B decay to radially excited D

Benoît Blossier

CNRS/LPT Orsay

Lattice 2013, Mainz, 29 July - 3 August 2013

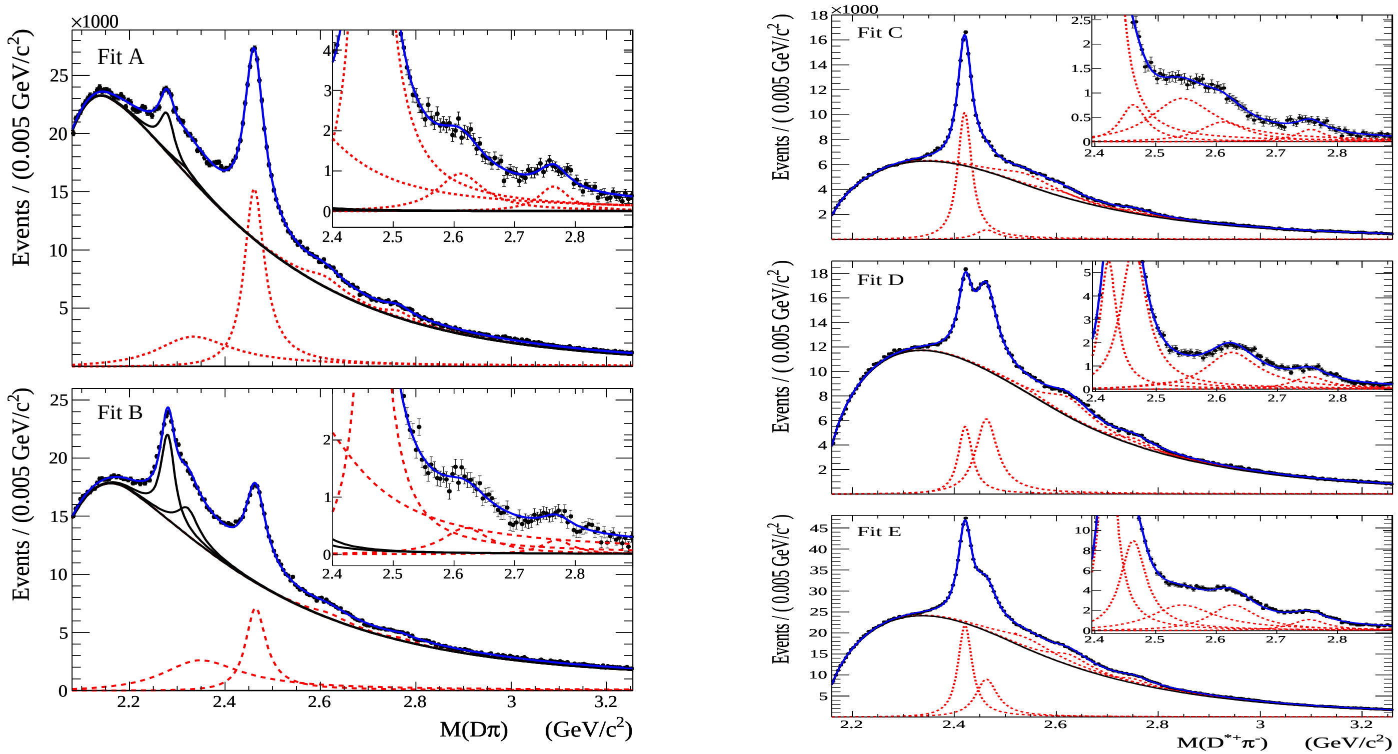
- Excited D mesons states in questions
- $B \to D'$ non leptonic decay
- Lattice measurement of $f_{D'}/f_D$
- Outlook

D. Becirevic, BB, A. Gérardin, A. Le Yaouanc and F. Sanfilippo,
Nucl. Phys. B **872**, 313 (2013) [arXiv:1301.7336 [hep-ph]]

Excited D meson states in questions

Recently the BaBar Collaboration claimed to have isolated a couple of excited D states

[BaBar Collaboration, '11]



$D\pi$ distribution: a clear peak is observed for $D_2^*(2460)$, "enhancements" are seen and correspond to $D^*(2600)$ and $D^*(2760)$

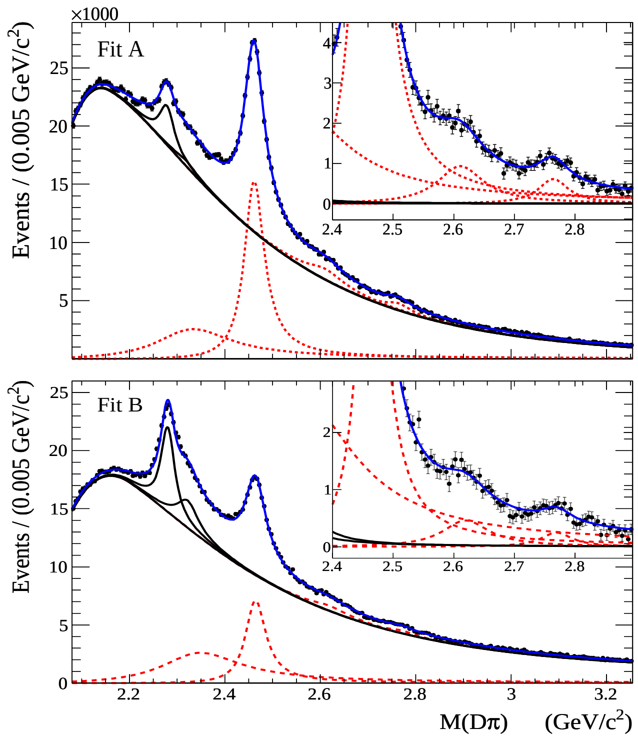
$D^*\pi$ distribution: a peak is visible for $D_1(2420$ and 2 structures are observed, interpreted as $D(2550) \equiv D'$ and $D(2750)$

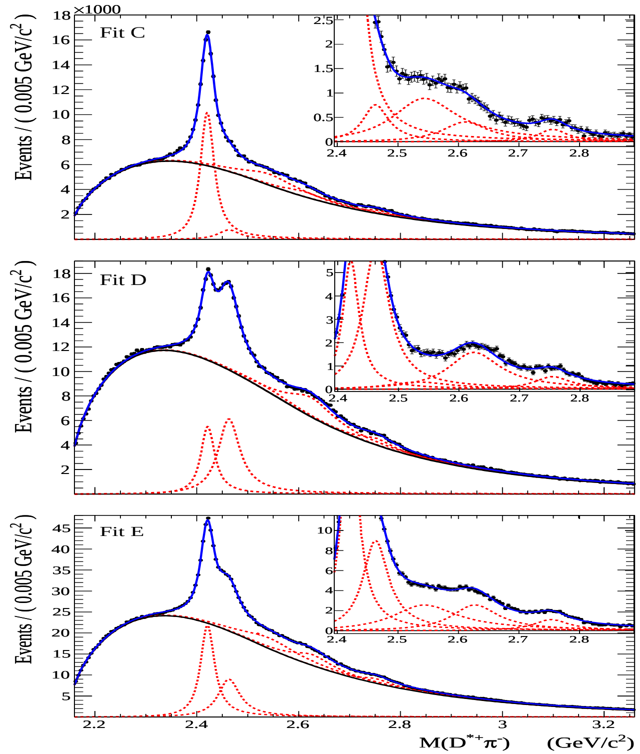
A fit gives $m(D') = 2539(8)$ MeV and $\Gamma(D') = 130(18)$ MeV

Excited D meson states in questions

Recently the BaBar Collaboration claimed to have isolated a couple of excited D states

[BaBar Collaboration, '11]



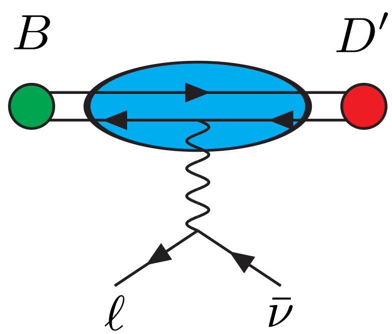


Question: is this interpretation correct? Popular quark models obtain roughly the same mass (2580 MeV) but a much smaller width (70 MeV) [F. Close and E. Swanson, '05; Z. Sun *et al*, '10]

☹ Radial excitations are very sensitive to the position of the nodes of wave functions, that depends strongly on the model.

$J = \frac{1}{2} \oplus j_l$, $H = B, D$

j_l^P	J^P	ground state	radial excitation
$\frac{1}{2}^-$	0^-	H	H'
	1^-	H^*	${H^*}'$
$\frac{1}{2}^+$	0^+	H_0^*	${H_0^*}'$
	1^+	H_1^*	${H_1^*}'$
$\frac{3}{2}^+$	1^+	H_1	H_1'
	2^+	H_2^*	${H_2^*}'$



[F. Bernlochner *et al*, '12]:
Assume a large $\mathcal{B}(B \to D' l\nu)$
$\Gamma(D' \to D_{1/2}\pi)$ much larger than $\Gamma(D' \to D_{3/2}\pi)$
$\Longrightarrow$ Excess of $B \to D_{1/2}(\pi) l\nu$ events with respect to $B \to D_{3/2}(\pi) l\nu$

Question: could this potentially large $B \to D' l\nu$ width explain the "1/2 vs. 3/2 puzzle"?
$[\Gamma(B \to D_{1/2} l\nu) \simeq \Gamma(B \to D_{3/2} l\nu)]^{\text{exp}}$ while $[\Gamma(B \to D_{1/2} l\nu) \ll \Gamma(B \to D_{3/2} l\nu)]^{\text{th}}$
[V. Morénas *et al*, '01; N. Uraltsev, '04]

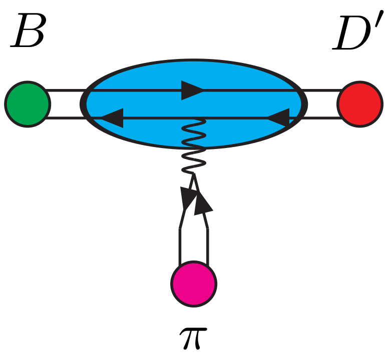
In the OPE formalism, a large $B \to D'$ form factor is going together with a small suppression of $B \to D^{(*)}$ form factors [P. Gambino *et al*, '12]

Question: can a large $B \to D'$ form factor solve the tension of $\sim 3\sigma$ observed between V_{cb}^{excl} and V_{cb}^{incl}? [M. Bona *et al*, '10; J. Charles *et al*, '11]

Non leptonic $B \to D'$ decay

Our proposal: let's look at $B \to D'\pi$ non leptonic decay to check the largeness of $\mathcal{B}(B \to D' l \nu)$

Class I non leptonic decay

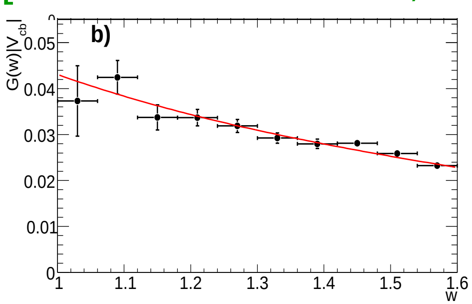


Factorisation approximation works well

$$\frac{\mathcal{B}(\bar{B}^0 \to D'^+\pi^-)}{\mathcal{B}(\bar{B}^0 \to D^+\pi^-)} = \left(\frac{m_B^2 - m_{D'}^2}{m_B^2 - m_D^2}\right)^2 \left[\frac{\lambda(m_B, m_{D'}, m_\pi)}{\lambda(m_B, m_D, m_\pi)}\right]^{1/2} \left|\frac{f_+^{B\to D'}(0)}{f_+^{B\to D}(0)}\right|^2$$

$$\lambda(x,y,z) = [x^2 - (y+z)^2][x^2 - (y-z)^2] \quad f_+^{B\to D^{(\prime)}}(m_\pi^2) \sim f_+^{B\to D^{(\prime)}}(0)$$

[BaBar Collaboration, '10]



$V_{cb} f_+^{B\to D}(0) = 0.02642(8)$ and $|V_{cb}| = 0.0411(16)$:
$f_+^{B\to D}(0) = 0.64(2)$

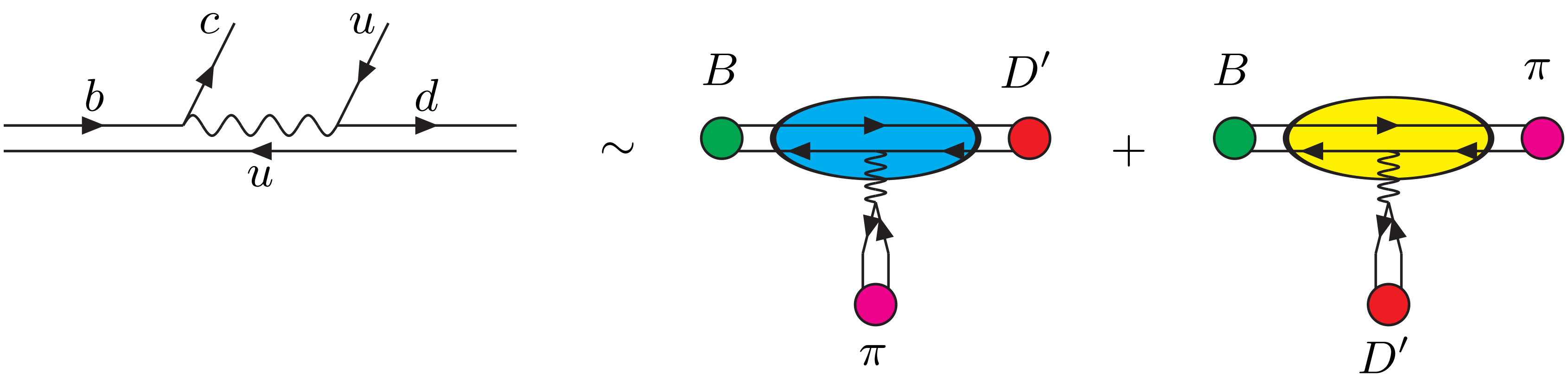
$m_{D'} = 2.54$ GeV: $\frac{\mathcal{B}(\bar{B}^0 \to D'^+\pi^-)}{\mathcal{B}(\bar{B}^0 \to D^+\pi^-)} = (1.65 \pm 0.13) \times \left|f_+^{B\to D'}(0)\right|^2$

$\mathcal{B}(\bar{B}^0 \to D^+\pi^-) = 0.268(13)\%$: $\mathcal{B}(\bar{B}^0 \to D'^+\pi^-) = \left|f_+^{B\to D'}(0)\right|^2 \times (4.7 \pm 0.4) \times 10^{-3}$

Theoretical estimates of $f_+^{B\to D'}(0)$ are in the range $[0.1,\ 0.4]$
[F. Bernlochner *et al*, '12; D. Ebert *et al*, '99; N. Faustov and V. Galkin, *'12*; Z. Wang *et al*, '12]

$\mathcal{B}(\bar{B}^0 \to D'^+\pi^-)^{\rm th} \sim 10^{-4}$: it can be measured with the B factories samples and at LHCb.

Class III decay



Factorised amplitude:

$$A^{III}_{\rm fact} = -i\frac{G_F}{\sqrt{2}}V_{cb}V^*_{ud}\left[a_1 f_\pi [m_B^2 - m_{D'}^2] f^{B\to D'}(m_\pi^2) + a_2 f_{D'}[m_B^2 - m_\pi^2] f^{B\to\pi}(m_{D'}^2)\right]$$

Normalisation by the Class I decay

$$\frac{\mathcal{B}(B^- \to D'^0\pi^-)}{\mathcal{B}(\bar{B}^0 \to D'^+\pi^-)} = \frac{\tau_{B^-}}{\tau_{\bar{B}^0}}\left[1 + \frac{a_2}{a_1} \times \frac{m_B^2 - m_\pi^2}{m_B^2 - m_{D'}^2} \times \frac{f_0^{B\to\pi}(m_{D'}^2)}{f_+^{B\to D'}(0)}\frac{f_{D'}}{f_D}\frac{f_D}{f_\pi}\right]^2$$

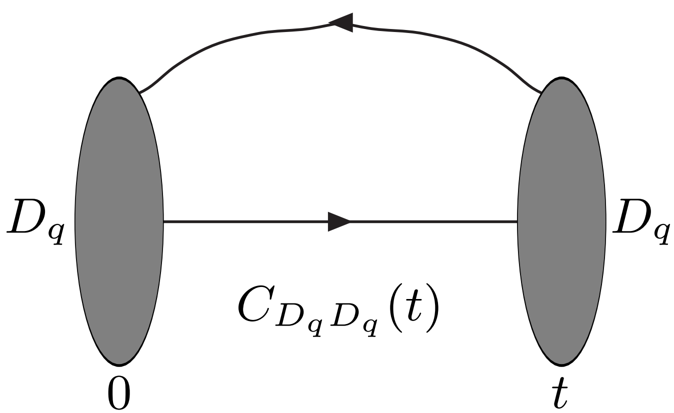
a_2/a_1 determined from $\frac{\mathcal{B}(B^-\to D^0\pi^-)}{\mathcal{B}(\bar{B}^0\to D^+\pi^-)}$, known experimentally

f'_D/f_D and f_D/f_π extracted from lattice QCD simulations

Lattice measurement of $f_{D'}/f_D$

Lattice set up

N_f	action	a	$m_{\rm sea}$	configurations
2	MtmQCD	[0.055, 0.1] fm	$[m_s/6, m_s/2]$	ETMC ensembles
2	Wilson-Clover	0.065 fm	$\sim m_s$	QCDSF ensembles
0	Wilson-Clover	0.065 fm		



$$C_{D_qD_q}(t) = \langle \sum_{\vec{x}} P_{D_q}(\vec{x};t) P^\dagger_{D_q}(0;0)\rangle$$

$$\xrightarrow{t\gg 0} \left|\mathcal{Z}_{D_q}\right|^2 \frac{\cosh[m_{D_q}(T/2-t)]}{m_{D_q}} e^{-m_{D_q}T/2}$$

Subtraction of the ground state contribution:

$$C'_{D_qD_q}(t) = C_{D_qD_q}(t) - \left|\mathcal{Z}_{D_q}\right|^2 \frac{\cosh[m_{D_q}(T/2-t)]}{m_{D_q}} e^{-m_{D_q}T/2}$$

Effective mass: $$\frac{\cosh\left[m^{\rm eff}_{D'_q}(t)\left(\frac{T}{2}-t\right)\right]}{\cosh\left[m^{\rm eff}_{D'_q}(t)\left(\frac{T}{2}-t-1\right)\right]} = \frac{C'_{D_qD_q}(t)}{C'_{D_qD_q}(t+1)}$$

$f_{D'_q}$ is related to $\mathcal{Z}_{D_q}$

Alternative approach: Generalised Eigenvalue Problem

Interpolating fields $P_{D_q\,i} \equiv \bar{\psi}_{c\,i}\gamma^5\psi_{q\,i}$, different Gaussian smearing levels i are used to build a matrix of correlators $C_{D_q D_q\,ij}(t)$

$\psi_{q\,i} = \left(1 + \frac{\kappa_G}{1+6\kappa_G}\Delta\right)^i$, $\kappa_G = 4.0$, $i = \{0,\ 2,\ 10, 32\}$

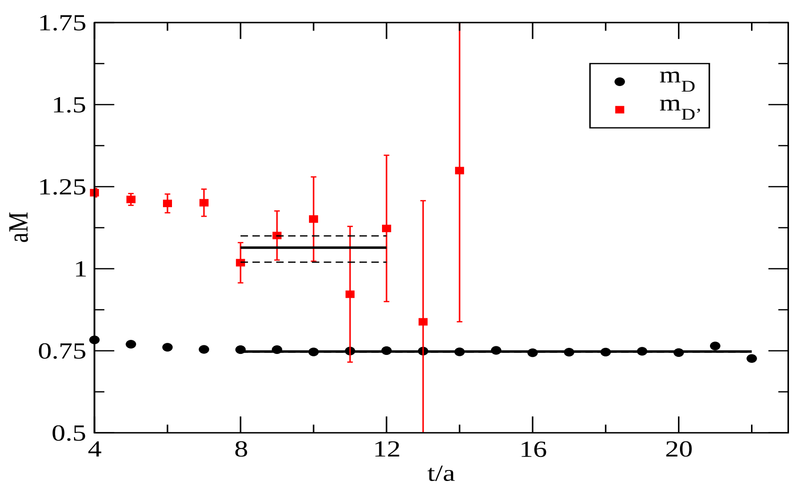
Solving the GEVP: $C_{D_q D_q\,ij}(t)v_j^{(n)}(t,t_0) = \lambda^{(n)}(t,t_0)C_{D_q D_q\,ij}(t_0)v_j^{(n)}(t,t_0)$

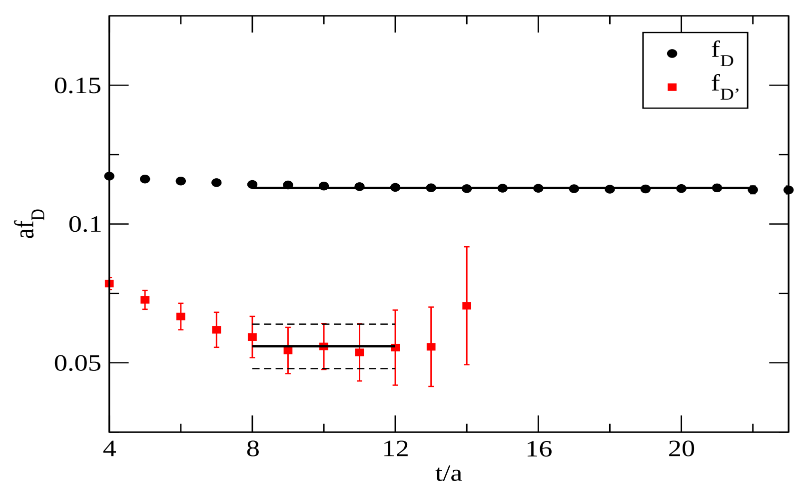
$\widetilde{P}_{D_q}^{(n)}(t,t_0) = \sum_i v_i^{(n)}(t,t_0)P_{D_q\,i} \quad \langle D_q^{(m)}|\widetilde{P}_{D_q}^{(n)\dagger}|0\rangle = A_n\delta_{mn}$

Effective mass: $m^{\mathrm{eff}}_{D_q^{(n)}}(t) = \mathrm{arccosh}\left[\frac{\lambda^{(n)}(t+1,t_0)+\lambda^{(n)}(t-1,t_0)}{2\lambda^{(n)}(t,t_0)}\right]$

Decay constant: $\mathcal{Z}_{D_q^{(n)}} = \lim_{t\to\infty} \frac{\sqrt{A_n}\quad \sum_i C_{D_q D_q\,0i}(t)v_i^{(n)}(t,t_0)}{\sum_{ij} v_i^{(n)}(t,t_0)C_{D_q D_q\,ij}(t)v_j^{(n)}(t,t_0)}$

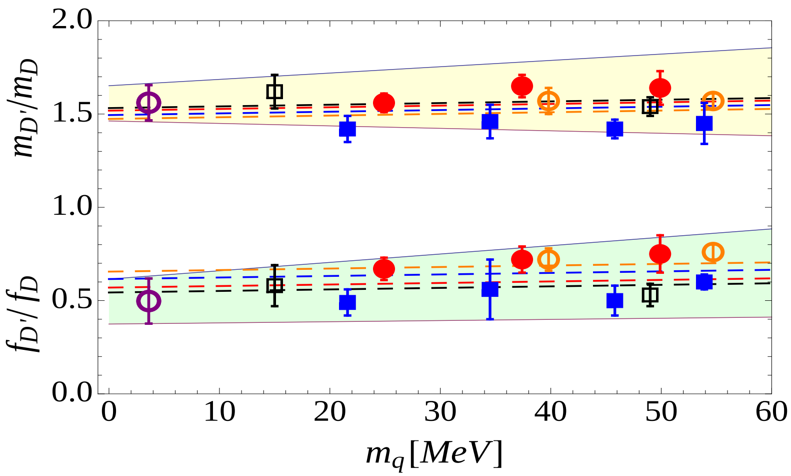
[ETMC ensemble ($a = 0.085\,\mathrm{fm} \quad m_\pi = 350\,\mathrm{MeV}$)]





Combined fit of ETMC data at different a and m_{sea}:

$$\mathcal{F}^{\text{latt.}} = A_{\mathcal{F}} \left[1 + B_{\mathcal{F}} m_q + C_{\mathcal{F}} \left(\frac{a}{a_{\beta=3.9}} \right)^2 \right] \qquad a_{\beta=3.9} = 0.085 \text{ fm}$$



$$\frac{m_{D'_s}}{m_{D_s}} = 1.53(7) \qquad \frac{f_{D'_s}}{f_{D_s}} = 0.59(11)$$

$$\frac{m_{D'}}{m_D} = 1.55(9) \qquad \frac{f_{D'}}{f_D} = 0.57(16)$$

$f_{D'_q}/f_{D_q} < 1$ while $f_{B'_q}/f_{B_q}\Big|_{\text{static HQET}} > 1$

[T. Burch *et al*, ’09; B. Blossier *et al*, ’10]

$(m_{D'}/m_D)^{\text{exp}} = 1.36$: is there any issue?

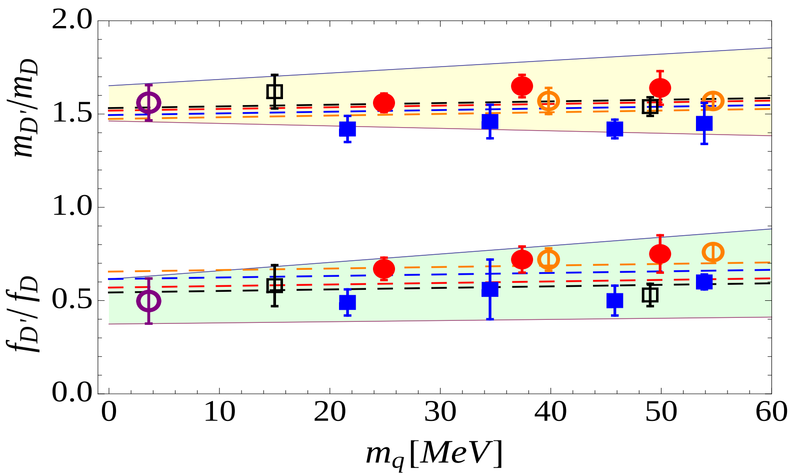
- MtmQCD breaks parity at finite lattice spacing $\Longrightarrow$ calculation made with Wilson-Clover fermions at $a \sim 0.065$ fm:

$$\text{MtmQCD}: \quad \frac{m_{D'_s}}{m_{D_s}}\Big|_{a=0.065\text{fm}} = 1.55(6) \qquad \frac{f_{D'_s}}{f_{D_s}}\Big|_{a=0.065\text{fm}} = 0.69(5)$$

$$\text{Clover}: \quad \frac{m_{D'_s}}{m_{D_s}}\Big|_{a=0.065\text{fm}} = 1.48(7) \qquad \frac{f_{D'_s}}{f_{D_s}}\Big|_{a=0.065\text{fm}} = 0.77(9)$$

Combined fit of ETMC data at different a and $m_{\rm sea}$:

$$\mathcal{F}^{\rm latt.} = A_{\mathcal{F}}\left[1 + B_{\mathcal{F}} m_q + C_{\mathcal{F}}\left(\frac{a}{a_{\beta=3.9}}\right)^2\right] \qquad a_{\beta=3.9} = 0.085 \text{ fm}$$



$$\frac{m_{D_s'}}{m_{D_s}} = 1.53(7) \qquad \frac{f_{D_s'}}{f_{D_s}} = 0.59(11)$$

$$\frac{m_{D'}}{m_D} = 1.55(9) \qquad \frac{f_{D'}}{f_D} = 0.57(16)$$

$f_{D_q'}/f_{D_q} < 1$ while $f_{B_q'}/f_{B_q}\Big|_{\rm static\ HQET} > 1$

[T. Burch *et al*, '09; B. Blossier *et al*, '10]

$(m_{D'}/m_D)^{\rm exp} = 1.36$: is there any issue?

- At $N_f = 2$, channels with a pion or a kaon in the final state may open: D' can decay into $D^*\pi$ (P wave) and $D_0^*\pi$ (S wave), D_s' into D^*K and D_{s0}^*K. No such a "danger" in the quenched approximation!

$$\mathrm{N_f} = 0: \quad \frac{m_{D_s'}}{m_{D_s}}\Big|_{a=0.065\rm fm} = 1.41(9) \quad \frac{f_{D_s'}}{f_{D_s}}\Big|_{a=0.065\rm fm} = 0.67(12)$$

$$\mathrm{N_f} = 2: \quad \frac{m_{D_s'}}{m_{D_s}}\Big|_{a=0.065\rm fm} = 1.48(7) \quad \frac{f_{D_s'}}{f_{D_s}}\Big|_{a=0.065\rm fm} = 0.77(9)$$

Back to phenomenology

Lattice inputs: $m_{D'}/m_D = 1.55(9)$ $f_{D'}/f_D = 0.57(16)$ $f_D/f_\pi = 1.56(3)(2)$
Phenomenological inputs: $a_2/a_1 = 0.368$ $\tau_{\bar{B}^0}/\tau_{B^-} = 1.079(7)$ $f_+^{B\to D}(0) = 0.64(2)$
$f_0^{B\to\pi}(m_D^2) = 0.29(4)$

$$\frac{\mathcal{B}(B^- \to D'^0\pi^-)}{\mathcal{B}(\bar{B}^0 \to D'^+\pi^-)} = \frac{\tau_{B^-}}{\tau_{\bar{B}^0}}\left[1 + \frac{0.14(4)}{f_+^{B\to D'}(0)}\right]^2$$

$$\frac{\mathcal{B}(\bar{B}^0 \to D'^+\pi^-)}{\mathcal{B}(\bar{B}^0 \to D^+\pi^-)} = (1.24 \pm 0.21) \times |f_+^{B\to D'}(0)|^2$$

$$\left.\frac{\mathcal{B}(\bar{B}^0 \to D'^+\pi^-)}{\mathcal{B}(\bar{B}^0 \to D^+\pi^-)}\right|_{(m_{D'}/m_D)^{\rm exp}} = (1.65 \pm 0.13) \times \left|f_+^{B\to D'}(0)\right|^2$$

This ratio does not depend so much on $m_{D'}$

Fixing $f_+^{B\to D'}(0) = 0.4$ and taking $(m_{D'}/m_D)^{\rm exp}$ we have also:

$$\frac{\mathcal{B}(\bar{B}^0 \to D'^+\pi^-)}{\mathcal{B}(\bar{B}^0 \to D_2^{*+}\pi^-)} = 1.6(3)$$

$$\frac{\mathcal{B}(B^- \to D'^0\pi^-)}{\mathcal{B}(B^- \to D_2^{*0}\pi^-)} = 1.4(3)$$

Conclusion: if $f_+^{B\to D'}$ is large, as claimed by many authors, the measurement of $\mathcal{B}(B \to D'\pi)$ should be as feasible as $\mathcal{B}(B \to D_2^*\pi)$

Outlook

- Excited meson states are massively produced in experiments. To exploit fruitfully the numerous data at B factories and LHCb, theorists do have to put an important effort in confronting their models predictions with measurements, by proposing to experimentalists unambiguous observables to look at.

- The case of the radially excited D' meson is illuminating: understanding its physics will help to control systematics on V_{cb}.

- We have proposed to check the claim that $\mathcal{B}(B \to D')$ is large in semileptonic decays by analysing non leptonic decays. In particular, we have computed $f_{D'}/f_D$ that enters the Class III factorised amplitude.

- We have shown that the largeness of $\mathcal{B}(B \to D' l\nu)$ implies a good feasibility to measure $\mathcal{B}(B \to D'\pi)$.

- The possibility to extract the $B \to D' l\nu$ form factor directly on the lattice has not been explored yet. A first step is to study the $B^{*'} \to B$ transition in static HQET. [talk by A. Gérardin]

  A pretty similar discussion can be made for the $B \to D_0^*$ decay: it is an on-going project.