UCRL-10486

University of California

Ernest O. Lawrence Radiation Laboratory

TWO-WEEK LOAN COPY

This is a Library Circulating Copy
which may be borrowed for two weeks.
For a personal retention copy, call
Tech. Info. Division, Ext. 5545

Berkeley, California

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

UCRL-10486

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

MEASUREMENT OF THE BRANCHING RATIO FOR PION BETA DECAY

Robert Bacastow, Tom Elioff, Rudolph Larsen,
Clyde Wiegand, and Tom Ypsilantis

September 24, 1962

Measurement of the Branching Ratio for Pion Beta Decay*

Robert Bacastow, Tom Elioff, Rudolph Larsen,†
Clyde Wiegand, and Tom Ypsilantis††

Lawrence Radiation Laboratory
University of California
Berkeley, California

September 24, 1962

We have investigated the pion decay process $\pi^+ \rightarrow \pi^0 + e^+ + \nu$.[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 γ rays, the positron, and also the positron annihilation radiation from the reaction $\pi^+ \rightarrow \pi^0 + e^+ + \nu$. We find a branching ratio (see Table I) 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 $\pi^+ \rightarrow \pi^0$ 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 γ rays produced by stopping π^- mesons in counter 5. The γ-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 γ 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 approx 1×10^{-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 $\pi^+ \rightarrow \pi^0$ 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 from counter 8, a NaI crystal placed near counter 5 in order to detect one of the 1/2-MeV γ 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 $2\,4\,5\,\bar{3}\,\bar{6}\,\bar{7}\,\bar{T}_D$. 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 $\bar{T}_D$ demands that no other beam particle enter the system during the time we are awaiting a possible $\pi^+ \rightarrow \pi^0$ decay. This signature opens a 40-nsec gate (G_2) 6 nsec after the pion stops. Within the gate, if any fourfold 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-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 collinearity of the π^0 γ 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 1/2-MeV γ 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 γ 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 that had a NaI signal. In an acceptable event, the NaI signal of the proper pulse height (this was previously determined with 1/2-MeV γ rays 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 greater than about 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 γ 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 γ-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 γ 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; the result is unchanged. The measured pion lifetime from the 10 events in the first line of Table I is given to show its consistency with the known pion lifetime. In the entire experiment 5.6×10^{10} π^+ mesons were stopped.

Dunaitsev, Petrukhin, Protkoshkin, and Rykalin[10] have measured a branching ratio of $1.1\pm^{1.0}_{0.5}\times10^{-8}$ from four events with an expected background of 1.3 events. Depommier, Heintze, Mukhin, Rubbia, Soergel, and Winter[9] have obtained a value $1.7\pm0.5\times10^{-8}$ for the $\pi^+\rightarrow\pi^0$ 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 γ rays. Without the requirement of the positron annihilation our background subtraction was too large to permit a meaningful result.

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

We thank Mr. James Vale and the 184-inch cyclotron crew for their cooperation. Useful discussions with Professor Thomas Slantis (Brookhaven National Laboratory) are acknowledged.

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 ($\times 10^{-8}$)
$i = j \pm 0,1$	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.

Footnotes and References

* Work done under the auspices of the U. S. Atomic Energy Commission.

† Now at Stanford Linear Accelerator Center, Palo Alto, California.

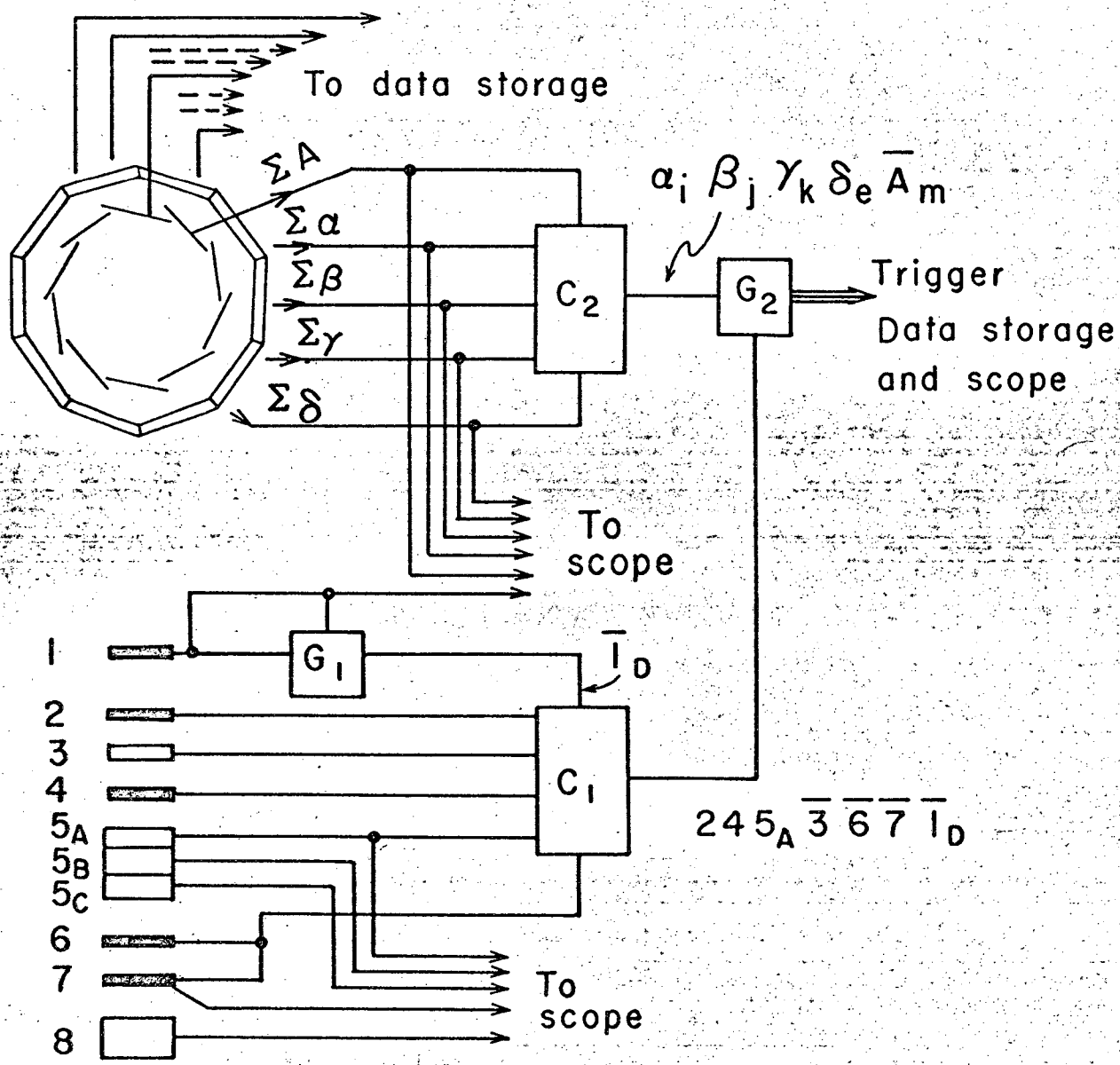
†† Now at Brookhaven National Laboratory, Upton, New York.

1. A preliminary report of our work has been given at the Washington meeting of the American Physical Society, April 5, 1962 and at the 1962 International Conference on High Energy Physics at CERN.
2. E. Feenberg and H. Primakoff, Phil. Mag. 3, 328 (1958).
3. Ya. B. Seldovich, Doklady Akad. Nauk, SSSR 97, 421 (1954).
4. R. P. Feynman and M. Gell-Mann, Phys. Rev. 109, 193 (1958).
5. S. Gershtein and I. Zeldovitch, Soviet Physics (Engl. Transl.) JETP 2, 576 (1956).
6. W. H. Barkas and A. H. Rosenfeld, Data For Elementary Particles, Lawrence Radiation Laboratory Report UCRL-8030 Rev., Oct. 1, 1961 (unpublished).
7. G. Da Prato and G. Putzolu, Nuovo Cimento 21, 541 (1961).
8. R. Bardin, C. Barns, W. Fowler, and P. Seeger, Phys. Rev. 127, 595 (1962).
9. P. Depommier, J. Heintze, A. Mukhin, C. Rubbia, V. Soergel, and K. Winter, Phys. Letters 2, 23 (1962).
10. A. Dunaitsev, V. Petrukhin, Yu. Prokoshkin, and V. Rykalin, Phys. Letters 1, 138 (1962).
11. A. Dunaitsev, V. Petrukhin, Yu. Prokoshkin, and V. Rykalin, Zh. Eksperim. i Teor. Fiz. 42, 1680 (1962).
12. Clyde E. Wiegand, in Proceedings of an International Conference on Instrumentation for High-Energy Physics (Interscience Publishers, Inc., New York, 1960), p. 182.

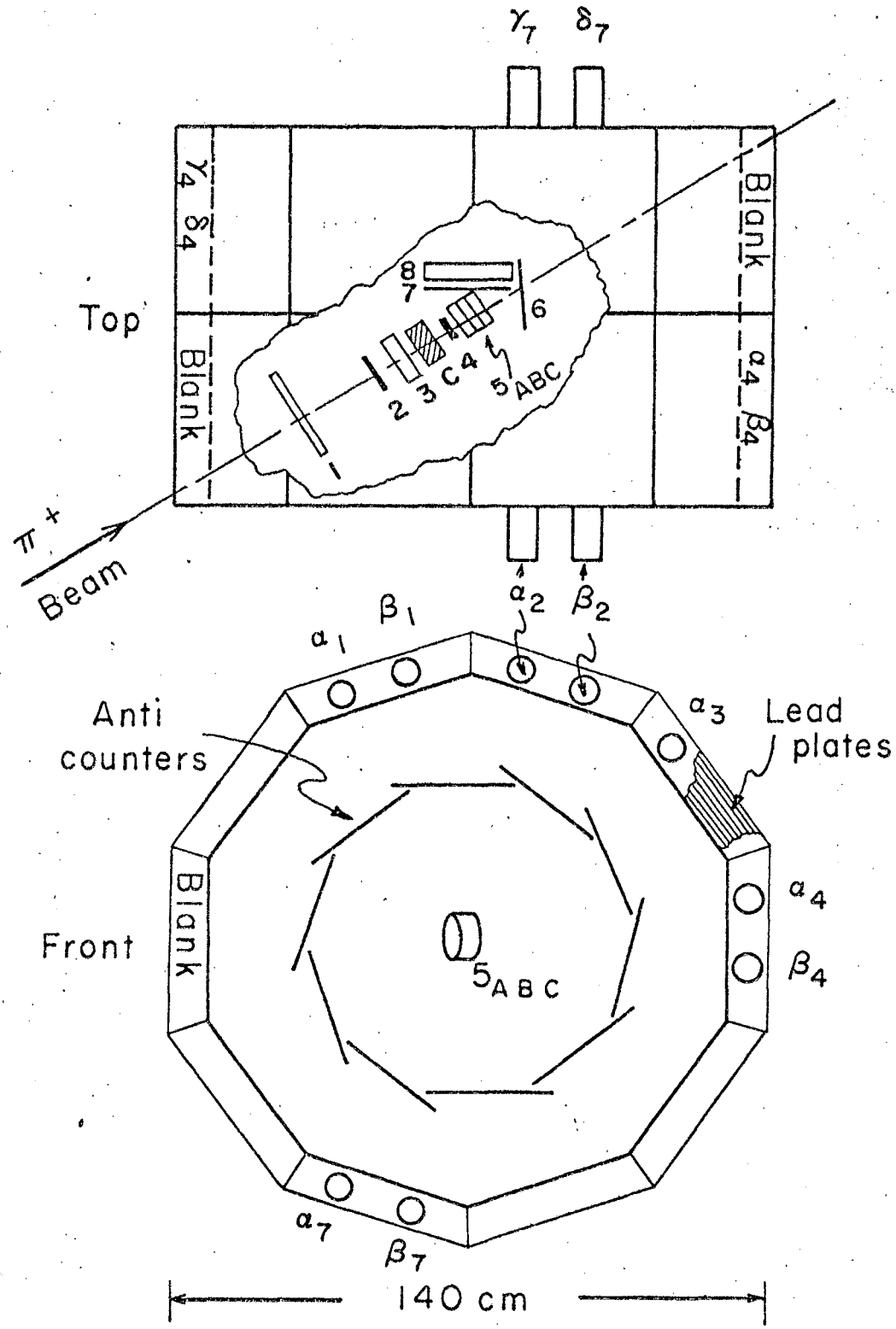
Figure Legends

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

Fig. 2. Simplified electronic schematic.


To data storage
ΣA
$\Sigma \alpha$
$\Sigma \beta$
$\Sigma \gamma$
$\Sigma \delta$
C_2
$\alpha_i \beta_j \gamma_k \delta_e \bar{A}_m$
G_2
Trigger
Data storage
and scope
To
scope
1
2
3
4
5_A
5_B
5_C
6
7
8
G_1
$\bar{I}_D$
C_1
$245_A \bar{3} \bar{6} \bar{7} \bar{I}_D$
To
scope

MU-28013


γ7 δ7
γ4 δ4
Blank
Top
8
7
6
2 3 C 4
5 ABC
α4 β4
Blank
π +
Beam
α2 β2
α1 β1
Anti
counters
α3
Lead
plates
Blank
Front
α4
β4
5 A B C
α7
β7
140 cm

MU-28014

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.