Calculating weak matrix elements using HYP staggered fermions*

T. Bhattacharya[a], G.T. Fleming[b], G. Kilcup[c], R. Gupta[a], W. Lee[d] and S. Sharpe[e]

[a]MS–B285, T-8, Los Alamos National Lab, Los Alamos, New Mexico 87545, USA

[b]Jefferson Laboratory, MS 12H2, 12000 Jefferson Avenue, Newport News, VA 23606, USA

[c]Department of Physics, Ohio State University, Columbus, OH 43210, USA

[d]School of Physics, Seoul National University, Seoul, 151-747, South Korea

[e]Department of Physics, University of Washington, Seattle, WA 98195, USA

We present preliminary results of weak matrix elements relevant to CP violation calculated using the HYP (II) staggered fermions. Since the complete set of matching coefficients at the one-loop level became available recently, we have constructed lattice operators with all the g^2 corrections included. The main results include both $\Delta I = 3/2$ and $\Delta I = 1/2$ contributions.

1. Introduction

Staggered fermions preserve enough chiral symmetry to calculate the weak matrix elements for CP violations (B_K, ϵ'/ϵ) and have an advantage over DWF [1,2] of requiring less computing, which makes dynamical simulations possible below the physical strange quark mass. In the previous attempt to calculate ϵ'/ϵ using unimproved staggered fermions [3], we observed, in B_6, a large dependence on the implementation chosen for the quenched approximation as well as large perturbative corrections at the one loop level. In addition, it has been known that unimproved staggered fermions have large scaling violations of order a^2 [4]. Some of these problems can be alleviated by improving staggered fermions using fat links.

In order to find the best improvement scheme to reduce perturbative correction and taste symmetry breaking, we calculated explicitly one loop matching coefficients for various improved staggered fermion actions and operators [5]. As a result of this study, it turned out that the Fat7 [6] and HYP [7] fat links, after a higher level of mean field improvement, lead to the greatest reduction. In addition, the key features of fat links of HYP type are (i) that they are local in the sense of involving only gauge links contained in hypercubes connected to the original links; (ii) that they lead to the largest reduction in taste symmetry breaking in the spectrum [7]; and (iii) that the one-loop renormalization is identical between the HYP (II) (perturbatively improved coefficients) and $\overline{\text{Fat7}}$ (SU(3) projected Fat7) [8]. Several useful properties of HYP and $\overline{\text{Fat7}}$ links are presented in [8].

Recently we have calculated the current-current diagrams to obtain the perturbative matching coefficients for the four-fermion operators constructed using the HYP/$\overline{\text{Fat7}}$ links [9]. We find that the perturbative corrections are reduced down to about 10% level by using the HYP/$\overline{\text{Fat7}}$ links. We also have calculated the penguin diagrams and the results are reported separately [10]. These two calculations provides a complete set of matching formula to calculate ϵ'/ϵ using the HYP/$\overline{\text{Fat7}}$ staggered fermions.

Here, we will present preliminary estimates of B_K, $B_7^{(3/2)}$, $B_8^{(3/2)}$ and $B_6^{(1/2)}$ calculated using the HYP (II) staggered fermions at $\beta = 6.0$ on a

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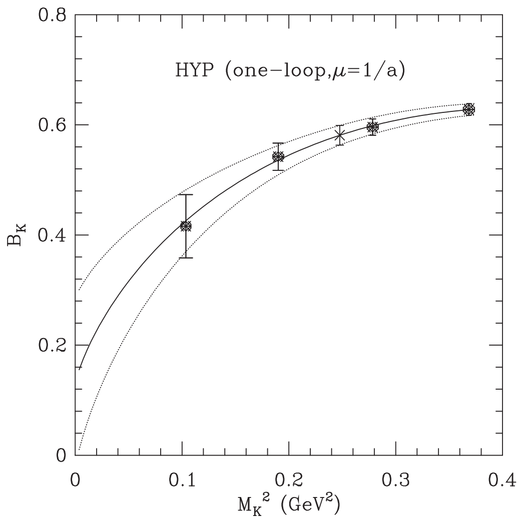

Figure 1. $B_K(\mu = 1/a)$

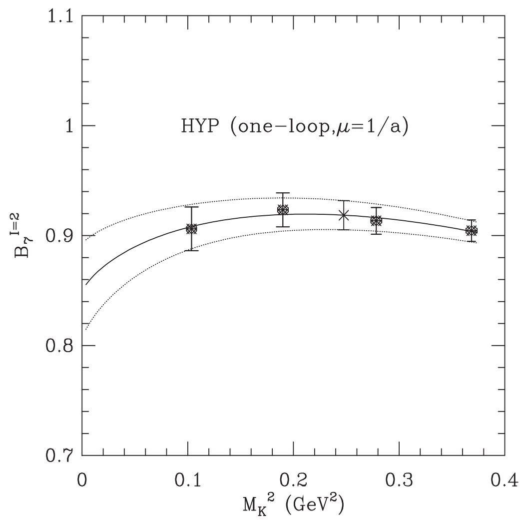

Figure 2. $B_7^{\Delta I=3/2}(\mu = 1/a)$

$16^3 \times 64$ lattice with 218 configurations.

2. B_K

Fig. 1 shows B_K as a function of M_K^2, where the mesons are made of degenerate quarks. We fit B_K to the form suggested by (quenched) chiral perturbation theory: $B_K = c_0 + c_1(M_K)^2 + c_2(M_K)^2 \log(M_K)^2$. The cross symbol in Fig. 1 corresponds to the value interpolated to the physical kaon mass. Our preliminary result is $B_K = 0.581(18)$, which is consistent with the continuum extrapolated value calculated using unimproved staggered fermions [4]. In the chiral limit, we obtain $c_0 = 0.13(15)$, which is also consistent with those results obtained using the NLO, large N_c calculation [11]. The value for c_2/c_0 is consistent with the predictions of quenched chiral perturbation theory [12] within large errors.

3. $B_7^{(3/2)}$ and $B_8^{(3/2)}$

A major contribution to the $\Delta I = 3/2$ amplitudes comes from $B_7^{(3/2)}$ and $B_8^{(3/2)}$ The results are presented in Fig. 2 and Fig. 3. We fit B_7 and B_8 to the form suggested by chiral perturbation theory: $B_{7,8} = c_0 + c_1(M_K)^2 + c_2(M_K)^2 \log(M_K)^2$. Our preliminary values at the physical kaon mass are $B_7^{(3/2)} = 0.919(13)$ and $B_8^{(3/2)} = 1.047(15)$. Note that we calculated $B_7^{(3/2)}$ at the scale $\mu = 1/a$ using the HYP staggered fermions, which would not have been meaningful for unimproved staggered fermions due to large perturbative corrections. Compared with previous calculation done using Landau-gauge operators [13], the systematics of the HYP staggered operators are significantly reduced and the results are more reliable.

4. $B_6^{(1/2)}$

A major contribution to $\Delta I = 1/2$ amplitudes comes from $B_6^{(1/2)}$. There are two independent methods to calculate $B_6^{(1/2)}$: the standard (STD) method and the Golterman-Pallante (GP) method [14]. Fig. 4 shows $B_6^{(1/2)}$ as a function of M_K^2. Note that unlike the unimproved staggered fermion calculations where the perturbative corrections to the STD calculation are $\approx 50\%$, the perturbative corrections in this calculation are modest for both the STD and GP methods. We also observe that the gap between the STD and GP methods is reduced at the physical kaon mass using the HYP staggered fermions compared that of the unimproved staggered fermions. We fit B_6

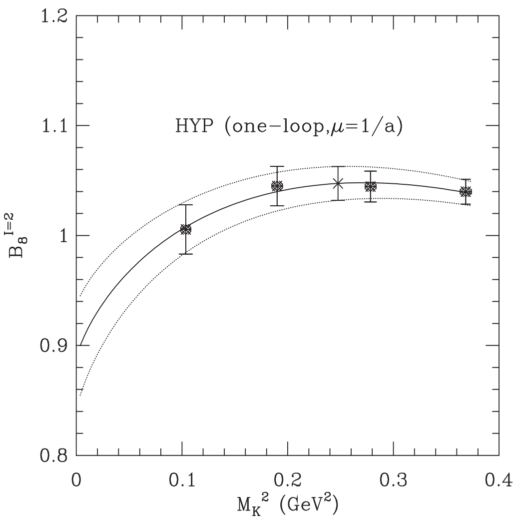

Figure 3. $B_8^{\Delta I=3/2}(\mu = 1/a)$

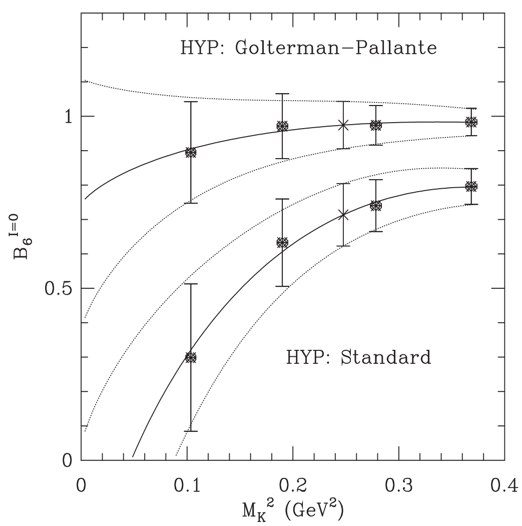

Figure 4. $B_6^{\Delta I=1/2}(\mu = 1/a)$

to the form suggested by chiral perturbation theory: $B_6 = c_0 + c_1(M_K)^2 + c_2(M_K)^2 \log(M_K)^2$. Our preliminary values at the physical kaon mass are

$$B_6^{(1/2),STD}(\mu = 1/a) = 0.714(91)$$
$$B_6^{(1/2),GP}(\mu = 1/a) = 0.974(69)\,.$$

5. Preliminary ϵ'/ϵ

We use the formula given in [15] to convert $B_6^{(1/2)}$ and $B_8^{(3/2)}$ into ϵ'/ϵ. When we use the STD method for $B_6^{(1/2)}$, $\epsilon'/\epsilon(STD) = 0.00046(23)$. For the GP method for $B_6^{(1/2)}$, $\epsilon'/\epsilon(GP) = 0.00115(17)$. These values are very preliminary and we have not included an analysis of the systematic errors. In addition, we did not use lattice values for any $B_i^{(1/2)}$ except for $B_6^{(1/2)}$, since we have not yet extracted them. Hence, we plan to calculate all the $B_i^{(1/2)}$ and incorporate all of them into the calculation of ϵ'/ϵ. We also plan to obtain the optimal matching scale, q^* [16]. We plan to extend our calculation to dynamical simulation using the HYP staggered fermions.

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