Department of Energy
Office of Nuclear Physics

Reviewer Excerpts from the Science Review of the proposed 12 GeV CEBAF Upgrade

for the

Thomas Jefferson National Accelerator Facility
(TJNAF)

April 6-8, 2005

EXCERPTS FROM PANEL MEMBER REPORTS

The Science review of the 12 GeV CEBAF Upgrade at Thomas Jefferson National Accelerator Facility (TJNAF) was held at TJNAF on April 6-8, 2005. Excerpts from the individual reports of the reviewers regarding their findings are provided below organized according to the review criteria they were asked to address.

GENERAL COMMENTS

The Jefferson Laboratory (JLab) 12 GeV upgrade constitutes a coherent and well-designed program that promises to advance our understanding of the strong force to a new level of sophistication. Further, a parallel program of electroweak measurements at the upgraded facility will be able to address the accuracy of the Standard Model at energy scales similar to those accessed by the Large Hadron Collider, using high-precision rather than high-energy experiments to accomplish this feat . . .

This program as a whole represents an impressively coherent framework of research directed towards one of the top frontiers of contemporary science: the exploration of confinement, a unique phenomenon of the Strong Interaction, one of the four fundamental forces in nature. Investigations will be focused in large part at momentum scales interpolating between the perturbative and the non-perturbative domains of QCD. Understanding the mechanisms at work in this transition region is of basic importance to our understanding of the rich variety of structures and phases that emerge out of QCD: from quarks and gluons to hadrons and nuclei, and matter under extreme conditions as encountered in the astrophysics of compact stars.

The 12 GeV upgrade program strongly builds on previous and present accomplishments which have earned JLab worldwide recognition as a leader in the field. Complementary work is presently performed in limited areas at other facilities using electromagnetic probes (MIT/Bates, Bonn/ELSA, DESY/HERMES, Mainz/MAMI, Osaka/SPring8, CERN/COMPASS), and at hadron or heavy-ion facilities (Fermilab, RHIC, COSY, GSI). In the foreseeable future the JLab 12 GeV upgrade will provide the only facility using electromagnetic probes with the required kinematic reach, luminosity and duty factor to pursue the physics goals decribed above. Other upcoming or planned facilities (JPARC in Japan and FAIR/PANDA at GSI in Germany) use hadron beams and concentrate on more specialized areas of hadron physics such as systems with strange and charmed quarks.

Progress in the physics of hadrons and nuclei has always been based on the strong interplay between experiment and theory. In the future, Lattice QCD simulations on high-performance computers are expected to figure as a third major component in driving this field of research. JLab is optimally positioned in this area, on a worldwide level, by the upgrade of its accelerator and detector systems in parallel with its computational capabilities. Expansion of the JLab Lattice QCD facility, rapid improvements of its performance and power, and further developments of smart algorithms, point in the proper direction . . .

In terms of theory support, this program needs support from three different directions: phenomenology, simulation (lattice QCD), as well as "continuum QCD."

Phenomenology is essential to help guide the experiments. Lattice QCD and continuum approaches to QCD are essential for the interpretation of the results.

Lattice QCD is currently the only technique to describe non-perturbative QCD where systematic errors are understood (at least in principle) and is expected to provide accurate numerical solution for many observables, once technology and algorithms have advanced sufficiently over the next 10 years. This endeavor requires a large investment in terms of computing power and manpower and the effort is worth it. Nevertheless, there are many reasons why other approaches towards QCD should be pursued in parallel. For example, parton distribution functions, particularly at large x do not have a simple interpretation in terms of lattice degrees of freedom. The same observable has a very direct and natural interpretation in terms of light-cone wave functions. Therefore, even if the lattice will eventually succeed to calculate these observables, it will be difficult to understand the physics beneath the numbers. Because of such reasons it is important to further develop continuum based approaches to QCD, such as light-cone techniques, Schwinger-Dyson methods, many body approaches, effective field theory and others. These techniques not only have the potential of providing a more intuitive description but may eventually also provide a more efficient numerical approach for some specific observables such as PDFs.

Although lattice QCD is currently by far the best developed method to solve strong QCD, it is not the only method for doing so. While it is highly desirable to have a strong lattice program in place, such an effort should only complement, but not substitute other approaches to solve strong QCD. It is therefore recommended that the Jlab theory program focus their efforts not only on phenomenology and lattice QCD, but also on "continuum QCD" . . .

The hadron and nuclear physics topics that can be probed at JLab at 12 GeV are central to testing quantum chromodynamics. Some highlights:

- The proposed upgrade will allow a large increase in the dynamic range of quark and gluon phenomena that can be studied in electroproduction. High statistics experiments will provide accurate determinations of the quark distributions within both the proton and the neutron in the crucial valence domain.
- The quark distributions of the proton are strongly modified when it is bound within the nuclear environment (the "EMC" effect), much more than expected from the strength of the nuclear binding. Electroproduction at 12 GeV is essential to investigate this central issue in nuclear physics. It should also be possible to measure the structure function of the deuteron at $x_{bj} \to 2$; i.e., the domain where one quark carries nearly all of the momentum of the entire nucleus. Another phenomenon not well understood is "antishadowing," the observed excess of the quark distribution at $0.1 < x_{bj} < 0.2$ in a nucleus beyond what could be expected by simply adding the contributions of all of its nucleons. Jefferson lab will be able to explore the flavor dependence of antishadowing and the the possible dependence of the antishadowing phenomena on the polarization of the virtual photon probe.
- The use of the polarized electron beam and polarized targets provide essential tools for studying the spin and angular momentum structure of the proton over a large dynamic range. This includes studying the critical question of whether, as predicted

by perturbative QCD, the spin of the quarks carrying large light-cone momentum fractions of the proton are aligned parallel rather than antiparallel to the the proton spin. In particular pQCD predicts that the ratio of parallel to antiparallel spin distribution behaves as $(1-x)^2$ at large x. The measurement of single spin asymmetries provides a new window into the angular momentum of quarks within the proton. The remarkable beam and target polarization capabilities at JLab will thus provide critical information on how the proton's spin is created by it's constituent quarks and gluons.

- The higher energy measurements of deeply virtual Compton scattering (DVCS) and other hard QCD processes such as pion electroproduction will provide new insights into the transverse spatial dependence of the quark distributions. The central object of interest are the "generalized parton distributions" (GPDs) which can provide a 3-dimensional picture of the quark distributions. More precisely, the GPDs represent overlaps of the initial and final wavefunctions of the proton where the quarks have different longitudinal and transverse dimensions. In addition, there are contributions to the GPDs measured in DVCS which arises when the initial wavefunction has an extra quark-antiquark pair compared to the final state proton. One of the interesting issues is the correlation between the average transverse separation between the quarks as a function of the struck quark's longitudinal momentum.
- The "handbag" approximation used to relate the DVCS amplitude to the generalized parton distributions begins to break down when the momentum transfer squared t to the proton becomes comparable to the virtuality of the incident photon. This regime provides a transition of DVCS to wide angle Compton scattering, a key test of pQCD. Single spin asymmetries play an essential role in determining the interference with the Bethe-Heitler amplitude as well as corrections to the phase of the Compton amplitude from corrections to the handbag diagram.
- Jlab at 12 GeV will provide comprehensive measurements of quark hadronization and how it is influenced by the nuclear medium. The manner in which the struck quark converts into hadrons and how the quark loses energy and scatters in the environment nucleus are essential tools for understanding the mechanisms for color confinement. This phenomenon involves the quantum-mechanical Landau-Pomeranchuk-Migdal (LPM) effect which is due to the destructive interference of the quark inelastic scatterings on two different nucleons within the nucleus at high energies.
- Jlab at 12 GeV can detect the effect of "hidden color" in the nuclear wavefunction. For example, the scaling and magnitude of the deuteron form factors measured in elastic electron-deuteron scattering at high moment transfer is directly affected by the magnitude of the hidden color components of the deuteron wavefunction. Recent measurements at JLab have confirmed the s^{-11} scaling behavior for deuteron photodisintegration $\gamma d \rightarrow np$ cross section at fixed θ_{cm} at large momentum transfer as predicted by the pQCD dimensional counting rules. Hidden color can be tested by checking to see if deuteron photodisintegration into two resonances $\gamma d \rightarrow \Delta^{++}\,\Delta^{-}$ has a comparable cross section. This final state reflects the fact that the hidden color Fock state of the deuteron has a strong overlap with Δ^{++}(uuu) and Δ^{-}(ddd).

- One of the most important novel experiments that can be performed at JLab with 12 GeV beams is the search for the contact interaction arising when two photons interact on the same quark. The interference of the Bethe-Heitler amplitude where the electron emits a photon with the real part of the virtual Compton amplitude in $ep \to ep$ where the scattered proton emits the photon: the contact interaction predicts an amplitude which is independent of the photon energy and even its virtuality at fixed momentum transfer – the J = 0 "fixed-pole" phenomenon. This experiment tests whether the initial and final photons can act together locally on the same quark, a consequence of the QCD prediction that quarks carry the electromagnetic current within the proton. It is a direct contradiction to conventional Regge theory which predicts that hadron amplitudes have a decreasing energy dependence as the momentum transfer increases.

- The Jlab upgraded energy will allow an essential extension of present measurement of the proton and pion form factor to high momentum transfers. In particular it is essential test whether to the proton form factor ratio $G_E(Q^2)/G_M(Q^2)$ continues to decrease with momentum transfer. PQCD predicts a near constant behavior of this ratio at the largest momentum transfers that can be reached at JLab.

- A crucial test of QCD color transparency in pion photoproduction in quasielastic scattering at large momentum can be made.

- Remarkably precise measurements with polarized beams and targets of parity violating weak interactions will not only test fundamental symmetries of the Standard

- Model, but will also provide new sensitive tests of QCD, such as testing the universality of nuclear antishadowing. It will also provide a clear separation of the *u* and *d* quark distributions in the proton without the complications of a nuclear target. The same measurements on a nuclear target can explore the universality of the antishadowing and EMC effects.

- The high intensity 12 GeV JLab beam wlll allow the exploration of charm production at threshold, open charm channels such as $\gamma p \to \Lambda_c D$ and hidden charm channels such as $\gamma p \to J/\psi\, p$. One can study the dynamics of confinement as the charm quarks emerge at non-relativistic velocities, including the analog of the Coulomb Sommerfeld effect which enhances the production rate at low relative velocities. Such measurements in a nuclear target are highly sensitive to Fermi motion and other nuclear effects. An early measurement of $\gamma A \to J/\psi\, A$ from Cornell shows anomalous behavior in the threshold region.

- Hard exclusive processes such as $\gamma^* p \to \pi^+ n$ at large momentum transfer not only test QCD factorization theorems, PQCD predictions for their power-law fall-off and angular dependence, but they also provide information on the form of the light-front wavefunctions (LFWFs) of the interacting hadrons. This information, besides being of fundamental interest, is also critical to the interpretation of the exclusive *B* decays measured at the *B* factories.

- Recently it has been discovered that one cannot ignore the final state interactions of the struck quark in deep inelastic electron-proton scattering with the remaining spectator system of the target proton. The gluonic final state interactions cause diffractive deep inelastic scattering $ep \to X + p$ where the proton emerges intact. In the case of nuclear targets, these diffractive channels cause nuclear shadowing an even antishadowing. Most important, the final-state interactions cause different phases for different partial waves, leading to time-reversal odd single-spin asymmetries such as the correlation between the target proton spin and the production plane of the incident photon and outgoing hadron or quark jet. These spin asymmetries (the "Sivers" effect) measure the orbital angular momentum carried by the struck quark in the proton. The strength of the asymmetries for a given quark flavor is proportional to the contribution of that quark to the proton anomalous moment. All of this physics can be measured in detail using the upgraded JLab beam.

NUCLEON STRUCTURE

The significance and merit of specific scientific questions addressed in the 12 GeV scientific program.

The spin-dependent parton momentum distributions as a function of the momentum fraction x, contain the information about the quark-gluon dynamics. So far, relatively little attention has been paid to the polarized structure functions in the pure valence region at large x. The lack of data in the valence region is particularly obvious in the case of the neutron, where there is no data with useful accuracy on the polarization asymmetry A_{n1} for $x \geq 0.4$. (The only exception is the recent preliminary Hall A A_{n1} data which extend to x =0.6; recent Hall B data on $Ap1$ and A_{d1} have also been extended to a maximum of x =0.6.) So far, the extracted ratio $Rnp = F^2_{\mathrm{n}} / F^2_{\mathrm{p}}$ of neutron to proton structure functions can differ by ≈ 50% already at x = 0.75. These large uncertainties have prevented answers to such basic questions as why the d quark distribution at large x appears to be smaller (or "softer") than that of the u, softer even than what would be expected from flavor symmetry. Also preclude those large errors on the current data any definitive conclusions about the fundamental nature of quark-gluon dynamics in the valence quark region . . .

Fundamentally new and important physics is foreseen by the determination of unpolarized and polarized nucleon structure functions in the valence quark region at large Bjorken-x (x >0.3), and of nucleon and pion form factors with so far unmatched precision. Highlights are:

a) the accurate measurement of d(x)/u(x) with its capability to discriminate between descriptions of the nucleon which differ significantly in their predictions in the limit $x \to 1$. This includes a precision test of the detailed power-counting behaviour $(x - 1)^n$ suggested by perturbative QCD;

b) new results concerning the spin structure of the nucleon are expected by measuring $\Delta u/u$ and $\Delta d/d$ in the valence region;

c) completely new insights by a precision determination of d_2 with the possibilty of extracting for the first time information about alignment correlations between quark spin and gluon field in the nucleon;

d) clarification of the G^p_E/G^p_M puzzle at large Q^2 up to 14 GeV^2;

e) accurate determination of the pion form factor at large Q^2, with implications for the transition to the perturbative QCD regime . . .

The proposed JLAB measurements of the flavor- and spin-specific distributions will give the most accurate picture of the underlying quark momentum distributions within the proton and neutrons; in particular they will test a prediction derived from perturbative quantum chromodynamics: that the spin-anti-parallel quark distribution falls faster than spin-parallel as $(1-x)^2$ at large light-cone momentum fractions x. The SU(6) symmetry of the proton wavefunction predicts that there are twice as many anti-parallel *d* quarks as *u* quarks. The pQCD prediction can be contrasted with a quark-diquark prediction which predicts no *d* quarks with antiparallel spin projections . . .

The 12 GeV upgrade renders for the first time high accuracy measurements of the structure function and spin structure function of the nucleons feasible in the valence region. The large x region is very poorly understood. There have been long-standing mysteries about the high-x behavior of parton distributions. The best measurement at high x is that of the pion structure function. The shape of this distribution should have a $(1-x)^2$ behavior, but the Drell-Yan data at a momentum transfer of 16 GeV^2 indicate a $(1-x)^{1.25}$. If these data hold up under further scrutiny, this represents a serious breakdown in our understanding of how to apply QCD or in QCD itself. Thus, there could be more surprises when good data from this program become available for the nucleon. The d/u ratio and the A_1 measurements are particularly important for these studies. The isolation of the flavor dependence of the spin structure function of the proton provides a sensitive test of the nucleon models. These studies require the assumption that the scattering process and the subsequent hadronization process factorize . . .

The proposed upgrade will provide a conclusive answer to the long-standing question of the relative behavior of the up and down quarks within the proton in the $x\rightarrow 1$ limit. In this extreme limit, the struck quark carries the entire momentum of the proton. The anticipated data will directly address the question of the best way in which to think about proton substructure, on an intuitive level, as a number of widely-varying predictions exist based on different hypotheses for the best degrees-of-freedom with which to treat the problem. The precision of the 12 GeV data will be able to clearly distinguish between these different intuitive pictures of the proton for the first time."

The nucleon form factors provide information on the non-perturbative regime of QCD. Confinement and dynamic chiral symmetry breaking are fundamentally non perturbative in nature. Data of these kind challenge theory to solve a relativistic quantum field theory in the truly non-perturbative, strong coupling domain. The pion is a relativistic two-body bound state problem. Thus, the pion form factor is particularly important since two-body problems in the continuum can be solved exactly. The pion is also very interesting since it is both a Goldstone mode and a bound state of two very heavy constituents. Thus, data for the structure functions and form factors of these hadrons are exceedingly important . . .

The Sivers effect provides insight into some remarkable aspects of proton dynamics -- how the quark interacts in the final state and how individual quarks contribute relative orbital angular momentum in the proton wave function as well as to its fundamental properties - - the proton anomalous magnetic moment and Pauli form factor. For example, it is known that the Sivers effect is only possible if the hadron wave function contains wave function components with a nonzero orbital angular momentum . . .

The feasibility of the near and long-term goals for the implementation of the planned program.

These experiments are feasible with the 12 GeV electron beam plus the upgraded JLAB detectors CLAS12 and SHMS. The polarized neutron measurements will be performed using a polarized *^3He* target. The separation of *u* and *d* quarks in a neutron can be done using an unpolarized Deuterium target together with the measurement of the recoil proton. The required validation of the spectator nucleon method will be carried out in the near future . . . The proposed SHMS spectrometer is absolutely necessary for the pion form and proton electric form factor measurements as well as the semi-inclusive deep inelastic scattering tests of factorization.

The factorization of the quark structure functions from the fragmentation functions must be explored experimentally to validate the flavor-separated data. This involves studies over a large range of kinematic variables of x, z and Q^2. These studies have been carried out at 6 GeV in Hall C and indicate that factorization holds up to an x and z of approximately 0.5. It is plausible with the 11-GeV beam, the HMS, SHMS, and high luminosity that the factorization tests can be performed in a reasonable amount of time over a large x and z range. Although no issues were raised, the CLAS12, being a new detector design, should be given a technical review . . .

The impact of the planned scientific program on the advancement of nuclear physics in the context of current and planned world-wide capabilities.

Experiments lead the way. QCD in the non-perturbative domain must be mapped out. Such benchmark experiments as pion and nucleon form factors as well as polarized and unpolarized structure functions in the valence region must be known if we are to say with any confidence that we have solved QCD. Without these data, we will never know whether we can perform realistic QCD calculations in the non-perturbative regime where 98% of the known mass of the Universe resides . . .

The measurements of the quark structure functions will provide precise measurements of the fundamental spin and flavor structure of nucleons in the large x region. Of particular interest is the end-point behavior of the structure functions near x->1. In this regime, the measurements will decisively determine the applicability of perturbative QCD analyses to the short-distance properties of a nucleon. If the pQCD prediction is validated it will greatly affect confidence in using such methods in other contexts.

The separation of the proton form factors provides new insights into the coherent quark structure of the proton. The high Q^2 behavior provides additional spin-sensitive tests of the perturbative QCD for hard exclusive processes . . . These results on spacelike from factors will be particularly valuable in combination with new results being obtained for timelike momenta at electron-positron colliders using the initial state radiation method . . .

The behavior of the pion form factor at large Q^2 is also a basic test of pQCD, provided the extrapolation to the pion pole can be controlled. The experiment can also be interpreted in terms of a theoretically interesting transition form factor between a virtual and a real pion. Both for the on-shell pion form factor as well as for the transition form factor between a virtual and real pion, pQCD makes definitive predictions, which can be validated (or falsified) in these experiments . . . These tests have become particularly important in view of new predictions from lattice gauge theory and AdS/CFT . . .

In summary, both the large x as well as the form factor experiments will provide decisive tests of perturbative QCD predictions. While the outcome of the experiments does not affect the structure of the QCD Lagrangian itself, it will decisively clarify whether or not pQCD is applicable to exclusive and/or inclusive processes . . .

If these experiments are not done, there will be a critical gap in our knowledge of fundamental features of the nucleon, and the opportunity to decisively test the applicability of perturbative QCD to the high x_{bj} domain where one quark carries most of the hadron momentum will be lost. Important insight into the behavior of the proton and pion form factors at the highest momentum transfers and their basic interpretation in terms of QCD degrees of freedom will be lost. A unique measure of the effect of the gluon field on the proton's polarizability will remain unknown.

The theoretical efforts and technical capabilities needed in order to accomplish the planned scientific program.

Strong theoretical support is required both by the local theory group and through collaborations with theorists elsewhere . . . The goal of developing an ab-initio model of QCD and testing lattice gauge calculations in the non-perturbative regime are necessary to compare with the expected data. The theoretical community must remain involved in the effort to fully exploit the physics from the data . . . The necessary theoretical expertise exists but needs to be coordinated . . . The precise interpretation of the deep inelastic data involves knowledge of QED radiative corrections, and the flavored-tagged measurements require the detailed knowledge of the quark fragmentation functions. There are possible corrections from the non-additive properties of the deuteron itself, including hidden-color, meson exchange currents, etc. . . .

The JLab Lattice QCD group is progressing towards providing the computing power to confront observables resulting from this experimental program . . . Lattice gauge theory is now beginning to provide predictions for observables which are relevant to the experimental program discussed here. For example, the pion form factor is now being computed over a large range of momentum transfers, although at present the quark masses available in such simulations are still too heavy. With time, improved actions and increasing computer power, accurate simulations of observables are anticipated at smaller quark masses which permit reliable extrapolations. It is thus anticipated that the JLab experimental results will provide incisive tests of lattice gauge theory predictions . . .

In addition to lattice gauge calculations, other theoretical approaches should be pursued to enhance our ability to interpret this precious data. For example, although light-cone or Schwinger-Dyson approaches to QCD are at present on a less rigorous foundation than lattice QCD, offer the opportunity to illucidate the physics of hadron structure from a complementary angle which may be particularly valuable in these high momentum transfer experiments . . .

For the Sivers effect, no viable plans exist to evaluate this observable in lattice gauge theory. Because of the importance of the final state interaction of this observable along the light-cone, QCD approaches that are based in a Minkowskian geometry seem more promising, but must first be further develop in order to maximize the insight gained from a measurement of the Sivers effect . . .

Some parts of this program can be carried out at the GSI facility: parton distribution functions can also be probed using the Drell-Yan process $ppbar \rightarrow l^+ l^-$. However, it will be much more difficult to make separate determinations of the flavor and spin dependence at GSI without polarized beams and targets as well as deuteron targets.

Measurements of the valence quark distributions can also be carried out using $pp \rightarrow W^\pm X$ using the polarized proton-proton collider at RHIC. However, these measurements also involve uncertainties from the anti-quark distributions and complications from the Drell-Yan physics. No comparable form factor measurements will be possible at present/planned machines elsewhere. Since all other planned machines are hadron colliders, there will be no precise form factor measurements above the momentum transfers already explored today. The Sivers effect can also be studied in Drell-Yan, where it is predicted to occur with opposite sign and the same magnitude. However, we will be unable to test the QCD prediction that the Sivers effects in semi-inclusive DIS and in Drell-Yan are equal and opposite.

GENERALIZED PARTON DISTRIBUTION FUNCTIONS

The significance and merit of specific scientific questions addressed in the 12 GeV scientific program.

The recent theoretical development of Generalized Parton Distributions offers a more complete description of the partonic structure of the proton than has ever been available before. Measuring these distributions using hard-exclusive processes (e.g. Deeply-Virtual Compton Scattering and exclusive meson production) offers access for the first time to:

- A spatial map of the transverse arrangement of individual quarks at different values of their longitudinal momentum fraction x (“femto-photography” of the proton).
- As GPD’s are sensitive to off-forward scattering amplitudes, they are the only known method to determine the orbital angular momentum of quarks and gluons in the proton.
- The GPD’s give amplitude-level access (via overlap integrals) to the light-cone wave functions which are at the heart of all hadron phenomenology.
- GPD’s provide a decomposition of the form factor with respect to the momentum of the active quark. That way, knowledge of GPDs would allow us for example to distinguish between the pQCD mechanism, where the form factor at large t is supported by quarks carrying average momentum x, and the Feynman mechanism, where the form factor at large t is supported by by quarks at large x. GPDs thus provide additional tests of pQCD.

- In particular, for large t, where the relevant overlap integrals are dominated by the valence components, the GPDs will provide many constraints on the light-cone wave functions in the lowest Fock component of the hadron.
- Of particular interest is also the line x=ξ where GPDs can be directly measured from the beam-spin asymmetry. Along this line, the GPDs probe the light-cone wave function when one of the quarks has zero momentum. Since such a configuration is expected to be suppressed for the valence wavefunction, pQCD predicts that the t-fall off for x=ξ should be stronger than that of the form factor. This pQCD prediction could be validated/falsified model-independently from DVCS measurements since the imaginary part of DVCS does not contain an integrated quantity."

The 12 GeV upgrade will permit unique, exploratory data on the . . . unknown role of orbital angular momentum in the proton . . . the familiar concept of angular momentum as a "good quantum number" must be abandoned in the relativistic current-quark picture of the proton's interior. Are the quarks within the proton also orbiting, and contributing to the proton's total angular momentum of $\hbar/2$? At present, the only known way to observe the quarks' angular momentum in a direct, model-independent way is through the measurement of newly-defined theoretical objects called Generalized Parton Distributions (GPDs). JLab at 12 GeV is poised to make a unique contribution to this new area of investigation.

The feasibility of the near and long-term goals for the implementation of the planned program.

<u>Near term</u>: The first 5 years of running at the upgraded 12 GeV CEBAF, together with an upgraded CLAS target and detector will yield the following information:

- Unintegrated information about the GPD's along the $x = \xi$ line in kinematic space and at various values of Q^2 and t (source: DVCS data on the sin(ϕ) variation in the beam-spin asymmetry A_{LU})
- Data on the integrated information $\int dx \frac{GPD(x,\xi,t)}{x-\xi}$ also at various values of Q^2 and t. (source: DVCS cross-section measurement).

These measurements will provide unique and powerful new constraints on models of the GPD's, which will provide good sensitivity to the total u-quark angular momentum and the transverse spatial distribution of quarks in the valence region, as they are parametrized in those models. Also, data that is currently being collected will soon reveal if hard-exclusive meson production scales at the Q^2 values accessible to CLAS12. If so, information on GPD's and light-cone wavefunctions for individual quark flavors will also be provided by the first 5 years of data at 12 GeV.

<u>Long term</u>: Doubly-virtual DVCS has a much lower cross-section than DVCS (factor of 200 – 1000), but is accessible with additional years of running. Measurement of this process will allow direct measurement of the GPD's at independent values of x and ξ. This will allow model-independent access to quark orbital angular momentum, spatial distributions, and light-cone wavefunctions.

The impact of the planned scientific program on the advancement of nuclear physics in the context of current and planned world-wide capabilities.

Without this program, we will lose the only known source of model-independent experimental information about the orbital motion or spatial distribution of partons within the proton . . . Knowledge of GPDs will provide a dissection of form factors with respect to the momentum of the active quark. This will provide essential clues about the physics of form factors, particularly at large momentum transfers. For example, once GPDs have been determined we will know if form factors at large momentum transfers are supported mostly by quarks with x around 1/3 (pQCD) or by quarks with x->1 (Feynman mechanism). In addition GPD measurements will provide information such as "how does the spatial distribution of soft quarks (small x) differ from the distribution of hard quarks (large x)", or stated from a different viewpoint, "are parton distributions in the periphery of the nucleon different from PDFs in the center?" . . .

In the next several years, CLAS & HERMES will supplement their first results on hard-exclusive processes with additional data. However, those data will be exploratory only, as they are sharply limited by luminosity and energy. Real and virtual Compton scattering are the only probes capable of expanding our knowledge about GPDs and those can only be done on a high luminosity lepton-hadron machine . . .

The theoretical efforts and technical capabilities needed in order to accomplish the planned scientific program.

The near-term DVCS data from the 12 GeV program will be analyzed within the context of GPD model parameterizations. To exploit these data maximally, it is important to fully explore all model-independent theoretical constraints that can be placed on these new functions, e.g. positivity and polynomiality. This work is being intensely pursued at present, and must continue. Furthermore, GPDs are a relatively new concept and it is highly likely that additional physical information (on top of what is listed above under "significance" above) can be related to GPDs. Also, it is important to use lattice calculations and other approaches to QCD to help guide the construction of theoretical GPD parametrizations. In terms of the light-cone wave functions, GPDs involve also transition matrix elements with a change of parton number. Modeling GPDs thus also requires modeling higher Fock components . . .

EXOTIC MESONS

The significance and merit of specific scientific questions addressed in the 12 GeV scientific program.

One of the main intellectual conundrums we face in understanding the strong force is the fact that gluonic fields make such an enormous contribution (around 50%) to the momentum of the proton, and yet appear to play no role at all in the spectrum of observed hadronic states . . . Mesons are the simplest system for studying strong (non-perturbative) QCD, providing the unique possibility of exploring the interaction of non-Abelian fields in the strong interaction limit. Photon beams, with J=1 and mixed I=0,1, can be used to produce a rich spectrum of mesons with a variety of spins and flavors. With a 12 GeV electron beam the threshold above which the origins of confinement can be investigated will be crossed, as it is at such energies that the non-Abelian fields are expected to be excited in strong QCD . . . The Hall D / GlueX segment of the 12 GeV upgrade will perform a search of unprecedented precision for so-called “exotic mesons”, bound states where the gluons are excited and create new, as-yet unobserved hadronic states . . . i.e. quark-antiquark systems coupled to excited modes of the gluon field that binds the quarks together. The existence of such states is a key issue in QCD . . . Most studies of mesons have been limited by kinematical reach or by statistics or both. It is for these reasons that little is known about $q\bar{q}$ mesons above 1.8 GeV/c^2; there is evidence only for the lightest glueball and that hybrids, which have a small signal, are only now beginning to be observed . . . Presently, there are no uncontested exotic meson signals. QCD predicts that exotic mesons should exist. Both quenched and unquenched lattice gauge calculations predict the existence of exotic mesons in the energy region accessible the upgraded JLab . . .

This will change completely with the 12 GeV upgrade, which will have the kinematical reach, up to masses of 2.5 GeV/c^2, and the necessary statistical accuracy . . . The GlueX experiment is specifically designed to perform precision spectroscopy of these states. Its potential for new discoveries is strong . . . Real photons, because they have the properties of a vector meson, provide outstanding potential for exciting exotics. The linear polarization of the photons will provide an additional handle on identifying the exotic particle . . . The proposed new Hall D facility and GlueX detector can perform a unique and thorough search for “exotic” hadronic states, one which cannot be performed at any other existing or planned facility. Such states are predicted (by lattice QCD) to exist in precisely the mass range available to the proposed new facility . . .

The insights gained by these investigations are crucial for our understanding of non-perturbative QCD and the dynamics of the gluon fields . . . This is probably the experiment in the JLab 12 GeV program with the greatest potential for making an important discovery . . . This is the experiment on the horizon most likely to find low mass hybrid exotics . . . If they are not observed, sober re-evaluation of QCD as the correct theory of the strong interaction will have to be performed . . .

Most expected nonets up to a mass of about 1.8 GeV/c^2 are well established, but above that, only a limited number of states have been identified. A good example of missing states occurs with $s\bar{s}$ strangeonium where only five states have been identified. The $s\bar{s}$ states are important as they are a bridge between the light u,d quarks and the heavy c,b quarks. Photo-production is an excellent technique for producing $s\bar{s}$ mesons as, in effect, the incident beam is a vector-meson beam with a large φ component. Sometimes the s-quark behaves like a light quark as part of an $SU(3)_{light}$ multiplet and sometimes as a heavy quark as part of an $SU(3)_{heavy}$ multiplet . . .

Theoretical progress is being made and lattice QCD, based on first-principle calculations, will ultimately be able to predict a detailed spectrum, including masses and decays, of hybrid mesons and glueballs. The experimental information about the spectrum of this new form of matter as predicted by QCD is an essential ingredient for the ultimate understanding of the confinement mechanism . . .

The feasibility of the near and long-term goals for the implementation of the planned program.

The goal of the new Hall D GlueX program is to discover and characterize the quark dynamics of exotic mesons. Photon beams are expected to be particularly favorable for the production of exotics because the photon can behave as a virtual vector meson (a qqbar pair with spins aligned), and so the Hall D program is focused solely on real photon beams. PWA is aided significantly by the use of linearly polarized beams, since linearly polarized photons are eigenstates of parity. Coherent bremsstrahlung in diamond has been selected as the production mechanism of these photons. The crystal radiator, photon tagging spectrometer and electron beam dump are housed in a separate building 75 m in front of Hall D. Collimation at the entrance to the Hall produces 3 mm beam spots with about 40% linear polarization on target.

GlueX is a hermetic detector with an effective 4π coverage for both charged and neutral particles, capable of measuring large numbers of decay products with sufficient resolution to reconstruct multi-particle final states. A 2 Tesla magnetic field is provided by a large warm-bore superconducting solenoid. Rate estimates with 10^8 photons/s project to 15 kHz after the 1st level trigger, leading to 1 P[eta]B[yte]/yr. While this is a formidable rate, data acquisition and analysis plans seem well in hand . . .

The project will make use of linearly polarized photons at 9 GeV in order to study the photoproduction of Hybrids in the anticipated mass range up to 2.5 GeV. This chosen energy range is optimally tuned to the primary 12 GeV electrons provided by the Upgrade. The GlueX detector design optimizes hermeticity, resolution and particle identification . . . To identify the J^{PC} quantum numbers of a meson it is necessary to perform a partial wave analysis (PWA) of multi-meson systems. While the implementation of a PWA is in principle straightforward there are both empirical and intrinsic difficulties. These can be minimized by careful experimental design and high statistics. Even so the PWA is subject to mathematical ambiguities for certain final states because two or more different amplitudes may lead to identical final states. This difficulty can be handled by assuming some a priori physics knowledge or, preferably, by studying simultaneously several final states. This latter information is required in any event as it is critical in understanding the underlying dynamics of the mesons and their interactions. The knowledge of the photon polarization can be used to simplify the PWA and access additional information on the production mechanism, so a tagged polarized photon beam is essential. PWA requires that the entire event be kinematically identified. All particles should be detected and measured, and there should be sensitivity to a wide variety of decay channels. The excellent hermeticity of this detector for charged and neutral final state particles is a necessary pre-condition for the reliable partial wave analysis of low-momentum baryonic systems, especially those involving small amplitudes . . .

Given the equipment envisioned for the upgrade, these experiments appear to be feasible . . . The GlueX collaboration demonstrated feasibility for the committee by including a description of a careful PW analysis of E852 data (which included participation by many GlueX collaborators). This was followed by pointing out that the acceptances of the GlueX detector are substantially larger and more uniform for many essential kinematic variables than those of the E852 detector. Uniform and nearly complete acceptance [is] essential for successful PWA studies of the complex states that are expected. However, the committee has not seen discussion of how detector capabilities such as resolution and segmentation are consistent with the goals of the experiment . . . Realistic Monte Carlo simulations of the detector response for the exotics should be improved to determine the level of sensitivity for the signal of an exotic meson. . . PWA studies of Monte Carlo simulations (perhaps fast parameterized studies backed up by substantial Geant studies) with reasonable assumptions of non-exotic meson and baryon production should be among the next steps in the GlueX program . . . Work, aimed at minimizing the assumptions, should continue on the partial wave analysis techniques . . .

The impact of the planned scientific program on the advancement of nuclear physics in the context of current and planned world-wide capabilities.

The discovery of Hybrids will have a fundamental impact on our understanding of gluon dynamics in hadrons . . . [If this program is not pursued] there will remain a gap in our knowlegde about the hadron spectrum as suggested by theory with guidance by Lattice QCD . . . If exotics could be identified, then this would give confidence in QCD predictions in the non-perturbative regime. If exotics are not found at a significant level, then our ideas of how to do calculations with QCD in the perturbative regime would have to be re-thought . . .

An extensive program to explore glueballs and hybrids will also be conducted with the PANDA experiment at GSI, using antiproton-proton collisions to generate those states . . . Panda at GSI will have sensitivity for detection of glueball and hybrid states. However, Panda will not have the unique opportunity to illuminate the spin and parity of the meson states using polarization of the photon beam . . . For hybrids the focus at PANDA will be on systems with charmed quarks. The JLab program is complementary in that it concentrates on light-quark hybrids . . . Glueball search in the charmed sector is also the main topic of the CLEO-c research program . . . CLEO-c may observe glueballs in J/ψ decays, but only diagonal hybrid states, such as $s\bar{s}\,g$, can be observed in that experiment. On the other hand, GlueX can observe non-diagonal states such as $\bar{s}ug$ (excited K+) that could be photo-produced in association with a a strange baryon . . . The vector $s\bar{s}$ states can also be studied in $e^+ e^-$ annihilation at Novosibirsk and as well through initial state radiation (ISR) at BABAR and Belle.

The theoretical efforts and technical capabilities needed in order to accomplish the planned scientific program.

Exotic hybrids, even though they carry unusual quantum numbers, have potentially large couplings to the multi-meson continuum. The interpretation of the data requires detailed partial wave analysis using advanced methods beyond the restrictions imposed by isobar model assumptions . . . Although the committee realizes that this is not a problem that has been solved unambiguously, it encourages further effort along these lines. Concerted efforts should be made to estimate the partial widths of these states using lattice QCD . . . It is important to secure, over the next decades, the theoretical expertise needed to perform such calculations . . . The ability to perform large scale partial wave analyses must be developed, optimized and maintained for the duration of the project . . . PWA will be a challenge but this issue is being actively studied by the collaboration . . . Further guidance comes from Lattice QCD . . .

Theoretical studies of the phenomenology of non-exotic and exotic meson states and photoproduction of these states are important adjuncts of the GlueX program. These studies could be very useful guides for physics analysis and can illuminate the significance of upper limits for conjectured states that are not found. The lattice QCD program may provide guidance by predicting the mass spectrum of hybrid states, and partial decay widths . . .

Many long years of experience in hadron spectroscopy have revealed the crucial importance of using a perfectly hermetic detector to perform the required partial-wave analyses of the decay products of hadronic states (i.e., a detector which has sufficient acceptance to view all particles produced in each scattering event). It is entirely clear that the detectors presently existing at JLab (and elsewhere) can neither achieve the required hermeticity for the precision exotic-meson search proposed for the Hall D / GlueX facility, nor can they match the necessary kinematic range of the upgraded 12 GeV beam. A new detector (GlueX) is absolutely required to accomplish the exotic-meson search that is such a key part of the 12 GeV upgrade proposal . . .

The Hall D detector . . . must be constructed and brought on-line in addition to providing the full 12 GeV beam to the experiment . . . Hall D and the GlueX detector system will be required as specified in the project proposal. Complete coverage of final states is necessary; the GlueX instrumentation is prepared for this. Monte Carlo simulations of the expected detector capabilities should be performed and presented . . .

PHYSICS OF NUCLEI

The significance and merit of specific scientific questions addressed in the 12 GeV scientific program.

A fundamental issue in our understanding of nuclear physics is to determine at which length scale the description of nuclear properties in terms of meson-baryon based interactions must be replaced by descriptions that use quark and gluon degrees of freedom. With the proposed 12 GeV upgrade, a kinematical region becomes accessible where a few selective experiments on nuclear targets can be performed. These will probe that part of the nuclear response where nucleons are in such close proximity that they may change their internal structure or even may fuse into six quark clusters. Aspects of these high-density configurations are described by the poorly known short-range part of the NN-interaction, normally defined in terms of heavy-meson exchange . . . As the protons and neutrons of which atomic nuclei are composed are bound states of quarks, the highly-complex nucleon-nucleon interaction (and so the structure of nuclei) must ultimately be explainable from the underlying strong interaction. Excellent ideas have been proposed for using the 12 GeV JLab upgrade to make forward steps in this noble undertaking. However, explaining the nucleon-nucleon interaction in terms of the QCD Lagrangian is an extremely complex problem. I feel that given the many more-elementary questions which presently plague our understanding of the strong force, this endeavour is overly ambitious at the moment . . .

Investigations of the EMC Effect: The new proposed explorations of the EMC-effect focus on:

- The high precision investigations in regions of Björken-x where a separation of valence and sea quark effects in the nuclear medium becomes possible for the first time.
- The study of changes of the nucleon spin structure in a nuclear environment.
- The study of the spin dependence of the anti-shadowing effect.

[These] projects address the fundamental quest for the role of quarks in the nuclear many body system at an unprecedented level of precision.

The EMC-effect provides one of the most visible experimental results in the two last decades which eludes a "classical" microscopic description . . .

Quark propagation and hadronization in nuclei: The aim of this project is to investigate the evolution of a fast moving quark from its initial point of production over a distance in nuclear matter at which hadronization sets in. The nucleus is used to provide the scale to determine this characteristic distance and to study energy loss mechanisms . . .

The basic idea is to strike a quark in the nucleus (by knocking it out of a nucleon) and to observe how it propagates. These processes are studied with theories also used to analyze RHIC experiments; the measurements driven by an electromagnetic probe would provide a base or baseline in analyzing high energy heavy ion collisions. In DIS, the struck parton undergoes a complex process that generates hadrons in the final state. The study of this process inside the nucleus when the time required to reach complete hadronization (formation time) and the time required for the hadron to emerge from the nucleus are comparable, can yield important information about the hadronization mechanisms.

The formation time is expected to depend on the energy, ν and the momentum, Q^2, transferred to the struck quark as well as on the fraction, z , of the energy, ν, carried by the outgoing hadron. This formation time can be varied by appropriate choices of the initial kinematical conditions. On the other hand the choice of different nuclei would allow one to study the process inside nuclear volumes of different size. In a simplified picture, when the formation time is smaller than the nuclear transit time, the hadron that carries the struck quark strongly interacts with the surrounding nuclear medium, thereby degrading its initial momentum. For larger formation times, meaning that the hadronization process is completed outside the nucleus, the propagating quark and the partially-formed hadrons are expected to have little interaction with the nuclear medium . . .

The precise knowledge of the hadronization processes in nuclear matter is an essential piece to extract fragmentation functions in combination with the information derived from deep inelastic scattering. The results of those measurements are not only of importance for their own sake but also of great relevance for a wider physics community interested in the physics of matter under extreme conditions . . .

In summary, what we can learn from these experiments is

a) how the quark structure of nucleons differs from the quark structure of nuclei

b) how hadron formation in the nuclear medium differs from hadron formation in the vacuum . . .

The feasibility of the near and long-term goals for the implementation of the planned program.

The 11-GeV energy, planned for the existing Halls and the high luminosity are necessary for these experiments. The CLAS12 will be necessary for the quark propagation studies while the SHMS will be essential for color transparency experiments involving a pion or proton in the final state . . .

The realization of the project is based on the high energy and luminosity of the electron beam, the application of polarized targets and the extension to semi-inclusive channels. Starting with ^{3}He and ^{4}He targets is an excellent choice motivated by the existing microscopic theory for those nuclei. The measurements of $g_1^A(x)$ with polarized nuclear targets will be first performed on ^{7}Li, taking advantage of the high degree of polarization achieved with this target.

The quark propagation and hadronizaion studies can be carried out with the planned upgraded equipment . . .

The upgrade is necessary for the experiments in order to ensure scaling. It is not clear whether flavor tagging can be used in nuclei because at 11GeV the quarks are still likely to fragment inside the nucleus. However, this only means that flavor separation may not be unambiguously possible, but this does not affect the ability of the planned experiments to determine the EMC effect without flavor separation . . .

The impact of the planned scientific program on the advancement of nuclear physics in the context of current and planned world-wide capabilities.

The role of quarks as an essential degree of freedom in nuclei will be established in an unambiguous way. The traditional picture of nuclei in terms of nucleons interacting through phenomenological potentials will undergo radical changes by establishing the connection towards the underlying QCD . . .

The origin of the EMC effect has been a long-standing issue in nuclear physics. It is not understood how the quark momentum distribution in a nucleon can be modified so greatly in a nucleus. In heavy nuclei, there is essentially a universal shape to the medium modification. The present program will teach us how the EMC effect evolves from deuterium to heavy nuclei by performing measurements on nuclei such as ^{3}He and ^{4}He. It is essential to perform high-accuracy studies of these nuclei not only because the effect is expected to change dramatically in these light nuclei, but also because exact quantum Monte Carlo calculations can be performed for these nuclei.

The determination of whether there exists a "spin EMC effect" will provide us with valuable information on the nature of the coupling of the nuclear medium to the nucleon. For example, scalar and vector couplings would give rise to different spin effects. Thus, a measurement of the spin structure function in a polarized light nucleus such as ^3He or ^7Li will be essential. Again, these nuclei are particularly amenable to theoretical interpretation from exact Quantum Monte Carlo calculations as well as the quark meson coupling model . . .

Quark propagation in nuclei has emerged as a major issue in nuclear physics. Interest in this phenomenon has burgeoned because of the RHIC results indicating the formation of a quark-gluon liquid. Definitive proof of the existence of quantum interference phenomenon such as the Landau-Migdal-Pomeranchuk effect will give new insight into the parton energy loss mechanism in the nuclear medium . . .

The precise knowledge of the hadronization processes in nuclear matter is essential to extract fragmentation functions in combination with the information derived from deep inelastic scattering. The results of those measurements are not only of importance for their own sake but also of great relevance for a wider physics community interested in the physics of matter under extreme conditions . . .

Although HERMES has begun studies of these phenomena, the HERMES data are limited by luminosity and selection of targets. The expected CLAS12 data will set the standard and provide definitive results for quark propagation. No other program is expected to provide the required data to understand the EMC effect in nuclei . . .

A low statistics measurement on ^{14}N and ^{84}Kr has recently been performed at HERMES. Results from the proposed 12GeV measurements could be important for interpretation of experiments at other facilities like HERA, RHIC and even LHC . . .

There exist no other programs worldwide to study the EMC effect . . .

The theoretical efforts and technical capabilities needed in order to accomplish the planned scientific program.

The 11 GeV beam and high luminosity are essential. Continued theoretical support aimed at using . . . exact quantum Monte Carlo calculations to the DIS regime will be essential. Also, theoretical development aimed at understanding the time evolution of hadronization or confinement will be essential . . .

The realization of the [EMC effect] project is based on the high energy and luminosity of the electron beam, the application of polarized targets and the extension to semi-inclusive channels. Starting with ^3He and ^4He targets is an excellent choice motivated by the existing microscopic theory for those nuclei. The measurements of $g_1^A(x)$ with polarized nuclear targets will be first performed on Li7, taken advantage of the high degree of polarization achieved with this target . . .

The theory for the light nuclei –^3He, ^3H and ^4He- is well developed in terms of microscopic calculations. This will enable to separate nuclear structure effects from modifications of the nucleon structure. Support from the local theory group is required and available. Issues of factorization in the extraction of fragmentation functions from the semi-inclusive experiments must be addressed in order to reach firm conclusions . . .

More QCD based work on PDFs in nuclei, in particular for x>1, rather than just "QCD-inspired" models needs to be done to fully exploit the potential insights that are to be gained from this experiment. Unfortunately, those observables are not within reach for lattice gauge calculations and other (continuum-based) approaches to QCD need to be developed further in order to understand this regime . . .

COMMENTS

The significance and merit of specific scientific questions addressed in the 12 GeV scientific program.

The Standard Model of strong and electroweak interactions has been broadly successful in describing phenomena in nuclear and particle physics. It is amenable to tests at the Z pole and high-energy searches for new particles. It is also now widely appreciated that the Standard Model is amenable to tests at low energy. These include neutrino physics, atomic parity violation and searches for double beta decay. Deviations from the Standard Model could signal the presence of new gauge bosons (Z), the existence of lepto-quarks or particles predicted by supersymmetric theories. Jefferson Lab has recently entered this field by developing and proposing the proton Q_{Weak} experiment and is considering parity violation in deep inelastic scattering, DIS parity, and in Möller scattering. These new directions open a new promising field of research well adjusted to other activities in this field worldwide . . . With the high-current, polarized 11 GeV electron beam, high-accuracy parity-violating Möller [and] deep inelastic scattering become possible. These experiments are essential for constraining new physics beyond the Standard Model even after the LHC produces its first results. Also, these measurements can give a high-accuracy determination of the structure functions for the proton at high *x* . . .

The near-term goal of this experimental program is the high-accuracy measurement of the asymmetry in parity violating deep inelastic scattering from the deuteron. It permits extraction of the axial-vector neutral boson coupling to the light quarks at a level of precision exceeding the current limits by a factor of more than 20. A measurement of this accuracy could indicate new physics beyond the Standard Model. It can also address issues related to the NuTeV anomaly, where a three-sigma deviation from the Standard Model has been reported, [and] . . . the precise determination of the quark distribution ratio *d/u* at large Bjorken-*x*. This measurement can resolve the shape of the parton distribution at high *x* and give further insights into the quark structure of the proton . . . These measurements on a nuclear target can test whether the anti-shadowing phenomena is universal; i.e., the same for weak an electromagnetic currents, recent theoretical work indicates that anti-shadowing is not universal . . .

In the longer term, a high-profile measurement of the asymmetry in parity violating Möller scattering is planned. The goal of this experiment is to yield a clean measurement of parity violation in a purely leptonic process at low Q_2 and at the same level of accuracy as the LEP measurements. This measurement represents an outstanding complement to the scientific program at LHC . . .

The feasibility of the near and long-term goals for the implementation of the planned program.

The 11-GeV high-current, highly-polarized electron beam is critical for these studies.

The expected asymmetry in parity violating deep inelastic scattering from the deuteron is relatively large. It is feasible to measure the asymmetry to less than 1%. A technical challenge will be improving the Compton polarimeter to less than 1%. Novel technical developments will be necessary . . .

Near-Term Goal:

The parity violation in deep-inelastic scattering that can provide a stringent constraint on the vector–axial-vector coupling constant as well as a check of the NuTeV anomaly can be performed with the HMS and SHMS spectrometers . . . The asymmetry is relatively large: 10^{-4} Q^2/GeV^2 and it is feasible to measure the asymmetry to less than 1% . . . experiments of comparable accuracy have already been demonstrated at JLab. A technical challenge will be improving the Compton polarimetry to less than 1% accuracy. Work on this issue is underway within the present 6 GeV program.

Mid-Term Goal:

In the mid-term, a special toroidal spectrometer will be necessary to perform the nucleon structure studies.

Long-Term Goal:

The experiment must measure the asymmetry to 0.6 ppb . . . the Möller experiment will require target development to handle 5 kW of beam power and a special spectrometer and detectors . . . The 5-kW power in the target could lead to significant fluctuations. Linearity of the electronics is an issue. Technical developments will be necessary . . .

The impact of the planned scientific program on the advancement of nuclear physics in the context of current and planned world-wide capabilities.

This experimental program is one of the outstanding highlights of the 12 GeV upgrade project. Without this experiment, important information to understand the NuTeV anomaly will not be obtained. The opportunity will be lost to determine the C_2 couplings to *u*- and *d*-quarks at a level of precision never reached before. For the Möller scattering measurement, if not performed, the next opportunity will only be at the ILC. This science cannot be performed elsewhere. It complements the program at the LHC. This project has a strong potential for new physics and should be carried out with top priority . . .

A mystery is emerging in low energy tests of the Standard Model. The community aimed at providing accurate results for V_{us} are converging on a value that indicates that the sum of $V_{ud}+V_{us}+V_{ub}$ is consistent with unity, again suggesting only three generations. However, this new value of V_{us} means that the NuTeV anomalous result moves from a 3 sigma deviation from the Standard Model to a 3.75 sigma deviation. This means that a Q_{weak} experiment and a new parity violation experiment in deep inelastic scattering (PVDIS) will be even more important. Because of the sensitivity of the neutrino scattering experiment (NuTeV) to the value of V_{us}, a deep inelastic electron scattering experiment, free of this problem, will permit a definitive test of the NuTeV anomaly in the DIS region . . . Without this experiment, important information to understand the NuTeV anomaly will not be obtained and the opportunity to isolate basic symmetry parameters of the standard model will be lost . . .

The very high-accuracy Möller scattering experiment would provide an error limit that is comparable with those from the LEP experiments. Such a high accuracy experiment has the potential for either discovery of new physics, say a new Z boson, or assisting the LHC experiments in pinning down the parameters of a possible supersymmetric theory. No other existing or planned facility, short of the ILC, can provide data that would have such an impact . . .

The proposed precision measurements of certain Standard Model parameters will constrain the Standard Model and test its validity. The proposed measurements make elegant and cost-effective use of high precision, rather than high energy, to test the Standard Model at the same multi-TeV energy scales that the Large Hadron Collider at CERN will explore. Some of the measurements proposed in this area for JLab at 12 GeV cannot be duplicated until the High Energy physics community realizes their long-term goal of a completely new accelerator facility, typically termed the “Next Linear Collider” . . .

The theoretical efforts and technical capabilities needed in order to accomplish the planned scientific program.

Theoretical support is required in order to understand higher twist and charge symmetry breaking effects at the partonic level in order to extract the combination $2C_u^2 - C_d^2$ at the required level of precision.

A 90 μA 11 GeV, 85% polarized electron beam.

Near Term:

A 60-cm LD_2 target and the HMS and SHMS spectrometers.

Mid Term:

- A 60cm LD_2 target
- A special 200 msr spectrometer
- Detectors with good π/e separation at high counting rates.

Long Term Goal:

- A 150cm LH_2 target
- A special toroidal spectrometer, and new detectors

In the near term, the PVDIS experiment on the deuteron can be performed with the planned upgrade and the HMS and SHMS spectrometers. The SHMS would reduce the beam time for this experiment by a factor of two, a significant amount of beam time, and provide additional systematic error checks.

In the mid-term and far term, new special purpose spectrometers and detectors would have to be developed. For the Möller experiment, a high-power cryotarget (5 kW) and electronics would have to be developed . . .

Recommendations

Near Term Goal:

It is recommended that a detailed assessment be carried out concerning the accuracy that can be achieved for the input parton distributions.

Mid Term Goal:

This experiment should be performed as soon as possible.

Long Term Goal:

R & D aimed at the technical issues of the target and electronics should be proposed.