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Nuclear Research with the
Electromagnetic Probe
A Final Progress Report for Contract
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I. Scientific Motivation of the Research Program

This is the final report on the research carried at Stanford University under contract DE-FG03-88ER40439. All the work accomplished under this grant is reported in the publications listed as part of the Principal Investigator bibliography at the end of this report. This research is continued at Temple University under a new contract DE-FG02-94ER40844.

In the last few years our research was directed at some of the forefront questions in nuclear physics. We investigated the nuclear medium effects on the intrinsic properties of bound nucleons, specifically the electromagnetic form factors. For these studies we performed a number of specialized electron scattering experiments with specific sensitivity to nuclear medium effects. At the next level of structure, elementary constituents of matter are quarks and gluons. Defining the energy regime where the quark-gluon description of nuclear systems becomes more relevant than the nucleon-meson description is of great importance in thoroughly understanding the nuclear structure. To explore this transition region, we studied the scaling region in the disintegration of the deuteron, the simplest nuclear system with high energy photons. Finally we focused on the investigation of the nucleon internal spin structure along with the test of the Björken sum rule a fundamental sum rule of QCD.

I.1 Physics addressed and goals

- Nuclear medium effect on the intrinsic properties of the bound nucleon.
- Search for the transition regime between the nucleon-meson versus the quark-gluon picture at short distances in light nuclear systems.
- Study of the internal spin and flavor structure of the nucleon and fundamental test of Perturbative QCD.

II. Accomplishments

II.1 Medium effects on Nucleon Properties

We have carried the first measurement of the transverse (R_T) and longitudinal (R_L) response functions in quasielastic electron scattering at high momentum transfer. The experiment was performed at SLAC using the Nuclear Physics Injector. In previous work, several groups had measured the

separate response functions for longitudinal and transverse virtual photons in quasielastic electron scattering have been measured for various nuclei at three-momentum transfers, q , limited to 550 MeV/c. The results show a surprising common feature: the experimental longitudinal response functions, R_L , were lower than Fermi gas calculations by up to 50%. This 'quenching' of R_L diminishes when q increases but it still is as much as 30% at $q = 600$ MeV/c, the highest momentum transfer for which previous data were available. The experimental Coulomb sum rule, which is the integral of R_L over the energy loss, is also suppressed. This has been one of the most puzzling and outstanding problems in nuclear physics. The problem has motivated considerable theoretical effort. One approach invoked an effective change in the form factors of the nucleon in the nuclear medium, resulting from manifestations of the quark substructure. Other calculations attempted to improve agreement with the previous experiments by including final state interactions, relativistic effects, two and many body correlations, and off-shell effects. Relativistic models within the framework of quantum hadrodynamics using the random phase approximation have also been used to calculate R_L , R_T , and the Coulomb sum. These models reduced the discrepancy with the experimental values, but they generally failed to reproduce both response functions. So far, no single explanation has succeeded in explaining both the longitudinal and the transverse response functions over the full range of the available data. However, the various models predicted different behavior of the response functions at the higher momentum transfers corresponding to our work. Our results show that the quenching tends to vanish as the momentum transfer increases. Although several attempts to introduce nucleon form factors modified by the nuclear medium have been made recently only one model based on chiral symmetry by Brown, Rho and Soyeur explains both part of the quenching of R_L observed in the measurement at low transfer, as well as our results on ${}^4\text{He}$ that the medium effects vanishes for $q \geq 1 - 2\text{GeV}/c$. Experiment NE-9 has been performed as a stepping stone for a significant part of the Hall A program at CEBAF.

II.2 Transition from Nucleonic to Quark Degrees of Freedom

The study of few-body systems (deuterium and helium isotopes) has been extremely valuable to unfold the relevant ingredients for an adequate description of nuclear systems in the low and medium energy regime. The challenge for nuclear physics is to bridge the gap between the nucleon-meson and the quark-gluon picture with a description adequate both the low and the high

energy regime. The study of the charge and magnetization distributions of the few body systems has been a very powerful tool to test mesonic exchange currents, nucleon electromagnetic form factors, three body forces and relativistic effects. The challenge now is to reach the same level of sophisticated calculation in the high energy regime (very short distances) as was achieved in the medium energy regime. Of course both the experimental measurements and theoretical calculations have to progress to describe high energy data. We started the study of the disintegration of the Deuteron using high photon energies at SLAC with experiment NE-8 and NE-17. A careful measurement of the cross section at 90° CM angle as a function of photon energy was undertaken. The results suggests that scaling as predicted by the constituent quark-counting rules already set in at $1 - 2\text{GeV}$. However one calculation based on a meson-baryon reaction is also able to describe the energy dependence as well as the magnitude of the cross section. This situation is still unsettled and need further systematic measurements at CEBAF

II.3 Spin Structure of the Nucleon and Testing PQCD

Within the last three years we played a major role in performing and analyzing experiment E-142, a new world-class measurement of the deep inelastic spin dependent structure function $g_1(x, Q^2)$ of ^3He . This measurement was motivated by a series of previous experimental and theoretical work, beginning with the pioneering work of Björken in 1966 and 1970. Björken suggested that large asymmetries could be observed in deep-inelastic polarized-electron scattering off polarized-nucleon targets. Furthermore, he derived a fundamental relation known as the Björken sum rule. The test of the latter, described by Feynman as one that would have a decisive influence on the future of high-energy physics, required a measurement of both proton and neutron spin-structure functions. Theoretical work initiated by Gilman, within the framework of $\text{SU}(3)$ symmetry, focused on writing separate sum rules for the proton and the neutron. This idea was further developed by Ellis and Jaffe, who assumed that the strange sea in the nucleon was unpolarized, and derived what is known as the Ellis-Jaffe sum rule (E-J) for the proton and the neutron in the QPM model

Two early experiments performed in 1976 (E-80) and in 1983 (E-130) by the Yale-SLAC collaboration at SLAC on a polarized proton target confirmed the existence of large asymmetries as suggested by of Björken, giving support to the naive picture of the QPM. While a good agreement with the QPM prediction was observed in the x region dominated by the valence quarks,

no comparison was possible in the region of sea quarks due to a limited kinematics coverage. A first experimental test of the E-J sum rule found it to be fulfilled, but with a large uncertainty due the extrapolation uncertainty of A_1^p in the unmeasured low x region. The debate on the detailed spin structure of the proton was revived in 1988, when the European Muon Collaboration (EMC) reported new results on polarized muon scattering off a polarized proton target extending the measurements of A_1^p to low values of x . An re-evaluation of the E-J sum rule on the proton using this new proton data disagreed with the predicted value by 2.5 standard deviations. A QPM analysis of this result revealed a small net total spin contribution of the quarks in the proton, with a large negative strange-sea quark component. It was clear that more experiments were needed to set limits on various speculations arising from these results, and to improve our understanding of the nucleon spin structure.

Our hardware responsibility in E-142 was to construct new four threshold Cerenkov counter used to identify scattered electrons in the 4.5 and 7 degrees scattering angle spectrometers. The detectors had outstanding performance, achieving 7 photoelectrons for a 4 meter tank filled with nitrogen at a pressure of 3psi. This was accomplished by careful mirror quality control and use of a wavelength shifter on the phototube. The high performance of these detectors were crucial for the much needed pion rejection in this experiment.

On the physics side we have analyzed experiment E142 and published the first neutron deep inelastic spin structure function extracted from a ^3He target measurement with the following physics conclusions; a) the Ellis-Jaffe sum rule is confirmed by the E-142 results to within one standard deviation. b) The QPM interpretation of E-142 results lead to a small (few percent at most) strange-sea quark contribution to the nucleon net polarization, but a large total quark contribution to the spin of the nucleon (50%), c) within the uncertainties of the existing proton and the new neutron data, the Björken sum rule is verified when the comparison is performed at high- Q^2 . A more reliable and precise test at high- Q^2 is desirable because of the unsettled debate over the role and contribution of higher twist terms in the finite Q^2 formulation of the Björken sum rule. This should be achieved by a new generation of experiments that we have proposed to perform at SLAC (E-154) on ^3He combined with those on the proton and the deuteron (E-155).

III. Plans for the Near Future

The higher electron beam energy (50GeV) and higher beam polarization

(90%) presently available at SLAC are crucial to the test of the Björken sum rule at high Q^2 . The E-142 collaboration has put forward a proposal to extend the high precision measurement of the spin structure function of the neutron at lower values of the Björken variable x and higher Q^2 . The newly proposed experiment known as E-154 has recently been approved by the Program Advisory Committee at SLAC. Our group activity in the next two years will focus on preparing and performing experiment E-154. The experiment is tentatively set to run during Fall 1995-Winter 1996.

At CEBAF our effort shall increase in the next few years to get ready for using the electron beam in Hall A. Two experiments on few body systems along with our newly approved third experiment (94-010) to test the Drell-Hearn-Gerasimov sum rule using a ^3He target in Hall A have the highest priority for our CEBAF participation. In the first two experiments we will measure the elastic electromagnetic form factors of ^3He and ^4He to the highest possible momentum transfer, and also study the photo-disintegration of the deuteron with a measurement of the outgoing proton polarization. The third experiment allows a test of the Drell-Hearn Gerasimov sum rule and important sum rule to understand the low Q^2 evolution of the Björken sum rule at low momentum transfer. These experiments we believe have a good chance to be among the first round of physics experiments in Hall A. Temple University will provide for all capital equipment necessary to build the high pressure polarized target within the next three years in collaboration with Princeton University and CEBAF. An MOU between CEBAF and Temple University is being prepared. The future research is supported with a DoE grant sponsored by Temple University.

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