CHARGE TRANSFER IN MULTIPARTICLE PRODUCTION AND THE BEHAVIOUR OF PARTONS DURING THE HADRONIC COLLISION

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Presently available data on fluctuations of charge transfer across $y = 0$ and in particular on their energy dependence have serious implications for quark-parton models of multiparticle production. The data indicate that quarks and antiquarks are to a large extent uncorrelated and move rather freely and independently along the rapidity axis before recombining into final state hadrons.

In most of quark-parton models of multiparticle production [1, 2, 3] hadrons in the final state are formed by the recombination of $Q\bar{Q}$ to mesons and QQQ and $\bar{Q}\bar{Q}\bar{Q}$ to baryons and antibaryons[1]. Thus a typical hadronic collision is supposed to proceed in two steps:

— the rapidity space is populated by quarks and antiquarks;

— the recombination takes place.

The first step is probably a rather complicated process in which the two colliding hadrons form a compound state consisting of two sets of valence quarks plus something which might be denoted "a sea of the compound system" (referred to simply as "the sea" in what follows).

Within the parton model approach [5] one also assumes that

— partons recombining into a particular hadron are near to each other in rapidity.

Both the recombination and decays of resonances are short range processes in rapidity $\Delta y \sim 1$ and none of them is capable of transferring more than one unit of charge, strangeness or isospin. Consequently

— the rapidity distribution of quantum numbers of hadrons in the final state is similar to the quark quantum number distribution just before the recombination.

In average the sea is locally neutral. The shape of the rapidity distribution of various

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[1] Other quark models [4] assume that gluons form clusters which subsequently decay in to hadrons.

quantum numbers in the final state is then essentially given by the distribution of the valence quarks [6].

In order to learn more about the behaviour of Q's and $\bar{Q}$'s in the sea one has to study fluctuations of quantum numbers in the central region.

Since both recombination and resonance decays are of a short range in rapidity we can assume that

— fluctuations of quantum numbers in the central region are essentially given by fluctuations of quantum numbers of Q's and $\bar{Q}$'s from the sea.

We neglect the contribution of valence quarks because they are supposed to populate predominantly the ends of the rapidity plot [3, 6].

In applying this assumption to a particular situation one has to try to separate the short range effects of recombination and resonance decays from the contribution due to fluctuations of Q's and $\bar{Q}$'s from the sea. The simplest way to do that is either to study quantum number transfer across a rapidity gap $\Delta y \sim 1$–2 or to study the energy dependence of a particular quantum number transfer, assuming that short range processes contribute only to the energy independent part of the effect. The simplest quantity characterizing fluctuations of quantum numbers in the final state is the charge transfer across $y = 0$. For the proton-proton collision

$$\Delta Q = \tfrac{1}{2}(Q_{\mathrm{R}} - Q_{\mathrm{L}}),$$

where Q_R and Q_L are charges in the right and left hemispheres respectively.

In the present note we shall try to understand what are the available data on ΔQ indicating about the behaviour of quarks and antiquarks in the sea.

With respect to fluctuations of quantum numbers the present quark-parton models of multiparticle production can be divided into two broad classes.

The first group contains approaches [1, 2, 3] where one assumes (either without specifying the details [1, 2] or invoking the gluon conversion [3] to Q's and $\bar{Q}$'s) that a sufficient amount of Q's and $\bar{Q}$'s is created in the first stage of the collision. In these models Q's and $\bar{Q}$'s from the sea are not correlated except for conservation laws. In these models one would expect large quantum number fluctuations, and in particular $\langle(\Delta Q)^2\rangle$ should be proportional to average number of Q's and $\bar{Q}$'s present. Consequently, $\langle(\Delta Q)^2\rangle$ should be proportional to $\ln s$.

The second group of models contains approaches by Van Hove, Pokorski and Fiałkowski [4] and by Low [7]. According to Van Hove et al. [4] the final state hadrons in the central region come from decays of relatively light neutral clusters. In Low's model the original bag breaks gradually into smaller bags until a bag reaches a sufficiently small size and decays to hadrons. Bags in the central region should contain strongly correlated $Q\bar{Q}$ pairs. In these models one expects smaller fluctuations which are either energy independent or approach a limiting value. Such a limiting behaviour follows also from link-correlated models [8] with a limited charge transfer in a link.

The data [9, 10, 11] on $\langle(\Delta Q)^2\rangle$ available at present (Fig. 1) seem to prefer the former possibility. The data show a linear rise in $\ln s$:

$$\langle(\Delta Q)^2\rangle = 0.14 \ln s + \text{const.} \tag{1}$$

According to arguments given above the energy dependence of $\langle (Q)^2 \rangle$ should be given by the fluctuations of charge of Q's and $\bar{Q}$'s in the sea.

Let us suppose that in the average there are $\langle n_Q \rangle$ quarks and $\langle n_{\bar{Q}} \rangle$ antiquarks in the sea. In parton models of multiparticle production $\langle n_Q \rangle$ has to rise linearly with ln s:

$$\langle n_Q \rangle = \langle n_{\bar{Q}} \rangle = \alpha \ln s + \text{const.} \tag{2}$$

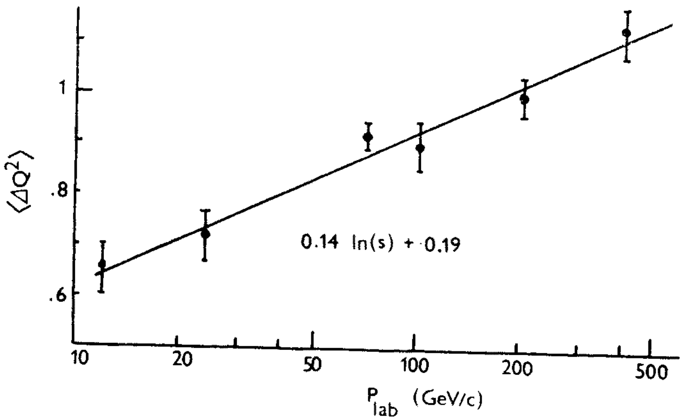

Fig. 1. The data on energy dependence of the mean squared charge transfer across $y = 0$ [10]. The full line is our (by hand) parametrization of the data

If rules of parton recombination to hadrons are known the coefficient α can be estimated from the observed energy dependence of the mean charged multiplicity [12]

$$\langle n_{ch} \rangle = 1.77 \ln s + \text{const.} \tag{3}$$

For instance the rules for recombination described in [3] give in the average about 1.1 charged particle per $Q\bar{Q}$ pair present in the sea. Consequently[2] $\alpha = 1.6$.

If one assumes that there is no short range correlation between Q's and $\bar{Q}$'s in the sea, then one can easily calculate the $\langle (Q)^2 \rangle$ for random distribution (in rapidity) of $\langle n_Q \rangle$ quarks and $\langle n_{\bar{Q}} \rangle$ antiquarks. After a simple exercise from probability theory one finds[3]

$$\langle (Q)^2 \rangle = \tfrac{1}{2} \lambda^2 \langle n_Q \rangle + \text{const}, \tag{4}$$

where λ^2 is the mean squared charge of quarks.

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[2] This estimate of α is based on a particular model. In an almost model independent way one can assume that $0.88 < \alpha < 1.77$. The upper limit corresponds to $\langle n_{ch} \rangle = \langle n_Q \rangle$ (a $Q\bar{Q}$ pair recombines in average to one charged particle), the lower one corresponds to $\langle n_{ch} \rangle = 2 \langle n_Q \rangle$ (a $Q\bar{Q}$ gives two charged particles). The value of β in Eq. (6) is obtained by taking $\alpha = 1.6$. Since $\beta \sim 1/\alpha$, for lower values of α one obtains higher values of β.

[3] There are additional processes contributing to the charge transfer such as decays of resonances and the recombination. We assume that their contribution to $\langle (\Delta Q)^2 \rangle$ is energy independent and we include them into the constant additional term which is not important for our considerations.

There is still a possibility that a part of Q's and $\bar{Q}$'s is ordered into $Q\bar{Q}$ pairs in rapidity and another part is randomly distributed. We shall take this into account simply by assuming that the number of randomly distributed Q's ($\bar{Q}$'s) is only $\beta\langle n_Q\rangle$ ($\beta\langle n_{\bar{Q}}\rangle$) where $\beta < 1$. Instead of Eq. (4) we now obtain

$$\langle(\Delta Q)^2\rangle = \tfrac{1}{2}\beta\lambda^2 \langle n_Q\rangle + \text{const} = \tfrac{1}{2}\alpha\beta\lambda^2 \ln s + \text{const}. \tag{5}$$

Inserting here $\alpha = 1.6$, $\lambda^2 = 1/3\,(4/9+1/9+1/9) = 0.22$ and comparing the coefficient in front of $\ln s$ with Eq. (3) we obtain[4]

$$\beta = 0.8. \tag{6}$$

This relatively large value of β suggests that a large fraction of Q's and $\bar{Q}$'s fluctuates rather freely in rapidity.

This conclusion is in fact based on the assumption that the linear dependence of $\langle(\Delta Q)^2\rangle$ on $\ln s$ continues to higher energies. If this assumption turns out to be correct the conclusion made above can hardly be avoided.

It is of course still possible that the logarithmic increase of $\langle(\Delta Q)^2\rangle$ at present energies is a transient phenomenon. If $\langle(\Delta Q)^2\rangle$ were to approach an asymptotic limit smaller than ~ 2 one could probably interpret such behaviour in models with strong correlations of Q's and $\bar{Q}$'s to $Q\bar{Q}$ pairs.

The data on charge transfer fluctuations at ISR energies would be most helpful in distinguishing between various parton models of multiparticle production. In a similar way the data on baryon number or strangeness transfer across $y = 0$ would be very instructive. Unfortunately such data are not available at present. Further information on this question can come from the study of energy dependence of probabilities for fixed charge transfer ($\Delta Q = 1, 2, 3, \ldots$) and for charge transfer across a large rapidity gap Δy.

Let us note that our result about large fluctuations of Q's and $\bar{Q}$'s before recombination is not very surprising. Soon after being proposed as a useful variable [13], $\langle(\Delta Q)^2\rangle$ was studied in cluster models [14] and compared both with the data and with predictions of models where charges of final state particles are randomly distributed. While cluster models give about the right values for $\langle(\Delta Q)^2\rangle$, models with random distribution of charges predict values of $\langle(\Delta Q)^2\rangle$ 2–4 times larger [10] than the data. Quark parton models [1, 2, 3] have also a random distribution of charges of sea quarks, but $\langle\Delta Q)^2\rangle$ is proportional to the mean squared charge of quarks: $\lambda_Q^2 = 2/9$. This is just by a factor 3 lower than the mean squared charge of pions $\lambda_\pi^2 = 2/3$. Consequently the fluctuations in quark-parton models with random distribution of charges have about a correct order of magnitude.

Finally let us make explicitly the point which was actually the motivation of the present note. We believe that the multiparticle production should either be understood from the quark-parton model point of view or it might happen that it will in some time play just a marginal role in the development of particle physics (something like collisions of two molecules at high energies in the context of the study of atomic structure). We still

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[4] Taking "model independent" limits $0.88 < \alpha < 1.77$ we get $0.7 < \beta < 1$.

hope that the first possibility is true. Because of that we believe that it is necessary to improve gradually one's view on multiparticle production within the framework of quark-parton model by investigating as many features of this process as it is possible. We think quantum number fluctuations are very instructive from this point of view.

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