Progress on the Linac and RLAs

at Jefferson Lab

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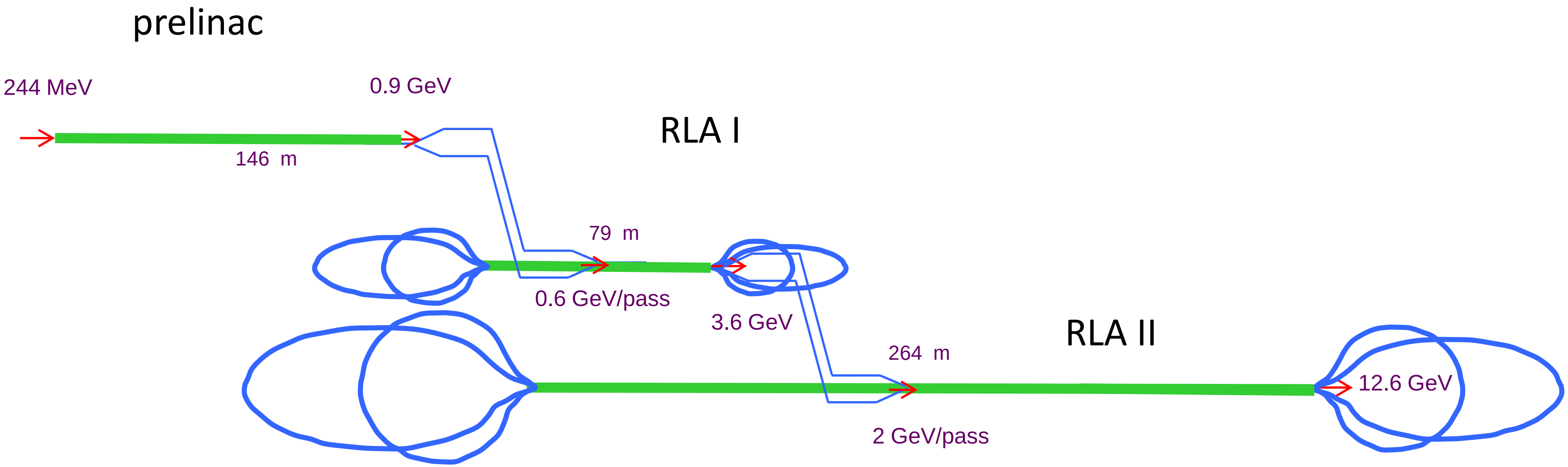
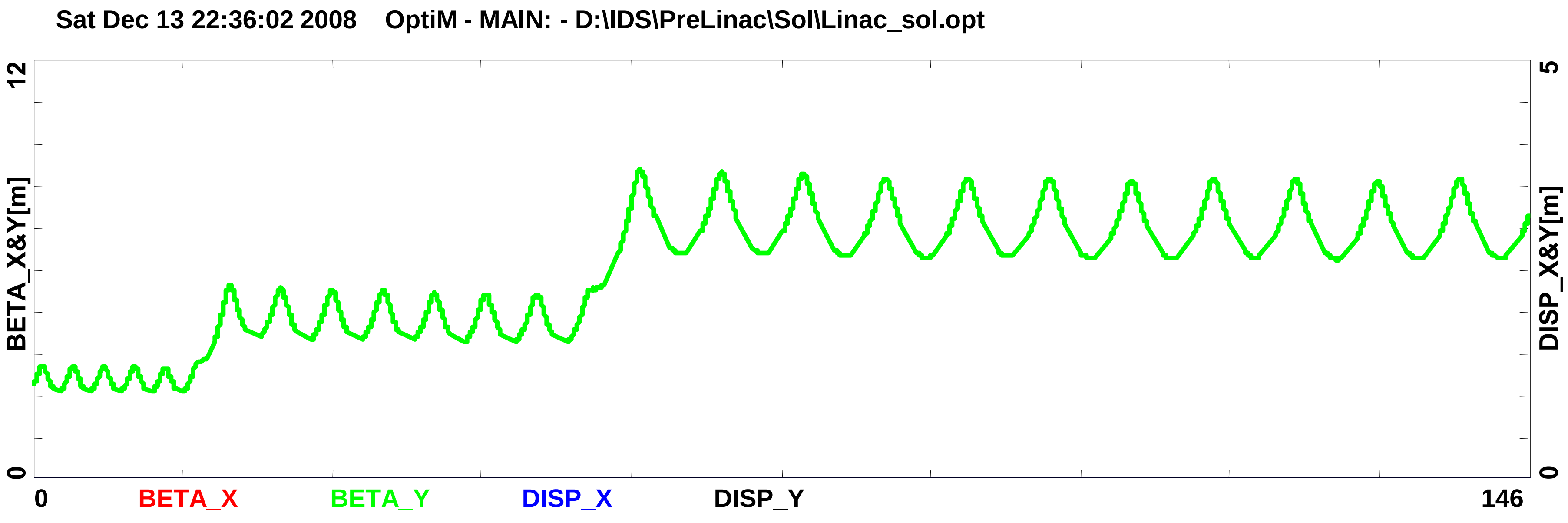
Linac and RLAs – ‘Big picture’



- IDS Goals:
  - Define beamlines/lattices for all components
  - Resolve physical interferences, beamline crossings etc
  - Error sensitivity analysis
  - **End-to-end simulation (machine acceptance)**
  - Component count and costing

Solenoid Linac (244 -909 MeV)



6 short cryos

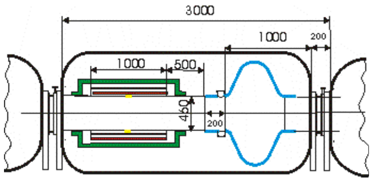
15 MV/m

8 medium cryos

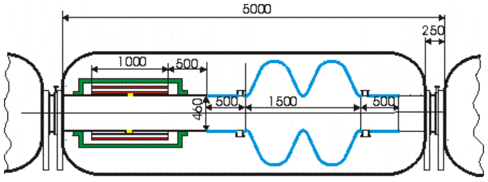
17 MV/m

11 long cryos

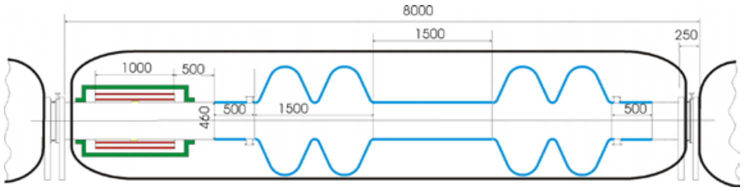
17 MV/m



1.1 Tesla solenoid

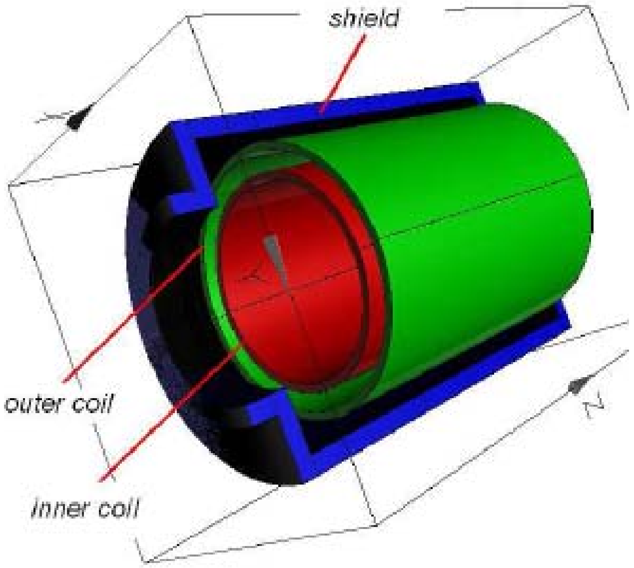


1.4 Tesla solenoid



2.4 Tesla solenoid

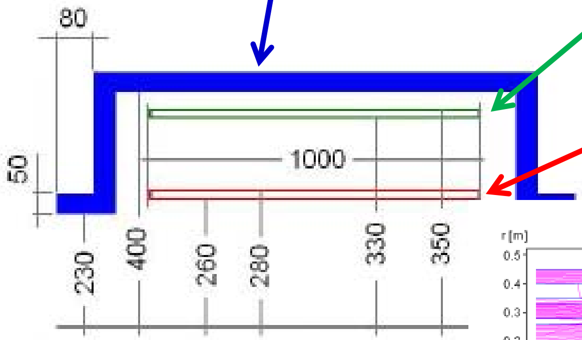
Solenoid Model (Superfish)

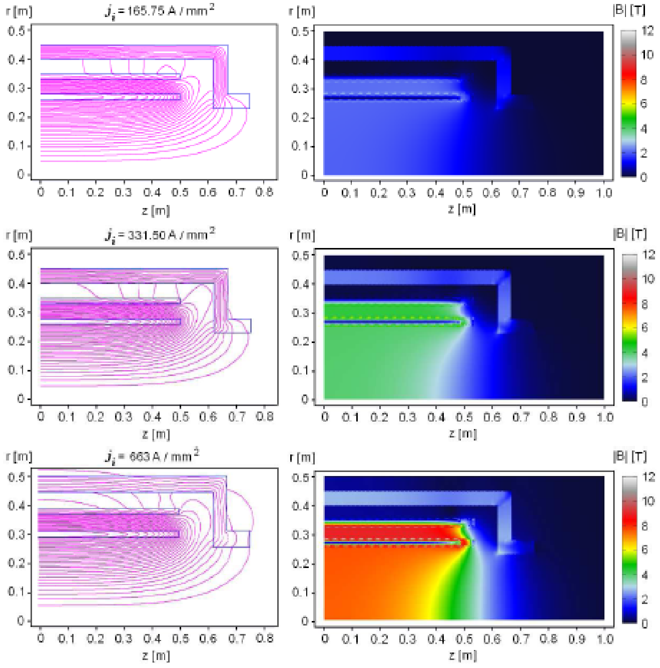


shield

outer coil

inner coil





Morteza Aslaninejad
Cristian Bonţoiu
Jürgen Pozimski

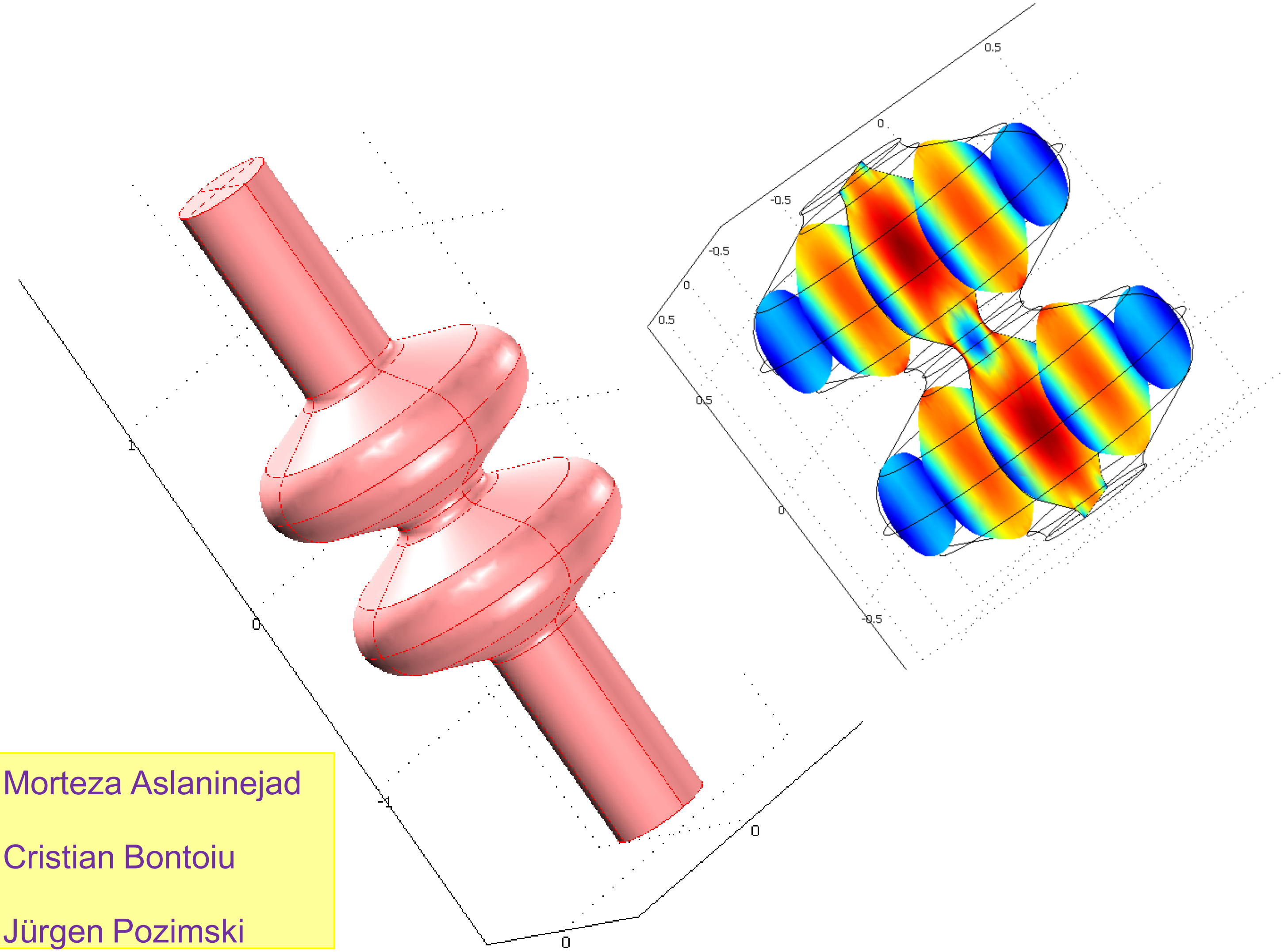
'Soft-edge' Solenoid

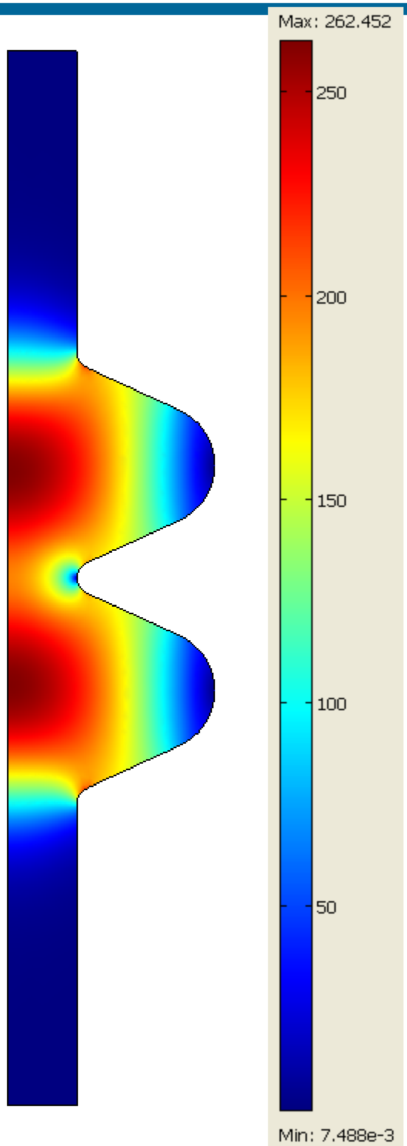
$$B_z(s) = \frac{1}{2}B_0\left[1-\tanh\left(\frac{s-L/2}{a}\right)\right]$$

$$\Phi_{edge} = \frac{1}{2}\left(\frac{e}{pc}\right)^2\left(\int_{-\infty}^{\infty} B_z^2(s)\,ds - B_0^2\,L\right) = -\frac{k^2 a}{8}$$

$$k = \frac{e}{pc}B_0$$

Two-cell cavity (201 MHz) – COMSOL



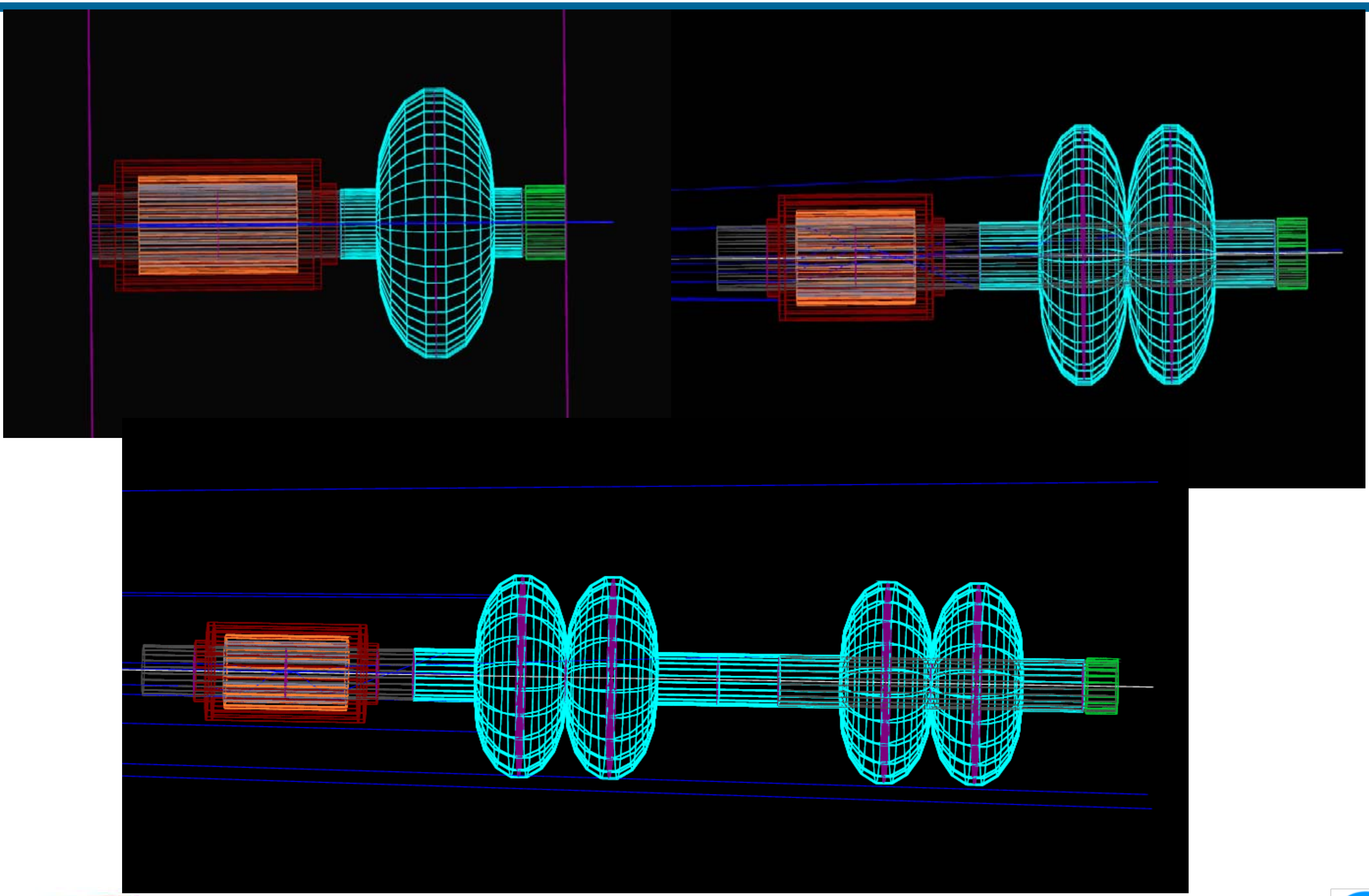


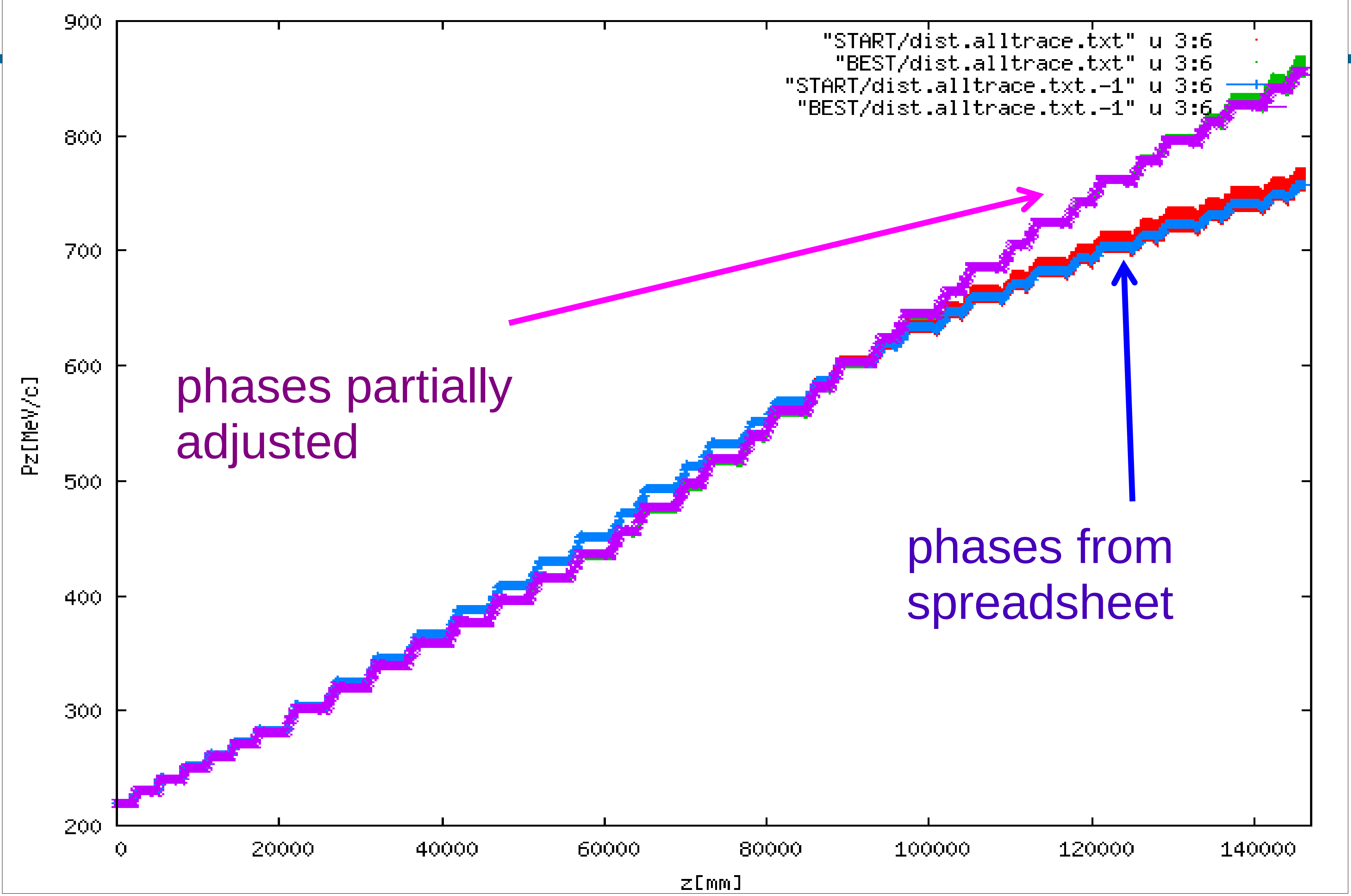
Morteza Aslaninejad

Cristian Bontoiu

Jürgen Pozimski

G4beamline model





phases partially adjusted

phases from spreadsheet

Comparison of GPT, OptiM, g4beamline

GPT

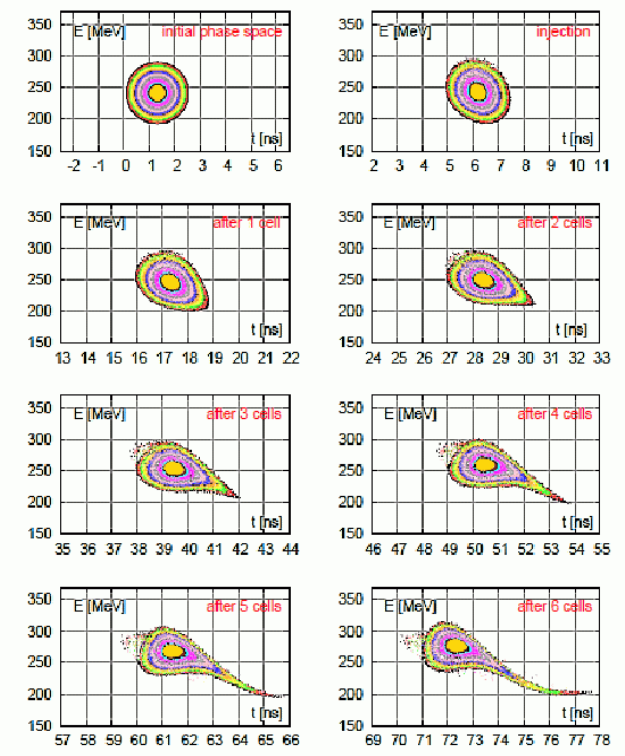
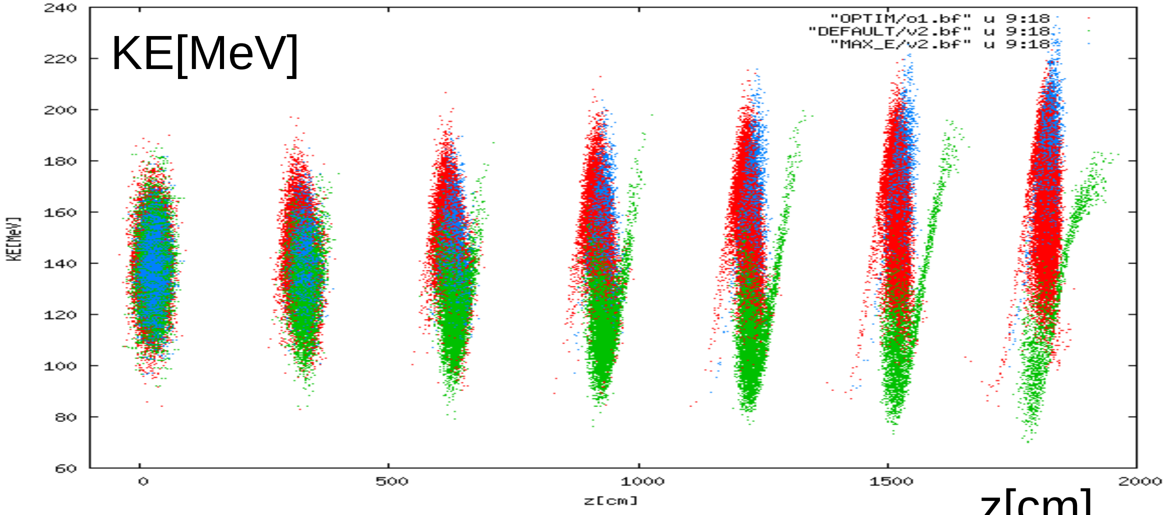
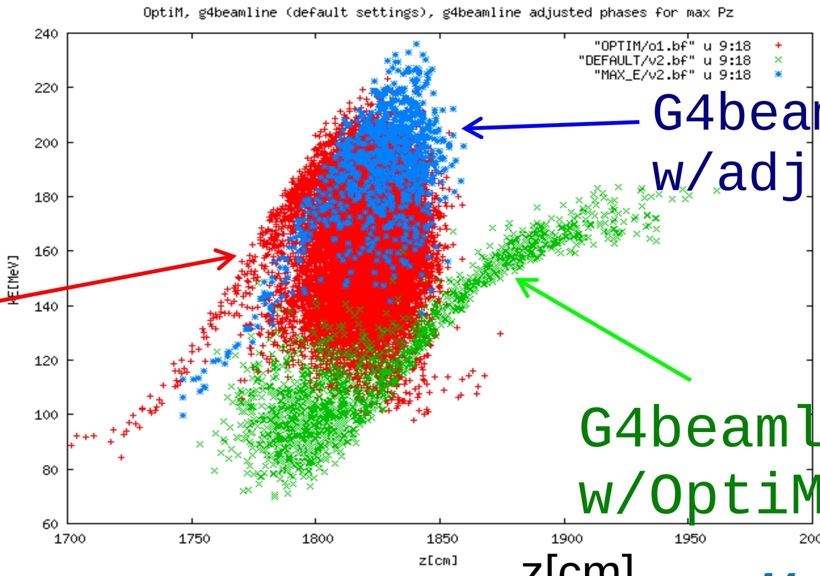


Figure 4: Filamentation of the longitudinal phase space.



KE[MeV]

z[cm]



G4beamline w/adj. φ's

OptiM

G4beamline w/OptiM's φ's

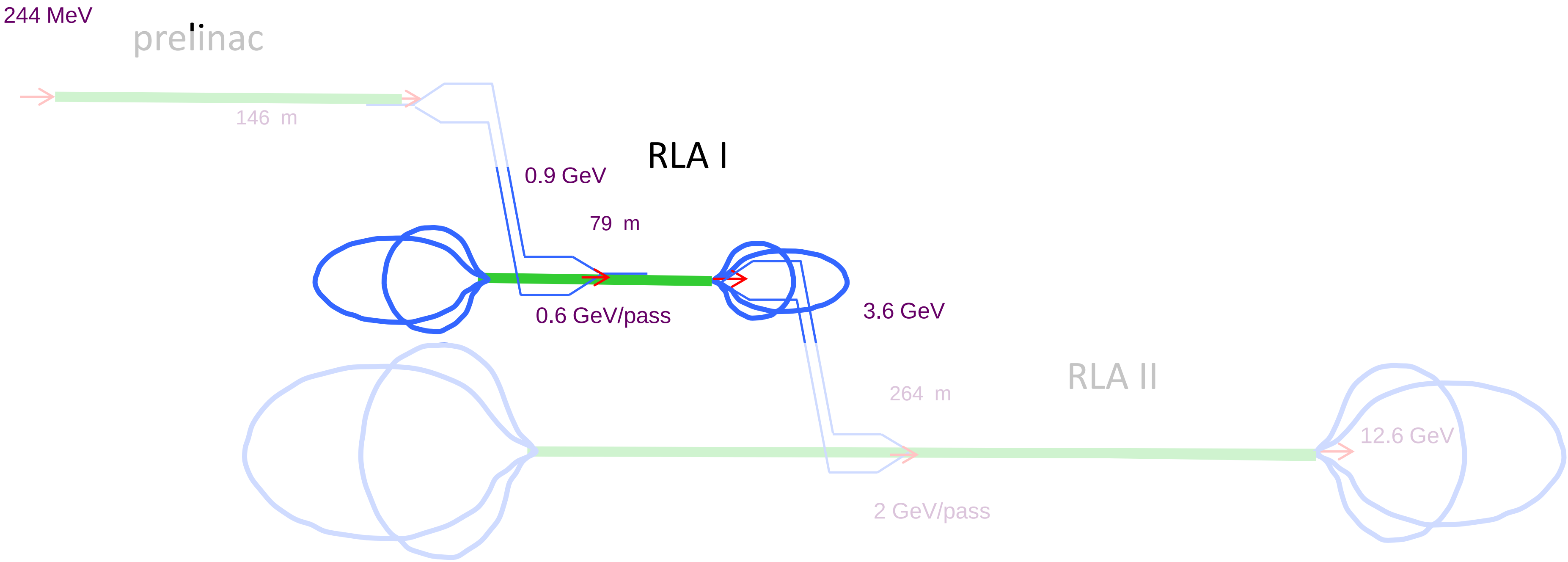
KE[MeV]

z[cm]

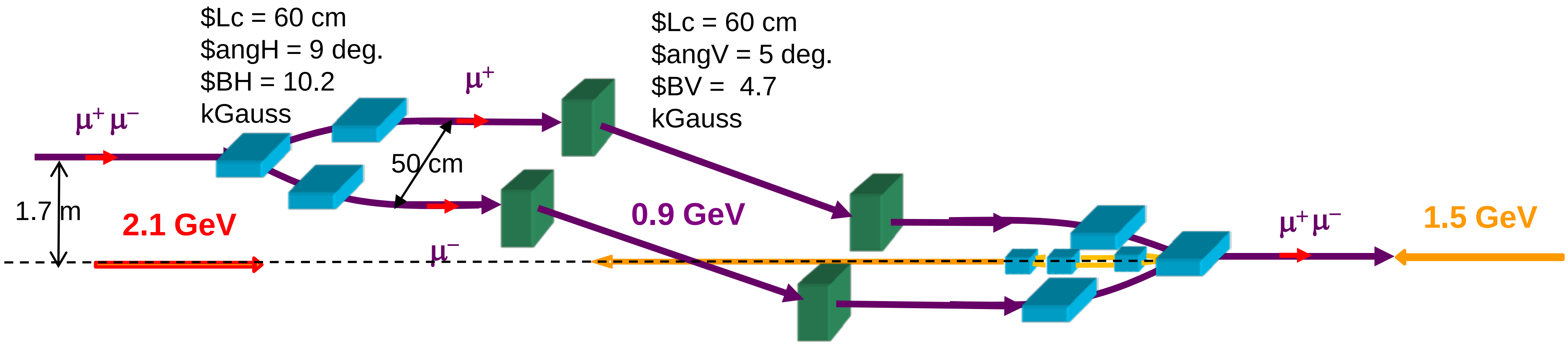
Linac – near term plans

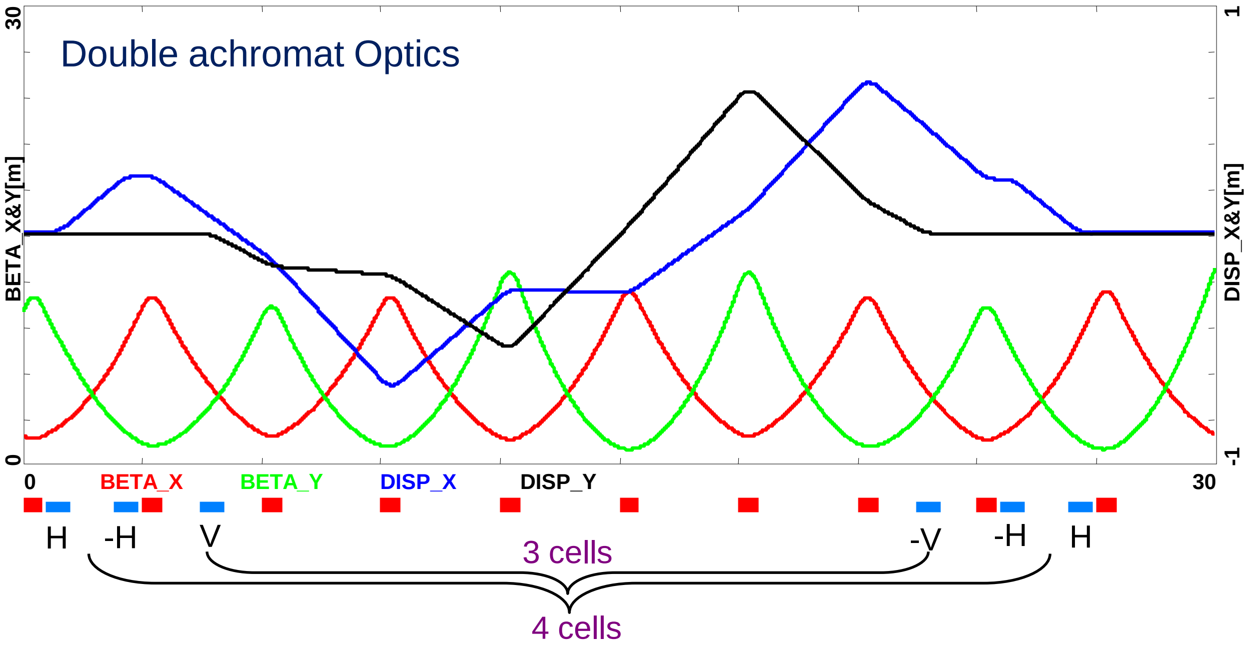
- greatly improve RF phasing capability of G4beamline
- optical rematch of linac to cooling channel
- optimize longitudinal and transverse acceptance
- determine energy deposition in components
- prepare the transfer line to RLA I
- finish the standard for exchanging data files

RLA I


244 MeV
prelinac
146 m
RLA I
0.9 GeV
79 m
0.6 GeV/pass
3.6 GeV
RLA II
264 m
12.6 GeV
2 GeV/pass

Injection/Extraction Chicane

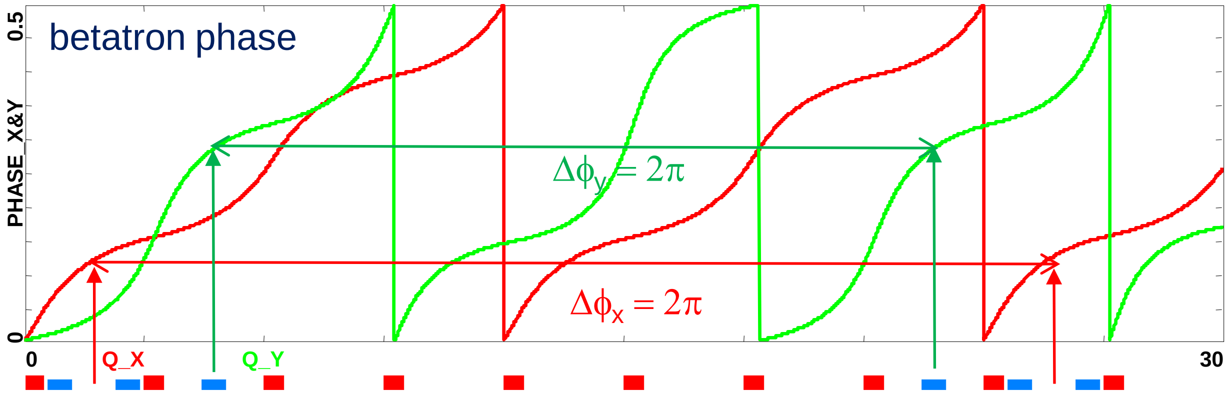


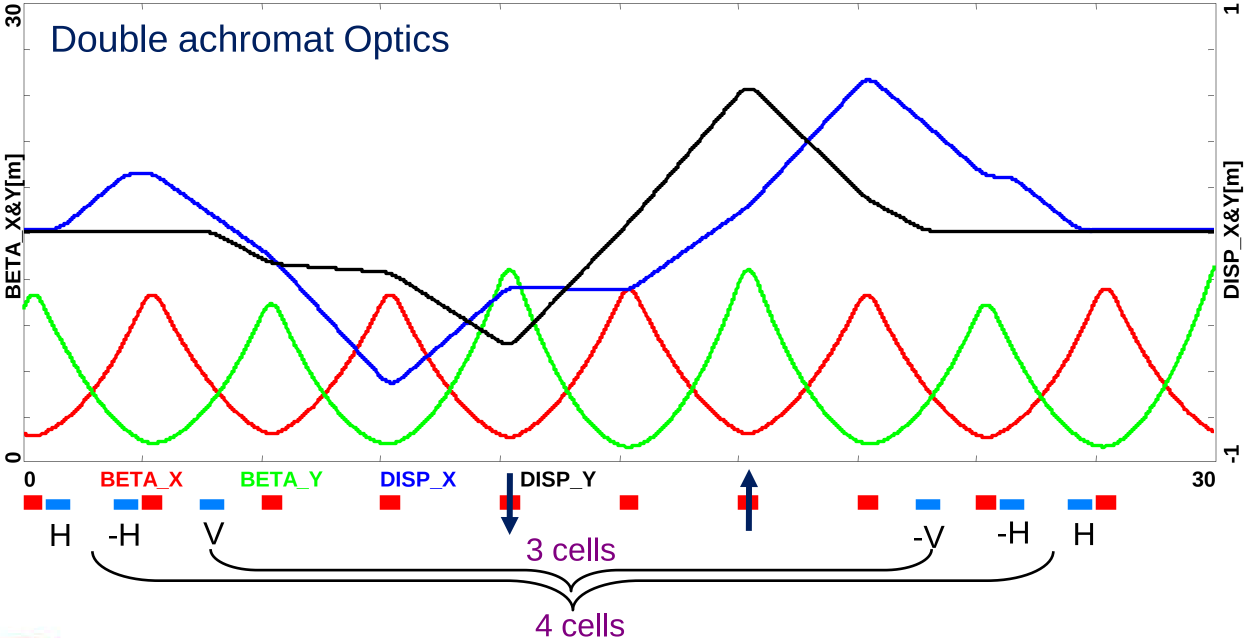


FODO lattice:

$90^0/120^0$ (h/v) betatron phase adv. per cell

Chicane - Double Achromat Optics





FODO quads:

L[cm] = 50

F: G[kG/cm] = 0.322

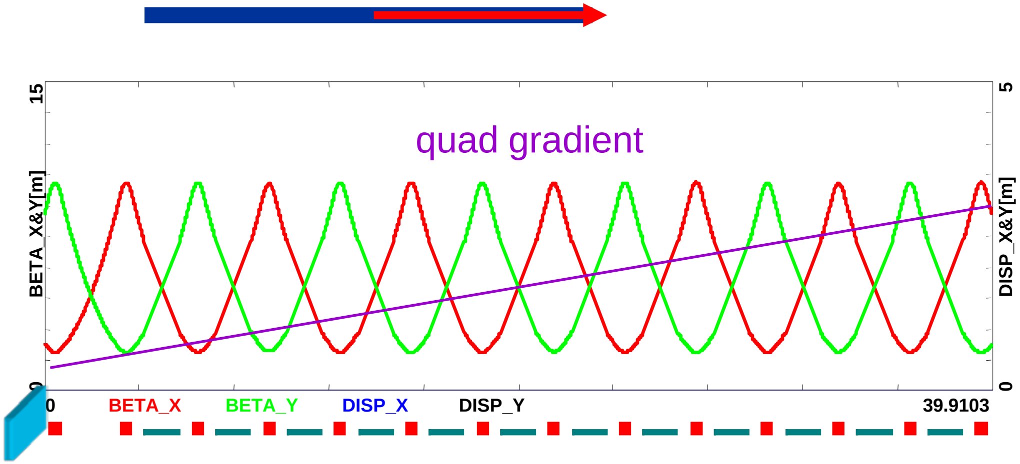
D: G[kG/cm] = -0.364

sextupole pair to correct vert. emittance dilutoin

Multi-pass Linac Optics – Bisected Linac

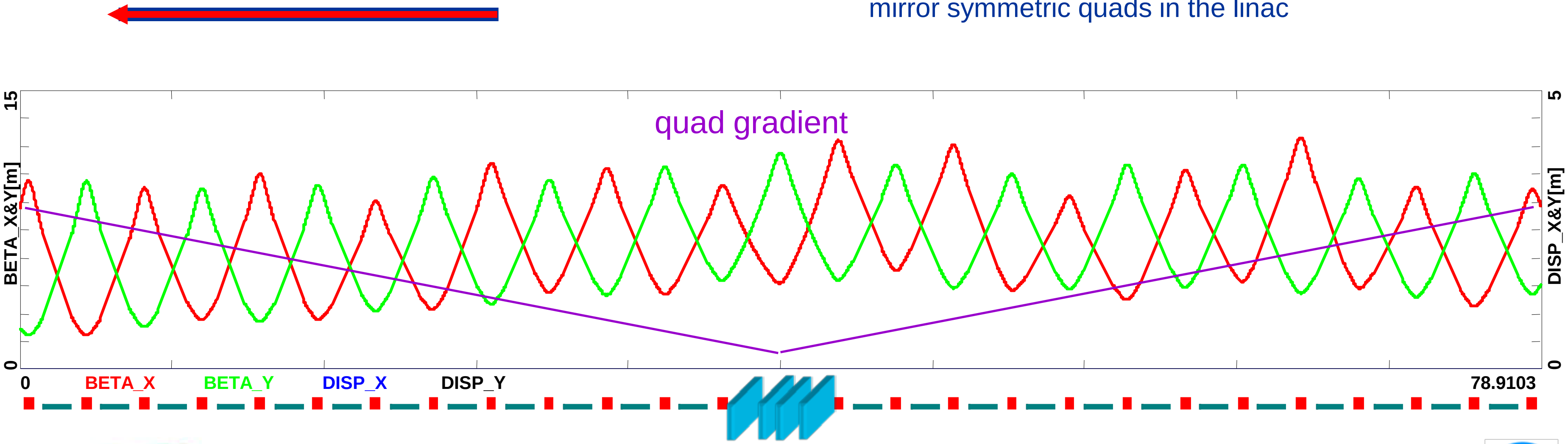
‘half pass’ , 900-1200 MeV

initial phase adv/cell 90 deg. scaling quads with energy

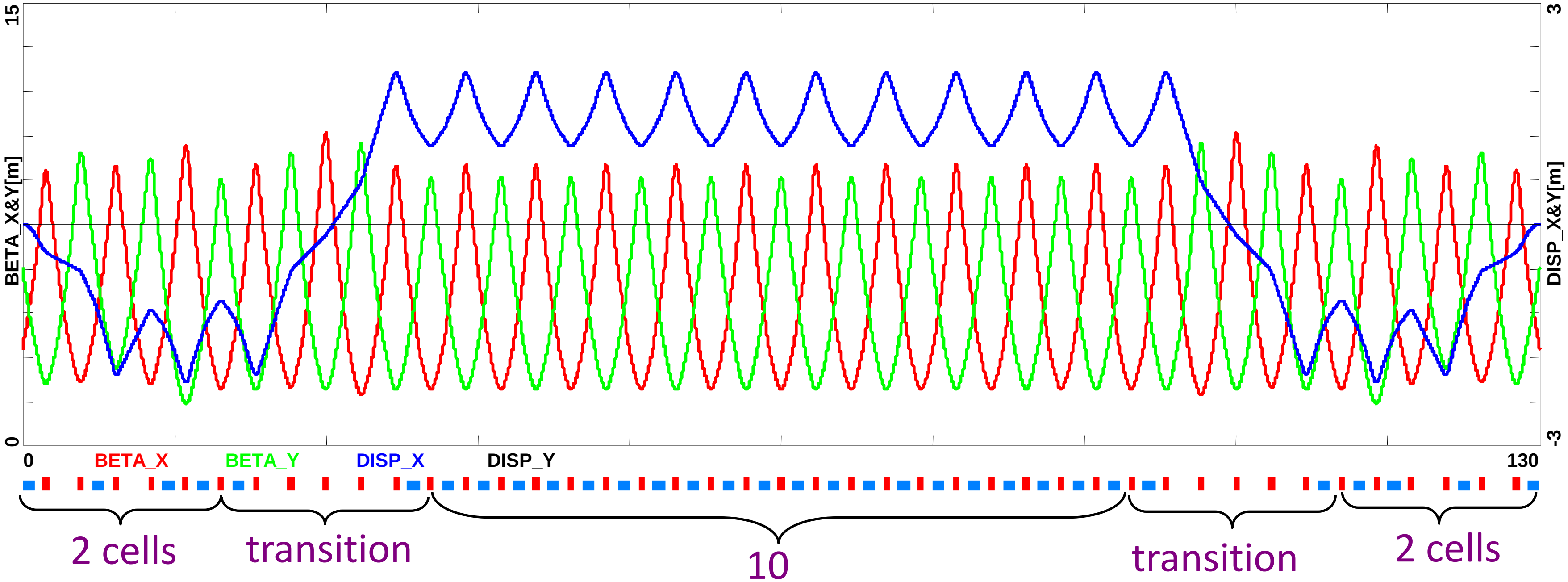


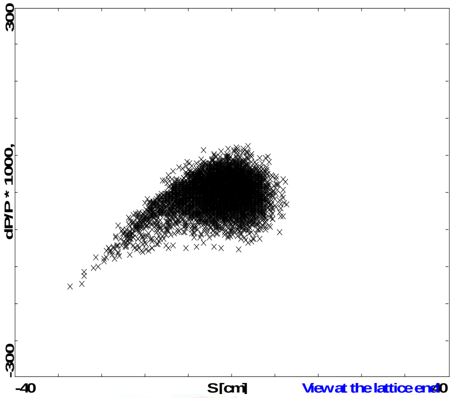
1-pass, 1200-1800 MeV

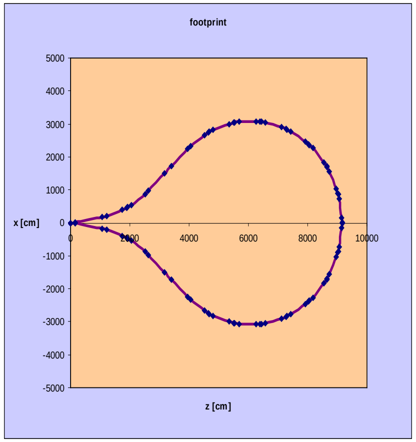
mirror symmetric quads in the linac

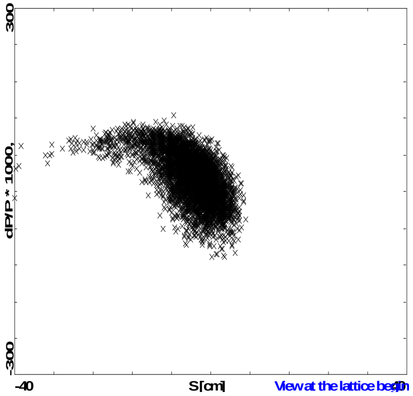


Mirror-symmetric 'Droplet' Arc – Optics



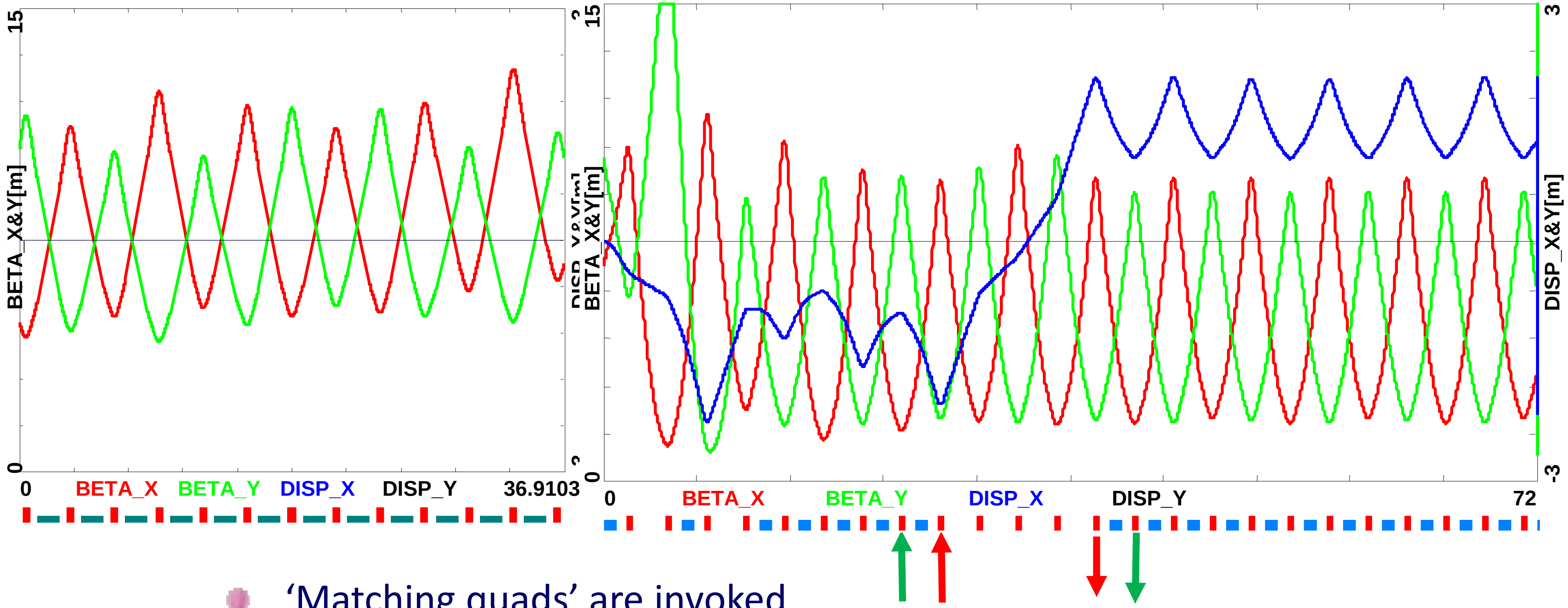






Linac-to-Arc – Chromatic Compensation

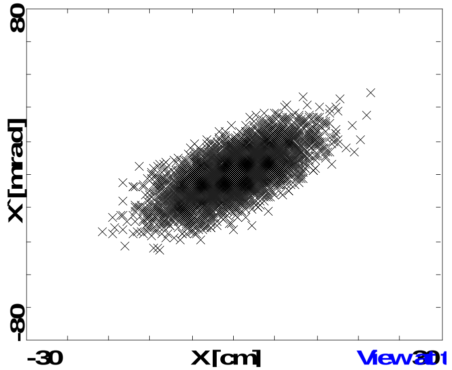
E =1.8 GeV



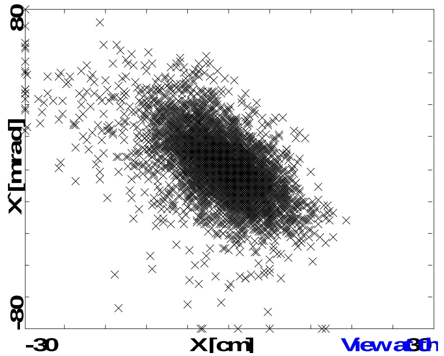
- ‘Matching quads’ are invoked
- No 90^0 phase adv/cell maintained across the ‘junction’
- Chromatic corrections needed – two pairs of sextupoles

Linac-to-Arc – Chromatic Corrections

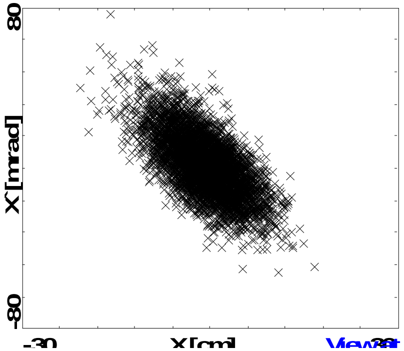
initial

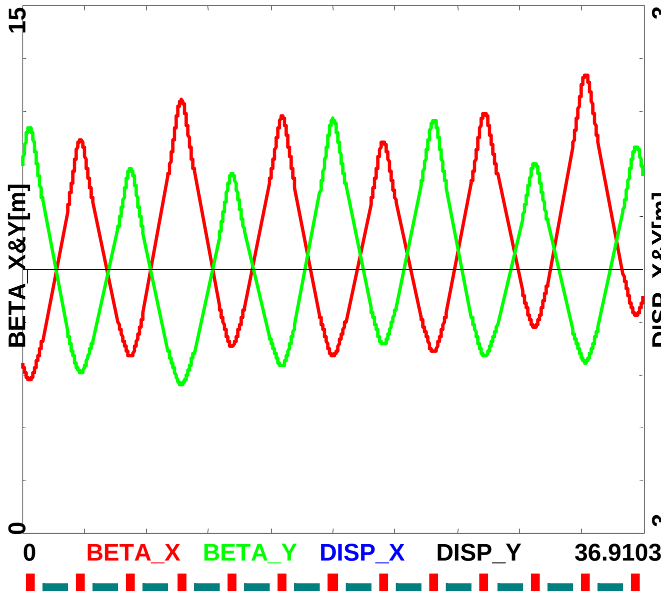


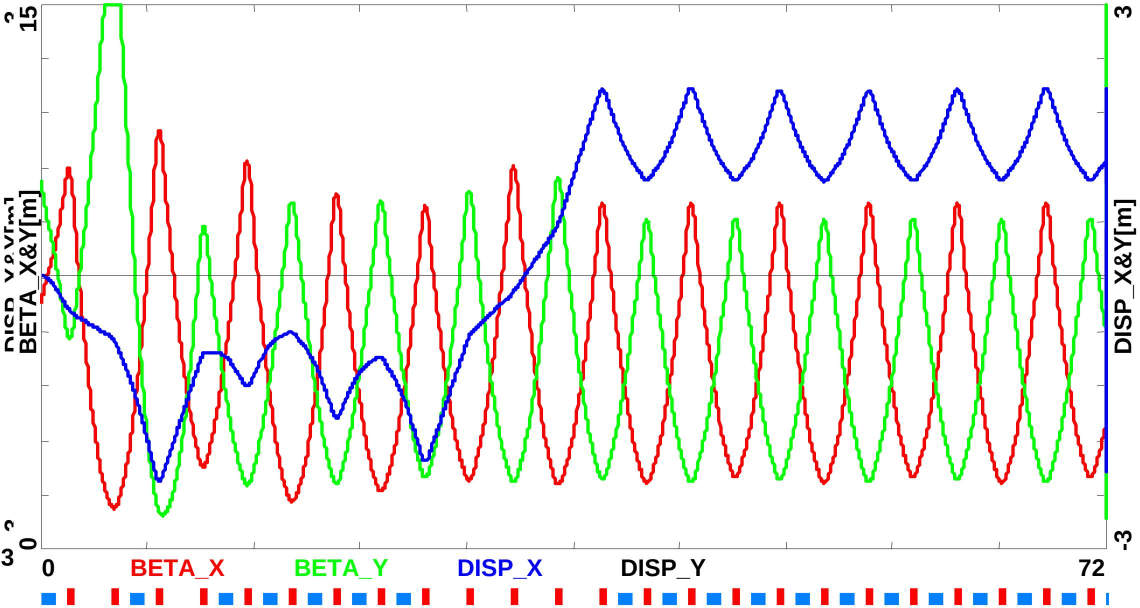
uncorrected



two families of sextupoles

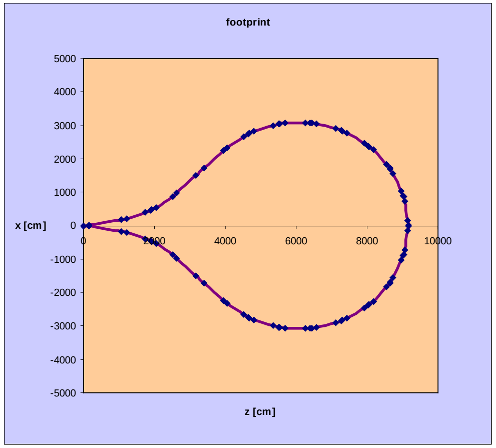






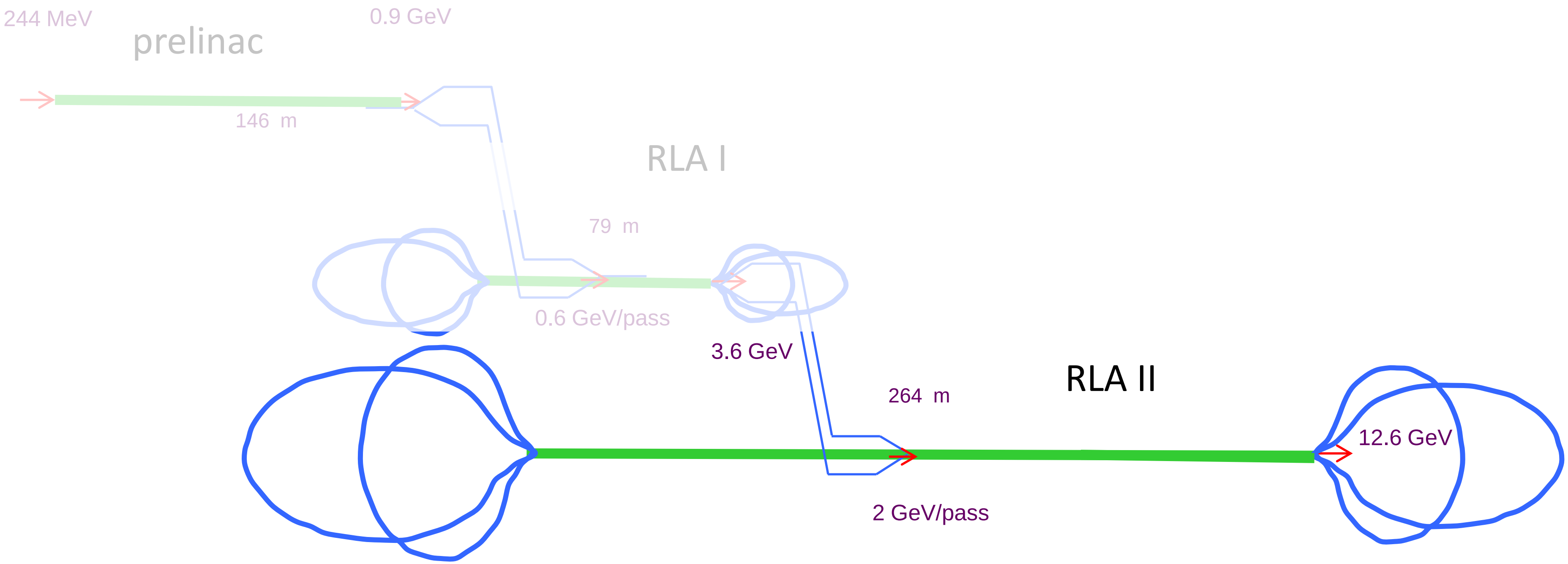
‘Droplet’ Arcs scaling – RLA I

i = 1…4	E_i [GeV]	p_i/p_1	cell_out	cell_in	length [m]
Arc1	1.2	1	2 2	10	130
Arc2	1.8	1.43	2 3	15	172
Arc3	2.4	1.87	2 4	20	214
Arc4	3.0	2.30	2 5	25	256



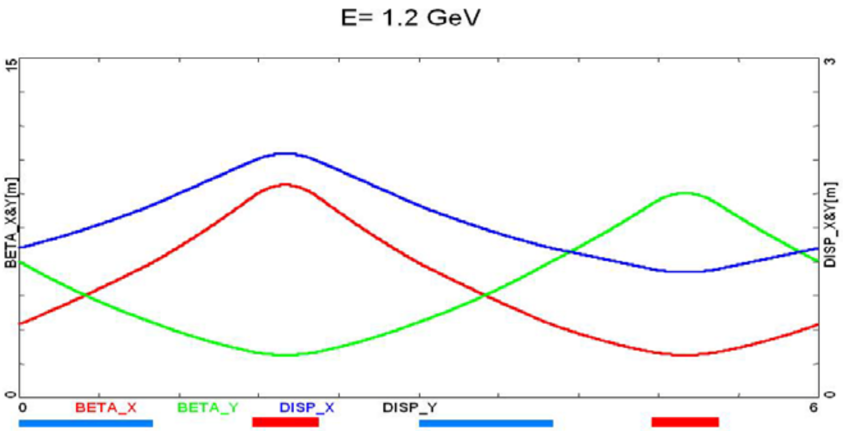
- Fixed dipole field: B_i =10.5 kGauss
- Quadrupole strength scaled with momentum: $G_i = \frac{p_i}{p_1}$ 0.4 kGauss/cm
- Arc circumference increases by: (1+1+5) 6 m = 42 m

RLA II



- Very similar to RLA I
- cells 2X as long

RLA I and II linac cells



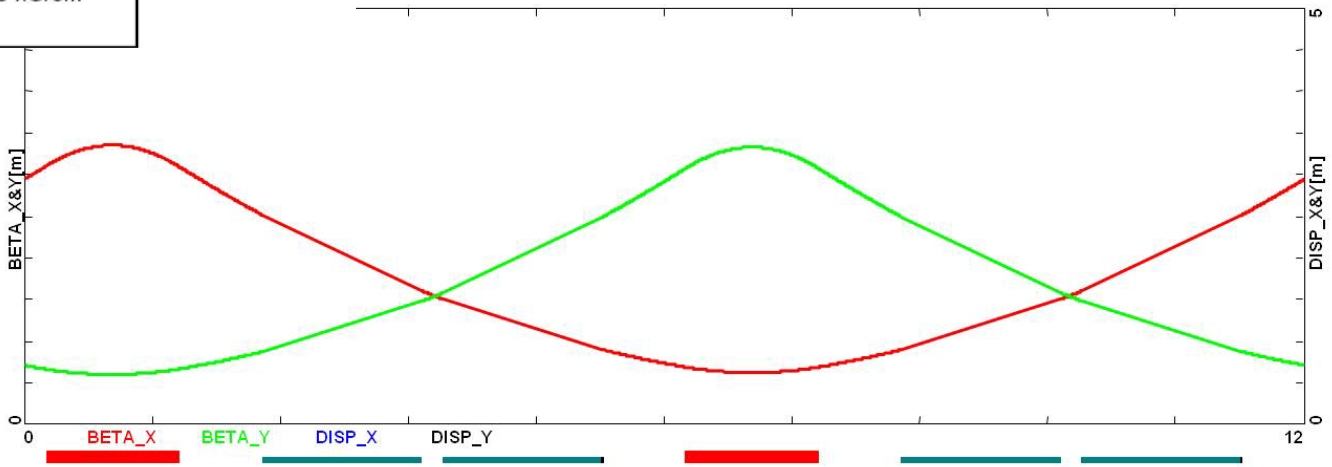
quads

G_F = 0.385 kG/cm

G_D = -0.349 kG/cm

L = 50 cm

RLA I cell



E_{kin} = 3550 MeV

E_{kin} = 3600 MeV

RLA II cell

F quad

G = 0.244 kG/cm

L =125 cm

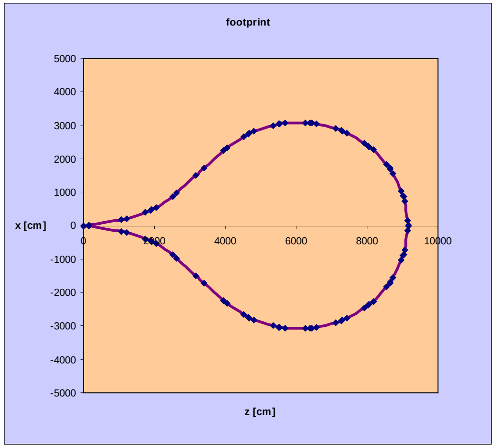
D quad

G = -0.247 kG/cm

L= 125 cm

‘Droplet’ Arcs scaling – RLA II

i = 1…4	E_i [GeV]	p_i/p_1	cell_out	cell_in	length [m]
Arc1	4.6	1	2 2	10	260
Arc2	6.6	1.435	2 3	15	344
Arc3	8.6	1.870	2 4	20	428
Arc4	10.6	2.305	2 5	25	512

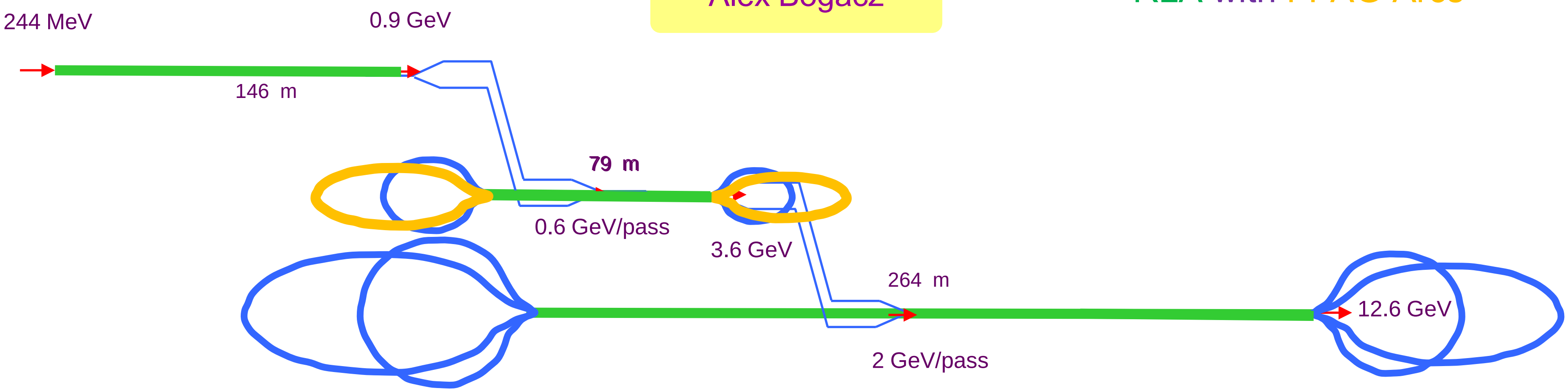


- Fixed dipole field: B_i = 40.3 kGauss
- Quadrupole strength scaled with momentum: $G_i = \frac{p_i}{p_1}$ 1.5 kGauss/cm
- Arc circumference increases by: (1+1+5) 12 m = 84 m

RLA with Two-Pass FFAG Arcs

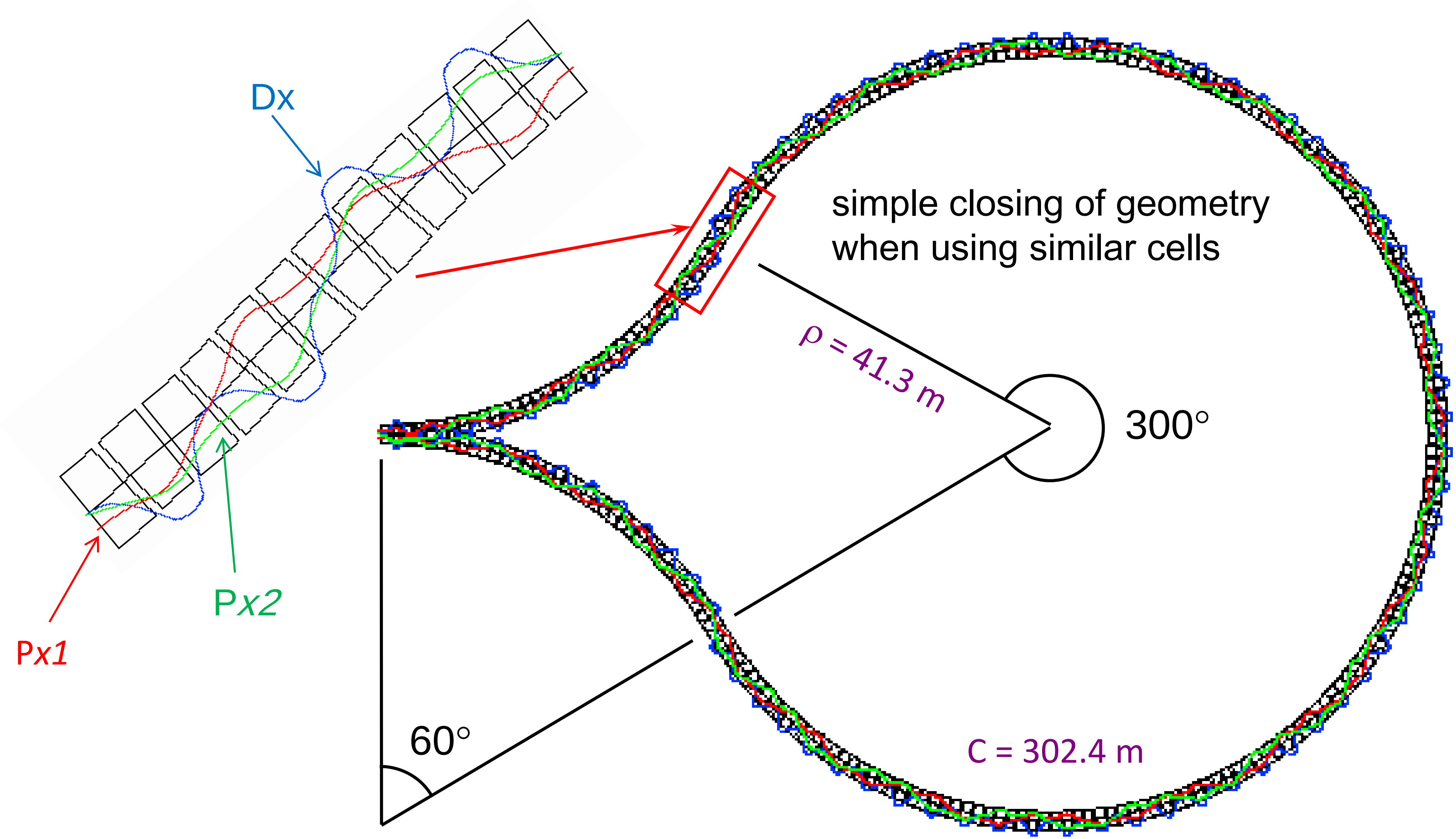
Alex Bogacz

RLA with FFAG Arcs



- Two regular droplet arcs replaced by one two-pass FFAG arc
- Reduced beam line length, perhaps reduced costs
- Simplified scheme
- No need for a complicated switchyard
- Non-linear and linear FFAG solutions with linear solution likely preferable

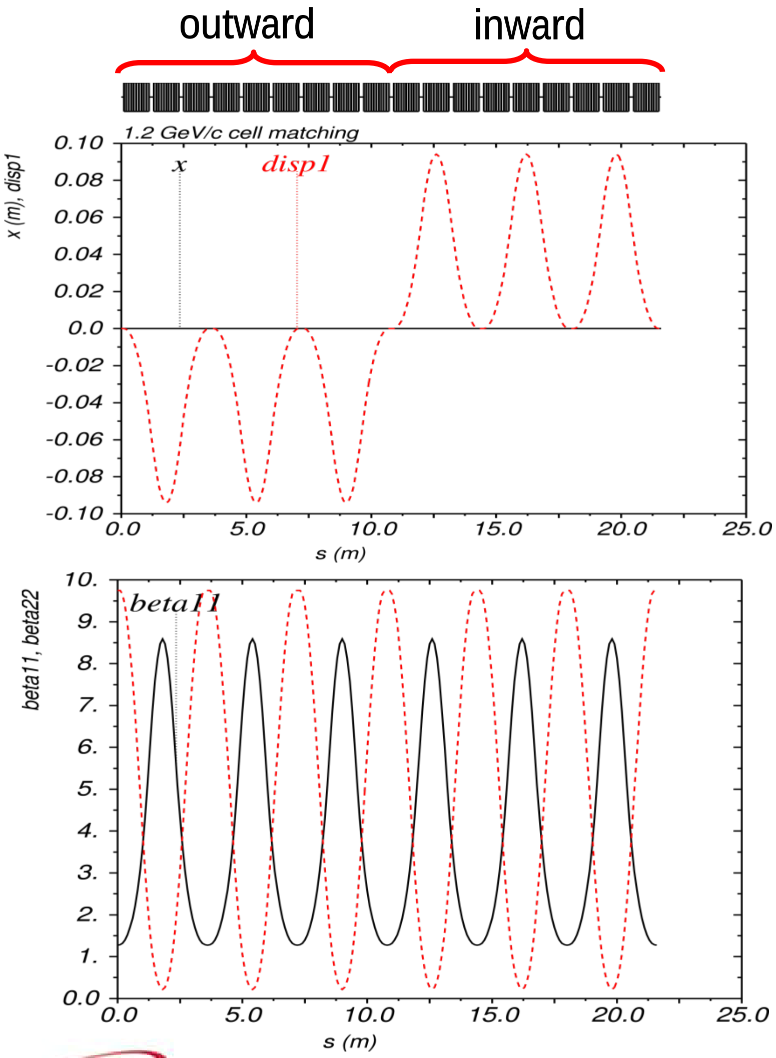
Two-Pass FFAG Arcs



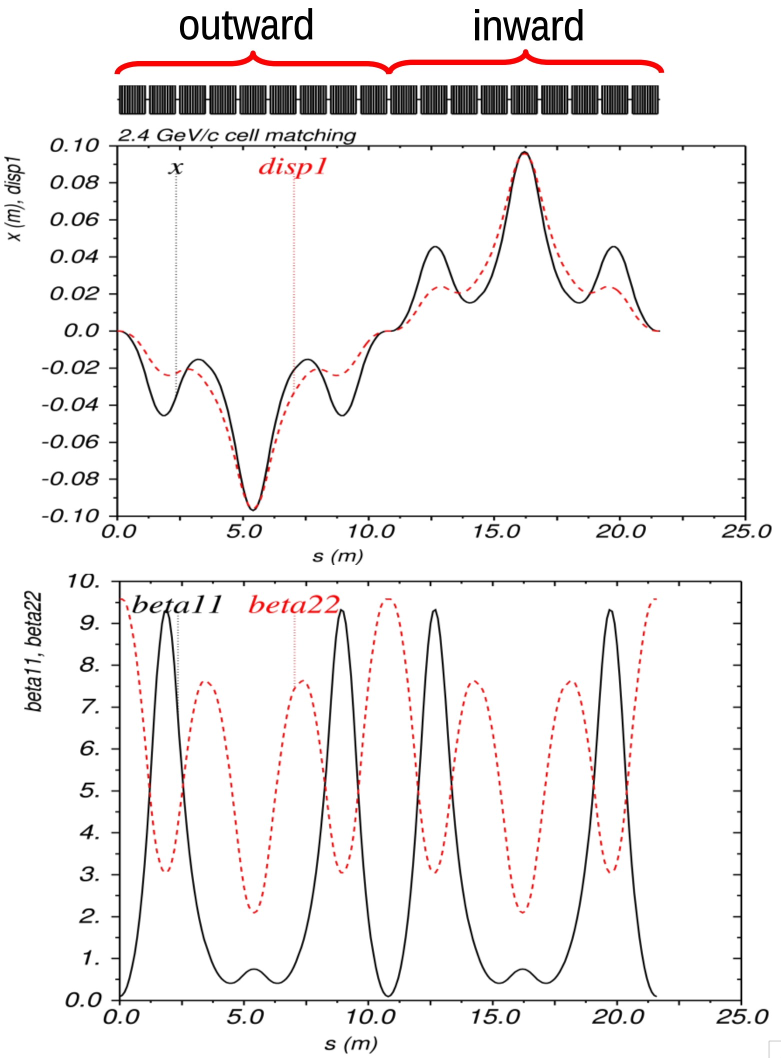
simple closing of geometry when using similar cells

Cell Matching

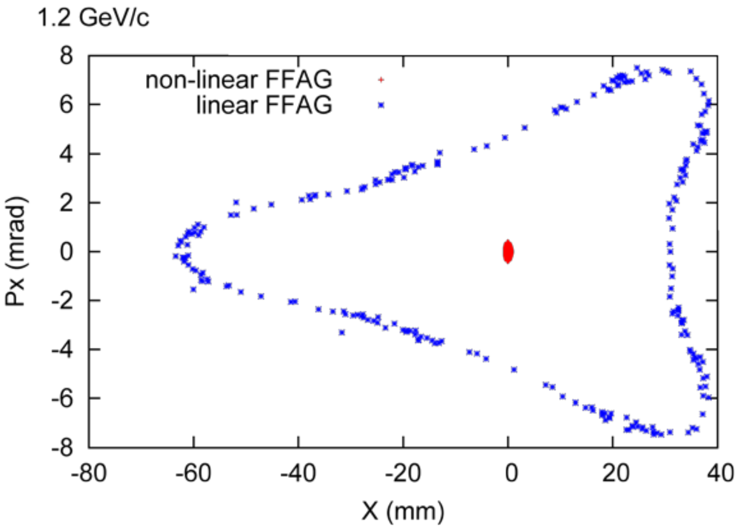
- 1.2 GeV/c

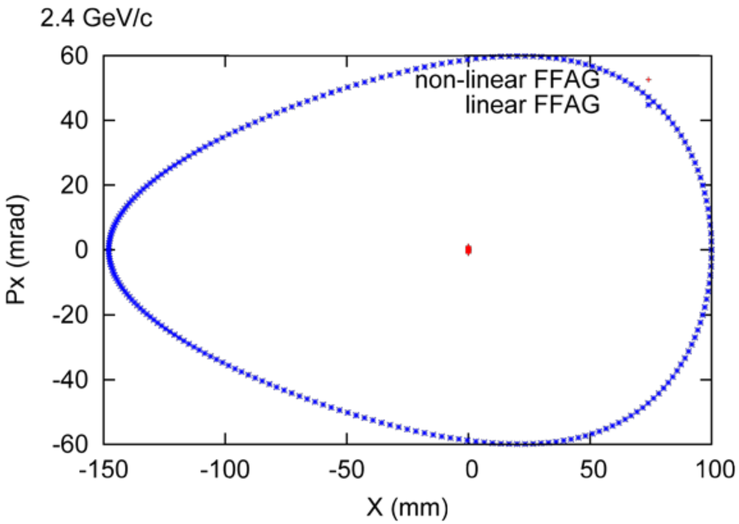


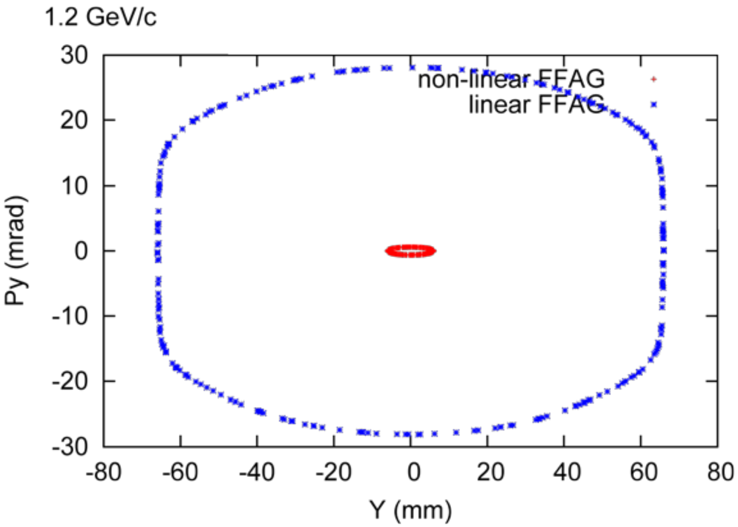
- 2.4 GeV/c

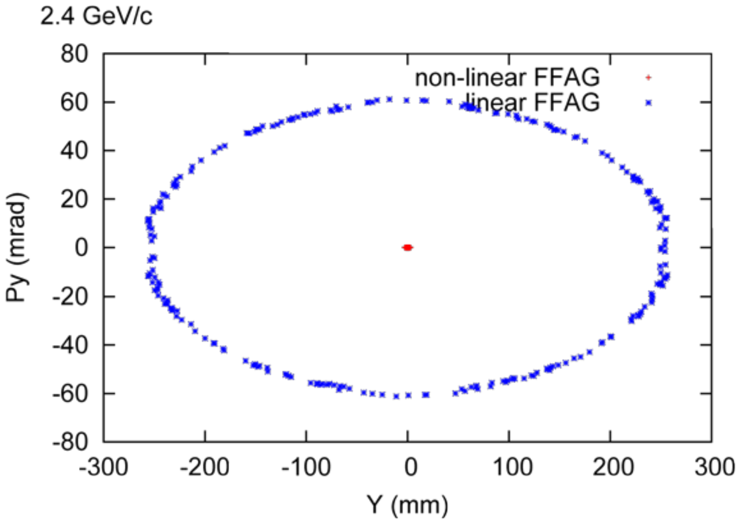


Dynamic Aperture


1.2 GeV/c


2.4 GeV/c


1.2 GeV/c


2.4 GeV/c

Two-Pass Linear FFAG Arcs

- Same concept as with the non-linear FFAG arcs
  - Droplet arcs composed of **symmetric FFAG cells**
  - Each cell has **periodic solution** for the orbit and the Twiss functions
  - For **both energies**, at the **cell's entrance** and **exit:**
    - Offset and angle of the periodic orbit are zero
    - Alpha functions are zero
    - Dispersion and its slope are zero
  - Outward and inward bending cells are automatically matched

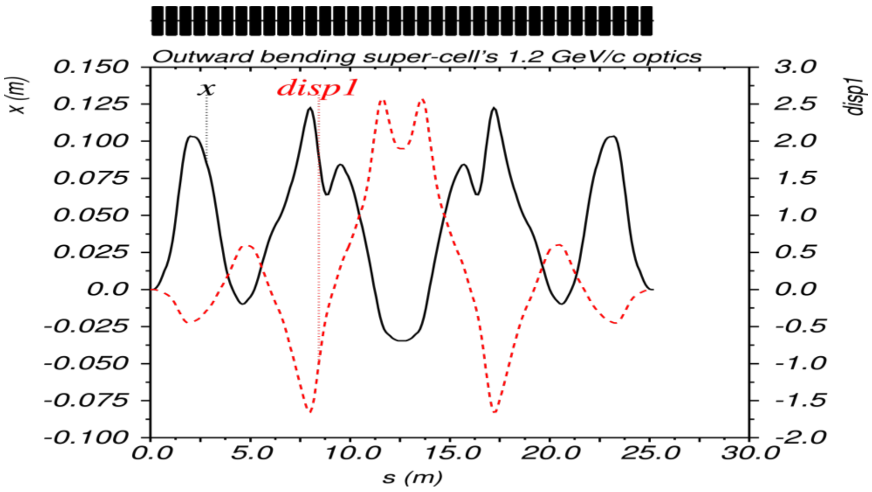
- More elements needed for each unit cell to satisfy diverse requirements

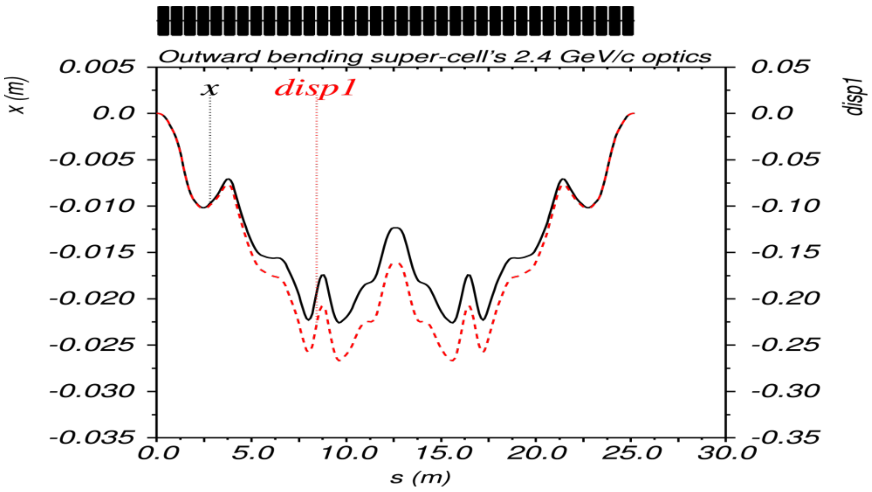
Two-Pass Linear FFAG Arcs

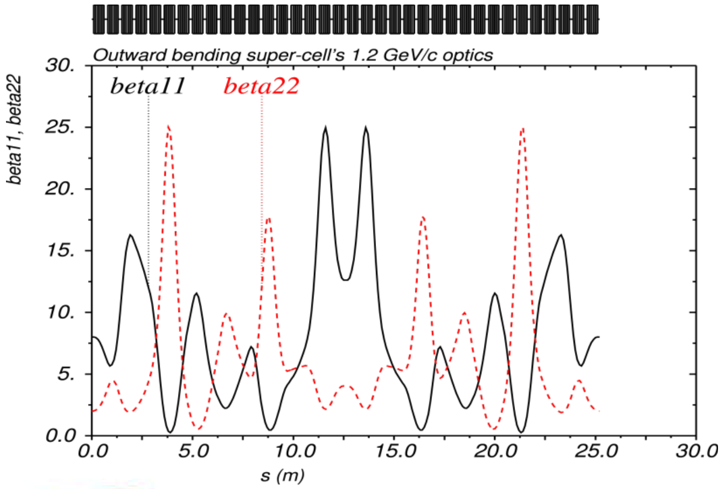
- Combined function magnets with **dipole** and **quadrupole** field components **only**
  - Much greater **dynamic aperture** expected than in the non-linear case
  - Easier to adjust the **pass length** and the **time of flight** for each energy
  - Easier to control the beta-function and dispersion values
  - Initial beta-function values **chosen** to simplify **matching to linac**
  - Much simpler **practical implementation** without non-linear fields

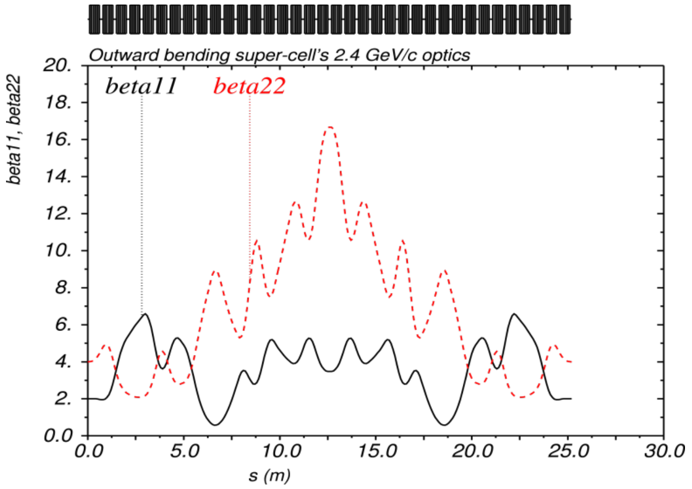
Linear FFAG: Linear Optics of Arc 1 Unit Cell

- Path lengths adjusted to give **time of flight difference** of **one period of RF**
- 1.2 GeV/c
- 2.4 GeV/c

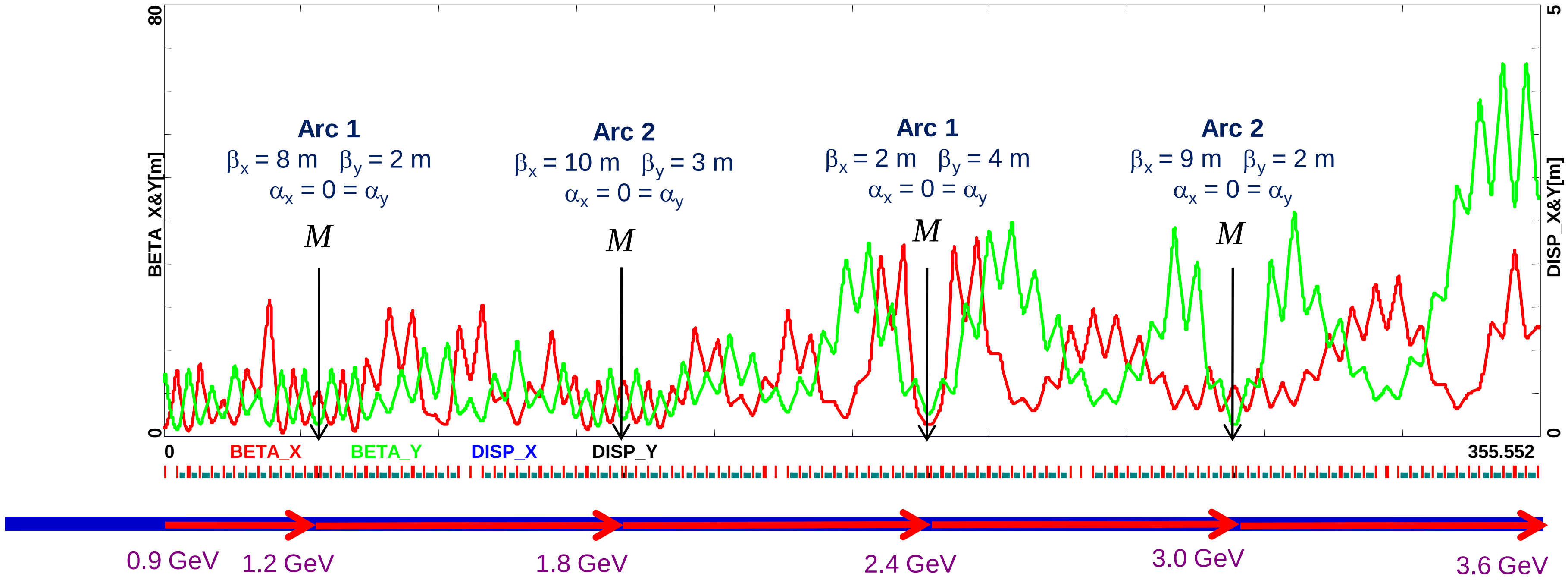








Multi-pass linac Optics w/ FFAG arcs



$$M = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$$

RLA I & II – near term plans

Single pass arc design:

- straight-forward continuation of design of RLA I & II
- determine RF phasing along linac *(v<c)* & Adjust arc timing
- fill in details of transfer lines
- complete component lists for costing
- continue linac simulations into RLAs for matching, heat & radiation loads

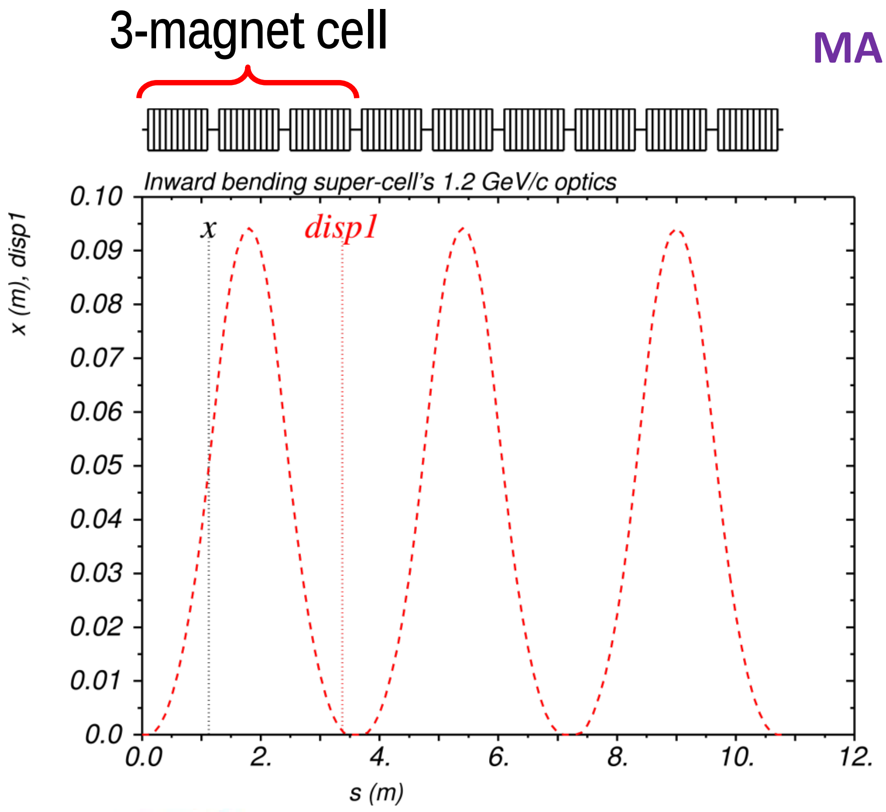
FFAG arc design:

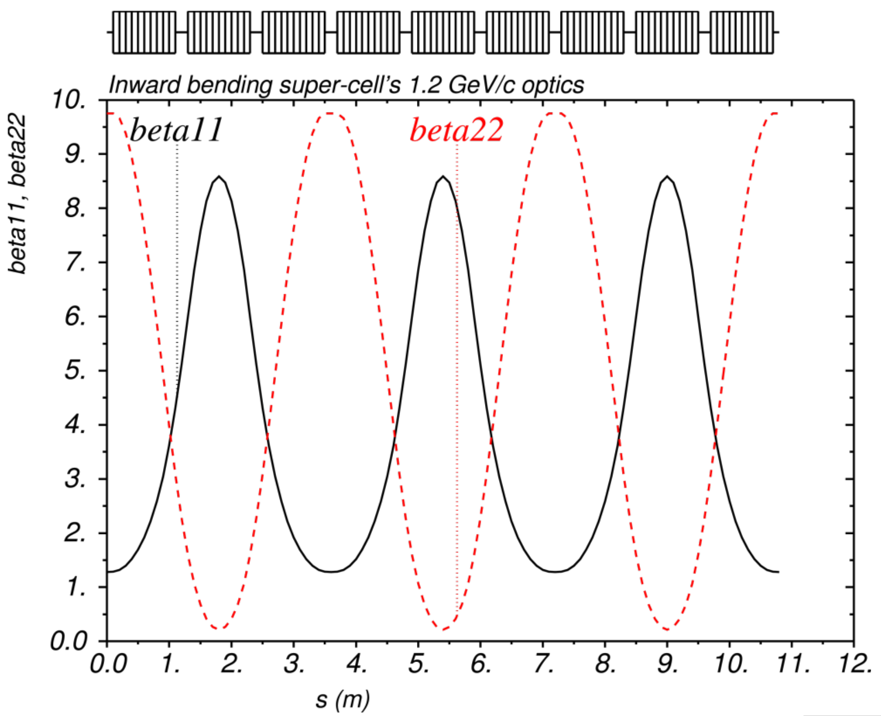
- determine dynamic aperture
- determine error sensitivity
- examine & optimize chromatic tune dependence
- match RF phasing in linac and arcs
- create a magnet specification for costing

Non-Linear FFAG: 1.2 GeV/c Linear Optics of Arc 1 Unit Cell

- Combined-function bending magnets are used
- 1.2 GeV/c orbit goes through magnet centers
- Linear optics controlled by quadrupole gradients in symmetric 3-magnet cell
- Dispersion compensated in each 3-magnet cell

MAD-X (PTC)

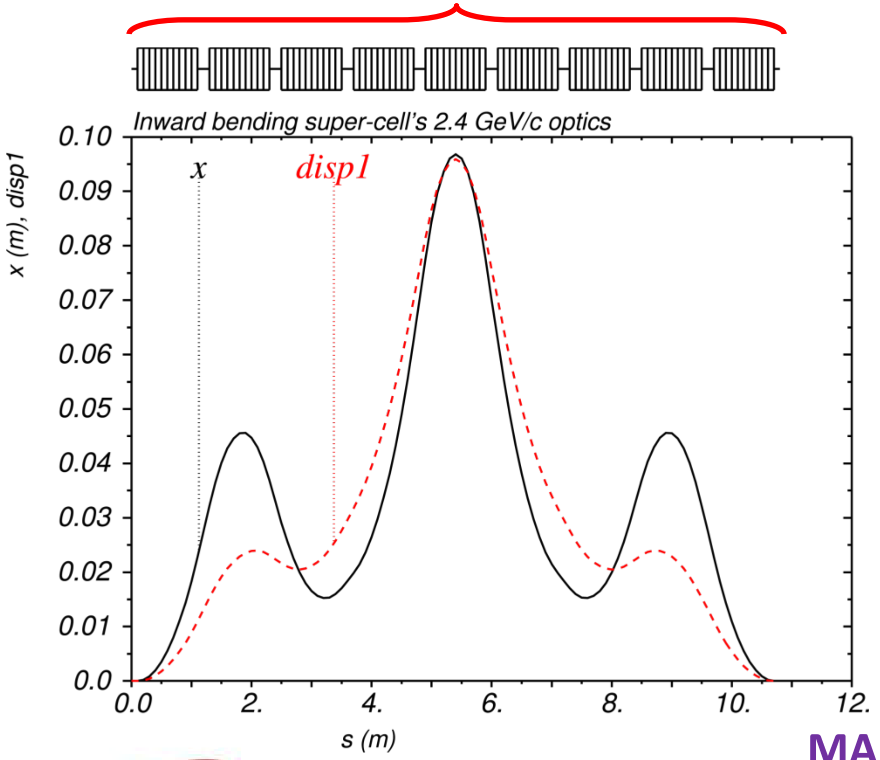




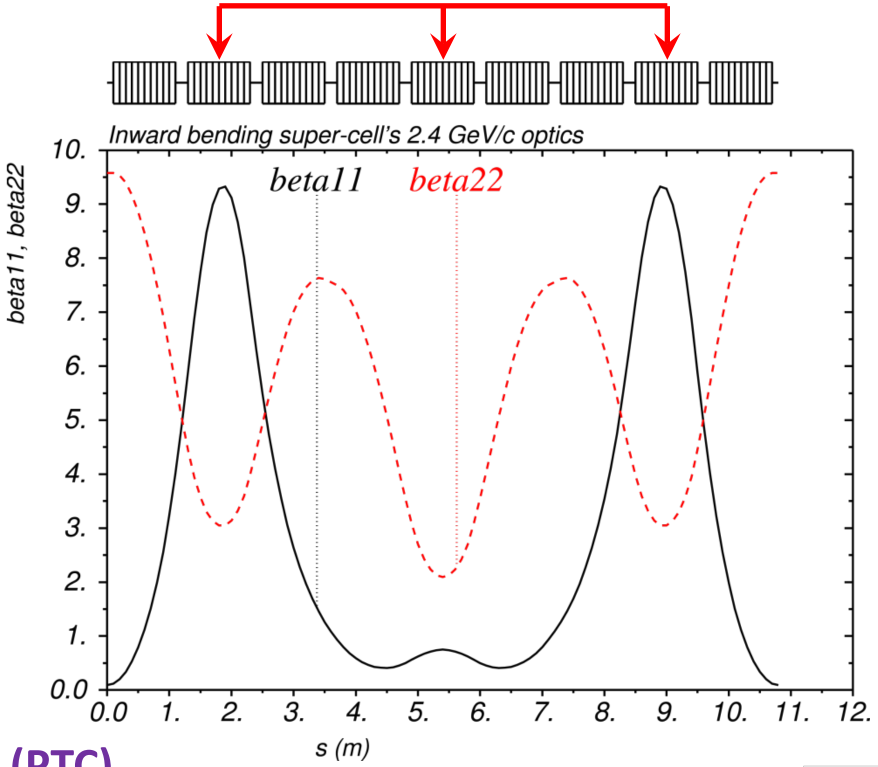
Non-Linear FFAG: 2.4 GeV/c Linear Optics of Arc 1 Unit Cell

- Unit cell composed symmetrically of three 3-magnet cells
- Off-center periodic orbit
- Orbit offset and dispersion are compensated by symmetrically introducing sextupole and octupole field components in the center magnets of 3-magnet cells

symmetric unit cell



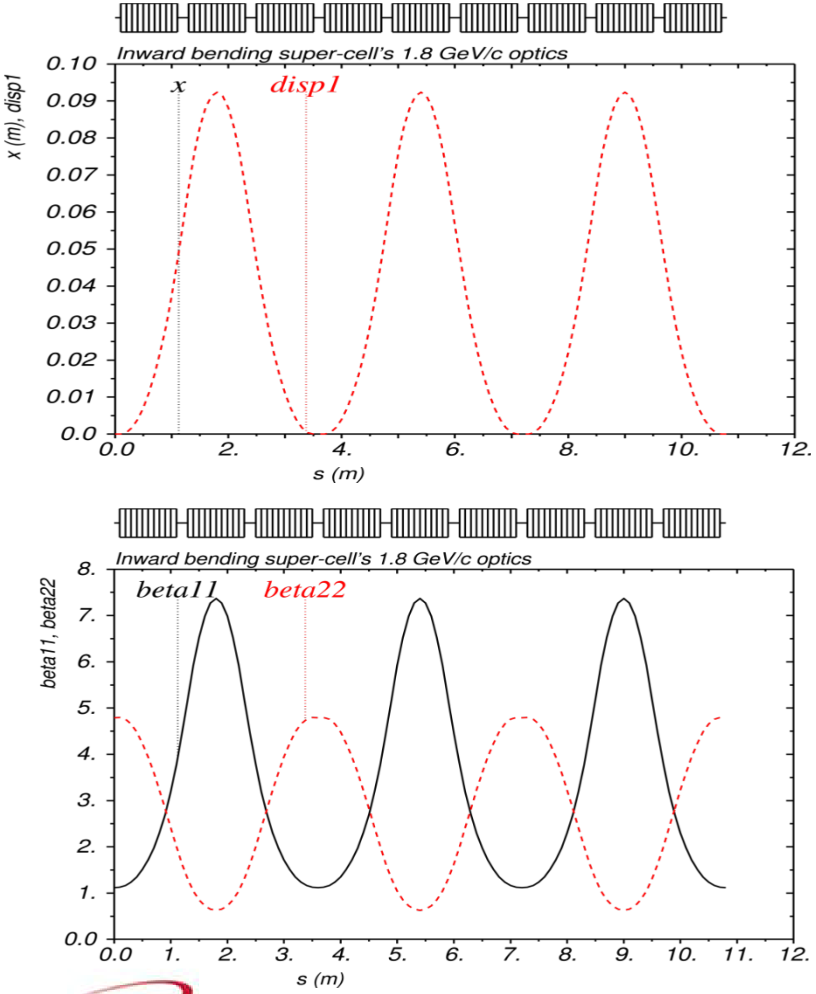
sextupole and octupole components



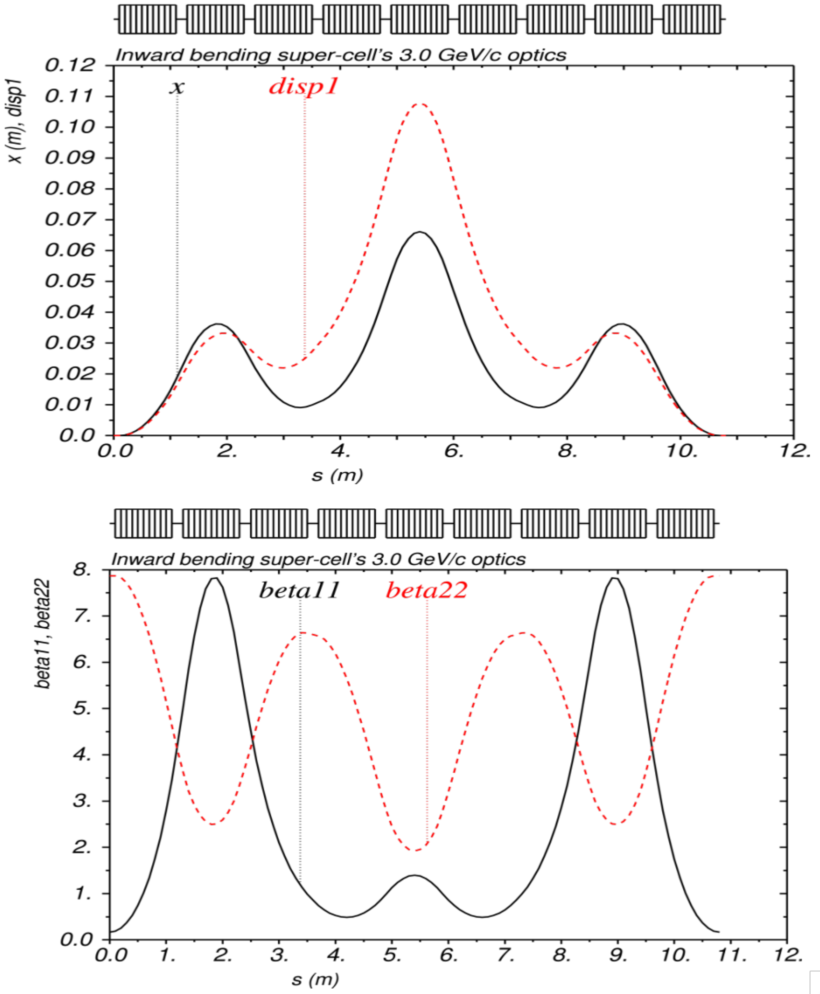
MAD-X (PTC)

Non-Linear FFAG: Linear Optics of Arc 2 Unit Cell

- Same concept as 1.2 GeV/c linear optics of Arc #1
- 1.8 GeV/c

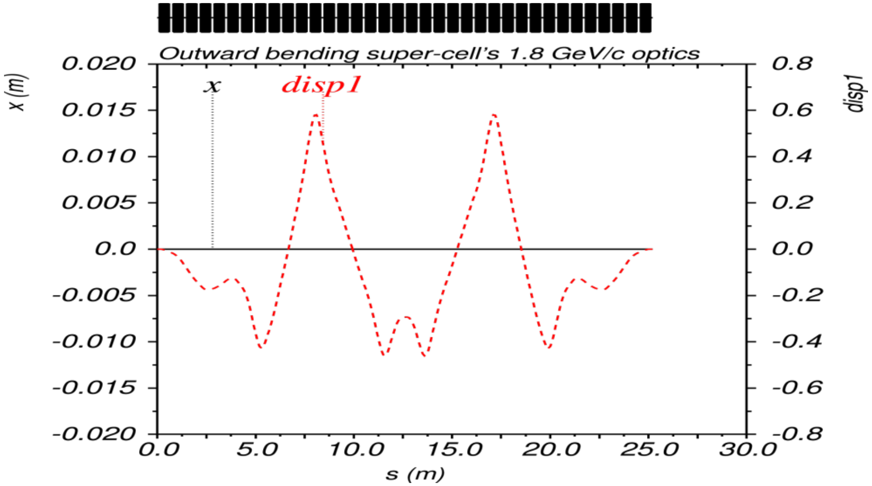


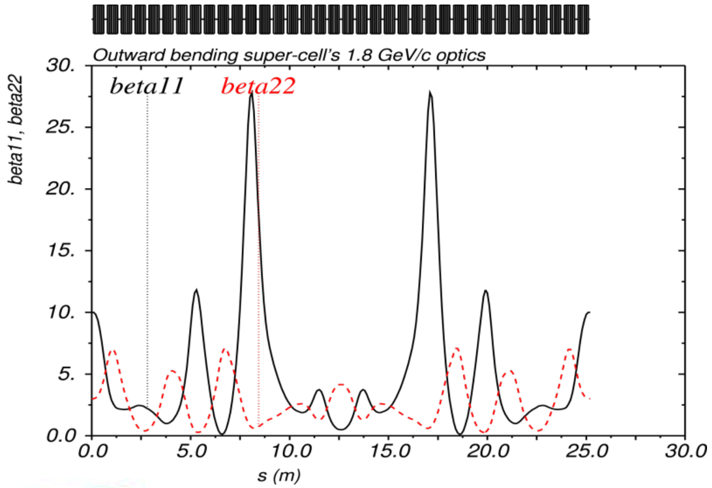
- 3.0 GeV/c



Linear FFAG: Linear Optics of Arc 2 Unit Cell

- Path lengths adjusted to give **equal times of flight** for the two momenta
- 1.8 GeV/c





- 3.0 GeV/c