Systematic Study of Spin Effects at SPASCHARM Experiment at 70-GeV Accelerator in Protvino

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Published 29 February 2016

A new experiment SPASCHARM for systematic study of polarization phenomena in the inclusive and exclusive hadronic reactions in the energy range of IHEP accelerator U-70 (12–50 GeV) is currently under development. The universal experimental setup will detect dozens of various resonances and stable particles produced in collisions of unpolarized beams with the polarized target, and at the next stage, using polarized proton and antiproton beams. At the beginning, the final states consisting of light quarks (u , d , s) will be reconstructed, and later on the charmonium states will be studied. Measurements are planned for a variety of beams: $\pi^\pm$, $K^\pm$, p , antiprotons. Hyperon polarization and spin density matrix elements of the vector mesons will be measured along with the single-spin asymmetry (SSA). The 2π -acceptance in azimuth, which is extremely useful for reduction of systematic errors in measurements of spin observables, will be implemented in the experiment. The solid angle acceptance of the setup, $\Delta\theta \approx 250$ mrad vertically and 350 mrad horizontally in the beam fragmentation region, covers a wide range of kinematic variables p_T and x_F . This provides the opportunity for separating dependences on these two variables which is usually not possible in the setups with a small solid angle acceptance. Unlike some previous polarization experiments, the SPASCHARM will be able to simultaneously accumulate and record data on the both, charged and neutral particle production.

Keywords: Spin; polarization; asymmetry; decays; protons; antiprotons; charmonium.

PACS numbers: 41.85.-p, 13.30.-a, 13.88.+e, 13.85.Dz

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1. Introduction

The interest in studying spin dependences in strong interactions arises from the study of hadron's spin structure through interactions of the constituent partons having non-zero spin. In recent years, there has been a considerable progress achieved in the experimental study of spin effects at high energies. Theoretical understanding of spin effects is being developed. Today, however, there is still no theory, claiming a complete and consistent description of polarization phenomena in strong interactions.

New experimental results in this difficult area for theorists are important and relevant to the development of the theory. The new experimental program, the SPASCHARM for 70-GeV proton synchrotron (U-70), is currently under development at the Institute for High Energy Physics (IHEP), Protvino, Russia. The main physics motivation of the SPASCHARM experiment is the systematic study of spin phenomena for a wide range of inclusive and exclusive reactions in collisions of high-energy polarized hadrons in the QCD non-perturbative region. This opens the possibility to detect charged and neutral particles in the final state in a large solid angle in the energy range of 12–50 GeV. Along with a number of various beams available in the channel, including polarized proton and antiproton beams at the second stage of the experiment, the large acceptance would allow us to explore dozens of different reactions.

2. Physics Motivation

The most valuable information is related to the dynamics of strong interactions of quarks and hadrons in the scope of confinement. Spin effects may be associated with such fundamental issues as the spontaneous breaking of chiral symmetry, the mass of quarks and hadrons, formation of quasiparticles in hadrons — the constituent quarks [1].

In perturbation theory of QCD at leading twist, the transverse single-spin asymmetries are predicted close to zero [2]. Consequently, these asymmetries are very sensitive to the effects that go beyond the standard perturbative QCD. Large spin effects found in a number of experiments in the confinement region stimulated the development of theoretical models.

The theoretical models by Sivers [3], Collins [4], and the quark-gluon correlators [5] (twist-3 effects) are well known today. These models predict decreasing single-spin asymmetries in the formation of hadrons as the transverse momentum p_T increases. However, these predictions still are not confirmed in the experiments carried out over a wide energy range, $2 < \sqrt{s} < 200$ GeV, at a moderate $p_T < 3$ GeV/c.

Few phenomenological models qualitatively explain the polarization of hyperons. In the semi-classical Anderson model, it is considered due to creation of $s\bar{s}$ -pair

in the color string field [6]. Another quasi-classical model uses the known effect of Thomas precession [7] and the dependence of the precession sign on the quark acceleration or deceleration in the process of quark recombination into hadrons [8].

Model of multiple scattering of quarks at quarks and gluons describes the polarization of baryons with large transverse momenta [9]. The orbital motion of the constituent quarks may be the cause of the observed polarization effects as well [10, 11]. The orbital motion of a current quark in the internal structure of constituent quarks is considered in the Troshin-Tyurin's model [12]. We should also mention the chiral quark model in combination with the unitarity and an impact parameter picture [13].

The coupling of a quark chromomagnetic moment to chromomagnetic field of a QCD string leads to an appearance of additional quark transverse momentum, the direction of which depends on the direction of the quark spin in polarized proton [14, 15].

In order to discriminate the various theoretical approaches, the systematic studies of single-spin transverse asymmetries in a large number of exclusive and inclusive reactions are needed. Such a program can be carried out at the first stage of polarization program of the proposed SPASCHARM experiment. The measurements of single-spin asymmetry A_N in exclusive and inclusive light resonance production at polarized target are planned. These measurements would allow the determination of impact of quark flavor on spin asymmetry along with the discrimination of theoretical models.

3. The Main Objectives of the Experiment

At the first stage of SPASCHARM experiment, the main task is a detailed study of various polarization effects in the production of particles and resonances, consisting mainly of light u , d and s -quarks. Most of the measurements will be performed at the negatively charged unpolarized beam colliding with the polarized target. Composition of the beam ($\pi^-/K^-/\bar{p}$) = (97.9/1.8/0.3%) makes it possible to study the processes initiated by antiquarks and strange quarks. Such data can't be obtained, for example, at pp collider. It is known that single-spin asymmetries for majority of the studied reactions are close to zero in the fragmentation region of unpolarized protons. Surprisingly, in collisions of mesons with polarized targets, the non-zero single-spin asymmetries have been observed as in central [16, 17] as well as in unpolarized beam fragmentation [18–21] regions. This might be due to the asymmetry of initial states with respect to permutation of colliding particles.

Unlike in the most previous experiments, at SPASCHARM it will be implemented 2π -acceptance in azimuth which is very useful for reduction of the systematic errors in measurements of spin physics observables. The large acceptance setup allows us to carry out the spin measurements in a wide range of kinematic variables

(p_T, x_F) and separate the asymmetry dependences on these two variables. It is usually not possible in experiments with a narrow angular acceptance.

The exclusive reactions, such as $\pi^- p_\uparrow \rightarrow \omega(782)n$, $\pi^- p_\uparrow \rightarrow \eta'(958)n$, $\pi^- p_\uparrow \rightarrow f_2(1270)n$, $\pi^- p_\uparrow \rightarrow a_2(1320)n$ and others, will be investigated in various decay modes into neutral and charged particles. Previously, these reactions have been studied at the PROZA experiment only in the mode of their decays into π^0 -mesons and γ -quanta, which significantly restricted the accumulated statistics. In SPASCHARM, because of capabilities for detecting the charged decay channels, it is expected to increase the statistics compared to PROZA experiment by about an order of magnitude for reactions $\pi^- p_\uparrow \rightarrow \omega(782)n$ and $\pi^- p_\uparrow \rightarrow \eta'(958)n$, as well as, by a factor of 3–4, for the reactions $\pi^- p_\uparrow \rightarrow f_2(1270)n$ and $\pi^- p_\uparrow \rightarrow a_2(1320)n$. Spin effects observed at PROZA for all these reactions are at the scale of ~ 20 –40%. A significant increase in statistics in SPASCHARM will allow the precise measurement of t -dependence of single-spin asymmetries in these reactions as well as making discrimination against some theoretical approaches for the description of spin effects in these reactions. It worth noting that, for the first time, the asymmetry in reaction $\pi^- p_\uparrow \rightarrow a_0(980)n$ will be measured in the mode of $a_0(980)$ decaying into $\eta(550)$ and π^0 . The size of a single-spin asymmetry of more than 50% in this reaction has been predicted in Ref. [22].

A large amount of data on non-zero spin asymmetries in a variety of inclusive reactions has been accumulated up until now. The global analysis of all available data has revealed interesting peculiarities associated with the dependences of polarization effects on kinematic variables, the quark flavor and atomic weights of particles participating in reactions [23]. Significant effects are expected near the edges of kinematics allowed phase space, as the large spin effects have been seen in the respective exclusive charge-exchange reactions. Thus, it is believed that, for a wide range of reactions available for study at SPASCHARM setup with meson beams, a number of nonzero single-spin transverse asymmetries A_N will be uncovered. The asymmetry A_N will be measured in a variety of inclusive reactions with high precision due to full azimuth coverage within the wide aperture (see Table 1). The kinematic region to be covered is $0.2 < x_F < 1$ and $0.5 < p_T < 3 \text{ GeV}/c$. The energy range is $12 < E_{\text{beam}} < 50 \text{ GeV}$. The hyperon polarization and vector meson spin alignment will be measured as well.

At the second stage of the experiment, as soon as polarized proton (an intensity of up to $\sim 10^7$ per 9-second accelerator cycle) and polarized antiproton (an intensity of up to $\sim 4 \cdot 10^5/\text{cycle}$) beams with the average polarization of 40–45% are available, the charmonium studies will be carried out. These will include the measurements of double-spin asymmetry A_{LL} in spin-2 state χ_{2c} (3555) production in order to estimate the gluon contribution into the spin of proton.

Table 1. The anticipated numbers of events collected for the inclusive reactions for three months of detector exposition at π^- beam with the energy of 34 GeV at the first stage of SPASCHARM experiment. B/S is the background to signal ratio.

№	частица	N_{EV}	S/B	№	частица	N_{EV}	S/B
1	π^+	$4.2 \cdot 10^9$		20	$\eta \rightarrow \pi^+ \pi^- \pi^0$	$5.3 \cdot 10^6$	5
2	π^-	$8.7 \cdot 10^9$		21	$\omega(782) \rightarrow \pi^+ \pi^- \pi^0$	$3.5 \cdot 10^7$	4
3	K^+	$6.7 \cdot 10^8$		22	$\omega(782) \rightarrow \gamma \pi^0$	$3.8 \cdot 10^7$	0.5
4	K^-	$9.0 \cdot 10^8$		23	$\phi(1020) \rightarrow K^+ K^-$	$4.3 \cdot 10^6$	3.3
5	p	$9.2 \cdot 10^7$		24	$\rho^+(770) \rightarrow \pi^+ \pi^0$	$2.9 \cdot 10^8$	0.17
6	$\bar{p}$	$2.6 \cdot 10^8$		25	$\rho^-(770) \rightarrow \pi^- \pi^0$	$7.5 \cdot 10^8$	0.33
7	n	$3.2 \cdot 10^8$		26	$K_S^0 \rightarrow \pi^0 \pi^0$	$1.7 \cdot 10^7$	0.29
8	$\bar{n}$	$8.0 \cdot 10^7$		27	$a_0(980) \rightarrow \eta \pi^0$	$1.8 \cdot 10^7$	0.11
9	K_L^0	$1.0 \cdot 10^8$		28	$\Lambda \rightarrow p \pi^-$	$1.4 \cdot 10^6$	10
10	$\pi^0 \rightarrow \gamma\gamma$	$4.3 \cdot 10^9$	10	29	$\tilde{\Lambda} \rightarrow \bar{p} \pi^+$	$1.1 \cdot 10^6$	20
11	$\eta \rightarrow \gamma\gamma$	$4.2 \cdot 10^8$	2	30	$\Lambda \rightarrow n \pi^0$	$1.8 \cdot 10^6$	0.33
12	$\eta' \rightarrow \pi^+ \pi^- \eta$	$8.3 \cdot 10^5$	20	31	$\tilde{\Lambda} \rightarrow \bar{n} \pi^0$	$7.7 \cdot 10^5$	2.2
13	$K_S^0 \rightarrow \pi^+ \pi^-$	$1.3 \cdot 10^7$	3.3	32	$\Delta^{++} \rightarrow p \pi^+$	$9.3 \cdot 10^6$	0.5
14	$\rho^0(770) \rightarrow \pi^+ \pi^-$	$4.2 \cdot 10^8$	0.4	33	$\Delta^- \rightarrow \bar{p} \pi^-$	$2.5 \cdot 10^7$	0.18
15	$K^{0*}(892) \rightarrow K^+ \pi^-$	$1.1 \cdot 10^8$	1.4	34	$\Xi^- \rightarrow \Lambda \pi^-$	$1.9 \cdot 10^6$	10
16	$\tilde{K}^{0*}(892) \rightarrow K^- \pi^+$	$4.3 \cdot 10^7$	0.5	35	$\tilde{\Xi}^+ \rightarrow \tilde{\Lambda} \pi^+$	$1.6 \cdot 10^6$	10
17	$K^{+*}(892) \rightarrow K^+ \pi^0$	$1.9 \cdot 10^7$	0.38	36	$\Sigma^0 \rightarrow \Lambda \gamma$	$1.2 \cdot 10^6$	2
18	$\tilde{K}^{-*}(892) \rightarrow K^- \pi^0$	$3.8 \cdot 10^7$	0.77	37	$\Sigma^0(1385) \rightarrow \Lambda \pi^0$	$3.9 \cdot 10^6$	5
19	$\omega(782) \rightarrow e^+ e^-$	$1.7 \cdot 10^5$	2	38	$\rho^0(770) \rightarrow \mu^+ \mu^-$	$9.7 \cdot 10^4$	1.43

4. Experimental Setup

The experimental setup of the first phase of SPASCHARM experiment is a spectrometer for detection of charged particles, neutrons, K_L^0 -mesons and photons in the forward region. The setup has the 2π coverage in azimuth. This is the critical advantage for minimizing the systematic errors in the measurement of spin asymmetries. The layout of the setup is presented in Fig. 1. It consists of the polarized proton

Fig. 1. The layout of SPASCHARM experiment. See text for details.

target, tracking system with the excellent spatial resolution, spectrometric large aperture magnet, identification of the secondary particles, electromagnetic and hadron calorimeters, and muon detector. There are also charged particle multiplicity detectors which serve also as a time-of-flight system (three hodoscopes in front of and behind the spectrometer magnet as well as in front of the electromagnetic calorimeter), the guard system for the target, and trigger counters.

The tracking system is based on 3,000 channels of drift tubes with 15 and 30 mm in diameter and few GEM-detectors. Currently, we have the operational lead-glass electromagnetic calorimeter. Later on, we plan to replace it with the thin-segmented shashlyk-type calorimeter with the significantly better energy resolution (stochastic term is anticipated at the level of $\sim 3\text{--}4\%$) [24].

5. Summary

A new polarization experiment, the SPASCHARM, designed for systematic study of polarization phenomena in hadron-hadron interactions, is under commissioning now at the beam channel 14 of 70-GeV accelerator of IHEP, Protvino, Russia. Simultaneous detection of charged and neutral particles in the final state in a wide solid angle will allow us to explore dozens of inclusive and exclusive reactions with a number of beam particles in the energy range from 12 to 50 GeV and with various targets. The special feature of the experiment is the simultaneous measurements of different spin-physics observables: SSA, polarization of hyperons, spin density matrix elements for vector mesons, spin-transfer parameters. We expect to have the first physics results by the year 2017.

Polarized proton and polarized anti-proton beams at the second stage of the experiment will provide an unique opportunity for studying the single-spin spin effects in the polarized beam fragmentation region for various nuclear targets as well as studying the double-spin asymmetries in charmonium production with the goal to evaluate the gluon contribution into the spin of proton. The SPASCHARM setup has all the tools for high precision determination of all particle kinematic parameters which is crucial for charmonium study as well as for the extraction of resonance signals from combinatorial background. We plan to start working at the new channel 24 with polarized proton and antiproton beams in 2018.

Acknowledgments

We thank the IHEP management and the IHEP Accelerator, Beam and Electronics departments for their invaluable contribution in construction and commissioning of the setup at the beam, and for their support of the SPASCHARM program. This work was supported in part by the RFBR grants # 12-02-00737-a and # 15-02-01669-a.

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