Studies of Quadrupole Focused Muon Cooling Rings:

D.B. Cline, Y.Fukui, P.He, A.Garren, UCLA

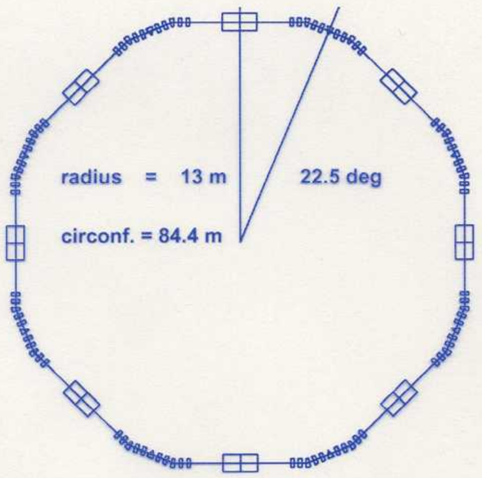
H.Kirk, BNL

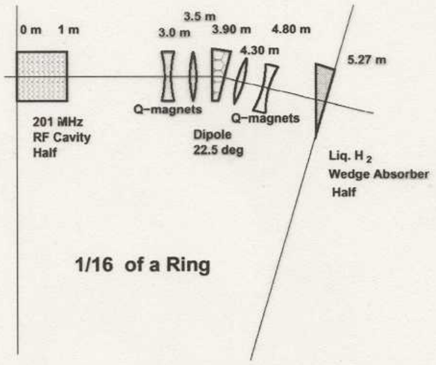
F.Mills, FNAL

Quadrupole rings

- Fukui,Cline,Garren,He,Kirk,Mills
- Easier to inject in and out of.

Overall Layout of the Muon Ring Cooler





Half Section of Bending Cell

A Quadrupole/Dipole Ring Cooler

Al Garren and Harold G. Kirk

Strategy

- Explore Ring Cooling Designs
- Use only Quadrupoles and Dipoles
- Obtain Longitudinal Cooling
- Maintain/Reduce Transverse Emittance
- Linear Lattice Design (SYNCH)
- Cooling Simulation (ICOOL)

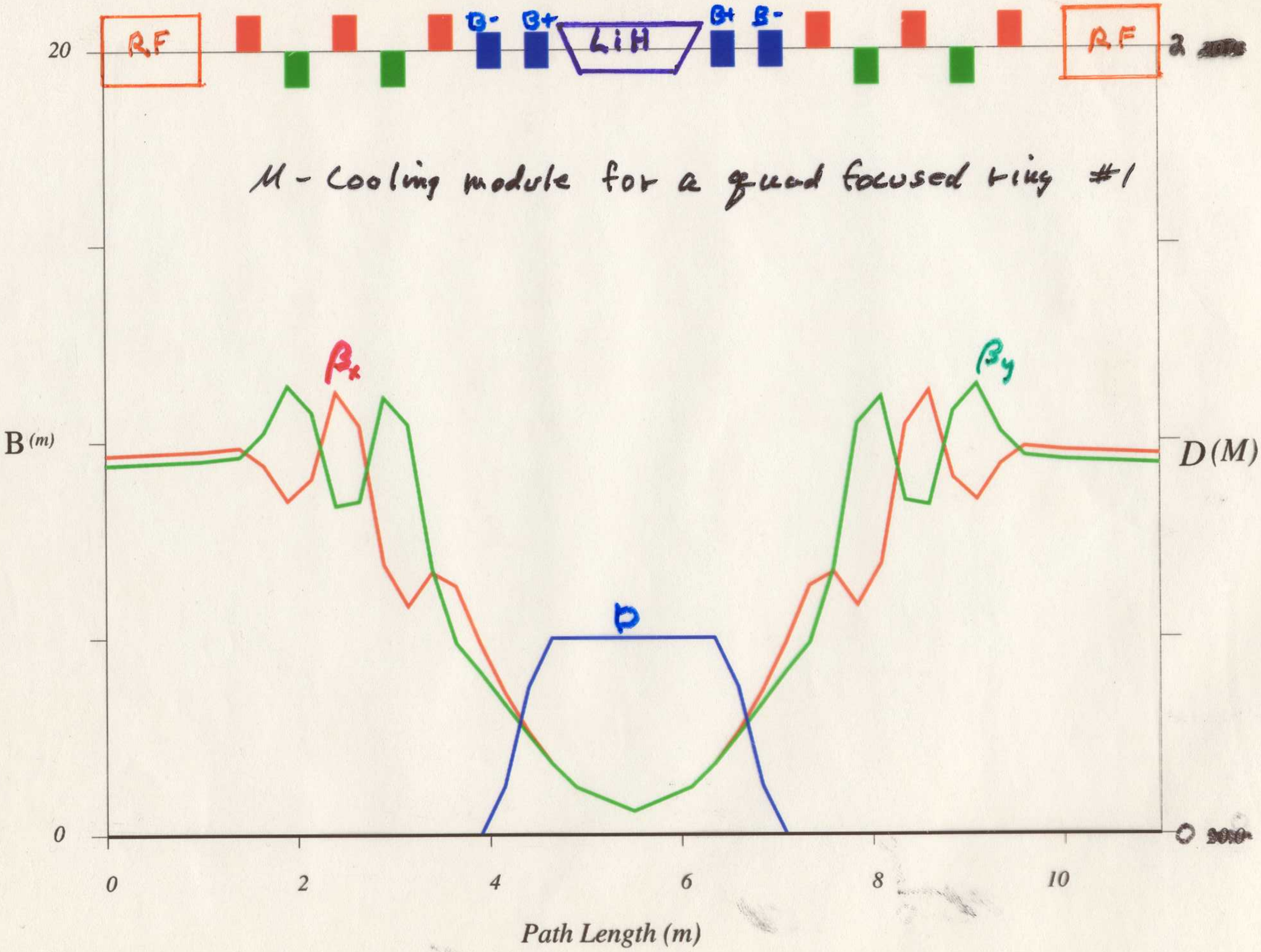
A muon storage ring configured for ionization cooling is an attractive option due to the possibility of 6-D cooling and economy from multiple passes through absorbers and RF acceleration cavities.

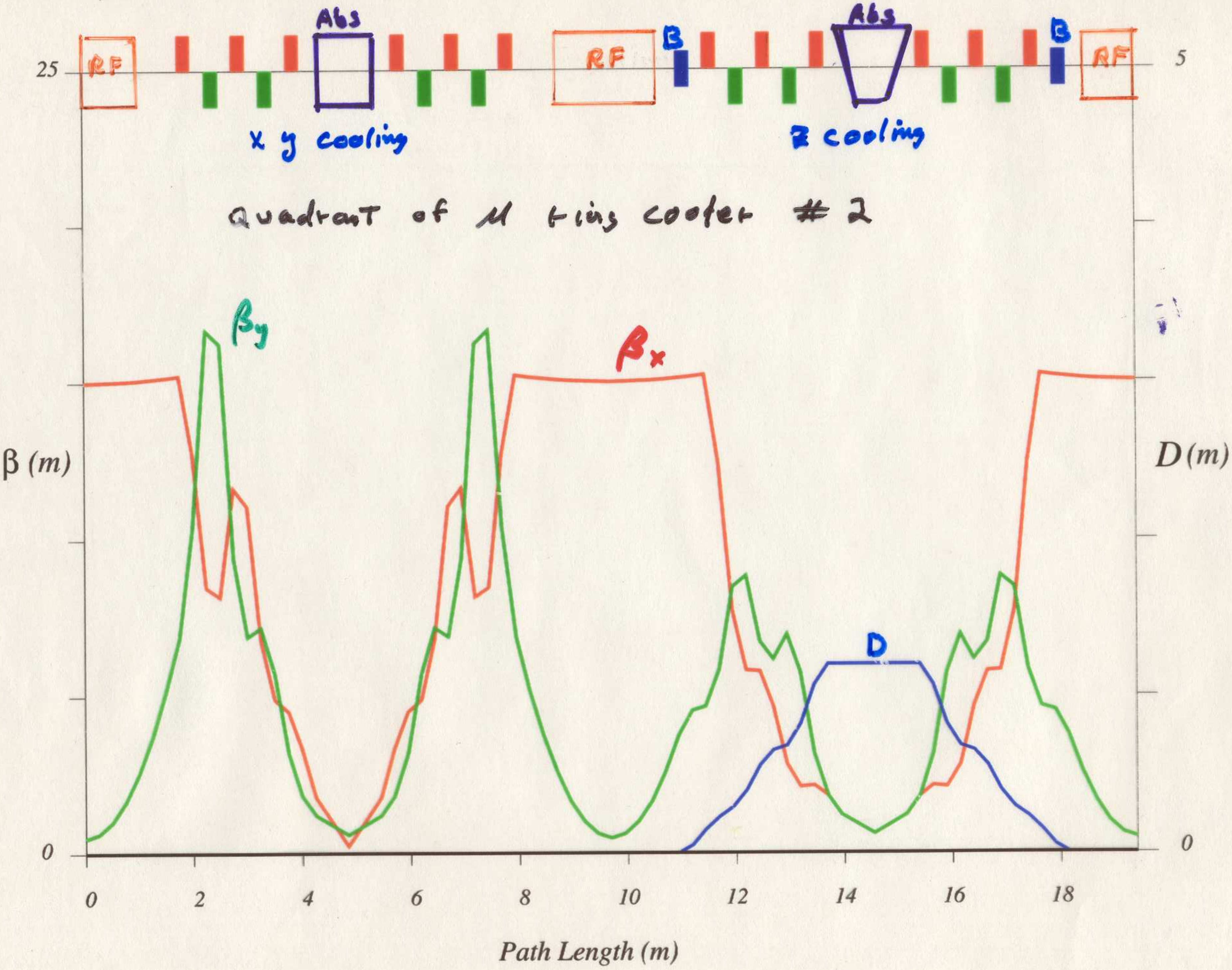
The transverse cooling mechanism is the ionization slowing of particles in absorbers coupled with RF acceleration.
The longitudinal cooling mechanism involves use of wedge-shaped absorbers in dispersed regions of the lattice.

Muon cooling is counteracted by heating due to multiple coulomb scattering and energy straggling in the absorbers. The straggling unfortunately causes emittance growth in absorbers in dispersed regions.

The effect of scattering is minimized by placing the absorbers at low-beta points of the lattice. But these low beta points tend to reduce the dynamic aperture of the lattice, which leads to particle losses.

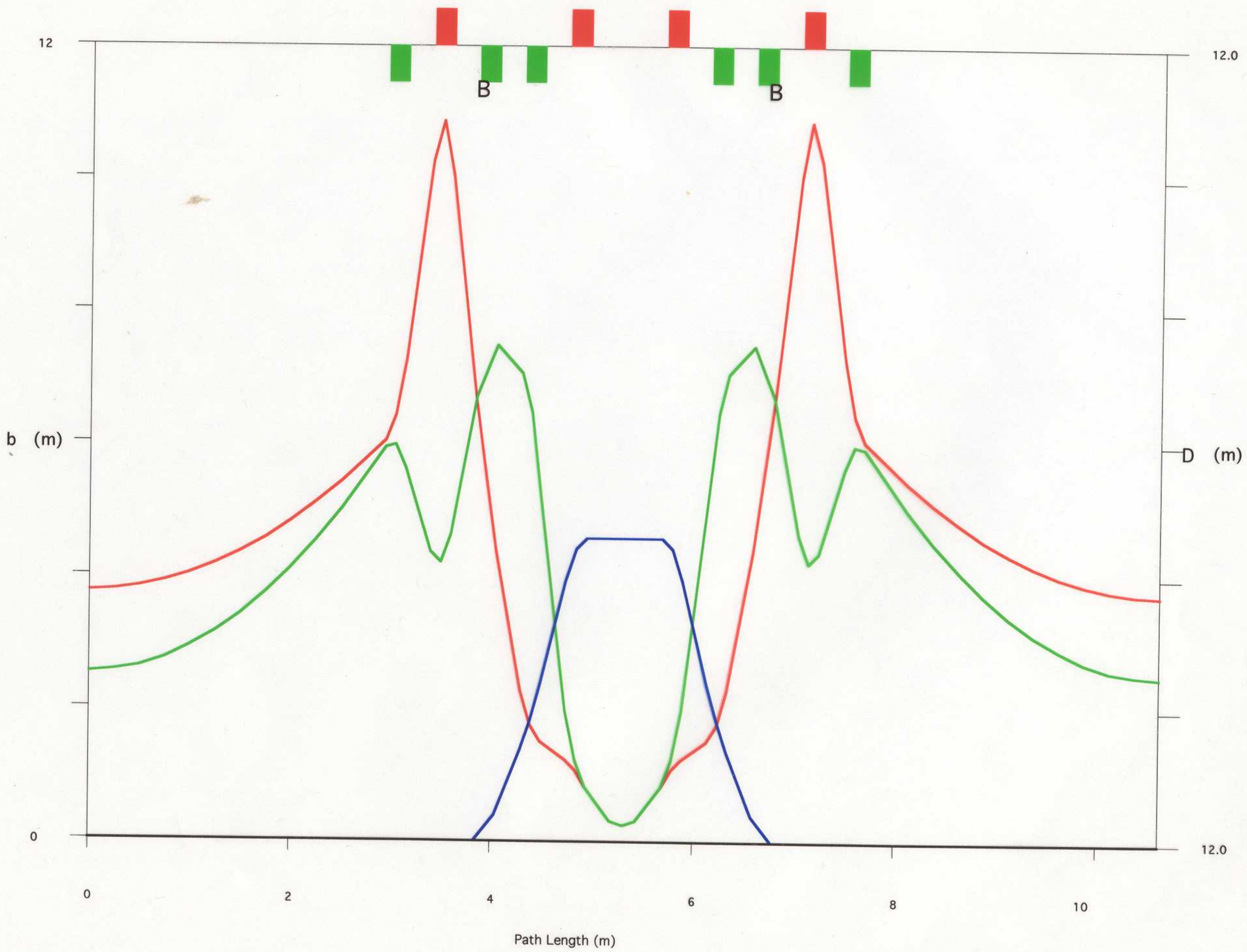
These often-contradictory requirements make for a considerable design challenge.


μ - Cooling module for a quad focused ring #1
RF
RF
B-
B+
LiH
B+
B-
20
B (m)
0
2
0
2
4
6
8
10
Path Length (m)
D(M)
0
β_x
β_y
D

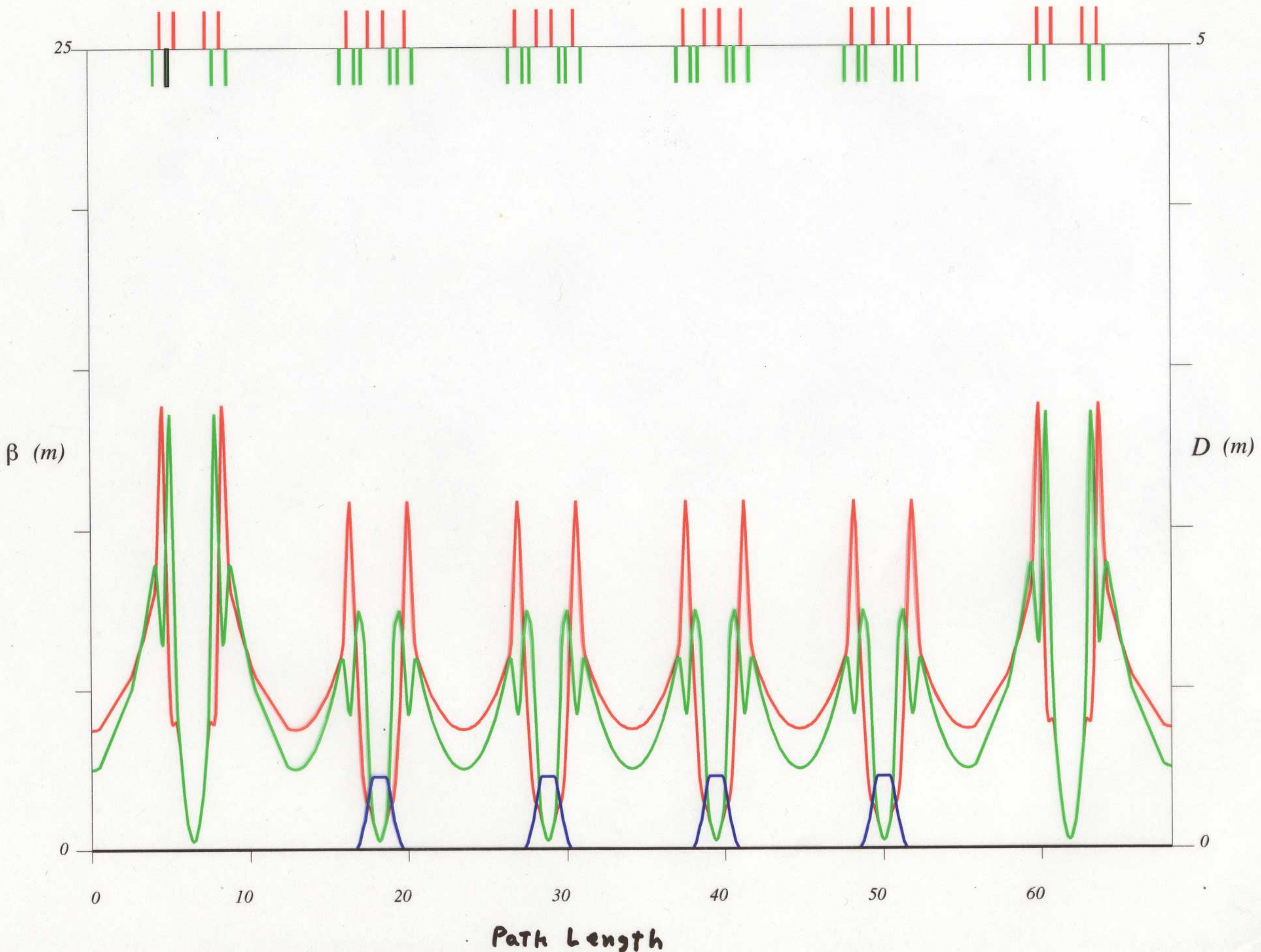


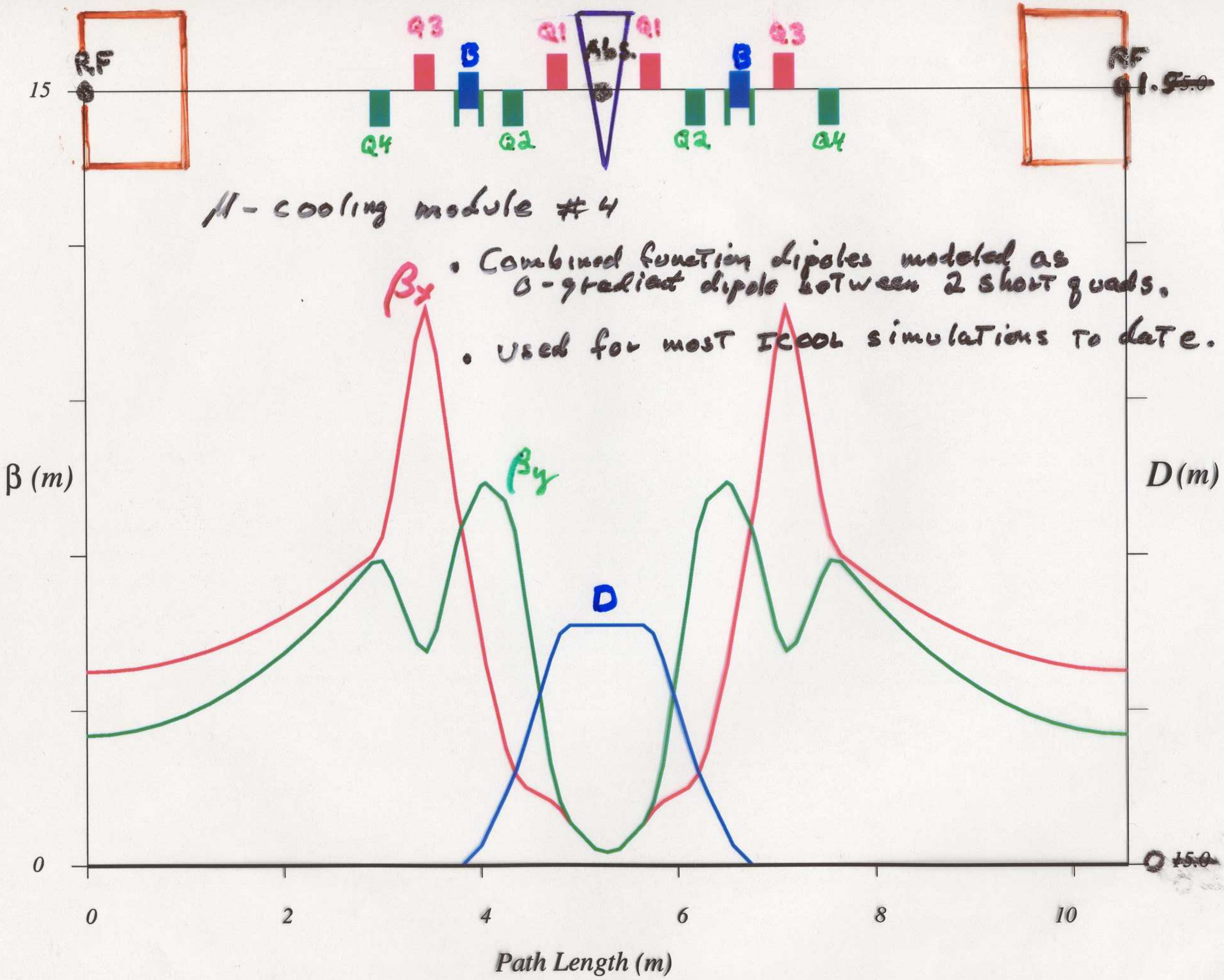
RF
Abs
B
x y cooling
z cooling
Quadrant of μ ring cooler #2
25
5
0
β (m)
D (m)
β_y
β_x
D
0
2
4
6
8
10
12
14
16
18
Path Length (m)

Combined Function Dipoles in Cooling Module



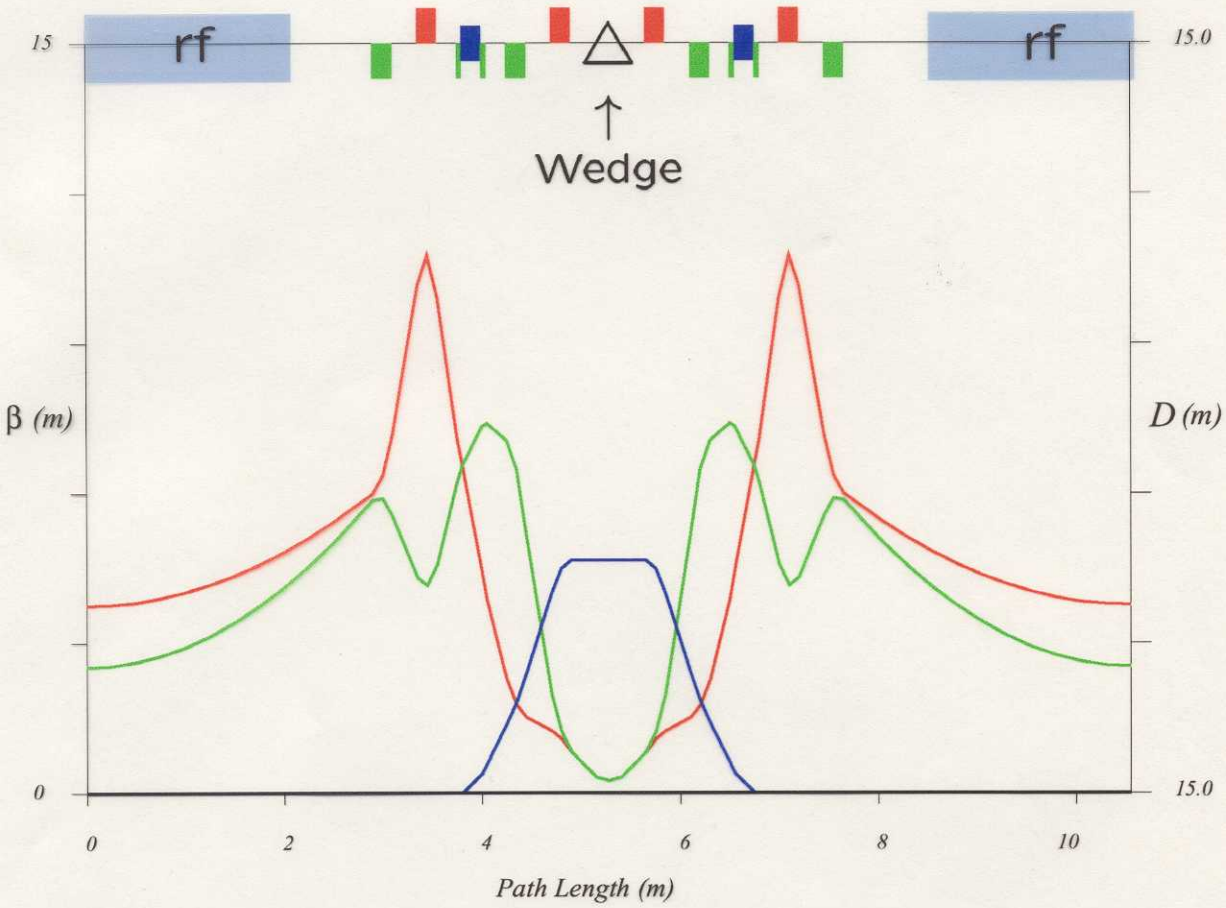
Combined Function Dipole Lattice - Half Ring





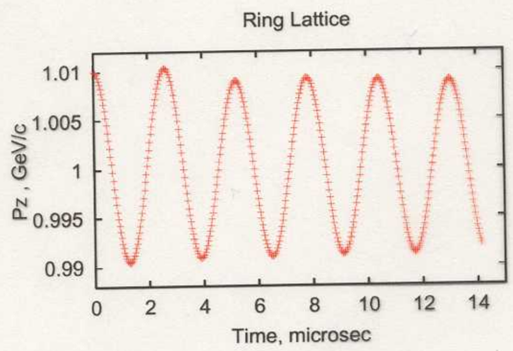
RF
Q3
B
Q1
Abs.
Q1
B
Q3
RF
15
Q4
Q2
Q2
Q4
μ-cooling module #4
• Combined function dipoles modeled as 0-gradient dipole between 2 short quads.
• Used for most ICOOL simulations to date.
βx
βy
β (m)
D (m)
D
0
0
2
4
6
8
10
Path Length (m)

Bending Cell Lattice for Cooling Ring

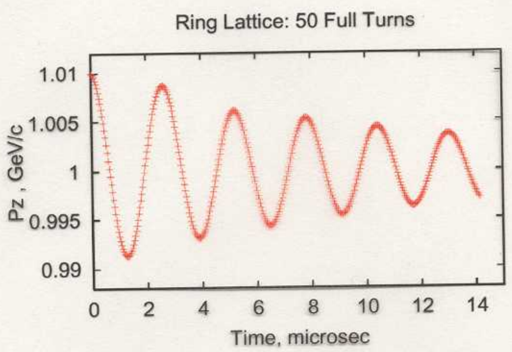


1 GeV/c Cooling Ring: Fifty Full Turns

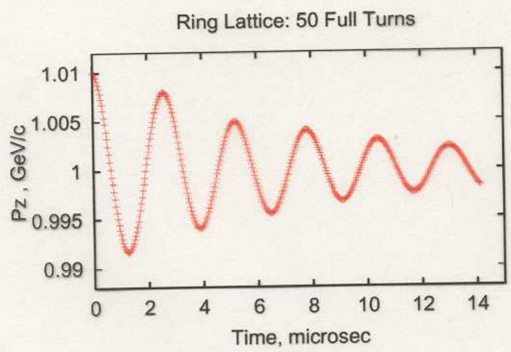
0° Absorber



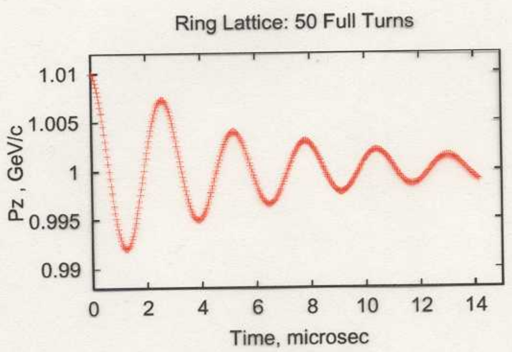
10° Wedge



15° Wedge

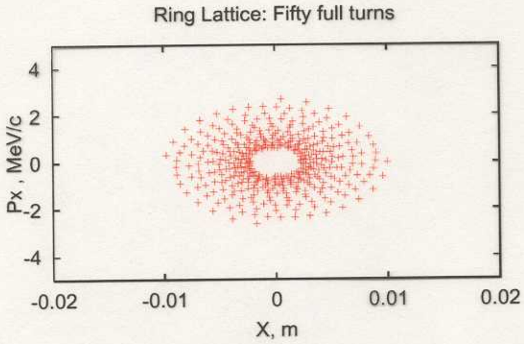


20° Wedge

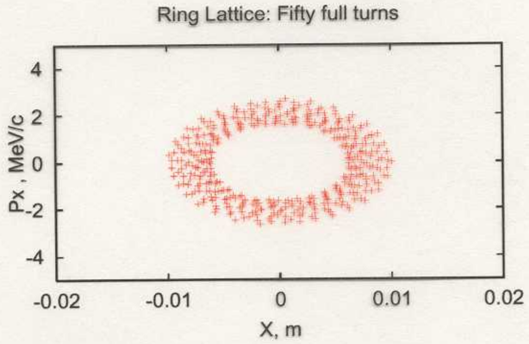


1 GeV/c Cooling Ring: Fifty Full Turns

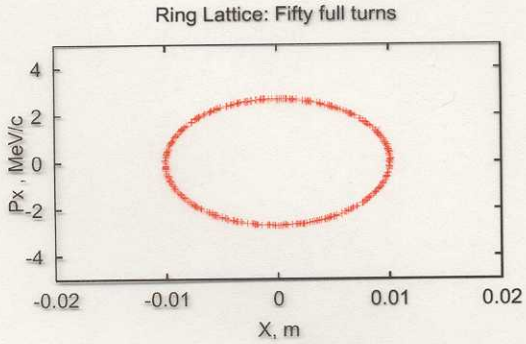
0° Absorber



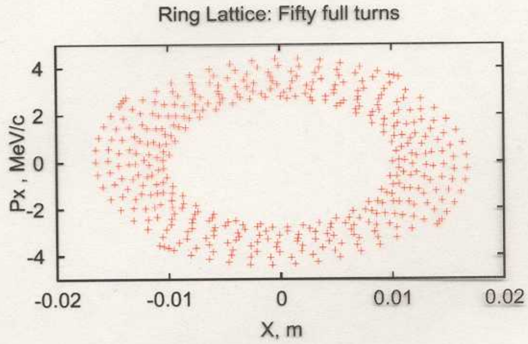
10° Wedge



15° Wedge



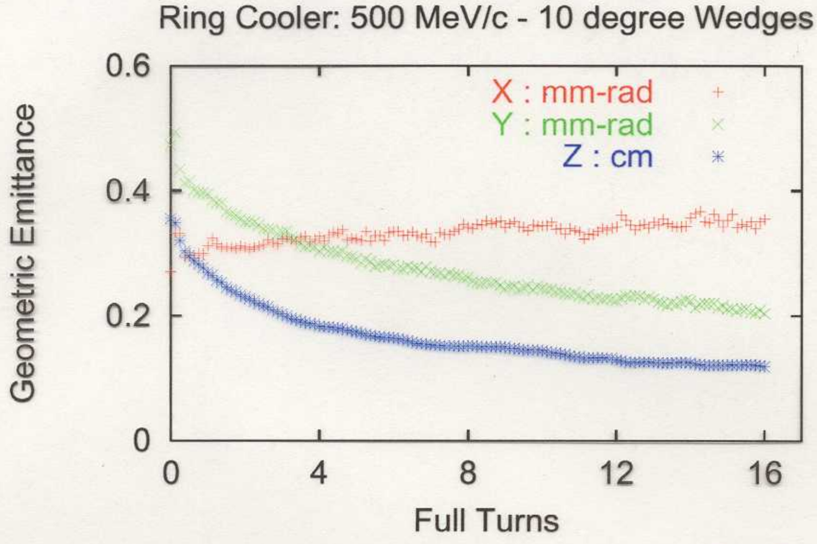
20° Wedge



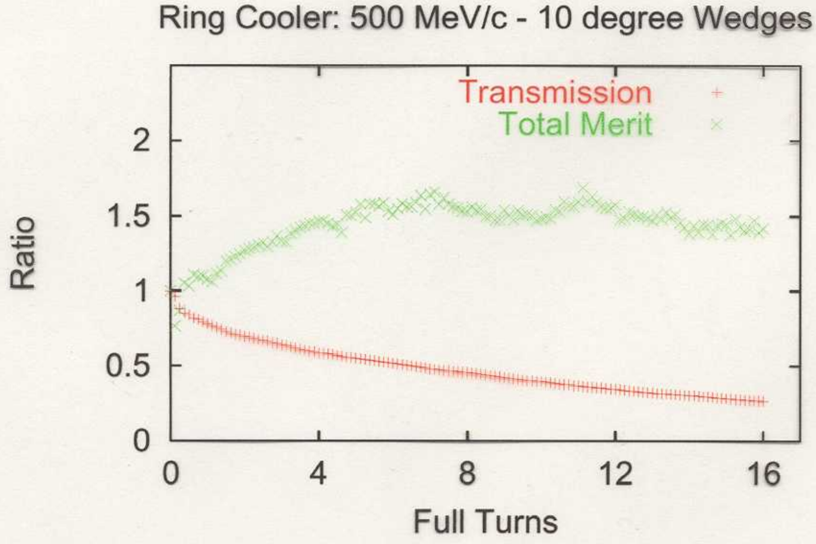
500 MeV/c Cooling Ring: 10° Wedges

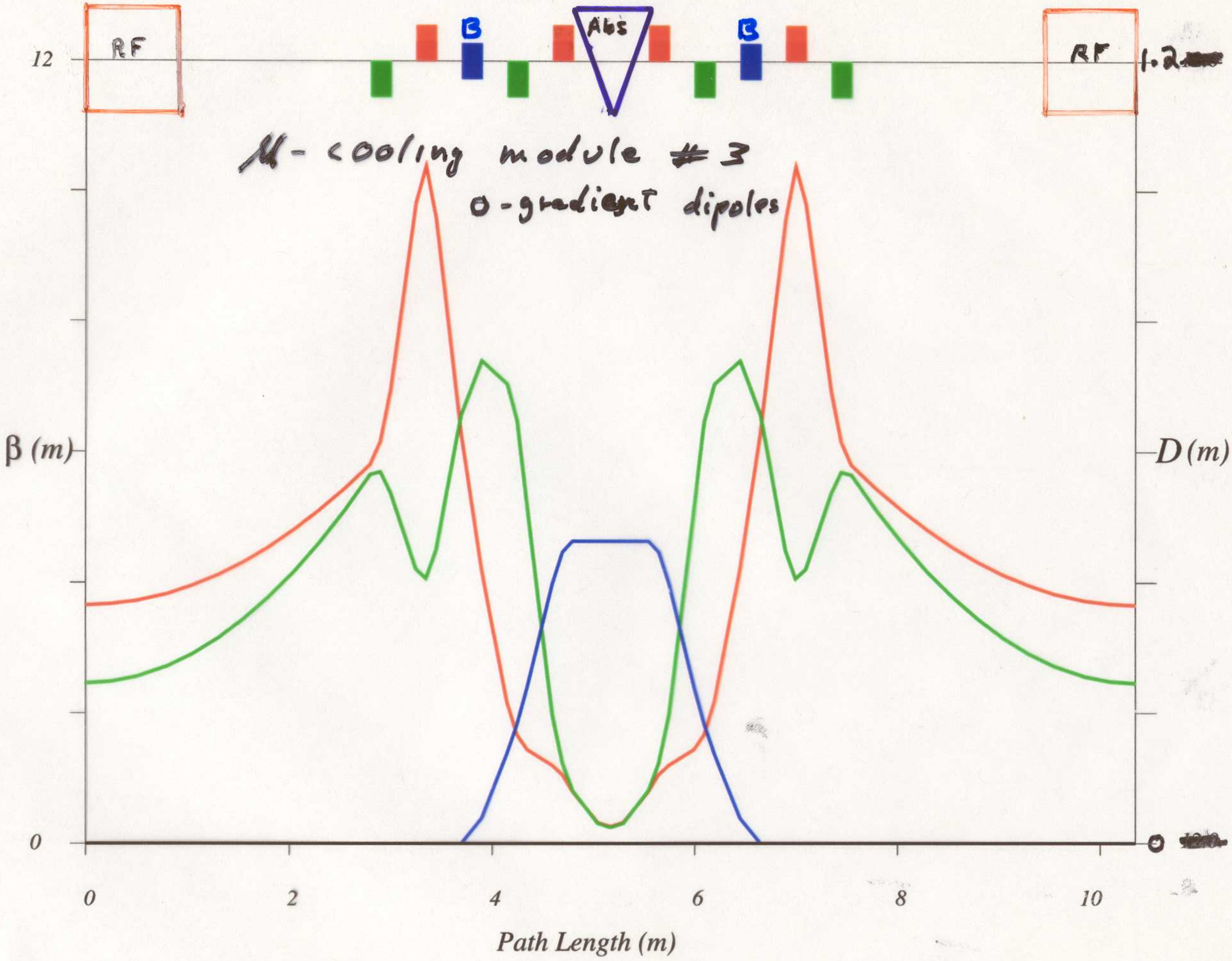
With Multiple Coulomb Scattering and Straggling

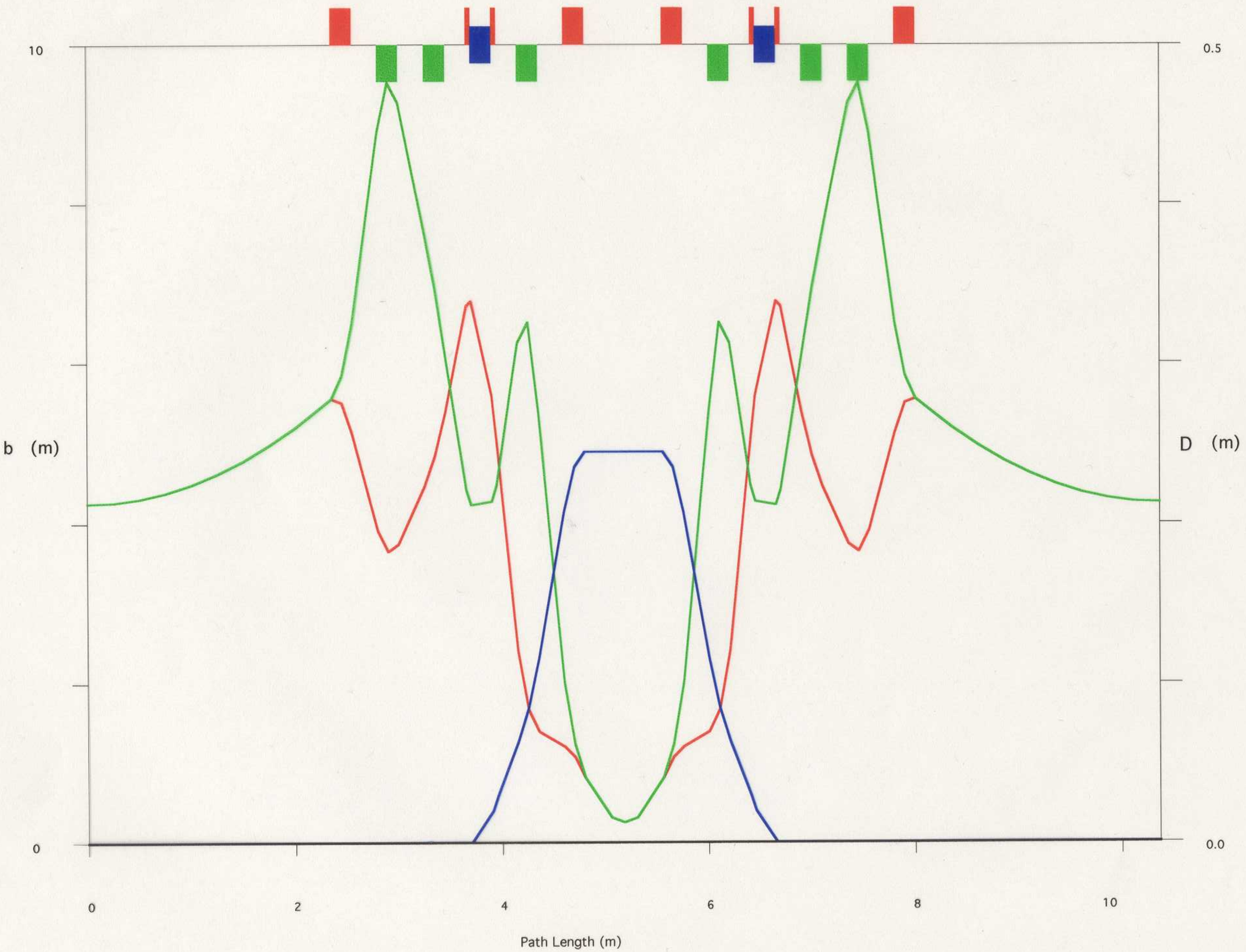
$$\gamma\beta\epsilon_{x_i} = 1.3mm;\ \gamma\beta\epsilon_{y_i} = 2.2mm\ ;\ \gamma\beta\epsilon_{z_i} = 16mm$$



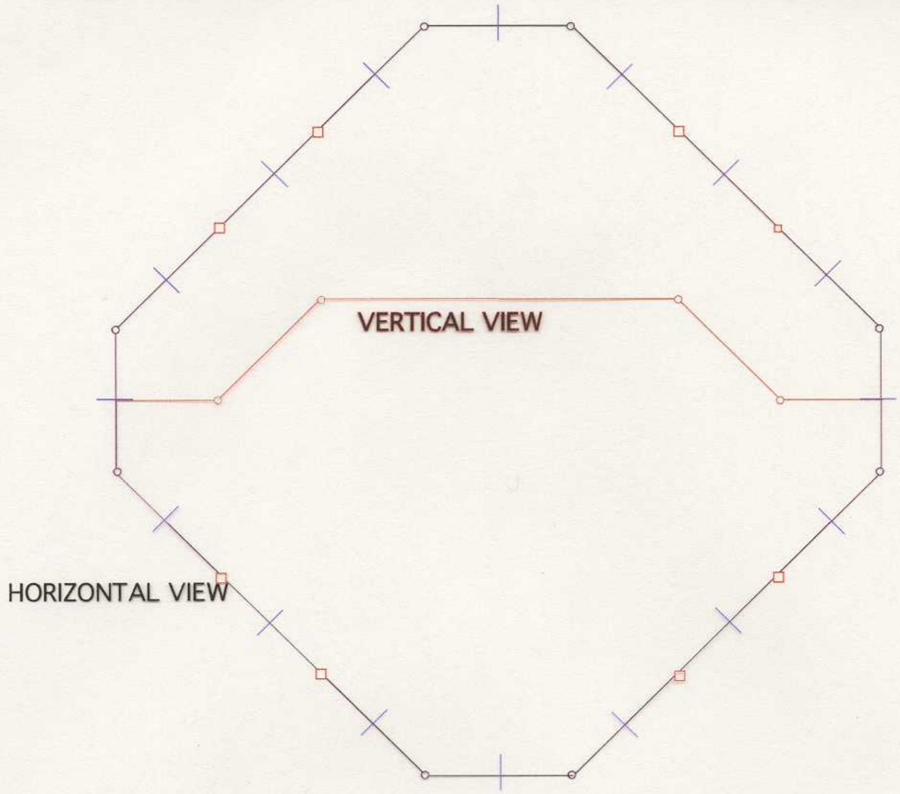
$$\text{Total Merit} = \text{Transmission} \times \frac{\epsilon_{x_i}}{\epsilon_{x_f}}\frac{\epsilon_{y_i}}{\epsilon_{y_f}}\frac{\epsilon_{z_i}}{\epsilon_{z_f}}$$




RF
B
Abs
B
RF
12
1.2
μ-cooling module #3
0-gradient dipoles
β (m)
D (m)
0
0
0
2
4
6
8
10
Path Length (m)


10
0
b (m)
0.5
0.0
D (m)
0
2
4
6
8
10
Path Length (m)

MUON COOLING RING WITH 8 HORIZONTAL AND 8 VERTICAL BEND CELLS



Summary

- SYNCH $\rightarrow$ ICOOL strategy works
- Emittance exchange demonstrated
- Transmission losses need study
- Need to consider realistic quads
- Need to incorporate soft edges

Future Work

Investigate ways to equalize horizontal and vertical cooling, for example by use of solenoids or skew quadrupoles or by use of cooling cells with vertical bending.

Seek to make ring more compact and increase dynamic aperture.

Design and study an FFAG cooling ring.

Design and study a cooling ring with lithium-lens absorbers.

Investigate open beam lines (not a ring).