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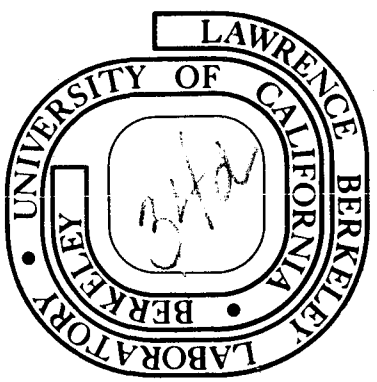

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INCLUSIVE ρ^0 PRODUCTION IN $\pi^- p$ INTERACTIONS AT 205 GeV/c*

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ABSTRACT

The inclusive ρ^0 production cross section has been measured in the reaction $\pi^- p \to \pi^+ \pi^- X$ at 205 GeV/c. We find $\sigma(\rho^0) = 13.5 \pm 3.4$ mb, with most of the production occurring in the central region. Assuming $\sigma(\rho^+) \approx \sigma(\rho^-) \approx \sigma(\rho^0)$, it is concluded that approximately one-third of the pions at this energy come from ρ-decay.

In contrast to inclusive single-particle production, very little detailed information now exists on inclusive production of meson resonances, particularly above 25 GeV/c.[1] The major reasons for this are the substantial difficulties of separating resonance from background because of small signal-to-noise ratios, especially when high multiplicities are involved, and the fact that many states, such as the ω and $\rho^\pm$, are difficult to study inclusively because π^0 detection is required. Nevertheless, resonance decays may account for a significant fraction of pion production at high energy. Furthermore, vector mesons may be an important source of the lepton production recently observed[2] in nucleon-nucleon collisions at Fermilab and the CERN ISR.

We describe in this paper a measurement of the inclusive ρ^0 production cross section in $\pi^- p$ interactions at 205 GeV/c ($s = 385$ GeV^2). The data were

obtained from a 48,000-picture exposure of the Fermi National Accelerator Laboratory 30-in. hydrogen bubble chamber. To improve the $\pi^+\pi^-$ mass resolution, only events occurring in a restricted fiducial volume located in the upstream half of the bubble chamber were considered for the present analysis, thus allowing at least 35 cm in the forward direction for measurement of outgoing tracks. View-to-view track matching was done by hand using bubble patterns when necessary. All of the 2- and 4-prong events, 72% of the 6- and 8-prongs, and 28% of the $\geq$ 10-prongs found in the restricted fiducial volume were measured on film-plane digitizers and geometrically reconstructed with TVGP, yielding a total of 2040 inelastic interactions. Additional details on the experimental arrangement, and on the scanning and measuring of events may be found in Ref. 3.

All charged outgoing tracks were taken to be pions except those of momentum less than 1.4 GeV/c, for which pion-proton separation by means of ionization is possible. From a study of K^o_S production[4] we estimate that $\sim 4\%$ of the charged tracks are kaons, assuming $\sigma(K^o_S) \approx \sigma(K^+) \approx \sigma(K^-)$. The $K^{*\pm}(892) \rightarrow K^o_S\pi^\pm$ and $\Delta^o(1232) \rightarrow p\pi^-$ signals in our data are sufficiently small that K^{*o} or Δ^o contamination in the ρ^o mass region (from $K^\pm\pi^\mp$ or $p\pi^-$ misidentified as $\pi^+\pi^-$) is negligible.

Figure 1 shows the inclusive mass distribution for all $\pi^+\pi^-$ combinations. This spectrum peaks at approximately 0.46 GeV and shows a distinct shoulder in the ρ^o region. For comparison, Fig. 1 also gives the corresponding distribution for pions of like charge ($\pi^+\pi^+$ and $\pi^-\pi^-$), which is observed to be structureless.

Figure 2 shows the inclusive $\pi^+\pi^-$ mass distribution for the following three intervals of center-of-mass rapidity, y, of the $\pi^+\pi^-$ system: $-3 < y < -1$ (backward or target fragmentation region), $-1 < y < 1$ (central region), and $1 < y < 3$ (forward or beam fragmentation region).[5] All regions show a shoulder

at the ρ^o mass. There is also some indication of f^o production in the central region.

The inclusive ρ^o cross section for each region in y was obtained by fitting the $0.48 < M(\pi^+\pi^-) < 1.12$ GeV mass range to a relativistic P-wave Breit-Wigner (with a fixed mass of 0.765 GeV and a fixed width of 0.150 GeV) plus a second-order polynomial background. A background of this form was found to provide a good description of the inclusive $\pi^\pm\pi^\pm$ distribution, Fig. 1, in the same mass range. A resolution function obtained from the measurement errors on $M(\pi^+\pi^-)$ was folded into the Breit-Wigner line shape. The average mass resolution is 12 MeV for $-3 < y < -1$, 23 MeV for $-1 < y < 1$, and 42 MeV for $1 < y < 3$. The resulting fits, shown by the smooth curves in Fig. 2, are excellent. The fit χ^2 per degree of freedom and $\sigma(\rho^o)$ for each rapidity interval are given in Table I. The errors given for $\sigma(\rho^o)$ are statistical only.

We note that ρ^o production is most copious in the central region, and that, at the present level of statistics, the forward and backward ρ^o cross sections are similar. This behavior is quite different from that observed in π^-p interactions at 8 GeV/c[6] where the ρ^o's come predominantly from excitation of the incoming pion and are therefore peaked strongly forward in the center of mass.

Summing over the three rapidity intervals, we obtain an overall ρ^o cross section of 13.5 ± 3.4 mb. For comparison, the inclusive ρ^o cross section at lower energy is 3.49 ± 0.42 mb in 24 GeV/c pp reactions[7] and is ~ 3.2 mb in 8 GeV/c π^-p reactions.[6] Thus $\sigma(\rho^o)$ has increased by about a factor of four in π^-p reactions between 8 and 205 GeV/c. Over the same momentum range, the average charged multiplicity has increased[6,3] from 3.4 to 8.0, a factor of 2.4.

The inelastic π^-p cross section at 205 GeV/c is 21.01 ± 0.46 mb,[3] so that an average of 0.64 ± 0.16 ρ^o are produced per inelastic interaction. The fraction of pions (charged plus neutral) coming from ρ decay can be estimated

assuming equal cross sections for ρ^+, ρ^-, and ρ^o production. Using $\sigma(\rho) \approx 3 \times \sigma(\rho^o) = 40.5 \pm 10.2$ mb and $\sigma(\pi) = 236 \pm 8$ mb[8] then gives that $(34.4 \pm 8.7)\%$ of all pions are products of ρ decay. The corresponding fractions at lower energy are $\sim 15\%$ in 24 GeV/c pp reactions[7] and $\sim 24\%$ in 8 GeV/c $\pi^- p$ reactions.[6]

The cross-section ratios $\sigma(\rho^o)/\sigma(\pi^+)$ and $\sigma(\rho^o)/\sigma(\pi^-)$ are given in Table I for the backward, central, and forward regions of ρ^o and $\pi^\pm$ center-of-mass rapidity. Here, the denominator includes all π^+ or π^-,[9] including those from ρ^o decay. The ρ^o/π^+ ratio in the central region is 0.26 ± 0.09, in agreement with a value of 0.21 obtained from a general peripheral calculation,[10] and with a value of 0.20 obtained from the quark model.[11]

We have also investigated the dependence of ρ^o production on overall charged multiplicity (n_{ch}). We find that a substantial fraction of the ρ^o cross section is associated with high charged multiplicity; for example, $\sigma(\rho^o) = 9.1 \pm 3.4$ mb for $n_{ch} \geq 10$.

Finally, using a $\rho^o \rightarrow \mu^+\mu^-$ branching fraction[12] of $(6.7 \pm 1.2) \times 10^{-5}$, we find a ratio

$$(\mu^- \text{ from } \rho^o \text{ decay}) / (\text{all } \pi^-) = (1.1 \pm 0.3) \times 10^{-5} ,$$

integrated over rapidity and over transverse momentum up to $p_T \approx 1$ GeV/c. However, due to limited statistics, we are unable to measure the $\rho^o/(\text{all } \pi^\pm)$ ratio for higher p_T, and thus no direct comparison is possible with the data of the lepton production experiments of Ref. 2, where $\mu^\pm/(\text{all } \pi^\pm) \approx 10^{-4}$ is observed for $p_T \gtrsim 1$ GeV/c.

Conclusions.—We have measured the cross section for $\pi^- p \rightarrow \rho^o$ + anything at 205 GeV/c to be 13.5 ± 3.4 mb and estimate that approximately one-third of the pions at this energy come from ρ decay. Thus ρ production is an important source of pions in πp collisions at high energy and can therefore be expected to have a substantial effect on single-pion inclusive distributions and two-

pion correlations.[13] With the present statistics we are not able to explore in detail other aspects of inclusive ρ^o production such as polarization, scaling, and ρ-π or ρ-ρ correlations.

Acknowledgments.—It is a pleasure to acknowledge the effort put forth by the 30-in. bubble chamber staff, the hadron beam group, the accelerator operations personnel, and our scanning and measuring staffs.

Table I. ρ^o cross sections and $\rho^o/\pi^\pm$ ratios in 205 GeV/c π^-p interactions.

rapidity interval	χ^2/dof	$\sigma(\rho^o)$ (mb)	ρ^o/π^+	ρ^o/π^-
$-3 < y < -1$	0.86	2.70±1.25	0.17±0.08	0.20±0.09
$-1 < y < 1$	0.82	8.10±2.81	0.26±0.09	0.25±0.09
$1 < y < 3$	1.08	2.66±1.39	0.13±0.07	0.10±0.05

FOOTNOTES AND REFERENCES

*Work supported by the U. S. Atomic Energy Commission, the National Science Foundation, and the French C.N.R.S.

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‡‡Now at Yale University, New Haven, Connecticut 06520.

1. The status of inclusive meson resonance production has been reviewed by F. C. Winkelmann, Lawrence Berkeley Laboratory Report No. LBL-3045 (1974), and Proceedings of the IVth International Conference on Meson Spectroscopy, Boston, Massachusetts (1974). This report also contains preliminary results of the present work.

2. J. P. Boymond et al., Phys. Rev. Letters 33, 112 (1974); J. A. Appel et al., Phys. Rev. Letters 33, 722 (1974); D. Bintinger et al., R. Birge et al., and F. W. Büsser et al., in Proceedings of the XVIIth International Conference on High Energy Physics, London, England (1974).

3. D. Bogert et al., Phys. Rev. Letters 31, 1271 (1973).

4. D. Bogert et al., Inclusive γ, K^o_S, Λ^o and $\bar{\Lambda}^o$ Production in 205 GeV/c $\pi^- p$ Interactions, Fermilab Report No. NAL-Conf-74/55 (1974).

5. Only 0.3% of the observed $\pi^+\pi^-$ combinations fall outside of the $-3 < y < 3$ rapidity range.

6. T. Kitagaki et al., An Inclusive Study of ρ^o Production in $\pi^- p$ Interactions at 8 GeV/c, submitted to the IVth International Conference on Meson Spectroscopy, Boston, Massachusetts (1974). See also Ref. 1.

7. V. Blobel et al., Phys. Letters 48B, 73 (1974).

8. We have used $\sigma(\pi) = \sigma(\pi^+) + \sigma(\pi^-) + \sigma(\pi^o)$, with $\sigma(\pi^-) = \langle n_{ch} \rangle \sigma_{inel}/2 - \sigma(K^-) = 80.4 \pm 2.0$ mb; $\sigma(\pi^+) = \langle n_{ch} \rangle \sigma_{inel}/2 - \sigma(K^+) - \sigma(p) = 70.0 \pm 2.0$ mb; and $\sigma(\pi^o) \approx \sigma(\pi^- p \rightarrow \gamma + \text{anything})/2 = 85.3 \pm 7.6$ mb (Ref. 4). Here, $\langle n_{ch} \rangle$ = average charged multiplicity = 7.99 ± 0.06, $\sigma_{inel} = 21.01 \pm 0.46$ mb (Ref. 3), and $\sigma(p) \approx \sigma_{inel}/2$; also, we assume $\sigma(K^+) \approx \sigma(K^-) \approx \sigma(K^o_S) = 3.49 \pm 0.60$ mb (Ref. 4) and neglect possible $\bar{p}$ contamination in the π^- sample.

9. The $\pi^\pm$ cross sections used have been corrected for $K^\pm$ contamination assuming a rapidity-independent $K^\pm/\pi^\pm$ ratio of 4%. In addition, $\sigma(\pi^+)$ for $-3 < y < -1$ has been corrected for an estimated 4.1 mb of contamination due to protons (with momentum $\gtrsim 1.4$ GeV/c) which could not be identified by ionization. Proton contamination in the central and forward regions is assumed to be negligible.

10. R. M. Barnett and D. Silverman, The Relative Production of ρ and π in the Central Plateau, University of California, Irvine, Report No. 74-27 (1974).

11. V. V. Anisovich and V. M. Shekhter, Nucl. Physics B55, 455 (1973) and erratum, Nucl. Physics B63, 542 (1973).

12. V. Chaloupka et al., Review of Particle Properties, Phys. Letters 50B, No. 1 (1974).

13. For discussion of the effects of meson resonance production and decay on one- and two-particle inclusive distributions see, for example, A. Bassetto, M. Toller, and L. Sertorio, Nucl. Physics B34, 1 (1971); T. Sasaki and N. Murai, Phys. Rev. D9, 3090 (1974); J. Randa, Inclusive Rho Effects on Two-Pion Production, Texas A and M University preprint (1974); and F. Hayot, Resonances in High Multiplicity Reactions, University of Michigan Report No. UM-HE-74-36 (1974).

FIGURE CAPTIONS

Fig. 1. Inclusive $\pi^+\pi^-$ and $\pi^\pm\pi^\pm$ mass distributions for $\pi^- p \to \pi^+\pi^- X$ at 205 GeV/c. The arrow indicates the expected position of the ρ^o at $M(\pi^+\pi^-) = 0.765$ GeV.

Fig. 2. $\pi^+\pi^-$ mass distribution for three intervals of center-of-mass rapidity, y, of the $\pi^+\pi^-$ system in $\pi^- p \to \pi^+\pi^- X$ at 205 GeV/c. The arrow indicates the expected position of the ρ^o at $M(\pi^+\pi^-) = 0.765$ GeV.

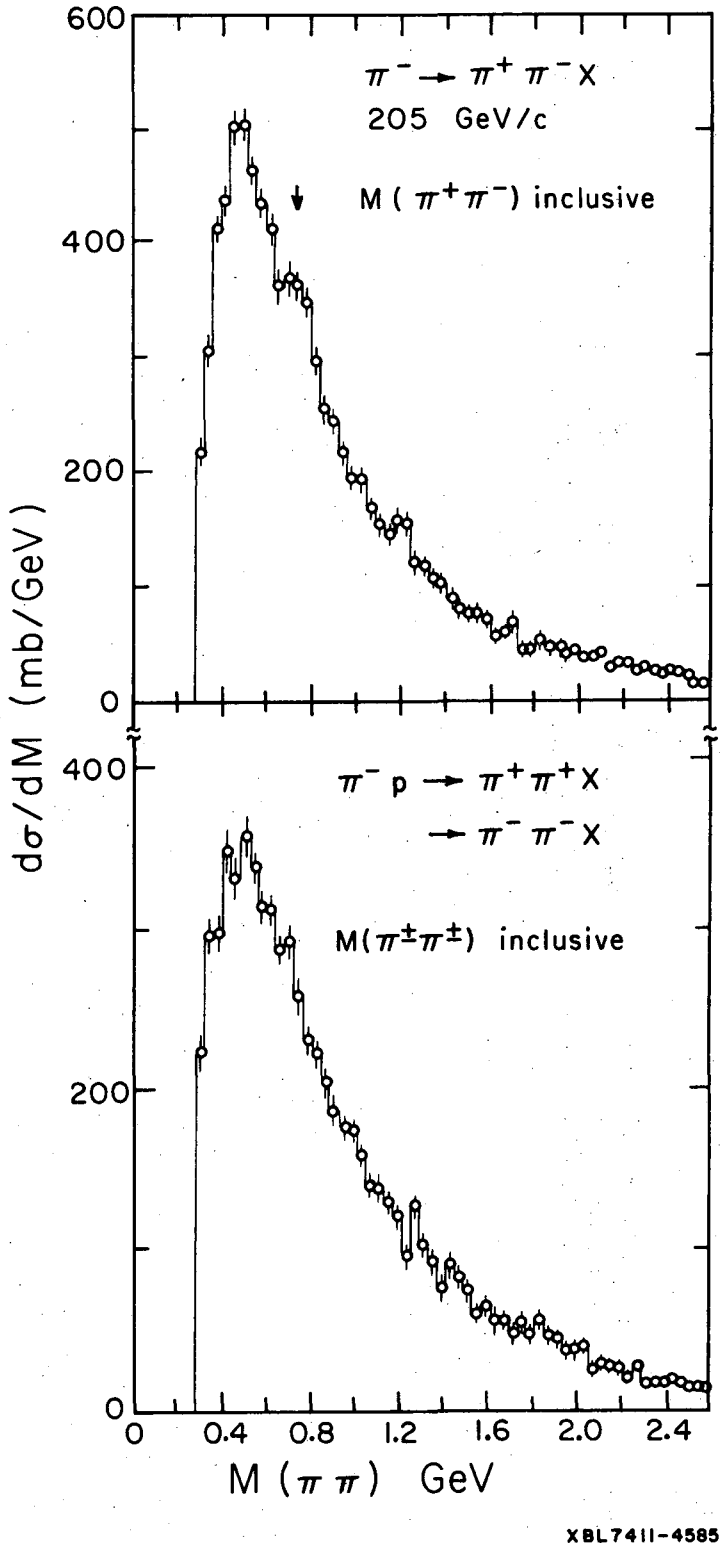
600
400
200
0
$\pi^- \rightarrow \pi^+ \pi^- X$
205 GeV/c
M ($\pi^+\pi^-$) inclusive
400
200
0
$\pi^- p \rightarrow \pi^+ \pi^+ X$
$\rightarrow \pi^- \pi^- X$
M($\pi^\pm\pi^\pm$) inclusive
0
0.4
0.8
1.2
1.6
2.0
2.4
M ($\pi\pi$) GeV
$d\sigma/dM$ (mb/GeV)
XBL7411-4585

Fig. 1

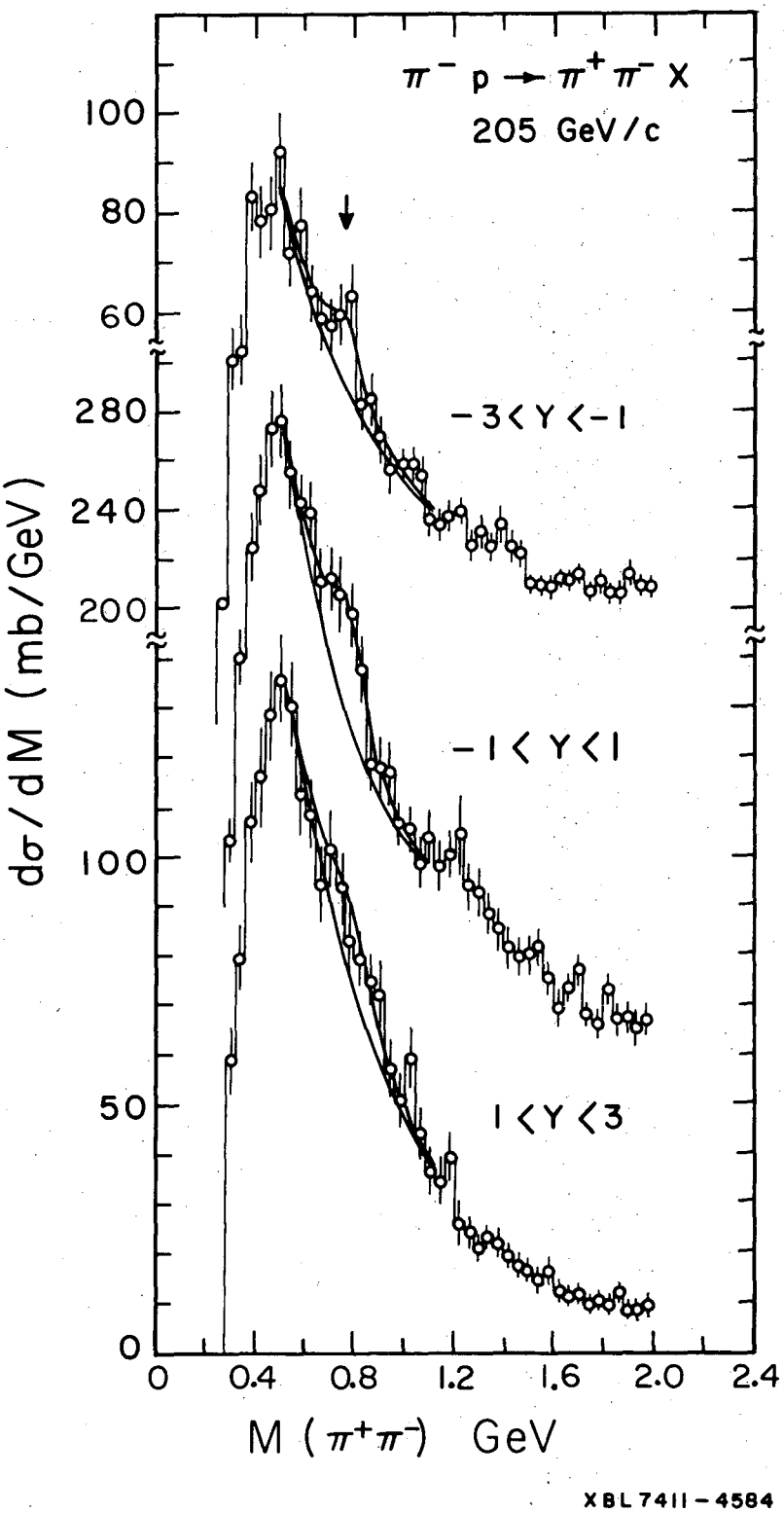
$\pi^- p \to \pi^+ \pi^- X$
205 GeV/c
$-3 < Y < -1$
$-1 < Y < 1$
$1 < Y < 3$
$d\sigma/dM$ (mb/GeV)
$M(\pi^+\pi^-)$ GeV
0
50
100
200
240
280
60
80
100
0.4
0.8
1.2
1.6
2.0
2.4
XBL 7411-4584

Fig. 2

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