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G. Barbiellini, G. Bologna, J. De Wire, G. Diambrini, G. P. Murtas, G. Sette: PHOTOPRODUCTION OF π^0 MESONS IN HYDROGEN FROM QUASI-MONOCHROMATIC AND LINEARLY POLARIZED PHOTONS AT THE FIRST RESONANCE.

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PHOTOPRODUCTION OF π^{o} -MESONS IN HYDROGEN FROM QUASI-MONOCHROMATIC AND LINEARLY POLARIZED PHOTONS AT THE FIRST RESONANCE

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Linearly polarized bremsstrahlung has been already used by Drickey and Mozley[1] to study π^{o} photoproduction at low energy. They used a small cone of the γ-ray beam of the Stanford linear accelerator from an ordinary radiator.

We used for the same purpose the coherent bremsstrahlung beam[2,3] of the Frascati 1 GeV electronsynchrotron, obtained by using diamong single crystal as a radiator. This beam has two essential advantages with respect to an ordinary one: first of all, its energy spectrum is "quasi monochromatic", i.e., there are some peaks which are movable along the spectrum by changing the angle θ between the electron beam and a crystal axis. Thus one can fix the position of a peak so as to obtain the largest number of useful photons in the required energy range. Further one of the peaks is strongly linearly polarized over the whole bremsstrahlung cone. Plots of the calculated energy spectrum and its polarization togheter with experimental results were already published[2,3].

Fig. 1 shows up-to-date results for diamond at room temperature. The abscissa is the fractional energy $x = k/E_1$ of the photons with respect to the primary electrons. The lower curve represents, in arbitrary units, the calculated bremsstrahlung intensity $I(x, \theta)$, i.e., a quantity which is proportional to the number kn(k), where n(k)dk is the number of photons of the entire bremsstrahlung cone, whose energy is between k and k + dk. The upper curve represents the polarization

$$P(x, \theta) = \frac{N_t - N_p}{N_t + N_p} \quad ; \qquad (1)$$

N_t and N_p are the number of photons of the entire beam with polarization perpendicular and parallel, respectively, to the plane determined by the momentum $\vec{p}_1$ of the incoming electron and the crystal axis [110]. The angle between $\vec{p}_1$ and the axis [110] is $\theta = 1^{o}10'$. The axis [001] is supposed to be in the plane determined by $\vec{p}_1$ and [110] . The electron energy is 1000 MeV. The two curves are corrected for the finite energy resolution of the pair spectrometer used to measure the spectrum[2], and for the dependence on k of the pair production cross section in the pair converter. No correction was made for the multiple scattering of the electrons in the diamond radiator (which is a slab 2 mm thick, cut perpindicular to the axis [110]), nor for the finite collimation of the γ-ray beam and for the finite size and angular divergence of the electron beam.

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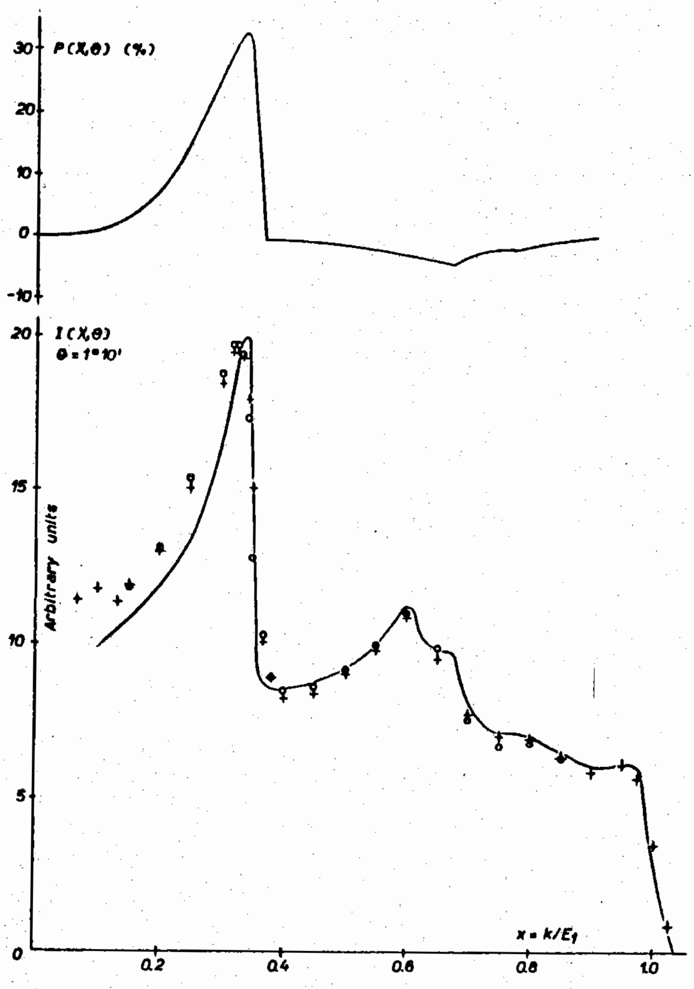

FIG. 1

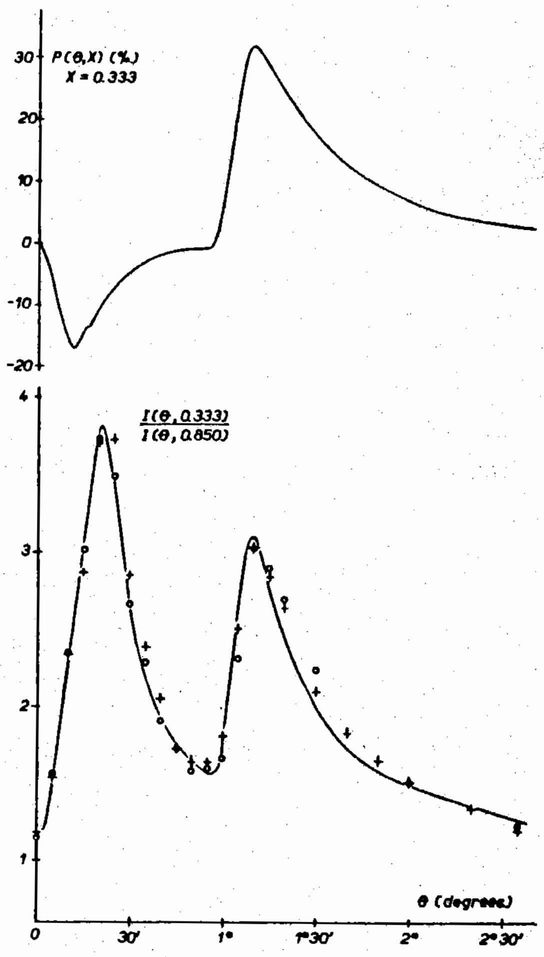

FIG. 2

FIG. 1 - Coherent bremsstrahlung intensity I(x, θ) and its polarization P(x, θ) as a function of the fractional energy $x = k/E_1$ of the photons. The diamond crystal is at room temperature, with the axis [110] at the angle $\theta = 1^o 10'$ with respect to the direction of the primary electron. The axis [001] lies in the plane determined by the primary electron and the axis [110]. The electron energy is $E_1 = 1000$ MeV. The lower curve gives, in arbitrary units, the calculated bremsstrahlung intensity I(x, θ), which is proportional to kn(k), n(k)dk being the number of photons of energy spread dk at k. The upper curve gives the polarization P(x, θ). The curves are corrected for the pair spectrometer resolution and for the variation of the pair production cross section in the converter. The crosses and the circles represent the experimental results, obtained with the plane of the axes [110] and [001] horizontal and vertical, respectively. The γ-ray beam collimation was 1. 5 mrad. The statistical error is of the order of the size of the crosses and circles.

FIG. 2 - Same conditions as in Fig. 1. The abscissa is the angle θ, between the electron direction and the crystal axis [110]. The lower curve represents the ratio of the bremsstrahlung intensities at x=0. 333 and x=0. 850. The upper curve represent the polarization for x=0. 333. The curves are corrected for the pair spectrometer energy resolution, for variation of pair production cross section in the pair converter, for multiple scattering in the diamond radiator, and for the finite collimation of the γ-ray beam. The crosses and the circles represent the experimental results obtained with the plane of the axes [110] and [001] horizontal (the polarization is vertical) and vertical (the polarization is horizontal) respectively. The collimation of the γ-ray beam is 1. 5 mrad.

The crosses and the circles in Fig. 1 represent, in arbitrary units, the measured number of electron pairs per constant number of monitor units, obtained with the plane of the axes [110] and [001] horizontal and vertical, respectively. The γ-ray beam collimation was 1.5 mrad. The statistical error is of the order of the size of the crosses and circles.

In Fig. 2 the lower curve represents the ratio $I(\theta, 0.333)/I(\theta, 0.850)$ of the bremsstrahlung intensities at $x = 0.333$ and $x = 0.850$, as a function of $\theta = \sphericalangle(\vec{p}_1, [110])$, the axis [001] being in the plane of $\vec{p}_1$ and [110]. The upper curve represent the polarization for $x = 0.333$. These curves include the correction for the pair spectrometer energy resolution (which is triangular, with the base equal to $\Delta k = 5 \cdot 10^{-2} k$), for the variation of the pair production cross section and, in a provisional way, for the multiple scattering of the electrons in the diamond and for the finite collimation of the γ-ray beam.

The crosses and the circles represent the experimental results obtained with the plane of the axes [110] and [001] horizontal and vertical respectively. In the former case we change θ by rotating the crystal around a vertical axis, in the latter case we rotate it around a horizontal axis. In these two measurements only the direction of the polarization is changed and is vertical or horizontal respectively. The measurements were made with a γ-ray beam collimation of 1.5 mrad. The statistical error is of the order of the size of the crosses and circles.

These and other measurements have to be done before using the γ-ray beam in the π^o experiment, in order to verify the proper positioning of the crystal.

Consider now the process

$$\gamma + p \rightarrow \pi^o + p$$

from linearly polarized photons. As is well known, in the region of the first resonance and below, where presumably only S and P waves contribute, the differential cross section per unit solid angle in the center-of-mass system can be written

$$\frac{d\sigma}{d\Omega^*} = A + B\cos\theta^* + C\cos^2\theta^* + \alpha\,\mathrm{sen}^2\theta^*\cos 2\varphi\,, \qquad (2)$$

where θ^* is the center-of-mass emission angle of the π^o, and φ is the angle between the polarization plane (i.e., the plane determined by the direction of the incoming photon and the direction of its polarization) and the production plane (i.e., the plane determined by the photon and the emitted pion). A, B, C, α are dependent on the photon energy, and are obtainable from the C.G.L.N. theory[4]. In the range of validity of this theory one obtains $\alpha = C$[1].

Our measurements consist in the determination of the number of neutral pions produced in liquid hydrogen at $\theta^* = 90^o$, from photons having polarization both perpendicular and parallel to the emission plane. The nominal energy of the photons is fixed at 325 MeV. In these conditions the π^o is emitted in the laboratory system at 73^o and the proton at 40.5^o, with a kinetic energy of 61 MeV.

The detection apparatus is completely conventional and is sketched in Fig. 3. It consists of a range telescope T (which includes the scintillators S_1, S_2, S_3 and the aluminium absorbers A_1, A_2, A_3 and the wedge - shaped one), an integral Cerenkov counter C for the detection of the π^o decay photons and a scintillator A, set in front of C, in order to discriminate against charged particles traversing C. In the actual arrangement the nominal production plane of the π^o is horizontal. The angle of acceptance of the telescope is $\pm 2.5^o$ both horizontally and vertically. The range of the protons (including liquid hydrogen target thickness) is equivalent to 3.8 ± 0.6 gr/cm^2 of aluminium. By making use of the wedge - shaped absorber, the kinematics of the process is so arranged that the photon energy resolution is approximately rectangular, with a width of $\pm$ 15 MeV. The acceptance angle of the Cerenkov counter is $\pm 14^o$ and its efficiency is about 25%.

A telescope event is defined by the anticoincidence

$$T = (S_1 + S_2) - (S_1 + S_2 + S_3)$$

where $S_1 + S_2$ and $S_1 + S_2 + S_3$ are coincidences among the telescope scintillators. This anticoincidence has a resolving time of 6 nsec. Further we consider the anticoincidence

$$Q = (T + C) - (T + C + A),$$

where T+C and T + C + A are coincidences between the telescope T and the Cerenkov counter C, and among T, C and the scintillator A, respectively. The anticoincidence Q opens a linear gate circuit through which the pulses coming from the scintillator S_1 are passed. The pulses coming from the gate circuit are sent to a 200 - channel pulse height analyzer, by means of which we discriminate between protons and other charged particles by a dE/dx method. The protons detected in this way represent the π^0 photoproduction events.

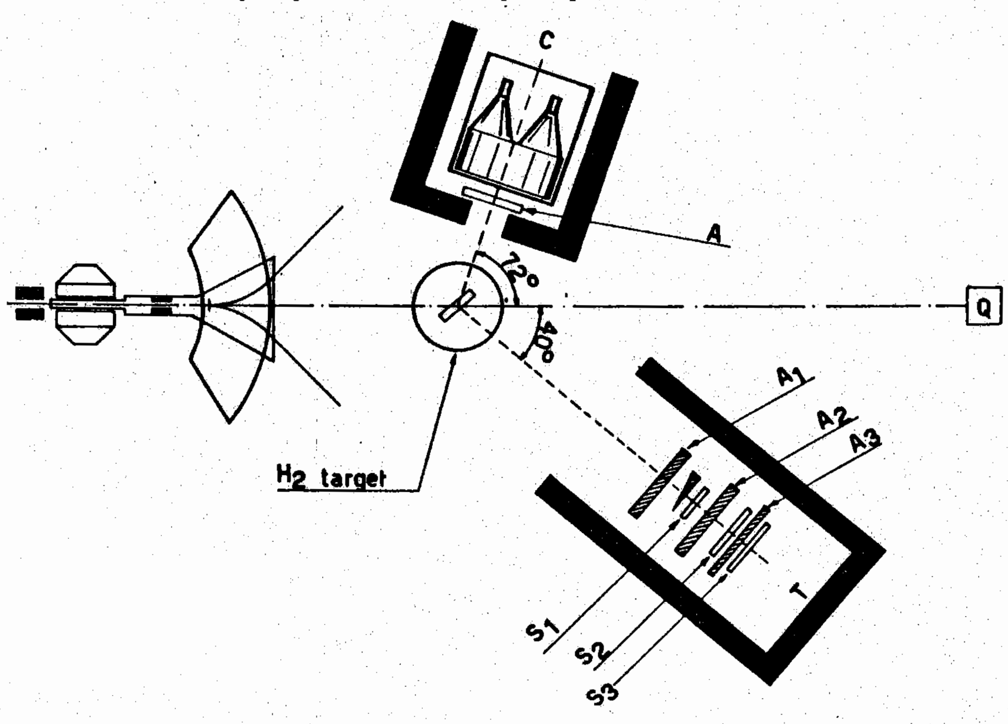

FIG. 3 - Sketch of the experimental apparatus.

Two sets of measurements were performed, corresponding to the two chosen directions of the polarization (horizontal and vertical) previously described. In each set the number of π^0 mesons was measured as a function of the angle θ between the electron beam and the axis [110]. By changing θ the photon peak is allowed to move along the spectrum (its height decreases by increasing θ). In this way one obtains a result similar to an excitation curve for the π^0's.

We define the counting rates

$$Y_{\parallel} = \frac{N_{\parallel}^{(p)}}{N_0} , \quad Y_{\perp} = \frac{N_{\perp}^{(p)}}{N_0} ,$$

where $N_{\parallel}^{(p)}$ and $N_{\perp}^{(p)}$ are the number of π^0 mesons produced from photons having polarization parallel and perpendicular to the (horizontal) production plane, respectively. N_0 is the number of 850 MeV photons, measured simultaneously with $N_{\parallel}^{(p)}$ or $N_{\perp}^{(p)}$ by means of the pair spectrometer (see on the left of Fig. 3). At an incident electron energy of 1000 MeV the coherence effect is small for 850 MeV photons, making N_0 nearly independent of θ. Thus N_0 is a suitable monitor.

The counting rates are given by

$$Y_{\parallel} = \varrho \frac{N}{N_0} \frac{d\sigma_0}{d\Omega} \left[1 - \frac{1}{2} RP\right]$$
$$Y_{\perp} = \varrho \frac{N}{N_0} \frac{d\sigma_0}{d\Omega} \left[1 + \frac{1}{2} RP\right] \qquad (3)$$

where ϱ is a constant; $N = N_t + N_p$ is the number of photons giving rise to the reaction; N_0

was already defined; P is the polarization of the photons, given by equation (1); $d\sigma_0/d\Omega$ is the π^0 photoproduction cross section from unpolarized photons per unit solid angle in the laboratory system, i.e.,

$$\frac{d\sigma_0}{d\Omega} = \frac{1}{2}\left[\frac{d\sigma_\parallel}{d\Omega^*} + \frac{d\sigma_\perp}{d\Omega^*}\right]\frac{d\Omega^*}{d\Omega} ,$$

where $d\sigma_\parallel/d\Omega^*$ and $d\sigma_\perp/d\Omega^*$ are the differential cross sections per unit solid angle in the center-of-mass system for π^0 emitted in the plane parallel and perpendicular to the photon polarization and given by equation (2) for $\varphi = 0$ or $\varphi = 90^o$, respectively. Finally in equations (3) we have

$$R = \frac{d\sigma_\perp - d\sigma_\parallel}{d\sigma_0} .$$

As we already said, we have chosen $\theta^* = 90^o$; thus we obtain from equation (2)

$$\frac{d\sigma_0}{d\Omega^*} = A; \quad R = -\frac{2\alpha}{A} .$$

We assumed $\alpha = C$ and evaluated A and C from C.G.L.N. theory. For instance, at k = 325 MeV we obtained[5] A = 26.6 barn/sterad and C = -15.7 barn/sterad. Further we evaluated the quantities N, N_o and P as a function of the angle θ between the γ-ray beam and the crystal axis [110] in our experimental conditions, which are: E_1 = 1000 MeV for the electron energy; k = 325 MeV for the photon energy; k_o = 850 MeV for the monitor photon energy; direction of the electron beam parallel to the crystal axes [110] [001] . N_o, N and P are corrected, in a provisional way, for the multiple scattering of the electrons in the diamond radiator and for the finite collimation of the γ-ray beam. In the calculation of the counting rates, we integrated equations (3) over the rectangular photon energy acceptance in order to correct for the finite photon energy resolution.

In Fig. 4 the results are shown. The continuous and the dashed curves represent, in arbitrary units, respectively $Y_\perp$ and $Y_\parallel$, as given by equations (3). The two curves are coincident in the neighborhood of $\theta = 50'$ and at large θ, where the polarization is nearly vanishing. In the last peak ($\theta = 1^o07'$) $Y_\parallel$ is lower than $Y_\perp$; the contrary happens for the first peak as the polarization reverses its sign (see Fig. 2). The experimental values of $Y_\perp$ and $Y_\parallel$ are given by the crosses and the circles, respectively, and were obtained with a collimation of 1.5 mrad. The errors quoted are statistical. A systematic error comes from double π^0 photoproduction, as the photon energy goes up to 1000 MeV, and from proton Compton effect; presumably these contributions amount only to several percent.

The measurements with the highest statistics were made at $\theta = 1^o10'$, where the polarization has about the largest value. The reason is that the statistical percentage error in the determination of $d\sigma_\perp/d\sigma_\parallel$ is inversely proportional to the product of the polarization and the photon beam intensity. At $\theta = 1^o10'$ we obtained[6]

$$\frac{Y_\perp}{Y_\parallel} = 1.37 \pm 0.01 \qquad \text{(Experimental)}$$

$$P = 30.6\% \qquad \text{(Calculated)}$$

Thus we have, for $\theta^* = 90^o$

$$\frac{\alpha}{A} = \frac{1-(d\sigma_\perp/d\sigma_\parallel)}{1+(d\sigma_\perp/d\sigma_\parallel)} = \frac{1}{P}\,\frac{1-(Y_\perp/Y_\parallel)}{1+(Y_\perp/Y_\parallel)} = -0.51 \pm 0.01$$

The value of this ratio, on the basis of the C.G.L.N. theory, is 3.88. Further we obtain

$$\frac{d\sigma_\perp}{d\sigma_\parallel} = \frac{A-\alpha}{A+\alpha} = \frac{[(1+P)/(1-P)]\,(Y_\perp/Y_\parallel)-1}{[(1+P)/(1-P)]-(Y_\perp/Y_\parallel)} = 3.1 \pm 0.1$$

Let us now consider the values of the coefficients A and C, obtained in other experiments by using unpolarized photons. At the first resonance (for an energy k = 320 MeV, slightly different from ours) the data by Berkelman and Waggoner[7] and the more recent ones by Highland

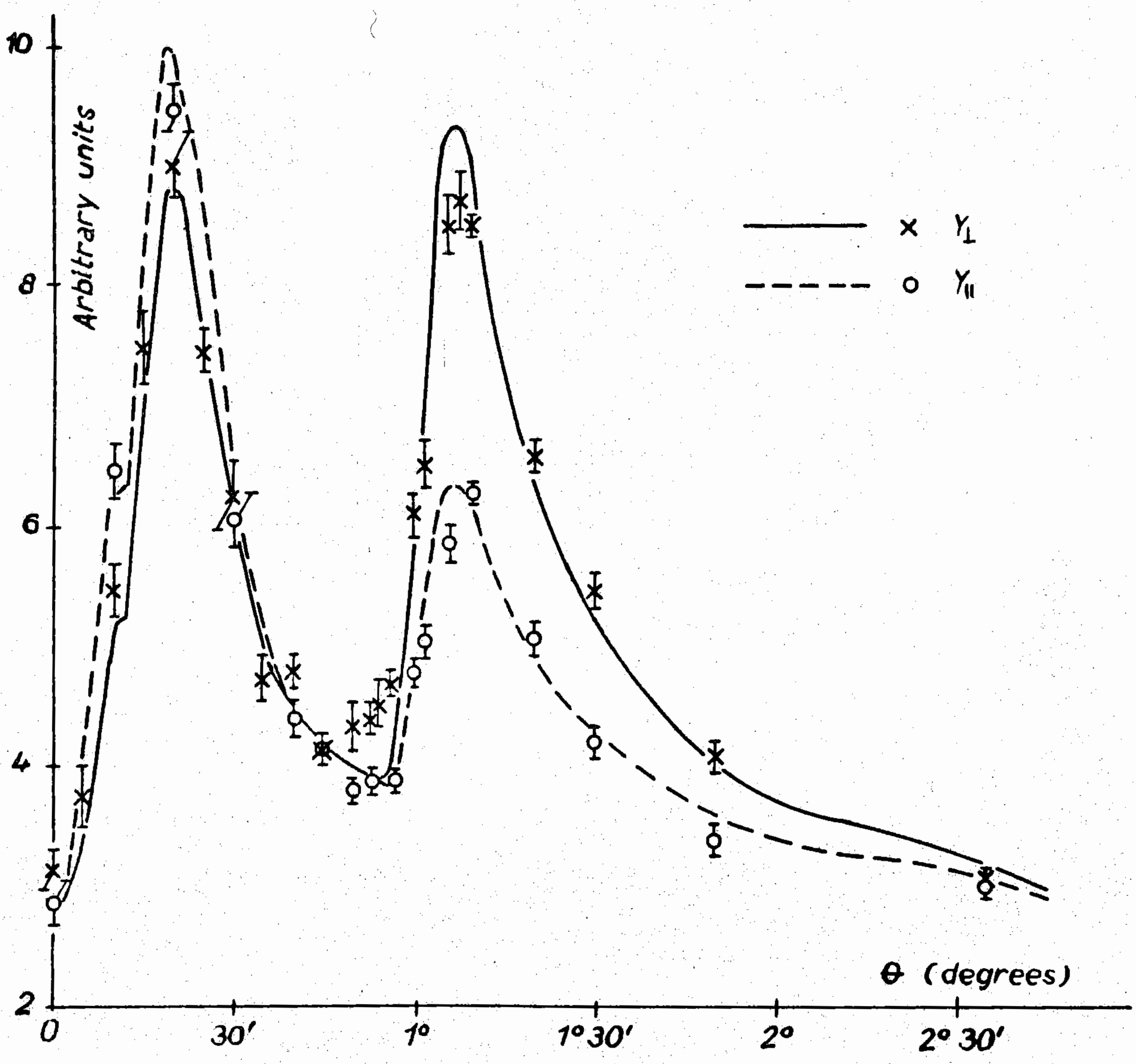

FIG. 4 - The abscissa is the angle θ in degrees. The ordinate is the π^0 counting rate. The continuous and the dashed curve represent, in arbitrary units, $Y_\perp$ and $Y_\parallel$, respectively, as given by equations (3), and corrected for the finite photon energy resolution. The points and the crosses represent the experimental values of $Y_\perp$ and $Y_\parallel$ respectively, obtained with a collimation of 1.5 mrad. All these data are relative to π^0 mesons emitted at $\theta^* = 90^o$ in the center-of-mass system and produced from 325 MeV photons.

and De Wire[8] are available. From these data one obtains

$$\frac{A}{C} = -1.65 \pm 0.10.$$

Then we obtain the very important quantity

$$\frac{\alpha}{C} = \frac{\alpha}{A} \cdot \frac{A}{C} = 0.84 \pm 0.06. \quad (4)$$

The error quoted in equation (4) is statistical. A systematic error arise from the preliminary way by which we calculated the polarization and from the contribution of double π^0 photoproduction and proton Compton effect. Measurements and calculations concerning the determination of these contributions are in progress.

Our preliminary result for α/C is in agreement with the measurement of Drickey and Mozley[1], but is in disagreement with the value expected from the dispersion theory of C.G.L.N., which, considering only S and P waves, predicts $\alpha/C = 1$. But this conclusion is not definitive at this stage of the experiment.

We are planing to do measurements also at lower energies, because a precise determination of α/C in this region is possible owing to the large value of the polarization. Also it is hoped that this low energy measurement will give information on the π-π interaction.

REFERENCES

(1) - D.J. Drickey and R.F. Mozley, Phys. Rev. Letters 8, 291 (1962)
(2) - G. Barbiellini, G. Bologna, G. Diambrini and G.P. Murtas, Phys. Rev. Letters 8, 454 (1962).
(3) - G. Barbiellini, G. Bologna, G. Diambrini and G.P. Murtas, Phys. Rev. Letters 9, 396 (1962).
(4) - G.F. Chew, M.L. Goldberger, E.F. Low and Y. Nambu, Phys. Rev. 106, 134 (1957).
(5) - J. De Wire, Laboratori Nazionali di Frascati, Internal Report LNF-61/39 (1961) (unpublished).
(6) - These and the following data differ from those presented at the conference, and represent an improovement obtained in a subsequent time.
(7) - K. Berkelman and J.A. Waggoner, Phys. Rev. 117, 1364 (1960).
(8) - V.L. Highland and J. De Wire (to be published).