Lattice for eRHIC and LHeC ERL based designs.

*Y. HAO, D. KAYRAN, V. N. LITVINENKO, **V. PTITSYN**, D. TRBOJEVIC, N.TSOUPAS*

BROOKHAVEN NATIONAL LABORATORY

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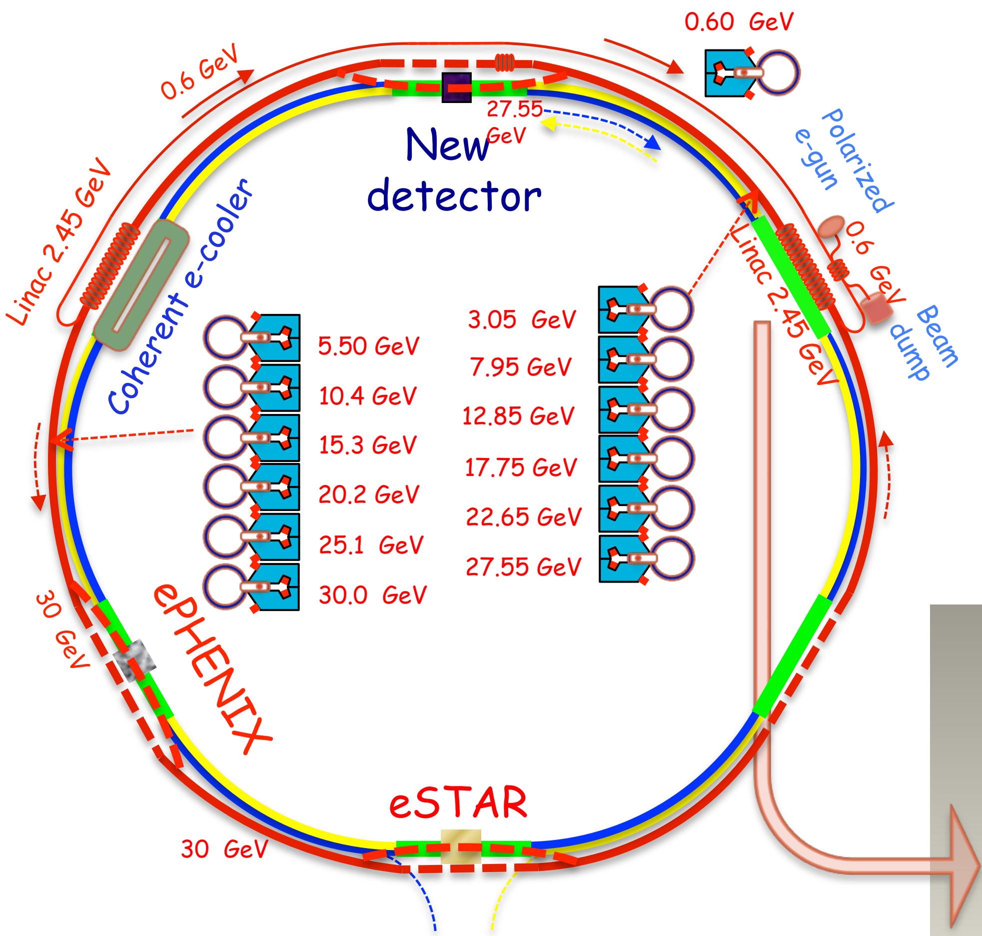
Exploring Nuclear Matter - Quarks to Stars

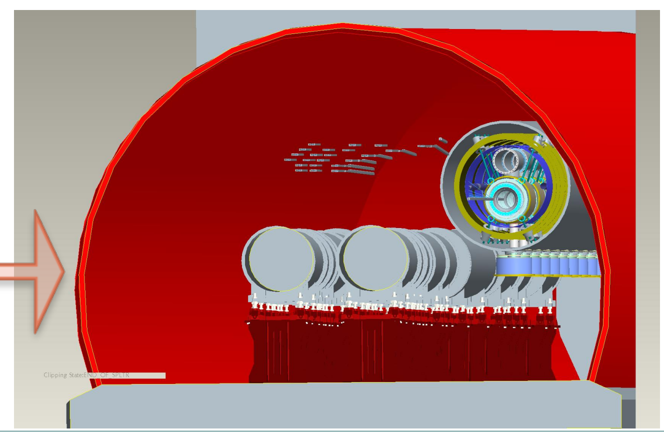
ERL-based eRHIC is future e-ion collider



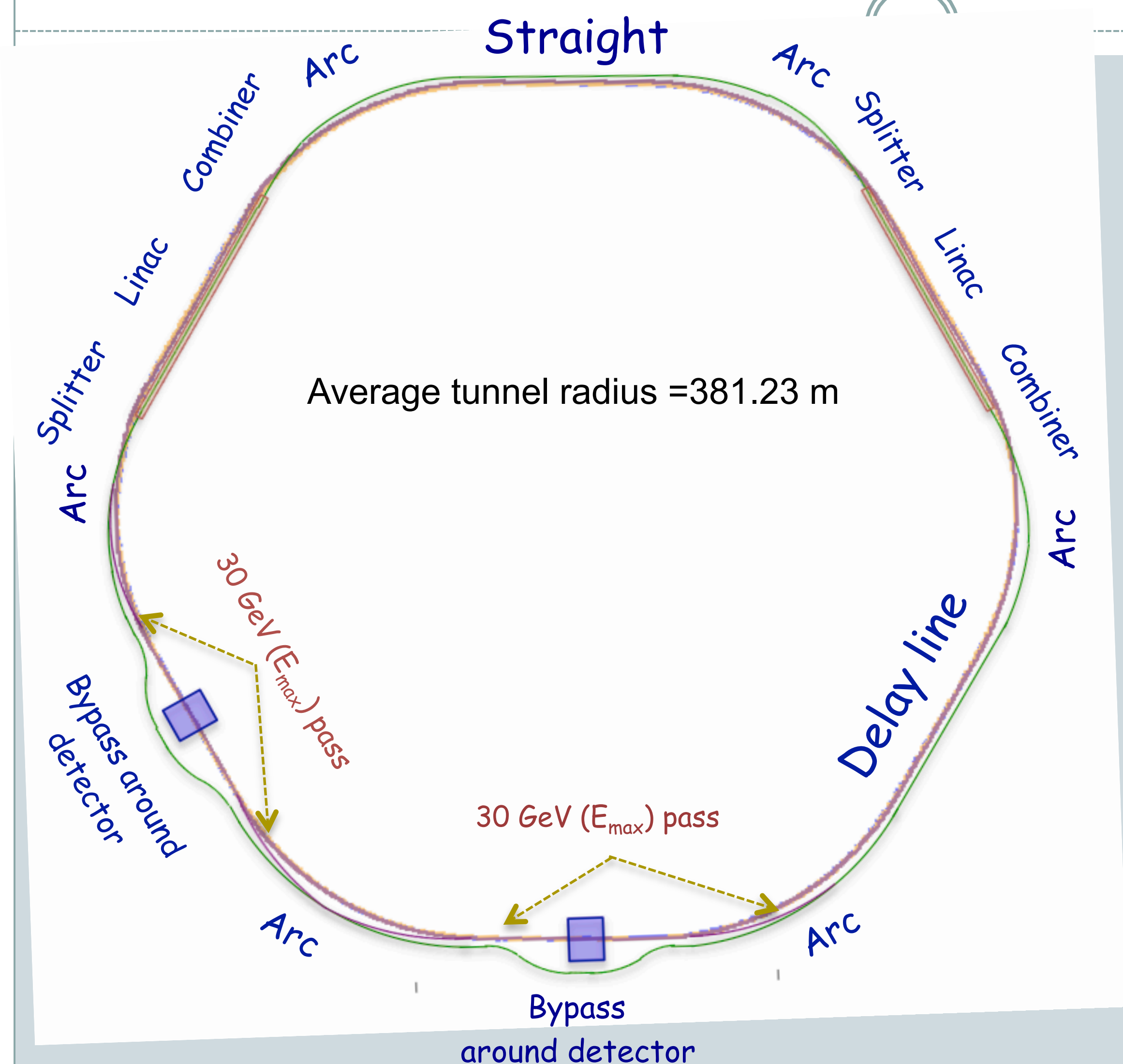
✓All-in tunnel staging approach uses two energy recovery linacs and 6 recirculation passes to accelerate the electron beam.

✓Staging: the electron energy will be increased in stages, from 5 to 30 GeV, by increasing the linac lengths .

✓Up to 3 experimental locations



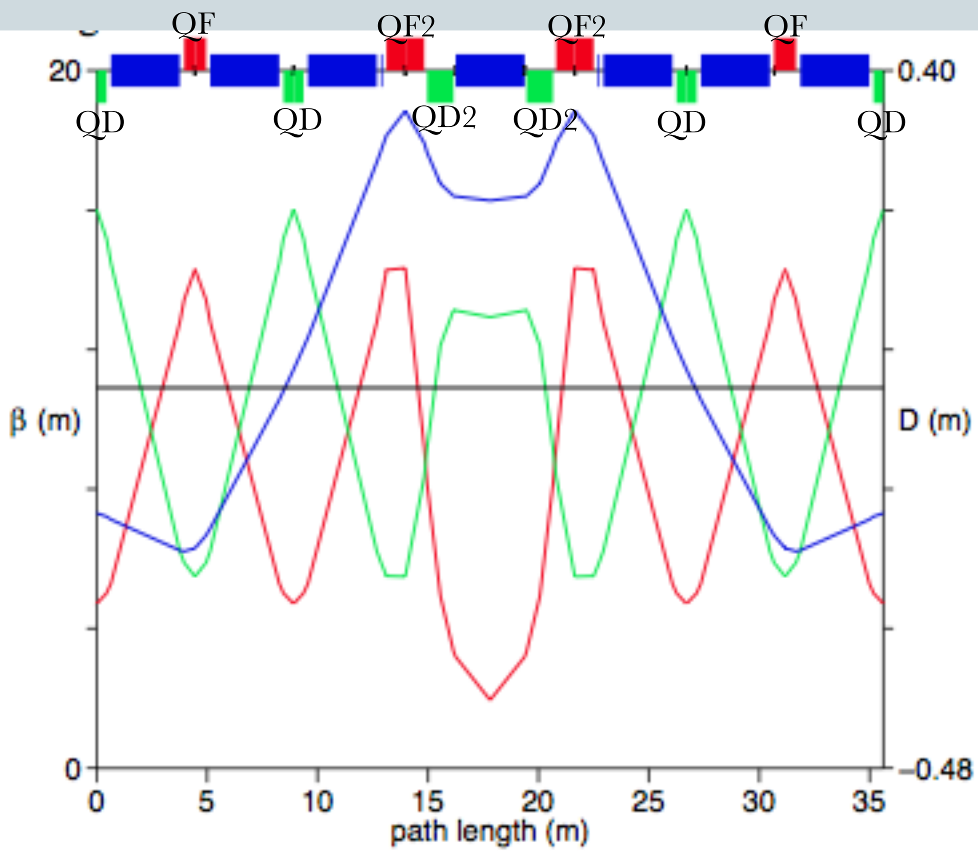
eRHIC Electron Lattice components

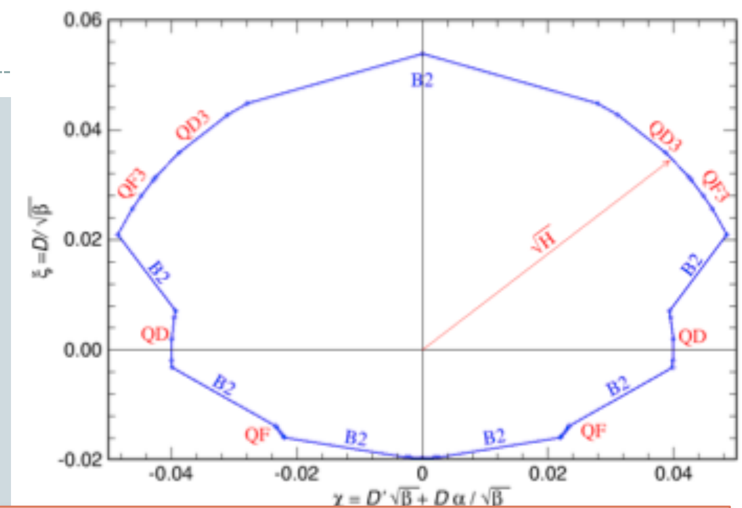


Main requirements:
- Isochronous beam transfer between the linacs.
- Minimization of synchrotron radiation and related effects.
- Ability to vary the path length of recirculation passes.
- Linac: compactness, low beta-functions.
- Small beam size throughout to allow for the compact magnets.
- By-passing experimental detectors without major tunnel reconstruction.
- Low background, high luminosity interaction region.

eRHIC isochronous cell

Based on asynchronous cell lattice developed by Dejan Trbojevic et al., AIP CONFERENCE PROCEEDINGS, V. 530, (2000) p. 333

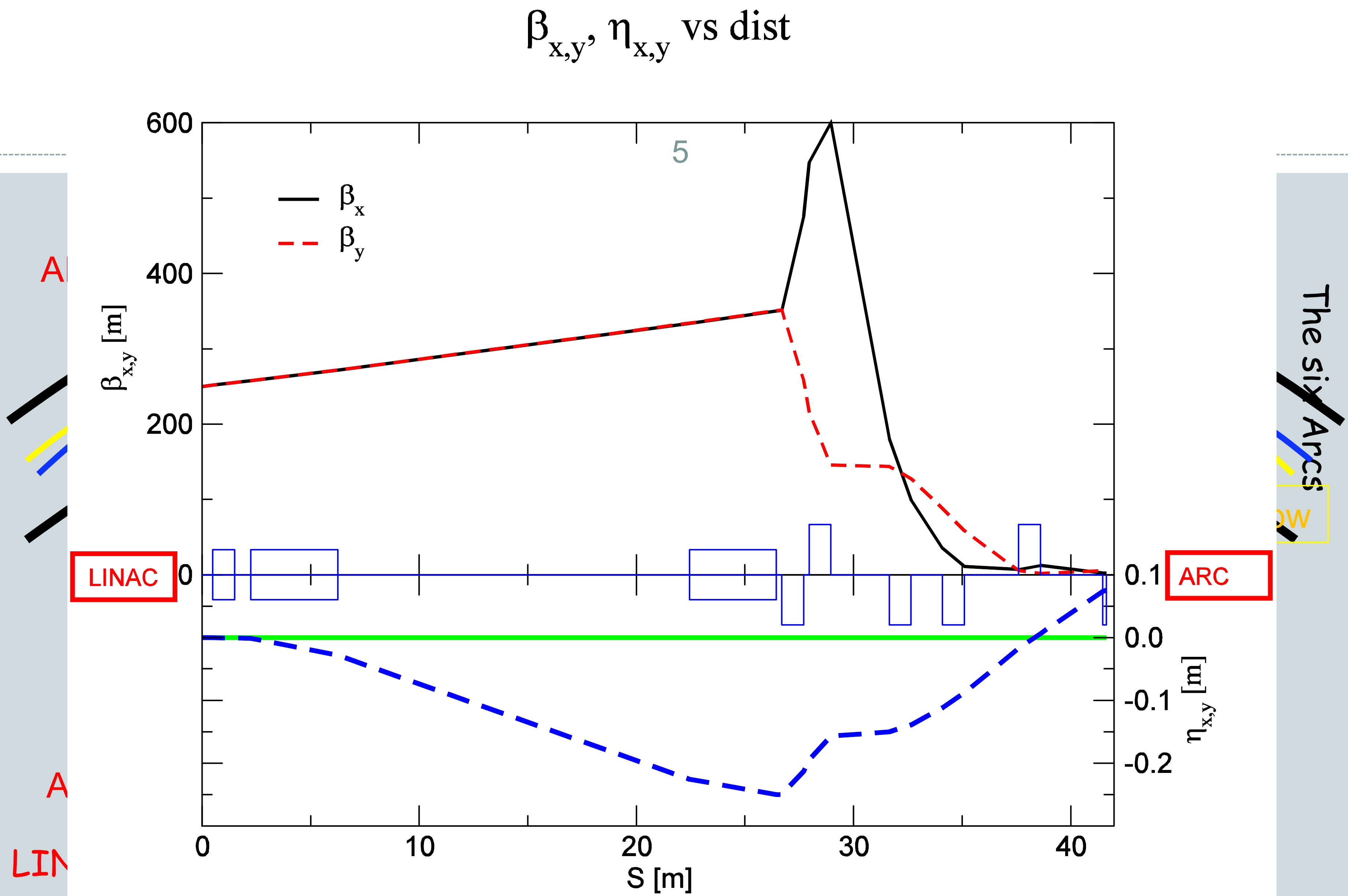




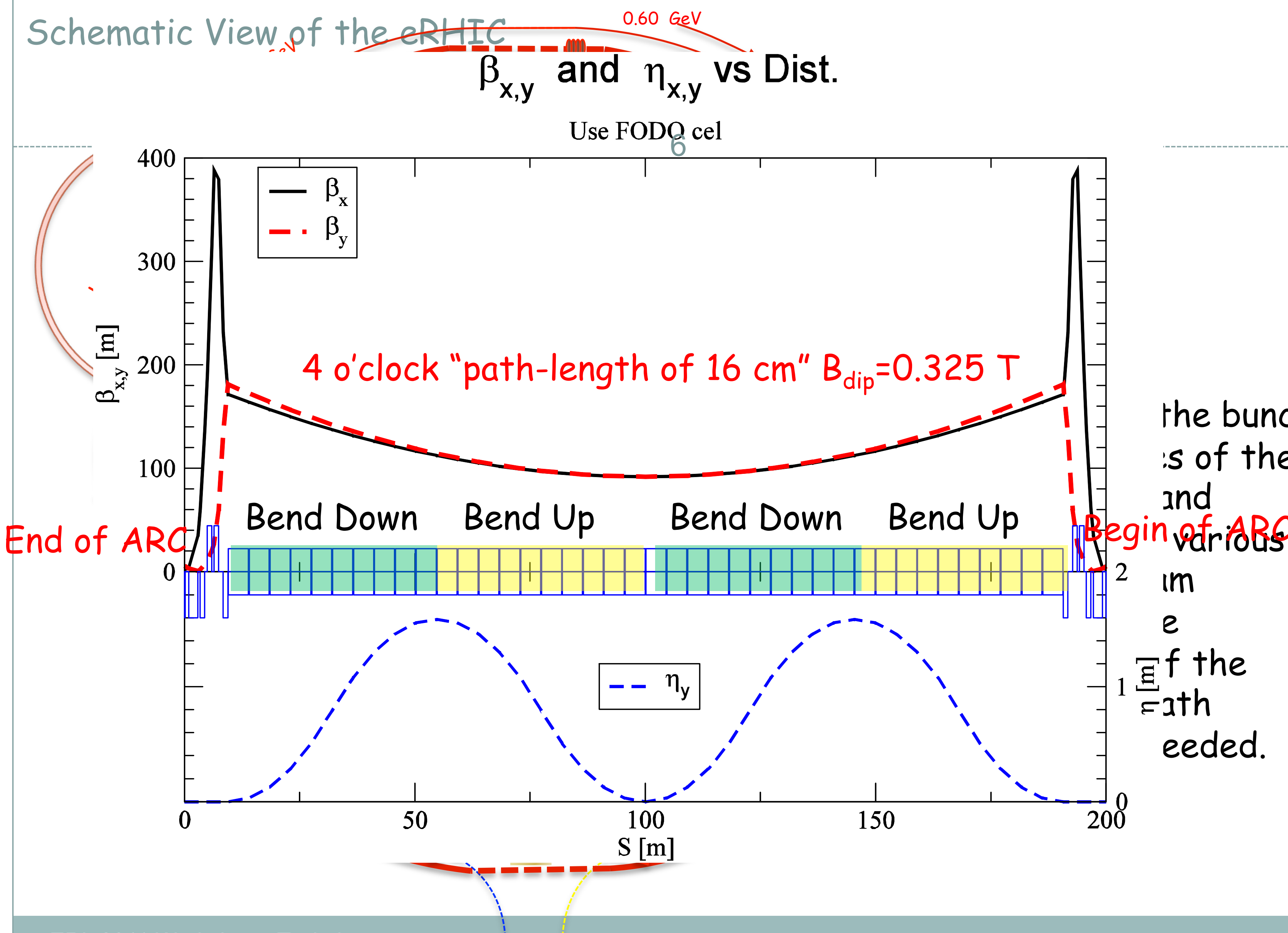
- Bending radius =234.2 m
- R_{56} tuning by the doublet quadrupoles
- Low beta and dispersion functions
- High dipole filling factor (61%)

- At 30 GeV:
  - Dipole field = 0.43 T
  - Quad gradients = 26-30 T/m

10 cells per 60° arc



βx,y, ηx,y vs dist
βx
βy
βx,y [m]
ηx,y [m]
600
400
200
0
0.1
0.0
-0.1
-0.2
0
10
20
30
40
S [m]
LINAC
ARC
The six Arcs



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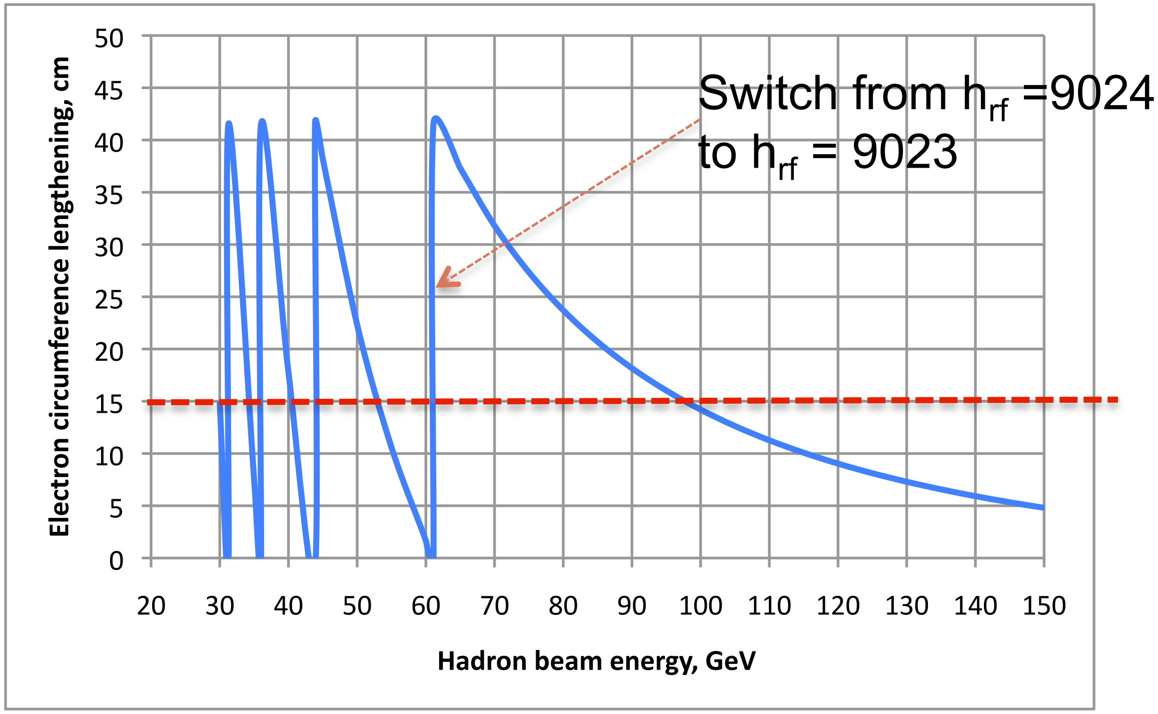
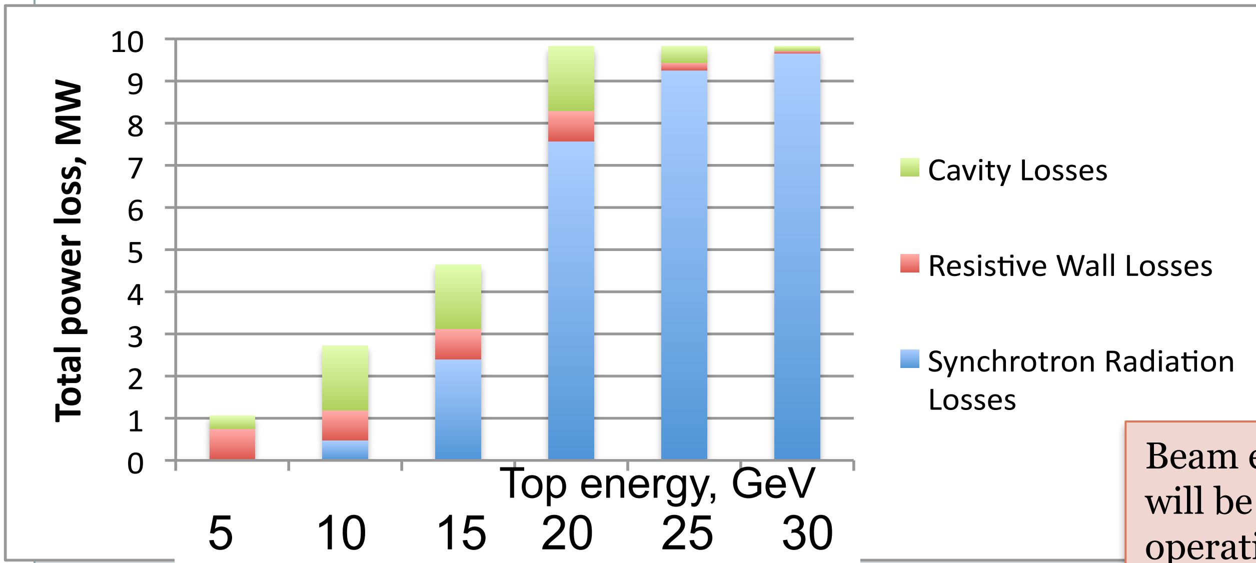
Electron-hadron frequency matching

With delay line able to increase the electron beam path length up to 15 cm the frequency matching in the hadron energy range from 98 to 250 GeV (with constant electron RF harmonic = 9024).

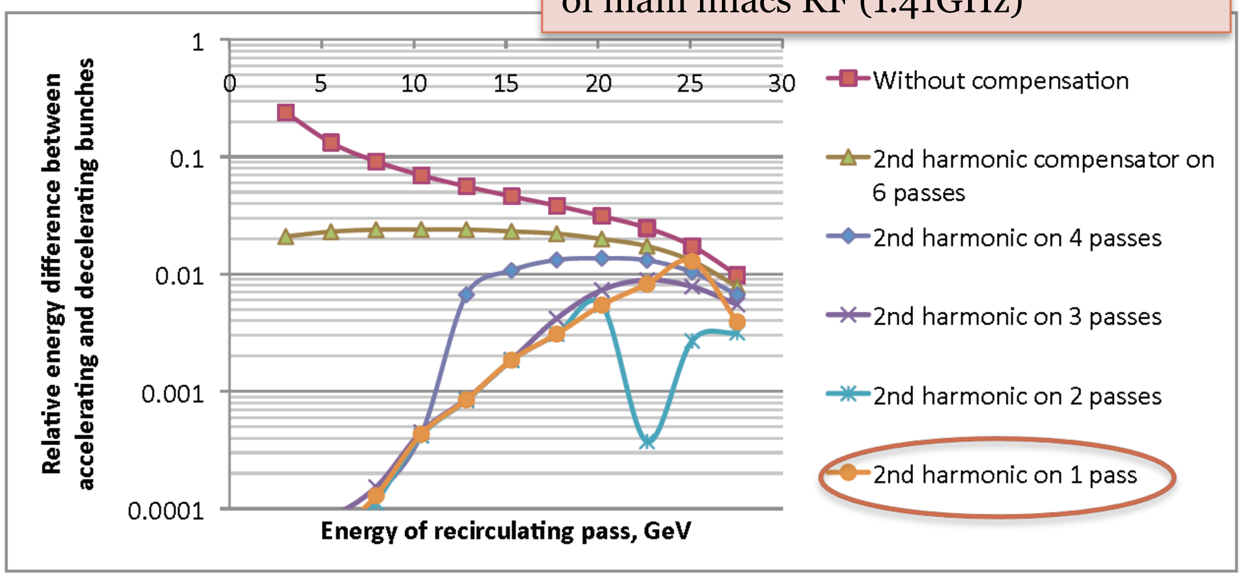


Switching of the RF harmonic to 9023 allows to work with hadron energies in the range from 53 to 61 GeV.

Power loss budget of eRHIC

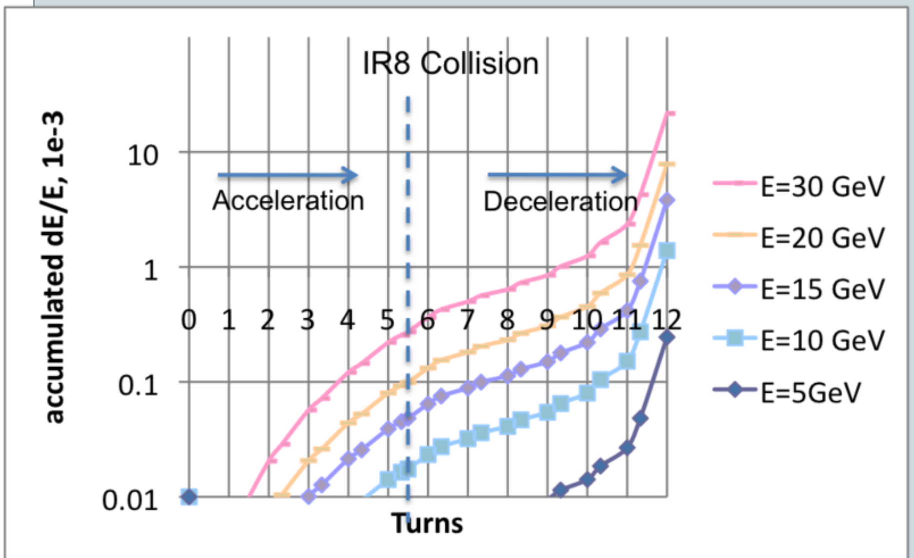


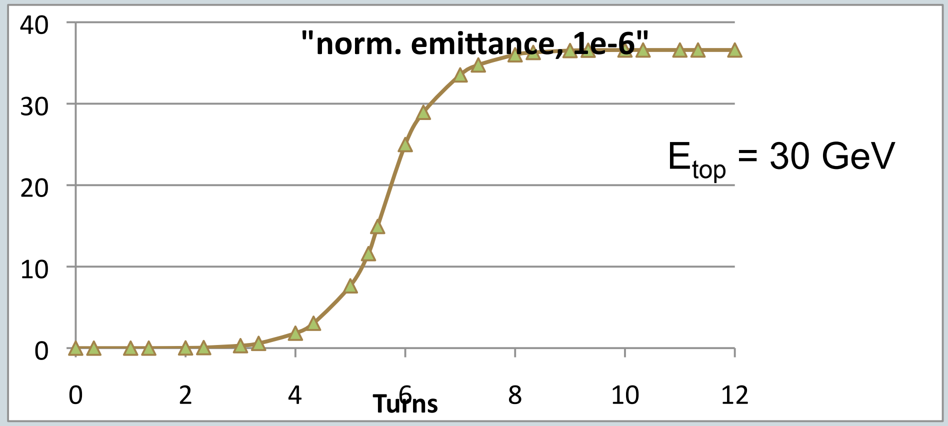
Beam energy loss compensation will be done with the dedicated cavities operating on second harmonic of main linacs RF (1.41GHz)



SR induced energy spread and emittance growth

The accumulation of SR induced energy spread on all 12 turns (6 accelerating + 6 decelerating) for the various top beam energies





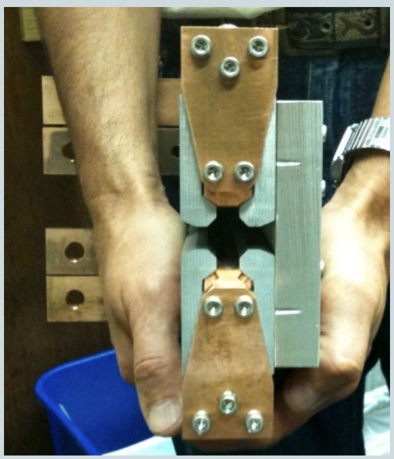
Turn 12 values are after deceleration in main ERLs, just before the entrance into the pre-accelerator ERL.(That is at 600 MeV energy for 30 GeV top energy, at 400 MeV energy for 20 GeV top energy and so on).

- The aperture of lowest energy pass (turn 12) has to be large enough to accommodate the resulting large energy spread.
- The energy spread compensation is required before deceleration to 10 MeV (beam dump)

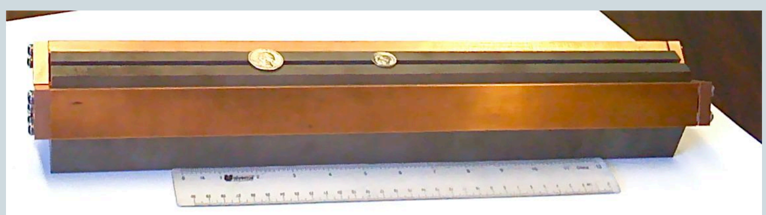
eRHIC Compact magnets

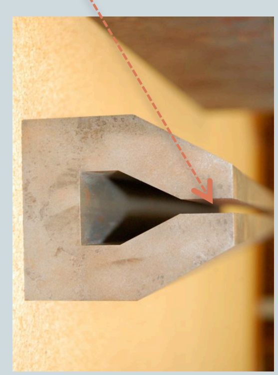
- ~7000 magnets in electron beam lines
- Small gap -> efficient and inexpensive-> low cost eRHIC
- Dipole, quadrupole and vacuum chamber prototypes have been constructed
- Magnetic measurements : dipole prototype meets specification

Gap 5 mm total
0.3 T for 30 GeV



Y.Hao,
G.Mahler,
V.Litvinenko





Linac Lattice

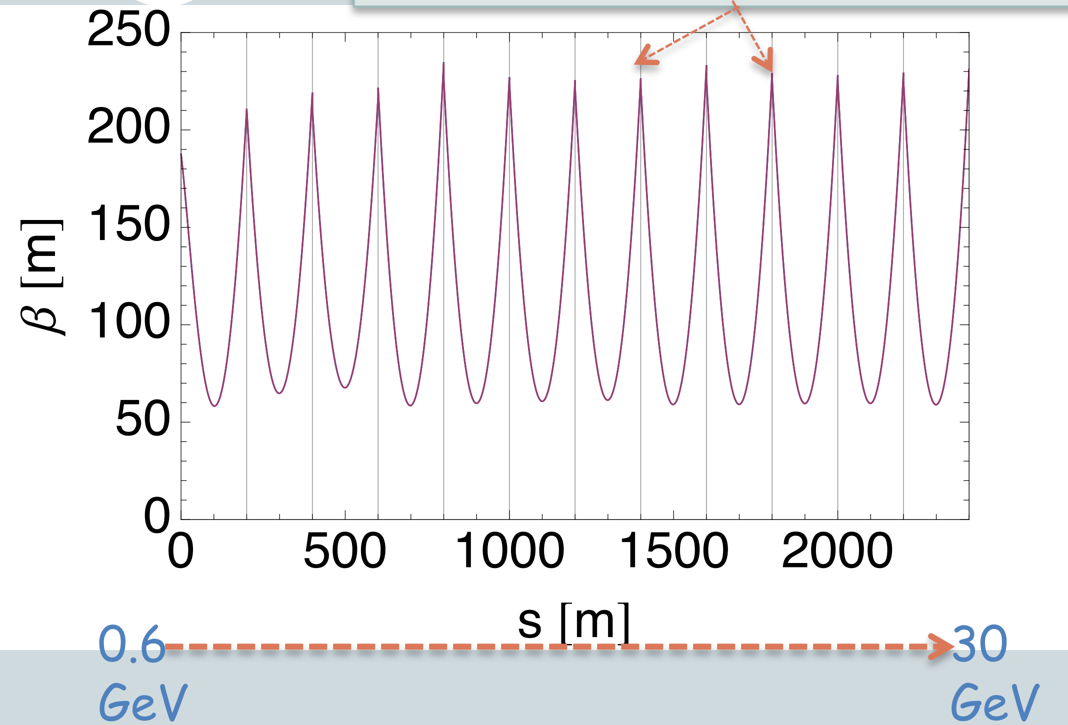
•Linac length is limited by available space of straights in RHIC tunnel (~200m).

•Quad-free linac lattice is preferred (to reach the higher average acceleration gradient)

•The found solution minimizes the average beta-function in the linacs (gaining leverage against BBU instability)

•RF cavity focusing has been included.
Important for lowest energy linac pass.
Focusing produced by multi-cell cavities is used.

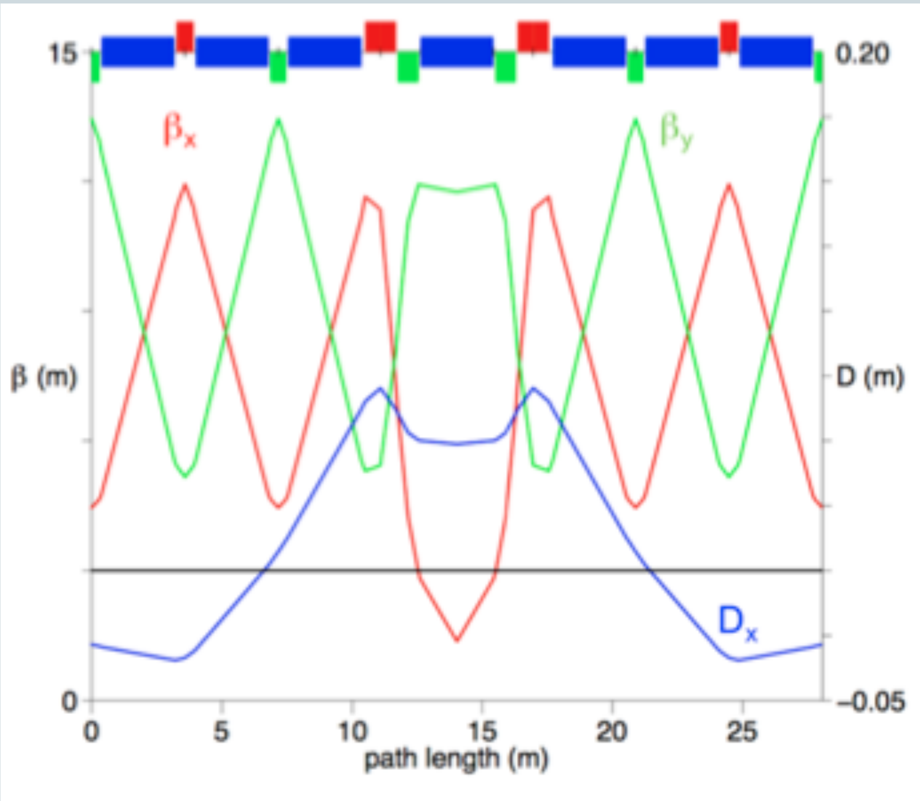
Vertical lines are the recirculation arcs, shown as the delta-function transformations



Multi-pass BBU simulations confirmed that quad-free lattice is acceptable choice.
(talk by D. Kayran tomorrow)

Variant of the lattice for LHeC linac-ring design

Isochronous cell design for LHeC lattice



Besides eRHIC we have considered the similar approach to the lattice of ERL-based option of the LHeC collider (E_{e_top} = 60 GeV)

- Length of cell is 27.8 m
- Bending radius = 697 m

The advantages:

- Small beam size in the arcs:
  < 0.3mm horizontal
  <0.18 mm vertical
- Small aperture beam pipe
- Excellent dipole filling factor
- Well controlled R_{56} parameter

LHeC 180-degree arc parameters

- Average R = 1000 m
- 113 isochronous cells
- Maximum field (in 60 GeV arc):
  - dipole magnet: 0.29 T
  - quadrupole magnet: 108 T/m
- ~1800 magnets per 180 degree arc
- Normalized horizontal emittance increase from the injection to 60 GeV: $8.6\ 10^{-6}$ m
- Energy spread at the ejection: ~12%
- SR power loss (for 6.6 mA): 13.5 MW

Summary

- ✓ For future ERL-based eRHIC collider all lattice components have been developed.
- ✓ Basic cell provides near 0 (and tunable) R56 parameter, and minimized synchrotron radiation effects.
- ✓ Lattice of the SRF linacs is quadrupole-free and with the beta-function at the acceptable level (for the sufficient BBU threshold).
- ✓ The variant of the lattice for LHeC on the basis of the same isochronous basic cell was demonstrated, which has all the advantages of the eRHIC lattice.

Backup Slides

Beam Parameters

eRHIC

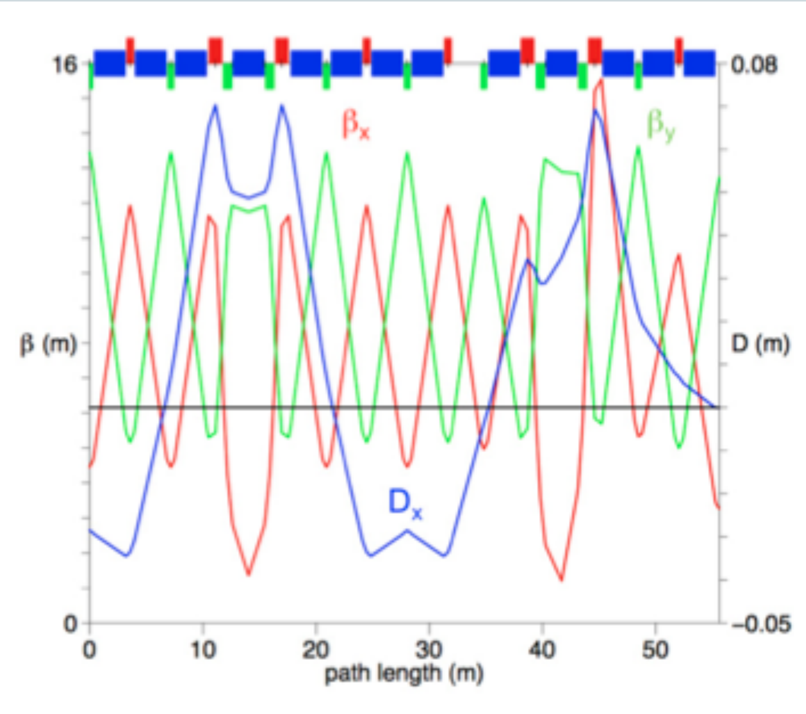
	Protons	Electrons
Energy [GeV]	250	20
#of bunches/bunch freq. MHz	166	14.08
Bunch intensity x10^{11}	2.0	0.22
Bunch charge [nC]	32	3.5
Beam current [mA]	415	50
Rms normalized emittance μm rad	0.18	20
Rms emittance nm rad	0.52	0.52
β^* [cm]	5	5
Beam-beam parameter/disruption	0.015	27.1
Rms bunch length [cm]	4.9	0.2
Polarization [%]	70	80
Luminosity [$cm^{-2}\ s^{-1}$]	1 x 10^{34}	

LHeC

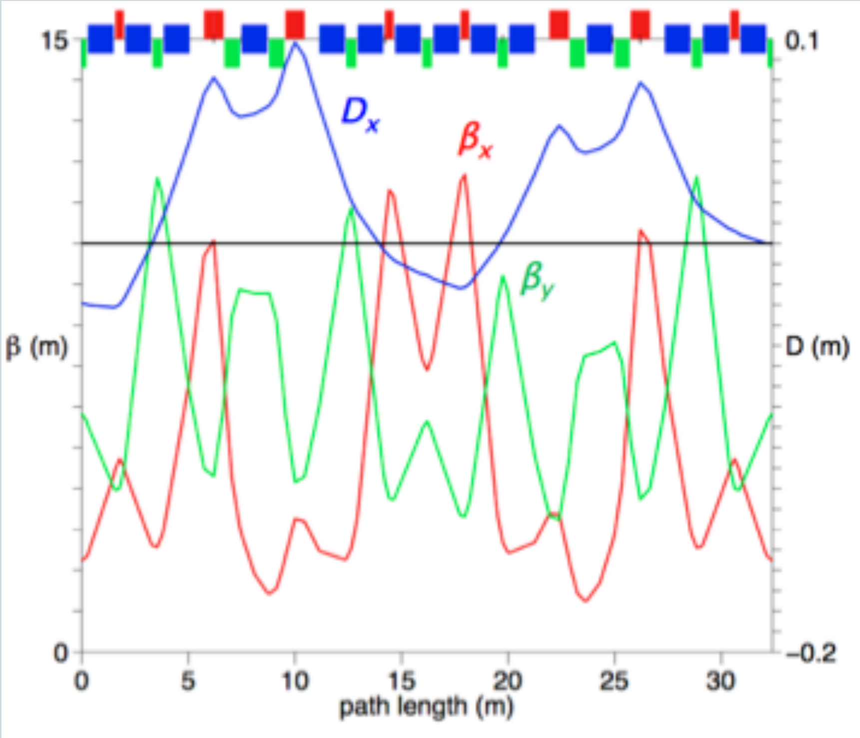
Electron energy at IP [GeV]	60
Luminosity [$cm^{-2}s^{-1}$]	1.01x10^{33}
Polarization (%)	90
Bunch population [10^9]	2.0
e− bunch length [μm]	300
Bunch interval [ns]	50
Transverse emittance. $\gamma\epsilon_{x,y}$ [μm]	50
Rms IP beam size [μm]	7
Hourglass reduction H_{hg}	0.91
Crossing angle θ_c	0
Repetition rate [Hz]	CW
Average current [mA]	6.6
ER efficiency η	94
Total wall power [MW]	100

Variants of arc-to-straight matching section

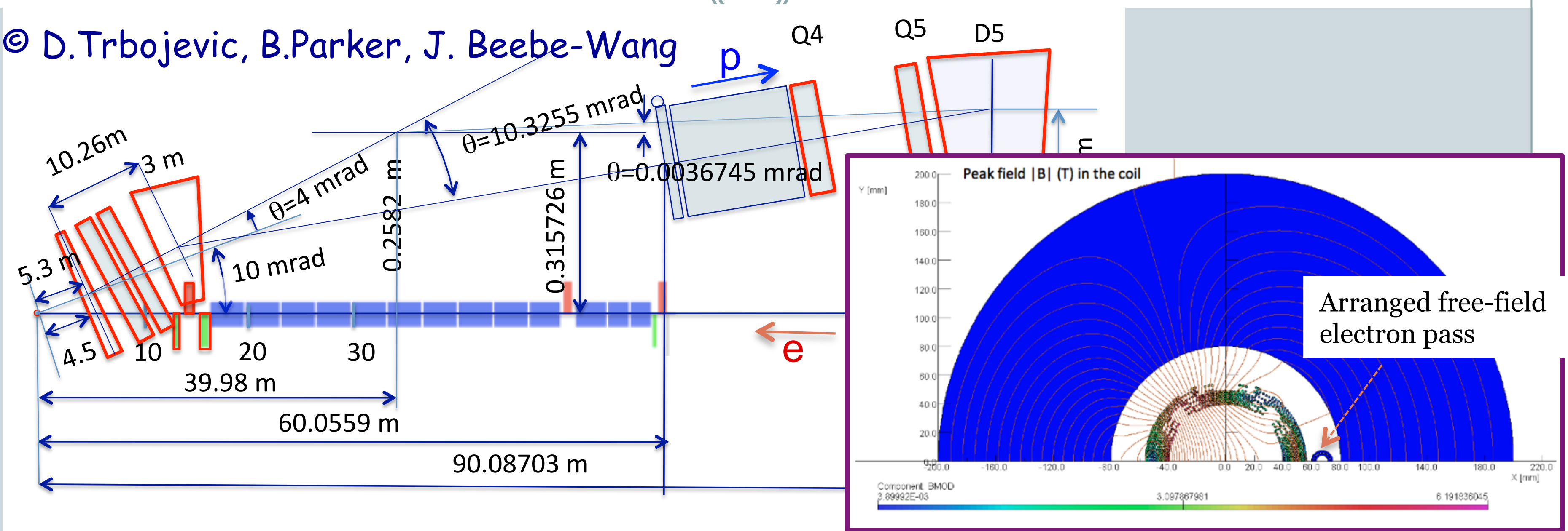
Variant 1:
basic cell with “missing” dipole



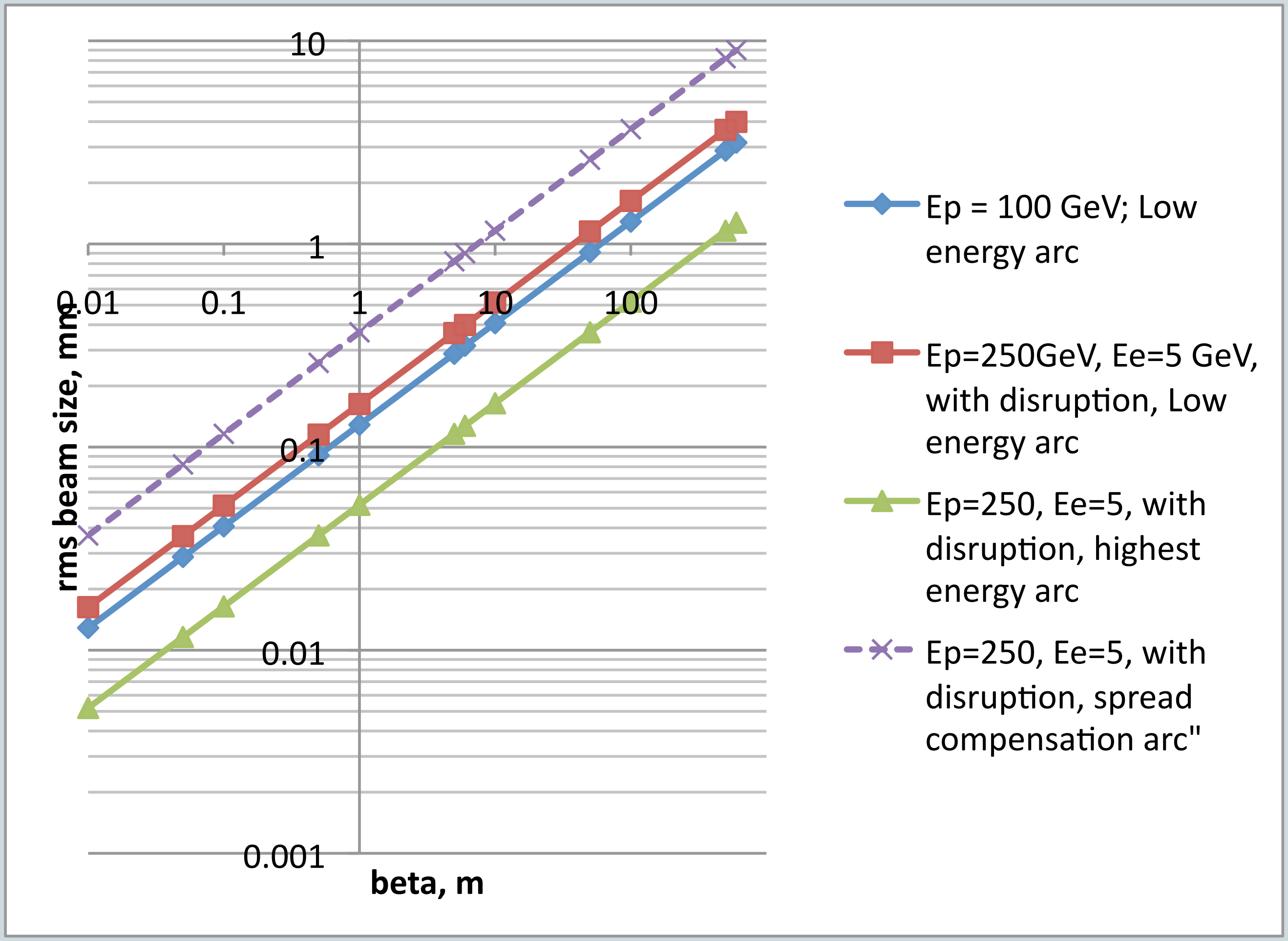
Variant 2:
basic cell with modified gradients



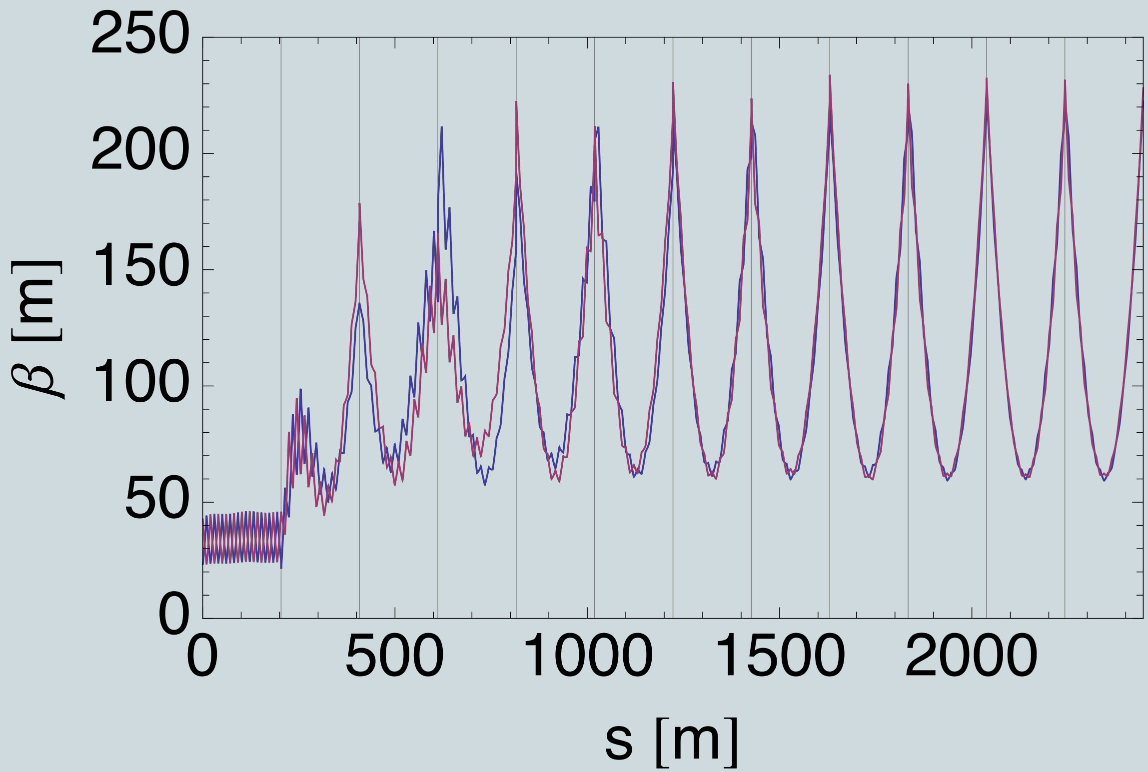
The design of high-lumi IR with β*=5 cm



- 10 mrad crossing angle and crab-crossing
- High gradient (200 T/m) large aperture Nb_3Sn focusing magnets
- Arranged free-field electron pass through the hadron triplet magnets
- Integration with the detector: efficient separation and registration of low angle collision products
- Gentle bending of the electrons to avoid SR impact in the detector
- Easy to vary the beam energies in wide ranges.


10
1
0.1
0.01
0.001
0.01
0.1
1
10
100
rms beam size, mm
beta, m
Ep = 100 GeV; Low energy arc
Ep=250GeV, Ee=5 GeV, with disruption, Low energy arc
Ep=250, Ee=5, with disruption, highest energy arc
Ep=250, Ee=5, with disruption, spread compensation arc"

Linac Design with Quadrupole 'FODO-Like' lattice,BackUp



With Quadrupole strength from 0.72T/m to 2.93T/m that scales with the electron beam energy in the first linac. The quad length is assumed to be 0.2m.

The resulting length of one linac is 203.8m+cold warm transition.