МФТИ
Лаборатория
Физики Ускорителей

NICA
NUCLOTRON BASED ION COLLIDER FACILITY

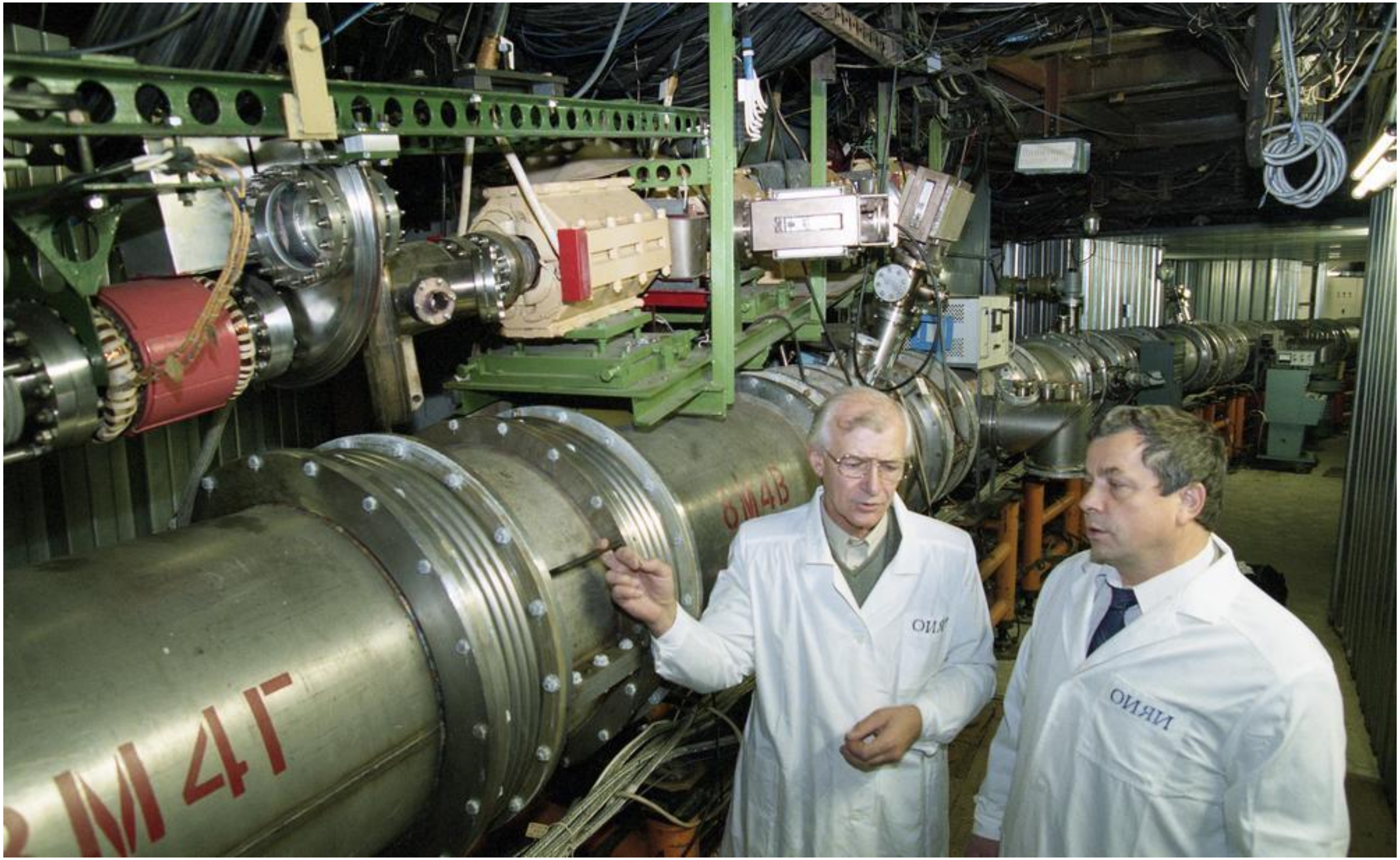
ОИЯИ

Polarized beams at NICA
(in memory of A. Kovalenko)

Y. Filatov, A. Kondratenko, M. Kondratenko

MIPT, Dolgoprudniy,   NTL Zaryad, Novosibirsk

10 June 2021, JINR, Dubna



In memory of Alexander Kovalenko

Outlook

1. Review of the development of the polarization control scheme at NICA
    a) Preservation of the proton polarization at Nuclotron
    b) Spin Transparency (ST) mode at the NICA collider
    c) Feasibility of measuring EDM in the ST mode at the NICA collider
2. The first stage of operating with polarized beams in the ST mode of the NICA collider
3. Experimental verification of the spin-flipping system at integer spin resonances in Nuclotron
4. Summary

Resonance depolarization at Nuclotron (2009)

Письма в ЭЧАЯ. 2009. Т. 6, № 1(150). С. 81–96

ФИЗИКА ЭЛЕМЕНТАРНЫХ ЧАСТИЦ И АТОМНОГО ЯДРА. ЭКСПЕРИМЕНТ

ПРОГРАММА ПОЛЯРИЗАЦИОННЫХ ИССЛЕДОВАНИЙ И ВОЗМОЖНОСТИ УСКОРЕНИЯ ПОЛЯРИЗОВАННЫХ ПУЧКОВ ПРОТОНОВ И ЛЕГКИХ ЯДЕР НА НУКЛОТРОНЕ ОИЯИ

С. Вокал [а], А. Д. Коваленко [а], А. М. Кондратенко [б],
М. А. Кондратенко [б], В. А. Михайлов [а], Ю. Н. Филатов [а],
С. С. Шиманский [а, 1]

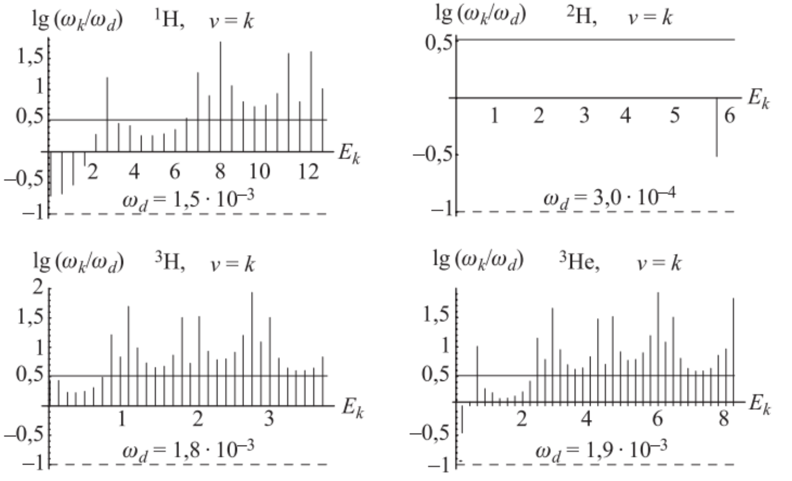


Рис. 2. Целые резонансы

Таблица 3. **Характеристики пересечения спиновых резонансов в нуклотроне**

Характеристика	Частицы пучка			
	^{1}H	^{2}H	^{3}H	^{3}He
G	1,793	−0,143	7,92	−4,184
$E_k^{\max}$, ГэВ/нуклон	12,84	6,00	3,74	8,28
$\nu_{\min} - \nu_{\max}$	1,8–26,3	−1,05– −0,144	7,92–39,5	−41,1– −4,19
ε', ($\tau_{\text{уск}} = 0{,}5$ с)	$7{,}0 \cdot 10^{-6}$	$2{,}8 \cdot 10^{-7}$	$1{,}0 \cdot 10^{-5}$	$1{,}1 \cdot 10^{-5}$
w_d, ($\tau_{\text{уск}} = 0{,}5$ с)	$1{,}5 \cdot 10^{-3}$	$3{,}0 \cdot 10^{-4}$	$1{,}8 \cdot 10^{-3}$	$1{,}9 \cdot 10^{-3}$

Solenoidal snake in Nuclotron (IPAC 2014)

5th International Particle Accelerator Conference   IPAC2014, Dresden, Germany   JACoW Publishing
ISBN: 978-3-95450-132-8   doi:10.18429/JACoW-IPAC2014-TUPRO057

SOLENOID SIBERIAN SNAKE WITHOUT COMPENSATION OF BETA-TRON OSCILLATION COUPLING IN NUCLOTRON@JINR

A.V. Butenko, A.D. Kovalenko, V.A. Mikhaylov, JINR, Dubna, Moscow Region
A.M. Kondratenko, M.A. Kondratenko, Science and Technique Laboratory Zaryad, Novosibirsk
Yu.N. Filatov, MIPT, Dolgoprudny, Moscow Region

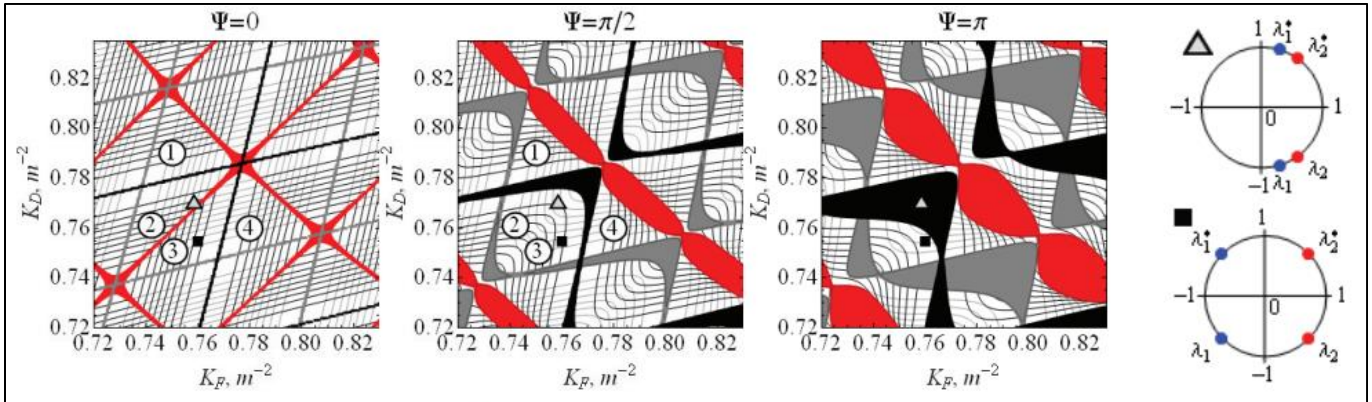
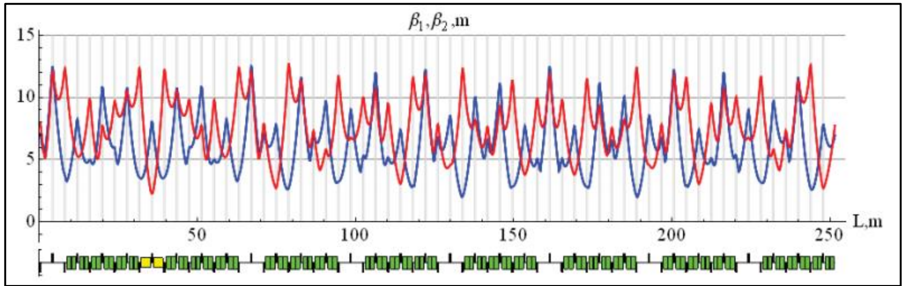
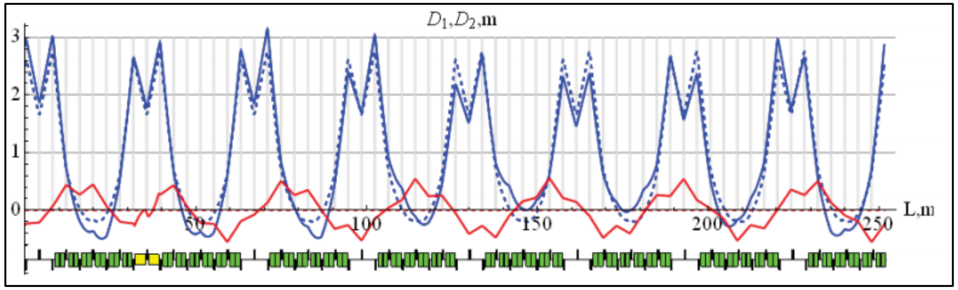


Figure 4: The dependence of stability regions deformations on spin angle Ψ of solenoid Siberian snake.





Proton polarization preservation in Nuclotron (IPAC 2017)

Proceedings of IPAC2017, Copenhagen, Denmark TUPVA112

ACCELERATION OF POLARIZED PROTON AND DEUTERON BEAMS IN THE NUCLOTRON AT JINR

Yu.N. Filatov[1], A.V. Butenko, A.D. Kovalenko, V.A. Mikhaylov, JINR, Dubna, Russia
A.M. Kondratenko, M.A. Kondratenko, STL "Zaryad", Novosibirsk, Russia
[1]also at MIPT, Dolgoprudny, Moscow Region, Russia

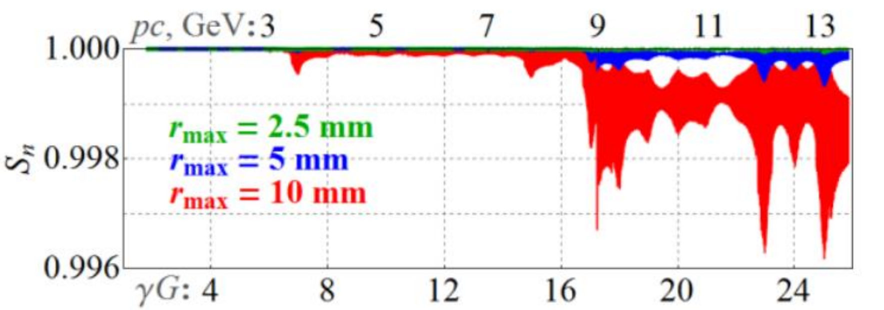


Figure 6: The S_n projections at acceleration of 3 protons in the Nuclotron with the 50% solenoidal snake.

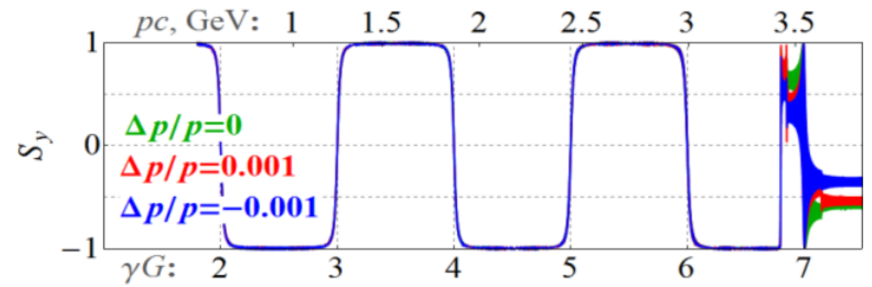


Figure 8: Vertical spin components at acceleration of protons in the Nuclotron with the 5% snake up to 3.5 GeV/c.

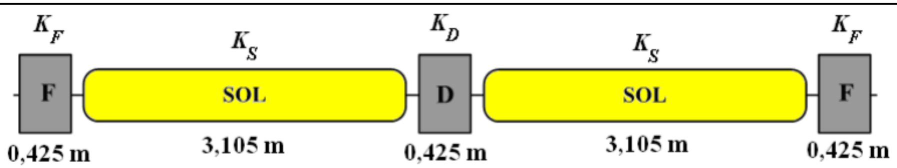


Figure 4: Layout of a 50% solenoidal snake without compensating quadruoles.

The **5%** solenoid snake requires of **0.65 T·m** at the momentum of **3.4 GeV/c**.

The **50%** solenoid snake requires of **25 T·m** at the momentum of **13.5 GeV/c**.

Conventional polarization control at NICA (IPAC 2011)

TUPZ004 Proceedings of IPAC2011, San Sebastián, Spain

THE NICA FACILITY IN POLARIZED PROTON OPERATION MODE

Alexander Kovalenko, Nicolai Agapov, Vladimir Kekelidze, Richard Lednicky, Igor Meshkov, Vladimir Mikhaylov, Anatoly Sidorin, Alexander Sorin, Grigoriy Trubnikov, JINR, Dubna, Moscow Region, Russia
Yury Filatov, JINR and MIPT, Dolgoprudny, Moscow Region, Russia

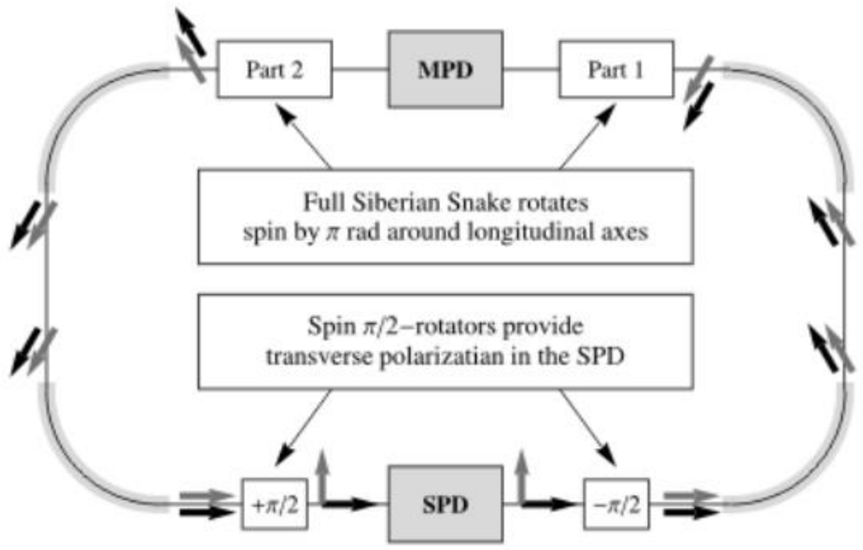


Figure 2: The polarization direction control in the NICA collider (black arrows are correspond to longitudinal and grey ones – to transverse directions respectively).

The use of Siberian Snake (Figure: 3) with longitudinal magnetic fields is proposed to suppress dangerous spin resonances in the booster.

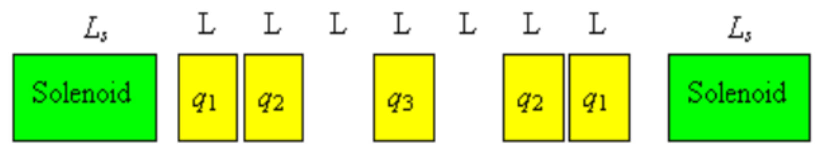


Figure 3: Structure of the Siberian Snake insertion.

Spin tune $\boldsymbol{\nu = \frac{1}{2}}$ (similarly RHIC)

NICA lattice enforces the single periodic spin direction

Two rotator based on strong transverse field are used to change polarization direction

Infeasible for deuterons

First paper about ST mode at NICA (SPIN 2012)

ISSN 1063-7796, Physics of Particles and Nuclei, 2014, Vol. 45, No. 1, pp. 321–322. © Pleiades Publishing, Ltd., 2014.

Polarized Deuterons and Protons at NICA@JINR[1]

A. D. Kovalenko[a], Yu. N. Filatov[b], A. M. Kondratenko[c], M. A. Kondratenko[c], and V. A. Mikhaylov[a]

[a]Joint Institute for Nuclear Research, Dubna, 141980 Russia
[b]Moscow Institute of Physics and Technology, Dolgoprudny, 141700 Russia
[c]Scientific and Technical Laboratory "Zaryad", Novosibirsk, 630090 Russia

Abstract—The novel scheme of proton and deuteron polarization control in the NICA collider at Dubna is proposed. By means of two Siberian Shakes with solenoid magnetic field the beam spin tune is shifted to the "zero" spin resonance vicinity, whereas manipulation of the polarization is realized by "weak" field solenoids. The scheme makes it possible to obtain any desired direction of the polarization in the both MPD and SPD detectors for any sort of the particles. The possibility of the beam polarization control in the orbit plane at any azimuth of the collider magnetic arcs exists also. The last gives necessary flexibility of optimal matching the beam polarization at injection into collider and at the polarimetery monitor points.

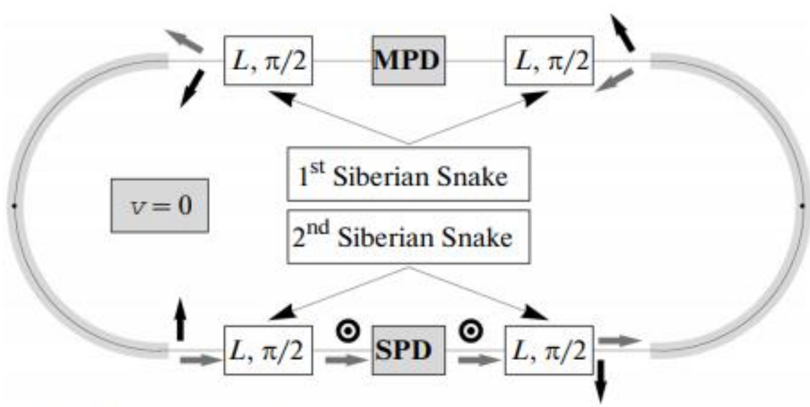


Fig. 2. Proton and deuteron polarization scheme with two solenoid Siberian Shakes in the NICA collider.

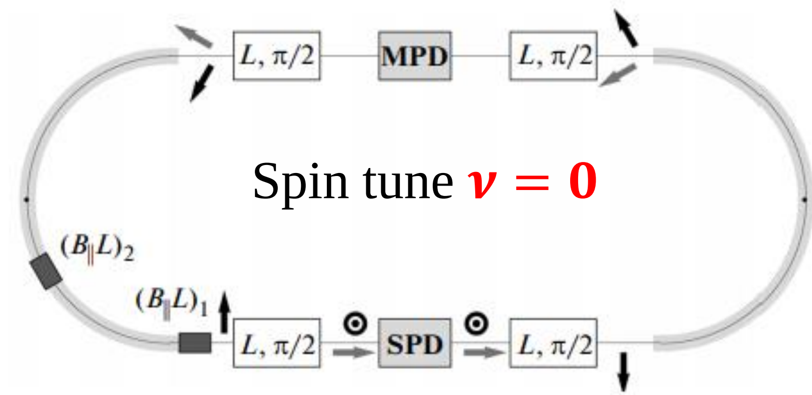


Fig. 3. Control of the deuteron and proton polarization by application of "weak" solenoids in the NICA collider.

Comparison of snakes (DSPIN 2013)

COMPARISON OF SOLENOID, HELIX AND DIPOLE SIBERIAN SNAKES IN THE NICA COLLIDER

A.M. Kondratenko[c], Yu.N. Filatov[b], A.D. Kovalenko[a], M.A. Kondratenko[c] and V.A. Mikhaylov[a]

Figure 2: Half Snake schematics: a) solenoid Snake, b) helix Snake with longitudinal axes.

	Helix	Solenoid	Helix	Solenoid	Helix	Solenoid
p, GeV/c	2,5		7		13,5	
ρ, cm	2,9	0	1,1	0	0,6	0
B, T	4	1,1	4	3,1	4	6
α, deg	3,6	16	0,5	16	0,15	16
L_{tot}, m	4,6	4,2	4,6	4,2	4,6	4,2

Table 2: Impact of the lattice elements on the spin and orbit motions.

Placement of snake solenoids in NICA (DSPIN 2015)

XVI Workshop on High Energy Spin Physics (D-SPIN2015) IOP Publishing
Journal of Physics: Conference Series **678** (2016) 012022 doi:10.1088/1742-6596/678/1/012022

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

A D Kovalenko[1], A V Butenko[1], V D Kekelidze[1], V A Mikhaylov[1], M A Kondratenko[2], A M Kondratenko[2] and Yu N Filatov[1,3]

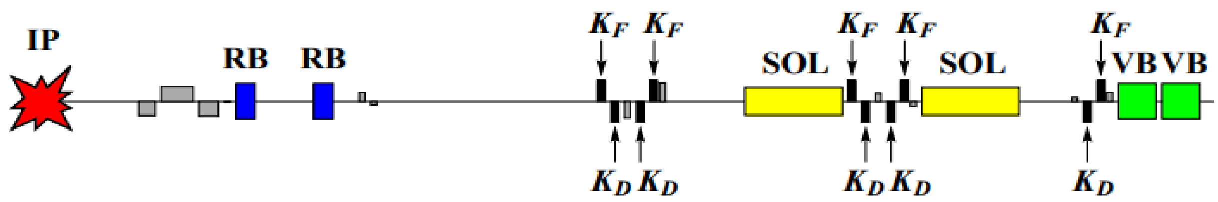


Figure 3. Placement of the snake solenoids in the NICA half straight.

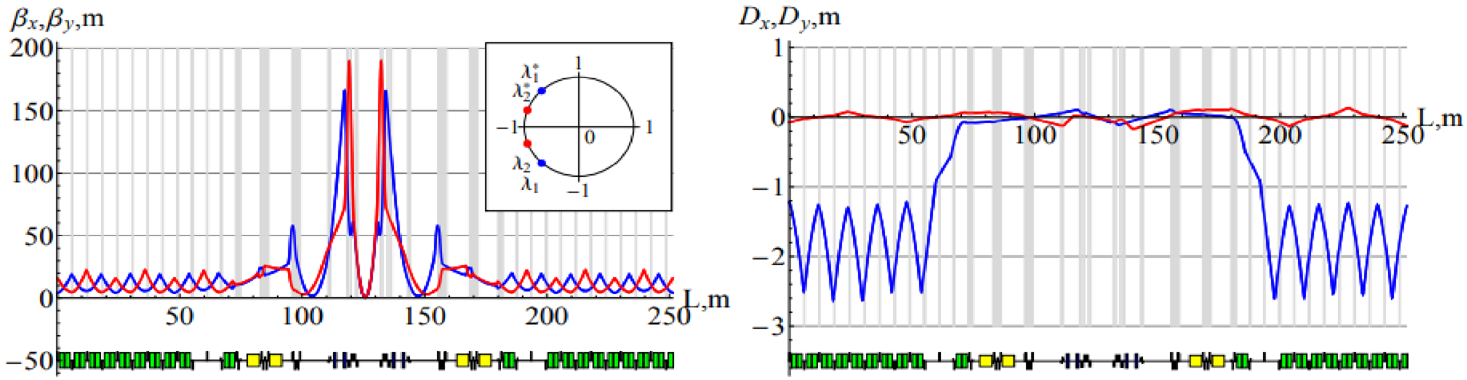


Figure 5. β-functions and dispersion functions in NICA with proton snakes.

Polarization control by small solenoids (DSPIN 2013)

PROTON AND DEUTERON POLARIZATION CONTROL IN NICA COLLIDER USING SMALL SOLENOIDS

Yu.N. Filatov[b], A.D. Kovalenko[a], A.M. Kondratenko[c], M.A. Kondratenko[c] and V.A. Mikhaylov[a]

Abstract

The insertion of two identical Siberian Snakes in the NICA collider allows to control effectively the beam polarization by means of small field integrals. The polarization control schemes by application of small solenoids are presented. These devices allow to adjust any proton and deuteron polarization in both MPD and SPD detectors. It makes possible to carry out ultra-high precision experiments with polarized beams.

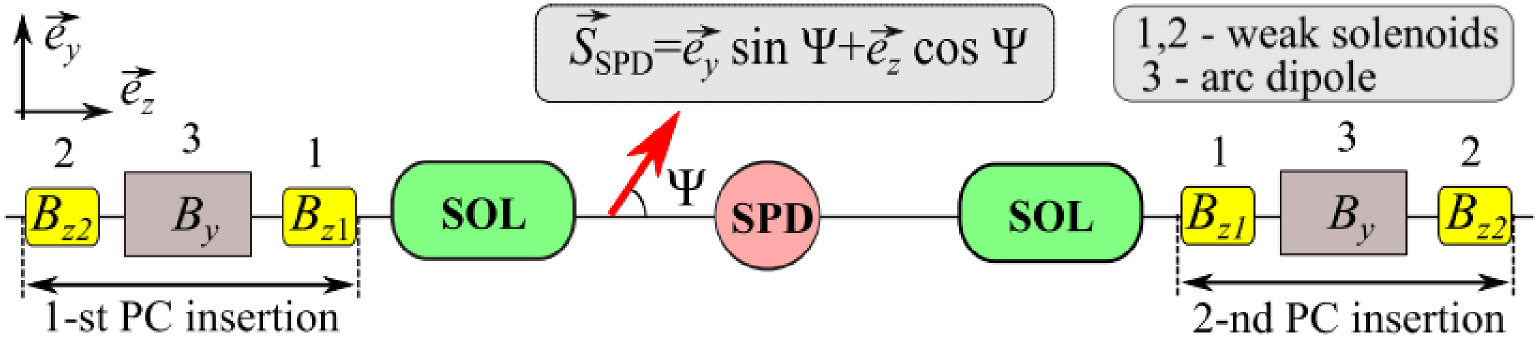


Figure 2: Polarization control by means of small solenoids in NICA collider.

Ion polarization control at SPD and MPD (IPAC 2015)

6th International Particle Accelerator Conference IPAC2015, Richmond, VA, USA JACoW Publishing
ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUPTY017

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

A.D. Kovalenko, A.V. Butenko, V.D. Kekelidze, V.A. Mikhaylov, JINR, Dubna, Russia
A.M. Kondratenko, M.A. Kondratenko, STL "Zaryad", Novosibirsk, Russia
Yu.N. Filatov, MIPT, Moscow, Russia

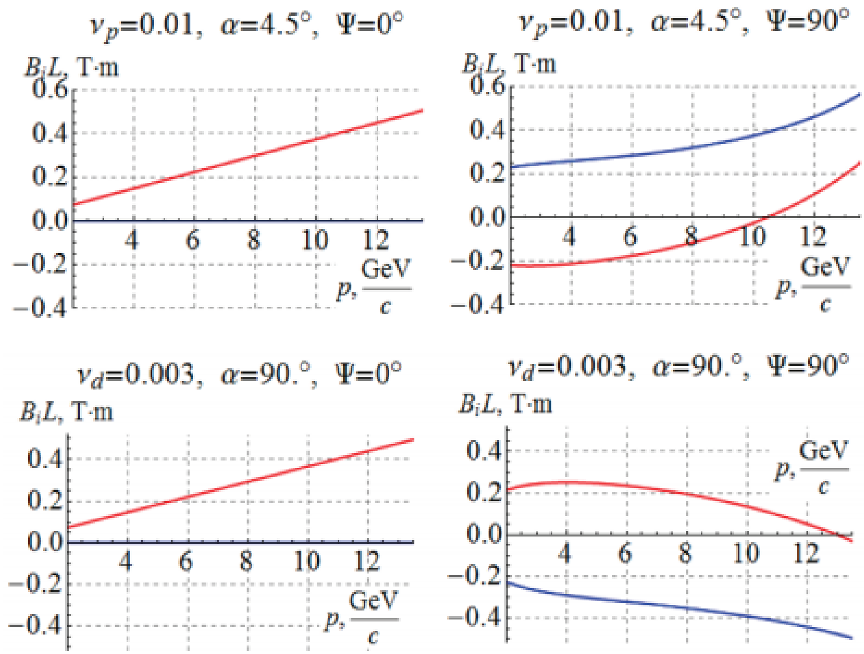


Figure 4: The dependences of the PC solenoid's field on the particle momentum for the longitudinal (left) and vertical (right) polarizations of the proton and deuteron beams.

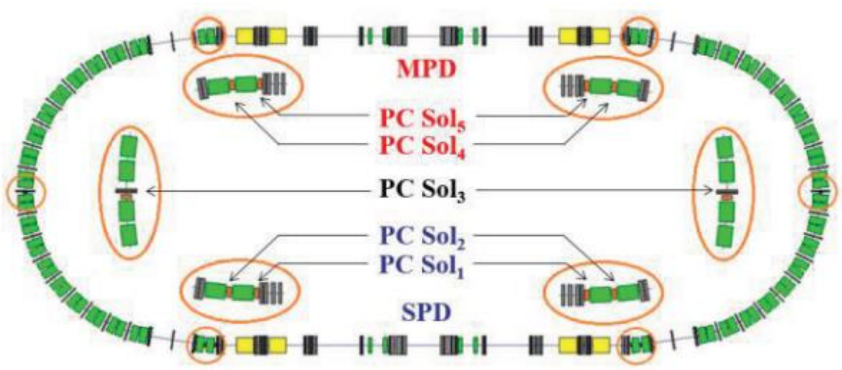


Figure 3: Placement of PC solenoids in NICA collider.

Calculation of ST-resonance strength at NICA (DSPIN 2015)

XVI Workshop on High Energy Spin Physics (D-SPIN2015) IOP Publishing
Journal of Physics: Conference Series **678** (2016) 012023 doi:10.1088/1742-6596/678/1/012023

Numerical calculation of ion polarization in the NICA collider

A D Kovalenko[1], A V Butenko[1], V D Kekelidze[1], V A Mikhaylov[1], M A Kondratenko[2], A M Kondratenko[2] and Yu N Filatov[1,3]

Eur. Phys. J. C (2020) 80:778
https://doi.org/10.1140/epjc/s10052-020-8344-5
THE EUROPEAN PHYSICAL JOURNAL C
Check for updates
Regular Article - Experimental Physics

Spin response function technique in spin-transparent synchrotrons

Y. N. Filatov[1,a], A. M. Kondratenko[1,2], M. A. Kondratenko[1,2], Y. S. Derbenev[3], V. S. Morozov[3,b], A. D. Kovalenko[4,c]

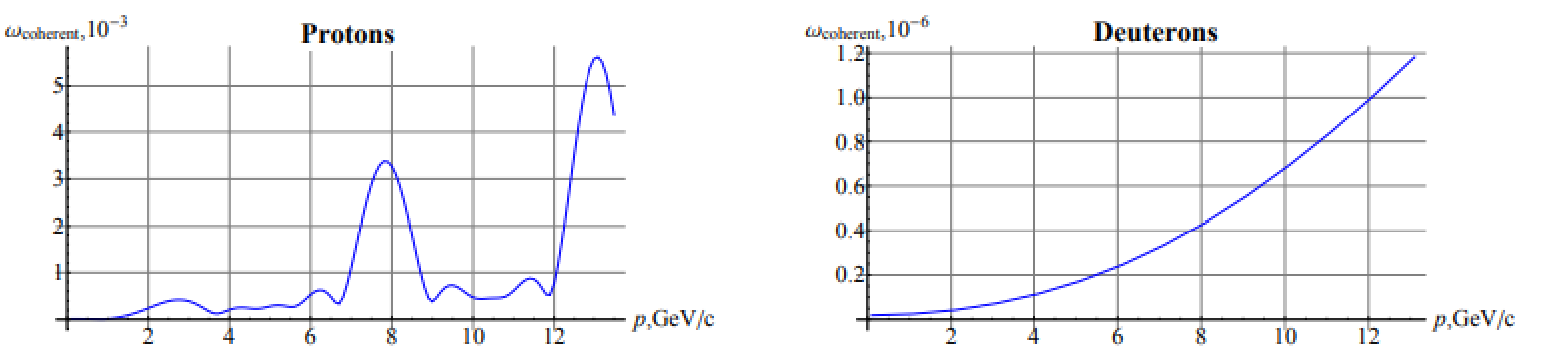


Figure 3. Coherent parts of the zero-integer spin resonance strength for protons and deuterons.

CDR (Baldin ISHEPP XXIV, 2018)

EPJ Web of Conferences **204**, 10014 (2019) https://doi.org/10.1051/epjconf/201920410014
Baldin ISHEPP XXIV

Spin transparency mode in the NICA collider

Yury Filatov[1], *Alexander* Kovalenko[2,*], *Andrey* Butenko[2], *Evgeniy* Syresin[2], *Vladimir* Mikhailov[2], *Stepan* Shimanskiy[2], *Anatoliy* Kondratenko[3], and *Mikhail* Kondratenko[3]

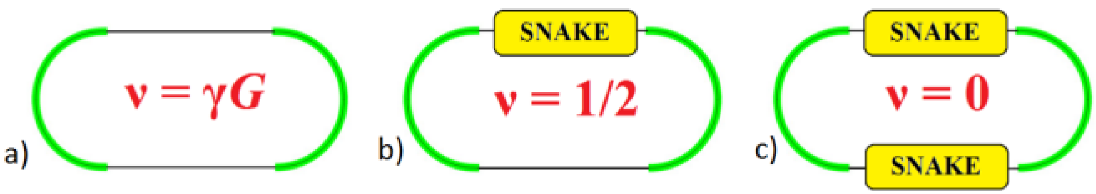


Figure 1. Possible operating regimes with polarized ions: a) the NICA collider without snakes, b) the NICA collider with one snake, c) the NICA collider with two snakes

Table 2. Possibilities at the operation with polarized protons and deuterons in the NICA collider

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

Feasibility of measuring EDM in the ST mode at NICA (2018)

EPJ Web of Conferences **204**, 10013 (2019) https://doi.org/10.1051/epjconf/201920410013
Baldin ISHEPP XXIV

Feasibility of measuring EDM in spin transparent colliders

Anatoliy Kondratenko[1,*], *Mikhail* Kondratenko[1], *Yury* Filatov[2], *Alexander* Kovalenko[3], *Yaroslav* Derbenev[4], and *Vasiliy* Morozov[4]

[1]Science and Technique Laboratory "Zaryad", Novosibirsk, Russia
[2]Moscow Institute of Physics and Technology, Dolgoprudny, Russia
[3]Joint Institute for Nuclear Research, Dubna, Russia
[4]Jefferson Lab, Newport News, VA, USA

Conclusion

In conclusion, let us summarize the main results presented in this paper.

- A theoretical analysis of the spin dynamics of a particle with the MDM and EDM in ST mode rings is completed in the linear approximation.
- It is proposed to measure the EDM at the JLEIC and NICA colliders using the method based on the interference enhancement of the EDM signal in the whole energy range using only the magnetic fields of the ST mode ring.
- Estimates of the EDM signal in the ST modes of the JLEIC and NICA colliders are presented demonstrating the possibility of measuring the EDM of proton and, especially, deuteron beams.
- Questions are formulated about the study of further enhancement of the limiting precision of the EDM measurement in ST mode rings.

Possibilities of ST mode in the NICA collider

Two full solenoidal snakes per ring provide ST mode.

Field integral for one snake:

BL = **(2÷51)** T·m for ***protons*** (pc= **(0.5÷13.5)** GeV) ,

BL = **(6÷165)** T·m for ***deuterons*** (pc= **(0.5÷13.5)** GeV)

Spin Navigator (SN) based on weak solenoids is used to manipulate the direction of the spins.

Maximum field integral of SN solenoids:

$(BL)_{SN} \leq$ **0.6** T·m for ***protons and deuterons***

The polarization control scheme allows one:

- to provide the longitudinal or the transverse polarizations at SPD/MPD (**SN**)
- to maintain polarization up to 70% during the lifetime of the beams (Snakes)
- to operate with polarized beams at any energy (maximum energy is defined by snake field integrals)
- to have the polarized beams during the asymmetric mode operation
- to have Spin-Flipper based on **SN** with reverse time less 1 sec.

Unique operation mode with spin-flippers at NICA

The new ring filling mode (all bunches with the same polarization in the both rings) and the **new operation** (sequential switching-on of the spin-flippers in the rings) [*S.S. Shimanskiy*]:

1st ring +++… |xxx| - - -… | | - - -… |xxx| +++ …| | +++…

2nd ring +++… | | +++…|xxx| - - -… | | - - - … |xxx| +++…

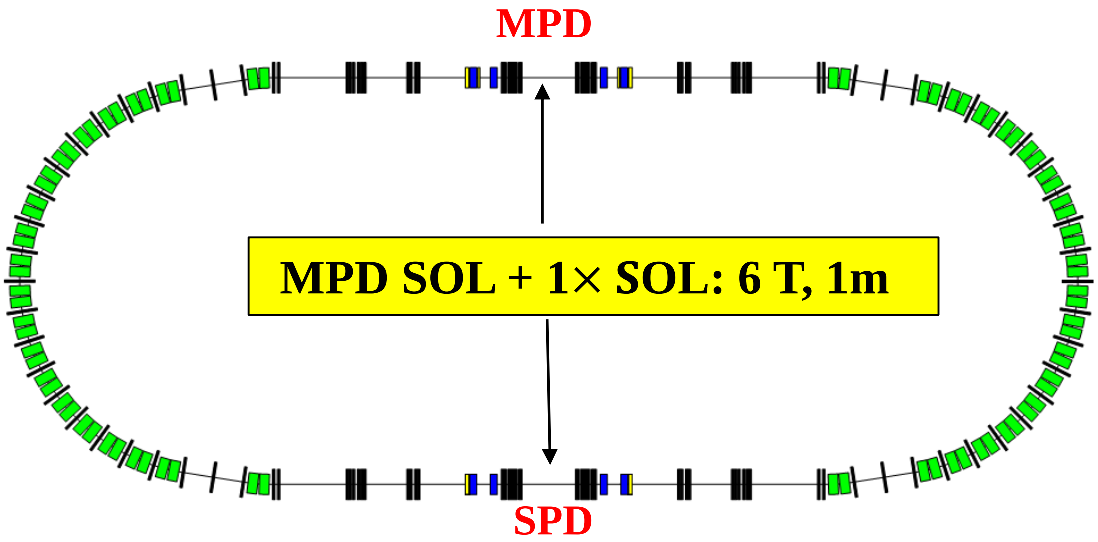
(+ +) (- +) (- -) (+ -) (+ +)

|xxx| - spin-flipper switching-on, no data taking

| | - spin-flipper switching-off, no data taking

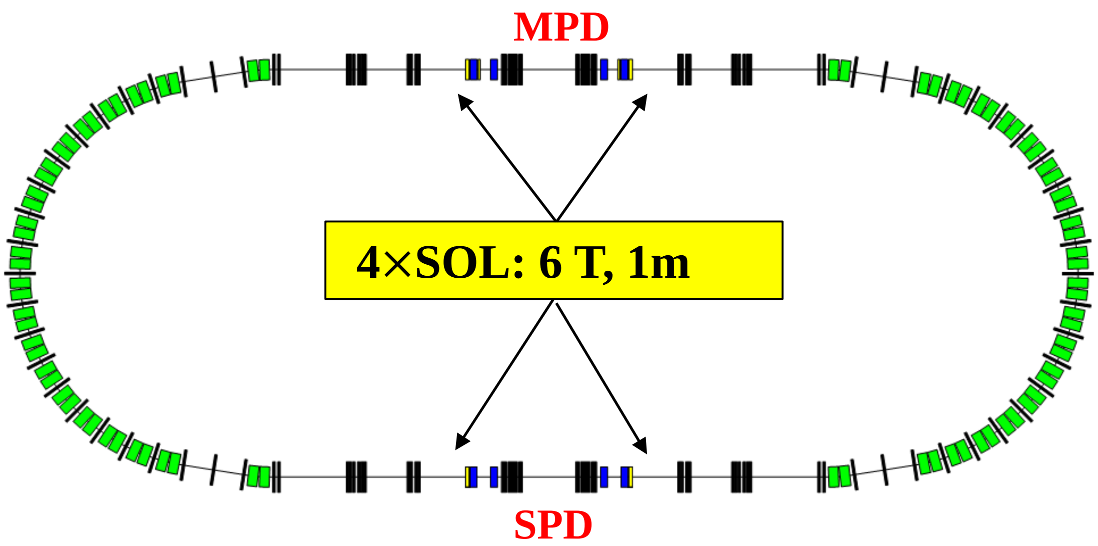
There are no problem with measurement of the bunch 2 bunch luminosity and ***no problem to reverse the polarization at the ion source during ring fillings***!

1-st stage of operating with polarized beams in the ST mode



First configuration:
ST mode with the
MPD and 6T-solenoid

p **up to 1.60 GeV/c**
d **up to 0.49 GeV/c**



Second configuration:
ST mode with four
6T-solenoid

p **up to 3.20 GeV/c**
d **up to 0.98 GeV/c**

Experimental verification of ST mode at integer spin resonances

Accepted Paper

Accepted 27 April 2021

Hadron polarization control at integer spin resonances in synchrotrons using a spin navigator

Phys. Rev. Accel. Beams

Yu. N. Filatov, A. M. Kondratenko, M. A. Kondratenko, V. V. Vorobyov, S. V. Vinogradov, E. D. Tsyplakov, A. D. Kovalenko, A. V. Butenko, Ya. S. Derbenev, and V. S. Morozov

ABSTRACT We consider the capability of flexible spin-transparent polarization control and manipulation in conventional synchrotrons at integer spin resonances by means of spin navigators. The latter are designed as a couple of small solenoids separated by a constant beam bend. We formulate the requirements to the navigator design considering the criteria for stability of the spin motion in the presence of synchrotron energy oscillations. We propose the design of a novel spin-flipping system free of resonant beam depolarization based on such a spin navigator. We discuss the possibilities of testing spin-flipping systems at an integer spin resonance with protons in the Nuclotron ring at JINR in Dubna, Russia and with deuterons in the RHIC rings at BNL in Upton, NY, USA. The results are relevant to the existing and future facilities where the spin transparency mode can be applied for polarization control.

TABLE II. Maximum field integrals of the navigator solenoids for control of the proton polarization in Nuclotron.

$\gamma G = k$	2	3	4	5	6
pc, GeV	0.46	1.26	1.87	2.44	3.00
$\vec{n}$ direction	any	any	$\pm\vec{e}_z$	any	any
$\lvert B_{zi}L\rvert_{\max}$, T·m	0.035	0.13	0.07	0.26	0.23

TABLE III. Maximum field integrals of the navigator solenoids for deuteron polarization control in RHIC.

$\lvert\gamma G\rvert = k$	2	3	4	5	6
pc, GeV	26.2	39.4	52.6	65.8	78.9
$\vec{n}$ direction	any	$\pm\vec{e}_z$	any	any	$\pm\vec{e}_z$
$\lvert B_{zi}L\rvert_{\max}$, T·m	7.4	4.8	14.8	18.6	9.6

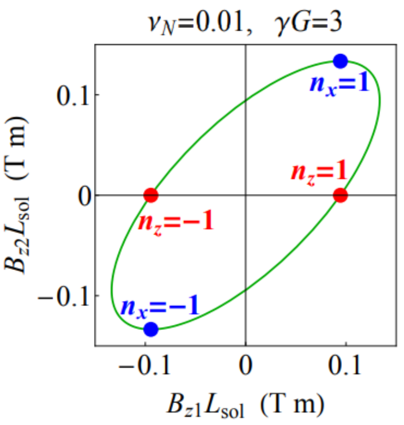


FIG. 4. Change of the solenoid field integrals that keeps ν_N constant while setting the required proton polarization direction.

A.D. Kovalenko. List of main ST mode papers

1. **Kovalenko, A.D.**, Filatov Yu.N., Kondratenko A.M., Kondratenko M.A., Vorobyov V.V., Vinogradov S.V., Tsyplakov E.D., Butenko A.V., Derbenev Ya.S., and Morozov V. S., ***Hadron polarization control at integer spin resonances in synchrotrons using a spin navigator***, Physical Review Accelerators and Beams, Accepted 27 April 2021
2. **Kovalenko, A.D.**, Filatov, Y.N., Kondratenko, A.M., Kondratenko, M.A., Derbenev, Y.S., Morozov, V.S., ***Spin response function technique in spin-transparent synchrotrons*** (2020) European Physical Journal C, 80 (8), 778
3. **Kovalenko, A.D.**, Kondratenko, A.M., Kondratenko, M.A., Butenko, A.V., Shimanskiy, S.S., Syresin, E.M., Vinogradov, S.V., Filatov, Y.N. ***Kinematics of proton and deuteron beam polarization in the transparent spin mode of the NICA collider***, (2020) Journal of Physics: Conference Series, 1435 (1), 012037
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