Matthew B. Wingate – Research Interests

1 Overview

My main research interest is in using field theory techniques to study strongly coupled systems. There are many exciting and important questions in this direction which I have studied in the past or would like to pursue in the future (a few are listed in Section 4). This brief statement focuses two topics to which I have devoted most of my recent effort. The first project is part of a large program in particle physics to use quark flavor-changing interactions to constrain the parameters of the Standard Model (see Sec. 2). Our lattice QCD calculations of B meson properties have reduced the theoretical uncertainties entering into fits of the Standard Model parameters. The second project is the application of field theory to problems in the interdisciplinary field of cold atomic gases (see Sec. 3). I have worked on numerical simulation of strongly interacting Fermi gases and on an effective field theory for phonon excitations in the superfluid phase.

2 Fundamental Parameters of the Standard Model

Since quarks are confined to nonperturbative bound states, lattice QCD calculations are crucial ingredients for constraining many of the Standard Model parameters. The lattice calculations connect the quark-level interactions of the Standard Model to the meson-level processes observed in experiments. My work has focused on determining the quark masses [3, 4, 13] and the parameters which govern quark flavor-changing interactions [24, 2, 26, 30, 6, 9, 14]. Flavor physics is particularly exciting because any physics beyond the Standard Model should contribute to some of the experimental measurements; fits to the data which only include Standard Model calculations should eventually see deviations and give indirect evidence for new physics.

In order for lattice QCD calculations to be useful, the theoretical uncertainties must be reliably estimated and systematically improvable. One obstacle to such a clean calculation was the inability to properly include virtual quark effects. We recently demonstrated [7] that we could clear this hurdle by using an improved version [19] of so-called "staggered" lattice fermions. Furthermore we demonstrated the benefits of using staggered fermions combined with standard heavy lattice fermions to study heavy-light mesons [8].

With this formulation, we have been working toward precise, accurate calculations of matrix elements involving B mesons (quark–antiquark states including a bottom quark). In particular, lattice calculations of $B^0 - \overline{B^0}$ mixing parameters, B and B_s leptonic decay constants, and semileptonic form factors for $B \to \pi\ell\nu$ and $B \to D\ell\nu$ are essential ingredients to the entire program of constraining the CKM matrix elements of the Standard Model. The first fruit of our efforts was the calculation of the B_s and D_s decay constants [6]. Recently we published results for the B decay constant, achieving much greater control over the light quark mass extrapolation [2] than previous work. Calculations of the form factors which parameterize $B \to \pi\ell\nu$ decay are in progress. These will help reduce the uncertainties on $|V_{ub}|$; in fact, our preliminary results [30, 26] are already as precise as the one quoted in the Particle Data Book. Our final results have recently appeared [24]. We have also embarked on calculating the matrix elements needed to combine lattice results with experimental measurements for the $B^0 - \overline{B^0}$ mass difference in order to determine $|V_{td}|$ [29].

In the summer of 2004, I was invited to review flavor physics on the lattice at the XXII International Symposium on Lattice Field Theory (*Lattice 2004*) [22] and the XXIV Physics in Collision Conference [23]. I am presently working on an invited brief review for *Modern Physics Letters A*.

3 Superfluidity of Cold Atomic Gases

Since the creation of a Bose-Einstein condensate in a gas of alkali atoms, a new genre of versatile experiments has emerged. For example, the physics of semiconductors can be modeled cleanly by atoms in an optical lattice. Vortices are more robust in dilute atomic superfluids than in liquid helium. Scattering lengths of dilute Fermi gases are tunable by application of a magnetic field, reproducing some of the physics of nuclear matter. Finally, the separation of length scales in these gases makes them amenable to description by effective field theory.

I have been focusing on dilute gases of 2-component fermions with large scattering lengths. Once the scattering length a becomes large compared to the average interparticle spacing, standard mean field analysis breaks down. Lattice field theory and Monte Carlo simulations allow one to study this system nonperturbatively. The case where $1/a = 0$ is especially interesting since the system becomes universal, insensitive to any short-distance properties of the system.

My first numerical studies using this method indicated the existence of a continuum limit for the lattice theory, a necessity for the theory to be a first-principles approach to studying this system [28]. The next step was an exploratory study searching for the critical temperature below which superfluidity occurs [25]. Presently the goal is to more precisely map the parameters of the simulations to physical quantities. As a result I will be able to determine the critical temperature from small positive scattering length where the fermions form molecules and Bose condense, to small negative scattering length where the fermions form Cooper pairs and a BCS superfluid, and the entire range of $-\infty < 1/a < \infty$.

Recently, Son and I have developed an effective field theory for phonon excitations in the low temperature superfluid, allowing one to calculate corrections to superfluid hydrodynamics and Thomas-Fermi theory [1]. I am working with J.-W. Chen to extend this effective field theory so that it may be used reduce uncertainties in lattice simulation results.

4 Future Directions

In addition to the questions above, there are several others which excite me and which I would like to address in the future. I list these here with brief remarks.

Nucleon structure and interactions: Despite the simplicity of the QCD Lagrangian, the structure of and interactions between nucleons emerges in a very complicated way from QCD. In order to validate existing models of hadron structure, or to inspire new ones, accurate lattice QCD calculations are needed. Going beyond single hadrons, it would be very rewarding to understand the building blocks of nuclei directly from QCD, specifically one would like to compute coefficients of the nuclear effective Lagrangian using lattice QCD.

Extreme QCD: The phase diagram of QCD could be very rich. I worked on lattice methods for hot QCD as part of my thesis work [16]. Finding a new avenue to study dense QCD, for which lattice QCD has a sign problem, would allow us to accurately map the QCD phase diagram. Nonrelativistic Fermi gases provide a new system to study: there is no sign problem for equal chemical potentials for the 2 species, but one can introduce a sign problem by taking $\mu_1 \neq \mu_2$.

Numerical methods for fermions: Algorithms for simulating fermionic systems are generally much slower than for bosonic systems. Despite the effort of many people, progress has been incremental. Nevertheless, I feel strongly that there must be a way to formulate many body problems for fermions which is on equal footing with bosonic many body problems. Given the enormity of the reward for a solution, it is worth investing some thought on this conundrum.

Matthew B. Wingate – Publications

1 Refereed Articles and Letters

1. **"General coordinate invariance and conformal invariance in nonrelativistic physics: Unitary Fermi gas"**
   D. T. Son and M. Wingate
   Annals of Physics **321**, 197 (2006), [arXiv:cond-mat/0509786] SPIRES entry

2. **"The B Meson Decay Constant from Unquenched Lattice QCD"**
   A. Gray, M. Wingate, C. T. H. Davies, E. Gulez, G. P. Lepage, Q. Mason, M. Nobes, and J. Shigemitsu
   Phys. Rev. Lett. **95**, 212001 (2005) [arXiv:hep-lat/0507015] SPIRES entry

3. **"The Upsilon spectrum and m_b from full lattice QCD"**
   A. Gray, I. Allison, C. T. H. Davies, E. Gulez, G. P. Lepage, J. Shigemitsu and M. Wingate
   Phys. Rev. D **72**, 094507 (2005) [arXiv:hep-lat/0507013] SPIRES entry

4. **"First determination of the strange and light quark masses from full lattice QCD"**
   C. Aubin *et al.* [HPQCD/MILC/UKQCD Collaborations]
   Phys. Rev. D **70**, 031504 (2004) [arXiv:hep-lat/0405022] SPIRES entry

5. **"One-loop matching of the heavy-light A_0 and V_0 currents with NRQCD heavy and improved naive light quarks"**
   E. Gulez, J. Shigemitsu and M. Wingate
   Phys. Rev. D **69**, 074501 (2004) [arXiv:hep-lat/0312017] SPIRES entry

6. **"The B_s and D_s decay constants in 3 flavor lattice QCD"**
   M. Wingate, C. T. H. Davies, A. Gray, G. P. Lepage and J. Shigemitsu
   Phys. Rev. Lett. **92**, 162001 (2004) [arXiv:hep-ph/0311130] SPIRES entry

7. **"High-precision lattice QCD confronts experiment"**
   C. T. H. Davies *et al.* [HPQCD Collaboration]
   Phys. Rev. Lett. **92**, 022001 (2004) [arXiv:hep-lat/0304004] SPIRES entry

8. **"Heavy-light mesons with staggered light quarks"**
   M. Wingate, J. Shigemitsu, C. T. H. Davies, G. P. Lepage and H. D. Trottier
   Phys. Rev. D **67**, 054505 (2003) [arXiv:hep-lat/0211014] SPIRES entry

9. **"Kaon matrix elements and CP-violation from quenched lattice QCD. I: The 3-flavor case"**
   T. Blum *et al.* [RBC Collaboration]
   Phys. Rev. D **68**, 114506 (2003) [arXiv:hep-lat/0110075] SPIRES entry

10. **"Non-perturbative renormalisation of domain wall fermions: Quark bilinears"**
    T. Blum *et al.* [RBC Collaboration]
    Phys. Rev. D **66**, 014504 (2002) [arXiv:hep-lat/0102005] SPIRES entry

11. **"Quenched lattice QCD with domain wall fermions and the chiral limit"**
T. Blum *et al.* [RBC Collaboration]
Phys. Rev. D **69**, 074502 (2004) [arXiv:hep-lat/0007038] SPIRES entry

12. **"Deconfinement transition and string tensions in SU(4) Yang-Mills theory"**
M. Wingate and S. Ohta
Phys. Rev. D **63**, 094502 (2001) [arXiv:hep-lat/0006016] SPIRES entry

13. **"Calculation of the strange quark mass using domain wall fermions"**
T. Blum, A. Soni and M. Wingate
Phys. Rev. D **60**, 114507 (1999) [arXiv:hep-lat/9902016] SPIRES entry

14. **"Lattice determination of heavy-light decay constants"**
C. W. Bernard *et al.*
Phys. Rev. Lett. **81**, 4812 (1998) [arXiv:hep-ph/9806412] SPIRES entry

15. **"Exotic mesons in quenched lattice QCD"**
C. W. Bernard *et al.* [MILC Collaboration]
Phys. Rev. D **56**, 7039 (1997) [arXiv:hep-lat/9707008] SPIRES entry

16. **"QCD thermodynamics with an improved lattice action"**
C. W. Bernard *et al.* [MILC Collaboration]
Phys. Rev. D **56**, 5584 (1997) [arXiv:hep-lat/9703003] SPIRES entry

17. **"The equation of state for two flavor QCD at $N_t = 6$"**
C. W. Bernard *et al.* [MILC Collaboration]
Phys. Rev. D **55**, 6861 (1997) [arXiv:hep-lat/9612025] SPIRES entry

18. **"Which chiral symmetry is restored in high temperature QCD?"**
C. W. Bernard *et al.*
Phys. Rev. Lett. **78**, 598 (1997) [arXiv:hep-lat/9611031] SPIRES entry

19. **"Improving flavor symmetry in the Kogut-Susskind hadron spectrum"**
T. Blum *et al.*
Phys. Rev. D **55**, 1133 (1997) [arXiv:hep-lat/9609036] SPIRES entry

20. **"Properties of the a_1 meson from lattice QCD"**
M. Wingate, T. DeGrand, S. Collins and U. M. Heller
Phys. Rev. Lett. **74**, 4596 (1995) [arXiv:hep-ph/9502274] SPIRES entry

21. **"From spectroscopy to the strong coupling constant with heavy Wilson quarks"**
M. Wingate, T. DeGrand, S. Collins and U. M. Heller
Phys. Rev. D **52**, 307 (1995) [arXiv:hep-lat/9501034] SPIRES entry

2 Invited Reviews

22. **"Status of lattice flavor physics"**
M. Wingate
Nucl. Phys. Proc. Suppl. **140**, 68 (2005) [arXiv:hep-lat/0410008]

Invited talk delivered at the 22nd International Symposium on Lattice Field Theory (Lattice 2004), Batavia, Illinois, 21-26 Jun 2004 SPIRES entry

23. **"Lattice QCD and flavor physics"**
Matthew Wingate
eConf **C0406271**, TUET01 (2004) [arXiv:hep-ph/0409099]
Invited talk at the XXIV Physics in Collision Conference (PIC04), Boston, USA, 27-29 June 2004 SPIRES entry

3 Preprints

24. **"B meson semileptonic form factors from unquenched lattice QCD"**
E. Gulez, A. Gray, M. Wingate, C.T.H. Davies, G.P. Lepage, and J. Shigemitsu
arXiv:hep-lat/0601021 SPIRES entry

25. **"Critical temperature for fermion pairing using lattice field theory"**
M. Wingate
arXiv:cond-mat/0502372 SPIRES entry

4 Conference Proceedings – Selected Contributions

26. **"B semileptonic decays with 2+1 dynamical quark flavors"**
E. Gulez, C. Davies, A. Gray, P. Lepage, J. Shigemitsu and M. Wingate
arXiv:hep-lat/0510002

27. **"B Decays on the Lattice and Results for Phenomenology"**
M. Wingate, C. Davies, A. Gray, E. Gulez, J. Shigemitsu and G.P. Lepage
Int. J. Mod. Phys. A **20**, 3651 (2005) [arXiv:hep-ph/0411236] SPIRES entry
Contributed to the Proceedings of American Physical Society's 2004 Meeting of the Division of Particles and Fields (DPF2004), Riverside, CA, 26-31 August 2004

28. **"Exploring lattice methods for cold fermionic atoms"**
M. Wingate
Nucl. Phys. Proc. Suppl. **140**, 592 (2005) [arXiv:hep-lat/0409060] SPIRES entry
Contributed to the 22nd International Symposium on Lattice Field Theory (Lattice 2004), Batavia, Illinois, 21-26 Jun 2004

29. **"B leptonic Decays and $B^0 - \overline{B^0}$ mixing with 2+1 flavors of dynamical quarks"**
A. Gray, C. Davies, E. Gulez, G. P. Lepage, J. Shigemitsu and M. Wingate
Nucl. Phys. Proc. Suppl. **140**, 446 (2005) [arXiv:hep-lat/0409040] SPIRES entry
Contributed to the 22nd International Symposium on Lattice Field Theory (Lattice 2004), Batavia, Illinois, 21-26 Jun 2004

30. **"Semileptonic B decays with $N_f = 2+1$ dynamical quarks"**
J. Shigemitsu *et al.*
Nucl. Phys. Proc. Suppl. **140**, 464 (2005) [arXiv:hep-lat/0408019] SPIRES entry
Contributed to the 22nd International Symposium on Lattice Field Theory (Lattice 2004), Batavia, Illinois, 21-26 Jun 2004

31. **"Heavy-light meson semileptonic decays with staggered light quarks"**
J. Shigemitsu, C. T. H. Davies, A. Gray, E. Gulez, G. P. Lepage and M. Wingate
Nucl. Phys. Proc. Suppl. **129**, 331 (2004) [arXiv:hep-lat/0309039] SPIRES entry
Contributed to the 21st International Symposium on Lattice Field Theory (Lattice 2003), Tsukuba, Ibaraki, Japan, 15-19 Jul 2003

32. **"Progress calculating decay constants with NRQCD and AsqTad actions"**
M. Wingate, C. Davies, A. Gray, E. Gulez, G. P. Lepage and J. Shigemitsu
Nucl. Phys. Proc. Suppl. **129**, 325 (2004) [arXiv:hep-lat/0309092] SPIRES entry
Contributed to the 21st International Symposium on Lattice Field Theory (Lattice 2003), Tsukuba, Ibaraki, Japan, 15-19 Jul 2003

33. **"The Υ spectrum from lattice QCD with 2+1 flavors of dynamical quarks"**
A. Gray *et al.* [HPQCD collaboration]
Nucl. Phys. Proc. Suppl. **119**, 592 (2003) [arXiv:hep-lat/0209022] SPIRES entry
Contributed to the 20th International Symposium on Lattice Field Theory (Lattice 2002), Boston, Massachusetts, 24-29 Jun 2002

34. **"B_s mesons using staggered light quarks"**
M. Wingate, J. Shigemitsu, G. P. Lepage, C. Davies and H. Trottier
Nucl. Phys. Proc. Suppl. **119**, 604 (2003) [arXiv:hep-lat/0209096] SPIRES entry
Contributed to the 20th International Symposium on Lattice Field Theory (Lattice 2002), Boston, Massachusetts, 24-29 Jun 2002

35. **"The determination of α_s from lattice QCD with 2+1 flavors of dynamical quarks"**
C. Davies *et al.*
Nucl. Phys. Proc. Suppl. **119**, 595 (2003) [arXiv:hep-lat/0209122] SPIRES entry
Contributed to the 20th International Symposium on Lattice Field Theory (Lattice 2002), Boston, Massachusetts, 24-29 Jun 2002

36. **"Heavy-light physics using NRQCD-staggered actions"**
M. Wingate, J. Shigemitsu and G. P. Lepage
Nucl. Phys. Proc. Suppl. **106**, 379 (2002) [arXiv:hep-lat/0110161] SPIRES entry
Contributed to the 19th International Symposium on Lattice Field Theory (Lattice 2001), Berlin, Germany, 19-24 Aug 2001

37. **"Light quark masses from quenched lattice QCD simulations with domain wall quarks"**
M. Wingate *et al.* [RIKEN-BNL-CU Collaboration]
Int. J. Mod. Phys. A **16S1B**, 585 (2001) [arXiv:hep-lat/0009022] SPIRES entry
Contributed to The Meeting of the Division of Particles and Fields of the American Physical Society (DPF 2000), Columbus, Ohio, 9-12 Aug 2000

38. **"Light hadronic physics using domain wall fermions in quenched lattice QCD"**
M. Wingate [RIKEN-BNL-CU Collaboration]
Nucl. Phys. Proc. Suppl. **94**, 277 (2001) [arXiv:hep-lat/0009023] SPIRES entry
Contributed to the 18th International Symposium on Lattice Field Theory (Lattice 2000), Bangalore, India, 17-22 Aug 2000

39. **"Domain wall fermions and the strange quark mass"**
M. Wingate
Nucl. Phys. Proc. Suppl. **86**, 224 (2000) [arXiv:hep-ph/9909382] SPIRES entry
Contributed to High Energy Physics International Euroconference on Quantum Chromo Dynamics (QCD 99), Montpellier, France, 7-13 Jul 1999

40. **"Quark masses using domain wall fermions"**
M. Wingate
Nucl. Phys. Proc. Suppl. **83**, 221 (2000) [arXiv:hep-lat/9909101] SPIRES entry
Contributed to the 17th International Symposium on Lattice Field Theory (Lattice 99), Pisa, Italy, 29 Jun - 3 Jul 1999

41. **"SU(4) pure-gauge phase structure and string tensions"**
S. Ohta and M. Wingate
Nucl. Phys. Proc. Suppl. **83**, 381 (2000) [arXiv:hep-lat/9909125] SPIRES entry
Contributed to the 17th International Symposium on Lattice Field Theory (Lattice 99), Pisa, Italy, 29 Jun - 3 Jul 1999

42. **"SU(4) pure-gauge string tensions"**
S. Ohta and M. Wingate
Nucl. Phys. Proc. Suppl. **73**, 435 (1999) [arXiv:hep-lat/9808022] SPIRES entry
Contributed to the 16th International Symposium on Lattice Field Theory (Lattice 98), Boulder, CO, 13-18 Jul 1998

43. **"Light quark masses using domain wall fermions"**
M. Wingate, T. Blum and A. Soni
Nucl. Phys. Proc. Suppl. **73**, 201 (1999) [arXiv:hep-lat/9809065] SPIRES entry
Contributed to the 16th International Symposium on Lattice Field Theory (Lattice 98), Boulder, CO, 13-18 Jul 1998

44. **"Heavy-light decay constants: Conclusions from the Wilson action"**
C. W. Bernard *et al.*
Nucl. Phys. Proc. Suppl. **73**, 372 (1999) [arXiv:hep-lat/9809109] SPIRES entry
Contributed to the 16th International Symposium on Lattice Field Theory (Lattice 98), Boulder, CO, 13-18 Jul 1998

45. **"MILC studies of high temperature QCD: A progress report"**
C. W. Bernard *et al.*
Nucl. Phys. Proc. Suppl. **60A**, 195 (1998) SPIRES entry
Prepared for International Workshop on Lattice QCD on Parallel Computers, Tsukuba, Japan, 10-15 Mar 1997

46. **"Towards the QCD spectrum with dynamical quarks"**
C. W. Bernard *et al.*
Nucl. Phys. Proc. Suppl. **60A**, 297 (1998) SPIRES entry
Prepared for International Workshop on Lattice QCD on Parallel Computers, Tsukuba, Japan, 10-15 Mar 1997

47. **"Heavy-light decay constants from Wilson and static quarks"**
C. W. Bernard *et al.*

Nucl. Phys. Proc. Suppl. **63**, 362 (1998) [arXiv:hep-lat/9709142] SPIRES entry
Contributed to the 15th International Symposium on Lattice Field Theory (Lattice 97), Edinburgh, Scotland, 22-26 Jul 1997

48. **"Light quark spectrum with improved gauge and fermion actions"**
C. W. Bernard *et al.* [MILC Collaboration]
Nucl. Phys. Proc. Suppl. **63**, 182 (1998) [arXiv:hep-lat/9711013] SPIRES entry
Contributed to the 15th International Symposium on Lattice Field Theory (Lattice 97), Edinburgh, Scotland, 22-26 Jul 1997

49. **"Heavy-light decay constants: MILC results with the Wilson action"**
C. W. Bernard *et al.* [MILC Collaboration]
Nucl. Phys. Proc. Suppl. **60A**, 106 (1998) [arXiv:hep-lat/9707013] SPIRES entry
Contributed to International Workshop on Lattice QCD on Parallel Computers, Tsukuba, Japan, 10-15 Mar 1997

50. **"Finite temperature lattice QCD with clover fermions"**
C. W. Bernard *et al.*
Nucl. Phys. Proc. Suppl. **53**, 446 (1997) [arXiv:hep-lat/9607085] SPIRES entry
Contributed to the 14th International Symposium on Lattice Field Theory (Lattice 96), St. Louis, MO, 4-8 Jun 1996

51. **"Thermodynamics for two flavor QCD"**
C. W. Bernard *et al.*
Nucl. Phys. Proc. Suppl. **53**, 442 (1997) [arXiv:hep-lat/9608026] SPIRES entry
Contributed to the 14th International Symposium on Lattice Field Theory (Lattice 96), St. Louis, MO, 4-8 Jun 1996

52. **"Assorted weak matrix elements involving the bottom quark"**
C. W. Bernard *et al.*
Nucl. Phys. Proc. Suppl. **53**, 374 (1997) [arXiv:hep-lat/9608088] SPIRES entry
Contributed to the 14th International Symposium on Lattice Field Theory (Lattice 96), St. Louis, MO, 4-8 Jun 1996

53. **"Update on f_B"**
C. W. Bernard *et al.* [MILC Collaboration]
Nucl. Phys. Proc. Suppl. **53**, 358 (1997) [arXiv:hep-lat/9608092] SPIRES entry
Contributed to the 14th International Symposium on Lattice Field Theory (Lattice 96), St. Louis, MO, 4-8 Jun 1996

54. **"f_B quenched and unquenched"**
C. W. Bernard *et al.*
Nucl. Phys. Proc. Suppl. **47**, 459 (1996) [arXiv:hep-lat/9509045] SPIRES entry
Contributed to the 13th International Symposium on Lattice Field Theory (Lattice 95), Melbourne, Australia, 11-15 Jul 1995

55. **"P wave meson properties with Wilson quarks"**
M. Wingate, T. DeGrand, S. Collins and U. M. Heller
Nucl. Phys. Proc. Suppl. **42**, 373 (1995) [arXiv:hep-lat/9411041] SPIRES entry

Contributed to the 12th International Symposium on Lattice Field Theory (Lattice 94), Bielefeld, Germany, 27 Sep - 1 Oct 1994