B-meson decay constants and $B^0 - \overline{B^0}$-mixing with domain-wall light and relativistic heavy quarks

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Time Requested: The equivalent of 10.4 million jpsi core-hours on the Fermilab clusters
plus 28.2 Tbytes of tape storage (the equivalent of $\sim$ 76000 jpsi core-hours)
and 0.25 Tbytes of disk storage (the equivalent of $\sim$ 6700 jpsi node-hours) at Fermilab.
Project webpage: `http://rbc.phys.columbia.edu/USQCD/B-physics/`

Abstract

We propose to continue and finish our determination of the B-meson leptonic decay constants f_{B_d} and f_{B_s}, the $B^0 - \overline{B^0}$ mixing matrix elements, and their ratio, $\xi \equiv f_{B_s}\sqrt{B_{B_s}}/f_{B_d}\sqrt{B_{B_d}}$, on the 2+1 flavor dynamical domain-wall fermion gauge field configurations generated by the LHP, RBC, and UKQCD Collaborations. Using the relativistic heavy quark action we expect to obtain precise results which will place strong constraints on the CKM unitarity triangle fits. In particular ξ provides an important constraint on the apex of the CKM triangle and was therefore highlighted as a key goal in flavor physics in the USQCD Collaboration's 2007 white paper. Our calculation will provide an independent and valuable crosscheck of the results by HPQCD and Fermilab/MILC who both use the same set of gauge field configurations. We request the equivalent of 10.4 million jpsi core-hours on the Fermilab clusters plus 28.2 Tbytes of tape storage (the equivalent of $\sim$ 76000 jpsi core-hours) and 0.25 Tbytes of disk storage (the equivalent of $\sim$ 6700 jpsi node-hours) for this project.

Scientific motivation

Studying the physics of B-mesons on the lattice enables the determinination of CKM matrix elements and helps to constrain the CKM unitarity triangle. It is therefore of special phenomenological interest. The standard global unitarity triangle fit uses the lattice determination of neutral B-meson mixing in combination with experimental measurements to constrain the apex of the CKM unitarity triangle [1, 2]. Experimentally $B_q - \overline{B}_q$ is measured in terms of mass differences (oscillation frequencies) Δm_q, where q labels the light quark content of the B-meson, either a d- or a s-quark. Within the Standard Model these oscillation frequencies are parameterized by [3]

$$\Delta m_q = \frac{G_F^2 m_W^2}{6\pi^2} \eta_B S_0 m_{B_q} f_{B_q}^2 B_{B_q} |V_{tq}^* V_{tb}|^2, \tag{1}$$

with m_{B_q} the mass of the B_q-meson, V_{tq}^* and V_{tb} are CKM matrix elements, and $f_{B_q}^2 B_{B_q}$ is the non-perturbative input to be determined on the lattice in terms of the leptonic decay constant f_{B_q} and the B-meson bag parameter B_{B_q}. Perturbative input is also needed in form of the Inami-Lim function, S_0, [4], and the QCD coefficient, η_B [3]. It is in particular advantageous to compute the ratio $\Delta m_s/\Delta m_d$ and to define the $SU(3)$-breaking ratio

$$\xi = \frac{f_{B_s}\sqrt{B_{B_s}}}{f_{B_d}\sqrt{B_{B_d}}} \tag{2}$$

because statistical and systematic uncertainties largely cancel and, moreover, the ratio of CKM matrix elements becomes accessible [5]

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s}}{m_{B_d}}\, \xi^2 \,\frac{|V_{ts}|^2}{|V_{td}|^2}. \tag{3}$$

Nevertheless the precision in the determination of the ratio of the CKM matrix elements $|V_{ts}|^2/|V_{td}|^2$ is still limited by the knowledge of the lattice quantity ξ. Although recent experimental measurements of the oscillation frequencies Δm_d and Δm_s established an accuracy of $\sim 1\%$ [6], the $SU(3)$-breaking ratio ξ is only known to $\sim 3\%$ [7–9]. Given the importance of ξ, this quantity was highlighted as one of three "key matrix elements" in the USQCD Collaboration's 2007 white paper "Fundamental parameters from future lattice calculations" [10].

Moreover, there is a drawback to the standard method for constraining the CKM unitarity triangle because the CKM matrix elements $|V_{ub}|$ and $|V_{cb}|$ enter. Both $|V_{ub}|$ and $|V_{cb}|$ exhibit an appreciable discrepancy between exclusive and inclusive determinations. In fact, the CKM matrix element $|V_{cb}|$ plays a particularly pivotal role in the standard CKM fit because the location of the ϵ_K band is sensitive to $|V_{cb}|^4$. Alternatively, one can constrain the CKM triangle with precise knowledge of the decay constant f_B as well as $BR(B \to \tau\nu)$ and Δm_s [11]. Therefore not only the ratio ξ but also the individual B-meson mixing matrix elements B_{B_q} and the decay constants f_{B_q} are of increased phenomenological interest.

Further constraining the CKM unitarity triangle will help to identify new physics. In fact, the current data may already show signs of physics beyond the Standard Model, seen as deviations of experimental values for $\sin(2\beta)$ (3.3σ) and $BR(B \to \tau\nu)$ (2.8σ) from the Standard Model [12, 13]. Lunghi and Soni argue that, given the current experimental and theoretical inputs, the most likely sources for new physics are in B_d mixing and $\sin(2\beta)$. Therefore a precise knowledge of B-meson mixing matrix elements B_{B_q} may play a key role in discovering new physics.

Currently, the Fermilab/MILC and HPQCD collaborations are also computing $B^0 - \overline{B^0}$-mixing matrix elements and decay constants f_{B_q} using dynamical 2+1 flavor gauge field ensembles. We list the latest results with corresponding references in Tabs. 1 and 2. Both of these computations rely on the 2+1 flavor Asqtad-improved-staggered ensembles generated by the MILC Collaboration. Therefore an independent crosscheck for such phenomenologically important quantity is highly desired. Two years ago we began a project using the 2+1 flavor dynamical domain-wall ensembles generated by the LHP, RBC and UKQCD collaborations with lattice spacings $a \approx 0.11$ fm and $a \approx 0.08$ fm [14, 15]. Our calculation uses domain-wall fermions for the light quarks [16, 17] and the relativistic heavy quark (RHQ) action developed by Christ, Li and Lin for the

	ξ	$f_{B_d}\sqrt{B_{B_d}}$ [MeV]	$f_{B_s}\sqrt{B_{B_s}}$ [MeV]	reference
FNAL/MILC	1.205(52) *4.3%*	—	—	[8, 9]
HPQCD	1.258(33) *2.6%*	216(15) *7.1%*	266(18) *6.7%*	[7]
RBC-UKQCD	1.13(12) *10%*	—	—	[22]

Table 1. Published results for the $SU(3)$ breaking ratio ξ and the B_q-meson mixing matrix elements computed with $2+1$ dynamical flavors. In italics we give the relative error in percent.

	f_{B_s}/f_{B_d}	f_{B_d} [MeV]	f_{B_s} [MeV]	reference
FNAL/MILC	1.21(2) *1.7%*	212(8) *3.8%*	256(8) *3.1%*	[23]
HPQCD	1.226(26) *2.1%*	190(13) *6.7%*	231(15) *6.3%*	[7]
RBC-UKQCD	1.15(12) *10%*	—	—	[22]

Table 2. Published results for the ratio of the decay constants as well as the determination of f_{B_d} and f_{B_s} computed with $2+1$ dynamical flavors. In italics we give the relative error in percent.

heavy b-quarks [18, 19]. The distinction of the RHQ action with respect to the Fermilab action [20] is that all parameters of the clover action are tuned non-perturbatively [21]. Properties of the RHQ action are that it is accurate to order $\mathcal{O}(a^2p^2)$ and to all orders in $(am_b)^n$. Thus it allows the computation of heavy-light spectrum quantities with discretization errors of the same order as in light-light quantities.

With the additional computing time requested in this proposal we intend to finish our computation of B-meson decay constants and mixing parameters achieving a precision comparable to those of the Fermilab/MILC and HPQCD collaborations. Moreover, utilizing non-USQCD resources Hao Peng, a Columbia University graduate student, will compute D- and D_s-meson decay constants. Given the fact that the RHQ action is a good description for b- as well as for c-quarks, he will use a similar setup and re-use our expensive domain-wall light quark propagators. This will allow for further valuable crosschecks of our method and increase the confidence in our B-meson calculations.

Computational method

Our computation of B-physics quantities is performed in two steps. The first step is to generate and save the expensive domain-wall light quark propagators while the second step is to generate cheap heavy b-quark propagators on the fly and compute 2-point and 3-point correlator functions. For the domain-wall propagators we use the same values of the domain-wall height ($M_5 = 1.8$) and extent of the fifth dimension ($L_s = 16$) as were used for the sea sector when generating the gauge field configurations. Therefore we can use the determinations of the light and strange quark masses and the residual quark mass from RBC-UKQCD's analysis of the light pseudoscalar meson masses and decay constants [14, 15].

The distinct feature of the RHQ action is the non-perturbative tuning of all three parameters in the clover action. This provides a big challenge because the statistical errors in any decay constant or $B-\overline{B}$-mixing matrix element are limited by the precision in the RHQ parameters. Therefore we decided to verify the initially performed tuning [21, 24] and if possible improve upon the used procedure. We concluded that in order to carry out our B-physics computation as precisely as possible, we should re-tune the RHQ parameters using the same set of gauge field configurations that we are using in our computation of B-meson decay constants and mixing matrix elements. This allows us to propagate the statistical uncertainties of our tuned RHQ parameters into the final results for decay constants and mixing matrix elements while accounting for correlations between the parameters.

We fix the three RHQ parameters of our action, m_0a, c_P and ζ, using the experimental values of the spin-averaged mass ($\overline{m}$) and the hyperfine splitting (Δ_m) for the B_s and B_s^* meson in addition to the constraint that the kinetic mass in our action has to match the rest mass ($m_1/m_2 = 1$). Generating light quark

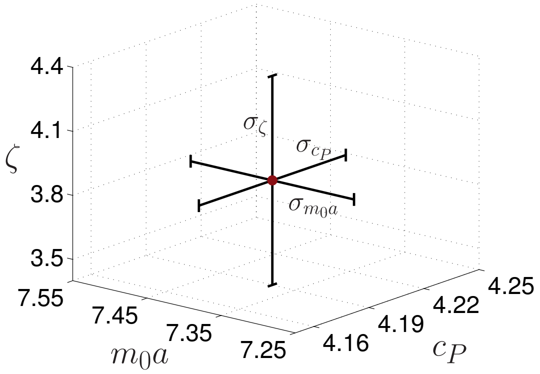

Figure 1. Position of RHQ input parameters in the parameter space m_0a, c_P and ζ varied by the uncertainties σ_{m_0a}, σ_{c_P} and σ_ζ.

propagators at the physical strange quark mass, we compute $\overline{m}$, Δ_m and m_1/m_2 for a set of seven RHQ parameters so that we can linearly interpolate to the tuned values. These seven parameter sets are chosen by selecting one central point and then varying each of the three parameters (m_0a, c_P, ζ) one at a time by adding/subtracting the chosen uncertainty (σ_{m_0a}, σ_{c_P}, σ_ζ, see Fig. 1). In order to propagate the statistical uncertainties of the RHQ parameters into decay constants and mixing matrix elements, we also compute these quantities with the same seven sets of RHQ parameters.

The 3-point functions needed to determine the $B^0 - \overline{B^0}$ mixing matrix elements are computed as shown in Fig. 2. We keep the location of the effective four-quark operator t_{Op} fixed and vary the locations of the B^0 and $\overline{B^0}$ mesons, t_1 and t_2, over all possible time slices. This setup requires one point-source light quark and one point source b-quark propagator originating from t_{Op}. These propagators can be used for the B^0 as well as the $\overline{B^0}$ mesons, thereby reducing the overall costs. For the heavy b-quarks we project out the zero momentum component using a gauge-invariant Gaussian smeared sink.

Similarly, we compute the decay constants with a point source light quark propagator but use a Gaussian-smeared source heavy quark propagator both originating at t_0 as shown in Fig.3. By identifying $t_{\text{Op}} \equiv t_0$, the same light quark propagators can be used in both computations.

For the computation of f_{B_s} we can make use of the light quark propagators generated at the physical strange quark mass and used in the RHQ parameter tuning, while for f_{B_d} a chiral extrapolation is needed. This computation of f_{B_d} therefore requires additional partially-quenched points. In the end we intend to obtain our final results by fitting data on the 24^3 and 32^3 lattices together and performing a simultaneous extrapolation to the physical light quark mass and the continuum using partially-quenched heavy-meson χPT [25] supplemented by analytic terms $\propto a^2$ to parameterize light-quark discretization effects. The matching of the lattice action to the continuum action will be performed through $O(pa)$. Thus we are left with errors of $O(p^2a^2)$ with a coefficient that is a function of m_ba. As El Kahdra, Kronfeld and Mackenzie showed this

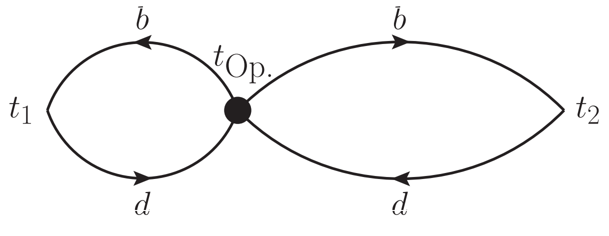

Figure 2. Three-point correlation function for computing $B^0 - \overline{B^0}$ mixing on the lattice.

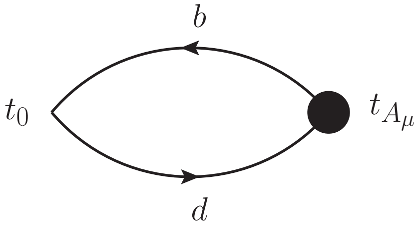

Figure 3. Two-point correlation function for computing the decay constant f_B.

L	a(fm)	$m_{\rm sea}^{l}$	$m_{\rm sea}^{h}$	$m_{\rm sea}^{\pi}$(MeV)	# configs.	trajectory #
32	≈ 0.08	0.004	0.030	289	628	[290:5:3425]
32	≈ 0.08	0.006	0.030	345	445	[272:8:3824]
32	≈ 0.08	0.008	0.030	394	544	[250:5:2965]
24	≈ 0.11	0.005	0.040	329	1636	[495:5:8670]
24	≈ 0.11	0.010	0.040	422	1419	[1455:5:8545]
24	≈ 0.11	0.020	0.040	558	345	[1890:5:3610]

Table 3. Analyzed RBC-UKQCD 24^3 and 32^3 domain-wall gauge field configurations. The pion masses are taken from [14, 15]. The analyzed trajectories are specified in the last column where the number between the colons specifies the separation. On the 32^3 ensembles 1 trajectory = 2 molecular dynamics time units, whereas on 24^3 1 trajectory = 1 molecular dynamics time unit.

function of $m_b a$ is always bounded to be of $O(1)$ or less [20].

In order to reduce discretization errors in the four quark operators and the axial-current operators for the decay constants, we implement $O(a)$ improvement. Only one additional matrix element is needed to improve the decay constant at $O(ap)$ to all orders in α_s. In practice we will compute the needed improvement coefficient at 1-loop in tadpole improved lattice perturbation theory; this will improve the axial-current operator through $O(\alpha_s ap)$, such that truncation errors are of $O(\alpha_s^2 ap)$. The Standard Model B_q-$\bar{B}_q$ mixing four-quark operator requires several additional matrix elements, and we are currently working on obtaining the minimal set needed for improvement through $O(\alpha_s ap)$. For the computation of the renormalization factors we will use tadpole-improved lattice perturbation theory, such that the truncation errors are of $O(\alpha_s^2 ap)$. We expect that for the most important quantity ξ much of the uncertainty due to the truncation of perturbation theory cancels in the ratio.

Recent progress

We list the analyzed configurations of the coarser "24^3" ensembles ($a \approx 0.11$ fm) and the finer "32^3" ensembles ($a \approx 0.08$ fm) in Tab. 3 and provide the number of available light-quark propagators, along with those we propose, in Tab. 4. Because the first step and expensive part of our calculation is straightforward, we generated domain-wall light quark propagators while still working on the code for the 2-point and 3-point functions and refining the tuning of the RHQ action.

Before re-tuning the RHQ parameters we studied different smearing parameters for the Gaussian sources. The same optimal smearing parameters are now used for the parameter tuning as well as for the decay constant computation. As can be seen in Fig. 4 finding the optimal smearing parameters can significantly enhance the signal and reduce excited state contamination. Searching for the optimal choice of the Gaussian smeared source for the heavy propagator used for the computation of heavy-light quantities, we find that a $r_{\rm rms}$ radius of 0.634 fm (blue data points in the plot) gives the best results on both the coarser 24^3 and the finer 32^3 ensembles.

The preliminary results for our re-tuned RHQ parameters on the 24^3 ensembles are summarized in Tab. 5 and we are about to finish the re-tuning on the 32^3 ensembles soon. A publication describing our method in detail as well as presenting the results is in preparation; preliminary results were presented at Lattice 2010 [26]. We demonstrate the accuracy of our tuning by computing the masses of heavy-heavy mesons such as the η_b and the Υ as well as the hyperfine splitting $\Upsilon - \eta_b$. For example we show in the left-hand plot of Fig. 5 a sample effective mass for η_b. In order to correctly propagate the statistical uncertainties of the RHQ parameter tuning into our prediction of e.g. the η_b mass, we compute the effective mass of the pseudoscalar-pseudoscalar heavy-heavy correlator for the same seven parameters sets as we used initially for the parameter tuning. In addition we choose one ensemble on which we verify our assumption of linearity in the parameter space by using three different choices for the variations $\sigma_{m_0 a}$, σ_{c_P} and σ_{ζ}. This allows us

L	$m^l_{\rm sea}$	$m_{\rm val}$	time source per config	# propagators 2009-2011	# propagators 2011/2012
32	0.004	0.004, 0.006, 0.008, 0.025, 0.030	2	628	628
32	0.004	0.0272	2	1256	—
32	0.006	0.004, 0.006, 0.008, 0.025, 0.030	2	445	1335
32	0.006	0.0272	2	1780	—
32	0.008	0.004, 0.006, 0.008, 0.025, 0.030	2	544	544
32	0.008	0.0272	2	1088	—
24	0.005	0.005, 0.010, 0.020, 0.030, 0.0343, 0.040	1	1636	—
24	0.010	0.005, 0.010, 0.020, 0.030, 0.0343, 0.040	1	1419	—
24	0.020	0.005, 0.010, 0.020, 0.030, 0.040	1	345	—
24	0.020	0.0343	8	2760	—

Table 4. Generated/proposed domain wall valence and sea quark mass combinations for the calculation of the $B^0 - \bar{B}^0$ matrix elements and B-meson decay constants using the finer lattices ($L = 32$) and the coarser ($L = 24$) lattices. To compensate for the lower number of gauge field configurations on some ensembles we intend to generate additional time source(s) per configuration. We tune the RHQ parameters using propagators with the physical value of the strange quark mass ($m_s = 0.0343$ on 24^3 and $m_s = 0.0272$ on 32^3 [15]). We discard the 24^3, $m^l_{\rm sea} = 0.020$ ensemble from our future computations because the low number of configurations insufficiently samples the QCD vacuum and cannot satisfyingly be compensated by additional time sources.

to show the dependence of the meson masses and splittings on the RHQ parameters m_0a, c_P and ζ. As one can see from the right-hand plot of Fig. 5, there is a statistically significant non-linear dependence of the η_b mass on c_P for the outer-most data points; however for the inner-most the assumption of linearity is justified. For heavy-light quantities that are our primary focus, however, we see no evidence for non-linear

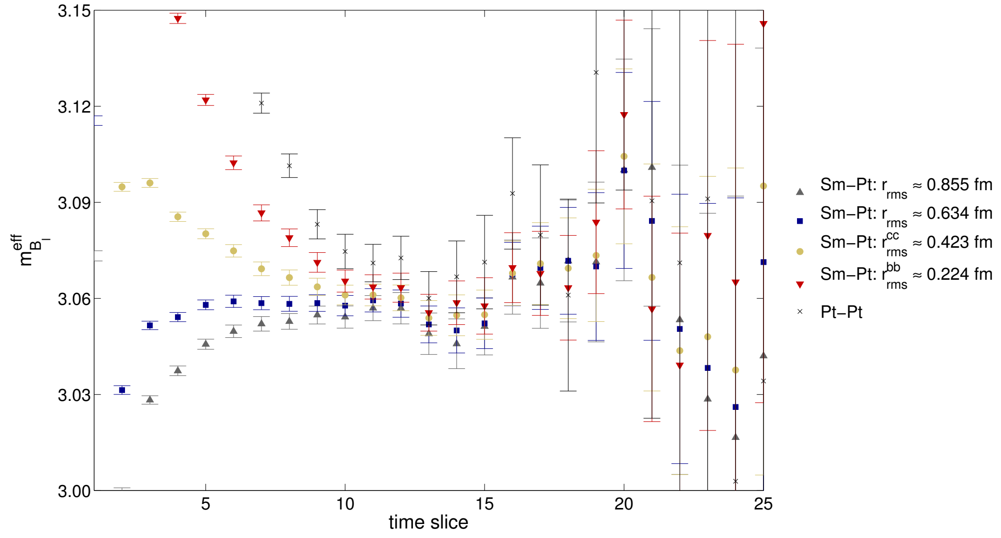

Figure 4. Comparison of different Gaussian smearing radii for the source of the heavy quark propagator on the 24^3 ensemble with $m^l_{\rm sea} = m^l_{\rm val} = 0.005$ using 816 configurations. The heavy quark is generated with $m_0a = 7.38$, $c_P = 3.89$ and $\zeta = 4.19$.

m^l_{sea}		m_0a	c_P	ζ
0.005	B_s	8.4(1)	5.7(2)	3.1(1)
0.010	B_s	8.5(1)	5.8(2)	3.1(1)
0.020	B_s	8.28(7)	5.3(2)	3.13(9)

Table 5. Preliminary results for the RHQ parameter tuning on the 24^3 ensembles using the heavy-strange spin-averaged mass, hyperfine-splitting and m_1/m_2 from pseudoscalar correlator.

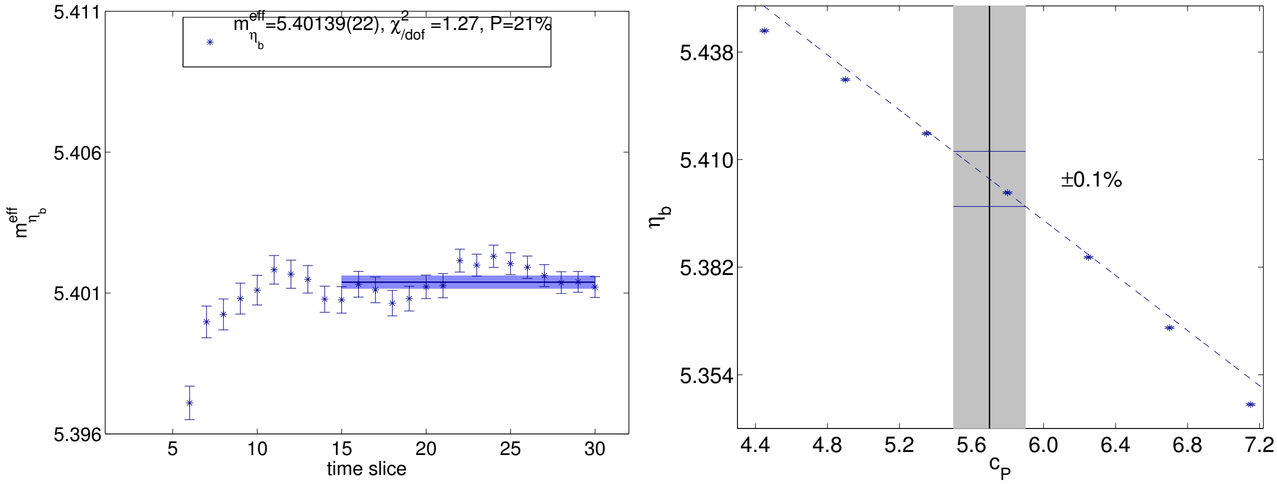

Figure 5. On the left we show the effective mass plot for η_b on 24^3, $m^l_{\text{sea}} = 0.005$ and $[m_0a,\, c_P,\, \zeta] = [8.40,\, 5.80,\, 3.20]$ (central parameter point). The figure on the right shows the dependence of the mass of η_b on the RHQ parameter c_P. The black vertical line with the gray error band indicate the tuned value for c_P and its statistical error. Computing our prediction for the mass of η_b we obtain in lattice units 5.40(1), where the error takes into account the statistical uncertainty of the RHQ parameter tuning. A naive estimate shows that the error due to the uncertainty in c_P is about 0.1%.

dependence upon the RHQ parameters within statistical errors. Fig. 6 shows the dependence of our predicted values on the lattice spacing and the comparison with the values from the experiments. Performing a simple extrapolation by eye to the continuum, our values agree well with the experiment although we still need to account for systematic uncertainties.

The extraction of the B-meson decay constants and B_q-$\overline{B}_q$ mixing parameters from data on the seven RHQ parameters is performed in the same manner. Our code for computing the $O(a)$ improvement of the decay constant is written and verified, and we expect to complete the 1-loop lattice perturbation theory calculation of the improvement coefficient in time to present $O(a)$-improved values for the decay constant f_{B_s} on 24^3 ensembles at the All Hands' meeting. Right now we are focusing on coding the four quark operators including the relevant terms for $O(a)$ improvement.

Run Plan and Resource Allocation

The computationally most expensive part of this project are the domain-wall inversions required to generate the light quark propagators. These inversions are performed using the optimized domain-wall inverter in the Chroma lattice QCD software package [27]. For the computation of $O(a)$ improvement operators and B-$\overline{B}$ mixing operators we write our code as Chroma inline-functions which allows us to combine various parts of our calculation efficiently and easily make use of already existing Chroma and QDP++ libraries.

The domain-wall light quark propagators generated in the allocation periods 2009/10 and 2010/11 are listed in Tab. 4. Our propagators are computed with a random source position in space-time and we do

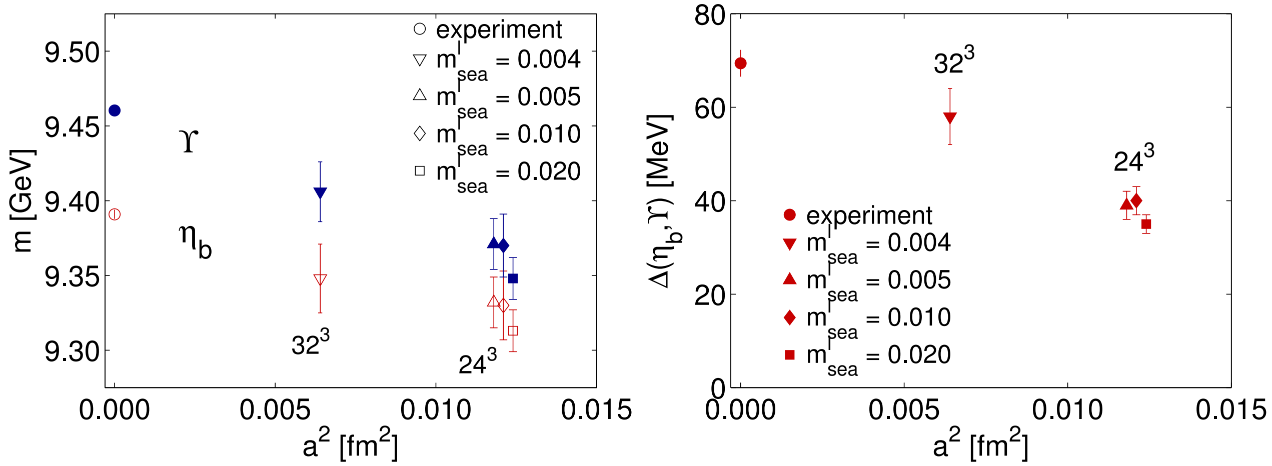

Figure 6. Dependence of the predicted values for the meson masses η_b and Υ (left plot) as well as the hyperfine splitting (right plot) on the squared lattice spacing a and comparison to the experimental values. The data shown are preliminary and include only statistical errors. Results for different sea-quark ensembles at the same lattice spacing are offset for clarity. Note thate we do not observe any statistically-significant sea-quark mass dependence.

a(fm)	L	m_l	nodes (jpsi)	time (hours)	jpsi core-hours
$\approx$ 0.08	32	0.004	32	4.06	1040
$\approx$ 0.08	32	0.006	32	3.07	786
$\approx$ 0.08	32	0.008	32	2.46	630
$\approx$ 0.08	32	0.025	32	0.96	246
$\approx$ 0.08	32	0.030	32	0.84	215

Table 6. Time to calculate a single 32^3 (a $\approx$ 0.08 fm) domain-wall propagator with $L_5 = 16$ using Chroma on the Fermilab "jpsi" cluster.

not observe noticeable effects of autocorrelation in any of our analysis for tuning the RHQ parameters or in determinations for the B_s-meson decay constants or bottomonium mass predictions. We have listed times needed to generate 32^3 domain-wall propagators on the jpsi-cluster at Fermilab in Tab. 6. For the coming allocation period 2011/12 we would like to generate on the finer 32^3 lattices a second time source for each of the valence quark masses listed and to also fill in propagators on every 4th trajectory on the ensemble with $m^l_{\text{sea}} = 0.006$. We demonstrate the need for the second time source in Fig. 7, where we show the effective mass plot for the decay amplitude $\Phi_{B_s} = f_{B_s}\sqrt{m_{B_s}}$ computed on the 32^3 ensemble with $m^l_{\text{sea}} = 0.004$. The upper plot shows the outcome using only one propagator ($t = 0$) per configuration. In comparison to that the lower plot shows the decay amplitude computed with two propagators ($t = 0$ and $t = 32$) per configurations; all other parameters remain unchanged. As one can see adding a second time source helps to decrease the statistical uncertainty by the naively expected factor of $\sqrt{2}$ indicating that the second time source is uncorrelated with the first. Decreasing the statistical uncertainty improves our calculation by decreasing the uncertainty in the RHQ parameters and in the computation of B-meson decay constants and matrix elements. While for one time source, our prediction for the decay amplitude Φ_{B_s} has a statistical error of about 3%, the second time source pushes us below 2%. We emphasize that this error already takes into account the statistical uncertainties from tuning the RHQ parameters.

Additionally we need time to generate the required seven heavy-quark propagators per light quark propagator on the 24^3 and the 32^3 lattices. The time needed to generate one heavy-quark propagator is given in Tab. 7, where the RHQ parameters m_0a, c_P and ζ are chosen according to the findings from our parameter tuning.

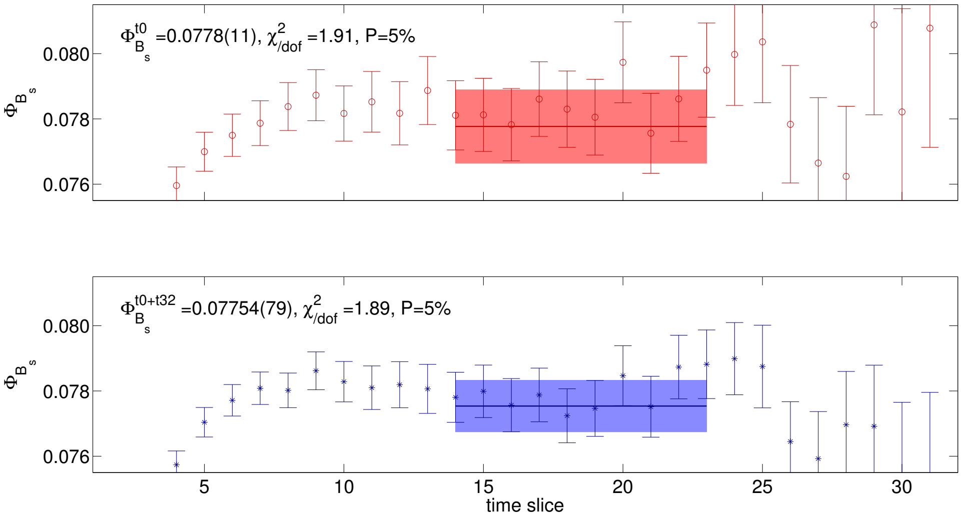

Figure 7. "Effective for the decay amplitude" Φ_{B_s} computed on the 32^3 ensemble with $m^l_{\rm sea} = 0.004$ and $[m_0a,\, c_P,\, \zeta] = [4.07, 3.80, 1.89]$. In the upper plot we analyze only measurements made for sources placed at $t = 0$, whereas the lower plot analyzes both sources at to $t = 0$ and $t = 32$.

a(fm)	L	nodes (jpsi)	time (hours)	jpsi core-hours
≈ 0.08	32	8	0.15	10
≈ 0.11	24	4	0.10	4

Table 7. Time to calculate a single clover propagator using Chroma on the Fermilab "jpsi" cluster.

Computing the domain-wall light propagator for the valence quark masses listed in Tab. 4 and computing every time seven heavy quark propagators for the correct propagation of the errors, we estimate the total computing request required to compute B^0-$\overline{B^0}$ mixing and the decay constants f_{B_d} and f_{B_s} with full statistics in Tab. 8. This estimate contains an additional 10% for the computation of 2-point and 3-point functions and analysis. As before we intend to store the expensive domain-wall propagators on tape at Fermilab to allow their use in other projects and by other groups. The size of one 32^3 domain-wall propagator is 2.25 GB which equals an equivalent of 6.1 jpsi-core hours. Hence calculating the cheapest 32^3 domain-wall propagator is about 36 times more expensive than storing it. To save all domain-wall propagators we intend to generate in 2011/12, we determine the total tape storage needed in Tab. 9 and estimate a total request of 28.2 TB. In addition to tape-storage we require disk space in the "/project" area for keeping and backing up our code, data- and log-files. We estimate a total need of 250 GB in the allocation period 2011/12. We would like to continue running on the Fermilab clusters, in particular jpsi is suited for the computation of heavy-quarks as well as the computation of 2-point and 3-point correlation functions. For the generation of domain-wall light quark propagators the ds cluster is a viable alternative. Two of the authors (R.V. and O.W.) are highly experienced in running on the Fermilab clusters and our additions to the Chroma code are compiled for both jpsi and ds. Moreover, the domain-wall inverter in Chroma has proven its great performance.

32^3 $a \approx 0.08$ fm domain-wall propagators	7.313 $\times 10^6$ jpsi core-hours
32^3 $a \approx 0.08$ fm clover propagators	1.755 $\times 10^6$ jpsi core-hours
24^3 $a \approx 0.11$ fm clover propagators	0.428 $\times 10^6$ jpsi core-hours
2-point and 3-point correlators and analysis	0.915 $\times 10^6$ jpsi core-hours
Total	10.411 $\times 10^6$ jpsi core-hours

Table 8. Computer time needed to determine the B^0-$\bar{B}^0$ mixing matrix elements and B-meson decay constants using the sea quark ensembles, valence quark masses, and numbers of propagators listed in Table 4 for the allocation period 2011/2012.

	TB	jpsi core-hours
32^3 and 24^3 propagators 2009-2011	64.8	174573
32^3 propagators 2011/12	28.2	75971
Total	93.0	250544

Table 9. Mass storage needed to save all of the domain-wall propagators listed in Table 4. The equivalent cost to store the file on tape uses the conversion 1 Tbyte tape = 2,694 jpsi core-hours.

Summary

By the end of the allocation period 2010/11 we hope to complete this project and expect to have a precise determination of the B-meson decay constants f_{B_d} and f_{B_s} as well as the $B^0 - \overline{B^0}$ mixing matrix elements, along with their ratio ξ. Tab. 11 shows our currently projected error budget for f_B and ξ based on conservative estimates. We do hope that our final values may even be better than that. Obtaining this result would fulfill one of the key goals in flavor physics as stated in the 2002 strategic plan and the 2007 white paper "Fundamental parameters from future lattice calculations" [10] of the USQCD collaboration. Our final result will be based on computations on two lattice spacings, multiple quark masses and heavy meson chiral perturbation theory, allowing us good control over the systematic errors asscoiated with both chiral and continuum extrapolations. Hence we expect to provide a valuable and independent crosscheck with errors competitive with those of HPQCD and Fermilab/MILC. When used in the unitarity triangle analysis, our results will place an important constraint on physics beyond the Standard Model.

We encourage other members of the lattice QCD community to make use of the domain-wall propagators we generate as part of this project in order to compute other interesting physics quanities. Within this project we intend to compute $B^0 - \overline{B^0}$ mixing matrix elements, their ratio ξ as well as the decay constants f_{B_d}, f_{B_s} and their ratio f_{B_s}/f_{B_d}. We would also like to retain exclusive rights to calculate $D-$ and D_s-meson decay constants and beyond the Standard Model contributions to B- and D-meson mixing as well as the coupling

	2009/2010	2010/2011	2011/2012
estimated	0.10 TB	0.20 TB	0.25 TB
Total	0.10 TB = 2694 jpsi core-hours	0.20 TB = 5388 jpsi core-hours	0.25 TB = 6735 jpsi core-hours

Table 10. Cumulative disk storage needed to save 2-point and 3-point correlation functions, logfiles, and analysis files in the "/project" area at Fermilab. The equivalent cost to store the file on disk uses the conversion 1 Tbyte disk = 26,940 jpsi core-hours.

	f_B	ξ
statistics	3%	2%
chiral extrapolation	3%	2%
uncertainty in $g_{B^*B\pi}$	1%	1%
renormalization factors	5%	2%
scale and quark mass uncertainties	2%	1%
finite volume error	1%	0.5%
(heavy-quark) discretization	2%	1%
total	7%	4%

Table 11. Currently projected error budget for f_B and ξ.

constants $g_{B^*B\pi}$ and $g_{D^*D\pi}$ using these propagators in the future. In case of f_D and f_{D_s}, Hao Peng has already started a project using non-USQCD resources at Columbia University. All generated propagators will be stored at Fermilab and will be made available immediately for non-competing analyses. Researchers who wish to use them should contact us to arrange access.

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