Study of Inclusive Reactions of $\pi^+ + p \to X$ + Anything ($X = \pi^+, \pi^-, K_S^0$) at 6 and 22 GeV/c*

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We present new single-particle spectra and average charged multiplicity distributions for the inclusive reactions $\pi^+ + p \to X$ + anything at 6 and 22 GeV/c. We observe limiting behavior for exotic reactions ($X = \pi^-, K_S^0$) and nonlimiting behavior for the nonexotic reaction ($X = \pi^+$).

Inclusive reactions, $a + b \to c$ + anything, have been the subject of theoretical[1,2] and experimental[3] investigations recently. Various conjectures of limiting behavior as a function of energy have been proposed. In particular, Chan *et al.*[4] have suggested that those reactions where the quantum numbers of $ab\bar{c}$ are exotic may show limiting behavior at relatively low energies, whereas those reactions where the quantum numbers of $ab\bar{c}$ are nonexotic may approach limiting behavior with an energy dependence of $s^{-1/2}$. There is current experimental evidence[5] for this hypothesis. In this Letter, we present a systematic study of exotic and nonexotic single-particle spectra for π^+p interactions at 6 and 22 GeV/c.[6] This is the largest spread in s, 12 and 42 GeV^2, of any such π^+p data reported thus far.

The data come from exposures of the Brookhaven National Laboratory (BNL) 80-in. hydrogen bubble chamber. A total of 67 000 events at 6 GeV/c and 41 000 events at 22 GeV/c were measured on the BNL flying-spot digitizer (FSD). Both ionization measurements from the FSD and kinematical fitting of the events were used to identify particles. Nevertheless, about 15% at 6 GeV/c and about 30% at 22 GeV/c of fast positive tracks remained ambiguous after these criteria were imposed. We shall return to this point when we discuss the π^+ distributions. We consider the inclusive reactions $\pi^+p \to X$ + anything ($X = \pi^+$, π^-, and K_S^0) at 6 and 22 GeV/c. The events were normalized to counter measurements of the π^+p total cross sections[7] after making suitable corrections for losses due to scanning, measuring, and missed elastics. There is an overall normalization error of $\pm 5\%$ at each energy. Only statistical errors are used for the presentation of the data unless stated otherwise.

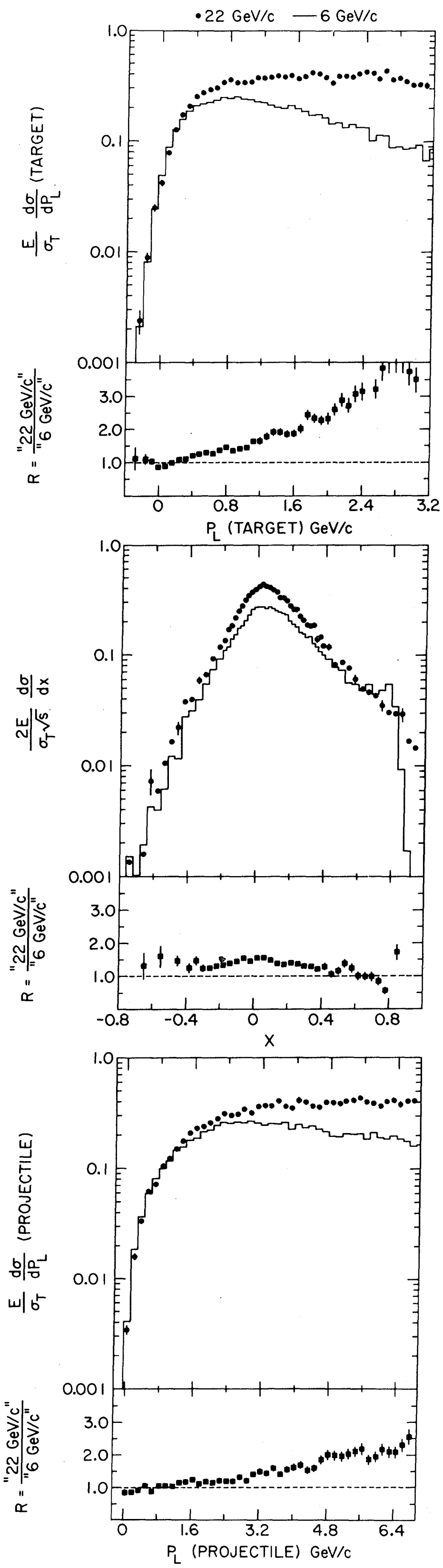
Single-particle spectra are presented in the following variables: P_L(target), the longitudinal momentum in the rest frame of the target (lab frame); $x \equiv 2p_L^*/\sqrt{s}$, where p_L^* is the longitudinal momentum in the overall c.m. system; and P_L(projectile), the longitudinal momentum in the rest frame of the projectile. In Figs. 1–3 we show the normalized, Lorentz-invariant, single-particle spectra for Reactions (1)–(4), integrated over the transverse momentum squared ($P_\perp^2$) and divided by the "asymptotic" π^+p total cross section (23.4 mb). The ratios (R) of the spectra at 22 GeV/c to those at 6 GeV/c are also presented for these variables. We note that there is no clear indication of any limiting behavior ($R = 1$) in x for a π^- or K_S^0. We discuss below limiting behavior in P_L for each of the inclusive reactions studied.

$\pi^+ + p \to \pi^-$ + anything ($ab\bar{c} \equiv \pi^+p\pi^+$, *exotic*).—We observe limiting behavior for the π^- for P_L(target) < 0.3 GeV/c (representing 23% of the π^- tracks at 6 GeV/c and 11% at 22 GeV/c) and for P_L(projectile) < 1.2 GeV/c (representing 19% of the π^- tracks at 6 GeV/c and 9% at 22 GeV/c). This limiting behavior is particularly apparent in the ratio plot where the value of R is consistent with unity for P_L(target) < 0.3 and P_L(projectile) < 1.2 GeV/c. The $P_\perp^2$ distributions (not shown) are also limiting in these regions. The integrated single-particle spectra,[8]

$$I(\pi^-) = \int \sigma_T^{-1} (d^2\sigma / dP_L\, dP_\perp^2)\, dP_L\, dP_\perp^2,$$

are 0.134 ± 0.007 at 6 GeV/c and 0.134 ± 0.007 at 22 GeV/c for the limiting region P_L(target) < 0.3 GeV/c and 0.113 ± 0.006 at 6 GeV/c and 0.108 ± 0.005 at 22 GeV/c for the limiting region P_L(projectile) < 1.2 GeV/c. Our observation here represents a quantitative measurement of the extent of the limiting in $\pi^+p \to \pi^-$ + anything *without* invoking the argument of factorization.

$\pi^+ + p \to \pi^+$ + anything ($ab\bar{c} = \pi^+p\pi^-$, *nonexotic*).—For fast positive tracks there is the difficulty of distinguishing between π^+'s and protons. A weighting procedure was used to calculate the contribution to the single-particle spectra from ambiguous π^+'s.[9] The ambiguity has $< 2\%$ effect for P_L(target) < 0.3 GeV/c and $< 13\%$ effect for P_L(projectile) < 1.2 GeV/c.[10] Within the limita-



tions of the weighting procedure used, there is no evidence for limiting behavior in any of the π^+ single-particle spectra with the possible exception of $0.2<x<0.5$. In fact, the difference between π^+ and π^- is evident by comparing their R ratios, particularly for P_L(target) <0.3 GeV/c and P_L(projectile) <1.2 GeV/c. The integrated single-particle spectra[8] $I(\pi^+)$ are 0.449 ± 0.022 at 6 GeV/c and 0.335 ± 0.017 at 22 GeV/c for the region P_L(target) <0.3 GeV/c, and 0.447 ± 0.022 at 6 GeV/c and 0.363 ± 0.018 at 22 GeV/c for the region P_L(projectile) <1.2 GeV/c.

$\pi^+ + p \rightarrow K_S{}^0 +$ *anything* ($ab\bar{c} = \pi^+pK^0$ or $\pi^+p\bar{K}^0$, *exotic*).—We observe that, within the experimental errors, the $K_S{}^0$ longitudinal momentum distribution[11] is limiting for P_L(target) $\lesssim 1$ GeV/c. The integrated single-particle spectra[8] $I(K_S{}^0)$ are $(6.8\pm0.6)\times10^{-3}$ at 6 GeV/c and $(6.4\pm0.7)\times10^{-3}$ at 22 GeV/c for the limiting region P_L(target) <1.0 GeV/c, and $(6.0\pm0.5)\times10^{-3}$ at 6 GeV/c and $(8.2\pm0.8)\times10^{-3}$ at 22 GeV/c for the region P_L(projectile) <4 GeV/c. It is interesting to note that this P_L(target) limiting region is larger than that of the π^- spectrum.

To investigate average charged multiplicity $\langle n_c\rangle$ with respect to the limiting or nonlimiting behavior observed here, we show in Fig. 4 for the reactions studied, $\langle n_c\rangle$ as a function of P_L(target), x, and P_L(projectile). The $\langle n_c\rangle$ distributions are similar for all particles, with the highest average charged multiplicity occurring at $x\sim0$. The $\langle n_c\rangle$ distribution for the π^- at 22 GeV/c is significantly larger than that at 6 GeV/c in the limiting regions of P_L(target) <0.3 GeV/c and P_L(projectile) <1.2 GeV/c. Thus contributions from all multipliticities at each energy are necessary to achieve limiting behavior. The total average charged multiplicity is 3.07 at 6 GeV/c and 4.33 at 22 GeV/c.

To summarize, we have presented new data on single-particle spectra and average charged multiplicities from inclusive π^+p interactions at 6 and 22 GeV/c. The exotic π^- spectra exhibit limiting behavior at 6 GeV/c for regions of longitudinal momenta in the target and projectile frames, whereas $K_S{}^0$ is limiting in a region of the target

FIG. 1. Single-particle spectra for π^-. Representative error bars on the cross sections are statistical. R is the ratio of the invariant cross section at 22 GeV/c to that at 6 GeV/c. Error bars on the ratio are shown for each point.

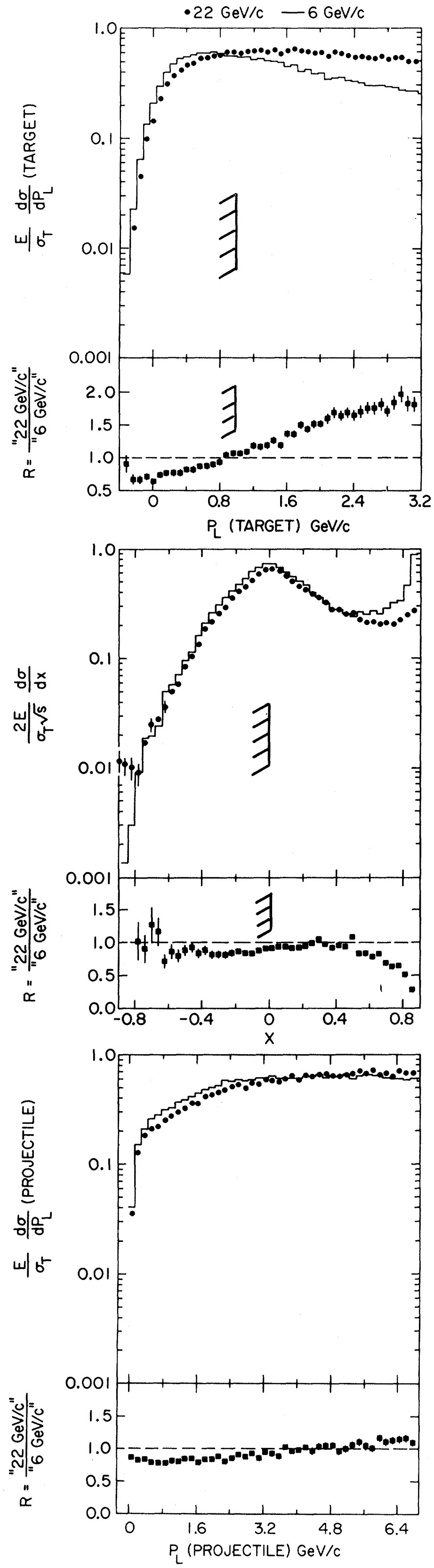


FIG. 2. Single-particle spectra for π^+. Representative error bars on the cross sections are statistical. R is the ratio of the invariant cross section at 22 GeV/c to that at 6 GeV/c. Error bars on the ratio are shown for each point. Cross-hatched areas indicate regions relatively unaffected by $\pi^+ - p$ ambiguity. See text for details.

frame. This limiting behavior is best described by the hypothesis of limiting target and projectile fragmentation[1] as opposed to limiting in x.[2] The nonexotic π^+ spectra, on the other hand, show no evidence for limiting behavior at 6 GeV/c. Our results support the conjecture of Chan *et al.*[4] that exotic inclusive reactions will exhibit limiting behavior at relatively low energies.

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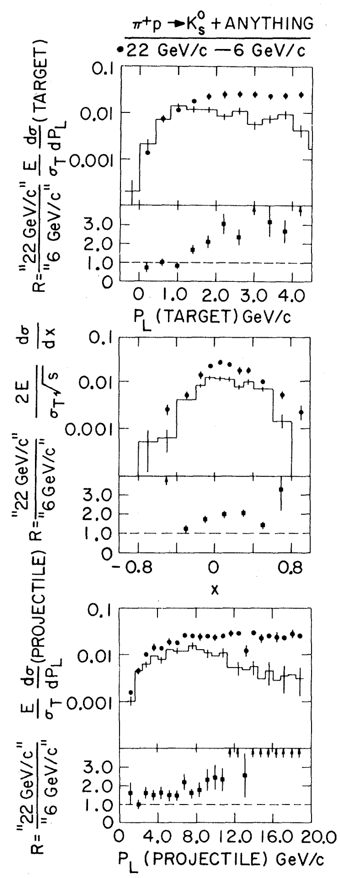

FIG. 3. Single-particle spectra for K_S^0. Representative error bars on the cross sections are statistical. R is the ratio of the invariant cross sections at 22 GeV/c to that at 6 GeV/c. Error bars on the ratio are shown for each point.

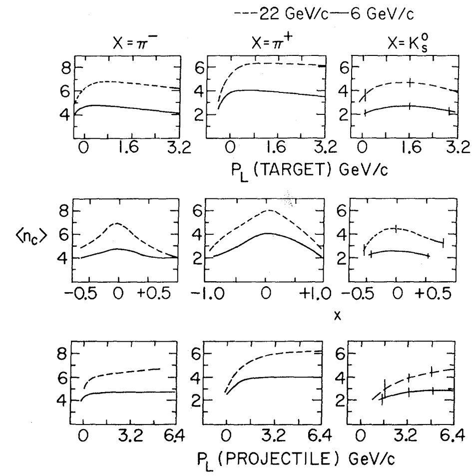

FIG. 4. Distributions of average charged multiplicity $\langle n_c \rangle$ for the reactions studied as described in text. Representative error bars shown for $x=K_S{}^0$. Other error bars are equal or less than the linewidth.

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[6]For 22-GeV/c π^+ beam design, see T. Ferbel and H. Foelsche, BNL Accelerator Department, EPNS Division, Internal Report No. 68-2, 1968 (unpublished).

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[8]Quoted errors include contributions from statistical and normalization errors.

[9]A π^+ weight was assigned to an ambiguous positive track equal to the number of times the track received a π^+ interpretation, consistent with ionization and/or kinematics, divided by the total number of interpretations for the event.

[10]The ambiguity effect for π^+ was determined by comparing the final weighted π^+ distribution with the unweighted distribution which contains both the unambiguous and ambiguous π^+ tracks. The ambiguity has ~ 5–30% effect on the π^+ spectrum for P_L(target) >1.0 GeV/c, but does not change as a function of P_L(projectile). The effect is ~ 2–6% for $x<0$ and 14–24% for $x>0$.

[11]Spectra for the K_S^0 have been corrected for unseen decays. We have not presented Λ spectra because they cannot be separated from $\Sigma^0 \to \Lambda\gamma$.

ERRATUM

CALCULATION OF LOCAL EFFECTIVE FIELDS: OPTICAL SPECTRUM OF DIAMOND. J. A. Van Vechten and Richard M. Martin [Phys. Rev. Lett. 28, 446 (1972)].

Figures 1 and 2 have been transposed. Their captions were not transposed.