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SDC RESPONSE TO THE MAY 1992 PAC REVIEW

10 July 1992

This report differs slightly from the version submitted to the PAC at its July 10-15, 1992 meeting. The version given to the PAC contained more detailed analyses of U.S. and non-U.S. contributions than given here. These details are viewed as too sensitive to be included in a public document, but the final results are given in Table 6 of this report.

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Table of Contents

1. Introduction and summary . . . 1
2. Central tracking system . . . 1
   2.1. Forward tracking system . . . 1
   2.2. Other tracking issues . . . 3
3. Superconducting magnet . . . 3
   3.1. The prototype magnet . . . 3
   3.2. Coil design . . . 4
   3.3. High stored energy/unit mass, quench warming . . . 4
   3.4. Internal and external axial stops . . . 4
   3.5. Return lead . . . 4
   3.6. Winding method . . . 5
   3.7. Structural epoxy in highly loaded structures . . . 5
   3.8. Cryogenics . . . 5
   3.9. Integration of the solenoid in the detector . . . 5
   3.10. Cost estimate . . . 5
   3.11. Risk reduction . . . 6
4. Calorimetry . . . 7
   4.1. Shower Maximum Detector Segmentation . . . 7
   4.2. Recent progress . . . 7
   4.3. Cost revisions . . . 9
5. Muon system . . . 9
   5.1. Magnet issues . . . 9
   5.2. Chamber issues . . . 11
   5.3. Alignment issues . . . 11
   5.4. R&D program . . . 12
   5.5. Fabrication issues . . . 12
6. Electronics . . . 12
7. Safety, experimental facilities, and installation . . . 13
8. Physics update . . . 15
   8.1. Radiative decays of W, Z, and t . . . 15
   8.2. Additional lepton backgrounds . . . 16
   8.3. Additional QCD backgrounds . . . 17
   8.4. Updated results . . . 17
   8.5. Summary . . . 18
9. Updated cost estimate . . . 19
10. Resources . . . 21
   10.1. Present funding plan . . . 21
11. Detector staging possibilities . . . 22
12. Impact of staging on physics performance . . . 24
   12.1. Physics program during the first years of SSC operation . . . 25
   12.2. Staging scenarios . . . 26
   12.3. Summary . . . 28

1. Introduction and summary

In this report we present the SDC response to questions and concerns raised in the Report of the SSC Laboratory Program Advisory Committee Review of May 4–9, 1992 [1]. We also present an updated cost estimate for the SDC detector and provide the present status of identifying U.S. and non-U.S. sources of funds for the construction of the detector. Finally, we discuss possible staging scenarios, the cost deferral that may result from staging and the impact of staging on the physics performance of the detector.

The estimated cost to construct the SDC detector, starting in FY1993, is presently about $575M (all costs will be expressed in U.S. FY1992 dollars). By the end of U.S. FY1992, approximately $20M from SSC detector project funds will have already been expended. Hence, a total of about $595M in total U.S. equivalent financial resources is required. We believe that it is plausible to identify now about $575M in U.S. equivalent terms of which $292M would come from the SSC detector project funds, about $223M from outside the U.S and about $60M from the U.S. base program and the Texas National Research Laboratory Commission. This would leave an apparent shortfall of about $20M in U.S. funds, which, unless additional funding were found, would necessitate the implementation of a staging scenario.

We have examined staging scenarios that would delay completion of the full detector by up to four years (including shutdown for installation of staged systems) after initial turnon of the SSC, and yet allow having a detector at turnon with substantial physics power. This approach is, in part, predicated on the assumption that it may take about three years for the SSC to reach design luminosity. If such staging does become necessary, we would primarily propose to delay completing the rapidity coverage of some subsystems of the detector and to delay full implementation of the trigger system. The maximum U.S. cost deferral obtainable by substantial staging (leading to a significantly incomplete detector at turnon) is estimated to be about $30M. In the case of substantial staging, additional funding at the level of about $15M per year (mostly from the U.S.) would be required after SSC turn-on, including enough non-U.S. funding to complete all staged non-U.S. obligations. To complete the detector for optimal operation near design luminosity, a shutdown of approximately one-year duration, about three years after turn-on, would be required. Some additional time for recommissioning of the collider and detector would be needed after completion of this installation.

The maximum $30M U.S. cost deferral allowed by our staging scenarios covers with a slight safety margin the $20M funding shortfall. Our major uncertainty at this time is the total level of non-U.S. contributions. We have some additional safety factor with respect to non-U.S. funding shortfalls or delays in that our staging scenarios also lead to maximum non-U.S. deferred costs of about $20M. Nevertheless, we would like to recommend that the $80M (FY92$) small-detector set-aside be held in reserve until these funding issues are resolved (as suggested already in the International Funding Plan submitted during the May PAC Review).

2. Central tracking system

2.1. Forward tracking system

We discuss in this section the rationale for the design of the forward tracking detector in the SDC baseline design, since this was the major question raised by the tracking subcommittee at the May PAC meeting. We believe that this part of the detector has been reasonably well optimized based on the extensive studies of the tracking in the central region, but further work is still needed. The concept for how the elements of the forward system function together is very similar to the central region tracking, although the silicon plays a larger role in the momentum resolution. Full simulation studies, including effects of the magnet field nonuniformity, however, still need to be completed. These are in progress and will be used for a final optimization.

We take the forward system to be the tracking in the pseudorapidity range $1.8 < |\eta| < 2.5$; that is, pseudorapidities beyond the strawtube coverage. In our baseline design, this region is covered by three superlayers of gas microstrip detectors and the silicon disk system (for any given pseudorapidity within the above range only a fraction of the disks are intercepted by the track).

The goals for the large η system are the same as for all the rest of the tracking, namely to provide good charged-particle momentum measurements and sign determinations as well as Level 1 and 2 high-p_t triggering capability, and to participate in electron and muon identification by providing well-measured tracks inside the SDC solenoidal magnet. The presence of this forward system increases the acceptance for the four leptons in 200 GeV mass Higgs decays by about 70%.

This added acceptance will be very important in all Higgs searches below 200 GeV. Both $\gamma\gamma t\bar{t}$ and four-lepton final states have very low rates and require maximum acceptance. The modest p_t of particles in these events is well matched to the baseline resolution of the forward system, as quantified below. The reconstruction of narrow Higgs mass peaks will be critical to define discovery in this mass regime. The $\gamma\gamma t\bar{t}$ final state will yield complex events with particles over a large pseudorapidity range. A high acceptance, high performance tracking device allows several techniques for top identification and background rejection. These may be useful if backgrounds are larger than anticipated. In particular, the vertexing capability allows a check that isolated leptons come from the primary vertex and that the event contains b decays displaced from the primary vertex.

The design of the detector is based on several considerations. The dimensions and number of gas microstrip planes are determined by the goals for the Level 1 trigger. High efficiency requires an OR of two planes per superlayer. Sufficient fake rejection requires three superlayers. The desire to have, at the trigger level, a p_t measurement of precision approximately 10% at 10 GeV/c defines the extent in z and segmentation in η for the system.

The number of silicon disks has been chosen to provide a radial lever arm within the silicon which varies with η by at most $\pm$ 10% from its average value of about 27 cm. This gives a smooth momentum resolution without large jumps or dips as a function of η. The silicon is a key element of the forward momentum determination, as quantified below. Finally, the baseline system has a maximum radial distance between the silicon and its nearest gas microstrip layer about equal to the radial displacement between the silicon barrel and the first strawtube layer, allowing for comparably good matching of tracks between systems.

The forward tracking system provides the main muon momentum measurement for p_t up to a few hundred GeV/c even at $\eta = 2.5$. The accurate momentum measurement of electrons, with typical p_t of 50 GeV/c, is necessary for calibrating the calorimeter. The length of time for such a calibration is a strong function of the resolution as is the ability to define well measured tracks. A good calibration will be very important for all Higgs searches, and in the case of the $\gamma\gamma$ final states from the $\gamma\gamma t\bar{t}$, we rely entirely on the calorimeter accuracy to reconstruct the narrow mass peak required for discovery.

To give an indication of the role of the silicon disks, we compare in Table 1 the momentum resolution at $p_t = 100$ GeV/c for the baseline system and for a system of gas microstrips alone, with and without a 10 micron beam constraint (B.C.). Numbers are the average over $1.8 \leq |\eta| \leq 2.5$. The numbers at $\eta = 2.5$ are about a factor of two worse than the average.

Table 1
Forward momentum resolution with and without the silicon system.

	Baseline		Gas microstrips only	
	B.C.	No B.C.	B.C.	No B.C.
σ_{p_t}/p_t at 100 GeV/c	3.0%	4.5%	13.2%	100%

Without the silicon the measurement is much poorer and very dependent on the beam constraint with little ability to verify that it is correct. Leptons from secondary vertices, decays, or beampipe conversions, can be assigned very inaccurate momenta. In the baseline design, the momentum measurement is much less dependent on the beam constraint and the impact parameter measurement of about 30 μm for p_t = 100 GeV/c and $\eta = 2.5$ provides a good check that a given track does come from the primary vertex.

Although these numbers make clear the critical need for at least a significant part of the silicon disk system, they do not answer whether the overall forward system is optimized. The principal issue here is one of robust pattern recognition in a very crowded environment. In this connection it should be noted that the silicon tracker sits in a region of nearly constant magnetic field (B varies from 2.0 to about 1.9 tesla), whereas the gas microstrip system is in a region where the magnetic field varies substantially (B drops to about 1.4 tesla at the outermost superlayer). Thus the pattern recognition in the silicon, where a constant solenoidal field can be assumed, should be significantly simpler at modest p_t values, so that it is advantageous to have an adequate number of measurements in this system. Although more simulation is required to establish a fully optimized design, the work to date indicates that the pattern recognition performance for the baseline would be sufficiently good in this pseudorapidity region. Further simulation work is in progress.

2.2. Other tracking issues

We respond here to several other issues raised. The PAC suggested that the tracking systems would benefit from an engineer responsible for overall integration. Such an engineer, M. Hechler, has been designated. We also plan to designate a physicist responsible for coordination of the whole tracking system. This should significantly improve our coordination and integration of all of the tracking subsystems.

A final decision on the choice of outer tracking technologies still needs to be made. We have scheduled an in-depth review of the issues in August. A tracking task force has been working to clarify the strengths and weaknesses, as well as risks, associated with each technology. A set of physics-related questions centering on acceptance and impact of material within the tracking volume will also be addressed.

3. Superconducting magnet

Specific comments from the Review Panel, and our response to them, are given below.

3.1. The prototype magnet

The panel states that the prototype must be completed in time to be useful. They even suggest acceleration of the schedule. It is also suggested that the insulation and test windings need not include the superconductor in the zinc-alloyed aluminum.

The construction of the prototype solenoid is in its middle stage. The production of the test conductor is completed, and the test winding is about to start. We already have enough experience to know that it is not enough for the winding R&D to use dummy conductor such as some aluminum alloy. This is due to the differences in stiffness as well as in the permanent distortion. That is why we are planning to use the actual superconductor for winding. The plan is to perform repeated winding tests for about 30 cm in axial length from June to August, 1992. After obtaining the optimum condition for winding, the plan is to proceed to the epoxy curing, followed by coil cutting to get samples. The samples will be used to examine the actual cross-sectional shape of the conductor-cylinder interface and to perform a series of stress tests to evaluate the strength of the conductor-cylinder joint. The final winding work of the prototype magnet will be done from September to December, 1992.

3.2. Coil design

The high strength conductor, small radiation thickness, and high axial and hoop load design are sufficiently aggressive to require a similarly aggressive test program.

The balance between thickness and weight of the solenoid was pointed out to be "aggressive" by the committee. However, by improving fundamental features of all magnet components, we have confidence that the current design carries higher safety margins than in the past from the overall mechanical and thermal points of view. The point of the current design is an overall optimization, not just a simple reduction of safety margins for thickness. One of the reasons for the prototype construction is to demonstrate the safety margin, just as the committee recommends.

3.3. High stored energy/unit mass, quench warming

The performance of the quench propagation strips should be verified in order to keep the local temperature differences below 75 K.

Our estimate of the temperature rise is at most 110 K even if the full energy is dumped into the coil. In addition, the time constant of thermal propagation between the coil and cylinder is about two orders of magnitude smaller than the critical dumping time of the stored energy. Therefore we do not agree with the opinion of the committee about the possibility of a temperature difference of more than 75 K. We have taken account of this point in the determination of the winding method. Our plan is to complete the formation of the insulation layer of 0.5 mm or less in thickness on the inner surface of the cylinder before we start internal winding of the coil by the roll-back technique. This is the way to guarantee the insulation layer between the coil and cylinder while keeping the thermal resistance minimum between them. We think that it is difficult to accomplish this with an epoxy vacuum impregnation method. The quench propagation can be speeded up by axial strips of pure aluminum. The effect was already demonstrated by the superconducting magnet built for a balloon experiment. We plan to examine the behavior of quench speed in the prototype magnet under construction.

3.4. Internal and external axial stops

A set of internal and external stops are recommended to address the possibility of a serious unbalance of forces in the 10's of tons that can be created by a magnet fault or an iron misassembly.

It is quite difficult to install any stops inside. However, it would be very effective to set, if possible, some stops outside the cryostat. The stops would avoid excessive displacement between the coil and calorimeter and also sustain any excessive decentering force in the unbalanced situation. It is, however, difficult to accommodate them into the present calorimeter design. The whole issue is still under study.

3.5. Return lead

The return lead creates a magnetic field disturbance at the beam line. The cooling and mechanical stability of the return lead must also be worked out.

Although the experience in TOPAZ at TRISTAN tells us that there is no significant effect on the beam from the return lead, we will study this for the SDC detector. The present design takes account of the requirements for cooling and thermal stability of the return lead.

3.6. Winding method

Significant changes relative to the coil winding technique used for TOPAZ are necessitated by the use of a stiffer conductor. This may lead to serious difficulties that may not appear until the first trials. This is the most crucial R&D. Particular attention must be given to ensure a radial prestress and sufficient axial compression to eliminate waviness or tilting of the conductor.

We think that there is adequate technical experience in the principle of the internal winding technique. It is our understanding that R&D is still required to examine the spring-back effects of the stiffened conductor. The radial prestress can be applied and its effectiveness is large. However, we believe that the axial prestress is not so strongly required. Even if we apply the axial prestress, in practice it is hard to maintain the prestress during the curing process. The axial prestress is not important enough to justify such a technical challenge. It is sufficient to take thorough measures so as not to generate gaps between windings.

3.7. Structural epoxy in highly loaded structures

The axial load is supported by the shear in the coil-to-spool B-stage epoxy joint and the loading of the compressive modulus of the half-winding. The distribution of load and the stresses have been calculated assuming 0.5 mm insulation, idealized geometry and perfect bond. The epoxy bonding technique should be carefully re-examined to make sure of its perfect integrity, and the epoxy vacuum impregnation be reconsidered as an alternative.

We do not understand the committee's proposal for an alternative method because, based on our R&D, the epoxy vacuum impregnation does not generate sufficient bonding strength of epoxy. It is commonly understood among experts that vacuum impregnation is accompanied by many technical risks. Without sufficient merits for this technique, it should not be adopted. The bonding technique proposed has been shown to be sufficiently stable in the construction of the TOPAZ solenoid. We will continue the structural analysis including the cases of imperfect bonding.

3.8. Cryogenics

The committee encourages a dedicated helium refrigeration system for the SDC solenoid to assure its continued and uninterrupted operation.

The SDC agrees with the panel's recommendation.

3.9. Integration of the solenoid in the detector

The long chimney, the service port, control dewar, transfer lines as well as solenoid suspension must be secured and protected from hazardous interference with other detector parts. They should never be reopened or dismounted for access to other parts.

We are proceeding just as the committee recommends.

3.10. Cost estimate

Although the detailed breakdown is not provided for the solenoid, the cost appears to be justified and should be sufficient. The cost of the refrigerator seems rather high.

The cost estimate of the coil includes substantial contingency as has been pointed out. We would like to keep the current estimate until we obtain results from the R&D for the prototype solenoid. The refrigeration power depends also on the recovery time from quench. It is not ruled out to extend the recovery time from present 4 hours to 8 hours to reduce the capacity of the refrigeration system, thus leading to a cost reduction.

3.11. Risk reduction

Electrical failures could be very serious, firstly because the induced axial forces might damage components besides the coil itself, and secondly because the repair would take a long time. Failures may occur after years of running. Successful testing does not guarantee that problems will not develop later. Therefore, we recommend that:

1. *A risk analysis be performed, using as data a review of previous failures.*

We are going to perform the risk analysis in the future.

2. *A more detailed structural analysis be made of the stress on the epoxy and coil elements in the region of ends of the solenoid, including allowances for imperfect epoxy filling and consequent reductions in ideal Young's modulus and strength of the filling.*

The R&D on epoxy as well as the structural analysis will be continued. The effects of imperfect epoxy bonding can also be studied experimentally with the prototype solenoid.

3. *Consideration be given to increasing the insulation between the coil and ground planes.*

We are not able to understand the real meaning of this comment. The strength of epoxy bonding will be reduced in the case of thicker epoxy bonding. The present bonding thickness is sufficient for electrical insulation. The proposed winding method allows a ground insulation test before the conductor winding starts, and thus provides redundant examination of the insulation. The vacuum impregnation, on the other hand, does not allow such step-by-step checks, resulting in thicker bond thickness for reliable insulation.

4. *The need for such a low radiation length thickness and consequent use of Zn-Al alloy be reconsidered.*

The necessity of thin radiation length comes directly from the requirement of high performance of the EM calorimetry. The coil must be long enough to cover a wide rapidity range. Consequently, at the high rapidity region around $\eta = 1.5$, the radiation thickness of the coil as seen by passing particles exceeds 2.8 X_0, as shown in Fig. 5.5 of the TDR. It is experimentally known that the EM energy resolution deteriorates very rapidly beyond 3.0 X_0. The use of a soft conductor would add material contributing at least 0.4 X_0 at $\eta = 0$ and 0.8 X_0 at $\eta = 1.5$. The use of aluminum-stabilized conductor with additives has already been investigated in the course of R&D on superconducting coils for space experiments, and therefore this is not a new challenge. Based on this experience, we have sufficient confidence in the success of stiffened aluminum-stabilized conductor with additives. As mentioned earlier the conductor for the prototype solenoid has been successfully fabricated.

5. *Consideration be given to extending the central part of the endcap calorimeters into the ends of the solenoid. This would greatly reduce, and could even eliminate, the large axial forces on the end turns of the solenoid.*

The comment is indeed natural if one does not consider other effects, such as large decentering force, performance of the EM calorimetry, space needed for supports and cables of the inner trackers, and access capability. We have some time ago evaluated the pro and cons of the reentrant endcap configuration. As described in page 6-20 of the SDC TDR, although such a configuration provides a more uniform field inside and a smaller compressive force in the coil, the reentrant endcap creates a discontinuity in the EM calorimetry plus difficulties in space and access capability. Based on recent technical progress through a series of construction experiences of superconducting coils and on finite element analysis, the support of the axial compressive force is realistic from the engineering and technical points of view. The real demonstration will be provided by testing the prototype solenoid.

4. Calorimetry

4.1. Shower Maximum Detector Segmentation

The PAC noted that further optimization of the Shower Maximum (SM) detector strip width and length as a function of η might result from additional studies of physics processes not described in the TDR, for example detection of τ leptons and separation of single photons from π^0's. The primary purpose of the SM detector is to aid in identifying electrons. The SM detector strip width in the baseline design was chosen to approximately match the typical size of an electromagnetic shower, while at the same time satisfying mechanical constraints in both width and length set by the construction technique in the EM section of the calorimeter. Cost considerations also led us to the longest length allowed by the mechnical constraints and studies of pileup at high luminosity. The strip width was chosen to be the largest value allowed by the mechanical constraints, consistent with our goals for electron identification.

We are in the process of studying the electron identification/pion rejection performance and the ability to discriminate between π^0s and single photons as a function of η and allowable strip widths. Similarly studies of τ identification via its $\rho\nu$ decay are underway. Both require the identification of π^0s, which depends on the SM detector strip width.

4.2. Recent progress

4.2.1. Calibration

The PAC noted that tile/fiber scintillator-based calorimetry requires careful attention to calibration. In the Technical Design Report, a radioactive source calibration scheme was described. Only a fraction of the tiles in a typical barrel tower could be exposed routinely to the sources. Precise calibration of all tiles required movement of the endcap calorimeter and mounting of temporary source drivers on the barrel. We are considering an alternative scheme to route all source tubes up through the barrel/endcap crack so that they may be accessed without moving the endcap. This layout allows source calibration of any tile at any time. It also avoids some of the complex machining of the source grooves in the absorber plates, which leads to a small reduction in the absorber cost.

4.2.2. Radiation damage

Scintillation based calorimetry requires a careful study of radiation resistance. Electron beam exposures have been conducted at IHEP (Beijing) at doses up to 6 Mrad to begin to simulate conditions in the endcap corresponding to significant accumulated luminosity. The test module was constructed with several wavelength shifting (WLS) fibers per tile to provide a reduced optical path length at short (blue) wavelengths. Preliminary results indicate the radiation resistance of such a configuration is at least double that of our standard tile/fiber configuration.

Studies with a longer wavelength tile/fiber (green/orange) combination at the University of Michigan and Tsukuba University are also underway. These studies are also aimed toward improving radiation resistance in the endcap. Preliminary results indicate the feasibility of operation up to doses of 4–5 Mrad, using red-sensitive phototubes to read out the two EM depth segments in the endcap.

We have obtained a faster green wavelength shifter dye (G2) and are testing it for radiation hardness properties. If this dye is sufficiently radiation hard, the calorimeter response time can be improved. We have also found a commercial source of silica fibers with thin coatings of WLS dyes, which opens up the possibility of radiation-hard silica-based WLS. This technique might be used for the parts of the endcap exposed to the highest radiation levels.

4.2.3. Dynamic range

The PAC noted that achieving the specified dynamic range (about 18 bits) was difficult. We note that the ZEUS collaboration has achieved a dynamic range near 17 bits [2]. We have also made some recent progress in this area. Hamamatsu is developing several green-extended PMT's with 6 dynode gain stages that are appropriate for the central calorimeter. R&D work at Tsukuba University has been directed toward reducing the switching noise in the Cockroft-Walton bases for these PMT's. Noise levels about 10% of those of the ZEUS Cockroft-Walton bases have been obtained. This implies that the Cockroft-Walton base and the PMT together could achieve the desired dynamic range. There has also been progress in tests of the options for front-end electronics (SCA and FADC) which indicate that the desired dynamic range is achievable. For example, bench tests of the SCA concept yield a dynamic range of better than 12 bits and preliminary tests of an SCA mounted on a VME card give a dynamic range of 13 bits. A twelve-bit range is sufficient in the dual-range system proposed to achieve an overall dynamic range of 18 bits.

4.2.4. Shower maximum detector readout

The PAC noted that the shower maximum detector readout choice has not yet been made. However, there has been progress along several fronts. For example, both Phillips and Hamamatsu are developing new designs of their multianode tubes that show improved crosstalk performance. Our intent is to make tests, including beam tests in 1993, of all three readout options (MCPMT, APD and APD-PMT), after which a choice will be made.

4.2.5. Endcap segmentation

The transverse segmentation in the endcap has been slightly revised to make a smoother transition from the basic 0.05×0.05 (EM) segmentation to larger tower sizes for rapidities greater than about two. These changes are reflected in the draft update of the SDC Parameters Book (Rev. E).

4.2.6. Barrel EM design

The baseline design for the EM barrel section described in the TDR is based on a cast lead absorber. An alternative to this concept would be to use lead plates for the absorber, with the lead/scintillator stack held together by wires under tension. These concepts were reviewed on June 21–22. The baseline design was retained, but the review has led to a number of ideas for reducing the cost of fabrication of the EM section. These include the concept of using "megatiles" rather than individual tile/fiber assemblies.

4.2.7. Prototype

A barrel wedge prototype is being designed and will be tested at Fermilab in summer of 1993. Additional FY1992 funding has recently been provided to initiate fabrication of the components for the prototype. This prototype is intended to have the final configuration of an actual barrel wedge and will be constructed as much as possible with the participation of the international team expected to be responsible for the final fabrication. Negotiations are underway with the PRC for fabricating part of the hadronic absorber. Japan is expected to provide tested scintillating tile/fiber assemblies and phototubes. Although a complete mechanical wedge will be constructed, it will only be partially instrumented with scintillator. One region of the wedge will be completely instrumented for tests of both EM and hadronic response. An EM region at the end of the wedge (near $\eta = 1.4$) will also be instrumented for comparison studies.

4.3. Cost revisions

The PAC raised a number of issues about the cost of the central calorimeter components. A detailed response to the specific concerns raised by the cost subgroup is available, but only a summary is given here. Many items are still under study, and new vendor information is anticipated soon for a few major items, *e.g.*, the barrel hadronic absorber structure.

The design has been modified to use a barrel wedge covering 1/32 of the azimuth. This decision leads to a reduction by a factor of two in the number of hadronic absorber plates. Tolerances are also considerably loosened since two wedges, each covering 1/64 of the azimuth, are no longer hermetically mated together. Alternative construction techniques for the hadronic absorber are still under study with possible vendors. New cost information from these vendors is expected to be available in July, at which time we will revise the detailed cost estimate. Preliminary revisions are included in the detector cost estimate given in section 9.

Since the PAC meeting, we have investigated production of "megatiles," namely large scintillator pieces that are grooved to produce the required lateral segmentation in an attempt to reduce the piece count and hence the scintillator tile/fiber assembly costs. For example, with such large tiles (2×2 towers), there are only 1/4 as many physically distinct scintillator pieces in HAD1 and HAD2 as in the TDR design. Test cuts of large tiles have been made at FNAL and Tsukuba University.

The use of "megatiles" in the EM compartment has also been contemplated. The number of physically distinct scintillator pieces in the electromagnetic (EM) compartment is then reduced by a factor of four with respect to the design presented in the TDR. For the HAD, EM and SM the use of larger assemblies decreases costs by reducing handling, storage and sorting. We expect that the cost estimates will be further refined as we gain experience with this technique.

We have revised the cost estimate to take account of phototube breakage during construction. We have also added the cost of additional lead castings to the estimate to allow for possible failure of a few of the castings during fabrication, transportation, or assembly. For the hadronic section, the prototype will represent an extra module.

Finally, we are in the process of revising the estimated cost of production facilities, based on the availability of known space and services at Fermilab, ANL and LBL. The estimate presented at the PAC review did not take into account the availability of such facilities.

5. Muon system

5.1. Magnet issues

One of the issues raised by the committee concerned the installed cost of the magnet. It was pointed out that, from past experience, the installed cost of large magnets is greater than \$1/lb. In calculating that measure for the SDC toroids, the committee apparently used more than the total weight of the detector including the calorimeters, namely 70 million pounds, giving a unit cost below \$1/lb. If the calculation had used the weight of only the magnet, namely about 50 million pounds, the overall cost estimate of \$59M would have been consistent with the unit cost from past experience.

In addition to the general concerns about cost, the committee made specific suggestions about possible cost saving measures that might be employed to reduce the overall cost of the detector. In particular, the possibility of reducing the thickness of the barrel toroid was raised. In the past we have considered reducing the toroid thickness from 1.5 to 1.0 m. This was rejected on the grounds that, with the reduced bending power, the trigger rate for the Level 1 muon trigger would be too close to our upper limit. Furthermore, the falloff of the rate with an increased p_t threshold would be too slow to provide an effective adjustment if the Level 1 trigger rate turned out to be higher than expected. In addition, a reduction in the thickness of the toroid would, for our current design, have the undesirable consequence of increasing the stresses in the bolts holding the iron blocks together.

The committee suggested that we consider an intermediate thickness between 1.0 and 1.5 m to see if substantial savings could be obtained without seriously compromising performance. In particular we have looked at the possibility of a magnet thickness of 1.3 m. We estimate a cost saving of $2.8M on the magnet and an additional saving of $1.7M on the muon measurement system for a total reduction of $4.5M.

The physics issue in this modification is again largely that of the Level 1 trigger rate. We are still in the process of doing detailed simulations of these rates, but based on our previous work, we estimate that the rate at design luminosity for a 20 GeV/c p_t threshold increases from about 3 kHz to about 4.5 kHz to be added to another 3 kHz from the forward muon system. These calculations assume a 5 cm rms longitudinal beam spot. The rates would further increase if the beam spot were to be larger, with the impact of the thinner toroid being greater in that case. Furthermore, past experience indicates that muon systems often have higher than expected trigger rates (as was for example the case for the new Central Muon Extension System in CDF). We therefore consider it risky to propose a reduction in toroid thickness at this time just on these physics performance grounds.

In addition, as already mentioned, there are structural issues to consider. While the weight of the barrel toroid varies approximately linearly with thickness, its stiffness goes as the cube of the thickness. A reduction in stiffness will increase the stresses in the bulk steel and in the corner bolts. The stress in the bulk steel is sufficiently low that this increase is not a problem. However the corner bolts are the critical mechanical component in the barrel toroid. Their size has been pushed to the maximum diameter geometrically possible with the current design. This provides a comfortable safety factor for the current stress levels, but a more marginal safety factor if the toroid thickness is reduced. Because such a reduction causes a larger fractional decrease in bolt lever arm than in barrel toroid weight, the bolt stress increases. Hence a reduction in the thickness of the barrel toroid would require a reevaluation of the engineering design. If the change is modest (say to 1.4 m), it may be possible to keep the current design of the barrel toroid. A major change (say to 1.1 m) would almost certainly mean that both the barrel toroid corner joint and the alignment system require new concepts. In conclusion, while it is difficult to argue about the difference between 1.5 m and, say, 1.4 m thickness, our opinion is that going to a thickness significantly below 1.5 m involves sufficient risk, both technical and physics, as to represent an undesirable descope.

The committee also suggested that we review the magnet support system for potential cost savings. It was suggested that since the expected motion of the magnet is slight and infrequent, there may be a potential cost savings by going to a "simpler" system, especially one with fewer jacks. In the support system the inclined plates provide the stiffening and allow for the inclusion of muon chambers with a minimum loss of solid angle. The girders between the plates provide torsional stability and balance the transverse forces. The jacking system responds to floor motion and magnet motion during installation of the calorimeter or forward toroids.

We are reviewing the design of the support system to see if it is possible to go to a "jack and shim" type of support. The weight of the magnet on the passive supports replacing some of the jacks will compress those supports by about 0.5 mm for one design that we have studied. The support must be jacked several millimeters to open enough space to insert a 1 mm shim. Because of the stiffness of the support, jacking at only one point by several millimeters creates very large local stresses. Therefore jacking will have to be coordinated over a substantial region of the detector. We are studying alternative designs to evaluate potential cost savings and risk. It is clear that substantial evaluation and assessment of risk will have to made before any alternate to our current baseline can be proposed. These studies are continuing.

5.2. Chamber issues

The Committee suggested that "the BW1 module may need additional redundancy, *e.g.*, doubling the layer number and reducing the tube diameter." Our original design had more redundancy in BW1, as well as in other layers. In descoping the detector to meet cost goals, we reduced the coverage to the minimum number of layers required for what we believe is still a robust system. We would prefer a greater margin of safety in this regard, but it is simply not possible to do this and still meet our cost goals.

5.3. Alignment issues

The purpose of the alignment system is to determine the drift tube wire locations relative to each other and relative to a coordinate system defined by the collider beam and interaction vertex. The alignment system relates the corners of the modules to each other, to the central tracker, and to the accelerator beam line. Information from these sensors, along with temperature data and structural information will provide a description of the behavior of the system and the location of all components.

The barrel and intermediate chambers are mounted on the barrel toroid. The forward chambers are mounted on the forward toroid and absorber system. Chambers must be placed in position well enough that the trigger can function properly. Deflections of the magnet or hall foundation are monitored; and, if necessary for magnet safety or for proper functioning of the muon trigger system, the magnet jacking system is employed to bring the magnet back into proper alignment. The role of the muon chamber alignment system is to monitor the muon chamber positions sufficiently well that off-line corrections to the data can be made. As long as the chambers are sufficiently well placed that the trigger functions properly, only precise knowledge of the muon system location is needed.

Appropriate tolerances for both placement and knowledge of the muon system positions are under study. Each module is considered a rigid body with deviations from that ideal calculated from measurements within the module. Thus for each module in the system there are six degrees of freedom, three coordinate measurements and three rotations about those coordinate axes (pitch, yaw, and roll are rotations about the x, y, and z axes in the local chamber coordinate system). The origin of the coordinate system is defined at the c.m. of the module. The intrinsic error in the trigger due to multiple scattering, uncertainty in vertex position along the beam axis, *etc.* has been calculated. The variation of each degree of freedom such that the error due to that variation corresponds to half the above intrinsic error is used to set the placement tolerance for each module of the system.

In a manner similar to the determination of trigger placement requirements, we can determine the tolerances for knowledge of the location of all chambers in the muon system. We consider the measurement in which the muon system is combined with the inner tracking system to give the full resolution. We require that the contribution to the momentum resolution from errors in our knowledge of muon wire location be limited to that from half the intrinsic resolution of the drift cells (*i.e.*, the contribution to the error by the alignment system is equivalent to that from 150 μm along the drift direction). This is evaluated in the multi-TeV momentum range where the measurement is dominated by the measurement accuracy of the chambers rather than multiple scattering.

The alignment system is still being evaluated. We are reviewing the requirements and evaluating the needs of the system so that specifications for individual components can be set.

5.4. R&D program

The program for the coming year includes the development of a detailed engineering design for the muon system. A central objective of the R&D program will be the verification of the engineering design. We are planning to build a full scale prototype of a barrel supertower beginning October 1992 to be completed by the following October. The supertower will be used to evaluate production techniques, substantiate engineering calculation, appraise the alignment system performance, and obtain operational experience with large scale systems. The latter will be done by fully instrumenting the supertower and testing with cosmic rays. When the IR8 assembly building is complete and the alignment stand is available, the supertower will be moved to the alignment stand and tested for final verification of the design before beginning production.

Similar programs are being started for the intermediate and forward systems. In each case, full verification of the design must be completed before we begin module production.

In addition to the cosmic ray tests, we are planning a test beam program. At BNL we are setting up to look at resolution and two track separation for our final tube design. In KEK we are setting up a "mini-tower" to study the efficiency and resolution of the trigger. Two-track separation measurements have already been made at IHEP (Protvino) and we plan to continue to make use of those particle beams as part of the chamber development program.

5.5. Fabrication issues

The PAC report observes that the muon system is large and complex, that the space available for assembly and storage is limited, that parts of the system come from large numbers of sources (a situation which would stress any QA/QC program), and that the installation schedule is very tight. We agree with all of these comments. In each case these limitations are driven by either budget or schedule or both. The limited storage space has driven us to a "just in time" schedule for delivery of components and fabrication of modules. We agree with the committee observation that failures in production planning or execution can lead to substantial delays and/or cost overruns. Given the budget and time constraints imposed on us, we have no choice other than to do careful planning and take great care in the production and installation process.

We have begun planning for the production of the muon system. A Resource Allocation Model (RAM) has been developed for the production of the muon measurement system. The early development of production models allows better understanding of the utilization of the assembly building, development of component delivery requirements, and provides feedback into the design of the devices. We have established that the space available is adequate to produce chambers, and have developed manpower profiles, component delivery schedules, and scenarios for storage space utilization. We expect to continue this production plan development.

6. Electronics

Although the PAC Subcommittee on Electronics, DAQ, and Computing said in their May report "that there are no substantive issues that need resolution for the July meeting," we comment here on some of the "concerns" which the committee pointed out "will be addressed on their own timescales," in order to reassure the committee that their concerns, which we share, are being addressed.

The SDC agrees that much of the front-end electronics are in the critical path of the detector assembly and that the schedules are extremely tight. In preparing our budget for FY1993, we continue to give high priority to completion of designs of front-end systems. For the major front-end systems, the manpower is now in place to provide timely completion.

The SDC also agrees with the subcommittee that, as the electronics of the SDC detector enter the current phase of systems integration, standardization of hardware and software protocols now demands technical choices in the area of data acquisition, particularly selection of a standard bus and specification of

other standard readout hardware, such as processors and data links. Accordingly, we have also given a high priority in FY1993 to these issues. The readout bus will be chosen jointly by the data acquisition group and the front-end groups, in order to simultaneously address bandwidth and noise performance issues.

The SDC feels that the preliminary definition of the functionality of the Level 1 trigger is now complete, including the division of tasks between Level 1 and Level 2. We will now forge ahead towards understanding the Level 2 trigger in more detail, ultimately leading to definition of the division of tasks between Level 2 and Level 3. We will continue to use Monte Carlo studies of physics and background processes to select and evaluate proposed trigger algorithms for these levels. At the same time we will continue with more detailed design of Level 1, particularly to complete specification of critical components, such as ASIC's, which may have long development times.

The SDC agrees that a well-defined management structure is important to achieving well-integrated electronics systems. Since May, the organization of the management structure has progressed. In the area of front-end electronics, detailed responsibilities for the continued development of straw tracker and muon system readout, which involve major participation by Japanese, U.S., and Canadian groups, have been assigned. A review of calorimeter readout options is now scheduled for late July. Responsibilities for silicon and gas microstrip readout were already in place in May. In addition, we are currently recruiting a physicist to head the SDC data acquisition group at SSCL and actively discussing the systems integration and project management for the trigger area. We are hoping to appoint soon an Electronics Systems Manager.

7. Safety, experimental facilities, and installation

The Subgroup concerned with the interaction hall, surface facilities, installation and safety expressed concerns about several items. We address each of these below.

The area assigned in this building (IR8 assembly building) to the assembly and storage of the muon system was shown to be inadequate during the latter portion of the muon assembly process. Potential solutions to this problem are the rental of space in the local area or an expansion of the storage area on the south side of the building.

We are actively exploring the possibility of renting space in the Palmer area in the vicinity of IR8 to provide additional assembly and possibly storage areas for the muon and other systems. Neither the precise location nor the cost of these temporary facilities can be specified at this time. The need for additional storage space in the assembly building is still under study. The need depends in detail upon the assembly and installation sequence of the muon chambers and upon other assembly needs in the building for calorimetry and tracking. Severe cost limitations have been imposed for all experimental facilities. The ability to expand the IR8 assembly building will depend on more detailed cost information that will be available after completion of Title I design. If these costs are lower than our present estimates, some expansion could be envisioned. However, if the costs are higher, additional reductions will likely be necessary to either the assembly building or to other experimental facilities.

The location of the muon chamber alignment and test stand presents a potential problem. As presently shown it is immediately adjacent to a roll-up door on the east end of the building. The alignment of these chambers is critical. Temperature variations caused by traffic through the door could cause distortions and alignment problems. Relocation of this area to an area more central in the building which could be isolated and temperature controlled is recommended.

We have looked at this question carefully. Our consensus is that an orderly flow of production is most important. We have tried to minimize interference between the final alignment measurement and the assembly process and subsequent storage, which will involve moving large pieces. Hence the alignment stand is located away from the major production flows.

The major disadvantage of the door is not temperature fluctuations but the dirt and dust that can be blown into the building. We did not want to locate the gluing stations near such an area. We have not requested a "clean room" *per se*, but would hope that the interior of the building would closely approximate a clean area.

Opening of the adjacent door should have a minimal impact on the alignment stand for the following reasons:

1. The door will have a standard "plastic drapery" fixture to limit the air exchange while it is open.
2. This is an export door only. The receiving area is at the other end of the muon assembly area. The door will be opened only to export towers for installation. The door will be open for only a small fraction of the time.
3. In an ideal sequence the tower on the alignment stand would be the next to be exported. Thus it would be rigged off the stand and onto a stratocarrier, then moved out the door. Another tower would not be on the stand yet.
4. We have discussed the possibility of building a baffle structure on the outside of the door to minimize air exchange. While this is possible, the plastic curtain should suffice.

During the SDC assembly, the peak personnel population is expected to reach 350 people. This includes personnel in the surface buildings and in the underground hall. Parking at the site is limited and will probably present a problem.

We will investigate the possibility of more and cheaper parking space. In addition to the parking problem, we recognize that there will be a severe problem of housing people at the site. Temporary space near the site as well as temporary on-site housing (trailers) will likely be needed.

After the assembly of the SDC detector, consideration should be given to converting the high bay of the assembly building into a local shop. The storage areas could be converted into offices for users.

We had already considered this and discussed it with the review subcommittee. The desirability of this depends upon the need for staging components and the availability of office space for users elsewhere on the site.

The installation scenario presented was credible. The schedule presented with it is generous and could be compressed. One area that could be compressed is the time allocated for magnetic measurements, which could be shortened to one month from its present three months. The committee felt that the schedule should be expanded to include cabling, gas system hookups and subsystem checkout to show areas of potential conflicts.

We note that the overall committee (see report from the muon subgroup) did not agree that the schedule was generous. The time allocated to magnetic field measurements was based on CDF experience. We will investigate the possibility of reducing the mapping time.

The schedule does include cabling, gas system hookup, *etc.*, although the detailed linkages among the various subsystems have not yet been worked out. The schedule explicitly includes time and resources (WBS 8.2.2) for checkout of all subsystems. Again the detailed linkages among subsystems will be worked out in the next few months.

Because of the complexity of the problem and the many system interfaces, the collaboration is encouraged to appoint an installation manager at an early stage.

We concur completely with this recommendation. The installation scenario is intimately connected to the overall integration of the detector components. Substantial interactions with the Project Manager and the Project Engineer are required. Tom Winch has been appointed as the engineer in charge of coordinating the surface assembly and installation scenario. He interacts with both engineers working on detector integration and with the SDC cost/scheduling group, under the overall direction of the Project Engineer and Project Manager.

The issue of beam loss and beam collimation with subsequent damage to the silicon tracker, the calorimeter and other detector elements was discussed. The SDC is encouraged to resolve this issue together with the SSC machine group... Silicon tracker/calorimeter radiation damage issue needs joint SDC and SSC machine resolution.

We agree completely with these recommendations. Some months ago, the SDC began a regular series of meetings with the SSC accelerator personnel. These meetings have recently expanded to include GEM. In addition, to the issues raised by the subgroup, there are many other common concerns—interaction region vacuum, muon halo, *etc.* The specific issue of possible radiation damage to the silicon tracker due to beam halo is under active investigation by T. Pal at the SSCL, in conjunction with the SSCL accelerator group.

8. Physics update

In the Technical Design Report [3], the SDC outlined a strategy for exploring the full range of Higgs masses allowed by the Minimal Standard Model. In the low mass region ($M_{\rm Higgs} < 130$ GeV), this strategy relied on the production of the Higgs boson in association with a $t\bar{t}$ pair or a W boson, thereby providing a lepton tag. The Higgs boson itself was detected via its decay to two photons, resulting in the final state $\ell + \gamma\gamma + X$. Since April, we have continued to improve our understanding of the backgrounds by carrying out more work in three areas. A brief summary of this work is given below.

8.1. Radiative decays of W, Z, and t

When the TDR was written, we expressed reservations about the lack of any calculations for the radiative decays of the heavy particles which produce the leptons in the background processes. We have been pursuing a program to complete these rather complex computations. The previous calculations of the processes $W + \gamma\gamma$, $W \to \ell\nu$ and $t\bar{t} + \gamma\gamma$ have been supplemented by new calculations that include the processes:

i) $W + \gamma$ with $W \to \ell\nu\gamma$.

ii) $Z + \gamma$ with $Z \to \ell\ell\gamma$.

iii) $t\bar{t} + \gamma$ with $t \to Wb\gamma$.

iv) $t\bar{t} + \gamma$ with $t \to Wb$ and $W \to q\bar{q}\gamma$ or $W \to \ell\nu\gamma$.

v) $t\bar{t}$, both γ are produced via the radiative decay chains in *iii* or *iv*.

The process $Z + \gamma\gamma$ has been ignored because it is expected to be roughly an order of magnitude smaller than the $W + \gamma\gamma$ process shown in the TDR. Work on the $t\bar{t}$ decays (items *iii* through *v* above) remains preliminary, and the figures in the present document do not include this contribution (indications are that it is not large compared to the W and Z decays).

A requirement that $M_{\ell\gamma} > 40$ GeV for both lepton-photon pairs has been imposed in order to reduce the radiative decay backgrounds. This results in roughly a 15% loss in signal with a rejection of about 10 against the $W + \gamma$, $W \to \ell\nu\gamma$ background. We note that the radiative decay contributions have been evaluated in the approximation that the W, Z, and t widths are small compared to their masses, and hence the interference between the radiative decays above and the two-photon matrix elements previously computed has been ignored (to the extent that the W, Z, or t are not asymptotic stable states, the resulting total cross section will not be completely gauge invariant). This approximation is known to work very well (better than 1%) for the simpler case of W production and decay into the final state $\ell\nu\gamma$, and it seems reasonable to expect that it will be accurate here as well.

8.2. Additional lepton backgrounds

The PAC pointed out an additional background source which we had not previously considered. The studies in the TDR included contributions from jets misidentified as photons, but did not include contributions from leptons misidentified as photons. There are two possible sources for such misidentification. The first is tracking inefficiency (an EM energy deposit with no associated track looks like a photon). The second is external bremsstrahlung arising from the material in the tracking volume, in which the primary lepton is not reconstructed (the internal bremsstrahlung contribution is included in the calculations described in Section 8.1).

The first source leads us to consider the process $Z + \gamma$, $Z \to e^+e^-$, where one of the Z decay electrons is misidentified as a photon. We have estimated that the fraction of events in which there is no track stub associated with an EM energy deposit should be very small, probably $\lesssim 0.1\%$ (note that only a pattern of hits in the outermost tracking layers would be required—it is not necessary to reconstruct the full track). Furthermore, the lepton-photon mass would be consistent with M_Z, allowing further discrimination. Hence, we believe that this source will prove to be negligible, but we include it in the background plot, assuming the above 0.1% inefficiency for finding a track stub.

The external bremsstrahlung source is more difficult to estimate. In order to properly assess its contribution, a detailed detector simulation, combined with actual algorithms for reconstructing and rejecting bremsstrahlung would be required (this would involve combining tracking and Shower Max information). In the absence of such simulations, we resort to simpler estimates. Based on the CDF experience studying internal and external bremsstrahlung in W decay, we know that internal bremsstrahlung can be approximated over a large range of photon energies by an equivalent radiator [4] of thickness $\sim 2.5\%$ X_0, and we assume a similar value should be correct for the Z. The precise equivalent radiator thickness will depend slightly on the photon angular and energy cutoffs, and hence on the photon definition used in the experiment. Since the SDC silicon tracker contains 7% X_0 averaged over all η, and the full SDC tracker, excluding the outermost superlayer, contains 13% X_0 averaged over all η, the equivalent radiator approximation allows us to predict that the external bremsstrahlung rate in SDC should be 3–5 times the internal bremsstrahlung rate, and that the kinematics should be very similar. The problem of separating primary photons from photons which arise from external bremsstrahlung of electrons is very similar to the problem one faces in a hadron collider in separating primary electrons from electrons produced by the conversion of photons in the detector (both will have a very small opening angle between the two outgoing particles). This problem has been extensively studied by CDF, and we base our estimates on this work. Their algorithm starts from a high p_t electron track, and searches for a second track of opposite charge which has a small difference in $\cot\theta$ and which has a small distance-of-closest-approach between the two track helices in the transverse plane. This algorithm has been measured by CDF to have an efficiency of roughly 95% when the second track has $p_t \gtrsim 1$ GeV/c.

We assume that we can achieve a similar level of performance for a bremsstrahlung algorithm (note that the track which will be associated with the photon is not required to be an identified electron), and therefore use a rejection factor of 20 against external bremsstrahlung for events in which there is a track within the detector acceptance with a $p_t > 1$ GeV/c. The fraction of events from the $Z + \gamma$ process with $Z \to \ell\ell\gamma$ in which the second lepton from the Z is either beyond $|\eta| = 2.5$ or below $p_t = 1$ GeV/c is found to be 8%. This leads to the following estimate for the additional rate arising from external bremsstrahlung: $5 \times 0.5 \times (0.08 + 0.92 \times 0.05)$ or 0.32, where the additional 0.5 accounts for the fact that external bremsstrahlung from muons is negligible. This total factor is used to renormalize the total cross section for $Z + \gamma$, $Z \to \ell\ell\gamma$ and predict the combined internal plus external bremsstrahlung rate.

8.3. Additional QCD backgrounds

A more complete study of the contribution of $t\bar{t}$ events in which both photons arise from misidentified jets has been performed (backgrounds of the form $t\bar{t} + \gamma$ where one photon arises from a misidentified jet have been found to be negligible). Two specific features make this background potentially more dangerous than one might initially estimate. First, due to the presence of real $W \to jj$ decays in $t\bar{t}$ events it is possible to generate a peak in the invariant mass distribution near the W mass. Second, the jets produced in t decays are all quark jets. The jet rejection factor assumed in the TDR (5×10^{-4}) was derived from CDF data using a sample dominated by gluon jets. The quark jets will have a harder fragmentation function, making it more likely that the initial parton can fragment into a single leading neutral meson. For this reason, we assume a rejection of 10^{-3} per jet in the present study.

Estimating the contribution of the $W \to jj$ decay to the background requires an estimate for the mass resolution which is expected for events in which both jets have passed the photon identification cuts. We would expect that the resolution should be closer to the inclusive $W \to jj$ mass resolution (a resolution of 8.5 GeV is found using a jet cone of $R = 0.3$), than to the $H \to \gamma\gamma$ mass resolution (a resolution of 1.2 GeV for $M_{\text{Higgs}} = 80$ GeV was given in the TDR). Monte Carlo studies using the PYTHIA generator and a sample of 10^5 $t\bar{t}$ events which have been passed through the detector model described in the TDR suggest that the expected resolution can be approximated by a Gaussian with a sigma of 6 GeV. This smearing has been applied to each of the six distinct jet pairs in the process $t\bar{t} \to \ell + 4jets$, and the resulting plot is rescaled by a factor of 10^{-6} to account for the fraction of jets misidentified as photons.

Table 4

A summary of the numbers of signal events produced in and detected by the SDC detector per SSC year as a function of the Higgs mass. The leptons and photons in the detected events are required to satisfy $p_t > 20$ GeV/c and $|\eta| < 2.5$. A $\Delta R = 0.4$ cut between all of the leptons and photons, and a mass cut $M_{\ell\gamma} > 40$ GeV on both lepton-photon pairs were also applied. A factor $(0.85)^3 = 0.614$ has been used to account for lepton and photon efficiency. An additional factor of 0.93 for $W + H$ events and 0.73 for $t\bar{t} + H$ events has been applied to account for the isolation requirement of less than 10 GeV of excess E_t in a cone of radius $R = 0.3$. All results are derived from a simulation using PAPAGENO, BR($H \to \gamma\gamma$) as given in Ref. 5, and BR($t \to \ell + X$) = BR($W \to \ell + X$) = 0.22 (only W leptons are accepted from the t quark decay—all others will fail the isolation cuts).

M_{Higgs}	$W + H$ events Produced	$W + H$ events Detected	$t\bar{t} + H$ events Produced	$t\bar{t} + H$ events Detected
80	16.3	2.4	42.1	8.7
100	15.8	2.6	38.9	10.2
120	14.1	2.5	38.1	10.6
140	8.2	1.5	24.2	6.9
160	1.4	0.3	4.4	1.3

8.4. Updated results

The effect of the event selection, including the requirement that $M_{\ell\gamma} > 40$ GeV for both lepton-photon pairs, is summarized in Table 4 for the signal processes. This table is to be compared with Table 3.4 in the TDR. The result is that the $t\bar{t} + H$ signal has decreased by 15%, while the $W + H$ signal has decreased somewhat more (20–30%) due to the smaller transverse momenta which characterize this production mechanism.

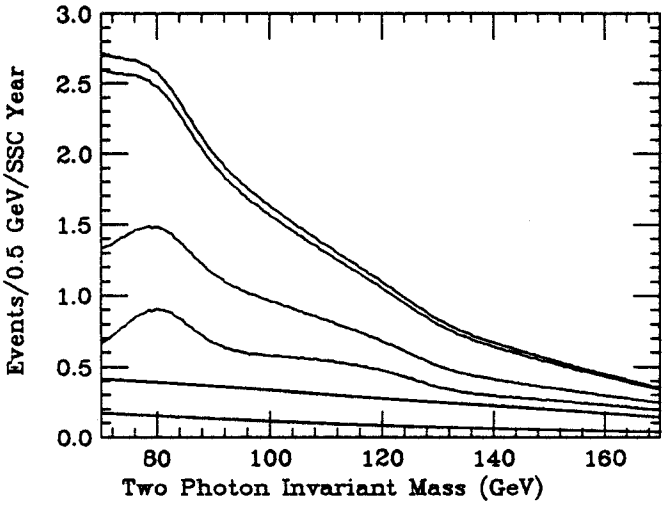

FIG. 1. The two-photon invariant mass distribution for the expected backgrounds to associated Higgs production. The background curves are cumulative, and are (from lowest to highest): $b\bar{b}+\gamma\gamma$, $t\bar{t}+\gamma\gamma$, $t\bar{t}$ (where the two γ candidates arise from misidentified jets), $W+\gamma\gamma$ (this includes the radiative decays arising from $W+\gamma$ with $W \to \ell\nu\gamma$), $Z+\gamma$ with $Z \to \ell\ell\gamma$ (this includes the contributions of both internal and external bremsstrahlung), and $Z+\gamma$ (this contributes through tracking inefficiency only).

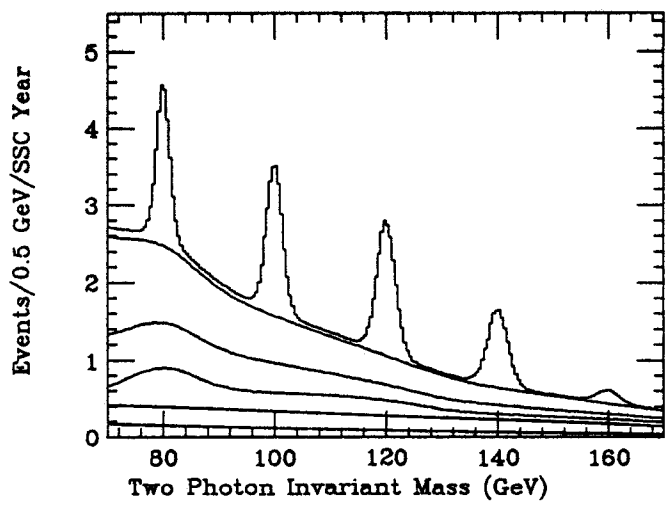

FIG. 2. The two-photon invariant mass distribution for the expected signals from Higgs bosons of mass 80, 100, 120, 140, and 160 GeV. The background curves are cumulative, and are the same as those shown in Fig. 1. The baseline detector resolution defined in the TDR has been assumed.

The various background contributions are summarized in Fig. 1. The large contributions from the process $Z+\gamma$ with $Z \to \ell\ell\gamma$ could be somewhat further reduced by identifying a second lepton in the event, with some associated loss of the signal from the $t\bar{t}+H$ process. Further studies are in progress to quantify the effects of this more exclusive strategy.

Finally, we present updated versions of the relevant figures in the TDR (Fig. 3-11 and Fig. 3-13) in Fig. 2 and Fig. 3.

8.5. Summary

In summary, the contributions from additional backgrounds to the $\ell+\gamma\gamma+X$ final state are substantial. In particular, the effects of radiative decays of W, Z, and t significantly increase the expected backgrounds relative to the calculations ignoring these decays. Kinematic cuts are effective against such backgrounds, but result in some erosion of the expected signal. The conclusion of this preliminary updated analysis is that the low mass Higgs search ($M_{\text{Higgs}} < 130$ GeV) is likely to require several years of SSC running at design luminosity before conclusive results can be expected.

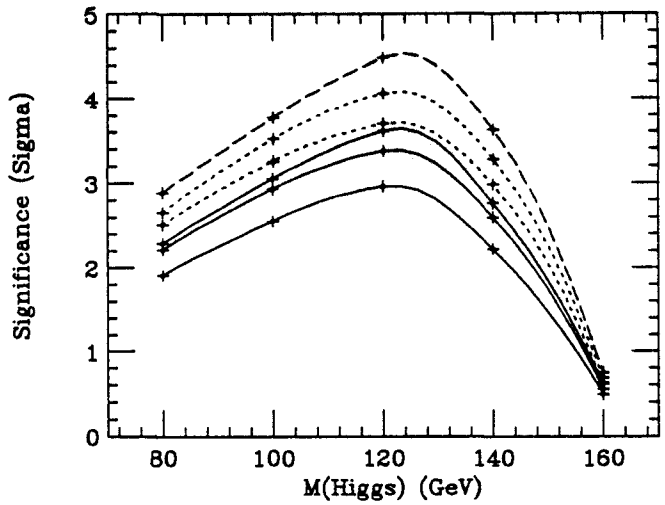

FIG. 3. A series of curves showing the expected significance of the combined $W + H$ and $t\bar{t} + H$ signal above the background for one SSC year of integrated luminosity for different Higgs masses. For the solid curves, the stochastic term is assumed to be that of the baseline detector defined in the TDR, and the constant term is taken to be, from highest to lowest, 0.5, 1.0, or 2.0%. For the dotted curves, the stochastic term is assumed to be that of the high performance option defined in the TDR, and the constant term is taken to be 0.5 and 1.0%. Finally, an additional dashed curve with $10\%/\sqrt{E}$ resolution is included for reference.

9. Updated cost estimate

Since the PAC Review in early May, there have been some changes in the estimated cost of the detector components. Some of the areas of potential cost reduction or increase identified in the PAC Report have been reviewed by us. Small changes to the detector layout have been made, primarily in the muon system, which result in a modified cost. Finally, our survey of base program resources in the U.S. has caused us to examine more carefully the labor rates used in the cost estimate, especially for those items assigned to U.S. universities.

In Table 5 we present the estimated cost as given in the Technical Design Report and a summary of the recent changes. In the second column we present the changes in cost as a result of modifications to the detector configuration made since submission of the TDR, the addition of extra silicon detectors, electronics, phototubes, *etc.*, to account for wastage during construction and correction of errors in the original estimate. Further cost modifications have been made and are summarized in column three of Table 5. These include revisions in the composite U.S. university labor rates used in the estimate, changes in the manufacturing technique for the central calorimeter and many other small changes resulting from proposed manufacturing changes or receipt of new vendor information. In addition, with the agreement of SSCL management, test beam costs at the SSCL are now assumed to be supported by SSCL operations. The revised estimated cost for construction of the SDC detector is \$575M (U.S. FY1992), not including costs incurred before FY1993. With the inclusion of these costs, the total estimated cost is \$595M.

We have started the process of improving the reporting format for the cost estimate, in preparation for a DOE review later this year.

Table 5

Detector cost estimate, not including $20M of costs incurred in FY1991 and FY1992. The first column contains the detector cost estimate given in the Technical Design Report (TDR). The second column summarizes cost changes from detector parameter modifications and correction of errors. The third column includes manufacturing and other changes. The revised estimated cost is given in the last column.

	TDR ESTIMATE	CORRECT. &PARAM. CHANGES	MANU. AND OTHER CHANGES	REVISED COST
1 TRACKING SYSTEMS	88.8	0.9	-1.4	88.3
1.1 SILICON TRACKING SYSTEM	41.2	0.9		42.1
1.2 BARREL TRACKER	31.5		-1.4	30.1
1.3 INTERMEDIATE TRACKER	16.1			16.1
2 CALORIMETRY	162.4	1.7	-3.2	160.9
2.1 BARREL CALORIMETER	90.6	0.3	-3.1	87.8
2.2 ENDCAP CALORIMETER	59.2	1.4	-0.1	60.5
2.3 FORWARD CALORIMETER	12.5			12.5
3 MUON SYSTEM	115.8	-1.8	-0.9	113.1
3.1 MAGNET SYSTEMS	59.6	-0.5	0.6	59.7
3.2 MUON MEASUREMENT SYSTEM	56.2	-1.3	-1.5	53.4
4 SUPERCONDUCTING MAGNET	42.4	0.0	-0.1	42.3
4.1 SUPERCONDUCTING SOLENOID	33.9			33.9
4.2 CRYOGENIC SYSTEM	8.5		-0.1	8.4
5 ELECTRONICS SYSTEMS	97.0	-1.0	-1.0	95.0
5.1 FRONT-END ELECTRONICS	43.9			43.9
5.2 DATA ACQUISITION SYSTEM	20.4			20.4
5.3 TRIGGER SYSTEMS	28.8	-1.0		27.8
5.4 ANCILLARY CONTROLS	3.9		-1.0	2.9
6 ON-LINE COMPUTING	9.3			9.3
7 CONVENTIONAL SYSTEMS	14.2			14.2
8 INSTALLATION AND TEST	36.2	0.0	-2.4	33.8
8.1 TEST BEAM PROGRAM	8.9		-2.4	6.5
8.2 SUBSYSTEM INSTALL. AND TEST	27.3			27.3
9 PROJECT MANAGEMENT	18.4			18.4
TOTALS	584	-0.3	-9.0	575

10. Resources

At the PAC review in early May, the SDC presented a draft International Funding Plan (referred to as IFP in subsequent discussion) that contained an estimate of the overall detector cost offset arising from the anticipated contributions of non-U.S. groups within the SDC. The cost offset quoted in that document, ($207M in FY92 dollars) from non-U.S. sources, was based upon preliminary negotiations of responsibilities within the collaboration, taking account of the interests, capabilities, and financial resources available to each non-U.S. group. In our discussion of funding needs, we took $200M as our working estimate, largely because of the very preliminary nature of the discussions. In light of the PAC charge to us to come back with a credible overall funding plan, we have subsequently greatly refined our estimate of the financial resources available to the collaboration from both the United States and from the non-U.S. members of the collaboration, and have revised the assignment of responsibilities to groups in the collaboration. Members of the SDC Management have visited the Russian Federation and the Peoples Republic of China to discuss contributions from these countries. In late May, a collaboration meeting was held at KEK, and the responsibilities of the Japanese members of the collaboration were reviewed and revised. The results of these discussions, as well as interactions with other countries in the collaboration, have been incorporated into an international funding matrix, which identifies WBS elements and costs in the detector cost estimate with countries in the collaboration.

To assess potential U.S. resources other than those from the SSC Project, we have asked each of the U.S. institutions in the SDC to provide an estimate of the engineering and technical manpower and other resources that could be provided during the construction period for the detector through NSF or DOE HEP base program support or through support from the institution itself. We have also quantified more precisely that part of the existing support from the TNRLC that could be used to offset detector costs in the form of support of engineering and technical labor and the procurement of equipment. In applying the results of our survey to the SDC funding needs, we assume that the level of base program and TNRLC support remains about constant.

10.1. Present funding plan

In Table 6 we summarize the sources of funding and our best estimate, at this time, of the amount of funding that could be obtained to offset the detector cost for both a seven-year construction period and a ten-year (staged) construction period. Each of the sources is addressed briefly below.

Table 6
SDC funding sources and funds for a seven-year construction plan and a ten-year (staged) construction plan.

Source	7 year construction ($M)	10 year construction ($M)
SSC Project	292	292
Non-U.S.	223	238
U.S. HEP Program	40	70
TNRLC	20	20
TOTALS	575	620

SSC Project

We assume that one-half of the funds assigned by the SSC Laboratory for large experiments will be provided, including those funds already spent on R&D through FY92.

Non-U.S.

We believe that it is reasonable to assume that $223M of the detector cost can be offset by contributions from outside the United States through 1999, as indicated in our funding matrix. This estimate is somewhat higher than the one from early May and reflects our improved understanding of the potential responsibilities that could be assumed by non-U.S. groups, especially those in Japan. In a ten-year (staged) construction scenario, we assume that a rather modest additional $5M per year, after initial turnon, would be available for completion of the SDC detector from outside the U.S.

U.S. HEP program

Given the results of our survey of U.S. SDC institutions, we consider it plausible to assume that about $40M can be contributed by the base program, eventually including the SSCL, through 1999. We assume that there will be substantial support at the level of at least $10M/year in equipment funding for the SDC detector available once the SSC Project is completed, consistent with the expectation that the SSC experiments represent about one-half of U.S. high energy physics program early in the next century. These funds would be essential under a staged, ten-year construction scenario.

TNRLC

We assume that the present effective level of support, about $2.7M per year, from the TNRLC will continue for a total offset of about $20M.

In summary, we can identify now about $575M of the present total $595M cost of the detector. This leaves a shortfall of about $20M. Although we shall continue to seek additional sources of funds and to work toward additional cost reductions in manufacturing, we are forced, at present, to consider possible scenarios for staging detector components. Staging possibilities are addressed in the next section.

11. Detector staging possibilities

The fabrication scenario overwhelmingly preferred by the SDC is one which provides a complete detector by the time of SSC turnon. However, given the possible funding limitations, we have considered staging scenarios that would delay completion of the detector by up to 3–4 years after turnon of the SSC at the end of 1999. Such scenarios need to satisfy three conditions:

1. Although incomplete, the detector turned on when the SSC begins operation must be capable of a wide range of physics well matched to the full energy but reduced luminosity (relative to the design value) expected initially.
2. The staging must allow a match between resources presently seen as available before SSC turnon and the funding needs of the detector during that period.
3. With appropriate funding after turnon, the delayed components can be completed and installed by the time that the SSC reaches design luminosity, perhaps three years after initial operation of the collider (probably requiring a shutdown of some length).

In the case of modest staging, for example delaying part of the Level 3 processing farm, the staged component could easily be added after SSC turnon, when new funds became available. However, if a more substantial system is staged, for example the forward muon system, it would not be possible to design, fabricate and install all components in just three to four years. Hence some funds for this system must be expended before 1999, if staging is to be a credible option. If such early funding were not implemented, we would end up with a descoped, rather than staged. detector with power not adequately matched to the potential of the SSC.

We have considered two general approaches to staging. One is to retain nearly full rapidity coverage with much reduced functionality, which could be subsequently added as the luminosity increases, and funds become available. The second approach is to preserve most of the functionality but stage the rapidity coverage for some of the systems. We have largely chosen the latter approach, since, after its considerable previous descoping, the detector is already near the limit of functionality, even at reduced luminosity. We believe that further significant "thinning" would lead to unacceptable technical and performance risks. Furthermore, in the first approach, if funds did not become rapidly available to complete the staged components, one could very well be left with a detector that could not operate successfully at the design luminosity.

In light of the above shortfall of about $20M and the present uncertainty in the availability of funds, we consider the maximum cost deferral that can plausibly be realized by staging, subject to the above three conditions. We need to reduce the demands for U.S. funding, which covers U.S. detector responsibilities as well as compensatory payments to the People's Republic of China and to the Russian Federation. Thus we must primarily consider staging those components for which the U.S. has a significant financial responsibility. In principle it is also possible to stage systems which at present are primarily the responsibilities of non-U.S. groups while shifting those groups' responsibilities toward components for which U.S. groups are presently responsible. There are two problems with this: 1) Viewed from a long term perspective, there are really no benefits in such an action since the staged components will eventually be needed, and it would be unfortunate to shift people motivated to pursue them to other areas in which they are less or not at all motivated; and 2) in such a process we would almost inevitably lose some of the non-U.S. collaborators, and thereby lose the intellectual and financial resources attached to those scientists. In consequence our emphasis has been toward staging components in which substantial U.S. responsibility is involved. Even so, as will be seen below, such actions would almost inevitably also reduce or delay the fulfillment of non-U.S. responsibilities.

The components, whose staging we have considered, include some elements of the tracking system, some parts of the central calorimetry readout, parts of the trigger system, including the Level 3 farm, and major components of the muon system, including the entire forward muon system, and the intermediate chambers (IW2 and IW3) and trigger scintillators (IS2) (see Fig. 2-7 of the TDR) not trapped by cables and utilities. For each of these components we have estimated the maximum deferred costs from delaying the start of installation up to three years after initial turn-on. By deferred cost we mean the difference between the cost of having the full component ready at turnon and the cost of whatever minimal work has to be done before turnon (for example, engineering design) to ensure that the component can be built and installed no later than three years beyond turnon. In Table 7 we summarize these staging candidates, along with the estimated total (U.S. plus non-U.S.) and U.S. deferred costs, and also indicate approximately at what point in time the decision to delay or not to delay must be made assuming SSC turnon in 1999. As indicated earlier, the existence of both U.S. and non-U.S. deferred costs for almost all of the staging candidates is a reflection of the very close interplay of U.S. and non-U.S. responsibilities. For example, a delay in the forward muon chambers (mostly U.S./Russian responsibility) would naturally entail a delay in the muon electronics (mostly a Japanese responsibility). Although some fraction of the non-U.S. deferred costs may be redirectable, the amount is likely to be small simply because, as stated earlier, the deferred components will still need to be supplied, albeit on a later time scale. If all items in Table 7 were staged, up to $30M in U.S. costs might be deferred before turn-on. This would include staging the entire forward muon system. We have not yet estimated the increase in overall cost that would inevitably be incurred by stretching out the design and construction of the staged components.

In addition, we have made a preliminary estimate of the time required to install staged components in the underground hall. If all items in Table 7 were staged, at least one year would be required to remove and reinstall accelerator components and to install the staged components. This does not include additional time for recommissioning the collider or the detector. At least nine months would be required to install the forward muon system, assuming that both ends were to be done in parallel, not including recommissioning. Removing, upgrading and reinstalling tracking elements would require 9–12 months. In

Table 7
Staging options. All costs are in U.S. FY1992 M$

WBS	Staged item	Total Deferred	U.S. Deferred	Decision Time
1.1	Silicon disks $\|\eta\| > 1.5$	3.1	2.2	1994
1.2	Straw tracker inner superlayer	0.7	0.7	1994
2.1, 2.2	Separate readout of massless gap	0.7	0.7	1996
2.2	Long. segment. in endcap EM	0.5	0.5	1996
3.1	Forward toroids	13.1	6.5	1994
3.2	Intermediate chambers	3.2	3.2	1995
3.2	Intermediate counters	0.8	0.8	1995
3.2	Forward chambers	7.6	4.6	1995
3.2	Forward counters	1.9	0.7	1995
3.2	Alignment of staged chambers	2.8	2.8	1995
3.2	Part of muon gas system	1.9	1.9	1995
5.1	Front-end electronics (channel count reductions)	5.8	1.6	various
5.2	Level 3 farm	2.0	2.0	1998
5.3	Tracking trigger and forward muon trigger	3.0	0.0	1995
8.2	Installation and test (staged items)	2.5	2.5	1995
TOTALS		49.6	30.7	

short, substantial staging would require a collider shutdown of 9–12 months about three years after initial operation to complete the detector.

12. Impact of staging on physics performance

In discussing the physics impact of the proposed staging scenarios for the SDC detector, it is first necessary to provide an overview of the expected physics program of the SDC during the first 3–4 years of machine operation. In doing so, we have used a luminosity model in which the initial luminosity of the SSC is $10^{30}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, and it increases by roughly one order of magnitude each year. We also assume that the Fermilab Main Injector Upgrade has provided about 1 fb^{-1} of data to the two major Tevatron detectors by the end of this decade.

In order to simplify the following discussion, we have chosen to concentrate on the major scenarios for new physics presented in the TDR. These include:

1. Higgs searches
2. Heavy quark searches and t studies
3. W' and Z' searches
4. Supersymmetry searches (squarks and gluinos)
5. Compositeness searches

We define a simple criterion in terms of the number of events which must be produced in each scenario in order to assure discovery (discovery is assumed to require some tens of observed events). The criteria have been constrained to agree with the TDR at SSC design luminosity, and hence provide a simple scaling mechanism for characterizing the SDC physics reach as a function of luminosity.

12.1. Physics program during the first years of SSC operation

The first observation is that the physics program can be divided into two major eras. During the several year period when the luminosity is less than or equal to $10^{32}\text{cm}^{-2}\text{s}^{-1}$, most new physics remains accessible, albeit at reduced mass scales. The notable exception is Higgs physics, which, due to the small production cross sections and branching ratios, is largely inaccessible with a data sample less than several fb^{-1}. Thus, the first few years of SSC operation are expected to be a pre-Higgs physics era—only after 3–4 years of operation can we expect to start detailed explorations of Higgs physics.

The physics reach of the SDC detector and the Tevatron are compared in Table 8. The integrated luminosity is assumed to correspond to one year (10^7 seconds) at the luminosity given in the table. It is clear that even one year of SSC running at low luminosity is sufficient to significantly extend the regions accessible for new physics searches. The one exception to this is the search for a Z' in which the benefits of an anti-proton machine (valence anti-quarks) play a role. For reference, we note that the production cross section for a t quark of mass 150 GeV is roughly 4000 times larger at the SSC than at the Tevatron, which would provide a sample of 75,000 produced events during the first year of SSC operation, compared to the 1800 produced at the Tevatron up to that time.

Table 8

A summary of the discovery reach of the SDC detector as a function of the luminosity, and a comparison with the expected reach of the Tevatron with 1 fb^{-1} of data. The integrated luminosity is assumed to correspond to one year (10^7 seconds) of data at the luminosity given in the table. The compositeness entries correspond to a $p_t(jet)$ threshold such that there are 100 events expected above that threshold—an actual compositeness limit should scale proportionately.

New physics signature	Requirement (produced events)	Luminosity ($\text{cm}^{-2}\text{s}^{-1}$)	Center-of-mass energy	Physics reach (mass or p_t)
heavy quarks	10^3	10^{33}	40 TeV	1500 GeV
		10^{32}		1000 GeV
		10^{31}		700 GeV
		10^{30}		450 GeV
		10^{32}	1.8 TeV	210 GeV
Gluino	10^3	10^{33}	40 TeV	2200 GeV
		10^{32}		1500 GeV
		10^{31}		1100 GeV
		10^{30}		700 GeV
		10^{32}	1.8 TeV	250 GeV
W' and Z'	10^3	10^{33}	40 TeV	5000 GeV
		10^{32}		2000 GeV
		10^{31}		1000 GeV
		10^{30}		500 GeV
		10^{32}	1.8 TeV	500 GeV
Compositeness	10^2	10^{33}	40 TeV	5500 GeV
		10^{32}		4500 GeV
		10^{31}		3000 GeV
		10^{30}		2000 GeV
		10^{32}	1.8 TeV	500 GeV

12.2. Staging scenarios

The previous chapter describes the staging scenarios that could be used by the SDC to cope with potential funding limitations. These scenarios retain most functionality over a limited region in rapidity, rather than significantly reducing the functionality over the full rapidity coverage. The primary impact of the proposed staging scenarios would be to reduce the rapidity coverage for electrons and muons. The intermediate muon chambers cover the rapidity range $1.3 < |\eta| < 1.5$ and the forward muon system $1.5 < |\eta| < 2.5$. Staging the silicon disks for $|\eta| > 1.5$ may impair electron identification in this region, although we have not yet completed the detailed simulations required to determine the electron tracking efficiency with a reduced system. Staging the forward muon trigger would delay the ability to trigger on muons for $1.5 < |\eta| < 2.5$. The Level 1 tracking trigger is primarily used in conjunction with the central calorimeter to form electron/photon triggers. Its staging would require the energy threshold to be raised to obtain the same rate as with the tracking trigger in operation.

The specific options defined in Table 7 have been mapped into a small set of rapidity coverage options which have been studied for their physics performance implications.

1. No coverage for either triggering or reconstruction for both electrons and muons beyond $|\eta| = 1.5$.
2. No coverage for either triggering or reconstruction for muons beyond $|\eta| = 1.5$.
3. No coverage for triggering for both electrons and muons beyond $|\eta| = 1.5$. Reconstruction over the full rapidity coverage is possible.

Note that the calorimeter coverage has not been staged (the reduction of electron coverage arises from a reduction of tracking coverage rather than calorimeter coverage). This is because a reduction of calorimeter coverage destroys the ability of the detector to study physics related to missing transverse energy.

In the following, we present the results of acceptance studies relevant to different possible new physics signals. Before doing so, we note that it is possible that a reduction of coverage can have a greater impact on the background than on the signal. This occurs when the increased uncertainty in reconstructing the event topology, caused by the loss of the "complete" coverage of the SDC baseline detector, allows additional background sources to contribute. We have no definitive understanding of this issue, but there are several particular examples which arouse concern. These occur when event topologies containing additional leptons or photons need to be rejected in order to see a signal. In this case, reducing the coverage can significantly decrease the veto efficiency for such backgrounds. Examples relevant to SDC occur when one is trying to veto events containing Z bosons or additional leptons from t quark decays. Such backgrounds do play a role in low cross section Higgs physics (see Section 8 in this document), but do not appear to present substantial problems during the first few years of SSC running.

In Table 9 we summarize the acceptances for the different t decay signatures used in the TDR. Note that the definition of acceptance used here includes only the kinematic effects of p_t and η requirements—the effect of branching ratios is normalized out. The single isolated lepton signature can be used to study the "lepton+jets" final state. The isolated dilepton signature is a clean signal for discovery, and can be used for heavy quark searches. The sequential dilepton signature can be used to measure the mass of the t quark. Finally, the single isolated lepton plus b-tag signature can be used to provide a clean sample for nonstandard decay searches (*e.g.*, the charged Higgs search).

In Table 10 we summarize a study performed one year ago by SDC [6] in which the effects of detector coverage on a Z' of mass 1 TeV were analyzed, using a set of models different from those discussed in the TDR. The importance of such a study is that the forward-backward asymmetry for a new Z' is sensitive to the couplings, and hence tells us about the nature of the new Z'. It is evident from this study that the full rapidity coverage is required to make a meaningful measurement of the forward-backward asymmetry. However, this analysis is only of interest when the SSC is operating at design luminosity.

In order to improve our understanding of the implications for lower luminosity running, we are presently engaged in a study of the effects of coverage on the analysis of a 500 GeV Z', where we use the E_6 family of models described in the TDR. This study is not yet complete, but it is evident that as the mass of the

Table 9

A summary of the acceptances for the detection of $t\bar{t}$ events as a function of the detector coverage.

Required Signature	Electron $\|\eta\| < 2.5$ Muon $\|\eta\| < 2.5$ b-tag $\|\eta\| < 2.0$	Electron $\|\eta\| < 2.5$ Muon $\|\eta\| < 1.5$	Electron $\|\eta\| < 1.5$ Muon $\|\eta\| < 1.5$ b-tag $\|\eta\| < 1.0$
$t\bar{t} \to \ell + X$ Isolated ℓ with $p_t > 40$ GeV/c	0.45	0.38	0.32
$t\bar{t} \to 2\ell + X$ Both ℓ isolated with $p_t > 20$ GeV/c	0.53	0.39	0.28
$t\bar{t} \to 2\ell + X$ Two sequential ℓ with $p_t > 20$ GeV/c	0.22	0.17	0.14
$t\bar{t} \to \ell + b\text{-tag} + X$ Isolated ℓ with $p_t > 40$ GeV/c b-tag with $p_t(b\text{-jet}) > 30$ GeV/c	0.29		0.14

Table 10

A summary of the results for forward-backward asymmetry (A_{fb}) measurements of a 1 TeV Z' as a function of the detector coverage for the e^+e^- final state. The values correspond to infinite statistics, but the statistical errors shown correspond to a data sample of 1 year at SSC design luminosity. The measurement requires $|y| > 0.3$ for the Z', and uses only those events with mass $M_{Z'} \pm \Gamma_{Z'}$. Several popular models are considered. In addition to a Z' with Standard Model couplings, we consider a Left-Right Symmetric model (LR) and an Alternate Left-Right Symmetric model (ALR). Details are contained in Ref. 6.

Model	Perfect Acceptance	Electron $\|\eta\| < 2.5$	Electron $\|\eta\| < 1.5$
Acceptance		0.71	0.35
A_{fb} for SM Z'	0.044	0.030 ± 0.010	0.025 ± 0.016
A_{fb} for LR Z'	0.095	0.056 ± 0.017	0.027 ± 0.026
A_{fb} for ALR Z'	-0.21	-0.14 ± 0.01	-0.069 ± 0.021

Z' decreases, it becomes increasingly difficult to make an asymmetry measurement even using the full SDC coverage. This is due both to the broader rapidity distribution of the produced Z' and its decay products, as well as the observation that the asymmetry is only large at greater values of the rapidity because it is necessary to ensure that the Z' was produced by a large x quark (at small x the number of quarks and anti-quarks is roughly equal, so the net polarization of the Z' is zero).

In Table 11 and Table 12, we summarize the effects of reduced coverage on Higgs acceptances. Although this physics remains inaccessible during early SSC running, the numbers provide further insight into the coverage requirements for the SDC detector.

Finally, we comment on the impact of staging only the trigger acceptance without staging the detectors themselves. For dilepton final states, the higher threshold expected for the single lepton trigger ($p_t > 40$ GeV/c) compared to the dilepton trigger ($p_t > 20$ GeV/c) means that staging the trigger acceptance is tantamount to staging the detectors. For multi-lepton final states the effect is more subtle, and is summarized in the final column of the last table.

Table 11
A summary of the acceptances for the detection of $W + H$ and $t\bar{t} + H$ events, assuming a lepton tag with $p_t > 20$ GeV/c and two photons with $p_t > 20$ GeV/c, as a function of the detector coverage.

Process	Mass	Electron $\|\eta\| < 2.5$ Muon $\|\eta\| < 2.5$	Electron $\|\eta\| < 2.5$ Muon $\|\eta\| < 1.5$	Electron $\|\eta\| < 1.5$ Muon $\|\eta\| < 1.5$
$W^+ + H$	80	0.27	0.19	0.13
$W^+ + H$	160	0.38	0.28	0.17
$W^- + H$	80	0.33	0.24	0.15
$W^- + H$	160	0.46	0.33	0.20
$t\bar{t} + H$	80	0.49	0.37	0.26
$t\bar{t} + H$	160	0.63	0.47	0.32

Table 12
A summary of the acceptances for the detection of direct Higgs production followed by the decay $H \to ZZ \to 4\ell$, assuming two leptons with $p_t > 20$ GeV/c and two leptons with $p_t > 10$ GeV/c, as a function of the detector coverage.

Process	Mass	Electron $\|\eta\| < 2.5$ Muon $\|\eta\| < 2.5$	Electron $\|\eta\| < 2.5$ Muon $\|\eta\| < 1.5$	Electron $\|\eta\| < 1.5$ Muon $\|\eta\| < 1.5$	Trigger $\|\eta\| < 1.5$
$H \to ZZ^*$	120	0.17	0.11	0.08	0.09
	140	0.32	0.21	0.14	0.25
	160	0.43	0.27	0.17	0.36
$H \to ZZ$	200	0.53	0.34	0.21	0.47
	400	0.58	0.38	0.23	0.53
	800	0.70	0.49	0.33	0.64

12.3. Summary

One of the major requirements imposed on the baseline SDC detector is the identification of photons and leptons and the precise measurement of their energies over the rapidity range $|\eta| < 2.5$. This requirement is well matched to the physics potential of the SSC as demonstrated by our detailed studies of possible new physics signatures described in the Technical Design Report. The primary physics impact of our proposed staging scenarios is to reduce the acceptance for muons and possibly photons and electrons. In addition, the ability to reduce backgrounds in those cases where detection of an additional lepton or photon is required for identifying the background will be impaired. The principal result of decreasing the rapidity coverage for electrons, muons and photons from about $|\eta| = 2.5$ to $|\eta| = 1.5$ is to reduce the acceptance by factors of 1.5–2.5 for those processes that we have studied. If only the muon acceptance is reduced, the reduction factors are about 1.2–1.6. For the measurement of the forward-backward asymmetry for a Z', which requires forward coverage because only a Z' produced at large rapidity gives rise to a measurable asymmetry, the consequences are more drastic. In this case the significance of the measurement is reduced by factors of 2–4, corresponding to a statistical reduction of roughly an order of magnitude.

Under the circumstances in which the SSC luminosity is rapidly growing towards its design value, the acceptance losses of the incomplete detector are not dramatic for most of the physics that we can now contemplate, with perhaps the exception of the Z' asymmetry. Indeed a significant physics program with a reduced detector could be carried out in the first few years of operation of the SSC. However, the following

should be noted:

1. The complete exploration of the Higgs physics requires every last bit of rapidity interval technically accessible for electrons, muons and photons, plus full SSC luminosity.
2. The understanding of both backgrounds and signals will be essential, and we have already identified some backgrounds which would be recognized with substantially reduced efficiency in the reduced detector (see Section 8).
3. It is important to remember that a major function of the SSC experimental program is the exploration and recognition of new physics. We strongly believe that the full rapidity coverage of the baseline detector will be needed to provide the redundant capabilities to establish new physics signatures in the presence of large backgrounds.

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