Study of $K^*(1780)$ in the Reaction $K^-p \rightarrow K^-\pi^+n$ at 6 GeV/c

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We observe a $K^-\pi^+$ state at 1786 ± 8 MeV with a width 95 ± 31 MeV in the reaction $K^-p \rightarrow K^-\pi^+n$ at 6 GeV/c, from an experiment carried out at the Brookhaven National Laboratory multiparticle spectrometer.

There have been numerous reports on K^* states decaying into $K\pi$ with masses between 1.7 and 2.0 GeV. However, there is very little agreement on the mass, width, and even the number of distinct states in this region.[1-7] We report in this Letter results of a high-statistics experiment on high-mass K^* production, in the reaction $K^-p \rightarrow K^-\pi^+n$ at 6 GeV/c, which shows a single, narrow bump at 1786 MeV.

Our K^* experiment has been carried out at the Brookhaven National Laboratory (BNL) multiparticle spectrometer (MPS) with a 50-cm-long liquid hydrogen (LH_2) target and the medium-energy separated beam tuned to K^- at 5.94 GeV/c.[8] Triggers were designed to be sensitive to wide-angle two-prong events, so that the acceptance tends to favor high $K^-\pi^+$-mass events with a maximum near 1.5 GeV. Trigger elements included a cylindrical scintillation hodoscope (S) and a cylindrical multiwire proportional chamber (C), both surrounding the target, a water Čerenkov counter (H) on the open side of the magnet for pion identification,[9] and two planar multiwire proportional chambers (P and Q) downstream of the target, as shown in Fig. 1. S was segmented into three separate parts, two semicylinders R and L and a circular disk D downstream of the target. Similarly C was divided into two separate readouts R and L, and P into three parts, L, C, and R.

The trigger logic was designed to pick up two distinct types of two-prong topologies; A SIDE event corresponds to a π^+ going to the water Čerenkov counter and a K^- going downstream approximately parallel to the beam line, while a DOWN event corresponds to both the π^+ and the K^- going downstream. Thus, the trigger requirements were, respectively,

$$T_{\rm SIDE} = BS_L(S_R+S_D)[C_L]^1\bar{C}_R\bar{P}_L[P_C]^1\bar{P}_R[Q]^1H,$$

$$T_{\rm DOWN} = BS_R(S_L+S_D)\bar{C}_L[C_R]^1\bar{P}_L[P_C]^1[P_R]^1[Q]^2\bar{H},$$

where B stands for the K^- beam signal and the superscripts denote the required multiplicity in each trigger proportional wire chamber. Capacitive-readout spark chambers R_1, R_2, R_3, and R_4

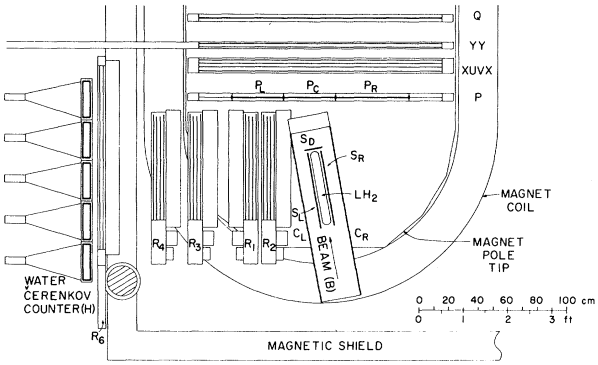

FIG. 1. Schematic drawing of the target region at the upstream end of the MPS magnet. Trigger elements S, C, P, Q, and H are shown as heavy lines (the subscripts denote segmentations in the readout). Off-line track measurements were done with capacitive- and magnetostrictive-readout spark chambers, each measuring planes shown as medium-heavy lines. The spark chambers denoted YY and $XUVX$ are the two upstream-end modules of a set of fourteen such modules situated within the MPS magnet.

were used to measure wide-angle tracks going towards the water Čerenkov counter, and magnetostrictive-readout MPS spark chambers were used to measure tracks downstream of the target.

In a 220-h alternating-gradient-synchrotron run, we have accumulated a data sample of $\simeq 8 \times 10^4$ events for the reaction $K^-p \to K^-\pi^+n$ at 6 GeV/c with a total K^- flux of 1.8×10^9. The visible sensitivity of our data has been calculated by estimating the inefficiencies in the apparatus and the processing programs, as well as the geometry acceptance obtained by processing through our acceptance program the BNL bubble-chamber data of $K^-p \to K^-\pi^+n$ at 7.3 GeV/c.[10] After applying several cuts designed to enhance the neutron signal, such as a tight target cut, vertex- and kinematic-fit χ^2 cuts, kinematic cuts[11] to remove $K^-p\pi^0$ events, and a peripheral cut $t'(p\to n) < 1.0$ GeV^2, we have accepted for the final moment analysis a total of 11100 SIDE events and a total of 23 030 DOWN events. The combined visible sensitivity of our final sample is 132 events/μb.

The $K^-\pi^+$ mass $[M(K^-\pi^+)]$ spectrum is shown for SIDE and DOWN events in Figs. 2(a) and 2(b), respectively (upper solid histograms). In addition to the dominant $K^*(1420)$ bumps, statistically significant bumps appear near 1780 MeV for both SIDE and DOWN events. In order to demonstrate that the bump is not due to a falloff in the acceptance for the high-mass region, we replot the SIDE and DOWN events, weighting each event by $1/A(\Omega_J)$, where $A(\Omega_J)$ is the probability for ob-

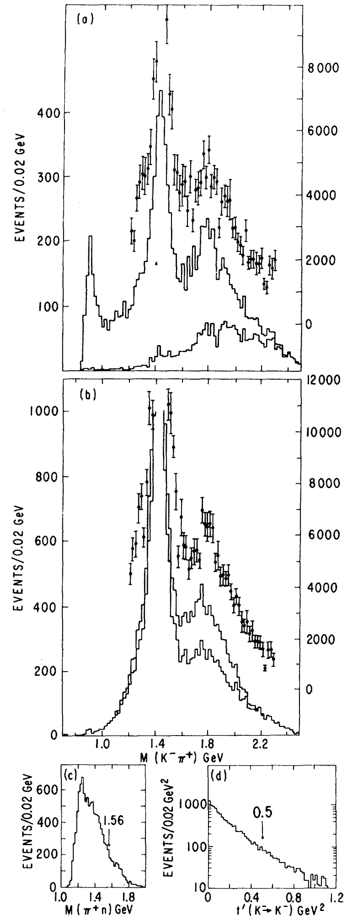

FIG. 2. (a) $M(K^-\pi^+)$ spectra for SIDE events. Histogram with error bars is that corrected for geometry acceptance. Upper solid histogram is the raw MPS data with cuts described in the text. The lower solid histogram is that corresponding to a further cut designed to enhance nondiffractive events. (b) Same as (a) for DOWN events. (c) $M(\pi^+n)$ spectrum for SIDE events. (d) $t'(K^-\to K^-)$ distribution for SIDE events.

serving an event with a given kinematic configuration (see below for details). The resulting $M(K^-\pi^+)$ spectra, shown with statistical error bars in Figs. 2(a) and 2(b), exhibit clearly the enhancement at 1786 MeV, showing that the high-mass falloff is not due to the geometry of our apparatus.

It should be emphasized that the bump for SIDE events comes from the region $\cos\theta_J \simeq 1$ (θ_J is the Jackson angle), which kinematically overlaps the diffractive-dissociation region (the DD region) for p(target) $\to \pi^+n$ as seen in Figs. 2(c) and 2(d). If one selects the predominantly nondiffractive region [defined by $M(n\pi^+) > 1.56$ GeV or $t'(K\to K) > 0.5$ GeV^2], one finds little evidence for a 1786-MeV bump in the SIDE events; see the lower solid histogram in Fig. 2(a). The DOWN events, which have a larger $\cos\theta_J$ acceptance, continue to exhibit structure in the 1786-MeV region even with the nondiffractive cut, as seen in the lower solid histogram in Fig. 2(b). We conclude, therefore, that there exists a genuine resonance at 1786 MeV with a strong asymmetry in the $\cos\theta_J$ distribution, peaking in the DD region at our energy.[2] We have fitted the structure with an s-wave Breit-Wigner form over a smooth polynomial background. The resulting masses and width are 1780 ± 13 and 97 ± 48 MeV for SIDE events and 1793 ± 10 and 93 ± 38 MeV for DOWN events.[12] The consistency of the parameters between SIDE and DOWN events indicates that the DD background, if it interferes with the resonance, is mostly imaginary relative to the Breit-Wigner resonance phase and relatively constant through the resonance region.

We have performed a maximum-likelihood analysis on the experimental moments combining SIDE and DOWN events together. For the purpose, both the angular distribution and the acceptance are expanded in terms of the moments,

$$I(\Omega_J) = \sum_{LM} \left(\frac{2L+1}{4\pi}\right) H(LM)\, D_{M0}{}^{L*}(\varphi_J, \theta_J, 0)$$

and

$$A_{S,D}(\Omega_J) = \sum_{LM} (2L+1) G_{S,D}(LM) D_{M0}{}^{L*}(\varphi_J, \theta_J, 0),$$

where $\Omega_J = (\theta_J, \varphi_J)$ describes the direction of the K^- in the Jackson frame and A_S (A_D) is the SIDE (DOWN) acceptance.[13] The acceptance moments $G_S(LM)$ and $G_D(LM)$ have been calculated by passing the Monte Carlo–generated phase-space events through our SIDE and DOWN acceptance programs.[14] The logarithm of the extended likelihood function[15] to be maximized is given by

$$\mathcal{L} = \sum_{i=1}^{N_S+N_D} \ln I(\Omega_J{}^i) - \sum_{LM} [G_S(LM) + G_D(LM)] H(LM),$$

where the unnormalized moments $H(LM)$ are the variables to be fitted, and N_S (N_D) is the number of SIDE (DOWN) events in a given mass bin.

We have used as variables in the fit those moments $H(LM)$ with $L \leq 6$ and $M \leq 2$ for the mass region between 1.2 to 2.1 GeV.[16] The results are shown in Fig. 3, where the unnormalized moments $H(00)$, $H(40)$, $H(50)$, and $H(60)$ are given. Again, a clear bump at 1786 MeV emerges with its mass and width consistent with those given earlier. The prominent peaks at 1420 MeV for $H(20)$ (not shown) and $H(40)$ but not for $H(60)$ confirm once again that the $K^*(1420)$ has spin 2. Likewise, the structure seen near 1800 MeV in $H(20)$ and $H(40)$ demands that the spin for $K^*(1780)$

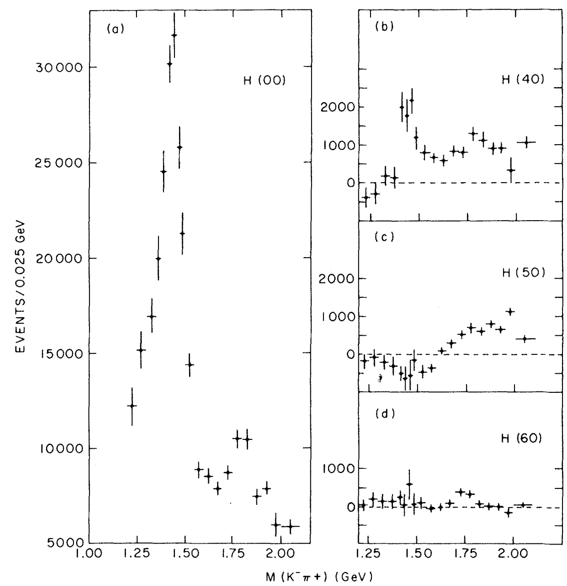

FIG. 3. Unnormalized moments $H(00)$, $H(40)$, $H(50)$, and $H(60)$ obtained from a maximum-likelihood fit in the $M(K^-\pi^+)$ region between 1.2 and 2.1 GeV.

must be equal to or greater than 2. The structure seen in this region in $H(60)$, although weak, indicates that the spin is at least 3, as suggested also by previous experiments.[1,5,6] A rapid rise and a shoulder in this resonance region of the moments $H(10)$, $H(30)$ (not shown), and $H(50)$ give additional support for a spin-3 object which presumably interferes with the DD events. A more complete analysis showing all the fitted moments as well as the detailed exposition of the techniques involved will be given in a future publication.

In summary, we conclude that there exists a K^* state with mass 1786 ± 8 MeV, width 95 ± 31 MeV, and spin and parity 3^- (or higher) which is produced predominantly, but not entirely, in the diffractive-dissociation region at our energy. Our experiment shows the best $K^*(1780)$ signal to date in the $K^-\pi^+$ spectrum. The seemingly contradictory reports of the mass and width of this resonance in the past are, as have been noted by others previously, most likely due to the fact that it is produced with a substantial overlap with diffractive dissociation. Because of our excellent coverage of the region $\cos\theta_J \simeq 1$, this resonance can be seen in our data already in the raw mass spectrum before any acceptance corrections. Our data indicate that the diffractive amplitude, if it interferes with the K^* resonance, is relatively monotonic in the resonance region and mostly imaginary relative to the Breit-Wigner resonance wave. We estimate that the product of cross section by branching ratio is 18 ± 7 μb for $K^*(1780)$ in the final state $K^-\pi^+n$ at 6 GeV/c, where the error includes systematic uncertainties in the normalization.

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[10]We emphasize that the acceptance has been calculated from real bubble chamber data (Ref. 3) at 7.3 GeV/c, kinematically transforming them to simulate those at 6 GeV/c.

[11]It was found that some of the $K^-p\pi^0$ background in the DOWN sample can be eliminated by leaving out events with low $t(p\to p)$ and extreme backward $\cos\theta_J(p\pi^0)$. These cuts have been devised to eliminate peripheral quasi two-body final states for the state $K^-p\pi^0$, where the π^0 can emanate from the meson vertex or from the baryon vertex. The same cuts have been applied to the Monte Carlo events to correct for the resulting bias in the $K^-\pi^+n$ sample.

[12]The width is sensitive to the shape of the assumed background. Quoted errors include uncertainties in the background shape. The experimental resolution in this mass region is estimated to be 20 MeV (rms) for SIDE events and 12 MeV (rms) for DOWN events. (There may be additional systematic errors of about 10 MeV.)

[13]Our moments $H(LM)$, which should be real from parity conservation, are related to the usual $\langle Y_{LM}\rangle$ by $H(LM)=[4\pi/(2L+1)]^{1/2}\,\mathrm{Re}\,\langle Y_{LM}\rangle$.

[14]In reality, the phase-space events have been modified according to $\exp[-bt'(p\to n)]$, where the slope b was determined as a function of $M(K^-\pi^+)$ from the BNL bubble chamber data (Ref. 3).

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[16]There are indications that for $M(K^-\pi^+)>2$ GeV the moments with $L>6$ are required to fit the data adequately.

Observation of Striking Shape Differences between 2_1^+ Angular Distributions for Heavy-Ion-Induced Two-Neutron Stripping and Pickup Reactions in Transitional Samarium Nuclei

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The reactions ^{148}Sm(^{18}O $\leftrightarrow$ ^{16}O)^{150}Sm and ^{150}Sm(^{12}C, ^{14}C)^{148}Sm have been performed as part of a heavy-ion study of the transitional samarium region. The angular distributions for the ground-state transitions have a typical bell shape. While the 2_1^+ angular distribution is bell shaped in the stripping reaction, it is flat with an interference minimum in both pickup reactions. The striking difference between the 2_1^+ angular distributions is not explained satisfactorily by current theories.

The even-even samarium isotopes are characterized by a rapid change of the nuclear structure with neutron number ($^{144}_{62}$Sm$_{82}$ is semiclosed while $^{154}_{62}$Sm$_{92}$ is a good rotor). Energy levels and electromagnetic moments of many of these isotopes have been explained (and in some cases