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G.J.Musulmanbekov[1], M.V.Tokarev[2]

SIMULATION OF SINGLE SPIN ASYMMETRY IN THE $p\uparrow p \to \pi^{\pm,0}X$ REACTION

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[1]E-mail: genis@axnua.jinr.subna.su
[2]E-mail: tokarev@sunhe.jinr.dubna.su

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1 Introduction

Inclusive pion asymmetry A_N in single spin $p\uparrow p \to \pi^{\pm,0}X$ process have been studied at 200 GeV in Fermilab (E-704 collaboration) [1] and at 13 and 18 GeV in BNL [2]. They found out that the asymmetry was small at low x_F and $p_\perp$ and reached ~ 40 % at high x_F and $p_\perp$. The sign of asymmetry strongly correlates with the sign of produced pion. The conclusion was made that the effects could not be explained in the frame of perturbative QCD. To explain the results some authors took into account high twist corrections [3] or used nonperturbative mechanisms [4, 5].

Comparison of Fermilab and BNL data shows that the asymmetry behaviour depends on the collision energy. A few models have been elaborated for the description of pion asymmetries ovserved in E-704 experiment [6, 7]. Since they were based on analytical calculations they could not take into account kinematical effects which are, from our point of view, very important, particularly, at BNL and lower energies.

So the purpose of this paper is to estimate the role of kinematical effects and intermediate particle production on the behaviour of inclusive pion asymmetry. The article is organized as follows. Section 2 gives a description of hadronic generator for unpolarized proton—proton collisions based on bremsstrahlung model and of the asymmetry simulation procedure. Comparison with experimental data and their analysis are given in Section 3. Section 4 contains the summary of results and conclusions.

2 Simulation of Left - Right Pion Asymmetry

We shall consider the inelastic scattering of polarized proton off unpolarized one in the fragmentation range of incoming particle. Azimuth asymmetry of the process is defined as

$$A_n = \frac{\sigma\uparrow - \sigma\downarrow}{\sigma\uparrow + \sigma\downarrow} = A(\theta) \cdot P_B \cos(\varphi), \tag{1}$$

where $\sigma\uparrow(\downarrow)$ is an inclusive cross section of pion produced by proton with spin directed up (down) relative to its momentum and orthogonal to scattering plane, θ and φ are zenith and azimuth angles, $A(\theta)$ is an analyzing power and P_B is polarization of the beam. Positive asymmetry for upward polarization of the beam means that pions tend to go to the left. The asymmetry A_n measured at azimuth angles $\varphi = 0$ and $\varphi = \pi$ depends on $x_F = 2p_L/\sqrt{s}$, where p_L is the pion longitudinal momentum in the cm system, $\sqrt{s}$ is the total cm energy, and transverse momentum $p_\perp$:

$$A_n(x_F, p_\perp) = \frac{\sigma(x_F, p_\perp, 0) - \sigma(x_F, p_\perp, \pi)}{\sigma(x_F, p_\perp, 0) + \sigma(x_F, p_\perp, \pi)} \tag{2}$$

We simulated inclusive pion asymmetry in polarized proton—proton interactions using the following assumptions: 1) Secondaries are direct pions, nucleons and resonances (ρ's, ω-mesons and Δ-isobars). The latter decay into final particles. 2) Only the secondary with maximal longitudinal momentum (first– rank or leading hadron) can be radiated asymmetrically. 3) Asymmetries of leading hadrons don't depend on x_F (their values for different hadrons are adjusted by comparing the results of simulation with experimental data). 4) Signs of asymmetry for them are defined in accordance to asymmetry sign rule [8, 9]. 5) Transverse momentum dependence of asymmetry is chosen in the form

$$f(p_\perp) = (a_1(1 - a_2 p_\perp)^2 + a_3) \qquad (3)$$

Therefore, the asymmetry of leading hadron is defined as

$$A_n^{lead} = a_0 \cdot f(p_\perp), \qquad (4)$$

where a_0, a_1, a_2, a_3 are adjustable parameters. The parametrization allows one to describe the experimental data both for x_F- and $p_\perp$-dependencies. Note here that the contribution of particle production with $p_\perp \simeq 0$ is kinematically suppressed.

For simulation of inelastic proton–proton collisions we used elaborated by one of the authors (G.M.) the model based on bremsstahlung approach [10]. According to the bremsstrahlung analogy the multiparticle production in hadronic interactions is considered as a result of emission of stable mesons, mesonic resonances and intermediate objects with non-fixed masses, clusters. Considering quasiclassically the collision of two extended hadrons one can say that the collision impact parameter is randomly distributed in such a way that only portion of their energies are involved into multiparticle production. Impact parameter distribution is in close relation with so called inelasticity distribution. On the first step the energy portion available for production of secondaries $W = \sum E_i = k\sqrt{s}$ is evaluated, where E_i is the energy of $i-th$ produced particle, k is inelasticity. Fluctuations of the inelasticity from event to event leads to the distribution $P(k)$. It has been shown in the paper [11] that one may fit the inelasticity distribution with beta distribution

$$P(k,s) = k^{a-1}(1-k)^{b-1}/B(a,b), \qquad (5)$$

where a and b are adjustable parameters, B – beta–function. Up to the ISR energies one can neglect its s – dependence.

On the second step the masses of secondaries are defined. At very high energies considerable amount of kinetic energy of colliding hadrons is converted into the excitation energy (effective mass) of produced clusters. For simulation of cluster mass we adopted the result of Chou Kuang-Chao and coauthors [12]. Taking into account general statistical considerations they derived mass spectra of emitted clusters:

$$P(M) = cM\exp(-bM) \qquad (6)$$

with

$$< M >= a_1 + a_2 s^{\nu}, \qquad (7)$$

where a_1, a_2 and ν are adjustable parameters. If M less than 1 GeV we put $M = m_\pi$, m_ρ, m_K in correspondence with their relative weights. In this paper we neglect cluster production because the collision energy under consideration is relatively low to produce these objects.

Kinematics of radiated particles and clusters corresponds to kinematics of cylindrical phase space model. Parameters of cylindrical phase space model are adjusted by comparing the results of simulation of pion – nucleon and nucleon – nucleon interactions with data in wide range of collision energy. The remainder of c.m. energy $(1-k)\sqrt{s}$ is

distributed between remnants of interacting particles according to energy – momentum conservation laws. Colliding nucleons can transform into nucleons and Δ – isobars. For transition probabilities we used the results of OPE – model [13]:

Table 1. Transition probabilities for particle production in the $p+p \to h+X$ reaction

$p \to p$	$p \to n$	$p \to \Delta^{++}$	$p \to \Delta^{+}$	$p \to \Delta^{0}$	$p \to \Delta^{-}$
0.167	0.311	0.274	0.143	0.085	0.0

3 Numerical Results and Analysis of Experimental Data

We have generated exclusive events for $p-p$ collisions at 13, 18, 40 and 200 GeV. The parameters in (4) were adjusted by comparing the results of simulation with experimental data of BNL at 13 GeV. The values of parameter a_0 are given in Table 2 and $a_1 = 0.75$, $a_2 = 1(GeV/c)^{-1}$, $a_3 = 0.25$.

Table 2. Input values and signs of asymmetry parameter a_0.

particle	a_0	particle	a_0	particle	a_0
π^+	+0.6	ρ^+	+0.13	Δ^{++}	−0.6
π^0	+0.2	ρ^0	+0.07	Δ^+	−0.6
π^-	−0.6	ρ^-	−0.13	Δ^0	+0.2
		ω	+0.13	Δ^-	+0.6

Figures 1, 3–5 show the simulation results for asymmetry A_N compared with experimental data [1, 2] on x_F and $p_\perp$. The x_F and $p_\perp$– dependencies are integrated over the regions $0 < x_t < 1$, where $x_t = 2p_\perp/\sqrt{s}$, and $0 < x_F < 1$, respectively.

One can see that the behaviour of asymmetries measured at BNL is different for π^- and π^+- mesons at the range $x_F < 0.5$: negative pion asymmetry is near zero whereas the magnitude of the asymmetry of positive pions starts to grow practically from $x_F \simeq 0$.

Although there is no x_F-dependence of A_n included in (4), our calculations result in x_F- dependence of final asymmetry. The sources of this dependence in our calculations are the following. Primarily, the asymmetry is assigned only to the leading hadron. Second–rank (subleading) and other secondaries are distributed in the average symmetrically in azimuth angles with taking into account energy-momentum conservation law. Abundant meson production in central region ($0 < x_F < 0.1$) dilutes the asymmetry going from the leading hadron with low x_F. In the range $0.1 < x_F < 0.5$ the multiplicity of emitted hadrons decreases, so the asymmetry given by direct leading pions increases. In this range the behaviour of the asymmetry is substantially influenced by resonances. First, the asymmetry of pions resulting from decay of leading vector mesons and Δ-resonances is small due to integration over decay angles, although the value of asymmetry parameters

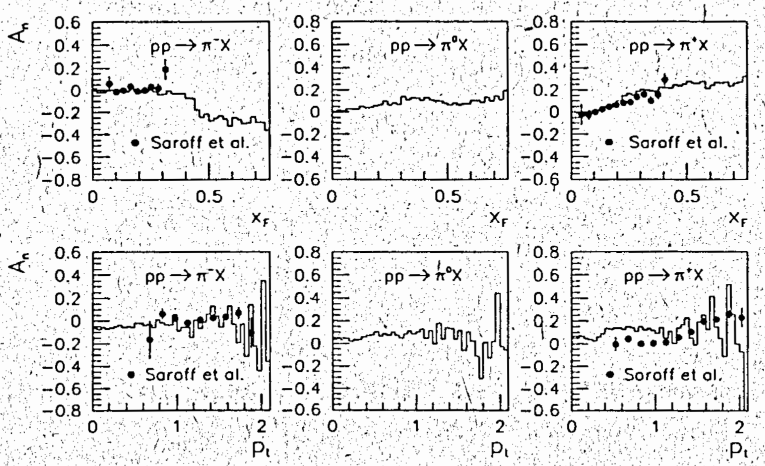

Figure 1: Dependence of left-right asymmetry of the $p\uparrow + p \to \pi^{\pm,0} + X$ process on x_F and $p_\perp$ at $E_p = 13\ GeV$. Experimental data are taken from [2].

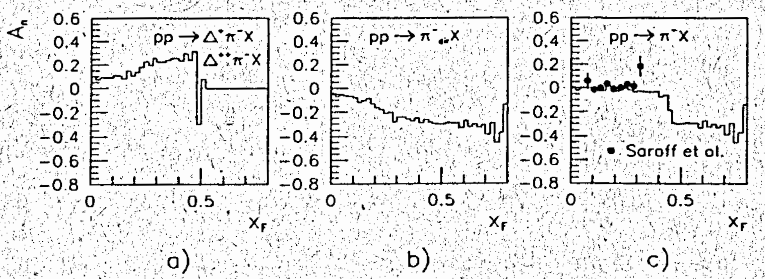

Figure 2: Dependence of pion asymmetry of the $p\uparrow + p \to \pi^- + X$ process on x_F at $E_p = 13\ GeV$. a), b) are contributions of channels with pion accompanied the leading Δ-isobar, with direct production and c) is total contribution, respectively.

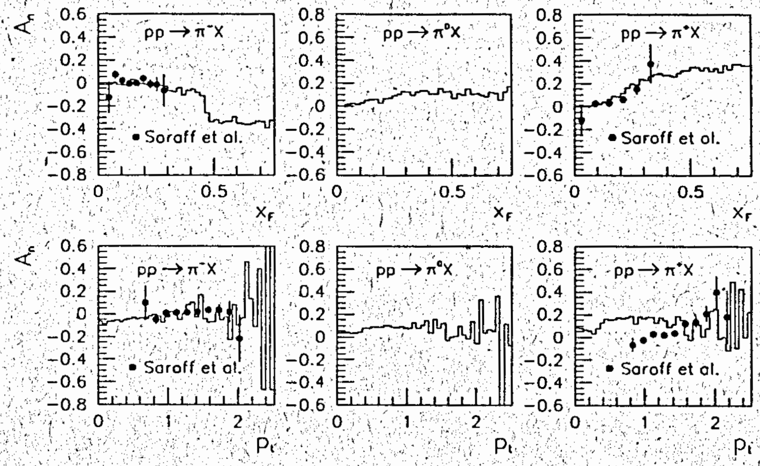

Figure 3: Dependence of left-right asymmetry of the $p\uparrow + p \to \pi^{\pm,0} + X$ process on x_F and $p_\perp$ at $E_p = 18\ GeV$. Experimental data are taken from [2].

for deltas are large (see Table 2). Second, the subleading pion accompanying the leading Δ-resonance and not assigned input asymmetry is distributed asymmetrically in azimuth angle due to local transverse momentum conservation law. Indeed, let us to analyze x_F-dependence of negative pions at 13 GeV (Fig. 1). According to our results zero value of negative pions asymmetry in the $0.1 < x_F < 0.5$ range can be explained by the substantial contribution of channels with leading Δ-resonance accompanied by subleading pion in the forward hemisphere (Fig. 2a). Due to local compensation of transverse momentum the subleading negative pion gets the asymmetry the magnitude of which is the same as for Δ-isobar and the sign is opposite to that one of delta. Since the channels with Δ^{++}- and Δ^+-isobars give maximal contribution to the inelastic cross section (see Table 1) we observe the positive asymmetry of final negative pions, produced in these channels. This positive asymmetry is compensated by the negative asymmetry given by channels with direct leading negative pions (Figs. 2b and 2c).

As regards to transverse momentum dependence of asymmetry, BNL data show that it is rather weak and near zero, at least, up to $p_\perp = 1.0$ (Fig. 1). Small magnitude of resulting asymmetry at low transverse momenta while integrated over x_F is explained again by abundant production of mesons with low transverse momenta which dilutes the asymmetry given by the leading hadron. At high values of transverse momenta the accuracy of our calculations is poor because of large statistical errors, however our results indicate the increasing asymmetry with $p_\perp$ for $p_\perp > 1.0\ GeV/c$.

Asymmetries at $E_{Lab} = 18\ GeV$ are shown in Figure 3. The results are in a good agreement with the data [2]. Some discrepancy is observed for $p_\perp-$ dependence of π^+- meson asymmetry for $p_\perp < 1.0$. Figure 4 shows the x_F- and $p_\perp-$ dependences for pion asymmetries at $E_{Lab} = 40\ GeV$. The experiment at this energy is in progress in Protvino [14]. The x_F- dependence of the magnitudes of asymmetry for π^+- and π^-– mesons

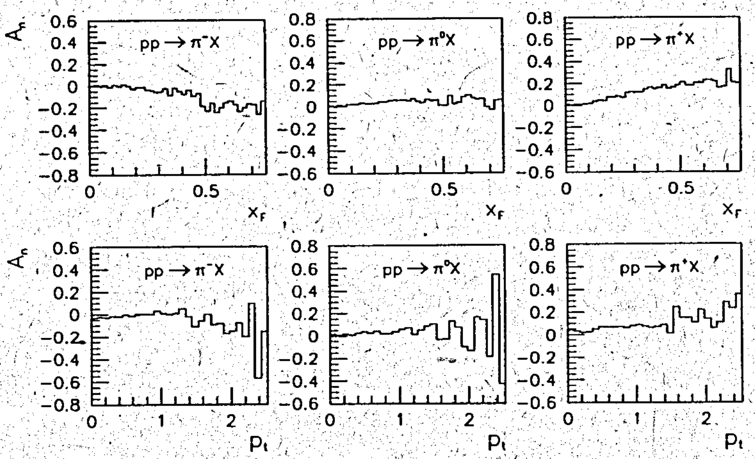

Figure 4: Dependence of left-right asymmetry of the $p\uparrow + p \to \pi^{\pm,0} + X$ process on x_F and $p_\perp$ at $E_p = 40\ GeV$.

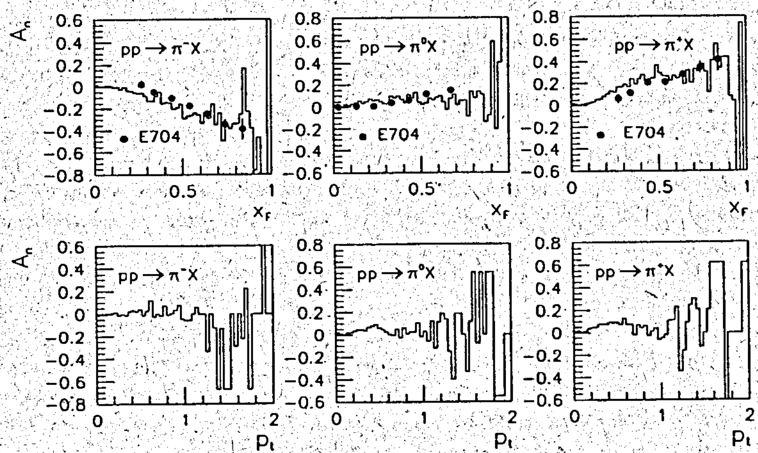

Figure 5: Dependence of left-right asymmetry of the $p\uparrow + p \to \pi^{\pm,0} + X$ process on x_F and $p_\perp$ at $E_p = 200\ GeV$. Experimental data are taken from [1].

is rather close at $E_{Lab} = 200\ GeV$ (Fig. 5). We can say that the difference in x_F behaviour of asymmetry for π^+- and π^-- mesons decreases with the increase of collision energy. This is a consequence of the fact that the contribution of channels with two direct secondaries in the forward hemisphere (leading delta accompanied by pion) decreases with increasing collision energy $\sqrt{s}$. Transverse momentum dependence of asymmetries becomes substantial at $p_\perp > 1\ GeV/c$.

4 Conclusions

Using hadronic event generator based on bremsstrahlung approach on a hadron level, the azimuth asymmetry of inclusive pions in single spin proton-proton collisions was simulated. The x_F and $p_\perp$ dependencies of asymmetry in the $p\uparrow p \to \pi^{\pm,0}X$ process at $E_{Lab} = 13, 18, 40, 200\ GeV$ have been obtained. We calculated single spin asymmetry of inclusive pions in $p\uparrow p$ collisions assuming that the asymmetry of the leading hadron is independent on x_F and dependent on $p_\perp$. Our results are in good agreement with experimental data (BNL, Fermilab). The verification of the predicted the x_F and $p_\perp$ dependencies of the asymmetry at $E_{Lab} = 40\ GeV$ is possible in Protvino (IHEP) and very important both to develop the simulation code and obtain a new information on polarization mechanism in the process.

The analysis performed shows that the behaviour of x_F dependence of asymmetry is influenced by the following factors: abundant particle production in central region, resonance production in intermediate region and energy-momentum conservation law. We found that the behaviour of x_F dependencies for π^+- and π^-- meson asymmetry except for sign becomes the same with the increase of colliding energy.

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References

[1] D.L. Adams *et al.*, *Phys. Lett.* **B261** (1991) 201;
D.L. Adams *et al.*, *Phys. Lett.* **B264** (1991) 462.

[2] S. Saroff, *et al.*, *Phys. Rev. Lett.* **64** (1990) 995.

[3] O.V. Teryaev, *Proceed. XI Int. Symp. on High Energy Spin Phys.* SPIN'94, Bloomington, 1994, p. 417.

[4] A.E. Dorokhov, N.I. Kochelev, *Phys. Lett.* **B259** (1991) 335.

[5] N.I. Kochelev, M.V. Tokarev, Phys. Lett. **B309** (1993) 416.

[6] X. Artru, J. Czyzewski, H. Yabuki, Preprint, LYCEN/9423, Marcel, 1994.

[7] Liang Zuo-tang, Meng Ta-chung, FU Berlin Preprint FUB-HEP/93-8, Berlin, 1993.

[8] G. Agakishiev, *et al., Proceed. Int. Seminar on High Energy Phys.* DEUTERON-93, Dubna, 1993.

[9] M.V. Tokarev, G.P. Škoro, Preprint JINR, E2-95-501, Dubna, 1995.

[10] J. Musulmanbekov, Preprint JINR, E2-88-809, Dubna, 1988; B.F. Kostenko, J. Musulmanbekov, JINR Rapid Communication, Coll., JINR-1-40-90, Dubna 1990, p. 21-34; *Proceed. XI Int. Symp. on High Energy Spin Phys.* SPIN'94, Bloomington, 1994, p.487.

[11] G.N. Fowler, R.M. Weiner and G. Wilk, *Phys. Rev. Lett.* **55** (1985) 173.

[12] Chou Kuang-chao, Liu-Lian-sou and Meng Ta-chung, *Phys. Rev.*, **D28** (1983) 1080.

[13] K.G. Boreskov, A.A. Grigorian, A.B. Kaidalov, *Yad. Fiz.* **24** (1976) 789.

[14] V.V. Abramov *et al., Proceedings VI Int. Workshop "High Energy Spin Physics"*, Protvino, 18-23 September, 1995.

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Мусульманбеков Ж.Ж., Токарев М.В. E2-95-512

Моделирование односпиновой асимметрии реакции $p \uparrow p \to \pi^{\pm,0} X$

Проведено моделирование лево-правой односпиновой асимметрии рождения пионов в протон-протонных взаимодействиях адронным генератором, разработанным на основе метода тормозного излучения. Получены x_F- и $p_\perp$-зависимости асимметрии реакции $p \uparrow p \to \pi^{\pm,0} X$ при энергии налетающего протона $E_{\text{Lab}} = 13$, 18, 40 и 200 ГэВ. Проведен анализ полученных событий и показано, что рождение Δ-изобар заметно влияет на поведение асимметрии. Сделаны предсказания для пионной асимметрии в области больших x_F и $p_\perp$.

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Simulation of Single Spin Asymmetry in the $p \uparrow p \to \pi^{\pm,0} X$ Reaction

Using hadronic event generator based on bremsstrahlung approach on hadron level, the left-right asymmetry of inclusive pions in single spin proton-proton collisions was simulated. The x_F- and $p_\perp$-dependencies of asymmetry for the $p \uparrow p \to \pi^{\pm,0} X$ process at $E_{\text{Lab}} = 13$, 18, 40 and 200 GeV have been obtained. Analysis of simulated events has been performed and it has been found that Δ-resonances play an important role in the behaviour of pion asymmetry. Some predictions for pion asymmetry are given for high x_F and $p_\perp$ region.

The investigation has been performed at the Laboratory of High Energies, JINR.

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