SLAC - PUB - 3943
April 1986
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THE SUPERCONDUCTING SUPER COLLIDER PROJECT*

MARTIN L. PERL

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

Paper presented at the Seminar on International
Research Facilities, London, England, 17–19 March 1986

I. INTRODUCTION

The elementary particle physics community in the United States is proposing the construction of a very high energy, high luminosity, proton-proton collider called the Superconducting Super Collider[1] (SSC) The proposed SSC has a maximum energy of 20 TeV per beam, yielding a total energy of 40 TeV; and a maximum luminosity of $10^{33} cm^{-2} s^{-1}$. The design is based upon the use of 6.6 Tesla superconducting bending magnets with niobium-titanium coils for the main rings. The circumference of these rings is 83 km. The SSC would provide an effective energy for studying the fundamental physics of elementary particles which is about twenty times larger than that provided by any collider operating or under construction.

This talk emphasizes those aspects of the work on the SSC of interest to the participants in this Seminar on Large Research Facilities. Section II presents an outline of the scientific need for the SSC and the history of the development of the SSC concept. A brief technical description of the SSC, based on the 1986 Conceptual Design Report,[2] is given in Sec. III. The construction cost and construction schedule are discussed in Sec. IV. Issues associated with the realization of the SSC are discussed in Sec. V.

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* This work was supported in part by the Department of Energy, contract DE-AC03-76SF00515 (SLAC).

II. SSC: SCIENTIFIC NEED AND CONCEPT HISTORY

In the last two decades, physicists have broken through to a deeper level of knowledge about the fundamental nature of matter and force.[3,4] The search for elementary particles -- particles which have no substructure or internal parts -- has resulted in the discovery and elucidation of three families of elementary particles:

the quarks which interact through all the four known forces: strong, weak, electromagnetic, and gravitational;

the leptons which interact only through the weak, electromagnetic, and gravitational forces; and

the force-carrying particles such as the photon and the gluon.

Six leptons are known, classified into three generations. Five quarks are known, a sixth (the top) is expected to exist; the quarks are also classified into three generations. We have a beautiful, unified theory of the weak and electromagnetic forces; and we have a probably correct theory of the strong force.

But our understanding of what lies behind these arrangements of particles is limited; and there are large gaps in our knowledge.[5] Indeed we face a set of basic questions:

What is the origin of mass?

What sets the masses of the different particles?

Why are there quark and lepton generations?

Are there more than three quark or lepton generations?

Are the quarks and leptons truly elementary?

Can the strong and electroweak interactions be unified?

Are there undiscovered fundamental forces?

Are there undiscovered new types of elementary particles?

A half dozen models and speculative theories have been proposed to answer some of these questions; but at present none have been verified through experiment, and most are incomplete. We must rely on experiment[6] to either demonstrate that one of these theories is in the right direction, or experiment[6] must provide clues to the right direction.

Some of the needed experiments can be carried out at existing particle accelerators or without accelerators. Other experiments, particularly those which push into higher energy regimes require the new accelerators now being commissioned or now under construction: the proton-antiproton collider at Fermilab; the new electron-positron colliders TRISTAN in Japan, the SLC in the United States, and LEP at CERN; and the electron-proton collider HERA at DESY. These new accelerators provide effective energies up to several hundred GeV.

However, our general understanding of basic concepts in particle physics strongly argues that yet higher energy experiments are required to answer some of the questions raised in the previous paragraph.[5] The world's elementary particle community has recognized for several years that proton-proton (pp) or proton-antiproton ($\bar{p}p$) colliders provide a technically feasible way to obtain effective energies in the several TeV range; a factor up to twenty times larger than the effective energies of the Tevatron, TRISTAN, LEP, the SLC or HERA. Effective energies in the several TeV range in pp or $\bar{p}p$ collisions require total energies of tens of TeV, because in such collisions the effective energy is that of the quarks and gluons, and depending on the specific reaction:

$$E_{effective} = \left(\frac{1}{3} \text{ to } \frac{1}{20}\right) \times E_{total} \tag{1}$$

The interest of the world's particle physics community in pp or $\bar{p}p$ colliders with 10 to 40 TeV total energy has strengthened dramatically in the last several years. In this paper I will describe the work being done in the United States on the SSC project. The work in Europe on the LHC (Large Hadron Collider) is described by R. Billinge[7] in these Proceedings.

Table I summarizes the highpoint of the organizational history of the SSC concept from 1982 to the completion this month of the Conceptual Design Report. This report presents a detailed design for the SSC, not only giving the technical parameters, but also describing the reasoning, calculations and prototype work which led to those parameters.

Table I. Highlights of Organizational History of SSC Concept

Date	Event
Summer, 1982	SSC concept developed at Snowmass, Colorado Workshop of Division of Particles and Fields of American Physical Society.
July, 1983	High Energy Physics Advisory Panel (HEPAP) of U.S. Dept. of Energy (DOE) recommends the construction of an SSC.
Spring, 1984	Reference Design Study shows feasibility of SSC.
Spring 1984	U.S. Universities Research Association (URA) selected by DOE as contractor for R&D on SSC.
Fall, 1984	Central Design Group (CDG) formed to conduct R&D under directorship of M.Tigner.
Summer, 1985	Selection of design for the superconducting bending magnets.
April, 1986	Completion of Conceptual Design Report.

The Conceptual Design Report is based on intensive R&D efforts and on experience with operating colliders. The efforts and the experience are summarized here:

Central Design Group (CDG): Several dozen full time physicists and engineers in the Central Design Group, based at the Lawrence Berkeley Laboratory, led the concept development and detailed design work. This group constitutes the technical and managerial heart of the R&D work on the SSC. The CDG is assisted by: many physicists and engineers who contribute on a part-time or visitor basis; by architecture and engineering firms; and by staff work at U.S. national laboratories.

Superconducting Magnet Devevlopment: The development and selection of the design for the crucial superconducting bending magnets was based upon prototype magnets, built and tested at the Brookhaven National Laboratory, Fermi National Laboratory, Lawrence Berkeley Laboratory, and the Texas Accelerator Center.

Workshops and Panels: Numerous workshops and panels provided both general scientific and technical guidance, and studies of specific technical issues.

DOE Funding: The three activities described above have been supported by the Department of Energy with an annual R&D budget of the order of 25 M$, thus enabling this intensive R&D effort.

Experience with Tevatron Superconducting Magnets: The experience gained in the construction and successful operation of the superconducting Tevatron magnets has been an important factor in providing knowledge for, and confidence in, the SSC design.

Operating Experience with Colliders: The other important general basis for the SSC design is the experience and accelerator physics knowledge which has been acquired in the operation and study of existing colliders, particularly the very successful CERN proton-antiproton collider at which the W and Z^0 particles were discovered.

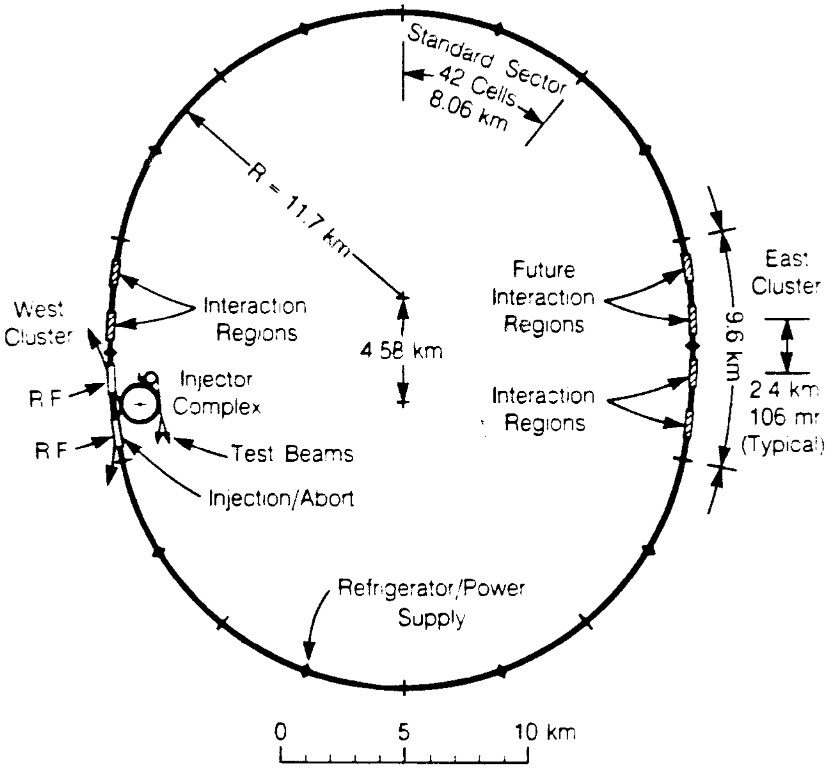

Fig. 1. SSC collider ring layout. The clusters form the concentrations of activity, with interaction regions and utility sections having the injection and rf acceleration equipment. Ten refrigerator and power supply units are distributed around the arcs at 8 km intervals. The total circumference is 83 km (52 miles).

III. SSC: BRIEF TECHNICAL DESCRIPTION

This section summarizes the main points of the SSC design in the Conceptual Design Report.[2]

Beam Parameters: This proton-proton collider has a maximum energy of 40 TeV and a maximum luminosity of 10^{33} $cm^{-2}s^{-1}$. This luminosity is obtained when there are 1.2×10^{14} protons in each main ring, distributed over 1.7×10^4 bunches.

Main Rings: The two main rings, arranged one above the other, with a circumference of 83 km (Fig. 1) are in a tunnel at least 7 m underground. As shown in Fig. 1 the six experimental halls, the beam injection and abort areas, and the RF cavities are arranged in two sections called the East and West Clusters. This arrangement provides operating efficiency and economic advantages. The aperature of the main rings has a diameter of 3.3 cm.

Main Ring Bending Magnets: These superconducting magnets have niobium-titanium coils. As shown in Fig. 2 the coils, stainless steel coil-retaining collars, and the iron flux return are all at a liquid He temperature of 4.35 °K. The magnets are 17.3 m long and provide a field of 6.6 T. Each ring has its own magnets, about 3800 per ring.

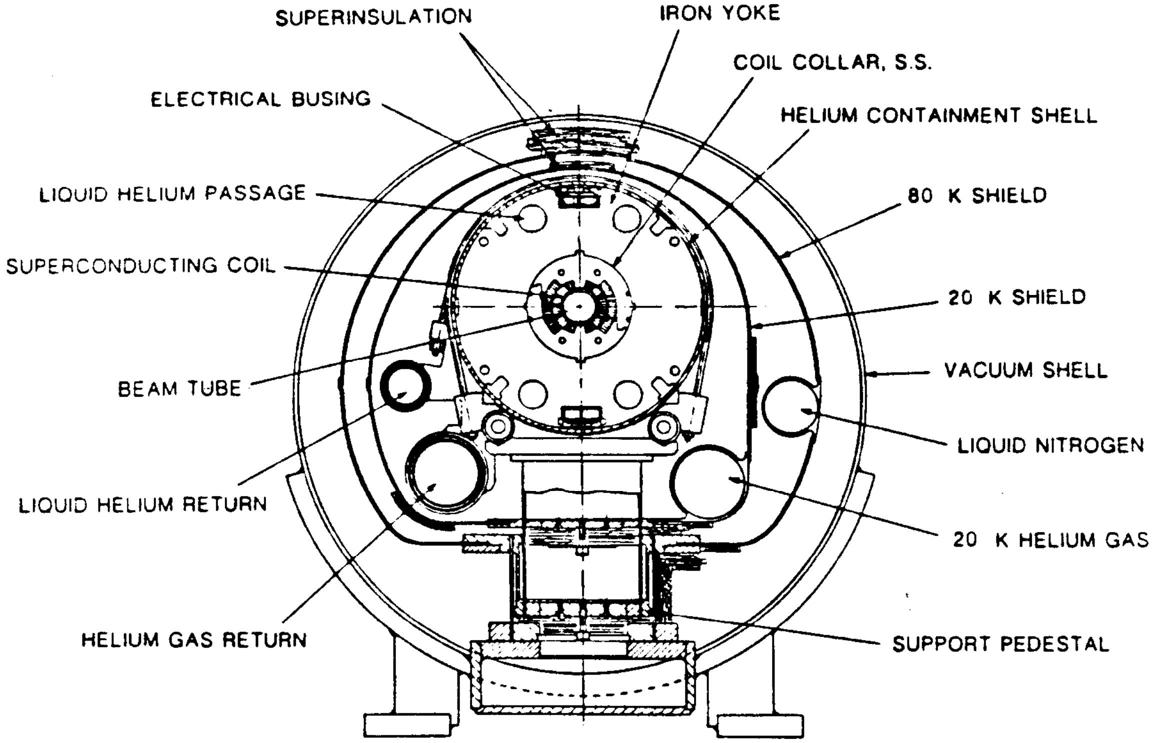

Fig. 2. Cross section of the SSC dipole magnet assembly at a support post. The magnetic components are in a stainless steel helium containment vessel, surrounded by helium liquid and gas tubes, an insulating layer, a liquid nitrogen region, more insulation, and finally an outer vacuum shell of steel. The outer shell is approximately 0.61 meter (24 in.) in diameter.

Other Main Ring Magnets: Each ring has about 900 superconducting quadrupole magnets and higher multipole correction magnets.

Main Ring Cryogenic System: Ten cryogenic systems are used for the main rings, each supplied by a 2.5 MW helium refrigerator.

Injection Systems: The injection system, Fig. 3, has four components. A 125 m long linac accelerates H^- ions to 600 MeV kinetic energy. Then the Low Energy Booster (LEB), a 40 m radius synchrotron with warm iron magnets, accelerates to 8 GeV/c. Next the Medium Energy Booster (MEB), a 300 m radius synchrotron also with warm iron magnets, accelerates to 100 GeV/c. The final High Energy Booster (HEB) uses superconducting magnets and has a radius of about 1 km. It injects at 1 TeV into the main rings.

Experimental Facilities: Of the six interaction regions, four will be used initially. The ring optics can be arranged to provide different luminosity and beam emittance conditions at the different interaction points. For example some of the interaction points can provide high luminosity for experiments while another provides suitable beam conditions for low luminosity, small-angle experiments. The main rings cannot provide external beams. A ring which could provide such beams would be substantially more expensive. However the High Energy Booster does provide 1 TeV external beams which would be used primarily for testing and calibrating detector components.

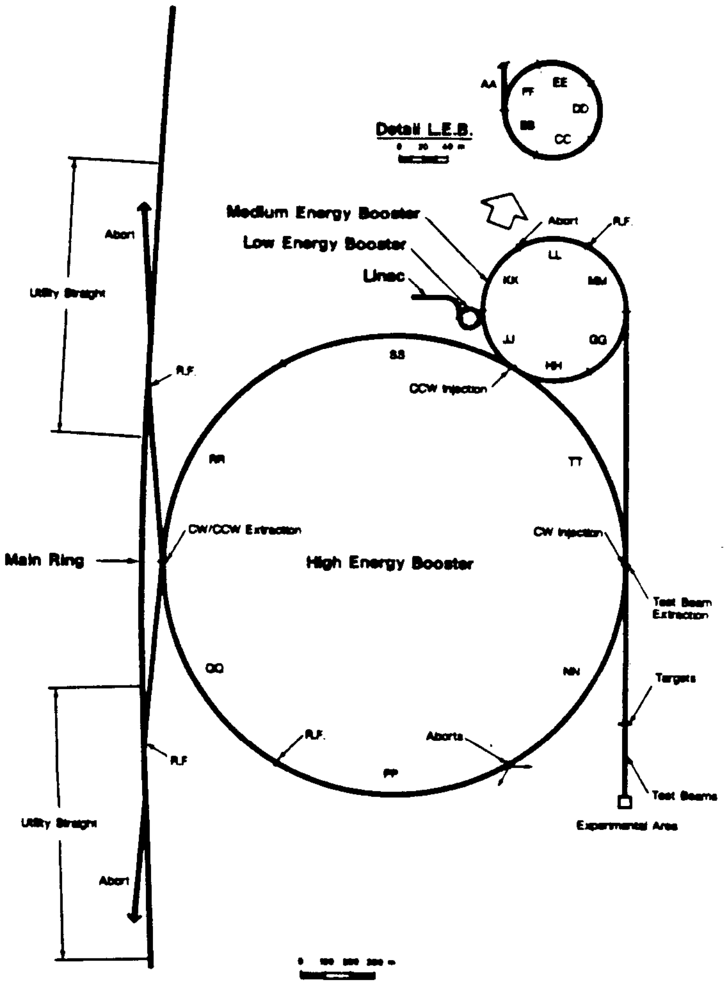

Fig. 3.

IV. CONSTRUCTION COSTS AND SCHEDULE

The Conceptual Design Report includes a very careful study of the construction cost. As shown in Table II, the total calculated construction cost is about 3,000 M $ in terms of FY86 dollars. This includes a contingency of about 20%. It does not include costs associated with R&D, pre-operations, or particle detector construction.

About half the cost is in the technical components, and the main ring bending magnets are a substantial part of the technical component cost, about 750 M $. The collider facilities cost of 346 M $ is primarily for the underground tunnels and interaction regions. This was calculated by studying costs for three different kinds of geological sites. The difference in costs between the cheapest and most expensive site is about 80 M $, and the calculated cost is the average for these two sites.

The Conceptual Design Report gives a construction schedule which is summarized in Table III. The schedule is given in terms of a proposed construction start date of 1987; and for convenience. Table III also designates this as construction year 0. The total construction time is 6-1/2 years.

An important aspect of this schedule is the provision for a several-year period for developing a superconducting magnet manufacturing capability in industry. Once the capability is attained and the quality verified, full-scale magnet production occurs.

Table II. Construction Cost of SSC in thousands of FY 86 dollars. Ref. 2.

Item	Cost in FY86 K$	
Total		3,010,318
Technical components		1,424,161
Injector systems	189,252	
Collider ring systems	1,234,909	
Conventional facilities		576,265
Site and infrastructure	85,433	
Campus area	42,860	
Injector facilities	39,758	
Collider facilities	346,803	
Experimental facilities	61,412	
Systems engineering and design		287,607
EDI	195,404	
AE/CM services	92,203	
Management and support		192,334
Project management	114,749	
Support equipment	52,635	
Support facilities	24,950	
Contingency		529,951

Table III. Proposed SSC Construction Schedule. Ref. 2

Year proposed	Years from start	Month	Activity
1987	0	Oct.	Construction started
1988	1	Sept.	Site selected
1989	2	Feb.	Ground breaking
1990	3	Jan.	Full-scale industrial magnet production started
1991	4	Oct.	Beneficial occupancy of 50% of service areas and tunnels
1991	4	Oct.	Linac installation completed
1992	5	July	LEB installation completed
1992	5	Oct.	Beneficial occupancy of 100% of service areas and tunnels
1992	5	Dec.	West cluster technical systems installation completed
1993	6	Jan.	50% of main rings technical systems installation completed
1993	6	Feb.	MEB installation completed
1993	6	Sep.	HEB installation completed
1993	6	Dec.	East cluster technical systems installation completed
1994	7	Feb.	100% of main rings technical systems installation completed
1995	7	April	Construction completed

V. REALIZATION OF THE SSC PROJECT

The Superconducting Super Collider project has become well known in the United States science community because of its tremendous experimental reach, its impressive technology, its large size, and its construction cost. Therefore, in the United States there has been a great deal of discussion as to how to bring this facility into being -- discussions in the particle physics community, in the broader physical sciences community, and in the science funding community. Incidentally, while the construction cost of the SSC would be larger than that of any previous single research facility, it is not an order of magnitude larger. For example, the total cost of the Hubbel Space Telescope, including launching costs, is above 1,500 M$. And the total construction cost of the Fermilab accelerator facility including its upgrading into the Tevatron is close to 1,000 M$, correcting for inflation.

The thinking of the United States particle physics community about the SSC begins with the axiom that research using the SSC will be international. In an ideal world, an international collaboration of the world's physicists would be formed, the members of that collaboration simultaneously seeking funding from their governments. But the complexity of the international and national negotiations which would be required, and the long time needed for such negotiation to be fruitful, has been overwhelming.

Therefore the United States particle physics community sees the first step in the realization of the SSC to be the initiation of the SSC construction by the United States. The community is proposing to the United States government that it undertake primary responsibility for the construction of the SSC in the United States, and that it also undertake primary responsibility for SSC operation. The community hopes that other nations or geographic regions will join in supporting this undertaking, either while the United States government is considering the SSC or when, hopefully, the SSC is authorized. Indeed such international support could play a crucial role in obtaining authorization.

One aspect of the proposed SSC construction warrants more discussion, even in this short paper: the budgetary source of the construction funds. The total yearly budget for high energy physics in the United States is about 500 M$, and is mostly operating funds. It is clear that additional funds must be found for most of the SSC construction cost. Furthermore the particle physics community and the federal funding agencies know that the research budgets for other areas of physics and for the physical sciences in general are already very tight. Therefore, the general belief in the particle physics community is that the United States government must be asked to direct new research funds into the construction of the SSC.

Once the SSC is completed, it is expected that its operation could be accomplished within a yearly budget not much larger than the present high energy physics budget. This would have to be accomplished by the reduced operation or shutting down of some existing accelerator facilities. There is a long history of this process occurring in the United States as well as in the rest of the world. With relatively fixed budgets, the high energy community has often made the choice to push into new experimental areas by building and using new facilities at the expense of discontinuing the use of old facilities.

I cannot predict at this time the pace at which the United States government will consider the authorization of the SSC project. It is a major new scientific initiative and it must be supported and approved by both the Executive and the Legislative Branches of the federal government. A very strong case has already been made for the scientific need for the SSC. The 1986 Conceptual Design Report[2] presents a very well documented design, a firm construction cost calculation, and a reasonable construction schedule. The SSC has received good support by the broader United States physics community.[8] Perhaps the crucial element in the realization of the Superconducting Super Collider project is international participation in its construction as well as in its use.

VI. ACKNOWLEDGEMENT

I am indebted to the Central Design Group of the SSC for technical information and figures, and to W.K.H. Panofsky for discussions on the issues involved in the national and international support of large research facilities.

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