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ELEMENTARY PARTICLES AND FIELDS
Experiment

Searches for Single-Spin Asymmetry in the Inclusive Production of Neutral Pions in the Central Region at a Proton Beam Energy of 70 GeV

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Abstract—Results are presented that were obtained by measuring single-spin asymmetry in the inclusive production of neutral pions in the reaction $p + p\uparrow \rightarrow \pi^0 + X$ at $x_{\rm F} \approx 0$. A beam of 70-GeV protons was extracted directly from the vacuum chamber of the accelerator by means of a bent single crystal. For transverse momenta in the range $1.0 < p_T < 3.0$ GeV/c, the single-spin asymmetry independently measured by two detectors is zero within the errors. This result is in agreement with Fermilab data obtained at 200 GeV, but it is at odds with CERN data measured at 24 GeV. © *2004 MAIK "Nauka/Interperiodica"*.

INTRODUCTION

Investigation of spin physical observables makes it possible to test theoretical models at a much more profound level than measurement of spin-averaged quantities. Among observables associated with polarizations, transverse single-spin asymmetries in high-energy processes involving nucleons are the most puzzling and interesting. Within perturbative QCD, single-spin effects in inclusive reactions must tend to zero in the limit of high energies and high transverse momenta.

A number of experiments devoted to measuring the asymmetry in inclusive neutral-pion production were performed over a period between the 1970s and the 1990s. A CERN experiment in the central region at a Feynman variable value of $x_{\rm F} \sim 0$ revealed significant effects at an energy of 24 GeV in $p + p_\uparrow \rightarrow \pi^0 + X$ reactions [1]. However, statistical uncertainties were large in that experiment, so that the result could only be treated as an indication of a possibly large asymmetry in hard processes. An experiment performed at the Institute for High Energy Physics (IHEP, Protvino, Russia) exhibited a large asymmetry in the inclusive production of neutral pions and eta mesons in the scattering of 40-GeV/c negatively charged pions on a polarized target [2, 3]. According to measurements performed at Fermilab, the asymmetry A_N in the production of neutral pions at a polarized-beam energy of 200 GeV is zero [4].

Taken together, these three results may imply the following: either the asymmetry in the central region decreases with increasing energy, or the effect in question depends on the sort of interacting quarks.

The objective of the PROZA-M experiment was to measure the asymmetry A_N in the inclusive production of neutral pions in the reaction

$$p + p_\uparrow \rightarrow \pi^0 + X \qquad (1)$$

at an angle of 90° in the c.m. frame, with the proton-beam energy being 70 GeV, which is an energy value intermediate between the energies of the experiments at CERN and Fermilab.

In this article, we present the results obtained by processing data of an experiment performed at the IHEP accelerator in March 1996.

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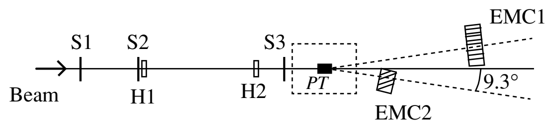

Fig. 1. Layout of the PROZA-M facility: (S1–S3) scintillation counters of the total flux, (H1, H2) hodoscopes, (EMC1, EMC2) electromagnetic calorimeters, and (PT) polarized target.

1. DESCRIPTION OF THE EXPERIMENT

Our investigations were performed with the aid of the PROZA-M facility, which was described in detail elsewhere [5]. The layout of this facility is shown in Fig. 1. Protons of momentum 70 GeV/c were scattered on a polarized frozen-type hydrogen target, where propanediol ($C_3H_8O_2$) was employed as a working substance [6]. The mean polarization of the target and its relaxation time were, respectively, 80% and about 1000 h. The pumping of polarization, together with its reversal, took about four hours. On average, it was performed once every two days.

1.1. Beam Equipment and Generation of a 70-GeV/c Proton Beam

The investigations in question were performed in beamline 14 of the U-70 accelerator complex. For the first time in the world, a bent single crystal was used for a hard-focusing accelerator to extract a 70-GeV proton beam owing to the channeling effect [7]. A crystal deflector in the form of a silicon single crystal bent at angle of 80 mrad was installed within the vacuum chamber of the accelerator.

The number of particles incident on the target was determined by the coincidence of signals from three scintillation counters (S1–S3). Two hodoscopes, H1 (with a step of 5 mm) and H2 (with a step of 2 mm), arranged in front of the polarized target at distances of 8.7 and 3.2 m, respectively, served for determining the coordinates of charged particles incident on the target. The dimensions of the beam were $\sigma_x = 4$ mm in the horizontal direction and $\sigma_y = 3$ mm in the vertical direction. The respective angular divergences of the beam were 2 and 1 mrad. The momentum spread of the beam was $\Delta p/p \sim 10^{-3}$. A description of the procedure for extracting the proton beam to the zone of beamline 14 can be found in [7, 8].

1.2. Electromagnetic Calorimeters

Photons from neutral-pion decays were recorded by two electromagnetic calorimeters (EMC1, EMC2). The mean multiplicity of photons per event was about 2.3. In seeking neutral pions, we selected photons of energy in the range between 1 and 20 GeV.

The calorimeters were arranged at angle of 9.3° with respect to the direction to the target center in the horizontal plane, this corresponding to an angle of 90° in the c.m. frame at a beam momentum of 70 GeV/c. If viewed from the polarized-target center, they covered the same solid angle. The distances to the calorimeters from the target center were 6.9 m for EMC1 and 2.8 m for EMC2. Total-absorption Cherenkov counters manufactured from TF1-00 lead glass were employed for photon detectors [9]. The EMC1 calorimeter consisted of 480 counters grouped into 24 columns containing 20 counters each and forming a rectangular matrix, while the EMC2 calorimeter comprised 144 counters (12 columns of 12 counters). In order to reduce the systematic error in measuring the asymmetry in question, the calorimeters were placed on different sides of the beam axis. An external view of the EMC1 calorimeter and a detailed description of the two calorimeters can be found in [5, 10].

The calibration of the calorimeters was performed by using an electron beam of momentum 26.6 GeV/c. It consisted in determining the coefficients that made it possible to go over from the signal of each counter A_{ij} to the energy E_{ij} [11]. Upon subtracting the beam-momentum spread of 2%, the energy resolution proved to be $\sigma(E)/E \approx 2.5\%$, which is characteristic of lead-glass electromagnetic calorimeters at the energy value being considered.

The energy scale of the calorimeters was additionally matched with the neutral-pion mass. The calibration accuracy reached within five hours of the measurements was 0.1% for EMC1 and 0.15% for EMC2.

1.3. Electronic Equipment and Transverse-Momentum Trigger

The electronic equipment used consisted of modules performed within the SUMMA standard [12]. Beam electronics included hodoscope registers and the rescaling instruments of the monitoring system. A zero-level trigger for an incident particle was formed within a 60-ns gate. A level-1 trigger (formed within a 350-ns gate), which was independent for each detector, ensured a selection of events where the transverse momentum was in excess of 1 GeV/c. A detailed description of the trigger was given in [5, 10]. The electronic equipment for a pulse-height analysis was based on P-267 12-bit analog-to-digital converters [13]. Data were read out by an SM-1420 computer and were logged on magnetic tapes. The electronic equipment used for data readout was described elsewhere [14].

With allowance for the efficiency of data-acquisition-system operation, about 350 events were recorded per accelerator spill, 250 and 100 of these coming from EMC1 and EMC2, respectively. In all, 20 million events were recorded over a 10-day run with a polarized target.

2. DATA ANALYSIS AND RESULTS

Preliminary data were reported in [15]. The resulting asymmetry was close to zero over the entire range considered there. Yet, neutral pions were reconstructed only for the EMC1 calorimeter at transverse momenta above 2.35 GeV/c. In order to reconstruct neutral pions at high energies, we modified the algorithm for reconstructing showers. Our main objective was to improve the separation of overlapping showers in EMC2, where the spacing between photons at transverse momenta in excess of 2 GeV/c became small because of the proximity of EMC2 to the target.

2.1. Reconstruction of Electromagnetic Showers

The algorithm for reconstructing photons is based on isolating an electromagnetic shower by the known shape. First, we found clusters containing at least three cells and satisfying the condition that there is an excess above the threshold of 300 MeV for a counter where the energy deposition is maximal. Upon selecting individual clusters, each of them was treated with the aid of the shower-reconstruction procedure involving the algorithm described in [16]:

(i) A cell where the energy deposition was maximal was found. The primary shower was considered in the region of a 3×3 cell in the vicinity of the maximum.

(ii) It was found out whether a given cluster consists of one or two photons. For this, the MINUIT code [17] was applied to a given shower (in the region of the 3×3 cell) with the aim of constructing, at a fixed energy E_0, a two-parameter fit (in terms of the coordinates X and Y) that minimizes the functional χ^2,

$$\chi^2 = \sum_i (E_i - F_i(X,Y))^2/\sigma_i^2, \qquad (2)$$

where E_i and $F_i(X,Y)$ are, respectively, the measured and the theoretical (from the shape of a shower) value of the energy in each cell and

$$\sigma_i^2 = cE_i(1 - E_i/E_0) + q. \qquad (3)$$

Here, c is a parameter that describes fluctuations of a shower and which is directly related to the resolution of lead-glass calorimeters ($\sqrt{c} \sim \sigma(E)/\sqrt{E}$, $c = 30$ MeV), $q = 1$ MeV^2 takes into account noise in the electronic equipment used, and $E_0 = \sum_i E_i$ is the total measured energy of the shower over the region of the 3×3 cell. The initial values of the parameters were determined as the coordinates of the shower center of gravity. If a value in the region $\chi^2/N < 3$, where N is the number of degrees of freedom, was obtained as the result of fitting, the cluster being considered was treated as a single shower, its energy being corrected for a leakage beyond the region of shower-shape summation in the 3×3 cell.

(iii) Otherwise, we considered the hypothesis that the cluster consists of two overlapping showers and that, in the region of a 5×5 cell around the maximum, there was a counter where the energy deposition was the closest to its maximum value. In seeking two showers, we had to determine six parameters, the energies and the coordinates of each photon. The total energy and the coordinates X_c and Y_c of the cluster center of gravity (in all, three quantities) are fixed. Therefore, the functional χ^2 was minimized with respect to three parameters—the asymmetry $Z_g = |E1 - E2|/(E1 + E2)$ of the energy between two showers, $\Delta X = X_1 - X_2$, and $\Delta Y = Y_1 - Y_2$—in the regions of a 3×3 cell around each maximum. The initial values of ΔX and ΔY were calculated on the basis of the second central moments M_{xx}, M_{yy}, and M_{xy}. The initial value of the asymmetry of the energy between the showers is $Z_g = (E_{\max1} - E_{\max2})/(E_{\max1} + E_{\max2})$, where $E_{\max1}$ and $E_{\max2}$ are the energy values in two counters of the cluster that are characterized by the two largest values of the energy deposition. The condition that $\chi^2_{2\gamma}/N$ is less than unity or is less than $\chi^2_{1\gamma}/N$ by five was used as the criterion for terminating the operation of the algorithm and for concluding that there were two photons in the cluster being considered. If this condition was not satisfied, the cluster was treated as a discrete unit. After that, a single shower was fitted anew, but, this time, over the region of a 5×5 cell.

(iv) After applying the above procedure, signals in the cells that were used for fitting were discarded, and a new shower was sought over the entire area of the calorimeter.

The shower shape, which is necessary for fitting, was obtained experimentally with the aid of a 26.6-GeV electron beam and is described in terms of an analytic function [16].

The algorithm described above made it possible to separate overlapping showers even in the case where the spacing between them did not exceed that which corresponded to one counter. A Monte Carlo simulation was performed to test the algorithm. The efficiency of the algorithm is given in Table 1 for the photon-pair energy of $E_{2\gamma} = 15$ GeV.

In analyzing our experimental data, we used only those showers for which $\chi^2/N < 3$, the asymmetry

Table 1. Efficiency of the algorithm for separating overlapping showers at the photon-pair energy of $E_{2\gamma} = 15$ GeV versus the spacing between photons

Spacing (in the size of a cell)	Efficiency (%)
1.5	91
1.2	88
1.0	71

Z_g of energy was less than 0.8, and the primary photon was at distance not less than half the counter size from the edge of the detector.

Figure 2 shows the mass spectra for the two calorimeters used. Distinct peaks associated with neutral pions can be seen there at all values of the transverse momentum p_T in the region being studied. The mass resolution for the neutral pion is 10 MeV for the far calorimeter EMC1 and 12 to 17 MeV for the near calorimeter EMC2 at different values of the neutral-pion energy.

The algorithm ensured an efficient reconstruction of neutral pions in the EMC2 calorimeter for transverse-momentum values up to $p_T = 3$ GeV/c. The distribution of photon pairs with respect to kinematical variables is displayed in Fig. 3a for the neutral-pion-mass region. The distribution is virtually symmetric in $x_{\rm F}$, the mean value of $x_{\rm F}$ being zero.

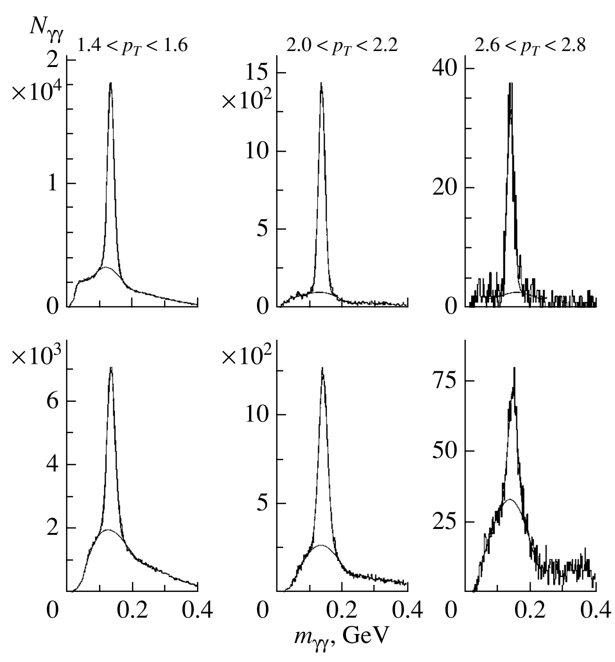

Fig. 2. Mass spectra obtained for proton pairs with (upper plots) EMC1 and (lower plots) EMC2 for various intervals of the transverse momentum p_T (in GeV/c).

In order to test the quality of data, we also determined the transverse-momentum dependence of the number of neutral pions that is normalized to the flux of beam particles that traversed the target (see Fig. 3b). The result proved to be in good agreement with data obtained with the aid of the FODS facility (Protvino) on the invariant cross sections for the inclusive production of charged pions for $p_T > 1.8$ GeV/c at 70 GeV [18], where the exponent in these cross sections was -5.68 ± 0.02 $[N/(\mathrm{GeV}/c)]^{-1}$ for positively charged pions and -5.88 ± 0.02 $[N/(\mathrm{GeV}/c)]^{-1}$ for negatively charged pions.

2.2. Calculation of the Single-Spin Asymmetry

For the EMC1 calorimeter, which is positioned to the left of the beam axis, the single-spin asymmetry A_N is defined as

$$A_N(x_{\rm F}, p_T) = \frac{1}{P_{\rm targ}} \frac{1}{\langle \cos\phi \rangle} \frac{\sigma^{\rm H}_{\uparrow}(x_{\rm F}, p_T) - \sigma^{\rm H}_{\downarrow}(x_{\rm F}, p_T)}{\sigma^{\rm H}_{\uparrow}(x_{\rm F}, p_T) + \sigma^{\rm H}_{\downarrow}(x_{\rm F}, p_T)}, \quad (4)$$

where $P_{\rm targ}$ is the polarization of the target, $\cos\phi$ is the cosine of the azimuthal angle between the target polarization vector and the normal to the plane spanned by the beam axis and the momentum of the outgoing neutral pion, and $\sigma^{\rm H}_{\uparrow}$ and $\sigma^{\rm H}_{\downarrow}$ are the invariant differential cross sections for neutral-pion production on hydrogen for opposite target-polarization directions. In our experiment, the azimuthal angle at which neutral pions were detected was in the range $0^\circ \pm 15^\circ$; therefore, $\cos\phi$ was set to unity over the entire range in question.

For a detector positioned to the left of the beam axis, the raw asymmetry $A_N^{\rm raw}$ actually measured in the experiment is related to A_N by the equation

$$A_N = \frac{D}{P_{\rm targ}} A_N^{\rm raw} = \frac{D}{P_{\rm targ}} \frac{n_\uparrow - n_\downarrow}{n_\uparrow + n_\downarrow}, \quad (5)$$

where D is the target-dilution factor and $n_\uparrow$ and $n_\downarrow$ are the normalized (to the monitor) numbers of recorded neutral pions for opposite directions of the target polarization vector. For the EMC2 calorimeter, which is arranged to the right of the beam axis, the asymmetry is taken with the opposite sign.

In measurements of the asymmetry, there can arise an additional instrumental asymmetry associated with a trigger-electronics jitter, failures of the monitor counters, or some other reasons. In view of this, the measured asymmetry is the sum of the actual and the instrumental asymmetry. In [10], a method was developed that makes it possible to remove this systematic bias under the assumption that the asymmetry of the background (that is, of photons off the neutral-pion-mass peak) is zero.

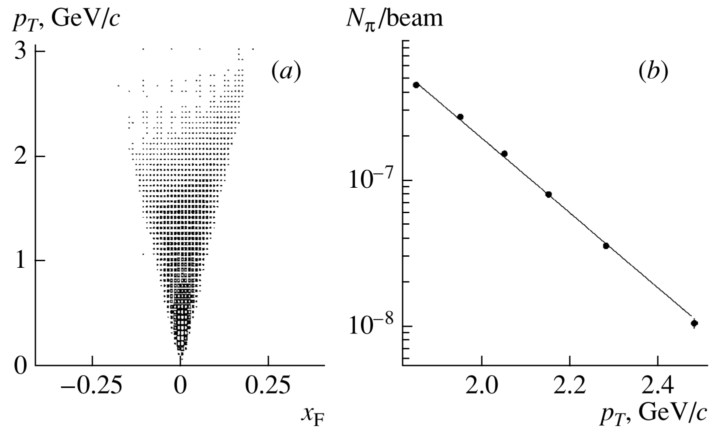

Fig. 3. (a) Two-dimensional distribution of neutral pions with respect to p_T and x_{F} and (b) p_T dependence of the relative cross section for $p_T > 1.8$ GeV/c (the word *beam* in the denominator on the ordinate stands for the number of beam particles that traversed the target), the respective exponent being $-5.89 \pm 0.08\,[N_\pi/(\,GeV/c)]^{-1}$. The resolution in p_T is 0.08 GeV/c.

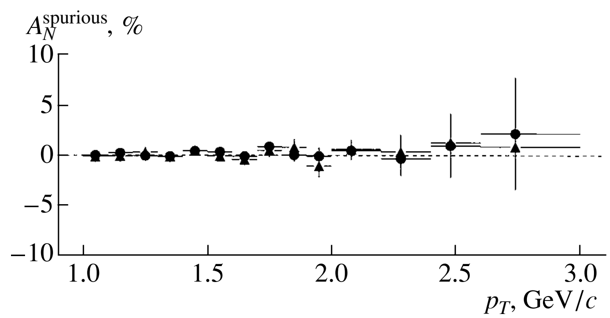

Fig. 4. Raw spurious asymmetry as a function of p_T for (●) EMC1 and (▲) EMC2.

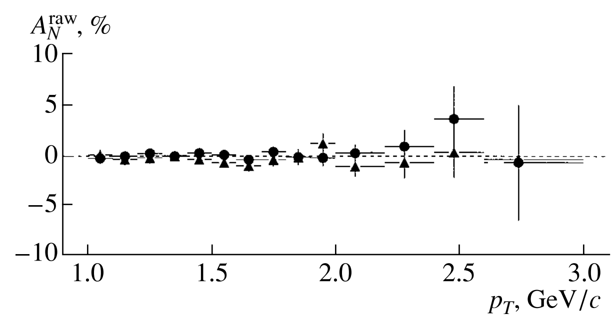

Fig. 5. Asymmetry A_N^{raw} for the two detectors: (●) data for EMC1 and (▲) data for EMC2.

2.3. Analysis of a Spurious Asymmetry

A spurious asymmetry is determined predominantly by the drift of the calorimeter energy scale, this leading to an inaccurate reconstruction of the kinematical parameters of the photon pair. The instability of the calorimeter energy scale was less than 0.1% for the EMC1 calorimeter and less than 0.15% for the EMC2 calorimeter. Accordingly, the contribution to the spurious asymmetry from the instability of the energy scale was less than 0.2 and 0.3% for, respectively, the former and the latter calorimeter (with allowance for the dilution factor and the target polarization, $D/P_{\mathrm{targ}} \sim 10$, this yields values below 2 and 3% for the spurious contribution to the sought quantity).

In order to estimate the spurious asymmetry, we broke down the total data sample for the same direction of the target polarization vector into two equal subsamples of events and determined the asymmetry for these two subsamples.

The result obtained by calculating the spurious asymmetry for the two calorimeters is presented in Fig. 4. The spurious asymmetry proved to be zero within the errors.

In order to verify the consistency of data on the asymmetry A_N^{raw}, we compared the results of the measurements for the two detectors (see Fig. 5). For the two calorimeters, the asymmetry takes values that are compatible with each other within the errors over the entire transverse-momentum range, this being also indicative of a small spurious asymmetry.

2.4. Determination of the Dilution Factor

In order to obtain the ultimate value of the asymmetry according to Eq. (5), it is necessary to determine the target-dilution factor. The procedure for calculating the target-dilution factor D was described in detail elsewhere [10]. In order to test the respective calculations, we used the experimental results for the dilution factor from [2]. A compendium of the data on the dilution factor is given in Table 2.

In the range $1.2 < p_T < 2.0$ GeV/c, the dilution factor is 8.1 ± 0.5, its value increasing to 10.1 ± 2.5

Table 2. Target-dilution factor versus the transverse momentum

p_T, GeV/c	D from [2]	D for the calculation
1.2–1.4	8.0 ± 1.0	8.1
1.4–1.6	8.1 ± 1.2	8.1
1.6–1.8	8.1 ± 0.7	8.1
1.8–2.0	8.2 ± 0.9	8.3
2.0–2.2	8.8 ± 1.3	8.7
2.2–2.4	9.2 ± 1.6	9.1
2.4–2.6	9.5 ± 2.0	9.5
2.6–3.2	10.1 ± 2.5	10.2

for $p_T > 2.6$ GeV/c. In the run of 1996, we tested the dilution factor on the basis of scarcer statistics. It complies well with the results of previous dedicated measurements and with calculated values. By way of example, we indicate that the dilution factor is $D = 8.4 \pm 1.2$ at $p_T \sim 1.8$ GeV/c and $D = 9.2 \pm 1.5$ at $p_T \sim 2.1$ GeV/c.

In assessing the asymmetry, we used the calculated values of the dilution factor from Table 2 without allowance for errors.

2.5. Results

The asymmetry summed over the two calorimeters is given in Fig. 6*a* and in Table 3. Over the entire range of the measurements, the resulting asymmetry is compatible with zero.

3. DISCUSSION OF THE RESULTS

3.1. Comparison with Other Results

The asymmetry A_N in the inclusive production of neutral pions in the central region of pp interaction was previously measured in two experiments (at 24 GeV in [1] and at 200 GeV in [4]), the results of those experiments being displayed in Fig. 6*b*. The asymmetry A_N that we measured in the reaction $p + p_\uparrow \to \pi^0 + X$ is zero within the errors over the entire range under study. Comparing our results at 70 GeV with the data for the same reaction at 24 GeV, we therefore arrive at the conclusion that it is advisable to perform measurements aimed at searches for the asymmetry at beam energies between 24 and 70 GeV.

At the same time, the measurements in the PROZA-*M* experiment (Protvino) for the reaction $\pi^- + p_\uparrow \to \pi^0 + X$ at 40 GeV yielded, for the asymmetry of neutral-pion production, a value of -30% for $p_T > 2.5$ GeV/c [3], this being indicative of the dependence of the asymmetry on the type of interacting particles.

Table 3. Asymmetry versus the transverse momentum

$\langle p_T \rangle$, GeV/c	$A_N^{\rm sum}$, %	$\langle p_T \rangle$, GeV/c	$A_N^{\rm sum}$, %
1.05	-1.0 ± 3.2	1.75	1.7 ± 4.1
1.15	-0.8 ± 3.2	1.85	-0.8 ± 5.0
1.25	1.5 ± 3.1	1.95	4.7 ± 6.6
1.35	0.2 ± 3.0	2.08	-3.1 ± 7.4
1.45	1.3 ± 3.0	2.28	1.7 ± 13.4
1.55	-1.1 ± 3.0	2.48	19.5 ± 23.6
1.65	-5.4 ± 3.5	2.74	-4.7 ± 35.4

3.2. Predictions of Theoretical Models

Owing primarily to the results obtained in the PROZA-*M* and E-704 experiments (see [2, 3] and [4], respectively), models have been developed over the past decade that explain large single-spin asymmetries in terms of various mechanisms.

These are

(i) the mechanism assuming the presence of an additional quark transverse momentum $\mathbf{k}_T$ in a polarized nucleon—the asymmetry of the quark-density distribution for opposite proton-polarization directions in the initial state (Sivers mechanism) [19–21] or the asymmetry of the fragmentation functions for opposite quark-polarization directions in the final state (Collins mechanism) [22];

(ii) the contribution of higher twists [23–28];

(iii) the effect of the orbital angular momentum of valence quarks (Berlin model) [29, 30] or current quarks within a constituent quark (U-matrix quark model) [31];

(iv) the interaction of the quark magnetic moment with a chromomagnetic field [32, 33];

(v) the formation of resonances or of excited states [34].

An overview of these models is given [30, 35, 36].

For the central region of the reaction $p_\uparrow + p \to \pi^0 + X$, almost all of these models predict an asymmetry of small magnitude. By way of example, Fig. 6*b* shows the results of Anselmino's calculations for the E704 experiment in the central region [37]. The behavior of the asymmetry within the Collins and Sivers models at an energy of 70 GeV is expected to differ only slightly in what is concerned with predictions for the E704 experiment [38].

The fact that, in the central region of the reaction being considered, a neutral pion is produced predominantly from gluons is thought to be the main reason for a small asymmetry in this reaction: since the contribution of the gluon component to the transverse

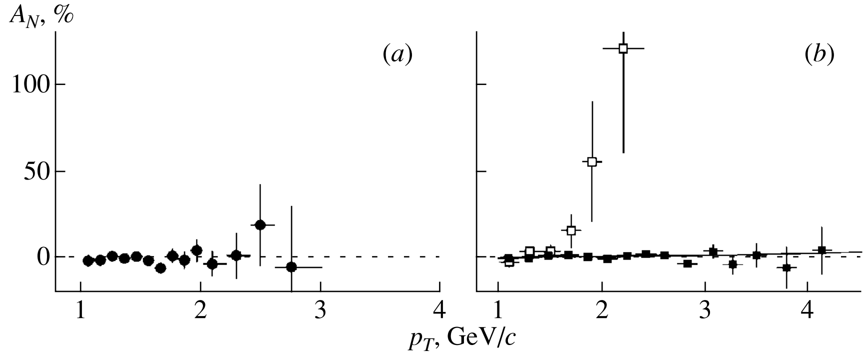

Fig. 6. (*a*) Total (for the two calorimeters) asymmetry A_N as a function of transverse momentum (the results of the present experiment are given here). (*b*) Asymmetry at (□) 24 GeV [1] and (■) 200 GeV [4] in the central region; the curve represents the results of Anselmino's calculations for 200 GeV and $x_F = 0$ [37].

proton spin is small in these models, the asymmetry is not expected to exceed a few percent. In this case, there must not be any difference between $pp_\uparrow$ and $\pi^- p_\uparrow$ interactions; yet, a significant asymmetry (up to -30%) was discovered in the latter case at 40 GeV [3].

Therefore, we have to assume either that a considerable contribution to neutral-pion production at an angle of 90° in the c.m. frame comes from quarks or that interaction dynamics changes strongly in response to the increase in energy from 40 to 70 GeV. In the case of the contribution to the asymmetry from quark interactions, the asymmetry is canceled in $pp_\uparrow$ interaction because of opposite-sign polarizations of u and d quarks in the proton and because of the mixing of channels from a polarized and an unpolarized proton. But in $\pi^- p_\uparrow$ interaction, a large asymmetry may arise in neutral-pion production from a valence $\overline{u}$ antiquark of the incident negatively charged pion and a valence u quark of a polarized proton, the contribution of the valence d quark of the proton being substantially suppressed in this case.

CONCLUSIONS

The basic results of the present study are the following:

(i) The asymmetry in the reaction $p + p_\uparrow \to \pi^0 + X$ at 70 GeV in the region $1 < p_T < 3$ GeV/c is zero within the errors. This result is in good agreement with the E704 data at 200 GeV, but it is at odds with the results obtained for 24 GeV at CERN, where a significant asymmetry was discovered. Thus, the asymmetry in the energy range between 70 and 200 GeV is indeed small and is independent of energy. If the asymmetry depends on energy, this takes place as the beam energy changes from 24 to 70 GeV.

(ii) Comparing the results presented here with those that were obtained by measuring the asymmetry over the same kinematical region at 40 GeV, but in a beam of negatively charged pions, we can conclude that the asymmetry depends on the sort of interacting particles; otherwise, we have to assume that the dynamics of interaction undergoes considerable changes as the beam energy grows from 40 to 70 GeV.

(iii) The predictions of the theoretical models considered above are compatible with the data reported here.

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