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SEARCH FOR ρ^o -MESON AND TEST OF DISPERSION RELATIONS IN PION-NUCLEON SCATTERING

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* The results were reported at the Conference on High Energy Physics, Kiev, 1959.

SUMMARY

Total $\pi^- p$ cross sections (σ_t^-) have been measured with an accuracy of 1.5 – 2% at 50 pion energy values ranging from 140 up to 360 MeV, the pion energy being known with an accuracy of ±1%.

In the energy dependence of σ_t^- there have been found no anomalies which might give evidence on the existence of ρ° -mesons with mass in the interval 270–410 MeV/c^2.

The data are not compatible with the energy value E_2 = 650 MeV for the second maximum in $\sigma_t^-(E)$ discovered by Frish et al./7/ but confirm the conclusion of Brisson et al./8/ that such a maximum is found at a smaller energy (E_2 = 610 MeV).

The data are in excellent agreement with dispersion relations for ($\pi^- p$)-scattering. They definitely show that the "Puppi-Stanghellini problem", as such, does not exist any more and that it arose only owing to inexact knowledge of the total cross section of ($\pi^- p$)-interaction.

INTRODUCTION

The energy dependence of the total cross section (σ_t^-) of the $\pi^- p$ -interaction was investigated in a wide interval of pion energies several years ago. In the energy region up to 360 MeV, where the most accurate data were obtained, the cross section was measured within accuracy not better than 5%. The energy at which the total cross section had been determined was known to within ± 6 MeV. On the other hand precision measurements of this cross section with a good energy resolution are undoubtedly of great interest for several reasons.

Firstly , as it was pointed out earlier/1/, when determining the energy dependence of the total cross section with great accuracy it is possible, in principle, to observe 'threshold anomalies' which might give information on the ($\pi-\pi$) -interaction and on the existence of a neutral hypothetical particle (ρ°).

Secondly, it is interesting to express the energy dependence of the total pion-nucleon cross section in the state with isotopic spin T= ½ ($\sigma_{1/2}$) in terms of a small number of Breit-Wigner 'resonance' curves. This requires experimental data of great accuracy.

Thirdly, some authors/2/ casted doubt on the validity of the dispersion relations for pion-nucleon scattering. From this point of view extensive measurements of σ_t^-, more accurate than those performed until now, are necessary for a reliable calculation of the real part of the ($\pi^- p$)-scattering amplitude.

In the present paper we describe the experimental investigations which have been undertaken according to the above programme.

EXPERIMENTAL

a) Experiment geometry

Total $\pi^- p$ cross sections were measured by attenuation of the pion beam in passing through a liquid hydrogen target. The experiment geometry is given in Fig. 1.

The pion beam falling on the hydrogen target was defined by a 3 cm rectangular collimator located in the yoke of the synchrocyclotron magnet, was then deflected through a magnet and defined by counter 1 and 2 coincidences. The mesons going through the target were detected by triple coincidences of counters 1, 2 and 3. Counters 1, 2, 3 were all plastic scintillators and had the dimensions: counter 1 – (0.8 x 3 x 6) cm, counter 2 – (0.5 x 3 x 6) cm, counter 3 – (1 x 10 x 10) cm, where the last figure for every counter represents vertical dimensions. The average detection angle for counter 3 was 10.5°. The liquid hydrogen used as a target was placed in a styrofoam container (wall thickness $\sim$ 0.8 gr/cm^2)/3/. The hydrogen density was taken as 0.0708 gr/cm^3, which corresponds to an average number of protons along the beam path $(0.4607 \pm 0.0023).10^{24}/\text{cm}^2$.

b) Stability of the detecting system

In the main the same electronic apparatus was used as in a previous investigation/3/. FEU –33 photomultipliers were used throughout. In order to increase the reliability of the registering apparatus and decrease various drifts, the resolving time of the coincidence scheme was increased up to 2.10^{-8}sec. Incoming pions as well as pions passing through the hydrogen target were counted with two scalers 'Kalina', the input of which was fed by two supplementary scalers of four with a dead time of 0.1 μsec. In view of the requirements on the accuracy in the determination of cross section ($\sim$2%), the stability in the registering apparatus must be a few hundredths of a per cent. Consequently there must be some kind of objective reliability criterion of the overall apparatus. Such a criterion could be the degree of reproducibility of results during a sufficiently long time (dozens of hours). If we measure, for example, the count (1 2 3) (the count (1 2) serving as a monitor) a sufficient number of times, we might expect that the deviations of every measurement from the average value will follow a Gauss distribution with a statistically calcuable variance, provided there are no instrumental errors and drifts. However, such control would require almost as much time as the cross section measurements. Consequently as a reliability test we used the information accumulated in the course of the cross section measurements. Usually measurements for one value of the pion energy were repeated 5–6 times. The deviations of the count N_{123} with hydrogen from its average value for various energies were used. The result of such an operation is given in Fig. 2. There it may be seen that the deviations follow very well a Gauss law with a dispersion equal to the value calculated by assuming that there are no apparatus drifts and other errors except the statistical fluctuations in the number of interaction acts of the pions after they have been registered in counters 1, 2. The continuous curve in Fig. 2, is, in fact, the distribution function of deviations of the count N_{123} with hydrogen from its average value and was calculated on the assumption of complete absence of drifts and systematic errors.

c) Determination of the π-energy momentum

In the region under investigation where the cross section strongly varies with energy, its determination with the abovementioned accuracy has a meaning only if the pion momentum is known with an accuracy of~1%. Besides, such an accuracy in the pion momentum determination is necessary in experiments aiming to detect anomalies giving evidence on ρ°-mesons, because the expected width of such hypothetical anomalies is small and, consequently, it was necessary to measure cross sections at energies differing by less than 5 MeV. Thus, it was necessary to devote special attention to this problem.

The deflecting magnet field usually was stabilyzed for measurements at one definite pion energy with an accuracy of 0.1% (on the basis of the Hall effect in a germanium plate) and occasionally even with a greater accuracy (making use of the nuclear resonance). The magnetic field was determined by measuring the Hall current in a germanium crystal. Such a current was measured with a class 0.5 meter. The meter readings were directly graduated in terms of values of pion momenta with an accuracy of 0.5% by means of the current-carrying wire method.

The desired pion energy was obtained as follows. At first the wanted deflecting magnet field was established and then by the remote control the position of the Be internal synchrocyclotron target was found which insured the maximum intensity of the pion beam. In view of the uncertainty in the establishment of the meson target position, the final accuracy with which the average pion momentum can be determined is 1%.

The beam energy spread depended upon the width of the collimator located in the synchrocyclotron magnet yoke and according to a graphical estimate was ± 5 MeV/cm, i.e. for the 3 cm collimator was ± 1.5 MeV. The full energy loss in the hydrogen target was close to 3 MeV.

RELATIVE MEASUREMENTS NEAR THE MESOPRODUCTION THRESHOLD
(150–180 MeV)

Three reactions of mesoproduction by measons are possible at pion energies $E > 150$ MeV.

1. $\pi^- + p \to \pi^- + \pi^+ + n$ (threshold: 172 MeV).
2. $\pi^- + p \to \pi^- + \pi^\circ + p$ (threshold: 165 MeV).
3. $\pi^- + p \to \pi^\circ + \pi^\circ + n$ (threshold: 160 MeV).

According to A.N. Baz', L.B. Okun , Ya.A. Smorodinsky, in the threshold region one can expect, in principle, anomalies due to the ($\pi-\pi$)-interaction. As the energy region considered here is only ~10 MeV, attention was given only to the energy dependence and in this section absolute cross section measurements are not described. The primary beam energy was kept constant and mesons of required energy were obtained by moderating the primary pions with graphite absorbers. Transmission measurements were performed at intervals of ~2 MeV. The results of two sets of measurements made on two different days are given in Fig. 3 . It is seen that to within experimental accuracy (~ 1.5%) no anomalies in the energy dependence of (σ_t^-) were found. It must be noted that the values of 'the hydrogen difference' in Fig. 3

are not proportional to cross sections. This is related to the fact that the method of moderating pions with a graphite absorber requires introducing corrections which are strongly dependent on energy. It should be stressed that the interaction in reactions 1,2,3 may cause threshold anomalies only when two pions form a bound system. Phenomenologically, such a system is a new particle. Thus, it is clear that the investigation should be carried out in a wider energy region, as a neutral boson (ρ°), different from the π°-meson, in principle, can have any mass.

ENERGY DEPENDENCE OF σ_t^- IN THE REGION 160–360 MEV

In this section experimental results on relative as well as absolute cross section values are described. Final results on absolute measurements of σ_t^- are listed in Table 1. There is no necessity to give the corrections for all the energies. We shall confine ourselves only to some remarks.

1. The muon contamination in the pion beam was determined as usually from the absorption curve of the beam in Cu.

2. The number of scattered pions and recoil protons falling upon counter 3 was evaluated by using known angular distributions.

3. The interference of Coulomb and nuclear scattering of pions was estimated according to formulas given in [4] and from the known phase shifts in ($\pi^- - p$)-scattering.

4. The Coulomb multiple scattering of pions by hydrogen was taken into account. The corresponding correction is appreciable on account of the beam divergence which always exists, say, due to scattering in counter 2.

5. Measurements with hydrogen and without it were carried out with different containers. The difference between the target and 'the dummy' was determined in separate experiments.

In Table 2 corrections only for two values of energy are presented for illustration.

DISCUSSION

a) Search for ρ°-meson

ρ°-meson is defined here as a pseudoscalar meson whose charge and isotopic spin are equal to zero. In the experiment, the results of which are given in the previous section, the presence of a relatively narrow anomaly in the energy dependence of the total cross section σ_t^- was looked for, since such an anomaly, in principle, could serve as an argument in favour of the ρ°-meson existence. The idea [1] is that in one or in both the reactions $\pi^- + p \rightarrow \pi^{\circ} + n$ and $\pi^- + p \rightarrow \pi^- + p$ an anomaly may appear near the threshold of the hypothetical reaction $\pi^- + p \rightarrow \rho^{\circ} + n$. The width of the anomaly can be obtained from the conditions $KR \ll 1$, where K is the momentum of the emitted ρ°-meson (c.m.s.) and R is the interaction radius. If $R \sim \frac{\hbar}{m_{\pi}c}$, the maximum width of the peak in the energy dependence turns out to be ~40 MeV (lab.s.) when $m_{\rho^{\circ}}$ is taken as ~400 MeV/c^2. In fact, the width can be considerably less than this magnitude and so a very good energy resolution must be used in the experiments. The anomaly amplitude $\frac{\sigma(\pi^- p - \rho^{\circ} n)_{K=1/R}}{\sigma_t(\pi^- p)}$, in principle, may reach several %.

In the energy interval from 140 to 360 MeV anomalies in the cross section, say, with an amplitude greater than 3–4% have not been found. This means that there is no evidence for a ρ°-meson with a mass between 270 and 410 MeV/c^2. Of course, the existence of such a meson cannot be excluded.

At the 1959 Kiev conference on high energy physics there was reported an investigation of Salvini and collaborators/5/ who, using a method entirely different from ours, also failed to find any evidence in favour of the ρ°-mesons existence.

b) Total cross section in the state with $T=1/2$

In 1959 N. Klepikov, V. Mescheryakov and S. Sokolov analysed the whole information on the total cross sections of πN-interaction including the data of the present paper. 'Total' cross sections in the states with isotopic spin $T = 3/2$ $(\sigma_{3/2})$ and $T = 1/2$ $(\sigma_{1/2})$ were approximated by resonance formulas of theBreit–Wignertype, the method of the maximum likelihood being used/6/. All the parameters of the curves and the corresponding corridor of errors were determined by means of this method. It should be noted that in the energy region 250–1500 MeV it is impossible to describe $\sigma_{1/2}$ as a function of the energy in terms of Breit-Wigner curves if the results of Frish et al./7/ obtained in their pioneer investigation are used together with our present data. These authors have found two maxima in the energy dependence of the cross section σ_t at $E_2 \sim 650$ MeV, $E_3 \sim 950$ MeV. This difficulty must be due to an error of the pion energy scale in the experiment of the American team. The contradiction between our data and the data of Frish et al. indirectly confirms the conclusion of the French team/8/ that the maxima are at energies $E_2 \approx 610$ MeV and $E_3 \approx 880$ MeV.

c) Pion-nucleon scattering and dispersion relations

At the 1958 conference on high energy physics the situation on the application of dispersion relations to ($\pi^+ p$) and ($\pi^- p$)-processes was summarised as follows:

1. The global information on $\pi^- p$ and $\pi^+ p$ -scattering was quite compatible with dispersion relations and gives the πN coupling constant f^2, which turns out to be equal to 0.08 to within 10%.

2. The data concerning only $\pi^+ p$ -scattering permitted a rather precise determination of f^2.

3. The information relating to $\pi^- p$-scattering was less satisfactory inasmuch as it was difficult to satisfy the pertinent data with the value of the constant f^2 which had been determined in the experiments on ($\pi^+ p$)-scattering (this is, in fact, the so-called Puppi-Stanghellini problem).

It can be said, however, that the possibility of a 'revolutionary' conclusion of the problem (especially stressed by some authors) should always have been looked at with suspicion not only because of the far reaching theoretical consequences it implies but also and especially in view of a logic internal contradiction of this conclusion which consists in the following: practically nothing was known of the interaction in the $T=\frac{1}{2}$ state, and therefore it is not clear how a real contradiction with dispersion relations can arise from the absence of knowledge.

In 1959 there were published some theoretical papers which brought about the absence of serious difficulties in the application of dispersion relations to (πN)-scattering/10/. The most convincing results are presented in the quoted paper of Klepikov, Mescheryakov and Sokolov/6/ who have made use of the data of the present paper and other investigations. On the basis of the total cross section curves obtained as indicated in the previous section these authors have calculated the real part of the $\pi^- p$ forward scattering amplitude together with the corresponding corridor of errors. Fig. 4. presents the calculated curve of the real part of the forward scattering amplitude obtained from 'the dispersion integral', and some of its values (affected by experimental errors) obtained for a few pion energy values from the angular distribution in elastic $\pi^- p$ -scattering and from total cross sections σ_t^-. It is necessary to stress that in plotting the 'experimental points' presented in Fig. 4 the values of (σ_t^-), which had been obtained from 'the calculation curves'/6/, were used. The use of the calculated curve $\sigma_t^-(E)$ rather than the use of a separate measurement of the total cross section decreases the error affecting any experimental points in Fig. 4 since the width of the error corridor in $\sigma_t^-(E)$ is quite small.

As it is seen, it would be difficult to expect a better agreement between the calculated curve D_-^b and the values obtained from angular distributions and total cross sections. Since the Puppi-Stanghellini problem, rightly or wrongly, was very widely discussed it is reasonable to ask why it arose at all. Now it is absolutely clear that 'the Puppi-Stanghellini discrepancy' was simply due to an inaccurate knowledge of the total $\pi^- p$ cross section which entered 'the dispersion integral' as well as 'the experimental values' of the real part of the forward scattering amplitude.

More accurate measurements of σ_t^- and better methods for analysing the experimental values of σ_t^- , aimed to calculate the dispersion integral, eliminate the divergence.

This is evident, for example, from the fact that the data on $\pi^- p$ interaction of Ashkin et al./15/ at pion energies of 150 MeV and 170 MeV, which served as the main source of discrepancy in 1956, are now in excellent agreement with the uptodate curve D_-^b, when the latest informations on total cross sections are used. (See Fig.4).

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Table 1.

Total cross sections of ($\pi^- p$)- interaction at different energies*

E_π (MeV)	σ_t^- (10^{-27} cm^2)	E_π (MeV)	σ_t^- (10^{-27} cm^2)
I58,2	56,4±2.0	254,7	39,8±0,8
I7I,7	67,2±I,I	258,0	38,8±0,8
I78,4	67,2±I,I	26I,4	36,8±0,8
I85,2	67,7±I,0	266,5	35,6±0,8
I89,9	67,8±0,8	27I,6	33,4±0,8
I96,2	64,0±I,I	276,7	3I,I±0,8
20I,0	63,8±I,0	28I,8	32,4±0,8
205,8	59,3±I,0	286,9	3I,6±0,8
2I0,6	58,7±I,I	292,0	30,5±0,8
2I5,4	55,6±I,0	297,2	29,3±0,8
220,2	52,2±I,0	302,5	28,9±0,8
225,0	50,2±0,9	307,7	28,I±0,8
228,3	48,2±0,9	3I3,0	28,7±0,7
23I,6	49,0±0,9	3I8,2	27,0±0,6
234,9	44,5±0,9	323,5	26,2±0,6
238,2	44,9±0,9	328,2	26,4±0,6
24I,5	42,7±0,9	334,2	26,0±0,6
244,8	43,I±0,9	345,0	24,9±I,0
248,I	4I,0±0,9	36I,0	25,2±I,0
25I,4	39,3±0,9		

*The cross section errors, listed in the Table, do not include uncertainties, connected with the determination of average number of hydrogen nuclei along the beam path (± 0.5%) and with the muon contamination in the beam (± 1/5%). These errors have a systematic character.

Table 2.

Values of the corrections, made in reducing data to obtain total cross sections (in %).

Pion energy (MeV)	Muon contamination	Pions and protons scattered forward	Interference of Coulomb and nuclear scattering	Coulomb multiple scattering in hydrogen	Difference in the hydrogen container and 'the dummy'
201,0±2	6,5±1,5	3,1±0,4	−0,3	−1,2±0,3	−0,3±1,0
297,2±3	3,5±1,5	3,5±0,4	+0,3	−0,8±0,2	−0,2±1,3

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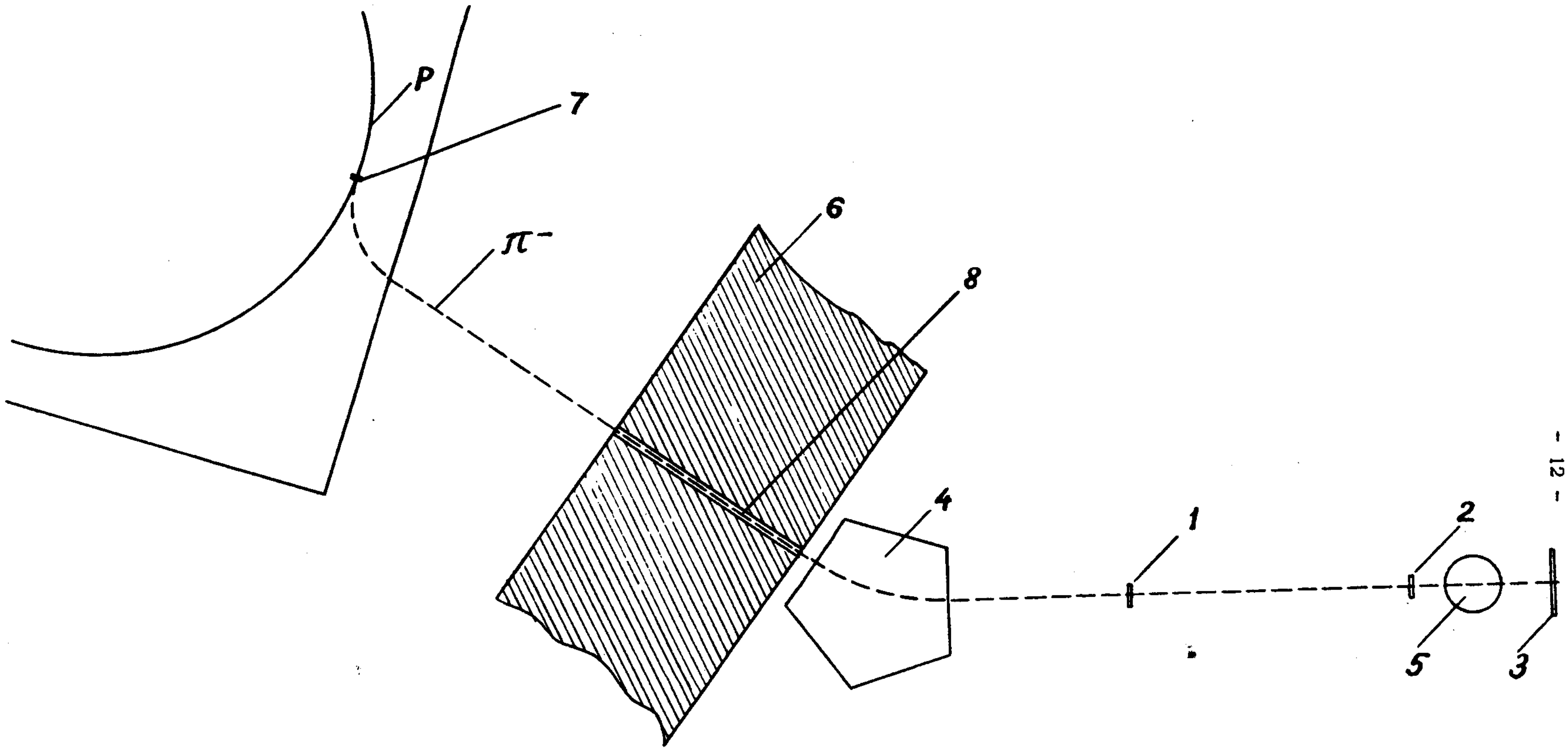

Fig. 1. *Experiment geometry.*

1,2,3 - scintillation counters.
4 - deflecting magnet.
5 - hydrogen scatterer.
6 - synchrocyclotron magnet yoke.
7 - Be target inside the synchrocyclotron chamber.
8 - pion collimator.

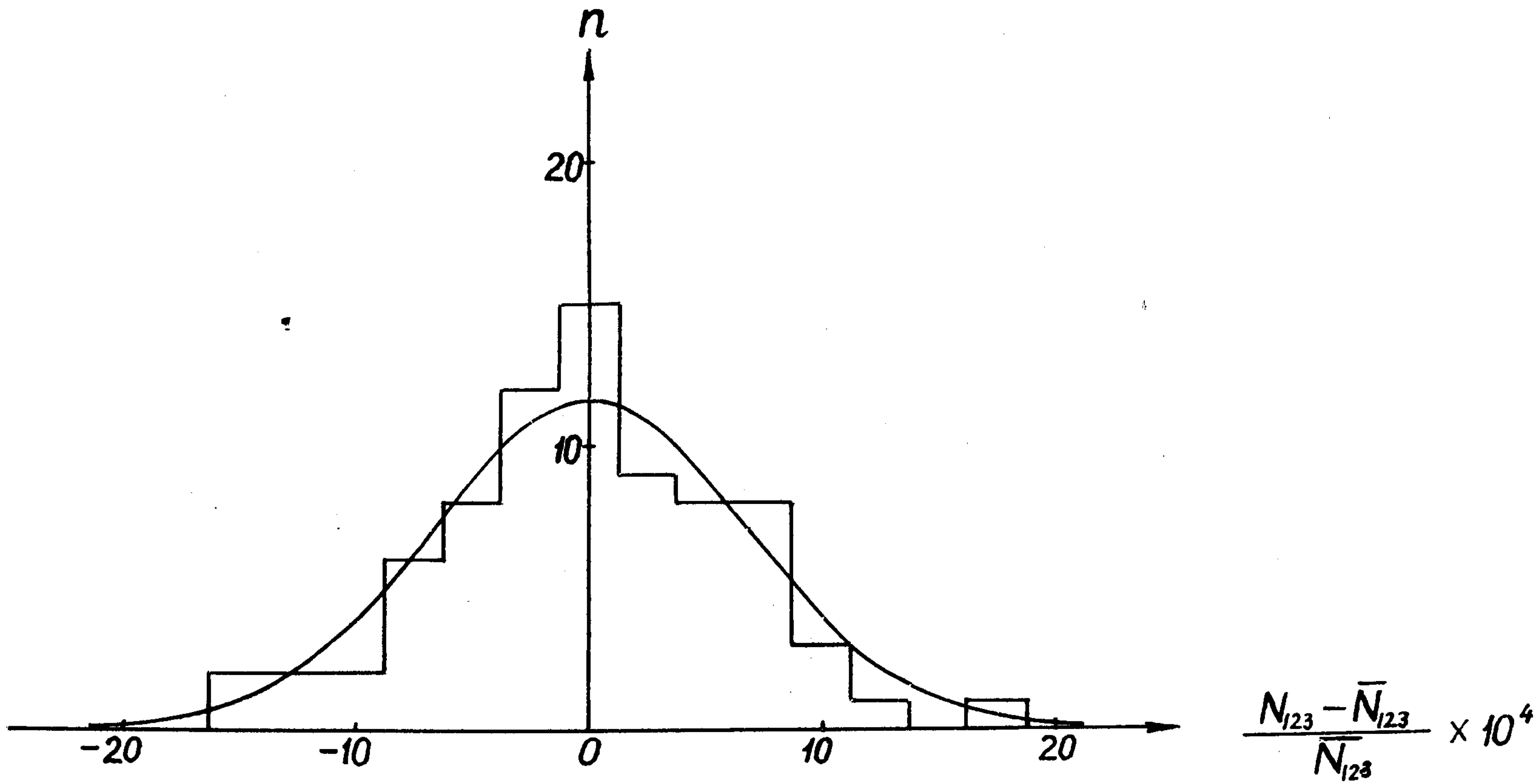

Fig. 2. *Spread of the deviations of the normalized count N_{123} (with hydrogen) from its average value.*
n - number of measurements having a given deviation.
The full curve is the distribution function calculated by assuming that the deviations are due only to statistical fluctuations in the number of pion-interactions.

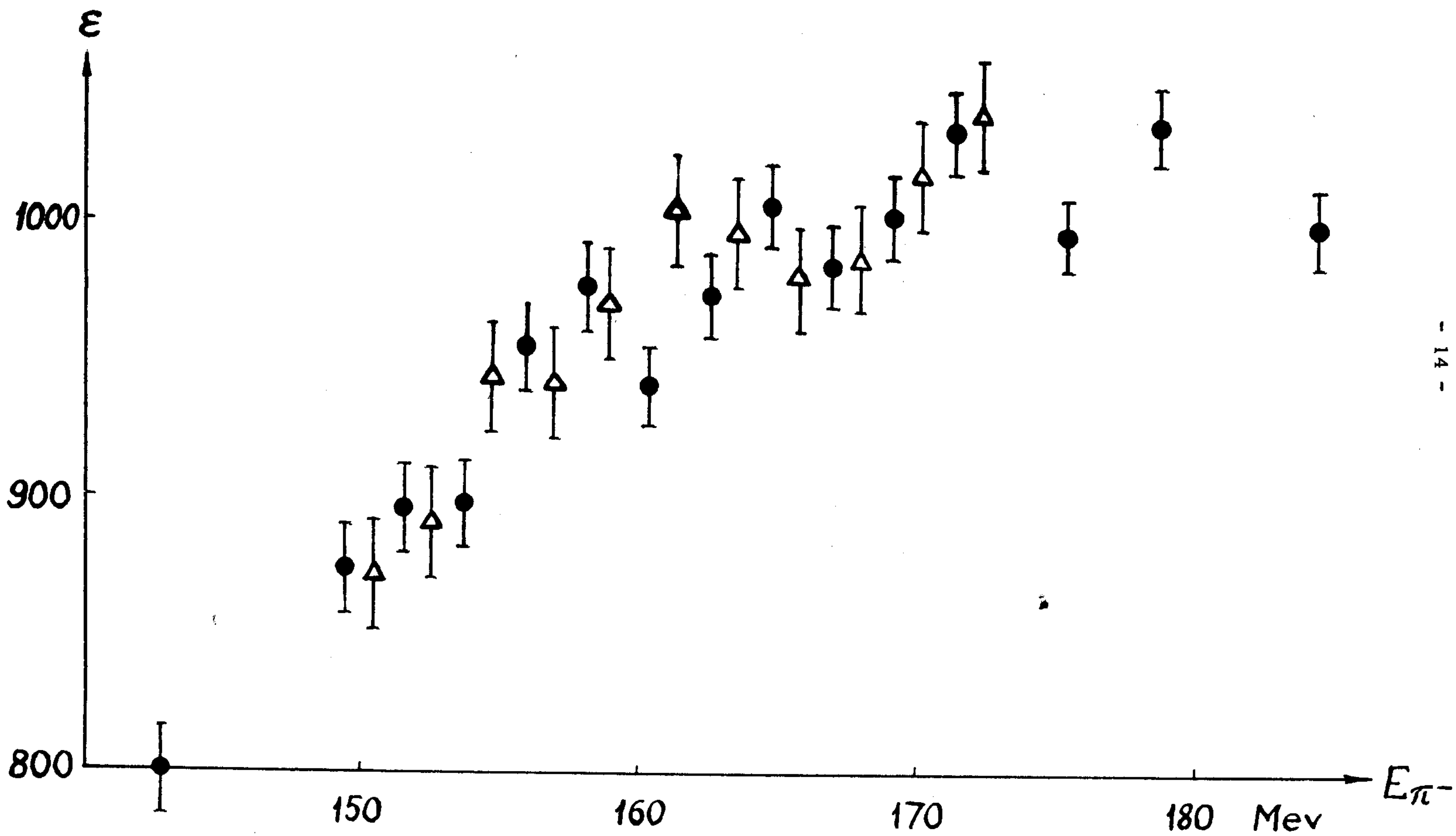

Fig. 3. *Energy dependence of the hydrogen effect ($\mathcal{E}$) in relative units near the mesoproduction threshold (results of two sets of measurements carried out on different days).*

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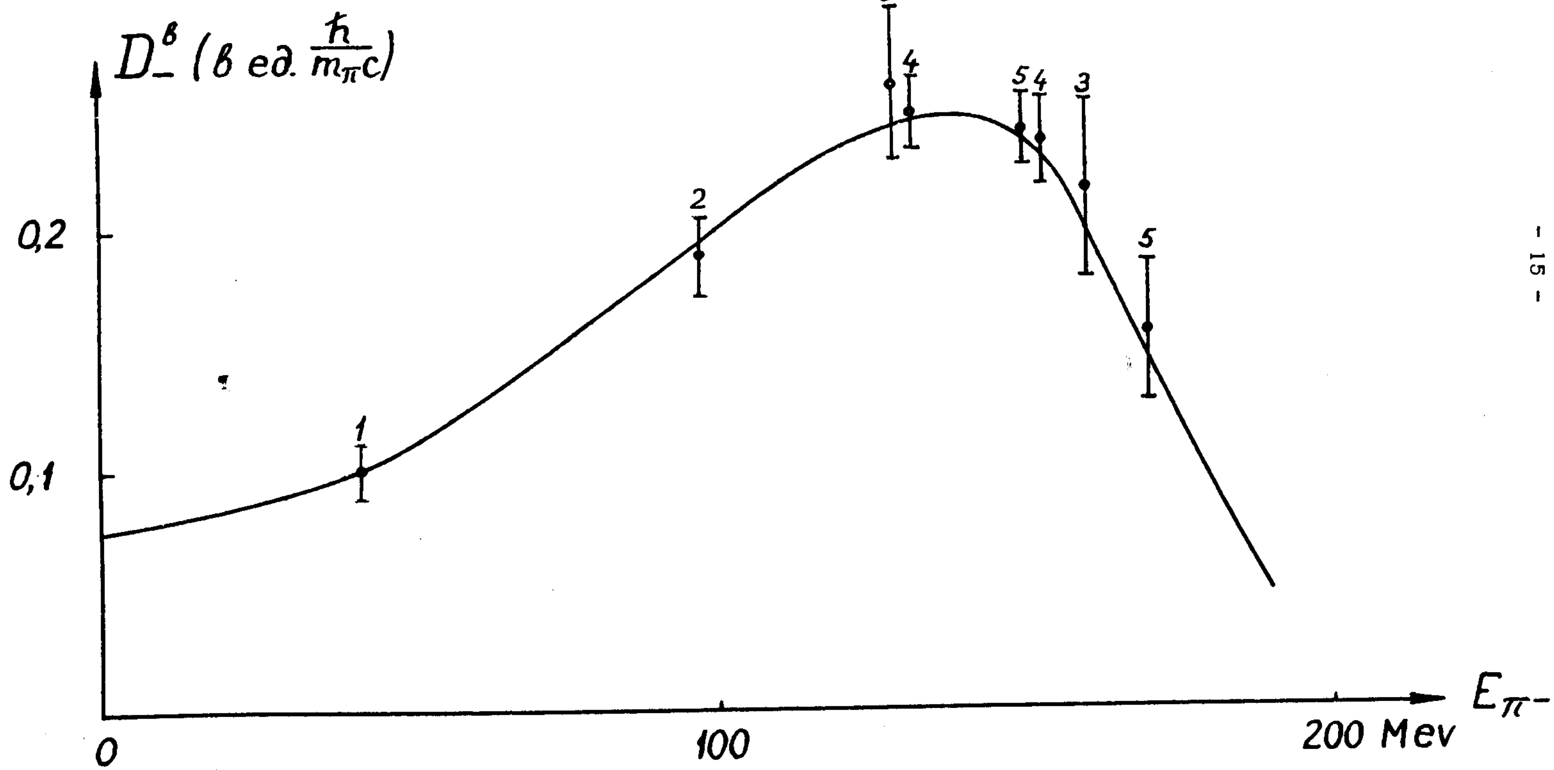

Fig. 4. Real part of the ($\pi^- p$) forward scattering amplitude (D_-^b). The full curve is calculated by Klepikov et al./6/ on the basis of all the measured total cross section values. 1-Barnes et al. (Rochester)/11/, 2 - Edwards et al. (Liverpool)/12/, 3 - Budagov et al. (Dubna)/13/, 4 - Kruse and Arnold (Chicago)/14/, Ashkin et al. (Carnegie)/15/. All 'the experimental points' are plotted the latest total cross section values being taken into account.