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Transverse single-spin asymmetry of very forward neutral pion

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Abstract. We present in this talk a recent work on the transverse single-spin asymmetry of the very forward neutral pion in polarized $p+p$ collisions at $\sqrt{s}$ = 510 GeV. The triple-Regge formalism remarkably well desribes the RHICf data at p_T < 1 GeV. We found that the neutral pion production at low p_T is interpreted as a diffractive one.

1 Introduction

Recently, the transverse single-spin asymmetry(TSSA) of the neutral pion in the inclusive polarized proton - proton collision was measured by the RHICf Collaboration [1]. The TSSAs in the high $p_T(\gtrsim 2$ GeV) have been understood via pQCD-based models such as the transverse momentum-dependent functions (TMDs) [2–4] or twist-3 factorization [5–12]. However, the produced pions in this measurement have large pseudorapidities($\eta > 6$) and small transverse momenta, so that those approaches may not be vaild in this kinematic region.

The Regge approach has been successfully applied to soft processes, where the center of mass energy s is very large and the transverse momentum is small. In 1970, Mueller found the generalized optical theorem [14], which allows one to approximate the two-body scattering in the high energies to a relevant Reggeon exchange processes of the three-body reaction. The triple-Regge process is one of the kinematic boundaries of the three-body Mueller amplitude which can be applied to the kinematic range of the RHICf experiment.

In the present talk, we show how to compute the TSSA of the neutral pion in the very forward direction by using the triple-Regge exchange diagram. The N, $N^*(1520)$, $\Delta(1232)$ and $\Delta(1600)$ baryon trajectories are introduced. The interefence between the trajectories yield the very foward TSSA. It might indicate that the TSSA of the neutral pion in the very forward direction can be interpreted as a diffractive one.

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2 The differential cross section in the $p^{\uparrow} + p \rightarrow \pi^0 + X$ reaction in the triple-Regge limit

The differential cross section in the inclusive $pp^{\uparrow} \rightarrow \pi^0 X$ collision at high-energies is given as

$$d\sigma^{\uparrow} = \frac{1}{s} \sum_{X} \left| A^{\mathrm{tot}}_{pp^{\uparrow} \rightarrow \pi^0 X}(M_X^2) \right|^2 , \tag{1}$$

where M_X is the missing mass which is defined as $M_X^2 = (p_p + p_{p^{\uparrow}} - p_{\pi^0})^2$ and $\sum_X$ denotes the summation over the phase space of the X. Since the RHICf energy is sufficiently large, $\sqrt{s} = 510$ GeV, the scattering amplitude can be described in terms of Reggon exchanges. The square of the two-body Reggeon exchange process is then analytically continued to the $3 \rightarrow 3$ reaction in the forward direction by Mueller's generalized optical theorem [14]:

$$d\sigma^{\uparrow} = \frac{1}{s} \sum_{i,j} \sum_{\lambda} \beta^{i}_{\uparrow\lambda}(t) \beta^{j}_{\uparrow\lambda}(t) \mathcal{P}_i(t) \mathcal{P}^{*}_j(t) \mathrm{Disc}\, A_{ip \rightarrow jp}(M_X^2), \tag{2}$$

where $\beta^{i}_{\uparrow\lambda}$ is a residue function in the Reggeized amplitude and λ is the helicity of the baryon. Since the Regge approach does not provide any information on the vertex structure, we adopt the effective Lagrangians to compute the residue function. The propagator of the Regge tajectory is defined as [15, 16]

$$\mathcal{P}_i(t) \equiv \alpha'_i \xi_i(t)^{\pm} \Gamma(J_i - \alpha_i(t))(1 - x_F)^{-\alpha_i(t)}, \tag{3}$$

where $\alpha_i(t)$ stands for the Regge trajectory of the i particle and x_F is the Feynman variable which is defined as a longitudinal momentum fraction between the polarized proton and its fragment π^0.

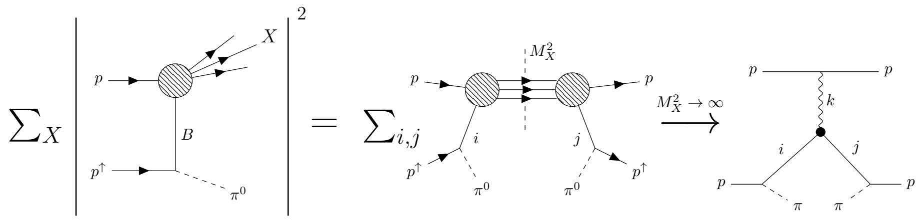

Figure 1. The triple-Regge approximation of the differential cross section. i, j and k indicate the Regge trajectories.

In the $M_X^2 \rightarrow \infty$ limit, the discontinuity on the M_X^2 plane also can be replaced by an appropriate Regge trajectory as shown in Fig. 1. Then the $d\sigma^{\uparrow}$ is written as the sum of the triple-Regge diagrams,

$$\mathrm{Disc}\, A_{ip \rightarrow jp}(M_X^2) = \sum_{k} G^{k}_{ij}(t) \left(\sum_{\lambda'} \beta^{k}_{\lambda'\lambda'}(t_k = 0) \right) \left(\frac{M_X^2}{s_0} \right)^{\alpha_k(0)} , \tag{4}$$

where s_0 is an energy scaling factor and fixed as 1 GeV^2. One could calculate the ppk vertex on the top side of the triple-Regge diagram by using the effective Lagrangian method. However, since we utilize the generalized optical theorem to derive the triple-Regge exchange process, k trajectories do not carry the momentum ($t_k = 0$). Thus the residue function of this vertex can be written as $\gamma^{k}_{pp} = \sum_{\lambda'} \beta^{k}_{\lambda'\lambda'}$. The coupling of three tracjectories G^{k}_{ij} are parametrized as a function of t.

Table 1. Parameter values in A_N.

	NN^*	N^*N^*	$\Delta\Delta$	$\Delta\Delta^*$	$\Delta^*\Delta^*$
g^k_{ij}	0.028	0.10	0.022	−0.018	0.079
b^k_{ij}	0.2	-	-	-	-

3 Transverse sinlge-spin asymmetry of the very forward π^0

The transverse single-spin asymmetry is given as a ratio of the spin-dependent($d\Delta\sigma$) and spin-averaged($d\sigma$) differential cross sections. In the course of the calculation, one can see that the ij diagonal terms do not contribute to the spin-dependent cross section. It implies that the interference between i and j exchange (more specifically between the signature factors of them) yield the TSSA in the very forward direction.

$d\sigma$ can be simplified by the parity invariance of the residue function β [17]. Firstly, $d\sigma^{\uparrow}$ vanishes when the trajectory k is unnatural parity state. So we introduce the Pomeron for k exchange as a leading trajectory, because it has the largest Regge intercept $\alpha(0)$ among the natural parity states. Secondly, $d\Delta\sigma$ vanishes if i and j trajectories have opposite naturalities. The leading contributions are N-$N^*(1520)$ and Δ-$\Delta(1600)$ interference for natural and unnatural part, respectively. One define the triple-Regge coupling as

$$G^k_{ij}(t) = \begin{cases} G^k_{ii}(0)e^{-B^k_{ii}|t|} & \text{for } i = j \\ G^k_{ij}(0)\frac{\sqrt{|t|}}{m_\pi}e^{-B^k_{ij}|t|} & \text{for } i \neq j. \end{cases} \tag{5}$$

In order to fit the RHICf data, we define the following new parameters as

$$g^k_{ij} = G^k_{ij}(0)/G^k_{NN}(0), \quad b^k_{ij} = B^k_{ij}(0) - B^k_{NN}(0). \tag{6}$$

Finally, we obtain the TSSA in terms of the triple-Regge amplitude as

$$A_N = \frac{\sum_\lambda \left[\beta^N_{+\lambda}\beta^{N^*}_{-\lambda}\mathrm{Im}\,\mathcal{P}_N\mathcal{P}^*_{N^*}(\sqrt{t}/m_\pi)g^P_{NN^*} + \beta^\Delta_{+\lambda}\beta^{\Delta^*}_{-\lambda}\mathrm{Im}\,\mathcal{P}_\Delta\mathcal{P}^*_{\Delta^*}(\sqrt{t}/m_\pi)g^P_{\Delta\Delta^*}e^{-b^P_{\Delta\Delta^*}|t|}\right]}{\sum_\lambda \left[\sum_i(\beta_{+\lambda})^2|\mathcal{P}_i|^2 g^P_{ii}e^{-b^P_{ii}|t|} + \sum_{i\neq j}\beta^i_{+\lambda}\beta^j_{-\lambda}\mathrm{Re}\,\mathcal{P}_i\mathcal{P}^*_j(\sqrt{t}/m_\pi)g^P_{ij}e^{-b^P_{ij}|t|}\right]}, \tag{7}$$

where P indicates the Pomeron. We list the values of the parameters in Table. 1.

4 Results and Discussion

Our main interest lies in describing the A_N for the soft diffractive π^0 production in the the large x_F region, employing the tripe-Regge formalism. The numerical results show a remarkable agreement with the RHICf experimental data up to $p_T \simeq 0.8$ GeV$/c$, as shown in Fig. 2.

The very forward π^0 A_N exhibits a rising trend as p_T increase. In Fig. 2, A_N is almost saturated in the region $0.25 \lesssim p_T \lesssim 0.45$ GeV$/c$. The $\sqrt{|t|}$ factor in the triple-Regge coupling can explain this data point, since t becomes zero at the point between third and fourth points. For the smaller p_T, A_N comes from NN^* interference term. As p_T increases, the contribution of NN^* becomes negative and large $\Delta\Delta^*$ term compensates it, so that the total contributions yield positive values at $p_T > 0.5$ GeV$/c$. In addition, A_N starts to increase rapidly and reaches over 20 % at about $p_T = 0.8$ GeV$/c$. The next leading pole contributions moderate A_N at higher p_T. N^*N^* contribution is not sufficient to suppress the large value of A_N, so $\Delta^*\Delta^*$ is required to describe the RHICf data.

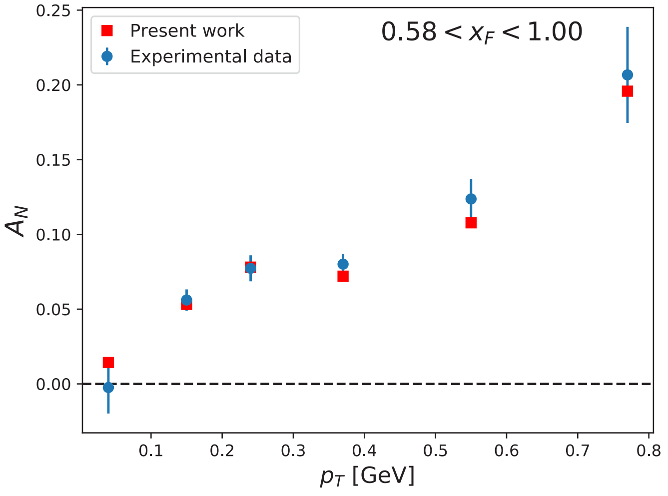

Figure 2. p_T distribution of A_N with $0.58 < x_F < 1$. The square symbol denotes the numerical result for the present work. The circles and solid lines are the RHICf experiment results and errors.

5 Summary and Conclusions

We investigate the transverse single-spin asymmetry for the neutral pion in the very forward direction via triple-Regge exchange processes. The numerical result with the various Regge trajectories show an excellent agreement with the data from the RHICf experiment at large x_F. It indicates that the most of the A_N in the $p_T < 1$ Gev/c and $x_F > 0.58$ is produced by interferences between diffractive scattering processes.

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