Limits on $\xi(2.2)$ Formation in $\bar{p}p \to K^+K^-$

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We report the results of a search at the Brookhaven National Laboratory's alternating-gradient synchrotron for the $\xi(2.2)$ observed by the Mark III group at the SLAC e^+e^- storage ring SPEAR. 37 000 $\bar{p}p \to K^+K^-$ events and 200 000 $\bar{p}p \to \pi^+\pi^-$ events were studied in the incident-momentum interval from 1.25 to 1.56 GeV/c, corresponding to a mass interval of 110 MeV/c^2 about the reported ξ mass. The mass resolution was 3 MeV/c^2. We find no evidence for ξ formation and determine that the product $B(\xi \to \bar{p}p)B(\xi \to K^+K^-)$ is $< 2\times10^{-4}$ for $J^{PC}=2^{++}$ and $\Gamma=35$ MeV/c^2.

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Baltrusaitis *et al.* (Mark III group) have reported evidence from the SLAC e^+e^- storage ring SPEAR for a narrow state observed at a mass of 2230 MeV/c^2 in both the K^+K^- and $K_S^0K_S^0$ mass spectra in the radiative decay $J/\psi \to \gamma KK$.[1] The quantum numbers of this new state are limited to the sequence $J^{PC}=0^{++}, 2^{++}, 4^{++}, \ldots$ by its observed decay to K^+K^- [requiring $C=P=(-1)^l$] and its detection in radiative J/ψ decay (requiring C even), or directly, by its decay via $K^0\bar{K}^0$ into the two identical bosons $K_S^0K_S^0$. The narrow width of the state, $26^{+20}_{-16}\pm17$ MeV/c^2, has led to speculation that it is not a conventional $q\bar{q}$ meson but perhaps a gluonium (gg) or hybrid ($q\bar{q}g$) state containing the fundamental quantum of QCD as at least one of its constituents.[2] Its observation in radiative J/ψ decay, long regarded as an excellent place to search for gluonium,[3] lends support to this speculation. Additional experimental evidence for the existence of this new state and clear-cut measurements which rule out its interpretation as a conventional $q\bar{q}$ meson are both required before the interesting possibilities put forth to explain the ξ can be taken seriously. In this regard three results, two experimental and one theoretical, are pertinent. First, Augustin *et al.* (DM2 Collaboration) at Orsay did not observe the ξ in a high-statistics study of radiative J/ψ decay, which contradicts the Mark III result.[4] Alde *et al.*[4] (CERN-IHEP experiment) do find evidence in $\pi^-p \to Mn$ for a narrow meson at a mass of 2220 MeV/c^2 with $J^{PC}=2^{++}$ decaying to $\eta\eta'$.[5] It is tempting to identify this state as the ξ. The most likely conventional interpretation of the ξ is as an $L=3$, $J^{PC}=2^{++}$ $s\bar{s}$ state, as proposed by Godfrey, Kokoski, and Isgur.[6] Using a quark model based on a relativistic Schrödinger-type equation they find that such a state might have a surprisingly narrow width, 45–60 MeV/c^2, and would decay with sizable branching ratios to $K\bar{K}$, $K^*\bar{K}$, $\bar{K}^*K$, $K^*\bar{K}^*$, $\eta\eta$, and $\eta\eta'$. The credibility of this model stems from its success in predicting the masses and widths of a wide variety of meson states. While the CERN-IHEP result[5] fits nicely into this picture, there is as yet no evidence in radiative J/ψ decay for the $K^*\bar{K}$ or $\eta\eta$ modes.

The ξ, with spin $0^{++}, 2^{++}, \ldots$, can be reached by $\bar{p}p$ annihilation in flight from the triplet state, which forms the ξ through a two-gluon intermediate state. We have searched for the reaction $\bar{p}p \to \xi \to K^+K^-$ with a mass resolution of 3 MeV/c^2 in a high-intensity 1.4-GeV/c negative beam at the Brookhaven National Laboratory's alternating-gradient synchrotron. The ξ should show up as a resonant enhancement at 1.43 GeV/c of the continuum $\bar{p}p \to K^+K^-$ cross section of 50 μb. The final state can be selected by decay-angle kinematics alone, without the need for particle identification or momentum measurements of the two detected secondaries.

The apparatus is shown schematically in Fig. 1. Antiprotons comprised 0.15% of the incident beam of 10^7 particles per second. They were distinguished from pions by a measurement of the time of flight between two counter arrays separated by 14 m and by the use of a Fitch-type plastic Cherenkov counter. The trajectory of the beam particle was measured by two crossed planes of scintillation counters having a spatial resolution of ±2 mm and separated by 4 m. The incident beam interacted in a 50-cm-long hydrogen target with thin Mylar windows on three sides to allow large-angle secondaries to escape with minimal multiple scattering. K^+K^- and $\pi^+\pi^-$ pairs were detected in proportional wire chambers (PWC's) with 2-mm wire spacing situated on either side of the beam line. The chambers nearest the beam line contained three planes of wires oriented at 0°, +20°, and −20° with respect to the vertical, while the rear chambers each contained planes of horizontal and vertical wires. Two banks of twelve scintillation counters behind the rear chambers were used to trigger on interactions that resulted in two large-angle secondaries. The detector covered 14% of the azimuth with uniform

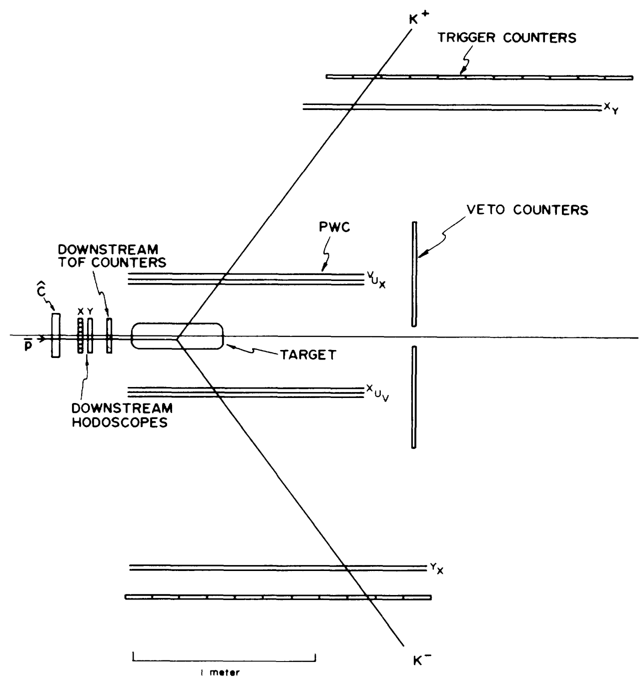

FIG. 1. Experimental arrangement.

acceptance in the region $-0.5 < \cos\theta_{\text{c.m.}} < 0.5$. Backgrounds from multibody final states were reduced by the rejection of events with more than one hit in either scintillator bank and by twelve veto counters covering most of the forward region outside the aperture of the PWC's. A further reduction in the trigger rate was achieved by our making a coarse coplanarity selection using a coincidence matrix of PWC outputs.

Data were collected in seven overlapping 70-MeV/c momentum intervals between 1.29–1.55 GeV/c. Our results are based on 37000 $\bar{p}p \to K^+K^-$ and 200000 $\bar{p}p \to \pi^+\pi^-$ events accumulated in the 110-MeV/c^2 interval about the reported mass of the ξ.

Two-body final states were selected by the requirement that the incident antiproton and the two secondaries in the PWC's lie in a plane (coplanarity). Specific two-body states were identified by the examination of the laboratory decay angles of the two tracks in the decay plane. Requiring the opening angle to exceed 105° eliminated π^-p and $\bar{p}p$ elastic scattering. K^+K^- and $\pi^+\pi^-$ final states were then separated by a comparison of the beam momentum reconstructed from the decay angles under either hypothesis to the momentum selected with a $\pm 2\%$ momentum bite by the beam-transport system. Figure 2 shows the reconstructed beam-momentum spectrum for the K^+K^- hypothesis and a beam-transport setting of 1.44 GeV/c. The $\bar{p}p \to K^+K^-$ events are peaked at the nominal beam momentum and are well separated from the more copious $\bar{p}p \to \pi^+\pi^-$ events which peak at a lower, incorrect momentum. The reconstructed momentum also determines the K^+K^- invariant mass with a resolution of 3 MeV/c^2 (1 standard deviation).

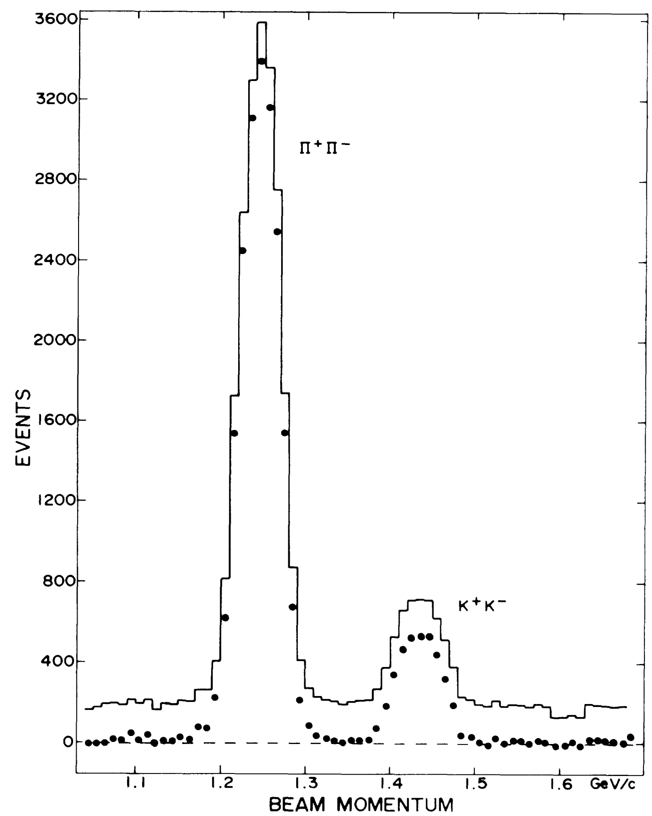

FIG. 2. Reconstructed antiproton momentum for two-track events with the assumption that the final-state particles are kaons. The lower points show data after background subtraction.

The flat background seen in Fig. 2 arises from residual multibody events. This background was removed by our dividing the data into 10-MeV/c momentum intervals (3.5-MeV/c^2 mass intervals) and fitting the coplanarity distribution in each interval by a flat background and a Gaussian peak. Figure 3 shows coplanarity distributions for events in 10-MeV/c momentum intervals under the K^+K^- peak [Fig. 3(a)] and in the background region [Fig. 3(b)]. The resulting background versus momentum distribution was smoothed by fitting with a quadratic function of momentum. This function was used to subtract the background in each momentum interval. The result, for the data taken at 1.44 GeV/c, is shown as the lower curve in Fig. 2. The background-subtracted data in the K^+K^- peaks were then added together for the seven momentum runs. The entire procedure was repeated for the $\pi^+\pi^-$ events.

We searched for a signal in the K^+K^- channel by examining the ratio $(\bar{p}p \to K^+K^-)/(\bar{p}p \to \pi^+\pi^-)$. The ratio, plotted in 3.5-MeV/c^2 mass intervals, is shown in Fig. 4. Because the $\pi^+\pi^-$ and K^+K^- final states are

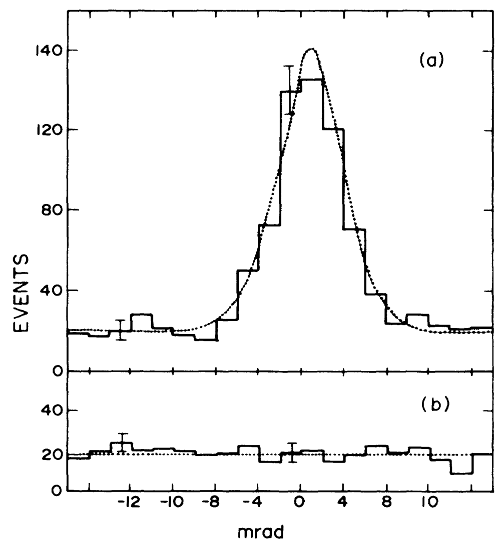

FIG. 3. Coplanarity distributions (a) for events which reconstruct to the proper beam momentum and (b) for off-momentum events. The dotted lines are fits to the data.

kinematically similar and are reconstructed with the same mass resolution, systematic corrections for momentum structure in the beam and for apparatus acceptance cancel in this ratio. Because the continuum $\bar{p}p \to \pi^+\pi^-$ cross section is 4 times the $\bar{p}p \to K^+K^-$ cross section, a ξ signal present in both channels would reduce our sensitivity by only a factor

$$1-\frac{1}{4}\frac{B(\xi\to\pi^+\pi^-)}{B(\xi\to K^+K^-)}.$$

Since $B(\xi\to\pi^+\pi^-)\leq\frac{1}{2}B(\xi\to K^+K^-)$ (Ref. 1) this amounts to at most a 12% reduction in signal.

We find no evidence of the $\xi(2.2)$. Translating the absence of significant enhancement in the data of Fig. 4 to a limit on the production cross section is model dependent, since the ξ would add coherently to the corresponding final state in the continuum background. This interference could either enhance or decrease our sensitivity; it would take a perverse combination of phases and amplitudes to cancel the signal. In the absence of any information on relative phases, we assume that the ξ signal would be superimposed incoherently upon the background. Using previously measured $\bar{p}p \to \pi^+\pi^-$ differential cross sections[7] integrated over our angular acceptance for normalization we obtain 3σ limits of 4.4 and 1.9 μb on the cross section $\sigma_{\rm peak}(\bar{p}p\to\xi\to K^+K^-)$ for assumed widths of 7 and 35 MeV/c^2, respectively.

Using the relationship

$$\sigma_{\rm peak}=\frac{4\pi(2J+1)}{s-4m_p^2}B(\xi\to\bar{p}p)B(\xi\to K^+K^-),$$

one obtains the limit on the product of the branching ratios, $B(\xi\to\bar{p}p)B(\xi\to K^+K^-)$, given in Table I separately for the $J^{PC}=0^{++},2^{++}$ assignments. The sensitivity improves with increasing width Γ approximately as $\sqrt{\Gamma}$. The $J^{PC}=2^{++}$ state is produced from a $\bar{p}p$ system

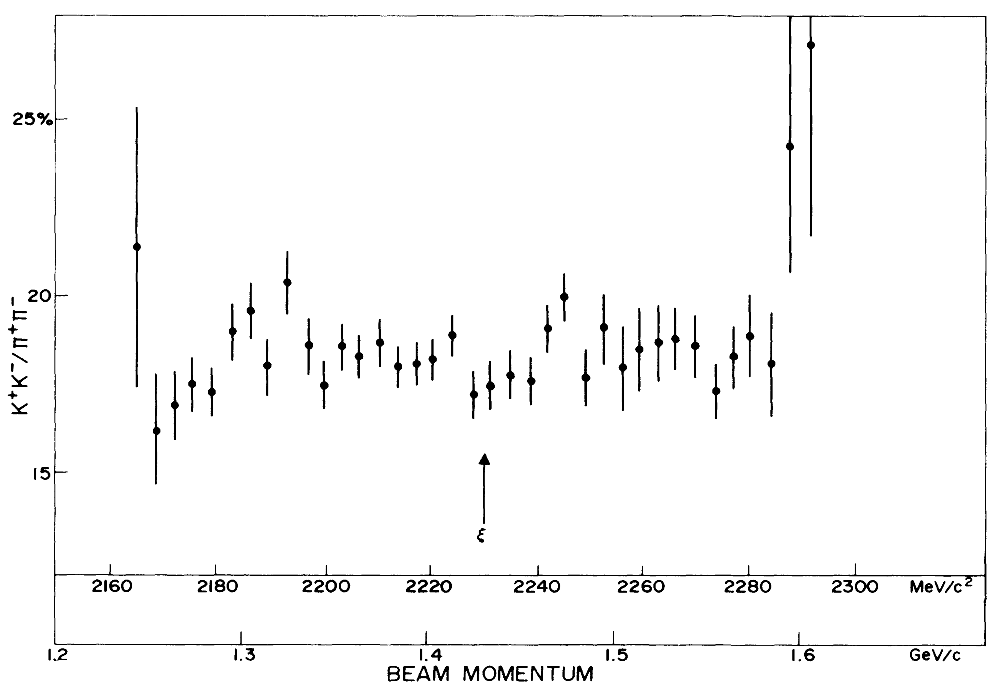

FIG. 4. Ratio of K^+K^- to $\pi^+\pi^-$ events plotted in 10-MeV/c momentum bins (3.5-MeV/c^2 mass bins).

TABLE I. Upper limits (3 standard deviations) on the product $B(\xi \to \bar{p}p) B(\xi \to K^+K^-)$.

J^{PC}	$\Gamma = 7$ MeV/c^2	$\Gamma = 35$ MeV/c^2
0^{++}	12×10^{-4}	5.6×10^{-4}
2^{++}	3.8×10^{-4}	1.8×10^{-4}

with $S=1$, and $L=1$ or 3. The $L=1$ case leads to a $1+3\cos^2\theta$ angular distribution and the $L=3$ case gives $1-2\cos\theta+5\cos^4\theta$. When integrated over our center-of-mass acceptance $(-0.5 < \cos\theta < 0.5)$ these distributions each lead to a reduced sensitivity compared to the isotropic $J=0$ case by a factor of about 1.6.

The signal observed in radiative J/ψ decay implies that the product of the branching ratios $B(J/\psi \to \gamma\xi) B(\xi \to K^+K^-)$ is 4×10^{-5}. The absence of a signal both in the $\pi^+\pi^-$ mode and in the inclusive photon spectrum suggests a large branching ratio to K^+K^-. If the ξ decays primarily to strange particles the branching ratio $B(\xi \to K^+K^-)$ would be approximately 15%, the value obtained in Ref. 6. Our data then imply, for a width $\Gamma = 35$ MeV/c^2, that $B(\xi \to \bar{p}p) < 0.4\%$ for $J^{PC} = 0^{++}$ and $B(\xi \to \bar{p}p) < 0.14\%$ for $J^{PC} = 2^{++}$.

A guess at this branching ratio can be made if the ξ decays to $\bar{p}p$ only through purely gluonic channels. The η_c width of ~ 11 MeV/c^2 agrees well with calculations based on annihilation to two gluons, and this intermediate state forms a $\bar{p}p$ final state with branching ratio $(0.12 \pm 0.06)\%$. This branching ratio would increase if the mass were lowered toward the $\bar{p}p$ threshold. Dimensional scaling[8] alone would give a tenfold increase, $(M_{\eta_c}/M_\xi)^8 = 10$, but this is reduced by phase-space and barrier-penetration factors, 0.7 and 0.3, respectively, for the p-wave ξ decay to $\bar{p}p$. The resulting estimate for $B(\xi \to \bar{p}p)$ is 0.25%,[9] of the same order as the limits from this experiment.

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