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Rapidity correlations of $K_S^0K_S^0$ pairs and the compensation of strangeness on the quark level in multiparticle production

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It is pointed out that $K_S^0K_S^0$ correlations can bring important information about the compensation of strangeness of quarks and antiquarks present in the intermediate stages of the process of multiparticle production in hadronic collisions. Due to the short-range character of parton recombinations and resonance decays $K_S^0K_S^0$ rapidity differences should reflect separations between strange quarks and antiquarks in rapidity. Thus the $K_S^0K_S^0$-correlation data can discriminate between the two extreme cases of strongly correlated and uncorrelated $s\bar{s}$ pairs in the intermediate state of the collision. These correlations are relatively easy to study from the experimental point of view.

In the past few years much attention was paid to the study of quantum-number compensation in multiparticle final states in hadronic collisions. The interest was originally stimulated by the neutral-cluster model, in which the local compensation of quantum numbers followed from basic assumptions. However, the data on quantum-number compensation are equally important also from the point of view of other models, e.g. in terms of quark-parton models they may bring valuable information about the space-time evolution of the collision and about the mechanism by which gluons are transformed to final-state hadrons. So far, only the charge (and partly transverse-momentum) compensation was thoroughly studied both experimentally and theoretically (see e.g. Refs. 1–4 and the literature cited therein); in the case of other quantum numbers one is faced with experimental difficulties. For instance, the simplest way for investigating the mechanism of strangeness compensation is to measure K^+K^- rapidity correlations. This, however, requires particle identification, which is impossible in bubble chambers at high energies.

On the other hand, there has quite recently appeared an experiment[5] measuring the neutral-particle production in $p\bar{p}$ interactions at 100 GeV/c in the Fermilab bubble chamber. The data contain also the cross section for $K_S^0K_S^0$ production.[5]

The purpose of this note is to point out that the data on $K_S^0K_S^0$ production and particularly on $K_S^0K_S^0$ rapidity correlations do contain information about the mechanism of strangeness compensation in hadronic collisions. As discussed in some detail below, the $K_S^0K_S^0$ pair in the final state implies the presence of an $s\bar{s}$ quark-antiquark pair in the intermediate stage of the collision, and thus the data on $K_S^0K_S^0$ correlations provide information about $s\bar{s}$ correlations in this stage. We therefore propose to study the $K_S^0K_S^0$ correlations in the final state, in the simplest case to extract from the data the probability distribution of rapidity differences between the K_S^0 mesons present in the events in which just two K_S^0's are produced. Such data can be obtained without particular difficulties at different energies (using the bubble chamber at Fermilab,[5] the streamer chamber RISK[6] at Serpukhov, or streamer and bubble chambers at CERN PS and SPS energies).

The relationship between $K_S^0K_S^0$ and $s\bar{s}$ correlations naturally follows from the contemporary quark-parton models of multiparticle production[7-11] where final-state hadrons are assumed to originate from the recombination of quarks and antiquarks present in the intermediate stages of the hadronic collision. The presence of two K_S^0 mesons in the final state indicates that there must have been in the intermediate state either

(i) a single $s\bar{s}$ pair (s recombined with a $\bar{d}$ quark to $\bar{K}^0$ and $\bar{s}$ with a d quark to K^0; both K^0 and $\bar{K}^0$ decayed via K_S^0), or

(ii) more $s\bar{s}$ pairs, from which two quarks materialized to K_S^0's (as above) and the rest led to other strange hadrons (not identified in most experiments).

As strange-particle production is suppressed relative to nonstrange-particle production, one can suppose that the latter case will not dominate and obscure the rather simple case (i).

Since the parton recombination is supposed to be of a short range in rapidity, the rapidity correlations of $K_S^0K_S^0$ (in the final state) and of the $s\bar{s}$ pair (in the intermediate stage) have to be closely related.

We shall now discuss this relationship in more detail and we shall show that the data can (at least) make a distinction between the two situations when

(i) s and $\bar{s}$ quarks in the intermediate stage are near to each other in rapidity,

(ii) s and $\bar{s}$ quarks are not correlated in the intermediate stage at all (except for correlations resulting from conservation laws).

Let us suppose that there is just one $s\bar{s}$ in the sea of quark-antiquark pairs and that it materializes into two K_S^0 mesons. These are separated by the rapidity gap G with the probability density dN_1/dG (Ref. 12),

$$\frac{dN_1}{dG} = \int \rho_{s,\bar{s}}(y_1, y_2) K(y - y_1) K(y + G - y_2) \times dy_1 dy_2 dy\,, \qquad (1)$$

where $\rho_{s,\bar{s}}(y_1, y_2)$ is the joint probability distribution function which gives the probability of having the strange quark-antiquark pair with rapidities y_1, y_2; $K(y - y')$ gives the probability density that a K_S^0 meson with rapidity y results from a strange quark (antiquark) with rapidity y'.[13]

We shall use here two particular forms of the joint distribution function $\rho_{s,\bar{s}}(y_1, y_2)$:

$$\text{(a)}\quad \rho_{s,\bar{s}}(y_1, y_2) = \rho_s(y_1)\rho_s(y_2)\,, \qquad (2a)$$

where $\rho_s(y)$ is the rapidity distribution function of the strange quark (the same for the antiquark).[13] This case corresponds to quarks and antiquarks moving in an uncorrelated way in the "sea" of $Q\bar{Q}$ pairs. It will be referred to as IQC (independent-quark case).

In the IQC Eq. (1) can be written in the form

$$\frac{dN_1}{dG} = \int f_I(y) f_I(y + G) dy \qquad (3)$$

with

$$f_I(y) \equiv \int \rho_s(y_1) K(y - y_1) dy_1\,.$$

The second form is

$$\text{(b)}\quad \rho_{s,\bar{s}}(y_1, y_2) = N \rho_s(y_1)\rho_s(y_2) \times \exp\left[-\frac{(y_1 - y_2)^2}{2\sigma^2}\right], \qquad (2b)$$

where N is the normalization constant. The exponential factor is to reflect the quark-antiquark correlation[14] and is characterized by the rapidity correlation length σ. We shall refer to this case as CQC (correlated-quark case).

To make our discussion more realistic we have to take into account contributions of events with two and more $s\bar{s}$ pairs in the intermediate stage of the collision. In the IQC more-pair contributions do not change anything; in fact, the distribution function dN/dG of rapidity gaps G between K_S^0's is

$$\frac{dN}{dG} = \frac{dN_1}{dG}\,. \qquad (4)$$

The CQC is more complicated. If both K_S^0 mesons come from s and $\bar{s}$ quarks from the same pair, the more-pair contribution is identical with the one-pair one; however, if they result from different pairs, the more-pair contribution should be similar to that expected in the IQC. A more detailed calculation yields[15]

$$\frac{dN}{dG} = \frac{8}{8 + 9n}\frac{dN_1}{dG} + \frac{9n}{8 + 9n}\frac{dN_2}{dG} \qquad (5)$$

where n is the mean number of $s\bar{s}$ pairs in the intermediate stage of the collision, dN_1/dG is given by Eq. (1), and

$$\frac{dN_2}{dG} \equiv \int f_C(y) f_C(y + G) dy \qquad (6)$$

with

$$f_C(y) \equiv \rho_{s,\bar{s}}(y_1, y_2) K(y - y_1) dy_1 dy_2\,.$$

To qualitatively estimate what Eqs. (4) and (5) lead to we have to choose a particular (plausible) form of $\rho_s(y)$ and $K(\Delta)$ and to estimate the value of n at different energies. We shall assume ρ_s to be

$$\rho_s(y) = \frac{m_s}{P_0} s\left(\frac{m_s}{P_0}\sinh y\right)\cosh y\,, \qquad (7)$$

where $s(x)$ is the distribution function of strange quarks in Feynman's variable x, P_0 is the mo-

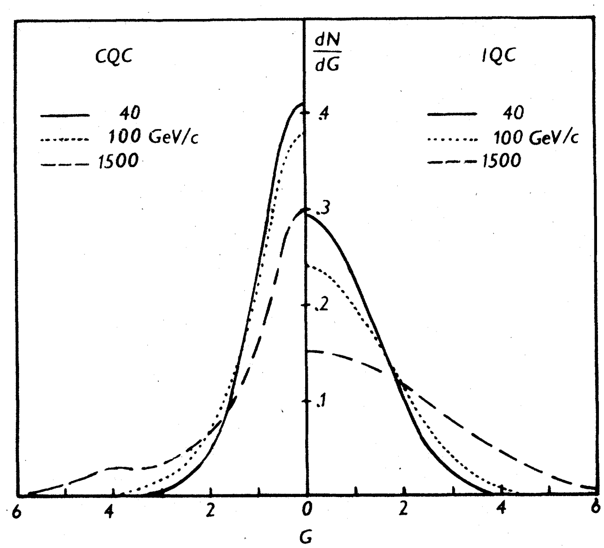

FIG. 1. The probability density dN/dG of rapidity gaps G between K_S^0 mesons in events with two K_S^0's in the final state (right-hand side: independent-quark case; left-hand side: correlated-quark case with $\sigma = 0.8$).

mentum of the incident hadron in the center-of-mass frame of the collision, and m_s is the mean transverse mass of the strange quark. In particular, $s(x)$ will be taken from the recent analysis of Duke and Taylor[16] and m_s will be fixed on the value of 0.45 GeV/c^2 (this was shown to be plausible in Ref. 9).

The precise form of the function $K(\Delta)$ depends on the mechanism of the recombination of quarks to hadrons and resonance decays. For lack of any direct information we assume it to have the Gaussian form with the variance $\sigma_K \sim 0.4$.[17]

The number n can be estimated:

$$n \approx \langle n_{K^+} \rangle + \langle n_{K^-} \rangle .$$

From the data[18] we see that while at lower (say, Serpukhov) energies the more-pair contribution in dN/dG is negligible ($n \sim 0.2$), in the CERN ISR energy range it becomes comparable with the one-pair contribution ($n \sim 0.85$).

The functions dN/dG were calculated at three different energies (corresponding to Serpukhov, Fermilab, and ISR energy range) for the value of $\sigma = 0.8$. The result is shown in Fig. 1. Two facts are clearly visible[19]:

(1) dN/dG is in the correlated case higher and narrower than in the independent-quark case; the difference is extremely clear at ISR energies;

(2) the width and height of the distribution function dN/dG in the IQC strongly depend on the energy, while in the CQC the energy dependence is much weaker.

In conclusion, we have shown that the measurement of $K_S^0 K_S^0$ correlations is a simple tool of studying the strangeness compensation on the quark level in multiparticle production. In particular, the data (which are relatively easy to obtain) can discriminate between the two extreme cases of strongly correlated and uncorrelated $s\bar{s}$ pairs in the intermediate stages of the hadronic collision. If the space-time evolution of the collision proceeds according to the Bjorken-Gribov picture,[20] then $K_S^0 K_S^0$ correlations can give an estimate of the rapidity length of the simultaneously excited region in the collision. The advantage of our suggestion is the possibility of avoiding difficulties with charged-strange-particle identification.

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[12]In fact, we do not take into account conservation laws, and the influence of other quarks present in the intermediate stages of the collision is supposed to be reflected in functions $\rho_{s,\bar{s}}(y_1, y_2)$ and $K(\Delta)$.

[13]All functions $\rho_{s,\bar{s}}$, ρ_s, and K are normalized to 1.

[14]One could imagine different mechanisms as to how such a correlation might arise; e.g., it can appear if s and $\bar{s}$ predominantly come from the conversion of gluons.

[15]In deriving Eq. (5) we assume that the number of strange $Q\bar{Q}$ pairs has the Poisson distribution with the mean n and that there is no correlation between quarks and antiquarks from different pairs.

[16]D. W. Duke and F. E. Taylor, Phys. Rev. D 17, 1788 (1978). However, we replaced the factor $1/x$ in $s(x)$ by a more realistic $[x^2 + (m_s/P_0)^2]^{-1/2}$ and the normalization constant was chosen so that

$$\int_{-1}^{1} s(x)dx = 1.$$

[17]The following argument makes this choice of σ_K more plausible: The s quark can turn into K_S^0 by the recombination with a $\bar{d}$ quark. In a fourth of such cases K_S^0 is produced directly; otherwise it comes from the decay of $\bar{K}^*$. Roughly we can take

$$\sigma_K^2 \approx \tfrac{1}{4}\sigma_Q^2 + \tfrac{3}{4}(\sigma_Q^2 + \sigma_*^2) = \sigma_Q^2 + \tfrac{3}{4}\sigma_*^2,$$

where σ_* characterizes the mean rapidity separation of $\bar{K}^*$ and $\bar{K}^0$ in the decay $\bar{K}^* \to \bar{K}^0 \pi^0$ (and can simply be found ~ 0.3), σ_Q is half of the mean distance between two quarks in rapidity (from multiparticle data it can again be estimated ~ 0.3). Then indeed $\sigma_K \sim 0.4$.

[18]A. M. Rossi *et al.*, Nucl. Phys. B 84, 269 (1975).

[19]The result, of course, depends on the particular choice of ρ_s, K, σ, and σ_K. However, by changing them within physically acceptable limits one does not change qualitative features of the result.

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