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Lattice design for the future ERL-based electron hadron colliders eRHIC and LHeC

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eRHIC and LHeC lattice design

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Basic characteristics electron-hadron colliders LHeC and eRHIC

Lattice concept for $M_{5,6} = 0$

LHeC

- LAYOUT
- Achromatic& basic cells
- Splitters/ Combiners
- Bypass/IR

eRHIC

- LAYOUT
- Achromatic& basic cells
- Splitters/ Combiners
- Bypass/IR

LHeC

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Electron Energy [GeV]	60
Luminosity [$cm^{-2}\ s^{-1}$]	1×10^{33}
Electron bunch length [μm]	300
Bunch interval [nm]	50
Transverse emittance $\gamma\varepsilon_{x,y}$ [μmrad]	50
rms beam size [μm]	7
Repetition rate	CW
Total wall power [MW]	100

eRHIC -β^*=5 cm

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	Protons	Electrons
Maximum energy [GeV]	325	30
# of bunches/bunch freq [MHz]	166	14.08
Bunch intensity	2×10^{11}	0.2×10^{11}
Bunch charge [nC]	32	3.5
Beam current [mA]	415	50
Transverse norm. emittan. [μmrad]	0.18	20
rms beam size [nm]	0.52	0.52
Polarization	70	80
Luminosity @ 25 GeV [$cm^{-2}\,s^{-1}$]	1.5×10^{34}	

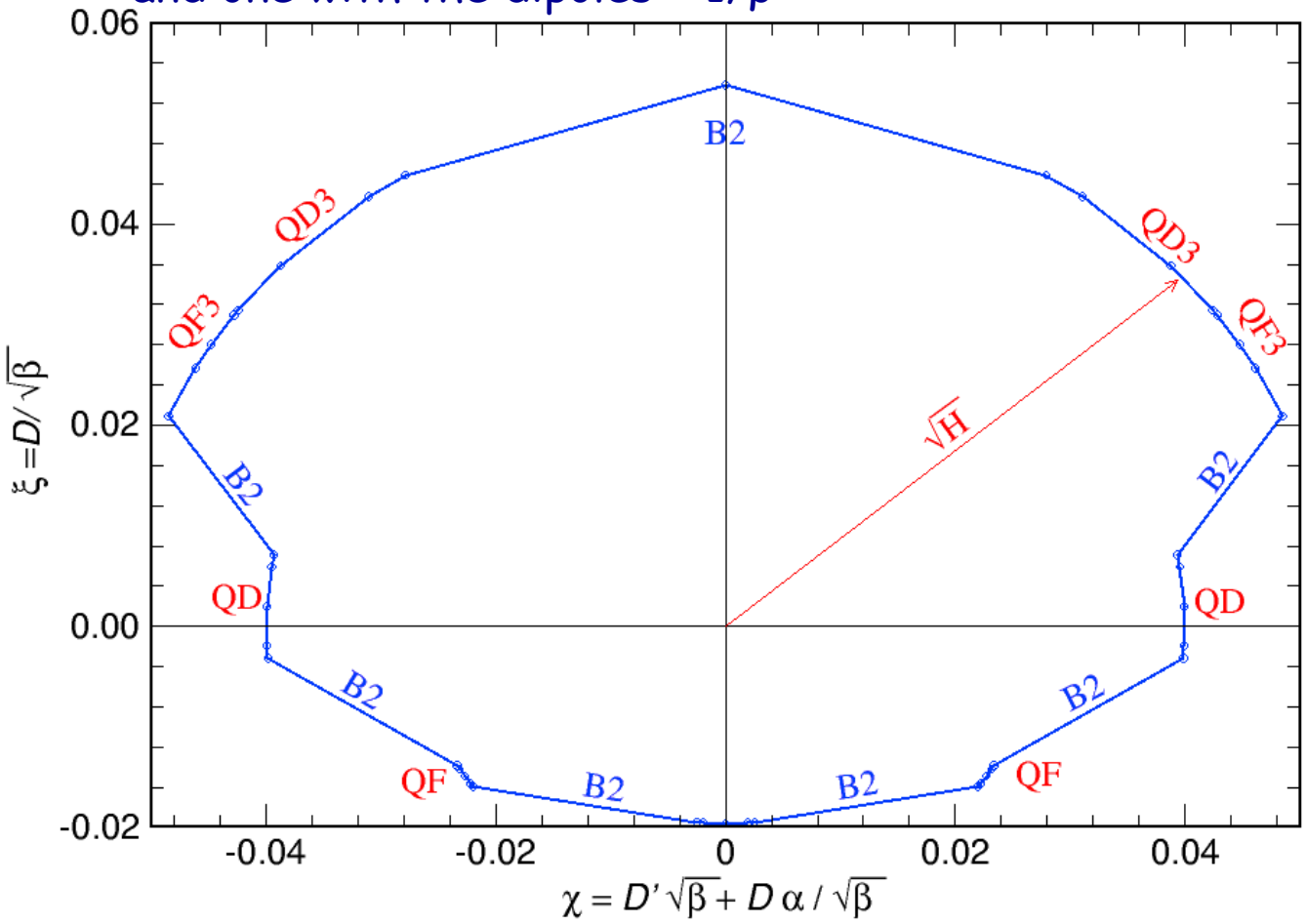
Basic concept of the adjustable momentum compaction lattice $M_{5,6} = 0$

$$D'' + kD = \begin{cases} = 0 \\ = 1/\rho \end{cases}$$

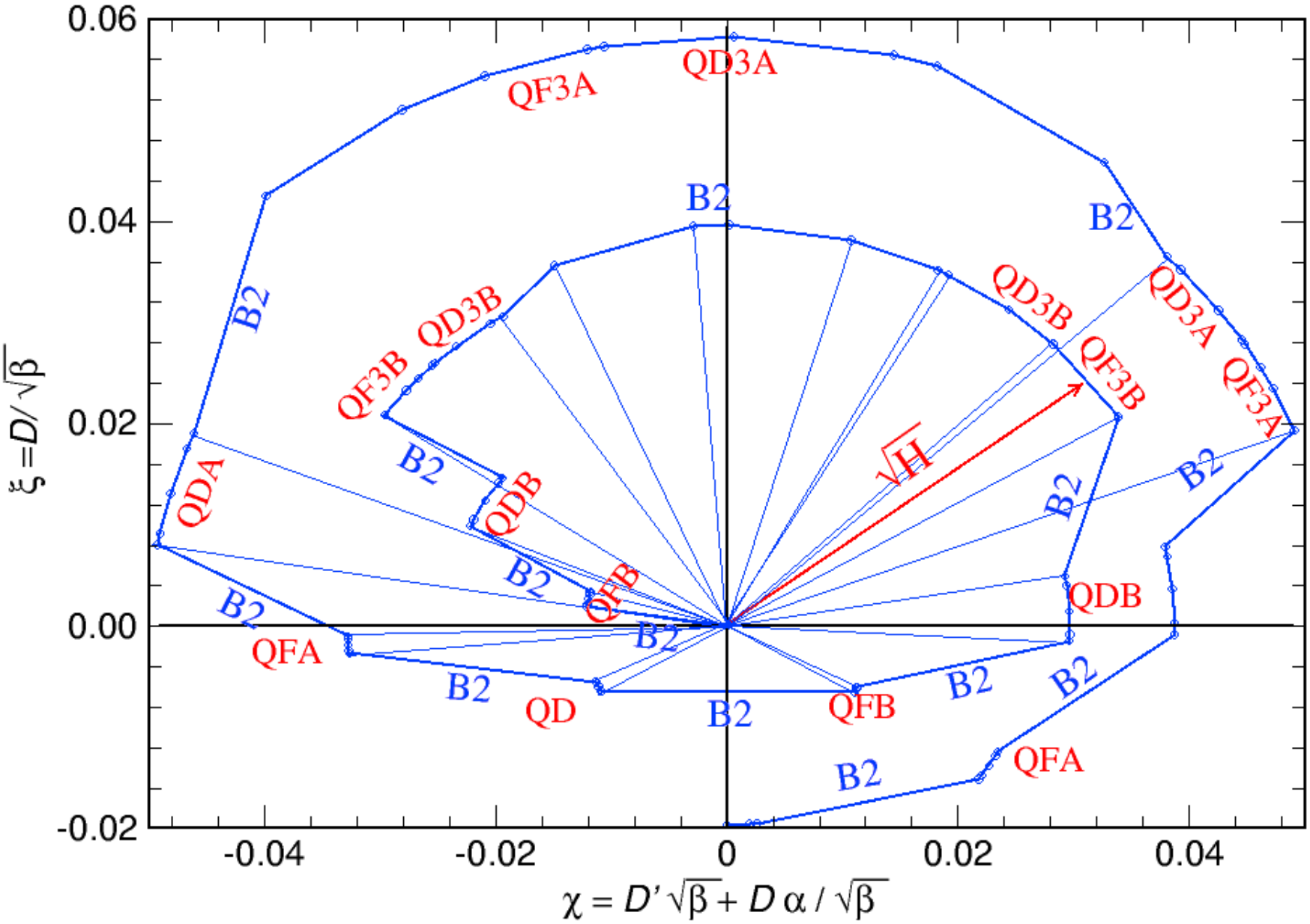
$$\chi = D'\sqrt{\beta} + D\frac{\alpha}{\sqrt{\beta}}$$

$$\xi = \frac{D}{\sqrt{\beta}}$$

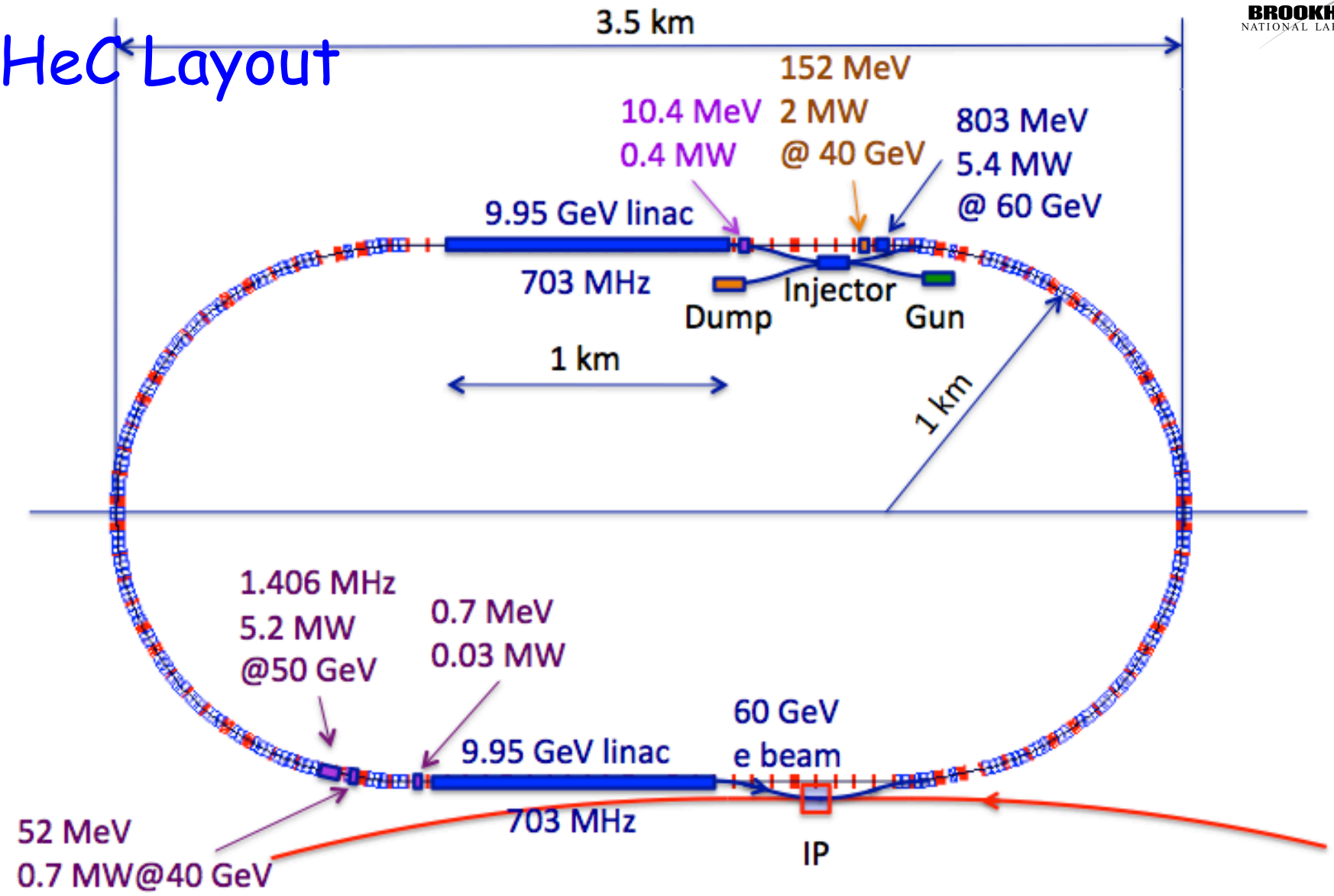
The homogeneous equation of the dispersion function *D* has two solutions: one without dipoles present (=0) and one with the dipoles = 1/ρ

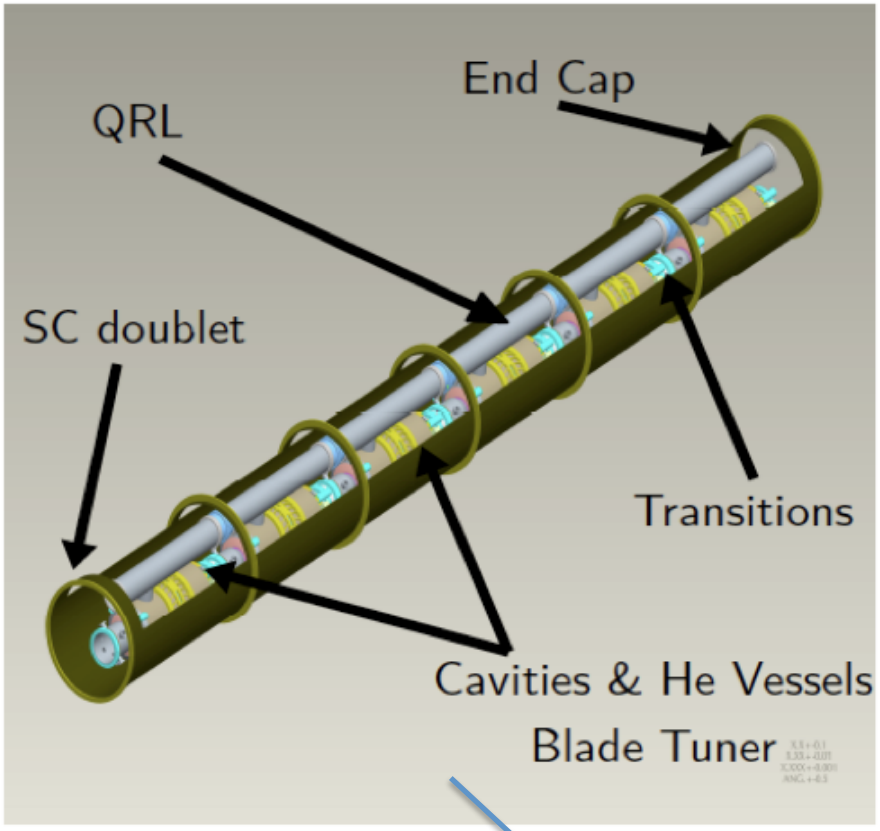


Normalized dispersion in the achromatic cells



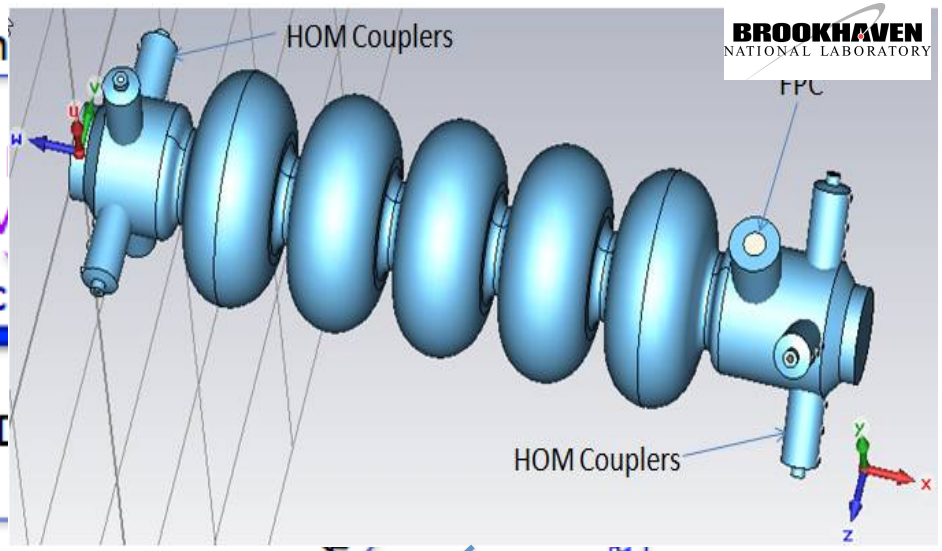
LHeC Layout


3.5 km
152 MeV
10.4 MeV
2 MW
0.4 MW
@ 40 GeV
803 MeV
5.4 MW
@ 60 GeV
9.95 GeV linac
703 MHz
Injector
Dump
Gun
1 km
1 km
1.406 MHz
5.2 MW
@50 GeV
0.7 MeV
0.03 MW
60 GeV
e beam
9.95 GeV linac
703 MHz
IP
52 MeV
0.7 MW@40 GeV


End Cap
QRL
SC doublet
Transitions
Cavities & He Vessels
Blade Tuner

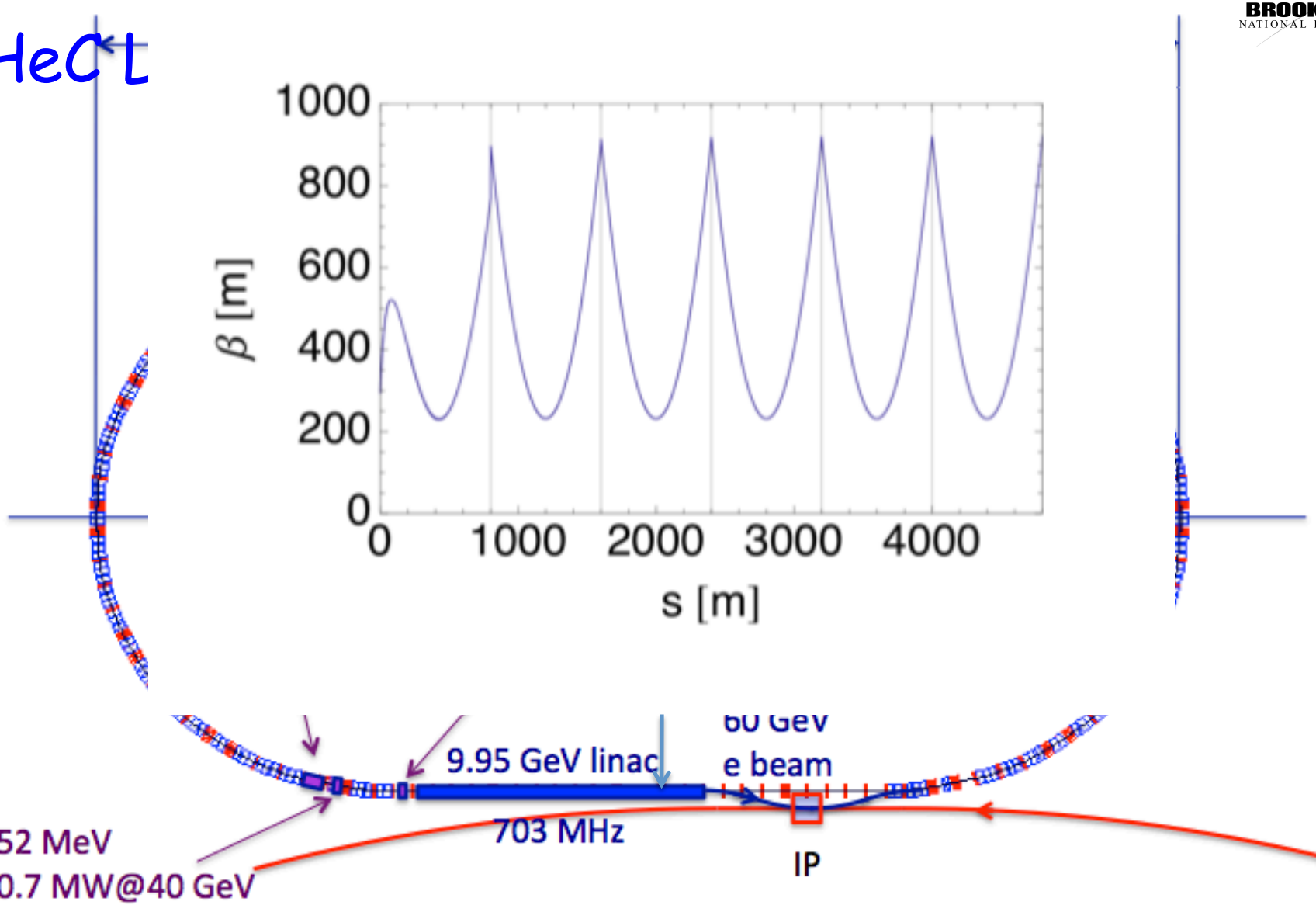
km
152 MeV
2 MW
@ 40 GeV
803 MeV
5.4 MW
@ 60 GeV
nac
Injector
Dump
Gun
1 km
@50 GeV
60 GeV
e beam
9.95 GeV linac
703 MHz
52 MeV
0.7 MW@40 GeV
IP

LHeC Layout

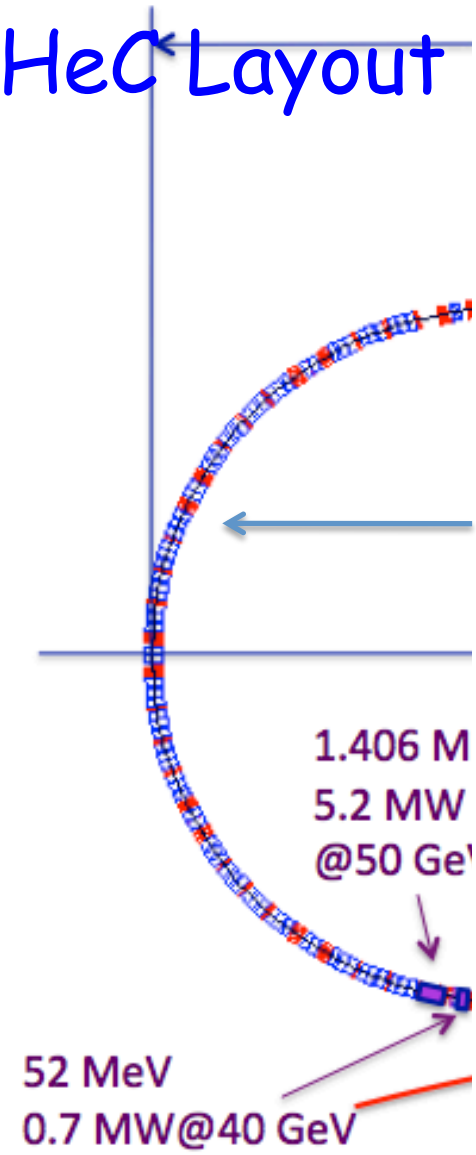

HOM Couplers
BROOKHAVEN
NATIONAL LABORATORY
FPC
HOM Couplers

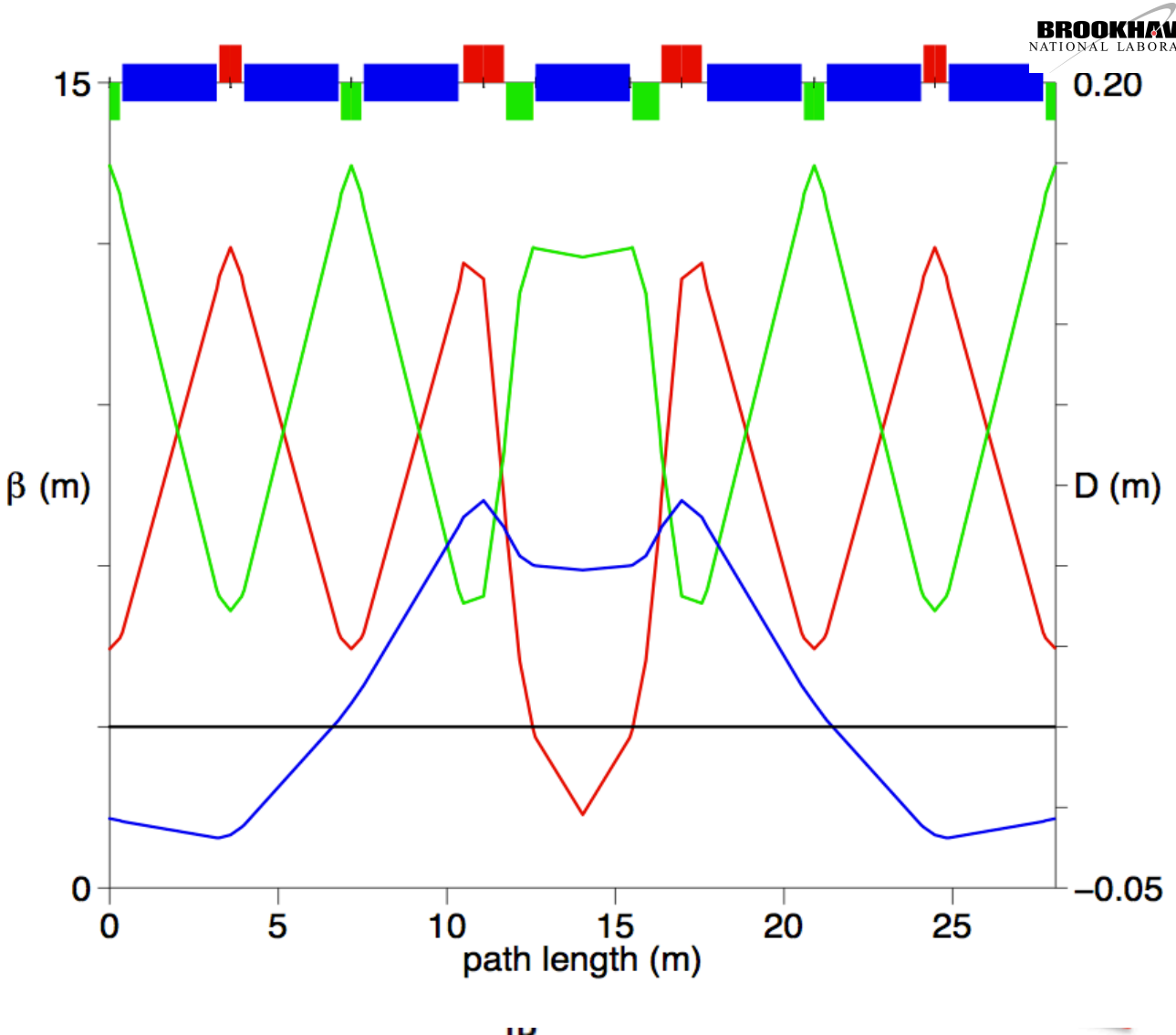
3.5 km
10.4
0.4 M
9.95 GeV linac
703 MHz
1 km
1.406 MHz
5.2 MW
@50 GeV
0.7 MeV
0.03 MW
60 GeV
e beam
9.95 GeV linac
703 MHz
52 MeV
0.7 MW@40 GeV
IP

LHeC-L


1000
800
600
400
200
0
β [m]
0
1000
2000
3000
4000
s [m]
9.95 GeV linac
60 GeV
e beam
703 MHz
52 MeV
0.7 MW@40 GeV
IP

LHeC Layout


1.406 M
5.2 MW
@50 Ge
52 MeV
0.7 MW@40 GeV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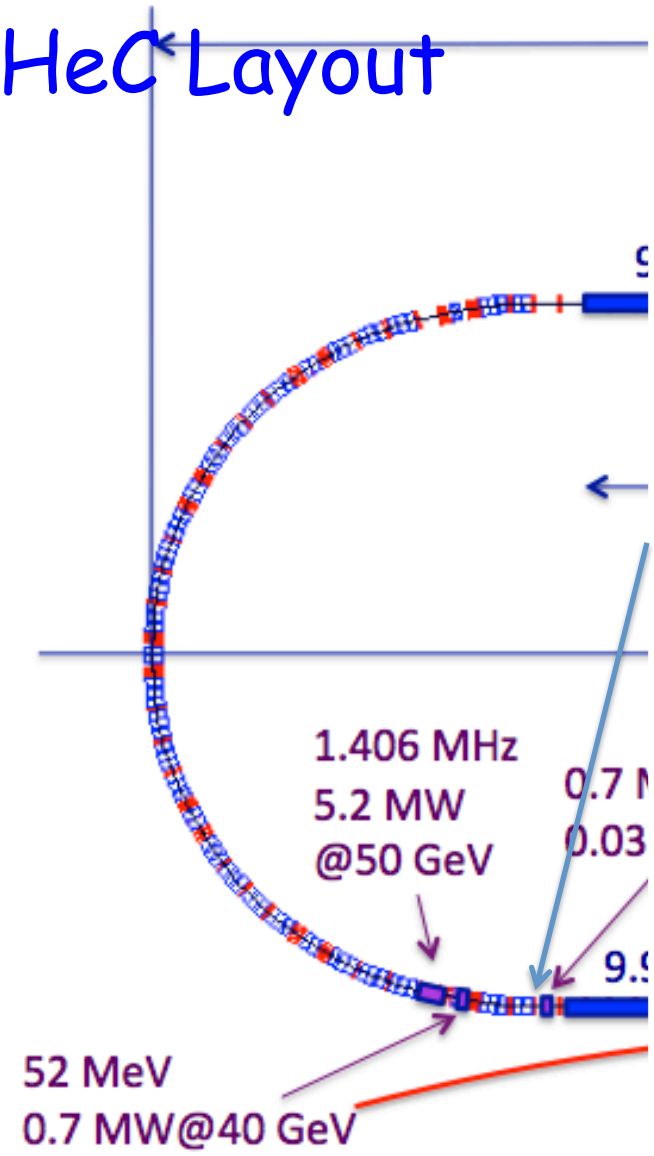
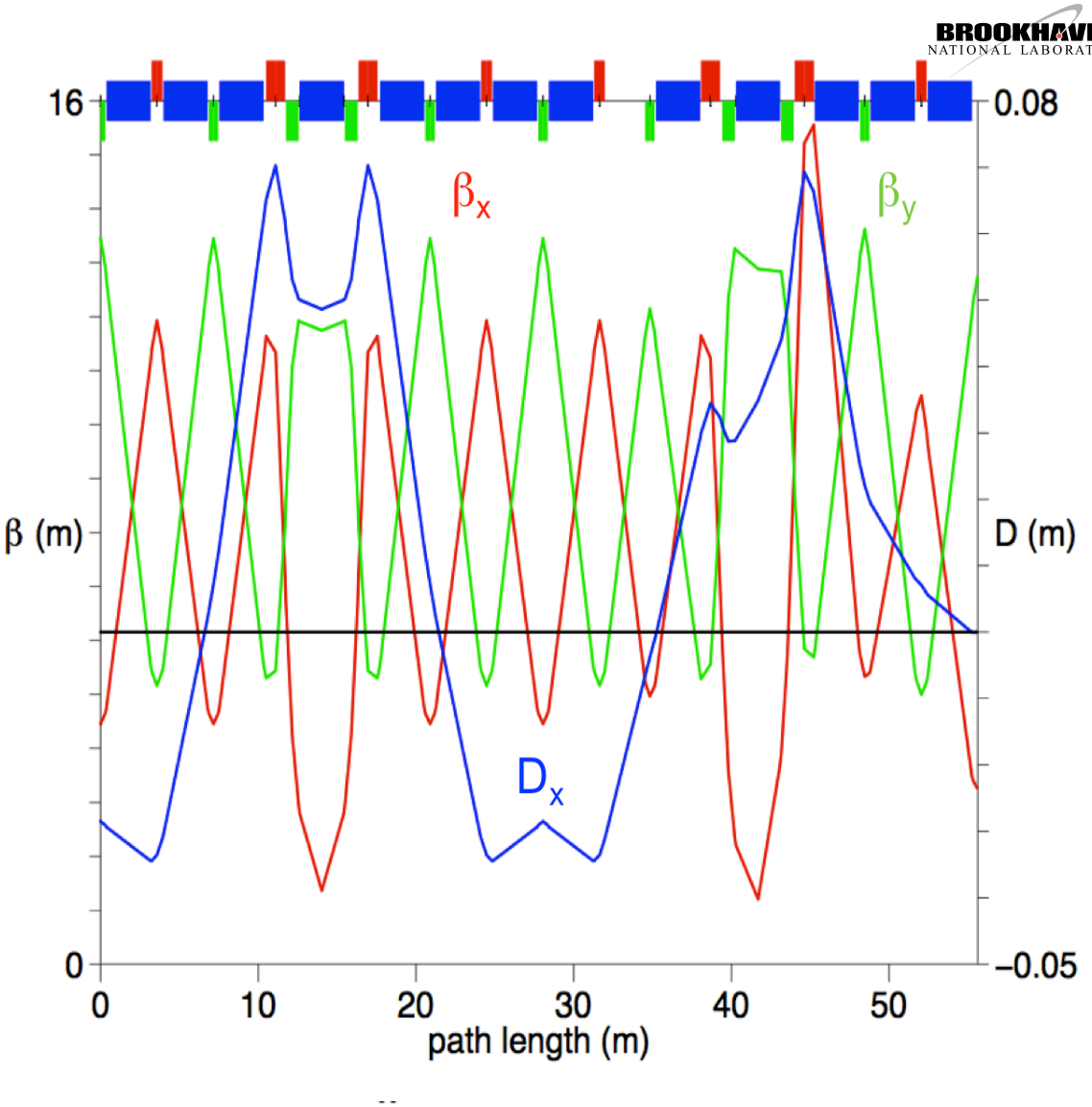
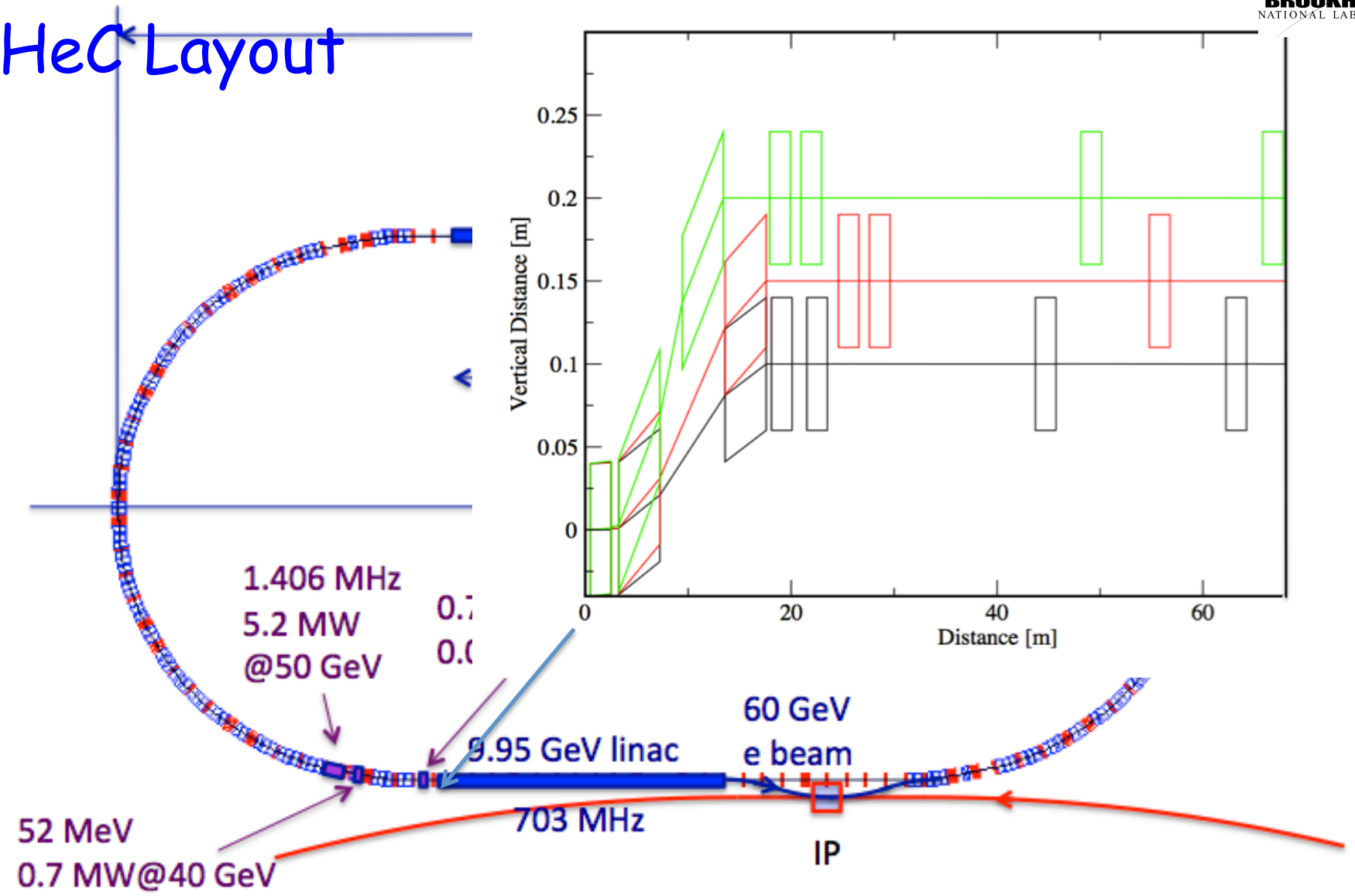
15
0
β (m)
0.20
D (m)
−0.05
0
5
10
15
20
25
path length (m)
IP

LHeC Layout

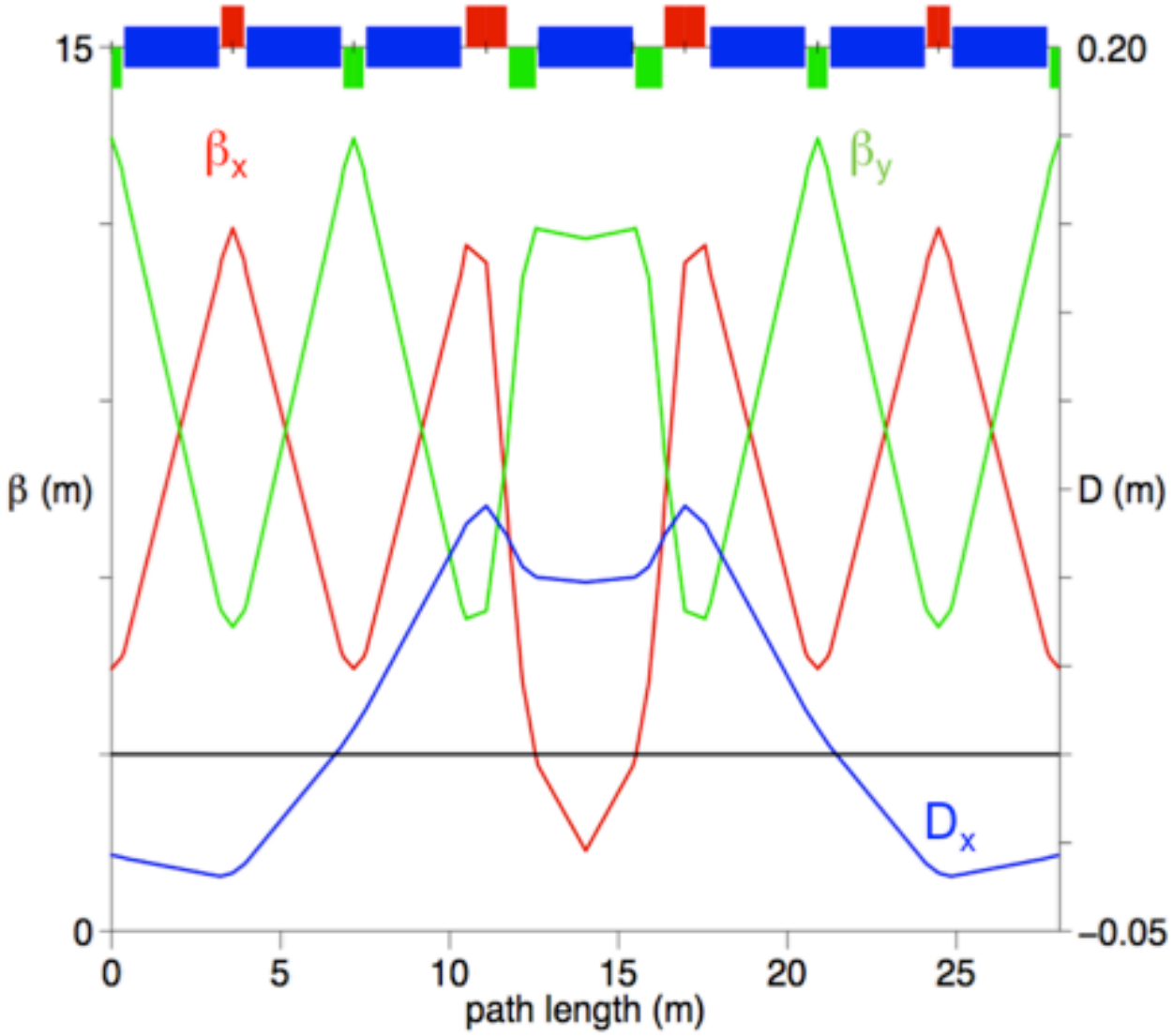

1.406 MHz
5.2 MW
@50 GeV
52 MeV
0.7 MW@40 GeV


16
0
β (m)
0.08
−0.05
D (m)
β_x
β_y
D_x
0
10
20
30
40
50
path length (m)

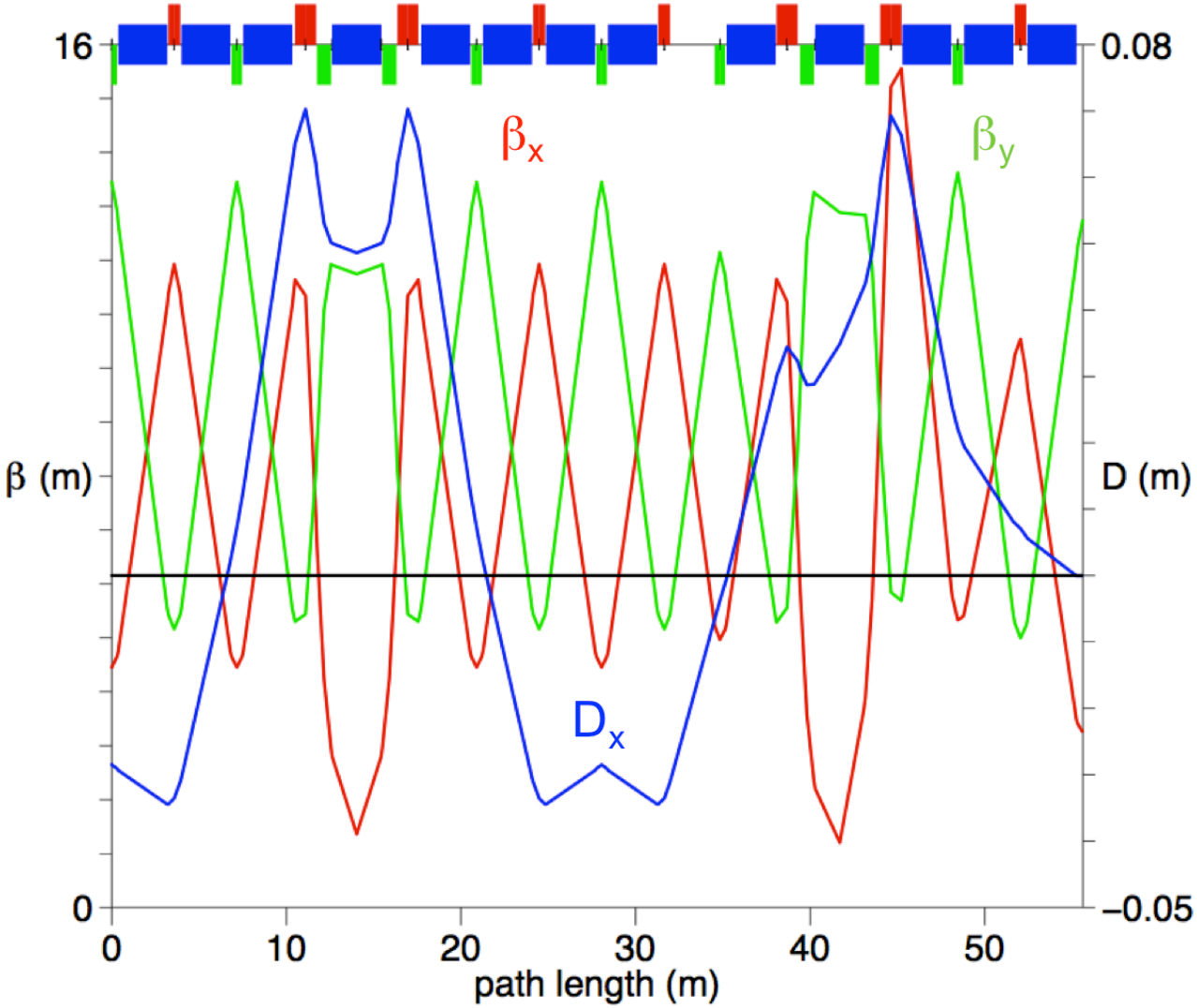
LHeC Layout


1.406 MHz
5.2 MW
@50 GeV
0.7
0.(
9.95 GeV linac
703 MHz
60 GeV
e beam
IP
52 MeV
0.7 MW@40 GeV
Vertical Distance [m]
0.25
0.2
0.15
0.1
0.05
0
0
20
40
60
Distance [m]

Basic arc cell of the LHeC with α=0



Achromatic cell with missing dipole scheme



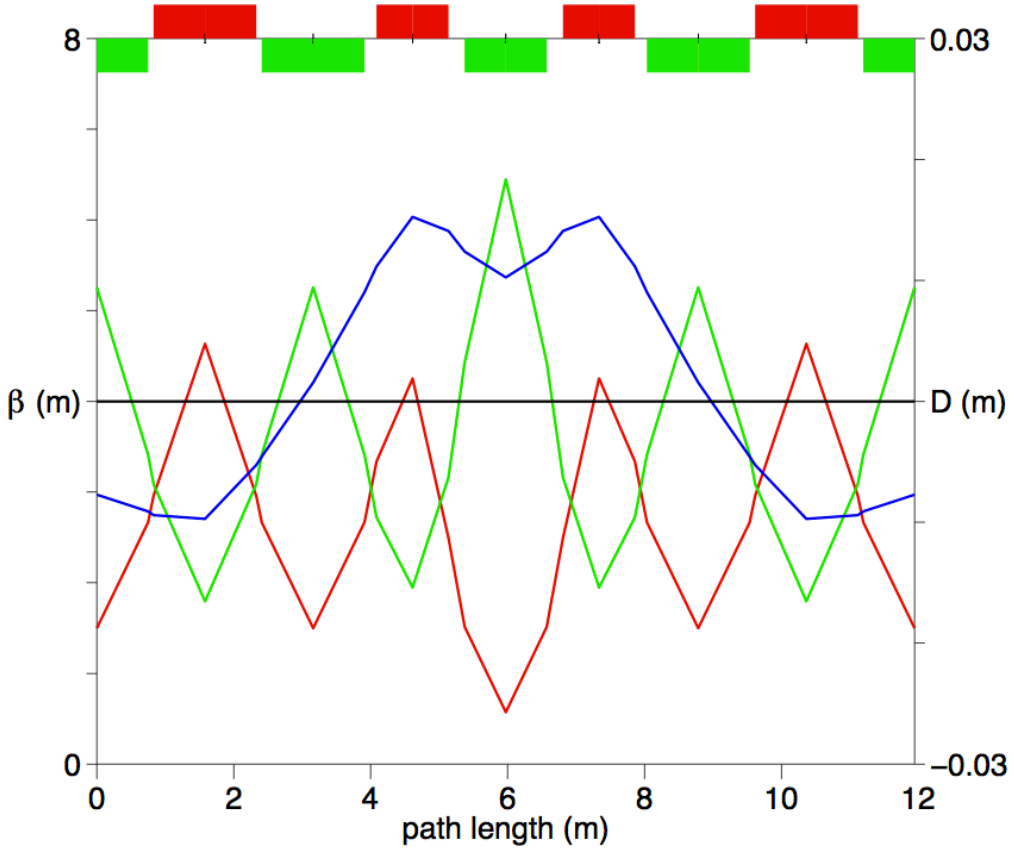
Small emittance strong focusing

Synchrotron Integrals
For separated functions:

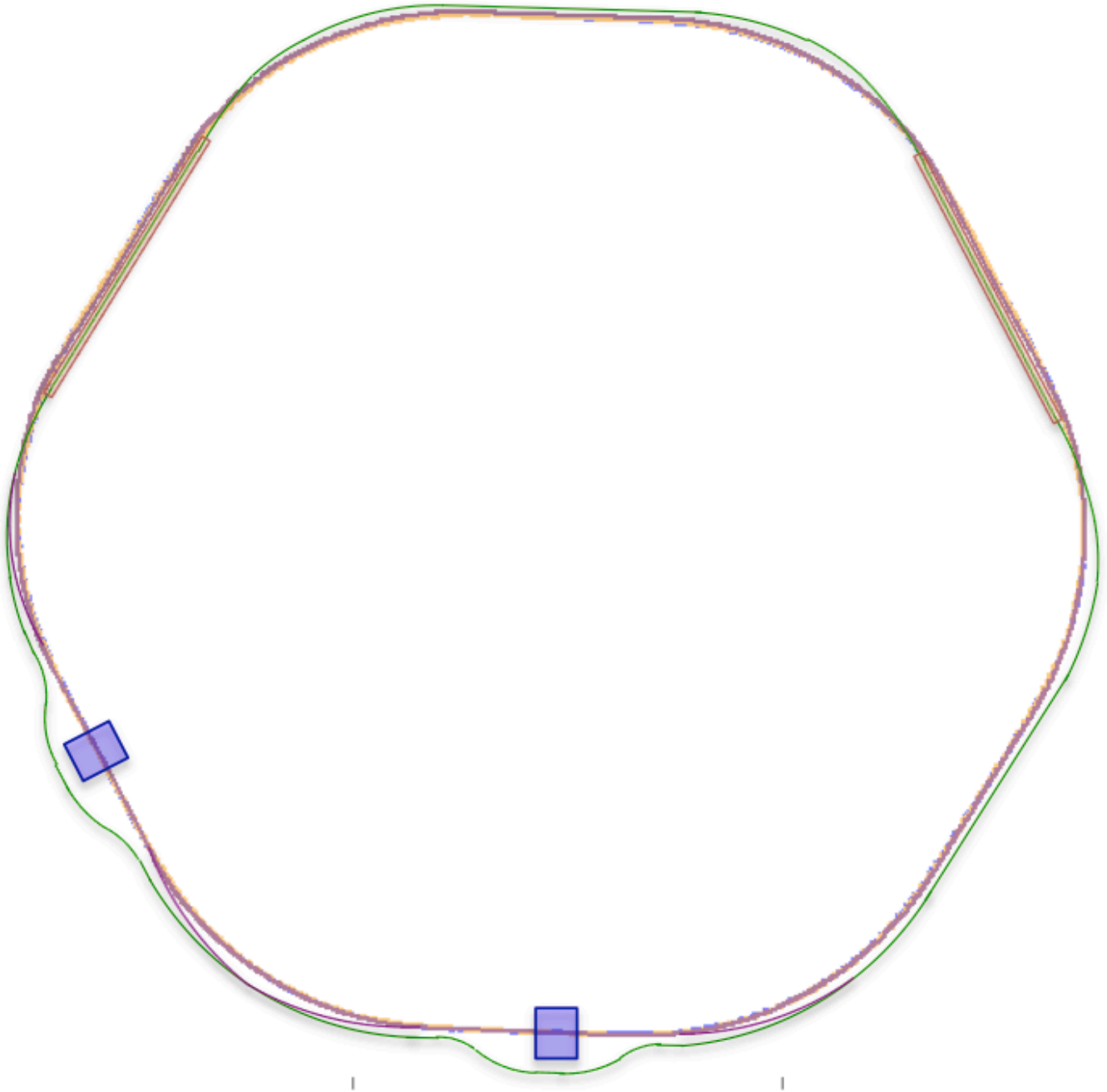
I1 = 0.19008E-01
I2 = 0.89124E-02
I3 = 0.12642E-04
I4 = 0.38244E-07
I5X = 0.10262E-07
EPX = 6.0829 nm rad

Synchrotron Integrals
For the combined function:

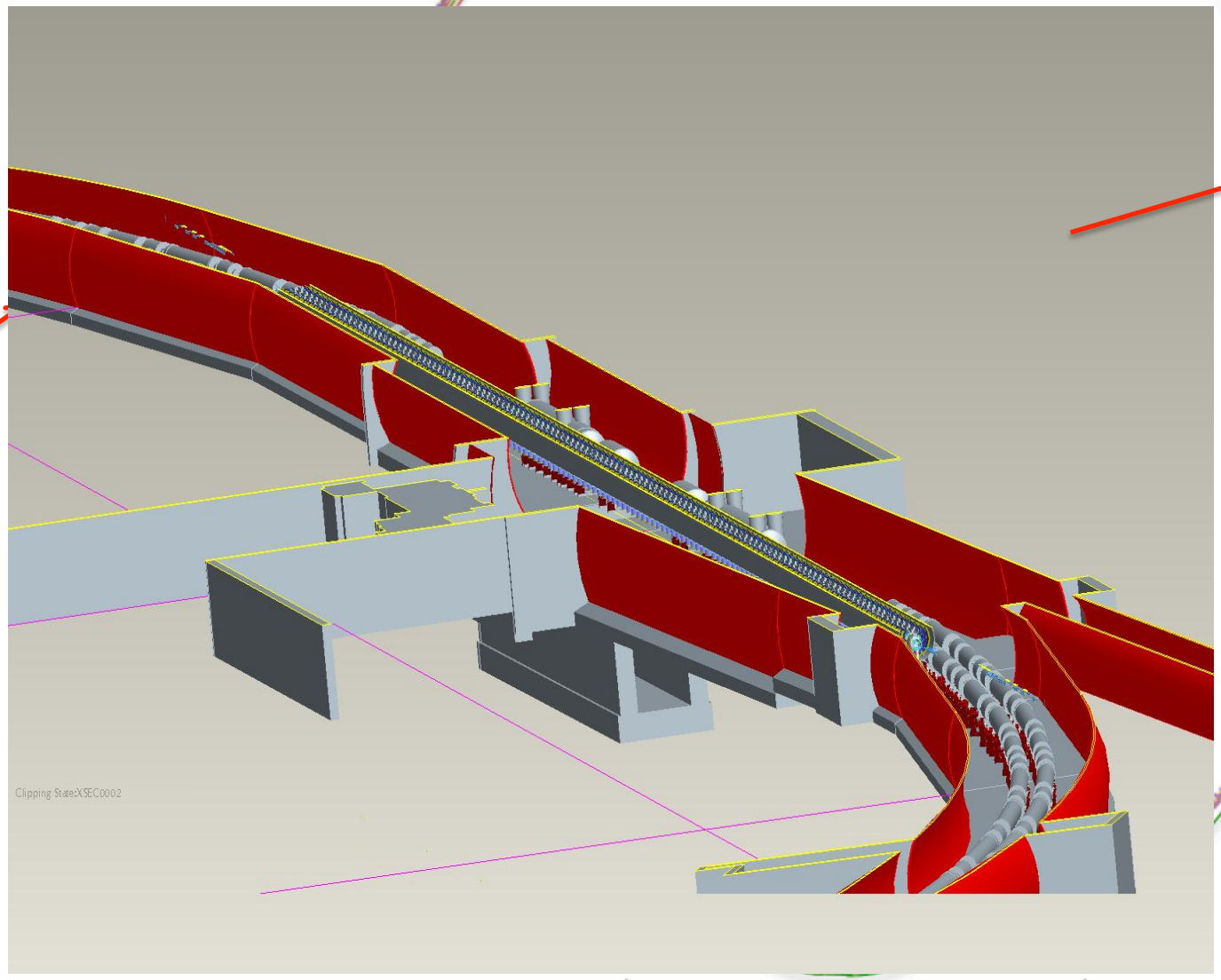
I_1 = 0.55866E-02
I_2 = 0.69494E-02
I_3 = 0.76864E-05
I_4 = 0.13899E-01
I_{5x} = 7.9684E-10



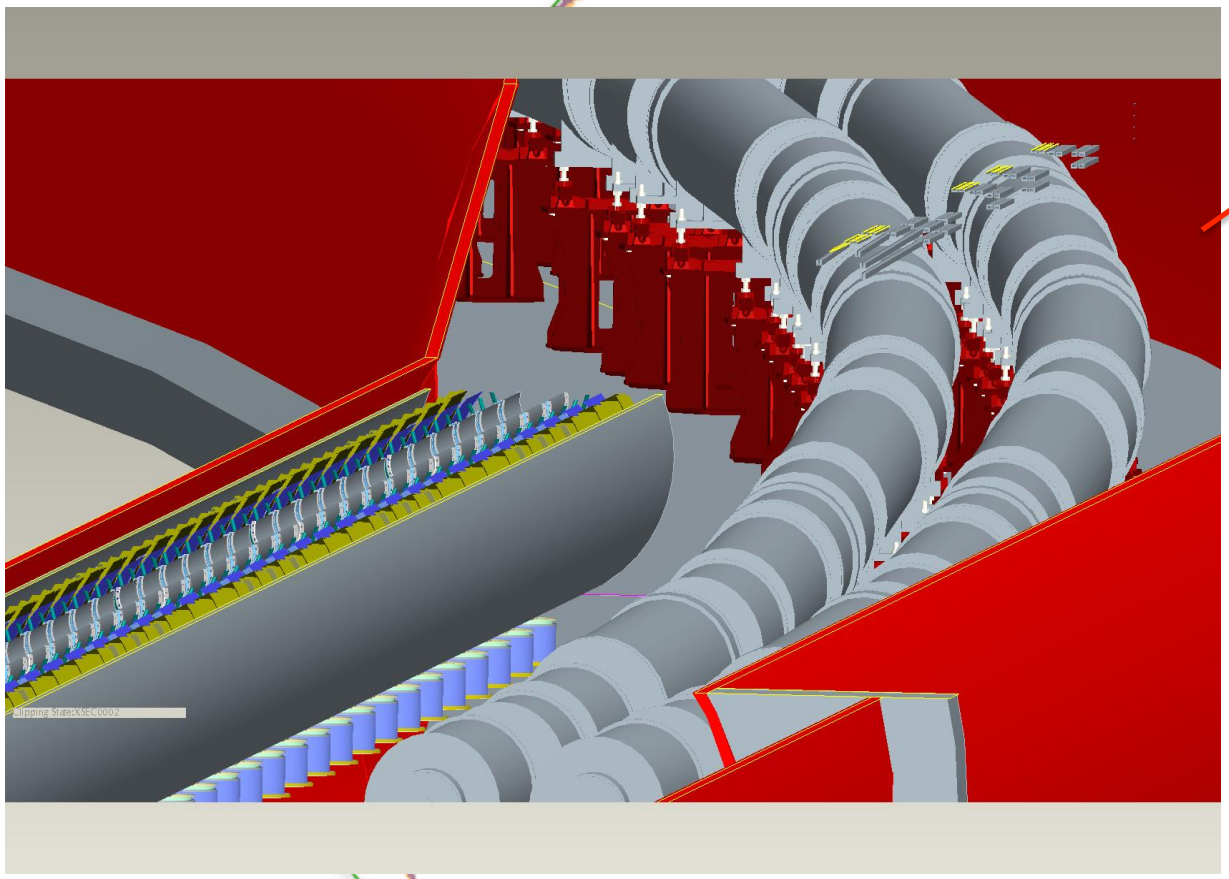
eRHIC



eRHIC



eRHIC



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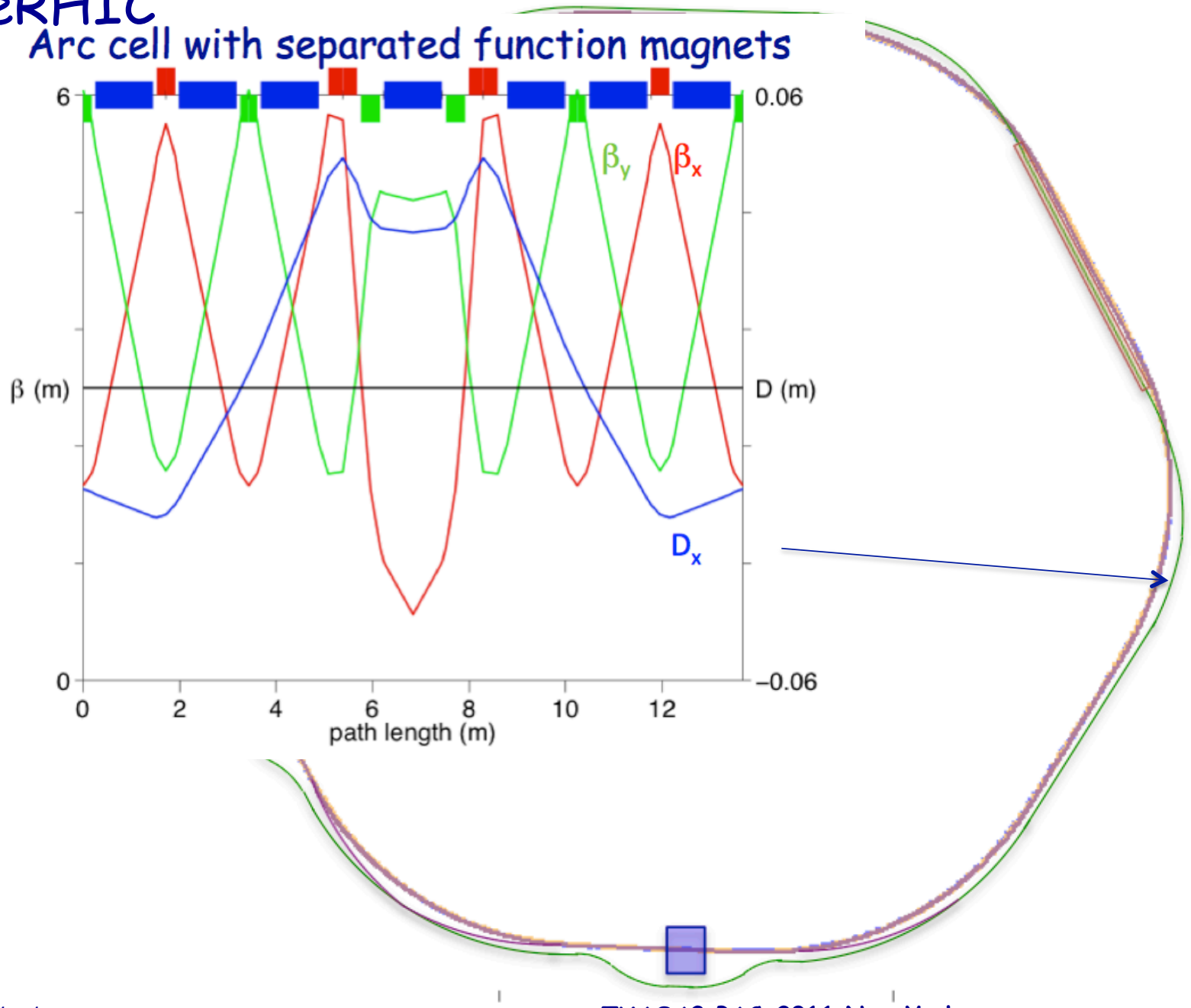
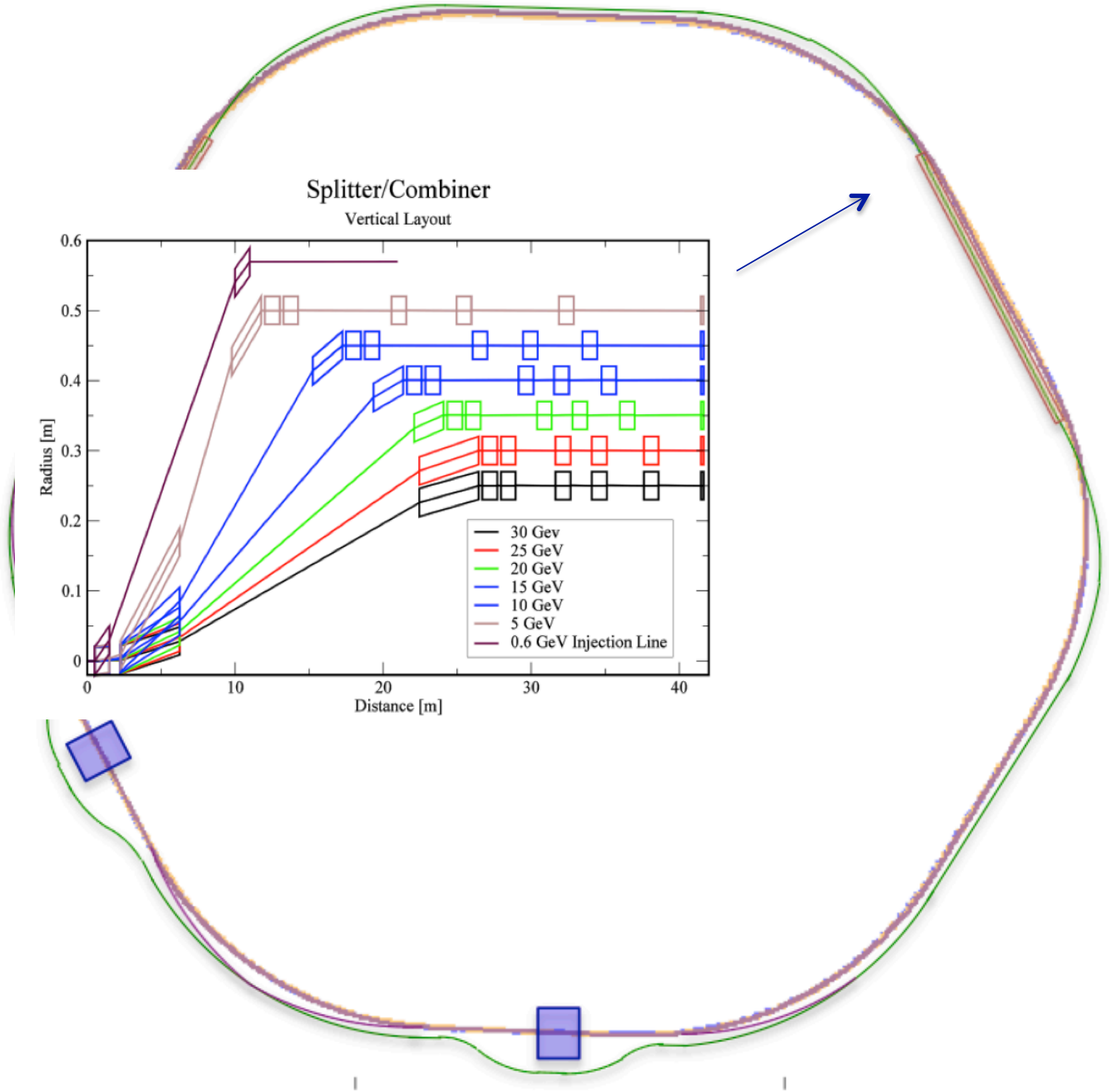
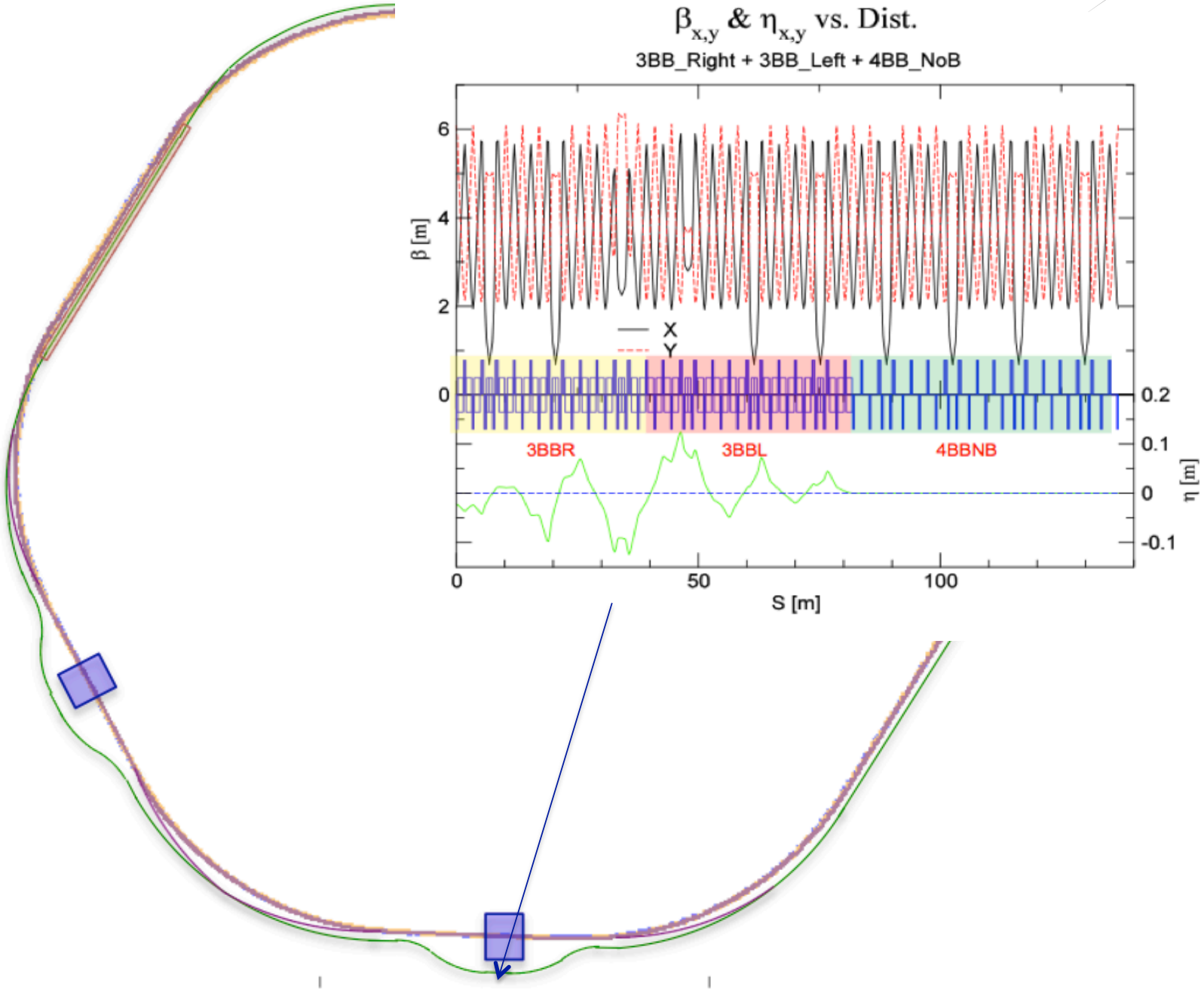
Arc cell with separated function magnets



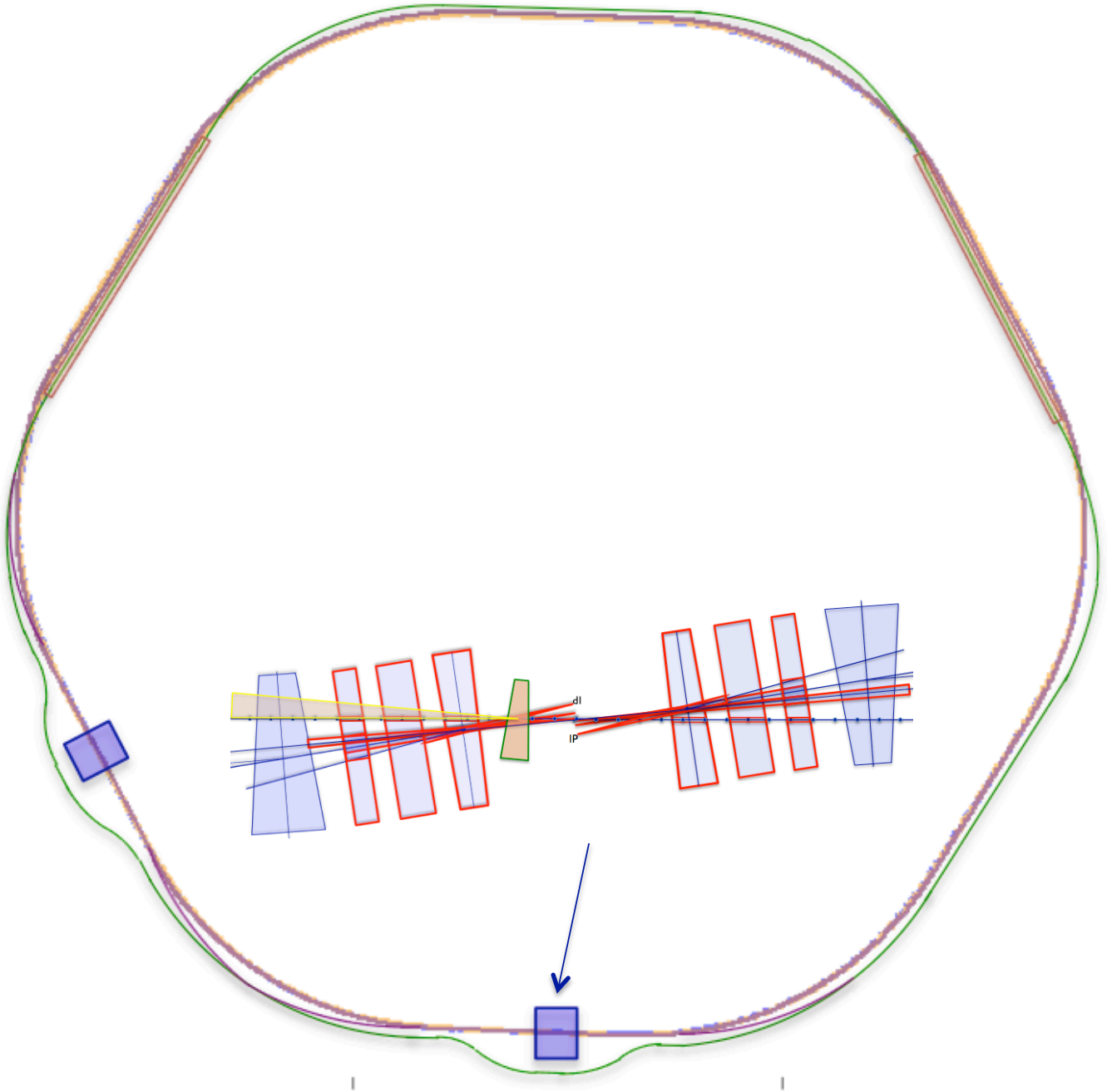
eRHIC


Splitter/Combiner
Vertical Layout
Radius [m]
Distance [m]
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
30 Gev
25 GeV
20 GeV
15 GeV
10 GeV
5 GeV
0.6 GeV Injection Line

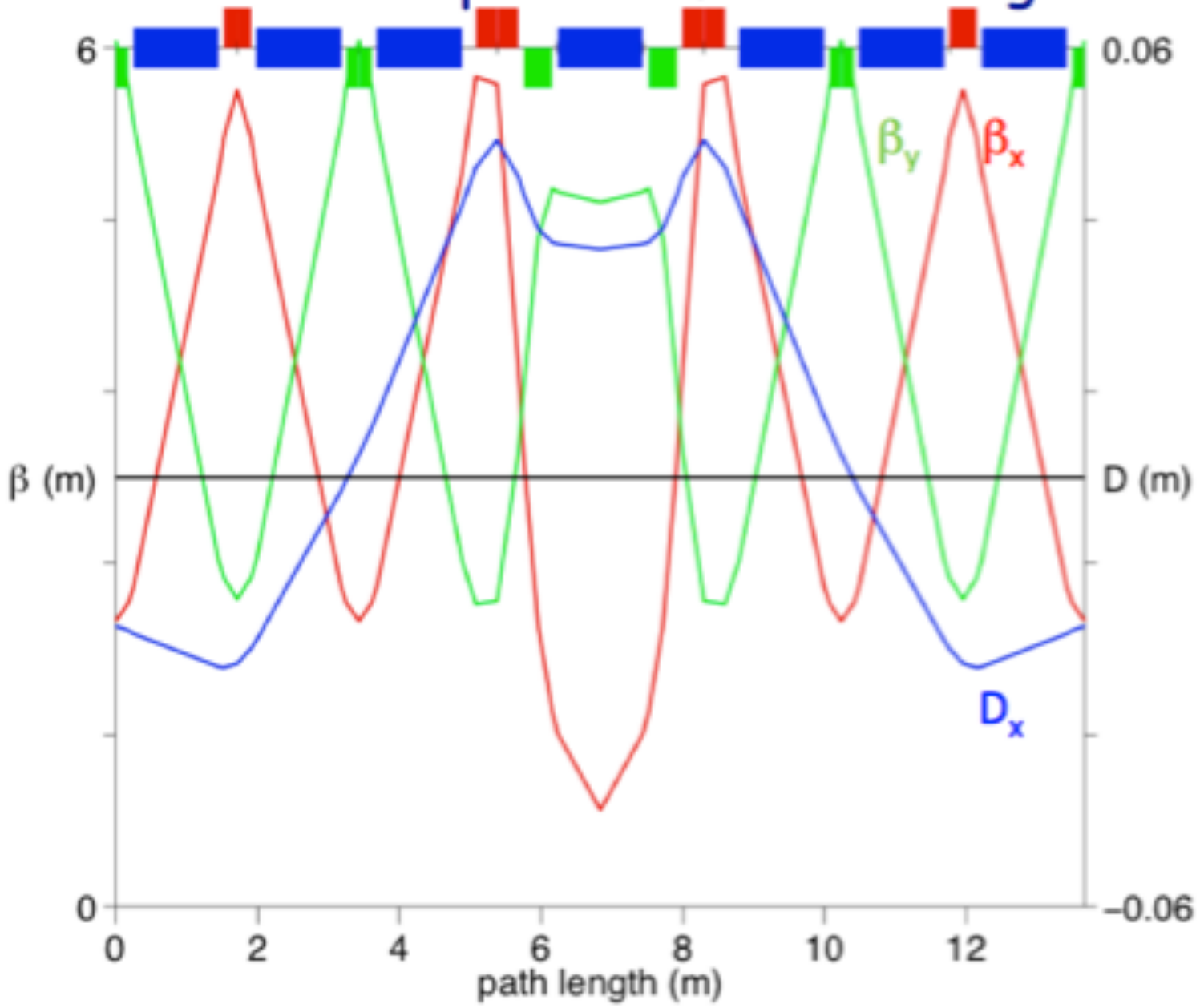
eRHIC


$\beta_{x,y}$ & $\eta_{x,y}$ vs. Dist.
3BB_Right + 3BB_Left + 4BB_NoB
β [m]
X
Y
3BBR
3BBL
4BBNB
η [m]
S [m]
0
50
100
2
4
6
0.2
0.1
-0.1

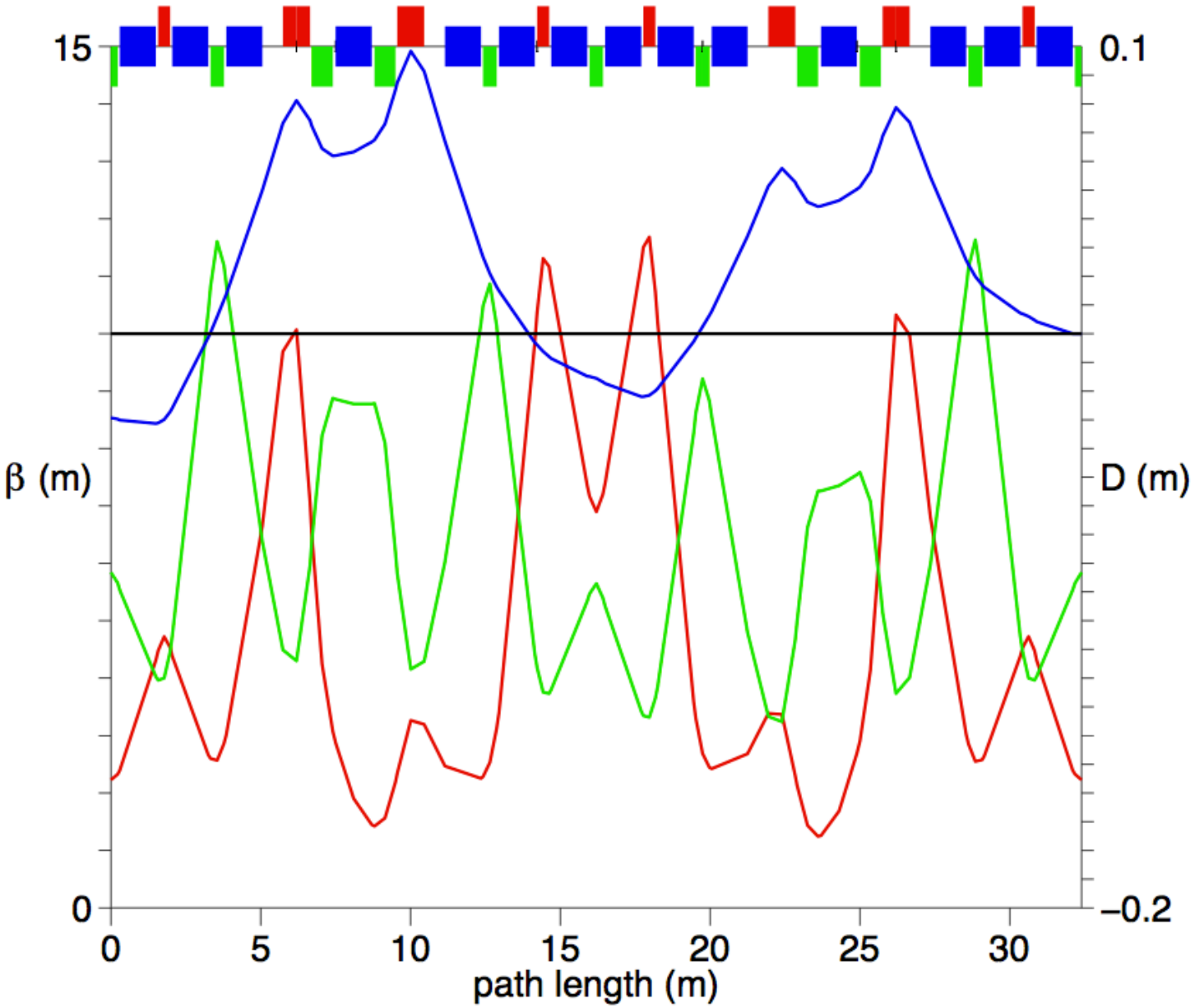
eRHIC



Arc cell with separated function magnets



Achromatic eRHIC cell



Arc lattice with separated function magnets

E_{MAX}=30.0 GeV, BRHO = 100.069228545 Tm

Dipoles:

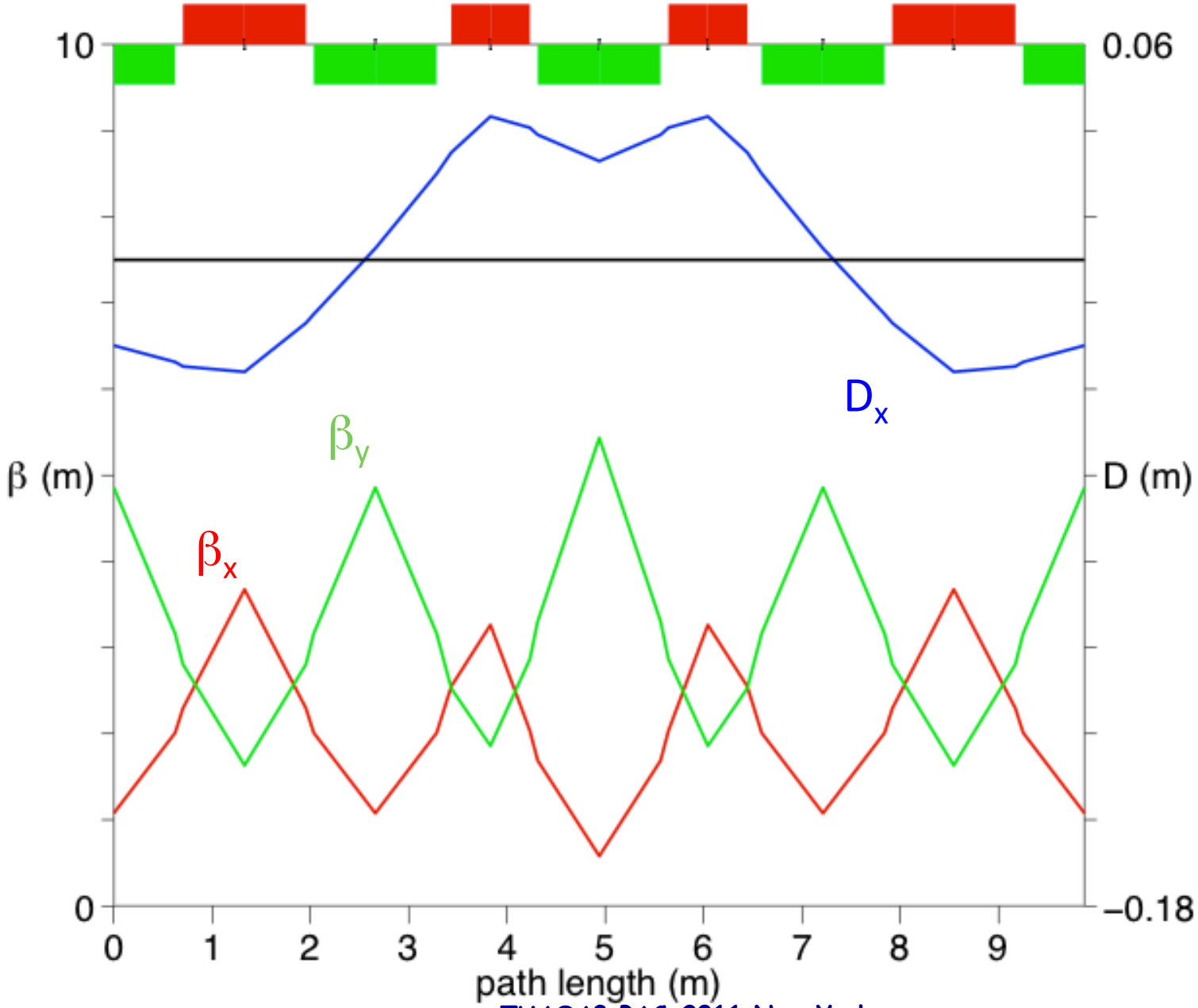
L=1.2 m, θ=0.005123124, B=0.427222589 T,
R=234 m (12 passes 7.5 GW) - 182 dipoles per sextant

Quadrupoles:

L_{fodo}= 0.40 m, G_f = 191.3245 T/m, G_d = -164.3118 T/m
L_{qf3} = 0.60 m, G_f = 212.739 T/m
L_{qd2} = 0.44 m, G_d =-202.53 T/m

Length of the arc cell= 13.6717 m
Seven dipoles per cell, 26 cells = 355.46433 m
Total dipole number per sextant 26•7=182.

Arc cell with combined function magnets



Arc lattice combined function magnets properties

E_{MAX}=30.0 GeV, BRHO = 100.0692 Tm
Combined Function Magnets:
L=1.2 m, θ=0.00356, B=0.28481 T,
R=351 m (For twelve passes deposited energy is 5.0 MW)

Gradients for focusing in the FODO cells:
G_f = 120 T/m and for defocusing G_d = -107 T/m.

Combined function magnets in the middle of the cell:
L_{qf3} = 0.80 m, G_f = 220 T/m L_{qd2} = 1.2 m, G_d =-121 T/m
Length of the arc cell= 9.8740 m
36 cells • 9.8740= 355.46433 m
Total dipole number per sextant 36•(6+2•QLF3/BL)=262.08

SUMMARY

• Lattice design of the future lepton-hadron colliders LHeC and eRHIC based on an ERL, with $M_{5,6}$= 0 as multiple passage electrons through linacs requires from the arcs has been described.

• Arc lattice provide very strong focusing – small size betatron and dispersion functions.

• Linacs lattice is defined by the triplet quadrupoles of the spreaders and combiners.