LATTICE 2018

Masses and decay constants of $B_c^{(*)}$ mesons with Nf=2+1+1 twisted mass femions

Giorgio Salerno (ETM Collaboration)

Università di Roma Tre, INFN Roma Tre, LPT Orsay

D. Becirevic, V. Lubicz, A. Melis, L. Riggio, G. Salerno, S. Simula, C. Tarantino

Motivations

- Determine the CKM matrix element V_{cb}

- Constrain possible NP effects, implied by $R(D^{(*)})$ anomalies:

$$\mathrm{Br}(B_c \to \tau\nu_\tau) = \tau_{B_c} \frac{m_{B_c} m_\tau^2 f_{B_c}^2 G_F^2 |V_{cb}|^2}{8\pi} \left(1 - \frac{m_\tau^2}{m_{B_c}^2}\right)^2 \left|1 + \epsilon_L + \underbrace{\frac{m_{B_c}^2}{m_\tau(m_b + m_c)}\epsilon_P}_{\text{possible NP}}\right|^2$$

M. Gonzalez-Alonso, J.M. Camalich, ArXiv:1605.07114, 2016

- Vector meson decays are dominated by strong and electromagnetic interactions: f_V not directly measurable

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

Simulation Details

Details of the ensembles used in this Nf =2+1+1 analysis

ensemble	β	V/a^4	$a\mu_{sea} = a\mu_\ell$	N_{cfg}	$a\mu_c$	$a\mu_h$
A30.32	1.90	$32^3 \times 64$	0.0030	150	0.21256, 0.25000,	0.34583, 0.40675,
A40.32			0.0040	90	0.29404	0.47840, 0.56267,
A50.32			0.0050	150		0.66178, 0.77836,
A40.24	1.90	$24^3 \times 48$	0.0040	150		0.91546
A60.24			0.0060	150		
A80.24			0.0080	150		
A100.24			0.0100	150		
B25.32	1.95	$32^3 \times 64$	0.0025	150	0.18705, 0.22000,	0.30433, 0.35794,
B35.32			0.0035	150	0.25875	0.42099, 0.49515,
B55.32			0.0055	150		0.58237, 0.68495,
B75.32			0.0075	75		0.80561
B85.24	1.95	$24^3 \times 48$	0.0085	150		
D15.48	2.10	$48^3 \times 96$	0.0015	60	0.14454, 0.17000,	0.23517, 0.27659,
D20.48			0.0020	90	0.19995	0.32531, 0.38262,
D30.48			0.0030	90		0.45001, 0.52928,
						0.62252

$$0.7 m_c^{phys} \lesssim m_c \lesssim 2.5 m_c^{phys}$$

$$2.5 m_c^{phys} \lesssim m_h \lesssim 0.9 m_b^{phys}$$

Three different values of the lattice spacing: 0.06 *fm* ÷ 0.09 *fm*

Different volumes: 2 *fm* ÷ 3 *fm*

Pion masses in range 220 ÷ 440 MeV

Lattice Spacings	
$a(\beta = 1.90)$	0.0885(36)fm
$a(\beta = 1.95)$	0.0815(30)fm
$a(\beta = 2.10)$	0.0619(18)fm

Three values of the bare charm masses are used to interpolate to m_c^{phys}

Decay Constants and Masses on the Lattice

Asymptotic behavior of 2-point correlation functions:

$$C_P(t) = \langle \sum_{\vec{x}} P(\vec{x},t) P^\dagger(\vec{0},0) \rangle \xrightarrow[t \gg a]{} \frac{|\langle 0|P(0)|H_c(\vec{0})\rangle|^2}{M_{H_c}} \cosh\left[M_{H_c}\left(T/2 - t\right)\right] e^{-M_{H_c} T/2}$$

$$C_V(t) = \frac{1}{3} \langle \sum_{i,\vec{x}} V_i(\vec{x},t) V_i^\dagger(\vec{0},0) \rangle \xrightarrow[t \gg a]{} \frac{\sum_i |\langle 0|V_i(0)|H_c^*(\vec{0},\lambda)\rangle|^2}{3M_{H_c^*}} \cosh\left[M_{H_c^*}\left(T/2 - t\right)\right] e^{-M_{H_c^*} T/2}$$

$$(\mu_h + \mu_c)\langle 0|P|H_c(\vec{0})\rangle = f_{H_c} M_{H_c}^2$$

$$Z_A \langle 0|V_i(0)|H_c^*(\vec{0},\lambda)\rangle = f_{H_c^*} M_{H_c^*} \epsilon_i^\lambda$$

Pseudoscalar density

Simultaneous fit of correlators obtained with local and smeared interpolators:

$$C_P^{LL}(t),\ C_P^{SL}(t),\ C_P^{SS}(t)$$

Ratios

$$R_{H_c}^M(m_h) = \frac{M_{H_c^*}}{M_{H_c}}$$

$$R_{H_c}^f(m_h) = \frac{f_{H_c^*}}{f_{H_c}}$$

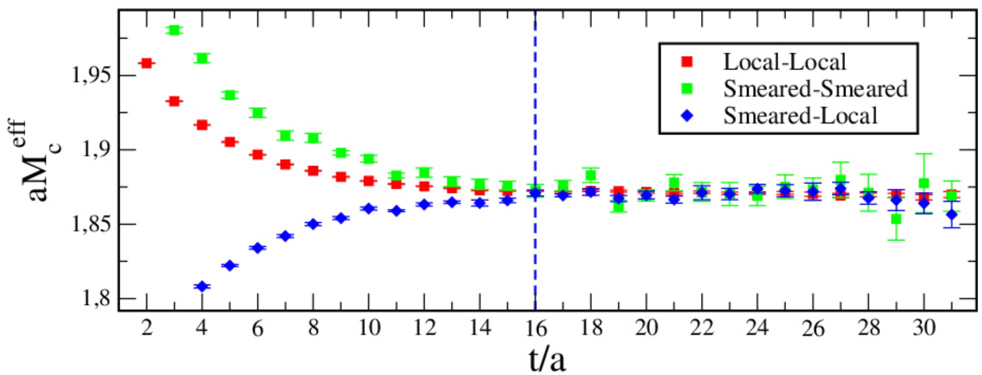
Better control of statistical and systematic uncertainties

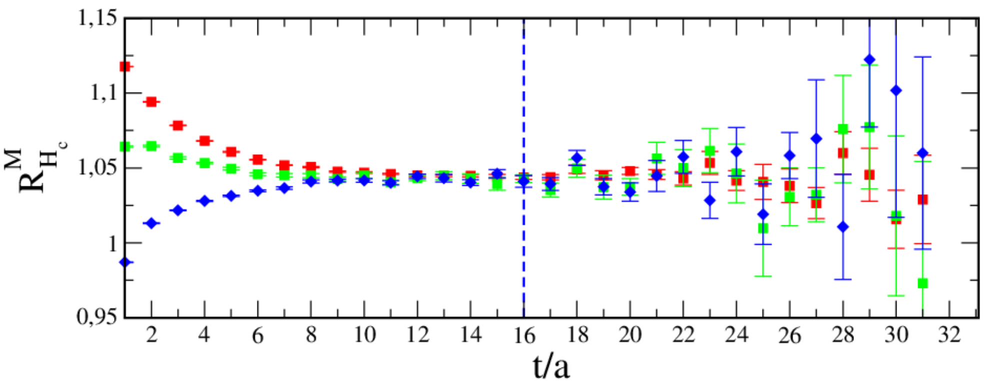
Decay Constants and Masses on the Lattice

Time distance behavior for the different ratios

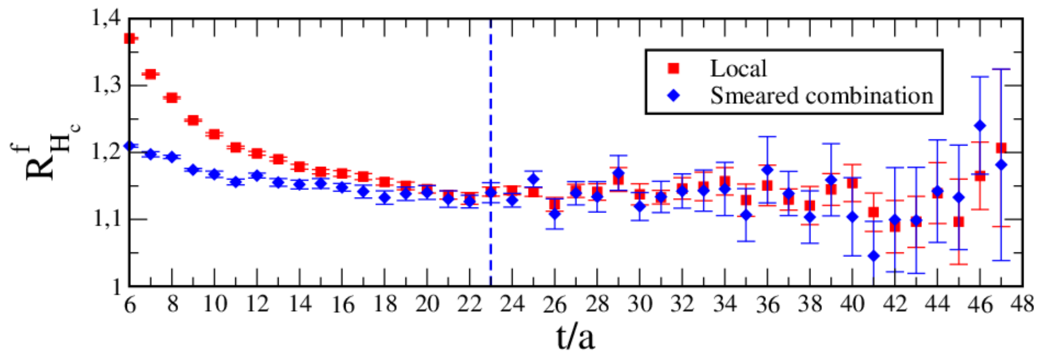
Time intervals are chosen differently for LL, SL and SS correlators

$\beta = 1.90,\ L/a = 32,\ a\mu_{sea} = 0.0040,\ a\mu_h = 0.66178$

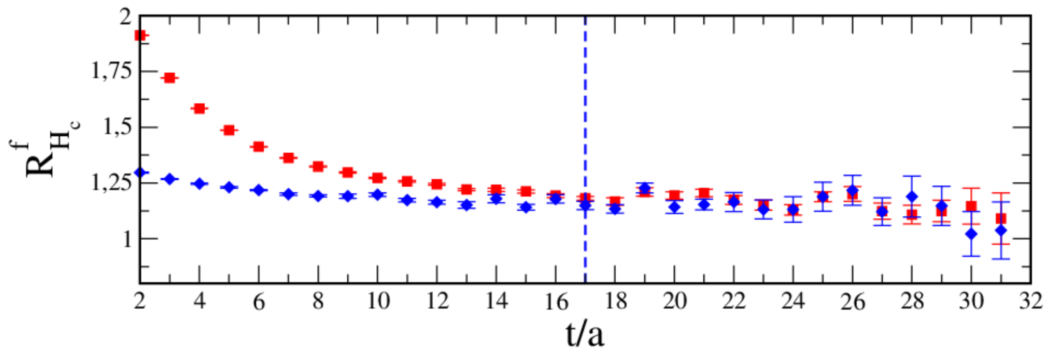




$\beta = 2.10,\ L/a = 48,\ a\mu_{sea} = 0.0020,\ a\mu_h = 0.45001$



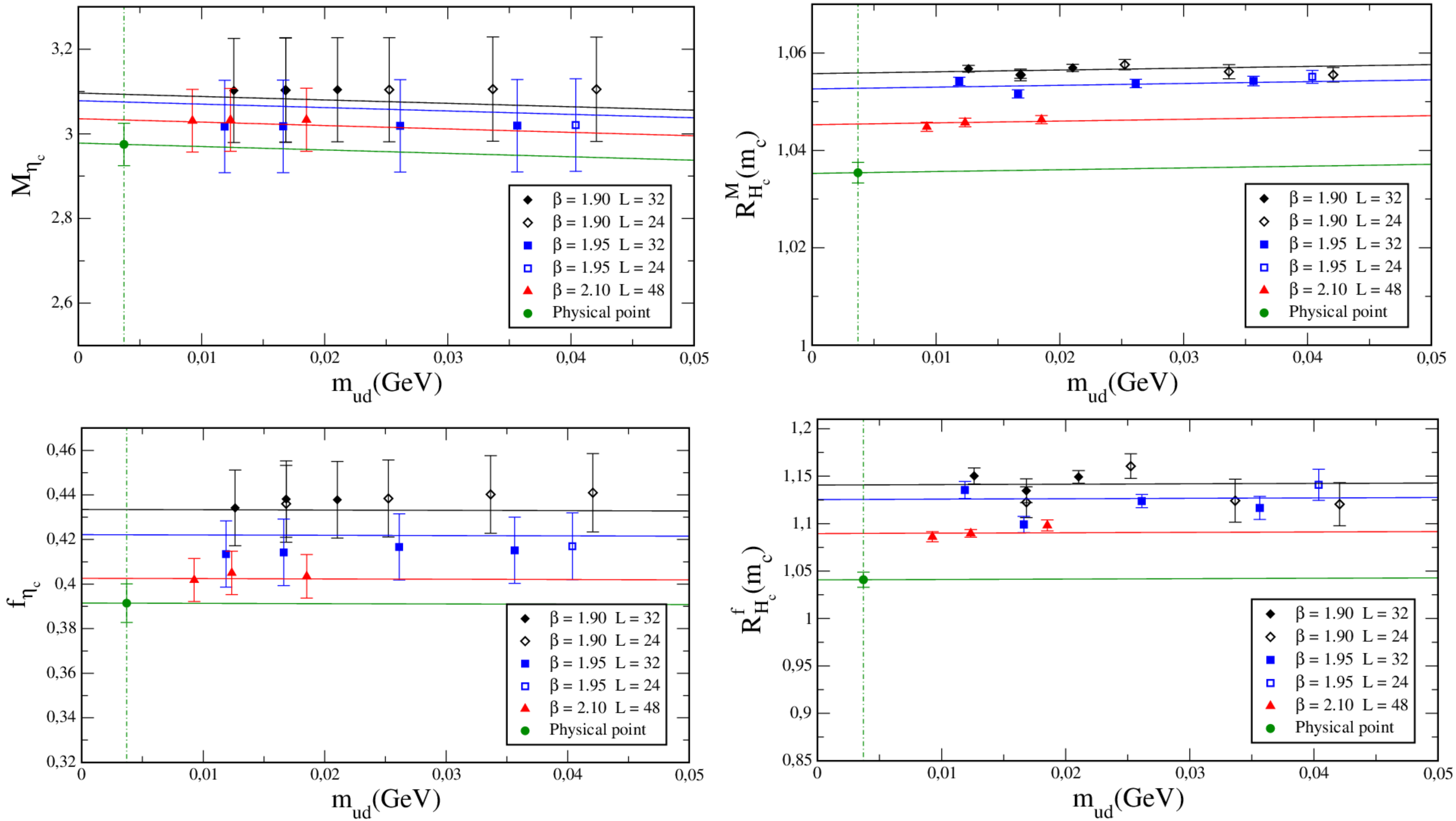
$\beta = 1.95,\ L/a = 32,\ a\mu_{sea} = 0.0035,\ a\mu_h = 0.49515$



Red and blue curves are constructed from the LL correlators and SL-SS combination respectively

η_c and J/ψ mesons analysis

Chiral and continuum extrapolation



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

Results

$$M_{\eta_c} = 2975\,(50)\mathrm{MeV}$$
$$M_{\eta_c}^{exp} = 2983.9\,(5)\mathrm{MeV}$$

$$f_{\eta_c} = 391.4\,(8.6)\mathrm{MeV}$$

$$M_{J/\psi} = 3080\,(50)\mathrm{MeV}$$
$$M_{J/\psi}^{exp} = 3096.900\,(6)\mathrm{MeV}$$

$$f_{J/\psi} = 407\,(10)\mathrm{MeV}$$

$$\frac{M_{J/\psi}}{M_{\eta c}} = 1.0354\,(21)$$
$$\frac{f_{J/\psi}}{f_{\eta c}} = 1.0409\,(80)$$

Results

$$M_{\eta_c} = 2975\,(50)\mathrm{MeV}$$

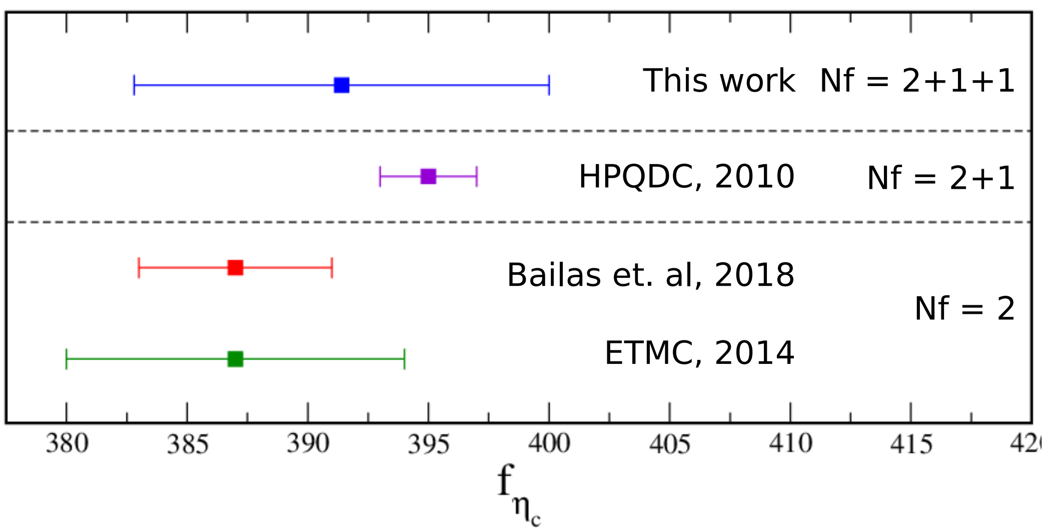
$$M_{\eta_c}^{exp} = 2983.9\,(5)\mathrm{MeV}$$

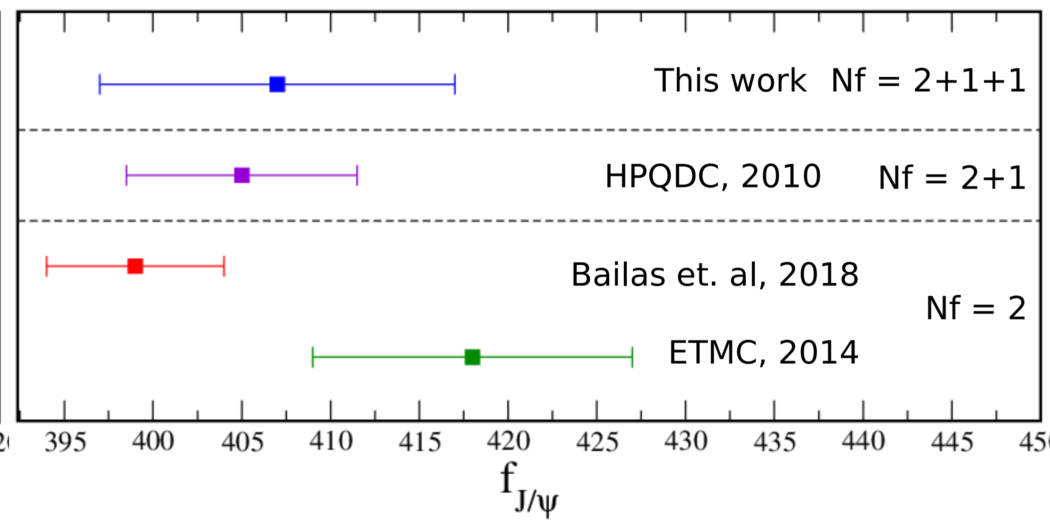
$$f_{\eta_c} = 391.4\,(8.6)\mathrm{MeV}$$

$$M_{J/\psi} = 3080\,(50)\mathrm{MeV}$$

$$M_{J/\psi}^{exp} = 3096.900\,(6)\mathrm{MeV}$$

$$f_{J/\psi} = 407\,(10)\mathrm{MeV}$$





$B_c^{(*)}$ mesons

HQET predictions in the

static limit $m_h \to \infty$

$$\lim_{m_h \to \infty} \frac{M_{H_c}(m_h)}{\mu_h^{pole}} = 1$$

$$\lim_{m_h \to \infty} \frac{f_{H_c}(m_h)\sqrt{\mu_h^{pole}}}{C_A(m_h)} = 1$$

$$\lim_{m_h \to \infty} R^M_{H_c}(m_h) = 1$$

$$\lim_{m_h \to \infty} \frac{R^f_{H_c}(m_h)}{C_W(m_h)} = 1$$

$$\mu_h^{pole} = m_h\, \rho(m_h, \mu)$$

Perturbative matching coefficients:

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

D.J. Broadhurst and A.G. Grozin, [hep-ph/9410240], 1995

$$C_A(m_h) = 1 - \frac{8}{3}\frac{\alpha_s(m_h)}{\pi} - (44.55 - 0.41 n_f)\left(\frac{\alpha_s(m_h)}{\pi}\right)^2$$

A. Czarnecki and K. Melnikov, [hep-ph/9712222], 1998

M. Beneke et al, [hep-ph/9712302], 1998

Ratio method

B. Blossier et al [ETMC], arXiv: 0909.3187, 2010

- Interpolate data to a sequence of reference masses such that two successive quantities have a common and fixed ratio:

$$m_h^{(n)} = \lambda m_h^{(n-1)}, \; n = 1, \ldots, K \qquad m_h^{(K)} = m_b$$

$$m_h^{(0)} = m_c$$

$$(\lambda, \; K) = (1.160, \; 10)$$

$$m_b = 5.20\,(90)\mathrm{GeV}$$

A. Bussone et al [ETMC], arXiv: 1603.04306, 2016

- The next step is to construct at each value of the sea quark mass and lattice spacing the following ratios

$$y_M(m_h^{(n)}, \lambda; \; \mu_\ell, a) = \frac{M_{H_c}(m_h^{(n)}; \mu_\ell, a)}{M_{H_c}(m_h^{(n-1)}; \mu_\ell, a)} \frac{\mu_{n-1}^{pole}}{\mu_n^{pole}}$$

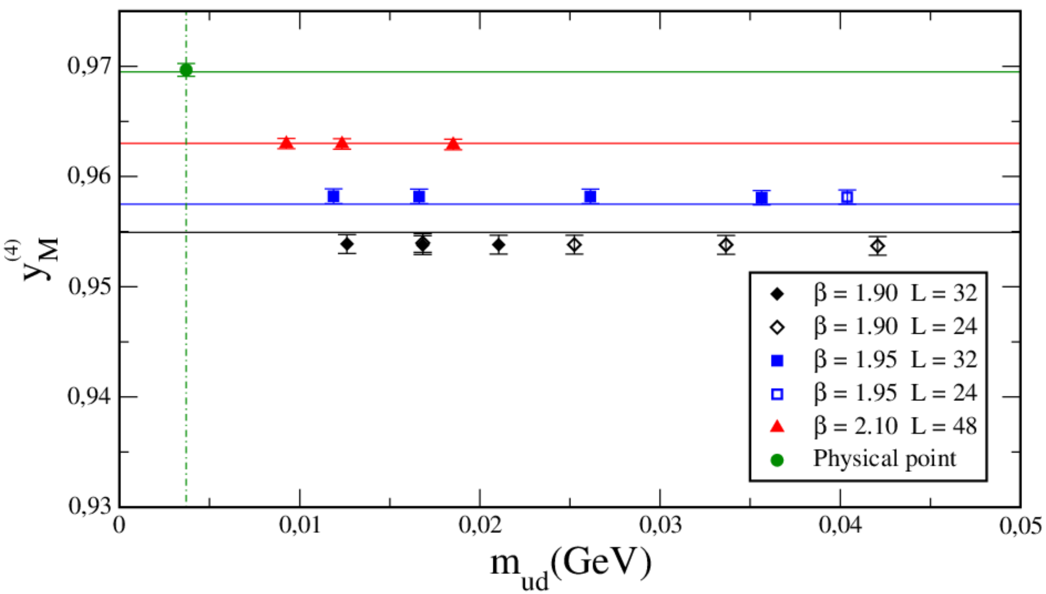
$$y_f(m_h^{(n)}, \lambda; \; \mu_\ell, a) = \frac{f_{H_c}(m_h^{(n)}; \mu_\ell, a)}{f_{H_c}(m_h^{(n-1)}; \mu_\ell, a)} \frac{\sqrt{\mu_n^{pole}}}{\sqrt{\mu_{n-1}^{pole}}} \frac{C_A(m_h^{(n-1)})}{C_A(m_h^{(n)})}$$

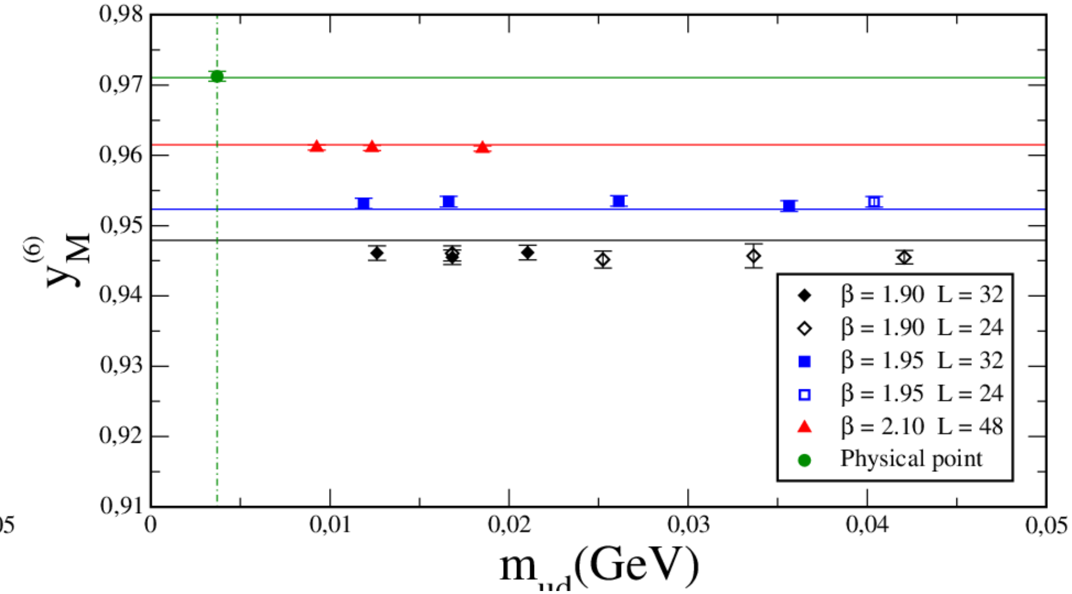
- Perform a chiral and continuum extrapolation for each ratio

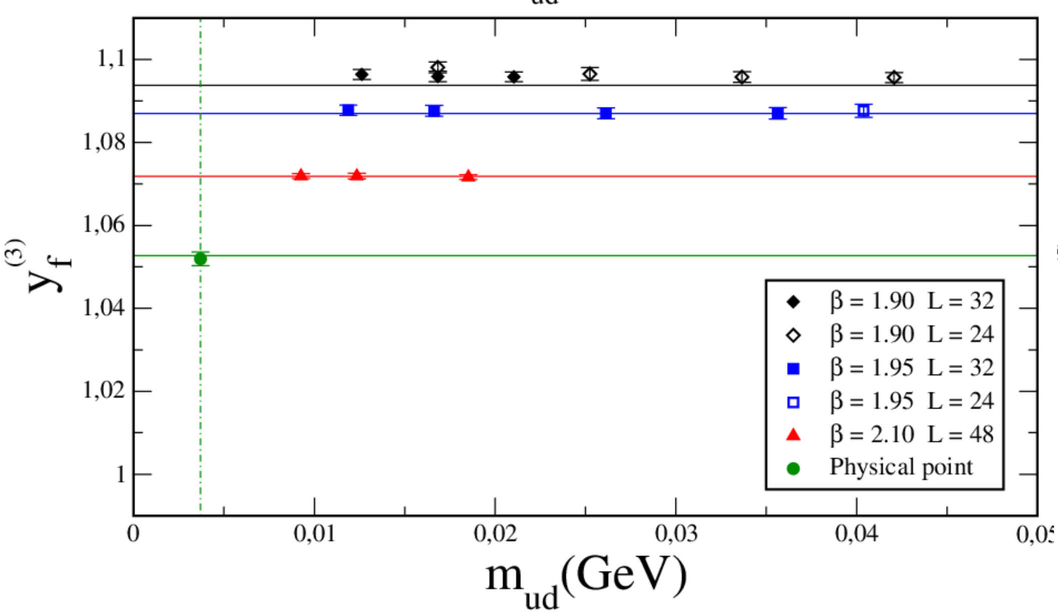
- Interpolate lattice data in $1/m_h$ to m_b imposing the static limit constraint

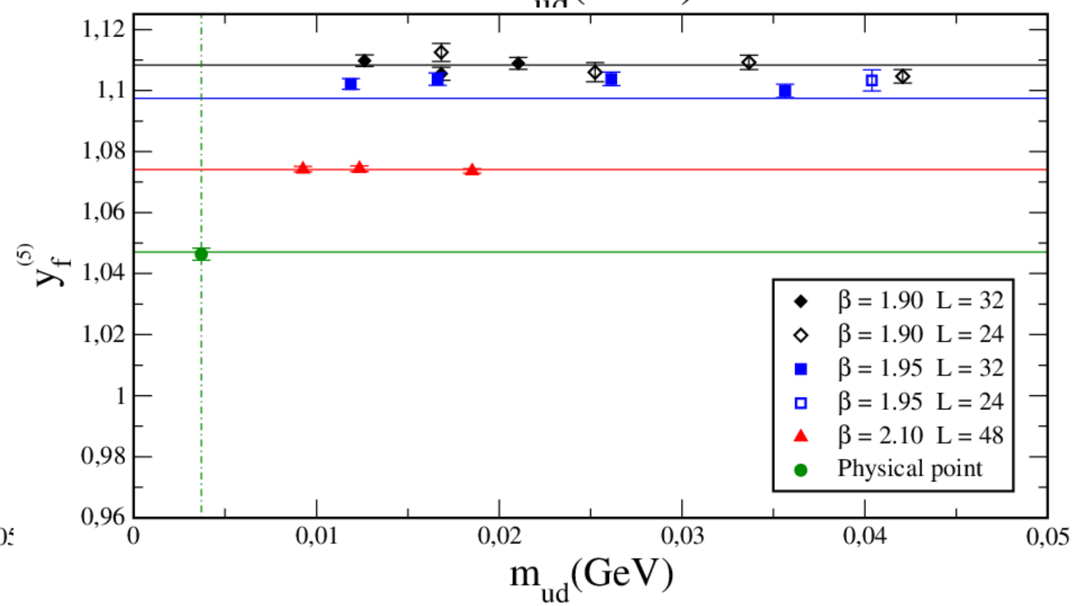
Ratio method

- Perform a chiral and continuum extrapolation for each ratio



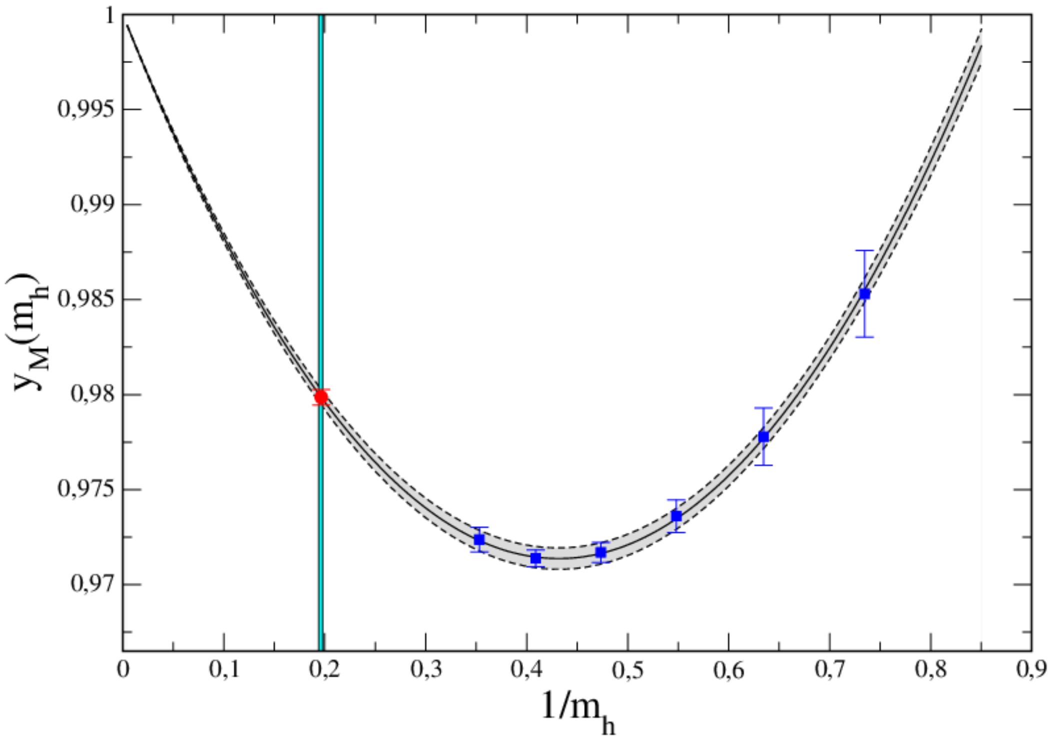


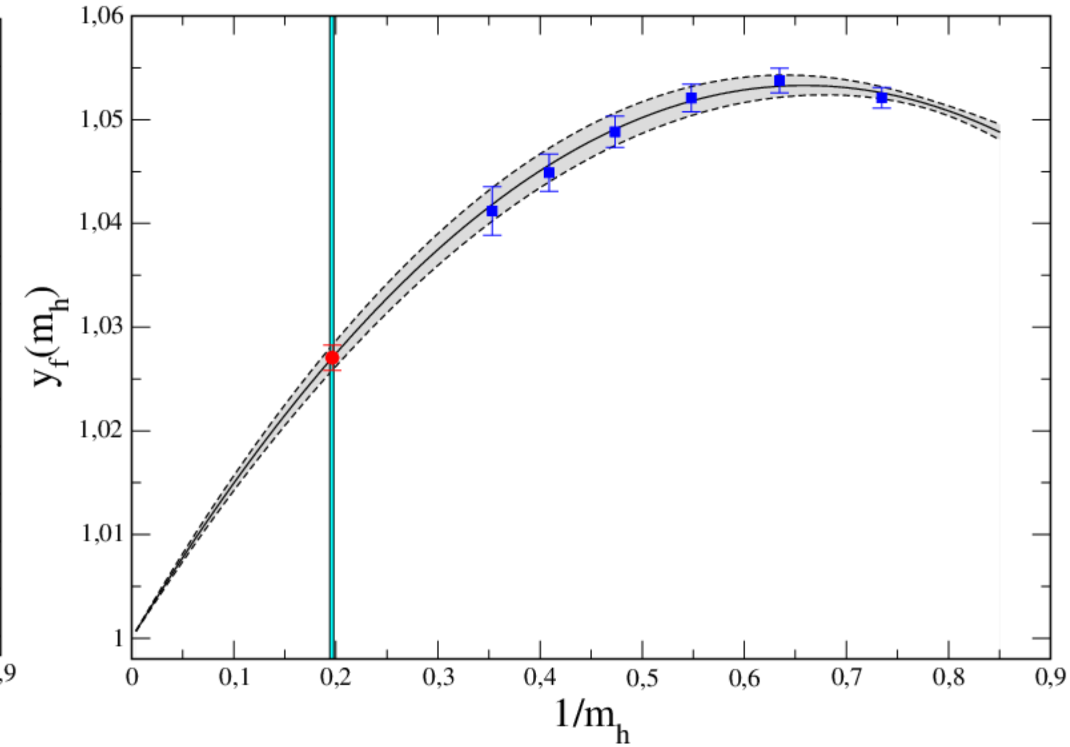




Ratio method

✦ Interpolate lattice data in $1/m_h$ to m_b imposing the static limit constraint





$$y_{M,f}(m_h) = \left(1 + \frac{A_1}{m_h} + \frac{A_2}{m_h^2}\right)\left(1 + P_1 m_h a^2 + P_2(m_h^{(n)} - m_c)a^4\right)$$

$$M_{\eta_c} \times y_M(m_h^{(1)}) y_M(m_h^{(2)}) \ldots y_M(m_h^{(K)}) = \lambda^{-K} M_{B_c} \frac{\rho(m_h^{(0)}, \mu)}{\rho(m_h^{(K)}, \mu)}$$

$$f_{\eta_c} \times y_f(m_h^{(1)}) y_f(m_h^{(2)}) \ldots y_f(m_h^{(K)}) = \lambda^{K/2} f_{B_c} \left(\frac{\rho(m_h^{(K)}, \mu)}{\rho(m_h^{(0)}, \mu)}\right)^{1/2} \frac{C_A(m_h^{(0)})}{C_A(m_h^{(K)})}$$

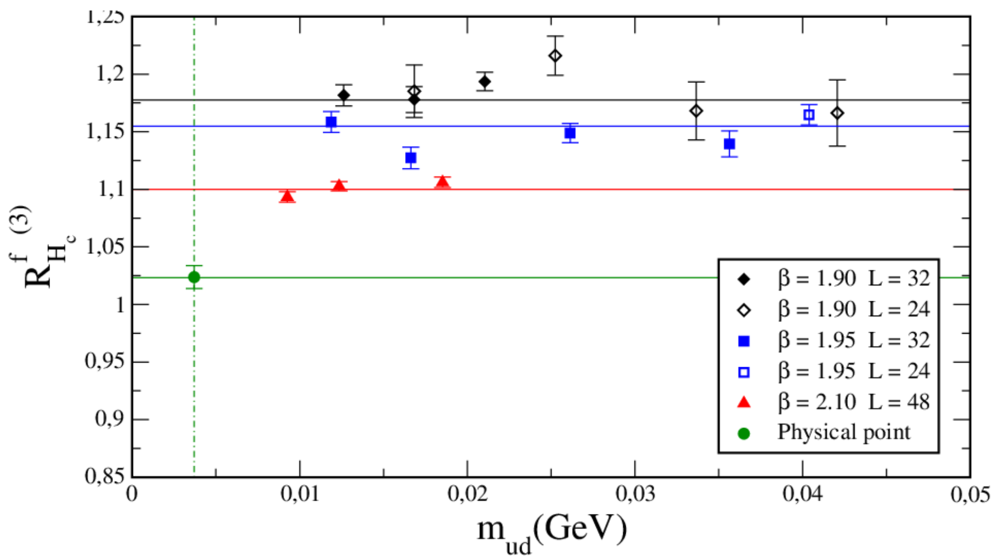
Chain equations

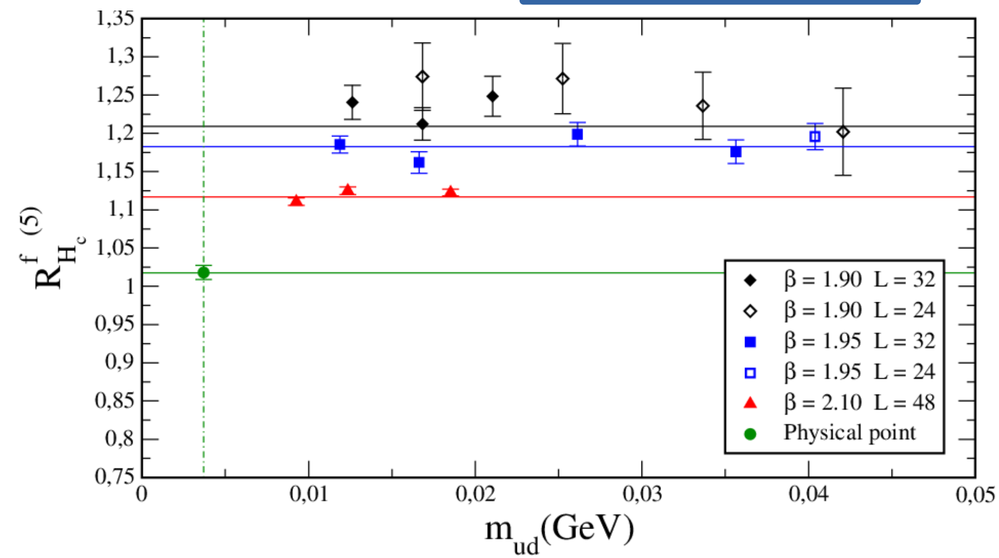
$B_c^{(*)}$ mesons

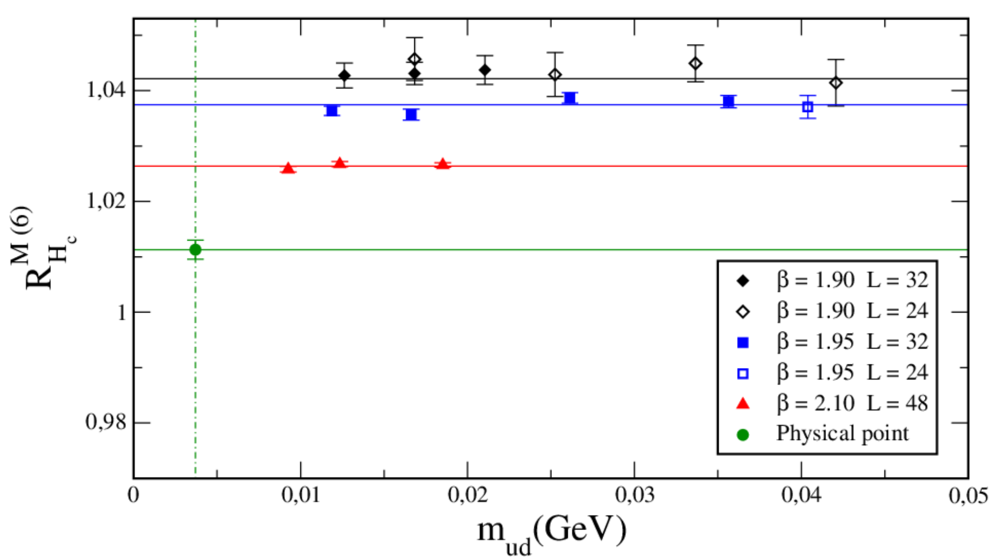
$$R^M_{H_c}(m_h) = \frac{M_{H_c^*}}{M_{H_c}}$$

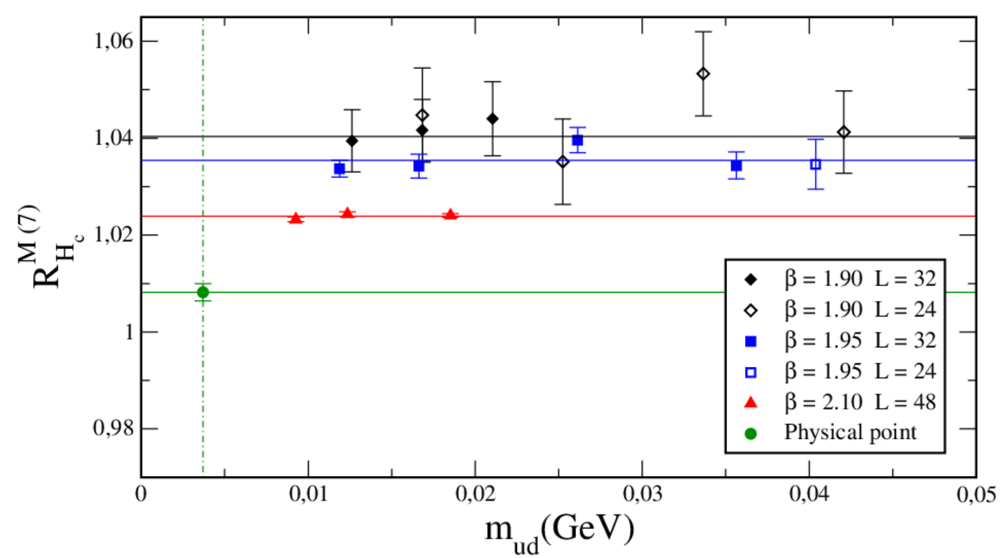
$$R^f_{H_c}(m_h) = \frac{f_{H_c^*}}{f_{H_c}}$$

- Perform a chiral and continuum extrapolation for each ratio



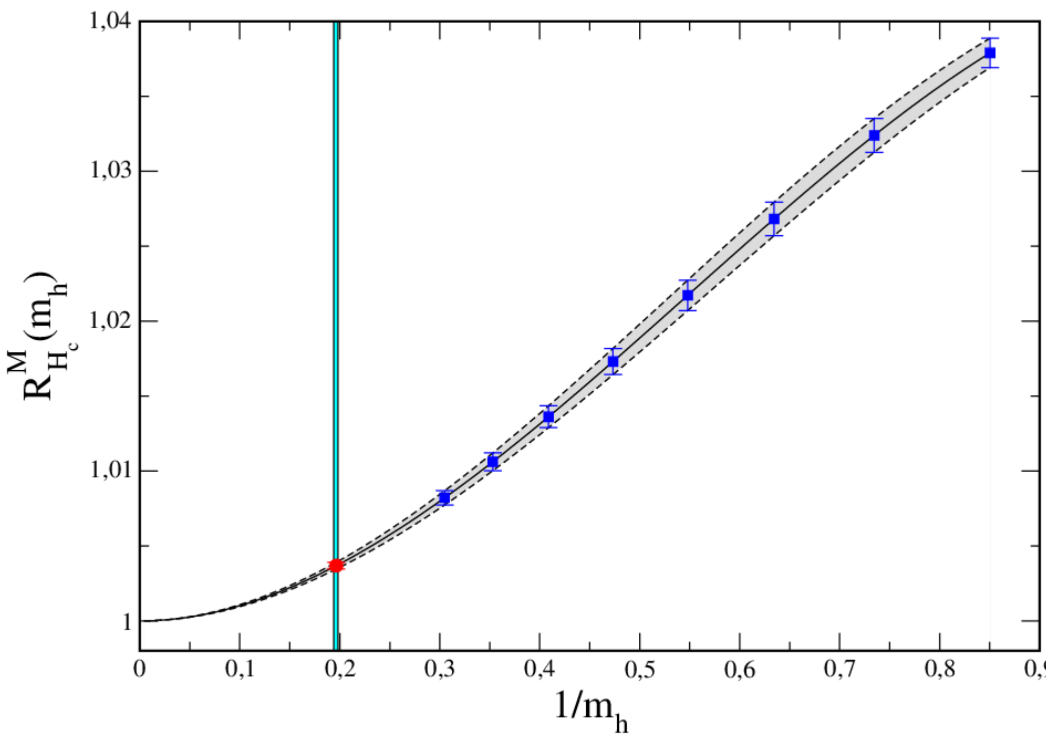


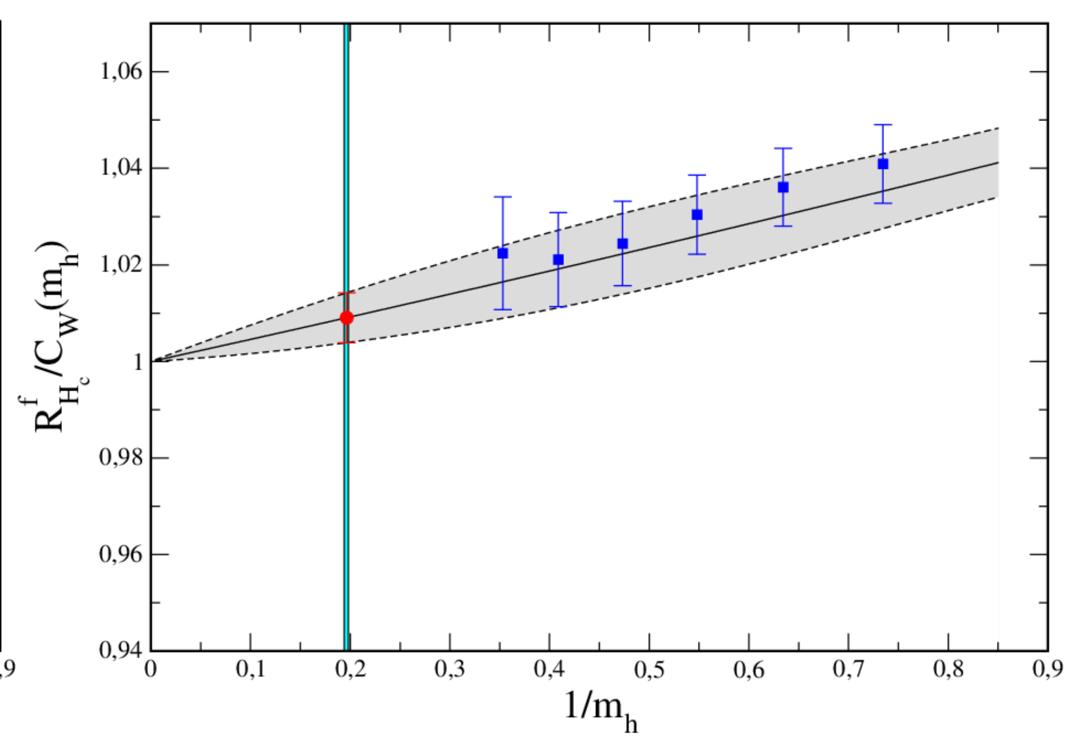




Ratio method

✦ Interpolate lattice data in $1/m_h$ to m_b imposing the static limit constraint





$$R^M_{H_c}(m_h) = \left(1 + \cancel{\frac{A_1}{m_h}} + \frac{A_2}{m_h^2} + \frac{A_3}{m_h^3}\right)\left(1 + D_1 m_h a^2 + D_2(m_h^{(n)} - m_c)a^4\right)$$

$$\frac{R^f_{H_c}(m_h)}{C_W(m_h)} = \left(1 + \frac{B_1}{m_h} + \frac{B_2}{m_h^2}\right)\left(1 + P_1 m_h a^2 + P_2(m_h^{(n)} - m_c)a^4\right)$$

Results

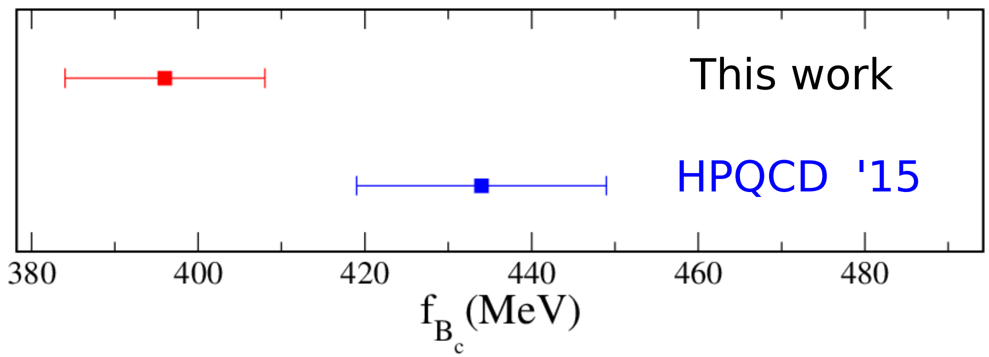
$$M_{B_c} = 6341\,(60)\,\mathrm{MeV}$$

$$M_{B_c}^{exp} = 6274.9\,(8)\,\mathrm{MeV}$$

$$\frac{M_{B_c^*}}{M_{B_c}} = 1.0037\,(39)$$

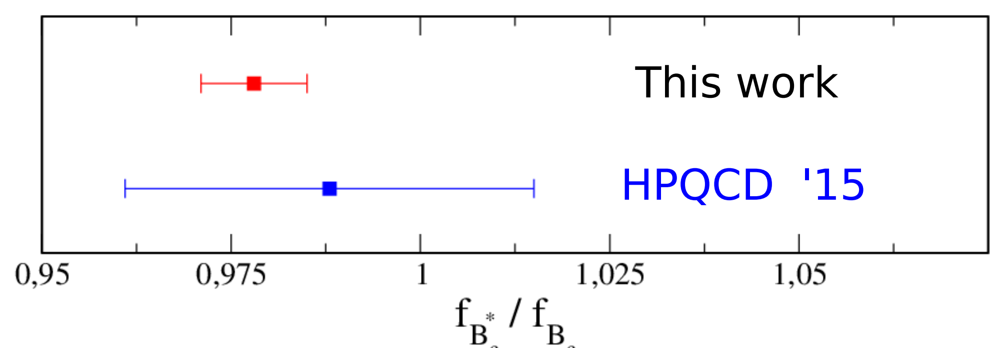
$$f_{B_c} = 396\,(12)\,\mathrm{MeV}$$ This work

$$f_{B_c} = 434\,(15)\,\mathrm{MeV}$$ HPQCD '15



$$\frac{f_{B_c^*}}{f_{B_c}} = 0.978\,(7)$$ This work

$$\frac{f_{B_c^*}}{f_{B_c}} = 0.988\,(27)$$ HPQCD '15



Conclusions & Outlooks

We have presented preliminary results for the masses and decay constants of $B_c^{(*)}$ mesons using ETMC gauge ensembles with Nf=2+1+1 dynamical quarks

In order to reach the physical b-quark mass we have employed the ETMC ratio method

As a triggering point for the analysis, also the mass and the decay constant of the η_c and J/ψ mesons have been computed

Results still preliminar: the next step is the analysis of systematic uncertaintes

Thank you for the attention

Simulation Details

Something on the action:

- Wilson Twisted Mass action at maximal twist with Nf=2+1+1 sea quarks
- Osterwalder-Seiler action for valence c and s quarks
- Iwasaki gluon action