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TEST OF VECTOR DOMINANCE MODEL BY FORWARD AND BACKWARD ρ^{0} PION-PRODUCTION*

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ABSTRACT

The validity of the Vector Dominance Model has been tested by ρ^{0} pion-production at 4 GeV, and π^{+} photoproduction data. In the forward direction, a remarkable agreement has been observed with the photoproduction data, down to t_{min}. ρ^{0} pion-production in the backward direction shows good agreement through this model with available photoproduction data in the u-channel. A comparison is made with a Δ-Regge trajectory exchange theoretical work.

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We discuss the validity of the Vector Dominance Model of the electromagnetic current using the reactions

$$\gamma p \longrightarrow \pi^+ n \tag{1}$$

and

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

at nearby beam energies.

Recently, π^+ photoproduction has been studied in the forward[1] and backward[2] directions, at 5.0 and 4.3 GeV energies, respectively. And, in collaboration with others, we have studied reaction (2) as part of a large compilation[3] of the reaction

$$\pi^- p \longrightarrow \pi^+ \pi^- n \tag{3}$$

near 4.0 GeV.

The comparison of Vector Dominance Model (VDM) for backward ρ^0 production is shown for the first time. Whereas a previous analysis[4] of VDM was performed, using this data for forward ρ^0 production, for completeness we present our analysis of forward ρ^0's because it markedly shows an improvement over the conclusion of Ref. 4, especially at $|t| < 0.1\ (\mathrm{GeV}/c)^2$.

The Vector Dominance Model is based on the assumption that the entire hadronic electromagnetic current operator can be expressed as a linear combination of the known neutral vector-meson fields. Reactions (1) and (2) can be connected through this model and the assumptions of time reversal invariance and isospin conservation. In the case where the ρ^0 contribution dominates the electromagnetic current, the differential cross sections connecting reactions (1) and (2) can explicitly be written as:

$$\frac{d\sigma}{d(\cos\theta_{CM})}(\gamma p \rightarrow \pi^+ n) = \frac{S_\rho}{S_\gamma} \cdot \frac{p_{\pi^+}}{p_\gamma} \cdot \frac{p_{\pi^-}}{p_\rho} \cdot \frac{1}{2}\left(1 - \rho^H_{00}(\theta_{CM})\right) \cdot \frac{\alpha\pi}{\gamma_\rho^2} \cdot \frac{d\sigma}{d(\cos\theta_{CM})}(\pi^- p \rightarrow \rho^0 n) \tag{4}$$

and, for distributions in u or t, the expression is:

$$\frac{d\sigma}{du}(\gamma p \rightarrow \pi^+ n) = \frac{S_\rho}{S_\gamma} \cdot \left(\frac{p_{\pi^-}}{p_\gamma}\right)^2 \cdot \frac{1}{2}\left(1 - \rho_{00}^H\right) \cdot \frac{\alpha\pi}{\gamma_\rho^2} \cdot \frac{d\sigma}{du}(\pi^- p \rightarrow \rho^0 n) \tag{5}$$

where, S_γ, p_γ, and p_{π^+} are the total energy squared, incident γ and outgoing π^+ momenta in the CMS of reaction (1), respectively; S_ρ, p_{π^-}, p_ρ are those corresponding for reaction (2). $\gamma_\rho^2/4\pi$ is the γ to ρ^0 coupling constant, which can be determined from experimental leptonic decays of the ρ^0 or from ρ^0 photoproduction on complex nuclei. A review[5] of the various methods in determining this constant shows that measurements vary between 0.27 - 0.67. The factor of $1/2\left(1 - \rho_{00}^H\right)$ projects out the transverse components of the ρ^0 polarization in reaction (2). This is found from the ρ^0 decay density matrix elements evaluation in the ρ^0 helicity reference frame.

Comparison of several other reactions which can be connected by this model have recently shown good agreement at forward production[5,7] where the most recent evaluation of the γ-ρ coupling constant is shown[7] to be $\gamma_\rho^2/4\pi \sim 0.6$.

From[3] a sample of 7984 events of reaction (3), we have analyzed for the percentages of ρ^0 production, and the helicity frame density matrix elements of ρ^0's, both as a function of cos θ_{CM}; θ_{CM} is the angle between incident π^- and outgoing dipions, in the overall reaction center-of-mass system. The intervals in cos θ_{CM} have been chosen such that in the density matrix element analysis the data would contribute in approximately equal parts of statistical significance within a mass interval of $0.680 < m(\pi^+\pi^-) < 0.880$ GeV. Within this interval about 1940 events are in the forward hemisphere and 200 events in the backward. Since reaction (3) is dominated by ρ^0 production, along with considerable f^0, $\Delta^+(1238)$ and $\Delta^-(1238)$, we have found it necessary to determine the percentages of ρ^0 production in several intervals of cos θ_{CM} with the aid of a maximum likelihood program — MURTLEBERT.[8] This program fits the event distribution to a normalized frequency function obtained by the incoherent addition of phase-space and several Breit-Wigner resonances, with their proper angular momentum dependencies. In this fashion, reflections from resonances in the $(n\pi^+)$ and $(n\pi^-)$ mass combinations are handled properly at ρ^0 region. This method can be used to determine the mass, width and percentage of each resonance produced in a given interaction, where a model of resonance production plus phase space applies. We find that the percentage of ρ^0 production as the function of cos θ_{CM} varies from $(64 \pm 4)\%$ down to $(17 \pm 2)\%$. This analysis especially improves the comparison in the region of $|t| < 0.1(\mathrm{GeV}/c)^2$. Similarly, in the background hemisphere the u dependence of ρ^0 production varies from $(31 \pm 6)\%$ down to $(3 \pm 2)\%$.

The ρ^0 density matrix elements have been determined for several intervals in cos θ_{CM} from an analysis of the ρ^0 decay angular distribution, using the functional form due to a p-wave resonance decay along with s-wave interference, and a trace normalization condition ($\rho_{00} + 2\rho_{11} + \rho^S_{00} = 1$):

$$I(\theta_{CM}, \theta, \phi) = \frac{1}{4\pi}\Big[1 + (\rho_{11} - \rho_{00})(1 - 3\cos^2\theta) - 6\sqrt{2}\,\rho_{10}\sin\theta\cos\theta\cos\phi$$
$$- 3\rho_{1-1}\sin^2\theta\cos 2\phi - 2\sqrt{6}\,\mathrm{Re}\left(\rho^{\mathrm{interf}}_{10}\right)\sin\theta\cos\phi \tag{6}$$
$$+ 2\sqrt{3}\,\mathrm{Re}\left(\rho^{\mathrm{interf}}_{00}\right)\cos\theta\Big]$$

where, θ and ϕ are the polar and azimuthal angles of the decaying π^- evaluated in ρ^0-rest-frame, with respect to the ρ^0 line-of-flight in the reaction center-of-mass system. We have used the program MINFUN[9] for this analysis. This program searches through a ravine-stepping procedure to minimize the negative logarithm of the maximum likelihood function.

For each interval in $\cos\,\theta_{CM}$ the right hand side of Eq. (4) has been evaluated to yield a predicted photoproduction angular distribution, which in turn is converted to a VDM predicted photoproduction distribution in t or u. Figure 1 shows the momentum transfer distribution[1] of reaction (1) at 5 GeV, for forward π^+ photoproduction (open circles), and the Vector Dominance Model points (closed triangles) from this analysis. The vertical error bars on our points are from a sum of errors in quadrature, as obtained by the maximum likelihood programs in evaluating the density matrix elements (including uncertainty in ρ^S_{00}) and percentages of ρ^o production. Moreover, in view of the experimental uncertainty in the value $\gamma_\rho^2/4\pi$, we have examined this comparison for values of the γ-ρ coupling constant in the range of 0.200 - 0.700. In Fig. 1 it is seen that the test applies best at $\gamma_\rho^2/4\pi = 0.450$; and that the trend of VDM points are in excellent agreement with that of photoproduction points. The region of $|t| < 0.1\ (\mathrm{GeV}/c)^2$ shows a remarkable comparison down to the kinematical limit of t_{min} for reaction (2). Because of the uncertainty in both $\gamma_\rho^2/4\pi$ and the energy dependence between 4 and 5 GeV, we take the shape more seriously than the absolute value.

Figure 2 shows the VDM comparison for ρ^o production in the backward direction. The open circle points are from π^+ photoproduction.[2] Again, in an identical procedure, the backward ρ^o VDM comparison points are obtained (closed triangles). At these energies the backward π^+ photoproduction data are limited, so that a direct comparison could only be made for $|u| < 0.5\ (\mathrm{GeV}/c)^2$. Here, our search for best comparison gave a value of $\gamma_\rho^2/4\pi = 0.670$, for the region of $|u| < 0.5\ (\mathrm{GeV}/c)^2$; although in view of the statistical limitations, the value of $\gamma_\rho^2/4\pi = 0.450$ would have been adequate.[10] The solid curve represents a theoretical calculation by Paschos,[11] based upon an understanding of the Δ-Regge trajectory from π^-p and π^+p elastic scattering, as a function of s and u. In the u-channel of reactions (1) and (2), both Δ and N_α trajectories could contribute. However, the absence of a dip at $u \approx -0.2\ (\mathrm{GeV}/c)^2$ in the photoproduction data, indicates the possibility that the N_{α} trajectory is not dominant. Based on this argument the solid curve is calculated using only the Δ-Regge-trajectory. Our VDM-comparison points, in the u region of - 0.9 to - 1.5 $(\text{GeV/c})^2$, lie considerably higher over the Paschos calculation. This observation, along with backward $\pi^- p$ elastic scattering behavior at high s and u, could indicate that a small quadratic term in u is required in the parameterization of the Δ-Regge trajectory.[11]

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analysis of Ref. 11 (Δ exchange dominance for the backward π^+), that would indicate a non-negligible isoscalar (ω) contribution in the forward direction.

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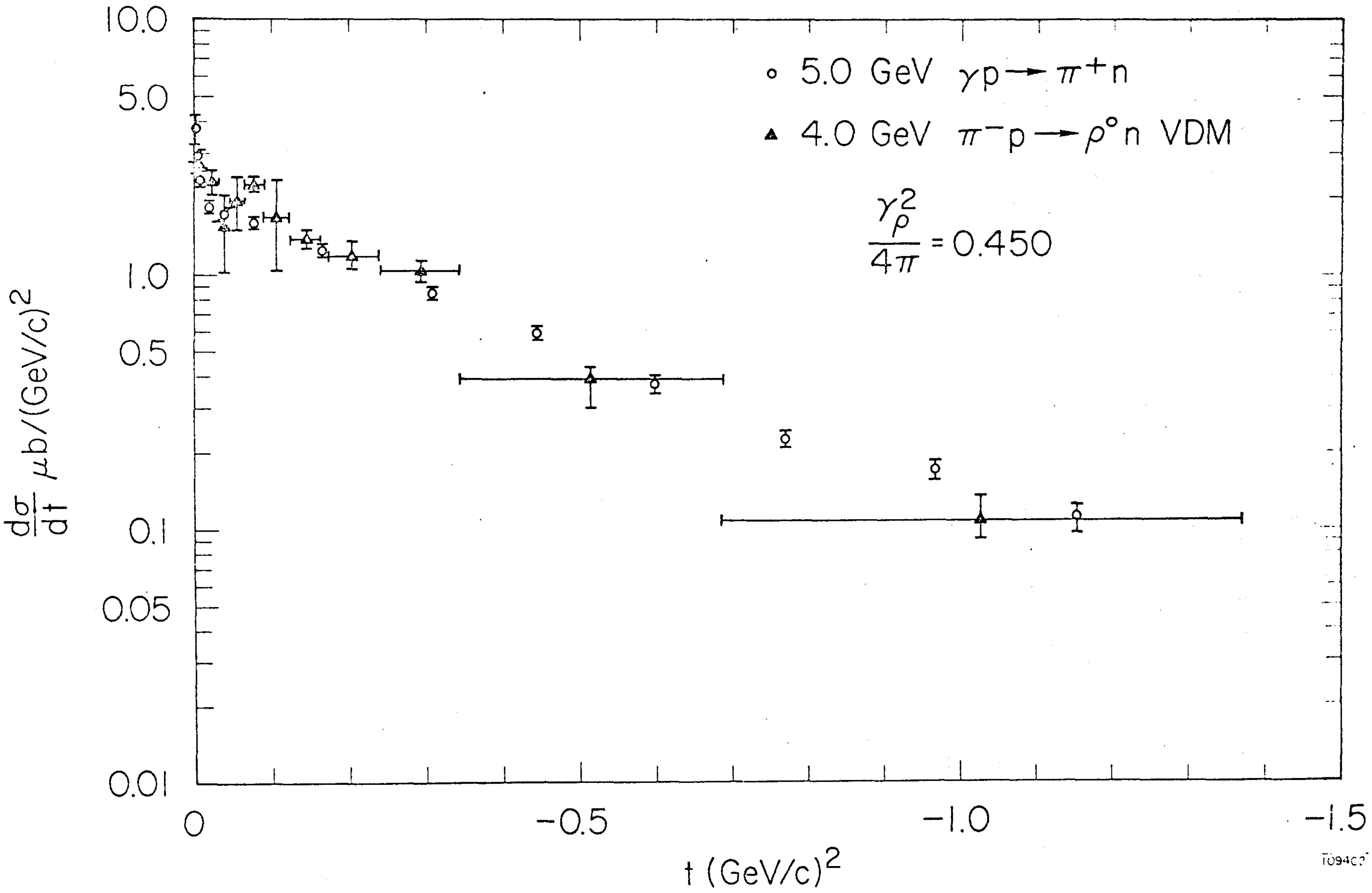
FIGURE CAPTIONS

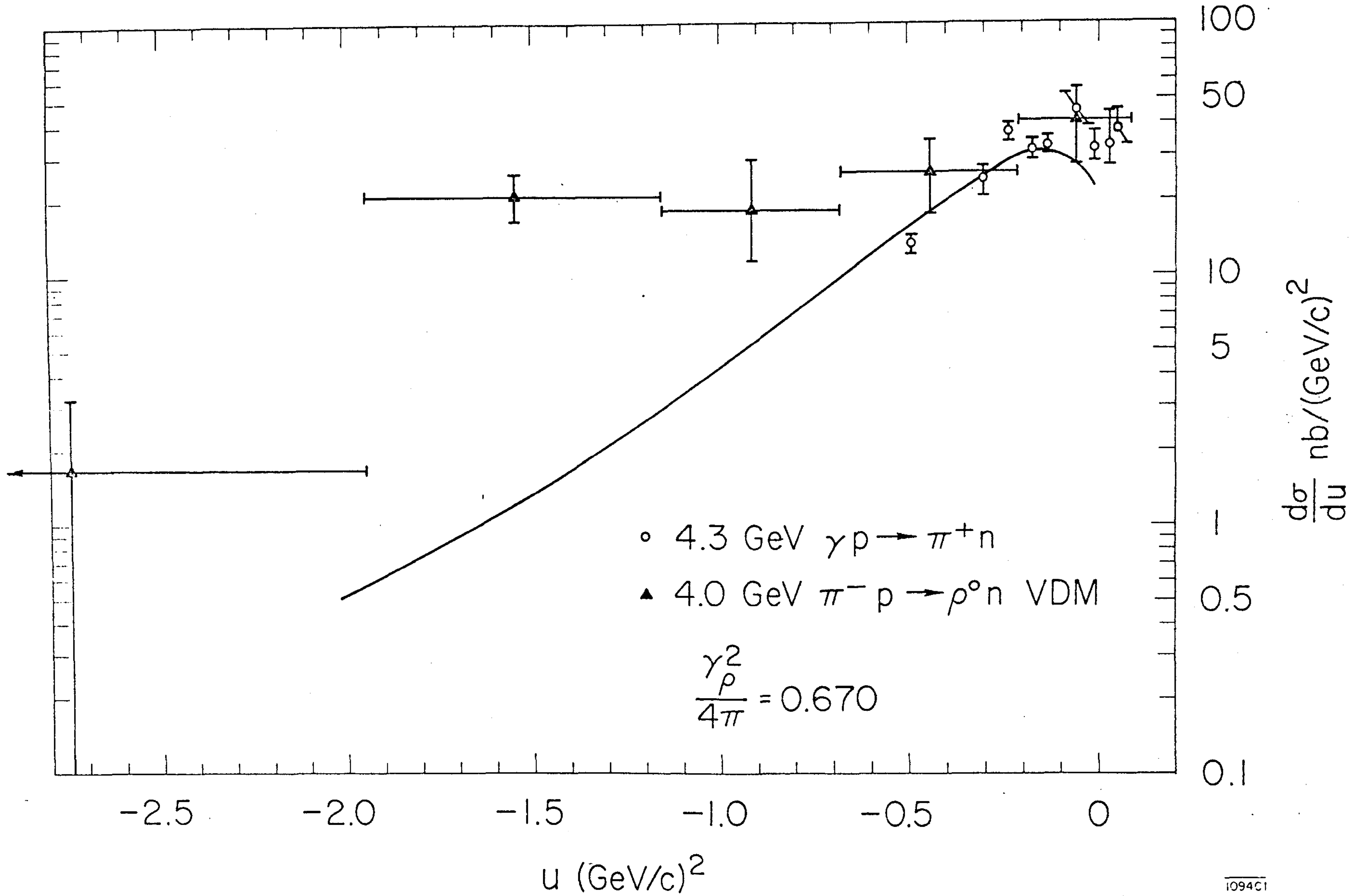
1. Comparison of Vector Dominance Model. Predictions (▵) from transversely polarized ρ^{o}'s, pion-produced in the forward direction, to the π^+ photoproduction data of Boyarski *et al*. (o).

2. The Vector Dominance Model test from transversely polarized ρ^{o}'s production by pions, in the backward u-channel (▲), to the π^+ photoproduction data of R. Anderson *et al*. (o). The solid curve is a calculation of Paschos based upon a Δ-Regge-trajectory parameterization.



10.0
5.0
1.0
0.5
0.1
0.05
0.01
○ 5.0 GeV $\gamma p \rightarrow \pi^+ n$
▲ 4.0 GeV $\pi^- p \rightarrow \rho^\circ n$ VDM
$\frac{\gamma_\rho^2}{4\pi} = 0.450$
$\frac{d\sigma}{dt}$ μb/(GeV/c)^2
0
−0.5
−1.0
−1.5
t (GeV/c)^2

Fig. 1



100
50
10
5
1
0.5
0.1
-2.5
-2.0
-1.5
-1.0
-0.5
0
u (GeV/c)^2
$\frac{d\sigma}{du}$ nb/(GeV/c)^2
○ 4.3 GeV $\gamma p \rightarrow \pi^+ n$
▲ 4.0 GeV $\pi^- p \rightarrow \rho^\circ n$ VDM
$\frac{\gamma_\rho^2}{4\pi} = 0.670$
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Fig. 2