Spin Physics Detector at NICA

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The Spin Physics Detector is one of two large setups at the NICA collider under construction at JINR (Dubna). The ultimate goal of the studies at SPD is the measurement of different spin observables in polarized proton-proton and deuteron-deuteron collisions sensitive to the polarized gluon structure of the nucleon at the luminosity up to \(10^{32} \text{ cm}^{-2} \cdot \text{s}^{-1}\) and \(\sqrt{s} \) up to 27 GeV. SPD will consist of the superconducting magnetic system, silicon tracker, straw mini-drift tubes tracker, time-of-flight system, electromagnetic ”shashlyk”-type calorimeter, muon (range) and local-polarimetry systems. The high performance free-streaming DAQ system will be able to operate at the collision rate up to 4 MHz.

**KEYWORDS:** polarized beams, spin effects, nucleon gluon structure

1. Introduction

The Nuclotron Based Ion Collider fAcility (NICA) devoted to relativistic nuclear, hadron and applied physics is under construction at the Joint Institute for Nuclear Research in Dubna, Russia [1]. NICA will accelerate different ions from proton to Au at the energies \(\sqrt{s_{NN}}\) up to 27 GeV and 11 GeV, respectively. The beams will collide in two interaction points, where the \(\sim 4\pi\) detectors will be installed. The Multi-Purpose Detector (MPD) will be focused on the study of the equation of the nuclear matter state at high nuclear densities and moderate temperatures. The Spin Physics Detector (SPD) will be dedicated mostly to the physics with polarized ion beams in the transition region between the perturbative and non-perturbative QCD.

The major goal of SPD [2] is to study the spin structure of the proton and deuteron and the other spin related phenomena with polarized proton and deuteron beams at the luminosity up to \(10^{32} \text{ cm}^{-2} \cdot \text{s}^{-1}\) and at the collision energy \(\sqrt{s}\) up to 27 GeV. The kinematical region accessible at SPD covers the transition region from non-perturbative to perturbative QCD. The symmetries of the strong interaction, the properties of the QCD vacuum, basic properties of particles as mass and spin will be studied through different processes. The kinematical range together with the high performances expected from a modern \(\sim 4\pi\) detector and availability of both polarized proton and deuteron beams make the scientific program at SPD unique.

2. Requirements to polarized beam facility

The physics at SPD [2] put serious requirements to the beams at NICA. The required energy ranges for pp- and dd- collisions are \(\sqrt{s}=12\sim 27\ \text{GeV}\) (5\sim 12.6 \text{GeV} kinetic energy) and \(\sqrt{s}=4\sim 13\ \text{GeV}\) (2\sim 5.5 \text{GeV/u kinetic energy}), respectively. The averaged luminosity for polarized pp- collisions at \(\sqrt{s} = 27\ \text{GeV}\) to be achieved is \(\sim 10^{32} \text{ cm}^{-2} \cdot \text{s}^{-1}\) [3]. The beam lifetime and polarization degree required by SPD are a few hours and \(\sim 70\%\), respectively. Both longitudinal and transverse proton polarizations at the SPD interaction point are needed. Asymmetric pd- collision mode should be also available after NICA upgrade.

The comparison of SPD with other hadron world facilities is illustrated in Fig.2.
to the world effort in understanding the strong interaction dynamics will be obtained by the measurements of the variety of polarization observables that are accessible with colliding proton and deuteron beams polarized along and transversal to the beam direction. The SPD experiment at NICA [2] will cover the kinematic gap between the low-energy measurements at ANKE-COSY and SATURNE and the high-energy measurements at the Relativistic Heavy Ion Collider, as well as the planned fixed-target experiments at the LHC. The possibility for NICA to operate with polarized deuteron beams at such energies is unique.

The experimental results will be obtained by implementing the spin transparency mode [4]. Two solenoidal Siberian snakes will be installed in the straight sections of the collider to control the polarization direction. Only $\sim 12 \, T \cdot m$ Siberian snakes in each ring will be used at the first stage of SPD. This will provide spin transparency mode only up to $\sqrt{s} \sim 6.7 \, GeV$ for pp-collisions. At higher energies spin transparency mode will be provided at the integer spin resonances [5]. The detailed description of two schemes of the polarized proton beam formation considered for the NICA is given in ref. [6].

The new Source of Polarized Ions (SPI) [7] has been developed at JINR using part of the equipment of the IUCF Ion Source CIPIOS [8]. It was commissioned and successfully used to provide polarized deuteron beam for the first priority experiments at Nuclotron: ALPOM-2 [9] and DSS [10, 11]. The typical values of the beam polarization were $\sim 65\%-75\%$ from the ideal values both for the vector and tensor components. The possibility to accelerate the polarized proton beam at Nuclotron at 500 MeV has been also demonstrated. The measured value of the proton beam polarization was $\sim 40\%$ [12]. Physics at SPD requires a significant increasing of the beam intensity as well as the development of the spin orientation preserving system [13]. Therefore, the facility operation in pp-mode at $\sqrt{s} = 27 \, GeV$ reaching average luminosity of $\sim 10^{32} \, cm^{-2} \cdot s^{-1}$ remains the first priority task for coming years.

3. Scientific mission of SPD

3.1 Gluon probes

The polarized gluon content of proton and deuteron at intermediate and high values of the Bjorken x will be investigated using three complementary probes: inclusive production of charmonia, open charm, and prompt photons [14]. The kinematic phase-space in x and $Q^2$ to be accessed by the SPD

![Fig. 1. SPD at NICA and the other past, present, and future experiments with polarized protons.](image-url)
is compared to the corresponding ranges of previous, present and future experiments in Fig.3.1.

Fig. 2. Kinematic coverage of the SPD in the charmonia, open charm, and prompt photon production processes.

SPD is planned to operate as a universal facility for a comprehensive study of the unpolarized and polarized gluon content of the nucleon at large and moderate $x$. The experiment aims at providing access to the gluon helicity, gluon Sivers, and Boer-Mulders parton distribution functions in the nucleon, as well as the gluon transversity distribution and tensor PDFs in the deuteron, via the measurement of specific single and double spin asymmetries [2].

The cross-section for the open charm, $J/\psi$ and prompt photons production processes is shown in Fig.3.1. The study of these three channels is complementary. The largest cross section is for open charm production. Since the D-meson is reconstructed from its decay channels, $D^+ \rightarrow \pi^+ K^- \pi^+$ and $D^0 \rightarrow K^- \pi^+$, a precise secondary vertex detection displaced by $\sim 100 \mu m$ from the interaction point is required. The reaction $J/\psi \rightarrow \mu^+ \mu^-$ gives a narrow signal over a background, with a relatively large cross section and branching ratio 6%. A large fraction of $J/\psi$ is produced in the decays of heavier resonances, making the analysis more complicated. Prompt photons are carrying the information of the gluon-quark or quark-antiquark interaction. However, they need to be disentangled from a large background, particularly at low transverse momenta where photons from secondary mesons largely contribute. This physics puts very high requirements on the detector.

The results expected to be obtained by SPD will play an important role in the general understanding of the nucleon gluon content and will serve as a complementary input to the ongoing and planned studies at RHIC, and future measurements at the EIC (BNL) and fixed-target facilities at the LHC (CERN). Simultaneous measurement of the same quantities using different processes at the same experimental setup is of key importance for the minimization of possible systematic effects.

3.2 Physics at the first stage of the SPD

SPD has an extensive physics program [15] for the first stage of the NICA collider operation with reduced luminosity and collision energy of the proton and ion beams, devoted to comprehensive tests
of the various phenomenological models in the non-perturbative and transition region.

It includes such topics as the spin effects in NN elastic scattering, in exclusive reactions, in hyperons inclusive production, multiquark correlations, di-quarks dynamics, dibaryon resonances, vector meson production, deuteron short-range spin structure, scaling properties of spin observables, diffractive and hard scattering, physics of the light and intermediate nuclei collisions, hypernuclei production, dark matter searches [15].

4. Spin Physics Detector status

The SPD is being designed as a universal 4π experimental setup with advanced tracking and particle identification capabilities based on modern technologies. It is shown schematically in Fig.4. The SPD will have a cylindrical symmetry around the collider beam axis, set at the collision point, with longitudinal and transverse dimensions of ~8 m and 6.5 m, respectively. The size of the detector is limited by its weight of less than 1200 tons.

The detector will be embedded in a solenoidal magnetic field of ~1 T at the axis. The main options of the magnetic system are the superconducting solenoid or a set of superconducting coils in a single cryostat that differs from the SPD CDR option [2]. The silicon vertex detector (VD) with a low material budget will provide the resolution for the vertex position on the level of ~100 µm needed for reconstruction of secondary vertices of D- meson decays. VD will be placed as close as possible to the beryllium beam pipe (at distances of 5≤R≤25 cm). The use of Monolithic Active Pixel Sensors (MAPS) designed and produced for ALICE with the pixel size of 29 µm×27 µm improves the signal-to-background ratio of D- meson peak by a factor of 3. Micromegas technology is considered for the vertex detector at the first stage of SPD operation. The tracking system (ST) based on the straw mini-drift tubes and placed inside a solenoidal magnetic field should provide the transverse momentum resolution σ_{p_T}/p_T ≈ 2% for a particle momentum of 1 GeV/c. Information on the charged
particles energy losses will be used additionally for the identification of particles with the momenta $\leq 0.7 \text{ GeV}/c$.

The time-of-flight system (PID) based on the mRPC with a time resolution of about 60 ps will provide $3\sigma$ $\pi/K$ and $K/p$ separation of up to about 1.2 GeV/$c$ and 2.2 GeV/$c$, respectively. Possible use of the aerogel-based Cherenkov detector in the endcaps could extend this range. The sampling lead-scintillator electromagnetic calorimeter of the "shashlyk"- type (ECal) with a low energy threshold of 50 MeV and an energy resolution of $\sim 5%/\sqrt{E}$ [16] will be used for the detection of prompt photons and photons from particle decays, as well as for the identification of electrons. To minimize multiple scattering and photon conversion effects for photons, the detector material will be kept to a minimum throughout the internal part of the detector. The range system (RS) [17] planned for muon identification is optimized for the $J/\psi \rightarrow \mu^+\mu^-$ decay. It can also act as a rough hadron calorimeter. 20 layers of Fe (3-6 cm) are interleaved with gaps for mini-drift tube detectors providing 2 coordinate readout. The total weight of RS is $\sim 800$ tons, it provides at least $4\lambda_I$. The pair of beam-beam counters (BBC) [18] will be responsible for the local polarimetry by the detection of inclusive charged particles. Two zero-degree calorimeters placed at the distances $\sim 13$ m from the detector center will be used as a luminosity monitor and for ensuring the separation between neutrons and gammas.

To minimize possible systematic effects, SPD will be equipped with a triggerless DAQ system. A high collision rate up to 4 MHz at the luminosity of $\sim 10^{32}$ cm$^{-2}$ s$^{-1}$ poses a significant challenge to the DAQ, online monitoring, offline computing system, and data processing software. We expect raw data stream of 20 GB/s (or 200 PB/year). The online filter will reduce data by the order of magnitude up to $\sim 10$ PB/year.

The detailed information on the performance of SPD can be found in ref. [2].

5. Conclusions

SPD at NICA at JINR is a multipurpose $\sim 4\pi$ detector for the comprehensive QCD studies with polarized proton and deuteron beams at $\sqrt{s}$ up to 27 GeV. SPD is a facility for the study of gluon content in proton and deuteron at large $x$ and the other spin related phenomena. It is an unique facility
for polarized deuteron-deuteron collisions.

A strong tradition for polarized beams and targets exists at JINR, where unique polarized proton, neutron and deuteron beams are available in the GeV range.

This contribution is dedicated to the memory of Profs A.V. Efremov and A.D. Kovalenko.

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