PUB-77-115-E
E-0002

Submitted to Phys. Rev. Letters, January, 1977

FERMILAB
MAR 8 1977
LIBRARY

Properties of Inclusive $\pi^{\pm}$ Production in 100 GeV/c Antiproton-proton Interactions

J. Whitmore, D. Y. Oh, M. Pratap, G. Sionakides, G. A. Smith
Department of Physics, Michigan State University
East Lansing, Michigan 48824 U.S.A.*

R. E. Ansorge, C. P. Bust, J. R. Carter, W. W. Neale,
J. G. Rushbrooke and D. R. Ward
Cavendish Laboratory, Cambridge, England**

C. T. Murphy, R. Raja, and L. Voyvodic
Fermi National Accelerator Laboratory
Batavia, Illinois 60510 U.S.A.***

January 1977

ABSTRACT

Inclusive spectra are presented for $\pi^{\pm}$ production in 100 GeV/c $\bar{p}p$ interactions. The rapidity distribution for the difference ($\bar{p}p$-pp) approximately scales as the difference in total cross-sections in the fragmentation region between 12 and 100 GeV/c and exhibits an approximate $s^{-1/2}$ dependence in the central region.

*Work supported in part by the National Science Foundation, U.S.A.
**Work supported by the Science Research Council, U.K.
***Operated by the Universities Research Association, Inc., under contract with the Energy Research and Development Administration, U.S.A.

E2B
FERMILAB-PUB-77-115-E

Extensive data from the CERN Intersecting Storage Rings (ISR) and from Fermilab now exist on inclusive particle production in baryon-baryon and meson-baryon scattering at high energies. Multipion production in antinucleon-nucleon interactions, however, has not been published above a laboratory momentum of 15 GeV/c.[1] Consequently, nothing is known about the high energy behaviour of multiparticle production in $\bar{p}p$ interactions and, in particular, about the baryon annihilation process above ~12 GeV/c.[2] In this letter we present the first results on inclusive $\pi^{\pm}$ production in $\bar{p}p$ interactions at 100 GeV/c. These data permit a study of the center of mass (CM) energy dependence of inclusive $\pi^{\pm}$ production in both the fragmentation and central regions. Although individual annihilation events cannot be identified in this experiment, by making comparisons with similar data from pp interactions we infer some features of inclusive pion production which may describe high energy baryon annihilation.

The data result from a 98,000 picture exposure of the Fermilab 30-in hydrogen bubble chamber-wide gap spark chamber hybrid system to a 100 GeV/c beam with typically 0.32 $\bar{p}$'s/negative particle in each picture. Results on the charged multiplicity distribution[3], a comparison[4] with pp data, and neutral particle production[5] have already been published. The results presented here are based on ~9300 inelastic events. We have removed $K^{\pm}$ and $p^{\pm}$ contamination from the charged particle distributions as follows: (a) protons with momentum $\lesssim$ 1.4 GeV/c were identified by ionization and removed, together with a corresponding number of negative tracks in the forward hemisphere; (b) $K^{\pm}$ contamination was subtracted using data on $\bar{p}p \to K_s^{\circ}$[5]; (c) the remaining $p^{\pm}$ contamination was estimated by requiring, by C-invariance, that the $\pi^{\pm}$ distributions in the forward (f) and backward (b

M hemispheres show symmetry, i.e., $\pi_f^{\pm} = \pi_b^{\mp}$ and $p_f^{\pm} = p_b^{\mp}$. All rapidity distri-
utions have been corrected in this way with due allowance for varying momentum
esolution.

Figure 1(a) shows the inclusive π^- invariant cross section[6]
ntegrated over transverse momentum, $G(P_L) = \int \frac{E}{\sigma_p(s)} \frac{d^2\sigma}{dp_T^2 dp_L} dp_T^2$, as a
unction of P_L, the longitudinal momentum in the laboratory system, together
ith some lower energy data[7]. The dominant feature is the decrease in
(P_L) for $P_L \lesssim 1.2$ GeV/c as the CM energy ($\sqrt{s}$) increases. To study this
nergy dependence in more detail, in Fig. 1(b) we show $G(p_L)$, integrated
ver the range $-0.4 \lesssim p_L \lesssim +0.2$ GeV/c, as a function of $s^{-1/2}$ and compared[8]
ith similar data from $\pi^{\pm}p$, $K^{\pm}p$ and pp interactions. The $\bar{p}p$ data show the
trongest energy dependence between beam momenta of 4.6 and 100 GeV/c and,
urthermore, are consistent with the same asymptotic value ($\approx$0.02 GeV) as
he πp, Kp and pp data. This may be taken as further evidence for Pomeron
actorization in high energy inclusive processes. Similar conclusions may
e drawn from the distributions for $\bar{p}p \to \pi^+$ (not shown).

Figure 2(a) shows the laboratory rapidity ($y = 1/2\ \ln(\frac{E+p_L}{E-p_L})$)
pectrum for $\bar{p}p \to \pi_b^-$, averaged with that for $\bar{p}p \to \pi_f^+$ reflected about $y_{cm}=0$.
lso shown are data for $pp \to \pi^-$ at 100 GeV/c[9]. We have shown elsewhere[4]
hat smooth extrapolations of the low energy annihilation multiplicity
oments are obtained by approximating the high energy annihilation moments
y differences between corresponding $\bar{p}p$ and pp topological cross sections.
n a similar vein we also show in Fig. 2(a) the differences

$$\Delta_y(\pi^-) = \frac{d\sigma}{dy}(\bar{p}p \to \pi^-) - \frac{d\sigma}{dy}(pp \to \pi^-). \qquad (1)$$

Because of the different techniques[10] that had to be used to remove proton
in the $\bar{p}p$ and pp experiments, the differences for $\Delta_y(\pi^+)$ are less reliable
and presentation of these data is deferred to a future report.

In view of these new high energy data, it is now possible to examine
the energy dependence of these differences. For comparison, we display as
the solid curve in Fig. 2(a) 12 GeV/c[2] data for $\Delta_y(\pi^-)$, normalized by the
ratio of the differences of total cross sections, $\Delta\sigma_T(p^{\pm}p) = \sigma_T(\bar{p}p) - \sigma_T(pp)$
at 100 and 12 GeV/c which we take to be 3.55[4] and 12.1 mb[2], respectively
We note that scaling for $\Delta_y(\pi^-)$ holds rather well in the target fragmentatio
region (interpreted broadly as $y \lesssim 1$). Since $\Delta\sigma_T(p^{\pm}p)$ is known to possess
an $\sim s^{-0.55}$ dependence, we conclude that $\Delta_y(\pi^-)$ displays a similar s-depender
We note that this similarity is to be expected from Mueller-Regge arguments.
Following Chan et al.[11] we write

$$E\frac{d^3\sigma}{dp^3}(p^{\pm}p \to \pi^- + X) = \beta_{pp}F_{pp\pi^-} + \sum_{m=\rho,\omega,f,A_2} s^{\alpha_m(0)-1}\tau_m\beta_{p^{\pm}m}F_{mp\pi^-}. \qquad (2)$$

For exchange degenerate couplings, $\beta_{pf} = \beta_{p\omega}$, $\beta_{pA_2} = \beta_{p\rho}$, and for
$F_{\rho p\pi^-} = F_{\omega p\pi^-}$ (from the relative s-independence of the process $\pi^+p \to \pi^- + X$,
see Ref. 8) one finds

$$\Delta_y(\pi^-) = s^{\alpha_m(0)-1}\ 2(\beta_{p\omega} + \rho_{p\rho})F_{\omega p\pi^-} \sim s^{-0.55} \qquad (3)$$

In Fig. 2(b) we show the ratio $R(y) = \Delta_y(\pi^-)/\frac{d\sigma}{dy}(pp \to \pi^-)$. We
note that R(y) appears to be decreasing slightly with increasing y, suggesti
that the "annihilation" rapidity spectrum is broader than that from nonannil
lations. This may be anticipated since the absence of leading baryons coul
result in pions of larger rapidity. Since our earlier results[3,4] suggest
that annihilations predominantly occur in the higher ($\gtrsim$ 10) charged multipl

final states and to enhance the possibility of observing annihilation effects, we have studied R(y) for different charged multiplicities (not shown). We find that the tendency for the rapidity spectrum to be broader than that for the nonannihilations is indeed attributable to the higher multiplicities. It is clear that future experimental determinations of explicit annihilation spectra from a few GeV/c up to 100 GeV/c are essential if the above differences of $\bar{p}p$ and pp data are to have a deeper meaning.

The energy dependences of the $p^{\pm}p$ cross-sections for central region inclusive $\pi^{\pm}$ production are shown in Fig. 3(a), where the 100 GeV/c $\bar{p}p \to \pi^{\pm}$ value at $y_{cm}=0$(where the $\pi^{\pm}$ cross sections are equal) is displayed together with lower-energy $\bar{p}p$ data as a function of $s^{-1/4}$. Again, these cross sections have been normalized[6] to $\sigma_p(s)$. Also shown are $pp \to \pi^{\pm}$ data. The trend of the data suggests that at asymptotic energies the $\bar{p}p$ and pp cross sections will be equal at $y_{cm}=0$.

In Fig. 3(b) we present $\frac{d\sigma}{dy}$ $(y_{cm}=0)$ versus P_{lab} for $(\bar{p}p\text{-}pp) \to \pi^c + X$, where $\pi^c = \pi^+ + \pi^-$. One may show that this quantity exhibits simple Mueller-Regge behavior in the central region (due predominantly to ω-ω exchange) with an $\sim s^{-0.55}$ dependence (for $\alpha_\omega(0) = 0.45$). Our 100 GeV/c data permit a test of such behavior; a straight line of the required slope is seen to connect quite well with the lower energy $(\bar{p}p\text{-}pp)$ data[1,2,7,12], as well as directly measured $\bar{p}p \to \pi^c$ annihilation values.[2,7]

In conclusion, the data presented here show that inclusive $\pi^{\pm}$ cross sections in $\bar{p}p$ interactions are different from those in pp interactions, but appear to share an asymptotic (i.e., $s \to \infty$) limit in the target fragmentation and central regions. A study of $(\bar{p}p\text{-}pp)$ differences in π^- rapidity distributions reveals: (a) that the π^- spectrum for higher multiplicities

is broader than that from nonannihilations, in accord with what one might intuitively expect for annihilations; and (b) evidence of Mueller-Regge behavior with the rapidity distribution scaling as $\Delta\sigma_T(p^{\pm}p)$ in the fragmentation region, and the central region rapidity cross section for $(\pi^+ + \pi^-)$ possessing the expected $\sim s^{-0.55}$ dependence.

We thank the Fermilab staff for their assistance in this exposure. We also acknowledge the dedicated contributions of our scanning and measuring personnel.

REFERENCES

1. F. T. Dao et al., Proc. of the Symposium on $\bar{N}N$ Interactions, Liblice-Prague, CERN 74-18, p. 255 (1974).
2. D. Gall et al., Proc. 1975 Symposium on $\bar{p}p$ Interactions, Loma-Koli, p. 414; and V. Blobel. Private communication.
3. R. E. Ansorge et al., Phys. Letters 59B, 299 (1975).
4. J. G. Rushbrooke et al., Phys. Letters 59B, 303 (1975).
5. D. R. Ward et al., Phys. Letters 62B, 237 (1976); R. Raja et al., Phys. Rev. D (to be published).
6. The data have been normalized to the Pomeron contribution to the $NN/\bar{N}N$ total cross-section as suggested by C. Quigg, private communication, with the parametrization, $\sigma_p(s) = (25.33\ \text{mb})\ p_{lab}^{0.0755}$.
7. P. Gregory, Private communication.
8. J. Whitmore et al., Phys. Letters 60B, 211 (1976).
9. C. Bromberg et al., Phys. Rev. D9, 1864 (1974).
10. The symmetry argument used to remove protons in our experiment is not applicable to pp interactions, so the authors of Ref. 9 corrected for proton contamination by assuming a flat x-distribution for secondary protons.
11. H. M. Chan et al., Phys. Rev. Letters 26, 672 (1971).
12. E. G. Boos et al., Single-Particle Inclusive Spectra of Charged Particles in $\bar{p}p$-Interactions at 22.4 GeV/c, Submitted to Nucl Phys. (1976).

FIGURE CAPTIONS

Fig. 1. (a) Invariant cross section as a function of the laboratory longitudinal momentum for π^- production.

(b) The invariant cross sections for π^- production integrated over all P_T^2 and $-0.4 \leq P_L \leq 0.2$ GeV/c versus $s^{-1/2}$. The curves are drawn to guide the eye.

Fig. 2. (a) Rapidity spectra for π^- production and the $(\bar{p}p\text{-}pp) \to \pi^-$ differences at 100 GeV/c. Also shown (solid curve) are the differences at 12 GeV/c scaled by $\Delta\sigma_T(100\ \text{GeV/c})/\Delta\sigma_T(12\ \text{GeV/c})$

(b) The ratio $R(y) = \Delta_y(\pi^-)/\frac{d\sigma}{dy}(pp \to \pi^-)$ as a function of the laboratory rapidity.

Fig. 3 (a) Normalized invariant cross sections at $y_{cm}=0$ for $\bar{p}p \to \pi^\pm$ and $pp \to \pi^\pm$ as a function of $s^{-1/4}$. The curves are drawn to guide the eye.

(b) Values of the invariant cross section at $y_{cm}=0$ for the differe $(\bar{p}p\text{-}pp) \to \pi^c$ as a function of P_{lab}. The dashed line is a fit by eye to the energy dependence expected by Mueller-Regge theory (see text).

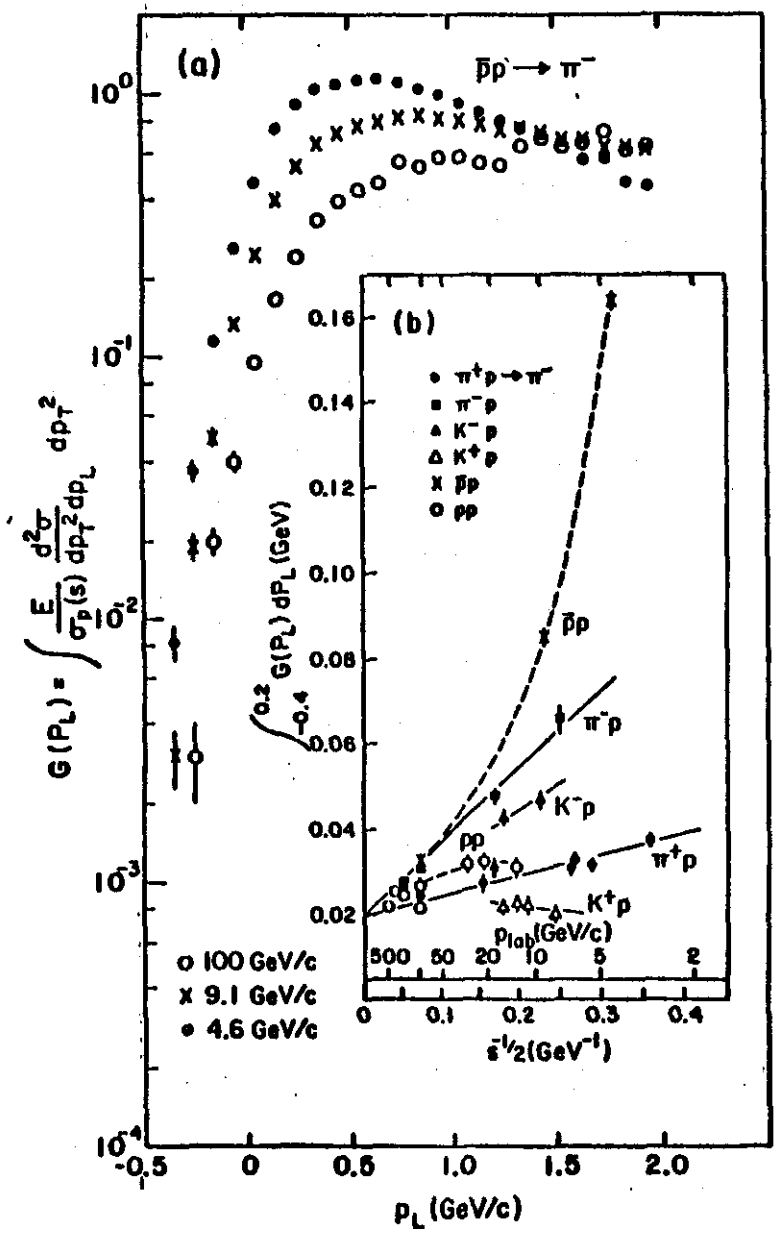

Figure 1

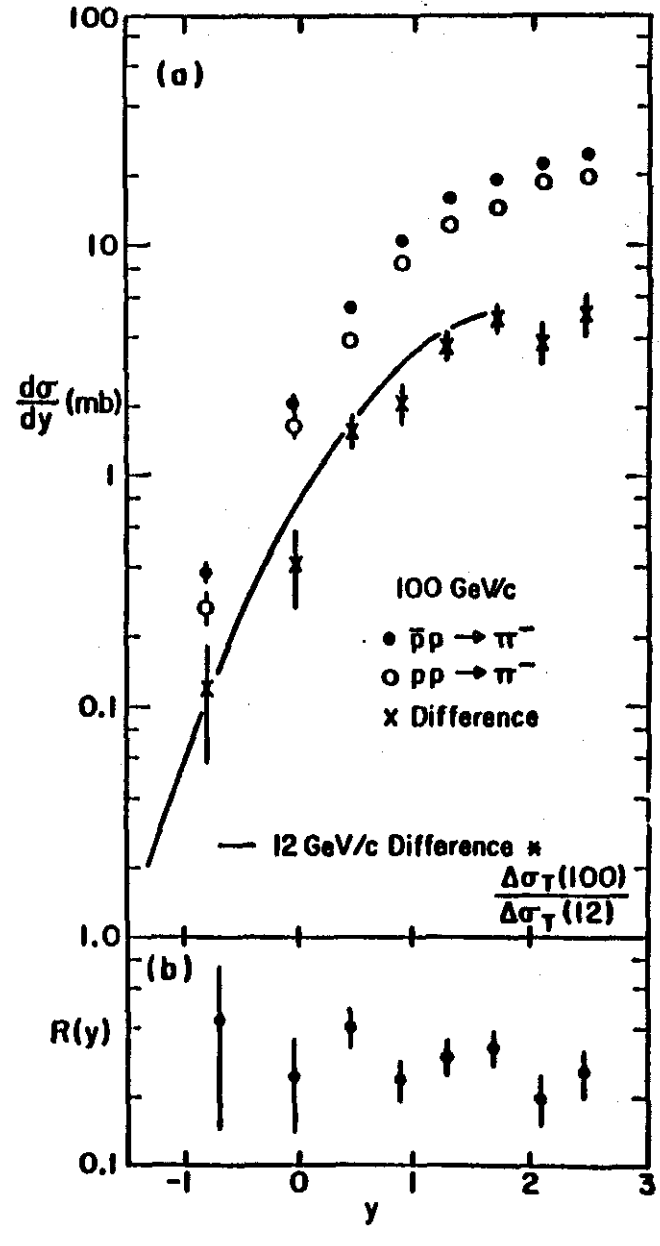

Figure 2

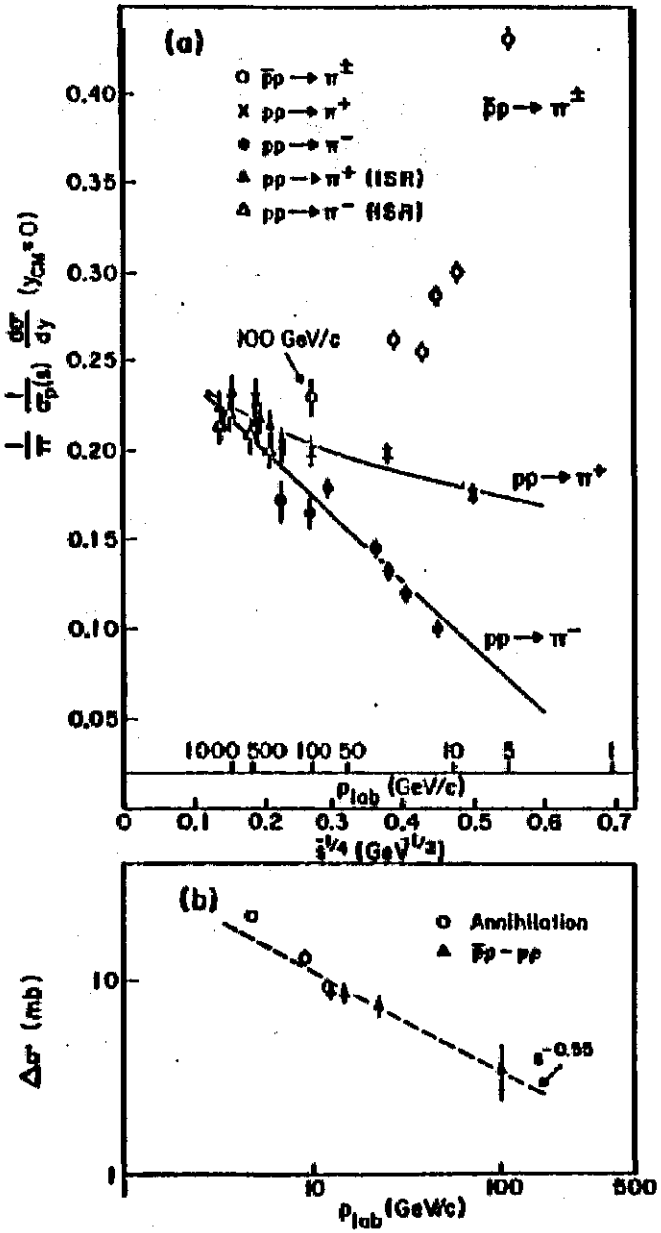
(a)
o p̄p → π±
x pp → π+
• pp → π−
▲ pp → π+ (ISR)
△ pp → π− (ISR)
p̄p → π±
100 GeV/c
pp → π+
pp → π−
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
1000 500 100 50 10 5 1
p_lab (GeV/c)
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7
s^1/4 (GeV^1/2)
(b)
o Annihilation
▲ p̄p − pp
s^−0.55
Δσ (mb)
10
1
10 100 500
p_lab (GeV/c)

Figure 3