REPORT OF THE

JEFFERSON LABORATORY
PROGRAM ADVISORY COMMITTEE

PAC 27
12 GeV REVIEW II

REVIEW OF BASE PLAN FOR
EXPERIMENTAL EQUIPMENT

MEETING OF JANUARY 10-11, 2005

Special PAC 27 Review

of any significant modifications and/or additions to the science program of the 12 GeV upgrade proposed for inclusion in the Conceptual Design Report for the Experimental Equipment that is in preparation.

Executive Summary

The Jefferson Lab management, Staff, and User community continue to develop the scientific research program for a 12 GeV electron beam. The work documented in the pre-Conceptual Design Report (pCDR) which led to the CD-0 decision for the JLab 12 GeV Upgrade by DOE serves as the basis for intensified studies. Parts of the science case have evolved to improve the coherence of the argumentation and develop a crisp description. Alternate equipment configurations are under discussion in order to define an optimal solution for the essential physics programs within the boundaries of likely budget limitations. By means of this ongoing process the pCDR will be developed into a CDR which will constitute the basis for the next important step on the way to the JLab 12 GeV Upgrade, namely CD-1 approval.

The Laboratory management has charged the JLab Program Advisory Committee (PAC) to make an evaluation of the progress made in the formulation of the science case since the pCDR, and to analyze and judge the merits and drawbacks of possible alternate equipment configurations for the JLab 12 GeV Upgrade. The Proposed Revised Structure of the CDR and reports, developed in a series of workshops, served as a guideline for the discussions of the PAC.

The PAC met on January 10-11, 2005 to respond to this charge. Presentations of the Science of the 12 GeV Upgrade and reviews of the Base Plan for Experimental Equipment took half of the available time and provided up-to-date information on various topics of relevance to the PAC discussions.

The committee concludes that the new framework for the Outline for the 12 GeV CDR is an appreciable improvement over that of the pCDR, and that it reflects in a more transparent way the key science that will be accessible as a direct result of the JLab 12 GeV Upgrade. The section dealing with "*The Physics of Nuclei*" has been improved in that it is now more coherent, but it is still in need of work. *Transverse parton distributions via SIDIS* and *Quark Structure and Nucleon Excitations* are new research programs which should be highlighted in the executive summary of the CDR.

The PAC still endorses the overall plan outlined in the pCDR, namely the implementation of the major components of the experimental program in all four halls. The emphasis in commenting on the merits and drawbacks of possible alternate equipment configurations has been upon the retention to the largest extent possible of the ability to carry out this rigorous program. Consequently, the PAC advocates that the GlueX detector should be built as described in the pCDR. A close collaboration between Hall B and Hall D in all phases of instrumentation and operation is strongly recommended. The CLAS upgrade is essential to the physics mission of the 12 GeV Upgrade. The possible staging scenarios which have been proposed are convincing. An appropriate spectrometer pair is also essential to the science program. Of the spectrometer configurations discussed the SHMS & HMS combination has the potential to reach the science goals of the 12 GeV Upgrade. While the two complementary spectrometers proposed in the pCDR would be preferable, this detector combination would at least deliver most of the relevant pCDR physics, albeit with a loss of overall efficiency by a factor of order two or more compared to that for the detector configurations described in the pCDR.

The Program Advisory Committee is excited by the research possibilities afforded by the JLab 12 GeV Upgrade. However, the potentially significant impact that it can have on physics issues of concern to a broad spectrum of the nuclear and particle physics community depends strongly on the availability of adequate funding.

Introduction

PAC18 and PAC23 reviewed the science case for the JLab 12 GeV Upgrade. In particular, PAC23 carried out an exhaustive review of the content, impact, and the formulation of the scientific case being developed in the context of the upgraded experimental facility with its new capabilities. In the judgment of the present PAC, the JLab Upgrade as envisioned offers an outstanding opportunity for exploring new and fundamental physics issues of strong interest to the community of nuclear and particle physicists. In many respects the new experimental facilities will be unique in the world. PAC27 enthusiastically endorses the JLab 12 GeV Upgrade in view of its timeliness and the high impact it should have on a broad range of physics issues of great relevance to the nuclear and particle physics community in general.

A topic-by-topic evaluation of the research in each area of the program led to the following four recommendations of PAC23 to the JLab management:

Recommendation #1

The PAC recommends that

a) *Gluon excitations of mesons and the origin of confinement, and*
b) *The unified description of the quark-gluon structure of the nucleon, primarily through the determination of Generalized Parton Distributions,*

continue to present the main driving motivations for the 12GeV Upgrade. The physics is well motivated and JLab has a unique opportunity to have strong impact in these areas.

Two additional areas have outstanding potential to develop into major components of the physics program.

Recommendation #2

The PAC recommends that the JLab management, staff, and User Community continue to define and formulate a coherent experimental and theoretical physics program to develop a unified description of high-density cold nuclear matter as it can be explored at the 12 GeV facility.

Recommendation #3

The PAC recommends that the JLab management, staff, and User Community continue an aggressive study of the feasibility and technical requirements for measurements that test the Standard Model, in the electro-weak sector as they relate to parity violation in deep-inelastic scattering, and the weak charge of the proton and the electron, as well as in the strong sector as they test the strong interaction Lagrangian through investigation of the radiative decay of the $\pi°$, η, and η' mesons.

Recommendation #4

The PAC endorses the overall plan for the major new instrumentation as being required to implement the new physics program and therefore recommends that the major components in all four halls be implemented.

The recommendations of PAC23 have been important cornerstones for the JLab management, staff and User Community in drafting the pre-Conceptual Design Report. While focusing mainly on science, the pCDR also provides a detailed description of the required detector and accelerator upgrades so that it can serve as an overview of the entire plan for the 12 GeV project. The work documented in the pCDR has been the basis of the presentations from the proponents of the 12 GeV Upgrade during a meeting of the Ad-hoc Facilities Subcommittee of the Nuclear Science Advisory Committee on February 15, 2003. The CD-0 decision for the JLab 12 GeV Upgrade in April 2004 has been the focus of the pCDR work, and at the same time has provided a new boost for the JLab 12 GeV Upgrade.

New results in theory and experiment allow a sharpening of the physics case. Alternate equipment configurations have to be discussed in order to arrive at an optimal solution regarding the envisaged experimental program within the constraints resulting from possible budget limitations. The pCDR must evolve into a CDR which will form the basis for the next important milestone on the way to the JLab 12 GeV Upgrade, namely the CD-1 approval. It has been the task of PAC27 to review and discuss these ongoing activities as carried out by the JLab management, staff, and User Community. In the two years since PAC23 a series of workshops and working groups has addressed the most pressing questions, and has continued to detail the science and instrumentation issues. With this background in mind, PAC27 took part in this ongoing process by hearing presentations by theorists and experimentalists on the main topics of the envisaged physics program, the planned new experimental facilities and about the adaptation of existing equipment to the 12 GeV JLab Upgrade.

The Outline Structure of the pCDR and the following Proposed Revised Structure of the CDR (changes indicated in bold characters) have served as a guideline for the deliberations of the PAC :

1.A Physics Overview

1.A.1 **QCD in the Confinement Regime**
Gluonic Excitations and the Origin of Quark Confinement
Spectroscopy (light mesons and baryons)

1.A.2 The Fundamental Structure of Nuclear Building Blocks
The 3D quark/gluon structure of the nucleon
(GPD's, form factors,....)
The spin structure of the nucleon
(transverse parton distributions via SIDIS, the extended GDH integral and sum rule,....)
Quark structure and nucleon excitations
(duality,.....)
Valence Quark Structure Parton Distributions

1.A.3 The Physics of Nuclei
The emergence of Nuclei from QCD
The onset of scaling behavior in nuclear cross sections
Helicity conservation in nuclear reactions
Learning about the N-N force by the measurement of the threshold J/ψ-N cross section and by searching for J/ψ – nucleus bound states
Short-range correlations in nuclei: the nature of QCD at high density and the structure of cold, dense nuclear matter
Fundamental QCD Processes in the Nuclear Arena
Color transparency
Pion photoproduction from the nucleon and in the nuclear medium
Quark propagation through cold QCD matter: nuclear hadronization and transverse momentum broadening

1.A.4 Symmetry Tests in Nuclear Physics
Standard Model Tests
Properties of Light Pseudoscalar Mesons via the Primakoff Effect
Test of Charge Symmetry at the Partonic Level

1.B Upgrade Project Summary
1.B.1 The Accelerator
1.B.2 The Experimental Equipment
Hall A and the Medium Acceptance Device (MAD)
Hall B Upgrade and CLAS12
Hall C and the Super High Momentum Spectrometer (SHMS)
Hall D and the GlueX Experiment

The laboratory has asked PAC 27 to review any significant modifications and/or additions to the science program that are proposed for inclusion in the Conceptual Design Report for the Experimental Equipment that is in preparation with the following charge:

- **Comment on the intellectual framework presented for the revised outline for the 12 GeV CDR.** Is this the best way to present the science case to DOE and to the larger nuclear physics community? Are there flaws or omissions in the framework? Is the new framework an improvement over that of the pCDR?
- **Review the new research programs that are under consideration for being highlighted in the executive summary of the CDR.** Do they represent compelling science that must be done to advance our understanding of nuclear physics? Have we omitted key science initiatives that should be used as primary motivations for the Upgrade?
- **Is the experimental equipment proposed in the pCDR and enhanced by further design work since the publication of that document well matched to the key physics experiments motivating the upgrade?** In cases where an experiment or program is proposed for more than one set of equipment, are the differences in capability and physics reach of the equipment essential for getting all of the physics, important for getting as much physics as possible, or simply useful in that, for example, an experiment could be done somewhat faster with one hall equipment compared to another?
- **Comment on the merits and drawbacks of possible alternate equipment configurations.** A variety of possible alternate equipment configurations under consideration will be presented. For each of these configurations, identify the essential physics programs that it can support roughly at the level of the equipment presented in the pCDR (as enhanced by further design work since the publication of that document), and for each identify critical physics "reach" that will be lost relative to the design-enhanced pCDR equipment.
- **Comment on the Letter of Intent received on a dedicated DVCS detector.**

Response to the First Charge

Comment on the intellectual framework presented for the revised outline for the 12 GeV CDR. Is this the best way to present the science case to DOE and to the larger nuclear physics community? Are there flaws or omissions in the framework? Is the new framework an improvement over that of the pCDR?

The PAC agrees with the statements of PAC23 that 1.A.1 and 1.A.2 represent the driving motivations for the 12 GeV Upgrade. The physics is well motivated and JLab has a unique opportunity to have a strong impact in these areas.

1.A.1 The new structure in two subtitles makes the original goal more transparent. The extension of the spectroscopy by including baryons is an important addition.

1.A.2 The emphasis on *3D quark/gluon structure of the nucleon* reflects the dramatic progress which has been achieved recently by the development of GPDs. However, it is necessary at this point to find a transparent description of the transition from the text-book discussion of form factors in the nonrelativistic regime to the new description in terms of GPDs in order to reach the physics community beyond the realm of nuclear physics.

The inclusion of the subtitles *The spin structure of the nucleon* and *Quark structure and nucleon excitations* constitutes a major improvement.

The unique possibility offered by the JLab 12 GeV Upgrade to investigate the "*Valence Quark Structure Functions"* in the large–x region cannot be over-emphasized.

1.A.3 By identifying two major lines of investigations, "*The emergence of Nuclei from QCD"* and "*Fundamental QCD Processes in the Nuclear Arena",* the whole topic has gained in coherence, but still needs work.

1.A.4 The topic *Test of Charge Symmetry at the partonic level* should not be included in the science justification at this time.

All together, the new framework is an appreciable improvement over that of the pCDR, and reflects the progress made in shaping the experimental program as a result of many meetings and discussions.

Response to the Second Charge

Review the new research programs that are under consideration for being highlighted in the executive summary of the CDR. Do they represent compelling science that must be done to advance our understanding of nuclear physics? Have we omitted key science initiatives that should be used as primary motivations for the Upgrade?

1.A.1 Spectroscopy (light mesons and baryons)

The inclusion of baryon spectroscopy as a research emphasis for the GlueX experiment is a clear improvement. 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.

The CLAS12 detector will provide very useful measurements of transition form factors for particular hadron resonances at high Q^2. The improved capabilities of an upgraded CLAS detector should be emphasized strongly. This topic should find its place in **1.A.2** "*Quark structure and nucleon excitations"*.

1.A.2 The spin structure of the nucleon (transverse parton distributions via SIDIS)

These measurements provide important information about the spin/ flavor structure of the nucleon. The main focus will be on studies of the orbital angular momenta of quarks, and parton distributions at large x. The proposed equipments in Hall C, Hall B and Hall A allow experiments of unprecedented accuracy in these areas.

1.A.3 The PAC has the impression that by proceeding along the path from accurate measurements on the nucleon as foreseen in **1.A.1/2** to precise measurements on few body systems, and continuing to the study of heavy nuclei, a field with significant discovery potential can be explored systematically. This topic might be incorporated under the heading *"The emergence of Nuclei from QCD"*.

1.A.4 The topic *Standard Model Tests* has been developed remarkably well in the last few years.

Also the program *Properties of Light Pseudoscalar Mesons via the Primakoff Effect* holds the promise of yielding precise data. Here, however, the results of the envisaged measurements should be put in perspective with others which might test the same physics by using data obtained by different methods. In particular, there should be some discussion of the anticipated systematic uncertainties associated with the various approaches considered.

The topic *Test of Charge Symmetry at the Partonic Level* should not be included in the science justification at this time. The PAC is not convinced that the Charge Symmetry Violation (CSV) effect could be extracted reliably from the data. In particular, the extraction of CSV relies on a leading-order expression assuming the validity of factorization.

Response to the Third Charge

Is the experimental equipment proposed in the pCDR and enhanced by further design work since the publication of that document well matched to the key physics experiments motivating the upgrade? In cases where an experiment or program is proposed for more than one set of equipment, are the differences in capability and physics reach of the equipment essential for getting all of the physics, important for getting as much physics as possible, or simply useful in that, for example, an experiment could be done somewhat faster with one hall equipment compared to another?

The design work for new equipment and for the adaptation of existing equipment to a future program with a 12 GeV beam is based on the combined experience of a large user community which has been conducting a highly successful physics program for many years. The PAC is impressed by the professionalism with which the proposals have been developed. New limits had to be explored in several directions: the energy increase was accompanied frequently with an increase of luminosity, of the overall acceptance for particle detection and of the necessary particle identification. By using the most recent technologies in detector design, and incorporating the newest generation of data acquisition and data analysis systems, convincing solutions for the envisaged experimental program have been proposed. An important aspect of the success story of the physics program at JLab consists of the availability of a broad range of instruments which may then be used to carry out complementary investigations. Such an instrumental basis allows the coverage of a wide kinematical range, and supports the quest for complete experiments which allow the most relevant, and most model-independent variables to be extracted from the data. This instrumental basis includes the preparation of high-current beams, many different types of targets (solid, gaseous, liquid), the preparation of polarized electron- and photon-beams, polarized targets and the detection of recoil polarization, not forgetting the recent accomplishment of providing a "free"-neutron target through the use of deuterium with spectator-proton tagging.

In different combinations these tools are needed to carry out the key experiments. All tools are not available in all halls, but the proposed solutions optimize their application to the research program. At this point the PAC cannot see any unjustified redundancy in the planned experimental set-ups.

Response to the Fourth Charge

Comment on the merits and drawbacks of possible alternate equipment configurations. A variety of possible alternate equipment configurations under consideration will be presented. For each of these configurations, identify the essential physics programs that it can support roughly at the level of the equipment presented in the pCDR (as enhanced by further design work since the publication of that document), and for each identify critical physics "reach" that will be lost relative to the design-enhanced pCDR equipment.

After hearing the presentations of the science case and the proposed equipment plan for all halls the PAC still considers the recommendation of PAC 23 as the most appropriate way to take on the challenges of the science program:

Recommendation #4 of PAC 23

The PAC endorses the overall plan for the major new instrumentation as being required to implement the new physics program and therefore recommends that the major components in all four halls be implemented.

However, the PAC was informed by the JLab management at the beginning of the deliberations that in the course of preparing the CDR it became clear that the estimated overall cost of the JLab 12 GeV Upgrade for the accelerator and the experimental equipment exceeds the foreseen budget. This new situation is reflected in the fourth charge to the PAC. In the likely event that it is necessary to scale down aspirations, the Lab management asked the PAC to comment on the merits and drawbacks of possible alternate equipment configurations. It is understood that in cutting overall costs the ability to carry out a rigorous program of broad scope should not be compromised. At present it is not known to what extent funding might be reduced in the context of the program outlined in the pCDR. A first step has been taken by the Lab. management by setting up a review commission with the charge to look into different realizations of four key experiments in order to compare the figures of merit (e.g. rate, kinematic reach, estimated systematic uncertainty, …). Four experimental configurations have been considered:

a) The one described in the pCDR (MAD & HRS in Hall A, SHMS & HMS in Hall C)
b) Either MAD & HRS in Hall A or SHMS & HMS in Hall C
c) MAD & HMS in Hall C
d) SHMS & HRS in Hall A

According to the preliminary conclusions of the review commission, a) remains the best option. At this time, the option that has the best combination of count rate, systematic uncertainty, minimum risk and physics reach appears to be SHMS & HMS. The highest counting rates could be achieved with configuration c). However, for this latter case the evaluation of reliability of calibration and of performance under large background conditions needs detailed study. For several experiments it has been stated that control of systematic uncertainty is more important than running time.

Another important aspect at this stage of deliberations relates to the point of the availability of the highest beam energy during the simultaneous operation of two or three experimental halls. The following issues have been discussed, and we summarize briefly the conclusions reached for each hall:

Hall D, GlueX

Issues: The merits of photoproduction versus electroproduction for the spectroscopy of light mesons and baryons, the option of locating Hall D behind Hall B, the importance of 12 GeV beam energy for the success of the experiment, the need for a close collaboration between Hall B and Hall D staffs.

Conclusions: GlueX represents one of the key projects requiring the JLab 12 GeV Upgrade. The PAC recommends adhering to the original plan outlined in the pCDR. Possibilities for cost reduction should be considered without compromising the proposed physics reach of the experiment. A close collaboration between Hall B and Hall D throughout the instrumentation and operation phases is highly recommended.

Hall B, CLAS12

Issues: Luminosity upgrade by a factor of ten, the availability of polarized targets, spectator fragment tagging capabilities, CLAS12 as a tool to check GPDs, staging scenario.

Conclusions: The PAC recognizes the CLAS upgrade as instrumental to the physics mission of the JLab 12 GeV Upgrade. If the funding of the whole upgrade cannot be granted at the outset, the proposed staging scenario appears reasonable but should be scrutinized again at the appropriate time.

Hall C and Hall A:

Issues: Installation and upgrade scenarios described in a), b) and c).

Conclusions: The PAC agrees with the findings of the review commission, in that a) remains the best option. For case b), in which one spectrometer can be built, and in view of the rich physics that can be accessed by a high luminosity hall, the PAC recommends a careful evaluation of the best options for the maximum physics output for both high luminosity Halls. This should include the Hall that will not be upgraded. SHMS & HMS can do most of the pCDR physics, however, with loss of overall efficiency by at least a factor of two. In case of a SHMS & HMS solution the PAC encourages all groups interested in experiments needing the highest beam energies and considering the SHMS & HMS set-up as the appropriate equipment, to form a common working group with the goal of achieving the best figure-of-merit and arriving at an optimal solution for the implementation of this new set-up.

General remarks: Given the recent and soon-to-be realized implementations of new methods for experimentation such as spectator fragment tagging, polarized frozen spin targets, polarized nuclear targets and use of a tritium target, an expanded experimental program for energies at 8.8 GeV or below will start. New directions, e.g. by using parity-violating electron scattering for studies of hadrons, are on the horizon. Studies on nuclei using high resolution equipment to identify excited states of final-state nuclei can serve as spin-isospin filters for the reaction investigated. There must be room for all these developments emerging in the next few years and an open perspective for such investigations in the context of the JLab 12 GeV Upgrade. Also the option to prepare two or even three high energy electron beams simultaneously, which is not achievable in the present planning, should be kept in mind as a goal which would be of utmost importance to the user community.

Response to the Fifth Charge

Comment on the Letter of Intent received on a dedicated DVCS detector

Individual Proposal Report

Proposal: LOI

Title: A Solenoidal Detector for Deeply Virtual Compton Studies at Luminosities $>10^{37}/\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and Energies 6-12 GeV

Spokespersons: Charles E. Hyde-Wright

Motivation: The construction of spatial images of the density of quarks inside the nucleon via Generalized Parton Distributions (GPDs) is the primary goal of the experiment. The observables providing the input data for the GPDs will be extracted from the following reactions: Deep Virtual Compton Scattering (DVCS) $ep\rightarrow ep\gamma$; Deep Virtual π° Production $ep\rightarrow ep\ \pi^\circ$; Doubly Virtual Compton Scattering (D^2VCS) $ep\rightarrow e'pl^+l^-$ and J/Ψ electro-production.

Measurement and Feasibility: This LOI explores the feasibility of a specialized detector designed specifically for these reactions. Using a solenoid detector, a fine grained $PbWO_4$ calorimeter, an array of plastic scintillators and a time projection chamber the exclusive final states indicated above will be studied. The huge electron background in the forward direction will be confined by the solenoidal field, and as a result detection of photons in the angular range larger than 5 deg. is possible. The luminosity goal is $>10^{37}/\mathrm{cm}^{-2}\mathrm{s}^{-1}$, to be compared with the projected CLAS12 luminosity of $>10^{35}/\mathrm{cm}^{-2}\mathrm{s}^{-1}$. This investigation of the benefits of such a specialized detector as compared to the more general purpose detectors described in the pCDR is still in an early stage.

Issues: The proponents have still to show whether this set-up can handle the huge singles rates of the order of 100 MHz. They should perform studies of a clean γ-π° - separation in this high background environment. It is not clear whether this detector provides the best configuration for every reaction mentioned in the LOI. It is possible that, e.g. for D^2VCS in comparison to the quite-different DVCS final state, a better solution involving a more-specialized detector can be designed. It has not been demonstrated that a hybrid solution involving part of the Lab.'s standard equipment with additions to take account of special kinematics would be inferior to the proposed solution. High rates can also be handled by using a larger detector with finer segmentation. The signal-to-background estimates must be extended by including correlated gamma-p coincidences originating from the virtual spectrum.

Conclusion: Contrary to the conclusions of the proponents, the PAC is not convinced that the proposed design is optimal and that it provides the best solution for all measurements of the reactions considered.