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OBSERVATION OF A NARROW ENHANCEMENT IN ϕKK AND $\phi\pi\pi$ FINAL STATES PRODUCED IN 400 GeV p-N INTERACTIONS*

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Observation of A Narrow Enhancement in ϕKK and $\phi\pi\pi$ Final States Produced in 400 GeV p-N Interactions

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Abstract

We observe a narrow enhancement in ϕK^+K^- and $\phi\pi^+\pi^-$ final states with a mass of $2.145\pm0.004\pm0.010$ GeV/c² and width less than 0.04 GeV/c². The relative branching ratio is $B(M\to\phi K^+K^-)/B(M\to\phi\pi^+\pi^-)=0.49 \pm 0.16$, inconsistent with M being a $q\bar{q}$ state.

Since the $\phi\pi\pi$ final state cannot arise from an OZI allowed decay of a $q\bar{q}$ meson[1], its study may reveal weak decay processes, multiquark mesons, or gluonic bound states.[2] Recent measurements[3] of the analogous Cabibbo-suppressed decay $D^{\pm}\rightarrow\phi\pi^{\pm}$ and subsequent observation in p-N collisions[4] underscore the utility of such studies.

An $s\bar{s}$ meson can decay into ϕKK by an OZI allowed transition. By comparison a $q^2\bar{q}^2$ = $(su)(\bar{s}\bar{u})$ state can decay into both ϕKK and $\phi\pi\pi$. Presumably the width, Γ, of such a $q^2\bar{q}^2$ state would then be comparable to that observed for $q\bar{q}$ mesons.

The non-Abelian nature of QCD implies that gluons will form bound states,[5] hereafter referred to as glueballs. Although the mass spectrum of these states is uncertain,[6] a tag for glueballs may be flavor symmetric decays. Hence comparable decay rates into $\phi\pi\pi$ and ϕKK are expected. In addition the width should be reduced by the $\sqrt{\text{OZI}}$ rule.[7]

We describe here the study of the final states $\phi\pi\pi$ and ϕKK in the reactions $pN\rightarrow(\phi\pi^+\pi^-)K^+K^-X$ and $pN\rightarrow(\phi K^+K^-)K^+K^-X$ at 400 GeV/c. Details of the apparatus, trigger and data reduction are given elsewhere.[8] The Fermilab Multiparticle Spectrometer (FMPS) was triggered on events consistent with $pN\rightarrow(K^+K^-K^+K^-)X$. We took 3×10^6 triggers and reduced them to 1.2×10^5 events with at least $2K^+$ and $2K^-$. The kaons exist in a restricted kinematic region of Feynman x(x) due to the Cherenkov counter particle identification which was employed. Hence we study central ($|x|\lesssim 0.1$) production and can say little about the x dependence of the final states.

In Fig. 1 we show the K^+K^- mass spectrum. This fit[8] gives a mass, $M=1.0199\pm0.0003$ GeV/c^2, consistent with the known ϕ mass,[9] and a width $\Gamma=0.0074 \pm 0.0004$ GeV/c^2 (FWHM). The ϕ meson is used to calibrate our mass scale. Moving the ϕ mass 5σ off of the accepted value[9] moves a 2.145 GeV/c^2 mass in $\phi\pi\pi$ by $\lesssim 0.025$ GeV/c^2 and in ϕKK by $\lesssim 0.015$ GeV/c^2. Extrapolating the mass resolution from the ϕ one finds 0.055 GeV/c^2 in $\phi\pi\pi$ and 0.040 GeV/c^2 in ϕKK at $M=2.145$ GeV/c^2.

We define ϕ candidates as K^+K^- mass combinations within ±0.006 GeV/c^2 of the nominal ϕ mass. The sidebands are defined using those K^+K^- pairs with invariant mass just above or below the ϕ mass ("ϕ") which yield roughly the same number of combinations.

We show the ϕKK and "ϕ"KK mass spectra in Fig. 2(a) and 2(b) respectively. There is a clear enhancement in ϕKK at a fitted mass $M = 2.140 \pm 0.005$ GeV/c^2 with a width $\Gamma = 0.020 \pm 0.022$ GeV/c^2. The chi squared per degree of freedom (χ^2/DF) is 51/36 with a 4.3 standard deviation (σ) excess of 222 ± 52 events above background. The "ϕ"KK background mass spectrum in Fig. 2(b) shows no apparent signal. The polynominal fit has χ^2/DF of 57/31. Also shown in Fig. 2(a) are the spectra for $pN\to(\phi K^+K^-)K^\pm X$ and $pN\to(\phi K^+K^-)K^+K^-X$. The best fit for the latter has $M=2.146 \pm 0.004$ GeV/c^2, with 157 ± 33 events (4.8 σ). Clearly, this enhancement is produced with additional spectator kaons. The dynamical origin of these extra kaons is unclear.

The $\phi\pi^+\pi^-$ and "ϕ"$\pi^+\pi^-$ spectra in $pN \to (K^+K^-\pi^+\pi^-)K^+K^-X$ events are shown in Fig. 3. The best fit to $\phi\pi\pi$ ($\chi^2/DF=35/39$) gives $M = 2.142 \pm 0.008$ GeV/c², $\Gamma = 0.046 \pm 0.016$ GeV/c², and a 3.9 σ excess of 213 ± 55 events above background. Clearly, the mass and width are consistent with those observed in the ϕKK final state. Using the $pN \to MK^+K^-X$ sample, and correcting for detection efficiencies, the relative branching ratio is $B(M \to \phi K^+K^-)/B(M \to \phi\pi^+\pi^-) = 0.49 \pm 0.16$. Since the intrinsic width is less than the experimental resolution, $\Gamma \lesssim 0.04$ GeV/c².

The "ϕ"$\pi^+\pi^-$ sideband is featureless. The best fit has χ^2/DF of 31/46. Fig. 4(a)shows the mass spectrum for $pN \to \phi\phi X$ events, while Fig. 4(b) contains $pN \to \phi\phi K^+K^-X$ events. The best fit for Fig. 4(a) (Fig. (4b)) has $M=2.125 \pm 0.016$ (2.139 ± 0.015) GeV/c², $\Gamma=0.049 \pm 0.027$ (0.061 ± 0.032) GeV/c², $\chi^2/DF=39/25$ (32/25) and 62 ± 29 (27 ± 12) events. The branching ratio is $B(M \to \phi\phi)/B(M \to \phi K^+K^-) = 0.39 \pm 0.24$ where, in this case, ϕKK has $\phi\phi$ events removed. A careful background subtraction of these data[8] continues to show this enhancement in the $\phi\phi$ final state. The existence of a $\phi\phi$ decay mode implies $I^G = 0^+$ and $C = +$. An S wave $\phi\phi$ state, which would be expected near threshold, has $J^{PC} = 0^{++}$ or 2^{++}.

The data in Fig. 4(a) is normalized using a Monte Carlo evaluation of geometric acceptance and trigger efficiency[8] to be

$$(d\sigma(pN \to MX)/dx)B(M \to \phi\phi)\Big|_{x=0} = 0.76 \pm 0.35\ \mu b \quad .$$

In a gluon fusion model[10] for glueball production, one can predict[1] $d\sigma(pN \to MX)/dx|_{x=0} = 48\mu b$. The branching ratio of the η_c, decaying through 2 gluons, is $B(\eta_c \to \phi\phi) = 0.009$.[12] Adopting this value, we get

$$(d\sigma(pN \to MX)/dx)B(M \to \phi\phi)|_{x=0} = 0.43\ \mu b.$$

This naive estimate is in reasonable agreement with the data.

In summary we observe an enhancement in the $\phi\pi^+\pi^-$ and ϕK^+K^- final states. The narrow width and large ratio $B(\phi\pi^+\pi^-)/B(\phi K^+K^-)$ argue against a 4^+ $s\bar{s}$ recurrence. An interpretation as a $(su)(\bar{s}\bar{u})$ state is discouraged by the narrow width. The $\phi\phi$ final state implies $C=+$, $I^G=0^+$, with $J^P=0^+$ or 2^+. The cross section times branching ratio is consistent with gluon fusion production of a glueball, followed by flavor symmetric decay with a $\phi\phi$ branching ratio similar to that of the η_c. This appears not to be the state seen at SLAC[13] since, although the widths are consistent, the mass of 2.220 GeV/c² is outside the quoted mass uncertainties. The difference in Γ implies that this is not the 2^{++}, 2.2 GeV/c² state reported in $\pi^-p \to \phi\phi n$.[14] The values of M, Γ and quantum numbers agree[15] with those of the $\varepsilon(2150)$; $J^{PC}I^G = 2^{++}0^+$, $M=2.141 \pm 0.002$ GeV/c², and $\Gamma=0.014 \pm 0.002$ GeV/c². The decay mode $M \to \omega^0\pi^+\pi^-$ where the ε was observed is analogous to the decay modes reported here.

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References

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Figure Captions

1) K^+K^- invariant mass distribution for $pN \to (K^+K^-K^+K^-)X$ events. The curve is described in the text.

2(a) ϕK^+K^- mass spectrum for $pN \to (\phi K^+K^-)X$ events. Closed circles are for $pN \to (\phi K^+K^-)K^{\pm}X$ events. Shaded spectrum is for $pN \to (\phi K^+K^-)K^+K^-X$ events. The curves are described in the text.

(b) "ϕ"K^+K^- mass spectrum for $pN \to (K^+K^-K^+K^-)X$ events. The curve is described in the text.

3) $K^+K^-\pi^+\pi^-$ mass spectrum for $pN \to (K^+K^-\pi^+\pi^-)K^+K^-X$ events. The solid curve is the fit to the $\phi\pi^+\pi^-$ spectrum, while the dashed curve is the fit to the "ϕ"$\pi^+\pi^-$ mass spectrum.

4) $\phi\phi$ mass spectrum for

(a) $pN \to (\phi\phi)X$

(b) $pN \to (\phi\phi)K^+K^-X$ events. The curves are described in the text.

Figure 1

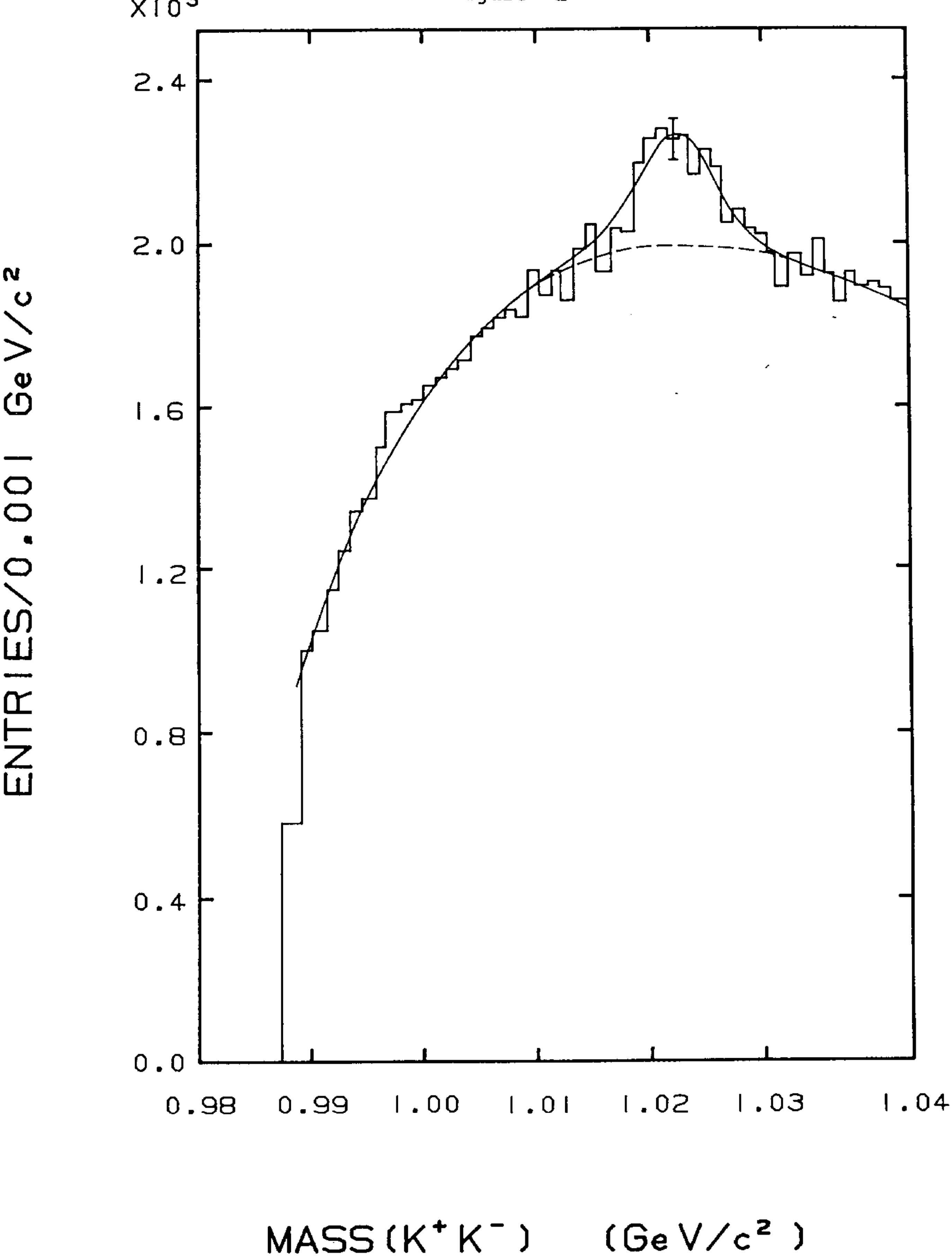

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Figure 2(a)

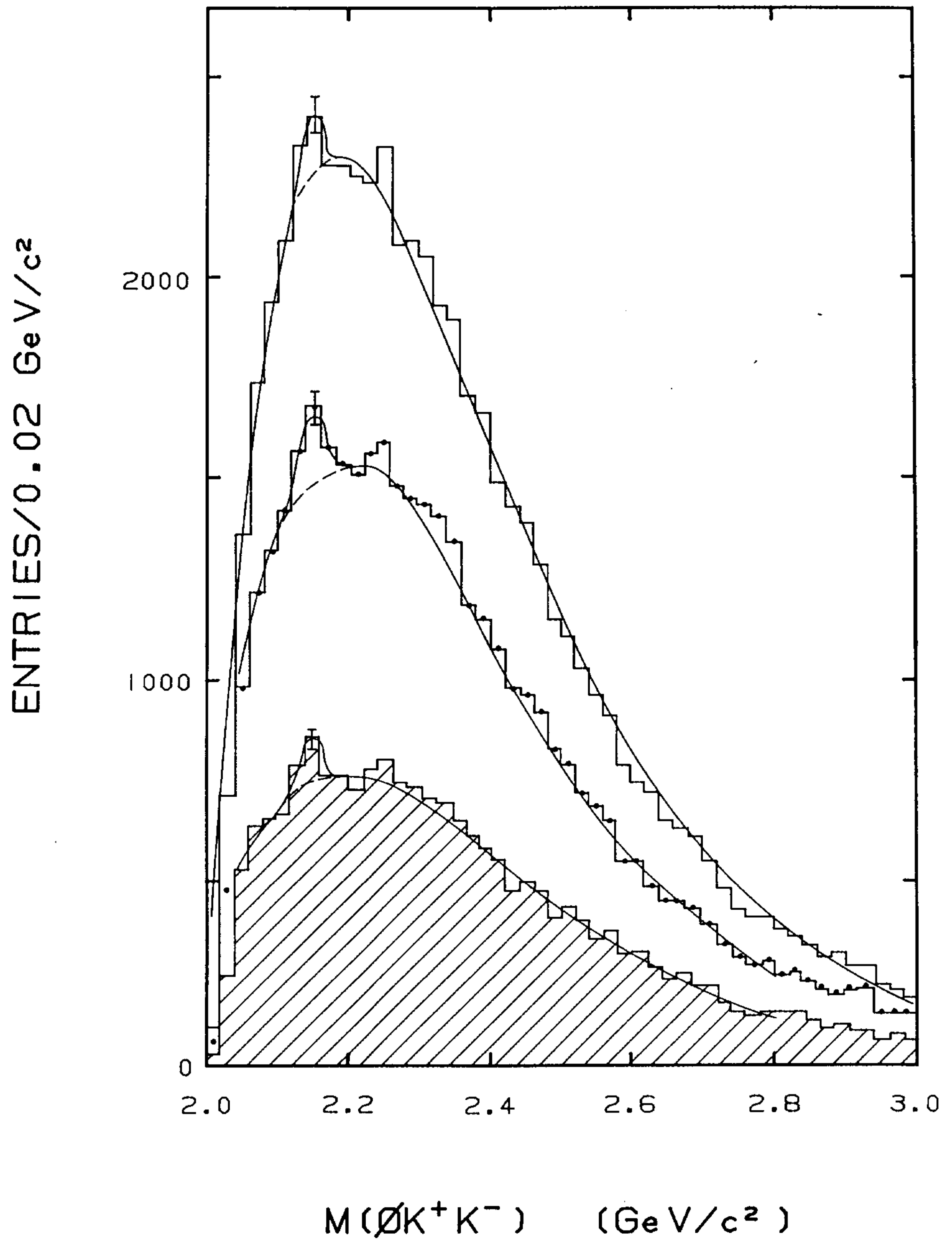

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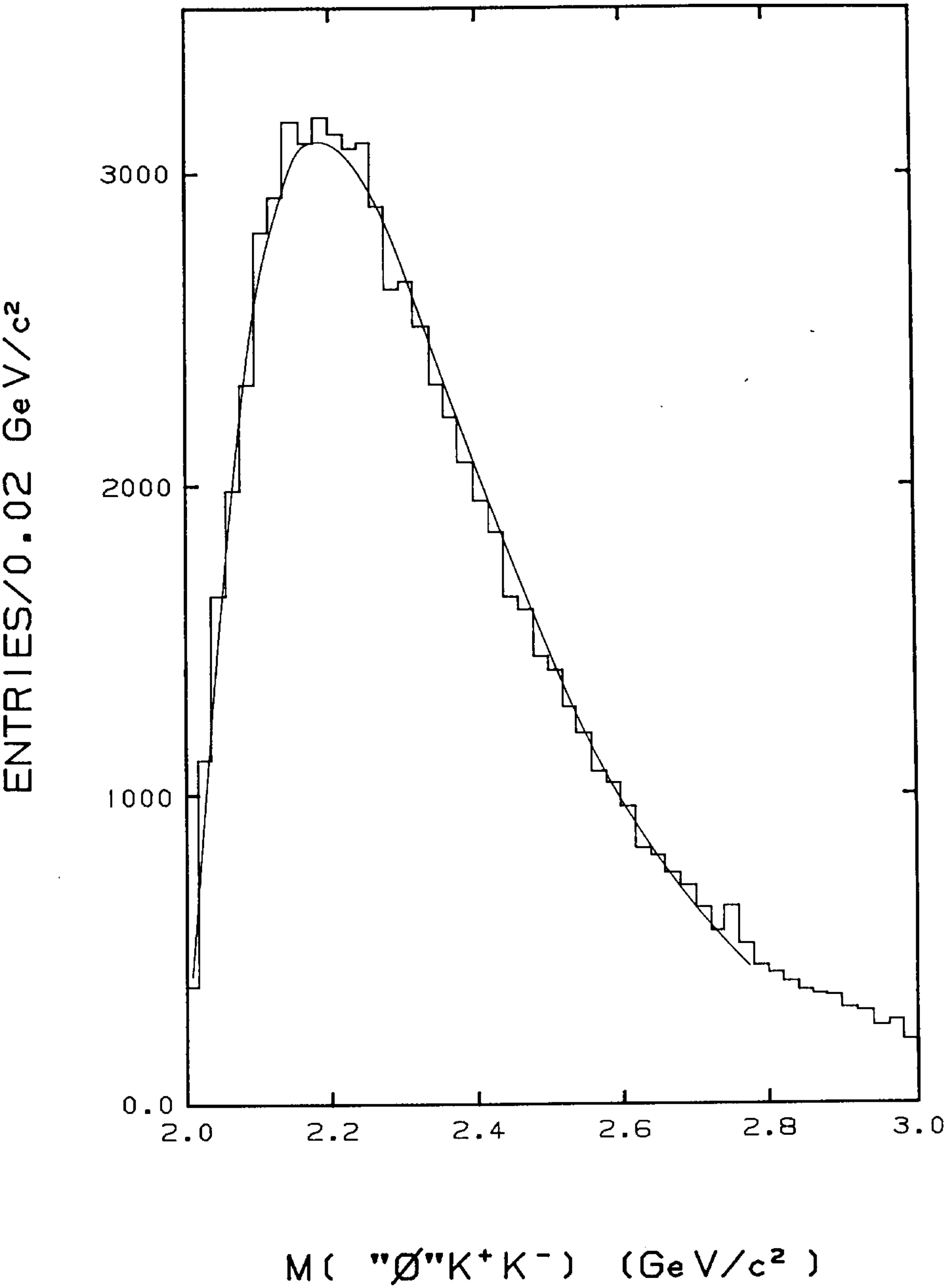
Figure 2(b)


3000
2000
1000
0.0
2.0
2.2
2.4
2.6
2.8
3.0
ENTRIES/0.02 GeV/c²
M("Ø"K⁺K⁻) (GeV/c²)

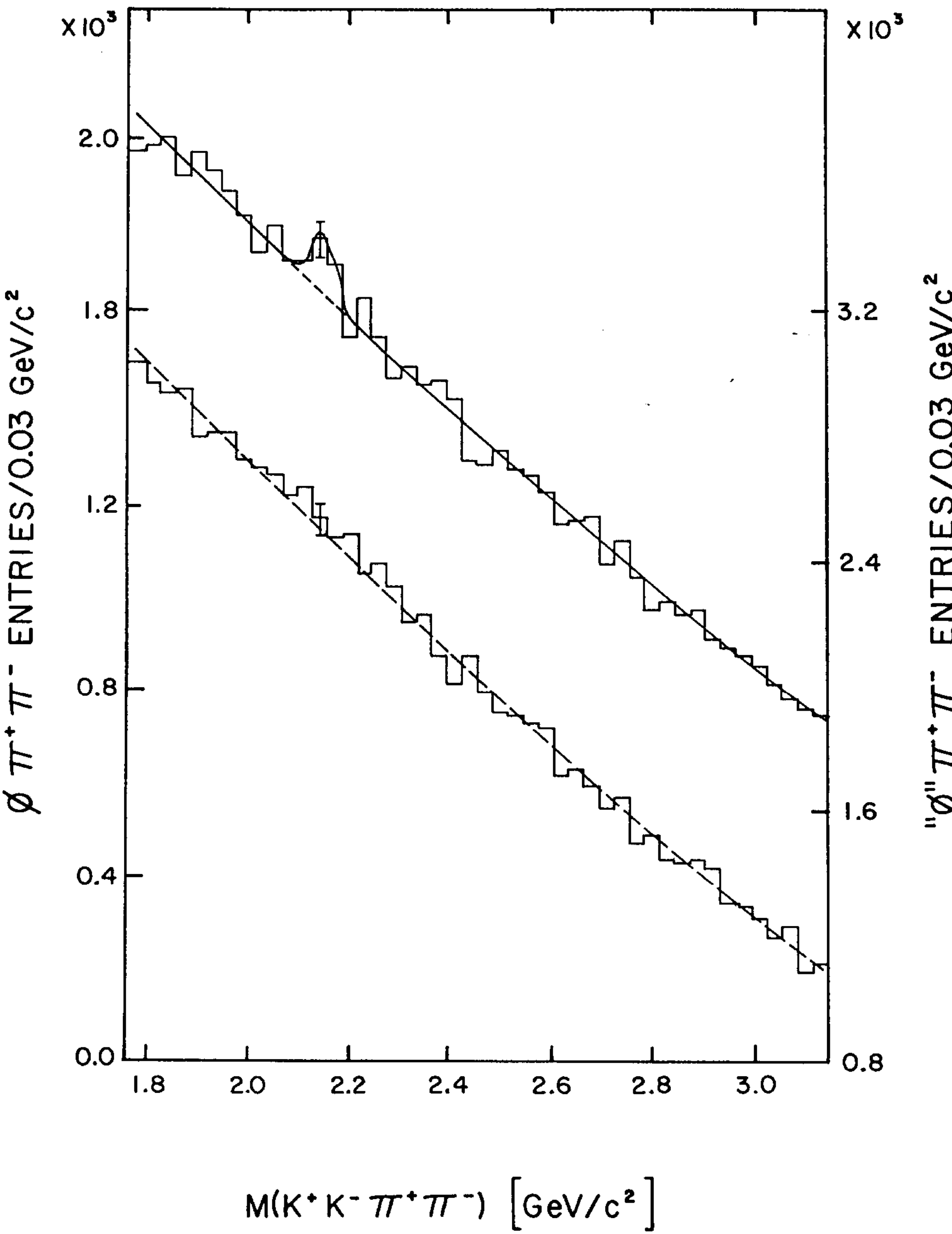
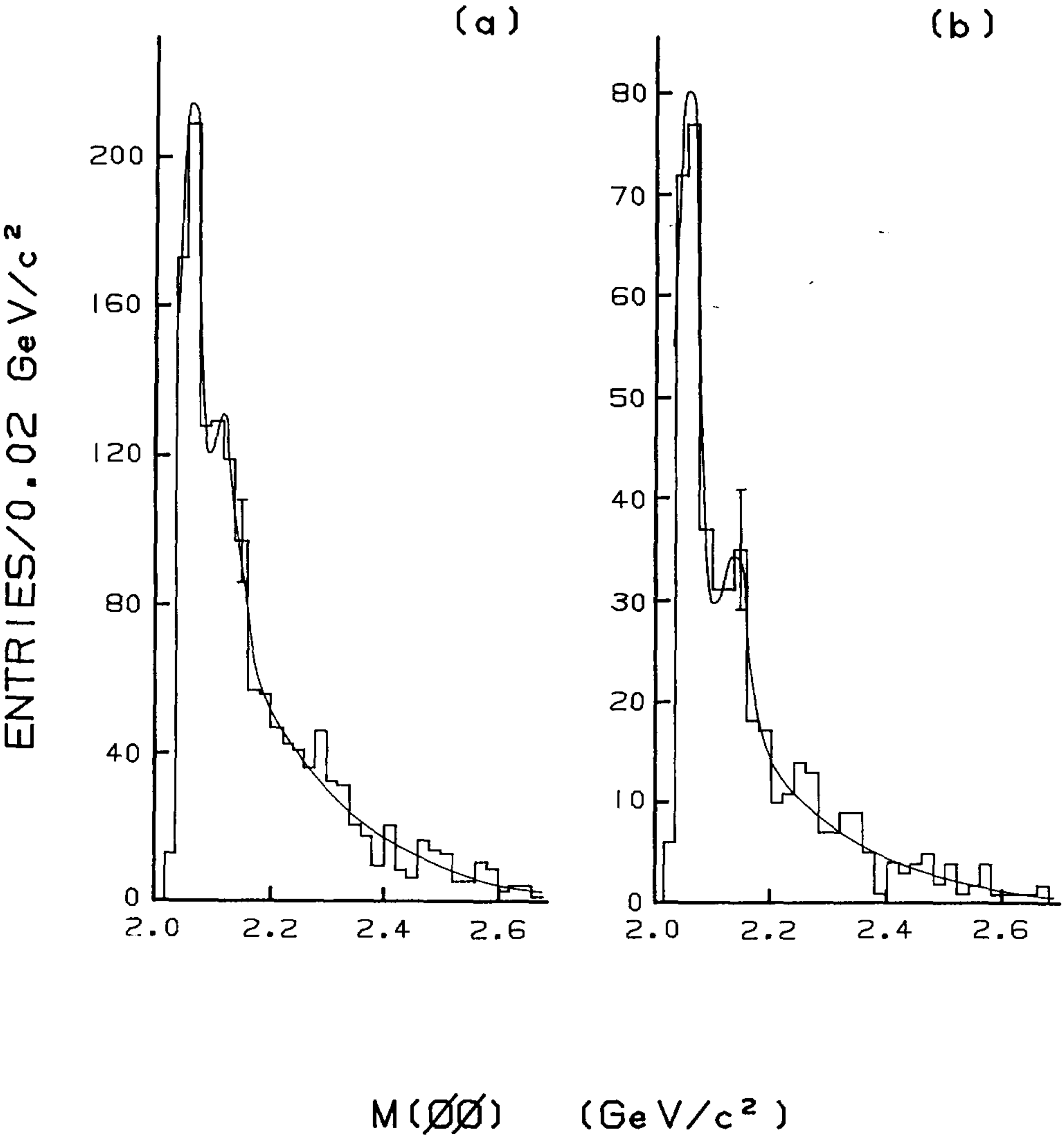

X10³
X10³
2.0
1.8
1.2
0.8
0.4
0.0
3.2
2.4
1.6
0.8
1.8
2.0
2.2
2.4
2.6
2.8
3.0
φ π⁺π⁻ ENTRIES/0.03 GeV/c²
"φ" π⁺π⁻ ENTRIES/0.03 GeV/c²
M(K⁺K⁻π⁺π⁻) [GeV/c²]

Figure 4


(a)
(b)
ENTRIES/0.02 GeV/c²
0
40
80
120
160
200
0
10
20
30
40
50
60
70
80
2.0
2.2
2.4
2.6
2.0
2.2
2.4
2.6
M(ØØ) (GeV/c²)