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Report of the GEM Review Panel

SSC Laboratory

May 24-29, 1993

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SUMMARY

Introduction

A panel composed of members of the PAC and other experts met at the SSC Laboratory from May 24 to 29, 1993 to begin Phase I of the Review of the Gamma-Electron-Muon Collaboration's (GEM's) proposed detector project. The Phase I Review is to be completed during the scheduled PAC meeting, from July 31 to August 6, 1993. The panel studied the Technical Design Report (TDR) and associated documents and heard presentations by members of the Collaboration on the physics goals, the design, construction, and expected performance of the key elements of the detector, as well as the management, cost, and schedule of the project. A list of panel members and the organization and agenda of the week-long review are given in Appendix J.

The detailed reports prepared by the subpanels on detector subsystems and global issues are attached as Appendices A through I. The subpanel reports also outline some concerns and questions that should be addressed by the Collaboration. Appendix K contains the report of the PRD ES&H Subcommittee that recently reviewed the Safety Analysis Report of the GEM detector.

In the following sections, the main conclusions drawn from the subpanel reports and from the deliberations of the panel as a whole are summarized.

General Comments

The panel was very impressed by the design of the GEM detector and by the high quality of the GEM Technical Design Report. The panel was also impressed with the progress that the Collaboration is making towards building a powerful detector. Difficult choices of technologies for the various subsystems have been made. It is the panel's consensus that the design of the detector described in the TDR is well matched to the physics potential of the SSC, including operation at higher than design luminosity.

The stretch-out of the SSC schedule will allow time for the necessary R&D and prototyping of the detector subsystems.

The panel acknowledges the efforts by the Collaboration to constrain the overall costs of the project, but is seriously concerned that the resources which can presently be identified do not match the estimated costs.

Scientific and Technical Issues

Comments and major concerns with regard to the various detector subsystems and their expected performance are given below. More detailed discussions and a list of questions and concerns are presented in the summary reports by the various subpanels.

Physics Capabilities

The panel's general impression of the physics capabilities of the detector described in the GEM Technical Design Report is very positive. In global terms, the GEM detector is well conceived for supercollider physics.

The simulation effort carried out in support of the Technical Design Report is very impressive. It represents a great amount of good work and has brought together an enthusiastic and competent group to think about the physics GEM will study. However, the role of the physics and detector simulations in the overall optimization of the GEM detector was not made visible in the TDR or in the presentations to the PAC. Closer links between the GEM physics group and hardware groups will strengthen the physics basis for refinements to the detector design.

The GEM group has made significant contributions to the study of the radiation environment of the detector, specifically the bath of neutrons and photons in the collision hall. The work reported to the panel is significant and coherent. It should provide the tools necessary to devise an optimal solution for neutron shielding.

Superconducting Magnet

The choice of a superconducting solenoid with a large diameter leads to a large magnetic volume in air which is well suited to high-precision, stand-alone muon measurement. The solenoid design is based on the use of an innovative type of conductor that has not yet been employed on existing magnets. This conductor offers the advantage of a very high stability margin. However, the design raises some questions as to the mechanism of quench protection. Although substantial analyses of the quench process have been carried out by the design team, with results that appear to be satisfactory, the panel is concerned about the full validity of the GEM modeling and recommends further theoretical and experimental confirmation.

- Theoretical studies of the quench behavior should be performed by an independent group.
- The test coil program should be more specifically oriented towards the quench validation issue. Experienced teams from the SSC Magnet Division might participate in the definition of specific measurements and in the data analysis.
- Early industrial development of the conductor, up to a full unit length prototype, is mandatory to demonstrate the feasibility of the design.

- For ultimate guarantee of safe and reliable operation of the magnet, a full cryogenic test of the first coil module would be desirable. Such a test, if performed with the coil in the vertical position, would also permit tests of the mechanical stability of the coil under thermal cycling. An analysis of the cost and schedule implications of this additional test is suggested.
- Given the requirement for early installation of the magnet in the collider hall and the tight schedule, the involvement of industry in the final design, with the choice of the prime contractor, should be initiated as soon as possible. The timely availability of the south assembly building should be assured.

Tracking System

The overall system design is well-advanced. The tracking group has demonstrated good progress in the design and basic R&D (long silicon strips, IPC operating conditions), as well as the electronics and simulation. The panel advises that the following issue be addressed:

- The Collaboration has not yet demonstrated that the GEM tracking system can achieve all of its goals. It would be desirable to show pattern recognition capabilities based on detailed simulations of the combined tracking system. These studies should address the overall track reconstruction as well as specific physics processes.

The R&D and prototyping program, which is essential to complete before construction can start, will require detailed planning and increased funding resources. The full-scale test of the tracking system in the Fermilab beam in 1995 will be a crucial milestone towards the successful completion of the GEM tracking system.

Calorimeters

Overall, the panel is impressed by the high quality of the proposed calorimeter system, and is pleased with the substantial progress that has been made since the presentation of the LoI. In general, the panel agrees with the choices made and performance goals set by the proponents, and has not identified any major flaw in the proposed design.

The main concern is an extensive R&D program that incorporates full-scale prototyping needed to identify problems as early as possible and to ascertain the Collaboration's ability to build the calorimeter as proposed. This task will require a strengthening of the staff.

- The Collaboration should thoroughly plan and launch an extensive R&D and full-scale prototyping program.
- An early system test of the noble liquid calorimeter modules, in as near a final version as possible, with heavy irradiation should be carried out with the aim of

detecting potential deterioration of performance due to radiation damage and impurities.

Muon System

A convincing case has been made for the feasibility of a high resolution muon system using detectors located in the relatively low radiation environment outside the calorimeter. This system will be capable of operating at higher machine luminosities, or under adverse background conditions at the design luminosity. Though substantial progress has been made on the design of the muon system, the panel has the following concerns:

- The choice of the large number of azimuthal (ϕ) modules needs to be substantiated by a quantitative cost/benefit analysis.
- The issue of short-turn-around access to the detector should be critically re-examined.
- To ensure the best performance and to minimize cost it is important to proceed expeditiously with construction and testing of a full-scale pre-production prototype, together with the associated tooling. Since the proposed resolution is very challenging it would be desirable to test a full azimuthal sector of the muon system on the Fermilab test beam.
- The loss in geometrical efficiency should be reviewed. It may be possible to recoup some of this loss without jeopardizing other aspects of the system.

Electronics, Data Acquisition, and Triggers

The panel is impressed with the quality of the work and the material that has been presented by the GEM Collaboration. The panel finds nothing at this stage of R&D that would prevent the eventual achievement of the stated performance goals. The principal concern is the successful operation of 1.5M precision analog electronics channels embedded in a 60 MHz digital environment.

- The R&D effort should be directed towards major integrated systems tests during the 1995 beam test.

Detector Installation and Access

The GEM Technical Design Report outlines installation plans for the detector in the underground collider hall. The schedule as presented in the TDR is extremely tight. The presently envisaged stretch-out schedule could be of great benefit to the Collaboration and may permit greater flexibility in the installation plan to meet future contingencies.

- The GEM Collaboration should undertake feasibility studies that address alternate sequences of installation in the underground collider hall and give a report at the August PAC meeting.

The ability to access critical elements of the GEM detector is severely limited. The present plan for accessing the detector for maintenance and repairs seems inadequate. The plan presented in the TDR involves cutting the services to the magnet coils and displacing coils along the beam line. The panel feels that movement of the largest elements of the detector is questionable and should be adopted only as a last resort.

- The Collaboration should explore alternatives to the existing access plan, in particular an option based on keeping the magnet in place. A detailed report is requested at the August PAC meeting.

ES&H

Although the process for implementing ES&H procedures is in an early stage and much needs to be done, the panel judges that the proposed organizational structure for carrying this out is well conceived. An overall safety plan for the experiment will be reviewed by the PRD ES&H Subcommittee in July. The results of this review should be transmitted to the PAC at the August meeting.

Issues of Cost, Schedule, Management, and Resources

Cost

The GEM cost estimate is credible for a project at this stage. The Collaboration has done a fine job in establishing the machinery for cost analysis and tracking. If the concerns expressed below are addressed, the GEM cost estimate will be well prepared for the DOE review in October.

- There is a need to establish a uniform cost estimating methodology across all systems.
- More consistency checks are needed both across systems and between system levels.
- More time and money are needed, for R&D on all systems. This requires relatively little additional expenditure but is crucial for the success of the project.

Schedule

The GEM schedule, aimed at completion in 1999, does not allow for the necessary R&D and prototype work to be completed prior to the beginning of construction. The times allotted for construction and installation are also extremely tight.

The Collaboration is advised to realistically assess the personnel needs and to minimize the cost increase for the stretched-out project. The panel advises the Laboratory to include the legitimate needs of the GEM detector in its budget and schedule plans for the coming years.

Organization, Management, and Resources

The GEM Collaboration consists of over 1000 members associated with 114 institutions in 17 countries. The intellectual, technical, and material contributions of the non-U.S. collaborators constitute an important component of the Collaboration. Judging by the quality of the Technical Design Report, the organization established to direct R&D and conceptual design has worked well.

The Collaboration is beginning to make the organizational changes required for the construction phase. All subsystem managers should be identified in the coming months and each subsystem manager should appoint a coordinator for the R&D program. The spokespersons and the project manager need to establish the matrix of responsibilities and the allocation of resources for the whole project. The panel is concerned that the scientific manpower available for some of the subsystems is inadequate. In particular, the tracking and calorimeter groups should be reinforced.

The Collaboration described the status of the GEM funding plan. Of the estimated total cost of $500M (1990 dollars), $275M will be provided from SSC project funds. The proponents have identified approximately $100M from other sources. Since the presently identified funds do not cover the cost of the detector, staging of detector components must be considered.

- The Collaboration is asked to investigate further staging scenarios and to present studies of the physics tradeoffs at the August PAC meeting.

APPENDIX A
SUPERCONDUCTING SOLENOID

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Introduction

The GEM solenoid is by far the largest magnet ever built and requires exceptional engineering and construction capabilities. The conceptual design has been carried out by a large team of highly competent groups from SSCL, MIT, LLNL, and ORNL-Y12. Design studies have been extensively developed in all areas of magnet construction, installation and operation. The team works within a well coordinated organization under efficient management. Specific developments are in progress and the project should soon be transferred to industry for detailed construction design.

The general design has been guided by physics requirements and by the need for overall optimization of the GEM detector layout and installation. Two options taken by GEM have noticeable consequences:

- The unshielded solenoid will produce a large and extended stray field, impacting the physical environment and requiring stringent safety measures.
- The split of the solenoid into two independent halves leads to a complicated mechanical structure necessary to transfer the 6400-ton axial magnetic load through the entire vacuum vessel at room temperature. Furthermore, making the two halves movable for access to the inner detector is an unusual requirement and creates added difficulties. Disconnecting and moving a magnet the size of a 7-story building is a considerable and hazardous operation which should only be envisaged as an extreme necessity.

The design is based on the use of a new type of conductor consisting of a cable-in-conduit clad in an external aluminum protective sheath. This conductor offers the advantage of a very large stability margin, which makes it tolerant of coil manufacturing flaws and does not require a fully bonded structure to guarantee stability. While releasing constraints on the mechanical integrity of the winding, this conductor raises additional complexity in other areas such as the cryogenics, the joints between coil modules and the high-current electrical circuitry, which all require the highest quality to guarantee full reliability. These problems have been consistently addressed by the design team and the overall feasibility is properly assessed in general.

The new feature of the conductor is the separation of the two crucial functions of stability and quench protection provided by the inner helium-immersed cable and by the external sheath, respectively. According to this scheme, the quench protection relies on a complex electrical and heat transfer mechanism which must function safely under any conceivable circumstance. Although substantial analyses of the quench process have been carried out by the design team, displaying satisfactory results, the panel was not able to evaluate the full validity of the analytical approach and was concerned about the lack of experimental validation relevant to the GEM conductor.

Such validation is expected to come in early 1994 from experimentation with a test coil at the University of Wisconsin. In view of the importance of the protection issue, the panel recommends that every effort be made to enable these tests, by means of adequate instrumentation and analysis, to provide complete and accurate data on the quench behavior of the conductor.

Furthermore, as the test coil is not fully representative of the actual solenoid, due to the shorter length of conductor (80 m. compared to 1140 m. in the coil module), the panel also suggests that a full cryogenic and electrical test of the first module be considered as the ultimate test. Such a test, though expensive, would be useful in any case as an overall verification of the operational reliability.

Conductor and Joints

Different manufacturing options for the proposed conductor are still being evaluated. Short dummy samples have been produced in the laboratory but no industrial development has been undertaken as yet. Such development may encounter unforeseen delays and should be initiated immediately. A full length prototype of 1140 m is necessary to demonstrate the industrial feasibility before series production can be pursued. A well specified quality assurance plan has to be implemented for the whole production.

An elaborate scheme for the fabrication of the conductor terminations is being developed. They include the electrically insulated inlets and outlets for the individual helium flow circuits. The terminations are planned to be assembled at both ends of each conductor segment at the factory and the complete segment is to be leak tested before delivery. However, if the length of the segments cannot be known precisely before the winding, one of the terminations may have to be left out and assembled *in situ* after the winding.

Coil Design

Each half-solenoid is made of 12 modules held together with bolted flanges. Each module contains 19 turns laid as a single layer inside a support shell or "bobbin" according to a classical inner winding method. The main departures from existing solenoids are the absence of resin impregnation of the windings in the bobbin and the hybrid cooling system combining indirect cooling and slow forced-flow cooling in the conductor.

Due to the lack of impregnation, the turns are not bonded together nor to the bobbin. This has two consequences:

The refrigeration power is distributed in two different types of cooling circuits: a two-phase thermosyphon-driven cooling system attached to the bobbins for cooling the entire cold mass, and a supercritical helium distributed flow for conductor stabilization and for cooling of the joints and of the current leads. The circuits are activated, with automatic process control, along different configurations according to the various operating sequences: cool down, steady state, quench, recovery, power failure, standby. The overall scheme is comprehensive at this stage of the conceptual design.

A few points were raised by the panel:

- The thermosyphon loop is different from existing systems by having the storage dewar at the surface, 50 m above the magnet. Due to the hydrostatic pressure of the column of helium above the magnet, the boiling temperature of helium will rise by 75°C. The helium vaporization, which drives the flow in the loop, can only occur in the upper part of the return leg instead of taking place in the parallel pipes attached to the bobbins where the heat is produced. A possible consequence of this feature is that the flow in each of these individual pipes or in a group of pipes is not self-regulated with regard to local heat inputs which may differ from one place to another. This effect might cause local instabilities or temperature variations and needs to be analyzed more precisely. A remedy would be to locate the small dewar below ground just above the magnet.
- The supercritical helium loop on each half-solenoid has to feed 24 circuits in parallel without individual flow controls. The question is whether the flow will distribute evenly and according to the required ratings. Analyses of this problem have not been shown.
- Valves intended for isolating the magnet when it has to be moved are shown to be hand actuated. Measures must be taken to ensure that these valves are correctly positioned when the magnet is operating.

Power/Protection/Controls

Due to lack of time, these items were not discussed. They mainly concern conventional equipment and appear to be well handled by an experienced team.

Two comments:

- The charge/discharge time of 8 hours could be easily reduced to 2 hours as far as the ramping losses are concerned. This would only require the output voltage of the power supply to be increased by 7 V. Also it could be useful to provide a dump of intermediate duration (between 5 minutes and 8 hours) since the 5-minute fast dump is liable to induce a quench.

- The dump protection switches are featured as solid state devices. Though the team is fully confident about this type of active device, additional assurance and repetitive tests are recommended to ensure their reliability, since failure of the switching action would be catastrophic.

Cost And Schedule

The magnet cost estimate was reviewed by a different subpanel (see Appendix H). It was judged to be adequate. The general schedule was presented briefly and needs a more detailed review. The general impression is that it is extremely tight in all areas and that contingencies for delays should be incorporated.

APPENDIX B
TRACKING SYSTEM

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Introduction

The GEM tracking system performs in a solenoidal magnetic field of 0.8 T and within a compact volume corresponding to a cylinder of 90-cm radius and 350-cm total length. The design goals described in the TDR require the tracking system, first, to support the primary objectives of GEM (detection of photons, electrons and muons at high p_t) up to luminosities of 10^{34} cm^{-2} s^{-1}, and, second, to reconstruct secondary vertices, low momentum tracks, and even complete events at design luminosity, in order to maximize the detector's potential, e.g., in terms of B-physics and top quark physics.

The baseline tracking detector consists of two components:

- an inner silicon microstrip detector of 200-cm length and extending in radius from 10 cm to 35 cm, which provides 6 "pseudo"-space points per track, with resolutions of 15 µm (r-ϕ) and 3 mm (r-z).
- a system of interpolating pad chambers (IPC) which provides 4 additional "pseudo"-space points per track, with resolutions of 50 µm (r-ϕ) and 0.7 mm (r-z).

With this tracker system, high-p_t tracks can be reconstructed over a pseudo-rapidity range of $|\eta| < 2.5$.

In general, the subpanel was impressed by the amount and quality of work performed by the GEM tracking group in preparation for the TDR, and is convinced that the proposed tracker can be built.

In the following, the subpanel successively comments on the various aspects of the proposed GEM tracking system: silicon detectors, IPC detectors, mechanics and cooling, front-end electronics (see also Appendix E), and overall performance. Some questions are raised which can hopefully be answered in time for the August PAC Meeting.

Both the subpanel and the proponents feel that the schedule described in the GEM TDR is extremely tight and leaves little room for the necessary R&D and prototyping work, which is crucial to the successful construction of the GEM tracking system. The probable stretch-out of the SSC schedule will help to alleviate this problem.

Comments

Silicon Detectors

The use of single-sided silicon microstrip detectors is a realistic approach in view of the present uncertainties and higher costs of alternative techniques. The choice of 18-cm-long microstrips leads to a simple and elegant mechanical design with electronics and cooling materials separated as much as possible from the detector elements. This design presents some risk due to the high capacitive load on the preamplifier, which results in a marginal signal to noise ratio. The choice of a binary readout is appropriate. It imposes a threshold-to-noise ratio of at least 4, which is hard to achieve with present electronics. We note, however, that the proponents are vigorously performing R&D to improve the noise performance.

If the performance of the 18-cm-long microstrips with their associated front-end electronics remains inadequate, the proponents would probably have to fall back on their original design with 12-cm-long microstrips, which would result in a larger number of channels, a major redesign of the mechanics with increased material thicknesses, and higher cost.

IPC Detectors

The proposed technique is in itself straightforward, consisting of 2-m-long planar chambers containing about 1000 wires of 25-cm length. It remains to be shown, however, that modules of this size will perform with the required resolution and reliability in the SSC environment.

In particular, the design goal of 50-μm resolution, obtained from precise analog measurements of the charge induced on the 2.5-mm-pitch cathode strips, is quite ambitious and requires careful evaluation with full size prototypes, near to final electronics, and realistic SSC-like conditions (magnetic field, occupancy, high rate operation, aging, sensitivity to neutrons...). Most of these studies are now under way and encouraging results from a prototype have been obtained very recently.

Although the design parameters of the IPC detectors have been studied quite thoroughly and are now well defined, several technical questions remain to be answered:

- which gas will be used in the volume of the outer support structure (CO_2-CF_4 or pure CO_2)?
- what fraction of a given chamber will be lost if a wire breaks?
- how will the chamber system be screened from electromagnetic noise originating from other GEM detector subsystems and from the large digital clock pulses of nearby analog front-end electronics?

Finally, given the group's limited experience in building large numbers of chambers of this type, a careful prototype program has to be developed, which should lead to the final design of the necessary production and assembly lines. The Collaboration intends to build the barrel IPCs at Yale and the forward IPCs at the SSC Laboratory.

Mechanics and Cooling

Considerable effort has gone into the mechanical design of the GEM tracking system, using state-of-the-art structural materials, such as the carbon-fiber/metal matrix space support frames for the silicon detector and the carbon-fiber/cyanide-ester-resin composites for the outer support structure. Although very extensive finite element analysis calculations and material property studies have been carried out, the subpanel recommends that these calculations be complemented by extensive and realistic size prototyping. Such studies are particularly needed for the thermally conductive adhesives and the long-term stability of the more exotic materials.

The silicon detector will operate at $0^{o}C$ (or less) and the heat from the electronics will be carried away through an evaporative butane cooling system. This system follows the design chosen for the SDC silicon detector and minimizes the material in the tracking volume, but it presents some safety and technical risks. Fluid cooling is being considered as a back-up option and should be pursued in parallel until the butane cooling system has been demonstrated to operate reliably and safely.

The IPC chamber design is less advanced, particularly in terms of wiring, testing, and assembly procedures. However, the subpanel does not foresee any fundamental problems in this area.

The outer shell structure is well designed and the proponents have made a thorough study of the assembly procedure prior to installation into the GEM detector and of the actual installation and alignment procedure inside the GEM detector. Some preliminary calibration studies have also been performed.

Given the complexity of the inner tracking system and the limited space available for connections, a mock-up of the cabling and services with their routing seems necessary to establish the whole assembly and installation procedure.

The main reason for concern is the access to the inner detector. Because of its location, this system will inevitably have the most difficult and most time-consuming access, thus dictating a design of high modularity and ultimate reliability.

The proponents intend to construct complete spare modules with electronics, ready to be inserted into the tracking system in case of breakdowns. The procedure for such operations needs to be worked out and, if at all possible, the time to access, repair and reinstall elements of the tracking system should be substantially decreased.

Electronics

The Collaboration proposes to build, assemble, and test the silicon ladders in industry. In particular, it is intended to replace wire bonding by a different substrate interconnection (e.g. tab bonding), which should also be compatible with inter-chip connections on a ceramic multi-chip module (MCM). This relatively new approach may lead to a more reliable detector unit but obviously requires very close collaboration with the manufacturers. Furthermore, the need to produce at least one fully equipped and tested ladder before going into production implies a vigorous and appropriately funded R&D effort.

The IPC performance depends crucially on the quality of the front-end analog electronics. The first prototype of the radiation hard preamp/shaper VLSI chip, which has to operate with low noise and large dynamic range, displayed a very high power consumption of 80 mW/channel. This would lead to a total power dissipation of 100 kW for the IPC detector, clearly an unacceptably high figure imposing a major strain on the cooling system.

The electronics beyond the front-end preamplifier and shaper are discussed more extensively by the electronics subpanel (see Appendix E).

Performance of the Tracking System

The subpanel encourages the GEM tracking group to evaluate in more detail the performance of the proposed tracking detector, which could greatly enhance the GEM physics capabilities. Such studies should address the issues of overall track reconstruction and electron identification, but also the contribution of the tracking system to specific physics processes for which it is expected to play an essential role. It is felt that the GEM Collaboration has not yet demonstrated that the tracking system can meet its physics goals and the subpanel suggests that the Collaboration report on the following topics at the August PAC meeting:

- realistic pattern recognition performance as a function of luminosity and the number of remaining silicon layers at high luminosity, and in particular, fake track rates as a function of the track p_t threshold. These studies should, wherever possible, display the sensitivity of the tracker performance to the individual detector resolutions and efficiencies.
- implication of these results for specific physics processes where the tracking system is expected to play a major role, such as electron/photon separation, τ-physics, and B-physics.

Summary and Conclusions

In summary, the subpanel recommends that:

1) the GEM tracker group study in detail how to benefit from the stretched-out schedule. This entails intensified prototyping with adequate funding in the coming years, in order to achieve the ambitious goal of a full-scale tracking prototype in the Fermilab test beam in 1995. This also entails careful organization of the necessary development work, in particular for the large number of custom integrated electronics circuits, and the construction and assembly of a full silicon ladder and a

complete IPC detector module.

2) the overall tracker performance be studied in more detail and based on firmer grounds, especially in terms of pattern recognition and on the basis of physics topics for which charged particle tracking is expected to play a major role. These include electron/photon separation, τ-physics, and B-physics.

APPENDIX C
CALORIMETER SYSTEMS

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Overview

The Calorimeter Subpanel heard a number of detailed presentations by members of the GEM Collaboration, which addressed physics requirements, design considerations, technical designs, simulation results, R&D results, assembly and installation, and issues of schedule and organization. The subpanel wishes to express its gratitude to the proponents for their help and cooperation at all stages of the review.

Overall, the subpanel was impressed by the high quality of the proposed calorimeters, and was pleased with the substantial progress that has been made since the presentation of the LoI. This concerns in particular the choice of a high-performance noble liquid calorimeter, and the improvements of the photon pointing in the electromagnetic calorimeter.

The chosen electromagnetic calorimeter is an "accordion" calorimeter, with lead as absorber and liquid krypton (in the endcap: liquid argon) as active medium. The hadronic calorimeter also has lead as the main absorber and liquid krypton (in the endcap: liquid argon) as active medium. It employs a conventional tower geometry. A tail catcher made of copper plates sandwiched with plastic scintillator tiles completes the barrel hadronic calorimetry. The forward calorimetry consists of a copper/liquid argon calorimeter, followed by a tungsten/liquid scintillator section, both designed to withstand very high radiation doses.

In general, the subpanel agrees with the choices made by the proponents, and has not identified any major flaw in the proposed design.

The proposed calorimetry is considered the highlight of the GEM detector, and is well suited to identify and measure photons, electrons, jets, and $\not{E}_T$. It is complementary to the SDC calorimetry in its design goals as well as in its technical realization. Also, the design permits operation with good performance at higher than design luminosity.

At the same time, however, the subpanel notes that the proposed calorimetry is very ambitious and is likely to stretch the abilities and resources of the proponents to their maximum.

The main concern of the subpanel is the need for a vigorous R&D and full-scale prototyping program, carried out with the support of a sufficiently large, competent, and well organized staff, with a view to identifying design flaws as early as possible and to demonstrating the ability to build the proposed system within budget and on schedule.

The first main recommendation of the subpanel is for the Collaboration to work out and launch this extensive R&D and full-scale prototyping program. A coordinator of high level of authority should be appointed for this effort. A commitment to a firm schedule should have high priority.

The second main recommendation is the performance of a system test with heavy irradiation of the noble liquid calorimeter modules, in as final a version as possible, so as to detect damage due to radiation and poisoning of the noble liquids as early as possible.

Performance of the Proposed Calorimeter System

The chosen transverse and longitudinal segmentation of the electromagnetic calorimeters is supported by the subpanel. The idea of measuring η with strips is appreciated: while photon pointing is adequate, the π^0 rejection is only slightly degraded with respect to measuring both η and ϕ with strips, a disadvantage which is compensated by the excellent energy resolution of the calorimeter for the $H \to \gamma\gamma$ search.

It has been demonstrated that an energy resolution in the $6\%/\sqrt{(E)}$ range is realistic for liquid krypton, rendering the ambitious goal of a constant term of 0.4% very desirable in order to match the good stochastic term.

The transverse segmentation of the noble liquid hadronic calorimeter is essentially dictated by noise considerations, and in the subpanel's view it is more than adequate from the point of view of jet mass reconstruction.

The requirements for the scintillator tile calorimeter are not demanding since it serves as tail catcher only, with the purpose of eliminating events with large $\not{E}_T$.

The depth of the calorimetry is not dictated by considerations of calorimetric resolution but rather by the need to absorb the hadronic debris before it enters the muon spectrometer. In the subpanel's view, the chosen thickness is more than adequate.

Technical Design

The "accordion" geometry is on the verge of becoming a proven technique, and the proposed design meets with the subpanel's approval. Perhaps the only disturbing feature is the lack of ϕ-symmetry in the electromagnetic endcap, and some vertical discontinuities in the energy resolution, caused by borders between modules. However, the subpanel agrees that there is no good reason why these effects should be detrimental to the performance.

Even if liquid krypton cannot be procured in sufficient quantity, the calorimeter filled with liquid argon would still be competitive. The first hadronic section would then become a *de facto* part of the electromagnetic calorimeter.

The design of the noble liquid hadronic calorimeter is conventional, and so is the design of the scintillator calorimeter. As for the latter, the subpanel is not convinced that the proponents adopted the best compromise between the relative complexity of the light readout of the scintillator tiles on the one hand, and the benefits of redundancy in the phototube readout on the other hand. In this area, a better compromise might even lead to cost savings.

A distinct feature is the location of the forward calorimeter relatively close to the vertex. This design helps to alleviate the problem of neutron background for the muon spectrometer, while the neutron background in the inner tracking cavern remains acceptable.

As for the forward calorimetry, the subpanel is concerned about the use of liquid scintillator because of its corrosive nature, especially in an environment which is expected to be highly radioactive and to have limited access.

Acceptance, Hermeticity, and Dead Zones

The choice of an "accordion" for the electromagnetic calorimeter ensures perfect hermeticity for electromagnetic showers, in the barrel and in the endcap region. The subpanel notes that great care has been invested in the design of the hadronic calorimeter to achieve a nearly hermetic calorimeter with a minimum of dead zones. The acceptance is as large as can be reasonably made.

Calibration and Monitoring

The procedures for calibration of the electromagnetic calorimeter rely on a novel method of charge injection which permits better accuracy than has been achieved before. The absolute calibration of the electromagnetic calorimeter as well as its monitoring will rely on test beam results and Z^0 events. This should not present a major problem.

The absolute calibration of the hadronic calorimeter also rests on charge injection but it is coupled with the necessity of test beam calibration, properly tuned simulation of the response of single hadrons and hadronic showers, and the determination of weight factors so as to make the electron/hadron ratio as close to unity as possible while maintaining a linear response. The chosen longitudinal segmentation of the calorimeter system, which is essentially dictated by technical constraints, is beneficial.

Front-end Electronics

The front-end electronics of the noble liquid calorimetry already exists in hybrid form, with specifications that match the performance requirements, in particular with regard to noise. The preamps operate at cryogenic temperatures and hold the promise of sufficient stability against radiation damage. A development program towards the use of ASICs is under way, which may be proposed for use in the experiment, schedule permitting.

The one unpleasant feature of the front-end electronics is the proposed non-linear characteristic of the preamps. The subpanel convinced itself that the non-linearity sets in at high enough energies so as not to impair trigger thresholds. The non-linear characteristic puts an additional burden on the calibration by charge injection, and its evaluation should be part of the full-scale prototype test program.

In the electromagnetic endcap calorimeter, the use of cold instead of warm electronics deserves further study and optimization.

Radiation Hardness and Radiation Safety

The subpanel, while impressed by the determination of the proponents to undertake a broadly based program of radiation damage testing of all sorts of materials, is still very concerned about the possible poisoning effects of materials under heavy radiation, especially in view of the purity requirements for krypton and the very intense radiation in the forward direction.

The subpanel urges the proponents to include in their program complete system tests under irradiation, so as to minimize potential dangers from contamination. For liquid krypton in particular, the purification system is vital and its design and test should be pursued vigorously.

The subpanel also urges the proponents to undertake neutron activation tests, to ascertain that impurities in the materials, especially in the forward calorimeters, do not lead to an unacceptable level of radioactivity.

R&D Plans and Beam Tests

In view of the ambitious goals of the proponents, the subpanel feels that a vigorous R&D and full-scale prototype test program must be pursued with a view to carrying out complete system tests as soon as possible. In the subpanel's view, both the importance and the complexity warrants the appointment of a coordinator at a high level of authority. The subpanel takes note of the plan for such a system test with a number of calorimeter modules in a Fermilab test beam in 1995. The schedule of this test should be maintained with high priority because a large fraction of the goals of this test can be achieved even without beam. Besides demonstrating the ability to build the planned number of modules, the test should give confidence in the expected uniformity of the calorimeter, resulting in a constant term of 0.4%, should demonstrate the validity of the absolute calibration by charge injection with a precision of 0.1%, and should provide experience on the rate of dead electronics channels.

Risks, Fault Tolerance, and Repair Possibilities

While the GEM calorimeter design is far from trivial, its risk is considered acceptable by the subpanel, provided that an unprecedented level of care and cleanliness at all stages of the construction is provided.

The subpanel concurs with the proponents that a random level of dead channels of the order of 2% is acceptable. However, only tests and experience will tell if this can actually be achieved.

The subpanel feels very concerned about the virtual impossibility of repairs. While this must be accepted for the interior of the cryostat, the very difficult access to elements like phototubes and the "junction boxes" is undesirable, and ways should be found to alleviate this problem, perhaps by redesigning the "passive absorber."

As for the problem of temperature uniformity within the noble liquid, the subpanel agrees with the goal of a variation of less than 1°C, but is not convinced that this will be achieved in the present design, in view of the heat dissipated by the preamps.

The risk associated with krypton impurity, intrinsic and as a result of high levels of radiation and exposure to materials, is underestimated. Tests should be pursued to ensure that the performance is well understood before all calorimeter materials are finally selected and the purification procedure is frozen.

The problem of the influence of the magnetic field on various safety-related elements of the cryogenic system, such as valves and pumps, has not been sufficiently addressed.

Mechanical Design

The subpanel concurs with the main lines of the mechanical design of the proposed calorimetry. It notes, however, that more effort should be invested to understand the degree of risk that the final welding of the cryostat might create for the nearby sensitive calorimeter elements as well as for the pressure vessel itself.

The subpanel cautions that not enough time was available to review the mechanical design in sufficient detail to ensure that the designs proposed can be built within budget and without compromising the physics performance.

Assembly and Installation

While the subpanel agrees in principle with the planned calorimeter assembly and installation procedures, it notes that these ideas represent only the beginning. Much more work has to be invested to make the assembly, transportation, and installation of the calorimetric system a credible operation, especially in view of the ambitious performance goals.

The difficulty of access to the calorimeter components is a concern, which is addressed in more detail in other sections of this report.

Requests to the Proponents

The proponents are asked to provide answers to the following questions by the August 1993 PAC meeting:

- How is the claimed constant term of 0.4% thought to be achieved, what are the present supporting R&D results, and what further R&D is being pursued to demonstrate the claimed performance?
- What are the detailed R&D plans for the calorimeters? Provide a description of the sharing of responsibilities and the manpower resources for the preparation and execution of the 1995 Fermilab test.
- Outline the plans and schedule for prototyping and tests of the scintillator barrel calorimeter and the forward calorimeters.

APPENDIX D
MUON SYSTEM

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Overview

During the two days of review the subpanel heard 13 presentations on various details of the muon system and toured the muon chamber test facility. In general, the subpanel is impressed with the high quality of the work and the progress toward a detailed understanding of the system and its final design.

Momentum Resolution and Acceptance

To achieve the proposed momentum resolution the track sagitta must be measured with an accuracy of 55 μm. The proponents call for individual track points to be measured with an accuracy of 75 μm. They have achieved such resolution in smaller test chambers and there are good indications that it can be obtained in full-sized detectors, but this has not yet been demonstrated. For this reason, and others outlined below, it is important that the GEM muon group proceed expeditiously toward tests of a full-scale prototype.

The proposed momentum error assumes that the magnetic field integrals are known to better than 0.4%. While this should be possible, the present analysis of the problem appears to be rather qualitative. The proponents are encouraged to address this issue in more detail as it affects the number and placement of monitors and the degree of testing that will be required before detectors are installed in the magnet.

For muons produced within the acceptance of the detectors ($|\eta| < 2.46$) the geometrical efficiency is about 86%, and is almost fully correlated among superlayers. This leads to a rather low overall efficiency for final states from $H \rightarrow 4\mu$. The proponents are encouraged to reconsider this loss. It may be possible to recover some of the efficiency loss if the correlation between gaps in the superlayers is reduced and the position of the interaction vertex is included in the track fit .

Alignment and Monitoring

The performance of the muon system depends critically on measuring and tracking the chamber alignment. The alignment between supermodules is to be measured with an optical straightness monitor similar in principle to those used in the L3 experiment. It is planned to make the GEM system projective so that the correction to the sagitta is measured directly. The system has been further developed to allow precise straightness measurements for offsets up to 9 mm. A prototype of the new system has been tested and shown to have an rms error of less than 5 μm. Additional uncertainties will be associated with the placement of the light sources/masks, lenses, and detectors with respect to the chamber strips, but the proposed error budget appears attainable. Based on experience with similar systems, we expect the proposed method to work well.

Radiation Environment and Backgrounds

It is important to demonstrate that backgrounds have only a small effect on the reconstruction efficiency. The three major sources of background are: a) hadron punch-through and decay muons; b) random neutrons and photons produced in the forward region; and c) electromagnetic showers generated by very high energy muons.

The calorimeter depth was chosen to reduce the hadron punch-through to a level that is small compared to the rate of prompt muons. The choice is the result of detailed calculations and comparisons with data. As a result, backgrounds from source a) are not serious, either for the trigger or for the reconstruction efficiency. Even correlated hadron punch-through from b jets has a negligible effect.

The forward region of the GEM experiment has been designed to make it easier to shield the muon chambers from neutrons and photons. The relevant design decisions were to move the quadrupole to a distance of 31 m from the interaction region, and to imbed the forward calorimeter in the endcap. After adding extensive shielding, the simulated fluences were reduced to levels $< 10^4$ n/cm^2/s and $< 10^3$ photons/cm^2/s. With these rates, the single strip occupancies range from 0.3% to 1.1% for a luminosity of 10^{34} /cm^2/s.

The third background arises from electromagnetic showers caused by muons of energy greater than about 500 GeV/c. The effect on the muon reconstruction efficiency was alleviated somewhat by placing the first muon superlayer 20 cm from the calorimeter. GEANT studies show that for 1 TeV muons the showers cause an additional occupancy which reaches a peak of 5% (20%) in the first superlayer of the barrel (endcap) muon chambers . Because of the photons in these showers it is important to avoid introducing unnecessary material into the muon system.

Studies of the muon reconstruction efficiency show that the electromagnetic showers reduce the efficiency for 500 GeV/c muons to 97% in the barrel, and 88% in the endcap detectors (exclusive of acceptance effects). Further degradation of these efficiencies due to neutron and photon backgrounds does not occur until the luminosity reaches $3 \cdot 10^{34}$ cm^{-2} s^{-1}.

Overall, the backgrounds appear to be well understood and have been reduced to quite acceptable levels.

Chamber Fabrication

Planning for the fabrication has been done, although some of the logistics are still evolving. The muon group has carefully considered many of the details and the subpanel finds no glaring omissions. Before volume construction can begin, however, further production engineering is required, as is the experience of assembling and testing a full-scale prototype. The proponents recognize these as essential steps which should precede the start of mass production. Under a schedule calling for turn-on in 1999 it would have been difficult to take full advantage of these steps. A more accurate estimate of the assembly costs will be possible once this phase has been completed.

Several production factories are planned for the chambers. It would appear desirable to locate one of them in the United States. This would facilitate the organization of the work and allow repairs and modifications to be carried out more easily.

Front End Electronics

Some of the chamber tests have been performed with early prototype versions of the preamplifiers because full prototype front-end electronics is not yet available. Before starting full chamber construction, system tests that incorporate pre-production electronics will be necessary.

There is some concern that the close proximity of analog and digital signals on the front-end electronics boards may introduce noise and affect the spatial resolution. This issue again emphasizes the importance of testing the full-scale prototype with pre-production front-end electronics.

Installation and Integration

The muon chambers are supported from a large aluminum truss structure, divided into two barrel sections and two end cap sections. The structure has been designed to have a low vibration response and a high degree of long term stability. The muon chambers are attached to the structure by kinematic mounts which provide the minimum constraints necessary to position and orient the chambers. The work on the support structure and the chamber interface supports is already well advanced and the designs presented were quite professional.

The proposed installation procedure involves a complete pre-assembly of the muon system on the surface prior to installation in the underground collision hall. This will assure best possible working conditions during assembly. Conceptual designs of assembly fixtures were presented. They present no particular concern, despite their large size and complexity. Some of the assembly stages involve very accurate handling of large structures. The relative deformation of all substructures must, therefore, be controlled to a high precision.

The installation of the complete muon support system into the magnet is conceptually simple, but the final attachment of the end cap structure to the barrel structure (moving the end cap structure off the FFS) must be regarded as a very delicate operation.

Questions and Recommendations

1. Access to the muon system is claimed to require 3-4 months. The subpanel views this as undesirable and encourage the proponents to explore short-turn-around emergency access, perhaps through a small section of the muon end cap.
2. The 48-fold azimuthal segmentation may be unnecessarily fine. The subpanel requests that the proponents perform a cost-benefit analysis of the degree of segmentation. Reduced segmentation could lead to a lower overall cost and less material to produce multiple scattering and backgrounds.
3. The measurement and monitoring of the magnetic field requires more detailed study.
4. The proponents are encouraged to consider methods to improve the geometrical efficiency of the system within the angular region covered.
5. The proponents should proceed expeditiously towards a full-scale pre-production chamber.

APPENDIX E
ELECTRONICS, TRIGGER, AND COMPUTING

C. Bebek, R. Chase, J. Dorenbosch, J. Patrick, S. L. Olsen, and M. Zeller

Introduction

The subpanel is impressed with the quality of the work and supporting material presented by the GEM Collaboration. At this stage of the design, the subpanel finds no obstacles that would prevent the group from achieving the stated performance goals. The GEM approach to front-end electronics (with the exception of the silicon vertex detector) is to buffer raw data in analog form for the latency of a single level of triggering. The silicon data are stored in digital form.

For purposes of developing a baseline electronics system, the latency of the level-1 trigger has been fixed at 2-μs. Trigger-qualified data are digitized, zero suppressed, and transferred to large buffer memories. The buffer memories can be selectively addressed by a processor farm to access data in regions of interest for the level-2 trigger algorithms. For events that pass the level-2 trigger, the event data are transferred in their entirety to the farm for detailed analysis by the level-3 trigger algorithms.

Reliability

Much of the front-end electronics is located inside the GEM detector and there is no easy access to make repairs. It is therefore going to be very important to analyze the reliability of the electronics. Furthermore, careful attention to isolating failure modes to small regions of the detector is required to minimize the effects of potential failures. This is needed to insure continuous operation with minimal degradation to the whole detector.

ASIC Development

The GEM detector is characterized by very large channel counts in all of the detector subsystems: 2M, 400k, 125k, and 1M channels in the silicon, IPC, calorimeter, and muon systems, respectively.

To reduce the per channel costs, an aggressive effort is underway to develop application specific integrated circuits (ASIC's). There are approximately 20 ASIC's under development. The subpanel is concerned about the reliance on such a large number of different ASIC's.

The GEM electronics management presented a matrix of projects, personnel, and status. An impressive team of IC designers has been assembled and many of the required ASIC's have been prototyped in part and/or in total. While the task is still daunting, the talent and resources seem to be available. It was stated that additional IC designers are available at

ORNL. To maintain the momentum of this team, it will be necessary to fund the many electronics R&D projects in parallel early in the GEM construction phase. The funding level should be such that production prototypes will be available for test beam running in early 1995.

Silicon Strip Readout

The silicon readout system is based on a 128-channel bipolar preamp/discriminator, a 128-channel CMOS time-stamp circuit and content-addressable memory, and a CMOS data compression and serializer IC.

The preamp, which is loaded with the capacitance of an 18-cm-long strip, needs to have an equivalent noise charge of 1500 electrons to allow operation with thresholds set to 0.25 of the pulse height for minimum ionizing particles. To date, the achieved noise level is 2300 electrons. While this may not critically affect the efficiency to detect charged particle tracks, it might seriously compromise the ability to assign the signals to the correct beam-crossing because of amplitude-dependent time shifts.

Because of component variations among different chips, there was also some concern about the ability to supply a single discriminator threshold to the 10 preamp IC's on a multi-chip carrier module (MCM). It is hoped that by using dies from a common production wafer one can obtain preamps with sufficiently uniform characteristics to permit the use of a common threshold.

The subpanel asks that the GEM Collaboration examine the reliability and failure mode implications of the bus-based readout system within the MCM module. The issue is single-point failures having larger impact within the MCM than would other readout schemes (such as redundant rings).

The silicon readout can be configured to return data from 1 to 4 adjacent beam crossings for each level-1 accept. It is not clear to the subpanel members whether it is possible to read dynamically the data for multiple adjacent beam crossings by continued assertion of the level-1 accept line. This might be a desirable feature if there are classes of triggers that cannot uniquely tag the associated beam crossing.

Interpolating Pad Chamber (IPC) Readout

The IPC front-end electronics consists of a preamp-shaper, switched capacitor array (SCA), and a controller IC. These parts are being developed in CMOS; they must be radiation hard. The present preamp dissipates 80 mW/channel to achieve the required noise level. The desired power is 20 mW/channel. To achieve the desired power level a bipolar design may be required.

The performance goal for the IPCs is to measure track positions to 1% of a strip width. The preamp design allows for relative gain calibration within a package to better than 1%.

It is not clear how this level of relative calibration can be extended across IC boundaries.

The coupling of the digital noise from the FADC and the SCA controller into SCA needs to be investigated. The subpanel is also concerned with the possible coupling of IPC electronic signals and other environmental noise into the chamber through the mylar window. R&D will be useful in evaluating and, if necessary, correcting this problem.

The time budget for the data conversion does not quite match the 100-kHz level-1 accept rate. This situation may be become worse as the design details are filled in. If the 100-kHz requirement is, in fact, retained, it should not be difficult to alter the design to meet this goal.

Calorimeter Readout

The challenge of the calorimeter readout electronics is to measure energies with 10-bit precision over an 18-bit dynamic range from 13 MeV to 8 TeV and to tag the time of the signal's beam crossing. The first component in the electronics chain is a low-noise preamp with a bi-linear response function. This compresses the 18-bit energy dynamic range into a 16-bit range. This analog signal is transported over cable to a differential line driver that drives 40m of cable to a receiver/shaper located on the west wall of the collider hall.

The received signal is split for the analog trigger sums and for the DAQ shaping circuits. The latter generates high and low gain outputs that are sampled at 60 MHz by separate SCA's. The SCA's must have 12-bit dynamic range and 10-bit resolution. The subpanel has the following concerns:

- The calibration requires a precise mapping of the bi-linear transfer function.
- The presently conceived calibration system does not exceed 3 TeV.
- The preamps will reside inside the cryostat and be totally inaccessible. It is essential that the reliability of these circuits be carefully tested.

The transport of analog signals over large distances and the mixing of analog and digital circuits on the readout boards expose the measurements to coherent noise problems. The least significant bit into the low range SCA corresponds to 50 μV on the differential cable. The calculation for the energy of a jet or e.m. shower requires the addition of a few tens of electronics channels over as many as five time samples. This greatly amplifies any coherent noise problems. This problem is exacerbated in those cases where high-range and low-range SCA measurements are combined.

The bi-linear preamp signal also complicates the analog trigger sums.

The subpanel members feel that it is important to work towards a test of a system that integrates an SCA, SCA controller, FADC, and trigger discriminators to understand the coupling of digital noise into the SCA. Here, it may be useful to learn from the experiences of the SDC electronics group, which prototyped a similar circuit.

If five samples are needed to reconstruct the energy of a shower, the present DAQ path will require 9-μs in FADC conversion time alone. With other overhead times, such as analog MUX settling and digital data storage, it may turn out to be difficult to meet the 10-μs time budget to support a 100-kHz level-1 accept rate.

Cathode-Strip Muon Chamber (CSC) Readout

The muon readout electronics uses a CMOS preamp for the cathode strips followed by a shaper and an SCA or T/H. It is required to measure the track position to 0.5% of a strip width. The anode wires are connected to a bi-polar preamp/shaper and this fast signal is used to determine the beam crossing time.

The cathode preamp requires a noise level of 2000 electrons or less. This has not yet been achieved. The preamp design allows for relative gain calibration of the preamps within a package to better than 0.5%. It is not clear how this level of relative calibration is extended across IC boundaries.

The CSC front-end printed circuit board contains analog inputs and digital logic in close proximity. The 0.5% precision and the 2000-electron noise requirements will be difficult to achieve in such an environment.

For an SCA implementation of the level-1 pipeline, there was a discussion of operating this device at 10 MHz. Some consideration should be given to operating any system at a different frequency from the 60 MHz that is present everywhere else. It is possible that some effects equivalent to baseline shifts in an AC-coupled system can arise.

A muon readout board has low occupancy. The DAQ interface makes use of this by using a 100-μs time budget for data conversion. This appears to violate 100-kHz readout rate. It is the subpanel's presumption that a CSC board responds to all level-1 accepts and that most such accepts are processed in much less than 10-μs. Only boards with data present take the full 100-μs to process a level-1 accept. This situation needs to be clarified.

Trigger

The GEM level-1 trigger is derived from calorimeter and muon chamber signals; it does not use any central tracking information. Simulations of several physics processes were presented and it was shown that they trigger the proposed system with good efficiency in the context of a total level-1 trigger rate of 10 kHz.

Electromagnetic trigger rates (e.g. for Higgs $\rightarrow \gamma\gamma$) are controlled by requiring isolation for low E_t e.m. showers, which seems to reduce rates to acceptable levels. Since the central tracking system is not included in the level-1 trigger, the detector cannot be triggered explicitly on electrons.

Calorimeter Trigger

Calorimeter trigger primitives are formed in the crates on the west wall of the collider hall, reducing the number of links to level-1. The trigger uses analog sums of individual, non-linear, preamplifier channels. The impact of the non-linearity on the timing and energy resolution of the trigger needs further study. The calorimeter jet trigger uses regions of 0.64 x 0.64 with fixed boundaries. It is claimed that this has equal performance to overlapping regions of the same size. This is a critical point, and adequate supporting information was not provided. As in the case of the DAQ readout, the e.m. and hadronic sums are susceptible to coherent noise problems due to the large number of elements in each sum.

The transport of the digitized level-1 trigger data to the counting logic is by 1 Gb/s fiber optics. Even though these fibers will be cut to length, the need for a mechanism to time-align the data at the receiver to a common beam crossing should be examined. The subpanel is concerned about the possibility of framing-time quantization due to differing phases of the 60 MHz used to drive the transmitters.

Muon Trigger

The muon level-1 trigger must combine information from more than a million strips and wires. It also must tag crossings without assistance from fast detectors like scintillators or RPCs. Solving this problem in a brute-force, synchronous way requires checking all relevant hit combinations for every crossing, which would take a huge electronics and cable plant. GEM has chosen a more advanced data-driven approach. Data for hits from a single crossing are transmitted in serial fashion, taking up to 200 ns. Local track primitives are formed on the superlayers to get the appropriate low rate. This approach is very sensitive to chamber occupancies. However, if occupancies remain at or below the present estimates, effects of associated dead time and mis-tagging will be less than the intrinsic trigger inefficiency of a few percent.

The muon trigger algorithm uses two different strategies and appears to be rugged. These strategies can be further qualified with straight tracks found in the non-bend plane. A muon module only sends data to the level-1 trigger if one or more track segments are found. Such data needs to be tagged with an absolute beam counter to be associated with other muon segments and with the calorimeter. This issue needs to be addressed more thoroughly. An on-board beam-crossing counter at the driving end or a crossing-time tag based on the message arrival-time at the receiving end can be made to work. In either case, the relative phase of all the modules must be established.

Level-1 Latency

The calorimeter trigger primitive formation, decision logic, and the cable path to deliver a level-1 accept to the silicon systems determine the level-1 latency. This is calculated to be in the range of 1875 ns to 2100 ns. The GEM collaboration is not adamant about a 2-μs latency and will chose an appropriately conservative value. We urge that this be done early so that the IC prototypes that depend on this value can be representative of the final designs at the prototype stage.

Level-2

GEM's approach to level-2 triggering is unique. The trigger is software based and resides in the level-3 processor farm. There are two possible modes of operation: all detector data are delivered to level-2 after a level-1 accept or only data in trigger regions pointed to by the level-1 trigger decision logic are read out. The latter approach makes better use of the available data collection bandwidth at the cost of extra complexity in flow control. Results of high-level simulations of the proposed DAQ system were shown to justify the choices of bandwidth and data buffering requirements. Level-2 algorithms are envisioned to refine e.m. triggers by examining shower shapes and to sharpen muon p_t thresholds by fitting to muon CSC positions. Silicon and IPC information is available for track matching to e.m. clusters to identify electrons and reject photons. No pattern-recognition simulation of the tracking system has been done and no performance numbers were presented to indicate that such track matching can be performed in the time allotted for level-2. Shower shape and muon tracking processing times appear to be achievable with anticipated processor technology.

Level-3

The level-3 trigger is a conventional software-based trigger using a subset of the complete off-line reconstruction code.

DAQ

The data acquisition system addresses the problem of taking the digitized data from approximately 10,000 60-Mbps serial links and routing it to processors in the level-2/level-3 farm. The baseline design includes EDC modules that multiplex the 10k 60-Mbps links onto 512 1-Gbps links, a custom-built time division multiplexing switch, and EDD modules to build complete events and distribute them to a particular processor.

While simulations have been performed that indicate the baseline design should easily meet the design goals for 10^{33} $cm^{-2}s^{-1}$ and be expandable to accommodate 10^{34} m^{-2} s^{-1}, optimal operation of the switch requires the 512 sources to have approximately equal amounts of data. The simulations should be extended to map the sources onto specific parts of the detector and include estimates of data sizes from Monte Carlo programs as a function of luminosity. Whereas the mean number of input channels per EDC is about 20 out of a total of 24, there should be a careful study to see whether an adequate data balance can be achieved.

The system provides hooks for a hardware based Level-2 trigger that would be added as an upgrade, based on initial experience with the detector. This is a good idea and should be incorporated in the initial system design.

The system requires a complex control network. Ideally a commercial standard should be used for this.

There is currently intense development activity on high speed networking in the commercial world. These developments should be carefully tracked and simulations on potentially suitable devices performed. Detailed design and construction of the event building system is not a critical path item; benefits in lower costs of the baseline system and/or more commercial options may develop with time.

We call attention to the importance of being able to operate the detector as several stand-alone systems during commissioning and maintenance. This is not completely described in the TDR and will require careful consideration of how to partition the trigger, clock distribution system, gating logic, and DAQ.

On-line Computing and Global Control

The proponents have recognized that the on-line computing effort for the GEM experiment is a monumental task that will require millions of lines of code and hundreds of man-years to implement. The Collaboration presented an outline of how this effort will be organized and estimates of the manpower needs between now and turn-on. The proposed organization and the projected manpower needs seem reasonable to the subpanel.

Organization

The GEM Electronics and Computing Group has a high quality R&D team in place that seems well matched to the task. While there appears to be some duplication of efforts (e.g., three different SCA's are being developed at three different laboratories) and a reluctance to rely on experience of laboratories outside of the collaboration (e.g., the electronics group was not very familiar with a similar SCA development recently carried out at LBL), the organization seems to be adequate for this stage of the project. The subpanel is concerned that the GEM group may have difficulty keeping this team together if, as a result of the SSC schedule stretch-out, the funding level is reduced. We recommend that this R&D be given high priority and that the team be kept on track for the development of a complete prototype system for the FNAL beam test scheduled in 1995.

APPENDIX F
ASSEMBLY, INSTALLATION, INTEGRATION, MAINTENANCE, AND ES&H

J. Bürger, H. Desportes, P. Grannis, L. Leistam, S. Olsen

The subpanel reviewed the status of facilities, assembly, installation, access, maintenance, and safety for the GEM detector. Presentations were given by members of the GEM Engineering and Integration Group and other Laboratory staff. Substantial progress has been made to prepare plans for installing the GEM detector and ensuring its safe operation. The Integration Group is to be commended for the analyses and the impressive tools and methodologies assembled to implement the studies. The group seems well matched in size and talent to the tasks.

The planning and design for GEM installation, operation, and maintenance has only begun. Much work remains and will continue through the life of the project. The challenges are amplified by the extremely hermetic character of the GEM detector, in particular the problem of adequate access to subsystems for maintenance and repairs.

A good organization is in place; frequent meetings of the Change Control Panel and other integration bodies involve members of the detector groups and the engineering and integration staff. The close contact among the detector builders and the project staff must be strongly encouraged as the installation and maintenance plans mature. Decisions taken at this phase of the project affect all of the subsystems and require exceptional attention to communication and broad input to the decision-making process.

Facilities

The IR5 site plan includes several surface buildings; the two largest are the North and South Assembly Buildings. These 6600-m^2 spaces have extensive high bay areas and are used for the on-site assembly of the magnet, calorimeters, muon trusses, and the central tracking system. On average, the spaces are used for two separate and consecutive operations over the full assembly cycle. The spaces seem adequate to the GEM needs and offer considerable flexibility. The provision for offices in the buildings is rather restricted, allowing space for about 100 persons at the site. We note that during assembly, installation, testing, and commissioning, the expected number of people working at IR5 will be substantially larger and that provisions for additional offices will have to be made. Additional buildings are planned to provide utility services and gas mixing. There are extensive hardstand areas intended for large scale activities such as the assembly of the magnet vessel.

The underground hall provides a space of approximately 100 m × 30 m centered on the IR, and with its long axis aligned with the beams, at a depth of over 50 m. Most of this area is covered by two independent 75-ton cranes with hook heights of 32 m. The completely assembled detector occupies an area of about 36 m × 28 m. The space available underground for the complex installation work appears to be adequate. Two large access shafts are provided for lowering large pieces of equipment into the hall; these are symmetrically positioned over the areas to the north and to the south of the IR. A large dismountable gantry crane serves both of these shafts. Use of a single crane would restrict installation flexibility. Smaller shafts are provided for power, cryogen, and gas services and for cables from the detector to the electronics racks. The electronics for trigger and digitization are located in three stories of rooms near the bottom of this latter shaft. Additional electronics and power supplies are located in racks mounted on walkways on the west wall of the collider hall.

Magnetic Shielding

The very large GEM solenoid has no flux return so that large magnetic fields extend over much of the site. In particular, the fields in the electronics rooms would be about 250 gauss without shielding. There is a plan to install about 300 tons of soft steel plates surrounding the electronics rooms. Preliminary calculations suggest that this shielding will reduce the magnetic field inside the rooms to about 50 gauss. Methods to reduce the magnetic field through shielding are, however, considered an uncertain art and calculations are not always reliable. A good safety margin for the shielding reduction would be prudent. Accurate maps of the fringe field of the magnet should be obtained.

Additional work is in progress to develop transformers with oversized flux linkages, capable of operating in the ambient field in the collider hall.

Installation

Installation of the GEM components will be a major and complex effort, likely to be conducted under considerable time pressure. Circumstances not now clearly foreseen will affect the installation tasks. The TDR plan for installing the GEM detector components has been developed under the very restrictive schedule assumptions leading to completion of the detector by 1999. This schedule is now expected to be stretched out. It will be of great benefit to the installation planning to have a new and more realistic schedule supplied by the SSC Laboratory.

The installation plan presented is a series of well-defined steps. It begins with placement of the central detector support across the mid-plane of the hall and the subsequent insertion of the scintillating barrel calorimeter. Installation and mating of the north and south magnet coils comes next, with a pause for preliminary magnet test and field mapping, followed by retraction of the magnet halves to the ends of the hall. The liquid barrel calorimeter is then installed with its cryogenic connections and cable attachments. After the calorimeter work is completed, the magnet coils are reinstalled in their final location and the north and south barrel muon trusses are lowered and moved into position inside the magnet cryostats. The inner detector is then completed by the installation of the central tracking system and end calorimeter detectors. The last elements to be installed are the north and south end muon trusses and the forward field shapers (FFS's). This full installation sequence requires almost three years of single shift operation. Double shift operation provides some contingency for schedule slippage.

The subpanel feels that these installation plans are technically feasible. They do involve manipulation of large delicate subsystems. In particular, the transfer of the end muon trusses to the barrel system will be an intricate operation.

In a project as complex as GEM, with the possibility of unexpected circumstances, there should be as much flexibility in the installation plan as possible. A particular example would be the slippage of the magnet assembly (or perhaps the desire to perform power test of the magnet coils at the surface). For example, magnet installation occurs early in the critical path sequence and it may be useful to proceed with the calorimeter installation while completing the magnet. A second example is a possible delay of the end muon detector until after the remaining detector is commissioned.

- In order to promote the greatest flexibility in the installation schedule to meet contingencies as exemplified above, the subpanel asks that GEM undertake feasibility studies that address alternate sequences of installation in the underground hall. The subpanel requests that these studies be presented at the August PAC meeting.

Access and Maintenance

Many of the GEM detector elements which may require servicing or replacement are located in quite inaccessible locations. Some, such as the liquid calorimeter preamps, are practically unreachable. Others, such as the liquid butane cooling system for the silicon detector, can be reached only by peeling all the layers of the surrounding detector. Providing efficient access to the detector subsystems is a formidable challenge.

Three levels of access were outlined in the TDR. In the first, an FFS is withdrawn along the beam axis by 6 m after disassembly of some neutron shielding. This allows access to the beam pipe vacuum pumps, and can be accomplished in about one week. No detector disconnections need be made.

The second access mode begins with FFS withdrawal by 6 m, followed by separation of the magnet coil halves and the enclosed muon trusses by 2 m. This involves disconnecting the magnet power busses and cutting (and re-welding) all cryogenic lines to the magnet. These steps permit access to the barrel muon chambers. The time required is about three weeks.

The third mode retraces much of the installation sequence. The FFS are retracted by 12 m and coil halves moved by 12 m to provide access to the calorimeters. Pulling back the end calorimeter and passive shield opens access to the calorimeter junction boxes and photomultiplier tubes. Access to the tracking detectors requires additional lateral displacement of an endcap calorimeter. This access mode requires about 10 weeks if the tracking system remains in place and about 14 weeks if the removal of the tracking system is necessary.

All access scenarios would be aided by a reduction of the eight-hour period required for discharge of the magnet.

The access plan does not allow any servicing of the calorimeter or tracking detectors except in the yearly three-month shutdown. The present plan for accelerator operation is to keep the yearly maintenance period to only one month, so this assumption is indeed questionable. Although GEM is being designed to very high standards of reliability, the risk seems high for detector failures that could impair its physics performance, if left unfixed for months. Means need to be found to improve the presently inadequate access to the detector. Several possibilities for improving flexibility were discussed, and indeed many have previously been considered by the GEM Collaboration. These possibilities include mounting the end muon trusses on the moveable FFS's and redesign of the passive absorber/barrel calorimeter interface to permit other access routes. Such changes may carry some price in physics performance, but the gain in detector reliability should be weighed.

In addition, the access plan entails cutting magnet services and moving the largest element of the GEM detector. This seems unwise to the subpanel and should only be adopted as a last resort. The subpanel felt that a permanently fixed magnet might itself lead to a simpler design. Introduction of an axial gap between coil halves could be contemplated as a pathway for access without undue effect on field uniformity.

- The subpanel asks that GEM develop alternatives to the existing access plan. An option based upon keeping the magnet fixed should be explored. The subpanel requests that a report on these alternatives be presented at the August PAC meeting. The report should include a comparison with the present plan and should also assess the physics benefits of the alternatives.

Hazards and Safety

Many hazards have been identified which must be mitigated during GEM installation and operation. They include fire and explosion, oxygen deficiency hazard (ODH), operation in a magnetic field, electrical shock, radioactivity, and the hazards of working at large heights.

The GEM collaboration has made a good start in analyzing these risks and in developing strategies for mitigating them. A first draft of the Safety Analysis Report was prepared and reviewed by the PRD ES&H Subcommittee. This review produced a list of action items aimed at increasing the level of detail and detector specificity and at clarifying safety responsibilities. The GEM Collaboration is working toward a new draft for review in July.

The subpanel felt that GEM has laid the groundwork for effective management of ES&H issues. The ES&H staff seem capable and well connected to the detector subgroup needs and requirements.

At this time, some of the solutions to known hazards have not been chosen; these include fire protection and ODH. We hope that these solutions can be established soon since their implementation may affect other aspects of the detector and hall design.

In GEM, much of the detector equipment and software will be built elsewhere and then brought to SSC Laboratory. A well-established process is needed to guide the design and fabrication of these elements, and test procedures assuring safe operability must be put in place.

Conclusions

The GEM effort in support of assembly, installation, and safety is effective, well-directed and adequate to the challenging task. The Engineering and Integration Group is to be congratulated on completing a major analysis of the broad range of logistical and integration support for the experiment. In the process, it has developed very effective tools and methods which should allow rapid adaptation to change. The main problems in the installation of the GEM detector stem from its strength as a hermetic physics detector: as it is difficult for particles to escape, so it is hard for personnel to enter. Nevertheless, to ensure timely completion and good physics performance for GEM, it is necessary to achieve maximum flexibility for installation and improved access to the internal hardware.

APPENDIX G
PHYSICS CAPABILITIES, PERFORMANCE OPTIMIZATION, AND TRIGGER

C. Bebek, G. Bobbink, S. Dawson, F. Dydak, D. Froidevaux, J. Patrick, C. Quigg, S. Sugimoto

The subpanel's general impression of the physics capabilities of the detector described in the GEM Technical Design Report is very positive. In global terms, the GEM detector is well-conceived for supercollider physics.

Physics Simulations

The simulation effort carried out in support of the Technical Design Report is quite impressive. It represents a great amount of good work and has brought together an enthusiastic and competent group to think about the physics GEM can study.

The tools for simulating the GEM detector elements are mostly state-of-the-art. A variety of tools that range from full GEANT simulations to fast parametrizations of detector response have been developed. The Collaboration has carried out many cross-checks to validate one simulation in terms of another, and recognizes the importance of tying the simulations to data. Overall, the coherence of the simulation effort is a very positive sign.

Although the physics generators (principally PYTHIA and ISAJET) have been generally appropriate to the preparation of the TDR, more modern tools that give more accurate descriptions of the hard-scattering matrix elements are available for many special cases. As GEM moves on to global detector optimization and preparation of component tests at Fermilab, it is important that physics simulations incorporate the latest theoretical developments and be closely linked to data from the CDF and D0 experiments.

The subpanel's greatest concern about the work of the GEM physics group is that its links to the hardware selection and development appear fragile. The role of the physics and detector simulations in the overall optimization of the GEM detector was not made visible in the TDR or in the presentations to the PAC. The GEM leadership expressed concern that the interface between hardware and simulation relied on a small number of "overworked individuals."

To cite a specific example, it was not made clear in the TDR or in the presentations where the relative weakness of the GEM tracking system compromises the physics performance of the detector. The subpanel suggests that the Collaboration use the physics and detector simulations to optimize the configuration and performance of the tracking system.

Closer interactions between the GEM physics group and hardware groups will strengthen the physics basis for refinements to the detector design. The panel agrees with the intent of the physics group to focus on the simulation and eventual analysis of a full wedge prototype in the Fermilab test beam. It seems appropriate to place a higher priority on this sort of integrated effort than on generating Monte Carlo samples for a great number of physics processes.

The *esprit de corps* and good work of the GEM physics group are great assets to the Collaboration and to the experimental program of the SSC. The subpanel urges the SSCL to sustain the group's sense of purpose beyond the TDR campaign by making the laboratory a lively intellectual setting with physics as the centerpiece, not just a meeting-place. The intellectual life of the laboratory should engage the GEM and SDC physics groups (and others), and should give people a reason to come to SSCL to talk about and do physics.

Trigger

The GEM trigger architecture is based on one hardware level and two software levels. The goal for the Level 1 trigger is an output rate of 10 kHz. The Level 2 and 3 triggers would be tuned for an output rate of 100 Hz. The first-level trigger uses specially processed calorimeter and muon information. Analog sums of e.m. and hadronic cells are formed at the readout crate level. Sums of the e.m. energy span 0.16 x 0.16 in (η,ϕ) and hadronic sums span 0.64 x 0.64. Electron and photon triggers are formed by an isolation criterion requiring an array of quiet cells centered on an energetic cell (one additional adjacent energetic cell is allowed). One- and two-photon (electron) trigger thresholds of 36 GeV and 12 GeV each give a few-kHz rate. Jet, total, and missing energy sums are formed for fixed η-ϕ regions. A study indicates that this technique performs as well as overlapping sums. Jet and $\not{E}_T$ thresholds of 150 GeV and 125 GeV give acceptable Level 1 trigger rates.

Level 1 also triggers on muon events. Three hardware primitives are generated: a sagitta measurement using all three superlayers, a $\delta\phi$ measurement using one or more pairs of superlayers, and a non-bendplane straight-track measurement using all three superlayers. The latter is not strongly correlated with the two bendplane measurements, but background tracks in the muon system are so sparse that this is unimportant. The sagitta measurement provides good discrimination at low p_t values; the $\delta\phi$ measurement is required for high p_t The hardware algorithms are robust against neutron and photon backgrounds.

The software-based Level 2 trigger resides in the Level 3 processor farm. There are two possible modes of operation: either all detector data are delivered to Level 2 after a Level 1 accept, or only data in trigger regions pointed to by Level 1 are read out. The latter approach makes better use of the data-collection bandwidth at the cost of extra complexity in flow control. High-level simulation results were shown to justify the requirements for bandwidth and data buffering. Level 2 algorithms are envisioned to refine EM triggers by examining shower shapes and to sharpen muon p_t thresholds by fitting to muon CSC positions. Silicon and IPC information are available for track matching to EM clusters to identify electrons and reject photons. The level 3 trigger is a conventional software based trigger using a subset of the off-line reconstruction code.

The Radiation Environment

The panel recognizes that the GEM group has made leading contributions to the study of the general environment around LHC/SSC detectors, specifically the bath of neutrons and photons in the collision hall. This work is comprehensive and coherent. It should provide the tools necessary to devise an optimal solution for neutron shielding.

At the same time, it seems important to inject a note of caution. Having in hand the tools for understanding the problem does not mean that a workable solution for GEM has been demonstrated. It is important to validate the calculations empirically. Can experience in the Tevatron tunnel be brought to bear on the problem? Are there new measurements that might be made incidentally or in brief dedicated runs at the Tevatron that would make the conclusions more secure? How can the solution presented for GEM be optimized for performance and cost?

Questions for the Summer PAC Meeting

The Technical Design Report contains much of the information the PAC needs to evaluate the global scientific capabilities of the GEM detector. The subpanel encourages the Collaboration to pursue further optimization within their design philosophy.

Physics and detector simulations must play an important part in this process.

To this end, the subpanel asks that the Collaboration submit for the August PAC meeting four studies of the physics potential of the GEM detector. The examples are chosen for the high demands they place on various detector elements, not to reorient the scientific program of GEM.

1. A study of Higgs-boson decays into four leptons (both muons and electrons) for Higgs masses in the range 130 - 800 GeV/c^2 that explores scenarios for improving effective muon coverage.
2. A study of Higgs decays into two photons in the face of backgrounds from the decay of $Z^o \rightarrow e^+e^-$ (plus photons) that includes a realistic evaluation of the tracking performance at design luminosity and above.
3. A study of neutral Higgs bosons in the supersymmetric standard model, including decays into two photons, τ pairs, and four leptons, comparing the performance of detector elements at luminosities of 10^{33} cm^{-2} s^{-1} and 10^{34} cm^{-2} s^{-1}.

4. A study of the GEM detector's capabilities for B physics that emphasizes triggering and tracking performance for the decay $B^o \rightarrow K_S\ J/\Psi$, for both electrons and muons.

Appendix H
Cost and Schedule

R. Chase, E. Heijne, G. Mulholland, J. Pilcher, F. Sciulli, H. Stredde, G. Tappern, D. Theriot, M. Zeller

Overview

The Cost and Schedule Subpanel split into subgroups to examine specific areas of cost and schedule for GEM construction. These subgroups were: Tracking Systems, Calorimeter, Muon Systems, Magnet, Electronics, Computing, Interface Systems, and Project Management. After coming together and comparing notes, the subpanel believes that the cost estimate for the GEM detector is credible for a project at this stage. The Collaboration has done well in attempting to identify and estimate all costs. While the subpanel cannot certify that the cost estimate is correct after so short a review, its members have not found any large errors which would indicate that it is grossly incorrect. The subpanel believes that if some of the concerns are addressed, the cost and schedule aspects of the GEM proposal will fare well in a DOE review this fall.

Some of the general issues that the GEM Collaboration should address prior to the DOE review follow.

- The collaboration should establish a consistent cost estimating methodology across all systems. The calorimeters are currently estimated in a significantly different way than the other systems.
- More consistency checks are needed for similar items across systems and between WBS costs and the "Basis of Estimate" sheets.
- WBS costs should only be developed to the lowest reasonable level.

Some systems need only three levels; others are known in sufficient detail to extend to much lower levels.

In addition, all detector subpanels that have looked at technical aspects of the detector point out that more time and resources are needed for R&D on their respective systems.

Specific Subgroup Summaries

Tracking Systems

- The silicon wafers are a large item mostly provided by vendors with specifications defined by physicists. Costs are modeled on the OPAL Detector.

  The collaboration received two bid estimates (ROM bids) in response to five requests. A ROM bid from a vendor is an estimate, but not a firm bid. The collaboration therefore assigns 30% cost risk to this item. This seems to be a reasonable procedure.

- WBS tracking is adequate. There is a slight mismatch between Basis of Estimate and Detailed Cost, because they are not linked by computer and are created at different times. A better agreement is desirable.
- An attempt to run through the cost estimate of the prototype ladder assembly was difficult because the estimate showed materials only. Apparently this is the method of listing costs incurred if an outside vendor is to provide the entire system. Clearly, if one wishes to determine how these costs are derived, more documentation is needed.
- The cost estimate for the ladder assembly contains reasonable assembly times based on past experience and engineering judgment. The risk assignment is appropriate.
- If the 36-cm ladder (2 × 18 cm) design were not successful, it would have a major impact on the schedule. This is because a major redesign allowing readout from the center (rather than the ends) of the structure would be required.
- For the IPC system, the cost estimates are not yet well enough developed to warrant the WBS level 4 and 5 which were presented.
- The tracking group has been very thorough in total project engineering, i.e., piping, cables, transport, etc. have been considered in the cost estimates. One missing item is a clean assembly area at SSCL (about $250 k). The GEM team is of the opinion that this facility should be provided by the SSC Laboratory.
- The schedule as presented would be extremely difficult to maintain. It requires a large concentration of design engineering over a short period of time, and does not have enough time allocated for installation. The core team of about ten engineers should be sufficient to allow delivery of prototypes on the original schedule.
- Delay of the 1998 installation date would prove to be very useful. It would reduce the serious peak demands on engineering, it would allow for much needed R&D, and it would also allow more time for assembly and installation.
- The subpanel finds no significant error in the cost estimate. If anything, the subpanel feels that the contingency is too high.

Calorimeters

The level of detail in the cost estimate is indeed impressive. The subpanel found that the costs as delineated in the WBS breakdown are defensible when traced back to raw input. This statement is based on only a few specific cases that were checked in the limited time available. Some general observations follow:

- The backup sheets are not, in every instance, kept current. The subpanel found two specific instances where the sheets were not current, though the WBS did reflect the final estimate. Before a detailed audit, responsible engineers need to make sure that the records are up-to-date.
- The labor estimates for the construction and installation of accordion calorimeter modules should be cross-checked against the experience of colleagues in the CERN RD collaboration.
- The parametrizations and algorithms for arriving at total manpower costs escalate the raw times required for various tasks by a substantial factor. It is not easy to verify these escalation factors. Examples are:
  - factors of 1.25 for quality assurance on installation and assembly;
  - factors of 1.96 for engineering support on design hours;
  - factors of 1.15 PFD (personal fatigue, delay) on assembly labor;
  - a factor effectively equal to 3.48 for learning (Crawford Learning Curve) on technical labor tasks performed for the first time.

  These factors result in conversion of raw required hours to much larger numbers. It should be noted that a contingency of typically 29 % is applied in addition.
- For the scintillating calorimeters, a more mature design is expected to result in lower costs and contingency.
- In the limited time available to the reviewers, it appeared that the overall cost estimate was adequate for the task of constructing the calorimeter systems.

Muon System

Cost estimates for this system are prepared by Draper Laboratory, using input from the physicists. Following presentations and discussions, and after reading the report of the PRD cost review performed in May 1993, the subpanel has a number of comments:

- The cost of fixtures is significantly underestimated. The subpanel reviewed the fixtures needed, in comparison to those currently budgeted, and judges that the costs are underestimated by as much as a factor of five.
- The subpanel finds that the same level of contingency has been applied to items with very different levels of uncertainty. Within the lowest WBS level all items have a common contingency. This leads to the same contingency on purchased equipment and computers as on the number of hours needed to assemble a chamber (e.g., WBS 30.02.2.1.3). At a higher level, the same contingency (30%) appears for such diverse items as storage, shipping, chamber components, and chamber assembly. The subpanel encourages a more critical review of the contingency assessments, particularly for the major items.

- Good management tools are in place but not uniformly applied. Draper personnel are using EXCEL while SUCCESS is used at SSCL. Separate data bases are maintained and individually updated.
- The description of tasks in the Basis of Estimate books should be more descriptive and detailed. Copies of vendor quotes should be included. In the course of a few spot checks, the vendor quotes had to be produced from files of individual engineers.
- The titles of tasks need to be more accurate and descriptive. For example, the "Machining/inspection" is applied to both purchased prefabricated items (e.g., cathode strip boards, WBS 30.02.2.1.5) and to items fabricated on site (e.g., detector support structure, WBS S 30.02.3.1.2). Within the latter item, assembly costs cover many diverse operations and should be broken down.
- More global cross checks are needed to spot problems. For example, the cost per pound of the fabricated aluminum support structure is $7.15 in the barrel section and $18.13 in the endcap, despite the very close similarity of the structures.

The subpanel believes that one of the largest uncertainties is the assembly time for the chambers. It has been estimated from the construction of similar devices and allowance is made for mass production. Nevertheless, until a full scale pre-production model has been built it will remain very uncertain. In the present estimate the ratio of materials to labor cost is 1.8, which seems high. The labor costs may be underestimates. There is, however, concerted work to improve production techniques and this could yield large dividends.

Magnet

Overall, the magnet costs are judged to be credible as given. However, the magnet design proposes a new type of conductor which has not been used before and the R&D costs shown in the cost estimate are not adequate. R&D is stated as being nearly complete, and a very low contingency is shown because level of effort contracts are in place and will terminate when the prime contractor is chosen. However, much more work needs to be done in order to prove the feasibility of the conductor in this application. Currently, test coil and full scale conductor fabrication studies are planned, but not yet completed. Consideration should be given to a full scale test of one of the solenoid modules prior to manufacture of all 24 modules. Additional costs for R&D are estimated to range between $1.0M and $3.4M.

Electronics

- The cost estimated for electronics covers a number of relatively conventional and available components for which detailed and documented costs are presented. The integrated circuit (IC) production is an exception to this and it represents 8% of the

$92M budget. The $17M contingency could cushion a possible need for additional IC production runs.

- The cost estimate is not always consistent in distinguishing between R&D and prototyping which should cover all activities up to the final production phase.
- The possibility of adding comments on the spread sheet (displayable on the computer screen) may be very useful.
- R&D and prototyping budgets should be increased due to the inherent uncertainties on the IC production. Further work in this area will reduce the possibility of difficulties in production. It is suggested to raise the contingencies related to IC development to 50% for all detector systems. This adds $1.8M to the contingency.

Computing

The cost estimate addresses software development and hardware. Software development by contractors is designated as materials. The cost of the real hardware is an educated guess based on a projection to 1997 processor prices.

The whole estimate is essentially top down, which is the best that one may be able to do now. The conversion to a bottom-up detailed cost estimate is not very meaningful at this time.

The cost related to the use of CASE tools has not been made explicit but probably can be accommodated in the projected cost.

Interface Systems

This part of the cost estimate is well thought out and identifies all necessary systems. The current knowledge is good. When questioned, the group gave correct answers on all systems, indicating that the GEM Collaboration has carefully thought about these tasks. However, nothing is completely designed yet, so contingency should be increased to 20% for an additional cost of $0.7M.

Project Management

The Project Management Office of the GEM Collaboration has put together an impressive system to track the costs and schedule of the GEM detector. It should satisfy all DOE requirements and allow the project manager to keep on top of the project. If the cost estimating methodology can be improved (see Overview comments) and the system kept updated, the DOE review should go well.

Schedule Stretch-out

In general, the subpanel believes that the proposed schedule stretch-out will give the GEM Collaboration time to accomplish much needed R&D. In the long run, this will result in a better detector. However, there will be additional costs associated with a stretched-out schedule.

Since the GEM project is currently funded at the level of $32M/year, three additional years may cost of the order of $96M. The GEM Collaboration has already informed the SSC Laboratory than such a stretch-out will add $100M - 120M to the current cost estimate. The Collaboration also believes that roughly $20M is needed in additional R&D, although they admit that this is not a precisely known figure.

APPENDIX I
COLLABORATION MANAGEMENT AND RESOURCES

D. Gross, H. F. Hoffmann, A.J.S. Smith, M. Witherell

The GEM collaboration currently consists of over 1000 members associated with 114 institutions in 17 countries. The Collaboration has carried out an R&D program on a range of detector technologies, has made the difficult choices among these technologies, and has developed a detailed design of the full detector. Judging by the quality of the Technical Design Report, the organization established to direct this effort has worked well.

The collaboration is now entering a period of rapid change as a new management structure suitable for detector construction is set up. The overall organization plan looks reasonable, and is similar to the one that has served in the period leading up to the TDR. The subpanel emphasizes the need to have a permanent project manager in place at the Laboratory as soon as possible. If the project manager is not also one of the two spokespersons, it would be advisable for one of the spokespersons to be resident at the laboratory.

The subpanel is concerned that the scientific manpower available for some of the subsystems is inadequate. In particular the tracking and calorimeter groups should be reinforced. The subpanel emphasizes the importance of identifying all the subsystem managers in the coming months. Each subsystem manager should appoint a coordinator to supervise the R&D program. The spokesperson and the project manager, together with the subsystem manager, should establish the matrix of responsibilities and the allocation of resources.

- The Collaboration is asked to give a detailed status report on the distribution of responsibilities at the August PAC meeting.

The Collaboration described the status of the GEM funding plan. Of the estimated total cost of $500M (1990 dollars), $275M will be provided from SSC project funds. The proponents have identified approximately $100M from other sources (the TNRLC, the US HEP base program, and foreign sources.)

Since the presently identified funds do not cover the cost of the detector, staging of detector components must be considered. Preliminary ideas about staging scenarios were discussed with the collaboration.

- The Collaboration is asked to investigate further staging scenarios and present studies of the physics tradeoffs at the August PAC meeting.

APPENDIX J
ORGANIZATION OF REVIEW

Panel Members (*PAC Member)

Chris Bebek	SSCL
Gerard Bobbink	CERN
Jochen Bürger	DESY
Robert Chase	Orsay
*Sally Dawson	BNL
Henri Desportes	Saclay
Jheroen Dorenbosch	SSCL
*Friedrich Dydak	CERN
Daniel Fournier	CERN
*Daniel Froidevaux	CERN
*Paul Grannis	Stony Brook
*David Gross	Princeton
Erik Heijne	CERN
Hans Hoffmann	CERN
Raghavan Jayakumar	SSCL
Lars Leistam	CERN
George Mulholland	SSCL
*Stephen Olsen	University of Hawaii
James Patrick	Fermilab
*James Pilcher	Enrico Fermi Institute
*Chris Quigg	Fermilab
*Frank Sciulli	Columbia University
*A.J. Stewart Smith	Princeton
Herman Stredde	Fermilab
Shojiro Sugimoto	University of Tokyo
Geoffrey Tappern	Rutherford
Dennis Theriot	Fermilab
Robert Watt	SLAC
*Michael Witherell	UC/Santa Barbara
*Michael Zeller	Yale

GEM TDR Review

May 24-29, 1993

	SUBSYSTEMS					GLOBAL ISSUES				
	A	B	C	D	E	F	G	H	I	
	S/C Solenoid	Tracking & Vertexing	Calori-meters	Muons Systems	Electronics & Computing DAQ	Installation ES&H	Physics Perform. Optimiz.	Cost & Schedule	Management/ Resources	
PAC			Gross						Gross	2
				Dawson			Dawson			2
			Dydak				Dydak			2
		Froidevaux					Froidevaux			2
			Grannis			Grannis				2
					Olsen	Olsen				2
				Pilcher				Pilcher		2
	Quigg						Quigg			2
			Sciulli					Sciulli		2
		Smith							Smith	2
				Witherell					Witherell	2
					Zeller			Zeller		2
CONSULTANTS					Bebek		Bebek			2
				Bobbink			Bobbink			2
		Burger				Burger				2
					Chase			Chase		2
	Desportes					Desportes				2
					Dorenbosch					1
			Fournier							1
		Heijne						Heijne		2
			Hoffmann						Hoffmann	2
	Jayakumar									1
				Leistam		Leistam				2
			Mulholland					Mulholland		2
					Patrick		Patrick			2
				Stredde				Stredde		2
				Sugimoto			Sugimoto			2
		Tappem						Tappem		2
	Theriot							Theriot		2
	Watt							Watt		2
	S/C Solenoid	Tracking & Vertexing	Calori-meters	Muons Systems	Electronics & Computing DAQ	Installation ES&H	Physics Perform. Optimiz.	Cost & Schedule	Management/ Resources	
	A	B	C	D	E	F	G	H	I	
	5	5	7	7	6	5	8	10	4	

GEM TDR Review

May 24-29, 1993

AGENDA

Time	Monday 24-May
8:30 AM	PLENARY
9:30 AM	PLENARY
11:00 AM	Break
	PLENARY
12:45 PM	Lunch
2:00 PM	PLENARY Auditorium
3:40 PM	Break
	PLENARY (Continued)
5:30 PM	

Time	Tuesday 25-May	Wednesday 26-May	Thursday 27-May	Friday 28-May	Saturday 29-May
8:30 AM	PLENARY	PLENARY	PLENARY	PLENARY	PLENARY
9:30 AM	PARALLEL A-E	PARALLEL A-E	PLENARY B-E Summary Reports and Discussions	PARALLEL F-I	F.H.I Summary Reports and Discussion
11:00 AM	Break	Break		Break	
	A-E	A-E		F-I	
12:30 PM	Lunch	Lunch	Lunch	Lunch	Lunch
2:00 PM	A-E	PARALLEL Discussions	F-I	PARALLEL Discussions	PLENARY Discussions
4:00 PM	PARALLEL		Break		
			F-I		
5:00 PM	PLENARY	PLENARY Summary: A		PLENARY Summary: G	

Open	Closed

PRESENTATIONS

24-May	PLENARY SESSION	Auditorium
9:30	Overview of the GEM Project	B. Barish
10:10	GEM Physics Capabilities	B. Zhou
11:00	Break	
11:30	Magnet	R. Stroynowski
11:55	Muon Detector	F. Taylor
12:45	Lunch	
2:00	Calorimeters	W. Willis
2:55	Central Tracker	C. Baltay
3:40	Break	
4:00	GEM Performance Features	H. Newman
4:35	Organization/Budget/Schedule/Resources	G. Sanders
5:15	Adjourn	

PARALLEL SESSION A: MAGNET — Directorate II

25-May — Desportes, Jayakumar, Quigg, Theriot, Watt

9:00	Overview: Management, Planning & Organization	P. Reardon
10:15	Overall Design Approach	G. Deis
10:45	Break	
11:00	Cold Mass Design and Development	N. Martovetsky
12:00	GEM Test Coil	R. Camille
12:45	Lunch	
2:00	Coil Winding—Design and Development	R. Vieira/J. Rollins
2:40	Vacuum Vessel Design	J. Bowers
3:10	Internal Components	R. Yamamoto
3:40	Assembly and Installation	L. Pedrotti
4:20	FFS	J. Bowers

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9:00	Cryogenics	J. Krupczak, R. Yamamoto
10:00	Power/Protection/Controls	G. Oberst
10:30	Break	
11:00	Discussion	
12:30	Adjourn	

PARALLEL SESSION B: CENTRAL TRACKER — Directorate I

Froidevaux, Bürger, Heijne, Smith, Tappern

9:00	General Discussion		C. Baltay
9:30	Silicon Detector		
		Overview	D. Lee
		Structural Components	T. Thompson
		Ladder Assembly, Cooling	R. Barber
		Silicon Strip Detectors	J. Brau
12:30	Lunch		
2:00	IPC Detector		
		Overview & Electronics	J. Musser
		IPC Modules	D. Pilon
		Support Structure	J.E. Hinckley
		Cooling & Gas Flow	R. Martin
4:00	Adjourn		

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9:00	Other Issues		
		Installation, Assembly & Alignment	T. Thompson
		Calibration	J. Thomas
		Radiation Environment	D. Lee
		Prototype Testing/Beam Test	K. Morgan
		R&D Program	J. Musser
11:30	Performance		
		Pattern Recognition	M. Brooks
		Physics Performance	J. Brau T. Thompson
12:30	Adjourn		

PARALLEL SESSION C: CALORIMETER — Auditorium

25-May **Dydak,** Fournier, Grannis, Gross, Hoffmann, Mulholland, Sciulli

9:30	Overall Design	W. Willis
10:00	Liquid Calorimeter	V. Radeka
10:45	Break	
11:15	EM Design Considerations and Simulation Results	M. Seman
12:00	Hadron/Jet Performance	Yu. Kamyshkov
12:30	Lunch	
2:00	Liquid Calorimeter Engineering	L. Mason
3:00	Forward Calorimeter	J. Rutherfoord
3:30	Scintillation Calorimeter Engineering	C. Wynn
4:00	Adjourn	

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9:00	Production of EM Calorimeter	D. Makowiecki
9:20	Cryostat	L. Mason
9:40	Cryogenics	D. Richied
10:00	Feedthroughs	P. Mockett
10:20	Break	
10:50	Calorimeter Assembly at the SSC	W. Wisniewski
11:30	Organization	W. Willis
11:40	R&D Program	V. Radeka
11:50	FNAL Test	P. Slattery
12:30	Lunch	
4:00		

PARALLEL SESSION D: MUON SYSTEM — Upstairs Conference

25-May — **Pilcher**, Bobbink, Dawson, Leistam, Stredde, Sugimoto, Witherell

9:00	Overview of Muon System	M. Marx
9:30	Magnetic Field and Momentum Measurement	J. Sullivan
10:00	Simulation of Backgrounds	V. Gavrilov
10:30	Break	
11:00	Event Reconstruction	R. McNeil
11:30	Chamber Technology & Electronics	V. Polychronakos
12:10	Lunch	
2:00	Chamber Design & Construction	S. Whitaker
2:40	Muon Trigger Concept	M. Atiya
3:10	Discussion	
4:00	Adjourn	

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9:00	Alignment System	G. Mitselmakher
10:30	Break	
10:50	Support Structure and Chamber Installation	F. Nimblett, K. Belser
12:00	Commissioning	C. Wuest
12:30	Adjourn	

PARALLEL SESSION E: ELECTRONICS/DAQ/COMPUTING — Strategy Room

25-May — **Olsen,** Bebek, Chase, Dorenbosch, Patrick, Zeller

9:00	Overview	M. Shaevitz
9:30	IPC Readout Overview	J. Musser
10:00	IPC Rad-hard SCA	C. Britton
10:25	Calorimeter Readout Overview	J. Parsons
10:55	Break	
11:15	Calorimeter Preamps/Driver/Shaper	S. Rescia
11:40	Muon Readout	R. Wixted
12:10	IPC & CSC Preamps	P. O'Conner
12:30	Lunch	
1:30	Calorimeter Level 1 Trigger	W. Cleland
2:10	Muon Level 1 Trigger	M. Atiya
2:50	Level 1 Trigger Simulations	H. Uijterwaal
3:15	Adjourn	

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9:00	DAQ Overview	M. Bowden
9:25	DAQ Simulations	J. Branson
9:45	Silicon Tracker Front End	S. Hahn
10:15	Integration Issues	N. Lau
10:45	Break	
11:15	Online Computing	K. McFarlane
11:55	Organization & Schedule	D. Marlow
12:30	Adjourn	

PARALLEL SESSION F: ASSEMBLY, INSTALLATION, INTEGRATION MAINTENANCE, TEST BEAMS, AND ES&H — D-305

27-May **Grannis**, Bürger, Desportes, Leistram, Olsen

2:00	Overview	M. Harris
2:40	Facilities, Installation and Integration	W. Eliot
3:10	Magnet	G. Deis
3:30	Break	
4:00	Calorimeter	B. Wisniewski
4:20	Muon	F. Nimblett
4:40	Tracker	T. Thompson
5:00	Adjourn	

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9:00	Electronics Integration	K. Freeman
9:20	Access and Maintenance	N. Gober
10:00	Break	
10:30	Review of Safety Analysis Report	H. Lynch
10:50	Detector ES&H Issues	R. Woolley
11:30	Adjourn	

PARALLEL SESSION G: PHYSICS PERFORMANCE/DETECTOR OPTIMIZATION/TRIGGERING — Upstairs Conference

27-May — Quigg, Bebek, Bobbink, Dawson, Dydak, Froidevaux, Patrick, Sugimoto

2:00	Triggering	D. Marlow
2:30	Modeling	T. Skwarnicki
3:00	Heavy Flavor and Jet Physics	J. Womersley
3:30	Break	
4:00	Radiation Environment and Radiation	M. Diwan
4:30	Discussion	

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9:00	Discussion of Detector Capabilities	
	Overview	B. Barish
	Missing Et	H. Uijterwaal J. Rutherfoord F. Paige
	Electronics and Trigger	W. Cleland G. Mitselmakher
	Higgs Search	R. Zhu, W. Cleland
11:30	Adjourn	

PARALLEL SESSION H: COST AND SCHEDULE **Auditorium**

27-May **Zeller,** Chase, Heijne, Mulholland, Pilcher, Sciulli, Stredde, **Theriot,** Tappern, Watt

2:00	Overview	G. Sanders
2:40	Formation of Working Groups	
3:00	Working Group Sessions	

Tracker	H. Pretty, T. Thompson
Calorimeter	J. Coulon, M. Montgomery
Muons	R. Gustavson, H. Baker
Magnet	G. Deis
Electronics	D. Marlow
Interface Systems	J. Coulon
Computing	K. McFarlane
Project Management	R. Fischer

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9:00	Working Group Sessions
12:30	Lunch

PARALLEL SESSION I: ORGANIZATION AND MANAGEMENT Directorate II

27-May **Witherell,** Gross, Hoffmann, Smith

2:00	Introduction	W. Willis
	GEM Overseas Collaborations	
2:30	China	Y. Guo
2:50	Korea	J. Kim
3:10	Russia	A. Golutvin
3:30	Taiwan	S. Lee
3:50	Break	
4:15	GEM Organization	C. Baltay
5:00	Project Management and Engineering	G. Sanders/M. Harris
5:45	Adjourn	

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9:00	Funding, Staging, Upgrades	W. Willis
9:30	Discussion	
10:30	Adjourn	

APPENDIX K
GEM SAFETY ANALYSIS REPORT

REVIEW BY PRD ES&H SUBCOMMITTEE
April 27, 1993

C. Milner, H. Lynch, J. Bull, M. Butalla, H. Carter, J. Elias, R. Harold, B. Hendrix, M. Keen, L. Marple, E. Verminski

This is a report on the April 23, 1993 Physics Research Division ES&H Subcommittee review of the "GEM Safety Analysis Report (SAR)" document. The assessments of the Subcommittee are in several forms: 1) this report, 2) forty-two individual "Review Action Items" submitted to the SAR authors, 3) editing comments concerning the document, and 4) general oral summary comments made to the authors regarding the document.

The Subcommittee finds this initial safety analysis to be a good start and in the right spirit, but that it does not demonstrate a safety plan for GEM. We perceive it to be a "top level" identification of major hazards. However, the mitigations proposed for the hazards are generic, lacking sufficient technical detail to be assessed by the Subcommittee. The hazard analysis needs concentrated effort. We recommend that engineers and physicists designing GEM take an active role in hazard analysis, providing hazard identification, risk classification, and quantitative studies of hazard mitigations. We look forward to reviewing a few months from now a safety plan, and responses to the "Action Items".

Many hazards discussed in the SAR concerning the magnet, cryogenics, and central tracker butane cooling have been the subject of previous reviews. The SAR does not use or refer to any results from these studies or reviews. In addition, many of the GEM subsystems are similar to those used in other physics laboratories around the world, so a large body of operational experience exists that could be incorporated into the SAR. In general, the Subcommittee finds the SAR lacking in historical context.

There are separate safety analyses for GEM facilities (a Safety Evaluation or SE for the assembly buildings and underground hall) and the detector (SAR). It was not clear to the Subcommittee how it will be ensured that ES&H measures will be uniform, comprehensive, and compatible for the entire IR5 GEM complex. We would like to see this clarified. The title of the SAR reviewed by the Subcommittee should be changed to "GEM Detector SAR", to reflect the fact that the analysis is confined to the detector components.

The radiation safety is addressed only briefly. The SAR correctly states that most of the radiation received by personnel will be caused by exposure to activated components. Design features should be considered for reducing personnel exposure to highly activated components like the forward calorimeter. These include quick connect-disconnect mounting, as well as the possibility of remote handling. Also, storage of activated components, and recovering and reusing parts of damaged components should be studied.

A comprehensive GEM safety plan must be made. The SAR should discuss the plan while at the same time being an integral part of it. It should address engineers and physicists working on the hazard analysis. It should draw on prior experience gained from commissioning the MDL, MTL, and ASST at the SSCL, and from plans in place at other HEP laboratories.

Forty-two (42) "Review Action Items" were generated by Subcommittee members during the review. The SAR authors should report to the Subcommittee on actions taken on each individual item as well as on other issues raised in this report. These action items are paraphrased, and in some cases combined for clarity below. The are not listed in any particular order.

1. A SAR section should be reserved to address operational staffing, training, and procedures.
2. Ingress and egress procedures require more analysis, in particular for the muon system.
3. Fire suppression by a nitrogen inerting system is proposed. ODH implications of actuation of this system when personnel are in the hall must be addressed.
4. LN2 magnet shield failure and subsequent leakage into the vacuum space needs to be included in the hazard analysis. SAR currently discusses only leaks from He circuit into vacuum space.
5. Standard SAR format should be used.
6. The SAR should be consistent with the GEM TDR. For example, magnet quench propagation and LN2 in the calorimeter issues are discussed in the TDR, but not in the SAR.
7. More emphasis is needed on engineering standards. Standards adopted by other SSCL divisions should be considered for over-current protection, regulation, interlocks, cable management, etc. The SAR specifies several MIL standards but IEEE standards may be more appropriate.
8. The SAR should address advance planning for personnel access systems, alarms and warning systems. These will be more effective, more compatible with other SSCL systems, and less expensive if they are planned from an early design stage.
9. A plan is needed for performing fire hazards analysis and fire protection design analysis.
10. More involvement is needed from engineers and physicists so that hazard analyses will begin to contain technical detail necessary to ensuring hazards are

identified, assessed, and mitigated. Hazard mitigation analysis should include discussions of preventive design features, safeguards, procedures, and training.

11. Hazard analysis of the central tracker butane cooling system could be improved by including a discussions of current state of the design, reviews of the similar SDC system, and historical reliability and safety data.

12. Confined space, ODH, and lock-out/tag-out procedures need more emphasis in both general issues and specific analysis.

13. A separate chapter is needed on Environmental issues. It should contain discussions of radioactive, hazardous, and mixed-wastes, environmental monitoring, identify materials producing mixed waste when irradiated, and analyze options for minimizing mixed-waste.

14. A separate chapter is needed on de-contamination and de-commissioning issues. Need to identify hazardous materials (as defined by RCRA, TSCA, etc.) and develop plans for handling and de-commissioning.

15. Address ALARA standards, i.e. designing equipment to reduce radiation exposure.

16. Discuss susceptibility of detector components to radiation- induced embrittlement.

17. Need to identify accident scenarios that might result in environmental releases of radioactive or chemically hazardous materials.

18. Clarify responsibility for safety of whole experiment.

19. Describe hazards as they exist in different phases of assembly, commissioning, maintenance, and operation. For example, the modes of fire suppression systems may be different in these phases.

20. Discuss preventing damage to the magnet caused by damage to conductor between magnet and dump resistor.

21. A list of hazards that are candidates for inclusion in the SAR: a) induced damage to cryogenic plumbing, b) Krypton ice effects of freezing and blocking or damaging fluid circulation components, c) induced damage to butane plumbing, d) loss of electronic cooling causing thermal or fire damage, e) induced damage to beam pipe, f) magnet quench causing eddy-current effects on GEM systems, g) cryogenic spill effects on structures and supports.

22. A plan is needed for high voltage hazard mitigation.

23. Need to acknowledge and be consistent with DOE standards for mitigating seismic hazards.

24. Need to discuss ways of preventing personnel from entering magnetic field with

metal objects. Active, physical screening should be considered in addition to a program of issuing access cards.

25. Earthquake loading design analysis of support and stairway structures should be made available to the Subcommittee.