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Spin Transparency Mode in the NICA collider

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Outline

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

2. Spin transparency mode in the NICA collider

3. Comparison of the NICA collider with the JLEIC and RHIC colliders

4. 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/Ψ, high p_T hadron physics, exotic states, etc) with luminosity 10^{30}-10^{32} $cm^{-2} \cdot s^{-1}$ in the momentum range from 2 to 13.5 GeV/c.

The polarization control scheme must satisfy the following requirements:

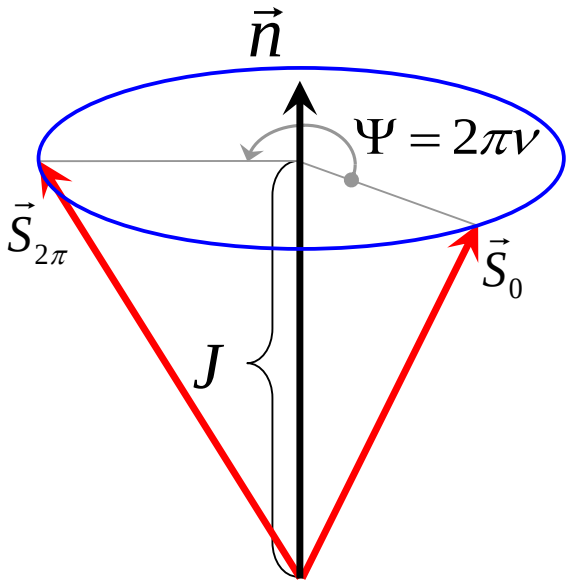
- to manipulate with longitudinal and transverse polarization at SPD/MPD
- to maintain polarization up to 90% during the lifetime of the beam
- allow to have the polarized beams in full energy range
- allow to have the polarized beams during the asymmetric mode operation
- to have Spin Flipping System with reverse time less 1 sec.

Spin Motion at Conventional Circular Accelerator

$$\frac{d\vec{S}}{d\theta} = [\vec{W} \times \vec{S}],$$

Thomas-BMT equation

$\theta -$ particle's azimuth



The spin equilibrium closed orbit

$\vec{n}(\theta + 2\pi) = \vec{n}(\theta)$ – periodical axis of precession

$$\vec{S} = J \cdot \vec{n} + \vec{S}_\perp, \qquad J = \vec{S} \cdot \vec{n}, \qquad \vec{S}_\perp \perp \vec{n}$$

Spin vector rotate around *n*-axis:

If $\vec{S}_0 \parallel \vec{n} \Rightarrow \vec{S}_{2\pi} = \vec{S}_0$

If $\vec{S}_0 \perp \vec{n} \Rightarrow \vec{S}_{2\pi} \perp \vec{n}, \quad \angle\left(\vec{S}_0, \vec{S}_{2\pi}\right) = \Psi = 2\pi\nu$

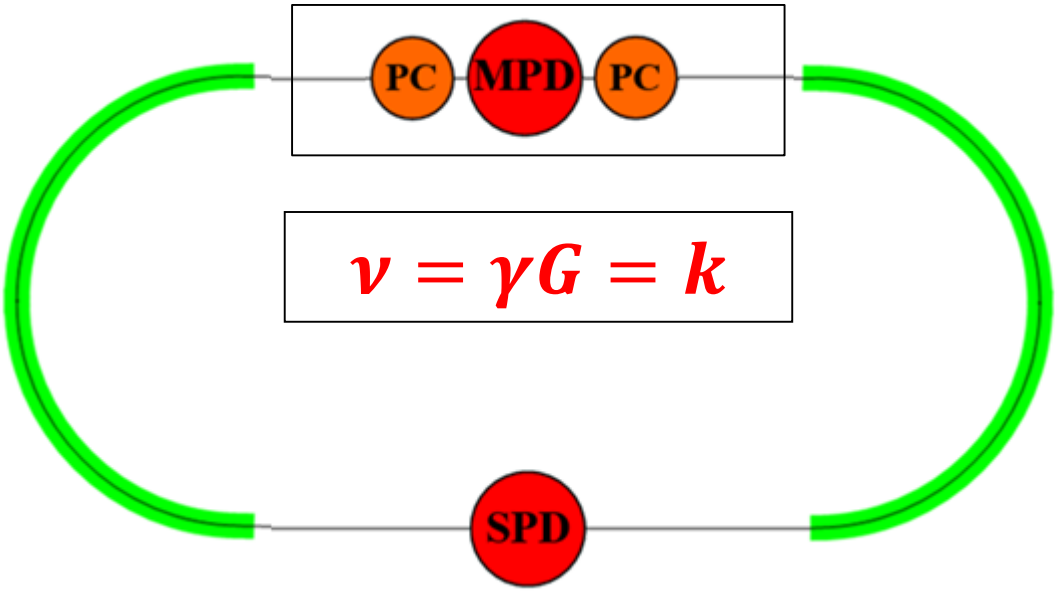
$\nu -$ spin precession tune

In ideal accelerator $\vec{n} = \vec{e}_z$, $\nu = \gamma G$ $G = (g-2)/2 -$ gyromagnetic anomaly

In colliders "*with preferred spin direction*", the periodic spin motion along the closed orbit is unique, i.e. the static magnetic lattice determines a single stable orientation of the beam polarization. The fractional part of *the spin tune differs from zero*.

In colliders "*transparent to the spin*", any spin direction repeats every particle turn along the closed orbit, i.e. the accelerator's magnetic lattice is transparent to the spin. The fractional part of *the spin tune is equal to zero*.

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



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

PC

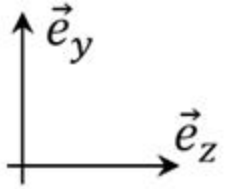
Polarization control insertion based on "weak" solenoids with maximum field integral ***BL*** **< 0.6 T·m** (***protons, deuterons***)

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

Protons: $E_{kin}^{min} = 108$ MeV, $\Delta E = 523$ MeV (25 energy points)

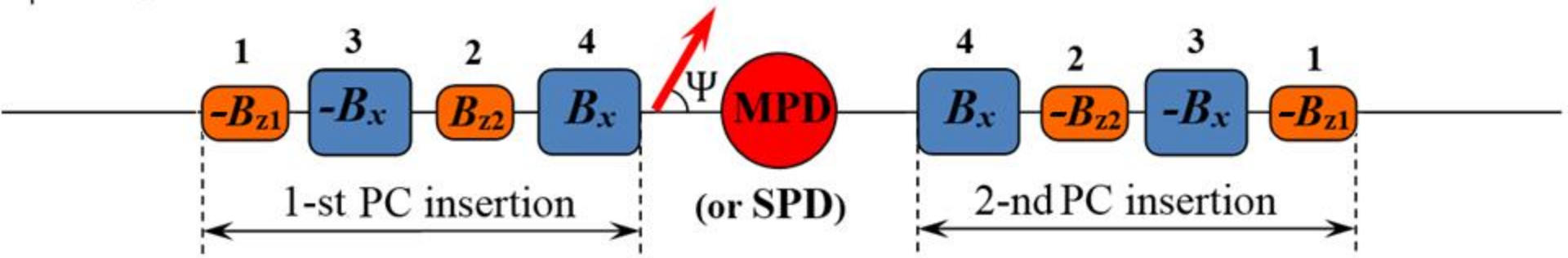
Deuterons: $E_{kin} = 5.63$ GeV/u, $pc = 13$ GeV (1 energy point)

Ion polarization control in NICA collider by means of "weak" solenoids

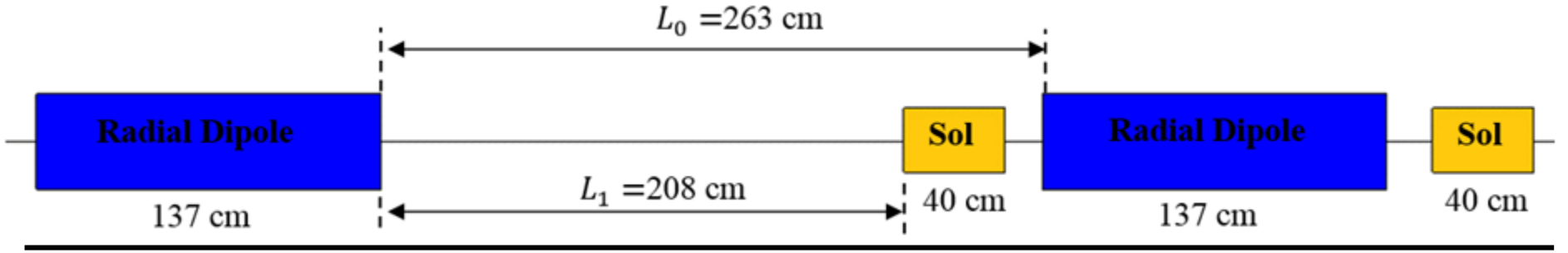


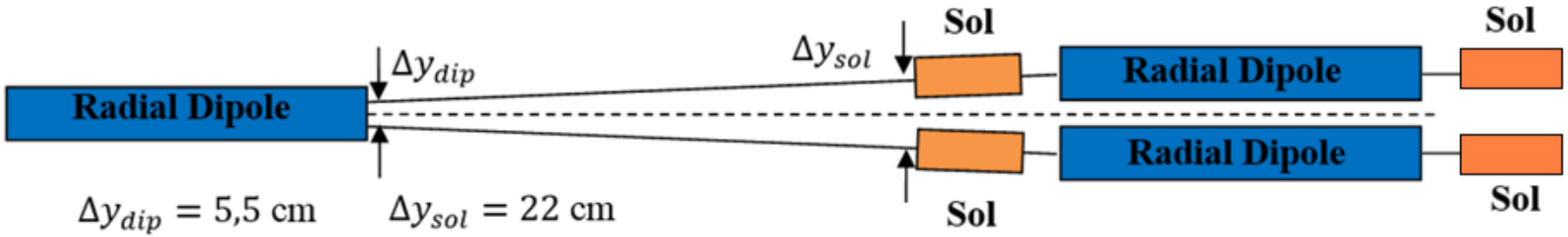
$$\vec{S}_{MPD} = \vec{e}_y \sin\Psi + \vec{e}_z \cos\Psi$$

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



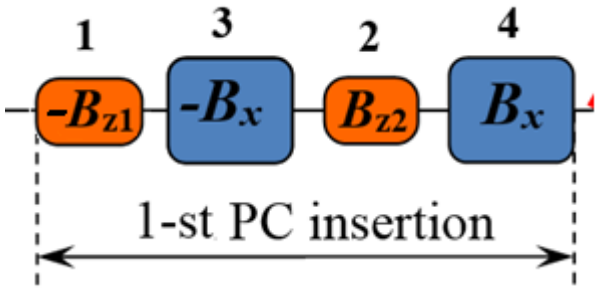
Ψ is the angle between the polarization and velocity directions





On-line spin direction control and Spin Flipping System

$$\vec{n} = \vec{n}(B_{z1}, B_{z2}), \qquad \nu = \nu(B_{z1}, B_{z2})$$



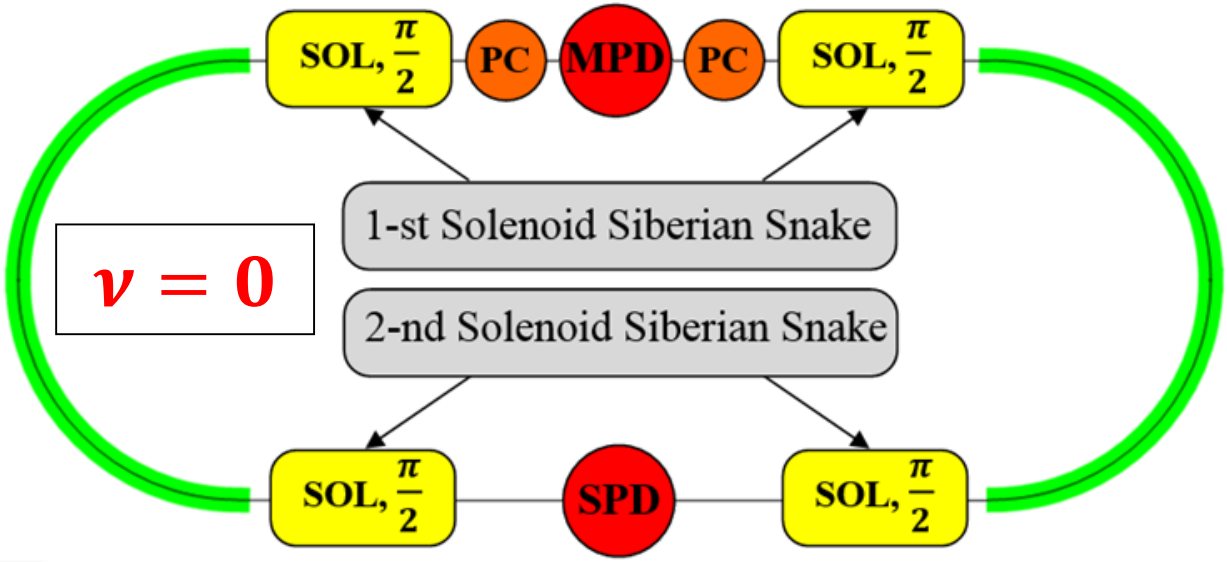
During spin manipulation one can keep the value of spin tune constant. It eliminates crossings of high order spin resonances and provides the stability of the SF system.

New concept of the on-line polarization control 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 polarization control in the spin-transparency mode of the NICA collider.

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



SOL, $\frac{\pi}{2}$ Solenoids for spin transparency mode:

BL = 1÷25 T·m (***protons***), BL = 3÷80 T·m (***deuterons***)

Orbital parameters do not depend on the beam energy

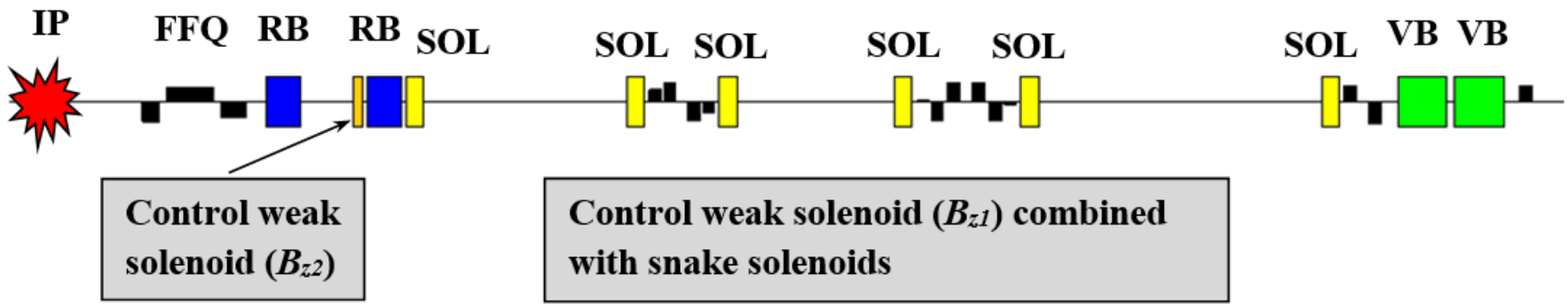
PC Polarization control insertion based on "weak" solenoids with maximum field integral BL < 0.6 T·m (***protons, deuterons***)

Polarization direction (***p, d, ^{3}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

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p **up to momentum of 13.5 GeV/c**

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

Available Spin Modes at the NICA Collider with solenoidal snakes

Snakes	Spin Tune	Spin Mode	SF System	On-line control	Scanning of energy	Particles
Without Snakes	$\gamma G \neq k$	PS	–	–	–	Any
	$\gamma G = k$	ST	+	+	–	Any
One Snake	½	PS	–	–	+	w/o deuterons
Two Snakes	0	ST	+	+	+	Any

PS is “Preferred Spin” mode,
ST is “Spin Transparency” mode

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| - - -… |----| - - - |xxx| +++…

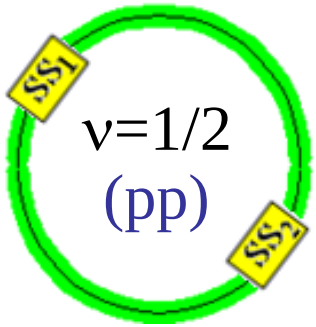
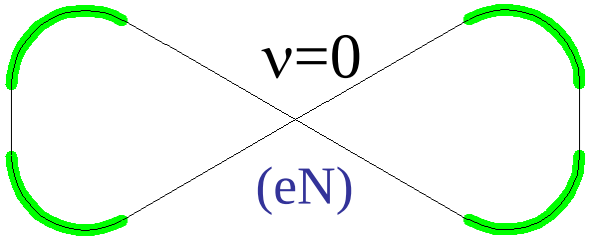
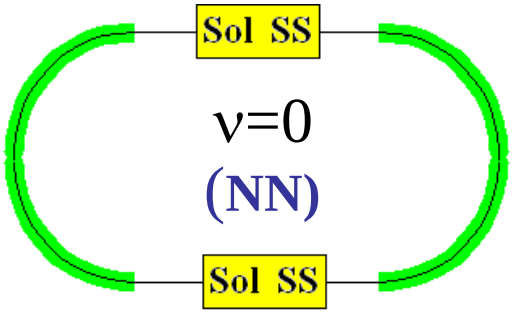
(+ +) (- +) (- -) (+ -) (+ +)

|xxx| — spin-flipper is turned on. There is no data collection.

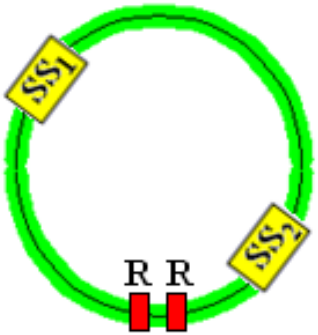
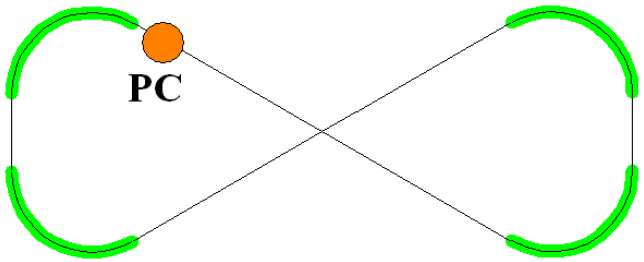
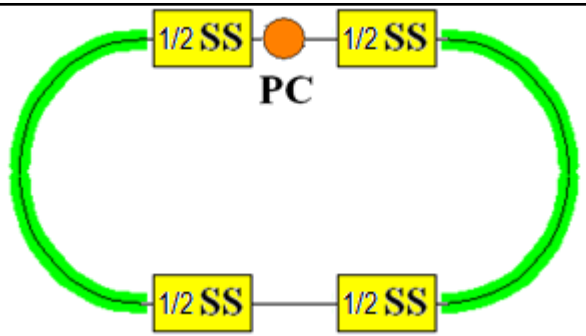
|----| — spin-flipper is not turned on. There is no data collection.

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

Polarization at NICA, JLEIC and RHIC colliders

Collider		Spin Mode
RHIC **(BNL)** **25÷250 GeV/*c***		**Preferred Spin mode (unique spin direction)**
JLEIC **(JLAB)** **25÷100 GeV/*c***		**Spin Transparency mode (any spin direction)**
NICA **(JINR)** **2.5÷13.5 GeV/*c***		**Spin Transparency mode (any spin direction)**

Polarization control at NICA, JLEIC and RHIC colliders

Collider	Control device	Orbital Parameters
RHIC ν=1/2 	Rotators based on "strong" fields (R)	**Change during control**
MEIC ν=0 	Solenoids with "weak" fields (PC)	**Do not change during control**
NICA ν=0 	Solenoids with "weak" fields (PC)	**Do not change during control**

Ion Polarization Control

Collider	Spin Rotators based on	Polarization Direction at IP	Spin Flipping	
			Reversal Time	Orbital Parameters
RHIC (*BNL*)	'**strong**' magnetic fields	Transversal Longitudinal (**w/o deuterons**)	Few **min**	Change
JLEIC (*JLAB*)	'**weak**' solenoids	Any directions (**any particles: *p, d, He*^{3}, …**)	from **ms** up to **sec**	Do not change
NICA (*JINR*)	'**weak**' solenoids	Any directions (**any particles: *p, d, He*^{3}, …**)	from **ms** up to **sec**	Do not change

Spin Flipping System allows one to make spin reversal during an experiment (high precision experiments with polarized ions).

Summary

- Spin transparency mode at the NICA collider makes it possible
  - to manipulate the polarization of any particle type (p, d, ^3He, …) at any orbital location without changing the orbital characteristics of the beam, including to provide longitudinal and vertical beam polarization in MPD and SPD detectors
  - to organize on-line spin direction control during the experiment (fast polarimetry)
  - to realize spin flipping system for carrying out experiments with polarized beams at a new precision level

Thank you for your attention!