The solid angle of the installation used to register the $\mu \to e + \gamma$ events was 1.6π sr.

The counting efficiency for a 53-MeV electron from the $\mu \to e + \gamma$ decay should be 40%. The counting efficiency of 53-MeV γ quanta was 15%. The overall counting efficiency for $\mu \to e + \gamma$ events, with account of the processing criteria employed, was 0.8%.

Altogether, 5.5×10^8 stopped π^+ mesons were counted in the O counter after 66 hours of operation.

The processing of the e, γ events resulted in six cases in which the angle between the electron and the γ quantum was in the interval 174—144° in the first projection and 180—140° in the second projection in chamber B; not one event was counted in the interval 180—174° in the first projection.

The remaining events are most likely $\mu \to e + \nu + \bar{\nu} + \gamma$ decays. From a theoretical estimate we can expect under the conditions of our experiment about 5 radiation decays in the 174—144° interval and one case in the 180—174° interval in the first projection.

It follows from our measurements that the upper limit of the $\mu \to e + \gamma$ decay constitutes 5×10^{-7} of the ordinary decay, with 90% reliability. The measurements are continuing at the present time.

The authors are grateful to V. P. Dzhelepov and A. A. Tyapkin for interest in the work, and also to A. S. Kronrod, Yu. A. Simonov, and M. V. Terent'ev for many calculations.

---

*The value 1.2×10^{-6} (90% reliability) given in [2] for the upper limit is an underestimate. Calculations by Poisson's method yield a limit of 1.6×10^{-6} for the data obtained in [2].

[1] Berley, Lee, and Bardon, Phys. Rev. Lett. **2**, 357 (1959).

[2] Frankel, Hagopian, Halpern, and Whetstone, Phys. Rev. **118**, 589 (1960).

[3] V. S. Kaftanov and V. A. Lyubimov, PTÉ (Instruments and Measurement Techniques), in press.

Translated by J. G. Adashko

EXPERIMENTAL ESTIMATE OF PROBABILITY OF β DECAY OF THE π^+ MESON

A. F. DUNAĬTSEV, V. I. PETRUKHIN, Yu. D. PROKOSHKIN, and V. I. RYKALIN

Joint Institute for Nuclear Research

Submitted to JETP editor December 9, 1961

J. Exptl. Theoret. Phys. (U.S.S.R.) **42**, 632-635 (February, 1962)

THE rare form of charged-pion decay

$$\pi^{\pm} \to \pi^0 + e^{\pm} + \nu, \qquad (1)$$

which can be called the pion β decay* in analogy with β decay of the nucleon, has remained practically uninvestigated experimentally, owing to its exceedingly low expected probability and the resultant large experimental difficulties. A theoretical analysis of this process first made by Zel'dovich[2] has shown that within the framework of the Fermi-Yang model the β decay of a pion is analogous to a Fermi nuclear β transition of the type J = 0 → J = 0, and should be consequently characterized by the same value of ft as the decays of nuclei belonging to this type (for example, $O^{14} \to N^{14*}$). It would follow therefore that the probability of pion β decay should amount to only about 10^{-8} of the probability of ordinary muon decay $\pi^{\pm} \to \mu^{\pm} + \nu$. With development of the theory of universal weak interaction,[3] interest in the pion β decay has increased greatly in connection with the need for an experimental verification of the conservation of vector current, a hypothesis derived from the deep analogy between weak and electromagnetic interactions. The first to call attention to this analogy were Gershteĭn and Zel'dovich,[4] who pointed out as long ago as in 1955 that the constant of weak vector interaction may possibly not be normalized by strong interactions. If the foregoing hypothesis is accepted, then the probability of pion β decay should be calculated exactly, in spite of the fact that strongly-interacting particles participate in the decay process:[3]

$$w(\pi^{\pm} \to \pi^0 + e^{\pm} + \nu) = G^2\Delta^5/30\pi^3 \qquad (\hbar = c = 1). \qquad (2)$$

Here G is the weak vector interaction constant and Δ is the mass difference between the charged and neutral pion. The electromagnetic and kinematic corrections to formula (2) are small [5] (several per cent). From a comparison of (2) with the known probability of ordinary charged pion decay it follows that if the vector current is conserved, then the relative pion β decay probability

$$\lambda = w(\pi^{\pm} \rightarrow \pi^0 + e^{\pm} + \nu)/w(\pi^{\pm} \rightarrow \mu^{\pm} + \nu)$$

should have a value 1×10^{-8}, with about 5% accuracy. Thus, pion β decay is a rarely encountered example of a process whose characteristics are predicted with great accuracy by the theory, and a study of which affords a possibility of establishing whether this theory should be accepted or rejected.

The present great interest in the hypothetical conservation of vector current has induced us to attempt, in spite of the exceedingly low expected value of the probability λ, to estimate this probability experimentally. The experimental setup is shown in Fig. 1. The π^+ mesons were stopped and decayed in the scintillator of counter 4, which had selective sensitivity to stopped pions ("stopped particle detector" described in [6]). To count the γ quanta from the π^0-meson decay accompanying the process (1), two total-absorption Cerenkov spectrometers were used, with high time resolution and insensitive to the background of extraneous radiation.

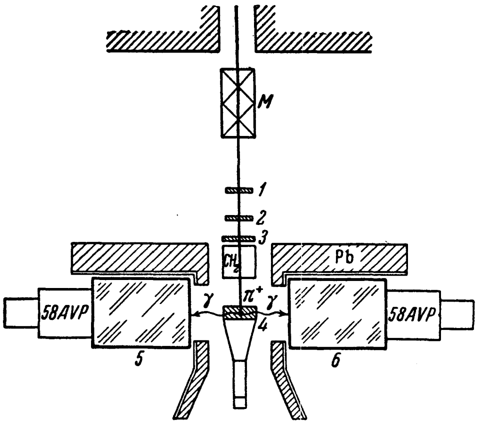

FIG. 1. Setup of the experiment. M – magnetic focusing lens, 1, 2 – scintillation counters for the π^+-meson beam monitor (with FÉU-33 photomultiplier), 3 – scintillation counter (with 56 AVP photomultiplier), 4 – "stopped particle detector" counter (FÉU-33), 5, 6 – Cerenkov spectrometers (58 AVP), CH_2 – polyethylene filter to slow down the beam, Pb – lead shielding of spectrometers.

The most dangerous concurrent process hindering the registration of the π^+-meson β decay is in-flight charged exchange of π^+ mesons in the scintillator of counter 4. We have measured previously the cross section of this process for 65-MeV π^+-mesons, using the apparatus illustrated in Fig. 1; this cross section was found to be $(10 \pm 3) \times 10^{-27}$ cm^2 per carbon nucleus. If we use this cross section in our estimates at lower energies (where the charge-exchange process was not investigated previously), we can expect under the conditions of our experiments the π^+-meson charge exchange intensity to be four orders of magnitude greater than the intensity of process (1). This estimate, which gives the upper limit of the expected background, shows how serious the difficulties in investigations of pion β decay are. Since the question of charge-exchange intensity at low π^+-meson energies plays a primary role in setting up experiments on π^+-meson β decay, we have investigated the energy dependence of the charge-exchange probability. One could expect the charge-exchange cross section to decrease with decreasing π^+-meson energy, owing to the Pauli principle and the Coulomb repulsion. The measurements have disclosed (see Fig. 2) that the charge-exchange probability does indeed decrease rapidly with energy, and consequently the real background is not as large under the conditions of our experiments as was tentatively estimated; nonetheless, it did exceed the expected intensity of process (1) by almost three orders of magnitude.

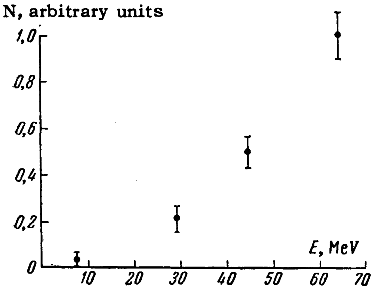

FIG. 2. Dependence of π^+-meson charge exchange probability in carbon on the pion energy, E. N – counting rate of coincidences between counters 3, 4 and spectrometers 5, 6.

The use of a "stopped-particle detector" has made it possible to suppress the probability of charge-exchange registration by approximately one order of magnitude, so that in the final analysis the intensity of registration of the charge exchange exceeded the expected intensity of the process (1) by 100 times. Further effective suppression of the charge-exchange registration efficiency was obtained by a fast-delay coincidence circuit. Counters 3 and 4 and spectrometers 5 and 6 were connected in this circuit in such a way that the system registered only those simultaneous events in spectrometers 5 and 6 which were delayed in time relative to counters 3 and 4, which recorded the instant when the π^+ mesons were stopped. The timing of the counters and spectrometers was reconciled with the aid of a high-energy electron beam obtained and investigated by us earlier.[7]

We used the setup described to make two series of measurements, during which about 1.4×10^9 π^+ mesons passed through the apparatus. In the course of the measurements we monitored periodically the calibration of the spectrometers and scintillation counters by using the γ quanta produced by π^+-meson charge exchange in counter 4. In 30 hours of measurements the apparatus produced one count, which corresponds in λ units to $\lambda_c = 5 \times 10^{-8}$. This count can be attributed either to π^+-meson β decay or to charge exchange. The probability of recording the latter, according to control measurements, was (in the same units) $\lambda_b = 8.5 \times 10^{-8}$. The result obtained can be represented in the form of a distribution $W_1(\lambda > \lambda_{max})$ of the probability that, for one registered event, the sought value of λ, which characterizes the intensity of the π^+ meson decay, exceeds λ_{max}. Integrating the normalized Poisson distribution, we obtain

$$W_1(\lambda > \lambda_{max}) = e^{-\lambda_{max}/\lambda_c}\left(1 + \frac{\lambda_{max}/\lambda_c}{1 + \lambda_b/\lambda_c}\right). \qquad (3)$$

Substituting the obtained values for λ_c and λ_b, we see that the function W_1 differs little in our case from an exponential function with decrement 7×10^{-8} (see Fig. 3). The value of this exponent can be conveniently used as an estimated limit of λ:

$$\lambda < 7 \cdot 10^{-8}.$$

In this case the probability of λ being outside the indicated interval is 1/e. The estimate obtained for λ is quite close to the theoretically expected value. We note that estimates that can be based on the analysis of the previously obtained experimental data deviate from the theoretically expected value at best by three orders of magnitude.[8]

Starting from this estimate for λ, we can find the upper limit of the constant G, which determines the intensity of the pion β decay. Using formula (2), which is valid if vector current is conserved, we arrive at the inequality

$$G < 2.5\, G_\beta,$$

which shows that this constant does not exceed in practice the vector interaction constant $G_\beta = 1.4 \times 10^{-49}$ erg-cm^3, determined from the study of the $O^{14} \rightarrow N^{14*}$ decay.[3]

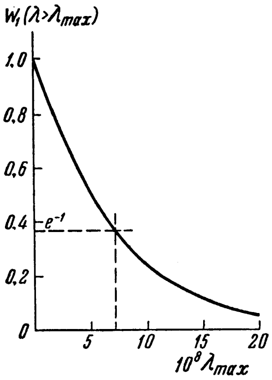

FIG. 3. Integral probability $W_1(\lambda > \lambda_{max})$, obtained as a result of the measurements.

The experiments have shown that when certain improvements are introduced the apparatus will permit a quantitative investigation of the process (1) at a level corresponding to its theoretically expected probability.

In conclusion we take this opportunity to thank D. I. Blokhintsev, V. N. Sergienko, V. P. Dzhelepov, A. A. Tyapkin, and A. A. Logunov for great help in the performance of this experiment. We are grateful to Ya. B. Zel'dovich, S. S. Gershteĭn, B. Pontecorvo, and L. I. Lapidus for useful discussions.

---

*The term "pion β decay" is sometimes used to describe a different process, $\pi^\pm \rightarrow e^\pm + \nu$, which should more correctly be called the electronic type of pion decay.[1]

[1] Anderson, Fujii, Miller, and Tau, Phys. Rev. **119**, 2050 (1960).

[2] Ya. B. Zel'dovich, DAN SSSR **97**, 421 (1954).

[3] R. P. Feynman and M. Gell-Mann, Phys. Rev. **109**, 193 (1958). E. C. G. Sudarshan and R. E. Marshak, Proc. of Padua Conf. (1957).

[4] S. S. Gershteĭn and Ya. B. Zel'dovich, JETP **29**, 698 (1955), Soviet Phys. JETP **2**, 576 (1956).

[5] G. Da Prato and G. Putzolu, Nuovo cimento **21**, 541 (1961).

[6] Dunaĭtzev, Prokoshkin, and Tang Syao-wei, Nucl. Instr. **8**, 11 (1960).

[7] Yu. D. Prokoshkin and T'ang Hsiao-wei, JETP **36**, 10 (1959), Soviet Phys. JETP **9**, 6 (1959); PTÉ (Instruments and Measurement Techniques) No. 3, 32 (1959).

[8] Budagov, Viktor, Dzhelepov, Ermolov, and Moskalev, JETP **37**, 878 (1959), Soviet Phys. JETP **10**, 625 (1960). Impeduglia, Plano, Prodell, Samios, Schwartz, and Steinberger, Phys. Rev. Lett. **1**, 249 (1958).

Translated by J. G. Adashko
97