ERHIC – ELECTRON-PROTON COLLIDER WITH POLARIZED BEAMS

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The layout and main parameters of the e-ring for eRHIC project are presented. The optics properties to fulfill the so-called spin-transparency condition to obtain sufficient polarization degree at IP are given. The possibility of using super-bends for the polarization time in a wide energy range be decreased is also discussed.

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INTRODUCTION

In the Brookhaven National Laboratory (BNL) experiments at the new collider RHIC have successfully started with both ion-ion and polarized proton-proton beams. To enhance the experimental capability of the RHIC complex, different schemes of *e - p* collisions arrangement are under discussion for the last few years. High-luminosity polarized *e - p* scattering will open a unique opportunity for physics beyond limits of today experiments in polarized DIS.

This paper presents a study of the ring-ring option of eRHIC. A project of the electron ring with the energy 5…10 GeV and luminosity up to 5…10× 32 cm^{-2}s^{-1} was developed in collaboration with BINP (Novosibirsk) and BNL. We suggest (see Fig.1) to construct mainly outside the RHIC tunnel the electron storage ring which will have the circumference 4/15 of the RHIC orbit and an intersection with ions in the one of the existing RHIC experimental area (on 12 o'clock).

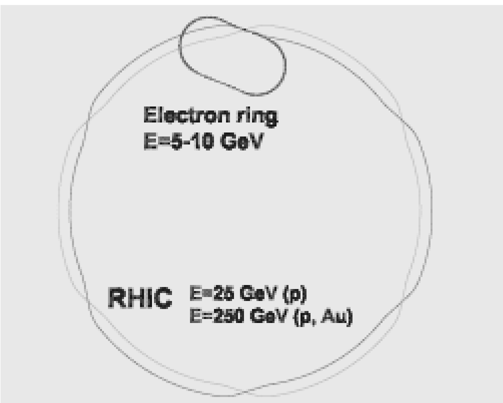

Fig.1. The general layout of the e-ring installed into the RHIC complex

The radiative polarization of the electron beam and a combination of solenoids and bending magnets will provide a high degree of the longitudinal polarization of the electron beam in the IP. To minimize the reconstruction of the RHIC rings while adding the new electron ring two possible schemes of the interaction region arrangement are proposed: so-called horizontal "dog-leg" scheme and vertical one. Spin-transparency conditions which are needed for obtaining sufficient polarization degree in the electron beam have been found for both options of the IP layout.

THE LUMINOSITY CONSIDERATION

Achieving the high luminosity value of 5×10^{32} cm^{-2}s^{-1} is a main challenge and needs a special consideration that have to take into account a world wide experience of many machines, electron and proton ones, as well as results of beam-beam interaction simulations. In particular, the simulations predict a number of advantages for the round beam geometry by the collision due to a conservation of the angular momentum [1]. To keep the round beams we should meet 3 conditions: equal emittances of the both beams ($\varepsilon_e = \varepsilon_i = \varepsilon$); equal tunes of betatron oscillations; equal β-functions in the IP ($\beta^*_e = \beta^*_i = \beta^*$). In favour of the round beams the HERA and SPS experiences witness a bad life time and high background for unmatched beam sizes even with moderate beam currents.

The round beam luminosity is given by the equation:

$$L = F_{coll} \frac{4\pi\gamma_e\gamma_i}{r_e r_i} \xi_e \xi_i \cdot \frac{\varepsilon}{\beta^*} ,$$

where *Fcoll* is the collision repetition frequency, γ and *r* are the relativistic factors and classical radii for electrons and ions respectively. Space charge parameters ξ_e and ξ_i for electrons and ions are determined by the expressions: $\xi_{e,i} = \frac{N_{i,e} r_{e,i}}{4\pi\gamma_{e,i} V_{e,i}\varepsilon}$,

where N_e and N_i are electron and ion bunch populations; V_i is the ion velocity (V_e= c =1). The world wide experience shows that achievable values of the space charge parameters due to the beam-beam effects do not exceed 0.5 for electrons and 0.05 for protons. Collision frequency F_{coll} is determined in our case practically by the ion bunch spacing in the RHIC. Single bunch populations N_e and N_i are limited except the beam-beam interaction by different kinds of instabilities. For electrons the most severe intensity threshold is set by the head-tail transverse mode-coupling instability that limits the one-bunch population. The modern accelerator experience (for instance, in the both B-factories or in the LEP collider), tells us, that $N_e = 5\cdot10^{10}$ is, more or less, a safe number. The proton bunch population is admitted to $N_p = 1\cdot10^{11}$, which is based on BNL and FNAL experimental results. To achieve the specified luminosity of $L = 5\cdot10^{32}$ cm^{-2}s^{-1} the beam size at the IP should be $\sigma^* = 80$ μ*m* together with the other fixed above parameters and with the assumption $\beta^* = 10$ *cm.*

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RADIATIVE POLARIZATION AND E-RING DESIGN

The radiative polarization has been observed at the many electron storage rings. According to this experience the energy range 5…10 GeV is quite comfortable for obtaining the polarization degree of about 80 percents. If the equilibrium polarization direction (vector **n**) is vertical in the arcs we can expect a relatively low polarization losses caused by spin manipulations around the IP.

A radiative polarization time strongly depends on the bending field ($\tau_p \sim B^{-3}$). On the other hand the high magnetic field increases the energy losses for the synchrotron radiation ($\Delta E_{turn} \sim B^2$). A possible compromise here may be a special design of the bending magnets. We propose to use so-called super-bend magnets with a relatively high field in a short central part of each magnet. It allows us strongly decrease the polarization time at low energies and suppress spin resonances by the relatively minimal energy losses.

The possible optimum is to use high field in the super-bends at low energy (so to keep the polarization time at the level of 15 minutes at 5 GeV) and the uniform field at 10 GeV. But the final strategy of using the super-bends can be found during practical work with the beam polarization.

We considered the e-ring which consists of two arcs with regular FODO structure and two straight sections: one for the beam collisions and other for technical usage. To deliver spin longitudinal into the IP we need to install two spin rotators on both sides of the interaction area. At first, the spin is rotated by a solenoidal field relatively to the horizontal plane and then by low-field dipoles (including final focus of quadrupole magnets) exactly to the longitudinal direction at the medium energy 7.5 GeV. On the opposite side of the interaction straight, the spin is restored to vertical direction by the mirror symmetrical spin rotator. As a result, due to this anti-symmetry and the spin transparency of the solenoidal rotators, the spin phase advance along the whole interaction region is zero, spin is always restored to the vertical direction in the next arc at an arbitrary energy and the polarization behavior is mainly the same as without the spin rotators. The main parameters of the e-ring are listed in Table.

Parameter	e-ring	p-ring
Circumference, m	1022	3833
Energy, GeV	5…10	250
Number of bunches	96	360
Bunch population	$5 \cdot 10^{10}$	$1 \cdot 10^{11}$
RMS emittance, mm·μrad	45…63	9…13
Beta function at IP, cm	10	50
Beam-beam parameter	0.05	0.005
Luminosity, $cm^{-2}\ s^{-1}$	$5 \cdot 10^{32}$	

THE DETECTOR AREA LAYOUT

Besides the spin manipulations there are other issues for the IR design: beam separation to avoid the parasitic beam-beam interactions; focusing to the low beta; detector background; protection from the synchrotron radiation, etc. In this consideration we did not touch the ion ring final focus system except the assumption $\beta^*=10\ cm$. Both suggested schemes have transverse fields around the IP that additionally to the spin rotation will separate the beams due to their big energy difference. The same fields could be used for a detector momentum analysis. In the case of a longitudinal field in the detector compensating solenoids are needed to keep the zero spin rotation along the IR. The first option supposes the lift up (about 1 m) one of the RHIC ion ring for the zero angle intersection with the flat electron ring. Fig.2 (left) shows schematically the interaction region (IR) and the spin vector behavior. Since the spin is lying in the horizontal plane between the two solenoidal spin rotators, some depolarization comes from the bending magnets in this area. A choice of moderate field magnitudes (few KGauss) helps to avoid considerable polarization losses. Calculations with the ASPIRRIN code [2] give the equilibrium polarization degree about 90% and the polarization time about 500 s at 10 GeV.

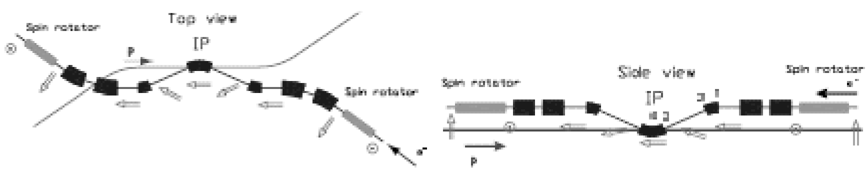

Fig.2. The layout of the e-ring interaction region

One can see that this scheme looks well for the electron polarization, but it might require serious rebuilding in the RHIC machine. That's why we considered other scheme with flat ion ring and a vertical orbit bump (about 0.5 m) in the electron ring, see the Fig.2 (right). In this variant the proton ring of the RHIC is almost unchanged except a new final focusing to get the low beta.

As the polarization calculations by ASPIRRIN show, despite of the spin transparency, the vertical bend initiates some spin resonances even in the ring without any imperfections. The situation is drastically changed due to random vertical fluctuations of the arc quadrupoles positioning. The polarization does not exceed 50 percents with the RMS shift of 0.5 mm.

CONCLUSION

The present study show that the ring-ring option of the electron-proton collider is able to provide the luminosity up to $5 \cdot 10^{32}\ cm^{-2}s^{-1}$ in the SCM energy range 15…100 GeV. The project of the electron ring with the super bend magnets and the solenoidal spin rotators performs to obtain not less than 70 percents of the longitudinal polarization in the IP. Two possible layouts of the interaction region are considered. The scheme with the flat electron ring (horizontal "dog leg") looks preferable for the electron polarization. A serious consideration of a new RHIC final focus design for the low beta is needed together with a number of other topics which have not be mentioned in this paper.

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ERHIC – ЭЛЕКТРОННО-ПРОТОННЫЙ КОЛЛАЙДЕР С ПОЛЯРИЗОВАННЫМИ ПУЧКАМИ

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Представлены основные параметры и расположение е-кольца в проекте eRHIC. Даны оптические свойства для выполнения так называемого условия спиновой прозрачности для получения достаточной степени поляризации в IP. Также обсуждается возможность использования сверхизгибов для уменьшения времени поляризации в широком энергетическом диапазоне.

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Представлені основні параметри і розташування е-кільця в проекті eRHIC. Дані оптичні властивості для виконання так званої умови спінової прозорості для одержання достатнього ступеня поляризації в IP. Також обговорюється можливість використання надвигинів для зменшення часу поляризації в широкому енергетичному діапазоні.