Photoproduction of φ^0 Mesons from Hydrogen, Deuterium, and Complex Nuclei*

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The photoproduction of φ^0 mesons from hydrogen, deuterium, and complex nuclei has been measured at energies from 6.4 to 9.0 GeV. Results are presented on the t dependence from hydrogen and carbon. Forward cross sections for φ^0 photoproduction from D_2, C, Mg, Cu, Ag, and Pb are analyzed in terms of the φ^0-photon coupling constant, the φ-nucleon total cross section, and the real part of the φ-nucleon scattering amplitude.

The study of the photoproduction of φ^0 mesons from hydrogen and more complex nuclei at high energies bears on several important questions: Is the process mainly diffractive from single nucleons, and correspondingly, coherent from complex nuclei? In the vector-dominance model (VDM),[1] where the photoproduction is directly related to φ^0 elastic scattering, what is the φ^0-nucleon total cross section $\sigma_{\varphi N}$ and the real-to-imaginary ratio $\alpha_{\varphi N}$; and what is the direct φ^0-photon coupling strength, $4\pi/\gamma_\varphi^2$? This question also relates to the quark models[2] which predict values for $\sigma_{\varphi N}$ and $\alpha_{\varphi N}$ on the basis of the quark decomposition of the φ^0, and use measured results on $K^\pm$-nucleon and $\pi^\pm$-nucleon scattering to predict the behavior of φ^0-nucleon scattering. Finally, it has been suggested,[3,4] partly on the basis of the strange-quark decomposition of φ^0 mesons, that the elastic scattering of φ^0 mesons is a particularly favorable reaction for the study of the Pomeranchuk trajectory since it is supposed to be "inert" to the exchange of any other type of trajectory. Through VDM again, the same conclusions apply to the photoproduction of φ^0 mesons.

The present paper describes a series of measurements of φ^0 photoproduction from hydrogen, deuterium, and heavier nuclei, including t dependences from hydrogen and carbon and the A dependence at 0°; finally, the polarization asymmetry of φ^0 photoproduction from carbon and hydrogen is described in the following paper.[5] Nearly symmetric decays of the φ^0 mesons into K^+K^- pairs are detected in the pair spectrometer. The apparatus is the same as the one used for ρ^0 photoproduction[6] except for the inclusion of Freon-116 gas Cherenkov counters within the second magnet, which veto pion and electron pairs with an efficiency over 99.5%. The entire magnet system is mounted on a platform which rotates vertically (to ~7°) about the target, thus varying the production angle without varying the geometry of the pair detection system.

The mass acceptance of the system is broad enough to cover the entire mass spectrum of the φ^0 without appreciable distortion, with a mass resolution of about ±4 MeV using spark-chamber reconstruction. Also, mass spectra have been

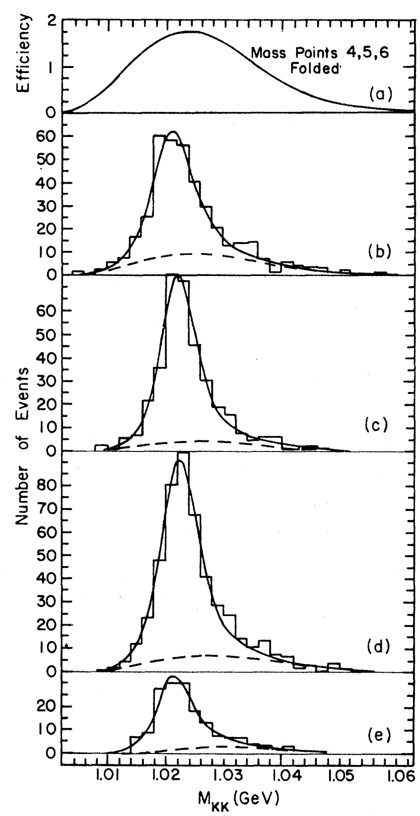

FIG. 1. K-pair mass spectra; data combined from three mass settings, $\langle E_\varphi\rangle = 8.3$ GeV. (a) Mass acceptance of the spectrometer. Mass spectra obtained from (b) hydrogen, (c) magnesium, (d) copper, and (e) lead. The smooth solid curves in (b), (c), (d), and (e) show the results of fits described in the text; the dotted curves show the nonresonant "background" contribution to each fit.

Table I. 0° differential cross sections for the various elements. The effective extrapolation factor is the result of the optical-model–calculation extrapolation to $\theta = 0°$ from the actual production angle averaged over the spectrometer aperture. The errors do not include an overall systematic error in normalization of ±12%.

$\langle E_\varphi \rangle$ (GeV)	Element	$(d\sigma/dt)_{0°}$ (μb/GeV^2)	Extrapolation factor (Optical model)
6.4	Hydrogen	2.40 ± 0.70	1.00
	Deuterium	9.30 ± 1.40	1.08
	Carbon	184 ± 14	1.12
	Magnesium	626 ± 93	1.23
	Copper	2163 ± 370	1.41
	Silver	3222 ± 695	1.59
	Lead	9580 ± 2070	2.25
8.3	Hydrogen	3.76 ± 0.50	1.00
	Deuterium	11.2 ± 1.3	1.12
	Carbon	251 ± 15	1.19
	Magnesium	989 ± 94	1.35
	Copper	4114 ± 550	1.59
	Silver	7580 ± 920	1.84
	Lead	19 250 ± 2100	2.37
9.0	Hydrogen	3.58 ± 0.70	1.00
	Carbon	241 ± 16	1.20

studied by varying the central-mass setting in small steps to provide a near-uniform efficiency over the φ^0 width. Figure 1 shows the acceptance obtained with three mass steps. Also shown are several typical reconstructed mass spectra using this acceptance. The spectra are dominated by the φ^0 resonance. Preliminary results were presented[7] using the total counter data with no background subtractions. The present results are obtained using detailed mass fits to the observed spectra. Typical fits are shown in Fig. 1. The fitting procedure included the following features: The φ^0 was represented by a relativistic Breit-Wigner resonance with energy-dependent width[6] $\Gamma_0 = 4.1$ MeV and mass $1020 < m_0 < 1023$ MeV. A $\sin^2\theta^*$ decay distribution in the φ^0 rest system was assumed. Decays in flight at 8.3 GeV occurred for about 39% of the φ's in our aperture, and some of these were counted and gave an apparent mass shift. These were fitted by a background curve with free normalization and shape given by the mass acceptance of the apparatus. This background also allowed for nonresonant K-pair production which was believed to account for about half of it. There is no apparent A dependence of the line shape or of the fractional background. In calculating cross sections a branching ratio for decay into charged K's of 0.47 ± 0.02 was used. Because of uncertainties in the background, geometric factors, and the

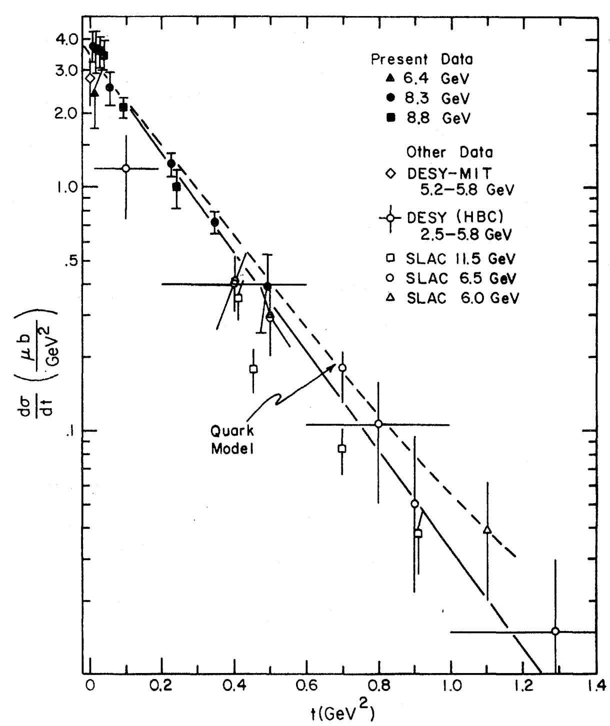

FIG. 2. The t dependence of the hydrogen cross section. The straight line represents the best fit to data from the present experiment only. An "inelastic" contribution believed to be about 10% has not been subtracted from the data. Solid points are present data; open points are data from SLAC (Ref. 8), DESY-MIT (Ref. 9), and DESY hydrogen bubble chamber (Ref. 10).

branching ratio a systematic normalization error of ±12% has been assigned.

Table I lists the cross sections obtained at 0°. The t dependence from hydrogen is shown in Fig. 2; data from other laboratories[8-10] have been included for comparison. A fit to the present data at 8.3 and 9.0 GeV with the expression $d\sigma/dt = ae^{bt}$ gives the results $a = 3.41 \pm 0.15$ μb/GeV², $b = 4.68 \pm 0.23$ GeV⁻². The t dependence agrees reasonably well with that predicted by quark models. Inelastic contributions to the hydrogen cross sections have been measured in a recent experiment.[11] Preliminary results indicate that the inelastic cross section is small at t values from $|t| = 0.17$ to 0.5 GeV². An upper limit at 0° (by extrapolation) is ~12% of the elastic cross section. No inelastic contributions have been subtracted in obtaining the cross sections in Table I. The deuterium-to-hydrogen ratio, extrapolated to $t=0$, is found to be $R(0) = 3.6 \pm 0.6$. The predicted ratio, assuming no isospin exchange,[6] is $R(0) = 3.89$. The data are thus consistent with the assumption of no isospin exchange.

The t dependence from carbon at 6.4 GeV is shown in Fig. 3. The smooth curve is a fit to the data with the expression[13] $d\sigma/dt = a_1|S(t)|^2 + a_2[1 - S(t)]|f_0(t)|^2$. $S(t)$ is the carbon elastic form factor, approximated by $|S(t)|^2 = \exp(52t)$, as a result of an optical-model calculation using $\sigma_{\varphi N} = 12$ mb and using $\alpha_{\varphi N} = -0.3$ from quark-model predictions. $|f_0(t)|^2 = \exp(4.68t)$ represents the hydrogen result. The results of the fit are: $a_1 = 267 \pm 11$ μb/GeV², $a_2 = 19.5 \pm 1.2$ μb/GeV².

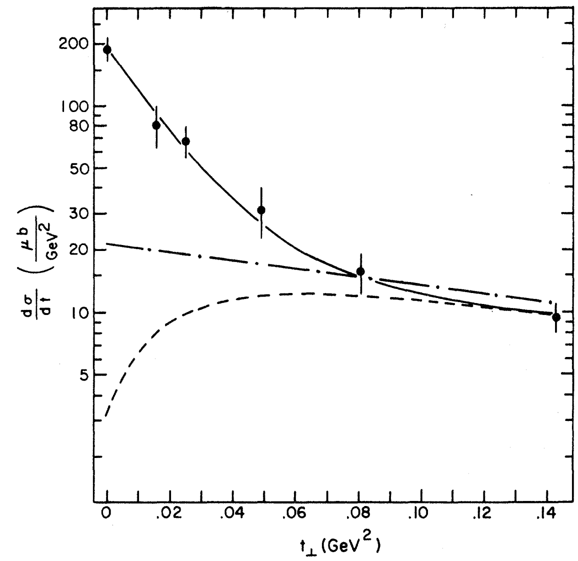

FIG. 3. The t dependence from carbon, $\langle E_\varphi \rangle = 6.4$ GeV. The solid curve is a fit using the equation given in the text. The dashed curve is the incoherent contribution to this expression. The dot-dashed straight line is a calculation of the incoherent cross section following Kolbig and Margolis (Ref. 12) normalized to the elastic contribution at $t=0$, shown for comparison.

The A dependence of the 0° data is shown in Fig. 4. The smooth curves are the results of simultaneous fits to the data at all three energies using an optical-model calculation.[14] Three values of $\alpha_{\varphi N}$ were tried. The resultant values of

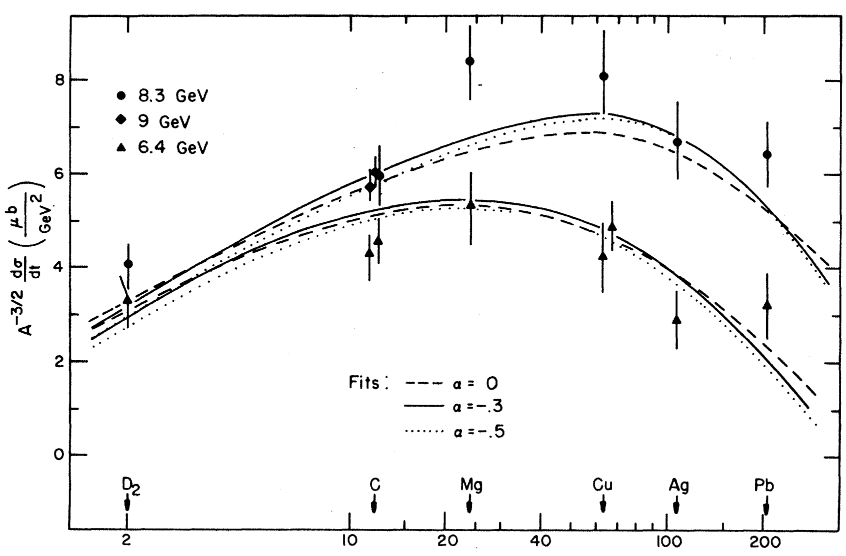

FIG. 4. A dependence of the 0° cross sections. The curves are the results of simultaneous fits to the data at 6.4 GeV and the combined data at 8.3 and 9 GeV. Three values of $\alpha_{\varphi N}$ were used, as indicated.

Table II. Values of the parameters.

$\alpha_{\varphi N}$	$\sigma_{\varphi N}$	$\gamma_\varphi^2/4\pi$	Description
−0.5	9.2 ± 2.8	4.3 ± 2.1	All data
−0.3	12.1 ± 3.0	5.9 ± 2.4	All data
−0.0	17.6 ± 4.3	10.7 ± 4.1	All data
−0.25	12	5.5	8.3 GeV only
−0.35	12	6.3	6.4 GeV only
−0.12	12	5.3	D_2 excluded
−0.22	12	5.4	D_2 reduced by 10%

the free parameters $\sigma_{\varphi N}$ and $\gamma_\varphi^2/2\pi$ are shown in Table II. A unique solution is not determined. The quark-model value $\sigma_{\varphi N} = 12$ mb leads to a value for $\alpha_{\varphi N}$ in agreement with the quark-model prediction of −0.3, but the value of $\gamma_\varphi^2/4\pi = 5.8 \pm 2.4$ is above the colliding-beam value of 2.8 ± 0.2.[15] Also shown in Table II are values for fits to specified portions of the data. In each case $\sigma_{\varphi N}$ is constrained at 12 mb. The slight systematic energy-dependent deviation of the data from the fits in Fig. 4 can be seen to be consistent with an energy dependence of $\alpha_{\varphi N}$, with γ_φ constant. Similarly the parameters are so correlated that changes in the deuterium cross section leave γ_φ reasonably stable. This is of interest because of an apparent nondiffractive contribution in hydrogen (following paper) which may be significant even in deuterium.

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