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INCLUSIVE REACTIONS WITH A POLARIZED TARGET IN THE BEAM FRAGMENTATION REGION

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I. Introduction

Only few studies have been made on polarization effects in inclusive processes at high energies. At the same time it is well known that such effects in elastic scattering and other binary reactions are very sensitive to their mechanism.

In the present paper reactions with a polarized target are considered in the beam fragmentation region. Of course, the results obtained are applicable to reactions with a polarized beam in the target fragmentation region as well.

Polarization phenomena in inclusive processes with a polarized target in the region of its fragmentation do not provide entirely new information except that of binary reactions and we shall not touch upon them. For some polarization effects in this region, see, e.g., ref. /1/.

Abarbanel and Gross /2/ have noted that the asymmetry in the reactions

$$a + b(\uparrow) \to c + x \qquad (1)$$

with the polarized target b in the beam fragmentation region vanishes if one restricts oneself by pole approximation in the Mueller-Kanchely diagram (Fig.1)

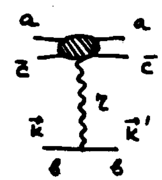


Fig. 1

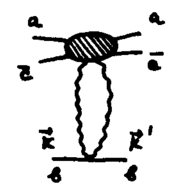
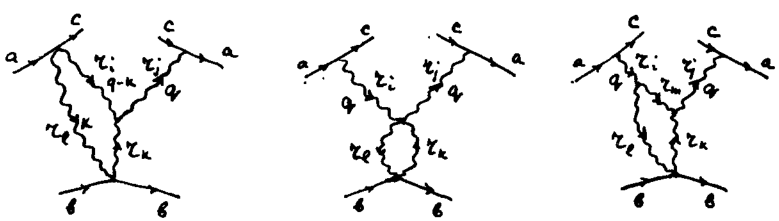


Fig. 2

This is due to the factorization property of the reggeon amplitude, which admits the particle b polarization to be correlated with the vector $[\vec{k}, \vec{k}']$ only, where $\vec{k}$ and $\vec{k}'$ are the initial and final momenta of the particle b. However, $\vec{k} = \vec{k}'$ and the spin dependence of the process (1) cross section vanishes.

It should be emphasized that this result is not general and takes place in pole approximation only. Contrary to the binary process the particle b can flip its helicity in the forward scattering $ab\bar{c} \to ab\bar{c}$, even if a and c are spinless due to the change of the $a\bar{c}$ particle system helicity. So, the nature of the cross section asymmetry in the region of the beam fragmentation is quite similar to the spin-spin correlation in the binary forward scattering amplitude. In both cases, there is no effect in the pole approximation but it emerges when the Regge cuts are taken into account (Fig. 2).

The content of the paper is arranged as follows: Section II considers the triple Regge region of reaction (1). The graphs making the main contribution to the inclusive cross section and its asymmetry are identified. Some of the triple-Regge vertices are known from the analysis of the inclusive reactions with unpolarized particles[3], those of them which cannot be extracted from the available data are estimated in the one-pion exchange model (OPE). So, the contribution of the diagram in Fig. 3a can be calculated. Formulas for the general diagram contribution to the scattering asymmetry of this type are obtained in Section II.



a) b) c)

Fig. 3

The charge exchange reaction

$$\pi^{\pm} p \to \pi^{0} X \qquad (2)$$

is considered in Section III. The numerical estimation of the asymmetry is performed.

In Section IV the reaction

$$\pi^{\pm} p \to \pi^{\pm} X \qquad (3)$$

is analysed. The asymmetry in this reaction turns out to be very small.

In Section IV it is shown that the large asymmetry (about 10%) for small M^2 measured in the experiment at 8 GeV/c may be explained

by the direct interaction of the incident pion with the polarized proton quark.

The graphs shown in Figs. 3b and 3c do not contribute to spin-spin correlations in the reactions $pp \to pX$, $pp \to \Lambda X$, etc. The numerical estimation of such correlations for the reaction $pp \to pX$ is given in Section V. The C_{mm} component of the correlation tensor turns to be of the order of 10^{-3}.

II. Scattering Asymmetry in the Triple Regge Region

Consider the triple-Regge region of reaction (1): $S \gg M^2 \gg S_o$, where S is c.m. total energy squared, M is the X system effective mass, S_o is a scale factor, for which we adopt the value $S_o = 2\, m_N^2$ in accordance with ref.[5]. The graph in Fig.1 can be redrawn in the form of an ordinary triple Regge graph. Its contribution to the cross section is dominant. The graph in Fig. 2 can be replaced by the sum of graphs shown in Fig. 3.

In accordance with the Kanchely[6]-Mueller[7] generalized optical theorem the reaction (1) cross section is determined by the M^2 discontinuity of the forward scattering amplitude $ab\bar{c} \to ab\bar{c}$ denoted by $F_{\lambda\lambda'}(s, q^2, M^2)$, λ, λ' are the particle b initial and final helicities, $\vec{q}$ is the transversal momentum transferred. The inclusive cross section is equal to

$$\frac{1}{16\pi^2 S}\,\frac{1}{2i}\,Disc_{M^2}\, F_{++}(s, q^2, M^2)$$

and is given by the well-known expression:

$$S\frac{d^2\sigma}{dt\,dM^2} = \sum_{ijk} \frac{1}{16\pi^2 S_0} N^{(i)}(q^2)\, N^{(j)}(q^2)\, N^{(k)}(0)\, g_{ijk}(q,q,0)\times \eta_i(q^2)\,\eta_j^*(q^2)\,(1-x)^{\alpha_k(0)-\alpha_i(q^2)-\alpha_j(q^2)}\left(\frac{S}{S_0}\right)^{\alpha_k(0)-1} \qquad (4)$$

Here $N^{(i)}(q^2)$ are the Regge-particle interaction vertices;

$F_{ijk}(k_i, k_j, k_k)$ is the triple Regge vertex depending on the Reggeon momenta; $\eta_i(q^2) = -\dfrac{1+\sigma\exp[-i\pi\alpha(q^2)]}{\sin\pi\alpha_i(q^2)}$

is the signature factor; $\alpha(q^2) = \alpha(0) - \alpha' q^2$ is the

Regge trajectory; $x = 2P_c^{\parallel}/\sqrt{S} \approx 1 - M^2/S$ is the Feynman invariant.

The asymmetry parameter ε is defined as

$$\varepsilon(S, q^2, M^2) = \frac{\sigma_{inv}^{(+)} - \sigma_{inv}^{(-)}}{\sigma_{inv}^{(+)} + \sigma_{inv}^{(-)}} \qquad (5)$$

where $\sigma^{(\pm)}_{inv} = s \frac{d^2\sigma}{dq^2 dM^2}$ is the reaction (1) invariant cross section with the target b 100% polarized "up" or "down" relative to the vector normal to the scattering plane. One can rewrite (5) using $F_{\lambda\lambda'}$ in the following form[1],

$$\mathcal{E}(s,q^2,M^2) = i\,\frac{\mathrm{Disc}_{M^2} F_{+-}(s,q^2,M^2)}{\mathrm{Disc}_{M^2} F_{++}(s,q^2,M^2)} \, . \qquad (6)$$

The contribution to the numerator of this expression arising from the graph in Fig. 3a and the graph symmetrical to it relative to the Reggeon r_k can be found by using the Gribov calculus rules[8]

$$\mathrm{Disc}_{M^2} F_{+-}(s,q^2,M^2) = -\frac{q\,\sigma_k}{4\pi m_N s_0}\left(\frac{s}{s_0}\right)^{\alpha_\ell(0)+\alpha_k(0)-1} \times$$
$$\times (1-x)^{\alpha_k(0)-\alpha_i(0)-\alpha_j(0)} N^{(j)} N^{(i,\ell)} N^{(\ell,k)}_{+-}\, g_{ijk} \times$$
$$\times \mathrm{Re}\left\{ \eta_i(0)\eta_\ell(0)\eta_j^*(0)\, \frac{\Lambda_i}{\Lambda^2} \exp\left[-q^2\left(\Lambda_j^* + \frac{\Lambda_i(\Lambda_k+\Lambda_\ell)}{\Lambda}\right)\right]\right\} . \qquad (7)$$

The following notations are used here :

$$\Lambda_i = R_i^{(a)2} + r_i^2 - \alpha_i'\left[\ln(1-x) + \frac{i\pi}{2}\right]$$
$$\Lambda_j = R_j^{(a)2} + r_j^2 - \alpha_j'\left[\ln(1-x) + \frac{i\pi}{2}\right]$$
$$\Lambda_k = R_k^{(b)2} + r_k^2 + \alpha_k'\left[\ln(1-x) - \ln s/s_0\right]$$
$$\Lambda_\ell = R_\ell^{(a)2} + R_\ell^{(b)2} + \alpha_\ell'\left[\ln s/s_0 - \frac{i\pi}{2}\right]$$
$$\Lambda = \Lambda_i + \Lambda_k + \Lambda_\ell$$

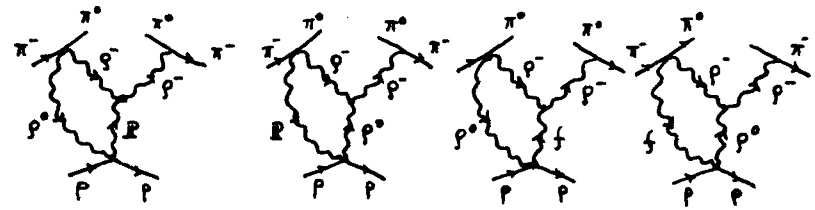
The calculation of the graphs 3b and 3c is more complicated and we shall return to them below.

III. Reaction $\pi^\pm p \to \pi^0 X$ with Polarized Protons

The contributions of the $\mathbb{P}$ and Reggeons with $\alpha(0)\approx 1/2$ will be taken into account.

Then the diagram of Fig. 3b does not contribute to the asymmetry of reaction (2) because of the identity of ρ^- Reggeons. The graph in Fig. 3c in the j representation contains the pole

and the cut contributions in the r_i channel. The pole contribution vanishes because of the identity of Reggeons and the contribution of the cut has been already taken into account by diagram 3b. For the estimation of the latter the eikonal approximation was used. The small spin-flip part of the $pp\mathbb{P}$ and ppf vertices was adopted to be absent. As a result the diagram in Fig. 3a reduces to the number of graphs in Fig. 4.



a) b) c) d)

Fig. 4.

The graphs in a) and b) lead to the asymmetry decreasing as $S^{-1/2}$; the contribution of the graphs in Fig. c), d) behave as S^{-1} when S rises.

Note that the asymmetry parameters for the inclusive reactions of π^+ and π^- charge exchange are connected by the "mirror symmetry" equation:

$$\mathcal{E}(\pi^+ p \to \pi^0 X) = -\,\mathcal{E}(\pi^- p \to \pi^0 X) . \qquad (8)$$

The asymmetry parameter $\mathcal{E}$ corresponding to the graphs in Fig. 4 was calculated using expression (12), the parameters being taken from ref.[3] .

Triple Regge couplings with zero momenta transferred were calculated in the framework of the one-pion exchange model[8,9]. Their momenta dependence was parametrized as in ref.[3], the corresponding radii were adopted to be equal to those of the two-pion Reggeon verticies.

The numerical results at $S = 80$ GeV^2 are shown in Figs.5 and 6. Note, that the use of the quasi-eikonal model requires this value of $\mathcal{E}$ to be multiplied by the shower strengthening factor (which takes into account the graph in Fig.3c contribution as well) about 1.5 .

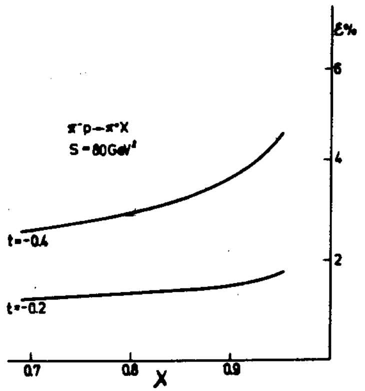


Fig. 5

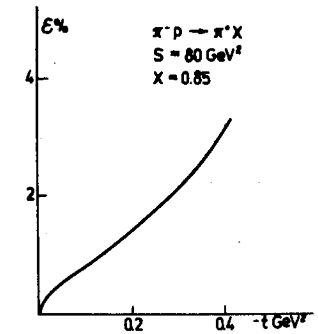


Fig. 6

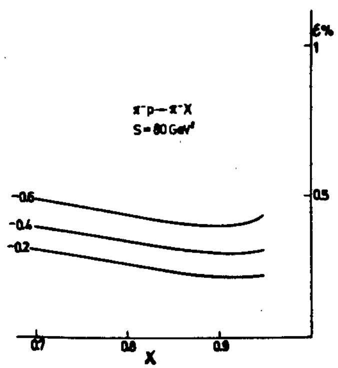


Fig. 7

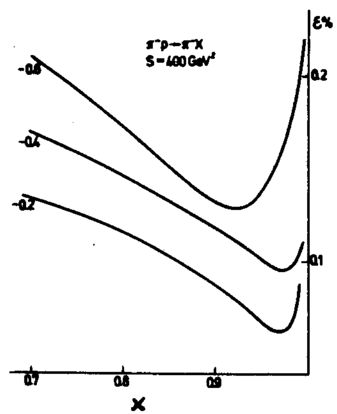


Fig. 8

IV. Asymmetry Parameter in the Reaction $\pi^{\pm}p \to \pi^{\pm}X$

The calculation of the contribution made by the diagrams of the type shown in Fig. 3a is quite similar to that for the reaction $\pi^{\pm}p \to \pi^{0}X$ which has been considered in the previous section. This contribution to the asymmetry parameter of the reactions $\pi^{\pm}p \to \pi^{\pm}X$ is shown in Fig.7,8. Note that in this case the parameter ε has the opposite sign and is by an order of magnitude smaller compared to the elastic asymmetry. This suppression is due to the excessive factor $\sigma_{tot}^{\pi N}/16\pi\Lambda$ entering into the expression for inclusive asymmetry as compared to the expression for the elastic asymmetry. It is clear that this expression takes place for the diagram in Fig. 3b as well which we have failed to estimate correctly because of the presence of the unknown four-Reggeon coupling. This graph has been considered in detail in ref./10/. Then we expect the contribution of the graphs of this type to be of the same order as that of the diagrams shown in Fig. 3a. So, the statement about the smallness of the asymmetry of this process seems to be true though the contribution of graph 3b is unknown.

V. The Quark Model

The measurements at 8 GeV/c/4/ have shown that the asymmetry parameter ε (, s, q^2, M^2) in reaction (3) is relatively large in the small M^2 region (see Fig. 9). But it has been found in the previous section that ε should be suppressed ($\lesssim$ 1%). Strictly speaking there is no contradiction here, because the triple Regge region, where all the calculations have been performed, emerges in inclusive reactions at few tens GeV only. Nevertheless, such dramatic distinction between theory and experiment is surprising because the duality allows one to use approximately high energy calculations in the low energy region. Formula (4), for instance, reproduces on average the inclusive cross section behaviour at small M^2 values. Nevertheless, such extrapolation is not permissible in the case of the asymmetry parameter. Indeed, let us consider the diagram in Fig. 10, where the incident pion is scattered elastically on one of the proton quarks. If quarks after interaction combine the proton, then the elastic event takes place. The

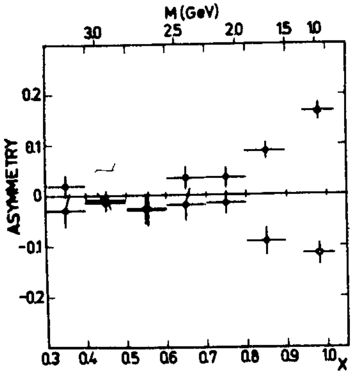


Fig. 9.

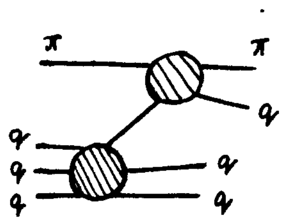


Fig. 10.

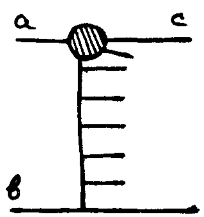


Fig. 11.

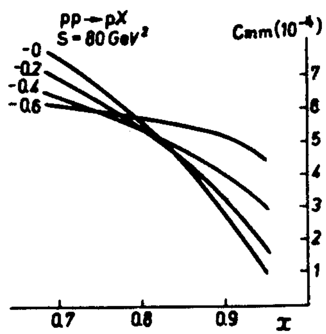


Fig. 12.

inclusive process occurs when the quarks build few hadrons in the final state. Since quarks are polarized, the inclusive scattering asymmetry should be equal to the elastic one and not depend on the final interactions:

$$\mathcal{E}^{quark}_{incl.}(s, t, M^2) = \mathcal{E}_{el} (s,t) \quad . \qquad (9)$$

As M^2 increases the Fig. 10 graph contribution to the inclusive cross section is decreased as compared to the multiperipheral (MP) type processes, where particles are emitted in succession, as is shown in Fig. 11. Such processes give a very small contribution to the scattering asymmetry as has been shown in the previous section. So, one can write down the following relation:

$$\mathcal{E}_{incl.}(s,t,M^2) = \sigma^{quark}_{inv} / \sigma_{inv}\, \mathcal{E}_{el}(s,t) + \sigma^{MP}_{inv}/\sigma_{inv} \times$$
$$\times\, \mathcal{E}_{(MP)} (s, t, M^2) \qquad (10)$$

If $M^2 \sim s_o$, then the first term dominates and $\mathcal{E}_{incl} \approx \mathcal{E}_{el}$ in accordance with the experimental data. $\mathcal{E}_{incl.}$ is decreased with increasing M^2 and at $M^2 \gg s_o$ the second term in (10) dominates, i.e., the previous section results are valid. Experimental data in Fig. 9 do not contradict the zero value of $\mathcal{E}$.

VI. Polarization Correlations

There are polarization phenomena where the diagram in Fig.3b does not contribute to the effect. It is interesting to study them. The charge exchange reaction which was considered above is the first example. Here we consider the second one. If a and b in (1) are particles of spin 1/2 ($pp \to pX$, $pp \to \Lambda X$, etc.) there is a concept of the polarization correlation tensor C_{ik} and a tensor of polarization transferrence K_{ik} (the definition is analogous to the usual one for the binary reactions /11/).In the first case the polarized beam and the polarized target are necessary. In the second case , it is convenient to study the reaction $pp(\uparrow) \to \Lambda X$, where the polarization of Λ may be determined by the study of the Λ decay distribution. The factorization of Regge residues requires the diagram in Fig. 3b to contribute to the tensor components C_{nn} and K_{nn} only. Other nonvanishing components C_{mm}, C_{ml} (K_{mm}, K_{ml}) contain the contribution of the graphs of the type shown in Fig. 3a. These components were computed and are equal to

$$C_{mm} = K_{mm} = \frac{\gamma_{j,0}^{\pi N}\,\Delta}{\sigma_{inv}} \qquad (11)$$

$$C_{ml} = K_{ml} = \frac{\gamma_{j,1}^{\pi N}\,\Delta}{\sigma_{inv}}\,\frac{q}{2m_N} \qquad (12)$$

$$\Delta = \frac{8\pi s_0^2 g_{ijk}}{m_N^2}\,\gamma_{l0}^{NN}\left(\gamma_{k0}^{\pi N}\frac{\gamma_{l1}^{NN}}{\gamma_{l0}^{NN}} - \gamma_{k1}^{\pi N}\right)\times \left(\gamma_{i0}^{\pi N}\frac{\gamma_{l1}^{NN}}{\gamma_{l0}^{NN}} - \gamma_{i1}^{\pi N}\right)\left(\frac{s}{s_0}\right)^{\alpha_l+\alpha_k-1}(1-x)^{\alpha_k-\alpha_i-\alpha_j}\times \qquad (13)$$

$$\mathrm{Re}\left\{(i\sigma_k\eta_i\eta_l\eta_j^*)\Lambda^{-2}\exp\left[-q^2(\Lambda_i+\Lambda_j^*-\Lambda_i^2/\Lambda)\right]\right\};$$

$$8\pi\gamma_{j0(1)}^{\pi N}s_0 = g_j^{\pi} g_{j0(1)}^{N};\quad 8\pi\gamma_{j0(1)}^{NN}s_0 = g_{j0}^{N} g_{j0(1)}^{N},$$

where $g_{j0,1}^{(N)}$ are the non-flip and spin-flip two-nucleon Reggeon couplings.

The numerical values of these components turn to be very small. The X and t dependence of $C_{mm} = K_{mm}$ at p = 40 GeV/c is shown in Fig. 12. The value of $K_{ml} = C_{ml}$ is still two orders of magnitude smaller.

VII. Conclusions

So far we have searched for the effects to which graph 3b does not contribute. On the other hand, it is of interest to study the phenomena where the contribution of this graph is anyhow outlined. Consider the correlation of the asymmetry in process (1) and the multiplicity of particles produced in this reaction.

When the number of the X-system particles is larger than the mean X-multiplicity, the contributions of the triple Regge graph in Fig. 2 and the graph in Fig. 3a,c decreases. At the same time, the discontinuity through both the Reggeons K and ℓ which correspond to the simultaneous production of two multiperipheral ladders, the mean multiplicity in each ladder is about $\langle n\rangle$.

Then, if $n > \langle n\rangle$, the comparative contribution of the diagram in Fig. 3b to the numerator and denominator of expression (6) increases. So, in the multiplicity region $n \simeq 2\langle n\rangle$ the

weight of the contribution of the graph in Fig. 3b. to both F_{+-} and F_{++} in expression (6) increases, the asymmetry rises due to the decrease of the denominator in (6).

The results of this work prove the interest in and importance of the theoretical and experimental study of polarization phenomena in inclusive reactions.

References

1. R.J.Field. Proc. Summer Studies on High Energy Physics with Polarized Beams. ANL/HEP 75-02, 1975
2. H.D.Abarbanel, D.J.Gross. Phys.Rev.Lett., 26, (1971) 732.
3. Yu.M.Kazarinov, B.Kopeliovich, L.I.Lapidus, I.K.Potashnikova. JETP 70 (1976) 1152.
4. L.Dick et al. Phys.Lett., 57B (1975) 93.
5. K.G.Boreskov, A.M.Lapidus, S.T.Sukhorukov, K.A.Ter-Martirosyan. Jad. Fiz., 14 (1971) 814.
6. O.V.Kanchely. JETP Lett.,11 (1970) 397.
7. A.H.Mueller. Phys.Rev., D2 (1970) 2963.
8. V.N.Gribov. JETP, 53 (1967) 654.
9. K.G.Boreskov, A.B.Kaidalov, I.A.Ponomarev. Preprint ITEP-43, Moscow, USSR
10. F.E.Paige, T.L.Trueman. Phys.Rev., D12 (1975) 2422.
11. S.M.Bilenky, L.I.Lapidus, R.M.Ryndin. Usp.Fiz.Nauk, 84(1964)243.

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