Hadron Spectroscopy, Chiral Symmetry and Relativistic Description of Bound Systems

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κ , σ Mesons in J/ψ Decays Analyzed by VMW Method

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1. Introduction

[Two contrasting viewpoints of Level Classification]

	Non-Relativistic Q.M.	Relativistic Q.M.
Model	Non–Rel. Q.M.	NJL model
Approx. Symm.	LS-Symm.	Chiral Symm.
Evidence	Bases for PDG	$\pi-$octet as NG Boson

(Recent Progress) It seems to be established !?

Existence of light $\sigma(600)$

, as chiral partner of $\pi(140)$, in $\pi\pi-$prod. processes

$\Rightarrow$ Seemingly contradictory two viewpoints

; Serious Problem in Hadron Spectroscopy !

New level classification scheme

Unifying the above two viewpoints was proposed recently

$\tilde{U}_{SF}(12) \otimes O_L(3,1)$ sheme

$\uparrow$ relativistic extension

$SU(6) \otimes O_L(3)$ sheme

- ∘ S. Ishida and M. Ishida, PLB**539** (2002), 249.
- ∘ S. Ishida et al., PTP**104** (2000), 785.

$\rightarrow$ Existence of chiral particles/states are predicted

This was reviewed by Prof. S.Ishida in this symposium

One of the Candidate for Chiral States

σ−nonet $\quad S^{(N)}(^1S_0)\ 0^{++}$; $\sigma(600), \kappa(900), a_0(980), f_0(980)$

[Porpose]

- $J/\psi \rightarrow K^*(892) + \underbrace{(K\pi)}_{\kappa}$ BESII
- $J/\psi \rightarrow \omega + \underbrace{(\pi\pi)}_{\sigma}$

2. Method of Analysis of $K\pi-$, $\pi\pi-$ Production Processes

[Strong interaction and right bases of S-matrix]

(Basic consideration of Strong interaction)

$H^{strong}(\bar{\phi}_i) =$ "residual interaction" of QCD

$\bar{\phi}_i$: color-neutral bound states of $q, \bar{q}, g$
(bare state)

Unitarity of $S-$Matrix ; $S^\dagger S = SS^\dagger = 1 \quad \Leftarrow \quad H_I^\dagger = H_I$

(Bases of $S-$Matrix)

History of picture on strong interaction of πN System

	Chew-Low Theory		After quark physics
Switch off $\mathcal{H}^I$	Basic fields	$\pi,\ N$	$\bar{\pi}=(q\bar{q}),\ \bar{N},\ \underline{\bar{\Delta}=(qqq)}$ "zero" Γ
Switch on $\mathcal{H}^I$	Resonance	$\Delta=(N\pi+N\pi\pi)$	$\pi_{\text{phys.}},\ N_{\text{phys.}};\ \underline{\Delta_{\text{phys.}}}$ "finite" Γ
	Compl. Set of S-bases	$\vert\pi\rangle,\ \vert N\rangle,\ \vert\pi N\rangle,\ \cdots$	$\vert\bar{\pi}\rangle,\ \vert\bar{N}\rangle,\ \underline{\vert\bar{\Delta}\rangle}\ \vert\bar{\pi}\bar{N}\rangle,\underline{\vert\bar{\pi}\bar{\Delta}\rangle},\ \cdots$

As is summarized in above Table , there are two pictures; the one is Chew-Low theory and the other one is of quark physics. In the former the basic fields are only π and N, while in the latter they include also the bare $\bar{\Delta}$ field with zero-width as a three-quark stable bound state $\bar{\Delta}=(qqq)$. After switching on $\mathcal{H}_{\rm I}^{\rm str.}$, in the former the physical Δ particle appears as a resonance of πN system, while in the latter the $\bar{\Delta}$ becomes $\Delta_{\rm phys.}$ with finite width. These two pictures may be phenomenologically consistent with each other in so far as concerned with interactions of the πN system. However, we recognize presently the latter as a true one from the general and fundamental viewpoint.

(Present Problem ; $K\pi$, $\pi\pi$ systems)

[VMW Method] : Right bases of S-matrix

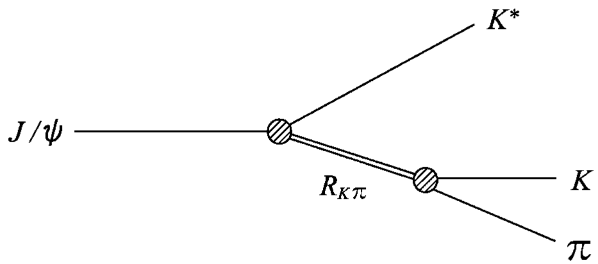
Basic field	$\bar{\pi},\bar{K}\ ;\ \bar{\sigma},\bar{\kappa},\bar{f}_0\ \ (q\bar{q})$ Γ :Zero
Complete set of base	$\vert\bar{\pi}\rangle,\vert\bar{K}\rangle,\vert\bar{\sigma}\rangle,\vert\bar{\kappa}\rangle,\vert\bar{f}\rangle$ $\vert\bar{\pi}\bar{\pi}\rangle,\cdots$

We must take into account the $\kappa(\sigma)$ as a basic field as well as K and π (π)

3. Method of Analysis of $J/\psi \to K^*(892)K\pi$

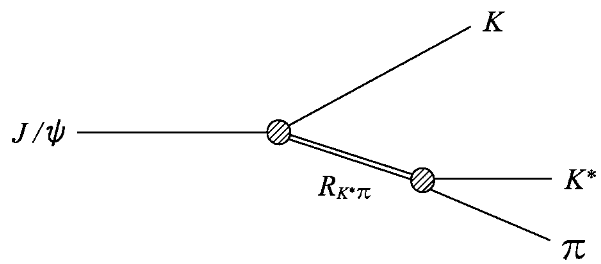
We shall use the VMW method to analyze relevant data, where all resonant particles are treated as the basic fields describing the S-matrix elements. The propagator of resonant particles is given by the conventional Feynman propagator with substitution of $i\varepsilon$ by $i\sqrt{s}\,\Gamma(s)$, here $\Gamma(s)$ and s being, respectively, width and 4−momenta squared of the resonant particles.

(The three mechanisms of relevant decay process)



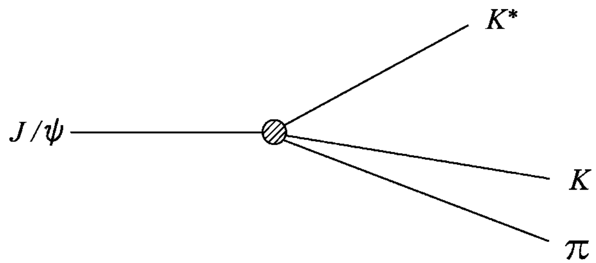
(a) $J/\psi \to K^*(892)R_{K\pi} \to K^*(892)\ \ (K\pi)$

($R_{K\pi} = \kappa$, $K_0^*(1430)$, $K_2^*(1430)$, $K_2^*(1922)$)



(b) $J/\psi \to KR_{K^*\pi} \to K\ \ (K^*(892)\pi)$

($R_{K^*\pi} = K_1(1270)$, $K_1(1400)$)



(c) $J/\psi \to K^*(892)K\pi$

In the case (a) of intermediate $K\pi$ resonances, we take into account the possible cases of $R_{K\pi}$ with, $J^P = 0^+,\ 2^+$, decaying into the S and D wave states of $K\pi$ system, respectively.

The most simple $\mathcal{L}$agrangians relevant for production and decay of respective intermediate resonances, and the amplitudes in the respective cases of $S-$ and $D-$wave decays are given, respectively, by

Mechanism (a) (intermediate $K\pi$ resonance)

(S-wave)

$$\mathcal{L}_S \sim \xi_\kappa \psi_\mu K_\mu^* \kappa + g_\kappa \kappa K \pi + \cdots$$

$$\mathcal{F}_S = S_{h_\psi h_{K^*}} (r_\kappa e^{i\theta_\kappa} \Delta_\kappa(s_{K\pi}) + r_{K_0^*} e^{i\theta_{K_0^*}} \Delta_{K_0^*}(s_{K\pi}) + r_{K\pi} e^{i\theta_{K\pi}})$$

(D-wave)

$$\mathcal{L}_D \sim \xi_{K_2^*} \psi_\mu K_\nu^* K_{2\mu\nu}^* + g_{K_2^*} K_{2\mu\nu}^* (\partial_\mu K \partial_\nu \pi + \cdots)$$

$$\mathcal{F}_D = D_{h_\psi h_{K^*}} \ r_{K_2^*} e^{i\theta_{K_2^*}} \Delta_{K_2^*}^D(s_{K\pi})$$

$$\Delta_{K_2^*}^D(s_{K\pi}) = \frac{m_{K_2^*} \Gamma_{K_2^*} \left(\frac{F_D(s_{K\pi})}{F_D(s_{m_{K_2^*}^2})}\right)}{m_{K_2^*}^2 - s_{K\pi} - i\sqrt{s_{K\pi}}\ \Gamma_{K_2^*}(s_{K\pi}) \left(\frac{F_D(s_{K\pi})}{F_D(s_{m_{K_2^*}^2})}\right)^2},\ \Gamma_{K_2^*}(s_{K\pi}) = \frac{\mathbf{p}^5 g_{K_2^*}^2}{8\pi s_{K\pi}},\ F_D(s_{K\pi}) = \frac{1}{s_{K\pi} + m_{K_2^*}^2}$$

In the case (b) of intermediate $K^*\pi$ resonances with $J^P = 1^+$ decaying into the $S-$wave $K^*\pi$ system the corresponding formulas are given by

Mechanism (b) (intermediate $K^*\pi$-resonance)

$$\mathcal{L}_{K_1} \sim \xi_{K_1} \psi_\mu K_{1\mu} K + g_{K_1} K_{1\mu} K_\mu^* K$$

$$\mathcal{F}_{K_1} = B_{h_\psi h_{K^*}} \ r_{K_1} e^{i\theta_{K_1}} \Delta_{K_1}(s_{K^*\pi})$$

Mechanism (c) (direct $K^*K\pi$)

In the case of (c) the corresponding formulas are

$$\mathcal{L}_{\text{direct } K\pi} \sim \xi_{K\pi} \psi_\mu K_\mu^* K \pi$$

$$\mathcal{F}_{\text{direct } K\pi} = S_{h_\psi h_{K^*}} r_{K\pi} e^{i\theta_{K\pi}}$$

In $\mathcal{F}_S, \mathcal{F}_D, \mathcal{F}_{K_1}$ and $\mathcal{F}_{\text{direct } K\pi}$ the S, D and B are the factors due to helicity-combinations among relevant particles given by

$$\begin{aligned}
S_{h_\psi h_{K^*}} &= \varepsilon_\mu^{h_\psi} \tilde{\varepsilon}_\mu^{h_{K^*}} \ , \\
D_{h_\psi h_{K^*}} &= \varepsilon_\mu^{h_\psi} \tilde{\varepsilon}_\nu^{h_{K^*}} \frac{1}{4}\{(r_\mu - \frac{q_\mu(m_K^2 - m_\pi^2)}{s})(r_\nu - \frac{q_\nu(m_K^2 - m_\pi^2)}{s}) - \frac{4\mathbf{p}_K^2}{3}(\delta_{\mu\nu} + \frac{q_\mu q_\nu}{s})\} \ ; \\
& \quad\ r_\mu = (p_K - p_\pi)_\lambda \ ; \\
B_{h_\psi h_{K^*}} &= \varepsilon_\mu^{h_\psi} \tilde{\varepsilon}_\nu^{h_{K^*}} (\delta_{\mu\nu} + \frac{p_{K^*\pi\mu} p_{K^*\pi\nu}}{s_{K^*\pi}})
\end{aligned}$$

Then the amplitude $\mathcal{F}$ squared for the process is given by

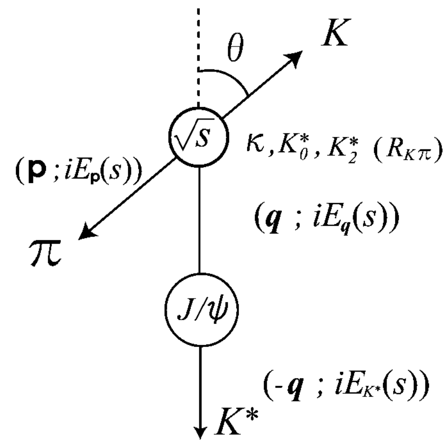
$$\overline{|\mathcal{F}|^2} = \frac{2}{3}\left\{\frac{1}{3}\sum_{h_\psi, h_{K^*}} |\mathcal{F}_S + \mathcal{F}_D + \mathcal{F}_{K_1}|^2\right\} + \frac{2}{3}\left\{\frac{1}{3}\sum_{h_\psi}|\sum_{K_P^*}\mathcal{F}_{K_P^*}|^2 + |\mathcal{F}_{K_S}|^2\right\}$$

where summation is taken for $h_\psi, h_{K^*} = +, -, 0$ and the factor $\frac{2}{3}$ comes from the fact that the initial J/ψ has only $\pm$ polarization. The 2nd term is the possible contribution from the background processes; The former $\mathcal{F}_{K_P^*}$ represents the contribution from P-wave resonances $K_{\mathrm{P}}^*(= K^*(892), K^*(1410))$ $J/\psi \to (K\pi)_{\mathrm{BG}} K_{\mathrm{P}}^*$ with $m_{K\pi}$ being within the required region of $K^*(892)$ (where $(K\pi)_{\mathrm{BG}}$ are possibly coming from κ and non-resonant $K\pi$) while the latter does $J/\psi \to K^*(892)K_S$ ($K_S \to \pi\pi$, where one π was misidentified with K). Corresponding formulas are given by

$$\begin{aligned}
\mathcal{F}_{K_P^*} &= A_{h_\psi} r_{K_P^*} e^{i\theta_{K_P^*}} \Delta_{K_P^*}(s_{K\pi}) \\
A_{h_\psi} &= \varepsilon_\mu^{h_\psi}(\delta_{\mu\nu} + \frac{q_\mu q_\nu}{s}) r_\nu \ ; \\
\mathcal{F}_{K_S} &= S_{h_\psi h_{K^*}} \ \ r_{K_S} \Delta_{K_S}(s_{K\pi}) \ .
\end{aligned}$$

The differential decay width is given by

$$\begin{aligned}\Gamma &= \frac{1}{64\pi^3 M_\psi^2}\int d\sqrt{s_{K\pi}}\int_{-1}^{1} dcos\theta \quad \mathbf{q}(s_{K\pi})\mathbf{p}(s_{K\pi})\ \overline{|\mathcal{F}|^2} \\ &= \frac{1}{64\pi^3 M_\psi^3}\int d\sqrt{s_{K\pi}}\int d\sqrt{s_{K^*\pi}}\quad \sqrt{s_{K\pi}}\sqrt{s_{K^*\pi}}\ \overline{|\mathcal{F}|^2}\end{aligned}$$



Kinematical variables

[VMW method]

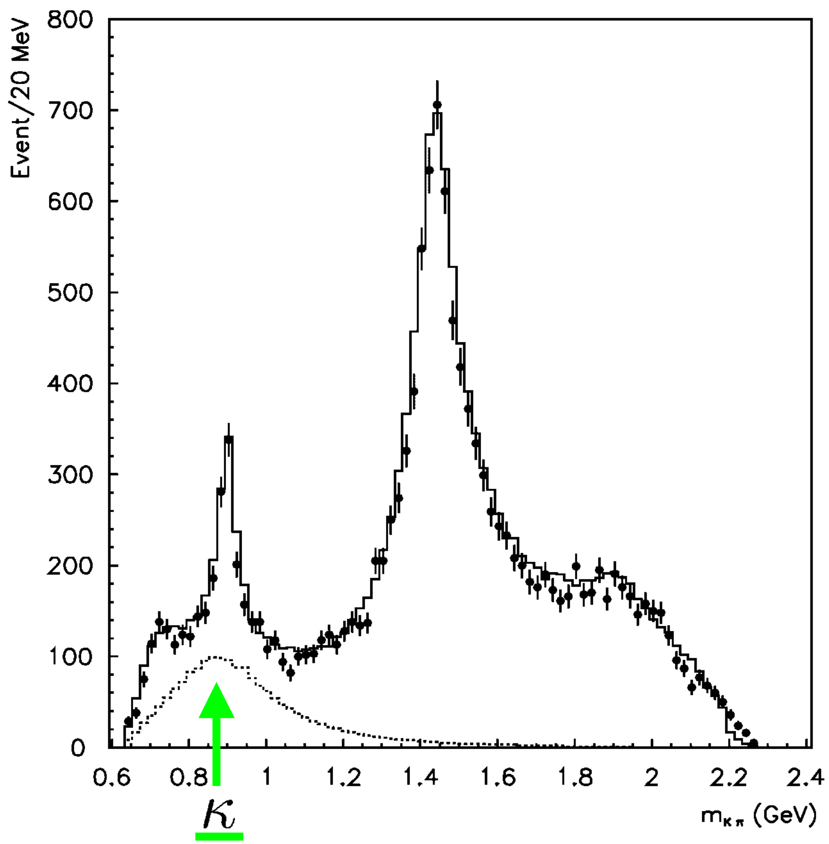
Parameters

masses	m_i
$K\pi$ width	$\Gamma_{i,K\pi}$
$K^*\pi$ width	$\Gamma_{i,K^*\pi}$
prod. coupl.	r_i
initial phase	θ_i

⇒ $\mathcal{F}$ is directly represented by physically meaningful parameters.

4. Results of analysis

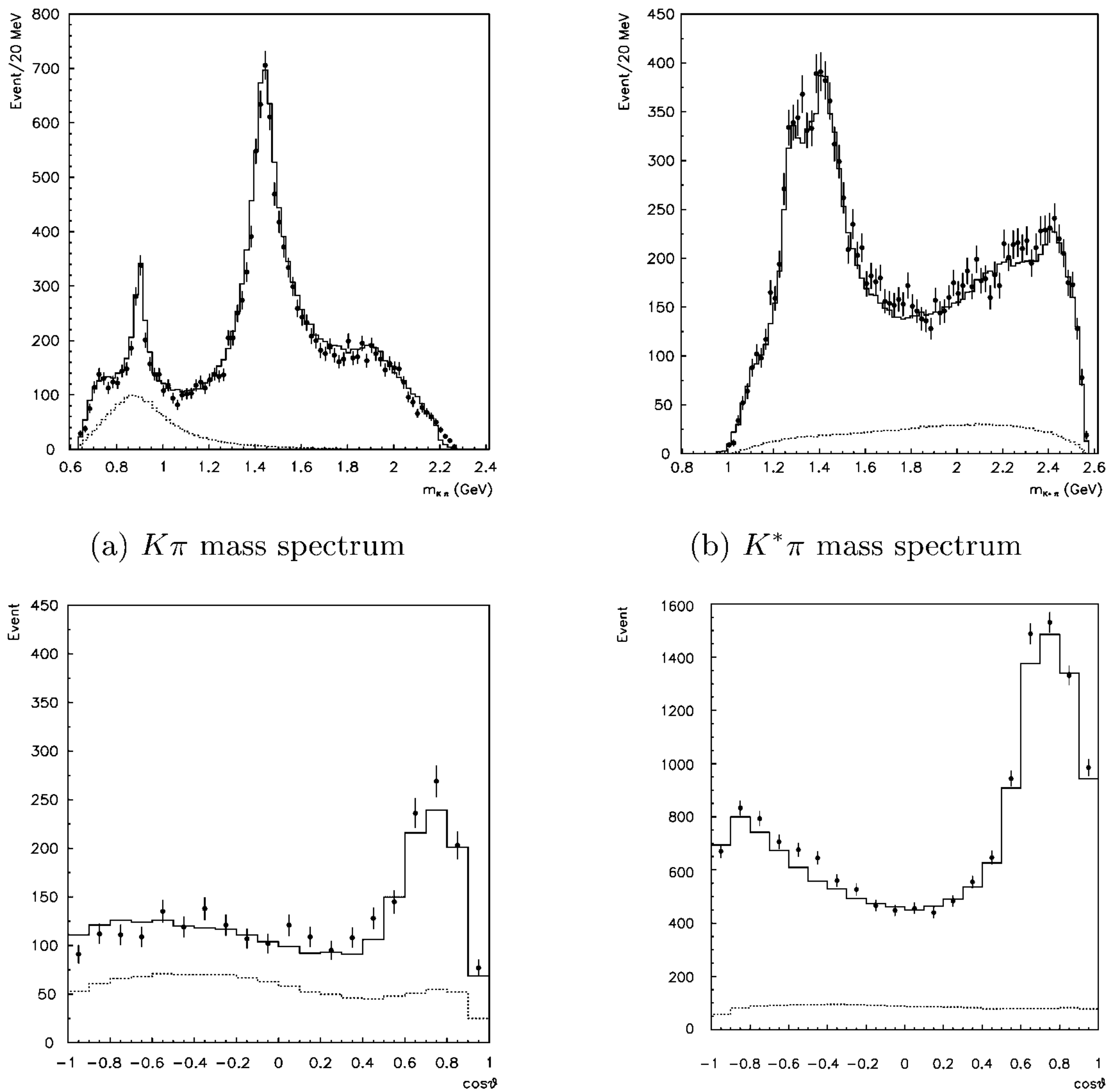
With κ ($J^P = 0^+$)



(a) $K\pi$ mass spectrum

$$m_\kappa = 882 \pm 24 \text{ MeV}$$
$$\Gamma_\kappa = 335 \pm 82 \text{ MeV}$$

$$\mathrm{BR}\left(\frac{J/\psi \to \kappa\ K^*}{J/\psi \to K^* K\pi}\right) = 0.115$$



(a) $K\pi$ mass spectrum

(b) $K^*\pi$ mass spectrum

(c) $K\pi$ angular distribution (1) $m_{K\pi} \leq 1$ (GeV)

(d) $K\pi$ angular distribution (2) $m_{K\pi}$ in whole region

Fig. 1. Results of Analysis. The experimental data and fitted curves are given. The respective contributions of resonances and of direct process are also shown. The data of angular distribution are taken into account in the two ways (depending on $K\pi$ mass); one with a restriction $m_{K\pi} \leq 1$ (GeV) and the other with $m_{K\pi}$ in whole region.

With κ $(J^P = 0^+)$

$$\chi^2/N_F = 375.8/(203-37) = 2.26$$

$$\chi^2(m_{K\pi})/N_D(bin) = 2.27\ (82)\ ,\ \chi^2(m_{K^*\pi})/N_D(bin) = 1.40(81)\ ,$$
$$\chi^2(\text{ang. dist.})/N_D(bin) = 1.91\ (40)$$

Table 1: Obtained values of the parameters.

Process (J^P)	mass (MeV)	Γ(MeV)	g (GeV)	r	θ (Deg.)
$\kappa \to K\pi$	881.67	335.27	4.829	6759.92	0.00
$K^*(892)\ (1^-)\ \to K\pi$	904.03	49.00	6.204	-17355.73	0.00
$K_0^*(1430)\ (0^+)\ \to K\pi$	1430.00	250.33	4.551	-10731.95	55.73
$K^*(1410)\ (1^-)\ \to K\pi$	1445.00	190.00	6.320	-6255.44	-0.37
$K_2^*(1430)\ (2^+)\ \to K\pi$	1437.02	89.00	6.957	34722.19	122.04
$K_2^*(1922)\ (2^+)\ \to K\pi$	1940.00	200.00	5.637	-8622.34	1.43
$K_1(1270)\ (1^+)\ \to K^*\pi$	1266.34	86.39	3.452	-7190.82	185.08
$K_1(1400)\ (1^+)\ \to K^*\pi$	1427.68	185.22	4.772	10337.64	101.13
$K\pi$ B.G. around 700 MeV	726.00	146.00	0.527	7140.70	—
Direct $K\pi$				-1357.88	276.55

5. Conclusion

- $J/\psi \to K^*(892)K\pi$ process (58M J/ψ-Data in BESII) was analyzed by VMW method
  - $K\pi$ and $K^*\pi$ Mass spectra and $K\pi$ Angular distributions

With κ

$$\chi^2/N_F = 375.8/(203-37) = \underline{2.26}$$

$\Uparrow$

Without κ

$$\chi^2/N_F = 882.0/(203-32) = 5.16$$

κ is indispensable to reproduce low-mass peak

$m_\kappa = 882 \pm 24$ MeV

$\Gamma_\kappa = 335 \pm 82$ MeV

$\Longleftrightarrow$ Comparable

The analysis of $K\pi$ scattring Phase shists $m_\kappa = 905^{+65}_{-30}$ MeV $\Gamma_\kappa = 545^{+235}_{-110}$ MeV
$m_\kappa = 877 \pm 85$ MeV $\Gamma_\kappa = 346 \pm 89$ MeV Wu Ning (BESII)

S. Ishida et al., PTP**98**(1997)621.

This symposium