DEUTSCHES ELEKTRONEN-SYNCHROTRON DESY

DESY 67/17
May 1967

On the Photoproduction of Multipion Systems

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2 HAMBURG 52 · NOTKESTIEG 1

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Summary: Combining vector meson dominance and quark model with isospin independence of production reactions above the resonance region, we predict the cross-sections for multipion photoproduction from the corresponding π-N data.

For many aspects in the description of the electromagnetic interaction of hadrons the vector meson dominance model (VDM)[1] has met with considerable success[2]. Using the electromagnetic current $j_\mu(x)$ as interpolating vector meson field

$$j_\mu(x) = \sum_V \frac{m_V^2}{2\gamma_V} \psi_\mu^V(x) = \frac{m_\rho^2}{2\gamma_\rho} \rho_\mu(x) + \frac{m_\omega^2}{2\gamma_\omega} \omega_\mu(x) + \frac{m_\phi^2}{2\gamma_\phi} \phi_\mu(x) \qquad (1)$$

(with constants γ_V) and assuming a slow variation of the corresponding matrix elements as we extrapolate from photon mass $k^2 = 0$ to vector meson mass $k^2 = m_V^2$, the VDM gives a connection between γ-induced and V-induced hadronic reactions. Neglecting interferences between ρ, ω, and ϕ we thus have

$$\sigma(\gamma p \to x) = \sum_V \frac{\alpha\pi}{\gamma_V^2} \sigma(Vp \to x) \qquad (2)$$

with $\alpha = 1/137$; X denotes any compatible hadronic final state and $\sigma(Vp \to X)$ describes the cross-section of the V-p reaction with transversally polarized vector mesons.

In the present note we wish to apply (2) to obtain a prediction of multipion photoproduction processes from available π-N data. Since experiments on ρ^o-photoproduction[3] indicate a ratio $\bar\gamma_\rho^2 : \bar\gamma_\omega^2 : \bar\gamma_\phi^2$ of about 16:3:1/2, we shall here include only ρ and ω in (2). As coupling constant values we take $\gamma_\rho^2/4\pi = 1/2$, $\bar\gamma_\omega^2 = (3/16)\bar\gamma_\rho^2$, in accord with the mentioned ρ^o-photoproduction data as well as with most other VDM applications[2].

To connect V-p with π-p processes, we appeal to the sum rule

$$\sigma_{tot}(\rho^o p) = \sigma_{tot}(\omega p) = \frac{1}{2}\left[\sigma_{tot}(\pi^+ p) + \sigma_{tot}(\pi^- p)\right] = \sigma_{tot}(\pi^o p) \qquad (3)$$

derived from the quark model[4,5] with additivity of quark scattering amplitudes. This and the agreement of diffraction peak widths[3] yield equal ρ^o-p and π^o-p elastic cross-sections; therefore we shall assume (3) to hold term by term

$$\sigma(\rho^o p \to x) = \sigma(\omega p \to x) = \sigma(\pi^o p \to x) \qquad (4)$$

for incident energies well above threshold; (an "additive" quark model for inelastic reactions would presumably also lead to (4), since ρ^o and π^o have the same quark content). Thus we obtain

$$\sigma(\gamma p \to x) = 4.33 \times 10^{-3}\, \sigma(\pi^o p \to x) \qquad (5)$$

where X denotes any hadronic final state with more than two pions.

Beyond VDM and the extended sum rule (4) we lastly assume the isospin independence of π-N amplitudes for energies above the main resonance region ($\gtrsim$ 2 - 3 GeV/c). Neglecting interferences, this reduces the relation between π-N cross-sections of identical pion and nucleon number final and initial states but of different charge configurations to a relation of the corresponding Clebsch-Gordan coefficients. Thus we have[6] e.g.

$$\sigma(\pi^o p \to p 2\pi^+ 2\pi^-) \Big/ \sigma(\pi^- p \to p\pi^+ 2\pi^- \pi^o) = \frac{.201}{.358}, \text{ etc.} \qquad (6)$$

Isospin independence, suggested by statistical considerations, is rather well supported both by the near-equality of π^+ and π^- total cross-sections and by analyses of various multipion experiments[7,8].

Our predictions obtained via (5) and isospin independence from the available π-N data[9] are shown in Figures I and II. The errors given are those from the π-N experiments, assuming here an exact value of the γ-V coupling constant.

In Fig. I we compare our result with the measured values[3,10] for the reaction $\gamma p \to p\, 2\pi^+ 2\pi^-$, so far the only multipion photoproduction cross-section for which the energy dependence has been established. The agreement is seen to be very good.

Fig. II gives the prediction for the seven-prong $\gamma p \to p\pi 3\pi^+ 3\pi^-$ as well as the predicted behaviour of the no-fit channels $\gamma p \to p\, 2\pi^+ 2\pi^- \pi^o$, $p\, 2\pi^+ 2\pi^- 2\pi^o$. It is seen that the smallness of the seven-prong cross-section is essentially due to isospin effects, not to a small p 6π cross-section relative to p 5π.

In conclusion we find that the VDM successfully relates electromagnetic and hadronic multipion production. On one hand this gives additional experimental checks of the γ-V coupling constant, on the other one can generally apply

the method used here to evaluate contributions from no-fit events in multipion photoproduction. Finally we consider our results as an indication that perhaps quark concepts may eventually also lead to useful "sum-rules" for genuinely inelastic reactions.

I wish to thank Dr. E. Lohrmann and Mr. H. Spitzer for information about the photoproduction experiment and for the cross-section values, Professor H. Joos and Mr. G. van Keuk for some interesting discussions.

Note added in proof: After completion of this note, data on the seven-prong reaction have come in[10] and are found to agree with our predictions (see Fig. II).

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Figure Captions

Fig. I: The predictions for $\sigma(\gamma p \to p\, 2\pi^+2\pi^-)$ as calculated from π-p data ($\bullet$: $\pi^-p \to n\, 2\pi^+2\pi^-$: Δ : $\pi^-p \to p\, \pi^+2\pi^-\pi^o$: $\square$: $\pi^+p \to p\, 2\pi^+\pi^-\pi^o$: $\blacksquare$: $\pi^+p \to n\, 3\pi^+\pi^-$): the measured[10] $\sigma(\gamma p \to p\, 2\pi^+2\pi^-)$ is denoted by $\boxplus$.

Fig. II: The prediction for $\sigma(\gamma p \to p\, 3\pi^+3\pi^-)$ ($\square$), $\sigma(\gamma p \to p\, 2\pi^+2\pi^-2\pi^o)$($\Delta$), and $\sigma(\gamma p \to p\, 2\pi^+2\pi^-\pi^o)$ (o) as calculated from $\pi^+p \to p\, 3\pi^+2\pi^-$, $p\, 3\pi^+2\pi^-\pi^o$ data. The measured $\sigma(\gamma p \to p\, 3\pi^+3\pi^-)$ is denoted by $\boxplus$.

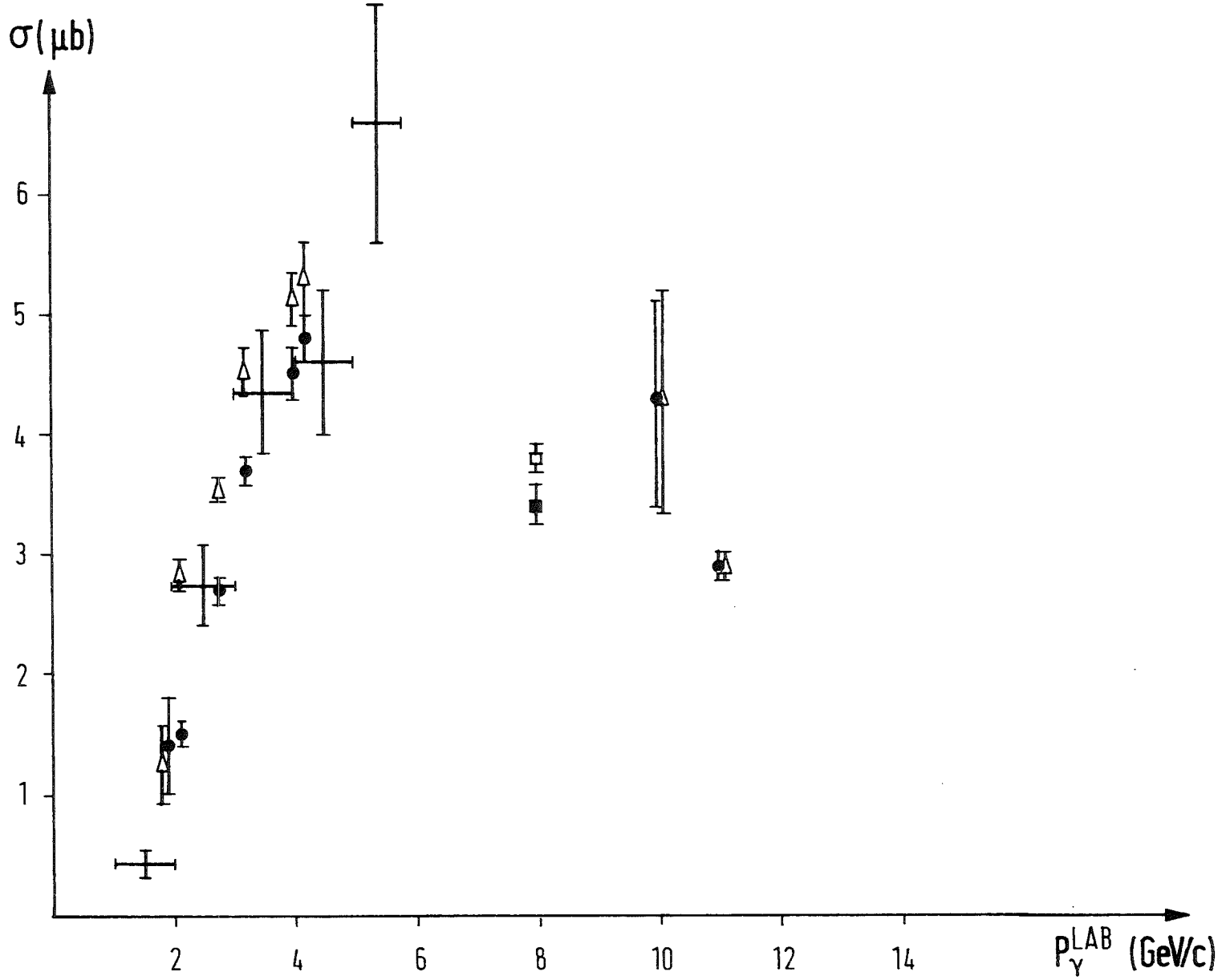

Fig.1

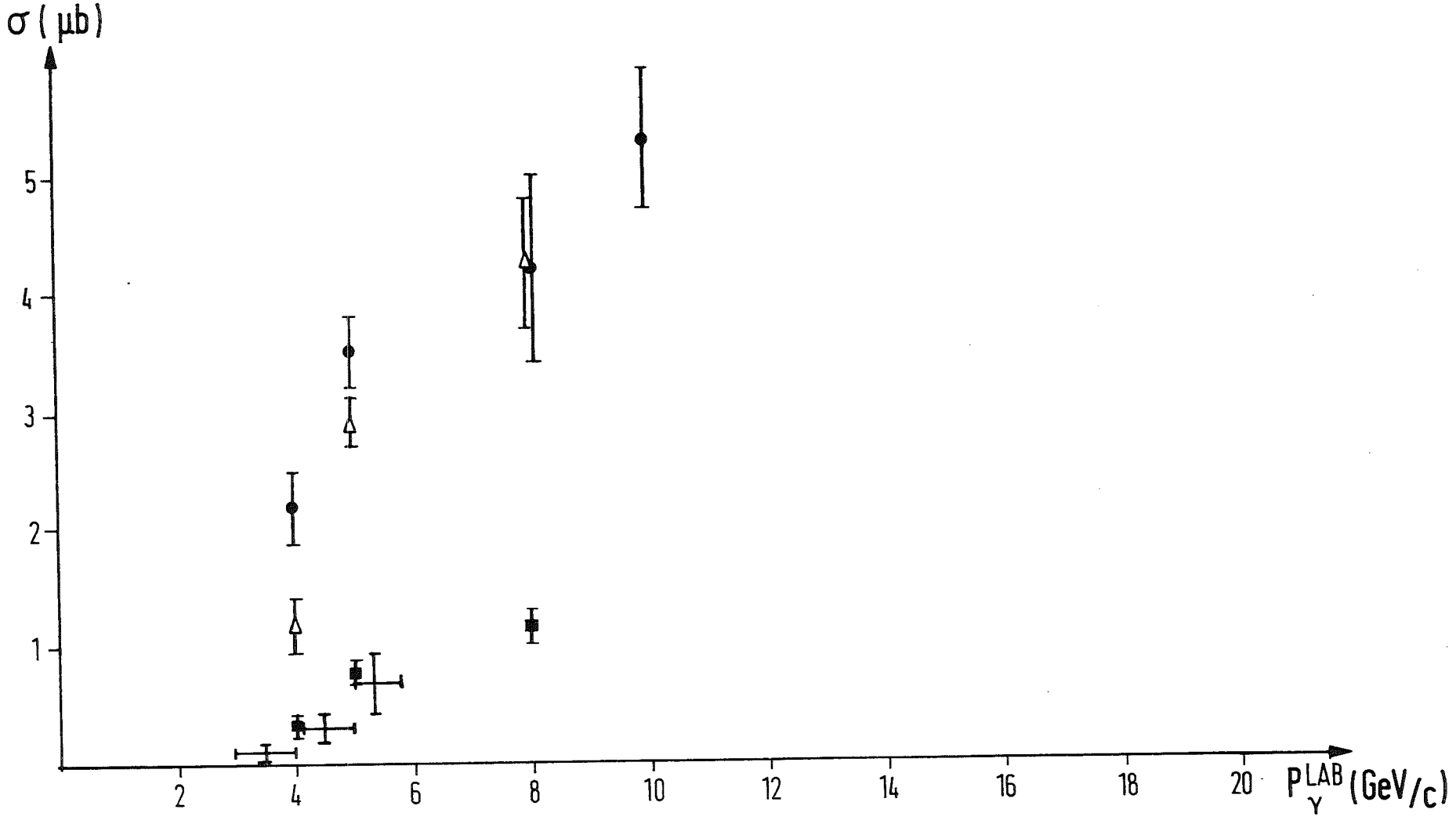

Fig.2