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eRHIC EIC: PLANS FOR POLARIZED BUNCH R&D AT CORNELL RAPID-CYCLING SYNCHROTRON *

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Abstract

A rapid-cycling synchrotron (RCS) is foreseen as the electron injector for eRHIC. Cornell's 10-20 GeV injector at CESR offers a good opportunity for dedicated experiments regarding rapid acceleration of polarized bunches. It can also serve as a test bed for source and polarimetry R&D in the framework of the EIC project, as polarization transmission experiments in the RCS require a polarized electron source and dedicated polarimetry in the linac region and in the RCS proper. This paper introduces the topic and possible plans.

INTRODUCTION

An RCS is the preferred technology for injection into the eRHIC 18 GeV electron storage ring [1]. Rapid acceleration of polarized electron bunches has never been demonstrated and deserves experimental investigation. It was pointed out a few months ago that the Cornell 10-20 GeV RCS [2] (C-RCS in the following) would be the appropriate facility to undertake the necessary technological developments and polarized bunch studies [3].

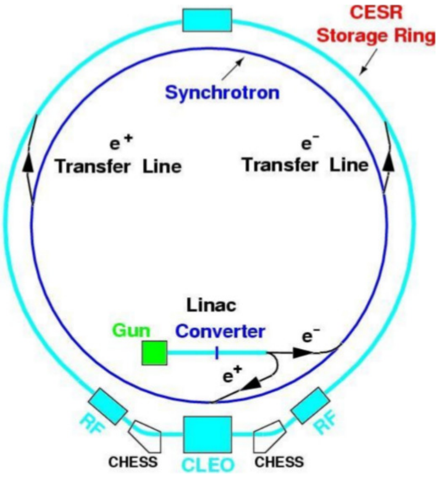

Figure 1: CESR accelerator complex.

This paper discusses the feasibility of the acceleration of polarized bunches at C-RCS, and comments on some aspects of the necessary polarization infrastructure equipment planned for eRHIC, in view especially of later moving this equipment to eRHIC. Figure 1 shows the accelerator installation at Cornell, Table 1 lists typical parameters of the Cornell RCS.

Table 1: Parameters of the Cornell RCS

Top energy	GeV	>10
Injection energy	MeV	320
Circumference C	m	755.87
Bunch		
Bunch charge	nC	0.03
Nb. of bunches/cycle		16
Interval between bunches	ns	14
ε_x, ε_y norm., at 5.3 GeV	mm	4.15, 1.14
Bunch length	mm	6
dE/E at 0.32, 5.3 GeV		$<10^{-2}$, $2\,10^{-4}$
Combined function lattice		48×FFDD
Nb of dipoles		192
ρ	m	98
Field at 10 GeV	T	0.33
Max. β_x, β_y	m	$25 \sim 30$
Q_x, Q_y, typical		10.75
RF, synch. radiation		
f_{rf}	MHz	714
Repetition rate	Hz	up to 60
Ramp duration to 5.3 GeV	ms	4.4
E-loss per turn at 5, 10 GeV	MeV	0.6, 9
τ_x ($\approx \frac{2.5}{E^3}$) at 5, 10 GeV	ms	16, 2

POLARIZED BUNCH ACCELERATION

Intrinsic Depolarizing Resonances

Figure 3 shows the strength of intrinsic resonances (of the form $a\gamma \pm Q_y$ = integer) up to 22 GeV. The strongest resonance in the energy range considered is at $a\gamma = 21 - Q_y \approx 10.18$ (just preceding $a\gamma = 0 + Q_y \approx 10.82$, $E \approx 4.77$ GeV), its strength at nominal emittance 1 mm norm. is 5×10^{-3}. Its depolarizing effect is $< 1\%$ [3], whereas the upstream resonances are all weaker. Thus, an upper limit of the cumulated effect of the N intrinsic resonances to be crossed from injection to $a\gamma < Q_y$ is

$$\frac{P_{a\gamma=Q_y^-}}{P_{inj.}} = \prod_{j=1,N} \frac{P_{j,f}}{P_{1,i}} \approx 1 - \sum_{j=1,N} \frac{\pi|\epsilon_j|^2}{\alpha_j} \approx 0.93 \qquad (1)$$

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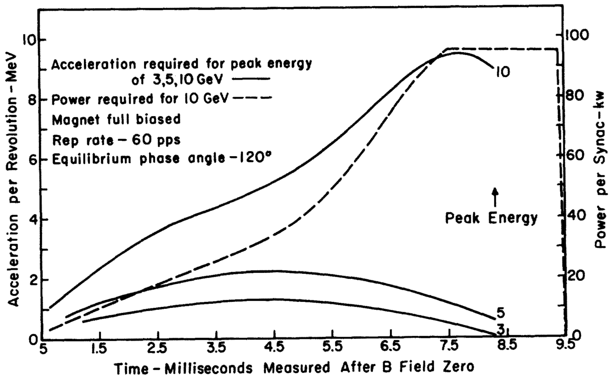

Figure 2: Acceleration cycles for 3, 5, 10 GeV [2,4].

with $P_{f,N}$ the final polarization (next to the N-th resonance) and $P_{i,1}$ the initial polarization (before the i-th resonance). The numerical data yielding this are (i) acceleration rate, a low $\alpha_j = da\gamma_j/d\theta \approx 10^{-3}$ (actually up to $\sim 3\,10^{-3}$ over 0.6 ~ 4.8 GeV; the lower energy resonance in Fig. 3 is at ≈1.2 GeV), (ii) a pessimistic $|\epsilon_j| = 1.5\,10^{-3}$ for all j (the resonance strength actually scales as $1 + a\gamma$); (iii) and the time-dependent RF voltage, Eq. 2, and energy loss $0.088 \times E^4_{[GeV]}/\rho_{[m]}$ (MeV/turn).

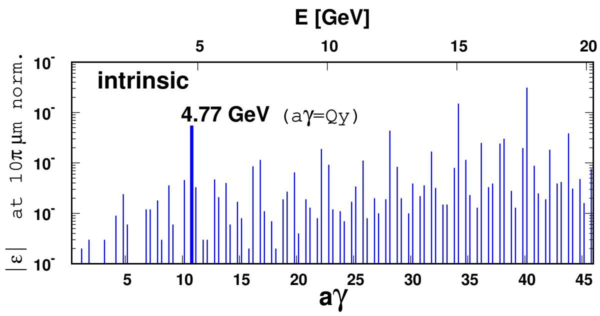

Figure 3: Strength of intrinsic resonances in Cornell RCS, at $\varepsilon_y = 10\pi$ μm normalized.

Imperfection Resonances

They satisfy $a\gamma$=integer, their orbit-dependent strength is (with $y_{co,i}$ the vertical orbit at the main magnets) $\epsilon = \frac{1+a\gamma}{2\pi}\Sigma_{\rm Qpoles}\left\{\begin{array}{l}\cos(a\gamma\alpha_i)+\\ i\,\sin(a\gamma\alpha_i)\end{array}\right\}(KL)_i y_{co,i}$. Thus their assessment requires insight in vertical orbit correction performance. Preliminary bunch transport simulations introduced here indicate that this should not be an issue [3].

Polarized bunch transmission - The simulation results given here for illustration [5] consider a set of 960 particles, Gaussian-distributed with large initial emittance $\epsilon_x/\pi = \epsilon_y/\pi = 25$ μm geometrical at 320 MeV (9 mm normalized), and with initial dp/p taken random uniform in $\pm 10^{-3}$. Various defects, of different amounts, are introduced in the C-RCS lattice. The acceleration voltage applied is (Fig. 2)

$$V(t) = 4.4\sin(2\pi ft) + 8.8\sin^8(2\pi ft/2), \quad f = 60\,\text{Hz} \quad (2)$$

The tracking uses a Monte Carlo synchrotron radiation (SR) process [6]. Sample outcomes are displayed in Fig. 4, they indicate that good polarization transmission is achievable at C-RCS, and allows eRHIC R&D.

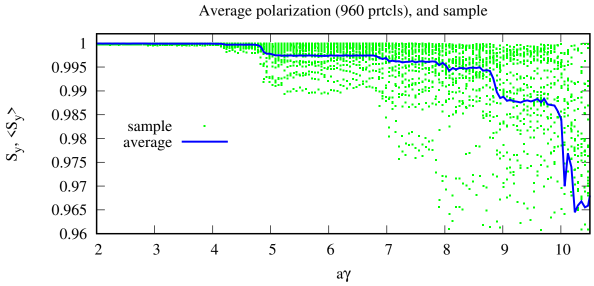

Figure 4: Polarization transmission with defects. 0.6 mm *rms* orbit contribution from vertical kickers, 1 mm orbit from 0.01 degree roll angle in the bends, and an additional 1% gradient error in bends: polarization ends up 98.5% at $a\gamma = 10.2$ (4.5 GeV). A similar simulation with 1.2 mm *rms* orbit yields 96.4% polarization transmission.

PRACTICAL CONSIDERATIONS

The Cornell linac, positron source, and 6 GeV synchrotron (Fig. 1) serve as dedicated injector for the storage ring for the x-ray program at present and for the foreseeable future. The time available for studies of polarization transmission and installation of instrumentation to enable those studies will be limited. Careful planning and coordination will be required to ensure compatibility of the polarization program with routine acceleration for CHESS. That new instrumentation will presumably include a polarized source, and polarimetry for the high energy beam.

The linac is equipped with a high current thermionic gun and eight 2856 MHz accelerating waveguide sections that accelerate electrons to 300 MeV for transfer to the synchrotron. Installation of a polarized source would require some creative design as space at the front end of the linac is very tight. There is however some drift space between section eight and the synchrotron for low energy polarimetry.

CHESS presently requires electron and counter-rotating positron beams to deliver x-rays to all of the beam lines. But at the completion of the upgrade in Fall 2018, the storage ring will operate exclusively with positrons in the clockwise direction. The beam line that presently transfers electrons from the synchrotron to the storage ring will no longer be required for CHESS operation, and may become available for installation (and reconfiguration if necessary) of high energy polarimetry. Alternatively, electrons could be injected and stored in CESR if it turns out more convenient to measure polarization of a stored beam.

Beam instrumentation in the synchrotron is very basic. The beam position monitor system has limited functionality and there are almost no corrector magnets. While optics in the storage ring are routinely characterized and corrected with considerable precision, the synchrotron diagnostics provide very little information. It is difficult, for example, to measure the evolution of the betatron tunes through the injection cycle. Furthermore, as all of the synchrotron magnets are combined function and powered in series there is no adjustment of high energy optical functions or orbit, short of moving magnets. Upgrade of the beam diagnostics in the RCS is probably essential for an effective study of polarization transmission. Any upgrade that enhances performance and reliability of the synchrotron would be beneficial to the CESR program, as well as the study of polarization transmission.

POLARIMETRY

Compton back-scattering is the established non-invasive method to measure lepton beam polarization at high energies over a wide range of beam energies and was used at HERA [7].

A Compton polarimeter can be operated in the RCS ring and provide bunch by bunch polarimetry, depending on the required precision and measurement time. A Compton polarimeter could be operated at flat-top or in multiple-ramp mode depending on the required measurement time. The Compton polarimeter could be operated in multiphoton mode, which would provide a more precise measurement at low beam energies where the analyzing powers are smaller. The luminosity of a Compton polarimeter is given by the laser power and the beam current. The analyzing power which varies from low to high as function of the beam energy influences the precision to be achieved for the same luminosity.

At HERA, a Compton back-scattering polarimeter was used to measure the transverse polarization of the beam through a position asymmetry. The systematic uncertainties were 3.5% during RUN-I and 1.9% during Run-II. Unlike the HERA electron ring, each bunch in the RCS will circulate a very short time before extraction to the eRHIC storage ring. This poses a significant challenge to measure polarization and to monitor bunch-to-bunch fluctuations of both intensity and polarization as well as polarization losses from the polarized source to full energy.

An alternative technique is Møller polarimetry, it would provide advantages from the point of view of cost, technological difficulty, operation. Møller polarimetry has possible limitations. It is invasive and the polarization of the target foil limits the incident beam current on the foil. The luminosity of this polarimeter is given by the beam current and the foil thickness. At JLab a 1% dP/P has been achieved in 15 min for a 4 µm foil and few µA average current, whereas in the RCS the average current is 10 nA (repetition-rate 1 Hz, bunch charge 10 nC). The low RCS average current results in long measurement time.

A possible location of the polarimeter would be in the extraction line of the RCS. Defining the best polarimeter technology and designing a polarimeter for the Cornell RCS would be of great benefit for eRHIC, as it would allow verifying the requirements for measuring polarization with an accuracy better than 10% in around 20 minutes for a beam energy range up to 18 GeV. In the case of a Compton polarimeter, especially regarding the specifications for the laser to achieve the statistical precision, and in the case of a Møller polarimeter, regarding the requirements for the polarized target foil. The polarimeter developed for the C-RCS could be transferred to the eRHIC-RCS, such all the investment is fully amortized.

POLARIZED ELECTRON SOURCE

At present the generation of highly spin polarized electron beams is based on the use of III-V semiconductor technology. The use of GaAs based photocathodes is justified by the high efficiency attainable from these materials when the Negative Electron Affinity (NEA) condition is achieved at the surface of the photoemitting surface and by the large achievable polarization. Very recently, GaAs/GaAsP multilayer strained super-lattices with a distributed Bragg reflector structure successfully showed an enhanced QE of 6.4% with a high polarization of 84% [8]. Another obvious advantage is related to the fact that the sign of spin polarization can be changed simply by inverting the helicity of the circularly polarized light used to excite electron in the photocathode. Due to the extreme vacuum sensitivity of the surfaces activated to NEA the use of a polarized electron source is compatible only to DC photoguns where extreme vacuum condition can be achieved allowing sufficiently long lifetime for the operation of such sources.

The Cornell group has recently initiated a dedicated R&D activity on highly spin polarized electron sources for the EIC, demonstrating that alternative approaches to produce NEA condition on GaAs can improve lifetime without affecting the spin polarization properties of the electrons [9]. However, a simple proof of principle injection of spin polarized electron can be designed to use bulk GaAs (up to 40% polarization can be achieved [10]) operated in a HV DC gun with a dedicated laser system capable of photoemission at about 800 nm.

Due to physical constraint in the Cornell linac tunnel and the limited beam energy (150 keV) required at the linac entrance we speculate that a small footprint electron gun with design based on the use of inverted ceramic insulator [11, 12] could be used to replace or operate in parallel with the existing thermionic electron gun to provide the spin polarized electron bunches. In order to measure the degree of electron spin polarization of the electron beam a Wien filter in conjunction with a Mott scattering polarimeter will be required. Such instrumentation could be designed and realized based on those used at CEBAF [13] and eventually implemented keeping in mind the physical constraints posed by the Cornell linac tunnel.

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