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DETECTOR SIMULATION NEEDS FOR DETECTOR DESIGNERS*

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ABSTRACT

Computer simulation of the components of SSC detectors and of the complete detectors will be very important for the designs of the detectors. The ratio of events from interesting physics to events from background processes is very low, so detailed understanding of detector response to the backgrounds is needed. Any large detector for the SSC will be very complex and expensive and every effort must be made to design detectors which will have excellent performance and will not have to undergo major rebuilding. Some areas in which computer simulation is particularly needed are pattern recognition in tracking detectors and development of shower simulation code which can be trusted as an aid in the design and optimization of calorimeters, including their electron identification performance. Existing codes require too much computer time to be practical and need to be compared with test beam data at energies of several hundred GeV. Computer simulation of the processing of the data, including electronics response to the signals from the detector components, processing of the data by microprocessors on the detector, the trigger, and data acquisition will be required. In this report we discuss the detector simulation needs for detector designers.

1. INTRODUCTION

In this section we briefly review the conceptual designs for SSC detectors developed at the recent Berkeley SSC Workshop[1]. More detail can also be found in the report by Trilling in these Proceedings[2]. Some examples of the Berkeley SSC detectors for high-p_T and medium-p_T physics are the following:

- Nonmagnetic detector
- Compact solenoid
- Large solenoid
- B spectrometer

Schematic drawings of these detectors are shown in Figs. 1–5. These detectors contain all or most of the following components:

1. Magnetic tracking
2. Vertex detection

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3. Electromagnetic calorimetry
4. Hadronic calorimetry
5. Electron identification
6. Muon identification
7. Hadron identification
8. Electronics
9. Trigger
10. Data acquisition

Computer simulation is needed to understand the design and performance of all of these components.

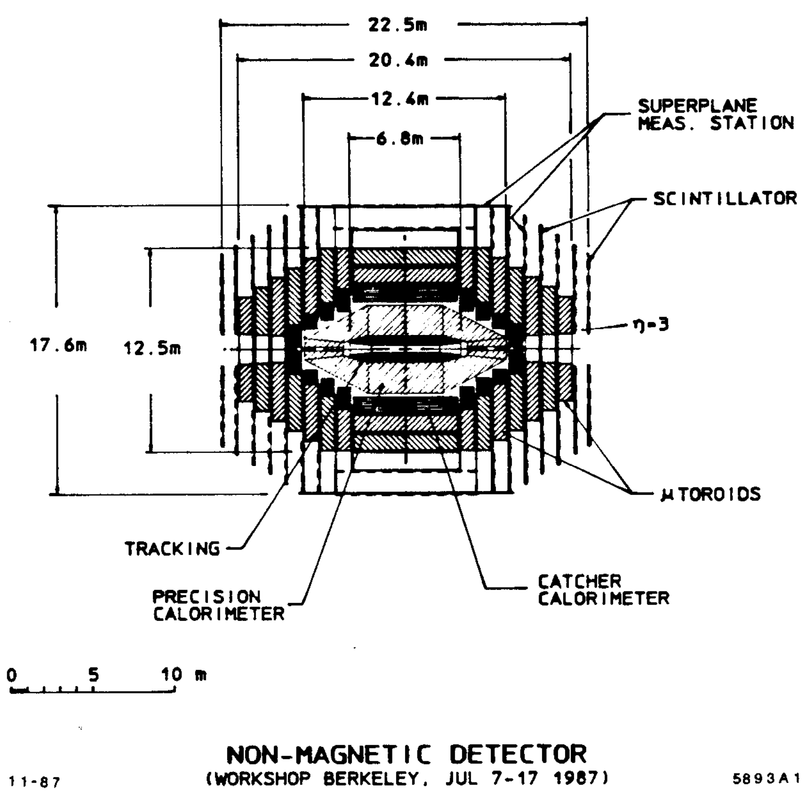


Fig. 1. Nonmagnetic Detector from the Berkeley SSC Workshop.

An excellent review of detector simulation needed to support detectors at the SSC is given in the Report of the Working Group on Detector Simulation in the Proceedings of the Snowmass 86 Workshop[3]. Computer simulation of detector responses begins with the input from the models for physical processes of interest at the SSC – production and decay of Higgs bosons, supersymmetric particles, heavy quarks, new W's and Z's, etc.,

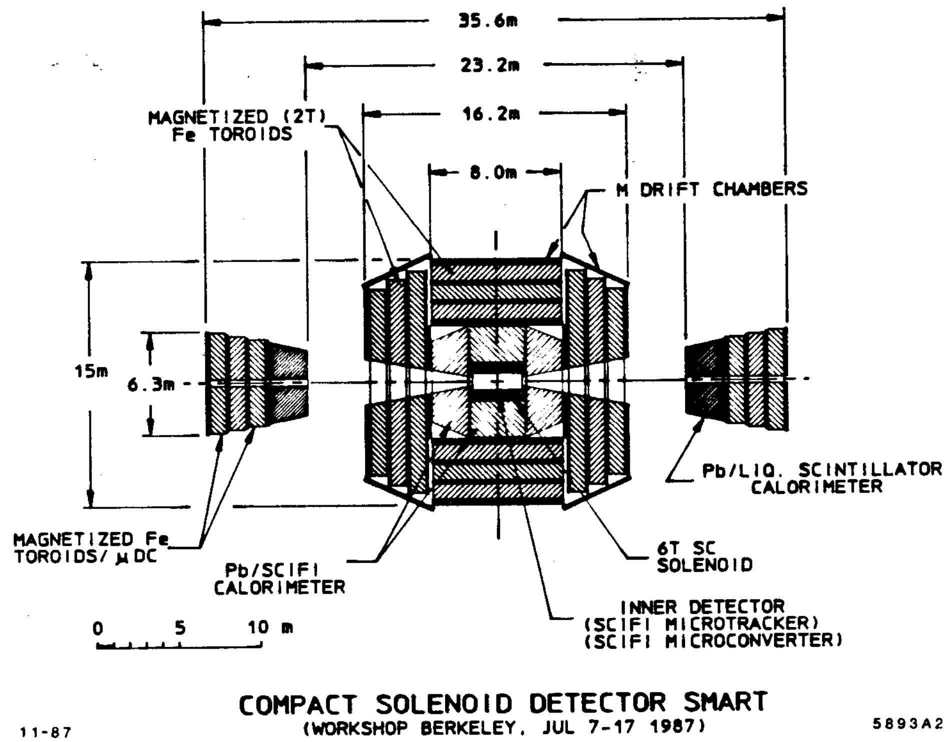


Fig. 2. Compact Solenoid Detector SMART from the Berkeley SSC Workshop.

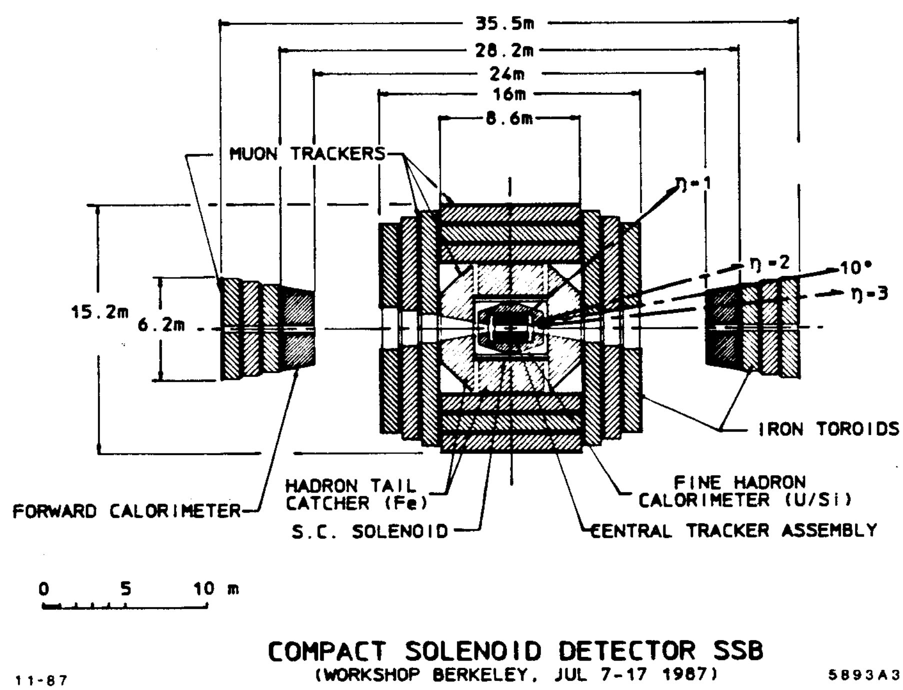


Fig. 3. Compact Solenoid Detector SSB from the Berkeley SSC Workshop.

and backgrounds from QCD events of less interest. The responses of the various detector components to the physics processes need to be simulated and compared with data, for example, from test beams. The computer simulations can then be used to optimize the designs of the components. Most important, computer simulations can then be used to put together the components into complete detectors. Deficiencies in the detector due to realistic engineering designs – mechanical supports, cracks, and cables – can then be examined and minimized. Simulated detector data from interesting physics and backgrounds can then be used to develop triggering strategies, data structures, and analysis algorithms. The detector simulation programs should be made simple enough to use that physicists primarily interested in design of hardware can run them to help answer design questions. Also, three-dimensional graphics output of the detector design and of the response of the detector to particle interactions is needed.

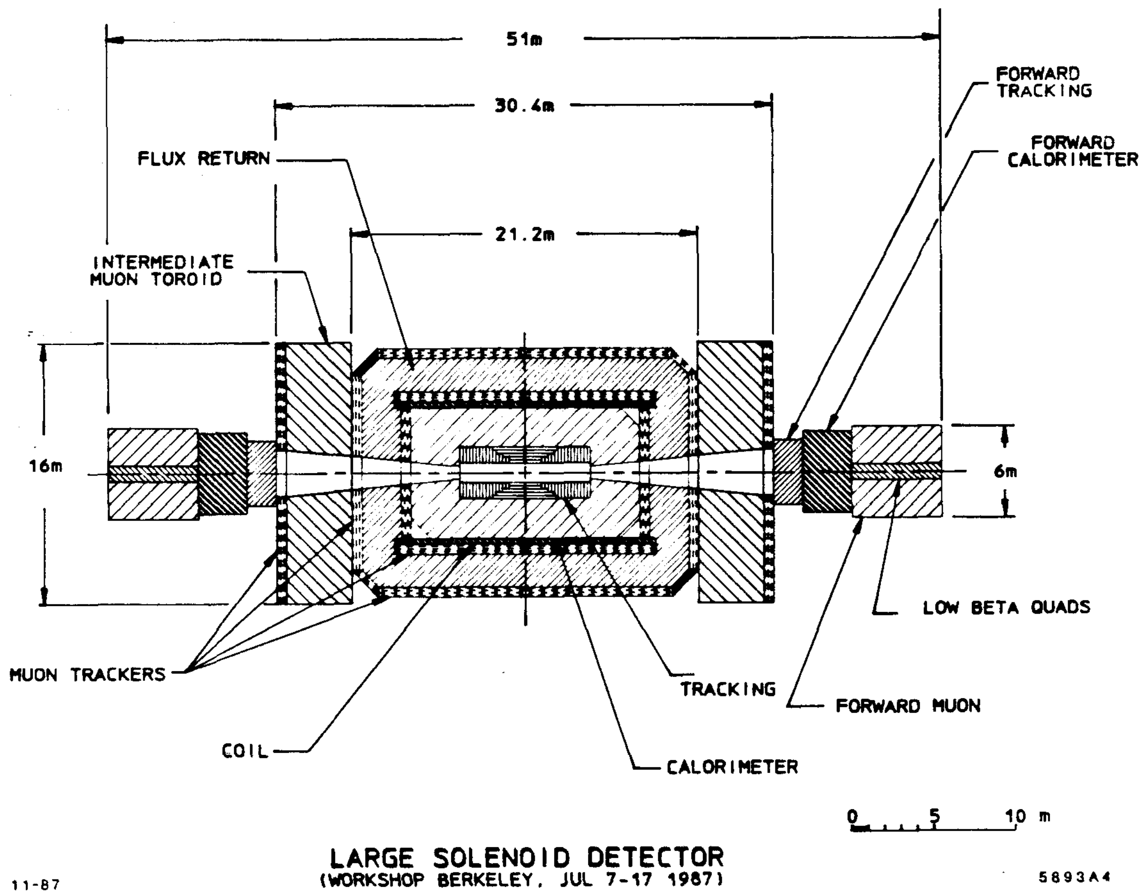


Fig. 4. Large Solenoid Detector from the Berkeley SSC Workshop.

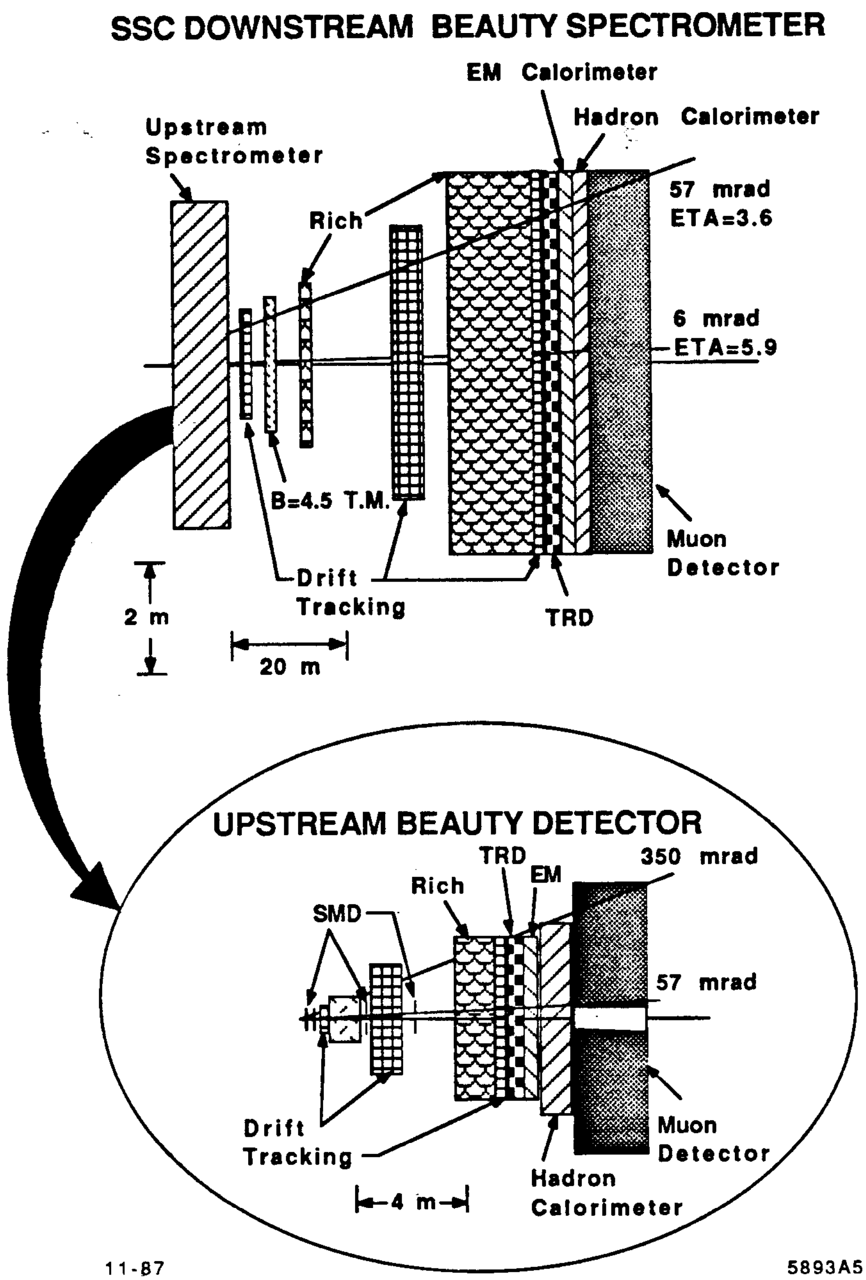


Fig. 5. B Spectrometer from the Berkeley SSC Workshop.

2. OVERVIEW OF PHYSICS AT THE SSC

The design luminosity of the SSC is 10^{33} cm^{-2}s^{-1} with an energy of 40 TeV in the center of mass. The inelastic cross section at 40 TeV is expected to be about 100 mb, which gives 10^8 interactions per second at the design luminosity. The bunch separation is 4.8 m, so the time between bunches is 16 ns. The average number of interactions per bunch crossing is 1.6 at the design luminosity. The probability distribution for the number of interactions per bunch crossing, shown in Table I, is, of course, given by a

Poisson distribution. There will be exactly one interaction per bunch crossing only 32% of the time, so unless a detector can handle multiple interactions in the same bunch crossing, the effective luminosity will be reduced. At the very least, the detector should be able to discriminate the number of interactions which occurred.

Table I. Probability Distribution for Number of Interactions per Bunch Crossing.

Number of Interactions	Probability
0	0.20
1	0.32
2	0.26
3	0.14
4	0.06
> 4	0.02

The pseudorapidity variable, η, which is approximately equal to the rapidity for relativistic particles, is given by

$$\eta = -ln\ (tan\ \theta/2) \quad , \tag{1}$$

where θ is the angle relative to the beam direction. For minimum-bias events, particle production is expected to be uniform in rapidity, and the average number of charged particles per unit of rapidity is expected to be six.

The physics processes which are expected to be of interest at the SSC include:

- Higgs bosons
  - Heavy ($m_H > 2m_W$)
  - Intermediate mass ($\sim$ 100 GeV/c$^2 < m_H < 2m_W$)
  - Nonstandard ($H^{\pm}$)
- Supersymmetry
- Heavy quarks
- Heavy leptons
- New W's and Z's
- Compositeness
- B physics (CP violation)

We should keep in mind that the new physics actually found at the SSC may be something other than what we expected. The signatures for new heavy particle production at the SSC involve:

- High-p_T e's
- High-p_T μ's

- High-p_T jets of hadrons
- Missing energy due to neutrinos.

The cross section[4] for $pp \to H^0X$ is ~ 10 pb, as compared with the inelastic cross section of 100 mb. We can see from this example that we need a rejection power of $\sim 10^{10}$, which is quite a challenge for background simulation! Of course, several orders of magnitude can be trivially obtained. The interesting events from heavy particle production will have several hundred charged particles and several hundred neutrals. A typical high-p_T SSC event is shown in Fig. 6.

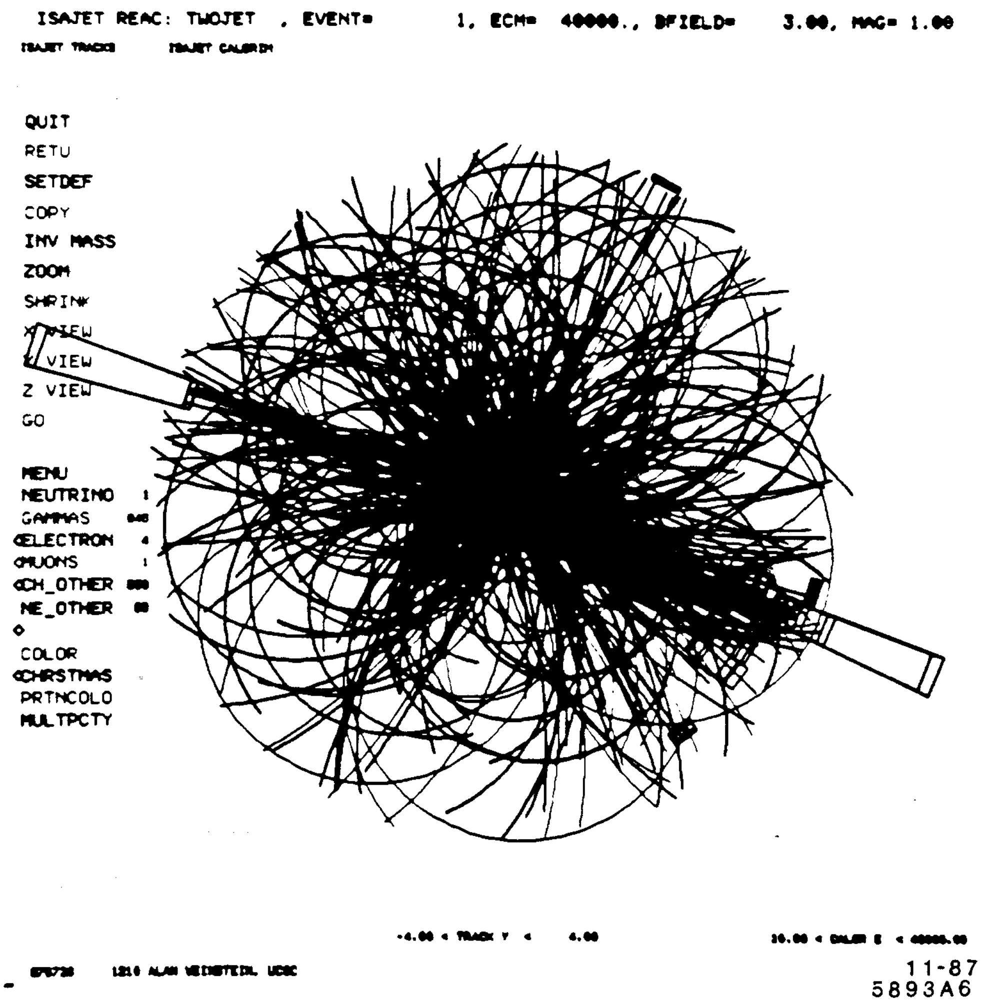


Fig. 6. Typical high-p_T SSC event.

The event generators ISAJET and PYTHIA include the best approximations of the processes of interest, although there are significant differences between the two generators and neither can be considered to be complete. The event generators need to be interfaced to the detector simulation package. For some purposes we can use "canned" events, that is, events which have been generated with all particle decays completed. For other purposes, e.g., vertex detectors, the decay routines need to be called as the particles are stepped through the detector.

3. TRACKING

Detector simulation of tracking is needed for studies of pattern recognition in the high-rate SSC/LHC environment. The time between bunch crossings is only 16 ns at the SSC, which is much shorter than the resolving time for realistic tracking devices. A drift distance of 2 mm corresponds to a drift time of 40 ns using a typical drift velocity of 50 μm/ns. Thus a tracking detector must be capable of handling multiple bunch crossings in any event. Sensitivity to multiple bunch crossings leads to high cell occupancies (fraction of wires with hits in an event), unless very small "cell" devices such as silicon microstrips, pixel devices, or scintillating fibers are used. A detailed discussion of radiation damage, rates, and occupancies for tracking devices is given in Reference 5.

Possibilities for "conventional" central tracking ($|\eta| < 1.5$) include

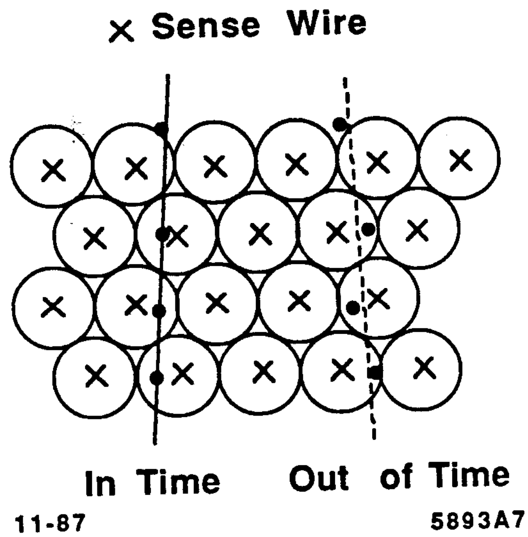
- Small cells, e.g., straw tubes, with radii $\sim$ 2–3 mm and occupancy $\sim$ 10%.
- Jet cells with cell half-width $\gtrsim$ 5 mm and occupancy $\sim$ 30%.

A central tracking system for the SSC might be built of superlayers of 6–8 layers of straw tubes. Within each superlayer every other layer is staggered by half the cell width, as shown in Fig. 7. Hits from out-of-time bunch crossings can then be easily rejected because they do not form tracks. (A simple algorithm would be the requirement for an in-time track that the drift times from two adjacent layers add up to the maximum drift time.) Left-right ambiguities in drift direction are also easily resolved. Local track segments can be found in each superlayer, much as in jet cells, and then linked together to form tracks. Computer simulation of this system is needed to find out how well this would actually work for SSC events.

Another solution, proposed by Elsen and Wagner[6] for the LHC, is central tracking with jet cells, as shown in Fig. 8. The jet cells have maximum drift distances of 0.5 to 1.5 cm, so the occupancies are quite high ($\sim$ 30%). The true limitation to track finding comes from the finite double-hit resolution, which is about the same ($\sim$ 2 mm) for either small straw tubes or jet cells. However, there are many more hits from out-of-time bunch crossings to remove in the case of jet cells. Computer simulation will help to answer the question of how high the occupancy can be without posing severe difficulties for pattern recognition.

The double-hit resolution of a straw tube is probably limited to the straw radius. Fast leading-edge timing using a double-threshold or constant-fraction discriminator is probably appropriate. For jet cells one would use pulse digitizers such as Flash ADCs or

Fig. 7. Layers of straw tubes in a superlayer with every other layer staggered by the straw tube radius. A single in-time track will appear as a series of hits on the wires on alternate sides of the track. The left-right ambiguity is easily resolved locally. A track from an out-of-time bunch crossing is easily sorted out because the left and right drift times do not add up to the maximum drift time.



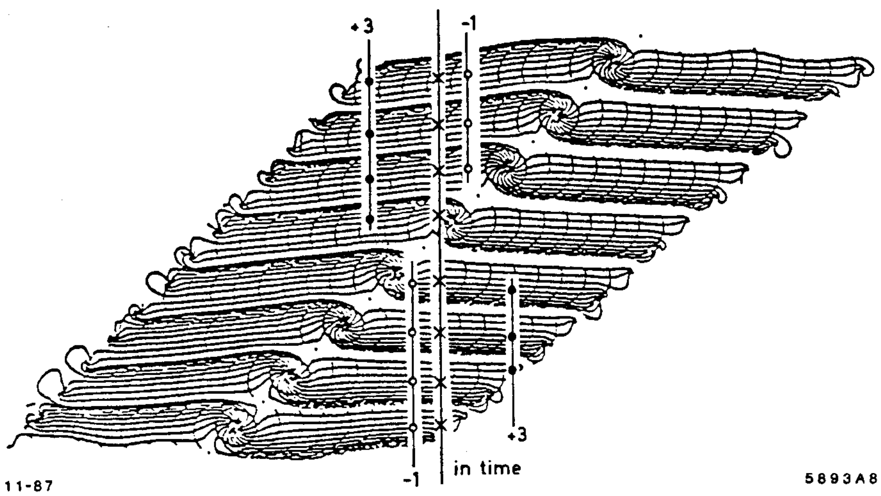


Fig. 8. Jet cell, showing electron drift lines and isochrones. Superimposed on this is a high-momentum track, together with its associated hits, and the apparent hits for a similar track from the previous bunch crossing or the one occurring three crossings later. Left-right ambiguities are omitted for clarity. (From Reference 6.)

analog storage devices. Computer simulation of the electronics response to drift chamber pulses would be useful. In any case, double-hit resolution must be considered in tracking simulations.

Measurement of the coordinate along the wire (the wires in the central tracking system are assumed to run parallel, or nearly parallel, to the beam direction) would probably be by small-angle stereo and cathode strips or pads. The resolution obtained from charge division ($\gtrsim$ 1% of the length of the wire) would not be adequate for the SSC. Stereo wires have the advantage that the same electronics is used to read out all wires. However, it will undoubtedly be difficult to associate the hits on stereo wires with the correct tracks. Cathode pads or strips will be useful in resolving stereo ambiguities. They are also needed for bunch assignment since the propagation time along the wires is about the same as the time between bunch crossings. Computer simulation will help in designing the optimal system of stereo wires plus cathode pads for central tracking.

A schematic drawing of the central and intermediate ($1.5 < |\eta| < 2.5$) tracking systems for the Large Solenoid Detector from the Berkeley SSC Workshop[7] is shown in Fig. 9. The central tracking is assumed to be built of superlayers of straw tubes. The intermediate tracking would be built of planes of parallel wires or radial tracking chambers. Computer simulation of the pattern recognition and triggering capabilities of intermediate tracking chambers is needed.

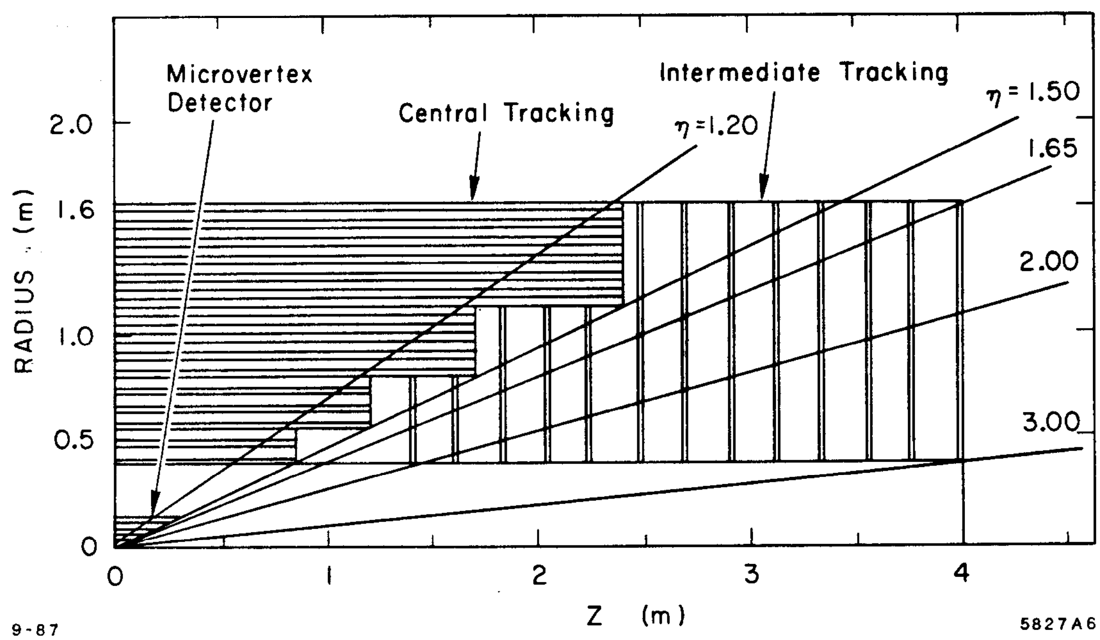


Fig. 9. Schematic view of central and intermediate tracking systems in the Large Solenoid Detector from the Berkeley SSC Workshop.

We have some experience with using the GEANT3 detector simulation package[8] to simulate central tracking detectors for the SSC. We found that GEANT3 did not include some of the necessary software tools for simulating drift chambers. These should be included as general-purpose tools for designing SSC tracking systems:

1. Stereo wire geometry. (Stereo wires do not fit naturally into the GEANT geometry of tubes.)

2. Routines to calculate electron drift trajectories or distances of closest approach to

tracks in the electric and magnetic fields which exist for particular drift chamber cell geometries.

3. Digitizations from events from out-of-time bunch crossings.
4. Removing hits in the tails of hits from previous bunch crossings.
5. Spatial resolution.
6. Double-hit resolution, or keep only the earliest time if single-hit electronics is used.
7. Radial wire chambers for intermediate angle tracking.

A number of computer simulation studies of tracking in SSC detectors should be carried out. These include:

1. How well can hits from out-of-time bunch crossings be removed from consideration in track finding?
2. What is the effect on tracking of hits which are lost and are therefore unavailable for reconstruction because they were too close to a previous hit, either from the same event or from another event within the same bunch crossing or from an event from a different bunch crossing?
3. How well can tracks be found, even if the information is available, given that there are many nearby tracks? Can we find only isolated tracks or those at large transverse momentum relative to the beam direction?
4. How well can hits on stereo wires be associated with the correct tracks and what is the improvement with cathode strips or pads?
5. How much of a problem are photon conversions in the material in chamber or straw tube walls?
6. Is multiple scattering a problem?
7. How well can events from interesting physics be reconstructed, and what does tracking add to the overall event analysis?
8. How much does tracking add to event analysis if there is no magnetic field?
9. What are suitable mixes of pixel devices, silicon strip devices, high-precision drift chambers, and large straw tube or drift chamber systems for SSC tracking?
10. Detailed designs of tracking systems:
    (a) Cell size
    (b) Number of layers
    (c) Radial spacing of layers
    (d) Placement of cathode strips
11. Development of algorithms for finding track segments and momentum vectors for use in track processors on the detector and in the trigger.

4. CALORIMETRY

Calorimetry is the most important component of an SSC detector. It is used for detecting and measuring the masses of hadronic jets, e.g., in $W \to q\bar{q}'$, for identifying electrons, for measuring the total energy and the missing transverse energy of events, and, most important, for triggering on interesting events. Some of the requirements for calorimetry for SSC detectors are listed below:

- Coverage for $|\eta| < 5.5$ ($\sim 0.5°$) and hermetic (no cracks)
- Electromagnetic: $\sigma_E/E = (0.10 \text{ to } 0.15)/\sqrt{E} + 1\%$
- Hadronic: $\sigma_E/E = (0.30 \text{ to } 0.40)/\sqrt{E} + 2\%$.

Considerable progress has been made in recent years[9] in understanding how to obtain better performance from hadron calorimeters. In order to obtain the above goals for hadronic energy resolution, the calorimeter must be compensating, that is, have the ratio of the response to the electromagnetic and nonelectromagnetic components of hadron showers, or e/h ratio, equal to 1 ± 0.05. If the e/h signal ratio $\neq 1$, the energy resolution σ_E/E is not proportional to $E^{-1/2}$ and there is a large constant term. At SSC energies, the constant term dominates. The calorimeter signal is then not proportional to the hadron energy. Also, if $e/h \neq 1$, the response to monoenergetic hadrons is non-Gaussian, and the measured e/π signal ratio is energy dependent. The e/h signal ratio for almost any combination of absorber and sampling medium can be reliably predicted. However, the ratio of absorber to sampling medium which gives $e/h = 1$ will not necessarily produce adequate energy resolution because, for example, the sampling layer may be too thin. Another conclusion of these studies is that no totally active calorimeter can be compensating. Calorimeters for which compensation has been demonstrated experimentally include uranium/scintillator and lead/scintillator. The most promising candidates for calorimetry at the SSC are:

- Uranium/liquid argon + methane
- Lead/TMS
- Lead/scintillating fibers
- Uranium/silicon + polyethylene.

An example of a design for a lead/scintillating fiber calorimeter is shown in Fig. 10.

No calculations or computer simulations of calorimeter response can be believed unless verified by carefully executed beam tests. Of course, many problems with calorimetry, e.g., calibration, radiation hardness, and purity of liquids, can be addressed only by hardware tests. Electromagnetic and hadronic energy resolutions and the e/π rejection ratio must be measured. Hadron misidentification probabilities of $10^{-4} - 10^{-3}$ are needed for SSC physics. To address e/π rejection by computer simulation, fluctuations at levels $< 10^{-4}$ must be investigated. Computer simulation of calorimetry is a bootstrap process: simulations must be compared with beam tests under controlled conditions and the results fed back into the simulations in order to make predictions under more compli-

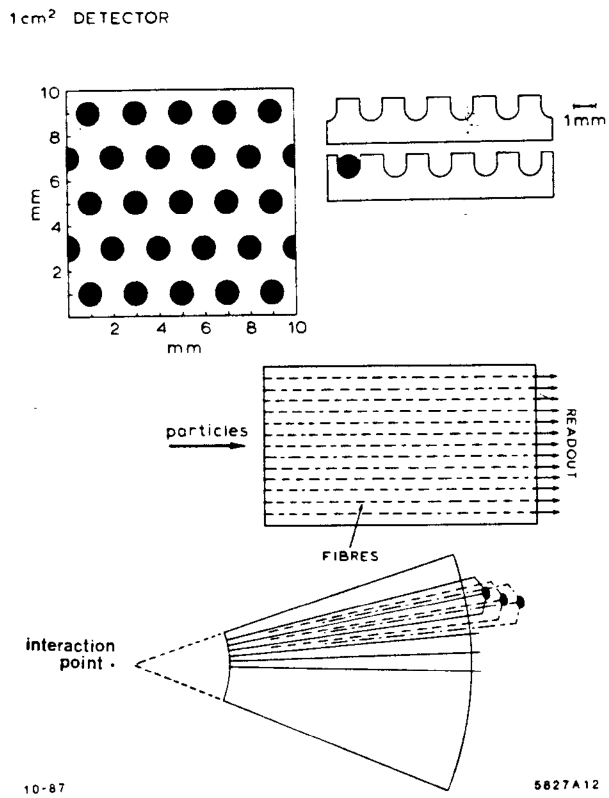


Fig. 10. Schematic design for a lead/scintillating fiber calorimeter. (From Reference 7.)

cated circumstances. Setting up the geometry for simulation of a lead/scintillating fiber calorimeter such as that shown in Fig. 10 should be challenging since it is irregular.

There exist detailed shower simulation programs – EGS and GEANT3 for electromagnetic showers and GHEISHA and HETC for hadronic showers – which we will hear much more about during this Workshop. These work well for many applications; however, they need to be compared with multi-TeV test beam data for use in simulating SSC detectors. The main problem with full shower simulation is that it is too slow. Various estimates give $\sim$ one VAX 780 day to fully simulate a typical SSC event. Clearly, this is not practical. Possible solutions are the following:

1. Make the simulations run faster or use many processors, that is, parallel or vector processors.
2. Parametrize the showers. This method involves fitting the energy distribution of a shower from test beam data or simulation to an analytical expression. Details of fluctuations in shower development are usually lost, but parametrized showers can be useful for some purposes. Another problem with parametrization is the handling of cracks or boundaries between different materials.
3. Files of fully-simulated showers or test beam data with interpolation in energy and angle. This method allows fluctuations to be handled more realistically, although

there is still difficulty in handling relatively unlikely fluctuations. The most serious problem with this method is realistic description of cracks and boundaries.

All three of these methods have been used with varying degrees of success by different experiments. Probably all three are needed as options, depending on the application, for simulating calorimetry in SSC detectors.

Other problems with calorimetry which can be addressed with computer simulation are the production and collection of charge or light in the sampling medium and two problems with liquids: signal-to-noise ratio and speed of charge collection. These would probably ultimately be included in parametrized form in a full detector simulation after stand-alone studies.

5. PARTICLE IDENTIFICATION

The identification of high-p_T electrons and muons has proven to be instrumental in discovering new physics, particularly in the complex events produced at hadron colliders. This will be even more crucial at the SSC. Identified electrons and muons will be used to search for almost all of the new physics expected at the SSC – the Higgs boson, new W's and Z's, heavy quarks, compositeness, supersymmetry, and B physics. High-p_T electrons and muons will be an important part of the trigger.

Realistic simulation of the electron identification performance of the calorimetry of SSC detectors is the most important detector simulation need for electron identification. The probability that a hadron will be misidentified as an electron depends on fluctuations of hadronic showers at the 10^{-4} level. Monte Carlo studies can also help in studying what level of hadron rejection is needed to reduce the background from misidentified hadrons below the level of real "prompt" electrons for various physics processes of interest. It can also be useful for studying electron identification in jets. Two devices which can improve the electron identification capability of SSC detectors are transition radiation devices (TRDs) and synchrotron radiation devices. These should be included in a detector simulation package.

For muon momenta $\gtrsim$ 200–300 GeV/c, ionization is no longer the dominant mechanism for loss of energy as the muon passes through matter, as shown in Fig. 11. Pair production, bremsstrahlung, and nuclear interactions become important sources of energy loss. These processes must be correctly calculated in a detector simulation package for SSC detectors. Multiple Coulomb scattering must also be treated correctly. Computer simulation studies can then be used to determine the effects of these interactions on muon identification, momentum measurement, and triggering.

Hadron identification is needed in some SSC detectors. The B spectrometer, for example, uses ring-imaging Čerenkov detectors. Simulation of Čerenkov radiation should therefore be included in a detector simulation package.

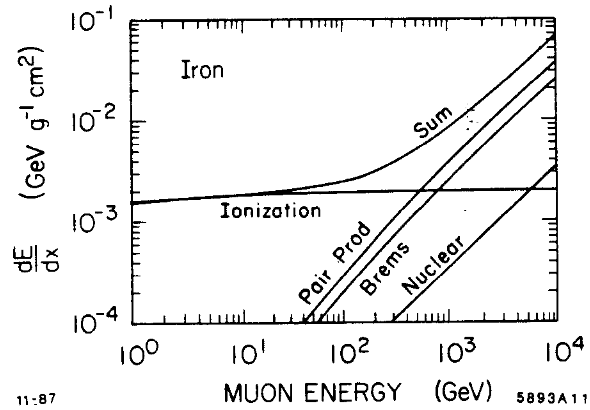


Fig. 11. Contributions to the energy loss in iron from ionization, bremsstrahlung, pair production, and nuclear interaction and their sum as functions of the muon energy. (From Reference 10.)

6. TRIGGER AND DATA ACQUISITION

The goal of triggering at the SSC is to reduce the event rate from 10^8 interactions per second to something which can be realistically handled, or $\sim$ 1 Hz, without rejecting events from interesting physics. It will be necessary to have a sophisticated trigger based on the fundamental signatures of high-p_T electrons, muons, and jets and missing transverse energy. The architecture of SSC triggers has been discussed at previous workshops[11]. A multi-tiered scheme is dictated by limitations to the ability to buffer and transfer large blocks of detector data until a final trigger decision is complete. The Level 1 trigger will use analog sums of calorimeter data and some clustering to reduce the event rate to $10^4 - 10^5$ Hz. The Level 2 trigger will use shower shape and track segment or TRD information to reduce the rate by another factor of 10^2. The Level 3 trigger will make the final trigger decision based on a more-or-less complete event reconstruction using data from all parts of the detector.

Computer simulation of the trigger selection is crucial to the understanding of how to design the detectors, front-end electronics, and trigger processors for optimum performance. Simulated detector signals from events from both backgrounds and new physics must be subjected to trigger algorithms to determine efficiencies and rejection rates. One must be conservative in estimating rejection rates for backgrounds since these are often more severe than originally estimated. One must also be careful to allow for problems in detecting the interesting physics due to detector inefficiencies or other problems. Computer simulation is absolutely necessary in determining cuts which will be made on the data in the trigger since these are essentially analysis cuts made before the data is ever seen. Computer simulation might also be useful in studying the flow of the enormous amount of data needed for a quick trigger decision.

The goal of computer simulation of data acquisition is to simulate the "raw" data as it will appear on the "data tapes." However, at the SSC there will be the very important intermediate step of simulating the processing of detector signals by processors located on the detector; this processing may very well take the place of off-line analysis. Detector simulation will be useful for developing the algorithms to be used in the processors. Computer simulation can be used to help determine how much processing can or should be done on the detector. The ultimate would be all tracking done on the detector and only momentum vectors read out. In other words, it is possible that at the SSC all off-line processing, other than final physics analysis, will be accomplished by microprocessors on the detector. This would be very practical from the point of view of reducing the amount of data read out and the amount of off-line computer resources needed. However, it may not be practical in terms of the on-detector processing needed, and most important, in terms of the information lost for later physics analysis. Computer simulation of signals from the entire detector is needed to help decide these issues.

7. GENERAL DETECTOR SIMULATION NEEDS

Many general detector simulation needs are discussed in Reference 3. From the point of view of detector designers, it is extremely important to have fast turnaround so that problems with detector designs are discovered before the designs are frozen. Detector designers need flexible, easy-to-use interfaces to the detector simulation package so that they do not have to be computer wizards to use it. This interface should be menu-driven and have "help" files. Documentation which is easy to understand, examples, and tutorials are also needed. Interfaces which work on the various computers available to high energy physicists need to be provided. Graphics capability is another very important need for detector designers. The graphics should be three-dimensional, color, and high-resolution. A very difficult problem is the different graphics standards in use internationally and commercially. Detector designers must have graphics output available on local devices, so a standard, at least within the high energy physics community, is needed. However, this is still a problem because we are dependent to a large extent on what is commercially available. If we build our own system, then we often cannot take advantage of commercially available products.

Of course, the most basic need is sufficient computer power to run the simulation programs. A detailed discussion of CPU needs is given in Reference 3. It is very important to have enough CPU time early in the design stage so that unfortunate short cuts aren't taken. Many approaches have been suggested:

1. Speeding up shower simulation by using parametrized showers or files of fully-simulated showers, as discussed in Section 4.
2. Adapting the detector simulation code to run on vector processors.
3. Using parallel processors.
4. Using farms of microprocessors.

These methods are discussed in more detail in other reports in these Proceedings. It would probably be useful to have a central computer which contains the source and object files and can be accessed remotely by physicists running detector simulation code. The job could be set up on this central computer and then run on another large computer (a supercomputer?) where time is available. Computer dependence could be handled at the time the job is set up.

Computer simulation of detectors for the SSC should make use of modern computing techniques and commercially available systems wherever feasible in order to save time and reduce costs. Modern code management techniques should be used (not PATCHY). If the main body of code resides on a central computer, this should be relatively easy since such systems already exist for several computers. Detector simulation packages should also be interfaced to CAD and CAE systems. The same data base should be used by both the detector simulation package and the engineering design packages; this would prevent many of the mistakes which have been made in the past by using different numbers to specify the geometry in the engineering design and the Monte Carlo simulation.

Conventions should be established for interfacing all of the relevant event generators (ISAJET, PYTHIA, FIELDAJET, GOTTSCHALK, EUROJET) to the detector simulation package. A standard particle numbering scheme is needed. Decay histories should be kept for each particle. One should be able to call any of the event generators from the same program which is running the detector simulation package. Each event generator should be available as a package which is updated as needed by the authors. This scheme is already implemented by some collaborations, except that the translation routines for particle types and kinematic variables are written by the specific collaborations. If we establish a convention for the detector simulation package, then all event generators can provide output in the format needed by that package.

8. AN EXAMPLE OF DETECTOR SIMULATION

The Mark II Collaboration[12] at the SLAC SLC has a number of working groups to study how to do various physics analyses on SLC data. Several workshops have been held to report on these studies. As a culmination of this effort, the Mark II Mock Data Challenge was devised. Raw data from the Mark II detector for ~ 10,000 events from

$$Z^0 \rightarrow u\bar{u},\ d\bar{d},\ s\bar{s},\ c\bar{c},\ b\bar{b},\ \mu^+\mu^-,\ \tau^+\tau^- + \text{New Physics}$$

was simulated and analyzed as normal data. The new physics was said to "violate no known physics." Only two people in the collaboration know what is on the tapes. The challenge to the other data-starved physicists was to try to figure it out. A Mark II Mock Data Meeting is represented in Fig. 12. This exercise has been very useful for getting analysis programs ready. Actually, the most challenging aspect has been that there seems to be more than one kind of new physics, so one type of new physics becomes a background for another. (We should be so lucky with our real data!) Of course, in our working groups we had originally studied how to find signals from new physics against a background of only old physics.

This sort of exercise would be even more useful for SSC physics since very unrestrictive triggers can be used in e^+e^- physics. Can we do this for SSC detectors?

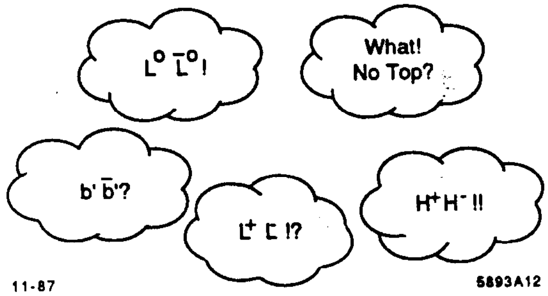


Fig. 12. Mark II Mock Data Meeting.

9. CONCLUSIONS AND RECOMMENDATIONS

A great deal of computer simulation is needed for the intelligent design of SSC detectors. Since the ratio of interesting physics to background is very small, detector responses to relatively unlikely background fluctuations must be understood. High rates in the detectors cause additional problems. SSC detectors will be expensive, so major rebuilding should be avoided. Some of the areas in which detector simulation is particularly needed are pattern recognition in tracking detectors, shower simulation in calorimeters including electron identification performance, data acquisition, and trigger.

Computer simulation of SSC detectors will require a large amount of computer time and manpower. Excessive duplication of effort should be avoided. It will be most efficient to have a standard detector simulation package. GEANT3 is the only general-purpose detector simulation package available, and it works rather well. Rather than starting over and writing another general-purpose detector simulation package, it makes sense to adopt GEANT3 and provide the interfaces and routines necessary to make it generally useful to everyone designing SSC detectors.

It would be useful to have a central computer which contains the latest working versions of all software needed for detector simulation. One could then log on to this computer remotely to set up Monte Carlo programs, or transmit the necessary files to the user's computer. A code management system could keep track of code changes on the central computer. Coordination of computer simulation of SSC detectors is also needed. This can be accomplished partly through workshops and individual efforts, but in order to make a centralized system work there should be one or more people who coordinate the effort. Someone needs to manage the central computer, establish standards for inclusion of new code, write interfaces and other service software, and provide a means of communication. The suggested manpower would be a physicist and a systems programer.

In addition, computer resources for running the simulations are needed. Efforts must be made to improve the speed of GEANT for SSC energies and to make available the computers needed. It will be more cost-effective in the long run to spend the money needed to do an adequate amount of detector simulation before building the detectors.

However, we should not wait for the perfect system before beginning to work on SSC detector simulation. There is much that can be accomplished with what we already have. Some experience is also needed to develop ideas for realistic improvements.

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REFERENCES

1. Proceedings of the Workshop on Experiments, Detectors, and Experimental Areas for the Supercollider, Berkeley, California, July 7–17, 1987.
2. G. Trilling, "Detectors for the SSC," in these Proceedings.
3. L. E. Price and P. Lebrun, "Report of the Working Group on Detector Simulation," Proceedings of the 1986 Summer Study on the Physics of the Superconducting Supercollider, edited by R. Donaldson and J. Marx, Snowmass, CO (1986), p. 469.
4. J. F. Gunion *et al.*, UCD–86–15 (1986).
5. D. G. Cassel and G. G. Hanson, "Report of the Central Tracking Group," Proceedings of the 1986 Summer Study on the Physics of the Superconducting Supercollider, edited by R. Donaldson and J. Marx, Snowmass, CO (1986), p. 377.
6. E. Elsen and A. Wagner, "Tracking Detectors for Large Hadron Colliders and for e^+e^- Linear Colliders," Proceedings of the Workshop on Future Accelerators at High Energies, La Thuile/CERN (1987).
7. G. G. Hanson, S. Mori, L. G. Pondrom, H. H. Williams *et al.*, "Report of the Large Solenoid Detector Group," to appear in the Proceedings of the Workshop on Experiments, Detectors, and Experimental Areas for the Supercollider, Berkeley, California, July 7–17, 1987, SLAC–PUB–4434.
8. R. Brun, F. Bruyant and A. C. McPherson, GEANT3 User's Guide, CERN DD/EE/84–1.
9. R. Wigmans, Nucl. Instr. and Meth. **A259**, 389 (1987); R. Wigmans, "Calorimetry at the SSC," to appear in the Proceedings of the Workshop on Experiments, Detectors, and Experimental Areas for the Supercollider, Berkeley, California, July 7–17, 1987, and references therein.
10. S. Loken, "Report of the Muon Spectrometer Group," talk given at the Workshop on Experiments, Detectors, and Experimental Areas for the Supercollider, Berkeley, California, July 7–17, 1987.

11. Proceedings of the Workshop on Triggering, Data Acquisition and Offline Computing for High Energy/High Luminosity Hadron–Hadron Colliders, edited by B. Cox, R. Fenner and P. Hale, Fermilab, Batavia, IL (1985); T. J. Devlin, A. Lankford, and H. H. Williams, "Electronics, Triggering, and Data Acquisition for the SSC," Proceedings of the 1986 Summer Study on the Physics of the Superconducting Supercollider, edited by R. Donaldson and J. Marx, Snowmass, CO (1986), p. 439.

12. Proposal for the Mark II at SLC, SLAC–PUB–3561, CALT–68–1015, April, 1983.