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Inclusive and Semi-Inclusive ρ^0 Production in $\pi^- p$ Interactions at 147 GeV/c*

by

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ABSTRACT

We present data on inclusive and semi-inclusive ρ^0 production in 147 GeV/c $\pi^- p$ interactions. We find a total cross section of 7.3 ± 1.3mb. Most of this cross section is found in the lower topology events ($\lesssim$10 prongs), and in the central and forward rapidity regions. The P_T^2 dependence of ρ^0 production, $\langle n \rangle_{\rho^0}$ per event, and the ρ^0/π^+ratios are also discussed.

There has been a great deal of interest recently in the study of inclusive ρ^0 production at medium and high energies. Previous work on πp interactions from 8 to 23 GeV/c [1,2] has indicated that there are two different mechanisms involved in this process: one which tends to produce ρ^0's in the central region of rapidity and a second component which is associated with beam dissociation, producing these mesons in the forward region of rapidity. It has also been observed that the ρ to π ratio at these energies varies with the transverse momentum (P_T) of the two particles, approaching a value of one for high P_T.[3] This has been proposed as a part of the explanation for the production of leptons at high P_T observed in nucleon-nucleon collisions at Fermilab and the CERN ISR.[4]

One high momentum $\pi^- p$ experiment, at 205 GeV/c, has presented results on inclusive ρ^0 production.[5] This experiment, based on $\sim$2000 inelastic events in the Fermilab 30" HBC, finds a cross section for ρ^0 production of 13.5±3.4mb. This is an increase

of over 8 mb from 15 GeV/c $\pi^- p$ results with almost all of the rise occurring in the higher topology events (10-16 prongs) and in the central region of rapidity.[1] The cross section in the forward region of rapidity appears relatively constant over this large energy range. Their large ρ^0 cross section, together with some assumptions about relative production of ρ^+ and ρ^- leads the authors of Ref.5 to conclude that approximately one third of the pions seen at this energy could have come from ρ meson decay.

In this paper we present results on the inclusive and semi-inclusive production of ρ^0 mesons in $\pi^- p$ interactions at 147 GeV/c. Using the Fermilab 30" HBC and the downstream proportional wire hybrid system we have measured a sample of $\sim$7000 inelastic events of all topologies less than 18 prongs. Details of the experimental setup, topological cross sections, and the complete analysis of the two prong final states have already been presented.[6,7] The use of the downstream proportional wire chamber system allows good mass resolution ($\lesssim$50 MeV) for dipion systems in the ρ^0 mass region up to the highest momentum.

In Fig. 1a we show $d\sigma/dM$ for the $\pi^+\pi^-$ system for the entire sample. Cross sections have been obtained by normalizing the number of events successfully measured in each topology to the topological cross sections previously reported.[6] Approximately 20% of those events which failed in the first pass were remeasured and examined separately. They indicated that there were no observable biases in the ρ^0 production in the original

sample. These remeasurements were included in the final analysis.

The curve on Fig. 1a shows our best fit to the data. We have used a p-wave Breit-Wigner shape for the resonance and an exponential shape for the background.[8] The mass and width of the ρ^0 have been fixed at M_0 = 765 MeV and Γ_0 = 177 MeV. This width is consistent with the natural width of the ρ^0 folded with our mass resolution, which is ± 50 MeV for $\pi^+\pi^-$ combinations with an effective mass in the ρ^0 region and center-of-mass rapidity > -1. The shape of the background was tested by fitting it to the summed $\pi^+\pi^+$ and $\pi^-\pi^-$effective mass distributions over the same region (520 - 1080 MeV) as used in the ρ^0 fits. The exponential background parametrization gave a good fit to these data.

Using these fits we find a total cross section for ρ^0 production of 7.3± 1.3mb. Figures 1b - 1e show $d\sigma/dM$ for the $\pi^+\pi^-$ combinations in the 4,6,8, and ≥10 prong events. There are clear signals for ρ^0 production in the three lower topologies (the two prongs, not shown, have no discernible ρ^0 signal[7]). In the higher topologies (≥10 prongs)there is a small signal evident on a large background. Because of the large number of $\pi^+\pi^-$ combinations possible for each event, the resonance is very difficult to separate from the background. The curves represent our best fits to the data; the cross sections are given in Table I. Also listed are the average number of ρ^0 per event.

Table I also shows the results from the π^-p experiment at 15 GeV/c.[1] Although the topological cross sections are significantly different, $\langle n \rangle_{\rho^0}$/event as a function of topology appears quite similar over this large energy range.

We can also compare the ρ^0 cross section for each of these topologies with the number of π^+ mesons produced. In order to do this comparison we have identified all protons of momentum $\leq$1.4 GeV/c by ionization. All other positive tracks have been considered as π^+ mesons. We estimate, based upon K_S^0 production and the assumption that $\sigma(K^+) \sim \sigma(K^-) \sim \sigma(K^0)$, that there is $\leq$5% K^+ contamination in this sample.

Table I shows the results of this calculation. The ratio of ρ^0/π^+ is relatively constant with an average value of $\sim 0.13 \pm 0.03$ for the four to ten prong events and 0.11 ± 0.02 over the entire sample. We can compare this with the ρ^0/π^- ratio in π^+p interactions at 23 GeV/c,[2] and find our values generally smaller than theirs, especially in the four prong sample. The average number of ρ^0/π^+ for the entire sample and the equivalent ratio in πp interactions from 16 to 205 GeV/c are shown in Fig. 2c.

Our total cross section of 7.3±1.3mb is considerably smaller than the value of 13.5±3.4mb reported at 205 GeV/c.[5] The difference between these experiments is almost entirely in the high topology events. For eight prongs and less, we have a cross section of 4.4 ± 0.7mb compared with the Ref. 5 cross section of 4.4mb. The cross section of 2.9±1.1mb in the high topology events ($\geq$10 prongs) is sensitive to the width used for the ρ^0 and to the amount of curvature in the background, which are highly correlated. The summed $\pi^+\pi^+$ and $\pi^-\pi^-$ distribution for the 10-16 prongs was adequately fit by the exponential form without curvature.[8] The width used in the fits, 177 MeV, is that obtained in a fit to the lower topologies and is consistent with our

mass resolution. As an indication of the quality of our fits, Fig. 1f shows the difference between our 2-8 prong data and the background term of the fit. The curve is the pure Breit-Wigner term with M_0 = 765 MeV and Γ_0 = 177 MeV.

Using our total inelastic cross section of 21.1mb[6] we calculate that there are an average of $0.35\rho^0$/event. Figure 2 shows both the total inclusive cross section and the average number of ρ^0/event from 16 to 205 GeV/c.

We have also examined the production of the ρ^0 as a function of center-of-mass rapidity (y^*) and transverse momentum (P_T). For these studies we have made cuts on the entire $\pi^+\pi^-$ sample as functions of P_T^2 and y^*, and fit the mass distribution of each subsample to determine the amount of ρ^0 present. This method determines the ρ^0 distributions independent of the behavior of the background. In Fig. 3a we show $d\sigma/dy^*$ for rapidity between -3 and +3. Most of our production occurs for $y^* > 0$. Figure 3a also shows the data from the π^-p experiments at 15 and 205 GeV/c,[1,5] and a π^+p experiment at 16 GeV/c.[2] The rapidity range for the lower momentum experiments is, of course, smaller than for the two high momentum results. They do however, show the same tendency for production of the ρ^0 in the forward hemisphere. When we compare our results with the 205 GeV/c data there is good agreement in the forward or beam dissociation region. In the central region, however, a cross section of $8.10^{\pm}2.81$mb ($-1 < y^* < 1$) is reported at 205 GeV/c while for the same region we obtain a value of $2.5^{\pm}1.0$mb. In Fig. 3b we show the ρ^0/π^+ ratio as a function of rapidity. There is a quark model prediction that in the central region

this ratio should be ~ 0.2.[9] Although low, our value is not inconsistent with this prediction. Our ratio rises to a maximum in the very forward direction. This may indicate that many of the forward pions come from beam dissociation and may be relatively often the decay products of the ρ^0 produced by the beam dissociation.

Figure 3c shows $d\sigma/dP_T^2$ for the ρ^0 for $P_T^2 \leq 2$ $(GeV/c)^2$. We have fit the data to an exponential form $Ae^{-bP_T^2}$ and find a slope of $2.7 \pm 0.5 (GeV/c)^{-2}$. As mentioned before, this determination of slope is independent of the background behavior. This slope can be compared with a value of $3.45 \pm 0.01 (GeV/c)^{-2}$ found at 16 GeV/c.[2] Using this fit we can calculate a mean squared transverse momentum for the ρ^0 of 0.38 $(GeV/c)^2$. We also show in Fig. 3c the $d\sigma/dP_T^2$ for π^+ mesons in this experiment. This cross section is dropping more rapidly at low P_T^2 than the ρ^0 cross section indicating that the ρ^0/π^+ ratio is, in fact, increasing from a small value to near unity as a function of transverse momentum.

The authors of reference 2 have pointed out that the non-resonant background in their experiment had a P_T^2 dependence similar to that of the ρ^0 signal. We have examined the background for $\pi^+\pi^-$ combinations in the ρ^0 mass region and find an exponential P_T^2 shape with a slope of 3.3 ± 0.1 $(GeV/c)^{-2}$, consistent with the ρ^0 slope. Thus, as found in reference 2 for π^+p interactions at lower energies, the P_T^2 dependence of the resonant signal may be a feature of the $\pi^+\pi^-$ system in this mass region rather than a unique characteristic of ρ^0 production.

In summary, we have found a cross section for inclusive ρ^0 production in π^-p interactions at 147 GeV/c of 7.3 ± 1.3mb. Most of the production which we can identify is in the lower topology events (≤ 10 prongs) and takes place in the forward hemisphere. There is good agreement in this region with results from lower energy π^+p and π^-p experiments. The very forward or beam dissociation production of ρ^0 appears relatively constant with energy.

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8. We have fit the background to a shape $\propto e^{A_1 M + A_2 M^2}$ following Ref. 2. Since A_2 was consistent with 0 in all fits to our data, cross sections presented in this paper were obtained with A_2 fixed at 0. The errors quoted on these cross sections are from the fits and do not include possible systematic errors due to the particular parametrization used. Other parametrizations, such as using a polynomial background, were tried and gave results within one standard deviation of our quoted cross sections.

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Table I: Cross sections and ratios obtained in this experiment and in a 15 GeV/c $\pi^- p$ experiment.[1]

	$\sigma(\rho^0)$ mb		$\langle n \rangle_{\rho^0}$/event		ρ^0/π^+
PRONGS	15 GeV/c[1]	147 GeV/c	15 GeV/c[1]	147 GeV/c	147 GeV/c
2	0.27±0.04	0.04±0.04	0.05±0.01	---------	---------
4	2.18±0.20	0.9 ±0.2	0.24±0.02	0.21±0.05	0.15±0.03
6	1.65±0.20	1.8 ±0.4	0.34±0.04	0.41±0.08	0.16±0.03
8	0.61±0.23	1.6 ±0.5	0.45±0.17	0.38±0.11	0.10±0.03
10	---------	1.7 ±0.5	---------	0.54±0.17	0.11±0.04
12-16	---------	1.2 ±1.0	---------	0.39±0.32	0.06±0.05
TOTAL	4.72±0.37	7.3 ±1.3	0.22±0.02	0.35±0.06	0.11±0.02

FIGURE CAPTIONS

Fig. 1. $d\sigma/dM$ for $\pi^+\pi^-$ combinations. The curves represent our best fits to the data. a) All events, b) 4 prongs, c) 6 prongs, d) 8 prongs, e) $\geq$10 prongs. f) The difference between the 2-8 prong sample and the background parametrization. The curve is the p-wave Breit-Wigner.

Fig.2. a) $\sigma(\rho^0)$ as a function of momentum for $\pi^{\pm}p$ interactions. We start at 15 GeV/c to minimize the contribution from quasi-two body resonance production such as $\Delta^{++}\rho^0$. b) $\langle n \rangle_{\rho^0}$ for the same experiments. c) ρ^0/π ratio. The non-beam pion is used to eliminate leading particle effects.

Fig.3. a) $d\sigma/dy^*$ for ρ^0 production for this experiment (·), π^-p experiments at 15 GeV/c (x) and 205 GeV/c (o),[1,5] and π^+p at 16 GeV/c (solid line). b) ρ^0/π^+ ration as a function of rapidity. c) $d\sigma/dP_T^2$ for ρ^0 production (+) and π^+ production (x).

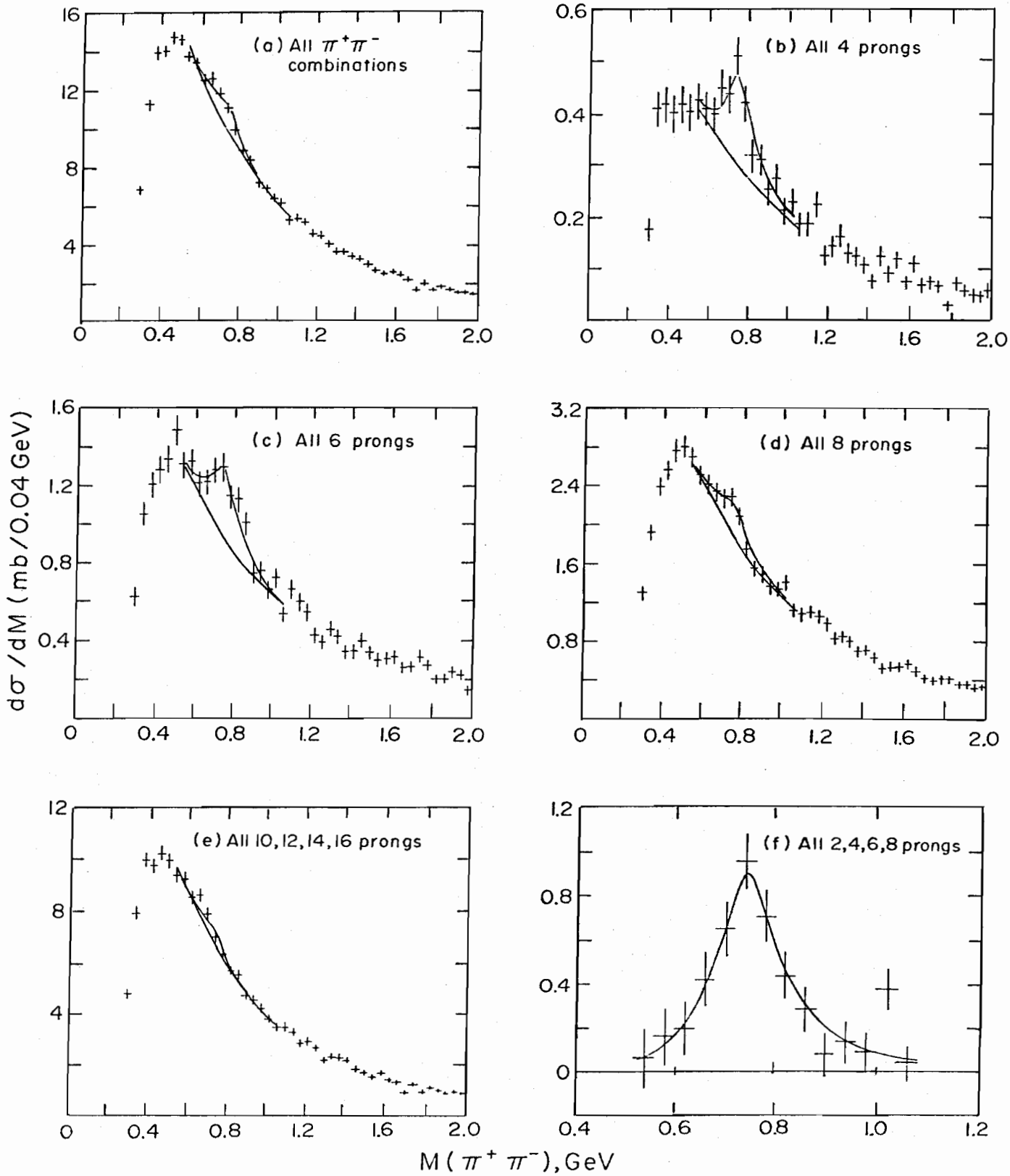
(a) All $\pi^+\pi^-$ combinations
(b) All 4 prongs
(c) All 6 prongs
(d) All 8 prongs
(e) All 10, 12, 14, 16 prongs
(f) All 2,4,6,8 prongs
$d\sigma/dM$ (mb/0.04 GeV)
$M(\pi^+\pi^-)$, GeV

FIGURE 1

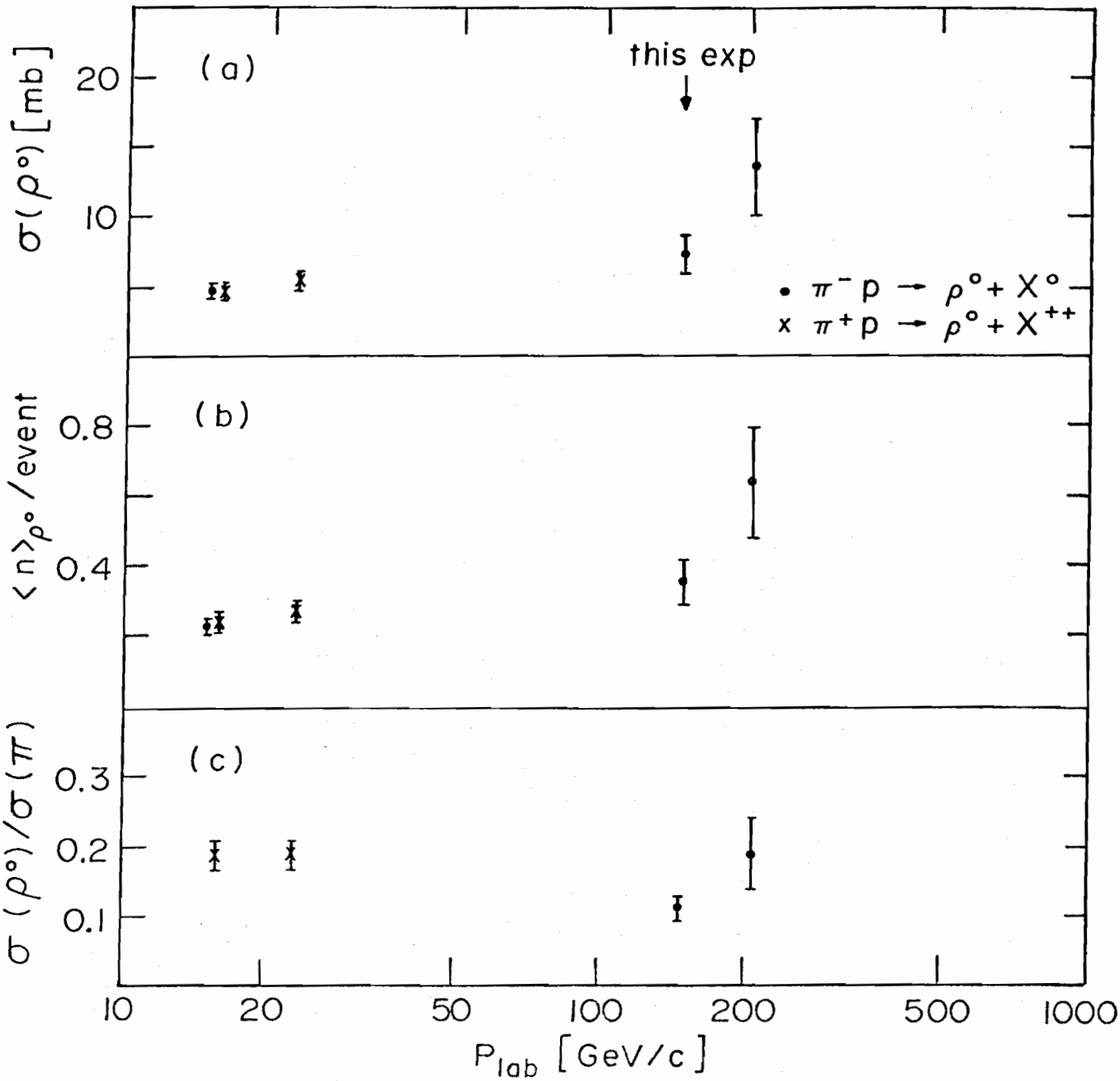
(a)
this exp
σ(ρ°) [mb]
20
10
• π⁻p → ρ° + X°
x π⁺p → ρ° + X⁺⁺
(b)
⟨n⟩ρ° /event
0.8
0.4
(c)
σ (ρ°)/σ (π)
0.3
0.2
0.1
10
20
50
100
200
500
1000
Plab [GeV/c]

FIGURE 2

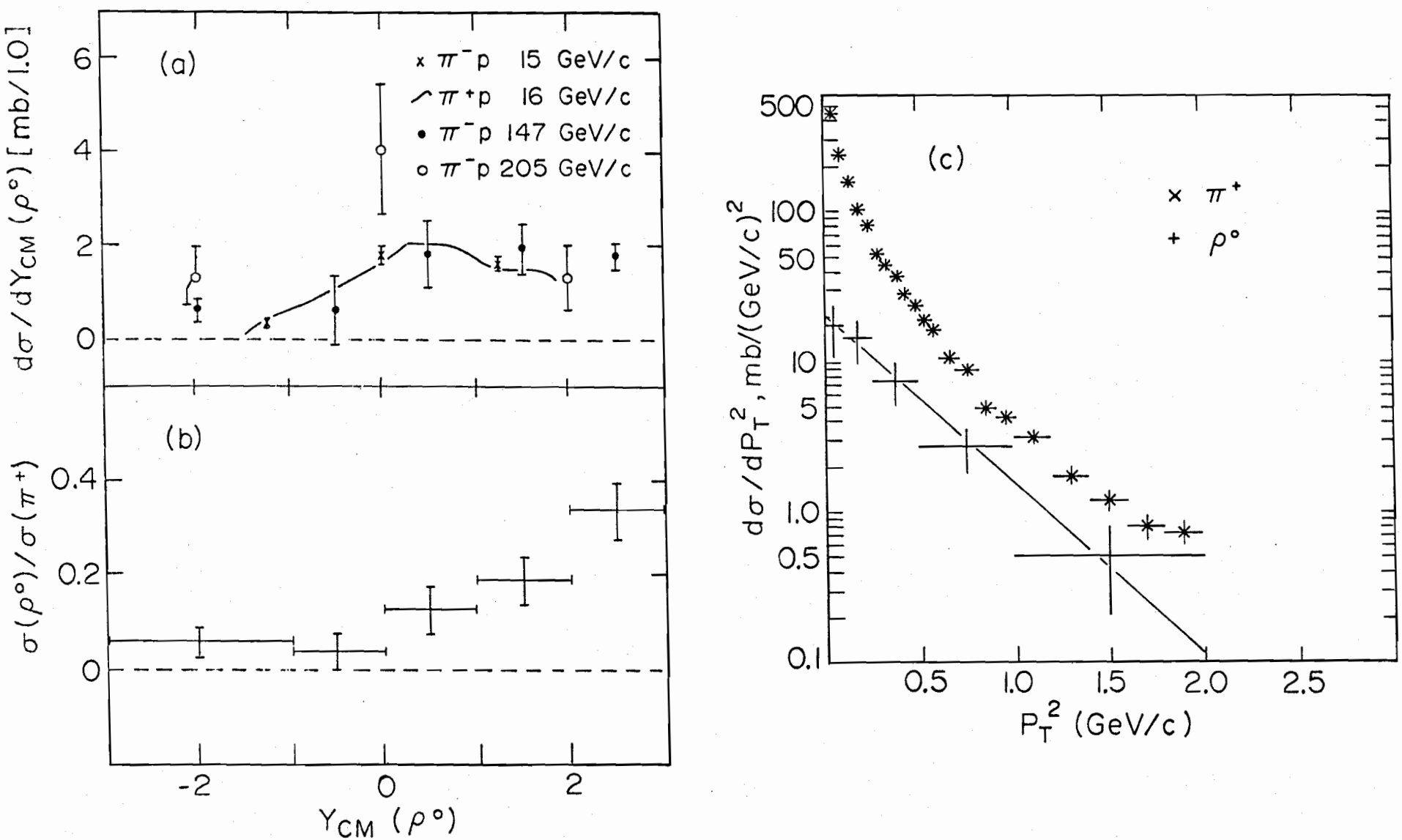
(a)
× π⁻p 15 GeV/c
π⁺p 16 GeV/c
• π⁻p 147 GeV/c
○ π⁻p 205 GeV/c
dσ/dY_CM (ρ°) [mb/1.0]
(b)
σ(ρ°)/σ(π⁺)
Y_CM (ρ°)
(c)
× π⁺
+ ρ°
dσ/dP_T², mb/(GeV/c)²
P_T² (GeV/c)

FIGURE 3