Kinematics of proton and deuteron beam polarization in the transparent spin mode of the NICA collider

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Outline

1. Manipulation of the beam polarization in the Transparent Spin Mode of NICA

2. Kinematics of proton and deuteron polarization in the Transparent Spin Mode of NICA

3. The direction of polarization at the injection place and at the location of the polarimeter.

4. Summary
Distinct Spin mode (DS mode)

Periodic spin motion along the closed orbit is unique

Transparent Spin mode (TS mode)

Any spin direction repeats every particle turn
<table>
<thead>
<tr>
<th>Collider’s configuration</th>
<th>Spin mode</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Without snakes</strong></td>
<td>((\gamma G \neq k )) Distinct Spin (unique spin direction) ((\gamma G = k )) Transparent Spin (any spin direction)</td>
</tr>
<tr>
<td><strong>With one snakes</strong></td>
<td>Distinct Spin mode (unique spin direction)</td>
</tr>
<tr>
<td><strong>With two snakes</strong></td>
<td>Transparent Spin mode (any spin direction)</td>
</tr>
</tbody>
</table>
Transparent Spin Mode in NICA Collider at integer spin resonances (discrete values of energy).

Spin Navigators based on “weak” solenoids with maximum field integral $BL < 0.6 \, \text{T} \cdot \text{m}$ (protons, deuterons)

Polarized beam is injected from Nuclotron to the NICA collider at energy which correspond to integer spin resonance

$\nu = \gamma G = k$

Polarization direction in SPD or MPD — any direction in vertical plane ($z$-$y$)

Protons: $E_{kin}^{min} = 108 \, \text{MeV}, \ \Delta E = 523 \, \text{MeV}$ (25 energy points)
Deuterons: $E_{kin} = 5.63 \, \text{GeV/u}, \ p c = 13 \, \text{GeV}$ (1 energy point)
Transparent Spin Mode in NICA Collider at zero-spin tune (continuous values of energy).

Solenoids for spin transparency mode:

\[ BL = 1 \div 25 \text{ T} \cdot \text{m (protons)}, \quad BL = 3 \div 80 \text{ T} \cdot \text{m (deuterons)} \]

Orbital parameters do not depend on the beam energy.

Spin Navigators based on “weak” solenoids with maximum field integral \( BL < 0.6 \text{ T} \cdot \text{m (protons, deuterons)} \)

Polarization direction \((p, d, {}^3\text{He}, \ldots)\):

- in SPD or MPD — any direction in vertical plane \((z-y)\);
- in arcs — any direction in orbit plane \((z-x)\).
Schematic layout of the half experimental straight section

**Control weak solenoid** \((B_{z2})\) combined with snake solenoids

**SOL** – **6T Solenoid of 0.7 m** (One Siberian Snake = 12×SOL)

**VB** – arc’s Vertical-field Bending magnets,

**RB** – Radial-field Bending magnets,

**FFQ** – Final Focus Quadrupoles

\[
p \text{ up to momentum of } 13.5 \text{ GeV/c} \\
d \text{ up to momentum of } 4.12 \text{ GeV/c}
\]
The direction of the stable polarization $\vec{n}$ coincides with the navigator solenoid axis $\vec{e}_z$ at the solenoid’s location. Outside of the navigator, the direction of $\vec{n}(z)$ is determined by magnetic fields of the lattice.
Ion polarization control in NICA by means of spin navigators

$\varphi_{z1}$ stabilizes the longitudinal polarization before the dipole ($\varphi_y = \gamma G \alpha_{orb}$)

$\varphi_{z2}$ stabilizes the longitudinal polarization after the dipole

Vector diagram for calculation of navigator’s solenoid field integrals (SPD)

$\varphi_{z1} = 2\pi \nu \left( n_z - \frac{n_x}{\tan \varphi_y} \right)$

$\varphi_{z2} = 2\pi \nu \frac{n_x}{\sin \varphi_y}$

$B_{zi}L_z = \frac{\varphi_{zi}}{1 + G \beta} B\rho$

$\varphi_y = \gamma_{max} G \alpha_{orb} < \pi$

Control in horizontal plane ($xz$) of SPD

Control in vertical plane ($yz$) of SPD

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Ion polarization control in NICA collider by means of “weak” solenoids

\[ \mathbf{S}_{MPD} = \mathbf{e}_y \sin \Psi + \mathbf{e}_z \cos \Psi \]

1, 2 – weak solenoids
3, 4 – radial dipoles

\( \Psi \) is the angle between the polarization and velocity directions

\[ L_0 = 263 \text{ cm} \]
\[ L_1 = 208 \text{ cm} \]
\[ \Delta y_{dip} = 5.5 \text{ cm} \]
\[ \Delta y_{sol} = 22 \text{ cm} \]
Polarization at the injection place and the location of the polarimeter

Three TS-mode schemes for comparison of spin kinematics
Radial Proton Polarization at SPD ($\gamma G = 6$)

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Vertical Proton Polarization at SPD ($\gamma G = 6$)

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Longitudinal Proton Polarization at SPD ($\gamma G = 6$)

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Deuteron Polarization at SPD ($\gamma G = -1$)

Radial polarization at SPD ($S_x = 1$)

Vertical polarization at SPD ($S_y = 1$)

Longitudinal polarization at SPD ($S_z = 1$)

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Deuteron Polarization at SPD ($\gamma G = -0.5, B_L^{\text{snake}} \approx 56 \, T \cdot m$)

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### Deuteron Polarization Direction in the NICA TS-mode

<table>
<thead>
<tr>
<th>TS-mode scheme</th>
<th>SPD</th>
<th>Injection</th>
<th>Polarimeter</th>
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<td>MPD</td>
<td>$\vec{e}_x$</td>
<td>$\approx \vec{e}_x$</td>
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<tr>
<td>SPD</td>
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<tr>
<td></td>
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</tr>
<tr>
<td>MPD</td>
<td>$\pi/2$</td>
<td>$\vec{e}_x$</td>
<td>$-\vec{e}_y$</td>
</tr>
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$(yz)$ is the vertical plane

$(xz)$ is the collider plane
### Proton Polarization Direction in the NICA TS-mode

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**π/2 MPD π/2**

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**π MPD π**

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Summary

The kinematics of beam polarization is calculated when vertical, longitudinal or radial polarization is set in the SPD detector for different schemes of placement of snake solenoids.

The results are relevant to solve the tasks of injection and polarimetry for conducting experiments with polarized beams in the spin transparency mode.
Thank you for your attention!