Charmed meson decay constants from 2+1-flavor lattice QCD

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2020.08.06
APLAT 2020

Outline

- **Motivation**
- **Lattice setup and data analyses**
- **Results and summary**

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What we calculate

- $f_{D_{(s)}^{(*)}}$ and their ratios (f_{ϕ} is also computed)

$$\langle 0|\overline{q}(0)\gamma_\mu\gamma_5 c(0)|P(p)\rangle = if_P p_\mu, \quad q = d, s$$

$$(m_q + m_c)\langle 0|\overline{q}(0)\gamma_5 c(0)|P(p)\rangle = f_P m_{PS}^2$$

$$\langle 0|\bar{q}(0)\gamma^\mu q'(0)|V(p,\lambda)\rangle = f_V m_V e_\lambda^\mu$$

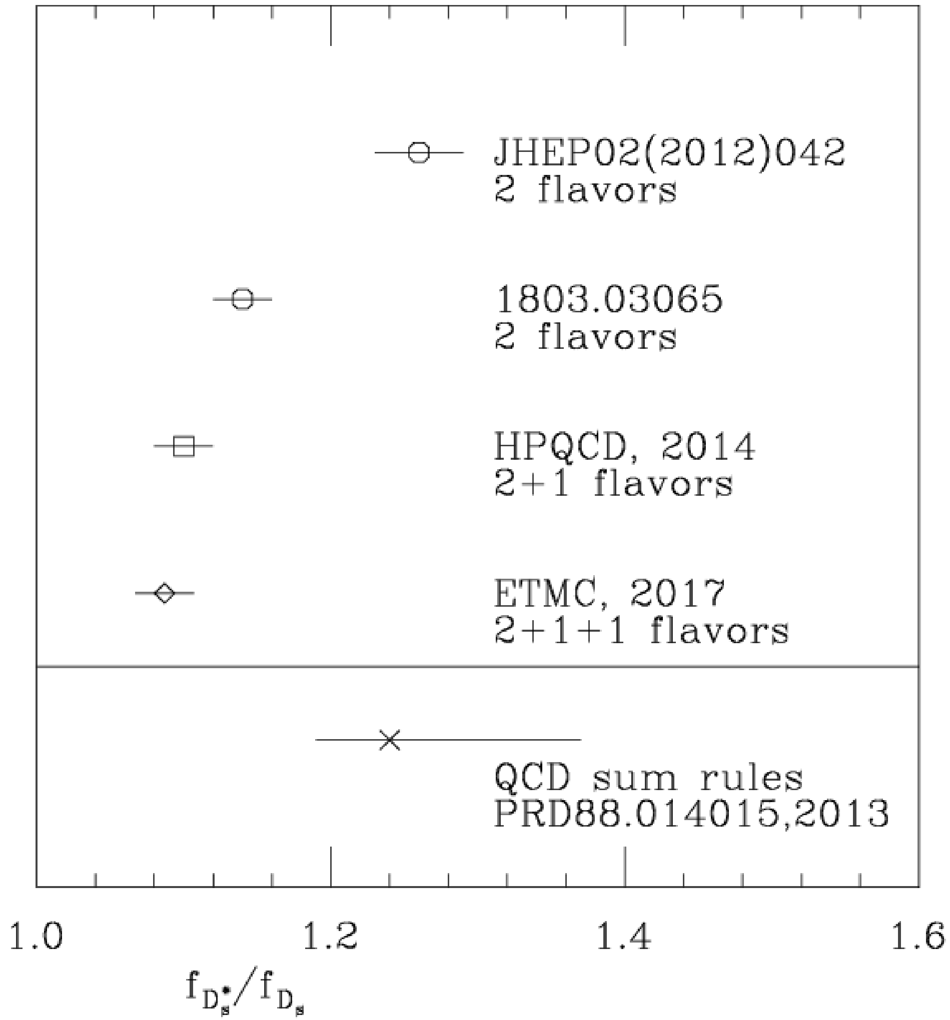
- f_V^T/f_V

$$\langle 0|\Big(\bar{q}(0)\sigma^{\mu\nu}q'(0)\Big)(\mu)|V(p,\lambda)\rangle = if_V^T(\mu)\big(e_\lambda^\mu p^\nu - e_\lambda^\nu p^\mu\big)$$

Motivation

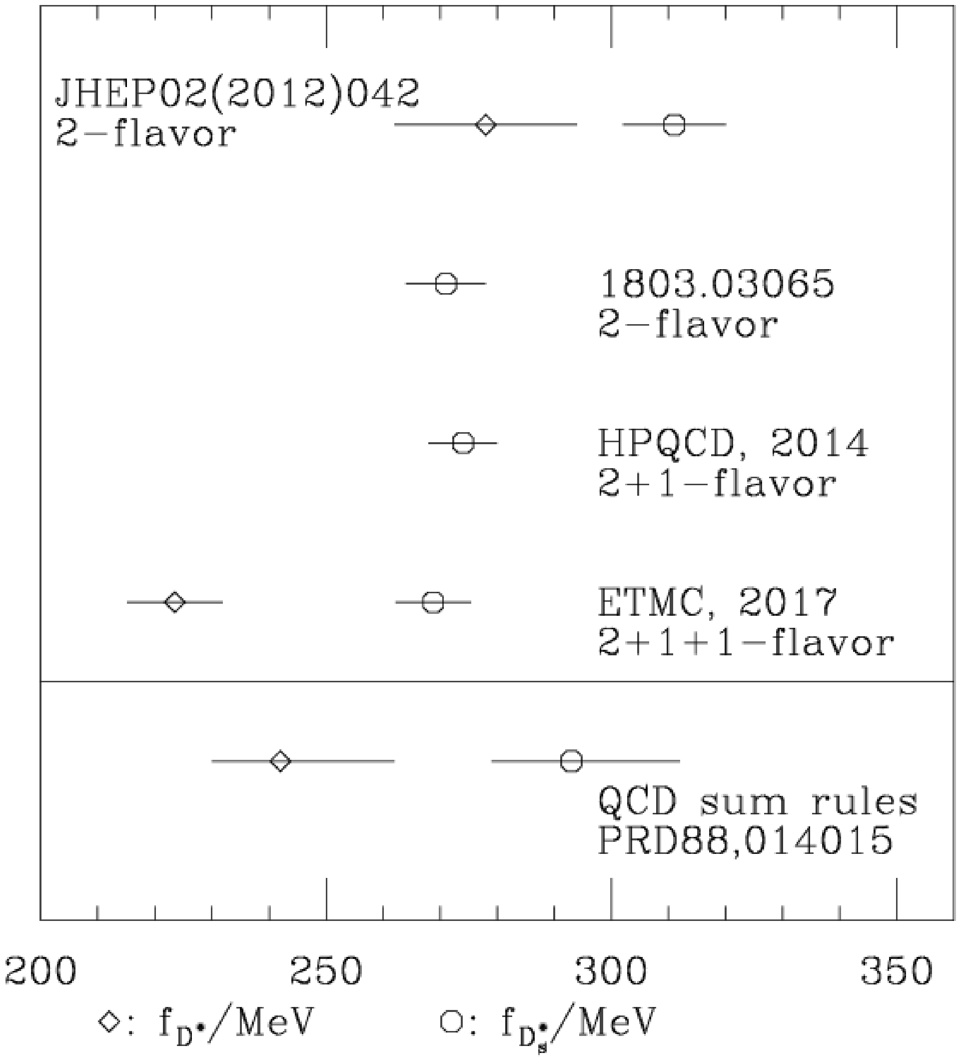
- **CKM elements** $$\Gamma(P \to \ell\nu) = \frac{G_F^2 |V_{q_1 q_2}|^2}{8\pi} f_P^2 m_\ell^2 M_P \left(1 - \frac{m_\ell^2}{M_P^2}\right)^2$$
- f_V **is not easy to measure**
  - **Leptonic decay BRs are much smaller than those of strong decays**
- **Test the accuracy of HQET,**
  $$f_V / f_{PS} = 1 + O(1/m_Q)$$
- f_V^T / f_V **for** D^* **&** D_s^* **can be used as inputs for LCSR in calculations of** $B \to V$ **form factors at low** q^2
- **Input parameters for QCD factorization in studies of nonleptonic B decays, e.g.,** $B \to D^{(*)} M$

$f_{D_s^*}/f_{D_s}$



- **Becirevic et al., JHEP02 (2012) 042**
  - **4*a*, 2-flavor, tmQCD**
- **Blossier, Heitger, Post, PRD98.054506 (1803.03065)**
  - **2*a*, 2-flavor, Clover fermions**
- **HPQCD, PRL112.212002 (2014)**
  - **2*a*, 2+1-flavor, HISQ+asqtad**
- **ETMC, PRD96.034524 (2017)**
  - **3*a*, 2+1+1-flavor, tmQCD**
- **Sea quark effects from the strange quark?**

f_{D^*} and $f_{D_s^*}$



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- **Sea quark effects from the strange quark?**

Lattice setup

- **2+1-flavor ensemble (RBC/UKQCD Collab.)**
- **Physical sea quark mass:**

$m_\pi^{\text{sea}} = 139.2(4)$ **MeV**

- **45 configurations**

$L^3 \times T$	$48^3 \times 96$
$a^{-1}(\text{GeV})$	1.730(4)
N_{conf}	45
$am_l^{(\text{val})}$	0.0017, 0.0024, 0.0030, 0.0060
m_π/MeV	114(2), 135(2), 149(2), 208(2)
$am_s^{(\text{val})}$	0.0580, 0.0650
$am_c^{(\text{val})}$	0.6800, 0.7000, 0.7200, 0.7400

- **Overlap valence and domain wall fermion sea**
- **Partial quenching effects are small:** $\Delta_{\text{mix}} = 0.030(6)(5)\ \text{GeV}^4$ [PRD86.014501, 2012]
- **4 light val. quark masses:** $m_\pi \sim 114 - 208$ **MeV**
- $Lm_\pi = 3.2/3.7/4.1/5.8$
- **2 strange val. quark masses, slightly** $< m_s^{\text{phy.}}$

m_π, f_π, m_K

- m_π & m_K are extracted from pseudoscalar density 2-point functions
- Use to fix the physical light and strange valence quark masses

$am_l^{\rm val}$	0.0017	0.0024	0.0030	0.0060
m_π/MeV	114(2)	135(2)	149(2)	208(2)
f_π/MeV	130.3(9)	131.0(9)	131.6(8)	---

- A linear interp. in m_π^2 gives $f_\pi = 131.3(6)$ MeV
- Consistent with the RBC/UKQCD result on the same ensemble [arXiv:1411.7017(hep-lat)]

D-meson 2-point functions

- **Coulomb gauge wall source propagators are used to improve overlapping with the ground state**
- **Sink operators are with spacial displacement**

$$O_\Gamma(\vec{x}, t;\ \vec{r}) = \bar{\psi}_1(\vec{x}, t)\Gamma\psi_2(\vec{x} + \vec{r}, t)$$

$\Gamma = \gamma_5$ or γ_i

$\vec{r} = 0$: local operator

- **Same $r = |\vec{r}|$ averaged to get the correct J^P**

$$C_P(r,t) = \frac{1}{N_r} \sum_{\vec{x},|\vec{r}|=r} \langle 0|O_{\gamma_5}(\vec{x}, t; \vec{r}) O_{\gamma_5}^{(W)\dagger}(0)|0\rangle,$$

$$C_V(r,t) = \frac{1}{3N_r} \sum_{\vec{x},i,|\vec{r}|=r} \langle 0|O_{\gamma_i}(\vec{x}, t; \vec{r}) O_{\gamma_i}^{(W)\dagger}(0)|0\rangle$$

$$C^W(t) = \langle 0|O^{(W)}(t)O^{(W)\dagger}(0)|0\rangle$$

Data analysis

1. **Simultaneous correlated fittings to several correlators**

   Common parameter: m_H

2. **Fit combined correlators**

$$C(\omega, t) = C(r = 1, t) + \omega C(r, t)$$

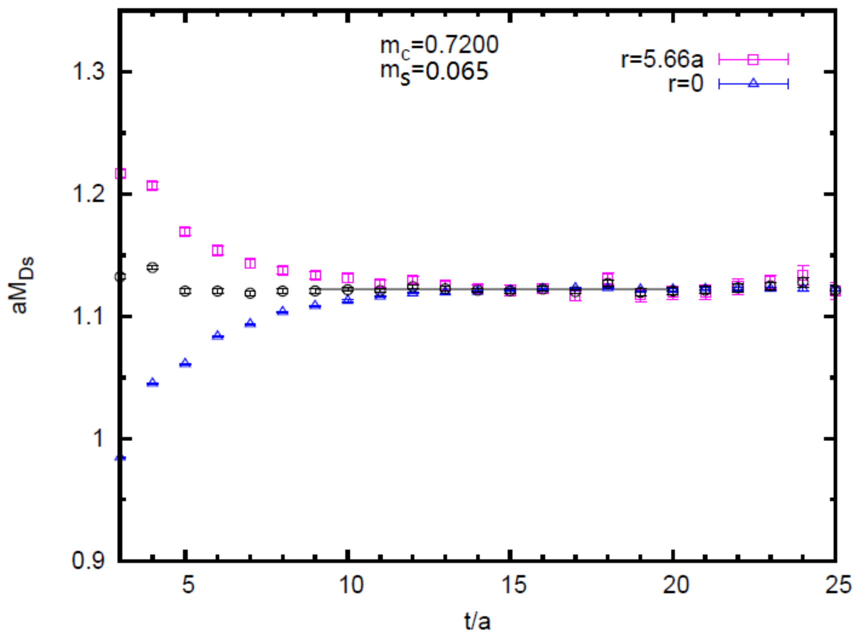
Adjust r and ω to get the best mass plateau

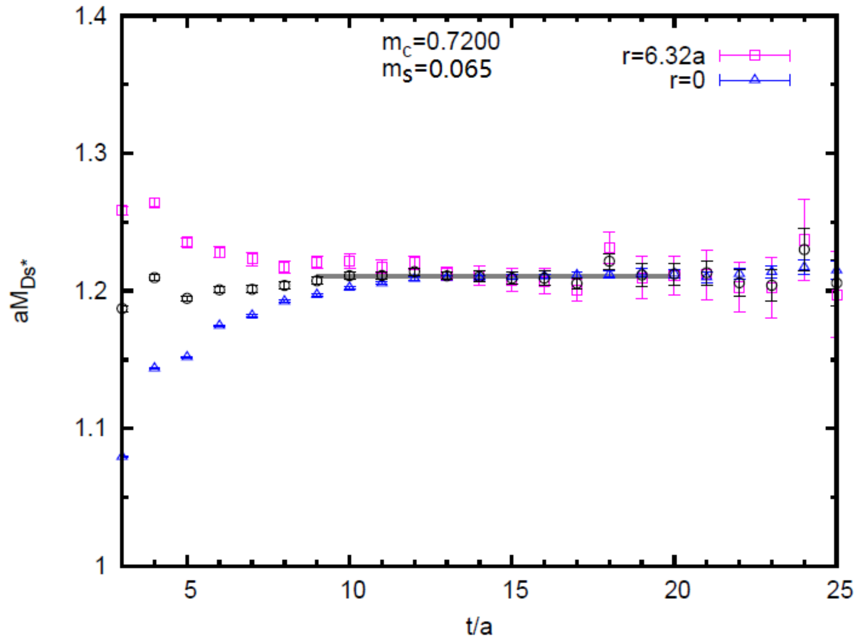
✓**The two methods give consistent m_H**

✓**The result of m_H is insensitive to ω**

- **Combine the spectral weights from $C(r = 0, t)$ and $C^W(t)$ to get the decay constants**

Mass plateau



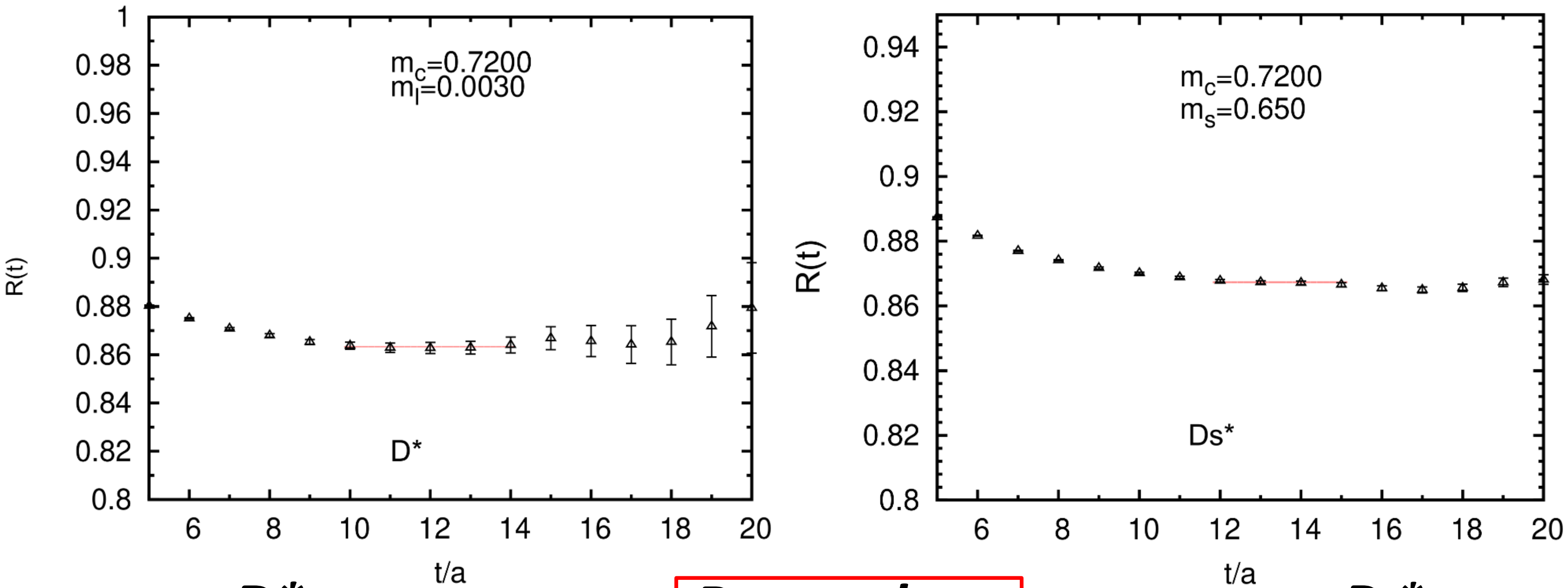


- **Black circles:** $C(\omega, t) = C(r = 1, t) + \omega C(r, t)$
- $t_{\max}$: $\frac{\delta C(t)}{C(t)}$ **<10%(5%) for V(PS) mesons**
- $t_{\min}$: **varied to get stable results,** χ^2**/dof** $\lesssim$ **1.0**

f_V^T/f_V

$$R(t) = C_T(t)/C_V(r=0,t) = \frac{\sum_i \langle T_{0i} O_V^{(W)\dagger}\rangle}{\sum_i \langle V_i O_V^{(W)\dagger}\rangle} \xrightarrow{t\to\infty} \frac{f_T}{f_V}$$

$$C_T(r=0,t) = \frac{1}{3}\sum_{\vec{x},i} \langle 0|O_{\sigma_{0i}}(\vec{x},t) O_{\gamma_i}^{(W)\dagger}(0)|0\rangle$$



D*

Bare values

D_s*

Interp./extrap. to physical point

- $m_\pi^2, m_{ss}^2 \equiv 2m_K^2 - m_\pi^2$ and m_{D_s} are used to set the physical quark masses
- Our quark masses are close to their physical values
- Linear Interp./extrap. in m_π^2, m_{ss}^2 and m_{D_s}
- For a meson mass or decay constant:

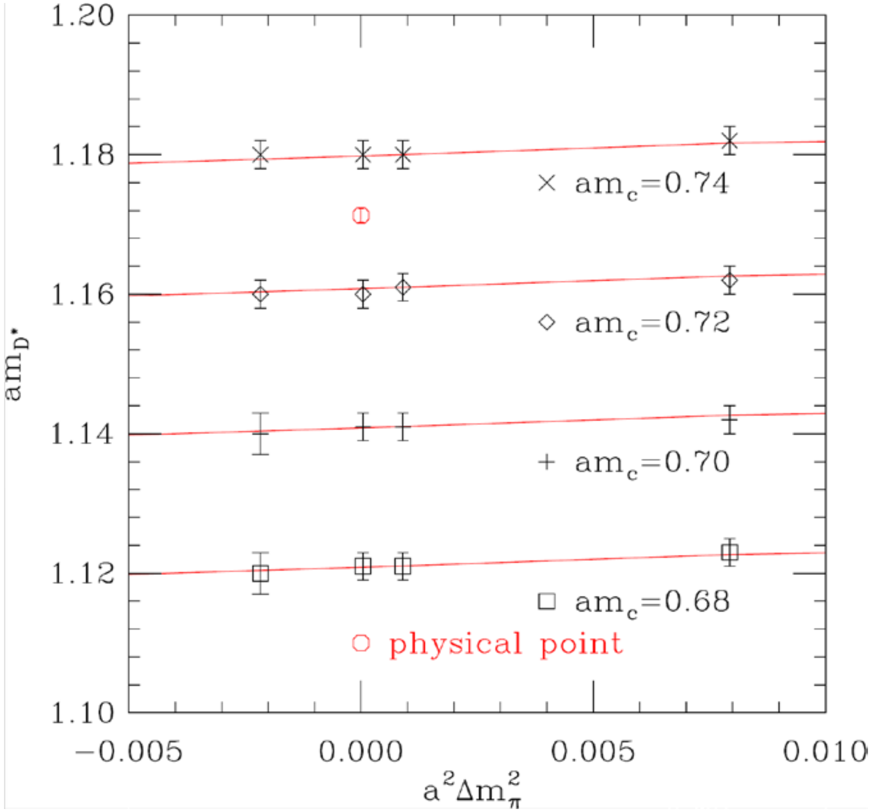
$$A(m_{u/d}, m_s, m_c) = A^{(phy)} + b_1 \Delta m_\pi^2(m_{u/d}) + b_2 \Delta m_{ss}^2(m_s) + b_3 \Delta m_{D_s}(m_c)$$

$$\Delta m_\pi^2 = m_\pi^2 - m_\pi^2(\mathrm{phy}), \ \ \Delta m_{ss}^2 = m_{ss}^2 - m_{ss}^2(\mathrm{phy}), \ \ \Delta m_{D_s} = m_{D_s} - m_{D_s}^{\mathrm{phy}}$$

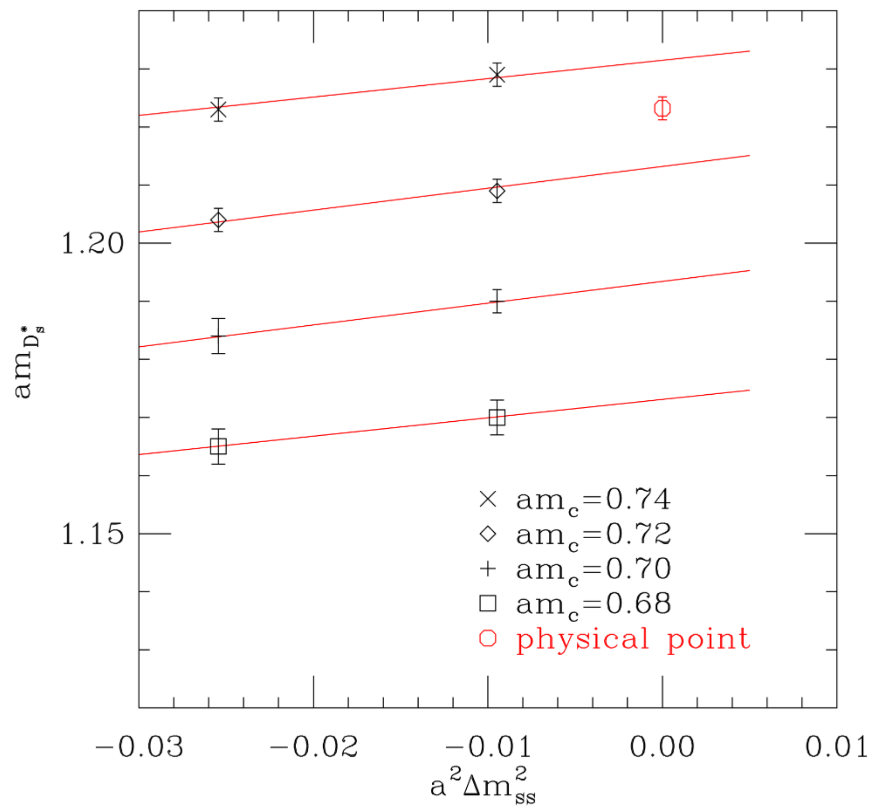
- Supported by the data with good χ^2/dof

Interp./extrap. to physical point

m_{D^*}

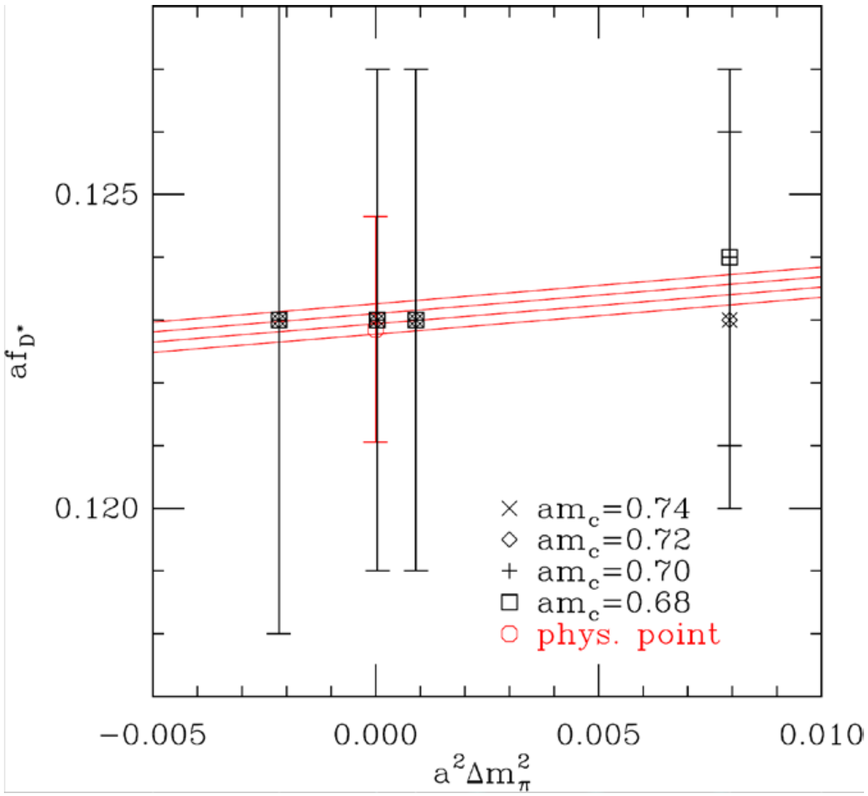


$m_{D_s^*}$

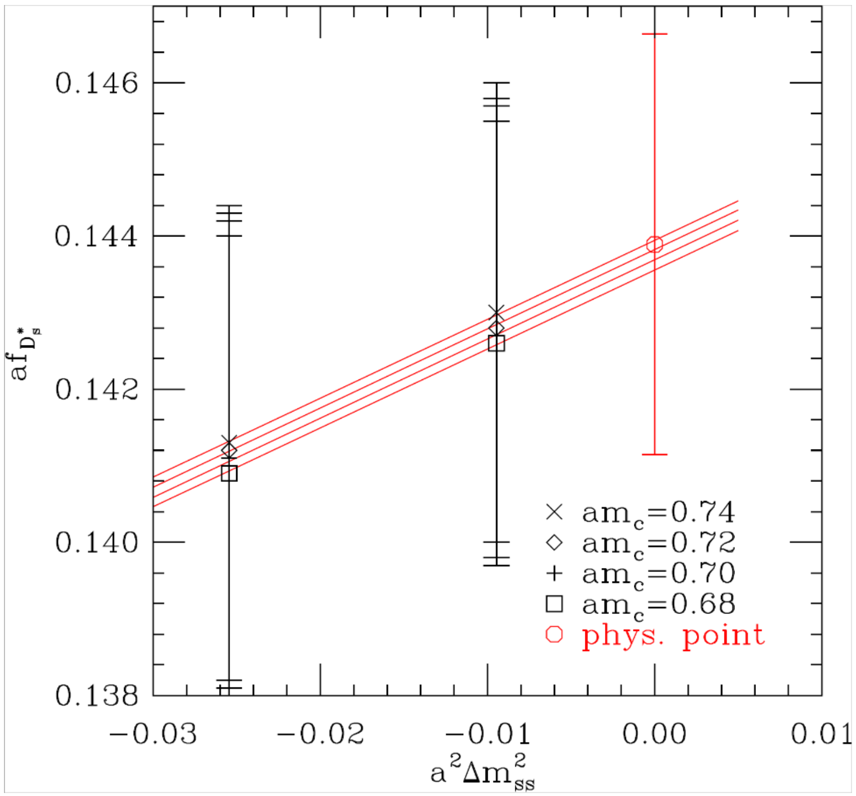


Interp./extrap. to physical point

f_{D^*}



$f_{D_s^*}$



- **Quark mass dependences of decay constants can barely be seen with the statistical uncertainties**

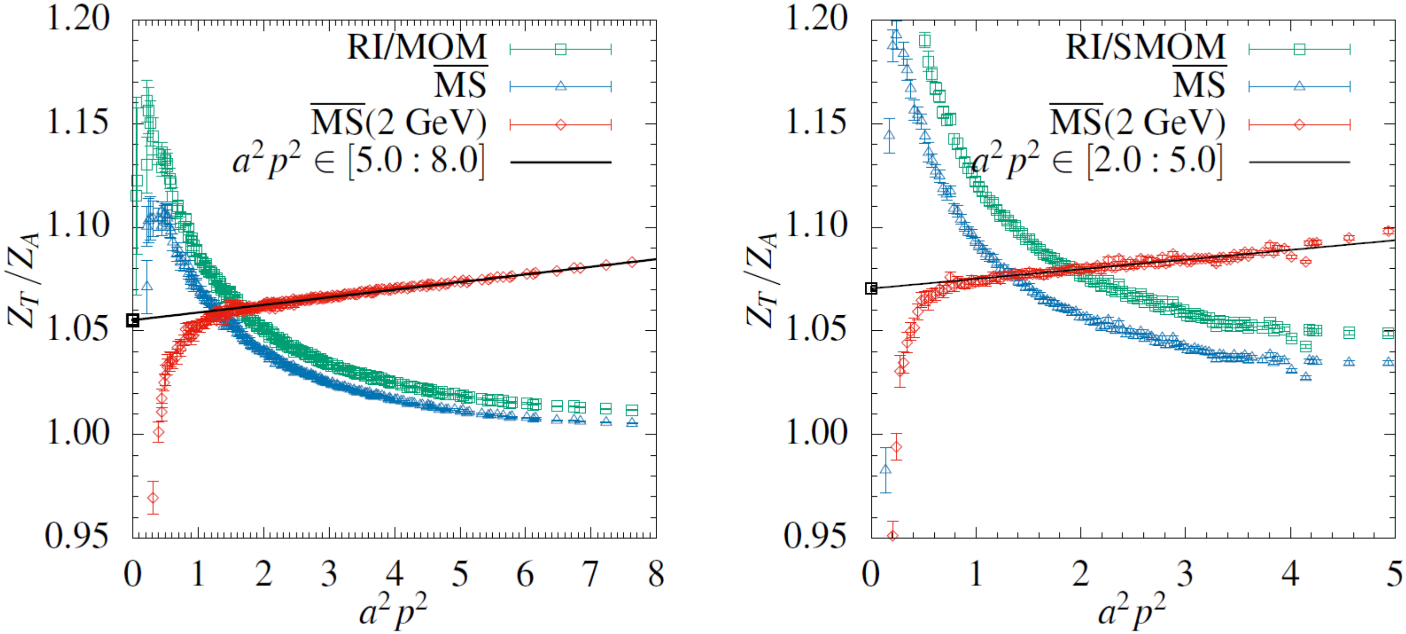
RI/(S)MOM renormalization

- **Renormalization constants are needed to get**
  - f_P **using the local axial vector current**
  - f_V **using the local vector current**
  - f_V^T **from the tensor operator**
- **RI/MOM and RI/SMOM schemes are used and matched to the $\overline{\mathrm{MS}}$ scheme**
- **Matching hadronic matrix elements calculated on the lattice to the continuum**

$$\bar{\psi}\Gamma\psi, \quad \Gamma = I, \gamma_5, \gamma_\mu, \gamma_\mu\gamma_5, \sigma_{\mu\nu}$$

Bi et al., arXiv:1710.08678(PRD97.094501)

RI/(S)MOM renormalization



Z_T in the RI/MOM, RI/SMOM and $\overline{\text{MS}}$ schemes

- **Final results for all renormalization constants**

TABLE IX. Matching factors to the $\overline{\text{MS}}$ scheme for the quark field and bilinear quark operators.

Z_A	Z_q(2 GeV)	Z_T(2 GeV)	Z_S(2 GeV)	Z_P(2 GeV)
1.1025(16)	1.216(23)	1.163(34)	1.118(29)	1.123(56)

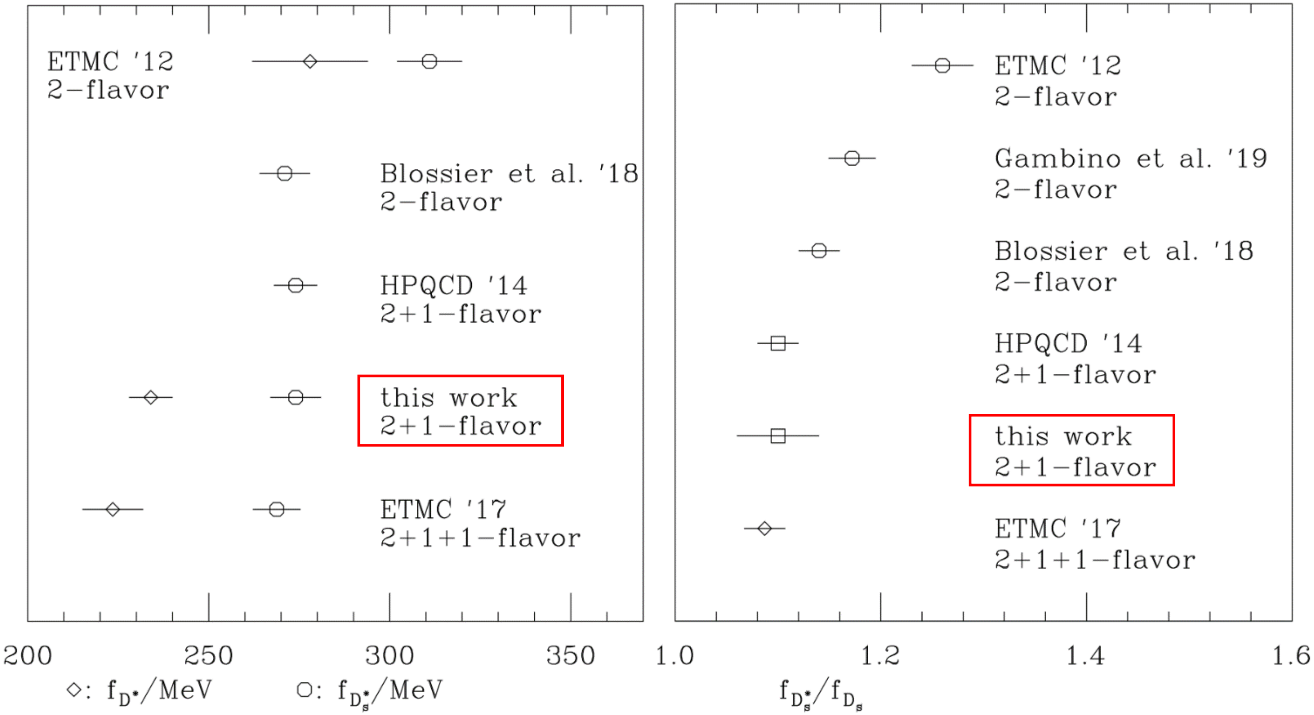
Results

	D	D^*	D_s	D_s^*	ϕ
Mass/MeV	1873(5)	2026(5)	-	2116(6)	1018(17)
M^{exp}/MeV	1869.6	2010.3	1968.3	2112.2	1019.5
f_M/MeV	213(2)(4)	234(3)(5)	249(5)(5)	274(5)(5)	241(9)(2)
f_V^T/f_V		0.91(3)(2)		0.92(3)(2)	

- The mass of D^* is ~1% higher than experiments
- $f_{D_s} = 249(5)$ MeV **vs.** 254(2)(4) MeV [PRD92.034517]
- The 1st error from stat. and interp./extrap.
- The 2nd error from Z-factors and finite a (~2%)
- f_D agrees with FLAG2019 (2+1-flavor): 209.0(2.4) MeV
- $f_{D_{(s)}^*}^T / f_{D_{(s)}^*}$ are the first lattice QCD results

Results

- **Heavy quark symmetry breaking (~10%)**
  - $f_V/f_{PS} = 1 + O(1/m_Q)$
  - $f_{D^*}/f_D = 1.10(2)(2), \quad f_{D_s^*}/f_{D_s} = 1.10(3)(2)$
- **SU(3) flavor symmetry breaking (~17%)**
  - $f_{D_s}/f_D = 1.163(14)(23), \quad f_{D_s^*}/f_{D^*} = 1.17(2)(2)$



- Becirevic et al., JHEP02 (2012) 042
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- Gambino et al., J. Phys. Conf. Ser. 1137, 012005 (2019)
- HPQCD, PRL112.212002 (2014)
- ETMC, PRD96.034524 (2017)

Summary

- $f_{D_{(s)}^{(*)}}$, $f^T_{D^*_{(s)}}/f_{D^*_{(s)}}$ and f_ϕ are calculated with overlap fermion on 2+1-flavor domain wall fermion configurations
- RI/(S)MOM are used for renormalization
- More lattice spacings are needed to better control discretization effects

Thanks for your attention!