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OBSERVATION OF THE CABIBBO-SUPPRESSED DECAY $D^{\pm} \rightarrow \phi\pi^{\pm}$

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We observe the Cabibbo-suppressed decay $D^{\pm} \to \phi\pi^{\pm}$ in pN interactions at 400 GeV/c incident proton momentum. No evidence for $F^{\pm} \to \phi\pi^{\pm}$ decays is seen.

The final state $\phi\pi^{\pm}$ cannot arise from an OZI allowed strong decay of a quark-antiquark meson. For this reason, study of this final state has long been advocated as a filter for multiquark mesons or for weak decay processes.[1] In particular the decay of the $F^{\pm}$ meson is expected to have a substantial branching fraction to the Cabibbo-allowed $\phi\pi^{\pm}$ final state .[2] Recently, this decay mode has been reported[3] and confirmed[4] in e^+e^- collisions with a mass of 1.970 ± 0.005 GeV/c^2 and a branching fraction to $\phi\pi^{\pm}$ of about 4.4%[3] .

We describe here an experiment to study the $\phi\pi^{\pm}$ final states in the reaction $pN \to K^+K^-K^+K^-X$ at 400 GeV/c, where X includes up to 6 charged particles. One of the reasons this final state was chosen is that inclusive production of the DFK strange-charm-anticharm state will yield 4 kaons for Cabibbo-allowed decays : one spectator, one from the D, and two from the F.

The Fermilab Multiparticle Spectrometer (FMPS) was triggered by a high speed processor[5] (150 nanosecond decision time) seeking events with at least two pairs of oppositely charged kaons having an effective mass compatible with the ϕ mass. We obtained 3×10^6 triggers, which after pattern recognition and kinematic fitting were reduced to a sample of 120,000 events with at least $2K^+$ and $2K^-$. The experiment was designed to select ϕ's in the restricted kinematic region $|x_F| < 0.1$. Hence we study central production and can say little about the x_F dependence of the final states.

Particle identification was accomplished using a nitrogen-filled Cherenkov counter whose thresholds for light emission for pion, kaon, and proton were 5.8, 23.0, and 38.3 GeV/c respectively. Particles not giving light with momenta between 5.8 and 23.0 GeV/c are assumed to be kaons. Particles giving light with momenta between 23.0 and 38.3 GeV/c are assumed to be pions, while those which do not are unambiguous protons. Particles below pion threshold (5.8 GeV/c) and above proton threshold (38.3 GeV/c) are also assumed to be pions. The mass spectrum of all K^+K^- pairs found in the 120,000 events of the type $pN \rightarrow K^+K^-K^+K^-X$ is shown in Fig. 1. A fit with a polynomial background and a Gaussian with mean and sigma free to vary, gives a mass of 1.0199 ± 0.0003 GeV/c^2, and a width of 0.0074 ± 0.0004 GeV/c^2 (FWHM). These results are consistent with the accepted values[6] given our resolution of 0.006 GeV/c^2 (FWHM) at the ϕ mass determined using Monte Carlo techniques. The fit gives 2012 ± 97 ϕK^+K^- events. The χ^2/DF for this fit is 50/48. The ϕ signal serves as a calibration point for the mass scale.

We define as ϕ candidates the K^+K^- mass combinations within $\pm$ 0.006 GeV/c^2 of the nominal ϕ mass. Invariant mass combinations are then made with π's from the same event. The resulting $\phi\pi^\pm$ mass distribution is shown in Fig. 2a. A clear enhancement is seen near the D mass while nothing is seen at the F mass. A polynomial plus a Gaussian fit gives a mass of 1.8654 ± 0.0087 GeV/c^2 and a width of 0.053 ± 0.018 GeV/c^2 (FWHM), with a χ^2/DF of 41/44. The width is consistent with our experimental resolution of 0.052 GeV/c^2 as determined by a Monte Carlo simulation of events which were propagated through the experimental apparatus and passed through the track reconstruction and fitting programs. The fit gives a 5.4 standard deviation excess of 234 ± 43 events above background. Using the ϕ we can set an upper limit on our mass scale error of $\pm$ 0.02 GeV/c^2 at the D mass. Hence this enhancement can not be the F meson. In Fig. 2b the $\phi\pi^\pm$ background mass spectrum is shown, where the "ϕ" candidates are K^+K^- pairs with invariant mass just below or just above the ϕ mass yielding roughly the same number of combinations as in Fig 2a. No apparent signal is observed. The smooth curve has a χ^2/DF equal to 31/47.

Further evidence that this enhancement is the $D^\pm$ meson comes from the separately fitted yields of $\phi\pi^+$ and $\phi\pi^-$. One finds that the D^+/D^- ratio is 0.91 ± 0.16, consistent with unity as expected if valence quarks did not play a role in the production. In Fig. 3a the $\phi\pi^{\pm}$ spectrum is shown for events with $p_T(\phi\pi^{\pm}) > 0.5$ GeV/c where the the mass and width are fixed at the best fit values from Fig. 2a. The improved signal/noise ratio (6.7 standard deviations) with respect to Fig. 2a implies that this enhancement is produced with large p_T compared to uncorrelated $\phi\pi$ background, as expected of charm. In Fig. 3b the $\phi\pi^{\pm}$ mass spectrum is shown for events of the type $pN \rightarrow (\phi\pi^{\pm})(K^{\pm}\pi^{\mp})K^{\mp}X$ where the $K\pi$ mass combination is in the $K^*(890)$ region between .86 and .94 GeV/c^2. The improved signal to noise ratio (5.7 standard deviations) implies a charge correlation between the $D^{\pm}$ and the charge of the $K^{\pm}$ from associated $K^*(890)$ decay as expected from charm pair production.

We have examined the angular distributions of the decay products from the above enhancement to see whether they are consistent with the decay characteristics of a spin 0 object (D) going to a spin 1 (ϕ) and a spin 0 (π). There are two independent angular distributions to be checked. First, the angular distribution of the ϕ in the $\phi\pi$ rest frame, $\cos\theta_{\phi}$, should be isotropic. Second, since the helicity of the ϕ in the $\phi\pi$ rest frame must be zero, the angular distribution of the K^+ with respect to the ϕ direction should be $\cos^2\theta_K$. These distributions together with the expected distributions as modified by experimental acceptance and trigger bias using Monte Carlo events are seen in Fig 4. The angular distributions of the signal are consistent with those expected for a spin 0 object but other spins cannot be precluded.

The $D^{\pm} \rightarrow \phi\pi^{\pm}$ enhancement is observed in events with at least $2K^+$ and $2K^-$. From $D\bar{D}$ production we would expect only 3 charged kaons. Thus the role of the additional $K^{\pm}$ required by our trigger processor is unclear and it is difficult to reliably estimate the product of the production cross section and the branching fraction, since our geometric acceptance and trigger efficiency are strongly dependent on the model used to generate the 4th kaon. However, for the charm and strangeness conserving process $pN \rightarrow DFKX$ one knows the decay branching fractions $D \rightarrow KX$,[6] and $F^{\pm} \rightarrow \phi\pi^{\pm}$.[3] Hence, given our failure to observe the F meson we can set an upper limit on the cross section for F production. The 90% confidence level upper limit of the differential cross section $\left.\frac{d\sigma(F)}{dx_F}\right|_{x_F=0} = 53 \pm 37\ \mu b$. corrected for acceptance and detection efficiency. This limit can be compared to the ISR data on D^0 production[7] where $\left.\frac{d\sigma(D^0)}{dx_F}\right|_{x_F=0} = 700 \pm 300\ \mu b$. If we assume a $F^{\pm}$ cross section dependence of: $\frac{d^2\sigma}{dx_F dp_T^2} \propto (1-|x_F|)^n\ e^{-1.1 p_T^2}$, with n=7 as predicted by QCD counting rules[8], then the upper limit on the cross section for hadronic production of $F^{\pm}$ is $\sigma(F) < \left(\frac{2}{n+1}\right) \left.\frac{d\sigma(F)}{dx_F}\right|_{x_F=0} = 13 \pm 9\ \mu b$ per nucleon for pN interactions at 400 GeV/c. This limit is rather model dependent.

In summary, we have found an enhancement in the $\phi\pi^{\pm}$ final state which is consistent with the mass, spin, and width of the $D^{\pm}$. Its production is central, charge symmetric, with high p_T, and consistent with charm pair production. Recently, hadronic production of both the D and the F followed by decay into $\phi\pi^{\pm}$ has been reported in 200 GeV/c π^-N interactions at $x_F > 0.11$.[9] In that experiment the cross section times branching fraction ($\sigma.B$) is comparable for the Cabibbo-favored F and the Cabibbo-suppressed D. By comparison at $x_F = 0$. in 400 GeV/c pN interactions we see no indication of $F^{\pm}$ decays with respect to the observed $D^{\pm}$ decays.

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FIGURE CAPTIONS

Fig. 1. K^+K^- invariant mass distribution from events containing at least $2K^+$ and $2K^-$. The curve is described in the text.

Fig. 2. $\phi\pi^\pm$ invariant mass distribution where the (a) ϕ band is chosen to be between 1.014 and 1.026 Gev/c^2 and (b) "ϕ" candidates are K^+K^- pairs chosen just outside the ϕ mass band.

Fig. 3. $\phi\pi^\pm$ invariant mass distribution for (a) $p_T(\phi\pi^\pm) > 0.5$ GeV/c^2 and (b) $\phi\pi^\pm(K^\pm\pi^\mp)K^\mp$ events with $.86 < M_{K\pi} < .94$ GeV/c^2.

Fig. 4. Measured angular distributions for signal compared with those expected for a spin 0 object decaying to a ϕ and a π. (a) $\cos\theta_\phi$ (b) $\cos\theta_K$.

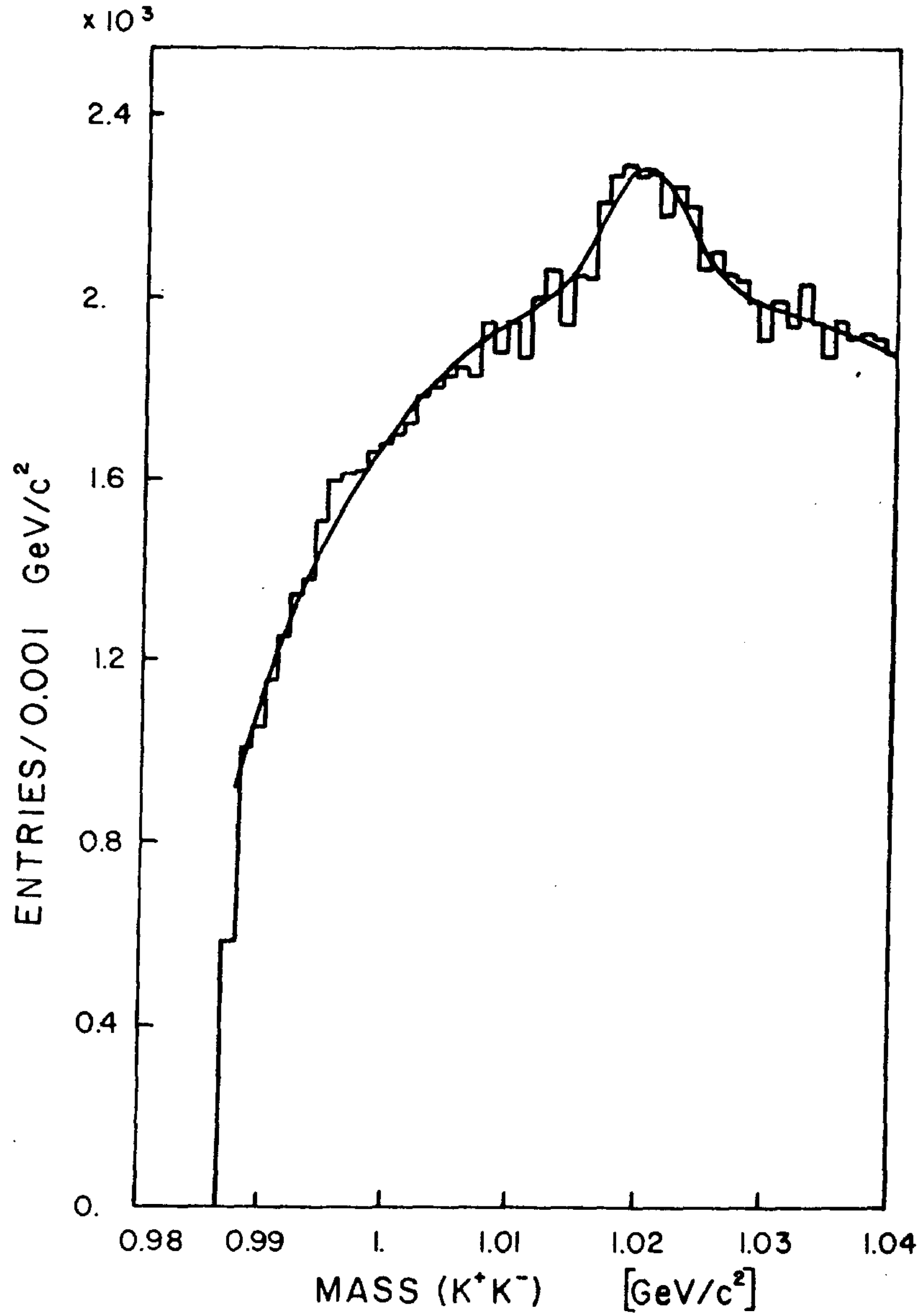

x 10^3
2.4
2.
1.6
1.2
0.8
0.4
0.
ENTRIES/0.001 GeV/c^2
0.98
0.99
1.
1.01
1.02
1.03
1.04
MASS (K+K-) [GeV/c^2]

Fig. 1

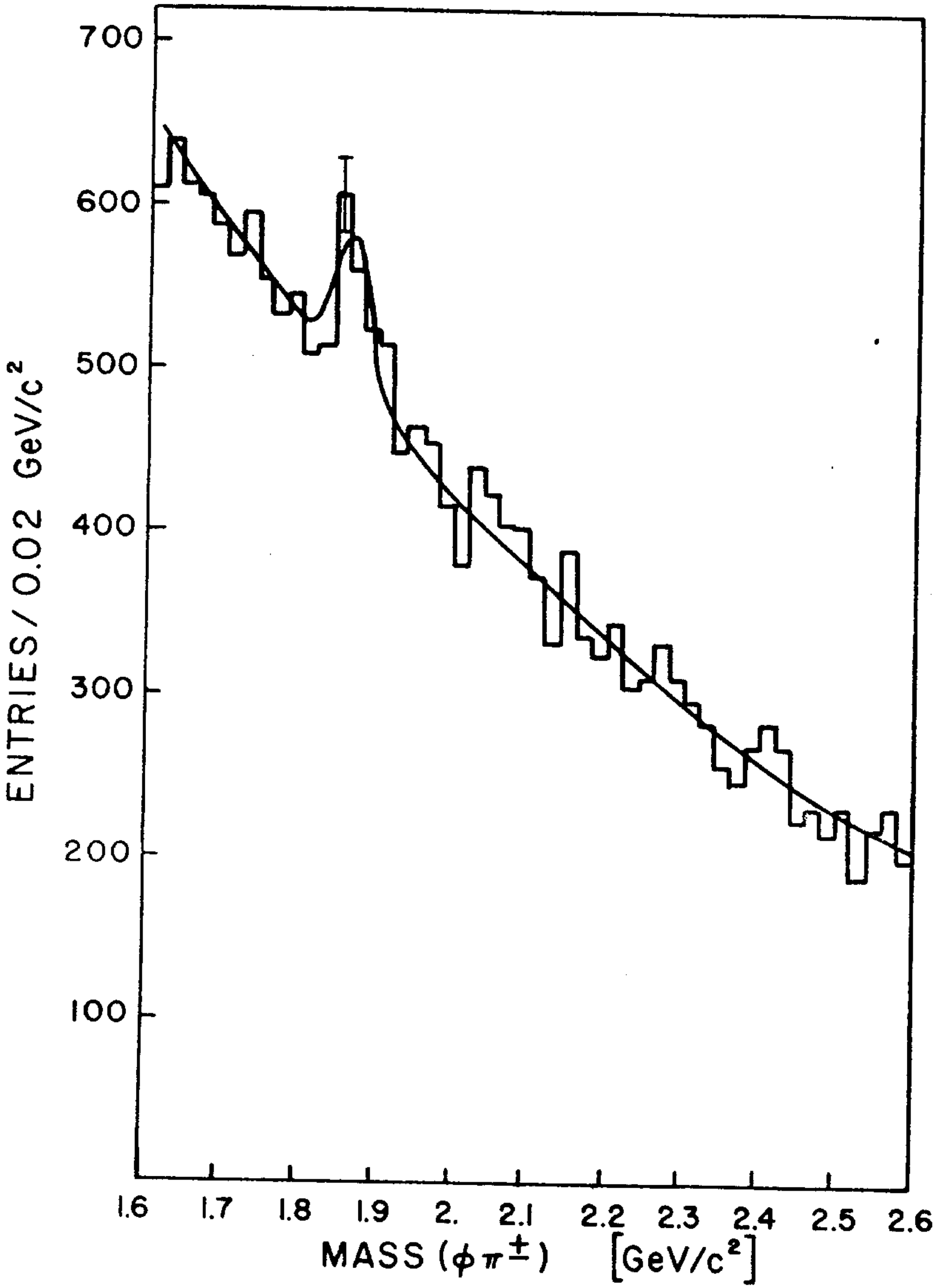

700
600
500
400
300
200
100
ENTRIES / 0.02 GeV/c²
1.6
1.7
1.8
1.9
2.
2.1
2.2
2.3
2.4
2.5
2.6
MASS (ϕπ±) [GeV/c²]

Fig. 2a

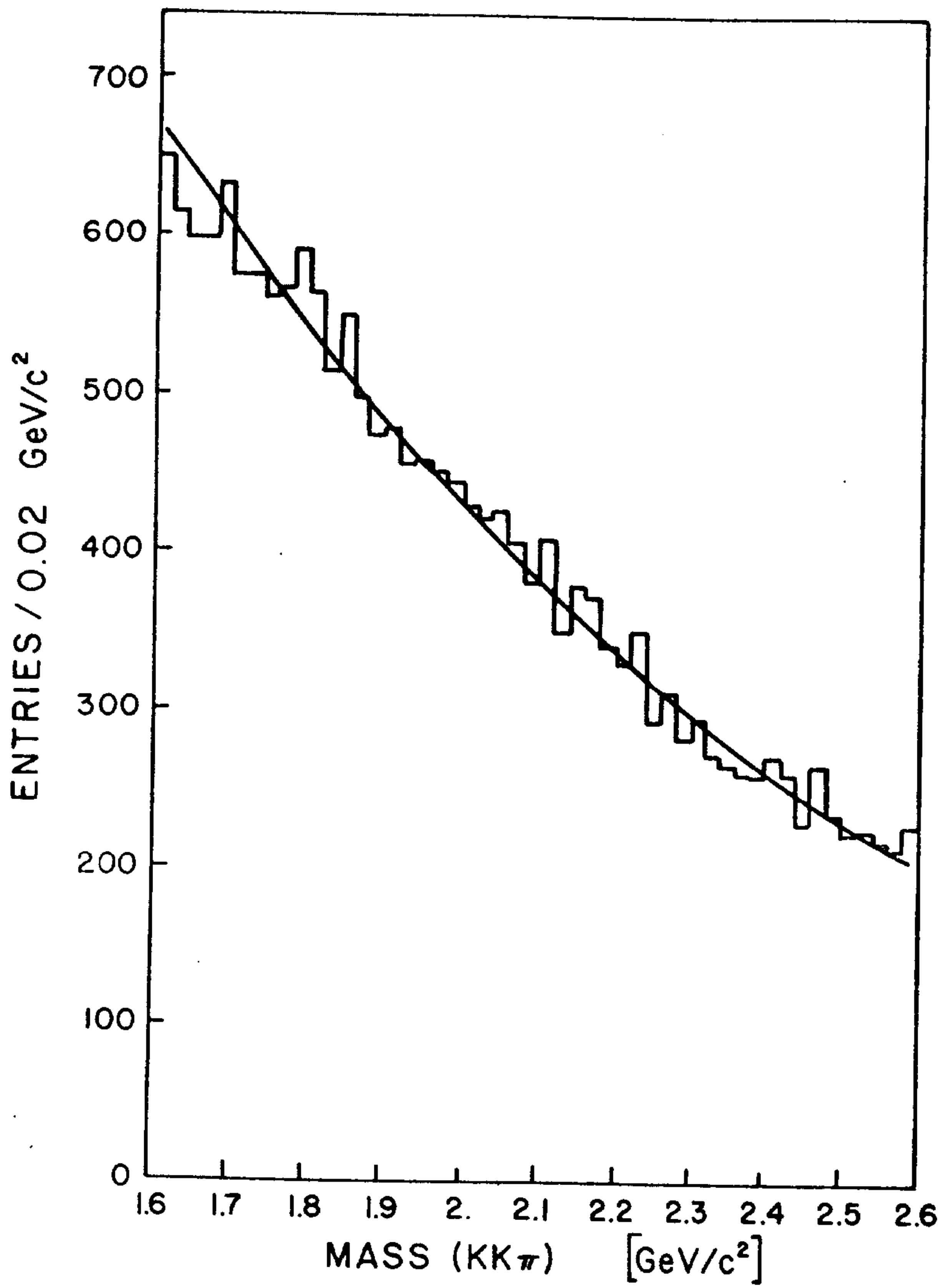
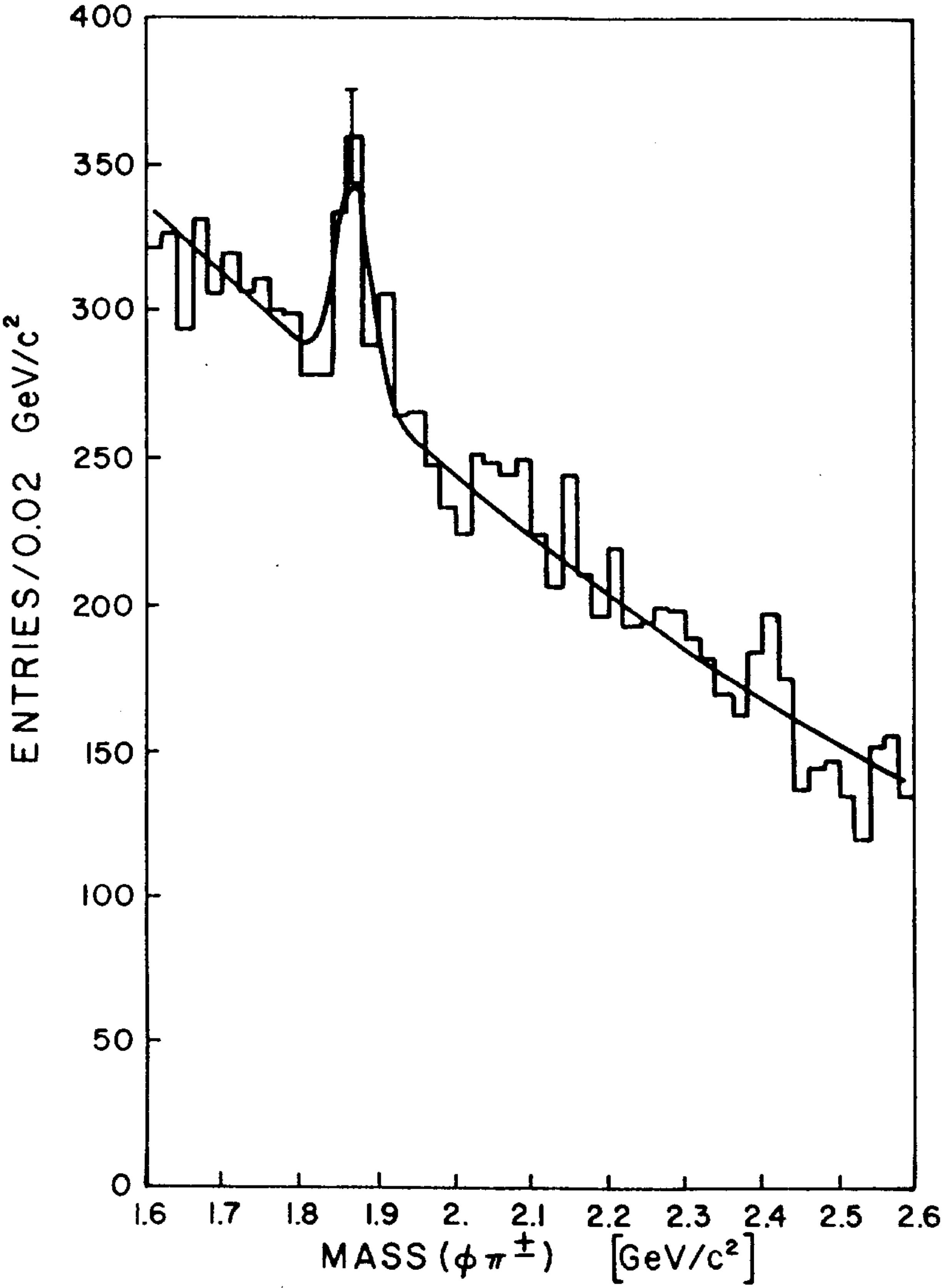
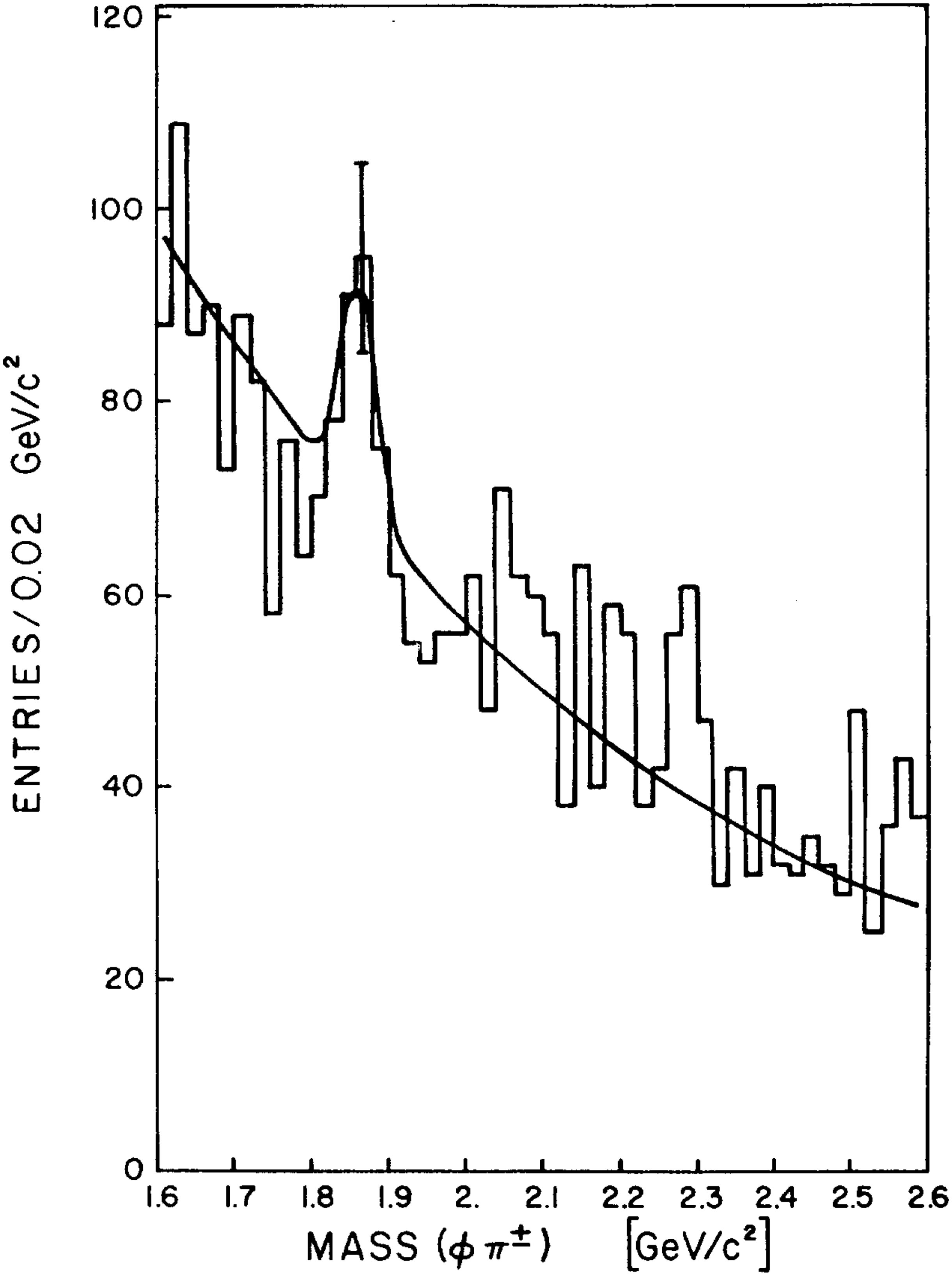

ENTRIES / 0.02 GeV/c²
700
600
500
400
300
200
100
0
1.6
1.7
1.8
1.9
2.
2.1
2.2
2.3
2.4
2.5
2.6
MASS (KKπ) [GeV/c²]

Fig. 2b



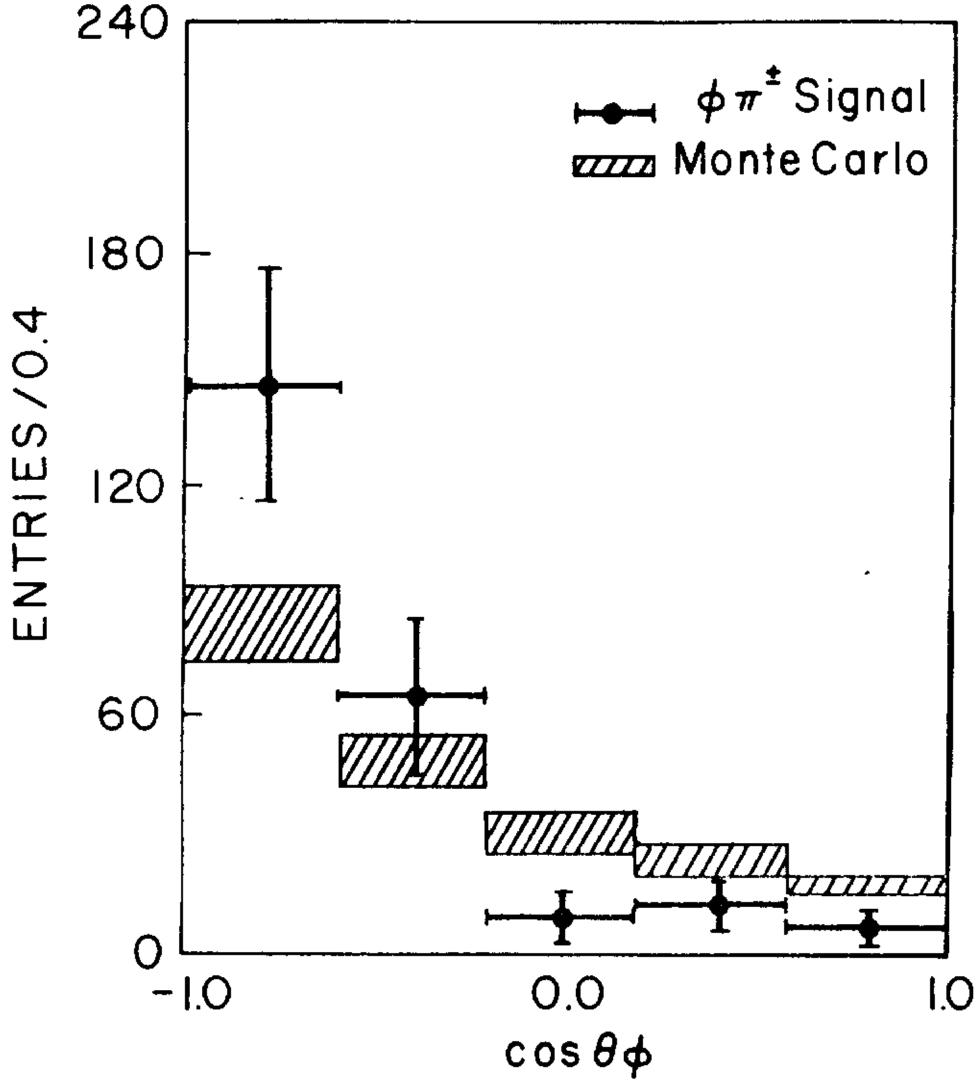
ENTRIES/0.02 GeV/c^2
400
350
300
250
200
150
100
50
0
1.6
1.7
1.8
1.9
2.
2.1
2.2
2.3
2.4
2.5
2.6
MASS ($\phi\pi^{\pm}$) [GeV/c^2]

Fig. 3a



120
100
80
60
40
20
0
1.6
1.7
1.8
1.9
2.
2.1
2.2
2.3
2.4
2.5
2.6
ENTRIES/0.02 GeV/c²
MASS (φ π±) [GeV/c²]

Fig. 3b



240
180
120
60
0
ENTRIES/0.4
$\phi\pi^{\pm}$ Signal
Monte Carlo
-1.0
0.0
1.0
cos $\theta\phi$

Fig. 4a

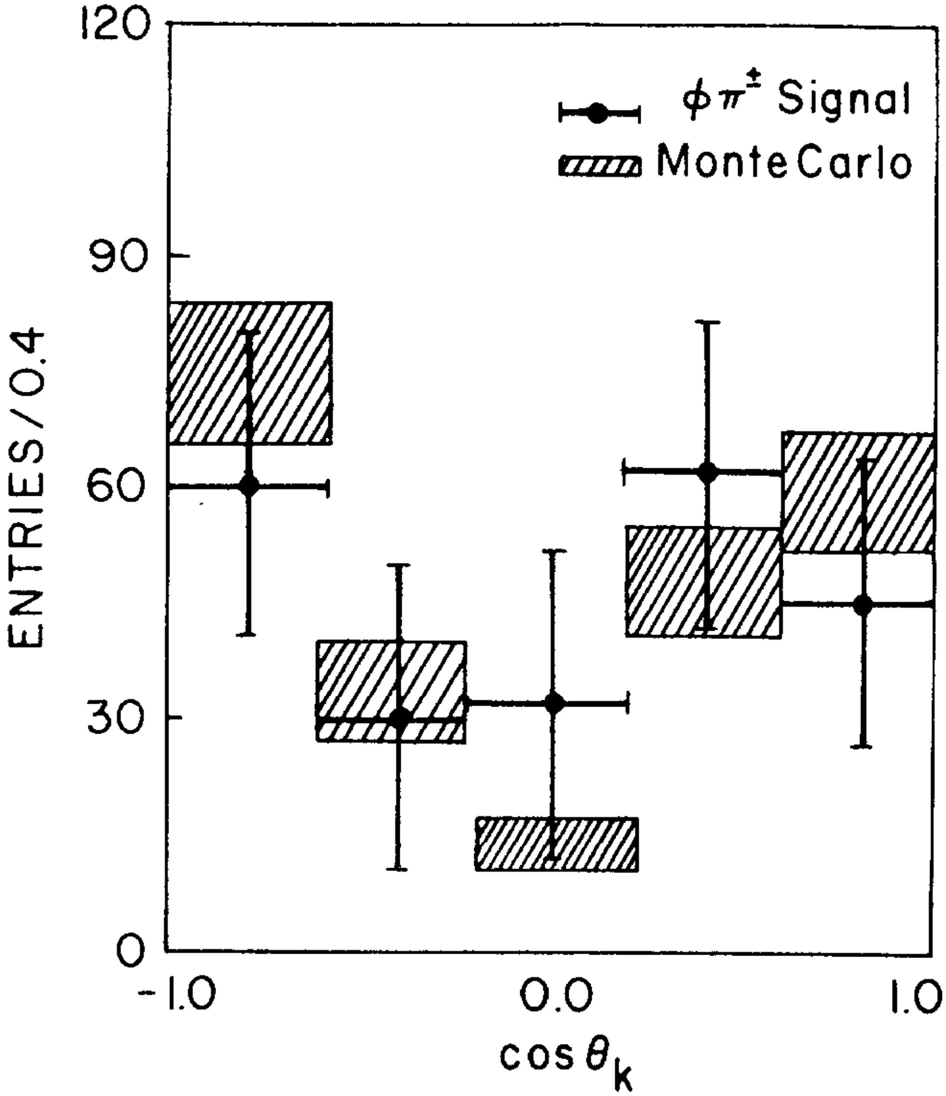

120
90
60
30
0
ENTRIES/0.4
$\phi\pi^{\pm}$ Signal
Monte Carlo
-1.0
0.0
1.0
$\cos\theta_k$

Fig. 4b