Heavy-light mesons in $2+1$ flavor lattice QCD
– Progress Report –

Yusuke Namekawa(Univ. of Tsukuba)
for the PACS-CS collaboration

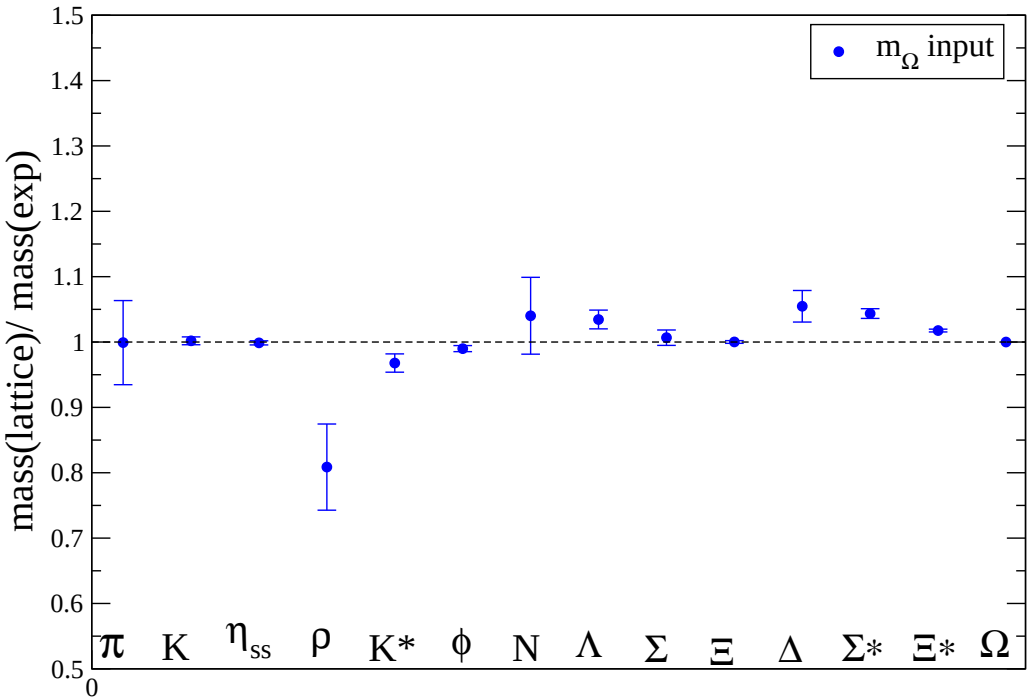
S.Aoki, K-I.Ishikawa, N.Ishizuka, T.Izubuchi, K.Kanaya, Y.Kuramashi, Y.Namekawa, M.Okawa,

Y.Taniguchi, A.Ukawa, N.Ukita, T.Yamazaki, T.Yoshie

Contents

1 Introduction

[Light hadron spectrum]
PACS-CS collaboration reaches the physical point of dynamical ud, s quarks.
Light hadron spectrum is reproduced well. PACS-CS, 2008; Y.Kuramashi talk
→ The next target is the heavy quark system.



2 Simulation setup

We perform a lattice QCD simulation of a charm quark system using a relativistic heavy quark (RHQ) action on the PACS-CS configurations.

- Action : RG improved gauge + $O(a)$ improved Wilson fermion for light sea quarks + RHQ for valence charm quark
- Lattice size : $32^3 \times 64$ ($L = 3$ fm, $a^{-1} = 2.2$ GeV ($\beta = 1.90$))
- Sea quark masses : $m_{ud} = 3 - 10$ MeV, $m_s = 75 - 80$ MeV ($m_\pi = 160 - 300$ MeV, $m_\pi L = 2.3 - 4.3$)
- Inputs : m_π,m_K,m_Ω for m_{ud},m_s,a; $\overline{m}(1S) \equiv \frac{1}{4}(m_{\eta_c} + 3m_{J/\psi})$ for m_{charm}

[Statistics of heavy-light measurements] – Preliminary –

- Heavy-heavy measurements have been finished with full statistics of 1000 – 2000 MD times.

κ_{ud}	κ_s	m_{ud}^{AWI}[MeV]	m_s^{AWI}[MeV]	N_{conf} (MD time)
0.13770	0.13640	10	80	45 (1125)
0.13781	0.13640	3	80	25 (625)
0.13770	0.13660	10	75	50 (1250)
0.137785	0.13660	3	75	200 (1000)

[Relativistic Heavy Quark(RHQ) Action]

We employ a RHQ action(Tsukuba-type) for heavy quarks. S.Aoki et al, 2001

- Since the charm quark is not too heavy, relativistic approach is needed.
- RHQ action can control heavy quarks on the lattice. It reduces $O((ma)^n)$ to $O(f(ma)(g^2 a\Lambda_{QCD}))$ where f is smooth around $ma = 0$.

  ◇ For r_s, $C_{SW}^{s,t}$, tadpole improved 1-loop values are used. S.Aoki et al, 2003
  $C_{SW}^{s,t}$ are non-perturbatively improved at the massless point,
  $C_{SW}^{s,t} = C_{SW}(NP, m=0) - C_{SW}^{s,t}(PT, m=0) + C_{SW}^{s,t}(PT, m \neq 0)$.

  ◇ ν is non-perturbatively tuned.

$$
\begin{aligned}
S_{RHQ} &= \sum_{x,y} \bar{q}(x) D(x,y) q(y), \\
D(x,y) &\equiv \delta_{x,y} - \kappa_{heavy} \Big\{ (1-\gamma_4) U_4(x) \delta_{x+4,y} + (1+\gamma_4) U_4^\dagger(x) \delta_{x,y+4} \\
&\quad + \sum_i \Big((r_s - \nu\gamma_i) U_i(x) \delta_{x+i,y} + (r_s + \nu\gamma_i) U_i^\dagger(x) \delta_{x,y+i} \Big) \Big\} \\
&\quad - \delta_{x,y} \kappa_{heavy} \left\{ C_{SW}^s \sum_{i<j} \sigma_{ij} F_{ij} + C_{SW}^t \sum_i \sigma_{4i} F_{4i} \right\}.
\end{aligned}
$$

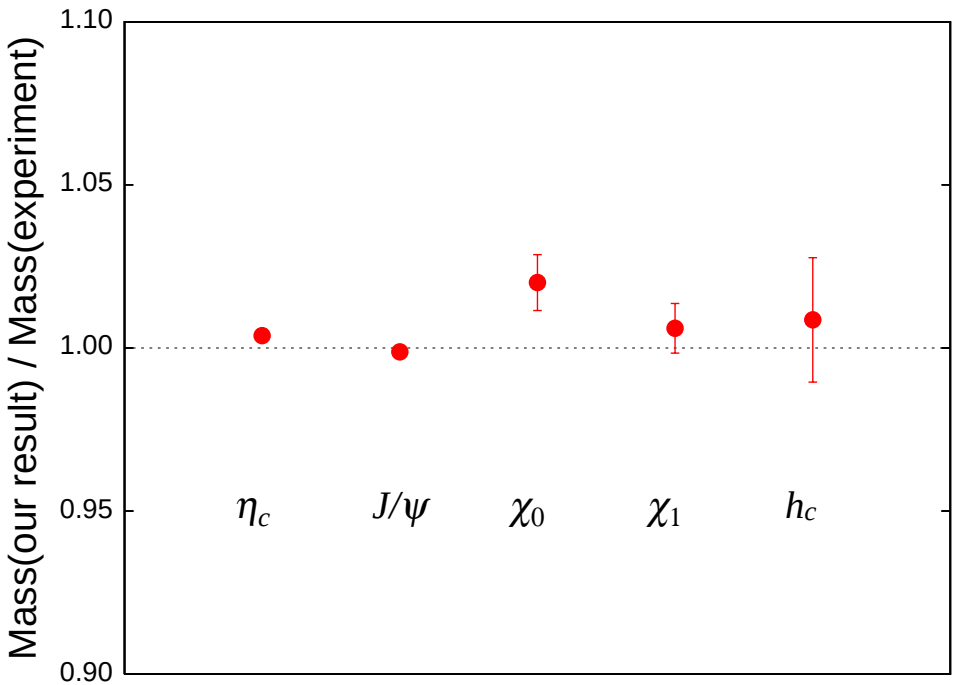
3 Results

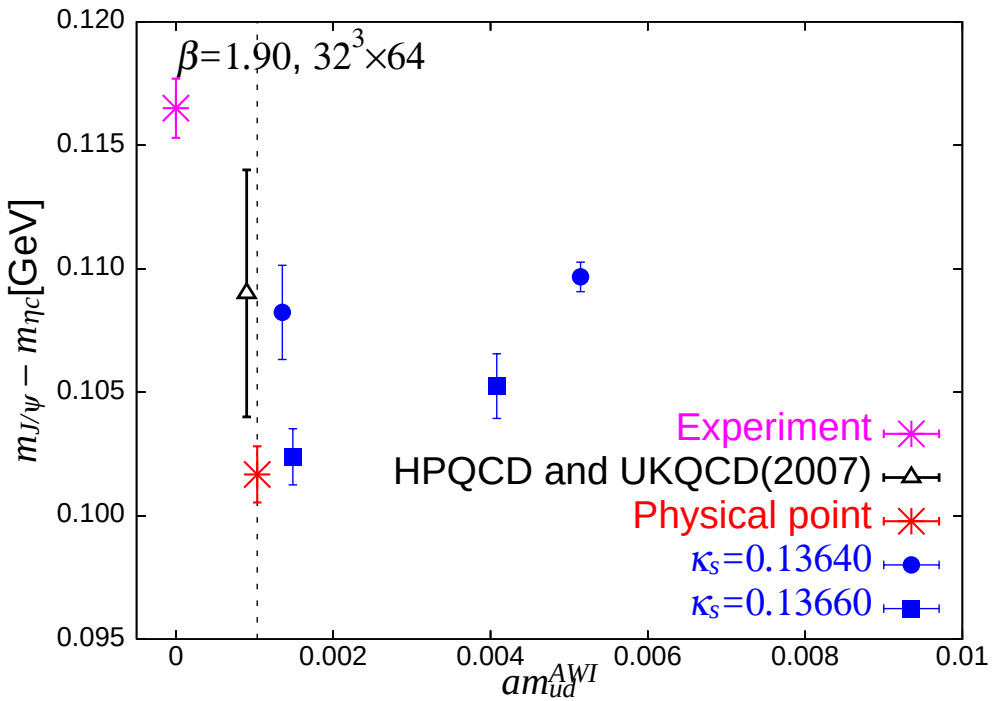
3.1 Charmonium spectrum

- Charmonium spectrum is reproduced well except for the hyperfine splitting.
- The hyperfine splitting is slightly underestimated.

  → Possible origins of the discrepancy are $O(g^2 a)$ effects in RHQ action, disconnected loop contributions, dynamical charm quark effects. cf. Posters by L.Levkova,S.Gottlib

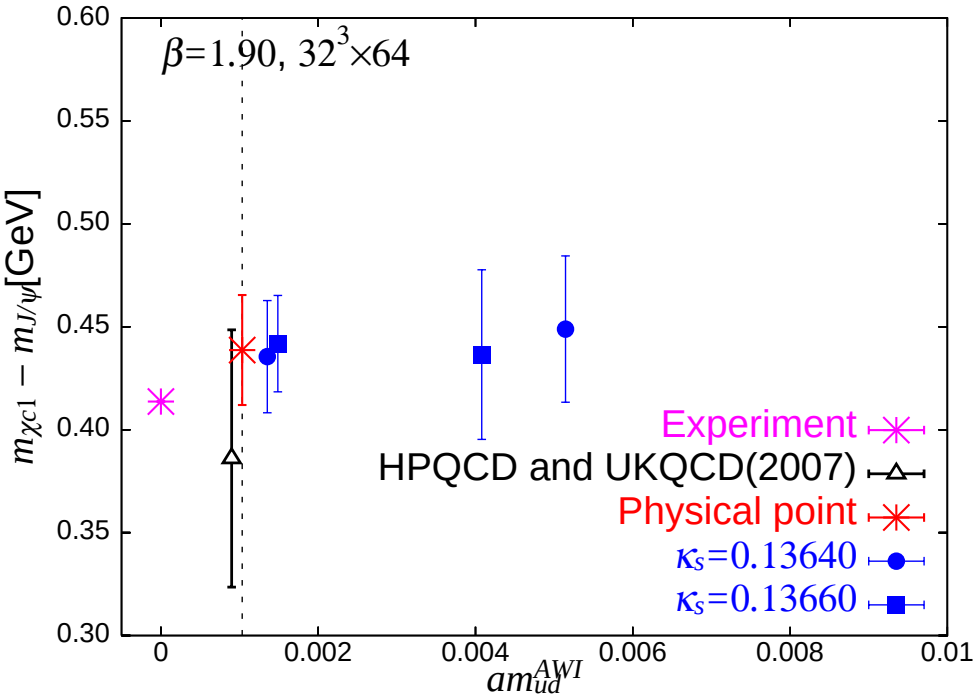
  ◇ Lattice data are extrapolated to the physical point with
  $m_{J/\psi} - m_{\eta_c} = A + B(m_{ud} - m_{ud}^{phys}) + C(m_s - m_s^{phys})$.

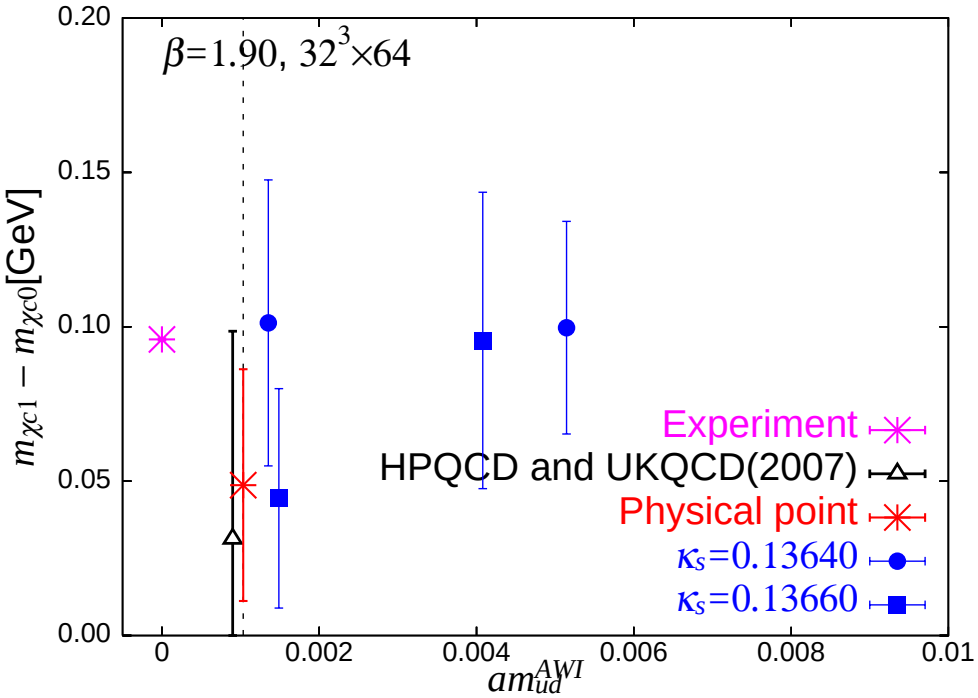




[Orbital excitation and fine structure]

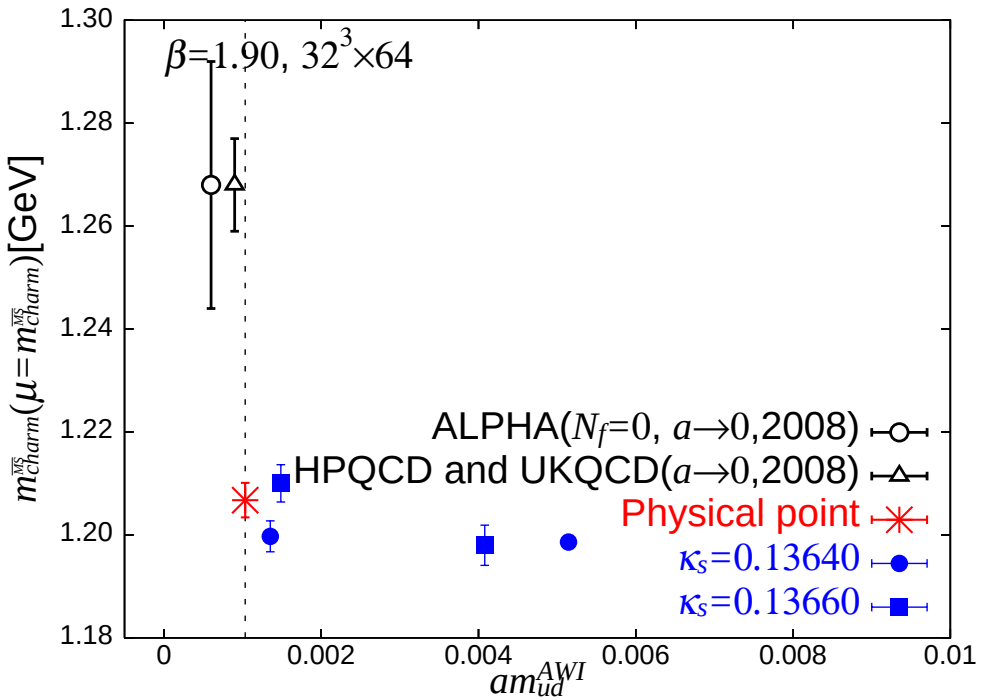
- Sea quark mass dependence is mild.
- Orbital excitation and fine structure are reproduced well.





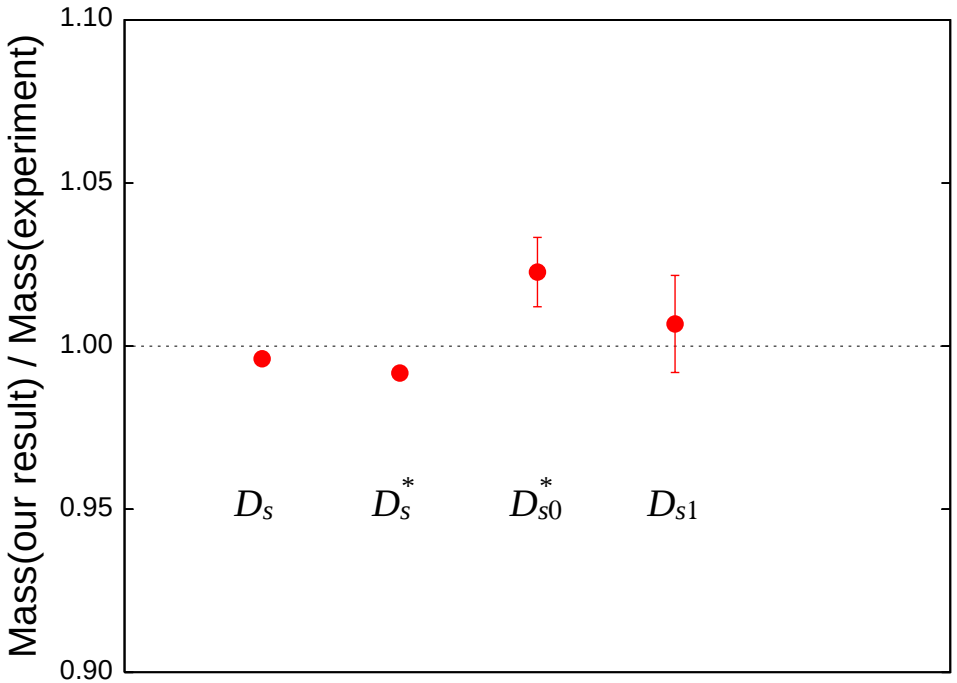
[Charm quark mass]

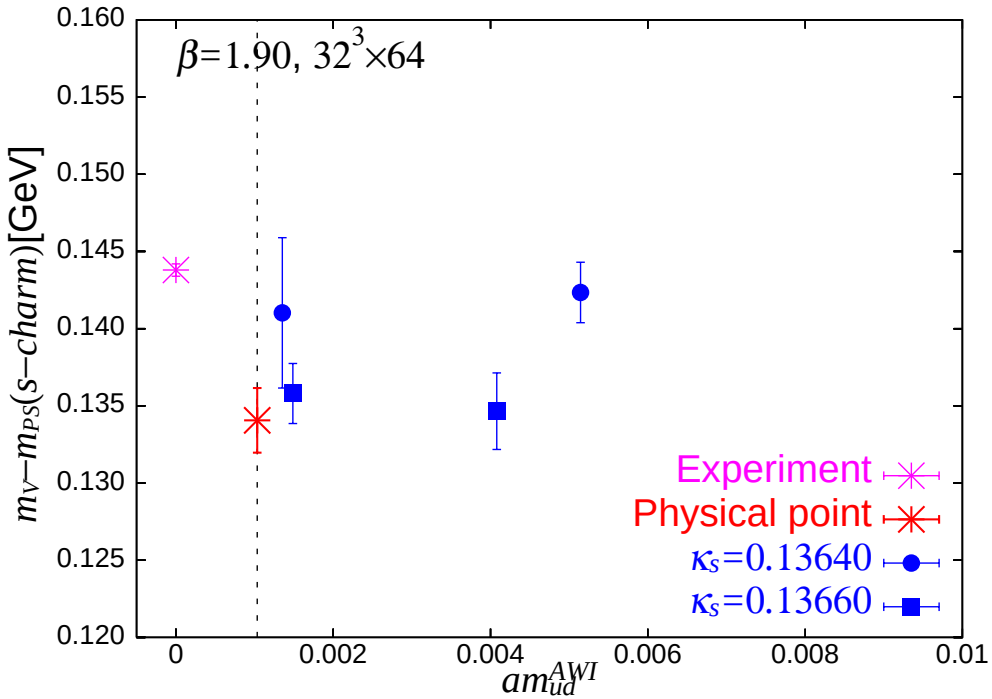
- $m_{charm}^{\overline{MS}}(\mu = m_{charm}^{\overline{MS}})$ is determined using the axial Ward identity.
- One-loop values are employed for Z_P, Z_{A_4}.
- 4-loop beta function is used for mass running.
- Our value of $m_{charm}^{\overline{MS}}(\mu = m_{charm}^{\overline{MS}})$ is smaller than the previous results. Continuum extrapolation is needed for a conclusion.



3.2 Charm-strange spectrum

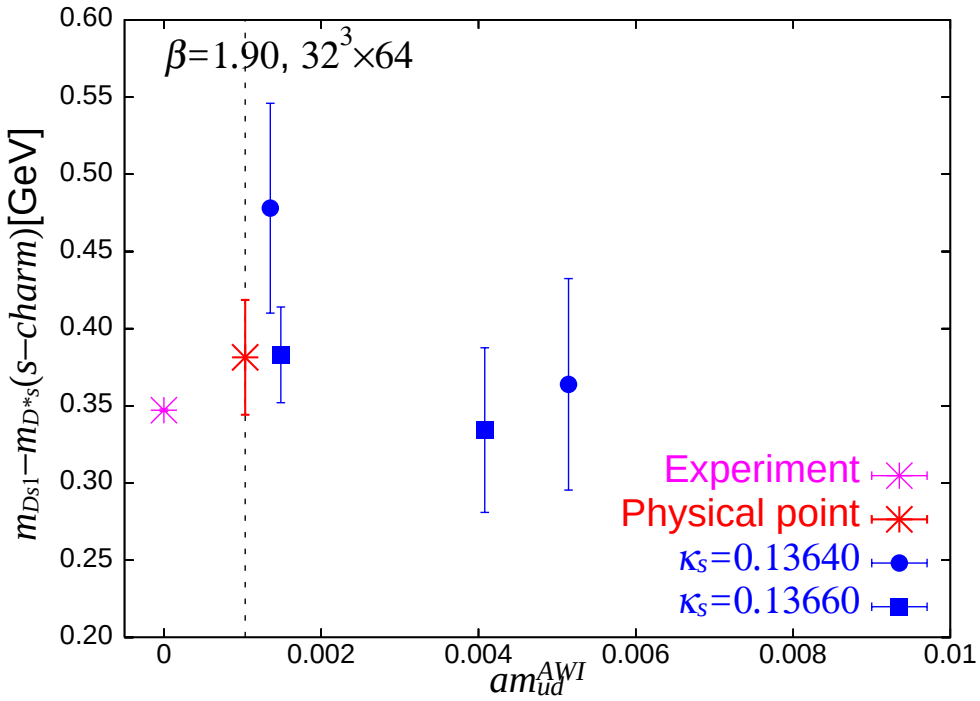
- Spectrum is reproduced well except for the hyperfine splitting.
- The hyperfine splitting is slightly underestimated.
  → Possible origins of the discrepancy are $O(g^2a)$ effects in RHQ action, dynamical charm quark effects.
- (For unstable particles, more detailed analysis using Lüscher's formula is needed.)

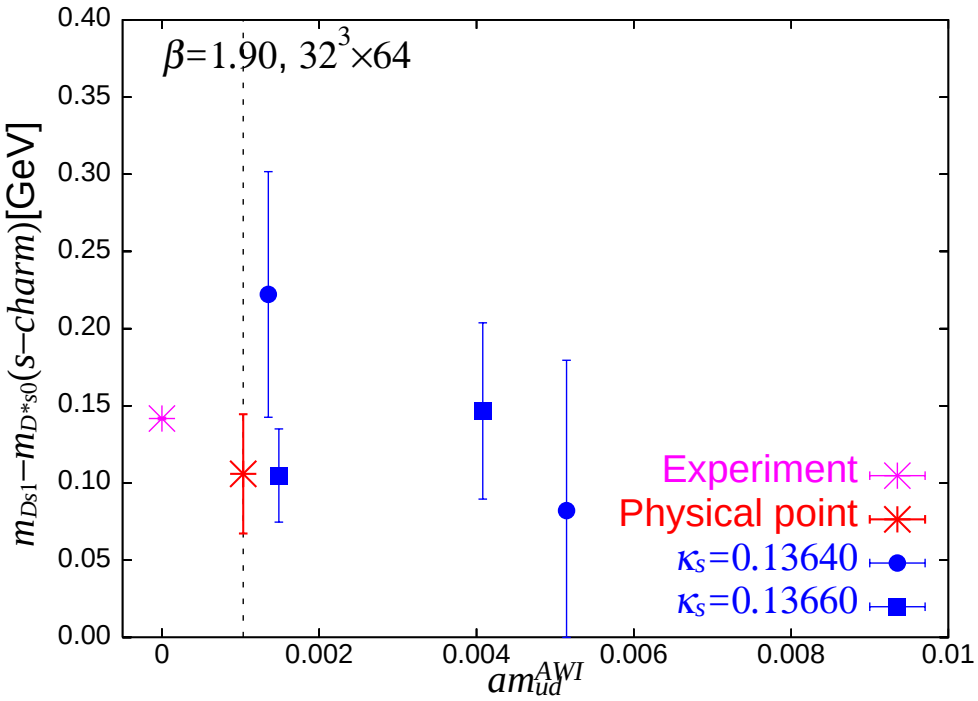




[Orbital excitation and fine structure]

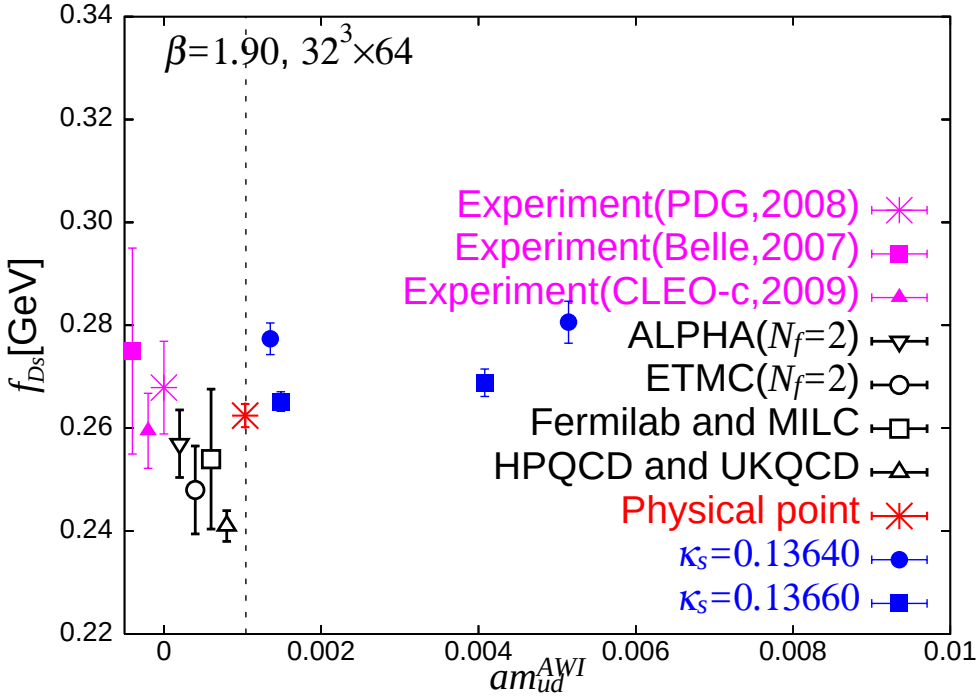
- The orbital excitation and fine structure are reproduced well.

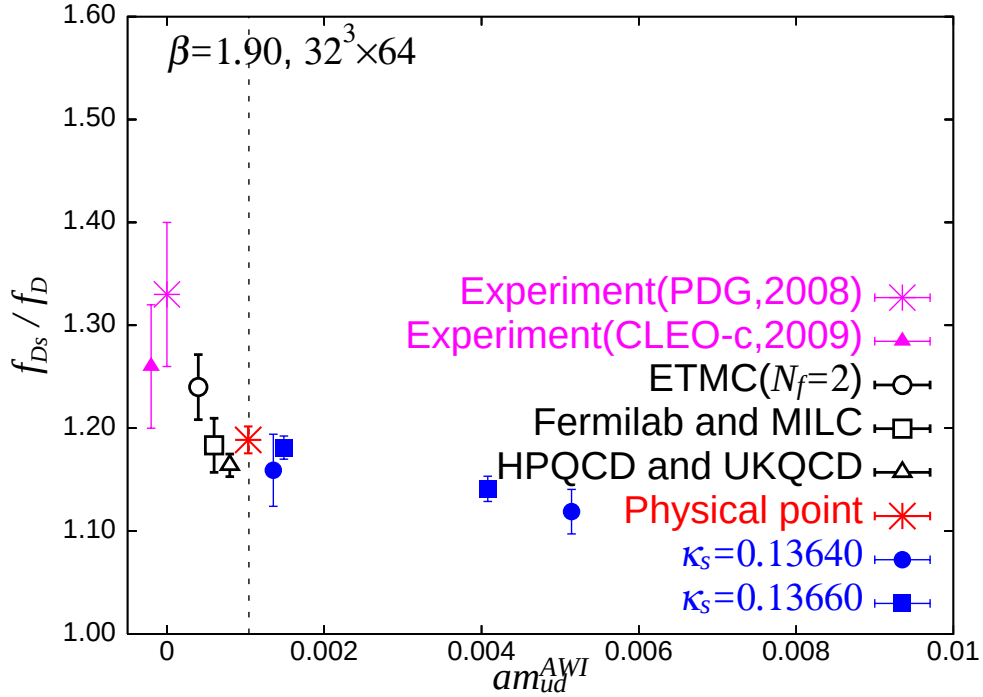




[Decay constant f_{Ds}]

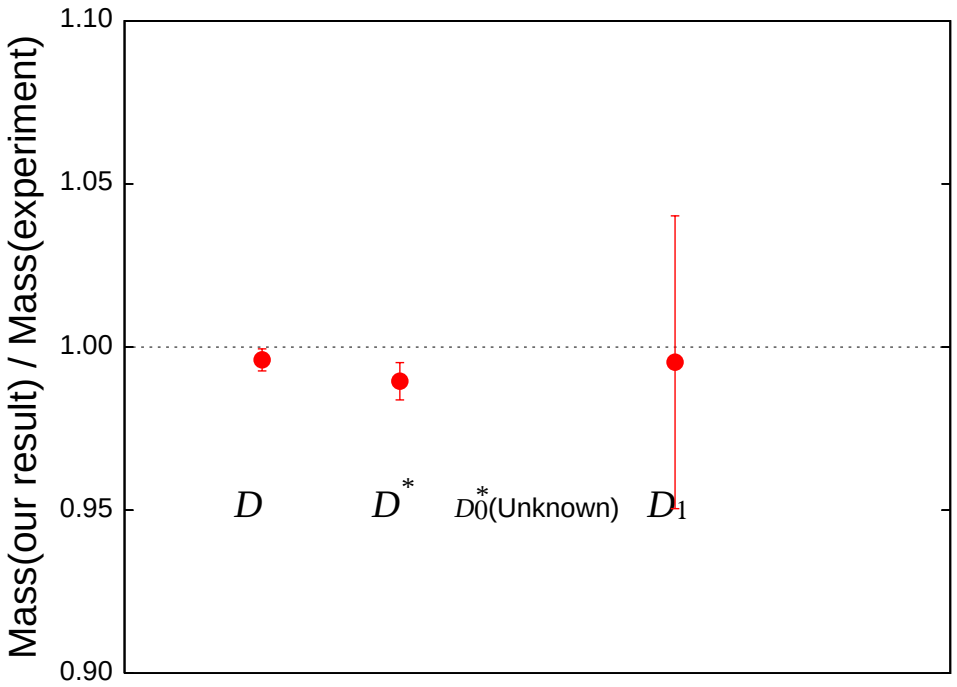
- Our result does not show any clear deviation from experimental values and other group data except for HPQCD and UKQCD result.
  - ◇ HPQCD and UKQCD result increases if new r_1 data is employed.
  - ◇ We employ 1-loop values for renormalization factors of decay constants. Continuum extrapolation is needed. Effects of renormalization factors are reduced in the ratio of f_{D_s}/f_D.

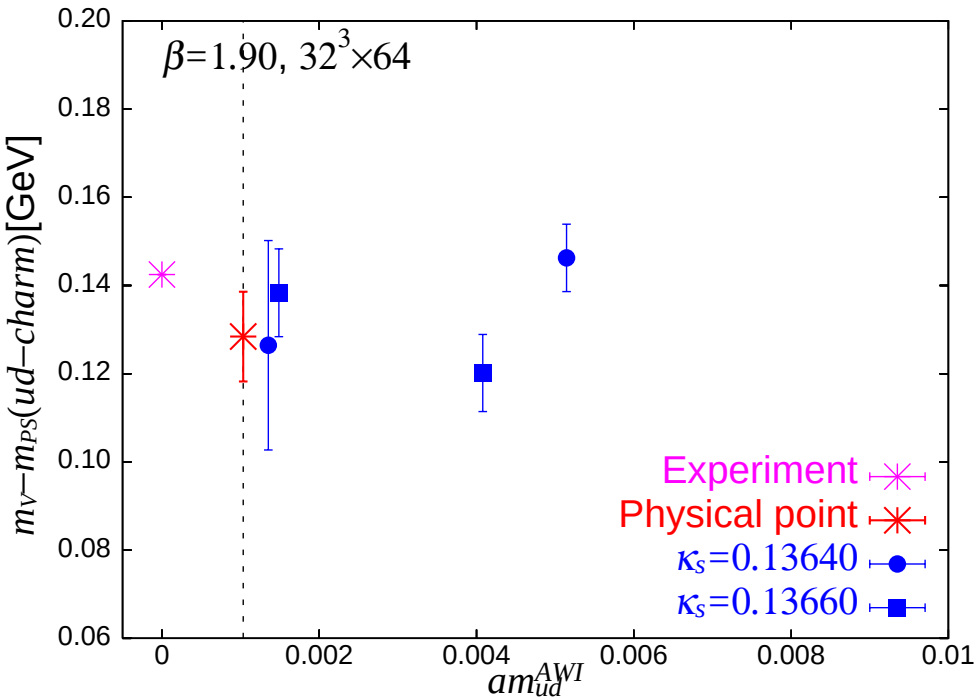




3.3 Charm-ud spectrum

- Spectrum is reproduced, though our statistical errors are still large.
  → We increase the statistics now.
- (For unstable particles, more detailed analysis using Lüscher's formula is needed.)

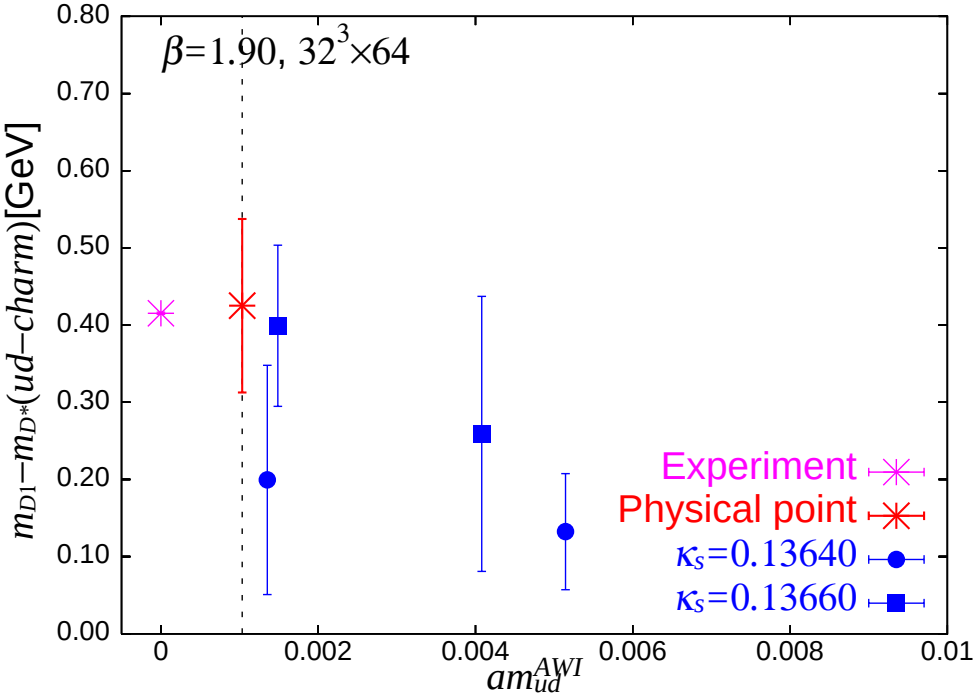


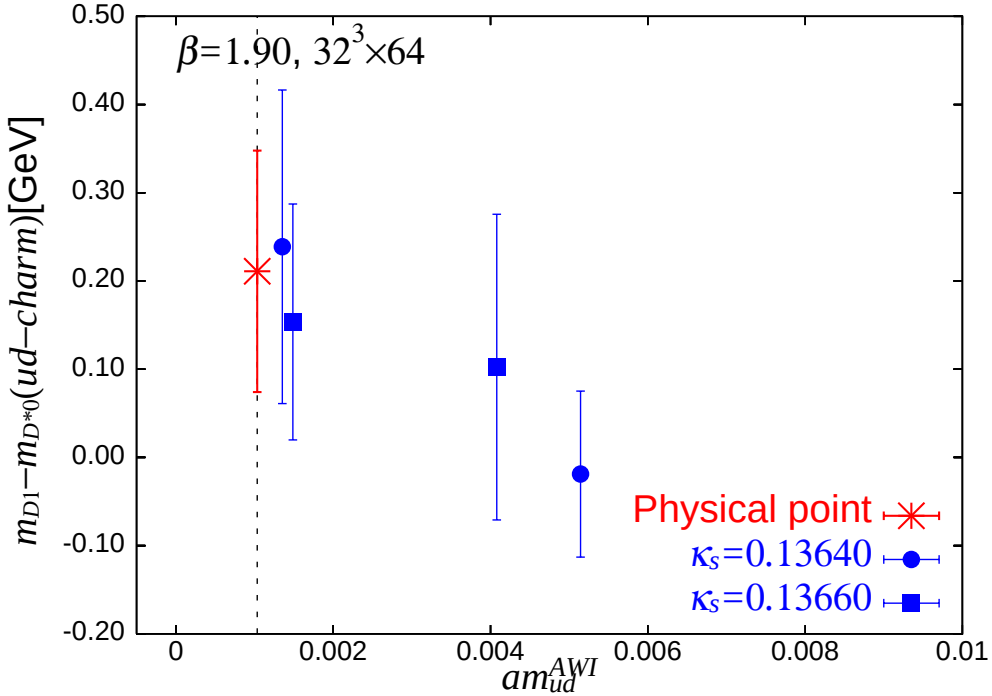


[Orbital excitation and fine structure]

- Orbital excitation is reproduced well, though our statistical errors are still large.

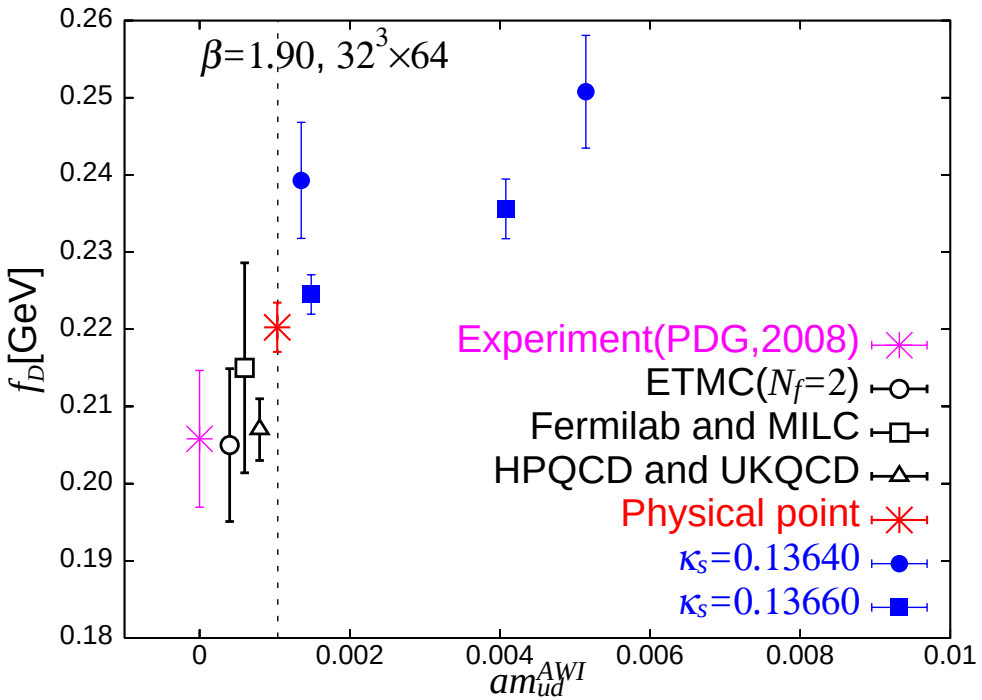
  ◇ (D_0^*(scalar) has not been confirmed experimentally, yet)





[Decay constant f_D]

- Our result does not show any clear deviation from experimental value and other group data except for HPQCD and UKQCD result.
  - ♢ HPQCD and UKQCD result increases if new r_1 data is employed.
  - ♢ We employ 1-loop values for renormalization factors of decay constants. Continuum extrapolations is needed.



4 Summary

We performed a simulation of a charm quark system using RHQ action on $N_f = 2+1$ PACS-CS configurations. Our preliminary data showed the followings.

- Mass spectrums are reproduced well except for hyperfine splittings.
- Our data of the hyperfine splitting are slightly smaller than the experimental value.
  $\rightarrow$ Possible origins of the discrepancy are $O(g^2 a)$ effects in RHQ action, dynamical charm quark effects.
- Decay constants f_{D_s}, f_D do not show any deviations from experimental values. But, since we employ 1-loop renormalization factors, continuum extrapolations are needed for a conclusion.

Appendix