Proposal to the

Texas National Research Laboratory Commission

Research and Development Program

Development of Detectors for the Superconducting Super Collider

(October 31, 1990)

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Executive Summary

We seek **$300k** from the TNRLC in FY1991 for infrastructure improvements and major test equipment to be used to advance our ongoing program of detector R&D for the Superconducting Super Collider. Matching funds of $150k will be provided by Princeton University.

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1 Introduction

Members of the Princeton University high-energy-physics group have expressed their interest in three experiments at the Superconducting Super Collider Laboratory.[1, 2, 3] We are presently involved in preparation of Letters of Intent to the SSC Laboratory for these experiments, as well as research and development on detectors for such experiments.[4, 5, 6, 7, 8, 9]

The ongoing detector development efforts at Princeton, as sponsored by the Generic and Subsystem R&D programs of the SSC Laboratory, include:

- Silicon drift and pixel detectors.[4, 5, 7]
- Straw-tube tracking chambers.[6]
- Parallel computing farms.[8]
- BaF_2 calorimetry.[9]

Copies of a recent report[10] summarizing our work on straw-tube chambers have been included with the present proposal.

In this proposal we seek funding for infrastructure improvements and major test equipment that are essential to the progress of our ongoing R&D program as we make the transition from proof-of-principle studies to production techniques with high reliability on a large scale as needed for a practical detector at the SSC.

Funding for this would be of immediate benefit to all aspects of our R&D program, as well as providing the technical base necessary in the years to come. Because the items we propose to purchase cannot be identified solely with one subproject it has not been possible to obtain them within the context of our yearly DoE funding of particular tasks, or via the SSC funding for detector development. The result is an extreme scarcity of major equipment, a situation which the Texas National Research Laboratory Commission could be very effective in correcting.

Specifically, we seek funding to purchase 14 items as discussed case by case below. We also seek partial salary support (direct costs only) for a new electrical engineer. The request is summarized in the following section.

2 Infrastructure Improvements and Major Test Equipment

2.1 Infrastructure, Mechanical

2.1.1 Cleanroom

Our SSC R&D program includes development of precision detectors for tracking of charged particles: silicon strip and pixel detectors, as well as straw-tube chambers. To attain the level of reliability needed for remote operation at the SSC for extended time periods without personnel access, the detectors must be assembled to a higher standard than typical in high-energy physics at present. A key aspect is the cleanliness of the assembly environment, as demonstrated by the semiconductor processing community.

For this purpose we request funds to purchase a $16' \times 20'$, class-100 cleanroom, which would be erected inside an existing room in our assembly building. Having obtained numerous bids for such a facility, we estimate the cost as about $80k.

2.1.2 Crane for the Assembly Building

We are fortunate at Princeton to have a sizable assembly building, including a machine shop, solely for use by the high-energy-physics group. Elements of several large detector systems have been assembled here before being shipped to Brookhaven and Fermilab for use in experiments there. This work has been accomplished without the benefit of an overhead crane, at considerable inconvenience and inefficiency, as well as some personal risk on the part of the technicians.

Detector systems for the SSC will certainly be larger than those we have built thus far. So if we are to maintain a relevant capability we need to install an overhead crane in our main assembly room. We seek $40k for this.

2.1.3 Bridgeport Milling Machine

The high-energy group's mechanical shop in the assembly building is equipped with four manual-control milling machines each over 15 years old, and one CNC milling machine about 5 years old, which facilities provide a strong capability for general apparatus fabrication. For prototype work the manual milling machines are actually more useful, but the wear they have suffered through constant use renders them less precise than is acceptable. We therefore seek to purchase a new, precision milling machine, a Bridgeport model 12BR2J, with digital readouts (but not computer control) for $15k.

2.1.4 Model-Shop Lathe

Our complement of five rather ancient lathes has recently been augmented by a new 13″ toolroom lathe capable of very precise work. It would be best to retire all of the other lathes, but our work load requires access to at least one other. For this we seek a smaller, model-shop lathe, Hardinge DV59, at a cost of $15k.

2.1.5 Optical Comparator

The standard of dimensional tolerance for detectors at the SSC is the micron rather than the mil. In addition to having machines that can produce parts to sub-mil tolerances it is important to be able to verify that we have succeeded in doing so on a regular basis. For this we need a precision optical comparator, Mitutoyo model 302, whose cost is also about $15k. Our existing comparator was purchased in 1940 for use in ballistics tests.

2.2 Infrastructure, Electronic

The Princeton group has a strong capability for electronics development, most recently evidenced by its work on the Bismuth Germanate (BGO) electromagnetic calorimeter for the L3 detector at LEP. The group designed the entire system, a particularly sophisticated project because of the requirements for high precision, large dynamic range, and low noise. At the SSC the group plans to exploit this expertise by R&D work on the electronics readout for a calorimeter based on Barium Fluoride. Development of a fast, UV light-sensitive readout to selectively collect and measure the fast scintillation component is a most challenging problem. Similarly demanding electronics development is involved in the design and construction of systems to read out and trigger on information from large tracking detectors.

2.2.1 Printed-Circuit-Board-Layout Software

While we produce numerous printed circuit boards for detector readout electronics at Princeton, our techniques have fallen well behind industry standards – some board layouts are still taped by hand. We seek to inaugurate a modern CAD capability, beginning with PC-board layout, and evolving into ASIC design in the coming years. For this we wish to use a vendor that supports a full range of CAD software, compatible with that in common use at other high-energy-physics facilities. A natural choice is then the Prance GT software, distributed by Cadence, at a cost to universities of $24k.

2.2.2 Unix Workstation

A dedicated workstation with 8-plane color graphics should be available for the electronics CAD facility. We propose to purchase either a DECstation 5000 or a Silicon Graphics 4D/35 with 700MB hard disk at a cost of slightly under $15k.

2.2.3 Electrical Engineer

The Princeton high-energy-physics group includes one digital electronics engineer and two electronics technicians, but has no analog electrical engineer. We propose to hire a new engineer to lead our analog-electronics design effort. The salary level, including fringe benefits is $78k, and indirect costs are $52k (67%). The latter costs would be borne entirely by existing sources, and are not included as part of the present proposal.

2.3 Major Test Equipment

2.3.1 2-Gsample/sec Digital Oscilloscope

With one or more events every 16 nanoseconds at the SSC, the timing performance of detectors must be understood to better than a nanosecond. Such capability will only come with an investment in test equipment of higher quality than generally in use in high-energy physics, although many of the needed standards have been set by the microwave community.

There is need to analyze both repetitive and transient signals with 1-GHz and higher bandwidth. This cannot be done with a single instrument at present. For transients, a 2-Gsample/sec digital oscilloscope is the best readily available tool. We propose to purchase an HP model 54111D at a cost of $23k. This device has a 500-MHz bandwidth limit, so is not optimal for repetitive signals.

2.3.2 Gas Chromatograph

The performance of gas-filled detectors such as straw-tube chambers is quite sensitive to trace impurities in the gas. We need the capability of continuous analysis of gas composition at the level of a few ppm. This be done with a research grade gas chromatograph, equipped with some specialized detectors to sample different classes of impurities. Several competing devices could be used, such as the Varian 3400 system along with many needed accessories, at a cost of about $30k.

2.3.3 20-GHz Digitizing Oscilloscope

For repetitive signals a superb test device is available in the HP model 54121T digitizing oscilloscope. Its bandwidth is 20-GHz. It also features a capability for time-domain-reflectometry whereby the impedance at a specified frequency can be analyzed as a function of position along a circuit. The cost of this device and some important accessories is about $34k.

2.3.4 1-GHz Pulse Generator

To test the high-frequency transient response of circuits for the SSC we need a high-quality pulse generator. The HP model 8080 system offers many useful features at the considerable cost of about $18k.

2.3.5 80-Channel Logic Analyzer

The inevitable large channel count for detectors at the SSC will place a premium on having more of the electronics in VLSI chips. Sophisticated readout schemes must be implemented, requiring rather complex control logic. We need a high-performance logic analyzer to test the performance of such circuitry. The HP model 16500 system offer analysis of 80 channels (expandable to 120), with test pattern generation on 12 channels (expandable to 60), as well a precision timing analysis, and digital capture of waveforms at 400 Msample/sec. The cost of an initial configuration of this device is $25k.

2.3.6 Picoammeter/DC Voltage Source

In the characterization of silicon detectors it is necessary to identify rather small currents, both signal and background. For diagnostic purposes it is useful to have a precision voltage source, and precision current measurement. These capabilities are packaged together in the HP model 4140A picoammeter/DC voltage source, whose cost is $9k.

2.3.7 22-GHz Spectrum Analyzer

In complex electronic systems operating at high frequencies coupled oscillations can develop at a number of frequencies simultaneously. An oscilloscope is of limited use in diagnosing such situations; rather, a spectrum analyzer is called for. We need a device that is sensitive to higher harmonics of the fundamental frequencies we are dealing with. The latter will extend up to an slightly beyond 1 GHz at the SSC, so a multi-GHz spectrum analyzer is indicated. An excellent device is available in the HP model 8562A, at a cost of $29k.

3 Budget Proposal for FY1991

We summarize our proposed budget in the Table below. Within the three categories the items are ranked by priority. The only salary support is item B3.

The total request to the Texas National Research Laboratory Commsion is for **$300k**. Matching funds of 50% ($150k) are available from Princeton University, and would be allocated as in the Table below.

Table 1: The proposed budget. Column 'TNRLC' are the funds requested of the Texas National Research Laboratory Commisions, and column 'PU' is matching funds to be provided by Princeton University.

		Item	PU	TNRLC	Total
A.		Infrastructure, Mechanical			
	1.	Cleanroom	$25k	$55k	$80k
	2.	Crane for assembly building	$15k	$25k	$40k
	3.	Milling machine (Bridgeport 12BR2J)	$5k	$10k	$15k
	4.	Model-shop lathe (Hardinge DV59)	$5k	$10k	$15k
	5.	Optical Comparator (Mitutoyo 302)	$5k	$10k	$15k
B.		Infrastructure, Electronic			
	1.	Printed-circuit-board-layout software (Cadence Prance)	$8k	$16k	$24k
	2.	Unix workstation with color monitor and hard disk	$5k	$10k	$15k
	3.	Electrical Engineer	$26k	$52k	$78k
C.		Major Test Equipment			
	1.	2-Gsample/sec digital oscilloscope (HP54111D)	$8k	$15k	$23k
	2.	Gas chromatograph (Varian 3400 system)	$10k	$20k	$30k
	3.	20-GHz digitizing oscilloscope (HP54121T/006/008)	$11k	$23k	$34k
	4.	1-GHz pulse generator (HP 8080A/91/92/93)	$6k	$12k	$18k
	5.	80-channel logic analyzer (HP16500A/10/15/20/30/31)	$9	$16k	$25k
	6.	Picoammeter/DC voltage source (HP4140A)	$3k	$6k	$9k
	7.	22-GHz Spectrum analyzer (HP8562A)	$9k	$20k	$29k
		Total	$150k	**$300k**	$450k

This proposal covers FY1991. We will seek continued support for infrastructure improvements and major test equipment in the following years as our future needs become clearer. A likely direction will be to increase our capability for electronic design.

6 Current and Pending Support

The Princeton High Energy Physics Group is supported by the ongoing DoE contract DE-AC02-76ER-03072. Personnel supported by this contract include the signees of the present proposal, Prof. V.L. Fitch, eight graduate students, one mechanical engineer, four mechanical technicians, one electrical engineer, two electrical technicians, and a computer-systems manager. The research supported includes ongoing experiments at Brookhaven Lab, CERN, and Fermilab, as well as detector development for the SSC.

The R&D for the SSC has been supported by one grant from the Generic Detector Program (silicon drift chambers), and four grants from the Subsystem Program silicon drift chambers, straw-tube chambers, pixel detectors, and parallel computer farms. Support for a new Subsystem Program, BaF_2 calorimetry, is pending.

The funds sought in the present proposal, although to be used in support of our SSC detector R&D program, go beyond that requested in our various proposals to the SSC Laboratory. Matching funds for the present proposal are available from Princeton University only as a supplement to funding from outside the University.

7 Facilities and Resources

Princeton University provides the high-energy-physics group with office space, and six laboratory rooms in Jadwin Hall, as well as a separate assemply building, totaling some 15,000 ft^2 in all. The assembly building houses a dedicated machine shop, a wood shop, an electronics shop, and includes several large rooms in which detectors can be constructed. The group has access to, at hourly fees, the Physics Department Electronics Shop for insturment repair, the University Machine Shop, and the Princeton Plasma Lab Machine Shop for very large work. We also have ready access to the vast industrial base of the New Jersey area.

8 Biographical Sketch

Kirk Thomas McDonald

Born: Oct. 20, 1945, Vallejo, California

Married: Nancy C. Schaefer

Children: Alex and Owen

Education:

B.S. (with highest honors) in physics and mathematics, University of Arizona, 1966.
Ph.D in physics, California Institute of Technology, 1972.

Professional history:

1972-74: NSF Postdoctoral Fellow, CERN, Switzerland
1975-76: Enrico Fermi Fellow, U. of Chicago
1976-80: Assistant Professor, Princeton U.
1980-85: Associate Professor, Princeton U.
1985–: Professor, Princeton U.

Professional Societies:

American Physical Society
American Association of Physics Teachers
American Association for the Advancement of Science

Honors:

Fellow of the American Physical Society

Research:

Prior to 1985 I participated in several high-energy-physics experiments at Caltech, U.C. Berekley, CERN, Fermilab, and Brookhaven that are not discussed here.

In 1983 I became spokesman of Fermilab experiment 615: forward production of muon pairs. In this we studied the quark structure of the pion, as well as that of the nucleon. Journals publications in the last five years from this are:

1. S. Palestini *et al.*, *Pion Structure as Observed in the Reaction* $\pi^- N \rightarrow \mu^+\mu^- X$ *at 80 GeV/c*, Phys. Rev. Lett. **55**, 2649 (1985).

2. C. Biino *et al.*, *An Apparatus to Measure the Structure of the Pion*, Nucl. Instr. & Meth. **A243**, 323 (1986).

3. W.C. Louis *et al.*, *Upper Limits on the Decay* $D^o \rightarrow \mu^+\mu^-$ *and on* D^o-$\bar{D}^o$ *Mixing*, Phys. Rev. Lett. **56**, 1027 (1986).

4. J.P. Alexander *et al.*, *Longitudinal Photon Polarization in Muon Pair Production at High* x_F, Phys. Rev. D **34**, 315 (1986).

5. C. Biino *et al.*, J/ψ *Longitudinal Polarization from* πN *Interactions*, Phys. Rev. Lett. **58**, 2523 (1987).

6. J.S. Conway *et al.*, *Experimental Study of Muon Pairs Produced by 252-GeV Pions on Tungsten*, Phys. Rev. D **39**, 92 (1989).

7. J.G. Heinrich *et al.*, *Measurement of the Ratio of Sea to Valence Quarks in the Nucleon*, Phys. Rev. Lett. **63**, 356 (1989).

I am presently involved in studies of strong-field QED at Brookhaven Lab. This effort has a significant component of accelerator physics concerning energy-transfer mechanisms between electron beams and intense laser beams. Two journal publications have emerged thus far:

1. K.D. Bonin *et al.*, *Observation of Interference Between Čerenkov and Synchrotron Radiation*, Phys. Rev. Lett. **57**, 2264 (1986).

2. K.T. McDonald, *Design of the Laser-Driven RF Electron Gun for the BNL Accelerator Test Facility*, IEEE Trans. Electron Devices, **35**, 2052 (1988).

I have become quite interested in exploring b-quark physics at hadron colliders. The greatest opportunity here is at the SSC, which has lead to my involvment in the BCD (Bottom Collider Detector) collaboration,[2] as well as the SSC Detector Development programs.[4, 5, 6, 7, 8, 10] This interest has lead to expressions of interest in numerous fora. I was a principal author of the following:

1. N.W. Reay *et al.*, *Collider Architecture Working Group Summary*, Proceeding of the Workshop on High Sensitivity Beauty Physics at Fermilab, ed. by A.J. Slaughter, N. Lockyer and M. Schmidt (Nov. 1987), p. 253.

2. N. Lockyer *et al.*, *Status Report of the Fermilab B Collider Study Group*, DOE/ER/3072-45 (June 1988).

3. H. Castro *et al.*, *Letter of Intent for the BCD: A Bottom Collider Detector for the Fermilab Tevatron*, (Oct. 1988).

4. H. Castro *et al.*, *Proposal for Research and Development: Vertexing, Tracking and Data Acquisition for the Bottom Collider Detector*, submitted to the Fermilab P.A.C. (Jan. 2, 1989), approved as Fermilab T784.

5. K.T. McDonald, *Prospects for Beauty Physics at Hadron Colliders*, in *Glueballs, Hybrids and Exotic Hadrons*, ed. by S.-U. Chung, A.I.P. Conf. Proc. No. **185**, 526 (1989).

6. K.T. McDonald, *Prospects for Beauty Physics at Hadron Colliders*, in *The Fourth Family of Quarks and Leptons*, ed. by D.B. Cline and A. Soni, Ann. N.Y. Acad. Sci. **578**, 215 (1989).

7. K.T. McDonald, *Detectors for B Physics at Hadron Colliders*, Invited Talk, B.A.P.S. **34**, 1149 (1989).

8. BCD Collaboration, *Response to the SSC PAC*, (July 11, 1990).

9. J.G. Heinrich and K.T. McDonald, *B-Physics Options at TEV I*, Princeton U. preprint DOE/ER/3072-61 (Aug. 10, 1990).

10. BCD Collaboration, *Proposal for a B-Physics Experiment at TEV I, The μBCD*, (Oct. 8, 1990).

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[1] EMPACT Collaboration, *The EMPACT Experiment at the Superconducting Super Collider*, submitted to the SSC Laboratory (May 25, 1990), EOI0006.

[2] BCD Collaboration, *Bottom Collider Detector Expression of Interest*, submitted to the SSC Laboratory (May 25, 1990), EOI0008.

[3] L* Collaboration, *Expression of Interest to the Superconducting Super Collider Laboratory*, (May 25, 1990), EOI0010.

[4] K.T. McDonald and M.V. Purohit, *Proposal for Generic Detector Development (Silicon Drift Chambers)*, (August 31, 1988); C. Lu *et al.*, *Proposal for Generic Detector Development in FY 1990 (Silicon Drift Chambers)*, (June 1, 1990).

[5] W. Chen *et al.*, *SSC Detector Subsystem R&D Proposal to Develop Track and Vertex Detector Based on Silicon Drift Devices*, (Oct. 1, 1989); *SSC Detector Subsystem R&D Interim Report on Silicon Drift Devices for Tracking and Vertex Detection*, (Sept. 1, 1990).

[6] C. Lu *et al.*, *Proposal to the SSC Laboratory for Research and Development of a Straw-Tube Tracking System*, (Sept. 30, 1989); B. Brabson *et al.*, *SSC Detector Subsystem Summary Report and Proposal for FY 1991 (Central and Forward Tracking)*, (August 31, 1990).

[7] E. Arens *et al.*, *SSC Detector R&D Proposal: Development of Technology for Pixel Vertex Detector*, (Oct. 1, 1989); Pixel Detector Development Collaboration, *Summary Report for FY90 and Proposed Effort for FY91*, (Sept. 1, 1990).

[8] L.D. Gladney *et al.*, *Proposal to SSC Laboratory for Research and Development for a Parallel Computing Farm*, (Sept. 29,1989); *Subsystem Renewal Proposal to SSC Laboratory for R&D of a Parallel Computing Farm*, (Sept. 11, 1990).

[9] M. Chen *et al.*, *A Precision BaF_2 Crystal Calorimeter for the Superconducting Super Collider*, (Sept. 1, 1990).

[10] W.S. Anderson *et al.*, *Addendum to the Progress Report and Renwal Request for R&D on Central and Forward Tracking*, Princeton U. preprint (Sept. 4, 1990).