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[10]From unitarity we have $\mathrm{Im}A^{-1}=(s-4)/(4s)^{1/2}$, but from the Breit-Wigner formula $\mathrm{Im}A^{-1}=(\sqrt{s_R})\text{-}4/s_R$; s_R is the fixed position of the resonance.

[11]It should be remarked that if the $\pi\pi$ cross section is nearly flat, such as curves 2 or 3 in Fig. 2, it would be hard to see it experimentally in the usual comparison of an effective $\pi\pi$ mass with the phase-space curve unless the absolute value of the phase-space normalization is known.

MAGNETIC MOMENT OF THE Λ*

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We have measured the magnetic moment of the Λ, using 8553 decays $\Lambda\to p+\pi^-$ from Λ produced via the reaction $\pi^-+p\to\Lambda+K^0$ in the Alvarez 72-inch hydrogen bubble chamber. The Λ's are almost completely polarized, for all production angles (see Fig. 1). Of the 8553 Λ's, 6263 are produced by 1030-MeV/c π^- in an average field of 15.5 kG, and 2290 at 1170 MeV/c in 17.9 kG. At 17.9 kG the Λ-spin precession is 2.7 deg per Λ mean life for $|\mu_\Lambda|=1$. (The unit is $e\hbar/2m_pc$, one Bohr nucleon magneton. In these units the neutron has $\mu_n=-1.91$.) We find

$$\mu_\Lambda=-1.39\pm0.72.$$

Our result can be compared with the two previous measurements. Cool et al.[1] find $\mu_\Lambda=-1.5\pm0.5$. Kernan et al.[2] find $\mu_\Lambda=0.0\pm0.6$. Our result is in good agreement with that of Cool et al. It is also consistent with the theoretical prediction of Coleman and Glashow,[3] $\mu_\Lambda=\frac{1}{2}\mu_n=-0.95$, based on SU(3) symmetry.[4]

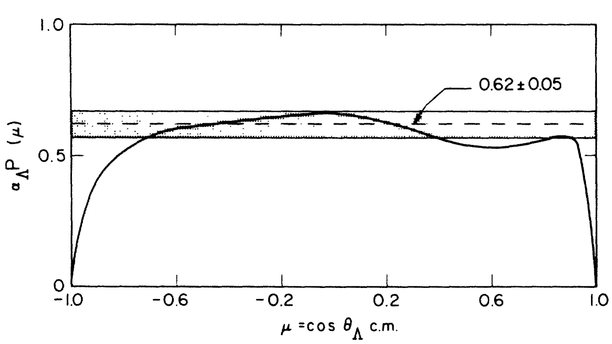

FIG. 1. Decay asymmetry of Λ. The curve was calculated from the least-squares fits to $\sigma(\mu)$ and $\sigma(\mu)\alpha_\Lambda P(\mu)$. The value $\alpha_\Lambda P(\mu)=0.62$ corresponds to $|P|=1$, according to J. W. Cronin and O. E. Overseth [Phys. Rev. 129, 1795 (1963)].

The equation of motion of $\vec{P}$, the Λ polarization in the Λ rest frame, is

$$d\vec{P}/dt=(e/m_pc)\mu_\Lambda\vec{P}\times\vec{H}'\equiv M\vec{P}\times\vec{H}', \quad (1)$$

where $\vec{H}'$ is the magnetic field in the Λ frame, t is the Λ proper time, and $M\equiv e\mu_\Lambda/m_pc$ includes the sign (positive if the magnetic moment is along $+\vec{P}$). We detect the precession of $\vec{P}(t)$ by means of the precession of the decay asymmetry $\alpha_\Lambda\vec{P}(t)=\alpha_\Lambda P(\mu)\hat{n}(t)$, where $t=0$ at production and

$$\hat{n}(0)=(\hat{\pi}_{\text{inc}}\times\hat{\Lambda})/|\hat{\pi}_{\text{inc}}\times\hat{\Lambda}|;$$

$\hat{\pi}_{\text{inc}}$ and $\hat{\Lambda}$ are the directions of the incident π and of the Λ in the laboratory frame, and μ is the cosine of the Λ production angle in the c.m. frame. Because Eq. (1) is homogeneous in P, the signs of α_Λ and of $P(\mu)$ are irrelevant.

In our experiment the precession angles are small. We therefore write the solution of Eq. (1), including only the terms linear in t:[5]

$$\alpha_\Lambda\vec{P}(t)=\alpha_\Lambda P(\mu)\{\hat{n}(0)+M[\hat{n}(0)\times\vec{H}']t\}. \quad (2)$$

Figure 1 shows $\alpha_\Lambda P(\mu)$, which is obtained from the decay asymmetry by omission of the correlation with the magnetic-field direction. By our sign convention, $\alpha_\Lambda P(\mu)$ is positive for all values of μ. The decay pions prefer to go along $+\hat{n}(0)$ at $t=0$.

We now choose a particular coordinate system. The incident π^- are horizontal. The laboratory field H is approximately uniform and points vertically upwards. We choose Cartesian axes $\hat{z}=\hat{\pi}_{\text{inc}}$, $\hat{x}=$ vertical (upwards), and $\hat{y}=\hat{z}\times\hat{x}$. Then $\vec{H}=H\hat{x}$, with H positive.[6] In ordinary spherical coordinates, the x, y, and z components of $\hat{\Lambda}$ are $\sin\theta\cos\varphi$, $\sin\theta\sin\varphi$, and $\cos\theta$. The component of $\alpha_\Lambda\vec{P}(t)$ along $\hat{\Lambda}$ is then

$$\alpha_\Lambda\vec{P}(t)\cdot\hat{\Lambda} = -MH\alpha_\Lambda P(\mu)\gamma_\Lambda t\cos\theta\cos\varphi,$$
$$= -MHa(\mu)t\cos\varphi, \qquad (3)$$

where H is the lab field, γ_Λ comes from the Lorentz transformation, and $a(\mu) = \alpha_\Lambda P(\mu)\gamma_\Lambda\cos\theta$ is a known function of μ. The component of $\alpha_\Lambda\vec{P}(t)$ along $\hat{n}(0)\times\hat{\Lambda}$ is small and we do not use it.[7] The normalized distribution of N decay pions in the Λ rest frame is given by

$$dN = N\sigma(\mu)d\mu(d\varphi/2\pi)f(t)dt(d\xi/1.9)$$
$$\times[1-MHa(\mu)t\xi\cos\varphi], \qquad (4)$$

where $\xi = \hat{\pi}_{\rm decay}\cdot\hat{\Lambda}$; $\sigma(\mu)d\mu$ is the measured Λ-production angular distribution normalized to unity; the production aximuth φ ranges from 0 to 2π and its distribution is observed to be flat, i.e., $d\varphi/2\pi$; $f(t)$ is the observed time distribution—it would be $\exp(-t/\tau_\Lambda)dt/\tau_\Lambda$ for an infinite chamber with no cutoff for short times. The values of ξ range from -0.9 to +1.0. The cutoff at $\xi = -0.9$ eliminates decays where the decay pion has less than 2-cm range in hydrogen. After integrating over φ, we then find the ξ distribution to be $d\xi/1.9$, as expected if parity is conserved in the production process.[8] We obtain M by calculating the average over the events of $a(\mu)t\xi\cos\varphi$. The first term in Eq. (4) contributes zero.[9] We therefore have

$$M = -\langle at\xi\cos\varphi\rangle/H\langle a^2\rangle\langle t^2\rangle\langle\cos^2\varphi\rangle\langle\xi^2\rangle. \qquad (5)$$

We find $M = (-1.33\pm0.69)\times10^4$ gauss^{-1} sec^{-1}, which gives $\mu_\Lambda = -1.39\pm0.72$.[10,11]

The sign of μ_Λ can be expressed in a manner independent of all sign conventions (and without counting mirrors) by the following three observations: (a) The π^- beam in the chamber bends away from the rake markers that extend along the inside of the chamber; (b) for Λ's that dip towards the top glass the decay pions prefer to go away from the rake; and (c) for upwards Λ, the decay pions acquire with time a direction component along the $+\hat{\Lambda}$ direction.

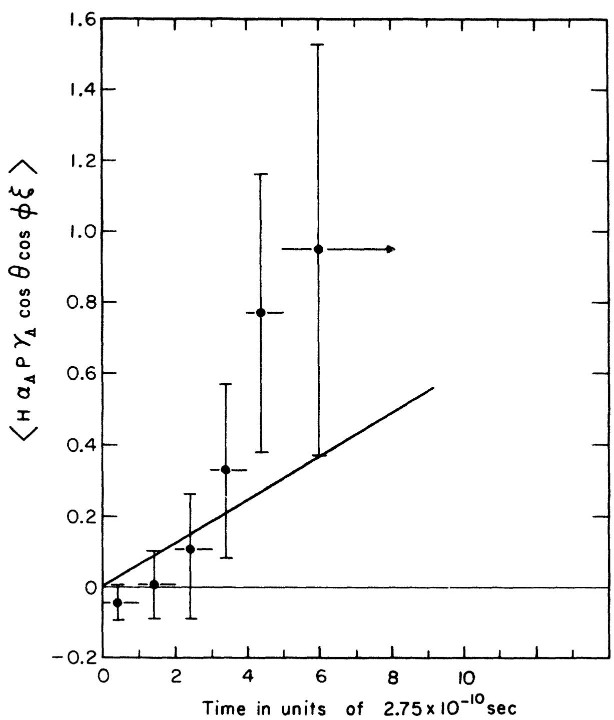

FIG. 2. Time dependence of precession-induced decay asymmetry. The number of events in the six histogram intervals are 5441, 2049, 696, 230, 97, and 40. The straight line through the origin is the expected result for $\mu_\Lambda = -1.39$, and corresponds to a precession of 3.8° per Λ mean life for $H = 17.9$ kG. The χ^2 confidence level is 60%.

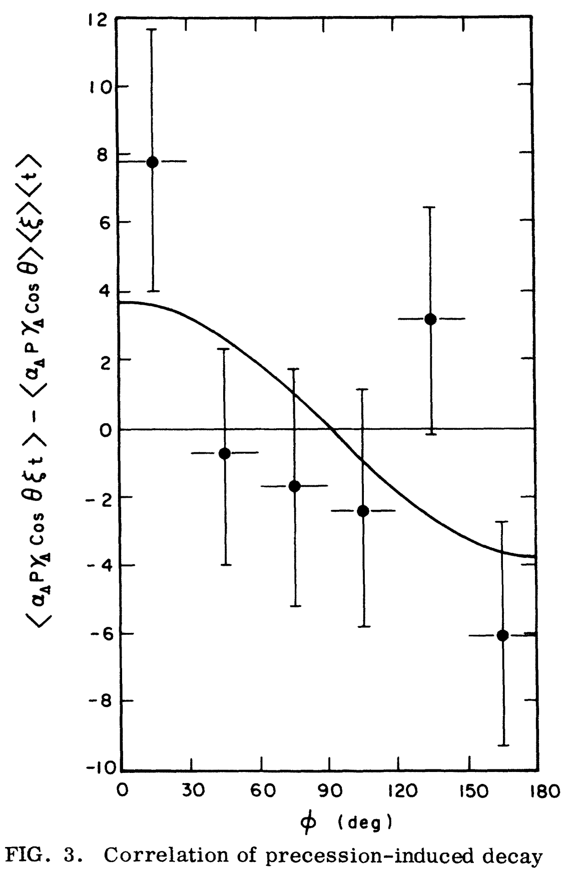

FIG. 3. Correlation of precession-induced decay asymmetry with magnetic field direction. We have folded $\varphi = 0$ to -180 with 0 to +180. The curve corresponds to $\mu_\Lambda = -1.39$. The χ^2 confidence level is 25%.

Two crucial tests of the reality of the effect can be made. The first is that the precession angle must increase linearly with t. We calculate the average over the data of $\langle Ha\xi \cos\varphi\rangle$, which is proportional to the precession angle. According to Eq. (4) the result should be $-MH^2 \times\langle a^2\rangle\langle\cos^2\varphi\rangle\langle\xi^2\rangle t$, a linear function of t with slope proportional to $-M$. Figure 2 shows our result. The second test is that the precession-induced polarization must have the proper correlation with the magnetic-field direction. We calculate $\langle at\xi\rangle$. The result according to Eq. (4) should be $\langle a\rangle\langle t\rangle\langle\xi\rangle - M\langle a^2\rangle\langle t^2\rangle H\cos\varphi$. We subtract the (known) first term and plot against φ, folding $\varphi = 0$ to -180 deg with 0 to +180 deg. The result is shown in Fig. 3. Within the limited statistical accuracy, the data satisfy the tests.

We wish to thank Professor Luis W. Alvarez for his encouragement and support. We also thank Lester John Lloyd for his many contributions to this experiment.

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[4]According to M. Nauenberg (Phys. Rev., to be published), if the baryons are composite states of triplets then $\mu_\Lambda = (1+\frac{1}{6}q)\mu_n$. For quark triplets, $q = -\frac{1}{3}$ and $\mu_\Lambda = \frac{1}{2}\mu_n = -0.95$. For singly charged triplets, $q = -1$ and $\mu_n = \frac{5}{6}\mu_n = -1.59$. Nicola Cabibbo has pointed out to us that present calculations based on SU(3) must take $m_\Lambda = m_n$ and thus have uncertainties of the same order as the fractional mass difference, which is 17%.

[5]Terms in t^2 do not contribute to our final result because they are odd in $\cos\varphi$. Terms in t^3 would lead to a correction of about 1%.

[6]Our final result ($\mu_\Lambda = -1.39$) is based on an analysis that takes into account both the inhomogeneity of H and the small components not along $\hat{x}$. The simpler analysis described here gives $\mu_\Lambda = -1.33$.

[7]For a forward Λ, $\hat{n}(0)\times\hat{H}$ is along $\hat{\Lambda}$. For our sample, the laboratory angular distribution of the Λ's is strongly peaked forwards (maximum angle ≈ 30 deg), and the average component of $\hat{n}(0)\times\hat{H}$ along $\hat{n}(0)\times\hat{\Lambda}$ is about a fifth of that along $\hat{\Lambda}$.

[8]Even if there were a parity-nonconserving polarization component along $\hat{\Lambda}$ at $t = 0$, i.e., an additional term in Eq. (3), it would not affect our result for μ_Λ because such a term has no correlation with the magnetic field and gives no contribution after the average over φ.

[9]We expect $\langle\cos\varphi\rangle = 0$ and find 0.0036. We expect $\langle\xi\rangle = 0.05$ and find 0.0617. Their product makes the first term negligible.

[10]The error in $\langle at\xi\cos\varphi\rangle$ is $[\langle(at\xi\cos\varphi)^2\rangle/N]^{1/2}$. Equation (5), which expresses M in terms of the moments of the distribution, is completely equivalent to the method of maximum likelihood, for our case. For a distribution of the form $1+ax$, the likelihood function is $\Pi_i(1+ax_i)$ and the most likely value of a is given by the solution of the equation $\Sigma_i x_i/(1+ax_i) = 0$. For $|a| \ll 1$, we expand the denominator and obtain $a = \Sigma x_i/\Sigma x_i^2$, which is equivalent to Eq. (5). We are indebted to Frank T. Solmitz for this observation.

[11]Average values over the 8553 events (with the brackets omitted) are $t = 2.748\times10^{-10}$ sec, $t^2 = 14.07 \times 10^{-20}$ sec^2, $\cos\varphi = 0.0036$, $\cos^2\varphi = 0.496$, $\xi = 0.0617$, $\xi^2 = 0.295$.

KINEMATICAL INTERPRETATION OF THE FIRST π-ρ RESONANCE*

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Evidence for a pi-rho resonance has recently been pointed out on the basis of π-p reaction experiments involving four final-state particles.[1-3] It is the purpose of this note to indicate, by means of a simple model for the dynamics of the production process in such reactions, a possible explanation for an observed peak in the final state π-ρ mass spectrum. The calculation reported here presumes only to be an improvement over the phase-space calculation with which the π-ρ production data were compared. The complexity of the kinematics in a many-particle final state and the uncertainties in the behaviors of off-mass-shell matrix elements make a more elaborate calculation at present unfeasible.

The reaction which is analyzed corresponds to the process

$$\pi^+ + p \to \pi^+ + p + \rho \to \pi^+ + p + \pi^- + \pi^+. \qquad (1)$$

It is assumed that the reaction associated with the observed peak in the π-ρ spectrum proceeds principally via peripheral collisions which are dominated by the one-pion-exchange diagram of Fig. 1(a). The cross section associated with

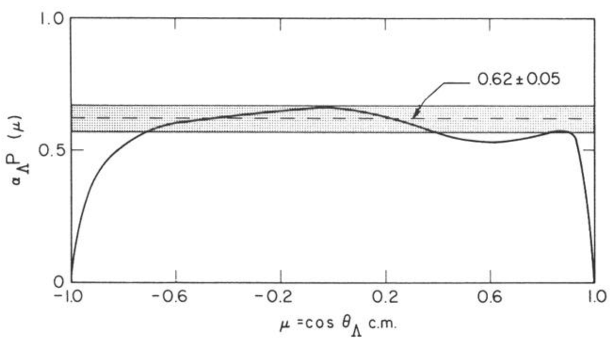

FIG. 1. Decay asymmetry of Λ. The curve was calculated from the least-squares fits to $\sigma(\mu)$ and $\sigma(\mu)\alpha_\Lambda P(\mu)$. The value $\alpha_\Lambda P(\mu) = 0.62$ corresponds to $|P| = 1$, according to J. W. Cronin and O. E. Overseth [Phys. Rev. 129, 1795 (1963)].