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SPIN PHYSICS AT JINR: PRESENT AND FUTURE

A. P. Nagaytsev

Joint Institute for Nuclear Research, Dubna

A short review of spin physics program at JINR is presented. The proposals on spin program at the NICA collider are discussed. The main purpose of this program is to study the nucleon spin structure and other phenomena with polarized proton and deuteron beams.

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JINR was one of the scientific centers which started to develop the high energy spin physics in the early 1950s. Many experimental and theoretical inventions were originated in Dubna. The first measurements on pp and pn elastic scatterings [1], production of polarized proton beams in 1954, development of polarized targets and other experimental equipments, were realized in Dubna. These achievements were developed and extended in a number of experiments in 1970s, 1980s and 1990s, in the world's largest centers for high energy physics. Outstanding works of JINR theorists contributed essentially in spin physics and international workshops on spin physics (DSPIN) taking place every two years in Dubna that is also essential to promote and develop spin physics. One of the most important early achievements at JINR was construction of polarized targets and development of their technology. A polarized solid-state target is one of the most important elements in the technique of polarization experiments. A new technique to produce low temperatures by dissolving ^{3}He in ^{4}He, which was worked out at JINR in 1966 by the group headed by B. S. Neganov [2], enabled one to construct frozen spin polarized targets (Fig. 1), which are still working in the major experimental setups on spin physics, such as COMPASS, COMPASS-2 and others. Dubna physicists built a new type of very efficient polarized target, the so-called «frozen spin» target [3]. This target was very intensively used to study the polarization phenomena in the exclusive charge-exchange reactions induced by negative pions of 40 GeV/c and later — in inclusive reactions.

A set of experiments on spin physics were performed at JINR with the Movable Polarized Proton Target (MPPT) [4]. It was a large target, 20 cm long and 3 cm in diameter, transported to Dubna and reconstructed at the Dzhelepov Laboratory of Nuclear Problems (DLNP) during 1994 by Russian, Ukrainian, and French experts. It was installed at the Synchrophasotron beam line and

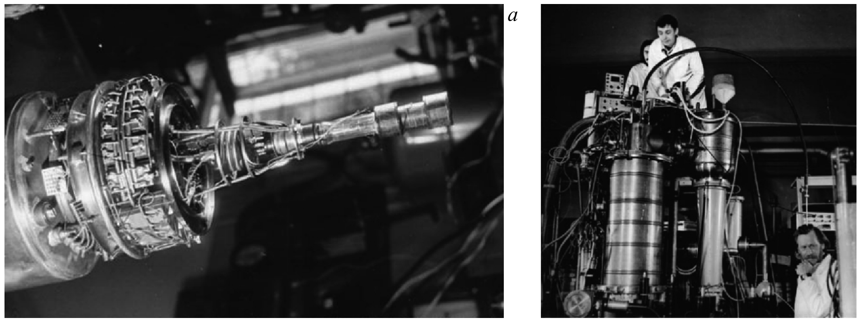

Fig. 1. *a*) Ultralow part of the cryostat of the dilution refrigerator. *b*) The first «frozen» polarized target (right — B. S. Neganov)

used in the first experiment in March 1995. During 1996 and 1997, a new polarizing solenoid for the MPPT was constructed at the Laboratory of High Energies (LHE). The MPPT is to be completed by the vertical superconducting holding coils, constructed in Kharkov and tested in Dubna. The target can work using hydrogenous as well as deuterated polarizable compounds, including ^{6}LiD (MDT). It is operated by the international polarized target group from several laboratories.

The main accelerator complexes to investigate polarization phenomena and spin structure of the nucleon are the Nuclotron and NICA collider (to be built). Construction and development of this complex are top projects of JINR. The development of the Nuclotron and planned NICA parameters allow us to consider the main physics goals: to study hot and dense baryonic matter, nucleon spin structure and polarization phenomena in heavy ion collisions. Figure 2 shows the scheme of the NICA complex. The aim of the NICA project is to construct new accelerator facility which consists of a cryogenic heavy-ion source, a source of polarized protons and deuterons, old linac LU-20, a new heavy-ion linear accelerator, a new Booster-synchrotron, the existing proton synchrotron, upgraded to the Nuclotron-M, two new superconducting storage rings of the collider, a set of transfer channels. The facility will have to provide: ion–ion (Au) and ion–proton collisions 1–4.5 GeV/u, $L \sim 10^{27}$ cm$^{-2} \cdot$ s^{-1}, collisions of polarized proton–proton (deuteron–deuteron) beams 5–12.6 GeV (2–5.8 GeV/u), $L \sim 10^{30}$ cm$^{-2} \cdot$ s^{-1}, fixed target experiments, experiments with an internal target, two interaction points (IP), two detectors.

The MultiPurpose Detector (MPD) is aimed at experimental studying of the hot and dense strongly interacting QCD matter and search for possible manifestation of signs of the mixed phase and critical endpoint in heavy-ion collisions. The second IP is used for the Spin Physics Detector (SPD).

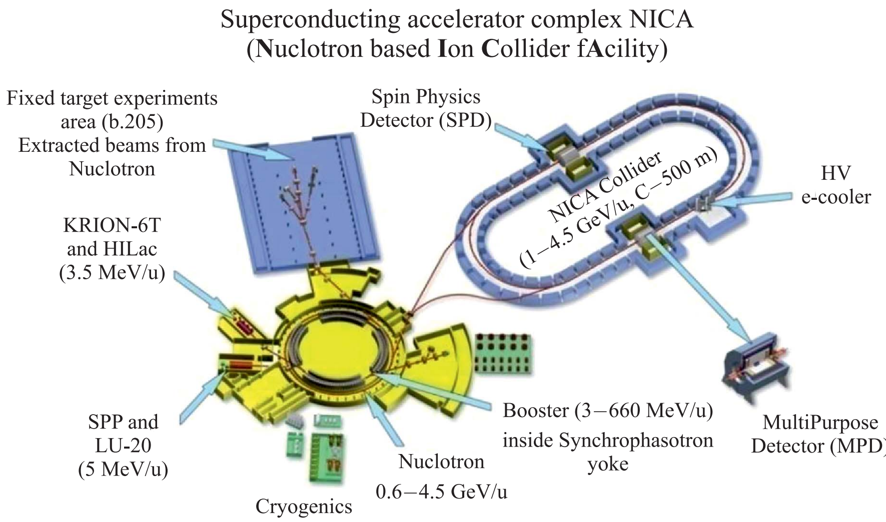

Fig. 2. The view of NICA complex

The spin physics program at the Nuclotron is mainly dedicated to the following topics [5]: polarized beams and polarimetry, experiments with polarized target MPPT, investigation of deuteron spin structure with deuteron breakup in nonlinear and noncollinear kinematics, spin-dependent observations in the cumulative region, analyzing power for cumulative proton production, proton–nucleon analyzing power, analyzing powers in inelastic deuteron reactions.

The spin physics program at the Nuclotron was based on the source of polarized deuterons POLARIS with the average values of the polarization degree equal up to 0.65.

One of the top projects of the Nuclotron spin program is DSS experiment [6]. The main goal of the DSS project is to study the deuteron and the short-range spin structure in three-nucleon systems via measuring the polarization observables in the deuteron induced reactions. The measurements of the analyzing powers A_y, A_{yy}, and A_{xx} for dp elastic scattering and dp nonmesonic breakup are planned at the Internal Target Station. The measurements of the tensor analyzing power T_{20} and spin correlation parameter C_{yy} in the $d^3\mathrm{He} \to p(0)\,{}^4\mathrm{He}$ reaction at the energies between 1000 and 2000 MeV will be performed by using the extracted polarized deuteron beam. In the framework of the project, the deuteron beam polarimetry will be developed at the Internal Target Station and for the extracted deuteron beam at the Nuclotron.

The ALPOM experiment is purposed to study the analyzing powers in reaction $p + \mathrm{CH}_2$ for proton momenta up to 7 GeV/c and calibration of the polarimeter for JLab GEp/GMp experiment at TJNAF [7]. The experiment is carried out in collaboration with groups from TJNAF, College of William and Mary–Norfolk State University, DAPNIA Saclay, Rutger University and P. J. Safarik University. The GEp collaboration at Jefferson Lab is preparing to measure the ratio of the electric and magnetic form factors of the proton G_E/G_M, by the recoil proton polarization method. This experiment requires knowledge of the recoil proton polarization of the momentum up to 7 GeV/c.

The main measurements in the framework of the spin physics program at the Nuclotron are performed to investigate pp, pd, dd, p^3He, d^3He, ^{3}He^{3}He collisions with polarized beams; strong polarization effects in NN interactions at $p_{\rm lab} > 6$ GeV in the region of limited large p_T; problems of P and T parity violation in NN interactions; cumulative (subthreshold) processes; violation of quark counting rules; and to determine the region of their applicability; to study the resonance behavior of color transparency at $p_{\rm lab} \sim 9.5$ GeV/c ($p_T \sim 2$ GeV/c).

The spin studies being carried out at the Nuclotron are given in the schematic view of spin experiments versus the deuteron and nucleon beam intensity in Fig. 3. The current experimental area with a schematic view of experiments on spin physics being performed now is shown in Fig. 4.

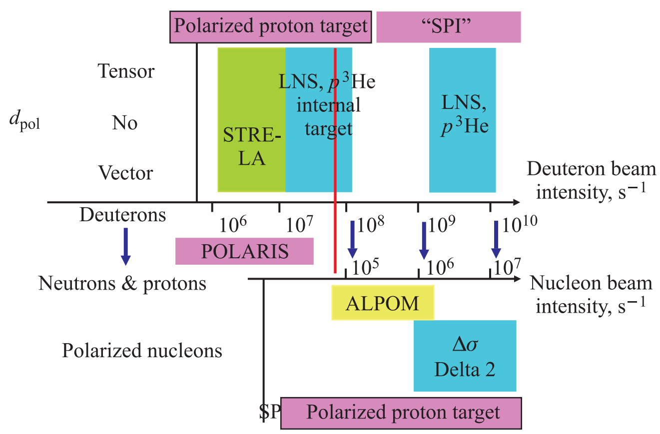

Fig. 3. The schematic view of spin experiments at the Nuclotron versus the deuteron and nucleon beam intensity

The new project SPRINT was recently approved at JINR. This project is mainly purposed to support experiments on various polarization phenomena and nucleon spin structure at the Nuclotron and NICA.

As is mentioned above, one of the top JINR projects is NICA collider preparation. The following two main subjects are included in the NICA spin physics program: 1) polarization effects in heavy-ion collisions by using spin-dependent

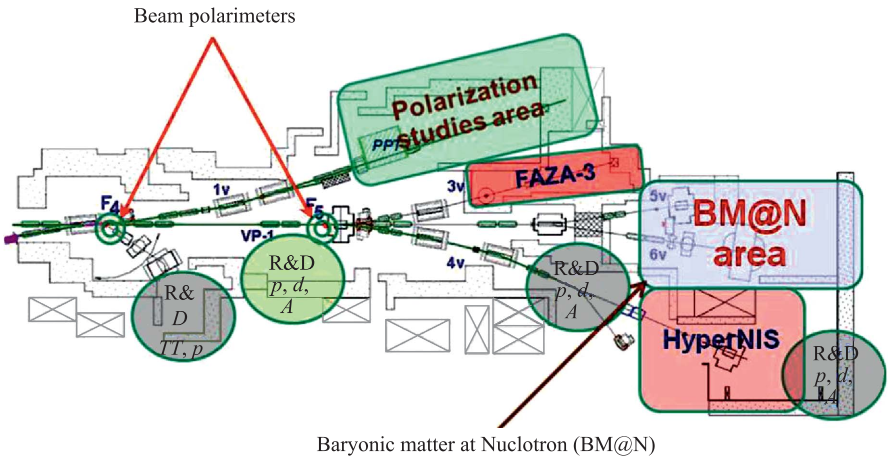

Fig. 4. The schematic view of the Nuclotron experimental area

observables in multiparticle production reactions; 2) the nucleon spin structure via Drell–Yan and J/ψ production processes and others.

Both detectors, MPD and SPD [8] (Fig. 5), will be prepared for spin measurements: Drell–Yan (DY) and J/ψ studies; λ polarization as a probe of isotropic matter formation; correlations of λ polarization with charge separation as a complementary signal for CP violation in the dense matter; transverse handedness as a probe for collective orbital momentum of the matter; tensor polarization of dileptons as a complementary probe of matter formation; dilepton production mechanisms and collective orbital momentum.

Currently the following subjects to be included in the physics program for SPD are under considerations: polarization effects in multiparticle production

Fig. 5. The location of MPD and SPD detectors at the NICA collider complex

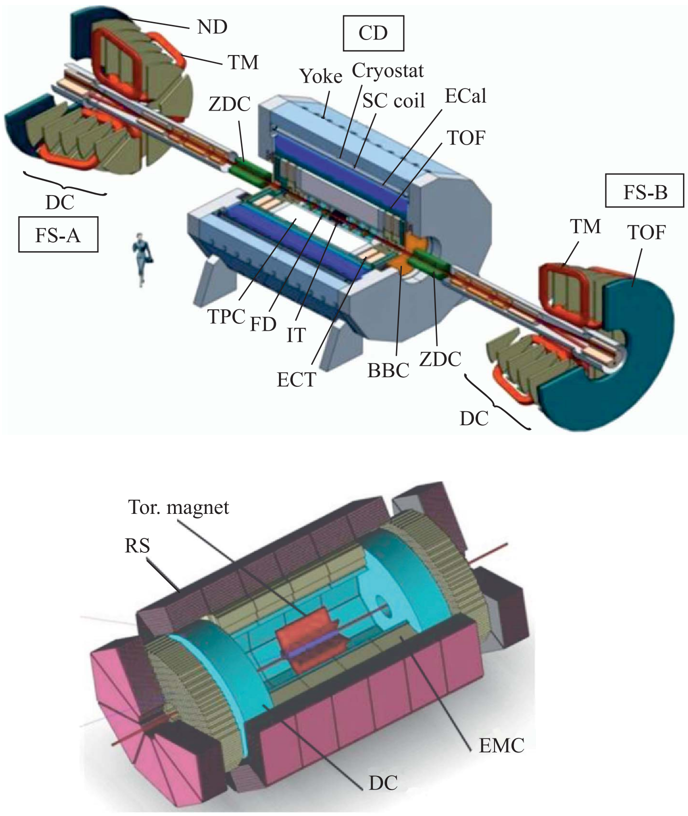

Fig. 6. The MPD (already approved) and SPD (proposed for consideration) experimental setups [8]

by heavy ions, Drell–Yan and J/ψ production processes in proton (deuteron) collisions, studies of various spin-dependent PDFs/TMDs (transverse momentum-dependent PDFs) in nucleons, elastic reactions (Krisch effect), spin effects in one- and two-hadron production processes, spin effects in inclusive high-p_T reactions, spectroscopy of quarkonia with any available decay modes.

The studies of DY processes in collisions of transversely polarized protons and deuterons provide an access to a very important and still poorly known sea and valence transversity, Boer–Mulders and Sivers parton distribution functions (PDFs) in proton. To determine Boer–Mulders and Sivers PDFs, the following measurements must be performed: unpolarized and single polarized DY processes with pp and pd collisions; J/ψ production processes with unpolarized and single polarized pp and pd collisions, which cannot be completely duplicated by other experiments (COMPASS, RHIC, PAX, and J–PARC). The test of the following two relations is also planned to be performed at the NICA collider:

$$f_{1T}^{\perp}(x,k_T)\Big|_{\mathrm{SIDIS}} = -f_{1T}^{\perp}(x,k_T)\Big|_{\mathrm{DY}},\, h_{1T}^{\perp}(x,k_T)\Big|_{\mathrm{SIDIS}} = -h_{1T}^{\perp}(x,k_T)\Big|_{\mathrm{DY}}. \quad (1)$$

Note, that it is one of the crucial tests of our understanding of T-odd effects within QCD and the factorization approach to the processes which are sensitive to transverse parton momenta. The measurements of J/ψ production processes are very important to test the duality model.

The estimation of the cross sections and possible statistics for Drell–Yan events are given in Table 1 [9]. This statistics can be collected with the SPD at NICA during one month of data taking. To compare, the data from the PAX proposal [10] is also presented. These estimations, dependent on the cut applied to Q, are given in Table 2.

Table 1. **The estimation of the cross sections and number of DY events for the NICA and PAX kinematics**

Experiments	σ_{DY} total, nb	L, cm$^{-2}\cdot$s^{-1}	Thousand events
PAX	2	$\sim 10^{30}$	~ 10
NICA	1	$\sim 10^{30}$	~ 5

Table 2. **The estimation of the cross sections and number of DY events (in thousand) for the NICA and PAX kinematics**

	Cut on Q, GeV					
	1.5	1.6	1.7	1.8	1.9	2.0
NICA						
σ_{DY} total, nb	2.54	1.94	1.59	1.32	1.1	0.9
N events per month	14.1	10.5	8.8	7.3	6.1	5
PAX						
σ_{DY} total, nb	5.1	4.33	3.5	2.9	2.46	2.09
N events per month	24.4	20.7	16.7	13.9	11.8	10

To estimate a possible precision of measurements of the asymmetries, a set of original software packages (MC simulation, generator, etc.) was developed in [9]. The single-spin asymmetries (SSA), which can be measured with the SPD NICA detector (see below), are shown in Fig. 7. The two panels present the dependence of the SSA on x_F, giving an access to transversity and the Boer–Mulders and Sivers PDFs. All SSA are estimated for 100000 of DY events, which could be collected during three years of data taking [9].

The spin physics studies are in progress at JINR. The SPD project at NICA is under preparation. The main purpose of the project is to study the nucleon spin

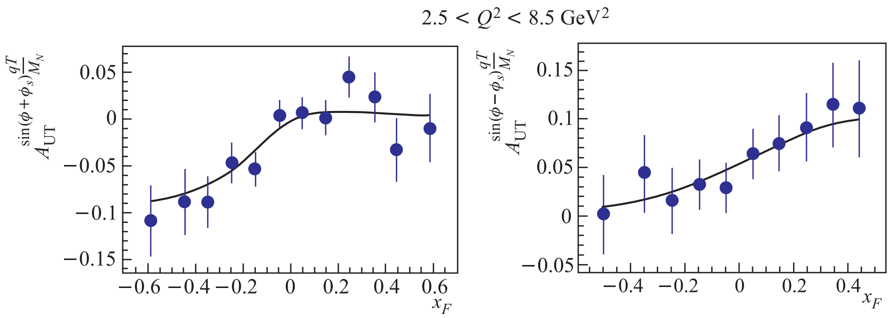

Fig. 7. The SSAs, which can be measured with the SPD NICA detector

structure with high-intensity polarized light nuclear beams. The main NICA parameters (high collision proton (deuteron) energy, high enough average luminosity and high degree of beam polarization) allow us to perform unique measurements which are sure to contribute essentially to understand the nucleon spin structure.

REFERENCES

1. *Nurushev S. B.* Debut of Spin Physics at Dubna. Invited talk presented at the 7th Intern. Workshop on High Energy Spin Physics «SPIN97». Dubna: JINR, 1997.
2. *Neganov B., Borisov N., Liburg M.* // Sov. Phys. JETP. 1966. V. 23. P. 959.
3. *Usov Yu. A.* // Nucl. Instr. Meth. A. 2004. V. 526. P. 153–156.
4. *Lehar F. et al.* // Nucl. Instr. Meth. A. 1995. V. 356. P. 58–61.
5. *Lehar F.* // Phys. Part. Nucl. 2005. V. 36. P. 501–528.
6. *Gurchin Yu. V. et al.* // Phys. Part. Nucl. Lett. 2011. V. 8. P. 571–575.
7. *Gayou O. et al.* arXiv:nucl-ex/0111010. JLAB-PHY-01-63.
8. *Sissakian A. N. et al.* MultiPurpose Detector — MPD (LoI). http://nica.jinr.ru/; *Nagaytsev A. P.* Plenary talk at the 19th Intern. Symp. on Spin Physics «SPIN2010». Jülich, Germany, 2010.
9. *Sissakian A. N. et al.* // Phys. Part. Nucl. 2010. V. 41. P. 64–100.
10. *Barone V. et al.* Antiproton–Proton Scattering Experiments with Polarization. PAX Collab. Julich, 2005.