Measurement of single-spin asymmetry for charged pions in the SPASCHARM experiment at U70 accelerator

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Abstract. The SPASCHARM experiment at U70 aims an exploration of a fundamental problem in modern particle physics, the role of spin in strong interactions. At present, the first physics data have been accumulated at a negative 28 GeV beam, interacting with a frozen polarized proton target. The SPASCHARM wide-aperture spectrometer can detect both charged and neutral particles in the large solid angle with 2𝜋 azimuthal coverage in the fragmentation region of beam-particles. It covers the kinematic region of non-perturbative quantum chromodynamics (QCD), where the theoretical predictions are difficult and unreliable due to the full strength quark confinement at low and medium momentum transfers. In this report, the current status of the experiment is presented. The algorithm for reconstructing charged tracks is discussed along with its results on real data and the comparison with the Monte Carlo (MC) simulations. Based on a real track reconstruction, the statistical errors for the measurements of single-spin asymmetries in inclusive charged pion production are estimated. The data analysis is in progress.

1. Introduction

The new SPASCHARM project [1,2], which is under development now at U-70 accelerator, will become a unique tool for experimental studies of spin phenomena in strong interactions with the use of polarized proton and antiproton beams and polarized targets. The main physics motivation for the SPASCHARM experiment is the systematic study of spin effects for a wide range of inclusive and exclusive reactions in collisions of high-energy polarized hadrons in the QCD non-perturbative region.

The first stage of the SPASCHARM experiment is limited to studying single-spin effects at unpolarized beam, interacting with the polarized target. The single-spin asymmetry (SSA) \( A_N \) is defined as the dependence of particle production’s differential cross section \( d\sigma/d\Omega \) on the azimuth \( \varphi \), see equation (1):

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

In the formula above, \( \hat{n}_i \) is 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 azimuth

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angle $\varphi$ is represented in the frame, where an initial particle moves along the Z-axis, and the polarization vector $\xi$ is directed along the Y-axis.

Some results from previous measurements of $A_N$ asymmetry are shown in figure 1 for four experiments [3-6] at $\sqrt{s}$ varied from 4.9 to 62.4 GeV. Contrary to the earlier theoretical expectations [7], the behaviour of the asymmetry rather weakly depends on energy. Most of the currently popular models (Sivers [8] and Collins [9] functions, higher twist contributions [10]) predict the decrease of $A_N$ as the transverse momentum of secondary particles increases. This is not confirmed by the experiments either.

![Figure 1](image1.png)

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

Earlier, non-zero asymmetry in non-polarized beam fragmentation region has been observed in inclusive $\pi^0$ production at 40 GeV [11] (see figure 2).

![Figure 2](image2.png)

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

The main goal of the first stage of the experiment is the transverse SSA measurements in the unpolarized beam fragmentation region for inclusive and exclusive reactions for the hadrons built from light quarks ($u, d, s$). An important advantage of the SPASCHARM detector is its full $2\pi$ acceptance for both charged and neutral secondary particles. This is extremely helpful for reduction of the systematic errors in measurements of the spin-dependent asymmetries. Most of the measurements will be performed at the negatively charged unpolarized beam colliding with the polarized target. At the next stage of the SPASCHARM experiment, the physics of spin will be studied with the usage of unique polarized proton and antiproton beams [12].

### 2. Experimental setup and alignment

The experimental setup of the first phase of the SPASCHARM experiment is shown schematically in figure 3. It represents the spectrometer capable of detecting of charged particles and photons in the forward region with the full $2\pi$ coverage in azimuth.
The wide-aperture spectrometer magnet (X×Y= 200×100 cm$^2$), dedicated for the SPASCHARM, has been specially designed and built. The newly developed SPASCHARM tracker (see figure 3) 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 proportional chambers (PC1-3) and 5 drift tube stations (DTS0-5). 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·m.

The tracking system has been aligned, using the specially developed iterative method, which was tuned up and verified by the MC simulations. This method provides an accuracy for the lateral displacements at about 100 microns. This is illustrated in figure 4 by some distributions over residuals for the reconstructed tracks from real data.

![Figure 3. Experimental setup SPASCHARM.](image)

![Figure 4. An example of residual distributions for "drift" chambers X1 (a), Y3 (b), U5 (c), Y4 (d).](image)
3. Data taking and analysis
For the beam line of the SPASCHAR experiment, the secondary particles are produced at the internal target of the U-70 accelerator. Then, the negative particles (mainly \( \pi^- \)) are extracted from the accelerator ring and formed into the 28 GeV beam which is transported to the polarized pentanol target. In the beam run of Spring 2018, the statistics has been accumulated in eight measurement cycles: four with the target proton polarization up and four with the polarization down. The average polarization of the target protons was about 68% at the beginning of a measurement cycle and, by the cycle end, decayed down to 57%. About 1 billion triggers have been accumulated. In the next, special test-beam run in the Fall of 2019, the tracking system has been additionally tuned up, and the higher efficiency has been achieved for all the sub-planes of tracking detectors (figure 5).

![Efficiencies of the fts sub-planes](image)

**Figure 5.** The efficiency of the tracking system sub-planes for the test-beam data.

The Hough transform is used to find track candidates. Figure 6 presents examples of the obtained Hough spaces in the ZY plane for MC with one and three muons per event. It was found that the reconstruction efficiency for one track in event is 98%, for two tracks – 93%, for three tracks – 85% and for four tracks – 77%. The developed method is tuned up with MC and is now used for the real track reconstruction.

![HoughSpaceZY](image)

**Figure 6.** Examples of the obtained Hough spaces in the ZY plane for one (a) and three (b) tracks.
The obtained results are shown in comparison with the MC simulation using Pythia8 event generator in min-bias mode: $\pi^- p \rightarrow \pi^\pm + X$, 28 GeV/c ($\pi^-$), 10$^7$ events.

The momentum distributions of reconstructed tracks from MC and from the real data (run34 of Spring 2018) are shown in figure 7. In figure 8, the transverse momentum distributions for MC and real data are compared.

Figure 7. Momentum distributions for MC (a) and for run34 (b). The positive momentum half-axis is for the positive pions, the negative half-axis is for the negative ones.

Figure 8. The $p_T$ distributions for MC (a) and for run34 (b).

The distribution shapes for the MC and experimental data are quite close to each other except of the elastic-scattering peak in figure 7 (a), which is suppressed by the trigger in the real data.

The expected statistical errors for the SSA $\delta A_N$ from the Spring 2018 data are estimated on the base of experience with the track reconstruction in the data sub-sample. These estimates are given in tables 1 and 2 for various $p_T$ and $x_F$ bins.

| $0.0 < x_F < 0.1$ | $0.1 < x_F < 0.2$ | $0.2 < x_F < 0.3$ | $0.3 < x_F < 0.4$ | $0.4 < x_F < 0.5$ | $0.5 < x_F < 0.6$ | $0.6 < x_F < 0.7$ | $0.7 < x_F < 1.0$ |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| $0.0 < p_T < 0.5$ | 0.004 | 0.004 | 0.007 | 0.011 | 0.017 | 0.025 | 0.035 | 0.035 |
| $0.5 < p_T < 4.0$ | 0.106 | 0.019 | 0.012 | 0.013 | 0.016 | 0.021 | 0.026 | 0.021 |
4. Summary
The new SPASCHARM experiment at the U70 accelerator has been commissioned and started physics data taking for measuring transverse SSA with the polarized proton target at the 28 GeV negative beam. Charged tracks reconstruction algorithm is validated with the MC simulation and is currently used for the data analysis. The presented results of real track reconstruction are in good agreement with the MC simulations. The data analysis of Spring 2018 beam-run is now in progress aimed to get the first physics results on $A_N$ in inclusive production of charged pions. Expected statistical errors $\delta A_N$ for the most of selected bins vary at about 1.0-2.5%. The various sources of systematic errors are currently under investigation. The new data taking run at the U70 accelerator is expected in the Spring 2021 with the full and optimized tracking system.

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