Measurement of ($\pi^\pm$, ^{4}He) Elastic Scattering at 97 MeV with a High-Pressure Streamer Chamber.

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(ricevuto il 10 Gennaio 1972)

At the present there are two series of experiments that have been performed in order to study the pion interaction on helium. The first group of measurements ([1,2]) was aimed at obtaining detailed information on the mechanism of interaction of low- and intermediate-energy pions with nuclei ([3,4]), but the experimental apparatus adopted (high-pressure diffusion cloud chamber) did not permit to obtain high statistics. The second group of measurements ([5-7]) was started by the proposal of STERNHEIM and HOFSTADTER ([8]) to study the elastic scattering of positive and negative pions on helium, at the same energies, to extract information on the pion electromagnetic structure. At the present there exist discrepancies between the results from these last measurements, as was also pointed out by OADES and RASCHE ([9]).

In the laboratory of nuclear problems of JINR our group has developed a high-pressure helium streamer chamber technique ([10]). Such chambers combine features of a

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([1]) M. S. KOZODAEV, R. M. SULAYEV, A. I. FILIPPOV and YU. A. SHCHERBAKOV: *Žurn. Èksp. Teor. Fiz*,. **31**, 701 (1955); **33**, 1047 (1957).

([2]) YU. A. BUDAGOV, P. F. ERMOLOV, E. A. KUSHNIRENKO and V. I. MOSKALEV: *Žurn. Èksp. Teor. Fiz.*, **42**, 1191 (1962).

([3]) G. B. WEST: *Phys. Rev.*, **162**, 1677 (1967).

([4]) E. H. AUERBACH, D. M. FLEMING and M. M. STERNHEIM: *Phys. Rev.*, **162**, 1683 (1966).

([5]) M. E. NORDBERG and K. F. KINSEY: *Phys. Lett.*, **20**, 692 (1966).

([6]) M. M. BLOCK, I. KENYON, J. KEREN, D. KOETKE, P. MALHOTRA, R. WALKER and H. WINZELER: *Phys. Rev.*, **196**, 1074 (1968).

([7]) K. M. CROWE, A. FAINBERG, J. MILLER and A. PARSON: *Phys. Rev.*, **180**, 1349 (1969).

([8]) M. M. STERNHEIM and R. HOFSTADTER: *Nuovo Cimento*, **38**, 1854 (1965).

([9]) G. C. OADES and G. RASCHE: *Nucl. Phys.*, **20** B, 333 (1970).

([10]) I. V. FALOMKIN, M. M. KULYUKIN, D. B. PONTECORVO and YU. A. SHCHERBAKOV: *Nuovo Cimento*, **34**, 1394 (1964).

particle detector and of a gauses target and may be used for scattering experiments in helium ([11]). We are now studying the $\pi^{\pm}$-mesons interaction on helium at 60, 100 and 140 MeV, with a streamer chamber spectrometer ([12]). In this paper the preliminary results obtained from measurements of the differential cross-section for π^- and π^+ scattering on ^{4}He at about 100 MeV are presented.

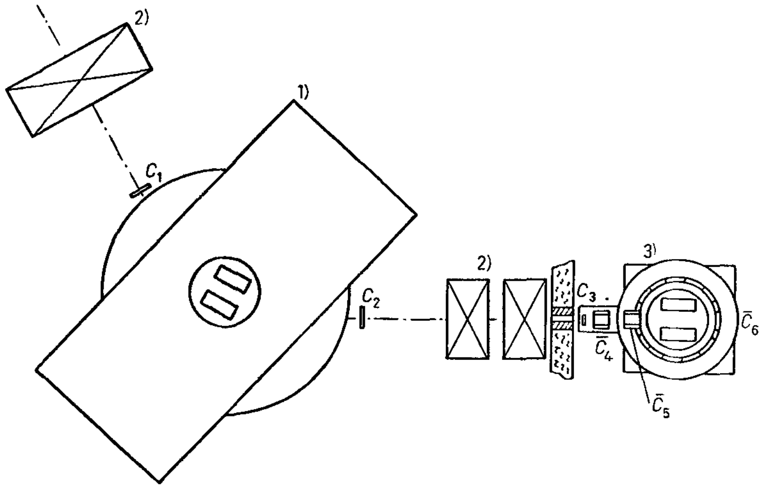

Fig. 1. – Diagram of the experimental set-up: 1) bending magnet with the helium streamer chamber at atmospheric pressure; 2) quadrupole lenses; 3) helium-filled streamer chamber (4 atm), surrounded by an hodoscope of scintillation counters.

Figure 1 shows a diagram of the experimental set-up used at the synchrociclotron of the JINR. A high-pressure streamer chamber (50 cm diameter), filled with helium at 4 atm, is surrounded by an hodoscope of scintillation counters. The hodoscope covers a solid angle of about 1.4 sr with an angular range from 25° to 170°. The hodoscope counters are placed within the steel vessel surrounding the streamer chamber itself, so that the pions scattered by the helium traverse only the thin lucite chamber wall (about 0.4 g cm^{-2} thick). A second streamer chamber, filled with helium at atmospheric pressure, is placed inside a bending magnet (Mc-4-2 type) and is used for measuring the momenta of the incident pions. In order to obtain highly luminous tracks, both the chambers are operated in the method worked out earlier and the details of which we described in ref. ([13]). The filling gas is commercial helium with N_2, H_2 admixtures smaller than 0.01%. For the stability of the dicharge, to the helium in the chambers about 0.01% of hydrocarbons and CCl_4 are added. The contribution of the nuclei of the admixtures to the total numbers of events is smaller than 0.5%. The trigger for the chambers is given by the coincidence between a telescope counters and any one of the hodoscope counters: $(C_1 + C_2 + C_3 + \bar{C}_4 + \bar{C}_5 + \bar{C}_6) + C_{\text{hod}}$. The telescope, composed of the sintillation counters $C_1 \div C_6$, forms the beam and measures the flux of the particles passing trough the high-pressure chamber. The monitoring of the beam

([11]) I. V. Falomkin, M. M. Kulyukin, V. I. Lyashenko, A. G. Petrov, G. B. Pontecorvo and Yu. A. Shcherbakov: *International Symposium on Nuclear Electronics*, Vol. 1 (Versailles, 1968), p. 16.
([12]) I. V. Falomkin, M. M. Kulyukin, V. I. Lyashenko, G. Piragino, G. B. Pontecorvo and Yu. A. Shcherbakov: *Boll. S.I.F.*, **79**, 109 (1970).
([13]) I. V. Falomkin, M. M. Kulyukin, G. B. Pontecorvo and Yu. A. Shcherbakov: *Nucl. Instr. and Meth.*, **53**, 266 (1967).

is stopped whenever the high-voltage pulse generators of the chambers are being recharged (the recharging time is ~ 0.1 s). The average intensity of the $\pi^\pm$-meson beams, passing through the high-pressure chamber is of about 10^4 pions per second at about 100 MeV. The measured mean energy of the pions is (97 ± 6) MeV. It was deduced both from absorption measurements in lucite and copper and measurements of momenta with the chamber in the magnetic field. The beam composition is determined by using a 25 cm lucite Čerenkov counter, placed behind the high-pressure chamber. It is possible in this way to have a continuous control of the beam. The muon and electron contamination is of about 50% of the beam. In order to reduce the background of the events not induced by pions, the time-of-flight technique is used, involving the C_1 and C_3 counters, the base being 4 m. In this manner we obtain an « enriched » beam with about 75% of pions.

In the preliminary runs about 40 000 photographs with π^- and about 10 000 photographs with π^+ were taken and a total number of about 1250 elastic scattering events were obtained. Figure 2 presents a typical photographs of a (π^+, ^{4}He) scattering. As

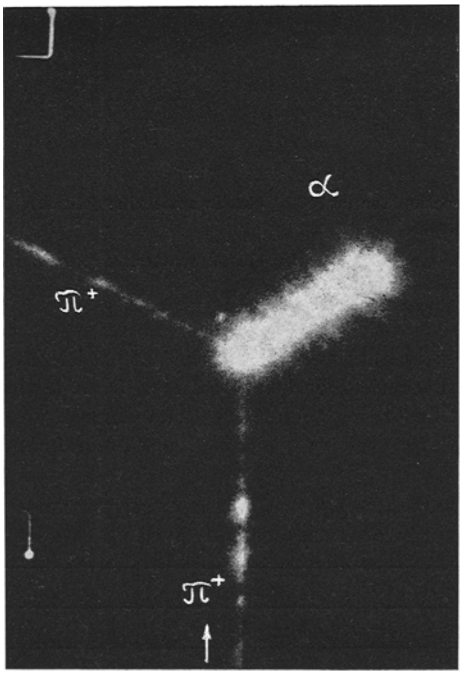

Fig. 2. – Picture of a typical (π, ^{4}He) elastic scattering event, obtained with the high-pressure streamer chamber.

a result of scanning all two prongs stars were selected for further measurement. The efficiency of the double scanning is $\geqslant 99\%$. The scattering angles of the pion and of the recoil nucleus were measured (the track image of the recoil nucleus differs greatly visually from that of the pion). When the scattering angle of the pion is $\leqslant 80°$, the range of the recoil nucleus is measured also. Due to the geometry of the hodoscope, the events in the chamber are located in planes close to the horizontal one, and the dip angle of the scattered pion is not grater than 20°. The final results were deduced by measuring about 800 events of elastic (π^-, ^{4}He) scattering and about 200 (π^+, ^{4}He) events. Corrections, taking into account the geometry of the experimental set-up and the linear dimensions of the target were carried out.

In Fig. 3 and 4 are the differential cross-sections for (π^-, ^{4}He) and (π^+, ^{4}He) scattering, respectively. The behaviour of the (π^-, ^{4}He) differential cross-section agrees

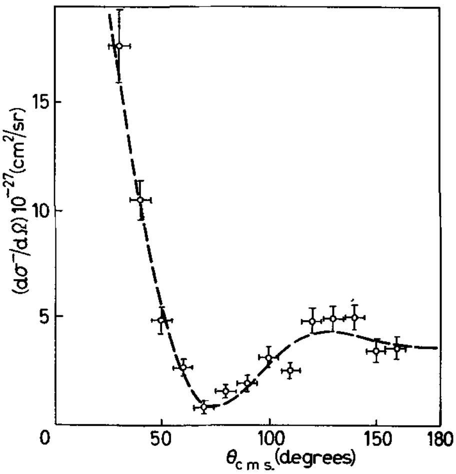

Fig. 3.

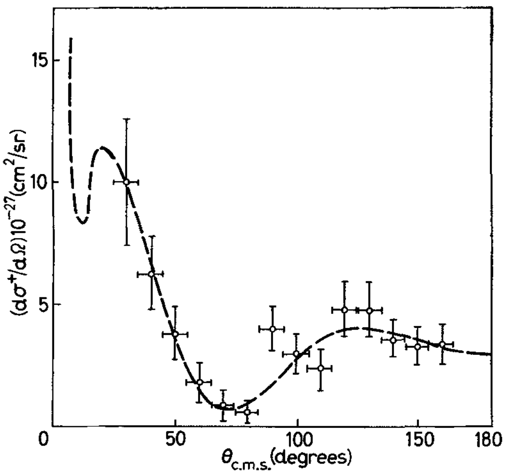

Fig. 4.

Fig. 3. – Differential cross-section for (π^-, ^{4}He) elastic scattering (c.m.s.). The dashed line is the best fit from the phase-shift analysis.

Fig. 4. – Differential cross-section for (π^+, ^{4}He) elastic scattering (c.m.s.). The dashed line is the best fit from the phase-shift analysis.

very well with that recently obtained at 110 MeV at CERN by STROOT *et al.* [14]. The dashed curves are the theoretical best fits deduced from a phase-shift analysis. This analysis was carried out according to ref. [15]. The differential cross-section was taken to be $d\sigma/d\Omega = |f^n(\theta) + f^c(\theta)|^2$, where $f^c(\theta)$ is the Coulomb scattering amplitude and

TABLE I. – *Results of the phase-shift analysis with six parameters.* The contribution of $\mathrm{Im}\,\sigma_2$ is negligible (a five parameters best fit gives essentially the same results).

	π^-	π^+
$\mathrm{Re}\,\delta_0$	$-\ 8.74 \pm 2.50$	$-\ 8.69 \pm 5.47$
$\mathrm{Im}\,\delta_0$	5.04 ± 3.43	4.12 ± 9.42
$\mathrm{Re}\,\delta_1$	20.05 ± 0.52	17.73 ± 1.00
$\mathrm{Im}\,\delta_1$	8.35 ± 5.02	6.32 ± 10.30
$\mathrm{Re}\,\delta_2$	6.38 ± 0.99	5.74 ± 1.86
$\mathrm{Im}\,\delta_2$	0.1 ± 27.14	0.1 ± 45.33
χ^2	20.95	10.47

[14] J. P. STROOT: *Rapporteur talk at IV International Conference on High-Energy Physics and Nuclear Structure* (Dubna, 1971).
[15] S. N. SOKOLOV and I. N. SILIN: Preprint D-810, JINR (1961).

$f^n(\theta)$ is the nuclear-scattering amplitude. The amplitudes were chosen to have the usual form ([16]). Three complex phases for the elastic scattering were considered and the S, P, D waves were taken into account. In Table I the phase shifts δ_1 (corresponding to the τ_1-phases of ref. ([9])) are given. As one can see the Re δ_1, as in the case of pion-nucleon scattering, is the largest phase shift.

Figures 5 and 6 show our π^- and π^+ elastic scattering cross-section values and those obtained by other authors ([2,6,7]) at different pion energies. These cross-section values

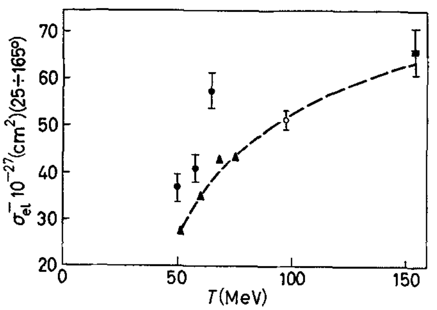

Fig. 5.

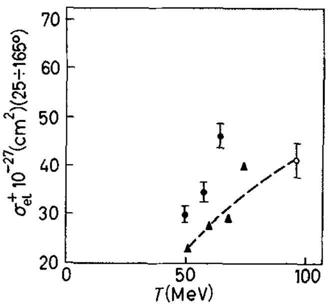

Fig. 6.

Fig. 5. – Energy behaviour of the (π^-, ^{4}He) elastic scattering cross-section in the (25÷165)° angular interval: ●, ref. ([6]); ▲, ref. ([7]); ■, ref. ([2]); o, present work. The dashed line has been drawn to guide the eye.

Fig. 6. – Energy behaviour of the (π^+, ^{4}He) elastic scattering cross-section in the (25÷165)° angular interval: ●, ref. ([6]); ▲, ref. ([7]); o, present work. The dashed line has been drawn to guide the eye.

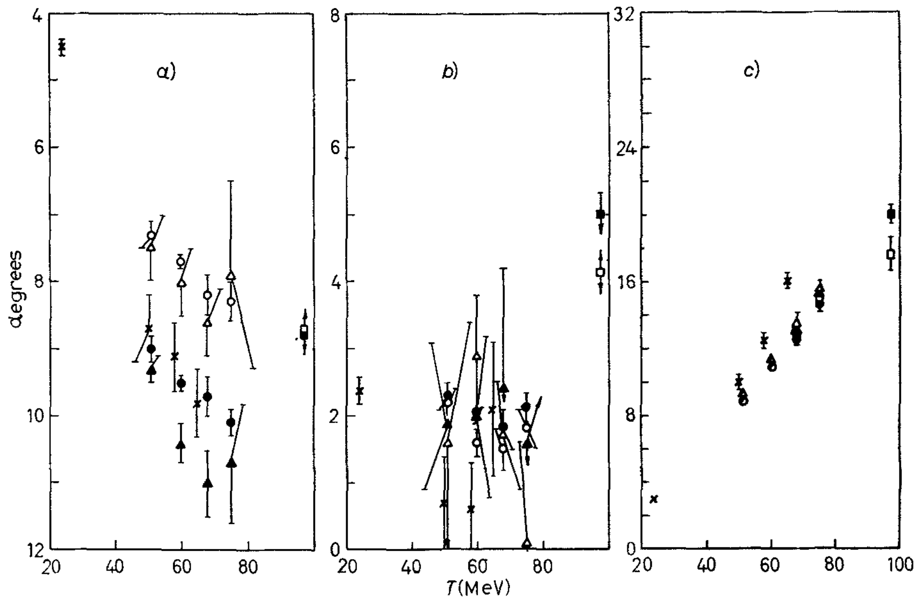

Fig. 7. – Dependence of the phases *a*) Re δ_0, *b*) Imδ_0, *c*) Re δ_1 on the positive pion energy (open symbols) and on the negative pion energy (full symbols); ×, ref. ([6]); o and ●, ref. ([17]); △ and ▲, ref. ([7]); □ and ■, present work.

([16]) L. I. SCHIFF: *Quantum Mechanics* (New York, 1955), p. 114.

([17]) C. T. MOTTERSHEAD: preprint UCRL-19216 (1969).

were obtained integrating the differential cross-sections between 25° and 165°. As one can see there exists a systematic discrepancy between the values quoted by different authors ([6,7]), which may be resolved only by further experiments. In Fig. 7 and 8 the

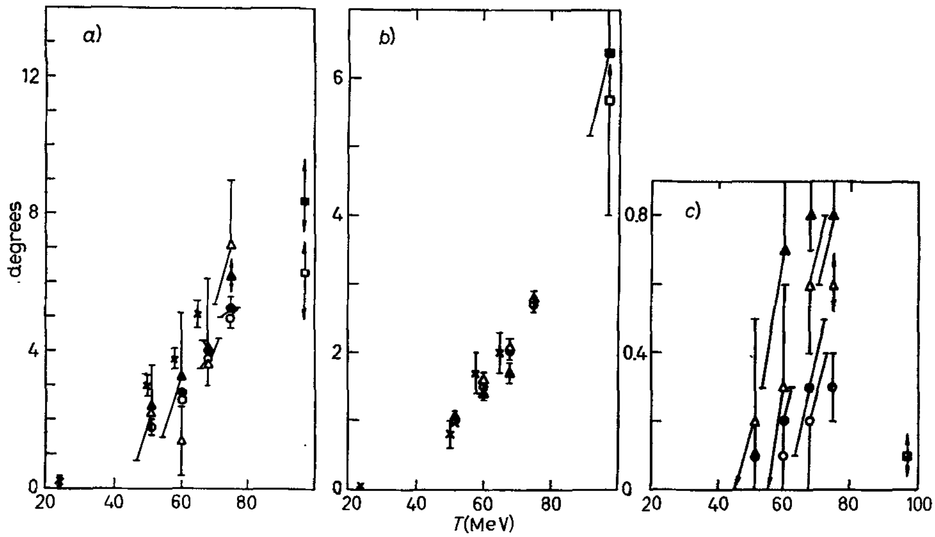

Fig. 8. – Dependence of the phases *a*) Im δ_1, *b*) Re δ_2, *c*) Im δ_2 on the positive pion energy (open symbols) and on the negative pion energy (full symbols); ×, ref. ([6]); ○ and ●, ref. ([17]); △ and ▲, ref. ([7]); □ and ■, present work.

energy behaviours of the phase shifts, deduced from different measurements, are showed In the case of Crowe's data ([7]), also the results of the analysis performed by MOTTHERSHEAD ([17]) are given. The dominant phase Re δ_1 is that most accurately deduced.

This comparison of data from different experiments shows significant discrepancies and additional measurements are necessary. At the present the results are too inaccurate to give a reasonable estimate for the electromagnetic form factor of the pion ([18]).

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We are grateful to Profs. V. P. DZHELEPOV and L. I. LAPIDUS for continuous interest in this work and to Dr. I. N. SILIN for very useful discussions. One of us (G.P) wishes to thank the JINR Directorate for the kind hospitality at the Dubna Laboratories.

([18]) G. C. OADES, G. RASCHE and H. ZIMMERMANN: *Nuovo Cimento*, **2** A, 438 (1971).