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SIZE OF POLARIZATION IN INCLUSIVE PROCESSES

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A B S T R A C T

We study polarization in inclusive processes in the beam fragmentation region in the framework of a simple Regge cut model. We obtain predictions for the dependence on the kinematic variables, and we estimate the magnitude of polarization.

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1. In this paper, we study the polarization asymmetry in inclusive reactions. Experimental data for polarized target in the process $\pi^\pm p \rightarrow \pi^\pm + \text{anything}$ will soon become available for the beam fragmentation region ¹⁾. Theoretically, this kinematic region is of interest since, on studying this process in the Mueller-Regge picture, any factorizing Regge pole gives zero contribution to leading order ²⁾. Hence the main contribution to polarization for this kinematic region is expected to come from a Regge cut. Here we study such models, and we obtain predictions for the magnitude of the polarization asymmetry and for its dependence on the kinematic variables.

In the Mueller picture the polarization asymmetry is given by

$$\Sigma = \frac{\text{Disc } \langle + | M | - \rangle}{\text{Disc } \langle + | M | + \rangle} \quad (1)$$

where $\langle \lambda | M | \mu \rangle$ is the forward amplitude for $p\pi^+\pi^- \rightarrow p\pi^+\pi^-$ and the protons have helicity λ, μ , respectively. The model we take for $\langle + | M | - \rangle$ is shown in Fig. 1. In our model, we have taken a ρ -P cut because the helicity flip coupling of a ρ to nucleons is large.

We will first discuss the general properties expected for Σ from such a model and then we will estimate the size of this polarization in a simple model for the cut.

2. We now consider the dependence of Σ on the kinematic variables to be expected in models of the form of Fig. 1. For the unpolarized amplitude, the diagram of Fig. 2 gives the scaling contribution :

$$\langle + | M | + \rangle \propto \left(\frac{s}{M^2} \right)^{\alpha_i(t) + \alpha_j(t)} (M^2)^{\alpha_P(0)} \quad (2)$$

Here we have defined $s = (p + q_1)^2$, $t = (q_1 - q_2)^2$, $M^2 = (p + q_1 - q_2)^2$

and we take $\alpha_P(0) = 1$. For the polarized amplitude of Fig. 1, one expects a contribution :

$$\langle + | M | - \rangle \propto \sqrt{-t} \left(\frac{s}{M^2} \right)^{\alpha_i(t) + \alpha_j(t)} (M^2)^{\alpha_P(0)} \quad (3)$$

if log terms are neglected. The $\sqrt{-t}$ factor, which, for large s is proportional to $p_{\perp}$ (transverse momentum of the outgoing pion) is a required kinematic factor ³⁾. Near the kinematic boundary, $x \approx 1$, (x is the usual Feynman variable) one expects $i=P$, $j=\rho$ to dominate in $\langle +|M|-\rangle$ and $i=j=\text{Pomeron}$ in the unpolarized amplitude $\langle +|M|+\rangle$ ^{*}). Hence one obtains from Eqs. (1), (2) and (3)

$$\Sigma = a \frac{\sqrt{-t}}{\sqrt{s}}$$

where a is a constant. For the missing mass equal to the nucleon mass, one should recover the elastic polarization, which allows one to determine " a " by normalizing to the elastic data ⁵⁾ for small t . In this way we find :

$$\Sigma \sim 2 \frac{\sqrt{-t}}{\sqrt{s}} \sim \frac{2 p_{\perp}}{\sqrt{s} \sqrt{\alpha}} \quad (4)$$

where the sign is, of course, the same as in the elastic case. One might expect this to be valid very near the kinematic boundary.

For x values in the range 0.4 to 0.8, one may expect $i=(\rho-f)$, $j=f$ to dominate in $\langle +|M|-\rangle$ (the ρ trajectory does not contribute to j by isospin), and one expects $i=\rho$, $j=\rho$ to dominate in $\langle +|M|+\rangle$. This is because $i=j=\text{Pomeron}$ contributions have died down in this x range and the $\rho-f$ trajectory then provides the leading contribution. Hence, using Eqs. (1), (2), (3) and $M^2 \approx s(1-x)$, one gets :

$$\Sigma = \frac{b \sqrt{-t}}{\sqrt{s} \sqrt{1-x}}$$

We estimate the magnitude of b in a simple model described below and find ^{**)}

$$\Sigma \sim 0.45 \sqrt{\frac{-t}{s}} \frac{1}{\sqrt{1-x}} \sim \frac{0.45 p_{\perp}}{\sqrt{s} \sqrt{\alpha(1-x)}} \quad (5)$$

*) Alternatively, if one assumes that the unpolarized amplitude is dominated ⁴⁾ by $i=j=\text{Pomeron}$ and ρ in the M^2 channel (instead of Pomeron), one obtains

$$\Sigma \sim 2 \frac{\sqrt{-t}}{\sqrt{s}} \sqrt{M^2} \sim 2 p_{\perp} \frac{\sqrt{1-x}}{\sqrt{\alpha}}$$

For $t=-0.1$, $x=0.9$ (i.e., $p_{\perp} \sim 0.3$), $s=16 \text{ GeV}^2$, this gives $\Sigma \sim 0.2$.

**) For $p_{\perp}=0.3$, $s=16 \text{ GeV}^2$, this gives $\Sigma \sim 0.07$ at $x=0.5$ and $\Sigma \sim 0.08$ at $x=0.8$.

The results (4) and (5) are different because they describe different x regions where two different mechanisms dominate.

3. We now want to estimate the size of the polarization using a simple cut model. We are only aiming to obtain a very approximate value, which will, nevertheless, be of value to experimentalists. It is for this reason, as a start, that we will not appeal to very refined arguments.

We are interested in the x region where $i, j = \rho$ -f trajectory dominates in Figs. 1 and 2. By factorization, the polarization is given by the ratio of forward Regge proton elastic scattering with helicity flip, compared with the same amplitude for helicity non-flip. In our model, we assume that this ratio is the same as that obtained when the ρ -f trajectories are extrapolated to the ρ poles. This means we are neglecting any contributions which vanish on the pole. Hence, we consider physical ρ -proton scattering, with kinematics and helicities as in Fig. 3. The helicity non-flip amplitude for this process is then given by

$$A_{2\mu; 2'\mu'}^P = -\sigma_{tot} M^2 i e^{At/2} \delta_{22'} \delta_{\mu\mu'} \quad (6)$$

where we assume a helicity conserving Pomeron, and neglect non-leading contributions. In order to calculate the ρ -P cut contribution to the flip amplitude for the on-shell process, we need to know the contribution of ρ exchange, and hence the $\rho\rho f$ flip coupling. In view of the lack of information about this latter coupling, we estimate it in the following somewhat crude way. We assume a ρ - ρ - ρ vertex given by (see Fig. 4)

$$V = g_1 (\epsilon_1 \epsilon_2 \epsilon_3 q_1 + \epsilon_2 \epsilon_3 \epsilon_1 q_2) + g_2 \epsilon_3 \epsilon_1 \epsilon_2 q_3 + g_3 \epsilon_1 q_2 \epsilon_2 q_3 \epsilon_3 q_1$$

By symmetry $g_1 = g_2$. By vector dominance, one obtains $g_1 = 2g_{\rho\pi\pi}$ where the matrix element for ρ decay is $2g_{\rho\pi\pi} \epsilon \cdot q$ and $g_{\rho\pi\pi}^2/4\pi \sim 2.3$ from the ρ width. In our case (for helicity flip), one ρ trajectory decouples by isospin and we are left with a $\rho\rho f$ vertex. In this case g_1 is no longer equal to g_2 and we will take as our approximation $g_2 = 0$.

We then obtain the following contribution to the amplitude A of Fig. 3 from ρ -Regge exchange, normalized to ρ particle exchange :

$$A_{0\frac{1}{2};-1-\frac{1}{2}}^R = (-t') \frac{g_{\rho\pi\pi} \gamma_{+-}^{\rho}}{\sqrt{2} m_{\rho}} \frac{i e^{-i\pi\alpha_{\rho}/2}}{m_{\rho}^2 - t'} \left(\frac{M^2}{M_0^2} \right)^{\alpha_{\rho}(t')} \quad (7)$$

where ^{*)} we have taken a $\rho\pi\pi$ helicity flip coupling $\sqrt{-t'} \gamma_{+-}^{\rho}$ with $\gamma_{+-}^{\rho} \sim \sim 17 \text{ GeV}^{-1}$ from Ref. 6) and with our normalization. The g_3 term in the $\rho\pi\pi$ vertex contributes as $(-t')^{\frac{3}{2}}$ and we have neglected it since we only expect contributions to the cut from small t' .

One may now calculate the ρ -P cut in the standard way ^{6) **)} using the above expression A^P for Pomeron exchange and A^R for ρ exchange. We find in the forward direction :

$$A_{0\frac{1}{2};-1-\frac{1}{2}}^{\rho\text{cut}} = \lambda \frac{\sigma_{\text{tot}} \gamma_{+-}^{\rho}}{2\pi(A+B)^2} \frac{g_{\rho\pi\pi}}{m_{\rho}^2 \sqrt{2}} i e^{-i\pi\alpha_{\rho}/2} \left(\frac{M^2}{M_0^2} \right)^{\alpha_{\rho}} \quad (8)$$

$$\frac{B}{2} = \frac{1}{m_{\rho}^2} + \alpha' \left[\log \left(\frac{M^2}{M_0^2} \right) - i \frac{\pi}{2} \right]$$

where λ is a factor introduced to take account of inelastic channels. We take $\lambda \sim 2$ ⁶⁾. In our model, the polarization is then given by

$$\Sigma = \frac{\text{Im } A_{0\frac{1}{2};-1-\frac{1}{2}}^{\rho\text{cut}}}{\text{Im } A_{1\frac{1}{2};1\frac{1}{2}}^P} = \text{Im} \left(\frac{i e^{-i\pi\alpha_{\rho}/2}}{(A+B)^2} \right) \frac{\gamma_{+-}^{\rho} g_{\rho\pi\pi}}{\sqrt{2} \pi m_{\rho}^2} \frac{1}{\sqrt{M^2}}$$

The polarization is expected to vanish as $p_{\perp}$ by angular momentum ³⁾, but our result obtained in this model does not have this dependence. This is because we are normalizing to the ρ poles and so cannot obtain any t dependence.

*) We find the amplitude $A_{1\frac{1}{2};0-\frac{1}{2}}^R = 0$ because of the symmetry of the $\rho\pi\pi$ vertex.

**) In our case, however, we have no net helicity flip but helicity flip at both vertices.

More refined calculations with off-shell Reggeons should give these factors automatically. In our model we will include this feature by multiplying by $\sqrt{|t|}/m_\rho$ which gives 1 at the ρ pole where we have normalized. One would expect, in general, other t dependent factors (for example, exponential) but we hope that all those factors cancel in the ratio we are calculating. Taking $A = 8 \text{ GeV}^{-2}$ (assuming the slope is the same as in πN elastic), $M_0^2 = 1$, $\alpha' = 1 \text{ GeV}^{-2}$ and $\log M^2/M_0^2 \sim 1$ we obtain our result for the size of the polarization Eq. (5).

To conclude, we would like to make the following remarks.

- 1) Our model gives, as expected, the mirror symmetry ⁷⁾ between $\pi^+ p \rightarrow \pi^+ X$ and $\pi^- p \rightarrow \pi^- X$. The sign is the same as for the elastic case, except if, for some dynamical reason, Σ vanishes at a certain value of x above ~ 0.8 .
- 2) By factorization, our results predict the same asymmetry for $ap \rightarrow cX$ for any a and c provided the ρ trajectory couples strongly to the $a\bar{c}$ system.
- 3) We do not have any prediction for the fragmentation region of the target ($x < 0$). This is also an interesting problem which requires separate study.

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FIG.1

FIG.2

FIG.3

FIG.4