

Testing the Structure of the Scalar Meson $K_0^*(1430)$ in
 $\tau \rightarrow K_0^*(1430)\nu$ Decay

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Abstract

The decay constant of $K_0^*(1430)$ is the key quantity to determine the production rate of $K_0^*(1430)$ in τ decays. By assuming $K_0^*(1430)$ is the lowest scalar bound state of $s\bar{q}$, the decay constant can be calculated reliably in QCD sum rule. Then the decay branching ratio of $\tau \rightarrow K_0^*(1430)\nu$ is predicted to be about $(7.9 \pm 3.1) \times 10^{-5}$. If this branching ratio can be measured by experiment, it should be helpful to make clear the structure of $K_0^*(1430)$.

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The structure of light scalar mesons is still a common problem for physics of light hadrons. There are too many light scalar mesons to be accommodated into one $SU(3)$ nonet. There are: 1) κ and $K_0^*(1430)$ with strange number $|S| = 1$ and isospin $I = 1/2, 2$) σ , $f_0(980)$, $f_0(1370)$, $f_0(1500)$ and $f_0(1710)$ with both strange number and isospin 0, and 3) $a_0(980)$, $a_0(1450)$ with isospin $I = 1$ [1, 2]. It is most possible that these scalar mesons make up at least two nonets. One is below 1GeV, the other is above 1GeV. Which of them belong to the $q\bar{q}$ scalar nonet is still an unsolved problem [3]. Up to now, there is still no general agreement for the structure of light scalar mesons. They can be understood as four-quark states, meson-meson molecular states [4, 5], or ordinary quark-antiquark bound states. From the point of view of quark model and QCD, there must be scalar mesons composed of quark and antiquark.

κ and $K_0^*(1430)$ have the same strange number and isospin, but different masses. Therefore, they must belong to different nonets. Whether they are composed of quark-antiquark, if they are, where the lowest scalar bound state of quark-antiquark exists are interesting questions. To answer these questions, a large amount of experiments and theoretical analysis need to be done to analyze the production and decay properties of the scalar mesons. In this note, we calculate the production rate of $K_0^*(1430)$ in the heavy lepton τ decay process $\tau \rightarrow K_0^*(1430)\nu$. There is only one hadron evolved in this decay process, the interaction in the leptonic vertex can be calculated with high precision, therefore the decay branching ratio depends on the decay constant of $K_0^*(1430)$ directly. The decay constant is determined by the meson's structure. Therefore, if the branching ratio can be measured by experiment, comparing the theoretical prediction with experimental data will indicate information on the structure of the scalar meson.

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We analyzed the mass of the lowest scalar bound state of two quarks $s\bar{q}$ with QCD sum rule, where $q = u, d$, denotes light quarks [6]. We find that it is impossible to obtain the mass of κ in QCD sum rule for $s\bar{q}$ bound state. However, QCD sum rule can give stable prediction of the mass of $K_0^*(1430)$. Therefore, we assume that $K_0^*(1430)$ is the lowest scalar bound state of $s\bar{q}$, and κ is irrelevant to $s\bar{q}$ scalar channel. With this assumption, the decay constant of $K_0^*(1430)$ is calculated to be

$$f_{K_0^*} = 427 \pm 85 \text{MeV} \quad (1)$$

which is defined by the matrix element

$$\langle 0 | \bar{q}s | K_0^*(1430) \rangle = m_{K_0^*} f_{K_0^*} \quad (2)$$

where $m_{K_0^*}$ is the mass of $K_0^*(1430)$.

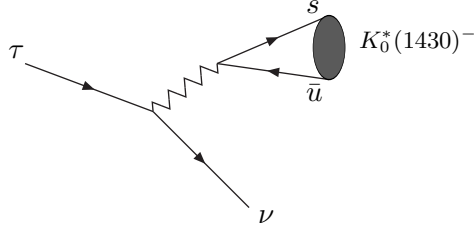


Figure 1: Feynman diagram for $\tau \rightarrow K_0^*(1430)\nu$

The diagram for $\tau \rightarrow K_0^*(1430)\nu$ is shown in Figure 1. According to the diagram, we can write the decay amplitude directly

$$A = \frac{ig^2}{8} V_{us}^* \langle K_0^*(1430) | \bar{s}\gamma_\mu(1 - \gamma_5)u | 0 \rangle \frac{1}{p_1^2 - m_W^2 + i\epsilon} \bar{\nu}\gamma^\mu(1 - \gamma_5)\tau \quad (3)$$

where g is the weak coupling constant, V_{us} is the CKM matrix element, and p_1 the momentum of $K_0^*(1430)$. Let us denote the momenta of τ lepton and neutrino as p_τ and p_ν , respectively.

From the parity of $K_0^*(1430)$ and the axial vector current, we know that the contribution of axial vector current to the matrix element must be zero

$$\langle 0 | \bar{u}\gamma_\mu\gamma_5s | K_0^*(1430) \rangle = 0 \quad (4)$$

therefore, only the contribution of vector current should be considered. From the Lorentz property of the matrix $\langle 0 | \bar{u}\gamma_\mu s | K_0^*(1430) \rangle$, we can write

$$\langle 0 | \bar{u}\gamma_\mu s | K_0^*(1430) \rangle = f_{K_0^*}^V p_{1\mu} \quad (5)$$

where $f_{K_0^*}^V$ is a new constant defined for the scalar meson.

Using Dirac equation, we can get the following operator equation

$$\partial^\mu(\bar{u}\gamma_\mu s) = i(m_u - m_s)\bar{u}s \quad (6)$$

then we get the following relation

$$\begin{aligned} i(m_u - m_s)\langle 0 | \bar{u}s | K_0^*(1430) \rangle &= \langle 0 | \partial^\mu(\bar{u}\gamma_\mu s) | K_0^*(1430) \rangle \\ &= -ip_1^\mu \langle 0 | \bar{u}\gamma_\mu s | K_0^*(1430) \rangle \end{aligned} \quad (7)$$

From the above relation, and using the definition of the decay constant $f_{K_0^*}$ and $f_{K_0^*}^V$, we get

$$f_{K_0^*}^V = \frac{m_s - m_u}{m_{K_0^*}} f_{K_0^*} \quad (8)$$

Then considering eqs.(4, 5, 8), from eq.(3) the result of the decay amplitude squared is

$$\sum_{\lambda_1 \lambda_2} |A|^2 = \left| \frac{G_F}{\sqrt{2}} V_{us}^* \frac{m_s - m_u}{m_{K_0^*}} f_{K_0^*} \right|^2 2m_\tau (m_\tau^2 - m_{K_0^*}^2) \quad (9)$$

where G_F is Fermi constant, λ_1 and λ_2 are the polarization freedom of τ lepton and neutrino, respectively.

Finally we obtain the decay width of $\tau \rightarrow K_0^*(1430)\nu$

$$\Gamma = \frac{1}{4\pi} \left| \frac{G_F}{\sqrt{2}} V_{us}^* \frac{m_s - m_u}{m_{K_0^*}} f_{K_0^*} \right|^2 \frac{(m_\tau^2 - m_{K_0^*}^2)^2}{2m_\tau} \quad (10)$$

The branching ratio of this decay mode is defined as

$$Br(\tau \rightarrow K_0^*(1430)\nu) = \Gamma/\Gamma_{total} \quad (11)$$

The total decay width of τ lepton is related to its mean life time as

$$\Gamma_{total} = \hbar/\tau \quad (12)$$

In the numerical calculation, we take

$$\begin{aligned} \tau &= 2.9 \times 10^{-13} \text{s}, & V_{us} &= 0.22 \\ m_{K_0^*} &= 1.412 \text{GeV} & m_\tau &= 1.777 \text{GeV} \\ m_s &= 0.14 \text{GeV}, & m_q &\sim 0 \end{aligned}$$

With the input parameters taken above, and the decay constant calculated in QCD sum rule (eq.(1)), the result of the branching ratio is

$$Br(\tau \rightarrow K_0^*(1430)\nu) = (7.9 \pm 3.1) \times 10^{-5} \quad (13)$$

where the error bar is mainly contributed by the uncertainty of the decay constant, and the effects of the other uncertainties are negligible.

The above prediction is several times smaller than the present experimental upper limit [1]

$$Br(\tau \rightarrow K_0^*(1430)\nu)^{Exp.} < 5 \times 10^{-4} \quad (14)$$

It is most possible that this decay branching ratio can be measured in e^+e^- collision experiments with high luminosity, such as CLEO-c, the incoming BESIII, or the asymmetric B-factories. If this branching ratio can be measured in the future, the comparison of the experimental data with theoretical prediction, which is obtained by assuming that $K_0^*(1430)$ is the lowest scalar bound state of quark-antiquark pair $s\bar{q}$, will give some information about the component of this scalar meson. Then we may know where the $q\bar{q}$ $SU(3)$ nonet exists in the spectroscopy of light scalar mesons.

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