high degree of accuracy (practically "infinite"), then the degree of accuracy of measuring time by the proposed "nuclear" method will be limited only by the statistical accuracy, i.e., the value of $N^{-1/2}$, where N is the number of disintegrations recorded by the counter. Thus a specified high accuracy in measuring time can be attained by selecting a sufficiently large N. This evidently reduces in turn to the choice of a high source power (number of disintegrations) and a low-inertia transducer capable of recording (without being "swamped") all the disintegration events. In order to obtain some practical figures let us consider the following examples: 1 g-atom of Li^8 is needed to measure 0.1 sec with an accuracy of 10^{-11}, ~ 1 g-atom of C^{11} is required to measure 1 min with an accuracy of 10^{-11}, and to measure 1 year with a degree of accuracy of 10^{-11}, either $\sim 10^8$ g-atoms of U^{238} or 10 g-atoms of Ni^{63} are required. To achieve 100% registration of all the disintegration events, one can use either a large number of ordinary (inertial) transducers or low-inertia ones recording the particles through stimulation of very short-lived nuclear energy levels.

It is evident that the accuracy of the proposed "nuclear" clock increases with increasing time interval to be measured, i.e., with increasing clock operating time.

Even though various technical problems may be encountered in the course of developing the proposed "nuclear" method for measuring time (such as the production of thin films of very large amounts of radioactive substance, the need to eliminate "collective effects," etc), it would be natural to attempt it experimentally, because the method enables us in principle to obtain a sharp increase in the accuracy of time measurement, in comparison with even the most highly developed contemporary "frequency" methods.

Finally, let us note that the development of a very accurate method for measuring time will permit a detailed investigation of the decay law of short-lived physical systems (especially the deviation of the decay law from the exponential), particularly of elementary unstable particles, thus yielding valuable information on elementary-particle interactions.[2]

In conclusion, I express my gratitude to Academician I. E. Tamm, Professor V. L. Ginzburg, Professor E. L. Feĭnberg, and to all the participants in the theoretical seminar at the Physics Institute of the Academy of Sciences, and also to Professor G. I. Petrashen, Professor S. É. Khaĭkin, Yu. N. Demkov, and A. M. Khalfin for valuable discussions and comments.

*It must be noted, to be sure, that it is not absolutely necessary to use very long-lived states for the proposed method of measuring time, because corrections for decay can be obtained by determining the lifetime by means of an experiment on resonance scattering of decay products, which is independent of the experiment on the time measurement. Let us also note that the choice of very long-lived states is not convenient for practical purposes, because it will involve a very large amount of radioactive substance.

[1] H. Byers and R. Stump, Phys. Rev. **112**, 77 (1958).

[2] L. A. Khalfin, Doklady Akad. Nauk SSSR **115**, 277 (1957), Soviet Phys.-Doklady **2**, 340 (1958).

L. A. Khalfin, JETP **36**, 1088 (1959), Soviet Phys. JETP **9**, 774 (1959).

L. A. Khalfin, Quantum Theory of Decay of Physical Systems, Dissertation, Phys. Inst. Acad. Sci. (1960).

Translated by G. E. Halpern
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DETERMINATION OF THE CHARGE-EXCHANGE CROSS SECTION FOR PION-PION COLLISION FROM THE ANALYSIS OF THE $\pi^- + p \rightarrow \pi^- + \pi^+ + n$ REACTION AT 290 Mev

Yu. A. BATUSOV, S. A. BUNYATOV, V. M. SIDOROV, and V. A. YARBA

Joint Institute for Nuclear Research

Submitted to JETP editor June 7, 1960

J. Exptl. Theoret. Phys. (U.S.S.R.) **39**, 506-509 (August, 1960)

THE importance of studying π-π interactions is evident and has been reiterated earlier.[1,2] However, the experimental determination of π-π scattering data is very difficult because one has to use only indirect methods. All the available information on π-π interaction is given in Table I. It should be pointed out that only order-of-magnitude measurements of the π-π interaction cross section were attempted in references 1, 2, and 3.

In the present paper use was made of photoemulsion data (200 events) obtained from the study of the reaction

$$\pi^- + p \rightarrow \pi^- + \pi^+ + n \quad (1)$$

TABLE I. Data on π-π interaction cross sections

Process	$\sigma_{\pi\pi}$, mb	Initial reaction
$\pi^+ + \pi^+ \rightarrow \pi^+ + \pi^+$	$\sim$250 [7] *	$\tau^+ \rightarrow \pi^+ + \pi^+ + \pi^-$
$\pi^+ + \pi^- \rightarrow \pi^+ + \pi^-$	$\sim$20 [8] **	$\pi^- + p \rightarrow \pi^+ + \pi^- + n$ (960 Mev)
$\pi^- + \pi^0 \rightarrow \pi^- + \pi^0$	$\sim$40 [8] **	$\pi^- + p \rightarrow \pi^- + \pi^0 + p$ (960 Mev)
$\pi^- + \pi^0 \rightarrow \pi^- + \pi^0$	$\sim$30 [9] **	$\pi^- + p \rightarrow \pi^- + \pi^0 + p$ (1 Bev)
$\pi^+ + \pi^- \rightarrow \pi^0 + \pi^0$	(4^{+6}_{-4}) *,***	$\pi^- + p \rightarrow \pi^+ + \pi^- + n$ (290 Mev)

* At zero meson energy.
** Averaged over meson energy.
*** Present paper.

The emulsion stacks were irradiated in the negative-pion beam of the synchrocyclotron of the Laboratory of Nuclear Problems (Joint Institute for Nuclear Research). The average energy of the primary pions was found to be 290 ± 15 Mev, after correction for the slowing down in the emulsion. The preliminary results on the energy and angular distributions of the secondary particles from reaction (1) were reported at the Kiev Conference on High Energy Physics in July, 1959, and published.[3]

As a theoretical basis for the reduction of the experimental data we used the results of A. A. Ansel'm and V. N. Gribov[4] in which it is shown that the amplitude of the charge-exchange process $\pi^- + \pi^+ \rightarrow \pi^0 + \pi^0$ at zero energy can be determined from the energy distribution of secondary particles in a reaction such as (1) near threshold. The inclusion of the interaction of particles in the final state, under the assumption that the interaction is non-resonant, permits one to write for the energy distribution of the secondary particles (correct to terms linear in kr_0, where k is the meson momentum and is of the same order as the total kinetic energy of the three particles in the c.m.s. and r_0 is the reaction radius)

$$d\sigma / d\Gamma = A(1 + ck_{12} + dk_{13}). \qquad (2)$$

Here A is a constant determined by the total cross section for reaction (1). The coefficients c and d are associated with the π-π and π-n charge-exchange amplitudes at zero energy, k_{12} and k_{13} are the absolute values of the relative π^+-π^- and π^+-n momenta, respectively; $d\Gamma$ is an element of phase volume. Making use of isotopic invariance one can write:

$$c/d = (a_2 - a_0) / \sqrt{3}(b_{1/2} - b_{3/2}), \qquad (3)$$

where a_0 and a_2 are the amplitudes of pion-pion scattering at zero energy in states with isotopic spin 0 and 2, $b_{1/2}$ and $b_{3/2}$ are the amplitudes of pion-nucleon scattering at zero energy in states with isotopic spin $1/2$ and $3/2$. Since the difference $(b_{1/2} - b_{3/2})$ is known,[5] one can find the difference of the amplitudes $a_2 - a_0$ and, hence, the exchange amplitude $a_{12} = 1/3\,(a_2 - a_0)$ from the experimentally determined ratio c/d. However, this theory may not be quite applicable at 290 Mev. The point is that the theory is linear in kr_0, so that it is necessary that terms quadratic in kr_0 be small compared to the linear terms and, hence, that the P phase shifts of the π-n and π-π scattering be small. In our case the kinetic energy in the c.m.s. is about 90 Mev. The average energy of the particles in the final state is about 40 Mev. At this energy one of the P-phase shifts of π-n scattering, δ_{33}, is comparable with the S phases δ_3 and δ_1.

Nevertheless, we attempted to reduce the experimental data in an effort to find out how well Eq. (2) describes the experimental situation. With this aim, the entire kinematically available region in the k_{12}, k_{13} plane was divided into regions containing 13 points or more, the density of points within a region being approximately constant. Thus, the whole region was divided into 9 parts. Owing to the energy dispersion (±15 Mev), only those events were chosen which were situated in a region internal to the limiting values (see Fig. 1). If Eq. (2) is correct, the points having the coordinates x_i, y_i, z_i should lie on a plane. Here x_i and y_i are approximately equal to the average values $\overline{k_{13}}$ and $\overline{k_{12}}$ for each region and z_i is equal

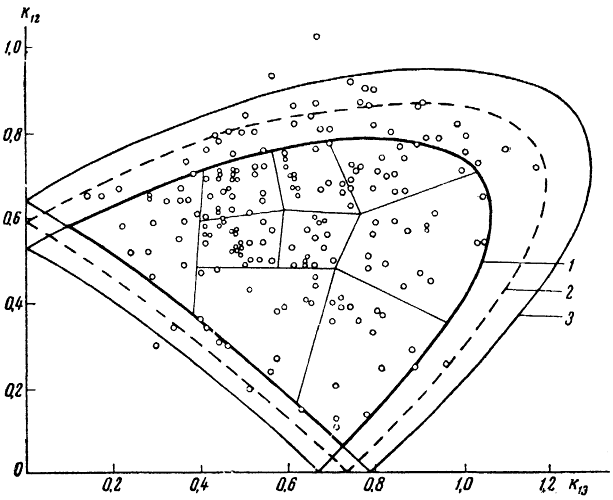

FIG. 1. Distribution of events for $\pi^- + p \rightarrow \pi^- + \pi^+ + n$ reaction at 290 ± 15 Mev in the k_{12}, k_{13} plane. Here k_{12}, k_{13} are the relative momenta $(\pi^+ - \pi^-)$ and $(\pi^+ - n)$ in units of $\mu_\pi c$. Curves 1, 2, 3 restrict the kinematically available regions for energies of 275, 290, 305 Mev, respectively.

to the total number of points in each region divided by the average value of the phase volume. The analysis carried out with a χ^2 distribution[6] has shown that within the experimental errors the points lie on a plane. The ratio c/d as obtained from the equation of the plane is equal to $-(0.76 \pm 0.65)$. It should be noted that other divisions analogous to that shown in Fig. 1 lead to the same value of c/d. From Eq. (3) one obtains a value $-(5 \pm 4) \times 10^{-14}$ cm for the difference $(a_2 - a_0)$; this corresponds to a charge-exchange cross section $\sigma_{\pi^+-\pi^- \to \pi^0+\pi^0} = 4\pi a_{12}^2 = 4^{+6}_{-4}$ mb. The given experimental errors are determined by statistics and not by inaccuracies of the theory at our energy which have not been included.

All the data available at present concerning the amplitude of S-wave π-π scattering are listed in Table II. As is seen from the table, the results of various authors differ both in absolute value and in sign. In such a situation it is of great interest to obtain more accurate data. Since in our treatment the accuracy of the theory is the main problem, it is more useful to run an experiment at lower energies, where the theoretical assumptions are more valid. At present such an experiment is being performed at an energy of 240 — 250 Mev (40 — 50 Mev in the c.m.s.).

TABLE II. S wave π-π scattering lengths ($\hbar/\mu_\pi c$ units)

a_2	a_0	$a_2 - a$	Initial reaction
~ 1			$\tau^+ \to \pi^+ + \pi^+ + \pi^-$ [7]
		$-(0,35 \pm 0,30)$	$\pi^- + p \to \pi^+ + \pi^- + n$*
	~ 1		$\pi + N \to \pi + N$ [10]
$-0,48$	$-0,8$	0,3	$K^\pm \to 3\pi$ [11]
$-0,3$	-1	0,7	$K^\pm \to 3\pi$ [12]
	~ 1		$\pi + N \to \pi + N$ [13]

*Present paper.

The authors are grateful to Prof. V. P. Dzhelepov for his interest and attention and also to A. A. Ansel'm and V. N. Gribov for valuable discussions and advice and to S. N. Sokolov for help in the data reduction.

[1] G. F. Chew and F. E. Low, Phys. Rev. **113**, 1640 (1959).

[2] G. F. Chew, University of California Preprint UCRL-9028 (1960).

[3] Batusov, Bogachev, Bunyatov, Sidorov, and Yarba, Doklady Akad. Nauk SSSR **133**, 52 (1960), Soviet Phys.-Doklady, in press.

[4] A. A. Anselm and V. N. Gribov, JETP **37**, 501 (1959), Soviet Phys. JETP **10**, 354 (1960).

[5] J. Orear, Phys. Rev. **96**, 176 (1954).

[6] N. P. Klepikov and S. N. Sokolov, "The Analysis of Experimental Data by the Method of Least Squares," Joint Institute for Nuclear Research, Preprint P-235 (1958).

[7] B. S. Thomas and W. G. Holladay, Phys. Rev. **115**, 1329 (1959).

[8] F. Bonsignori and F. Sellari, Nuovo cimento **15**, 465 (1960).

[9] J. Derado, Nuovo cimento **15**, 853 (1960).

[10] Efremov, Mescheryakov, and Shirkov, JETP (in press).

[11] R. F. Sawyer and K. C. Wali, Preprint (1960).

[12] N. N. Khuri and S. B. Treiman, Preprint (1960).

[13] Ishida, Takahashi, and Ueda, Preprint (1960).

Translated by A. Skumanich
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THE NATURE OF THE PARTICLE BEAMS IN THE CORE OF EXTENSIVE AIR SHOWERS

S. N. VERNOV, I. P. IVANENKO, G. V. KULIKOV, and G. B. KHRISTIANSEN

Nuclear Physics Institute, Moscow State University

Submitted to JETP editor June 20, 1960

J. Exptl. Theoret. Phys. (U.S.S.R.) **39**, 509-512 (August, 1960)

IN a previous article,[1] the existence of a peculiar feature in the lateral distribution of shower particles in the core region of extensive air showers (EAS) was reported. Narrow beams consisting of a large number of particles (from four to fifteen) were detected in studying the core structure by means of a diffusion chamber. The experimental results obtained previously made it possible to regard the observed particle beams either as the cores of electron-photon showers produced by π^0 mesons, or as groups of high-energy μ mesons. It will be shown that the second hypothesis is the more likely one.

Let us assume that the beams under consideration represent the cores of electron-photon showers initiated in the decay of π^0 mesons produced in nuclear interactions. We shall estimate the energy of the primary particle which produced