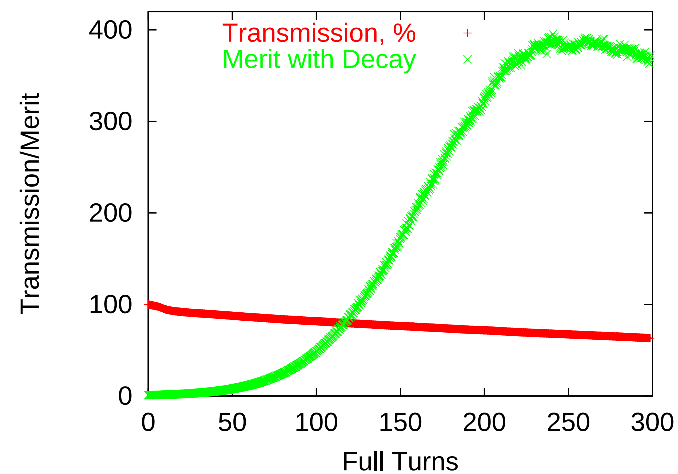
B = 2.6T Po = 125 MeV/c





B = 5.2T   Po = 250 MeV/c





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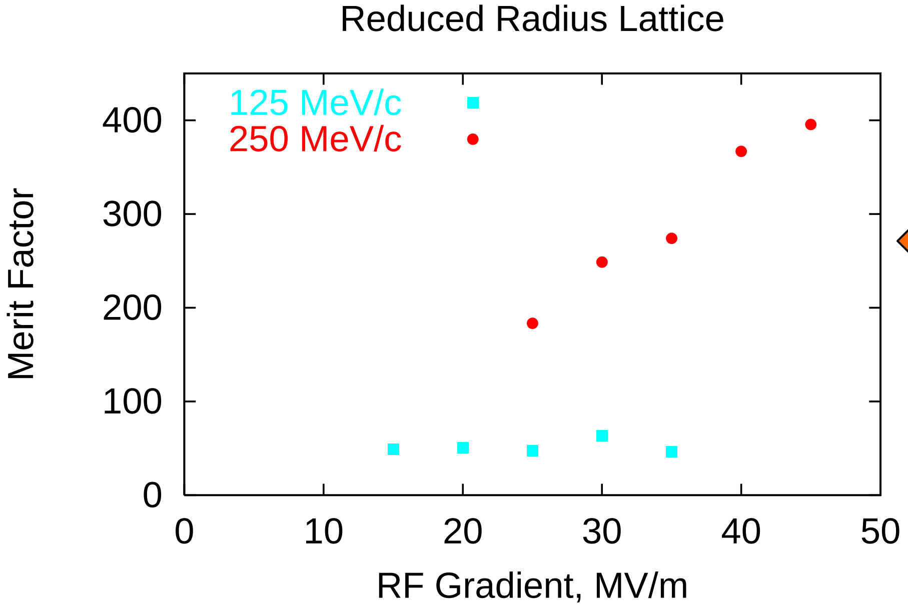
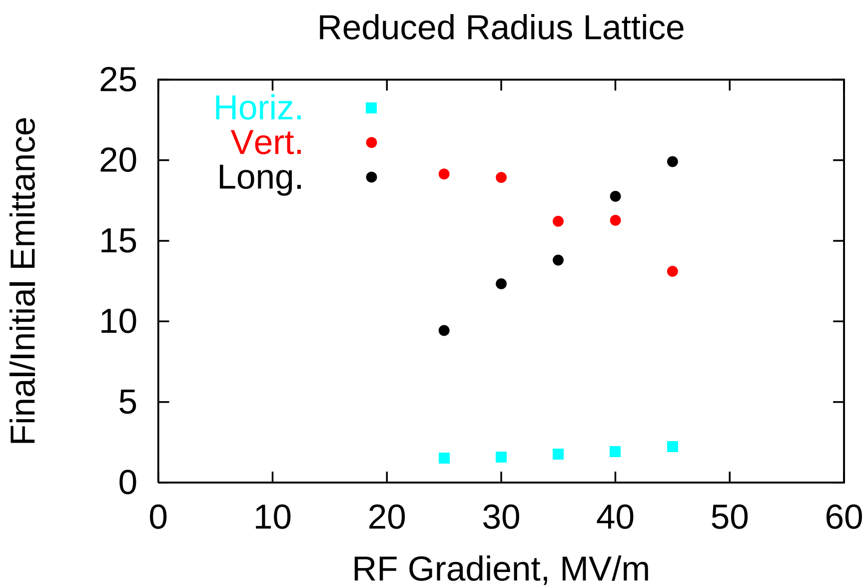
Impact of RF on Performance



Gain in total merit factor results from increasing the rf gradient. Gain is only seen for the high-field, Po=250 MeV/c case.

10 deg. Wedges

High-field case. Gain comes from longitudinal cooling.



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Strong Focusing Scaling Rings

Following are two examples, both with 12 FFAG cells, one with and one without drifts.

Advantages

Allows lower magnetic fields and rf gradients

Large size > Accepts larger transverse beam size and longer bunch train

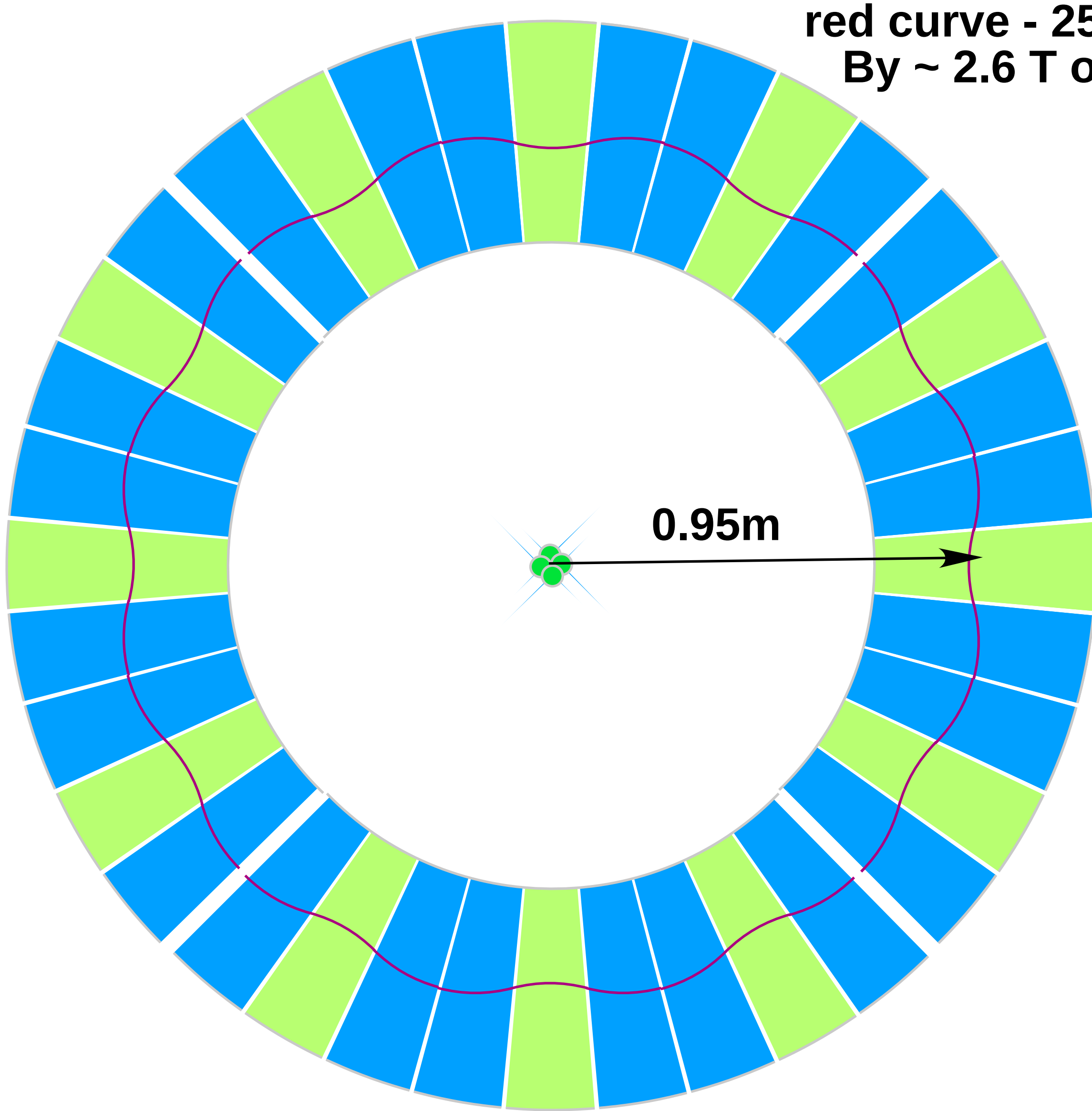
Disadvantage

More complicated, higher cost

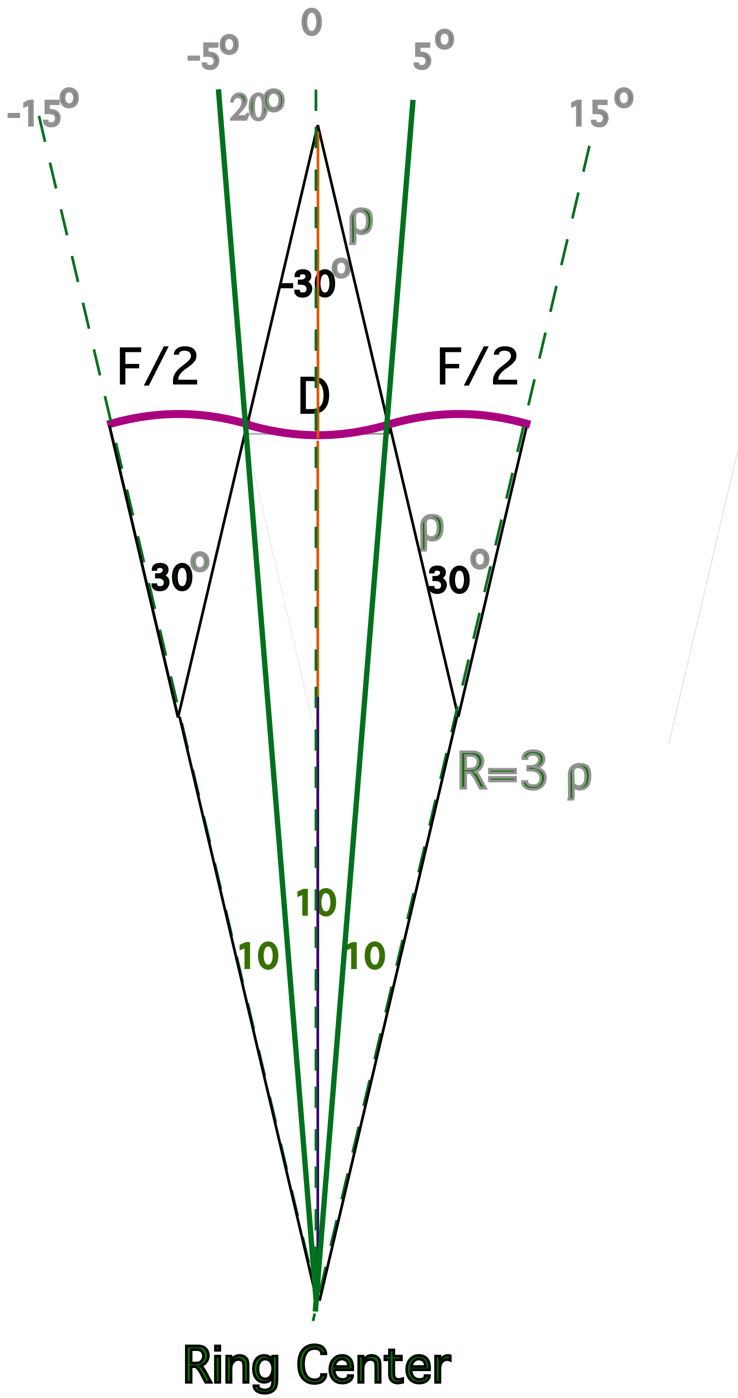
12 CELL FFAG RING W/O DRIFTS

red curve - 250 MeV/c closed orbit

By ~ 2.6 T on closed orbit



12 Cell Ring without Drifts
Layout of 1 Cell



$k = nd = -nf = 0.9$

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

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

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

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

Lf = .3333m ; Ld = .1667m

Lcell = 0.5m ; Circumference = 6m

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

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

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

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

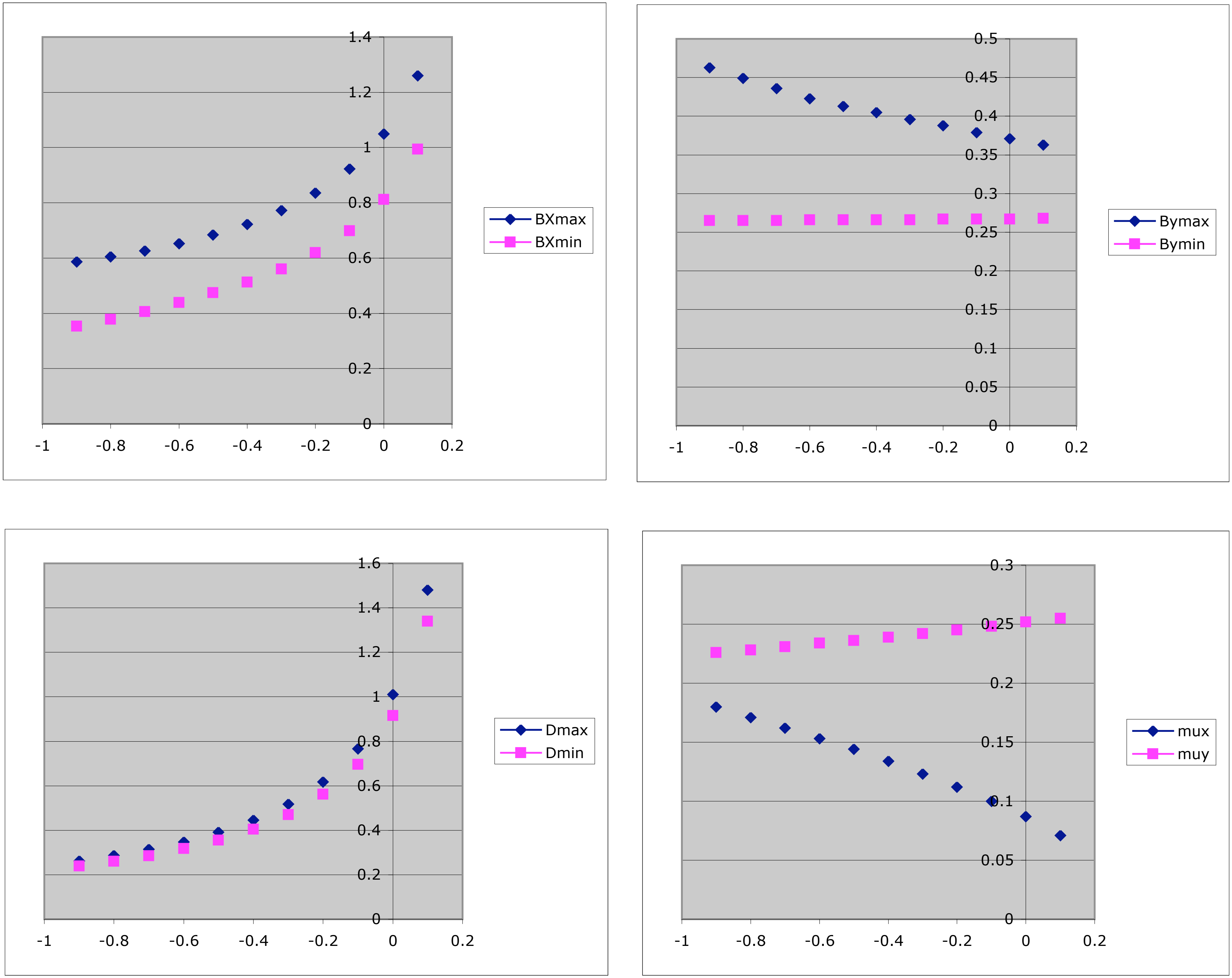
$D = dR/d(p/po) = R/(k+1)$ = .2581m

Lf = .3333m ; Ld = .1667m

Lcell = 0.5m ; Circumference = 6m

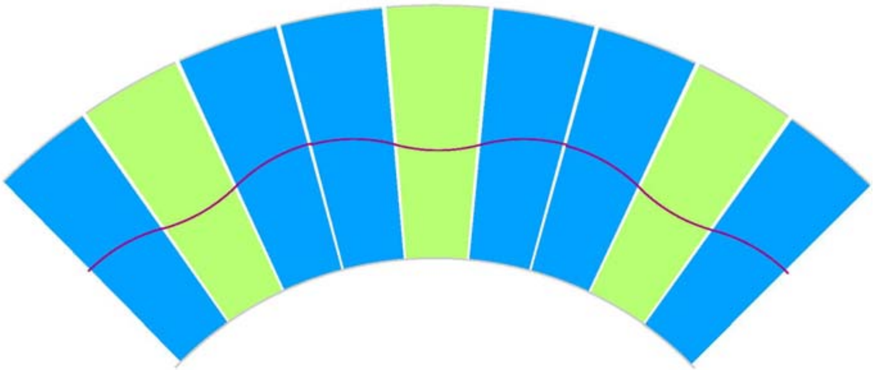
ρ0 = .3183m ; R0 = .9549m ; B0 = 2.620T

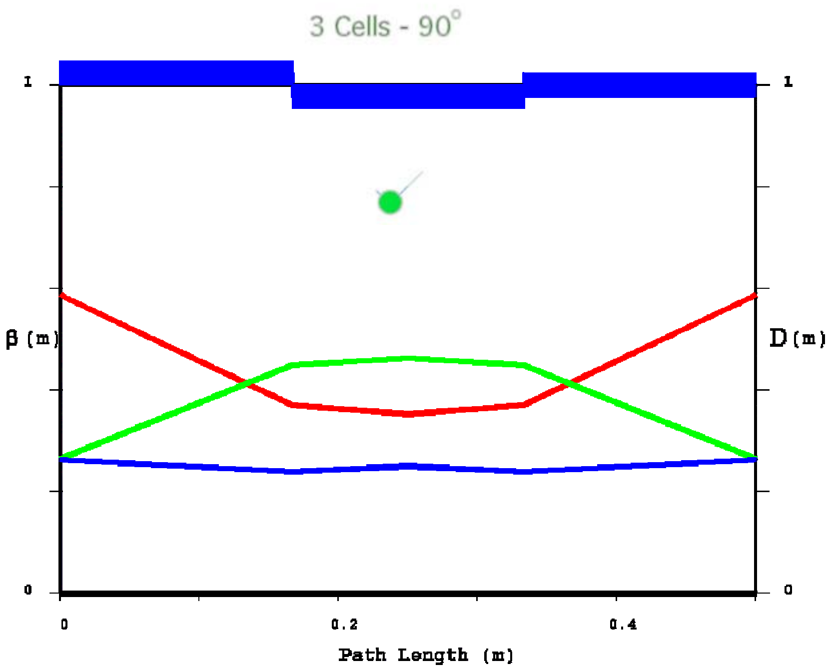
12-CELL STRONG FOCUSING COOLING RING: ORBIT FUNCTIONS VS. FIELD INDEX n



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

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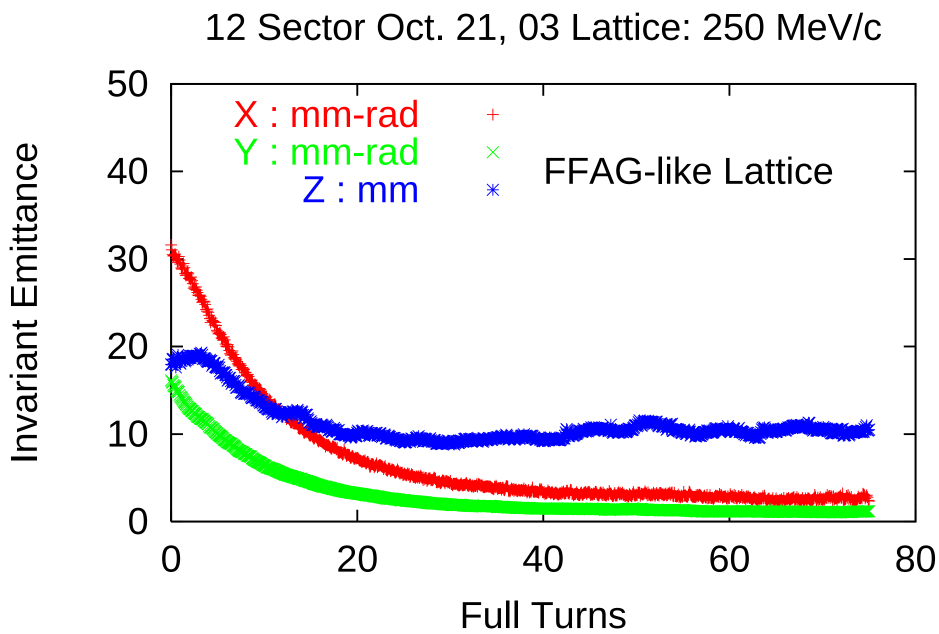
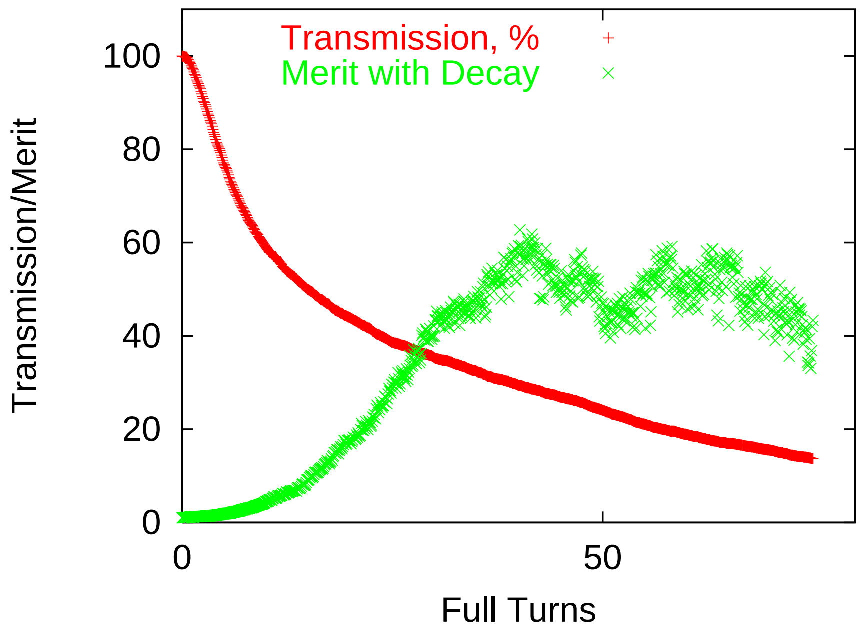
P/PO	P	R/RO	ρ	R	R-RO
	GeV/c		m	m	m
1.3	.325	1.0735	.342	1.025	.0702
1.2	.300	1.0505	.334	1.003	.0482
1.1	.275	1.0261	.327	0.980	.0249
1.0	.250	1.0000	.318	0.955	.0000
0.9	.225	.9719	.309	0.928	-.0268
0.8	.200	.9415	.300	0.899	-.0559
0.7	.175	.9081	.289	0.867	-.0878

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



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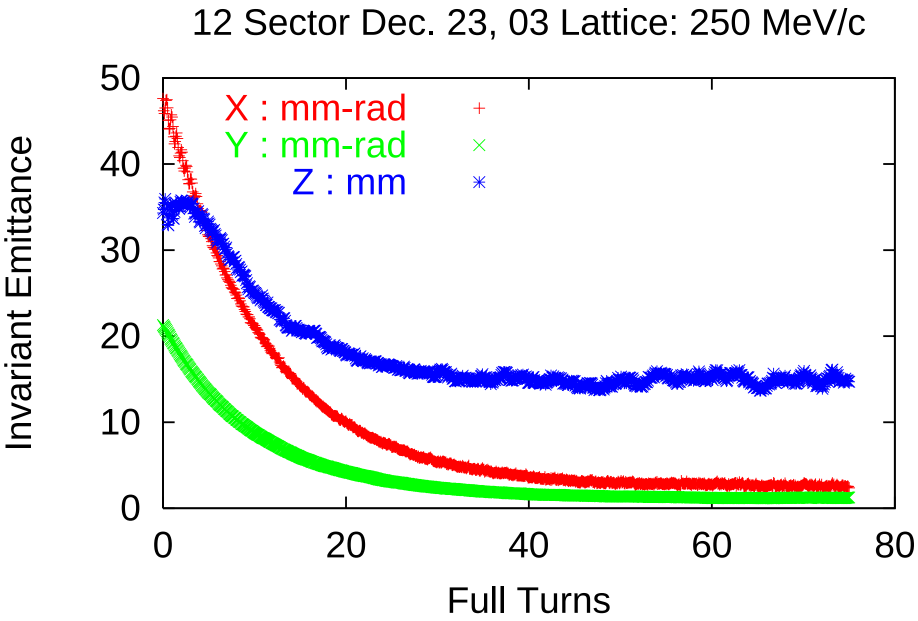
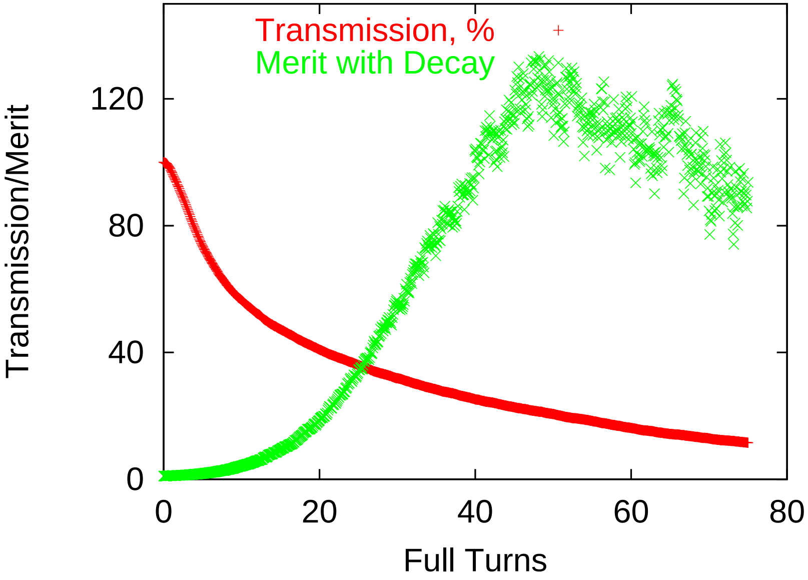
Strong Focusing Ring Performance

n = -0.6   rf at 8 MV/m





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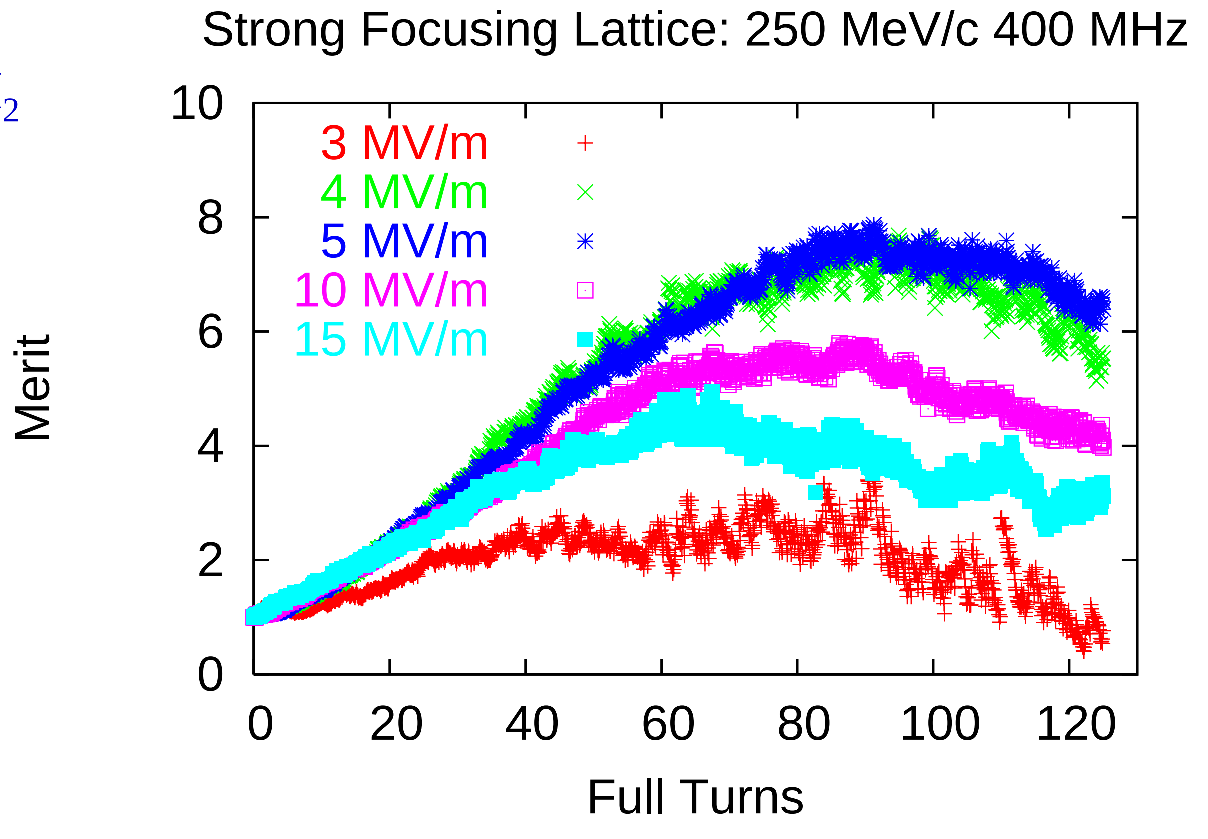
Strong Focusing Lattice

Lattice Parameters

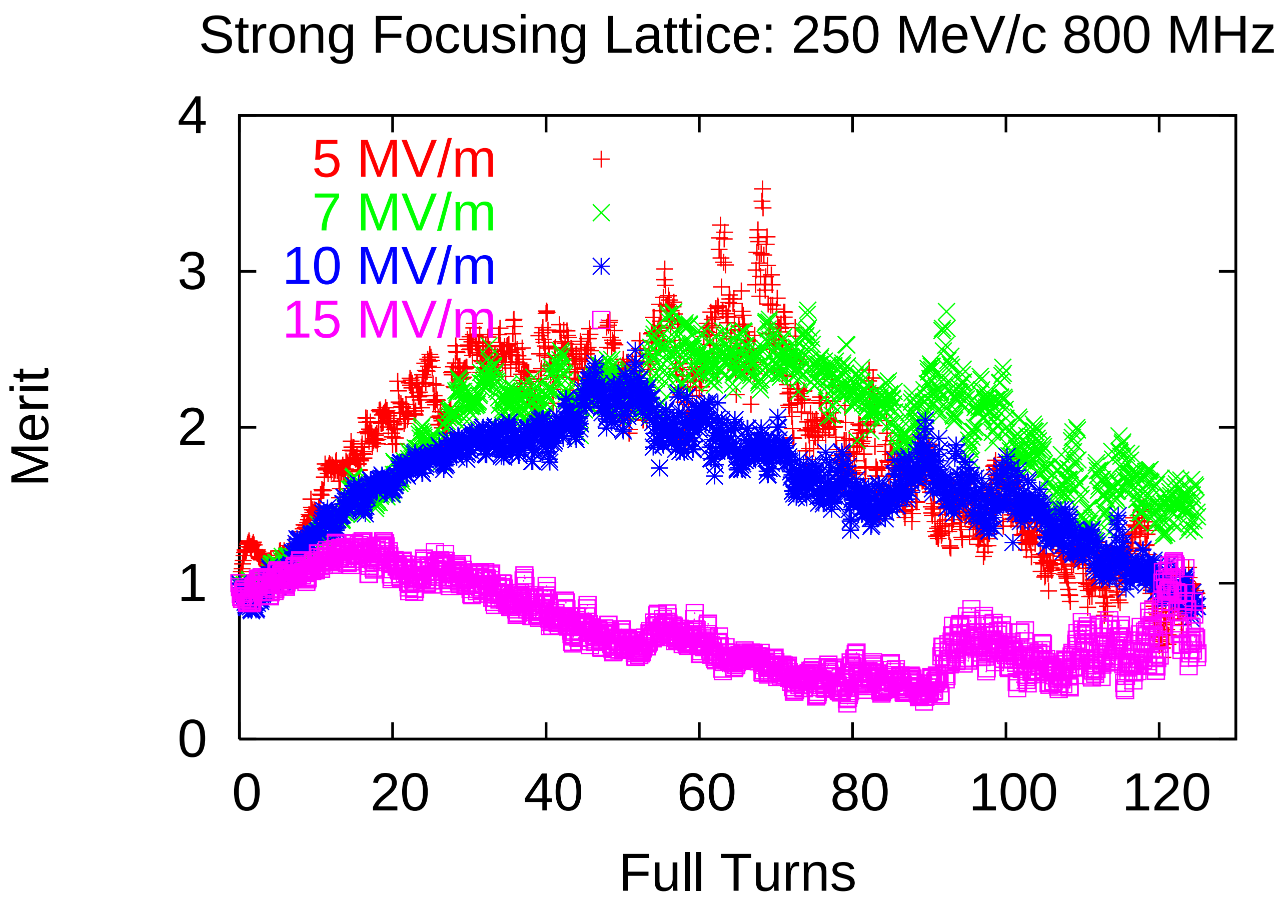
- RF at 400 MHz
- 40 Atmospheres GH_2
- Aperture ± 10 cm
- Merit without decay
- $B_0 = 2.62$ T



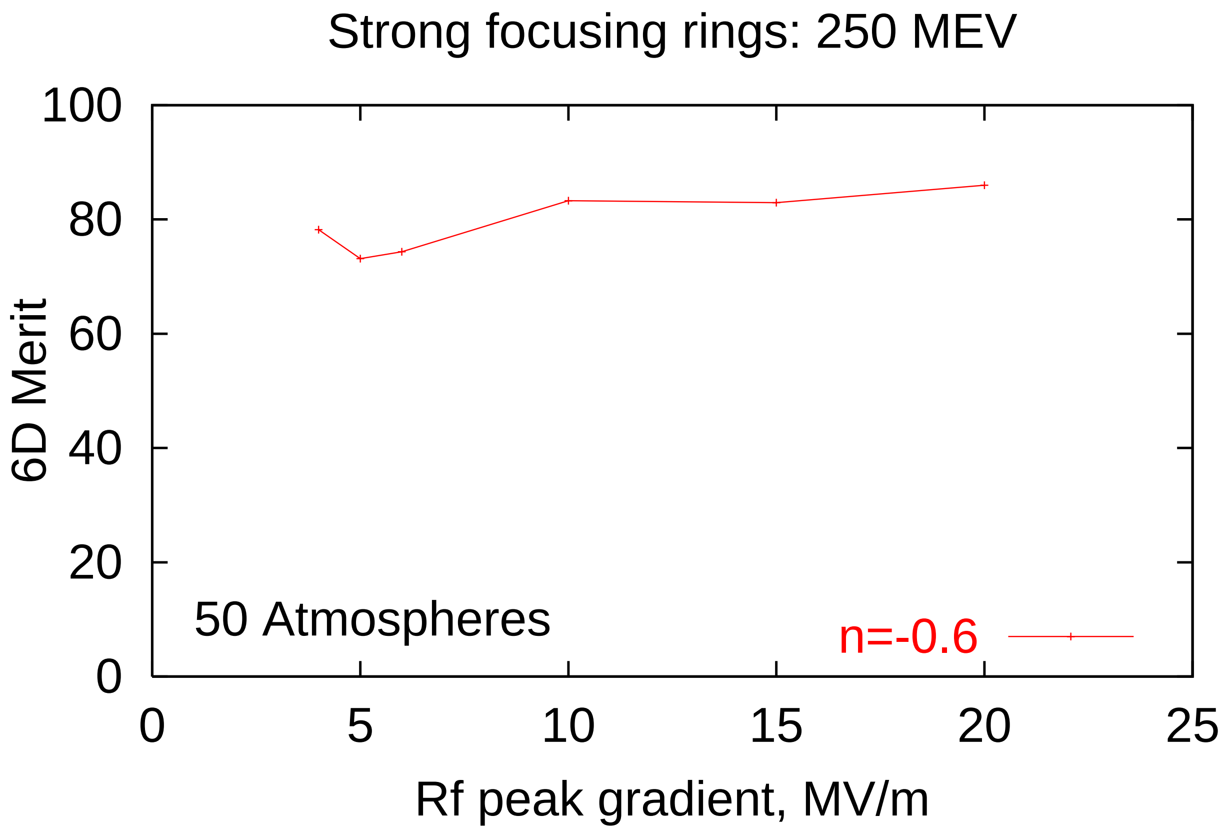
Strong Focusing Lattice (cont)

Lattice Parameters

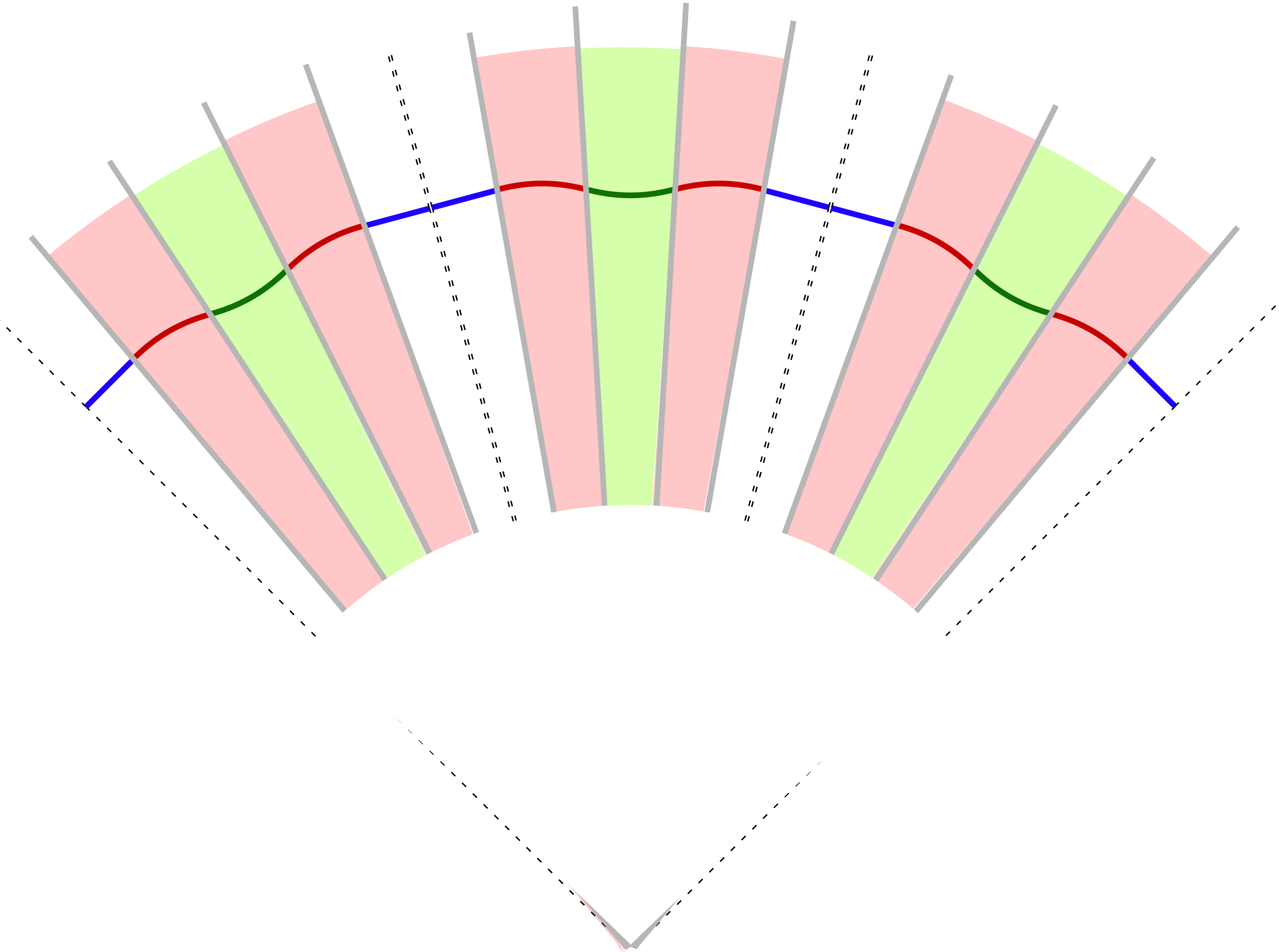
- RF at 800 MHz
- 40 Atmospheres GH_2
- Aperture ± 7.5 cm
- Merit without decay
- $B_0 = 2.62$ T

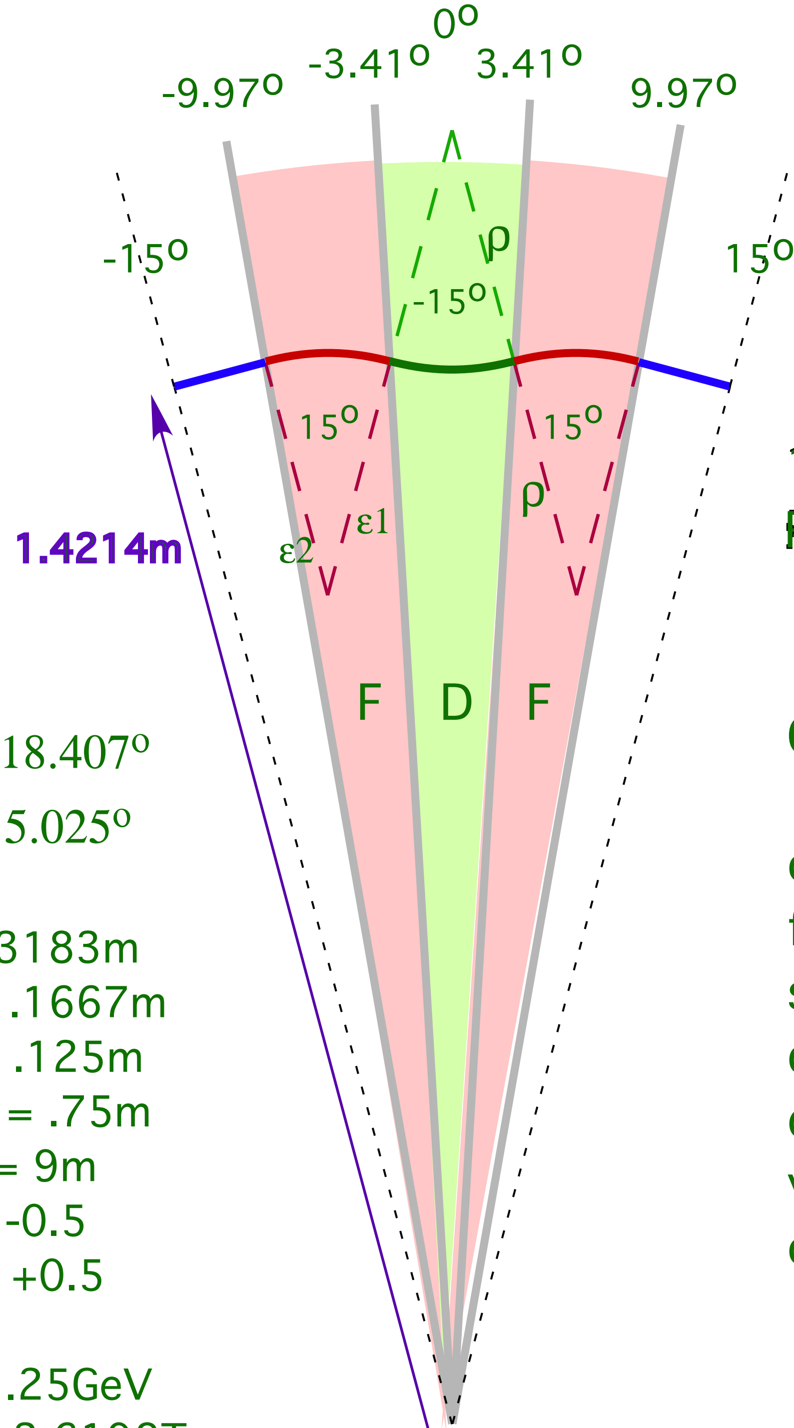


50 Atmospheres Performance



3 CELLS OF THE 12-CELL RING





12 CELL STRONG FOCUSING RING WITH DRIFTS

$\varepsilon 1 = 18.407^{o}$

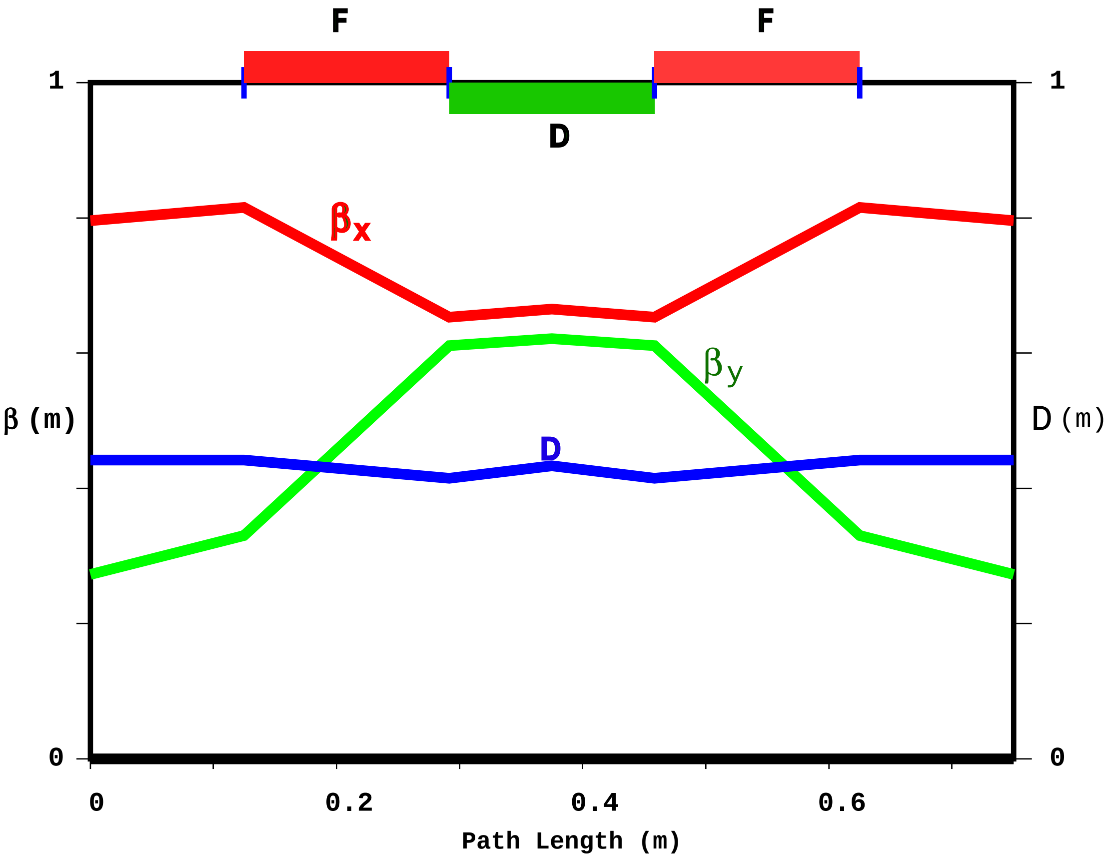
$\varepsilon 2 = 5.025^{o}$

ρ = .3183m
LB = .1667m
LO = .125m
Lcell = .75m
Circ = 9m
nF ~ -0.5
nD ~ +0.5

Pc = .25GeV
B0 = 2.6198T

Cell Diagram

The magnets have equal and opposite field strengths and field indices. The diagram shows the central, 0.25GeV closed orbit. Closed orbits of different momenta are scaled versions of the central closed orbit.



Beta functions of one cell of FFAG 12-cell ring with drifts

Summary

- The ICOOL fix (> V2.66) significantly affected the performance of rings with gas loaded rf cavities
- The wedge dipole-only rings are still viable but with a reduction in scale or with the introduction of X/Y coupling.
- For weak-focusing lattices, high magnetic field , high rf gradients are favored.
- For strong-focusing lattices, low rf gradients are favored.

Summary – continued

- Weak focusing lattices are simpler and more compact than FFAG lattices and therefore are cheaper. The drift and magnet lengths are similar for best performance. Cooling is best vertically and longitudinally. For some cases skew-quadrupole correction is needed to cool horizontally.

- FFAG lattices give better performance at moderate fields than weak focusing lattices do. They have larger circumference and can contain a longer bunch train. They cool better transversly than longitudinally.

- The cell lengths of the two lattice types are roughly comparable to keep the beta functions low (0.5 – 1.0 m).

- A 200 Mhz RF systerm gives better cooling than 400 Mhz or 800 Mhz.