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Strange-baryon production asymmetry in K$^{\pm}$N interactions

G.H. Arakelyan[1], C. Merino[2,a], and Yu.M. Shabelski[3]

[1] YerPhI, Armenia
[2] Departamento de Física de Partículas, Facultade de Física, and IGAE, Universidade de Santiago de Compostela, Galicia, Spain
[3] SPNPI, Gatchina, St. Petersburg, Russia

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Abstract. The asymmetry of strange-baryon production in Kp interactions at high energies is considered in the framework of the Quark-Gluon String Model. The contribution of the string-junction mechanism to the strange baryon production is analysed.

PACS. 12.40.-y Other models for strong interactions – 13.60.Rj Baryon production – 13.75.Jz Kaon-baryon interactions

The Quark-Gluon String Model (QGSM) is based on the Dual Topological Unitarization (DTU) and it describes quite reasonably and in a theoretically consistent way many features of high-energy production processes, including the inclusive spectra of different secondary hadrons, their multiplicities, etc., both in hadron-nucleon and hadron-nucleus collisions [1–3]. High-energy interactions are considered as taking place via the exchange of one or several Pomerons, and all elastic and inelastic processes result from cutting through or between those exchanged Pomerons [4,5]. The possibility of different numbers of Pomerons to be exchanged introduces absorptive corrections to the cross-sections which are in agreement with the experimental data on production of hadrons consisting of light quarks. Inclusive spectra of hadrons are related to the corresponding fragmentation functions of quarks and diquarks, which are constructed in terms of the intercepts of well-known Regge trajectories [6].

In the string models baryons are considered as configurations consisting of three strings attached to three valence quarks and connected in one point, which is called string junction (SJ) [7]. Thus the SJ mechanism has a nonperturbative origin in QCD.

It is very important to understand the role of the SJ mechanism in the dynamics of high-energy hadronic interactions, in particular in processes implying baryon number transfer. Significant results on this question were obtained in [8–11], where the SJ mechanism was used to analyse the strange-baryon production in πp and pp interactions. The detailed analysis of SJ contribution into strange-baryon production in KN interaction was presented in [12].

The present report is devoted to the calculation of asymmetry of strange-baryon production in the case of kaon beams. We analyse the existing data on asymmetry of Λ and $\bar{\Lambda}$ production on K-beams [13], and we compare the experimental data with the result of our calculations for a value of the SJ intercept $\alpha_{SJ} = 0.9$.

The $\bar{\Lambda}/\Lambda$ asymmetry is defined as

$$A(\bar{\Lambda}/\Lambda) = \frac{N_{\Lambda} - N_{\bar{\Lambda}}}{N_{\Lambda} + N_{\bar{\Lambda}}} \tag{1}$$

for each x_F bin.

The formula describing the inclusive spectrum (*i.e.*, Feynman-x, x_F, distribution) of a secondary hadron h in KN scattering in QGSM is given by the following expression [1]:

$$\frac{x_E}{\sigma_{inel}} \cdot \frac{d\sigma}{dx_F} = \sum_{n=1}^{\infty} w_n \cdot \varphi_n^h(x_F), \tag{2}$$

where $x_E = E/E_{max}$, and

$$w_n = \sigma_n \bigg/ \sum_{n=1}^{\infty} \sigma_n \tag{3}$$

is the weight of the diagram with n cut Pomerons. The n cut Pomeron cross-sections σ_n are calculated using the quasi-eikonal approximation with a supercritical Pomeron [5]:

$$\sigma_n = \frac{\sigma_P}{n \cdot z}\left(1 - e^{-z}\sum_{k=0}^{\infty}\frac{z^k}{k!}\right), \; n \geq 1, \tag{4}$$

[a] e-mail: Merino@fpaxp1.usc.es

$$z = \frac{2C_P \gamma_P}{R_P^2 + \alpha'_P \ln(s/s_0)} \cdot \left(\frac{s}{s_0}\right)^{\Delta} , \quad (5)$$

$$\sigma_P = 8\pi\gamma_P \cdot \left(\frac{s}{s_0}\right)^{\Delta} , \quad (6)$$

where s is the cms energy, σ_P is the Pomeron contribution to the total cross-section, $\Delta = \alpha_P(0) - 1$ is the excess of the Pomeron intercept over 1 (supercritical Pomeron), and parameters γ_P, R_P^2, and C_P take the values for the case of Kp interactions presented in [14]. The normalization parameter $s_0 = 1.$ and Pomeron slope $\alpha'_P = 0.21$ are well-known parameters (see, for instance [1]).

The function $\varphi_n^h(x_F)$ in eq. (2) determines the contribution of the diagram, in which n Pomerons are cut. In the case of Kp collisions this function has the form [3]:

$$\begin{aligned}\varphi_n^{Kp\to h}(x_F) = {} & f_{\overline{q}}^h(x_+,n) \cdot f_q^h(x_-,n) \\ & + f_q^h(x_+,n) \cdot f_{qq}^h(x_-,n) \\ & + 2(n-1) f_s^h(x_+,n) \cdot f_s^h(x_-,n) , \end{aligned} \quad (7)$$

with

$$x_\pm = \frac{1}{2}\left[\left(\frac{4m_\perp^2}{s} + x_F^2\right)^{\frac{1}{2}} \pm x_F\right] . \quad (8)$$

The quantities f_{qq}, f_q, $f_{\overline{q}}$, and f_s in eq. (7) correspond to the contributions of the diquark, the valence quark and antiquark, and the sea quarks, while the contributions of the incident particle and the target proton depend on the variables x_+ and x_-, respectively.

The values of $f_{qq}^h(x_\pm,n)$, $f_q^h(x_\pm,n)$, $f_{\overline{q}}^h(x_\pm,n)$, and $f_s^h(x_\pm,n)$ can be obtained through the convolution of the corresponding momentum distribution of the diquarks, valence quarks, and sea quarks in the colliding hadrons, $u(x)$, and the fragmentation function $G^h(z)$ of either diquarks or quarks into secondary hadrons:

$$f_i^h(x_\pm,n) = \int_{x_\pm}^1 u_i(x_1,n) \cdot G_i^h(x_\pm/x_1)\mathrm{d}x_1, \quad i = q,\overline{q}, \quad (9)$$

$$\begin{aligned} f_{qq}^h(x_-,n) = {} & \frac{2}{3}\int_{x_-}^1 u_{ud}(x_1,n) \cdot G_{ud}^h(x_-/x_1)\mathrm{d}x_1 \\ & + \frac{1}{3}\int_{x_-}^1 u_{uu}(x_1,n) \cdot G_{uu}^h(x_-/x_1)\mathrm{d}x_1, \end{aligned} \quad (10)$$

$$\begin{aligned} f_s^h(x_\pm,n) = {} & \frac{1}{2+\delta} \\ & \cdot \left[\int_{x_\pm}^1 u_{\overline{u}}(x_1,n)\frac{G_{\overline{u}}^h(x_\pm/x_1) + G_u^h(x_\pm/x_1)}{2}\mathrm{d}x_1 \right. \\ & + \int_{x_\pm}^1 u_{\overline{d}}(x_1,n)\frac{G_{\overline{d}}^h(x_\pm/x_1) + G_d^h(x_\pm/x_1)}{2}\mathrm{d}x_1 \\ & \left. + \delta \cdot \int_{x_\pm}^1 u_{\overline{s}}(x_1,n)\frac{G_{\overline{s}}^h(x_\pm/x_1) + G_s^h(x_\pm/x_1)}{2}\mathrm{d}x_1\right] . \end{aligned} \quad (11)$$

The parameter $\delta \sim 0.2$–0.32 determines here the relative suppression of strange quarks in the sea. As shown in [15] (see also discussion in [12]), the better agreement of QGSM with data on strange-baryon production on nucleus was obtained with $\delta = 0.32$, instead of the previous value $\delta = 0.2$. In principle one cannot exclude the possibility that the value of δ would be different for secondary baryons and for mesons (*i.e.*, for Λ-baryon and for kaon).

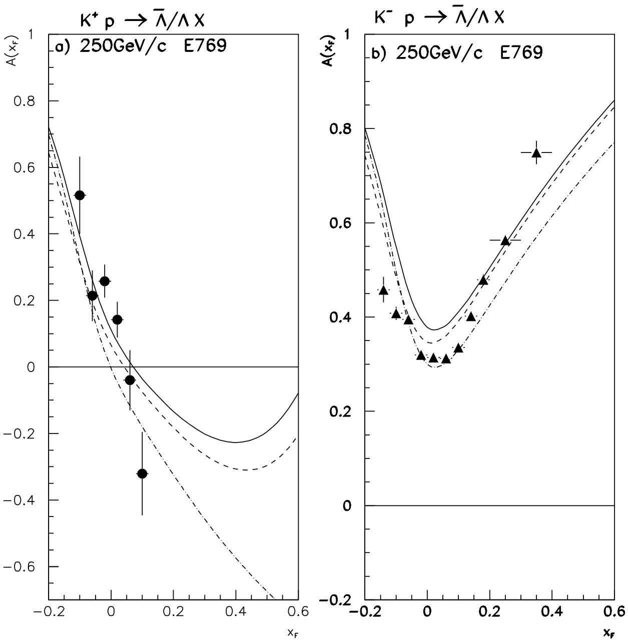

Fig. 1. The $\bar{\Lambda}/\Lambda$ asymmetry in (a) K^+p and (b) K^-p collisions. Experimental data at 250 GeV/c [13] and the corresponding QGSM description. The solid curve corresponds to $\alpha_{SJ} = 0.9$, $\varepsilon = 0.024$, and $\delta = 0.32$, the dashed curve to $\delta = 0.2$, and the dashed-dotted curve to $\varepsilon = 0$.

The detailed description of high-energy hadron-nucleon cross-sections on the base of the Reggeon calculus has been presented in many papers (see, for instance [1,3]).

The diquark and quark distribution functions and the fragmentation functions are determined by the Regge intercepts [6].

The complete set of distribution and fragmentation functions used in this paper is presented in the appendix of ref. [12].

The SJ mechanism has a nonperturbative origin and since it is at present not possible to determine the value of α_{SJ} in QCD from first principles. Thus we treat α_{SJ} and ε (the weight of the diagramm describing the SJ contribution, see [12]) as phenomenological parameters which should be determined from experimental data. In the present calculation, we use the values $\alpha_{SJ} = 0.9$ and $\varepsilon = 0.024$, as done in [9,12,15].

The fragmentation functions into $\bar{\Lambda}$ do not depend on the SJ mechanism, so the $\bar{\Lambda}$ spectra obtained for different values of α_{SJ} are the same, and they have a very small dependence on the strange quark suppression factor δ (see [12]).

In fig. 1 we show the comparison of the QGSM calculations with the data on the $\bar{\Lambda}/\Lambda$ asymmetry $A(\bar{\Lambda}/\Lambda)$,

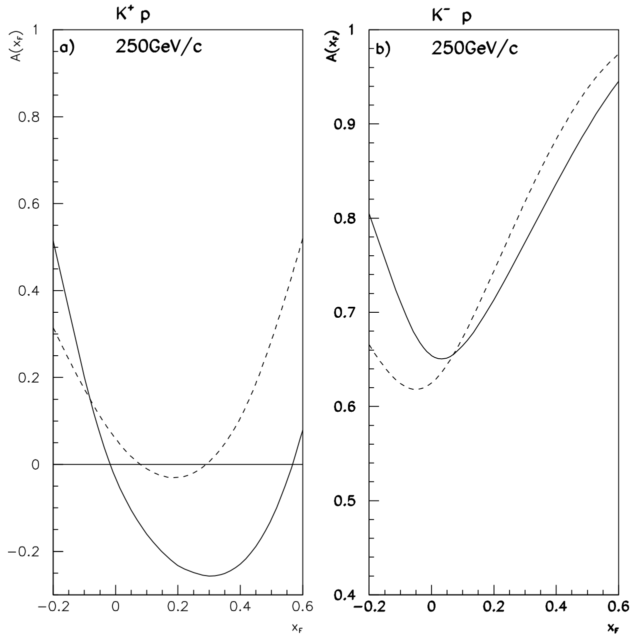

Fig. 2. QGSM prediction for the x_F-dependence of the asymmetry of heavy strange baryons in (a) K^+p and (b) K^-p collisions at 250 GeV/c. Solid curves are for Ξ^-, dashed curves for Ω^-.

produced in K^+p (fig. 1a) and K^-p (fig. 1b) interactions at 250 GeV/c [13].

The asymmetry data are rather interesting. In the proton fragmentation region the values of $A(\bar{\Lambda}/\Lambda)$ are close to unity, and that is natural since a proton fragments into Λ with significantly larger probability than into $\bar{\Lambda}$. In the kaon fragmentation region $A(\bar{\Lambda}/\Lambda)$ becomes negative and decreases very fast in the case of K^+ beam at the x_F values where experimental data exist. In the case of K^- beam $A(\bar{\Lambda}/\Lambda)$ increases very fast with x_F and the variation among calculations with different values of the parameters is rather small. Both these behaviors are also natural since the K^+ contains a $\bar{s}$ valence quark which preferably fragments into $\bar{\Lambda}$, while the valence s quark in the K^- fragments rather often into Λ. However, in both cases the $A(\bar{\Lambda}/\Lambda)$ experimental x_F-dependences are much steeper than the theoretical predictions. This is a probable indication that the fragmentation functions $s \to \Lambda$ and $\bar{s} \to \bar{\Lambda}$ should be further enhanced.

In the K^+ fragmentation region (fig. 1a) the predicted values of $A(\bar{\Lambda}/\Lambda)$ at $x_F > 0.4$ show a change of behavior since they start increasing. In this region the contribution of the direct fragmentation of $\bar{s} \to \bar{\Lambda}$ which makes $A(\bar{\Lambda}/\Lambda)$ to decrease becomes smaller than the effect of SJ diffusion which increases the multiplicity of Λ. The measurement of the asymmetry $A(\bar{\Lambda}/\Lambda)$ in the region $x_F \geq 0.4$ in K^+p collisions could make the situation clearer.

The predictions for the asymmetry in Ξ and Ω baryon production in K^+p and K^-p interactions are presented in fig. 2. Here the general situation is similar to that of the case of asymmetry in Λ production shown in fig. 1. In fig. 2 we present the predictions for asymmetries in Ξ^- and Ω production in K^+p and K^-p collisions at 250 GeV/c. In the central region of K^+p collisions the yields of Ξ^- and $\bar{\Xi}^+$, as well as those of Ω^- and $\bar{\Omega}^+$ are predicted to be practically the same. The smaller fragmentation function of valence $\bar{s}$-quark into strange baryon is compensated by the larger fragmentation function of the target diquark. In the case of K^- beam (fig. 2b) the asymmetry for both Ξ and Ω productions increases in the whole region of positive x_F.

The situation for K^- beam seems worse than in the K^+ case since all curves are, as a rule, below the experimental data, but both the number and the quality of experimental data on K^- beam are not not very high.

The QGSM predicts a weak energy dependence of the Λ and $\bar{\Lambda}$ production cross-section in Kp collisions at the considered energies.

The experimental data on high-energy Λ production are not in contradiction with the possibility of baryon charge transfer over large rapidity distances, and the $\bar{\Lambda}/\Lambda$ asymmetry is provided by SJ diffusion through baryon charge transfer.

The presence of baryon asymmetry in the projectile hemisphere for Kp collisions provides good evidence for such a mechanism.

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