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Nota interna: n. 230

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G. Barbiellini, G. Bologna, J. De Wire[(x)], G. Diambrini, G. P. Murtas and G. Sette: PHOTOPRODUCTION OF π°-MESONS IN HYDROGEN FROM QUASI-MONOCHROMATIC AND LINEARLY POLARIZED PHOTONS AT THE FIRST RESONANCE.

(Work presented at the Sienna International Conference on Elementary Particles, 30 September, 1963)

Linearly polarised bremsstrahlung has been already used by Drickey and Mozley[(1)] to study π° photoproduction at low energy. They used a small cone of the γ-ray beam of the Stanford linear accelerator from a normal radiator.

We used for the same purpose the coherent bremsstrahlung beam[(2,3)] of the Frascati 1-GeV electronsynchrotron, obtained by using a diamond single crystal as a radiator.

This beam has two essential advantages with respect to a normal one: first of all, its energy spectrum is "quasi-monochromatic", i.e., there are some peaks 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 in an energy region at which a larger number of photons is useful.

Further one of the peaks is strongly linearly polarized over the whole bremsstrahlung cone. Plots of the theoretical spectrum and of its polarization, together with experimental results, were already published[(1,2)].

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In fig. 1 are represented up-to-date results for diamond at room temperature. In abscissa the fractional energy $x = k/E_1$ of the photon with respect to the electron is given. The continuous curve in the lower part of the figure represents, in arbitrary units the theoretical 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 whose energy is between k and $k+dk$, in the entire bremsstrahlung cone. The crystal is supposed to be infinitely thin.

In the upper part of fig. 1 the polarization

$$P = \frac{N_t - N_r}{N_t + N_r}$$

is represented; N_t and N_r 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 $\theta = 1°9'$ and is chosen in such a way to locate the position of the highest peak at $k = 330$ MeV for a $E_1 = 1$ GeV electron beam. The axis [001] is supposed to be parallel to the plane determined by $\vec{p}_1$ and [110]; this arrangment gives the largest polarization compatibly with the simplest experimental situation. The dashed curve in fig. 1 represents in arbitrary units the energy spectrum as corrected for the energy resolution of the pair spectrometer by means of which the spectrum was measured(2), and for the dependence on k of the pair production cross section in the pair converter.

No correction for the multiple scattering in the actual diamond radiator (which is a slab 2 mm thick, cut perpendicular to the axis [110]), nor for the collimation effect of the γ-ray beam and for the electron beam was made. Also the effect of the atomic electrons is not included.

The points in fig. 1 represent the experimental results, obtained with a γ-ray beam collimation of 1 mrad; they are normalized to the dashed curve at $x = 0.850$. The statistical error is less than the size of the points.

In fig. 2 the continuous curve represents the ratio $I(\theta, 0.850)$ of the bremsstrahlung intensities at $x = 0.325$ and $x = 0.850$, as a function of $\theta = \sphericalangle \vec{p}_1, [110]$, in the preceding conditions. This ratio includes the correction for the pair spectrometer energy resulution (which is triangular, with the base equal to $\Delta k = 5 \times 10^{-2}$ 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 γ-ray beam collimation effect.

The crosses and the dots represents the experimental results, relative to measurements performed with the plane of the axes [110], [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 mrad.

The statistical error is of the order of the size of the experimental points.

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 polarized photons. As is well known(1), 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 can be written in the form

$$(1) \qquad \frac{d\sigma}{d\Omega} = A + B\cos\theta^* + C\cos^2\theta^* + \alpha\,\mathrm{sen}^2\theta^*\cos 2\psi ,$$

where θ^* is the center-of-mass-emission angle of the π^o, ψ 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 independent of θ^*.

Now, the use of polarized photons allows the ratio of some coefficients in equation (1) to be determined without making any absolute measurement.

Our measurement consists in the determination of the numbers of neutral pions produced in liquid hydrogen at $\theta^{*} = 90°$, from photons having polarization perpendicular and parallel to the emission plane.

In the actual set of measurements the nominal energy of the photons is fixed at 330 MeV. In these conditions the $\pi°$ is emitted in the laboratory system at 73° and the proton at 40.5° 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 (scintillators S_1 S_2 S_3 and aluminum absorbers A_1 A_2 A_3) for the detection of the recoil proton, an integral Cerenkov counter C for the detection of the $\pi°$ 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 production plane of the $\pi°$ is horizontal.

The angle of acceptance of the telescope is ± 1.5° both horizontal and vertically. The range of the protons including the target is 3.8 ± 0.8 gr/cm² of aluminum. The acceptance angle of the Cerenkov counter is ± 14° and its efficiency is about 25%.

A telescope event T is defined by the anticoincidence

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

where S_1 + S. and $S_1 + S_2 + S_3$ are coincidences among the telesc cintillators. The anticoincidence has a resolving of 6 nsec.

er we consider the anticoincidence

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

where T + C and T + C + A are coincidence 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 telescope 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 charged pions by a dE/dx method. The protons measured in this way represent the $\pi°$ photoproduction events. By making use of a wedge-shaped absorber in the telescope, the kinematics of the process is so arranged that the photon energy resolution is approximately rectangular, with a width of $\pm$ 20 MeV.

The measurements are performed placing the diamond radiator in the positions previously described and changing the angle θ. Hence the photon peak is allowed to move along the spectrum (its height increases decreasing θ). In this way one is expected to obtain a result similar to an excitation curve; further we are able to energy-calibrate our telescope, as we shall show.

In fig. 4 some preliminary results are given. The abscissa is the angle θ between the electron beam and the crystal axis [110]. The axis [001] is always parallel to this plane. The continuous and the dashed curve in the lower part of the fig. represent, in arbitrary units, $C_\perp$ and $C_\parallel$, the counting rates of π^0 mesons from photons having polarization perpendicular and parallel, to the horizontal production plane, respectively. It results

$$(1) \qquad C_\perp = \rho \bar{N} \frac{d\sigma}{d\Omega} \left[1 + \frac{1}{2} R \bar{P} \right]$$

$$C_\parallel = \rho \bar{N} \frac{d\sigma}{d\Omega} \left[1 - \frac{1}{2} R \bar{P} \right]$$

where

$$d\sigma = \frac{d\sigma_\parallel - d\sigma_\perp}{2},$$

$$R = \frac{d\sigma_\perp - d\sigma_\parallel}{d\sigma};$$

$d\sigma_\perp$ and $\sigma_\parallel$ are the differential cross section for π^0 emitted in the plane perpendicular and parallel to the photon polarization, respectively. $\bar{N}$ and $\bar{P}$ are the number of photons and their polarization, respectively, averaged over the $\pm$ 20 - MeV energy resolution at 330 MeV. $\bar{N}$ (in arbitrary units) and $\bar{P}$ are represented in the upper part of fig. 4. These quantities were calculated from curves similar to those of fig. 1, taking also into account in a provisional way the multiple scattering in the diamond radiator and the effect of collimation, which was 1 mrad.

Obviously the behaviour of $C_\perp$, $C_\parallel$ is the same as $\bar{N}$, as follows from equations (1).

In the last peak (θ = 1°09') $C_\parallel$ is lower than $C_\perp$;

the contrary happens for the other peaks, because the polarization reverses its sign, as can be seen from fig. 4.

In $C_{\perp}$ and $C_{\parallel}$ we assumed $d\sigma_{\perp}/d\sigma_{\parallel} = 3.5$.

The experimental values of $C_{\perp}$ and $C_{\parallel}$ are given by the points and the crosses respectively. They were obtained by measuring as a function of θ the number of π^{o} events per constant number of 850 - MeV photons. This quantity is nearly independent of θ (at 850 MeV the coherence effect as negligible); thus it represents a suitable monitor.

The measurement of C was obtained placing the plane of the crystal axes [110] and [001] horizontal, and moving it around vertical axis of rotation, in which case the polarization is vertical, i.e., it is perpendicular to the π^{o} production plane. The measurement of $C_{\parallel}$ was obtained by rotating the crystal slab of 90° in its plane in which case the polarization is parallel to the π^{o} photoproduction plane .

The experimental points were normalized making the experimental value of $C_{\parallel}$ coincident with the proper curve at 1°9'. For $C_{\perp}$ the same normalization factor was used. Notwithstanding the experimental values of $C_{\perp}$ and $C_{\parallel}$ are coincident at $\theta = 2°35'$, were $P \simeq 0$, thus giving an internal check of the selfconsistency of the method.

The errors drawn in fig. 4 are statistical. The sistematic error due to the incertitude in the discrimination of charged pions in the proton telescope is not included and is of the order of the statistical error. Measurements with a very much better discrimination are in progress.

The contribution of double pion photoproduction is not subtracted. In order to calibrate the energy of the experimental device we observe that the calculated values of $C_{\perp}$, $C_{\parallel}$ fit well enough the experimental points. The increasing of $C_{\parallel}$, $C_{\perp}$ begin at 57', where the highest peak of fig. 1 enters the photon energy region accepted by the experimental device. The decreasing begin at 1°8', where the peak comes out from that region. As we know with sufficient precision the correspondence between the angles θ and the energy of the peak, we may say that the central energy of the photons accepted by the apparatus is 330 $\pm$ 5 MeV and that its energy spread is $\pm$ (20 $\pm$ 2) MeV.

The measurements of $C_{\perp}$ and $C_{\parallel}$ were made at the highest statistics at $\theta = 1°09'$, were the polarization has about the largest value P = 34% (see fig. 4). In fact the statistical percentage error in the determination of $d\sigma_\perp / d\sigma_\parallel$ is inversely proportional to the product of the polarization by the photon beam intensity.

At $\theta = 109'$ we obtained,

$$C_\perp / C_\parallel = 1.46 \pm 0.03$$

Thus, for P = 34% we obtained

(2) $$\frac{d\sigma_\perp}{d\sigma_\parallel} = \frac{\frac{1+P}{1-P}\frac{C_\perp}{C_\parallel} - 1}{\frac{1+P}{1-P} - \frac{C_\perp}{C_\parallel}}$$

We keep now in mind that in our measurement the c.m. π^0 emission angle is $\theta^* = 90°$, and that for $d\sigma_\perp$, $\varphi = 90°$ and for $d\sigma_\parallel$, $\varphi = 0$. Hence

$$\frac{d\sigma_\perp}{d\sigma_\parallel} = \frac{A - \alpha}{A + \alpha}$$

and

(2) $$\frac{\alpha}{A} = \frac{1 - \frac{d\sigma_\perp}{d\sigma_\parallel}}{1 + \frac{d\sigma_\perp}{d\sigma_\parallel}} = \frac{1}{P}\frac{1 - \frac{C_\perp}{C_\parallel}}{1 + \frac{C_\perp}{C_\parallel}} = -0.55 \pm 0.03$$

Thus, as we already noticed the use of a polarized γ-ray beam has enabled is to determine the ratio of the coefficient α and C of equation (1), without making any absolute measurement. Let us now consider the values of the coefficients A,C, obtained in other experiments by using unpolarized photons. At the first resonance (for an energy k = = 320 MeV, slightly different than ours) the data by Berkelman and Waggoner[4] and the more recent ones by Higland and De Wire[5] are available. From these data one obtain

(3) $$A/C = -1.65 \pm 0.10.$$

Then we obtain the very important quantity

(4) $$\alpha/C = (\alpha/A) \cdot (A/C) = 0.91 \pm 0.07,$$

a result which is in agreement with Drickey and Mozley[1].

The errors quoted in equations (2), (3), (4) are purely statistical. Besides this we have some sistematic error due to the already explained incertitude in the discrimination of charged pions from protons in the telescope. Another source of sistematic error can be the way by which we take into account the influence of the experimental conditions on the value of the polarization. Finally the contribution of double pion photoproduction is to determine. All these source of errors and the way to eliminate them are considered in the measurements now in progress.

Our very preliminary results for α/C seems to be in agreement with the value expected from the dispersion theory of C.G.L.N[6], which, considering only S and P waves, predicts $\alpha/C = 1$. But this conclusion is not definitive at this stage of the experiment.

We have in mind to do measurements also at lower energies, because a precise determination of α/C in this region is possible owing to the high value of the polarization, and it is also wished, because it should give information on the $\pi - \pi$ 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) - K. Berkelman and J.A. Waggoner, Phys. Rev. 117, 1364 (1960).

(5) - V.L. Highland and J.W. De Wire, (to be published).

(6) - G.F. Chew, M.L. Goldberger, E.F. Low, and Y. Nambu, Phys. Rev. 106, 134 (1957).

FIGURE CAPTIONS.

FIG. 1 - Coherent Bremsstrahlung intensity I(x) and its polarization P(x) as a function of the fractional energy $x = k/E_1$ of the photons. Case of diamond crystal at room temperature, with the axis [110] at the angle $\theta = 1°9'$ with the direction of the primary electron. The axis 001 is in the plane of the primary electron and of the axis [110]. Electron energy E_1 = 1 GeV. In the lower part of the figure the continuous curve give the pure theoretical bremsstrahlung intensity (which is proportional to k n (k), with n (k) dk number of photons of energy spread k at k. The dashed curve represent the bremsstrahlung intensity as correct for the pair spectrometer resolution and for variation of pair production in the couverter. The experimental points were obtained with a 1 mrad collimation and are normalized to the curve at x = 0.9.

FIG. 2 - Same conditions as in fig. 2. The abscissa is the angle θ between the electron direction and the crystal axis [110]. The continuous curve represents the ratio of the bremsstrahlung intensities at x = 0.325 and x = 0.850. The curve is corrected for pair spectrometer energy resolution, for variation of pair production in the converter, for multiple scattering in the diamond radiator and for the collimation effect of the γ-ray beam. The crosses and the dots represent the experimental results obtained when the plane [110], [001] horizontal and vertical respectively.

FIG. 3 - Sketch of the experimental apparatus.

FIG. 4 - The ascissa is the angle θ. In the lower part are given the counting rates $C_{\parallel}$, $C_{\perp}$. The continuous and the dashed curve represent $C_{\perp}$ and $C_{\parallel}$, respectively, as given by equations (1). The points and the crosses represent the experimental values of $C_{\perp}$ and $C_{\parallel}$ respectively obtained with a collimation of 1 mrad. Normalization to the curve of $C_{\parallel}$ at 1°9' was made.

All these data are relative to photons of energy (230 ± 20) MeV.

In the upper part of the fig. are represented the number of photons $\overline{N}$ in arbitrary units and their polarization, $\overline{P}$ for the energy 230 MeV and averaged over the energy spread ± 20 MeV. Correction was made for the multiple scattering in the radiator and for the collimation effect.

The crystal conditions are the usual ones.

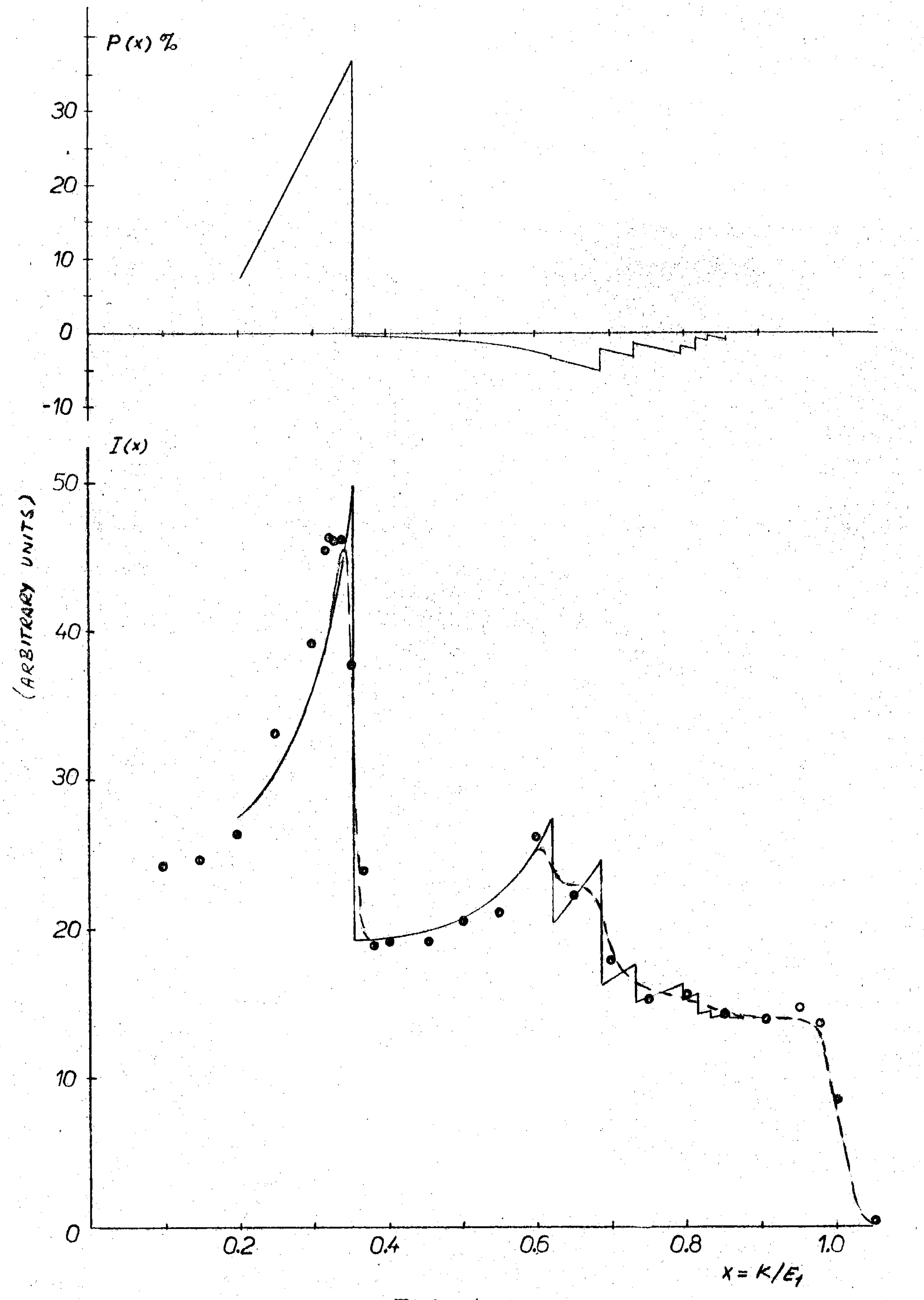
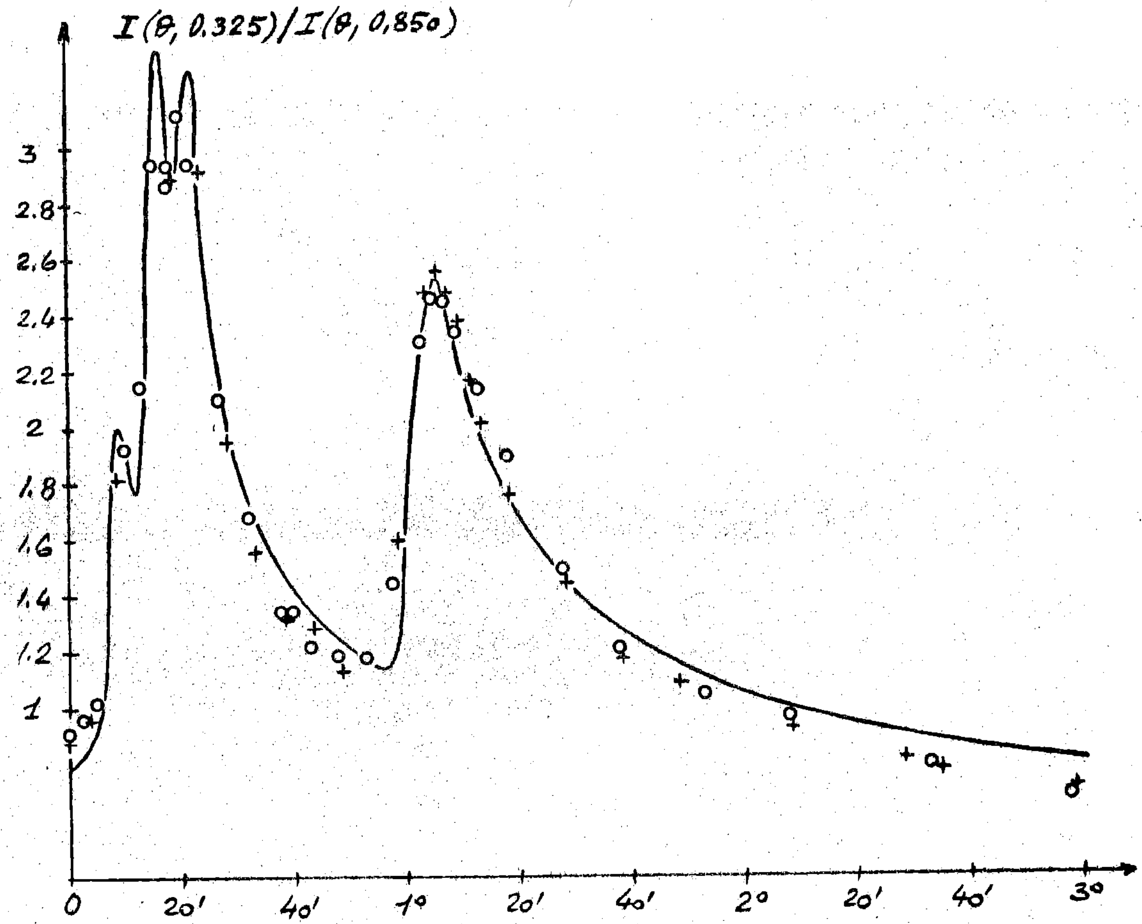
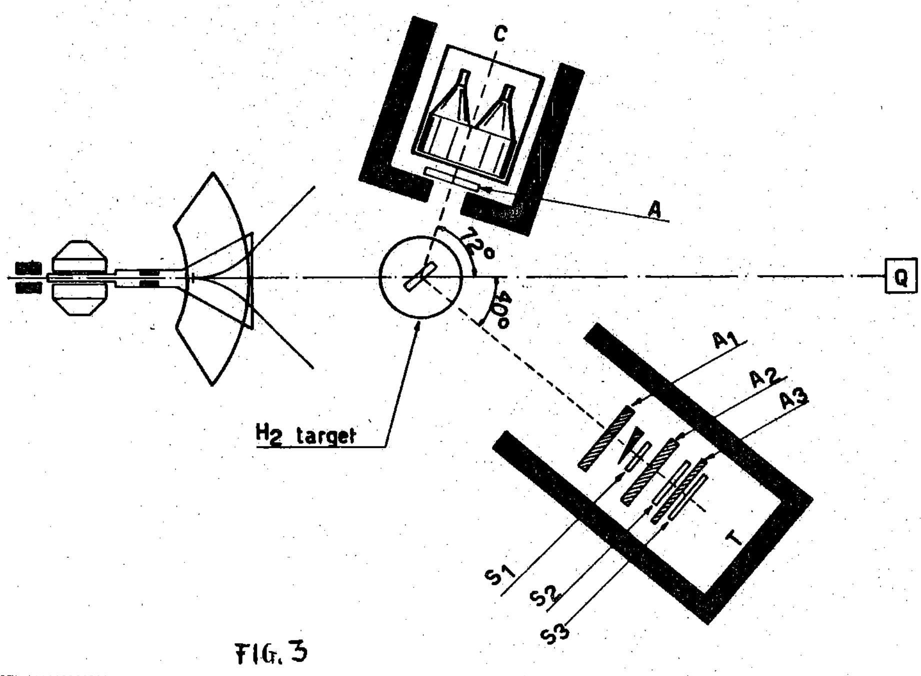

P(x) %
30
20
10
0
-10
I(x)
(ARBITRARY UNITS)
50
40
30
20
10
0
0.2
0.4
0.6
0.8
1.0
x = K/E1

FIG. 1



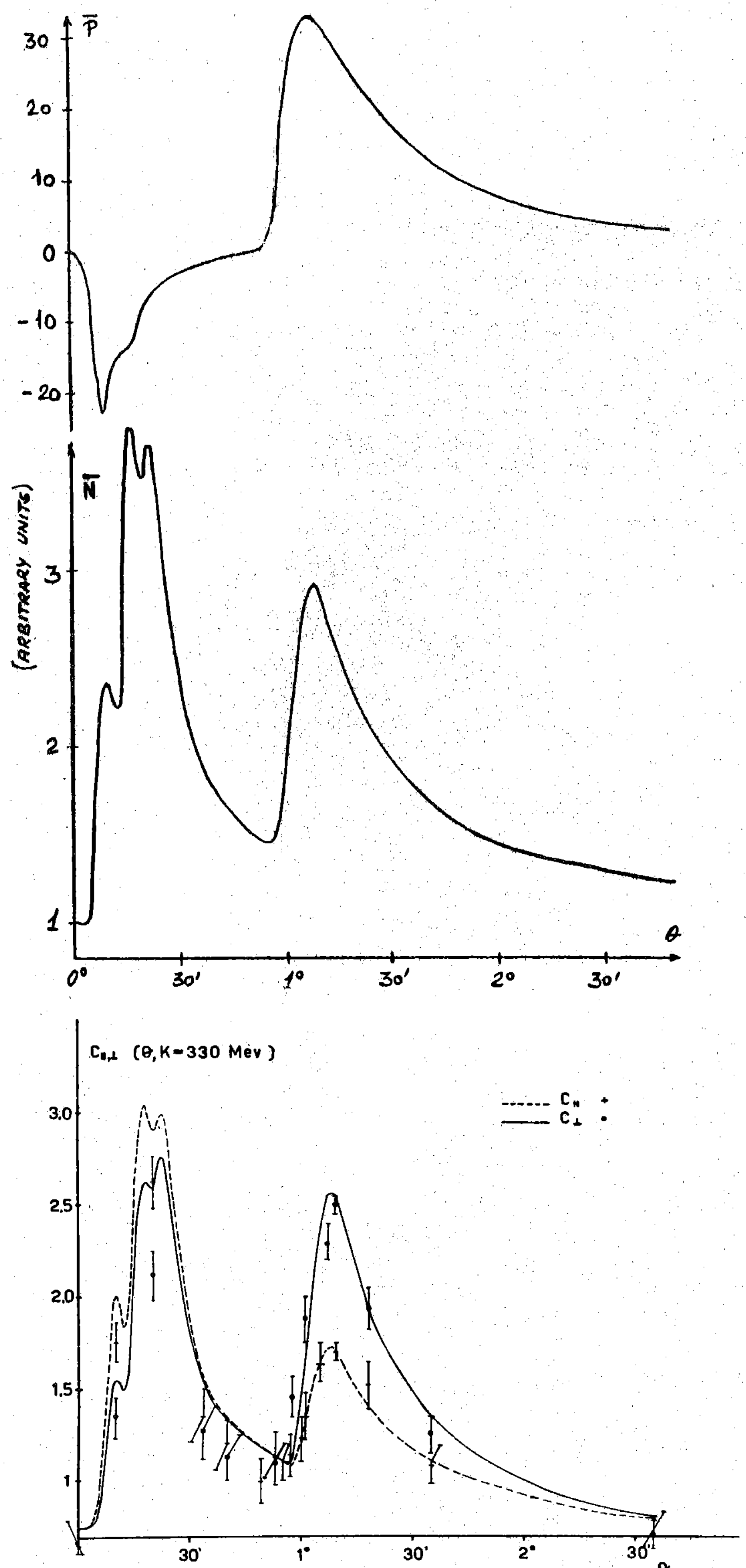
I(θ, 0.325)/I(θ, 0,850)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0
20'
40'
1°
20'
40'
2°
20'
40'
3°

FIG. 2



C
A
72°
40°
Q
A1
A2
A3
H2 target
T
S1
S2
S3

FIG. 3



P̄
30
20
10
0
-10
-20
N̄
(ARBITRARY UNITS)
3
2
1
θ
0°
30'
1°
30'
2°
30'
$C_{\parallel,\perp}$ (θ, K=330 Mev)
$C_{\parallel}$
$C_{\perp}$
3,0
2,5
2,0
1,5
1
30'
1°
30'
2°
30'
θ

FIG. 4