PRODUCTION PROPERTIES OF LOW-MASS SYSTEMS IN pp COLLISIONS AT 102 GeV/c *

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We examine in detail the properties of low-mass systems produced in the inclusive reaction p + p → p + anything at 102 GeV/c. We find that the internal characteristics of these low-mass nucleon-multipion systems (the "anything"), at fixed values of mass (M), are similar to those found for produced hadrons in high-energy collisions at fixed incident hadron energies ($\sqrt{s}$). The resemblance between the properties of the M^2 system and the characteristics of γp collisions at $s = M^2$ is particularly striking.

Stimulated by recent suggestions concerning the predicted characteristics of low-mass systems produced in association with a proton in the reaction [1]

$$p + p \to p + \text{anything}\,, \qquad (1)$$

we report here the results of a detailed investigation of the properties of reaction (1). The data are from a 31 000 picture exposure of the 30-inch ANL/NAL liquid-hydrogen bubble chamber to 102 GeV/c protons and from a preliminary 12 000 picture exposure at 400 GeV/c. We consider those events when the final-state proton in reaction (1) has a momentum $\lesssim 1.2$ GeV/c and is consequently well measured and easily separated from π^+ background through a visual estimation of track ionization. The scaling and other general properties of reaction (1) at 102 GeV/c and 400 GeV/c have been discussed previously in the literature [2]. Here we wish to examine the multiplicity and the single-particle production aspects of the "anything" system as a function of the mass (M) of the produced nucleon-multipion state.

Fig. 1 displays, for the data at 102 GeV/c and 400 GeV/c, the averaged charged-particle multiplicity of the "anything" system, and the value of the Mueller f_2 moment [3] as a function of the values of M^2. (The cross section for reaction (1), for production in one hemisphere in the center of mass, at 102 GeV/c and at 400 GeV/c, as a function of M^2, is also shown in the figure [2].) The resemblance between the data presented in figs. 1(b) and (c) and the analogous moments of multiplicity distributions in hadronic collisions for $s = M^2$ has been noted previously [4]. The data displayed in fig. 1 indicate that the f_2 moment at fixed M^2 (referred to as $f_2^{M^2}$) is independent of the s-value of reaction (1); also, the data lend additional support to the verification of the prediction that the average value of the charged-particle multiplicity at fixed M^2 (labeled $\langle n\rangle_{M^2}$) is not a function of s [e.g. 5]. For comparison with reaction (1) we display the moments $\langle n\rangle$ and f_2 observed in γp collisions as a function of s [6].

The similarity between the multiplicity data of reaction (1) as a function of M^2 (at fixed s_{pp}) and the dependence of $\langle n\rangle$ and f_2 in γp collisions on the value of $s_{\gamma p}$ is remarkable, and leads naturally to an interpretation of these data in terms of the exchange diagram pictured in fig. 1. That is, it appears natural to consider the process involved in the production of the M^2 system as being mediated through the collision of some virtual object (or objects) R with the proton at the pion-production vertex. Consequently, it would further appear reasonable to interpret the process:

$$R + p \to \text{anything} \qquad (2)$$

at fixed M^2, as representing the characteristics of all the channels available to Rp scattering (i.e., the total

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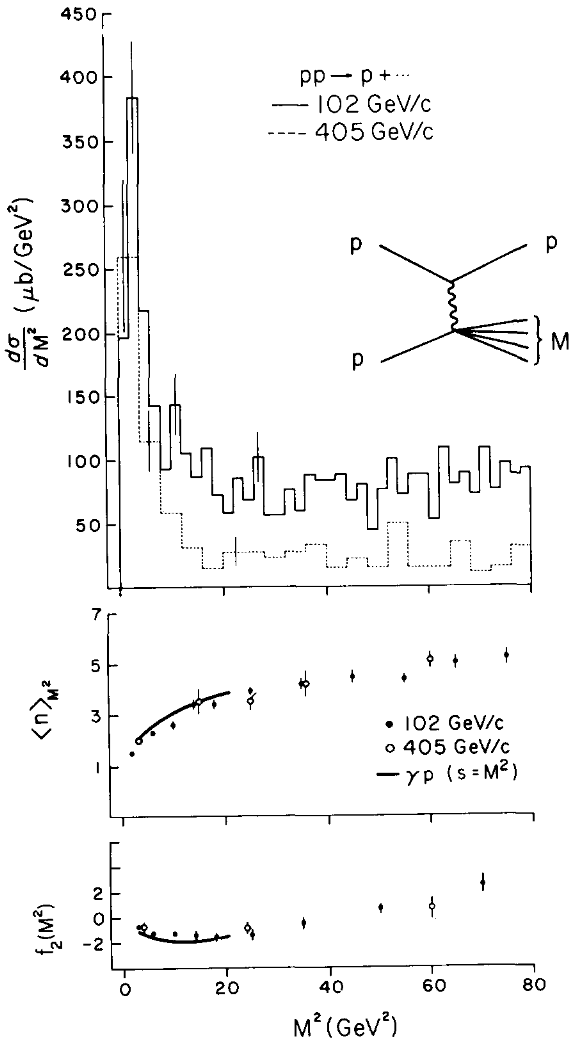

Fig. 1. Multiplicity and f_2 moment of the system, having mass M, produced in reaction (1). The data are shown integrated over p_T.

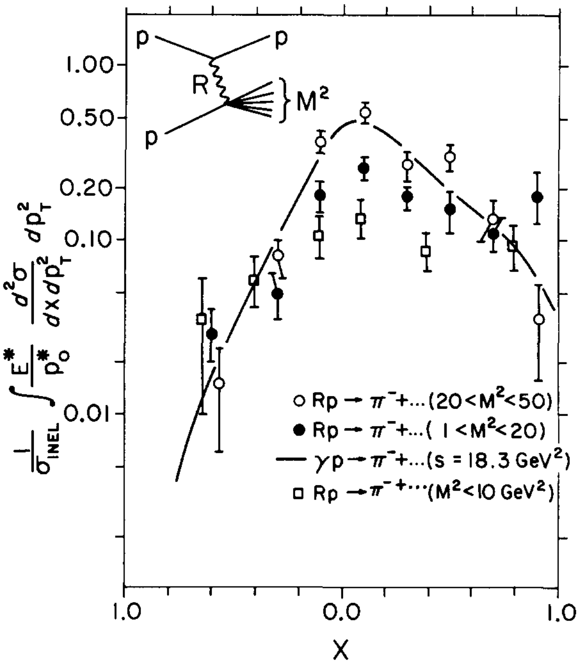

Fig. 2. "Production" spectra for π^- mesons produced in the virtual RP collision (reaction (3)), as a function of M^2, at an incident proton momentum of 102 GeV/c. Positive x corresponds to π^- emission along the direction of R in the M^2 rest frame.

inelastic RP cross section)*. Because real hadronic collisions appear to be describable through a sum of a peripheral diffraction-production process (~20% of the inelastic cross section) and a more central multiperipheral process (~80% of the inelastic cross section), we might expect that similar properties may be distinguishable in the virtual RP channel [1]. Furthermore, because R is electrically neutral, we might expect the properties of Rp collisions to be qualitatively similar to those observed in γp collisions.

In fig. 2 we display the single-particle inclusive x-distribution for the "reaction"**

$$R^0 + p \to \pi^- + (\text{anything})^{++} . \qquad (3)$$

Because of poor statistics, the data have been integrated over t (the square of the invariant mass of the R object, t, is restricted to the values $|t| \leqslant 0.6$ GeV^2), and over all transverse momenta (p_T) of the produced π^- as calculated in the Rp center of momentum frame (rest frame of the M^2 system with the longitudinal direction chosen along the Rp "collision" axis, i.e., the usual

* For $M^2 \lesssim 10$ GeV^2 at 102 GeV/c, R would be expected to display properties characteristic of the Pomeranchukon (P).

** The data at 400 GeV/c are statistically poorer than at 102 GeV/c and the resolution is also substantially worse at the higher energy, we consequently present only the results at 102 GeV/c.

quantization axis in the t-channel). The x variable is defined in the M^2 rest-frame choosing the following normalization:

$$x = p_L \left[\frac{1}{4M^2}(M^2 - (m+\mu)^2)(m^2 - (m-\mu)^2)\right]^{-1/2} \quad (4)$$

where p_L is the longitudinal momentum, m and μ are the proton and π-meson masses respectively. The differential spectra have been divided by the cross section for the chosen M^2 interval and, consequently, the integrals of the distributions over the invariant phase space (for all x values) yield the average values $\langle n \rangle_{M^2}$ as normalizations. Data for three intervals of M^2 are displayed in fig. 2: $M^2 < 10$ GeV^2, $M^2 < 20$ GeV^2 and $20 < M^2 < 50$ GeV^2. The data for the $M^2 < 10$ GeV^2 range may be easiest to interpret in that R is expected to have dominantly the properties of the Pomeranchukon at these M^2 values. The other two ranges were chosen so as to compare the features of reaction (3) with published studies of the reaction

$$\gamma p \to \pi^- + \text{anything} \ . \quad (5)$$

The data for reaction (5) are available at s = 18.3 GeV^2 [6]; this value of s corresponds approximately to the average M^2 value for the $M^2 < 20$ GeV^2 and $20 < M^2 < 50$ GeV^2 data. We have, again [6], excluded the "elastic" $\gamma p \to \rho^o p$ contribution from the π^- spectrum as well as from the normalization factor σ_{INEL}; conquently, the integration of the γp data in fig. 2 yields $\langle n \rangle$. (It might be argued that because we have not excluded, for example , the $Rp \to f^o p$ contribution to reaction (3) we should have consequently also retained the $\gamma p \to \rho^o p$ data for reaction (5). This is probably not a valid argument because we are comparing the virtual Rp reactions (3) with real γp scattering, and it is expected that elastic-like processes initiated by virtual particles, such as the virtual γp reaction $\gamma_v p \to \rho^o p$, are greatly suppressed*. The cross section for $Rp \to f^o p$ is, in fact, negligible.)

Before discussing the results of fig. 2 we wish to stress again that, while it is nor unreasonable at 102 GeV/c to regard R as a unique object (the Pomeranchukon) for $M^2 < 10$ GeV^2, for higher mass values R may represent a rather complicated sum of contributions to reaction (3). Nevertheless, from a phenomenological point of view it is of interest to examine the region of $M^2 > 10$ GeV^2. From fig. 2 we observe that the similarity between the known properties of reaction (5) [6] and the data presented for reaction (3) is striking. In particular, we point out the following: 1) The asymmetry in x characterizing reaction (5) is clearly evident in reaction (3). 2) The invariant cross section for reaction (3) does not scale near $x = 0$, but, in fact, rises as M^2 increases. (The relatively rapidly falling cross section near $x \sim +0.9$ may be attributed to the two-body reaction $Rp \to \pi^- \Delta^{++}$ which has its direct analog in $\gamma p \to \pi^- \Delta^{++}$ for $s \lesssim 10$ GeV^2 [6].) Considering that the uncertainty in the relative normalization between our experiment and the γp data is ~10%, we regard the overall agreement which is observed between the two reactions, particularly in the asymmetry of the inclusive π^- cross section about $x = 0$, as quite remarkable. The similarity in the scaling properties, although quite interesting, may be accidental in light of the fact that R is not a unique object for $M^2 > 10$ GeV^2.

The photon, as well as other hadronic particles, appears to participate in two types of diffractive processes: One is the elastic-like channel $\gamma p \to \rho^o p$; and the other is an inelastic multiparticle process, as typified by the reaction $\gamma p \to \rho'(1600)p$ [7]. We have attempted to ascertain whether a diffractive-like inelastic channel also contributes to reaction (3). Namely, we investigated the reaction:

$$Rp \to p + \text{anything} \quad (6)$$

in the Rp rest frame. The proton in reaction (6) unfortunately cannot be identified through ionization information because it is produced at a high momentum (forward in the overall pp CM). We can, however, employ the known characteristics of pion production in pp collisions to identify the final-state protons in reaction (6): The inclusive pion spectrum peaks markedly near $x = 0$ in the overall center of mass of the pp collision and there are essentially no pions produced for $|x| > 0.6$ (the p/π^+ ratio is greater than 100/1). We may therefore assume that any positive particle having $x \gtrsim 0.6$ is a proton. Because of poor momentum resolution for fast proton tracks, however, we can unfortunately only make a rough estimate of the fraction of events for which the proton in reaction (6) has an x-value less than -0.9. It is interesting that we obtain values for these probabilities which are

* We thank C. Quigg for a discussion of this point.

consistent with those observed for inelastic proton production in this same x-range of reaction (1) [8]. Assuming that this agreement is significant, we may interpret the data as qualitatively suggesting the presence of a diffractive component in Rp scattering (reaction (6)).

We can summarize our conclusions as follows. The detailed characteristics of low-mass systems produced in association with protons in pp collisions (reaction (1)) are remarkably similar to those observed in hadronic, and, in particular γp collisions. This result is important for evaluating the applicability of multiperipheral ideas to processes involving diffractive excitation of hadrons*.

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* As is often the case in hadronic collisions, the data are in good agreement with models which are used even outside of their strict region of applicability. Thus, although at 102 GeV/c we should have expected agreement between an exchange picture and the data for $M^2 \lesssim 10$ GeV^2, we find that the model appears to apply for far larger M^2, where R can no longer represent just the P-trajectory.

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