PION PHOTOPRODUCTION NEAR THRESHOLD

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I. Introduction

The present meeting marks the end of the first generation experiments on pion photoproduction near threshold. It is thus appropriate to try to have an overall view on what has been achieved using this investigation method which was prompted by the advent of the new high intensity electron accelerators. Since detailed reviews on the subject have been presented at the International Symposium on Photopion Nuclear Physics [1] held in Troy in August 1978, I shall only quickly summarize the present status of the field from the view point of an experimentalist. I will then, place particular emphasis on two topics which in my personal opinion are the original and relevant contributions to nuclear physics of this type of study. First I will review the high accuracy π^+ threshold photoproduction cross-section determinations on deuterium and helium-3. These must be considered on the same footing as the data on electromagnetic observables, with reference to the important question of the description of the non nucleonic degrees of freedom in the nucleus. Second I will discuss the π° threshold photoproduction on very light nuclei which conveys information on the elementary nucleonic amplitudes in an energy region where one is sensitive to the break down of isospin symmetry as revealed by the $\pi^\pm$, π° and the n,p mass splittings.

The interest in studying pion photoproduction in the threshold energy region results essentially from the good knowledge we have of the elementary interaction – at least for charged pions – and of the relatively moderate interaction of low energy pions with the nucleus. Because of these characteristics pion photoproduction near threshold, and its natural extension pion electroproduction near threshold, can be viewed as probes very similar to electromagnetic and weak interaction processes. These general particularities of pion photoproduction at threshold have been appreciated for a long time and they motivated the experimental and theoretical effort invested in the study of the inverse process, stopped pion radiative capture which has proved to be a very productive source of information on nuclear problems. The specific features of a given threshold photoproduction reaction are determined by the elementary production and scattering processes on the nucleon and in the case of charged pions by the important Coulomb interaction with the residual nucleus.

The photoproduction amplitude on a free nucleon is calculated using the operator

$$O_\pi = \vec{K}\,\vec{\sigma} + L.$$

In the vicinity of threshold $\vec{K}$ and L can be accounted for using a limited number of multipolar amplitudes. At threshold the only non vanishing term is the spin flip operator $E_{0+}\,\vec{\sigma}\,\vec{\varepsilon}$.

In the isospin symmetry frame, for a given configuration of spins and pion nucleon orbital momentum there exists only 3 independent isospin amplitudes. For instance the s wave multipolar amplitudes, E_{0^+}, corresponding to the four photoproduction channels are related by

$$E_{0^+}(p\pi^\circ) - E_{0^+}(n\pi^\circ) = \left[E_{0^+}(p\pi^-) + E_{0^+}(n\pi^+)\right]/\sqrt{2} \qquad (1)$$

In table I we observe that the charged s wave pion amplitudes E_{0^+} are one order of magnitude larger than the neutral ones ; on the other hand the p wave dominant amplitudes M_{1^+} do not differ very much for the different channels. Since M_{1^+} increases with energy like qk, the product of the pion and the photon momenta, and E_{0^+} stays almost constant, neutral pion photoproduction is already dominated by the p wave amplitude of mixed spin and non spin flip character, 3 MeV above threshold. Contrarily the charged pion photoproduction is governed by the s-wave spin flip amplitude even 20 MeV above threshold.

Table I

The E_{0^+} and M_{1^+} photoproduction amplitudes in units of m_π^{-1} for the four photoproduction channels.
(q and k are the pion and photon momenta in the c.m. system).

Production channel	E_{0^+}	M_{1^+}
$\gamma + n \to \pi^+ + n$	$28.3 \pm 0.5^{a)}$	$-5.2 \quad qk/m_\pi^2$
$\gamma + p \to \pi^- + n$	$-31.9 \pm 0.5^{b)}$	$6.6 \quad qk/m_\pi^2$
$\gamma + p \to \pi^\circ + p$	$-1.8 \pm 0.6^{a)}$	$11.2 \quad qk/m_\pi^2$
$\gamma + n \to \pi^\circ + n$	$0.7 \pm 0.8^{c)}$	$10.2 \quad qk/m_\pi^2$

a) Ref. [2] ; b) from Panofsky ratio Ref. [3] ; c) deduced using relation (1) ; d) extrapolations using multipole analysis ref. [4].

Pion nucleon scattering at low energy is essentially determined by the s wave scattering lengths. From the experimental values given in Table II one can recognize that the πN interaction is weak for charged pions and almost negligible for π° elastic scattering.

As pointed out by Tzara [6], near threshold the effect of the Coulomb potential is crucial in the distorsion of the pion wave for charged pion photoproduction on nuclei. In the case of π^+ photoproduction the cross-section is strongly attenuated. For π^- photoproduction there is formation of pionic atoms below threshold ; above threshold, the cross-section has a step dependence with energy. In the assumption of a point charge nucleus the Sommerfeld factor s describes the π^+ cross section attenuation $S = 2\pi\gamma/e^{2\pi\gamma} - 1)$ or the π^- cross-section enhancement $S = 2\pi\gamma/(1 - e^{2\pi\gamma})$; ($\gamma = Ze^2/\hbar v$ v is the pion nucleus relative velocity).

Table II

The pion nucleon scattering length in units of m_π^{-1} for the different charge channels

Scattering channel	$a(\pi N)^{a)}$
$\pi^- p \to \pi^- p$	0.083 ± 0.003
$\pi^- n \to \pi^- n$	-0.092 ± 0.002
$\pi^- p \to \pi^\circ n$	0.124 ± 0.003
$\pi^\circ n \to \pi^\circ n$	-0.004 ±

a) experimental values from ref. [5].

The finite extension of the nuclear charge introduces only an attenuation of the point Coulomb potential effects.

Traditionnaly two methods have been utilized for the interpretation of pion photoproduction data. The first one is a generalization to the nucleus of the low energy theorems applied successfully to the photon and to the pion in the nucleon case. However the fundamental character of the approach is somewhat lost because of the important corrections needed to correct for the real pion mass and for the presence of nuclear excited states [7]. The second method uses a microscopic description of the process : pions are created on the individual nucleons with the free nucleon complete amplitude. The nuclear amplitude is obtained by adding the nucleonic amplitudes in the nucleus as described by its wave function ; Fermi motion of the nucleons can be taken into account by using invariant photoproduction amplitudes [8]. The nuclear amplitude must be corrected for many-body effects ; up to now only Coulomb distorsion and pion-nucleus rescattering effects have been treated. For light nuclei one must be especially careful in the description of the pion rescattering in order to avoid double counting of the pion scattering on the nucleon on which photoproduction took place. The latter is already included in the *effective* production amplitude [9] (see Fig. 1). For this reason pion optical potential of the residual nucleus, which has been very often used, is not adequate.

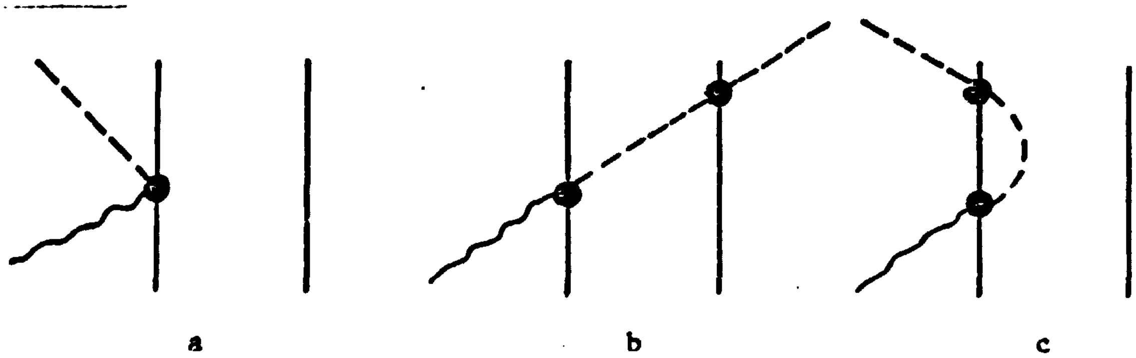

Fig. 1 - Simple scattering in π photoproduction in deuterium ; a) impulse approximation ; b) single scattering ; c) diagram already included in a).

From an experimental point of view there are some general features of all threshold pion photoproduction measurements. So far, only electron Bremsstrahlung has been utilized. The resulting high photon fluxes constitute an important advantage owing to the smallness of the cross-sections investigated. The measured quantity is the yield corresponding to a given end-point energy of the photon spectrum ; it is the result of the folding of the nuclear cross-section with the Bremsstrahlung spectrum and the detection efficiency. No identification of the final nuclear state is possible and usually only the transition to the ground state of the final nucleus can be measured with precision. In addition a large level spacing in the final nucleus is needed to describe accurately the yield variation by changing the Bremsstrahlung end-point energy. These very severe limitations almost prevent the investigation of heavy nuclei. Normalization is a difficult problem which can be overcome by carrying out relative measurements.

The information which can be deduced from the study of threshold photoproduction reactions on nuclei as well as the experimental methods differ according to the charge of the emitted pion. We will thus discuss separately the three charge channels.

II. π^+ photoproduction near threshold

The experimental technique utilized consists in a measurement of the π^+ photoproduction yield for reaction

$$\gamma + (A,Z) \rightarrow (A,Z-1) + \pi^+ \tag{2}$$

relative to the one on hydrogen

$$\gamma + p \rightarrow n + \pi^+. \tag{3}$$

The very low energy pions stop in the reaction target and the positrons of the $\pi \rightarrow \mu \rightarrow e$ decay chain are counted in Cerenkov detectors after the beam burst. The energy dependent π^+ production cross-section is dominated by the Sommerfeld factor and by phase space ; it can be parametrized as

$$\sigma = a(A,Z) S\, q/k.$$

The quantity a(A,Z) is a slowly varying function, which can be considered as a constant in the first few MeV above threshold at least for light nuclei ; q and k are the pion and photon momenta in the c.m. system. From the yield curves obtained for reactions (2) and (3), in varying the end point of the photon spectrum, one can extract the ratio $a(A,Z)/a_p$ with a precision of a few percent. Using this technique ^{2}H [10,11], ^{3}He [12], ^{6}Li [13], ^{9}Be [14], ^{12}C [15,16], ^{14}N [17] and ^{16}O [14] have been measured. The experimental results of the most important cases are displayed in table III.

In a microscopic description

$$\frac{a(A,Z)}{a_p} = \left[\frac{1 + m_\pi/M}{1 + m_\pi/(AM)}\right]^2 C_+^2 |M_+(Q_+)|^2$$

m_π and M are the pion and nucleon masses. C_+ is the modification of the π^+ amplitude due to pion multiple scattering and the effect of the nuclear charge extension,

$$|M_+(Q_+)|^2 = \frac{1}{|E_{0^+}(n\pi^+)|^2} \frac{1}{(2J+1)} \sum_{m_i m_f \lambda} \left| \langle A,Z-1 \left| \sum_{j=1,A} O_j\, e^{i\vec{Q}.\vec{r}_j} \right| A,Z \rangle \right|^2$$

Table III

<u>The $\pi \to \mu \to e$ measurements</u> .(q k ω are the pion momentum, photon momentum, energy above threshold, in the c.m. system all quantities in MeV/c or MeV ; the normalization provided by the proton cross-section $\sigma_p = a_p\, q/k$ $a_p = (201 \pm 7)\mu b$ [2]).

Target	Model cross-section	Experimental result
^2H	$a_d \left(\frac{\omega}{1+\sqrt{1+6.5\omega}}\right)^2 (1-0.58\omega)$	$\frac{a_d}{a_p} = 0.159 \pm 0.004$ a)
^3He	$a_{^3He} \frac{q}{k} \frac{6.1/q}{e^{6.1/q}-1}$	$\frac{a_{^3He}}{a_p} = 0.62 \pm 0.02$ b)
^6Li	$a_{^6Li} \frac{q}{k} \frac{12.5/q}{e^{12.5/q}-1}$	$\frac{a_{^6Li}}{a_p} = 0.098 \pm 0.004$ c)
^{12}C	$a_{^{12}C} \frac{q}{k} \frac{31.6/q}{e^{31.6/q}-1}$	$\frac{a_{^{12}C}}{a_p} = 0.076 \pm 0.005$ d) $= 0.083 \pm 0.004$ e)

a) Ref.[11] ; b) Ref.[12] ; c) Ref.[13] ; d) Ref.[15] ; e) Ref.[14].

where O_j is the full one body photoproduction operator which contains in addition to leading $E_{0+}\,\vec{\sigma}_j.\vec{\varepsilon}_\lambda$, momentum dependent terms. J is the initial nucleus spin and Q_+ the momentum transfer at threshold in the c.m. system.

In the assumption of frozen nucleons $M_+(Q_+^2)$ reduces at threshold to the spin flip form factor $F_{sf}(Q_+^2)$. Fermi motion of the nucleons brings a contribution of the momentum dependent terms which in the case of ^6Li decreases the cross-section by 10 %.

The analogy of charged pion photoproduction with other electromagnetic or weak processes (magnetic electron scattering , Gamow-Teller β decay, axial vector term in muon capture) where the matrix elements are dominated by spin-flip has been very often used to make theoretical predictions of the data. For instance the magnetic form factor measured in backward electron scattering reduces also to the spin-flip form factor when the orbital contribution is neglected. Taking advantage of this circumstance, wave functions tailored to reproduce electron scattering data were utilized for calculating threshold π photoproduction and indeed agreement with experiment was reached at the level of 10 to 15 % for nuclei like ^6Li [19] and ^{12}C [20]. Because of the various uncertainties in the models this agreement seems satisfactory.

However because of the high accuracy of the data which were collected it is tempting to ask the question : do meson exchange currents affect threshold photoproduction in the same way as other axial electromagnetic and weak processes? Because of the nuclear structure uncertainties, the only place where the contribution of mesonic degrees of freedom can be investigated are the two and three nucleon systems for which "exact" wave functions generated by realistic nucleon-nucleon potentials are available.

As shown in Fig. 2, the complete calculation of Laget [35], which includes the full nucleonic amplitude and uses a realistic wave function, agrees perfectly with the deuterium measured cross-section. However one must correct the theoretical estimate for the pion rescattering. Using the simple model of the fixed scatterer approximation which predicts correctly the pion deuterium scattering length, the factor C_+ describing the first order scattering is

$$C_+ = 1 + (1 + m_\pi/M)\, a(\pi^+ n) \left\langle \frac{1}{r} \right\rangle_{m_\pi} ;$$

the inverse nucleon separation at momentum transfer k, $\langle \frac{1}{r} \rangle_k$, is defined using the radial wave functions of the initial and final nuclear states by

$$\left\langle \frac{1}{r} \right\rangle_k = \left[\int \phi_f^* \frac{e^{i\vec{k}\vec{r}}}{r} \phi_i \, d^3r \right] \Big/ \left[\int \phi_f^* e^{i\vec{k}\vec{r}} \phi_i \, d^3r \right].$$

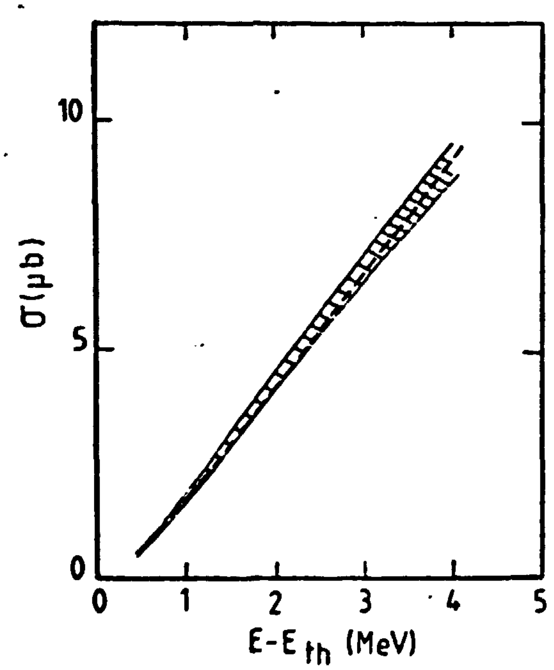

Fig. 2 – The deuterium π^+ photoproduction total cross-section as a function of the photon energy above threshold. Shaded area : experimental determination of ref. [11] ; dashed line : theoretical calculation of ref. [35].

For deuterium and nn wave functions generated by the Reid soft core potential, $\langle \frac{1}{r} \rangle_{m_\pi} = 0.54\ m_\pi$ and $C_+^2 = 1.08$. This correction makes the calculated cross-section approximately 5 % larger than the experimental determination.

The related process of backward electrodisintegration near threshold

$$e + d \rightarrow e + n + p$$

which is driven essentially by the spin flip operator $\sum_j (\mu_p - \mu_n)\, \vec{\sigma}_j \tau^3$ connects the same nuclear states (deuterium to the singlet np which is the analog of nn). Its cross-section in the m_π momentum transfer region is approximately 20 % higher than the impulse approximation estimations [21] ; this discrepancy is known to be one of the cleanest evidences of the contribution of mesonic exchange currents.

In the case of helium-3, there is unfortunately no complete calculation of threshold pion photoproduction available. Only the values of the spin flip form factor at momentum transfer m_π have been calculated for various realistic wave functions [22]. Because of the negligible isoscalar pion nucleon scattering length, there is almost no modification of the pion wave by the multiple scattering, even when the calculation is pursued to second order. $C_+^2 = 0.99$. Assuming that the momentum dependent terms in the amplitude have a negligible effect we can compare the experimental value $|M_+|^2$ to the estimations of F_{sf}^2. From the experimental values [23,3] of the helium-3 and hydrogen Panofsky ratios we can extract the value of the π^- threshold photoproduction matrix element M_- (defined similarly to M_+).

$$|M_-|^2 = (0.59 \pm 0.02)\ C^2_{-0}/C^2_-.$$

C_{-0} and C_- account for the pion multiple scattering in $\pi^-\pi^\circ$ charge exchange and radiative π^- capture. For the same reason invoked in the case of C_+, C_- is close to 1 ; $C^2_- = 0.98$. For charge exchange there is an important contribution of double scattering

$$C_{-0} = 1 + (1 + m\ /M)\left[a(\pi^-p) + a(\pi^-n)\right]\langle\frac{1}{r}\rangle_o + (1 + m_\pi/)^2\left[3\ a(\pi^-p)a(\pi^-n) + a^2(\pi^-p) - 3\ a^2(\pi^-p,\pi^\circ n)\right]\langle\frac{1}{r^2}\rangle_o \ ;$$

using $\langle\frac{1}{r}\rangle_o = 0.60\ m_\pi$ and $\langle\frac{1}{r^2}\rangle_o^2 = 0.39\ m^2_\pi$, as suggested by the Coulomb energy of ^3H in Laverne and Gignoux [23] wave function generated by the Reid soft core potential, $C^2_{-0} = 0.92$. We deduce $|M_-|^2 = 0.56 \pm 0.02$ where the error does not include the uncertainties in the pion distorsion evaluation. From the measured magnetic form factors of ^3He and ^3H [25], one can extract the magnetic form factor, at momentum transfer $Q^2_+ = 0.481\ fm^{-2}$ for the transition $^3He \rightarrow {}^3H$, corrected for the proton size

$$F^2_M(Q^2_+) = 0.64 \pm 0.02.$$

All the numerical values are displayed on Table IV. Comparing first the experimental values, we observe that pion photoproduction matrix elements M_+ and M_- agree within the quoted uncertainties, whereas the squared body magnetic form factor is 20 % higher. This proves that many body contributions affect differently pion photoproduction and electron scattering. On the other hand the theoretical impulse approximation values are in the average in reasonable agreement with the pion photoproduction matrix elements. This confirms the trend already observed in deuterium, suggesting that many body contributions are much smaller in pion photoproduction than in magnetic electron scattering. By measuring pion photoproduction, we thus measure essentially the one body spin flip form factor. In order to substantiate this conclusion, there is an urgent need for complete photoproduction calculations in the 2N and 3N systems including the evaluation of many body effects.

Table IV

Threshold π^+ photoproduction and magnetic electron scattering for the 3N system

Experiment	$\gamma + {}^3He \rightarrow {}^3H + \pi^+$	$\|M_+\|^2 = 0.52 \pm 0.02$		
	$\pi^- + {}^3He \rightarrow {}^3H + \pi^\circ$	$\|M_-\|^2 = 0.56 \pm 0.02$		
	magnetic electron scaterring	$\|F_m\|^2 = 0.64 \pm 0.02$		
Theory a)	NN potential	RSC	SSC	MT 13
	$P(D)^{b)}$	9.3	7.9	0.
	$\|F_{sf}(Q^2_+)\|^2$	0.49	0.52	0.57

a) data from ref. [22] ; b) D state percentage in the 3N wave function.

Extension of the measurements to different momentum transfers is in principle achievable by the study of pion electroproduction near threshold. However these coincidence experiments necessitate, in order to reach the required level of accuracy, electron accelerators with larger duty cycle than those presently in operation.

III. π^- photoproduction near threshold

π^- threshold photoproduction measurements are extremely difficult experiments. There are so far only two cases which have been studied : ^{11}B [26] and ^{12}C [27]. Both experiments use the activation method ; the radioactivity of the final nucleus is counted in the absence of the beam.With this technique it not possible to separate the contribution from the individual bound levels of the final nucleus. Below threshold, activity due to competing processes give a high level background which extrapolation above threshold and subsequent subtraction,causes large uncertainties in the data taken close from threshold. Normalization is achieved through comparison with the activity produced by a photoneutron reaction on a neighbouring nucleus, leading to the same final state, which cross-section is known. The overall accuracy of these measurements is of the level of 15 % to 20 % and agreement with DWIA theoretical estimations is satisfactory within these limits.

One should note the original method proposed by B. Schoch et al. [28] for measuring the deuterium case. The low energy negative pions stop and get captured inside the deuterium target ; the 68.2 MeV neutrons of the $d(\pi^-,n)n$ reaction are detected by a time of flight method and separated from the photodisintegration ones by choosing suitable kinematics. Normalization is achieved relatively to the deuterium photodisintegration. The feasibility of the experiment has been demonstrated by these authors.

Neutral pion photoproduction near threshold

Because of the large value of the non spin flip part L, relatively to the spin-flip part $\vec{K}$, in the nucleon π° photoproduction amplitude, the nuclear matrix element

$$< A,Z \left| \sum_{j=1}^{A} (\vec{K}\,\vec{\sigma}_j + L)\, e^{i(\vec{k}-\vec{q})\vec{r}_j} \right| A,Z >$$

is dominated by the coherent addition of the spin independent contributions of the A nucleons. Since neutrons and protons contribute almost equally, π° elastic photoproduction is a probe of the nucleon matter density. As such it has been used successfully by Schrack et al. [29] to measure nuclear matter radii.

It is only for very light nuclei and in the vicinity of threshold that the spin flip s wave contributions can be detected. However because the neutral amplitudes $E_{0^+}(\pi^\circ)$ are much smaller than the charged ones $E_{0^+}(\pi^\pm)$, large rescattering effects, involving charged pion production and virtual charge exchange, compete with the one body amplitude.

The basic motivations of π° photoproduction measurements near threshold on light nuclei are twofold : i) obtain information on the poorly known s wave photoproduction amplitudes on the nucleons. The $E_{0^+}(\pi^\circ)$ discriminante between the various theoretical models of pion photoproduction, whereas the $E_{0^+}(\pi^\pm)$ which are determined by the Born terms are almost completely unsensitive to the model utilized. ii) test our understanding of the many body effects in the photoproduction process, in a place where they are more important than the one body amplitude. The experimental procedure of the experiment performed at Saclay [30] consists in the comparison of the π° photoproduction yields on $^1H, ^2H, ^3He$ and ^4He. Measurements are made for several end point energies of the Bremsstrahlung spectrum ranging up to 10 MeV above threshold. The two gammas from the π° decay are converted in a lead foil and detected in two Cerenkov counters. The measured photoproduction yields are displayed in Fig. 3.

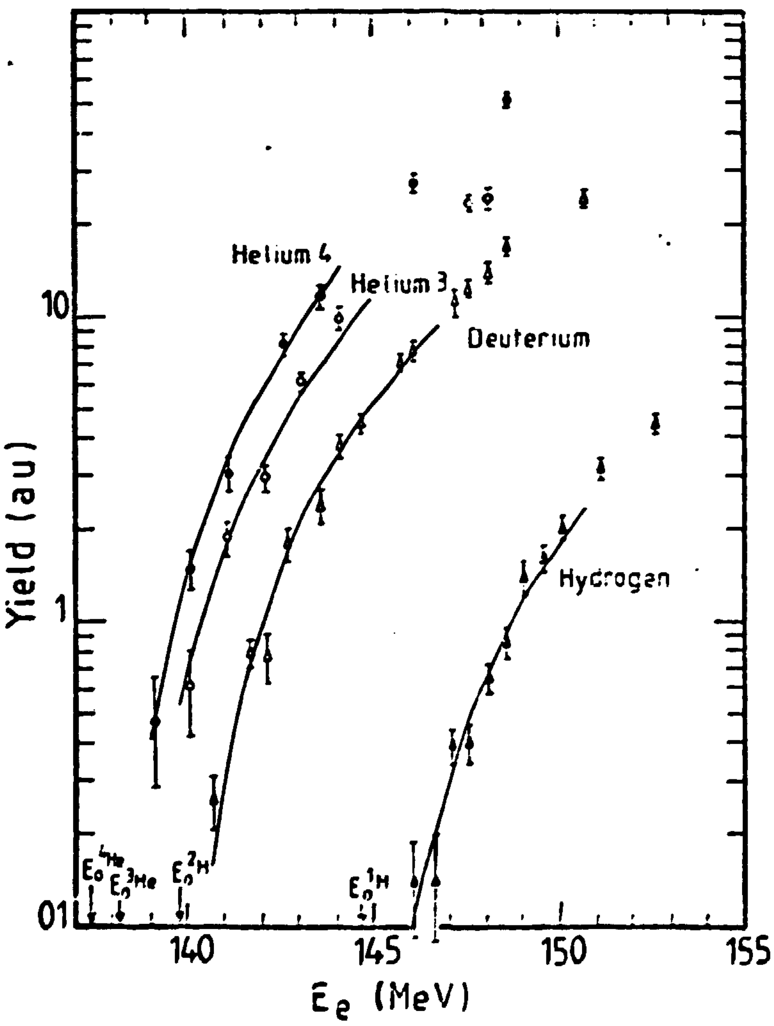

Fig. 3 - The measured π° photoproduction yields as a function of the end-point Bremsstrahlung energy E_e. Curves are theoretical yields adjusted as described in the text.

The absolute value of the detection efficiency is not known ; its variation with the π° energy is calculated using a Monte Carlo method. In order to provide the model cross-sections necessary for extracting information from the measured yields, some simplifying assumptions have been made. The π° photoproduction cross-section is supposed to be given exactly by the impulse approximation, except for a modification of the s wave amplitude to allow for s wave pion scattering effects. The frozen nucleon approximation is used and the nucleon density distribution in the nucleus is described by the charge form factor measured in elastic electron scattering. The elementary p wave photoproduction amplitude on the nucleon is restricted to the dominant M_{1^+} multipole contribution. The dependence of $M_{1^+}(p\pi^\circ)$ with energy is such that $M_{1^+}(p\pi^\circ) = Mqk$ and the value above $M_{1^+}(n\pi^\circ)$ has been taken to be 0.9 $M_{1^+}(p\pi^\circ)$ as suggested by the multipole values at 180 MeV [4]. Because the π° elastic photoproduction near threshold is only p wave, the impulse approximation cross-section of this reaction is thus used to calibrate all measurements. The ratios of the s wave production amplitudes $E^{(A)}$ by M are left as free parameters to be adjusted on the data. In table V we give the determinations of $E^{(A)}$ corresponding to the value $M = 11.2 \times 10^{-3}\ m_\pi^{-1}$ extrapolated from the multipole analysis of Pfeil and Schwela [4]. The comparison of $E^{(2)}$ and $E^{(3)}$ with the impulse approximation estimates for deuterium and helium-3 shows the importance of the rescattering effects.

Table V

The s-wave π° photoproduction amplitudes in units $10^{-3}\ m_\pi^{-1}$

Target nucleus	Impulse approximation		Experimental value
^1H	$E_{0^+}(p\pi^\circ)$	-1.8 ± 0.6	$E^{(1)} = -2.7 \pm 0.1$
^2H	$E_{0^+}(p\pi^\circ) + E_{0^+}(n\pi^\circ)$	$-1.1 \pm 1.$	$E^{(2)} = -7.4 \pm 0.3$
^3He	$E_{0^+}(n\pi^\circ)$	0.7 ± 0.8	$E^{(3)} = -4.8 \pm 0.4$

Let us note at this point that because of the coupling of the 3 channels $\gamma(A,Z)$, $\pi^+(A,Z-1)$ and $\pi^\circ(A,Z)$ there is a discontinuity in the s wave amplitude of the reaction : $\gamma + (A,Z) \to (A,Z) + \pi^\circ$, at the threshold of the reaction $\gamma + (A,Z) \to (A,Z-1) + \pi^+$ (unitarity of the S matrix). The threshold energy for π^+ photoproduction in hydrogen, deuterium and helium-3 are situated respectively 6.7 MeV, 8.7 MeV and 5.4 MeV above the corresponding π° photoproduction threshold energy ; at this energy a cusp is expected in the π° cross-section. This effect has been investigated by various authors [31,32] in the case of hydrogen. It leads below threshold to an enhancement of the s-wave amplitude relatively to the "isospin symmetry" value $E_{0^+}(p\pi^\circ)$; the amplitude at threshold is approximately $1.35\ E_{0^+}(p\pi^\circ)$. In the case of deuterium early calculations [33] including first order pion rescattering failed to reproduce the experimental value by a factor of 2 when realistic wave functions were used. Surprisingly, in the fixed scatterer approximation the first order rescattering amplitude is

$$(1 + m/M) \langle \frac{1}{r} \rangle_m \ a(\pi^- p, \pi^\circ n) \left[E_{0^+}(p\pi^-) - E_{0^+}(n\pi^+) \right] = -6.3 \times 10^{-3}\ m^{-1}$$

in good agreement with the data.

Recently Fäldt [32] has shown that this unexpected result could be explained by the overall concellation of the binding corrections when they are computed to all orders. In a complete calculation including pion rescattering up to third order, binding corrections and p wave contributions, Fäldt obtains at threshold the value : $\frac{E^{(2)}}{E^{(1)}} = 2.6$ in excellent agreement with the experimental values (which is free of the uncertainties on M) $\frac{E^{(2)}}{E^{(1)}} = 2.7 \pm 0.2$. For helium-3 the situation is very similar. Bosted and Laget [34] underestimate the rescattering effects. The fixed scatterer approximation gives the same structure of the rescattering ampiitude than in the case of deuterium ; introducing the $\langle \frac{1}{r} \rangle_{m_T}$ value of He we get $-5.4 \times 10^{-2}\ m_\pi^{-1}$ which again agrees with the experimental data.

The quality of the agreement of the detailed calculation of Fäldt with the deuterium data proves that the reaction mechanisms aspects of π^0 photoproduction can now be well mastered. This represents a necessary intermediary stage in view of the extraction of a reliable $E_{0+}(n\pi^0)$ determination from the calculated data.

In order to relax some of the hypothesis used in the data analysis, an extension of this type of calculation to the region above threshold is needed. Likewise, an absolute measurement of the cross-section of one of the reactions should solve the calibration problem,which up to now is based on the validity of the impulse approximation for the ^{4}He case and on the extrapolation of multipole values measured at much higher energy.

The absolute measurement of the π^0 photoproduction cross-section on the proton near threshold, using a monochromatic photon beam, is planned in Saclay. Besides the reasons discussed above, this experiment is important on its own right. It would allow the observation of the cross-section variation in the region of the expected discontinuity induced by the n,p and $\pi^{\pm},\pi^0$ mass splittings and possibly give information on the dynamics of the effect. In addition, an improved $E_{0+}(p\pi^0)$ determination should be in turn used to determine an "isospin symmetry" value of $E_{0+}(n\pi^0)$ which could be confronted to the one extracted from the light nuclei study (including hopefully ^{3}H).

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