EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/EP 79-106
26 September 1979

QUANTUM NUMBER EFFECTS IN EVENTS WITH A CHARGED PARTICLE
OF LARGE TRANSVERSE MOMENTUM

(PART 2: CHARGE CORRELATIONS IN JETS)

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Submitted to Nuclear Physics B

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ABSTRACT

Charge correlations of particles in an event with a large p_T triggering particle have been investigated applying a new method, which has been developed for non-diffractive inelastic hadronic events. The correlation length for charge compensation of the fragments of the hard scattered partons and of the spectators, respectively, are equal to that one in normal inelastic events. Part of the charge of the high p_T trigger particle is compensated by the soft particles of the "away jet". These results support the idea that the rearrangement of quantum numbers in quark fragmentation shows a universal behaviour.

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Charge correlations of particles in an event with a large p_T triggering particle have been investigated applying a new method, which has been developed for non-diffractive inelastic hadronic events. The correlation length for charge compensation of the fragments of the hard scattered partons and of the spectators, respectively, are equal to that one in normal inelastic events. Part of the charge of the high p_T trigger particle is compensated by the soft particles of the "away jet". These results support the idea that the rearrangement of quantum numbers in quark fragmentation shows a universal behaviour.

1. INTRODUCTION

The phase space structure of events, associated with the production of a particle of large transverse momentum p_T , can be described in the framework of the quark parton model [1,2], where one assumes that each of the incoming protons dissociates into a parton and an accompanying spectator. The latter denotes the system of proton constituents remaining after the removal of one or more of them by a hard scattering process (fig. 1). The fragmentation products of the parton systems are called "jets". In total four "jets" are expected to be produced in a large transverse momentum production process. Experimental evidence supporting this picture exists [2,3].

In order to study the quark fragmentation process in more detail, it is necessary to investigate how quarks evolve into the observed particles, from which they differ by their colours and flavours. In a foregoing paper [4] it was shown that the leading particles from a "jet" carry information about the quantum numbers of the scattered parton in the sense that their momentum distributions depend on the quark content of the fragmenting parton. In the present paper we go one step further and try to tackle the question: how are the quantum numbers - specifically the electric charges - of the observed hadrons rearranged in phase space in order to be adjusted to the quantum numbers of the fragmenting parton? To investigate this question we have exploited a procedure, which has been developed to study charge correlations in non-diffractive inelastic events [5]. The basic idea of the method is sketched in the next chapter.

A sample of events with a positive or a negative high transverse momentum particle ($\langle p_T \rangle \simeq 2.5$ GeV/c) produced at a polar angle of $\langle \theta \rangle \simeq 45^\circ$ has been used in the present analysis (see also ref. [2]). The measurements have been performed at a centre of mass energy of $\sqrt{s} = 52.5$ GeV. The apparatus, the trigger, the analysis procedure and the applied acceptance corrections have been described previously [2,4,5]. For comparison we use results from a study of non-diffractive inelastic events taken with the same detector [5,6].

2. METHOD OF ANALYSIS

In our analysis we want to get insight into the rearrangement process of quantum numbers in phase space, which correlates the flavour and colour of the detected particles to those of the fragmenting partons. In this paper we concentrate on the aspect of charge compensation.

If a particle of given charge is produced in a hadronic interaction, compensating secondaries of opposite charge necessarily exist because of charge conservation. The phase space distribution of the compensating particles reveals details of the fragmentation process of the primary partons. In order to study the dynamics of this charge compensation process in large transverse momentum reactions, we select a particle from one of the four "jets" and determine the "associated" (conditional) density [5,7] of particle number and charge. These "associated" densities are obtained by selecting a particle (s) from one of the four "jets" in a phase space interval around $\vec{p}^{(s)}$, and then evaluate the density of interest (particle density, charge density) for the particles h_1 in the phase space interval around $\vec{p}$ for the rest of the event.

The "associated particle density" $\rho^{Q,Q^{(s)}}(y|y^{(s)})$ is the density of particles of charge Q at rapidity y under the condition that a particle of charge $Q^{(s)}$ is detected at the rapidity $y^{(s)}$. It is connected to the inclusive two-particle density $\rho^{Q,Q^{(s)}}(y,y^{(s)})$ by

$$\rho^{Q,Q^{(s)}}(y|y^{(s)}) = \frac{\rho^{Q,Q^{(s)}}(y,y^{(s)})}{\rho^{Q^{(s)}}(y^{(s)})} \quad (1)$$

The "associated net charge density" $q(y|Q^{(s)},y^{(s)})$ is the net charge density at rapidity y under the condition that there exists a particle of charge $Q^{(s)}$ at rapidity $y^{(s)}$

$$q(y|Q^{(s)},y^{(s)}) = \rho^{+,Q^{(s)}}(y|y^{(s)}) - \rho^{-,Q^{(s)}}(y|y^{(s)}) \quad (2)$$

Instead of determining the net charge density it is advantageous to study the "associated charge density balance"

$$\Delta q(y|y^{(s)}) = q(y|-,y^{(s)}) - q(y|+,y^{(s)}) \quad (3)$$

It is a measure of the change of the "associated net charge density", when the charge of the selected particle (s) of one of the "jets" is changed from negative to positive. Hence this distribution is a direct measure of the charge compensation effect.

The normalization of the "associated charge density balance" is given by

$$\int \Delta q(y, y^{(s)}) dy = 2.$$

The following simple model allows to gain an intuitive idea of the physical meaning of the "associated charge density balance". If one assumes that a correlated and an uncorrelated component contribute to the "associated particle density" $\rho^{Q, q^{(s)}}(y|y^{(s)})$ it can easily be shown that the "associated charge density balance" is determined by the correlated component. Therefore, in a sense, the "associated charge density balance" allows to select out of the "associated charge density" distributions the correlated fraction.

The "associated charge density balance" has the further advantage that it is less sensitive to acceptance corrections than the "associated charge density" itself [6]. The connection of Δq to quantities preferred by other authors in their analysis of the charge compensation mechanism is discussed in ref. [5].

3. EXPERIMENTAL RESULTS

3.1 Charge density balance associated with the trigger particle

Taking the trigger (t) of a large transverse momentum event as the selected particle (s), the dependence of the "associated charge density balance" Δq on the rapidity of other particles is plotted in fig. 2. The distribution peaks in the rapidity region of the trigger particle η_2 . For comparison the "associated charge density balance" of non-diffractive inelastic events, taken at the same $\sqrt{s}$ as the large transverse momentum data, is included in fig. 2 [5,6]. In the region of the peak the two distributions coincide (correlated component), hence the charge correlation length λ_{ch} of the "associated charge density balance" for a large p_T trigger particle and for particles in a non-diffractive inelastic event is

the same. Besides a local correlated component a weaker global component may exist in the case of the large transverse momentum event.

To investigate the contribution of the four "jets" (fig. 1) of a large p_T event to the charge compensation of the triggering large transverse momentum particle at $(y^{(t)}, \phi^{(t)}, p_T^{(t)})$, the dependence of the "associated charge density balance" Δq is shown in fig. 3 as a function of the rapidity y and the azimuthal angle ϕ of the additional particles for two event configurations. They differ from each other by the position in rapidity of the "away jet", fixed in phase space by its leading particle (f) which by definition is that particle in the "away region" ($\phi = \langle \phi^{(t)} \rangle + 180^\circ \pm 30^\circ$) with the highest transverse momentum. Only events, where the leading particle has a transverse momentum $p_T^{(f)} > 0.6$ GeV/c were taken into account, in order to minimize the chance of its misidentification and to have at the same time still a reasonable statistic. In the upper part of the figure (fig. 3(a)) the leading particle of the "away jet" and the trigger particle are in the same rapidity interval ("back to antiback" configuration), while in the lower part of the figure (fig. 3(b)) the rapidity difference of the trigger particle and the "away jet" is large ($|y^{(f)} - y^{(t)}| > 2$) (back to back configuration).

In both cases (figs 3(a) and (b)) a peak of the "associated charge density balance" Δq is observed in the ϕ region of the trigger particle ($\phi \simeq \phi^{(t)}$), independent of the rapidity position of the leading particle of the "away jet". A peak in the azimuthal angular region opposite to the trigger particle ($\phi \simeq \langle \phi^{(t)} \rangle + 180^\circ$) is also observed for both configurations (figs 3(a) and (b)), but in contrast to the first case its position in rapidity follows that of the leading particle of the "away jet". In addition to these two peaks a flat contribution in ϕ to the "associated charge density balance" Δq is observed, which is in a broad interval independent of the rapidity y .

These three contributions to the "associated charge density balance" Δq show that the charge of the trigger particle is compensated by three components. The peak in the phase space region of the trigger particle indicates that part of the trigger charge is compensated by low p_T

particles of the "trigger jet" in agreement with the experimental results of ref. [2] and the theoretical expectations of the parton model [1]. The peak in the phase space region of the "away jet" can be connected to a charge flow between the "trigger jet" and the "away jet". Taking into account the results of ref. [4], where it was shown that the charges of the leading particles of the "away jet" are uncorrelated from the charges of the trigger particle, it follows from the present observation that the charge flow is connected to the low p_T particles of the "away jet". The observation of the global component indicates that in addition also a charge flow between the "trigger jet" and the "spectator jet" takes place in order to adjust the charges. These results are in qualitative agreement with the expectation of the parton model [8] and with the results of ref. [4], where the properties of the leading particles of a "jet" were investigated.

3.2 Charge density balance associated with particles of the "away jet"

In order to investigate the charge compensation process for particles in the "away jet", a particle (s) is selected in that part of the phase space, which is predominantly populated by the fragments of the "away jet". Taking into account the results of ref. [1,2], in the present analysis this part of the phase space is defined by the cuts $|y^{(s)}| < 2.5$, $\phi^{(s)} = \langle \phi^{(t)} \rangle + 180^\circ \pm 40^\circ$ and $p_T^{(s)} > 0.1 \text{ GeV}/c$.

In fig. 4(a) the "associated charge density balance" $\Delta q(y|y^{(s)})$ is plotted for five different intervals of the transverse momentum of the selected particle $p_T^{(s)}$. The distribution has been integrated over the azimuthal angle ϕ of the associated particles and their transverse momentum $p_T > 0.2 \text{ GeV}/c$. No restriction on the rapidity y has been applied. $\Delta q(y|y^{(s)})$ peaks at $\Delta y = |y - y^{(s)}| = 0$ and the width of the distribution decreases with increasing transverse momentum $p_T^{(s)}$ of the selected particle (s). This observation gives a first hint that the charge compensation for particles in the "away jet" is dominantly localized within that part of phase space populated by the fragments of the "away jet".

For a further check of this interpretation, the azimuthal angular dependence of the "associated charge density balance" $\Delta q(\phi|\phi^{(s)})$ has been studied. It is shown in fig. 4(b) for five different intervals of $p_T^{(s)}$. Only associated particles with a rapidity in the interval $\Delta y = |y - y^{(s)}| < 1$ around the selected particle were taken into account. For small $p_T^{(s)}$ the distribution $\Delta q(\phi|\phi^{(s)})$ peaks at $\Delta\phi \simeq 180^\circ$. The same behaviour has been observed for non-diffractive inelastic events [5,6]. It can be interpreted in the present case to be due to the strong admixture of spectator fragments to the sample of selected particles at low $p_T^{(s)}$. With increasing transverse momentum $p_T^{(s)}$ the maximum of $\Delta q(\phi|\phi^{(s)})$ shifts to $\Delta\phi = |\phi - \phi^{(s)}| = 0^\circ$ in accordance with the interpretation of fig. 4(a), since for larger $p_T^{(s)}$ of the particle (s) one selects preferentially fragments of the "away jet".

Figs 4(a) and (b) therefore support the assumption that the charge of particles in the "away jet" is dominantly balanced within the same jet. This conclusion correspond to the results derived for the "trigger jet" in sect. 3.1.

3.3 Charge density balance associated with particles of the "spectator jet"

To study the charge compensation process for the fragmentation products of the "spectator jet", the perturbation by particles of the "trigger jet" and the "away jet" has to be minimized. To achieve this goal, only events have been analyzed, where the "trigger jet" and the "away jet", fixed by its leading particle, are in the same rapidity hemisphere. The rapidity of the trigger particle is $y^{(t)} < -0.7$. The cuts applied for the selection of the leading particle of the "away jet" are $\phi^{(f)} = \langle \phi^{(t)} \rangle + 180^\circ \pm 30^\circ$, $p_T^{(f)} > 0.6$ GeV/c and $y^{(f)} < -1$. The selected particles of the "spectator jet" have a rapidity $y^{(s)} > 0.5$, a transverse momentum $p_T^{(s)} > 0.175$ GeV/c and are unrestricted in their azimuthal angle. A cut on the multiplicity of observed tracks $n_{vis} > 7$ has been applied in order to compare the results of the present analysis with those of non-diffractive inelastic events of ref. [5,6].

Fig. 5 shows the conditional two-particle density correlation

$$C'(y|y^{(s)}) = \rho(y|y^{(s)}) - \rho(y), \quad (4)$$

derived from eq. (1), for two intervals of the selected particle in the "spectator jet" at $\langle y^{(s)} \rangle = 2$ and $\langle y^{(s)} \rangle = 4$ respectively. The correlation function peaks in the rapidity region of the selected particle. For comparison the corresponding distributions, measured for non-diffractive inelastic events [5,6], are included. The two distributions agree within the error limits.

In figs 6(a) and (b) the "associated charge density balance" $\Delta q(y|y^{(s)})$ is plotted as a function of the rapidity y of the associated particles for two intervals of the rapidity of the selected particle from the "spectator jet". Again the corresponding distributions for non-diffractive inelastic events are included in the figure. The two distributions are in good agreement.

From this agreement between the conditional two-particle density correlation and the "associated charge density balance" for non-diffractive inelastic events and the "spectator jet" of large transverse momentum events follows that in both event types the fragmentation of the partons is similar. Since evidence exists that the "spectator" partons are dominantly a di-quark system [4], while the experimental results for the non-diffractive inelastic events are in agreement with the assumption that a three-quark system fragments [9], it follows from the present analysis that the charge adjustment between the observed hadrons and the partons is at utmost weakly dependent on the quark contents of the fragmenting parton system.

4. CONCLUSIONS

The present analysis shows that the width of the "associated charge density balance" for a selected particle in the "trigger jet", "away jet" and the "spectator jet" of a large transverse momentum event is the same as that for selected particles in a non-diffractive inelastic event.

This observation shows that the jet fragmentation is universal [10] in the sense that the charge adjustment between the hadronic fragments and the partons is independent of the latter's quark content.

Moreover, the observed correspondence between the correlation data of non-diffractive inelastic events and of events with a large p_T trigger particle is in qualitative agreement with the expectation based on a recent analysis on "jet" evolution in the framework of quantum chromodynamics [11]. In ref. [11] it is shown that during jet evolution a "preconfinement" stage appears, which consists of colour singlet states of finite mass. The arguments of ref. [11] can easily be generalized to show that these singlet states are flavour neutral. If the confinement process does not disturb the arrangement of colour lines, one expects that the predicted properties of the singlet states propagate to the observed hadronic clusters. This expectation is in agreement with the detailed cluster analysis of ref. [5] for the data set, which we have used to compare with the results of the large transverse momentum events in the present analysis.

Acknowledgement

This experiment was greatly helped by contributions from the SFM Detector Group. We are indebted to H.F. Hoffmann and the ISR Experimental Support Group. We greatly profited from discussions with Profs S. Brodsky, H. Genz, W. Schmidt and J. Wess. The Heidelberg and Dortmund Groups were supported by a grant from the Bundesministerium für Forschung und Technologie of the Federal Republic of Germany, the Collège de France Group was funded by IN2P3 and the CEA. The experiment has been supported in part in an earlier stage by the Kernforschungszentrum Karlsruhe.

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FIGURE CAPTIONS

- Fig. 1 Pictorial representation of the quark-quark scattering process resulting in a four-jet structure of the large transverse momentum event.
- Fig. 2 "Charge density balance" $\Delta q(y|y^{(t)})$ as a function of the rapidity y of particles associated with a large transverse momentum trigger particle at $y^{(t)} = -0.9$. The full line reproduces the corresponding distribution for non-diffractive inelastic events [5,6].
- Fig. 3 "Charge density balance" $\Delta q(\phi|\phi^{(t)})$ as a function of the azimuthal angle ϕ of particles associated with a large transverse momentum particle for two event configurations: leading particle of the "away jet" ($\phi^{(f)} = 180^\circ$) and trigger particle ($\phi^{(t)} = 0^\circ$):
- (a) in the same rapidity region ("back to antiback" configuration),
 - (b) in opposite rapidity regions ("back to back" configuration).
- The full lines serve to guide the eye.
- Fig. 4 "Charge density balance" Δq for particles associated with a selected leading particle s of the "away jet" for different transverse momentum intervals $p_T^{(s)}$:
- (a) $\Delta q(y|y^{(s)})$ as a function of the rapidity difference $\Delta y = |y - y^{(s)}|$ between the selected and the associated particle
 - (b) $\Delta q(\phi|\phi^{(s)})$ as a function of the azimuthal angle difference $\Delta\phi = |\phi - \phi^{(s)}|$ of the particles associated with the selected jet leader of the "away jet" ($\Delta y = |y - y^{(s)}| < 1$).
- Fig. 5 "Conditional two-particle density" of formula (4) of particles associated with a selected particle in the spectator fragmentation region. The full line reproduces the corresponding result of a non-diffractive inelastic event [5,6]. The fragments of the "trigger jet" and the "away jet" are localized at negative rapidities.

FIGURE CAPTIONS (Cont'd)

Fig. 6 "Charge density balance" $\Delta q(y|\bar{y}^{(s)})$ of particles associated with a selected spectator fragment at $y^{(s)} = 2$ and $y^{(s)} = 4$ respectively. The full line reproduces the corresponding results of a non-diffractive inelastic event [5,6]. The fragments of the "trigger jet" and the "away jet" are localized at negative rapidities.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6