Abstract. SPD-NICA project is under preparation at second interaction point of the NICA collider. The purpose of this experiment is the study of the nucleon spin structure with high intensity polarized light nuclear beams. It is argued that the design of the collider can allow us to reach with proton beams a very high collision energy up to $\sqrt{s} \sim 26$ GeV with average luminosity up to $10^{30}$-10$^{31}$ cm$^2$/s. At the same time, the respective number for deuteron collisions is also quite considerable: at a collision energy per nucleon up to $\sqrt{s} \sim 12$ GeV, the average luminosity reaches up to $10^{29}$ - $10^{30}$ cm$^2$/s. It is of great importance that both proton and deuteron beams can be effectively polarized, with a polarization degree not less than 50%. All these advantages give us unique possibilities to investigate at NICA polarization phenomena which are of crucial importance for the solution of the nucleon spin problem ("spin puzzle") - one of the main tasks of the modern hadron physics.

1. Introduction
Since the famous “spin crisis” in 1987, the problem of the nucleon spin structure remains one of the most intriguing puzzles of high energy physics. The central component of this problem which has attracted for many years enormous both theoretical and experimental efforts, is the search for an answer to the question, how the spin of the proton is build up from the spins and orbital momenta of its constituents. The searches brought up a concept of the parton distribution functions (PDFs) in the nucleon, at the beginning two of them, $f_1$, for unpolarized, and, $g_1$, for polarized nucleons. Now we know that there must be about 50 different parton distributions functions for a complete description of the nucleon structure. While today a part of the polarized distributions can be considered as sufficiently well known, there is a number of PDFs which either are absolutely unknown, or poorly known, especially the spin dependent ones. These are longitudinally polarized distributions of valence light sea, strange quarks and gluons, and both sea and valence transversely polarized distributions of all flavours. This new class of PDFs, is characterized by its non-trivial dependence on the transverse quark momentum. The most significant among them are Sivers and Boer-Mulders PDFs. The studies of these open questions of the nucleon structure is the first priority task for the scientific program of the second interaction point of the NICA facility.

The purpose of the Spin Physics program at NICA is the study of the nucleon spin structure with high intensity polarized proton and deuteron beams in the collider mode. The collider will allow us to reach a very high collision proton energy up to $\sqrt{s} \sim 26$ GeV with a luminosity up to $10^{30}$-10$^{31}$ cm$^2$/s. For deuteron beams, the collision energy per nucleon up to $\sqrt{s} \sim 12$ GeV with an average luminosity up to $10^{29}$-10$^{30}$ cm$^2$/s. Both proton and deuteron beams can be effectively polarized. All these advantages
give us unique possibilities to investigate at NICA the polarized phenomena which are of crucial importance for the solution of the nucleon spin problems- one of the main tasks of modern high energy physics.

2. The NICA project
The goal of the NICA project is the construction of a new accelerator facility at JINR that consists of a cryogenic heavy ion source, a source of polarized protons and deuterons, the "old" linac LU-20, a new heavy ion linear accelerator, a new Booster-synchrotron, the existing proton synchrotron (Nuclotron), upgraded to Nuclotron-M, two new superconducting storage rings of the collider, and a set of transfer channels (see figure 1).

![Figure 1. Scheme of the Nuclotron-based Ion Collider fAcility (NICA).](image-url)

The facility will have to provide: ion-ion (Au) and ion-proton collisions in the energy range of 1 to 4.5 GeV/u at a luminosity up to $L \sim 10^{27}$ cm$^{-2}$s$^{-1}$ and collisions of polarized proton-proton (deuteron-deuteron) beams in the energy range 5 to 12.6 GeV (2 to 5.8 GeV/u) at a luminosity $L > 10^{30}$ cm$^{-2}$s$^{-1}$ (see table 1). The main parameters of NICA for polarized beams are given in table 1. Using Nuclotron-M and NICA facilities the following set of experiments is presently being planned: fixed target experiments, experiments with an internal target, collider experiments with two interaction points and respectively with two detectors. The first one is the Multi Purpose Detector (MPD), aiming at experimental studies of hot and dense strongly interacting QCD matter and the search for a possible manifestation of signs of the mixed phase and critical endpoint in heavy ion collisions. The second one will be used for the spin physics studies and is called Spin Physics Detector (SPD).
Table 1. NICA bunch parameters for polarized $pp$ collisions.

| ENERGY (GeV) | 5   | 12   |
|-------------|-----|------|
| Proton number per bunch | $6 \times 10^{10}$ | $1.5 \times 10^{10}$ |
| Number of bunches | 10  | 10   |
| rms relative momentum spread | $10^{-3}$ | $10^{-3}$ |
| rms bunch length (m) | 1.7 | 0.8  |
| rms unnormalized emittance ($\pi$ mm mrad) | 0.24 | 0.027 |
| Beta-function in the IP (m) | 0.5 | 0.5  |
| Lasslet tune shift | 0.0074 | 0.0033 |

3. Spin Physics at NICA

3.1 Polarized Beam Source

The source for the project involving polarized ions is based on the design and construction of a universal high-intensity source of polarized deuterons (D) and protons (P) using a charge-exchange plasma ionizer. The output $\uparrow D^+ (\uparrow H^+)$ current of the source is expected to be at a level of 10 mA. The polarization will be up to 90% of the maximal vector (±1) for $\uparrow D^+ (\uparrow H^+)$ and tensor (+1,-2) for $\uparrow D^+ (\uparrow H^+)$ polarization. The new source will make it possible to have the polarized deuteron (proton) beam intensity up to the level of $10^{10}$ d(p)/pulse. The realization of the project is carried out in close cooperation with INR of RAS (Moscow).

The equipment formerly used in the CIPIOS ion source (IUCF, Bloomington, USA) will be recuperated. A detailed description of the preparation of the polarized beam source preparation by V. Fimushkin (JINR, Dubna) [1].

3.2 Polarimetry

The proper measurements of the beam polarization at Nuclotron-M and the NICA collider are very important and aimed to provide an absolute measurements with an accuracy better than 3-5%, and in additional relative monitoring the polarization. These measurements are based on investigations of the analyzing powers in various elastic, quasielastic, and inelastic processes (see figure 2). Project on Beam Polarization measurements is under preparation:

- Absolute calibration of the beam polarization,
- Efficient calibrated polarimeters,
- Permanent monitoring of the beam polarization,
- Local polarimetry.

To perform these tasks, the measurements of analyzing power of various elastic and quasielastic processes ($dp$, $pp$, $pC$, $dC$) can be performed. A detailed description of the preparations of the required polarimetry was given by V. Ladygin (JINR, Dubna) [2].
3.3 Proposed measurements

The parameters of the NICA collider allow us to perform:

- Studies of Drell-Yan (DY) processes,
- Studies of $J/\psi$ production processes,
- Studies of elastic reactions,
- Spin effects in one and two hadron production processes,
- Spin effects in inclusive high-$p_T$ reactions,
- Polarization effects in heavy ion collisions,
- Spectroscopy of quarkonia with any available decay modes.

The studies of DY processes in collisions of transversely polarized protons and deuterons provide access to the very important and still poorly known sea and valence transversity, Boer-Mulders and Sivers PDFs in the 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; $J/\psi$ production processes with unpolarized and single polarized $pp$ and $pd$ collisions, which cannot be completely duplicated by other experiments (COMPASS [3], RHIC [4], PAX [5] and JPARC [6]).

The test of the following two relations is also planned to be performed using the NICA collider:

$$f_{1T}^+(x,k_T)\bigg|_{SIDIS} = - f_{1T}^+(x,k_T)\bigg|_{DY}, \quad h_1^+(x,k_T)\bigg|_{SIDIS} = - h_1^+(x,k_T)\bigg|_{DY}$$

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 is sensitive to transverse parton momenta. The measurements of $J/\psi$ production processes are very important for tests of duality model (see figure 4).

![Figure 2](image1)

**Figure 2.** The view of the polarimeter setup (left) and results on the analyzing powers in dp-elastic scattering at 270 MeV as function of the scattering angle in the c.m. (right).

![Figure 3](image2)

**Figure 3.** Ratios of cross-sections for prediction of $J/\psi$ in $pp$ and $p\pi$ interactions calculated with three models in comparison with the experimental data: the solid line corresponds to the ``duality'' model, the dashed line corresponds to the ``gluon evaporation'' model, and the dot-dashed line corresponds to ``gluon evaporation'' model without gluon contribution. The data points are taken from [7].
The data on unpolarized J/ψ production, which can be obtained with the SPD at NICA, will essentially improve the theoretical approach to the understanding of J/ψ production. This can be performed with various energies of NICA beams. The kinematical ranges for two Q^2 intervals are shown in figure 5.

Figure 4. Center of mass energy √s vs the range of the Bjorken x variable at NICA for two different ranges of Q^2.

Table 2 shows the estimation of the cross-sections and possible statistics for DY events, which can be collected with the SPD at NICA during one month in comparison with those from the PAX proposal. These estimations depend on the cut applied to Q (see table 3).

Table 2. The estimation of the cross-sections and number of DY events for NICA and PAX kinematics.

| Cut on Q, GeV | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 | 2.0 |
|---------------|-----|-----|-----|-----|-----|-----|
| NICA, √s=20 GeV |     |     |     |     |     |     |
| σ_{DY}, total (nb) | 2.5 | 1.9 | 1.6 | 1.3 | 1.1 | 0.9 |
| Number of events per month (in thousand) | 14  | 11  | 9   | 7   | 6   | 5   |
| NICA, √s=26 GeV |     |     |     |     |     |     |
| σ_{DY}, total (nb) | 3.3 | 2.7 | 2.3 | 1.9 | 1.6 | 1.3 |
| Number of events per month (in thousand) | 18  | 15  | 13  | 10  | 9   | 7   |
| PAX, √s=14.6 GeV |     |     |     |     |     |     |
| σ_{DY}, total (nb) | 5.1 | 4.3 | 3.5 | 2.9 | 2.5 | 2.1 |
| Number of events per month (in thousand) | 24  | 21  | 17  | 14  | 12  | 10  |

Table 3. The estimation of the cross-sections and number of DY events for NICA and PAX kinematics.

To estimate the possible precision of measurements of the asymmetries a set of original software packages (MC simulation, generator etc.) was developed [8]. The single-spin asymmetries (SSA), which can be measured with the SPD NICA detector (see below), are shown in figure 6. The two left panels present the dependence of the SSA on x_F, giving access to transversity and the Boer-Mulders
PDFs, the two right panels show the same for the Sivers PDFs. All SSA are estimated for 100000 DY events, which could be collected in two-three year periods of data taking.

**Figure 5.** The SSA asymmetries, which can be measured with the SPD NICA detector. The points show the expected precision. The two left panels demonstrate the access to transversity and Boer-Mulders PDFs (lines are from [9]), and the two right panels show the prediction to access the Sivers PDFs (solid lines are from [8]).

Starting 1970s of the last century, studies of elastic reactions in high energy physics have been one of the main probes of various polarization effects. In the framework of these studies the following measurements can be performed with the NICA collider:

- Differential cross section measurements in \( pp \), \( A_n \) and \( A_{nn} \) up to maximal values of \(-t \sim 20 \text{ GeV}^2\),
- Krisch effect [10], especially important for \( pd \) and \( dd \) elastic reactions,
- Comprehensive measurements on amplitudes of elastic \( pp \) cross section,
- Total cross section measurements of elastic \( pp \) and \( pd \) reactions in pure initial spin states,
- Comparison of the differential cross sections and analyzing powers of elastic and quasielastic \( pp \) reactions.

Figure 6 shows the set of the experimental results on these effects, which consist of an anomalous (unpredicted by QCD) rise of the ratio of the cross sections with parallel and anti-parallel spin states.

**Figure 6.** The experimental results on the so-called Krisch effect [10].

The new experimental data on Krisch effect which can be obtained at NICA with proton and deuteron beams will essentially add to understanding of the nature of this effect.

Concerning the studies of polarization effects in heavy ion collisions with MPD detector, the following polarization observables may be studied:

- Polarization of \( \Lambda \) as a probe of formation of isotropic matter,
- Correlations of \( \Lambda \) polarization with charge separation as a complementary signal for CP-violation in 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.

3.4 SPD detector
The preliminary design of the SPD detector for spin physics studies is based on the requirements imposed by the DY and J/ψ productions studies. These requirements are the following: almost 4π geometry for secondary particles; precise vertex detector; precise tracking system, precise momentum measurement of secondary particles, good particle identification capabilities (µ, π, p, e, etc.). Most of these requirements are also important for other studies mentioned above. The preliminary design of the SPD is shown in figure 7. The main parts of this scheme are described below. The toroid magnet of the spectrometer provides a field free region around the interaction point and does not disturb the trajectories. The toroid magnet can consist of 8 superconducting coils, symmetrically placed around the beam axis.

![Figure 7. The views of SPD.](image)

Preliminary studies show that the use of superconducting coils allows us to reach an azimuthal detector acceptance in excess of 85%, while the radius of the inner magnet volume can be about 0.3 m and the outer one about 0.7 m, with \(|BdL| \sim 1T m\). Several layers of double-sided Silicon strips can provide a precise vertex reconstruction and tracking of the particles before they reach the magnet. With a pitch of 50-100 \(\mu m\), it is possible to reach a spatial resolution of 20-30 \(\mu m\). Such a spatial resolution would provide a precision of about 50-80 \(\mu m\) for the vertex reconstruction, and permits to reject the secondary decays of mesons into leptons. The coordinate resolution of 150-200 \(\mu m\) can be achieved with conventional drift chambers (DC). This can provide a momentum resolution of the order of 1-3 % over the kinematic range of the detector. The electromagnetic calorimeter (EM) will consists of “shashlyk” modules with the application of new readout techniques based on Avalanche Multi Pixel Diode (AMPD) technology. The modules can have an area of 4\(x\)4 cm\(^2\) and a length of 30-40 cm. The expected energy resolution can be \(\sigma (E) / E = (5 \sim 8)%/ E\). The calorimeter can be used also for the triggering of DY electrons. Sets of hodoscope planes will be used for triggering. The system of mini-drift layers with Fe layers, called Range System (RS), is the main part of the detector (see figure 8). It can provide a clean (> 99%) muon identification for muons with momenta greater than 1 GeV. The combination of responses from the EM calorimeter and the RS can be used for the identification of pions and protons in a wide energy range. The final version of the SPD will be defined after detailed Monte-Carlo simulations and consideration of requirements for other spin effects studies.
4. Conclusions

The project on Spin studies at NICA is under preparation. The purpose of the proposed measurements is the study of the nucleon spin structure with high intensity polarized light nuclear beams. It is possible to perform the above discussed studies using the main parameters of the NICA polarized beams: high collision proton (deuteron) energy up to $\sqrt{s} \sim 26(12)$ GeV, the average luminosity up to $10^{30}-10^{31} \text{ cm}^2/\text{s}$; it should be noted that both proton and deuteron beams can be effectively polarized. The milestones of the spin physics program are: i) during 2010-2014, it is planned to prepare Conceptual Design Report and subsequently a Technical Design Report; ii) to organize the SPD collaboration and to carry out the R&D for development of the SPD detector; iii) in 2015-2018 we plan to finish the preparation of polarized beams for NICA and finalize the R&D studies for the SPD detector, being with the production of the SPD detector; iv) in 2018 it is planned to start the SPD with installation a and tests, following by commissioning in 2019 and start of data taking. The spin studies with the MPD detector, which shall start operation in 2015-2016 is also under consideration.

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