COMITATO NAZIONALE PER L'ENERGIA NUCLEARE
Laboratori Nazionali di Frascati

LNF - 67/18
21 Marzo 1967

M. Grilli, M. Nigro, E. Schiavuta, F. Soso, P. Spillantini and V. Valente : RECENT MEASUREMENTS OF π^+ PHOTOPRODUCTION WITH COHERENT BREMSSTRAHLUNG (E_γ = = 200-450 MeV). -

(Nota interna : n. 356)

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M. Grilli, M. Nigro(x), E. Schiavuta(x), F. Soso, P. Spillantini and V. Valente(x): RECENT MEASUREMENTS OF π^+ PHOTOPRODUCTION WITH COHERENT BREMSSTRAHLUNG (E_γ = 200-450 MeV)(o).

We have measured the asymmetry ratio

(1) $$A(\theta) = \frac{\sigma_\perp(\theta) - \sigma_\parallel(\theta)}{\sigma_\perp(\theta) + \sigma_\parallel(\theta)}$$

for the reaction

(2) $$\gamma + p = n + \pi^+$$

in the energy range E_γ = 200-450 MeV and for θ (production angle of π in the c. m. system) from 30^o to 145^o.

The quantities $\sigma_\perp(\sigma_\parallel)$ are defined as the differential cross sections for the process (2) by photons with the electric vector perpen dicular (parallel) to the π's production plane.

(x) - Istituto di Fisica dell'Università di Padova and INFN, Sezione di Padova.

(o) - Presented by M. Grilli at the International Conference on Electro magnetic Interactions at Low and Intermediate Energies, Dubna, February 7-15, 1967 (Revised version).

Events from the reaction (2) were identified by observing a selected momentum interval in a magnetic spectrometer, using conventional counter techniques to select the pions. The experimental method used for the measurements of $A(\theta)$ has been briefly described in [1,2] and more extensively reported in [3].

The source of linearly polarized γ-rays was the coherent bremsstrahlung beam of the Frascati synchrotron[4].

The results of our measurements for $A(\theta)$ are summarized in Fig. 1 (a, b, c, d, e)[x]. In this figure we report, separately, the statistical error as well as the maximum possible error on each point. This error includes:

(1) - The statistical error.
(2) - The error coming from a possible maximum error $\Delta P = \pm 0.01$ on knowledge of the beam's polarization P.
(3) - The maximum error on the multipion background's subtraction.

This multipion contamination is due to the fact that the production mechanism of the coherent bremsstrahlung forced us to fix $E_{\gamma M}$ (maximum energy of bremsstrahlung spectrum) above the threshold of the reactions:

$$\gamma + p = p + \pi^+ + \pi^- \qquad (3)$$

$$= n + \pi^+ + \pi^0 \qquad (4)$$

We have worked with $E_{\gamma M} = 1000$ MeV, whereas the kinematical thresholds, for the reactions (3) or (4) were, taking into account the kinematical conditions used for the reaction (2), from about 500 to 700 MeV.

The background due to the multipion photoproduction has been accurately measured by means of the method indicated in [1] and extensively described in [3]. We will, in the near future, carry out some new measurements of this background in order to reduce our present errors on this contamination.

The main results of our measurements and analysis can be summarized as follows:

(i) The general trend of $A(\theta)$ vs E_γ agrees with the prediction of recent theories[5,6].

There is, however, some clear quantitative disagreement. For example for $\theta = 71^\circ$ and 90° (Fig. 1, c, d) and $E_\gamma > 300$ MeV our measured values of A are larger than that predicted by these theories.

(x) - See also Appendix A.

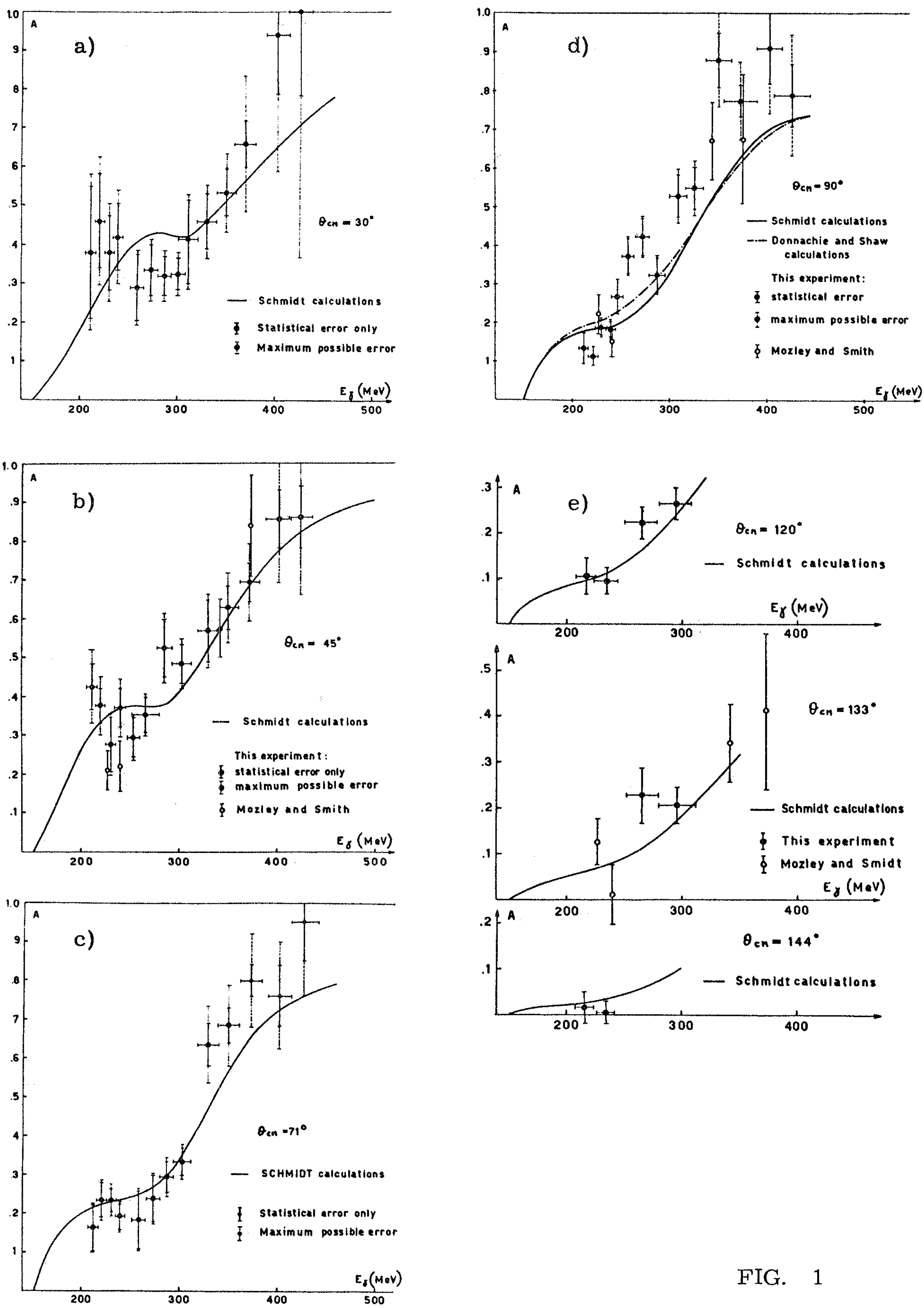

a)
A
θ_{cn} = 30°
Schmidt calculations
Statistical error only
Maximum possible error
E_γ (MeV)
b)
A
θ_{cn} = 45°
Schmidt calculations
This experiment :
statistical error only
maximum possible error
Mozley and Smith
E_γ (MeV)
c)
A
θ_{cn} = 71°
SCHMIDT calculations
Statistical error only
Maximum possible error
E_γ (MeV)
d)
A
θ_{cn} = 90°
Schmidt calculations
Donnachie and Shaw calculations
This experiment:
statistical error
maximum possible error
Mozley and Smith
E_γ (MeV)
e)
A
θ_{cn} = 120°
Schmidt calculations
E_γ (MeV)
A
θ_{cn} = 133°
Schmidt calculations
This experiment
Mozley and Smidt
E_γ (MeV)
A
θ_{cn} = 144°
Schmidt calculations

FIG. 1

Very probably, in order to obtain a quantitative agreement between the theory and the experiment some non resonating multipole must be revaluated, as suggested in [7,8].

(ii) The following general conclusions can be deduced by the analysis of the results connected with $\sigma_\perp$.

As is known, this cross section is given by :

$$\sigma_\perp(\theta) = \sigma(\theta)\left[1 + A(\theta)\right]$$

where $\sigma(\theta)$ is the differential cross section for single photoproduction by unpolarized γ-rays. It is important to remind that in $\sigma_\perp$ there is no contribution from the "photoelectric term" (γ-pion's current interaction).

(ii. a) Our data for $\sigma_\perp(\theta)$(x), in the energy range 200-400 MeV, can be fitted with a 2^{nd} order polynomial in $\cos\theta$:

$$\frac{K}{q}\,\sigma_\perp(\theta) = A_\perp + B_\perp \cos\theta + C_\perp \cos^2\theta \qquad \text{(S+P waves)} \tag{6}$$

Examples of such fitting are reported in Fig. 2(a,b,c) for E_γ = 240, 280 and 380 MeV.

We note that our fitting agree with the zero degree measurements of Bizot et al. [10] and Knapp et al. [11].

From such polynomial analysis of $\sigma_\perp$ we deduce that there is certainly no significant contribution in $\sigma_\perp$, from waves higher than P, for $E_\gamma \lesssim 400$ MeV. However, in order to reach a more definite conclusion we would like to have more measurements at backward angles(o).

(ii. b) In Fig. 3 the coefficients $A_\perp$, $B_\perp$, $C_\perp$ of (6) as a function of E are reported. For comparison we report in this figure the same coefficients (A_o, B_o, C_o) of the angular distribution of the π^o (unpolarized γ-rays), measured in different Laboratories. We note a similarity of $A_\perp$, $B_\perp$, $C_\perp$ with A_o, B_o, C_o respectively(+).

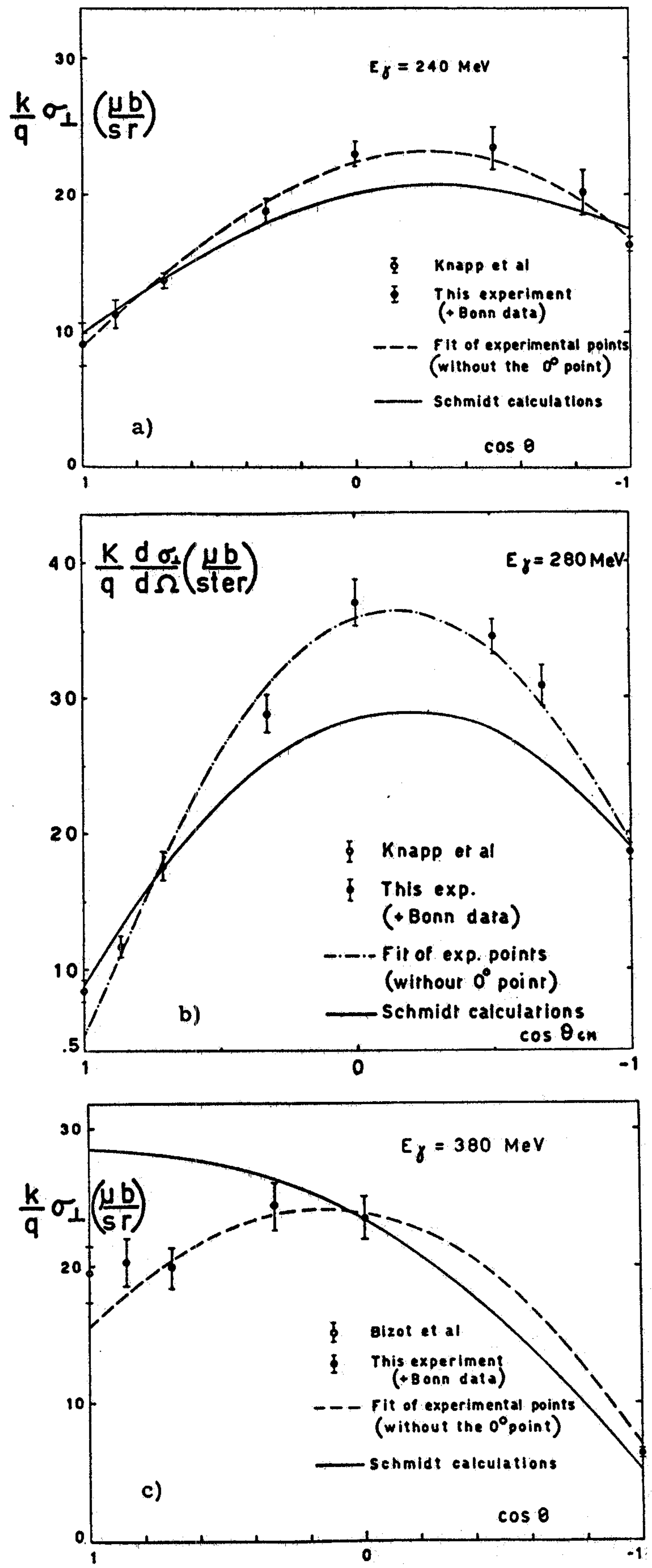
(iii) We reach the same conclusions, as in (ii. a) and (ii. b) if we look at the following representation of our asymmetry measurements.

If we have no contribution of waves higher than P from terms different from the photoelectric term we can write[17]:

(x) - We have used for σ the Bonn[9] data. In particular, the $\sigma(180^o)$ has been deduced by a Moravcsik fit of these data.

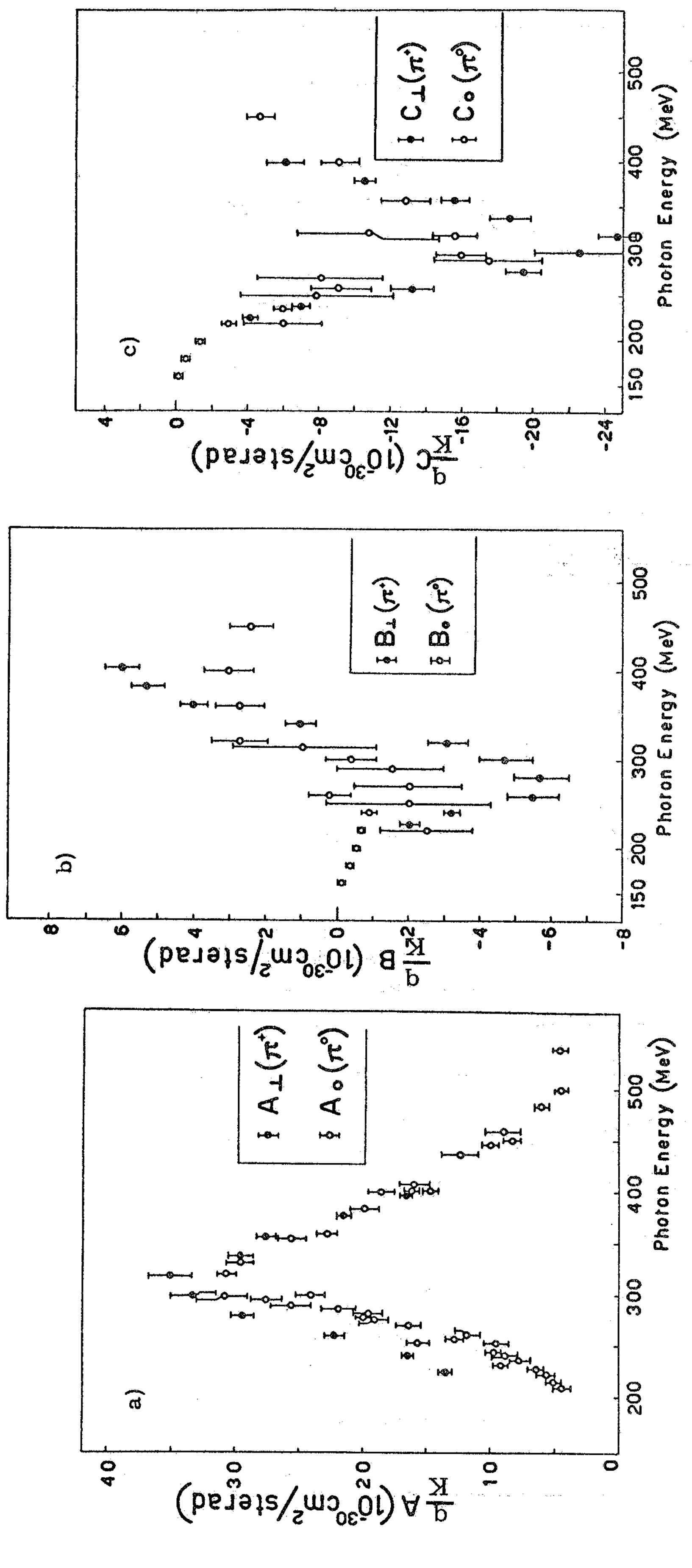
(o) - Such measurements are now in progress at Frascati.

(+) - We are indebted to Prof. G. Höhler and Dr. W. Schmidt for an illuminating discussion about the physical meaning of this result.



Eγ = 240 MeV
Knapp et al
This experiment (+ Bonn data)
Fit of experimental points (without the 0° point)
Schmidt calculations
a)
cos θ
Eγ = 280 MeV
Knapp et al
This exp. (+ Bonn data)
Fit of exp. points (without 0° point)
Schmidt calculations
b)
cos θ CM
Eγ = 380 MeV
Bizot et al
This experiment (+ Bonn data)
Fit of experimental points (without the 0° point)
Schmidt calculations
c)
cos θ

FIG. 2



a)
b)
c)
$A_\perp(\pi^+)$
$A_0(\pi^0)$
$B_\perp(\pi^+)$
$B_0(\pi^0)$
$C_\perp(\pi^+)$
$C_0(\pi^0)$
$\frac{q}{K}A\ (10^{-30}cm^2/sterad)$
$\frac{q}{K}B\ (10^{-30}cm^2/sterad)$
$\frac{q}{K}C\ (10^{-30}cm^2/sterad)$
Photon Energy (MeV)

FIG. 3

(7) $$H(\xi) = \alpha_+ \xi + \gamma$$

where $\xi = (1 - \beta \cos \theta)$ ($\beta = \pi$'s velocity) and

$$H(\xi) = -\frac{1}{\xi}\left[\frac{K}{q}\frac{1}{\mathrm{sen}^2\theta}(\sigma_\perp - \sigma_\parallel)\xi^2 + \delta\right].$$

The coefficients δ, γ, α_+ have the following physical meaning :

1) δ is proportional to the residue of the $\sigma(\theta)$ for $\xi \to 0$.
2) γ is due to the interference of the photoelectric term with the (S, P) multipoles (E_{0+}, E_{1+}, M_{1-}, M_{1+}).
3) α_+ is proportional, essentially, to the asymmetry coming from terms different from the photoelectric term.

From an analysis of this type we derive the following conclusions :

(iii. a) The fact that our data are fitted (see Fig. 4) by the relation (7) confirms our conclusion (ii. a), about the small importance of waves higher than P in $\sigma_\perp$.

(iii. b) In Fig. 5 we compare the coefficient α_+ deduced, by means of the relation (7), from our π^+ measurements with the corresponding coefficient α_0, given by :

(8) $$\frac{1}{\mathrm{sen}^2\theta}\frac{K}{q}(\sigma_\perp - \sigma_\parallel) = \alpha_0$$

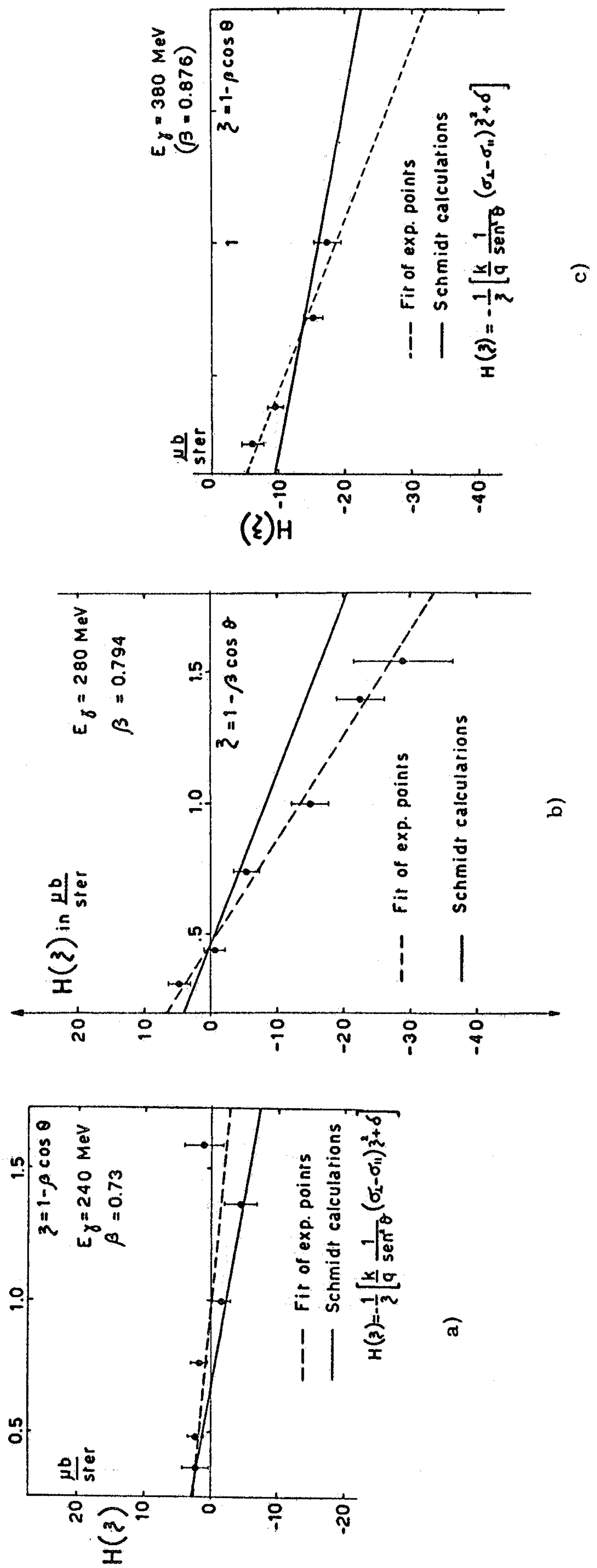
The values of α_0 have been deduced by measurements on π^0 photoproduction by linearly polarized γ rays at Stanford[12], and Frascati[13].

The similarity between α_+ and α_0 (see Fig. 5) confirms our conclusion (iii. b), about the similarity of π^0 and π^+ photoproduction results when the effects of the photoelectric term in the π^+ case are properly eliminated.

(iv) Our results for $\sigma_\perp(90^0)$ are shown in Fig. 6. The $\sigma_\perp(90^0)$ cross section is given by a very simple expression, in terms of the $\mathcal{F}_i$ (i = = 1, ... 4) amplitudes of C. G. L. N.[14] :

(9) $$\sigma_\perp(90^0) = \frac{q}{K}(|\mathcal{F}_1|^2 + |\mathcal{F}_2|^2).$$

Therefore, this cross section results to be particularly useful for a quantitative analysis.



H(ζ) in μb/ster
ζ = 1 - β cos θ
E_γ = 240 MeV
β = 0.73
Fit of exp. points
Schmidt calculations
H(ζ) = -1/ζ [k/q 1/sen²θ (σ⊥-σ∥)ζ² + δ]
a)
E_γ = 280 MeV
β = 0.794
b)
E_γ = 380 MeV
(β = 0.876)
c)

FIG. 4

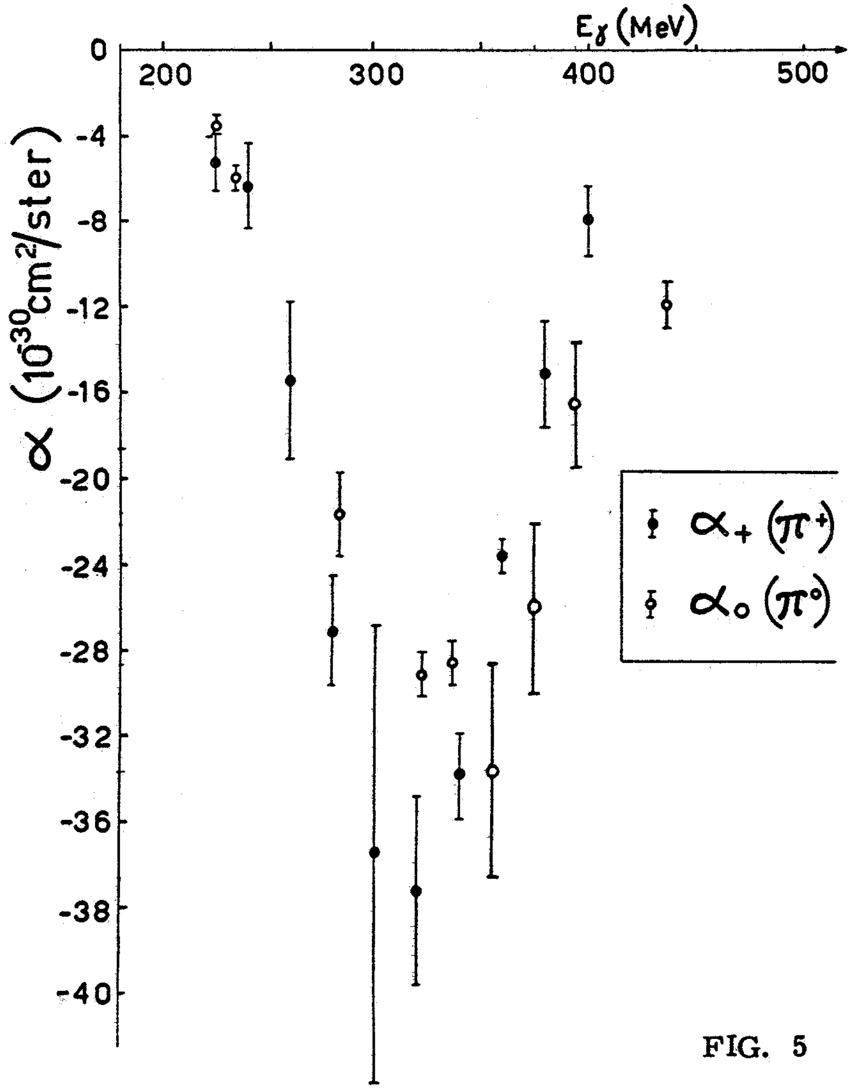

Eγ (MeV)
0
200
300
400
500
-4
-8
-12
-16
-20
-24
-28
-32
-36
-38
-40
α (10^-30 cm^2/ster)
α+ (π+)
αo (π°)

FIG. 5

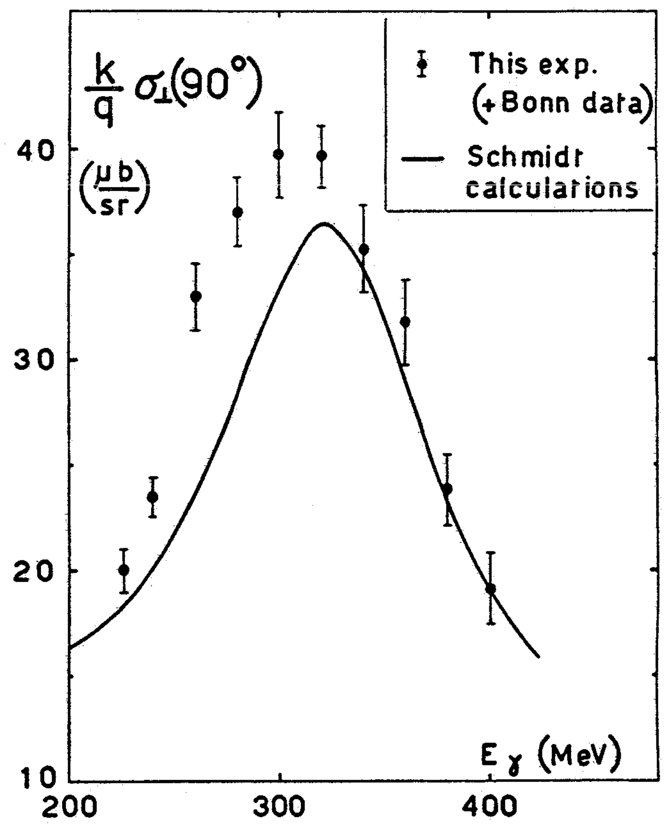

k/q σ⊥(90°)
(μb/sr)
This exp.
(+Bonn data)
Schmidr
calculations
40
30
20
10
200
300
400
E γ (MeV)

FIG. 6

Moreover, for a P_{33} resonance and at $\theta = 90^o$, we have a resonating contribution ($\mathcal{F}_{2R}$) only in $\mathcal{F}_2$, i. e.

$$\mathcal{F}_1 = f_1 , \qquad \mathcal{F}_2 = f_2 + \mathcal{F}_{2R} .$$

It therefore follows :

(10) $$\sigma_\perp(90^o) = \frac{q}{K} \left(|f_1|^2 + |f_2|^2 + |\mathcal{F}_{2R}|^2 + 2R_e(f_2 \mathcal{F}^*_{2R}) \right)$$

where f_1, f_2 contain only a non resonating background. In particular we have $f_1 = E_{0+}$ + waves higher than P. If we evaluate f_1, f_2 from the Born approximation we find that

$$\Sigma = |f_1|^2 + |f_2|^2$$

contributes to the $\sigma_\perp(90^o)$ for about 1/3 of the measured cross section at resonance.

Moreover, the main contribution to Σ, about 90%, comes from E_{0+} for which the estimate given by the Born term is considered by many authors quite good in the case of π^+ production. Indeed, according to C. G. L. N.[14], the dispersion integral contribution of the resonant amplitude to E_{0+} is rigorously zero in the static limit for π^+ production. We can therefore conclude that the non resonating background Σ can be evaluated, taking the value given by the Born term, with enough accuracy.

Assuming, as it is usual, that the background amplitude f_2 is real, the interference term vanishes at resonance (E_γ = 345 MeV), and $\mathcal{F}_{2R}$ can be calculated from[(x)]:

$$\sigma_\perp(90^o, 345 \text{ MeV}) - \frac{q}{K}\Sigma = \frac{q}{K}|\mathcal{F}_{2R}|^2$$

Since $\mathcal{F}_{2R}$ does not contain the resonating E_{1+}, we have simply

$$\mathcal{F}_{2R} = - \frac{2\sqrt{2}}{3} M^3_{1+} .$$

Following the analysis given by Dalitz[15], we take for M^3_{1+} a Breit-Wigner formula[(o)]

(11) $$M^3_{1+} = \sqrt{\frac{1}{qK}} \frac{\sqrt{3}}{4} \frac{\Gamma_\gamma^{1/2} \Gamma^{1/2}}{(E^* - E) - i\Gamma/2}$$

(x) - For more details see (18).

(o) - The quantities entering in the formulas (11), (12), (13) are defined in the paper (15).

and evaluate the quantity $\mu^{\times}$, i. e. the partial width which describes the vertex function for the transition $N^{\times} \rightleftarrows N + \gamma$.

Taking for Γ the value quoted in (15), $(q/K)\Sigma = 8.7 \mu b/ster$, and the experimental value

$$\sigma_{\perp}(90^{o}, 345\ MeV) = (29.1 \pm 1.0)\mu b/ster$$

we obtain $\Gamma_{\gamma} = 0.62 \pm 0.03$ MeV.

As Γ_{γ} is related to $\mu^{\times} = \langle p, m = +1/2 | M_z | N^{\times}_{3/2}, m = +1/2 \rangle$ by the relation

(12) $$\Gamma_{\gamma} = (\alpha K^{\times 3}/2ME^{\times})\mu^{\times 2}$$

we find(x)

(13) $$\mu^{\times} = (1.23 \pm 0.03)\frac{2\sqrt{2}}{5}\mu_{v}$$

This value of $\mu^{\times}$ is compatible with that calculated by Dalitz et al.(15) from π^{o} photoproduction data.

Our evaluation of $\mu^{\times}$ suffers from the presence of the non negligible background Σ (in $\sigma_{\perp}(90^{o})$).

Of course, $\mu^{\times}$ can be calculated also from the analysis of all the existing data, including the values of the ordinary cross sections(16). Nevertheless we remark that :

(i) the non resonant background is much higher in the ordinary (unpolarized) cross section, than in $\sigma_{\perp}(90^{o})$;

(ii) for energies far from resonance the interference terms becomes very important and the bad knowledge of small non resonating multipoles can introduce large errors in the estimate of $\mu^{\times}$. In our case, we have that not only the background is not too high, but also that it comes mainly from terms which must be considered well evaluated from the theory.

Summarizing the general conclusions of the present analysis we have :

(i) A qualitatively good agreement between theory and experiment. Very probably a better quantitative agreement will be obtained by revaluating some non resonating multipoles.

(x) - The prevision for $\mu^{\times}$ given by the SU(6)w symmetry is(16):

$$\mu^{\times} = \frac{2\sqrt{2}}{3}\mu_{v}, \quad \text{where } \mu_{v} = \mu_{p} - \mu_{n},$$

$\mu_{p,n}$ = magnetic moment of the proton (neutron), $\mu^{\times}$ as μ_{v} are expressed in nuclear magnetons.

(ii) In the "perpendicular" cross section $\sigma_{\perp}$ there is, pratically, no contribution of waves higher than P, for $E_{\gamma} \lesssim 400$ MeV.

(iii) A similarity in the π^+ and π^o results, when we exclude (as it happens in $\sigma_{\perp}$) the contribution coming from the photoelectric term.

(iv) An estimate of $N^{*}N\gamma$ transition magnetic moment from our data agrees with that coming from the analysis of the π^o photoproduction(15) and it is close to the SU(6)W prevision(16).

APPENDIX A. -

θ_{CM}	E_γ	A	ΔA (1)	ΔA (2)
30°	211 ± 5	.380	.199	.168
	220 ± 5	.459	.167	.121
	230 ± 5	.381	.126	.096
	239 ± 5	.422	.118	.086
	259 ± 7	.289	.097	.086
	273 ± 7	.334	.081	.066
	287 ± 7	.318	.064	.048
	301 ± 7	.323	.057	.039
	311 ± 10	.414	.114	.099
	330 ± 10	.458	.094	.071
	350 ± 11	.536	.097	.057
	370 ± 11	.663	.175	.058
	402 ± 12	.940	.349	.148
	425 ± 12	1.000	.637	.213
45°	211 ± 5	.427	.094	.061
	220 ± 5	.373	.077	.046
	230 ± 5	.273	.082	.071
	240 ± 6	.372	.074	.051
	254 ± 6	.293	.060	.050
	267 ± 13	.353	.056	.047
	285 ± 8	.525	.088	.075
	303 ± 10	.487	.064	.048
	330 ± 10	.568	.096	.081
	351 ± 10	.629	.091	.056
	372 ± 10	.693	.105	.052
	403 ± 13	.859	.166	.075
	428 ± 12	.866	.199	.081
71°	211 ± 5	.158	.062	.059
	220 ± 5	.231	.052	.043
	230 ± 5	.231	.042	.030
	239 ± 5	.190	.036	.028
	258 ± 7	.180	.079	.077
	273 ± 7	.235	.066	.062
	287 ± 7	.291	.048	.038
	303 ± 9	.331	.046	.033
	330 ± 11	.635	.102	.055
	351 ± 11	.686	.105	.044
	373 ± 11	.791	.117	.036
	402 ± 12	.761	.141	.079
	427 ± 12	.952	.198	.098
90°	211 ± 5	.136	.040	.039
	221 ± 5	.117	.026	.025
	229 ± 6	.192	.026	.022
	239 ± 5	.183	.025	.022
	246 ± 6	.270	.046	.043
	257 ± 6	.376	.050	.045
	272 ± 7	.425	.052	.048
	287 ± 8	.326	.048	.043
	309 ± 9	.530	.068	.055
	326 ± 9	.552	.068	.055
	351 ± 13	.879	.118	.071
	373 ± 17	.775	.101	.040
	403 ± 13	.911	.163	.088
	426 ± 19	.791	.156	.079
120°	217 ± 8	.105	.041	.041
	235 ± 10	.095	.027	.027
	265 ± 15	.231	.035	.033
	295 ± 15	.261	.030	.028
133°	265 ± 15	.215	.063	.062
	296 ± 16	.204	.043	.042
144°	217 ± 8	.016	.037	.037
	235 ± 10	.002	.026	.025

(1) - Maximum possible error (see text).
(2) - Statistical error.

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