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ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ
Лаборатория ядерных проблем

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EXPERIMENTAL EVALUATION OF THE $\pi^+ \to \pi^0 + e^+ + \nu$ DECAY PROBABILITY

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EXPERIMENTAL EVALUATION OF THE $\pi^+ \to \pi^\circ + e^+ + \nu$ DECAY PROBABILITY

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БИБЛИОТЕКА

By means of γ-γ coincidences it has been shown that the probability of positive pion β-decay does not exceed 7.10^{-8} of the probability of muon decay of pion. For the constant G which determines the intensity of this process in the case of vector current conservation the following evaluation has been obtained: $G < 2.5\ G_\beta$, where G_β is the constant of weak vector β - interaction.

A rare mode of a charged pion decay

$$\pi^{\pm} \to \pi^{o} + e^{\pm} + \nu \qquad (1)$$

which by analogy with a nucleon β -decay may be called a pion β -decay† has not been practically investigated experimentally up till now due to an extremely small expected value ot its probability and, hence, to great experimental difficulties. The theoretical analysis of this process was first performed by Zeldovich/2/, who showed that in the framework of the Fermi-Yang model a pion β -decay is analogous to $J = 0 \to J = 0$ beta transition of nuclei and, consequently, it should be characterized by the same value ft as the decay of nuclei of the above type (for instance, $O_{14} \to N^{*}_{14}$). Hence, it follows that the probability of the pion β -decay should be one hundred millionth of the probability of the conventional decay $\pi^{\pm} \to \mu^{\pm} + \nu$.

When the weak universal interaction theory was developed/3/ the interest to the pion β -decay increased sharply due to a necessity of experimental checking the conserved vector current hypothesis which followed from a deep analogy between weak and electromagnetic interactions. For the first time this analogy was noticed by Gerstein and Zeldovich/4/ who as long ago as 1955 indicated that the vector coupling constant for beta decay might not be renormalized by strong interactions. If one takes the above hypothesis, the probability of pion β -decay may be calculated accurately despite the fact that strong interacting prticles take place in the process/3/:

$$w(\pi^{\pm} \to \pi^{o} + e^{\pm} + \nu) = \frac{G^2 \Delta^5}{30\pi^3}, \qquad (\hbar = c = 1) \qquad (2)$$

Here G is the weak interaction vector constant, Δ is the difference of masses of charged and neutral pions. Electromagnetic and kinematic corrections to formula (2) are not large/5/ (a few per cent). From comparison (2) with the known probability of a conventional pion decay it follows that if the

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† Sometimes another process $\pi^{\pm} \to e^{\pm} + \nu$ is called a pion β -decay. It would be more correct to call it an electron mode of pion decay/1/.

vector current is conserved, the relative probability of the pion β -decay

$$\lambda = \frac{w(\pi^{\pm} \to \pi^{o} + e^{\pm} + \nu)}{w(\pi^{\pm} \to \mu^{\pm} + \nu)}$$

should be equal to 1.10^{-8} to an accuracy of $\approx 5\%$.

Thus, the pion β -decay is a rare example of the process the properties of which are predicted by the theory with high accuracy and the investigation of which provides thus a possibility to choose whether one should accept or reject the theory. A great interest paid at present to the conserved vector current hypothesis urged us, despite the extremely small expected value of the probability λ, to make an attempt to evaluate experimentally this probability.

The experimental arrangement is shown in Fig. 1. Positive pions stopped and disintegrated in the

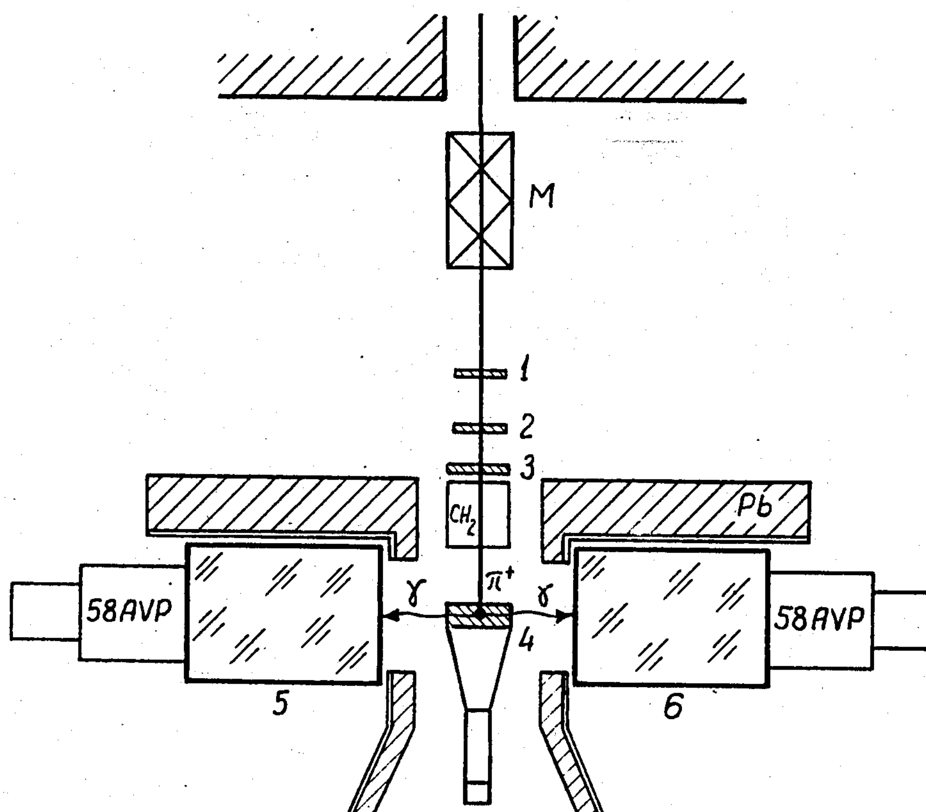


Fig. 1.

Experimental arrangement. M is a focusing magnet lens, 1,2 are scintillation counters of the monitor of the π^+ beam (with photomultipliers FEU–33), 3 is a scintillation counter (with a photomultiplier 56 AVP), 4 is a counter 'stop detector' (FEU–33), 5,6 are Čerenkov counters (58 AVP), CH_2 is a polythene moderator used to slow the beam down, Pb is lead shielding of the spectrometers.

scintillator of counter 4 which had a selective sensitivity to pion stoppings (the 'stop detector' described in paper[6]). The characteristics of this detector are shown in Fig. 2. In order to register

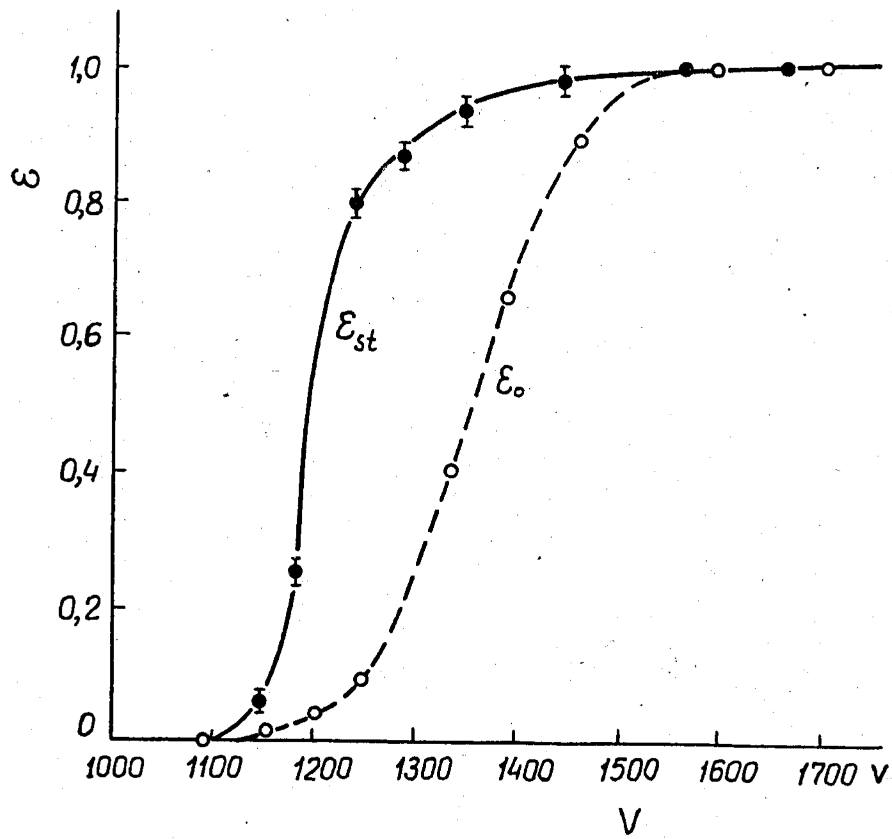


Fig. 2.

The efficiency ϵ of the 'stop detector' to the stoppings of positive pions (ϵ_{st}) and to relativistic pions (ϵ_o) versus various voltages V of the detector photomultiplier.

γ quanta from a neutral pion decay accompanying process (1), two Čerenkov total absorption spectrometers were used which had a high time resolution and were insensitive to outside radiation background.

Charge exchange of positive pions in flight in the scintillator of counter 4 was the most dangerous accompanying process which complicated the registration of the pion β -decay. The cross section of this process with 65 MeV pions was measured by the authors earlier with the help of the device presented in Fig. 1 and is $(10 \pm 3) \cdot 10^{-27}$ cm^2 per carbon nucleus. Using for the sake of evaluation the obtained value of the cross section in the lower energy region also (where the process of charge exchange had not been studied earlier) with the conditions of our experiment one should expect that the intensity of π^+ charge exchange will be 4 orders higher than the intensity of process (1). This evaluation which gave the upper limit of the expected background showed how serious the difficulties of pion β-decay investigations were. In view of the fact that the problem of charge exchange intensity at lower energies is of paramount importance in carrying out the experiments on pion β-decay investigations, we studied the energy dependence of charge exchange probability. One could expect that the charge exchange cross section would decrease with pion energy decreasing due to the influence of the Pauli principle and the Coulomb repulsion. As a result of measurements it was found (see Fi.g 3)

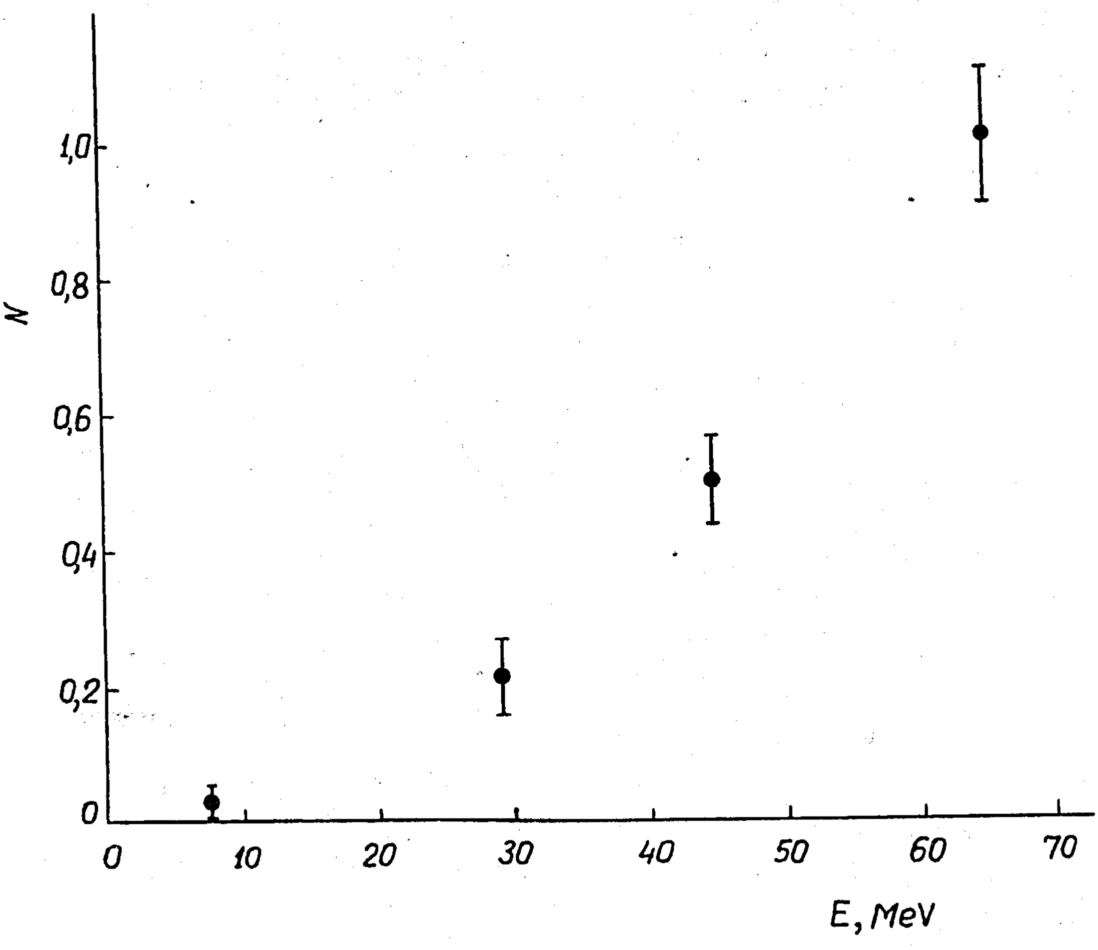


Fig. 3.

The dependence of the probability of pion charge exchange in carbon upon their energy E. N is the counting rate of coincidences of counters 3,4 and spectrometers 5,6 (in relative units).

that the charge exchange probability decreases in fact sharply with decreasing energy and, consequently, the real background in conditions of our experiment is not so large as it was shown by a preliminary evaluation. Nevertheless, it exceeds the expected intensity of process (1) nearly 3 orders.

The use of the 'stop detector' permitted to suppress the probability of charge exchange registration approximately by an order (see Fig. 2) so that in the end the intensity of charge exchange registration exceeded the expected intensity of process (1) a hundred times. Further essential suppression of the charge exchange registration efficiency was performed with the help of a fast delayed coincidence circuit. Counters 3,4 and spectrometers 5,6 were connected with the coincidence circuit so that it registered only those simultaneous events in spectrometers 5,6 which were delayed in time relative to counters 3,4 which marked the moment of a pion stop. The spectrometer delay relative to the scintillation counters was chosen to be equal to 8.10^{-9} sec., the width of the resolution curve (the so-called 'gate') was 6.10^{-9} sec. Time adjustment of counters and spectrometers was performed with a high energy electron beam obtained and studied earlier in paper /7/. The energy characteristics of spectrometers have been measured with the same beam (see Fig. 4). The energy threshold of spectrometers was taken to be 20 Mev. This allowed to register γ quanta from π^0 decay with an efficiency close to a unity.

In the described situation we carried out two runs of measurements during which about $1.4.10^9$ positive pions passed the experimental equipment. In course of measurements we periodically performed test calibration of spectrometers and scintillation counters with the help of γ quanta, produced in counter 4 as a result of pion charge exchange. During measurements which lasted about 30 hours one count of the apparatus was registered which in the units of λ corresponds to the value

$$\lambda_r = 5.10^{-8}.$$

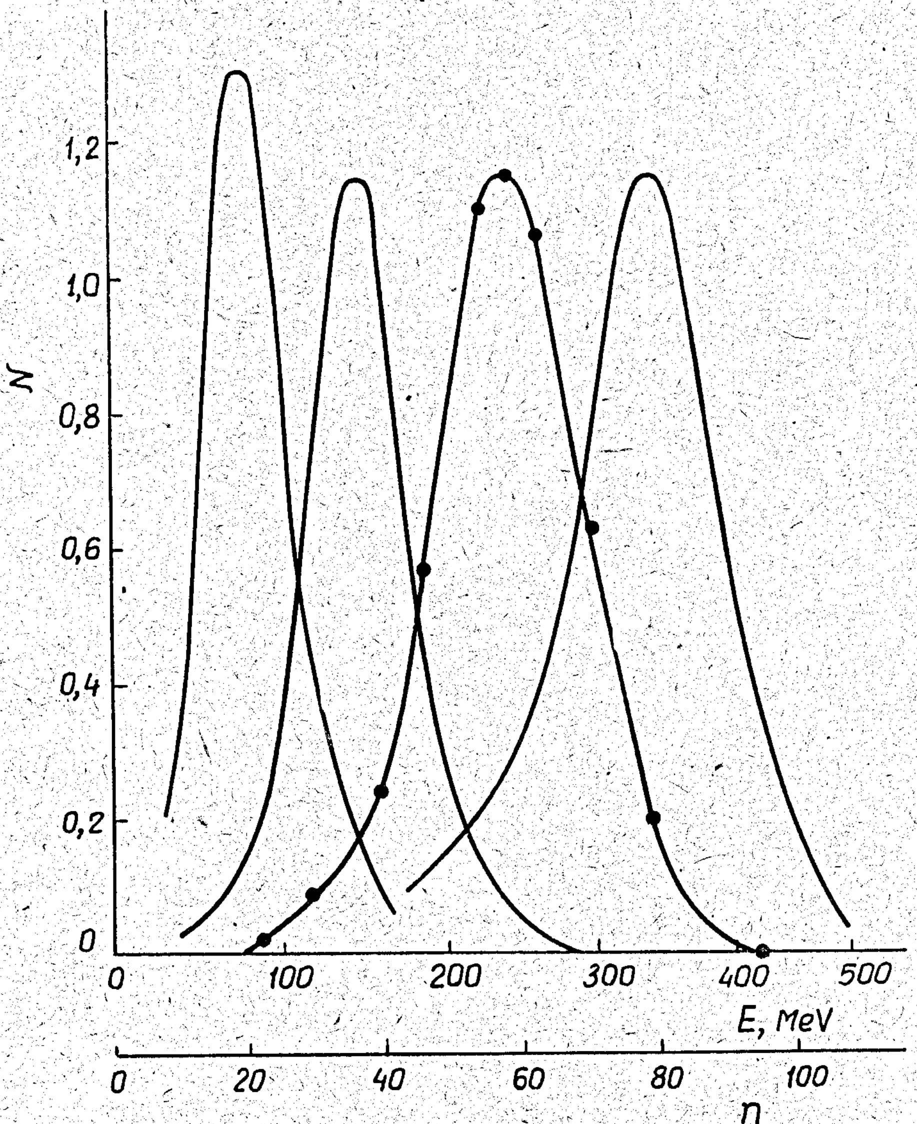
This count may be attributed both to pion β-decay and to the charge exchange process. The probability of registering of the latter according to test measurements was, (in the same units) $\lambda_b = 8.5.10^{-8}$.

The obtained result may be given in the form of the distribution function of the probability $W_1(\lambda > \lambda_m)$ of the fact that with one registered event the value λ in question characterizing the pion β-decay intensity exceeds λ_m. Integrating the normalized Poisson distribution we get:

$$W_1(\lambda > \lambda_m) = e^{-\lambda_m/\lambda_r}\left(1 + \frac{\lambda_m/\lambda_r}{1 + \lambda_b/\lambda_r}\right) \qquad (3)$$

Substituting in (3) the obtained values of λ_r and λ_b we see that the function W_1 in our case differs little from the exponential function with the index 7.10^{-8} (see Fig. 5). The value of this index is appropriate to be taken as the limit evaluation of λ:

$$\lambda < 7.10^{-8}.$$



F i g. 4.

Energy resolution of total absorption spectrometers measured with an electron beam of various energy E by means of a pulse height analyser. n is the number of an analyser channel, E is the energy corresponding to the given channel, N is the counting rate in a channel (in relative units).

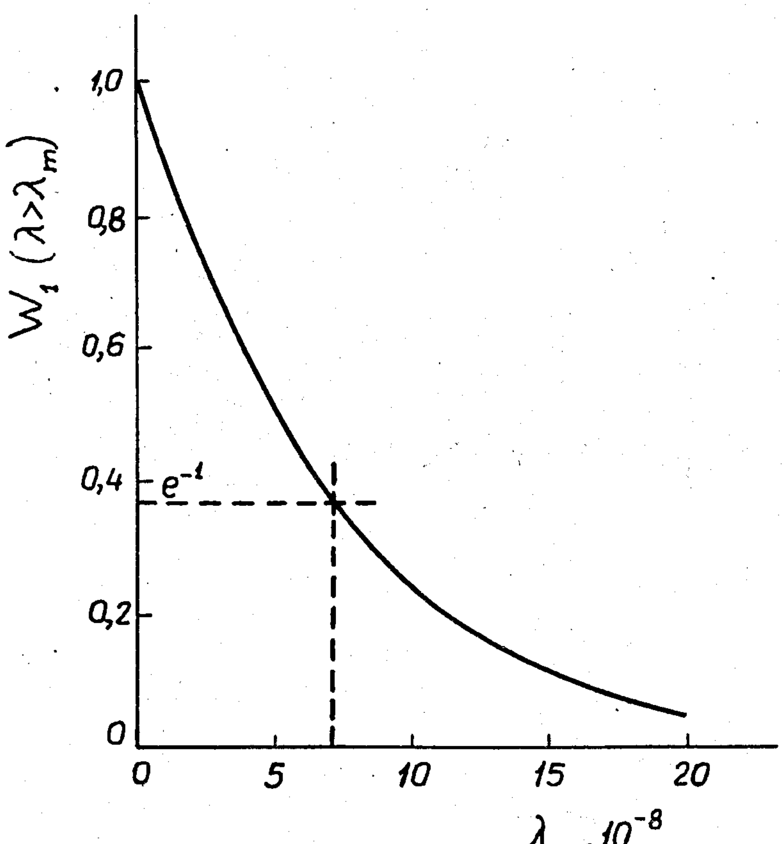


Fig. 5.

The integral probability $W_1 (\lambda > \lambda_m)$ obtained as a result of measurements.

The probability that λ is outside the indicated range equals 1/e. The obtained evaluation of λ is rather close to the theoretically expected value. Note that evaluations which can be made on the basis of the analysis of earlier obtained experimental data, in the most perfect case differ from the theoretically expected value by 3 orders/8/.

Basing on the evaluation for λ, it is possible to find the upper limit for the value of the constant G which determines the intensity of the pion β-decay. Making use of the formula (2) which is justifiable in the case of the vector current conservation, we obtain the inequality

$$G < 2.5\ G_\beta$$

which shows that this constant does not exceed practically the constant of the vector interaction $G_\beta = 1.4.10^{-49}$ erg.cm^3 obtained/3/ on the basis of the $0_{14} \to N^{*}_{14}$ decay investigation.

The experiments performed have shown that after some improvements the described technique will give a possibility to carry out quantitative investigation of the process (1) at the level of the theoretically expected value of its probability.

In conclusion we take an opportunity to express our gratitude to D.I. Blokhintsev, V.N. Sergienko, V.P. Dzhelepov and A.A. Logunov for the great help in carrying out the above experiment. We are thankful to Ya.B. Zeldovich, S.S. Gerstein, B. Pontecorvo and L.I. Lapidus for valuable discussions.

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