Search for the $D_{sJ}^*(2632)^+$ at BaBar

The *BABAR* Collaboration

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Abstract

We have performed a search for the $D_{sJ}^*(2632)^+$ state recently reported by the SELEX Collaboration at FNAL. This preliminary analysis makes use of an integrated luminosity of 125 fb^{-1} collected by the *BABAR* detector at the PEP-II asymmetric-energy e^+e^- collider. The resulting $D_s^+\eta$ and $D^0 K^+$ mass spectra show no evidence for the $D_{sJ}^*(2632)^+$ state. In addition, no signal is observed in the $D^{*+} K_S$ mass spectrum.

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7

1   INTRODUCTION

The SELEX Collaboration at FNAL has recently reported the existence of a narrow state at a mass of 2632 MeV/c^2 decaying to $D_s^+\eta$ [1]. That analysis was based on a sample of about 500 D_s^+ events. Evidence for the same state in the corresponding D^0K^+ mass spectrum was also presented. This work has generated considerable theoretical interest [2] because of the anomalous decay mode and since the state appears to have a small width despite having a mass significantly above D^0K threshold.

In the present analysis, inclusive production of the $D_s^+\eta$, D^0K^+, and $D^{*+}K_S$ systems in e^+e^- collisions near 10.58 GeV center-of-mass energy is investigated in a search for the $D_{sJ}^*(2632)^+$ state. All results are preliminary.

2   DETECTOR AND DATASET

This analysis is performed using a 125 fb^{-1} data sample collected on or near the $\Upsilon(4S)$ resonance with the *BABAR* detector at the PEP-II asymmetric-energy e^+e^- storage rings. The *BABAR* detector, a general-purpose, solenoidal, magnetic spectrometer, is described in detail elsewhere [3]. Charged particles were detected and their momenta measured by a combination of a drift chamber and silicon vertex tracker, both operating within a 1.5-T solenoidal magnetic field. A ring-imaging Cherenkov detector is used for charged-particle identification. Photons are detected and measured with a CsI electromagnetic calorimeter.

3 $D_s^+\eta$ EVENT SELECTION

A clean sample of $K^\pm$ candidates is obtained using particle identification by requiring a Cherenkov photon yield and angle consistent with the $K^\pm$ hypothesis. This information is augmented with energy loss measurements in the tracking systems. The efficiency of $K^\pm$ identification is approximately 85% in the kinematic range used in this analysis with a $\pi^\pm$ contamination of less than 2%. A similar procedure is used to produce a sample of $\pi^\pm$ candidates.

Each D_s^+ candidate[6] is constructed by combining a K^+K^- candidate pair with a π^+ candidate in a geometric fit to a common vertex. An acceptable $K^+K^-\pi^+$ candidate must have a fit probability greater than 0.1% and a trajectory consistent with originating from the e^+e^- luminous region. Backgrounds are further suppressed by selecting decays to $\overline{K}^{*0}K^+$ and $\phi\pi^+$. Additional details of this selection procedure can be found elsewhere [4].

The resulting $K^+K^-\pi^+$ mass distribution is shown in Fig. 1. The D_s^+ signal peak is centered at a mass of 1.968 GeV/c^2 and has rms deviation 5.2 MeV/c^2, as determined by a fit that includes a double-Gaussian representation of the signal with a second-order polynomial to describe the background. The fit determines a yield of approximately 196,000 signal events.

For events containing a D_s^+ candidate, η candidates are selected in the $\gamma\gamma$ decay mode. It is assumed that each η originates from the interaction point (i.e., the $D_{sJ}^*(2632)^+$ is short lived). The η signal-to-background ratio has been enhanced by means of the following selection criteria:

- Each γ cannot be part of any π^0 which has momentum greater than 150 MeV/c.

- Any γ compatible with the decay $D_s^*(2112)^+ \to D_s^+\gamma$ is removed.

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[6]Inclusion of charge conjugate states is implied throughout this paper
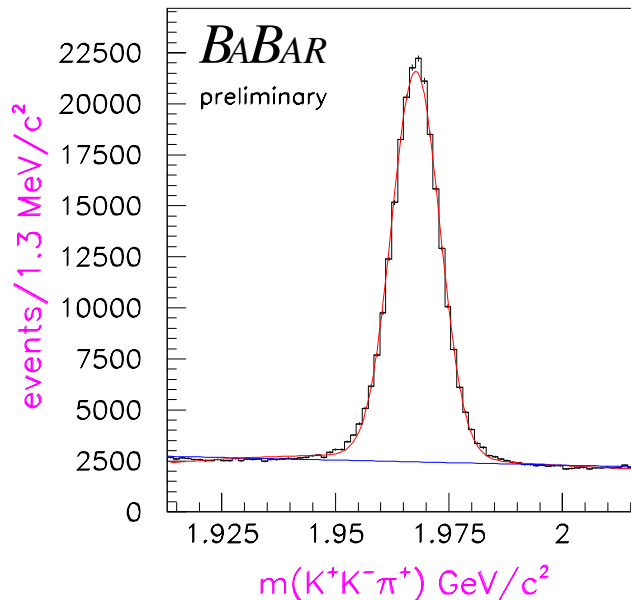
Figure 1: The $K^+K^-\pi^+$ mass distribution after applying the selection procedure described in the text.

- Each γ energy must be greater than 350 MeV, and the energy sum for a candidate γ pair must be greater than 1.15 GeV.

- The quantity $|\cos\theta_\gamma|$ must be less than 0.85, where θ_γ is the helicity angle of one γ in the $\gamma\gamma$ rest frame with respect to the η candidate direction in the laboratory frame.

The resulting $\gamma\gamma$ effective mass distribution is shown in Fig. 2. A fit to the mass spectrum using a Gaussian signal function and a second-order polynomial background function yields the following parameter values (statistical errors only) for the η:

$$m = [547.4 \pm 0.5] \text{ MeV}/c^2 \quad \sigma = [17.1 \pm 0.5] \text{ MeV}/c^2 . \tag{1}$$

The mass value is in excellent agreement with the PDG value [5]. The resulting η signal consists of approximately 3900 events.

4   THE $D_s^+\eta$ SYSTEM

The $\gamma\gamma$ mass distribution of Fig. 2 is for events containing a D_s^+ candidate. However, the background under the D_s^+ signal (Fig. 1) and the substantial background under the η signal (Fig. 2) mean that it is not clear whether there is any correlation between the D_s^+ and η signals.

Figure 3a shows the scatterplot of $m(\gamma\gamma)$ versus $m(K^+K^-\pi^+)$ with the additional requirement that the e^+e^- center-of-mass momentum $p^*(D_s^+\eta)$ of the $D_s^+\eta$ system is at least 2.5 GeV/c to suppress background. The η and D_s^+ signal regions are quite clear, and the distribution appears

9
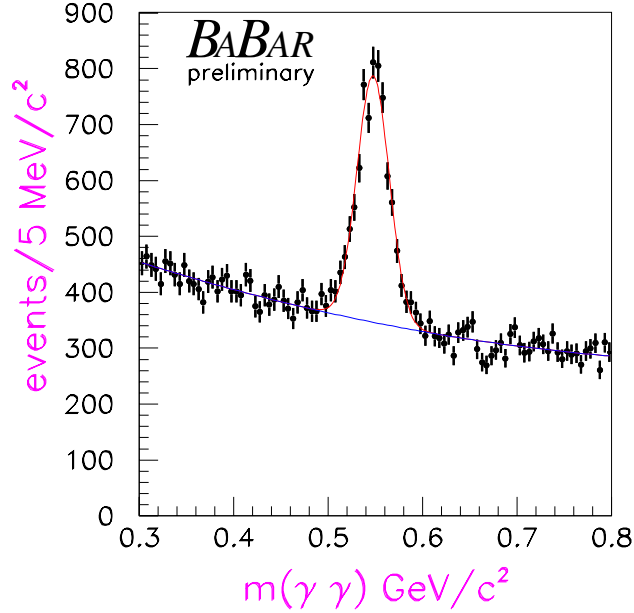
Figure 2: The $\gamma\gamma$ effective mass distribution in the η region after the selection procedure described in the text. The presence of a D_s^+ candidate is required.

rather uniform in the background regions and within the signal bands, except in the region of overlap. In order to establish the presence of an excess of events in the overlap region corresponding to correlated D_s^+ and η production, we perform a two-dimensional subtraction. The scatterplot is divided into the nine subregions of equal area indicated in Fig 3a. These subregions are centered on the D_s^+ and η mass values and extend by plus or minus 2.5 standard deviations in each mass variable. Figure 3b and Fig. 3c show the $\gamma\gamma$ and the $K^+K^-\pi^+$ mass projections, respectively, for the selected mass region.

Labeling the subregions of Fig. 3a from 1 to 9, from left to right and bottom to top, the excess number of events $N(D_s^+\eta)$ in the central subregion (5) is estimated from the following linear equation:

$$N(D_s^+\eta) = N_5 - (N_2 + N_4 + N_6 + N_8)/2 + (N_1 + N_3 + N_7 + N_9)/4 , \qquad (2)$$

under the assumption (consistent with Fig. 3a) that any mass dependence in the selected region is at most linear. This procedure yields the estimate

$$N(D_s^+\eta) = 1102 \pm 75 \qquad (3)$$

(statistical error only), so that there is clear evidence of correlated D_s^+ and η production.

In order to obtain the $D_s^+\eta$ mass distribution $m(D_s^+\eta)$ corresponding to this excess, a $D_s^+\eta$ invariant mass distribution (m_i) is produced for each of the nine subregions, i. In calculating the invariant mass, the candidate D_s^+ or η three-momentum vector is combined with the relevant PDG mass value to obtain the energy. The unshaded histogram of Fig. 4a shows this mass distribution for the center subregion (i.e., m_5), while the shaded histogram is obtained from

$$m_b = (m_2 + m_4 + m_6 + m_8)/2 - (m_1 + m_3 + m_7 + m_9)/4 . \qquad (4)$$

10

The distribution of Fig. 4b is obtained by subtracting the shaded distribution of Fig. 4a from the unshaded distribution. It follows that this distribution corresponds to correlated $D_s^+ \eta$ production under the assumption of linear signal and background behavior.

There appear to be two distinct regions in this mass distribution. The region above 3.5 GeV/c^2 can be interpreted as being the result of continuum production of two (or more) jets with the D_s^+ and η produced in opposing jets. The region below 3 GeV/c^2 shows a monotonic rise toward threshold. This is interpreted as being the result of D_s^+ and η production within a single jet, and hence is the region in which any resonant structures in $D_s^+ \eta$ mass should be seen.

The mass region of Fig. 4b below 3.0 GeV/c^2 is shown in detail in Fig. 5. The arrow indicates the location at which the $D_{sJ}^*(2632)^+$ state should appear. There is no evidence for a signal.

The requirements imposed on the selection of the η candidates are rather stringent, but are not expected to entirely remove any $D_{sJ}^*(2632)^+$ signal. As a check, we use similar requirements to select $D_s^+ \pi^0$ candidates. The resulting $D_s^+ \pi^0$ mass spectrum is shown in Fig. 6. A large $D_{sJ}^*(2317)^+$ signal is observed.

5 THE $D^0 K^+$ SYSTEM

The $D^0 K^+$ mass spectrum has been investigated using the $D^0 \to K^- \pi^+$ decay mode.

A D^0 candidate is constructed by combining a π^+-K^- pair in a geometric fit to a common vertex. An acceptable candidate must have a fit probability greater than 1% and a trajectory consistent with originating from the $e^+ e^-$ luminous region. In addition, the D^0 candidate must have $p^* > 0.5$ GeV/c.

The resulting $\pi^+ K^-$ mass distribution for the D^0 mass region is shown in Fig. 7. The signal peak is centered at 1.864 GeV/c^2 and has an rms deviation of 8.2 MeV/c^2. There are approximately 3.7×10^6 signal events above background.

A D^0 candidate with mass within 20 MeV/c^2 of the central value is combined with a well-identified K^+ track in a fit to a common vertex. The vertex fit probability must be greater than 1% and the vertex position must be consistent with the $e^+ e^-$ luminous region.

Requiring $p^*(D^0 K^+) > 4.0$ GeV/c we obtain the $D^0 K^+$ mass spectrum shown in Fig. 8. The large peak is due to the decay $D_{s2}(2573)^+ \to D^0 K^+$; the skewing of the signal toward high mass is consistent with a spin 2 interpretation of this state. The shaded histogram is the mass distribution for wrong-sign $D^0 K^-$ pairs. There is no evidence for structure in the 2.632 GeV/c^2 mass region.

6 THE $D^{*+} K_S$ SYSTEM

A D^0 candidate with mass within 25 MeV/c^2 of the central mass value (Fig. 7) is combined with a well-identified π^+ track in a fit to a common vertex. The vertex fit probability must be greater than 1% and the vertex position must be consistent with the $e^+ e^-$ luminous region. We define the difference δM between the $D^0 \pi^+$ and D^0 invariant mass values by:

$$\delta M = \sqrt{\left(p_{K^-} + p_{\pi_1^+} + p_{\pi_2^+}\right)^2 - \left(p_{K^-} + p_{\pi_1^+}\right)^2} , \tag{5}$$

where π_1^+ is from the D^0 candidate and π_2^+ is from the D^{*+} candidate. The distribution of δM for the $D^*(2010)^+$ region is shown in Fig. 9; there is a clear D^{*+} signal consisting of approximately 1.4×10^5 events over a small background. We require a D^{*+} candidate to have δM in the interval 145.4 ± 1.6 MeV/c^2.

A candidate K_S track is reconstructed by vertexing a well-identified $\pi^+\pi^-$ pair. The vertex fit probability is required to be greater than 1%, and the $\pi^+\pi^-$ invariant mass must be within 16 MeV/c^2 of the K_S PDG mass value [5]. The candidate K_S trajectory is then required to be consistent with the vertex of a D^{*+} candidate such that the K_S flight length exceeds 1 mm. The distribution of the resulting difference in invariant mass between the $D^{*+}K_S$ and D^{*+} track combinations is shown in Fig. 10 with the requirement that $p^*(D^{*+}K_S) > 4$ GeV/c. The large, narrow peak just above threshold results from production of the $D_{s1}(2536)^+$. The vertical dashed line indicates the mass position at which the $D^*_{sJ}(2632)^+$ state might be observed. There is no evidence for production of this state.

7   SUMMARY

The SELEX Collaboration has reported the existence of a charm meson state, the $D^*_{sJ}(2632)^+$, with $D_s^+\eta$ and D^0K^+ decay modes. We have searched for this state using $e^+e^- \to c\bar{c}$ collision data from 125 fb^{-1} of integrated luminosity collected by the *BABAR* experiment. In this preliminary analysis we find no evidence for this state in inclusive production of $D_s^+\eta$, D^0K^+, or $D^{+*}K_S$.

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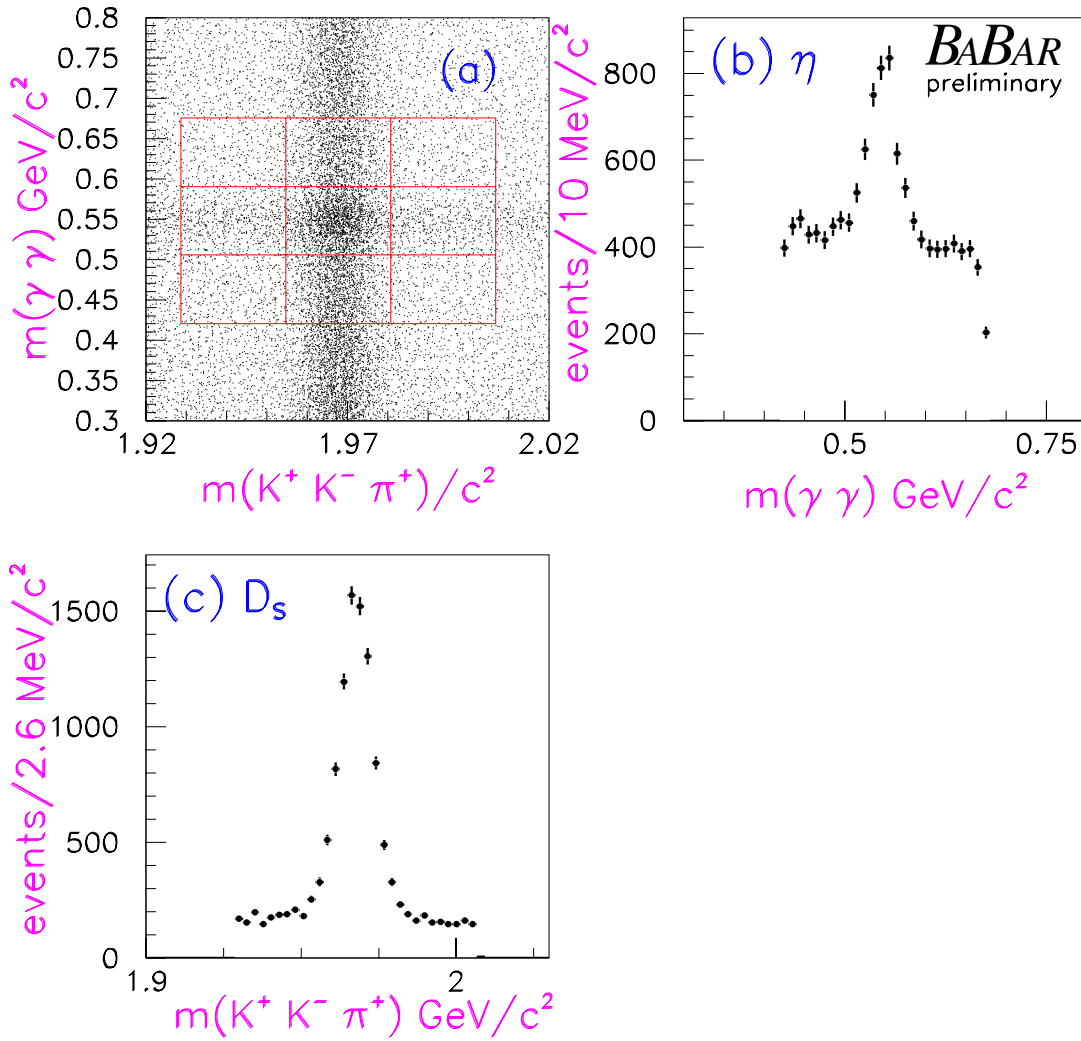
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Figure 3: (a) The scatterplot of $m(\gamma\gamma)$ vs. $m(K^+K^-\pi^+)$ for $p^*(D_s^+\eta) > 2.5$ GeV/c. (b) The $\gamma\gamma$ and (c) $K^+K^-\pi^+$ mass projections for the selected region.
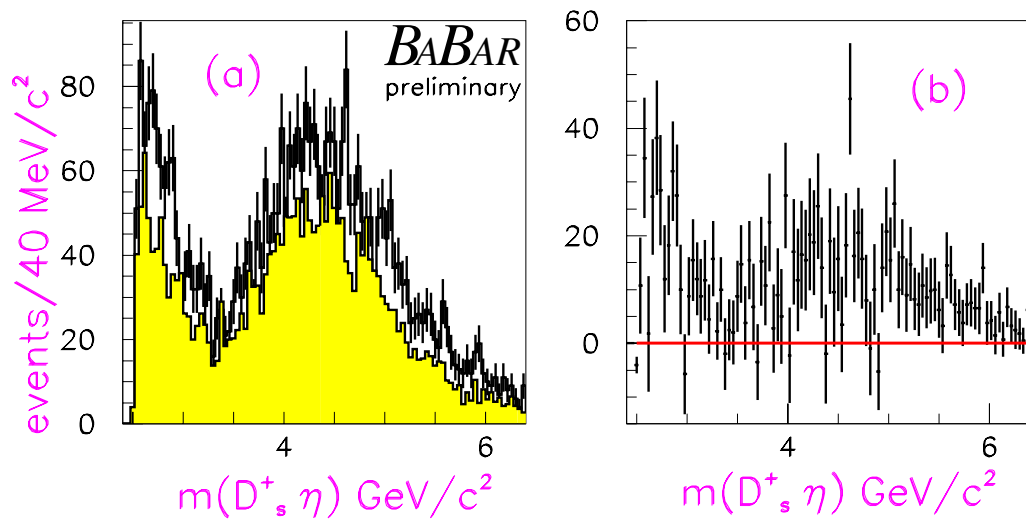
Figure 4: (a) The $D_s^+ \eta$ invariant mass distribution. The unshaded distribution (m_5) corresponds to the central region of Fig. 3a while the shaded distribution is obtained using Eq. 4. (b) The $D_s^+ \eta$ mass distribution obtained by subtracting the distributions of (a).
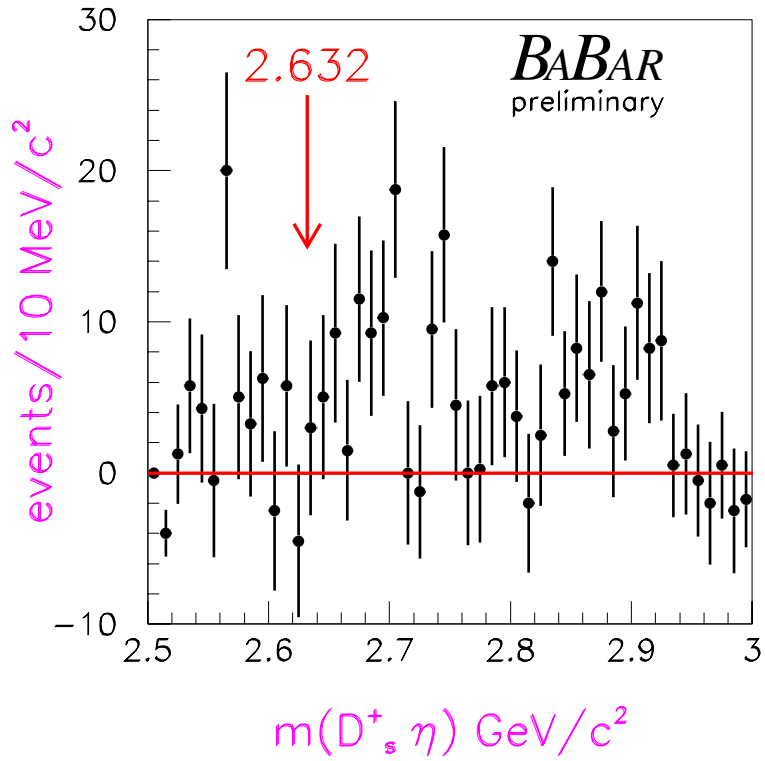
Figure 5: The $D_s^+\eta$ invariant mass distribution of Fig. 4b for the region below 3 GeV/c^2. The arrow indicates the mass location at which the $D_{sJ}^*(2632)^+$ state should appear.
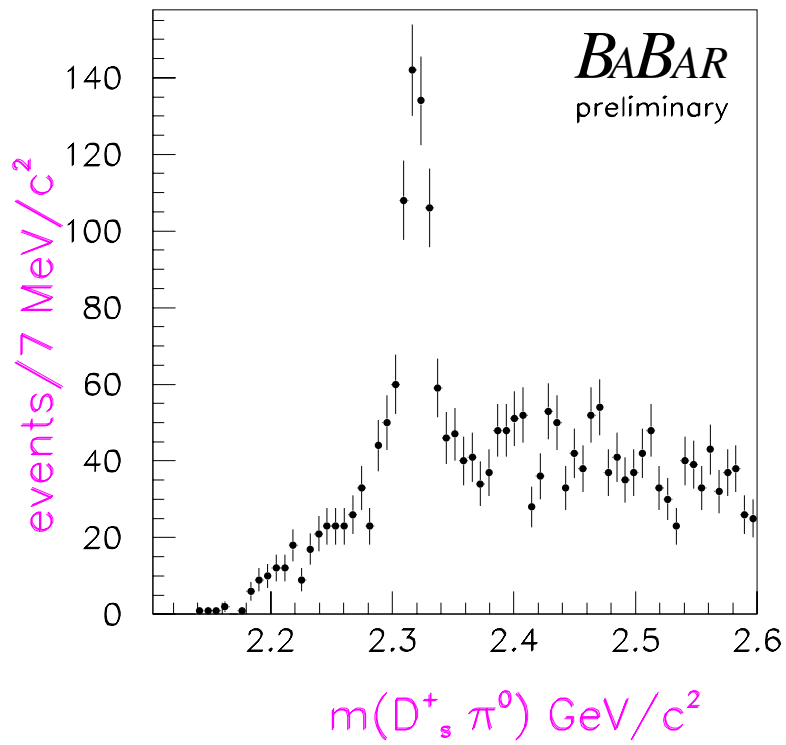
Figure 6: The $D_s^+ \pi^0$ invariant mass spectrum for selection criteria similar to those used in the $D_s^+ \eta$ candidate selection.
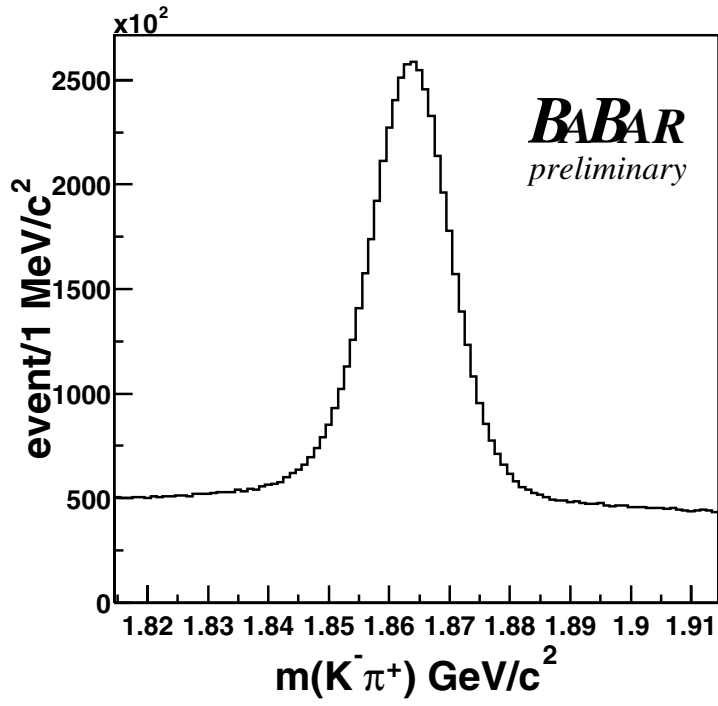
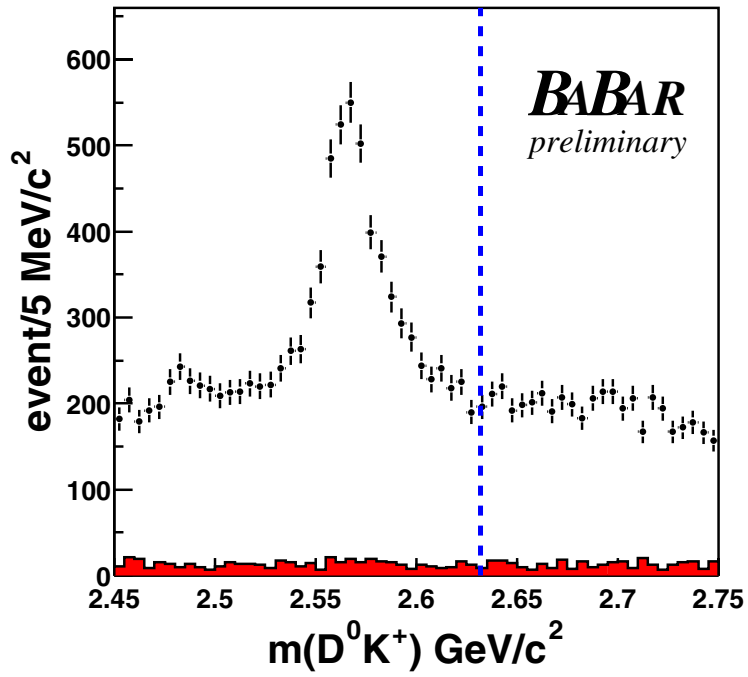Figure 7: The $K^-\pi^+$ mass distribution after applying the selection procedure described in the text.

Figure 8: The D^0K^+ invariant mass distribution after applying the selection procedure described in the text. The dashed line indicates the location at which the $D^*_{sJ}(2632)^+$ state should appear. The shaded histogram is the mass distribution for wrong-sign D^0K^- pairs.
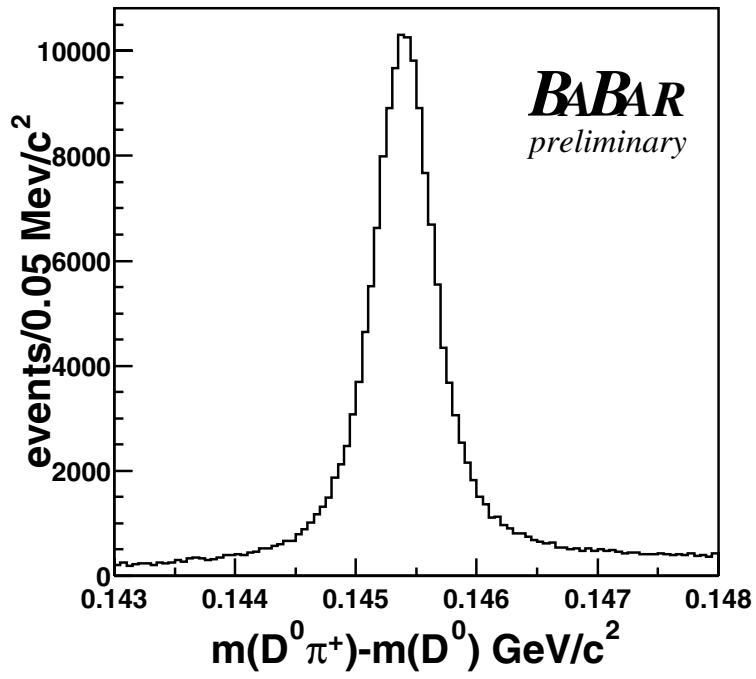
Figure 9: The δM mass distribution after applying the selection procedure described in the text.
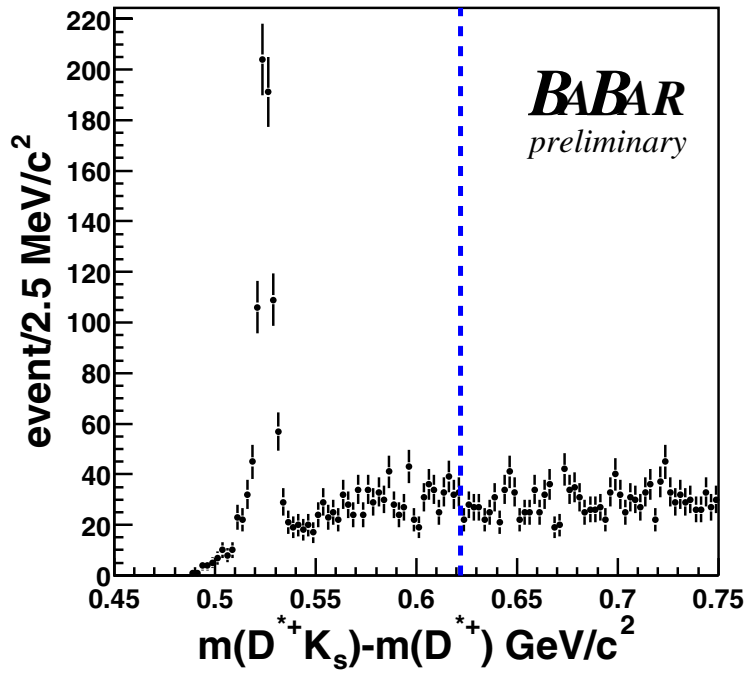
Figure 10: The $D^{*+}K_S$ invariant mass distribution after applying the selection procedure described in the text. The dashed line indicates the mass location at which the $D^*_{sJ}(2632)^+$ state might appear.