ИФВЭ
IHEP

STATE RESEARCH CENTER OF RUSSIA

INSTITUTE FOR HIGH ENERGY PHYSICS

IHEP 97-61

E.A.Andreeva[1], A.A.Bogdanov[1], S.B.Nurushev[2], M.N.Strikhanov[1],
K.E.Shestermanov[2], A.N.Vasiliev[2]

THE INCLUSIVE NEUTRAL PION POLARIMETER FOR RHIC

[1]Moscow Physics Engineering Institute, 115409, Moscow, Russia
[2]Institute for High Energy Physics, 142284 Protvino, Russia

Protvino 1997

UDK 539.1.07 M–24

Abstract

Andreeva E.A., Bogdanov A.A., Nurushev S.B. et al. The Inclusive Neutral Pion Polarimeter for RHIC: IHEP Preprint 97-61. – Protvino, 1997. – p. 8, figs. 4, refs.: 6.

A particular scheme of the inclusive π^o polarimeter is proposed for the RHIC collider. The specific features of such polarimeter are high counting rate, high analyzing power, complete azimuthal coverage. This polarimeter can be easily used in a fixed target or in a collider mode.

Аннотация

Андреева Е.А., Богданов А.А., Нурушев С.Б. и др. Инклюзивный π^o-поляриметр для RHIC: Препринт ИФВЭ 97-61. – Протвино, 1997. – 8 с., 4 рис., библиогр.: 6.

Для RHIC коллайдера предлагается конкретная схема инклюзивного π^o-поляриметра. Особенностями такого поляриметра являются высокая скорость счета, высокая анализирующая способность, полный захват по азимуту. Такой поляриметр может быть легко использован как в моде фиксированной мишени, так и в коллайдерном режиме.

The approved at RHIC Spin Program is based on the acceleration of polarized proton beam from AGS (injected into RHIC at 23 GeV/c) up to 250 GeV. The main tool keeping a high degree of beam polarization during its acceleration is a Siberian Snake technique. For measuring the beam polarization during a passage through strong depolarizing resonances (in the acceleration stage) and in the collider regime (physics run) one needs to apply a polarimeter with a high factor of merit [1]. According to the classification of polarimeters introduced in [2], the best choice would be the absolute, local and on-line polarimeter. But such polarimeter sensible to an accelerator environment is not yet established. In each practical case, like the polarized RHIC, we are looking not only upon the factor of merit but also the cost of such device. Stemming from this approach the inclusive charged pion polarimeter has been recently proposed in [3]. Current proposal bases on a high analyzing power, $A_N^{\pm}$, discovered by the E704 Collaboration at Fermilab in inclusive charged pion production at large x_F, at 200 GeV/c [4]. Such process has also a large cross-section ($\Delta\sigma \simeq 0.1 - 1$ mb in the region of interest), allowing to determine a RHIC beam polarization very quickly. According to [3] 10^4 events can be accumulated by two-arm spectrometer in about 0.5 sec at 25 GeV/c and 100 sec at 250 GeV/c. In this estimate the assumptions are made that RHIC is expected to run with 120 bunches at $2 \cdot 10^{11}$ protons/bunch with a beam revolution frequency of 78 kHz. The carbon fiber of diameter 5 μm with the following material properties will be used: density = 1.75 g/cm^3, heating capacity = 0.48 cal/(g.^{o}C), emissivity = 0.8. The only complicated and costly item in this project is a toroidal magnet, which is not yet specified. The detectors are not chosen either.

In the current paper we propose to apply the inclusive neutral pion polarimeter (INPP) to the RHIC environment. We argue that a high analyzing power and a large cross-section are very attractive features of such polarimeter. Some additional advantages such as a full azimuthal coverage, easy fit to the RHIC environment, availability the bulk of the apparatus, etc. will be discussed later. The result of the E704 measurement of analyzing power for inclusive π^o production is shown in Fig.1. As is seen from Fig.1a, $A_N^o(x_F)$ is practically zero in the range $0 < x_F \leq 0.3$ and an onset of non zero values appears at $x_F = 0.4$. Then $A_N^o(x_F)$ rises linearly with x_F and reaches $A_N^o(x_F) = 0.15 \pm 0.03$ in the interval from $x_F = 0.6$ to 0.8. If we use for polarimetry the last 3 points for the determination of beam polarization, then we write

$$\bar{P}_B = \sum_{i=1}^{3} w_i P_{Bi} / \sum w_i, \tag{1}$$

where P_{Bi} is the value of beam polarization extracted from the measurements at point i; w_i is the weight of point i (in our case $w_i = (1/\Delta P_{Bi})^2$). The relative error, $\Delta P_B/P_B$ in the polarization measurement (assuming that the beam polarization does not depend on i and the raw asymmetry precision, $\Delta\epsilon(\epsilon = A_N^o \cdot P_B)$ is negligible in comparison with ΔA_N^o) can be found

$$\Delta P_B/P_B = 1/\sqrt{\sum_{i=1}^{3} (A_{Ni}^o/\Delta A_{Ni}^o)^2}. \tag{2}$$

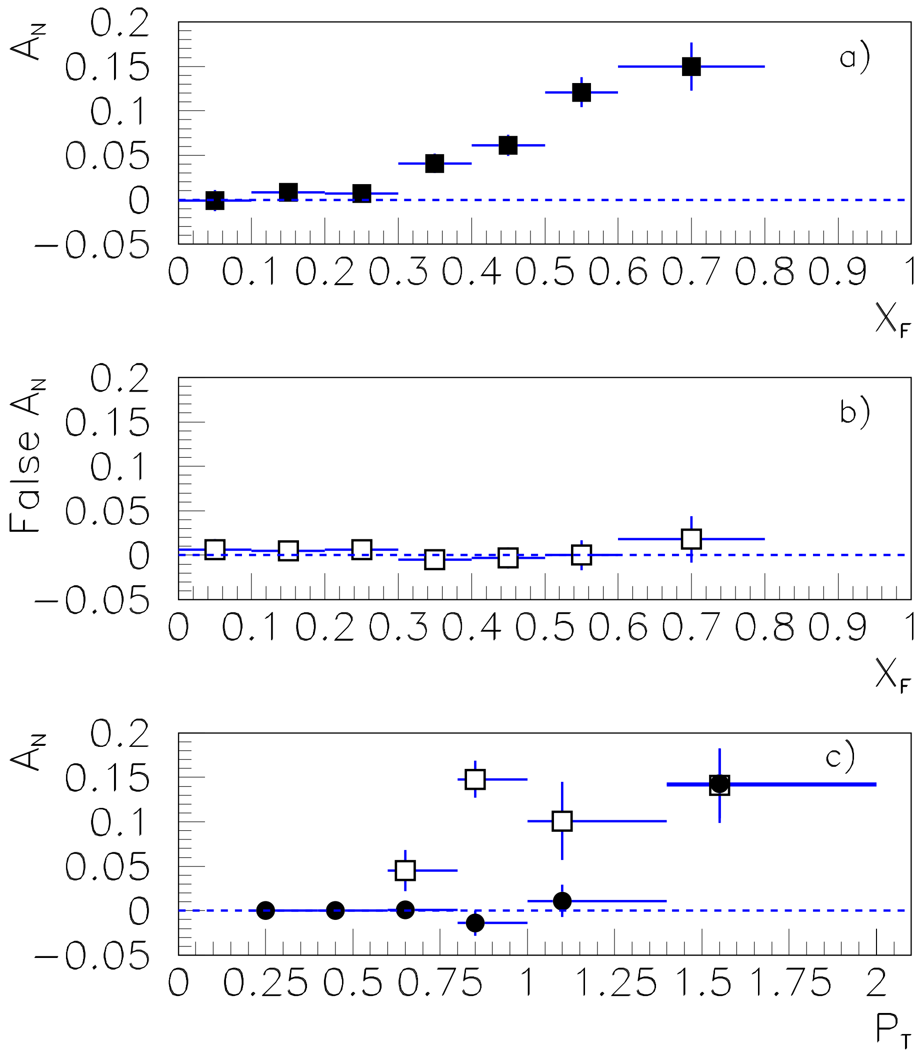

Fig. 1. The analyzing power, $A_N^o(x_F)$, of inclusively produced neutral pion, measured at 200 GeV/c by E704 Collaboration at Fermilab: a) versus x_F, b) a fake asymmetry versus x_F, c) asymmetry versus p_T for two groups of events: closed circles-for $0 < x_F < 0.3$ and open squares for $0.5 < x_F < 0.8$.

Taking the face values of the analyzing power $A_N^o(x_F)$ from [5], we come to the conclusion that the E704 data allow one to determine the beam polarization with the precision

$$\Delta P_B/P_B = \pm 9\%. \tag{3}$$

The systematic error introduces a contribution of the same order of magnitude as is seen from Fig.1b.

In order to select the applicable p_T region for $A_N^o(p_T)$, we have to look at Fig.1c. The full circles correspond to the region $0 < x_F < 0.3$, while the open squares — to $0.5 < x_F < 0.7$. To keep analyzing power $A_N^{\pi^o}(p_T) \geq 5\%$, we have to limit p_T region by $p_T \geq 0.6$ GeV/c. Therefore, for the application of INPP we select the following useful region:

$$0.4 < x_F < 0.8,$$
$$0.6 < p_T(GeV/c) < 2.0. \tag{4}$$

The scheme of the proposed detectors is shown in Fig.2. They are supposed to be installed in 2 o'clock straight section of RHIC. The INPP consists of two Electro-Magnetic Calorimeters EMC1 and EMC2. The EMC1 has dimensions: the outside diameter is $d_2 = 1200$ mm and the internal hole of diameter $d_1 = 80$ mm determined by a vacuum pipe (V.P.). It is installed at the distance $l_1 = 8$ m from Interaction Point (IP). The EMC1 covers the rapidity region $3.3 \leq \eta \leq 10.0$ (angular region $5 \leq \Theta(mrad) \leq 75$). The EMC2 is placed behind DX magnet at the distance $l_2 \simeq 20$ m. It takes the shape of disc and subtends a solid angle $\Omega_2 = \frac{\pi R^2}{l_2^2}$, where R = 10 cm is its radius. Therefore $\Omega_2 = 7.8 \cdot 10^{-5}$ ster. The EMC2 covers the rapidity region $10.0 \leq \eta < \infty$ (the corresponding angular interval is $0 \leq \Theta(mrad) < 5$). So, EMC2 covers completely a hole in the EMC1. In such a way the EMC1 and EMC2 together represent one integrated EMC covering the whole azimuthal angle and subtending with high efficiency the useful kinematical interval (4). Such EMC resembles somehow the E704 calorimeter (CEMC) configuration but exceeding the latter twice in an azimuthal acceptance. Moreover, the central part of CEMC, that is, the EMC2, is removed from beam and put behind the DX magnet. Therefore, it is not radiated by a direct beam, moreover one hopes that charged secondary particles will not reach it either due to a strong magnetic field of DX. The combination of two calorimeters offers some flexibility for experiments as we will see later. To separate the showers from photons and from charged particles, each EMC1 and EMC2 are supplied with scintillating hodoscopes

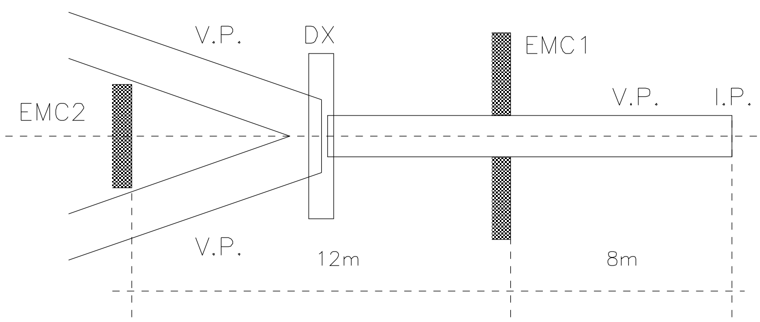

Fig. 2. Layout of the inclusive neutral pion polarimeter at 2 o'clock interaction section of RHIC. EMC1 and EMC2 are the electromagnetic calorimeters. DX is an analyzing magnit.

installed in front of them (not shown). These hodoscopes will also carry other important features: they measure the time of flight of charged particles accompanying neutral pion and such information can be used to suppress backgrounds in shower analyses.

In order to generate the inclusive π^o in reaction

$$p + p \to \pi^o + X, \tag{5}$$

at the initial momentum of 200 GeV/c PYTHIA program version 5.7 was used. The cross-section for reaction (5) is presented in Fig.3. The $2 \cdot 10^5$ events were generated and their distributions on momentum of π^o are shown in Fig.3a. Four kinds of distributions are shown in Fig.3a:

- both detectors are combined in one EMC=EMC1+EMC2 (the solid line);
- only EMC1 is used (the dashed line);
- only EMC2 is used (the dotted line);
- it is required that one gamma from π^0 would strike EMC1, while the second one strikes EMC2 (hatched area).

All the distributions fall steeply in the region of interest. The EMC detects 93% of all the events. If we use independently either EMC1 or EMC2, their efficiences are 68.8% and 2.3%, correspondingly. Fig.3b is obtained after matching conditions (4). It is seen (compare entries in Fig.3a and Fig.3b) that only $2.4 \cdot 10^{-3}$ portion of all the events is useful for polarimetry. The shaded area presents the same illustrations as above, but for the case when one gamma from π^o-decay goes to one detector, say, to the EMC1, while the second gamma strikes another detector, that is, the EMC2. Such a combination is very important, since results in building an on-line INPP. The reason is that we can make signal S1 from EMC1 and S2 from EMC2 coincide. We can take advantage of the following features of such combination:

- signal S2 coming from EMC2 should correspond to very energetic π^o (photons) (see Fig.3f). Therefore, we can obtain a fast analog sum of all counters in EMC2, set sufficiently high threshold on energy E_1^{th} and use this signal as a trigger. The fact that EMC2 is far from IP and stays behind strong magnetic field of DX assures that signal S2 will be prevailing by photons from π^o decay, that is, S2 must be a clean trigger;
- signal S1 corresponds to the soft photons (see Fig.3e) and the energy threshold E_2^{th} must be lower than E_1^{th};
- we can use E_1^{th} and E_2^{th} in order to optimize a π^o trigger;
- we can build a fast p_T trigger similar to the one used in E704 [4]. As is seen from Fig.3c, a cut on $p_T < 0.6$ GeV/c might be very useful to suppress fake events;
- a special fast processor may be developed at the later stage in order to make a cut for π^o mass region by using a relation

$$m_{\pi^o}^2 \simeq E_1 \cdot E_2 \cdot \Theta_{12}^2, \tag{6}$$

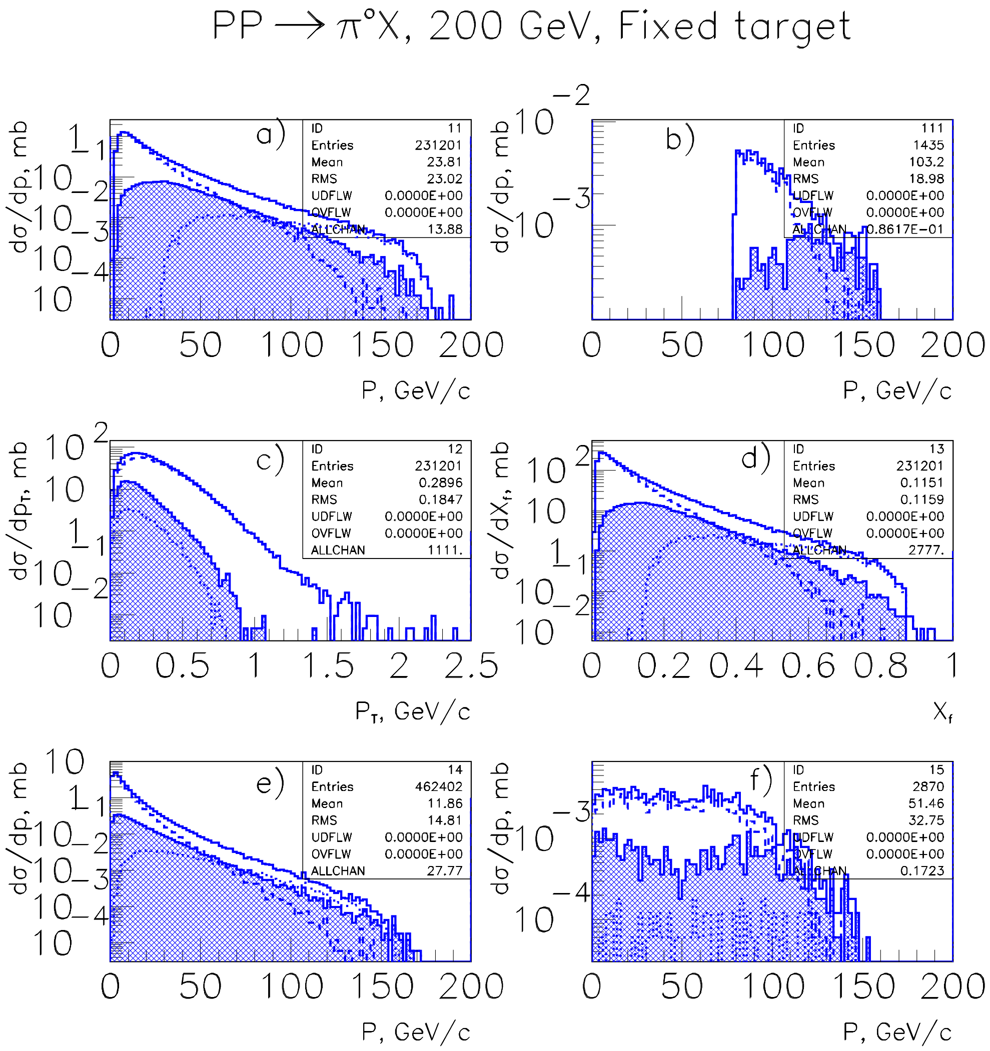

Fig. 3. The inclusive π^o cross section for pp interaction at 200 GeV/c in Fixed Target mode (PYTHIA, vers.5.7): a) versus momentum of produced π^o; b) the same in a) but with selected range of $0.4 < x_F < 0.8$, $0.5 < p_T < 2.0$ GeV/c; c) versus p_T, d) versus x_F; e) photon momentum spectrum for all events and f) photon momentum spectrum for useful events. $2 \cdot 10^5$ events were generated.

where E_1 and E_2 are shower energies deposited in the EMC1 and EMC2, correspondingly, Θ_{12} is an opening angle between two photons. All these values are accessible for on-line analysis. Fig.3c and 3d present p_T and x_F distributions of π^o, while Fig.3e and Fig.3f show the gamma distributions for all the events and for the events of interest, correspondingly. We have set the following cuts: a) energy deposit in the EMC1 is greater than 20 GeV; b) energy deposit in the EMC2 is greater than 20 GeV, and c) the sum of the energy deposit in both calorimeters is greater than 80 GeV. This gave us the background/signal ratio equal to ~ 23. After an additional cut on radii in both calorimeters ($r_{EMC2} > 2$ cm and $r_{EMC1} < 10$ cm we decreased this ratio down to ~ 11. We continue to study this problem in order to realize the on-line regime. The energy calibration of both calorimeters can be done by reconstructing π^o-events and normalizing to the mass of π^o. Additionally, the EMC1 energy scale may be calibrated by muons or charged hadrons. The LED and radioactive sources will be used to monitor calorimeter functioning.

We made an estimate of expected counting rate to use the EMC1 and EMC2 as one EMC. Two scenarious of using a fixed target were considered. In the first case we took the hydrogen jet target with density $n_t = 3 \cdot 10^{13}$ atoms/cm^2 [6]. In the second case — the same 5 μm fiber as in [3]. For the first case, having taken $j = 70$ mA for RHIC ($L = 1.31 \cdot 10^{31}$ cm^{-2}$\cdot s^{-1}$) and cross-sections from Fig.3b, we got the following expected counting rates:

x_F	0.5	0.6	0.7
N(counts/sec)	52	90	65

It means that one can accumulate useful 10^4 π^o-events in 50 seconds. Our goal is to measure beam polarization with a precision of 10% limited by the accuracy of analysing power A_N determined in the E704 experiment. Assuming that an averaged analysing power A_N is 10%, the required statistics $N = 4.2 \cdot 10^4$ can be accumulated in $4'$. But in order to make the counting statistics contribution negligible (to 10% precision), we increased the number of useful events by a factor of 3, that is, we need useful $1.26 \cdot 10^5$ π^o-events. Evidently, this takes $15'$ of the beam run proper. Since the background-to-signal ratio is at present estimated to be ~ 11, we must accumulate 1.40 M events on tape. To analyze them, it will take us 2 hours of CPU time at SGI Challenge L computer, or, $45'$ at Alpha Server 8200 5/300.

The counting rate in the case of fiber target is expected to be higher by 6 orders of magnitude. The use of jet target is preferable for continuous monitoring of beam polarization, since an accepted level of its density (see above) does not disturb the main collider experiments.

Comparing INPP with ICPP (inclusive charged pion polarimeter), one can outline the following advantages of INPP over ICPP.

- full azimuthal coverage. This allows one to measure any transverse component of beam polarization in the same run;
- practically full coverage of useful x_F range and p_T range;
- the readiness: major parts of detectors are available (from E704 experiment);
- no use of magnetic spectrometer and extra particle identification detectors. The EMC fulfils all these functions itself.

We propose to use the inclusive Neutral Pion Polarimeter (INPP) at RHIC for the following reasons:

- its high analyzing power, A_N^o;
- its large production cross section, σ^o. Due to these two factors, the INPP has high factor of merit, M $= (A_N^o)^2 \cdot \sigma^o$;
- it fits well to the RHIC environment; it can be easily used in the fixed target as well as in the collider modes. Fig.4 illustrates that in the collider mode in pp it keeps mostly the same features as in fixed target mode;

- it serves as a local polarimeter;
- it is a constructive (non disturbing) polarimeter allowing to make a continuous control of beam polarization;
- it may be used as on-line polarimeter (on part of statistics) or as off-line polarimeter (full statistics is included);
- it is less sensitive to the background due to the required high energy threshold;
- most part of equipments is already available.

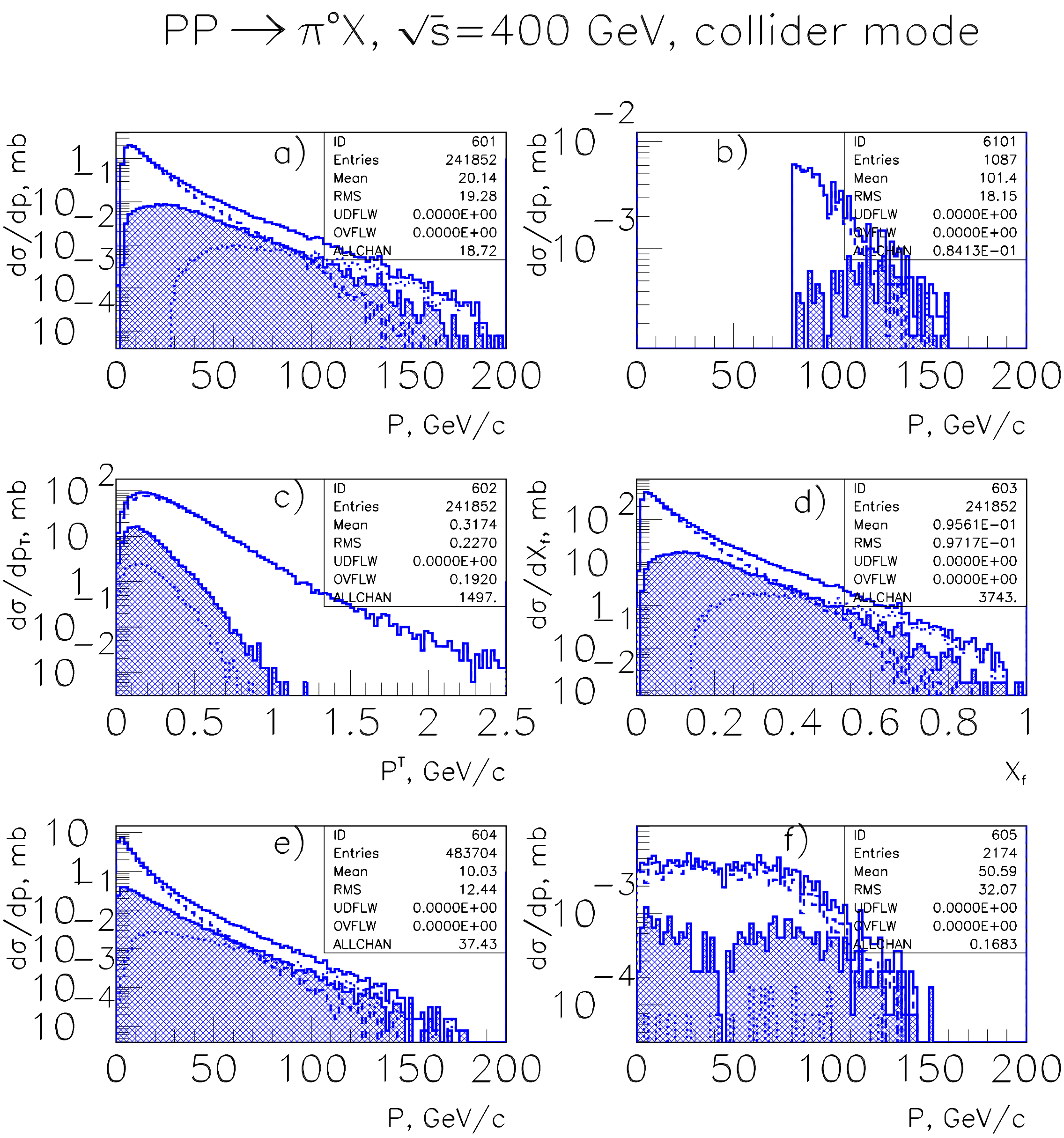

Fig. 4. The same as in Fig.3, but for colliding mode.

References

[1] Kuroda K. — In: AIP Conf.Proc., 1983, 95, p.546.

[2] Nurushev S.B. — In: Proc. of Intern.Workshop on Spin Phenomena in High Energy Physics, September 14-17, 1983, Protvino, Russia, p.5.

[3] Mariam F.G. et al. — In: Proc.of 12th Intern. Symp. on High-Energy Spin Physics, September 10-14, 1996, Amsterdam, The Netherlands, p.797.

[4] Adams D.L. et al.//Phys.Lett., B264, 462(1991).

[5] Adams D.L. et al.//Z.Physik C, 56, 181(1992).

[6] Nowak W.-D. — Possible Measurements of Single and Double Spin Asymmetries with HERA-$\vec{N}$. DESY 96-095, May 1996.

Received September 23, 1997

Е.А.Андреева, А.А.Богданов, С.Б.Нурушев и др.
Инклюзивный π^o-поляриметр для RHIC.

Оригинал-макет подготовлен с помощью системы LaTeX.
Редактор Е.Н.Горина. Технический редактор Н.В.Орлова.

Подписано к печати 29.09.97. Формат $60 \times 84/8$. Офсетная печать.
Печ.л. 1. Уч.-изд.л. 0.76. Тираж 180. Заказ 1139. Индекс 3649.
ЛР №020498 17.04.97.

ГНЦ РФ Институт физики высоких энергий
142284, Протвино Московской обл.

Индекс 3649

П Р Е П Р И Н Т 97-61, И Ф В Э, 1997