Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

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To cite this article: V A Okorokov *et al* 2017 *J. Phys.: Conf. Ser.* **938** 012014

IOP Conf. Series: Journal of Physics: Conf. Series **938** (2017) 012014 doi:10.1088/1742-6596/938/1/012014

Comparative study of the inclusive asymmetries induced by polarized protons and antiprotons at 16 GeV/c at the U–70 accelerator

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Abstract. The only comparative study of the inclusive pion single-spin asymmetries produced in the interactions of the polarized protons and antiprotons in collisions with unpolarized proton was carried out at E–704 experiment. Significant asymmetries were found at large x_F and middle p_T, π^+ and π^0 asymmetries have positive signs while π^- has negative one in the $p^\uparrow + p$ collisions, while in the $\bar{p}^\uparrow + p$ interactions the π^- and π^0 asymmetries have positive signs while π^+ has negative sign. Similar experimental study can be done in the SPASCHARM experiment at U–70 accelerator at IHEP for various secondary particles with the use of 16 GeV polarized proton and antiproton beams.

1. Introduction

Inclusive reactions measured with polarized (anti)proton beam give insight into the spin dependence of the underlying partonic processes and add new input regarding the problem of the spin structure of polarized protons. Significant polarization effects appear already at relatively low values of the transverse momentum p_T ($p_T \sim 1.0$ GeV/c), where perturbative quantum chromodynamics (pQCD) is not expected to be applicable. Therefore the new experimental measurements with high statistics as well as phenomenological studies are essential for future progress in quantitative description of spin observables.

The following inclusive reactions are used for study of single-spin asymmetries for pions

$$p^\uparrow + p \to \pi^{\pm,0} + X, \tag{1}$$

$$\bar{p}^\uparrow + p \to \pi^{\pm,0} + X. \tag{2}$$

The analyzing power A_N is the physics observable under consideration here. The A_N is deduced from the measured yields of pions produced in a well defined azimuthal angular interval around the beam axis using vertically polarized p ($\bar{p}$) of both polarization signs:

$$A_N(z) = \frac{1}{P_B\langle\cos\phi\rangle}\frac{N_\uparrow(z,\phi) - N_\downarrow(z,\phi)}{N_\uparrow(z,\phi) + N_\downarrow(z,\phi)}. \quad (3)$$

Here $z \equiv (p_T, x_F, \sqrt{s})$ – a set of kinematic variables, p_T is the pion transverse momentum, $x_F = 2p_L/\sqrt{s}$ – Feynman variable for pion with longitudinal momentum p_L at the collision energy $\sqrt{s}$, P_B is the beam polarization, and ϕ is the azimuthal angle between the beam polarization axis directed upward and the normal to the production plane. $N_\uparrow$ ($N_\downarrow$) is the number of pions produced for positive (negative) spin orientation of the beam (anti)protons at the target, normalized to the corresponding beam flux. The reactions (1) and (2) were studied at $p = 200$ GeV/c ($\sqrt{s} = 19.4$ GeV) with the E–704 setup [1] and here it is suggested to continue such a study in deeply non-perturbative region at $p = 16$ GeV/c ($\sqrt{s} = 5.64$ GeV) in the SPASCHARM project [2, 3, 4].

2. The E–704 results for secondary pions

The magnitude of A_N increases for both π^+ and π^- particles with x_F for $p^\uparrow$ beam, but the sign of A_N is negative for the π^- data. The values of A_N are large for high values of x_F, up to 0.29 ± 0.09 for π^+ and down to 0.37 ± 0.07 for π^-. Detailed analysis of data at $p = 200$ GeV/c shown a threshold effect in which A_N increases dramatically above $p_T = 0.7$ GeV/c [1]. The E–704 experimental results obtained for $A_N(x_F)$ above and below p_T threshold indicated that the increase of A_N is primarily x_F effect above a p_T threshold. The situation is similar for study of the $A_N(x_F)$ with $\bar{p}^\uparrow$ beam with taken into account the change of signs of electric charge for the beam and secondary particles under consideration. Furthermore the p_T dependence was obtained for A_N for charged pion production in inclusive reaction (2) with $\bar{p}^\uparrow$ beam [5]. As example, figure 1 shows the dependence of A_N on x_F (left) and p_T (right) for secondary charged pions in (2). In this case the E–704 data exhibit an almost mirror symmetric dependence in x_F. The analyzing power for π^- production increases from 0.0 to about +0.25 with increasing x_F above $p_T \sim 0.5$ GeV/c while, for π^+ production, A_N decreases from 0.0 to about -0.35 with increasing x_F above the same p_T. The E–704 results with $\bar{p}^\uparrow$ show a threshold effect about $p_T \sim 0.5$ GeV/c, above which A_N increases in magnitude for both π^+ and π^- and for transverse momenta below this p_T value, A_N is significantly smaller and compatible with zero [5]. The threshold effect was also confirmed by the results of additional analysis for $p_T \geq 0.5$ GeV/c. Therefore the E–704 experimental results for (2) show the magnitude of A_N increases for both types of charged pions with increasing x_F, but the sign of A_N is positive for the π^- data and negative for π^+ data above the same $p_T \sim 0.5$ GeV/c. It appears that A_N depends primarily on x_F namely, and reaches large values above the p_T threshold of about 0.5 GeV/c as well as for inclusive reaction (1) with charged pions at some higher threshold p_T.

Therefore A_N seems similar (in the sense of behavior and magnitude) for $p^\uparrow$ / $\bar{p}^\uparrow$ beams in the case of opposite charges for pions, i.e. the reaction (1) with proton beam and inclusive π^+ the A_N appears to be similar to that in reaction (2) with antiproton beam and inclusive π^- and vise versa. One can note that the models based on non-perturbative approaches, such as a soft pion exchange mechanism [6], resonance-decay interference between real and virtual channels [7] and rotating constituents in the polarized (anti)proton [8] appear to be in good qualitative agreement with the features of the data on the pion production asymmetry measured with the both polarized protons and antiprotons.

The kinematic dependencies of A_N on x_F, p_T were also studied for the π^0 production in the inclusive reactions (1) and (2) in E–704 experiment [1, 9, 10, 11]. For the π^0 data obtained with

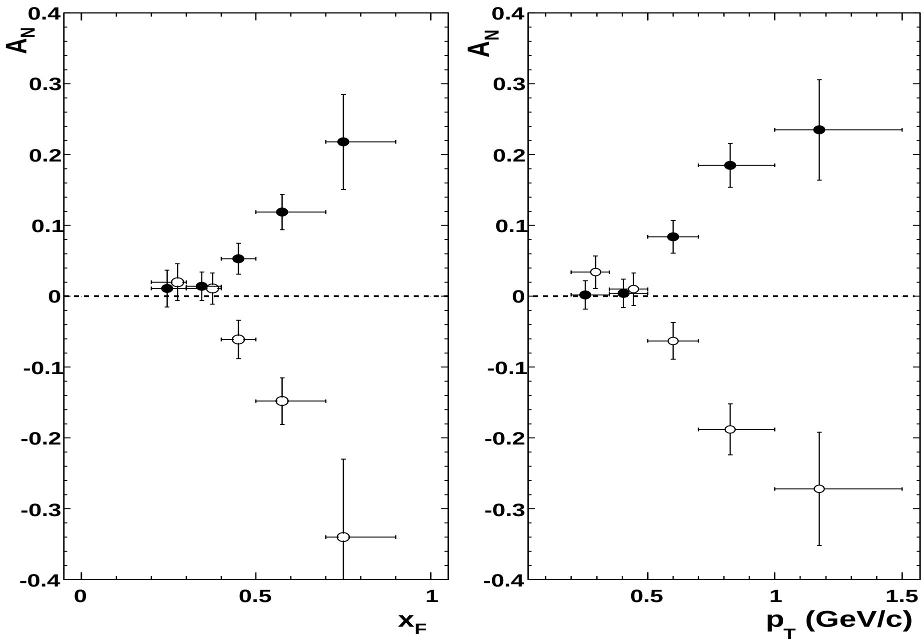

Figure 1. A_N data for $\bar{p}^{\uparrow}$ beam as a function of x_F integrated over p_T in the range $0.2-1.5$ GeV/c (left) and depends on p_T in the x_F range of $0.2-0.9$ (right) for charged pions. Experimental points for π^- are shown by solid symbols, for π^+ – by open ones. For clarity, first two π^- (π^+) data points are slightly shifted on left (right) in each panel. Data are taken from [5].

$p^{\uparrow}$ beam, $A_N(x_F)$ has the same sign as for π^+ data and is about half as large [1, 10]. The similar situation is observed for $A_N(x_F)$ in the $\bar{p}^{\uparrow}+p$ inclusive reaction for comparison π^0 results with π^- analyzing power [5, 10]. Thus the π^0 productions by polarized $p^{\uparrow}$ and $\bar{p}^{\uparrow}$ are related by charge conjugation of the beam and the produced particle. The measured asymmetries have the same sign and similar x_F dependence [10]. At large x_F, there is an indication that the magnitude of A_N for π^0 production by incident antiprotons is less than for incident protons. This would mean that the interactions involve constituents other than gluons and quark-antiquark pairs in the target proton. The A_N is observed to be zero for single-spin inclusive π^0 production in $p^{\uparrow}+p$ and $\bar{p}^{\uparrow}+p$ inclusive reactions in the $1 < p_T < 3$ GeV/c region within a statistical accuracy [11]. But it should be noted that in this case the amount of data for studying (2) interactions was an order of magnitude less than that for (1) interactions. In general in perturbative QCD single-spin transverse asymmetries are expected to be practically zero. Thus this expectation in the $1 < p_T < 3$ GeV/c region is confirmed by the data from the E–704 experiment, if perturbative QCD is applicable to these p_T values at beam momentum $p = 200$ GeV/c. Moreover the experimental errors are large for A_N at $p_T > 2.5$ GeV/c [11]. Therefore new experimental data with high statistics seem important for verification of some predictions of the QCD.

3. The SPASCHARM project

The SPASCHARM (**SP**in **A**symmetry in **CHARM**onia) is the project for world-class research works in fixed target mode for high energy spin physics [2, 3, 4]. The main goals of the SPASCHARM project are the studies of the (i) spin structure of the nucleon and (ii) possible spin dependence of the strong interaction for matter and antimatter with help of the systematic physical analysis for a wide set of hadronic reactions and secondary particles. The same name experimental setup is the core part of the SPASCHARM project. It is suggested to have two stages of the SPASCHARM project: first of all, studies with unpolarized proton beams using a polarized target and second phase of the project is the using of polarized beams.

The polarized $p^{\uparrow}$ ($\bar{p}^{\uparrow}$) beam is obtained by selecting $p^{\uparrow}$ ($\bar{p}^{\uparrow}$) from the weak decay of Λ ($\bar{\Lambda}$) produced in a primary target by extracted proton beam. This method is used for both the E–704 experiment and the SPASCHARM setup. The main features are shown in table 1 for U–70 and Tevatron beams. As seen from table 1 there are some advantages of the expectations for U–70 (for instance, intensities for primary and polarized proton beams) with respect to corresponding Tevatron beam parameters. It should be noted the U–70 allows the study of single-spin asymmetry in deeply non-pertubative region for some range of $\sqrt{s}$.

Table 1. Some main characteristics for U–70 and Tevatron beams.

	Beam parameter	U–70	Tevatron
1	primary proton beam, p (Gev/c)	50–60	800
2	primary beam intensity, c^{-1}	$\sim 2 \times 10^{12}$	1.5×10^{11}
3	polarized beam, p (Gev/c)	15–45^{a}	185 ± 17
4^{b}	beam intensity at the target, c^{-1}	$(0.9 - 6.8) \times 10^{6}$	1.5×10^{6}
		$(0.8 - 4.0) \times 10^{4}$	1.5×10^{5}
5^{b}	beam polarization	$\pm(0.45 \pm 0.05)$	$\pm(0.40 \pm 0.12)$
		–//–	$\pm(0.45 \pm 0.03)$

^{a}The minimum (maximum) relative uncertainty for beam momentum δp is 4.5% (11%) for $p = 15$ GeV/c and 3.0% (9.0%) for $p = 45$ GeV/c.
^{b}The first / second line corresponds to the $p^{\uparrow}$ / $\bar{p}^{\uparrow}$ beam.

Dependence of polarized beam intensity on momentum is shown in figure 2 for p (left) and $\bar{p}$ (right). The difference in intensities of $p^{\uparrow}$ and $\bar{p}^{\uparrow}$ beams increases dramatically with a growth of beam momentum. As seen for polarized proton beam the contribution of π^{+} from neutral kaon decays is small, furthermore this contribution decreases rapidly with beam momentum. Therefore the U–70 allows the polarized proton beam with good quality (purity). Figure 2 (right) shows that the beam of $\bar{p}^{\uparrow}$ with $p = 16$ GeV/c seems optimal in terms of intensity and background conditions. The number of π^{-} is approximately 3 times higher than the intensity of the antiproton beam. The separation of antiprotons at this level of background is quite possible with the help of Cherenkov beam counters.

The SPASCHARM detector is an open geometry setup with good particle identification and relatively large acceptance. Schematic view of the SPASCHARM is shown in figure 3. The SPASCHARM setup consists of the following main subsystems [2, 4]:
– various targets (liquid hydrogen, nuclear from Be up to Pb; polarized / unpolarized),
– spectrometer for registration of charged particles (magnet, GEM detector, multiwire proportional chambers – PC and drift ones – DC),
– electromagnetic calorimeter (ECAL) is shown in figure 4 and it is made by ”shashlik” technology which is well established and used successfully, for instance, during preparation the PANDA experiment,
– hadronic calorimeter (HCAL),
– set of detectors for particle identification and multiplicity measurement (ring image Cherenkov detector – RICH, muon spectrometer – MuD and time-of-light system – TOF).

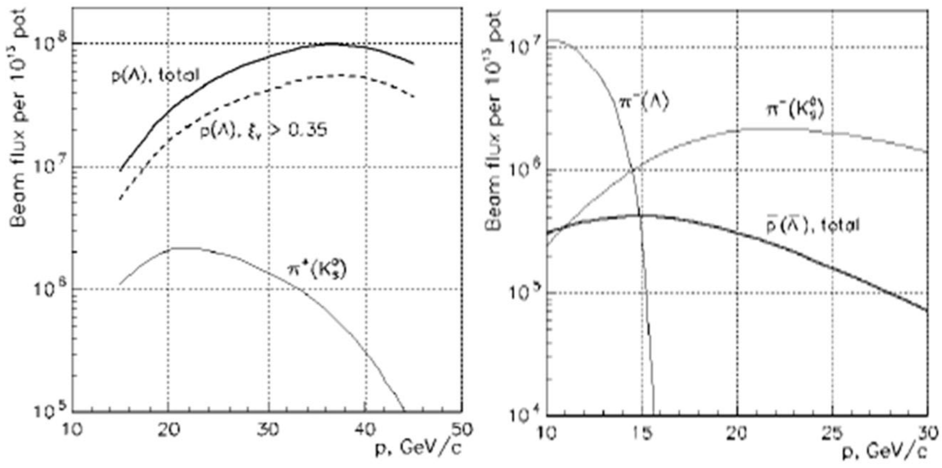

Figure 2. Intensity for beam of $p^{\uparrow}$ (left) and $\bar{p}^{\uparrow}$ (right) along with pion background of appropriate sign of electric charge for maximum δp shown in table 1. The quantity is calculated for 10^{13} primary protons with energy 60 GeV, where ξ_y is the transverse polarization averaged over ensemble. Data are taken from [4].

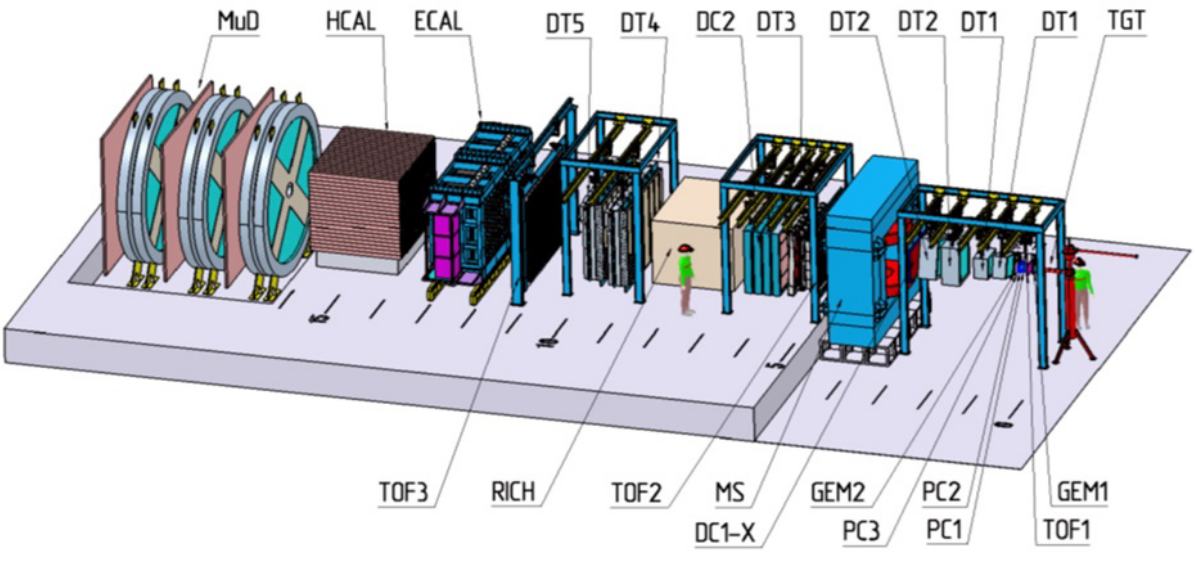

Figure 3. Schematic 3D view of the SPASCHARM setup. Here liquid hydrogen target (TGT) is shown, DT1–5 – a sets of thin-walled drift tubes, other subsystems are described in the text. Distances are shown in meters along the beam direction with respect to the center of the target.

Subsystems of the SPASCHARM detector are designed for high quality particle identification. According to the Conceptual design report (CDR) [4] the SPASCHARM will provide registration of charged particles from 0.5 up to 50 GeV/c in full azimuth 2π, registration of γ from 0.2 up to 50 GeV/c with the same angular range as for charged particles, identification of charged particles for momentum domain 1–20 GeV/c, registration of decay particles from hyperons with future reconstruction of parent particle, high coordinate resolution for beam particles, especially, for elastic scattering study [4]. Furthermore there are following special requests for charmonium

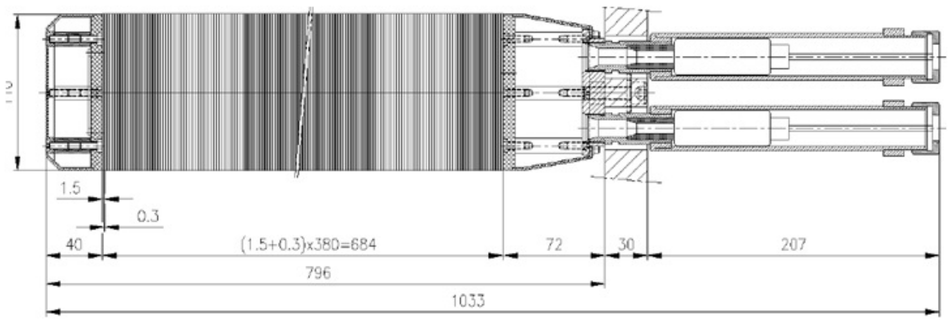

Figure 4. Scheme of supermodul for ECAL ("shashlik" consists from layers of Pb-absorber and scintillator). Picture is taken from [4].

study: momentum resolution is $\sim 2\%$ at 10 GeV/c and energy resolution for electromagnetic calorimeter is $3\%/\sqrt{E}$. Therefore there are some advantages of the SPASCHARM project regarding of earlier experiments, for instance, E–704. In particular, addition of new detectors (GEM, MDC, high quality EMC etc.) allows the increase of statistics significantly compared to the previous experiments. Due to 2π acceptance on azimuthal angle of the SPASCHARM setup one can expect that the systematic errors in A_N will be small. With the use of polarized proton beam at SPASCHARM a precision measurement of A_N for inclusive production in the transverse polarized beam fragmentation region in a wide (x_F, p_T)-region will be worthwhile [2]. One can expect that the kinematic ranges $0.2 < x_F < 1.0$ and $0.5 < p_T < 3.5$ GeV/c will be covered. Also the estimations will be obtained for accuracy of the A_N measurement in the reactions (1), (2) and for corresponding time of data collection for various accelerator parameters (beam intensity, run duration etc.).

Within SPASCHARM project the software is constructed for on-line and off-line data analyses. The software is developed as object-oriented environment and it is based on the ROOT package. Also SPASCHARM software includes GEANT 3, 4 and some event generators (PYTHIA, PLUTO etc.) for Monte-Carlo simulation of hadronic interactions. At present the software environment SpascharmRoot has been developed and partially implemented. The SpascharmRoot allows the simulation, reconstruction, on- and off-line analysis of experimental data. The environment is under active development. The SPASCHARM software is permanently improving, for instance, the possibility is considered for using of the GRID technology for distributed data analysis.

4. Summary

Analyzing power shows the significant magnitude for inclusive pions above $p_T \sim 0.5$ GeV/c but there is only one measurement of the A_N for inclusive pions with polarized antiproton beam. At present phenomenological models describe the experimental data at qualitative level only and precision of experimental results do not allow the clear discrimination between various models. Consequently the new high-precision measurements seem important for better understanding of single-spin asymmetry and more definite physics conclusions. Hopefully, the SPASCHARM experiment will provide the high-statistics data which will shed new light for single-spin pion asymmetry as well as in general for spin structure of the proton.

Acknowledgments

The work has been supported in part by the RFBR Grant No 16–02–00667 and by the NRNU MEPhI Academic Excellence Project (contract No 02.a03.21.0005, 27.08.2013).

References

[1] Adams D L *et al.* 1991 *Phys. Lett.* B **264** 464
[2] Vasiliev A N *et al.* 2007 *arXiv*: 0712.2691 [hep-ex]
[3] Mochalov V V *et al.* 2013 *Phys. Part. Nucl.* **44** 930; 2016 *Int. J. Mod. Phys.: Conf. Ser.* **40** 1660106
[4] Abramov V V *et al.* 2017 *CDR for SPASCHARM experiment.* v. August 13
[5] Bravar A *et al.* 1996 *Phys. Rev. Lett.* **77** 2626
[6] Soffer J and Törnqvist N A 1992 *Phys. Rev. Lett.* **68** 907
[7] Barni R, Preparata G and Ratcliffe P G 1992 *Phys. Lett.* B **296** 251
[8] Boros C, Zuo-tang L and Ta-chung M 1993 *Phys. Rev. Lett.* **70** 1751; 1995 *Phys. Rev.* D **51** 4867
[9] Bonner B E *et al.* 1988 *Phys. Rev. Lett.* **61** 1918
[10] Adams D L *et al.* 1991 *Phys. Lett.* B **261** 201
[11] Adams D L *et al.* 1996 *Phys. Rev.* D **53** 4747