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DISCLAIMER

LATTICE DESIGN FOR THE ERL ELECTRON ION COLLIDER IN RHIC*

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Abstract

We present electron ion collider lattice design for the Relativistic Heavy Ion Collider (eRHIC) where the electrons have multi-passes through recirculating linacs (ERL) and arcs placed in the existing RHIC tunnel. The present RHIC interaction regions (IR's), where the electron ion collisions will occur, are modified to allow for the large luminosity. Staging of eRHIC will bring the electron energy from 4 up to 20 (30) GeV as the superconducting cavities are built and installed sequentially. The synchrotron radiation from electrons at the IR is reduced as they arrive straight to the collision while ions and protons come with 10 mrad crossing angle using the crab cavities.

INTRODUCTION

A future "QCD factory" the eRHIC would provide collisions between electrons with: polarized protons in an energy range of 50-250 (325) GeV, light ions (d,Si,Cu), heavy ions 50-200 (130) GeV/u, as well as of the polarized He^3 215 GeV/u. There are two fundamental reasons for choosing the ERL instead of electron storage ring for the future electron ion collider in RHIC: one is the limitation in luminosity of the ring-ring option due to the beam-beam tune shift, and the other is recovering of the enormous energy ~1 GW which is very difficult to remove using the beam dump. The high luminosity of the collider assumes the high intensity polarized electron source. Development and design of the "Gatling gun" source is in progress. It uses 24 of existing sources making by a " brute" force intensity of 50 mA/cm^2. At the same time an aggressive R&D program at Bates lab in Boston is in progress. The recirculating linacs and lattice of the multi-pass arcs will be placed in the RHIC tunnel, as shown in Fig. 1. Energy of electrons during the staging of the eRHIC would rise, as the lengths of linacs will increase during production. In the previous eRHIC staging proposal the initial energy of electrons was 4 GeV. One of two 650 MeV energy linacs is placed outside of the RHIC tunnel. A part of this previous design is presented. A new eRHIC design assumes six dimensional coherent electron cooling which should bring the normalized transverse emittance to $\varepsilon=1\cdot10^{-6}$ mm mrad with the *rms* bunch length of 4.5 cm. The latest IR design provides very high focusing with the $\beta^*=5$ cm using the gradients of 200 T/m the recent results from the 1m long superconducting quadrupoles built for the upgrade of the Large Hadron Collider (LHC) [1] bringing the luminosity to $2\cdot10^{34}$ s^{-1}cm^{-2}.

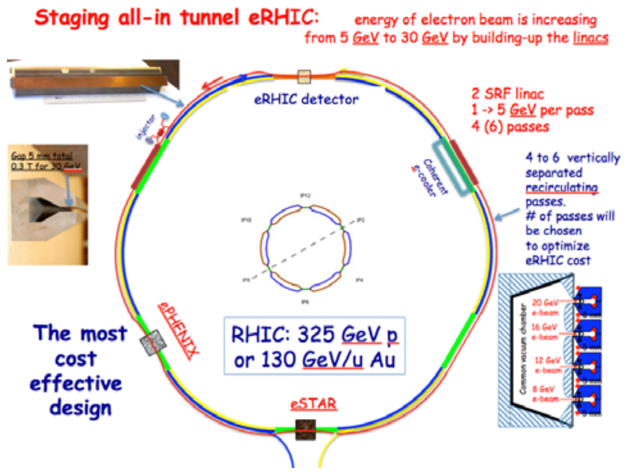

Fig.1. New eRHIC layout with two linacs (brown color) inside of the RHIC tunnel. Magnets and recirculating arcs are shown (side).

LATTICE DESIGN OF THE 4 GEV REL FROM THE PREVIOUS STAGING E-RHIC

The 4 Gev RLA was designed provide collisions of 4 GeV electrons with 50-250 GeV polarized protons or 20-100 GeV/u heavy ions. The 100 MeV RLA injector, starting with the "Gatling gun" polarized electron source, brings the beam to the racetrack with two linacs. They are placed in the opposite sides, as presented in Fig. 2. Three passes through each 650 MeV linac reaches 4 GeV, the final electron energy. A detail cost estimate of the design included magnets, cavities for ERL and other elements *needed for: the injector with electron ion source, three isochronous arcs on both sides of the racetrack, dispersion and betatron function matched spreaders, beam lines including the IR, necessary instrumentation, power supplies, cryogenic system, control system, civil construction etc.

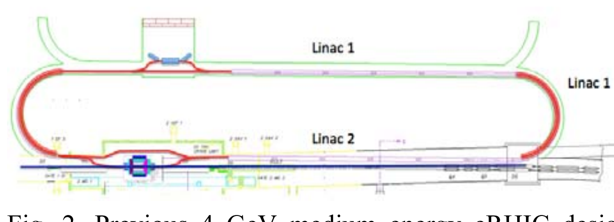

Fig. 2. Previous 4 GeV medium energy eRHIC design with two RLA placed in the racetrack.

Due to a very limited available space the return isochronous arcs had to be very compact. A sophisticated

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design of the IR allows passages of three beams at the same time reducing the synchrotron radiation from electrons going in and out of collisions, at the same time. The RHIC proton and ion lattice in the previous layout was not affected.

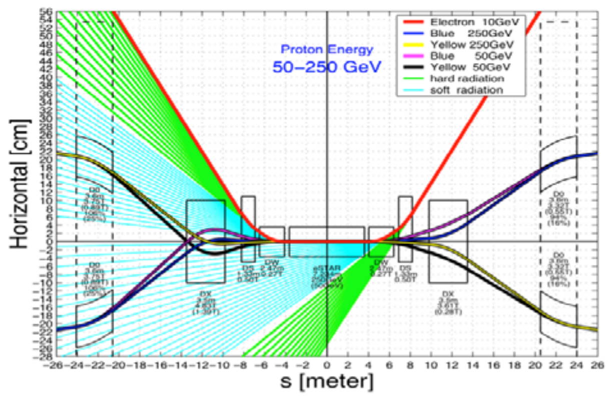

Fig. 3. The previous IR design for 4 GeV. The 4 GeV electrons (red line) and 50 and 250 protons from "yellow" and "blue" RHIC beams.

A major difference was a replacement of the large superconducting separation (DX) magnets with two warm dipoles as presented in Fig. 3. Two dipoles on each sides of the IR had double roles: first one was to remove any synchrotron radiation getting into the detector from electrons, and the second to was allow passage of two RHIC beams with different energies of 50 or 250 GeV protons.

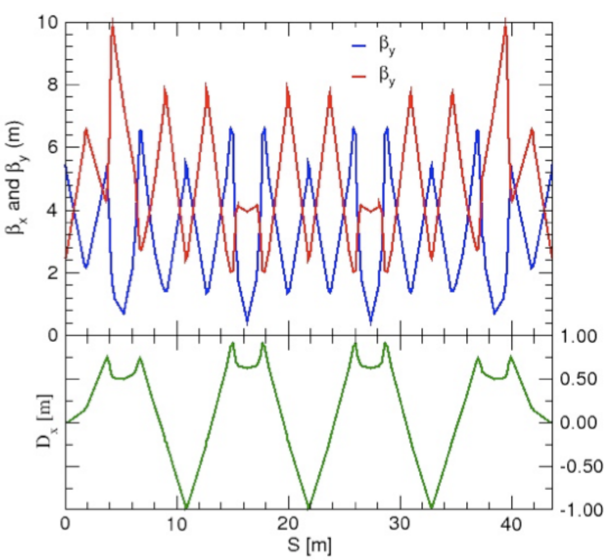

Fig. 4. Betatron functions of the isochronous arc (M56=0). Dispersion function oscillates $|D_x| \leq \pm 1$ m around zero of the dispersion function.

The lattice functions of the isochronous compact arcs are presented in Fig. 4 while details of compactness could be seen in Fig. 5.

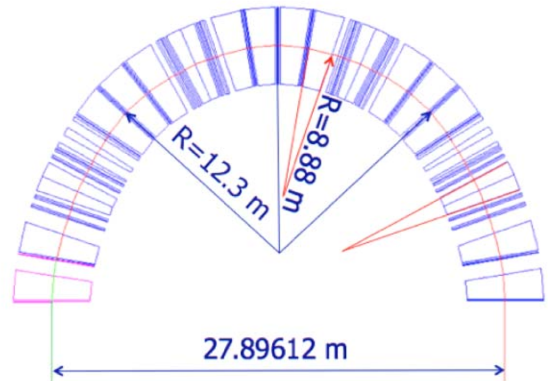

Fig. 5. Compact design of the isochronous arcs.

THE LATEST E-RHIC DESIGN

The staging of eRHIC will be established without additional civil construction. The re-circulating linacs and arcs will be placed inside of the existing RHIC tunnel. Non-colliding electron beams will bypass the existing two large detectors 4-6 times. It is assumed that at least one of the present large detectors would be accommodated for the electron-ion collisions. Another dedicated eRHIC detector could be placed at the available large interaction region in RHIC at 12 o'clock. Two RLA will be installed in the straight sections at 10 and 2 o'clock. To achieve very large luminosities of the order of $2 \cdot 10^{34}$ $s^{-1}cm^{-2}$ cooling in six the dimensional phase space of the ions or protons is. The cooling proof of principle will be done at in RHIC. The additional important R&D program is a development of the high intensity polarized electron ion source. Recently, other significant progress was shown [2] in studying of the kink instability and the beam disruption. A design of the interaction region with the β^*= 5 cm could be performed only if the beams were cooled down to the transfer size of the normalized emittance of $\varepsilon = 1 \cdot 10^{-6}$ mm and the *rms* bunch length of 4.5 cm. The electron beam arrives straight to the collision point avoiding any bending. This simplifies dramatically the synchrotron radiation problems. The proton and ion beams arrive with a crossing angle of 10 mrad with a crab cavity in RHIC. The IR layout is shown in Fig. 6.

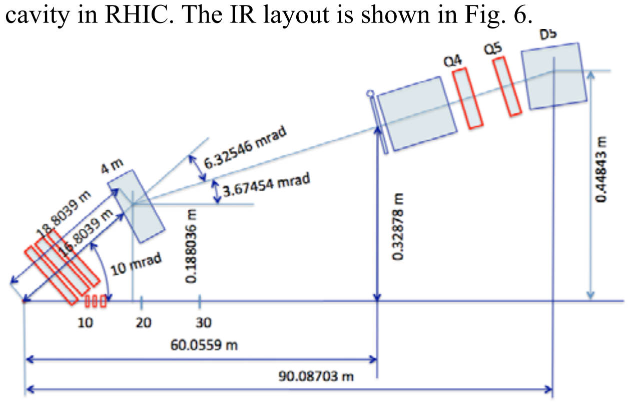

Fig. 6. Layout of the eRHIC IR with a distorted view: the vertical axis is in cm while the horizontal is in meters.

The RHIC elements to the end of the rotator valve at 60 m are not disturbed. The betatron functions in the interaction region are shown in Fig. 7. The matching is established to the rest of the RHIC existing lattice with the required matched geometrical constraints. The natural chromaticity of the overall RHIC lattice with the new eRHIC-IR is even smaller than presently used lattice during the 2010 Au-Au run with 100 GeV/u and with the β^{*}~0.7 m.

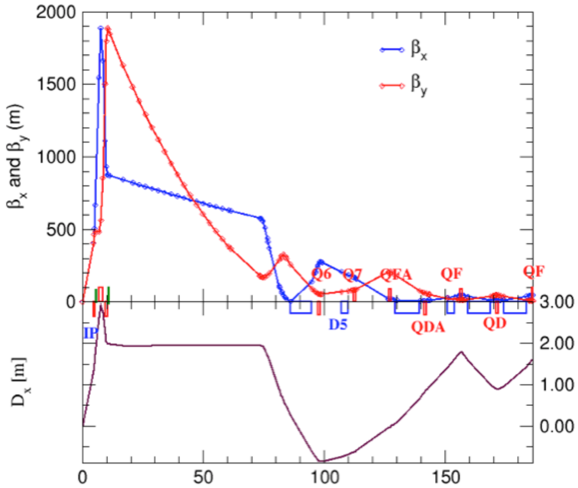

Fig. 7. Betatron functions of the eRHIC with β^{*}=5 cm. The gradients of the Q_1, Q_2, and Q_3 triplet quadrupoles are ~200 T/m with lengths of 0.85 m, 1.6, and 1 m, respectively.

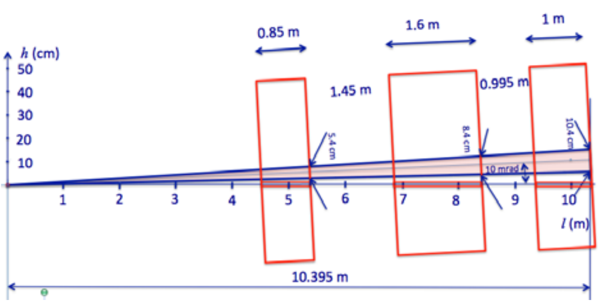

Fig. 7. The proton-ion triplet layout with the opening angle of ± 5 mrad.

The local chromatic correction uses the dispersion in the triplets following previous works [3,4].

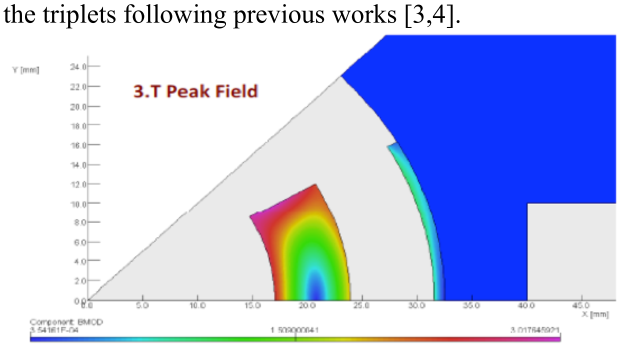

Fig. 8. Preliminary design of the first quadrupole for eRHIC interaction region.

The arc lattice design is made of momentum compaction adjustable lattice [5]. The geometrical layout of the triplet magnets is presented in Fig. 7 where the vertical axis is in cm while the horizontal axis in meters. Experiments have ability to detect within ±5 mrad. A preliminary design of the first triplet quadrupole with electron beam passing through the free magnetic field region is shown in Fig. 8.

The 4 m long warm magnet is required due to the geometrical constraints but it might be very useful for measurements of the fragmentations. This is shown in Fig. 9.

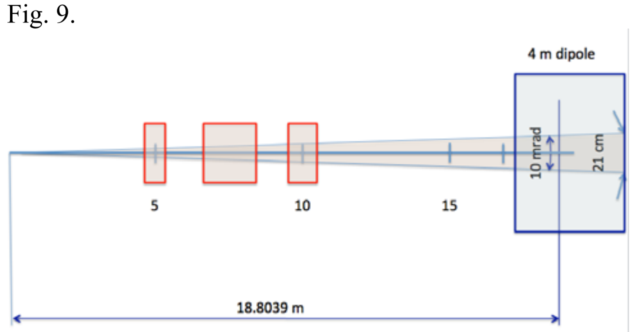

Fig. 9. Triplet magnets together with the 4 m long warm dipole could be used for fragmentation measurements.

SUMMARY

A new "QCD factory" eRHIC project is being studied as a possible continuation of the existing very successful and exciting nuclear physics program at RHIC – a new electron ion collider. A design of the ERL lattice with a β^{*}=5 cm at the collision point is presented. With a transverse emittance of $\varepsilon=1\cdot10^{-6}$ mm mrad and the longitudinal rms size of 4.5 cm the luminosity as high as $2\cdot10^{34}$ $s^{-1}cm^{-2}$ could be achieved. The recirculating arcs are momentum compaction adjustable.

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