SLAC-PUB-979
LBL-507
(TH) and (EXP)
October 1971

COMPARISON OF THE INCLUSIVE π^- DISTRIBUTIONS FROM γp, K^+p, AND pp COLLISIONS*

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ABSTRACT

The inclusive reactions $\gamma p \to \pi^- +$ anything, $K^+p \to \pi^- +$ anything and $pp \to \pi^- +$ anything are compared for small π^- laboratory momenta. We discuss in detail their relative shapes and magnitudes and present a theoretical interpretation of these characteristics.

(Submitted to Phys. Letters.)

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[*] Supported by the U. S. Atomic Energy Commission.

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The concepts of limiting fragmentation[1] and factorization[2] have been proposed as characteristic properties of inclusive reactions. According to the first, the double differential cross section $\frac{\partial^2 \sigma}{\partial P_L \partial P_T}$, evaluated in the laboratory system, should become independent of energy for small P_L. According to the second, if the Pomeronchuk trajectory dominates, then when this limit is attained, the differential cross section for a given target should be independent of the projectile particle, when divided by σ_T (the asymptotic total cross section).

In this letter, we present laboratory distributions $\frac{1}{\sigma_T} \frac{\partial^2 \sigma}{\partial P_L \partial P_T}$ for low-momentum π^- from the reactions

$$\gamma p \rightarrow \pi^- + \text{Anything} \qquad (\bar{E}_\gamma = 10.4 \text{ GeV}) \qquad (1)$$

$$K^+ p \rightarrow \pi^- + \text{Anything} \qquad (P_{K^+} = 11.8 \text{ GeV/c}) \qquad (2)$$

$$pp \rightarrow \pi^- + \text{Anything} \qquad (P_p = 28.5 \text{ GeV/c}) \qquad (3)$$

We compare the relative shapes and normalizations of these distributions. Previously, it has been shown[3] that reaction (1) decreases by about 30% over the E_γ range from 5.5 to 15 GeV, and so has not reached a limiting distribution in the target-fragmentation region at these energies.[4] An energy-dependent study of reaction (2) has not been made. The distribution for reaction (3) is approximately independent of energy over the range 13.5-28.5 GeV/c.[5] Thus the data at hand consist of two reactions, (1) and (2), at about the same incident energy, and a third, reaction (3), that is almost independent of energy.

The data of reaction (1) consist of 39,000 events (58,000 π^- tracks) with E_γ in the range 6-18 GeV studied in the SLAC 2-meter streamer chamber using an 18-GeV bremsstrahlung beam. To obtain sufficient statistics for a detailed comparison, we have combined these data to obtain a single distribution at an effective $\bar{E}_\gamma = 10.4$ GeV.[3] The data of reaction (2) consist of 280,000 events

(360,000 π^- tracks) produced by an 11.8 GeV/c K^+ beam in the LRL-SLAC 82-inch liquid hydrogen bubble chamber.[6] The data of reaction (3) consist of 12,200 events (25,000 π^- tracks) studied in the BNL hydrogen bubble chamber at incident momentum 28.5 GeV/c.[5] For all three reactions, the measured momenta of the negative tracks were used without kinematic fitting and were assumed to be π^-. The overall normalization errors are estimated to be 13%, 5%, and 5% for reactions (1), (2) and (3), respectively.

On Fig. 1, we plot the laboratory distributions $\frac{1}{\sigma_T} \frac{\partial\sigma}{\partial P_L}$ for all three reactions as functions of P_L (uppermost points). Beneath these data, we show $\frac{1}{\sigma_T} \frac{\partial^2\sigma}{\partial P_L \partial P_T}$ for 0.1-GeV/c intervals of P_T. The values $\sigma_T = 0.1$ mb[7], 17.5 mb[8] and 39.8 mb[9] were assumed for the γp, K^+p, and pp asymptotic total cross sections, respectively. The errors shown in Fig. 1 are statistical and do not reflect uncertainties in overall normalization of the three experiments nor in the asymptotic cross sections used.[10]

From Fig. 1 we see that:

(a) The three reactions have similar shapes in $\frac{1}{\sigma_T} \frac{\partial\sigma}{\partial P_L}$ and in $\frac{1}{\sigma_T} \frac{\partial^2\sigma}{\partial P_L \partial P_T}$ for small laboratory momenta ($|P| < 0.5$ GeV/c),[11]

(b) Statistically significant differences in shape are present at larger $|P|$; in particular, the γp distribution is relatively larger at large P_T and small P_L.[12]

(c) Where differences are statistically significant, the γp distribution is largest throughout the region shown, and the K^+p distribution is smallest.

We can arrive at a simple quantitative statement about these observed differences in magnitude in the fragmentation region by integrating the distributions over all P_T and negative P_L. This region of backward π^- is likely to be richer in target fragmentation than the entire range of Fig. 1. We find 0.031 ± 0.004, 0.0180 ± 0.0008, and 0.0132 ± 0.0006 for γp, pp, and K^+p, respectively. Thus these integrals are in the ratios $\gamma p : pp : K^+p \simeq (2.4 \pm 0.3) : (1.36 \pm 0.10) : 1$. The two errors quoted reflect the overall normalization in the K^+p experiment, combined with the error in the γp and pp experiments, respectively. From their relative magnitudes we see that if factorization is to hold at high energies, at least two of the reactions have not reached their limiting values.[13]

We have no explanation for the relatively small deviations between the K^+p and pp distributions (20-40%), but we advance a tentative explanation for the rather large differences in magnitude and shape between the γp reaction and the other two. This difference can be discussed in the framework of Mueller.[2] The quantum numbers of the $\pi^+ pK^+$ and $\pi^+ pp$ systems are exotic,[14] and hence are characterized by Pomeron factorization. The $\pi^+ p\gamma$ system, on the contrary, is nonexotic and hence the π^- distribution will also receive contributions from non-Pomeron exchanges that do not limit at these energies. The distribution from such a nonexotic reaction has been conjectured[2] to be of the form $f(P_L, P_T) + g(P_L, P_T)/\sqrt{s}$. We can test this conjectured energy dependence[15] using the γp cross sections at the energies of Ref. 3. In Ref. 3, the integrated distributions for reaction (1) for $P_L < 0.0$ were evaluated at photon energies of 5.5, 7.5, 10.5 and 15 GeV. A decreasing trend in the values was observed: 0.038 ± 0.004, 0.038 ± 0.003, 0.031 ± 0.003, 0.025 ± 0.003. In addition to these four values, we take the value found above for the K^+p integrated distribution as a conjectured asymptotic value for the γp reaction. All five values are fit to a function of the form $A + B/\sqrt{s}$. We obtain $A = 0.013 \pm 0.001$, and $B = 0.082 \pm 0.008$ GeV with a χ^2 of 2.6 for 3 degrees of freedom. Hence the data are consistent with an interpretation in which the nonexotic γp reaction will fall with increasing energy to eventually limit at the distribution for the exotic K^+p reaction (The γp data are also consistent with the pp cross section as a limit.)

These differences in magnitude and also the relative differences in shape between the γp reaction on the one hand and the K^+p and pp reactions on the other hand can be formulated in terms of a specific dynamical model, the Regge-exchange model.[2,16,17] In this model (see Fig. 2), the proton emits the π^- and propagates as a Reggeized Δ^{++} in the t-channel; this Δ^{++} then scatters with the projectile particle. The cross section for this process is given by [16,17]

$$d^3\sigma = \frac{d^3P}{\pi E} \left(\frac{s}{M^2} \right)^{2\alpha(t)-1} \beta^2(t) \ \sigma_B(M^2) \qquad (4)$$

where $\alpha(t)$, $\beta(t)$ are the trajectory and residue of the exchanged Reggeon, and σ_B is the total cross section for the Δ^{++} — beam interaction. If the Pomeron dominates, σ_B is a constant b; otherwise, σ_B will also include a decreasing resonance term of the form a/M. In terms of the π^- momentum P_L and energy E, and the target mass m, we have $M^2 \approx s\left[1 + \frac{P_L - E}{m}\right]$.

In Ref. 17, detailed fits to π^- spectra from pp counter data at energies ranging from 12.4 to 30 GeV/c were obtained; expressions for $\alpha(t)$, $\beta^2(t)$ and σ_B are given there. The prediction of Eq. (4), integrated over P_T with these parameters, is shown in Fig. 1. We see that Eq. (4) describes the pp data for small P_L ($P_L \leq 0.1$ GeV/c) reasonably well.[18]

For the γp reaction, we have $\sigma_B = b + a/M$. We would then predict the ratio of the γp and pp inclusive normalized distributions to be $1 + C\left[1 + \frac{P_L - E}{m}\right]^{-1/2}$. The parameter C is an average of $(ab^{-1}s^{-1/2})$ over the bremsstrahlung spectrum. To test this conjecture, we compare the ratios of the γp and pp distributions of Fig. 1 to this prediction. An adequate fit to the data is obtained with C = 1. The experimental ratios and the predicted curves are shown in Fig. 3.[10] We see that at small P_T and large P_L (corresponding to large M) both experiment and theory give a ratio of 2. At large P_T and small

P_L (small M), the model predicts a ratio larger than 2 because of the low-M resonances in the $\Delta^{++}\gamma$ process. This feature qualitatively agrees with the experimental data, though the data suggest perhaps a sharper increase at small M than that provided by the term a/M.[19]

In summary, we conclude that in the target fragmentation region the K^+p and pp distributions are similar in magnitude and shape to within 20-40%, but that the γp distribution: (1) has a magnitude over two times larger than the K^+p and pp distributions and (2) falls with increasing energy, perhaps to eventually limit at the K^+p distribution, and (3) at the energy studied has a different relative shape attributable to the nonexotic contributions.

ACKNOWLEDGMENT

We wish to thank R. F. Mozley and members of the SLAC Streamer-Chamber Group, M. Davier, I. Derado, D.C. Fries, F.F. Liu, A.C. Odian, J. Park, F. Villa and D.E. Yount, for the use of the photoproduction data. We are indebted to the following members of Group A at the Lawrence Berkeley Laboratory for generously allowing us to participate in the analysis of the K^+p exposure: A. Barbaro-Galtieri, P.J. Davis, S.M. Flatté, J.H. Friedman, M.A. Garnjost, G.R. Lynch, M.J. Matison, J.M. Murray, M.S. Rabin, F.T. Solmitz, N.M. Uyeda, V. Waluch, and R. Windmolders and to J. Anderson, T.B. Day, J. Kirz, and R.J. Sprafka for help in obtaining the proton data. We have had helpful discussions with K. C. Moffeit of SLAC.

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10. We point out that data of Reaction (1) may contain some e^- contamination of tracks arising from e^+e^- production. Such contamination would be present only in the $0.0 < P_T < 0.1$ GeV/c interval and only for $P_L > 0.0$. The other P_T intervals would be unaffected.

11. We also remark that the double distributions do not factorize into separate functions of P_L and P_T.

12. Moreover, significant differences can be seen at large P_L; this corresponds to $x > 0$ in the c.m. and is beyond the proton fragmentation region. The c.m. variable x is defined in Ref. 1(b) as $x \equiv 2 \cdot P_L\,(\text{c.m.})/\sqrt{s}$.

13. We also have evaluated the distributions, integrated over all P_T and over $P_L < 0.5$ GeV/c. We find these quantities to be 0.43 ± 0.01, 0.174 ± 0.009 and 0.204 ± 0.010, respectively. The latter two values may be compared with the values found in Ref. 9: 0.20 ± 0.02, and 0.22 ± 0.02, respectively.

The corresponding ratios based on the present experiment are $\gamma p : K^+p : pp = (2.6 \pm 0.3) : (1.20 \pm 0.08) : 1$ for this more extended range in P_L. However, note that this region of P_L includes contributions from $x > 0$ (see Fig. 1).

14. By exotic we mean that no resonances are known to decay into these particles (see Ref. 2).

15. A similar analysis has been performed for the reaction $\pi^-p \rightarrow \pi^-$ + anything, by W.D. Shephard, J.T. Powers, N.N. Biswas, N.M. Cason, V.P. Kenney, R.R. Riley, D.W. Thomas, J.W. Elbert and A.R. Erwin, Notre Dame-Wisconsin preprint (unpublished).

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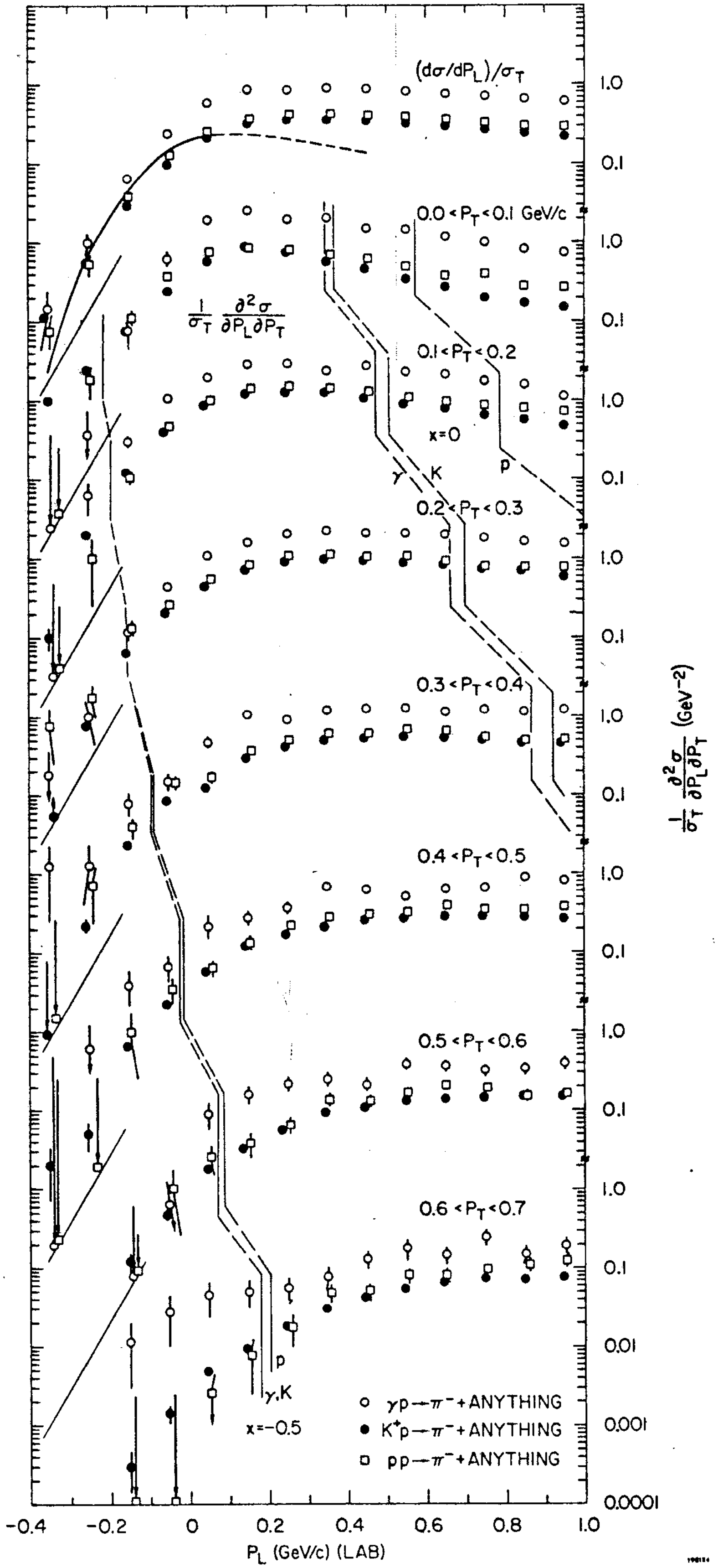
18. The curve of Fig. 1 represents the contribution to the total π^- distribution that comes from the single π^- produced by the baryon exchange mechanism of Fig. 2. This process is related through duality to the backward decay of the various N^* resonances of the proton. In this picture, the remaining portion of the spectrum in Fig. 1 then arises from the π^- produced by other mechanisms.

19. Thus the model of Fig. 3 could lead one to use the ratio of the inclusive distributions to study the nature of the $\gamma\Delta^{++}$ total cross section. Here, we have taken this cross section to be of the form $b + a/M$.

FIGURE CAPTIONS

1. Differential cross sections $\frac{1}{\sigma_T} \frac{\partial^2 \sigma}{\partial P_L \, \partial P_T}$ for $\gamma p \rightarrow \pi^- +$ anything (open circles), $K^+ p \rightarrow \pi^- +$ anything (closed circles), and $pp \rightarrow \pi^- +$ anything (squares) as a function of P_L for a range of intervals in P_T. Also shown is $(d\sigma/dP_L) / \sigma_T$ (uppermost points). The curve is the theoretical prediction of Eq. (4) for the pp reaction (see text). The diagonal lines at the left are intended to distinguish the P_T selections at small P_L. The approximately-vertical broken lines show the value of P_L corresponding to $x = -0.5$ and $x = 0.0$, respectively, where $x \equiv 2 \cdot P_L(\mathrm{c.m.}) / \sqrt{s}$.
2. Regge model for proton fragmentation in proton- and photon-induced inclusive reactions.
3. The ratio $\Omega_{\gamma p}$ of the normalized distributions. The curve indicates the prediction of Eq. (4) over the entire P_L, P_T region with $C = 1$ (see text); solid portion indicates the P_L, P_T region for which Eq. (4) adequately accounts for the π^- distribution in the pp reaction; dashed portion indicates the prediction of Eq. (4) over the rest of data.



$(d\sigma/dP_L)/\sigma_T$
$\frac{1}{\sigma_T}\frac{\partial^2\sigma}{\partial P_L \partial P_T}$
$0.0 < P_T < 0.1$ GeV/c
$0.1 < P_T < 0.2$
x=0
γ
K
p
$0.2 < P_T < 0.3$
$0.3 < P_T < 0.4$
$0.4 < P_T < 0.5$
$0.5 < P_T < 0.6$
$0.6 < P_T < 0.7$
p
γ,K
x=-0.5
○ $\gamma p \rightarrow \pi^- +$ ANYTHING
● $K^+ p \rightarrow \pi^- +$ ANYTHING
□ $pp \rightarrow \pi^- +$ ANYTHING
1.0
0.1
0.01
0.001
0.0001
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1.0
P_L (GeV/c) (LAB)
$\frac{1}{\sigma_T}\frac{\partial^2\sigma}{\partial P_L \partial P_T}$ (GeV^{-2})

Fig. 1

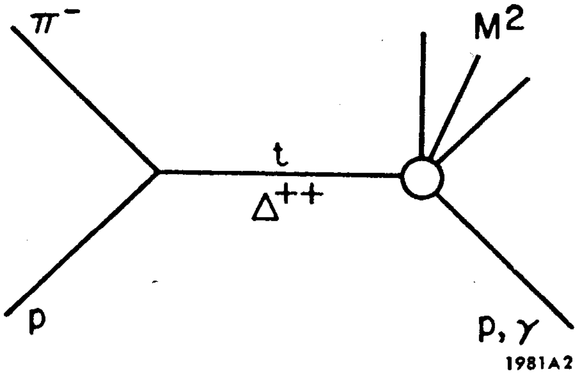
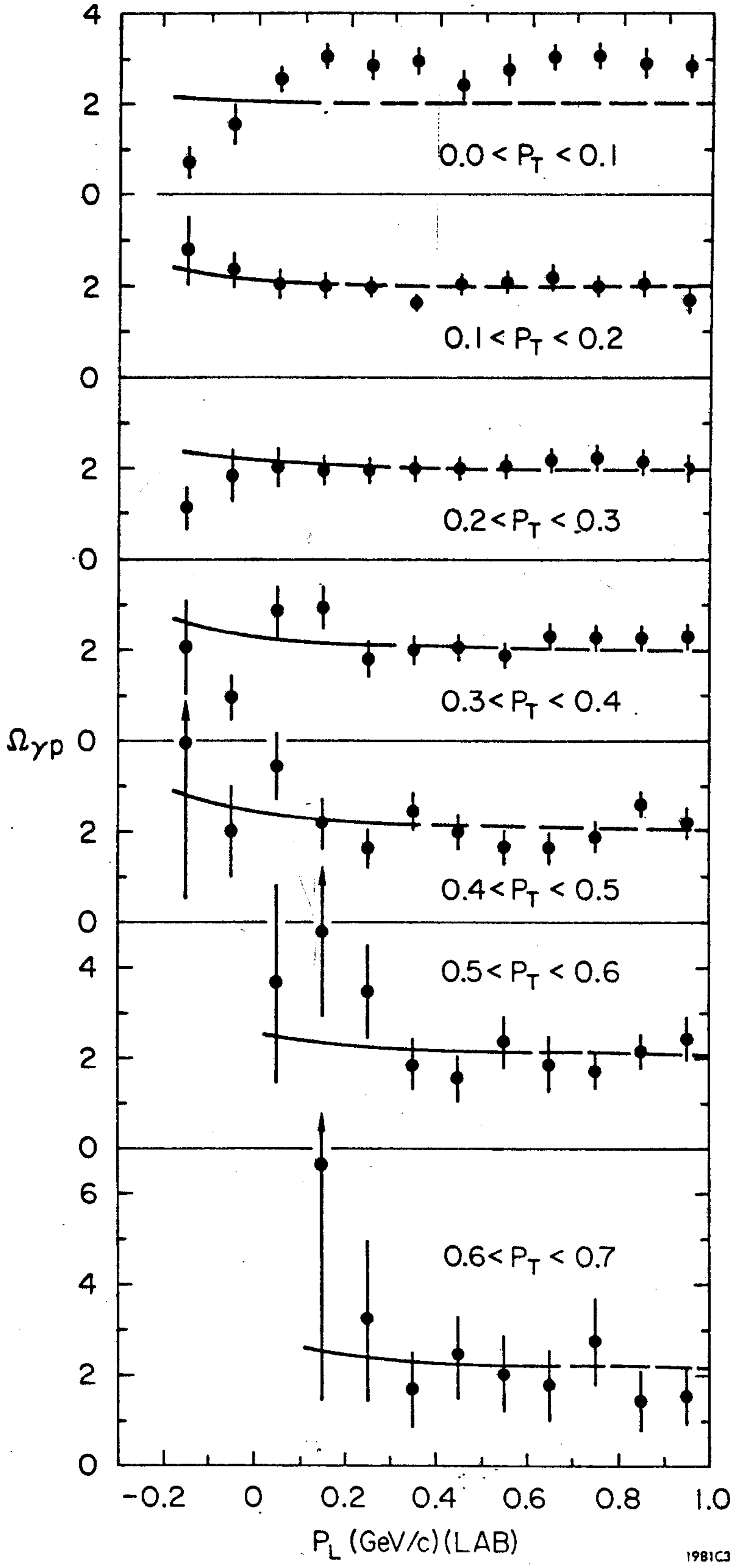


Fig. 2



4
2
0
2
0
2
0
2
0
2
0
4
2
0
6
4
2
0
$\Omega_{\gamma p}$
$0.0 < P_T < 0.1$
$0.1 < P_T < 0.2$
$0.2 < P_T < 0.3$
$0.3 < P_T < 0.4$
$0.4 < P_T < 0.5$
$0.5 < P_T < 0.6$
$0.6 < P_T < 0.7$
-0.2
0
0.2
0.4
0.6
0.8
1.0
P_L (GeV/c) (LAB)
1981C3

Fig. 3