BARYONIC AND ELECTRIC CHARGE DISTRIBUTIONS IN MULTIPARTICLE PRODUCTION AND QUARK PARTON MODELS

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It is pointed out that the baryonic charge distribution in multiparticle production may bring valuable information about the mechanism of hadronic collisions at high energies. The CERN ISR data, supplemented by some plausible assumptions, are then used to construct the baryonic and electric charge distributions of final state particles at $p_T = 0.4$ GeV/c. Both the distributions are found similar. Finally, the conjecture, that the same simple relation holds also for overall (i. e. integrated over p_T) rapidity distributions of both charges, is qualitatively shown to be compatible with quark-parton models of multiparticle production.

1. Introduction

Studies of various features of charge distribution in multiparticle final states[1] have largely contributed to the present understanding of multiparticle production. The most successful description of the data is provided by models based on the independent emission of relatively light clusters [1] decaying to about two charged particles on the average. Originally these clusters were assumed neutral, but the recent evidence [2] indicates that charged clusters are present even in the central region of center-of-mass rapidities. In this way models with light clusters may phenomenologically be quite similar to quark-parton models where copious production of resonances is assumed.

In quark-parton models [3] it is quite natural to believe that processes responsible for the transition from the initial state of colliding hadrons to the state after the collision are of a short range in rapidity. As a consequence, the rapidity distributions of quantum

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[1] The charge distribution is understood here in a broader sense including also fluctuations of charge across a fixed rapidity position, distribution of gaps between charged particles, charge transfer across a gap, etc.

numbers of final state particles should in some hopefully simple way be related to the distributions of quantum numbers of hadronic constituents just before the collision. It is then quite reasonable to expect that not only the charge distribution, but also distributions of other additive quantum numbers (e. g. of the baryonic charge) may bring valuable information on the mechanism of multiparticle production.

Both the electric and baryonic charge distributions in multiparticle final states are — if the quark-parton model is not far from the truth — related to the distribution of partons in colliding hadrons. Thus, one might expect a certain relation between both the distributions. This depends on the inner structure of hadrons and on the way how the final state is connected with the initial state of colliding hadrons. In this manner, the study of the relation of the electric and baryonic charge distributions may contribute to our understanding of multiparticle production.

However, the data on baryon production inclusive cross sections are available only for limited regions of (y, p_T) space. This is connected with experimental difficulties:

– in bubble chamber experiments identification of charged particles with momenta $\gtrsim 1.5$ GeV/c is impossible;

– in the ISR experiments data usually give inclusive cross sections only at fixed values of p_T; moreover, almost nothing is known about the behaviour of the production for very low values of transverse momentum ($p_T \lesssim 0.1$ GeV/c);

– sophisticated techniques have to be used to detect neutral particles (neutrons and antineutrons which are relevant for the baryonic charge distribution).

For these reasons, any attempt to obtain the distribution of the baryonic charge has to rely on assumptions about the behaviour of inclusive invariant cross sections as functions of rapidity y and transverse momentum p_T. Despite this fact, we believe that it makes sense to have a look at the data, add a few assumptions about the behaviour of the inclusive cross sections and try to find out indications or hints which the data may contain.

The paper is organized as follows: In Sect. 2 we construct the baryonic and electric charge distributions at $p_T = 0.4$ GeV/c from the CERN-ISR data and find them similar. This leads to the conjecture that this simple relation remains unchanged also for overall (i. e. integrated over p_T) rapidity distributions of the electric and baryonic charge (Sect. 3). In Sect. 4 we briefly show that the similarity of both the distributions follows naturally from various quark-parton models of multiparticle production. Comments and concluding remarks are given in Sect. 5.

2. *Rapidity distributions of the electric and baryonic charge at* $p_T = 0.4$ *GeV/c*

The most complete set of high energy inclusive invariant cross sections comes from the ISR measurements at $p_T = 0.4$ GeV/c ([4, 5] and references therein) and is shown in Figs 1 and 2. These pictures clearly illustrate our difficulties at extracting the baryonic and electric charge distributions at $p_T = 0.4$ GeV/c: the data points come from various ISR energies, have rather large fluctuations and do not uniformly cover the whole rapidity interval. On the other hand, the inclusive cross sections if plotted as functions of rapidity

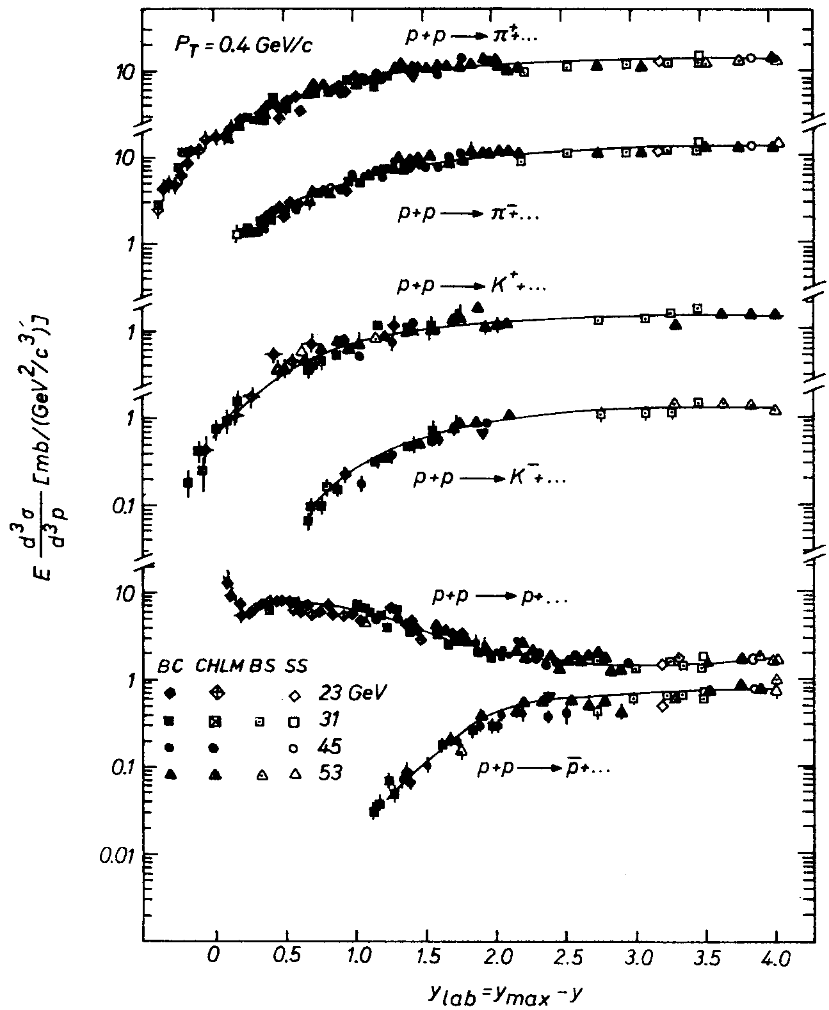

Fig. 1. The invariant cross sections for the inclusive production of pions, kaons, protons, and antiprotons versus y_{lab} at $p_{\text{T}} = 0.4$ GeV/c (from pp collisions at the ISR, see [4] and references therein). The solid lines were drawn by hand to smooth the experimental points

(see Fig. 1) do not seem to depend strongly on the energy[2], so we drew "lines to guide the eye" over experimental points and used them to estimate "smoothed" cross sections listed in Table I. The neutron spectra, which are expressed as functions of the Feynman variable x in Fig. 2, were first transformed into rapidity. These data do not cover the x-region from 0 to 0.1 ($0 < y \lesssim 1.7$). However, we noticed in Fig. 1 that the cross sections

[2] π^+, π^-, K^+ and p invariant cross sections were found energy independent within errors over the whole ISR energy range, while for K^- and p^- almost no energy dependence was observed above 45 GeV c. m. energy (see [4]).

TABLE I

The invariant cross sections are for π^+, π^-, K^+, K^-, p, $\bar{p}$, $n+\bar{n}$ inclusive production in pp collisions at the CERN ISR as functions of c. m. rapidity y at $p_T = 0.4$ GeV/c (in mb/(GeV^2/c^3)). The values listed ar not true experimental ones, they were estimated from lines drawn by hand to smooth the experimental points (Figs 1 and 2). Two last columns contain $\hat{\varrho}_{Q,B}$ (y, $p_T = 0.4$ GeV/c) calculated using the listed cross sections and Eqs (1a, 1c)

y	π^+	π^-	K^+	K^-	p	$\bar{p}$	$n+\bar{n}$	$\hat{\varrho}_Q$	$\hat{\varrho}_B$
0.1	13.1	13.1	1.5	1.4	1.6	0.8	2.0	0.9	1.2
0.3	12.9	12.9	1.4	1.4	1.5	0.7	2.0	0.8	1.4
0.5	12.6	12.6	1.4	1.3	1.5	0.7	2.0	0.9	1.4
0.7	12.2	12.2	1.4	1.3	1.5	0.7	2.0	0.9	1.4
0.9	11.9	11.9	1.3	1.2	1.4	0.6	2.0	0.9	1.6
1.1	11.6	11.6	1.3	1.2	1.4	0.6	2.0	0.9	1.6
1.3	11.1	11.1	1.3	1.1	1.4	0.6	2.0	1.0	1.6
1.5	10.8	10.8	1.3	1.1	1.5	0.5	2.0	1.2	2.0
1.7	10.7	10.5	1.3	1.0	1.6	0.5	2.0	1.6	2.1
1.9	10.4	10.1	1.2	0.9	1.8	0.5	2.3	1.9	2.6
2.1	10.1	9.3	1.2	0.8	2.2	0.4	2.5	3.0	3.5
2.3	9.9	9.0	1.2	0.7	2.7	0.2	2.7	3.9	4.8
2.5	9.4	7.9	1.1	0.6	3.5	0.1	2.9	5.4	6.1
2.7	9.0	7.1	1.0	0.4	4.6	0.1	3.1	7.0	7.4
2.9	8.3	6.0	0.8	0.3	5.5		3.0	8.3	8.5
3.1	7.1	4.9	0.7	0.2	6.5		2.9	9.2	9.4
3.3	5.9	3.8	0.5	0.1	7.5		2.7	10.0	10.2
3.5	4.7	2.7	0.3		7.7		2.2	10.0	9.9
3.7	3.5	1.7	0.2		5.9		1.7	7.9	7.6
3.9	2.1		0.1		10.9		0.7	~13	11.6

for charged particle production at $p_T = 0.4$ GeV/c vary only slightly in this region. This lead us to extrapolate the neutron distribution into the interval $0 \leqslant y < 1.7$ by a constant.

The values listed in Table I were used to estimate the rapidity distributions of the electric and baryonic charge at $p_T = 0.4$ GeV/c. They are given by the following expressions, respectively

$$\hat{\varrho}_Q(y, p_T = 0.4\ \mathrm{GeV}/c) = \left[E\frac{d^3\sigma_p(y)}{d^3\vec{p}} + E\frac{d^3\sigma_{\pi^+}(y)}{d^3\vec{p}} + E\frac{d^3\sigma_{K^+}(y)}{d^3\vec{p}} - E\frac{d^3\sigma_{\bar{p}}(y)}{d^3\vec{p}} - E\frac{d^3\sigma_{\pi^-}(y)}{d^3\vec{p}} - E\frac{d^3\sigma_{K^-}(y)}{d^3\vec{p}}\right]\Bigg|_{p_T=0.4\ \mathrm{GeV}/c}, \tag{1a}$$

$$\hat{\varrho}_B(y, p_T = 0.4\ \mathrm{GeV}/c) = \left[E\frac{d^3\sigma_p(y)}{d^3\vec{p}} + E\frac{d^3\sigma_n(y)}{d^3\vec{p}} - E\frac{d^3\sigma_{\bar{p}}(y)}{d^3\vec{p}} - E\frac{d^3\sigma_{\bar{n}}(y)}{d^3\vec{p}}\right]\Bigg|_{p_T=0.4\ \mathrm{GeV}/c}. \tag{1b}$$

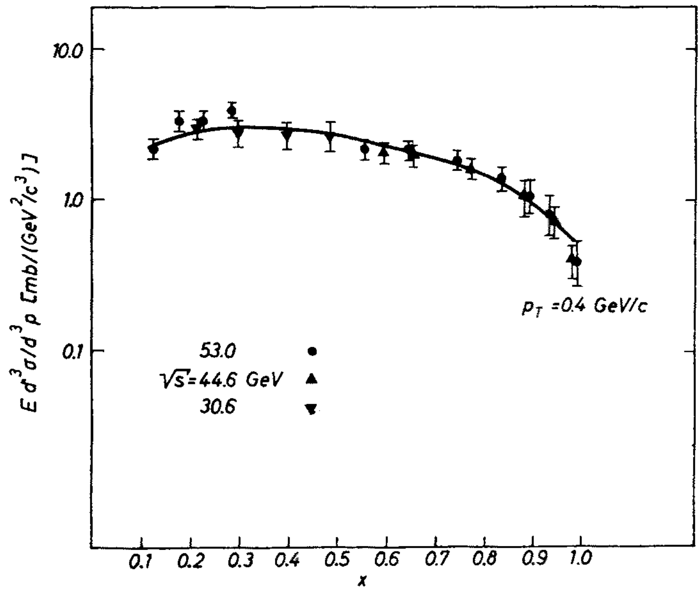

Fig. 2. Neutron and antineutron production cross sections plotted as a function of the Feynman variable x for $p_T = 0.4$ GeV/c (from pp collisions at the ISR, see [5]). The solid curve is given to guide the eye

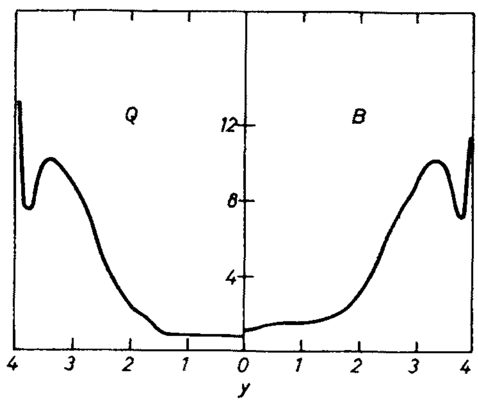

Fig. 3. The electric (Q) and baryonic (B) charge rapidity distributions at $p_T = 0.4$ GeV/c, estimated from the ISR data [4, 5] (in mb/(GeV^2/c^3))

However, Eq. (1b) cannot be directly used because the neutron and antineutron inclusive invariant cross sections are not given separately by the data, just their sum (Fig. 2, Ref. [5]). To separate their contributions we assumed that the antineutron spectrum is identical with that of antiproton (the latter estimated from the solid line in Fig. 1). This assumption is partly motivated by the quark-parton model philosophy since here both $\bar{\text{p}}$ and $\bar{\text{n}}$ consist of antiquarks from the "sea" of quark-antiquark pairs.

Consequently, we used the values in Table I and the formulae (1a) and

$$\hat{\varrho}_{\text{B}}(y, p_T = 0.4\,\text{GeV}/c) = \left[E\frac{d^3\sigma_{\text{p}}}{d^3\vec{p}} + E\frac{d^3\sigma_{\text{n}+\bar{\text{n}}}}{d^3\vec{p}} - 3E\frac{d^3\sigma_{\bar{\text{p}}}}{d^3\vec{p}} \right]\Bigg|_{p_T=0.4\,\text{GeV}/c}, \qquad (1\text{c})$$

and obtained the baryonic and electric charge distributions in rapidity at $p_T = 0.4$ GeV/c at the ISR energies which are pictured in Fig. 3. It is clearly visible that *both these distributions are similar*.

The assumptions which we used to get the distributions in Fig. 3 seem plausible and justified by the data and/or the quark-parton ideas. Some errors might arise from the procedure of smoothing and combining data from various ISR energies. Nevertheless we believe that this procedure did not substantially influence the shape of distributions in Fig. 3 and that both the electric and baryonic charge distributions in rapidity at $p_T = 0.4$ GeV/c are genuinely similar.

3. *A conjecture about the distributions integrated over p_T*

In the previous section we attempted to construct the electric and baryonic charge distributions at $p_T = 0.4$ GeV/c. However, rapidity distributions integrated over transverse momenta would be of more interest. They are given by the expressions

$$\varrho_Q(y) = \sum_h Q_h \varrho_h(y), \tag{2}$$

$$\varrho_B(y) = \sum_h B_h \varrho_h(y) \tag{3}$$

where $Q_h(B_h)$ is the electric (baryonic) charge of the hadron h and

$$\varrho_h(y) = \int dp_T^2 \left(E \frac{d^3\sigma_h}{d^3\vec{p}} \right) \tag{4}$$

is the rapidity density of the hadron h normalized to the average multiplicity $\langle n_h \rangle$ of h

$$\int_{-y_h/2}^{y_h/2} \varrho_h(y) dy = \langle n_h \rangle \tag{5}$$

and $y_h/2$ is the maximum c. m. rapidity of h.

The outlined procedure cannot, however, be used to obtain reliable results as the data are not complete enough. Still, the similarity of the electric and baryonic charge at $p_T = 0.4$ GeV/c tempts us to formulate the following *conjecture*: *The rapidity distributions of the electric and baryonic charge integrated over p_T are similar.* This conjecture lacks convincing justification at present. Nevertheless, the value of $p_T = 0.4$ GeV/c, at which the similarity of $\hat{\varrho}_B(y, p_T)$ and $\hat{\varrho}_Q(y, p_T)$ was found, is of no particular physical significance; it just belongs to the "soft" region of transverse momentum (compared with the high p_T phenomena). If the similarity found at $p_T = 0.4$ GeV/c were not only coincidental and the relation $\hat{\varrho}_B(y, p_T) = \hat{\varrho}_Q(y, p_T)$ held in the whole "soft" p_T region, we would immediately get also the resemblance of the electric and baryonic charge distributions integrated over p_T.

Now we will turn our attention to some quark-parton models and examine whether the conjectured similarity of the rapidity distributions of the electric and baryonic charge fits into the scheme of these models.

4. The relation of electric and baryonic charge distributions in quark-parton models

The hypothesis of *quark quantum number retention* (QQNR) was originally formulated by Feynman [6] in a rather weak, non-local form. According to this formulation the region of the quark fragmentation in deep inelastic lepton-nucleon scattering should in average bear the additive quantum numbers of the original quark. In the discussion which followed [7] it was shown that oversimplified mechanisms cannot lead to the simultaneous retention of electric charge, baryonic charge and the third component of isospin.

It is however easy to believe that in more sophisticated dynamical situations, like in multiparticle production where valence quarks are immersed in a relatively large sea of $Q\bar{Q}$ pairs, the QQNR works.[3]

In the extreme and severely simplified model of Ref. [9], where valence quarks are assumed to be immersed into the infinite sea of $Q\bar{Q}$ pairs with almost no momentum, the QQNR holds strictly in the sense that the distribution of the additive quantum number A of final state hadrons in non-diffractive multiparticle production is the same as the distribution of A of valence partons from the initial state hadrons.

In this simple case we immediately get [9]

$$\varrho_Q(x) = (2/3)u_v(x) - (1/3)d_v(x), \tag{6}$$

$$\varrho_B(x) = (1/3)u_v(x) + (1/3)d_v(x) \tag{7}$$

where u_v, d_v are standard probability distribution functions of valence up and down quarks respectively.

The condition

$$\varrho_Q \approx \varrho_B \tag{8}$$

is then equivalent to

$$u_v(x) \approx 2d_v(x) \tag{9}$$

This relation is directly built into the framework of the Kuti–Weisskopf model [10]. In a more refined version of Ref. [11] the approximate equality of u_v and $2d_v$ is violated only in the region at $y \sim 0$ and at the edges of the rapidity plot. Nevertheless, in the major part of rapidities the value of u_v/d_v is close to 2. The situation is also similar in other currently used phenomenological distributions. Thus in oversimplified local models of quark quantum number retention the approximate equality of ϱ_Q and ϱ_B follows immediately.

This picture, of course, cannot be literally true, since both the recombination of $Q\bar{Q}$ pairs and QQQ and $\bar{Q}\bar{Q}\bar{Q}$ triplets to hadrons and decays of hadronic resonances modify the distribution of quantum numbers. On the other hand, both these processes are of a short range in rapidity and cannot cause essential modifications of the global features of quantum number distributions.

A realistic quark-parton model of multiparticle production in this spirit has recently been proposed by Černý, Lichard and Pišút [12]. Their Monte Carlo model is based on the following picture of the hadron-hadron collision: During the collision both hadrons

[3] This is briefly commented upon e. g. in [8].

form a compound system in which quarks and antiquarks are distributed according to the longitudinal phase space modified by Kuti-Weisskopf weights pushing valence quarks to larger values of momentum in the center-of-mass system. $Q\bar{Q}$ pairs and QQQ or $\bar{Q}\bar{Q}\bar{Q}$ triplets nearby in rapidity form mesons, baryons and antibaryons respectively which are either stable or decay into stable particles. All the process is simulated on a computer using the Monte Carlo method.

To obtain the electric and baryonic charge distributions of final state particles in high energy pp collisions comparable with data we made a computer calculation for

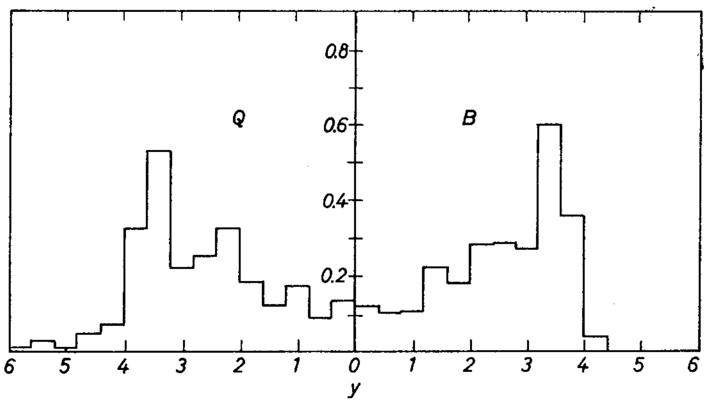

Fig. 4. The baryonic and electric charge distributions in multiparticle final states in pp collisions at the c. m. energy $\sqrt{s} = 53$ GeV, calculated using the Monte Carlo quark-parton model of Ref. [12]

the c. m. energy of colliding protons $\sqrt{s} = 53$ GeV[4]. The resulting distributions are pictured in Fig. 4. In spite of rather large fluctuations the comparison of the histograms in Fig. 4 with each other and with distributions in Fig. 3 is favourable. Both distributions (Fig. 4) are similar and their shapes agree quite good with that of distributions in Fig. 3. Of course, model results do not reproduce the peaks in Fig. 3 at large $|y|$. We believe these peaks come from diffraction dissociation of colliding protons, which is not included in the model of Ref. [12].

The satisfactory results of the model [12] are not surprising: In this model quarks and antiquarks from the sea are uncorrelated (except for conservation laws). On the average the sea is neutral and the distribution of various quantum numbers in the final state is predominantly influenced by the distribution of single valence quarks.

The equality of the electric and baryonic charge distributions is also expected in the *quark-glue model of Van Hove and Pokorski* [14]. In this model in an inelastic pp collision valence quarks form leading particles (clusters) while gluons give rise to central, independently produced clusters. In the prevailing majority of events the quantum numbers of leading

[4] The free constants of the model (coupling constant G, probabilities P_u, P_d, P_s for a $Q\bar{Q}$ pair to be up, down or strange, see [12]) were adjusted to give approximately correct total multiplicity of charged hadrons and multiplicities of charged kaons [13]: $G = 0.615$, $P_u = P_d = 0.4572$, $P_s = 0.0856$. Quark masses were fixed at values $m_u = m_d = 0.3$ GeV/c^2 and $m_s = 0.45$ GeV/c^2.

clusters are identical with quantum numbers of initial protons. Central clusters then carry vacuum quantum numbers and — in the average – do not contribute to the quantum number distributions of final state hadrons. Leading particles are mainly either protons or baryonic resonances with proton quantum numbers. The electric and baryonic charges must then be distributed identically. This picture cannot be essentially changed by decays of baryonic resonances since these are short-range phenomena in rapidity. Moreover, when assuming an isotropic decay of the resonance in its rest frame, we just obtain the broadening of the original quantum number distribution, but no shift in rapidity.

It has already been pointed out that various features of multiparticle production are successfully reproduced by *cluster models* (see e. g. [1] and references therein). In neutral cluster models where both the electric and baryonic charges are carried by leading clusters one immediately obtains ϱ_Q and ϱ_B identical. If, however, there are also charged clusters in the central region [2], the simple connection between $\varrho_Q(y)$ and $\varrho_B(y)$ is not so obvious.

5. *Summary and concluding remarks*

It was found that the data on inclusive particle production at the CERN ISR indicate the resemblance of the electric and baryonic charge distributions in multiparticle final states in proton-proton collisions at $p_T = 0.4$ GeV/c. On the basis of this result we conjectured that also overall (i. e. integrated over p_T) rapidity distributions of both charges are similar.

It was shown that such similarity naturally follows from various versions of quark--parton models of multiparticle production.

As a consequence, the similarity found is unable to distinguish between various versions of the model. Such a distinction could more probably be found [8] by comparing predictions of these models with data on quantum number fluctuations (see e. g. [15] and references therein).

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