Feasibility studies for the measurement of single-spin asymmetry in inclusive $K^0_s$ production at pion beam at U-70

N K Kalugin$^1$, V V Mochalov$^{1,2}$, V V Moiseev$^1$, D A Morozov$^1$, M B Nursheva$^2$, V L Rykov$^2$, P A Semenov$^{1,2}$ and A N Vasiliev$^{1,2}$

$^1$NRC «Kurchatov Institute» - IHEP, Protvino, Moscow region, 142281, Russia
$^2$National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Moscow, 115409, Russia

*E-mail: Nikita.Kalugin@ihep.ru

Abstract. In the Spring 2018, the first physics data was accumulated in the new SPASCHARM experiment at U-70 accelerator of IHEP, Protvino. The first stage of SPASCHARM’s physics programs pursues the goal of studying spin effects in the beam fragmentation region at an unpolarized negative 28 GeV beam, interacting with a frozen polarized proton target. In this report, the feasibility of measuring the single spin asymmetry $A_N$ in the reaction: $\pi^- + p^\uparrow \rightarrow K^0_s + X$ is evaluated by Monte-Carlo simulations. We present estimates of the detection efficiency as well as for expected event statistics. It is shown that, in the process of interest above, the attainable statistical errors for $A_N$ would be at the scale of a few percent.

1. Introduction

Numerous studies of the recent decades have shown the presence of significant spin effects in various physical processes, which have not yet been explained within the framework of the standard QCD perturbation theory. The particularly intriguing results are observed [1-4] in a wide energy range, $\sqrt{s}$ from ~5 to 62 GeV, for single-spin asymmetry (SSA) $A_N$. Transverse SSA $A_N$ is defined as the dependence of particle production’s differential cross section $d\sigma/d\Omega$ on the azimuth $\varphi$:

$$\frac{d\sigma}{d\Omega} \propto 1 + A_N \frac{\langle \hat{n}_i \cdot [\hat{n}_f \times \hat{\zeta}] \rangle}{\sqrt{1-(\hat{n}_i \cdot \hat{n}_f)^2}} = 1 + A_N \cdot |\zeta| \cdot \cos \varphi$$

(1)

In the formula above, $\hat{n}_i$ is for the unit vector along momentum of the initial beam particle; $\hat{n}_f$ is the unit vector along momentum of the produced particle; $\hat{\zeta}$ is the target polarization vector. The dependence on the azimuth $\varphi$ is written in the frame, where an initial particle moves along $Z$-axis, and the polarization vector $\zeta$ is directed along $Y$-axis.

A partial compilation of the $A_N$ measurements made up to date is shown in figure 1 [1-4]. To the surprise of early theoretical expectations [5], the $A_N$ in $p^\uparrow p \rightarrow \pi^\mp + X$ reaction depends on energy rather weakly. This makes it even more important to study the $A_N$ behavior for other reactions in a wide range of energies and production kinematics.

[1-4]
The new SPASCHARM (SPin ASymmetry in CHARMonia) experiment [6][7] pursues the goal of studying the fundamental problem of modern particle physics - the origin of spin asymmetries in production of hadrons. It covers the kinematic region of nonperturbative Quantum Chromodynamics (QCD) where the theoretical predictions are still difficult and unreliable.

**Figure 1.** The results of four different SSA measurements in the reaction $p^+ p \rightarrow \pi^\pm + X$ [1-4].

The first stage of the SPASCHARM experiment is limited to the studies of single-spin effects in unpolarized beam’s fragmentation region, using the frozen polarized proton target. Previously, the surprisingly large $A_N$ (see figure 2) has been seen in this region by PROZA collaboration in inclusive $\pi^0$ production: $\pi^- + d^1 \rightarrow \pi^0 + X$ [8].

**Figure 2.** $A_N$ in the reaction $\pi^- d^1 \rightarrow \pi^0 + X$.

The experimental setup of the SPASCHARM experiment (figure 3) covers a wide kinematic range in the forward hemisphere\(^1\) with the full $2\pi$ coverage in azimuth for both, charged particles and photons. The momentum analysis for charged particles takes place, using the special wide-aperture spectrometer magnet ($X \times Y = 200 \times 100 \text{ cm}^2$).

**Figure 3.** Experimental setup SPASCHARM.

The newly developed SPASCHARM tracker comprises of 3000 channels of drift tubes with 15 and 30 mm in diameter and the proportional chambers. The tracking system includes 3 stations of

\(^1\) In the center-of-mass reference frame.
proportional chambers (PC1-3) and 5 drift tube stations (DTS0-5). Chambers PC1-3 and DTS0-1 are located in front of the spectrometric magnet, and stations DTS3-5 are positioned behind the magnet. Each "drift" chamber consists of three layers of tubes glued together. The middle row is laterally displaced by a half of tube’s diameter relative to the outer ones. The chambers PC1-3 and DTS0-1 are located in front of the spectrometric magnet, and stations DTS3-5 are positioned behind the magnet. The magnetic field is directed upwards, the magnet bending power for the central track is approximately 0.72 T\cdot m.

The spin asymmetries in $K$-meson production are of special interest because there is the $s$-quark in final state which, unlike $u$- and $d$-quarks, is taken from the ‘sea’ of initial projectiles. The separation of charged kaons from pions is still unavailable in the first stage SPASCHARM’s setup, because there is no detectors for charged particle’s identification. However, the short-lived $K^0_S$ can be detected as a narrow peak in the invariant mass spectrum of two-body decays: $K^0_S \to \pi^+\pi^-$. Charged particle identification here is not absolutely necessary because pions dominate in the produced inelastic events.

The first and the only measurements of single-spin asymmetry for inclusive $K^0_S$ production were carried out about 30 years ago at two energies in the reaction: $p^+ + Be \to K^0_S + X$ [9], covering a relatively small $x_F$-range. The results for $A_N$ are shown in figure 3.

![Figure 4. Asymmetry in the reaction $p^+ + Be \to K^0_S + X$ [9]](image)

2. Monte-Carlo simulation of inclusive $K^0_S$ production and reconstruction at the SPASCHARM experiment

For this Monte-Carlo (MC) simulations the Pythia-8 code [10] has been used as an event generator for $\pi p$ collisions at $\sqrt{s} = 7.311$ GeV ($\pi$ beam energy 28 GeV) with the soft QCD processes ‘on’, and hard QCD processes ‘off’. The generated inclusive $K^0_S$ events were embedded into the minimum bias background. The absolute values for the $K^0_S$ cross-sections from Pythia were checked with the experimental data and found in a reasonable agreement: 2.207 mb from Pythia and $(1.89\pm0.72)$ mb from the experiment [11].

The GEANT-IV code [12] has been used for tracing produced particles through the experiment setup. Efficiency of each layer of tracking detectors was supposed to be 95 %. The position resolution of each tracking detector was simulated as 500 microns. The Hough transform is used to find track candidates. The developed method was tuned up with MC and is described in Ref [13].

$10^7$ of min-bias and $10^6$ of inclusive events have been generated and analyzed. In figure 5 at left, the invariant mass spectrum for all True MC generated $\pi^+ \pi^-$ pairs is shown before entering the SPASCHARM setup. It clearly demonstrates the high, almost zero-width peak right at the table mass of $K^0_S$-meson equal to 497.6 GeV/$c^2$. This mass spectra for True MC v demonstrates only the correctness of the simulation and calculations.
Figure 5. Reconstructed mass $M$ for $\pi^+\pi^-$ pairs for True MC tracks (a) and for reconstructed MC $h^+h^-$ tracks (b).

The plot at right shows the $h^+h^-$ spectrum, but for the tracks, scattered in the SPASCHARM setup and reconstructed from hits in the tracking detectors, before any kinematics selection cuts applied. The narrow peak at the mass of $K^0_S$-meson is still clearly seen. In this plot, all charged tracks, $h^+$ and $h^-$ are treated as pions, since there are no particle identification detectors.

Then, the additional kinematics cuts were applied in order to select a pure inclusive $K^0_S$ sample:

- secondary vertex cut: the minimal distance between $h^+$ and $h^-$ tracks is less than 0.6 cm;
- primary vertex cut: the secondary vertex is at the distance more than 8 cm from the primary interaction point along the incoming beam.

These cuts were defined by analyzing MC reconstructed inclusive events with verified reconstruction algorithm [13]. The accuracy of reconstruction of $K^0_S$ decay vertex is presented in figure 6.

Figure 6. Difference between MC- reconstructed and MC-True positions of $K^0_S$ decay vertex along the incoming primary beam for X(a), Y(b) and Z(c) coordinates.

The invariant mass spectrum of reconstructed $h^+h^-$ pairs after applying all cuts above are is presented in figure 7. The spectrum was is fitted by the sum of the exponential and the Gaussian functions. It gives the position of $K^0_S$ mass peak at $495.5\pm0.1$ MeV/c$^2$ (PDG value is $497.6\pm0.01$ MeV/c$^2$) with the width $\sigma=7.80\pm0.01$ MeV/c$^2$ and the signal-to-noise ratio of 2.35 within $\pm3\sigma$ window.
The $K^0_S$ detection efficiency was evaluated as a ratio of the number of reconstructed $K^0_S$-mesons to the number of MC generated ones. It is presented in table 1 for a number of kinematics bins. For the most bins, it is at the scale of about $10\%$.

**Table 1.** Detection efficiency of the $K^0_S$ production for SPASCHARM setup.

| $0 < p_T \leq 4.0$ | $4.0 < p_T \leq 8.0$ | $8.0 < p_T \leq 12.0$ | $12.0 < p_T \leq 16.0$ | $p_T > 16.0$ |
|---------------------|-----------------------|-----------------------|-----------------------|-------------|
| $0 < p_Z \leq 4.0$  | 0.013                 | 0.091                 | 0.093                 | 0.042       | 0.02       |
| $4.0 < p_Z \leq 8.0$| 0.004                 | 0.077                 | 0.096                 | 0.069       | 0.041      |
| $8.0 < p_Z \leq 12.0$| -                     | 0.03                  | 0.093                 | 0.084       | 0.065      |
| $12.0 < p_Z \leq 16.0$| -                     | -                     | 0.031                 | 0.071       | 0.081      |
| $p_Z > 16.0$        | -                     | -                     | -                     | -           | -          |

The estimates for expected statistics of reconstructed $K^0_S$-mesons for a 20 days long data-taking run at the beam intensity of $10^6$ particles per 10 sec cycle are presented in table 2. In these estimates, the limitations of the bandwidth of the SPASCHARM’s Data Acquisition System (25 000 per cycle [7]) are taken into account too.

**Table 2.** The expected number of detected $K^0_S$-mesons for a 20 days long data taking run.

| $0 < p_T \leq 0.25$ | $0.25 < p_T \leq 0.5$ | $0.5 < p_T \leq 1.0$ | $p_T > 1.0$ |
|---------------------|-----------------------|-----------------------|-------------|
| $0 < p_Z \leq 4.0$  | 6.6⋅10^5              | 3.0⋅10^5              | 3.0⋅10^5    |
| $4.0 < p_Z \leq 8.0$| 1.6⋅10^6              | 2.4⋅10^6              | 1.0⋅10^6    |
| $8.0 < p_Z \leq 12.0$| 5.0⋅10^5              | 1.1⋅10^6              | 1.3⋅10^5    |
| $12.0 < p_Z \leq 16.0$| 9.3⋅10^4              | 3.0⋅10^5              | 4.6⋅10^5    |
| $p_Z > 16.0$        | 3.2⋅10^4              | 1.1⋅10^5              | 5.0⋅10^5    |
In table 3, the estimates for statistical errors on SSA $A_N$ in inclusive $K^0_S$ - production are given. In these estimates, the proton polarization in the frozen pentanol target [7] was assumed at 70%, the target dilution factor of 7.3, which is the ratio of the total number of interactions to the number of interactions on polarized protons, is also taken into account.

**Table 3.** The estimates for statistical errors on the $A_N$ measurements in inclusive $K^0_S$ - production for 20 days long data taking run.

| $0 < p_T \leq 0.25$ | $0.25 < p_T \leq 0.5$ | $0.5 < p_T \leq 1.0$ | $p_T > 1.0$ |
|---------------------|------------------------|----------------------|-----------|
| $0 < p_Z \leq 4.0$  | 0.016                  | 0.024                | 0.237     |
| 4.0 $< p_Z \leq 8.0$| 0.01                    | 0.008                | 0.013     |
| 8.0 $< p_Z \leq 12.0$| 0.018                  | 0.012                | 0.019     |
| 12.0 $< p_Z \leq 16.0$| 0.043                 | 0.024                | 0.019     |
| $p_Z > 16.0$        | 0.073                  | 0.039                | 0.033     |

3. Summary
The new SPASCHARM experiment at the U70 accelerator has been commissioned and started physics data taking for measuring transverse single spin asymmetry $A_N$ with the polarized proton target at the 28 GeV negative beam.

Simulation of $K^0_S$ inclusive reaction is performed for the real SPASCHARM detector description. Single-spin asymmetry in inclusive $K^0_S$ production could be measured at SPASCHARM experiment at the statistical accuracy of about 2-3% in the most of 15 kinematics bins at $x_F < 0.6$ and $p_T < 1$ GeV/c.

The new data taking run at the U70 accelerator is planned for the Spring 2021.

The reported study was funded by RFBR, project numbers 18-02-00006 and 19-32-90068 and Ministry of Science and Higher Education of the Russian Federation, Project “Fundamental properties of elementary particles and cosmology” No 0723-2020-0041.

References
[1] Klem R D et al. 1976 *Phys.Rev.Lett* 36 929
[2] Allgower C E et al. 2002 *Phys. Rev. D* 65 092008
[3] Adams D L et al. 1991 *Phys.Lett. B* 264 462
[4] Arsene I et al. 2008 *Phys.Rev.Lett.* 101 042001
[5] Kane G L, Pumpkin J and Repko W 1978 *Phys. Rev. Lett.* 42 1689
[6] Mochalov V V 2013 *Phys. Part. Nucl.* 44(6) 930
[7] Abramov V V et al 2019 Conceptual Design Project of the SPASCHARM Experiment *IHEP Preprint* 2019-12 (in Russian)
[8] Bonner B E et al. 1990 *Phys. Rev. D* 41 13
[9] Mochalov V V et al. 2010 *Phys.Atom.Nucl.* 73 2017
[10] Sjöstrand T et al. 2014 An Introduction to PYTHIA 8.2 *Preprint* 1410.3012
[11] Kladnitskaya E N 1982 *Sov. J. Part. Nucl.* 13(3) 278
[12] Agostinelli S et al 2003 *Nucl.Inst.Meth.* A 506 250
[13] Abramov V V et al 2020 *J.Phys.Conf.Ser.* in print.