Decay Constats and Masses of $D^*_{(s)}$ and $B^*_{(s)}$ mesons in Lattice QCD with Nf =2+1+1 Twisted mass fermions

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Vector Decay Constants

Why are they interesting parameters?

DCs parametrize the matrix element of a weak current between the vacuum and the meson of interest. They characterize a meson as much as its mass.

$$\langle 0|\underbrace{\overline{h}\gamma_\mu \ell}_{V_\mu}|H^*_\ell(p,\lambda)\rangle = m_{H^*_\ell} f_{H^*_\ell} \epsilon^\lambda_\mu$$

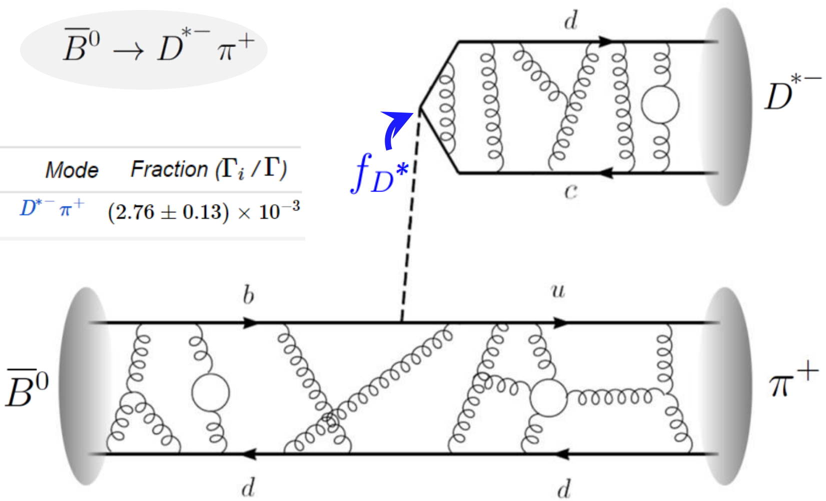
$$\langle 0|\underbrace{\overline{h}\gamma_\mu\gamma_5 \ell}_{A_\mu}|H_\ell(p)\rangle = p_\mu f_{H_\ell}$$

Vector meson decays are dominated by the strong and electromagnetic ones.

$\longrightarrow$ f_V is **not** directly measurable.

$\overline{B}^0 \to D^{*-}\pi^+$

	Mode	Fraction (Γ_i/Γ)
Γ_{41}	$D^{*-}\pi^+$	$(2.76 \pm 0.13) \times 10^{-3}$



Vector DCs are involved in the description of semileptonic form factors and non-leptonic decays of hadrons through the factorization approximation:

$$A_{\text{fact}} = -\frac{G_F}{\sqrt{2}} V_{ub} V_{cd} \left[C_2(m_b) + \frac{C_1(m_b)}{N_c} \right] \underbrace{\langle D^{*+}|\bar{c}\gamma^{\mu L} d|0\rangle}_{f_{D^*}} \langle \pi^-|\bar{b}\gamma^{\mu L} u|B^0\rangle$$

Simulation details

Data Ensembles

ETMC gauge configurations with Nf=2+1+1 dynamical quarks [1]

β	$L^3 \times T$	$a\mu_{sea} = a\mu_{ud}$	$a\mu_s$	$a\mu_c$	$a\mu_h > a\mu_c$
1.90	$32^3 \times 64$	0.0030	0.0180	0.21256	0.34583
($a^{-1} \sim 2.19$ GeV)		0.0040	0.0220	0.25000	0.40675
		0.0050	0.0260	0.29404	0.47840
	$24^3 \times 48$	0.0040			0.56267
		0.0060			0.66178
		0.0080			0.77836
		0.0100			0.91546
1.95	$32^3 \times 64$	0.0025	0.0155	0.18705	0.30433
($a^{-1} \sim 2.50$ GeV)		0.0035	0.0190	0.22000	0.35794
		0.0055	0.0225	0.25875	0.42099
		0.0075			0.49515
	$24^3 \times 48$	0.0085			0.58237
					0.68495
					0.80561
2.10	$48^3 \times 96$	0.0015	0.0123	0.14454	0.23517
($a^{-1} \sim 3.23$ GeV)		0.0020	0.0150	0.17000	0.27659
		0.0030	0.0177	0.19995	0.32531
					0.38262
					0.45001
					0.52928
					0.62252

Physical units:

- $a \sim (0.06 - 0.09)\mathrm{fm}$
- $m_\pi \sim (210 - 450)\mathrm{MeV}$
- $3\, m_{ud}^{phys} \lesssim m_{ud} \lesssim 12\, m_{ud}^{phys}$
- $0.7\, m_s^{phys} \lesssim m_s \lesssim 1.2\, m_s^{phys}$
- $0.7\, m_c^{phys} \lesssim m_c \lesssim 2.5\, m_c^{phys}$
- $2.5\, m_c^{phys} \lesssim m_h \lesssim 0.9\, m_b^{phys}$

1 N.Carrasco et al. [ETMC], arXiv:1403.4504 [hep-lat]

Decay Constants and Masses on the Lattice

Smearing technique and effective mass curves

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We have considered **ratios** for better control of statistical and systematic uncertainties

$$R^f_{H\ell} = \frac{f_{H^*_\ell}}{f_{H_\ell}} \quad \text{and} \quad R^m_{H\ell} = \frac{m_{H^*_\ell}}{m_{H_\ell}}$$

Extraction from the asymptotic behaviour in time of 2-point correlation functions:

$$C_V(t) = \frac{1}{3}\langle\sum_{i,\vec{x}} V_i(\vec{x},t)V_i^\dagger(0,0)\rangle \xrightarrow[t\geq t_{\min}]{} \frac{\sum_i |\langle 0|V_i(0)|H^*_\ell(\vec{0},\lambda)\rangle|^2}{3m_{H^*_\ell}} \cosh[m_{H^*_\ell}(T/2-t)]\exp^{-m_{H^*_\ell}T/2}$$

$$\partial_\mu A_\mu(x) = (\mu_h + \mu_\ell)P_5(x)$$

$$C_P(t) = \langle\sum_{\vec{x}} P(\vec{x},t)P^\dagger(0,0)\rangle \xrightarrow[t\geq t_{\min}]{} \frac{|\langle 0|P(0)|H_\ell(\vec{0})\rangle|^2}{m_{H_\ell}} \cosh[m_{H_\ell}(T/2-t)]\exp^{-m_{H_\ell}T/2}$$

Gaussian smearing (*kG=4, NG=30*) both in sink and source operators: $C^{LL}_{P,V}(t)$ $C^{LS}_{P,V}(t)$ $C^{SL}_{P,V}(t)$ $C^{SS}_{P,V}(t)$

$$m_{\text{eff}}(t) = \text{arccosh}\left[\frac{C_{P,V}(t) + C_{P,V}(t+2)}{2C_{P,V}(t+1)}\right] \xrightarrow[t\geq t_{\min}]{} m$$

Mass ratios are extracted from the Smeared-Local effective mass curves: $C^{SL}_{P,V}(t)$

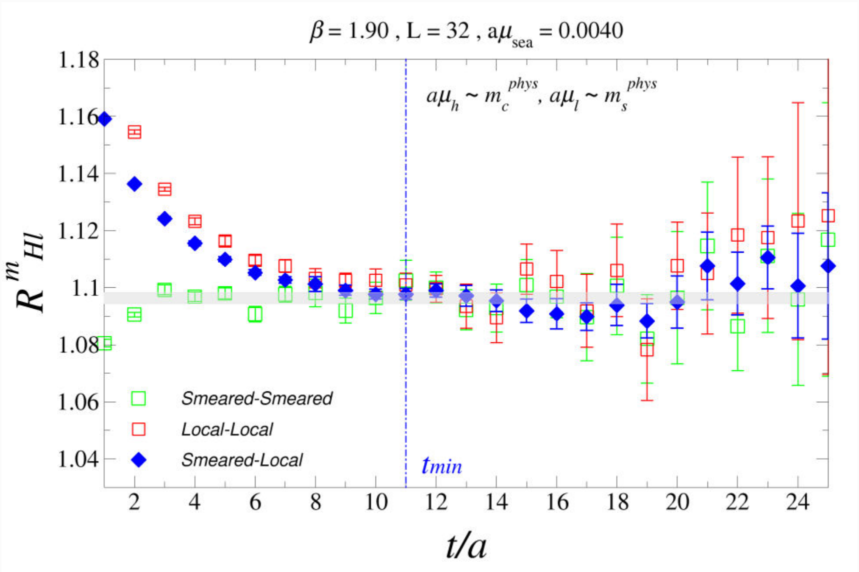
$$Z_A\langle 0|V_i|H^*_\ell(\vec{0},\lambda)\rangle = f_{H^*_\ell} m_{H^*_\ell}\epsilon^\lambda_i$$

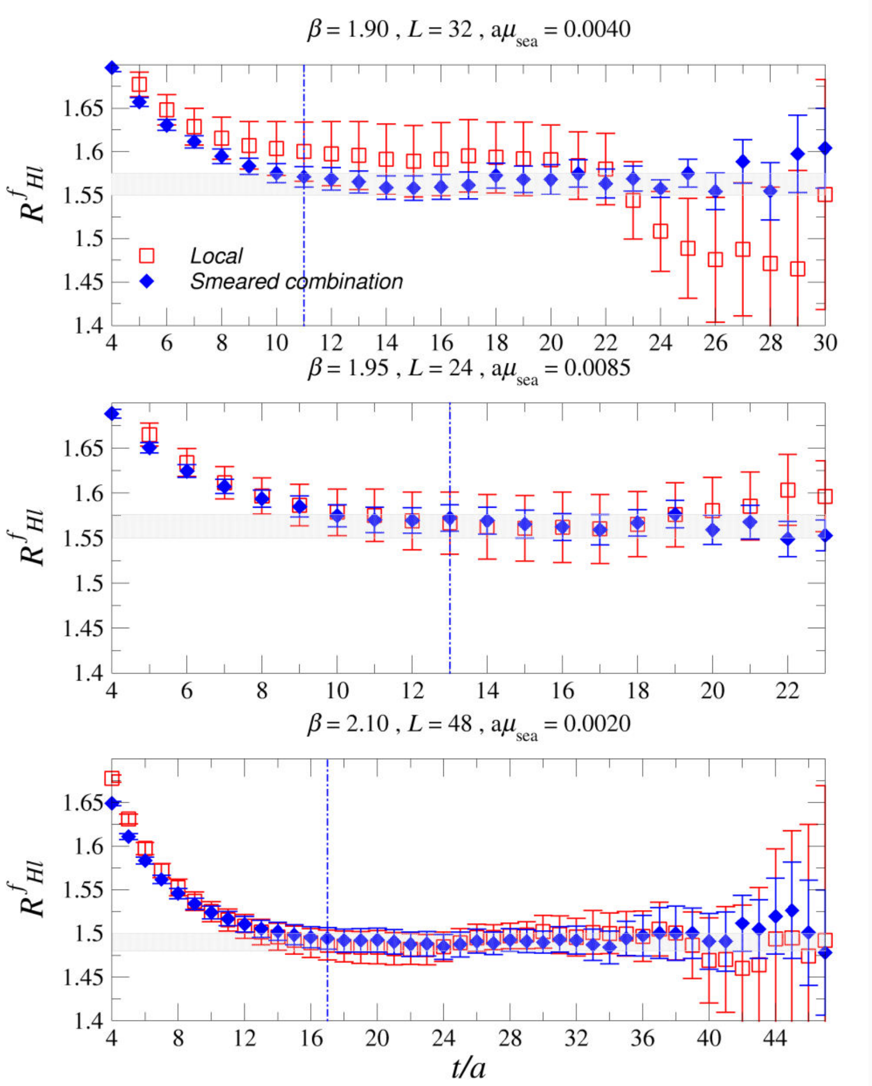
$$(\mu_h + \mu_\ell)\langle 0|P|H_\ell(\vec{0})\rangle = f_{H_\ell} m^2_{H_\ell}$$

DCs ratios are extracted from a smeared combination: $C^{SL}_{P,V}(t)/\sqrt{C^{SS}_{P,V}(t)}$

Decay Constants and Masses on the Lattice

Ratios plateaus examples



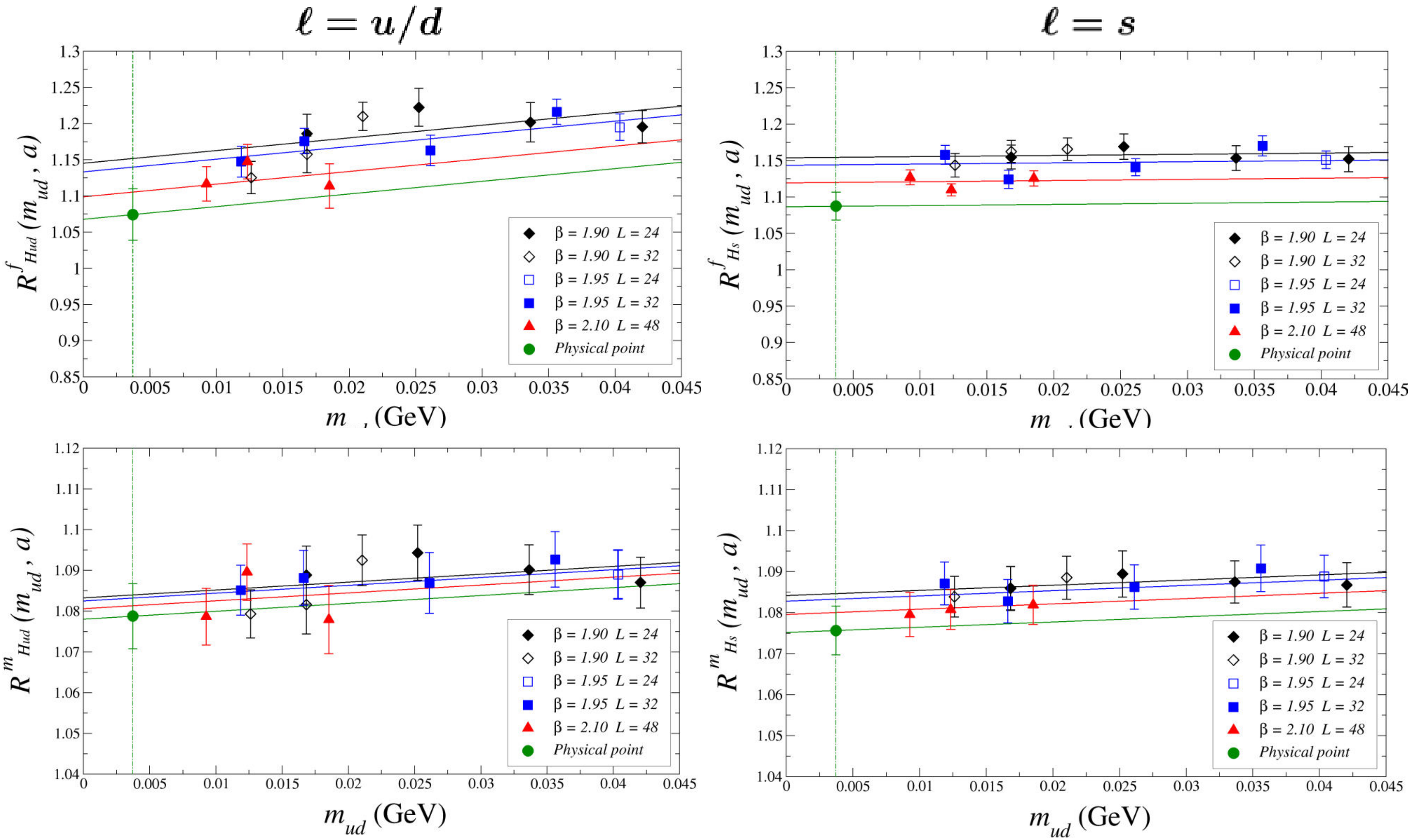


Red and blu curves are constructed from the ***LL*** correlations and ***SL-SS*** combination respectively.

tmin is chosen comparing ***SL*** and ***SS*** effective mass curves and scaling with β.

$D^*_{(s)}$ mesons analysis

Chiral and continuum extrapolations



$$R^{fit}_{h\ell}(m_{ud}, a) = \boldsymbol{P_0 + P_1 m_{ud} + P_2 a^2} + P_3 m_{ud}^2 + P_4 a^4$$

D*(s) mesons analysis

Results

Ratios

$$\frac{f_{D^*}}{f_D} = 1.078\,(31)_{stat}(9)_{chir}(8)_{disc}(6)_{tmin}(5)_{inp}\,[36],$$

$$\frac{f_{D_s^*}}{f_{D_s}} = 1.087\,(16)_{stat}(7)_{disc}(6)_{inp}(6)_{tmin}(5)_{chir}\,[20],$$

$$\frac{m_{D^*}}{m_D} = 1.0769\,(71)_{stat}(30)_{inp}(13)_{tmin}(8)_{disc}(5)_{chir}[79],$$

$$\frac{m_{D_s^*}}{m_{D_s}} = 1.0751(49)_{stat}(27)_{inp}(8)_{disc}(4)_{tmin}(2)_{chir}[56].$$

Decay constants and Masses Results

$f_{D^*} = 223.5(8.4)\mathrm{MeV}$ [1] , $m_{D^*} = 2013(14)\mathrm{MeV}$

$M^{exp}_{D^{*\pm}} = (2010.27 \pm 0.05)\mathrm{MeV}$

$f_{D_s^*} = 268.8(6.6)\mathrm{MeV}$ [1] , $m_{D_s^*} = 2116(11)\mathrm{MeV}$

$M^{exp}_{D_s^{*\pm}} = (2112.1 \pm 0.4)\mathrm{MeV}$

1 R. Baron et al. [ETMC], arXiv: 1005-2042 [hep-lat]

D*(s) mesons analysis

Results

Our results Nf = 2+1+1

$$\frac{f_{D_s^*}}{f_{D_s}} = 1.087\,[20] \qquad \frac{f_{D^*}}{f_D} = 1.078\,[36]$$

Previous Determinations

Nf = 2: (ETMC ’12) $f_{D^*}/f_D = 1.208(27)$ [1] —

Nf = 2+1: (HPQCD ’13) — $f_{D_s^*}/f_{D_s} = 1.10(2)$ [2]

1 D. Becirevic, V. Lubicz, F. Sanfilippo, S. Simula and C. Tarantino [ETMC], arXiv:1201.4039 [hep-lat]

2 G. C. Donald, C. T. H. Davies, J. Koponen [HPQCD} arXiv: 1312.5264 [hep-lat]

B*(s) mesons analysis

How to reach the beauty physical point

HQET predicts that vector over pseudoscalar ratios are equal to one in the static limit:

$$\lim_{m_h \to \infty} \frac{R^f_{H\ell}}{C_W(m_h)} = 1 \qquad \left(R^f_{H\ell} = \frac{f_{H^*_\ell}}{f_{H_\ell}} \qquad R^m_{H\ell} = \frac{m_{H^*_\ell}}{m_{H_\ell}} \right)$$

Perturbative matching coefficient

$$C_W(m_h)^{[1]} = 1 + \frac{2}{3}\frac{\alpha_s(m_h)}{\pi} + \left[-\frac{1}{9}\zeta(3) + \frac{2}{27}\pi^2 \log 2 + \frac{4}{81}\pi^2 + \frac{115}{36} \right] \left(\frac{\alpha_s(m_h)}{\pi} \right)^2$$

Reaching the b physical point :

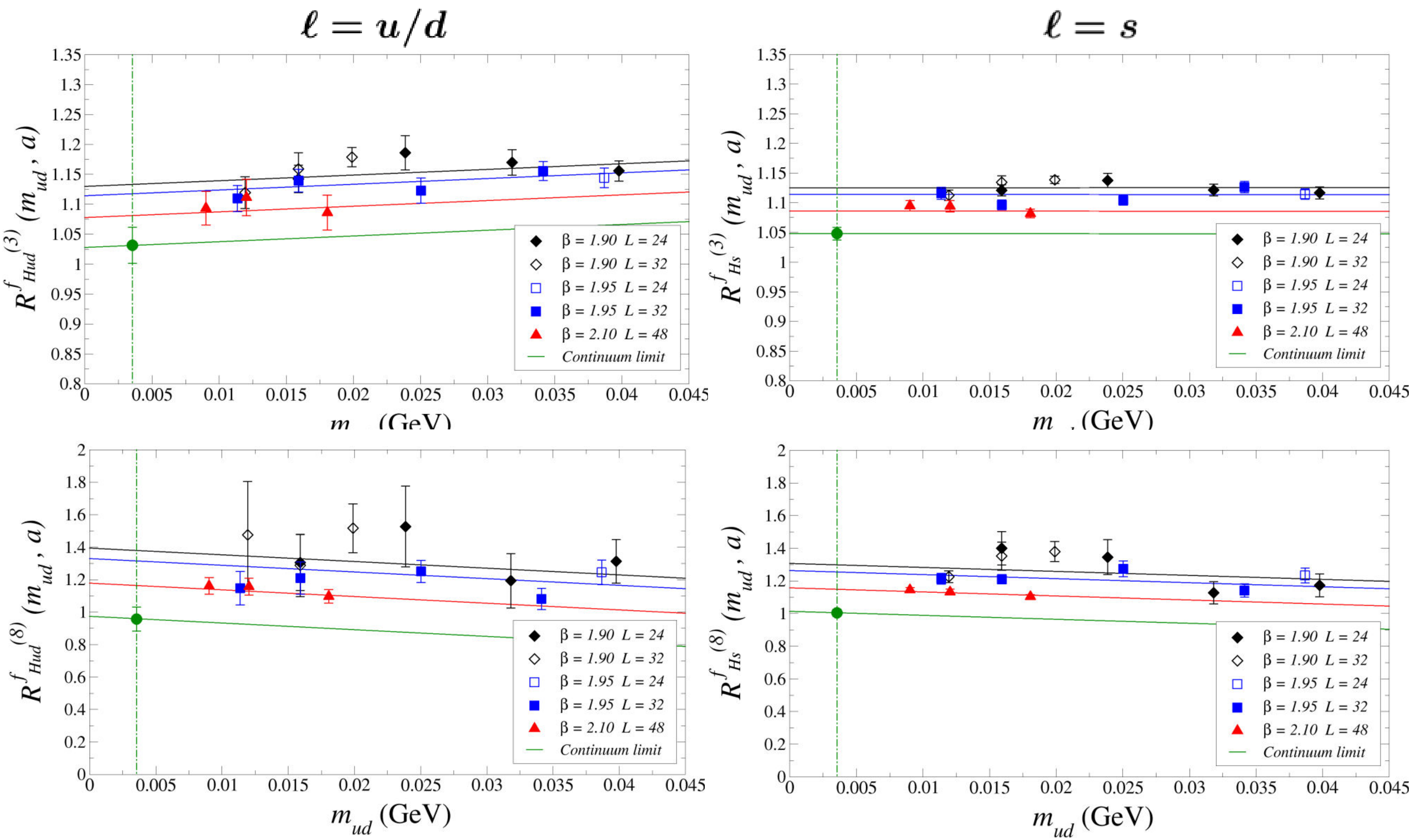
- Interpolate data to a list of reference masses $\overline{m}_h^{(k)}$ where $\overline{m}_h^{(1)} \sim m_c^{phys}$
- Perform a chiral and continuum extrapolation of each ratio *k* = 1,…,8
- **Interpolate lattice data in** $1/m_h$ **to** $m_b^{phys} = 5.20(90)$GeV [2] (ETMC '16) **imposing the static limit constraint**

1 D.J. Broadhurst and A.G. Grozin, [hep-ph/9410240]

2 A. Bussone et al [ETMC], arXiv: 1603.04306 [hep-lat]

B*(s) mesons analysis

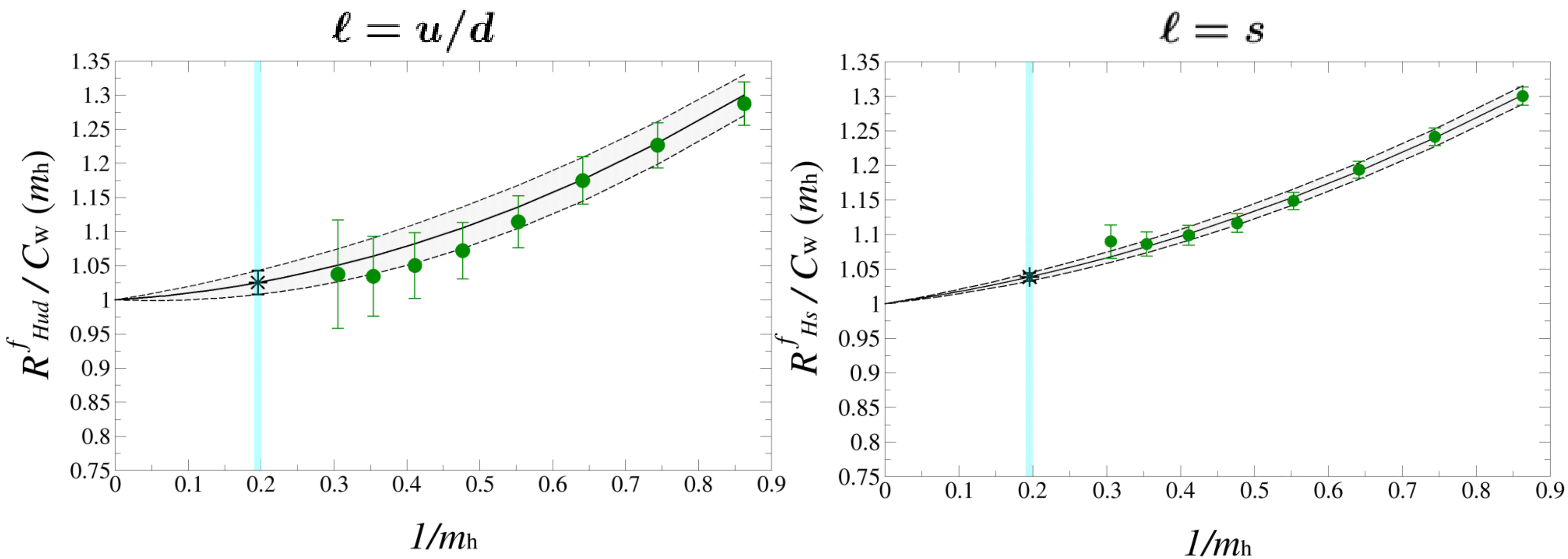
Decay Constants ratios: chiral and continuum extrapolations



$$R^{fit}_{h\ell}(m_{ud}, a) = \boldsymbol{P_0 + P_1 m_{ud} + P_2 a^2} + P_3 m_{ud}^2 + P_4 a^4$$

B*(s) mesons analysis

Decay Constants ratios: inverse heavy quark mass interpolation

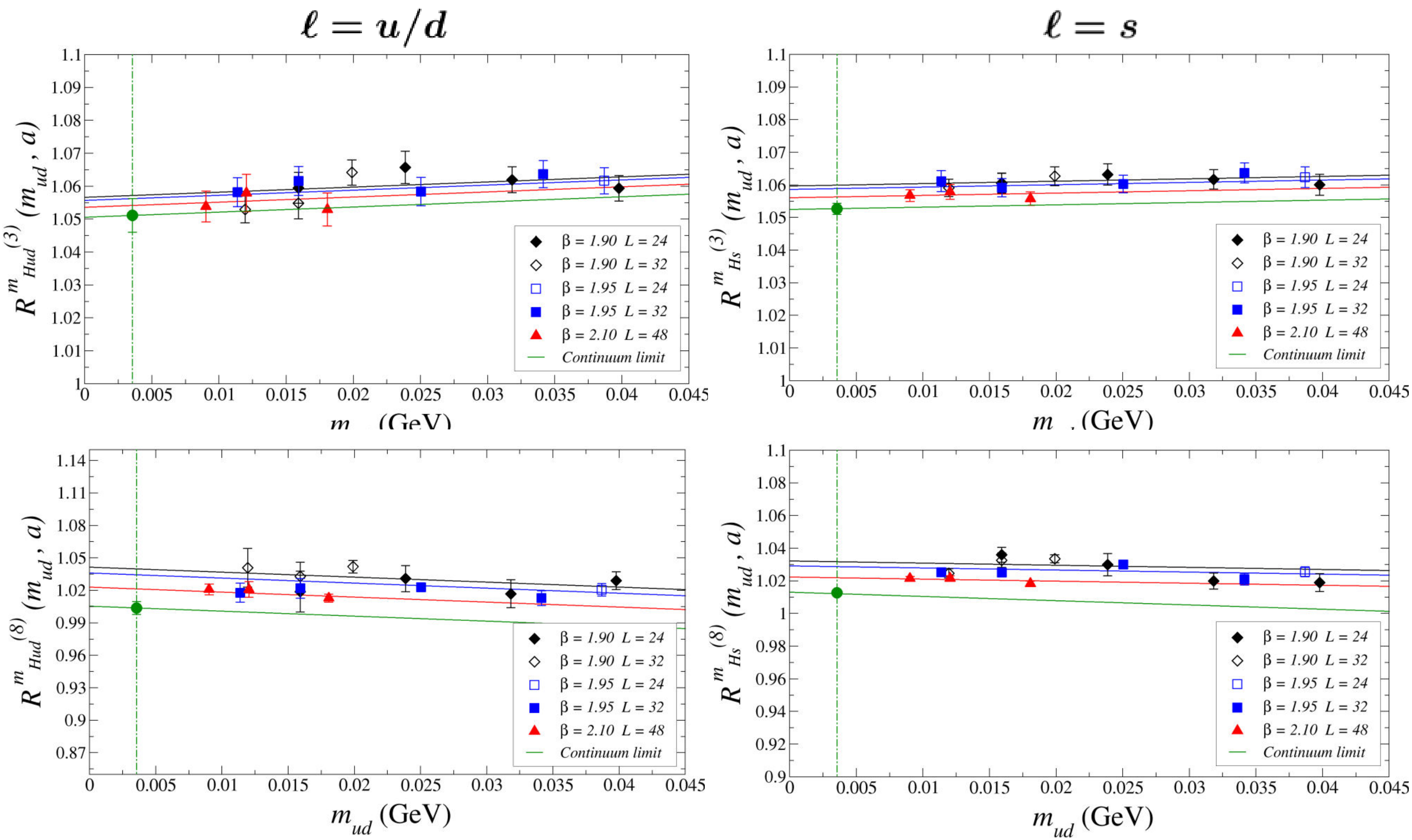


We performed a correlated fit of lattice data

$$\frac{R^{fit}_{H\ell}}{C_W(m_h)} = 1 + \frac{D_1}{m_h} + \frac{D_2}{m_h^2}$$

B*(s) mesons analysis

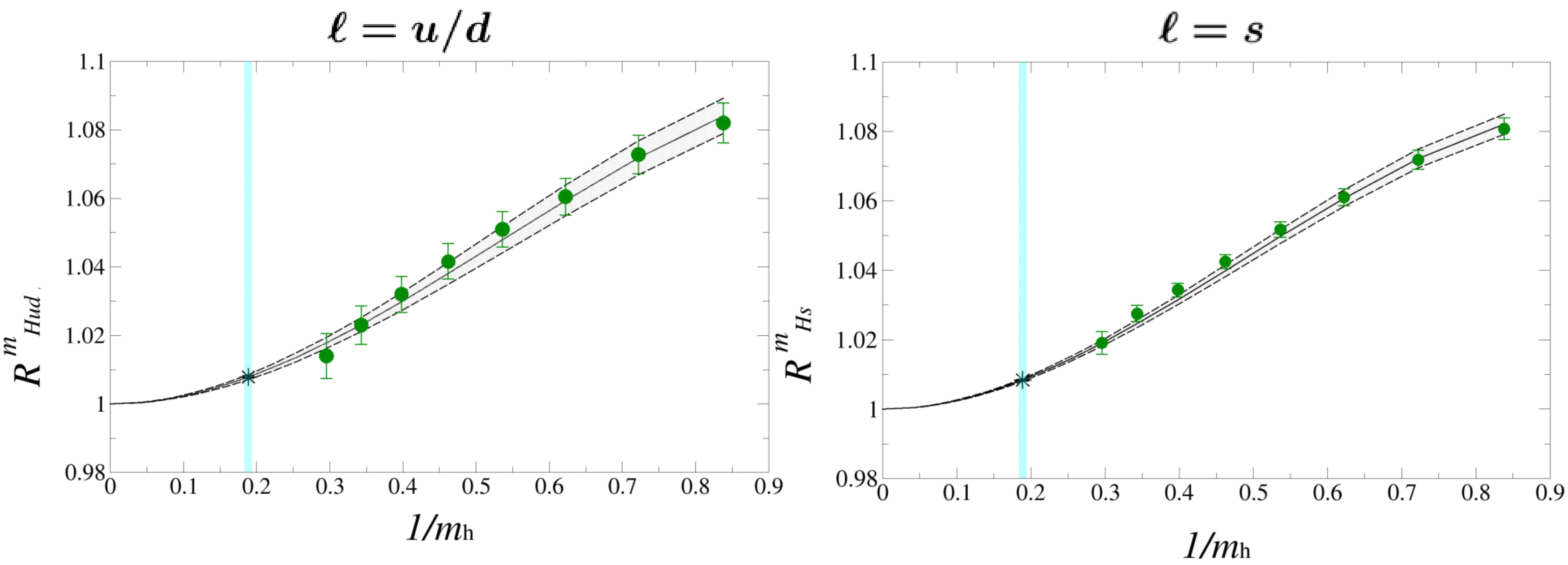
Masses ratios: chiral and continuum extrapolations



$$R_{h\ell}^{fit}(m_{ud}, a) = \boldsymbol{P_0} + \boldsymbol{P_1 m_{ud}} + \boldsymbol{P_2 a^2} + P_3 m_{ud}^2 + P_4 a^4$$

B*(s) mesons analysis

DCs ratios: inverse heavy quark mass interpolation



We performed a correlated fit of lattice data

$$R^{fit}_{H\ell} = 1 + \cancel{\frac{D_1}{m_h}} + \frac{D_2}{m_h^2} + \frac{D_3}{m_h^3}$$

B*(s) mesons analysis

Results

Retios results

$$\frac{f_{B^*}}{f_B} = 0.958\,(18)_{stat}(10)_{disc}(6)_{chir}(5)_{tmin}(2)_{par}\;[22],$$
$$\frac{f_{B_s^*}}{f_{B_s}} = 0.974\,(7)_{stat}(6)_{disc}(3)_{tmin}(2)_{par}(1)_{chir}\;[10],$$
$$\frac{m_{B^*}}{m_B} = 1.0078\,(8)_{stat}(8)_{chir}(7)_{tmin}(5)_{disc}(2)_{par}\;[14],$$
$$\frac{m_{B_s^*}}{m_{B_s}} = 1.0083\,(6)_{stat}(7)_{chir}(6)_{disc}(3)_{tmin}(2)_{par}\;[11],$$

Decay constants and masses results

$$f_{B^*} = 185.9(7.2)\text{MeV} \quad , \quad m_{B^*} = 5320.5(7.6)\text{MeV},$$
$$M^{exp}_{B^{*\pm}} = (5324.83 \pm 0.32)\ \text{MeV}$$

$$f_{B_s^*} = 223.1(5.4)\text{MeV} \quad , \quad m_{B_s^*} = 5411.8(6.2)\ \text{MeV}$$
$$M^{exp}_{B_s^*} = (5415.4 \pm 1.6)\ \text{MeV}$$

1 A. Bussone et al [ETMC], arXiv: 1603.04306 [hep-lat]

$B^*_{(s)}$ mesons analysis

Results

Our results Nf = 2+1+1

$$\frac{f_{B^*}}{f_B} = 0.958\ [22] \qquad \frac{f_{B_s^*}}{f_{B_s}} = 0.974\ [10]$$

Previous Determinations

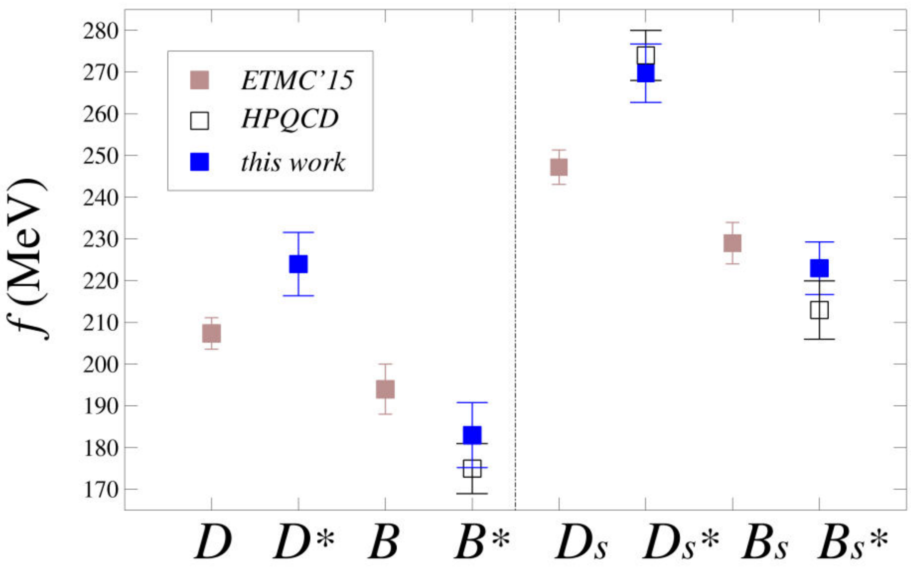
Nf = 2: (ETMC ’14) $f_{B^*}/f_B = 1.051(17)$ [1] —

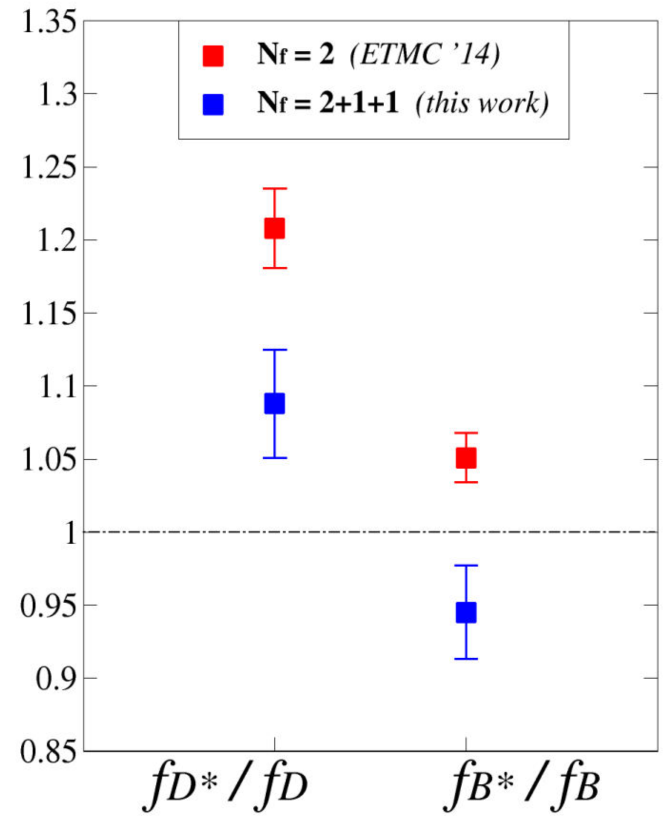
Nf = 2+1+1: (HPQCD ’15) $f_{B^*}/f_B = 0.944(23)$ $f_{B_s^*}/f_{B_s} = 0.947(30)$ [2]

Sum Rules: (LMS ‘15) $f_{B^*}/f_B = 0.941(26)$ $f_{B_s^*}/f_{B_s} = 0.953(23)$ [3]

1 D. Becirevic, A.L. Yaouanc, A. Oyanguren, P. Roudeau and F. Sanfilippo [ETMC], arXiv:1407.1019 [hep-ph]
2 B. Colquhoun et al. [HPQCD] , arXiv: 1503.05762 [hep-lat]
3 W. Lucha, D. Melikhov and S. Simula, arXiv: 1504.03017 [hep-ph]

Summary and conclusions





- ***fD*(s) ≠ fD(s)*** and ***fB*(s) ≠ fB(s) :*** 1/mh corrections are visible, 5% at the b quark mass
- ***fD*> fD*** while ***fB*< fB :***
- Different results between Nf = 2 and Nf=2+1+1, **quenching effect of the strange quark?**