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WHERE IS THE SSC TODAY?*

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Summary

The SSC is a high luminosity pp collider designed to achieve 40 TeV in the center of mass. Depending on the final magnetic field chosen the main ring will be between 90 and 165 km in circumference. Construction of the SSC has been recommended to the DOE by HEPAP for completion in the early 1990's. The Universities Research Association has been designated by the DOE to do R/D and prepare a design proposal, construction plan and cost estimate. Model magnets are being tested and a field level will be chosen before October 1985. A design proposal will be submitted in April 1986.

Physics Requirements

Penetration of the 1 TeV mass domain for elementary interactions is a major priority for experimental particle physics in the next decade and beyond. Revelations about our current understanding of elementary physics and totally unexpected surprises can be anticipated in this energy regime. If, as assumed by many, the Higgs mechanism is responsible for dynamic symmetry breaking and if, as now seems likely, its mass is 1 TeV or greater, it is sure that the present electroweak dynamics will become a strong interaction at that energy and qualitatively new phenomena will occur at energies of 1 TeV and above. The other postulated means of dynamic symmetry breaking have similar consequences. Perhaps the quarks and leptons are not the ultimate constituents of matter. They may be composites, built from some more basic entities (techniquarks, preons). Such ideas inevitably lead to families of yet undiscovered particles with masses in the range 0.1 to 2 TeV or to evidences of compositeness to be seen in collisional processes with sub-energies in the same range. Perhaps these manifestations will be detected at the Tevatron Collider, but higher energies are likely needed. Even now there are hints and perhaps more from the CERN collider of phenomena not explicable in the standard picture or simple extension of it. Some physicists believe the peculiar events (so-called monojets) are evidence of supersymmetric particles, necessary consequences of a fundamental (broken) symmetry between fermions and bosons. Others have other explanations, conventional and unconventional. Regardless of the outcome, sub-energies well above 100 GeV = 0.1 TeV are clearly of vital interest. The SppS collider, with its total collisional energy of 0.6 TeV, and the Tevatron Collider, with 1.8 TeV available soon, can explore thoroughly the mass range up to about 0.3 TeV. The SSC, with its 20 TeV proton beams, will be able to extend the exploration to roughly 3 TeV, more for some specific processes and less for others.

Technicolor, supersymmetry, and other theories can sometimes make rather specific predictions of the magnitudes of cross sections for new phenomena. Using the constituent-constituent energy distributions with the theoretical cross section, an estimate can be made of the probability of creation of a Higgs or other particle per collision between protons (or protons and antiproton) of a given total energy. [Some examples from a recent compilation[1] (EHLQ) are shown in Fig. 1.] For a conventional heavy Higgs particle decaying into W pairs, the SSC can reach out to a Higgs mass of 1 TeV. For comparison, a proton-antiproton collider with a plausible luminosity of $10^{31} cm^{-2} s^{-1}$ and total energy of 10 TeV could not search successfully for such decays. For supersymmetric particles, the SSC could find a gluino (the spin 1/2 partner of the Gluon) if its mass were less than about 1.6 TeV, while the 10 TeV, lower luminosity machine could probe up to 0.4 TeV. Similarly, the limits for squark masses would be 1.5 TeV and 0.3 TeV, respectively.

The various theoretical estimates and machine assumptions can be challenged in detail, but the message is clear. To probe effectively into the TeV mass range, a very high-energy, high-luminosity collider is needed. Quantitatively, a goal of 20 TeV per beam and a luminosity of $10^{33} cm^{-2} s^{-1}$ seems prudent as the next advance in the energy frontier. Less energy and/or luminosity begins to compromise the discovery potential. The argument for the highest possible energies is reinforced when the possibility of discrete energy thresholds is included. If the maximum available energy lies just below the threshold for the onset of some radically new physics, that physics will be undiscovered, no matter what the luminosity!

Figure 1 displays examples of discovery limits for new particles in hadron-hadron colliders. A discovery is defined as the creation of from 10 to 100 real and uniquely identified events in one year

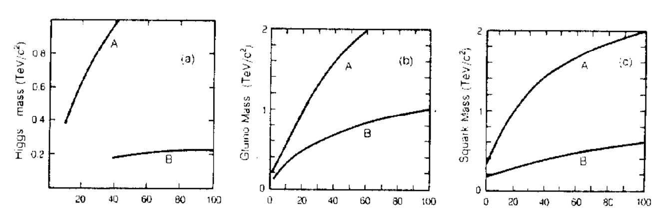

Fig. 1. (a) $H \rightarrow W^+W^-$. The SSC (curve A at 40 TeV cm) can plausibly discover any Higgs particle with a mass between 0.2 and 1.0 TeV. The lower-luminosity collider has a very narrow window for discovery of a heavy Higgs via the W^+W^- decay mode.

(b) Supersymmetric gluinos (spin 1/2 partners of the gluons). The upper discovery limit is 1.6 TeV for the SSC, and 0.3 TeV (0.5 TeV) for a lower luminosity collider with 5 TeV (10 TeV) beams.

(c) Supersymmetric squarks (spin 0 partners of the quarks). Here the upper limit in mass is 1.5 TeV for the SSC. The lower luminosity collider could reach to 0.4 TeV at the same beam energy.

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* SSC-33

† Operated by Universities Research Association for the Department of Energy.

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of data taking, after allowance for backgrounds and other spurious signals. In each figure, the abscissa is the center of mass energy in the collider and the ordinate is the mass of the new particle. The curves represent approximate upper limits on the mass of particles of each particular type, discoverable with a collider of a given beam energy and luminosity. Curve A corresponds to a collider luminosity of $10^{33}cm^{-2}s^{-1}$, projected for the SSC. Curve B corresponds to $10^{31}cm^{-2}s^{-1}$, appropriate for a proton-antiproton collider.

History of the SSC

Already in 1978 and 1979 ICFA workshops began evaluating the physics and accelerator aspects of the TeV domain. Synchrotrons capable of 20 TeV were discussed among other possibilities. In 1982 the Division of Particles and Fields held a summer workshop at Snowmass, Colorado, to study the physics opportunities and discuss possible accelerator configurations that might produce the required beam energies. Attention focused on possible alternative superconducting magnet options for a 20 TeV proton collider. In 1983 workshops were held at Cornell University and the University of Michigan to examine technical feasibility, cost and accelerator physics issues for the SSC. These workshops were followed by an ANL/University of Chicago workshop in January 1984 on $p\bar{p}$ options for an SSC. In July of 1983 HEPAP unanimously recommended that the DOE proceed with plans for an SSC. In 1984 the DOE and the Directors of the U.S. HEP accelerator labs commissioned a Reference Designs Study to examine closely all aspects of technical feasibility and cost for three different technical approaches to the SSC. On the basis of that report, and extensive reviews of it, the DOE contracted with Universities Research Association to perform the R/D necessary to support a design proposal and to develop a design proposal and construction plan. The URA created a Central Design Group to oversee the work and, in concert with the DOE, established the SSC Design Center on the premises of Lawrence Berkeley Lab. Work began there in October of 1984. R/D and design work are being carried out at BNL, FNAL, LBL, Texas Accelerator Center and at other national labs, industrial firms and universities.

No commitment to construct the SSC has been made by the DOE.

Reference Designs Study

This effort, which was carried out in February April of 1984 involved about 150 scientists and engineers from U.S. accelerator labs, universities and industrial firms.[2] Primary parameters for which this study developed three approaches were

Beam Energy	20 TeV
Luminosity	$10^{33}cm^{-2}sec^{-1}$
Particle	pp
Number of Interaction Regions	6

Designs of Technical Systems were based on three possible magnet designs, a 2 in 1 cold iron, cosine theta magnet at 6.5 T with horizontal beam separation, a 1 in 1 cosine theta magnet without iron immediately around the coil intended for vertical beam separation, and a 2 in 1 cold iron, "superferric" magnet with vertical beam separation. Major features of the three designs are shown in Table 1.

Table 1.
Major Design Features

	Design A	Design B	Design C
Central dipole field [T]	6.5	5.0	3.0
2-in-1 cryostat	yes	no	yes
Cold iron yoke	yes	no	yes
Conductor dominated	yes	yes	no
Field shaped by iron	no	no	yes
Magnetically-coupled apertures	yes	no	no
Saturated iron	yes	no	yes
Length of dipole magnet [m]	17.5	14	140
Inside coil diameter [cm]	4.0	5.0	2.5x2.4[a)]
Main ring circumference [km]	90	113	164

[a)]Pole face dimensions.

While detailed parameters also vary for the three designs those listed in Table 2 for the low field design are exemplary.

Table 2
Abridged Parameter List-Low Field Design

General Parameters	
Maximum energy per ring [TeV]	20
Luminosity-each interaction region [$cm^{-2}sec^{-1}$]	10^{33}
No. of interaction regions	6
Injection energy [TeV]	1
Magnet type	superferric
Standard beam separation (vertical)[cm]	12.4
Peak magnet field [T]	3.0
Peak current [A]	10,000
Bunch spacing of overall design	variable
Bunch spacing used in this list [m]	10
No. of events per crossing (at a cross section of 100 mb)	3.3
Circumference [km]	164.4
Orbit frequency [kHz]	1.82
Orbit period [μsec]	548
No. of particles per bunch	$1.45x10^{10}$
No. of bunches per ring	16440
No. of particles per ring	$2.38x10^{14}$
Average beam current [mA]	69.7
Invariant transverse emittance [μm]	1.0
Beam-beam tune shift per crossing	0.0017
Magnets and Lattice	
Amplitude function at interaction point [m]	1
Free space at interaction point [m]	±20
Crossing angle [μrad]	30-100
Length of interaction region insertion [m]	750
Phase advance for interaction region insertions [deg]	360
Length of standard half-cell [m]	150
Phase advance per cell [deg]	80
Magnetic (physical) length of dipole [m]	139.5(140.2)
No. of dipoles per half-cell	1
No. of standard half-cells per ring	954
No. of half-cells per dispersion suppressor	4
No. of dipoles per dispersion suppressor*	2
No. of dispersion suppressors per ring	18
No. of dipoles per ring*	990
No. of standard quadrupoles per ring	1020
No. of utility insertions (abort, injection, RF)	3
Length of utility insertion [km]	2.0

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(Table 2 continued on next page)

Phase advance for utility insertion [deg]	200
Nominal tune (both planes)	121.76
RF System Related Parameters	
Frequency [MHz]	360
Peak voltage per turn [MV]	35
Total cavity length per ring [m]	43.7
Acceleration period [sec]	1000
Momentum spread at injection, σ_E/E	2.5×10^{-4}
Momentum spread at 20 TeV	5.0×10^{-5}
Bunch length at 20 TeV-rms [cm]	7.0
Longitudinal emittance at injection (95%) [eV·sec]	1.1
Longitudinal emittance at 20 TeV (95%) [eV·sec]	4.4
Injection System	
Linac energy [GeV]	1
Length [m]	200
Beam current [mA]	65
Ion species in linac	H^-
Invariant transverse emittance [μm]	0.22
Low energy booster energy [GeV]	70
Circumference [km]	1.2
RF frequency [MHz]	60
Cycle time [sec]	3
Bunch coalescing frequencies (typical) [MHz]	60/k, k=1,2,..5
High energy booster energy [TeV]	1
Circumference [km]	6
RF frequency [MHz]	60
Cycled time [sec]	45

*In units of standard length (139.5 m).

Typical lattice functions in the high field design for normal arcs and high luminosity experimental insertions are shown in Fig. 2 and 3 respectively.

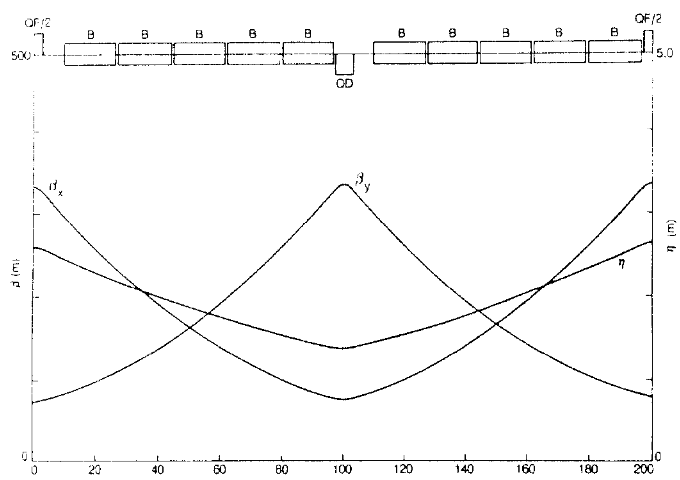


Fig. 2. The betatron amplitude functions (β_x,β_y) and the dispersion function (η) in the regular cells for the high field lattice.

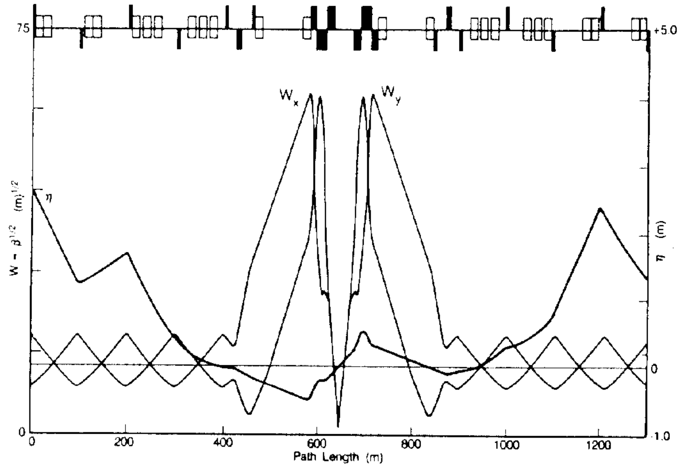


Fig. 3. The lattice functions in both planes (W_x, W_y) and the dispersion function (η) in the experimental insertions and the adjacent dispersion suppressors.

As can be seen, except for the overall scale of the machine, the parameters are close to or within common experience from the past. One possible exception is the synchrotron radiation from the proton beams, amounting to some 8 kw per beam in the high field design. This would not be remarkable were it not for the fact that the beam tube will be cryo-pumped. Perhaps the synchrotron radiation falling on the cryosorbed gas molecules can release them at a rate which could spoil the vacuum. Calculations indicate that this will not be the case. The physical mechanisms involved are complex enough, however, that experimental demonstration is needed to verify the calculation. If gas desorption is excessive an inner liner, permeable to gas but having a low transmission for scattered photons, will be necessary.

As a result of these studies the technical feasibility of the SSC is well established. The cost of such a facility is also a central issue and a considerable portion of the RDS effort was devoted to cost estimating. In carryjng out the estimating a detailed work breakdown structure was devised as a guide. Industrial firms, engineering consultants and national laboratory staffs experienced in building the various components and subsystems contributed to the estimates. The full details are presented in the RDS.[2] Table 3 gives a summary of the results. The distribution of costs is displayed graphically in Fig. 4.

Table 3
Total Project Cost Summary-High Field Design
(FY 1984 M$)

1. SSC Laboratory			2724.9
1.1 Project Management and Administration		113.5	
1.1.1 Construction Project Management	59.0		
1.1.2 Laboratory Support Services	54.5		
1.2 Central Laboratory Facilities		127.0	
1.2.1 Conventional Construction	86.0		
1.2.2 Equipment	41.0		
1.3 Injector Facilities		186.8	
1.3.1 Conventional Construction	39.6		
1.3.2 Injector Systems	147.2		
1.4 Collider Facilities		1402.4	
1.4.1 Conventional Construction	398.7		
1.4.2 Collider Accelerator Systems	1003.7		
1.5 Experimental Facilities		87.4	
1.5.1 Conventional Construction	87.4		
1.6 Systems Engineering and Design		255.5	
1.6.1 Conventional Construction	97.9		
1.6.1 Technical Components	157.6		
1.7 Contingency		552.3	
1.7.1 Conventional Facilities	164.6		
1.7.2 Technical Components	387.7		

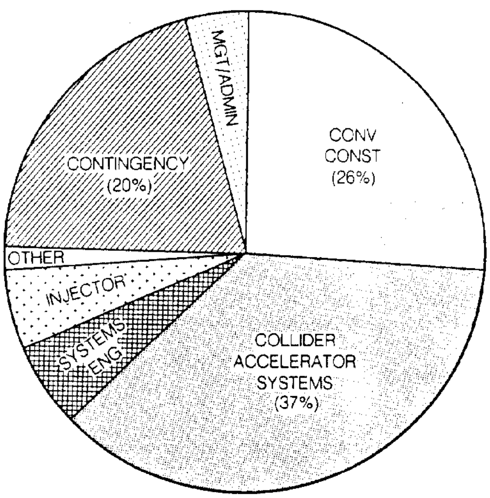


Fig. 4 Pie chart showing cost distribution.

Objectives and Accomplishments in 1985 and Beyond.

The single most costly technical sub-system is the superconducting magnet system. Conventional construction, largely the tunnel, is also a principal cost element. Consequently, particular attention was paid to these items. In estimating magnet costs an important assumption was made: It was assumed that the critical current of the superconductor at 4.5 K, 5 T would be at least 2400A/mm^2 by the time SSC magnets went into production. Also important for an economical magnet design is small heat leak to the low temperature parts and low heat leak was emphasized in the magnet designs. Substantial progress has been made in these areas. Details will be found in technical reports to this Conference.

In the area of superconductor, significant advances in current carrying capacity of commercially available NbTi cable have been registered. Improved understanding of the fundamentals and the translation of that understanding into improved processes resulted from close university-laboratory-industry collaboration with support from the DOE. Fig. 5[3] displays the recent progress that has been made. Already 2400A/mm^2 material is commercially available and there is evidence that even higher densities will be available soon.

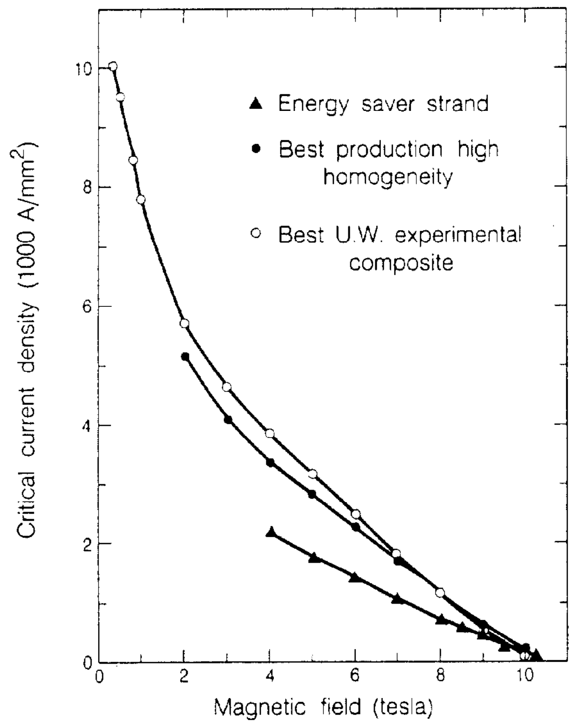
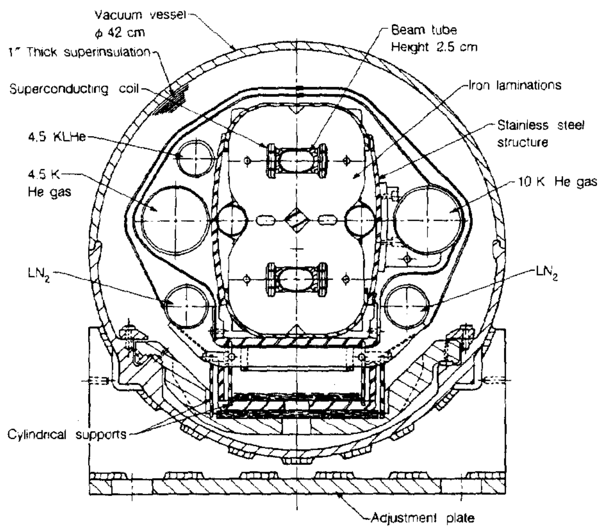


Fig. 5. History of superconducter performance (courtesy of D. Larbalestier, U. Wisconsin).

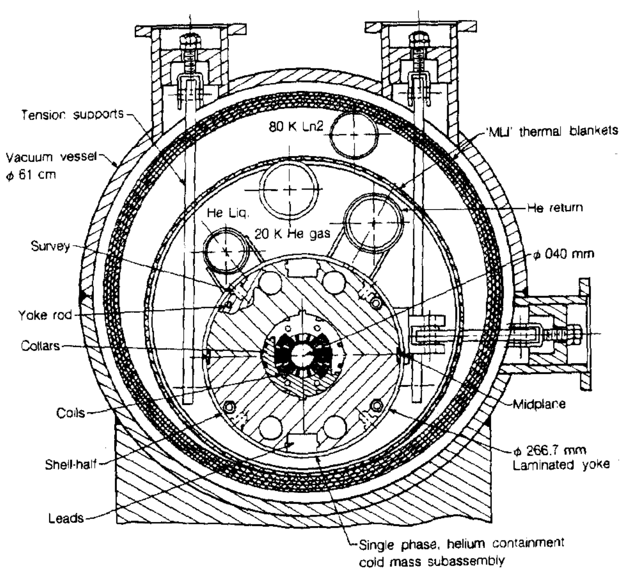
In the area of low heat leak there have been significant demonstrations of efficient supports and insulation blanket schemes. An example is given in FNAL work[4] reported to this Conference. In a realistic, 12 m length, model using multilayer insulation blankets and improved supports for the cold mass, a combined 4.5 K and 10 K static heat load of less than one quarter watt per meter has been measured. Not only is this level of heat leak satisfactory but it agrees rather well with the calculations, giving confidence in our cost estimates for the cryogenic systems.

Control of the conventional construction costs will be dependent upon obtaining a satisfactory site. Siting criteria for a machine the size of the SSC are not abnormally stringent as was shown by the RDS. Many siting possibilities exist. Nevertheless, certain topographical, geological and infrastructure requirements should be met to avoid excessive costs. These are described in more detail in a report to this Conference. They deal with physical setting, environmental issues, geology, community resources, utilities, manmade disturbances, climate and cost and schedule factors. About 11,000 acres, appropriately distributed around the ring, are needed. While many geological settings are possible for construction, uniformity of the material and absence of major water problems will help minimize costs. Naturally, a low level of local seismic activity is desirable. Facility power is estimated to be about 100 MW. A resident staff of about 3000 is expected. A technical site parameters document has been prepared and will be published soon.

Another major objective for 1985 work is the selection of a basic magnet type to carry forward to full scale prototyping and test. Five types are under consideration: 2 in 1 and 1 in 1 3 T, cold iron versions; 2 in 1 and 1 in 1, 6 to 6.5 T cold iron versions; and a 1 in 1 version with no cold iron. Examples of two of them are shown in Fig. 6 a, b.



(a)



(b)

Fig. 6. Two of five basic magnet types being studied for the SSC. (a) is a low field superferric type; (b) is a high field cosine theta type.

It is intended that a selection among the five will be made in the last quarter of FY 1985.

In FY 1986 the conceptual design will begin in earnest and a proposal submitted in the spring of 1986. It is hoped that a site can be selected by the DOE by the end of 1986. Provided that sufficient funding can be obtained, it is our intention to prototype and test sufficient of the major subsystems to support a construction start in 1988. Many models and a full scale prototype of the selected magnet type will be ready in early 1986 and one cell should be under test in early 1987.

As worked out in the Reference Designs Study, a construction period of six years is anticipated.

References

1. Eichten, Hinchliffe, Lane and Quigg, Supercollider Physics, Rev. Mod. Phys. 56, 4, pp. 579-707, October 1984.

2. Reference Designs Study, Div. of High Energy and Nuclear Physics, U.S. Dept. of Energy, May 8, 1984.

3. D. Larbalestier, U. Wisconsin, Private Communication.

4. P. Mantsch, FNAL, Private Communication.