Letter of Interest: The Spin Physics Detector (SPD) at the NICA collider

A. Guskov* on behalf of the SPD working group

29.8.2020

Abstract

The Spin Physics Detector at the future NICA collider at JINR (Dubna, Russia) aims to investigate the nucleon spin structure in collisions of longitudinally and transversely polarized protons and deuterons at $\sqrt{s}$ up to 27 GeV and luminosity up to 10^{32} cm^{-2} s^{-1}. The main purpose of the experiment is the test of basics of the QCD via the study of polarized gluon structure of proton and deuteron and spin-related phenomena in the collision of longitudinally and transversely polarized protons and deuterons at the center-of-mass energy up to 27 GeV (pp-collisions) and luminosity up to 10^{32} cm^{-2} s^{-1}. Other polarized and unpolarized physics is possible especially at the first stage of NICA operation with reduced luminosity and collision energy of proton and ion beams.

1 Introduction

Gluons, together with quarks, are the fundamental constituents of the nucleon playing a key role in generation of its mass and carry about half of its momentum. The spin of the nucleon is also built up from the intrinsic spin of the valence and sea quarks (spin-1/2), gluons (spin-1) and their orbital angular momenta. In spite of a progress has been made last decades, the gluon sector is much less developed than the quark one due to the difficulty to cleanly probe gluons in high-energy processes.

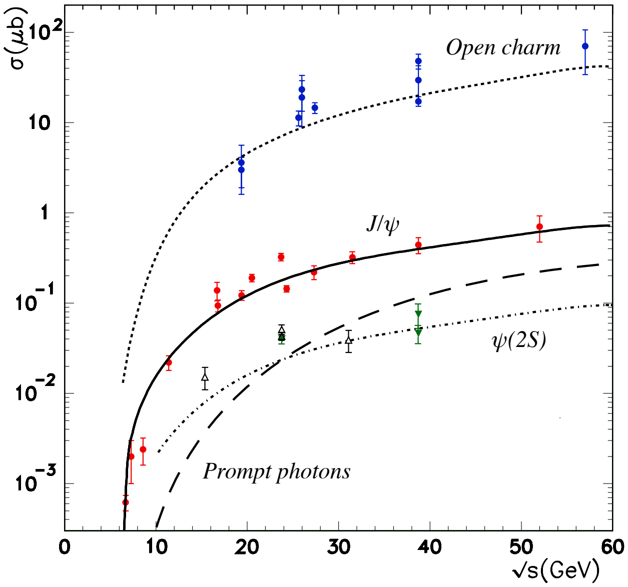
Three-dimensional partonic structure of the nucleon is a matter of a careful study in the last years. One of the ways to go beyond the usual collinear approximation is to describe nucleon content in the momentum space by the so-called Transverse-Momentum-Dependent parton distribution functions (TMD PDFs). While some experimental results exist for such LO TMD PDFs of quarks, only a few tentative attempts to measure TMD PDFs for gluon have been performed.

The simplest model of the deuteron, a weakly-bound state of a proton and a neutron, is not really helpful in the description of the deuteron structure at large Q^2. Possible non-nucleonic degrees of freedom in deuteron could play an important role in understanding of the nuclear modification of PDFs (the EMC effect). Since the gluon transversity function of nucleons as for the spin-1/2 particles is equal to zero they can not contribute directly to the gluon transversity of the deuteron. So the non-zero transversity could be an indication of a non-nucleonic component or some other exotic hadronic mechanisms within the deuteron.

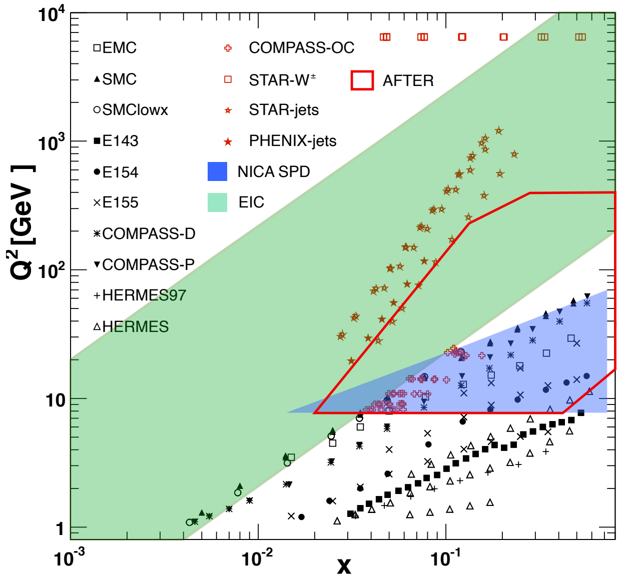
2 The Spin Physics Detector project

The Spin Physics Detector (SPD) project [1–4] at the NICA collider that is under construction at JINR (Dubna, Russia) aims to investigate the nucleon spin structure and polarization phenomena in polarized p-p and d-d collisions. The planned center-of-mass energy is up to 27 GeV while the luminosity is expected to reach 10^{32} cm^{-2} s^{-1} in the p-p collisions at maximal energy [5]. The d-d collisions will be possible at $\sqrt{s_{NN}} \leq 13.5$ GeV with of about one order of magnitude lower luminosity. Asymmetric p-d collisions

*JINR, Dubna, Alexey.Guskov@cern.ch



(a)



(b)

Figure 1: (a) The kinematic domain in the (x, Q^2) plane expected to be covered by NICA SPD by charmonia, open charm and prompt-photon production is shown in blue in comparison with other past, present, and future experiments. (b) Cross section for the processes of open charm, J/ψ, $\psi(2S)$ and prompt photons ($p_T > 3$ GeV) production as a function of center-of-mass energy.

at $\sqrt{s_{NN}} \leq 19$ GeV where one beam is polarized are also under discussion. Both vector and tensor polarizations for deuterons will be available. Spin physics programme at the SPD is expected to start after 2025 and to extend for about 10 years.

The SPD will have a unique possibility to probe gluon content employing three gluon-induced processes in parallel: the inclusive production of charmonia (J/ψ and higher states), open charm production ($gg \to c\bar{c}$), and production of the prompt photons ($gq(\bar{q} \to \gamma q(\bar{q}))$. The expected cross section (see Fig. 1(a)) and event rate for all three processes is sizable in the discussed kinematic range and the experimental setup is designed to effectively register the final states of interest. For effective registration of each above-mentioned gluon probes, the SPD setup is planned to be equipped with a range (muon) system, an electromagnetic calorimeter, a time-of-flight PID system and a silicon vertex detector. The coverage of the detector close to 4π and low material budget in the inner part of the setup should provide a large acceptance for the detected final states. The data is expected to provide inputs for gluon physics mostly in the region around $x \sim 0.1$ and to give as well a glimpse on higher x. The kinematic region to be covered by the SPD (see Fig 1(b)) is unique and has never been accessed before in polarized hadronic collisions.

3 Gluon content of proton and deuteron with SPD

The unpolarized gluon distribution $g(x)$ and the gluon Boer-Mulders TMD function $h_1^{\perp g}(x, k_T)$ [6] could be tested in unpolarized collisions at SPD via the measurement of the open charm production cross section. Unpolarized collusions could also shed light of the role of gluons in the charmonia production mechanisms [7–11].

The double longitudinal spin asymmetries A_{LL} provide access to the gluon helicity function $\Delta g(x)$ [12–16]. Quadratic dependence of the asymmetry on $\Delta g(x)$ for the charm production and linear dependence in the case of the prompt-photon production, combines high sensitivity and independence of the assumption concerning the sign of the $\Delta g(x)$ in the measurement at SPD.

The azimuthal single transverse spin asymmetries A_N is a powerful tool to study the gluon Sivers function $\Delta_N^g(x, k_T)$ and higher-twist effects in hadronic interactions [17–20]. Due to the relatively small $\sqrt{s}$ the SPD results can be used to investigate possible limits of applicability of the TMD factorization approach.

Unpolarized gluon content of the deuteron can be studied from the explicit comparison of the differential cross sections for the *p*-*p* and *p*-*d* collisions for each of the probes. The effects related to possible non-nucleonic degrees of freedom and the Fermi motion could be explored at high x [21]. Exploration of the deuteron, the simplest nuclear system, is a bridge to another physics program at NICA – the study of hot and dense hadronic matter in heavy-ion collisions [22].

The double transverse spin asymmetries A_{TT} provide a unique opportunity to explore for the first time the gluon transversity function $\Delta_T g(x)$ in the collisions of transversely polarized deuterons [23, 24]. The measurements of the tensor asymmetries with tensor-polarized deuterons could lead us to understanding the role of gluons in the tensor structure of deuteron [25, 26].

Polarized quark distributions and fragmentation functions can be accessed via the production of high-p_T hadrons. Other polarized and unpolarized physics is possible especially at the first stage of NICA operation with reduced luminosity and collision energy of proton and ion beams.

4 Summary

The study of the gluon content in the proton and deuteron at NICA SPD will be an important contribution to understanding of the general spin structure of hadrons and the QCD basis. It will be an important step, complementary to the ongoing and planned efforts at RHIC, and future facilities like EIC and fixed-target LHC. The physics program of the SPD facility is open for future exciting and challenging ideas from theorists and experimentalists worldwide.

References

[1] I. Savin, et al., Spin Physics Experiments at NICA-SPD with polarized proton and deuteron beams, EPJ Web Conf. 85 (2015) 02039.

[2] R. Tsenov, The SPD project for spin physics studies at the NICA accelerator complex, PoS SPIN2018 (2019) 163.

[3] A. Guskov, SPD — the Spin Physics Project with Polarized Proton and Deuteron Beams at the NICA Collider, JPS Conf. Proc. 26 (2019) 021018.

[4] http://spd.jinr.ru, The SPD project at JINR .

[5] I. N. Meshkov, Luminosity of an Ion Collider, Phys. Part. Nucl. 50 (6) (2019) 663–682.

[6] C. Pisano, D. Boer, S. J. Brodsky, M. G. Buffing, P. J. Mulders, Linear polarization of gluons and photons in unpolarized collider experiments, JHEP 10 (2013) 024.

[7] M. Butenschoen, B. A. Kniehl, Reconciling J/ψ production at HERA, RHIC, Tevatron, and LHC with NRQCD factorization at next-to-leading order, Phys. Rev. Lett. 106 (2011) 022003.

[8] M. Butenschoen, B. A. Kniehl, World data of J/psi production consolidate NRQCD factorization at NLO, Phys. Rev. D 84 (2011) 051501.

[9] V. Saleev, M. Nefedov, A. Shipilova, Prompt J/psi production in the Regge limit of QCD: From Tevatron to LHC, Phys. Rev. D 85 (2012) 074013.

[10] A. Karpishkov, M. Nefedov, V. Saleev, Spectra and polarizations of prompt J/ψ at the NICA within collinear parton model and parton Reggeization approach, J. Phys. Conf. Ser. 1435 (1) (2020) 012015.

[11] A. V. Karpishkov, M. A. Nefedov, V. A. Saleev, $B\bar{B}$ angular correlations at the LHC in parton Reggeization approach merged with higher-order matrix elements, Phys. Rev. D 96 (9) (2017) 096019.

[12] Y. Feng, H.-F. Zhang, Double longitudinal-spin asymmetries in J/ψ production at RHIC, JHEP 11 (2018) 136.

[13] W. Vogelsang, Prompt photon production in polarized hadron collisions, in: Deep inelastic scattering. Proceedings, 8th International Workshop, DIS 2000, Liverpool, UK, April 25-30, 2000, 2000, pp. 253–254.

[14] M. Anselmino, E. Andreeva, V. Korotkov, F. Murgia, W. D. Nowak, S. Nurushev, O. Teryaev, A. Tkabladze, On the physics potential of polarized nucleon-nucleon collisions at HERA, in: Future physics at HERA. Proceedings, Workshop, Hamburg, Germany, September 25, 1995-May 31, 1996. Vol. 1, 2, 1996.

[15] L. E. Gordon, W. Vogelsang, Inclusive prompt photon production in polarized p p collisions at HERA-N(polarized), Phys. Lett. B387 (1996) 629–636.

[16] L. E. Gordon, Constraints on Delta G from prompt photon plus jet production at HERA-N (polarized), Phys. Lett. B406 (1997) 184–192.

[17] N. Hammon, B. Ehrnsperger, A. Schaefer, Single-transverse spin asymmetry in prompt photon production, J. Phys. G24 (1998) 991–1001.

[18] J.-w. Qiu, G. F. Sterman, Single transverse spin asymmetries, Phys. Rev. Lett. 67 (1991) 2264–2267.

[19] R. M. Godbole, A. Kaushik, A. Misra, V. Rawoot, B. Sonawane, Transverse single spin asymmetry in $p + p^{\uparrow} \to J/\psi + X$, Phys. Rev. D 96 (9) (2017) 096025.

[20] A. Karpishkov, M. Nefedov, V. Saleev, Estimates for the single-spin asymmetries in $p^{\uparrow}p \to J/\psi X$ process at PHENIX RHIC and SPD NICA .

[21] S. J. Brodsky, K. Y.-J. Chiu, J.-P. Lansberg, N. Yamanaka, The gluon and charm content of the deuteron, Phys. Lett. B 783 (2018) 287–293.

[22] V. Golovatyuk, V. Kekelidze, V. Kolesnikov, O. Rogachevsky, A. Sorin, Multi-Purpose Detector to study heavy-ion collisions at the NICA collider, Nucl. Phys. A 982 (2019) 963–966.

[23] R. Jaffe, A. Manohar, NUCLEAR GLUONOMETRY, Phys. Lett. B 223 (1989) 218–224.

[24] S. Kumano, Q.-T. Song, Gluon transversity in polarized proton-deuteron Drell-Yan process, Phys. Rev. D 101 (5) (2020) 054011.

[25] A. Efremov, O. Teryaev, ON HIGH P(T) VECTOR MESONS SPIN ALIGNMENT, Sov. J. Nucl. Phys. 36 (1982) 557.

[26] A. Efremov, O. Teryaev, On the oscillations of the tensor spin structure function, in: International Symposium: Dubna Deuteron 93, 1994.