DOE/ER/40762-521

THEORETICAL STUDIES IN HADRONIC AND NUCLEAR PHYSICS

Annual Progress Report for Research Supported by the U. S. Department of Energy

Submitted July 2012

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Period of Time This Report Covers: 2011 - (July) 2012

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DOE Award No.: DE-FG02-93ER-40762

Budget Periods: Budget Period: December 1, 2011–November 30, 2012 (Year 2 of 3)
Estimated Unexpended Funds: We do not anticipate any unexpended funds over 10%.

Contents

I. INTRODUCTION AND ADMINISTRATIVE OVERVIEW

1. Research

Abstract: Theoretical research is proposed with the goals of 1.) understanding particles such as protons and neutrons in terms of the fundamental theory of Quantum Chromodynamics (QCD), 2.) understanding the mass spectrum of particles, called hadrons, that can be formed from the binding of quarks and gluons, and 3.) understanding the origin of the forces between hadrons such as those that cause neutrons and protons to bind into nuclei.

The Theoretical Quarks, Hadrons and Nuclei group at the University of Maryland carries out a very broad research program centered on the study of hadronic physics. Its main goal is the understanding of the structure of particles such as protons and neutrons, and their interactions, in terms of the fundamental theory of Quantum Chromodynamics. For that we explore an array of analytical and numerical non-perturbative techniques in field theory and their impact on nuclear phenomenology. It also includes substantial effort in related areas such as neutrino physics, cold atoms, dark matter and non-perturbative techniques for gauge theories.

This progress report thus includes a large number of specific topics. They are organized below under the names of the faculty members more directly involved in each project but, given the highly interactive nature of our group, more than one group member may be involved in any of these topics. In addition, our postdocs (and students) are given the freedom and encouragement to pursue their own projects and have been very successful at that. Following the faculty sections are the reports of our postdoctoral research associates on studies they are carrying out independently.

2. The Theoretical Quarks, Hadrons and Nuclei Group at Maryland (TQNH)

A. Personnel and the Evolving History of the TQHN

The faculty of the TQHN presently consists of Professors Xiangdong Ji and Thomas Cohen, Associate Professor Paulo Bedaque and Research Professor Stephen Wallace.

Professor Cohen continued as the director of the Maryland Center for Fundamental Physics (MCFP) until July 1, 2012. This center is one of the largest theory centers in the country and includes research in particle theory, cosmology and gravity as well as nuclear physics. The Center is supported with state funding which will increase over the next few years. MCFP provides support for students, postdocs, visitors, workshops, *etc.* We have been able in many instances to use our DOE grant to leverage additional resources from the MCFP.

In addition to his duties at Maryland, Prof. Ji is Dean of Physics at Shanghai JiaoTong University. The position in Shanghai is part-time requiring Prof. Ji to spend approximately 1/3 of his time in China. As a result of this position, Prof. Ji's teaching load at Maryland has been reduced and his available time for research in nuclear physics has been essentially unaffected. This connection to China is extremely valuable in terms of international scientific collaborations and is of great benefit to the TQHN Group. We are able to attract some of the very best Chinese students and postdocs to Maryland; these are typically supported through Chinese sources.

Beginning Fall of 2012, Dr. Ilmo Sung will end his second year of a two-year term as a postdoctoral research associate, and Dr. Amy Nicholson will start her second year of a three-year term. Dr. Simin Mahmoodifar will join the group as a research associate after having recently completed her Ph.D. from Washington University, St. Louis under the supervision of Prof. Mark Alford. Dr. Naoki Yamamoto of the Inst. for Nuclear Theory, University of Washington will also join the group with his first year supported by a Research Fellowship for Young Scientists from the Japan Society for the Promotion of Science. We plan to continue his appointment for academic year 2013-2014 with salary supported from the grant, renewable for a third term for academic year 2014-2015, pending availability of grant funds.

The graduate students in the group include Evan Berkowitz (advisor: Prof. Bedaque), who held a SURA fellowship for academic year 2011-2012, Vojtech Krejcirik and Prabal Adhikari (advisor for both: Prof. Cohen), Srimoyee Sen (advisor: Prof. Bedaque), and Yong Zhao (advisor: Prof. Ji). From Spring 2011 to Spring 2012, Yang Xu of Peking University was supported through a scholarship from the China Scholarship Council supplemented with support from Peking University to pursue her studies in the U.S. as a joint Ph.D. student at the University of Maryland under the supervision of Prof. Ji. During Fall 2011 through Spring 2012 semesters, graduate student Chen Li was supported by the grant to work on a research project with Prof. Ji.

In Summer 2012, Arec Jamgochian, a recent graduate of Blair High School, and Patrick Jefferson, who will be an undergraduate at Maryland in Fall 2012, are working on projects with Prof. Cohen. Phillip Cai and Thomas Loomis, currently students at Blair High School, are also working with Prof. Cohen on research projects. Although the high school students are not supported by the group, they contribute notably toward their faculty's research projects.

A list of all TQHN personnel, graduate student tracking information and career history of recent research associates and graduate students follow the faculty biographical sketches.

The group's activities have been supported by one full-time administrative assistant, Loretta Robinette, providing logistical assistance, coordination of group events, and some administrative requirements related to the grant's operations for the faculty, postdocs, students and visitors; maintaining our inventory and overseeing repair service requests for over 20 computers and printers; assisting with the technical aspects and editing of research-related documents and DOE reports; serving as our group's webmaster; and assisting with arrangements for workshops. The Department of Physics provided $7,000 for secretarial support in the 2011-2012 academic year; $4,000 of which was from the Maryland Center for Fundamental Physics (MCFP). As of July 1, 2012, Mrs. Robinette will be retired, and the administrative assistance for the group's travel and visitor hosting will be handled by the MCFP office.

B. Research Environment

We have strived to maintain an informal, highly interactive atmosphere in the nuclear theory group. On a typical day there will be discussions on the blackboard involving several members of the group. During Spring and Fall we have our weekly nuclear seminar program (held jointly with the experimental group) and periodic MCFP colloquia. The interactions with the rest of the MCFP is likely to increase when, in the near future, the TQHN group will move together with all the other members of the MCFP to the top floor of the new "Physical Sciences Complex", a state-of-the-art facility housing also the Astronomy Department. This environment, in addition to all the activities in the other parts of the Department, makes our program very attractive to graduate students and postdocs.

C. Visitors Program

We maintain an active visitors program with seminar speakers and collaborators at all stages of their careers visiting Maryland from a few days to a year at a time. Associate Prof. Yu Jia visited for six months in 2011 from the IHEP, Chinese Academy of Science, Beijing, in 2011 and collaborated with Profs. Ji, Bedaque and Cohen on quantum chromodynamics, heavy quarkonium physics and effective field theory.

Altogether we had 46 national and international visitors in 2011-July 2012 including seminars speakers whose expenses were either covered by the experimental nuclear physics group or shared with the elementary particles group and nearby George Washington University. Their presence contributes enormously to the vitality of our group. We have also been able to reduce costs in our seminar program by scheduling local colleagues.

II. RECENT RESEARCH ACCOMPLISHMENTS BY FACULTY

This section of the Progress Report describes the research accomplished during the last period of DOE support (2011-2012).

1. Prof. Thomas D. Cohen

During the past year Professor Cohen's research has focused predominantly on aspects of large N_c QCD and on the Hagedorn Spectrum. Much of the work at large N_c focuses on nucleon-nucleon scattering.

A. Does the Empirical Meson Spectrum Support the Hagedorn Conjecture?

It has long been conjectured that strong interactions give rise to a Hagedorn spectrum and theoretical arguments have been presented in support of Hagedorn spectrum in large N_c QCD. This work evaluated the extent to which the meson spectrum should be viewed as evidence for a Hagedorn spectrum and concludes that data do not provide a strong evidence for the Hagedorn conjecture. The conclusion is based on three reasons. It is shown that "realistic" quark models have a spectrum in which the number of mesons up to 2.3 GeV grows with mass in a very similar way to the spectrum of physical mesons up to 2.3 GeV. However, these models can be shown not to have Hagedorn spectra. It is also shown that the available data are insufficient to determine the Hagedorn temperature. The data can be described with comparable accuracy by various functional forms of the prefactor that yield radically different Hagedorn temperatures. An analysis of the behavior of the spectrum for the various parity-spin-charge conjugation-isospin channels also appears to be inconsistent with what one expects if the data were in the regime dominated by exponential behavior.

This work was done in collaboration with graduate student Vojtech Krejcirik and published in Phys. G **39**, *055001 (2012).*

B. Total Nucleon-Nucleon Cross Sections in Large N_c QCD

The contracted spin-flavor symmetry which emerges in the large N_c limit of QCD was used to obtain relations between proton-proton and proton-neutron total cross sections for both polarized and unpolarized scattering. The formalism used is valid in the semiclassical regime in which the relative momentum of the incident nucleons is much larger than the inverse size of the nucleon, provided that certain technical assumptions are met. The relations should be phenomenologically useful provided that $N_c = 3$ is sufficiently large so that the large N_c results have at least semi-quantitative predictive power. The relations are model independent in the sense that they depend on properties of large N_c QCD only and not on any particular model-dependent details of the nucleon-nucleon interaction. We compare these model-independent results to experimental data. The relation for spin-unpolarized scattering works well empirically. For the case of polarized scattering, the data is consistent with the relations but the cross sections are too small to make sharp predictions.

This work was done in collaboration with Boris Gelman of CUNY and published in Phys.Rev. C **85**, *024001 (2012).*

C. Model-Independent Form Factor Relations at Large N_c

In this work a model-independent relation which holds for the long distance part of the Fourier transform of the electromagnetic form factors of the nucleon in the large N_c and chiral limits is demonstrated. This relation was previously conjectured based on the fact that it emerged in *all* semiclassical chiral models independent of the details of the model. Here it is shown that the result is, in fact, model independent by deriving it directly in large N_c chiral perturbation theory (which is known to capture the long distance behavior of the form factors.) The relation is valid when the large N_c limit is formally taken before the chiral limit. A new relation is derived for the case where the chiral limit is taken prior to the large N_c limit.

This work was done in collaboration with graduate student Vojtech Krejcirik and published in Phys. Rev. C 85, 035205 (2012).

D. Total Nucleon-Nucleon Cross Sections at Large N_c

It is shown that at sufficiently large N_c for incident momenta which are much larger than the QCD, the total nucleon-nucleon cross section is independent of incident momentum and given by $\sigma^{\text{total}} = 2\pi \log^2(N_c)/(m_\pi^2)$. This result is valid in the extreme large N_c regime of $\log(N_c) \gg 1$ and has corrections of relative order $\log(\log(N_c))/\log(N_c)$. A possible connection of this result to the Froissart-Martin bound was noted.

This work has been posted as arXiv:1203.5843v1 and has been submitted for publication.

E. Alternate $1/N_c$ Expansions and SU(3) Breaking from Baryon Lattice Results

A combined expansion in the number of QCD colors $1/N_c$ and SU(3) flavor breaking parameter epsilon has long been known to provide an excellent accounting for the mass spectrum of the lightest spin-1/2, 3/2 baryons when the quarks are taken to transform under the fundamental SU(N_c) representation, and in the final step N_c was set to 3 and epsilon is set to its physical value 0.3. Subsequent work shows that placing quarks in the two-index antisymmetric SU(N_c) representation leads to quantitatively equally successful mass relations. Recent lattice simulations allow for varying the value of epsilon and confirm the robustness of the original $1/N_c$ relations. In this work it was shown that the same conclusion holds for the antisymmetric quarks, and demonstrate that the mass relations also hold under alternate prescriptions for identifying physical baryons with particular members of the large N_c multiplets. Subtleties associated with the identification of states at large N_c are explored; there are different ways to associate states at large N_c with those at $N_c = 3$. Two obvious ways to do this are to associate states of given strangeness or states of given hypercharge. It was shown that the mass relations are independent of this choice.

This work was done in collaboration with Richard Lebed (Arizona State) and Aleksey Cherman (Cambridge). It has been posted as arXiv:1205.1009v2 and has been submitted for publication.

2. Prof. Xiangdong Ji

In the last year, Dr. Ji's theoretical research has been focused on two different directions: QCD physics and weakly-interacting massive particles (WIMPs) as dark matter. In QCD physics, Dr. Ji continues his work about the angular momentum study, in particular, he and his collaborators have studied the angular momentum sum rule in parton picture and light-front coordinates relevant for high-energy scattering. Ji and collaborators have also reconsidered the use of Wigner distribution functions in describing the properties of hadrons. They found that there is a choice of gauge link for transverse-momentum dependent distributions so that the momentum of the Wigner distribution yields the correct angular momentum sum rule. Such choice also renders this distribution calculable in lattice QCD. Finally, Ji's work on WIMP dark matter is mainly about the collider constraint. This is because recent experimental data indicated that the WIMPs are as light as 10 GeV. If so, they shall be copiously produced in a hadron collider.

A. Seeking Partonic Picture of Proton Spin

We analyze the protons longitudinal and transverse spin in terms of partons spin and orbital angular momentum contributions in the in?nite momentum frame, emphasizing experiment measurability. The simple partonic sum rule is shown to exist only for the transverse polarization and is related to the twist-two generalized parton distributions (GPDs). The longitudinal spin, however, necessarily involves parton transverse momentum and parton correlations. In a gauge-invariant approach, parton contributions to the proton helicity are shown to be related to twist-two and -three GPDs and are amenable to lattice QCD calculations. A simpler but subtler parton picture emerges in a light-cone gauge approach through a quantum phase-space Wigner distribution.

The proton's transverse polarization structure is examined in terms of the Lorentz-covariant Pauli-Lubanski vector in QCD. We learned that there are contributions from leading, subleading, and next-to-subleading partonic contributions in the light-front system of coordinates. The subleading and next-to-subleading contributions are related to the leading one through Lorentz symmetry. And the leading contribution obeys a simple partonic angular momentum sum rule that gives a clear physical interpretation to a relation known previously.

[1] X. Ji, X. Xiong, and F. Yuan, DOE/ER/40762-513 (2/2012). [arXiv: 1202.2843 [hep-ph]]

(X. Ji, X. Xiong (Peking U.), F. Yuan (LBNL))

B. Gluon Spin, Canonical Momentum, and Gauge Symmetry

X. Ji, Y. Xu, and Y. Zhao, Accepted for publication in JHEP

It is well known that in gauge theories, the spin (and orbital angular momentum) of gauge particles is not gauge invariant, although the helicity is; neither are the canonical momentum and canonical angular momentum of charged particles. However, the simple appeal of these concepts has motivated repeated attempts to resurrect them as physical descriptions of gauge systems. In particular, measurability of the gluon-spin-contribution to the proton helicity in polarized proton scattering has generated much theoretical efforts in generalizing it and others as gauge-invariant quantities. In this work, we analyze constraints of gauge symmetry, the signi?cance of gluon spin in the light-cone gauge, and what-is-possible-and-natural in QCD parton physics, emphasizing experimental observability and physical interpretation in the structure of bound states. We also comment on the measurability of the orbital angular momentum of the Laguerre-Gaussian laser modes in optics.

[1] X. Ji, Y. Xu, and Y. Zhao, DOE/ER/40762-519, accepted in JHEP [arXiv: 1205.0156 [hep-ph]]

(X. Ji, Y. Xu, and Y. Zhao)

C. Comment on "Do Gluons Carry Half of the Nucleon Momentum?" by X. S. Chen et. al. (PRL103, 062001 (2009))

In a recent paper by Chen et al. (PRL103, 062001 (2009)), the textbook definition of a charged-particle's momentum and angular momentum in gauge theories has been questioned. The authors claim they have found a "proper" definition, and challenge the well-known result in perturbative quantum chromodynamics (QCD) that the gluons carry one-half of the nucleon momentum in asymptotic limit. Here I argue that the textbook result stands, and the incorrect conclusion of the paper arises from a misunderstanding of gauge symmetry.

In Chen et al.'s paper, a "sound" definition of a charged particle's momentum in a U(1) gauge field A^μ is purported to be (see Eq. (6) in the paper)

$$P_q^\mu = P^\mu - qA^\mu_{\rm pure}/c \; , \tag{1}$$

where P^μ is the canonical momentum and $A^\mu_{\rm pure}$ is "a pure gauge term transforming in the same manner as does the full A^μ" and always gives "null field strength." This magical $A^\mu_{\rm pure}$ allows a "gauge-invariant" definition of P_q^μ and "physical" $A^\mu_{\rm phys} = A^\mu - A^\mu_{\rm pure}$. The authors claim that the quark's P_q^μ shall be measurable in deep-inelastic scattering (DIS) and shall contribute 1/5 of the nucleon momentum.

First of all, separating $\vec{A}$ into $\vec{A}_{\rm phys} + \vec{A}_{\rm pure}$ cannot be uniquely done by the conditions $\vec{\nabla}\cdot\vec{A}_{\rm phys} = 0$ and $\vec{\nabla}\times\vec{A}_{\rm pure} = 0$, contrary to the authors' claim. In fact, one can always add/subtract a term $\vec{\nabla}\phi$ with $\nabla^2\phi = 0$ to change the separation. A simple counterexample is that of a constant magnetic field in the z-direction. $\vec{A}_1 = (By, 0, 0)$ and $\vec{A}_2 = (By, -Bx, 0)/2$ both must be "physical" according to the authors. Of course, one can add more constraints to make the separation unique. However, this amounts to defining $\vec{A}_{\rm phys}$ by gauge fixing and performing calculations under a fixed gauge.

Next, what is theoretically sound to define and experimentally measurable in electromagnetism are already well known. The kinematic momentum of a charge particle is

$$\vec{\pi} = \vec{P} - q\vec{A}/c \; , \tag{2}$$

with the full gauge field $\vec{A}$ required. It is $\vec{\pi}$ which gives rise to the kinetic energy of the particle $E = \vec{\pi}^2/2m$, and it is $\vec{\pi}$ which generates the electric current, $\vec{j} = (q/m)\vec{\pi}$. Feynman in his famous lectures provided a beautiful example (Sec. 21-3) to demonstrate that $\vec{\pi}$ is the momentum related to the velocity of a charge particle measurable experimentally. $A^\mu_{\rm phys}$ has never been considered as a meaningful observable in electromagnetism.

In the context of QCD, it is π^μ which appears in the twist-2 operators of the operator product expansion for deep-inelastic scattering (DIS). The light-cone plus(+) component of the operators generates the light-momentum of a parton in $A^+ = 0$ gauge. There is no place for P_q^μ (Eq.(1)) in any QCD experimental observables. In particular, the parton distributions advocated by the authors do not appear in any factorization of hard processes.

[1] X. Ji, Phys. Rev. Lett., Phys. Rev. Lett. 106 (2011) 259101.

(X. Ji)

D. Light Dark Matter and Z' Dark Force at Colliders

Light Dark Matter, ¡ 10 GeV, with sizable direct detection rate is an inter-esting and less explored scenario. Collider searches can be very powerful, such as through the channel in which a pair of dark matter particle are produced in association with a jet. It is a generic possibility that the mediator of the interaction between

DM and the nucleus will also be accessible at the Tevatron and the LHC. Therefore, collider search of the me- diator can provide a more comprehensive probe of the dark matter and its interactions. In this article, to demonstrate the complementarity of these two approaches, we focus on the possibility of the mediator being a new U(1) gauge boson, which is probably the simplest model which allows a large direct detection cross section for a light dark matter candidate. We combine searches in the monojet+MET channel and dijet resonance search for the me- diator. We find that for the mass of Z between 250 GeV and 4 TeV, resonance searches at the colliders provide stronger constraints on this model than the monojet+MET searches.

[1] H. P. An, X. Ji and L. T. Wang, DOE/ER/40762-514 (2/2012), accepted in JHEP. [arXiv: 1202.2894 [hep-ph]]

(H.P. An (Perimeter), X. Ji, L. T. Wang (U. Chicago))

3. Assoc. Prof. Paulo Bedaque

A. *Vortons in neutron stars and atomic traps*

One of the main possibilities for the state of hadronic matter at the high densities present in the core of neutron stars is the formation of quark matter. If that is the case, color superconductivity is almost certain to occur. At asymptotically high densities the pattern of Cooper pairing is the one of the color-flavor-locked (CFL) phase. The low-lying excitations in the CFL phase form an octet of pseudoscalars named, in analogy to the zero density case, pions, kaons and etas. At lower, more realistic densities, the effect of the non-negligible strange quark mass is to act as a chemical potential for the kaons. At most relevant values of the parameters, this effective chemical potential leads to the condensation of K^0, a phase suggested by Prof. Bedaque in the past and known as "$CFL+K0$". It was observed by Kaplan and Reddy that this phase supports a topological soliton akin to Witten's superconducting cosmic strings, extensively researched in grand unified theories as a possible seed for galaxy formation. These strings arise when the condensation of two different scalars compete energetically. Inside of the vortex, the absence of one condensate triggers the condensation of the second one. In our case the two condensates are the K^0 (outside the vortex) and K^+ (inside the vortex). As the K^+ is a charged field, its condensation makes the inside of the vortex to be superconducting. This has a a side effect to stabilize *closed* vortex lines, a configuration known as a vorton.

Last year we made a more detailed, realistic study of the existence of vortons in the CFL-K0 phase, specially inside neutron stars. The bottom line of this study was that vortons will stabilize if and only if there a significant amount of electric charge in their cores, in addition to the current they have to carry. Their radii would be in the 100's fermi range. The charge the vortons have to charge is cancelled by electrons (positrons). These electrons will be attracted to the vorton and will orbit them, just like electrons orbit nuclei under more normal conditions. In fact, the only difference between these and atoms is the shape of the "nucleus", toroidal in our case. If the vorton is large enough and the electron orbits small enough, they will effectively neutralize the vorton charge, leading to their instability (the Coulomb repulsion between opposite sides of the vorton is the dominant stabilizing force in the vorton, notwithstanding inaccurate claims in the literature). It is important then to estimate the size of the electron cloud around a vorton. We studied this situation within a relativistic generalization of the Thomas-Fermi approximation. In order to explore the symmetry of the problem we used toroidal coordinates and boundary conditions on the surface of the vorton and numerically solve the non-linear relativistic Thomas-Fermi equation determining the electron density around the vorton. As predicted, the qualitative effect of the electron cloud was to significantly decrease the radius of the vorton.

An offshoot of our study of neutron star vortons was the realization that a close analogue could be made in cold atomic traps. There, we need two species of bosonic atoms, the analogues of the neutral and charged kaons. We also need to arrange for their interactions between different species to be repulsive enough that phase separation occurs, namely, it is energetically favorable for the two species to be spatially separated. This condition is the analogue of the competition between the neutral and charged condensates in the $CFL - K^0$ phase. We consider in particular the case where the two species correspond to two hyperfine states of ^{87}Rb and ^{7}Li. A Feshbach resonance between them allows the tuning of their interaction to the phase separation region. We found that a mismatch between the masses, as in the case of a ^{87}Rb-^{7}Li mixture, favors the stability of the vorton. We analyzed two possible ways of generating vortons in the lab. One by a combined use of Raman scattering and Gauss-Laguerre beams, capable of imparting angular momentum to the condensate. The other is a rapid quench from a higher temperature situation (the Kibble-Zurek mechanism extensively discussed in cosmological contexts), already demonstrated in atomic traps with one species. Again we find that a mismatch of atomic masses favors the formation of wound up vortex loops.

[1] P. Bedaque, E. Berkowitz, G. Ji and N. Ng, "Electron shielding of vortons in high-density quark matter", *Phys. Rev.* **D85**, 043008 (2012).
[2] Paulo F. Bedaque, Evan Berkowitz, Srimoyee Sen, "Stable vortex loops in two-species BECs," e-Print: arXiv:1111.4507

(P. Bedaque, E. Berkowitz, S. Sen)

B. Deuterium and helium condensates in white dwarfs and elsewhere

It has been pointed out that light elements (deuterium and ^4He), when compressed so that the typical distance between atoms (l) is in between atomic and scalar densities, and for a wide range of temperatures, lead to Bose-Einstein condensation. At these densities, atoms are crushed and we have nuclei immersed in a sea of electrons. For temperatures below $T_{cryst} \sim 180\alpha/l$ the energy of nuclei is dominated by the Coulomb energy and they will form a crystal. Above this temperature but below $T_{bose} \sim 1/(Ml^2)$ the nuclei will Bose condense. That means that for light bosonic nuclei there is a range of temperatures where this nuclear condensate is possible. Matter in this phase may occur in low mass brown dwarfs, failed stars not massive enough to burn helium or even deuterium. More importantly, it may be realized on experiments on Earth, either through the use of diamond anvils or through inertial confinement experiments. Even though the pressures obtained in these experiments are currently a factor of 10-100 below the estimated interesting range, it seems worthwhile to investigate this kind of matter theoretically given the large effort put into the inertial confinement program. From the purely theoretical point of view this system presents us with a rich variety of interesting phenomena, largely unexplored at this point, including a number of unusual solitons (semi-local monopoles, Alice strings, ...) known to exist in abstract models but not realized in Nature.

We show that in this regime there is a new gapless quasiparticle not previously noticed, arising when the constraints imposed by gauge symmetry are taken into account. This particle is gapless to all order of perturbation theory and can be thought as a Goldstone bosons, even though the spontaneously broken symmetry is, in this model, gauged. This unusual situation occurs due to the interplay of lack of Lorentz symmetry and electron shielding that renders some components of the electromagnetic field massive. One obvious phenomenological consequence of a gapless excitation is the change of thermodynamics and transport properties that may affect the cooling of white dwarfs. We started this exploration by considering the specific heat contribution of the new quasi-particle. The contribution of this quasiparticle to the specific heat of a white dwarf core turns out to be comparable, in a range of temperatures, to the contribution from the particle-hole excitations of the degenerate electrons. The specific heat in the condensed phase is two orders of magnitude smaller than in the uncondensed plasma phase, which is the ground state at higher temperatures, and four orders of magnitude smaller than the specific heat that an ion lattice would provide, if formed. Since the specific heat of the core is an important input for setting the rate of cooling of a white dwarf star, it may turn out that such a change in the thermal properties of the cores of helium white dwarfs has observable implications.

After that, we investigated the neutrino emission rate due to this gapless state and the resulting impact on the total luminosity of helium white dwarf stars, as a possible observable way of detecting this exotic phase. Simple dimensional analysis indicates that the neutrino luminosity should be of the form

$$Q \approx \frac{G_F^2 \sin^4(\theta_W)}{M^2} T^{11}, \tag{3}$$

where G_F is the Fermi constant, $\sin(\theta_W)$ the Weinberg angle ,M the helium mass and T the temperature. What this estimate misses is that the dependence on the velocity c of the colliding quasiparticles. Since $c \approx 10^{-2}$ a large correction may arise. We find, after a detailed calculation that the final result is

$$Q = \underbrace{\frac{2048}{33\pi^5}(\pi^{10} - 93555\zeta(11))}_{\approx 9.5} \frac{G_F^2 \sin^4(\theta_W)}{M^2 c^7} T^{11}. \tag{4}$$

Numerically, our result is that if the condensation temperature for the quantum liquid state, which is currently not known very precisely, turns out to be high enough, our calculations indicated that neutrino emission due to the gapless mode would make a large contribution to the total luminosity of the helium white dwarf stars. If the critical temperature is not so high the neutrino emission turns out to be negligible.

The previous result clearly indicates that a more solid estimate of the critical temperature is essential for the progress in this field. This problem turned out to be much more complex (and interesting) than initially suspected. We were able to make only partial progress towards its resolution due to a number of technical difficulties, among them i) the gauge dependence of the effective potential, ii) the parametrization dependence of the effective potential, iii) a breakdown of the loop expansion leading to complex effective potentials, and iv) the role played by the Friedel oscillations of the electron-screened interaction between nuclei. We disregarded iv) and effectively considered a model where the electrons screen the Coulomb force but don't have the full dynamics leading to Friedel oscillations. This is already one step beyond the literature where only the unscreened potential is considered. The problem with the complex effective potentials required us to limit the regions in parameter space where we could make definitive statements but we were careful to check the self-consistency of the results we claim as solid. We found evidence that, as the temperature is increased, there is first a first-order transition between two superconducting phases followed by a second-order transition to the normal state. These transitions occur, for realistic densities, at temperatures below the crystallization temperature and the crystalline state is likely to remain as the true ground state of the system. Unfortunately, this result, if it survives further studies, puts in check the existence of nuclear condensates in white dwarfs.

[1] Paulo F. Bedaque, Evan Berkowitz, Aleksey Cherman, "Nuclear Condensate and Helium White Dwarfs", *Astrophys. J.***749**, 5 (2012).
[2] Paulo F. Bedaque, Evan Berkowitz, Aleksey Cherman, "Neutrino Emission from Helium White Dwarfs with Condensed Cores", e-Print: arXiv:1203.0969
[3] Paulo F. Bedaque, Evan Berkowitz, Srimoyee Sen, "Thermodynamics of nuclear condensates and phase transitions in white dwarfs", e-Print: arXiv:1206.1059

(P. Bedaque, E. Berkowitz, S. Sen)

4. Res. Prof. Stephen J. Wallace

Progress in the past year includes publication in Phys. Rev. D of a paper entitled "Excited state baryon spectroscopy from lattice QCD", a paper published in AIP Conference Proceedings based on an invited talk at the 8^{th} International Workshop on the Physics of Excited Nucleons, and publication in Proceedings of Science of a presentation at Lattice 2011, Squaw Valley, CA. Also an unpublished invited talk was presented at the APS April Meeting in Atlanta, GA, April 2012. Progress has been made in extending the analysis of spectra to strange and hybrid baryons: Λ, Σ, Ξ and Ω. We also continue the development of an improved method for the extraction of spins from lattice QCD matrices of correlation functions.

A. *Excited State Baryon Spectroscopy from Lattice QCD.*

Baryon interpolating field operators have been developed in the Hadron Spectrum Collaboration based on incorporating covariant derivatives that transform according to the continuum symmetry group, SU(2), with spins $J \leq \frac{7}{2}$. These operators have been subduced to the lattice irreducible representations for half-integer spins and used in lattice QCD calculations to determine baryon spectra. The significant advance is that mass spectra are obtained with *spins identified*. The results for the N and Δ baryons are published in Ref. [1]. Figure 1 shows the nucleon excited states at $m_\pi = 396$ MeV. These lattice QCD calculations are the first to identify spins of baryon excited states.

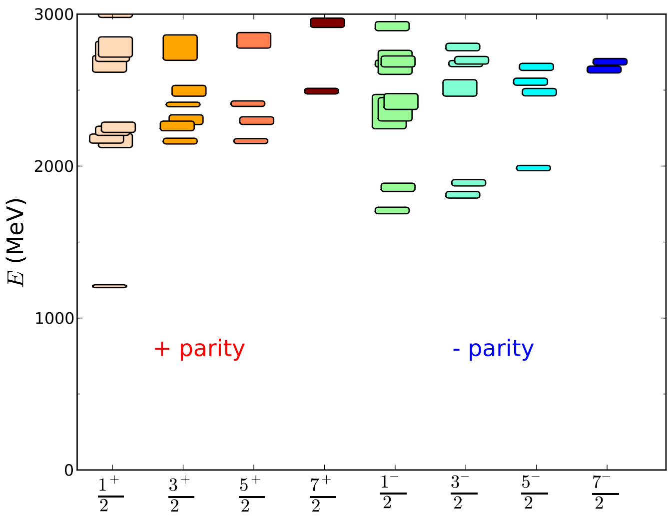

FIG. 1: Nucleon effective energies are shown in columns labelled by J^P.

B. *8^{th} International Workshop on the Physics of Excited Nucleons*

Professor Wallace was invited to present the results of the recent baryon spectroscopy work for N^* excited states at the workshop. The presentation is published in Ref. [2]. The excited states form bands of alternating parities as shown in Fig. 2. The spectrum does not exhibit degenerate states of opposite parities at high excitation energy, thus there is no evidence for parity doubling.

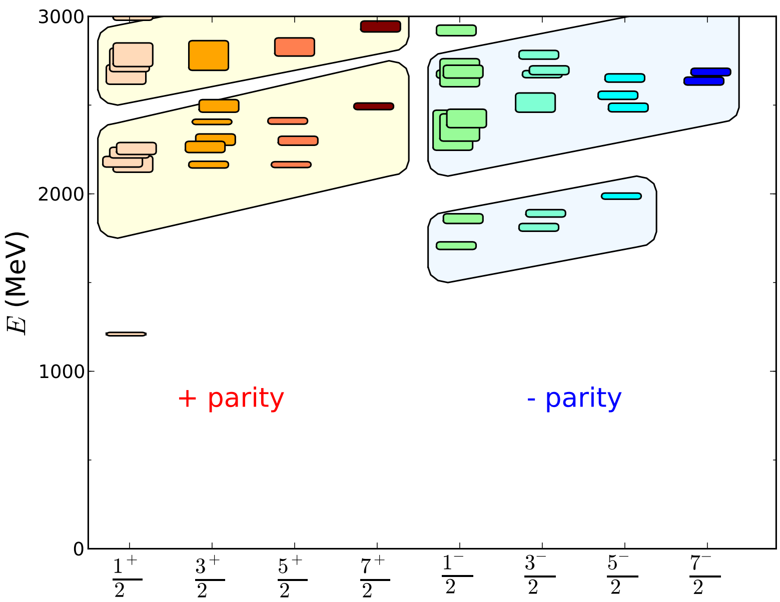

FIG. 2: Nucleon excited states on a $16^3 \times 128$ lattice form bands of alternating parities.

C. Lattice 2011 Presentation

Professor Wallace presented the results of the baryon spectroscopy work described in Subsection II 4 A at the Lattice 2011 Conference held at Squaw Valley, CA [3]. Figure 3 shows that the first band of five excited nucleon states is simply interpreted as the states that can be made from quark spins $S = \frac{1}{2}$ and $S = \frac{3}{2}$ in combination with $L = 1$. These states belong to the $(70, 1^-)$ representation of $SU(6) \otimes O(3)$. A similar explanation can be advanced for the second band of excited states at positive parity as shown in Fig. 4. There are thirteen states in the band and they correspond to combinations of $S = \frac{1}{2}$ and $S = \frac{3}{2}$ with $L = 0$, $L = 1$ and $L = 2$, where the positive parity $L = 1$ involves the cross product of two derivatives. The states belong to the $(56, 0^+)$, $(56, 2^+)$ and $(20, 1^+)$ representations of the $SU6 \otimes O(3)$ classification. The presence of states in the $(20, 1^+)$ representation is interesting: in quark-diquark models such states cannot appear.

D. Strange and Hybrid Baryon Spectroscopy from Lattice QCD

We are making good progress in extending the analyses of baryon spectroscopy in two directions. One is is to consider baryons with strange quarks and the other is to include hybrid baryon operators. Hybrid operators are formed when two covariant derivatives in the form of a cross product act on a quark. Such operators vanish in the quark model because the cross product is antisymmetric and the derivatives commute with each other. However, the gauge-field parts of two covariant derivatives produce a nonvanishing commutator such that the gauge-covariant cross-product gives a chromomagnetic glue contribution. Figure 5 shows spectra including strange baryons. Hybrid operators are included in the analysis.

The operators used in this work provide good sensitivity to the quark symmetry: there are SU(3) singlet, octet and decuplet operators. Particularly for the Λ, the singlet operators, Λ_1, and octet operators, Λ_8, are weakly coupled so that singlet and octet states can be identified. A goal is to finalize this work over the next few months. It is a collaboration involving Robert Edwards and David Richards of JLab, Nilmani Mathur of Tata Inst. and Prof. Wallace.

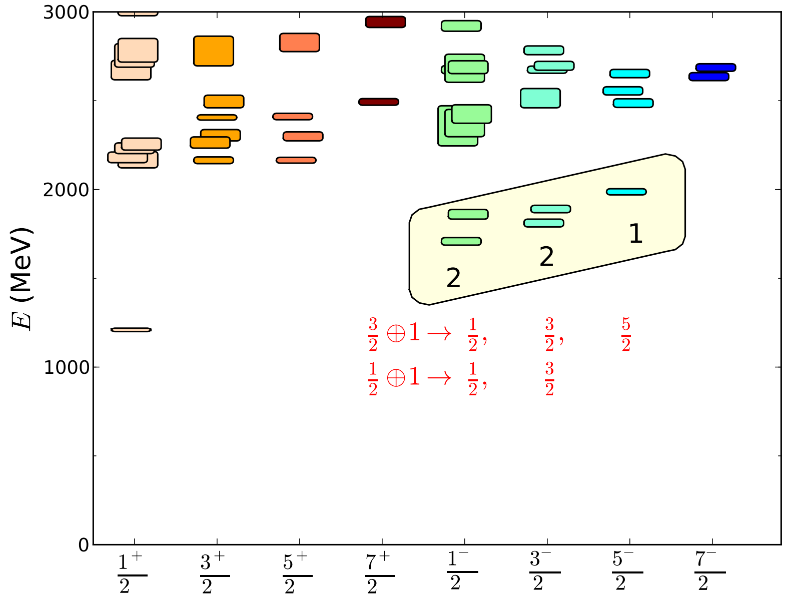

FIG. 3: Spins of the first N^* band that corresponds to SU(6)⊗O(3) representations.

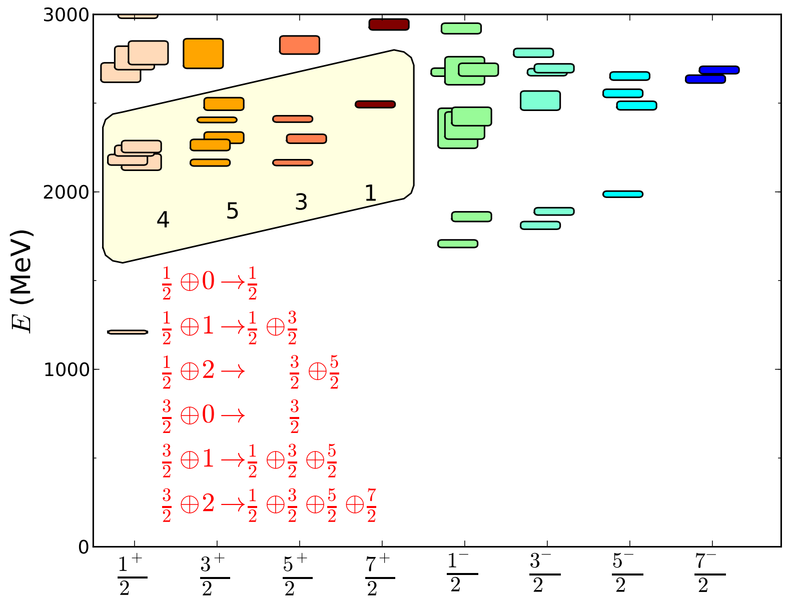

FIG. 4: Spins of the 2^{nd} N^* band that correspond to SU(6)⊗O(3) representations.

E. *Methods for Determination of Spins of Excited States in Lattice QCD*

Baryon operators have indefinite normalization. However, the normalization can be made definite by the prescription that the self-correlation function of each operator should equal one at a normalization time, t_n,

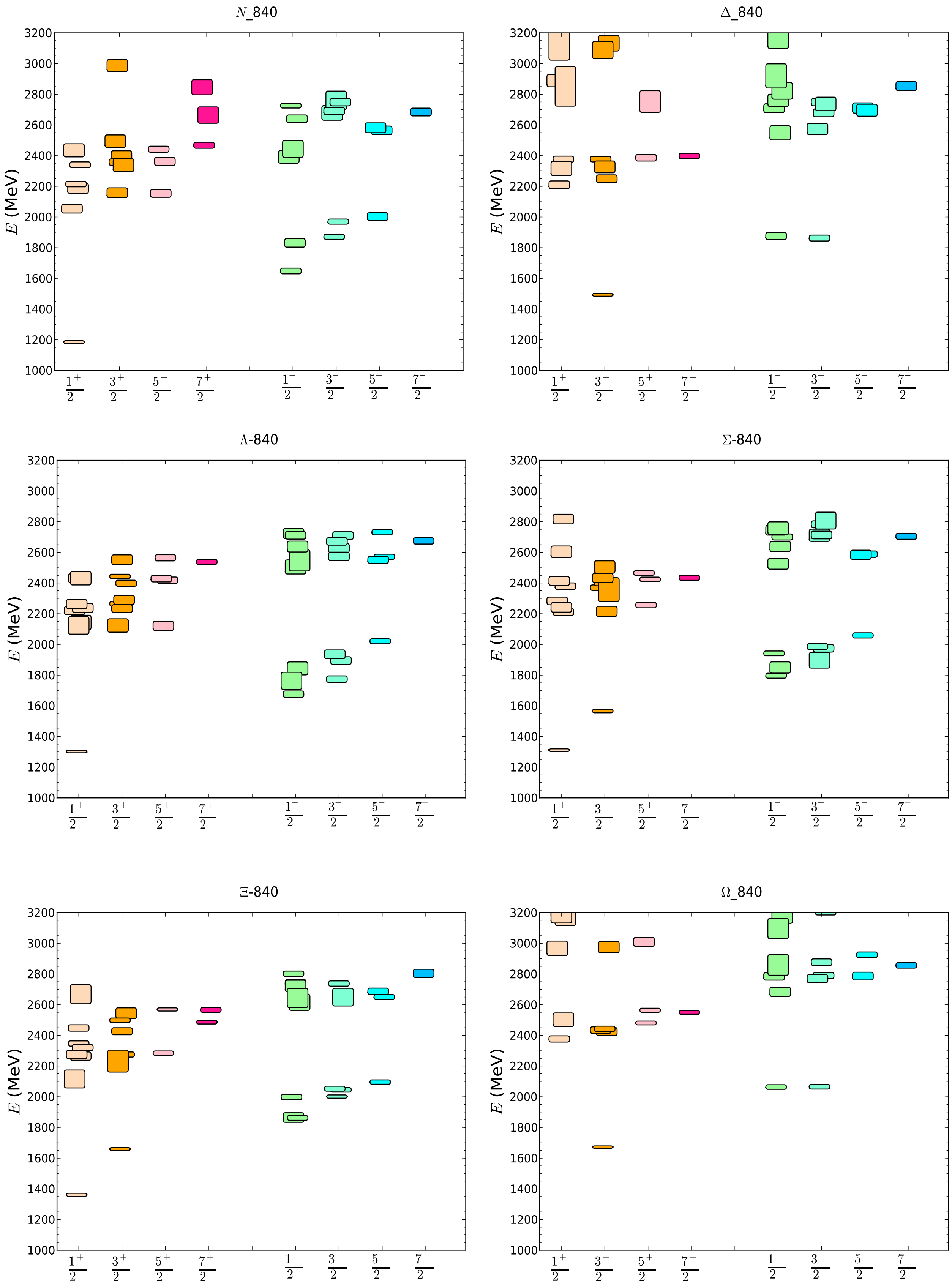

FIG. 5: Preliminary results for baryon excited states are shown versus J^P for N (top left), Δ (top right), Λ (middle left), Σ (middle right), Ξ (bottom left) and Ω (bottom right). Calculations are for a $16^3 \times 128$ lattice and $m_\pi = 396$ MeV.

as follows,

$$\begin{aligned} C_{ii}(t) &= \langle 0|\widetilde{\mathcal{O}}_i(t_n)\widetilde{\mathcal{O}}_i^\dagger(0)|0\rangle \\ &= 1. \end{aligned} \tag{5}$$

Working with such operators, the matrix of correlation functions is expanded in terms of a complete set of eigenstates of the lattice Hamiltonian as follows,

$$\begin{aligned} C_{ij}(t) &= \langle 0|\widetilde{\mathcal{O}}_i(t)\widetilde{\mathcal{O}}_j^\dagger(0)|0\rangle \\ &= \sum_n \langle 0|\widetilde{\mathcal{O}}_i(0)|n\rangle e^{-E_n t}\langle n|\widetilde{\mathcal{O}}_j^\dagger(0)|0\rangle \\ &= \sum_n X_{in} e^{-E_n t} X_{jn}^* \end{aligned} \tag{6}$$

where

$$\boxed{X_{in} = \langle 0|\widetilde{\mathcal{O}}_i(0)|n\rangle}. \tag{7}$$

Matrix element X_{in} expresses the amplitude for annihilation of eigenstate n by operator i. Using operators subduced from definite spins and observing which operators provide the dominant overlaps X_{in} for state n allows the spin to be determined.

Because the matrix of eigenvectors is unitary,

$$X(t)X^\dagger(t) = X^\dagger(t)X(t) = I, \tag{8}$$

it follows that

$$\sum_i |X_{in}(t)|^2 = \sum_n |X_{in}|^2 = 1. \tag{9}$$

Thus, the sum over operator indices i of the squares of overlap matrix elements is equal to one for each eigenstate, n, and the sum over eigenstate indices, n, of squares of overlap matrix elements is equal to one for each operator, i.

Generally the Hermitian eigenvalue problem provides a clean connection of operators to eigenstates through matrix X as in Eq. (7). Spin identification can be based on the relative weights of the operators to create states of spin J, i.e.,

$$W_n^J = \sum_{i\subset J} |X_{in}|^2. \tag{10}$$

Because of Eq. (9), the sum of the weights over J is one for each state. We find that the weights provide a clean identification of the spins because rotational symmetry is realized approximately.

However, the standard procedure is to solve the generalized eigenvalue problem, which does not provide as clean a connection between states and operators because the matrix that is diagonalized is $C^{-1/2}(t_0)C(t)C^{-1/2}(t_0)$, rather than $C(t)$. Although the analysis based on the generalized eigenvalue problem has been successful, it is desirable to develop a cleaner analysis based on the Hermitian eigenvalue problem,

$$C(t)X(t) = X(t)\Lambda_H(t), \tag{11}$$

which determines the matrix of eigenvectors, X, and the diagonal matrix of eigenvalues. In order to extract the energy, E_n, eigenvalues $\lambda_n(t)$ are divided by $\lambda_n(t_0)$, which allows the usual three-parameter fit as follows,

$$\frac{\lambda_n(t)}{\lambda_n(t_0)} = (1-A)e^{-E_n(t-t_0)} + Ae^{-E_n'(t-t_0)}. \tag{12}$$

An initial check for the Ω spectrum has been carried out and the initial results for energies are close but not the same as those based on the GEVP analysis. Identifications of spins and hybrid states are improved because of the clean connection between the operators and the eigenstates.

[1] R. G. Edwards, J. J. Dudek, D. G. Richards and S. J. Wallace, Phys. Rev. D **84**, 074508 (2011). [arXiv:1104.5152]

[2] R. G. Edwards, J. J. Dudek, D. G. Richards and S. J. Wallace, AIP Conf. Proc. 1432, 33-38 (2012).

[3] Stephen Wallace [Hadron Spectrum Collaboration], PoS (Lattice 2011) 146, (2011). [arXiv:1111.3972]

III. INDEPENDENT RECENT RESEARCH ACCOMPLISHMENTS BY RESEARCH ASSOCIATES

The TQHN Group has a string tradition of encouraging independent research by its postdoctoral research associates. Scientific independence plays a critical role in the development of young scientists. Over the years this independence has served the groups postdocs quite well; a very large number of whom now have faculty jobs.

1. Res. Assoc. Amy Nicholson

A. *Lattice Studies of Unitary Fermions*

One of the major advances in physics in the last decade has been in the field of ultracold atom experiments, leading to a resurgence in the theoretical study of such systems. Of particular interest is the limit of unitarity, a conformal fixed point in which the s-wave scattering length becomes infinite. In this limit, all scales of the problem vanish, leading to universal predictions which are insensitive to the details of the interaction. Thus, in addition to being directly relevant to cold atom experiments, studies of this system may serve as a stepping stone to more complicated systems such as nuclei, due to the anomalously large s-wave scattering lengths between nucleons.

Due to the strongly interacting character of these systems, non-perturbative numerical techniques become necessary in calculating many-body quantities. We have developed a lattice method for describing unitary fermions, and used this new method to calculate the ground state energies of up to N=66 unitary fermions in a box and up to N=70 unitary fermions in a harmonic potential for even N. In addition, we have explored several issues of wide interest in lattice field theory: in particular, how to extract the properties of conformal systems from calculations at finite lattice spacing, volume, and particle density, and how to construct optimal interpolating fields for strongly interacting, many-fermion systems. We have also performed an extensive study of the systematic errors in lattice calculations of such systems, and provided a new extraction of a quantity known as the Bertsch parameter which is currently one of the most important benchmarks for numerical calculations of unitary fermions. This work has been completed and may be found in "Lattice Monte Carlo Calculations for Unitary Fermions in a Harmonic Trap.", Phys.Rev. A84 (2011) 043644, and "Lattice Monte Carlo Calculations for Unitary Fermions in a Finite Box", arxiv:1203.3169. I am also currently writing up the results of these studies in a commissioned review article for Journal of Physics G entitled "Lattice Methods for Strongly Interacting Many-Body Systems" in collaboration with J. E. Drut (Los Alamos National Laboratory).

In addition to the results for even numbers of fermions, correlation functions for odd numbers have already been calculated. The analysis of these correlators and the extraction of the superfluid pairing gap is currently underway. Some preliminary results for the binding energies of N-body Efimov states have also been produced using the lattice method. Future work will involve improving the calculation to reduce systematic errors.

(M. G. Endres (RIKEN), D. B. Kaplan (U. of Washington), J.-W. Lee (U. of Washington), A. N. Nicholson)

B. *Understanding noise in lattice calculations*

Learning about the QCD phase diagram at low temperatures using lattice QCD has proven highly difficult due to the well-known sign problem, which manifests itself as a noise problem in canonical formalisms. This issue leads to two classes of problems when calculating many-body systems on the lattice: a signal-to-noise problem and an overlap problem, in which the statistical distributions sampled have poor overlap with the observable of interest. The latter problem can be seen by studying the probability distribution of the operator, where long tails are observed. Through the study of unitary fermions on the lattice with collaborators M. G. Endres, D. B. Kaplan, and J.-W. Lee, we have shown that such distributions tend to be lognormal in character, and that an expansion about lognormal called a cumulant expansion can greatly alleviate the overlap problem [1, 2]. Such distributions have since been shown to be ubiquitous in lattice QCD calculations [3].

Based on an effort to understand a physical mechanism behind these distributions in lattice studies of particles at unitarity, I found that the distribution for two particles at unitarity encapsulates information about the spectrum of N-body bound states at unitarity known as Efimov states. Using the lognormal nature of the probability distribution, I then extracted an analytical expression relating the N-body binding energies to the spectrum of the 3-body system. These energies are of interest to both experimentalists and theorists in the cold atom community, and preliminary numerical calculations of these energies have been performed by other groups. This work is contained in the article "N-body Efimov states from two-particle noise", arxiv:1202.4402.

(A. N. Nicholson)

To gain further insight into how the lognormal distribution arises in QCD and whether it may prove useful in solving the overlap problem at non-zero baryon number, we are currently studying probability distributions in the 2 + 1-d Gross-Neveu model at large N, which displays chiral symmetry breaking, a property which is crucial to understanding noise in lattice QCD but is lacking in the unitary fermion system. This system is particularly useful because it is amenable to perturbative methods in $1/N$, and because we have found two formulations, one which displays a signal-to-noise problem and an overlap problem and one which only has an overlap problem. This work is currently in preparation.

(D. B. Kaplan (U. of Washington), A. N. Nicholson)

C. Properties of Baryons in a Meson Condensate from Lattice QCD

Understanding how the diverse array of multi-hadron systems emerges from the deceptively simple underlying theory defining their interactions (QCD) has become a central goal for many nuclear theorists. Due to exponentially poor signal-to-noise ratios, lattice QCD calculations involving multiple baryon correlation functions are severely hindered. Thus, lattice QCD calculations of multiple hadron systems have been primarily limited to studies of mesons. Multiple meson systems are interesting in their own right, as they may provide crucial information about the equation of state of neutron stars or the late time evolution of heavy ion collisions. As strongly interacting bosonic gases, they also allow us to study the phenomenon of Bose-Einstein condensation.

As a first step toward calculations involving realistic systems of both baryons and mesons, we are currently calculating properties of systems with up to 11 mesons and a single baryon using lattice QCD. From the energy shift of the baryon due to the presence of the mesons we are able to extract previously unknown two- and three-body scattering parameters, as well as relevant low-energy constants from Chiral Perturbation Theory. The numerical work of calculating correlation functions has been performed on the Hopper system at NERSC, and the analysis of the results is in preparation.

(W. Detmold (William & Mary), A. N. Nicholson)

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[1] Michael G. Endres, David B. Kaplan, Jong-Wan Lee, and Amy N. Nicholson. Noise, sign problems, and statistics. *Phys.Rev.Lett.*, **107**, 201601 (2011).

[2] Michael G. Endres, David B. Kaplan, Jong-Wan Lee, and Amy N. Nicholson. Listening to Noise. 2011.

[3] Thomas DeGrand. Log-normal distribution for correlators in lattice QCD? 2012.

2. Res. Assoc. Ilmo Sung

Dr. Sung's research is rooted in QCD and related gauge theories, with an emphasis on the infrared structure of perturbative amplitudes. It can be cast in two (overlapping) categories: i) developing factorization and resummation formalisms to understand properties in non-abelian gauge theories that appear in higher order calculations, and ii) studying how these interesting properties can be used directly or indirectly to discover physics beyond the standard model (BSM) in collider experiments.

A. Applications of Perturbative QCD for Discovering Physics BSM

Color Flow for Extracting Properties in BSM

Dr. Sung's work in this category is based on the following connection between QCD and BSM at hadron colliders like the Tevatron and the LHC: QCD serves both to make predictions for signals of new physics and their backgrounds. This implies that applying QCD techniques for analyzing signals of new physics may provide new avenues to extract properties in physics beyond the standard model. Following this approach, in Ref. [1], Dr. Sung developed a method to determine the color SU(3) gauge content of BSM resonances from new physics signals by investigating the pattern of soft gluon radiation into specified regions of a detector. This work illustrates the use of energy flow, treated by perturbative QCD and factorization, as a tool to analyze properties of new physics. This allowed the prediction of the distribution of soft gluon radiation into a rapidity region of a detector, reflecting the gauge content of heavy resonances. The results, in general, predict more radiation for singlet than for octet resonances. Especially, for spin-1 resonance production, the work showed a quite large difference in radiation into a rapidity gap region from color singlet and octet resonances. In Ref. [2], this idea was extended to identify Higgs particles from QCD backgrounds where Higgs are color singlet while QCD jets carry colors, leading to a distinguished difference.

(I. Sung)

Substructure of High p_T Jets

The above work is focused on the role of soft gluon radiation. In Refs. [2–4], we used the collinear enhancement in perturbative QCD amplitudes to distinguish products of highly-boosted massive particle decay from QCD jets whose collinear structure is described by a factorized jet function. At the LHC, events with highly-boosted massive particles such as top, W, Z and Higgs may be a key ingredient for the discovery of physics beyond the standard model. In many decay channels, these particles would be identified as high-p_T jets, and any such signal of definite mass must be disentangled from a large background of QCD jets. We showed that this background far exceeds such signals, and relying solely on jet mass as a way to reject QCD background from signal would probably not suffice in most cases. For the solution to this problem, we found that jets from QCD are characterized by different patterns of intrajet energy flow compared to highly-boosted heavy particle decays. Based on this observation, we introduced several event shapes that could be used to disentangle signals from backgrounds.

(L. Almeida (CEA), G. Perez, S. Lee (Weizmann), G. Sterman (YITP, Stony Brook), I. Sung)

B. Developing Factorization and Resummation Formalisms in Non-Abelian Gauge Theories

Soft Anomalous Dimension Matrices

Understanding the higher-loop infrared structure of gauge theories caused great enthusiasm in recent years. Infrared poles in higher-loop calculations are organized by anomalous dimension matrices for color mixing through soft gluon exchange. In papers [6, 7] with Mitov and Sterman, we studied the soft anomalous dimension matrix for massive external particles. We used an analysis in Euclidean space, showing that the contributions to these matrices from diagrams that link three massive Wilson lines do not vanish in general. This differs from the pattern found with massless external lines in Ref. [5], where the authors discovered that massless soft anomalous dimension matrices at two loops are proportional to their one-loop values. We, however, found that, at ninety degrees in the center of mass, the massive anomalous dimension matrix also restores the proportionality to their one-loop value.

In Ref. [8], we provided a recursive diagrammatic prescription for the exponentiation of gauge theory amplitudes involving products of Wilson lines and loops. This construction generalizes the concept of webs, originally developed for eikonal form factors and cross sections with two eikonal lines, to general soft functions in QCD and related gauge theories. The arguments in this paper apply to arbitrary paths for the lines. This graphical exponentiation also has potential applications in the phenomenological treatment of cross sections. Because the underlying structure is fundamentally nonperturbative, webs have been used to organize the structure of power corrections due to soft radiation for Drell-Yan and related cross sections. The work in the massless soft anomalous dimension matrix for massless external lines at higher order is in preparation.

(A. Mitov (CERN), G. Sterman (YITP, Stony Brook) and I. Sung)

Infrared Safe Observable in 3D Gauge Theory

The classic analysis of Kinoshita and of Lee and Nauenberg showed that total transition probabilities remain finite in fully massless theories because the zero-mass limit does not violate unitarity in perturbation theory. Infrared safe quantities such as jet cross sections and energy correlation functions are generalizations of this analysis to less inclusive observables, and have been used successfully in QCD. To define an observable that is IR safe in massless super-renormalizable theories such as QED in $(2+1)$ dimensions or ϕ^3 theory in four dimensions, we need a detailed study of IR structures. Since these theories contain different IR structures from QCD, and which are more severe than in QCD, we may expect that new prescriptions may be necessary to get rid of IR sensitivity.

(I. Sung)

C. New Approach to Flavor and Grand Unified Theory

In the paper [9], we constructed an anomaly-free extension of the left-right symmetric model, where the maximal flavor group is gauged and anomaly cancellation is guaranteed by adding new vector-like fermion states. We addressed the question of the lowest allowed flavor symmetry scale consistent with data. Because of the mechanism recently pointed out by Grinstein et al., tree-level flavor changing neutral currents turn out to play a very weak constraining role. The same occurs, in this model, for electroweak precision observables. In the case where discrete parity symmetry is present at the TeV scale, this constraint implies lower bounds on the mass of vector-like fermions and flavor bosons of 5 and 10 TeV, respectively.

However, these limits are weakened under the condition that only $SU(2)_R \times U(1)_{B-L}$ is restored at the TeV scale, but not parity. For example, assuming the SU(2) gauge couplings in the ratio $g_R/g_L \approx 0.7$ allows the above limits to go down by half for both vector-like fermions and flavor bosons. This model provides a framework for accommodating neutrino masses and, in the parity symmetric case, provides a solution to the strong CP problem. The bound on the lepton flavor gauging scale is somewhat stronger, because of Big Bang Nucleosynthesis constraints. We argue, however, that the applicability of these constraints depends on the mechanism at work for the generation of neutrino masses. In an on-going project, we have been studying a grand unification of this model based on the gauge group $SU(5)_L \times SU(5)_R$ where the gauge flavor symmetry reduces to only a vector $SU(3)_H$ due to anomaly cancellation.

D. Guadagnoli (Orsay, LPT), R. Mohapatra (UMD) and I. Sung)

D. *Explaining Neutrino Masses from Inverse Seesaw in Warped Extra Dimension*

In the paper [10], we propose the inverse seesaw mechanism as a way to understand small Majorana masses for neutrinos in warped extra dimension models with seesaw scale in the TeV range. The ultra-small lepton number violation needed in implementing the inverse seesaw mechanism in 4D models is explained in this model as a consequence of lepton number breaking occurring on the Planck brane. We construct realistic models based on this idea that fit observed neutrino oscillation data for both normal and inverted mass patterns.

C. S. Fong (INFN), R. Mohapatra (UMD) and I. Sung)

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[6] A. Mitov, G. Sterman and I. Sung, Phys. Rev. D **79**, 094015 (2009) [arXiv:0903.3241 [hep-ph]].
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IV. RESEARCH PUBLICATIONS AND TALKS: 2011–JULY 2012

Published Papers 2011-June 2012

2011:

1. *Kaon Thresholds and Two Flavor Chiral Expansions for Hyperons*, F.-J. Jiang, B. C. Tiburzi, A. Walker-Loud, Phys. Lett. B **695**, 329 (2011). [arXiv:0911:4721 [nucl-th]]
2. *Effective Angular Momentum Operators in NRQED and Matching at One-Loop Order*, P. Chen, X. Ji, Y. Zhang, JHEP **1102**, 107 (2011). [arXiv:1012.3668 [hep-ph]]
3. *Gauged Flavor Group with Left-Right Symmetry*, D. Guadagnoli, R. N. Mohapatra, I. Sung, JHEP **1104**, 093 (2011). arXiv:1103.4170 [hep-ph]
4. *The Phases of Deuterium at Extreme Densities*, P. Bedaque, M. Buchoff, A. Cherman, JHEP **1104**, 094 (2011). [arXiv:1007.1972 [hep-ph]]
5. *Orbifold Equivalence and the Sign Problem at Finite Baryon Density*, A. Cherman, M. Hanada, D. Nobles-Llana, Phys. Rev. Lett. **106**, 091603 (2011).
6. *Quark Mass Variation Constraints from Big Bang Nucleosynthesis*, P. F. Bedaque, T. Luu, L. Platter, Phys. Rev. C **83**, 045803 (2011). [arXiv:1012.3840 [nucl-th]]
7. *Comment on 'Do Gluons Carry Half of the Nucleon Momentum?' by X.S. Chen et. al. (PRL103, 062001 (2009))*, X, Ji, Phys. Rev. Lett. **106**, 259101 (2011).
8. *Chiral Symmetry Restoration at Finite Density in Large N_c QCD*, P. Adhikari, T. D. Cohen, R. R. M. Ayyagari, M. C. Strother, Phys. Rev. C **83**, 065201 (2011). [arXiv:1104.2236 [nucl-th]]
9. *Baryons and Baryonic Matter in the Large N_c and Heavy Quark Limits*, T. D. Cohen, N. Kumar, K. Ndousse, Phys. Rev. C **84**, 015204 (2011). [arXiv:1102.2197 [nucl-th]]
10. *Vortons in Dense Quark Matter*, P. Bedaque, E. Berkowitz, A. Cherman, Phys. Rev. C **84**, 023006 (2011). [arXiv:1102.4795 [nucl-th]]
11. *The Phases of Deuterium and Extreme Densities*, P. F. Bedaque, M. I. Buchoff, A. Cherman, JHEP **1104**, 094 (2011). [arXiv:1007.1972 [hep-ph]]
12. *The Hagedorn Spectrum and Large N_c QCD in 2+1 and 3+1 Dimensions*, T. D. Cohen, V. Krejcirik, JHEP **08**, 138 (2011). [arXiv:1104.4783 [hep-ph]]
13. *Excited State Baryon Spectroscopy from Lattice QCD*, R. G. Edwards, J. J. Dudek, D. G. Richards, S. J. Wallace (for the Hadron Spectrum Collaboration), Phys. Rev. D **84**, 074508 (2011). [arXiv:1104.5152 [hep-ph]]
14. *O(a_s) Corrections to $J/\psi + \chi_c J$ Production at B Factories*, H.-R. Dong, F. Feng and Y. Jia, JHEP **10**, 141 (2011). [arXiv: 1107.4351 [hep-ph]]

Jan-June 2012:

1. *Sneutrino Dark Matter in Gauged Inverse Seesaw Models for Neutrinos*, H. An, P. S. Bhupal Dev, Y. Cai, R. N. Mohapatra, Phys. Rev. Lett. **108**, 081806 (2012). [1110.1366 [hep-ph]]
2. *Nuclear Condensate and Helium White Dwarfs*, P. F. Bedaque, A. Cherman, E. Berkowitz, Astrophysical J. **749**, 5 (2012). [1111.1343 [nucl-th]]
3. *Total Nucleon-Nucleon Cross Sections in Large N_c QCD*, T. D. Cohen, B. Gelman, Phys. Rev. C **85**, 024002 (2012). [1111.4465 [nucl-th]]
4. *Electron Shielding of Vortons in High-Density Quark Matter*, P. Bedaque, E. Berkowitz, G. Ji, N. Ng, Phys. Rev. D **85**, 043008 (2012). [arXiv: 1112.1386 [nucl-th]]

5. *Model-Independent Form Factor Relations at Large N_c*, T. D. Cohen and V. Krejcirik, Phys. Rev. C **85**, 035205 (2012). [arXiv: 1201.5389 [hep-ph]]
6. *Does the Empirical Meson Spectrum Support Hagedorn Conjecture?*, T. D. Cohen and V. Krejcirik, J. Phys. G: Nucl. Part. Phys. **39**, 055001 (2012). [arXiv: 1107.2130v5 [hep-ph]]
7. *Light Dark Matter and Z' Dark Force at Colliders*, H. An, X. Ji and L.-T. Wang, DOE/ER/40762-514 (2/2012), accepted in JHEP. [arXiv: 1202.2894 [hep-ph]]
8. *Gluon Spin, Canonical Momentum, and Gauge Symmetry*, X. Ji, Y. Xu, Y. Zhao, DOE/ER/40762-519, accepted in JHEP. [arXiv: 1205.0156 [hep-ph]]

Invited Papers: 2011-June 2012:

1. *The Hagedorn Spectrum and Large N_c QCD*, T. D. Cohen, Workshop on "Excited QCD 2011," Ecole de Physique des Houches, France, Feb. 20-25, 2011, DOE/ER/40762-500.
2. *Excited State Baryon Spectroscopy from Lattice QCD*, S. J. Wallace, XXIX Intl. Symp. on Lattice Field Theory, Squaw Valley, Lake Tahoe, CA, July 10-16 2011). [arXiv: 1111.3972 [hep-ph]]
3. *Nuclear and Hadronic Physics at Large N_c*, T. D. Cohen, Sixth Intl. Conf. on Quarks and Nuclear Physics, Ecole Polytechnique, Palaiseau, Paris, France, Apr. 16-20, 2012, DOE/ER/40762-520.

Papers Published in Proceedings or Books: 2011-June 2012

1. *Conference Discussion of the Nuclear Force*, F. Gross, T. D. Cohen, E. Epelbaum, R. Machleidt, in Few Body Systems **50** (2011) 31-44. [arXiv:1110.3761 [nucl-th]]
2. *Listening to Noise*, M. G. Endres, D. B. Kaplan, J.-W. Lee, A. N. Nicholson, in PoS(Lattice 2011) 17-29. [arXiv:1112.4023v1 [hep-lat]]
3. *Excited State Baryon Spectroscopy from Lattice QCD*, S. J. Wallace, PoS(Lattice 2011) 146-152. [arXiv: 1111.3972 [hep-lat]]
4. *Extended Study for Unitary Fermions on a Lattice Using the Cumulant Expansion Technique*, J.-W. Lee, M. G. Endres, D. B. Kaplan, A. N. Nicholson, in PoS(Lattice 2011) 203-209. [arXiv:1111.3793 [hep-lat]]
5. *The Hagedorn Spectrum and Large N_c QCD*, T. D. Cohen, Acta Phys. Polon. Supp. 4 (2011) 557-560. [arXiv: 1110.3761 [hep-ph]]
6. *Baryon Spectroscopy in Lattice QCD with Spin Identification*, R. G. Edwards, J. J. Dudek, D. G. Richards and S. J. Wallace, AIP Conf. Proc. 1432, 33-38 (2012).

Theses: 2011 - Summer 2012

1. *The Minimal Left-Right Symmetric Model and Neutron Electric Dipole Moment*
   by Haipeng An (2011) [Advisor: Xiangdong Ji]

Papers Submitted to Journals

1. *Majorana Neutrinos from Inverse Seesaw in Warped Extra Dimensions*, C. S. Fong, R. N. Mohapatra, I. Sung, DOE/ER/40762-504 (7/2011). [arXiv: 1107.4086 [hep-ph]]
2. *Stable Vortex Loops in Two-Species BECs*, P. F. Bedaque, E. Berkowitz, S. Sen, DOE/ER/40762-510 (11/2012). [arXiv: 1112.4507 [cond-mat.quant-gas]]
3. *Seeking Partonic Pictures of Proton Spin*, X. Ji, X. Xiong, F. Yuan, DOE/ER/40762-513 (2/2012). [arXiv: 1202.2843 [hep-ph]]

4. *N-Body Efimov States from Two-Particle Noise*, A. Nicholson, DOE/ER/40762-515 (2/2012). [arXiv: 1202.4402 [cond-mat.quant-gas]]

5. *Neutrino Emission from Helium White Dwarfs with Condensed Cores*, P. F. Bedaque, E. Berkowitz, A. Cherman, DOE/ER/40762-516 (3/2012). [arXiv: 1203.0969 [astro-ph.HE]]

6. *Alternate $1/N_c$ Expansions and SU(3) Breaking from Baryon Lattice Results*, A Cherman, T. D. Cohen, R. F. Lebed, DOE/ER/40762-521 (5/2012). [arXiv: 1205.1009 [hep-ph]]

7. *Thermodynamics of Nuclear Condensates and Phase Transitions in White Dwarfs*, P. Bedaque, E. Berkowitz, S. Sen, DOE/ER/40762-522 [arXiv:1206.1059 [astro-ph.HE]] (6/2012)

Unpublished Papers on arXiv: 2011 - July 2012

1. *Lattice Monte Carlo Calculations for Unitary Fermions in a Finite Box*, M. G. Endres, D. B. Kaplan, J.-W. Lee, A. N. Nicholson, DOE/ER/40762-517 [arXiv: 1203.3169 [hep-lat]] (4/2012)

2. *The Total Nucleon-Nucleon Cross Section at Large N_c*, T. D. Cohen, DOE/ER/40762-518 [arXiv: 1203.5843 [hep-ph]] (5/2012)

3. *Separable Potential Model for Meson-Baryon Interaction Beyond the S-Wave*, V. Krejcirik, DOE/ER/40762-523 [arXiv:1206.5168 [nucl-th]] (6/2012)

V. BIOGRAPHICAL SKETCHES OF FACULTY

THOMAS D. COHEN
Professor of Physics

Education:

B.Sc.	Harvard College, Cambridge, MA	1980
Ph.D.	University of Pennsylvania	1985

Experience in Higher Education:

1985-87	University of Maryland	Research Associate
1987-88	University of Maryland	Asst. Res. Scientist
1988-92	University of Maryland	Assistant Professor
1992-97	University of Maryland	Associate Professor
1994-95	University of Washington and the Institute for Nuclear Theory, Seattle	Visiting Scientist
1997-	University of Maryland	Professor
2009-12	Maryland Center for Fundamental Physics, University of Maryland	Director
2009-	University of Maryland	Assoc. Chair for Graduate Education

Synergistic Activities:

Director, Maryland Center for Fundamental Physics. This state supported center is aimed at promoting synergies between studies in various subfields of theoretical physics including nuclear, physics, particle physics, cosmology and gravitation (2009-2012).

Editorial Board, Physical Review C (2008-)

Convener, "QCD and nuclear physics" section at "Quark Confinement and the Hadron Spectrum" (2006,2008,2010)

Co-organizer, "Large Nc QCD" program at GGI (program in 2011) (Florence)

Convener, "Large N_C QCD" session at "Continuous Advances in QCD", Minneapolis (May 2006)

XIANGDONG JI
Professor of Physics

Education:

B.Sc.	Tongji University, Shanghai, China	1982
M.Sc.	Drexel University	1985
Ph.D.	Drexel University	1987

Experience in Higher Education:

1987	Drexel University	Postdoctoral Research Fellow
1987-1989	California Institute of Technology	Postdoctoral Research Fellow
1989-1991	Massachusetts Institute of Technology	Sponsored Research Staff
1991-1996	Massachusetts Institute of Technology	Assistant Professor
1996-1998	University of Maryland	Assistant Professor
1998-2001	University of Maryland	Associate Professor
2001-	University of Maryland	Professor
2004-	Peking University, P. R. China	ChangJiang Chair Vis. Professor of Theoretical Physics
2005-	Center for High-Energy Physics, Peking U.	Associate Director
2007-2009	Maryland Center for Fundamental Physics, University of Maryland	Director
2009-	Shanghai JiaoTong University,	ShuanQian Chair Professor (part-time)

Synergistic Activities:

Chairman, Gordon Conference on Nuclear QCD in 1999
Fellow, American Physical Society, 2000
Member, NSAC Nuclear Theory Subcommittee, 2003
Recipient of Outstanding Young Overseas Chinese Research Award, 2003-2006
Chair, APS Nuclear Division Hadronic Physics Town Meeting, Jan. 2007
Member, DOE and NSF Nuclear Science Advisory Committee, 2007-2010
Member, Executive Board of High-Energy Physics Society in China, 2011-

PAULO BEDAQUE
Associate Professor of Physics

Education:

B.Sc.	Universidade de Sao Paulo, Brazil, 1989
M.S.	Universidade de Sao Paulo, Brazil, 1985
Ph.D.	University of Rochester, Rochester, 1994

Experience in Higher Education:

1994-1996	Massachusetts Institute of Technology	Research Associate
1996-1999	Inst. for Nuclear Theory, U. of Washington	Research Associate
1999-2001	Inst. for Nuclear Theory, U. of Washington	Res. Asst. Professor
2001-2006	Lawrence Berkeley Laboratory	Divisional Fellow
2006	Lawrence Berkeley Laboratory	Senior Scientist
2006-2007	University of Maryland	Assistant Professor
2007-present	University of Maryland	Associate Professor

Synergistic Activities:

Co-organizer of INT Workshop on Effective Field Theory and Nuclear Physics, Seattle, 1999
Co-convenor of Few-Body Systems Workgroup of "Chiral Dynamics 2003", Bonn, Germany, 2003
Organizer of "Berkeley Effective Summer", Berkeley, 2003
Organizer of "Berkeley Summer of Lattice", Berkeley, 2004
Co-Organizer of the "2005 National Nuclear Physics Summer School", Berkeley, June 2005
Co-Organizer of the ECT* "Effective Theories in Nuclear Physics and Lattice QCD", Trento, Italy, July 2005
Advisory Board, "VIII Latin American Symposium on Nuclear Physics and Applications", Chile, 2009
Editorial Board, PMC Physics A
Steering Committee, National Nuclear Physics Summer School, 2009-present
Co-convener of Few-Body working group, "Chiral Dynamics 2009", Bern
Advisory Board, "IX Latin American Symposium on Nuclear Physics and Applications", Ecuador, 2011

STEPHEN J. WALLACE
Research Professor of Physics

Education:

B.Sc.	Case Institute of Technology	1961
M.Sc.	University of Washington, Seattle	1969
Ph.D.	University of Washington, Seattle	1971

Experience in Higher Education:

1972-74	Harvard University	Research Associate
1974-78	University of Maryland	Assistant Professor
1978-83	University of Maryland	Associate Professor
1983-09	University of Maryland	Professor
1989	Hebrew Univ. of Jerusalem	Sheinbrum Visit. Professor
1989	University of Utrecht	Visiting Professor
1994-99	University of Maryland	Chair, Department of Physics
1999-00	Jefferson Natl. Accelerator Facility	Visiting Professor
2009-	Univ of Maryland	Research Prof & Professor Emeritus

Honors and Awards

Appointed Donders Chair, Inst. of Theoretical Physics, Univ. of Utrecht,
The Netherlands, 1989
Fellow, American Physical Society, 1990

Synergistic Activities:

Member, Executive Committee, American Physical Society, Nuclear Physics Div., 1993-95
Southeastern Universities Research Association:
    Chair, Jefferson Laboratory Committee, 2000-02
    Vice-Chair, Board of Trustees, 2002-03
    Chair, Board of Trustees, 2004-05
    Past-Chair, Board of Trustees, 2006-07
Committee on Broadcast Journalism Award, American Physical Society, 2001-03
DNP Fellowship Committee, 2002
Chair, Committee on Constitution and Bylaws, American Physical Society, 2002
Divisional Associate Editor, Physical Review Letters, 2002-04
NSAC Subcommittee on Performance Measures for Nuclear Physics, 2003
NSF Panel for Nuclear Physics, 2004
Jefferson Science Associates:
    Chair, Programs Committee, 2007-09
    Member, Board of Directors, 2007-09
    Member, Search Committee for Lab Director, 2007

VI. LIST OF PERSONNEL, GRADUATE STUDENT TRACKING INFORMATION, AND CAREER HISTORY

TQHN Group Personnel (Dec. 1, 2011 - Nov. 30, 2012)

Faculty
Paulo F. Bedaque
Thomas D. Cohen
Xiangdong Ji
Stephen J. Wallace

Research Associates
Ilmo Sung (thru 8/31/2012)
Amy Nicholson
Simin Mahmoodifar (beg. 9/1/2012)
Naoki Yamamoto (beg. 9/1/2012)

Visiting Senior Research Scientist
John Kogut[1]

Research Graduate Assistants
Prabal Adhikari
Evan Berkowitz[2]
Vojtech Krejcirik
Srimoyee Sen
Yong Zhao (beg. Summer 2012)

Summer Research Students
Patrick Jefferson (UM senior undergraduate)
Arec Jamgochian (H.S. graduate)

[1] Non-salaried position.
[2] SURA Fellowship for academic year 2011-2012.

The Department of Physics provided $7,000 for secretarial support in the 2011-2012 academic year; $4,000 of which was from the Maryland Center for Fundamental Physics (MCFP). As of July 1, 2012, Mrs. Robinette will be retired, and the administrative assistance for the group's travel and visitor hosting will be handled by the MCFP office.

Graduate Student Tracking Information

Student Name	Date Entered Graduate School	Joined Group	Date Degree Awarded/Degree	Advisor
Michael Buchoff	08/2005	01/2007	05/2010/PhD	Prof. Paulo Bedaque
Aleksey Cherman	06/2008	06/2008	05/2010/PhD	Prof. Thomas Cohen
Haipeng An	06/2008	06/2008	05/2011/PhD	Prof. Xiangdong Ji
Evan Berkowitz	09/2008	06/2009	exp. 2012/PhD	Prof. Paulo Bedaque
Vojtech Krejcirik	08/2010	08/2010	exp. 2013/PhD	Prof. Thomas Cohen
Prabal Adhikari	08/2009	06/2010	exp. 2013/PhD	Prof. Thomas Cohen

Graduate Students in the Joint PhD Candidacy Program of the
China Scholarship Council, Ministry of Education of the P. R. China

Student Name	Date Entered Graduate School	Joined Group	Date Degree Awarded/Degree	Advisor
Fanrong Xu (Peking)	09/2005	10/2008-03/2010	06/2010/PhD	Prof. Xiangdong Ji
Yang Xu (Peking)	09/2007	02/2011-2012	*	Profs. T. Cohen & X. Ji

*Pursuing new topic in China

Career History of Recent Research Associates

Name	Originating Institute	Dates	Pres. Position & Location
Joydip Kundu	MIT, Cambridge MA	04-06	Staff Member, Ofc. of Management & Budget, Washington DC
Ahmad Idilbi	U. of Maryland	2006	Res. Assoc., Univ of Heidelberg, Germany
Yingchuan Li	U. of Maryland	2007	Res. Assoc., Brookhaven National Lab, Upton NY
Andre Walker-Loud	U. of Washington, Seattle	06-08	Res. Staff, Lawrence Berkeley Lab, CA
Brian Tiburzi	Duke Univ., Durham NC	2007-10	Asst. Prof., City College/City Univ New York
Shaolong Chen	National Taiwan Univ.	2008-10	Prof., Hua-Zhong Normal University, China
Ilmo Sung	CN Yang Inst, Stony Brook U	2010-12	
Michael Buchoff	U. of Maryland	2010	Postdoctoral Researcher, Lawrence Livermore Natl La
Aleksey Cherman	U. of Maryland	2010	Res. Assoc., DAMPT, Cambridge Univ,UK; Res. Ass
Haipeng An	U. of Maryland	2011	Res. Assoc., Perimeter Inst., Canada
Amy Nicholson	U. of Washington, Seattle	2011-	

Career History of Recent Graduate Students

Name and Present	PhD	Dissertation Research
Ahmad Idilbi	2006	*QCD Resummation of Soft Gluons in Effective Field Theory* (X. Ji, Adv.)

Current or Last Known Affiliation: Res. Assoc., Univ of Heidelberg, Germany

Yingchuan Li	2007	*A SUSY SO(10) GUT Model with Lopsided Structure* (X. Ji, Adv.)

Current or Last Known Affiliation: Res. Assoc., Brookhaven National Lab, Upton NY

Paul Hohler	2008	*Phenomenological Aspects of Heavy Quark Systems* (T. D. Cohen, Adv.)

Current or Last Known Affiliation: Res. Assoc., Univ. of Illinois at Urbana-Champaign

Hongwei Ke [Joint China-US PhD Program]	2008	*Diquark and Study of Hadron Physics* (X. Ji, Adv.)

Current or Last Known Affiliation: Lecturer, Tianjin University, China

Yue Zhang [Joint China-US PhD Program]	2009	*Phenomenology of Supersymmetry and Left-Right Symmetric Models* (X. Ji, Adv

Current or Last Known Affiliation: Res. Assoc., ICTP, Trieste, Italy

Elizabeth Werbos	2009	*Vacuum Properties of QCD in an Electromagnetic Field* (T. D. Cohen, Adv.)

Current or Last Known Affiliation: Senior Professional Staff, Johns Hopkins Applied Physics Lab, Laurel MD

Eric Engelson	2009	*Excited Nucleon and Delta Spectra from Lattice QCD* (S. J. Wallace, Adv.)

Current or Last Known Affiliation: Associate Engineer, In Depth Engineering Corp., Fairfax VA

Panying Chen	2009	*Non-Relativistic Decomposition of Angular Momentum Operator in Effective Field Theory* (X. Ji, Adv.)

Current or Last Known Affiliation: Analyst, Goldman Sachs & Co., Virginia

Michael Buchoff	2010	*Topics in Lattice QCD and Effective Field Theory* (P. Bedaque, Adv.)

Current or Last Known Affiliation: Postdoctoral Researcher, Lawrence Livermore Lab, CA

Aleksey Cherman	2010	*Transport Coefficients and Universality in Hot Strongly Coupled Gauge Theories* (T. D. Cohen, Adv.)

Current or Last Known Affiliation: Res. Assoc., DAMPT, Cambridge Univ,UK; Res. Assoc, U of Minnesota, Minnea

Fanrong Xu	2010	*Neutron Electric Dipole Moment in Minimal Left-Right Symmetric Model* (X. Ji, Adv.) [Joint China-US PhD Program]

Current or Last Known Affiliation: Research Associate, National Taiwan University

Haipeng An	2011	*The Minimal Left-Right Symmetric Model and Neutron Electric Dipole Moment*

Current or Last Known Affiliation: Research Associate, Perimeter Inst., Canada

VII. VISITORS PROGRAM: 2011–JULY 2012

Seminar Speakers - 2011-July 2012

2011

Mr. Emanuele Mereghetti, Univ of Arizona, Tucson: 1 day (1/4/11)
T-Violation in Nuclear Physics. An effective approach

Mr. Daekyoung Kang, The Ohio State University, Columbus: 2 days (1/18-20/11)
Universal Relations for Strongly Interacting Atoms

Mr. Gokce Basar, Univ of Connecticut, Storrs: 2 days (2/20-22/11)
Gap Equations and Phase Diagrams of Gross Neveu Models

Mr. Thomas Kelley, Univ of Minnesota, MN: 4 days (1/23-27/11)
The Thermodynamics of a 5D-Gravity-Dilaton-Tachyon Solution

Ms. Amy Nicholson, INT-Univ of Washington, Seattle: 2 days (1/30-2/1/11)
Lattice Approach for Studies of Particles at Unitarity

Dr. Jonathan Walsh, Lawrence Berkeley Natl Lab, CA: 2 days (2/1-3/11)
Using SCET for Jet Physics at Colliders

Mr. Chee Sheng Fong, Stony Brook University, NY: 2 days (2/8-10/11)
Soft Leptogenesis as a Viable Model of Baryogenesis

Dr. Daniel Phillips, Ohio University, Athens: 1 day (2/19/11)
Look Mum! No pions! Addressing (some) nuclear-structure issues using effective field theories

Mr. Martin Hoferichter, HISKP - Univ of Bonn, Germany: 1 day (3/2/11)
Isospin Violation in Pion-Nucleon Physics

Dr. Thomas Mehen, Duke University, Durham NC: 1 day (3/9/11)
Effective Field Theory

Dr. Kostas Orginos, College of William & Mary, Williamsburg VA: 1 day (3/16/11)
Hadron Interactions from Lattice QCD

Dr. Zhong-Bo Kang, RIKEN BNL Res Ctr, Upton NY: 2 days (3/29-31/11)
Single Transverse Spin Asymmetry: Progresses and Puzzles

Dr. Simone Marzani, Univ of Manchester, United Kingdom: 4 days (4/5-8/11)
QCD Resummation for Jet Physics at the LHC

Dr. Dan Pirjol, Natl Inst for Physics & Nucl Eng, Bucharest: 1 day (4/6/11)
Large N_c QCD and the Spin-Flavor Structure of the Quark Interactions

Dr. Andrew Ferroglia, New York City College of Technology, Brooklyn: 1 day (4/20/11)
Top Quark Pair Production Beyond Next-to-Leading Order

Dr. Guy Moore, McGill University, Montreal, Quebec: 2 days (4/12-14/11)
Second-Order Relativistic Hydrodynamics

Dr. Aleksey Cherman, University of Cambridge, United Kingdom: 1 day (5/18/11)
The Fermion Sign Problem and Large N Orbifold Equivalence

Dr. Jiunn-Wei Chen, National Taiwan University: 2 days (6/28-30/11)
Holographic Superconductors

Dr. William Newton, Texas A&M University, Commerce: 1 day (7/13/11)
The Nuclear Symmetry Energy and Neutron Star Observables

Dr. Ethan Neil, Fermilab, Batavia, IL: 2 days (9/7-9/8/11)
Lattice Strong Dynamics and Electroweak Symmetry Breaking

Dr. Thomas Luu, Lawrence Livermore Lab, CA: 3 days (9/26-29/11)
Recent Nuclear Science Signals (with Noise from Lattice QCD)

Dr. Joaquin Drut, Los Alamos National Lab., NM: 1 day (10/5/11)
Life on the Lattice: From QCD to Cold Atoms, Graphene and Beyond

Dr. Thomas Schaefer, North Carolina State Univ.: 2 days (10/12-13/11)
Nearly Perfect Fluidity in Cold Atomic Gases

Dr. Jesse Thaler, Mass. Inst of Technology, Cambridge: 3 days (10/25-28/11)
N-Subjettiness

Dr. Bingwei Long, Jefferson National Accelerator Lab, Newport News VA: 3 days (10/31-3/11)
Correct Dr. Weinberg's Prescription–Renormalization and Power Counting of Chiral Nuclear Forces

Dr. Kevin Dusling, North Carolina State Univ., Raleigh: 1 day (11/9/11)
Bulk Viscosity, Particle Spectra and Flow in Heavy-Ion Collisions

Dr. Bjoern Schenke, Brookhaven National Lab., NY: 2 days (11/29-12/1/11)
Analyzing the Quark-Gluon Plasma with Higher Flow Harmonics
Dr. Simin Mahmoodifar, Washington Univ. St. Louis, MO: 2 days (12/11-13/11)
High Amplitude Bulk Viscosity of Dense Matter and Probing Phases of Cold Dense QCD with Neutron Star Physics
Dr. Naoki Yamamoto, University of Washington, Seattle: 3 days (12/13-16/11)
The QCD Plasma Diagram: Universality and Continuity

2012

Dr. Sichun Sun, University of Washington: 3 days (1/1-4/12)
Effective Field Theory Approach to Equation of States and Strongly Coupled Systems
Dr. Lance Labun, The University of Arizona: 2 days (1/11-13/11)
Signature of Spontaneous Particle Production in Converging Laser Pulses
Dr. Gaute Hagen, Oak Ridge National Lab, TN: 2 days (2/7-9/12)
Towards Model Independent Description of Nuclei with Coupled-Cluster Theory
Dr. Jozef Dudek, Old Dominion Univ., VA: 1 day (2/14-15/12)
Gluonic Excitations in QCD
Dr. William Detmold, College of William & Mary, VA: 1 day (2/21-22/12)
Ab Initio Nuclear Physics
Dr. Javier von Stecher, JILA & Univ. of Colorado at Boulder: 2 days (2/27-29/12)
Universality in Few-Boson Systems and the Efimov Effect
Dr. Madappa Prakash, Ohio University, Athens: 2 days (3/13-15/12)
Rapid Cooling of the Neutron Star in Cassiopeia-A
Dr. Thomas DeGrand, University of Boulder, CO: 2 days (4/10-12/12)
Checking Technicolor Candidates Using the Lattice
Dr. Aron Bernstein , Massachusetts Institute of Technology: 1 day (4/25/12)
Measurement of the $\pi 0$ *Lifetime: QCD Axial Anomaly and Chiral Symmetry*
Dr. Shina Tan, Georgia Inst of Technology: 1 day (5/1-2/12)
Beyond the Efimov Effect for Three Particles in Three Dimensions
Prof. Yong-Zhong Qian, Univ. of Minnesota, Tate Lab., Minneapolis: 2 days (5/8-10/12)
Collective Oscillations of Supernova Neutrinos
Dr. Huey-Wen Lin and Saul D. Cohen, Univ. of Washington, Seattle: 1 day (5/11/12)
Probing Physics, Beyond the Standard Model with Nucleons on the Lattice

Local Speakers

Mr. Evan Berkowitz, University of Maryland: 1/26/11
Vortons at High Density
Dr. Ahmad Idilbi, Ciudad University, Madrid, Spain, and College Park MD: 5/4/11
Regular and Singular Cases: What is Wrong with Soft-Collinear Effective Theory?
Mr. Vojtech Krejcirik, University of Maryland: 9/21/11
The Hagedorn Spectrum: theory and practice
Mr. Clayton Davis, University of Maryland: 11/16/11
Double-beta Decay in Xenon 136
Dr. Andrei Alexandru, George Washington University: 12/9/11
QCD Thermodynamics Using the Canonical Partition Function
Dr. Xiangdong Ji, University of Maryland: 3/7/12
Seeking Partonic Pictures of Proton Spin

Collaborative Visitors

Dr. Yue Zhang, Abdus Salam ICTP-Trieste, Italy: 1 week (5/12-20/11)
Dr. Yu Jia, IHEP, Chinese Academy of Sciences, Beijing: 6 months (5/24-11/30/11)
Some Recent Progress in Understanding Heavy Quarkonia Electromagnetic Decays
Mr. Jonathan Hall, CSSM-Univ of Adelaide, Australia: 1 week (7/9-17/11)

Chiral Effective Field Theory Beyond the Power-Counting Regime

Mr. Lu Ma, Zhi Yuan , Zhi Yuan College, Shanghai Jiao Tong University: 2 weeks (3/11-22/12)
it Direct Measurement of Xenon Purity by RGA and Cold Trap Method

Dr. Andre Walker-Loud, Lawrence Berkeley Lab., CA: 1 week (4/15-23/12)
$M_n - M_p$

Dr. Su Houng Lee, Inst. of Physics & Applied Physics, Yonsei Univ, Seoul Korea (7 weeks)