AN EXPERIMENT FOR MEASURING THE COMPTON EFFECT ON PROTONS BEYOND PION THRESHOLD

L. B. AUERBACH, G. BERNARDINI, I. FILOSOFO, A. O. HANSON, A. C. ODIAN and T. YAMAGATA

University of Illinois, Urbana (Ill.)

(presented by G. Bernardini)

1. An experiment has been performed at the University of Illinois for studying the scattering of high energy photons by protons. It was started about two years ago by Hanson, Yamagata and myself and then continued with the invaluable collaboration of the other authors.

The main difficulties in performing this experiment are well known. First of all, according to any reasonable theorical prediction, the cross-section is supposed to be quite small; i.e. of the order of the differential Thomson cross section

$$\sigma_0 = [(8\pi/3)\,(e^2/M)^2]/4\pi = 1.57 \times 10^{-32}\ \text{cm}^2/\text{ster}.$$

Secondly, the background due to the π^0 swamps the correlated pairs of the scattered photon and proton-recoil. Actually, also, the π^0's produce similar photon-nucleon pairs. To overcome these difficulties a quite rigid selection of the "good" pairs has been devised. This selection is based on the kinematic-characteristics of those photon-proton pairs which are created by the Compton-scattering.

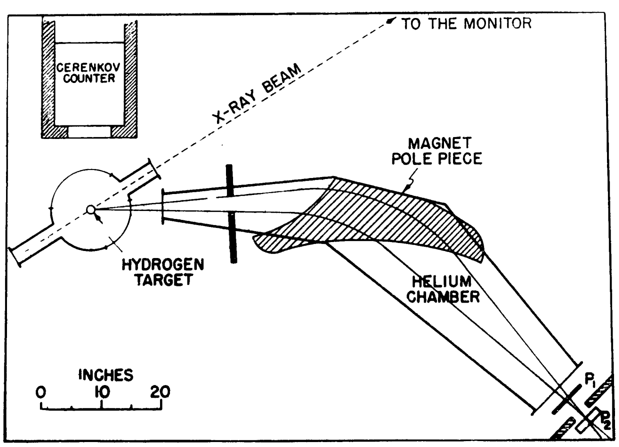

Fig. 1. Experimental layout — P_1 and P_2 are the proton counters. The magnet aperture and magnet diaphragm are indicated. The liquid hydrogen target (3″ long, 1.2″ diameter) had a Mylar wall only 1.5 mils thick. See [1].

The selection was somewhat "overdone" merely by ensuring by several cross checks the identity of the selected processes. The experimental layout is given in its essentials in fig. 1.

i) *The magnet selected*

(*a*) the proton angle with a definition which was usually $\pm$ 2° and some times $\pm$ 3.0°. The magnet was provided by an aperture defining the solid angle of the recorded protons. This was the solid angle to be considered in the evaluation of the cross-section. The aperture now mentioned was placed on the side of the magnet facing the target and in a region where the fringing field was still quite small. Thus the solid angle was practically independent from the value of the selected proton momentum. The aperture of the Čerenkov counter used for the detection of the scattered photons largely overlapped the solid angle correlated to the mentioned solid angle of the proton-recoils.

(*b*) obviously the proton-momentum. The allowed spread in momentum was regulated by the diaphragm placed at the focusing point of the magnet, between the first and the second proton counters. The maximum spread in the proton momentum was $\pm 10\%$. Usually it was $\pm 5\%$ or less.

ii) *The pulse heights of the two proton counters* were used for a check on the identity of the recoiling proton. The first proton counter, $^1/_8$″ thick, tested with cosmic rays, showed an efficiency of 100% over all the effective area (6.5″ × 9″) and a pulse height distribution well in agreement with the expected energy-losses of fast μ mesons. See fig. 2.

The second proton counter ($1^1/_8$″ thick) also had 100% efficiency and a resolution in energy of $\pm 10\%$. This spreading was mostly due to the incompletely uniform collection of the light emitted by particles crossing the scintillator near the edges.

iii) *The Čerenkov counter selected*

(*a*) the photon angles ($\pm 14°$)

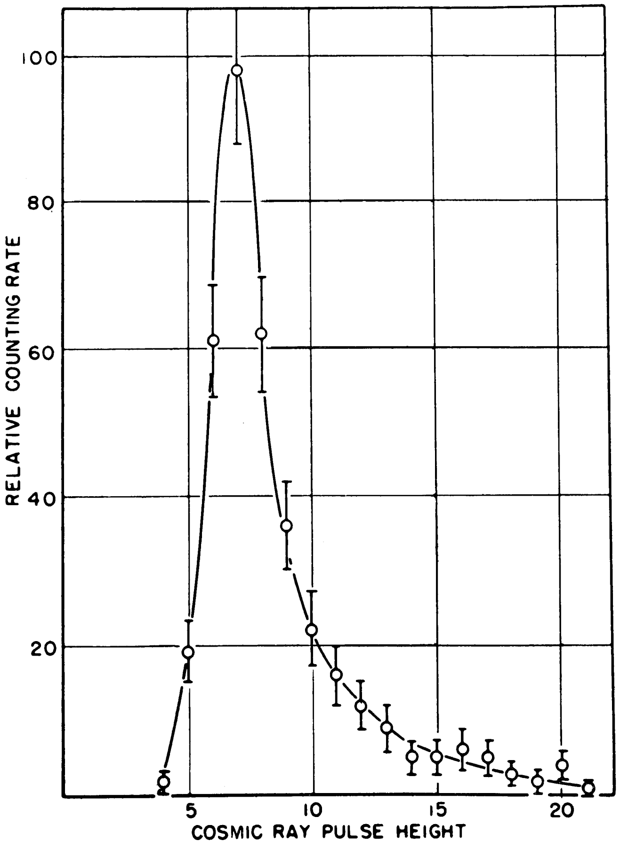

Fig. 2. Pulse height distribution of the thin ($^1/_8''$ thick) proton counters. The pulses are due to μ-cosmic rays normal to the counter.

(*b*) the pulses due to the scattered photons. The resolution was about $\pm 25\%$ for photons of $\approx$ 200 Mev and about $\pm$ 30% for photons of $\approx$ 100 Mev.

The counter was previously calibrated by monochromatic electrons. See [2]).

iv) *The electronics* made a final and essential selection based on the measurement of the time of flight between the proton and the photon pulses. The three pulses were displayed on the traces of a fast oscilloscope. These traces were triggered by a fairly slow (200 μsec) master coincidence circuit. It was so slow because the traces thus recorded included automatically a few accidental coincidences. Thus the traces allow to estimate properly the ratio between true and accidental counts giving at the same time a check of the pulse height selection. Fig. 3 shows few typical traces and fig. 4 a typical distribution in time of the Čerenkov pulses in respect to the proton pulses. Together with these "slow" master coincidences the block diagram given in fig. 5, shows also a "fast" master coincidences set. It was very useful during the actual running period of the experiment to follow closely the behaviour of the experiment itself. In fig. 5 are also indicated two pen-recorders and a pulse analyzer. On them, in an arbitrary order one may display, depending on the convenience, the three counter pulses. These devices also have been most useful for following closely the course of the experiment.

2. The essential criterion in designing the experiment was the following: *The neutral pion background can be practically eliminated by combining properly the maximum bremsstrahlung photon energy and the interval of allowed proton momenta, selected (by the magnet).*

Thus it is possible that for a given proton angle and momentum practically no photons except those due to Compton scattering are able to reach the Čerenkov counter.

This situation is made clear by fig. 6 where energies of the two competing sets of proton recoils, those due to the Compton scattering and those due to the production of π^0 are plotted versus photon energy. The two strips correspond to the angular aperture of the magnet for a laboratory angle of 43.5° ($\approx$ 90° c.m.). The upper strip is the Compton one, the lower one that of the neutral pions. In fig. 6 are also indicated the two photon-areas effectively used respectively at 250 and 210 maximum betatron energy. It is evident that in both cases the *minimum* energy for a

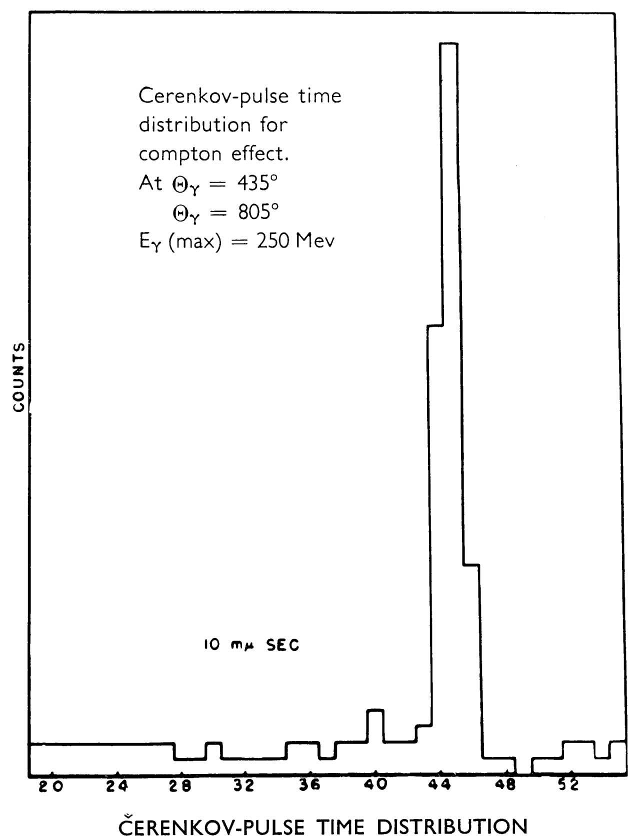

Fig. 4. Time-of-flight distribution of Čerenkov-pulses.

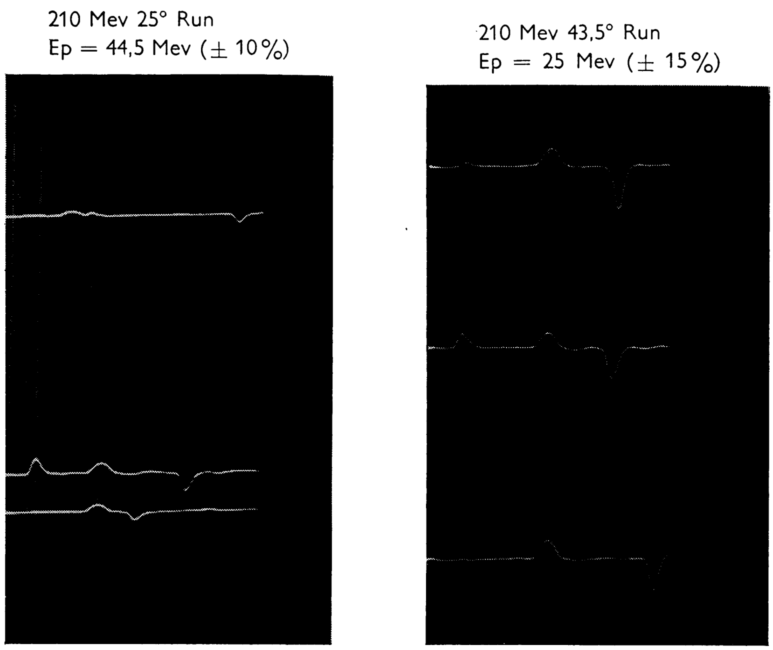

Fig. 3. Scope traces of the three counter pulses. The first is the pulse of P_2, the second is that of the Čerenkov, the last that of P_1. At left they are "good" and "bad" photon-proton pairs with proton recoils of (44.5 ± 10%) Mev. The good one is in the middle. At right the pulses are those due to photon-proton pairs with protons of (25 ± 15%) Mev.

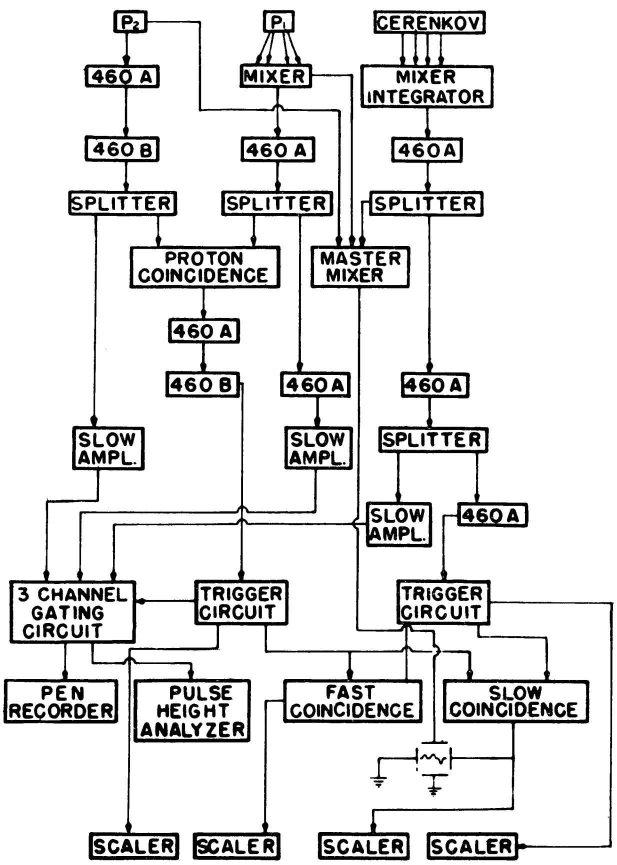

Fig. 5. Block diagram.

proton kicked out by a scattered photon is too high to be confused with any possible proton recoil due to the emission of a neutral pion.

The experimental procedure was the following :

(*a*) Set the magnet at the desired angle ϑ_p.

(*b*) Set the (maximum) betatron energy at the desired value. In the worst cases the spreading in this energy was less than 1%.

(*c*) Set the Čerenkov counter at one angle ϑ_0 and simultaneously the magnet current and diaphragm such that a *definite* amount of the correlated coincidences due to the neutral pions *is expected.* In making this estimate the averages of the cross-sections given by M.I.T., Cornell and Cal Tech have been used. Then by the counting rate of coincidences the good performance of the overall equipment is tested.

(*d*) *Raise* the magnet current up to the value wanted for the selection of the proton momenta required by the Compton scattering and set the magnet diaphragm for the allowed momentum interval. The Čerenkov counter being at a *wrong* angle ϑ_0 *a negligible* number of counts is expected, and should be actually found to be so.

(*e*) Move back the Čerenkov counter to the *right* angle ϑ_γ for the scattered photons. These photons are now correlated with those recoiling protons emitted at ϑ_p and falling in the momentum interval selected as indicated in (*d*).

At all photon energies the new angle ϑ_γ is $\approx 20°$ larger than ϑ_0. Here the counting rate is mostly ($\gtrsim 90\%$) due to Compton-scattering.

(*f*) Move the Čerenkov counter at a new angle $\vartheta_1 = \vartheta_\gamma + 20°$. Again the counting should be negligible and it was so.

(*g*) Repeat all operations.

3. Because of the fairly low counting rate (on an average one count in 10 minutes) the experiment took a large machine time. Thus far only a pretty good set of measurements at several photon energies for c.m. angle of $\approx 90°$ has been obtained. The results are plotted in fig. 7. On the abscissae the *effective* photon-curves are also indicated. They are normalized to the same maximum height. They are the product of the photon spectrum for the efficiency of several (for a total of 22) sections of the liquid hydrogen target. Each section was small enough to consider constant for it :

i) the angular and the momentum shift due to the lateral shift of the section itself.

ii) the thickness of hydrogen to be traversed by the recoiling protons before getting out of the target.

Thus each section had well defined minimum and maximum angles (and proton energies) allowed by the magnet.

In fig. 7 the cross-section σ is expressed using σ_0 as unit.

The quick rise of σ beyond the photo pion threshold is remarkable but was somewhat expected. Actually, with the use of dispersion relations (which are certainly

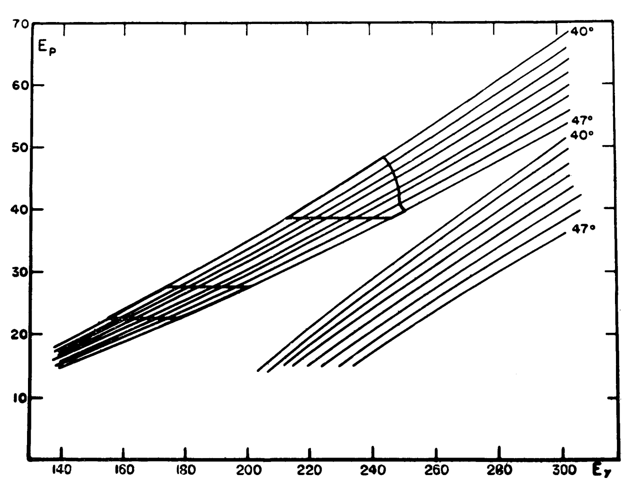

Fig. 6. See text for explanation.

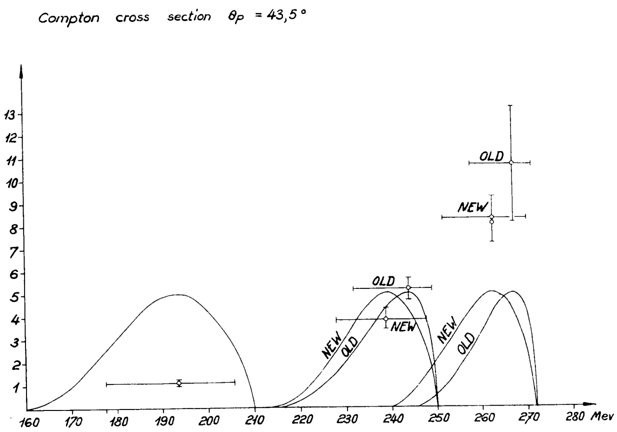

Fig. 7. Cross-section for photon-proton scattering at 90 °c.m. versus laboratory photon energy. The unit is 1.57×10^{-32} cm^2.

valid for zero mass particle) Gell-Mann, Goldberger and Thirring [3] predicted an energy dependence for total cross-section σ_T exactly of the type found experimentally for the differential cross-section $\sigma_{90°}$ c.m. On the energy range here investigated the two cross-sections are expected to be proportional. The quick rise is due to the excited nucleon structure, i.e. mainly to the α_{33} pion-nucleon state. A less complete, but simpler prediction in the same sense has been given by Yamaguchi [4] on the basis of the Chew and Low theory. Yamaguchi considers two cases:

i) all pion-nucleon "dynamical" states give a negligible amplitude except the α_{33} state. He considers then only the Thomson amplitude and the 33 part of the magnetic dipole;

ii) the same as before but subtracting *its Born value* and adding the contribution of the static *magnetic* scattering.

The differences between the two cases are mainly in the angular distribution and in the derivative $d\sigma/d\nu$, but at present the accuracy of data is too low to risk any definite conclusion. Of course since α_{33} dominates Yamaguchi's results are more or less equivalent to those of Gell-Mann et al. because in the dispersion relations the absorption cross-section has been considered to be almost exclusively the cross-section for pion production.

The angular distribution will provide very accurate information about the poles involved. At present only the photon backward angle $\vartheta = 130_{c.m.}$ has been investigated at 250 and 210 Mev. The following values have been found:

E_γ	$\simeq 240$	$\simeq 195$
σ_{130}	6.9	1.8

These figures, if any, will show a forward-backward asymmetry much smaller then that due to the interference of the Thomson and α_{33} amplitudes only.

LIST OF REFERENCES

1. Nicolai V. O. Mylar-walled liquid hydrogen target. Rev. sci. Instrum., *26*, p. 1203, 1955.
2. Filosofo, I. and Yamagata, T. A large Čerenkov counter for the detection of high energy photons and electrons. See p. 85.
3. Gell-Mann, Goldberger, M. L. and Thirring, W. E. Use of causality conditions in quantum theory. Phys. Rev., *95*, p. 1612-27, 1954.
4. Yamaguchi, Y. University of Illinois, 1955. (private communication.)