Measurement of the Radiative Width of the $K^{*+}(890)$

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Coherent production of $K\pi$ systems observed in the excitation of 200-GeV/c positive kaons on nuclear targets has been analyzed, including both electromagnetic and strong contributions, to yield a new value for the radiative width for the process $K^{*+}(890)\rightarrow K^+\gamma$ of 51 ± 5 keV.

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Radiative decays of vector mesons present one of the simplest regimes for testing unitary symmetry schemes and quark models of hadrons. In particular, the decay (vector meson) $\rightarrow$ (pseudoscalar meson) $+\gamma$, which can be interpreted as a magnetic dipole transition between two quark levels, provides a rather sensitive probe of the symmetry of quark-antiquark systems. Much theoretical work has been devoted to the phenomenology of such decays from the viewpoint of unitary symmetry, simple quark models, and vector-dominance ideas.[1]

Predictions for the rates $K^{*\pm}(890)\rightarrow K^\pm\gamma$ and $K^{*0}\rightarrow K^0\gamma$ are independent of octet-singlet mixing within the vector or pseudoscalar nonets. Also, as a result of the near equality of the $K^{*\pm}$ ($K^\pm$) and K^{*0} (K^0) masses, predictions for the ratio of widths $\Gamma(K^{*0}\rightarrow K^0\gamma)/\Gamma(K^{*\pm}\rightarrow K^\pm\gamma)$ are insensitive to final-state phase-space factors. Assuming that quark magnetic moments are simply proportional to the quark charges yields a value of 4.0 for this ratio. If we take the quark moments, instead, to be given by values extracted from measurements of baryon magnetic moments[2,3] [i.e., allowing a phenomenological SU(3) symmetry breaking], the ratio becomes 1.64. The absolute predictions for $K^{*\pm}\rightarrow K^\pm\gamma$ range between 46 keV [nonrelativistic phase space and exact SU(3)] and 122 keV [for relativistic phase space with SU(3) breaking].[4]

We have studied the coherent reactions (1) $K^+Z\rightarrow K^+\pi^0Z$ and (2) $K^+Z\rightarrow K_s{}^0\pi^+Z$, using 200-GeV/$c$ kaons incident on copper and lead targets. We have extracted the partial width for the decay $K^{*+}(890)\rightarrow K^+\gamma$ by means of a Primakoff analysis of the inverse reaction $K^+ +\gamma\rightarrow K^{*+}(890)$,[5] where the photon is supplied by the Coulomb field of the target nucleus. At high energies the extraction of radiative widths becomes less sensitive to the pheonomenology of the nuclear models employed in the analysis.[6] We used copper and lead targets (0.44 and 0.22 radiation length thick, respectively) to check the scaling behavior of the Coulomb and of the competing strong production mechanism (ω exchange) with nuclear charge Z and nucleon number A. Data were also taken without a target in position for performing background (empty-target) subtractions.

The total coherent differential cross section can be written as $d\sigma/dt=|T_C+e^{i\varphi}T_s|^2$, where T_C and T_s represent, respectively, the electromagnetic and strong amplitudes, and φ is the relative phase. The formalism for calculating T_C and T_s, which depend on nuclear form factors, is presented elsewhere.[6-8] For our purposes, we need only say that $\Gamma(K^{*+}(890)\rightarrow K^+\gamma)$ is proportional to $|T_C|^2$, and that $|T_s|^2$ is proportional to C_s, a normalization factor for strong coherent production on single nucleons.

The experiment was carried out in a secondary beam at the meson detector building of Fermilab. The kaon fraction of the beam was enriched through selective hadron filtration, using a beryllium absorber,[9] from a nominal value of 2.5% to ~15%. The kaon flux at the experimental target was typically $(4-5)\times 10^4 K^+$/sec. We utilized a forward high-resolution spectrometer optimized for precision charged-particle tracking and momentum determination, as well as for accurate position and energy measurements of high-energy photons.[10] The detailed layout of our spectrometer is presented elsewhere.[11]

Veto counters surrounding the target were used to select coherently produced events such as $K^{*+}(890)$ final states of reactions (1) and (2). Concurrently, with these events, topologically similar beam decays $K^+\rightarrow\pi^+\pi^0$ ($K_{\pi 2}$) and $K^+\rightarrow\pi^+\pi^+\pi^-$ ($K_{\pi 3}$) were collected, for use in Monte Carlo and resolution studies.[11]

The trigger for reaction (1) required that only one charged track leave the target and only one charged track be counted in the downstream charged-particle spectrometer. Also, a minimum energy (~10 GeV) was required to be deposited in either the upper or lower half of our photon calorimeter, with no same-half accompanying charged particle. The trigger for reaction (2) required one charged particle to leave the target, and three charged tracks to be detected downstream. Both triggers required that the beam particle be tagged by at least one of the Cherenkov counters, and that charged particles be scattered by more than 0.3 mrad from the incident beam direction.

Monte Carlo simulations of reactions (1) and (2) indicated that the transverse momentum (p_T) resolutions for the two $K^{*+}(890)$ decay modes were essentially the same; namely, 14 and 12 MeV/c, respectively, for the copper and lead targets. This information was used to account for resolution smearing of the experimental t distributions for $K^{*+}(890)$ production.

The beam K^+ decays were also used to normalize the topologically similar $K^{*+}(890)$ yields to the observed yields of beam K^+ decays. This procedure obviated the need for relying on absolute trigger, reconstruction, and analysis efficiencies.

To isolate $K^{*+}(890)$ events produced in reactions (1) and (2), the following criteria were applied in data analysis: (i) that there be a single incident beam particle per event and that it be tagged as a kaon, (ii) that there be one charged track and two photons (or three charged tracks) reconstructed in the final state, (iii) that the total reconstructed event energy be consistent with the incident beam energy, and (iv) that the reconstructed interaction point be in a small range centered on the target. [Because there was no particle identification downstream of the target, in calculating the invariant mass we assumed that the charged particles were kaons for reaction (1), and pions for reaction (2).]

For reaction (1), we also required (v) that the 2γ invariant mass be in accord with that expected for a π^0, and (vi) that the invariant mass for the final state, assuming a π^+ interpretation for the charged track, be greater than 0.580 GeV. This last cut was needed to diminish the background from $K_{\pi 2}$ decays that contaminated reaction (1). This restriction reduced the K^* yield by ~25% and cut out primarily low-mass $K\pi$ events. The effects of this cut can be seen in the sharp drop in acceptance at low masses in Fig. 1(a).

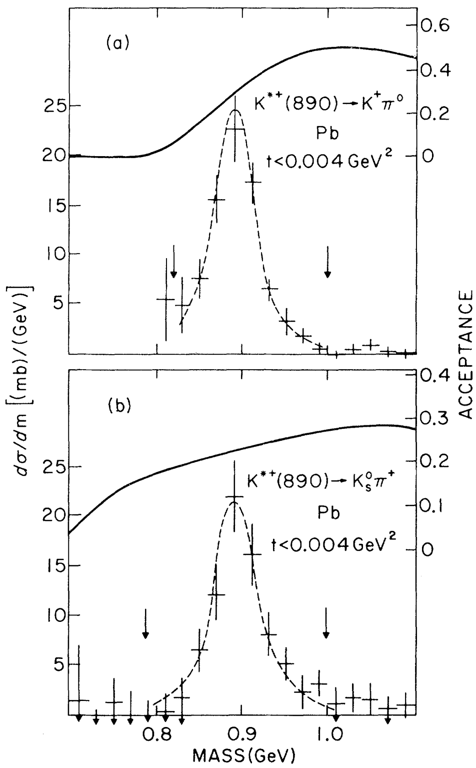

FIG. 1. Fully corrected $K\pi$ mass distributions with fits assuming p-wave decay of coherently excited $K\pi$ systems. The total acceptances as a function of mass are given by the smooth curves above the data.

For reaction (2), we imposed the further constraint that two oppositely charged particles form a neutral vee in the decay tank, and have an invariant mass (assuming both to be pions) consistent with that of a K_s^0.

Figures 1(a) and 1(b) show the $K\pi$ invariant-mass distributions for events produced on the lead target for $t < 0.004$ GeV^2. These data have been corrected for branching ratios and acceptance,[12,13] normalized to beam K^+ decays, and corrected by an empty-target subtraction (typically 2%–3%). The distributions show clear $K^{*+}(890)$ signals. The superimposed curves are fits to the data, in the range between the arrows, assuming a relativistic p-wave Breit-Wigner line shape distorted by the coherent production processes.[13] These fits give resonant parameters consistent with world averages. The solid curves above the distributions show the acceptance as a function of mass.

Figures 2(a) and 2(b) show the differential cross sections in t for $K^{*+}(890)$ events found in reactions (1) and (2), respectively. The sharp forward peaks characterize Primakoff production,

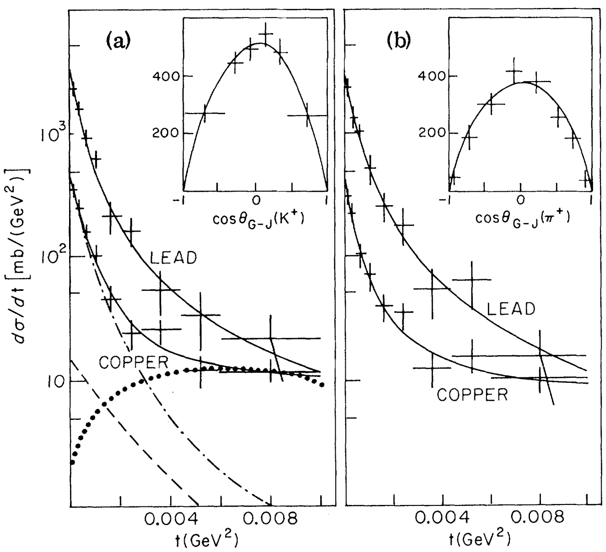

FIG. 2. Fully corrected t distributions for $K^{*+}(890)$ events with fits to the data (solid curves). The components of the fit for copper in (a), namely the Coulomb (dot-dashed curve), the strong (dotted curve), and the interference term (dashed curve), are also shown. Insets: The corrected Gottfried-Jackson decay-angle distributions, with the expected $\sin^2\theta$ dependence superimposed.

which scales as the square of the nuclear charge; the weaker dependence at larger t values is due to coherent strong production. The superimposed solid curves are the results of three-parameter fits, based on an optical model for the nucleus. In Fig. 2(a) we show, after resolution smearing, the three separate contributions to the fit for copper, namely, the Coulomb, the strong, and the interference terms. The insets in Fig. 2 are the decay-angle distributions in the Gottfried-Jackson frame, summed for the two targets. Results follow the expected $\sin^2\theta$ form for coherent $K^*(890)$ production. Results of the parametrization are given in Table I. Results of a global fit to the four data sets for $t < 0.01$ GeV^2, assuming Γ_γ, C_s, and φ to be independent of target material, are also given in Table I.

The sensitivity of the extracted values of $\Gamma(K^{*+}(890) \to K^+\gamma)$ to the fitting procedure was investigated by separately fixing C_s and φ in the ranges 1–4 mb/GeV^4 and 0–2π, respectively, and repeating the fits.[11] In no case did Γ_γ vary by more than two standard deviations from the values quoted in Table I. Single-parameter fits with C_s constrained at 0 (i.e., assuming pure Coulomb production) yielded an average value for Γ_γ of 62 ± 2 keV, where the quoted error is purely statistical.

Systematic effects on the fitted results for Γ_γ include contributions from uncertainties in the normalization to K^+ decays [estimated to be 5% for reaction (1) and 10% for reaction (2)], and from uncertainty in the p_T resolution, which is an input to the fitting formalism. Changing the p_T resolution by ±10% resulted in variations in Γ_γ of ~±8%. Because we believe that we know the p_T resolution to ±5%, we estimate a ±4% systematic error due to this uncertainty.

Taking a weighted average of the fitted values for Γ_γ (weighted by the inverse squares of the statistical errors) yields $\Gamma(K^{*+}(890) \to K^+\gamma) = 51 \pm 3 \pm 4$ keV, where the errors represent overall statistical and systematic uncertainties, respectively. If we add these sources of error in quadrature, we have the result $\Gamma(K^{*+}(890) \to K^+\gamma) = 51 \pm 5$ keV, which implies a radiative branching ratio for the $K^{*+}(890)$ of (0.10 ± 0.01)%.

This measurement is in agreement with the upper limit of 80 keV first reported for the

TABLE I. Results of the parametrization of the $K^{*+}(890)$ data (all errors are statistical).

Reaction type[a]	Target	Γ_γ (keV)	C_s (mb/GeV^4)	φ (deg)	χ^2/DF
(1)	Cu	62 ± 6	2.9 ± 1.0	85 ± 26	6.1/6
(2)	Cu	51 ± 7	2.8 ± 1.1	85 ± 32	4.4/6
(1)	Pb	48 ± 4	4.2 ± 2.0	84 ± 28	8.6/6
(2)	Pb	47 ± 6	4.9 ± 2.2	82 ± 30	5.8/6
Global fit[b]		51 ± 3	2.4 ± 0.8	64 ± 26	31/33

[a]There are, respectively, 333 events, 177 events, 486 events, and 256 events with $t < 0.01$ GeV^2 in the individual data samples.

[b]Fit to all data constraining Γ_γ, C_s, and φ to be independent of target material.

$K^{*+}(890)$.[8] It also agrees with the first, but statistically poorer, measurement by our group [for the charge conjugate $K^{*-}(890)$; Berg *et al.*, Ref. 6].

If we compute the ratio of the rate for $\overline{K}^{*0} \to \overline{K}^0\gamma$ decay[14] to the rate we have measured for $K^{*+} \to K^+\gamma$, we obtain 1.47 ± 0.70. This is in excellent agreement with expectations from broken SU(3) symmetry, where the effective magnetic moments of quarks are deduced from baryon magnetic moments. However, the absolute rate for $K^{*+}(890) \to K^+\gamma$ agrees best with predictions of nonrelativistic quark models that do not provide phenomenological SU(3) symmetry breaking.[4] Clearly, in addition to an improved measurement of the radiative width of the K^{*0}, a complete theoretical reappraisal of vector-meson radiative decays is in order.

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[12]The acceptance calculation includes all corrections, namely geometry, trigger efficiency, analysis cuts, π^0 conversion, absorption in targets, spectrometer, etc.

[13]For details see Jensen *et al.*, Ref. 6, and Chandlee, Ref. 11.

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