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Brief Reports

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Limit on the radiative width of the $K^{0*}(1430)$

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An upper limit $\Gamma(K^{0*}(1430)\rightarrow K^0\gamma)<84$ keV (90% C.L.) has been derived from a search for Primakoff production of the $K^{0*}(1430)$ in the energy range 60–200 GeV. The radiative width depends upon the values of the strange- and down-quark magnetic moments and is much smaller than the related radiative width of the $K^{+*}(1430)$. A naive quark-model calculation is presented which explains this result.

Electromagnetic decays of excited hadrons are a proving ground for quark models of hadron structure. Magnetic multipole transitions in particular provide constraints on the values of the quark magnetic moments. While precise experimental results and refined theoretical predictions exist for vector-meson to pseudoscalar-meson magnetic dipole transitions, less attention has been paid to the radiative decays of light-quark tensor mesons. We report and discuss here the first significant limit on the radiative width of the $K^{0*}(1430)$.

The limit was derived from a search for Primakoff production of the $K^{0*}(1430)$. Here Primakoff production refers to the excitation of a high-energy K_L meson by the absorption of a virtual photon from the electromagnetic field of a nucleus.[1] In the narrow-resonance approximation, the excitation differential cross section is related to the radiative width by[2]

$$\frac{d\sigma}{dt}(K^0+Z\rightarrow K^{0*}+Z)$$
$$=\pi\alpha Z^2\frac{2S^*+1}{2S+1}\frac{\Gamma(K^{0*}\rightarrow K^0\gamma)}{k^3}\frac{t-t_{\min}}{t^2}F(t)\ .$$

In this expression, α is the fine-structure constant, Z is the atomic number of the target nucleus, S and S^* are the spins of the K^0 and K^{0*}, respectively, and k is the rest-frame decay momentum in the transition $K^{0*}\rightarrow K^0\gamma$. The four-momentum transfer t has a minimum value $t_{\min}\simeq[(m_*{}^2-m^2)/2P_{\text{lab}}]^2$ where m and m_* are the masses of the K^0 and K^{0*}, respectively. The function F is the nuclear electric form factor including nuclear absorption.

From a measurement of the Primakoff production cross section, the radiative width may be deduced. The excitation amplitudes for the K^0 and anti-K^0 components of the K_L have opposite sign for single-photon exchange. Consequently a K^* produced with a K_L beam decays strongly to the $K_S\pi^0$ final state. Forward produced K^* mesons with this decay mode are a clean signal for Primakoff production. A determination of the radiative width of the $K^{0*}(890)$ by this method was previously performed.[3] Here we extend the analysis to the case of the $K^{0*}(1430)$.

The experiment was carried out in the M-center beam line at Fermilab. The apparatus (Fig. 1) is described in detail elsewhere.[4] Briefly, K_L mesons produced by 400-GeV protons striking a beryllium target were collimated to form two side-by-side beams of rectangular cross section, each subtending a solid angle of about 4×10^{-8} sr. At a distance of 406 m from the production point, a copper target (0.635 cm thick) was placed in one beam and a lead target (0.635 cm thick) was placed in the other. Reaction products from these Primakoff targets were observed simultaneously with a downstream spectrometer. Charged particles were momentum analyzed with a large aperture magnet and four drift chambers. The positions and energies of photons were measured with a 1-m-by-2-m 804-element lead-glass array.

The trigger was designed to select events of the form $K_L+Z\rightarrow K^{0*}+Z\rightarrow(K_S\pi^0)+Z$ with the decay $K_S\rightarrow\pi^+\pi^-$ occurring inside a 12.7-m evacuated decay pipe. The trigger required precisely two hits in both scintillation-counter hodoscopes HV and G and no signal

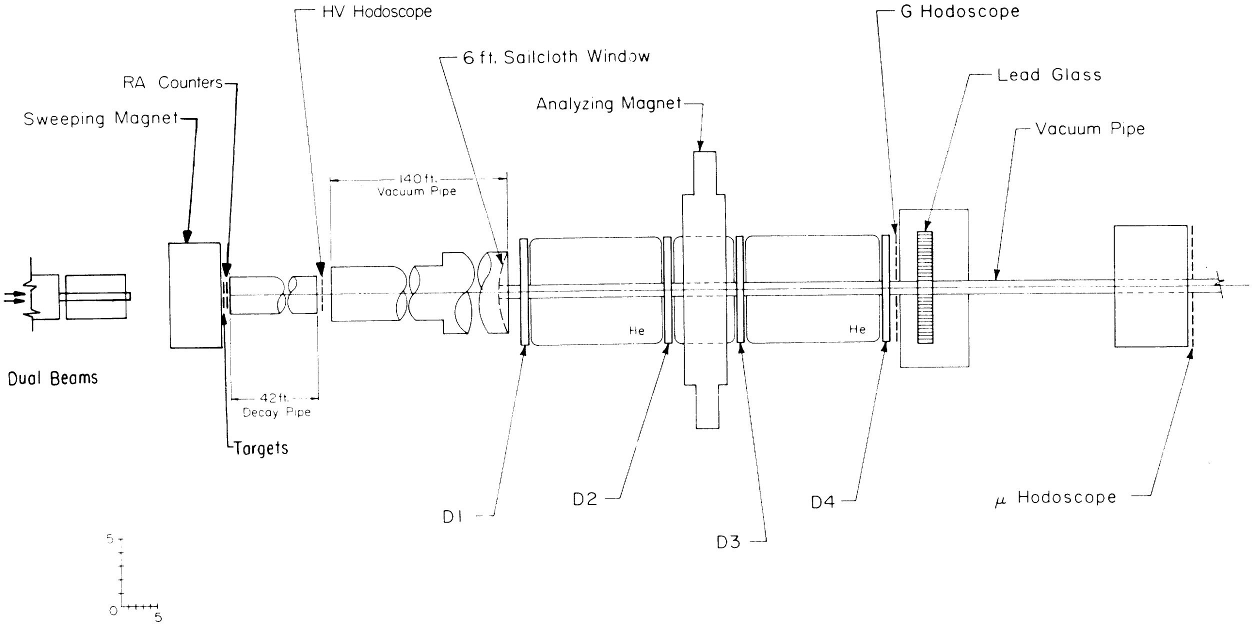

FIG. 1. Schematic of the apparatus.

in either of two target scintillation counters RA. A minimum energy of 1.8 GeV was required in at least one sextant of the lead glass in anticoincidence with G hodoscope counters in front of that region, signaling the presence of a high-energy photon. In addition, scintillation counters placed outside the apertures of the apparatus were placed in veto.

Event reconstruction proceeded as follows. Under the assumption that the charged particles were pions, the K_S momentum vector was reconstructed. This vector was extrapolated through the track vertex to the plane of the Primakoff production targets to determine the transverse location of the K^{0*} production point, in particular the target in which the K^{0*} was produced. This point and the positions and energies of the photons at the lead glass were used to reconstruct the photon momentum vectors. The momentum transfer in the production of the K^{0*} was given by the component of the $K_S\pi^0$ momentum transverse to the line drawn between the K^{0*} production point and the known K_L production point.

We required that the $\pi^+\pi^-$ invariant mass be within 30 MeV/c^2 of the K_S mass. The reconstructed K_S decay point was required to be at least 0.5 m upstream of the HV hodoscope to suppress events resulting from neutron interactions in the hodoscope. The two-photon invariant mass was required to be within 15 MeV/c^2 of the π^0 mass.

Primakoff production is a peripheral process characterized by relatively small momentum transfer. In Fig. 2 we show for the selected events the distribution of $K_S\pi^0$ mass for transverse momentum squared less than 0.01 (GeV/c)^2 with the data from both targets combined. The background for this region was estimated from the number of events obtained by applying the same selection criteria with the exception that the $\pi^+\pi^-$ mass was required to be either above or below the allowed K_S mass range. These events resulted largely from neutron interactions in the Primakoff targets, the RA counters and the vacuum window at the entrance to the K_S decay region. While a clean signal for forward production of the $K^{0*}(890)$ may be seen, no signal is seen for the production of the $K^{0*}(1430)$. In the mass range 1.32–1.52 GeV/c^2 we found 11 events with an estimated background of 9 events.

To calculate our sensitivity to Primakoff production of the K^{0*} (1430), we determined as a function of momentum the total number of K_L mesons incident on the separate targets from the number of observed decays of the type $K_L \rightarrow \pi^+\pi^-\pi^0$. The geometrical acceptance of

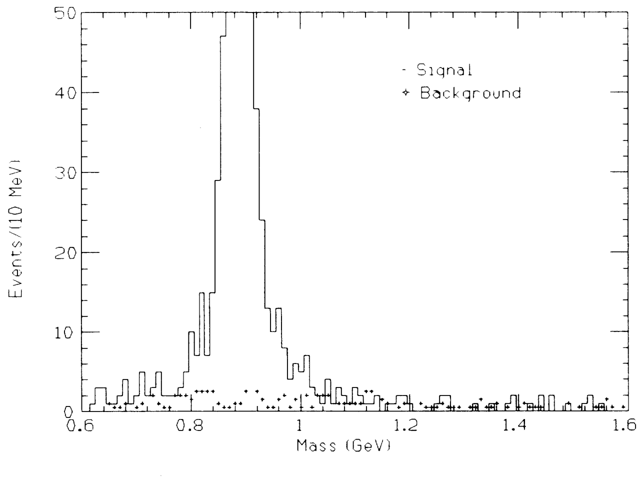

FIG. 2. Distribution of the $K_S\pi^0$ mass M for the two targets combined. The estimated background (see text) is also shown.

the apparatus was found by the technique of Monte Carlo simulation assuming a decay-angular distribution in the Gottfried-Jackson frame of the form[5]

$$\frac{dN}{d\Omega}(K^{0*}\ (1430)\to K_S\pi^0)\propto |Y_{2,1}+Y_{2,-1}|^2$$

$$\propto \sin^2\theta\cos^2\theta\sin^2\phi\ .$$

We calculated the loss of photons to pair production in the targets which was a correction to the efficiency not common to K^{0*} production and the normalization K_L decays. The total production cross section was calculated assuming a black sphere model[6] for the effect of nuclear absorption at the mean accepted K^{0*} energy of 145 GeV. Combining the sensitivities for the two targets we derived an upper limit for the radiative width of the $K^{0*}(1430)$ of 84 keV (90% C.L.). The error in the cross section resulting from uncertainties in the absorption model is estimated to be 3% while the smooth energy dependence of the cross section is effectively averaged over. Interference from strong-exchange amplitudes will not materially affect the upper limit as these amplitudes are expected to be relatively small.

The limit may be compared with the radiative width of the $K^{+*}(1430)$ which has been measured[7] to be 240±45 keV. The relative size of the radiative widths of the charged and neutral tensor mesons is in striking contrast to the vector-meson case where the neutral-meson radiative width is approximately twice as large as the charged-meson radiative width.[8] We describe below how these results may be understood in a nonrelativistic quark model.

In the naive quark model, the tensor meson is described as a bound state of an antistrange quark and a down quark with unit relative orbital angular momentum and with the quark spins aligned. In the vector-meson state the orbital momentum is zero and the spins are aligned while in the scalar-meson state, both the orbital and spin angular momenta vanish. The electromagnetic interaction of the jth quark is given in the Pauli approximation by

$$H_{\text{int}}=\frac{-q_j}{m_j}\mathbf{A}(\mathbf{x}_j)\cdot\mathbf{p}_j+\boldsymbol{\mu}_j\cdot\mathbf{B}(\mathbf{x}_j)\ ,$$

where $\boldsymbol{\mu}_j=\mu_j\boldsymbol{\sigma}_j$ is the quark magnetic-moment operator. For transitions between eigenstates of the total spin, the first term may be neglected.

The amplitude describing a transition from an initial hadronic state h_i to a final hadronic state h_f with the emission of a photon described by a plane wave of wave vector $\mathbf{k}$ and polarization vector $\boldsymbol{\epsilon}$ is

$$H_{fi}\propto\left\langle h_f\left|\sum_j\boldsymbol{\mu}_j\cdot(\boldsymbol{\epsilon}\times\mathbf{k})e^{i\mathbf{k}\cdot\mathbf{x}_j}\right|h_i\right\rangle\ .$$

Because the meson states are considered as eigenstates of the relative quark orbital angular momentum, it is appropriate to change to center-of-mass coordinates. Changing variables and expanding the exponentials, one obtains the long-wavelength approximation to the transition operator in the form $\boldsymbol{\epsilon}\times\mathbf{k}\cdot\mathbf{M}$ where

$$\mathbf{M}=(\boldsymbol{\mu}_1+\boldsymbol{\mu}_2)+\left[\boldsymbol{\mu}_1\frac{m_2}{m}-\boldsymbol{\mu}_2\frac{m_1}{m}\right]i\mathbf{k}\cdot\mathbf{r}+\cdots\ ,$$

where $\mathbf{r}=\mathbf{x}_1-\mathbf{x}_2$ and $m=m_1+m_2$. The first term is the spin magnetic moment operator $\boldsymbol{\mu}=\boldsymbol{\mu}_1+\boldsymbol{\mu}_2$ and contributes to the $M1$ transition $K^*(890)\to K\gamma$. The second term contributes to the $M2$ transition $K^*(1430)\to K\gamma$. The next term in the expansion gives the $O(k^2)$ correction to the $M1$ operator and has been neglected.

From this expression the ratio of the neutral- to charged-tensor-meson radiative widths may be deduced by inspection. Assuming that the spatial wave functions in the neutral and charged states are the same, the matrix element of the relative quark coordinate operator $\mathbf{r}$ cancels in the ratio of the radiative widths. Since phase-space factors may also be expected to cancel, the transition rate ratio is determined solely by the ratio of the squares of the spin matrix elements for the two transitions

$$\frac{\Gamma(K^{0*}(1430)\to K^0\gamma)}{\Gamma(K^{+*}(1430)\to K^+\gamma)}=\left[\frac{\mu_s m_d-\mu_d m_s}{\mu_s m_u-\mu_u m_s}\right]^2\left[\frac{m_s+m_u}{m_s+m_d}\right]^2\ .$$

A similar result obtains in the case of the vector-meson decay:

$$\frac{\Gamma(K^{0*}(890)\to K^0\gamma)}{\Gamma(K^{+*}(890)\to K^+\gamma)}=\left[\frac{\mu_s+\mu_d}{\mu_s+\mu_u}\right]^2\ .$$

Aside from the quark mass factors, the tensor- and vector-meson transition amplitude ratios differ in the relative sign of the amplitudes for the two quarks.

In the naive quark model, the magnetic moments of the u, d, and s quarks may be deduced from the values of the proton, neutron, and Λ magnetic moments. If these quark moments are assumed equal to the Dirac moments $\mu_i=q_i/2m_i$ where q_i is the electric charge, the effective constituent-quark masses may be found. The values for these masses are $m_u=335$ MeV/c^2, $m_d=309$ MeV/c^2, and $m_s=510$ MeV/c^2. With these values for the masses, the above formula predicts a ratio of 0.054 and if the measured value of the $K^{+*}(1430)$ radiative width is taken as input, the $K^{0*}(1430)$ radiative width is predicted to be 13 keV, in agreement with our upper limit. Explicit calculation in the naive quark model of the tensor-meson radiative width yields

$$\Gamma(T\to P+\gamma)=\frac{k^5}{120\pi}\frac{(m_P{}^2+k^2)^{1/2}}{m_T}|m_{TP}|^2|r_{TP}|^2\ ,$$

$$r_{TP}=\int dV\,f_P{}^*(r)rf_T(r)\ ,$$

where f_P and f_T are the radial parts of the spatial wave functions for the pseudoscalar and tensor states and, for the decay of the $K^{0*}(1430)$,

$$M_{TP}=(\mu_s m_d-\mu_d m_s)/(m_s+m_d)\ .$$

If the transition radius r_{TP} is 1 F, the $K^{+*}(1430)$ radiative width is predicted to be 174 keV and the $K^{0*}(1430)$ radiative width is predicted to be 9.4 keV. In the SU(6)-symmetry limit the naive quark model predicts that the radiative width of the $K^{0*}(1430)$ vanishes.[9] The disparity between the radiative widths of the neutral and charged states even in the presence of symmetry breaking may be understood in the naive quark model as a consequence of the destructive interference of the spin-flip transition amplitudes for the two quarks. The agreement between the experimental results and the theoretical predictions confirms this simple picture.

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