Preparation of new polarization experiment **SPASCHARM** at IHEP

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Abstract. A new experiment SPASCHARM devoted to a systematic study of polarization phenomena in hadron-hadron interactions in the energy range 10-70 GeV is under preparation at IHEP (Protvino). The physical observables will be single-spin asymmetries, hyperon polarizations and spin-density matrix elements. A universal setup will detect and identify various neutral and charge particles in the full azimuthal angle and a wide polar angle range. A polarized target is used to measure the SSA. The SPASCHARM sub-detectors are being designed and constructed now. The possibility of obtaining a polarized proton beam for the SPASCHARM experiment from Lambda decays is under study.

1. Introduction

Numerous experiments measured significant spin effects in exclusive and inclusive reactions for hadron-hadron, hadron-nucleus, nucleus-nucleus and lepton-nucleon interactions. A lot of models have been proposed to explain the data. None of them is able to describe the full sample of the data.

The single-spin effects are very large at moderate p_T and large x_F mostly. The energy dependence of single-spin observables is, as a rule, rather weak. The possible non-pertubative nature of the large spin effects requires high statistics and high accuracy measurements in a large variety of processes in order to reveal general regularities and to build later an adequate model or a mechanism.

A new experiment SPASCHARM is a continuation of the PROZA experiment at IHEP and is devoted to a systematic study of polarization phenomena in hadron-hadron interactions in the energy range 10-70 GeV in a lab. frame. In the PROZA experiment particles, which decay into photons, were detected. At the SPASCHARM setup we will measure both neutral and charge secondary particles.

2. Physical motivation

Usually the main motivation for polarization studies is to study the spin structure of the proton. However, the most valuable information of the polarization data is related to the dynamics of the strong interaction of hadrons and quarks, and the phenomenon of confinement in particilar. Spin effects can be linked to such fundamental problems as the spontaneous chiral symmetry breaking, the appearance of mass for quarks and hadrons, the formation in a hadron quasiparticles - constituent quarks and the quark confinement. For the discrimination of different theoretical approaches the systematic studies of single-spin asymmetry and hadron polarization are required in a large number of exclusive and inclusive processes. Such a program can be done using the proposed setup SPASCHARM.

3. The first stage of SPASCHARM experiment

The program for the first phase of polarization studies in the SPASCHARM experiment is devoted to measurements of single-spin asymmetry (A_N) on a polarized target in exclusive and inclusive production of light particles. In addition, the hyperon and vector meson polarization (alignment) is going to be studied for different beams and targets. A possible and very interesting option is the creation of a polarized proton beam using decays of the Λ hyperons, produced in the internal IHEP accelerator target (Prof. S Nurushev's idea) [1]. The use of light ion beams (d, ¹²C) is another option, which is under study. Single spin effects for an ion beam could be large due to the superposition of the color fields of many projectile quarks [2]. All the above could be combined with the spin transfer studies.

3.1. Observables

The measured observables are: an analyzing power A_N , which can be measured with high accuracy due to the full azimuthal setup coverage; the hyperon transverse polarization P_N , which can be measured using angular distributions of the hyperon decay products in its rest frame; the density matrix element ρ_{00} , which can be measured for 2-boson decays of vector mesons; another observable $\alpha = (\sigma_T - 2\sigma_L)/(\sigma_T + 2\sigma_L)$ can be measured for vector meson decay into a fermion-antifermion pair [3]. The SPASCHARM setup will measure the charged particle multiplicity, as an additional variable, which could be related to the intensity of the color field in the interaction volume [2].

3.2. Detected particles

The SPASCHÂRM setup will detect charged particles, such as π^{\pm} , K^{\pm} , p, \bar{p} , e^{\pm} , μ^{\pm} and neutral ones, such as K_L^0 , n, and γ . A lot of resonances, charged and neutral, can be detected via their decay products, listed above: π^0 , η , $\eta'(958)$, K_S^0 , $K^{*\pm}(892)$, $K^{*0}(892)$, $\omega(782)$, $\rho(770)$, $\rho^0(770)$, $\phi(1020)$, $\Delta^{++}(1232)$, $\bar{\Delta}^{--}(1232)$. Hyperons Λ , Ξ^- , Ξ^0 , Σ^0 and corresponding antihyperons can also be detected. The above variety of detected particles, combined with the different beam options, allow us to study in a systematic way tens of reactions, the exclusive and inclusive.

3.3. Examples of exclusive and inclusive data

As an example of the exclusive reaction, which can be studied at the SPASCHARM experiment, is the reaction of $\pi^- p \rightarrow \omega(782)n$. The result from the PROZA experiment, shown in figure 1, indicates the existence of a significant single-spin asymmetry [4]. After 90 days of data taking,

using the SPASCHARM setup, and the two decay modes, into $\pi^+\pi^-\pi^0$ and $\pi^0\gamma$, the statistics could be increased by a factor of 20, up to 600000 events.

An example of interesting inclusive data for medium energy Au-Au collisions is shown in figure 2. The transverse Λ hyperon polarization at $\sqrt{s} = 4.86$ GeV was measured at BNL by the E896 Collaboration [5]. The curve shows the Effective Color Field model prediction [2]. At the SPASCHARM experiment light ion beams, d and ¹²C, can be used to study the hyperon polarization and vector meson alignment.



Figure 1. Asymmetry in the reaction of $\pi^- p^{\uparrow} \rightarrow \omega(782)n$ at the beam energy of 40 GeV, where the $\omega(782)$ -meson decays into π^0 and γ . The measurements were performed at the PROZA setup [4].



Figure 2. The polarization of the Λ hyperon vs x_F in the reaction Au + Au $\rightarrow \Lambda + X$ at $\sqrt{s} = 4.86$ GeV. The curve shows the Effective Color Field model prediction [2].



Figure 3. Analyzing power A_N vs x_A for π^0 production in pp and $\pi^- p$ collisions in E704 [6,7], STAR [8] and PROZA [9] experiments. Line is a linear function fit for $x_A > 0.2$.

A comparison of A_N for the inclusive reactions $p^{\uparrow}p \to \pi^0 X$ and $\pi^- p^{\uparrow} \to \pi^0 X$ in the fragmentation region of the polarized proton is shown in figure 3. The data is taken in the E704 [6,7], STAR [8] and PROZA [9] experiments at energies 19.4, 200 and 8.7 GeV in c.m., respectively. The results are plotted as a function of a scaling variable $x_A = (x_R + x_F)/2$, where $x_R = p/p_{max}$ and $x_F = p_Z/p_{max}$ in c.m. frame. We can conclude from the results, shown in figure 3, that there is an approximate scaling $A_N(x_A)$ in a wide energy range. The existence of an approximate scaling $A_N(x_A)$ means, that at the IHEP accelerator energies we can study the origin of polarization effects, which are seen also at much higher energies. The advantage of such studies at the SPASCHARM setup is the ability to detect and identify a large variety of hadrons in a wide kinematic range and for different observables.

3.4. Beams

In the first phase of the polarization studies we plan to use a secondary negative meson (mostly pion) beam and a primary proton beam, in energy range 10 - 34 GeV and 50 - 60 GeV, respectively. The intensity of the above beams will be up to $3 \cdot 10^6$ /spill and spill duration is up to 1.5 s. The extraction of the positive pion beam is under study. The particle composition of the negative beam $(\pi^-/K^-/\bar{p})$: 97.9/1.8/0.3%, measured using beam Cherenkov counters, will allow us to study the beam flavor dependence for the most intense reactions. An electron beam in the energy range 1-34 GeV is available for the calorimeter calibration. A possible polarized proton beam, with the polarized protons from decays of Λ hyperons, produced in the internal IHEP accelerator target, can have up to 40% transverse polarization and the intensity up to $10^6/\text{spill}$.

3.5. Polarized Target

In the first phase of the polarization studies we plan to use the "frozen" type polarized propandiol target, which is currently upgraded by our JINR (Dubna) colleagues. The main parameters of the polarized target are: chemical composition - $C_3H_8O_2$, length - 20 cm, diameter - 2 cm, proton polarization up to 90%, dilution factor about 10. The target is inside a magnet with the magnetic field induction value of 2.1T/0.45T for closed/open magnet, respectively. The target temperature is T=0.3 K⁰/0.04 K⁰ (during the microwave irradiation/frozen stage, respectively). The magnet is going to be open during the analyzing power measurements. Irradiation with microwaves (56 GHz at 2.08T) transfers most of the electron polarization to the protons in the material. The microwave generator delivered up to 300 mW to the target volume. The target thickness is 15.2% of interaction length for 60 GeV protons and 10% for 34 GeV π^- mesons.

4. Experimental setup SPASCHARM

The setup is a spectrometer, which detects charged particles, neutrons, K_L^0 -mesons and photons in the forward direction. The schematic view of the setup is shown in figure 4. The apparatus has an aperture of 2π in the azimuthal angle ϕ , which allows us to minimize the systematic errors for different spin observables. Drift tube chambers inside the magnet have the acceptance $420x310 \text{ mrad}^2$. The setup contains a polarized proton target, a tracking system (fractional momentum resolution 0.4% at 10 GeV/c), a spectrometer magnet (1.5 T·m), a secondary particle identification system (multi-channel Cherenkov counters and hopefully TOF), electromagnetic and hadron calorimeters and a muon detector. There is also a charged particle multiplicity detector, which has three planes of hodoscopes H1, H2 and H3 and is also planned to be used as a time-of-flight system, a target guard system and trigger counters (not shown).

4.1. Electromagnetic calorimeter

The lead glass part of the calorimeter will have 960 channels (24x40 matrix). The energy resolution is $10\%/\sqrt{E}$, where energy E is in GeV. The module size is 3.8x3.8x45 cm³. The



Figure 4. The schematic plan view of the SPASCHARM setup.

peripheral part of the ECAL consists of two sandwich type calorimeters, each containing 640 modules or 40 supermodules. The sandwich type calorimeters are adjacent to the left and right sides of the lead glass ECAL.

4.2. Multi-channel Cherenkov counters

The multi-channel Cherenkov counter No.1 is 1.5 m long, uses freon-22 as a radiator and has 8 detection channels. The Cherenkov light is reflected by the spherical mirrors and is collected by the PMTs (FEU-174 type). It detects pions above 3 GeV/c and kaons above 11 GeV/c. The counter No. 2 is 3 m long, uses air as a radiator, and has 16 channels. It detects pions above 6 GeV/c and kaons above 23 GeV/c.

4.3. The target magnet and the guard system

The target guard system should detect charged particles and photons at large polar angles $(14^{\circ} < \theta < 166^{\circ})$ in the laboratory frame. The device works in the magnetic field of 0.45 T and has 4 channels for charged particle detection and 2 channels for photon detection, with a corresponding segmentation in azimuthal angle ϕ . The polarized target magnet and the target guard system have been constructed and will be tested in 2010.

4.4. The GEM detectors

Two GEM detectors are located downstream the target. Their purpose is a precise measurement of the track parameters. The GEM detectors will be used also for the registration of resonances and hyperons. The strip pitch is 0.4 mm, the transverse detector size is $30x30 \text{ cm}^2$. The beam GEM size is $10x10 \text{ cm}^2$.

5. Monte Carlo simulation of the mass plots for the SPASCHARM setup

A Monte Carlo simulation of particle detection at the SPASCHARM setup is presented in figures 5 and 6 for inclusive reactions. The simulation is performed by using the PYTHIA 6.2 generator [10] and pure geometrical cuts for the different detectors. The expected energy and

momentum resolution was also taken into account. The trigger requires that in the ECAL or in the HCAL calorimeter the energy deposition exceeds 12 GeV. The statistics for the shown figures corresponds in all cases to $6 \cdot 10^7$ interactions in the propan-diol target and could be collected during one hour of data taking at the beam intensity 10^6 /spill.





Figure 5. The invariant mass of $\gamma\gamma$ pairs (GeV) for the reactions $\pi^-p^{\uparrow} \rightarrow \pi^0 X$ (a) and $\pi^-p^{\uparrow} \rightarrow \eta X$ (b).

Figure 6. The invariant mass of $p\pi^+$ pairs (GeV) for the reaction $pp^{\uparrow} \rightarrow \Delta^{++}(1232)X$ (a) and the invariant mass of $\Lambda\pi^-$ pairs for the reaction $pp^{\uparrow} \rightarrow \Xi^- X$ (b).

5.1. Mass plots for 34 GeV negative pion beam

Examples of mass plots for the 34 GeV negative pion beam are shown in figure 5. The expected statistics for different inclusive reactions is shown in tables 1 and 2 for $6 \cdot 10^{10} \pi^- p$ or pp interactions, respectively. In figures 5a and 5b an effective mass of the $\gamma\gamma$ system is shown with clear peaks of π^0 or η , respectively.

5.2. Mass plots for 60 GeV proton beam

Examples of mass plots for 60 GeV proton beam are shown in figure 6. In the figure 6a The $\Delta^{++}(1232)$ signal is shown for the π^+p final state. The $\Xi^- \to \Lambda \pi^-$ decay product effective mass is seen in figure 6b. In all cases the expected statistics is high and the background to signal ratio B/S is acceptable. The expected statistics for 31 different inclusive reactions is shown in table 2.

6. SPASCHARM status and plans

The SPASCHARM setup has to be designed and constructed during 2010-2013. The major milestones for the SPASCHARM construction are the following: 2011: polarized target, spectrometer magnet, target magnet and multi-channel Cherenkov; 2012: hadron calorimeter, fiber and GEM detectors; 2013: full tracking system, EVRO-MISS electronics, multiplicity hodoscopes, muon detector and DAQ system. Data taking with a full setup is expected in 2013.

No.	Final state	N_{EV}	B/S	No.	Final state	N_{EV}	B/S
1	π^+	$4.2\cdot 10^9$		20	$\eta \to \pi^+ \pi^- \pi^0$	$5.3\cdot 10^6$	0.2
2	π^{-}	$8.7\cdot 10^9$		21	$\omega(782) \to \pi^+ \pi^- \pi^0$	$3.5\cdot 10^7$	0.25
3	K^+	$6.7\cdot 10^8$		22	$\omega(782) \rightarrow \gamma \pi^0$	$3.8\cdot 10^7$	2.0
4	K^{-}	$9.0\cdot 10^8$		23	$\phi(1020) \to K^+ K^-$	$4.3\cdot 10^6$	0.3
5	p	$9.2\cdot 10^7$		24	$\rho^+(770) \to \pi^+\pi^0$	$2.9\cdot 10^8$	6.0
6	$ar{p}$	$2.6\cdot 10^8$		25	$\rho^-(770) \to \pi^-\pi^0$	$7.5\cdot 10^8$	3.0
7	n	$3.2\cdot 10^8$		26	$K_S^0 o \pi^0 \pi^0$	$1.7\cdot 10^7$	3.5
8	$ar{n}$	$8.0\cdot 10^7$		27	$a_0(980) \rightarrow \eta \pi^0$	$1.8\cdot 10^7$	9.0
9	K_L^0	$1.0\cdot 10^8$		28	$\Lambda \to p\pi^-$	$1.4\cdot 10^6$	0.1
10	$\pi^0 \to \gamma \gamma$	$4.3\cdot 10^9$	0.1	29	$\bar{\Lambda} \to \bar{p}\pi^+$	$1.1\cdot 10^6$	0.05
11	$\eta \to \gamma \gamma$	$4.2\cdot 10^8$	0.5	30	$\Lambda \to n\pi^0$	$1.8\cdot 10^6$	3.0
12	$\eta' ightarrow \pi^+\pi^-\eta$	$8.3\cdot 10^5$	0.05	31	$\bar{\Lambda} \to \bar{n} \pi^0$	$7.7\cdot 10^5$	0.45
13	$K_S^0 \to \pi^+ \pi^-$	$1.3\cdot 10^7$	0.3	32	$\Delta^{++}(1232) \to p\pi^+$	$9.3\cdot 10^6$	2.0
14	$\rho^0 \to \pi^+ \pi^-$	$4.2\cdot 10^8$	2.5	33	$\bar{\Delta}^{}(1232) \to \bar{p}\pi^-$	$2.5\cdot 10^7$	5.5
15	$K^{0*}(892) \to K^+\pi^-$	$1.1 \cdot 10^{8}$	0.7	34	$\Xi^{-}(1232) \rightarrow \Lambda \pi^{-}$	$1.9\cdot 10^6$	0.1
16	$\bar{K}^{0*}(892) \to K^- \pi^+$	$4.3\cdot 10^7$	2.0	35	$\bar{\Xi}^+(1232) \to \bar{\Lambda}\pi^+$	$1.6\cdot 10^6$	0.1
17	$K^{+*}(892) \to K^+ \pi^0$	$1.9\cdot 10^7$	2.6	36	$\Sigma^0 ightarrow \Lambda \gamma$	$1.2\cdot 10^6$	0.5
18	$\bar{K}^{-*}(892) \to K^{-}\pi^{0}$	$3.8\cdot 10^7$	1.3	37	$\Sigma^0(1385) \to \Lambda \pi^0$	$3.9\cdot 10^6$	0.2
19	$\omega(782) \to e^+e^-$	$1.7 \cdot 10^5$	0.5	38	$\rho^0(770) \to \mu^+ \mu^-$	$9.7\cdot 10^4$	0.7

Table 1. The expected number of events N_{EV} for different final states and $6 \cdot 10^{10} \pi^- p$ interactions. The B/S is a ratio of a background to a signal under the resonance peak.

7. Summary

We propose a new experiment SPASCHARM, devoted to a systematic study of polarization phenomena in hadron-hadron interactions in the energy range 10-70 GeV. We will continue the study of exclusive and inclusive reactions (which we began in the PROZA experiment) in collisions of different hadron beams with a transversely polarized target.

A special feature of the project is the simultaneous measurement of several spin-dependent physical observables (the single-asymmetry, the polarization of hyperons, the spin density matrix elements for vector mesons, the parameters of spin transfer).

The measurement of the charged hadron multiplicity in an event opens up new possibilities for investigating the nature of polarization phenomena.

Registration of charged and neutral particles in the final state in the large solid angle of the experimental setup in interactions of different beams will allow us to explore dozens of different reactions, including a comparison of the spin effects in the interactions of particles and antiparticles with a polarized target.

The tracking system allows the precise charged particle momentum measurement (0.4% at 10 GeV/c), which is critical for the separation of resonances from combinatorial background.

The SPASCHARM setup will allow us to measure polarization effects with record high accuracy, especially if a polarized beam is successfully implemented.

Interesting spin physics is expected in a few years!

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No.	Final state	N_{EV}	B/S	No.	Final state	N_{EV}	B/S
1	π^+	$6.1\cdot 10^9$		17	$\rho^+(770) \to \pi^+\pi^0$	$3.0\cdot 10^8$	2.5
2	π^-	$3.6\cdot 10^9$		18	$\rho^-(770) \rightarrow \pi^-\pi^0$	$1.5\cdot 10^8$	3.2
3	K^+	$5.5\cdot 10^8$		19	$a_0(980) \rightarrow \eta \pi^0$	$5.7\cdot 10^6$	0.8
4	K^{-}	$2.5\cdot 10^8$		20	$\eta \to \pi^+ \pi^- \pi^0$	$7.8\cdot 10^6$	0.25
5	p	$4.7\cdot 10^9$		21	$\omega(782) \to \pi^+ \pi^- \pi^0$	$3.0\cdot 10^7$	0.7
6	$ar{p}$	$2.3\cdot 10^6$		22	$K^{+*}(892) \to K^+ \pi^0$	$3.4\cdot 10^7$	3.5
7	n	$3.5 \cdot 10^9$		23	$\bar{K}^{-*}(892) \to K^{-}\pi^{0}$	$9.7\cdot 10^6$	1.4
8	$ar{n}$	$2.5\cdot 10^6$		24	$\omega(782) \to \gamma \pi^0$	$7.8\cdot 10^6$	0.4
9	$\pi^0 ightarrow \gamma \gamma$	$2.5\cdot 10^9$	0.11	25	$\Lambda \to p\pi^-$	$2.3 \cdot 10^7$	0.1
10	$\eta \to \gamma \gamma$	$1.3 \cdot 10^{8}$	0.4	26	$\Lambda \to n\pi^0$	$2.1 \cdot 10^{7}$	1.5
11	$\phi(1020) \to K^+K^-$	$3.7\cdot 10^6$	0.04	27	$\Delta^{++}(1232) \to p\pi^+$	$1.0\cdot 10^9$	1.7
12	$K_S^0 o \pi^+ \pi^-$	$6.7\cdot 10^7$	1.1	28	$\Xi^{-}(1232) \rightarrow \Lambda \pi^{-}$	$3.5 \cdot 10^{7}$	0.12
13	$ \rho^0(770) \to \pi^+\pi^- $	$3.6 \cdot 10^{8}$	2.7	29	$\Sigma^0 \to \Lambda \gamma$	$3.5 \cdot 10^{7}$	4.0
14	$K^{0*}(892) \to K^+\pi^-$	$5.8\cdot 10^7$	1.3	30	$\Sigma^0(1385) \to \Lambda \pi^0$	$9.8\cdot 10^7$	1.3
15	$\bar{K}^{0*}(892) \to K^- \pi^+$	$3.1 \cdot 10^7$	0.8	31	$ \rho^0(770) \to \mu^+ \mu^- $	$1.0\cdot 10^5$	0.25
16	$\omega(782) \to e^+e^-$	$2.0 \cdot 10^{5}$	0.25				

Table 2. The expected number of events N_{EV} for different final states and $6 \cdot 10^{10} pp$ interactions. The B/S is a ratio of a background to a signal under the resonance peak.

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