Study of single-spin asymmetries with polarized target at the SPASCHARM experiment at U70 accelerator

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Abstract. A new experiment SPASCHARM for systematic study of polarization phenomena in inclusive and exclusive hadronic reactions is currently under commissioning at IHEP. 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 beams. At the first stage with polarized target, the final states composed of light quarks ($u$, $d$, $s$) will be reconstructed. Hyperon polarization and spin density matrix elements of the vector mesons will be measured along with the single-spin asymmetries. The $2\pi$-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.

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. 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 physics for a wide range of inclusive and exclusive reactions in collisions of high-energy polarized hadrons in the QCD non-perturbative region.
2. Physics Motivation

In perturbation theory of QCD at leading twist, the transverse single-spin asymmetries are predicted close to zero [1]. Large spin effects found in a number of experiments in the confinement region stimulated the development of theoretical models. The theoretical models by Sivers [2], Collins [3], and the quark-gluon correlators [4] 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 [5-7]. 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 [8,9]. 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 [10].

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 required. Such a program can be carried out at the first stage of polarization program of the proposed SPASCHARM 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 $(\pi/K) = (97.9/1.8/0.3\%)$ makes it possible to study the processes initiated by antiquarks and strange quarks. Surprisingly, in collisions of mesons with polarized targets, the non-zero single-spin asymmetries have been observed as in central [11, 12] as well as in unpolarized beam fragmentation [13-15] regions.

Unlike in the most experiments, at SPASCHARM it will be implemented $2\pi$-acceptance in azimuth for both charged and neutral secondary particles, 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 to separate the asymmetry dependences on these two variables.

The exclusive reactions, such as $\pi p \rightarrow \omega(782)n$, $\pi p \rightarrow \eta(958)n$, $\pi p \rightarrow f_2(1270)n$, $\pi p \rightarrow a_2(1320)n$ and others, will be investigated in various decay modes into neutral and charged particles. Previously, these reactions have been studied at PROZA experiment only in the mode of their decays into $J/\psi$-mesons and $\gamma$-quanta. In SPASCHARM, because of its 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 $\pi p \rightarrow \omega(782)n$ and $\pi p \rightarrow \eta(958)n$, as well as, by a factor of 3-4, for the reactions $\pi p \rightarrow f_2(1270)n$ and $\pi p \rightarrow a_2(1320)n$. 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 $\pi p \rightarrow a_2(980)n$ will be measured in the mode of $a_2(980)$ decaying into $\eta(550)$ and $J/\psi$.

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. The expected statistics with pion beam presented earlier [16-17]. Expected statistics in the interaction of antiprotons on polarized target is presented in table 1. The kinematic region to be covered is $0.2 < x_F < 1$ and $0.5 < p_T < 3$ GeV/$c$. 
Table 1. The anticipated numbers of events collected for the inclusive reactions for three months of detector exposition at $\bar{p}$ beam with the energy of 34 GeV at the first stage of SPASCHARM experiment.

| № | частица | $N_{EV}$ | № | частица | $N_{EV}$ |
|---|---------|----------|---|---------|----------|
| 1 | $\pi^+$ | $2.1\cdot10^8$ | 7 | $n$ | $1.6\cdot10^7$ |
| 2 | $\pi^-$ | $2.6\cdot10^8$ | 8 | $\bar{n}$ | $1.4\cdot10^8$ |
| 3 | $K^+$ | $1.7\cdot10^7$ | 9 | $\bar{A}\rightarrow \bar{p}\pi^+$ | $2.1\cdot10^6$ |
| 4 | $K^-$ | $2.2\cdot10^7$ | 10 | $\bar{A}\rightarrow \bar{n}\pi^0$ | $1.1\cdot10^6$ |
| 5 | $p$ | $1.6\cdot10^7$ | 11 | $\bar{A}^-\rightarrow \bar{p}\pi^-$ | $4.2\cdot10^7$ |
| 6 | $\bar{p}$ | $1.8\cdot10^8$ | 12 | $\Xi^-\rightarrow \Lambda\pi^-$ | $1.0\cdot10^5$ |

3. 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 $2\pi$ 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 figure 1. It consists of the polarized proton 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.

Figure 1. The layout of SPASCHARM experiment.

Special spectrometer magnet of wide aperture ($X\times Y=200\times100$ cm$^2$) has been specially designed and build (see figure 2). The newly developed tracking system is based on 3,000 channels of drift tubes with 15 and 30 mm in diameter and few GEM-detectors. Drift tube system consists of five thin-wall drift tube chamber stations (16 planes, 48 sub-planes). The tracking system has been designed with goal of achievement of the momentum resolution $\Delta P/P=0.4\%$ at 10 GeV/c with the maximum field.

Three of such stations were commissioned (two of them are shown on figure 3). The on-line profile of the events in $X$-plane of station DC3 is shown on figure 4 (left). The resolution of the drift chambers has been tested. The result of the test (residual distribution) is presented in the same figure 4 (right). It was found in accord with the specification requirements (<160 μm).
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 \(\sigma(E)/E = 1.3 \oplus 2.8/\sqrt{E}\) [18-19] with the cell transverse dimensions of 55×55 mm\(^2\) and the total area of 2×3 m\(^2\).

The compensated lead-scintillator hadron calorimeter has a cell size 10×10 cm\(^2\), thickness 8 nuclear interaction lengths and sampling of 16 mm lead, 4 mm scintillator. The hadronic energy resolution of the calorimeter is 57%/\(\sqrt{E}\), the nonuniformity is better than 10% and the measured ratio \(e/h = 1.01\) [20].

Two multichannel Cherenkov counters will be used for particle identification. The first one registers \(\pi\)-mesons above 3 GeV/c and \(K\)-mesons above 11 GeV/c, while the second one registers pions above 6 GeV/c and kaons above 23 GeV/c. We plan in future to produce also the TOF wall (marked as H3 in figure 1) for \(p/K\)-separation up to 2.5 GeV, and \(K/\pi\) separation up to 1.5 GeV. Muon detector will consist of 3 layers of iron and drift tube chambers.

New DAQ with parallel reading of electronics has been designed and successfully tested for the SPASCHARM experiment. The information can be read at the speed of about 20 \(\mu\)sec/event from an ADC station and 30-50 \(\mu\)sec/event from a TDC crate. In the test run, the achieved rate for accepted events was 10000 events/0.8 sec. We expect to store about \(5 \cdot 10^4\) events/cycle, while the total event rate expected to be at about \(10^5\) per cycle.
The first experience with the system confirmed its capabilities for measuring the spin asymmetry for charged particles. We successfully reconstructed about the expected number of $\Delta^-$ and of $\Delta^{++}$ in $h^+/h^+\perp$ spectra even without particle identification.

4. The experiment schedule
The current schedule of the experiments looks as follows:

- Autumn 2015 – data taking run about one week long to test the new electronics and DAQ system and tune up their characteristics, commissioning of inclined planes of TDC station, calibration of the electromagnetic calorimeter with the new ADCs.
- 2016 – commissioning of the 4th TDC station, testing and preparation of the new “narrow” TDC station, data taking with “pions” (without Cherenkov counters) to measure a single-spin asymmetry in production of $h^\pm$, $h^\mp$, $\omega(782)$, $f_0(980)$, $a_0(980)$, $f_2(1270)$.
- 2017 – commissioning of the full tracking system, consisting of five stations of Drift Tube chambers, installation of the Cherenkov counter with the goal to measure spin effects in production of $K$-mesons, hyperons and especially of $\phi$-meson.

In the Spring of 2019, we plan to move to the polarized beam channel 24A [16, 21] which is expected to start operating by the end of the same year. The measurements with the polarized proton and antiproton beams would bring the new quality into the spin physics studies at SPASCHARM. However, the 2nd stage of the SPASCHARM program [16] is beyond the scope of this paper.

5. Summary
The new experiment, SPASCHEAR, designed for systematic studies of polarization phenomena in hadron-hadron interactions, is under commissioning now at the 70-GeV accelerator of IHEP, Protvino, Russia. The detection capabilities for the charged and neutral final state particles in a wide acceptance of SPASCHEAR spectrometer provide an opportunity for exploring dozens of inclusive and exclusive reactions with a number of beam particles.

It worth mentioning the possibility of simultaneous measurements of different spin-physics observables: SSA, polarization of hyperons, spin density matrix elements for vector mesons, spin-transfer parameters. In the year 2016, we expect to begin taking data at the existing channel with unpolarized beam. The first physics results are expected in about a year later.

An availability of the polarized proton and antiproton beams at the second stage of the experiment will provide an unique opportunity for studying the single-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 the charmonium studies as well as for the extraction of resonance
signals from combinatorial backgrounds. We plan to start working at the new channel 24 with polarized proton and antiproton beams in the year 2019.

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