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ION POLARIZATION CONTROL IN THE MPD AND SPD DETECTORS OF THE NICA COLLIDER

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Abstract

Two solenoid Siberian snakes are placed in the opposite collider's straight sections are used to control deuteron's and proton's polarization in the NICA collider. Solenoid snakes substantially reconstruct beam's orbital motion. The change of the polarization direction in the vertical plane of MPD and SPD detectors occurs due to insertion of polarization control (PC) solenoids in the magnetic lattice of the collider. The solenoids rotating particle's spin by small angels practically do not influence on the beam's orbital motion parameters. The dynamic of the polarization vector as function of the orbit length for cases of longitudinal and vertical polarization in the MPD and SPD detectors are presented.

SPIN TRANSPARANCY MODE IN NICA

NICA project at JINR is aimed at the experiments with polarized protons and deuterons at both SPD and MPD detectors over beam momentum range from 2 to 13.5 GeV/c [1, 2]. To control efficiently polarization of protons and deuterons as well it was proposed to use the collider in, so called, "spin transparency" mode, which is realized if two identical solenoid Siberian Snakes are placed in the opposite straight sections of the collider (Fig. 1) [3].

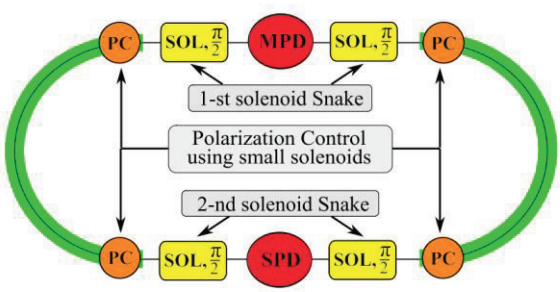

Figure 1: The polarization control scheme of protons and deuterons in the NICA collider.

The Snakes are divided symmetrically onto two parts by MPD and SPD setups. The transparency mode means that the influence of the fields generated by the two Snakes and the collider's arcs doesn't change the spin direction from turn to turn, i.e. the magnetic system is transparent for the spin. The NICA collider with two Snakes becomes similar to the figure-8 collider project at JLAB [4]. The field integrals of half solenoid Snake for protons and deuterons at maximum momentum are equal to 12.5 T·m and 40 T·m respectively.

BEAM POLARIZATION MANIPULATION IN SPD AND MPD DETECTORS

The unique feature of a spin transparency accelerator is the possibility to obtain any particle polarization using small magnetic field integrals [3]. The proton and deuteron polarization in the NICA collider ring can be efficiently controlled by weak solenoids. Any angle between the polarization and the beam direction lying in the vertical plane of SPD (MPD) detector can be obtained by introducing polarization control (PC) insertions. Each PC insertion is based on two weak solenoids separated by arc's dipoles. A symmetric scheme of polarization control with two PC insertions located at the both sides of the SPD (MPD) detector is presented in Fig. 2.

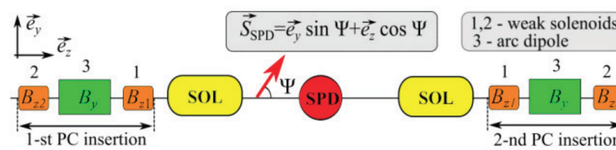

Figure 2: Polarization control by means of weak (PC) solenoids in SPD (MPD) detector.

The spin tune ν induced by PC insertions should exceed substantially the strength of $\nu = 0$ spin resonance. The strength is determined by the beam's emittances and by misalignments and manufacturing imperfections of the collider's magnetic system elements. Spin tune values are estimated to $\nu_p = 0.01$ and $\nu_d = 0.003$ for proton and deuteron case respectively.

A scheme of the snake's solenoids and weak PC solenoids positions is presented in Fig. 3. The eight snake's solenoids of 5.5 m long each are marked with yellow. The ten PC solenoids of 0.4 m long each are marked with orange. The snake solenoid fields are equal to 2.3 T for protons and 7.3 T for deuteron at the maximum momentum.

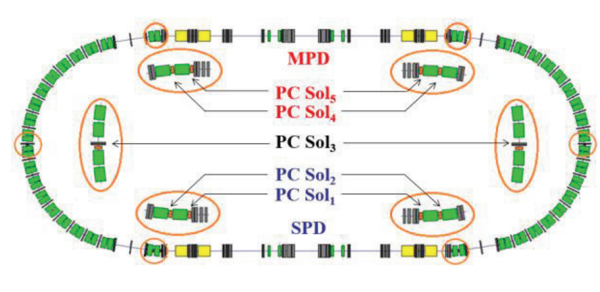

Figure 3: Placement of PC solenoids in NICA collider.

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Four pairs of PC solenoids with the field values B_{z1} and B_{z2} are placed in the straight sections and behind the last structural dipole (α = 4.5°) respectively for proton or in the middle of the arcs (α = 90°) for deuteron case.

Necessary combination of the PC solenoids switching on in the cases of the spin control in SPD or MPD detectors is shown in Table 1.

Table 1: PC Solenoids in NICA Collider

Detector	Protons	Deuterons
SPD	PC Sol$_1$, PC Sol$_2$	PC Sol$_1$, PC Sol$_3$
MPD	PC Sol$_4$, PC Sol$_5$	PC Sol$_5$, PC Sol$_3$

The field integrals required in each insertion to obtain the longitudinal $\Psi = 0^0$ and vertical $\Psi = 90^0$ proton and deuteron polarizations are shown in Fig. 4 as functions of the beam momentum. The spin tunes of protons and deuterons in the collider for the given field integrals have values of $\nu_p = 0.01$ and of $\nu_d = 0.003$, which exceed much the zero spin resonance strength caused by imperfections of the collider magnetic structure. The maximum field integral of each PC solenoid at the maximum momentum does not exceed 0.6 T·m, thus practically no disturbance of the particles orbital characteristics in the collider will be occurred.

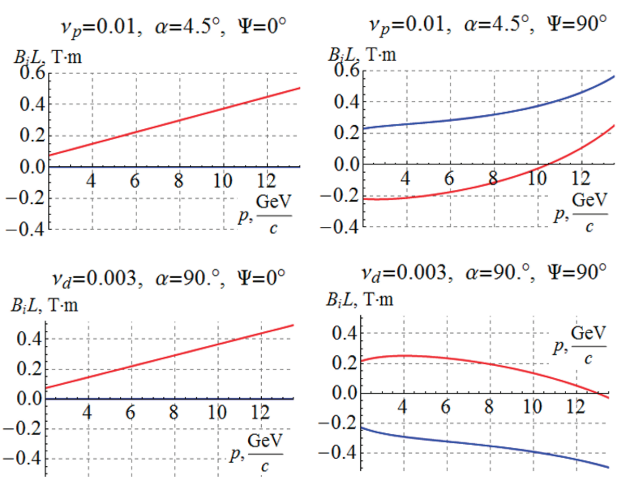

Figure 4: The dependences of the PC solenoid's field on the particle momentum for the longitudinal (left) and vertical (right) polarizations of the proton and deuteron beams.

SPIN-FLIPPING MODE

The presented scheme of polarization control allows obtaining not only vertical and longitudinal polarization in each detectors but also any polarization lying in vertical plane of the detector. The dependences of the field integrals on the angle Ψ at minimum and maximum beam momentum are shown in Fig. 5.

The longitudinal (vertical) polarization can be flipped by reversing the fields of the PC solenoids. To preserve the polarization when changing its direction, the spin tune must remain constant during the solenoid fields' change. This eliminates the possibility of crossing of spin resonances. To preserve the polarization, one must then only satisfy the condition of adiabatic regime, which means that the characteristic spin reversal time in the indicated examples should not be shorter than 0.3 ms for protons and 1 ms for deuterons.

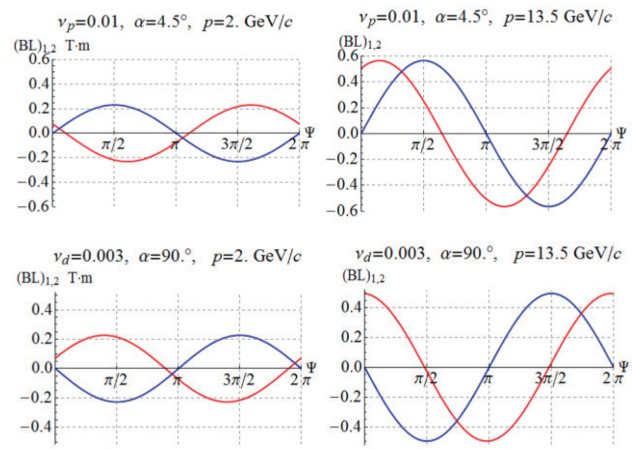

Figure 5: Dependences of the PC solenoid field integrals on the angle between the polarization and the beam direction Ψ for proton and deuteron mode of the collider.

INFLUENCE OF MPD SOLENOID

The MPD setup contains a solenoid ~ 7.5 m long and 0.66 T field [5]. The solenoid does not effect to the longitudinal polarization. The angle of transverse polarization rotation after particle moves throughout the region with longitudinal field B_s and a length L can be calculated as:

$$\Psi_d[\text{deg}] \approx 15\frac{B_s[\text{T}]\,L[\text{m}]}{p[\text{GeV}/c]},\quad \Psi_p[\text{deg}] \approx 48\frac{B_s[\text{T}]\,L[\text{m}]}{p[\text{GeV}/c]}. \qquad (1)$$

The particle collisions will occur not exactly at the middle of the setup but due to the momentum spread within the bunch length. For vertical polarization in the center of the detector, the rotation angles of polarization at bunch edge are equal to 1.1 and 3.6 degrees for deuterons and protons respectively at the momentum of 2 GeV/c and to 0.17 and 0.53 degrees at the momentum of 13.5 GeV/c. We assume the MPD solenoid field of 0.6 T and bunch length of 0.5 m.

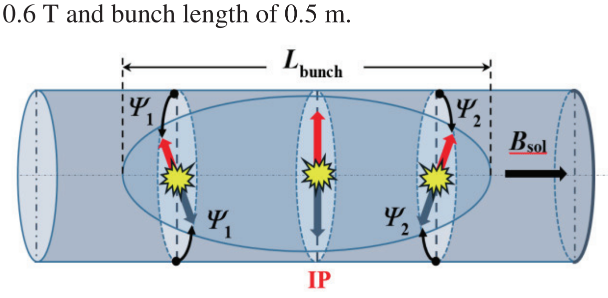

Figure 6: Polarized particles collision within a bunch length in the MPD setup.

The relative spin orientation of the colliding identical particles (pp, dd, etc.) will not be changed within the

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bunch length (see Fig. 6). The angle Ψ_i between spin and vertical directions is determined by collision point and can be calculated using the Eq. 1.

CALCULATION OF BEAM POLARIZATION IN NICA COLLIDER

As an example, the equilibrium polarization components of 2 GeV/c proton beam as functions of the orbital length z around the collider ring for the cases of vertical polarization (n_y=1) at the center of MPD detector are shown in Fig. 7, for an ideal collider structure. The blue, red, and green curves show the radial, longitudinal, and vertical polarization components, respectively.

This example demonstrates influence MPD's solenoid field on beam's polarization. One can see that vertical polarization occurs exactly at the center of MPD detector and significantly changes at the entrance and exit of MPD's solenoid.

The equilibrium polarization components of 13.5 GeV/c deuteron beam as functions of the orbital length z around the collider ring for the cases of longitudinal polarization (n_z=1) at the SPD detector are shown in Fig. 8, for an ideal collider structure.

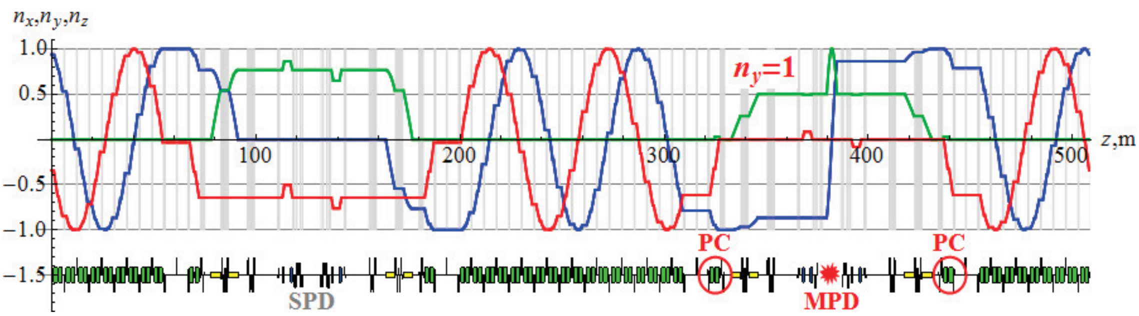

Figure 7: Proton beam vertical polarization in the MPD detector of the NICA collider at 2 GeV/c.

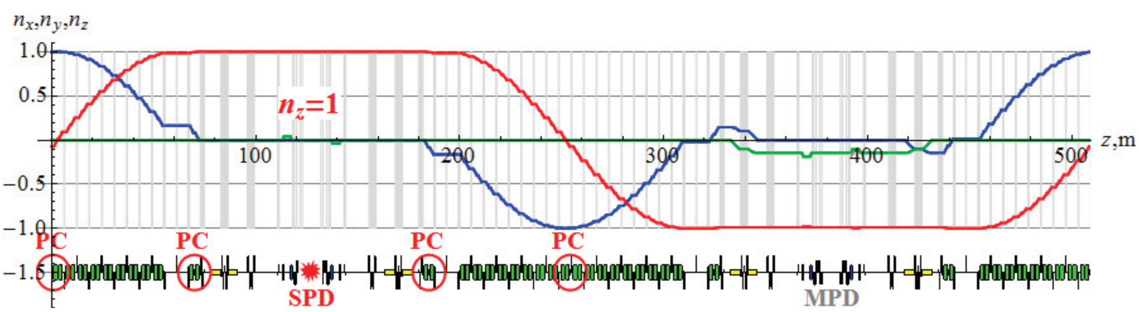

Figure 8: Deuteron beam longitudinal polarization in the SPD detector of the NICA collider at 13.5 GeV/c.

CONCLUSION

Polarization control system in the NICA complex makes it possible:

- to provide polarization control of different particles (p,d,^{3}He,…);
- to provide any direction of polarization in the vertical plane of SPD and MPD detectors;
- to solve the problems of spin matching at injection in the collider and polarization measurement as well;
- to eliminate resonance depolarization during acceleration;
- to realize Spin Flipping System;
- to control polarization in SPD and MPD detectors without any change of beam orbital characteristics.

NICA collider in transparent spin mode can provide high quality polarized proton and deuteron beams.

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