THE FIRST STAGE OF POLARIZATION PROGRAM SPASCHARM AT THE ACCELERATOR U-70 OF IHEP

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Abstract

The first stage of the proposed polarization program SPASCHARM includes the measurements of the single-spin asymmetry (SSA) in exclusive and inclusive reactions with production of stable hadrons and the light meson and baryon resonances. In this study we foresee of using the variety of the unpolarized beams (pions, kaons, protons and antiprotons) in the energy range of 30-60 GeV. The polarized proton and deuteron targets will be used for revealing the flavor and isotopic spin dependencies of the polarization phenomena. The neutral and charged particles in the final state will be detected.

Introduction

In shaping the new polarization program at U-70 we were guided by three conditions: by our own experiences, by theoretical status of subject and the reliability of the new program. As concerns of the first condition one may refer on the comparative study of polarizations in the elastic scattering of particles and antiparticles by using the polarized proton target [1], [2], measurements of the spin transfer tensor [3], [4] (HERA Collaboration), study of the SSA in the exclusive and inclusive charge exchange reactions at 40 GeV/c [5] (PROZA Collaboration), study of polarization effects at 200 GeV/c by using the polarized proton and antiproton beams (E581/E704 Collaboration, FNAL) [6]. The fourth example of polarization data came recently from the STAR Collaboration at energy in the center of mass \(\sqrt{s}=200\) GeV [7], [8].
The second condition is the status of the relevant theoretical models. Since the energies and transfer momenta with which we are dealing are not large enough, so there is a doubt about the possible application of the perturbative quantum chromodynamics p(QCD). Therefore either the specific models should be used for the interpretation of the experimental data or the general asymptotic predictions might be applied.

The third condition is relevant to the reliability of the experiment, that is, availability of robust equipments, manpower, money and other resources.

Below we shall briefly describe all these conditions.

1 The preceding study of polarization effects at U70

In 1970-1976 at U70 Collaboration of physicists from Saclay (France), Protvino, Dubna and Moscow (Russia) (HERA Collaboration) had performed the measurements of the polarization parameters P and R (spin rotation parameter) in elastic scattering of particles and antiparticles at $\sim 40$ GeV/c by using the polarized proton target. The polarization data are presented in Figure 1 with one panel for pair of particle and antiparticle.

In papers [9] and [10] it was considered some consequences of the hypothesis of the approximate $\gamma_5$ invariance of the strong interactions. According to this hypothesis at high energies and large momentum transfers $s$, $-t \gg m^2$ (m is the mass of the particles involved in reactions) the polarization in any elastic scattering of particles or antiparticles should be equal to zero. From Figure 1 the following results stem out of:

1. polarizations are not zero in reactions induced by pions, protons and antiprotons. It means that the hypothesis of $\gamma_5$ invariance does not work for that reactions yet,

2. the polarizations are zero for reactions induced by kaons. It means that the hypothesis of $\gamma_5$ invariance may work in these reactions. But the large error bars in the measured polarizations make this statement doubtful. The future experiments measuring the polarizations in kaon induced elastic scattering with better statistics are needed.

For all of above reactions the next comment follows. Though the asymptotic regime was reached for $s$ it’s not fulfilled for $t$, since for $|t| > 1(\text{GeV/c})^2$ the experimental errors are large. This is the next item for the future measurements with high statistics. There is a good measurement of the polarization parameter in $\pi^\pm p, K^\pm p, pp, \bar{p}p$ elastic scattering at 6 GeV/c [11]. In this case the $\gamma_5$ invariance does not work too for all reactions, exception is $\bar{p}p$, where polarization is compatible with zero in small -t region in frame of the large error bars.

Figure 1: (a) P in elastic scattering: $\pi^- p(\bullet)$ and $\pi^+ p(\blacksquare)$. (b) P in elastic scattering: $K^- p(\bullet)$ and $K^+ p(\blacksquare)$. (c) P in elastic scattering: $\bar{p}p(\bullet)$ and $pp(\blacksquare)$. 
In paper [12] the study was made of the asymptotic relations between polarizations in cross channels of a reaction. Using the crossing symmetry and Fragman-Lindeloff theorem they arrived at the following result: polarizations in the elastic scattering processes (see Figure 1) induced by particle and antiparticle at a given energy and a given angle should be equal in magnitude and opposite in sign. If we look at Figure 1 one may note that this statement is approximately correct for the pion induced reactions, not correct for reactions initiated by proton and antiproton and ambiguous for reactions involving kaons (thanks to the small statistics). Therefore the new elastic scattering experiment should clarify this interesting problem by gathering a large statistics, specially at large transverse momenta.

The HERA Collaboration making use of the simple Regge pole model concluded that the elastic scattering polarizations induced by pions and kaons follow the predictions of such model, while polarization in elastic pp scattering reveals the drastic deviation from the prediction of the Regge pole model. Such behavior may be explained by assuming that at 40 GeV/c momentum the dominant contribution to the polarization in elastic pp scattering comes from the pomeron with the spin flip term of the order of 10% with respect to the spin non flip term. Involving in the analysis the data on the spin rotation parameter [3], [4] they strengthened their conclusion. But the statistics are not so large to be unambiguous in such conclusion. One needs more measurements.

The PROZA Collaboration measured the single spin asymmetries in the charge exchange binary and inclusive reactions at the incident beam momentum 40 GeV/c [5]. With the different statistics the results were obtained for the exclusive reactions containing in the final states the mesons of the different mass and quantum numbers Figure 2, Figure 3.

The polarization data for reactions 1, 2 and 3 (the mesons in the final states are spinless) were extensively analyzed in frame of the different models. For example, in the asymptotic model [12] the polarizations in all of these three reactions should be zero. But such predictions are in contrast to the experimental data (see Figure 2). In the Regge pole model with inclusion of the odderon [13], [14], the best approximation predicting the new dip in polarization around the crossing point at -t \sim 0.2(\text{GeV}/c)^2 was obtained in the

![Figure 2: (a) Polarization in reaction $\pi^- + p \rightarrow \pi^0 + n$. (b) Polarization in reaction $\pi^- + p \rightarrow \eta + n$. (c) Polarization in reaction $\pi^- + p \rightarrow \eta' + n$.](image)


model [13]. After analyzing the reaction (Figure 2a) the authors of the paper [14] noted:

The surprising results of the recent 40 GeV/c Serpukhov measurement of the polarization in $\pi^-p \rightarrow \pi^0n$ are shown to support the conjecture that the crossing-odd amplitude may grow asymptotically as fast as is permitted by general principles.

This model in contrast to other ones predicts the shift of the left zero crossing point farther to left and the increase of polarization with growth of the incident momentum. This is an attractive subject for experimental check.

The reactions 2,3 were also analyzed in frame of the Regge pole model and data are consistent with model prediction. Other reactions 4-6 showing also the significant spin effects (see Figure 3) did not yet attract the attention of theoreticians.

These data are unique in the sense that nobody made (30 years later) the similar measurements at higher energies. This fact may confirm the assumption that the U-70 accelerator occupies a good niche for such studies of exclusive reactions dying rapidly with growth of energy.

By using the experimental set-up PROZA the inclusive asymmetries were measured at 40 GeV/c in the following charge exchange reactions:

$$\pi^- + p \rightarrow \pi^0 + X \ (1). p + p \rightarrow \pi^0 + X \ (2)$$

in the central, polarized target and unpolarized beam fragmentation regions [5]. In central region the asymmetry about 30% was found at $p_T > 2$ GeV/c, while in the beam fragmentation region it was around 10-15% at $p_T > 1$ GeV/c in reaction (1). In contrary the analyzing power for reaction (2) is almost zero at the same regions. These are the puzzling results of the (SSA) measurements in the inclusive charge exchange reaction (1) at the incident momentum of 40 GeV/c (PROZA). There is no any independent experimental confirmation of these results.

![Graphs](image)

Figure 3: (a) asymmetry in reaction $\pi^- + p \rightarrow \omega + n$. (b) asymmetry in reaction $\pi^- + p \rightarrow a_2 + n$. (c) asymmetry in reaction $\pi^- + p \rightarrow f + n$. 
2 First stage of the SPASCHARM polarization program

In composing the new scientific program we are guided by the recent theoretical and experimental developments in polarization physics. Its obvious also that this program is also strongly influenced by our own experiences, by resources and competitions with other collaborations over the world. Therefore we attempt of using efficiently our proton synchrotron U70, existing experimental equipments and fit to the environmental requirements. So we are going to propose the following first stage polarization program:

1. Asymmetry measurements in charge exchange exclusive reactions at 34 GeV/c with emphasis to increase the statistics of the most of reactions shown in the Figures 2 and 3 by approximately by factor 10 and move to the larger t region.

2. Comparative studies of asymmetries induced by particles and antiparticles in binary and inclusive reactions.

3. Study of spin transfer mechanism by using the unstable spin carrying particles like hyperons, vector mesons, etc. We emphasize, that only fixed target experiments, like ours, may measure spin transfer tensors for stable final particles, like antiprotons and protons.

4. Asymmetry measurements in inclusive productions of various stable hadrons containing partons of different flavors (u,d,s,c quarks).

5. The systematic studies of the isospin dependence of single spin asymmetry.

6. The comparative studies of asymmetries in production of particles and antiparticles in final state.

7. Asymmetry studies by using the light ion beams and polarized target.

8. Check more accurately the puzzle caused by differences of the single spin asymmetries induced by pion and proton beams in the central and fragmentation regions at 34 GeV/c.

9. The new upcoming polarized proton beam will lead to the measurements of the inclusive single spin asymmetries with unprecedented precisions.

10. Finally with the availability of the polarized beam and polarized target the way will be opened for the intense studies of the double spin asymmetries in many reactions.

For the inclusive reactions the extensive Monte Carlo simulations were made for beam particles $\pi, K, p$ and $\bar{p}$ for momentum of 34 GeV/c. For the sake of brevity we present, as an example, only the results of calculations for the $\bar{p}$ beam. According to the negative beam composition the fraction of the $\bar{p}$ particles is only 0.3% at momentum of 34 GeV/c. Therefore the absolute flux of $\bar{p}$ beam is only $9 \times 10^3 \bar{p}/\text{cycle}$. The yields of the secondary particles on this beam are very important for comparison to the yields of the same particles in the proton beam. For detection of the secondary resonances with the rare decay modes produced on the propandiole target the request was imposed: the energy deposit
in calorimeters should be $> 2$ GeV. Knowing the $\bar{p}$ interaction cross section with target the yields of the secondary particles with higher cross section for 30 days beam run are presented in the next Table 1.

Table 1. The estimated yields $N_{EV}$ of the secondary particles from the propandiole target ($C_3H_8O_2$, 20 cm long) stricken by the $\bar{p}$ beam of 34 GeV/c. One month beam run was assumed ($3.6 \times 10^8$ interactions). B/S means the background to signal ratio.

| # | particle | $N_{EV}$ | * | # | particle | $N_{EV}$ | B/S |
|---|---------|---------|---|---|---------|---------|-----|
| 1 | $\pi^+$ | $2.1 \times 10^8$ | * | 7 | $n$ | $1.6 \times 10^7$ | * |
| 2 | $\pi^-$ | $2.6 \times 10^8$ | * | 8 | $\bar{n}$ | $1.4 \times 10^8$ | * |
| 3 | $K^+$ | $1.7 \times 10^8$ | * | 9 | $\Lambda \rightarrow p + \pi^+$ | $2.1 \times 10^6$ | 0.1 |
| 4 | $K^-$ | $2.2 \times 10^8$ | * | 10 | $\Lambda \rightarrow \bar{n} + \pi^0$ | $1.1 \times 10^6$ | 8.0 |
| 5 | $p$ | $1.6 \times 10^8$ | * | 11 | $\Delta^{--} \rightarrow p + \pi^-$ | $4.2 \times 10^7$ | 7.0 |
| 6 | $\bar{p}$ | $1.8 \times 10^8$ | * | 12 | $\Xi^- \rightarrow \Lambda + \pi^-$ | $1.0 \times 10^9$ | 0.1 |

Two comments are in order to this Table 1. First, the number of events for polarized protons are less than indicated in Table 1 by one order of magnitude. Second on the level of several percents the asymmetries produced by protons and antiprotons may be compared if the statistics are larger than $10^5$. It mens that such comparisons may be done for sure for pions, kaons, barions, antibarions, but doubtful for $\Xi^-$. The estimates were done for ideal apparatus and not taking into accounts the real backgrounds.

3 The experimental apparatus

The experimental apparatus for the SPASCHARM program consists of the following elements:

1. Beam apparatus consisting of the scintillation and Cherenkov counters, scintillation hodoscopes for detecting and identifying the beam particles (not shown in Figure 4).

2. The polarized proton (deuteron) target (target in Figure 4).

3. The guard system surrounding the polarized target (PT).

4. The polarization building-up and holding magnet (target magnet).

5. GEM1, GEM2

6. The large aperture magnetic spectrometer.

7. Micro drift chambers (MDC).

8. Two large aperture multichannel threshold Cherenkov counters for identifications of the secondary particles.

9. Multiwire proportional chambers (MWPC).

10. Electromagnetic calorimeter (ECAL).

11. Hadron calorimeter (HCAL).
12. Muon system.

13. Scintillation hodoscopes.

The layout of the SPASCHARM detectors is presented in Figure 4.

![Figure 4: Layout of the SPASCHARM experimental apparatus.](image)

are listed in the Table 2.

Table 2. The parameters of the main elements of the experimental apparatus. L-distance from detector to polarized target (PT), DS-detector structure, WS-wire spacing, GS-gross size, $N_{ch}$-number of channels

| detector | L, m | DS         | WS    | GS    | $N_{ch}$ |
|----------|------|------------|-------|-------|----------|
| GEM1     | 0.5  | X, Y       | Strip 0.4 | 20 x 20 | 1000     |
| GEM2     | 0.75 | X, Y       | Strip 0.4 | 30 x 30 | 1500     |
| 1.MDC    | 1.0  | X', Y', Y, U, V' | 6     | 65 x 54 | 1200     |
| 2.MDC    | 1.5  | X', Y', Y, U, V' | 6     | 111 x 81 | 1920     |
| 3.MDC    | 2.0  | X', Y', Y, U, V' | 6     | 150 x 111 | 2610     |
| 4.MWPC   | 3.5  | X, Y, U, V  | 2     | 150 x 100 | 2500     |
| 5.MWPC   | 6.5  | X, Y, U, V  | 2     | 150 x 100 | 2500     |

**Conclusions**

The SPASCHARM program presents the natural extension of our previous polarization experiments. Proposed experiment will open new and wider perspectives due to the several reasons. First it contains the magnetic spectrometer with the high resolution tracking detectors allowing to register all secondary charged particles with precise angular and momentum resolutions. Secondly it has the fast particle identification system allowing to reconstruct the resonances with high probability. Third, the electromagnetic and hadronic calorimeters practically allow (together with threshold Cherenkov counters) to identify all hadrons in final state having sufficiently large cross sections. The large angular and
momentum acceptances will finally allow to increase by a factor of 10 the statistics than in previous PROZA experiments. Using the forward detectors with the guard counters around the polarized target one can select the binary charge exchange reactions with one order better statistics and also detect new reactions. The detections of hyperons and vector mesons permit to study not only polarization but also the spin transfer mechanism in strong interaction. It is assumed that the full apparatus for the first stage of the SPASCHARM polarization program will be ready to 2013 beam run. The distinct feature of our program will be the comparative studies of the polarization phenomena induced by the particles and antiparticles.

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