Lattice Design of Lepton Ring of e-RHIC

D. Wang, F. H. Wang, M. Farkhondeh, W. Franklin, C. Tschalaer, J. van der Laan, T. Zwart
MIT Bates Lab, Middleton, MA 01949, USA

C. Montag, B. Parker, S. Peggs, V. Ptitsyn
BNL, Upton, NY 11973, USA

Y. Shatunov, A. Otboev
BINP, Novosibirsk, Russia

D. P. Barber
DESY, Hamburg, Germany

The e-RHIC complex is a proposed lepton-hadron collider with center of mass energies from 25 to 100 GeV(lepton-proton) or 60 GeV/A(lepton-ion), luminosities at $10^{33}cm^{-2}s^{-1}$ with high polarization(at least 70%) in both electron and proton beams. The ring-ring option for eRHIC features a lepton storage ring that can operate at 5-10 GeV colliding with hadron beams (up to 250 GeV for protons and 100GeV/A for gold ions) at the existing RHIC machine. The main features of eRHIC lepton ring include wide operating energy ranges, intense beam current, high polarization for electron (5~10 GeV) and positron (5 GeV) beams, various optics with very different emittance requirements and IR parameters, etc. This paper presents the recent lattice designs that fulfill all those design goals with moderate circumference(1/3 of that of RHIC).

1. INTRODUCTION

The e-RHIC complex is a lepton-hadron collider with center of mass energies between 25 to 100 GeV(lepton-proton) or 60 GeV/A(lepton-ion), luminosities at $10^{33}cm^{-2}s^{-1}$ with high polarization(at least 70%) in both elelctron and proton beams. The ring-ring option for eRHIC proposes to build a lepton storage ring that can operate at 5~10 GeV colliding with hadron beams (up to 250 GeV for protons and 100GeV/A for gold ions) at the existing RHIC machine. The main features of eRHIC lepton ring include wide operating energy ranges, intense beam current, high longitudinal polarization for electron (5~10 GeV) and positron (5 GeV) beams, various optics with very different emittance requirements and IR parameters, etc.

2. LATTICE AND LAYOUT

2.1. The eRHIC Complex

The eRHIC, a high luminosity lepton-hadron collider, is proposed to be built in the Brookhaven National Laboratory. The hadron beam will be produced in the existing RHIC complex with necessary modifications and upgrades. The lepton machine is being designed to match with the hadron beams. Figure 1 shows the general layout of the eRHIC machine complex. The lower part is the existing AGS-RHIC complex that has been in operation for years [1]. The yellow and blue curves represent two main rings of RHIC (Relativistic Heavy-Ion Collider) where hadron beams, from protons to very heavy gold ions, collide at up to six interaction points. The lepton ring will provide up to 10 GeV energy intense polarized electron and positron beams colliding with hadron beams at one of six RHIC interaction points, presumably at so-called '12 o'clock' IP. The eRHIC interaction region design is being carried out in parallel to this study [2]. At this point, extra vertical orbit excursions for two hadron rings are envisioned, while the lepton ring remains flat.

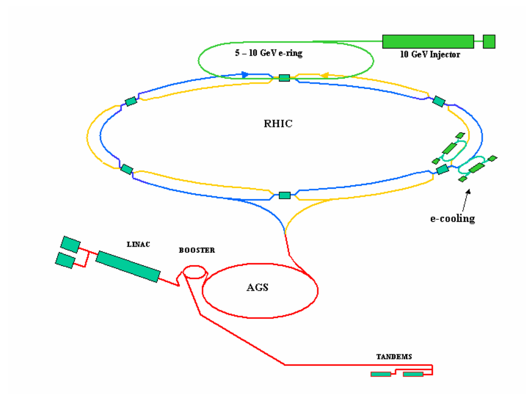


Figure 1, layout of eRHIC complex

2.2. ARC Design

The bending radius of arc dipoles is determined by the following considerations:

Synchrotron radiation linear density

$$P_{linear}(kW/m) \approx 14.085\frac{E^4(GeV)I(A)}{\rho^2(m)}$$

E is beam energy, I is total beam current, ρ is bending radius of main dipoles. The linear synchrotron radiation power density needs to be controlled under the level of current lepton factories.

Synchrotron radiation power

$$P(MW) = U_0(MeV) * I(A) \approx 0.0885\frac{E^4(GeV)}{\rho(m)}$$

Polarization time

The electron beam is pre-polarized in full energy injector with a polarized electron gun. Positron beam can only be polarized at high energy end in the main storage ring. The polarization time of positron beam should be short compared to the luminosity life time.

$$\tau^{-1} = \frac{5\sqrt{3}}{8} \frac{e^2 \gamma^5 \hbar}{m^2 c^2} \frac{I_3}{2\pi R}$$

e is electron charge, γ is relative energy factor, I_3 is synchrotron integral, m is electron mass, c is speed of light, R is the average radius of storage ring.

The current design value for the bending radius is 81.03 meters. The linear synchrotron radiation power density is 9.6 kW/m with 0.45 A beam current at 10 GeV. The Sokolov-Ternov polarization build-up time is about 22 minutes.

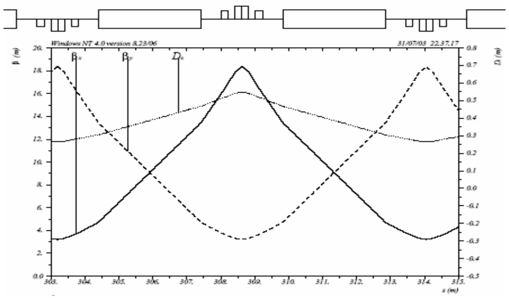
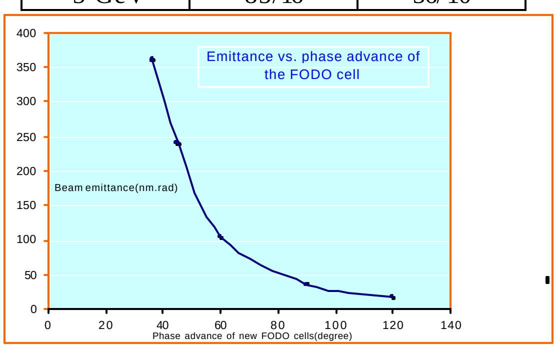


Figure 2, FODO cell in arc

Each arc consists of 40 FODO cells. See Figure 2. The length of each arc dipole is 3.03 m. There is still some room to lengthen the dipole in case the synchrotron radiation level needs to be further lowered for higher beam current operation. The phase advance is adjustable to meet various emittance requirements.

Table 1, x/y emittance of 4 operation modes (nm.rad)

E of lepton	e-p	e-Au
10 GeV	52/9.5	60/12
5 GeV	85/16	56/10



Plot 2, Emittance(10GeV) vs. phase advance per cell

The dispersion suppressors are able to work with significantly different cell configurations. Each dispersion compressor can accommodate two emittance wigglers if needed.

Figure 3 shows how the ring emittance varies with phase advance of a FODO cell.

2.3. IR straight

There are four sections in the interaction region (IR) straight, as shown in Figure 3.

- Mini-beta section: squeeze beam at IP to match hadron beams
- Separation section: separate lepton and hadron beams outside IP
- Spin rotator dipole and polarimeter section: dipoles for spin rotations and drift for a longitudinal polarimeter, also functions as the dispersion suppressor
- Spin rotator solenoid section: solenoids and coupling compensation schemes

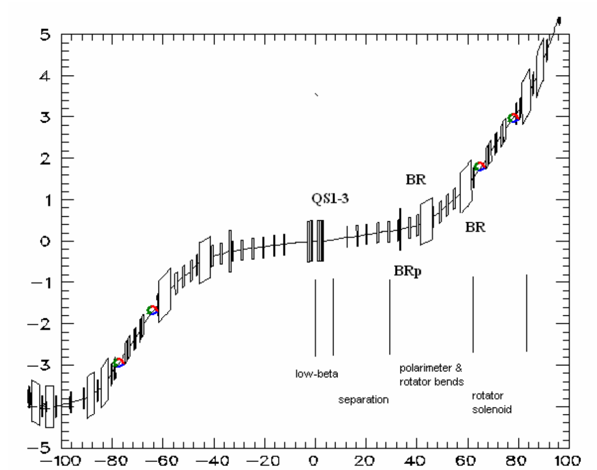


Figure 3, Layout of IR straight of eRHIC lepton ring, unit is meter

The beta-functions at IP for different collision modes are summarized in Table 2. Three superconducting combined-function magnets with different inner and outer apertures are placed inside the detector to provide final focusing to squeeze the beam size and finite bending angles to separate the lepton and hadron beams. A detailed description of magnet designs and synchrotron radiation considerations mini-beta section can be found in reference [2]. In this paper we mainly describe the beam optics.

Table 2, h/v beta-function at IP of 4 operation modes (cm)

	e-p	e-Au
10 GeV	19/27	19/34
5 GeV	35/20	19/19

The total bending angles for lepton beam in the insertion quadrupoles are 8-9 mrad on each side of IP. The hadron and lepton beams are separated by the septum magnet at 5 meters away from IP. The horizontal beta-function is made small to meet the tight aperture requirement.

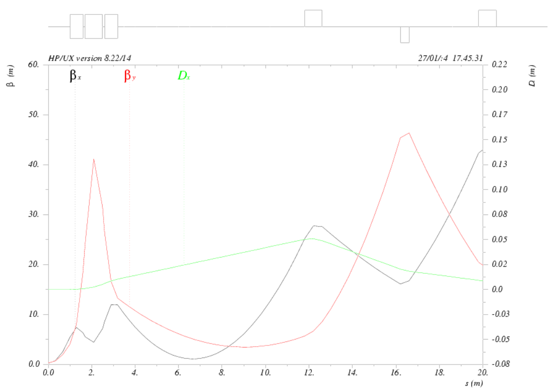


Figure 4, optics in mini-beta and separation sections, 10 GeV lepton vs. 250 GeV proton collision.

For longitudinal polarimeter section current design considerations include

- Some separation from beam collision IP (a small bending)
- spin direction close to longitudinal
- Some drift space for laser-beam IP(~ a few m)
- Small beam divergence (beta not too small)
- Compton back-scattering detector downstream.
- E' detection if possible (after one rotator dipole), etc. [3]

The spin rotator scheme is designed workable for a wide energy range, say, 5 to 10 GeV. The total bending angle of dipoles in each side of the IR straight is 92.29 mrad, corresponding to 90 degrees of spin rotation at 7.5 GeV.

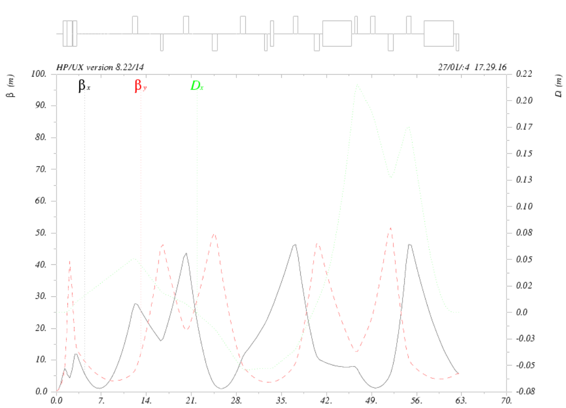


Figure 5, optics from IP to rotator dipoles.

The solenoids rotate the spin by 90 degrees to ensure the spin vector is vertical in arcs. The strong coupling brought by rotator solenoids are locally compensated by a set of quadrupoles [4]. The maximum integrated longitudinal field in each rotator is about 52.3 Tesla meter.

The preliminary spin matching is carried out over the interaction region straight to minimize the depolarization effects. The equilibrium polarization level with all the rotator solenoids on is over 80% with ~0.3 mm rms close orbit distortions. See Figure 7.

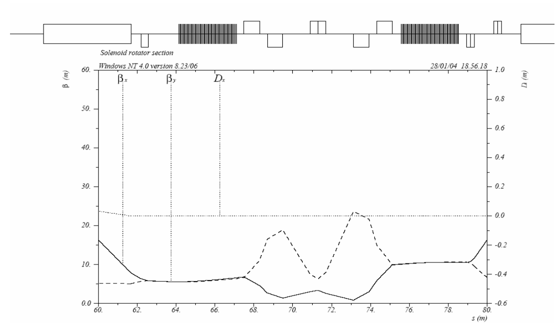


Figure 6, layout of rotator solenoid section

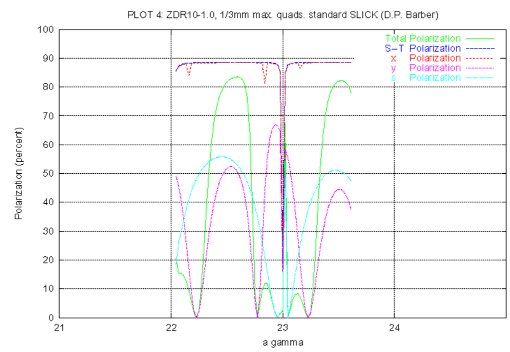


Figure 7, polarization simulation with SLICK [5]

2.4. Utility Section

The utility section will accommodate the injection and RF systems. It also provides tuning abilities for the ring. Two achromatic sections (anti-symmetric) are adopted to make the ring layout more (anti-)symmetric. The design without using any dipole is also performed.

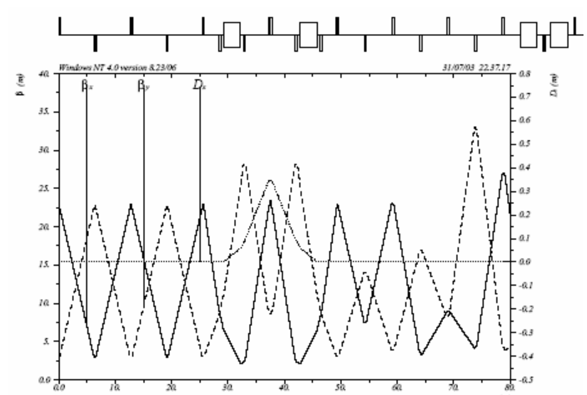


Figure 8, optics of utility section

Table 3, Main parameters of eRHIC lepton ring, 10 GeV lepton vs. 250 GeV proton operation

Energy	5-10 GeV
Circumference	1277.95 m
Beta-functions at IP	19/27 cm
Tunes	26.10/22.15
Bending radius(arc bends)	81.03 m
Linear SR density	9.6 kW/m
Total current	450 mA
Bunch populations	10^{11}
Bunch spacing	10.6 m
Emittance(h/v)	52/9.5 nm rad
Natural chromaticity(x/y)	-37/-34
Momentum compaction	0.0026
Energy spread	0.00095
Rad. polarization time	22 minutes
Damping time(x/y/s)	7.4/7.4/3.7 ms
Luminosity	$4.4\times10^{32}cm^{-2}s^{-1}$

The main parameters of one of operation mode of eRHIC lepton ring are summarized in Table 3. The ring circumference is 1/3 of that of RHIC rings. Bunch spacing is determined by AGS-RHIC complex. Currently the luminosity is primarily limited by the beam-beam effects.

In case the hadron beam energy is low the path length of lepton beams need adjustment by up to a few tens of cm. This is still under investigation.

3. DYNAMIC APERTURE

Four families of sextupoles in horizontal and six families in vertical plane are used to correct the chromatic effects. Preliminary particle tracking is done with LEGO simulation code [6]. It shows that the dynamic aperture is pretty good with both on- and off-momentum particles. See figure 9. More studies are underway.

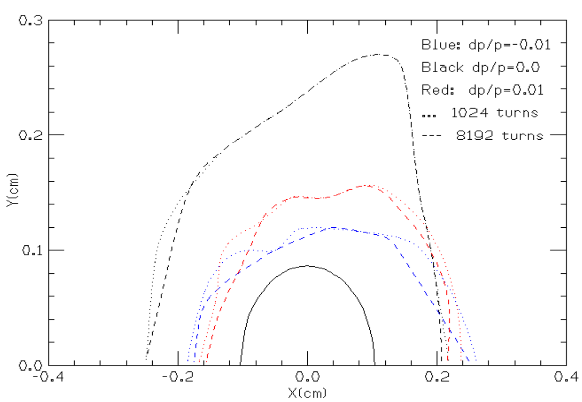


Figure 9, tracking results from LEGO

4. SUMMARY

A design of a 5-10 GeV lepton ring for eRHIC is performed. The optical and geometrical solutions are found to reach high luminosities and longitudinal polarizations with reasonable ring circumference and technical choices. The ring lattice is quite flexible for various operation conditions. The preliminary particle tracking studies show that dynamic aperture is pretty good. The anti-symmetric dipole-solenoid-type spin rotators are integrated into the ring optics and layout from very beginning.

Acknowledgments

The authors wish to thank Y. Cai, A. Deshpande, W. Mackay, R. Milner, T. Roser, U. Wienands for their helpful discussions.

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