Laboratori Nazionali di Frascati

LNF-73/45

G. Campos Venuti, G. Cortellessa, G. Farchi, S. Frullani, R. Giordano, P. Salvadori, K. Takamatsu, G. P. Capitani and E. De Sanctis:

PROTON ANGULAR DISTRIBUTION FROM THE ^{40}Ca(e, e'p) REACTION

Nuclear Phys. A205, 628 (1973).

2.L

Nuclear Physics **A205** (1973) 628–640; © *North-Holland Publishing Co., Amsterdam*

Not to be reproduced by photoprint or microfilm without written permission from the publisher

PROTON ANGULAR DISTRIBUTIONS FROM THE ^{40}Ca(e, e′p) REACTION

G. CAMPOS VENUTI, G. CORTELLESSA, G. FARCHI, S. FRULLANI,
R. GIORDANO, P. SALVADORI and K. TAKAMATSU [†]
Physics Laboratories, Istituto Superiore di Sanità, Rome, Italy
and
G. P. CAPITANI and E. DE SANCTIS
National Laboratories of CNEN, Frascati, Italy

Received 3 August 1972
(Revised 13 February 1973)

Abstract: Angular distributions of protons emitted in the (e, e′p) reaction on ^{40}Ca at an incident electron energy of 710 MeV and for missing energies $E_M = 39$ MeV and $E_M = 81$ MeV are presented. The interpretation of these angular distributions in terms of momentum distributions for the struck protons in the original target nucleus indicates $l \neq 0$ protons at $E_M = 39$ MeV and $l = 0$ protons at $E_M = 81$ MeV. Finally (p, 2p) and (e, e′p) results in calcium are compared.

E | NUCLEAR REACTION ^{40}Ca(e, e′p), $E = 710$ MeV; measured $\sigma(\vartheta_p)$. ^{40}Ca deduced proton momentum distributions for 39 and 81 MeV missing energies. Natural target.

1. Introduction

Within the framework of the nuclear shell model the study of separation energies and momentum distributions of protons belonging to inner shells is particularly important.

The number of reactions allowing a study of these features is limited by several difficulties, originating in particular from the need to use incoming particles of sufficiently high energy, so that the transferred momentum can be high enough to localize the interaction in a volume smaller than the nuclear volume. If this condition is fulfilled, the process may be analysed in terms of scattering on a single nucleon instead of on the nucleus.

Quasi-elastic reactions of the (p, 2p) and (e, e′p) type have been indicated as the most promising to study inner levels of nuclei, and in practice these reactions have for some time given interesting results.

The experimental results are only partially coincident, but the different properties and interactions of the particles involved generate different theoretical and experimental problems. The (p, 2p) reaction has the advantage of a higher cross section

---

[†] On leave from the Institute of Nuclear Study, Tokyo, Japan. Present address: National Laboratories of CNEN, Frascati, Italy.

and the absence of radiative processes of importance; the (e, e′p) reaction has, on the other hand, reduced problems connected with the very short mean free path of protons in nuclear matter.

After having summarized in sect. 2 the basic theoretical assumptions used to describe (p, 2p) and (e, e′p) reactions in terms of a direct interaction, a short review of the experimental features of the momentum distributions of protons ejected at different separation energies in ^{12}C and in ^{40}Ca is presented in sect. 3. The following sections are devoted to a description of the apparatus with which the present measurements were done and to a discussion of the experimental results on the angular distribution of (e, e′p) on ^{40}Ca; in sect. 6 some hints and conclusions are tentatively pointed out.

2. Theoretical features of quasi-elastic scattering

The simplest treatment of quasi-elastic scattering assumes the validity of the impulse approximation, i.e. the process is described as a direct interaction between an incoming particle and a target proton, that are then ejected while the residual nucleus participates in the process only as an average potential.

If E_i, p_i and T_i are the energy, momentum and kinetic energy of the incoming particle ($i = 0$), of the outgoing particles ($i = 1$ and $i = 2$) and of the initial ($i = A$) and residual ($i = A-1$) nuclei, the cross section of the process, in a coincidence measurement, for a definite separation energy E_s, is:

$$\left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega_1\,\mathrm{d}\Omega_2\,\mathrm{d}T_2}\right)_{E_s} = g\left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega_1}\right)_{\boldsymbol{q}}\rho(\boldsymbol{q}, E_s), \tag{1}$$

where

$$E_s = T_0 - T_1 - T_2 - T_{A-1} = M_{A-1} + M + E_{\mathrm{exc}} - E_A$$

(M_{A-1} and M are the residual-nucleus and proton mass respectively in energy units, and E_{exc} is the excitation energy of the residual nucleus); $\boldsymbol{q}$ is the momentum that the ejected proton had within the nucleus before the interaction with the incident particle, i.e.

$$\boldsymbol{q} = -\boldsymbol{p}_{A-1} = \boldsymbol{p}_1 + \boldsymbol{p}_2 - \boldsymbol{p}_0;$$

the term g is a kinematical factor; $(\mathrm{d}\sigma/\mathrm{d}\Omega_1)_{\boldsymbol{q}}$ is the cross section for free scattering on a proton moving with momentum $\boldsymbol{q}$; $\rho(\boldsymbol{q}, E_s)$ is the square modulus of a Fourier transform of the overlap integral between initial- and final-nucleus states.

If the single-particle model is valid, $\rho(\boldsymbol{q}, E_s)$ is proportional to the momentum distribution of protons bound within the nucleus with binding energy E_s, except for the distortion due to the nuclear potential. Moreover, if the dependence of $\rho(\boldsymbol{q}, E_s)$ on $\boldsymbol{q}$ is the same for residual-nucleus states even with different excitation energies, but coming from the ejection of protons belonging to the same single-particle state nlj, it is possible to write

$$\rho(\boldsymbol{q}, E_s) = A_{nlj}(E_s)\rho'_{nl}(\boldsymbol{q}), \tag{2}$$

where [1])

$$\rho'_{nl}(\boldsymbol{q}) = \frac{1}{2l+1}\sum_m \left| \frac{1}{(2\pi)^{\frac{3}{2}}}\int \mathrm{e}^{-i\boldsymbol{q}\cdot\boldsymbol{r}/\hbar c} D_0(\boldsymbol{r}, \boldsymbol{p}_0) D_1(\boldsymbol{r}, \boldsymbol{p}_1) D_2(\boldsymbol{r}, \boldsymbol{p}_2) \psi^m_{nl}(\boldsymbol{r}) \mathrm{d}^3 r \right|^2, \tag{3}$$

where D_0, D_1 and D_2 are distortion factors describing the effect of the nuclear potential on protons involved directly in the reaction (in the case of the (e, e'p) reaction $D_0 = D_1 = 1$); ψ^m_{nl} is the wave function that describes the single-particle state of the proton prior to the interaction with the incoming particle.

Under the assumption that the distortion factors do not modify substantially the shape of ρ'_{nl} as a function of $\boldsymbol{q}$, this function does not differ practically from the wave function, in momentum space, of protons belonging to the single-particle level *nlj* of the ground state of the target nucleus. It is thus possible to determine, using the parameters of the measured distribution, the quantum level of the ejected proton. Clearly the presence of one D-factor in eq. (3) for (e, e'p) reactions favors these reactions, in this respect, against (p, 2p) reactions [2]).

The factor $A_{nlj}(E_s)$ of eq. (2) is connected with the probability of finding a proton with energy E_s and quantum state *nlj*, and if the momentum distribution function $\rho'_{nl}(\boldsymbol{q})$ is normalized, $\int A_{nlj}(E_s)\mathrm{d}E_s$ is equal to the proton occupation number of state *nlj*. To simplify the analytical treatment, it is customary to assume, in the interpretation of momentum-distribution measurements, a harmonic-oscillator potential as the average potential in which nuclear protons move. Under this assumption the $\boldsymbol{q}$-dependence of $\rho'_{nl}(\boldsymbol{q})$ is, for the 1s and the 1p shells respectively,

$$\rho'_{1s}(\boldsymbol{q}) \propto \mathrm{e}^{-q^2/q^2_{01s}}, \tag{4}$$

$$\rho'_{1p}(\boldsymbol{q}) \propto (q/q_{01p})^2 \mathrm{e}^{-q^2/q^2_{01p}}. \tag{5}$$

3. Experimental features of quasi-elastic scattering

The experimental cross section of a quasi-elastic reaction as a function of the missing energy $E_M = T_0 - T_1 - T_2$ is peaked for a certain number of E_M values. The interpretation of such peaks as separation energies of protons belonging to definite single-particle levels may be substantiated by the measurement of the corresponding momentum distribution.

Experiments on the (p, 2p) reaction extend from 1957 [ref. [3])] up to the very recent results of ref. [4])[†]. The (e, e'p) reaction has been used by our group [6, 8]), by the University of Tokyo [9]) and by the Saclay Nuclear Study Center group [10]). Other (p, 2p) and (e, e'p) experiments have been performed with very different goals and kinematically very far from the direct-reaction conditions [11]).

The results obtained through (e, e'p) and (p, 2p) reactions are substantially the same as far as the missing-energy spectrum is concerned in light nuclei and for outer levels up to $A \leqq 40$, except for some still unresolved discrepancies.

[†] For a (p, 2p) review prior to 1967, see ref. [5]).

Table 1 gives, as an example, q_{01p} and q_{01s} values of the harmonic-oscillator parameters, obtained by different groups in ^{12}C. Generally, the parameters have been quoted by the authors; otherwise they have been computed by us using the published distributions and a best-fit program.

Under E_M has been indicated, in table 1, either the missing energy interval corresponding to the parameter measurement, or the average value of the energy stated by the authors. Parameter errors either have been indicated by the authors or have been evaluated to be of the order of 5–10 %.

TABLE 1

Data from angular distributions in ^{12}C

Laboratory	Reaction	E_0 (MeV)	1p		1s	
			E_M (MeV)	q_0 (MeV/c)	E_M (MeV)	q_0 (MeV/c)
Orsay [12])	(p, 2p)	155	15.8	90	34.5	160
Harvard [13])	(p, 2p)	160	12 –26	≈ 100	27 –40	≈ 150
Liverpool [14])	(p, 2p)	385	8.5–23.5	92	26.5–46.5	150
Chicago [15])	(p, 2p)	460	14.7	≈ 100		
CERN [4])	(p, 2p)	600	8 –20	94	32 –45	112
Brookhaven [16])	(p, 2p)	1000	10 –26	128	26 –50	135
Sanità [8])	(e, e′p)	605	8 –20	94 ±8	28 –38	157±18
Tokyo [9])	(e, e′p)	750	5 –18	92.3±4	25 –35	148^{+40}_{-25}

Attention has to be paid to the fact that the q_{01p} values are near to each other, except the Brookhaven measurement which is 3 errors off the average value. For the q_{01s} values, on the other hand, the CERN measurements are those more distant from the average value. The reasons for these differences, as already noted, are not yet clear and there is some significance in the fact that for a nucleus such as ^{12}C, studied so extensively and for which the values of missing energies are well established, there still exists some uncertainty. Radhakant's recent comments [17]) on (e, e′p) measurements in ^{12}C seem to suggest the need for more accurate measurements on this nucleus.

More pronounced divergences are present for high values of the missing energy for nuclei with $A \geqq 40$. The case of ^{40}Ca, from this point of view, is typical. The study of the inner levels of this nucleus was attempted for the first time by us in 1966 using the circulating beam of the Frascati electron synchrotron [7]). The missing-energy spectrum had the same features as (p, 2p) data for outer levels, but showed also (e, e′p) coincidences for missing-energy values over 80 MeV.

The interpretation of the spectrum in this region indicates the existence of a broad peak identified tentatively as 1s. Only the measurement of the proton momentum distribution could substantiate such an attribution. Unfortunately the geometrical limitations of the Frascati synchrotron did not allow a complete measurement at that time.

Measurements on ^{40}Ca and heavier nuclei have been performed by the Liverpool group [18]) using the (p, 2p) reaction, and the results show an apparent discrepancy with those previously obtained by our group. It is, in fact, evident that while the missing energy attributed by the Liverpool group to the 1p peak does not differ from our value, the proton momentum distribution shows, for missing energies over about 60 MeV, a flat shape, interpreted by the authors as multiple interaction events connected with the ejection of more than one particle from the nucleus. Very recently Koltun [19]) has shown that by comparing the average separation energy of protons deduced from a mass formula and the same value obtained from the Liverpool measurement, better agreement is obtained through the addition of events with missing energies over 60 MeV. This may indicate a 1s contribution from higher energies than those indicated in the Liverpool work.

The (p, 2p) measurements of the CERN group at $A \geqq 40$ nuclei [4]) have yielded results in good agreement with those obtained by the Liverpool group. Unfortunately the CERN group has not measured the momentum distribution for $E_M \geqq 60$ MeV.

Finally, previous results of the (e, e′p) reaction on ^{40}Ca by the Saclay group [10]) did not show evidence of protons with missing energies of more than 60 MeV. In this case, however, the accidental/true ratio was quite high (between 0.5 and 1), and there is some doubt that statistical fluctuations could mask the broad peaks coming from inner-shell proton extraction. This remark is obviously more applicable to the 1s peak than to the 1p one, because the former has a smaller cross section and a larger natural width.

In such a situation, our group felt the necessity of further studies to clarify, at least for one value of the missing energy over 60 MeV, this aspect under debate. We therefore have compared momentum distributions in calcium for two values of the missing energy, over 60 MeV and in the 1p peak region.

4. Experimental apparatus

The experimental conditions under which the measurements of momentum distributions of protons in ^{40}Ca have been performed are given in table 2 [†]. In fig. 1 the momentum balance of the reaction for the missing energy of 81 MeV, in the usual form of the "onion cut" diagram, is drawn. The corresponding diagram for 39 MeV missing energy is similar, but for the parameters which can be deduced from table 2.

An overall view of the experimental set-up is shown in fig. 2. The experiment was performed using the extracted beam of the Frascati electron synchrotron. Some characteristics of the extracted beam at $E_0 = 710$ MeV are: maximum intensity $\approx 4 \times 10^{11}$ electrons/s; duty ratio 3 %; energy spread $\Delta E_0 = \pm 1$ MeV.

The extracted beam was focussed and guided under vacuum by five quadrupoles and two bending magnets up to the target point where its vertical section was 4 mm

---

[†] In table 2 and in the following, the subscripts 1 and 2 for scattered particles are replaced by the subscripts e (electron) and p (proton) when referring to the (e, e′p) reaction.

and its width 6 mm.

Scattered electrons, edge-focussed horizontally by a flat-pole magnet, were counted by 11 scintillation counters E_i. The first eight $E_1, \ldots, E_8$ were mounted on a frame which could be moved along the focal line so that it was possible, with four successive settings, to explore the whole line from a momentum of 500 MeV/c to 610 MeV/c. Three other large counters behind the focal-line counters assured for a multiple coincidence to reduce the accidental rate.

TABLE 2

Experimental conditions

	E_M = 39 MeV	E_M = 81 MeV
E_0 (MeV)	710	710
E_e (MeV)	570	528
θ_e (deg)	39	39
$\Delta\Omega_e$ (msr)	0.9	0.9
T_p (MeV)	101	101
$\theta_p{}^0$ (deg)	53.3	48.16
$\Delta\Omega_p$ (sr)	0.149	0.152

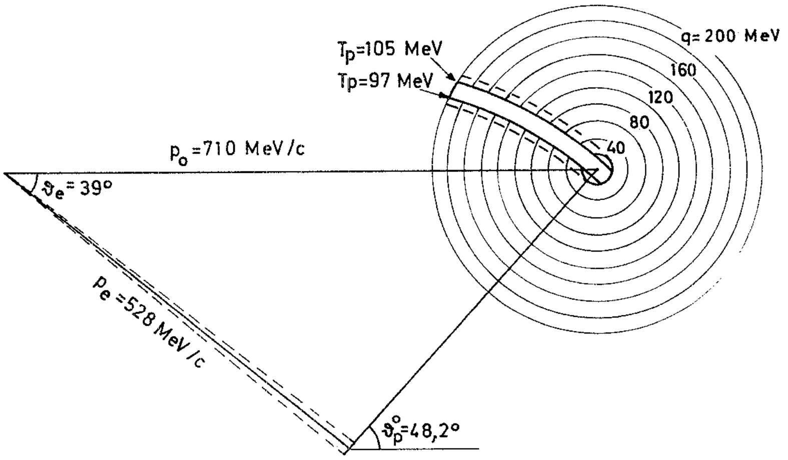

Fig. 1. Kinematic conditions. "Onion cut" diagram for proton angular distribution at 39 MeV missing energy.

Protons were energy selected by a range telescope of three coincidence scintillation counters and one anticoincidence scintillation counter, P_4, with proper absorbers. Angular selection was obtained by a system of ten concentric counters shown in fig. 3. The central counter A_1 of the system is circular, the remaining nine counters $A_2, \ldots, A_{10}$ are annular portions of constant width. This geometry immediately follows from the choice of parameters as in table 2 and fig. 1. The counters are positioned, for each value of the missing energy interval under study, so that the center of counter A_1 is in the median plane at the angle θ_p^0 corresponding to the direction of the ejected proton with initial momentum in the nucleus equal to zero. The assumption is here made, supported by theoreticians 2,20), that no shift in θ_p^0 is induced by distortions.

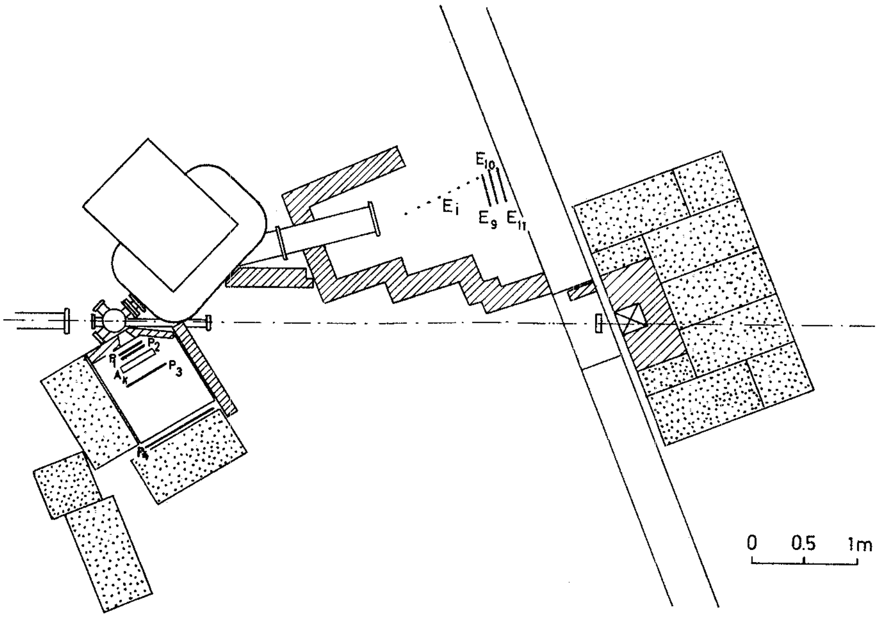

Fig. 2. Sketch of the experimental set-up.

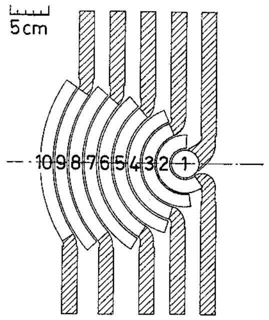

Fig. 3. Sketch of the angular counters. Solid angles subtended by counters are different: these differences are taken into account by data normalization.

Under these kinematical conditions the product $g(\mathrm{d}\sigma/\mathrm{d}\Omega)_q$ of expression (1) does not vary with $\boldsymbol{q}$ for each value of the missing energy, and varies within few percent between the two values of the missing energy here considered.

In fig. 4 is shown the block diagram of the electronics. All resolving times are 10 ns, and separate delayed channels allow the counting of accidentals.

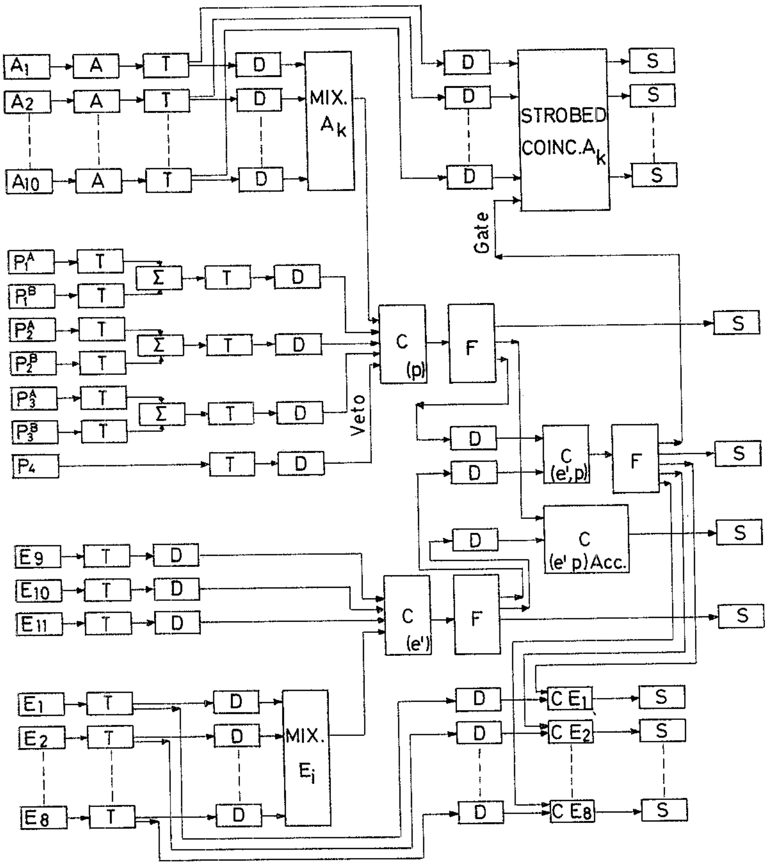

Fig. 4. Electronics block diagram. A: amplifier; T: trigger discriminator; D: delay; Σ: mixer; C: coincidence; F: fan-out; S: scaler.

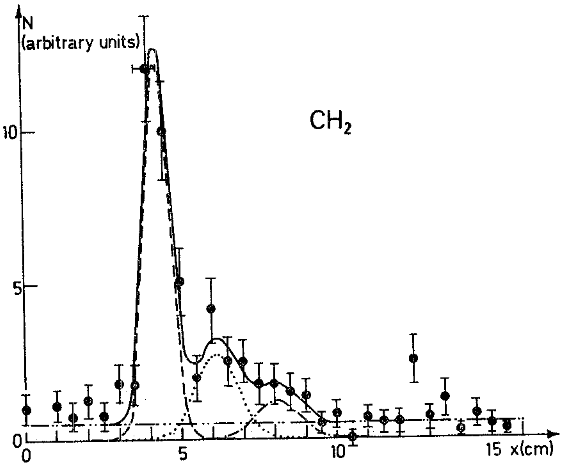

Fig. 5. CH_2 spectrum as a function of the scattered electron's coordinate along the focal line.

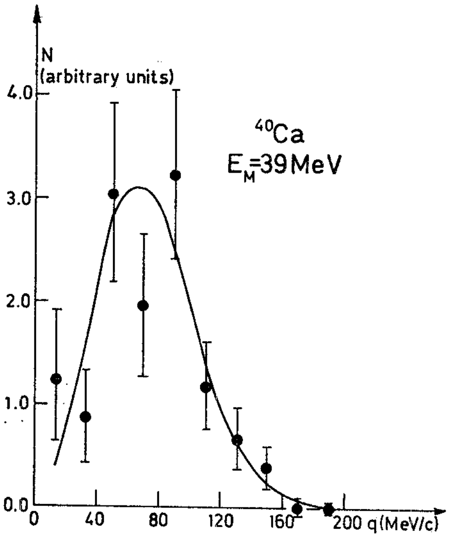

Fig. 6. Momentum distribution of bound protons for 39 MeV missing energy in calcium.

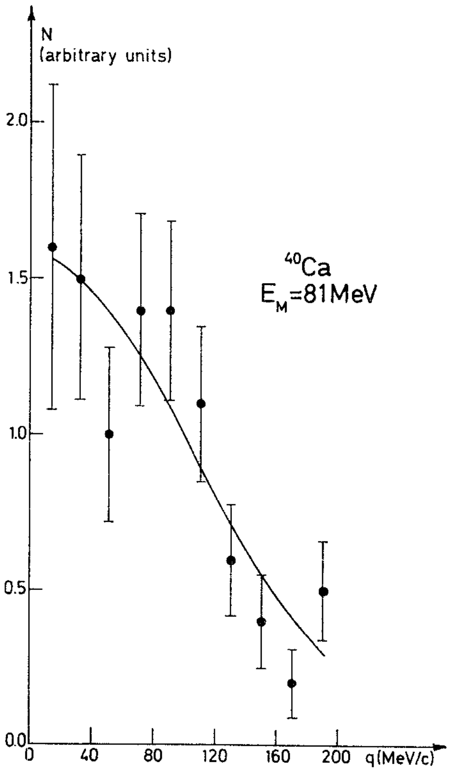

Fig. 7. Momentum distribution of bound protons for 81 MeV missing energy in calcium. Same arbitrary units of fig. 6 are used.

5. Experimental results

In order to check the experimental set-up several tests were done. As an example the spectrum obtained with a CH_2 target is shown in fig. 5. The abscissae are the positions of the $E_1, \ldots, E_8$ counter frame; the counting rate is plotted vertically in arbitrary units. The spectrum has been analysed in the three expected peaks due to free scattering on hydrogen and quasi-elastic scattering on 1p and 1s carbon levels. The overall experimental resolution is in quite good agreement with the expected one, while the dispersion along the focal line agrees completely with the computation made by using the map of the magnetic field and with trajectory simulation with the wire method. The annular counter system has been checked with free scattering from hydrogen. All measurements have been corrected for proton multiple scattering on the telescope absorbers.

The missing-energy spectrum measured with a calcium target was in good agreement with our previous results [7]). The momentum distribution in ^{40}Ca has been measured for the two missing-energy values $E_M = 39$ MeV and $E_M = 81$ MeV, with the parameters listed in table 2. A narrow band of scattered electrons was selected using a single counter out of $E_1, \ldots, E_8$; detected momenta varied from 0 MeV/c to 200 MeV/c, in steps of about 20 MeV/c, in each counter. The energy interval accepted by the telescope was ±2.4 MeV for $E_M = 39$ MeV, and ±4.2 MeV for $E_M = 81$ MeV: consequently, the overall resolution was ±4 MeV at $E_M = 39$ MeV and ±5.5 MeV at $E_M = 81$ MeV.

TABLE 3

Parameters of angular distributions of protons in ^{40}Ca in the present experiment

E_M	A	q_0
39 MeV	1.2	65
81 MeV	1.6	148

The counting rates for the counters A_k, as a function of q, are given by figs. 6 and 7. Accidentals have been subtracted, having been maintained in each run below 10 % of the true coincidence rate. The multiple scattering of protons in the absorbers has been taken care of using first-order Molière theory. The experimental data of figs. 6 and 7 have been fitted with the functions:

$$A(q/q_0)^2 e^{-q^2/q_0^2}, \qquad E_M = 39 \text{ MeV},$$

$$A e^{-q^2/q_0^2}, \qquad E_M = 81 \text{ MeV},$$

respectively, varying the parameters A and q_0. Because the numbers of events is limited, particular attention has been paid to the choice of interpolation criteria. For a preliminary evaluation of the reliability of the hypothesis concerning the distributions in both cases, the χ^2 test has been used. The final values of A and q_0 have been computed, instead, with the maximum-likelihood method assuming a Poisson distribution for the counts in each A_k channel. It is important to state that there is very little difference in the parameter values computed by either method. Parameter values are given in table 3. The errors on the q_0 values, computed with the χ^2 method, are of the order of 15 %.

Radiative corrections have not been applied because, at present, we are not interested in the absolute value of the cross section, but we want only to understand the quasi-free scattering behaviour at high missing energies. A computation by Borie [21]) using the kinematic conditions of our measurement and formulae for the radiative corrections in (e, e′N) coincidence experiments given in ref. [22]) shows that even putting the peak of the 1s level at 50 MeV in ^{40}Ca, with a reasonable width, the parameter value of a measured distribution at 80 MeV could be overestimated by only 10–15 % with respect to a distribution in which the radiative effects are subtracted. It is to be noted that if the peak of the 1s level is at a higher energy, the error in the parameter measurement is much less.

As far as contamination by other reactions was concerned, a close scrutiny of all possibilities excluded contaminations of more than a few percent.

6. Conclusions

The values of the (p, 2p) and the present (e, e′p) measurements on calcium are compared in table 4.

It is easily seen that the harmonic-oscillator parameters used to interpolate the momentum distributions measured with different reactions are the same within the errors (surely of the order of 10 %). It is necessary, nevertheless, to point out that in the case of the (e, e′p) reaction, the q_{01s} parameter has been determined from angular distributions measured in an energy interval very different from that used in the (p, 2p) experiments. Additionally, in the missing energy region of the (e, e′p) experiment, the Liverpool measurement of the momentum distribution gives a flat shape hardly capable of interpretation as a direct reaction. If, thus, there is numerical agreement between the q_{01s} parameters of Liverpool and our measurements, the discrepancy is large in respect of the extension of the region of missing energies pertaining to the 1s level. We have confirmed what was already evident in our previous paper on the missing-energy

TABLE 4

Parameters of angular distributions of protons in ^{40}Ca in different experiments

Laboratory	Reaction	E_0 (MeV)	1p		1s	
			E_M (MeV)	q_0 (MeV/c)	E_M (MeV)	q_0 (MeV/c)
Liverpool [18])	(p, 2p)	385	36–41	89	46 –51	148
CERN [4])	(p, 2p)	600	35–40	87.5	40 –60	126
Sanità	(e, e′p)	710	35–43	65	75.5–86.5	148

spectrum in calcium ^{7}), i.e. that a direct reaction mechanism persists at missing energies over 80 MeV.

It is thus necessary to pose the question how it could be justified that harmonic-oscillator parameters giving a good fit in different experiments remain the same, in the missing energy interval from 40 MeV to over 80 MeV, without accepting the hypothesis that the 1s level is so wide as to be extended up to such high energies. It is to be noted that even in ^{12}C the 1s peak has a tail up to about 70 MeV [ref. ^{4})].

Conversely, if the interpretation of the 80 MeV missing energy in calcium as the separation energy of 1s protons is rejected, then serious doubt is cast upon the corresponding interpretation of peaks measured with the same (p, 2p) and (e, e′p) reactions for lower values of the missing energy.

As a further comment on the Liverpool measurements ^{18}), there still remains to be analysed the amount of absorption and distortion produced by the nuclear potential, which is particularly important for protons coming from inner levels. The distortions, as already pointed out, could completely alter the dependence of $\rho(\boldsymbol{q}, E_s)$ on $\boldsymbol{q}$. A deeper insight could either justify the apparent discrepancies among experiments, or lead to the conclusion that, at least for (p, 2p) experiments, a simple picture such as that currently used for defining a measurable $\rho(\boldsymbol{q}, E_s)$, is out of the question.

Finally it is necessary to stress the difficulties encountered when a simple interpretation of the processes at high missing energies is attempted. As an example, there must be some meaning in the fact that from early (p, 2p) data to recent CERN measurements, from our initial (e, e′p) data to the last measurements of many groups, the attribution of the proton number of the 1s level, e.g., in ^{40}Ca is unreasonable from the point of view of a shell-model description of the nucleus.

In conclusion, a systematic measurement of the momentum distributions of protons in nuclei for different intervals of missing energies (up to values over those already explored so far) seems necessary to check the consistency of the approximations and hypotheses normally used to interpret these reactions, even if the excitation energy of the residual nucleus is so high that there are serious doubts that the reaction mechanism should be very different from what is generally adopted theoretically.

It is our duty to thank the group technical staff, A. Calicchia, M. Gricia and G. Grisanti, for their cooperation in testing the experimental equipments, R. Orlando, L. Pecchi and L. Cesarini, and the electronic shops and the mechanical shops both of Istituto Superiore di Sanità, Laboratori di Fisica, and of Frascati Laboratories for continuous technical support. Finally we are indebted to the machine group of the Frascati electron synchrotron for efficiency in running the machine and especially the extracted beam. This work has been done within the framework of the activity of the Sezione Sanità of the INFN.

References

1) G. Jacob and Th. A. J. Maris, Rev. Mod. Phys. **38** (1966) 121
2) G. Jacob and Th. A. J. Maris, Nucl. Phys. **31** (1962) 139, 152;
C. Ciofi degli Atti, Nucl. Phys. **A106** (1968) 215, and private communication
3) H. Tyrén, Th. A. J. Maris and P. Hillman, Nuovo Cim. **6** (1957) 1507;
H. Tyrén, P. Hillman and Th. A. J. Maris, Nucl. Phys. **7** (1958) 10
4) G. Landau *et al.*, Nucl. Phys. **A173** (1971) 337;
S. Kullander *et al.*, Nucl. Phys. **A173** (1971) 357
5) M. Riou and Ch. Ruhla, Prog. Nucl. Phys. **11** (1970) 195;
T. Berggren and H. Tyrén, Ann. Rev. Nucl. Sci. **16** (1966) 153;
M. Riou, Rev. Mod. Phys. **37** (1965) 375
6) U. Amaldi, Jr., *et al.*, Phys. Rev. Lett. **13** (1964) 341; Nuovo Cim. suppl. **3** (1965) 1149;
U. Amaldi, Jr., *et al.*, Atti Accad. Nazl. Lincei, Rend., Classe sci. fis. mat. e nat. **38** (1965) 499; **39** (1965) 470;
U. Amaldi, Jr., *et al.*, Atti Accad. Nazl. Lincei, Rend., Classe sci. fis. mat. e nat. **41** (1966) 494
7) U. Amaldi, Jr., *et al.*, Phys. Lett. **22** (1966) 593
8) U. Amaldi, Jr., *et al.*, Phys. Lett. **B25** (1967) 24
9) S. Hiramatsu *et al.*, University of Tokyo, Institute for Nuclear Study, report INS J-122 (1970)
10) A. Bussière, J. Mougey, Phan Xhuan Ho, M. Priou and I. Sick, Nuovo Cim. Lett. **2** (1971) 1149
11) O. Chamberlain and E. Segrè, Phys. Rev. **87** (1952) 81;
J. B. Cladis, W. N. Hess and B. J. Moyer, Phys. Rev. **87** (1952) 425;
M. Croissiaux, Phys. Rev. **127** (1962) 613;
A. Johansson, Phys. Rev. **136** (1964) 1030;
P. Bounin, Ann. de Phys. **10** (1965) 475
12) J. P. Garron *et al.*, Nucl. Phys. **37** (1962) 126
13) B. Gottschalk, K. H. Wang and K. Strauch, Nucl. Phys. **A90** (1967) 83
14) A. N. James, P. T. Andrews, P. Butler, N. Cohen and B. G. Lowe, Nucl. Phys. **A133** (1969) 89
15) H. Tyrén, S. Kullander, O. Sundberg, R. Ramachandran and P. Isacsson, Nucl. Phys. **79** (1966) 321
16) W. D. Simpson *et al.*, Nucl. Phys. **A140** (1970) 201
17) S. Radhakant, Nucl. Phys. **A188** (1972) 353
18) A. N. James, P T. Andrews, P. Kirkby and B. G. Lowe, Nucl. Phys. **A138** (1969) 145
19) D. S. Koltun, Phys. Rev. Lett. **28** (1972) 182
20) C. D. Epp and T. A. Griffy, Phys. Rev. **C1** (1970) 1633
21) E. Borie, private communication
22) E. Borie and D. Drechsel, Nucl. Phys. **A167** (1971) 369