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ABSTRACT

A measurement of the difference between π^+ and π^- lifetimes gave $(\tau_+/\tau_-) - 1 = 0.0056 \pm 0.0028$, while the absolute π^+ lifetime was found to be 26.6 ± 0.2 ns.

A check on CPT invariance in weak interactions has been made by comparing the lifetimes of the charged pion and its antiparticle. The fraction of surviving pions as a function of distance in vacuum has been measured by using a liquid-hydrogen differential Cerenkov counter in π^+ and π^- beams which were nearly identical in their spatial and momentum distributions. In this way the π^+/π^- ratio was determined at each point to give a relative lifetime measurement. By analyzing the data differently, the absolute lifetimes were found also.

Pions were produced by the external proton beam of the Lawrence Radiation Laboratory's 184-inch synchrocyclotron, then momentum analyzed by two bending magnets and geometrically defined by five 0.025-in.-thick scintillators and four annular anticoincidence counters, as shown in fig. 1. This system provided (1) a nearly parallel beam of small momentum spread ($\Delta p/p = \pm 0.4\%$) and (2) a monitor of the intensity of that beam. The actual selection of pions was done by the movable Cerenkov counter. The latter used liquid hydrogen because operation at cyclotron momenta required a refractive index of about 1.1, and multiple scattering had to be minimized. The counter [1] (fig. 2), which had both a coincidence and an anticoincidence ring aperture to receive Cerenkov light, discriminated both in velocity ($\Delta\beta/\beta = \pm 0.005$) and in angle ($\pm 3$ deg). The pions had $\beta = 0.912$, muons in the beam had $\beta = 0.947$, and those muons from pion decay with $\beta = 0.912$ were emitted at 7 deg with respect to the beam direction, and hence were rejected.

To check accurately the equality of π^+ and π^- lifetimes, it is important to ascertain (a) there is no change in the nature of the monitor counts with time, and that there are no important differences between π^+ and π^- with respect to (b) beam geometry, (c) momentum, and (d) Cerenkov response with distance. These items are now discussed in order.

(a) Monitor. It is important that the fraction of pions in the beam not change with time, or (for relative measurements) that the change be the same for π^+ and π^- beams. The muon fraction (6% at counter A_4) was constant and the same for both polarities, but the electron fraction could change with proton beam position at the target. Hence an electron veto counter was used, as well as a split ion chamber to control the proton beam position to better than 1 mm, keeping changes in the electron fraction to $< 0.1\%$ for the negative beam and $< 0.02\%$ for the positive.

Accidental coincidence also did not contribute to fluctuations in the monitor, since the only significant accidental rate was 0.28% for positives and 0.23% for negatives and was very constant with time.

There were no measurable accidentals in the pion counts (monitor-Cerenkov coincidence).

The fraction of monitor counts per $S_1S_2S_3\bar{A}_1$ (see fig. 1) coincidence, the fraction of electrons vetoed, and the fraction of accidentals were all scaled. The distribution of each of these quantities for the 1200 individual readouts was Gaussian with the expected variance. Thus there was no indication of systematic fluctuations in the monitor system.

(b) Beam Geometry. Detailed beam profiles, as shown in fig. 3, were taken with a digitized spark chamber, [2] as well as by scanning laterally and vertically with the Cerenkov counter at each position along the beam at which data were obtained. The positive and negative beams were nearly identical in shape, but their centers became displaced gradually along the decay path because of the stray cyclotron field (≈3 gauss), and hence the counter was recentered at each polarity change.

(c) Momentum. The field at the position of the gaussmeter in each of the bending magnets was held constant and the same for both polarities to within 0.1%. Field setting errors averaged out in the many field reversals (over 100 π^+-π^--π^+ sequences), while the constant stray cyclotron field could have produced a π^+-π^- momentum difference of at most 0.1%. Checks on such a difference gave $(\langle p_+\rangle/\langle p_-\rangle) - 1 = -0.002 \pm 0.004$ from range measurements 0.001 ± 0.001 from the Cerenkov counter momentum dependence, and -0.002 ± 0.001 from a separate magnetic analysis, giving a weighted average of -0.0005 ± 0.0007. The second of these methods involved comparing the steep-sided curves, obtained for each sign of particle, of the Cerenkov counter efficiency as a function of beam momentum. This efficiency was a fold of beam momentum spread and counter response.

The third method employed, after counter A_4, an auxiliary magnet which bent the beam through 78 deg. Beam profiles were determined by placing the digitized spark chamber at six positions; the profile at the final position is shown in fig. 3(b). Relative momenta could be determined very precisely, but uncertainty in the chamber positions gave the absolute momentum (311.2 MeV/c) to only $\pm$1.0 MeV/c. The full width at half maximum of both beams was 2.5 MeV/c.

(d) Cerenkov Counter Response. It is an important feature of our method that the efficiency of the movable Cerenkov counter neither has to be known nor does it have to be the same for π^+ and π^-. For absolute lifetime measurements the efficiency must not change over one sequence of counter positions. However, for the lifetime difference it is required only that the efficiency, if it changes, do so approximately linearly over the time required for one π^+-π^--π^+ sequence (about 3 hours). The counter response as a function of momentum needs to be the same for π^+ and π^-, and that this was so has been discussed in (c).

Having discussed the four items of particular importance in achieving reliable results, we now turn to the data analysis. "Relative" and "absolute" lifetime analyses were performed on the data, which was based on 12×10^6 π^+ and 6×10^6 π^-. The results of the relative lifetime analysis for a distance of 0.58 of a lifetime were $(\tau_+/\tau_-) - 1 = 0.0058 \pm 0.0024$ without the Cerenkov anticoincidence ring and 0.0056 ± 0.0028 using the ring. The standard deviation given includes the relative momentum error, while the statistical and consistency errors are the same, since χ^2 per degree of freedom is 1.0 for over 100 data points. As a check on data consistency over a larger period, the absolute lifetime analysis (with the anticoincidence ring) gives $(\tau_+/\tau_-) - 1 = 0.0060 \pm 0.0031$. The corresponding value for the π^+ lifetime is shown in table 1 with a standard deviation which includes statistical and consistency errors, as well as that in the absolute momentum.

As shown in the table, the comparison of π^+ and π^- lifetimes agrees with the other two contemporaneous experiments [3, 4]. The three experiments employed quite different methods, and ours requires no corrections except for the almost negligible one for the difference in momenta. By using the same method with improved beam and apparatus, the experiment will be repeated shortly with greater precision.

We wish to thank James Vale and the cyclotron personnel for assistance with the apparatus and for giving us such stable operating conditions, E. F. McLaughlin and R. V. Schafer for cryogenic design of the hydrogen Cerenkov counter, H. Weisberg for assistance with the digitized spark chamber, G. R. Farrar for aid in the analysis, and A. C. Helmholz and B. J. Moyer for support and encouragement. Particularly we want to thank R. D. Eandi and B. Macdonald for the extensive help they gave with the apparatus and in the early running of the experiment.

FOOTNOTES AND REFERENCES

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1. The optical system is the same as that described by D. A. Hill, D. O. Caldwell, D. H. Frisch, L. S. Osborne, D. M. Ritson, and R. A. Schluter, Rev. Sci. Instr. **32** (1961) 111. Further details of this counter are given by D. O. Caldwell, R. W. Kenney, E. F. McLaughlin, W. L. Pope, R. V. Schafer, and B. F. Stearns, in Proc. 1966 International Conference on Instrumentation for High Energy Physics, Stanford, p. 201; Lawrence Radiation Laboratory Report UCRL-17129, November 1966.
2. H. Weisberg and V. Perez-Mendez, Lawrence Radiation Laboratory Report UCRL-16704, February 15, 1966 and Nucl. Instr. and Methods **46** (1967) 233.
3. M. Bardon, U. Dore, D. Dorfan, M. Krieger, L. Lederman, and E. Schwarz, Phys. Rev. Letters **16** (1966) 775.
4. F. Lobkowicz, A. C. Melissinos, Y. Nagashima, S. Tewksbury, H. von Briesen, Jr., and J. D. Fox, Phys. Rev. Letters **17** (1966) 548. The two values given for lifetime difference arise from different methods of averaging the data.

Table 1

Comparison of π^+ lifetime values and π^+/π^- lifetime ratios in recent experiments.

Reference	τ_+ (ns)	$\tau_+/\tau_- - 1$
Ashkin et al.[a]	25.46 ± 0.32	---
Eckhouse et al.[b]	26.02 ± 0.04	---
Kinsey et al.[c]	26.40 ± 0.08	---
Bardon et al. [3]	25.6 ± 0.3	0.0040 ± 0.007
Lobkowicz et al. [4]	26.67 ± 0.24	{0.0040 ± 0.0018 0.0023 ± 0.0040
This experiment	26.6 ± 0.2	0.0056 ± 0.0028

a. J. Ashkin, T. Fazzini, G. Fidecaro, Y. Goldschmidt-Clermont, N. H. Lipman, A. W. Merrison, and H. Paul, Nuovo Cimento **16** (1960) 490.

b. M. Eckhouse, R. J. Harris, Jr., W. B. Shuler, R. T. Siegel, and R. E. Welsch, Phys. Letters **19** (1965) 348. The numbers quoted differ from the published values in accordance with a communication of the authors to A. H. Rosenfeld.

c. K. F. Kinsey, F. L. Lobkowicz, and M. E. Nordberg, Jr., Phys. Rev. **144** (1966) 1132.

FIGURE LEGENDS

Fig. 1. Experimental arrangement. EPB: 732-MeV external proton beam; SIC: split ion chamber; T: 6-in. Be target; M_1: 9- by 12-in. C magnet; C: 1-1/2-in.-diam Pb collimator; M_2: 12- by 36-in. C magnet; Q: 16- by 32- by 16-in. quadrupole triplet; S_1-S_5: 0.02-in.-thick scintillators; A_1 through A_4: ring anticoincidence scintillators; A_e: 36-in.-long, CO_2-gas Cerenkov counter (10 psia); LH_2C: movable liquid-hydrogen Cerenkov counter.

Fig. 2. Schematic drawing of the liquid-hydrogen differential Cerenkov counter. Cerenkov light from paraxial particles is focused onto a ring aperture, the diameter of which depends on the angle of emission of the Cerenkov light (and hence the velocity of the particle), and the lateral position of which depends on the direction of the particle. The optically coaxial cylindrical mirror provides full efficiency across the 4-in. diameter of the radiator. LH_2: 4- by 8-in.-long liquid-hydrogen radiator; S: 1/4-in. sapphire window; M: 45-deg mirror; L_1, L_2: quartz lenses; Q: quartz vacuum window; A: ring aperture; LP: anticoincidence ring light pipes; C: coincidence photomultiplier; A_R, A_L: anticoincidence photomultipliers; CM: cylindrical mirror.

Fig. 3. Beam profiles taken with a digitized spark chamber. Data were taken in 0.1-in. intervals, but pairs of channels have been added together here for clarity. (a) Profiles at the end of the 36-ft

decay path for π^+ and π^-, showing the similarity in their beam shapes. The relative horizontal scale has been shifted to permit easier comparison. Note that the tails of the profiles, which are the same for positives and negatives, were not due to pions, since the Cerenkov counter gave no counts in those regions.

(b) Profiles 12 ft beyond a 78-deg bend, showing the similarity in central momentum and momentum spread for the π^+ and π^- beams.

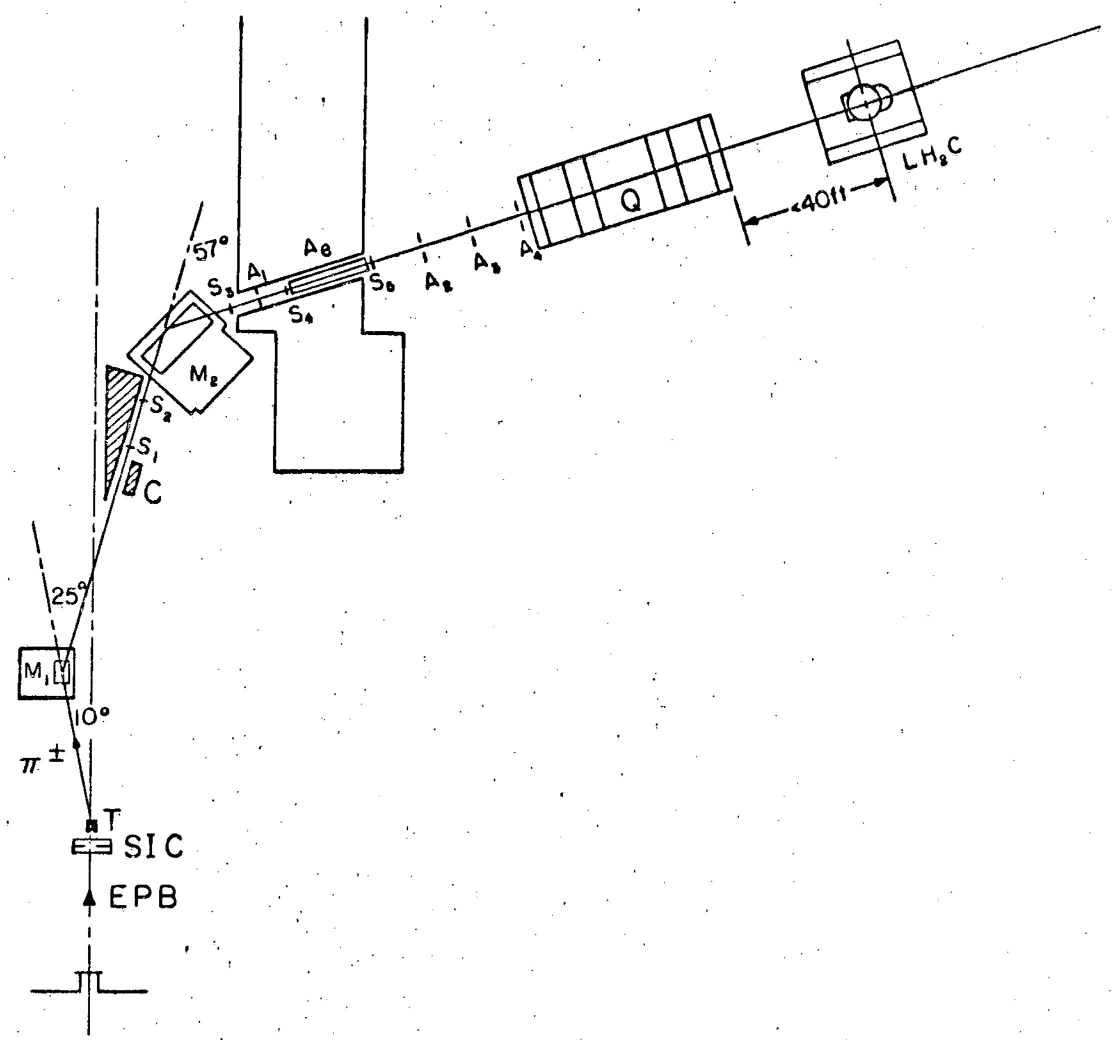
LH$_2$C
Q
40 ft
A$_4$
A$_3$
A$_2$
S$_5$
A$_6$
A$_1$
S$_3$
S$_4$
57°
M$_2$
S$_2$
S$_1$
C
25°
M$_1$
10°
$\pi^{\pm}$
T
SIC
EPB
MUB-13670

Fig. 1

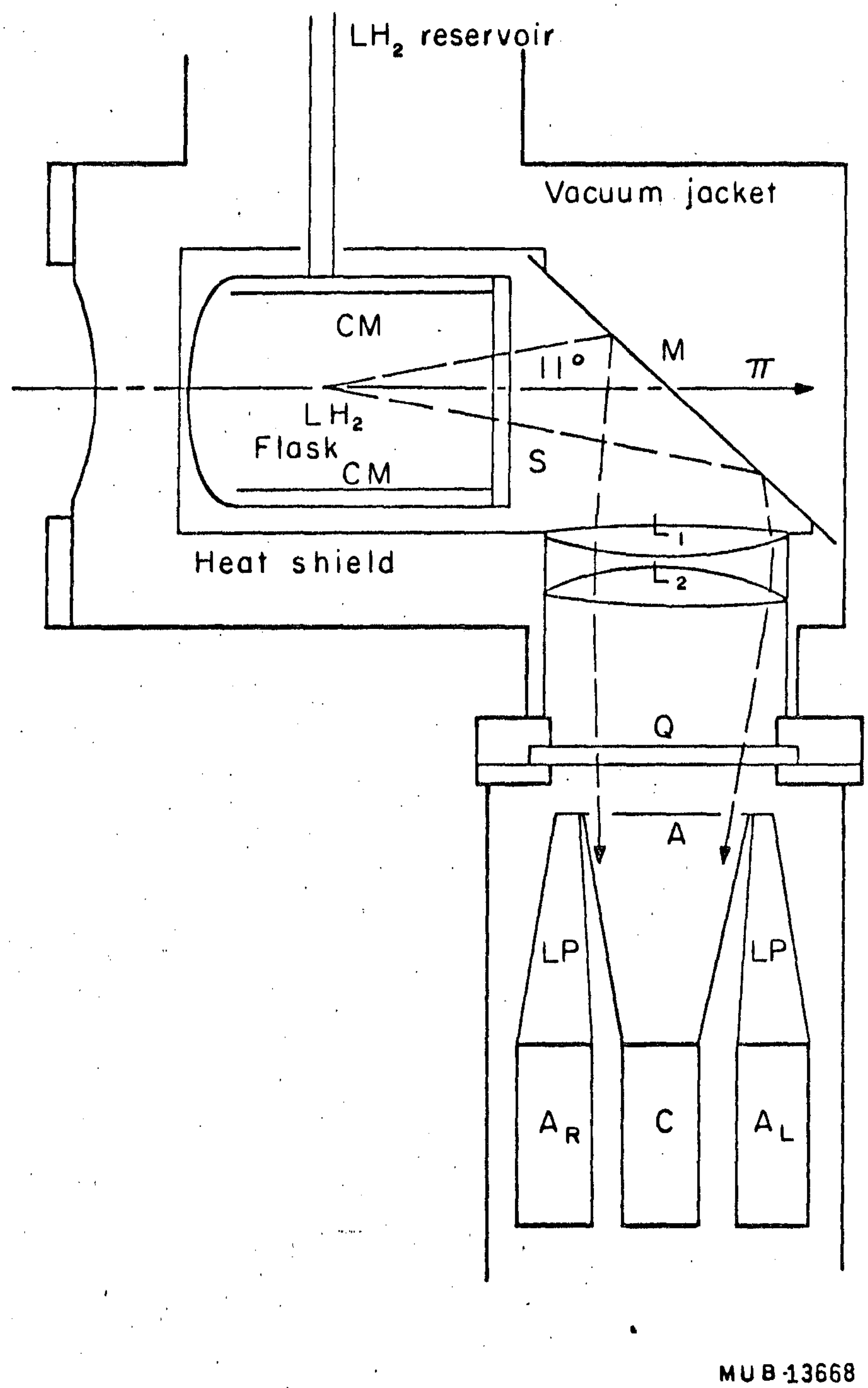
LH2 reservoir
Vacuum jacket
CM
M
11°
π
LH2
Flask
CM
S
Heat shield
L1
L2
Q
A
LP
LP
AR
C
AL
MUB-13668

Fig. 2

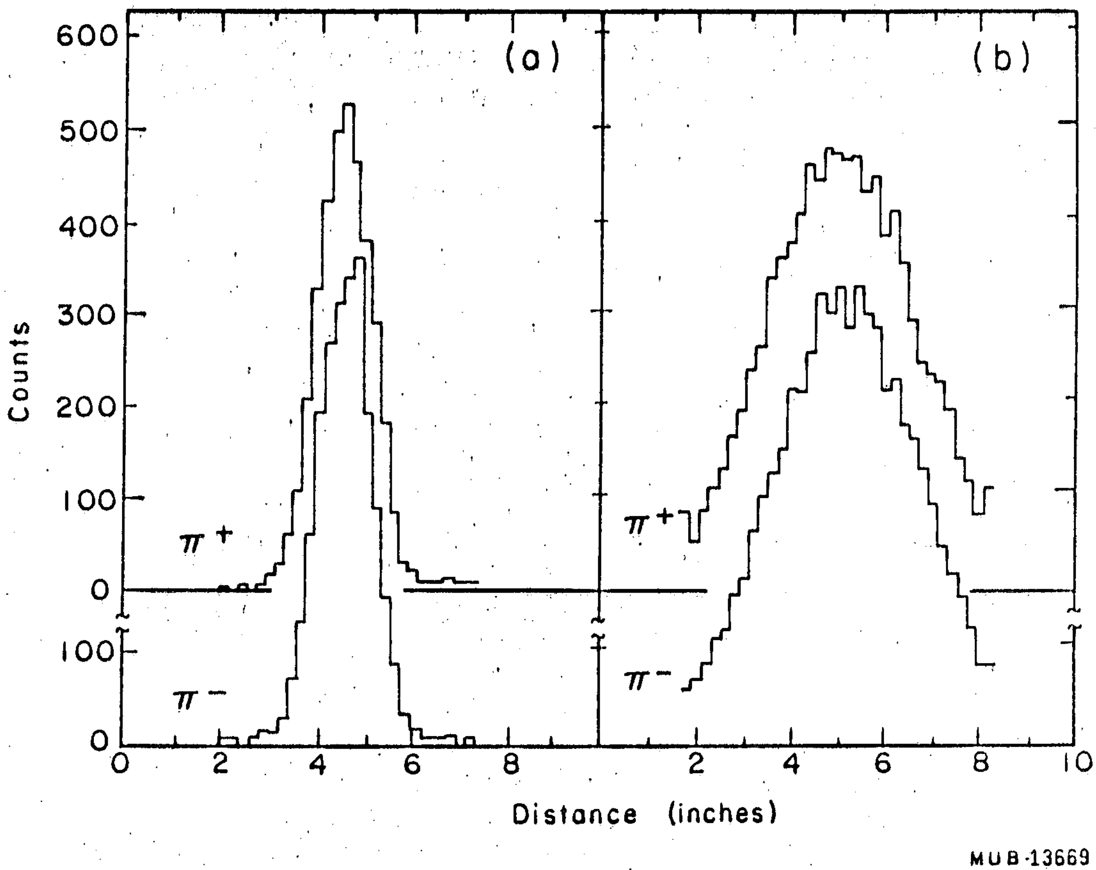
600
500
400
300
200
100
0
100
0
Counts
(a)
(b)
π⁺
π⁻
π⁺
π⁻
0
2
4
6
8
2
4
6
8
10
Distance (inches)
MUB-13669

Fig. 3