eRHIC - FUTURE MACHINE FOR EXPERIMENTS ON ELECTRON-ION COLLISIONS*

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Abstract

The paper presents recent developments for the design of the high luminosity electron-ion collider, eRHIC, proposed on the basis of the existing RHIC machine. The goal of eRHIC is to provide collisions of electrons and positrons on ions and protons in the center-of-mass energy range from 30 to 100 GeV. Lepton beams as well as the beam of protons (and, possibly, light ions) should be polarized. Two independent designs are under development, the so called 'ring-ring' and 'linac-ring' options. The 'ring-ring' option is based on a 10 GeV electron storage ring. The design issues for the 'ring-ring' option are similar to those at existing B-factories. In the 'linac-ring' option the electron beam is accelerated in a 10 GeV recirculating energy recovery linac. This option may provide higher luminosities (>1e33 cm-2s-1 for e-p collisions), but requires considerable R&D studies for a high current electron polarized source. In order to maximize the collider luminosity, ion ring upgrades, such as electron cooling and ion beam intensity increase are considered.

INTRODUCTION

Initial design of future electron-ion collider eRHIC has been developed by a collaboration of accelerator scientists from BNL, MIT-Bates, BINP and DESY [1]. The design extends capabilities of existing heavy ion collider RHIC at Brookhaven National Laboratory by adding an electron accelerator which will provide polarized electron (and positron) beams for collision with ions and polarized protons circulating in RHIC. RHIC has interaction regions where no detectors for ion-ion collision have been installed and which are available for possible utilization for electron-ion collisions. The electron accelerator will produce the electrons in the energy range from 5 to 10GeV. It will lead to the electron-proton collisions with the center of mass energy range from 30 to 100 GeV.

RING-RING OPTION

There are two independent design options of eRHIC, which differ by the design of the electron accelerator. In the *ring-ring* scenario the electron beam circulates in a storage ring, which intersects an existing ion ring in one point [2]. The injection into the storage ring is done from a recirculating linac injector which accelerates the electron beam up to 10 GeV energy (no additional acceleration is done in the storage ring). The electron beam is produced by a polarized electron source and hence it is initially polarized. Depolarization effects in the storage should be minimized to keep the electron beam polarization at the high level of >70% with storage times of order of several hours. It provides strict tolerances on the beam vertical orbit errors. Nevertheless at some energies, corresponding to spin resonance conditions, the polarization can not be preserved.

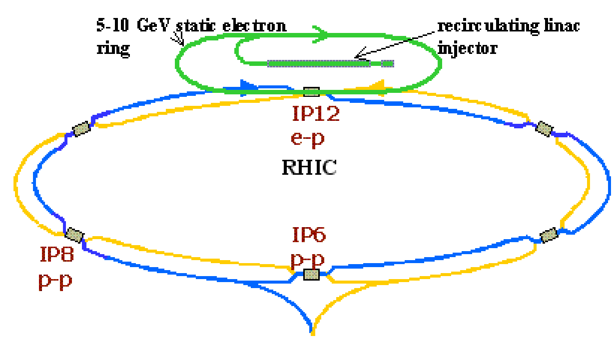

Figure 1: Ring-ring option of the eRHIC uses the electron (or positron) beam from a storage ring for collisions with ions or protons, circulating in RHIC, in one of the RHIC existing interaction points.

Unpolarized positrons are produced in a conversion system, which is a part of the injector system. After the production, the positrons are accelerated to 10 GeV and injected into the storage. While circulating in the storage ring the positron beam acquires the polarization due to synchrotron radiation self-polarization process. Effective self-polarization with short enough polarization time (~15min) is possible at 10 GeV energy. Since the polarization time increases sharply as the beam energy decreases, the use of polarized positrons in the current design is limited to energies close to 10 GeV.

Spin rotators based on solenoidal magnets are used to convert the electron (or positron) beam polarization direction into the longitudinal one at the interaction point.

The electron energy and required electron current range (0.5-1 A) are comparable to those used in the storage

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rings of B-meson factories. Many design features and technology developed and used in the B-factories can be effectively applied for the eRHIC electron ring. Thus the electron accelerator design for the ring-ring option is based on currently available accelerator technology and does not require extensive R&D.

One of major design challenges for the ring-ring option is to provide the capability to vary the electron ring circumference in order to match the revolution frequencies at different energies of the proton beam. The energy of the proton beam in eRHIC can be varied from 50 Gev to 250 GeV.

Another important issue is to provide the efficient engineering design for the accommodation of considerable synchrotron radiation power load on the vacuum chamber walls. The efficient solution of this problem may allow to operate with the electron currents higher than 0.5A, opening the way to the luminosities of e-p collisions higher than 5.e32 cm^{-2} s^{-1}.

LINAC-RING OPTION

Figure 2 shows another design option which is under development, the *linac-ring* option [3]. This option uses fast developing energy recovery linac technology. High current polarized electron beam is accelerated to collision energies (5-10 GeV) by a superconducting energy recovery linac (ERL). Since the electron beam is used for the collisions only on one pass, the electron beam-beam parameter is not the limiting factor for the achievable luminosity, opening a way to luminosities higher than 10^{33} $cm^{-2}s^{-1}$.

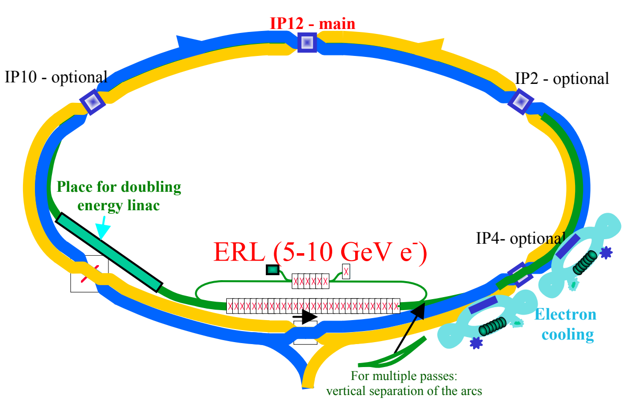

Figure 2: Linac-ring design option of eRHIC uses the energy recovery linac as the electron accelerator.

Two recirculating passes of the ERL are placed in the RHIC tunnel near presently existing Blue and Yellow ion rings. With this configuration of the recirculating passes more than one electron-proton collision points can be organized. The handling of electron polarization is much simpler, than in the ring-ring design, since there is no depolarization effects from spin resonances present. Creating the longitudinal polarization in the interaction point does not require the spin rotators, it can be set up by a proper choice of the energy gains in two ERLs used for the electron beam acceleration. The interaction region design are also simpler in the linac-ring option. The IR design provides round beam collisions, gaining by about factor 2.5 in the luminosity. It also allows to move interaction region quadrupoles to 5m, or even further, from the interaction point, giving simpler solutions for the large acceptance detector design.

To include the positron beam into the linac-ring design, the compact storage ring should be added, for the positron accumulation and storage.

The major challenge for the linac-ring design is the task of developing high current polarized electron source. Several hundred milliamps of electron current from the polarized injector would be required, assuming that no efficient transverse cooling for high energy protons can be applied. With the proton transverse cooling the requirement on the electron current may be considerably relaxed, proportionally to the efficiency of the cooling. The R&D for energy recovery linac technology is also needed in order to provide the ERL operation with high electron currents. This development is completely inline with the ERL technology development for the e-cooling project at RHIC [4]. The state-of-art design of basic element of the ERL, 703.75 MHz 5-cell RF cavity, was developed in BNL. The design allows minimization and efficient damping of the HOM, opening a way for higher electron currents. The cold tests of the cavity prototype are planned for later this year.

In order to investigate the beam stability issues in the ERL, the studies are underway on the multipass beam break-up instability and on the so-called kink instability.

ACHIEVABLE LUMINOSITIES

Figure 3 below shows the luminosities achievable in linac-ring and ring-ring options as the function of proton beam-beam parameter. The achievable proton beam-beam parameter depends on the number of collision points and on the eRHIC operation mode (the dedicated mode, with only e-p collisions or the parallel mode with the operation on e-p and p-p collisions in the same time), but in any case it is not expected to be higher than 0.02.

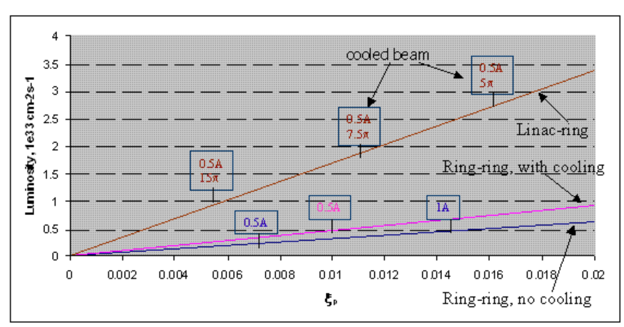

Figure 3: Comparison of the luminosities versus proton beam-beam parameter for the linac-ring and the ring-ring option, with and without the transverse electron cooling of the proton beam. 330 bunches are assumed in the proton ring with 1.e11 proton per bunch. Markers demonstrate the luminosities for the indicated electron

current and the indicated proton normalized transverse emittances.

The electron cooling is under consideration in order to reduce transverse emittances of the proton beam. Even with the cooling the luminosity for the ring-ring option does not exceed 10^{33} $cm^{-2}s^{-1}$ with the main luminosity limitation coming from the beam-beam effects.

In the linac-ring option the beam-beam tune shift for the electron beam is not limiting factor anymore and e-p luminosity beyond 10^{33} $cm^{-2}s^{-1}$ may be achieved. The luminosity limitation in this case comes from the maximum achievable proton (ion) beam intensities, as defined by the effects related with electron clouds and the pressure rise as well as the heating of ion ring cryogenic vacuum pipe due to the resistive wall impedance. The luminosity in the linac-ring version may benefit considerably from the application of the transverse electron cooling (at the fixed electron beam current), as the Figure 3 shows.

INTERACTION REGION DESIGN

Initial interaction region design described in the ZDR suggested acceptable solutions for the fast beam separation, preventing parasitic beam-beam collisions, and for avoiding the synchrotron radiation load inside the detector region and on cold IR magnets. The crossing angle can not be accommodated in the eRHIC IR design without a considerable sacrifice of the luminosity.

Later work on the detector design demonstrated significant difficulties for the detector acceptance at the initial IR design with IR quadrupoles as close as 1m to the interaction point. Upgraded IR design pushed the IR quadrupoles to 3m from the interaction point for the ring-ring option. Though it comes with the factor of two of the luminosity reduction. For fast beam separation a dipole magnet will be incorporated into the detector design [5].

For the linac-ring option the IR quadrupoles can be put as far as 5m from the IP. The Table 1 summarizes the important features of the interaction region designs developed so far.

Table 1: Summary of features of different eRHIC IR designs

	Distance to nearest IR quad from IP	Beam separation	Magnets used	Hor/Ver beam size ratio at the IP
Ring-ring, l*=1m	1m	Combined field quadrupoles	Warm and cold	0.5
Ring-ring, l*=3m	3m	Detector integrated dipole	Warm and cold	0.5
Linac-ring	5m	Detector integrated dipole	Warm	1

SUMMARY

Two possible variants of the eRHIC design, ring-ring and linac-ring options, are under the development.

The ring-ring design employs much of the accelerator technology used in B-factories. The achievable e-p luminosity is below 1.e33 $cm^{-2}s^{-1}$.

The linac-ring design provides a way to the luminosities above 1.e33 $cm^{-2}s^{-1}$. But considerable R&D is required for the polarized electron source.

The design work continues towards the conceptual design report.

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