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TECHNICAL PROGRESS REPORT

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TITLE: RESEARCH IN THEORETICAL PHYSICS

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Period: March 1, 1989 - present

1. Overview

The past two and a half years has involved a considerable change in the direction and scope of this program. The addition of Dr. Tony Williams as an Assistant Professor in Fall 1989 and as Co-Principal Investigator in March 1990 allowed the program to become broadened in scope and in manpower. Currently there are five graduate students associated with the program plus a research associate - Adam Szczepaniak - who began in November 1990. There is now a strong program in the area of covariant relativistic wave equations for a variety of QCD based models with applications ranging from e^+e^- scattering to meson and baryon spectroscopy. At the same time the work on the Hamiltonian form of Lattice Gauge Theory has been continued.

The collaboration with Professor Siu Chin (Texas A&M) in lattice gauge calculations reached the tantalizing glueball results summarized¹⁾ in a presentation by one of us (D.R.) in 1989. The glueball sector is known to be a particularly difficult calculational problem while at the same time it involves glueballs - a very significant prediction of QCD. New ideas in this area have been developed by Chris Long and Don Robson and a new graduate student (George Frichter) is now involved in implementing them.

The role of chiral symmetry continues to be a major thrust of the group. Allison Haydel continues to use the chiral potential model²⁾ extended to three flavors with a desire to understand the pion-nucleon sigma term problem and the role of strangeness in the baryon spectrum. An alternative study by Dr. Williams and various collaborators studies dynamical chiral symmetry breaking, the role of local gauge invariance, involving a graduate student (Fred Hawes), and the non-perturbative quark propagator. Various

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covariant models are considered and in particular light cone techniques have been studied by Drs. Szczepaniak and Williams with a new graduate student Joel Parramore. The increase in the number of graduate students to five has allowed us to involve them in a broader range of topics than was possible in the previous 3 year period.

This has been a stimulating transition period for us and the last six months of the award period should be enhanced as one of us has now completed the term of department chairman and will as a Distinguished Professor (awarded April 1990) receive teaching relief for the fall semester of 1991. Past visitors have included G. Krein, C. Roberts and J. Vary. Currently L.R. Dodd is visiting us for two months. A list of collaborators is provided in section 3. A major effort has been made to set up communication links and discussions with CEBAF nuclear theorists (Nathan Isgur, Franz Gross and Wally Van Orden) and Jorge Piekariwicz (Supercomputer Computations Research Institute-SCRI/FSU) with an idea to developing calculational tools and ideas for CEBAF related physics. An initial meeting also attended by Chuck Horowitz (University of Indiana) will be followed by a second working meeting at CEBAF in early October 1991. We believe such discussions combined with the natural development of our work will lead to a significant fraction of our work being relevant to experiments planned or being planned for CEBAF in the mid 1990's.

The major results of each area of investigation are discussed in more detail in the ensuing sections and a list of publications is given in appendix 1. In addition, a number of submitted preprints and papers in press have been appended to the proposal. One Ph.D. dissertation was completed by Jonathan Hoffman during the award period and represents perhaps the first understanding of the failure of perturbative QCD to explain the exclusive process of elastic proton-proton transverse asymmetry and spin correlations at momenta up to 24 GeV/c.

2. Description of the program

We limit our description to the major thrusts of the program.

A. Hamiltonian Lattice Gauge Theory - G. Frichter, C. Long and D. Robson

The collaboration with Professor S.A. Chin (Texas A&M) has continued to a natural completion with supercomputer time being used to calculate four parameter variational estimates of the 0^{++} glueball mass. The summary of these “small loop” and “few states” variational calculations are given in the publication (1). Since then we realized that any continuation to a more realistic calculation would require new ideas and better computer resources. The computer resources were realized by the acquisition of three DEC5000 workstations and an agreement with SCRI to manage the operational aspects for us in their network of such workstations. The glueball sector in the Hamiltonian form is really a scalar calculation and so vector processing is of no great use. By identifying those calculational components where round-off errors are important we have been able to show quite clearly that loops involving only eight links on the lattice at a time cannot yield scaling. The earlier work with Chin used an approximate vacuum state which makes the estimates of glueball masses suspect. The recent work used eleven basis states and an exact vacuum state and shows no evidence for scaling behavior. The positive aspects of these calculations is that they can be done in a reasonable time on a workstation and that we must include larger loops if the calculations are to simulate the approach to the continuum limit. Work on the inclusion of square loops up to 6×6 or more are being considered (see proposed work).

B. Relativistic Potential Model - Jonathan Hoffman and D. Robson

This work on the proton-proton elastic scattering spin observables is completed and involved an extension of the one-boson exchange model up to 24 GeV/c. Relativistic dynamics being mandatory led to the use of the continuum form of the instantaneous Bethe-Salpeter equation. The inclusion of a Lorentz scalar imaginary potential to allow for the large inelasticity occurring at high energies is absolutely necessary to describe the data. This absorptive potential dominates at high energies greatly attenuating the low partial waves. This suggests that perturbative quantum chromodynamics (PQCD) cannot be applied to elastic scattering at the energy scale examined here, since absorptive effects prevent the quarks in each proton ever being close enough together for PQCD to be valid for elastic events. The observations are consistent with hadronic degrees of freedom dominating at separations

consistent with peripheral partial waves (see publication 5).

C. Chiral Potential Models - T. Gutsche, A. Haydel and D. Robson

The Ph.D. work of Thomas Gutsche on a two-flavor chiral potential model was completed with the publication of the finiteness of the self-energy of the ground state nucleon (publication 2). This work extended the model suggested by Tegen and Wiese²⁾ and is being re-examined by Allison Haydel as a Ph.D. project for three flavors. A new method of solving a general Dirac equation using double Heaviside functions and the diagonalization of a tri-diagonal matrix has allowed the form of the chiral potential to be made more flexible. The application of this approach to calculate the pion-nucleon and kaon-nucleon sigma terms is in progress and represents (see proposed work) an interesting test of the accuracy of the linearization approximation usually used in such chiral potential models.

D. Covariant Dynamical Chiral Symmetry Breaking Models of Hadronic Structure - F.T. Hawes, A. Szczepaniak and A.G. Williams

Covariant models of chiral symmetry breaking in QCD (publications 7,9,10) have been developed. Considerable effort has been put into the study of dynamical chiral symmetry breaking and the nonperturbative quark propagator. These studies involve the iterative solution of Schwinger-Dyson equations (coupled integral equations) and were made possible by supercomputer time on the CRAY Y-MP at FSU and by the purchase of the DEC5000 workstations. The more recent work with a graduate student (Fred Hawes) studies the importance of the non-perturbative quark-gluon vertex and gauge invariance (publication 11). This publication shows that commonly used prescriptions for the vertex not only underestimate the degree of dynamical chiral symmetry breaking but also violate gauge invariance. Further work (publication in preparation 6) has resulted in an ansatz solution of a simplified Schwinger-Dyson equation which gives rise to a confined quark in the time-like region. This is a significant advance in this type of modelling and should allow more quantities of physical interest to be calculated, such as the electromagnetic form factor of the pion. Investigations of the potential importance of including these nonperturbative quark propagators in studies of relativistic bound states are in progress (see proposed work) and will be

carried out with a graduate student (Fred Hawes). A paper discussing the general implications of confinement for models of this type has also been submitted for publication (publication submitted 2).

E. Light-cone Calculations and Models - J. Parramore, A. Szczepaniak and A.G. Williams

The application of light-cone techniques as a tool for investigating perturbative and nonperturbative QCD is a recent development at F.S.U. The application of these techniques to the problem of the high Q^2 -behavior of the pion form factor has been studied (publication 12). For the first time a perturbative formula for the pion form factor is obtained which is unambiguous and free of the soft small x contributions. Although the analysis involves the notion of a light cone hadron wave function it has been done without referring to the poorly known low energy structure of the wave function. A covariant generalization of a Dirac oscillator model for two fermions has been found as one of the dynamical models of confinement and solutions for the $J^P=0^-$ channel explicitly calculated together with the corresponding light cone wavefunctions (publication 13). General ideas of how to construct covariant dynamical models have been used to find a simple covariant mass formula for the meson spectrum (publications submitted 3) which depends only on the collective properties of the hadronic states. This approach invokes symmetry arguments (similar to the earlier work of Iachello³⁾) and collective or stringlike excitations and describes the meson spectrum quite accurately.

The development of models for the light cone wave functions goes in parallel with the study of light cone field theory which if done properly should lead to the same results as the covariant approach. It is interesting that the $1/k^+$ poles encountered in the light cone formalism are quite unphysical and result from an unjustified exchange of limits. Although it is well known that these false poles do not contribute in tree level calculations, it remains unclear whether or not there are false contributions in calculations involving one or more loops. This question and others are being investigated and involve a graduate student (Joel Parramore).

F. Strangeness in the Nucleon - A.G. Williams

Investigations with E.M. Henley, G. Krein and S.J. Pollock on possible experimental tests of the strangeness content of nucleons have been recently accepted for publication (publication 14). In this work several probes of strange matrix elements of nucleons are studied: (i) the difference between neutrino and anti-neutrino scattering from isospin zero targets, and (ii) electro- and neutrino-production of ϕ -mesons. A more definitive calculation (publication submitted 5) compares electro-production of ϕ -mesons from $s\bar{s}$ -knockout in a simple quark model with diffractive production predictions from a vector dominance model. With an $s\bar{s}$ component of order 10-20% the two predictions are of comparable size and agree reasonably with the sparse existing data on electroproduction. This is an exciting result because more accurate experiments on ϕ -production are already planned, for example, at CEBAF. The spin structure function of the nucleon, the OZI rule, and models of hadron structure discussed above are topics closely related to this investigation. Investigations of polarization experiments as a means of isolating the knockout mechanism as well as the development of more sophisticated models for this type of calculation are underway (see proposed work).

G. Additional Projects - D. Robson and A.G. Williams

One of us (D.R.) has been involved in several projects ranging from J-dependent absorption in ${}^6\text{Li}$ scattering (publication 6) to the use of Barut's two-fermion equation⁴⁾ to search (unsuccessfully) for resonances in e^+e^- scattering (publication in preparation 4). Similarly the interest by one of us (AGW) in tests of symmetries (e.g. charge-symmetry, etc.) has led to work with W.C. Haxton on first-forbidden contributions to $2\nu\beta\beta$ -decay (publication in preparation 7). This work examines the potential importance of relativistic corrections to β -decay operators which as well as improving our description of $2\nu\beta\beta$ -decay rates has implications for tests of the symmetries in the standard model. In particular a sound understanding of the same nuclear physics issues is important for extracting reliable limits on Majorana neutrino masses from upper limits on $0\nu\beta\beta$ -decay rates.

References

1. D. Robson, C. Long and S.A. Chin, in Relativistic Many-Body Physics, World Scientific (Eds. Clark, Perry and Vary) 31, (1989).
2. R. Tegen, M. Schedl and W. Wiese, Phys. Letters **B125**, 9 (1983). R. Tegen and W. Wiese, Z. Phys. **A314**, 357 (1983). D. Robson, in Topical Conference on Nuclear Chromodynamics, World Scientific (Eds. Giu and Sivers) 174, (1988).
3. F. Iachello, N.C. Mukhopadhyay and L. Zhang, Phys. Letters **B256**, 295 (1991). F. Iachello, in Symmetries in Physics Symposium in Honor of Professor Marcos Moshinsky, Mexico 1991.
4. A.O. Barut and S. Komy, Forts. der Physik **33**, 309 (1985).

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3. Personnel Involved during Period March 1, 1989- present

D. Robson   Principal Investigator 1989-present
                         Professor and Chairman (ended August 1991)

A.G. Williams   Co-Principal Investigator March 1990-present
                         Assistant Professor

A. Szczepaniak   Research Associate November 1990-present

C. Long   Assistant Research Scientist terminated Dec. 1989

Collaborators: S.A. Chin (Texas A&M)
                         G. Krein (Universidade Federal de Santa Maria, Brazil)
                         L.R. Dodd (University of Adelaide, Australia)
                         C.D. Roberts (Argonne National Laboratory)
                         E.M. Henley (University of Washington)
                         W.C. Haxton (University of Washington)
                         L. Wilets (University of Washington)
                         C.F. Moore (University of Texas)
                         K.W. Kemper (Florida State University)

Graduate Students: J. Hoffman (graduated)
                         A. Haydel (since March 1989) (CEBAF supported 1990-91)
                         G. Frichter (since May 1990)
                         F. Hawes (since May 1990) (SCRI supported)
                         J. Parramore (since December 1990)
                         R. Fulwood (since May 1991)

Staff: L. Crew, 25% time, secretarial/fiscal

Appendix 1

Publications during Period March 1, 1989-present

A. Papers published or accepted for publication

1. Hamiltonian Lattice Gauge Calculations for SU(N) Gauge Groups, D. Robson, Chris Long and S.A. Chin, in Relativistic Many-Body Physics, World Scientific (Eds. Clark, Perry and Vary) 31, (1989).
2. Positive and Convergent Self-Energy in a Chiral Potential Model, T. Gutsche and D. Robson, Physics Letts. **B229**, 333 (1989).
3. Comment on "Parity Doubling in Baryons and its Relevance to Hadronic Structure", D. Robson, Phys. Rev. Letts. **63**, 1890 (1989).
4. The A=3 Nolen Schiffer anomaly and the up-down quark mass difference, M. Encinosa and D. Robson, Physics Letts. **B244**, 19 (1990).
5. Relativistic potential model of proton-proton scattering spin observables, Jonathan Hoffman and D. Robson, Phys. Rev. **C42**, 1225 (1990).
6. Angular momentum dependent absorption in ${}^6\text{Li}$ scattering, D. Robson with D. Trcka *et al.*, Phys. Rev. **C41**, 2134 (1990).
7. Covariant model of chiral symmetry breaking in QCD, G. Krein and A.G. Williams, Mod. Phys. Lett. **A5**, 399 (1990).
8. The chromo-dielectric model: confinement, chiral symmetry breaking and the pion, G. Krein, P. Tang, L. Wilets and A.G. Williams, Nucl. Phys. **A523**, 548 (1991).
9. Dynamical chiral symmetry breaking in dual QCD, G. Krein and A.G. Williams, Phys. Rev. **D43**, 3541 (1991).
10. Modelling the quark propagator, A.G. Williams, G. Krein and C.D. Roberts, Ann. of Physics (Aug. or Sept. 1991).

11. Proper vertex in studies of dynamical chiral symmetry breaking, F.T. Hawes and A.G. Williams, to appear in Physics Letts. B.
12. End point behavior of the pion distribution amplitude, Lech Mankiewicz and Adam Szczepaniak, to appear in Physics Letts. B.
13. Hamiltonian formulation of a simple covariant harmonic oscillator for bosons and fermions, Adam Szczepaniak, to appear in Springer-Verlag Lecture Notes in Physics.
14. Measuring strangeness matrix elements of the nucleon, E.M. Henley, G. Krein, S.J. Pollock and A.G. Williams, to appear in Phys. Letters. B.

B. Papers submitted or in preparation

1. States at high excitation in heavy nuclei observed in pion double charge exchange whose configuration is identical to its parent, D. Robson with C.F. Moore *et al.*, submitted to Phys. Rev. C.
2. On the implications of confinement, C.D. Roberts, A.G. Williams and G. Krein, submitted to Int. Journal of Mod. Phys. A.
3. Covariant formulation of the collective model for meson structure, Adam Szczepaniak, submitted to Phys. Letters B.
4. Lack of resonances at relativistic energies in e^+e^- scattering, D. Robson, in preparation.
5. Phi-production as a measure of strangeness in nucleons, G. Krein, E.M. Henley and A.G. Williams, submitted to Phys. Lett. B.
6. Confinement ansatz in the Schwinger-Dyson equation for the quark propagator, Adam Szczepaniak and A.G. Williams, in preparation.
7. The effects of first forbidden corrections on $2\nu\beta\beta$ -decay rates, W.C. Haxton and A.G. Williams, in preparation.

8. Survey of the ($^9\text{Be}, ^6\text{He}$) Reaction on ^9Be , ^{10}B , ^{11}B and ^{12}C , D. Robson with L. Comer *et al.*, in preparation.

C. Ph.D. Dissertations

A relativistic potential model of proton scattering spin observables, Jonathan Hoffman, Fall 1989.

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