ELECTRON-ION COLLISIONS AT RHIC USING A HIGH INTENSITY SELF-POLARIZING ELECTRON RING*

V. Ptitsyn, J. Kewisch, B. Parker, S. Peggs, D. Trbojevic, BNL, Upton, NY, USA
D.E. Berkaev, I.A. Koop, A.V. Otboev, Yu.M. Shatunov, BINP, Novosibirsk, Russia
C. Tschalaer, J.B. van der Laan, F. Wang, MIT-Bates, Middleton, MA, USA
D.P. Barber, DESY, Hamburg, Germany

Abstract

We consider the design of an electron-ion collider realized by adding a self-polarizing electron ring to the existing RHIC collider. It would provide polarized electron-proton and unpolarized electron-ion beam collisions in the center of mass energy range of 30-100 Gev and at luminosities up to 10^{33} $cm^{-2}s^{-1}$ for e-p and 10^{31} $cm^{-2}s^{-1}$ for e-Au collisions. An electron storage ring lattice has been developed which provides a short polarization time for an electron beam in the 5-10 GeV energy range and which satisfies the luminosity goals. We describe the modifications to the RHIC interaction region layout required for both efficient beam separation and also for longitudinal electron and proton beam polarization at the collision point.

INTRODUCTION

In recent years a strong physics interest in an electron-ion collider has emerged. An electron-ion collider would probe QCD in a manner not previously possible through collisions between electrons and beams of atomic nuclei as well as collisions between polarized electron and proton beams. The availability of longitudinally polarized electron and proton beams at the collision point is a prerequisite for such an electron-ion collider.

The RHIC collider at Brookhaven National Laboratory (BNL) is currently providing beams of gold ions, deuterons and polarized protons for colliding beam physics experiments at the positions of four experimental detectors [1]. The possible scenarios and accelerator issues of the addition of an electron accelerator to the RHIC complex have been discussed in [2]. The addition should be done in a way which involves minimal reconstruction of RHIC itself and should be financially acceptable. Here we describe a design for the new ‘‘eRHIC ’’ collider based on a self-polarizing electron storage ring and developed in collaboration between BNL, the Budker Institute for Nuclear Physics (BINP) and the MIT-BATES laboratory.

DESIGN LAYOUT

This design suggests construction of an electron ring with an energy, E, of 5-10 GeV which will have a circumference of 5/16 of that of RHIC and an intersection with RHIC in one of the existing experimental areas (see Fig.1). The electron beam from an unpolarized electron source is accelerated in the linac to 2GeV and injected into the ring. In the later stages of the project the linac energy can be increased to 5 GeV. After injection the electron beam is accelerated to collision energies of 5-10 GeV where it becomes spin polarized through the emission of synchrotron radiation (the Sokolov-Ternov effect). Thus it is important for the design to ensure a short enough polarization time. Stored positrons could be polarized in the same way.

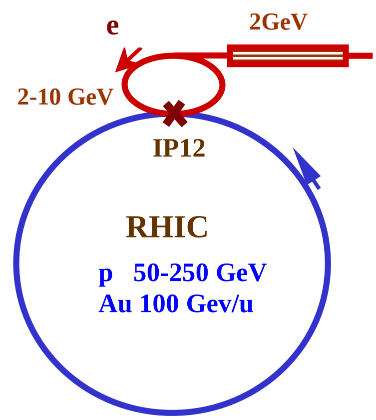

Figure 1: Design layout

The lattice of the electron ring consists of two arcs with regular FODO structures and two straight sections: one for the beam collisions and the other for accelerating cavities and other necessary equipment. For fixed bending radii the polarization time τ_p is proportional to E^{-5}. But a short polarization time over the whole energy range is achieved by a special design for the electron ring bending magnets. These so-called “superbend” magnets consist of three parts (see Fig.2). The magnetic fields, B, of the short central parts and of the longer outer parts are scaled differently with the beam energy, while keeping the total bending angle of the magnet the same. Such a field arrangement allows an optimal balance to be maintained between the quantities of the interest: τ_p , which at a chosen energy is proportional to B^{-3} and synchrotron radiation losses, proportional to B^2 at a chosen energy. At 5 GeV energy the relatively high field of 2T in the central part of the magnet is used to decrease polarization time, while at 10 GeV the field is reduced to decrease the synchrotron radiation power load. At 10 GeV the setup with a uniform field in the outer and central parts of the superbend at provides a polarization time of 8min and

* Work performed under Contract No. DE-AC02-76CH00016 with the U.S. Deparment of Energy

7MW of synchrotron radiation. Ways to accommodate this power load are under consideration. The polarization time and beam emittance dependence on beam energy are shown in Figure 3.

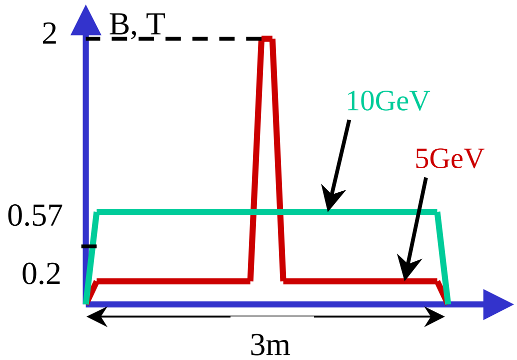

Figure 2: Field distribution (B) along the superbend magnet for 5 and 10 GeV beam energies.

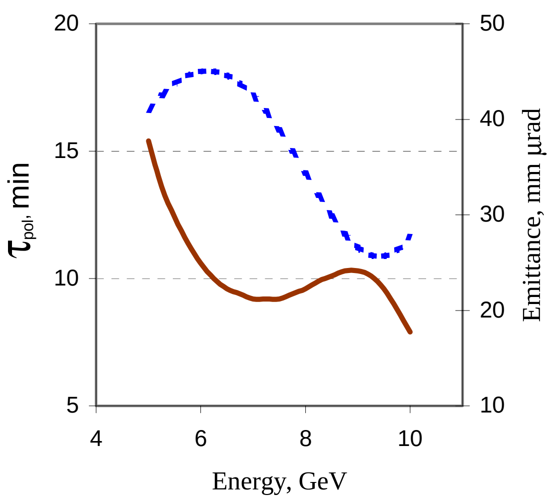

Figure 3: Electron beam polarization time (solid) and emittance (dashed) versus the beam energy for the superbend central field changing linearly from 0.57T (at 5GeV) to 2T (at 10 GeV).

Since the magnet fields in the superbend magnet do not scale linearly with the beam energy, the beam path inside the magnet depends on the energy. In order to control the change of path length with the energy and thus eliminate radial shift of the orbit, special dipole magnet insertions are being considered.

LUMINOSITY CONSIDERATIONS

The maximum luminosity of a collider depends, among other things, on the tolerable beam-beam parameters ξ. It has been predicted that the destructive effect of beam-beam forces can be minimized by using round beam collision geometry based on conservation of the angular momentum [3]. This involves 2 conditions: equal beam sizes and equal betatron tunes. Then the luminosity is

$$L = \left(\frac{4\pi\gamma_e\gamma_i}{r_e r_i}\right)\cdot\xi_e\cdot\xi_i\cdot\sqrt{\frac{\varepsilon_e\varepsilon_i}{\beta_e^*\beta_i^*}}\cdot F_c$$

Following world wide experience, we have assumed limiting values of 0.05 (electrons) and 0.005 (protons) for the beam-beam parameters. Since the origins of the formation of the beam emittances are quite different, as well as their dependences on energy, tools for emittance control in both the electron and the ion ring are needed for keeping the beam sizes matched at the collision point. For the electron ring the superbends provide the flexibility for emittance manipulations. In the ion ring the emittance control should be done by a beam cooling device.

Following experience (B-factories or LEP for electrons; RHIC, Tevatron for protons) we have accepted 10^{11} particles per bunch as a reasonably achievable number.

The main parameters of eRHIC for the current variants of the electron and ion ring lattices are listed in Table 1 for the cases of e-p and e-Au collisions.

Table 1:Basic beam parameters

Parameters	e-ring	ion ring	
		p	Au
C, m	1022	3833	
E, GeV	5–10	250	100/u
n_b	96	360	
N_b	$1\cdot10^{11}$	$1\cdot10^{11}$	$1\cdot10^{9}$
I, A	0.45	0.45	
ε_{rms}, mm µrad	45–25	17–9	
β^*, cm	10	27	
σ^*, mm	0.07–0.05	0.07–0.05	
ξ	≤ 0.05	≤ 0.005	
L, $cm^{-2}\ s^{-1}$		$(0.5\text{-}0.9)\cdot10^{33}$	$(0.5\text{-}0.9)\cdot10^{31}$

To achieve the required proton and ion beam parameters some parts of RHIC will have to be upgraded.

First, in order to achieve and maintain the required gold beam emittance during collisions, a cooling system should be developed and installed in the ion rings. Cooling would also be required for experiments involving proton beams with energy below 200 GeV. The development of an electron cooling system for RHIC is currently underway[4].

Also, the reduction of the proton (ion) β^* from the currently used 1m to the 27cm required by the eRHIC design, will possibly call for longitudinal cooling to prevent luminosity reduction by the hour-glass effect.

The upgrade to 360 bunches from the current 55 or 110 bunches was foreseen at the RHIC design stage and looks feasible. Some modifications in the injection system will be needed. Also, better theoretical and experimental understanding of the pressure rise and electron cloud effects observed during RHIC operation is needed in order to improve the maximum achievable total current of the ion and proton beams[5].

IR DESIGN

The interaction region design should provide focusing to the low β^* and effective beam separation to avoid parasitic collisions (with the about 35ns between consecutive bunches). At the same time it would be preferable to minimize the reconstruction of the existing RHIC rings.

Two possible schemes for the interaction region layout have been proposed so far with horizontal and vertical beam separation (see Figure 4).

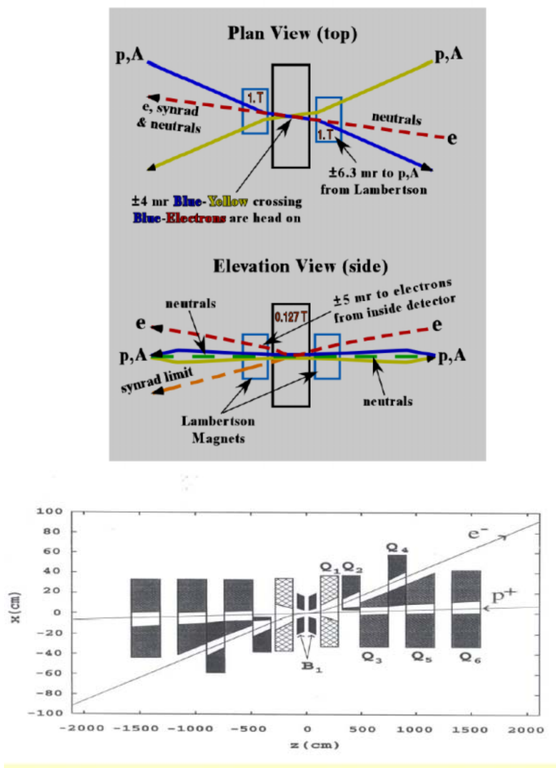

Figure 4: Two suggested schemes of the interaction regions: with vertical (top) and horizontal separation (bottom).

In both schemes the beam separation is initiated by the magnetic field inside the experimental detector itself. The focusing quadrupoles nearest to the collision point could also be put inside the detector. Thus the further development of the interaction region design should be coupled with the initial development of the experimental detector itself. During this work the important issues of minimizing detector background and the protection of the detector from synchrotron radiation should be resolved.

In order to transform the vertical polarization in the arcs of the electron and proton rings into longitudinal polarization, spin rotators will be installed around the interaction region. For the proton ring the rotators will be similar to the rotators, based on helical dipoles, already used at two RHIC interaction regions for proton-proton beam experiments. For the electron ring the use of a pair of solenoidal spin rotators has been suggested. They would produce exactly longitudinal polarization at an energy of 7.5 GeV. The spin-transparency conditions needed for obtaining sufficient electron polarization are well known [6].

POLARIZATION ISSUES

For an ideal machine without errors and beam-beam forces an electron polarization of about 90% is achieved after 8-15min of beam storage. But misalignments and beam-beam forces can lead to strong depolarization. The effect of the extra magnetic fields in and around the detector can also be significant. A first order calculation of the polarization shows that with a rms vertical closed orbit error of 0.5 mm the maximum equilibrium polarization might drop to the 50-60% level if no specific corrections are made. Fortunately, it has been demonstrated at HERA that depolarizing effects can be minimized with harmonic correction of the closed orbit [7]. Such schemes should be used at eRHIC. Together with feedback from a fast polarimeter, based on the Compton backscattering of a laser beam, it might be possible to optimize the polarization continuously on-line. Also, the storage ring design itself can be re-optimized to provide less sensitivity to depolarizing resonances.

CONCLUSIONS

The design of an electron-ion collider (eRHIC) presented here is based on the construction of a self-polarizing electron ring. The collider will provide polarized electron-proton and unpolarized electron-ion beam collisions in the center of mass energy range of 30-100 Gev and at luminosities up to 10^{33} $cm^{-2}s^{-1}$ for e-p and 10^{31} $cm^{-2}s^{-1}$ for e-Au collisions. The polarization time of 8-15min is achieved using superbend magnets in the electron ring. The collider design could be realized using the present level of the accelerator technology and could also be used to store and collide polarized positrons.

REFERENCES

[1] T. Satogata et al., “Commissioning of RHIC Deutron-Gold Collisions”, these proceedings.
H. Huang et al., “Polarized Proton Operations in the AGS and RHIC”, these proceedings.

[2] I. Ben-Zvi, J. Kewish, J. Murphy, S.Peggs, Nucl. Instr. Meth. **A463**, 2001, p.94.

[3] A.N. Filippov et al., Proc. of 15th Int. Conf. High Energy Accelerators, Hamburg , 1992, p.1145.

[4] I. Ben-Zvi et al., “R&D towards Cooling of the RHIC Collider”, these proceedings.

[5] S.Y. Zhang et al., “RHIC Pressure Rise and Electron Cloud”, these proceedings.

[6] Yu.M. Shatunov et al., “Status of e-ring design for EIC”, presented at SPIN2002 , Upton, 2002.

[7] D.P. Barber et al., Physics Letters, **B343**, 1995, p.436.