CHARGE ASYMMETRY IN π^{-}p INTERACTIONS AT 40 GeV/c AS A FUNCTION OF CHARGED MULTIPLICITY AND TRANSVERSE MOMENTUM

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The asymmetry between average charged multiplicities in the forward and backward c.m. hemispheres is studied in π^{-}p interactions at 40 GeV/c. Also the asymmetry in the spectra of secondary pions $d\sigma_{\pi}/dP_{||}$ is examined. Both phenomena are found to have practically the same dependence on n_{ch} and $P_{\perp}$. This is indicative of their common origin.

From studies of the reaction $\pi^{-}p \to \pi^{\pm}\ldots$ at 25 GeV/c Elbert, Erwin and Walker have found [1] that the gross asymmetry observed in the c. m. longitudinal momentum distribution $d\sigma_{\pi}/dP^{*}_{||}$ of secondary charged pions (the spectral asymmetry) essentially vanishes in the reference frame, where the momenta of the incident particles are related as $\vec{P}_{\pi} = -\frac{2}{3}\vec{P}_{p}$, that is in the quark centre-of-mass system.

The result of paper [1] was confirmed in a number of later experiments [2] and stimulated further discussion of the quark model for multiparticle production [3, 4].

Later on from investigations of π^{-}p interactions at 40 GeV/c it was observed that there was another effect, presumably of the same nature, namely the charge asymmetry, i. e. the asymmetry between average multiplicities of charged particles in the forward and backward c. m. hemispheres [5]. The common origin of the charge asymmetry and spectral asymmetry of secondary pions was demonstrated by comparing the dependence of both effects on charged multiplicity.

In this paper we present the data on these effects, based on higher statistics, and investigate their dependence on the transverse momenta of secondaries.

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This experiment has been performed with the Dubna 2 m propane bubble chamber exposed to a 40 GeV/c π^- beam from the Serpukhov accelerator. We have used the same event selection criteria as in paper [6], and the total number of events is 12736 for π^-p inelastic interactions. We identified slow protons in the chamber with $P^{\rm LAB} \lesssim 0.7$ GeV/c by ionization. The rest of the particles were considered as pions. The kaon and hyperon contamination was about 4–5%, and approximately 15% of the "positive pions" were misidentified fast protons [7].

We have obtained the following values for the average charged multiplicities in the forward (F) and backward (B) c. m. hemispheres[1]:

$$\left.\begin{aligned} \langle n_{\rm ch}\rangle_{\rm F} &= 2.96\pm0.016 \\ \langle n_{\rm ch}\rangle_{\rm B} &= 2.50\pm0.014 \end{aligned}\right\} \text{c.m.s.} \tag{1}$$

Thus one sees that there is a considerable charge asymmetry between the forward and backward hemispheres:

$$\left.\begin{aligned} \langle n_{\rm ch}\rangle_{\rm F}-\langle n_{\rm ch}\rangle_{\rm B} &= 0.46\pm0.02 \\ A = \frac{\langle n_{\rm ch}\rangle_{\rm F}-\langle n_{\rm ch}\rangle_{\rm B}}{\langle n_{\rm ch}\rangle_{\rm F}+\langle n_{\rm ch}\rangle_{\rm B}} &= 0.084\pm0.004 \end{aligned}\right\} \text{c.m.s.} \tag{2}$$

Here A denotes the asymmetry coefficient. The errors in Eqs. (1) and (2) are purely statistical. Besides, there is a systematic effect related to the misidentification of some protons as positive pions. This effect enhances A, and we have estimated its contribution to A as $+0.026$ [5].

From the point of view of the naive quark model the forward-backward asymmetry of charged particles may be explained in the following way. For quark–quark collision the c. m. s. momentum of a quark from the incident pion is 3/2 times as large as that of the incident proton quark. Hence the quark centre-of-mass system (q. s.) moves in the direction of the primary pion (for high energies $Y_{\rm q.s.}-Y_{\rm c.m.s.} \approx 0.5 \ln \frac{3}{2} \approx 0.2$). If the quark–quark collision is the case, one expects to observe the symmetry in the q. s. For the q. s. we obtain

$$\left.\begin{aligned} \langle n_{\rm ch}\rangle_{\rm F} &= 2.65\pm0.015 \\ \langle n_{\rm ch}\rangle_{\rm B} &= 2.80\pm0.015 \\ A &= -0.028\pm0.004 \end{aligned}\right\} \text{q.s.} \tag{3}$$

From (3) we see that in this system the charge asymmetry decreases significantly (by a factor of three) and changes its sign. We have found that this is due to the high multiplicity events.

The A values for a given multiplicity $n_{\rm ch}$ are shown in Fig. 1. It is seen that in the centre of mass the charge asymmetry is close to 0.1 up to $n_{\rm ch} = 8$, and then it decreases sharply to zero and even becomes negative. In the quark system $A = 0$ for $n_{\rm ch} = 6$, i. e.

[1] These data were obtained for events, where all of the charged secondary particles were measured.

just in the region of the average multiplicity, $n_{ch} \sim \langle n_{ch} \rangle$, where most of the events occur. For larger n_{ch}, $A < 0$ whereas for $n_{ch} = 2,4$ A is positive.

The contribution of higher multiplicity events appears to be greater than that of low multiplicities since the total value of the charge asymmetry is negative.

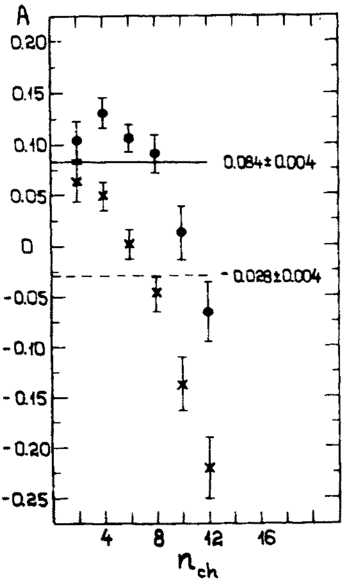

Fig. 1. Dependence of the asymmetry coefficient A on the charged multiplicity n_{ch}. The straight lines show the average values of A. The black circles and the solid line correspond to the c.m.s.; the crosses and the dashed line correspond to the quark system

In order to show that the forward-backward charge asymmetry depends on n_{ch} in the same way as the spectral asymmetry of secondary pions [1], we present in Table I the n_{ch} dependence of the R parameter. It is defined as the ratio of the absolute magnitudes of the incident proton and pion momenta in the system, where the symmetry exists either in the secondary pion spectra $d\sigma_\pi/dP_{||}$ in the interval $-1 \leqslant P_{||} \leqslant 1$ (R_{spectral}) or in the

TABLE I

The charged multiplicity dependence of $R_{\text{F-B}}$ and R_{spectral}

n_{ch}	$R_{\text{F-B}}$	R_{spectral}
2	2.61 ± 0.45	$2.6\,^{+2.5}_{-1.5}$
4	1.91 ± 0.10	1.98 ± 0.35
6	1.51 ± 0.05	1.56 ± 0.14
8	1.29 ± 0.04	1.32 ± 0.13
10	1.04 ± 0.04	1.08 ± 0.13
$\geqslant 12$	0.83 ± 0.04	0.79 ± 0.15
Total	1.35 ± 0.03	1.34 ± 0.06

average numbers of charged hadrons going in the forward and in the backward directions ($R_{\text{F-B}}$).

To obtain R_{spectral}, we searched the frame, where $d\sigma_\pi/dP_{||}$ of the forward π^+ and of the backward π^- mesons are symmetric. Following Ref. [1] we considered the spectra to be symmetric when the χ^2 function achieved its minimum. The χ^2 function was defined as

$$\chi^2 = \sum_{i=1}^{20} \frac{(\sigma_i^+ - \sigma_i^-)^2}{(\delta_i^+)^2 + (\delta_i^-)^2},$$

where σ_i^+ and σ_i^- are the cross sections for production of π^+ and π^- in the i-th interval of $|P_{||}|$, respectively, and δ_i^+ and δ_i^- are the statistical errors in σ_i^+ and σ_i^-. We computed χ^2 for $0 \leqslant |P_{||}| \leqslant 1$ GeV/c using bins 0.05 GeV/c wide. The errors in R_{spectral} were determined by permitting χ^2/N.D.F. to deviate from χ^2_{min}/N.D.F. by unity.

As seen from Table I, for all multiplicities the values of $R_{\text{F-B}}$ and R_{spectral} are the same within the errors. This means that the spectral asymmetry and the forward-backward charge asymmetry are apparently the phenomena of the same origin. However, the values of $R_{\text{F-B}}$ are more precise than those of R_{spectral}. In the spectral case there is an additional uncertainty related to the choice of the interval in $P_{||}$.

TABLE II

Dependence of $R_{\text{F-B}}$ and R_{spectral} on the transverse momenta $P_\perp$ of charged secondaries and charged pions, respectively

$P_\perp$ (GeV/c)	$R_{\text{F-B}}$	R_{spectral}
0—0.2	1.15±0.045	1.24±0.17
0.2—0.6	1.30±0.037	1.32±0.13
0.6—1.0	1.35±0.08	1.36±0.22
>1.0	1.42±0.16	1.51±0.45

Next, we compare the dependence of $R_{\text{F-B}}$ and R_{spectral} on the transverse momenta of charged secondaries. The results are given in Table II. Similar to Table I, $R_{\text{F-B}}$ and R_{spectral} coincide within the errors in each interval of $P_\perp$. But again the errors in $R_{\text{F-B}}$ are substantially smaller.

The $P_\perp$ dependence of $R_{\text{F-B}}$ is illustrated by Fig. 2. The value of $R_{\text{F-B}}$ is seen to increase with $P_\perp$. This is consistent with the notion that the secondaries with large transverse momenta come from the hard direct collisions of the incident quarks. The fall-off of R towards low $P_\perp$ seems to be of the same nature as the similar effect of the decrease in R with increasing charged multiplicity (see Table I). A possible explanation of this effect in the framework of the quark model has been discussed in Ref. [5].

In conclusion we would like to notice that at least two explanations for both of the above discussed kinds of asymmetry characteristic of particle production in π^-p interactions are possible: a difference in the fragmentation of a pion and a proton or some effect, related to the central region, of the sort predicted by the quark model. At present we cannot distinguish between the two possibilities. Nevertheless, apart from the actual nature of the spectral and charge asymmetries our results reveal the same dependence of both effects on n_{ch} and $P_{\perp}$ and thus demonstrate their common origin.

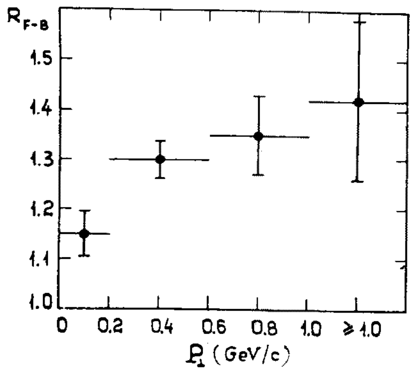

Fig. 2. $R_{F\text{-}B}$ versus the transverse momenta of charged secondaries

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