Semileptonic B Decays into Orbitally Excited D Mesons

Rebecca Klein

in collaboration with
Thomas Mannel, Farnoush Shahriaran

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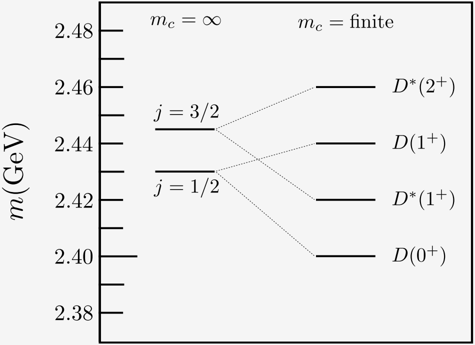
Motivation

- extract V_{cb} from comparison of predictions with measurements
  - inclusive decay: $B \to X_c \ell\nu$ (see talk by D. Rosenthal)
  - exclusive decays: $B \to \{D, D^*, D^{**}\} \ell\nu \Rightarrow$ this talk
- measurements of $B \to D^{**}\ell\nu$
  - increase confidence in V_{cb} extracted from exclusive decays
  - D^{**} emerge as resonances in the spectrum of $B \to D^{(*)}\pi\ell\nu$
  - only $\mathcal{B}[B \to D^{**}\ell\nu] \times \mathcal{B}[D^{**} \to D^{(*)}\pi]$ can be extracted from data
- need precise predictions for
  - semileptonic decays $B \to D^{**}\ell\nu \Rightarrow$ this talk
  - strong decays $D^{**} \to D^{(*)}\pi \Rightarrow$ later project?

Spectroscopy of Orbitally Excited D Mesons

- D^{**} arranged in two doublets of $j = 1/2$ and $j = 3/2$
  - j: total angular momentum of light degrees of freedom
  - $D^{**} = \{D_{j=1/2}, D_{j=3/2}\} = \{D(0^+), D(1^+), D^*(1^+), D^*(2^+)\}$



- theory prediction: only two different masses in the heavy mass limit $m_c \to \infty$, for finite mass m_c they split up into four masses
- $D(1^+), D^*(1^+)$ have the same angular momentum
  - study mixing effects

Mixing of $D(1^+)$ and $D^*(1^+)$

- transition between $D(1^+)$ and $D^*(1^+)$ requires flip of heavy quark spin
- consider HQET Hamilton density up to $1/m_c$

  $$\mathcal{H}_{1/m_c} = \bar{h}_c(v \cdot iD)h_c + \frac{1}{2m_c}\bar{h}_c(iD_\perp)^2 h_c + \frac{g_s}{2m_c}\bar{h}_c(\vec{\sigma} \cdot \vec{B})h_c$$

  - spin flip only induced by chromomagnetic operator
  - generates off-diagonal entries in the Hamilton operator such as $\langle D(1^+)|\mathcal{H}_{1/m}|D^*(1^+)\rangle$
  - diagonalize Hamilton operator using orthogonal transformation parameterized through mixing angle θ
- mass eigenstates heavy/light

  $$|D_H(1^+)\rangle = +\cos\theta\,|D(1^+)\rangle + \sin\theta\,|D^*(1^+)\rangle$$
  $$|D_L(1^+)\rangle = -\sin\theta\,|D(1^+)\rangle + \cos\theta\,|D^*(1^+)\rangle$$

Extracting the Mixing Angle

$$\mathcal{H}_{1/m_c} = \bar{h}_c(v \cdot iD)h_c + \frac{1}{2m_c}\bar{h}_c(iD_\perp)^2 h_c + \frac{g_s}{2m_c}\bar{h}_c(\vec{\sigma} \cdot \vec{B})h_c$$

- Hamilton operator in the $D(1^+)$, $D^*(1^+)$ basis

  $$\mathbf{H} = \begin{pmatrix} M & a \\ a & M + \Delta \end{pmatrix}$$

  - different gyromagnetic factors for contribution of angular momentum $\vec{J}$ and the quark spin $\vec{s}$ of the light degrees of freedom

    $\vec{B} \sim \alpha \vec{J} + \beta \vec{s}$
  - $a \mathrel{\widehat{=}} \langle D(1^+)| g(\vec{\sigma} \cdot \vec{J}) + g'(\vec{\sigma} \cdot \vec{s}) | D^*(1^+) \rangle = \frac{\sqrt{2}}{3} g'$
- assuming equal mass splitting:
  - $g = -g' \approx 25\,\text{MeV}$
  - prelimenary result: $\theta \approx 29^\circ$

$B \to D^{**}$ Form Factors

- now consider form factors for $B \to D(1^+)$ and $B \to D^*(1^+)$
- take the limit $m_c \to \infty$ und $m_b \to \infty$ and $m_c/m_b = \text{const.}$
  - matrix elements $\langle B(v)|\bar{c}\Gamma b|D(1^+)\rangle$ and $\langle B(v)|\bar{c}\Gamma b|D^*(1^+)\rangle$ can be described by only one function τ_j respectively for $j = 1/2$ oder $j = 3/2$

$$\begin{aligned} \langle B(v)|\bar{c}\Gamma b|D(1^+)(v')\rangle &\sim \tau_{1/2}(\omega) \\ \langle B(v)|\bar{c}\Gamma b|D^*(1^+)(v')\rangle &\sim \tau_{3/2}(\omega) \end{aligned} \qquad \text{where } \omega = v \cdot v'$$

  - since experiments can only distinguish mass eigenstates we need to consider mixing effects

$$\left.\begin{aligned} &\langle B(v)|\bar{c}\Gamma b|D_H(v')\rangle \\ &\langle B(v)|\bar{c}\Gamma b|D_L(v')\rangle \end{aligned}\right. \sim \tau_{1/2}(\omega),\, \tau_{3/2}(\omega),\, \theta$$

Prelimenary Results

- Our predictions

Channel	GI	VD	CCCN	ISGW
$\frac{\mathcal{B}(B^- \to D(1^+)\ell\bar{\nu})}{\mathcal{B}(B^- \to D^*(1^+)\ell\bar{\nu})}$	6.6	11.3	77.6	3.1
$\frac{\mathcal{B}(B^- \to D_H\ell\bar{\nu})}{\mathcal{B}(B^- \to D_L\ell\bar{\nu})}$	1.5	1.8	2.7	1.1

[Godfrey, Isgur, 1985]
[Veseli, Dunietz, 1996]
[Cea, Colangelo, Cosmai, Nardulli, 1988]
[Isgur, Scora, Grinstein, Wise, 1998]

- Experimental results

$$\frac{\mathcal{B}(B^- \to D(1^+)\ell\bar{\nu}) \times \mathcal{B}(D(1^+) \to D^*\pi)}{\mathcal{B}(B^- \to D^*(1^+)\ell\bar{\nu}) \times \mathcal{B}(D^*(1^+) \to D^*\pi)} \approx 2.2$$

[HFAG]

Summary and Outlook

- considered mixing effects in D^{**} system
  - mass eigenstates D_H and D_L
  - mixing angle of $\theta \approx 29^\circ$ (prelimenary)
- applied mixing effects to semileptonic decays
  - new results for $\mathcal{B}(B^- \to D_{H/L}\ell\bar{\nu})$
- outlook: application to strong decays $D^{**} \to D^{(*)}\pi$
  - how does the mixing affect these decays?
  - new results for $\mathcal{B}(B^- \to D_{H/L}\ell\bar{\nu}) \times \mathcal{B}(D_{H/L} \to D^*\pi)$?