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

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Abstract. The new SPASCHARM experiment for systematic studies of polarization phenomena in strong interactions is under construction now at IHEP, Protvino. The technical beam runs for the experiment first stage are planned for the Fall 2016 and Spring 2017. At this stage, the polarization measurements will be carried out with unpolarized hadronic beams of various compositions ($\pi^{\pm}$, $K^{\pm}$, p, antiprotons), using the polarized target. The universal large acceptance experimental set-up is capable detecting and identification most charged and neutral particles and reconstructing a large number of resonances produced in beam interactions at polarized proton target, and later on at the second stage, in collisions of polarized proton and antiproton beams with fixed targets of various materials. The large acceptance and wide data acquisition bandwidth would provide the capabilities for simultaneous data accumulation for a number of physics analyses from the measurements of single-spin asymmetries in inclusive and exclusive reactions to reconstructions of final state hyperon polarizations and spin density matrix elements for vector mesons in a wide range of kinematic variables (p_T, x_F).

1. Introduction

The new experiment SPASCHARM is currently under development at the 70 GeV proton synchrotron in the Institute for High Energy Physics National Research Centre Kurchatov Institute (Protvino). The main physics motivation for 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.

The concept of spin was introduced first time almost 100 years ago and is a fundamental intrinsic property of elementary quantum objects, including leptons, hadrons, atomic nuclei and atoms. Spin properties of hadrons are not fully understood. "Experiments with spin have killed more theories than any other physical parameter"[1].

Physicists expected naively the proton spin being a simple sum of spins of quarks, but the experiments have found that only 1/3 of the proton spin is carried out by quarks. The contribution of gluon spin and of orbital angular momentum of quarks to the proton spin still are not well established.

The main goal of the SPASCHARM experiment is studying the spin structure of nucleons as well as the dynamics of strong interactions of polarized hadrons.

2. Physics Motivation

The first stage of the SPASCHARM experiment is devoted to the study of single-spin effects. The single-spin asymmetry (SSA) A_N is defined as the dependence of particle production cross-section on the direction perpendicular to the plane defined by the vectors of initial proton momentum and spin. In a simple terms, with nonzero A_N, for the vertical polarization of initial proton, there is a difference in a number of particle in final state going to the left and to the right.

The experimentally observed sizeable single-spin asymmetries in a number of inclusive and exclusive hadronic reactions still are not understood from the first principles of the current theory of strong interactions.

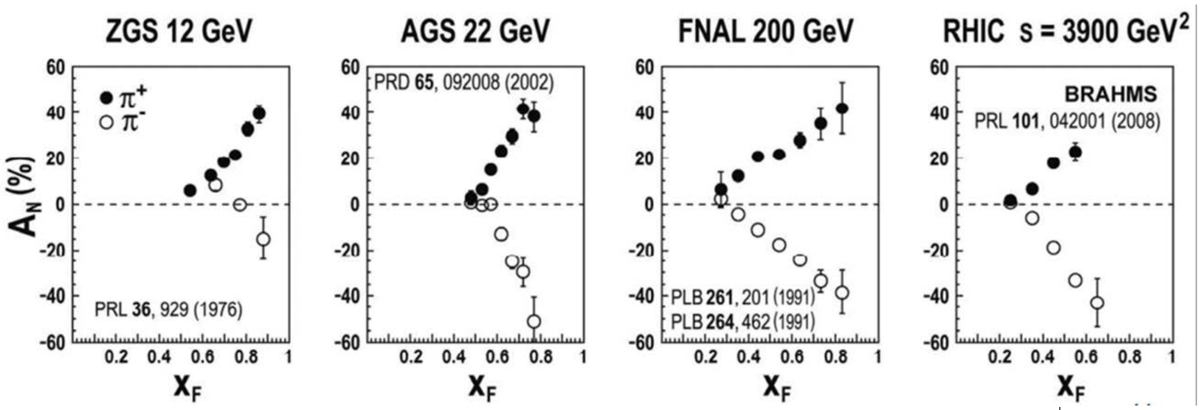

Figure 1. The results of four different SSA measuremens in the reaction $p_{\uparrow}p \rightarrow \pi^{+}X$.

Some results of the SSA measurements are presented in figure 1 for four experiments [1-4] at the energies varied in the wide range. Contrary to the earlier theoretical expectations [5] the behaviour of the asymmetry virtually does not depend on energy. Most of the currently popular models (Sivers [6] and Collins [7] functions, higher twist contributions [8]) predict the decrease of A_N as the transverse momentum of secondary particles increases. This is not confirmed by by the experiments either.

Due to the observed weak dependence of A_N on energy, it is not unnatural to assume the commonality of the underlying mechanism behind the SSA at all energies. Such an assumption makes it sensible to attempt exploring this mechanism at any available energy.

The main goal of the first stage of the experiment is the study of SSA in inclusive and exclusive reactions, including elastic scattering, for the hadrons consisting of light (u, d, s) quarks in the un-polarized beam fragmentation region with the use of polarized frozen target. Unlike in the most experiments, the acceptance of the SPASCHARM detector covers full 2π in azimuth for the both charged and neutral secondary particles. This is extremely helpful for reduction of the systematic errors in measurements of spin physics observables. Most of the measurements will be performed at the negatively charged un-polarized beam colliding with the polarized target. Composition of the beam

[1] Eliot Leader, Spin in particle physics, Cambridge U. Press (2001)

($\pi^-/K^-/\tilde{p}$) = (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 not only in the central [9-10] and polarized target fragmentation region [11-13], but also in the un-polarized beam fragmentation region [14-16]. The hyperon and vector mesons polarization and depolarization will be measured too.

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Table 1. The estimated numbers of events for the inclusive reactions collected for one month of detector exposition to K^--beam of the energy 34 GeV at the first stage of the SPASCHARM experiment.

№	*Secondary particle detected*	N_{EV}	*№*	*Secondary particle detected*	N_{EV}
1	π^+	$6.7\cdot10^8$	*13*	$\rho^-(770)\to\pi^-\pi^0$	$7.5\cdot10^7$
2	π^-	$8.9\cdot10^8$	*14*	$\eta'\to\gamma\gamma$	$7.3\cdot10^5$
3	K^+	$8.9\cdot10^7$	*15*	$\varphi(1020)\to K^+K^-$	$1.0\cdot10^7$
4	K^-	$4.0\cdot10^8$	*16*	$K^{0*}(892)\to K^+\pi^-$	$1.3\cdot10^7$
5	p	$6.8\cdot10^7$	*17*	$\tilde{K}^{0*}(892)\to K^-\pi^+$	$6.6\cdot10^7$
6	$\tilde{p}$	$3.7\cdot10^7$	*18*	$K^{-*}(892)\to K^-\pi^0$	$3.4\cdot10^7$
7	n	$6.2\cdot10^7$	*19*	$\Xi^-\to\Lambda\pi^-$	$2.5\cdot10^6$
8	$\pi^0\to\gamma\gamma$	$4.2\cdot10^8$	*20*	$\Lambda\to p\,\pi^-$	$1.8\cdot10^6$
9	$\eta\to\gamma\gamma$	$2.5\cdot10^7$	*21*	$\tilde{\Lambda}\to\tilde{p}\,\pi^+$	$2.9\cdot10^5$
10	$K^0_S\to\pi^+\pi^-$	$2.2\cdot10^7$	*22*	$\Lambda\to n\,\pi^0$	$4.0\cdot10^5$
11	$\rho^0(770)\to\pi^+\pi^-$	$6.8\cdot10^7$	*23*	$\Sigma^-\to n\,\pi^-$	$3.1\cdot10^6$
12	$K^0_S\to\pi^0\pi^0$	$4.2\cdot10^6$			

The estimated statistics in various reactions at kaon beam are presented in table 1 (earlier, the same information has been presented for pion [16] and un-polarized antiproton [17] beams). The simulated mass spectra for a number of reactions with kaon beam are presented in figure 2.

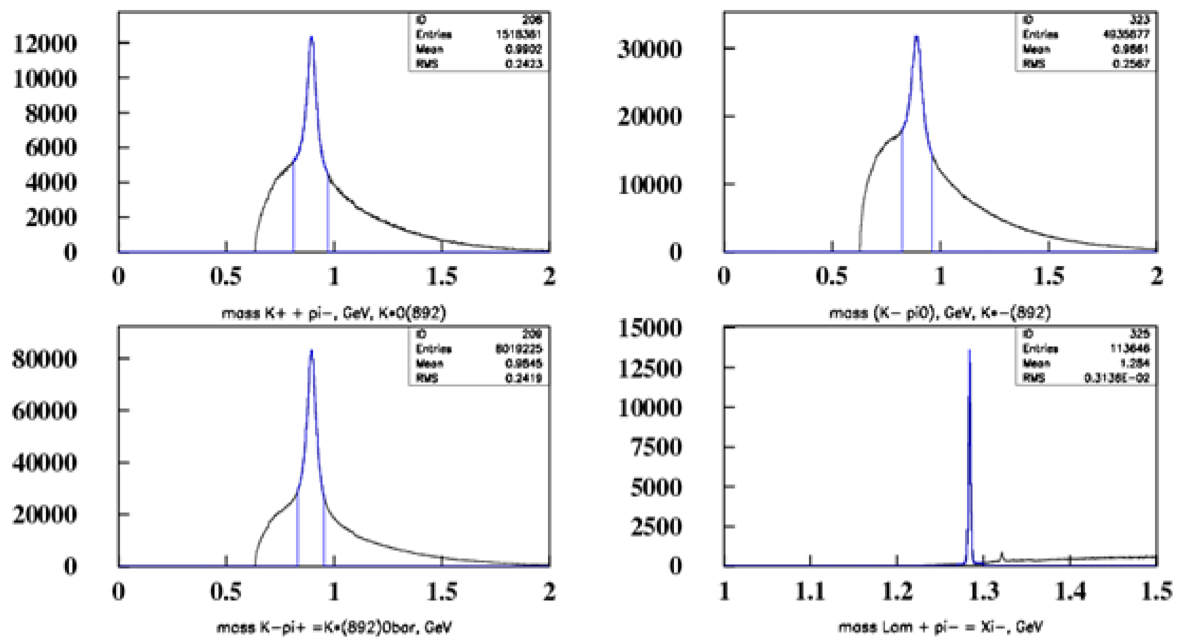

Figure 2. Effective mass distributions for secondary particles in reactions $K^-p\to h+x$: $h=K^{0*}(892)\to K^+\pi^-$; $h=\tilde{K}^{0*}(892)\to K^-\pi^+$; $h=K^{-*}(892)\to K^-\pi^0$ and $h=\Xi^-\to\Lambda\pi^-$.

Later on, the SSA measurements will be studied using polarized beams. The anticipated high precision results will cover the spin-effect dependences on kinematic variables ($0<x_F<1$, $0<p_T<2.5$, $12<E_{Beam}<50$ GeV) as well as on event multiplicity, and for various target nuclei.

The ultimate goal of the experiment is the measurement of spin effects in charmonium production. Single-spin asymmetry A_N in J/ψ and χ_1/χ_2 inclusive production will be measured using the both polarized proton and antiproton beams. In the order to study gluon polarization $\Delta G/G(x)$ at large x_F, the double-spin asymmetry A_{LL} in charmonium production will be measured. An attempt for A_{NN} measurements for Drell-Yan pairs will be undertaken with purpose to reach the transversity *h(x)*. The statistics on the order of 20000 J/ψ events and of 2500 χ_1/χ_2 states are expected for about 40 days of data taking. In order to highlight the mechanism of charmonium production, the cross-section ratio for χ_1/χ_2 production will be measured at the pion, antiproton and proton beams.

3. Experimental setup

The experimental setup of the first phase of the SPASCHARM experiment represents the spectrometer capable of detecting of charged particles, neutrons, K_L^0-mesons and photons in the forward region. It has the full 2π coverage in azimuth. This is an important advantage for minimizing the systematic errors in the measurement of spin asymmetries. The layout of the setup has been presented in details earlier [18].

The dedicated for the SPASCHARM wide-aperture spectrometer magnet ($X\times Y$=200×100 cm^2) has been specially designed and build. The newly developed tracking system is comprises of 3,000 channels of drift tubes with 15 and 30 mm in diameter and few GEM-detectors. The tracking system has been designed with goal to achieve the momentum resolution $\Delta P/P$=0.4% at 10 GeV/c with the maximum field. Four drift tube stations have been were commissioned. Their resolution, better than 160 μm, is agreement with the specification requirements.

Currently, we have the operational lead-glass electromagnetic calorimeter. Later on, we plan to replace it with the thin-segmented shashlyk-type calorimeter of the much better energy resolution: $\sigma(E)/E=1.3\oplus2.8/\sqrt{(E)}$ [20-21], with the cells of transverse dimensions 55×55 mm^2 and of the total covered area 2×3 m^2. The compensated lead-scintillator hadron calorimeter has the cell size of 10×10 cm^2, the thickness of 8 nuclear interaction lengths and the sampling of 16 mm lead, 4 mm scintillator. The hadronic energy resolution of the calorimeter is 57%/√E, the longitudinal response nonuniformity is better than 10% and the measured ratio e/h=1.01 [21].

Two multichannel Cherenkov counters will be used for particle identification. The first one detects π-mesons above 3 GeV/c and K-mesons above 11 GeV/c, while the second one detects pions above 6 GeV/c and kaons above 23 GeV/c. In the future, we plan to install also the TOF wall for p/K-separation up to 2.5 GeV, and K/π separation up to 1.5 GeV. The muon detector will consist of 3 layers of iron and drift tube chambers.

The new DAQ with parallel reading of electronics has been designed and successfully tested for the SPASCHARM experiment. The information is capable of reading at the speed of about 20 μsec/event from an ADC station and 30-50 μsec/event from a TDC crate. In the test run, the achieved rate for accepted events has been 10000 events/0.8 sec. In the future runs, we plan to store about $5\cdot10^4$ events/cycle, while the total event rate is expected to be at about 10^5 per cycle.

The current schedule of the experiments looks as follows:

- 2016 fall – commissioning of the Chamber 4, tuning the polarized target magnet, test data taking with “pions” (without Cherenkov counters) - 4 stations of DT stations, EMC: single-spin asymmetry in production of h+, h-, ρ(770), ω(782), η'(958), f_0(980), a_0(980), f_2(1270).omega, delta isobars
- 2017 spring – data taking with “pions”, test prototype of Chamber 5
- 2017 fall – addition of one Cherenkov counter in order to select kaons and reconstruct ϕ-meson
- 2017-2020 – – Construction and commissioning tof he polarized beam line.

Completion of the polarized proton [17] beam and particularly of the anti-proton one [22] is of a great importance and is the subject of three talks at this conference, devoted to the polarized beam [23], tagging system and polarimetry [24]. In the Spring of 2020, we plan to move the SPASCHARM detector to the polarized beam-line which is expected to start operating by the end of the year. The measurements with the polarized proton and anti-proton beams would bring the new quality into the spin physics studies at SPASCHARM.

4. Summary

The new experiment, SPASCHARM, devoted to systematic study of polarization phenomena in hadron-hadron interactions, is under commissioning now at the 70-GeV accelerator of IHEP, Protvino, Russia. The detection of charged and neutral particles in the final state in a wide solid angle will allow to explore dozens of reactions using various beams and targets. A special feature of the SPASCHARM experiment is the simultaneous measurements of various spin-dependent physics observables.

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.

Acknowledgments

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