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Observation of $e^+e^- \rightarrow F^{\pm}F^{*\mp}$ at $\sqrt{s} = 4.14\,\mathrm{GeV}$ *

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Abstract

The Mark III collaboration at SPEAR observes charm-strange associated production in the reaction $e^+e^- \rightarrow F^{\pm}F^{*\mp}$ at $\sqrt{s} = 4.14\,\mathrm{GeV}$. The $F^{\pm}$ is reconstructed in the $\phi\pi^{\pm}$ mode and the $F^{*\mp}$ is detected in the recoil mass distribution from the $F^{\pm}$. The observed F mass is $(1977.6 \pm 4.3\ (stat.) \pm 4.0\ (syst.))\,\mathrm{MeV}/c^2$ and the F^* mass is $(2106.8 \pm 1.8 \pm 6.2)\,\mathrm{MeV}/c^2$. The production rate at $\sqrt{s} = 4.14\,\mathrm{GeV}$ is $\sigma(e^+e^- \rightarrow F^{\pm}F^{*\mp}) \cdot B(F^{\pm} \rightarrow \phi\pi^{\pm}) = (36 \pm 7 \pm 13)$ pb.

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This paper reports the first evidence for the reaction $e^+e^- \to F^\pm F^{*\mp}$, $F^\pm \to \phi\pi^\pm$ and a precise measurement of the F^* mass. Previous evidence for the charm-strange vector meson, the F^*, has been the observation of a narrow state that decays into an F meson and a photon.[1] This was consistent with the quark model expectations that the F^* can decay only via a single photon to the F meson since they are both isosinglets. The observation of associated production of $F^\pm F^{*\mp}$, which conserves both charm and strangeness, is stronger evidence that this state is the vector meson partner of the charm-strange F meson.

The events in this analysis are from a data sample with an integrated luminosity of $(6.30 \pm 0.46)\,\mathrm{pb}^{-1}$, collected at a center-of-mass energy of 4.14 GeV with the Mark III detector at SPEAR. The Mark III detector is a general purpose magnetic solenoidal spectrometer optimized for the SPEAR energy region. A detailed account of the detector has been given elsewhere.[2] This analysis used tracking information from the drift chamber and time-of-flight (TOF) measurements from scintillation counters outside the drift chamber. The charged tracks were constrained to originate at a common vertex.

A charged particle was identified as a kaon if its measured TOF was closer, in number of standard deviations, to the TOF predicted for a kaon than to that for a pion. The TOF resolution, measured with Bhabha scattering events, is $\sigma = 200\,\mathrm{ps}$ when averaged over all 48 counters. This results in a π-K separation of better than 5 standard deviations for all kaons from $F \to \phi\pi$.

Fig. 1 shows the mass distribution of all pairs of oppositely charged tracks when both were identified as kaons by TOF. The K^+K^- mass distribution has a clear ϕ peak. A maximum likelihood fit was made using a Breit-Wigner shape and a polynomial background, with the width of the ϕ fixed at $4.22\,\mathrm{MeV}/c^2$. This fit yielded a mass of $(1019.6 \pm 0.4)\,\mathrm{MeV}/c^2$ and a σ of $(2.2 \pm 0.6)\,\mathrm{MeV}/c^2$. The mass is in excellent agreement with the accepted ϕ mass[8] and σ agrees with the resolution expected from Monte Carlo studies.

The $\phi\pi$ mass was calculated using each identified K^+K^- pair within 10 MeV/c^2 of the ϕ mass and considering all of the remaining charged tracks to be pions. In addition, the mass recoiling against each $\phi\pi$ was calculated ignoring the other particles in the event.

A scatter plot of the $\phi\pi$ mass versus the recoil mass is shown in Fig. 2. A cluster of events near $M(\phi\pi) = 1.97\,\mathrm{GeV}/c^2$ and $M(\mathrm{recoil}) = 2.10\,\mathrm{GeV}/c^2$ provides evidence for $F\bar{F}^*$ production. Another cluster near $M(\phi\pi) = 1.87\,\mathrm{GeV}/c^2$ and $M(\mathrm{recoil}) = 2.01\,\mathrm{GeV}/c^2$ shows the production of $D^{\pm}D^{*\mp}$, where $D^{\pm} \to \phi\pi^{\pm}$.

Fig. 3 shows the recoil mass distribution when the $\phi\pi$ mass is restricted to the F region, 1.925 to $2.025\,\mathrm{GeV}/c^2$. A clear peak is seen at $M(\mathrm{recoil}) = 2.1\,\mathrm{GeV}/c^2$. No significant evidence for $e^+e^- \to F\bar{F}$, $F \to \phi\pi$ is observed.

The $\phi\pi$ mass distribution can also be studied for different recoil mass intervals. If the recoil mass region from 2.05 to $2.15\,\mathrm{GeV}/c^2$ is selected, there is a clear peak at $M(\phi\pi) = 1.97\,\mathrm{GeV}/c^2$, as shown in Fig. 4(a). Fitting the distribution with a Gaussian plus background yields

$$M_F = (1977.6 \pm 4.3 \pm 4.0)\,\mathrm{MeV}/c^2.$$

The fitted resolution (σ) of $21\,\mathrm{MeV}/c^2$ is consistent with the value $15\,\mathrm{MeV}/c^2$ expected from Monte Carlo studies. The background shape was determined from a fit to the mass distribution created from the data by combining ϕ's and π's from different events. The systematic error includes contributions from uncertainties in the background shape and momentum scale.

If the recoil mass region from 1.97 to 2.05 GeV/c^2 is selected, there is a clear peak at the mass of the D (Fig. 4(b)). A fit of this peak to a Gaussian and a flat background, assuming the same σ as above, yields a D mass of $(1857 \pm 9 \pm 7)$ MeV/c^2 for a signal of 9 events above a background of 4. This is consistent with the expected production rate of $D^{\pm}$ at this center-of-mass energy and the measured $B(D \to \phi\pi)$.[4]

In order to improve the F^* mass resolution, the mass of the F determined by the above fit was imposed as a constraint in the calculation of the recoil mass. The resulting recoil mass distribution is shown in Fig. 5. There is a peak at 2.11 GeV/c^2, with a broader structure between 2.07 and 2.15 GeV/c^2. This is consistent with the distribution expected for $e^+e^- \to F^{\pm}F^{*\mp}$, $F^* \to \gamma F$, where half of the $\phi\pi$ events are from the decay of the initially produced F and the other half are from the decay of the F from the F^*. The shape of the distribution and the resolution (5.2 MeV/c^2) were determined from Monte Carlo studies. A fit including a background shape determined from ϕ sidebands gives

$$M_{F^*} = (2106.8 \pm 1.8 \pm 6.2)\,\mathrm{MeV}/c^2.$$

The systematic error includes the $\sqrt{s}$ uncertainty of 2 MeV added in quadrature with the error in the F mass, 5.9 MeV/c^2. A variation of δM_F in the F mass leads to a change in the F^* mass of $\delta M_{F^*} \cong -\delta M_F$. The systematic errors due to the choices of cuts and the background shape are negligible. The resulting mass difference, $M_{F^*} - M_F$, is $(129 \pm 2 \pm 12)\,\mathrm{MeV}/c^2$, where the systematic error is from the uncertainty in the F mass and the energy scale of SPEAR.

As a check that the $\phi\pi$ are consistent with being the decay products of an F, in Fig. 6 is shown the distribution of the angle θ_K between the π and the K^+ momenta in the ϕ rest frame. Three of the 31 events in the plot are attributed to background. A $\cos^2\theta_K$ distribution is expected for the decay of a helicity 0 vector particle into two pseudoscalars. The curve in the figure is the prediction of the Monte Carlo for that case, scaled to the number of events in the sample.

The cross section $\sigma(e^+e^- \rightarrow F^\pm F^{*\mp}) \cdot B(F \rightarrow \phi\pi)$ is determined assuming a decay chain of $e^+e^- \rightarrow F^\pm F^{*\mp}$, $F^* \rightarrow \gamma F$, $F \rightarrow \phi\pi$. The number of observed $F \rightarrow \phi\pi$ events is 29.4 ± 5.4. The detection efficiency for $F \rightarrow \phi\pi$ as determined from Monte Carlo studies is 0.063. The resulting cross section is

$$\sigma(e^+e^- \rightarrow F^\pm F^{*\mp}) \cdot B(F \rightarrow \phi\pi) = (36 \pm 7 \pm 13)\,\mathrm{pb}.$$

The systematic error includes the uncertainty in the integrated luminosity, and the effects of varying the cuts and background shape.

These results are in good agreement with previous measurements of the F and the F^* masses. [1] Predictions of the mass difference $M_{F^*} - M_F$ vary from 80 to $150\,\mathrm{MeV}/c^2$.[8] This measurement favors models that predict equality for the difference between the square of the masses of vector and pseudoscalar mesons.

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Figure Captions

1. K^+K^- invariant mass distribution. The fit is described in the text.

2. Scatter plot of $M(\phi\pi)$ versus $M(\text{recoil})$.

3. The projection of $M(\text{recoil})$ when when $1.925 < M(\phi\pi) < 2.025\,\text{GeV}/c^2$.

4. (a) The projection of $M(\phi\pi)$ when $2.05 < M(\text{recoil}) < 2.15\,\text{GeV}/c^2$. (b) The projection of $M(\phi\pi)$ when $1.97 < M(\text{recoil}) < 2.05\,\text{GeV}/c^2$. The fits are described in the text.

5. F^* mass distribution with the F mass constrained at $1977.6\,\text{MeV}/c^2$. The fit is described in the text.

6. Distribution of $\cos\theta_K$, the angle between the π and K^+ momenta in the ϕ rest frame. The curve is the prediction of the Monte Carlo scaled to the number of events in the sample.

Figure 1

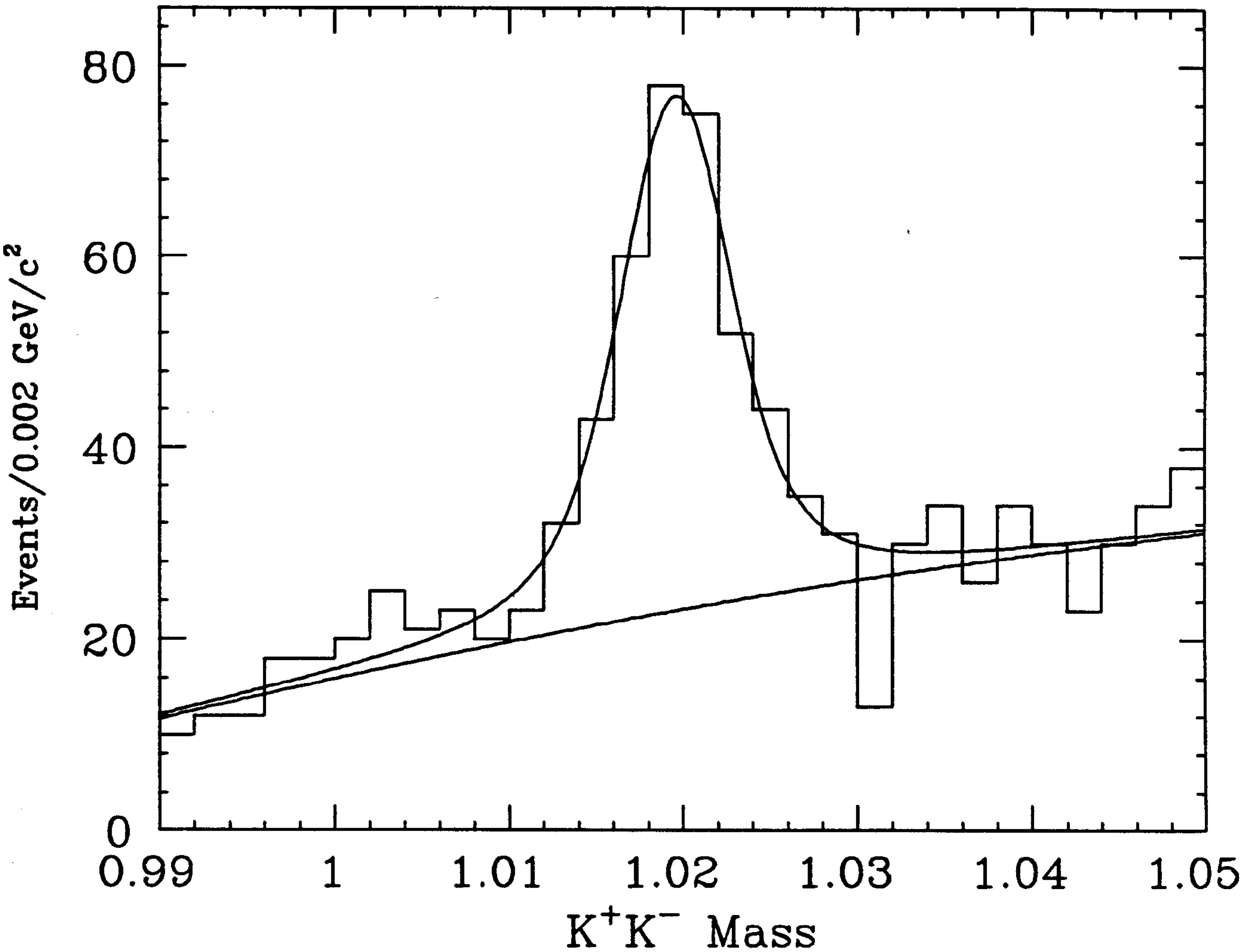

Figure 2

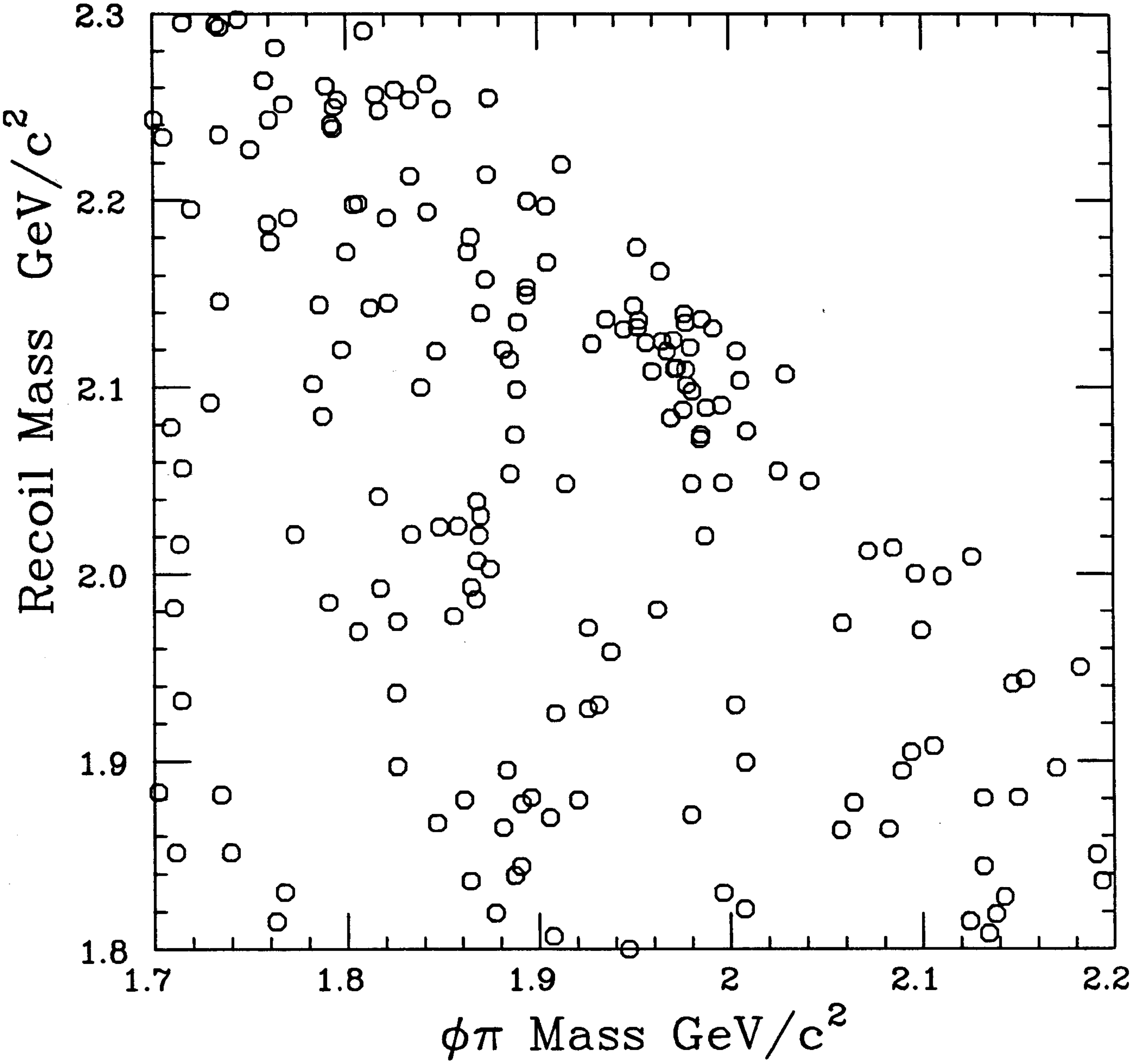

Figure 3

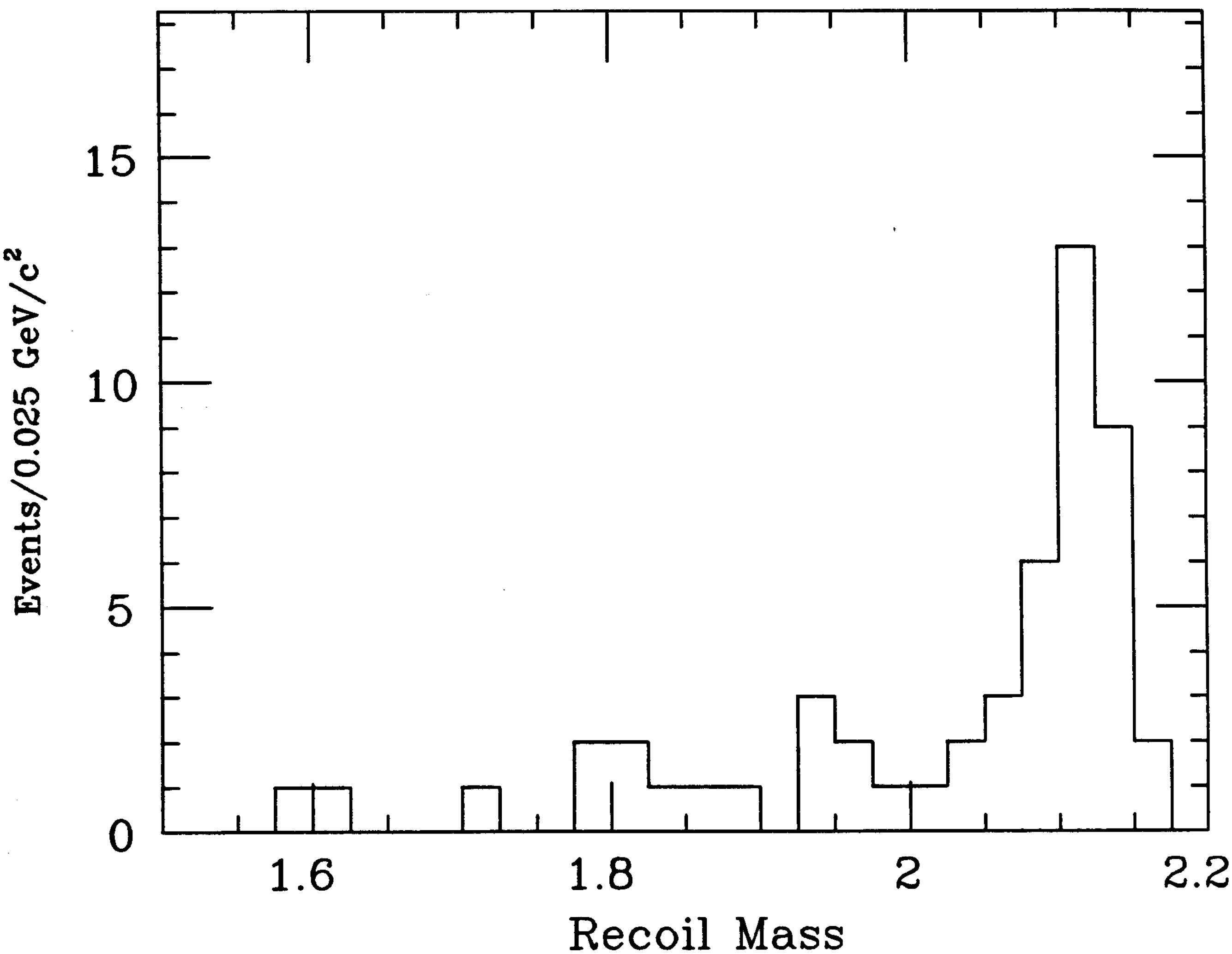

Figure 4(a)

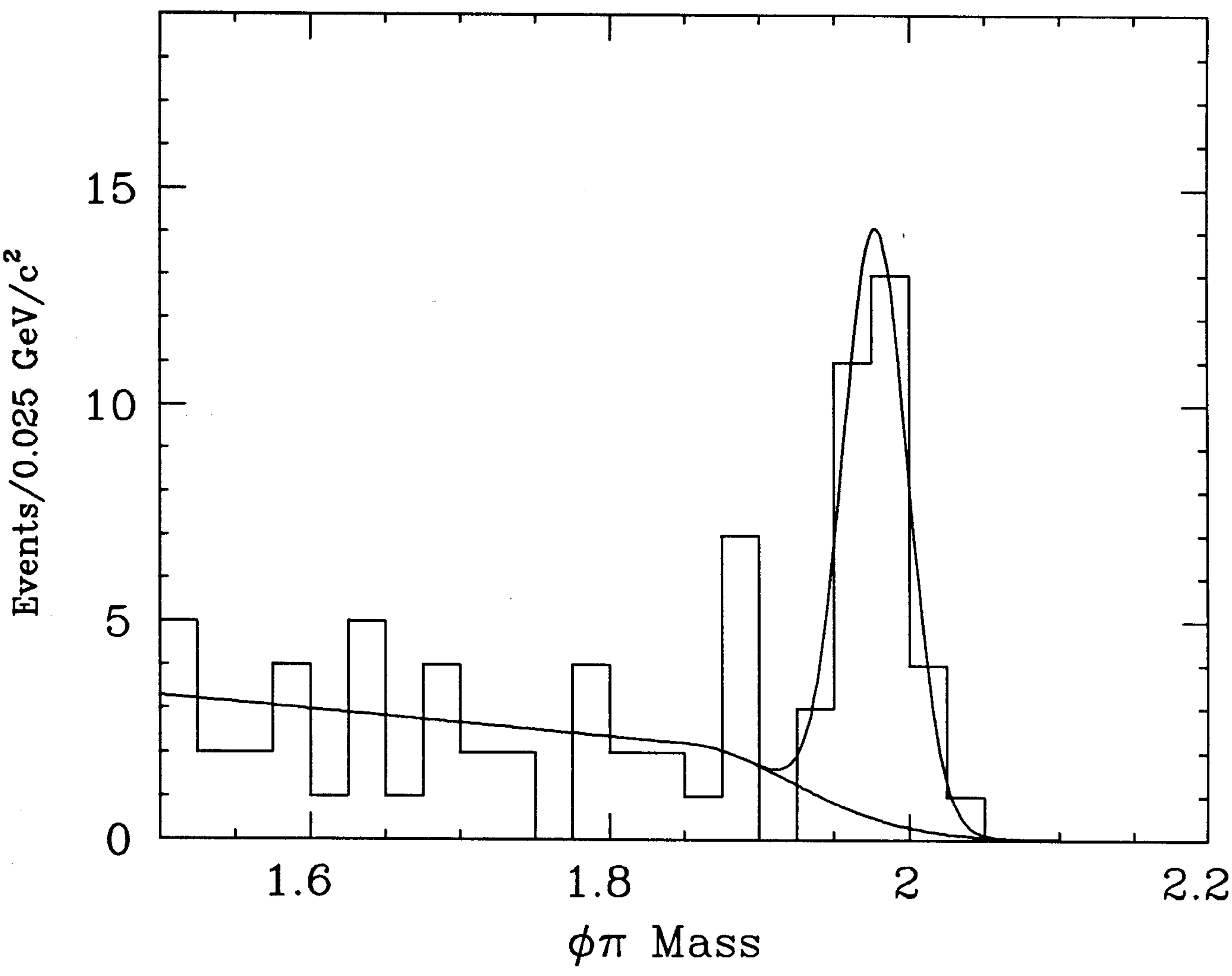

Figure 4(b)

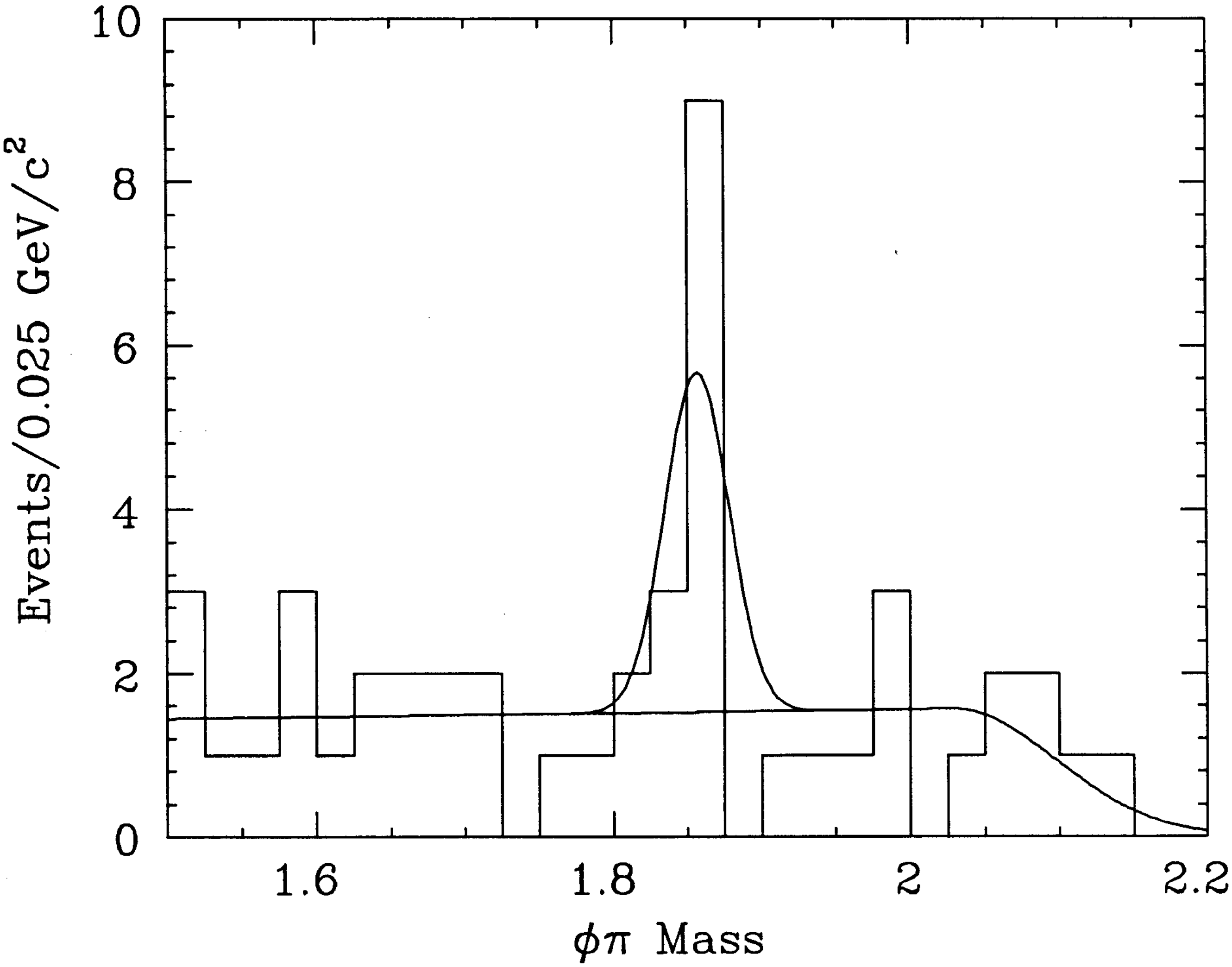

Figure 5

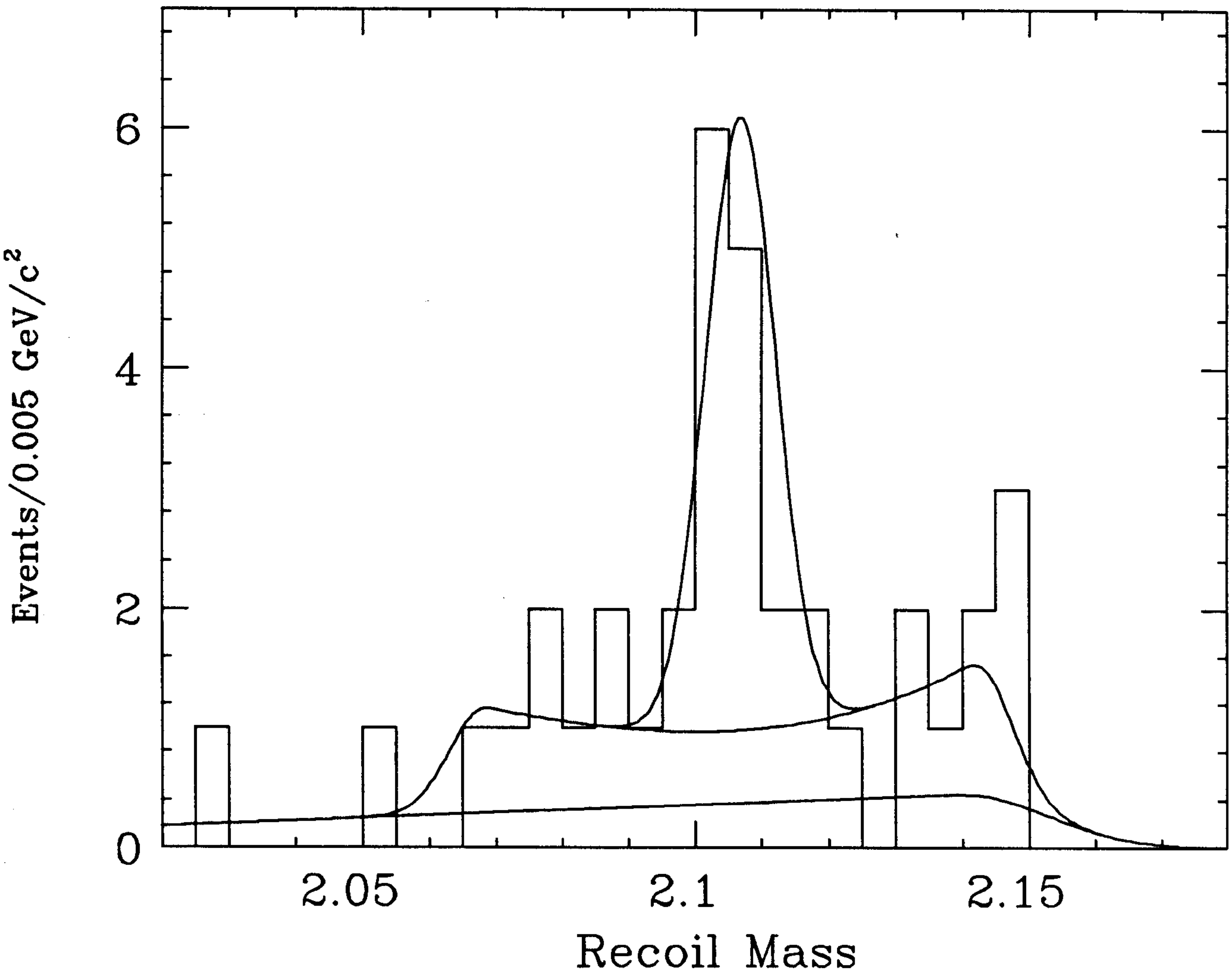

Figure 6