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Analysis of $A_2^- \to K^- K_L^0$ †

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In the reaction $\pi^- p \to A_2^- p$ at 4 BeV/c, 474 rare $A_2^- \to K^- K_L^0$ decays were observed. The A_2 mass spectrum has a shape which is compatible with a simple Breit-Wigner resonance, although the dipole hypothesis cannot be ruled out. Assuming the A_2 has $J^P = 2^+$, an analysis of 318 events yields the following A_2 spin density matrix elements: $\rho_{00} = 0.24$, $\rho_{11} = 0.38$, $\rho_{22} = 0$, and $\rho_{1-1} = 0.23$. Thus the A_2^- is produced, in part, by unnatural spin-parity exchange.

I. INTRODUCTION

The A_2 meson has been found to have a mass distribution characteristic of a standard resonance in several recent conclusive experiments,[1] although the possibility that the A_2 deviates from this distribution under certain conditions is difficult to rule out.[2] Independent of any exotic properties of the A_2, it is of interest to study its production and decay characteristics. We have performed an experiment at the Argonne zero-gradient synchrotron (ZGS) to study the rare $K^- K_L^0$ decay mode of the A_2^- produced in $\pi^- p \to A_2^- p$ at 4 BeV/c. The t' interval covered is $-0.72 \leq t' \leq -0.12$ (BeV/c)^2.

II. EXPERIMENTAL LAYOUT

The layout of the experiment is shown in Fig. 1. The momentum and direction of the incident pion were measured by means of the beam dipole and quadrupole magnets and an assembly of multiwire proportional chambers. The recoil proton four-momentum was determined with a wire-spark-chamber magnetic spectrometer. The beam and proton spectrometers were used in an A_2 missing-mass experiment and are described in Ref. 1. The event vertex was determined from the beam and recoil proton information. The K^- direction was measured by using the vertex position and two wire spark chambers located just upstream of an SCM 105 analyzing magnet as shown in Fig. 1. The magnetostrictive readouts for these chambers were remotely located in a magnetic field $\lesssim 100$ G, and then shielded with Armco electromagnetic iron. The SCM 105 had a 76-cm vertical aperture and an average field of 9 kG. The geometric center of this magnet was located 37 cm above the beam line; assuming parity conservation, the entire A_2-decay phase space could thereby be accepted with 100% efficiency. The K^- momentum was calculated by measuring its trajectory after leaving the SCM 105 using wire spark chambers.

A novel trigger was used to select event candidates for the reaction of interest. An extensive array of charged-particle and γ anticoincidence (veto) counters surrounded the hydrogen target, covering the solid angle not subtended by the beam, proton, and K^- detectors. These veto counters observed charged particles with $\geq 99\%$ efficiency and γ's with ~70% efficiency. The K^- scintillator, labeled K in Fig. 1, was a six-element γ and charged-particle detector. A trigger required beam and proton signals, no signal from any veto counter, and a K signal from one and only one of its elements. Only neutrons and K_L^0's could pass through the veto counters with negligible probability of being noticed. Since a positive proton identification is made in the trigger by time of flight, there can be no final-state neutron. Ideally, therefore, only elastic scattering and $\pi^- p \to K^- K_L^0 p$ events triggered the system. Elastic events could be eliminated because of the high proton momentum, but some were purposely accepted in order to continuously monitor the system with a four-constraint reaction. This scheme produced a trigger rate which was less than the pure one-arm missing-mass trigger rate by a factor of 60. The primary source of background in the trigger was $\pi^- p \to \pi^- \pi^0 p$, with the π^- detected by the K counters and the γ's from the π^0 undetected. The K^- spectrometer information cleanly separated this background from desired events in the kinematic reconstruction. The missing mass recoiling from the pK^- system, assuming that the particle in the K spectrometer was a K^-, is shown in Fig. 2(a). A strong K_L^0 signal with an experimental mass of 495 MeV is prominent. There is a background which is presumably composed primarily of $\pi^- p \to \pi^- p \pi^0 \pi^0$ events in which all four γ's eluded the veto counters.

III. RESULTS

The missing mass recoiling against the proton, which we will refer to as the A_2 mass spectrum, is shown in Fig. 2(b). The events have been

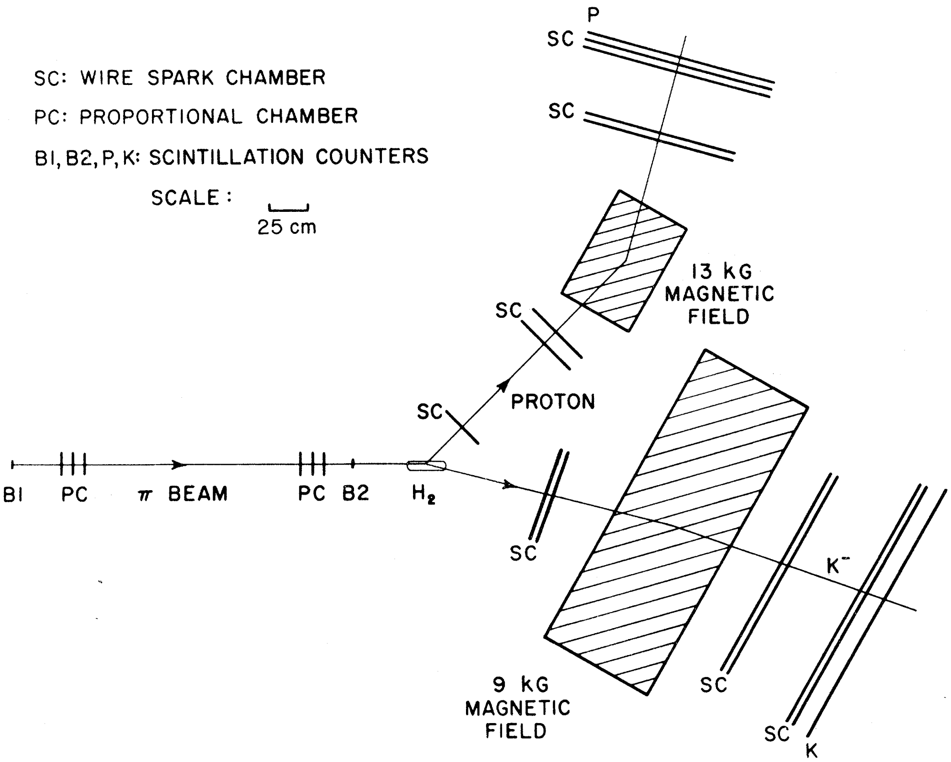

FIG. 1. The experimental layout.

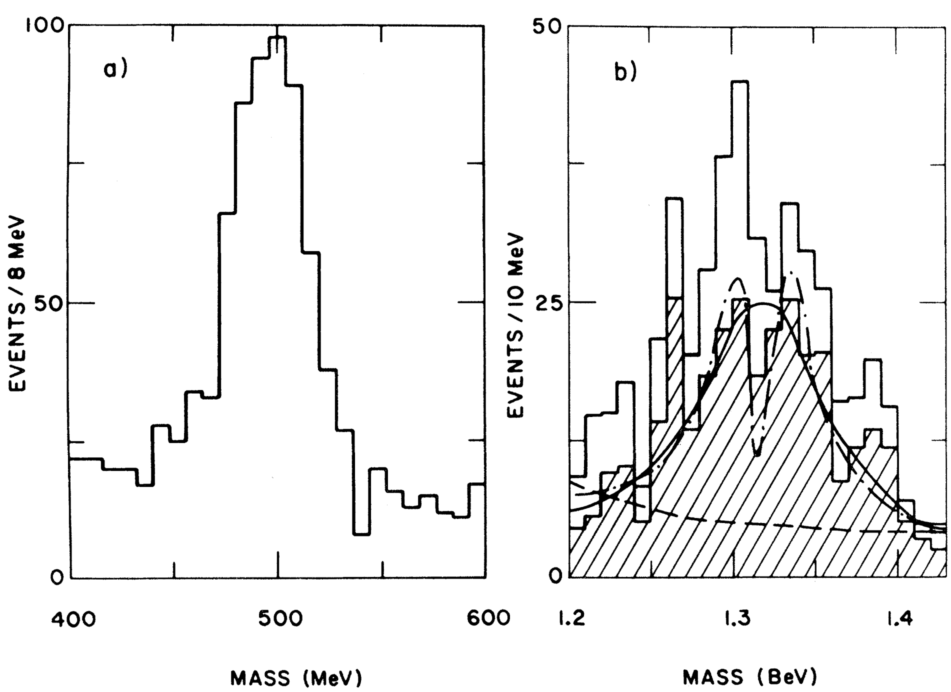

FIG. 2. (a) The mass of the unobserved final-state particle(s), assuming that the particle in the K^- spectrometer is a K^-; (b) the $A_2^- \rightarrow K^- K_L^0$ mass spectrum. See the text for a discussion of the shading and the smooth curves.

weighted to correct for the geometric efficiency of the proton spectrometer. The weight varies innocuously from 1.43 to 0.83, and is shown as a dashed line in Fig. 2(b). (The average weight is 1.) The mass resolution has a standard deviation of 3.9 MeV.[3] The unshaded histogram, 474 events, corresponds to all events in the K_L^0 peak (460 to 536 MeV) in Fig. 2(a). A background subtraction of 6 events/bin was made before plotting. (A study of control regions on either side of the K_L^0 peak suggests that the background under the K_L^0 peak has a flat A_2 mass spectrum.) In the t-channel A_2 rest frame θ and ϕ are defined as the polar and azimuthal angles, and $W(\theta, \phi)$ is the K^- distribution function.[4] Parity conservation in A_2 production and decay requires $W(\theta, \phi) = W(\pi - \theta, \pi + \phi)$ and $W(\theta, \phi) = W(\theta, -\phi)$. The 318 shaded events in Fig. 2(b) correspond to A_2 decays with $-1 \leq \cos\theta \leq 1$ and $90° \leq \phi \leq 180°$. The detection efficiency for events in this region was essentially 100%. Using the parity conservation conditions, this is equivalent to detecting the entire A_2 decay phase space. The smooth curve in Fig. 2(b) is a Breit-Wigner fit to the shaded data. The χ^2 for 20 degrees of freedom is 17.1. The dipole fit to the data, the dash-dot curve, has $\chi^2 = 18.9$. Both fits yield an A_2 mass of 1.318 BeV.[5] The Breit-Wigner fit is preferred, but there is no statistically significant difference between the two fits. The original $A_2 \to K\bar{K}$ experiment (for A_2's produced in $\pi p \to A_2 p$) found an A_2 mass spectrum with a significant dipole-type tendency,[6] whereas subsequent experiments[7,8] have not observed this behavior.[9]

A $\cos\theta$ vs ϕ scatter plot is shown in Fig. 3. The $\cos\theta$ and ϕ projections show the raw distributions (unshaded) and the 318 events which remain after subtracting the non-$K^-K_L^0$ background (shaded). [The background subtraction was determined by studying control regions near the K_L^0 peak in Fig. 2(a).] Each dot represents one event; there is no weighting. These two decay distributions were fitted separately by taking $J^P = 2^+$ for the A_2. The $\cos\theta$ fit yields for the A_2 density matrix elements $\rho_{00} = 0.24$, $\rho_{11} = 0.38$, $\rho_{22} = 0.$[10] Because $\rho_{22} = 0.$, the ϕ distribution depends only on ρ_{1-1}. The depletion of events near $\phi = 180°$ shows ρ_{1-1} is nonzero. The result is $\rho_{1\,-1} = 0.23$.[11] In a simple t-channel-exchange picture, ρ_0 and f_0 exchange can explain the ρ_{11} and $\rho_{1\,-1}$ domination of the two distributions. The significantly nonzero ρ_{00} which we observe requires an unnatural spin-parity exchange, such as the B meson. Similarly, Crennell *et al.* found $\rho_{00} = 0.19 \pm 0.05$ at 4.5 BeV/c.[8] Thus the present experiment and the experiment described in Ref. 8 have established the existence of unnatural spin-parity exchange at low momen-

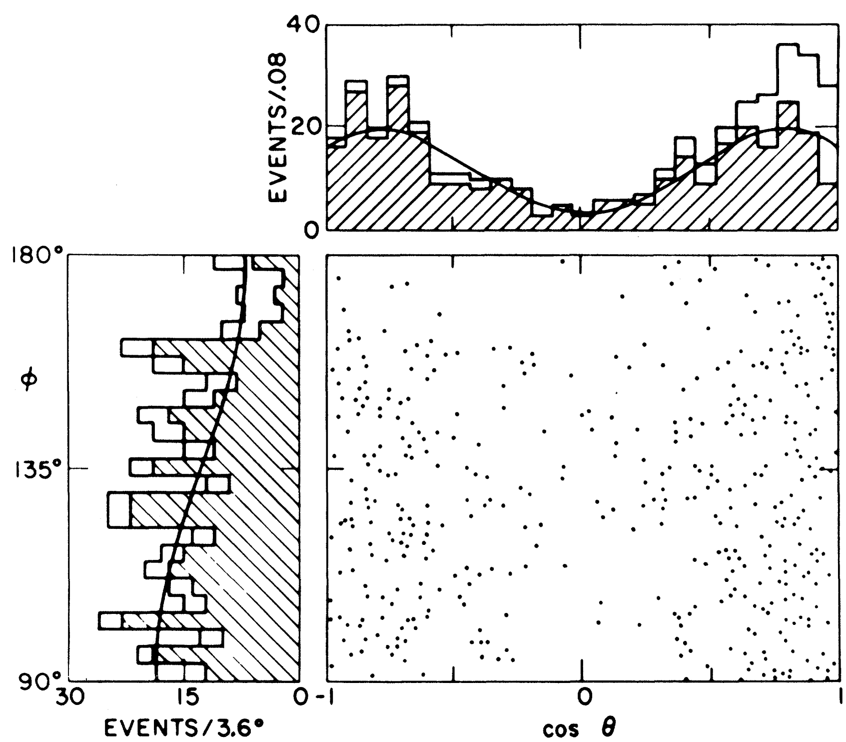

FIG. 3. A_2 t-channel rest frame $\cos\theta$ vs ϕ scatter plot with projections. See the text for a discussion of the shading and the smooth curves.

tum. The element ρ_{00} appears to approach zero at high momentum.[12]

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[1]See C. M. Ankenbrandt, B. B. Brabson, R. R. Crittenden, R. M. Heinz, J. C. Krider, J. E. Mott, H. A. Neal, and A. J. Pawlicki, Phys. Rev. Lett. 29, 1688 (1972) and references contained therein.

[2]Of the experiments which have found peculiar A_2 mass shapes, only the experiment by G. Chikovani *et al.* [Phys. Lett. 25B, 44 (1967)] has apparently been contradicted by a subsequent experiment. [See D. Bowen *et al.*, Phys. Rev. Lett. 26, 1663 (1971).]

[3]The A_2 mass was calculated using only the beam and recoil proton information, as in Ref. 1. See Ref. 1 for a discussion of the mass resolution.

[4]K. Gottfried and J. D. Jackson, Nuovo Cimento 33, 309 (1964).

[5]See Ref. 1 for details of the fits.

[6]R. Baud *et al.*, Phys. Lett. 31B, 397 (1970) (at 7.0 BeV/c).

[7]M. Alston-Garnjost *et al.*, Phys. Lett. 33B, 607 (1970) (at 7.0 BeV/c); K. Foley *et al.*, Phys. Rev. Lett. 26, 413 (1971) (at 20.3 BeV/c); G. Grayer *et al.*, Phys. Lett. 34B, 333 (1971) (at 17.2 BeV/c).

[8]D. Crennell *et al.*, Phys. Lett. 35B, 185 (1971) (at 4.5 BeV/c).

[9]D. Crennell *et al.* [Phys. Rev. Lett. 20, 1318 (1968)] found a single narrow A_2^0 in the $K_S^0K_S^0$ mass spectrum from $\pi^-p \to K_S^0K_S^0$ + neutrals at 6 BeV/c.

[10]These numbers are accurate to about ± 0.04. The error is primarily systematic and was estimated by the sensitivity of the density matrix elements to various subsets of the data. When the positivity condition $\rho_{ii} \geq 0$ was not imposed on the fit, ρ_{22} was found to be -0.01.

[11]The $\cos\theta$ fit had a χ^2 of 9.1 for 11 degrees of freedom. The ϕ-fit χ^2 was 42.2 for 24 degrees of freedom.

[12]K. Foley *et al.*, Phys. Rev. D 6, 747 (1972); J. Rosner, in *Phenomenology in Particle Physics*, edited by C. Chiu, G. Fox, and A. Hey (Caltech, Pasadena, Calif., 1971).