Charm quark system on the physical point in 2+1 flavor lattice QCD

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1 Motivation

- Determine fundamental parameters in the standard model.
- Check the effectiveness of heavy quark action on the lattice.

2 Simulation setup

We use $N_f = 2 + 1$ configurations on the physical point. PACS-CS, 2009

- Action : Iwasaki gauge + $O(a)$ improved Wilson fermion for light sea quarks + relativistic heavy quark(Tsukuba-type) for valence charm quark
- Lattice size : $32^3 \times 64$ ($L = 3$ fm, $a^{-1} = 2.194(10)$ GeV ($\beta = 1.90$))
- Quark masses : on the physical point(i.e. $m_\pi = 135$ MeV) $m_{ud}^{\overline{\rm MS}}(\mu = 2\text{ GeV}) = 3.0(3)$ MeV, $m_s^{\overline{\rm MS}}(\mu = 2\text{ GeV}) = 93(1)$ MeV
  - ◇ Inputs for m_{ud},m_s,a : $m_\pi = 135$ MeV, $m_K = 498$ MeV, $m_\Omega = 1673$ MeV
  - ◇ Input for m_{charm} : $\overline{m}(1S) := \frac{1}{4}(m_{\eta_c} + 3m_{J/\psi}) = 3068$ MeV

$\kappa_{\rm ud}$	$\kappa_{\rm s}$	$\kappa_{\rm charm}$	conf(MD time)
0.13779625	0.13663375	0.10959947	80(2000)

3 Our relativistic heavy quark action

Since the charm quark is not too heavy, relativistic approach is needed.

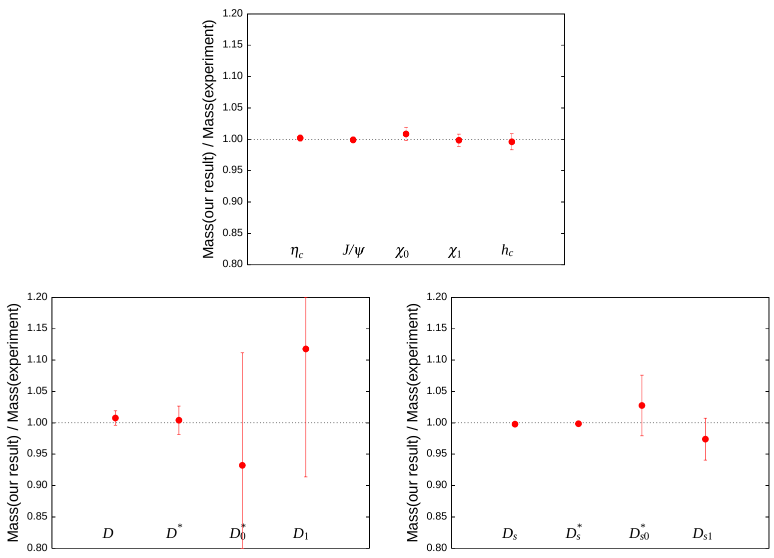
- The relativistic heavy quark action reduces mass corrections $O((ma)^n, ^\forall n)$ to $O(\alpha_s^2 f(ma)(a\Lambda_{QCD}))$ where f is smooth around $ma = 0$. S.Aoki et al, 2001
  - ◇ For $r_s, C_{SW}^{s,t}$, tadpole improved 1-loop values are used. S.Aoki et al, 2003
    $C_{SW}^{s,t}$ are non-perturbatively 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 s.t. the speed of light of 1S charmonium becomes unity.

$$S_{RHQ} = \sum_{x,y} \bar{q}(x) D(x,y) q(y),$$

$$D(x,y) \equiv \delta_{x,y} - \kappa_{charm} \Big\{ (1-\gamma_4)U_4(x)\delta_{x+4,y} + (1+\gamma_4)U_4^\dagger(x)\delta_{x,y+4} + \sum_i \Big((r_s - \nu\gamma_i)U_i(x)\delta_{x+i,y} + (r_s + \nu\gamma_i)U_i^\dagger(x)\delta_{x,y+i} \Big) \Big\} - \delta_{x,y}\kappa_{charm} \Big\{ C_{SW}^s \sum_{i<j} \sigma_{ij}F_{ij} + C_{SW}^t \sum_i \sigma_{4i}F_{4i} \Big\}.$$

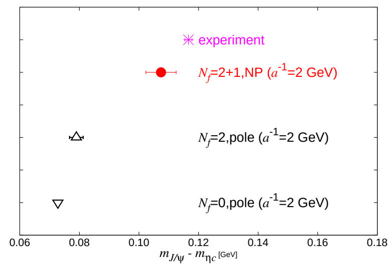
4 Heavy-heavy and heavy-light spectrum

- Heavy-heavy and heavy-light spectrums agree with experiment.



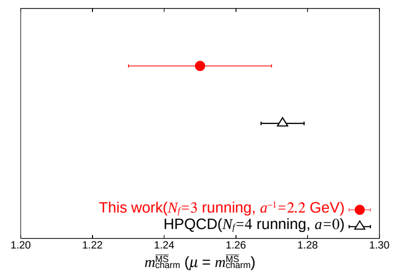
5 Hyperfine splitting of charmonium

- Hyperfine splitting of charmonium agrees with experiment in 2 σ.
  - ◇ Disconnected diagram has not been included, yet.
  - ◇ Continuum extrapolation has not been performed, yet.



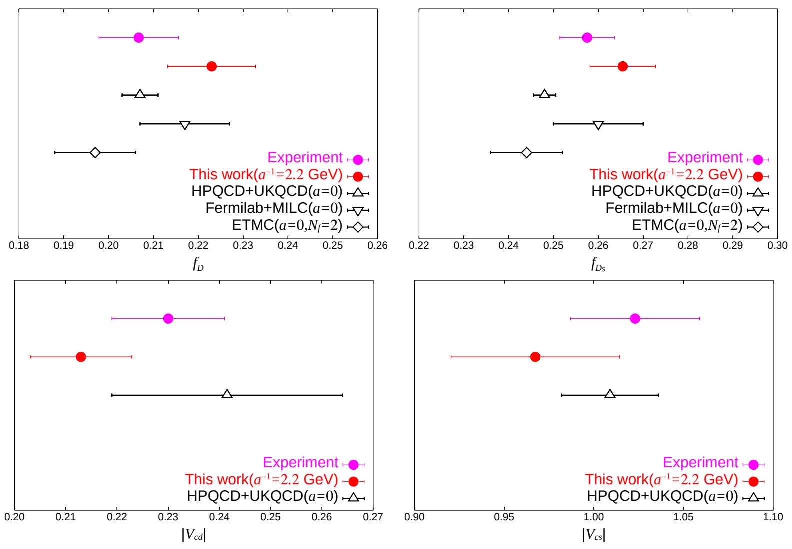
6 Charm quark mass

- Our result for the charm quark mass is consistent with HPQCD value.
  - ◇ Continuum extrapolation has not been performed, yet.
  - ◇ Our error is mainly from the scale determination and the non-perturbative renormalization factor.



7 Decay constants and CKM matrix elements

- Our decay constants agree with experiment in 2 σ.
- CKM matrix values are consistent. The errors are mainly from $\Gamma^{exp}(D \to l\nu)$.



8 Conclusion

- Charm quark mass and CKM matrix elements are obtained in a few percent accuracy.
- Mass spectrums and decay constants are reproduced well.
  - ◇ Systematic errors are still large.
  - ◇ Continuum extrapolations will be performed.