Search for the $\xi(2230)$ in the BES-II J/ψ data

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Abstract

I report preliminary results of a search for the $\xi(2230)$ in a sample of 24M J/ψ decays registered in the BES-II detector. No signals are seen for the chains decay $J/\psi \to \gamma\xi(2230)$; $\xi(2230) \to \pi^+\pi^-$, K^+K^-, K^0K^0 and $p\overline{p}$ where, based on BES-I and Mark-3 results, signals with significance in excess of $\sim 6\sigma$ are expected *for each channel.* Preliminary 90%CL upper limits on the branching fraction product $\mathcal{B}(J/\psi \to \gamma\xi)\mathcal{B}(\xi \to h\overline{h})$ are reported for $h\overline{h} = \pi^+\pi^-$, K^+K^-, K^0K^0, and $p\overline{p}$. that are, in all cases, substantially below the BES-I and Mark-3 observation values.

I. INTRODUCTION

In 1983, the Mark-3 group reported evidence for a narrow ($\Gamma \sim 20$ MeV) resonance with mass $M = 2.23$ GeV, produced in in the radiative decay $J/\psi \to \gamma K\overline{K}$. In a sample of 5.8M J/ψ decays, they reported signals of 93 events for $\xi \to K^+K^-$ and 23 events for $\xi \to K^0K^0$, with statistical significances of 4.5σ and 3.6σ, respectively [1]. The K^+K^- and K^0K^0 mass distributions shown in their paper are reproduced here as Figs. 1(a) and (b), respectively. Note in particular the signal to noise ratio for the $\xi \to K^0K^0$ signal, where the signal to background ratio at the peak is almost 2:1 (as measured from the inset in Fig. 1(b)). The two lower-mass peaks in both distributions are identified with the $f_2'(1525)$ and the $f_0(1710)$. The striking feature of the $\xi(2230)$ state is its narrow width; the Mark-3 group reported total width measurements of $\Gamma = 26^{+20}_{-16} \pm 17$ MeV for the K^+K^- mode and $\Gamma = 18^{+23}_{-15} \pm 10$ MeV for the K^0K^0 mode. Such a narrow width is unexpected for a high mass resonance and, thus, the $\xi(2230)$ has attracted considerable attention both theoretically and experimentally [2].

A number of experiments have tried to confirm the Mark-3 result. A search by the DM2 group set an upper limit at the level of the Mark-3 observation [3]. The BES-I experiment, using a sample 8M J/ψ decays, confirmed the Mark-3 results for $\xi \to K^+K^-$ and K^0K^0, and also reported evidence in the $\pi^+\pi^-$, $p\overline{p}$, and $\pi^0\pi^0$ decay channels [4,5], with numbers of events and statistical significances ranging from 3.6 to 4.6σ. Figures 2(a) through (d), taken from ref. [4], shows the BES-I mass distributions for the $\pi^+\pi^-$, K^+K^-, K^0K^0, and $p\overline{p}$ channels, respectively. Note that the signal to noise in the K^+K^- and K^0K^0 channels is similar to that of Mark-3. The results from the Mark-3 and BES-I experiments as summarized in Table I.

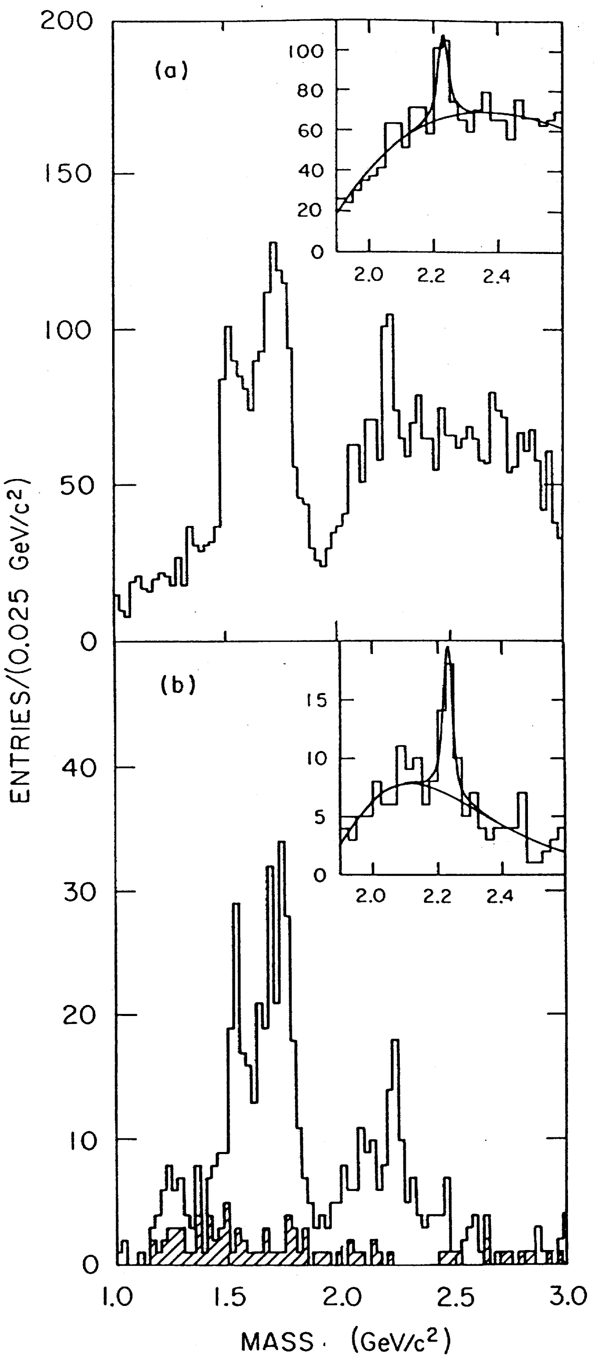

FIG. 1. Mark-3 mass distributions for **a)** K^+K^- and **b)** K^0K^0 from radiative $J/\psi \to \gamma K\overline{K}$ decays. This figure is Fig. 1 in R. Baltrusaitis *et al.* (Mark-3 Collab.), Phys. Rev. Lett. **56**, 107 (1986).

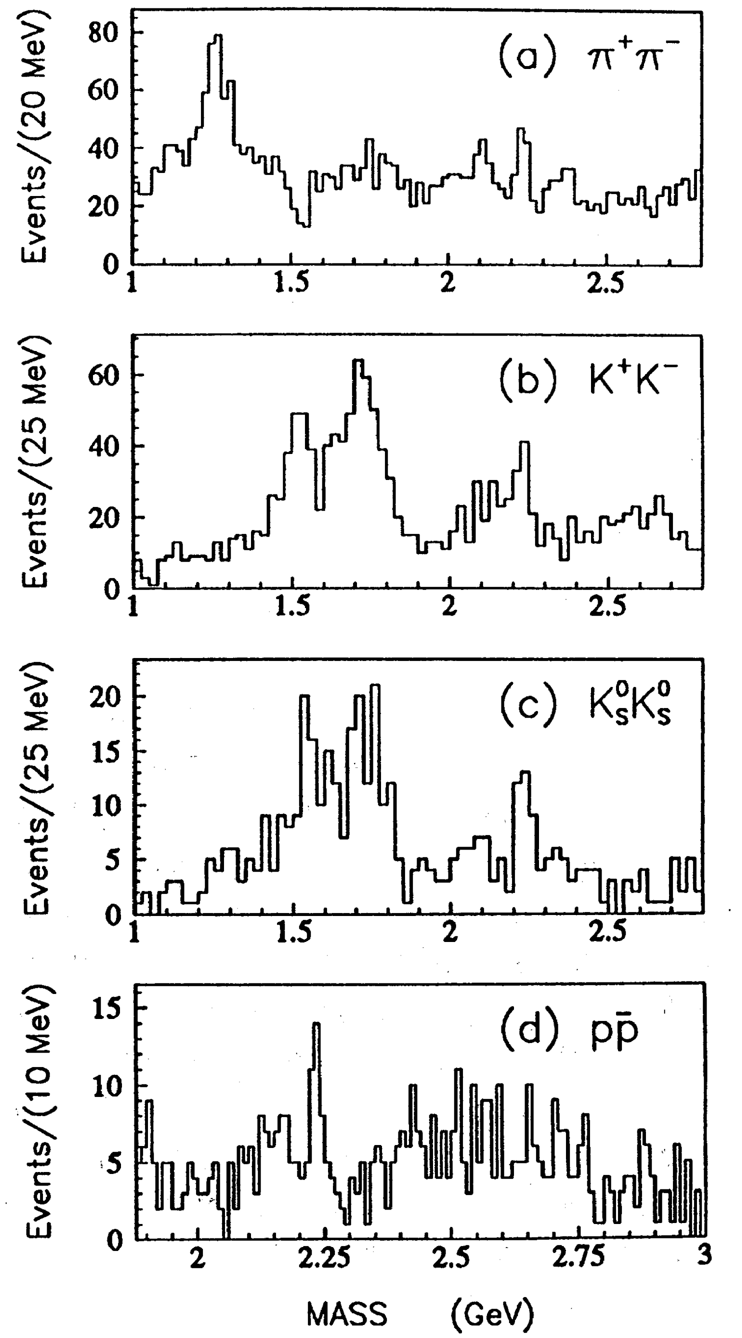

FIG. 2. BES-I mass distributions for **a)** $\pi^+\pi^-$ **b)** K^+K^-, **c)** K^0K^0 and **d)** $p\overline{p}$ from radiative $J/\psi \to \gamma h\overline{h}$ decays. This figure is Fig. 1 in J.Z. Bai *et al.* (BES-I Collab.), Phys. Rev. Lett. **76**, 3502 (1996).

During the 1999-2000 running period, the BES-II experiment accumulated a 24M event sample of J/ψ decays, corresponding to a three- and four-fold increase over the BES-I and Mark-3 data sets, and in a very similar experimental environment. Thus, it can be expected that the $\sim 4\sigma$ significance signals seen previously would translate into unmistakable peaks with at least 6σ significance. Signals of this size should be visible in the data after the application of very simple selection requirements—*no sophisticated analyses or complicated cuts should be necessary.*

In this memo, I report the results of a search for $J/\psi \to \gamma\xi(2230)$; $\xi \to K^0K^0$, K^+K^-, $\pi^+\pi^-$ and $p\overline{p}$ using the year 2000 BES-II J/ψ data sample.

II. THE $J/\psi \to \gamma K^0 K^0$ CHANNEL

Experimentally, of the four channels reported in ref. [4], the simplest channel to study is $J/\psi \to \gamma K^0K^0$. Here, for the $\xi(2230)$, there are four relatively high momentum charged tracks and a high energy γ. Because of the BES detector's good momentum resolution for $K^0 \to \pi^+\pi^-$, no particle identification is necessary.

A. $\gamma\pi^+\pi^-\pi^+\pi^-$ event selection

I select events with four $mfit = 2$ charged tracks with zero net charge and at least one neutral BSC cluster. I apply the neutral cluster energy correction in the NCOR routine. The charged tracks are all required to be in the region $|\cos\theta| < 0.8$, which is well covered by the MDC. If both the highest momentum positive and negative tracks have a shower counter energy above 0.8 GeV, it is rejected. Neutral clusters are required to have a measured energy greater than 50 MeV, be within $|\cos\theta| < 0.8$, and have no more than 80% of their total energy in one BSC layer.

The selected events are subjected to a four constraint kinematic fit to the hypothesis $J/\psi \to \gamma\pi^+\pi^-\pi^+\pi^-$. For events with more than one good neutral cluster, I select the one that gives the best χ^2. I select events with a fit confidence level that is greater than 5%. In order to maximize efficiency, I use no particle identification nor K^0 vertexing to select events.

TABLE I. Summary of Mark 3 and BES-I $\xi(2230)$ signals

Decay Channel	N_{ev}	Significance	$\mathcal{B}(J/\psi \to \gamma\xi)\mathcal{B}(\xi \to h\bar{h})$ (10^{-5})	Reference
$\xi \to K^+K^-$	93	4.5σ	$4.2^{+1.7}_{-1.4} \pm 0.8$	[1]
$\xi \to K^0K^0$	23	3.6σ	$3.1^{+1.6}_{-1.3} \pm 0.7$	[1]
$\xi \to K^+K^-$	46	4.1σ	$3.3^{+1.6}_{-1.3} \pm 1.2$	[4]
$\xi \to K^0K^0$	23	4.0σ	$2.7^{+1.1}_{-0.9} \pm 0.8$	[4]
$\xi \to \pi^+\pi^-$	74	4.6σ	$5.6^{+1.8}_{-1.6} \pm 2.0$	[4]
$\xi \to p\overline{p}$	32	3.8σ	$1.5^{+0.6}_{-0.5} \pm 0.5$	[4]
$\xi \to \pi^0\pi^0$	18	3.6σ	$4.5 \pm 2.6 \pm 1.3$	[5]

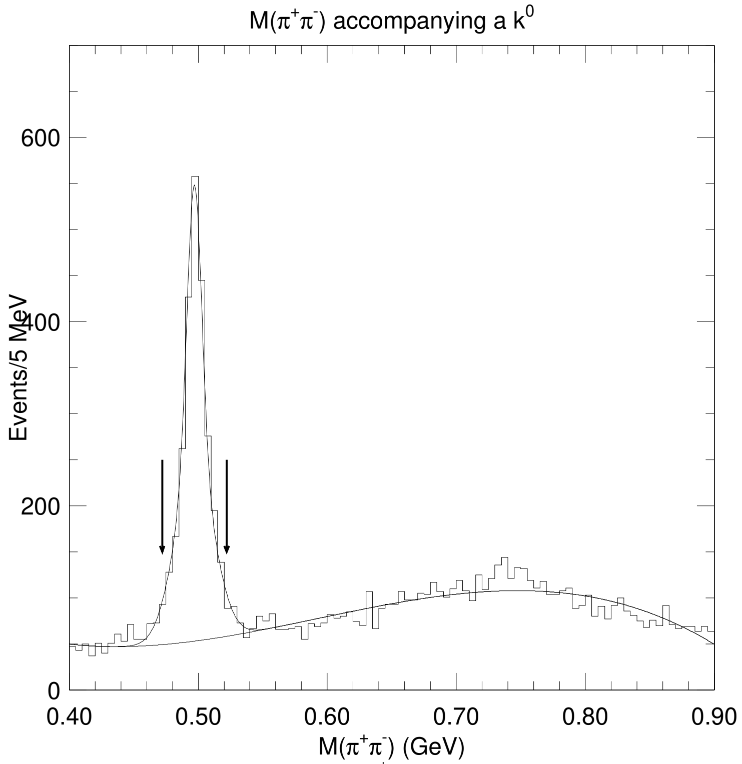

FIG. 3. The invariant mass distribution for $\pi^+\pi^-$ pairs that are accompanied by a $\pi^+\pi^-$ pair with invariant mass within ± 27.5 MeV of the K^0 mass peak.

B. $K^0 \rightarrow \pi^+\pi^-$ selection; no vertexing

Figure 3 shows the invariant mass distribution for $\pi^+\pi^-$ pairs where the accompanying pair has an invariant mass that is within 25 MeV of M_{K0}. The prominent K^0 peak in the figure is well fit by a two-Gaussian resolution function with a peak position at 497 MeV and an average resolution of $<\sigma>= 11$ MeV. Based on this, we select K^0K^0 events as those where there are two $\pi^+\pi^-$ pairs with invariant mass within $\pm 2.5 <\sigma>= 27.5$ MeV of 497 MeV. The fit shown in Fig. 3 indicates that the signal/background for this cut is 3.4/1. The acceptance with these cuts, calculated assuming $J = 2$ for the $\xi(2230)$, is 11.8%, which is comparable to that of ref. [4] (10.6%).

C. The K^0K^0 invariant mass distribution.

Figure 4 shows the K^0K^0 invariant mass distribution. This distribution can be compared directly with the Mark-3 and BES-L group's results (Figs. 1(b)) and 2(c), respectively); all the plots have the same bin size, namely 25 MeV. There are prominent peaks near 1.5 and 1.7 GeV that correspond well with those seen in the previous experiments; the peak heights are about twice those in the Mark-3 plot and almost four times those in the BES-I plot. The solid curve is the results of a fit to two Breit Wigner functions with total widths fixed at $\Gamma = 75$ MeV and $\Gamma = 125$ MeV and peak positions allowed to float, a Breit Wigner with mass around 2.1 GeV plus narrow Gaussian around 2.23 GeV and a third order polynomial.

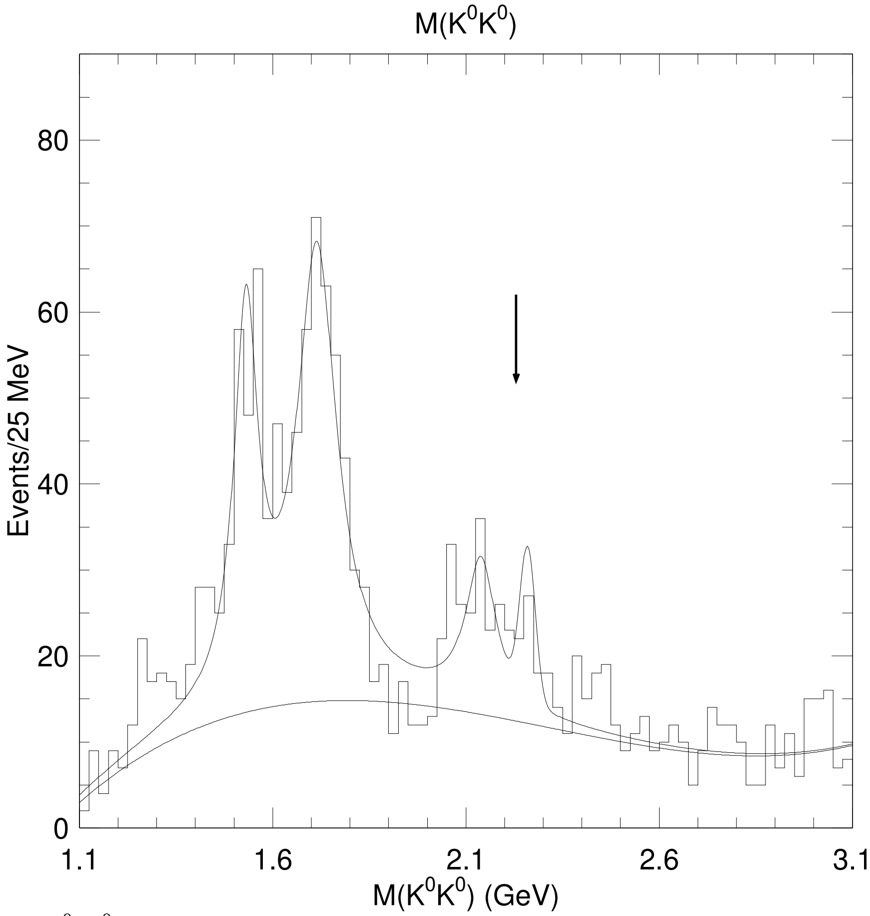

FIG. 4. The K^0K^0 invariant mass distribution. The curve is the result of a fit that has $\Gamma = 75$ MeV and $\Gamma = 125$ MeV Breit Wigner functions with peaks near $M_{f_2'(1525)}$ and $M_{f_0(1710)}$, respectively plus a broad resonance around 2.1 GeV and a Gaussian near 2.23 GeV. The narrow peak at 2.26 GeV indicates the 90%CL upper limit for a possible ξ signal. The arrow indicates the expected mass position for the $\xi(2230)$; the tip of the arrow represents where the ξ peak would be expected based on an extrapolation of the BES-I results.

The fitted peak position for the $\Gamma = 75$ MeV function is $M = 1.531 \pm 0.008$ GeV, in good agreement with the PDG mass value of $M_{f_2'(1525)} = 1.525 \pm 0.005$ GeV. The fit value for the peak position of the $\Gamma = 125$ MeV function is $M = 1.714 \pm 0.006$ GeV, which agrees well with the PDG mass value of $M_{f_0(1710)} = 1.715 \pm 0.007$ GeV. The mass and width of the third Breit Wigner are $M = 2.14 \pm 0.02$ GeV and $\Gamma = 0.10 \pm 0.04$. The fit results for the narrow Gaussian are a small 23.1 ± 9.3 event peak at $M = 2.26$ GeV. In the fitted curve in the figure, for purposes of display, the area of the ξ "signal" peak has been inflated to 35.0 events, the 90% CL upper limit of the number of counts. The arrow in the figure indicates the expected mass position of the $\xi(2230)$; the tip of the arrow indicates an estimate of where the peak maximum would be expected expected based on an extrapolation of the BES-I results.

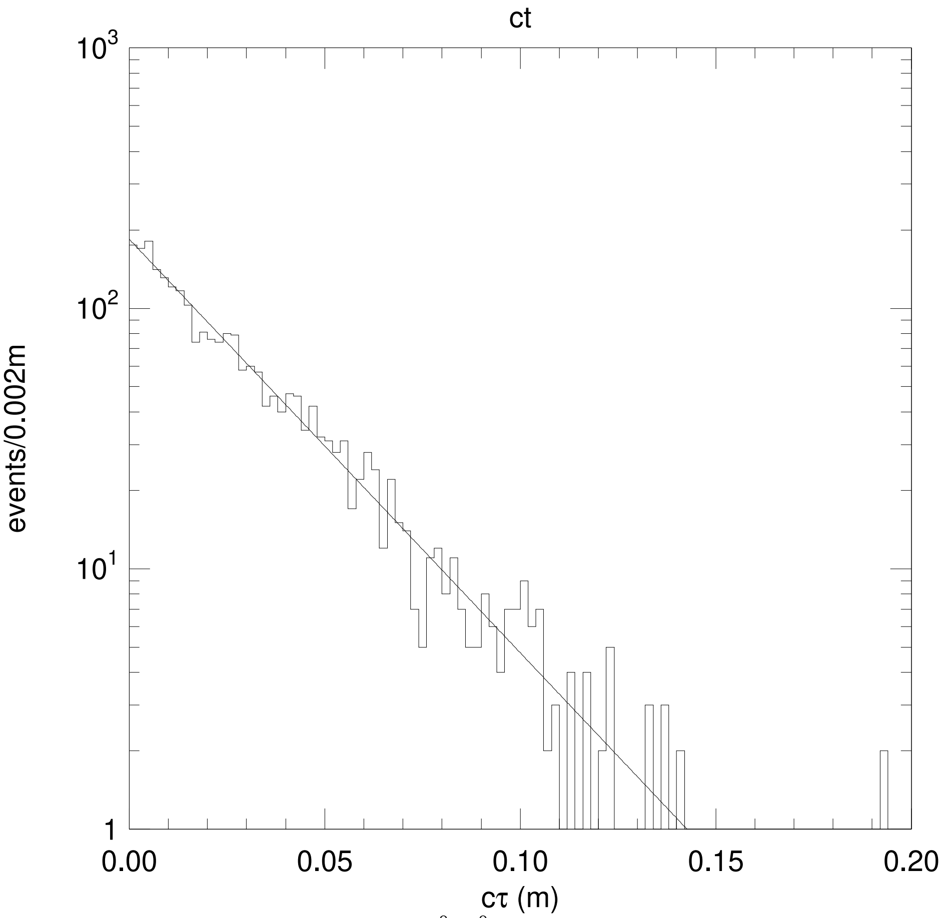

FIG. 5. The $c\tau$ distribution for selected $K^0K^0\gamma$ events. The straight line is the result of a fit with a single exponential function.

D. $K^0 \to \pi^+\pi^-$ selection; with vertexing.

Somewhat better resolution is expected if the KLAMS program is used to select the K^0's. I reprocessed the same data sample with the same charged and neutral particle selection and then used KLAMS to select and refit the K^0 candidate tracks. Events with two possible K^0's were subjected to a 6-C kinematic fit and events with a fit confidence level greater than 5% are selected. The prefit K^0 mass distribution for selected events has an improved resolution ($<\sigma>= 7.5$ MeV), as expected. Moreover, the signal is very clean. Figure 5 shows the $c\tau$ distribution for all selected K^0's. The curve is a fit to a simple exponential function, which gives a fitted $c\tau = 2.84 \pm 0.10$ cm, which is reasonably near the PDG value of 2.69 cm. There is no sign of a prompt excess near $c\tau = 0$, where backgrounds would be expected. In this case the acceptance is 10.6%, the same as that of ref. [4].

The resulting K^0K^0 mass distribution, shown in Fig. 6, is very similar to the distribution obtained with no vertex fitting. Both the $f_2'(1525)$ and $f_0(1710)$ peaks are within one bin of the PDG values, there is a broad structure around 2.1 GeV, which I fit with a Breit Wigner with $M = 2.165$ GeV and $\Gamma = 0.129$ GeV, and no sign of a narrow resonance near 2.23 GeV. Adding a narrow resonance around $M = 2.23$ GeV to the fit gives an insignificant 14 ± 14 event peak at $M = 2.256$ GeV. In the curve in the figure, this peak is inflated to its 90% CL

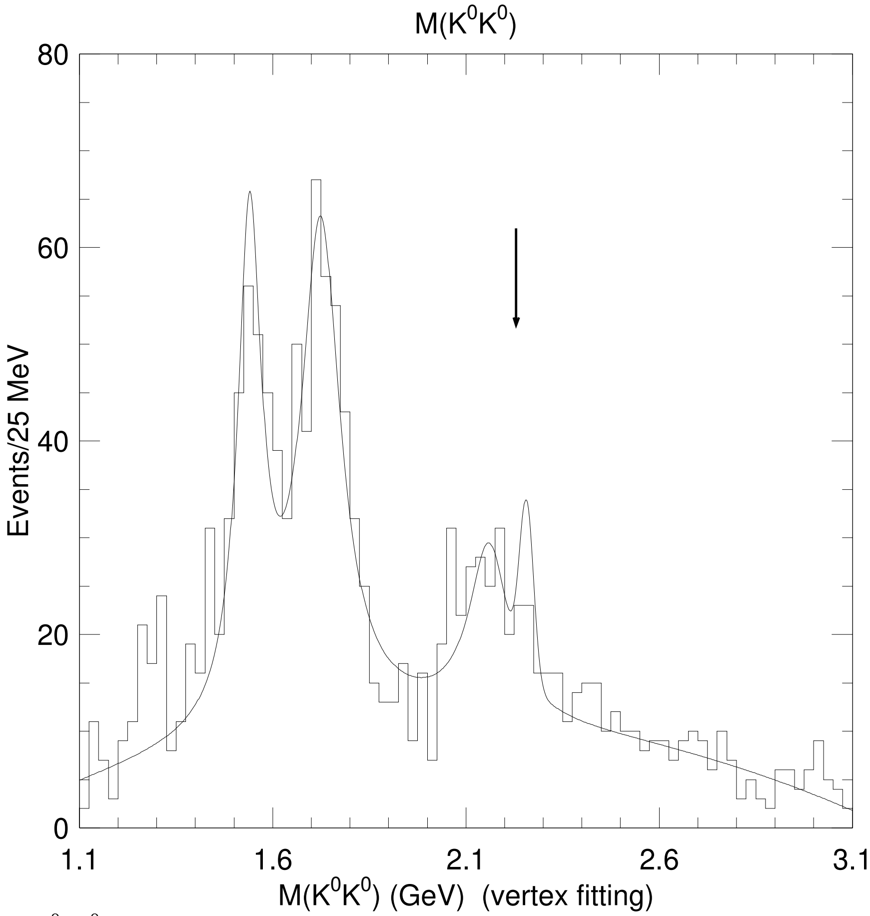

FIG. 6. The K^0K^0 invariant mass distribution using the KLAMS routine to select K^0's. The curve is the result of the fit described in the data. The narrow peak near $M \sim 2.26$ GeV represents the 90% CL upper limit for a possible signal. The tip of the arrow indicates the expected peak position based on an extrapolation of BES-I results.

upper limit. The arrow includes the position and height expected from the BES-I ξ results.

III. THE $J/\psi \to \gamma K^+K^-$ CHANNEL

For the K^+K^- channel, I require two oppositely charged tracks in the polar angle region $|\cos\theta| < 0.8$, not both identified as muons, and where neither has an associated BSC energy that is greater than 0.8 GeV. The (NCOR-corrected) γ candidates are required to have $|\cos\theta| < 0.8$, and have no more than 70% of the shower energy in one BSC layer. Both tracks are required to have a kaon identification CL greater than 0.05. Cosmic rays are eliminated by the requirement $|tof_+ - tof_-| < 3.5$ ns. Events are subjected to a 4-C kinematic fit and those with a fit confidence level greater than 5% are accepted. Background from $J/\psi \to K^+K^-\pi^0$, where the π^0 decays asymmetrically are removed by requiring $M_{K\gamma} > 1.0$ GeV for both $K\gamma$ combinations. The acceptance, 14.1%, is a little lower than that of ref. [4] (17.4%).

Figure 7 shows the resulting K^+K^- invariant mass distribution. Peaks corresponding to the $f_2'(1525)$ and $f_0(1710)$ are apparent and there is a broad enhancement near 2.1 GeV,

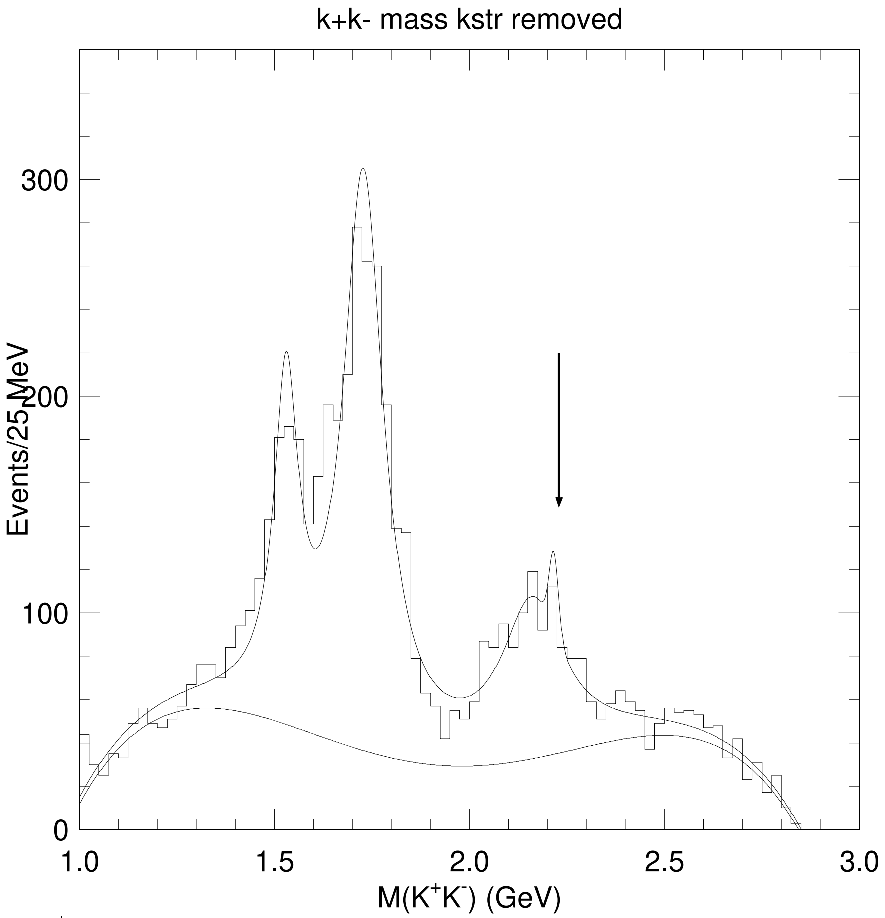

FIG. 7. The K^+K^- invariant mass distribution. The curve is the result of a fit similar to that for Fig. 4. The arrow indicates the expected position of the $\xi(2230)$. The area of the small peak at 2.21 GeV corresponds to the 90%CL upper limit on the number of possible ξ events.

similar to that seen in the K^0K^0 mass spectrum. A fit, similar to that done for the K^0K^0 case, gives an $f_2'(1525)$ mass value of 1.529 GeV and an $f_0(1710)$ mass of 1.718 GeV, both within a few MeV of their PDG values. Again, there is no strong evidence for an narrow structure near 2.23 GeV. There is a high bin at $\simeq$ 2.21 GeV, 20 MeV below the nominal ξ mass that, when fit to a narrow peak, gives a 22 ± 17 event "signal." The area of the narrow peak at 2.21 GeV in the figure is expanded corresponds to the 90%CL upper limit of 44.2 events.

IV. THE $J/\psi \to \gamma\pi^+\pi^-$ CHANNEL

My selection for the $\pi^+\pi^-$ channel is essentially the same as for the K^+K^- case, with π identification required instead of kaon id. If there is more than one γ in the event I try all $\gamma\gamma$ combinations in a 5-C fit to $J/\psi \to \pi^+\pi^-\pi^0$. I select events where the confidence level to $\pi^+\pi^-\gamma$ is higher than that for $\pi^+\pi^-\pi^0$. In addition, backgrounds from $J/\psi \to \rho^\pm\pi^\mp$, where the π^0 decays asymmetrically are removed by requiring $|M_{\pi^\pm\gamma} - M_\rho| > 0.1$ GeV for both charged pions. This selection is much simpler than that used in ref. [4] and my efficiency is higher: 26.1% compared to 16.4%. Figure 8 shows the resulting $\pi^+\pi^-$ invariant

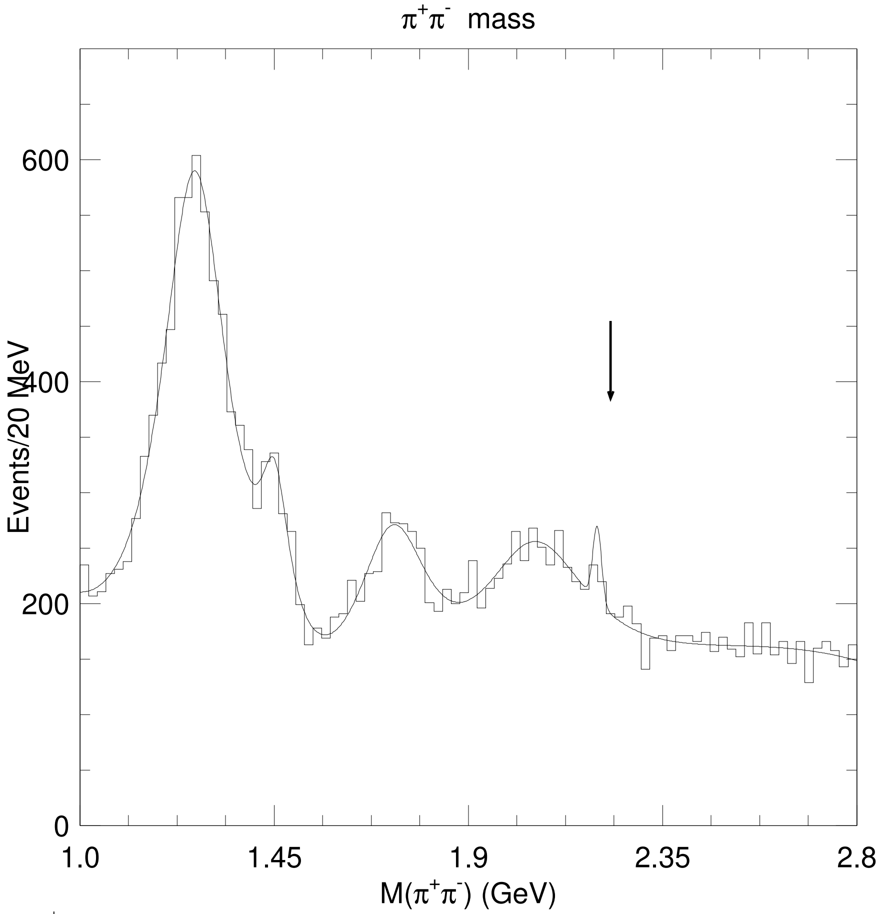

FIG. 8. The $\pi^+\pi^-$ invariant mass distribution. The curve is the result of a fit to an $f_2(1270)$, $f_0(1710)$, $f_4(2050)$ and something narrow near 1.45 GeV. The narrow peak in the curve near 2.20 GeV corresponds to the 90% CL upper limit of 86 events. The arrow indicates the expected position and height of the $\xi(2230)$ extrapolated from BES-I results.

mass distribution. A large peak corresponding to the $f_2(1270)$ is evident and has a peak height above background that is $\sim$ 6 times that of ref [4]. A fit gives a peak mass of 1.267 ± 0.002 GeV, which is 8 MeV below the PDG mass value for the f_2. I see evidence for some $f_0(1710)$, something near 2.05 GeV (that has a mass and width consistent with the $f_4(2050)$) and something near 1.45 GeV. There is no narrow structure near 2.23 GeV. The best I can do there is a small (54 ± 25 event) peak at $M_{\pi^+\pi^-} = 2.20$ GeV; BES-I reported 74 $\xi(2230)$ events. The narrow peak in the figure at 2.20 GeV is inflated to correspond to the 90% CL upper limit of possible ξ signal events. The arrow tip indicates the expected peak position determined by extrapolating the BES-I results.

V. THE $J/\psi \to \gamma p\overline{p}$ CHANNEL

My selection for the $p\overline{p}$ channel is similar to that for the K^+K^- and $\pi^+\pi^-$ channels, with proton identification required instead of kaon or pion id. Here, however, the simple $|tof_+ - tof_-| < 3.5$ ns cut is not efficient because of the much larger range of particle

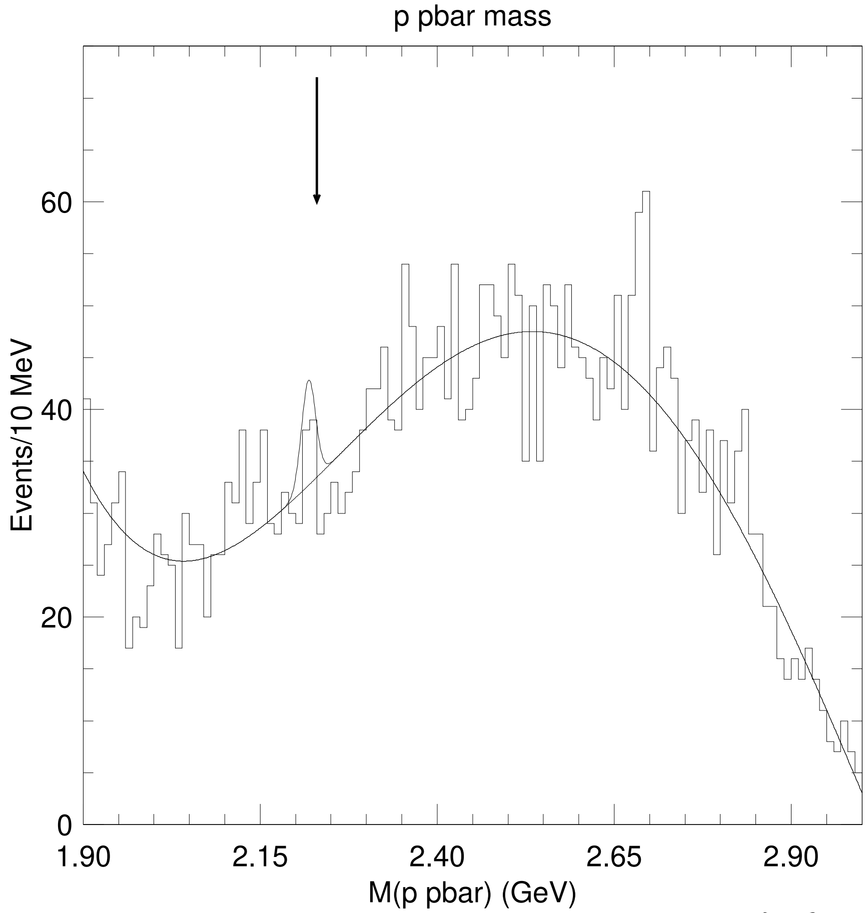

FIG. 9. The $p\overline{p}$ invariant mass distribution. The curve is the result of a fit to a fourth-order polynomial and a narrow peak near 2.23 GeV. The arrow indicates the expected position and height of the $\xi(2230)$. (Note that the bin size in this figure, chosen to match that of Fig. 2(d), is 10 MeV and smaller than that used for the other modes.)

velocities. Instead I apply the cut $|tof_i - (2.0 + 3.5/p_i \sin\theta_i)| < 2$ ns for each track where p_i is the track momentum and θ_i the polar angle. Studies with data and MC indicate that this requirement is $\sim$100% efficient for proton and antiprotons that register in the TOF counters. Backgrounds from $J/\psi \to p\overline{p}\pi^0$ with asymmetric π^0 decays are removed by requiring $M_{p\gamma} > 1.1$ GeV for the p and $\overline{p}$. With these requirements, the acceptance is 26.0%, which is nearly equal to that in ref. [4] (26.9%). Figure 9 shows the resulting $p\overline{p}$ invariant mass distribution. A fit gives a small narrow peak with 8 ± 13.4 events at $M_{p\overline{p}} = 2.22$ GeV. In the figure, the area of this peak is inflated to the 90% CL upper limit of 25.4 events. An extrapolation of the results in ref. [4] leads to an expectation of $\sim$ 93 events. A signal at that level would be a peak extending to around the position of the tip of the arrow shown in the figure.

VI. SUMMARY AND DISCUSSION

In the absence of any compelling signal, I compute preliminary 90% CL upper values for the product of branching fractions $\mathcal{B}(J/\psi \to \gamma\xi)\mathcal{B}(\xi \to h\overline{h})$ for the four channels under study.

TABLE II. Preliminary 90% CL upper limits on the decay branching fractions $\mathcal{B}(J/\psi \to \gamma\xi)\mathcal{B}(\xi \to h\overline{h})$

Decay Channel	N_{ev} (90% CL)	acceptance	$\mathcal{B}(J/\psi \to \gamma\xi)\mathcal{B}(\xi \to h\overline{h})$ (10^{-5})
$\xi \to K^0K^0$	35.0	0.12	< 1.4
$\xi \to K^+K^-$	44.2	0.14	< 1.5
$\xi \to \pi^+\pi^-$	85.7	0.26	< 1.6
$\xi \to p\overline{p}$	25.4	0.26	< 0.5

The upper limits on the numbers of events and the acceptances, computed assuming $J = 2$ for the ξ, are listed in Table II. To compute the upper limits, I take acceptance uncertainties into account by decreasing the calculated acceptance by 10%. I take uncertainties in the number of J/ψ's by deflating the number from the generally accepted value of 24M to 23M. The upper limits on the branching fraction products, listed in the right-hand column of Table II are all a factor of two or three below the "observation levels" listed in Table I.

In the K^0K^0 and K^+K^- channels, I observe signals for the $f_2'(1525)$ and $f_0(1710)$ with the expected masses and widths and with about 4 times the number of events seen in BES-I. However, the most I can do for narrow structures is a $\sim$ 23 event K^0K^0 peak that is 30 MeV above, and a $\sim$ 23 event K^+K^- peak that is 14 MeV below the nominal ξ mass. (BES-I reports 23 $\xi \to K^0K^0$ and 46 $\xi \to K^+K^-$ events with one third the data.) Note that the kinematics for $J/\psi \to \gamma f_0$ are very similar those for $\gamma\xi$: the gamma energies are 1.08 and 0.84 GeV, respectively, and the kaons have similar momenta in both modes. Moreover, there does not seem to be any problem with K^0 reconstruction and the K^0 mass resolution seems reasonable. The K^0K^0 measurement does not use particle identification.

For the $J/\psi \to \gamma\pi^+\pi^-$ channel, I find about 6 times as many $f_2(1270)$ events as BES-I with mass and width consistent with the PDG values [6]. In the ξ region, the best I can do is a $\sim$ 54 event peak that is 30 MeV below the nominal mass. BES-I reported a 74 event $\xi \to \pi^+\pi^-$ signal. Neither is there a significant signal in the $p\overline{p}$ channel.

So, in contrast to expectations for striking signals of $6 \sim 7\sigma$ significance, I do not find any significant signals. This calls into question the existence of the $\xi(2300)$.

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[6] The six-fold gain in yield is consistent with expectation from the larger data sample and the higher acceptance.