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PRELIMINARY RESULTS ON RAW ASYMMETRY IN THE π^o-PRODUCTION ON A POLARIZED TARGET AT 70 GeV

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Abstract

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Single-spin raw asymmetry in π^o-inclusive production has been measured for the first time in collisions of 70 GeV beam protons with transversely polarized target protons. The preliminary results offered an indication for the x_R-scaling behaviour of asymmetry.

Аннотация

Беликов Н.И., Белоусов В.И., Чуйко Б.В. и др. Предварительные результаты по асимметрии в рождении π^o-мезонов на поляризованной мишени при 70 ГэВ: Препринт ИФВЭ 97-51. – Протвино, 1997. – 9 с., 4 рис., библиогр.: 12.

Впервые измерена односпиновая асимметрия в рождении π^o-мезонов на 70-ГэВ протонах на поперечно-поляризованной водородной мишени. Предварительные данные дают указания на возможную масштабную инвариантность в x_R-переменной.

INTRODUCTION

Single-spin asymmetries in inclusive pion production in hadron-hadron interactions were previously measured in the energy range from 13 to 200 GeV [1]-[5]. In a pioneer work at CERN [1] an essential asymmetry has been observed in reaction $pp_{\uparrow} \to \pi^o X$ at 24 GeV. About ten years ago a significant asymmetry was seen at IHEP in reaction $\pi^- p_{\uparrow} \to \pi^o X$ at 40 GeV [2] and at BNL in reaction $p_{\uparrow} p \to \pi^+ X$ at 13 and 18 GeV [3]. In all these measurements a spin dependence of the pion production has been studied in the central region for transverse momenta p_T ranging from 1 to 3 GeV/c. The similarity between π^+ and π^o production asymmetries may be expected considering that both pions were involved in valence u-quark scattering. The observed asymmetry manifested the similar behaviour in these experiments. It started rising from zero to significant values, 20-30%, at a fixed value of the hard scattering transverse scaling variable x_T, which is $2p_T/\sqrt{S}$, where $\sqrt{S}$ is total reaction energy in C.M. Within the accuracies of the experiments this x_T^o value has been found to be between 0.35 and 0.4. This x_T-value can be interpreted as point x_T^o, where the difference in phases of spin flip and nonflip amplitudes goes to zero and probably changes the sign. Thus, from these experimental data the asymmetry may be expected to have the x_T -scaling behaviour.

The π^o-asymmetry was measured in the E704 experiment at FNAL in $p_{\uparrow} p$-interactions at 90^o in C.M. at 200 GeV [4]. The precise measurement has excluded a significant asymmetry for p_T of 1 to 3 GeV/c (x_T of 0.1 to 0.3, respectively). It could be considered as an indirect observation of the asymmetry x_T-scaling in E704, because a rise of asymmetry in the previous low energy experiments started in the p_T-region from 1 to 2 GeV/c, and asymmetry reached 20-30% at p_T between 2 and 3 GeV/c. Unfortunately, statistical errors in E704 for $x_T > 0.3$ were not so precise to investigate directly the scaling behaviour.

Recently a new experiment has been carried out at IHEP. Asymmetry in reaction $p_{\uparrow} p \to \pi^+ X$ measured by the FODS group [5] at 40 GeV in the central region also confirmed the x_T-asymmetry scaling.

The goal of our experiment at 70 GeV was to study single-spin asymmetry in reaction $p + p_{\uparrow} \to \pi^o + X$ in order to a) expand essentially the energy range for the search of scaling effect and b) approach a region of polarized proton fragmentation, where it is expected to observe a significant spin effect. The last point is crucial for the polarimetry of high energy polarized proton beam.

1. EXPERIMENTAL SETUP

The experiment was carried out in the Spring of 1996 at the U-70 accelerator in Protvino with the use of the PROZA-M setup. About 19 mln. interactions on a polarized target were selected and stored on the magnetic tapes. The results presented in this paper are based on 65% of the statistics, which corresponded to about 10 days of data taking.

The experimental setup consisted of a beam apparatus, a polarized target and three electromagnetic calorimeters (see Fig.1).

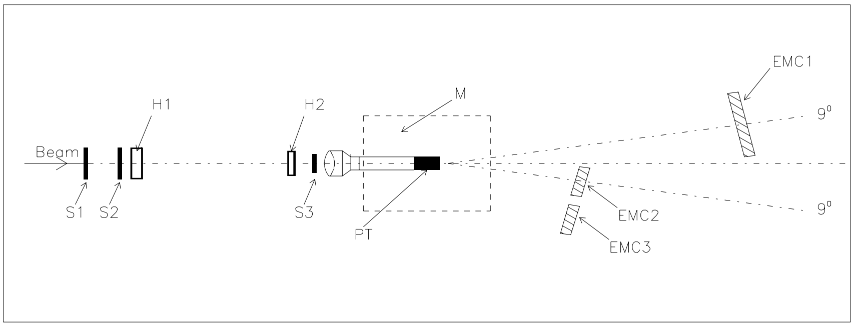

Fig. 1. Diagram of the experimental setup PROZA-M. S1, S2 and S3 are scintillator zero-level trigger counters. H1 and H2 are the two-coordinate hodoscopes. PT is the polarized target. M is the magnet of the target. EMC1, EMC2, and EMC3 are three electromagnetic calorimeters. 9^o in Lab. system corresponds to 90^o in CM for 70 GeV.

A 70 GeV proton beam was extracted from the accelerator by a bent crystal installed in the vacuum ring of the U-70. This technique successfully implemented at IHEP for strong focusing accelerators has been working reliably during recent several years [6]. The beam parameters on the polarized target were as follows :

$$\text{momentum: } 70 \text{ GeV/c}, \ \Delta p/p = 10^{-3},$$
$$\text{intensity: } 4 \cdot 10^6 \text{ p/cycle}, \ \tau_{cycle} = 1 \text{ sec},$$
$$\sigma_X = 4 \text{ mm}, \ \sigma(\theta_X) = 2 \text{ mrad},$$
$$\sigma_Y = 3 \text{ mm}, \ \sigma(\theta_Y) = 1 \text{ mrad}.$$

The angular divergence of beam particles was measured with two-coordinate hodoscopes H1 and H2 having 5 mm and 2 mm scintillator strips. The hodoscopes were located at 8.5 m and 3.2 m upstream of the target, respectively. The beam intensity was controlled by a telescope of scintillating counters S1-S3.

The polarized-proton target [7] used in this experiment was of a frozen-spin type based on the method of dynamic nuclear polarization to align the target proton spins transversely to the beam axis. The polarized-target volume was cylindrical, with a 2 cm diameter and 20 cm length. It was filled with beads of frozen propane-diol ($C_4H_8O_2$).

A mean target polarization value was 80%. The proton spin relaxation time was greater than 50 days. A reverse of the polarization sign was made once per 2 days, and it usually took 3 to 4 hours.

Three electromagnetic calorimeters were used to detect photons from the decays of neutral mesons (see Fig.1). All of them consisted of some numbers of lead-glass counters $3.8 \times 3.8 \times 45$ cm^3 (18 radiation lengths). Before the measurements, the calorimeters were calibrated by electrons with the energy about 26.5 GeV. The gain stability in each channel during the exposition was controlled by LED system once per spill. Energy (E) and spatial (x) resolutions of a single gamma-quantum in these calorimeters were as follows: $\sigma(E)/E = 0.01 + 0.12/\sqrt{E}$ and $\sigma(x) = \pm 1.5$ mm. The calorimeters were labeled as EMC1, EMC2 and EMC3 in Fig.1.

The EMC1 was an array of 480 counters, stacked in 24 columns by 20 raws. It was located to the left of the beam axis at about 7 m from the target and 90^o in C.M. A special system based on radiative source and LED monitored stability of the energy scale of the EMC1 with an accuracy of $\pm 0.2\%$. The EMC1 had an average sensitivity 8.5 MeV per ADC channel.

The EMC2 was assembled of 144 counters (12×12). It was located to the right of the beam axis at about 3 m from the target and 90^o in C.M. The EMC2 arrangement had an average sensitivity 11.5 MeV per ADC channel.

The arrangement of the EMC3 and the EMC2 was identical. The EMC3 was located to the right of the beam axis at about 3 m from the target, very close to the EMC2 and covered x_F-region from -0.15 to -0.34. The ADC sensitivity was 12.2 MeV per channel.

Signals from all the phototubes of lead-glass counters in each calorimeter array came to the front-end electronics consisting of 12-bit ADCs. A small amount of each signal (5%) went to trigger electronics, where two signals could be produced: either the sum of the transverse momenta of photons hitting the calorimeter (EMC1 and EMC2), the so called high p_T-trigger signal, or the sum of an energy deposit in the calorimeter (EMC3). The high p_T-trigger signal allowed a selection of events with large p_t and suppressed the recording of lower-p_T events. The p_T-trigger threshold was about 1.0 GeV/c for EMC1 and about 1.4 GeV/c for EMC2. The energy-trigger threshold for EMC3 was about 1 GeV. With these trigger thresholds the Data Acquisition system (DAQ) accepts 500 events per second at a beam intensity of about 4×10^6 protons per sec. The DAQ had 74% efficiency and allowed 370 events to be stored on a magnetic tape, in average: 230 ones for EMC1, 90 for EMC2, and 50 for EMC3.

2. DATA ANALYSIS

Some events in the calorimeters, especially in EMC2, contained overlapping electromagnetic showers from π^o decays. The energies and coordinates of the photons were determined using a special reconstruction program [8], which included an experimentally measured electromagnetic shower shape [9].

The two-photon invariant-mass distributions for π^o production are presented in Fig.2. For each p_T bin mass distribution, the π^o signal was described by a Gaussian curve and extracted from the combinatorial background, due mostly to pairs of uncorrelated photons, described by a third-order polynomial. For EMC1 the width of the mass spectra was changing from 11 MeV/c^2 (rms) at p_T about 1.5 GeV/c to 15 MeV/c^2 at p_T near 2.5 GeV/c. The mass resolution deteriorated with increasing p_T due to an increase in the number of events that had shower overlap. The combinatorial background was 25% and practically did not depend on p_T in this region. The EMC1 mass spectra for p_T around 1.75 and 2.25 GeV/c are presented in Fig.2a and 2b, correspondently. The x_F was increasing from 0 at $p_T = 1.3$ GeV/c to about 0.1 at $p_T = 3$ GeV/c.

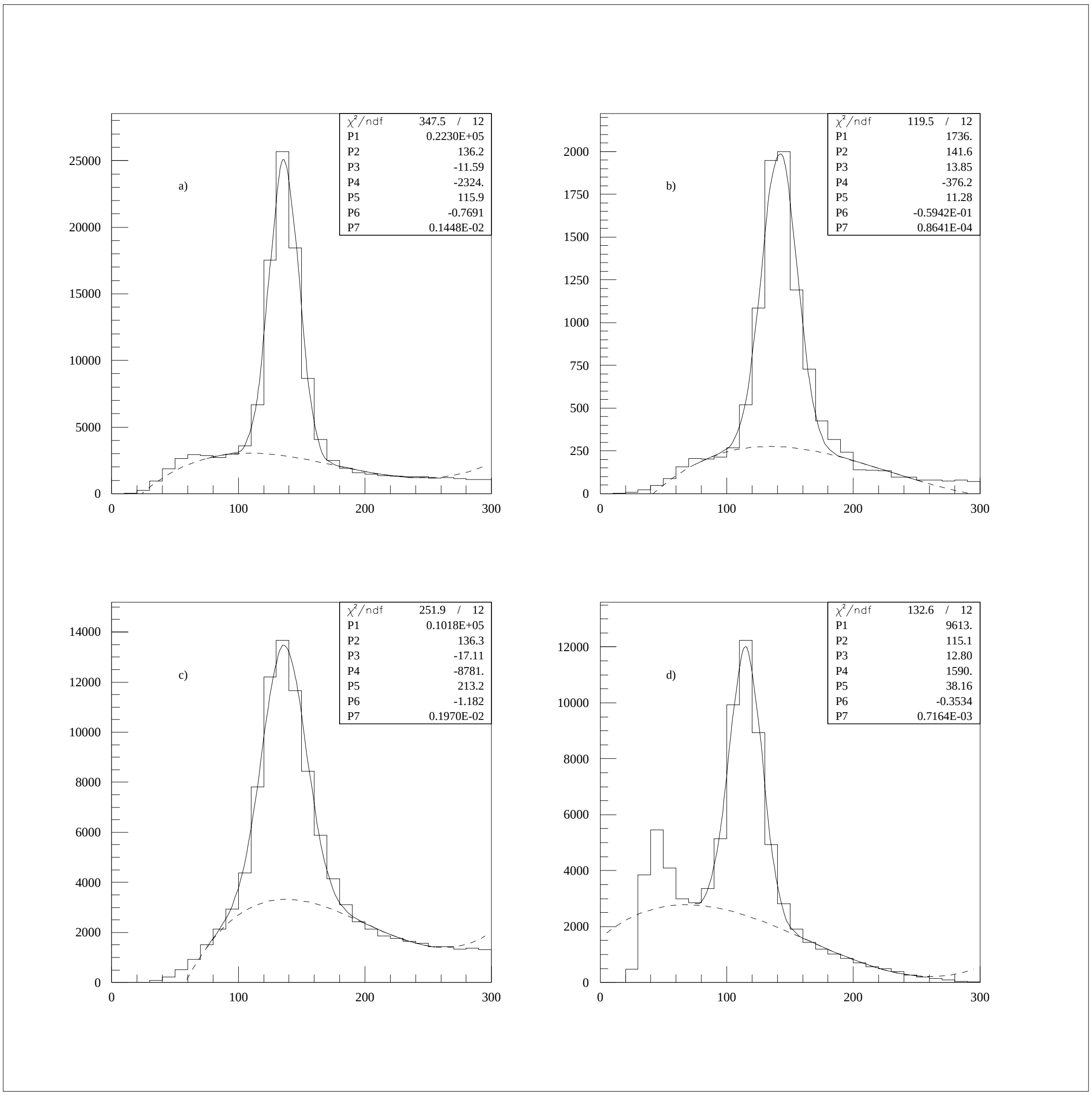

Fig. 2. The two-photon invariant-mass distributions for π^o production at a) EMC1 for the p_T region from 1.7 to 1.8 GeV/c; b) EMC1 for the p_T region from 2.2 to 2.3 GeV/c; c) EMC2 for the p_T region from 1.7 to 1.8 GeV/c; d) EMC3 for the p_T region from 1.2 to 1.3 GeV/c (after energy scale corrections (see text) the mean mass value has changed from 115 to 129 MeV/c^2).

The EMC2 mass spectrum for p_T around 1.75 GeV/c is presented in Fig.2c. The mass width was increasing from 17 to 25 MeV/c^2 for p_T between 1.7 and 2.5 GeV/c. In average, it was over 1.5 times greater than the one for EMC1, because of a smaller distance between EMC2 and the target. As a result, two showers from π^o decay in almost all the events in EMC2 were overlapping. The combinatorial background depending on p_T was 20-30%. The x_F was about -0.02 in the whole p_T-region of interest and was almost independent of p_T.

In Fig.2d the EMC3 mass spectrum for p_T near 1.25 GeV/c is presented. The mass width was 13-14 MeV/c^2 in the p_T region between 1 and 2 GeV/c. The combinatorial background was increasing from 40% at p_T near 1 GeV/c to over 50% at p_T near 2 GeV/c. The x_F strongly depended on p_T and was changing linearly from -0.15 at $p_T = 1$ GeV/c down to -0.34 at $p_T = 2.1$ GeV/c. Such a strong p_T-dependence was because of a small acceptance of EMC3, which was changing from 1 to 2.5% (for $\Delta x_F = 0.1$), while p_T was increasing from 1 to 2 GeV/c. For comparison, the acceptances of EMC1 and EMC2 were close to each other and were about five times higher than the one for EMC3.

The following criteria were used to select π^o candidates from all the combinations of photon pairs: (1) the showers must be within a distance of at least 0.5 counter width away from the edge so that the energy did not leak out of the calorimeter; (2) the asymmetry in the energies for the two photon showers, $A_E = \mid E_1 - E_2 \mid /(E_1 + E_2)$, was less than 0.8 to reduce the combinatorial background; (3) the two-photon invariant mass was selected a) for EMC1 between 100 and 170 MeV/c^2 for $p_T < 2.6$ GeV/c, and between 100 and 200 MeV/c^2 for $p_T > 2.6$ GeV/c to account for the change in the width of the mass distribution; b) for EMC2 between 100 and 200 MeV/c^2, and c) for EMC3 between 90 and 150 MeV/c^2.

We should mention that the energy range of π^o in EMC3 was 1 to 4 GeV, and 10 to 20 GeV in EMC1 and EMC2. Due to the energy threshold in each counter, about 40 MeV, part of the energy deposit was lost in the calorimeters. The relative loss was maximal in EMC3. We have analyzed the dependence of energy loss on the energy value, and used this correction in the data presented in the paper.

For EMC2 and EMC3 photon pairs in the effective mass regions of the π^o were required to have the same mass values for all expositions. These values were 135 MeV/c^2 in the $1.2 < p_T < 1.7$ GeV/c region for EMC2, and 129 MeV/c^2 in the $1.0 < p_T < 1.4$ GeV/c region for EMC3. Correction factors varied from 1 up to 1.039 for different expositions. For EMC1 we have relied on the special monitoring system, which was watching the energy stability with a statistical accuracy of 0.1% per hour. We should mention, that an energy calibration based on π^o mass gave us an accuracy of 0.15% per 10 hours.

We have checked the alignment of the beam apparatus and the target using the data. We defined the target edge on the empty target data, and by subtraction the pure beam distribution from the one defined by the interactions in the target material. We found the alignment in agreement with a survey.

For each run, which took us 45 minutes in average the mean horizontal x_{TAR}- and vertical y_{TAR}-positions in the target have been calculated. An instant move of the beam around a mean x_{TAR} value in a run was studied. It turned out that the beam had been moving within 5 mm during 1.5 hours of a beam time. For EMC1 and EMC2 the dependence of an effect (number of π^o normalized to the incident beam) on x_{TAR} was seen. To keep the effects stable on x_{TAR} for different p_T, we applied the cut to the data, $\mid \Delta x_{TAR} \mid < 4$ mm, where Δx_{TAR} was the deviation of the x_{TAR} in a run from the center of the target.

A beam was stable in y-direction within 3 mm around the center through all 10 days of the measurements. No y_{TAR} cut was applied to the data for all three calorimeters.

3. RESULTS AND DISCUSSION

The data presented in this paper include a total of 10^{11} protons having passed through the polarized target. The analysis identified for EMC1 about 7.5×10^5 π^o events satisfying the above criteria for p_T between 1.0 and 3.2 GeV/c (5.300 events of them for $p_T >$ 2.5 GeV/c). For EMC2 about 2.2×10^5 and for EMC3 about 3.0×10^5 π^o events were selected (29.900 events of them for $p_T > 1.6$ GeV/c for EMC3). The corresponding p_T regions were from 1.7 to 2.4 GeV/c for EMC2 and from 1.0 to 2.2 GeV/c for EMC3.

First, we calculated invariant cross sections per nucleon. They were in agreement with the known $pp \rightarrow \pi^o X$ cross sections for 70 GeV [10] within a factor of 1.5 for three calorimeters for all p_T and x_F of interest.

Then we calculated raw asymmetry as a difference of invariant cross sections on propan-diole with polarized target proton spin directions vertically up and down divided by their sum. Positive values of raw asymmetry correspond to a larger cross section for the production to the left when the target particle spin is pointed vertically upward. A dilution factor of the target (ratio of effects on propan-diole to the one on pure protons) and the target mean polarization value were not taken into account in this paper. We should mention, that the product of these two values is expected to be about 10 for three calorimeters for any p_T of interest in the paper.

Raw asymmetries of inclusive π^o production in the interactions of 70 GeV protons with the polarized proton target near 90^o C.M. are presented in Fig.3 for EMC1(a) and EMC2(b). The errors of asymmetry measuremens in this paper are only statistical for all the three detectors. The systematic errors, including the ones caused by beam instability, are under study.

The idea was to detect π^o with the use of EMC1 in a wide p_T region, and to use EMC2 as an additional detector in a restrictive p_T region to decrease systematic errors common for both detectors. We present single-spin asymmetries measured by EMC1 for π^o in the $1.0 < p_T < 3.2$ GeV/c region and measured by EMC2 in the $1.7 < p_T < 2.4$ GeV/c region. A dead time of the DAQ did not allow us to measure asymmetries at low and high p_T in EMC2 simultaneously. That is why a high p_T trigger threshold was higher for EMC2 rather than for EMC1. A data analysis in EMC2 for $p_T > 2.4$ GeV/c demands some upgrade in the reconstruction program [8], as the distance between photons from π^o decays became of the order of one counter, and the reconstruction efficiency significantly decreases.

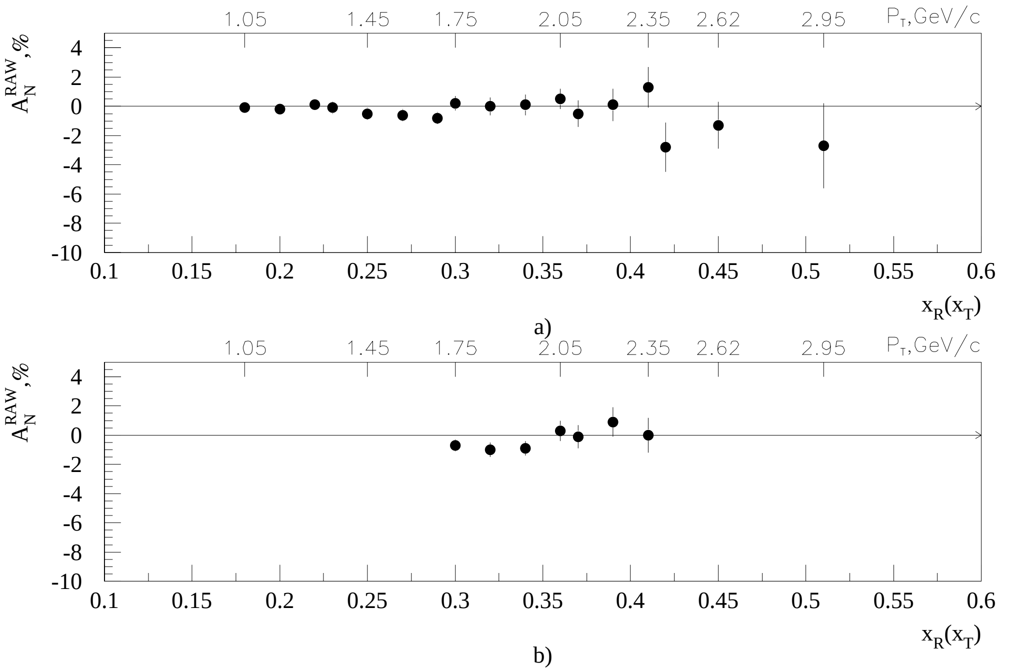

Fig. 3. The raw asymmetry parameter as a function of $x_R(x_T)$ for a) EMC1 and b)EMC2.

In the $1.0 < p_T < 2.4$ GeV/c region, asymmetries are in a good agreement between EMC1 and EMC2, and both consistent with zero values within the errors of 0.3 to 1.4%. In EMC1 asymmetry equals (-2.1±1.1)% for $2.4 < p_T < 3.2$ GeV/c. This is a hint that asymmetry becomes negative at $p_T > 2.4$ GeV/c. This behaviour does not contradict x_T-asymmetry scaling seen at lower energies.

Raw asymmetries for EMC3 of inclusive π^o production in the target fragmentation region are presented in Fig.4. The asymmetry is consistent with zero in the $1.0 < p_T < 1.6$ GeV/c within the errors of 0.4 to 0.7%. Starting from $p_T = 1.6$ GeV/c the asymmetry becomes negative and decreases with p_T increase. The asymmetry is equal to (-3.0±0.9)% for $1.7 < p_T < 1.9$ GeV/c, and (-4.3±1.3)% for $1.9 < p_T < 2.2$ GeV/c. We should stress, that the errors in asymmetry are only statistical. An estimate of systematic errors in this p_T-region is of great importance and is under study.

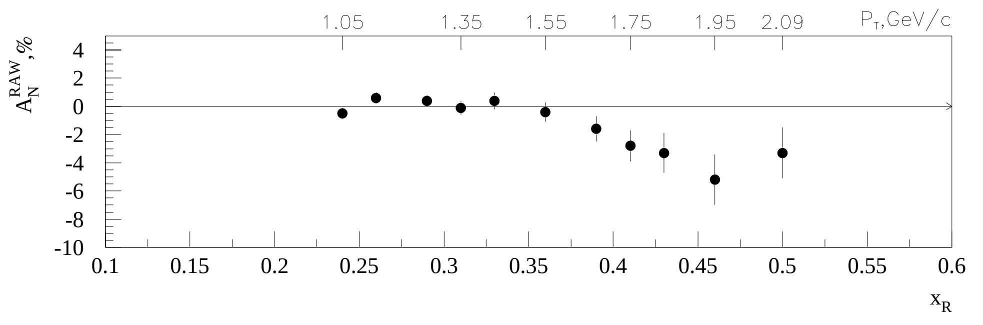

Fig. 4. The raw asymmetry parameter as a function of p_T (or x_R) for EMC3.

In EMC3 x_F = -0.25 at p_T = 1.6 GeV/c, and a radial scaling variable, $x_R = \sqrt{(x_F^2 + x_T^2)}$, is 0.38 for this p_T value. In the lower energy experiments we can substitute x_T by x_R, because the measurements were made at x_F close to 0. Comparing our new 70 GeV data with the previous "under 40 GeV" data, we can note, that the asymmetry has a x_R-scaling behaviour at p_T greater than 1.5 GeV/c in the energy range from 13 to 70 GeV.

There is another important aspect of our data. As is well known, the E704 discovery of large analyzing power of inclusive pion production in the polarized proton fragmentation region [11] stimulated the development of pion polarimeters for RHIC spin physics [12]. But E704 experiment was fulfilled at one energy, namely, 200 GeV. One needs more experimental data at RHIC beam energy range $20 \leq E \leq 250$ GeV. Our results on analyzing power $A_N(\pi^o)$ at 70 GeV will serve as an additional calibration point for RHIC polarimetry.

CONCLUSION

The spin measurements in inclusive pion production have been carried out at 70 GeV for the first time. The preliminary results based on 65% of the data with statistical errors only are presented in this paper.

The asymmetry is observed to have zero values within the errors for single-spin inclusive π^o production in pp interactions in the $1.0 < p_T < 2.5$ GeV/c region near 90^o in C.M. There is a hint that the asymmetry is getting negative in the $2.5 < p_T < 3.2$ GeV/c region. The 70 GeV data at 90^o in C.M. do not contradict the x_T-asymmetry scaling observed at lower energies.

The spin measurements in inclusive pion production have been carried out in a polarized target fragmentation region. In this experiment x_F values varied from -0.15 down to -0.34 and the corresponding p_T from 1.0 to 2.2 GeV/c. The asymmetry has zero values in the $1.0 < p_T < 1.6$ GeV/c region. In the $1.6 < p_T < 2.2$ GeV/c region the asymmetry is negative and grows up in absolute value with p_T increased.

Taking into account x_R-dependence of asymmetry measured with all three calorimeters, we can conclude that this experiment has given an indication of x_R-asymmetry scaling in π^o inclusive production. More data are needed to establish this scaling, especially in a wideer polarized target fragmentation region in x_F and x_T variables.

The measured analyzing power $A_N(\pi^o)$ in pp-interactions at 70 GeV might be used as a reference point in polarized proton beam polarimetry at colliders like RHIC.

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