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B and D semileptonic decays to light mesons

FERMILAB-CONF-99/241-T

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We present an update of our calculation of the form factors and partial widths of semileptonic heavy-to-light meson decays, in the quenched approximation. Our complete data set has now been analysed and our results include chiral extrapolations and a study of the lattice spacing dependence.

1. Introduction

We report on the progress made in our study of B and D meson semileptonic decays. A description of the analysis and some more preliminary results are in Refs. [1,2]. The CKM matrix element $|V_{ub}|$ plays an important rôle in over-constraining the unitarity triangle but is only determined to $\sim 20\%$. The advent of B -factories will reduce the experimental error in exclusive decays considerably, which must be matched by more precise theoretical determinations of the nonperturbative contribution. With the increase in data, experiments will be able to study the q^2 distribution in B and D semileptonic decays, as shown by the CLEO collaboration, which recently presented a new analysis of $B \rightarrow \rho l \nu$ [3]. Thus, lattice and experimental data could be combined in a range of q^2 's where both are reliable, making the model-dependent extrapolation to $q^2 = 0$, traditionally done in lattice analyses, redundant.

A summary of our work is as follows. We have results at three lattice spacings ($\beta = 5.7, 5.9$ and 6.1) with heavy quarks at the b and c quark masses and a light quark (daughter and spectator) at the strange quark mass. This allows us to study the lattice spacing dependence of the matrix elements, $\langle s \bar{s}(p) | V_\mu | B_s(0), D_s(0) \rangle$ and experience leads us to believe the a -dependence does not change after chiral extrapolation, see Ref. [4]. We have additional light quarks at $\beta = 5.9$ and 5.7 allowing chiral extrapolations on these lattices. The quark fields are rotated but the per-

turbative matching coefficients we use are those of light quarks; the full mass-dependent calculation is underway. The final results are at $\beta = 5.9$, after chiral extrapolation.

The matrix elements are extracted from three-point correlation functions in which the heavy meson is at rest and the light meson has momentum of $(0,0,0)$, $(1,0,0)$, $(1,1,0)$, $(1,1,1)$ and $(2,0,0)$, in units of $2\pi/aL$. In an approach different to other groups [5–7] we study the a -dependence and perform the chiral extrapolations in terms of the matrix elements and not the form factors.

For B and D decays the form factors are determined from matrix elements in the usual way,

$$\begin{aligned} \langle \pi(p) | V_\mu | B(p') \rangle &= f^+(q^2) \left[p' + p - \frac{m_B^2 - m_\pi^2}{q^2} q \right]^\mu \\ &+ f^0(q^2) \frac{m_B^2 - m_\pi^2}{q^2} q^\mu \end{aligned} \quad (1)$$

and thence we determine the partial widths

$$\frac{d\Gamma}{d|\vec{p}_\pi|} = \frac{2m_{B,D} G_F^2 |V_{ub}|^2 |\vec{p}_\pi|^4}{24\pi^3 E_\pi} |f^+(q^2)|^2. \quad (2)$$

2. $B \rightarrow \pi l \nu$

We interpolate the spatial and temporal matrix elements, extracted from fits to the three-point functions, to fixed physical momenta in the range $\{0.1, \dots, 1.0\}$ GeV as shown in Figure 1. A significant systematic error is evident in the interpolation of the matrix elements. The temporal component, V_4 , is defined at zero momentum so all physical momenta are obtained by interpolation. In contrast, the spatial matrix element is not ...

*talk presented by S. Ryan.

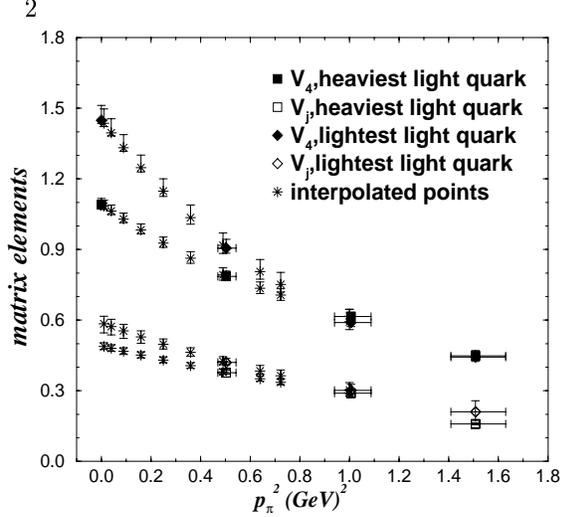


Figure 1. Comparing matrix elements at $\beta = 5.9$, with the heavy quark at the b mass.

the first point is $p_{lat}(1, 0, 0) \approx 0.7$ GeV. All momenta below this are obtained by extrapolation (see Fig. 1). Thus for lighter quarks the temporal component captures the effect of the nearby B^* pole at $p = 0$ and rises rapidly, whereas the spatial component misses this effect. Now one has a choice: introduce a model, eg. pole dominance, to reproduce the behaviour of the matrix elements in the vicinity of the B^* pole or impose a cut in momentum, below which the extrapolation of the spatial matrix element is considered unreliable. We wish to avoid any model dependence so we make a cut in momenta at $p = 0.4$ GeV.

At $\beta = 5.7$ and 5.9 the matrix elements are extrapolated to the chiral limit. The data at $\beta = 5.9$ are discussed here (the findings are similar at $\beta = 5.7$). Three functional forms were compared in the chiral extrapolations: linear, quadratic and including a term $\propto \sqrt{m_q}$. For $0.4 \leq p \leq 0.8$ GeV the best fit to the data was the quadratic form. At $p > 0.8$ GeV all three functions resulted in unreliable fits, with bad $\chi^2/d.o.f.$, due to large cutoff effects and an increasingly noisier signal. Therefore the range of momenta we consider is $0.4 \leq p \leq 0.8$ GeV. The error due to extrapolation is estimated by considering the spread in results from the three possible fit forms, in this range. Figure 2 shows the a -dependence of our results (with strange light quarks) is very mild. The matrix elements show a similarly mild a -dependence [1]. The scale to determine the phys-

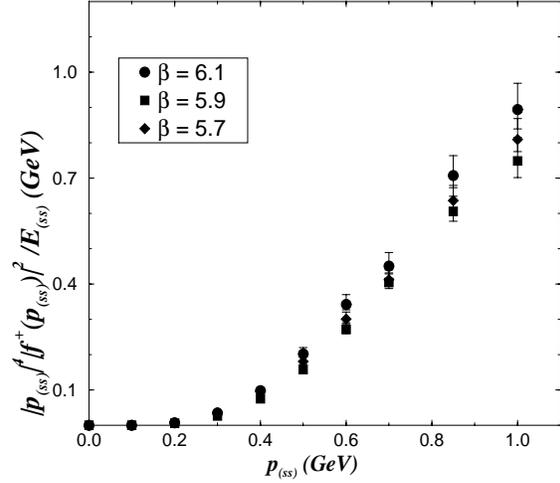


Figure 2. Differential decay rate at 3 lattice spacings, with strange light quarks.

ical momenta is set from the spin-averaged 1P-1S splitting in Charmonium. The quenched approximation introduces a dependence on the quantity used to set the scale and this is often used to estimate quenching effects. We repeated the procedure with $a^{-1}(f_{\pi})$ and found only a small effect which is included in our error estimates, with the caveat that it is almost certainly an underestimate of quenching. The partial width of $B \rightarrow \pi l \nu$, for $0.4 \leq p \leq 0.8$, is shown as the shaded region in Figure 3. This width and the statistical error is: $2m_B \int_{p=0.4}^{p=0.8} |p_{\pi}|^4 f^{+}(p_{\pi})^2 / E_{\pi} = 12.17(11)$.

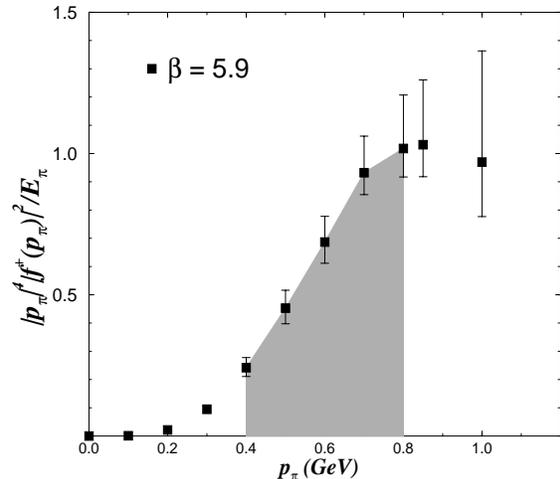


Figure 3. Differential decay rate at $\beta = 5.9$ and partial width

3. $D \rightarrow \pi l \nu / D \rightarrow K l \nu$

In Ref. [2] it was suggested that calculating the ratio of partial widths $D \rightarrow \pi l \nu / D \rightarrow K l \nu$ is a nice way to reduce the uncertainty on $|V_{cd}|/|V_{cs}|$, from its current $\sim 17\%$. The Focus Collaboration at Fermilab expects to have of $\mathcal{O}(10^6)$ fully reconstructed D decays so the experimental error will be considerably reduced. By calculating a ratio of rates it is expected that much of the theoretical uncertainties will cancel. In particular, the renormalisation factors cancel, eliminating the perturbative uncertainty. The analysis of D decays proceeds as described for B decays with further details in Ref. [2]. Here, we report on the update since last year. The chiral extrapolations at $\beta = 5.9$ have been done for the pion and kaon final states so we can now calculate the ratio $D \rightarrow \pi l \nu / D \rightarrow K l \nu$, as shown in Figure 4. The

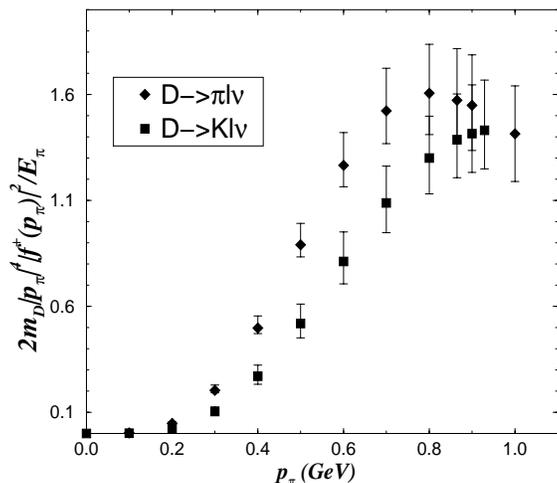


Figure 4. A comparison of rates for D decays

ratio of partial widths in the range $0.2 \leq p_\pi \leq 0.7$ is 1.61(19), where the error is statistical. We also calculate the ratio $B \rightarrow \pi l \nu / D \rightarrow \pi l \nu$, shown in Figure 5. With the expected experimental precision in D decays this ratio has the advantage that many uncertainties are reduced and therefore may prove an interesting avenue for a determination of $|V_{ub}|$.

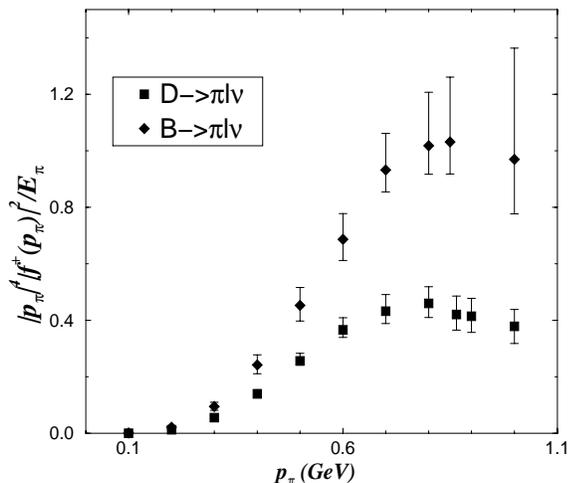


Figure 5. The rates for B and D decays

4. Conclusions

In conclusion we present a preliminary summary of the systematic errors contributing to the theoretical error in $|V_{ub}|$ and $|V_{cd}|/|V_{cs}|$. The uncertainty due to the perturbative matching is not yet included. Adding in quadrature gives an error of $\sim 10\%$ on $|V_{ub}|$ and $\sim 13\%$ on $|V_{cd}|/|V_{cs}|$ and we expect to improve upon this in the final result.

	$ V_{ub} $	$\frac{ V_{cd} }{ V_{cs} }$
Statistics	4%	5%
χ -extrapolation, p-interpolation	8%	10%
a -dependence	5%	5%
Determining a^{-1}	3%	3%
Fits, excited state contamination	2%	2%
m_Q -dependence	1%	1%

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