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SPIN, PARITY AND ISOSPIN OF $Y^*(1760)$

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In this Letter we present evidence for the reaction sequences :

$$K^- + p \longrightarrow Y^*(1760) \longrightarrow Y^*(1520) + \pi^0 \qquad (1)$$

$$Y^*(1520) \longrightarrow \begin{cases} \Sigma^\pm \pi^\mp & (2) \\ \Lambda \pi^+\pi^- & (3) \end{cases}$$

From reaction (1) the isospin of $Y^*(1760)$ is established to be 1. The production angular distribution of $Y^*(1520)$ in the overall centre of mass is found to be most consistent with a spin-parity assignment $J^P = 5/2^-$ for $Y^*(1760)$, while the decay distribution in reaction (2) confirms this assignment.

The general experimental details and the scanning-measuring procedures of this 800 to 1200 MeV/c K^- bubble chamber exposure in the Saclay 81 cm hydrogen bubble chamber at the CERN protonsynchrotron are discussed elsewhere[(1),(2)]. The $\Sigma^\pm$ decay is accepted if its projected length is greater than 0.35 cm and each event is given a weight to correct for the loss of short Σ. The angular distribution of $\Sigma^\pm$ decay in the Σ rest system was verified to be consistent with isotropy. Cross sections are based upon K^- path-lengths obtained from τ-decays.

Among the 10,000 measured events in which a charged Σ was produced, nearly 3,000 were found to fit the three-body reaction $\Sigma^\pm \pi^\mp \pi^0$. The invariant-mass distribution of $\Sigma^\pm \pi^\mp$ from the three-body reactions for all K^- momenta is shown in Fig. 1a. The salient feature is the production of $Y^*(1520)$, with some evidence for $Y^*(1385)$ and $Y^*(1405)$ production. Selecting those events in the mass band from 1495 to 1540 MeV as representing $Y^*(1520)$, one can extract the cross section for production of the resonance as a function of incident K^- momentum. At each momentum

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a background has been estimated from the adjacent mass intervals, 1472 to 1495 and 1540 to 1562 MeV. This has been subtracted, and a correction factor has then been applied to compensate for those $Y^*(1520)$ events falling outside the mass interval 1495 to 1540 MeV [3]. The cross sections obtained (Fig. 2a) manifest an enhancement at $\sim$940 MeV/c, corresponding to the c.m. energy of $\sim$1760 MeV.

Under the presumption that the entire cross section arises from the formation of a single resonance, a Breit-Wigner equation has been fitted to the data. The momentum dependence of the widths used in the formula has been taken to correspond to a d-wave decay in the elastic channel and to a p-wave decay in the $Y^*(1520) + \pi^0$ channel, as will be justified later. Both interaction radii have been chosen equal to 1 fermi. The solid curve in Fig. 2a represents the best fit to the data under the above hypotheses. The mass and total width of the resonance are found to be $M = (1755 \pm 10)$ MeV and $\Gamma = (105 \pm 20)$ MeV.

Similar considerations have been applied to the reaction sequence (1, 3) representing an alternative decay-mode of $Y^*(1520)$. The invariant-mass of $\Lambda\pi^+\pi^-$ for all K^- momenta is shown in Fig. 1b and the corresponding cross sections appear in Fig. 2b. Although this channel has less statistical precision, the mass and width of the enhancement are in good agreement with those found above. The ratio of the cross sections for (1, 2) and (1, 3) is 4.5 ± 1.0, in agreement with previous measurements of the $Y^*(1520) \longrightarrow \Sigma\pi/\Lambda\pi\pi$ branching ratio of 3.4 ± 0.7 [4].

A study of the reaction $K^- + p \longrightarrow \bar{K}^0 + n$ reported previously [2], taken in conjunction with analysis of elastic scattering, has displayed a behaviour suggestive of two resonances with opposite isospins in the 800 to 1200 MeV/c region, one of mass $M = 1760$ MeV, $\Gamma = 90$ MeV and the other of mass $M = 1820$ MeV, $\Gamma = 45$ MeV. We can now definitely associate $I = 1$ with $Y^*(1760)$ and therefore $I = 0$ with $Y^*(1820)$. The behaviour of the angular distribution coefficient A_5 in charge-exchange scattering suggested that the resonance both have $J = 5/2$ but opposite parities [2]. However, without further polarization studies, the individual parities cannot be established by this reaction, due to the Minami ambiguity. On the other hand, the decay into a spin 3/2 and spin 0, particle under the circumstances discussed below, is not subject to this ambiguity so that the parity of $Y^*(1760)$ may be obtained by means of an investigation of angular distributions.

Consider the formation of a resonance with spin-parity J^P by a collision of a spin 0 and spin 1/2 particles and the subsequent decay into a spin 0 and 3/2 particles. For each $J \geqslant 3/2$ there are two possible decay angular momentum states, differing by two units, which conserve spin and parity. Thus, for $J^P = 5/2^-$ the decay can proceed via p- or f-wave. Since the decay c.m. momentum for $Y^*(1760) \longrightarrow Y^*(1520) + \pi$ is low ($\approx$200 MeV/c), the decay amplitude into the higher-ℓ state is expected to be suppressed by at least an order of magnitude by the higher centrifugal barrier and can safely be neglected. Because $Y^*(1520)$ is formed with its spin aligned, such that $J_z = \pm 1/2$ (z is along the incident K^- direction), a unique decay distribution is predicted for each J^P assignment. These are exhibited in Fig. 3 for $J^P = 5/2^{\pm}$ and compared with the data obtained from reaction (1, 2). Only the $5/2^-$ possibility describes satisfactorily the data. In order to obtain a purer sample of this process, the $Y^*(1520)$ events were limited to a mass interval between 1505 and 1525 MeV and the production momenta from 910 to 1070 MeV/c.

For quantitative comparison, Table I gives the expected Legendre polynomial coefficients in the production angular distribution of $Y^*(1520)$ for $J^P = 3/2^{\pm}$ and $5/2^{\pm}$, together with the experimental values obtained when the moments of the distribution of Fig. 3 are evaluated through A_6 (coefficients are normalized so that $A_o = 1$). Moments through A_2 seem to be necessary and sufficient to describe the data. The experimental A_2 coefficient appears somewhat smaller than expected for $5/2^-$. This could arise from the unsubtractable background under the $Y^*(1520)$ peak of Fig. 1a, as well as from some production of $Y^*(1520) + \pi^o$ proceeding through a non-resonant s-wave. The probabilities that the various J^P hypotheses agree with the experimental angular distributions are given in the last line of Table I. It can be seen that the $5/2^-$ hypothesis is strongly favoured over the other possibilities. The same procedure, when applied to reactions (1, 3), yields coefficients in good agreement with those for reactions (1, 2), although statistically less significant.

We furthermore note that each J^P hypothesis for $Y^*(1760)$ leads to a well defined alignment for $Y^*(1520)$ and therefore to a characteristic decay distribution in the centre of mass of $Y^*(1520)$. For this purpose a quantization axis normal to the production plane (rather than the beam direction or the $Y^*(1520)$ line of flight) yields the best discrimination between the two parity possibilities for each assumed spin of $Y^*(1760)$. After integration over all production angles, this decay angular distribution is displayed in Fig. 4 and compared with the expected distribution for $5/2^{\pm}$. Table II lists the experimental Legendre polynomial coefficients and those expected for $5/2^{\pm}$. Again the data strongly favour the $5/2^{-}$ hypothesis.

Using an elasticity $\Gamma_{e\ell}/\Gamma \approx 0.5$ for $Y^{*}(1760)$ obtained from the study of the reaction $K^{-} + p \longrightarrow \bar{K}^{0} + n$ [2], the known branching fraction of $Y^{*}(1520)$ into $\bar{K}\,N$, $\Sigma\,\pi$, $\Lambda\,\pi\,\pi$ [4] and the cross sections for reactions(1, 2, 3) measured in this experiment, we calculate the branching fraction of $Y^{*}(1760)$ into $Y^{*}(1520) + \pi$ to be 0.15 ± 0.03.

With the results of this analysis indicating $J^{P} = 5/2^{-}$ for $Y^{*}(1760)$, one can then utilize the interference phenomena observed in elastic and charge-exchange scattering to conclude that $J^{P} = 5/2^{+}$ for $Y^{*}(1820)$. These quantum number assignments were shown by Barbaro-Galtieri <u>et al</u>. to be the most plausible set satisfying the earlier fragmentary data; they also agree with recent investigations of $Y^{*}(1820)$ [6].

Other reaction channels are currently under investigation. Among them, the reactions described in this Letter provide the best evidence for the presence of a hyperonic resonance at a mass of 1760 MeV. Other channels appear to require, as a minimum complexity, resonances at 1760 or 1820 MeV or both, depending on their isospin composition. On the other hand, further structure is not excluded and may yet be necessary in order to achieve a global understanding of this mass region. The analysis of the reactions discussed here is however predicated on the assumption that they are excited by one resonant state, $Y^{*}(1760)$, and within limited statistics the data appear to conform to this model.

Table I

Legendre polynomial coefficients for the process $(0^- + 1/2^+) \longrightarrow J^P \longrightarrow (0^- + 3/2^-)$. Numbers in parenthesis are the orbital momenta of the final state. The experimental values refer to the reactions :

$$K^- p \longrightarrow Y^*(1760) \longrightarrow Y^*(1520)\,\pi^o \; ; \; Y^*(1520) \longrightarrow \Sigma^\pm \pi^\mp .$$

The probabilities have been derived from a χ^2 test on the coefficients.

Coefficient	Experimental value	J^P			
		$3/2^+$ (ℓ=0)	$3/2^-$ (ℓ=1)	$5/2^+$ (ℓ=2)	$5/2^-$ (ℓ=1)
A_o	1	1	1	1	1
A_1	0.11 ± 0.11	0	0	0	0
A_2	0.65 ± 0.14	0	-0.80	0.41	0.80
A_3	-0.32 ± 0.16	0	0	0	0
A_4	-0.12 ± 0.19	0	0	-0.98	0
A_5	-0.22 ± 0.20	0	0	0	0
A_6	-0.16 ± 0.22	0	0	0	0
probability		$8\ 10^{-5}$	10^{-22}	$5\ 10^{-5}$	0.25

Table II

Legendre polynomial coefficients for $Y^*(1520)$ decay with respect to the production normal. The experimental values refer to the reactions :

$$K^- p \longrightarrow Y^*(1760) \longrightarrow Y^*(1520)\,\pi^o \; ; \; Y^*(1520) \longrightarrow \Sigma^\pm \pi^\mp .$$

Coefficient	Experimental value	J^P	
		$5/2^+$	$5/2^-$
A_o	1	1	1
A_1	0.02 ± 0.10	0	0
A_2	-0.34 ± 0.13	0.78	-0.70
A_3	-0.04 ± 0.15	0	0
A_4	0.10 ± 0.17	0	0
probability		$4\ 10^{-13}$	0.10

References

(1) R. Armenteros et al., Phys. Letters (to be published)

(2) Paper presented by M. Ferro-Luzzi, Proceedings of the Argonne Users' Meeting (1965).

(3) For K^- momenta lower than 870 MeV/c the occurrence of $Y^*(1385)$ in the $\Sigma^\pm \pi^0$ combination (ref.1) gives rise to a large kinematical overlap between reaction (1) and the reaction $K^-p \longrightarrow Y^{*\pm}(1385)\ \pi^\mp$. For the three momenta below 870 MeV/c the relative yields have been determined directly from the distribution of events on the Dalitz plots.

(4) M.B. Watson, M. Ferro-Luzzi and R.D. Tripp, Phys.Rev., 131, 2248 (1963)

(5) A.Barbaro-Galtieri, A.Hussain and R.D. Tripp, Phys. Letters 6, 296 (1963)

(6) R.W.Birge, R.P.Ely, G.E.Kalmus, A.Kernan, J.Louie, J.S.Sahouria and W.M.Smart, UCRL - 16252 (June 1965), presented at the Resonant Particles Conference at Athens, Ohio.

Figure Captions

Fig. 1. Effective-mass spectrum of : a) the $\Sigma\pi$ neutral system from 2748 reactions $K^-p \longrightarrow \Sigma^\pm \pi^\mp \pi^0$; b) the $\Lambda\pi^+\pi^-$ system from 422 reactions $K^-p \longrightarrow \Lambda\pi^+\pi^-\pi^0$.

Fig. 2. Cross section as a function of K^- laboratory momentum for the reaction $K^-p \longrightarrow Y^*(1520)\ \pi^0$: a) $Y^*(1520) \longrightarrow \Sigma^\pm \pi^\mp$ and b) $Y^*(1520) \longrightarrow \Lambda\pi^+\pi^-$.

Fig. 3. Production angular distribution of 332 reactions $K^-p \longrightarrow Y^*(1520)\ \pi^0$, $Y^*(1520) \longrightarrow \Sigma^\pm \pi^\mp$ with the K^- laboratory momentum between 910 and 1070 MeV/c, and the $\Sigma^\pm \pi^\mp$ effective-mass between 1505 and 1525 MeV. $\vartheta_{\text{production}}$ is the c.m. angle of $Y^*(1520)$ with respect to the incident K^- direction.

Fig. 4. Decay angular distribution of 332 reactions $K^-p \longrightarrow Y^*(1520)\ \pi^0$, $Y^*(1520) \longrightarrow \Sigma^\pm \pi^\mp$ with the K^- laboratory momentum between 910 and 1070 MeV/c and the $\Sigma^\pm \pi^\mp$ effective-mass between 1505 and 1525 MeV. ϑ_{decay} is the angle of the Σ in the $Y^*(1520)$ centre of mass with respect to the normal to the $Y^*(1520)$ production plane.

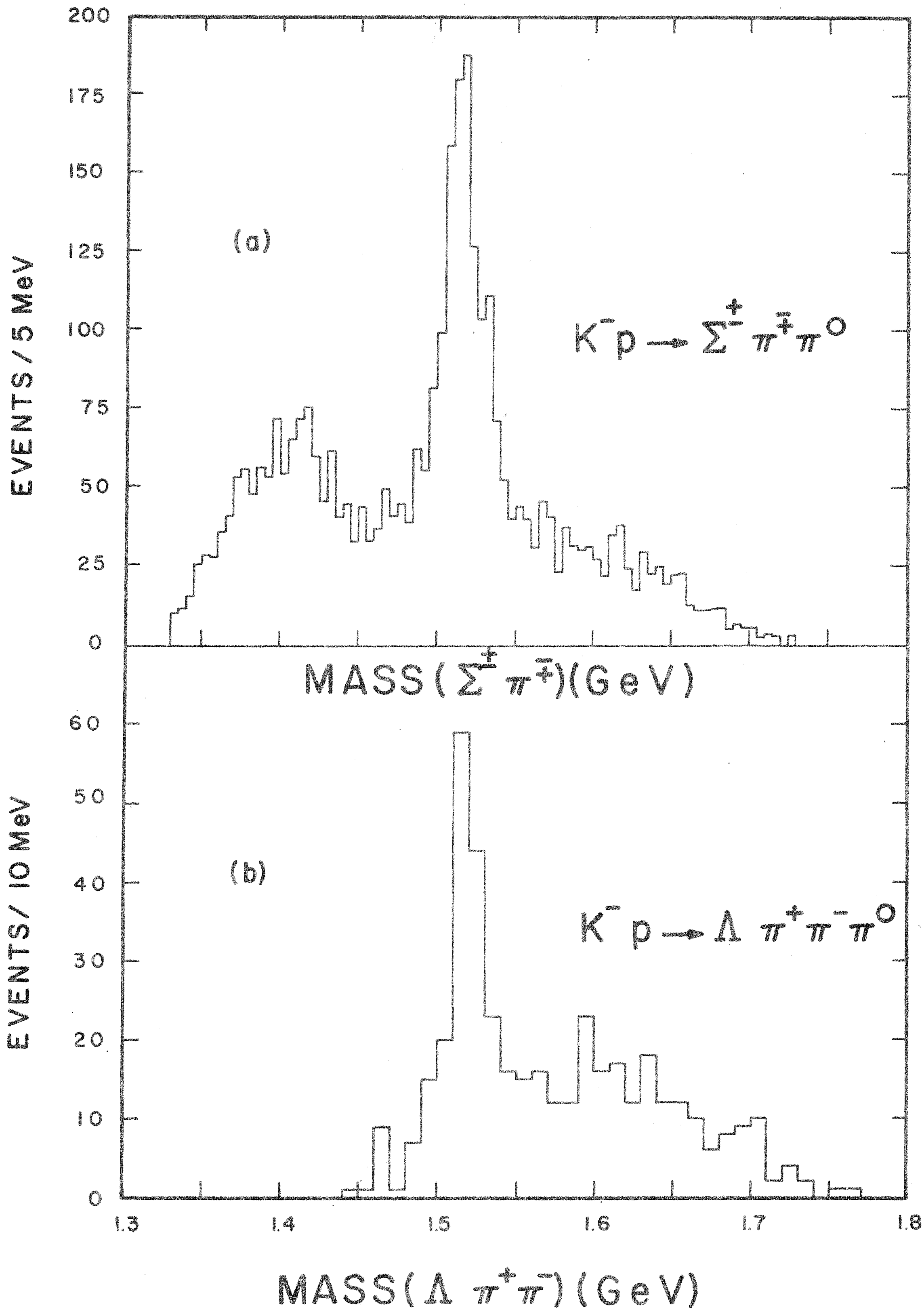

FIG. 1

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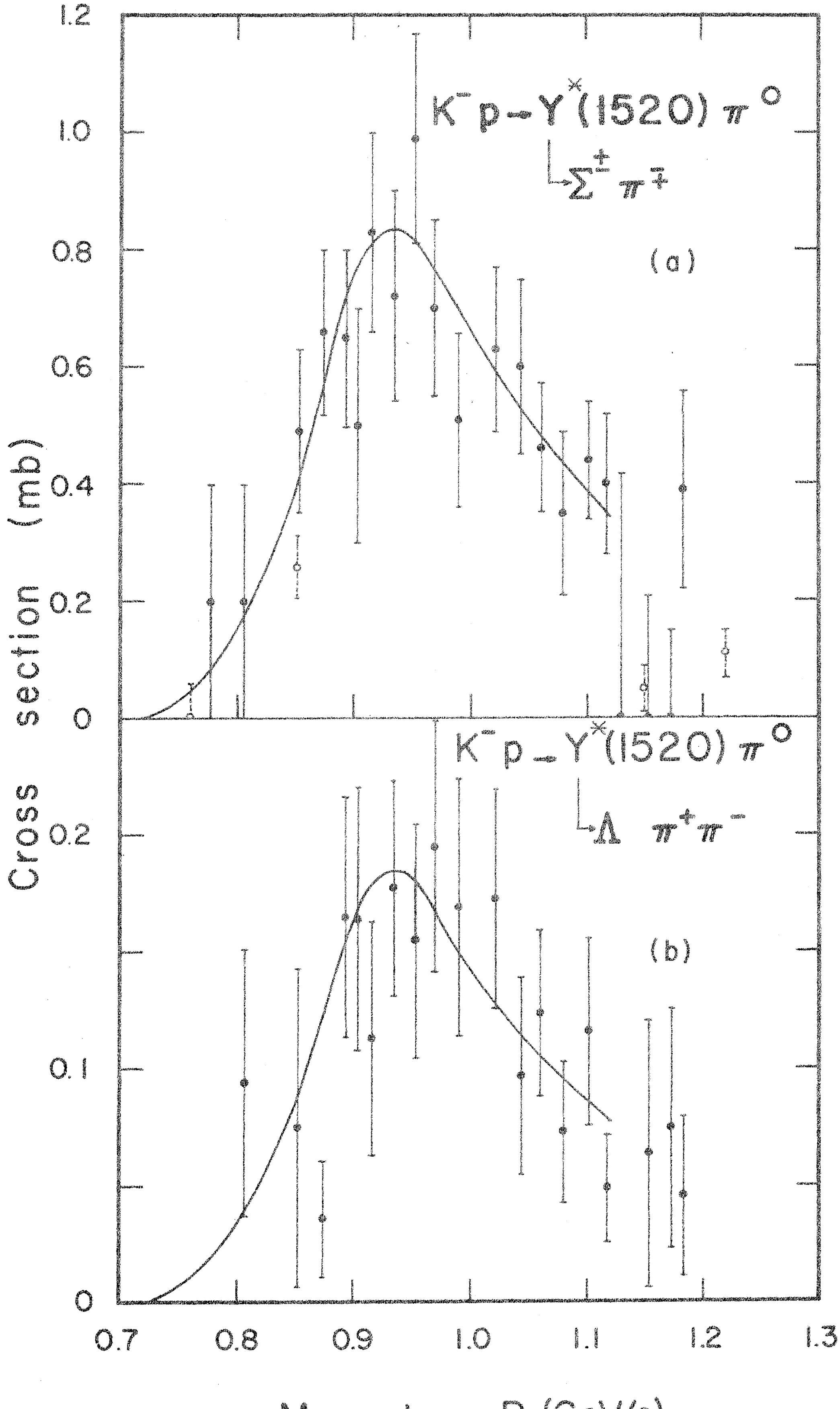

FIG. 2

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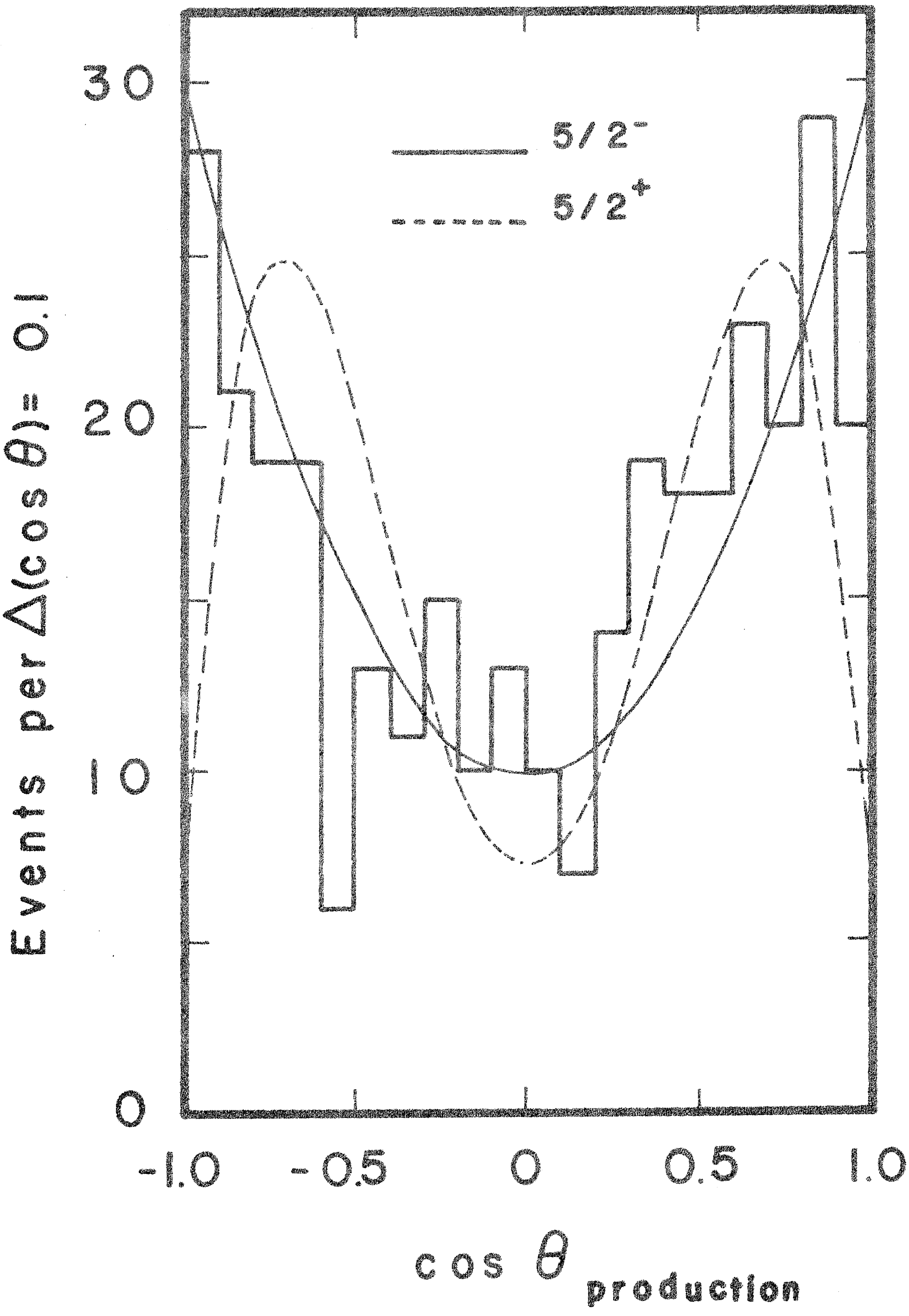

FIG. 3

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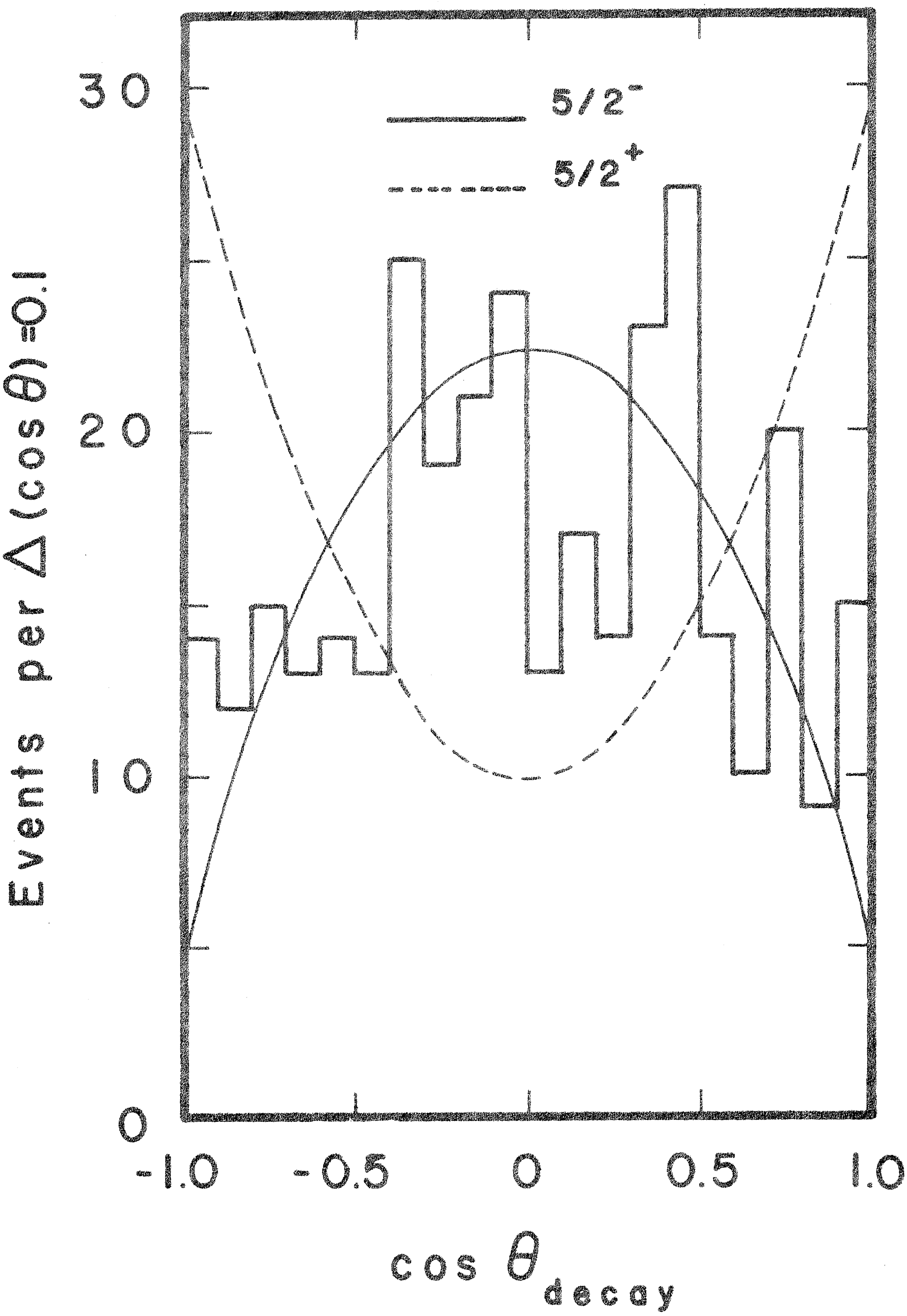

FIG. 4

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