Charged Multiplicities of High-Mass Diffractive $\pi^{\pm}$, $K^{\pm}$, and $p^{\pm}$ States

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A measurement is reported of charged multiplicity distributions of high-mass diffractive $\pi^{\pm}$, $K^{\pm}$, and $p^{\pm}$ states produced in 100 and 200 GeV/c hadron-proton collisions, $h+p \to X+p$. The distributions are described well by a Gaussian function that depends only on the available mass $M=M_x-M_h$, has a maximum at $n_0 \cong 2M^{1/2}$, and a peak-to-width ratio $n_0/D \cong 2$.

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We have measured the charged multiplicities of the diffractive states X produced in the reaction

$$h+p \to X+p \quad (h=\pi^{\pm}, K^{\pm}, p^{\pm}) \tag{1}$$

at incident beam momenta of 100 and 200 GeV/c in the kinematic range $0.025<|t|<0.095$ (GeV/c)^2 and $1-x \cong (M_x^2-M_h^2)/s<0.1$, where t is the square of the four-momentum transfer, M_x is the hadron excitation mass, and x is the Feynman scaling variable. These measurements were performed in the course of experiment E-396 at Fermilab. Results from this experiment on the M_x^2 distribution and on the factorization properties of reaction (1), reported previously,[1] shed light on the production dynamics of the high-mass diffractive states, in particular on the role of the triple Pomeron coupling. The charged multiplicities provide insight into their decay mechanism. In this report, we present the data and describe their general characteristics. In the following Letter[2] we relate the diffractive multiplicities to hadronic multiplicities in general.

The experiment was performed in a tagged hadronic beam, the M6W beam line. The apparatus (Fig. 1), which is described in detail in previous publications discussing the elastic scattering[3] and the diffraction dissociation[1] results, consisted of a gas H_2 target at atmospheric pressure and a detector that measured the polar angle, θ, and the kinetic energy, T, of protons recoiling from the interaction point. The missing mass was determined, to an accuracy of $\Delta M_x^2/M_x^2=3\%$, from θ, T, and the incident momentum, p_0:

$$M_x^2=M_h^2+2p_0(2m_pT)^{1/2}[\cos\theta-(T/2m_p)^{1/2}]. \tag{2}$$

The charged multiplicities were obtained from the pulse height recorded by two scintillation counters located downstream of the recoil detector. The two counters were cross calibrated using elastic scattering events. Landau fluctuations were reduced by accepting the smaller of the two pulse heights. An example of a pulse-height distribution for a particular M_x^2 bin is shown in Fig. 2. One can see that low multiplicities are well resolved but some overlap occurs at high multiplicities. The pulse-height spectra were fitted to Landau distributions, calculated for each multiplicity, using the maximum likelihood method. The curve in Fig. 2 represents such a fit.

The raw multiplicities obtained in this manner were corrected for background tracks, for extra (accidental) beam particles, and for the acceptance of the multiplicity counters. The background was estimated by using events with negative (unphysical) M_x^2 and was subtracted from

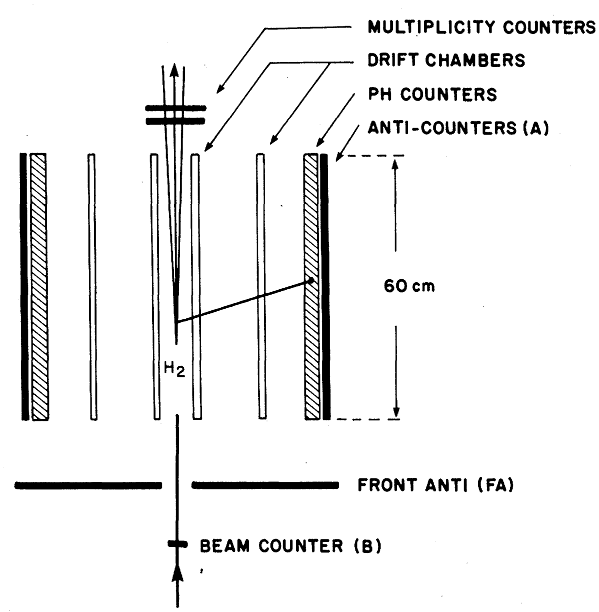

FIG. 1. Apparatus (plan view, to scale).

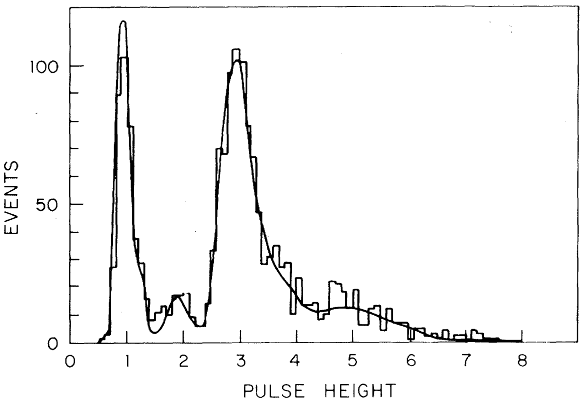

FIG. 2. Multiplicity-counter pulse-height distribution for $\pi^- + p \rightarrow X + p$ at 100 GeV/c and $3 < M_x^2 < 5$ GeV^2. For each event the smaller of the two pulse heights was used.

the topological cross sections at the corresponding positive M_x^2. Negative M_x^2 events are either due to the low side of the resolution tail of the elastic peak or due to random tracks that fulfilled the trigger requirements. The elastic events are symmetric about the peak. The distribution of the random events is flat over the negative M_x^2 region and it is assumed to extend to the positive M_x^2 region. The charged multiplicity of all negative M_x^2 events is mostly $n = 1$ with some $n = 2$. The background subtractions were generally $\lesssim 10\%$. The fraction of events with an extra beam track was measured to be $\lesssim 10\%$ by comparing elastic events with charge 2 to those of charge 1. With the assumption of an isotropic decay distribution in the center of mass of the diffractive state, the calculated average acceptance of the counters is 95%, which agrees well with that estimated from the number of unphysical even-charged multiplicity events caused either by an extra beam track or by a track missing the counters.

The corrected data are presented in Figs. 3, 4, and 5. The following features are noted:

(i) Within the statistical accuracy, the multiplicities of all three hadrons are the same when compared at the same mass available for the production of pions, $M = M_x - M_h$. This would not be true if the comparison were made at the same M_x.

(ii) The average multiplicity increases with M, approximately as $\langle n\rangle \cong 2M^{1/2}$, where M is in gigaelectronvolts, while the ratio $\langle n\rangle/D$, where $D = (\langle n^2\rangle - \langle n\rangle^2)^{1/2}$, remains constant at the value of ~ 2.2 (see Fig. 3). The function $\langle n\rangle = a + b \ln M$ would also provide a good fit to our data but we

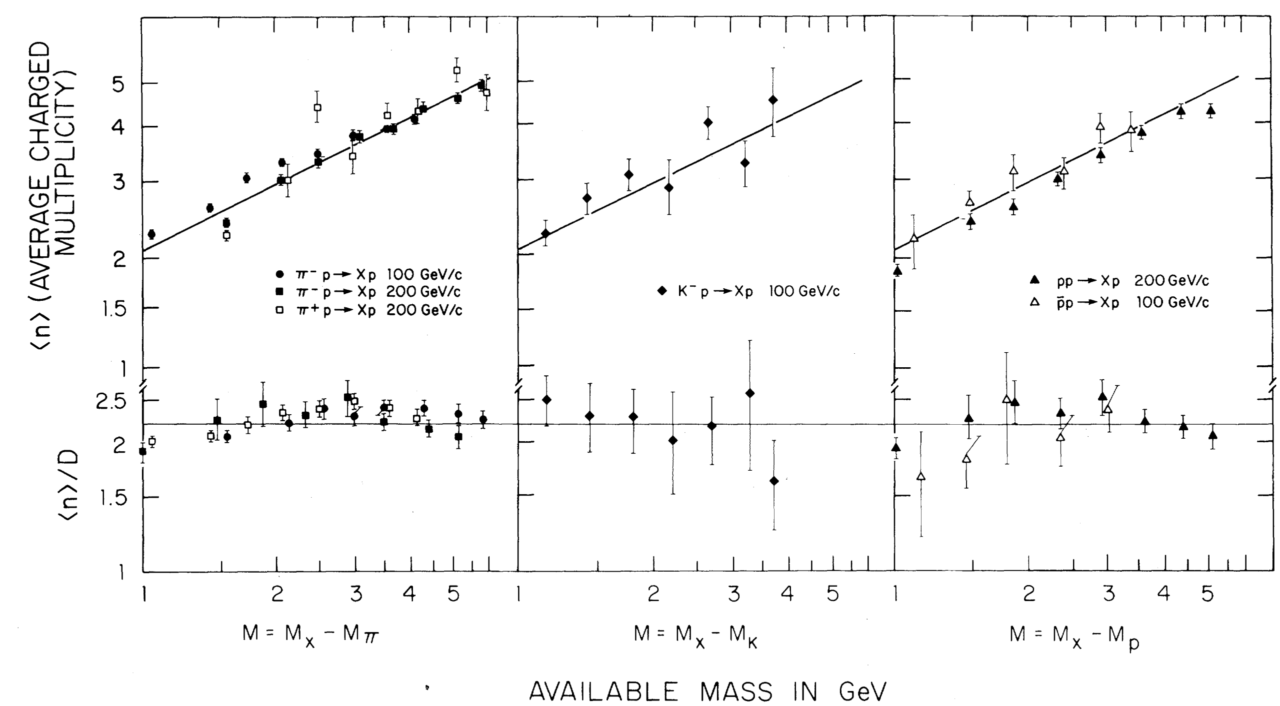

FIG. 3. The average charged multiplicity and the ratio of the average to the width as a function of available mass. The curves represent $\langle n\rangle = 2.08M^{1/2}$ and $\langle n\rangle/D = 2.2$ as discussed in the text.

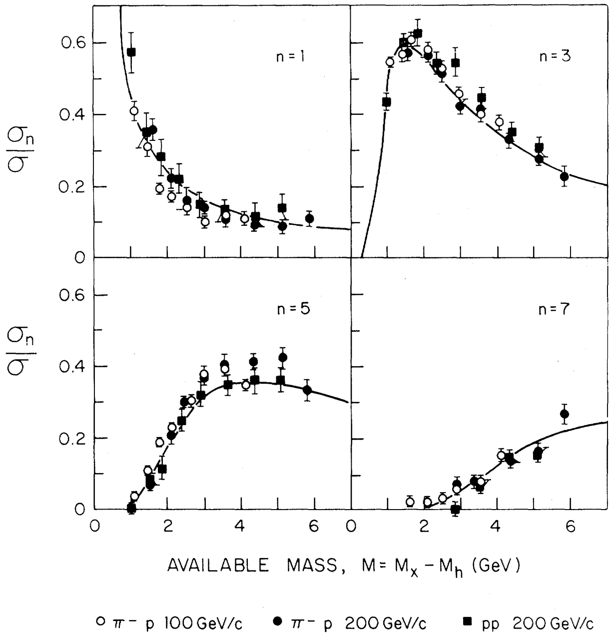

FIG. 4. Topological cross sections σ_n/σ vs available mass for $h + p \rightarrow X + p$ ($h = \pi^-$, p).

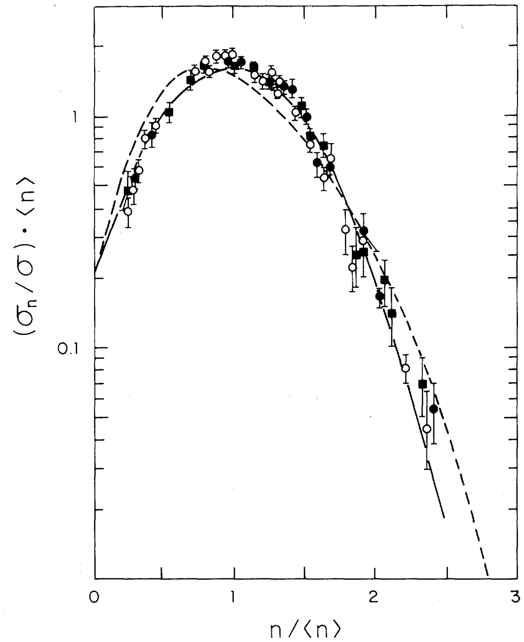

FIG. 5. The product $(\sigma_n/\sigma)\langle n\rangle$ vs $n/\langle n\rangle$ for the data presented in Fig. 4. The solid line represents the Gaussian function discussed in the text [Eq. (4)]. The broken line is from a fit to the inclusive data $h + p \rightarrow$ anything (Ref. 6).

prefer the power dependence because it characterizes the average multiplicity of many processes at higher available energy whereas a simple logarithmic dependence falls too low.[2,4]

(iii) The ratio of the topological cross section σ_n to the total diffractive cross section σ (see Fig. 4) is described well by the Gaussian function

$$\frac{\sigma_n}{\sigma} = P_n = \frac{2}{(2\pi)^{1/2}D}\exp\left(-\frac{(n-n_0)^2}{2D^2}\right), \tag{3a}$$

where

$$n_0 = 2M^{1/2}, \tag{3b}$$

and

$$n_0/D = 2. \tag{3c}$$

The normalization of P_n is such that at any value of M the sum of P_n over odd values of n is unity to within ~1%. In calculating values of $\langle n\rangle$ and D to compare with experimental data, one must sum over positive values of n only. This shifts the average by ~4% above the value of n_0 and the width down by ~6% so that the average multiplicity becomes $\langle n\rangle = 2.08M^{1/2}$ and the $\langle n\rangle/D$ ratio is increased by 10% above the value of n_0/D, to the measured value of 2.2.

The form (3) of the probability function suggests that the multiplicity distributions satisfy Koba-Nielson-Oleson (KNO) scaling[5]; i.e., that the product $P_n\langle n\rangle$ is a function of $n/\langle n\rangle$ only and not a function of M. Indeed, from Eqs. (3a), (3b), and (3c) it follows that

$$P_n n_0 = 1.6\exp[-2(1-n/n_0)^2]. \tag{4}$$

Figure 5 shows $P_n\langle n\rangle$ vs $n/\langle n\rangle$ for the π^-p and the pp data. Ignoring the small differences between $\langle n\rangle$ and n_0, one sees that function (4) represents the data well. In contrast to the fully inclusive reactions[6] $pp \rightarrow$ anything and $\pi p \rightarrow$ anything whose KNO scaling curve, also shown in Fig. 5, is asymmetric and peaks at $n/\langle n\rangle \cong 0.8$, the distribution for the diffractive data is symmetric about the peak at $n/\langle n\rangle = 1$.

Our results for $\langle n\rangle$ and $\langle n\rangle/D$ are in satisfactory agreement with previous data.[7] Multiplicity distributions have been reported[8] only for the FNAL bubble-chamber data. Within our mass range, they are consistent with ours, particularly if one corrects for their large M_x^2 binning, which integrates the data over large variations in average and width and tends to distort their distributions.

In conclusion, we find that the charged multiplicity distributions of high-mass diffractive pion, kaon, and nucleon states follow a universal Gaussian function that depends only on the available mass M, has a peak that varies with M as $n_0 \cong 2M^{1/2}$, and a peak-to-width ratio $n_0/D \cong 2$.

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Universality of Charged Multiplicity Distributions

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It is shown that the charged multiplicity distributions of the diffractive and nondiffractive components of hadronic interactions, as well as those of hadronic states produced in a variety of other reactions, follow a universal function which depends only on the mass available for pionization. This function is Gaussian, peaks at $n_0 \cong 2M^{1/2}$, where M is the available mass in gigaelectronvolts, and has a width $D = (\langle n^2 \rangle - n_0^2)^{1/2}$ such that $n_0/D \cong 2$.

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The preceding Letter[1] reported that the charged multiplicity distributions of high-mass pion, kaon, and nucleon states produced diffractively in the reaction

$$h + p \to X + p \quad (h = \pi^\pm, K^\pm, p^\pm) \tag{1}$$

are described well by a Gaussian function which depends only on the mass available for pion production, $M = M_x - M_h$, as follows:

$$P_n = \frac{2}{(2\pi)^{1/2} D} \exp\left(-\frac{(n-n_0)^2}{2D^2}\right), \quad n_0 = 2M^{1/2}, \quad n_0/D = 2, \tag{2}$$

where $D = (\langle n^2 \rangle - n_0^2)^{1/2}$.

For singly charged hadrons, at any given mass M, the sum of P_n over odd values of n should be normalized to unity. The nominal normalization constant given above is good to ~1%. Koba-Nielson-Oleson (KNO) scaling,[2] which states that the product $P_n \langle n \rangle$ is a function of $n/\langle n \rangle$ only, is manifestly satisfied by Eq. (2), as can be seen by rewriting it as

$$P_n n_0 = \left(\frac{8}{\pi}\right)^{1/2} \exp[-2(1 - n/n_0)^2]. \tag{3}$$

The diffractive data of Ref. 1 agree well with this formula. In comparing experimentally measured multiplicity moments with those calculated using Eq. (2), care must be taken to sum only over the allowed positive values of n. This procedure increases the calculated average multiplicity and decreases the width of its distribution so that $\langle n \rangle$ is generally somewhat larger than n_0 and $\langle n \rangle / D$ greater than 2.

It is well known[3-5] that charged multiplicity data of inclusive hadronic reactions do not agree with Eq. (2). For example, for $pp \to$ anything,[3-6] the increase of the average multiplicity with energy is slower than $2s^{1/4}$ [see Fig. 1(a)], the $\langle n \rangle / D$ ratio decreases as the energy increases [see Fig. 1(b)], and the KNO distribution of the data is asymmetric about $n/\langle n \rangle = 1$ (see Fig. 2), in disagreement with Eq. (3). On the other hand, data on $e^+e^- \to$ anything are consistent[7] with $\langle n \rangle = 2s^{1/4}$ (see Fig. 3) and their KNO scaling curve is symmetric.[8]

In this paper, we analyze the inclusive $pp \to$ anything charged multiplicities, recognizing that they derive from two distinct parts of the inelas-

