Distribution of charge in π^+p interactions at 15 GeV/c

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Inclusive and semi-inclusive distributions of charge from a 15-GeV/c π^+p experiment are presented in terms of the Feynman variable x and the transverse momentum $p_\perp$. The charge distributions are found to have different n_{ch} and $p_\perp$ dependences in different kinematic regions. Our distributions are compared to similar ones calculated from published single-particle distributions in π^-p and pp experiments at several energies.

The study of electric-charge distributions in hadronic collisions was first suggested by Van Hove[1] and their importance has since been recognized by several authors.[2-6] Although charge distributions are relatively easy to determine (they are projections of the average charge in different kinematic variables), surprisingly little systematic information is available on the experimental distribution of charge in different reactions and at different energies. In this note, we present inclusive and semi-inclusive distributions of charge from π^+p interactions at 15 GeV/c. The variables used to present our data are the Feynman variable, $x = 2p_\parallel^{\text{c.m.}}/\sqrt{s}$, and the transverse momentum, $p_\perp$.

The data used in this analysis are derived from an 866 000-picture exposure of the Stanford Linear Accelerator Center 82-in. hydrogen bubble chamber to an rf-separated 15-GeV/c π^+ beam.[7] All tracks of all relevant interactions in the exposure were measured on the Columbia University HPD operating in an automatic pattern-recognition mode. About 750 000 events were measured and subsequently processed by an event-finding program followed by three-dimensional geometrical reconstruction.

For the purpose of this analysis, we considered all positive tracks with momenta below 1.4 GeV/c to be protons if they were so identified by the scanners on the basis of relative ionization. All other positive and negative tracks were regarded as pions. A study of four-constraint fits indicated that the scanners' proton identification was correct in ~99% of the cases for protons below 1.4 GeV/c. The $K^\pm/\pi^\pm$ ratio was estimated from a measurement of inclusive K_S^0 production, assuming equal cross sections for charged- and neutral-kaon production, and from a study of four-prong, four-constraint events. Both methods indicated that

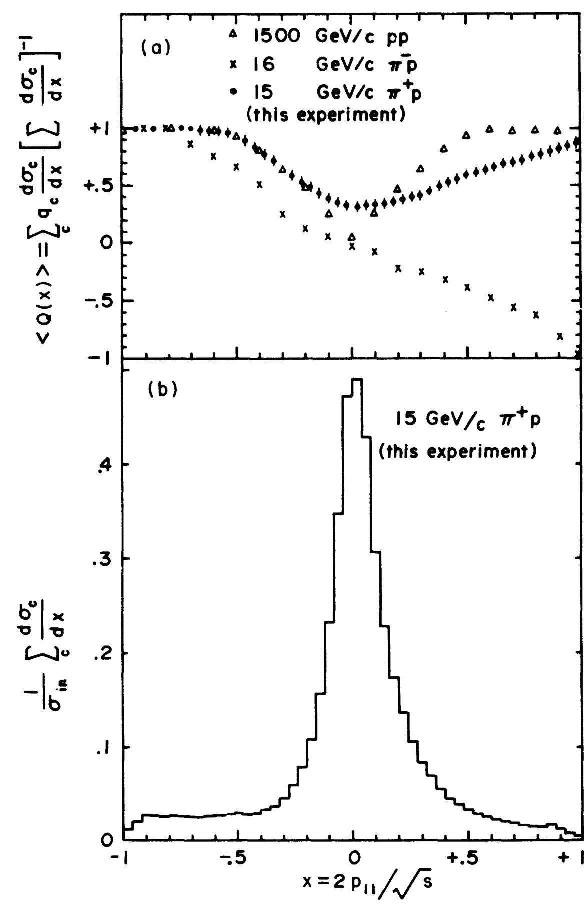

FIG. 1. (a) The inclusive distribution of charge in x. No errors have been estimated for the π^-p and pp distributions. Statistical errors are shown for our data. The K^+, K^-, and $\bar{p}$ spectra have been included where available. (b) The x distribution of the average charged multiplicity in our experiment.

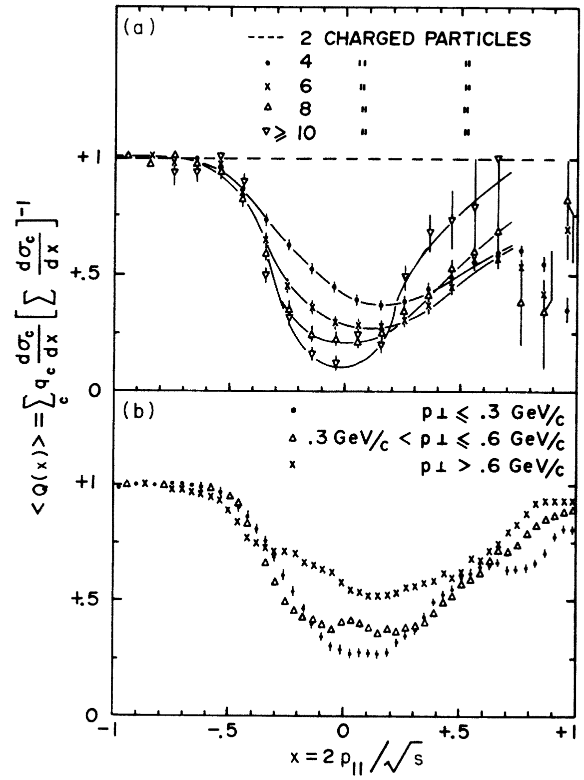

FIG. 2. (a) The semi-inclusive distributions of charge in x. Smooth curves have been drawn through points belonging to the same topology. (b) The contribution of different $p_\perp$ domains to the inclusive distribution of charge in x. No error bars are shown if they are smaller than the indicated points.

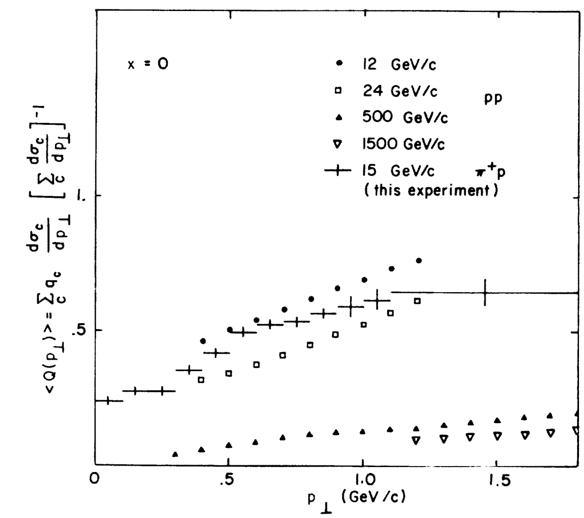

FIG. 3. The inclusive distribution of charge in $p_\perp$ at $x=0$. The pp distributions have been calculated from Refs. 12 and 13. The K^+, K^-, and $\bar{p}$ spectra have been included where available.

~ 3% of the pion sample was kaons. The latter method also indicated that less than 1% of the pion sample was pair-produced protons and antiprotons. From a study of the momentum dependence of the scanners' efficiency for recognizing protons, we estimated that ~5% of the positive particles taken as pions were, in fact, protons not identified by ionization. The effect of this mass uncertainty on our distributions is small ($p_\perp$ is nearly independent of the mass assumed for the particle), and it does not affect the general results of our analysis.

After removing elastic-scattering events, there were 413 906 events left, with 163 137 protons, 1 078 896 π^+, and 414 221 π^-. Each event was given a weight to compensate for differences between measuring efficiencies for different topologies. This sample was used to isolate the inclusive reactions:

$$\pi^+ p \to c + \text{anything} \tag{1}$$

where c can be a proton, π^+, or π^-.

We have studied the charge distribution defined as[6,8]

$$\langle Q(k)\rangle = \sum_c q_c \frac{d\sigma_c}{dk}\left(\sum_c \frac{d\sigma_c}{dk}\right)^{-1} \tag{2}$$

where k is a kinematic variable, $d\sigma_c/dk$ is the differential cross section for reaction (1), q_c is the charge of particle c, and the sum is restricted to charged particles only. The quantity $\langle Q(k)\rangle$ is the average charge of a charged particle produced at the value k of the kinematic variable. If no neutral particles are included in the sum, $\langle Q(k)\rangle$ is a measure of the charge asymmetry in the given kinematic region.

The inclusive charge distribution $\langle Q(x)\rangle$ is shown in Fig. 1(a). For comparison, we also show the same distribution from $\pi^- p$ interactions at 16 GeV/c and pp interactions at 1500 GeV/c which we have calculated from published data.[2]

Before the interaction, all charge is concentrated at $x=+1$ and $x=-1$. In the final state, the over-all average charge is

$$\langle Q\rangle = Q_{\text{Initial}}/\langle n_{\text{ch}}\rangle\ . \tag{3}$$

For our experiment, $\langle n_{\text{ch}}\rangle = 4.48 \pm 0.03$, which yields $\langle Q\rangle \simeq 0.45$. If there is no correlation between the variable x and the charge of the produced particles, the average charge should be 0.45 at any x.

The experimental distributions have considerably more structure. Some features seem to be present independent of the nature of the interacting particles or the energy of the interaction: (i) The average charge of the beam and the target fragments is close to the charge of the beam and the target particles. (ii) The average charge of particles produced in the central region is small.

From Fig. 1(a), it is also evident that the charge distribution for $x < -0.2$ does not change much between 15-GeV/c π^+p and 1500-GeV/c pp interactions. The π^-p distribution is systematically lower above $x = -0.8$. [The charge distributions for π^-p and pp in Fig. 1(a) have large errors–not shown–since we obtained them by reading published graphs of single-particle distributions.] One would expect all three distributions to reach asymptotically the same limiting shape in the proton-fragmentation region if zero charge exchange between the right and left hemispheres should become dominant, as predicted by certain fragmentation and multiperipheral models.[9,10]

From our π^+p data, we note that the average charge of proton fragments is higher than that of pion fragments; in fact, it is quite close to $+1$ for $x < -0.6$. This suggests that the proton is a more tightly bound object than the pion. A similar observation regarding protons and kaons has been made from the distribution of "net charge" in K^-p interactions.[3]

In Fig. 1(b), the average charged multiplicity is plotted as a function of x. Multiplying $\langle Q(x)\rangle$ by the average charged multiplicity in each bin, one gets the x distribution of "net charge"[2,3]: dQ/dx (not shown). Since most particles are produced in the central region and only a few near $|x| = 1$, dQ/dx has a large maximum at $x = 0$ and is very small at $|x| = 1$. Thus, dQ/dx reflects the distribution of charge over a large number of collisions, rather than the average charge distribution in any single interaction.

Next, we consider the contribution of different topologies and different $p_\perp$ domains to $\langle Q(x)\rangle$.

The semi-inclusive charge distributions are shown in Fig. 2(a). Statistical errors are considerably higher in the forward direction, especially in the higher charged multiplicities. The charge distribution clearly decreases with n_{ch} at $x = 0$, while for $x > +0.2$ it has a general upward tendency. For $x < -0.6$, $\langle Q(x)\rangle$ is close to $+1$ in all topologies.

While the decrease of the over-all average charge with n_{ch} is readily explained by relation (3), it is interesting to note that only the centrally produced particles follow this trend, while beam and target fragments have an average charge close to $+1$. This can be interpreted as an indication that secondary particles are the result of two different mechanisms[11]: fragmentation of the incident particles plus central production of particle-antiparticle pairs. The observed distributions are then the result of the superposition of the two spectra.

An investigation of the $p_\perp$ dependence of $\langle Q(x, p_\perp)\rangle$ shows the overall tendency of the charge distribution to increase with increasing $p_\perp$ [Fig. 2(b)]. The effect is most pronounced near $x = 0$, where it is essentially controlled by the π^+/π^- ratio. A similar behavior of the π^+/π^- ratio has been observed in pp interactions at higher energies.[12]

In order to study the $p_\perp$ dependence at $x = 0$, we plot in Fig. 3 $\langle Q(x = 0, p_\perp)\rangle$ from our experiment, together with the same distribution which we have calculated from published fits to single-particle distributions[12,13] from pp collisions at several energies. For our data we have used the interval $|x| < 0.02$. From Fig. 3, we see that $\langle Q(p_\perp)\rangle$ increases with $p_\perp$ and decreases with $\sqrt{s}$, and that there is little difference, if any, between π^+p and pp data.

The observed energy dependence is due to the approach to unity of the particle-to-antiparticle ratio with increasing energy at $x = 0$, a feature embodied in most theories. The increase with $p_\perp$ of the average charge at $x = 0$ disagrees with the multiperipheral model which predicts local compensation of charge in large-$p_\perp$ events,[14] but it is in qualitative agreement with the parton model. Regarding large-$p_\perp$ events as the result of hard collisions between constituents of the initial particles,[15] one would expect more positive than negative particles to be produced at large $p_\perp$ in π^+p and pp interactions, since there should be more positive than negative partons in the initial state. By the same argument, the average charge of particles produced at $x = 0$ in π^-p interactions should be quite close to zero even at high $p_\perp$. This is also confirmed experimentally.[16]

In conclusion, we have found that the average charge of particles produced in the forward and backward directions is close to the charge of incoming particles, while centrally produced particles have a small average charge (~ 0.3 in our experiment), which is decreasing with energy. The distribution of charge was found to have different n_{ch} and $p_\perp$ dependences in different kinematic regions. The average charge of particles produced near $x = 0$ is decreasing with n_{ch} and increasing with $p_\perp$, whereas for $x > +0.2$ the average charge is increasing with $p_\perp$ as well as with n_{ch}. The average charge of proton fragments is close to $+1$ in all distributions. These results are suggestive of the production of secondary particles by two competing reaction mechanisms. The observed $p_\perp$ dependence is in qualitative agreement with the parton picture of large-$p_\perp$ phenomena.

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$$\frac{dQ}{dk} = \frac{1}{\sigma}\sum_c q_c \frac{d\sigma_C}{dk}.$$

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