### **Joint Institute for Nuclear Research**

**International Workshop "SPD at NICA-2019"** 



## Protons and Deuterons Polarization Control in the Transparent Spin Mode of the NICA collider

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 7 June, 2019, Dubna

## Outline

1. Polarization control scheme requirements for spin physics program at the NICA collider

- 2. Polarization control at SPD/MPD in the NICA collider with two solenoidal snakes
- 3. Spin flipping and on-line monitoring systems4. Summary

### **Main Requirements for the Polarization Control Scheme at NICA**

Experiments with polarized beams of **protons, deuterons, and helium-3** are planned at the NICA collider to investigate various issues (Drell-Yan, J/ $\Psi$ , high  $p_T$  hadron physics, exotic states, etc) with luminosity  $10^{30}$ - $10^{32}$  cm<sup>-2</sup>·s<sup>-1</sup> in the momentum range from 2 to 13.5 GeV/c.

The polarization control scheme must satisfy the following requirements:

- > to manipulate with longitudinal and transverse polarization at SPD/MPD
- > to maintain polarization up to 90% during the lifetime of the beam
- allow to operate in the energy scan mode for polarized beams:
   step ~ 1 GeV (DY, J/Psi ets.)
  - > step ~ 1 MeV (high  $p_T$  hadron physics, exotic states ets.)
- > allow to have the polarized beams during the asymmetric mode operation
- > to have Spin Flipping System with reverse time less 1 sec.

**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

### **TS and DS modes at the NICA collider with two snakes**

<b>Collider's configuration</b>	Spin mode	
WithoutSnake offsnakes $\nu = \gamma G$ Snake off	$(\gamma G \neq k)$ Distinct Spin (unique spin direction) $(\gamma G = k)$ Transparent Spin (any spin direction)	
With one snakesSnake on $\nu = 1/2$ Snake off	<b>Distinct Spin mode</b> ( <b>unique spin direction</b> )	
With two snakesSnake on $\nu = 0$ 	Transparent Spin mode (any spin direction)	

## Possible directions of the polarization at the SPD/MPD

Collider's configuration	Spin tune	Spin mode	Polarization at the SPD/MPD	
Without snake	$\gamma G \neq k$	DS	<b>Vertical direction</b> at SPD and MPD	
Without snake	$\gamma G = k$	TS	<b>Any direction</b> at SPD or MPD	
With one snake (SPD)	1/2	DS	<b>Longitudinal direction</b> at MPD	
With one snake (MPD)	1/2	DS	<b>Longitudinal direction</b> at SPD	
With two snakes	0	TS	Any direction at SPD or MPD	

**DS** is "Distinct Spin" mode,

**TS** is "Transparent Spin" mode

# **Transparent Spin Mode in NICA Collider at integer spin resonances (discrete values of energy).**



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

**Protons:**  $E_{kin}^{min} = 108 \text{ MeV}, \quad \Delta E = 523 \text{ MeV} \quad (25 \text{ energy points})$ **Deuterons:**  $E_{kin} = 5.63 \text{ GeV/u}, \quad pc = 13 \text{ GeV} \quad (1 \text{ energy point})$ 





Yu.N. Filatov et al. *Protons and Deuterons Polarization Control in the Transparent Spin Mode of the NICA collider*. International Workshop "SPD at NICA-2019", June 7, 2019, JINR, Dubna

8

### **Transparent Spin Mode in NICA Collider at zero-spin tune (continuous values of energy).**





Solenoids for spin transparency mode:  $BL = 1 \div 25$  T·m (*protons*),  $BL = 3 \div 80$  T·m (*deuterons*) **Orbital parameters do not depend on the beam energy** 



Polarization control insertion based on "weak" solenoids with maximum field integral BL < 0.6 T·m (*protons, deuterons*)

### **Polarization direction** (*p*, *d*, <sup>3</sup>*He*, ...) :

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



**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 up to momentum of 13.5 GeV/c d up to momentum of 4.12 GeV/c

### **Polarization at the Transparent Spin Modes**



Transparent Spin mode at zero-spin tune gives advantage even at energies which corresponds to the integer spin resonances  $\gamma G = k$ .

In the case of v = 0 two solenoidal snakes eliminate impact of synchrotron oscillations on polarization which allow to significantly improve quality of polarized beam and increase lifetime of the polarization by factor of ~  $\gamma G$ .

### **On-line spin direction control and Spin Flipping System**

$$\vec{n} = \vec{n}(B_{z1}, B_{z2}), \quad v = v(B_{z1}, B_{z2})$$



During spin manipulation one can keep the value of spin tune constant. It eliminates crossings of high order spin resonances and provides the stability of the SF system.

#### New concept of the on-line monitoring of the polarization at the NICA collider

- 1. It is necessary to provide the stability of polarization *during the operation* of the collider.
- 2. To measure the degree of polarization, it is sufficient to know only the direction of the n-axis, which "measurement" reduces to measuring the control solenoid fields.

There is a unique possibility of the on-line monitoring of the polarization in the spin-transparency mode of the NICA collider.

### Spin Flipping System at the NICA collider

New regimes of filling the rings: all bunches with the same polarization in both rings. New modes of operation (spin-flippers are turned on by turns):

 1-st ring
 +++...
 |XXX| - - -...| |XXX| + ++ |----| + ++... 

 2-nd ring
 +++...
 |----| |----| |----| |----| |----| 

 (++) (-+) (--) (+-) (++) 

|xxx| — spin-flipper is turned on. There is no data collection.|----| — spin-flipper is not turned on. There is no data collection.

- The measurement of the luminosity between the bunches is resolved
- Operation with the same polarized ion mode in all bunches during the filling ring

# Possibilities at the operation with polarized protons and deuterons in NICA

Collider's configuration	Spin mode	SF system	On-line monitoring	Scanning of energy	Impact synchrotron oscillations on spin
without snakes	DS	No	No	No	Impact
without snakes	TS	Yes	Yes	No	Impact
with one snake	DS	No	No	Yes	Doesn't impact
with two snakes	TS	Yes	Yes	Yes	Doesn't impact

**DS** is "Preferred Spin" mode, **TS** is "Spin Transparency" mode

### EXPERIMENTAL VERIFICATION OF TRANSPARENT SPIN MODE IN RHIC\*, IPAC2019, Melbourne, paper MOPRB094

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#### TS MODE IN RHIC AND ERHIC

Polarization in each ring of RHIC is controlled using two helical snakes rotating the spin about the axes at  $+45^{\circ}$  and  $-45^{\circ}$  with respect to the beam direction.

RHIC operates in the DS mode, the spin tune equals 1/2 and the stable polarization orientation is unique and is vertical in the collider's arcs. Any other polarization direction lying in the collider's plane rotates by  $180_{\circ}$  every orbit turn and, due to the spin tune spread, vanishes in a few thousand turns.

The existing snakes can also be used for operation of RHIC in the TS mode.

### CONCLUSION

- A new mode of RHIC operation with a polarized proton beam, a transparent spin mode, has been proposed.
- It offers new opportunities for manipulation of the proton polarization at any location in the collider. BNL's RHIC has all of the necessary components for an experimental test of the new mode.
- The experiment will validate the TS concept as a new tool for polarization preservation and control in the existing and future synchrotrons.



# **Summary**

To perform the spin physics program at JINR, it is **necessary to use the transparent spin mode** in the NICA collider with two snakes, which allows one to apply a **completely new approach** to carry out experiments with polarized ions at the **high precision level** 

