Appendix D

The GlueX Detector Review

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D.1 Introduction

The GlueX Collaboration has proposed an experiment to produce hybrid mesons with a high energy linearly polarized photon beam incident on a hydrogen target, and to search for evidence of such mesons with an efficient, hermetic detector capable of charged particle tracking, electromagnetic shower reconstruction, and particle identification. At this review the Collaboration reported on the status of detector subsystems, which are presently in varying stages of development, ranging from conceptual design to full scale prototyping. This Committee evaluated the experiment according to the Charge which is included in Appendix A.

The Committee was satisfied overall with the detector concepts and the strategy the Collaboration has taken with respect to detector design. Designs are well based on prior experience which is either from local experiments (CLAS), or from elsewhere (LASS,KLOE), and on proven technology, which includes existing devices (LGD, magnet), or existing infrastructure (DAQ). Local experience with photon beams is also an important element which allows reliable estimates of rates and backgrounds.

The Committee was also impressed at the amount of R&D the Collaboration has managed to achieve over a period of years in which the prospects have been so uncertain. This speaks to strong physics motivation, coherent leadership, and a vibrant sociology within the Collaboration.

We begin this review with several comments of a global nature, and then proceed with a more detailed discussion of each subsystem.

D.2 Overall Comments

1. The collaboration urgently needs to take a global perspective in making design choices. Most critically, this implies that they should start as soon as possible using full GEANT MC with (a) real detector material (structural material, electronics, cables, etc) in place, (b) primary hit generation, (c) reasonable representations of noise levels (occupancy) in detectors, and (d) event reconstruction and analysis, in order to assess *combined* performance of all detectors. This analysis should include both signal *and* hadronic background. Some of the GEANT infrastructure appears to exist but it has not propagated to the detector designers, and pattern recognition and reconstruction software need yet to be written. Even rudimentary versions of a complete simulation will be helpful.

2. The Collaboration needs to develop a global perspective also in technology choices so that as much as possible common solutions can be adopted. Where differences are necessary to achieve performance goals or cost minimization, the choices should be clearly justified.

3. The open issue of downstream PID (threshold Cherenkov? DIRC? other?) is crucial to resolve soon. The Collaboration intends to do so by early spring 2005, but at present the DIRC option is the only one obviously on the table. In view of the considerable technical, cost, and schedule risk that a DIRC would involve, the Collaboration needs to develop at least one viable alternative so that they c an make a genuine decision between options in order to avoid a Hobson's choice. The Collaboration should also study the impact of having no Cherenkov device downstream. If the outcome of the study confirms the need for such a device, the Collaboration should either be actively trying to revive the threshold Cherenkov option or should explicitly drop it; keeping a non-viable option on the table distorts decision making.

4. Tracking is not yet optimized. The Collaboration should explore ways to reduce the inner radius of the CDC and provide good z measurements at low radius. This will reduce the p_T threshold for tracking, improve vertex reconstruction, and K_S and Λ identification. It is not clear that the start counter is needed, and currently it occupies real estate that tracking might better use.

5. Current manpower levels are somewhat marginal. While sufficient for developing the main aspects of individual subsystems, the present staffing level is not sufficient to permit critical intersystem and global issues to be addressed. In particular there is the problem of the missing overall simulation, discussed in item 1, above. Even a single additional full-time person, for instance a post-doc, on each of the major subsystems could have a large impact.

6. Overall technical coordination is essential and the Collaboration or the Laboratory should appoint a Project Manager and give him or her sufficient authority to act decisively. A management structure *is* in place within the collaboration, and some formalities such as MOUs, leadership assignments for subsystems, and a system of regular teleconferences do exist. Nevertheless the system is largely informal, and mechanisms for resolving or enforcing global or intersystem issues are essentially absent. A more robust structure with a clear Project Manager will be critical for progress beyond this point.

7. Several individual subsystems showed schedules and milestones, but a fully integrated plan remains rather sketchy at this point. One clear starting task for a Project Manager would be to establish the schedule and plan, with milestones and a well-identified critical path.

D.3 Overview of Subsystem Status

D.3.1 Photon Beam and Tagging Spectrometer

The design of the photon beam line and the tagging spectrometer aims at taking full advantage of the small emittance of the 12 GeV electron beam to create a tagged photon beam with a high degree of linear polarization between 8 and 9 GeV. The layout of the beamline elements, especially the arrangement of collimators and sweeping magnets, seems to be optimized to support that goal. The tagging spectrometer consists of two separate dipole magnets, thus facilitating construction and installation. A potential concern is the high flux of electrons with energies close to the endpoint interacting with the mechanical structure of the vacuum chamber or the dump pipe. Because of the shallow bend angle of the spectrometer, downstream spray could cause background in the tagging detectors. The segmentation of the detectors into a lower resolution but broad coverage hodoscope and a high resolution system covering the region of the coherent peak is a sensible solution. The choice of scintillating fibers read out by Silicon photomultipliers (SiPMs) is well matched to the high rate environment.

> *Recommendation:* Perform a Monte Carlo simulation of the tagging system with particular attention to background in the tagging counters caused by high-energy electrons.

D.3.2 Forward Calorimeter

The forward calorimeter design makes use of the availability of a large number of lead glass blocks which have seen prior service in the BNL E852 experiment. Segmentation, resolution, and rate capability are well matched to the GlueX requirements. A potential concern is the large electromagnetic background close to the central hole causing high rates and potential radiation damage in the lead glass elements.

> *Recommendation:* Evaluate the benefits of covering part of the central region of the calorimeter with higher granularity, rad-hard detectors, e.g. lead tungstate crystals.

D.3.3 Barrel Calorimeter

The barrel calorimeter consists of scintillating fibers embedded in a lead matrix. This technique has been used successfully in the KLOE detector, and the present design follows that example very closely. The group has made good progress in constructing a prototype. An open issue is the choice of the readout for the scintillating fibers in the high-field environment. The newly developed SiPMs (Silicon photomultipliers) are presently favored by the group. The committee is concerned that due to their small active area SiPMs are not well matched to the large area of scintillating fibers.

> *Recommendation:* Develop a good understanding of the light output budget of the calorimeter and evaluate the impact of different readout schemes on the energy and timing resolution of the calorimeter.

D.3.4 Start Counter

The function of the 40-element start counter was described as aiding the Level-1 trigger and the identification of the correct beam bucket in the final analysis. The committee was concerned that the benefits of using the start counter could easily be offset by negative aspects, like the start counter material (5mm of scintillator) causing multiple scattering and (occasional) particle conversion in front of the tracking system.

> *Recommendation:* Make sure that the start counter has an essential role for triggering or event analysis. If it does not, then remove it; if it does, then look into a substantial reduction of the scintillator thickness.

D.3.5 Upstream Photon Veto UPV

The upstream region from polar angles 135° to about 160° is covered by a lead-scintillator sandwich electromagnetic calorimeter to provide offline rejection of events where the target proton has been excited, for example to a Δ^+. Backward photons from π^0s in this case are soft (20 to 120 MeV) and as the current plan is only to veto such events the simple detector they have proposed is adequate. On the other hand, it is conceivable that actual measurement of the photon momentum vector would be useful for physics, in which case a more elaborate detector is called for.

> *Recommendation:* Study the physics impact of upgrading the UPV to provide real shower energy and position information.

There are also alternative technologies that could be considered. The scintillator paddles could be read out using embedded wavelength-shifting fibers, a technology that is now well established and enables one to put the photomultipliers clear of the magnetic field (and use smaller PMTs).

D.3.6 Time of Flight Counters

The time of flight TOF counters are x,y arrays of scintillation counter bars in the forward direction, used in the trigger and to identify charged pions, kaons and protons at lower momentum than the Cherenkov counter. The goal is 80 ps time resolution, which has been reached in tests. The Committee considers this to be a good design which is at an advanced stage of R&D, and it has no real concerns in this area.

D.3.7 Cherenkov Counter

The gas threshold Cherenkov counter, which was previously the default device for identifying hadrons with higher momenta than covered by the TOF, is not being actively worked on at the present time. An alternative technology, the DIRC Cherenkov ring imaging counter similar to that used in BaBar, is being considered. The DIRC is a powerful and compact approach to Cherenkov-based particle ID. The main components of the DIRC are synthetic quartz bars, a standoff tank containing water and an array of 1500 PMTs. There are groups from Oak Ridge National Laboratory and the University of Tennessee who are proposing to build this detector, and they bring with them valuable experience from BaBar.

The Committee notes that a DIRC detector would be technically challenging and demanding of manpower. If adopted as the choice for high momentum particle ID, it is likely to present considerable technical, cost, and schedule risk for the project. Simpler or more conventional alternatives do not appear to have been explored, at least not since the departure of members who had previously proposed building a threshold gas Cherenkov detector.

Recommendations:

1. Quantify the difference in physics capability of GlueX under various particle ID scenarios including: no Cherenkov device, a gas threshold Cherenkov, and a DIRC. If another technology could be competitive (for example a device exploiting K/π separation in the relativistic rise of dE/dx) include it.
2. Estimate the cost, timescale, and manpower requirements of each.
3. Investigate what kind of help might be available from SLAC for a DIRC project. This could include testing and evaluation equipment, spare bars, and consultation.
4. Identify collaborators who would build a non-DIRC particle ID system if the final decision goes against DIRC.
5. Based on the above, choose a particle ID technology prior to the CD1 review.

D.3.8 Central Drift Chamber

The primary goal for this system is to provide charged track reconstruction over the range of polar angle 10–150 deg. w.r.t. target center in z, with momentum resolution better than 4 % at all angles. In addition, particle identification (PID) information in the form of specific energy loss (dE/dx) measurements should be obtained with resolution $\sim$ 0.10 (dE/dx).

A straw-tube Drift Chamber, referred to as the Central Drift Chamber (CDC), has been chosen as the technology to be used to attain these goals. Straw tubes (actually aluminized mylar) of diameter 1.6 cm. are assembled in 23 layers (8 stereo at ±6°.) to form a cylindrical detector of length 1.7–2.0 m. to be mounted coaxial with the photon beam direction; the radial extent of the package is from 14 - 58 cm.

Simulation indicates that the required spatial resolution can be achieved, although the choice of gas mixture has yet to be optimized. A leak-proof feedthrough system has been designed, built and tested extensively, with excellent results. A full-scale prototype has been built, and wire-tension tests conducted. Pre-amps are being developed by Alberta and JLAB, and FADC's by Indiana and JLAB. HV, signal and structural tests will be performed in 2005. QC problems were encountered with the mylar straws, and the next prototype will make use of kapton (more expensive, but much more robust).

A concern with respect to the present design is that the first stereo layer does not occur until radius 24 cm. This means that charged tracks from the collision axis with transverse momentum (Pt) less than about 100 MeV/c cannot be reconstructed in the CDC. This seems like an unreasonably large loss. In addition, vertex resolution in z will be seriously impacted for tracks produced at small polar angle, and this in turn will make it difficult to clearly define event topology.

It is recommended at the very least that the first four layers of the CDC should provide stereo information; this would reduce the Pt limitation to about 60 MeV/c, and would provide first z information significantly closer to the production vertex. If the Start Counter is eliminated, the radial region down to about 6 cm becomes available to tracking, and it is recommended that the cylindrical tracking system be extended into this volume. This might be done by reducing the inner radius in the present design. However, if there were a need to incorporate a Start Counter at some future date (e.g. in the context of some specialized trigger), it might be better to introduce a separate vertex detector package which could then be removed without impact on the remainder of the CDC.

A further concern relates to the present thickness of the downstream end-plate (5 mm Al in the prototype). An effort should be made to reduce this material as much as possible. A reliable estimate of the impact on track and vertex resolution would benefit greatly from a detailed simulation involving coordinate generation, pattern recognition, track-fitting and event vertexing. The collaboration is moving to create such software, and is encouraged to give this effort high priority (see Section 3.11 below).

Charged tracks with Pt less than about 220 MeV/c cannot reach the Barrel Time-of- Flight (TOF) system. Such tracks which are either backward-going, or which stop or interact before reaching the Forward Drift Chambers and/or TOF system, rely on the CDC (or a kinematic fit) for PID information. It seems to be of high priority to demonstrate via the prototype that dE/dx information of the desired quality can in fact be obtained from the proposed straw-tube chamber design.

Recommendations:

1. Explore ways to obtain z information at the lowest radii possible in the CDC.
2. Explore ways to extend tracking into the volume presently occupied by the Start Counter.
3. Investigate designs that reduce the endplate material of the CDC as much as possible.
4. Study dE/dx resolution in prototypes soon to determine actual capability of the straw system.

D.3.9 Forward Drift Chamber

The primary goal for this system is to provide stand-alone charged track reconstruction for the region of polar angle less than 10° w.r.t. target center in z, and to contribute to joint CDC – FDC track reconstruction over the range of polar angle $10 - 30°$.

The present detector design proposes to achieve these goals by means of four packages of planar drift chambers spread over a 2 m range in z, beginning at the downstream end of the CDC. Each package consists of six individual chambers, each individual chamber being rotated by 60° about the z axis w.r.t. the preceding (i.e. further upstream) chamber. An individual chamber consists of an anode wire plane, for which the design is not yet final, sandwiched between two cathodes with strip readout at ±45° w.r.t. the anode wires. For a 5 mm anode-cathode separation and a 5 mm strip pitch, the cathodes should yield 150 μm resolution for avalanche position along an anode wire, and drift time-to-distance conversion should yield similar position accuracy in the direction transverse to the wire orientation. Fast Monte Carlo studies indicate that momentum resolution better than 1.5% should be possible throughout the range 0.5 - 4.0 GeV/c for FDC stand-alone track reconstruction. There is a proposal for the On- and Off-chamber electronics which incorporates the same preamp being developed for the CDC; the FADC clock speed has not yet been defined, since it may be possible to achieve significant cost savings by going to a lower clock speed. A serious prototyping effort is underway, and a well-considered Test Plan has been laid out. Future prototyping efforts aimed at addressing mechanical and electronics layout issues, gas system design, cathode measurement resolution, chamber failure modes, etc. are being planned in the context of a full-scale chamber.

Concern was expressed as to whether the resolution in the anode plane could be achieved in practice given the isochrone structure, Lorentz angle effects, etc. In this regard, has the Collaboration considered other possible technologies for the Forward Tracking System?

A second concern pertained to the possibility of obtaining dE/dx information from the proposed FDC system. Low Pt looping charged tracks may not yield sufficient PID information in the CDC, and may stop or interact before reaching the forward TOF counter. The possibility of supplementing the CDC information with dE/dx information from both the anode and cathode planes of the FDC system should be explored in the course of the prototyping efforts. In this regard, it might be worth noting that in the LASS experiment, useful dE/dx information was obtained from the cathode strip pulse heights from the cylindrical chambers, but nothing of use was obtained from the corresponding cathodes of the planar chambers. This was never understood, but it should be noted that the cylindrical chamber foils were mounted on hexcel cylinders (i.e. uniform anode-cathode spacing was maintained), whereas the planar chamber cathodes consisted of aluminized mylar which was susceptible to local wrinkling and sagging [aren't we all!]. In any prototyping effort concerning dE/dx, it might be worthwhile to investigate the possibility of using a rigid cathode in order to maintain more uniform anode-cathode gap size.

The present detector layout has equal spacing between the packages of the FDC system. Since low P_t, low P_z tracks loop rapidly in the strong field of the solenoid, it might prove better from the standpoint of pattern recognition and track reconstruction efficiency to have the second package quite close in z to the first, with the third and fourth packages spaced equally over the remaining total z range. As for the CDC, a detailed simulation package based on coordinate generation, and incorporating pattern recognition and track fitting would be invaluable for such a study (see Section 3.11 below).

Recommendations:

1. Explore the possible physics advantage and design implications of obtaining dE/dx information from the FDC.
2. Use a fully integrated GEANT based Monte Carlo with pattern recognition to optimize the spacing of the FDC planes.
3. Demonstrate that the isochrones of the present design provide adequate spatial resolution, or consider design modifications to improve

drift properties.

D.3.10 Particle ID

The experiment relies on a diverse set of particle identification schemes, which include dE/dx in the straw tubes, time-of-flight in the BCAL and the downstream TOF wall. The choice of downstream PID for high momentum tracks remains uncertain though the Committee was shown rudimentary concepts for a DIRC detector. We discuss the key subsystems below.

1. dE/dx: In the present detector design, the CDC is the only source of dE/dx information. As discussed previously it is important to demonstrate by means of the prototype that dE/dx information of the required quality can be obtained, and also to explore the desirability of obtaining dE/dx information from the FDC system. This possibility should be investigated in the context of the ongoing prototyping effort.

2. TOF: Information on charged particle velocity is obtained from the Barrel Calorimeter, and also from the forward TOF wall located just upstream of the Forward Calorimeter.

   The Barrel Calorimeter is very similar in design to that used in the KLOE detector, and so it is reasonable to expect that time resolution of 250 psec or better can be achieved. However, until the readout scheme has been finalized and prototype measurements carried out, the actual time resolution which can be obtained must be considered somewhat uncertain.

   The forward TOF counter should be capable of achieving the desired time resolution (see Section 3.6). Systematic timing shifts which can result from hadronic interactions in the scintillator material should probably be investigated. Such interactions can yield large pulse height signals which result in an under- estimation of the time-walk correction.

3. Calorimetry: Electron identification, and photon detection and measurement, in the Barrel and Forward Calorimeters should be satisfactory for the proposed devices, although there is some concern about the impact of the readout scheme being considered for the Barrel Calorimeter (see Section 3.3).

   The possibility of neutron and K_L detection should be considered, especially for the Barrel. For example, for events for which the kinematics yield a missing mass consistent with a neutron or K_L, a corroborating calorimeter cluster might be used to enhance signal-to-background at the expense of some loss in efficiency.

4. Cherenkov Counter: This is discussed in Section 3.7. The impact of the absence of such information should be investigated (e.g. in the context of kinematic fits to events in which all low momentum charged tracks are identified and any photons are detected), as should the effect of having the simpler threshold device instead of a DIRC. Again, such studies would be performed best in the context of a full detector simulation and track reconstruction program, as discussed in Sections 3.8 and 3.9.

D.3.11 Software

The brief overview presented indicates that the proposed software structure is well-conceived, and that the framework appears to incorporate those aspects of data-flow and data-management which will be essential to the handling of the very large data samples which the experiment is designed to produce. Code management and documentation schemes are being evaluated, and there is a significant ongoing effort to develop the complicated Partial Wave Analysis programs and procedures which are crucial to the success of the experiment.

A fast-simulation procedure exists, and work has begun on a more-detailed simulation at the coordinate generation and Calorimeter/TOF response level. As discussed already, it is the feeling of the review committee that this latter effort should be given very high priority, in particular with a view to the development of pattern-recognition and track- and vertex- reconstruction software, and the incorporation of Kalman fitting. As indicated in Section 2.1, this will be extremely important to the detailed design of the individual detector systems, and to an understanding of their impact on one another and upon the data quality which can be achieved under differing background conditions.

It is recommended that the collaboration consider a change from GEANT3 to GEANT4. The time scale for GlueX is rather long, and GEANT3 is already falling out of favor; in ten years there will likely be no support for it at all. In addition, as time moves on, it will become harder and harder to find young physicists willing or able to work in FORTRAN, which further argues for early migration to GEANT4. In any case, it might be of value to initiate discussions with e.g. Dennis Wright of SLAC (the BaBar expert on GEANT4) in order to evaluate the merits of such a transition. Similarly, the BaBar expert on the Kalman filter is Dave Brown of LBL, and he could prove to be a very useful resource with regard to GlueX software developments in this area. Ray Cowan of M.I.T. (but based at SLAC) is the BaBar Webmaster, and he could be of help to the expanding GlueX documentation and code management effort.

Recommendation: Evaluate merits of transitioning to GEANT4.

D.3.12 DAQ and Electronics

Although not requested to review DAQ and electronics, we note that design developments since the July 2004 electronics review have ameliorated or eclipsed some of the issues pointed out in that review. Notably, the vertex detector has vanished, removing all concerns about VLPCs; and the original plan to seek single TDC and FADC designs to serve all detector systems no longer appears optimal. With the addition of the Alberta group available manpower has grown, but still needs to grow more. Detector subsystems need to specify front-end electronics prior to the "Lehman Review".

D.3.13 Integration and Milestones

Plans for civil construction of Hall D and provision of power, infrastructure, and utilities are in development. Although the choice of Cherenkov PID is still very much undecided, Hall D plans show the old gas Cherenkov device, which requires the rest of GlueX to stand on a platform. This concept may not be optimal if a more compact PID detector such as DIRC is ultimately selected. Strategies for detector installation, particularly for the installation and mounting of the massive BCAL, are in a conceptual stage but moving forward with appropriate engineering work. The need for interface documents specifying electronics paths was explicitly called out by the Collaboration, and is supported by this Committee.

Schedules and milestones are sketchy. This is true both for individual subsystems, where schedules and tables of milestones, if shown, were limited in depth, and it is true of the overall detector integration. The schedules seen by the Committee lack adequate detail to be used as effective management tools, *i.e.*, to be used prescriptively rather than merely descriptively, and it is not clear that critical paths can be accurately identified with existing information. In preparation for a "Lehman Review" the Collaboration and the Laboratory will have to evolve to a WBS-driven system, with managers in place at each level and a clear reporting structure.

Manpower levels throughout the Collaboration are minimal, as noted in the global overview at the front of this document, and this appears also to be true in the Laboratory-based staffing. A concept for Hall-D staff increase was shown but any underlying plan to achieve or approach that concept will be very funding-dependent and was outside the domain of discussion at this review. Nevertheless, Laboratory manpower for the GlueX project is important and will soon become critical. The Hall-D Coordinator position, which would be the same as the Project Manager position discussed above, is not yet officially filled.

Recommendations:

1. The Laboratory should move rapidly to confirm the Hall-D Coordinator and ensure the Coordinator is invested with broad authority and provided with sufficient supporting manpower to act decisively in all aspects of GlueX development, construction, integration, and commissioning.
2. The Hall-D Coordinator, when formalized, should bring standard management tools such as WBS organization fully into play and use these to drive the progress of the project.

Appendix A: Charge to Review Committee.

The scope of this review is to include the GlueX detector and the coherent bremmstrahlung/tagger system. It does not include the magnet, beamline, or civil systems. Nor does it include electronics or data acquisition per se (which were covered in a review held last year) except to the extent that this committee feels important for this review.

You are asked to address the following questions:

- Is the GlueX detector design sound? Are there any special areas of concern that deserve special study?
- Does the collaboration have a sensible plan for management and are their estimates of manpower needs realistic? Also, does the collaboration have realistic milestones as they prepare for the CD-1 Lehman review and beyond to construction?
- Are there design studies and/or prototyping efforts that, if undertaken in a timely manner, could strengthen the estimates of performance and cost of the planned experiment? Are each of the studies currently in progress given the appropriate priority at this stage?
- Does the collaboration have a plausible plan for assembly and maintenance of the detector? Is the collaboration properly addressing issues of subsystem integration?
- Are there technologies or developments which we have overlooked that may allow cost savings and/or improved technical performance?