EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/EP 81-67
2 July 1981

FORWARD AND BACKWARD MULTIPLICITIES IN K^-p INTERACTIONS AT 110 GeV/c

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Submitted to Zeitschrift für Physik C

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** Supported by S.R.C. Fellowship. Now at Nuclear Physics Laboratory,
Oxford.

*** Supported in part by Österreichischer Forschungsrat.

ABSTRACT

Multiplicity distributions and correlations between charged particles in the forward and backward c.m. hemispheres are studied in K^-p interactions at 110 GeV/c and compared with other data on meson-nucleon scattering. The interpretation in terms of a simple quark-parton picture assuming that the forward multiplicity is dominated by quark fragmentation and the backward multiplicity by diquark fragmentation is supported by the experimental fact that the forward and the backward mean multiplicities are approximately equal to half of the e^+e^- and pp multiplicities, respectively. The 110 GeV/c K^-p data show significant correlations between the numbers of slow forward and slow backward particles, whereas the multiplicities of fast forward and fast backward particles are independent.

1. INTRODUCTION

The study of forward and backward charged multiplicity distributions and of the correlations between the number of charged particles in the forward and backward hemispheres in different experimental circumstances provides information on the production mechanism in high energy hadron-hadron collisions.

The similarity of many features (average charged multiplicities, limited transverse momenta (p_T) of produced particles, etc.) of hadron-hadron interactions to those seen in e^+e^- annihilations at high energies [1,2] and in deep inelastic neutrino scattering off nucleons [3] suggests that although mechanisms of quark production are different, there is a universal quark-parton picture unifying all of these processes. The success of quark recombination [4] and quark fragmentation models [5] and models based on Topological Expansion/Dual Unitarization schemes [6] in describing various aspects of low p_T hadron-hadron reactions would suggest that hadrons interact via the interactions of their low momentum (wee) quarks [7] (fig. 1(a)). The remaining fast spectator quarks would then fragment into hadrons resulting in longitudinal jets. The picture of a fast fragmenting quark moving in the direction of the incoming meson in a meson-nucleon reaction resembles the picture of a fragmenting quark produced in leptonic interactions (fig. 1(b)). On the other hand slightly different fragmentation of the di-quark system could give different properties of the backward jets. This leads naturally to studying the properties of hadrons in the forward and backward c.m. hemispheres separately^(*).

In this paper we report a study of the charged particle multiplicities in the forward and backward hemispheres for inelastic K^-p interactions at 110 GeV/c. The data were obtained from exposures of the 3.7 m hydrogen bubble chamber (BEBC) to the RF separated, tagged K^- beam from the CERN SPS. Details of the experiment are described in refs [9,10]. The data sample consists of about 11000 inelastic K^-p events. The charged

(*) Present data on charge distributions in meson-nucleon interactions [8] support the idea of the separation of meson and nucleon fragments in forward and backward c.m. hemispheres.

multiplicity distributions in the forward and backward hemispheres are presented in the following section. We compare the high energy meson-nucleon scattering with nucleon-nucleon and lepton induced interactions and try to interpret them in a quark-parton model of hadron-hadron interactions. The correlations between forward and backward multiplicities are discussed in sect. 3.

2. FORWARD AND BACKWARD HEMISPHERE MULTIPLICITIES

The multiplicity distributions for charged particles in the forward and backward c.m. hemispheres are presented in fig. 2, showing that there are more particles going forward than backward, as was previously observed in π^+p interactions at 8, 16 and 23 GeV/c [11] and in π^-p interactions at 40 GeV/c [12]. The values of the average charged multiplicity and corresponding dispersions are given in table 1 for the total samples and for the forward and backward hemisphere separately, $\langle n_{TOT} \rangle$, $\langle n_F \rangle$ and $\langle n_B \rangle$ respectively.

In fig. 3 the mean multiplicity of forward going particles, $\langle n_F \rangle$, for a given total charged multiplicity n_{TOT} is presented. The figure indicates that for all n_{TOT} (except 2 prongs) the distributions are not symmetric about $\langle n_F \rangle = 1/2 n_{TOT}$. For low multiplicity events the difference between the properties of diffraction dissociation of protons and mesons can be responsible to some extent for this effect. To investigate the influence of the diffractive components on the forward and backward multiplicities, we removed from our sample all events having a charged track with $|x| > 0.85$, where x is the Feynman variable defined as $x = 2 p_L / \sqrt{s}$ (p_L is the longitudinal c.m. momentum of the particle and $\sqrt{s}$ is the total c.m. energy). This removes the bulk of the diffraction dissociation events [1,8]. As shown in table 1, the difference $\langle n_F \rangle - \langle n_B \rangle \approx 0.6$ persists indicating that this difference is not simply due to diffractive processes.

In a quark-parton picture of meson-nucleon interactions as mentioned in the previous section, the forward going particles come from the fragmentation of a quark or antiquark and the backward going particles from

the fragmentation of a di-quark. In e^+e^- annihilation at high energies hadrons are produced in two back to back jets arising from the fragmentation of the produced quark-antiquark pair. Similarly in $\nu(\bar{\nu})p$ interactions the hadrons produced forward in the hadronic c.m. system are thought to be produced by the fragmentation of a u (d) quark. If the fragmentation process is independent of the production mechanism and the charged multiplicity of the fragmentation process is independent of the quark flavour then we would expect the following relationship to hold, when comparing the reactions at the same c.m. energy

$$\langle n_F \rangle \approx 1/2 \langle n_{e^+e^-} \rangle \approx \langle n_F^{\nu} \rangle \approx \langle n_F^{\bar{\nu}} \rangle \quad (1)$$

where $\langle n_{e^+e^-} \rangle$ is the average charged multiplicity in e^+e^- annihilation and $\langle n_F^{\nu} \rangle$, $\langle n_F^{\bar{\nu}} \rangle$ the average charged multiplicity in the forward direction in the hadronic c.m. system in νp and $\bar{\nu} p$ reactions. With similar assumptions $\langle n_B \rangle$ in meson-nucleon interactions can be compared with diquark fragmentation in nucleon-nucleon collisions or $\nu(\bar{\nu})p$ interactions, suggesting the approximate relationship

$$\langle n_B \rangle \approx 1/2 \langle n_{pp} \rangle \approx \langle n_B^{\nu} \rangle \approx \langle n_B^{\bar{\nu}} \rangle \quad (2)$$

at the same hadronic c.m. energy.

In fig. 4 we plot $\langle n_F \rangle$ and $\langle n_B \rangle$ for various meson-proton interactions as a function of s . For $s \gtrsim 50 \text{ GeV}^2$ we note that the difference $\langle n_F \rangle - \langle n_B \rangle$ is approximately constant. To check the above relations we also show in fig. 4(a) the distributions of $1/2 \langle n_{e^+e^-} \rangle$ and $1/2 \langle n_{e^+e^-} \rangle$ [2]. Fig. 4(b) shows the same data but with the e^+e^- results replaced by the forward and backward neutrino results. From fig. 4 we see that relationship (1) is approximately satisfied. However the $\langle n_F \rangle$ for meson-nucleon reactions lie systematically below the lepton data. This effect can be at least partially attributed to the presence of low multiplicity diffractive dissociation processes in the hadronic reactions. Indeed the result of $\langle n_F \rangle$ for the non diffractive sample of our data (as defined above), shown by a star in fig. 4, is in excellent agreement with $1/2 \langle n_{e^+e^-} \rangle$. We conclude that at the higher energies the forward meson-nucleon data are in good agreement with this simple quark-parton picture.

We also observe general agreement with the relationship (2) between the backward average multiplicities and $1/2 \langle n_{pp} \rangle$. The difference between $\langle n_F \rangle$ and $\langle n_B \rangle$ can be interpreted as evidence for the different properties of quark and diquark fragmentation, originating mainly from the high probability of producing a leading nucleon in a diquark jet^(*) (fig. 1). However we note that the relationship $\langle n_B \rangle = 1/2 \langle n_{pp} \rangle$ is expected to hold in all factorised fragmentation models and therefore cannot be taken as strong evidence for a quark-parton mechanism of hadron-hadron interactions. Further at present energies we expect some overlap of particles from the forward and backward jets in the central rapidity region [8]. The agreement of the factorization relation (2) for meson-nucleon and nucleon-nucleon reactions at higher energies indicates that this overlap does not bias the measured multiplicities of particles in jets. Approximately the same number of particles "spill over" from the forward to the backward hemisphere as in the opposite direction. The "spill over" should however give rise to correlations between the number of particles observed in the forward and in the backward hemisphere. This effect will be discussed in the next section.

3. FORWARD-BACKWARD MULTIPLICITY CORRELATIONS

To examine the correlations between particles produced in the forward and backward hemispheres the mean charged multiplicity in one hemisphere is plotted against the charged multiplicity in the opposite hemisphere (fig. 5). The low values for the average multiplicity in one hemisphere for low odd topologies in the other hemisphere is due to the influence of diffractive processes. Using the diffraction free sample (as defined in sect. 2) yields a smooth variation as a function of n_F or n_B (the open points in fig. 5). There are significant correlations between the multiplicities. To study in more detail the properties of these correlations the particles are assigned to the central region if $|x| < 0.1$. If $|x| > 0.1$ the particles are considered as "fast". In

(*) This possibility was considered in more detail in pp reactions [13,14] leading to the conclusion that quark and diquark fragments are indeed similar after the subtraction of leading nucleon effects.

fig. 5 the corresponding multiplicities are plotted. There are no correlations between fast particles in opposite hemispheres. The multiplicities of charged particles in the central region are strongly correlated. The same effect was seen in pp interactions at 205 GeV/c [17] and interpreted in a cluster model of hadron production.

Following ref. [18] we have fitted the dependence of the mean multiplicity in one hemisphere on the charged multiplicity in the opposite hemisphere with the linear formula

$$\langle n_F \rangle = a + b n_B \quad (3)$$

where a and b are fitted parameters [18]. Using the non-diffractive sample we obtain $a_F = 3.70 \pm 0.07$, $b_F = 0.09 \pm 0.02$ and $a_B = 3.02 \pm 0.07$, $b_B = 0.08 \pm 0.02$ for the mean forward and backward multiplicity respectively.

Recently the forward-backward correlations were calculated under the assumption that in hadron-hadron collisions the fast spectator quarks and di-quarks form two "super-clusters" moving in the forward and backward directions [19]. The overlap of particles from these super-clusters gives rise to the correlations. The fraction of particles from a forward (backward) super-cluster going backward (forward), δ , is calculated as specified in ref. [20]. For our data we obtain the overlap $\delta = 0.19$. If the two super-clusters are independent and if strong long range correlations dominate within each super-cluster then forward-backward correlations in forward-backward symmetric pp collisions are given by the approximate formula [19]

$$\langle n_F \rangle = \frac{\delta}{2 - \delta} n_B + \frac{1 - \delta}{2 - \delta} \langle n_{TOT} \rangle \quad (4)$$

where $\langle n_{TOT} \rangle$ is the average total charged multiplicity. The parameters a and b of the linear formula (3) are then predicted by this model. For our K^-p data formula (4) should be slightly modified to allow for the observed asymmetry of forward and backward mean multiplicities

$$\langle n_F \rangle = \frac{\delta}{2 - \delta} n_B + \frac{1 - \delta}{2 - \delta} (\langle n_{TOT} \rangle + c) \quad (5)$$

$$\langle n_B \rangle = \frac{\delta}{2 - \delta} n_F + \frac{1 - \delta}{2 - \delta} (\langle n_{TOT} \rangle - c) \quad (6)$$

where the additional parameter c measures the difference between the mean multiplicity of a quark and a di-quark super-cluster. The parameter b of formula (3) depends only on the overlap δ . For $\delta = 0.19$ we obtain $b = 0.11$ in good agreement with the experimental values both for the forward and the backward hemisphere. Using the values of the parameters a_F and a_B from the non-diffractive sample we obtain $c = 0.66 \pm 0.07$.

We conclude that our data are consistent with the model and within this model the mean multiplicity of a quark jet in K^-p interactions at 110 GeV/c is about 0.7 higher than the mean multiplicity of a di-quark jet.

4. CONCLUSIONS

The results from the study of forward and backward charged multiplicity distributions in K^-p inelastic interactions at 110 GeV/c show qualitative agreement with a quark-parton picture of low p_T hadron-hadron interactions. The average forward charged multiplicity in meson-nucleon interactions is approximately equal to one half of the average charged multiplicity in e^+e^- annihilations at the same c.m. energy and, at the higher energies, not inconsistent with the average forward charged multiplicity in $\nu(\bar{\nu})p$ interactions. This charged multiplicity of a quark jet does not depend significantly on the production process or the quark flavour. Our results confirm that the properties of hadrons in meson-nucleon scattering should be studied separately in the forward (quark fragmentation) and in the backward (di-quark fragmentation) c.m. hemispheres. The observed correlations between the number of slow particles in the forward and the backward c.m.s. hemisphere are well described by the "super-cluster" model. We estimate the mean multiplicity of a quark jet in K^-p interactions at 110 GeV/c to be about 0.7 higher than the mean multiplicity of a di-quark jet.

We gratefully acknowledge the contributions made by the BEBC staff, the members of EF Divisions, CERN who worked on the S3 beam and tagging system, and the scanning, measuring and computing staffs at our laboratories.

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TABLE 1

Parameters of distributions of the total charged multiplicity and multiplicities in the forward and backward hemisphere for the total sample and for the non-diffractive sample

	Total sample	Non-diffractive sample
$\langle n_{\text{TOT}} \rangle$	6.91 ± 0.07	7.37 ± 0.08
D_{TOT}	3.18 ± 0.04	3.08 ± 0.04
$\langle n_{\text{F}} \rangle$	3.75 ± 0.03	4.01 ± 0.03
$D[n_{\text{F}}]$	2.14 ± 0.03	2.17 ± 0.03
$\langle n_{\text{B}} \rangle$	3.16 ± 0.03	3.37 ± 0.04
$D[n_{\text{B}}]$	2.04 ± 0.03	2.06 ± 0.03

FIGURE CAPTIONS

Fig. 1 (a) Meson-nucleon scattering in a quark-parton picture. Two high momentum hadron jets come from fragmentation of fast (spectator) quarks or di-quarks.

(b) Two hadron jets production in e^+e^- annihilation in a quark-parton picture.

Fig. 2 The charged multiplicity distributions in the forward and backward c.m. hemisphere for inelastic K^-p interactions at 110 GeV/c.

Fig. 3 For each total charged multiplicity, the average number of charged particles $\langle n_F \rangle$ in the forward c.m. hemisphere.

Fig. 4 Average number of charged particles in the forward (backward) c.m. hemisphere versus total c.m. energy squared.

(a) The data for meson nucleon scattering are compared with one half of the mean charged hadron multiplicity in e^+e^- annihilation computed using the best fit to the e^+e^- data [2] and with one half of the mean total charged multiplicity in pp interactions [21]. The mean forward multiplicity for the non-diffractive sample in K^-p interactions at 110 GeV/c is denoted by a star.

(b) The data for meson nucleon scattering are compared with ν and $\bar{\nu}$ data [15,16]

Fig. 5 Average number of charged particles in the forward (backward) c.m. hemisphere versus the number of charged particles in the backward (forward) hemisphere for the total sample and for particles in the central ($|x| < 0.1$) and outward ($|x| > 0.1$) regions of the hemispheres. The mean multiplicities for non-diffractive sample are denoted by open circles. The lines are fits to formula (4).

Fig.1

Fig.2

Fig.3

Fig.5