Appendix B

The report of the Cassel committee

Review of the Jefferson Laboratory "Hall D Project": December 6& 7, 1999

Review Committee:

David Cassel	Cornell University
Frank Close	Rutherford Laboratory
John Domingo	Jefferson Laboratory
William Dunwoodie	Stanford Linear Accelerator
Donald Geesaman	Argonne National Laboratory
David Hitlin	California Institute of Technology
Martin Olsson	University of Wisconsin
Glenn Young	Oak Ridge National Laboratory

Report Date: January 12, 2000

Executive Summary

The Committee was asked to address three principal questions, whose answers were to be based on the answers to more detailed questions. This Report contains the Committee's response to these questions, and advice to the Jefferson Laboratory management and the Hall D collaboration. Our answers to these questions are summarized in this Executive Summary and then given in more detail in the following Sections of this Report.

1. Evaluate the Scientific Opportunities Presented by the "Hall D Project"

This collaboration proposes to explore systematically the light mesons (with masses up to about 2.5 GeV) with capabilities far beyond those of previous experiments. The copious spin and flavor initial states produced by photon beams will be an extremely useful tool in this endeavor. Thorough study of the masses, spins, parities, and charge conjugation states of these light mesons will require a complete partial wave analysis. This will provide a much deeper understanding of quark-antiquark states, and will permit a definitive search for mesons with exotic quantum numbers, particularly hybrid states and glueballs. This search is very high priority physics; since the states involving excited glue, as well as quarkless glueball states, must exist if QCD is the correct theory of the strong interactions.

JLab is unique in being able to provide high quality, low emittance, CW photon beams that are required for this experiment. In addition, JLab and a significant segment of the JLab physics community are committed to this physics program. Together these provide a unique opportunity for exploring light meson states and making definitive searches for exotic states in this mass region.

2. Review the Collaboration's Approach to the Realization of that Facility

The general design of the detector is technically sound. This is verified by a detailed comparison (included in the Appendix of this Report) of the capabilities of the proposed Hall D detector with those of the successful LASS detector. This comparison leads to the conclusion that the proposed detector and beam combination will be able to realize the physics goals of the Project.

However, substantial effort must be invested to optimize the detector design and minimize the cost. The items requiring optimization that we have identified are described in detail in Section 2 of this Report. These optimizations are part of the R&D required to prepare a Conceptual Design Report for the Hall D Project. Preparation of a CDR with the associated WBS and resource-loaded cost and schedule will require a Project Office at JLab with a Project Director and a well-structured organization designed to address the necessary R&D and optimization efforts.

3. Recommend R&D Needed to Optimize the Facility Design and to Minimize the Overall Project Cost.

The R&D item of greatest concern is ensuring that the magnet is still functional, particularly the fourth coil, which has not been used for at least 15 years. R&D should also include construction of prototypes to optimize detector design, to validate mechanical, electronic, and software choices; and ensure the feasibility of the proposed coherent bremsstrahlung system.

Conclusions

In conclusion we find that:

- The experimental program proposed in the Hall D Project is well-suited for definitive searches for exotic states that are required according to our current understanding of QCD.
- JLab is uniquely suited to carry out this program of searching for exotic states.
- The basic approach is advocated by the Hall D Collaboration is sound.
- The Collaboration will be ready to begin work on a Conceptual Design Report once a Project Office with a Project Director is in place.
- An R&D program is required to ensure that the magnet is usable, to optimize many of the detector choices, to ensure that novel designs are feasible, and to validate cost estimates.

1 Evaluate the Scientific Opportunities Presented by the “Hall D”Project

1.1 Is this High Priority Physics That Must Be Done to Understand QCD?

Low energy QCD confines quarks into hadrons. Monte Carlo simulations of QCD demonstrate that the gluonic field (glue) collapses into a flux tube at large distances. Due to its self-interaction the glue should possess excited states which can be thought of as vibrations of the flux tube. Mesons with excited glue are called hybrids. Their existence is a firm prediction of QCD which has not yet been experimentally verified. In addition, quarkless mesons, known as glueballs, must also exist if QCD is the correct theory of the strong interactions.

These additional meson states should be plentiful in the mass range from 1 to 3 GeV. It would be important and in fact a crucial step in hadron physics to find these unconventional meson states as well as to identify the numerous conventional ones in this mass range. The proposed Hall D upgrade offers a unique opportunity to explore this mass region. The use of a photon beam is another special feature of the proposal, particularly since the photon beam carries both spin and flavor, which allows a large number of states to be excited.

The most convincing demonstration of the existence of hybrids and glueballs is likely to involve identification of exotic mesonic states — those with quantum numbers that cannot be formed by a quark-antiquark pair. A number of such exotic mesons are predicted to lie in the mass range that will be thoroughly mapped out as a result of this initiative.

Because of the nature of QCD, many hadron states are approximately degenerate in mass, so a detailed partial wave analysis must be done to disentangle them. A photon beam at JLab is particularly well-suited for this task, and the proposed linear polarization would substantially enhance the partial wave analysis by separating natural and unnatural parity contributions to t–channel exchanges.

1.2 Will the Facility's Capabilities be unique?

Photon beams bring the unique aspect of spin–aligned quarks to meson spectroscopy that is not available in the entrance channel with hadronic beams. This leads to the expectation of large cross sections for a number of states with exotic quantum numbers. While meson-production in baryon-baryon interactions , in principle, can populate the same states, the experimental situation is much more complicated.

The photon beam requirements for this project are initially 10^7 linearly polarized tagged photons per second in the energy range of 6–10 GeV with 100 percent duty factor and good emittance. The final goal is a tagged beam of 10^8 photons/s. JLab, with the energy upgrade, will be uniquely suited for providing such a beam. In particular, the excellent emittance of the JLab electron beam allows for strong collimation of the coherent bremsstrahlung radiation to enhance the polarization and ratio of tagged to untagged photons in the tagged photon beam. No other facility in the world will be able to provide a beam of this quality, with this combination of energy, duty factor, and emmitence. If such a project were pursued at other existing high-energy facilities, either the data taking rate would be dramatically reduced, compromising the physics goals, or a much more complicated detector would be required. We do not see any project at an existing accelerator complex (*e.g.* SLAC, CESR, DESY) which is likely to be able to compete with the Hall D initiative in this area.

2 Review the Collaboration's Approach to the Realization of that Facility

2.1 Is it Technically Sound?

- The technical solutions put forward in the proposal are, in the main, sound, but remain to be optimized
- It is worthwhile to spend time in optimizing individual component designs, in the context of the global scheme, rather than launching immediately into parallel prototyping efforts
- To this end, we recommend that, prior to assigning construction responsibilities, a set of "Task Force" efforts be launched to optimize the following detector systems:
  - ○ Tracking
  - ○ Calorimetry
  - ○ Particle Identification
  - ○ Trigger and Data Acquisition
- When specific approaches to detector design have been adopted, parametric studies should be carried out on items such as:
  - ○ drift cell size,
  - ○ support material distribution,
  - ○ energy versus angular resolution in the barrel calorimeter,
  - ○ particle ID capability, and
  - ○ data acquisition concept and realization.
- Responsibility for each Task Force should be clear, and each Task Force should have an explicit charge and a definite reporting deadline.

2.1.1 Civil Construction

Since there was no detailed presentation of the civil construction, the Committee's comments are confined to the cost estimate and the brief outline in the document. The cost estimate provided by the JLab civil group appears reasonable for a project in this preliminary stage within the normal accuracy of 25% claimed by that group. We were more concerned by the 10–12 m of Fe shielding needed to range out the high energy muons from the photon collimator and the same amount probably required around the tagger dump. (The 1 m found in the document appears to be an error.) This suggest to the Committee that one should reexamine the decision to have a surface tagger dump and main building. By pointing the deflected electron beam downward and placing the dump in the earth one could probably substantially reduce the required Fe shielding. In the same manner, placing the level of the hall floor below grade might also considerably reduce the required Fe shielding from the photon collimator. We suggest reexamining these questions in order to optimize costs.

2.1.2 Photon Beam

- The proposed tagger is essentially the same as that for Hall B and does not constitute a problem.
- Linear polarization from coherent bremsstrahlung is a well-understood phenomenon and the kind of beam proposed for Hall D has been used routinely in earlier experiments. However, achieving a beam of the quality desired for this experiment (*i.e.*, the flux, the concentration into a narrow band of photon energies, and the collimation needed to adequately enhance the fraction of photons that are linearly polarized) will require ongoing R&D efforts in conjunction with JLab Hall B developments. The R&D efforts that will be required include:
  - growth of synthetic diamond crystals of suitable thickness,
  - thinning of natural diamond crystals to the relevant thickness ($\leq 50\mu m$), and
  - a collimator feedback system to regulate photon beam targeting an polarization.
- Hall B tests indicate that the proposed Hall D incident flux will result in drift chamber occupancies well within acceptable range.

We conclude that the proposed photon beam design is compatible with the goals of the experiment, contingent on a successful R&D outcome.

Should it prove impossible to achieve the proposed level of linear polarization, it will be necessary for the collaboration to make the appropriate modifications to the proposed physics program.

2.1.3 Solenoid

- It is extremely important to ascertain very soon whether the MEGA/LASS magnet is still functional - especially the fourth coil, which has not been operated since $\sim$ 1982. If the potential Los Alamos collaborators can make such tests in situ, this should be done soon.

- If the magnet cannot be used, a reliable replacement cost estimate is needed to see if the experiment could still be funded. For example, if a replacement would cost ∼ $ 10 million, would this be a showstopper?

- If the magnet is functional, experts, (*e.g.* John Alcorn, Steve Lorant) should be consulted to estimate anticipated lifetime and identify possible likely failure modes.

- A decision on coil configuration (*i.e*, gaps or no gaps?) is needed, since this has an impact on *e.g.*, the length of the barrel calorimeter to the extent of 60-80 cm.

2.1.4 Target

The cost estimate for the 30 cm hydrogen target system is based on the replacement cost for the Hall B cyrotarget. However, since the maximum power delivered by the photon beam is limited to 15 W, and the only cryogenic target envisaged is hydrogen (or deuterium), a small commercial closed cycle helium refrigerator would probably be much simpler and cheaper. We suggest that the collaboration investigate this option.

2.1.5 Barrel and Forward Calorimetry

Forward Calorimeter

The forward calorimeter design is based on:

- repackaging of the Pb Glass used successfully in E852/RadPhi and

- replacement of the balance of the PMT bases with a Cockcroft-Walton design already used in RadPhi.

The carriage, restacking, and acceptance match to the solenoid are all straightforward. In addition, the required manpower is clearly in place. Hence we expect that the Forward Calorimeter will not be a serious technical challenge.

Barrel Calorimeter

- The concept is sound. JETSET calculations and more recently KLOE experience provide proof-in-principle and proof-of-performance at the appropriate scale.

- Prototyping is needed, partly for reasons of technology-transfer and partly to show that the groups responsible can obtain the projected energy, time, and spatial resolutions at this detector length. This is likely to lead to development of the needed manufacturing technique. It will lend urgency to choices of scintillator configuration, metal, and sampling fraction, as well as coupling of photosensors to the calorimeter and their integration with the solenoid magnet and tracking chambers.

- Calibration and monitoring concepts need to be addressed in order to ensure that energy, time, and spatial resolutions can be maintained throughout the duration of the experiment.

- Further development of the requirements for front-end electronics is needed

- Manpower and group sizes still seem low for this effort, and engineering support needs to be identified for the structure, module manufacturing, supports, and front-end electronics.

2.1.6 Tracking Chambers

The overall geometry and anticipated performance of the tracking system appears to be reasonable. However, much work needs to be done to optimize the tracking system. This includes:

- A definite decision between the TPC option and the Central Drift Chamber needs to be made as soon as possible.

- The study of the TPC option must include an understanding of the problems that will be encountered with the non-uniform magnetic field of the solenoid and consideration of the data rate and volume issues that will arise from the anticipated very high occupancy.

- The overall design of the tracking system must be optimized. This optimization should include: studying the possibility of reducing the number of different types of chambers, optimization of cell sizes, and optimization of chamber geometry and locations. In addition, options for eliminating the separate Beam Vertex Chambers by combining them with the Forward Drift Chambers should be studied carefully.

- Prototyping of the selected drift chamber option(s) should be included in the R&D effort for a Conceptual Design Report.

- The proposed Vertex Detector system will require serious R&D effort.

2.1.7 Particle Identification Systems: Time of Flight, Cherenkov and dE/dx

The basic detector technologies for the ToF and Cherenkov systems are not a concern.

- ToF system:
  - Coupling of the active region to photosensors needs development, particularly a decision whether the photodetectors will be in the magnetic field and the resulting requirements on photodector design and magnetic shielding.
  - Prototyping of ToF elements would be useful to establish attainable timing resolution for chosen configuration and materials.
- Cherenkov system:
  - The proposed Cherenkov vessel would operate at pressures up to 5.6 atmospheres using an inert gas. This requires timely engineering attention to structural and safety issues.
  - The tradeoffs between threshold and imaging Cherenkov detectors should be examined.
- dE/dx system:
  - The proposed use of dE/dx information seems unsettled.
  - Extraction of dE/dx from straw tubes is possible but requires better understanding of the number of samples needed, electronics signal-to-noise, treatment of ambiguities in dE/dx versus momentum, and the resolution needed to obtain adequate $\pi/K/p$ separation without overdesigning this aspect of the spectrometer.
  - Prompt resolution of the choice of tracking system and whether a TPC would be employed will help in the timely resolution of these dE/dx issues.

Manpower is being addressed. Core institutions are identified for the ToF and Cherenkov detectors, while the effort on dE/dx is still a bit tentative.

2.1.8 Trigger System

- The basic concept for the Level-1 trigger is sound. This includes input from flash converters, a fully-pipelined formation of trigger primitives from several subsystems, appropriate front-end buffering during Level 1latency, feature extraction from a settable time window, and local event buffering, zero-suppression, and packet formation in response to issuance of a global Level-1.
- The choice of pipeline architecture is not clearly motivated. Within a pipelined architecture, the choice of 250MHz for TDCs to preserve drift chamber spatial resolution is clear, but it remains to be shown if this is the optimum choice, both in terms of cost and performance, compared to other systems. Similarly, choices of ADC and TDC step size and bit count should be optimized.
- There is some reliance on continued commercial development of high-speed FADCs, memories, and gate-array logic, but this does not seem to be an area for present concern.
- The speeds proposed will require that fully functional prototypes be developed soon to ensure proper performance at speed, handling of pipeline synchronization, and noise immunity of front-end sections.

Core manpower is identified for this subsystem

2.1.9 Data Acquisition

- The general Online effort would benefit from early appointment of a manager to promulgate and ensure a uniform approach to front-end electronics; data transmission to the event-building stage; and distribution of trigger, timing, and exception (*e.g.* calibration) events. This will yield significant benefits over the life of the project.
- The basic readout and event building architecture is sound. It depends somewhat on continued applicability of Moore's Law. The challenge will be to flesh this out to a buildable design.

Core technical staff are identified, but added manpower, especially in areas of online software is likely to be needed.

2.1.10 Computing Hardware and Software

- The partial wave analysis software developed by the collaboration makes a significant contribution to understanding the physics potential of the proposed experiment.

- The projections of computer hardware requirements appear to be reasonable. However, economic realization of these requirements depends on the continued validity of Moore's law.

- The principal software effort required for the Conceptual Design Report is the development of a Monte Carlo simulation of detector options that can aid the process of optimizing detector components while providing an upgrade path to a full simulation of the detector for physics analysis.

- In developing software infrastructure, the collaboration should be aware of similar efforts in other collaborations and should utilize the resulting software that matches collaboration requirements whenever possible.

2.2 Will the Detector/Photon Beam Combination be Able to Realize the Physics Goals in Terms of Rates, Resolution, etc.?

The proposed Hall D detector instrumentation is compared to that used in the LASS experiment in a table in the Appendix. The primary goal of the latter was the performance of partial wave analysis in the same mass region up to $\sim$ 2.4 GeV for forward-produced strange meson systems using incident $K^{\pm}$ beams. It is generally acknowledged that this endeavor met with a significant degree of success. Consequently, it provides proof of principle for the configuration proposed for Hall D. However, the proposed instrumentation is superior or equal to that employed in LASS in almost every instance.

Therefore — if the proposed Hall D detector capabilities are realized — it should be eminently possible to acquire data of sufficiently high quantity and quality that the collaboration can achieve its analysis goals.

2.3 Can the Approach to the Facility and Its Physics Program Be Improved Significantly?

While the committee saw several issues where substantial optimization and cost minimization studies are required, it did not identify significant alternative approaches that the collaboration should investigate before proceeding. The collaboration should continue to remain alert to new ideas and technologies as the project proceeds.

2.4 Is the Approach to Cost Estimation Sound, and Are the Cost Estimates Reasonable for a Project at this Early Stage of Development?

The equipment and material cost estimates appear reasonable for a project at this stage except for the absence of contingency assignments. The Committee was more concerned with the accuracy of the manpower estimates, in particular, with the absence of any explicit engineering manpower, except for the chamber frame system. While some engineering jobs can probably be met by technicians, professional engineers will undoubtedly be required for many of the detailed designs. The collaboration should work to make a detailed estimate of the various manpower requirements in order to proceed to a CDR.

2.5 Is the Collaboration Ready to Begin Work toward a Conceptual Design Report?

The physics motivation, detector design concept, and status of data-analysis methods all are mature enough for the collaboration to proceed to develop a CDR. However, we feel that:

- The detector design is not yet optimized, and the Collaboration would benefit from appointing the Task Forces described above to carry out these optimizations.
- It is important for the collaboration to establish how the detector resolution requirements determine the quality of the physics output in order to have verifiable criteria to understand the costs versus performance optimization.
- The organizations need to be put into place to prepare a CDR. Both Collaboration and Project organizations need to be fleshed out to support this. The effort will benefit from early identification of a Project Director and formation of a Project Office at JLab to support preparation of the CDR and associated WBS with resource-loaded cost and schedule.
- The Collaboration should work closely with JLab management to define
    - a prioritized R&D funding plan and
    - a Conceptual Design Report, working to a budget envelope.

2.6 Comments on the Contents of the CDR

The Conceptual Design Report should contain:

- reasonably detailed descriptions of the individual detector systems;
- parametric optimization;
- relationship of detector performance to physics goals;
- budget and schedule;
- assembly and commissioning plans; and
  - project organization,
  - Collaboration organization,
  - funding profile,
  - contingency allocation and management procedure,
  - use of planning, scheduling and cost-tracking tools,
  - detailed budget with a year-by-year profile,
  - resource-loaded schedule, and
  - system integration.

3 Recommend R&D Needed to Optimize the Facility Design, and Minimize the Overall Project Cost

When system designs have been optimized, prototype construction should begin on items such as:

- mechanical prototypes
- electronics prototypes, and
- prototypes for online and offline software.

R&D objectives and their relation to the construction project should be clearly defined. These include:

- proof of principle of novel designs,
- establishment of the project schedule,

- refinement of fabrication techniques,
- validation of cost estimates, and
- measurement of actual system performance in test beams.

Appendix:
Comparison of LASS and Proposed Hall D Detectors

System	**LASS**	**Hall D**
Target	85 cm LH_2	30 cm LH_2
Magnetic Field (solenoid)	22.4 kG	$\sim$ same field coil configuration may differ
Cylindrical Chambers	6 PWC's $5 \leq r \leq 50$ cm $\sigma \sim 600\mu m$ 2 mm wire spacing and cathode strip readout dE/dx: limited π/p separation below $\sim$ 500 MeV/c Inner 2 cylinders used in definition of interaction trigger	Straw chamber $15 \leq r \leq 45$ cm $\sigma \sim 200\mu m$ dE/dx: capability proposed but needs optimization Dedicated start counter Scintillating fiber Immediately outside target
Planar Chambers	*Full Bore:* 6 PC's with 2 mm wire spacing 3 with (x,y,e) planes 3 with cathode strips $\sigma \sim 600\mu m$ (planes) $\sigma \sim 200\mu m$ (strips) *Beam Region:* 6 PC's with 1 mm wire spacing: all with (x,y,e) planes $\sigma \sim 300\mu m$ dE/dx: none First beam chamber package in trigger to close "target box"	5-6 drift chamber packages 6 planes in each package $\sigma \sim 300\mu m$ dE/dx: capability Configuration needs optimization
Cherenkov Counter	Segmented threshold counter Freon at atmospheric pressure π threshold $\sim$ 2.6 GeV/c	Segmented threshold counter Capable of pressures up to 5 or 6 atmospheres in order to vary threshold momentum
ToF	Pie-shaped 1 PMT per counter $\sigma \sim 500ps$ Large hole on axis ($r \sim 20$–$25cm$) Downstream of Cherenkov Nothing in barrel region	Rectangular array 2 PMT's per counter $\sigma \leq 100ps$ Complete coverage except for small hole in beam region Downstream of Cherenkov EMC in barrel region capable of $\sigma \leq 250ps$
EMC	None	Barrel: Pb-scintillating fiber Downstream: Pb glass Almost hermetic coverage $\sigma(E)/E \sim 5$–10%