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<sup>2</sup>If all  $\psi$  production were via  $\psi'(3.7)$  production only ( $7 \pm 4\%$ ) of the yield in the  $\psi$  region of our data would be from  $\psi'(3.7) \rightarrow \mu^+ + \mu^-$ . This is based on the branching ratios from A. M. Boyarski *et al.*, Phys. Rev. Lett. **34**, 1357 (1975), and J. A. Kadyk *et al.*, Lawrence Berkeley Laboratory Report No. 3687 (unpublished).

<sup>3</sup>Fits to  $d^2\sigma/dx dP_{\perp}^2 \propto \exp(-b' P_{\perp}^2)$  give  $b_{\pi'} = 0.81 \pm 0.14$  GeV<sup>-2</sup> and  $b_{\psi'} = 1.1 \pm 0.3$  GeV<sup>-2</sup>.

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## Measurement of the Radiative Decay Width $\Gamma(\bar{K}^{*0}(890) \rightarrow \bar{K}^0\gamma)$

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The differential cross sections for coherent production of  $\bar{K}^{*0}(890)$  were measured with nuclear targets. These measurements are interpreted using a two-component model which accounts for Coulomb production and  $\omega$  exchange. The radiative decay width is determined to be  $\Gamma(\bar{K}^{*0}(890) \rightarrow \bar{K}^0\gamma) = 75 \pm 35$  keV, which is 3 times lower than expected from a simple quark model.

Exact SU(3) symmetry leads to definite relations among the radiative widths for the various examples of the generic reaction: vector meson - pseudoscalar meson +  $\gamma$ .<sup>1</sup> In a less restrictive quark model, the rate for this reaction is proportional to the transition magnetic moment between quark levels.<sup>2</sup> In either case, the octet radiative transition is an important (electromagnetic) probe of SU(3) symmetry breaking. Following the original suggestion of Primakoff,<sup>3</sup> several experiments have measured radiative widths using virtual photons in the Coulomb field of heavy nuclei as a target. We report a measurement of the radiative width  $\Gamma(\bar{K}^{*0} \rightarrow \bar{K}^0\gamma)$  using the Primakoff effect.

The experiment was carried out in the 4.7° neutral beam at the Brookhaven National Laboratory alternating gradient synchrotron (AGS). The  $\bar{K}^0$  component of the incident  $K_L^0$  beam produces  $\bar{K}^{*0}$  coherently from the target nuclei according to

$$\bar{K}^0 + A \rightarrow \bar{K}^{*0}(890) + A \rightarrow K^- \pi^+ \quad (1)$$

The outgoing  $K^- \pi^+$  system was detected in a modified version of a proportional-wire-chamber spectrometer originally developed for  $K_L^0$  decay studies and described in detail by Carithers *et al.*<sup>4</sup> Pions were identified with a threshold Cherenkov counter.

Thin targets of Pb, U, Cd, Cu, Al, and C ranging in thickness from 0.1 to 0.25 radiation lengths were used. The targets were enclosed in an evacuated volume and surrounded by a lead-scintillator-sandwich anticoincidence system to suppress nuclear breakup reactions.

The  $K_L^0$  beam decays provide a convenient calibration reference for measuring both the  $t'$  resolution and the flux normalization. A 50-cm decay region upstream of the target was maintained under vacuum and events with a vertex in this region were identified as  $K_L^0$  decays. Thus the relative cross-section normalization for the six targets was provided by  $K_L^0 \rightarrow$  (all charged) decays. Since these data were recorded simultaneously with Reaction (1), beam-rate effects and ineffi-

ciencies cancel. The absolute normalization was obtained from special runs taken with the target removed. Here the two-body decay  $K_L^0 \rightarrow \pi^+\pi^-$  was identified and the ratio  $(K_L \rightarrow \pi^+\pi^-)/(K_L \rightarrow \text{all charged})$  was measured. A Monte Carlo calculation of the  $K_L \rightarrow \pi^+\pi^-$  acceptance then provides the absolute flux normalization factor. The combined systematic and statistical error on the absolute normalization is estimated to be 30% and the error on the relative normalization to be 10%.

Since the  $K_L^0 \rightarrow \pi^+\pi^-$  decays have no missing transverse momentum, they provide a measure of the  $t'$  resolution near  $t'=0$  where Coulomb effects are important. We measure the resolution in the scattering angle,  $\theta_{\pi\pi}$ , between the reconstructed  $\pi^+\pi^-$  total momentum and the incident  $K_L^0$  to be 0.6 mrad. From these data, we infer a  $t'$  resolution of  $0.0004 \text{ (GeV}/c^2)^2$  and a 6-MeV (standard deviation) mass resolution for the  $K^-\pi^+$  data in the Coulomb region at the average incident momentum.

A total of 21858 events with  $K^-\pi^+$  total momentum,  $P$ , between 8 and 16 GeV/c survived the geometric and kinematical cuts. The  $K^-\pi^+$  invariant mass distribution for these events is shown in Fig. 1. The major source of background in the experiment comes from coherent production of the three-body enhancement in the 1.3–1.4-GeV

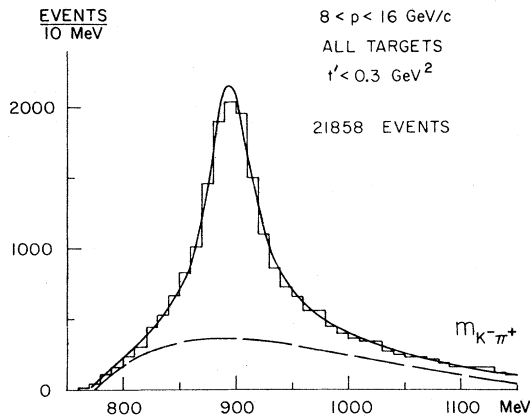


FIG. 1. Invariant mass distribution of the  $K^-\pi^+$  system. The distribution is not corrected for the acceptance which is zero below 770 MeV. The solid curve is the result of fitting a relativistic Breit-Wigner function and an empirical expression for the nonresonant background. The resonance parameters were fixed at the literature values,  $m_0 = 896.5 \text{ MeV}$ ,  $\Gamma_0 = 50.6 \text{ MeV}$  (Ref. 5).

region usually referred to as the  $Q$  region:

$$\bar{K}^0 + A \rightarrow \bar{Q}^0 + A.$$

$$\quad \quad \quad \downarrow$$

$$\quad \quad \quad K^-\pi^+(\pi^0).$$

A background subtraction was applied by performing fits similar to those in Fig. 1 to the mass distributions for each nuclear species and each  $t'$  bin independently. The resulting  $t'$  distributions are shown in Fig. 2. A forward dip and first-diffraction minimum are clearly visible in the case of the heavy elements.

The angular distributions in the Gottfried-Jackson (GJ) frame are shown in Fig. 3. Although the expected  $\sin^2\theta_{GJ}$  distribution is badly distorted by acceptance effects, the data are reproduced by a Monte Carlo simulation assuming a  $\sin^2\theta_{GJ}$  distribution. The azimuthal distribution agrees well with a  $(1 + a \sin^2\varphi_{GJ})$  distribution expected for both one-photon and  $\omega$  exchange. The angular distributions can be used to place a limit of 10% on the remaining contamination from  $\bar{Q}^0$  production for the Pb data.

The background-subtracted  $t'$  distributions are interpreted in terms of a model developed for co-

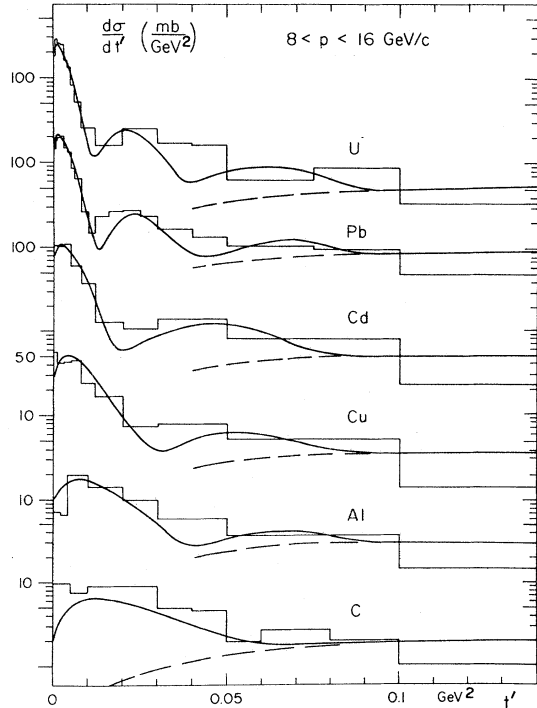


FIG. 2. Differential cross sections for the six nuclear targets. The model curves include a correction for experimental resolution. The incoherent contributions are shown as dashed lines.

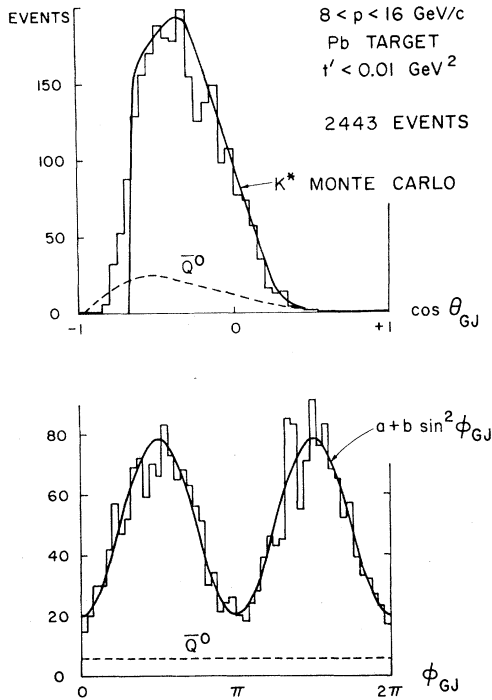


FIG. 3. Decay angular distributions in the Gottfried-Jackson frame. The curves are the results of Monte Carlo calculations for  $\bar{K}^*(890)$  production (solid lines) and  $\bar{Q}^0$  production misinterpreted as  $\bar{K}^*(890)$  production (dashed lines).

herent production of the  $K^{*+}(890)$ .<sup>6</sup> The differential cross section can be expressed as

$$d\sigma/dt' = |T_C + e^{i\varphi} T_S|^2 + d\sigma_I/dt',$$

where  $T_C$  is the Coulomb amplitude proportional to  $\sqrt{\Gamma_{K^*K\gamma}}$ ,  $T_S$  is the  $\omega$ -exchange amplitude proportional to a scale factor  $\sqrt{C_S}$ , and  $d\sigma_I/dt'$  is the incoherent contribution from  $K^*$  production on individual nucleons. Both  $T_C$  and  $T_S$  contain nuclear form factors calculated with an optical-model integration over the nuclear density, assumed to be of the Woods-Saxon type for the strong-interaction term. The angle  $\varphi$  is the relative phase between the Coulomb and  $\omega$ -exchange amplitudes.

The nuclear radius and skin thickness were taken to be  $1.12A^{1/3}$  fm and 0.545 fm, respectively.<sup>7,8</sup> The only other nuclear parameters which enter are the total cross section,  $\sigma$ , and the ratio of real to imaginary amplitude,  $\alpha$ , for  $\bar{K}^{*0}$  and  $\bar{K}^0$  on single nucleons. These were assumed to be the same as the  $K^-$ -nucleon values;  $\sigma = 21.5$  mb,  $\alpha = -0.1$ .<sup>9,10</sup> This assumption has been checked for  $\bar{K}^0$  in many regeneration experiments and found to be very reliable.

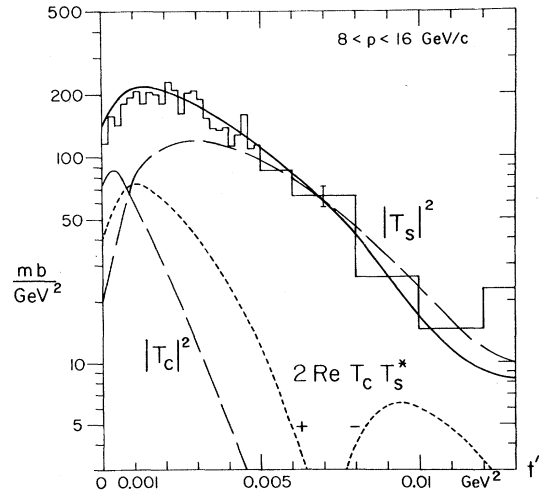


FIG. 4. Enlargement of the small- $t'$  portion of the differential cross section for Pb. The solid curve is the best simultaneous fit to all nuclei. The dashed lines show the Coulomb-, strong-, and interference-term contributions, respectively.

The general features of the differential cross section are well represented by such a two-component model, including the forward dip and first-diffraction minimum. The solid curves of Fig. 2 are the result of a simultaneous fit for  $\Gamma_{K^*K\gamma}$ ,  $C_S$ , and  $\varphi$  to the  $t'$  distributions for the six targets. The incoherent distributions are fixed by the large  $t'$  behavior. The best fit yields the values  $C_S = 12.0$  mb/GeV<sup>4</sup>,  $\Gamma_{K^*K\gamma} = 68$  keV, and  $\varphi = 60^\circ$ .

Figure 4 is an enlargement of the small- $t'$  portion of the differential cross section for Pb including the best-fit model curve. Here the contributions of the pure Coulomb term,  $\omega$ -exchange term, and interference term are separately shown.

The differential cross sections were also fitted under various assumptions to investigate the sensitivity of the fits to the input data. The results of fits in the  $t'$  region corresponding to the forward peak are shown in Table I. Variations in the nuclear parameters result in minor changes in  $C_S$  and  $\Gamma_{K^*K\gamma}$ . The most significant changes are for a radius of  $1.18A^{1/3}$  fm and  $\sigma = 30$  mb. Attempts to fit the data without a Coulomb term ( $\Gamma_{K^*K\gamma} = 0$ ) or with the value given by the quark-model calculation of Ref. 2 ( $\Gamma_{K^*K\gamma} = 280$  keV) give an unacceptably large  $\chi^2$ . We have also made fits to the raw  $t'$  distribution of Pb to establish upper limits,  $C_S < 14.5$  mb/GeV<sup>4</sup> and  $\Gamma_{K^*K\gamma} < 180$  keV, which are independent of the background-subtraction technique.

TABLE I. Results of model fits to the  $t'$  distributions. The error on  $\Gamma_{K^*K\gamma}$  corresponds to a change of  $\chi^2$  by 1.

Data used in the fit	$\Gamma_{K^*K\gamma}$ (keV)	$C_S$ (mb/GeV <sup>4</sup> )	$\chi^2/\text{d.f.}^c$
U	$55^{+40}_{-3}$	10.7	4/5
Pb	$39^{+26}_{-6}$	11.4	6/5
C to U	$72^{+39}_{-30}$	11.8	40/34
Al to U	$50^{+45}_{-6}$	10.9	26/29
Al to U, variation 1 <sup>a</sup>	$87^{+27}_{-40}$	13.5	29/29
Al to U, variation 2 <sup>b</sup>	$85^{+29}_{-43}$	18.0	35/29
Al to U	[0]	15.9	118/29
Al to U	[280]	14.2	64/29

<sup>a</sup>Radius changed to  $1.18A^{1/3}$  fm.

<sup>b</sup> $\sigma$  changed to 30 mb.

<sup>c</sup>d.f. is degrees of freedom.

From the results of all the fits, we conclude that the best values are given by  $C_S = 11 \pm 3$  mb/GeV<sup>4</sup>,  $\Gamma_{K^*K\gamma} = 75 \pm 35$  keV, where the errors contain estimates of the uncertainties in the absolute normalization and the sensitivity to assumptions in the analysis. The data are not sensitive to the relative phase,  $\varphi$ . Values for  $\varphi$  between  $-80^\circ$  and  $+80^\circ$  give acceptable fits. The strong-interaction scale parameter,  $C_S$ , is in reasonable agreement with the value inferred from  $K^{*+}(890)$  production on hydrogen.

This experiment is the first reported measurement of the radiative width  $\Gamma_{K^*K\gamma}$ . It can be compared with the simple quark-model predictions using the well-established  $\omega \rightarrow \pi\gamma$  rate as input.<sup>5,11</sup> The measured value is less than the quark-model prediction by a factor of 3. Such a large discrepancy was unexpected. A recent experiment using a similar technique finds  $\Gamma_{\rho\pi\gamma} = 35 \pm 10$  keV, which is also substantially less than the quark-model prediction.<sup>12</sup> The ratio of the  $\rho$  and  $K^*$  radiative widths, however, agrees very well with the SU(3)

prediction.

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