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RECENT RESULTS FROM PROTVINO POLARIZED EXPERIMENT PROZA-M

V. V. Mochalov[1,], N. S. Borisov[2], A. M. Davidenko[1], A. N. Fedorov[2],*
V. N. Grishin[1], V. Yu. Khodyrev[1], V. I. Kravtsov[1], A. A. Lukhanin[3],
V. N. Matafonov[2], Yu. A. Matulenko[1], V. A. Medvedev[1],
Yu. M. Melnick[1], A. P. Meschanin[1], D. A. Morozov[1], A. B. Neganov[2],
L. V. Nogach[1], S. B. Nurushev[1], Yu. A. Plis[2], A. F. Prudkoglyad[1],
P. A. Semenov[1], K. E. Shestermanov[1], V. L. Solovianov[1],
L. F. Soloviev[1], Yu. A. Usov[2], A. N. Vasiliev[1], A. E. Yakutin[1]

[1]Institute for High Energy Physics, Protvino, Russia
[2]Joint Institute for Nuclear Research, Dubna
[3]Kharkov Physical Technical Institute, Kharkov, Ukraine

Single-Spin Asymmetry A_N (SSA) was measured at the Protvino 70 GeV accelerator. Asymmetry in the reaction $p + p_\uparrow \to \pi^0 + X$ is close to zero within error bars at small $|x_F|$ and $p_T < 1.5$ GeV/c. SSA in the reaction $\pi^- + p_\uparrow \to \pi^0 + X$ at polarized target fragmentation region equals $(-13.8 \pm 3.8)\%$ at $|x_f| > 0.4$. There is an indication that the asymmetry begins to rise up at the same centre-of-mass system pion energy.

Одиночная спиновая асимметрия A_N (ОСА) была измерена на 70-ГэВ ускорителе в Протвино. Асимметрия в реакции $p + p_\uparrow \to \pi^0 + X$ близка к нулю в пределах ошибок измерений при малых $|x_F|$ и $p_T < 1,5$ ГэВ/c. ОСА в реакциях в области фрагментации поляризованной мишени равна $(-13,8 \pm 3,8)\%$ при $|x_f| > 0,4$. Есть указание на то, что асимметрия начинает расти при одинаковой энергии пиона в системе центра масс.

Large polarization effects were found during last few decades. Single-Spin Asymmetries were observed to be of the order of 20–40% while Perturbative Quantum Chromodynamics (pQCD) makes a qualitative prediction that the single-spin transverse effects should be very small due to the helicity conservation [1]. Here we present new SSA measurements carried out at the 70 GeV accelerator (Protvino) in the reaction $p + p_\uparrow \to \pi^0 + X$ at 70 GeV in the central region ($x_F \approx$ 0) and in the reaction $\pi^- + p_\uparrow \to \pi^0 + X$ in the polarized target fragmentation region at 40 GeV.

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*E-mail: mochalov@mx.ihep.su

ASYMMETRY IN THE REACTION $p + p_\uparrow \to \pi^0 + X$ AT 70 GeV

The goal of our measurements was to measure asymmetry in the reaction $\pi^- + p_\uparrow \to \pi^0 + X$ and to compare it with the previous contradictory results.

Asymmetry in the reaction $p + p_\uparrow \to \pi^0 + X$ in the central region was measured earlier in two experiments. Experiment at 24 GeV (CERN) manifested large SSA in inclusive π^0 production [2], while E704 (FNAL, 200 GeV) claimed zero asymmetry [3].

PROZA-M experiment observed significant effects in the reaction $\pi^- + p_\uparrow \to \pi^0 + X$ at 40 GeV (Protvino) [4]. New measurements at the Protvino U-70 accelerator facility were carried out. 70 GeV protons were extracted from the accelerator vacuum chamber using a bent crystal. The experimental setup is presented in Fig. 1.
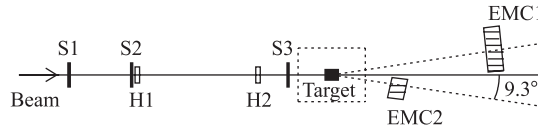

Fig. 1. The experimental setup PROZA-M. S1–S3 — trigger scintillation counters; H1–H2 — hodoscopes; EMC1 and EMC2 — electromagnetic calorimeters; Target — polarized target

Three scintillation counters S1–S3 were used for zero level trigger with a coincidence from two hodoscopes H1–H2 (two subplanes each). γ quanta were detected by two electromagnetic calorimeters EMC1 and EMC2 (arrays of 480 and 144 lead-glass cells) placed at 7 and 2.8 m downstream the frozen polarized target with the average polarization of 80%. First level trigger on transverse energy was set up to be independent for each detector.

We were able to detect π^0 till $p_T = 3.0$ GeV/c using specially developed algorithm for overlapping showers reconstruction [5]. π^0 mass resolution was 10 MeV/c^2 for EMC1 and from 12 to 16 MeV/c^2 for EMC2 (Fig. 2).

Angle 9.3° in the laboratory frame corresponds to 90° in the centre-of-mass system (c.m.s.). Kinematical characteristics of detected π^0's (p_T vs x_F bi-plot) are presented in (Fig. 3, a). $|x_F|$ did not exceed 0.15 and the distribution was symmetrical on x_F.

The slope of relative π^0 cross section presented in Fig. 3, b was used as an additional cross-check of data quality. The result is in good agreement with the previous charged pion invariant cross-section measurements. Exponential constant $\alpha = -5.89 \pm 0.08$, while FODS experiment (Protvino) announced $\alpha = -5.68 \pm 0.02$ for $\pi+$'s and $\alpha = -5.88 \pm 0.02$ for π^- mesons [6].
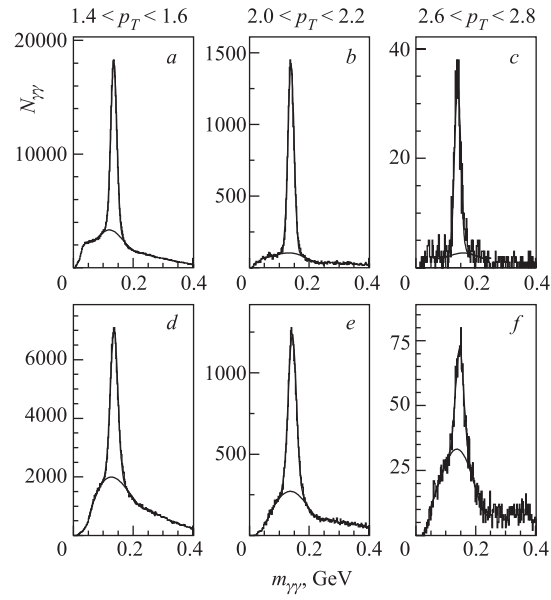
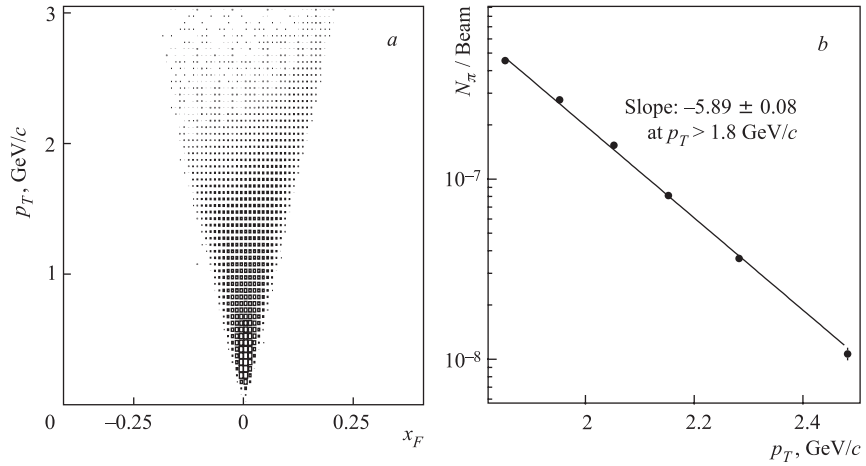Fig. 2. Mass spectra for EMC1 (a–c) and EMC2 (d–f) for different p_T intervals

Fig. 3. Two-dimensional π^0 distribution on p_t and x_F (a) and relative π^0 cross section ($N_\pi/$Beam) (b)

The asymmetry A_N was defined as

$$A_N = \frac{D}{P_{\text{target}}} A_N^{\text{raw}} = \frac{D}{P_{\text{target}}} \frac{n_\downarrow - n_\uparrow}{n_\downarrow + n_\uparrow}$$

for EMC2 and had the opposite sign for EMC1. D is the polarized target dilution factor; P_{target} — average target polarization; $n_\downarrow$ and $n_\uparrow$ — normalized numbers of π^0 mesons for opposite target polarizations.

False asymmetry A_N^{false} appears mainly due to the instability of the calorimeters energy scale. We recalibrated both calorimeters independently using π^0 mass with an accuracy of 0.15%, which corresponded to raw false asymmetry value of 0.3% and $A_N^{\text{false}} \approx 3\%$ taking into account the dilution factor divided by target polarization ($D/P_{\text{target}} \approx 10$).

The false asymmetry was investigated by dividing statistics with the same target polarization into two data samples and calculating the asymmetry for them. A_N^{false} was zero within error bars (Fig. 4, a). We also compared the asymmetry for the two detectors and did not find any difference (Fig. 4, b).
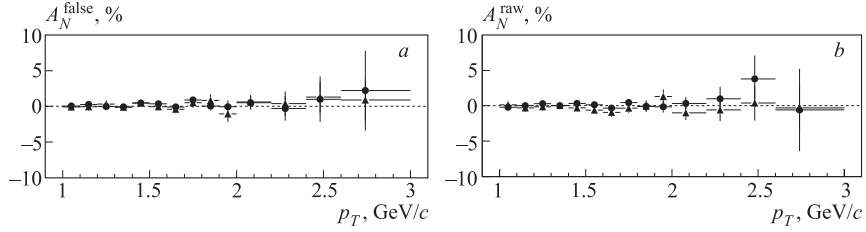

Fig. 4. a) Raw false asymmetry; b) asymmetry for two detectors. ● — EMC1; ▲ — EMC2

The final result for both detectors is presented in Fig. 5, a. The asymmetry is zero within error bars. Our result is in good agreement with the FNAL data at 200 GeV [3] and contradicts to the previous CERN measurements at 24 GeV [2].

Almost all theoretical models expect small effects in the reaction $p_\uparrow + p \rightarrow \pi^0 + X$ in the central region, because π^0 is supposed to be produced mainly from the gluons. The gluons transversal spin component is considered to be small. The Anselmino prediction [7] for 200 GeV at small x_F is presented together with the E704 experimental data (Fig. 5, b).

By comparing the presented data with the π^0 asymmetry $A_N \approx -40\%$ in the reaction $\pi^- + p_\uparrow \rightarrow \pi^0 + X$ at 40 GeV at the same kinematic region [4], we may conclude that the asymmetry depends on quark flavour. Otherwise we have to suppose significant changes in the interaction dynamics in the energy range between 40 and 70 GeV.
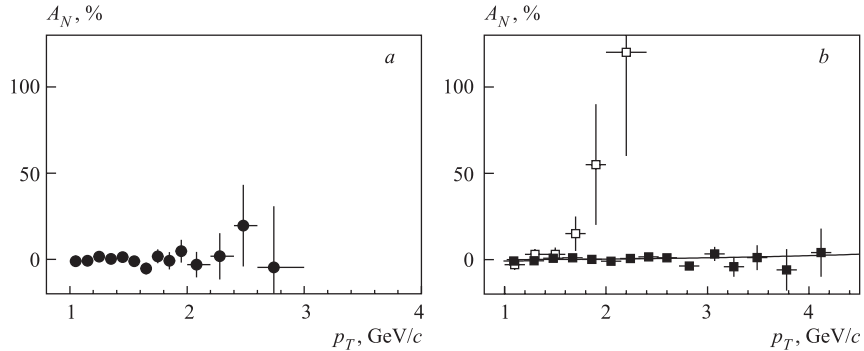
Fig. 5. *a*) Summed A_N for two detectors, $\bullet$ — this experiment. *b*) Asymmetry at 24 GeV [2] ($\square$) and 200 GeV [3] ($\blacksquare$) at central region; Anselmino calculations [7] for 200 GeV and $x_F = 0$ are drawn

The asymmetry in the reaction $p_\uparrow + p \to \pi^0 + X$ is cancelled because of various channel interference from a polarized and nonpolarized proton and a large contribution of gluonic channels. In the $\pi^- p_\uparrow$ collisions the valence u quark from a polarized proton combining with the valence $\bar{u}$ quark from π^- gives the main contribution to π^0 production, while other channels are suppressed.

A_N IN THE REACTION $\pi^- + p_\uparrow \to \pi^0 + X$ AT THE POLARIZED TARGET FRAGMENTATION REGION

The asymmetry in the polarized target fragmentation region was measured for the first time. The aim of the current experiment was to check our expectations that the asymmetry in the polarized particle fragmentation region is the same for both the beam and the target projectile. The experiment was carried out at the modified experimental setup PROZA-M (see above).

The electromagnetic calorimeter from 720 cells was placed at 2.3 m downstream the target at the angle of $40°$ in the laboratory frame in two exposions in the 2000 and at the angle of $30°$ in the 1999 data taking run.

We detected γ quanta in the energy range between 0.5 and 3.5 GeV. Monte-Carlo simulation of the electromagnetic showers in the PROZA-M lead-glass calorimeter based on GEANT3.21 shows that significant part of the γ-quanta energy (up to 20%) was lost during reconstruction procedure mainly due to an electronic threshold. Cherenkov light was simulated taking into account light absorbtion and reflection from crystal surface wrapped by mylar. The dependence of detected energy on simulated γ-quanta energy is shown in Fig. 6 as well as
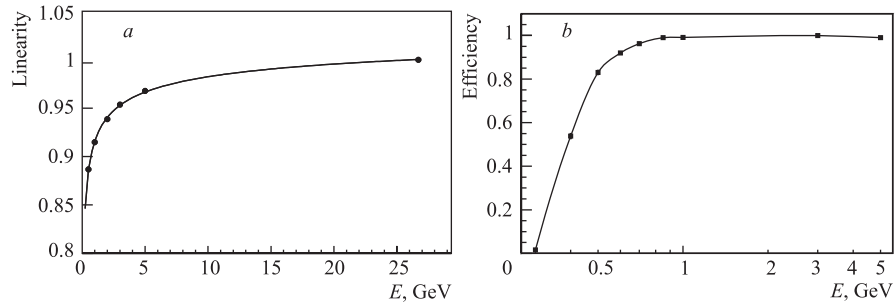
Fig. 6. The dependence of the energy reconstructed (*a*) and the efficiency on true γ-quantum energy from MC simulation (*b*)

reconstruction efficiency. The efficiency is higher than 80% starting from the energy 0.8 GeV. A special algorithm was developed to correct these energy losses.

A mass spectrum and the detector kinematic region are presented in Fig. 7. The π^0-meson width $\sigma_m = 16$ MeV/c^2 and mainly depends on detector energy resolution. Kinematic parameters p_t and x_F are correlated. It means that the measurement was carried out at rather narrow solid angle.

Single armed experimental setup can bring additional apparature systematic asymmetry displacement. Special algorithm was developed to eliminate this displacement. The method was based on the fact that the asymmetry of 2γ pairs between π^0 and η mass is zero [4]. The method is described in [8].
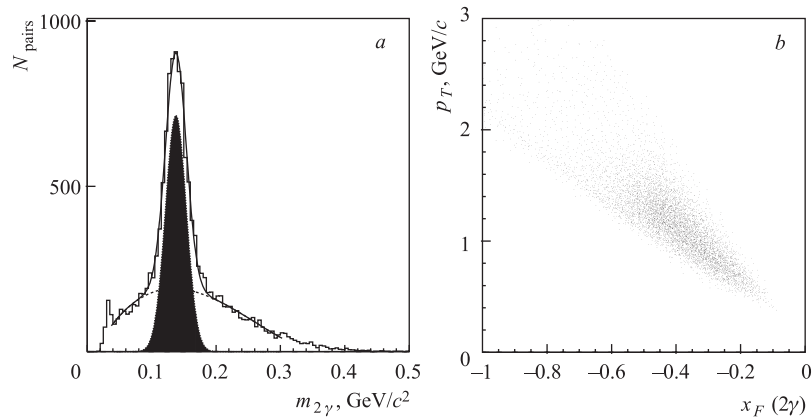

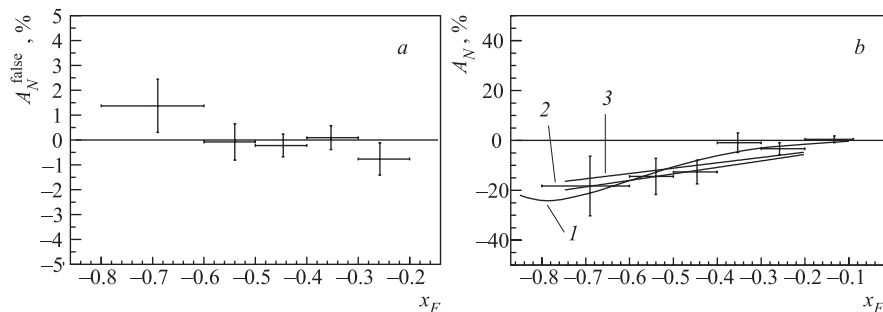Fig. 7. γ-pairs mass spectrum (*a*) and kinematic parameters in the π^0-mass region (*b*)

Fig. 8. *a*) Raw false asymmetry. *b*) A_N in the reaction $\pi^- + p_\uparrow \to \pi^0 + X$ at 40 GeV at the polarized target fragmentation region. Curve *1* —- Anselmino prediction for Collins mechanism; curves *2, 3* — calculation in quark model for U matrix

False asymmetry is zero and is presented in Fig. 8, *a*.

Measured asymmetry A_N is close to zero at low values of $|x_F|$ and p_T (Fig. 8, *b*). $A_N = (-13.8 \pm 3.8)\%$ at $-0.8 < x_F < -0.4$. The result is similar to π^0 asymmetry in the polarized beam fragmentation experiments E704 $((12.4 \pm 1.4)\%, \sqrt{s} = 20$ GeV, [9]) and STAR $((14 \pm 4)\%, \sqrt{s} = 200$ GeV [10]).

We can make a conclusion that the asymmetry does not depend on beam energy at large x_F. Analyzing power in this reaction can be used for proton beam polarization measurements.

The result was compared with theoretical predictions. The Anselmino calculation for the reaction $p_\uparrow + p \to \pi^0 + X$ is based on the E704 data and is drawn by curve *1* in Fig. 8, *b*. [11]. The predictions of the quark model for U matrix [12] are drawn by curves *2* and *3* [13] in the same figure.

Earlier the asymmetry in this reaction was measured in the central region. A_N was found to be small at $p_t < 1.6$ GeV/c and rose up linearly starting from $p_T \approx 1.65$ GeV/c

Fig. 9. The dependence of $A_N^{\pi^0}$ on the energy in the centre-of-mass system in the central region ($\triangle$ — [4]) and in the target polarization region ($\blacktriangle$ — current result)

[4]. To compare the results from the two measurements we studied the asymmetry dependence on π^0 energy in the centre-of-mass system. Surprisingly the asymmetry begins to rise up at the same energy (Fig. 9).
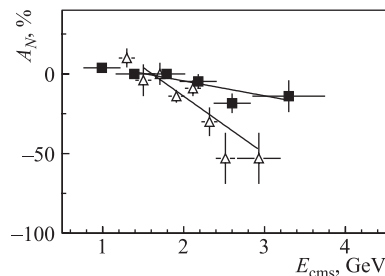
CONCLUSIONS

Finally we can summarise:

• A_N in the reaction $p + p_\uparrow \to \pi^0 + X$ is zero within error bars in the central region at $1.0 < p_T < 3.0$ GeV/c. The result is in good agreement with the E704 measurements at 200 GeV and differs from the CERN 24 GeV data.

• By comparing presented asymmetry with the measurements in the reaction $\pi^- + p_\uparrow \to \pi^0 + X$, we can conclude that the asymmetry depends on quark flavour in the central region. Another possibility is that the interaction dynamics changes dramatically in the energy range between 40 and 70 GeV.

• The asymmetry in the polarized target fragmentation region was measured for the first time in the reaction $\pi^- + p_\uparrow \to \pi^0 + X$. $A_N = (-13.8 \pm 3.8)\%$ at $-0.8 < x_F < -0.4$ and p_T range from 1 to 2 GeV/c and is close to zero at $-0.4 < x_F < -0.1$ and p_T from 0.5 to 1.5 GeV/c.

• Asymmetry at large $|x_F|$ is in good agreement with E704 (200 GeV) and BNL (equivalent to 20 TeV in the laboratory system) data in the reaction $p_\uparrow + p \to \pi^0 + X$ in the polarized beam fragmentation region. It was experimentally established, that A_N appears in the polarized particle fragmentation region (independent of beam or target). Analyzing power of π^0 inclusive production can be used for the measurements of the proton beam polarization.

• By comparing the asymmetry in the reaction $\pi^- + p_\uparrow \to \pi^0 + X$ at 40 GeV in the central region and in the polarized target fragmentation region we found that the asymmetry starts to rise up at $E^0_{\text{cms}}(\pi^0) \approx 1.7$ GeV/c in the centre-of-mass system for the two different kinematic regions.

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