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THE BETA DECAY OF THE LAMBDA PARTICLE

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1. INTRODUCTION

All observed strangeness-conserving weak interactions can be explained in terms of a Universal Fermi Interaction based on a V-A current. The experimental evidence concerning these interactions is consistent with the conserved vector current hypothesis, which predicts a universal value for the vector coupling constant. The axial vector coupling constant, to which this hypothesis does not apply, is modified slightly from its "universal" value by renormalization effects.

If this theory is extended without modification to strangeness-changing interactions, it predicts a rate for the β decay of the Λ.

$$\Lambda \rightarrow p + e^- + \bar{\nu} ,$$

of 5.3×10^7 sec^{-1} [1]. However, on the basis of 15 β-decay events, the experimental rate is known to be approximately 1/10 of this value[2]. It has been suggested[3] that this result is consistent with the same Universal Fermi Interaction; the apparent discrepancy is to be explained by stronger renormalization effects than in the strangeness conserving case.

In this note we propose an experiment on the β-decay of polarized Λ particles. The experiment is designed to measure the following correlation functions, familiar from the β-decay of polarized neutrons[4].

a) The correlation between the neutrino direction $\hat{p}_\nu$ and the electron direction; $1 + \alpha \hat{p}_e \cdot \hat{p}_\nu$.

b) The correlation between the electron direction, $\hat{p}_e$, and the Λ polarization, $\vec{p}_\Lambda$, which has the form $1 + A \hat{p}_e \cdot \vec{p}_\Lambda$.

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c) The correlation between the neutrino direction and the Λ polarization; $1 + B\hat{p}_\nu \cdot \vec{P}_\Lambda$.

d) The correlation $1 + D\,\vec{P}_\Lambda \cdot \hat{p}_e \times \hat{p}_\nu$.

The coefficient D is zero if the interaction is invariant under time reversal. If we assume, for example, that the interaction is time-reversal-invariant and is a mixture of V and A with left-handed two-component neutrinos, then the coefficients are given by

$$a\zeta = C_V^2 - C_A^2$$

$$A\zeta = -2C_A^2 - 2C_V C_A$$

$$B\zeta = 2C_A^2 - 2C_V C_A$$

where $$\zeta = C_V^2 + 3C_A^2 :$$

ζ is known from the branching ratio and the known lifetime of the Λ. From these measured quantities, one computes

$$C_V^2 = 1/4\ \zeta(1 + 3a)$$

$$C_A^2 = 1/4\ \zeta(1 - a)$$

$$\frac{C_A}{C_V} = -\frac{(1 - a)}{1 - a + 2A}$$

A value for B can then be calculated from these results and compared with the experimental quantity. This is a test of the hypothesis that the antineutrino is right handed in this interaction. All combined, one thus establishes, for this process, time reversal invariance, lepton conservation, the magnitude of V and A, and their relative sign. Observation of an asymmetry in the electron distribution establishes non-conservation of parity, independent of the particular form of the couplings.

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2. APPARATUS

The experimental arrangement is shown in Fig. 1. A 900 MeV π^- beam is led into a CH_2 target of cross-section matched to the size of the beam (~ 1 cm diameter). At this energy the Λ production cross-section in the reaction $\pi^- + p \rightarrow \Lambda + K^o$ reaches its maximum value of 1.2 mb,[5] and the polarization is at least 0.8[6][7][8].

The reactions which are observed are:

$\pi^- + p \rightarrow \Lambda^o + K^o$ in the target, followed by

$$\Lambda^o \rightarrow p + \pi^- \quad (1)$$

$$\rightarrow p + e^- + \bar{\nu} \quad (2)$$

$$K_1^o \rightarrow \pi^- + \pi^- \quad (3)$$

The Λ and K_1^o, being neutral, pass through an anticoincidence counter A without causing a count. The charged decay modes of these particles are observed in the thin plate spark chamber S_1. The decay products are detected in counters C_3 and C_4. Each plate of spark chamber S_2 consists of plastic scintillator C_5 sandwiched between sheets of aluminium and lead. Spark chamber S_3 has simple brass plates. The proton from the decaying Λ passes into S_2 and S_3, where its range is measured. The electron produces a shower in S_2, which is detected by the scintillators C_5. The directions of all the particles are observed in a 90° stereo system in a single camera.

The spark chambers are triggered by the following electronic requirements:

1) A C_1C_2 coincidence, defining a beam particle.

2) No count in A, i.e. only neutral particles are entering S_1.

3) A coincidence between a count in C_3 and a >3 times minimum ionizing signal in the thick counter C_4. We thus require the simultaneous occurrence of one of the charged Λ modes ((1) or (2)) and the charged K_o^1 mode[(3)]. The thin counter C_3 serves to reduce the number of C_4 signals caused by knock-on protons from neutrons.

4) A shower in the first half of S_2C_5 produced by electrons from (2).

3. BACKGROUND

Charge exchange in the target.

An incoming π^- can make a charge exchange collision with the hydrogen or the carbon in the target, producing one or more neutral pions and a neutron. In many of these events a star will be produced in the carbon, sending charged particles into the anticoincidence counter. When no star is produced a trigger might occur when one of the photons from the π^o decay converts into an electron pair in the material of S_1 or C_3. Since the bias level on counter C_4 is set to more than three times the minimum-ionising energy loss, a trigger will result only if the neutron causes a knock-on proton to make a C_3-C_4 coincidence. A similar experiment[8)], in which a single counter C_3 was used, gave less than 3 false triggers per 10^5 incident pions. The proposed arrangement differs from this experiment to the extent that a coincidence C_3, C_4 will be required, that there is pulse height discrimination on C_4, and that there is a hole in the centre of C_3 and C_4. The rate from this process is thus expected to be negligible.

Shower production by $\pi^\pm$.

The most frequent Λ decay mode is $\Lambda \to p + \pi^-$; it is 300 times more frequent than the β decay mode. The triggering system requires the K^o to decay into two charged pions. Any of these three charged pions can have a charge-exchange scatter in S_2 followed by a shower. The pion from Λ decay has a maximum energy of 175 MeV; the maximum energy of the K^o pions is 500 MeV. (See Table I for the calculated maximum and minimum momenta and angles in the various reactions involved). A rough upper limit for the charge-exchange cross-section on lead in this energy region can be estimated from the ratio of the charge-exchange to total cross-sections in hydrogen[9][10] and the geometrical cross-section of lead. The upper limit obtained is about 1/3 of the geometrical cross-section over this energy region. An experimental measurement at 125 MeV[11] gives a ratio of 1/25 in lead, showing that the effect is strongly inhibited in complex nuclei.

The shower detector S_2C_5 contains seven radiation lengths of lead. If we take a charge-exchange ratio of 1/25 for the lower energy pions from Λ decay and a ratio of 1/3 for the higher energy K^o pions we obtain a probability of 0.18 that a shower is produced by an event $\Lambda \rightarrow p + \pi^-$, $K^o \rightarrow \pi^+ + \pi^-$. This leads to 0.32 false triggers per pulse. This rate will be reduced by a factor of about two by electronically requiring the development of the shower to start in the first half of S_2C_5, since a shower from an electron will start in the first radiation length while a pion does not initiate a shower until it undergoes charge-exchange scattering.

4. RATE OF EVENTS

The rate of events from the hydrogen in the target is estimated on the basis of the following data:

a) The total cross-section for the reaction $\pi^- + p \rightarrow \Lambda + K^o$ is 1.2 mb, and the angular distribution is as given in reference[5].

b) 50% of the K^o decay through the K_1^o modes and 50% decay through K_2^o modes. The long-lived K_2^o escapes.

c) The branching ratio $$K_1^o \rightarrow \frac{\pi^+ + \pi^-}{\pi^o + \pi^o} = \frac{2}{1} .$$

d) The branching ratio $$\frac{\Lambda \rightarrow p + \pi^-}{\Lambda \rightarrow n + \pi^o} = \frac{2}{1}$$

e) The lifetime of the Λ is 2.51×10^{-10} sec, that of the K_1^o is 1.00×10^{-10} sec.

f) The observed β-decay of the Λ is 2×10^{-3} (2).

We assume a beam intensity of 2×10^{5} negative pions per pulse. The following factors are taken into account:

Decay of the Λ and K^{0} before reaching the anti counter (see fig.2)
The solid angle defined by counters C_3 and C_4.
The angular distribution in the ΛK production reaction 6)
The limitation of the trigger rate to at most 1 trigger per pulse.

The triggering rates are then:

$\Lambda \rightarrow p + e^- + \bar{\nu}$ 5.4×10^{-3} triggers per pulse
$\Lambda \rightarrow p + \pi^-$ less than 0.16 triggers per pulse

giving a ratio of β decay events to background events of better than 1:30.

If the PS is operated at 1 pulse per 1.2 sec (at 10.5 GeV/c with a 100 ms flat-top), one can obtain in one day 390 β-decay events in less than 11,600 pictures. Additional β-decay events are to be expected from the carbon in the target.

$\Lambda \rightarrow p + \pi^-$ events will be rejected firstly in scanning on the basis of the characteristic appearance of the shower and secondly by kinematic fitting.

The time required is 20 parasitic shifts and 10 shifts of actual running.

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CAPTION TO THE FIGURES

FIG.1 - Experimental arrangement. C_1, C_2 = Beam defining counters. A = Anticoincidence counter, rejecting charged particles from the target. T = 2 cm long, 1 cm diameter CH_2 target. S_1 = thin plate aluminium spark chamber, total thickness $\sim$ 0.3 mm Al. C_3 = 4 mm plastic scintillator, C_4 = 2 cm plastic scintillator to detect $>$ 3X minimum ionizing events. $S_2 + C_5$ = spark chamber - shower detector combination. Each plate consists of $\approx$ 2 mm Al, 2 mm Pb, 2 mm plastic scintillator, 2 mm Al. Total thickness $\approx$ 7 radiation lengths. The scintillators of the first half of C_5 are connected to one photomultiplier, those of the second half to another. S_3 = thick plate brass spark chamber. Total thickness of $S_2 + S_3$ is 145 g/cm^2 Cu-aequivalent.

FIG.2 - Efficiency ε for escape of both Λ and K_o into spark chamber S_1 before decay, as a function of the point of production in the target. The integrated escape efficiency for a 3 cm long target is 0.295. The cm angular distribution, used in calculating ε is taken from Ref. 6.

TABLE I

Calculated maximum and minimum values of momenta, ranges, mean free paths for decay, and angles for ΛK production, $K_1^o \to \pi^+ + \pi^-$, $\Lambda \to p + \pi^-$ and $\Lambda \to p + e^- + \bar{\nu}$.

		$\pi^- + P \to \Lambda^o + K^o$		$K_1^o \to \pi^+ + \pi^-$		$\Lambda \to P + \pi^-$				$\Lambda \to P + e^- + \bar{\nu}$			
		K^o	Λ	$\pi^\pm$		P		π^-		P		e^-	
				K momenta		Λ momenta		Λ momenta		Λ momenta		Λ momenta	
				MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN
MOMENTUM MeV/c (Labsy)	MAX	605	970	621	233	948	469	279	172	1029	534	352	234
	MIN	57.5	422	−19	−175	686	257	17	−40	-	-	-	-
RANGE (g/cm^2 in Cu) or MEAN FREE PATH FOR DECAY (cm)	MAX	3.67cm	6.52cm	300	58	135	14	84	28.5	145	21.5	Shower	Shower
	MIN	0.35cm	2.84cm	-	-	47	1.8	17	-	-	-	-	-
	MAX	51°	20°	180°	180°	7°	16°	55°	180°	11.4°	26.6°	180°	180°

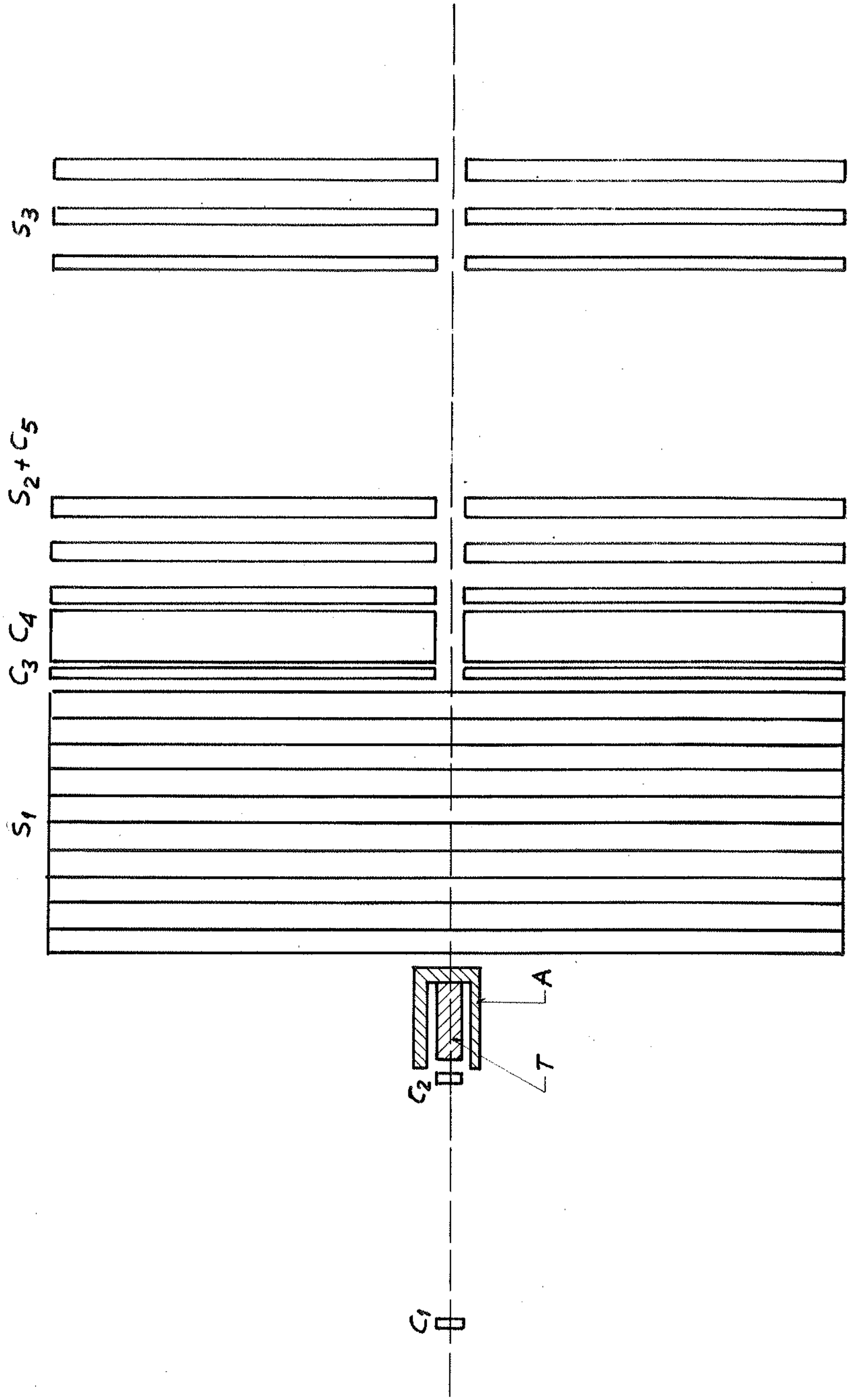

Fig.1

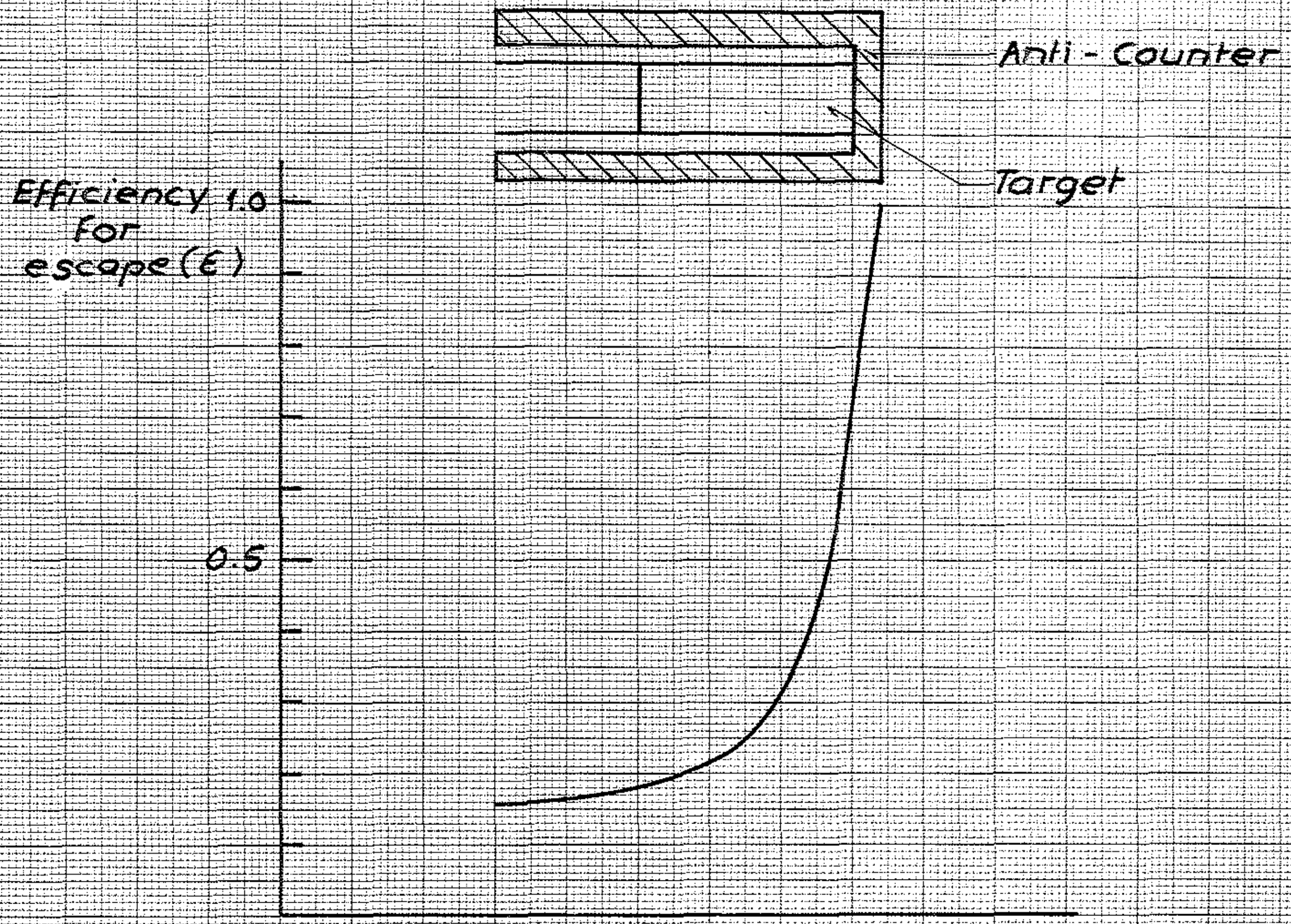

Fig. 2

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