ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

Дубна

E2-95-501

M.V.Tokarev[1], G.P.Škoro[2]

ON POLARIZATION MECHANISM IN INCLUSIVE MESON PRODUCTION AND ASYMMETRY SIGN RULE

Submitted to the VI International Workshop «High Energy Spin Physics», Protvino, 18—23 September, 1995

[1]E-mail:tokarev@sunhe.jinr.dubna.su
[2]E-mail:goran@sunhe.jinr.dubna.su
INS «Vinca», Belgrade, Yugoslavia

1995

1 Introduction

The experimental investigations of polarization phenomena in $p-p$ [1, 2, 3] and $p-A$ [4] collisions at high energies show that single spin pion asymmetry (or analyzing power) does not vanish with increasing transverse momentum p_T and Feynman variable x_F of produced particles. Asymmetry measurements in the $p\uparrow + p \to \pi^{\pm,0} + X$ inclusive processes at the incident proton momentum $k_p = 200\ GeV/c$ performed at Fermilab [3] show that asymmetry is close to zero up to $x_F \simeq 0.3$ and then increases linearly up to the absolute value of 40% near $x_F \simeq 1$. Similar results have been obtained in experiments with polarized antiproton beam. It was, also, observed the strong correlation between the asymmetry sign and pions charge [3]. Large single spin asymmetries have been also measured in $p\uparrow + d \to \pi, K + X$ reactions at proton momentum of 11.75 GeV/c at BNL [4].

In order to explain these results, considerable theoretical work has been undertaken. The large number of theoretical models based on spin-dependent mechanisms of the quark interactions [5, 6, 7] has been developed. Results of these studies indicate that the asymmetry could be a consequence of orbital motion of the valence quarks in a polarized proton [5]. In the frame of the parton model, asymmetry is related to the spin-dependent parton distributions [8], parton cross-sections [9] and parton fragmentation functions [10].

The mechanism [11], based on the quark interaction with the nonperturbative vacuum fluctuations of gluon field [12], was used to explain the experimental data [3] and to predict the A-dependence of single spin pion asymmetry.

In [13] the parton-recombination model has been developed to explain experimental data on hyperon polarization in $p-p$ and $p-A$ collisions (see Ref. [14]). Assuming minimal complexity for the quark transitions and using SU(6) symmetry for barion wave function numerous predictions have been made [13, 14]. But authors noted that the obtained results are independent of the dynamical origin of the polarization on the quark level. The semiclassical Thomas precession effect in the quark recombination process has been proposed as a polarization mechanism. The main features of this model are

- Production of fast hadrons involves recombination of maximum number of valence quarks in beam projectile with a minimum number of the sea.
- All barions are described by minimal three-quark SU(6) wave function.
- The factorization of multiquark wave function into separate valence and sea pieces takes place.
- All sea quarks are initially unpolarized. The recombination mechanism generate asymmetry by enhancing recombination in single spin state over another.
- The baryons are treated as bound states of a quark and a diquark.

It was concluded in [13, 14]. that a polarization asymmetry will arise only if there is a correlation between the spin and transverse momentum of the recombinating quarks. The heuristic rule was formulated: *Slow partons preferentially recombine with their spins down in the scattering plane while fast partons recombine with their spin up.*

In this paper the transverse polarization mechanism for transverse asymmetry in the inclusive meson production at high energy is discussed. The mechanism is based on the suggestion that the scattering of the transversely polarized quark on nonperturbative gluon configuration induce the spin flip of the quark and creation of the $q\bar{q}$ sea pair. The spins of the sea quarks are directed opposite to the direction of the spin of initial quark. The single spin meson asymmetry in $p\uparrow - p$ and $\bar{p}\uparrow - p$ collisions at high energies (in the fragmentation region of projectile) is a result of such quark interaction with nonperturbative gluon configurations. The mechanism is motivated by t'Hooft mechanism [15] for interaction induced by instantons in the case of longitudinally polarized quarks. Using the polarization mechanism on the quark level and taking into account the recombination mechanism the asymmetry sign rule was formulated. The rule was used to explain the experimental data on asymmetry sign in the inclusive meson production and some predictions were made. The suggestion has been made that the mechanism of such kind contribute not only at high energies, but in the intermediate energy region, too.

For example, measurements of single spin asymmetry in the $d\uparrow + p \to \pi^{\pm}(90^{\circ}) + X$ reactions at beam momenta from 3 to 9 GeV/c [16] show that asymmetry reaches large values (about 40%) in the kinematical regions where resonance channels of pion production dominate. These results was a motivation for us to develop a model which could explain the single spin asymmetry in inclusive meson production in a wide beam energy range and at different kinematical conditions.

The paper is organized as follows. Section 2 is devoted to the description of the qualitative picture of the polarization mechanism. Our results for the signs of single spin meson asymmetry in $p\uparrow - p$ and $\bar{p}\uparrow - p$ collisions at high energies are compared with the experimental data and predictions for asymmetry signs of vector mesons are made. In section 3 we apply the polarization mechanism to explain the signs of asymmetry in the $d\uparrow + A \to \pi^{\pm}(90^{\circ}) + X$ process. The influence of the intermediate Δ-resonance states on the signs of single spin pion asymmetry at the intermediate energies is discussed and the two step polarization mechanism is proposed.

2 Polarization Mechanism in $p(\bar{p})\uparrow - p$ Collisions at High Energies and Asymmetry Sign Rule

The transverse polarization mechanism is shown in Figure 1. This mechanism is some kind of analogy with model proposed in ref. [12]. Here, we consider transversal polarization of the beam (the direction of projectile spin is normal to the momentum of projectile and scattering plane).

As a result of interaction of valence quark with nonperturbative gluon configuration, spin of valence quark flips and simultaneously $q\bar{q}$ pair is produced. Quark spins of $q\bar{q}$ pair is directed opposite to the spin direction of the valence quark. The orbital momentum (double line arrow in Figure 1) of the created $q\bar{q}$ pair is directed up in accordance with the total angular momentum conservation law. The final meson is formed when the anti-quark "pick up" the corresponding quark. The sign of the meson asymmetry is defined by the sign of the orbital momentum of $q\bar{q}$ pair (**asymmetry sign rule**). To make full use of this mechanism for prediction of the single spin asymmetry sign in the $p\uparrow + p \to meson + X$ reactions, a number of requirements should be met with. These are:

1. Quark configuration in proton is chosen according to quark-diquark model. It means that in proton with polarization up, spin of leading u-quark is most probably oriented up. If we have d-leading quark, its spin is oriented down.

2. Flip of quark's spin may produce only $q\bar{q}$-pair of different flavour.

3. The spin flip of the flavour which participate in final meson is preferable.

4. It is considered only process when we have the minimal number of spin flips needed to produce anti-quark(s) participating in final meson. The leading quark must flip. To produce wanted meson anti-quark(s) pick up the quark(s) from projectile or target.

5. Spin flip of projectile (target) quark determines the asymmetry in the beam (target) fragmentation region, respectively.

With all this in mind we here suggest the diagrammatic representation, where the "polarized" proton is defined by the $u(\uparrow)u(\uparrow)d(\downarrow)$ component of the wave function. For purposes of illustration the asymmetry mechanism for the $p\uparrow + p \to h + X$ (, where $h = \pi^+, \rho^-, K^+$) process is shown in Figure 2. For example, because the quark configuration of π^+-meson is $u\bar{d}$-pair, the u-quark spin must flip and produce $d\bar{d}$-pair. The final π^+-meson is formed from the $\bar{d}$-quark and u-quark having opposite spin. The sign of the asymmetry is defined by the sign of the orbital momentum of $d\bar{d}$-pair. Considering all possible quark configurations in proton, it can be seen that in $p\uparrow - p$ collision the scalar mesons are mainly produced when created antiquark pick up the needed quark from target's proton (π^-, π^0, η). For π^+-meson production the final state can be formed using either projectile's or target's u-quark. However, for the vector mesons, it is assumed that after spin flip the leading quark and created antiquark formed the final meson.

Table 1. The predictions for the asymmetry signs of inclusive meson production from $p(\bar{p})\uparrow - p$ collisions.

meson	$p\uparrow - p$	$\bar{p}\uparrow - p$
π^+	$+$	$-$
π^-	$-$	$+$
π^0	$+$	$+$
η	$+$	$+$
η_c	$+$	$+$
ρ^+	$+$	$-$
ρ^-	$-$	$+$
ρ^0	$+$	$+$
ω^0	$+$	$+$
K^+	$+$	0
K^-	0	$+$
K^0	$-$	0
$\bar{K}^0$	0	0
ϕ	$(+)$	$(+)$
J/Ψ	$(+)$	$(+)$
Υ	$(+)$	$(+)$

For the $\bar{p}\uparrow - p$ collision, the formalism remains the same but it is considered the antiquark configurations in the polarized antiproton. According to item 3 the single spin asymmetry in the $\bar{p}\uparrow + p \rightarrow \pi^+ + X$ reaction is a result of $\bar{d}$-quark spin flip. Created u-quark has no possibility to pick up the $\bar{d}$-quark having opposite spin so the non-zero effect can be realized only if leading $\bar{d}$-quark pick up the u-quark from target's proton.

The predictions for the asymmetry signs for inclusive mesons produced in $p(\bar{p})\uparrow - p$ collisions are given in Table 1 and compared with existing experimental data (Table 2) [3].

Using the proposed formalism it is easy to calculate the sign of single spin asymmetry in inclusive charmed or strange mesons production. We propose that for the vector mesons ϕ, J/Ψ, Υ the asymmetry will be positive (see Table 1).

Table 2. Experimentally obtained asymmetry signs of inclusive mesons from $p(\bar{p})\uparrow - p$ collisions. Experimental data are taken from [3].

meson	$p\uparrow - p$	$\bar{p}\uparrow - p$
π^+	+	−
π^-	−	+
π^0	+	+
η	+	

We would like to note that the results presented in Table 1. are related to beam fragmentation region. According to item 5 single spin meson asymmetry in $p(\bar{p})\uparrow - p$ collisions should be zero in the target fragmentation region.

3 Polarization Mechanism in $d\uparrow - A$ Collisions at Intermediate Energies

Recently the new data on the single spin pion asymmetry in the $d\uparrow + A \rightarrow \pi^{\pm}(90^{\circ}) + X$ process are presented [16]. The measurements were performed at JINR Dubna Synchrophasotron using the polarized deuteron beam and proton and carbon targets. The incident beam momenta were from 3 to 9 GeV/c. The single spin asymmetries of positively and negatively charged pions with momenta in the range $300 \div 350$ MeV/c from $d\uparrow - p$ collision as a function of incident beam momentum are reproduced in Figure 3(a) [17]. The measurements were performed at angle of $\theta_{\pi} = 90^{\circ}$ in the laboratory system. The large single spin asymmetries, at the level of about 40%, have been observed at relatively low beam momenta. It was found that the asymmetry sign is a function of pion charge and asymmetry values decrease with increasing beam momentum. Figure 3 (b,c) shows the Monte Carlo (MC) [18] calculated relative contributions of different channels of pion production in the $d + p \rightarrow \pi^-(90^{\circ}) + X$ reaction, at the $\theta_{\pi} = 90^{\circ}$ and beam momenta - 4 and 9 GeV/c. The results of MC simulations indicate that the value and the sign of pion asymmetry are affected by the contribution of the intermediate Δ-resonance state. The similar picture can be drawn up for positively charged pions where, at low beam momenta, dominate Δ^{++}-channel of π^+-meson production. The signs of the single spin pion asymmetries observed in the experiment [16] and MC calculated most important pions "sources" in the

corresponding kinematical regions are presented in Table 3. As can be seen, the sign of the single spin pion asymmetry sign is strongly correlated with the type of the resonance involved.

Table 3. Signs of asymmetry in the $d\uparrow + A \rightarrow \pi(90^{\circ}) + X$ process. Data are taken from [16, 17].

reaction	$A_y^{\pi^+}$	$A_y^{\pi^-}$
$d\uparrow + H$	$+ (\Delta^{++})$	$- (\Delta^0)$
$d\uparrow + C$	$+ (\Delta^{++})$	$+ (\Delta^-)$

The high accuracy measurements of single spin asymmetry in the $d\uparrow + C \rightarrow h(24^{\circ}) + X$, (where $h = \pi, K, p$) processes [19] performed in the similar kinematical region confirm that π^+ and π^--meson asymmetries in the $d\uparrow - C$ collision have the same sign. The value of single spin asymmetry for K^+-meson is found to be $A_y^{K^+} = (3 \pm 3)$ % [19]. To explain these results (Table 3), we propose a mechanism similar to described in previous section (with few additional features) to illustrate the effects of resonances. Let us elaborate point we wish to make. Considering deuteron as a proton - neutron system, as it should at low energies, an analysis of the $d\uparrow - A$ collision practically lead up to the independent analyses of the interactions of polarized deuteron nucleons with the nucleons in nucleus. Thus, we propose that the single spin pion asymmetry, in the kinematical region where resonance channels of pion production dominate, results from two step mechanism:

1. "transfer of polarization" from polarized nucleon to Δ-resonance
2. decay of "polarized" Δ-resonance.

The first step - "transfer of polarization" process in the most important exclusive reactions with participation of Δ-isobars (determined on the basis of experimentally obtained cross-section data [20]) is shown in Figure 4. Closer inspection of quark diagrams shows that:

- spin flip of the one quark, needed to produce wanted final state configuration in the reactions $p + p \rightarrow \Delta^{++} + n$ (d-quark spin flips) and $n + n \rightarrow \Delta^- + p$ (u-quark spin flips) generate the asymmetry. According to the total angular momentum conservation law, spin flip must be compensated by the orbital momentum which, at the same time, define the asymmetry sign of the reaction;
- spin flip of the u-quark followed by creation of sea ($d\bar{d}$) pair generate asymmetry in the reaction $p + p \rightarrow \Delta^0 + p + \pi^+$;
- it is clearly seen that the final state in the reaction $n + p \rightarrow \Delta^0 + p$ can be produced if the two u-quarks having opposite spins change their places. In accordance with the mechanism, the asymmetry in this case is equal to zero.

Next we look into the decay of "polarized" Δ-resonance presented in Figure 5. Double line arrow denotes the direction of orbital momentum of created $q\bar{q}$-pairs and defines the sign of the asymmetry. As can be seen, this model provides a consistent qualitative explanation of the asymmetry signs observed in the experiment [16].

4 Polarization Mechanism and Sign of Asymmetry for $d\uparrow + p \to \pi^{\pm}(90^o) + X$ Process in Cumulative Region

Finally, we would like to give a qualitative description of polarization mechanism for π-meson production in the $d\uparrow - p$ collision in the kinematic range forbidden for production in nucleon-nucleon collision. This region is known as a cumulative one [21].

In the cumulative region only the direct mechanism of meson production takes the place [22]. The direct production of cumulative particle is connected with the high momentum component of a deuteron wave function (DWF). The S-wave component of DWF has the cross-over point in the range $q \simeq 0.4 - 0.42\ GeV/c$. This is the fact known as dynamic enhance of D-wave in a deuteron. The particles in the non-cumulative range are produced by nucleons in S-state (the nucleon's spins are directed parallel to the initial deuteron spin and to normal of scattering plane). Therefore, the sign of asymmetry is similar to the one in $N\uparrow + N$ collision. With increasing nucleon momentum in deuteron the D-wave becomes dominant and particles are produced by nucleons in D-state (the nucleon's spins are directed opposite to the initial deuteron spin and antiparallel to normal of scattering plane). Taking into account mentioned above, we predict the changing of the meson asymmetry sign in the transition from non-cumulative to cumulative range. Asymmetry signs for $\pi^{\pm}$-mesons produced in the $d\uparrow - p$ interactions at $\theta_\pi = 90^\circ$ (in the cumulative region) should be negative for both particles. We would like to emphasize that the change of asymmetry sign is connected with D-wave enhancement of DWF and it is the direct consequence of the validity of the total angular momentum conservation law.

5 Conclusions

The description of the mechanism which can generate asymmetry in inclusive meson production in single spin nucleon-nucleon collisions at intermediate and high energies is given. The main point of the mechanism is that the asymmetry in inclusive meson production in single spin nucleon-nucleon collisions occurs as a result of interaction of polarized quarks with the non-perturbative qluon configuration. A number of predictions for the asymmetry signs of inclusive mesons from $p(\bar{p})\uparrow - p$ collisions are given. Two step polarization mechanism for the $d\uparrow + A \to \pi^{\pm} + X$ process are proposed. The explanation of experimental data [16] for pion asymmetry signs is presented. One of the most important features of the proposed polarization mechanism is that the "source" of polarization phenomena in different kinematical regions could be universal. However, further experiments in the field are essential for justification of proposed model and for solving a number of open questions, especially those connected with quantitative description of asymmetry behaviour.

Acknowledgments

We would like to thank Yu.A. Panebratsev, A.E. Dorokhov, N.I. Kochelev and A.A. Baldin for helpful discussions. This work was supported in part by the Russian Foundation for Fundamental Research, Grant No. 95-02-05061.

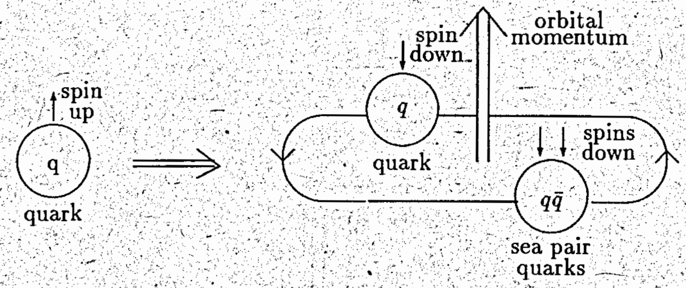

Figure 1: The transverse polarization mechanism.

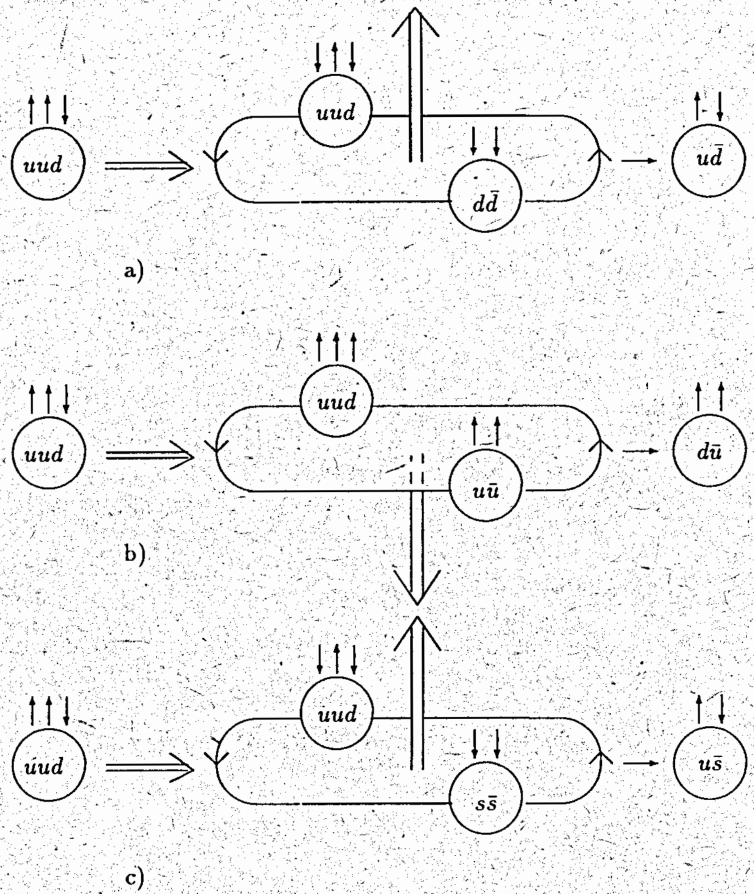

Figure 2: Asymmetry mechanism for meson production processes: a) $p\uparrow + p \to \pi^+ + X$, b) $p\uparrow + p \to \rho^- + X$, c) $p\uparrow + p \to K^+ + X$.

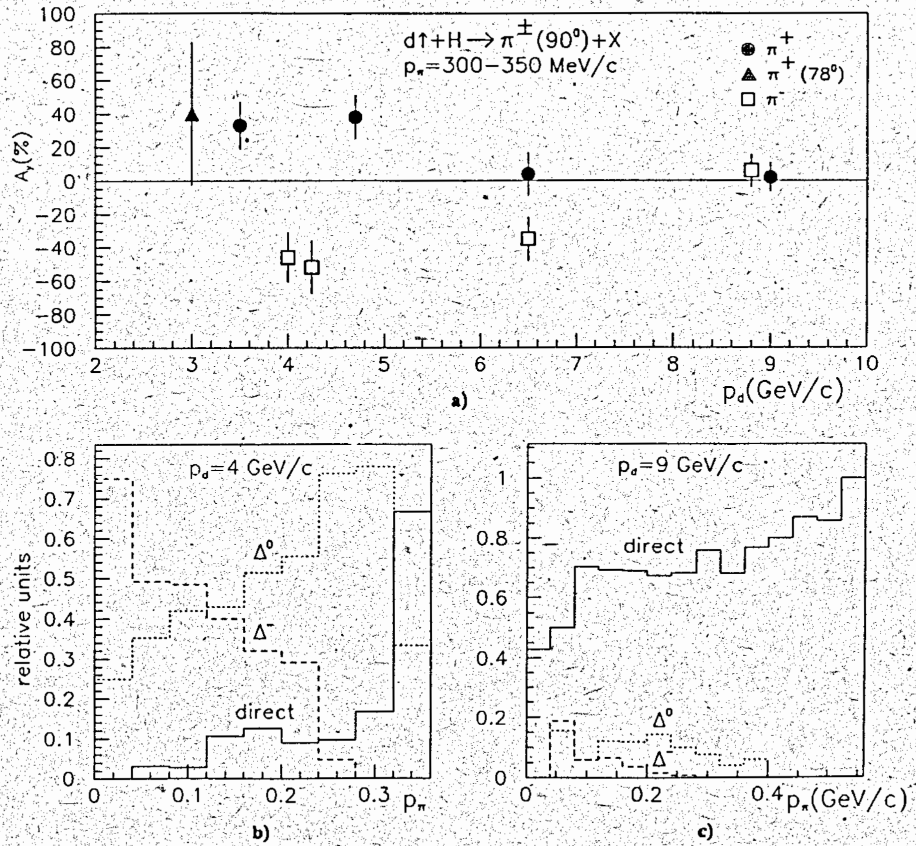

Figure 3: a) The dependence of the asymmetries of positively and negatively charged pions from the reactions $d\uparrow + H \to \pi^{\pm} + X$, ($p_\pi = 300 \div 350\ MeV/c$), as a function of incident beam momentum; b) MC calculated relative contribution of different channels of pion production in the $d + H \to \pi^- + X$ reaction, ($p_d = 4\ GeV/c$), as a function of pion momentum; c) the same as in b) but for $p_d = 9\ GeV/c$.

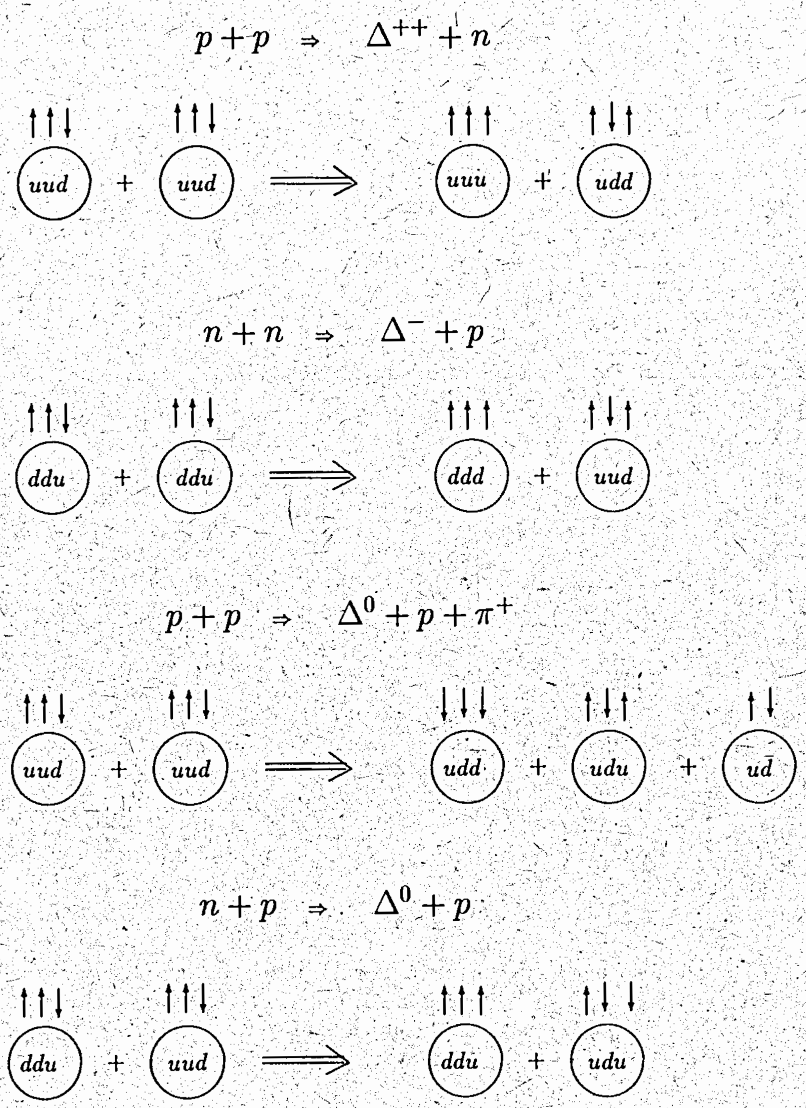

Figure 4: Transfer of polarization from nucleon to Δ - resonance.

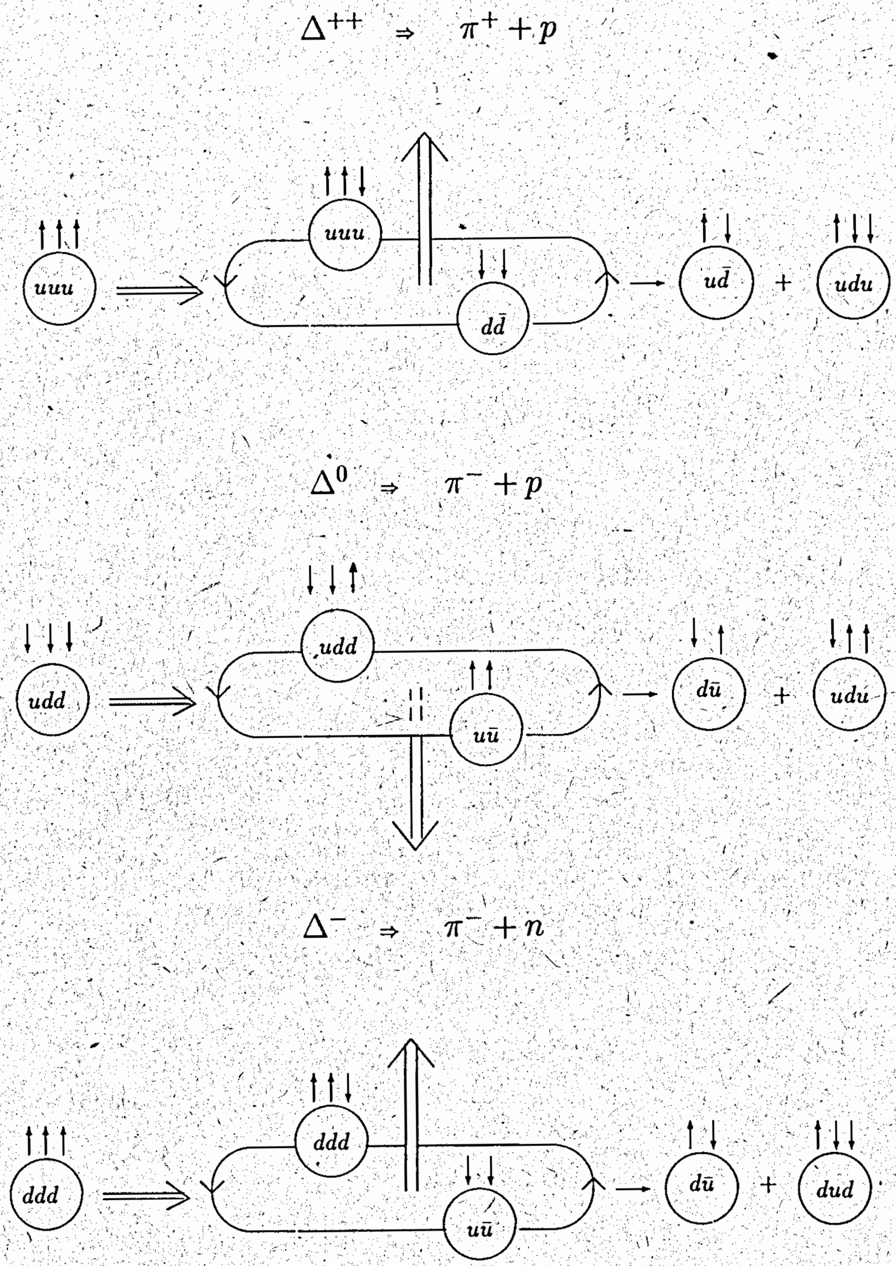

Figure 5: Decay of polarized Δ - resonance.

References

[1] J. Antille et al., Phys. Lett. **B94** (1980) 523.

[2] B.E. Bonner et al., Phys. Rev. **D41** (1990) 13;
S. Saroff et al., Phys. Rev. Lett. **64** (1990) 995.

[3] D.L. Adams et al., Phys. Lett. **B261** (1991) 201;
D.L. Adams et al., Phys. Lett. **B264** (1991) 462;
D.L. Adams et al., Z. Phys. **C56** (1992) 181;
D.L. Adams et al., Phys. Lett. **B276** (1992) 531

[4] W.H. Dragoset et al., Phys. Rev. **D18** (1978) 3939.

[5] Liang Zuo-tang, Meng Ta-chung, Phys. Rev.**D42** (1990) 2380; FU Berlin preprint, FUB-HEP/91-8;
C.Boros, Liang Zuo-tang, Meng Ta-chung, Phys. Rev. Lett. **70** (1993) 1751.

[6] X.Artru, H.Yabuki, J.Czyzewski, Preprint LYCEN/9423, TPJU 12/94, May 1994.

[7] J. Antille et al., Phys. Rev. **D23** (1981) 1227; Phys. Rev. **D24** (1981) 2419.

[8] D. Sivers, Phys. Rev. **D41** (1990) 83; Phys. Rev. **D43** (1991) 261.

[9] J. Szwed, Phys. Lett. **B105** (1981) 403.

[10] J. Collins, Nucl. Phys. **B396** (1993) 161.

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

[12] A.E. Dorokhov, N.I. Kochelev, Phys. Lett. **B259** (1991) 335;
A.E. Dorokhov, N.I. Kochelev, Yu.A. Zubov, Int. J. Mod. Phys. **A8** (1993) 603.

[13] T.A. De Grand, H.I. Miettinen, Phys. Rev. **D23** (1981) 1227;
T.A. De Grand, H.I. Miettinen, Phys. Rev. **D24** (1981) 2419;
T.A. De Grand, J.Markkanen, H.I. Miettinen, Phys. Rev. **D32** (1985) 2445.

[14] B.E. Bonner et al., Phys. Rev. **D38** (1988) 729.

[15] G. t'Hooft, Phys. Rev. **D14** (1976) 3432.

[16] G.S. Averichev et al., JINR Rapid Communication N1-[69]-95 (1995), p.27, Dubna

[17] G.S. Averichev et al., in Proc. of the 3rd International Symposium "Dubna Deuteron-95", Dubna, Russia, 1995 (to be published)

[18] N.S. Amelin et al., Yad. Fiz. **52** (1990) 272.

[19] A.A. Baldin et al., JINR Rapid Communication N5-[73]-95 (1995), Dubna.

[20] V. Flaminio et al., Preprint CERN-HERA 84-01, Geneva (1984).

[21] V.S. Stavinsky, Particles and Nuclei **10** (1979) 949.

[22] M.A. Braun, M.V. Tokarev, Particles and Nuclei **22** (1991) 1238.

Received by Publishing Department
on December 6, 1995.

Токарев М.В., Шкоро Г.П.

E2-95-501

О механизме поляризации в реакции инклюзивного рождения мезонов и правило знаков асимметрии

Рассматривается возможный механизм поляризации, приводящий к асимметрии рождения мезонов в $p(\overline{p})\uparrow - p$ столкновениях при промежуточных и высоких энергиях. Обсуждаются его качественные особенности и предсказываются знаки односпиновой асимметрии рождения мезонов в $p\uparrow - p$ и $\overline{p}\uparrow - p$ столкновениях при высоких энергиях. Сформулировано правило знаков асимметрии. Приводится качественное обоснование, что такой механизм работает и при промежуточных энергиях и объясняются экспериментальные данные по знакам асимметрии процесса $d\uparrow + A \to \pi^{\pm}(90°) + X$. Обсуждается механизм поляризации в $N\uparrow - N$ и $d\uparrow - N$ взаимодействиях в области резонансного рождения Δ-изобары.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 1995

Tokarev M.V., Škoro G.P.

E2-95-501

On Polarization Mechanism in Inclusive Meson Production and Asymmetry Sign Rule

The transverse polarization mechanism which can generate asymmetry in inclusive meson production in single spin nucleon-nucleon collision at intermediate and high energies is considered. The main qualitative features of the mechanism are discussed as well as a number of predictions for the sign of single spin asymmetry of inclusive mesons in $p\uparrow - p$ and $\overline{p}\uparrow - p$ collisions at high energies. The asymmetry sign rule is formulated. It is shown that the mechanism of such kind contributes also at intermediate energies and that it can explain the experimental data on asymmetry sign in the $d\uparrow + A \to \pi^{\pm}(90°) + X$ process. The influence of Δ-resonances on the sign of single spin pion asymmetry in $N\uparrow - N$ and $d\uparrow - N$ collisions is discussed.

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

Preprint of the Joint Institute for Nuclear Research. Dubna, 1995