Orbital parameters of proton and deuteron beams in the NICA collider with solenoid Siberian snakes

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Abstract. Two solenoid Siberian snakes are required to obtain ion polarization in the "spin transparency" mode of the NICA collider. The field integrals of the solenoid snakes for protons and deuterons at maximum momentum of 13.5 GeV/c are equal to 2×50 T·m and 2×160 T·m respectively. The snakes introduce strong betatron oscillation coupling. The calculations of orbital parameters of proton and deuteron beams in NICA collider with solenoid snakes are presented.

1. The NICA collider in the spin transparency mode

The scheme of proton and deuteron polarization control at the NICA collider in the spin transparency mode has been presented in 2012 [1]. The scheme of polarization control is based on the use of two types of solenoids, namely, strong-field solenoids and weak-field solenoids (see figure 1). The strong-field solenoids are used for Siberian snakes, which create the spin transparency mode in the NICA collider. Two solenoidal snakes are inserted in the opposite straight sections of the racetrack-shaped collider. The snakes are divided symmetrically onto two parts by MPD and SPD setups. Such snake design allows one to control the beam polarization in vertical plane of SPD and MPD detectors while the polarization leis in the plane of the collider in the NICA arcs.

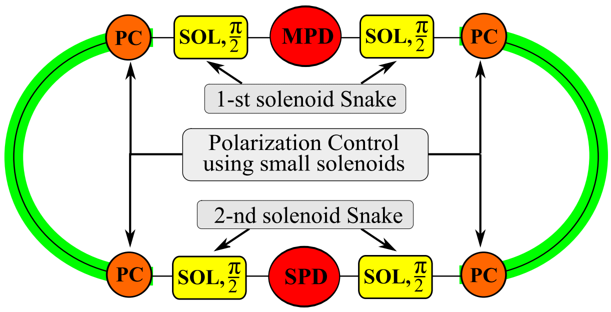

Figure 1. Polarization control scheme in the NICA spin transparency mode.

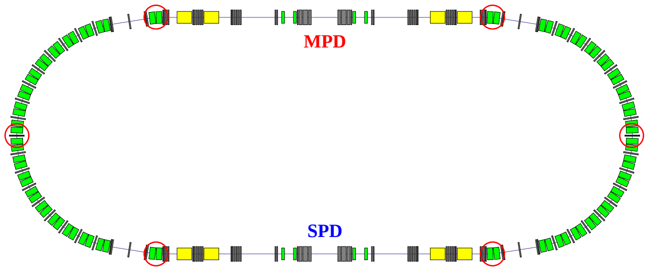

Figure 2. Placement of the snake solenoids in the NICA collider.

The spin transparency mode means that the influence of the fields generated by the two solenoidal snakes and the collider's arcs does not change the spin direction from turn to turn, i.e. the magnetic system is transparent for the spin. The NICA collider with two solenoidal snakes becomes similar to the figure-8 collider project at JLAB [2]

The weak-field solenoids with small integral of the longitudinal field are used directly for the control of the beam polarization by means of polarization control insertions (PC insertions). Thus, there is unique opportunity for efficient spin manipulation of any particle species (p, d, ^3He,...) in any orbit place without affecting of the collider orbital characteristics [3]. For example, it is possible to arrange both vertical and longitudinal directions of the beam polarization in MPD and SPD detectors. One can provide any direction in the collider arcs, which is necessary for the matching of the polarizations during the beam injection from Nuclotron. One can provide the spin reversals in the detectors during an experiment (spin flipping systems) [4]. It allows to carry out high quality experiments with polarized proton and deuteron beams.

2. Orbit matching of the snake solenoids to the NICA collider lattice

The control solenoids with weak fields do not influence on the collider orbital characteristics. On the contrary, the snake solenoids introduce a strong coupling of the betatron oscillations. The snake solenoid fields are proportional to the momentum and the collider optics remains unchanged during the beam acceleration. At maximum collider momentum of 13.5 GeV/c, the solenoid integral field of the one snake is 50 T·m for protons and is 160 T·m for deuterons. So, one has to provide the matching of the snake solenoids to the collider lattice for proton and deuteron beams.

2.1. Placement of the snake solenoids in the NICA collider

The schematic of placement of the solenoids in the NICA collider lattice is presented in figure 2. Here snake solenoids are marked yellow bars and PC insertions marked in circles. The one snake consist of four solenoids of 5 m length each. At maximum momentum the solenoid field is 2.5 T for protons and is 8 T for deuterons.

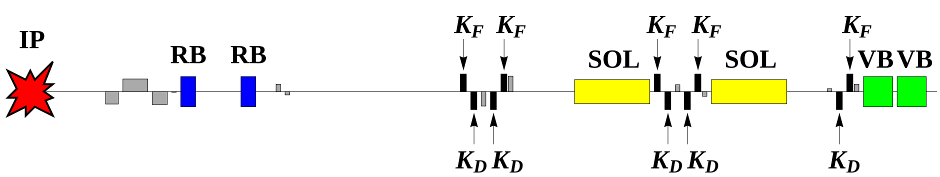

Figure 3. Placement of the snake solenoids in the NICA half straight.

The placement of the snake solenoids in the collider half straight is shown in figure 3 in more details. Here SOL are solenoids, VB are arc's vertical-field bending magnets and RB are radial-field bending magnets, which provide beams collisions at interaction point IP.

Two families of focusing K_F and defocusing K_D quadrupoles are used for matching the snake solenoids to the collider optics. Additional quadrupoles for compensation of the coupling of the betatron oscillations are not used in our matching scheme [5].

2.2. Optical functions in the NICA collider

We present an example, when matching the snake solenoids to the NICA collider lattice occurs at the same values of the quadrupole gradients K_F and K_D for three cases, namely, for NICA without snakes, NICA with proton snakes and NICA with deuteron snakes. The β-functions and dispersion functions for these cases are shown in figures 4-6. Also these figures show unit circles with eigenvalues $\lambda_{x,y} = \exp(i\nu_{x,y})$ of the transfer matrix, where $\nu_{x,y}$ are radial and vertical betatron tunes.

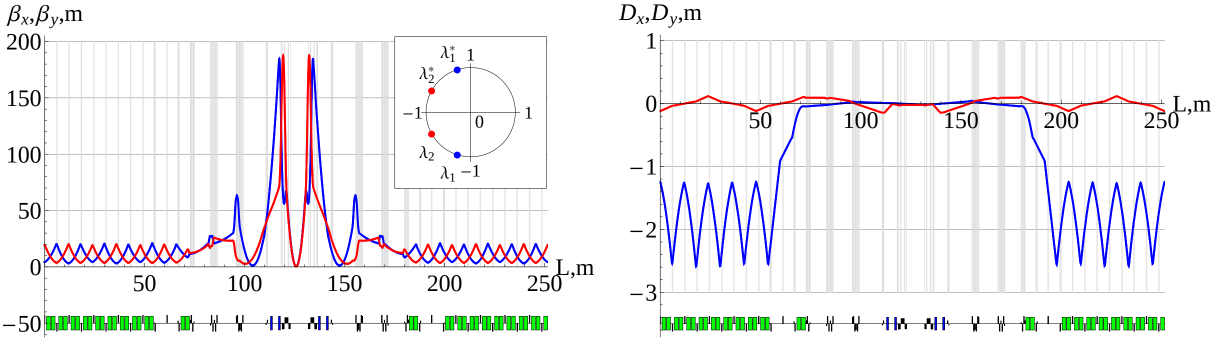

Figure 4. β-functions and dispersion functions in NICA without snakes.

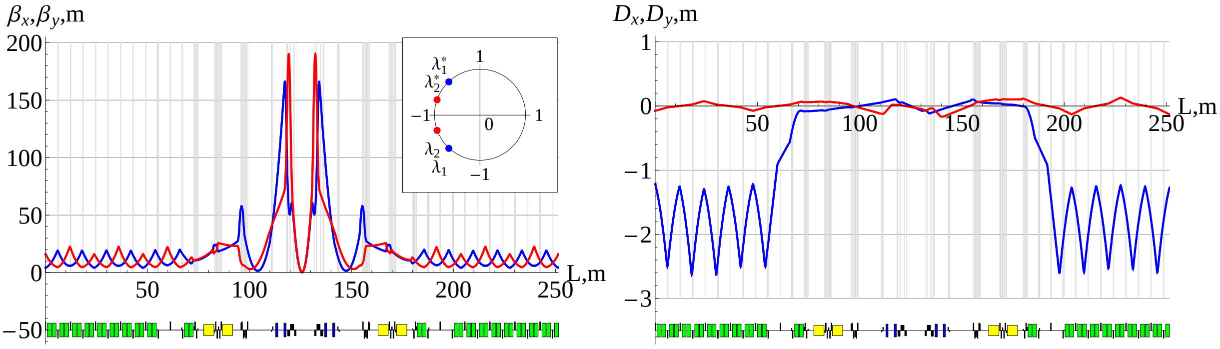

Figure 5. β-functions and dispersion functions in NICA with proton snakes.

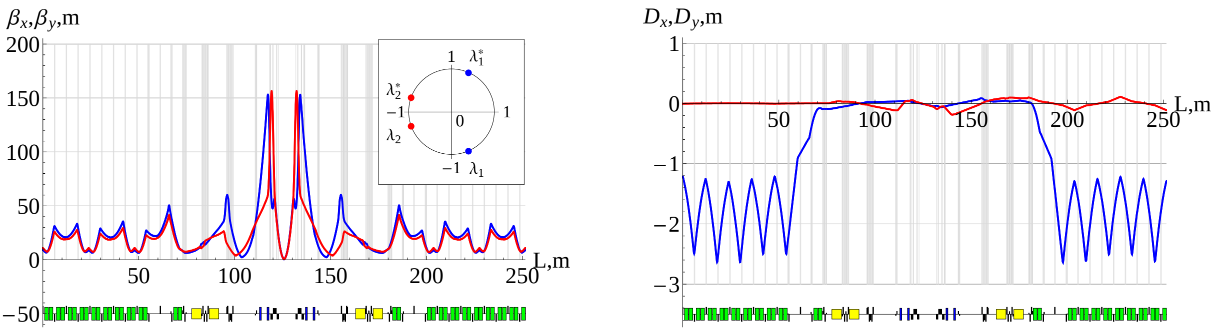

Figure 6. β-functions and dispersion functions in NICA with deuteron snakes.

The value of gradients in unit of the magnetic rigidity is 0.597 m^{-2} for focusing quads K_F and is 0.586 m^{-2} for defocusing quads K_D.

2.3. Optical parameters at the interaction point

The values of β-functions and dispersion functions at the interaction points of MPD and SPD detectors are presented in table 1.

Table 1. Optical parameters at the interaction points.

Mode	β_x^*, cm	β_y^*, cm	D_x^*, cm	D_y^*, cm
without snakes	36	34	-1	-2
proton snakes	33	36	-1	-2
deuteron snakes	54	52	-1	-1

Proton snakes practically do not change beam's orbital parameters at the interaction points. Deuteron snakes also practically do not change the dispersion functions in the given examples, but increase values of β-functions about of 20 cm. Such β-functions increasing can be compensated by optimization of lattice of the collider straights.

Conclusion

In summary, one can draw the following conclusions:

- the possibility of matching the snake solenoids to the NICA collider lattice without compensation of betatron oscillations coupling is demonstrated for proton and deuteron beams,
- proton snakes practically do not change orbital parameters of the NICA collider,
- influence of deuteron snakes on collider orbital parameters can be compensated at interaction points by optimization of lattice of the collider straights,
- the spin transparency mode in the NICA collider is feasible and can provide high quality experiments with polarized proton and deuteron beams.

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