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COMPARISON OF u-CHANNEL ρ^0 PION-PRODUCTION WITH THE ISOVECTOR PART OF π^+ PHOTOPRODUCTION*

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ABSTRACT

The Vector Dominance Model predictions are used on the measurement of u-channel $\pi^- p \rightarrow \rho^0 n$ cross sections and a complete transversality system analysis on the ρ^0 spin density matrix elements. The photon isovector part in $\gamma p \rightarrow \pi^+ n$ is isolated using the u-channel cross-sectional measurements and a specific Regge pole fit for the Δ, N_α and N_γ trajectory exchanges. Both results are compared to examine their consistency.

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In u-channel single pion photoproduction processes:

$$\text{(a) } \gamma p \rightarrow \pi^+ n, \qquad \text{(b) } \gamma n \rightarrow \pi^- p \quad \text{and} \quad \text{(c) } \gamma p \rightarrow \pi^0 p \tag{1}$$

the isovector part of photonucleon interactions is related with the u-channel ρ^0 pion-production process:

$$\pi^- p \rightarrow \rho^0 n \tag{2}$$

Specifically, a direct relationship exists between reaction (1(a)) and (2). With the assumptions of time-reversal invariance and isospin conservation, the Vector Dominance Model (VDM) requires that the dynamical processes entering in the isovector part of reaction (1(a)) be the same as in reaction (2), in the u-channel. The cross-sectional u dependences are related by:

$$\frac{d\sigma}{du}\left(\gamma_V p \rightarrow \pi^+ n\right) = \frac{\alpha}{4}\left(\frac{\gamma_\rho^2}{4\pi}\right)^{-1} \left(\frac{p_{\pi^-}}{p_\rho}\right)^2_{c.m.} \frac{E(s_\gamma)}{E(s_\rho)} P_{\rho^0}(u) \frac{d\sigma}{du}(\pi^- p \rightarrow \rho^0 n) \tag{3}$$

where $\gamma_\rho^2/4\pi$ is the γ-to-ρ^0 coupling constant, E(s) is the cross-sectional energy dependence of reaction (2) and γ_V denotes the photon's isovector part. The ρ^0 transverse polarization projection $P_{\rho^0}(u)$ is $\rho_{11}(u)$, $\left(\rho_{11}(u) + \rho_{1-1}(u)\right)$ for unpolarized (perpendicularly polarized) photoproduction process, $\rho_{ij}(u)$ are the ρ^0 spin density matrix elements.

Together with the consistency requirement on VDM, this relation can be used to test the validity of dynamical models in the description of recent u-channel measurements[1,2] of reactions (1(a)) and (1(c)) cross sections. That is, we propose to use VDM predictions as a reasonable representation for the isovector part of single pion photoproduction and introduce an additional constraint on the various dynamical model parameterizations. In the absence of u-channel measurements for reaction (1(b)), this VDM constraint may be used to discriminate between various phenomenological fits to the data of reactions (1(a)) and (1(c)). In turn, the present VDM results may be checked with such fits to the data of all single pion photoproduction channels, when the isovector part is isolated.

Since the validity of VDM application in the t-channel of reaction (2) is demonstrated,[3] in this letter we use VDM in the u-channel of reaction (2) to abstract the isovector amplitude entering in the processes of reactions (1). Specifically, a direct test is made on a phenomenological description by Beaupre and Paschos,[4] where Regge poles for the Δ, N_{α} and N_{γ} trajectory exchanges are used.

First, we present our analysis for the u-channel properties of reaction (2) which are relevant to this investigation. The data from a large compilation[5] of the reaction $\pi^- p \rightarrow \pi^+ \pi^- n$ near 4.0 GeV is used. The measurement of ρ^0 differential cross section from this reaction, requires a knowledge on the amounts of competing processes. In a manner discussed[6] previously, maximum likelihood fits are made on the data divided in $\cos\theta_{c.m.}$ intervals, to solve for the percentages of ρ^0 production. The production angular selections are made to yield samples of equal statistical significance. Reflections from isobar formation are handled directly along with ρ^0 and f^0 resonance parameter fits and phase space. Figure 1(a) shows the u-channel reaction (2) differential cross section. The backward peak has a value of $64.5 \pm 12.9\ \mu b/(GeV/c)^2$. The ρ^0 spin density matrix elements in the u-channel are determined in a complete transversality system that decouples longitudinal and transverse ρ^0 polarizations. The analysis methods of a recent t-channel VDM study[3] is also employed here. Figure 1(b) shows the u-channel behavior of ψ, the dynamical rotation angle which is required to suppress the polarizations admixture due to the spin density element ρ_{10}. The validity of this $\rho_{ij}(u)$ evaluation in the transversality system is manifested in Fig. 1(c). One of the four eigenvalues for the ρ^o-region spin density matrix with s-wave contributions is the quantity $\rho_{11} + \rho_{1-1}$. The ratio ϵ of this invariant, evaluated in the transversality system over a previous evaluation in the helicity system[6] is tested for unity. Figure 1(d) gives the ratio $\rho_{1-1}(u)/\rho_{11}(u)$. In VDM this behavior represents the isovector part of cross sectional polarization asymmetry Σ_V, for $\gamma_V p \to \pi^+ n$; Σ is $(\sigma_\perp - \sigma_\parallel)/(\sigma_\perp + \sigma_\parallel)$ for single pion photoproduction by linearly polarized photons. The measurement of Σ_V in the ratio ρ_{1-1}/ρ_{11} has exceeded unity at the largest $|u|$ value. In reaction (2), this effect may be due to final state $\rho^o n$ rescattering depolarization of the ρ^o, from its original process-formation polarization. We have kept this region for the following discussion, since the sharp drop at large $|u|$ in the VDM comparisons comes mainly from the cross sectional behavior of Fig. 1(a).

Using isospin decomposition, the u-channel scattering amplitudes for the reactions in (1) are separated in terms of isovector and isoscalar photon parts. Further, the isovector part is decomposed in terms of I = 3/2 and I = 1/2 u-channel baryon exchange contributions. Thus,

$$\begin{aligned}
A(\gamma p \to \pi^+ n) &= \sqrt{1/3}\,A_V(s,u,3/2) - \sqrt{2/3}\,A_V(s,u,1/2) - \sqrt{2/3}\,A_S(s,u,1/2) \\
A(\gamma n \to \pi^- p) &= \sqrt{1/3}\,A_V(s,u,3/2) - \sqrt{2/3}\,A_V(s,u,1/2) + \sqrt{2/3}\,A_S(s,u,1/2) \\
A(\gamma p \to \pi^o p) &= \sqrt{2/3}\,A_V(s,u,3/2) + \sqrt{1/3}\,A_V(s,u,1/2) - \sqrt{1/3}\,A_S(s,u,1/2)
\end{aligned} \tag{4}$$

In any phenomenological parametrization[4,7] to fit the available data of reactions (1(a)) and (1(c)), the fractional contributions to the u-channel cross section can be isolated in terms of the I = 3/2, I = 1/2 exchanges and their interference. The normalized contributions are $I_\Delta(s,u)$, $I_N(s,u)$ and $I_{\Delta N}(s,u)$, where the sum of these is unity. A free parameter in such fits is δ, the isocalar over the isovector parts in the I = 1/2 u-channel exchanges, that represents the isoscalar-isovector photon admixture in the photo-nucleon system. Therefore, using these parameter values, the isovector photon contribution in reaction (1(a)) can be isolated and this can be compared directly with the VDM results of Eq. (3) by the following relation:

$$\frac{d\sigma}{du}(\gamma_V p \rightarrow \pi^+ n) = \frac{d\sigma}{du}(\gamma p \rightarrow \pi^+ n)\left[I_\Delta(u) + \frac{I_N(u)}{(1+\delta)^2} + \frac{I_{\Delta N}(u)}{1+\delta}\right] \quad (5)$$

From the isospin decomposition in Eq. (4) the phenomenologically parameterized value of δ is expected to be a negative fraction.

In Fig. 2(a) the u-channel differential cross section of reaction (1(a)) from 4.16-5.23 GeV photon energies[1] is shown, where we have made an energy extrapolation to 4.0 GeV using the experimentally determined[1] energy dependence of k^{-3}. In the absence of any isoscalar photon contribution, that is with Δ-exchange dominance, the VDM predictions of Eq. (3) should agree with the results in this figure. The presence of large N-exchange contributions enter subtractively in the $I = 1/2$ parts of the scattering amplitude and cause a relative depression in the u-channel cross section of reaction (1(a)), with respect to the VDM predictions of Eq. (3). Figure 2(b) shows the normalized fractional contributions in the u-channel cross section of reaction (1(a)) due to Δ-exchange, N-exchange (N_α and N_γ) and their interference, from a specific Regge pole phenomenological parameterization[4] to this reaction. A value of $\delta = -0.376$ is used[4] at 4.0 GeV. In this fit, it is also found that a satisfactory solution is obtained only when the N_γ trajectory contribution is included with a relatively large value for its residue function.

Figure 3(a) shows the VDM-predicted measure on the isovector part of $\gamma p \rightarrow \pi^+ n$ u-channel cross section at 4.0 GeV, by photons which are linearly polarized and their electric polarization vector is perpendicular to the reaction (1(a)) production plane. This representation is obtained from Eq. (3), with the

ρ^0 transverse polarization projection in the form of $P_{\rho^0}(u) = \rho_{11}(u) + \rho_{1-1}(u)$. The value of $\gamma_\rho^2/4\pi$ used in Eq. (3) is 0.40 ± 0.03, as discussed in a previous study.[3]

Figure 3(b) is a VDM measure on the isovector part $\gamma p \to \pi^+ n$ u-channel cross section at 4.0 GeV by unpolarized photons. The comparison of VDM results between Fig. 3(a) and 3(b), shows an interesting difference on the cross-sectional u-channel behavior for the isovector part of reaction (1(a)), when produced by polarized and unpolarized photons. This difference may introduce additional constraints on the phenomenological parameterizations which describe the u-channel dynamics of the reactions in (1). The curve drawn in Fig. 3(b) is from Eq. (5), the parameterization shown in Fig. 2(b) and the cross sections in Fig. 2(a). Accordingly, the abstracted isovector part of $\gamma p \to \pi^+ n$ agrees well with the VDM predicted isovector cross section in the u range of $|u| < 1.0\ (\mathrm{GeV}/c)^2$. A direct comparison, between the VDM points in Fig. 3(b) and the $\gamma p \to \pi^+ n$ cross-sectional measurements in Fig. 2(a), indicate the presence of large contributions from $I = 1/2$ u-channel exchanges.

Beaupre and Paschos[4] find that a large value is required for the N_γ trajectory residue function, over that for the N_α trajectory. Our comparison in Fig. 3(b) together with this, implies a strong coupling of $N_\gamma(1512)$ with the isovector γ-nucleon channel, or equivalently in VDM, a strong coupling of $N_\gamma(1512)$ with the virtual-ρ^0 nucleon channel. Their parameterization of N_γ, N_α and Δ trajectories for the u-channel process of reactions (1(a)) and (1(c)) is supported in the range of $|u| < 1.0\ (\mathrm{GeV}/c)^2$, over[6] an earlier parameterization of only the Δ trajectory. Further evidence in support of the predominant $N_\gamma(1512)$ coupling to the γ-nucleon channel comes from the observation[8] of an overenhancement at the $N_\gamma(1512)$ region in the $\sigma_{tot}(\gamma p)$ energy spectrum.

The indicated predominance of N_γ coupling to the isovector γ-nucleon (or virtual-ρ^o-nucleon) channel requires a detailed investigation. The study of this interesting effect can best be performed by currently available laser induced, polarized and monochromatic photon beams for the s-channel investigation of $\gamma p \rightarrow N_\gamma(1512) \rightarrow p\pi^o$, $n\pi^+$ and $p\pi^+\pi^-$. Moreover, we suggest for the measurement of u-channel cross sections of $\gamma n \rightarrow \pi^- p$ which would introduce additional constraints on the presently discussed comparisons.

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substantial overenhancement exists in $\sigma_{tot}(\gamma p)$. $\sigma_{tot}(\pi^o p) = 1/2\left(\sigma_{tot}(\pi^+ p) + \sigma_{tot}(\pi^- p)\right)$ and the proportionality factor f, when re-expressed in terms of VDM, $f = \frac{\alpha}{4}\left(\frac{\gamma_\rho^2}{4\pi}\right)^{-1}$, gives a value of the γ-ρ coupling constant close to the one used in our studies.

FIGURE CAPTIONS

1. (a) u-channel cross section of 4.0 GeV $\pi^- p \to \rho^o n$, obtained by maximum likelihood fits to processes in the $\pi^- p \to \pi^+ \pi^- n$ data.

   (b) Evaluations of the transversality condition's dynamical rotation angle ψ, to suppress the ρ^o polarizations admixture due to the spin density element ρ_{10}, in $\pi^- p \to \rho^o n$.

   (c) Measurement of the ρ^o spin density matrix eigenvalue $\rho_{11} + \rho_{1-1}$. ϵ is the eigenvalue ratio as evaluated in the transversality over the helicity systems.

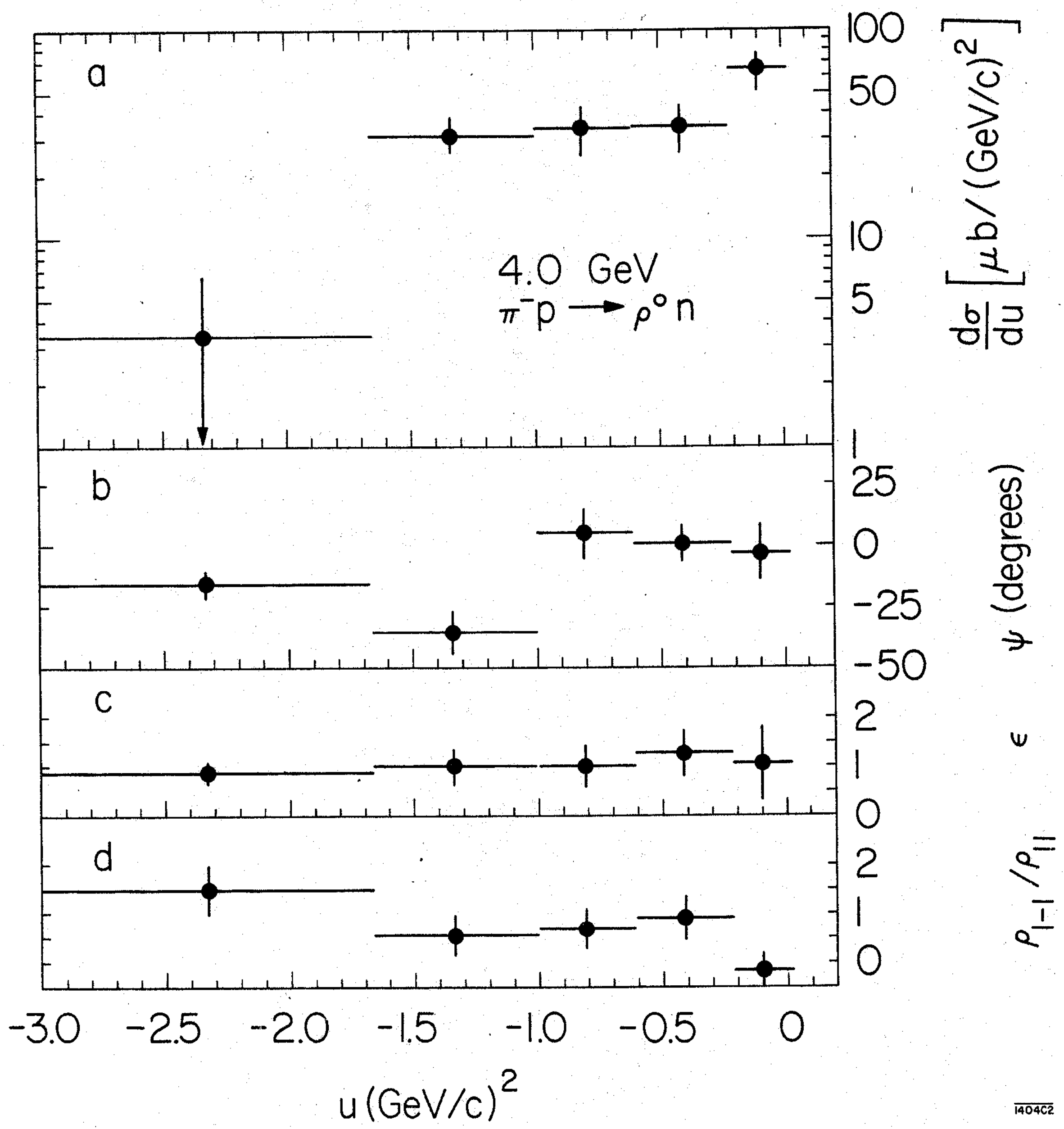
   (d) Vector Dominance Model representations of the polarization asymmetry in the isovector part of u-channel $\gamma p \to \pi^+ n$, as determined by 4.0 GeV $\pi^- p \to \rho^o n$ data. The ratio ρ_{1-1}/ρ_{11} is measured in the transversality system of ρ^o's.

2. (a) u-channel differential cross section of 4.16-5.23 GeV $\gamma p \to \pi^+ n$ (data from Anderson et al.,[1]), energy extrapolated to 4.0 GeV.

   (b) Percentage contributions, in the cross section of u-channel $\gamma p \to \pi^+ n$ at 4.0 GeV, of amounts due to Δ-exchange, N-exchange (N_α and N_γ) and their interference, as parameterized in Regge pole fits by Beaupre and Paschos.[4]

3. (a) VDM predication on the isovector part of u-channel $\gamma p \to \pi^+ n$ by photons linearly polarized perpendicular to the production plane, at 4.0 GeV.

   (b) Behavior in the isovector part of u-channel $\gamma p \to \pi^+ n$, by unpolarized photons at 4.0 GeV, from VDM application to transversely polarized ρ^o's in $\pi^- p \to \rho^o n$. The solid curve is abstracted from the isovector part of Δ, N_α and N_γ Regge pole fits[4] to $\gamma p \to \pi^+ n$ and $\gamma p \to \pi^o p$ data.



a
b
c
d
4.0 GeV
π⁻p → ρ° n
100
50
10
5
25
0
−25
−50
2
1
0
2
1
0
−3.0
−2.5
−2.0
−1.5
−1.0
−0.5
0
u (GeV/c)²
dσ/du [μb/(GeV/c)²]
ψ (degrees)
ε
ρ₁₋₁ / ρ₁₁
1404C2

Fig. 1

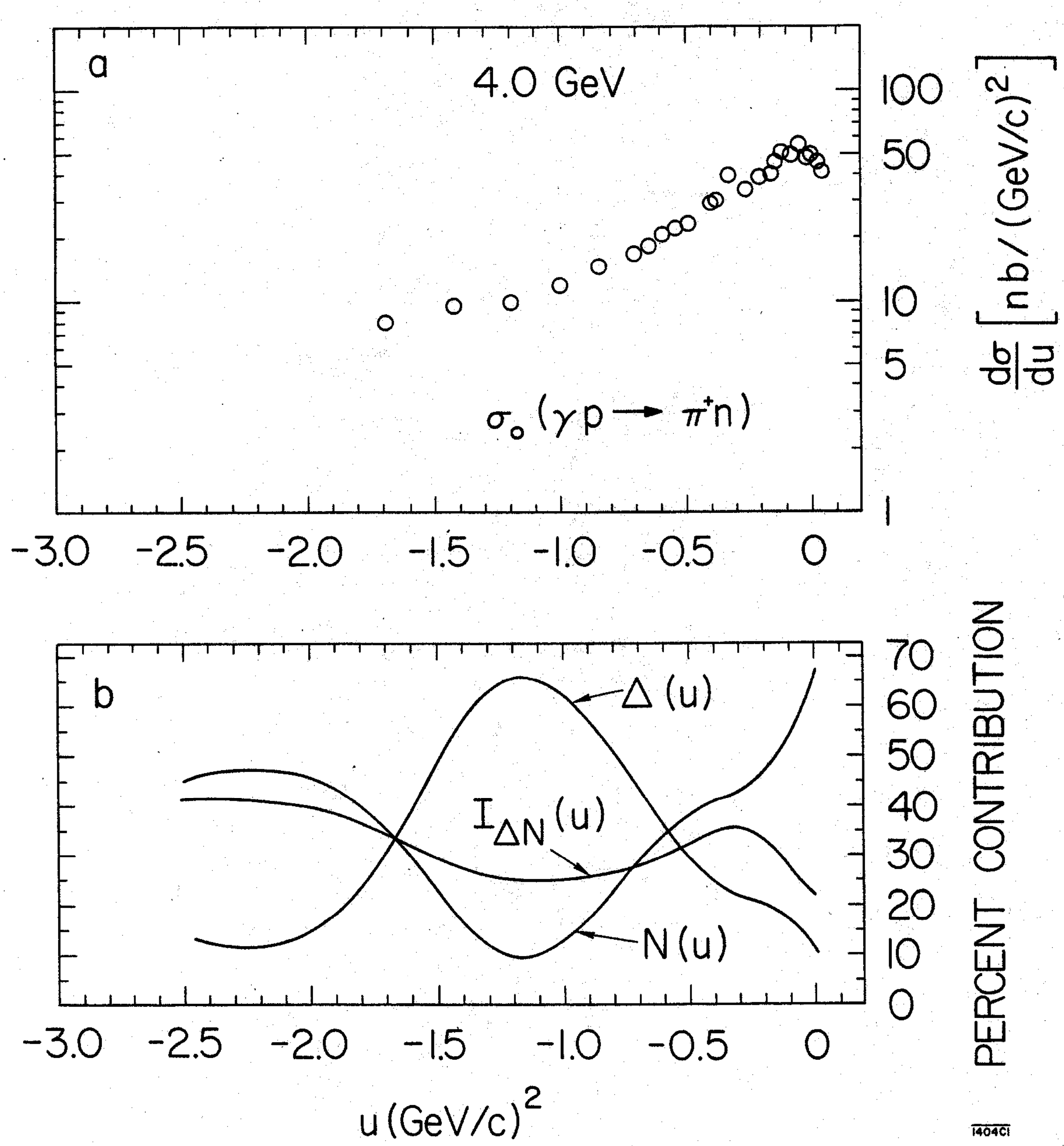
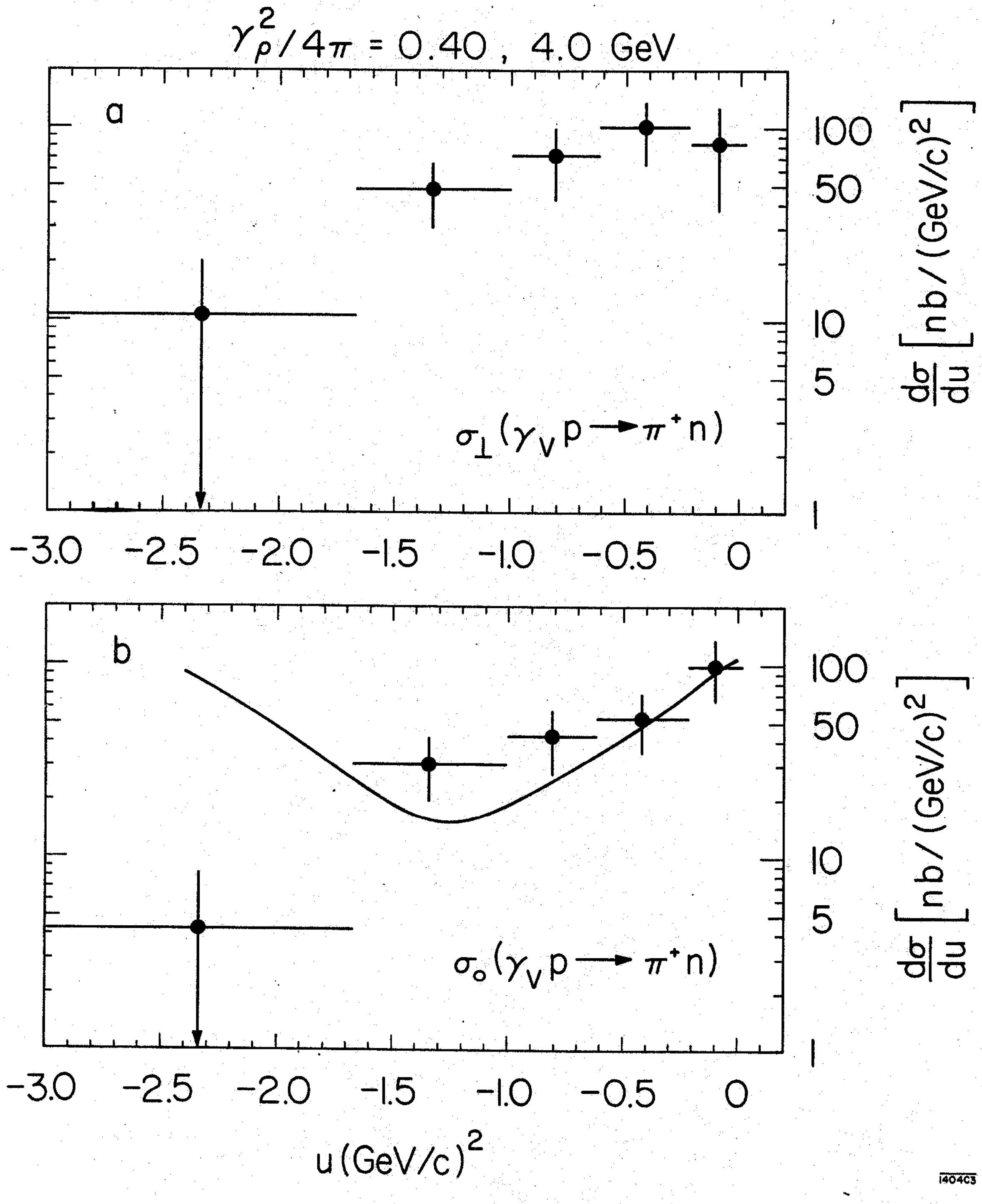

a
4.0 GeV
$\sigma_0 (\gamma p \to \pi^+ n)$
$\frac{d\sigma}{du} \left[nb/(GeV/c)^2 \right]$
100
50
10
5
1
-3.0
-2.5
-2.0
-1.5
-1.0
-0.5
0
b
Δ (u)
$I_{\Delta N}$ (u)
N (u)
70
60
50
40
30
20
10
0
PERCENT CONTRIBUTION
u $(GeV/c)^2$
1404C1

Fig. 2



$\gamma_\rho^2/4\pi = 0.40$, 4.0 GeV
a
100
50
10
5
1
$\frac{d\sigma}{du}\left[nb/(GeV/c)^2\right]$
$\sigma_\perp(\gamma_V p \rightarrow \pi^+ n)$
−3.0 −2.5 −2.0 −1.5 −1.0 −0.5 0
b
100
50
10
5
1
$\frac{d\sigma}{du}\left[nb/(GeV/c)^2\right]$
$\sigma_o(\gamma_V p \rightarrow \pi^+ n)$
−3.0 −2.5 −2.0 −1.5 −1.0 −0.5 0
u $(GeV/c)^2$
1404C3

Fig. 3