Heavy-light meson spectrum and decay constant by $N_f = 2 + 1$ lattice QCD

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1 Introduction

[Motivation (I)]
CKM matrix element $|V_{cs}|$ can be extracted through leptonic decay with lattice data of f_{Ds}.

$$\Gamma(D_s \to l\nu) = \frac{G_F^2}{8\pi} f_{Ds}^2 m_l^2 m_{Ds} \left(1 - \frac{m_l^2}{m_{Ds}^2}\right)^2 |V_{cs}|^2$$

$|V_{cd}|$ can be determined precisely by neutrino and antinuetrino scattering experiments. On the other hand, determination of $|V_{cs}|$ is hard, due to uncertainty of strange quark sea contribution.

[Motivation (II)]
f_{Ds} may give a signal beyond the standard model.

- HPQCD collaboration reported that their f_{Ds} from lattice QCD disagrees with experimental data by 3.8σ.

$$\begin{aligned} f_{Ds}(experiment) &= 277(9)\text{MeV} \\ f_{Ds}(lattice) &= 241(3)\text{MeV} \quad \text{HPQCD,2008} \end{aligned}$$

  $\leftarrow$ A two-Higgs doublet model predicts there may be substantial contribution of charged Higgs to f_{Ds} (in addition to $W^{\pm}$, $H^{\pm}$ propagates) J.L.Hewett,1995;A.G.Akeroyd,2004;A.G.Akeroyd and C.H.Chen,2007.

  The contribution to f_D is negligible.

We try to check this problem using a relativistic heavy quark on the $N_f = 2 + 1$ configurations.

2 Simulation setup

We perform a lattice QCD simulation of a charm quark system using a relativistic heavy quark on the PACS-CS configurations.
[Statistics] – Preliminary –

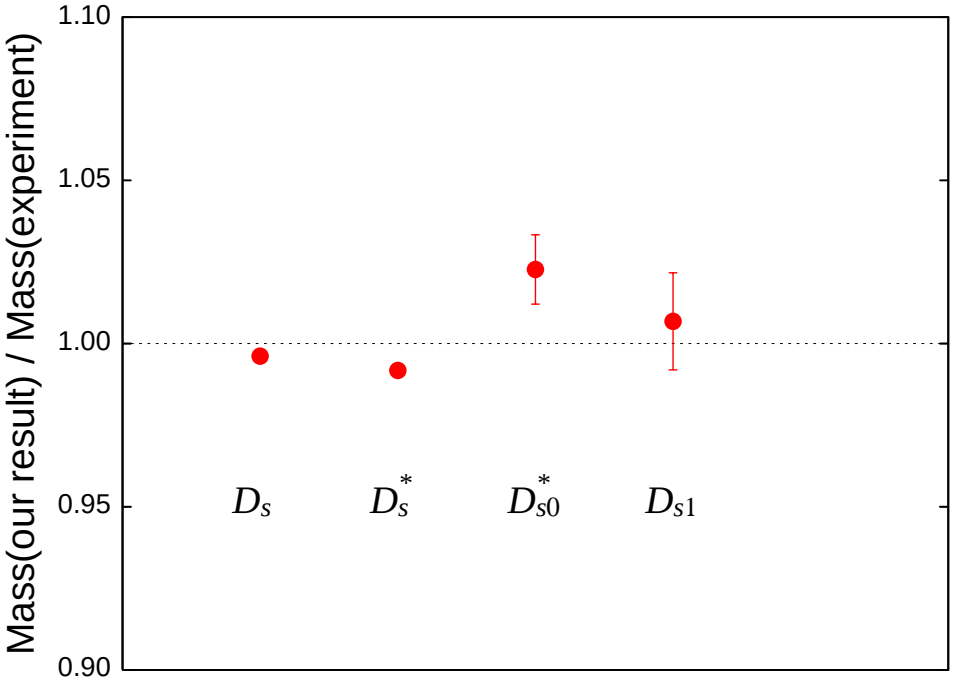
- Action : RG improved gauge + $O(a)$ improved Wilson fermion for light sea quarks + relativistic heavy quark for valence charm quark
- Lattice size : $32^3 \times 64$ ($L = 3$ fm, $a^{-1} = 2.2$ GeV ($\beta = 1.90$))
- Sea quark masses : $m_{ud} = 3 - 10$ MeV, $m_s = 70 - 80$ MeV
  ($m_\pi = 160 - 300$ MeV, $m_\pi L = 2.3 - 4.3$)
  ← Calculation just on the physical point is ongoing.
- 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}

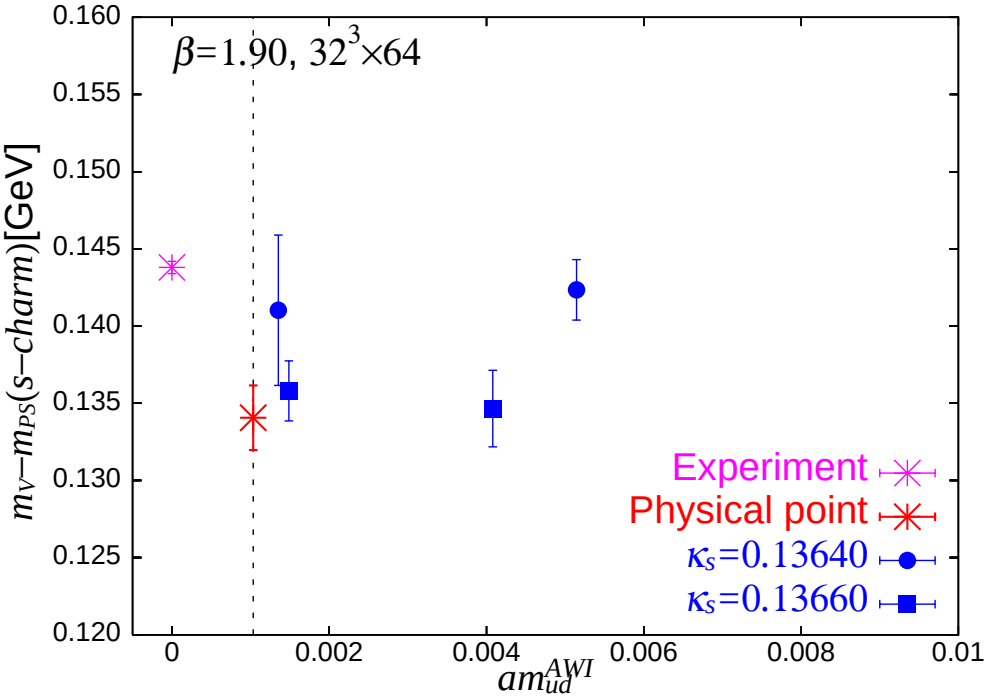
κ_{ud}	κ_s	m_{ud}^{AWI}[MeV]	m_s^{AWI}[MeV]	N_{conf} (MD time)
0.13770	0.13640	10	80	80 (2000)
0.13781	0.13640	3	80	65 (1625)
0.13770	0.13660	10	70	60 (1500)
0.137785	0.13660	3	70	200 (1000)

3 Results

3.1 Charm-strange spectrum

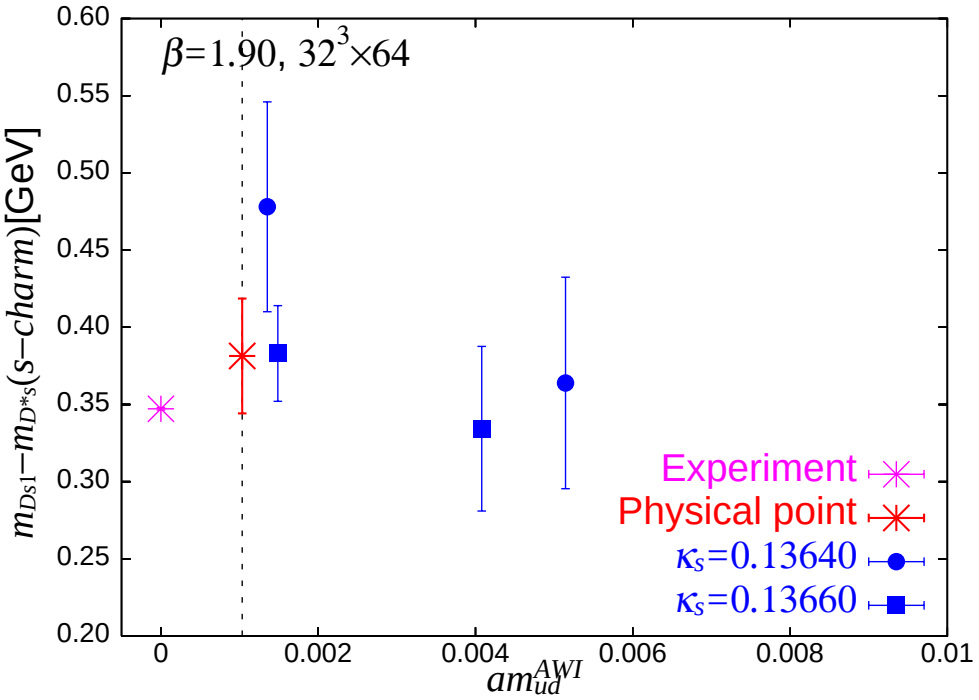
- Spectrum is reproduced well except for the hyperfine splitting.
- The hyperfine splitting is slightly underestimated.
  → Possible origins of the discrepancy are $O(g^2a)$ effects in RHQ action, dynamical charm quark effects.
- (For unstable particles, more detailed analysis using Lüscher's formula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

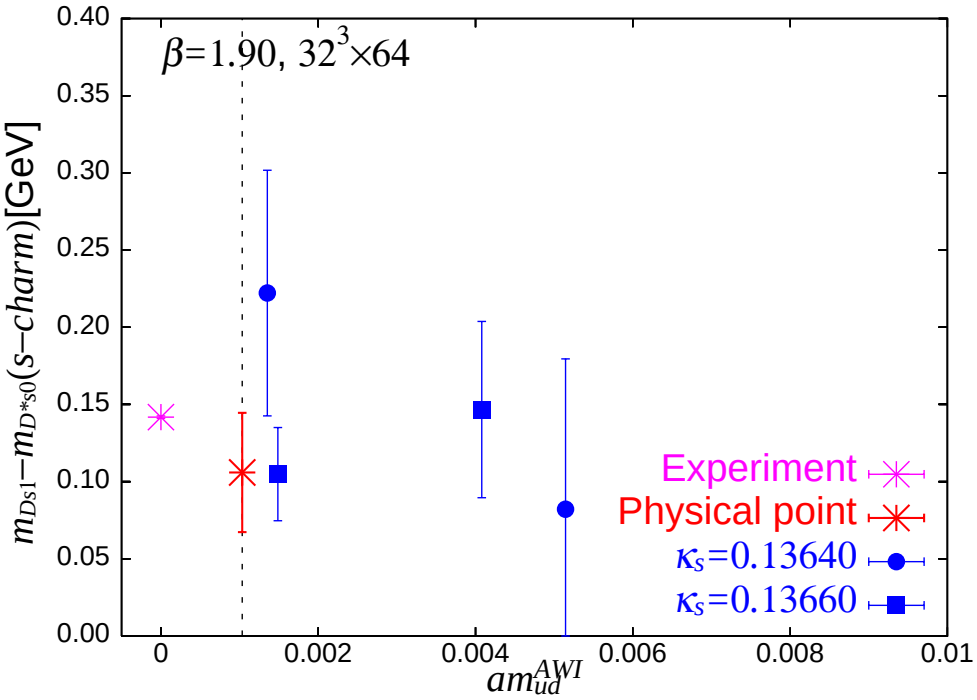




[Orbital excitation and fine structure]

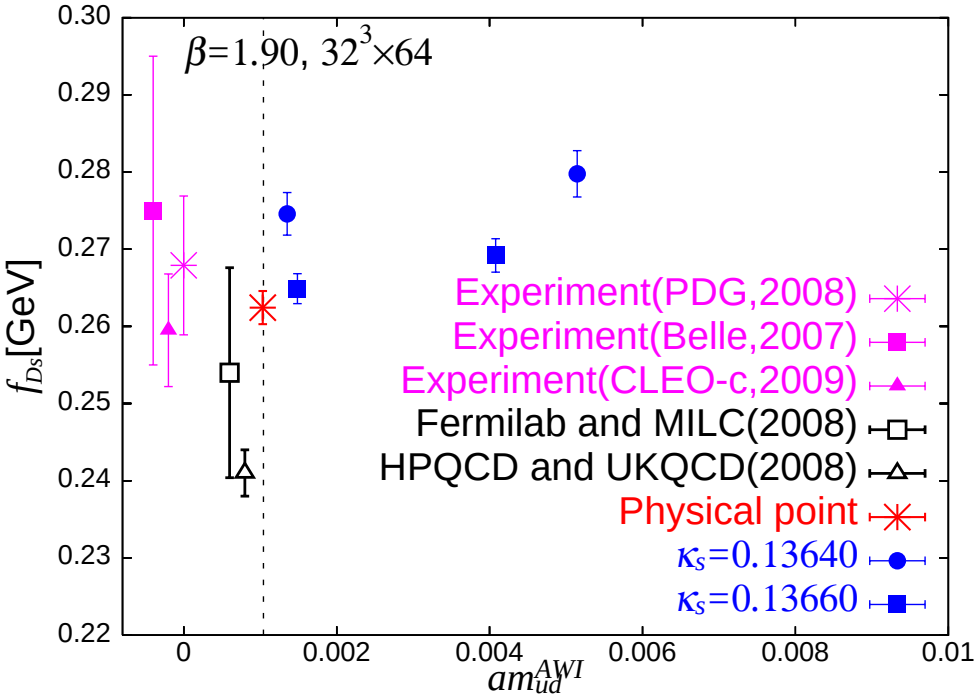
- The orbital excitation and fine structure are reproduced well, though our statistical errors are still large.

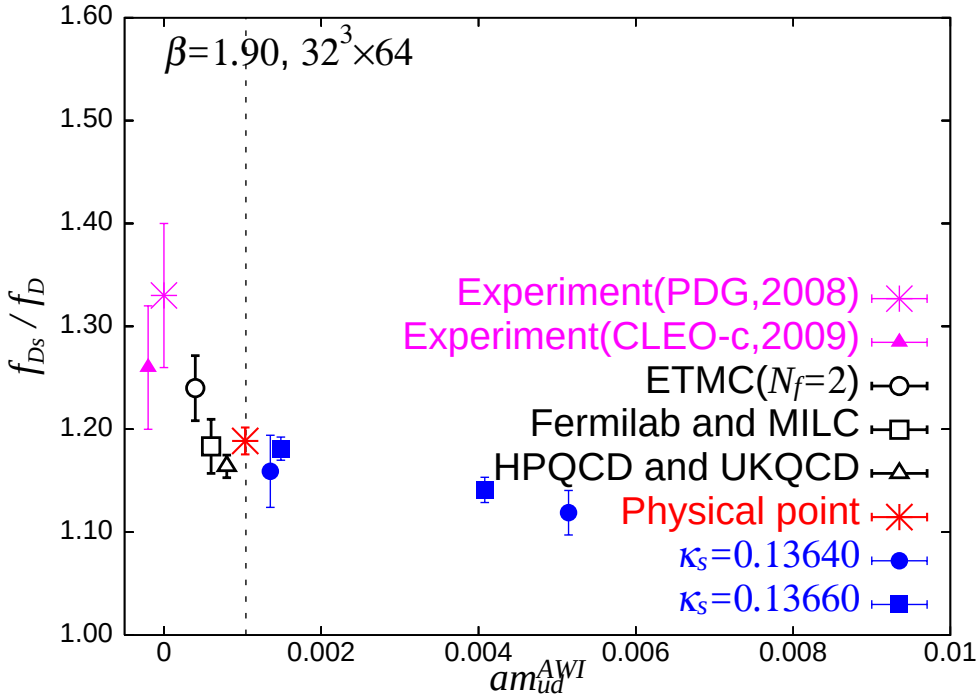




[Decay constant f_{Ds}]

- 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 is updated recently. Their result goes up if new r_1 data is employed. HPQCD and UKQCD,2009
  - ♢ 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_{Ds}/f_D.





[CKM matrix element $|V_{cs}|$]

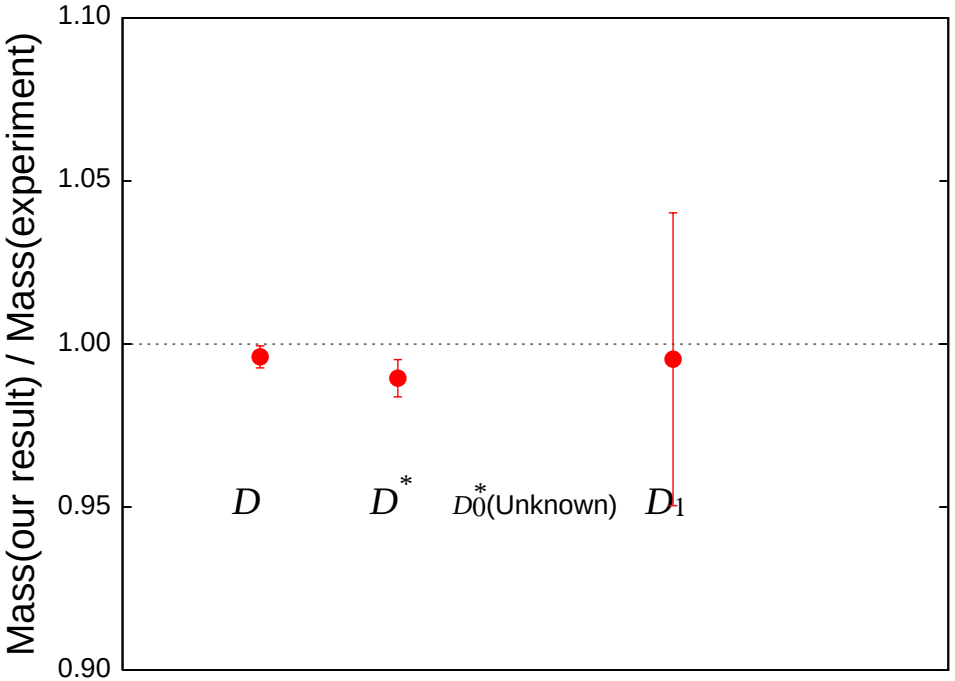
- Combining our results of m_{Ds} and f_{Ds} with experimental value of $\Gamma(D_s \to l\nu)$ CLEO,2009 gives $|V_{cs}|$.
- Our result is consistent with PDG value, though our value include systematic errors due to finite lattice spacing.

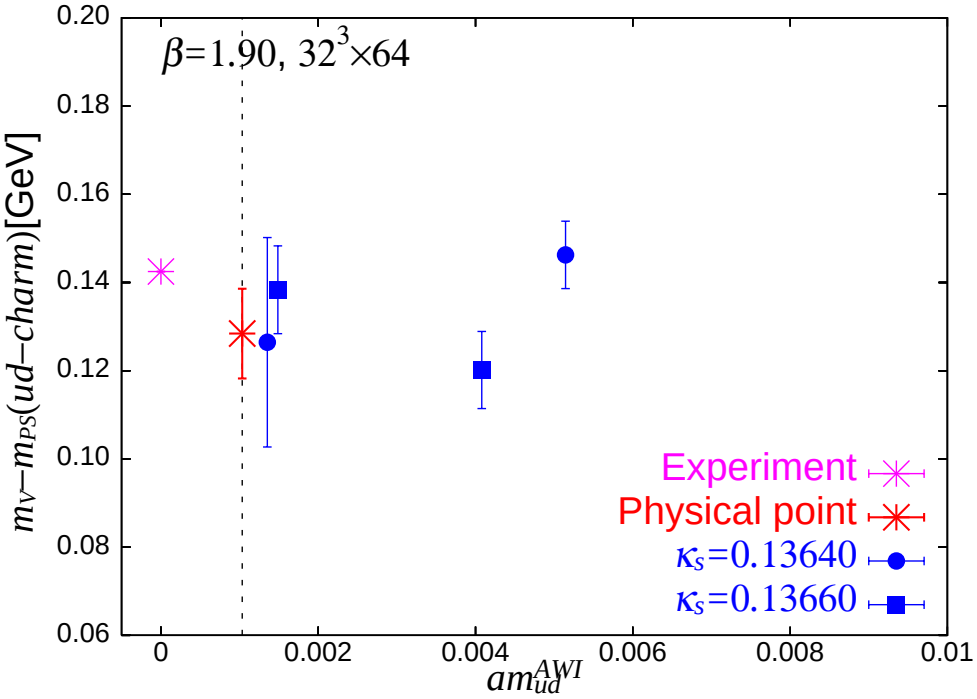
$$\Gamma(D_s \to l\nu) = \frac{G_F^2}{8\pi} f_{Ds}^2 m_l^2 m_{Ds} \left(1 - \frac{m_l^2}{m_{Ds}^2}\right)^2 |V_{cs}|^2$$

$$\begin{aligned} |V_{cs}|(\text{our result}) &= 0.99(3) + (\text{systematic error}) \\ |V_{cs}|(PDG, 2008) &= 1.04(6) \end{aligned}$$

3.2 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.)

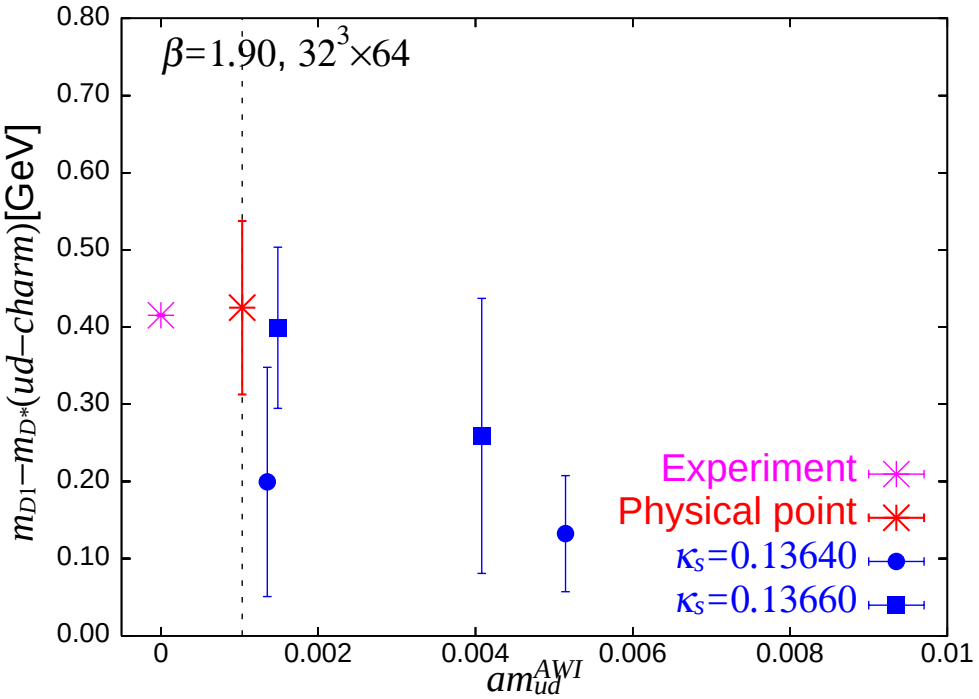


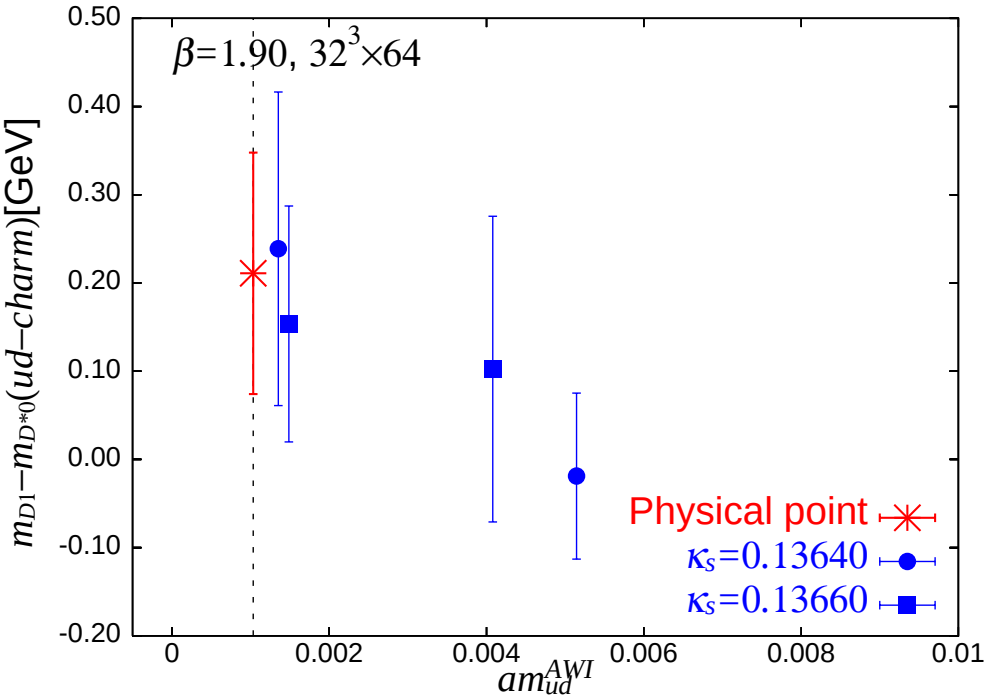


[Orbital excitation and fine structure]

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

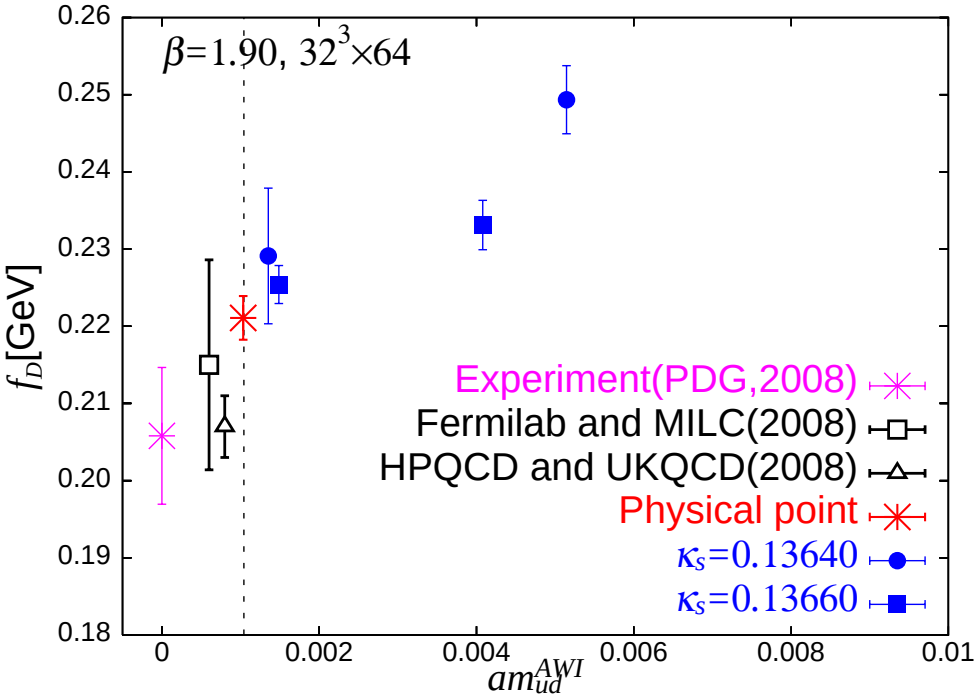
  ♢ (D_0^*(scalar) has not been confirmed experimentally, yet)





[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 goes up 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.

- 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, and disconnected loop contributions.
- Decay constant f_{D_s} do not show any deviations from experimental values.
  $\leftarrow$ But, since we employ 1-loop renormalization factors, continuum extrapolations are needed for a conclusion.

Appendix