ФИЗИКА ЭЛЕМЕНТАРНЫХ ЧАСТИЦ И АТОМНОГО ЯДРА
2013. Т. 44. ВЫП. 6

SPIN PHYSICS AT IHEP

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IHEP has rich program devoted to the spin physics studies. New experimental program will significantly increase the number of reactions investigated at large kinematic region. The experiment will measure different polarization variables in inclusive and exclusive reactions, including single- and double-spin asymmetry, polarization, spin transfer parameters. One of the most important tasks is the creation of the polarized beam and especially polarized antiproton beam.

PACS: 13.88.+e; 13.85.Ni

INTRODUCTION

Protvino spin physics has long history, which began even before IHEP creation. Prof. S. Nurushev, young guy 55 years ago, participated in the construction of the polarized beam and polarization studies at Dubna accelerator [1, 2]. As soon as IHEP accelerator was launched, the investigation of the polarization in the elastic π^+ scattering was carried out [3]. It was discussed that pomeron may carry the spin-flip interaction.

The cycle of measurements of the polarization effects in exclusive charge-exchange reactions was carried out later [4] at the PROZA experimental setup with the use of the JINR polarized frozen target [5]. The asymmetry measured was significant and oscillated. As examples, the polarization in the reaction $\pi^- p_\uparrow \to \eta n$ and asymmetry in the reaction $\pi^- p_\uparrow \to f_2(1270)n$ are presented in Fig.1.

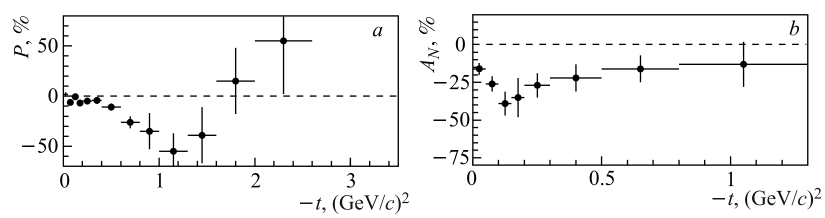

Fig. 1. The polarization in the reaction $\pi^- p_\uparrow \to \eta n$ (*a*) and asymmetry in the reaction $\pi^- p_\uparrow \to f_2(1270)n$ (*b*) [4]

IHEP POLARIZATION RESULTS

Asymmetry measurements in inclusive reactions were carried out at two experiments.

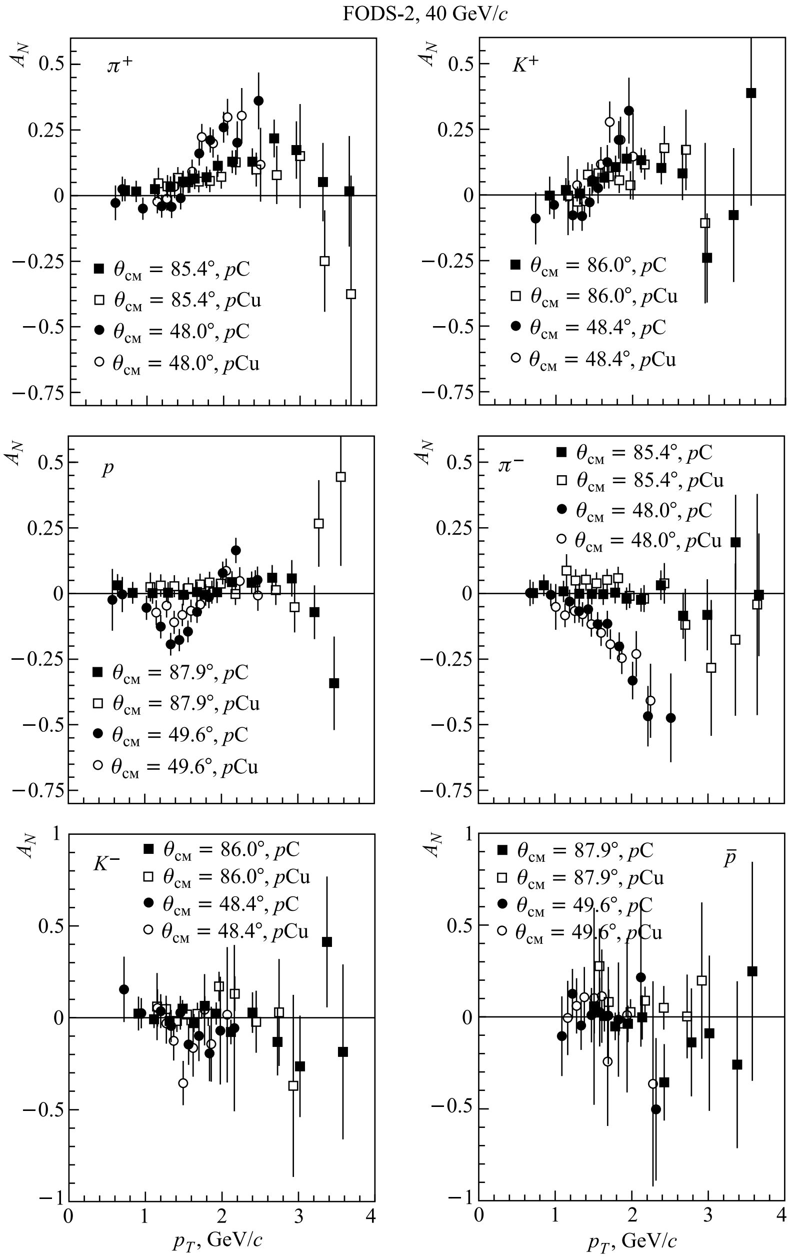

Fig. 2. FODS inclusive results [6]

The FODS experiment measured inclusive production of charged particles using two-arm narrow spectrometer. The FODS experimental setup was built to measure charged hadrons at different angles at high intensities (up to 10^9 p/10 s cycle). Special beam-line was constructed in 1994 to have intensive (up to $3 \cdot 10^7$ $p_\uparrow$/10 s cycle) beam from Λ decay.

The asymmetry was measured in inclusive production of $\pi^\pm, K^\pm, p^\pm$. Significant asymmetry was found in the most of the reactions at different solid angles [6]. The indication on oscillation behavior was also observed.

The FODS experimental setup was modified to increase significantly aperture (4 times) and tracking efficiency (Fig. 2). Physics goals of future polarization measurements at FODS are to increase the statistics (improve accuracy) in single-spin asymmetry measurements and study possible oscillation effects. The solid angle increase will give also a possibility of measuring spin effects in the reaction $p_\uparrow p \to \pi^+\pi^- X$.

Significant effects were found at the PROZA-M experimental setup in inclusive neutral meson production. The most interesting results are presented in Fig. 3. The asymmetry in the reaction $\pi^- p_\uparrow(d_\uparrow) \to \pi^0 X$ in the central region increased with transverse momentum p_T and achieved 40% [7]. A_N in the polarized target fragmentation region was observed at the level of 6% for both pion [8] and proton [9] beams. Even in the unpolarized beam fragmentation region the asymmetry was not equal to zero [10].

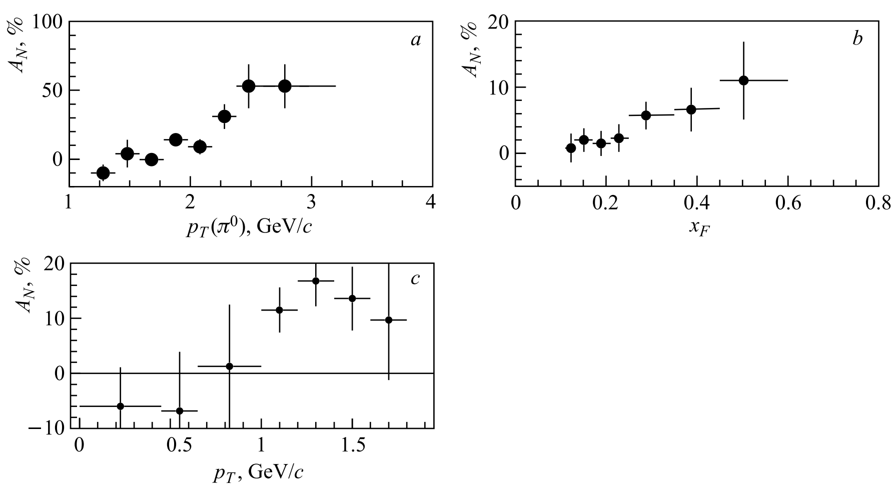

Fig. 3. PROZA-M inclusive results. A_N in the central region in the reaction $\pi^- N(p,d)_\uparrow \to \pi^0 X$ [7] (*a*), in the reaction $pp_\uparrow \to \pi^0 X$ [9] in the polarized target fragmentation region (*b*) and in the reaction $\pi^- d_\uparrow \to \pi^0 X$ [10] in the unpolarized beam fragmentation region (*c*)

Nevertheless, the accuracy of the existing experiments does not allow one to discriminate different theoretical models that try to describe single-spin asymmetry. New experimental program at IHEP will contribute significantly to the polarization studies.

SPASCHARM EXPERIMENT

The main motivation of the first stage of the SPASCHARM experiment is to study the dynamics of the strong interaction of hadrons and quarks. The program is devoted to the 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.

The measured observables are: an analyzing power A_N, which can be measured with high precision due to the full azimuthal setup coverage and large acceptance; 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.

The most intriguing goal of the second stage of the experiment is to measure double-spin asymmetry A_{LL} in charmonium production to study gluon polarization $\Delta G/G(x)$ at large x_F [11].

The experimental setup is designed to minimize systematic errors by measuring charge and neutral particle in a full (2π) azimuthal range and in a wide kinematic range. The layout of the SPASCHARM setup is presented in Fig. 4.

Beam detectors will include two scintillation fiber hodoscopes (fiber width 0.44 cm), GEM station, and threshold Cherenkov counters to separate between $\pi^-/K^-/\bar{p}$.

Tracking system will consist of the spectrometer magnet (1.5 $\mathrm{T \cdot m}$ field, full aperture 250×500 mrad), two GEM stations, and five thin-wall drift-tube

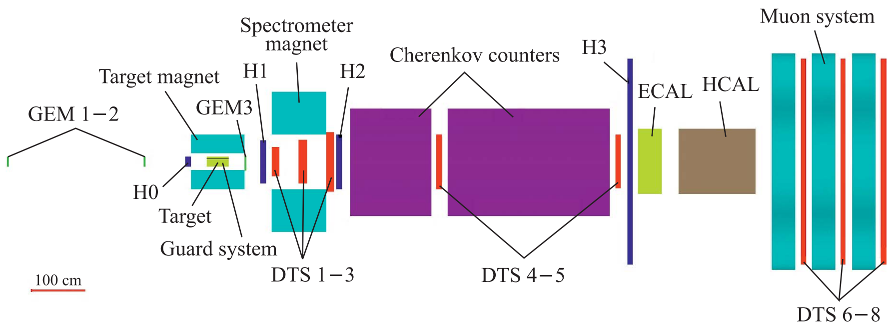

Fig. 4. Experimantal setup SPASCHARM

chamber stations (61 subplanes). Drift tubes allow one to measures coordinate with the accuracy $\sigma_x = \sigma_y < 160\ \mu$m, the momentum will be measured with the accuracy $\Delta P/P = 0.4\%$ at 10 GeV/c.

Two multichannel Cherenkov counters will detect pions above 3 GeV/c and kaons above 11 GeV/c. Three hodoscopes H1–H3 will be used as a multiplicity and trigger detector, as well as TOF, to separate p/K up to 2.5 and K/π up to 1.5 GeV.

Fine-segmented lead-scintillator electromagnetic calorimeter will be used to measure γ's with the accuracy $\sigma(E)/E = 1.3 \oplus 2.8/\sqrt{(E)}\%$ [12]. Cell dimensions are $5.5 \times 5.5 \times 70$ cm, full detector transverse size will be about 2×3 m. Compensated lead-scintillator hadron calorimeter with the resolution about $50/\sqrt{E}$ and muon detectors will be necessary to separate between electrons and pions and to measure reactions with secondary muons.

Veto system around polarized target will provide the possibility of measuring exclusive reactions.

The example of the particle reconstruction simulation is presented in Fig. 5. The experimental setup will allow one to measure asymmetry for the most of the light particles. The setup will allow one even to separate χ_c states if we will measure charmonium production (see Fig. 6).

New DAQ will provide event rate at the level of $5 \cdot 10^4$ events/cycle. The statistics for one month data taking run with the use of 34 GeV pion beam is presented in Table 1. Single-spin asymmetry can be measured precisely also with the use of proton [13] and $\bar{p}$ beams [14].

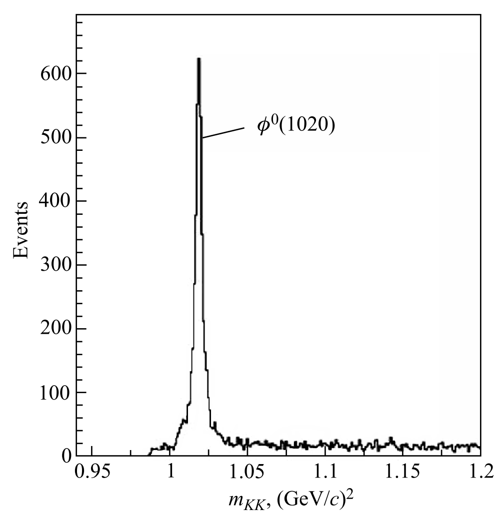

Fig. 5. Mass spectrum of the K^+K^- pairs in the ϕ-mass region

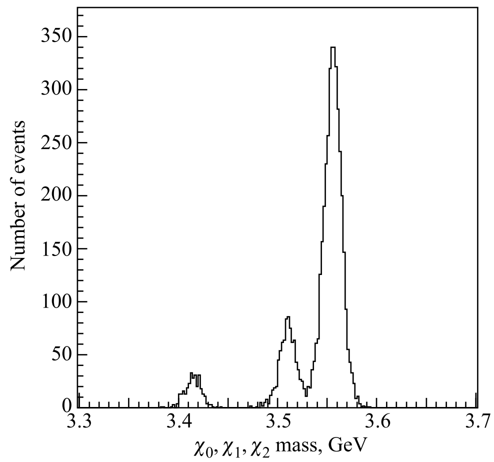

Fig. 6. Separation between χ_c states with SPASCHARM detector with the use of 1C fit on J/Ψ mass

Table 1. **The expected number of events N_{events} for different final states and for one month measurements with the use of 34 GeV π^- beam. The B/S is a ratio of a background to a signal**

Particle	N_{events}	B/S	Particle	N_{events}	B/S
π^+	$4.2 \cdot 10^9$		$\eta \to \pi^+\pi^-\pi^0$	$5.3 \cdot 10^6$	0.2
π^-	$8.7 \cdot 10^9$		$\omega(782) \to \pi^+\pi^-\pi^0$	$3.5 \cdot 10^7$	0.25
K^+	$6.7 \cdot 10^8$		$\omega(782) \to \gamma\pi^0$	$3.8 \cdot 10^7$	2.0
K^-	$9.0 \cdot 10^8$		$\phi(1020) \to K^+K-$	$4.3 \cdot 10^6$	0.3
p	$9.2 \cdot 10^7$		$\rho^+(770) \to \pi^+\pi^0$	$2.9 \cdot 10^8$	6.0
$\bar{p}$	$2.6 \cdot 10^8$		$\rho^-(770) \to \pi^-\pi^0$	$7.5 \cdot 10^8$	3.0
n	$3.2 \cdot 10^8$		$K_S^0 \to \pi^0\pi^0$	$1.7 \cdot 10^7$	3.5
$\bar{n}$	$8.0 \cdot 10^7$		$a_0(980) \to \eta\pi^0$	$1.8 \cdot 10^7$	9.0
K_L^0	$1.0 \cdot 10^8$		$\Lambda \to p\pi^-$	$1.4 \cdot 10^6$	0.1
$\pi^0 \to \gamma\gamma$	$4.3 \cdot 10^9$	0.1	$\bar{\Lambda} \to \bar{p}\pi^+$	$1.1 \cdot 10^6$	0.05
$\eta \to \gamma\gamma$	$4.2 \cdot 10^8$	0.5	$\Lambda \to n\pi^0$	$1.8 \cdot 10^6$	3.0
$\eta\prime \to \pi^+\pi^-\eta$	$8.3 \cdot 10^5$	0.05	$\bar{\Lambda} \to \bar{n}\pi^0$	$7.7 \cdot 10^5$	0.45
$K_S^0 \to \pi^+\pi^-$	$1.3 \cdot 10^7$	0.3	$\bar{\Delta}^{++} \to p\pi^+$	$9.3 \cdot 10^6$	2.0
$\rho_0(770) \to \pi^+\pi^-$	$4.2 \cdot 10^8$	2.5	$\Delta^{++} \to p\pi^+$	$2.5 \cdot 10^7$	5.5
$K^{0*}(892) \to K^+\pi-$	$1.1 \cdot 10^8$	0.7	$\Xi^- \to \Lambda\pi^-$	$1.9 \cdot 10^6$	0.1
$\bar{K}^{0*}(892) \to K^-\pi^+$	$4.3 \cdot 10^7$	2.0	$\bar{\Xi}^+ \to \bar{\Lambda}\pi^+$	$1.6 \cdot 10^6$	0.1
$K^{+*}(892) \to K^+\pi^0$	$1.9 \cdot 10^7$	2.6	$\Sigma^0 \to \Lambda\gamma$	$1.2 \cdot 10^6$	0.5
$\bar{K}^{-*}(892) \to K^-\pi^0$	$3.8 \cdot 10^7$	1.3	$\Sigma^0(1385) \to \Lambda\pi^0$	$3.9 \cdot 10^6$	0.2
$\omega(782) \to e^+e^-$	$1.7 \cdot 10^5$	0.5	$\rho^0(770) \to \mu^+\mu^-$	$9.7 \cdot 10^4$	0.7

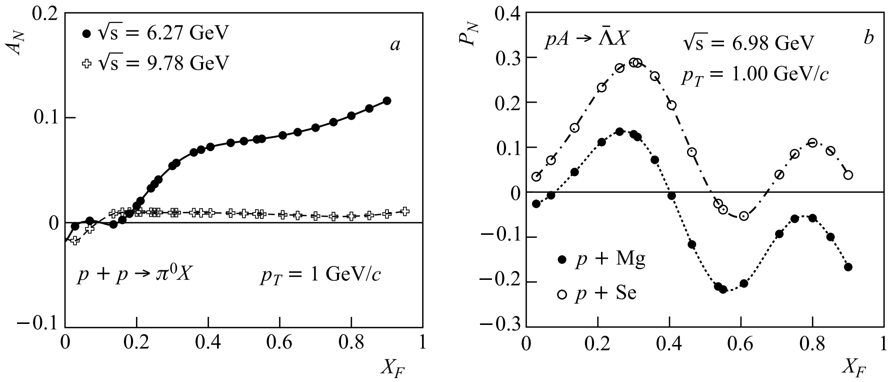

Fig. 7. Predictions for A_N in π^0-meson inclusive production (*a*) and $\bar{\Lambda}$ polarization (*b*) [16]

High precision of proposed measurements will give us a good possibility of discriminating different theoretical models describing polarization effects. Moreover effective color model [15] has predictions for most of the reactions in differnet kinematic regions. Two examples of such predictions are presented in Fig. 7 for the single-spin asymmetry of π^0-meson inclusive production and for the $\bar{\Lambda}$ polarization. More predictions were presented at this Conference by V. Abramov [16].

The asymmetry in exclusive reaction can be measured at least few times better, than in the previous experiments [4], due to the registration of the charged particles. For example, the error bars in the asymmetry measurements in the reaction $\pi^- p_\uparrow \to f_2(1270)X$ will be from 0.1 to 1% for different t intervals.

The SPASCHARM setup will measure the charged particle multiplicity, as an additional variable. Possible measurement of the elastic scattering was discussed by S. Nurushev [17]. There is also a suggestion to measure Sivers function in the Drell–Yan production [18].

Spin program with polarized target and unpolarized beam is very interesting, nevertheless, polarized beam gives much more advantages, since precision is better and effects are higher.

PHYSICS WITH POLARIZED BEAM

Current IHEP program includes the construction of the external target to obtain high quality external beams at IHEP. The position of the future facility inside IHEP experimental hall is presented in Fig. 8. Beam will be delivered to external target (up to $2 \cdot 10^{13}$ p/10 s cycle) to create two secondary beams:

— upper line(24A) is specially designed as polarized beam channel;

— lower line (24B) will be used for the spectroscopy experiment VES.

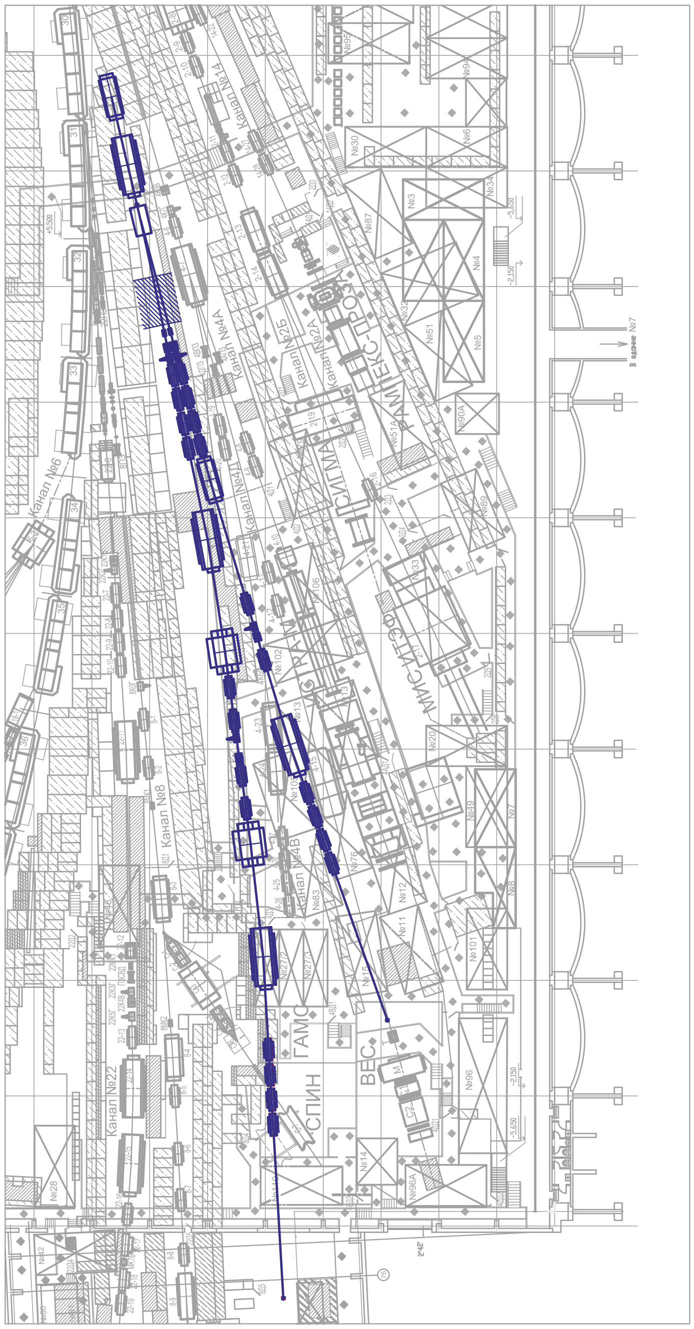

Fig. 8. High-intensity extracted beams from external target

Polarized beam will be created from hyperon decay using standard procedure [19]. Main optical scheme is presented in Fig. 9. The channels will consist of 12 quadrupoles and four magnets to decline the beam on about 160 mrad. Beam-line total length will be about 120 m. High intensive polarized proton beams with energy between 12 and 50 GeV can be delivered to the experiment target.

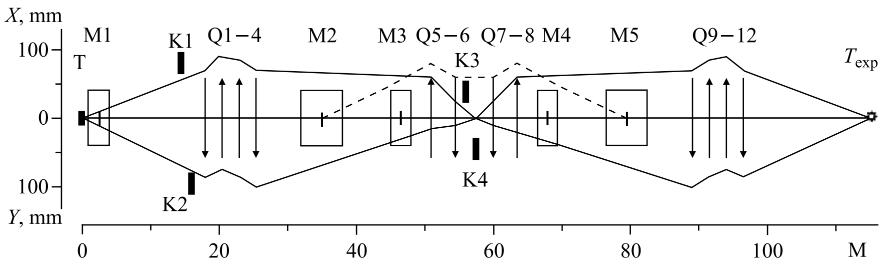

Fig. 9. Optical scheme of the polarized particle channel

Table 2. **Parameters of the polarized proton and antiproton beams**

Collimator opening	Proton beam		Antiproton beam	
	Min	Max	Min	Max
Momentum spread $\Delta p/p$, %	± 4.5 ($\sigma = 2.1$)	± 11.0 ($\sigma = 5.3$)	± 5.5 ($\sigma = 2.3$)	± 12.0 ($\sigma = 5.6$)
Beam size σ_X, σ_Y, mm	13×11	17×14	18×19	20×19
Beam divergence σ_X, σ_Y, mrad	1.6×2.0	1.5×1.9	1.6×1.9	1.5×2.0
Full intensity for 10^{13} prot./spill at 60 GeV	$4.9 \cdot 10^7$	$1.3 \cdot 10^8$	$1.4 \cdot 10^5$	$3.9 \cdot 10^5$

One of the most interesting features of the channel is the possibility to obtain polarized $\bar{p}$ beam with the optimal energy 14 GeV. Main parameters of both 40 GeV polarized proton and 14 GeV antiproton beams are presented in Table 2. The $\bar{p}$ intensity can be increased, but additional developments are required.

We are planning also to use spin flipper to decrease systematic errors. Additionally, we require not only reverse spin, but also transform the vertical spin to longitudinal one. This longitudinal polarization is required for double-spin measurements.

The description of the spin flipper is presented at the Shatunov's talk [20]. The flipper has to have significant apperture due to relatively large beam size. The simplest rotator, which can be used in our case, consists of two helical magnets with opposite helicities with the following parameters: $B_{\max} = 47$ kGs; $\lambda = 2.5$ m.

To compensate the beam particle displacements, we will use four dipole correctors with the folloiwing parameters: $L = 30$ cm; $B = 23$ kGs; $\mathrm{tilt} = \pm 0.1$ rad.

Total length of the spin flipper is 6.5 m. Flipper optics practically is equal to empty straight space with spin transparency about 97%.

We are planning to construct polarized beam at the beam-line 24A in the next three years, commisioning it at 2016.

SCHEDULE

We are planning to construct the main part of the experimental setup SPASCHARM in the fall of 2014. The experimental setup will include polarized target, full system of drift-tube chambers, fiber hodoscopes, multichannel Cherenkov counters, old lead-glass calorimeter. All detectors will be equipped with new electonics. We are planning to start SSA measurements in the beam fragmentation region with the new Dubna polarized target at the beam-line 14 in 2014. New electromagnetic calorimeter («shashlyk type») will be ready in 2016 as well as GEM detectors.

In a parallel, a new beam-line will be constructed. We are expecting to have beam-line commisioning in 2016. At the same time, the SPASCHARM will be transited to the new position to measure asymmetry in the polarized beam fragmentation region.

We are hoping to have first test data taking run with the use of polarized beam in the fall of 2016 and start intensive SSA measurements with the polarized beam in 2017.

CONCLUSIONS

New experiment SPASCHARM, devoted to systematic study of polarization phenomena in hadron–hadron interactions, is under preparation.

Detection of charged and neutral particles in the final state in a wide solid angle will allow one to explore dozens of reactions using different beams and targets in inclusive, exclusive, and elastic reactions.

A special feature of the experiment is the simultaneous measurements of different spin-dependent physical observables.

The experimental setup will have full azimuthal angle coverage, which will allow one to minimize systematic errors.

Polarized antiproton beam gives us unique possibility to measure spin effects in the interaction of matter and antimatter.

The setup allows one to detect particles kinematic parameters with high precision, which is crucial for charmonium study as well as for the separation of resonances from combinatorial background.

SPASCHARM will measure polarization effects with unprecedent accuracy, especially with polarized beam.

SPASCHARM will start physics in 2014 (in 2016 with polarized beam).

Acknowledgements. This work was prepared by IHEP spin physics group. The main asisstance was provided by V. Abramov and A. Vasiliev. SPASCHARM setup was designed inside laboratory of polarized experiments. The Monte-Carlo simulation was done by V. Abramov, N. Minaev and D. Morozov. The idea of the polarized beams was for the first time formulated many years ago by S. Nurushev, the calculations of the polarized beam were carried out by IHEP beam department, mainly by V. Garkusha and V. Zapolsky. The IHEP directorate approved the development of the polarized beam channel. FODS data were presented by V. Kryshkin.

The work was partially supported by RFBR grant 12-02-00797.

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