POLARIZED ION BEAMS IN FIGURE-8 RINGS OF JLAB'S MEIC[*]

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Abstract

The Medium-energy Electron-Ion Collider (MEIC) proposed by Jefferson Lab is designed to provide high polarization of both colliding beams. One of the unique features of JLab's MEIC is figure-8 shape of its rings. It allows preservation and control of polarization of all ion species including small-anomalous-magnetic-moment deuterons during their acceleration and storage. The figure-8 design conceptually expands the capability of obtaining polarized high-energy beams in comparison to conventional designs because of its property of having no preferred periodic spin direction. This allows one to control effectively the beam polarization by means of magnetic insertions with small field integrals. We present a complete scheme for preserving the ion polarization during all stages of acceleration and its control in the collider's experimental straights.

INTRODUCTION

The invention of Siberian snakes provided a wide range of opportunities for production of intense polarized beams at high energies [1,2]. In the traditional scheme of two Siberian snakes, the angle between the snake rotation axes is 90°, the spin tune is equal to one half, and the spin is vertical in the arcs (RHIC, BNL) [3,4]. When using two identical snakes with zero angle between their rotation axes, the spin tune becomes equal to zero. A collider project with two solenoidal snakes is proposed at Dubna (NICA, JINR) [5]. The most natural representative of a collider with zero spin tune is a collider shaped as figure "8" (MEIC, JLAB) [6, 7]. From the point of view of the spin dynamics, the MEIC and NICA projects are equivalent. The role of identical snakes in a figure-8 accelerator is played by its arcs: the spin first rotates about the vertical field in the first arc and then its rotation is compensated by the opposite field in the second arc.

A distinct feature of a figure-8 collider is that the resulting effect of the "strong" arc dipoles on the spin dynamics reduces to zero over one particle turn and becomes "transparent" for the spin. Any spin orientation at any orbital location repeats every turn. This topological property of figure 8 allows one to provide dynamic control of the beam polarization by "weak" fields, which have essentially no impact on the beam orbital properties. Here particularly stands out the role of weak solenoids, which do not affect the closed orbit at all and essentially do not change the beam orbital parameters. This property is universal and does not depend on the particle type. Figure-8 colliders provide a real opportunity for obtaining intense polarized beams of high-energy particles with a small anomalous magnetic moment (for example, deuteron beams with energies greater than a few tens of GeV). Let us demonstrate the main features of figure-8 colliders for preservation and manipulation of the polarization in the ion complex of MEIC during experimental running.

ACCELERATION AND SPIN MATCHING IN FIGURE-8 RINGS

Figure-8 accelerators allow one to preserve the beam polarization in the whole energy range of MEIC by means of weak solenoids. Such solenoids have no problem with ramping of their fields during the acceleration cycle. Figure 1 shows schemes for preservation of the polarization in the pre-booster and large booster of MEIC [8, 9]. The solenoid stabilizes the polarization in the longitudinal direction in the straight where it is placed. Beam injection and extraction occur in the same straight of the accelerator

Table 1 lists the solenoid parameters providing preservation of the proton and deuteron polarizations in the full energy ranges of the accelerators.

The required solenoid field integral does not exceed 2 T·m at the top energy of the large booster. In accelerators with Siberian snakes, avoiding crossing of spin resonances requires a solenoidal snake with a field integral of about 70 T·m for protons and of about 250 T·m for deuterons. Note the universality of the polarization preservation scheme with respect to the particle type. Figure-8 rings allow easy preservation of the deuteron polarization up to the top energy of the complex, which is completely unfeasible in rings with non-zero spin tune.

Table 1: Solenoid Parameters Preserving the Polarization in the Pre-Booster and Large Booster

Accelerator	$\frac{p_{\text{inj}}}{p_{\text{ext}}}$, GeV/c	$\frac{(B_\parallel L_\parallel)_{\text{inj}}}{(B_\parallel L_\parallel)_{\text{ext}}}$, T·m	$L_\parallel$, cm	$\frac{\nu_{\text{deut}}}{\nu_{\text{prot}}}$
Pre-booster	$\frac{0.785}{3.83}$	$\frac{0.06}{0.28}$	60	$\frac{0.003}{0.01}$
Large booster	$\frac{3.83}{25}$	$\frac{0.28}{1.9}$	120	$\frac{0.003}{0.01}$

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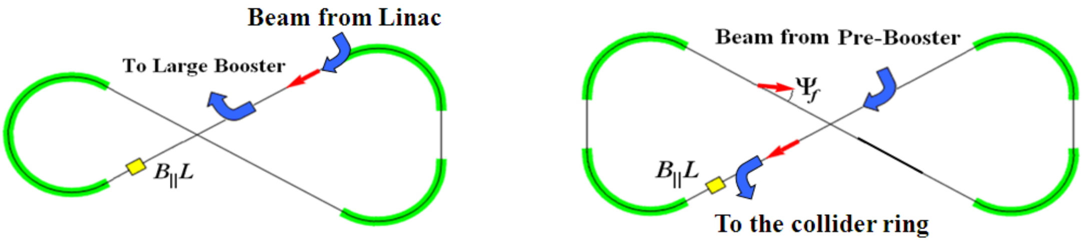

Figure 1: Acceleration and spin matching in the pre-booster and large booster.

BEAM POLARIZATION MANIPULATION IN FIGURE-8 COLLIDERS

One of the advantages of a figure-8 collider becomes especially prominent when there is a need to manipulate the polarization at the interaction point during an experiment. While the usual polarization control techniques relying on strong fields (snakes, rotators) remain applicable to figure-8 accelerators [10], their unique capability to control the polarization with weak solenoids allows manipulation of the particle spin at the interaction point without affecting the orbital motion. This greatly enhances the precision level of polarized beam experiments. By contrast, to manipulate the polarization during an experiment in a collider with two Siberian snakes, one uses a pair of spin rotators with the first one rotating the spin to the necessary orientation at the interaction point and the second one returning the spin to its original orientation [3, 4]. Such spin rotators must use "strong fields", which affect not only the spin direction but also the orbital motion. It may result in adverse effects on the beam orbital properties such as betatron tune shift, changes of the dispersion and beta functions, etc., which must be taken into account during the experiment.

The main elements of the polarization control in the MEIC collider are 3D spin rotators for protons and deuterons. The 3D rotators are designed on the basis of weak solenoids and allow performance of the following tasks: matching of the polarization direction at the beam injection into the collider, measurement of the beam polarization at any orbital location, spin manipulation at the interaction point during experimental running.

Figure 2 shows an example of a 3D rotator for deuteron polarization control located at the entrance into an experimental straight [9]. The rotator uses three existing arc dipoles and two existing radial-field dipoles bringing the deuteron beam down to the electron beam's plane [7]. Polarization control is provided by three "small" solenoids placed near these dipoles. An advantage of such a 3D rotator is its exceptional compactness: essentially no significant space is required for placement of the solenoids among existing dipoles, quadrupoles, sextupoles, etc.

Under the approximation of a small spin tune, the required spin rotation angles of the solenoids φ_{zi} are determined by the following equations ($|\vec{n}| = 1$):

$$\varphi_{z1} = 2\pi\nu\frac{n_x}{\sin\varphi_y}, \qquad \varphi_{z2} = 2\pi\nu\left(n_z - \frac{n_x}{\tan\varphi_y} - \frac{n_y}{\tan\varphi_x}\right),$$

$$\varphi_{z3} = 2\pi\nu\frac{n_y}{\sin\varphi_x}$$

where n_x, n_y, and n_z are the radial, vertical, and longitudinal polarization components, respectively, at the rotator's exit, $\varphi_x=\gamma G\alpha_x$ and $\varphi_y=\gamma G\alpha_y$ are the spin rotation angles of the aforementioned radial- and vertical-field dipoles, respectively, and α_x and α_y are the respective orbit bending angles of these dipoles. The calculation assumes that, with the solenoids off, the spin tune in the collider is zero.

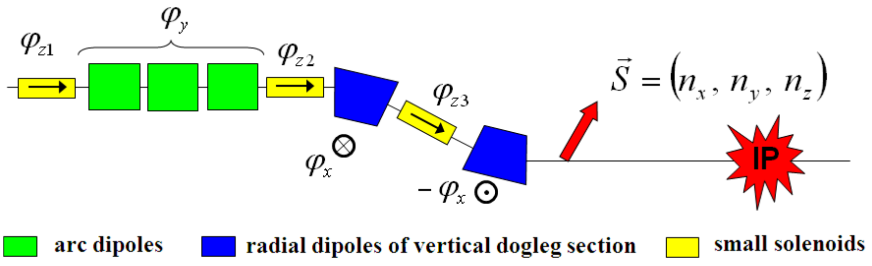

Figure 2: A scheme for obtaining any deuteron polarization direction (3D spin rotator).

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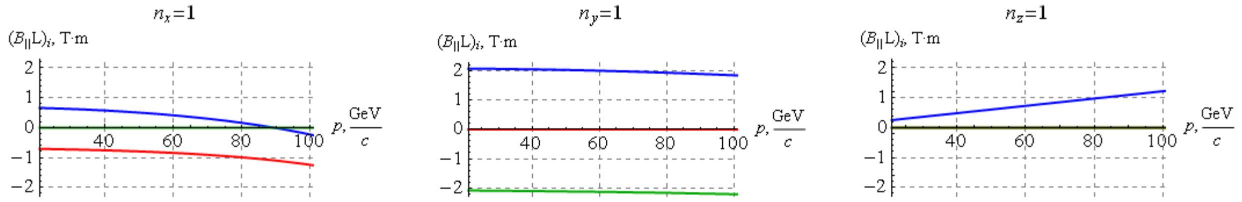

Figure 3: Dependencies of the solenoid field integrals on the deuteron beam momentum in MEIC for the cases of radial ($n_x = 1$), vertical ($n_y = 1$), and longitudinal ($n_z = 1$) polarizations.

Figure 3 shows dependencies of the required solenoid field integrals on the beam momentum for the radial, vertical, and longitudinal deuteron polarizations in MEIC. Here, $(B_{\parallel}L)_i = \varphi_{zi}\, B\rho/(1+G)$ is the solenoid field integral, $B\rho$ is the magnetic rigidity. We assume bending angles of $\alpha_x = 4.4^\circ$ for the radial-field dipole (one standard magnet) and $\alpha_y = 13.2^\circ$ for the arc dipoles (three standard magnets). Two such rotators located symmetrically at the exit and entrance of an experimental straight provide a spin tune of $\nu = 0.001$ (see Fig. 4).

Thus, when manipulating the spin during an experiment, the solenoid field integral does not exceed 2 T·m in the whole momentum range. The magnetic fields of such solenoids can be changed rather quickly on the time scale of 0.1-1 sec that allows using the 3D rotator as a spin-flipping system. A description of the proton 3D spin rotator on the basis of small solenoids can be found in [9].

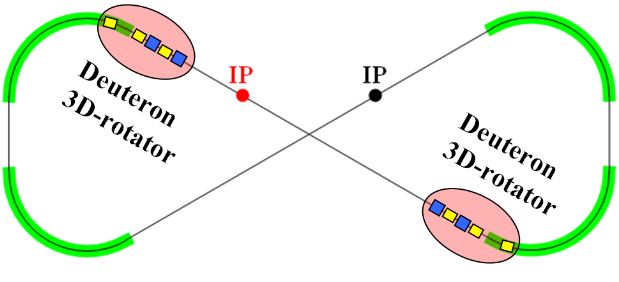

Figure 4: Symmetric placement of two deuteron 3D spin rotators in the MEIC collider.

CONCLUSION

Let us briefly summarize the main features of the figure-"8" design. Such a design allows for:

- use of weak solenoids for polarization control at high energies of any particle type including deuterons;
- compact placement of the control solenoids among the structural collider elements without affecting the closed orbit;
- elimination of the resonant depolarization at all stages of the beam acceleration from the linac to the collider ring;
- adjustment of any polarization orientation at any orbital location (polarization matching at the beam transfers between the components of the accelerator complex, polarimetry, spin-flipping systems);
- manipulation of the particle spin during an experiment without affecting the beam orbital properties, which provides a capability of carrying out polarized beam experiments at a new precision level;
- compensation of the manufacturing and alignment errors of lattice magnetic elements, which additionally substantially enhances the precision of polarized beam experiments;
- an easy adjustment of the spin dynamics to meet any experimental requirements, which may arise in the future.

REFERENCES

[1] Ya.S.Derbenev, A.M.Kondratenko, Dokl. Acad. Nauk SSSR, v.223, p. 830 (1975) [Sov.Phys.Dokl. v20, p.562 (1976)].

[2] Ya.S.Derbenev, A.M.Kondratenko, Proc. of the X Intern. Conf. on High Energy Accelerators, Protvino, USSR v.2. p.70 (1977).

[3] V.Ptitsin and Y.Shatunov, NIM A398, p. 126 (1997).

[4] E.Willen et al., in Proc. PAC'99, New York, NY, p. 3161 (1999).

[5] A.D. Kovalenko et al, "*Polarized Deuterons and Protons at NICA@JINR*", Pepan, 2014, Vol. 45, No. 1, pp. 321–322.

[6] Ya.S. Derbenev, University of Michigan report UM HE 96-05 (1996).

[7] S. Abeyratne et al., "*Science requirements and conceptual design for a polarized medium energy electron-ion collider at Jefferson lab*", edited by Y. Zhang and J. Bisognano, arXiv:1209.0757 [physics.acc-ph] (2012).

[8] Ya.S. Derbenev et al., "*Ion polarization control in MEIC rings using small magnetic field integrals*", in Proc. XVth International Workshop on Polarized Sources, Targets, and Polarimetry (PSTP 2013), Charlottesville, VA.

[9] A.M. Kondratenko at all, *"Ion Polarization Control in Figure-8 Rings Using Small Magnetic Field Integrals"*, The Inter. Workshop EIC14, March 17-21, 2014, JLab, Newport News, VA.

[10] V. Morozov et al., "*Ion Polarization in the MEIC Figure-8 Ion Collider*", in Proc. IPAC'12, New Orleans, LA.