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A COMPARISON OF $\pi^- p \to \rho^0 n$ WITH SINGLE PION PHOTOPRODUCTION AT 15 GeV/c *

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ABSTRACT

We present a comparison of new data on $\pi^- p \to \rho^0 n$ at 15 GeV/c with polarized and unpolarized single pion photoproduction data. Particular emphasis is placed upon the behavior of the differential cross sections and asymmetries in the forward direction, $(-t < m_\pi^2)$.

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Studies of single pion photoproduction at SLAC[1] and DESY[2] have shown a sharp increase in the differential cross section, $d\sigma/dt$, for momentum transfers to the nucleon $-t < m_\pi^2$, over a large energy range. In addition, experiments with linearly polarized photons have shown that the asymmetry parameter, which is zero in the forward direction, rises rapidly to unity[3] at $-t \approx m_\pi^2$. Single pion photoproduction is related to the reaction

$$\pi^- p \rightarrow \rho^o n \qquad (1)$$

through the vector dominance model (VDM).[4] Since the small t behavior of the photoproduction processes is so striking, it is important to look for similar structure in the forward direction in reaction (1). Furthermore, this reaction is interesting from the point of view of exchange models which also make predictions concerning forward structure in $\pi^- p \rightarrow \rho^o n$. The strong cut absorption model[5] shows a sharp peak in the transverse cross section for momentum transfers less than m_π^2. In contrast, the one pion exchange model requires that the cross section should vanish in the forward direction, whereas Avni and Harari[6] have predicted no pronounced structure in the transverse cross section. Although previous comparisons of $\pi^- p \rightarrow \rho^o n$ with single pion photoproduction have been published,[7] the new data presented in the previous letter[8] allow this comparison to be made in the small t region ($-t < m_\pi^2$) for the first time.

In the preceding letter we presented the differential cross sections and density matrix elements for the reaction $\pi^- p \rightarrow \pi^+ \pi^- n$ at an incident beam momentum of 15 GeV/c. The density matrix elements for the ρ^o in the helicity frame are shown in Fig. 1. They have been obtained from the dipion density matrix elements described in Ref. 8 by imposing the normalization condition $2\rho_{11} + \rho_{00} = 1$ after subtracting the S-wave. The S-wave cross section was assumed to be of the form

$$\frac{d\sigma}{dt}(\text{S-wave}) = B \frac{|t|}{(t-m_\pi^2)^2} \; e^{7t}$$

as obtained from the data of Sonderegger and Bonamy[9] for the reaction $\pi^- p \rightarrow \pi^o \pi^o n$ and extrapolated to 15 GeV/c. The behavior of the ρ^o density matrix elements for small t does not depend strongly on the assumed t dependence of the S-wave background.[8]

The VDM directly relates the reaction $\gamma N \rightarrow \pi N$, to the reaction, $\pi^- p \rightarrow V^o n$, where N is the nucleon and V^o is a mixture of ρ^o, ω, and ϕ. Since the coupling of the ϕ to nonstrange mesons is small, we can neglect its contribution in the direct term and in ω-ϕ interference. The VDM then predicts[4]

$$\frac{1}{2}\left[\frac{d\sigma}{dt}(\gamma p \rightarrow \pi^+ n) + \frac{d\sigma}{dt}(\gamma n \rightarrow \pi^- p)\right] = \frac{\pi\alpha}{\gamma_\rho^2}\left[\rho_{11}\right]_\rho \frac{d\sigma}{dt}(\pi^- p \rightarrow \rho^o n) + \frac{\pi\alpha}{\gamma_\omega^2}\left[\rho_{11}\right]_\omega \frac{d\sigma}{dt}(\pi^- p \rightarrow \omega n) \quad (2)$$

where $[\rho_{11}]_\rho\left([\rho_{11}]_\omega\right)$ is the density matrix element which projects out the transversely polarized ρ^o (ω) mesons. We take the sum of the photoproduction cross sections to cancel ρ-ω and ρ-ϕ interference effects. The photon-vector-meson coupling constants have been measured[10] to be in the ratio $(1/\gamma_\rho^2):(1/\gamma_\omega^2) = (7.51 \pm 1.52):1$ and $(d\sigma/dt)\ (\pi^- p \rightarrow \rho^o n):(d\sigma/dt)(\pi^- p \rightarrow \omega n)$ is approximately 10:1 in the forward direction at 8 GeV.[11] Assuming that this ratio does not change greatly at 15 GeV/c, the second term in Eq. (2) contributes only a few percent compared with the ρ^o term and can be ignored. Equation (2) then becomes

$$\frac{(1+R)}{2}\frac{d\sigma}{dt}(\gamma p \rightarrow \pi^+ n) = \frac{\pi\alpha}{\gamma_\rho^2}\rho_{11}^H \frac{d\sigma}{dt}(\pi^- p \rightarrow \rho^o n)\ , \quad (3)$$

where

$$R = \frac{d\sigma}{dt}(\gamma n \rightarrow \pi^- p)/\frac{d\sigma}{dt}(\gamma p \rightarrow \pi^+ n)$$

is taken from the π^-/π^+ ratio on deuterium.[1] For the comparisons in this paper, we take $\gamma_\rho^2/4\pi = 0.50$.[10]

It is also possible to extract the components of linear polarization for the ρ^o which may be compared with the photoproduction data obtained with linearly polarized photons. The VDM predicts[4]

$$\frac{1}{2}\left[\frac{d\sigma_{\perp}}{dt}(\gamma n\to\pi^- p)+\frac{d\sigma_{\perp}}{dt}(\gamma p\to\pi^+ n)\right]=\frac{\pi\alpha}{\gamma_\rho^2}\left(\rho^H_{11}+\rho^H_{1-1}\right)\frac{d\sigma}{dt}(\pi^- p\to\rho^o n) \quad (4)$$

$$\frac{1}{2}\left[\frac{d\sigma_{\parallel}}{dt}(\gamma n\to\pi^- p)+\frac{d\sigma_{\parallel}}{dt}(\gamma p\to\pi^+ n)\right]=\frac{\pi\alpha}{\gamma_\rho^2}\left(\rho^H_{11}-\rho^H_{1-1}\right)\frac{d\sigma}{dt}(\pi^- p\to\rho^o n) \quad (5)$$

where $\sigma_\perp(\sigma_\parallel)$ denotes the cross section $d\sigma/dt$ for pions produced in a plane perpendicular (parallel) to the electric vector of the photon, and where we have neglected the small contribution of the other vector mesons as before. Equations (4) and (5) correspond to processes with natural and unnatural parity exchanged in the t-channel.[12] Equation (4) is invariant under rotations about the normal to the production plane, and is thus independent of certain frame ambiguities of the VDM which arise since the helicity of a massive particle is not Lorentz invariant.[13] Several theoretical arguments have been made,[14] however, which suggest that at high energies the helicity frame is the correct choice.

A consequence of Eqs. (4) and (5) is

$$\frac{\rho_{1-1}}{\rho_{11}}=\frac{A^+ + RA^-}{1+R} \quad , \quad (6)$$

a comparison which is independent of the normalization of the two sets of data, and the value of the rho-photon coupling constant. The asymmetry parameters are defined by

$$A^{\pm}=\frac{\sigma^{\pm}_{\perp}-\sigma^{\pm}_{\parallel}}{\sigma^{\pm}_{\perp}+\sigma^{\pm}_{\parallel}}$$

where, for example, $\sigma^+_\perp$ is the cross section $d\sigma_\perp/dt$ for π^+ photoproduction.

In Figs. 2a, b, c and d the photoproduction data are compared to our results for reaction (1) using Eqs. (3), (4), (5), and (6) respectively. Since polarized photoproduction cross sections are not yet available at high energy, the photoproduction data shown in Figs. 2b-d were obtained by combining the asymmetry parameters $A^{\pm}$ measured at lower energies[3, 15] with the unpolarized cross sections and π^-/π^+ ratios at 16 GeV/c.[1]

The overall behavior in t of the data in Fig. 2a, b, c, d shows qualitative agreement, and indeed, the forward, t=0, cross sections are in good agreement. The transverse rho cross section (Fig. 2a) agrees rather well for larger t, but falls more sharply than the unpolarized photoproduction cross section for $-t < m_\pi^2$. Except for the forward point in Fig. 2b, the rho data fall a factor of two below the photoproduction data, but display similar shape. It is interesting to note in Fig. 2c the dramatic rise of the cross sections for $-t < m_\pi^2$, and the remarkable agreement between the rho production and photoproduction data. The asymmetry comparison, shown in Fig. 2d, shows good agreement for momentum transfers less than $2m_\pi^2$, but the asymmetry in the rho data falls more rapidly for larger t.

Cho and Sakurai[16] have extended the vector dominance model to predict the dominant longitudinal amplitude for reaction (1) in addition to the usual predictions of the transverse amplitudes. In Fig. 3 we show both the transverse and total rho cross sections. The dotted line is the input to the calculation of Cho and Sakurai based on the single pion photoproduction cross sections, while the solid line is their prediction for the total rho cross section. The agreement in the total cross section is good for $-t < 0.1$ $(\text{GeV/c})^2$.

In drawing quantitative conclusions from Figs. 2 and 3, it should be noted that the errors shown are statistical only and do not include the contribution from the uncertainty in the S-wave normalization.[17]

In conclusion, our rho production results show structure similar to the single pion photoproduction data. The magnitudes of the forward cross section are the same and the existence of a sharp forward peak and the rapid change in the asymmetry are features present in both reactions. In detail, the unnatural parity exchange cross section agrees very well, as does the asymmetry for $-t < 2m_{\pi}^2$. However, elsewhere either in the sharpness of the structure or the absolute cross section, there are pronounced differences which may not be resolved by changes of scale (e.g., change in value of $\gamma_{\rho}^2/4\pi$). These differences indicate some inadequacy in the VDM description of the details for the rho production process.

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FIGURE CAPTIONS

1. The spin density matrix elements in the helicity frame for the ρ^o with the normalization $2\rho_{11} + \rho_{00} = 1$. The data are obtained from Ref. 8.

2. Differential cross sections and asymmetries for single pion photoproduction and rho production in $\pi^- p \to \rho^o n$, $(d\sigma/dt)_\rho$;

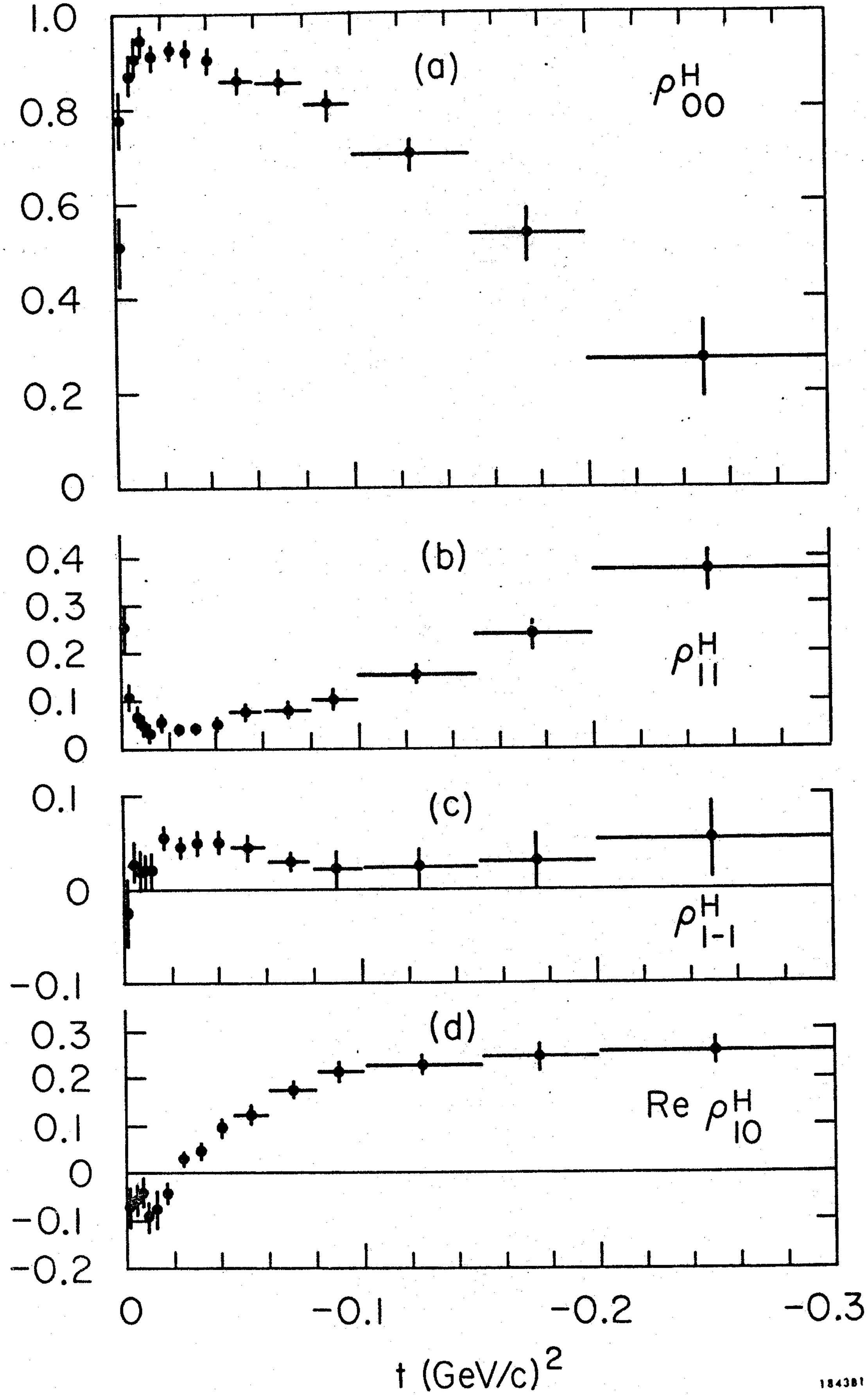
   (a) the unpolarized cross section (see Eq. (3) of text);

   (b) the natural parity cross section (see Eq. (4) of text);

   (c) the unnatural parity cross section (see Eq. (5) of text);

   (d) the asymmetry (see Eq. (6) of text).

3. Differential cross sections $d\sigma/dt$ and $2\rho_{11}(d\sigma/dt)$ for $\pi^- p \to \rho^o n$ at 15 GeV. The solid line represents the prediction of Cho and Sakurai,[16] and the dotted line represents the input to their calculation.


1.0
0.8
0.6
0.4
0.2
0
(a)
ρ^H_{00}
0.4
0.3
0.2
0.1
0
(b)
ρ^H_{11}
0.1
0
-0.1
(c)
ρ^H_{1-1}
0.3
0.2
0.1
0
-0.1
-0.2
(d)
Re ρ^H_{10}
0
-0.1
-0.2
-0.3
t (GeV/c)^2

184381

Fig 1

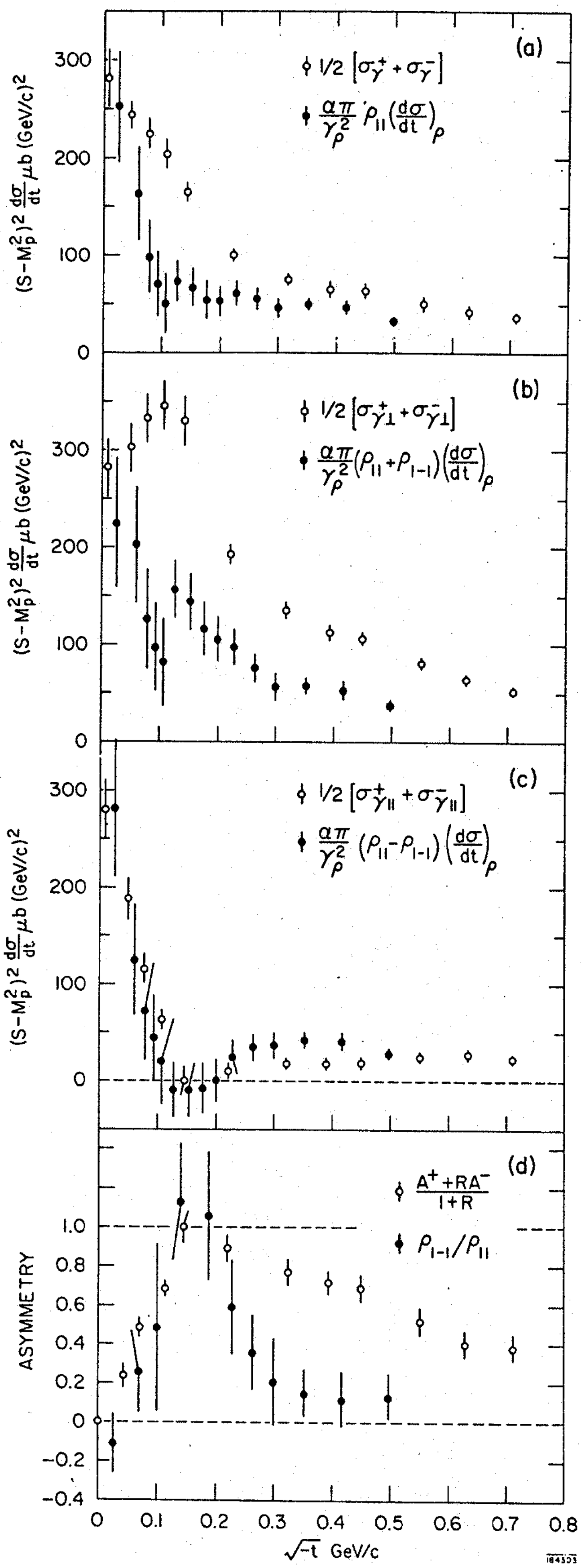

(a)
1/2 [σ̄γ⁺ + σ̄γ⁻]
$\frac{\alpha\pi}{\gamma_\rho^2}\rho_{11}\left(\frac{d\sigma}{dt}\right)_\rho$
(b)
1/2 [σ̄γ⊥⁺ + σ̄γ⊥⁻]
$\frac{\alpha\pi}{\gamma_\rho^2}(\rho_{11}+\rho_{1-1})\left(\frac{d\sigma}{dt}\right)_\rho$
(c)
1/2 [σ̄γ∥⁺ + σ̄γ∥⁻]
$\frac{\alpha\pi}{\gamma_\rho^2}(\rho_{11}-\rho_{1-1})\left(\frac{d\sigma}{dt}\right)_\rho$
(d)
$\frac{A^+ + RA^-}{1+R}$
ρ_{1-1}/ρ_{11}
$(S-M_p^2)^2 \frac{d\sigma}{dt} \mu b\ (GeV/c)^2$
ASYMMETRY
$\sqrt{-t}$ GeV/c

Fig 2

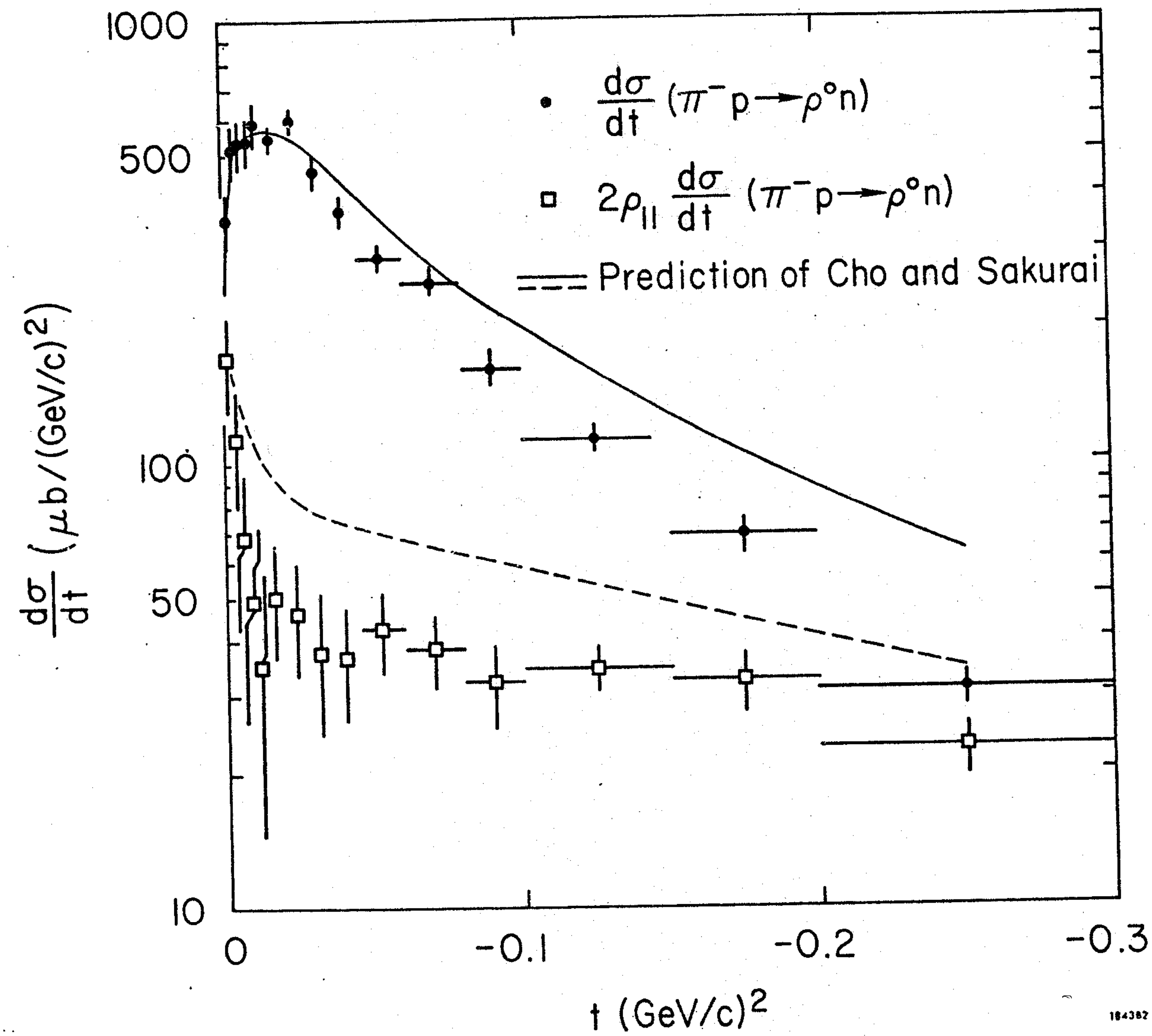

1000
500
100
50
10
$\frac{d\sigma}{dt}$ ($\pi^- p \to \rho^\circ n$)
$2\rho_{11} \frac{d\sigma}{dt}$ ($\pi^- p \to \rho^\circ n$)
Prediction of Cho and Sakurai
$\frac{d\sigma}{dt}$ (μb/(GeV/c)^2)
0
−0.1
−0.2
−0.3
t (GeV/c)^2
184382

Fig. 3