MEASUREMENT OF THE BRANCHING RATIO FOR PION BETA DECAY*

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We have investigated the pion decay process $\pi^+ \to \pi^0 + e^+ + \nu$.[1] Whereas various model calculations[2,3] lead to branching ratios for this process of the order of magnitude 10^{-8}, the conserved vector current (CVC) hypothesis[4,5] allows a precise prediction. Using the accepted values for the masses[6] of the particles involved and considering the calculated radiative corrections,[7] one obtains a branching ratio between 1.00×10^{-8} and 1.06×10^{-8} depending on the choice of coupling constant.[8] Thus considerable attention has been focused on the pion beta decay, since a precise measurement of its branching ratio can serve as a test of the CVC hypothesis. Experimental investigations have been undertaken also at CERN[9] and Dubna.[10]

This experiment was designed to detect the two π^0 gamma rays, the positron, and also the positron annihilation radiation from the reaction $\pi^+ \to \pi^0 + e^+ + \nu$. We find a branching ratio (see Table I) which is compatible with CVC.

A schematic diagram of the experimental arrangement is shown in Fig. 1. Positive pions (175 MeV/c) are degraded in carbon and brought to rest in scintillation counter 5. In order to detect the π^0 mesons produced in the $\pi^+ \to \pi^0$ decay, 18 lead-scintillator sandwich counters were arranged cylindrically about counter 5. Each of these sandwich counters had two photomultipliers (e.g., α_1 and β_1) that viewed alternate layers of scintillator separated by lead. Coincident signals from α_1 and β_1 required that a charged particle penetrate at least one thickness of lead (2.7 g/cm^2) in that counter. γ_1 and δ_1 were similarly situated photomultipliers on the diametrically opposite counter. A concentric array of thin scintillators used in anticoincidence was placed between the lead-scintillator-sandwich counters and counter 5 to guard against charged particles. Thus a π^0 produces a fourfold coincidence $\alpha_i\beta_i\gamma_i\delta_i$, $i = 1,2,\cdots,9$, without anticounters. Because of the geometrical resolution of the system, events of the type $\alpha_i\beta_i\gamma_j\delta_j$, $j = i \pm 1$, are also acceptable. The efficiency of this system was measured by detecting π^0 gamma rays produced by stopping π^- mesons in counter 5. The gamma-ray efficiency of counters $\gamma_i\delta_i$, for example, was determined by the ratio of fourfold events, $\alpha_i\beta_i\gamma_i\delta_i$, to threefold and fourfold events, $\alpha_i\beta_i\gamma_i + \alpha_i\beta_i\delta_i + \alpha_i\beta_i\gamma_i\delta_i$, together with the calculated probability of converting a π^0 gamma ray by the lead plates within the counter. From this result we find that the number of π^0 mesons produced per π^- stop in scintillator is 1.3×10^{-3}. The work of Dunaitsev et al.[11] leads to a value of $\sim1\times10^{-3}$ for this ratio, while the CERN group[9] obtains 2×10^{-3}. Utilizing our measurements, we find that the total efficiency of our apparatus for the detection of a π^0 meson produced in the $\pi^+ \to \pi^0$ decay is 11%.

The positron in the decay was observed by two methods: (1) We looked for the e^+ signal following the stopping π^+ signal in counter 5. This counter was divided into three sections, A, B, and C (each viewed by a different photomultiplier), in order to enhance the e^+ signal relative to that of the stopping π^+. (2) We looked for the signal

Table I. Summary of results for pion beta decay.

Criterion for π^0 counters $\alpha_i\beta_i\gamma_j\delta_j$	e^+ detected by	Acceptable events	Background events ($i \neq j \pm 0,1$)	Total efficiency (%)	π^+ mean life (nsec)	Branching[a] ratio $\times10^8$
$i = j \pm 0,1$	NaI	10	1	0.86	24 ± 10	2.0
$i = j \pm 0,1$[b]	NaI	6	0	0.77	-	1.4
$i = j$[b]	NaI	4	0	0.66	-	1.1
$i = j$[b]	NaI and 5	2	0	0.33	-	1.1

[a]The errors to be assigned to the branching ratio are dominated by the statistics on the number of events.
[b]The $i = 9$ counters are excluded.

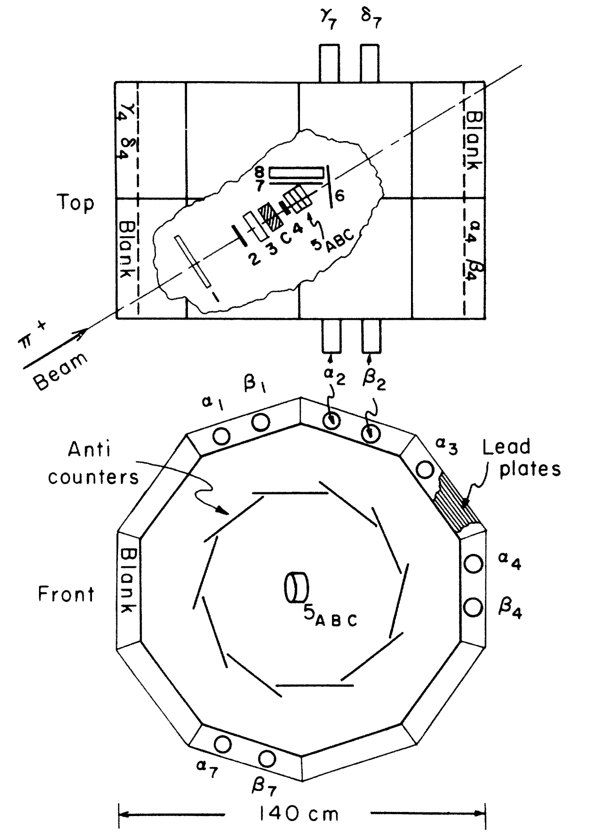

FIG. 1. Schematic of experimental system. Counters $1,2,4,5_A,\bar{3},\bar{6},\bar{7}$ define a stopping pion. Counter 3 is a water Cherenkov to guard against beam positrons. All other counters are scintillators. Counter 8 is a 2-inch thick NaI crystal for the detection of the positron annihilation radiation. C represents carbon degrader. $\alpha_1\beta_1$, $\alpha_2\beta_2,\cdots$, and their respective 180° counterparts, $\gamma_1\delta_1$, $\gamma_2\delta_2,\cdots$, are lead-scintillator sandwich counters for the detection of the π^0 gamma rays.

from counter 8, a NaI crystal placed near counter 5 in order to detect one of the $\frac{1}{2}$-MeV gamma rays from the e^+ annihilation.

The logic of the electronic system was as follows (see Fig. 2): A π^+ meson stopping in 5 generates the signature $245\bar{3}\bar{6}\bar{7}\bar{1}_D$. The 1_D signal occurs if another beam particle enters the system within an interval of 10 to 60 nsec following the pion stop. Consequently, $\bar{1}_D$ demands that no other beam particle enter the system during the time we are awaiting a possible $\pi^+ \to \pi^0$ decay. This signature opens a 40-nsec gate (G_2) 6 nsec after the pion stops. Within the gate if any four-fold coincidence of the lead-scintillator sandwich counters—$\alpha_i\beta_j\gamma_k\delta_l$—occurs without anticounters, a trigger is produced which activates the data storage system[12] and triggers a four-

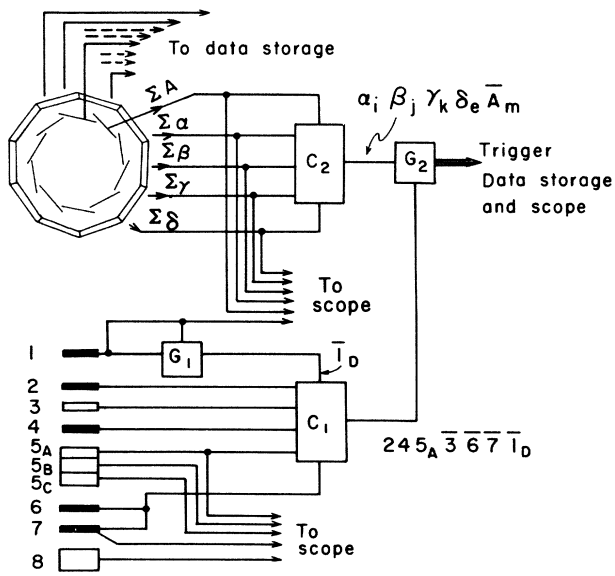

FIG. 2. Simplified electronic schematic.

beam oscilloscope. The data storage system interrogates all sandwich counters and records on magnetic tape those that have signals. Simultaneously the oscilloscope records pulses from the sandwich counters, the NaI, and some of the beam counters. The magnetic tape was processed by an IBM-7090 computer. The correlated magnetic tape and oscilloscope records allow us to determine the colinearity of the π^0 gamma rays (to within the geometrical resolution of the counters), the timing of all counters activated by the event, the pulse height of the e^+ in counter 5 (A, B, or C), and the pulse height of the $\frac{1}{2}$-MeV gamma in the NaI.

Our trigger rate was 6 per 10^7 stopped pions; the stopping π^+ rate was 10^5 sec^{-1}. The computer analysis indicated that 10% of these triggers were caused by opposite gamma rays (i.e., $\alpha_i\beta_i\gamma_i\delta_i$ events) and thus needed further investigation of the oscilloscope film for the remainder of the identification. However, in order to investigate possible background effects, the film was analyzed independently by scanning all events which had a NaI signal. In an acceptable event, the NaI signal of the proper pulse height (this was previously determined with $\frac{1}{2}$-MeV gammas from Na^{22} positron annihilation) occurred in time with the α, β, γ, and δ signals. The e^+ signal could not be reliably observed in counter 5 until 18 nsec after the π^+ stop, and even then only if its energy was $\gtrsim\frac{1}{2}$ MeV. Eleven events were found, seven of which had observable positron pulses in counter 5. Of these eleven events, only one can be definitely attributed to background (the angle between the gamma rays was too small to have been produced by a decay π^0). These results are shown in the first line of Table I. It was noticed in the analysis that the gamma-ray counters near the beam contribute a disproportionately large fraction of the trigger rate. If we discard the events from these counters ($i = 9$ counters) we are left with six events, all of which satisfy the criteria. These events are listed in the last three lines of Table I. The third line of the table shows the effect of requiring that the two gamma rays be in diametrically opposite counters. In the last line of the table we impose the requirement that the e^+ pulse be visible in counter 5 and the result is unchanged. The measured pion lifetime from the ten events in the first line of Table I is given to show its consistency with the known pion lifetime. The branching ratio as determined from these ten events is $(2.0 \pm 0.6) \times 10^{-8}$. In the entire experiment 5.6×10^{10} π^+ mesons were stopped.

Dunaitsev, Petrukhin, Protkoshkin, and Rykalin[10] have measured a branching ratio of $(1.1^{+1.0}_{-0.5}) \times 10^{-8}$ from four events with an expected background of 1.3 events. Depommier, Heintze, Mukhin, Rubbia, Soergel, and Winter[9] have obtained a value $(1.7 \pm 0.5) \times 10^{-8}$ for the $\pi^+ \to \pi^0$ branching ratio, having detected 14 events. Our experiment differs chiefly in the requirement of the positron annihilation radiation, whereas the other experiments required some energy resolution for the π^0 gamma rays. Without the requirement of the positron annihilation, our background subtraction was too large to obtain a meaningful result.

The results verify the existence of the pion-decay process $\pi^+ \to \pi^0 + e^+ + \nu$. Although the statistical accuracy is poor, the results are compatible with the CVC hypothesis.

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