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Light-cone meson-baryon fluctuations and single-spin asymmetries

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We show that energetically favored meson-baryon fluctuations present in the light-cone wave function of a transversely polarized proton can account for the left-right asymmetries measured in inclusive meson production processes. [S0556-2821(99)50303-2]

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Recently, remarkable left-right asymmetries have been measured in inclusive meson production using transversely polarized projectile hadrons and unpolarized hadron targets [1]. It is observed that these asymmetries have many striking features characteristic of leading particle production. They are significant in and only in the fragmentation region of the transversely polarized projectile, they depend on the quantum numbers both of the projectile and of the produced particles, but are insensitive to the quantum numbers of the target.

While considerable amount of experimental information has been collected over the last few years [1], there is still no accepted theoretical concept for the explanation of the experimental findings [2]. Since such asymmetries are expected to vanish because of helicity conservation of the almost massless quarks [3] in leading twist, leading order QCD, it has become widely accepted that modeling of higher twist, nonperturbative effects is needed to understand these phenomena. Here, we make such an attempt and show that energetically favored meson-baryon fluctuations present in the light-cone wave function of the projectile, can account for the nonvanishing left-right asymmetries in the projectile fragmentation region.

It is instructive to review briefly the connection between light-cone fluctuations and leading particle production. Mesons produced in the fragmentation regions in hadron-hadron collisions are known to reflect the quantum numbers of the projectile and, thus, carry information about its wave function. It has been realized that the production of leading mesons for moderately large transverse momenta, especially the flavor asymmetry between leading and nonleading particle production, can be understood on the basis of higher Fock states present in the light-cone wave functions of hadrons [4]. In this picture, the projectile can fluctuate into higher Fock states containing quark-antiquark pairs in addition to the valence quarks which carry its quantum numbers. The most probable fluctuations are those which have minimal invariant mass. Coalescence of the antiquark with valence quarks of the projectile produces then leading particles in the projectile fragmentation region [4,5]. Alternatively, one can think of leading particles as preexisting in the higher Fock states of the projectile in form of energetically favored meson-baryon fluctuations [4,6,7]. Then, production of leading particles happens when soft interactions between the projectile and target break the coherence of the light-cone meson-baryon fluctuation and bring the particles on shell. Since these soft interactions involve small momentum transfers between target and projectile, the momentum distribution of the produced leading particles should closely resemble the momentum distribution of the Fock state (light-cone wave function) [4,5]. Since the transverse momenta of the produced particles in the single-spin experiments are typically $p_\perp \sim 0.7\,\mathrm{GeV}/c$, a picture based rather on meson-baryon than on quark degrees of freedom should be more appropriate for the description of the asymmetries.

Let us recall the definition of the left-right asymmetries for the reaction $p(\uparrow)+p(0)\rightarrow M+X$, where $p(\uparrow)$ and $p(0)$ stand for the transversely polarized projectile and unpolarized target protons, respectively; M stands for the inclusive produced meson and X for the unobserved final states:

$$A_N(x_F|M)=\frac{N_L(x_F,\uparrow|M)-N_L(x_F,\downarrow|M)}{N_L(x_F,\uparrow|M)+N_L(x_F,\downarrow|M)}, \tag{1}$$

where

$$N_L(x_F,i|M)=\frac{1}{\sigma_{in}}\int_{(D)}d^2p_\perp\,\frac{d\sigma(x_F,\mathbf{p}_\perp,i|M)}{dx_F d^2p_\perp} \tag{2}$$

($i=\uparrow$ or $\downarrow$) is the normalized number density of the produced mesons observed in a given kinematical region D ($p_\perp > 0.7\,\mathrm{GeV}/c$ for example) on the left-hand side of the beam (L) looking down stream. σ_{in} is the total inelastic cross section, x_F is the usual Feynman-x $x_F=2p_\parallel/\sqrt{s}$, where $p_\parallel$, $p_\perp$ are the longitudinal and transverse momenta of the produced mesons and $\sqrt{s}$ is the c.m. energy. Since $N_L(x_F,\uparrow|M)=N_R(x_F,\downarrow|M)$ and $N_L(x_F,\downarrow|M)=N_R(x_F,\uparrow|M)$, where $N_R(x_F,i|M)$ are the corresponding number densities measured on the right-hand side, it is clear why A_N is usually referred to as left-right asymmetry.

According to this definition, nonvanishing left-right asymmetries reflect a remarkable correlation between the direction of transverse motion of the produced particles and the transverse polarization of the projectile. In the above picture for leading particle production, this correlation is expected to be *present* in the wave function of the projectile and to be carried over to the leading particle appearing in the final state. Thus, left-right asymmetries resemble rather a correlation *preexisting* in the initial state than a correlation produced in the final state, for example, by fragmentation. We note that this conjecture is in agreement with recent experimental observations by the Tasso [8], ALEPH [9], and SLD Collaborations [10] showing no transverse polarization of the produced particles in e^+e^- annihilations.

In pion production, the lowest Fock states involving $u\overline{u}$ and $d\overline{d}$ fluctuations are $p(uud)=\pi^+(u\overline{d})n(udd)$, $p(uud)=\pi^0[(1/\sqrt{2})(u\overline{u}+d\overline{d})]p(uud)$, and $p(uud)=\pi^-(d\overline{u})\Delta^{++}(uuu)$, respectively. Since higher mass fluctuations have relatively small probabilities, the energetically favored lowest fluctuations play the most important role. However, for the sake of completeness, we also include the relatively less important π^+ and π^- fluctuations $p(uud)=\pi^+(u\overline{d})\Delta^0(udd)$ and $p(uud)=\pi^0[(1/\sqrt{2})(u\overline{u}+d\overline{d})]\Delta^+(uud)$. While the lowest lying meson-baryon fluctuations for π^+ and π^0 contain spin-1/2 baryons, the lowest fluctuation for π^- contains the spin-3/2 baryon Δ^{++}. This will be crucial for understanding the left-right asymmetries. Therefore, let us examine the wave functions of the meson-baryon fluctuations containing spin-1/2 and spin-3/2 baryons, respectively. The form of the wave function follows from the requirement that the total quantum numbers of the proton must be conserved. Since pions and kaons are pseudoscalar particles with negative parity and the baryons involved have the same parity as the proton, the meson-baryon system must have odd angular momentum. Thus, the total angular momentum part of the wave functions, $\Psi^{MB(S)}_{J,J_z,L,S}$ in the center-of-mass reference frame of the pseudoscalar meson-baryon $(MB(S))$ fluctuation containing a spin 1/2-baryon $B(\frac{1}{2})$ is given by

$$\Psi^{MB(1/2)}_{1/2,1/2,1,1/2}=\sqrt{\frac{2}{3}}\,\psi_1^{+1}\chi_{1/2}^{-\,1/2}-\sqrt{\frac{1}{3}}\,\psi_1^{0}\chi_{1/2}^{+\,1/2}. \tag{3}$$

Here, J, L, S and J_z, L_z, S_z are the total angular momentum, total orbital angular momentum, and total spin of the meson-baryon fluctuation and their z components, respectively. $\psi_L^{L_z}$ and $\chi_S^{S_z}$ are the total orbital-angular momentum and total spin part of the wave function. It follows that the $MB(\frac{1}{2})$ fluctuation is predominantly in a state with positive orbital angular momentum $L_z=1$ in a transversely upwards polarized proton. Thus, the meson and the baryon perform orbital motion around their center of mass; since the baryons involved are much heavier than the mesons (pions and kaons), it is essentially the meson which ''orbits'' around the baryon. Hence, one can speak of effective ''pion currents'' in such Fock states. This current is anticlockwise with respect to the polarization axis (z axis) of the transversely polarized proton for pseudoscalar mesons (M) in a $MB(\frac{1}{2})$ state, since the $L_z=1$ component dominates.

On the other hand, the total angular momentum part of the wave function of the meson-baryon fluctuation of an upwards polarized proton containing a spin-3/2 baryon $B(\frac{3}{2})$ and a pseudoscalar mesons M is given by

$$\Psi^{MB(3/2)}_{1/2,1/2,1,3/2}=\sqrt{\frac{1}{2}}\,\psi_1^{-1}\chi_{3/2}^{+\,3/2}-\sqrt{\frac{1}{3}}\,\psi_1^{0}\chi_{3/2}^{+\,1/2}+\sqrt{\frac{1}{6}}\,\psi_1^{+1}\chi_{3/2}^{-\,1/2}. \tag{4}$$

We see that the $MB(\frac{3}{2})$ system is more likely to have negative than positive orbital angular momentum. Thus, pseudoscalar mesons in these Fock states perform orbital motion mainly clockwise with respect to the polarization axis of the transversely polarized proton.

In order to understand the significance of these observations, we discuss the formation of the leading mesons. It is convenient to work in the center of mass of two particle system. In this system, the projectile is an extended object and the target is Lorentz contracted. Soft interaction between the projectile and target become effective when the target and the projectile partially overlap. In leading meson production, the meson is expected to be brought on mass shell through soft interaction with the target. If this happens on the front surface of the extended baryon-meson state, i.e., when the target begins to overlap with the target, the freed meson will have a larger probability to ''go'' left or to ''go'' right if it belongs to a $MB(\frac{1}{2})$ or $MB(\frac{3}{2})$ fluctuation. This is because, on the front surface, $L_z=1$ $(L_z=-1)$ of the $MB(\frac{1}{2})$ $(MB(\frac{3}{2}))$ system means that the probability for the pion to have transverse momenta pointing to the left (to the right) is larger than to have one pointing to the right (to the left) [11,12] . However, when this happens on the back surface, i.e., after the target went through the projectile, the soft interactions of the spectator quarks with the target destroy the coherence of the Fock state and the produced mesons can not retain their preferred transverse direction. Our expectation that initial state interactions with spectator quarks in leading particle production plays an important role agrees with the observation that leading particle production occurs dominantly when the spectator quarks interact strongly in the target, leading to strong nuclear dependence [4]. Preliminary results from the E704 Collaboration showing a strong A dependence of A_N are also consistent with such an expectation [13].

Since the leading π^+ and π^0 are mainly produced by light-cone fluctuations containing spin-1/2 baryons, we expect positive left-right asymmetries for both π^+ and π^0. On the other hand, the asymmetry for π^- should be negative, since, here, the lowest lying Fock state contains a spin-3/2 baryon. Furthermore, the remarkable ''mirror'' symmetry of the left-right asymmetries between transversely polarized proton and antiproton projectiles follows immediately from the proposed picture. This is because the lowest lying Fock states of the antiproton containing π^+ and π^- are $\overline{p(\overline{uud})}=\pi^+(u\overline{d})\overline{\Delta}^{++}(\overline{uuu})$ and $\overline{p(\overline{uud})}=\pi^-(d\overline{u})\overline{n}(\overline{udd})$, respectively. Thus, contrary to the situation in pp collision, the partner of the π^+ is a spin-3/2 and that of the π^- is a spin-1/2 baryon. Therefore, we expect positive left-right asymmetry for π^- and negative asymmetry for π^+. Note that the asymmetry for π^0 remains unchanged. Furthermore, we also expect to see left-right asymmetries for η meson production. These asymmetries should be similar in magnitude to that in π^0 productions and positive for both proton and antiproton projectiles. All these features have been observed experimentally [1].

Encouraged by the good qualitative agreement with the experimental data, we want to describe the asymmetries quantitatively. While leading mesons are predominantly produced by meson-baryon fluctuations and populate the large x_F region, nonleading mesons are produced by other mechanisms such as string fragmentation, higher Fock states and populate the central rapidity region. For large enough transverse momenta, the production of mesons in the central region (and also in the fragmentation regions) can be described by leading twist perturbative QCD. However, since the typical transverse momenta involved in left-right asymmetry measurements are in the order of $p_\perp \sim 0.7\,\mathrm{GeV}/c$, we cannot expect perturbative QCD (PQCD) to be applicable and factorization to be valid. Therefore, in the following, we calculate the spectra in the projectile fragmentation region using the light-cone wave functions of the meson-baryon fluctuation and use a fit to the nonleading spectra of the produced mesons. In separating the leading from the nonleading spectrum, we can use kaon-production as guideline. This is because K^- has no common valence quarks with the projectile proton, i.e., there are no leading K^- in proton-proton collisions. Thus, the inclusive K^- spectrum is equivalent to the nonleading spectrum of K^+. Assuming that the *form* of the nonleading spectrum is independent of the produced mesons, we can use the exact same form as obtained by fitting the K^- spectrum for the nonleading parts of the pion production allowing for a normalization [14].

In the meson-baryon fluctuation model, the differential cross section for producing leading mesons is given by

$$\frac{d\sigma_{MB}}{dx_F d^2p_\perp} = \sigma_{pB}\frac{1}{2}\sum_{Ss}\frac{dP^{Ss}_{MB}}{dy\,d^2p_\perp}\,\delta(x_F - y). \tag{5}$$

Here, σ_{pB} is the total inclusive proton-baryon inelastic cross section at c.m. energy of $s(1-x_F)$. We use σ_{pp} and the numerical value 40 *mbarn* for σ_{pB}. $dP^{Ss}_{MB}/dy\,d^2p_\perp$ is the probability that the proton fluctuates in a meson and baryon with longitudinal momentum fractions y and $1-y$, transverse momentum $\mathbf{p}_\perp$ and $-\mathbf{p}_\perp$, respectively. S and s denote the spin projections of the proton and the baryon with respect to a conveniently chosen axis. In the following, we use both a nonrelativistic toy model and the meson-cloud model to calculate these probabilities.

In a nonrelativistic approximation, the probabilities for different angular momenta are simply related by Clebsch-Gordan coefficients as given by Eq. (3) and in Eq. (4). For the spin-independent momentum-space part, we use a simple phenomenological ansatz, used in Ref. [15]:

$$\frac{dP_{MB}}{dy\,d^2p_\perp}(\mathcal{M}) = A_{MB}(1+\mathcal{M}^2/\alpha^2)^{-p}. \tag{6}$$

Here, $\mathcal{M}$ is the invariant mass of the meson-baryon fluctuation $\mathcal{M}^2 = (p_\perp^2 + m_M^2)/y + (p_\perp^2 + m_B^2)/(1-y)$ and m_M and m_B are the meson and baryon masses. A_{MB} is a normalization constant, for the other parameters, we use the values, $\alpha = 330\,\mathrm{MeV}$ and $p = 3.5$ Ref. [15]. The relative weights of fluctuations containing proton, neutron, and Delta baryons are given by the isospin factors: $(\pi^+ n):(\pi^0 p):(\pi^+\Delta^0):(\pi^0\Delta^+):(\pi^-\Delta^{++}) = 2:1:\frac{1}{3}:\frac{2}{3}:1$ [18]. We fixed the normalization by fitting the π^- cross section. Then, the probabilities for the above fluctuations, are 16%, 8%, 0.8%, 1.6%, and 2.4%, respectively. The probability for the $K^+\Lambda$ fluctuation is 1.7%. These probabilities have approximately the right magnitude to account for the Gottfried sum rule violation [16–18] measured by the New Muon Collaboration (NMC) [19]. We calculated the invariant cross sections $E d\sigma/d^3p = (x_F/\pi)\,d\sigma/dx_F dp_\perp^2$ for pion and kaon production as a function of x_F at $p_\perp = 0.75\,\mathrm{GeV}/c$. The result is shown in Fig. 1(a)–1(c) together with the data [20].

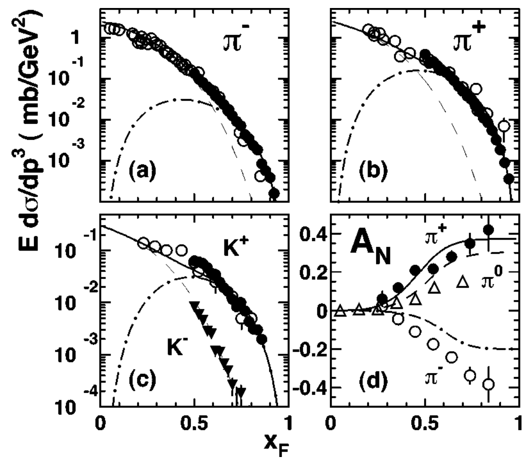

FIG. 1. The invariant cross section $Ed\sigma/d^3p$ for π^- (a), π^+ (b), and $K^\pm$ (c) production as a function of x_F. The dash-dotted curves represent the calculated contributions of leading particle production. The dashed curves stand for the spectra of the nonleading particles obtained by fitting the K^- distribution. The full curves are the sum of the leading and nonleading contributions. The solid and open circles are for the $p_\perp = 0.75\,\mathrm{GeV}/c$ and $p_\perp = 0.8\,\mathrm{GeV}/c$ data points, respectively. The $0.8\,\mathrm{GeV}/c$ data have been normalized to the $0.75\,\mathrm{GeV}/c$ data to account for the difference between the transverse momenta in the two experiments. The data are taken from Ref. [20]. (d) The calculated left-right asymmetries; the solid, dashed, and dash-dotted curves are for π^+, π^0, and π^-, respectively. The data are taken from Ref. [1].

In the meson-cloud model, the probabilities in Eq. (5) are given by

$$\frac{dP^{Ss}_{MB}}{dy\,d^2p_\perp} = \frac{g^2_{NBM}}{16\pi^3}\frac{|\mathcal{T}^{Ss}_{MB}|^2}{y(1-y)}\frac{|G_{NMB}(y,p_\perp^2)|^2}{(m_N - \mathcal{M}^2_{MB})^2}. \tag{7}$$

Here, $|\mathcal{T}^{Ss}_{MB}|^2$ contains the spin-dependence of the probabilities and can be obtained by calculating traces over nucleon and baryon spinors [6,7]. $G_{NMB}(y,p_\perp^2)$ are phenomelogical vertex functions. They are often parametrized in a power form

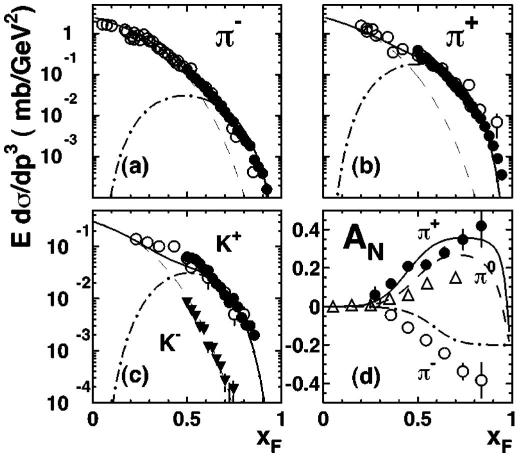

FIG. 2. The same as in Fig. 1 calculated in the meson-cloud model. The parameter C is set to 0.4.

$$G_{NMB}(y,p_\perp^2)=\left(\frac{\Lambda_{MB}^2+m_N^2}{\Lambda_{MB}^2+\mathcal{M}_{MB}^2}\right)^n. \tag{8}$$

We found a good fit to the data by choosing $n=3$ and $\Lambda_{\pi N},\Lambda_{\pi\Delta},\Lambda_{K\Lambda}=1.6,1.25,1.7\,\mathrm{GeV}$. The coupling constants are $g_{pp\pi^0}^2/4\pi=13.6$, $g_{p\Delta^{++}\pi^-}^2/4\pi=12.3\ \mathrm{GeV}^{-2}$, and $g_{p\Lambda K^+}^2/4\pi=14.7$. The results are shown in Fig. 2.

In order to calculate the left-right asymmetries, we note that only the leading particles will contribute to the asymmetry. In the nonrelativistic toy-model, the probability, $P_{MB}^{J_z,L_z}(x_F,\mathbf{p}_\perp)\equiv dP_{MB}^{J_z,L_z}/dx_F d^2p_\perp$, for a meson-baryon fluctuation containing a baryon with spin s to be in an orbital angular momentum state with L_z, when the projectile has total angular momentum projection, J_z, is equal to the unpolarized probabilities, $P_{MB}(x_F,p_\perp)$ multiplied by appropriate Clebsch-Gordan coefficients.

According to the proposed picture, only mesons produced by MB fluctuation contribute to the difference of the measured number densities, $\Delta N_L(x_F,\mathbf{p}_\perp|M)\equiv N_L(x_F,\mathbf{p}_\perp,\uparrow|M)-N_L(x_F,\mathbf{p}_\perp,\downarrow|M)$. Obviously, this quantity should be proportional to $\Delta P_{MB}(x_F,\mathbf{p}_\perp)\equiv P_{MB}^{1/2,1}(x_F,\mathbf{p}_\perp)-P_{MB}^{1/2,-1}(x_F,\mathbf{p}_\perp)$, the difference of the probabilities for the MB fluctuations to have $L_z=1$ and $L_z=-1$ in an upwards polarized proton. [Note that we have the relations $P_{MB}^{J_z,L_z}(x_F,\mathbf{p}_\perp)=P_{MB}^{-J_z,-L_z}(x_F,\mathbf{p}_\perp)$ and $P_{MB}^{J_z,-L_z}(x_F,\mathbf{p}_\perp)=P_{MB}^{-J_z,L_z}(x_F,\mathbf{p}_\perp)$.] The proportionality constant, C ($0\leq C\leq 1$), between $\Delta N_L(x_F,\mathbf{p}_\perp|M)$ and $\Delta P_{MB}(x_F,\mathbf{p}_\perp)$, effectively describes how strong spectator quarks interact in the target. The sum of the number densities $N_L(x_F,\mathbf{p}_\perp)=N_L(x_F,\mathbf{p}_\perp,\uparrow|M)+N_L(x_F,\mathbf{p}_\perp,\downarrow|M)$ is twice the corresponding unpolarized number density measured on the left-hand side and is given by $N^{nl}(x_F,p_\perp)+P_{MB}(x_F,p_\perp)$. (There is no factor 2 in front of N^{nl} and P_{MB}, since both of them refer to quantities summed over "left" and "right," thus, they are already twice the unpolarized number densities measured on one side exclusively.) $N^{nl}(x_F,p_\perp)$ is the number density due to nonleading particle production and is obtained by fitting the K^- cross section as discussed above.

The asymmetries for π^+, π^-, and π^0 production are then given by

$$A_N^{\pi^+}(x_F)=\frac{C[\frac{2}{3}P_{\pi^+n}(x_F)-\frac{1}{3}P_{\pi^+\Delta^0}(x_F)]}{N^{nl}(x_F)+P_{\pi^+n}(x_F)+P_{\pi^+\Delta^0}(x_F)}, \tag{9}$$

$$A_N^{\pi^-}(x_F)=\frac{-\frac{1}{3}CP_{\pi^-\Delta^{++}}(x_F)}{N^{nl}(x_F)+P_{\pi^-\Delta^{++}}(x_F)}, \tag{10}$$

$$A_N^{\pi^0}(x_F)=\frac{C[\frac{2}{3}P_{\pi^0p}(x_F)-\frac{1}{3}P_{\pi^0\Delta^+}(x_F)]}{N^{nl}(x_F)+P_{\pi^0p}(x_F)+P_{\pi^0\Delta^+}(x_F)}. \tag{11}$$

Here, we dropped the $p_\perp$ dependence of $P_{MB}(x_F)$ for simplicity. For the parameter C, we use the value 0.6. The results, calculated for $p_\perp=0.75\,\mathrm{GeV}/c$, are shown in Fig. 1(d) and are compared to the data of the E704 Collaboration [1].

In the (relativistic) meson-cloud model, the probabilities for different angular momenta are not connected by Clebsch-Gordan coefficients. They have to be calculated explicitly. For a $MB(\frac{1}{2})$ fluctuation, we obtain

$$|\mathcal{T}_{BM}^{Ss}|^2=[(p\cdot P)-m_Nm_B][1+s\cdot S]-(p\cdot S)(P\cdot s). \tag{12}$$

[Note, that $|\mathcal{T}_{BM}^{Ss}(y)|^2=|\mathcal{T}_{MB}^{Ss}(1-y)|^2$.] Here, P, S and p, s are the four-momenta and spin of the nucleon and the baryon, respectively. We choose the z axis as polarization axis and x as "longitudinal direction" and consider the case $p_z=0$ which is relevant for the left-right asymmetry. Then, in the infinite momentum frame (IMF) the four-momenta and transverse spins vectors can be parametrized as $P=(P_L+m_N^2/2P_L,P_L,0,0)$, $p=[yP_L+(m_B^2+p_\perp^2)/2yP_L,yP_L,p_\perp,0]$, $S=(0,0,0,1)$, and $s=(0,0,0,1)$. We immediately see that $\mathcal{T}_{BM}^{(1/2)(1/2)}=0$ and $\mathcal{T}_{BM}^{1/2-1/2}$ is given by

$$|\mathcal{T}_{BM}^{1/2\,-\,1/2}|^2=\frac{1}{y}[(m_Ny-m_B)^2+p_\perp^2]. \tag{13}$$

The orbital angular momentum component L_z must be positive $(+1)$ in order to compensate the spin of the baryon. Thus, the left-right asymmetry is positive for π^+ and also for π^0.

For spin-$\frac{3}{2}$ baryons the amplitudes can be obtained by calculating the trace over the nucleon and the Rarita-Schwinger spin-vectors, u_α, for the baryon

$$|\mathcal{T}_{BM}^{Ss}|^2=\mathrm{Tr}[u(P,S)\overline{u}(P,S)u_\alpha(p,s)\overline{u}_\beta(p,s)]\times(P-p)^\alpha(P-p)^\beta, \tag{14}$$

$u_\alpha(p,s)=\Sigma_mC(\frac{3}{2}s|1m;\frac{1}{2}s-m)\boldsymbol{\epsilon}_\alpha(m)u(p,s-m)$ are the Rarita-Schwinger spin-vector u_α for the baryon. The polarization vectors are $\boldsymbol{\epsilon}(m)=[\boldsymbol{\varepsilon}_m\cdot\mathbf{p}/m_B,\boldsymbol{\varepsilon}_m+\mathbf{p}(\boldsymbol{\varepsilon}_m\cdot\mathbf{p})/m_B(p_0+m_B)]$ and we use the representations $\boldsymbol{\varepsilon}_{\pm1}=\mp(1,\pm i,0)/\sqrt{2}$ and $\boldsymbol{\varepsilon}_0=(0;0,0,1)$ in the rest frame of the Δ. Wehave $P.\boldsymbol{\epsilon}(0)=0$ and only two amplitudes are nonzero. We obtain $|\mathcal{T}_{BM}^{1/2-1/2}|^2=\frac{1}{3}|\mathcal{T}_{BM}^{(1/2)(3/2)}|^2$ and

$$|\mathcal{T}_{BM}^{(1/2)(3/2)}|^2 = \frac{1}{8y^3 m_B^2}[(m_N y + m_B)^2 + p_\perp^2]^2 \times [(m_N y - m_B)^2 + p_\perp^2]. \qquad (15)$$

Since the total orbital angular momentum of the meson-baryon system is ∓ 1 for the transitions $|\mathcal{T}_{BM}^{(1/2)(3/2)}|^2$ and $|\mathcal{T}_{BM}^{1/2-1/2}|^2$, respectively, and $|\mathcal{T}_{BM}^{(1/2)(3/2)}|^2 > |\mathcal{T}_{BM}^{1/2-1/2}|^2$, the left-right asymmetry is negative for π^- production.

Collecting all factors and defining the unpolarized probabilities as $P_{MB}(y)$, the left-right asymmetries A_N in the meson-cloud model can be expressed as

$$A_N^{\pi^+}(x_F) = \frac{C[P_{\pi^+ n}(x_F) - \frac{1}{2} P_{\pi^+ \Delta^0}(x_F)]}{N^{nl}(x_F) + P_{\pi^+ n}(x_F) + P_{\pi^+ \Delta^0}(x_F)},$$

$$A_N^{\pi^-}(x_F) = \frac{-\frac{1}{2} C P_{\pi^- \Delta^{++}}(x_F)}{N^{nl}(x_F) + P_{\pi^- \Delta^{++}}(x_F)},$$

$$A_N^{\pi^0}(x_F) = \frac{C[P_{\pi^0 p}(x_F) - \frac{1}{2} P_{\pi^0 \Delta^+}(x_F)]}{N^{nl}(x_F) + P_{\pi^0 p}(x_F) + P_{\pi^0 \Delta^+}(x_F)}. \qquad (16)$$

Note, that the probabilities for the special case, $p_z = 0$, are related to each other by ''Clebsch-Gordan-like'' expressions. The result we obtain for the asymmetries is shown in Fig. 2(d). Since $P_{\pi\Delta}$ peak at larger y values than $P_{\pi N}$, the asymmetries for π^+ and π^0 turn down at high x_F. To confirm this, relativistic effect data at higher x_F is needed.

In conclusion, we have shown that energetically favored light-cone meson-baryon fluctuations cannot only account for the leading meson spectrum in inclusive meson production at moderate transverse momenta, but also explain the substantial left-right asymmetries measured in such processes using transversely polarized proton projectiles and unpolarized proton targets. Left-right asymmetries, thus, reflect the correlation between total and orbital angular momenta of energetically favored light-cone meson-baryon fluctuations.

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