ᴵᴵᶻATION FOR NUCLEAR RESEARCH

PH III-68/8
19 January 1968

PHYSICS III COMMITTEE

PROPOSAL TO MEASURE THE CROSS-SECTIONS OF THE REACTIONS $\pi^- + p \to \pi^0 + n$ AND $\pi^- + p \to \gamma + n$ AT THE SC

by

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(received 17 January 1968)

INTRODUCTION

The pion nucleon scattering cross-sections in the region below 300 MeV (incident kinetic energy in laboratory) are known to an accuracy of 5-10% [1]. A unique phase-shift analysis of these data exists [2]. However, new accurate experimental results should improve our knowledge of phase shifts and, thereby [2,3], of interesting physical quantities such as pion-nucleon coupling constant, pion-nucleon scattering lengths and the π-π interaction. Also, our understanding of electromagnetic corrections and the validity of charge independence would be tested. Measurements of pion nucleon scattering in this energy region are thus being continued both at CERN (Waloschek group) and elsewhere, and are yielding interesting results.

The cross-section for the charge exchange reaction $\pi^- + p \to \pi^0 + n$ is in general known to a lesser accuracy then the cross-sections for the elastic reactions $\pi^+ + p \to \pi^+ + p$ and $\pi^- + p \to \pi^- + p$. In fact, below 300 MeV no direct measurements of the charge exchange scattering have been performed. The measured quantity [1] is the angular distribution of γ rays from the decay of the π^0's. The knowledge of the differential cross-section of the charge exchange scattering is therefore indirect and sometimes open to suspicion, as demonstrated by the comparison with existing measurements

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of outgoing neutrons above 300 MeV [4]. Figure 1 shows the measured coefficients of an expansion of the charge exchange differential cross-section in Legendre polynomials, together with the phase shift solution of Roper[5].

The most recent and detailed analysis of the photoproduction of pions from nucleons is due to Donnachie and his collaborators[6]. The existing experimental results are less copious and accurate than in the case of pion nucleon scattering. In particular, apart from the Panotsky ratio and one experimental point at 72 MeV, measured by Gatti et al.[7] at CERN, in 1961, no data on the reaction $\pi^- + p \rightarrow \gamma + n$ exist to our knowledge. The existing information on the inverse reaction $\gamma + n \rightarrow \pi^- + p$ as deduced from experiments on deuterons[8] is not very reliable because of three-body complications. Table 1 summarizes the experimental knowledge on the reaction $\pi^- + p \rightarrow \gamma + n$. The corresponding theoretical predictions[6] are also listed. Further experimental investigations of the radiative capture of negative pions would improve our knowledge of the pion photoproduction processes[3]. They should facilitate the determination of multipole transition elements and test the calculations based on dispersion relations. They should contribute towards a determination of the $\rho\pi\gamma$ coupling as well as towards tests of the Watson theorem, the $\Delta T \leqq 1$ rule[9] and predictions of PCAC [10].

The charge exchange and radiative capture of pions in nuclei may be expressed in terms of the corresponding elementary processes and nuclear form factors of various kinds. The latter are of interest for nuclear structure physics. Several theoretical calculations of these processes in nuclei have been performed[11,12,13], but existing experimental information is scarce[14]. We believe that techniques developed for the investigation of charge exchange and radiative capture of pions in hydrogen will be useful for nuclear studies as well.

For these reasons we propose to initiate an experimental programme at the SC, aimed at:

1) remeasuring the charge exchange of negative pions below 300 MeV with a different method and hopefully better accuracy than before;

2) measuring the cross-section for the radiative capture of negative pions in the same energy region;

3) investigating both reactions on bound protons in nuclei.

This programme would be a natural extension of the work by Waloschek and collaborators on the elastic pion nucleon scattering. It would exploit the excellent characteristics of the MSS beam which, for the time being, place CERN in a favourable position for this kind of research as compared to other laboratories.

EXPERIMENTAL METHOD

For a direct measurement of the charge exchange reaction as well as of the radiative capture it is advantageous to detect the outgoing neutrons. The kinematics of the reactions in the region of interest and the properties of neutron detectors dictate the experimental method.

In Fig. 2 we plot the laboratory kinetic energy of the neutron as a function of the laboratory neutron angle for both reactions and for two different incident energies in the range of interest. We also indicate the corresponding centre-of-mass angles of the π^0 and γ, respectively. It is seen that the neutron energies range from 0 to 200 MeV which sets high demands on measurement techniques and precludes the use of a unique detector. Furthermore, the knowledge of the neutron detector efficiency is likely to be one of the factors limiting the accuracy of the results. For these reasons we propose to measure at certain fixed neutron energies where the detectors have been well calibrated, as a function of the incident pion energy. A similar strategy has been adopted and found advantageous by Waloschek and collaborators in their measurement of the elastic π^- scattering.

A convenient, albeit somewhat arbitrary, classification of different regions of neutron energies, is the following:

1) 4-14 MeV. Here the two reactions are well separated in angle, for a given neutron energy. The energy resolution obtained by time-of-flight measurements is good and the detectors can be well calibrated with a neutron generator and neutrons from $\pi^- + p \rightarrow n + \gamma$ at rest. On the other hand, the copious production of high energy neutrons at forward angles may create background problems.

2) 14-80 MeV. In this region the time-of-flight technique is still feasible, but larger distances and therefore larger detector areas are

required. Also, the angular separation of the two reactions at given neutron energy becomes smaller.

3) 80-200 MeV. Here the separation of the radiative capture from charge exchange by time-of-flight would be very difficult. We believe that in this region the radiative capture should be identified by accurate determination of the angles of both the neutron and γ ray, presumably by spark chamber techniques. However, to measure the charge exchange reaction only, time-of-flight methods should in general still be adequate.

We propose to concentrate in the first stage of the experiment on the region of neutron energies from 4 to 14 MeV. This has the advantage that several members of our group have experience in neutron spectroscopy in this energy range and that the detectors can be tested and calibrated partly at the University of Lausanne. Simultaneously with the first stage of the experiment, we could perform tests with detectors needed to attack the other two regions of neutron energies.

EXPERIMENTAL ARRANGEMENT

The experiment should be performed in the MSS beam, with a liquid hydrogen target. The experimental arrangement is shown schematically in Fig. 3.

The number of incident particles is counted by $C_1C_2C_3$. The beam shape is constantly monitored by proportional counter hodoscopes $P_1P_2P_3P_4$. The beam composition is monitored by measuring the time-of-flight to C_4 (over a distance of about 7 m) and the spectrum in the Čerenkov counter Č.

A neutral event is indicated by $C_1C_2C_3\bar{A}_1\bar{A}_2$. The neutrons are detected by plastic scintillators with a surface of about 20 cm × 20 cm and about 10 cm thick. We shall use as many detectors as we can economically acquire and place at appropriate angles around the target. If necessary, the neutron detectors will be surrounded by additional anti-coincidence shields. The positions of the detectors will be slightly changed as a function of the incident pion energy so as to keep the central neutron energy at about 9 MeV.

The efficiency of neutron detectors between 4 and 14 MeV will be first determined at the neutron generator of the University of Lausanne with neutrons from the reaction d + t. With the equipment in place the 9 MeV neutrons from radiative capture of stopped π^- mesons in hydrogen will be used for additional calibration. Finally, if necessary, the detectors may be calibrated by the scattering on hydrogen of neutrons from an internal SC target and momentum determination of the recoil proton (using proton detectors from the π^+, 2p experiment).

The predicted differential cross-sections in the laboratory system for the two reactions at several laboratory neutron energies are shown in Fig. 4 as functions of the incident energy. The charge exchange cross-section has been calculated on the basis of CERN phase shifts[15)] while for the radiative capture the results of Ref. 6 have been applied. It is seen that radiative capture is much less probable than charge exchange. Therefore, while the determination of the neutron time-of-flight should suffice to identify a charge exchange event, coincident detection of the γ will most probably be necessary to identify a capture event. For this purpose we plan to use Čerenkov counters or spark chambers (see Fig. 4) whose efficiencies should be easily determined once the charge exchange cross-section has been measured.

We hope to cover a solid angle of about 0.1 steradian with capture detectors and about 0.02 steradian with the charge exchange detector. With detection efficiencies of the order of 20%, a 10 cm long hydrogen target, and pion intensities of the order of 2×10^5 π^-/sec we thus expect counting rates of the order of 100/hour for the radiative capture and several thousands/hour for the charge exchange. We should like to aim at a statistical accuracy of 1% for the charge exchange reaction and 3-10% for the radiative capture, which would require 1-2 data-taking shifts of SC time per incident energy value.

We plan to measure at about 10 different incident energies between about 100 and 300 MeV and eventually investigate the possibility of going to lower energies. This would require around 40 data-taking shifts and, with time for background measurements and calibration, as well as the usual "overhead" time, would constitute an experiment about 100 shifts long. We should like to have our first shifts in September and October 1968.

REFERENCES

1) References may be found in: L.D. Roper, R.M. Wright and B.T. Feld, Phys.Rev. 138, B190 (1965).

2) C. Lovelace, "Nucleon resonances and low energy scattering", CERN Preprint TH.837.

3) A. Donnachie, "Theoretical remarks on the need for studies of π^- nucleon interactions", PH III - 67/38 Rev., p. 28 (1967).

4) D.L. Lind, B.C. Barish, R.J. Kurz, P.M. Ogden and V. Perez-Mendez, Phys.Rev. 138, B1509 (1965).

5) L.D. Roper and R.M. Wright, UCRL-7846 (1964).

6) F.A. Berends, A. Donnachie and D.L. Weaver, "Photoproduction and electroproduction of pions", CERN Preprints TH.703 (1966) and TH.744 (1967).

7) J. Gatti, P. Hillman, W.C. Middelkoop, T. Yamagata and E. Zavattini, Phys.Rev.Letters 6, 706 (1961).

8) D. Garelick and G. Cooperstein, Phys.Rev. 136, B201 (1964).

9) G. Shaw, "Internal symmetries of the electromagnetic current: experimental tests", RHEL Preprint RPP/A 24.

10) S.L. Adler and F.J. Gilman, Phys.Rev. 152, 1460 (1966).

11) M. Ericson and T.E.O. Ericson, Ann.Phys. (N.Y.) 36, 323 (1966).

12) J.D. Murphy, R. Raphael, H. Überall, R.F. Wagner, D.K. Anderson and C. Werntz, Phys.Rev.Letters 19, 714 (1967).

13) M. Ericson and A. Figureau, "Radiative pion capture and axial currents in nuclei", CERN Preprint TH.847.

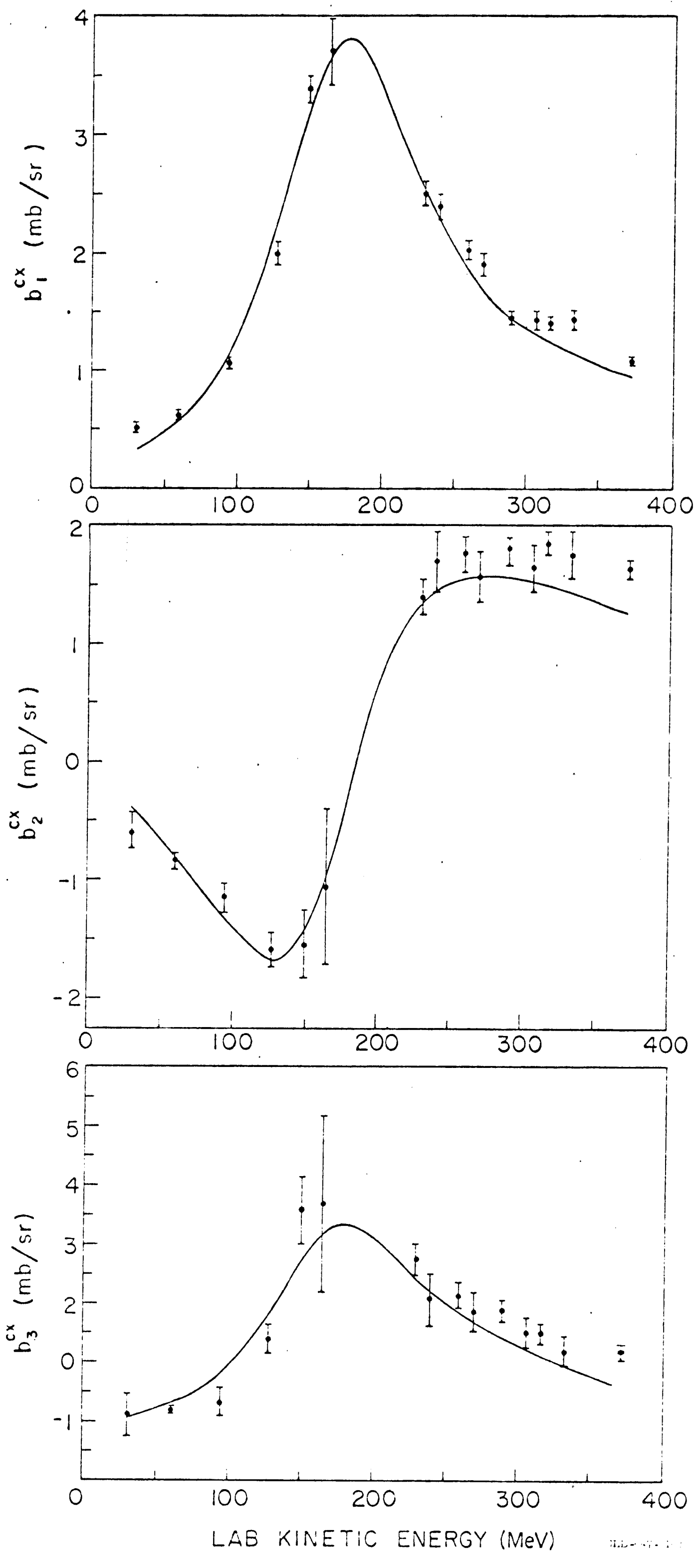
14) References may be found in: Č. Zupančič, Proceedings of the International Conference on High Energy Physics and Nuclear Structure, Rehovoth 1967, North-Holland Publ., p. 171.

15) A. Donnachie, R.G. Kirsopp and C. Lovelace, "Tables of pion-nucleon phase shifts", TH.838 Addendum.

Table 1

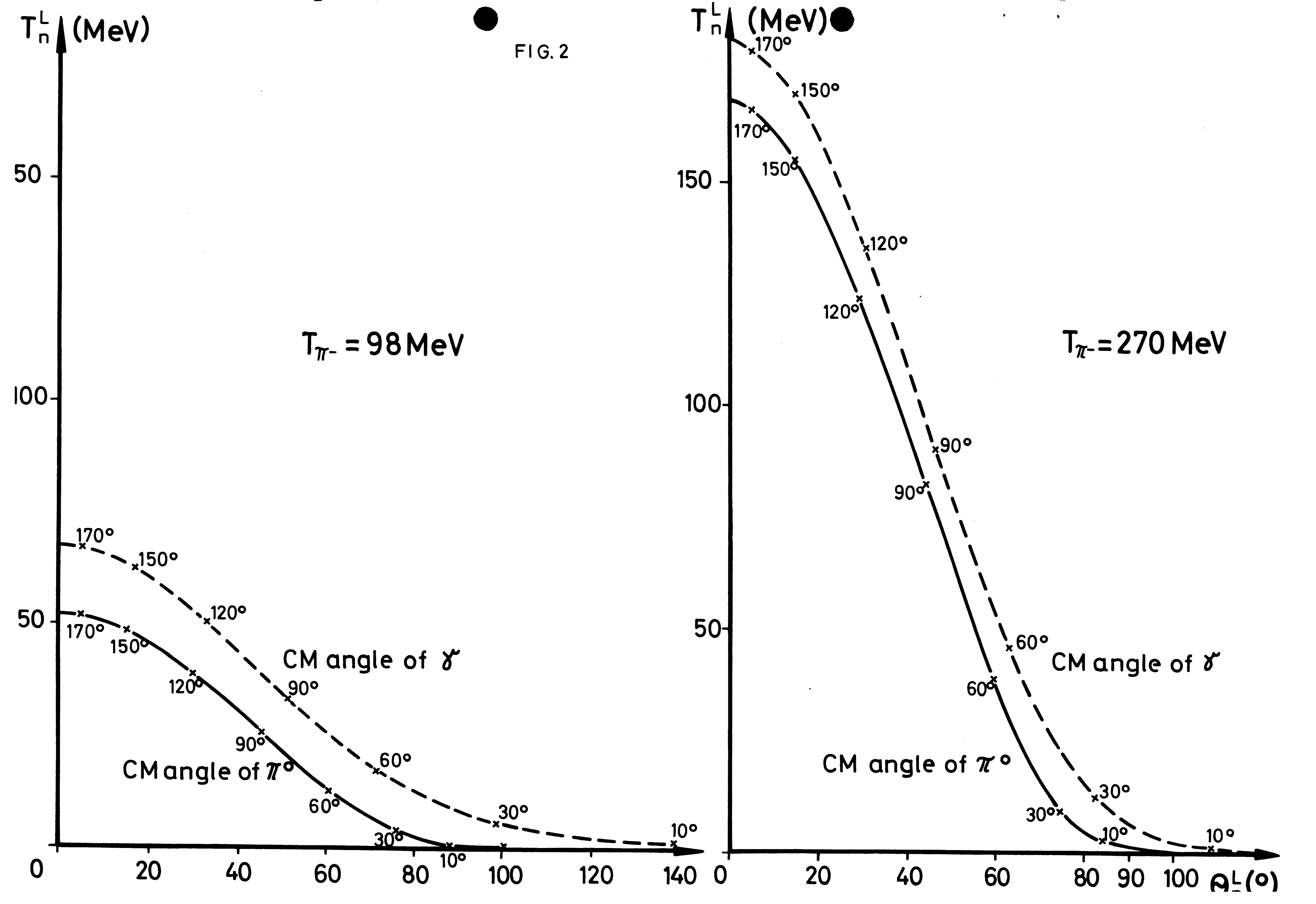
$T^{L}_{\pi^-}$	Θ^{CM}_{γ}	$\left(\frac{d\sigma}{d\Omega}\right)^{CM}_{exp}$	$\left(\frac{d\sigma}{d\Omega}\right)^{CM}_{theor}$	Experimental Reference	Comment
72 MeV	90°	70 ± 7 μb/sr	60 ± 3 μb/sr	Gatti et al.[7]	–
125 MeV	92°	55 ± 6 μb/sr	78 ± 3 μb/sr	Garelick and Cooperstein[8]	Calculated from the inverse reaction, which was determined by measuring γ+d → π^-+n+p and performing the Chew-Low extrapolation.
"	112°	52 ± 6 μb/sr	74 ± 3 μb/sr		
"	132°	49 ± 6 μb/sr	65 ± 3 μb/sr		

Fig. 1



The solution versus charge-exchange differential cross section coefficients (see Data section).

FIG. 2



T_n^L (MeV)
T_{π^-} = 98 MeV
CM angle of γ
CM angle of π°
170°
150°
120°
90°
60°
30°
10°
0
20
40
60
80
100
120
140
50
100
50
T_n^L (MeV)
T_{π^-} = 270 MeV
CM angle of γ
CM angle of π°
150
100
50
90
θ_π^L (°)

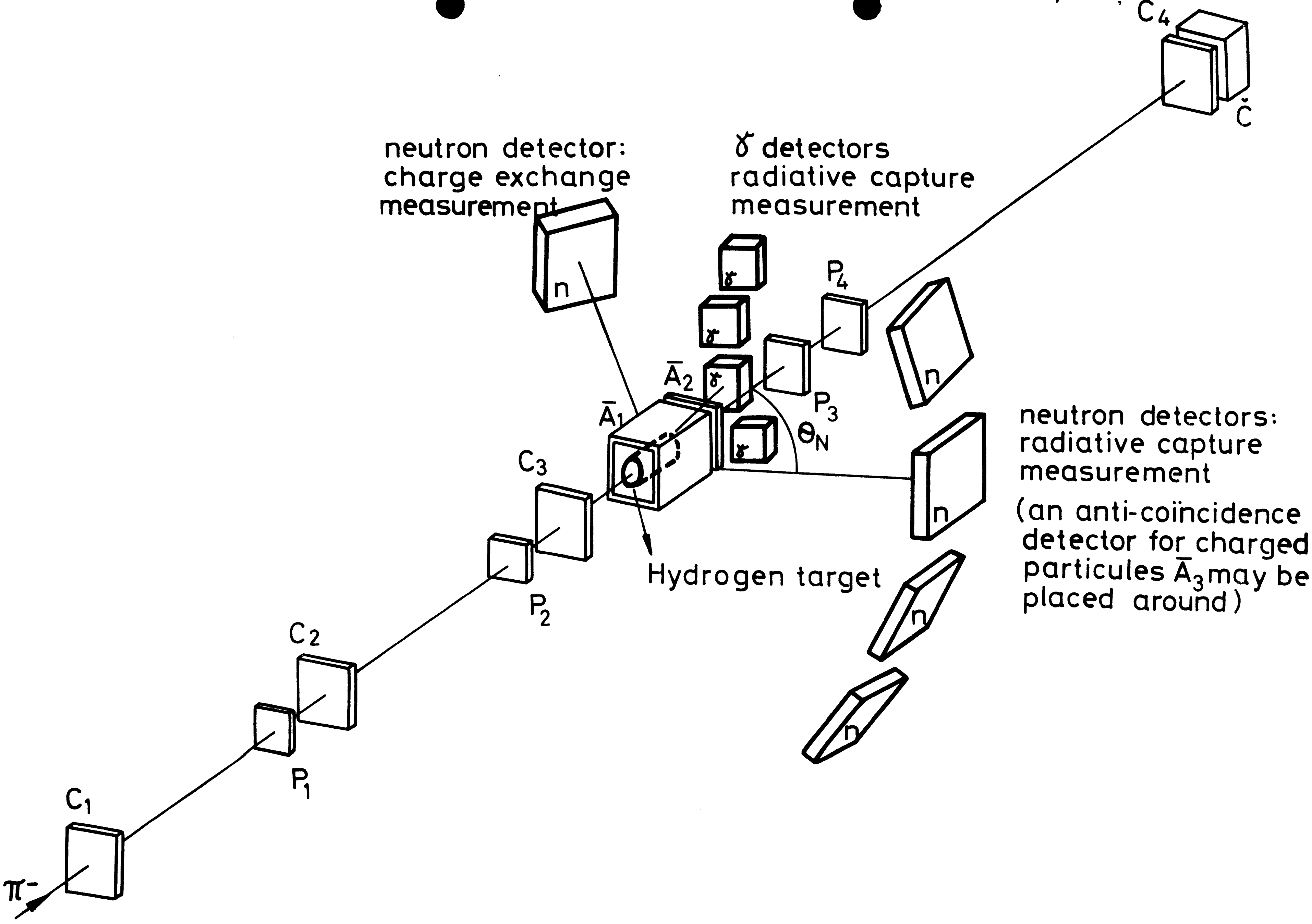
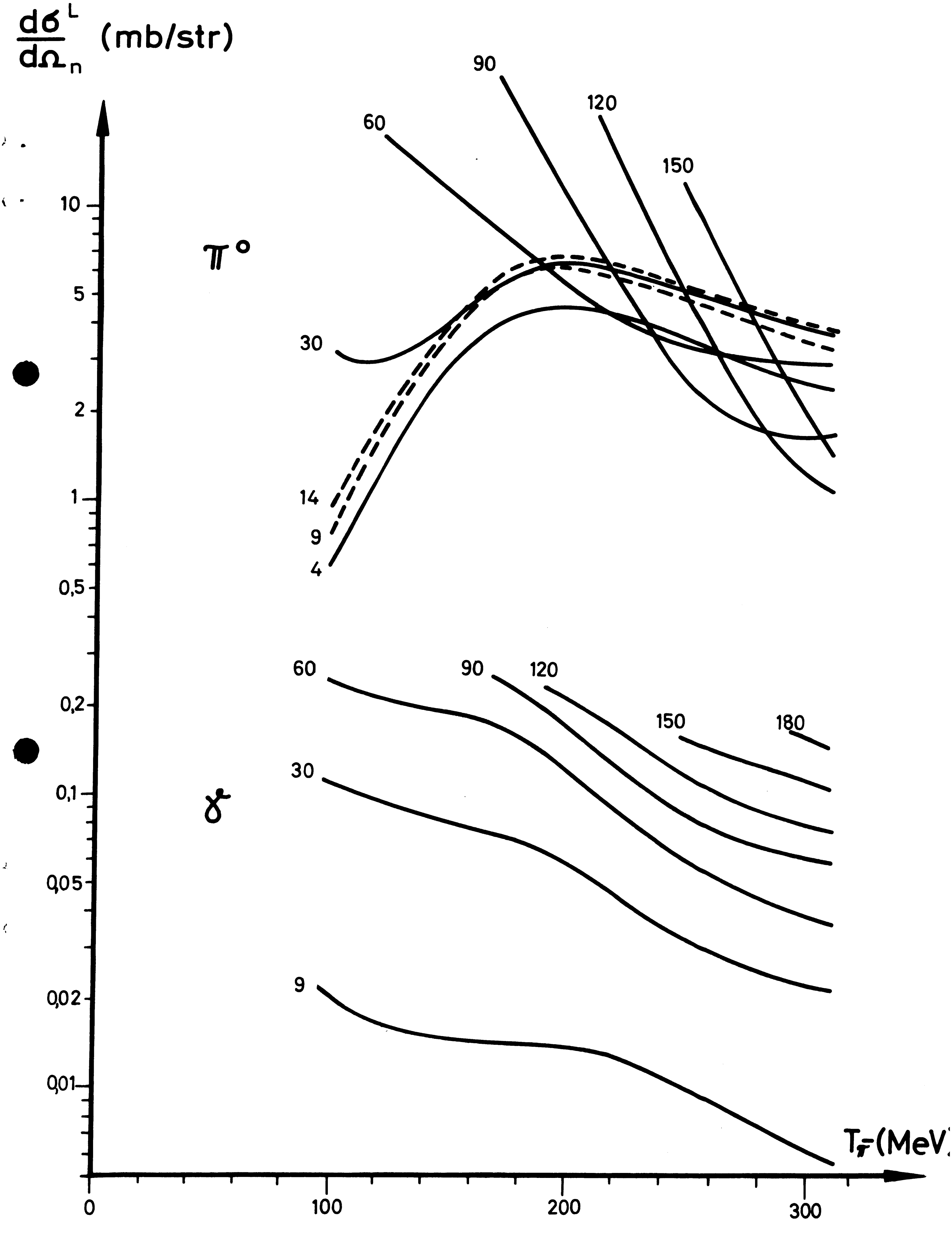

neutron detector: charge exchange measurement
γ detectors radiative capture measurement
neutron detectors: radiative capture measurement
(an anti-coïncidence detector for charged particules $\bar{A}_3$ may be placed around)
Hydrogen target
C_1
C_2
C_3
C_4
$\check{C}$
P_1
P_2
P_3
P_4
$\bar{A}_1$
$\bar{A}_2$
Θ_N
π^-
n
γ

Fig. 3

FIG.4



$\frac{d\sigma^L}{d\Omega_n}$ (mb/str)
10
5
2
1
0,5
0,2
0,1
0,05
0,02
0,01
π^0
γ
60
90
120
150
30
14
9
4
60
90
120
150
180
30
9
T_π (MeV)
0
100
200
300