Proton Compton Scattering and Neutral-Pion Photoproduction at Large Angles

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The differential cross sections for $\gamma p \to \gamma p$ and $\gamma p \to \pi^0 p$ have been measured from $|t| = 0.7$ to 4.3 GeV^2 and for incident energies in the range 2 to 6 GeV. The energy dependence of Compton scattering is well described by parton model ideas. However, the energy dependences of π^0 photoproduction and the ratio of Compton scattering to π^0 photoproduction are not consistent with dimensional counting arguments.

Proton Compton scattering and neutral-pion photoproduction have been extensively studied, both experimentally and theoretically, at small $|t|$. As in other elastic-scattering reactions, the Compton process has small-$|t|$ behavior characteristic of purely diffractive scattering: an exponential slope in t and a nearly energy-independent forward cross section. In this same t region, the π^0 photoproduction cross section may be parametrized by meson exchanges. Various models[1,2] have predicted that at large angles new scattering mechanisms would be encountered for both processes.

Measurements of the cross sections for wide angular sweeps at 3 and 4 GeV and energy sweeps at $t = -2.45$ GeV^2 and at the center-of-mass angle of 90° were made at the Wilson 12-GeV electron synchrotron. The experimental technique involved measuring the momenta and angles of a photon and a proton in a double-arm coincidence experiment. The apparatus is shown schematically in Fig. 1 and is described in more detail elsewhere.[3,4]

Compton-scattered photons were separated, on a statistical basis, from the more copious π^0-decay photons by coplanarity- and production-angle measurements. The reaction plane was determined with high accuracy by minimizing the electron beam spot size at the radiator and measuring the recoil proton trajectory in a precision magnetic spectrometer with arrays of fine-resolution multiwire proportional chambers (MWPC). Deviations of the scattered photon (or decay photon in the case of $\gamma p \to \pi^0 p$) from coplanarity were measured with high resolution by an unusual configuration of lead-glass Čerenkov counter blocks.[5] The photon production angle and momentum were predicted from the proton four-vector assuming $\gamma p \to \gamma p$ kinematics. The angular difference in the reaction plane, $\Delta\theta$, and perpendicular to the reaction plane (coplanarity), $\Delta\varphi$, between the observed photon and the predicted photon directions were then found.

The angular difference distributions were fitted to a combination of Monte Carlo–calculated distributions for single-π^0 photoproduction, proton Compton scattering, and a smooth background from other processes. Typical distributions are shown in Fig. 2. The amount of background (as much as 20% for some data points) was determined largely from the $\Delta\theta$ distribution while the coplanarity distribution was crucial for separating Compton scattering from π^0 photoproduction. The coplanarity was studied as a function of cuts placed on $\Delta\theta$; the final cuts were those beyond

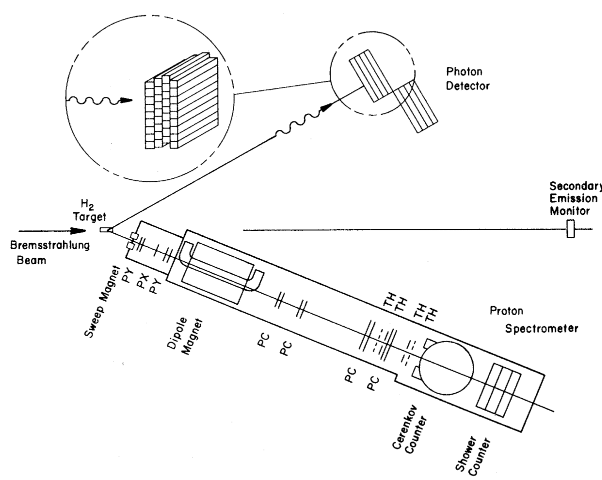

FIG. 1. Schematic floor plan of the apparatus. PY designates a pair of MWPC's with wires at ± 7° to the horizontal; PX, an MWPC with vertical wires; PC, a pair of MWPC's with wires horizontal and vertical; and TH, a scintillation-counter trigger hodoscope. A perspective view of one of the two lead-glass arrays is depicted in the inset.

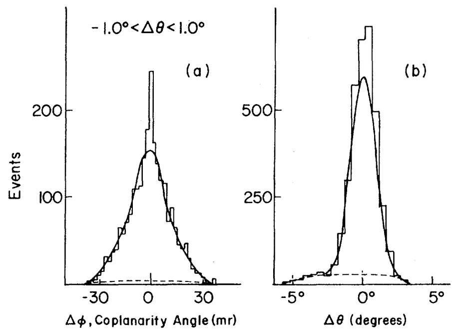

FIG. 2. Angular difference distributions at 6 GeV and $t = -2.45$ GeV^2. (a) Coplanarity-angle distribution. The solid line is a fit assuming neutral-pion photoproduction, the dashed line is the estimated background from other processes, and the peak at $\Delta\varphi = 0$ is due to proton Compton scattering. (b) Angular difference distribution in the reaction plane. The curves have the same interpretation as in (a). The excess at $\Delta\theta = 0^0$ is due to Compton scattering.

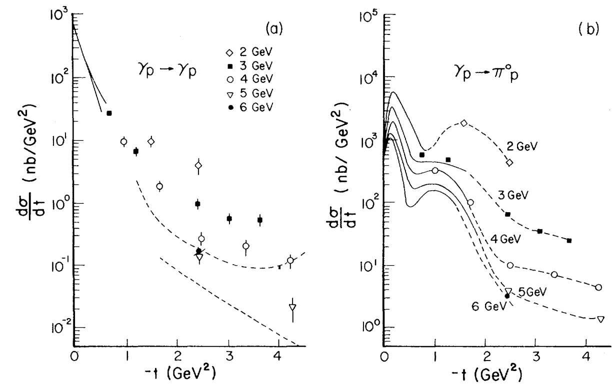

FIG. 3. Data from this experiment. The indicated energies are incident-photon laboratory energies. (a) Proton Compton-scattering differential cross sections. The solid lines summarize data from previous experiments and the split represents either energy dependence or a disagreement between experiments. The upper and lower dashed lines are VDM predictions at 4 and 6 GeV, respectively. (b) $d\sigma/dt$ vs t for π^0 photoproduction. The solid lines summarize earlier data at small $|t|$. The dashed lines are intended only to guide the eye. In general, error bars resulting from statistical errors and systematic errors, which vary from point to point, are smaller than the size of the data points. Overall systematic errors are not included.

which the $\Delta\varphi = 0$ peak showed no statistically significant increase. Within these cuts for different data points the ratio of the Compton peak to the π^0-plus-background distribution varied from 1:1 to 1:4.

Coplanarity resolution, the key to extracting the Compton signal, was typically 5 mrad full width at half-maximum (FWHM). For the data in Fig. 2(a) the calculated and observed resolutions were 2.4 and 3.0 mrad FWHM, respectively. For those data points where the statistics were good, the resolution observed agreed with the Monte Carlo–calculated resolution. For this reason at the low-statistics data points we constrained the coplanarity resolution in the fits to be that given by the Monte Carlo program. Uncertainties in the Monte Carlo calculations of the acceptance parameters contributed less to errors in the Compton data than did statistical errors. Corrections were made for empty-target effects (0.01), photon detector inefficiency (0.30), and proton spectrometer inefficiency (0.40).[3,4] Such corrections lead to overall systematic uncertainties on the order of 20%.[4]

Our proton Compton-scattering cross section data are presented in Fig. 3(a). In contrast to the small-$|t|$ data, the data at larger $|t|$ have a strong dependence on energy and a weak dependence on t. Some parton models,[1,2] by considering Compton scattering from individual quarks, predict that at fixed center-of-mass angles, θ^*, far from the forward and backward regions, the proton Compton–cross-section energy dependence should vary as $d\sigma/dt \propto s^{-6}$. The data are in good agreement with this hypothesis. For fixed $\theta^* > 50°$ and incident energy above 2 GeV, the cross section varies with energy as s^{-n} where $n = 6.1 \pm 0.3$.[4]

The decreasing slope of the π^0 cross sections [see Fig. 3(b)] at higher $|t|$ and $|u|$ suggests the existence of a scattering mechanism different from the t- and u-channel exchange mechanisms which dominate in the forward and backward directions. Dimensional counting arguments[2] suggest that at fixed center-of-mass angle in the central region the cross section, $d\sigma/dt$, for charged- or neutral-pion photoproduction should be proportional to s^{-7}. The data from the present experiment above 2 GeV incident energy are not consistent with this dependence. A fit of the data by the form s^{-n} gives a weighted average for $\theta^* > 50°$ of $n = 8.0 \pm 0.1$.[4]

Because we have measured *both* proton Compton-scattering cross sections and neutral-pion photoproduction cross sections *simultaneously*, many of the systematic errors cancel when we calculate the ratio of these cross sections,

$$R(s,t) = \frac{d\sigma(\gamma p \to \gamma p)/dt}{d\sigma(\gamma p \to \pi^0 p)/dt}.$$

Dimensional counting arguments[2] predict that at fixed θ^*, $R(s,t) \propto s^{1.0}$. When constraints of the constituent-interchange model[2] are added, the prediction at fixed t is $R(s,t) \propto s^{1.0}$. Figure 4(a) shows $R(s,t)$ at fixed $\theta^* > 50°$. Fitting the data at each angle by the form $R(s,t) = As^n$ and taking a weighted average give $n = 2.0 \pm 0.3$. In Fig. 4(b), $R(s,t)$ is plotted at fixed $t = -2.45$ GeV^2. A fit of the data by the same form as above gives $n = 1.8 \pm 0.4$. Neither of these results is in good agreement with predictions. The measurements of cross sections for the individual processes suggest that the π^0 prediction is the source of this disagreement.[4]

It has been traditional to compare the Compton cross section to vector-meson photoproduction through the vector-dominance model (VDM). At small $|t|$ there have been hints of a discrepancy in the t dependence,[6,7] and the overall normalization predicted by VDM is low by a factor of 2. Following the ideas of the generalized VDM we assume that this difference at small $|t|$ may be made up by the inclusion of additional hadronic constituents for the photon, and simply multiply the VDM prediction (using data from Anderson[8]) by 2. Figure 3(a) shows that the t dependence of the data and prediction are similar, but the normalization and s dependence differ. In particular, if at $\theta^* = 90°$ we fit the ρ and ω photoproduction data of Ref. 8 by the form $d\sigma/dt = As^{-n}$, we get $n = 8.4 \pm 0.8$, which is to be compared with $n = 7.1 \pm 0.4$ for Compton scattering.

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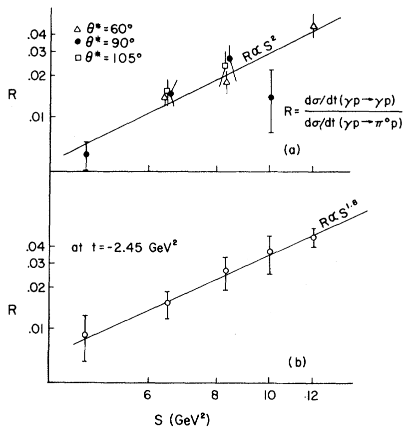

FIG. 4. Compton to π^0-photoproduction cross-section ratios at (a) constant θ^*, and (b) constant t.

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