DOE/ER/40448-T1

U. S. Department of Energy Grant No. DE-FG02-88ER40448-A006

Theoretical Aspects of Electroweak and Other Interactions in Medium
Energy Nuclear Physics: Interim Progress Report
[December 5, 1994]

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Abstract

Significant progress has been made in the current project year in the development of chiral soliton model and its applications to the electroweak structure of the nucleon and the Delta (1232) resonance. Further progress also has been made in the application of the perturbative QCD (pQCD) and the study of physics beyond the standard model. The postdoctoral associate and the graduate student working towards his Ph. D. degree have both made good progress. The review panel of the DOE has rated this program as a "strong, high priority" one. A total of *fifteen* research communications -- *eight journal papers and conference reports and seven other communications* -- have been made during the project year so far. The principal investigator is a member of the Physics Advisory Committee of two nuclear accelerator facilities.

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1. Introduction

The main focus of this work is to study the theory of electroweak structure of hadrons in the context of new research to be done at CEBAF. In the current project year, we have made progress in the development of the soliton model, perturbative QCD (pQCD) and studies for reactions that can probe the physics beyond the standard model. We have made new advances on the analysis of the eta photoproduction data. One highlight of the year is the result of the review by the DOE panel, which has found our program to be a "strong, high priority" one (Appendix A). The other is the completion of fifteen scientific communications this year [1-15].

We give a summary of the research progress in the project year in Section 2. Progress of the research associate and the graduate student is discussed in Section 3. In Section 4, research travels of the principal investigator (NCM) are summarized. Section 5 lists external collaborators who have contributed to our research progress this year. Section 6 contains other research-related developments. Section 7 lists papers and other communications quoted in this report.

Appendix A is the Report of the DOE panel. Appendix B lists the institutions or conferences where NCM and his associates have presented research results this year under the present grant. Appendix C lists papers and other scientific communications made in the current project year. We include a sample of them in the Appendix D.

2. Research Progress

In the year under review, eight papers have been published [1-8]. In addition, three conference abstracts [9-11] have been communicated. One invited paper is in print [13], and two invited papers that have been orally presented [14,15] are unpublished. Three other papers have been submitted for publication.

Below we itemize a few issues on which we have made progress in the current project year.

(1) New developments in the chiral soliton model

We have expanded the range of applicability of the chiral soliton model by incorporating, in a general chiral effective meson Lagrangian [1,3], the lowest mesons relevant to an $SU(2) \times SU(2)$ symmetry: the π , ρ , ω , a_1 and f_1 mesons. The parameters of the Lagrangian are fixed as much as possible, with the help of meson properties. The remainder are determined

by optimization to yield satisfactory baryon properties, as the baryon emerges in the form of a chiral soliton in the theory.

Our research communications [1,3,9] detail successes of the model in explaining electroweak and strong properties of the nucleon and the Delta(1232), in the leading order of $(N_c)^{-1}$ expansion, where N_c is the number of colors in the QCD Lagrangian. This firmly extends the program proposed by Witten [16] *to determine the baryon properties as much as possible from inputs of meson physics.*

Figs. 1 (a-b) illustrate the difficulties in reproducing the experimental value of the neutron axial vector coupling constant, G_A . In the figures, the model A reproduces the experimental value of G_A , while the model B takes it to be unity. In the figures, the cross-hatched region is the empirical dipole curve. Interestingly, the model B is phenomenologically more successful than the model A! The moral here seems to be that the exact value of G_A is beyond the scope of the leading order physics.

Perhaps quantum corrections or other subleading order effects are responsible for this, though effects from the neglected meson sectors could not be ruled out as possible culprits. It could also be "all of the above". Clearly more research is needed on this.

Fig. 1(a-b): Diagonal and off-diagonal nucleon axial form factors as functions of square of the four-momentum transfer, Q^2 . Models A, B are explained in the text. $C_A^5(Q^2)$ is the off-diagonal form factor.

(2) The role of the ϕ meson in the nucleon structure

Properties of the ϕ meson in the context of the chiral soliton model have been investigated by L. Zhang and NCM [8]. We have found that the Syracuse approach [17] to the phi structure, in which the phi meson is a mixture of the conventional ϕ and ω , such that

$$\phi_{\text{physical}} = \phi + \varepsilon\omega, \quad \phi = s\bar{s}, \quad \omega = (u\bar{u} + d\bar{d})/\sqrt{2}, \quad (1)$$

the phenomenological outcomes for the soliton properties are much worse in most cases, compared with the situation where the phi meson is excluded from the meson Lagrangian. This is underscoring the fact that *more research is needed in studying the OZI rule and its dynamical origins*, for example, in the context of the phi decays into pions.

(3) The eta and eta prime photoproduction

A comparison of the eta and eta prime photoproduction reactions [7,10,11] near their respective thresholds, is very instructive in seeing how the second and third nucleon resonance regions are probed differently by these two reactions:

$$\gamma + p \rightarrow p + M, \quad (2)$$

where M is π or η . In particular, we have already established the fact that the eta photoproduction is dominated by the excitation of the $N^*(1535)$ resonance [18,11]. Capstick and Roberts [19], in a recent quark model study, have identified a number of negative parity nucleon resonances, with masses between 1.9 and 2.2 GeV, which are likely to dominate the eta prime-nucleon channel.

The reactions (2) are being studied by NCM, the postdoctoral associate, Dr. J. Zhang, and Dr. M. Benmerrouche, our collaborator from SAL, Canada. Our study gives a preliminary conclusion that the E_{0+} amplitude in the eta prime photoproduction is likely to dominate the reaction near threshold. Further work is continuing in figuring out which observables are most efficient in exploring the N^* properties. The resonance $N^*(2080)$ should be the one most effectively probed by the eta prime photoproduction, in contrast to the eta case, where it is $N^*(1535)$.

(4) Quark model and the $\Delta(1232)$ electroweak excitation

The graduate student J. Liu is working on this problem for his Ph. D. thesis under the guidance of NCM. The fundamental question of the quark model is its adequacy in describing electroweak form factors and the

range of Q^2 it is applicable. Using the framework of the non-relativistic quark model of Isgur and Karl (IK) [20], we have calculated the nucleon to the Delta(1232) weak transition amplitudes. These can be converted into so-called Adler form factors, measured in the neutrino scattering experiments [21] for direct comparison with experiments.

The main results so far [12] are as follows: the form factor $C_A^5(Q^2)$, shown in Fig.1(b), is reproduced quite well in the IK model. The SU(6) breaking does not result here in a very big correction, akin to the situation for the nucleon to the Delta transition M1 amplitude. However, in contrast to the latter [22], there is no significant discrepancy here. Another important result is that the *off-diagonal Goldberger-Treiman relation* [23] is satisfied. We are continuing the investigation in the context of CEBAF experiments on the measurements of the weak amplitudes [23a].

(5) Studies in the application of the pQCD

Prof. C. Carlson (College of William and Mary) and NCM are continuing their investigations [5,6] of the Bloom-Gilman (BG) duality, which is a connection between physics of the resonance and the deep inelastic regions [24]. In the current project period, our main result is that the *inclusive* electron scattering data, compiled by Stoler [25], in the vicinity of the Bjorken x close to one, show indications of large logarithmic corrections, thereby breaking the BG duality. As Q^2 varies from 4 to 21 GeV^2 , the logarithmic correction to the quark distribution function

$$q(x, t_0) = N_0 (1-x)^b, \quad (3)$$

where the subscript indicates some benchmark $Q^2 = (Q_0)^2$, b is a constant, the correction to the form (3) varies [5,6] from 1 to 0.56. Further investigations are continuing.

(6) Nuclear weak interaction

The nuclear muon capture reaction

has been studied by NCM [4] as a test of our ability to find possible nuclear renormalization of the axial vector form factor. We estimate the

theoretical rate for this reaction to be

$$W^{Theory} = 1.33 \times 10^3 \text{ s}^{-1}, \quad (5)$$

where we include in the theory the impulse estimate plus the effects of the meson exchange currents. The best experiment on the reaction is an old one from the Louvain-CERN era [26]:

$$W^{Exp} = (1.6^{+0.33}_{-0.22}) \times 10^3 \text{ s}^{-1}. \quad (6)$$

This indicates a minor discrepancy. That needs to be tested in new experiments. Such experiments are under planning at the muon factories such as the PSI in Switzerland [27].

(7) Muon double charge exchange reaction as a possible test of physics beyond the standard model

Dr. J. Missimer (PSI, Switzerland), Prof. R. Mohapatra (Maryland) and NCM have studied [2] the reaction

$$\mu^- + (Z, A) \rightarrow (Z-2) + \mu^+, \quad (7)$$

as a means of probing the lepton number violation and *physics beyond the standard model*. The kinematic requirements are very severe, and only a few radioactive targets meet the requirements of the reaction. Under a number of extensions of the standard model, the most optimistic branching ratio of the process (7) comes out to be $\sim 10^{-18}$, for the target ^{44}Ti , leading to the daughter, ^{44}Ca . This is too low for the present capabilities of the muon factories to be of immediate experimental interest. Putting it another way, our investigation indicates processes like (7) simply *are not favored* in present extensions of the standard model. Previous to our investigation, the branching ratio as high as 10^{-14} in certain extensions of the standard model [28] was believed to be possible.

This investigation suggests a renewed need to investigate the nuclear physics issues of the *muon number violating* muon capture reactions that have been discussed in the literature.

3. Progress of the research associates

This research program has now a postdoctoral research associate, Dr. J. Zhang. She has made an excellent progress in her collaboration with NCM and Dr. M. Benmerrouche of SAL, Canada. Her contributions are in the area of photoproduction of eta and eta prime mesons. She is a coauthor of one paper [7] and several reports [10,11,13]. She has received an award granting her free attendance, board and lodging at the 1994 Photonuclear Gordon Conference (PGC), where she has presented a contributed paper [13]. She has participated in the Spring meeting of the American Physical Society (APS), and presented two papers [10,11].

Dr. L. Zhang, a postdoctoral associate with our program till June, 1994, has left our group in the last summer. He has chaired a session on Nuclear Theory at the APS Washington meeting, where he also has delivered a paper. He has been a very productive member of our group, coauthoring three papers [1,3,8] and three reports [9,12,13] in the current program period. He continues his valuable association with this group to this day, as do four alumni of the program.

Our program has currently one student, J. Liu, working on his Ph. D. thesis on the quark model and electroweak processes. He is a research assistant, who has participated in two conferences this year: the Spring meeting of the APS and the PGC, in the latter as an invited attendee. He has contributed two papers [12,13]. We also currently have a first-year graduate student, Z. Fan, associated with our group. He is studying hadron physics with us.

4. Outside travel by the principal investigator and associates

A list of institutions or conferences to which NCM has paid a visit for lectures, seminars and colloquia is given in Appendix B. This also includes the trips by the students and associates.

Among these visits, special mention should be made of those at the Mesons and Nuclei conference in Dubna, Russia, CEBAF II workshop and the Photonuclear Gordon conference in NH. On these occasions, NCM has given reviews of the progress achieved in this project. The IUCF at Bloomington, IN, has hosted NCM as a member of the PAC. The Saskatchewan Accelerator Lab has hosted NCM for a month of research sojourn. Our research associates have attended the Spring meeting of the APS and the Gordon conference, the latter as invited attendees. Dr. L. Zhang has chaired a session at the Spring meeting of the APS.

5. External collaborators in the current grant period

This year collaboration of NCM with Dr. J. Missimer (PSI, Switzerland) and Prof. R. Mohapatra (Maryland) has resulted in a paper [2] on physics beyond the standard model. Prof. C. Carlson (College of William and Mary) and NCM have exchanged visits, and coauthored 2 papers [5,6] in the present period, on pQCD. Dr. R. Davidson (NIKHEF-K), an alumnus of the program, has spent one summer month with NCM in 1994, and one new project has been started in that period, on the exclusive electroproduction. Prof. B. Holstein (U. Mass.) and one of his graduate students have been collaborating with NCM, on electroweak processes and chiral symmetry breaking. A paper on this is underway. Dr. P. Herczeg (LANL) has paid NCM a research visit, and our old collaboration on T violation has continued. Last, but not least, the program is still benefiting from the participation of four alumni, Dr. M. Benmerrouche (SAL, Canada), Dr. R. Davidson, already mentioned, Dr. B. Doyle (U. Kentucky) and Dr. R. Wittman (Westinghouse), all contributing to electroweak physics. Dr. Doyle's collaboration has been of help in the investigation of the physics of the $A=6$ nuclei [4].

6. Other research news

The latest edition of the compilation of the particle properties by the Particle Data Group (PDG) [29] has mentioned a number of works by NCM and collaborators in their definitive review. These include searches for axions and light scalars, and properties of the $\Delta(1232)$ and $N^*(1535)$. The U. S. Department of Energy Panel on Nuclear Physics has examined this program in a setting where it has been compared with others. It has earned the following overall rating from this Panel: *Strong, a high priority program (2)*.

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APPENDIX A: THE REPORT OF THE DOE PANEL

Panel-3: Quarks in Nuclei with Hadron Beams

Institution: Rensselaer Polytechnic Institute
Presenter: N. C. Mukhopadhyay

Panel Summary

- (1) **Intrinsic merit and importance of group's scientific goals:**
This group has a well focused program to study photo- and electroproduction of nucleon resonances, QCD-inspired models of hadronic structure and processes probing physics beyond the Standard Model. The first, in particular, is very relevant for experimental work at CEBAF, Bates and other electron facilities.
- (2) **Likelihood of group attaining stated goals based on group's achievements, vigor and focus:**
The PI has an impressive track record in this field and is one of the most active theorists working on problems relevant for electromagnetic production of Δ 's and N^* 's. The likelihood for continued success is very good.
- (3) **Scientific productivity and impact of group with available resources:**
The level of productivity of this group is quite high, especially given the relatively modest level of funding received by the group (and might even be increased with strengthened support). The isobar production work has an important impact on the experimental programs at CEBAF, Bates, *etc.*
- (4) **Ability of group to adapt to future interests and changing priorities of the field:**
The PI has always shown the ability to adapt to changing priorities in the past and will likely continue to do so in the future. The plans presented for near-term efforts, including work on QCD-inspired models, electroweak interactions and photo-/electroproduction of η and η' all bear this out.
- (5) **Contributions of group to related fields and/or national/international projects:**
The group collaborates well with theorists from other groups and has excellent connections with experimental efforts in this subfield.
- (6) **Effectiveness of group in the development of young scientists:**
The level of effectiveness in the development of young scientists is quite good given the relatively small size of the effort.
- (7) **Unique group aspects: community leadership, innovative instrumentation, special skills, etc.:**
None.

Overall group rating: Strong, a high priority program (2)

Summary of Panel Comments

The group is involved in a relatively focused program to study the photo- and electroproduction of excited baryons, QCD-inspired models of hadronic structure and physics beyond the Standard Model. The work on the excitation of the nucleon to the $\Delta(1232)$, including the nature of the M1/E2 character of this transition, has been noteworthy and relevant for experiments ongoing or to be mounted at several facilities in the U.S. and in Europe. The recent study of η photoproduction and the excitation of the $N(1535)$ will also impact on experimental work. The group's investigation of resonance-background duality and pQCD addresses one of the important issues involved in studying resonance structure functions.

Such phenomenological studies are of interest in their own right, but the principal strength of this effort lies in its good connection with the large international experimental program to study meson and excited baryon production with leptons (CEBAF, Bates, Mainz, Bonn. . .). Of special relevance in these efforts is the interpretation of measured responses in terms of resonance and background contributions. Where such issues arise, this group plays a leading role in providing the necessary theoretical framework and, as such, theirs is a high priority program.

In summary, this is a strong group with a high priority program. All panelists rated the group at "2."

APPENDIX B: THE INSTITUTIONS/CONFERENCES WHERE RESULTS OF THIS PROGRAM HAVE BEEN PRESENTED THIS YEAR

Presenter: Prof. Nimai C. Mukhopadhyay (seminars, colloquia, invited papers)

1. International Conf. on Mesons and Nuclei, Dubna, Russia
2. Luncheon Panel on the Future of Hadron Accelerators and Medium Energy physics, Dubna, Russia
3. CEBAF II Workshop, Newport News, VA
4. Saskatchewan Accelerator Lab., Canada
5. MIT Workshop on Chiral Symmetry and Dynamics, Cambridge, MA
6. Photonuclear Gordon Conf., Tilton, NH
7. The University of Maryland Nuclear Theory Seminar, College Park, MD

Presenter: Dr. J. Zhang (contributed papers)

1. American Physical Society Spring Meeting, Washington, DC
2. Photonuclear Gordon Conf., Tilton, NH

Presenter: Dr. L. Zhang (contributed papers)

1. American Phys. Soc. Spring Meeting, Washington, DC

Presenter: J. Liu (contributed papers)

1. American Physical Soc. Spring Meeting, Washington, DC
2. Photonuclear Gordon Conf., Tilton, NH

APPENDIX C: PAPERS AND OTHER RESEARCH COMMUNICATIONS COMPLETED IN THIS PROJECT YEAR

Out of a total of seventeen communications, listed in [1] through [15] in the Section 7 (item [14] lists three of them), first eight ([1] -[8]), and item [13] are regular papers, or talks given at scientific conferences. Items [9] through [12] are conference abstracts. Items [14] and [15] are oral presentations only.

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