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A lattice study of Λ_b semileptonic decay

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We present results from a lattice study of the semileptonic decay $\Lambda_b \to \Lambda_c l \nu_l$. We use $O(a^2, \alpha_s a^2)$ improved quenched lattices of the MILC collaboration, with lattice spacing ~ 0.13 fm. For the valence quarks, the tadpole-improved clover action is used, with the Fermilab method employed for the heavy quarks. Form factors are extracted from the vector as well as the axial-vector part of the current.

1. INTRODUCTION

Current knowledge of the CKM matrix element V_{cb} is derived from the mesonic decays $B \to \bar{D}^* l\nu$ or $B \to \bar{D} l\nu$. Experimental knowledge of the Λ_b semileptonic decay can lead to an independent estimate of V_{cb} if the effect of the strong interaction in the decay are understood, *e.g.*, via lattice QCD. A first lattice study of the baryonic semileptonic decay was performed by the UKQCD collaboration [1]. We report our initial results for the dominant form factors of this decay.

The semileptonic decay $\Lambda_Q \to \Lambda_{Q'} l\nu$ can be parametrized in terms of six form factors, F_i and G_i, for i = 1, 2, 3.

$$\begin{aligned}\langle \Lambda_Q^{(s)}(v)|\mathcal{J}_\mu|\Lambda_{Q'}^{(r)}(v')\rangle = \bar{u}_Q^{(s)}(v)[\gamma_\mu(F_1 - \gamma_5 G_1) \\ + \quad v_\mu(F_2 - \gamma_5 G_2) \\ + \quad v'_\mu(F_3 - \gamma_5 G_3)]u_{Q'}^{(r)}(v'). \qquad (1)\end{aligned}$$

Here $\mathcal{J}_\mu$ is the weak current and r, s are polarisation states of the baryons. Since both Λ_b and Λ_c are hadrons containing a single heavy quark, heavy quark effective theory (HQET) is applicable [3]. Hence the matrix element is taken between baryons of a given velocity, and the form factors are functions of the scalar $\omega = v \cdot v'$. To leading order in HQET, the combinations $F_1 + v_0 F_2 + v'_0 F_3$ and G_1 involving the dominant form factors F_1 and G_1 can be written in terms of a single function, called the (baryonic) Isgur-Wise function, $\xi(\omega)$. This function is normalised at zero-recoil, $\xi(1) = 1$.

*Presented by S. Tamhankar

2. SIMULATION PARAMETERS

The simulations are performed on the Asqtad quenched lattices at $\beta = 8.00$ generated by the MILC collaboration [2]. These are $\mathcal{O}(\alpha_s a^2)$ improved $20^3 \times 64$ lattices, with $a^{-1} = 1.33$ GeV, as determined from m_ρ. We use three light quark masses near the strange quark mass, $\kappa_l = 0.1343, 0.1333, 0.1323$. Two heavy quark κ values, 0.104 and 0.114 bracket the charm quark, and other two, 0.064 and 0.077 bracket the bottom. We use the clover action for the valence quarks, with a tadpole improved clover coefficient. The value for the tadpole improvement factor u_0 is taken from the Landau gauge fixed mean link. Fermilab formalism is used for the heavy quarks. Results are presented for 300 lattices for two-point functions, and 237 lattices for three-point functions.

3. TWO-POINT RESULTS

The dispersion relation is shown in Fig. 1. The fitted energy values agree very well with the expectation from the lattice dispersion relation. The chiral extrapolations for a fixed heavy quark mass are shown in Fig. 2. The baryon kinetic mass M_2 is estimated as $M_2 = M_1 + m_2 - m_1$, Where $M_{2(1)}$ and $m_{2(1)}$ are the baryon and heavy quark kinetic(rest) masses respectively. We use

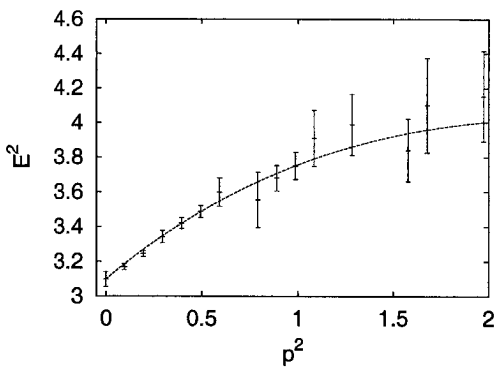

Figure 1. Dispersion relation for κ_h=0.114, κ_l = 0.1323/0.1323. The E here is E_1, the parameter obtained from exponential fits. The line shows the lattice dispersion relation.

a linear fit for these extrapolations. In Fig. 3, we have shown the chirally extrapolated baryon mass as a function of the heavy quark mass, along with the coresponding meson masses taken from the MILC collaboration. Our values for m_{Λ_b} and m_{Λ_c} are 5.626(36)GeV and 2.300(27)GeV.

4. THREE-POINT RESULTS

Different form factors contribute to different matrix elements in the three-point function. For $\mu = 0$, the dominant contribution to three-point functions comes from the vector form factors and for $\mu = i$, axial-vector form factor G_1 gives the dominant contribution. We present results for the Isgur-Wise function from vector as well as axial-vector data. Λ_b is created at time 0 and Λ_c is annihilated at time $t_x \equiv 16$ in lattice units. The time at which the current acts is varied, and we study three-point function as a function of this time $t_y \equiv t$. For the results presented here, the intial baryon is at rest and the final baryon is moving with different velocities giving different values for ω. On the lattice, one is restricted to region near $\omega = 1$ as data starts getting noisy for high momenta. In this region, v_0' can be approximated by 1. Then for an initial baryon of mass M' decaying to a final baryon of mass M moving with a momentum $\vec{q}$, if we consider the sum of the co-efficients of I and γ_0, for large t_y and $t_x - t_y$, the three-point expression simplifies to

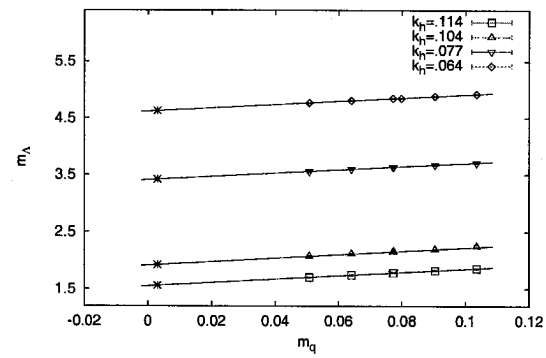

Figure 2. Chiral extrapolations of the measured heavy baryon masses to the u quark. We have used the light quark kinetic mass m_2 for the fit.

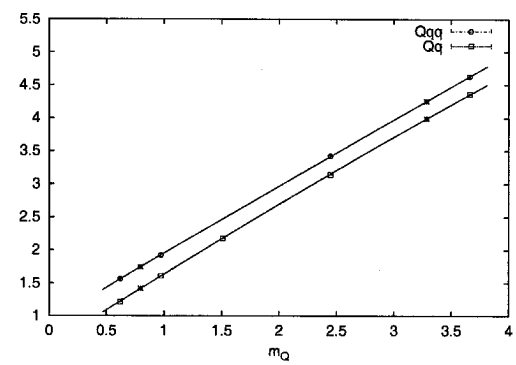

Figure 3. The heavy baryon mass, plotted as function of the heavy quark mass. Also shown are the heavy-light meson masses, taken from studies of the MILC collaboration. The bursts correspond to the b and c quark.

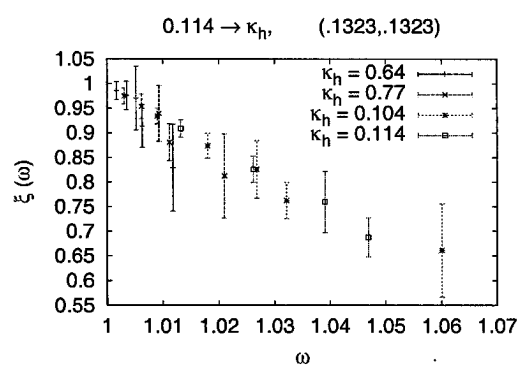

Figure 4. Isgur-Wise function from the vector current. κ_{h1} is 0.114 for all these points, and the points corresponding to four different κ_h are shown with four different symbols.

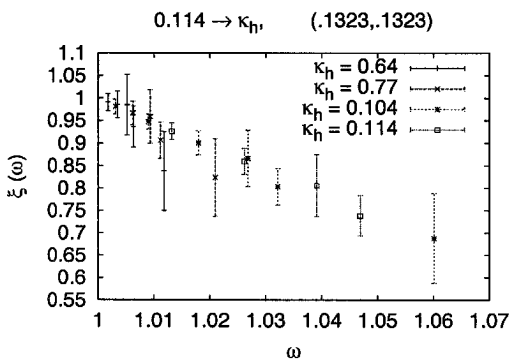

Figure 5. Isgur-Wise function from the axial-vector current. As before, κ_{h1} is 0.114 for all these points, and the points corresponding to four different κ_h are shown with four different symbols.

$$C(t_y)= \frac{Z_l Z_s'(|\vec{q}|)}{16M'E} e^{-t_x M'} e^{(M'-E)t_y} 4M' (F_1(\omega)+F_2(\omega)+F_3(\omega))2(E+M), \qquad (2)$$

where Z_l and Z_s' are known from the two-point functions. We fit this to a form Ae^{-Bt} and consider the ratio

$$\frac{A[(M',\vec{0}) \to (M,\vec{q})]}{A[(M',\vec{0}) \to (M,\vec{0})]} = \left(\frac{F_1(\omega)+F_2(\omega)+F_3(\omega)}{F_1(1)+F_2(1)+F_3(1)}\right) \cdot \left(\frac{Z_s'(|\vec{q}|)}{Z_s'(0)}\right) \cdot \left(\frac{E+M}{2E}\right). \qquad (3)$$

First factor on the RHS is[2] the Isgur-Wise function $\hat{\xi}_{QQ'}$. The second and third factors are known from the two-point functions. The third factor may be approximated by 1 to 0.5 per cent accuracy. The second factor differs from 1 by upto 10% over our range of $\vec{q}$. The ratio is independent of the renormalization constant Z_V because we have the same heavy quark transition in both numerator and denominator.

Our results for the Isgur-Wise function from the vector current are shown in Fig. 4. The Isgur-Wise function obtainted from the axial-vector current ($\mu = i$ case) is shown in Fig. 5. The

[2]We follow Ref. [1] in using this definition. This way of defining the Isgur-Wise function agrees with the conventional definition up to $\mathcal{O}(1/m)$ corrections, which are further multiplied by (1-ω). For the small momenta accessible on the lattice, $\hat{\xi}$ is a very good approximation to the baryonic Isgur-Wise function. The suffix QQ' emphasizes that the infinite mass limit has not been taken.

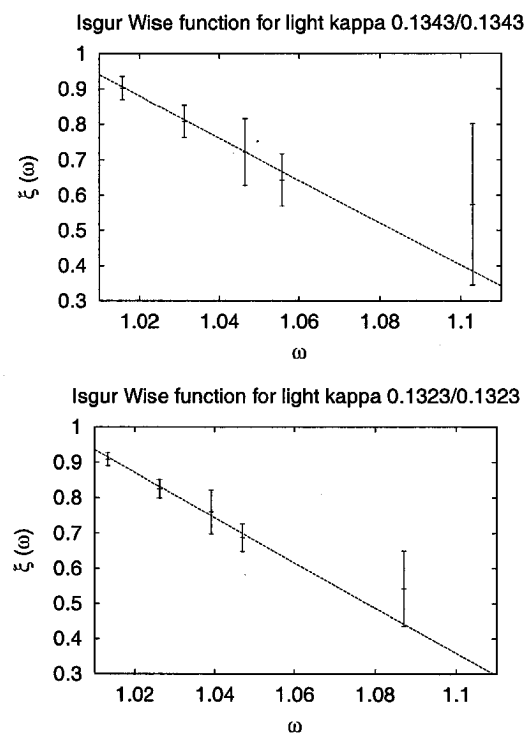

Figure 6. Isgur-Wise function for $\kappa_l = 0.1343/0.1343$, and $\kappa_l = 0.1323/0.1323$, our highest and lowest values for κ_l.

Isgur-Wise function seems to be quite insensitive to the heavy quark mass.

We have also studied the light quark mass dependence of the Isgur-Wise function. The Isgur-Wise function is expected to fall slower for smaller light quark masses, by a heuristic argument. We do see such a trend in this preliminary study, but it is very far from clear with the statistical errors we have. This is shown in Fig. 6.

The calculations were done on the IBM SP at Indiana University. We gratefully acknowledge the hospitality of the Fermilab Theory Group.

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