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OBSERVATION OF $\phi K\pi$ DECAY OF THE $K^{*\circ}(2060)$†

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We have studied inclusive $pN \to K^+K^-K^+K^-X$ final states at 400 GeV/c and present here evidence for $K^{*\circ}(2060) \to \varphi K^{\pm}\pi^{\mp}$ and $\varphi K^{*\circ}(890)$.

Excitations of the neutral kaon K(498), presumed to be a d and $\bar{s}$ quark in the $^1S_0$ ground state, have been observed: $K^*(890)$ ($^3S_1$), $K^*(1430)$ ($^3P_2$), $K^*(1780)$ ($^3D_3$) and $K^*(2060)$ ($^3F_4$) [1]. Possible decay modes for the $K^*(2060)$ excitation are $\varphi K(n\pi)$; those accessible in our experiment, which lacks neutral particle identification, are listed in Table I. We analyze the $\varphi K^{\pm}\pi^{\mp}$ and $\varphi K^{*0}(890)$ final states of the $K^*(2060)$ and compare the results with other experiments.

Experiment E623 used the Fermilab Multiparticle Spectrometer (FMPS) in the 400 GeV/c M6W beam line to study proton-nuclei interactions with φ mesons in the final state [2]. A fast trigger processor [3] identified events with at least two K^+K^- pairs whose effective masses in the magnet bend-plane were consistent with that of the φ. An atmospheric, multi-cell, nitrogen Cherenkov counter with momentum thresholds of 5.7 (π), 20.2 (K) and 38.3 (p) GeV/c provided track-by-track particle identification for this trigger.

Pattern recognition, a global 3-dimensional 6-parameter track fit, and particle identification reduced the 3.7×10^6 triggers to 1.8×10^6 events each having ≥ 3 tracks with ≥ 1 K^+ and ≥ 1 K^-. Tracks without Cherenkov light with $5.8 \leq P \leq 23.0$ GeV/c were defined as kaons and with $23.0 \leq P \leq 38.3$ GeV/c were defined as protons, while all particles with associated light were assumed to be pions. Events with ≥ 2 K^+ and ≥ 2 K^- (the 144,471 event 4-K sample) included 32,044 events with ≥ 1 K^+K^- mass combination within ± 6 MeV/c^2 of the nominal φ mass [4]. Of these, ~ 80% (25,482 events) had ≥ 1 additional $K^{\pm}\pi^{\mp}$. Our fitted φ mass (1.0199±0.0003 GeV/c^2) and resolution, described elsewhere [4], are used to establish the mass scale. A 4% systematic momentum error would have resulted in a φ mass 5σ from its nominal value, with a corresponding $\varphi K\pi$ mass shift of 17 MeV/c^2 at a $\varphi K\pi$ mass of 2060 MeV/c^2. Thus we are

confident of our mass calibrations.

In our fits we parameterize the background by $N(M-M_0)^{\alpha}e^{-\beta(M-M_0)}$, where the threshold mass (M_0), the normalization (N), α and β were varied. The resonance form is a Breit-Wigner convoluted with the Gaussian instrumental resolution (σ = 10 MeV/c^2 for $K^*(2060)$) determined by Monte Carlo.

The $\varphi K^{\pm}\pi^{\mp}$ mass spectrum is seen in Fig. 1. When tracks below pion threshold are included as pions a 502±188 event enhancement whose mass and width are 2048±10 and 60±59 MeV/c^2 is extracted (χ^2/DF=36/30). To insure that pions are positively identified, tracks with momentum below 5.8 GeV/c were excluded, a 431±116 event enhancement with mass and width 2079±7 and 61±58 MeV/c^2 (χ^2/DF=16/23) remained. These masses and widths are consistent with previous $K^*(2060)$ measurements [5-8].

In what follows we require positively identified pions ($P \geq 5.8$ GeV/c). The background is constructed of K^+K^- pairs with $1008 \leq M(K^+K^-) < 1014$ and $1026 \leq M(K^+K^-) < 1032$ MeV/c^2, the φ side-band ("φ"). These "φ"$K^{\pm}\pi^{\mp}$ fits, with fixed resonance mass (2079 MeV/c^2) and width (61 MeV/c^2), give 81±104 $K^*(2060)$ events (χ^2/DF=36/26), implying that the signal is entirely in the $\varphi K^{\pm}\pi^{\mp}$ submass of $K^+K^-K^{\pm}\pi^{\mp}$. Our measured $\varphi K^+\pi^+$ and $\varphi K^-\pi^-$ distributions are structureless, consistent with an isospin 1/2 assignment for this resonance.

The background-subtracted, acceptance-corrected transverse momentum distribution fitted to $\exp(-b\,P_T^2)$ gives b of 2.3±0.7 $(\mathrm{GeV}/c)^{-2}$, consistent with other K^* production [9]. The longitudinal momentum fraction distribution (X_F) could not be determined since our trigger acceptance limited the kaon momentum and hence our sensitivity to $|X_F| \leq 0.1$.

To investigate the two body decay mode $K^{*0}(2060) \to \varphi K^{*0}(890) \to \varphi K^{\pm}\pi^{\mp}$ we fit the $K^{\pm}\pi^{\mp}$ mass spectrum, seen in Fig. 2, by fixing the resonance mass and width (892 and 52 MeV/c^2), and obtain 405±137 $K^*(890)$ events

(χ^2/DF=72/50). We then fit the $\varphi K^{\pm}\pi^{\mp}$ mass, seen in Fig. 3, for $K^{\pm}\pi^{\mp}$ mass combinations within ±40 MeV/c^2 of the $K^{*0}(890)$, with fixed mass and width (2079 and 61 MeV/c^2). This fit when corrected for background and $K^*(890)$ combinations excluded by the cut gives 172±78 $\varphi K^{*0}(890) \to \varphi K^{\pm}\pi^{\mp}$ combinations. Given our trigger requirements, ~ 40% of the $K^{*0}(890)$ event sample is a decay product of $K^{*0}(2060)$.

Centrally produced resonances should be charge symmetric [10]. From the fits to the $\varphi K^{\pm}\pi^{\mp}$ mass spectra seen in Fig.4, $N[K^{*0}(2060) \to \varphi K^+\pi^-]/N[\bar{K}^{*0}(2060) \to \varphi K^-\pi^+] = 0.8\pm0.4$, consistent with $\bar{s}d$ and $s\bar{d}$ production rates being comparable and in agreement with $N(K^+)/N(K^-)$ data [11]. We see no evidence within our statistics for $K^*(2060)$ being pair produced with any known $\bar{K}^*$ resonance.

We evaluate the $K^{*0}(2060)$ cross section (σ) using a model to obtain the branching ratio (BR) from our measured $(d\sigma/dX_F|_{X_F=0}) \times$ BR. Our cross section normalization, details to be found elsewhere [2], includes geometrical acceptance; Cherenkov, trigger and reconstruction efficiencies; and corrections for kaon decays before the Cherenkov counter (0.621), the $\varphi \to K^+K^-$ branching fraction (0.49), and the $K^{*0}(2060) \to \varphi K\pi$ relative branching fraction to charged particles (0.667).

To study the acceptance fraction we generated $K^*(2060)$ events with a differential cross section of $(1-|X_F|)^{2.8} \exp(-2.5\, P_T^2)$ [9] and propagated them through the apparatus, trigger processor, and analysis software. The acceptance fraction is insensitive to the particular choice of transverse momentum distribution. However, it is rather sensitive to the model of the fourth (bachelor) kaon required by the trigger. The results reported in Table I are based on the Bourquin-Gaillard model [12] with local quantum number conservation, in this case strangeness. Hence, the bachelor kaon is produced close in phase space to the $K^{*0}(2060) \to \varphi K^{\pm}\pi^{\mp}$ which allows low

mass $K^{\pm}K^{\mp}$(bachelor) combinations to provide the second trigger φ.

The corrected $(d\sigma/dX_F|_{X_F=0}) \times BR(\varphi K\pi)$ is 1.16±0.32 μb. Extrapolating to the total cross section by $2(d\sigma/dX_F|_{X_F=0})/(n+1)$, using $n = 2.8$ from $K^{*0}(890)$ production [9], yields $\sigma \times BR(\varphi K\pi) = 0.64\pm0.17$ μb. The Bourquin-Gaillard model [12] estimates the total inclusive cross section $\sigma(\mu b) = 4\times10^9\, y_{max}^2 \exp(-5.13/y_{max}^{0.38})\, M'(M'+2)^{-12.3}$. M' is the mass of the simplest composite particle consistent with the production of resonance mass M and local conservation of quantum numbers. Here M is 2060 MeV/c^2, M' is (2060 + 490) MeV/c^2, and y_{max} is the maximum center-of-mass rapidity for M'. In this model $\sigma[pp \to K^{*0}(2060)\bar{K}X + \bar{K}^{*0}(2060)KX]$ is 22 μb. Using this estimated σ, the BR for $K^{*0}(2060)$ to $\varphi K\pi$ is .028 and to $\varphi K^{*0}(890)$ is .014. The errors, which depend on the accuracy of the model, are estimated to be ~50% of these values [13].

Using this model to infer the φK^* branching ratio, and using the measured [5] branching ratio to $K\pi$, (3/2)(.07±.01), we obtain $\Gamma(\varphi K^{*0}(890))/\Gamma((K\pi)^0) = .13\pm.07$. This result is consistent [6] with $\Gamma(\rho^0 K^{*0}(890))/\Gamma((K\pi)^0) = .06\pm.03$, implying comparable branching fractions for neutral isovector or isoscalar members of the same nonet. Our derived ratio, $\Gamma(\varphi K\pi)/\Gamma((K\pi)^0) = .27\pm.14$, when compared [7] with $\Gamma(\omega\bar{K}^0\pi^-)/\Gamma(\bar{K}^0\pi^-) = .50\pm.30$ and $\Gamma(\rho^0\bar{K}^0\pi^-)/\Gamma(\bar{K}^0\pi^-) = .56\pm.32$, agree within the measurement uncertainties.

The decays of $K^*(2060)$ to $K^{\pm}\pi^{\mp}$, $\varphi K^{\pm}\pi^{\pm}\pi^{\mp}$, and $\varphi K^{\pm}$ are not seen in our data. Fits with a resonance contribution, Table I, give nearly identical χ^2 to ones without a resonance contribution. The first decay mode is suppressed because the four-kaon trigger requirement excludes these events. The second decay mode is possibly suppressed because of small BRs and/or large combinatorial backgrounds when multiple pions are included. No other experiment has reported $K^*(2060)$ decay modes comparable to $\varphi K\pi\pi$, e.g. $\rho K\pi\pi$

and $\omega K\pi\pi$. In order to make further comparisons with existing data, we assume equal cross sections for $K^{*0}(2060)K^-X$ and $K^{*+}(2060)K^-X$ in the central region. Since we expect $\Gamma(K^{*0}(2060)\to\varphi K^0) = \Gamma(K^{*+}(2060)\to\varphi K^+)$, our $\varphi K^\pm$ limit implies a limit on φK^0, $\Gamma(\varphi K^0)/\Gamma(\varphi K^{*0}) = .11\pm.19$, to be compared [6] with $\Gamma(\rho^0 K^0)/\Gamma(\rho^0 K^{*0}) = .89\pm.60$. Alternatively, the the latter ratio predicts 297 ± 240 $\varphi K^\pm$ events from $K^{*\pm}(2060)$ decay, consistent with our 35 ± 58 events.

We conclude that strange meson resonances above the φK threshold have significant BR to φKX, comparable to those of $\rho^0 KX$ and ωKX.

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REFERENCES AND FOOTNOTES

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Table 1. Possible $\varphi K(n\pi)$ Final States of $K^{*\circ}(2060)$.

Reaction	Q Value (MeV)	Monte Carlo Acceptance Fraction	Fitted Events
$K^{*\circ}(2060) \to \varphi K^{\pm}\pi^{\mp}$	407	.0040	431±116
$\to \varphi K^{*\circ}(890)$	148	.0034	172±78
$K^{*\pm}(2060) \to \varphi K^{\pm}$	547	.0044	35±58
$\to \varphi K^{\pm}\pi^{\pm}\pi^{\mp}$	268	.0010	8±3
		.0037	107±128[$]

[$] Including tracks with $P \geq 5.8$ GeV/c as pions.

FIGURE CAPTIONS

Figure 1. The $\varphi K^{\pm}\pi^{\mp}$ mass spectra, crosses, fitted to background and $K^{*}(2060)$ for (a) all tracks; (b) tracks with $P \geq 5.8$ GeV/c excluded. The dotted histogram is the "φ"$K^{\pm}\pi^{\mp}$ data normalized to the background fit of the crossed histogram.

Figure 2. The $K^{\pm}\pi^{\mp}$ mass spectrum fitted to background and $K^{*}(890)$. Tracks having $P \geq 5.8$ GeV/c are excluded.

Figure 3. The $\varphi K^{\pm}\pi^{\mp}$ mass spectra for $K^{\pm}\pi^{\mp}$ in the $K^{*}(890)$, crosses, fitted to background and $K^{*}(2060)$. The dotted histogram is the "φ"$K^{*}(890)$ data normalized to the background fit of the crossed histogram. Tracks having $P \geq 5.8$ GeV/c are excluded.

Figure 4. The mass spectra fitted to background and $K^{*}(2060)$ for (a)$\varphi K^{+}\pi^{-}$; and (b)$\varphi K^{-}\pi^{+}$. Tracks having $P \geq 5.8$ GeV/c are excluded.

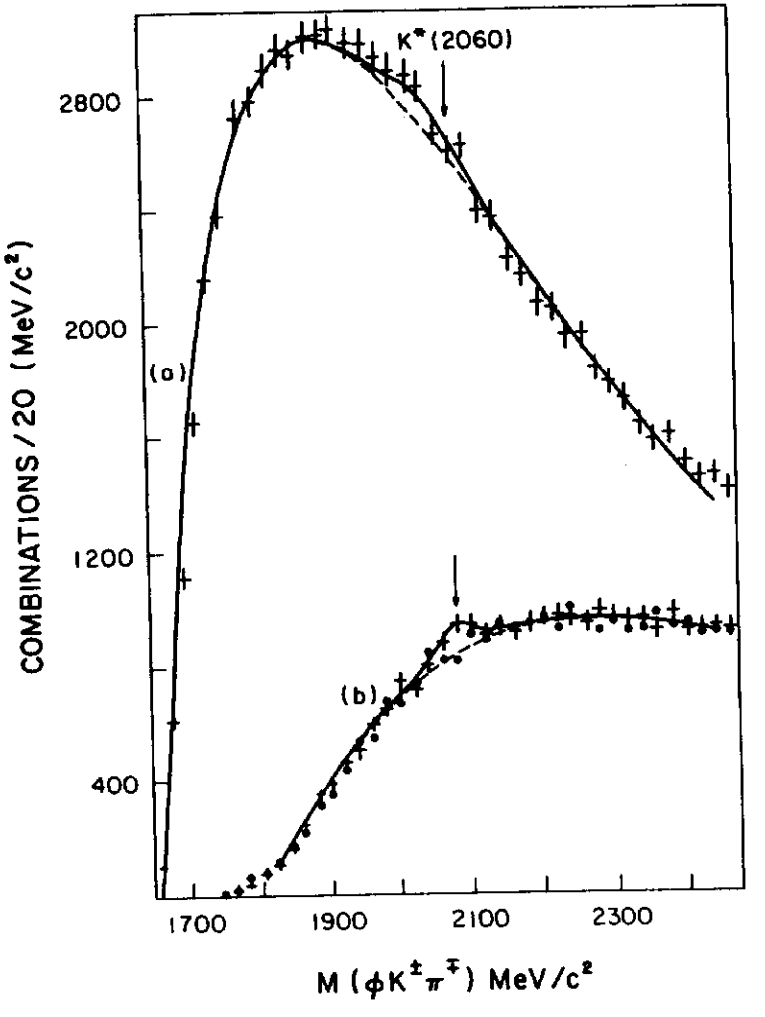

Fig. 1.

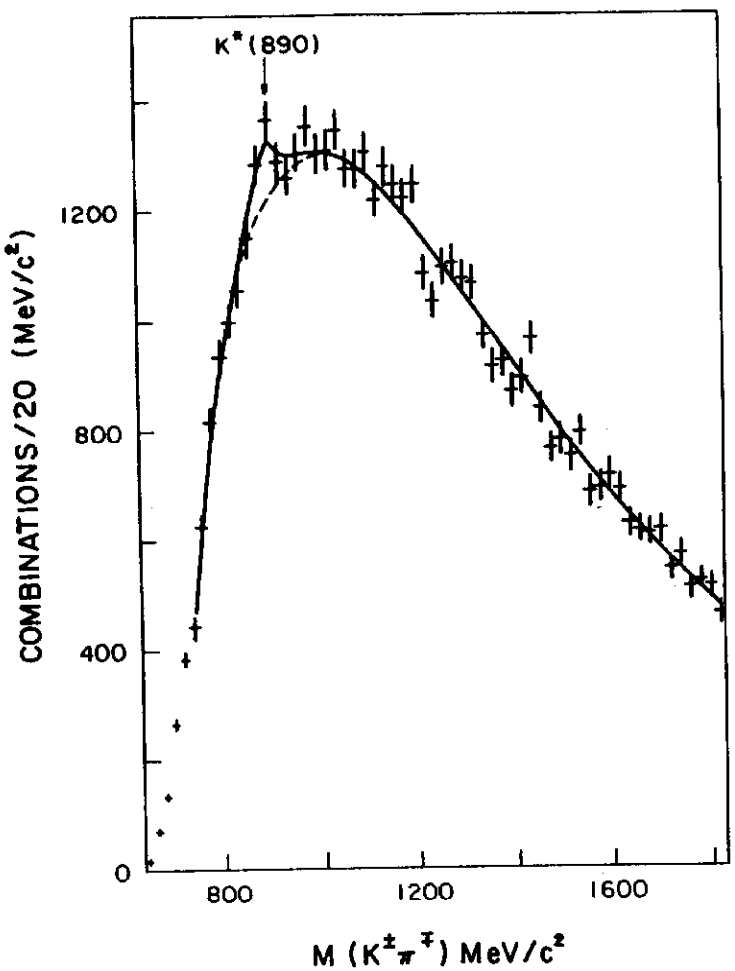
K*(890)
COMBINATIONS/20 (MeV/c²)
0
400
800
1200
800
1200
1600
M (K±π∓) MeV/c²

Fig. 2.

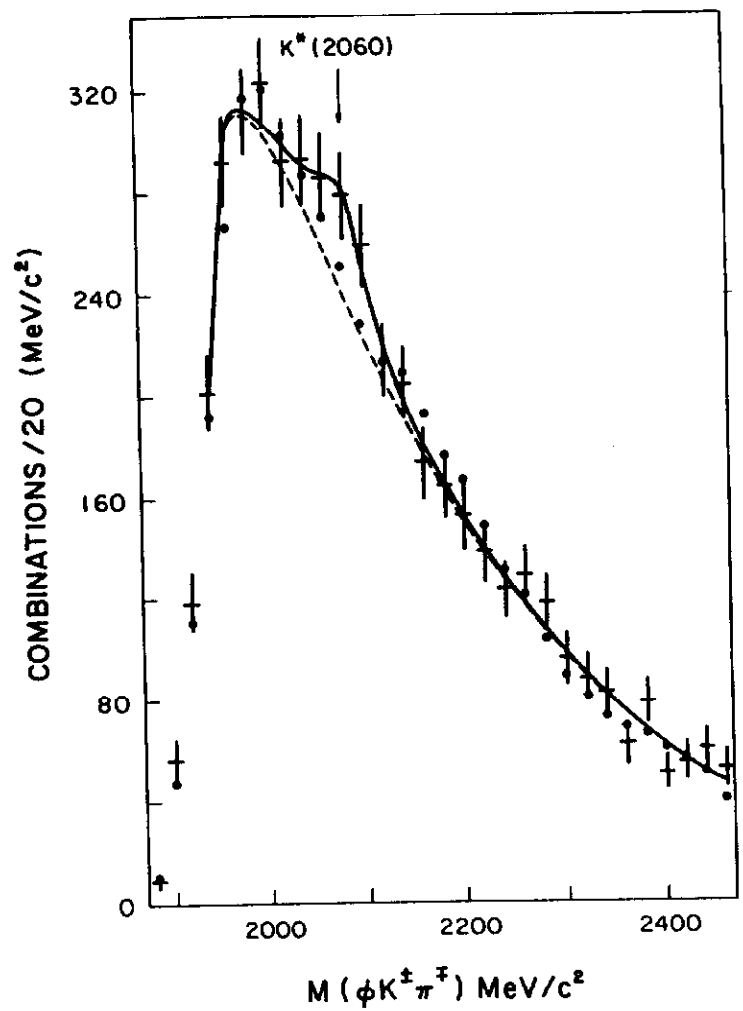
K*(2060)
COMBINATIONS/20 (MeV/c²)
0
80
160
240
320
2000
2200
2400
M (φK±π∓) MeV/c²

Fig. 3.

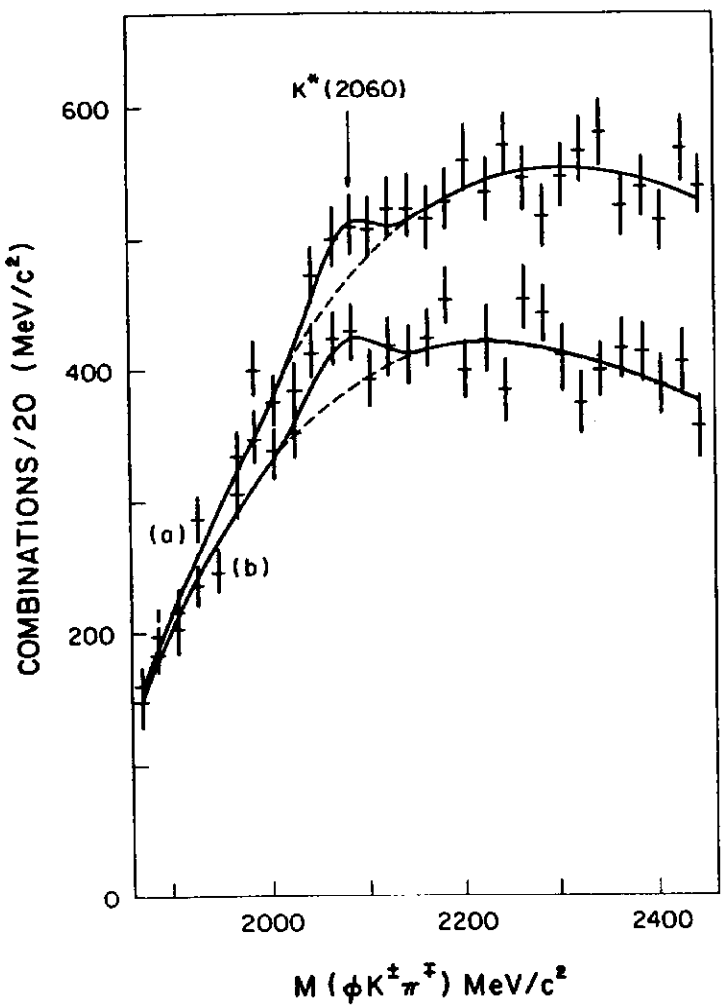
K*(2060)
600
400
200
0
(a)
(b)
COMBINATIONS/20 (MeV/c²)
2000
2200
2400
M (φK±π∓) MeV/c²

Fig. 4.