Preliminary results on $B \to D,\ D^*,\ D^{**}\ell\nu$ from Twisted mass Lattice QCD

hadronic matrix elements and Form factors

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Workshop Decay $B \to D^{**}$ and related issues
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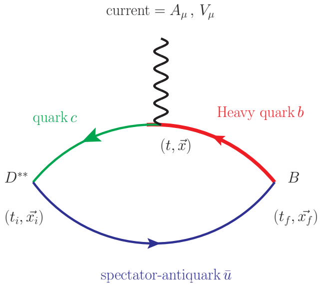
Three point correlation functions

$$C^{(3)} = \sum_{x_i,x,x_f} \langle 0|\mathcal{O}_D(x_i,t_i)\, A_\mu(x,t)\, \mathcal{O}^\dagger_B(x_f,t_f)|0\rangle$$
$$\cdot \quad e^{-i\vec{p}_f(\vec{x}_f-\vec{x})}\; e^{-i\vec{p}_i(\vec{x}-\vec{x}_i)}$$



Method to calculate : *Sequential propagator*

$$\Sigma_{bu}(x,x_i;t_f,t_i,\vec{p}_f) = \sum_{x_f} S^b(x,x_f)\,\underbrace{\gamma_5 S^u(x_f,x_i)}_{\text{sequential source}}\, e^{-i\vec{p}_f(\vec{x}_f-\vec{x}_i)}$$

$$C_{3pts}(t,t_i,t_f,\vec{p_i},\vec{p_f}) = \sum_{x,x_i} \langle Tr[S^c(x,x_i)\,\mathbb{1}\tilde{\Sigma}_{bu}(x_i,x;t_2,\vec{p}_f)\,\gamma_\mu\gamma_5]\rangle$$
$$\cdot \quad e^{i\vec{p}_f(\vec{x}-\vec{x}_i)}\; e^{-i\vec{p}_i(\vec{x}-\vec{x}_i)}$$

Hadronic matrix element

At large time

$$C^{(3)}(t, t_i, t_f, \vec{p}_i, \vec{p}_f) \xrightarrow[t-t_i\to\infty]{t_f-t\to\infty} \frac{\sqrt{Z_D}}{2E_D} \frac{\sqrt{Z_B}}{2E_B} \underbrace{\langle D|A_\mu,\, V_\mu|B\rangle}_{\text{hadronic matrix element}}$$

$$\cdot \qquad \exp^{[-E_B(\vec{p_f})(t_f-t)]} \exp^{[-E_D(\vec{p_i})(t-t_i)]}$$

Ratio :

$$R(t) \quad = \quad \frac{C^{(3)}(t, t_i, t_f, \vec{p}_i, \vec{p}_f)}{C^{(2)}_{(B)}(t_f - t, \vec{p}_f) \cdot C^{(2)}_{(D)}(t - t_i, \vec{p}_i)} \cdot \sqrt{Z_B} \cdot \sqrt{Z_D}$$

$$\xrightarrow[t-t_i\to\infty]{t_f-t\to\infty} \langle D(p_i)|A_\mu,\, V_\mu|B(p_f)\rangle$$

$Z_X = ||\langle 0|O_X|X\rangle||^2$ fitting $C^{(2)}_{(X)}$ in a defined time interval

Simulation setup

Preliminary study to learn how to catch, identify the states and improve the signal

- Lattice geometry $24^3 \times 48$
- Twisted mass Dirac operator with two degenerate flavors

$$Q^{(\chi)} = \gamma_\mu D_\mu + m + i\mu\gamma_5 + \frac{a}{2}\Box \quad , \quad m + 4 = \frac{1}{2\kappa}$$
$$\text{with} \quad \kappa = 0.160856$$

- Tree-level Symanzik improved with $\beta = 3.9$
- Lattice spacing $a \approx 0.0855(5)$ fm, so $L = 24 \times a \approx 2.05$ fm

$a\mu_l$	$a\mu_h$	m_π in MeV	nb. of gauge configurations
0.0085	0.25 0.345 , 0.45 , 0.667	448(1)	100

Simulation setup

Twisted boundary conditions : why?

Increase kinematical regions accessible for the investigation of form factors

How?

- $\mathbf{p} = \frac{2\pi}{L}\theta \qquad \theta = (\theta_x, \theta_y, \theta_z)$ for B meson

  $\theta_x = \theta_y = \theta_z \in \{0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 1.0, 1.4, 1.8\}$
- Charmed D meson at rest

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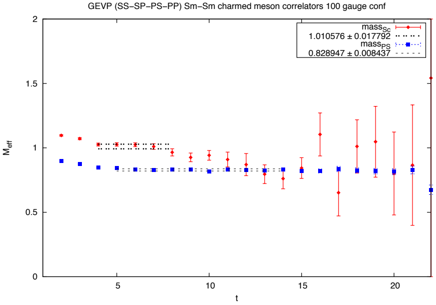
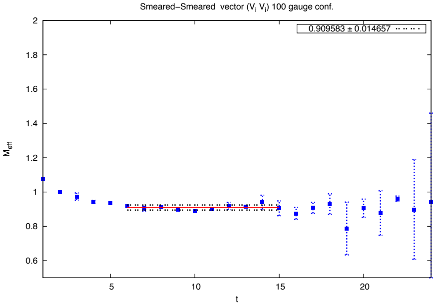
Smearing techniques : APE and Gaussian

- Decrease the impact of ultraviolet fluctuations
- Get rid of excited states contamination

$$N_{Gauss} = 30 \ \kappa = 0.15 \ N_{APE} = 10 \ \alpha_{APE} = 0.5$$

Spectroscopy of D *meson* $J = 0^{+,-},\ 1^-$



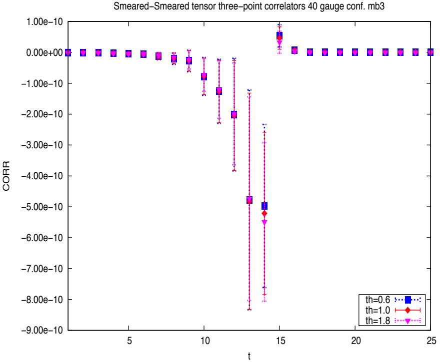


$$\Delta(M_D(1^-, 0^+, 2^+) - M_D(0^-))_{Lattice} - \Delta(M)_{Exper.} \approx 30\%$$

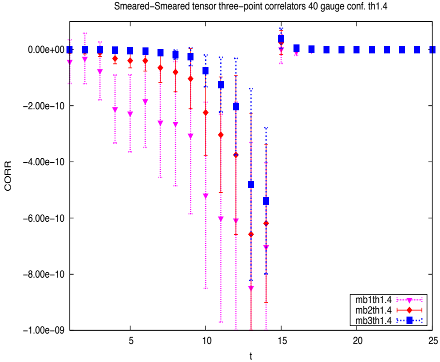
Extrapolated difference $\simeq 10\%$

D. Becirevic and F. Sanfilippo (2012)

$C_{3pts}(D^{**}(2^+))$ contributing to $\tilde{k} = \frac{1}{p}[\mathscr{T}_1^A(-2) + \mathscr{T}_1^A(+2)]$



$C_{3pts}(\theta)$

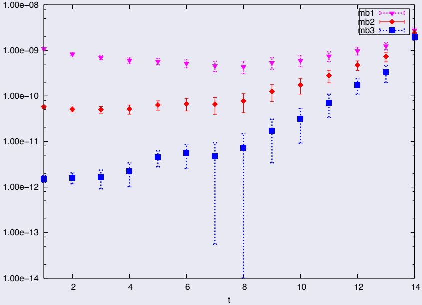


$C_{3pts}(m_b)$

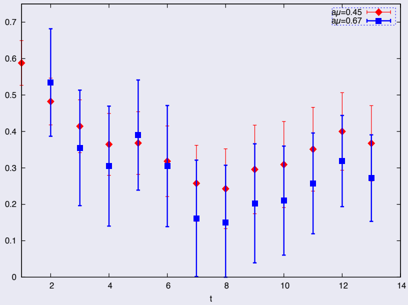
- No signal at small $\theta \in \{0.1,\ 0.2,\ 0.3,\ 0.5\}$
- Large $\theta_L \in \{0.6,\ 1.0,\ 1.4,\ 1.8\}$ (40 gauge configurations)
  (signal/error)$(\theta_L) = (4\%,\ 8.25\%,\ 14.25\%, 23.1\%)$ (signal/error)$(\theta = 0)$
- Best signal for $a\mu_b = 0.667$ but no easy way to estimate the form factor

$< D(0^+)|A_0|B >$ ***at zero recoil*** $\vec{p}_B = \vec{0}$

3-point correlators



$< D(0^+)|A_0|B >$

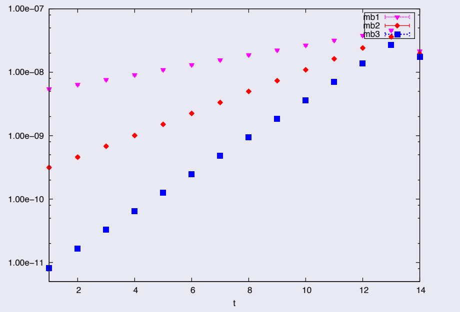


$$< D(0^+)|A_0|B > \neq 0$$

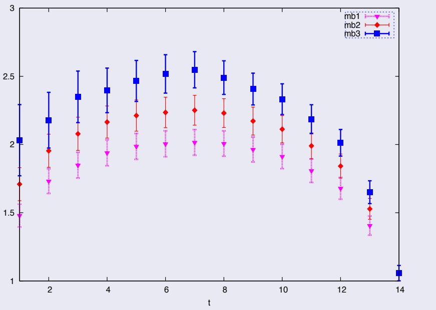
Difference with respect to what was found in the infinite mass limit

$< D(0^-)|V_0|B >$ *at zero recoil*

3-point correlators



$< D(0^-)|V_0|B >$

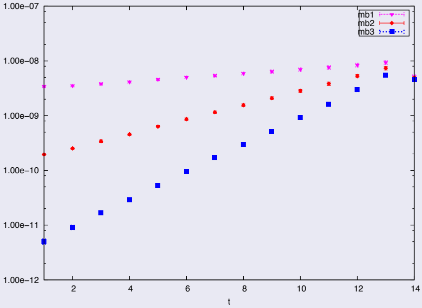


Good plateau t [4-5 :9-10]

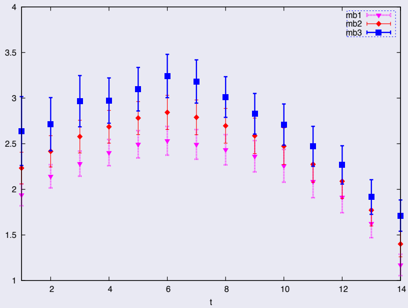
$$\frac{< D(0^+)|A_0|B >}{< D(0^-)|V_0|B >} = \begin{cases} 0.14 \pm 0.06 & a\mu = 0.67 \\ 0.12 \pm 0.04 & a\mu = 0.45 \end{cases}$$

$B \to D^* l\nu$ at zero recoil

3-point correlators



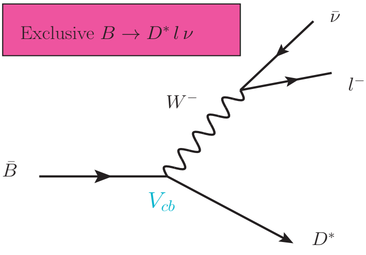
$< D^*|A_i|B >$



Form factor $\mathcal{F}_0(1)$

$$\frac{\langle D^*(M_{D^*},\vec{0})\,|\,A_\mu\,|\,B(M_B,\vec{0})\rangle}{2\sqrt{M_B \cdot M_D^*}} \cdot Z_A \qquad Z_A = 0.730(03)$$

Form Factor $\mathcal{F}_0(1)$ of $B \to D^* l\nu$



$a\mu_b$	$\mathcal{F}_0(1)$	
0.35	0.94	± 0.06
0.45	0.95	± 0.06
0.67	0.96	± 0.07

- Limited precision due to cutoff and finite size effects
- More work to reach the needed precision and extrapolate to the continuum limit

Perspective

- Form factors $B \to D^{**}$
- Runs of hundred measurements
- Different finite charm quark masses and lattice spacings
- Extrapolate to continuum limit

Smearing techniques

* **Jacobi smearing** of light quark operators

$$\psi^S(\vec{x},t) = \sum_{\vec{y}} F(\vec{x},\vec{y})\psi(\vec{y},t)$$

The Jacobi smearing function is computed using a recursive procedure

$$F^{(n)}(\vec{x},\vec{y}) = \frac{1}{1+6\kappa_s}(\delta_{\vec{x}\vec{y}} + \kappa_s \Delta_s)F^{(n-1)}(\vec{x},\vec{y})$$

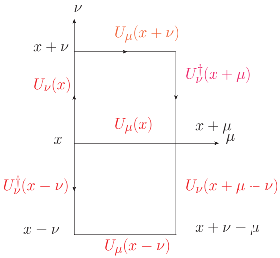
κ_s is the smearing parameter

smearing techniques

Smearing techniques

- **APE smearing**

  Smearing of gauge links present in the gaussian smearing function



APE smearing

$$U_\mu^{(n+1)}(x) = U_\mu^{(n)}(x) + \alpha_{APE} \sum_{\nu\neq\mu} U_\nu^{(n)}(x) U_\mu^{(n)}(x+\nu) U_\nu^{(n)\dagger}(x+\mu)$$