GEM TN-92-144

Report of the Superconducting Super Collider Program Advisor Committee

July 10-15, 1992

Abstract:

Report from the PAC on the operations of the SSC Laboratory. Included is a comparison of the physics capabilities of the proposed SDC and GEM detectors, an evaluation of the SDC plans for construction of a detector, an evaluation of the GEM plans for construction of a detector, and guidance for possible smaller experiments.

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July 10-15, 1992
Woods Hole, Massachusetts

1. Introduction

The Program Advisory Committee met from July 10 to 15, 1992, at the J. Erik Johnson Study Center of the National Academy of Sciences, at Woods Hole, Massachusetts. A copy of the agenda is given in Appendix I.

The charge to the PAC for this meeting was presented by Laboratory Director Roy Schwitters and is given in Appendix II. The committee heard presentations from Laboratory staff and from members of the SDC and GEM collaborations.

The conclusions and recommendations of the PAC are given in the following sections.

2. SDC

2.1 Recommendation

The PAC recommends that SDC be approved to proceed to the development of a formal baseline cost and schedule (to be approved by DOE) and a set of agreements between the Laboratory and SDC member institutions that will define respective roles, responsibilities, and commitments during SDC construction.

2.2 Discussion

The SDC submitted its Technical Design Report in April 1992. The Laboratory appointed a review panel (the "SDC Review Panel") composed of PAC members and others with relevant technical expertise, which met from May 4 to 9, 1992. The panel stated in its report that it was impressed by the broad scientific and technical base of the SDC and by the high quality of the Technical Design Report. We concur with the panel that the design of the detector described in the TDR is well matched to most of the physics goals stated by the collaboration. The major concern of the panel was the lack of a credible funding plan for the construction of that detector.

The SDC Review Panel stated:

> "The panel strongly urges the collaboration to examine its actual US. resources and those that can be reasonably anticipated from foreign countries, and present in July a plan to construct a detector within the available funds and with adequate capabilities to execute a strong physics research program at the start of the SSC operation."

The collaboration has now provided such a plan to cover the revised total cost of $595M (FY92), given certain assumptions. These assumptions include the availability of:

1) $225M of SSCL funds (FY90$) plus $50M (FY90$) of the reserve currently held by the Director;

2) $223M (FY92$) from non-US. collaborators;

3) $60M (FY92$) from other US. sources.

Leaving aside the uncertainties of some of these assumptions, the plan falls short of the estimated cost by approximately $20M. The shortfall is addressed by a staging scenario.

The SDC has begun to address the difficult issue of staging components of the detector. They have presented the first draft of a plan to deal with potential shortfalls without substantially degrading the physics program during the initial phase of collider operation. It is imperative that the collaboration continue to explore and develop flexible strategies, possibly including descoping, to deal with funding exigencies. As the available resources become better defined, the collaboration should develop a comprehensive plan describing the initial and final configurations of the detector. The plan should not assume more than $275 M (FY90$) from the SSC construction funds for detectors. The PAC would like a detailed report at its meeting in the summer of 1993.

2.3 Comments

Physics

The collaboration presented some new studies of detector performance on two main physics issues:

i) Intermediate-mass Higgs detection via H --> 2 gamma decay

ii) Impact of staging on selected benchmark processes.

On the first item, a further analysis of signal and backgrounds (beyond that in the TDR) was presented for the associated production processes W + H and t tbar + H, followed by H --> 2 gamma. The novelty of the analysis consists in a systematic evaluation of contributions to the background from radiative decays of W, Z and t or tbar as well as from misidentified electrons and/or jets faking photons. It has been shown by SDC that, assuming a jet rejection of 10-3, most important sources of background involve two real gamma's. The additional background being significant, the necessity of extra cuts has led to a reduction of the expected signal significance by roughly a factor of sqrt(3) with respect to the TDR. As a result, the proponents conclude that finding the intermediate mass Higgs by SDC at the SSC is likely to take several years at design luminosity.

The PAC acknowledges that the above analysis is rather solid and represents important progress toward completion of the TDR study of Higgs detection by SDC. However, the background analysis is not yet completely convincing. In any case, even accepting the analysis of background that was given, the small significance of a potential signal makes clear that the SDC cannot study H --> 2 gamma effectively enough to close the window at low masses for the standard Higgs.

The collaboration also presented a study of the effects on the early physics program that would result from staging parts of the detector. The staging strategy chosen would retain full functionality over a more limited range of rapidities. The principal effect is reduced lepton coverage. Calorimeter coverage would not be staged, since a reduction of its coverage would destroy hermeticity and damage missing ET physics. The study focused on physics topics accessible at luminosities below the design value, leaving aside those that need full luminosity and coverage.

The modest staging envisioned is not a serious disadvantage for most of the physics items considered (heavy quark searches and top studies, W' and Z' searches, SUSY searches,

compositeness limits). A decrease in rapidity coverage from letal < 2.5 to letal < 1.5 reduces the signal only by a factor of 1.5 - 2. The only physics goal that appears to be seriously damaged is the possibility of determining the nature of a newly discovered Z' by precisely measuring the charge asymmetry in Z' --> l+ l- decay -- a notoriously difficult problem.

Tracking

The committee is satisfied with the collaboration's procedure for choosing the technology for the outer tracker. The optimization of the forward tracking system is in progress, and the need for the full forward silicon tracking system is being reexamined. The collaboration is responding to the SDC Review Panel's recommendations for better coordination between the tracking systems. The outer tracking elements have not yet been fully incorporated into the pattern recognition system.

Calorimeter

The SDC Review Panel raised questions about the optimization of the segmentation of the shower maximum detector as a function of eta. The group's response was not complete and the description of the strategies for e-pi and gamma-pi0 discrimination remains inadequate. A more comprehensive discussion of the SDC's capabilities in this area, in particular of the shower maximum detector, is needed.

An alternative source-routing system with the capability of calibrating every tile without opening the end caps has been devised. Some progress has been made in devising cost-saving changes in the mechanical design and assembly techniques. Further efforts in this direction should continue. The group also reported progress in extending the dynamic range of the PMT readout system.

Muons

The SDC Review Panel recommended a reexamination of the thickness of the barrel toroid. The collaboration's response was to retain the 1.5m thickness. In response to the panel's request, the group is reexamining the alignment strategy. The long term stability of scintillation light yield, the design of the forward muon system and the performance of the forward muon trigger remain to be discussed. The PAC also has concerns about the effects of background neutron fluences on the operation of the trigger scintillators.

Magnet

A rather elaborate prototype coil is being constructed in Japan. Tests with this coil will address many of the concerns of the SDC Review Panel. We recommend that the expert consultants on the SDC Review Panel be kept apprised of the progress of these tests.

3. GEM

3.1 General

The PAC was pleased and impressed by the substantial progress made by the GEM collaboration in the design of its detector. The collaboration continues to make progress in forming an organization capable of constructing a major SSC detector. The PAC believes it likely that the collaboration will produce a Technical Design Report that will lead to a successful detector at the SSC.

The collaboration suggested December 15, 1992 as its TDR submission date. A later date would result in a more optimal design and a better TDR. A date in early 1993 should be agreed upon by the laboratory and the GEM collaboration. The committee was particularly concerned with optimization of the calorimetry and would like to hear a presentation on the chosen technology well before the TDR submission date.

The PAC strongly urges the collaboration to examine its actual US. resources and those that can be reasonably anticipated from other countries, and submit with the TDR a plan to construct a detector within the available funds and with adequate capability to execute a strong physics research program at the start of the SSC operation. This plan should not assume more than $275M (FY90$) from SSCL. Substantial effort will be needed to control costs as the detector is further defined and an engineering design is developed.

The GEM collaboration has credibly argued that the engineering for the magnet is on the critical path for the detector. Although the committee is not convinced of the overall optimization of GEM, and very significant technology choices remain for the calorimetry and muon systems, the committee is persuaded that the probability of significant changes in the magnet parameters is small. Consequently, the PAC recommends that the laboratory support and work with the GEM collaboration to develop an optimal design for the magnet, suitable for industrial fabrication and installation.

3.2 Calorimetry

The committee is concerned about the GEM approach to calorimetry, as described in the various documents submitted for the July review (GEM Baseline 1 and responses to the December 1991 PAC Report):

1) The overriding concern is the ability of GEM electromagnetic calorimetry to identify photons. The GEM group aims at excellent electromagnetic energy resolution; however, the ability to reject jet backgrounds was given insufficient emphasis in the design. An impressive and very thorough study of GEM performance, focused on H --> 2 gamma, has been described in GEM-TN-92-126, for both electromagnetic calorimeter options. The results are summarized in Tables 13 and 14 of that document. Some comments follow:

a) Jet backgrounds

From Table 13, we can extract the excess jet background (from gamma-jet and jet-jet), above the "irreducible" background, that remains after shower isolation and shape cuts; as compared to the "irreducible" backgrounds (from gamma gamma + irreducible gamma-jet and jet-jet). The expected rates correspond to 20pb for excess jet backgrounds versus 52pb for irreducible backgrounds with BaF2, and 77pb for excess jet backgrounds versus 58pb for irreducible backgrounds with LAr. For a Higgs mass of 90 GeV, this corresponds to 4-sigma and 2-sigma significances for BaF2 and LAr respectively, in one SSC year. The large uncertainties (of order of a factor of 5 or more) in the jet backgrounds indicate that even these levels of significance may not be achieved.

b) Measurement of photon direction

The BaF2 calorimeter has no longitudinal segmentation and therefore does not provide a measurement of the photon direction. The selection of the highest multiplicity vertex as the primary Higgs vertex has not been demonstrated to be a solution to this problem.

From these considerations, we are concerned that the GEM baseline design may not be adequate for H --> 2 gamma, and for gamma-identification in general.

2) The engineering of a 1-mm Pb LAr accordion calorimeter is difficult and a large scale prototype may well be needed to evaluate the construction method as well as a realistic performance and cost.

3) A coherent (electromagnetic + hadronic) calorimeter design with its associated performance characteristics should be presented. For a hybrid option with scintillating fiber hadronic calorimetry, issues such as calibration, radiation damage monitoring, and overall calorimeter integration and performance should be addressed, including prototype test results wherever possible.

4) The position of the very forward calorimeter, although conceptually attractive, raises concern about its survival and operation at high luminosity and possible increases of neutron fluences in the central cavity.

5) A thorough study of the effect of calorimeter thickness on rates in the muon chambers concluded that 12 lambda and 14 lambda were needed in the barrel and endcap calorimeters, respectively. The calorimetric requirements of instrumenting the last several lambda should be examined.

3.3 Muons

A design goal of the GEM system is to be robust and capable of operating at high luminosities. The GEM muon chambers reside outside the calorimeter system and cover the rapidity range $|\eta| < 2.5$. Momentum measurement is based primarily on a three-point sagitta technique independent of the beam interaction point. The momentum resolution is very good without the use of the inner tracker.

Multiple layers of chambers must be aligned to 25 micrometers in the bending coordinate in order to achieve the desired momentum resolution. L3 has achieved similar alignment but over a shorter distance. Work on the alignment problems should continue.

The technology for the barrel chambers has yet to be chosen. The suitability of the resistive plate counters (RPCs) for large area detectors in the GEM environment has not yet been demonstrated. While properties of the RPCs were presented in response to an earlier question, they should be demonstrated in a realistic prototype. The reliability and aging properties of these chambers in the GEM environment should also be studied.

The performance of the muon system, particularly at high luminosity, should be demonstrated with detailed simulation. The influence of neutrons on detector triggering and measurement must be further clarified. We note that the quoted neutron fluences discussed in section 16 of GEM TN-92-76 Rev C appear to be very large outside the central cavity.

3.4 Central Tracking System

The central tracking system proposed by the GEM collaboration consists of 6 silicon layers followed by interpolating pad chambers. The tracker, which covers the rapidity range $|\eta| < 2.5$, provides primary vertex measurement and sign determination of electrons for $p < 400$ GeV/c, and assists in the identification of electrons, photons and hadrons. The system is well matched conceptually to the physics goals of GEM, but important technical issues must be resolved.

The committee recommends that the performance of the IPC's be demonstrated in tests of large scale prototypes, including results on spatial resolution, integration time, and the effects of

aging. The implications of the analog pipeline readout scheme on such matters as the latency of the level-1 trigger, signal/noise, cost, etc. should be clarified. There is some concern that the close proximity to the beam and the proposed high-luminosity operation of the silicon tracker present serious risk of radiation damage. We recommend further study. Special attention should be paid to the danger of damage during commissioning and injection. More work is also needed to determine the electron identification performance at high luminosity. The collaboration should try to avoid duplication of effort in designing the silicon tracker and its electronics by collaborating with the SDC group.

4. The Initial SSC Physics Program

4.1 Preamble

The SSC Laboratory encourages and supports a diverse initial research program that addresses the rich new physics opportunities to be realized at the SSC. The Program Advisory Committee believes that a healthy initial program requires two detectors with complementary as well as overlapping strengths that address the physics at high transverse momentum. Two detectors are needed to provide for independent confirmation of discoveries and for the competition and breadth that will ensure effective exploration of the potential of the SSC. It is also important that as broad as possible a community of physicists have the opportunity to pursue research at the laboratory. These goals will be effectively served by having two distinct major detectors ready to do experiments at the turn-on of the accelerator.

The following sections give the PAC's evaluation of an SSC physics program based on the SDC and GEM detectors. In addition, we comment on the role of the smaller experiments.

4.2 The SDC and GEM Detectors

The SDC and GEM detectors are based on very different design architectures and subsystem technologies. SDC has emphasized outstanding tracking capabilities in a strong solenoidal field while GEM has focused on high quality electromagnetic calorimetry and robust muon measurement. The commissioning of two large multi-purpose detectors with distinct but complementary technologies allows a two-pronged probe of anticipated physics discoveries as well as radically new unanticipated phenomena. Together, such detectors enlarge the window of discovery opportunities and provide the means to confirm and thoroughly explore initial hints of "new physics" that are likely to be unveiled at the ultra-high energies of the SSC.

Below, we discuss the abilities of the SDC and GEM detectors to study the physics of the standard model and beyond, based on the material received and on discussions of the technical capabilities of the detectors.

4.3 Physics Potential

Finding the Higgs boson is a benchmark process for both SDC and GEM. Both detectors are extremely well suited for discovering a Higgs boson in the mass region 130 < MH < 800 GeV through the decay H --> 4 leptons. The missing ET capabilities of both detectors will also add to their ability to study the heavy Higgs, via modes like H --> Z Z --> l lbar nu nubar.

The mass region 80 < MH < 130 GeV is the most challenging for the detectors. The H --> 2 gamma decay mode is extremely difficult to observe. The required good photon identification, together with the excellent electromagnetic resolution aimed at in the GEM detector design, should provide the capability for discovery of the H --> 2 gamma decay channel.

Studies of WW, W gamma, WZ, and ZZ production at the SSC provide useful tests of the standard model as well as signatures for "new physics" such as heavy Higgs scalars, technicolor, etc. Both SDC and GEM are well designed to study those channels. Their strengths in electromagnetic calorimetry and missing ET determination should allow precision W gamma studies (e.g. the W anomalous magnetic moment) as well as good reconstruction of the WZ invariant mass.

If the top quark is not discovered at Fermilab before SSC turn-on, both SDC and GEM are capable of discovering it and thoroughly investigating its properties. The top quark mass will be measured with high precision and top decays will be studied. For those aspects of top physics that require b tagging, the SDC tracking advantage and GEM lower muon momentum trigger provide complementary strengths. Those features may be particularly useful for the associated production of a Higgs boson or other "new physics" with t tbar pairs and the search for top decays into charged Higgs bosons or other rare modes.

The B physics capabilities of SDC and GEM have not been extensively studied by the proponents. Such studies would be useful to complement studies of dedicated B physics experiments for the SSC.

The discovery potential for supersymmetric particles such as gluinos and squarks can be evaluated via different signatures that basically probe all detector components. The different detector technologies employed by SDC and GEM offer comparable discovery potentials for supersymmetric particles.

The current understanding of experimental signatures of supersymmetric (SUSY) Higgs bosons requires the identification of tau leptons in addition to the quoted Standard model Higgs channels. Excellent tracking and possible tau-trigger capabilities together with good calorimeter granularity should allow tau identification. Even though SDC has emphasized these requirements, a fair comparison can be only be performed after an evaluation of these processes has been presented. In order to cover a large area of the SUSY parameter space for the discovery potential of the h0 --> 2 gamma channel, experiments must deal with smaller event rates as compared to the standard model Higgs case. Therefore, a detector especially designed for excellent photon resolution and identification offers a clear advantage for this channel. The discovery potential using the 4-lepton mode is restricted to a limited area of parameter space and can be covered equally well by SDC and GEM.

The discovery of the heavy vector bosons (W', Z') requires lepton identification at high lepton transverse momenta. Since background is not expected to be a serious concern, the discovery potential is dictated by the available integrated luminosity, resulting in similar mass limits for SDC and GEM at design luminosity. The proposed muon system of GEM, expected to be robust at higher luminosity running, should allow access to very high masses in the mu+ mu- channel. Measurements of the Z' forward/backward asymmetry require lepton charge determination at large rapidities. High statistics and, depending on the heavy vector boson mass, high luminosity will be needed in this case.

Searches for substructure of quarks rely on the calorimeter response to jets at very high jet transverse momenta. Signatures of compositeness have been studied by both collaborations. Different calorimeter technologies and analysis techniques have been proposed by SDC and GEM, resulting in comparable discovery potentials, expected to be limited only by the available statistics.

4.4 Conclusions

The scientific program that can be addressed by these two detectors is very broad, covering a wide range of physics topics suggested by the standard model and its various extensions.

The two detectors employ different technologies. SDC emphasizes excellent tracking while GEM emphasizes electromagnetic calorimetry and muon robustness. Having these very different technologies reduces susceptibility to unforeseen problems encountered in the high rate, high energy domain of the SSC. The breadth of the program will also enhance our capability to search for and investigate unanticipated physics that almost certainly will be present in this unprecedented new energy domain.

4.5 Smaller Experiments

The PAC reiterates its recommendation to reserve $75M (FY90$) of SSC detector projects funds to support anticipated future proposals.

A strong and diverse SSC program must have the ability to mount experiments in addition to the two major detectors. There is a wide range of interesting and important topics that should be addressed and may require specialized detectors. In addition, discoveries in the years before SSC turn-on may well point the way to experiments that are not presently contemplated. The ability to use the power of the SSC to respond to such developments must be ensured.

The PAC, in its report of July 1992, recommended that the Laboratory issue a call for proposals to be due in late 1993 or early 1994, and that prior to such a call, workshops be held to encourage interest and focus efforts. We note that some workshops have already been held and others are planned. In our view, it is still appropriate to issue a first call for proposals to be due in 1993-94.

The PAC anticipates that the proposals for smaller experiments will span a range of physics topics, costs, and set-up times. We expect that such proposals will continue to be submitted throughout the lifetime of the collider.

Appendix I: Agenda of PAC meeting, July 10-15, 1992 at Woods Hole

Friday, July 10		
9:00-12:00	General discussion	
1:00- 6:00	SDC presentations and discussion with PAC	
1:00	Funding plan, detector scope	G. Trilling
1:45	Discussion	
2:15	Tracking	A. Seiden
2:45	Discussion	
3:00	Calorimetry	D. Green
3:30	Discussion	
3:45	Break	
4:15	Muon system	J. Bensinger
4:45	Discussion	
5:00	Electronics and trigger	W. Smith
5:25	Other electronics system issues	A. Lankford
5:45	Discussion	
6:00	Adjourn	
Saturday, July 11		
9:00-12:00	SDC presentations and discussion, continued	
9:00	Physics performance update	K. Einsweiler

9:40	Discussion	
10:00	Management update	T. Kirk
10:15	Discussion	
10:30	Break	
11:00	Discussions	
	Resources and funding plan	
	Staging scenario	
	Physics performance implications	
	Other	
1:00- 6:00	GEM presentations and discussion with PAC	
1:00	Progress and status of GEM	B. Barish
1:10	Discussion	
1:15	Overview of GEM baseline	M. Marx
1:45	Discussion	
2:00	Baseline physics performance	K. Lane
2:30	Discussion	
2:45	Central tracking	C. Baltay
3:10	Discussion	
3:20	Break	
3:50	Calorimetry	Y. Kamyshkov
4:25	Discussion	
4:40	Muon system	F. Taylor
5:15	Discussion	
5:30	Electronics/DAQ	D. Marlow
5:55	Discussion	
6:00	Adjourn	

Sunday, July 12

9:00-12:00	GEM presentations and discussion, continued	
9:00	Magnet	G. Deis
10:00	Discussion	
10:25	Path to TDR	W. Willis
10:30	Discussions	
	GEM organization	
	GEM costs/financial plan	
12:00	Adjourn	

Monday, July 13

8:30-12:00	Plenary session:
	Lab presentations/general discussions
1:00- 3:00	Detector subcommittee sessions:
	SDC
	GEM
3:00- 5:00	Physics subcommittee sessions:
	W, Z, top, Higgs, ...
	SUSY, compositeness, ...
5:00- 6:00	Plenary session: organize discussions

Tuesday, July 14

8:30-12:00	Plenary session: discussions
1:00- 6:00	Writing and discussions
	SDC
	GEM
	Comparison

Wednesday, July 15
9:00-12:00 Final discussions/summary
12:00 Adjourn

Appendix II: Charge to the Program Advisory Committee, July 10-15, 1992

The recent decision by the House of Representatives to cut funding for the SSC, while disturbing, is only the first step in a budget process that now moves to the Senate. We hope that the Senate will reverse the House action and restore funding and substantial efforts have been underway toward this end. In its deliberations at this meeting, the PAC should act as though the funds will be restored; only in this way can we assure that the experimental program remains on track.

I) Compare and contrast the physics capabilities of the proposed SDC and GEM detectors.

* Will an initial scientific program based on these detectors meet the expectations envisaged by the PAC in its 1990-91 guidelines?

* What, if any, significant gaps or deficiencies in physics coverage would exist in a program with these detectors?

* Describe the complementary features of the two detectors.

II) Evaluate SDC's plans for constructing their detector and consider recommending to the Laboratory proceeding to the development of a formal baseline cost and schedule (to be approved by DOE) and a set of agreements between the Laboratory and SDC member institutions that will define respective roles, responsibilities, and commitments during SDC construction. Such a recommendation would be the final PAC action leading to construction of SDC. Satisfactory development of the project baseline and agreements is still required before construction could begin. The PAC would be asked to review, but not necessarily approve, the baseline and agreements.

III) Evaluate GEM's plans for constructing their detector.

* Confirm the date of submission of the Technical Design Report and plans to review the report.

* Present to the Laboratory the PAC's views on the advisability of proceeding with further engineering and initial acquisition steps of the GEM solenoid coil prior to approval of the GEM TDR.

IV) Provide guidance on how the Laboratory should deal with expressions of interest for smaller experiments and/or new calls for proposals.