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PHOTOPRODUCTION OF VECTOR MESONS WITH A 16 GeV BREMSSTRAHLUNG BEAM*

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ABSTRACT

The high energy cross sections and t distributions for ω and ϕ photoproduction have been measured. Using our published ρ^0 data, these results, and the vector dominance model we calculate the total hadronic photon-proton cross sections obtaining values in good agreement with direct measurements.

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The high energy reactions

$$\gamma p \rightarrow \pi^+\pi^- p, \tag{1}$$

$$\gamma p \rightarrow K^+K^- p, \tag{2}$$

and

$$\gamma p \rightarrow \pi^+\pi^-\pi^o p, \tag{3}$$

have been studied in an experiment using the SLAC 2.2 meter streamer chamber in a 16 GeV pencil bremsstrahlung beam. Some details on the experimental arrangement and on the analysis of reaction (1) were reported earlier.[1] In this paper the cross sections and the momentum transfer distributions for ω and ϕ production are given. Using the assumption of vector meson dominance of the hadronic electromagnetic current (vector dominance model[2]), and the photon-vector meson coupling constants from recent colliding beam measurements[3] we evaluate the total hadronic photon-proton cross section and the total vector meson-proton cross sections.

A selection of event types (1) and (2) was made with the following criteria:

(a) a three constraint fit converges ($\chi^2 < 30$),

(b) the ionization information was consistent with the fitting hypothesis.

For those events which fitted both hypothesis (1) and (2) the selection was made on the basis of the fit with higher probability. In the mass region of the ϕ meson only one event fitted both hypothesis.

Events which did not satisfy the above criteria were analyzed as reactions with a single missing neutral (π^o or neutron). Again consistency with ionization information was required while a weak constraint was given by the peak energy of the bremsstrahlung available. Clearly these events contain a substantial background of multiple π^o production, but it appears that this background was reasonably small in the ω region at high energy.

Figure 1a shows the distribution of the invariant K^+K^- mass. The distribution of the four-momentum transfer to the K^+K^- system in the region of the ϕ meson (1.01 - 1.03 GeV) was fitted to a function of the form $A\, e^{-B|t-t_{min}|}$ and the values of the parameters A and B are given in Table I.

Figure 1b shows the $\pi^+\pi^-\pi^o$ mass distribution due to reaction (3) between 2 and 16 GeV incident photon energy separated into two energy regions. In order to obtain the intensity of the ω signal, we fitted our data to a superposition of a Gaussian and a polynomial background. A mass width (standard deviation) of the distribution of ± 20 MeV was obtained. The t distribution to the 3π system in the ω region was fitted to an exponential function for which parameters appear in Table I for photon energies between 5 and 16 GeV. The corresponding numbers for the energy interval 2-5 GeV are:

$$A = (35 \pm 12)\ \mu b/GeV^2,$$

$$B = (9.0 \pm 2.6)\ GeV^{-2},$$

$$\sigma = (3.9 \pm 0.9)\ \mu b;$$

these values are in very good agreement with bubble chamber measurements.[4]

Cross sections for both ω and ϕ have been computed by correcting the geometrical efficiency for each individual event following the method used for our $\gamma p \rightarrow \rho^o p$ data;[1] the numbers have also been corrected for unseen decay modes. In columns 3 and 4 of Table I are listed the differential cross sections at $t = t_{min}$ and the slope parameters B_V for the photoproduction of ρ, ω, and ϕ. The energy regions and the weighted average energies are given in column 1.

The Vector Dominance Model (VDM) permits one to write the following relation between amplitudes[2]

$$A(\gamma p \rightarrow \gamma p) = \sum_{V'} \frac{e}{f_{V'}} A(\gamma p \rightarrow V'_{tr} p) \qquad (4)$$

where

V', V	stands for Vector meson,
V_{tr}	means the transverse polarization states of V,

and

$\frac{em_V^2}{f_V}$	is the vector meson-photon coupling constant.

From Eq. (4) and the optical theorem one can derive a relation for the total γp cross section

$$\sigma_T(\gamma p) = 4\sqrt{\pi} \sum_V \frac{e}{f_V} \sqrt{\left[\frac{d\sigma}{dt}(\gamma p \rightarrow V_{tr} p)\right]_{t=0} \frac{1}{1+\alpha_V^2}} \qquad (5)$$

where

$$\alpha_V = \frac{\text{Re } A(\gamma p \rightarrow V_{tr} p)}{\text{Im } A(\gamma p \rightarrow V_{tr} p)}\Bigg|_{t=0}$$

allows for a possible contribution of a real part for the mostly diffractive amplitudes (5).

We can now test VDM by evaluating (5), knowing our measured data and recent measurements on the coupling constants,[3] and by comparing the result with independent measurements of $\sigma_T(\gamma p)$.[4,12]

There is some uncertainty about α_V. Experimental information is available only for α_ρ and indicates that α_ρ^2 is less than 10% and consistent with zero.[5,11] Assuming $\alpha_V^2 = 0$ we obtain $\sigma_T(\gamma p)$ from (5) accurate to about 20%, (the isoscalar amplitudes contribute in total only this amount).

Table II shows the relative contributions of ρ^0, ω and ϕ to $\sigma_T(\gamma p)$. The comparison with the directly measured total photon cross section is shown in Fig. 2a. The agreement appears to be very good and permits one to conclude that VDM is valid to ± 20% in this process.

Using VDM and our measured data we can also obtain information on the high energy total cross section for (Vp) reactions.

The optical theorem and the VDM equation

$$A(\gamma p \to Vp) = \sum_{V'} \frac{e}{f_{V'}} A(V'_{tr} p \to Vp)$$

yield the following relation[2] for the diffractive part of $\frac{d\sigma}{dt}(\gamma p \to Vp)$

$$\frac{d\sigma}{dt}(\gamma p \to Vp)\Big|_{t=0}^{\text{diff.}} = \left(\frac{e}{f_V}\right)^2 \frac{1}{16\pi} \sigma_T^2(Vp) \tag{6}$$

where we assumed

only 'elastic' amplitudes $V = V'$ contribute

and $\quad \mathrm{Re}\, A(Vp \to Vp) \approx 0$.

Although for the reaction $\gamma p \to p\rho^0$ all experimental evidence suggests a nearly pure diffractive process, a non-diffractive contribution in the reaction (3) is expected.[8]

From a fit of the energy dependence of reaction (3) between 2 and 16 GeV to a phenomenologic form[4]

$$\sigma(\gamma p \to \omega p) = C_{OPE}\, E_\gamma^{-1.6} + \sigma_{diff} \quad . \tag{7}$$

we extracted the diffractive part of this process. The experimental data and the diffractive part are shown in Fig. 2b. For reaction (2) we assumed a pure diffraction process, supported by theoretical models.[6,7]

The present experimental data give no information on a possible real part of the amplitude.

The results from the evaluation of (6) are listed in Table I.

The ρ^o, ω and ϕ proton total cross sections are in agreement with theoretical predictions from the Quark model[9] and from SU(3) with universality and symmetry breaking in the Pomeranchuk trajectory.[7] They are also in agreement with published cross sections at lower energy (3-5 GeV) obtained from photoproduction of ρ^o and ϕ on complex nuclei,[10] although we are aware of possible problems in making an accurate comparison between those data and ours.

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TABLE I

Cross Sections and Differential Cross Section Parameters for Photoproduction of ρ^o, ω and ϕ.

V	Photon Energy E_γ Interval ($\bar{E}_\gamma$) (GeV)	$\gamma p \to Vp$			$e^+e^- \to V$	$\sigma_{el}(Vp)$	$\sigma_T(Vp)$
		σ (μb)	$\left(\frac{d\sigma}{dt}\right)_{t=t_{min}}$ ($\mu b/GeV^2$)	B_V (GeV^{-2})	$\frac{f_V^2}{4\pi}$	(mb)	(mb)
ρ	8 - 16 (11.5)	13.8 ±2.9	152 ± 65	11.1 ± 2.8	2.10 ± 0.11	3.86 ± 0.6	29.4 ± 6
ω	5 - 16 (9.5)	2.6 ± 0.7	25 ± 10	9.5 ± 2.3	14.8 ± 2.8	3.84 ± 1.2	27 ± 8
ϕ	2 - 16 (6.5)	.61 ± 0.24	3.9 ± 2.1	6.3 ± 2.5	11.0 ± 1.6	.91 ± 0.6	10.7 ± 3.8

TABLE II

VDM Calculation of $\sigma_T(\gamma p)$ (in μb)

	2 - 4	4 - 8	8 - 16
ρ^0	110 ± 16	95.5 ± 13	102^{+22}_{-26}

	2 - 5	5 - 16
ω	$18.3^{+3.4}_{-3.7}$	$15.5^{+3.}_{-3.4}$

	2 - 16
ϕ	$7.1^{+1.5}_{-1.9}$

	2 - 4	4 - 8	8 - 16
$\sigma_T(\gamma p)$	135.6 ± 16	119.4 ± 14	124.5^{+22}_{-26}

FIGURE CAPTIONS

1a. Invariant mass spectrum $M_{K^+K^-}$ from the reaction $\gamma p \rightarrow p K^+ K^-$ (3 constraint).

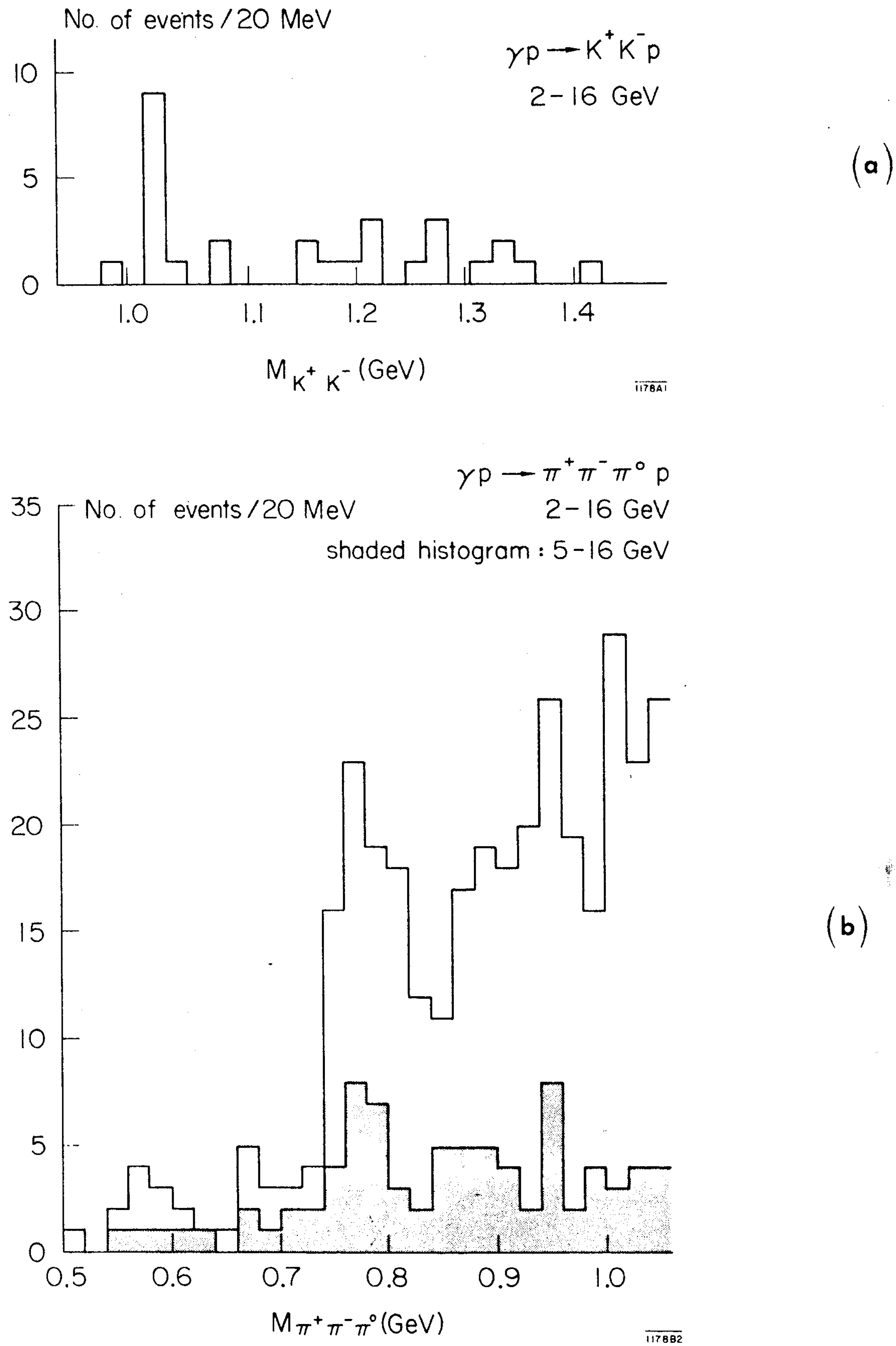
1b. Invariant mass spectrum $M_{\pi^+\pi^-\pi^0}$ from the reaction $\gamma p \rightarrow p \pi^+ \pi^- \pi^0$ (0 constraint)

for energy intervals $2 \leq E\gamma \leq 5$ GeV

and (shaded) $5 \leq E\gamma \leq 16$ GeV .

2a. Hadronic photon-proton total cross section measured points[4,12] together with calculated points (VDM + SLAC streamer chamber data).

2b. ω cross section from the reaction $\gamma p \rightarrow p\omega$ (SLAC streamer chamber data and lower energy data[4]). The solid line is a fit according to (7); the shaded region indicates the diffractive limits.



No. of events / 20 MeV
γp → K⁺K⁻p
2-16 GeV
(a)
10
5
0
1.0
1.1
1.2
1.3
1.4
$M_{K^+K^-}$ (GeV)
1178A1
γp → π⁺π⁻π° p
35
No. of events / 20 MeV
2-16 GeV
shaded histogram : 5-16 GeV
30
25
20
15
10
5
0
(b)
0.5
0.6
0.7
0.8
0.9
1.0
$M_{\pi^+\pi^-\pi^0}$ (GeV)
1178B2

Fig. 1

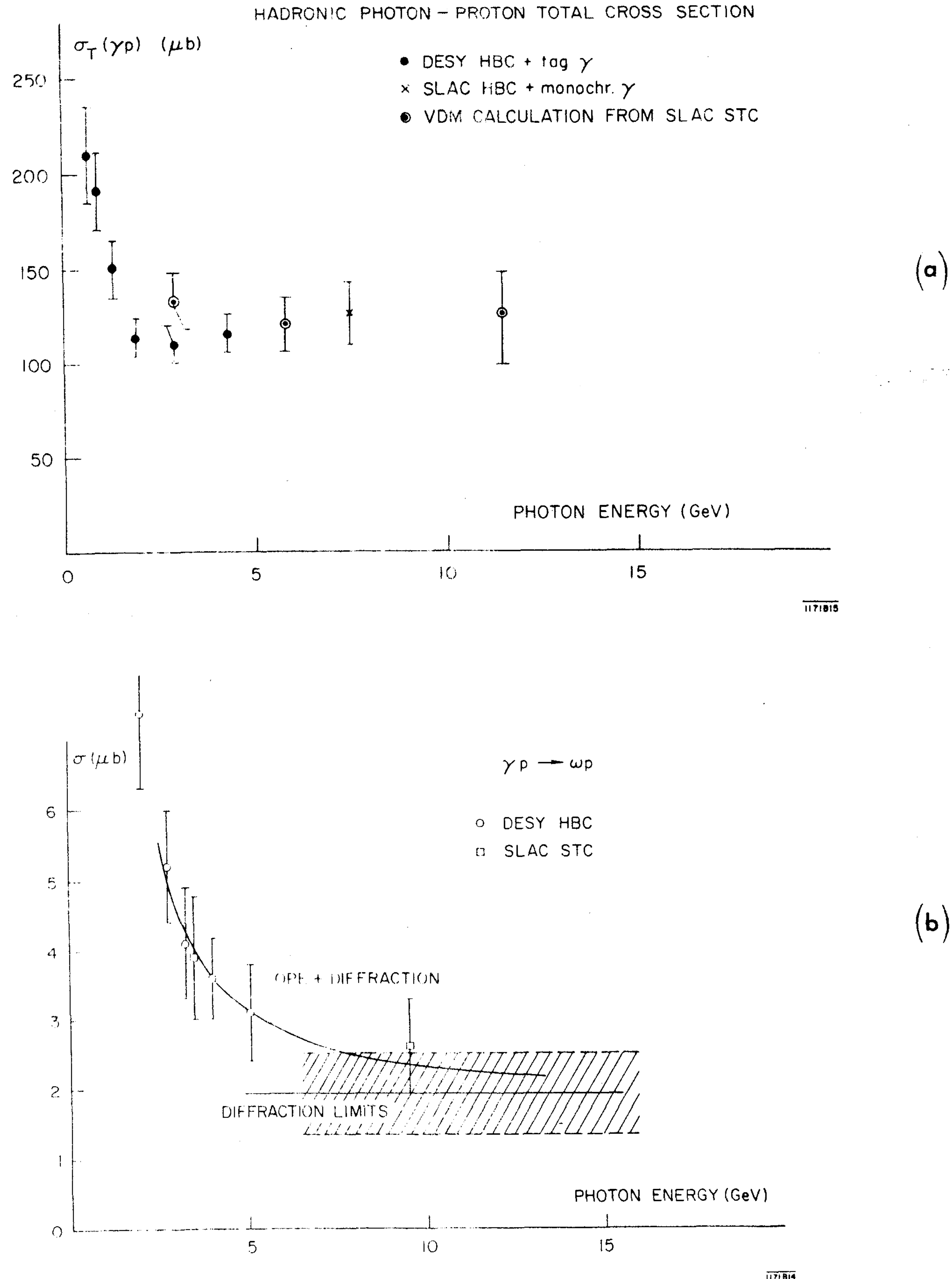

HADRONIC PHOTON – PROTON TOTAL CROSS SECTION
$\sigma_T(\gamma p)$ (μb)
DESY HBC + tag γ
SLAC HBC + monochr. γ
VDM CALCULATION FROM SLAC STC
PHOTON ENERGY (GeV)
(a)
σ (μb)
$\gamma p \rightarrow \omega p$
DESY HBC
SLAC STC
OPE + DIFFRACTION
DIFFRACTION LIMITS
PHOTON ENERGY (GeV)
(b)

Fig. 2