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SSC DESIGN STATUS

HELEN T. EDWARDS
Superconducting Super Collider Laboratory
2550 Beckleymeade Avenue
Dallas, Texas 75237

INTRODUCTION

Over the last year, steps have been completed to initiate the formation of a Superconducting Super Collider Laboratory (SSCL). The Department of Energy has chosen a site and an operating contractor to form the Laboratory and to direct construction of the Collider and its experimental detectors. The site selected is Waxahachie, Texas. Universities Research Association teamed with EG&G Intertech, and Sverdrup Corporation is the chosen contractor. Roy Schwitters has been chosen as Laboratory Director. Thus, work that had been ably carried out in the past by the Central Design Group now has been turned over to the new laboratory.

Coupled with the choice of site and the Director for the SSC Laboratory, site specific designs as well as a review of the design parameters have been undertaken. This report will discuss the proposed site specific geometrical layout and parameters of the Injector and Collider, the basic layout of test beams, and an interaction region IR bypass scheme, which allows for alternative use of pairs of detectors or IR's. This report also discusses work in progress to evaluate the dynamic aperture of the Collider and to try to determine the sensitivity of the calculated aperture to parameters such as half-cell length and injection energy. Finally, a brief discussion of the ongoing magnet R & D program is given.

LAYOUT

A schematic layout of the SSC is shown in Fig. 1 and basic parameters are given in Tables I and II. The SSC is a 20 on 20 TeV proton-proton collider with two rings of superconducting magnets, one above the other. Beams cross from upper to lower ring (or vice versa) at each IR.

The design luminosity of 10^{33} cm^{-2} sec^{-1} is realized with bunch intensities of about $3/4 \times 10^{10}$ particles, a β^* of 1/2 m, and bunch spacing of 5 m. The rings are about 8 km in circumference and will be divided into 8 arc sectors and two cluster regions. Cluster regions consist of a "diamond" IR bypass region with the possibility of two pairs of IR's and a utility straight section for injection into and abort out of each ring as well as space for

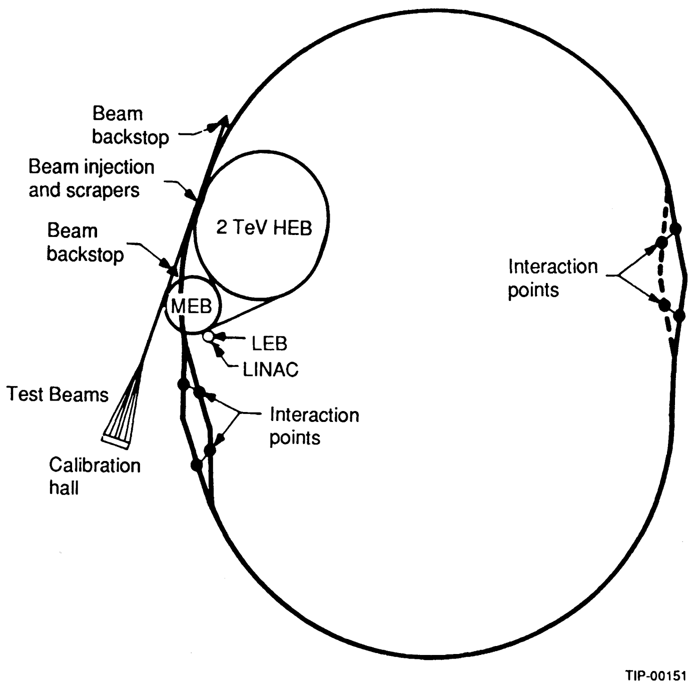

FIGURE 1. Schematic layout of SSC.

TABLE I. SSC Parameters

E (TeV)	20
N (10^{10})	0.75
Circumference	87,120 m
Bunches	17,424
BN (10^{13})	13
f_{rot}	3.4 KHz
$f_{collisions}$	60 MHz
S_b (m)	5.0 m
ε_N (σ)(10^{-6} m)	1
β^* (m)	1/2
σ(10^{-6} m)	5
L ($\times 10^{33}$)	1
L/hit ($\times 10^{25}$)	1.6
$\Delta\nu_{HO}$	0.003
$\Delta\nu_{LR}$	0.008
Power (KW) = 7×10^{14} NB	8.75/one ring

TABLE II. Collider Parameters

Energy	E	20	TeV
Magnetic radius	P	10187.1896	M
Magnetic field	Bo	6.54869524	T
Rigidity	Br	66712.8	T-m
Gradient	G	205.5892	T/m
	K = G/Br	0.0030817	m^{-2}
Betatron phase per cell	m	p/2	
Number of dipoles	No	5040	
Circumference	C	87120	m
		285826.8	ft
		54.13386	miles
		968	half-cell lengths
Half-cell length	LH	90	m
Bunch separation	SB	5	m
RF wavelength	lRF	0.83333	m
Tune		Approx. 140	

R.F. This arrangement differs from the original design which had a more linear cluster array with two utility straight sections and two interaction regions or the possibility of four IR's on the side of the ring not involved with injection. In the present layout of the east cluster, the utility and one leg of the east bypass are available for future development. The campus cluster region (Fig. 2) has been designed to try to be as compact as possible and has the following features:

a) "Diamond" Bypass (Fig. 3). The outer leg consists of two interaction regions separated by a bend region which makes up part of the required 360° of bend. In addition, there are regions without a bend and dispersion suppressor regions which adapt to the normal bend regions of the arcs. The inner leg of the bypass is made up of an additional region of reverse bend and equal compensating regions of normal direction bend. Path lengths are kept equal in the two alternative legs and a modular spacing of $n \times 180$ m is imposed between interaction points and muons that go straight ahead for one interaction point, and an adjacent interaction location is 34 meters which is felt to give sufficient separation.

The advantages of the bypass configurations include the elimination of the requirement to move detectors and have large additional assembly halls. On line detector assembly does not need to be complete prior to start up accelerator commissioning. In addition, detector off time for major modifications and concentrated analysis can be appropriately scheduled during operation.

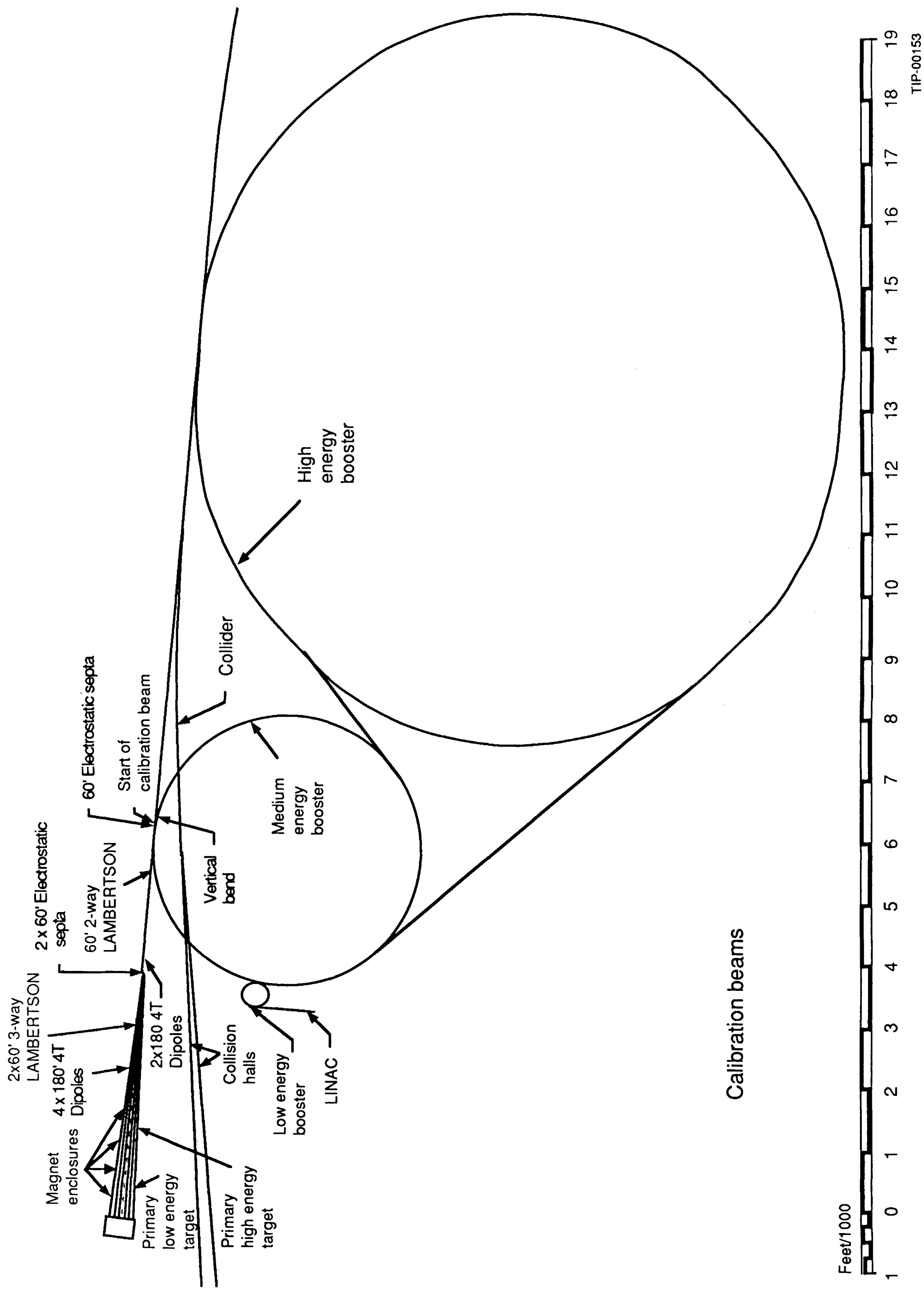

FIGURE 2. Layout of west campus region.

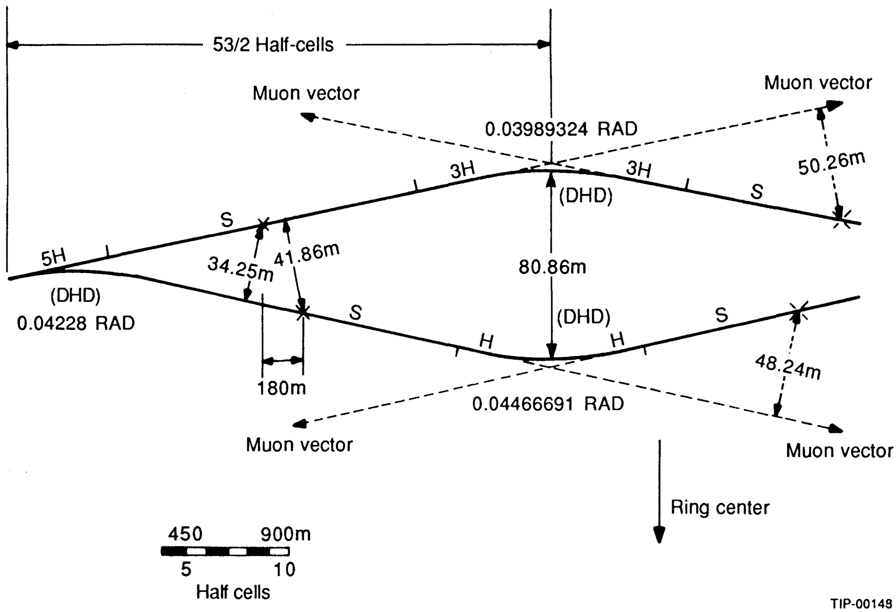

FIGURE 3. Diamond bypass configuration.

b) Injector Layout. The injector layout is driven by geographic and logistic factors. The High Energy Booster (HEB) has been chosen to operate up to 2 TeV in order to improve the operating margin of safety associated with the Collider dynamic aperture. The circumference of the HEB ring (~11 km) cannot be reasonably accommodated at surface elevation as the terrain is rolling meadow with significant elevation change over the required areas. Therefore, it has been decided to locate the HEB at approximately the same elevation as the Collider and to use one utility straight section for transfers in both directions. The other requirement is for a test beam area for calibration of detector modules. It is logistically effective to have the test beam hall located near the interaction regions and the industrial support areas they will require. Primary beams of slow spill are required from both the HEB and MEB (Medium Energy Booster). Thus, it is attractive to have straight sections from both rings tangent to the beam line, and to have this line bend up from the HEB and reach surface elevation prior to intersecting the MEB, which will be on the surface. After connection with the MEB, the beam is split for different target stations and secondary beam calibration areas.

c) Test Beams. The test beam lines are laid out to allow for up to six separate areas using electrostatic splitters for two-way, than two times three-way splits. Calibration requirements include hadron beams in the 1 to 100 GeV range with flux of 10^7/sec and particle identification of 100:1. Lepton (and π) studies at 100 Hz with particle identification of 1000:1 and energy resolution of 1/3% absolute and 0.05% relative accuracy are specified. The design of the lines should minimize muon fluxes at the detector hall to 100 KHz/m^2.

SITE

The location of the site selected for the SSC is shown in Fig. 4. Detailed geotechnical investigations are underway to evaluate optimization of the precise ring location. A "lampshade" drawing depicting elevation features is illustrated in Fig. 5. Three geological formations are indicated. Of these, the Austin Chalk is the preferable material for hall and tunnel construction. Three possible tunnel tilts are shown. Depth of the west halls is 150 ft. On the east, depths of 150–350 ft are possible depending on the tilt chosen. A tilt of $1/3^o$ would guarantee hall footings in the chalk and minimize tunneling outside the chalk in less favorable material.

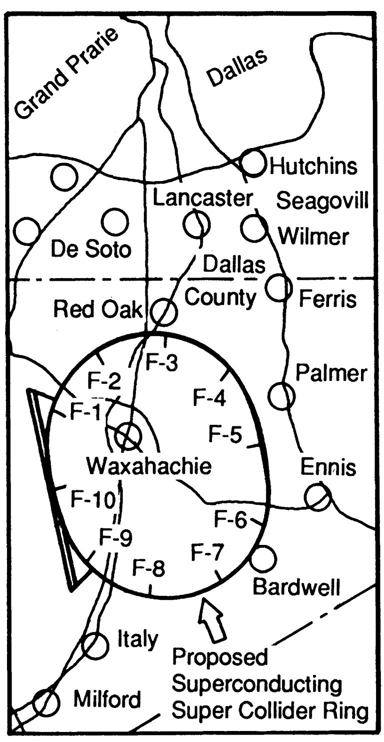

FIGURE 4. Texas site of SSC at Waxahachie.

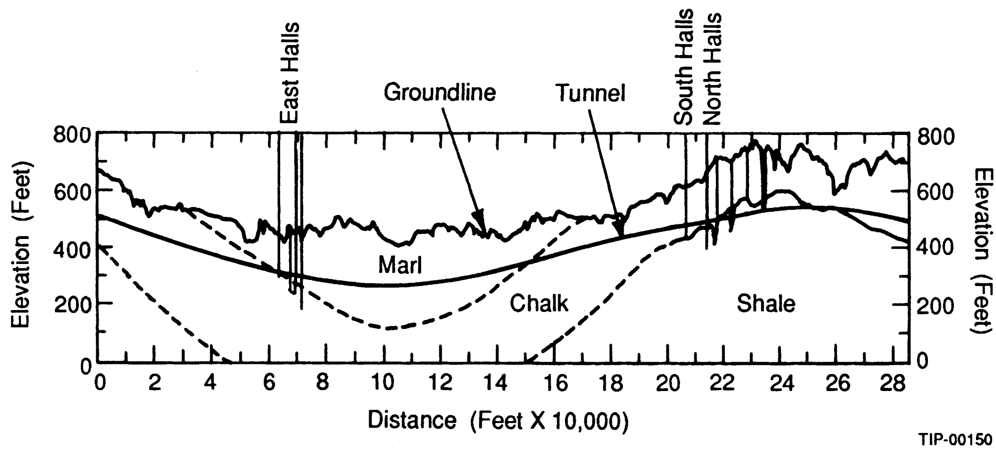

FIGURE 5. "Lampshade" of ring elevation showing marl, chalk and shale.

COLLIDER LATTICES

The Collider lattice is depicted in Figs. 6, 7, and 8. The standard half cell is 90 meters long with a phase advance of 90°/cell. There are six bend magnets of 12.7 m effective bending length being considered in the design at present with 5.2 m effective quadrupole length and 5 m for spool and correctors. An even number of bends per half cell allows for the possibility of mid half cell correctors. Dispersion suppressor half cells are 67.5 m long and contain 4 bend magnets. The phase advance per cell remains 90°. The "genetic code" of the SSC lattice depicting half of the ring is given in Fig. 7. The lattice functions for the outer path of the west cluster are given in Fig. 8.

INJECTOR

A summary of tentative injector parameters and design specifications is given in Tables III and IV. The primary requirement is to obtain normalized emittances of $1\pi \times 10^{-6}$ m, rms (i.e. $6\pi \times 10^{-6}$ 95%) for collider operation at bunch intensities of 10^{10}. Thus, emittance preservation is of paramount importance, and space charge tune spreads in both the Low Energy Booster (LEB) and MEB must receive proper attention. For this reason, injection and extraction energies of the LEB have not been finalized. With the increase in final energy of the HEB to 2 TeV, it appears difficult to design the injector chain without passing through transition in at least one of the rings (MEB). Significant lattice distortion would be required in the MEB to avoid transition and result in unreasonably high dispersion functions. An integrated design that allows transition in the MEB but not in the LEB is presently being done.

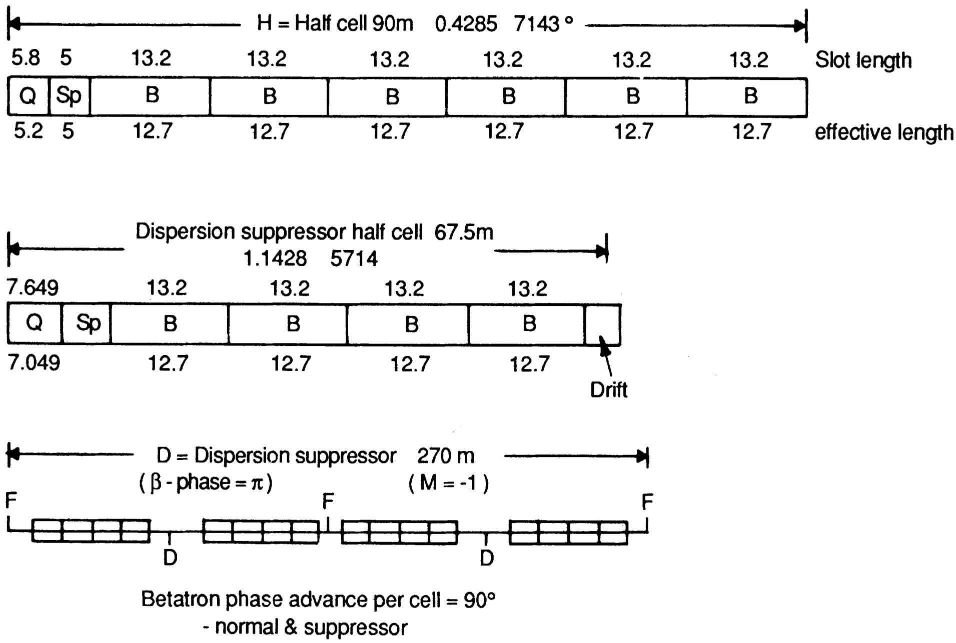

FIGURE 6. Half cell lay out of Collider.

Flexibility in possible bunch spacings can be preserved by judicious choice of harmonic number in the Boosters as well as in the Collider. Multiples of the nominal 5 m spacing are in principal possible (× 2,3,4,6,12,18).

Secondary design considerations make it desirable to investigate potential limitations to bunch intensities up to 5×10^{10} either by coalescing for collider operation or with larger emittances ($4\pi \times 10^{-6}$ m, rms) for extracted beam use. Both the MEB and HEB will be designed to provide external beam capability through resonant extraction.

Parameters for the linac are given in Table V. The design will allow the option of either adiabatic (preferred) or bunch-to-bunch capture in the LEB. Two standard RF frequencies (420 MHz and 1260 MHz for 1 GeV) will be used for the fundamental linac design. Space will be retained at the low energy end to allow for the possibility of bunch modulation should that become desirable. The choice between 600 MeV or 1 GeV linac energy has not been made.

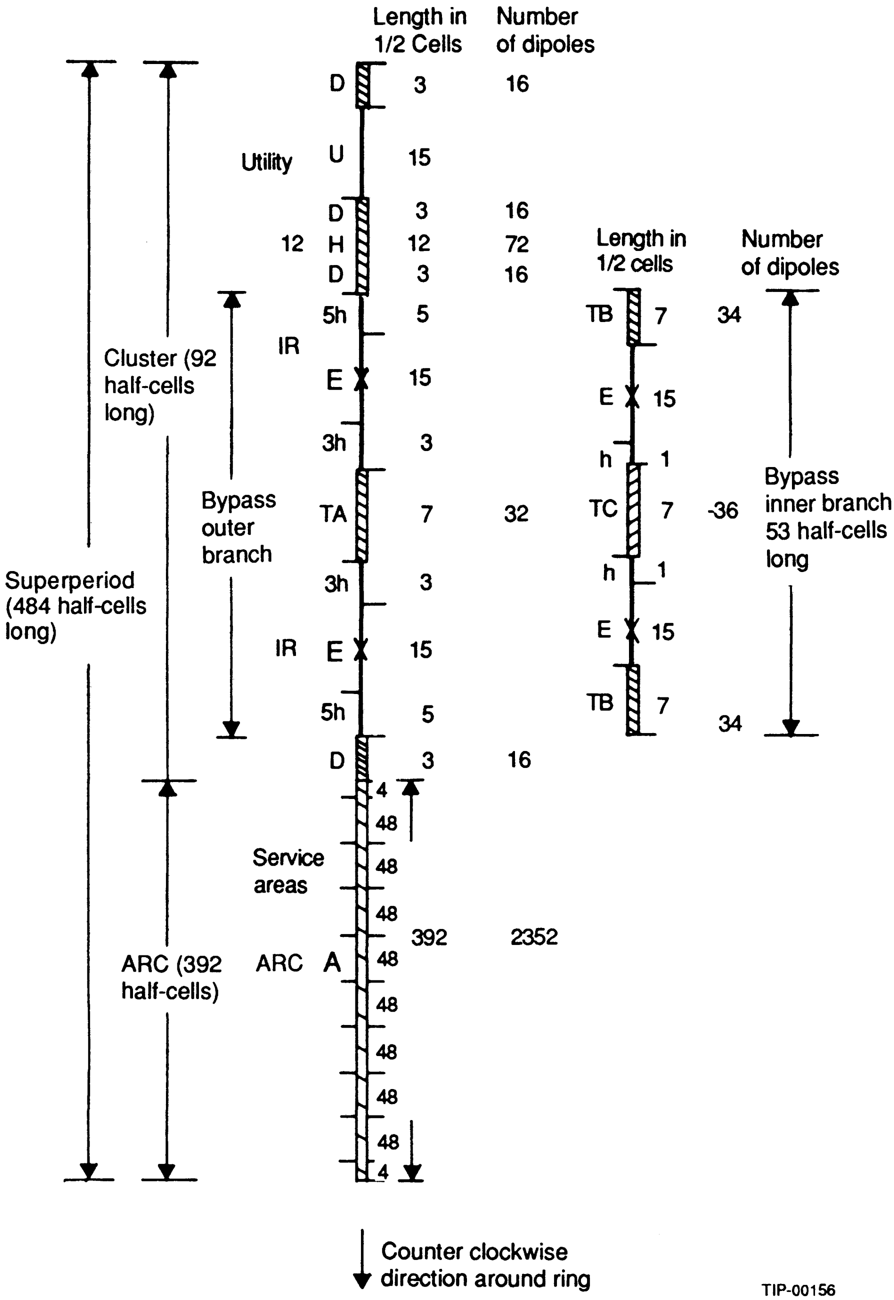

FIGURE 7. Shorthand description of optical elements of SSC Lattice showing standard arcs dispersion suppressors, utility strengths, bypass region and interaction regions.

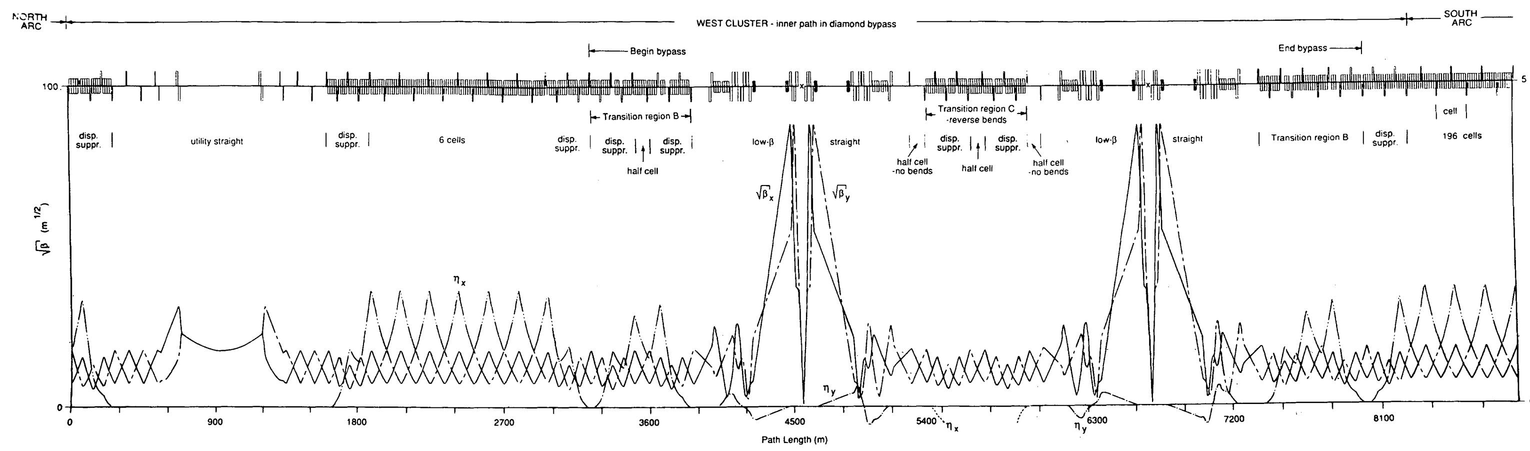

FIGURE 8. Detailed optics of the outer leg of the west cluster.

TABLE III. Injector & Collider General Parameters

Ring	Collider	HEB	MEB	LEB	Linac
Energy	20 TeV	2 TeV	200 GeV/c	1/11.1 GeV (kinetic)	0.6/1.0GeV (kinetic)
Momentum	20 TeV/c	2 TeV/c	200 GeV/c	9/12 GeV	
	1.2/1.7GeV/c				
Mono-bipolar	(2 rings)	bi	mono	mono	–
Super/normal	s.c.	s.c.	normal	normal	normal
Peak field	6.55 T	6.2 T	1.7 T	1.2/1.6 T	
Circumference	87.12 km	10.89 km	3.96 km	0.54 km	–
Bunch spacing	5 m	5 m	5 m	5 m	–
Harmonic number	17424	2178	792	108	
	$(2^4\ 3^2 11^2)$	$(2\ 3^2 11^2)$	$(2^3\ 3^2\ 11)$	$(2^2\ 3^3)$	
Emit for collider	1.0	0.8	0.7	0.6	<0.5
($\pi\ 10^{-6}$ m, rms, normalized)					
N_b at $1\pi\ 10^{-6}$ m	$1{\times}10^{10}$	$1{\times}10^{10}$	$1{\times}10^{10}$	$1{\times}10^{10}$	–
Emit for test beam	–	4	4	–	–
($1\pi\ 10^{-6}$ m, rms, normalized)					
N_b at $4\pi\ 10^{-6}$ m	–	$5{\times}10^{10}$	$5{\times}10^{10}$	$5{\times}10^{10}$	–
N_{tot}	$1.4{\times}10^{14}$	10^{14}	$4{\times}10^{13}$	$5{\times}10^{12}$	–
Cycle time	–	2 min	3 sec	0.1 sec	

TABLE IV. Injection Chain — Under Evaluation

Require: 1×10^{10} particle/bunch at 60 MHz, 5m bunch spacing

Emittance preservation all important

Require: 1π normalized emittance (6π -- 95%)

Need also higher bunch intensities (2×10^{10}, 4×10^{10}) at longer bunch spacings (10m, 20m, etc.) (bunch coalescing?)

Test beams would like of order $N_b = 5 \times 10^{10}$, 4π rms emittance, and reasonable cycle capability.

Must look at upgrade potential/limitations of injector chain

Linac: 600 - 1000 MeV (KE)

420, 1260 MHz

normalized emittance < 0.3π (rms) possible

LEB (Low Energy Booster): 9/12 GeV/C

space charge tune shift important

try to avoid transition

MEB (Medium Energy Booster): 200 GeV

resonant extraction

goes through transition

HEB (High Energy Booster): 2 TeV

superconducting -- bipolar

resonant extraction

TABLE V. SSC Linac Strawman Design

H^- SOURCE
Type: Magnetron or Penning
Voltage: 30-50 kV
Design Current: 30 mA
Length: 1 m (with non-neutralized LEB)

RFQ (Radiofrequency Quadrupole)
Type: 4-vane
Frequency: 428 MHz
Output Energy: 2.5-3.0 MeV
Design Current: 27 mA
Total Power: <0.5 MW - 1 Klystrode
Length: <3 m

DTL (Drift Tube Linac)
Type: Constant gradient, permanent magnet
Frequency: 428 MHz
Output Energy: 100–130 MeV
Design Current: 26 mA
Total Power: <21 MW – 6 Klystron
Length: <45 m

CCL (Coupled-cell Linac)
Type: Side-coupled
Frequency: 1284 MHz
Output Energy: 600 MeV
Design Current: 25 mA
Pulse Length: <36 μsec
Trans. Emittances (n,rms): 0.15 π mm-mrad (sim)
Long. Emittance (n,rms): 1.44 π mm-mrad (sim)
Total Power: 150 MW – 10 Klystrons
Length: 100 m

DYNAMIC APERTURE

The dynamic aperture of the SSC Collider is under evaluation. The requirements are most severe at injection where the beam size is largest and the non-linear fields in the magnets most important. Not only do geometrical construction errors affect the field quality, but also significant persistent current fields are present. Their time and temperature dependent effects produce systematic and random variations.

Computer simulations are underway to model particle survival time as a function of initial launch trajectory amplitude. Of the order of 10^7 turns are necessary to model the half hour time duration in which beam must remain at injection energy in the collider during the fill sequence. At present, 10^5 turns can be simulated, and activities are underway to push this to a few times 10^6 with reasonable computer time usage. With the proper computer capabilities in hand, studies will be carried out to explore the relative benefits of: a) stronger focusing 90 m vs. 11 m half cell length, b) 2 TeV injection energy vs. 1 TeV, which reduces the persistent current sextupole, b_2, from 7.4×10^{-4} at 1 TeV to 3.0×10^{-4}, c) increased coil diameter from 4 cm to 5 cm which would decrease the b_2 to about 60% of the above, and d) smaller size filaments, –2.5μm vs. 6μm which would reduce persistent currents' effects by about a factor of 2.

Results of simulations are shown in Fig. 9 for up to 10^5 turns. As can be seen, extrapolation to higher turns is difficult. Needed aperture is estimated to be about 4 mm. Simulations of this type need to incorporate synchrotron oscillation tune modulation, as well as power supply ripple or other sources of the modulation to approach realistic modeling conditions.

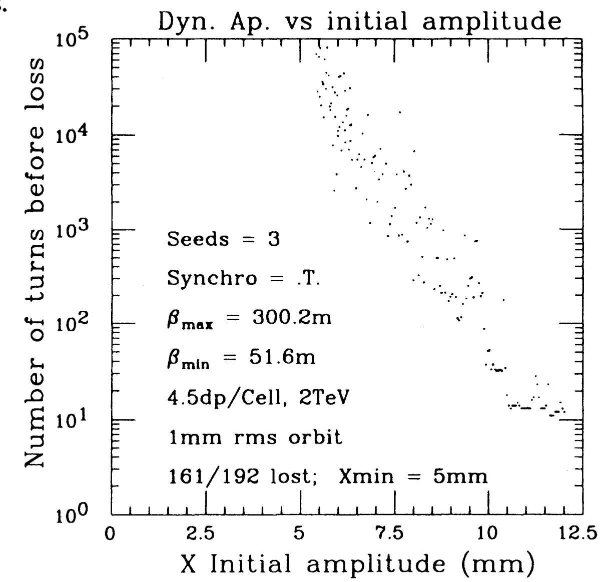

FIGURE 9. Dynamic Aperture calculation for SSC using specified field quality. Injection process takes of order 10^7 turns.

STATUS OF MAGNET R&D PROGRAM

A modified series of superconducting dipole collider magnets (C358D) have been under construction and testing. These magnets have been fabricated with upgraded tooling, including strengthened coil molding "form blocks" for prestress uniformity. The coil collars have a strengthened design with spot welded lamination pairs and tapered keys to reduce over stress when collaring. The collared coil assembly has axial restraint supplied by "line-to-line" fit in the yoke. The coil ends have improved molding and thick end plates. The ramp splice between inner and outer coils has been revised but still appears to be a problem. Three magnets of the modified series (DD16, 17, 18) have been tested, and six more will be tested over the next six months. On magnets 19–26, a new Helium flow scheme will be tested. This scheme allows for better coil cooling via channels in the yoke laminations. In addition, magnets 19 and 26 will use high manganese stainless steel collars.

Further assemblies initiated at BNL in 1990 will explore collar/yoke dimensional control. New tooling assembled at FNAL will be used in coil fabrication with variants of the ramp splice, coil ends and fabrication techniques.

The measurement program will be focused on retraining problems and quench conditioning. Also, primary emphasis will be given to field measurements and quality. Specifically, warm to cold correlation of magnetic data will be studied. Good correlation is necessary if cold measurements of production magnets are to be eliminated.

A 5 cm dipole design study is underway and will continue in FY90, depending on the outcome of the aperture investigation.

Results from recently produced magnets are shown in Figs. 10 and 11. Figure 10 indicates the substantial improvement in preload for magnets 16–18 and the favorable remaining preload reserve at high excitation. Figure 11 shows the good mechanical behavior of magnet DD17 to quench threshold as a function of temperature. Forces at 7500 A are 33% above SSC operating point. Quench threshold as a function of temperature variation follows predicted variation. Unfortunately, the two second thermal cycle gives indication of retraining after warm up.

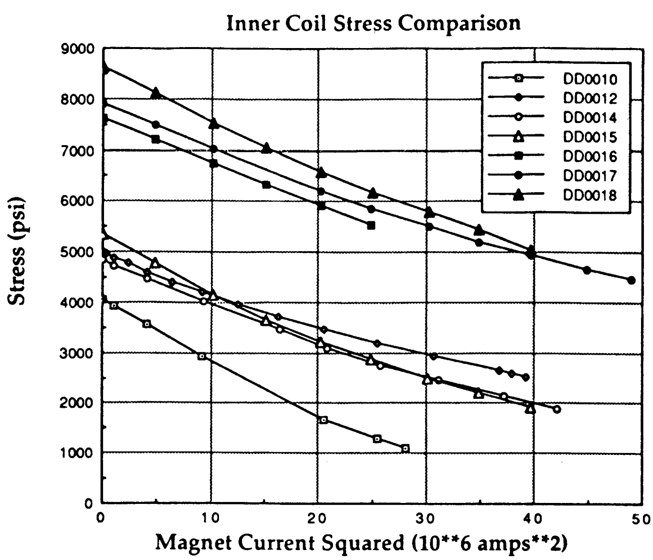

FIGURE 10. Coil stress as a function of excitation for old and new R&D magnets.

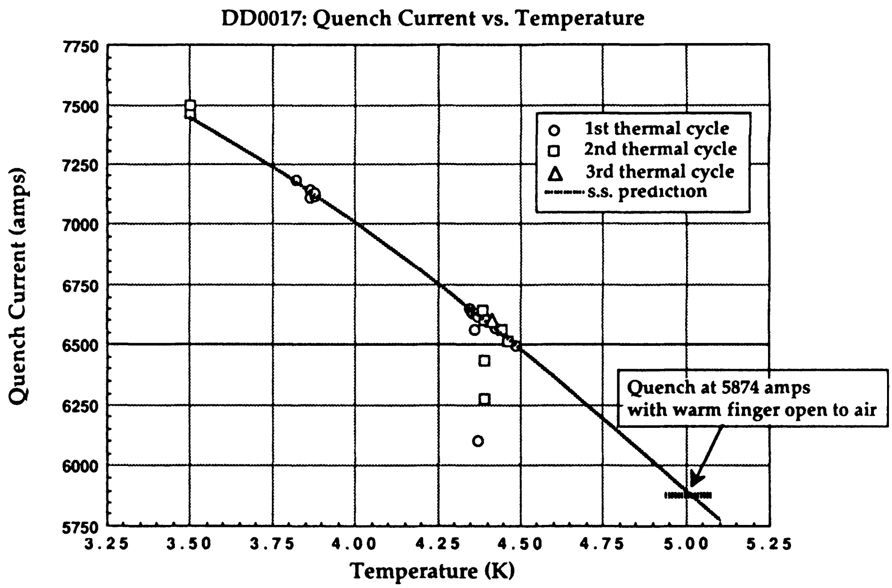

FIGURE 11. Quench level vs. temperature for magnet DD0017. When normalized to quench level at 4.3°, variation follow predicted curve.

ACKNOWLEDGMENTS

Work presented here is based on the efforts of a number of laboratories and individuals. The foundation of the SSC design and the R&D effort has been ably lead by Maury Tigner and members of the Central Design Group. Laboratory collaborations with Brookhaven National Laboratory, Lawrence Berkeley Laboratory and Fermi National Accelerator Laboratory have been, and will continue to be, a key factor to the success of the project. Many individuals within the SSC Accelerator Division deserve much credit for carrying on this design effort in the face of organizational changes and relocation.