

## I=1/2 Scalar and Axial Vector Mesons

---

**Scalar collaboration: Teiji Kunihiro<sup>a</sup>, Shin Muroya<sup>b</sup>, Atsushi Nakamura<sup>c</sup>, Chiho Nonaka<sup>d</sup>, Motoo Sekiguchi<sup>\*e</sup> and Hiroaki Wada<sup>f</sup>**

<sup>a</sup>*YITP, Kyoto University  
Kyoto 606-8502, Japan*

<sup>b</sup>*Tokuyama University  
Tokuyama 745-8511, Japan*

<sup>c</sup>*RIISE, Hiroshima University  
Higashi-Hiroshima 739-8521, Japan*

<sup>d</sup>*School of Physics and Astronomy, University of Minnesota  
Minneapolis, MN 55455, USA*

<sup>e</sup>*Faculty of Engineering, Kokushikan University  
Tokyo 154-8515, Japan*

*E-mail: motoo@kokushikan.ac.jp*

<sup>f</sup>*Faculty of Political Science and Economics, Kokushikan University  
Tokyo 154-8515, Japan*

We present our recent study of  $I = 1/2$  scalar ( $\kappa$ ) and axial vector mesons ( $K_1$ ) in the quenched approximation with the Wilson fermions. Our preliminary results show that these mesons are heavier than  $K^*$ .

*XXIIIrd International Symposium on Lattice Field Theory  
25-30 July 2005  
Trinity College, Dublin, Ireland*

---

\*Speaker.

## 1. Introduction

Recently, there has been interest in the structure of the scalar mesons in the hadron physics. In particular the existence of the  $\sigma$  meson ( $I=0, J^{PC}=0^{++}$ ) was obscure for many years. The confidence level of the  $\sigma$  meson has been increasing. There have been accumulation of experimental evidence of the  $\sigma$  with a low mass  $500 \sim 600$  MeV [1]. In the non-relativistic constituent quark model,  $J^{PC}=0^{++}$  meson is realized as  $^3P_0$  state, which implies that the mass of the  $\sigma$  should be in  $1.2 \sim 1.6$  GeV region. Therefore some mechanism is needed to down the mass. Many suggestions are discussed in the literature [2, 3, 6, 7, 8, 9, 10, 11, 12, 13, 14].

We have presented a lattice calculation of the  $\sigma$  meson, by full lattice QCD simulation on the  $8^3 \times 16$  lattice using the plaquette action and Wilson fermions. We have observed that the disconnected diagram makes the  $\sigma$  mass very light [9, 10, 11, 12]. The connected diagram alone gives heavy mass.

If the  $\sigma$  meson exists, it is natural to consider the  $\kappa$  meson as member of the nonet scalar states chiral  $SU(3)_C \times SU(3)_F$  symmetry. Recently, the  $\kappa$  with  $I=1/2$  is reported with mass  $m_\kappa \sim 800$  MeV [4, 5]. It is very important to investigate the  $\kappa$  meson by lattice QCD in order to establish the mass spectroscopy of the scalar mesons. Because lattice QCD provides a first principal approach of hadron physics and allows us to study non-perturbative aspects of quark-gluon dynamics. In the previous paper [12, 15], we have treated the  $s$  quark as a valence, while  $u$  and  $d$  quarks dynamical. And Prelosek [16] have presented a rough estimate by extrapolating the mass of  $\kappa$  obtained from the dynamical simulation. They assumed that the  $u$ ,  $d$  and  $s$  quarks are degenerate. In our previous simulation, the cutoff was not sufficiently high to accommodate large masses  $m_\kappa a > 1$ , where  $a$  is the lattice spacing. Hence, we present a quench simulation at weaker couplings on a larger lattice. And we shall also mention that our simulation suggests the existence of  $I=1/2, J^{PC}=1^{++}$  axial vector ( $K_1$ ) meson.

## 2. Propagator

We adopt the following interpolation operator for creating the  $\kappa^+$  meson with  $I=1/2$  and  $J^{PC}=0^{++}$  as

$$\hat{\kappa}(x) \equiv \sum_{c=1}^3 \sum_{\alpha=1}^4 \bar{s}_\alpha^c(x) u_\alpha^c(x), \quad (2.1)$$

where  $s$  and  $u$  indicate the corresponding quark spinors. Indices  $c$  and  $\alpha$  stand for color and Dirac spinor indices, respectively. The  $\kappa$  meson propagator is written as

$$\begin{aligned} G(y, x) &= \langle T \hat{\kappa}(y) \hat{\kappa}(x)^\dagger \rangle \\ &= \frac{1}{Z} \int DU D\bar{u} Du D\bar{s} Ds \\ &\quad \sum_{a,b=1}^3 \sum_{\alpha,\beta=1}^4 \bar{s}_\beta^b(y) u_\alpha^b(y) \\ &\quad \times (\bar{s}_\alpha^a(x) u_\alpha^a(x))^\dagger e^{-S_G - \bar{u} W_u u - \bar{s} W_s s}. \end{aligned} \quad (2.2)$$

Table.1 The mass ratios  $m_\pi/m_\rho$ 

$h_{u/d}$	0.1583	0.1589	0.1592
Number of Configurations	40	40	30
Our result	0.57(32)	0.45(39)	0.39(67)
CP-PACS	0.593(1)	0.491(2)	0.415(2)

Table.2 The mass ratios  $m_K/m_{K^*}$ 

	$h_s=0.1566$	$h_s=0.1574$
$h_{u/d}=0.1583$	0.63(13)	0.59(16)
$h_{u/d}=0.1589$	0.60(16)	0.55(19)
$h_{u/d}=0.1592$	0.59(19)	0.53(22)

We use 25 configurations for all hopping parameters.

In Eq.(2.2),  $W_u^{-1}$  ( $W_s^{-1}$ )'s is  $u$  ( $s$ ) quark propagator,  $U$ 's are link variables of gluon, and  $\mathcal{S}_G$  is the gauge action. By integrating over  $u$ ,  $\bar{u}$ ,  $s$  and  $\bar{s}$  fields, the  $\kappa$  meson propagator is given by

$$G(y, x) = - \langle \text{Tr} W_s^{-1}(x, y) W_u^{-1}(y, x) \rangle \quad (2.3)$$

where ‘‘Tr’’ represents summation over color and Dirac spinor indices. From Eq.(2.3), we can see that  $\kappa$  propagator is composed of a connected diagram and contains no disconnected part, the latter of which was the origin of the light mass of the  $\sigma$  meson. For  $K_1$ , the operator is  $K_1^+ = \bar{s} \gamma^\mu \gamma_5 u$  and also the  $K_1$  meson propagator is composed of a connected diagram. We employ Wilson fermions and the plaquette gauge action.

### 3. Numerical Simulations

As for the simulation parameters, we first note that CP-PACS performed the quenched approximation calculation of the light meson spectroscopy with great success[17]. Therefore, we use the same values of the simulation parameters as those used by CP-PACS, i.e.,  $\beta=5.9$ , and the following three values for the  $u$  and  $d$  quark hopping parameter  $h_{u/d}=0.1583$ ,  $0.1589$  and  $0.1592$ , and the two values for the  $s$  quark hopping parameter  $h_s=0.1566$  and  $0.1574$ , except for the lattice size; our lattice size is  $20^3 \times 24$ . The meson propagators are calculated on a configuration in every 2000 trajectories generated by the heat bath method. We shall use the point source and sink, which together with the smaller lattice size, leads to large masses due to mixture of higher mass states. In other words, the masses to be obtained in our simulation should be considered as upper limits. The mass ratios of  $m_\pi/m_\rho$  are summarized in Table 1. Our results have large error bars. The propagators of the  $K$ ,  $K^*$ ,  $\kappa$  and  $K_1$  are shown Fig. 1, 2. The mass ratios of  $m_K/m_{K^*}$ ,  $m_\kappa/m_{K^*}$  and  $m_{K_1}/m_{K^*}$  are summarized in Table 2 ~ 4.

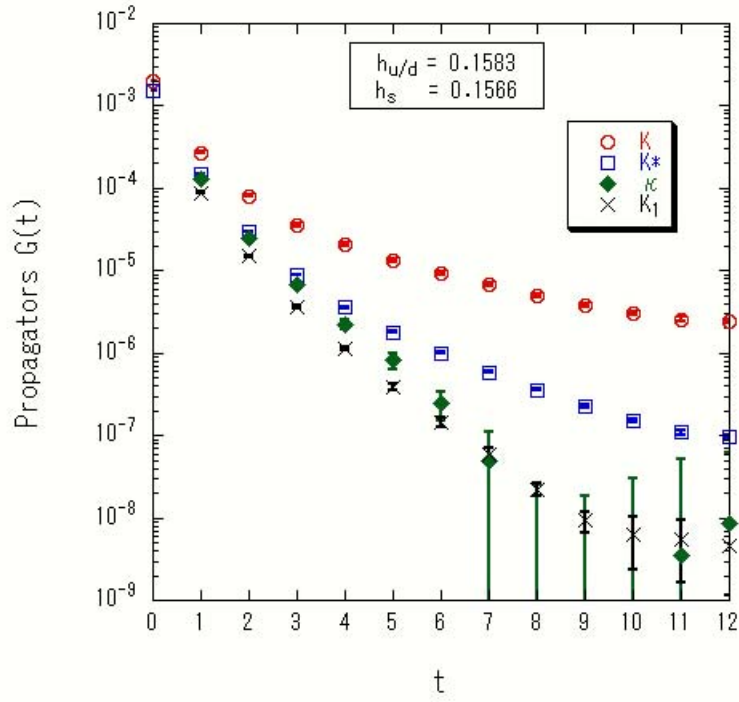


Figure 1: Propagators of  $K$ ,  $K^*$ ,  $\kappa$  and  $K_1$  for  $h_{u/d} = 0.1583$  and  $h_s = 0.1566$ .

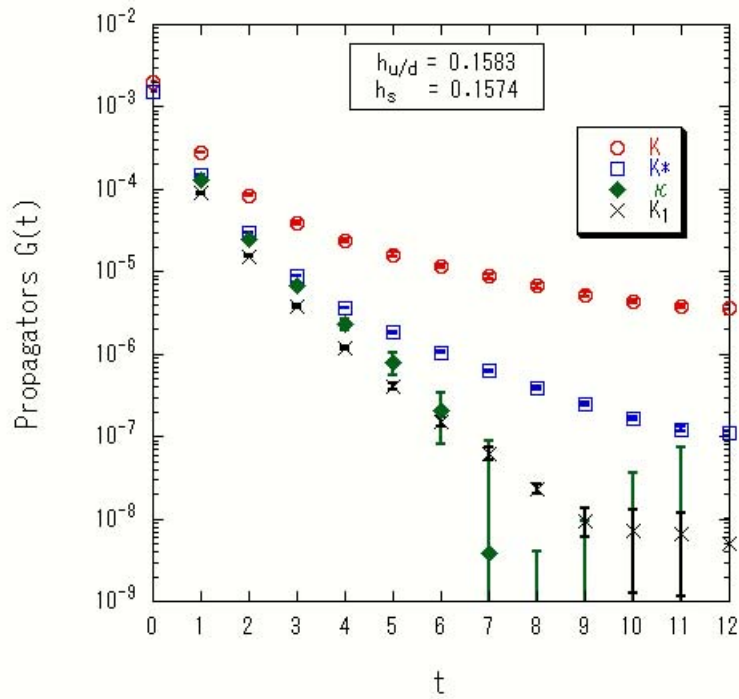


Figure 2: Propagators of  $K$ ,  $K^*$ ,  $\kappa$  and  $K_1$  for  $h_{u/d} = 0.1583$  and  $h_s = 0.1574$ .

Table.3 The mass ratios  $m_{\kappa}/m_{K^*}$ 

	$h_s=0.1566$	$h_s=0.1574$
$h_{u/d}=0.1583$	2.36(47)	2.28(42)
$h_{u/d}=0.1589$	2.150(89)	2.26(1.20)
$h_{u/d}=0.1592$	2.41(1.60)	2.66(2.41)

We use 25 configurations for all hopping parameters.

Table.4 The mass ratios  $m_{K_1}/m_{K^*}$ 

	$h_s=0.1566$	$h_s=0.1574$
$h_{u/d}=0.1583$	1.71(50)	1.77(54)
$h_{u/d}=0.1589$	1.77(63)	1.86(18)
$h_{u/d}=0.1592$	2.10(1.88)	2.07(1.22)

We use 25 configurations for all hopping parameters.

#### 4. Concluding remarks

We have reported our preliminary results on the  $\kappa$  and  $K_1$  meson propagator based on the quenched QCD. We see that the  $\kappa$  and  $K_1$  mass are almost twice as heavy as the  $K^*$  meson for all values of the hopping parameter. Our preliminary result of  $\kappa$  meson does not agree with recent experimental values. It is necessary to generate much more gauge configurations and improve the statistical precision of the estimation of  $\kappa$  and  $K_1$  propagators.

#### Acknowledgment

Simulations were performed on SX5 at RCNP, Osaka Univ., SR8000 at KEK.

#### References

- [1] **Particle Data Group**, S. Eidelman *et al.*, *Review of Particle Physics*, Phys. Lett. **B592** (2004) 1.
- [2] For example, see *Possible existence of the sigma-meson and its implications to hadron physics*, KEK Proceedings 2000-4, Soryushiron Kenkyu (kyoto) **102** (2001)E1.
- [3] F.E. Close and N. A. Törnqvist, *Scalar mesons above and below 1 GeV*, J. Phys. G: Nucl. Part. Phys. **28**(2002) R249 [hep-ph/0204205].
- [4] **E791** Collaboration, M. Aitala *et al.*, Phys. Rev. Lett. **89** (2002) 121801, [hep-ex/0204018].
- [5] **BES** Collaboration, *Evidence for  $\kappa$  meson production in  $J/\psi \rightarrow \bar{K}^* (892) K^+ \pi$  process*, [hep-ex/0506055]
- [6] M. Alford and R. L. Jaffe, *Insight into the scalar mesons from lattice calculation*, Nucl. Phys. **B578** (2000) 367, [hep-lat/0001023].
- [7] W. Lee and D. Weingarten, *Scalar quarkonium masses and mixing with the lightest scalar glueball*, Phys. Rev. **D61** (1999) 014015, [hep-lat/9910008].
- [8] C. McNeile and C. Michael, *Mixing of scalar glueballs and flavor singlet scalar mesons*, Phys. Rev. **D63** (2001) 114503, [hep-lat/0010019].

- [9] **SCALAR** Collaboration, *I=0 scalar channel*, Nucl. Phys. Proc. Suppl. **106** (2002) 272, [hep-lat/0112012].
- [10] **SCALAR** Collaboration, *Lattice study of “ $f_0(600)$  or  $\sigma$ ”*, Nucl. Phys. Proc. Suppl. **119** (2003) 275, [hep-lat/0210012].
- [11] **SCALAR** Collaboration, H. Wada, *Study of the  $0^+$  scalar mesons in lattice QCD*, Nucl. Phys. Proc. Suppl. **129** (2004) 432.
- [12] **SCALAR** Collaboration, *Scalar mesons in lattice QCD*, Phys. Rev. **D70** (2004) 034504, [hep-ph/0310312].
- [13] S. Prelovsek and K. Orginos, *Quenched scalar meson correlator with Domain Wall Fermions*, Nucl. Phys. Proc. Suppl. **119** (2003) 822, [hep-lat/0209132].
- [14]  **$\chi$ QCD Collaboration**, N. Mathur, et al., *A study of tetraquark mesonium on the lattice with overlap fermion*, these proceedings.
- [15] **SCALAR** Collaboration, *Lattice Study of the  $\kappa$  Scalar Meson*, Nucl. Phys. Proc. Suppl. **129** (2004) 242.
- [16] S. Prelovsek, C. Dawson, T. Izubuchi K. Orginos and A. Soni, *Scalar meson in dynamical and partially quenched two-flavor QCD: Lattice results and chiral loops*, Phys. Rev. **D70** (2004) 094503, [hep-lat/0407037].
- [17] **CP-PACS** Collaboration, S. Aoki, et al., *Light hadron spectrum and quark masses from quenched lattice QCD*, Phys. Rev. **D67** (2003) 034503, [hep-lat/0206009].