Light quark simulations with FLIC fermions

J. M. Zanotti[a*], D. B. Leinweber[a], W. Melnitchouk[b], A. G. Williams[a] and J. B. Zhang[a]

[a]Special Research Center for the Subatomic Structure of Matter, and
Department of Physics and Mathematical Physics, University of Adelaide, 5005, Australia

[b]Jefferson Lab, 12000 Jefferson Avenue, Newport News, VA 23606, U.S.A.

Hadron masses are calculated in quenched lattice QCD in order to probe the scaling behavior of a novel fat-link clover fermion action in which only the irrelevant operators of the fermion action are constructed using APE-smeared links. Light quark masses corresponding to an m_π/m_ρ ratio of 0.35 are considered to assess the exceptional configuration problem of clover-fermion actions. This Fat-Link Irrelevant Clover (FLIC) fermion action provides scaling which is superior to mean-field improvement and offers advantages over nonperturbative improvement, including reduced exceptional configurations.

1. INTRODUCTION

The Sheikholeslami-Wohlert (clover) action [1] is given by

$$S_{\rm SW} = S_{\rm W} - \frac{iC_{\rm SW}\kappa r}{2(u_0)^4}\,\bar\psi(x)\sigma_{\mu\nu}F_{\mu\nu}\psi(x)\ , \qquad (1)$$

where $S_{\rm W}$ is the standard Wilson action [2] and $C_{\rm SW}$ is the clover coefficient which can be tuned to remove $\mathcal{O}(a)$ artifacts. Nonperturbative (NP) $\mathcal{O}(a)$ improvement [3] tunes $C_{\rm SW}$ to all powers in g^2 and displays excellent scaling, as shown by Edwards *et al* [4].

However, the clover action is susceptible to the problem of exceptional configurations as the quark mass becomes small. In practice, this prevents the use of coarse lattices ($\beta < 5.7 \sim a > 0.18$ fm) [5,6]. Furthermore, the plaquette version of $F_{\mu\nu}$, which is commonly used in Eq. (1), has large $\mathcal{O}(a^2)$ errors, which can lead to errors of the order of 10% in the topological charge even on very smooth configurations [7].

Initial studies [8] using a Fat-Link Irrelevant Clover (FLIC) fermion action showed that, on a lattice with a spacing corresponding to $a^2\sigma \sim 0.08$, where σ is the string tension, it is possible to achieve superior scaling to that using a mean-field improved clover action. Furthermore, it is competitive with nonperturbatively improved clover without having to fine tune the coefficients of action improvement.

In this paper we expand on previous results [8] by examining the scaling of FLIC fermions at three different lattice spacings. We also investigate the problem of exceptional configurations by presenting preliminary results of simulations at light quark masses corresponding to $m_\pi/m_\rho = 0.35$.

2. GAUGE ACTION

The simulations are performed using a tree-level $\mathcal{O}(a^2)$–Symanzik-improved [9] gauge action on $12^3\times 24$ and $16^3\times 32$ lattices with lattice spacings of 0.093, 0.122 and 0.165 fm determined from the string tension with $\sqrt{\sigma} = 440$ MeV. A total of 200 configurations are used in the scaling analysis at each lattice spacing and volume. In addition, for the light quark simulations, 94 configurations are used on a $20^3 \times 40$ lattice with $a = 0.134$ fm. The error analysis is performed by a third-order, single-elimination jackknife, with the χ^2 per degree of freedom ($N_{\rm DF}$) obtained via covariance matrix fits.

3. FERMION ACTION

Fat links [6,10] are created using APE smearing [11] followed by a projection back to SU(3). We repeat this procedure of smearing and projection

---

*Presented by J. M. Zanotti

n times. Fat links are created by setting $\alpha = 0.7$ and $n = 4$. Further details of FLIC fermion actions can be found in Ref. [8]

As reported in Ref. [8], one finds that the plaquette measure $u_0 \approx 1$ for the fat links, so that the mean-field improved coefficient for C_{SW} is expected to be adequate. Also, one can now use highly improved definitions of $F_{\mu\nu}$. In particular, we employ an $\mathcal{O}(a^4)$ improved definition of $F_{\mu\nu}$ [12] in which the standard clover-sum of four 1×1 Wilson loops lying in the μ, ν plane is combined with 2×2 and 3×3 Wilson loop clovers. A fixed boundary condition is used for the fermions and gauge-invariant gaussian smearing [13] in the spatial dimensions is applied at the source to increase the overlap of the interpolating operators with the ground states.

4. RESULTS

The scaling behavior of the various actions is illustrated in Fig. 1. The present results for the Wilson action agree with those of Ref. [4]. The FLIC action performs systematically better than the mean-field improved clover, indicating that only 4 sweeps of smearing, combined with our $\mathcal{O}(a^4)$ improved $F_{\mu\nu}$, provides excellent results, without the fine tuning of C_{SW} in the NP improvement program. The FLIC results also compete well with those obtained with the NP-improved clover fermion action.

The two different volumes used at $a^2\sigma \sim 0.08$ suggest a small finite volume effect, which increases the mass for the smaller volume. Examination of points on the small and large volumes separately indicates scaling consistent with errors of $\mathcal{O}(a^2)$. This contrasts with mean-field improved results, where an extrapolation of the vector meson mass linear in $a^2\sigma$ cannot accommodate the continuum limit estimate. These results indicate that FLIC fermions provide a new form of nonperturbative $\mathcal{O}(a)$ improvement.

Previous work [8,14] has shown that the FLIC fermion action has extremely impressive convergence rates for matrix inversion, which provides great promise for performing cost effective simulations at quark masses closer to the physical values. Problems with exceptional configurations have prevented such simulations in the past.

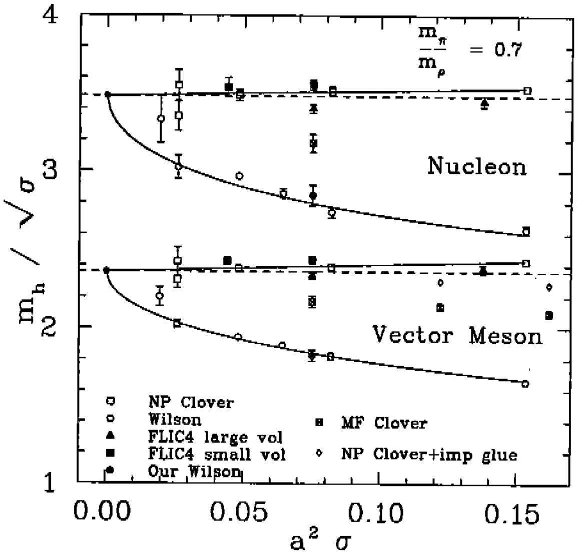

Figure 1. Nucleon and vector meson masses for the Wilson, NP-improved and FLIC actions obtained by interpolating the results to $m_\pi/m_\rho = 0.7$. For the FLIC action ("FLIC4"), fat links are constructed with $n = 4$ smearing sweeps at $\alpha = 0.7$. Results from the present simulations are indicated by the solid symbols; those from earlier simulations by open or hatched symbols.

The ease with which one can invert the fermion matrix using FLIC fermions leads us to attempt simulations down to small quark masses corresponding to $m_\pi/m_\rho = 0.35$. Previous attempts with Wilson-type fermion actions have only succeeded in getting down to $m_\pi/m_\rho = 0.47$ [15]. The simulations are on a $20^3 \times 40$ lattice with a physical length of 2.7 fm. We have used an initial set of 94 configurations, using $n = 6$ sweeps of smearing, and preliminary results indicate exceptional configurations at the 1% level [16]. Figure 2 shows the N and Δ masses as a function of m_π^2 for all eight masses considered. It is interesting to note an upward curvature in the Δ mass, increasing the $N - \Delta$ mass spitting for decreasing quark mass. This behavior has been predicted by Young *et al* [17].

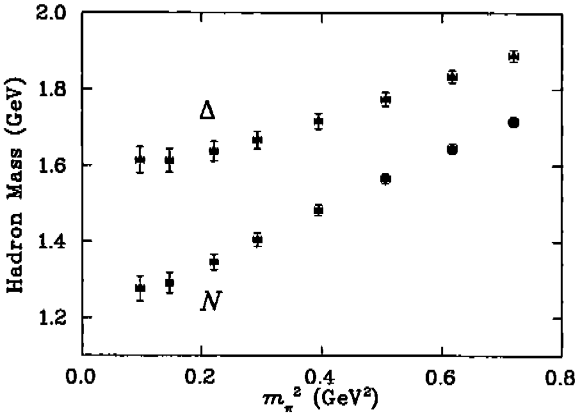

Figure 2. Nucleon and Δ masses for the FLIC action on a $20^3 \times 40$ lattice with $a = 0.134$ fm. 94 configurations were used and the fat links are constructed with $n = 6$ smearing sweeps at $\alpha = 0.7$.

5. CONCLUSIONS

We have calculated hadron masses to test the scaling of a novel Fat-Link Irrelevant Clover fermion action, in which only the irrelevant, higher-dimension operators involve smeared links. One of the main conclusions of this work is that the use of fat links in the irrelevant operators provides a new form of nonperturbative $\mathcal{O}(a)$ improvement. This technique competes well with $\mathcal{O}(a)$ nonperturbative improvement on mean field-improved gluon configurations, with the advantage of a reduced exceptional configuration problem.

Quenched simulations at quark masses down to $m_\pi/m_\rho = 0.35$ have been successfully performed on a $20^3 \times 40$ lattice with a lattice spacing of 0.134 fm. Simulations at such light quark masses hold promise for revealing non-analytic behaviour of quenched chiral perturbation theory.

We thank the Australian National Computing Facility for Lattice Gauge Theory, and the Australian Partnership for Advanced Computing (APAC) for supercomputer time. This work was supported by the Australian Research Council. W.M. was supported by the U.S. Department of Energy contract DE-AC05-84ER40150, under which the Southeastern Universities Research Association (SURA) operates the Thomas Jefferson National Accelerator Facility (Jefferson Lab).

REFERENCES

1. B. Sheikholeslami and R. Wohlert, Nucl. Phys. **B259** 572, (1985).
2. K.G. Wilson, in *New Phenomena in Subnuclear Physics*, Part A, A. Zichichi (ed.), Plenum Press, New York, p. 69, 1975.
3. M. Luscher *et al.*, Nucl. Phys. **B478**, 365 (1996). M. Luscher *et al.*, Nucl. Phys. **B491**, 323, 344 (1997).
4. R.G. Edwards, U.M. Heller and T.R. Klassen, Phys. Rev. Lett. **80**, 3448 (1998); see also R.D. Kenway, Nucl. Phys. Proc. Suppl. **73**, 16 (1999), for a review.
5. W. Bardeen *et al.*, Phys. Rev. D **57**, 1633 (1998); W. Bardeen *et al.*, Phys. Rev. D **57**, 3890 (1998).
6. T. DeGrand *et al.* (MILC Collaboration), hep-lat/9807002.
7. F.D. Bonnet *et al.*, Phys. Rev. D **62**, 094509 (2000).
8. J.M. Zanotti *et al.*, Phys. Rev. D **60**, 074507 (2002); Nucl. Phys. Proc. Suppl. **109**, 101 (2002).
9. K. Symanzik, Nucl. Phys. **B226**, 187 (1983).
10. T. DeGrand (MILC collaboration), Phys. Rev. D **60**, 094501 (1999).
11. M. Falcioni *et al.*, Nucl. Phys. **B251**, 624 (1985); M. Albanese *et al.*, Phys. Lett. B **192**, 163 (1987).
12. S. Bilson-Thompson *et al.*, Nucl. Phys. Proc. Suppl. **109**, 116 (2002); hep-lat/0203008.
13. S. Gusken, Nucl. Phys. Proc. Suppl. **17**, 361 (1990).
14. W. Kamleh *et al.*, Phys. Rev. D **66**, 014501 (2002).
15. M.D. Morte *et al.*, hep-lat/0111048.
16. J.M. Zanotti *et al.*, in preparation.
17. R.D. Young *et al.*, hep-lat/0205017.