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eRHIC interaction region and lattice design

**D. Trbojevic, E.C. Aschenauer, V.N. Litvinenko, Y. Luo,
J. Yichao, B. Parker, V. Ptitsyn**

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ERHIC INTERACTION REGION AND LATTICE DESIGN*

D. Trbojevic, E. C. Aschenauer, V. N. Litvinenko, Y. Luo, Jing Yichao, B. Parker, and V. Ptitsyn
BNL, Upton, New York, USA

Abstract

A proposal for the new high luminosity $L=10^{34}$ $s^{-1}cm^{-2}$ polarized electron proton/3He and other un-polarized heavy ions eRHIC based on Electron Recovery Linac (ERL), assumes a location in the existing tunnel of the operating Relativistic Heavy Ion Collider (RHIC). Requests of the experiments for the interaction region are very challenging: allow detection of neutrons, allow deep virtual scattering for protons-electron collisions, detection of partons with lower momentum, etc. We present an interaction region (IR) design with a vey high focusing where at the collision point IP of 5 cm, and a 10-mrad collision angle between electrons and ions using the crab cavities. We are introducing a combined function magnet for the first element in the high focusing triplet configuration to provide neutron and the lower energy parton detection, and allow at 4.5 cm distance passage of electrons through free magnetic field region. The 200 T/m gradient quadrupoles provide very small beam size at the IP and allows a passage with a very small magnetic field for electrons.

ERHIC PHYSICS

The RHIC stunning discoveries in quark-gluon plasma in recent years went above any expectations that have captured worldwide attention. First and foremost was the unexpected “perfect”-liquid nature of the 4-trillion-degree quark-gluon plasma that permeated the early universe. RHIC is now closing in on the transition from this hot quark-gluon plasma into ordinary matter made of protons and neutrons—namely everything we see in today’s world. Continuation of the RHIC success will be a new polarized electron-polarized proton/He^3 and electron-ion collider the QCD lab (the quantum chromodynamics describes the strong forces). It would be determining quark and gluon contribution to the proton spin, what is the polarization of gluons, and what is the flavor decomposition of the polarized sea, what is the spatial distribution of quarks and gluons in nuclei, and to explore the strong forces – understand in detail the transition to the non-linear regime of strong gluon fields and the physics of saturation, and have a probe to study deep inelastic scattering.

IR LATTICE FOR HIGH LUMINOSITY

A choice for ERL in the eRHIC is due possibilities of obtaining higher luminosity as the beam-beam effect represents a limitation the ring-ring option. From an injector the beam is accelerated by the superconducting linac using several passes and reaching energies up to 20-30 GeV to be able to reach luminosities of $L=10^{34}$ $s^{-1}cm^{-1}$. We describe an ion lattice and Interaction Region (IR) design to allow small beam sizes with β^*= 10 and 5 cm. It is assumed that coherent electron cooling will reduce the ion beam emittances, allowing very short bunches in the longitudinal space. The strong focusing is possible by placing the first magnet of the triplet at 4.5 m distance from the IP. The IR design is being developed together with the detector physicist designers. The IR in RHIC is made to be symmetric as shown in Figure 1 and in more detail in Figure 2.

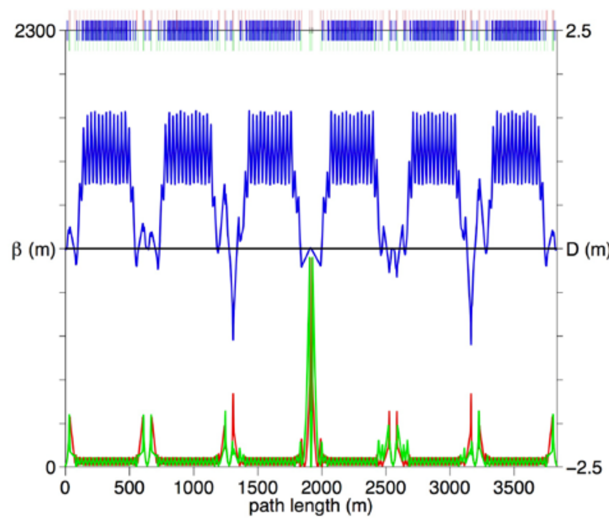

Figure 1: eRHIC lattice design with the β^*=10 cm at the single interaction region at 6 o’clock IP.

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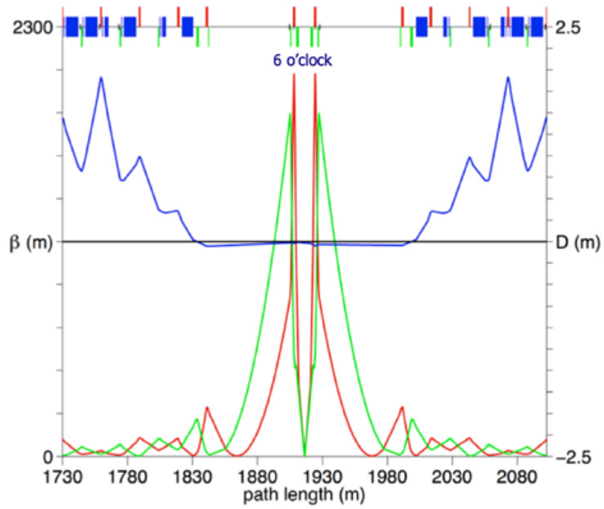

Figure 2: Details of betatron functions in the IR.

The maximum of the betatron function in the triplet magnets, the dispersion function, the chromaticities, and tunes for the β^*=10 cm are shown in Table 1. It is important to note that the natural chromaticities of the ion eRHIC lattice are smaller than the RHIC chromaticities at RHIC the operating conditions.

Table 1. Betatron Functions for β^*=10, 5 cm

β^*(cm)	β_{xmax}(m)	β_{ymax}(m)	ζ_x	ζ_y	D_{xmax}	D_{xmin}
10	1100	1103	-89	-83	1.56	-1.1
5	2209	2210	-134	-113	1.94	-1.6

The layout of the interaction region in eRHIC is schematically presented in Figure 3.

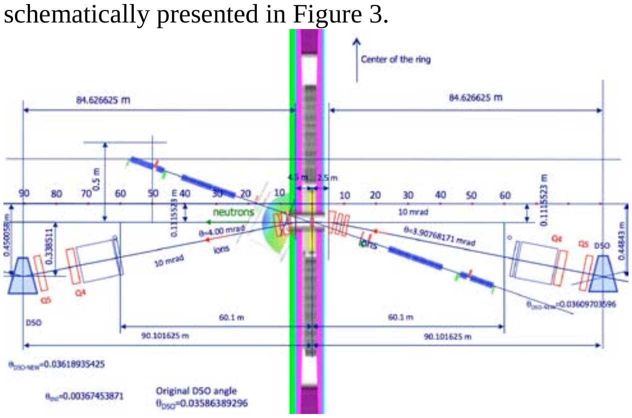

Figure 3: Layout of eRHIC interaction region.

Schematic presentation of the interaction region magnets downstream of the electron-ion or polarized proton or He^3 collisions is shown in Figure 4. The solid angle of neutron is obtained by use of a combined function magnet – (shown in orange color). The electron beam passes through the zero field region of the combined function magnet as shown in Figure 5.

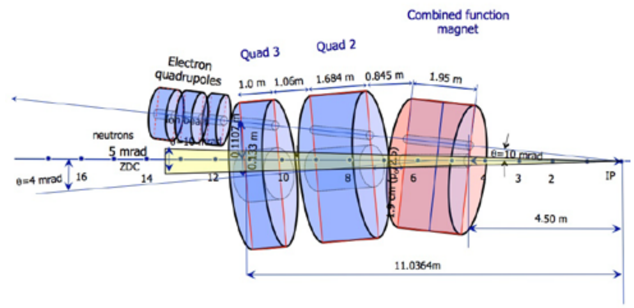

Figure 4: The triplets for both electron and ion lattice eRHIC IR layout with neutron solid angle (yellow).

A dipole coils are added to the solenoid of the detector to allow bending of electrons for an angle of 10 mrad. The combined function magnet is followed by the 200 T/m gradient quadrupoles. The combined function magnet bends the beam for 4.5 mrad allowing neutron detection downstream. The vertical axis in Figure 3 is centimeters while the horizontal axis is in meters. The detector is shown in looks distorted as due to different scale.

The RHIC lattice in the arcs is made of 90° phase difference per cell in the arcs. The LHC chromatic corrections were used in his design. The beam squeeze with a β^*=10 cm does not result in a very large natural chromaticities as shown in Table 1. The beam squeeze from 10 cm to 5 cm is realized by introduction of the betatron waves in both planes. The wave is created by changing the quadrupole gradients (ΔG= 7% with respect to the regular arc quadruple gradients) in two quadrupole pairs at the beginning of the arc before the IP.

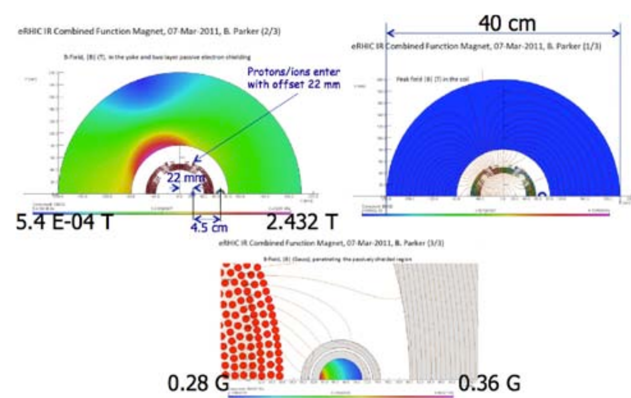

Figure 5: Combined function magnet with three different functions at the same time: bend the ions for 4.5 mrad, field free region for electron passage, and neutron detection downstream.

The layout of the sextupoles in the eRHIC ion lattice is shown in Figure 6.

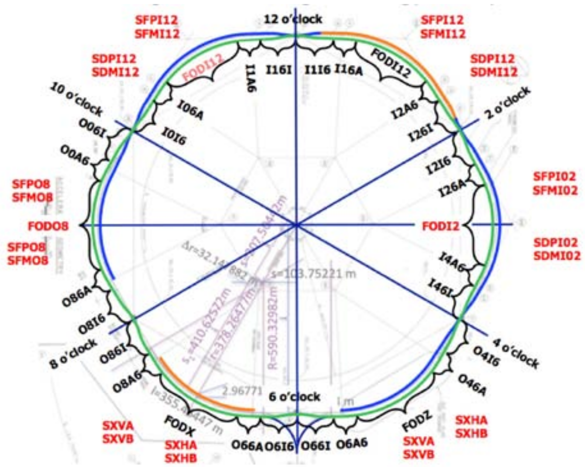

Figure 6: 24 families of sextupoles in the 90^o degrees lattice are able to correct the first and higher orders of chromaticitiies in eRHIC lattice.

The betatron wave, as in the LHC design [1], not only achieves a reduction of the β^* from β^*=10 to β^*=5 cm, but also allow easier chromatic correction as the beta functions in the arcs before and after the IP are increased, as well as the dispersion function, reducing the strength of the sextupoles. The betatron functions after the beta squeeze to β^*=5 cm are shown in Figure 7 with detail of the sextupoles in the arcs in Figure 8.

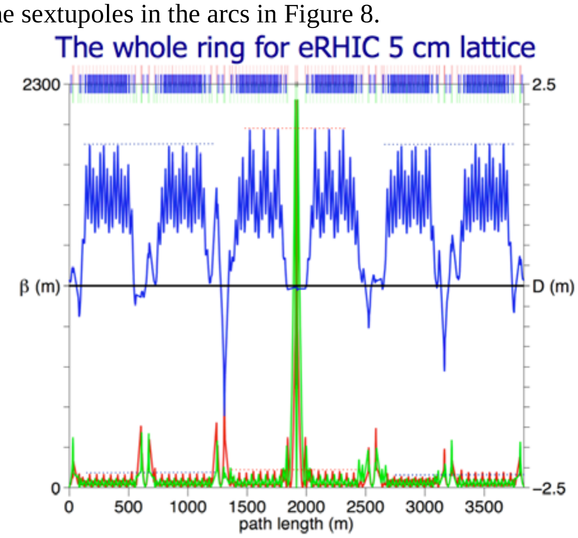

Figure 7. Betatron squeeze to β^*=5 cm.

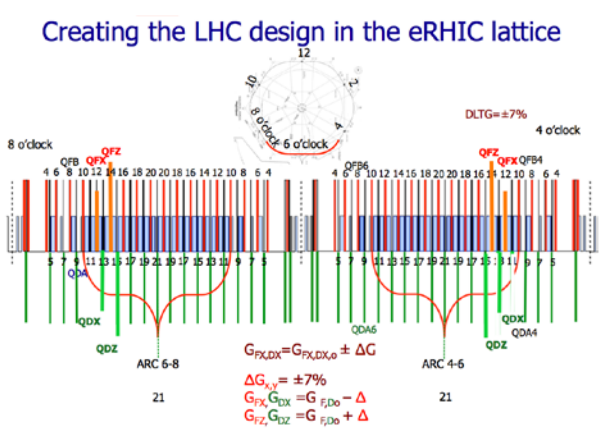

Figure 8. Sextupoles and pairs of quadrupoles used to create the wave in two arcs neighboring the IP.

The tune dependence on momentum after the sextupole corrections is shown in Figure 9.

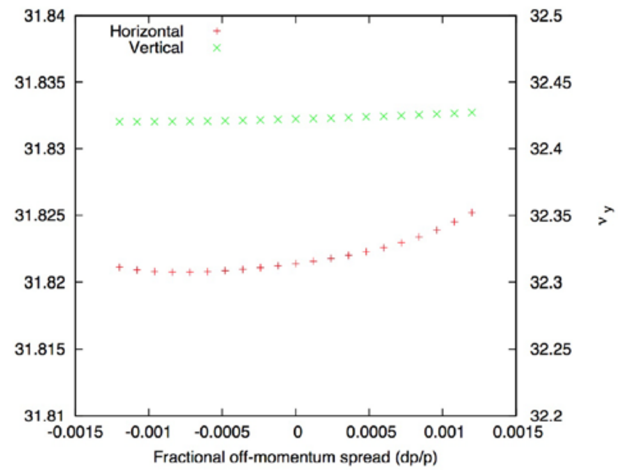

Figure 9: Tune dependence on momentum after sextupole correction

The dynamical aperture studied by applying only 8 families of sextupoles shown in Figure 10.

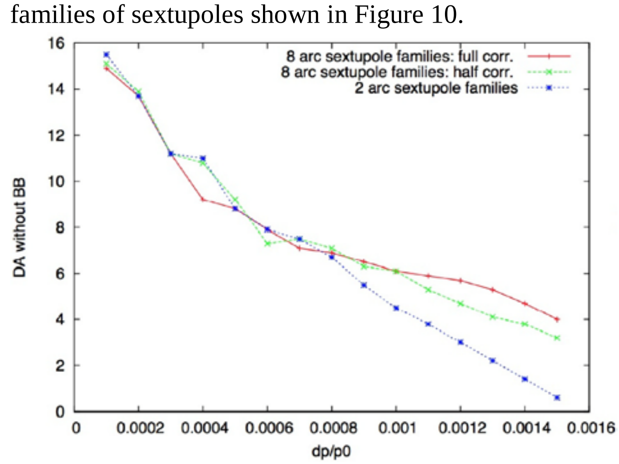

Figure 10: The dynamical aperture with 8 families of sextupoles.

The dynamical aperture after 24 families sextupole correction is shown in Figure 11.

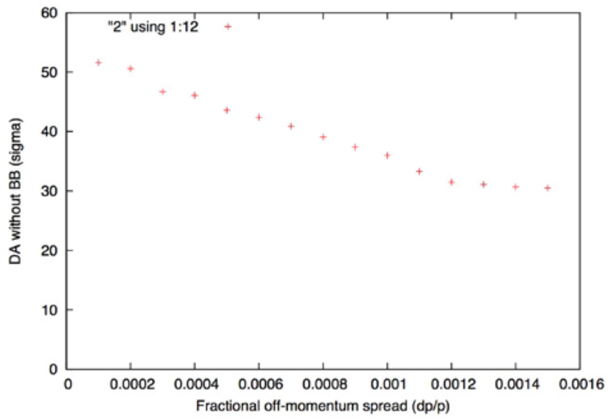

Figure 11: The dynamical aperture in the eRHIC lattice with β^*=10 cm after 24 family of sextupole correction.

SUMMARY

The eRHIC interaction region design with lattice design is presented. The LHC [1] beta squeeze was used as driving idea of the eRHIC lattice design. Initial results of the dynamical aperture are very favorable. A study of the dynamical aperture with the β^*=5 is in progress. Improvement in the interaction region design, with new superconducting triplet magnet design will follow.

REFERENCES

[1] S. Fartoukh, LHC Project Report 278, CERN.