Multi pass Energy Recovery Linac Design with a Single Fixed Field Magnet Return Line

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Abstract:

We present a new approach of the Energy Recovery Linac Design for the future projects: PERLE (Powerful Energy Recovery Linac for Experiments), LHeC/FCC eh and eRHIC. The concept uses superconducting linacs and a single fixed field beam lines with multiple energy passes of electron beams. This represents an update to the existing CBETA (Cornell University Brookhaven National Laboratory ERL Test Accelerator) where the superconducting linac uses a single fixed field magnet beam line with four times in energy acceleration and four passes for the energy recovery through the same single structure. To match the single fixed field beam line to the linac the CBETA uses the spreaders and combiners on both sides of the linac, while the new concept eliminates them. The arc cells from the single fixed field beam line are connected to the linac with an adiabatic transition arcs where its cells increase in length. The orbits of different energies merge into a single orbit through the interleaved linac within the straight sections as in the CBETA project. The betatron functions from the arcs are matched to the linac and the time of flight of different electron energies is adjusted for the central orbits by added kicker controlled induced beam oscillations.

OUTLINES

Introduction: ERL's, RLA's in LHeC, FCC eh (CERN), eRHIC(BNL), ELIC(CEBAF), EIC@HIAF(China),...

A new concept: Modeling by **Bmad** (David Sagan) the linear fixed field beam line adiabatically matched to the linac

Bmad lattice design of the large energy acceptance linear FFA arcs, adiabatic transitions and orbit merging and lattice functions matching to the straight section

SUMMARY: A combination of the Fixed Field Accelerators with the Energy Recovery Linacs (ERL's) or Recirculating Linac Accelerators (RAL's) show a novel and very promising combination in multiple applications: Electron Ion Colliders, hadron cooling, nuclear physics experiments, etc.

Introduction:

Large Momentum Acceptance Fixed Field Beam Lines

A concept of Fixed Field Large Energy Acceptance Lattice

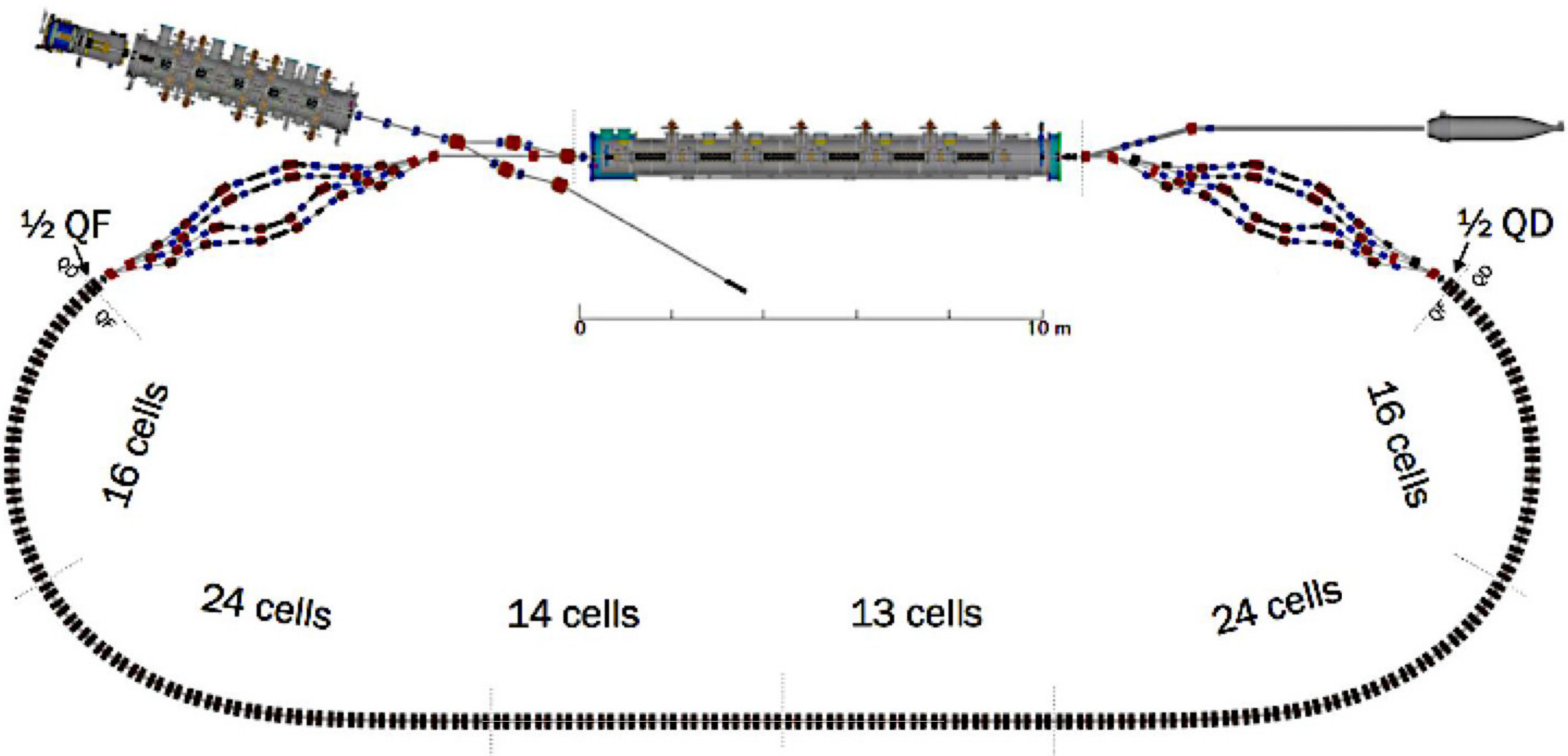
- Orbits in fixed field cells
- Tunes vs. energy
- Path length vs. energy

Confidence of success comes from 3D OPERA fields tracking presented in the previous talk by Francois Meot

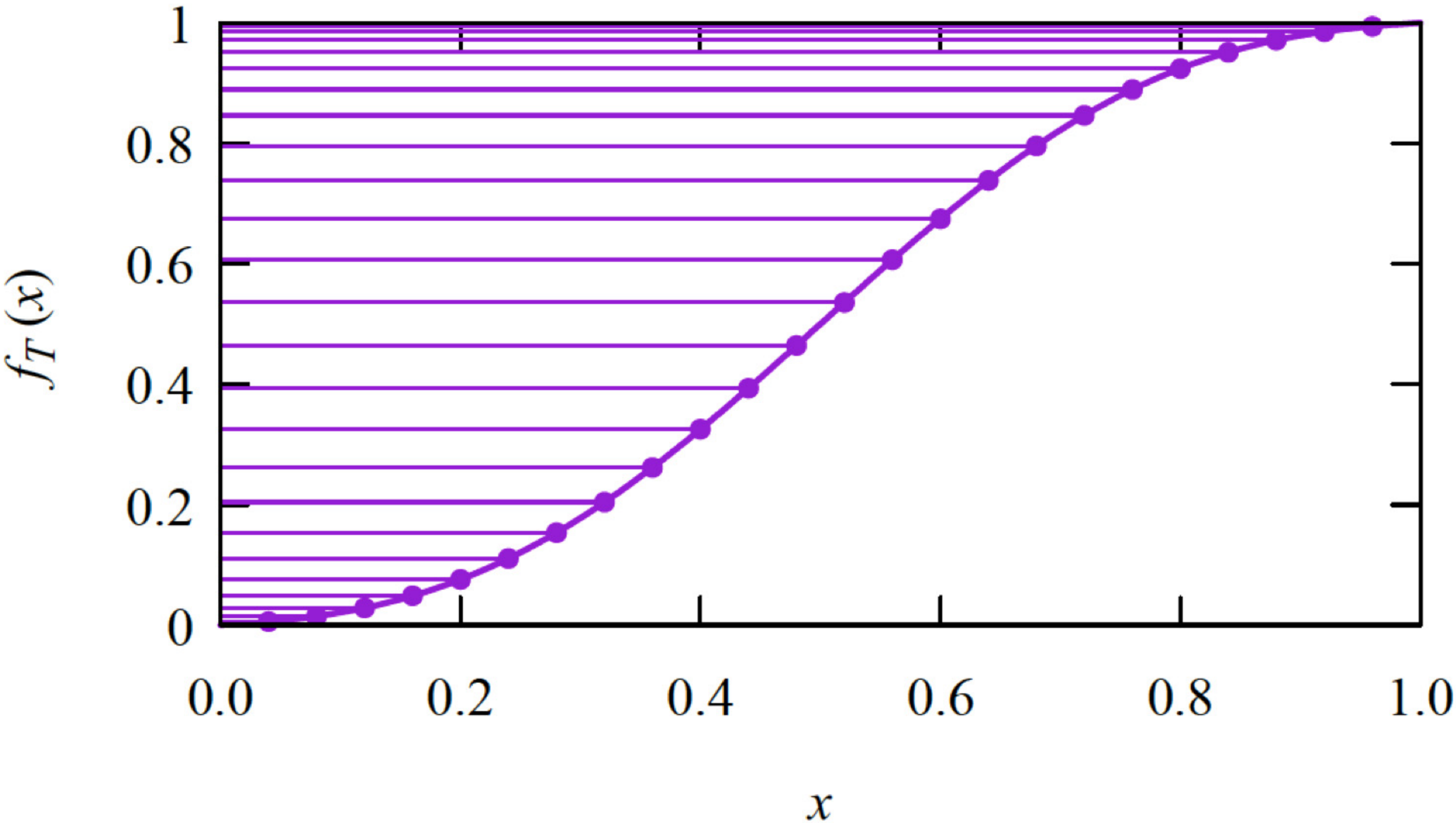
- High quality Halbach magnets
- Previous experiments in ATF and CBETA Fractional Arc Test

Adiabatic matching to the ERL Linac

Properties of the linear fixed field large energy acceptance lattice for the CBETA project

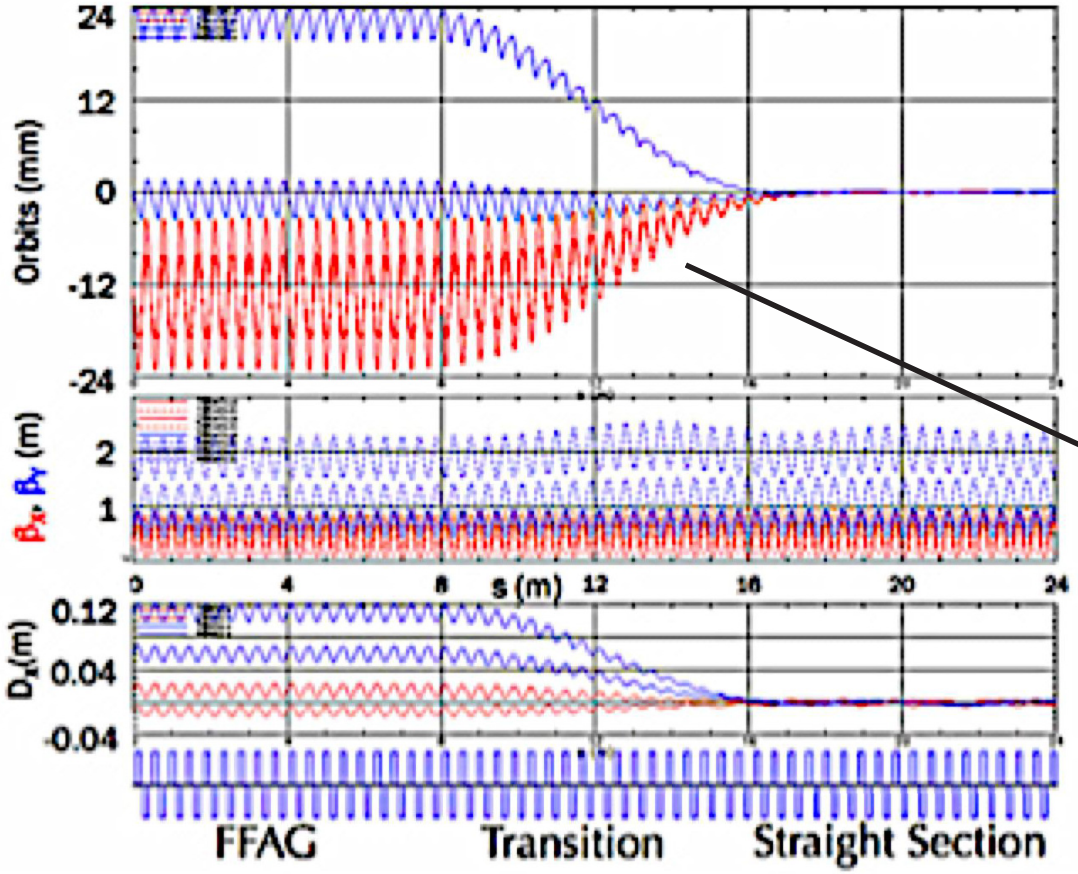


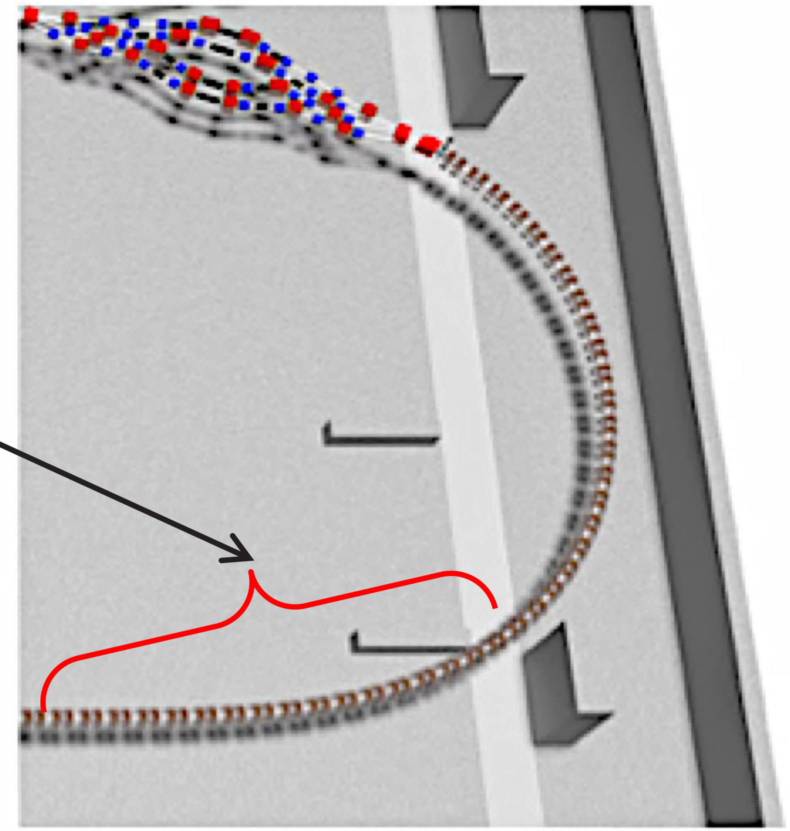
Adiabatic transition from the arc to the straight with expanding the transition cell lengths



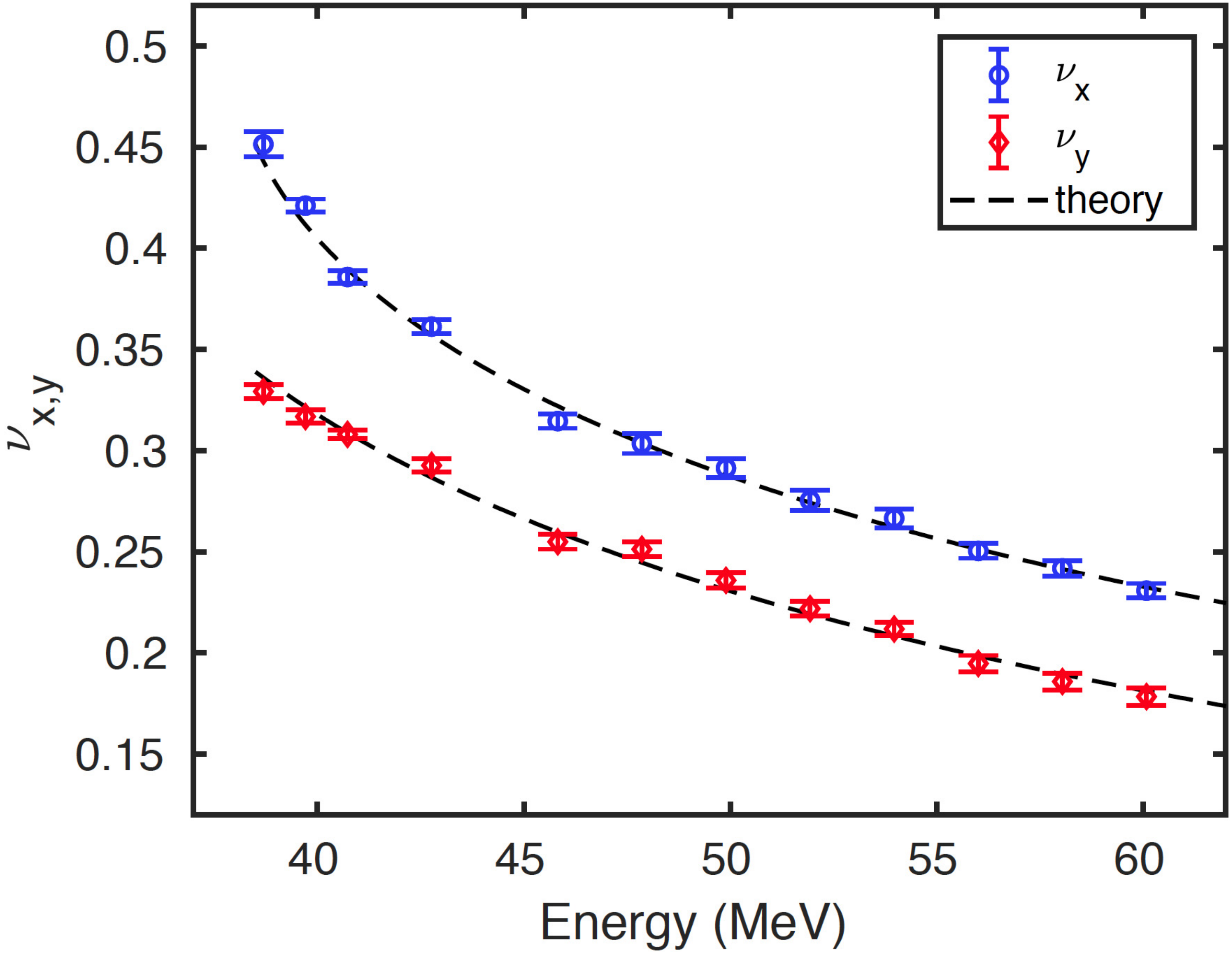
The Proton Gantry Design is based on few other examples

Merging of the orbits at the CBETA project





CBETA measured tunes dependence on energy in



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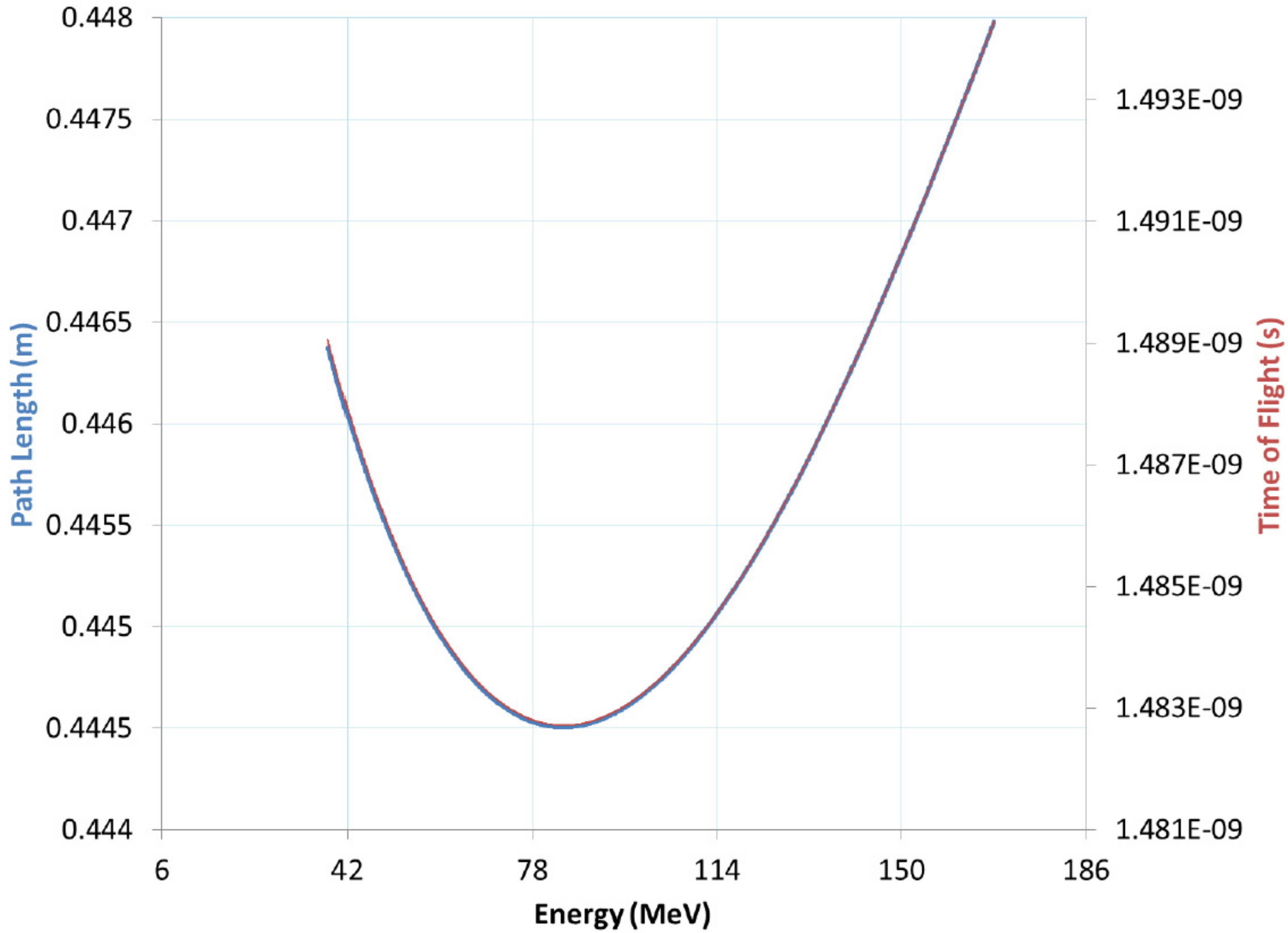
Path length and time of fight
in the CBETA arc cell as a function of energy.



The Fixed Field Alternating Gradient Experiment with bending 40° already tested at BNL

Electron energies in the experiment :18, 24, 36, 54, and 72 MeV

$$Electron\ p_{\max} = 18\ MeV/c \qquad \frac{\Delta p}{p} = -60\%$$

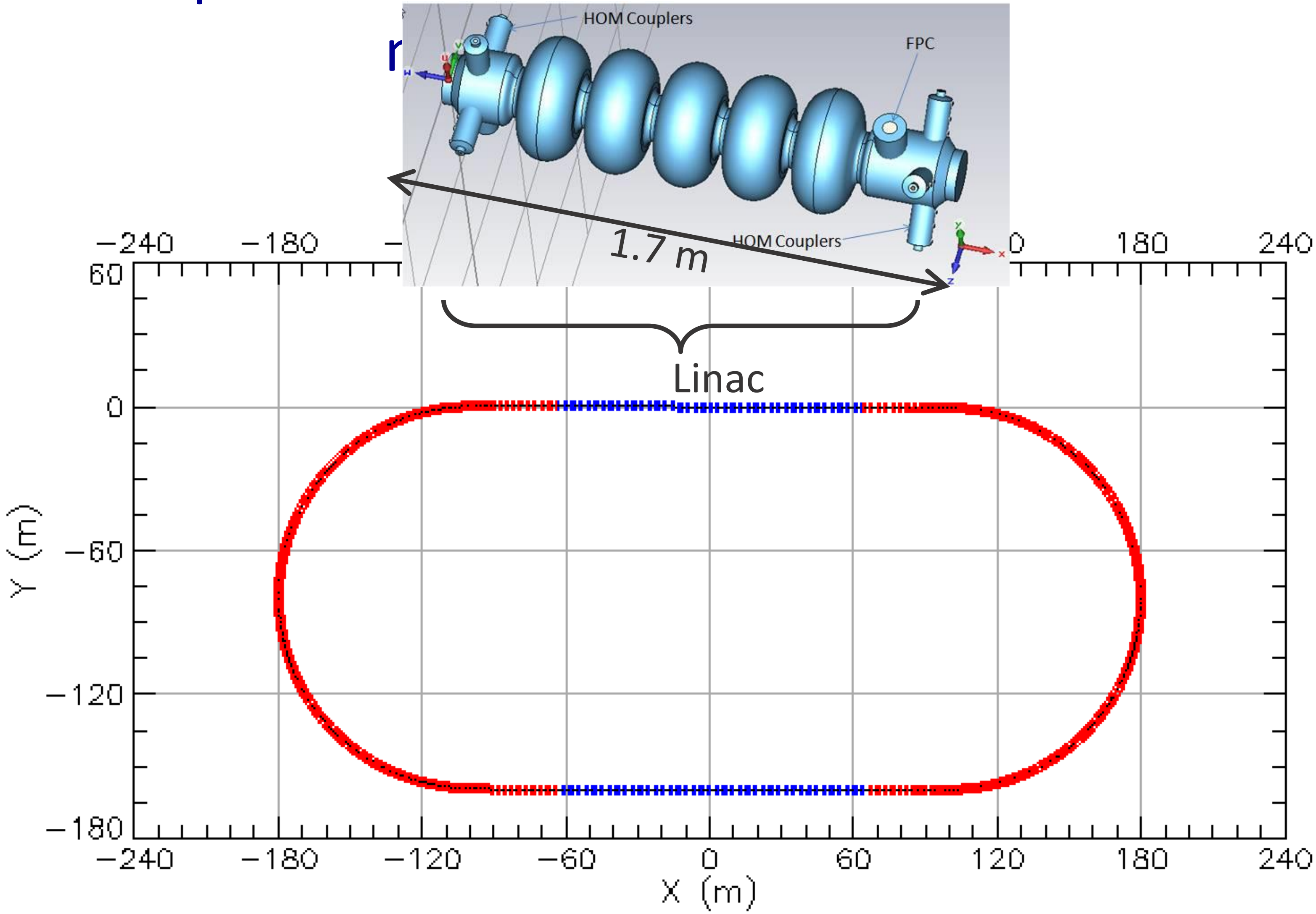
$$Electron\ \ p_{cent} = 45\ MeV/c$$

$$Electron\ \ p_{\min} = 72\ MeV/c \qquad \frac{\Delta p}{p} = +60\%$$

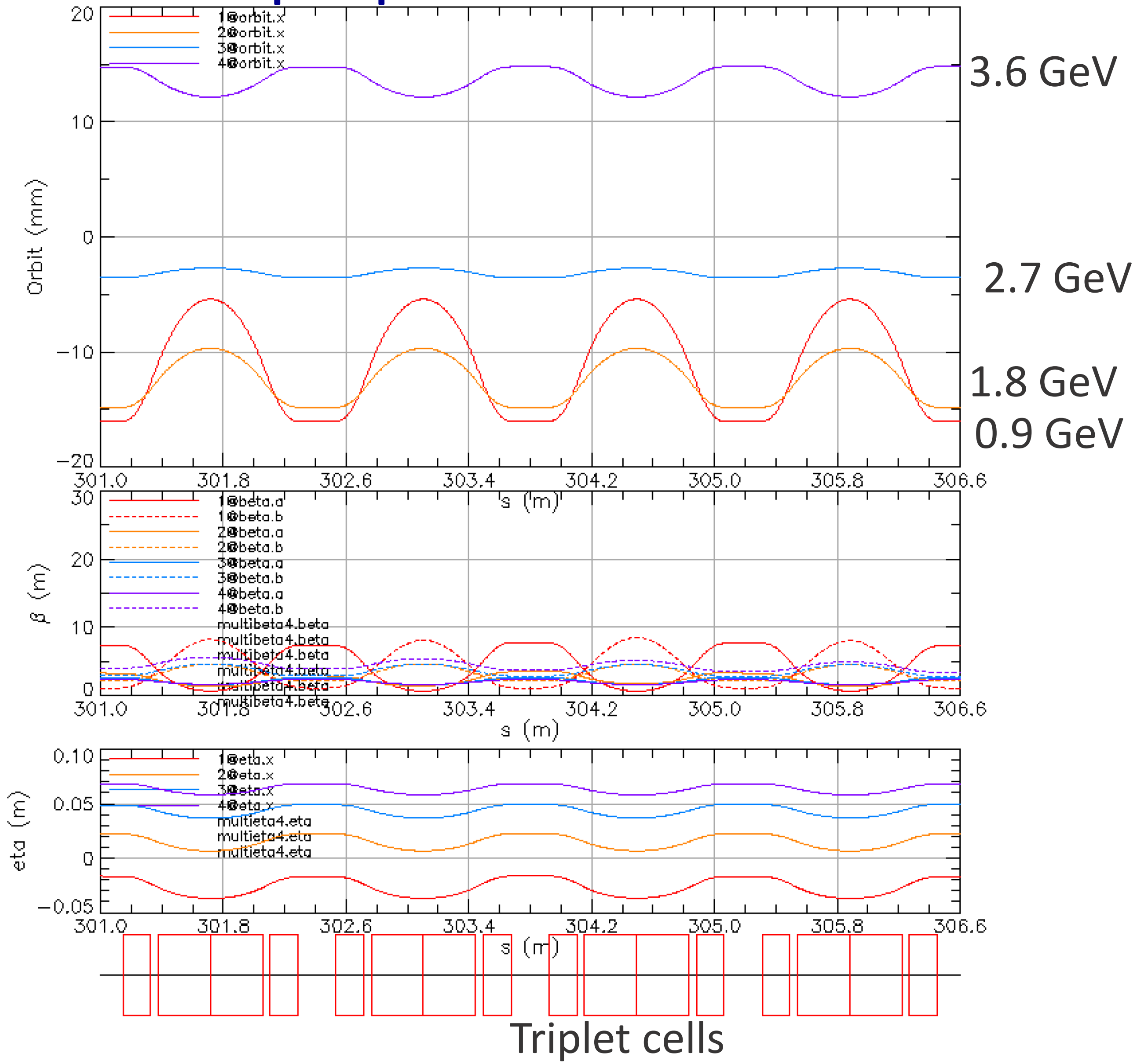
We are presenting for the first time an example of a novel approach in using the Fixed Field single beam line with large energy acceptance connected by an adiabatic transition to the ERL linac:

- This allows additional passes through the linac, this reduces the size of the linac
- Eliminates spreaders and combiners
- Simplifies the operation
- Significantly reduces the overall cost of the whole project

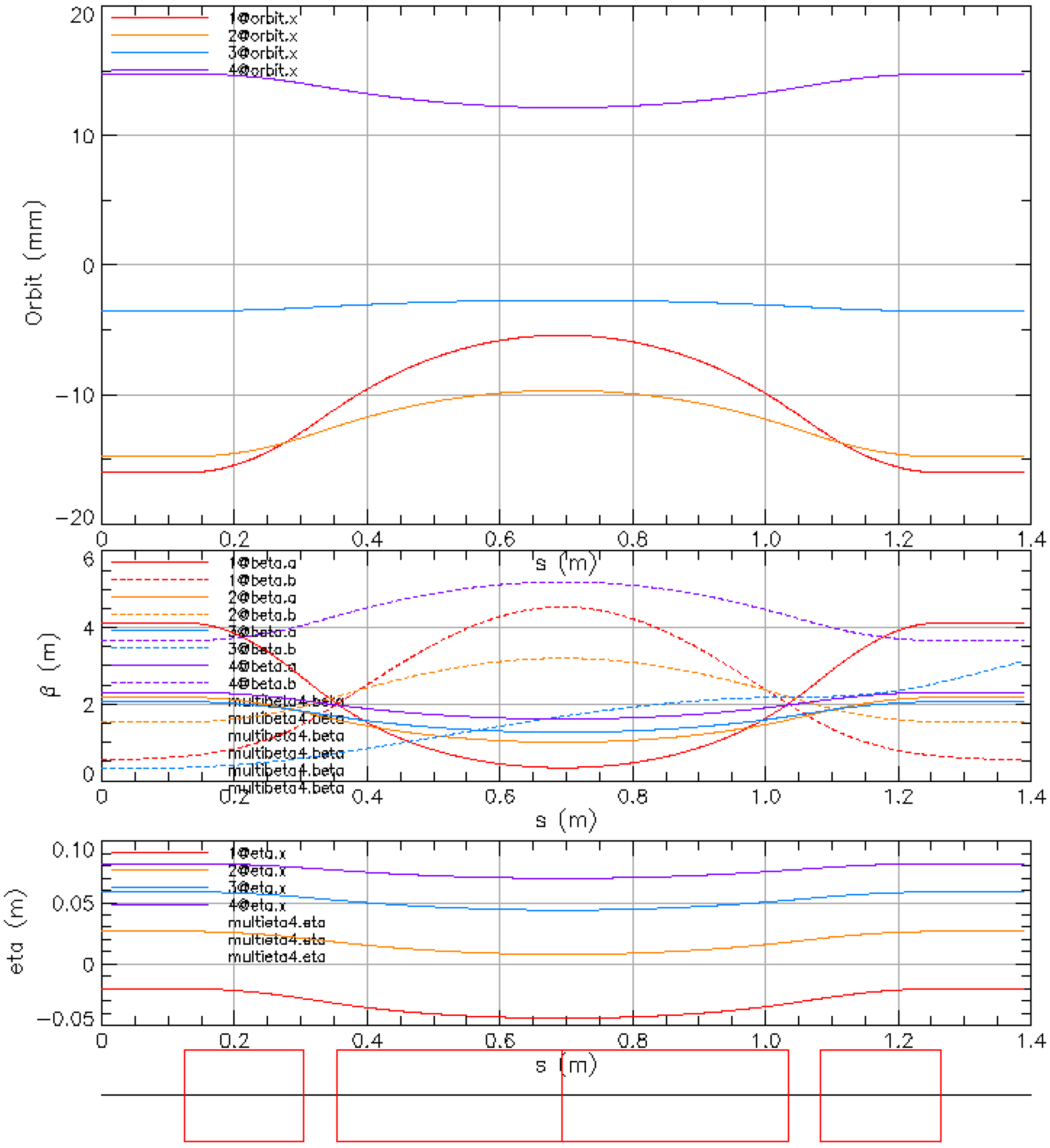
An example of the linear fixed field arcs adiabatically



Lattice properties of the few arc cells

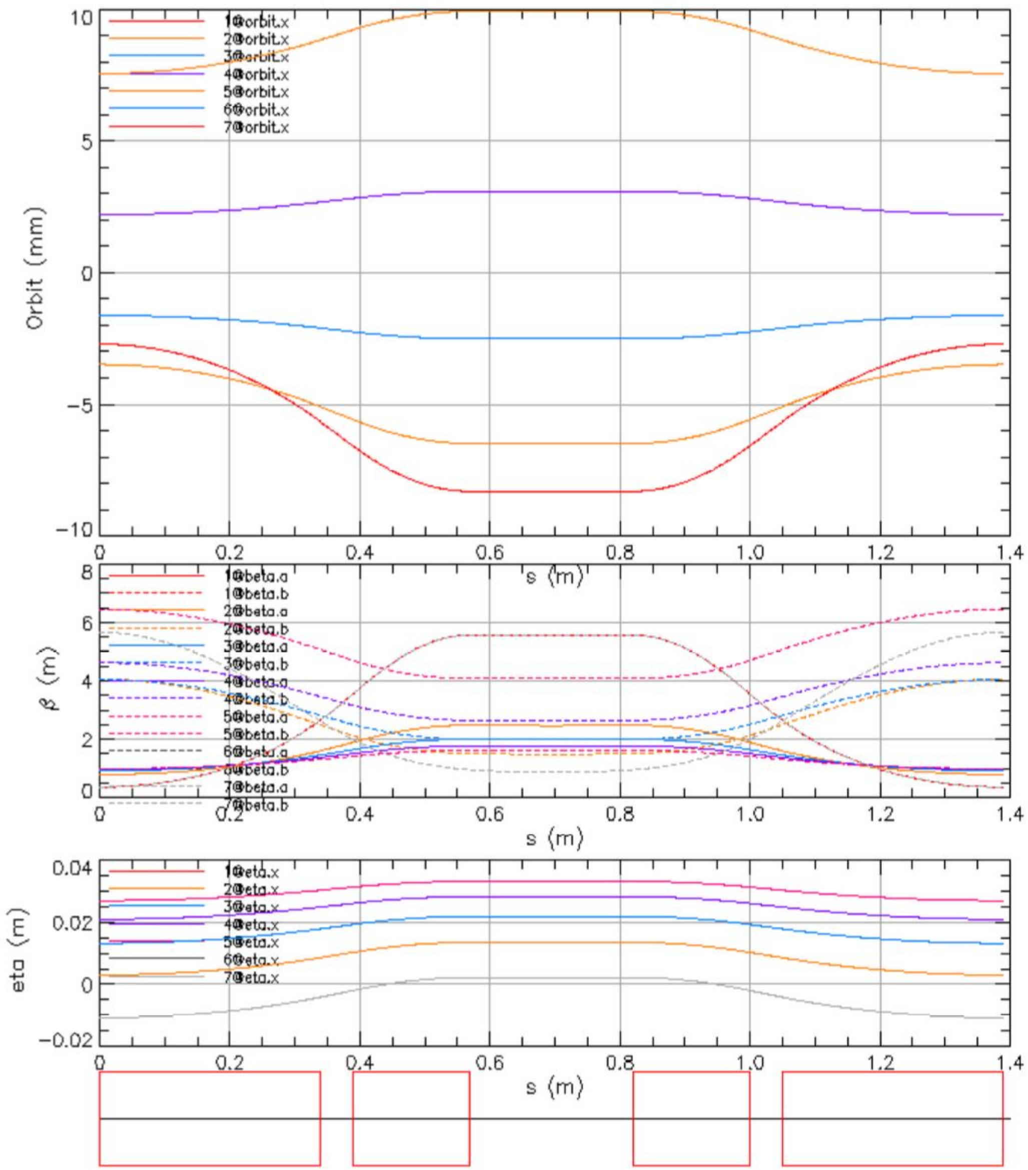


Lattice properties of the single arc cell



Lattice properties of the single arc cell – another example

LINAC
1.250 GeV



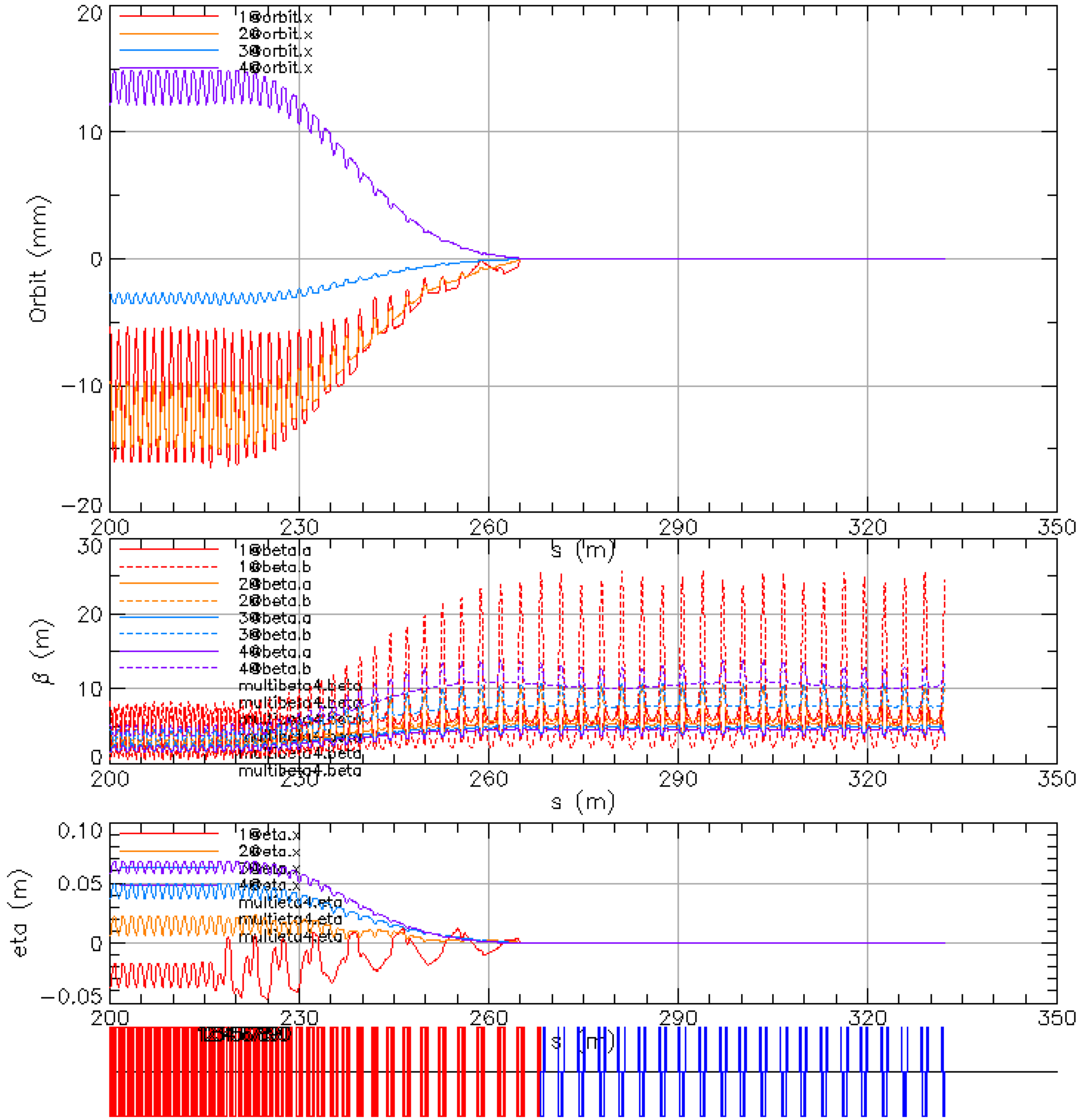
3.750 GeV

3.125 GeV

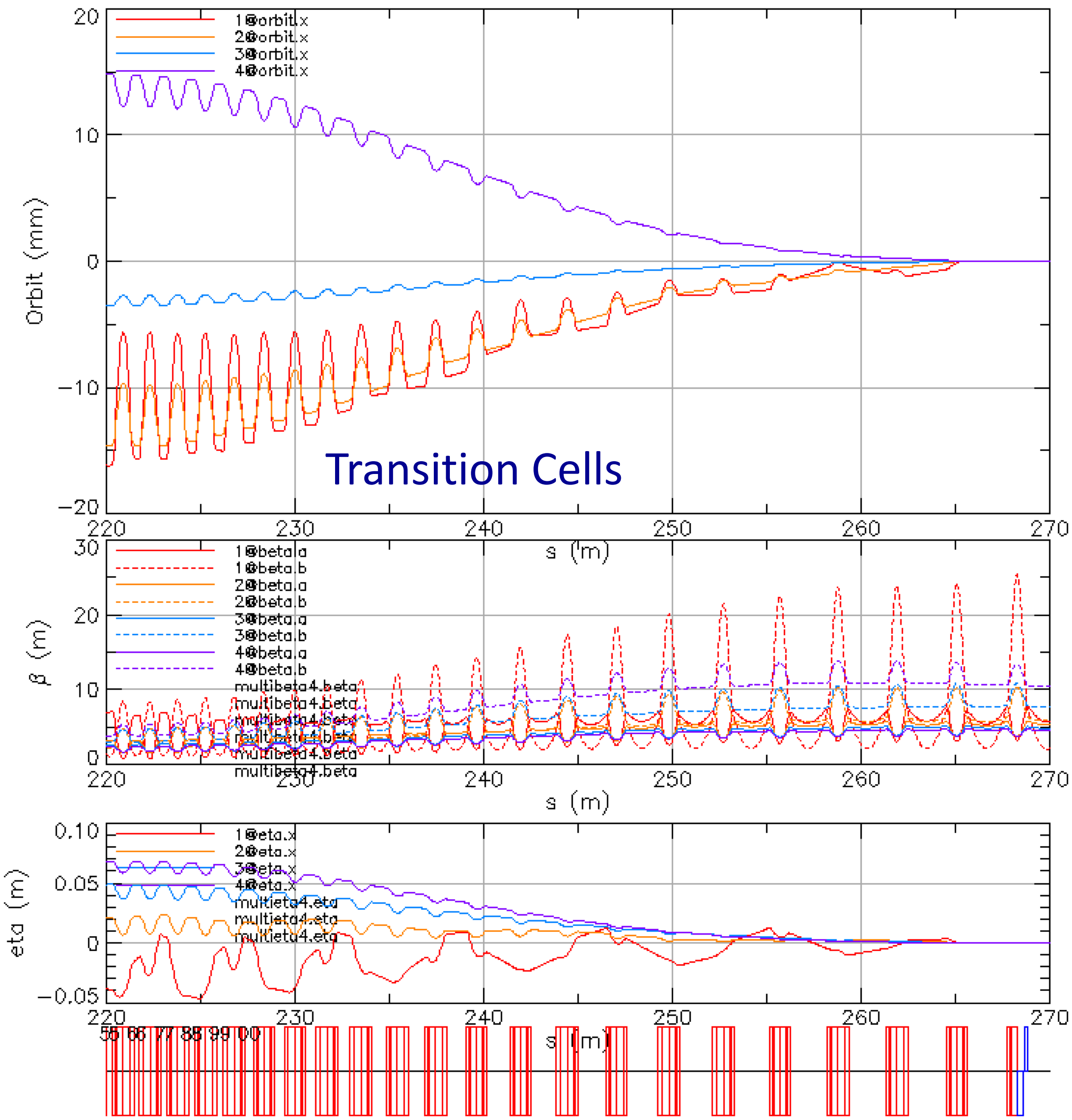
2.500 GeV
1.875 GeV

1.250 GeV

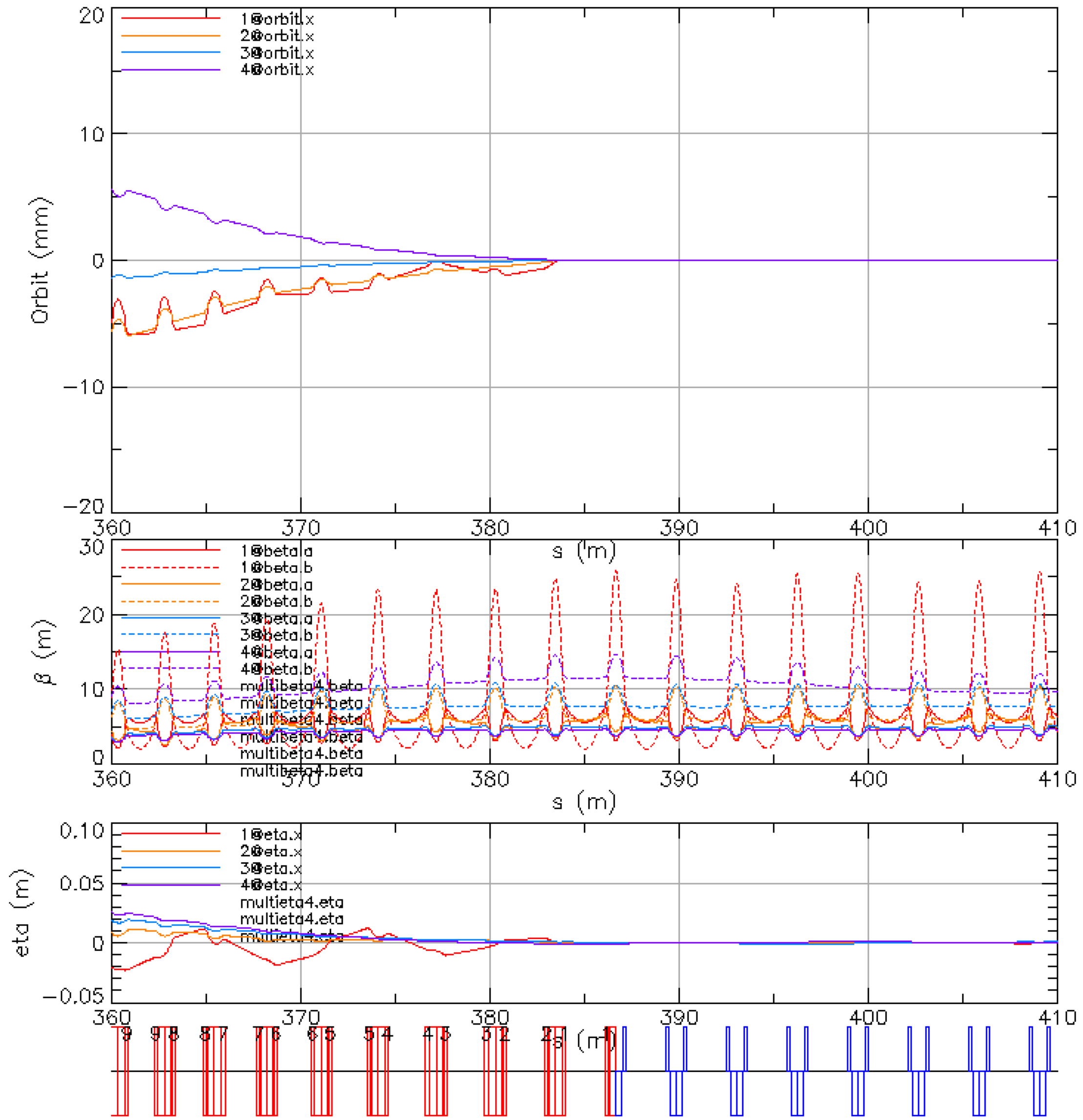
Adiabatic transition of the Fixed Field racetrack



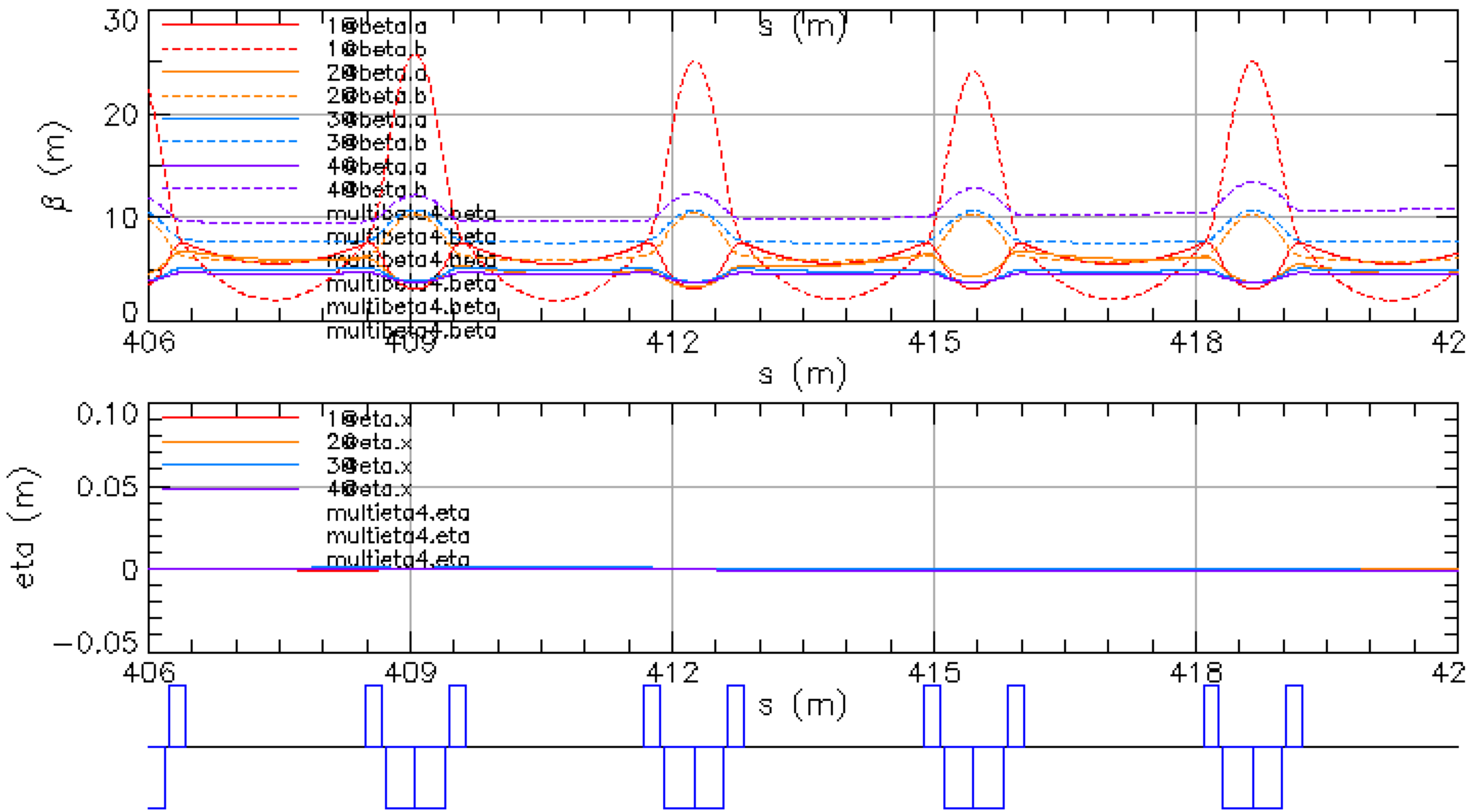
Details of the adiabatic transition



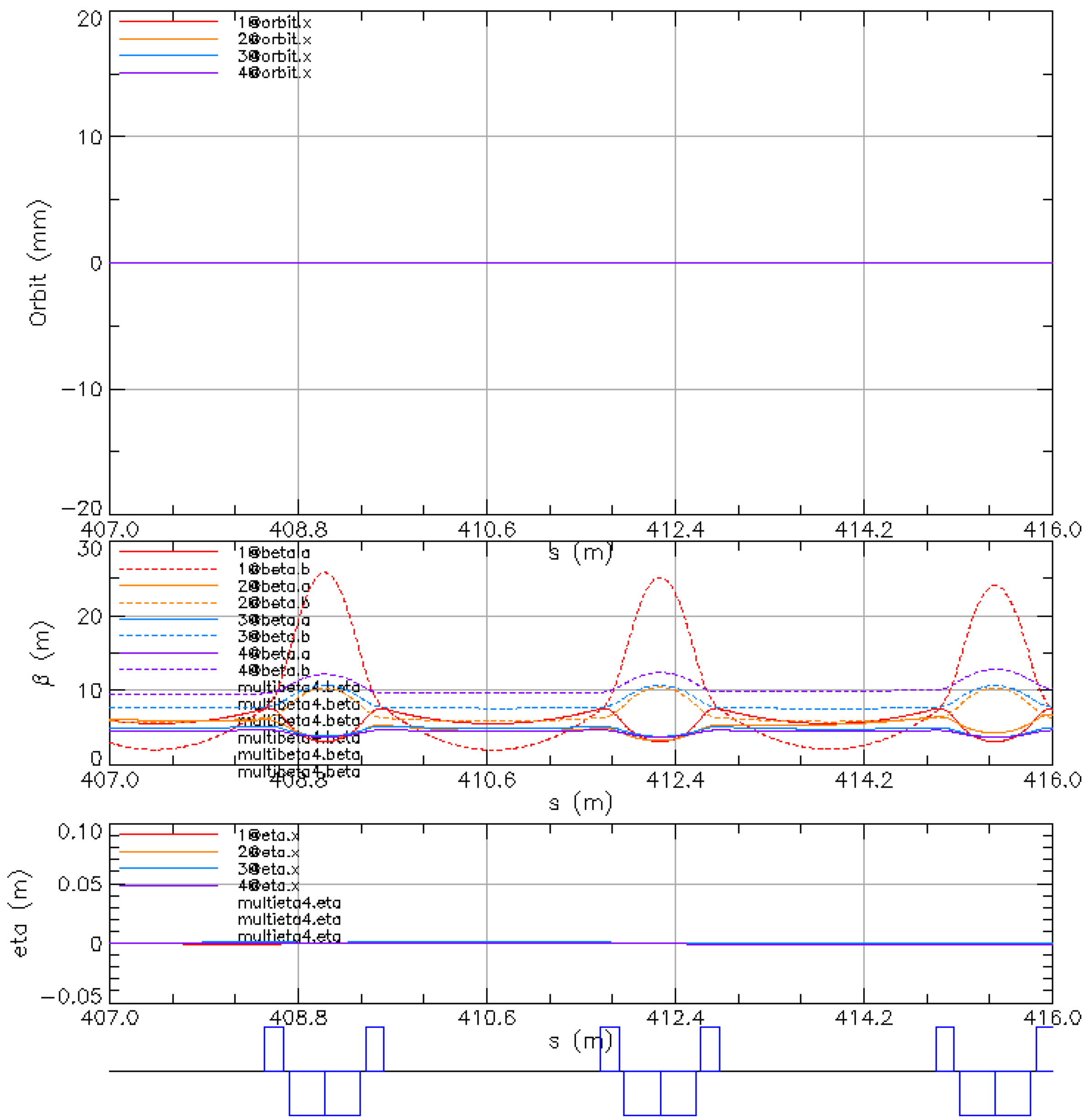
The adiabatic transition towards the straight section



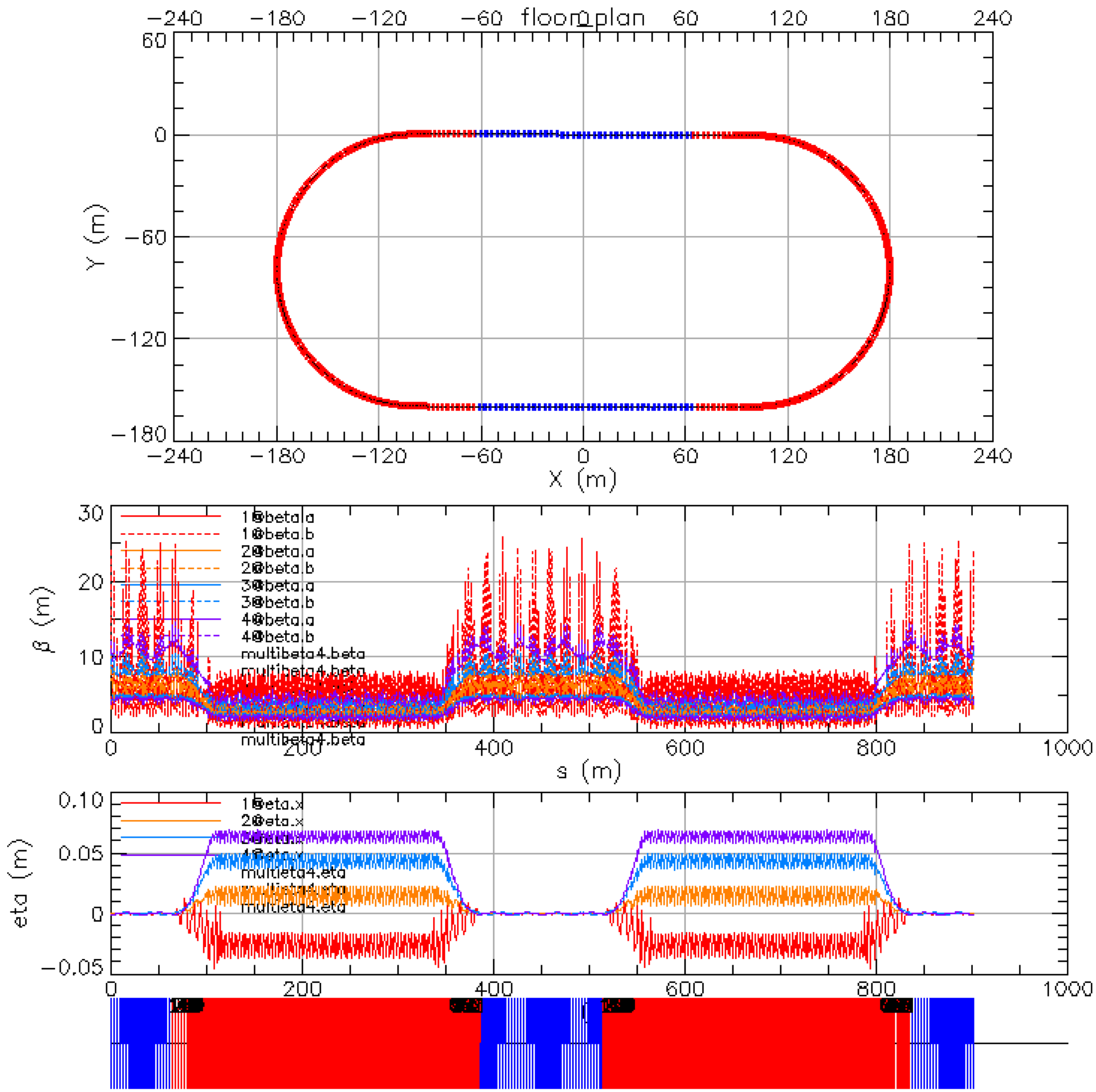
Lattice functions of the matched straight section (without including the linac)



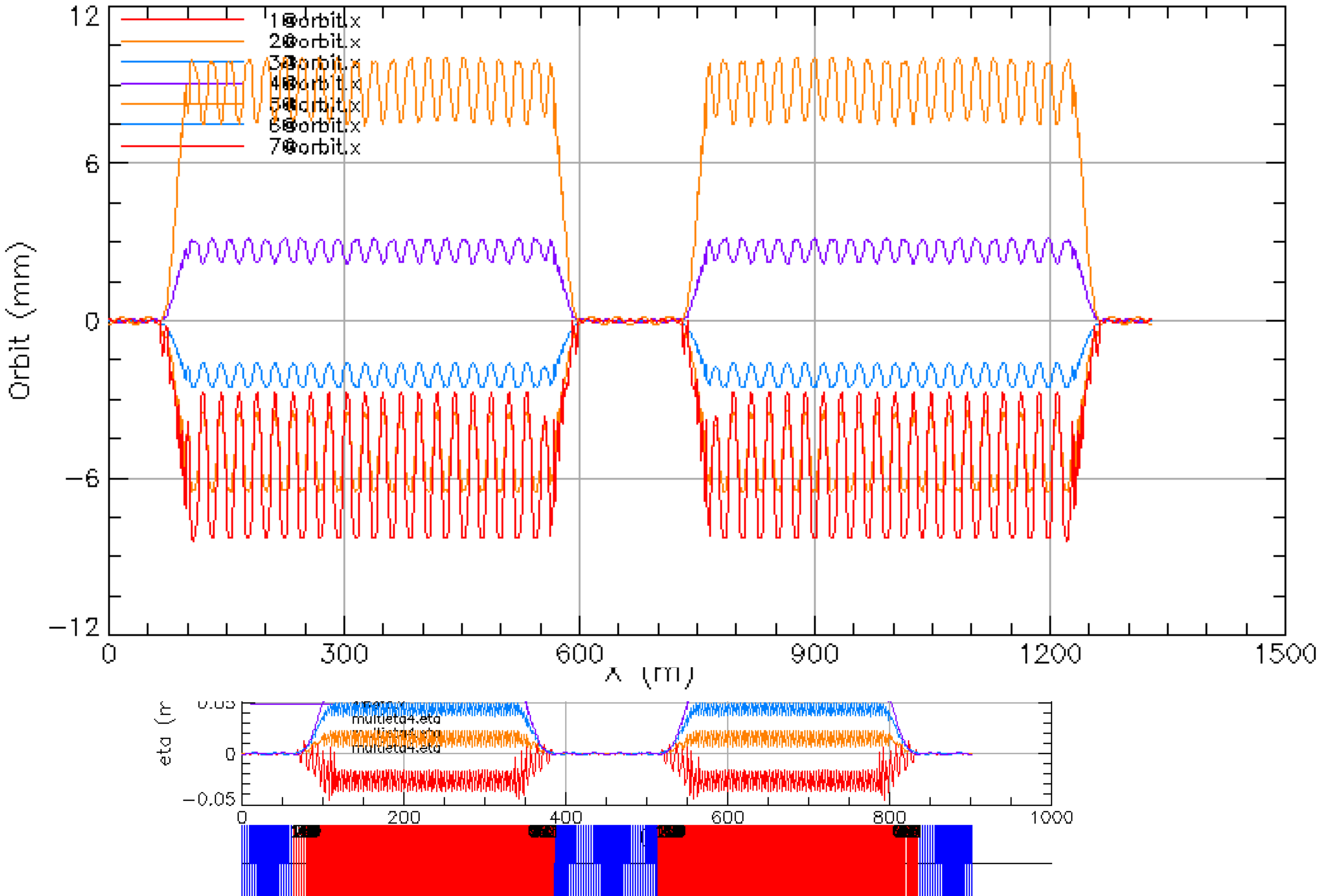
A detail part of the straight section



Fixed Field racetrack with linac



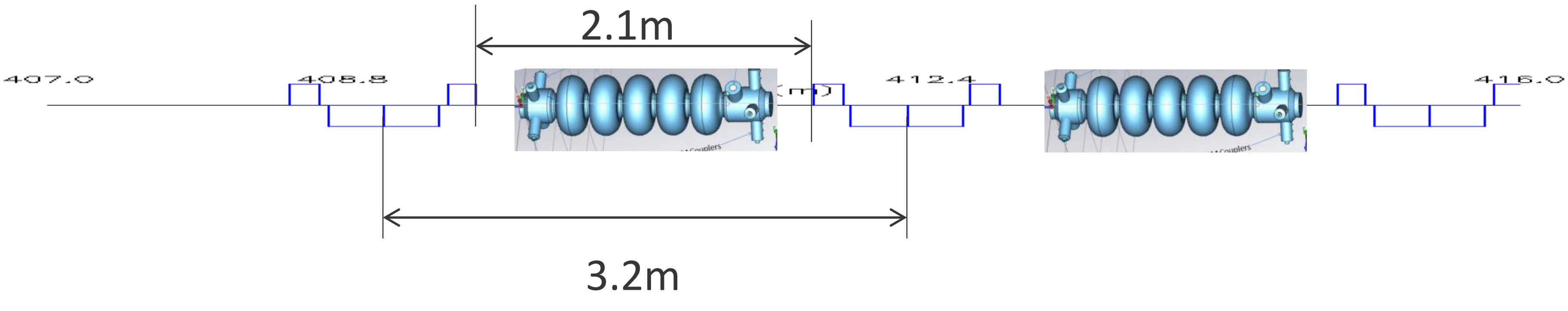
Fixed Field racetrack with linac

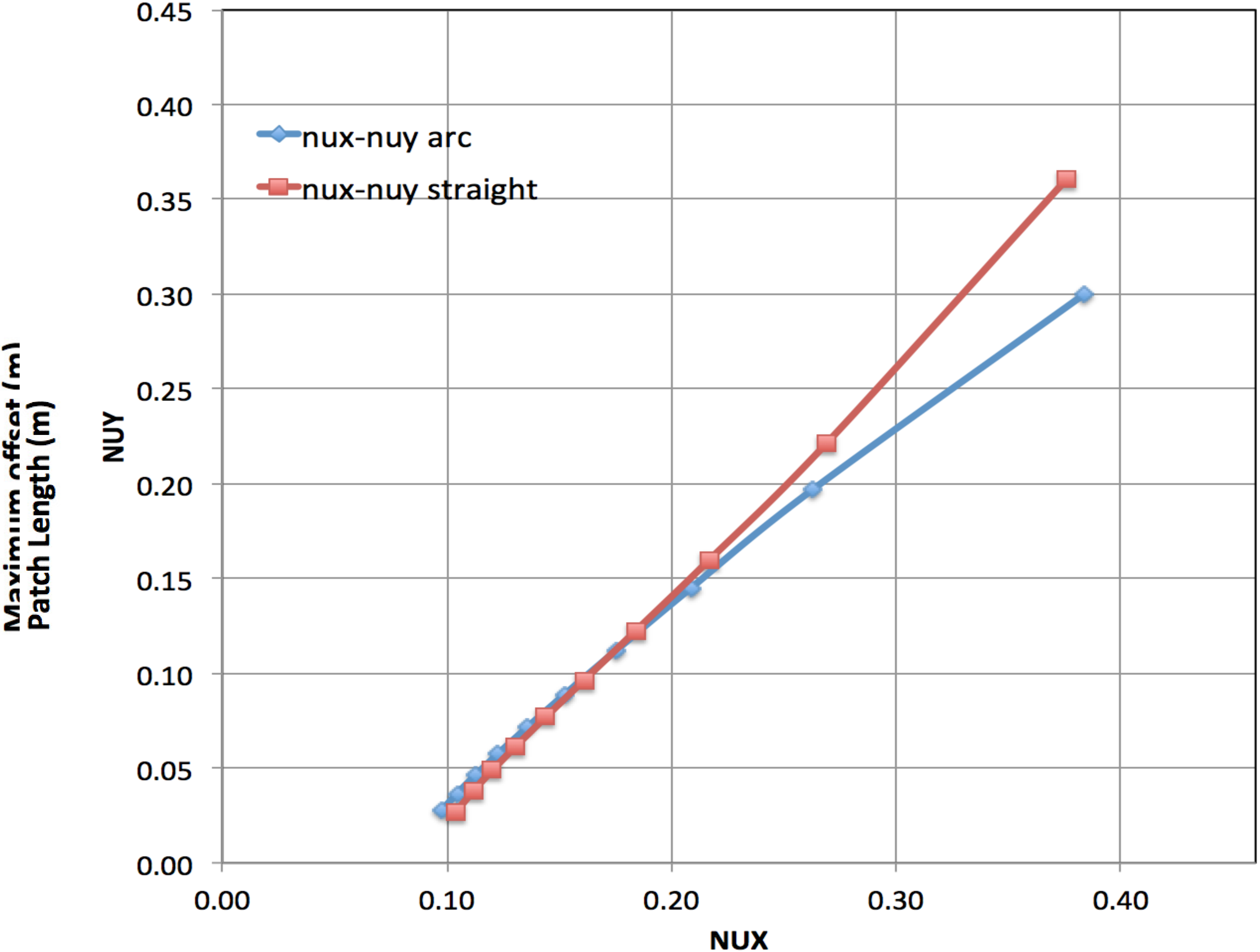


NS-Fixed Field racetrack with linac

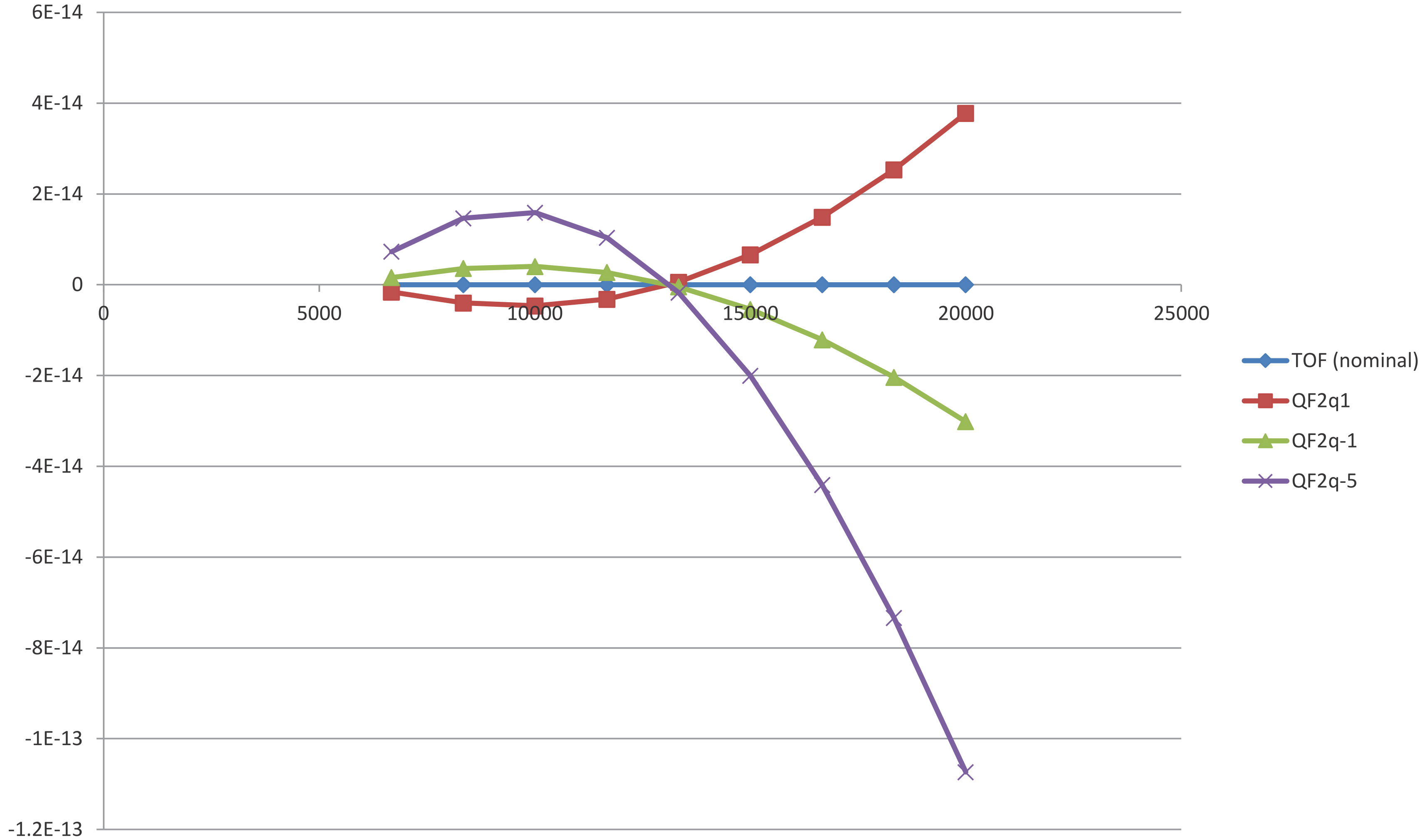
Straight Section combined with the linac (small Halbach Magnets with shielding iron around)

A report from RADIABEAM [WEPE077 IPAC 10 Kyoto Japan]
..“Praseodymium - Halbach magnets can operate at lower temperature than Nd-magnets and exhibit greater radiation hardness… Praseodymium cooled to 30 K exhibits a remnant field of 1.7 T and coercivity of 72 kOe.



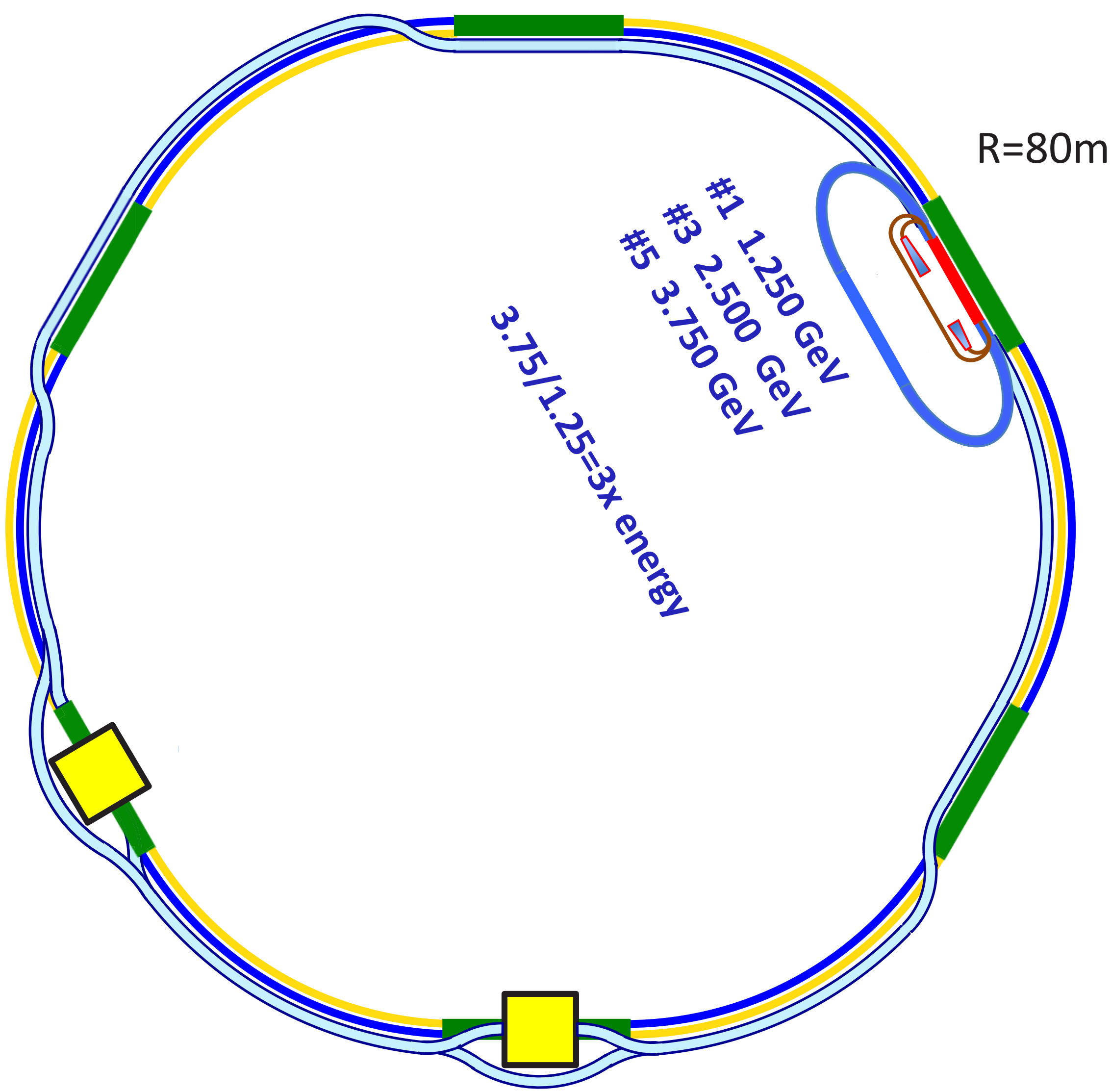

nux-nuy arc
nux-nuy straight
NUY
NUX
Patch Length (m)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.00
0.10
0.20
0.30
0.40

Time of flight adjustments by courtesy of Stephen Brooks



eRHIC with a single large FFA arc

Linac 1.25 GeV
#1 5.00 GeV
#2 6.25 GeV
#3 7.50 GeV
#4 8.75 GeV
#5 10.0 GeV
#6 11.25 GeV
#7 12.50 GeV
#8 13.75 GeV
#9 15.00 GeV
#10 16.25 GeV
#11 17.50 GeV
#12 18.75 GeV



Advantages of the Fixed Field Large momentum lattice:

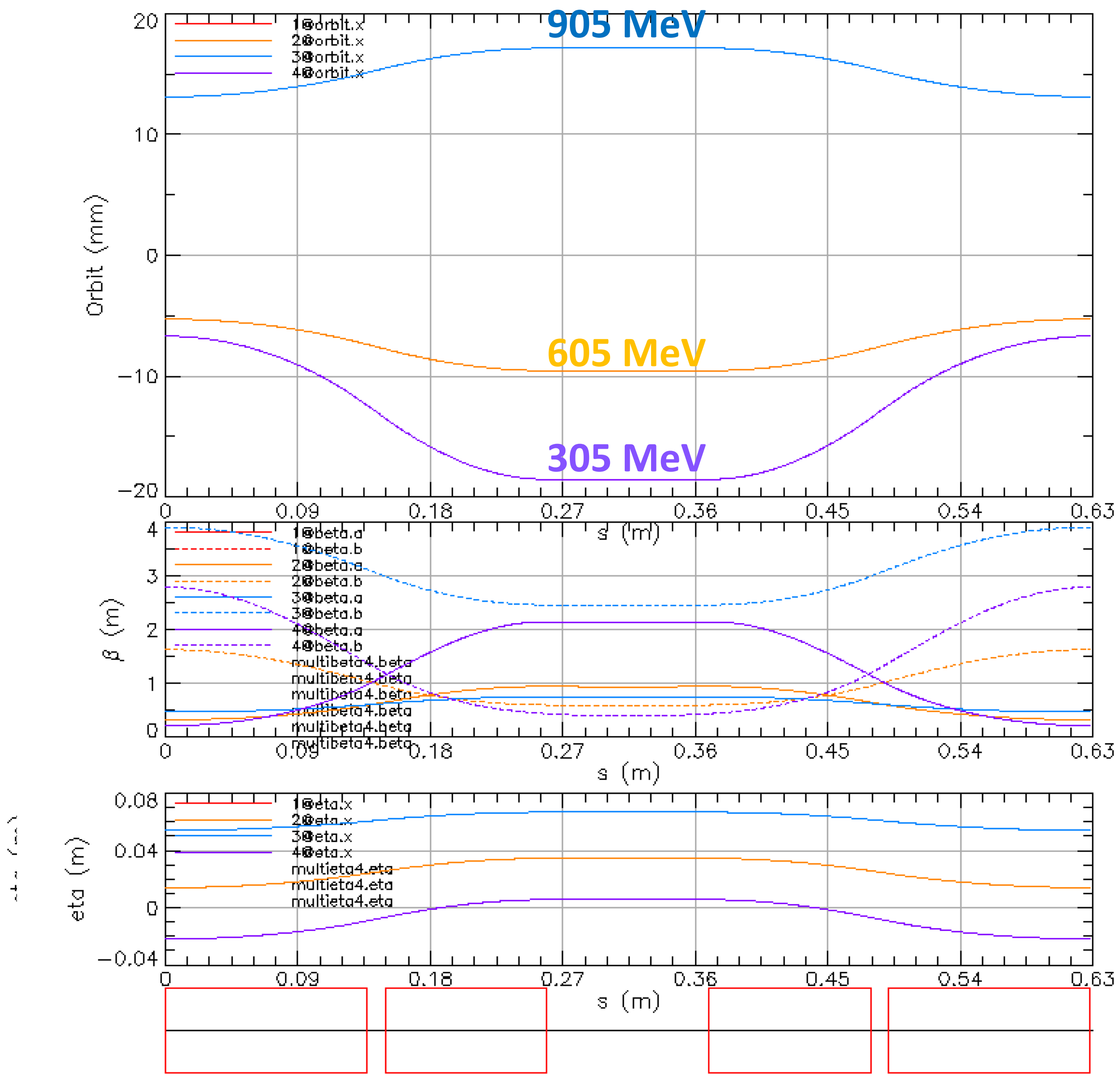
- For multiturn ERL's there is no other option but to use the fixed field magnets as with the present technologies it is impossible to change the magnetic field in a very short time (ns)

- With the exception of CBETA all ERL's use multiple beam lines with the fixed magnetic field to bring the beam back to linacs.

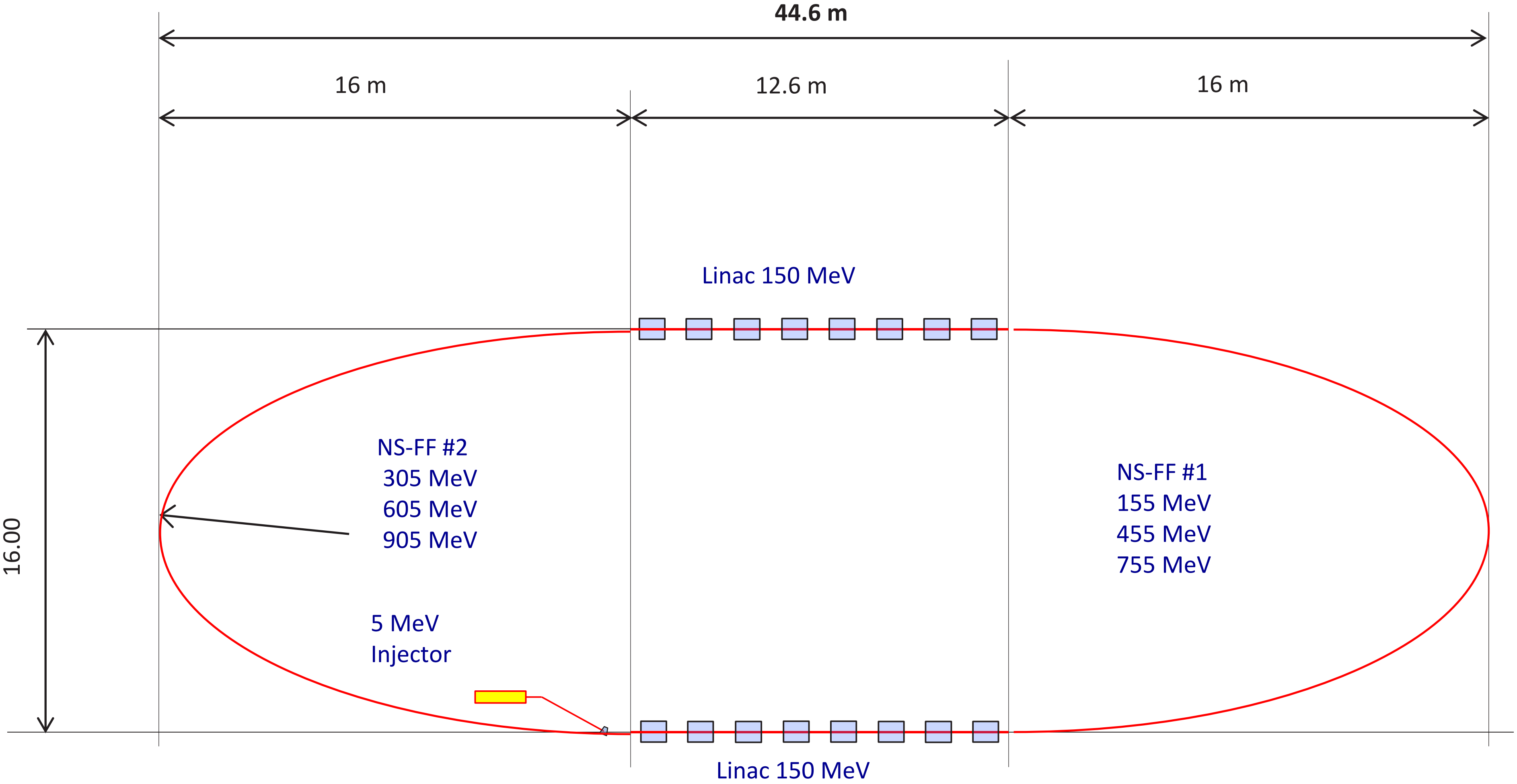
- The **fixed field large momentum acceptance beam lines** show multiple advantages in the multiple pass ERL's:
  - Multiple beam lines are replaced with a single one
  - Electron beam polarization is preserved
  - Operation is simplified

BACK UP SLIDES

Fixed Field Arc for PERLE 305-905 MeV– similar to CBETA

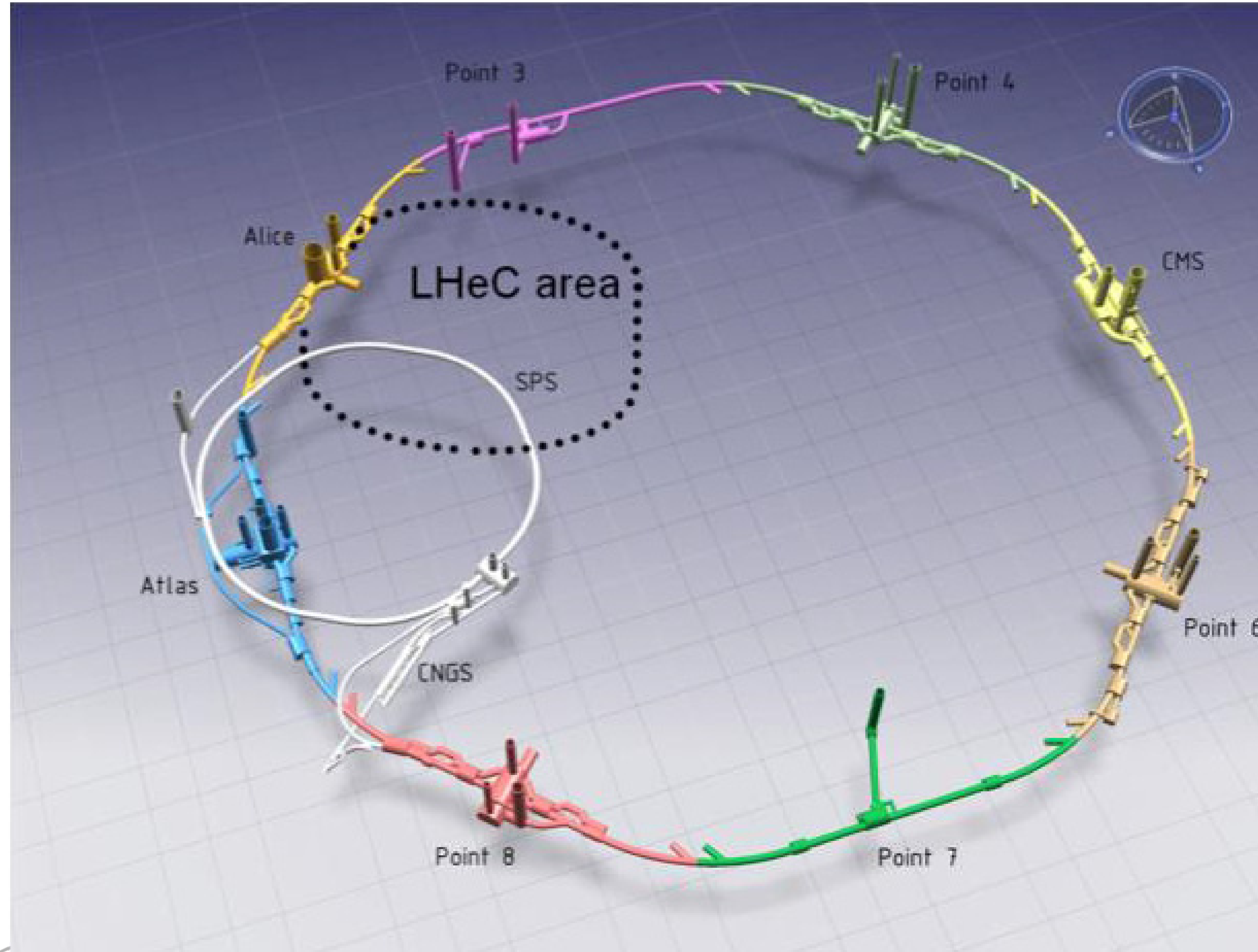


Fixed Field single arcs for PERLE – new proposal as previously described with the triplet magnets between the 5 RF cell units

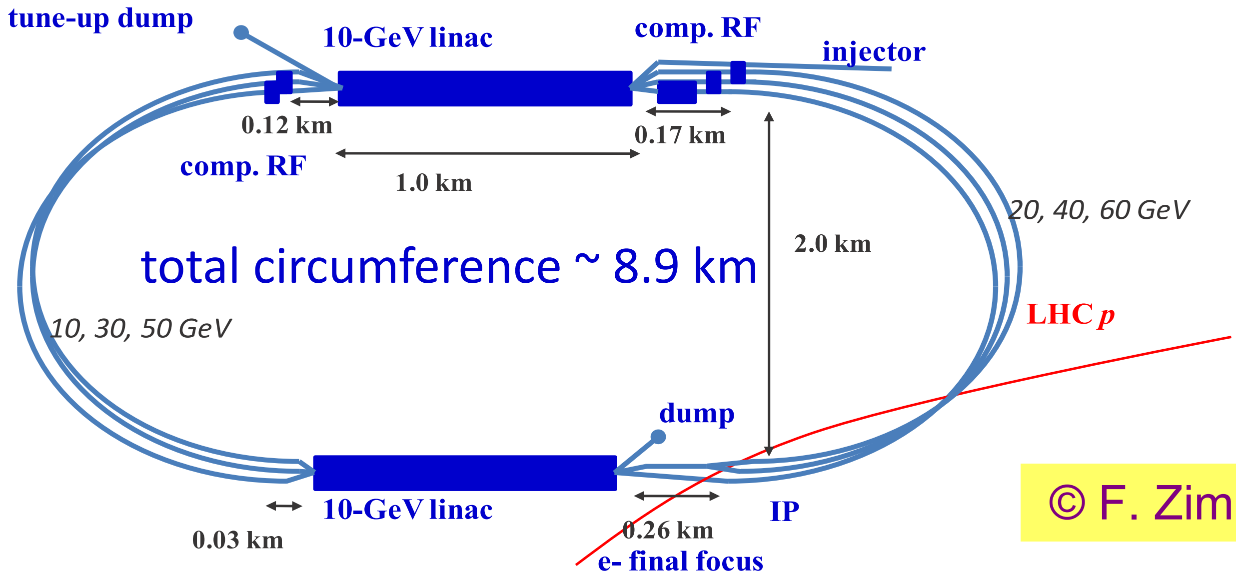


From Oliver Brüning

Layout of the LHeC-LHC-SPS



Linac-Ring Option – LHeC Recirculator



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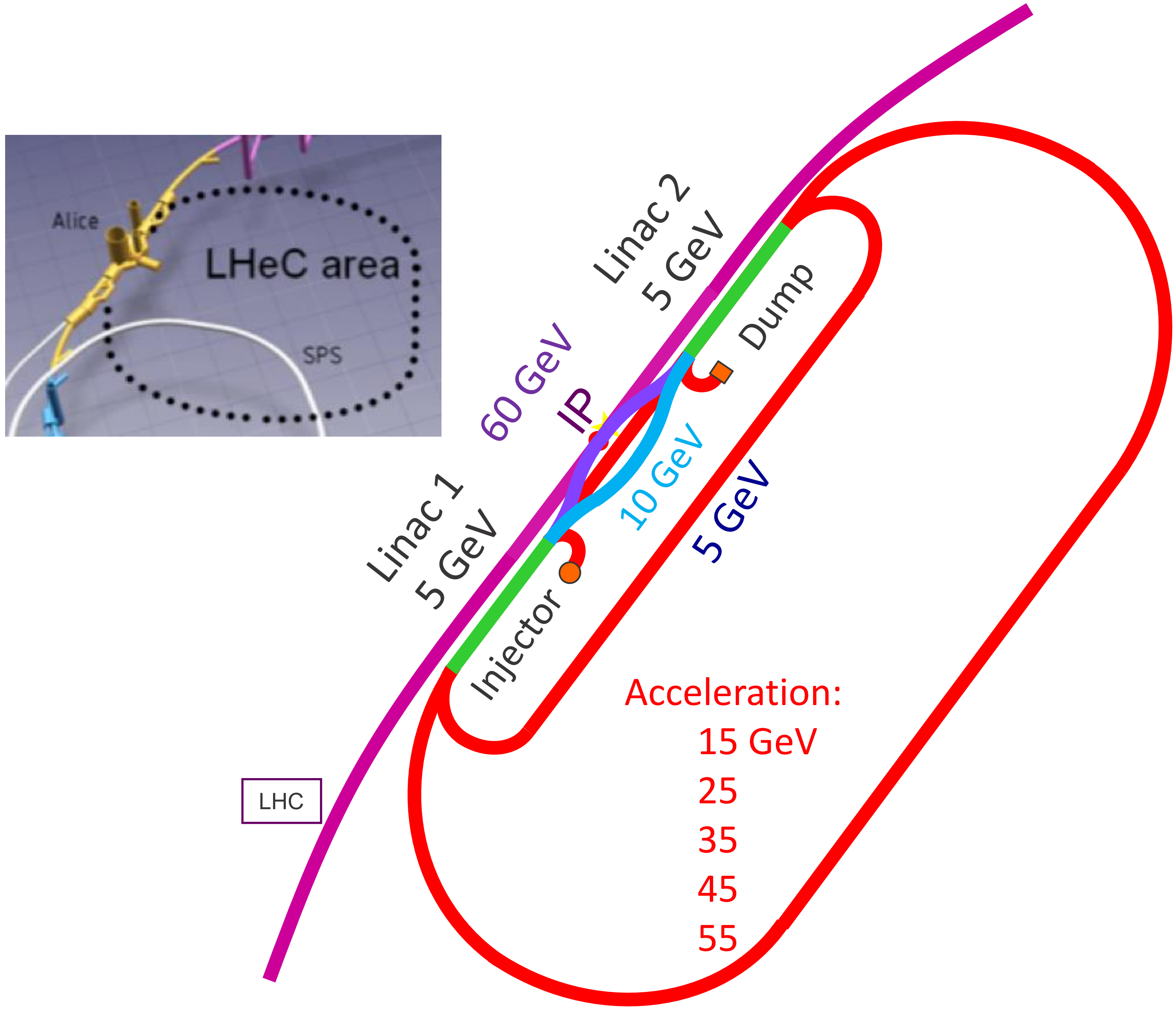
RECIRCULATOR COMPLEX

1. 0.5 Gev injector
2. Two SCRF linacs (10 GeV per pass)
3. Six 180° arcs, each arc 1 km radius
4. Re-accelerating stations
5. Switching stations
6. Matching optics
7. Extraction dump at 0.5 GeV

	PROTONS	ELECTRONS
Beam Energy [GeV]	7000	60
Luminosity [$10^{33}cm^{-2}s^{-1}$]	1	1
Normalized emittance $\gamma\varepsilon_{x,y}$ [μm]	3.75	50
Beta Function $\beta^*_{x,y}$ [m]	0.10	0.12
rms Beam size $\sigma^*_{x,y}$ [μm]	7	7
rms Divergence $\sigma'_{x,y}$ [μrad]	70	58
Beam Current [mA]	(860) 430	6.6
Bunch Spacing [ns]	25 (50)	25 (50)
Bunch Population	$1.7{*}10^{11}$	$(1{*}10^9)$ $2{*}10^9$

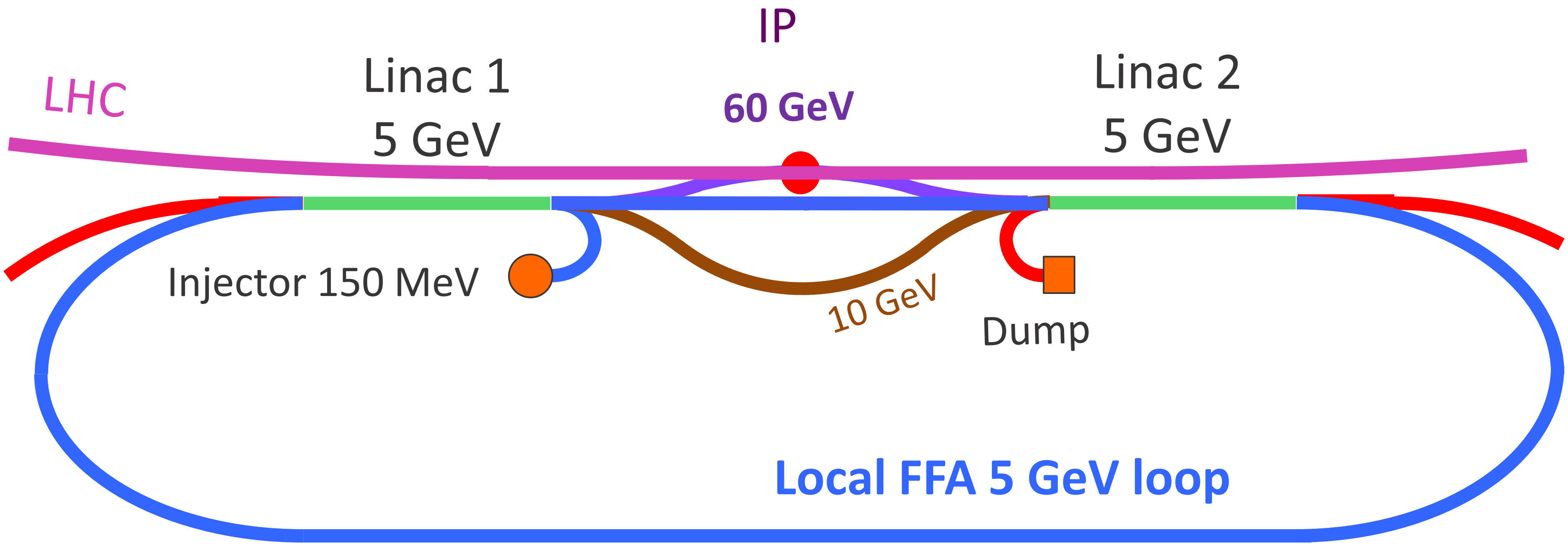
The baseline 60 GeV ERL option proposed can give an e-p luminosity of 10^{33} $cm^{-2}s^{-1}$ (extensions to 10^{34} $cm^{-2}s^{-1}$ and beyond are being considered)

Fixed Field LHeC Recirculator with ER



Recovery:
55 GeV
45
35
25
15

NS-FF LHeC Recirculator with ER

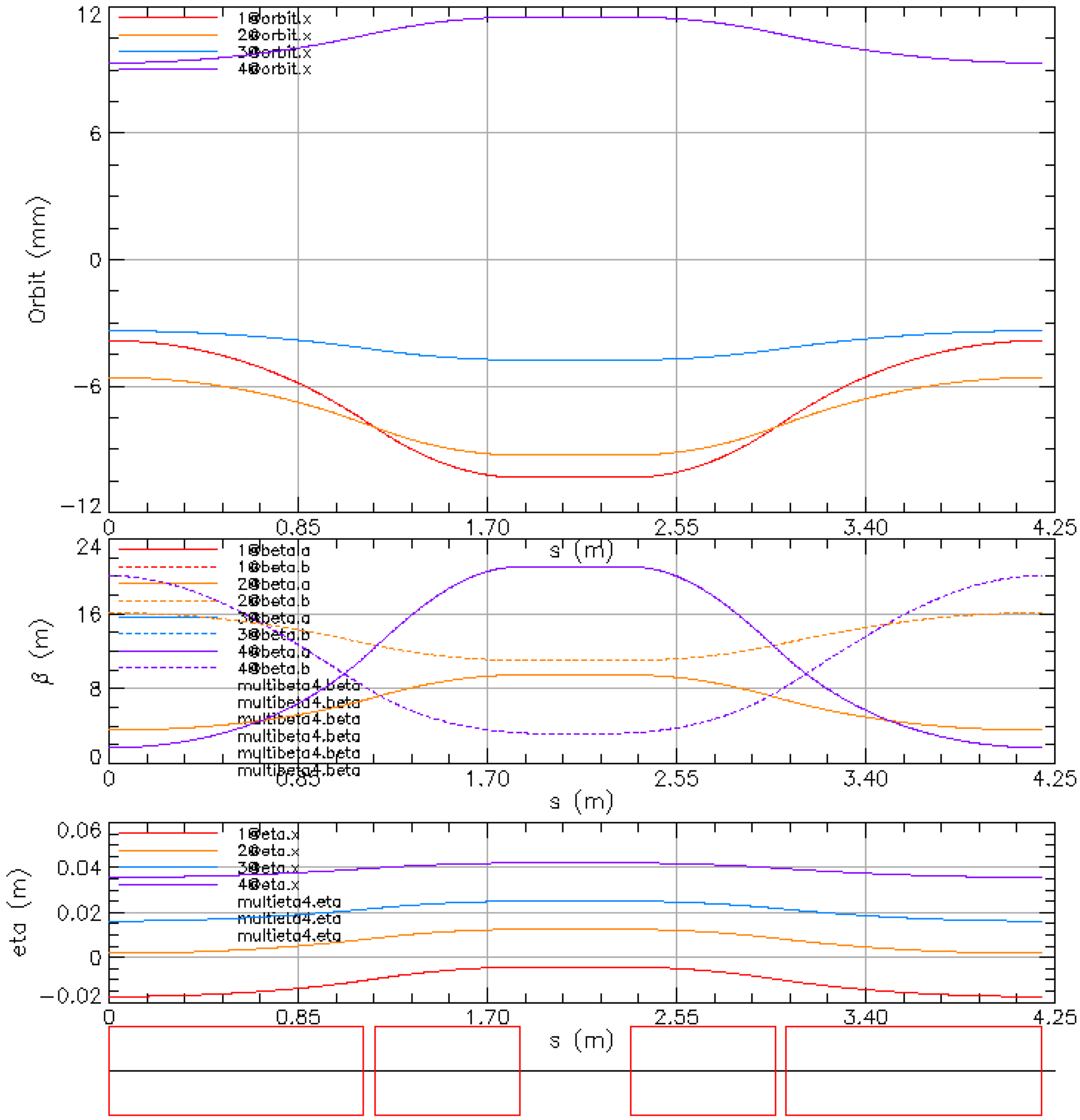


Acceleration
15 GeV
25
35
45
55

3.7 x energy

Recovery
55 GeV
45
35
25
15

Lattice Function in the LHeC FFA arc



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Synchrotron Radiation in LHeC with 2 x 5 GeV linacs
Maximum Collision Energy 60 GeV

E(GeV)	Total Power (MW) 8.87 mA	Total Power (MW) 6.6 mA
50	7.5779	5.6383
40	4.2080	3.1310
30	1.3902	1.0344
20	1.2881	0.9584
10	0.5359	0.3987
TOTAL	**15.000**	**11.1608**

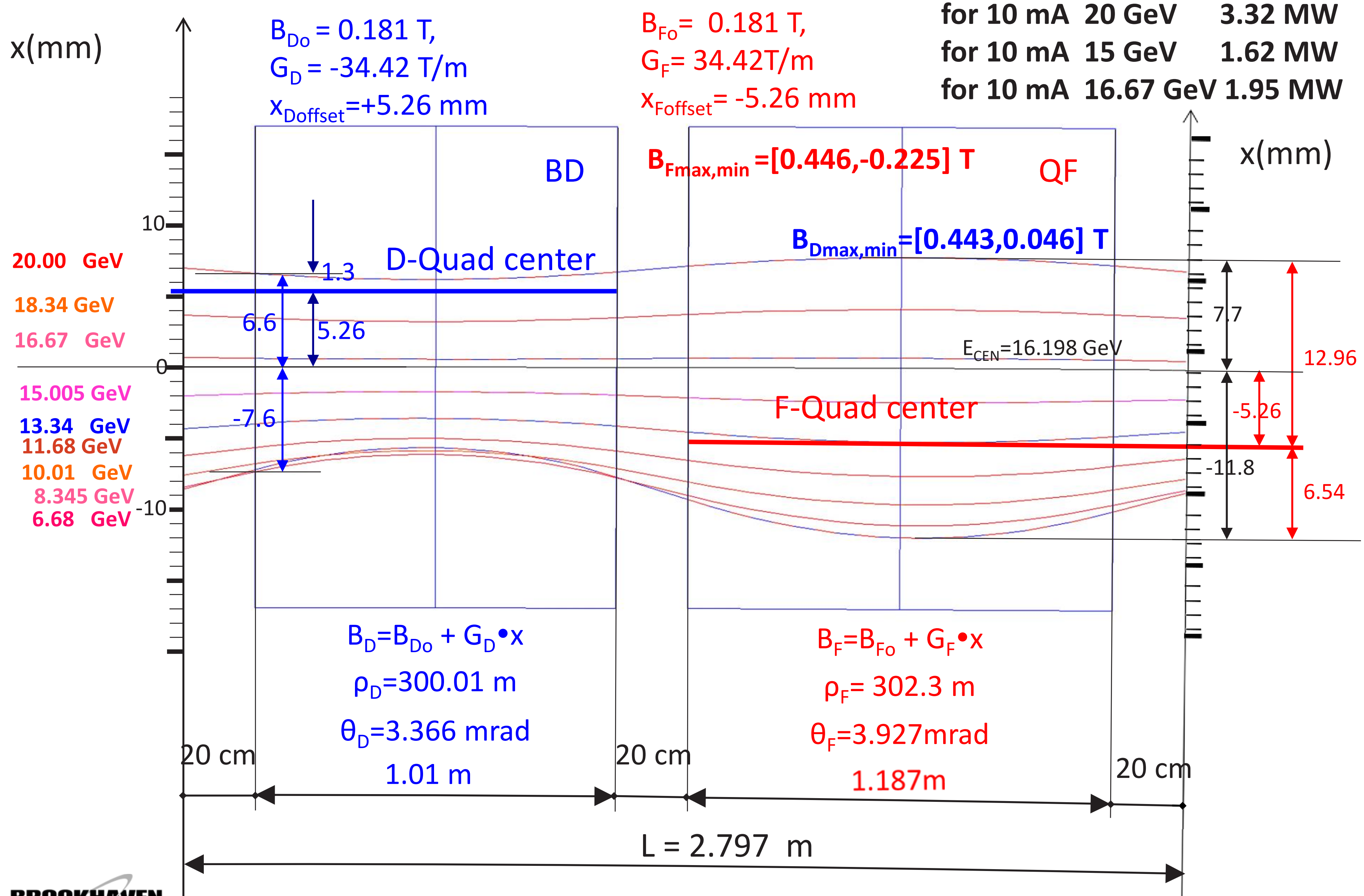
High Energy eRHIC NS-FF Cell

Synchrotron Radiation:

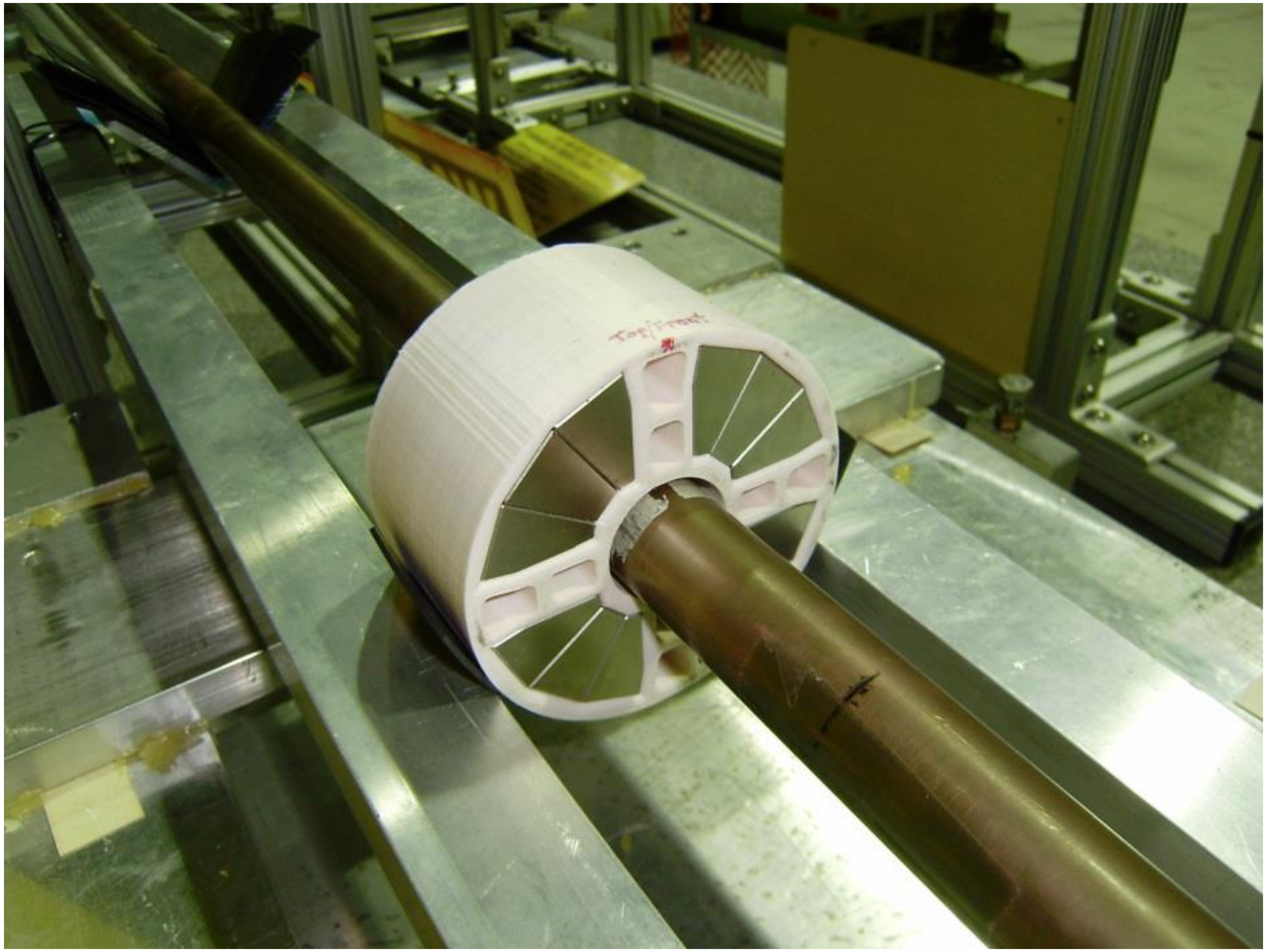
for 10 mA 20 GeV 3.32 MW

for 10 mA 15 GeV 1.62 MW

for 10 mA 16.67 GeV 1.95 MW



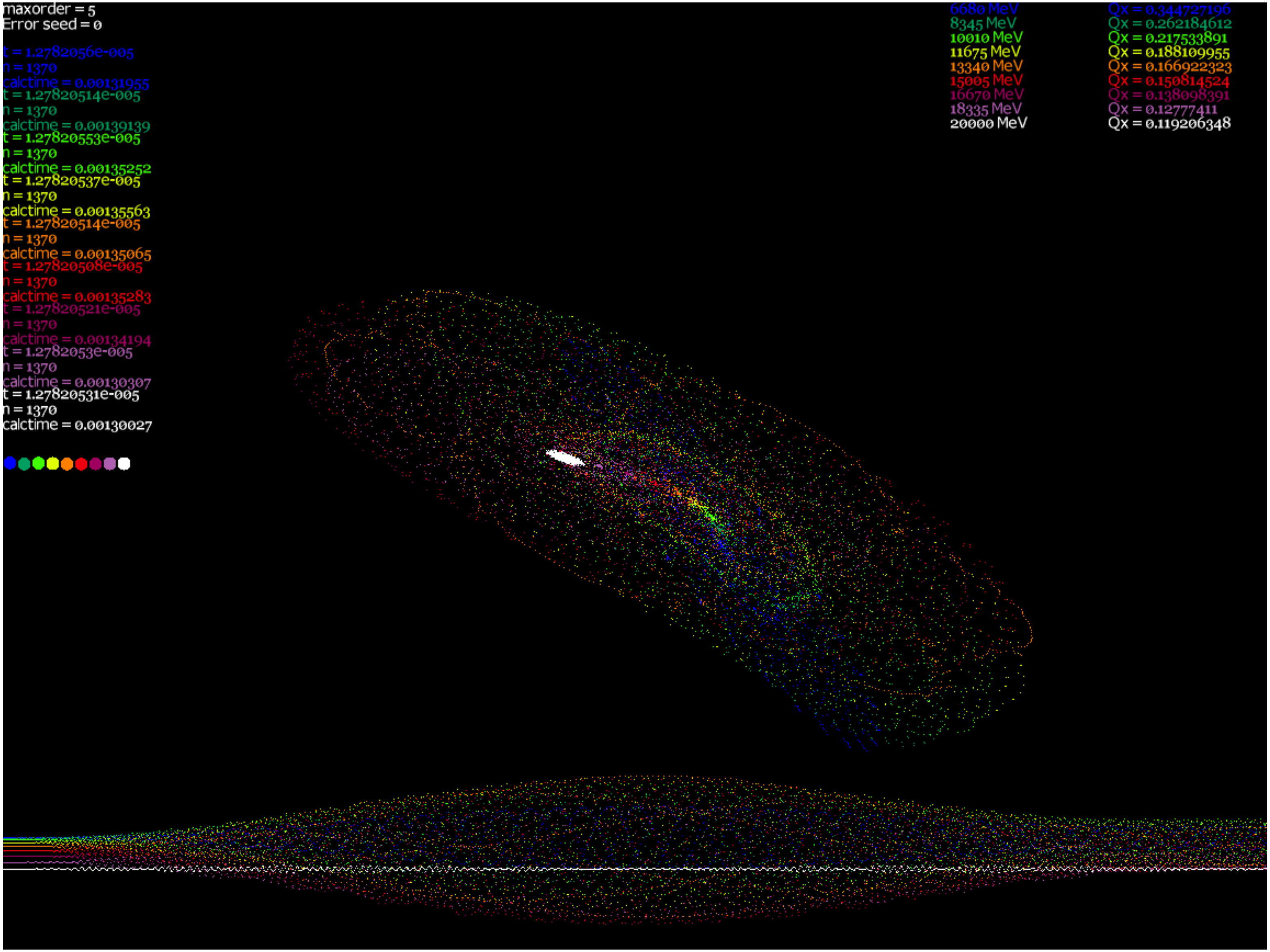
Built and successfully tested Halbach type of magnet with a horizontal gap for the eRHIC ERL type of solution



CONCLUSION

- Two lattice solutions are proposed for the PERLE design with a single arc line
- A new proposal could replace the fast cycling synchrotron with either 500 MeV with 36 passes of the single bunch RLA or 1 GeV linac with 18 passes preserving the polarization. This is a cost-effective solution.

Time of flight adjustments



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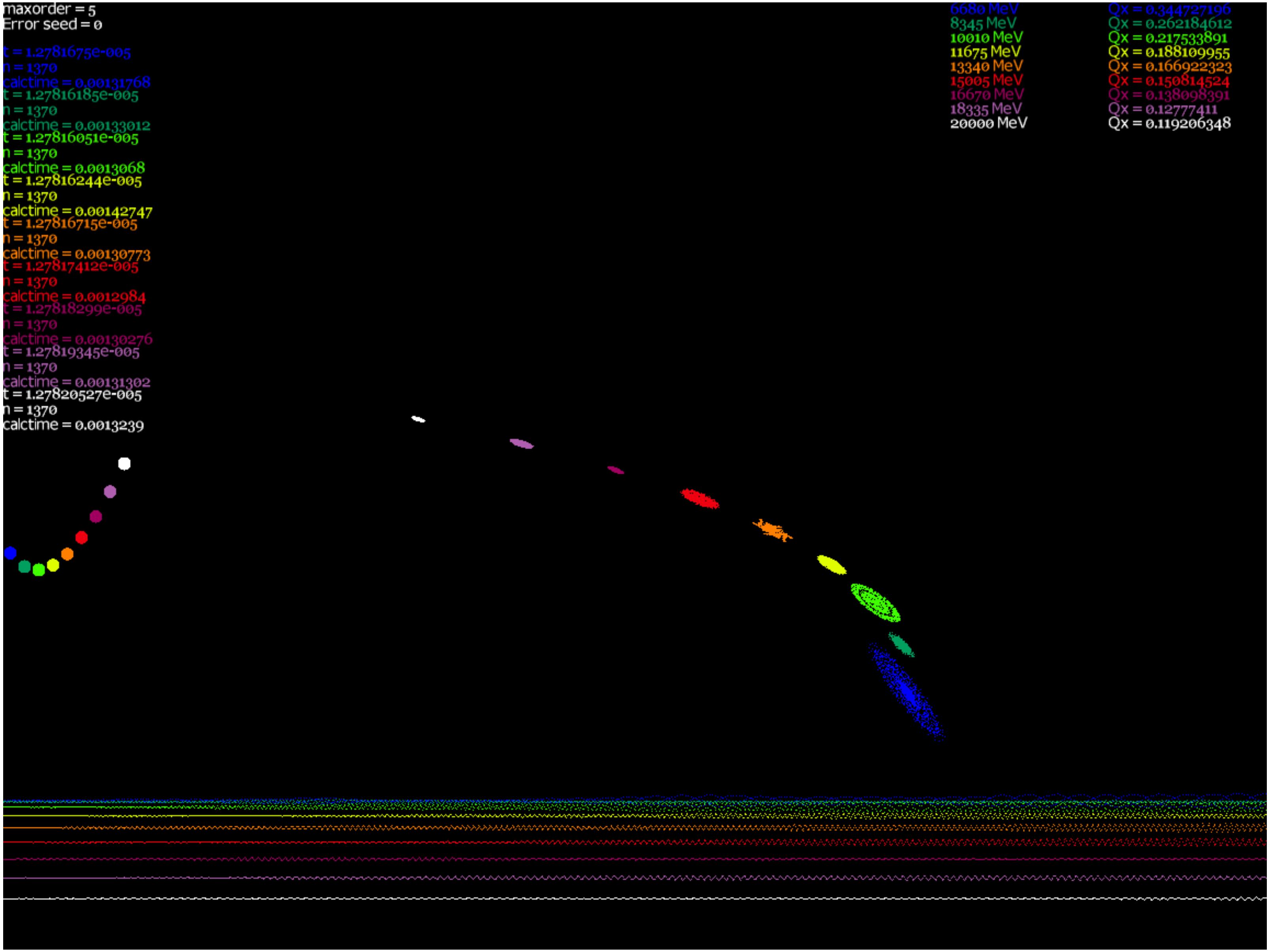

Time of flight adjustments