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Citation for published version:
Shigemitsu, J, T. H. Davies, C, Dougall, A, Foley, K, Gamiz, E, Gray, A, Gulez, E, P, Lepage, G & Wingate, M 2004, 'Semileptonic B Decays with Nf=2+1 Dynamical Quarks' Nuclear Physics B - Proceedings Supplements, vol 140, pp. 464–466. DOI: 10.1016/j.nuclphysbps.2004.11.123

Digital Object Identifier (DOI):
10.1016/j.nuclphysbps.2004.11.123

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Early version, also known as pre-print

Published In:
Nuclear Physics B - Proceedings Supplements

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Semileptonic $B$ Decays with $N_f = 2 + 1$ Dynamical Quarks

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Semileptonic, $B \to \pi \ell^-$, decays are studied on the MILC dynamical configurations using NRQCD heavy and Asqtad light quarks. We work with light valence quark masses ranging between $m_s$ and $m_s/8$. Preliminary simple linear chiral extrapolations have been carried out for form factors $f_1$ and $f_2$ at fixed $E_\gamma$. The chirally extrapolated results for the form factors $f_+(q^2)$ and $f_0(q^2)$ are then fit to the Becirevic-Kaidalov (BK) ansatz. Preliminary estimates of the CKM matrix element $|V_{ub}|$ are presented based on recently published branching fractions for $B^0 \to \pi^- l^+ \nu$ exclusive decays by the CLEO collaboration.

1. Introduction

First principles calculations of $B$ meson semileptonic decay form factors are crucial for determining the CKM matrix elements $|V_{ub}|$ and $|V_{cb}|$. Recent progress on the lattice towards this goal comes from two major developments: the ability to go beyond the quenched approximation with close to realistic dynamical quark content [1,2] and the use of improved staggered light quarks in heavy-light simulations [3]. We report here on unquenched studies of $B \to \pi$, $\pi$ decays on the lattice using one of the coarse MILC $N_f = 2 + 1$ dynamical sets [1], NRQCD $b$ quarks and improved staggered (Asqtad) light quarks. The light dynamical quark mass is fixed at $m_{dyn} = m_s/4$ and we vary the light valence quark mass between $m_s$ and $m_s/8$.

2. Form Factors

Semileptonic form factors parameterise the hadronic matrix elements of electroweak currents between a $B$ meson and a $\pi$ or a $\rho$. In particular, one has

$$
\langle \pi | V^{\mu} | B \rangle = f_+(q^2) \left[ p_\mu^B + p_\mu^\pi - \frac{M_B^2 - m_\pi^2}{q^2} q^\mu \right] + f_0(q^2) \frac{M_B^2 - m_\pi^2}{q^2} q^\mu
$$

(1)

with $q^\mu = \not{p}_B^\mu$, $p_\perp^B = p_\perp^B - (p_\pi \cdot v) v^\mu$, $q^\mu = p_\perp^B - p_\perp^\pi$.

A lattice calculation of the relevant matrix element starts with the three-point correlator

$$
C^{(3)}(\bar{p}_\pi, \bar{p}_B, t, T_B) = \sum_{\vec{x}} \sum_{\vec{y}} \left\langle \Phi_\pi(0) V^{\mu}_{\text{lat}}(\vec{z}, t) \Phi_B^\dag(\vec{y}, T_B) \right\rangle \times e^{i\vec{p}_B \cdot \vec{y}} e^{i(\vec{p}_\pi - \vec{p}_B) \cdot \vec{x}}
$$

(3)

where $\Phi_\pi$ and $\Phi_B$ are interpolating operators for the $\pi$ and $B$ mesons respectively. The three-point correlator is fit to the form

$$
C^{(3)}(\bar{p}_\pi, \bar{p}_B, t, T_B) \to \sum_{k=0}^{N_f-1} \sum_{j=0}^{N_f-1} (-1)^{k_\pi(t-1)} (-1)^j(T_B-t) \times A_{j,k} e^{-E^{(k)}_{\pi}(T_B-t)} e^{-E^{(j)}_{B}(T_B-t)}
$$

(4)
3. The Form Factors $f_+(q^2)$ and $f_0(q^2)$ at the Physical Pion

Although our simulations have been carried out with light quark masses as low as $m_s/8$ one still needs to extrapolate the form factors, determined above, to the physical pion. To date, we have only carried out simple linear chiral extrapolations. We first interpolate $f_{\parallel}$ and $f_{\perp}$ to common values of $E_\pi$, the pion energy in the $B$ rest frame. These are then extrapolated linearly to the physical pion for several fixed values of $E_\pi$.

From the chirally extrapolated $f_{\parallel}$ and $f_{\perp}$ one obtains the form factors $f_+(q^2)$ and $f_0(q^2)$ at the physical pion. This is shown as the circles in Fig.1. Our results are currently limited to the $q^2 \geq 15$ GeV$^2$ region. Recently, a very promising approach to low $q^2$ form factors has been developed, namely “Moving NRQCD”, which will allow us to overcome this limitation [5,6]. In the mean time, however, we will rely on a model ansatz to extend our form factor results into the low $q^2$ regime. Specifically, we employ an ansatz introduced by Becirevic & Kaidalov (BK) [7],

\[ f_+(q^2) = \frac{C_B (1 - \alpha_B)}{(1 - \tilde{q}^2)(1 - \alpha_B \tilde{q}^2)} \]  

\[ f_0(q^2) = \frac{C_B (1 - \alpha_B)}{(1 - \tilde{q}^2/\beta_B)} \]

(\tilde{q}^2 \equiv q^2/M_B^2). This ansatz satisfies the kinematic constraint $f_+(0) = f_0(0)$, HQET scaling laws and the requirement of a pole in $f_+(q^2)$ at $q^2 = M_B^2$. We find an excellent fit to this BK ansatz using the physical $M_B$ mass and this is shown as the full curves in Fig.1 (a satisfactory BK parametrization was not possible before the chiral extrapolation). The fit parameters are $C_B = 0.42(3)$, $\alpha_B = 0.41(7)$, $\beta_B = 1.18(5)$, which translates into

\[ f_0(0) = f_+(0) = 0.251(15) \]

and an effective pole in $f_0(q^2)$ at $q^2 = (M_{f_0}^{pole})^2 = 33.35(1.36)$ GeV$^2$. Both $f_{0,+}(0)$ and $M_{f_0}^{pole}$ are in good agreement with a recent semileptonic $B$ decay analysis based on Sum Rules [8]. The data
points in Fig.1 and the $f_{0,+}(0)$ quoted above include only statistical and fitting errors. Further systematic errors are discussed in the next section. A comparison of our new dynamical form factor results with old quenched data is given, for instance, in reference [9].

4. Estimating $|V_{ub}|$

The CLEO collaboration has published branching fractions for exclusive semileptonic $B$ decays, including binning into several $q^2$ ranges [10]. We combine these experimental inputs with lattice results for $f_+(q^2)$ to extract values for the CKM matrix element $|V_{ub}|$. The differential decay rate for $B^0 \to \pi^-, l^+\nu$,

$$\frac{1}{|V_{ub}|^2} \frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3} p^3 |f_+(q^2)|^2$$

(9)

can be integrated to give $\frac{F}{|V_{ub}|}$ and the partial width $\Gamma$ can be determined from CLEO’s branching fraction and the Particle Data Group’s $B^0$ lifetime of $1.542 \pm 0.016$ ps. Our preliminary estimate for $|V_{ub}|$ is then

$$|V_{ub}| = \begin{cases} 3.86(32)(58) \times 10^{-3} & 0 \leq q^2 \leq q_{max}^2 \\ 3.52(73)(44) \times 10^{-3} & 16 \text{GeV}^2 \leq q^2 \end{cases}$$

where the two values correspond to either using the entire allowed $q^2$ range or restricting both experiment and theory to the $q^2 \geq 16 \text{GeV}^2$ region. The first error is experimental and the second is our current best estimate of lattice statistical and systematic errors added in quadrature. In addition to $4 \sim 6\%$ statistical errors, we estimate $\sim 9\%$ higher order perturbative matching, $\sim 5\%$ chiral extrapolation, $\sim 5\%$ relativistic and discretization errors. This adds up to $\sim 12.5\%$ lattice errors for $|V_{ub}|$ obtained from the $q^2 \geq 16 \text{GeV}^2$ region. For $|V_{ub}|$ based on the full $q^2$ range we increase the lattice errors to $15\%$ (an additional $8\%$ added in quadrature) taking into account the need to rely on the BK parametrization to enter the low $q^2$ region.

5. Summary

Unquenched simulations of heavy meson semileptonic decays are now feasible and we report here on the first such calculations using NRQCD heavy and Asqtad light quarks (see talk by Okamoto for results using Fermilab heavy quarks [11]). The use of the improved staggered light quark action has allowed for significantly smaller statistical and chiral extrapolation errors than in the past. Combining lattice results for $f_+(q^2)$ with experimental branching fraction data has led to preliminary estimates of $|V_{ub}|$.

Many improvements are planned: inclusion of all dimension 4 $(1/M, \alpha_s/M$ and $\alpha_s\alpha$) current corrections, more sophisticated chiral extrapolations [12], and simulations at other dynamical quark masses and lattice spacings. Use of “Moving NRQCD” [5] will also allow us to simulate directly at lower $q^2$.

Acknowledgements : This work was supported by the DOE, PPARC and NSF. Simulations were carried out at NERSC.

REFERENCES

1. C.W.Bernard et al. (MILC); Phys.Rev. D64, 054506 (2001).
2. C.T.H.Davies et al. (MILC,HPQCD,UKQCD); Phys.Rev.Lett. 92, 022001 (2004).
3. M. Wingate et al.; Phys. Rev. D67, 054505 (2003).
4. E.Gulez; these proceedings; E.Gulez et al.; Phys.Rev. D69, 074501 (2004).
5. K.Foley; these proceedings
6. J.Sloan; Nucl.Phys. Proc. Suppl.119, 635 (2003).
7. D.Becirevic and A.B.Kaidalov; Phys. Lett. B478, 417 (2000).
8. P.Ball and R.Zwicky; hep-ph/0406232.
9. A.Gray; hep-ph/0407229.
10. S.B.Athar et al. (CLEO); Phys.Rev. D68, 072003 (2003), [hep-ex/0304019].
11. M.Okamoto; these proceedings
12. C.Aubin and C.Bernard; these proceedings and private communication.