Table 5: Charge pre-amplifier performance with C_d = 5.4pF, C_{fb} = 2pF, R_{fb} = 600KΩ

C_c (pF)	τ_r (nS)	S_p (nS)	Gain (V/pC)	Input inferred noise (e^- RMS)	S/N
10	4.0 (4.0)	8.5 (8.0)	0.6496 (0.6627)	4050 (3932)	1.2346 (1.2716)
50	5.0 (5.0)	10.0 (10.0)	2.5461 (2.6014)	1233 (1194)	4.0552 (4.1876)
100	6.0 (6.0)	11.5 (11.5)	4.0342 (4.1299)	896 (867)	5.5804 (5.7670)

Power Dissipation 45.1 mW (45.6 mW)

Table 6: Charge pre-amplifier performance with C_d = 5.4pF, C_{fb} = 3pF, R_{fb} = 600KΩ

C_c (pF)	τ_r (nS)	S_p (nS)	Gain (V/pC)	Input inferred noise (e^- RMS)	S/N
10	3.0 (3.0)	7.0 (7.0)	0.6226 (0.6365)	4368 (4174)	1.1447 (1.1979)
50	4.0 (4.0)	9.0 (8.5)	2.3180 (2.3586)	1295 (1261)	3.8610 (3.9651)
100	5.0 (5.0)	10.0 (10.0)	3.6695 (3.7538)	914 (885)	5.4705 (5.6497)

Power Dissipation 45.1 mW (45.6 mW)

Table 7: Charge pre-amplifier performance with $C_d = 5.4\text{pF}, C_{fb} = 4\text{pF}, R_{fb} = 600\text{K}\Omega$

C_c (pF)	τ_r (nS)	S_p (nS)	Gain (V/pC)	Input inferred noise (e^- RMS)	S/N
10	3.0 (3.0)	7.0 (7.0)	0.6305 (0.6493)	5241 (5359)	0.9540 (0.9330)
50	4.0 (4.0)	8.0 (8.0)	2.2539 (2.2988)	1384 (1347)	3.6127 (3.7120)
100	4.5 (4.5)	9.5 (9.0)	3.4629 (3.5221)	945 (921)	5.2910 (5.4289)

Power Dissipation 45.1 mW (45.6 mW)

DEFINITIONS :

- τ_r ← Pre-amplifier output rise time. Time in nanoseconds for pre-amplifier output to rise from 10% to 90% of final value.
- S_p ← Pre-ampüfier output shaping time. Time in nanoseconds for pre-amplifier output to rise from 0% to 100% of final value.
- Input inferred noise ← Noise level at input of pre-amplifier in number of electrons RMS.
- S/N ← Ratio of input signal (e^- RMS) to input referred noise (e^- RMS).

Fast Warm Liquid Calorimetry

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Abstract

We report measurements on a fast, ultra-sensitive charge preamplifier for warm liquid calorimetry that is manufactured in an industrial BiFET process with 5 Megarad (1 Gigarad) radiation hardness. The measured noise level of this device is less than 3.5 $nV/\sqrt{Hz}$ with a 37 (10) nsec risetime.

I. Introduction

Warm liquid ionization media have recently attracted interest as a competitive technology for calorimetry in high energy physics experiments. Mainly in response to the inherent limitations of speed, hermiticity, and accessibility of cryogenic technology, warm liquid calorimetry offers the advantages of faster detector response time, flexible modularity in detector design, and the ability to measure electromagnetic and hadronic energy with equal detector response[1)] (compensation). The choice of detector technology for hadron calorimetry at the SSC depends largely on the design considerations of detector medium speed, segmentation, and radiation hardness. Warm liquid hydrocarbon and silane media such as tetramethylpentane (TMP) and tetramethylsilane (TMS) appear to satisfy most detector requirements for radiation hardness[2),3)] and segmentation (either as longitudinally segmented modular vessels, or as "swimming pool" type detectors).

work supported by the Department of Energy, contract DE-AS05-81ER40039

Invited talk, DPF90 Meeting, Houston, TX, Jan. 4, 1990.

With the development of fast, radiation-hard charge preamplifers for warm liquid calorimetry[4),5)], fast detector response is possible despite the relatively slow drift velocities in these liquids. The current signal generated within these liquid ionization chambers contains information on the total charge deposited at the beginning of this pulse[6)]. Fast front-end amplifiers can now be designed with matching bandwidth which can therefore respond to this initial current pulse with an output amplitude proportional to the initial (total) charge. To maintain the intrinsically fast response of the front-end electronics ($\leq$10 nsec), the preamplifier must be mounted directly on the detector. Detector capacitance, in turn, must be kept as low as possible, either by the choice of small electrode size, or by series connection of much larger anodes.

II. Circuit Design

A monolithic charge preamplifier manufactured in a radiation-hardened industrial BiFET technology has recently been developed for warm liquid calorimetry[5)] with a 37 nsec risetime, 3.5 $nV/\sqrt{Hz}$ noise, and 5 Mrad radiation hardness. To compensate for the increase in flicker noise[7)] $(1/f_T)$ from lower transistor β value after exposure to radiation, this original circuit has been modified and manufactured in another industrial BiFET process with higher radiation hardness (order 1 Gigarad). This circuit is shown in Figure 1.

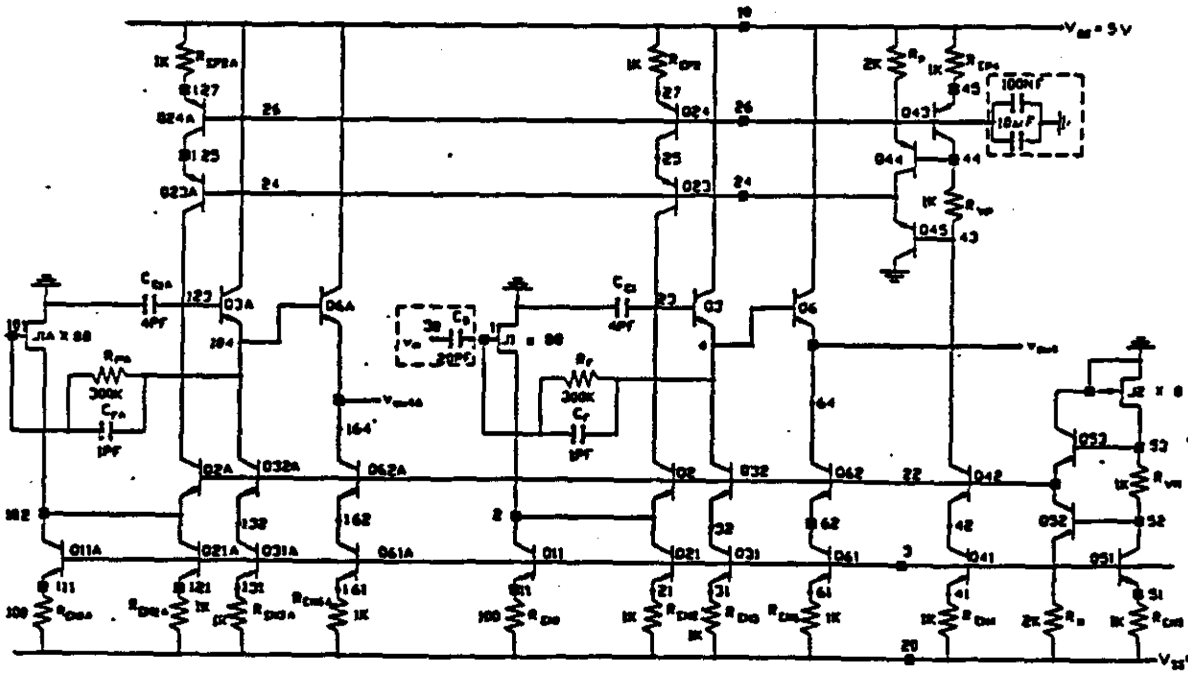

Figure 1. Circuit schematic of integrated low-noise BiFET charge preamplifier.

Scintillating Calorimetry for the SSC
A Progress report and Request for Funds
from the SSCintCal Collaboration

Boston University, Drexel University, Fairfield University, Fermilab,
Florida State University, Michigan State University, Purdue University,
Rockefeller University, Sandia Lab, Texas A & M University,
University of California at San Diego, University of Illinois, University of Iowa,
University of Michigan, University of Rochester, University of Tsukuba,
University of Washington, Yale University

Contact: A. Para, Fermilab; L. Sulak, Boston University

This document contains a report of progress made by the SSCINTCAL collaboration during the first year of its SSC subsystem effort, and a proposal for further research to continue this effort into its second year.

In February of 1990 we exchanged a memorandum of understanding with the SSC Laboratory which provided equipment and funding to develop scintillator-based calorimetry for possible use in future SSC detectors. We are committed to establish the physics capability, manufacturability, cost-effectiveness, and radiation survivability of scintillator-based calorimetry. To this end, we have constructed multi-ton prototypes of hadronic calorimeter modules and tested them in high-energy test beams at FNAL, performed systematic studies of radiation damage to plastic scintillator, carried out preliminary engineering and manufacturing designs for large-scale detector subsystem implementation, and studied the physics capabilities and design specifications for scintillating calorimetry.

Primary advantages of scintillating calorimetry include its intrinsic speed of response, modularity, uniformity and hermeticity, ease of construction and maintenance, stability, simplicity, safety, and proven performance in large detectors at hadron colliders. The capability of scintillating calorimetry to provide an equal response to electromagnetic and hadronic showers gives the potential for hadronic energy resolution surpassing that possible with any non-compensating calorimeter. The very high energies accessed by the SSC are best measured by precision calorimetry, which unlike magnetic momentum analysis increases its accuracy with increasing particle energy. To exploit fully this high-resolution potential, it is essential to provide a compensating calorimeter which is uniform in its response and thus insensitive to shower fluctuations or different particle incident positions. Missing energy signatures require in addition that the calorimeter be free of cracks and nonuniformities, and that it provide coverage out to high rapidity regions for hermetic containment.

Excellent energy resolution, both for electrons and for hadrons, achievable with the scintillating fiber technology has been demonstrated by the SPACAL Collaboration at CERN. We have directed our R&D program towards complementary studies of an implementation of this technology into a realistic SSC detector. In particular we have concentrated on methods of achieving a depth segmentation, which is known to provide excellent electron/pion separation capabilities and to provide fast signals necessary for a low-level electron trigger.

During the past year we have constructed several prototypes of electromagnetic and hadron calorimeters, which we have exposed to high energy test beams at Fermilab. Results of these test are being analyzed at present, and will be presented at the Ft. Worth Symposium. During the prototype construction we have developed methods of large scale production, and built auxiliary equipment for calibration, uniformity testing and handling of large volumes of scintillating fibers.

Despite a very late schedule of funding in FY'90 we have succeeded in achieving most of our goals for this year. Below we list projects which are completed, or nearing their completion.

1. Laminated Calorimeter Prototype

We have built and successfully tested in the test beam a large prototype of a combined electromagnetic and hadronic calorimeter. Its main purpose was to establish electron/pion separation and electron trigger capabilities of a monolithic calorimeter with an effective depth segmentation due to the projective geometry (by grouping fibers starting in depth separately from those starting in front). Preliminary results indicate that pion rejection better than 10**-3 is readily achievable. Within this project we have completed the following sub-projects:

1. development of a technique for large scale lead grooving. Construction of rollers, optimization of the rolling process to assure acceptable quality of lead plates. Some 3 tons of lead plates have been produced. (Fermilab, Vulcan Lead)
2. development of a method of cutting grooved lead plates to a projective shape. Several methods were investigated (laser cutting, water jet cutting, shearing), the optimal was found to be milling on a x-y milling machine. 1000 lead plates of 24 designs have been cut using Thermwood table. (Fermilab, University of Washington)

3. design and construction of auxiliary tooling and fixtures for the production of tower assembly (Fermilab)
4. construction of a 6 module projective prototype. Every module consisted of 6 towers. Tower size was 6 x 6 cm in front and 12 x 12 cm at the back, 2 meters long. Modules were built from alternating steel plates and grooved lead plates with fibers. Green, Y7 doped scintillating fibers (provided by Tsukuba University) were glued into lead plates. Lead strips were subsequently glued to the steel plates. Bicron BC600 glue was used. Total weight of the prototype was 5 tons. (Fermilab)
5. systematic studies of uniformity of light transmission and of mixing properties of light guides, as a function of their length and shape. Design of tapered light guides to reduce the required area of photodetectors. These light mixers are necessary to avoid problems with the non-uniformity of the photocathode surface. (University of Illinois, University of Washington).
6. design and construction of a computer-controlled scanning table for measurements of the transmission characteristics of the light mixers (University of Illinois)
7. development of software for simulations, and tools for making quantitative measurements of models for the light collectors. (U. of Washington)
8. construction of 36 hexagonal light guides and 36 tapered hexagonal light guides (U. of Illinois)
9. design and construction of the support structure for the test beam studies of the prototype. This structure has remotely controlled translation and rotation capabilities. This structure was used to support the laminated prototype and the "RGB" prototype in the CDF test area at the MT test beam at Fermilab. (Fermilab, Michigan State University)
10. Monte Carlo (EGS) studies of the expected performance of a laminated calorimeter prototype (Fermilab, Michigan State University)

In addition we have built prototypes of a fiber calorimeter with explicit depth segmentation using fibers of different colors in the electromagnetic section and hadronic section. We have constructed two prototypes of this kind:

1. "RGB" calorimeter with red fibers (electromagnetic section) spliced to blue fibers (hadronic section). Green wavelength shifter plate was used to separate different colors of light. Optionally, this prototype was equipped with a multianode photomultiplier to determine the position measurement accuracy. This prototype was successfully tested in a Fermilab test beam. It was constructed and operated by Tsukuba University.

2. a "dichromatic" calorimeter with green (electromagnetic) fibers spliced to blue (hadronic) ones. Color separation was achieved by a set of selective mirrors, or a set of low- and high- pass filters. This prototype was constructed by Michigan State U. , and it will be exposed to the test beam during the next cycle of the fixed target program at Fermilab.

2. Tile Calorimeter Prototype

In collaboration with the CDF group at Fermilab we have constructed and tested in the beam several electromagnetic and hadronic calorimeters using scintillating plates with a wavelength shifter fiber read-out. In the course of these studies the following sub-projects were completed:

1. development of a computer controlled tile mapping fixture. It consisted of a radioactive source held stationary. Above it we placed tiles on a computer controlled XY table. The fibers from the tile were coupled to a phototube. The phototube was DC coupled to a picoammeter which was in turn read out through CAMAC. Variations in the observed current allowed us to map the uniformity of the tile, and also inter-tile uniformities. (Fermilab)
2. development of software and procurement of necessary hardware to create masks to correct nonuniformities in tile response to radioactive sources. Wrapping reflective material around scintillator causes the light yield of the scintillator to increase, up to 20% depending on the wrapper. This happens because not all of the primary UV scintillation light is shifted by the primary shifter dye of the scintillator. Wrapping a UV reflective wrapper around the tile reflects this light back, increasing its likelihood of getting shifted. Wrappers of variable reflectivity can be used to "flatten" tile response. (Fermilab)
3. development of a computer program to take the measured response map and calculate the appropriate "Mask" pattern to flatten the tile response. This pattern was then printed onto reflective foil by laser printer. We verified the flattening by wrapping the tiles in the mask and then remeasuring them. Tiles with variations of a few percent could be flattened to about 1%. (Fermilab)
4. development, in collaboration with industry, of a technique for laser-cutting of tiles, cutting the groove for the fiber, and the glue injection port. (Fermilab)
5. construction of a set of 200 tiles to determine tile-to-tile uniformity. The tiles were laser-cut as above. We measured the tile-to-tile variation in average light yield to be $< 3\%$ sigma.

6. construction of a 9 tower EM calorimeter prototype, using the 200 tile set. It was instrumented with 9 Hamamatsu 580 phototubes. The device was exposed to FNAL test beams, and the results were analysed. The results will be presented at the SSC R/D conference in Fort Worth. Uniformity of about 2-3% was found. (Fermilab)
7. construction of a 12 X 12 cm single tower prototype and the test beam studies. The light yield was greater than 240 photoelectrons per GeV. (Fermilab)
8. construction of a large set of tiles to understand the required manpower for a larger calorimeter. We built 1000 tiles, each 6 X 6 inches. The tiles were used in two versions of a hadron calorimeter, each weighing 5 tons. We found that with no tooling, 1/2 manhour per tile was required. We estimate that we can cut the time in half by building an automated splicing machine and better gluing jigs. (Fermilab, U. of Rochester)
9. studies of the performance of the hadron calorimeter in the pion and electron test beam. Light yield, resolution, and e/h compensation were measured. These results will be presented at the Fort Worth workshop. During the process of construction we identified several strategies that should be used in building a real calorimeter. We learned how to assemble the entire optical assembly before installing it into the absorber material. We then used radioactive sources to trim the light yields to get a uniform device.(Fermilab, U. of Rochester)

3. Electromagnetic Prototypes

The following projects were completed here:

1. a series of prototypes constructed from scintillating fibers cast in eutectic Pb/Bi/Sn/Cd low-melting point alloy. Optimization of the casting technique to achieve adequate uniformity. (Boston U.)
2. development of a mass splicing technique using mass connectors. Studies of the uniformity and efficiency of the light coupling (Boston University)
3. construction of the electromagnetic prototype using newly developed fiber with a wavelength shifter core. (Fermilab)

4. Specialized Tooling

1. design and construction (nearly complete) of a fly cutter for large scale fiber cutting and polishing (Fermilab)
2. development of a technique for splicing clear fibers to the waveshifter fibers from the tile. This process was heat fusing the fiber splice inside a constricting glass capillary tube. (Fermilab)
3. design and construction of an apparatus for welding fibers using the above mentioned technique (Michigan State U.)
3. design and construction of an X-Y source scanner, development of software for the control and data acquisition (U. of Michigan)

5. Calibration System

Calibration, transport of the calibration from test beam to a detector and monitoring of the response is perceived as a problem for scintillator based calorimetry. We have addressed these issues in conjunction with the prototypes mentioned above. In particular the following projects were completed:

1. design, construction, testing and operation of the radioactive source calibration system for a laminated calorimeter prototype. The system consisted of a set of 45 stainless steel tubes traversing the test prototype transversely and longitudinally. Cs 137 source on a wire, was driven by a remotely controlled driver into these tubes. Current of the photomultipliers was read-out using the CDF RABBIT front-end electronics to provide channel-to-channel variation of gains. Analysis of the performance of this system is in progress. (Purdue University)
2. development of a Monte Carlo simulation of a gamma source in an inhomogeneous media (iron/lead lamination) to help with understanding of the performance and systematic errors of the calibration system mentioned above. (Purdue University)
3. design and construction of a (nitrogen) laser based system for monitoring of the response of the laminated prototype. This system ought to be completed in early fall of '90. It will be used in conjunction with a source calibration system to examine uniformity and long term stability of the prototype. (Fairfield U.)

6. Liquid Scintillator Calorimetry

Liquid scintillator seems to be the only hope for surviving the radiation field for $\eta > 3$. Good measurement of the missing energy down to η of 5 has been shown to be of great importance for the physics capabilities of the SSC detector. On a way to develop a realistic detector scheme we have completed the following sub-projects:

1. Measurement of the absolute light output and light attenuation length of liquid scintillator in teflon tubes. (TA&MU)
2. Study of properties of various combinations of coatings and scintillation liquids for use in the spaghetti calorimeters (TA&MU)
3. construction of prototypes of an electromagnetic calorimeter with lead/Teflon tubes. (Boston U.,TA&MU)
4. design and construction of a prototype using lead and glass tubes. Design and construction of plastic tubing/light guides assembly. (TA&MU)
5. Study of light transmission in glass tubes as a function of the radiation dose (Florida State University, TA&MU)

7. Preradiator

Groups from Rockefeller and Yale have continued their generic R&D program within our subsystem. The following objectives have been achieved:

1. design and construction of an imaging preradiator detector consisting of 8 layers of lead and fibers. Fibers were read out using image-intensifier chain. (Rockefeller, Yale)
2. installation, debugging and data taking with this detector in TPL beam line at Fermilab. Data were taken at different energies with and without magnetic field. Analysis of the test results is in progress. (Rockefeller, Yale)

8. Radiation Damage Studies

Radiation resistance of plastic scintillators is the chief problem of our technology. We have addressed these issues in the following way:

1. **organization of the Workshop on the Radiation Resistance of Plastic Scintillators (Florida State U., Fermilab)**
2. **studies of the radiation damage and annealing of the light yield and the attenuation length of commercially available scintillating fibers, as a function of the atmosphere. (Tsukuba U.)**
3. **studies of the radiation damage to a fiber calorimeter using Optectron S-101S, 3HF, RH1 and RH2 fibers (Boston U., Florida State U., U. of Illinois)**
4. **studies of new compounds for use as primary and secondary dopants in polystyrene based scintillators. Studies of the light output and absorption properties of derivatives of 3HF and HBT. (Fermilab)**
5. **study of radiation effects in pure polystyrene and in scintillator to quantify intrinsic light losses, polymer degradation and dopant degradation.(Fermilab)**

9. SPACAL at CERN

The UCSD group has participated in the construction, data taking and analysis of the SPACAL prototype. These studies have been extremely fruitful. Detailed description of these important results is given in an enclosed status report, together with a request to support the second phase of this experiment.

10. Other Completed Projects

1. **development of a generic simulation package for the SSC detector (SSC-SIM). This package is used to study an interplay between the detector parameters and physics capabilities of the experiment. The package is used by the SDC Collaboration and TEXAS Collaboration to answer question posed by the PAC (Fermilab)**
2. **development of an EGS-based package for simulation of a scintillating fiber calorimeter. This package is used to optimize a design of the electromagnetic section of the calorimeter.**

design
FAD techniques (um)
radiation hardness

Preshower:
readout: PSPMT
APD
Pixie
Simulation work

11. Proposed R&D Program and Budget Request for FY '91

In FY '90 our Collaboration has vigorously pursued a broad based R&D program, despite major delays in funding. Several prototypes were successfully constructed and tested in test beams and Fermilab, as described in this report. We believe that our goals could be achieved in a much more efficient way, and our progress could be much further along if adequate operating funds were made available. Lack of post-docs has put a tremendous strain on members of our collaboration and slows down the analysis of test beam results. Lack of adequate travel funds made the coordination of efforts at various labs difficult, thus reducing further our efficiency.

Based on the past year's experience, we strongly suggest that the following improvements in the funding scheme will make a qualitative change in the outcome of the R&D programme:

- Permission to pay salaries of physicists, and post-docs in particular from the subsystem budget. While in general it would not be good for the education of our young colleagues to be divorced from 'physics' at such an early stage of their careers, these funds would make it possible for our institutions to hire additional post-docs and have them working 50% on the detector R&D. The enthusiasm, experience and hard work of post-docs will make a tremendous differcnce to the outcome of our R&D.
- Adequate funds for travel. Timely construction of prototypes, given the distributed character of the collaboration, will necessitate regular meetings of working groups.
- Timely distribution of funds (we find it very ironic that the progress report is demanded very shortly, or in some cases even before the funds were made available). As our plans for the next year involve construction of a new round of prototypes which need to be tested in test beam at Fermilab, and given the Fermilab schedule, we consider it a condition *sine qua non*, that funding (or at least a part of it) is distributed not later than November '90

Analysing results of our R&D, especially having in mind existing proto-collaborations (EoI's) we judge that the following projects need to be carried through in the next year:

1. Establishment of a baseline design of the fiber-based calorimeter.

We have pursued various techniques for depth segmentation. We have built a large prototype with an effective depth segmentation by grouping fibers started in depth separately from those started in front. We have constructed a prototype with a different color of fibers in the front (electromagnetic) and back (hadronic) section and wavelength shifter plate to separate readout of different colors. Another prototype of this type, using filters for color separation is under construction. Although preliminary results on electron-pion separation are very encouraging, we consider it very desirable to demonstrate the capability of the fiber-based calorimetry to provide for a more traditional depth segmentation. At the same time, in view of a perceived very high cost of the fiber calorimeters we consider it very important to carefully examine possible trade-offs between cost and performance.

We have decided to concentrate our efforts in FY'91 on a design, construction and test beam studies of a prototype of a calorimeter composed of the electromagnetic section and hadronic section. Besides traditional capabilities for electron identification this design permits separate optimization of the sections of the calorimeter. We notice in particular, that the electromagnetic section, where the requirements of hermeticity, resolution and uniformity are most important constitutes only 5% of the overall volume of the calorimeter. It is quite likely that substantial savings can be achieved by relaxing some the requirements in the hadronic section without adverse effects on the physics capabilities of the detector.

The front section will be built from 1 mm scintillating fibers and lead in a canonical 1 : 4 ratio. These fibers will be spliced to 0.5 mm clear fibers, bundles of clear fibers will be carried through the body of the hadronic calorimeter in a non-projective fashion.

The hadronic section will be built out of 2 mm fibers in lead matrix again with a ratio of 1 : 4. Detailed studies of trade-offs between performance and cost, as a function of the fiber diameter will be conducted.

Calibration of a large assembly of photomultipliers is generally considered a major problem. This problem will be even more serious at the SSC, given an astronomical number of towers to be calibrated. We propose to continue R&D of radioactive source-based calibration system, but we feel that its augmentation by a laser and/or neutron source system is of a great importance.

We feel that it is imperative to demonstrate the performance of the proposed calorimeter by a thorough test beam studies. We would like to examine resolution, linearity and uniformity of response for electrons and hadron beams. We estimate that these studies will require of the order of 14 days of test beam time. The most logical place for these studies would be the MT test beam at Fermilab, where we have already constructed automatized support structure. Upgrade of this support structure to include remote control of all degrees of freedom would be very desirable to improve efficiency of the data taking.

The list of institutions participating in this project and request funding is the following:

Institution	Equipment funds	Operating funds
Boston University	60 K	40 K
Fairfield University	30 K	20 K
Fermilab	150 K	40 K
University of Iowa	70 K	30 K
Purdue University	10 K	20 K
University of Illinois	20 K	5 K
Michigan S. University	60 K	40 K
University of Washington	30 K	10 K
UCSD	30 K	10 K
Total	460 K	220 K

2. Engineering studies of the fiber calorimeter for the SSC detectors.

We need to develop a baseline configuration, evaluate large scale production techniques, develop an implementation schedule and cost estimate, identify R&D issues that require further studies. Scintillating fiber calorimetry is adopted as a possible option is 3 of the 4 proposed experiments. We feel that detailed engineering studies, specific to the detector geometry should be carried by the collaborations themselves. On the other hand, there is a large area of engineering studies related to large-scale manufacturing techniques, cost optimization, design of a sound support concept, fundamental material properties, fibers manufacturing etc... which is common to all applications of fiber calorimetry. We feel that the most cost effective way to conduct these studies is the collaboration of in-house engineering with an industrial partner. Our preliminary contacts with Martin-Marietta Astronautics and Draper Lab are very encouraging, and we propose to continue them.

Request support, operating budget:

Boston University	50 K
Fermilab	100 K
Industrial partners	
collaborating with BU	100 K
collaborating with FNAL	350 K

3. Design, construction and test beam studies of a liquid scintillator version of a 'spaghetti' calorimeter.

Fiber calorimetry offers an attractive possibility of extending the detector into deadly regions of $\eta > 3$ using basically the same type of a detector and changing the active medium only. Liquid scintillator appears to be the only technology capable of coping with the intense radiation field in the forward region. Therefore we consider it of great importance to continue and amplify our efforts to come up with a realistic design of the calorimeter, including mechanical, optical and plumbing aspects. A technique for low index, good optical quality coating, with an adequate radiation hardness must be developed (magnesium or sodium fluoride are possible candidates).

The goal is to construct and expose to the test beam in 1991 a set of electromagnetic towers to establish feasibility of this technique. The following groups will participate in this effort

Institution	Equipment fund.	Operating fund
Drexel U.	5 K	5 K
Fairfield U.	5 K	5 K
FNAL	30 K	20 K
TA&MU	60 K	40 K
Total	100 K	70 K

4. Studies of radiation hardness of plastic scintillators.

This is clearly the key problem for all applications including plastic scintillators. Available data are scarce and frequently conflicting. We propose to undertake the following studies:

- comprehensive survey of polymer radiation resistance. It is expected that structure-property correlation will result from these data, which may lead to new or modified polymers with enhanced radiation resistance. These studies will include effects of stabilizing additives on the radiation resistance.
- measurements of the radiation resistance of 12 scintillator dyes representing the major structural types of organic scintillators
- studies of nature of color centers in irradiated optical polymers using electron spin resonance, UV-Vis absorption spectroscopy and variety of wet-chemical techniques. Understanding of the mechanism of color center formation will allow more confident lifetime predictions for the SSC environment.

- systematic studies of damage to local light yield and attenuation length of 3HF doped scintillating fibers as a function of 3HF concentration.
- systematic studies of the annealing phenomenon, and its dependence on the environment (atmosphere, temperature,...)
- survey of the commercially available scintillating fibers, and their radiation resistance.
- construction and subsequent irradiation of electromagnetic calorimeter modules in an SSC-like environment. It appears that 2-5 GeV electron beams provide the best approximation of SSC-induced damage. These projects will be carried out at the following institutions:

Institution	Equipment funds	Operating funds
Boston University	40 K	50 K
Sandia		250 K
FSU	55 K	125 K
FNAL	20 K	20 K
U. of Illinois	45 K	30 K
U. of Tsukuba		
Total	160 K	375 K

5. Optical transducers

Scintillating fiber calorimeters can be built using comercially available photomultipliers. Large dynamic range required, space and heat load constraints, and large scale of the proposed experiments will certainly required optimization of the PMT/base assembly. Optimization of the spectral response to take advantage of enhanced radiation resistance in the long wavelength region will be important. We will continue our contacts with manufacturers (Hamamatsu, Philips) in order to develop specifications for the desired PMT. In parallel, we consider it very important to seek alternatives to the traditional photomultipliers to take full advantage of the speed, low noise and high linearity of the fiber calorimeter. We propose to acquire and evaluate properties of newly developed hybrid-photomultipliers using silicon diode in conjunction with a photocathode, (produced by DEP) and compare its performance with a standard PMT.

We propose to maintain close collaboration with CERN (De Salvo) and industry (DEP, Hamamatsu, Burle) to stimulate further development along these lines.

The institutions involved:

Institution	Equipment fund.	Operating fund.
Boston U.	40 K	10 K

Fairfield U	30 K	15 K
FNAL	10 K	5 K
Total	80 K	30 K

Summary of the Budget Requests

Institution (PI)	Equipment (K$)	Operating (K$)
Boston U. (L. Sulak, W. Worstell)	140	250
Fairfield U. (D. Winn)	65	40
Fermilab (M. Mishina, A.Para)	210	515
U. of Iowa (Y. Onel)	70	30
Purdue U. (V. Barnes)	10	20
U. of Illinois (D. Hertzog)	65	35
Michigan State U. (C. Bromberg)	60	40
U. of Washington (K. Young)	30	10
UCSD (M. Sivertz)	30	10
Drexel U. (C. Lane)	5	5
TA&MU (R. Webb)	60	40
Sandia Lab. (R. Clough)		250
Florida State U. (K. Johnson)	55	125
Total	800	1370

SUBSYSTEM PROPOSAL FOR
PRE-SHOWER AND SHOWER-MAXIMUM DETECTORS

Submitted to the SSC Laboratory Subsystem R&D Program

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SUMMARY

We would like to propose a program to develop and evaluate the necessary technologies for pre-shower and shower-maximum (PS/SM) detectors using scintillating fibers or tiles for the SSC. The authors of this proposal represent three of the four major high-p_t EOI's (SDC,[1] EMPACT[2] and TEXAS[3]) and BCD.[4] Much of the technology which needs to be developed is common to all four EOI's and we plan to investigate the overlapping areas, such as readout techniques, active detector elements and physics simulation.

A pre-shower detector is a device placed in or before an electromagnetic calorimeter to give detailed information about the early development of the shower. It usually consists of some high-Z material, approximately 2 radiation lengths thick, followed by a plastic scintillating fiber array or some other detector medium. For detectors with a magnet directly in front of the calorimeter, the magnet coil can be used as converter material, although such low-Z material is not optimum for electron/hadron rejection. A shower-maximum detector is a position sensitive device placed at a depth where the electromagnetic shower is maximum.

The proposed work to be undertaken by this group is to:

1) Build a flexible test module which can be easily configured to be either a pre-shower or shower-maximum detector for various EOI-specific geometries. The detector will be placed in the CDF test beam for studies in conjunction with the tile-fiber calorimeter subsystem.[5]

2) Develop, test and evaluate three different readout techniques for PS/SM detectors.

3) Develop simulation software with a special emphasis on the physical processes for which PS/SM detectors will be useful at the SSC.

4) Perform radiation damage studies of the different fiber types suitable for use with the different readout options.

PHYSICS JUSTIFICATION

A. Introduction

The use of PS/SM detectors is a common experimental technique in high energy physics. Recently, a rather complex pre-shower detector was implemented in UA2 at the CERN $p\bar{p}$ collider. UA2 demonstrated that use of an imaging pre-radiator can greatly improve the quality of their data analysis.[6] Pre-shower detectors supply detailed position information with a precision that is characteristic of tracking devices and, thus, of considerably higher accuracy than can be generally obtained using energy sharing between calorimeter modules. This technique exploits the fact that the radiation length in high-Z material is much shorter than the hadronic interaction length.

Shower-maximum detectors have been used with success at CDF to identify electrons and to separate low energy γ's from π^0's.[7] The advantage of a shower-maximum detectors is that the position measured is that of the electromagnetic calorimeter pulse, whereas a pre-shower detector could give the position of some other (possibly low-energy) charged or neutral track. The disadvantages are: they give little additional help in rejecting hadrons that deposit most of their energy electromagnetically; the showers have spread more by shower maximum, thus making it harder to separate overlapping showers; and the detector is located at a position inside the calorimeter where the radiation levels are highest. We believe that these differences need to be evaluated carefully.

B. Pre-Shower and Shower-Maximum Devices in 4π Detectors

PS/SM detectors have considerable potential for SSC experiments. They can provide information about the detailed structure in a complex event that would be unobtainable with presently conceived trackers and calorimeters alone. Moreover, they provide redundant information that could be important for interpreting complex events. Specifically they provide:

1. Improved electron/hadron separation in isolated events and electron identification within complicated events where isolation cuts cannot be applied;
2. Separation of direct single-γ's from π^0's on an event-by-event basis;
3. Reduction of fake electrons due to accidental π^0/charged-track overlaps;
4. Unambiguous assignment of the shower with bunch crossing;
5. An additional tracking layer with a long lever arm which, being an energy measuring device, does not degrade the energy resolution of the calorimeter behind it.

The capability of performing these tasks is limited by the quality of the track measurement and the physics of the shower development. We will discuss each of the above-mentioned items and their relevance to the different physics processes in turn.

C. Electron Identification

Electron identification in calorimeters is based on the differences between electromagnetic and hadronic shower development. The lateral and longitudinal development of a shower, as well as the time development of the sampling pulses, are different for electrons and hadrons. With methods based on these signals, hadron rejection down to levels of 0.1% $\sim$ 1.0% can be achieved. However, the different calorimeter signatures are highly correlated. The SPACAL collaboration has shown that a pre-shower detector with a lead pre-radiator can provide additional e - π separation by a factor of order 15 beyond that which can be achieved by cuts in the shower spreading.[8] Our own measurements and those of CDF[9] and OPAL[10] have shown that this improvement is degraded by placing a low Z material directly in front of the pre-shower detector. For example, placing a 1.5 χ_{RL} or 0.33 λ_I block of aluminium (corresponding to a thick magnet coil) in front of our detector during the FNAL test beam run significantly reduced the efficiency of our electron identification.

When an electron is accompanied by a nearby hadron, the usual calorimetric methods cannot be applied, restricting electron identification to isolated tracks only. PS/SM detectors do not suffer from these limitations and can identify electrons separated from other particles separated by several millemeters, depending on the design. This allows for some electron identification inside of and close to jets.

A detector capable of identifying electrons inside complicated events would have a great advantage over one that has to make an isolation cut. This is especially true in the case of tagging b jets, in particular from the decay of the top ($t \rightarrow W + b$). It is currently thought that the best way to tag b jets is to detect a lepton produced by the semi-leptonic decay of the B in association with a separated vertex. The lepton from the B decay has a maximum momentum of about 2 GeV/c in the rest frame of the B. Thus, without a preradiator only muons can be used to tag b jets reliably. For a b-jet with an energy of 40 GeV 60% of the B-decay electrons have momenta transverse to the jet axis of at least 1 GeV/c, and transverse distances from the jet core of at least 10 cm at 1 meter from the decay vertex. For these relatively large separations, PS/SM detectors should provide reliable electron identification.

D. Gamma/Pi-zero Separation

To separate direct single-γ's from π^0's on an event by event basis, the PS/SM detector has to be able to distinguish the two photon showers from a single one. The minimum opening angle of a π^0 is given by

$$\theta_{\text{min}} = \frac{2m_\pi}{p_\pi}.$$

Thus, for a 100 GeV/c π^0 , the two decay photons are separated by a distance of $\geq$ 2.7 mm per meter of flight path. This separation has to be measured sufficiently deep in the calorimeter so that the two photons have a high probability of converting, but not so deep that the two showers begin to merge. This is a task for which a deep pre-shower detector is particularly well suited.

The ability to identify direct photons on an event by event basis can be useful for studying processes where the production rate is low and there are insufficient statistics to use the conversion method. For direct photon production below p_t's of 200 GeV this is not expected to be the case, while above that energy the separation of two showers from a π^0 will be very difficult to achieve. However, the ability to discriminate between direct photons and π^0's will provide useful redundancy in precision measurements of direct photon production. These will be essential for an accurate determination of the gluon structure function which is important for estimations of the background levels for exotic processes.

For experiments which have sufficient energy resolution in their electromagnetic calorimeter, the intermediate mass Higgs can be detected via the decay $H \rightarrow \gamma\gamma$. For this decay the ability to reject π^0's reduces the background rate considerably. This is also true for the more easily recognized, but very low rate, signal due to the associated production of an intermediate mass Higgs and a W which then decay via the channel $H + W \rightarrow \gamma\gamma e\nu$ [13] . Good π^0/γ separation would also be essential to understand the physics of a fourth generation b', which could decay via b' $\rightarrow$ b+γ.[11 12]

There are other important physics processes where the ability to identify γ's for low rate processes will be essential. For example, the production rates and angular distributions of Wγ, Zγ and $\gamma\gamma$ which can be studied at SSC energies will provide experimental information about the vector boson self-interaction.[14,15] With a pre-shower detector capable of identifying photons on an event by event basis, such measurements will be possible at the SSC. The ability to identify single γ's would also allow one to search for new physics, which is expected to result in an enhancement in the direct photon yield.

In non-magnetic detectors and in the forward region of solenoidal magnetic detectors, the problem of low energy hadron tracks overlapping energetic π^0's and producing fake-electron signals is important. A pre-shower detector, matched to the tracking detector, can help eliminate these fake electrons at the trigger level.

A PS/SM made of scintillator tiles or with fibers 2 meters long, has an inherent time resolution < 15 nsec. It can thus identify which bunch crossing is associated with a shower or track detected by a slower technology such as straw tubes, LAC, or even a compensating spaghetti calorimeter.

E. Pre-shower Detectors in BCD

The BCD experiment would take advantage of the SSC's potential as a prolific B factory for a systematic study of CP violation, rare B decays, and B_s mixing. CP-violation studies require a tag on the particle-antiparticle nature of the second B in the event. Studies of mixing require that both B's decay to modes whose particle-antiparticle character can be determined. In both cases, leptons can provide a useful tag. In addition, both a single-lepton and a J/ψ trigger are part of the trigger strategy for BCD. Particle identification and specifically, electron identification, is therefore an important element in the design of BCD. The electrons of interest have p_t's from 1 to 10 GeV/c and momenta from a few GeV in the central region to a few 100 GeV/c in the forward region. Emphasis is placed on particle identification rather than on energy resolution. The backgrounds, both at the trigger level and in the analysis, are electrons from γ conversions and from π, K, vector meson and charm decays, misidentified pions, and charged tracks overlapping with gammas. The background electrons have a much softer p_t distribution than those from B decays. Successful background rejection must be based on an electron identification system with the best possible electron/pion rejection and p_t cuts. The signal from the calorimeter on its own does not supply sufficient electron/pion rejection. Furthermore, at the trigger level, tracking information correlated with the position of the shower in the calorimeter will be used to make a p_t cut and to reject photon-induced showers. The two requirements, electron/pion rejection and calorimeter-to-track matching, suggest a pre-shower detector as an important detector element for BCD.

PREVIOUS WORK

Under the Generic SSC Detector R&D Program, the groups from Rockefeller and Yale have built and tested a pre-shower detector designed to study the early development of electron showers and the feasibility of tagging electrons by observing the synchrotron radiation produced as the electrons pass through a high magnetic field.

The pre-shower detector is shown in Figs.[1] and [2]. The 10,000 500 μm diameter fibers were arranged in 8 layers, consisting of 6 fiber ribbons each. The layers were separated by 1.4 mm thick lead sheets, making a total thickness of 1.75 radiation lengths. The detector was read out through 2 image-intensifier/CCD chains. Analogue information with data compaction of a factor of 10^4 was achieved through special-purpose Fastbus digitizers.

Data were collected in a test beam at FNAL in 1990 for electrons with energies between 10 and 200 GeV and π^-'s at 50 GeV. The electron showers and pion tracks in the detector were seen to be very narrow. Fig. [3] shows a track of a 50 GeV π^- traversing the detector and Fig. [4] shows a 200 GeV electron starting a shower. The development of the electromagnetic shower as a function of depth can be clearly seen for the electrons.

Tracks or showers are identified offline in each of the three views individually and then combined to form a 3-dimensional trajectory. The energy and width of the showers can then be determined. In Fig. [5] the total shower energy deposited at a depth of 1.75 radiaton lengths is plotted for 50 GeV pions and for 200 GeV electrons. The shower width as a function of depth in the pre-shower detector is shown in Fig. [6]. We are currently studying electron/pion separation using energy deposition and width measurements at different depths within the first 1.75 radiation lengths of the showers. Using only the total energy deposited in the last superlayer, we can achieve pion rejections of 91% with an electron efficiency of 96%.

The emphasis in this work was the study of a detector for synchrotron radiation and thus it was overdesigned from the standpoint of a cost-effective SSC detector element. However, the detailed data we collected during the test run have proved crucial in developing a realistic Monte Carlo simulation. We have a working Monte Carlo of the detector in the GEANT 12.3 framework and are using our data to fine-tune it. With a Monte Carlo anchored to our data we intend to model various EOI-specific realizations of PS/SM devices with realistic estimates of photo-electron yield, properly including such effects as channeling, attenuation-length variations, saturation and efficiency.

PROPOSED R&D WORK

1.) READOUT STUDIES

A primary issue which concerns all those interested in fiber PS/SM detectors at the SSC is the readout. Such a system should be able to:

1) distinguish between events every 15 nsec,

2) supply simple information in time to participate in a 1st level trigger,

3) store the events for several μsec (until 1st level trigger decision),

4) readout selected events at KHz rates,

5) give pulse-height information for individual fibers,

6) be capable of operating in the presence of stray magnetic fields (SDC),

7) be radiation hard

8) and not compromise the hermeticity of the calorimeter.

All these requirements have to be satisfied at a reasonable cost. PS/SM detectors have specific features that are not necessarily shared by the tracker or the calorimeter. Since PS/SM detectors sample the electromagnetic shower, the number of photons per fiber is in the range of 20 - 1000. These detectors need not necessarily be sensitive to minimum ionizing particles, although this would be desirable. The segmentation required of a PS/SM detector is finer, and the light output less, than that of a calorimeter, and, therefore, more channels are required, with greater sensitivity; on the other hand, the linearity requirements can be relaxed. Earlier fiber pre-shower detectors used a CCD plus image intensifier chain, which was well matched to the light output and granularity of such devices; but this read-out system is too slow (5 msec) for SSC operation.

We propose to examine the feasibility and to compare the relative advantages of three types of readout systems for SSC PS/SM detectors: Position Sensitive Photomultiplier tubes (PSPMT), Avalanche Photodiodes (APD), and Image tubes with a LBL "smart pixel" detector as the anode (PIXIES). These will be tested by the various Universities involved in their development and in the PS/SM prototype to be placed in a test beam.

1.1) Position Senstive Photomultipliers. PSPMT's with crossed wire read out now exist at a cost of \$10 per channel and require 34 ADC channels to read out 228 fibers. This is a relatively recent development in photo-multiplier technology and it is to be expected that this type of read out could become more cost effective in the near future. It is, however, subject to ghosts in high occupancy environments, though pulse height sharing can give good position resolution. PSPMT's with anode pads are not subject to ambiguity problems and are now available at \$30 per channel, but will eventually be limited in the position resolution (> 1 mm) that can be achieved with independent anodes. This is a problem for tracking devices, but may not affect preradiators due to the less stringent requirements in granularity. The study of PSPMT's will be carried out at Yale.

1.2) Avalanche Photo-Diodes. APD's with a gain of 2000 are now currently available from GE and RCA with a signal-to-noise ratio which makes them suitable for both tracking and for pre-shower detectors. It is necessary to explore the application of these devices in both contexts to determine their suitability. In the case of pre-shower detectors where some pulse-height information is required an economical sparse readout needs to be designed.

Northeastern University has considerable experience with the use of APD's as part of their membership of the HCTC (Hybrid Central Tracking Collaboration) subsystem group. In conjunction with RCA of Canada they have been evaluating APD's which operate in the geiger mode for this purpose. They are currently awaiting the delivery of arrays of APD's for reading out fiber ribbons. Some work needs to be done to find a suitable pre-amplifier to use with APD's running in the proportional mode. The group at Saclay are also studying the use of APD's with scintillating fibers. Currently different types of APD's are being tested there. As suitable devices become available a test setup will be used for their evaluation.

A novel type of low-noise, high-gain APD is being developped at the University of Florida as part of a University of Florida Subsystem Proposal.[16] We plan to evaluate the performance of these new APD's along with those studied by Northeastern and Saclay

Since APD's have a different spectral response than conventional photocathodes we recognize that it is very important to test them with a PS/SM detector in a test beam as soon as possible. We believe that we have the expertise to put together a fiber-APD system in time to be tested in the current FNAL fixed target run.

1.3) Pixel image tubes. PIXIES are a development which could provide an economic readout for PS/SM detectors. These are conventional proximity focussed image tubes with the LBL smart pixel detector[17] as an anode to detect the accelerated photo-electrons. An outline of a possible device is shown in Fig. [7]. It would consist of a fiber-optic window with a conventional photo-cathode. The image at the photo-cathode is focussed onto a silicon anode which consists of a version of the LBL pixel array with a SMART readout. The amplification is achieved by applying a voltage of 10 kV between the photo-cathode and the anode. This would give a signal of 2,000 to 3,000 electron-hole pairs in the pixel device for each photo-electron. This would be amplified with an input noise of 100 - 200 equivalent electrons.

Hamamatsu, DEP and Burle have expressed an interest in developing devices of this kind with an expected final production cost of ~ $5k per tube. We attach Burle's proposal to this document and we are still waiting for official proposals from DEP and Hamamatsu; these are due by September 30th.

The Burle proposal was included in a SAHEP request for R&D money through the Texas Commission. However since the result of this application is not yet known, the funds have been included in the present budget request. It is our hope that between the TNRLC and the SSC laboratory we will be able to find the $150,000 needed to begin this R&D program.

The particular advantage of pixel image tubes is that they can read out up to 400 1.0 mm diameter fibers per channel. If a 1 mm fiber with a wavelength-shifting core of 500 μm coupled to a clear fiber of the same diameter is read out, then up to 1600 1.0 mm diameter fibers can be read out by each tube. Occupancy considerations must play a role in choosing the PS/SM detector configuration used in conjunction with PIXIES to prevent saturation of the SMART readout. For mimimum bias events, the rate in a 2 meter long, 1 mm diameter fiber located at a 2 meter radius is 40 KHz, for a luminosity of $10^{33} cm^{-2}.s^{-1}$. This corresponds to a pixel occupancy of 0.004/μsec. The development of PIXIE tubes will be performed at Rockefeller and South Carolina Universities, and some testing will be done at Yale.

1.4) Summary of the readout options. The different readout options that we want to investigate are summarized in Table [1].

Table 1. Comparison of PS/SM Readout Options

SYSTEM	FIBERS/ADC	COST/FIBER ($)	COMMENTS
PSPMT (wire anodes)	10	10	x-y readout with ghosting
PSPMT (pad anodes)	1.	30	1 readout channel per fiber
APD	1	?	High gain amplifier required
PIXIES	400-1600	2.5 - 10	Readout saturates at high occupancy

There are several factors which enter into the choice of readout to be selected for PS/SM detectors. These are cost, simplicity, and compatability with the rest of the detector. For the different EOI's represented in this proposal the specific application will define the preferred choice of readout. Before any informed decision can be made it is necessary to continue R&D on these possible readout schemes and conduct direct comparisons.

2.) SIMULATION

We will use the results of the Rockefeller/Yale beam test at Fermilab to compare with our GEANT Monte Carlo of the detector. This will enable us to fully understand the detector efficiencies, including contributions from both fiber effects and the readout chain. Through this comparison we will be able to refine the Monte Carlo itself, establishing the credibility of the shower generation for our application. Once we have a Monte Carlo which is anchored to data, we can use it to optimize PS/SM design for specific applications such as electron identification, $\pi^0 \rightarrow \gamma\gamma$ rejection, hadron rejection, $\pi\gamma$ overlap, or b-tagging inside jets. Depending on the relative importance of these issues in the specific EOI's, we will then establish optimized configurations for SDC, EMPACT, TEXAS, and BCD. This simulation work will be carried out at Yale.

In addition to modeling the detector response to different particles, we will also begin a program of event simulation so that different detector geometries can be evaluated in the context of the SSC events for specific physics processes. The effect of the high multiplicities upon event reconstruction and triggering will be evaluated. An intensive program will be undertaken to investigate the most desirable geometric configuration of the PS/SM detectors and their optimum location in the detector with respect to a magnet coil and the electromagnetic calorimeter. One goal is to develop good shower reconstruction and γ/electron/π^0 identification algorithms for non-isolated electromagnetic showers. In coordination with this algorithm development we will study which PS/SM detector geometries are most suitable for the physics process of interest. The physics simulation and the algorithm development will be carried out at CEN Saclay, France and Tel Aviv University, Israel for the SDC detector and at Northeastern for the TEXAS detector.

3.) PROTOTYPE CONSTRUCTION

We would like to build a modular prototype PS/SM detector system to be tested in conjunction with the calorimeter to be built by the tile-fiber calorimeter subsystem group (spokespersons G. W. Foster and J. Proudfoot).

The purpose of these tests will be to study:

1.) Different readout techniques. By the spring FNAL test it is likely that we will be able to test APD's and PSPMT's.

2.) Correlations between the response of the shower maximum detector, the pre-shower detector and the calorimeter. This will be done with particular emphasis on the e/π separation.

We will build at least three planes of fibers or mini-tiles which can be placed in front of the calorimeter, after 2 radiation lengths, and near shower maximum. The fibers will be readout at one end with PSPMT's and at the other end with APD's, if they are available. In this way it is ensured that for the test-beam measurement we have an understood readout against which the experimental APD's can be compared. The prototypes will be built at Rockefeller University. All members of the collaboration will participate in the test beam runs.

In addition, Yale University is building a prototype pre-shower detector for use in BNL experiment E821 (Muon g-2) and will be building up an expertise in mechanical issues and techniques for reducing light loss at the fiber/light guide splice. The Yale group will be setting up a BNL test beam for the g-2 pre-shower detectors and will also test the PS/SM device at BNL in 1992. The purpose will be to take advantage of the lower electron energies (1-3 GeV, a range of interest to BCD) and to provide a beam test for the PIXIE tubes, which will not be available in time for a Spring 1991 FNAL run.

4.) RADIATION DAMAGE STUDIES

The group at Northeastern University has already begun a testing program for radiation damage studies in collaboration with Quantum Research Services. The laboratories at Northeastern and at Saclay are fully equipped to study both light yields and attenuation lengths of fibers before and after irradiation. The Saclay group will use their ^{60}Co facilities for material irradiation. We would like to compare plastic scintillators (plates and fibers) to identify the best available materials. We intend to build prototype detectors to be exposed to radiation dose rates corresponding to those expected in the SSC environment. We would also like to investigate the effect of annealing fibers which have already undergone substantial radiation damage. Our interest here is motivated by an effect seen while running experiment E774 at FNAL. The scintillating fibers in the E774 calorimeter showed nearly complete recovery when exposed to pure oxygen for 12-24 hours, after receiving radiation doses of about 0.25 Mrad/day.

5.) TIME-OF-FLIGHT STUDIES

Since the BCD reference design includes a time-of-flight system as part of the hadron identification system, we want to evaluate the timing characteristics of the various pre-shower detector designs. Fiber timing studies have already been performed at Yale by M. Gai and collaborators for single fibers and for a CEBAF prototype calorimeter. We will use their testing facility to investigate time-of-flight options for PS/SM devices. M. Gai, in collaboration with Hamamatsu, is also developing a microchannel plate x-y-t readout device using delay line strips and multiple hit TDC's. If the rate tests prove that this device is a possible SSC candidate, then we would be interested in reading out the PS/PM prototype with it during the BNL test beam run in 1992.

6.) TRIGGER DESIGN

Preradiators can contribute significantly to the trigger at all levels by providing pulse-height information matched to the tracker and locally matched with clusters in the calorimeter. A possible trigger would require a track pointing to a pre-shower cluster in conjunction with a cluster in the calorimeter. Local matching, without reference to a central trigger system, between the clusters in the preradiator and energy deposition in the calorimeter can help remove spurious triggers from the electron trigger at level I. Experience in OPAL has indicated that triggers formed with the tracker, the calorimeter, and the preradiator are best combined as three separate pairs instead of one triplet. This provides a very useful degree of redundancy. Furthermore, if the preradiator can indicate the presence of a π^0 through fine spatial segmentation, then the purity of the electron trigger can be improved. Finally, the results of the Yale/Rockefeller preradiator test indicate that even for 2 T fields, the additional energy deposited by SR photons further enhances the electron signal (for $E_e > 100$ GeV), improving the purity of the electron trigger. Possible methods for making fast trigger decisions with PS/PM detectors will be evaluated at Saclay. The different schemes will be evaluated using the Monte Carlo simulations discussed above. Later they could be used to devise EOI-specific triggers for the relevant physics processes.

7.) ENGINEERING

The physical realization of a subsystem is an important task which is often neglected. The integration of a preradiator into the whole detector will, however, place some stringent demands on the design itself. These issues must be addressed early enough in the process that they can influence the choices made with respect to physics questions. We will need to build up an expertise in the tools needed to address the engineering aspects of the pre-radiator in conjunction with what already exists in the various Universities and Labs. We intend to study the simplest optimization schemes (such as reducing number of cables, simple and transparent support structures, and electronics integration) in common, rapidly moving on to the EOI-specific questions.

ORGANIZATION

Dr. Prisca Cushman and Dr. Roger Rusack will be co-spokesmen for this Subsystem Proposal. Dr. Cushman will be responsible for software development, specifically analysis of the test beam data and general coordination of the various simulation tasks. Dr. Rusack will organize the Spring test beam run at FNAL and is responsible for coordinating the readout options with respect to the PS/SM prototype. The resident Fermilab Contact Person for the test beam run will be Dr. Jeff Wilson.

RESPONSIBILITIES

TASKS BY INSTUTIONS

Northeastern University

1.) Radiation damage studies of fibers suitable for pre-shower detectors. Measure effects on the attentuation length and the light yield in fibers, as well as oxygen regeneration techniques for specific mechanical construction.

2.) Evaluation of APD's for pre-shower detector applications.

3.) Develop software for simulating events at the SSC with specific emphasis on pre-shower detector applications in the TEXAS detector.

The Rockefeller University

1.) Collaboration with industry (DEP, Hamamatsu or Burle) in the development and testing of the PIXIE Tube.

2.) Building the prototype PS/SM detectors.

3.) Continue data analysis of the previous test to address questions relevant to the EOI-specific configurations.

4.) Fiber splicing techniques.

CEN Saclay

1.) Simulation of SSC physics processes requiring electron identification, with specific emphasis on the SDC detector.

2.) Evaluation of APD's.

3.) Radiation Damage Studies.

4.) Trigger design.

5.) Engineering Studies.

South Carolina University

1.) Collaboration with industry in the development and testing of PIXIE tubes.

Tel Aviv University

1.) Detector Simulation in collaboration with Saclay.

Yale

1.) Comparison of various PSPMT (multianode primarily) and PIXIE tubes.

2.) Brookhaven tests of preradiators.

3.) Continue data analysis of the previous test to address questions relevant to the EOI-specific configurations.

4.) Detector simulation: evaluating the performance of GEANT for simulating early shower development, including fiber effects, and electron trigger studies related to BCD.

5.) Time-of-flight options for pre-shower devices.

REQUESTED BUDGET BY INSTITUTION

Table 2 Northeastern University Budget

ITEM		FUNDING ($K)
Personnel	Engineer (12 mo.)	45
	Fringe Benefits (@22%)	9.9
Travel	Domestic	5
Shop charges	Stock Material	1
	Time charges	3
	Gas System	1
Computing	Vaxstation 3100, Color Graphics	12
	8mm. Tape Drive and Interface	5
APD	Proportional mode APD's	10
	Readout electronics	10
TOTAL	Operations	64.9
TOTAL	Equipment	37.0
TOTAL		101.9

Table 3 Northeastern University Personnel

	Position	% of this task	Other tasks
G. Alverson	Faculty	25	L3
A. Grimes	Technician	50	HCTC
M. Glaubman	Faculty	50	L3
M. Hulbert	Graduate Student	25	E774
I. Leedom	Faculty/SSC Fellow	50	E774
J. Moromisato	Research Scientist		LVD
S. Reucroft	Faculty	25	E774 L3

Table 4. Rockefeller University Budget

ITEM		FUNDING ($K)
Technician	Salary (6mo.)	15.5
	Benefits (@23%)	3.6
	University Overhead (@68%)	13
PS/SM detector	Fibers	5
Equipment	Parts	5
	Cables	3
	Machine shop charges	10
	Laser for fiber testing	1.5
	Camac Readout Devices for Pixel Tube	10
Travel	Domestic	2
	Foreign (2 trips to Saclay)	4
	University Overhead	4
Visiting Scientist		20
	University Overhead	13.6
TOTAL	Operations	75.7
TOTAL	Equipment	34.5
TOTAL		110.20
Pixel Tube Development		150
TOTAL	Including Pixel Tube development	260.8

Table 5 Rockefeller University Personnel

	Position	% of this task	Other tasks
N. Giokaris	Faculty	10	CDF
K. Goulianos	Faculty	25	CDF
P. Melese	Senior Research Assoc.	50	UA6
R. Rusack	Faculty	50	CDF
S. White	Faculty	25	CDF

Table 6 CEN Saclay Personnel

	Position	% of this task	Other tasks
P. Bonamy	Physicist	30	UA2
J. Ernwein	Physicist	75	Frejus
J.R. Hubbard	Physicist	50	D0
P. Le Du	Physicist	50	OPAL
J.P. Pansart	Physicist	40	OPAL

Table 7. University of South Carolina Budget

ITEM		FUNDING ($K)
Electronics	Camac Readout for Pixel Detector	10
Travel	Domestic to FNAL for test-beam work	10
	University Overhead (@51%)	5.1
TOTAL	Operations	15.1
TOTAL	Equipment	10
TOTAL		25.1

Table 8. University of South Carolina Personnel

	Position	% of this task	Other tasks
C. Rosenfeld	Faculty	10	AMY
A. Wang	Research Asst. Prof.	10	AMY
J. Wilson	Faculty	30	FNAL E687

Table 9. Tel Aviv University Budget

ITEM		FUNDING ($K)
Salaries	Full time senior programmer	23.8
	Part time junior programmer	8.8
Travel	3 trips to US for collaboration meetings	6.375
Computer Time	IBM 3090/150	
	(60 hours @$850 per cpu hour)	51
University Support		51
TOTAL	Operations	38.975

Table 10. Tel Aviv University Personnel

	Position	% of this task
G. Bella	Assoc Research Prof	15
J. Grunhaus	Faculty	80
R. Heifetz	Physicist Programmer	15
A. Levy	Faculty	20
To be named	Senior-Programmer	100
To be named	Junior-Programmer	50

Table 11. Yale University Budget

ITEM		FUNDING ($K)
Personnel	Visiting Scientist from Novosibirsk (D. Grigoriev)	20
	2 summer Students 2 mo each	6.6
Equipment	Nitrogen Laser Photonics model LN103 For bench tests of PSPMT's and TOF fiber studies.	8.795
	1 Hamamatsu 256 anode PMT for tests	9.7
	1 Phillips 64 anode PMT XP4702 for tests	4.24
	Additional PSPMT's for Beam Tests	50
	Stockroom Purchases	2
	Miscellaneous electronic components for preamps/electronics for PSPMT's	9.1
	Design,Fabrication of preamps/electronics for PSPMT's (0.5 man year @ $38/hr.)	37.05
Travel	Domestic BNL and FNAL Test beam and SSC travel (SSC Lab and Empact meetings)	6
Indirect Costs	Off campus (30.3%) of $6,000	1.806
	On Campus (68%) of $20,000	13.6
TOTAL	Operations	48.006
TOTAL	Equipment	120.885
TOTAL		168,891

Table 12. Yale University Personnel

	Position	% of this task	Other tasks
P. Cushman	Faculty	50	g-2
M. Gai	Faculty	10	WNSL CEBAF
S. Sen	Student	10	WNSL
V. Singh	Student	25	UA6
J. Slaughter	Senior Research Scientist	25	FNAL E791 + BCD
Z. Zhao	Student	10	WNSL
To be named	Reseach Scientist	50	g-2

Table 13. Total Subsystem Budget Request

ITEM	FUNDING ($K)
OPERATIONS	243
EQUIPMENT	352
TOTAL	595

REFERENCES

1) Solenoidal Detector Collaboration, EOI to the SSC Lab., May 24th 1990.

2) EMPACT Collaboration, EOI to the SSC Lab., May 25th 1990.

3) TEXAS Collaboration, EOI to the SSC Lab., May 24th 1990.

4) Bottom Collider Detector Collaboration, EOI to the SSC Lab., May 25th 1990.

5) *The Development of a Compensating Scintillator Plate Calorimeter System for the SSC,* G.W. Foster and J. Proudfoot, cospokespersons, submitted to the SSC Laboratory, September 1990.

6) R. Ansorge *et al.*, *Performance of a Scintillating Fiber Detector in the UA2 Upgrade* NIM A265 (1988) 33.

7) L. Balka *et al.*, *The CDF Central Calorimeter*, NIM A267 (1988) 272.

8) D. Acosta *et al.*, *Results of Prototype Studies for a Spaghetti Calorimeter*, CERN Preprint EP/90-37.

9) B. Wicklund. Private Communication.

10) C. Beard *et al.*, *Thin, high gain wire Chambers for Electromagnetic Presampling in OPAL*, NIM A286 (1990) 117.

11) V. Barger *et al.*, *Possible ν-quark Signatures at e^+e^- Colliders* Phys. Rev. Lett. 57 (1986) 1518.

12) W.S. Hou and R.G. Stuart, *Flavor Changing Neutral Currents Involving Heavy Fermions: A General Survey.* Nucl. Phys. B320 (1989) 277.

13) Reply by the SDC to the questions from the PAC, 12th. July 1990

14) U. Baur and E.L. Berger, *Probing the $WW\gamma$ Vertex at the Tevatron Collider*, ANL Preprint HEP-PR-89-86

15) U. Baur *et al.*, *Hadronic Production of Electroweak Vector Bosons at Large Transverse Momentum.* Nucl. Phys. B318 (1989) 106 and references contained therein.

16) J. Walker *et al.*, *Proposal for the Development of an Advanced Structure Avalanche Photodiode for Scintillating Fibers at the SSC*, SSC Subsystem Proposal, September 1990.

17) D. Nygren, *Silicon Tracking Devices for the SSC*, Proceedings of the Summer Study on High Energy Physics in the 1990's, July 1988.

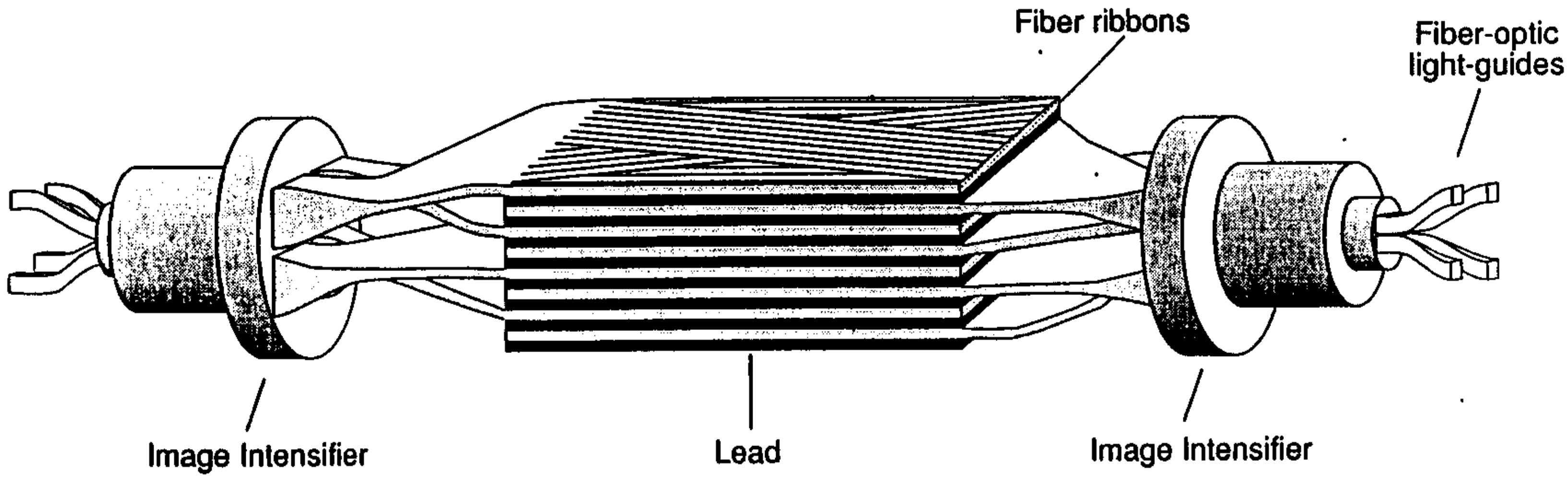

Figure 1. Schematic of the Yale-Rockefeller Pre-Shower Detector

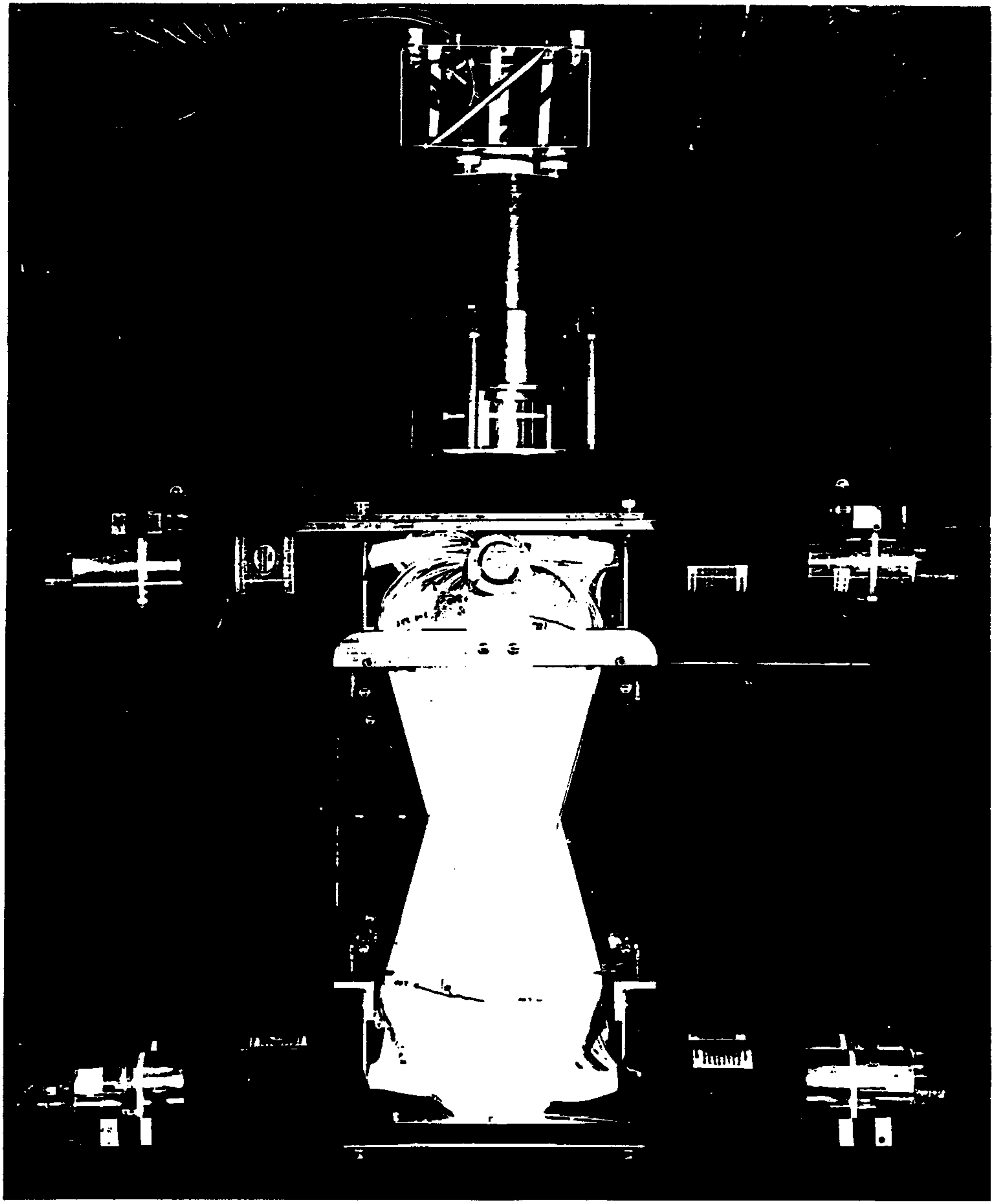

Figure 2. Front View Of Detector (top readout chain is shown)

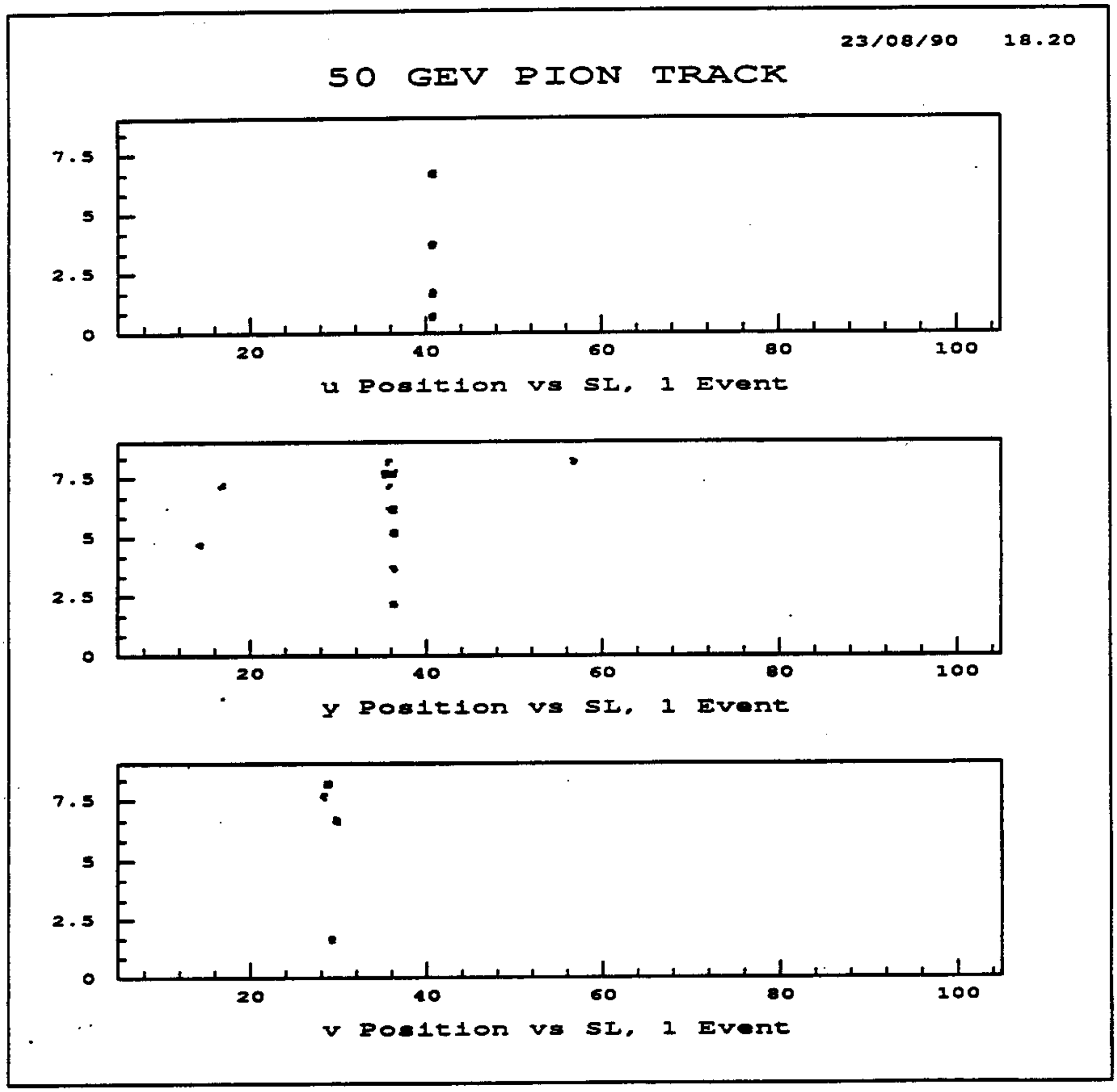

Figure 3. 50 GeV Pion Track In Dectetor (3 views)
The horizontal axis is the fiber position in mm and the vertical axis is the layer number (8 corresponds to 1.75 radiation lengths).

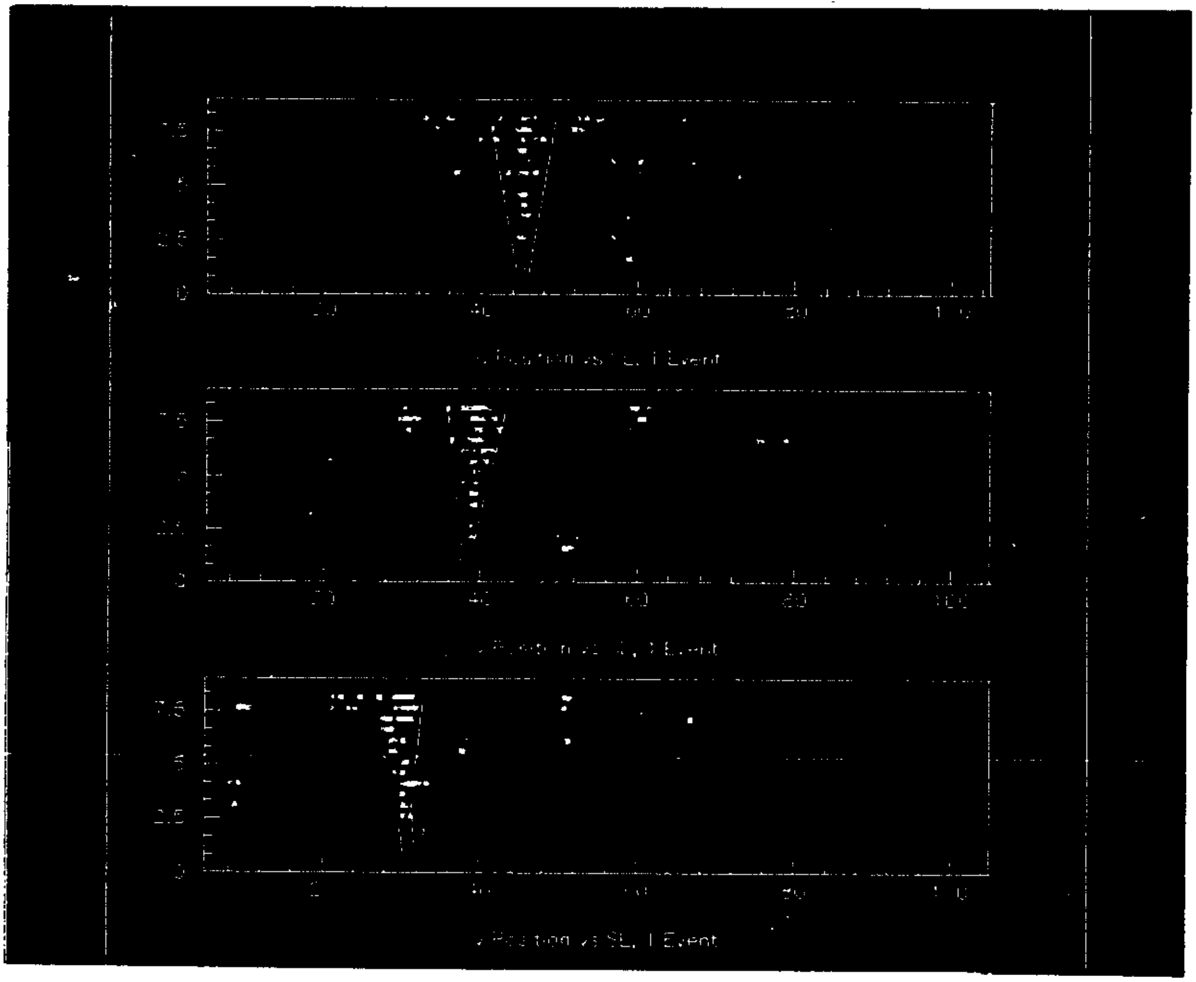

Figure 4. 200 GeV Electron Shower In Dectetor (3 views)
The horizontal axis is the fiber position in mm and the vertical axis is the layer number (8 corresponds to 1.75 radiation lengths).

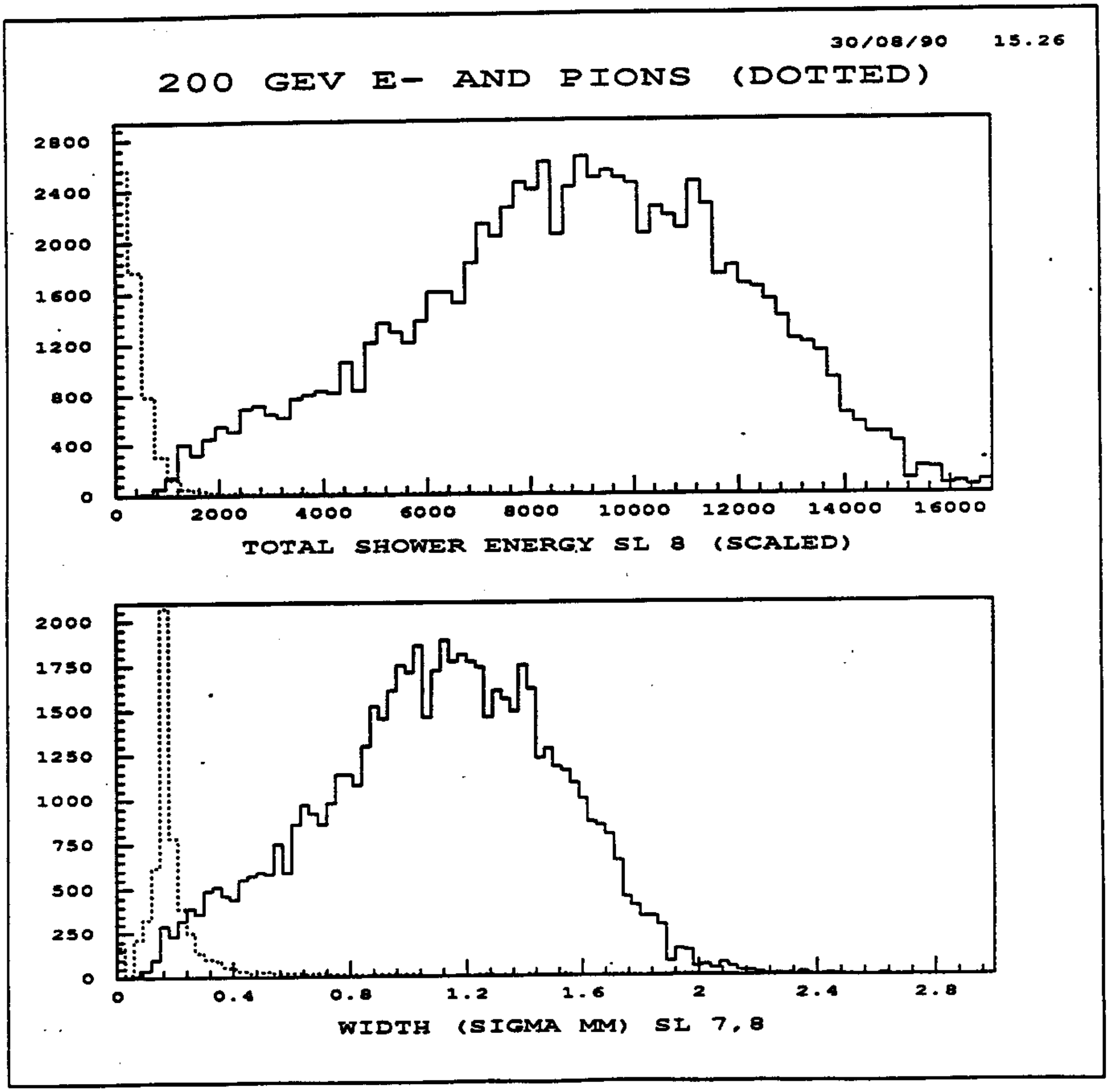

Figure 5 (top). Energy Deposited by Pions and Electrons at 1.75 Radiation Lengths

Figure 6 (bottom). Shower Widths for Pions and Electrons at 1.75 Radiation Lengths

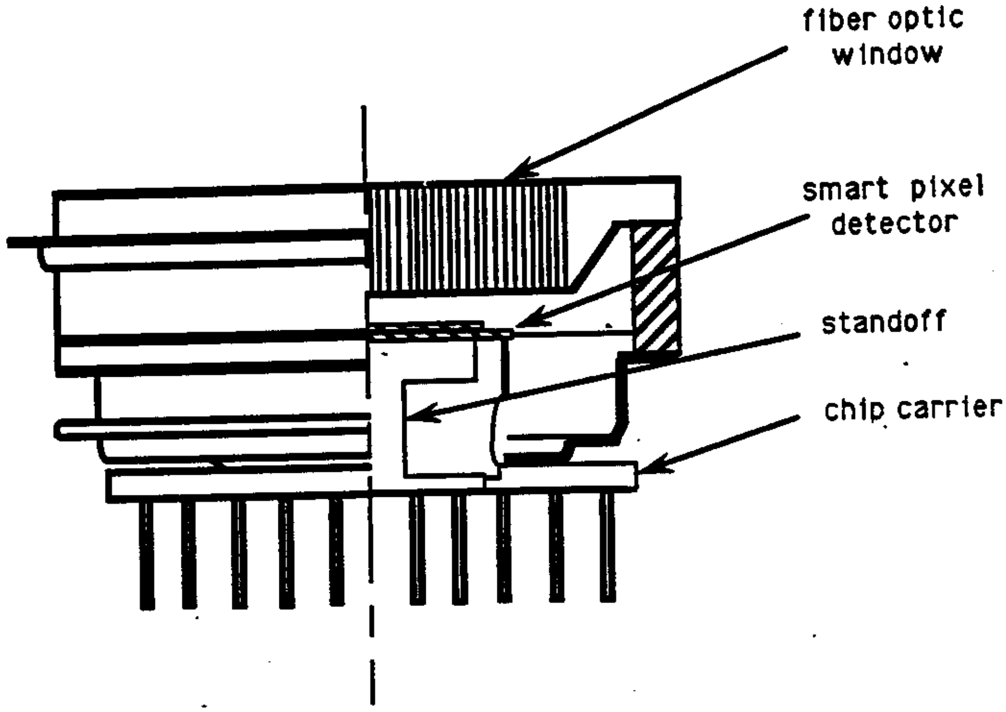

Figure 7. Pixie Tube Schematic
Based on a Suggestion From DEP.

BURLE INDUSTRIES, INC. | 1000 New Holland Ave. | Lancaster, PA 17601-5688 | Telephone (717) 295-6000

BURLE

March 2, 1990

Mr. Roger Rusack
Rockefeller University
1230 York Avenue
New York, NY 10021

Dr. Carl Rosenfeld
University of South Carolina
Department of Physics
Columbia, SC 29208

Subject: Budgetary Cost Proposal for the Fabrication of a Silicon Anode Tracking Detector

Dear Gentlemen:

In response to the Universities' request for proposal, BURLE INDUSTRIES, INC., is pleased to provide its budgetary proposal for the fabrication of up to 15 deliverable units of a Silicon Anode Tracking Detector. Pertinent details are covered in the attached documents.

We have attempted to address all of the salient matters concerning this program, however, should additional information be required, please advise. Matters of a technical nature may be pursued directly with J.D. Cammerata, Engineering Manager, at telephone 717-295-6696.

The Universities can feel assured that BURLE INDUSTRIES, INC., will direct its technical resources to help bring this program to a successful conclusion, and we look forward to joining the Universities in this effort.

Sincerely,

Carlton L. Rintz
Manager
Image & Display Tube Products
Marketing & Sales Operation
Tube Products Division

CLR40/ck

Enclosures

Proposed For: **Fabrication Of A Silicon Anode Tracking Device**

Proposed To: **Rockefeller University**
University of South Carolina
(Hereafter Referred to as "the Universities")

In Response To: **Request For Proposal**

Proposed By: **BURLE INDUSTRIES, INC.**
Tube Operations Division
Lancaster, PA 17604

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FORWARD

This budgetary proposal is submitted by BURLE INDUSTRIES, INC., in response to the Request for Budgetary Proposal. BURLE's response includes an estimate for the establishment of capabilities to fabricate Silicon Anode Tracking Devices as well as a budgetary price for up to 15 deliverable units.

A program of approximately 12 months duration has been defined to complete the tasks required by the Universities' request for proposal. A time based milestone schedule outlining the complete program has been provided.

The techniques and skills required for high vacuum, high voltage fabrication are well understood and in some cases, were developed by the employees of BURLE INDUSTRIES. With decades of experience in this field, we are confident that we can successfully complete this program to the satisfaction of the Universities.

INTRODUCTION TO BURLE INDUSTRIES, INC.

General

BURLE INDUSTRIES, INC., was formed on July 14, 1987, when the senior management of RCA's New Products Division purchased the Lancaster, PA, based facility. The Lancaster plant dates back to 1942 when RCA operated the Navy built manufacturing facility to produce radio transmitting tubes, and microwave tubes. After World War II, RCA acquired the plant and moved other business activities for industrial and consumer markets to Lancaster. Subsequently, Lancaster was home to black and white picture tube production, color TV tubes, camera tubes, photo tubes, solid state emitters, solid state imagers and most recently, production of closed circuit TV equipment and motion-sensing light-control security switches.

Headquartered in Lancaster, Pennsylvania, BURLE INDUSTRIES, INC., owns 75 acres including 1.3 million square feet of office and manufacturing space, and employs more than 1000 people worldwide.

BURLE encompasses three main businesses: Tube Products, Security Products, and Real Estate Leasing. BURLE's principal strengths include innovative R & D, experienced and comprehensive design engineering services, advanced technology manufacturing facilities for both large volume and specialized custom needs, and a well-trained, highly motivated work force.

The principals of the Company are: Dr. Erich Burlefinger, President, CEO and Chairman of the Board; Don R. Carter, Executive Vice President of Tube

Products; Carlton L. Rintz, Executive Vice president of Security Products; Randolph C. Rose, Executive Vice President of Finance; and John H. Cook, Executive Vice President of Employee Relations.

With over 100 combined years of experience with RCA, the management team has led the company to two successful years of profitability and sales growth.

PRODUCTS

BURLE's Tube Products Division designs and manufactures electron tubes in two product categories, Power Tubes and Conversion Tubes. Power Tubes include amplifier, RF source and high power switching devices, and Conversion Tubes include camera, photomultiplier and display devices. In each category, BURLE ranks consistently among the world's top suppliers.

Customers include all branches of the military, National Laboratories, Department of Energy and other Federal agencies, and major defense contractors including Martin Marietta, General Dynamics, Rockwell, Hughes, GE, Lockheed, Ball and AEL. In the commercial area, BURLE is a major supplier to the broadcast, medical and industrial markets. Our customers in the medical field include Picker, Siemens, and General Electric as well as many smaller equipment manufacturers in this market.

Conversion tubes are utilized in many medical instruments such as nuclear medicine diagnostic tools and blood analyzers, and in airport baggage and food inspection equipment.

BURLE has recently completed the design and development a new photomultiplier tube for use in large-scale Cerenkov radiation detector systems at Los Alamos National Laboratories. The C83061 is now the new standard by which photomultipliers are measured for neutrino detection.

BURLE camera tubes are utilized by TV stations to capture live broadcasts, in surveillance cameras that monitor activities in banks, stores and government facilities, in medical X-ray equipment, and various military systems.

BURLE display tubes are used in phototypesetting equipment, film processors, and for medical diagnostic instruments.

BURLE power tubes are used by most U.S. VHF TV stations to transmit broadcasts over the air to home TV sets. BURLE power tubes are also utilized by many countries in communication systems radar and other military applications.

RESOURCES

Members of BURLE's technical staff hold advanced degrees in engineering, electronics, science, and computer technology, and hold numerous patents related to vacuum tube technology. BURLE's areas of expertise include knowledge and skill in ultra-high vacuum technology; hermetic seals, thin-film vacuum coating and high power electron optics.

BURLE is committed to maintaining its technical edge in the industry through its emphasis on research and development. The Company invests approximately 10 percent of sales revenue in new products and engineering.

BURLE utilizes CAD/CAM equipment to maximize product quality and minimize the product cost impact on our customers. Forty-two design engineers and technicians utilize over twenty HP9000 CAD systems with supporting software.

BURLE has recently completed the construction of a new $1.2 million state-of-the-art industrial plating facility. Together with our on-site waste treatment plant, BURLE is able to offer unique, high quality plating and firing services to the commercial, industrial, and military markets while insuring all industrial wastes are treated in accordance with local, state and federal regulations.

GROWTH

In January 1989, BURLE purchased Imperial Machine and Tool, Inc., based in Winston-Salem, North Carolina, now known as Imperial Division of BURLE. Founded in 1972, this highly mechanized machining and tooling facility has the technology for manufacturing specialized components for tubes as well as parts for cameras and monitors.

BURLE strengthened its European presence in the past year with the acquisition of Hofer Electronics near Aachen, West Germany, and the start-up of a new design & manufacturing facility in Cork, Ireland

BURLE INDUSTRIES Aachen Division is a 40,000 square foot printed, circuit board, manufacturing company. The Aachen Division is manufactures single and double layer printed circuit boards and specializes in fast turn-around of 24 hours or less.

The Cork facility is BURLE's Alarm Products Skill Center, which is an integrated research, design, and highly automated manufacturing operation for security products such as sensors, alarms, electronic control systems and accessories.

The most recent acquisition occurred in October 1989, when BURLE purchased Robot Industries, Inc., a 20,000 square foot manufacturing company in Dearborn, Michigan, which manufactures a complete line of security turnstiles, gate operators, and barrier gates.

BURLE is strategically located in Lancaster, PA, near the major metropolitan centers of Baltimore, Harrisburg, Philadelphia, and Washington, D.C. There is easy access to highway, air, rail, and sea transportation.

For the future, BURLE looks forward to continuous, long-term growth and profitability, continuing to serve the existing customer base while seeking growth through new product development, new applications and new markets.

STATEMENT OF WORK

BURLE proposes to fabricate devices incorporating a customer supplied pixel silicon anode detector into a modified image inverter tube. This concept allows for the detector to be operated in an electron-in mode where significant gain in the silicon can be obtained from high energy electrons in the range of 10 KeV.

This proposal specifically is a "best effort" program based on manufacturing up to 15 quality tube starts and providing any/all resulting devices to the Universities. The proposal includes the delivery of three quarterly progress reports and a final report.

Information on the silicon detector (Smart Pixel Array) and the readout integrated circuit was provided by Dr. David Nygren, Lawrence Berkley Labs. Information on the exact dimensions of the device will be forwarded to BURLE INDUSTRIES after the final design review in April 1990. The verbal information supplied to date was sufficient for the development of budgetary pricing.

The device will be an electrostatic Image Inverter Tube design and shall consist of a brazed ceramic-to-metal bulb representing the vacuum enclosure. It will have a plano Fiber-Optic input window with an S-20 photocathode with emphasis on the "Blue" region of the spectrum. The minimum useful input diameter will be 18 mm.

The output shall consist of a Smart Pixel Array which is directly bonded over a silicon-on-sapphire chip, with the largest dimensions not to exceed 11 mm x 11 mm. The thickness of the bonded device will be 725 microns. This unit (supplied by the Universities) will be bonded to a support and vacuum tight header.

The entire device will be assembled using electrical arc welds, sealed on a vacuum system, evacuated, activated, sealed and separated from the vacuum system.

The device will have an attached voltage divider network, potted in silicon rubber and enclosed in a plastic housing.

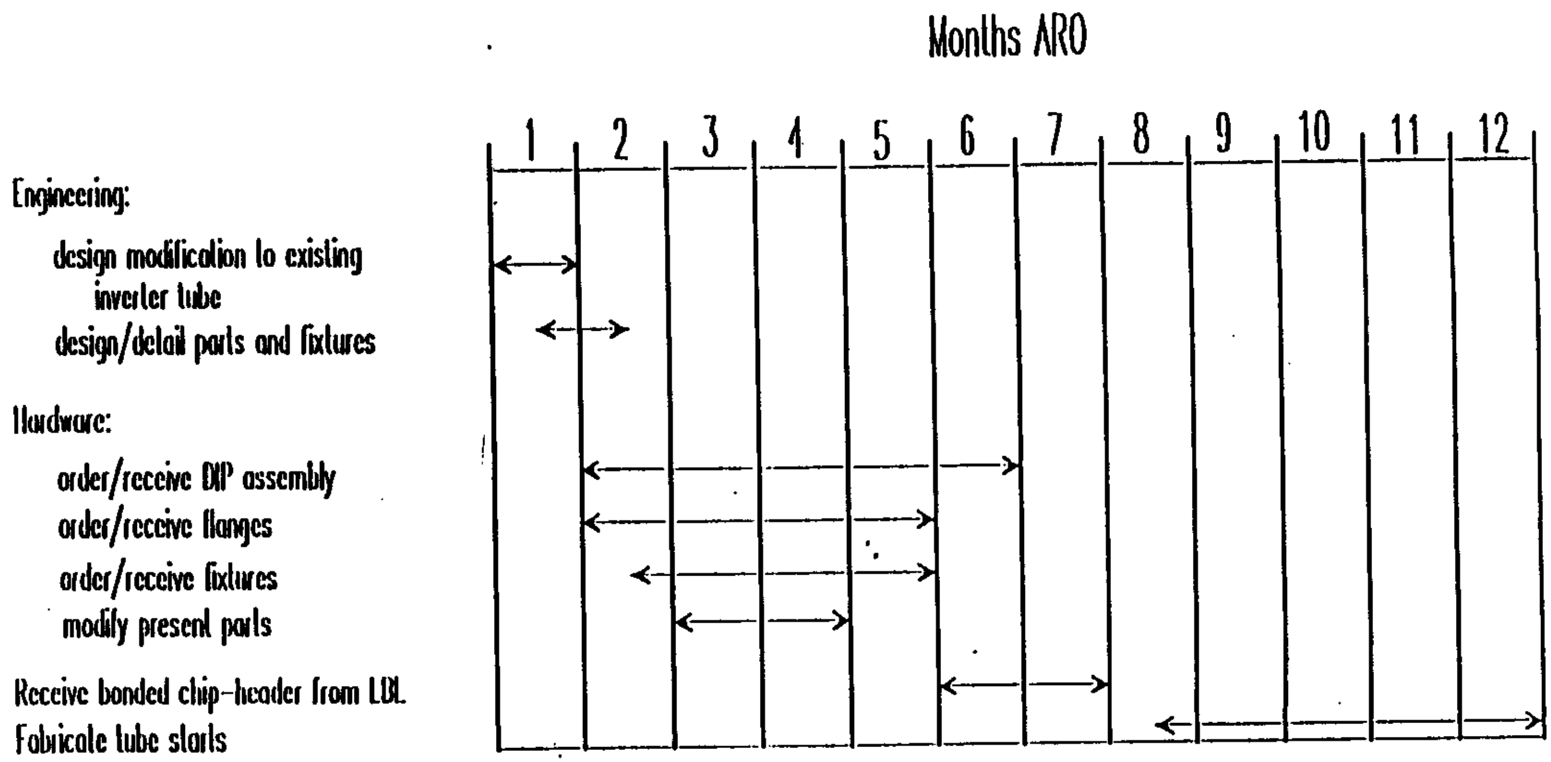
BURLE testing will consist of measuring photocathode sensitivity, uniformity, and vacuum integrity. At this point, devices will be supplied to the Universities to determine performance characteristics of the electron bombarded silicon array.

BURLE INDUSTRIES proposes to fabricate a silicon anode device utilizing a pixel silicon anode detector provided by the Universities. Therefore, it is anticipated that the hardware and documentation provided by the Universities will be sufficient to carry out this effort. No additional costing has been included for the design or fabrication of a suitable silicon anode detector.

PROGRAM COSTS

Non-Recurring Engineering (Tooling, Fixtures, Special Parts)	$ 59,500
Engineering	41,700
Deliverables	47,600
Hardware - Up To 15 Devices	
Reports - 3 Quarterly 1 Final	
Total Budgetary Cost	$148,800

Program Timing



TERMS AND CONDITIONS

BURLE INDUSTRIES, INC., Terms and Conditions of Sale, attached, are hereby made part of the agreement between BURLE and the Universities.

ANY SALE BY BURLE INDUSTRIES, INC. OR OTHER ENTITY INDICATED ON THE REVERSE SIDE HEREOF OR ATTACHMENT HERETO AS THE SELLER (HEREINAFTER REFERRED TO AS "BURLE") IS EXPRESSLY MADE CONDITIONAL ON CUSTOMER'S ASSENT TO THESE TERMS AND CONDITIONS OF SALE. CUSTOMER'S TAKING DELIVERY OF ANY PART OF GOODS SOLD SHALL CONSTITUTE SUCH ASSENT AND A WAIVER OF ALL TERMS AND CONDITIONS IN ITS PURCHASE ORDER OR SIMILAR DOCUMENT WHICH ARE DIFFERENT FROM OR ADDITIONAL TO THOSE SET FORTH HEREIN.

1. PRICES AND TERMS OF PAYMENT

(A) Unless otherwise specified by BURLE in writing, prices and terms of payment shall be those set forth in the applicable Price Schedule. BURLE reserves the right to change or withdraw prices for the products it offers for sale without prior notice. If BURLE's price for any product is increased, the price in effect prior to the increase will apply to orders received prior to the effective date of the increase and shipped within a period of 30 days after the effective date of increase. Partial shipments made within this period will not obligate BURLE to make further shipments at these prices after the expiration of the 30-day period.

(B) Prices are in United States dollars payable in Lancaster, Pennsylvania, USA, unless otherwise specified.

(C) Unless otherwise specified by BURLE in writing, all taxes and other charges imposed by federal, state, local or foreign governments on the manufacture, sale, shipment, import, export or use of the goods or services shall be added to the price and billed to and paid by Customer. Customer shall defend, indemnify and hold harmless BURLE from and against all liabilities for such taxes or charges and attorneys' fees or costs incurred by BURLE in connection therewith.

2. ACCEPTANCE

Any quotation or proposal is subject to change or cancellation by BURLE at any time without notice and in any event expires 30 days from its date, unless otherwise indicated therein or extended in writing by BURLE. BURLE's quotation or proposal does not constitute an offer by BURLE, and any order or orders placed thereon are not binding on BURLE until BURLE's acceptance in writing in Lancaster, Pennsylvania, USA has been sent to the Customer. The banking, negotiation, endorsement or other use of the Customer's down payment, if any, shall not constitute acceptance by BURLE.

3. MINIMUM ORDER RELEASE

The minimum order and shipping release for all products is $250 in billing value per order.

4. DELIVERY

Unless otherwise agreed by BURLE in writing, BURLE shall have the right to make deliveries in installments. Partial shipments will be billed as made and payments therefor are subject to the terms of payment referenced herein. All delivery indications are estimated and are dependent in part upon prompt receipt of all necessary information to service an order. BURLE reserves the right to allocate inventories and production when such allocation becomes necessary. In no event will BURLE be liable for any premium transportation, reprocurement, or other costs or losses incurred by the Customer as a result of BURLE's failure to deliver product in accordance with indicated delivery schedules.

5. PATENTS AND PATENT WARRANTY

The Customer agrees that BURLE has the right to defend, or at its option to settle, and BURLE agrees, at its own expense, to defend or at its option to settle, any claim, suit or proceeding brought against the Customer on the issue of infringement of any United States patent by any product, or any part thereof, supplied by BURLE to the Customer hereunder. BURLE agrees to pay, subject to the limitations hereinafter set forth in this paragraph, any final judgment entered against the Customer on such issue in any suit or proceeding defended by BURLE. The Customer agrees that BURLE at its sole option shall be relieved of the foregoing obligations unless the Customer notifies BURLE promptly in writing of any such claim, suit or proceeding, and at BURLE's expense, gives BURLE proper and full information and assistance to settle and/or to defend any such claim, suit or proceeding. If the product, or any part thereof, furnished by BURLE to the Customer becomes, or in the opinion of BURLE may become, the subject of any claim, suit or proceeding for infringement of any United States patent, or in the event of an adjudication that such product or part infringes any United States patent, or if the use, lease or sale of such product or part is enjoined, BURLE may, at its option and its expense: (1) procure for the Customer the right under such patent to use, lease or sell, as appropriate, such product or part, or (2) replace such product or part, or (3) modify such product or part, or (4) remove such product or part and refund the aggregate payments and transportation costs paid therefor by the Customer less a reasonable sum for use, damage and obsolescence. BURLE shall have no liability for any infringement arising from: (i) the combination of such product or part with any other product or part whether or not furnished to the Customer by BURLE, or (ii) the modification of such product or part unless such modification was made by BURLE, or (iii) the use of such product or part in practicing any process, or (iv) the furnishing to the Customer of any information, data, service or application assistance. The Customer shall hold BURLE harmless against any expense, judgment or loss for infringement of any United States patents or trademarks which results from BURLE's compliance with the Customer's designs, specifications or instructions. BURLE shall not be liable for any cost or expense incurred without BURLE's written authorization and in no event shall BURLE's total liability to the Customer under, or as a result of compliance with, the provisions of this paragraph exceed the aggregate sum paid to BURLE by the Customer for the allegedly infringing product or part, exclusive of any refund under option (4) above. The foregoing states the entire warranty by BURLE, and the exclusive remedy of the Customer, with respect to any alleged patent infringement by such product or part. In the event that the Customer is an authorized distributor of BURLE, such warranty, subject to the terms and conditions hereof, shall be extended to the direct purchasers from such distributor of the goods covered hereby.

No sale or lease hereunder shall convey any license by implication, estoppel or otherwise, under any proprietary or patent rights of BURLE, to practice any process with such product or part, or for the combination of such product or part with any other product or part.

6. OTHER WARRANTIES

(A) BURLE warrants that its products, at the time of shipment by BURLE, possess the electrical characteristics as set forth in, and will perform, for the respective warranty periods specified in the applicable Price Schedule, in accordance with, the applicable data sheet or agreed-upon specifications when operated within the operating condition limitations set forth therein.

(B) To assure conformance with such operating limitations, the Customer should refer to the applicable data sheet.

(C) Such warranty does not apply: (i) if the product has been exposed to unusual or excessive environmental, mechanical, electrical, or thermal stress during the course of installation or use, or (ii) if the absolute maximum ratings are exceeded for any reason including, but not limited to, equipment design and improper device installation or application, or (iii) if product malfunction is the result of misuse, abuse, improper installation or application, alteration, accident, or negligence in use, storage, transportation or handling, or if the original identification markings on the product have been removed, defaced or altered.

(D) In order to permit BURLE to properly administer this warranty, the Customer shall (i) notify BURLE promptly in writing of any claims, and (ii) provide BURLE with the opportunity to inspect and test the product claimed to be defective. Such inspection may be on the Customer's premises and/or BURLE may request the return of the product at Customer's expense, and such transportation charges paid by the Customer will be subsequently reimbursed if the product is found to be defective. However, BURLE shall not be responsible for packing, inspection, or labor costs in connection with the return of product. In order to avoid administrative difficulties that result from unauthorized returns, the Customer shall request a formal return authorization from BURLE before returning product for any reason.

(E) The liability of BURLE hereunder is solely and exclusively limited to replacement, repair or credit at the purchase price, as BURLE may elect, for any product which is returned by the Customer during the applicable warranty period and which is found by BURLE to be subject to adjustment under this warranty. IN NO EVENT SHALL BURLE BE LIABLE FOR SPECIAL, INDIRECT, INCIDENTAL OR CONSEQUENTIAL DAMAGES, LOSS OF ANTICIPATED PROFIT OR OTHER ECONOMIC LOSS OR FOR ANY DAMAGES ARISING IN TORT WHETHER BY REASON OF STRICT LIABILITY, NEGLIGENCE OR OTHERWISE.

(F) BURLE's warranty as herein set forth shall not be enlarged, diminished or affected by, and no obligation or liability shall arise or grow out of, BURLE's rendering of technical advice, facilities or services in connection with Customer's order or the goods furnished hereunder.

(G) The foregoing warranty extends to the Customer of BURLE and not to purchasers or users of such Customer's products, except that if the Customer is an authorized distributor of BURLE, the foregoing warranty (and no other), subject to the terms and conditions thereof, may be extended to purchasers from such distributor of the goods covered hereby. BURLE MAKES NO OTHER OR FURTHER WARRANTY, EXPRESS OR IMPLIED, INCLUDING ANY WARRANTY OF FITNESS FOR A PARTICULAR PURPOSE OR WARRANTY OF MERCHANTABILITY.

7. INSPECTION OF GOODS

Goods shall be inspected by the Customer upon delivery. Notice of rejection or claim for shortages or other non-conformity must be submitted by the Customer to BURLE in writing within 30 days of shipment and must specify the particular respects in which the delivery of goods are non-conforming. The Customer shall have no right to exercise any remedial rights until notice of non-conformity has been [illegible]lation (after shipment has been made) must be made within 30 days of shipment. If approval is given by BURLE to return product, a minimum charge of 15% of the value of product returned will be deducted from the amount of credit issued by BURLE.

8. RETURNS

Requests for the return of goods because of "ordered in error" or "cancellation" (after shipment has been made), must be made within 30 days of shipment. If approval is given by BURLE to return product, a minimum charge of 15% of the value of product returned will be deducted from the amount of credit issued by BURLE.

9. CANCELLATION, HOLD, OR STOP-WORK NOTICES

The Customer may send BURLE a cancellation, hold, stop-work, or similar notice at any time applicable to any unshipped portion of any order not involving a special or custom product, and such notice will be accepted by BURLE subject to the following conditions:

(A) Any hold, stop-work, or similar notice shall be treated as a cancellation notice if and when, in the opinion of BURLE, circumstances warrant such treatment;

(B) Customer pays a cancellation charge specified by BURLE which shall include adjustment of the billing price to BURLE's established price applicable to the quantity actually delivered, and may include, among other things, all costs, both direct and indirect, incurred and committed for with a reasonable allowance for prorated expenses; and

(C) BURLE will be under no further obligation with respect to filling the order against which such notice applies.

10. FORCE MAJEURE

BURLE shall not be under any liability whatsoever to the Customer for non-delivery or delay in delivery directly or indirectly caused by unforeseen circumstances or resulting from an Act of God, outbreak of hostilities (whether or not war is declared), insurrection, riot, civil disturbance, Government Act or regulation, fire, flood, explosion, production delays, accident, theft, climatic conditions, shortage of material, strike, lockout or trade dispute (whether BURLE's or another party's employees) or other cause beyond BURLE's reasonable control. In the event of any deliveries being suspended or delayed on account of any such aforementioned event or circumstances the period of the contract shall be correspondingly extended or, if deliveries are suspended for six months or more, BURLE may at its option, exercisable by notice in writing to the Customer, cancel the contract with respect to any undelivered goods without liability upon BURLE and without relieving the Customer of its obligation to pay for any goods which have been delivered.

11. SECURITY INTEREST

BURLE reserves a security interest in the goods sold hereunder and in proceeds thereof to secure payment of the purchase price.

12. CUSTOMER'S SOLVENCY

A Customer's order shall constitute a representation that the Customer is solvent, and BURLE is relying upon such representation. If BURLE at any time reasonably believes that the Customer is insolvent or that the Customer's credit is impaired, the Customer shall be in material breach hereof and BURLE may, without liability to the Customer, withhold performance hereunder, change the payment terms including without limitation declaring all amounts to be immediately due and payable, and/or repossess goods previously delivered.

13. BURLE'S DAMAGES

If Customer wrongfully rejects or revokes acceptance of goods covered hereby, or fails to make any payment when due, or repudiates this order, BURLE shall have all the rights and remedies provided by law and, without limitation of the foregoing, may recover as damages, where permitted by applicable law, the price including a late payment or interest charge from due date at one and one-half percent (1-1/2%) per month on the unpaid balance, but not to exceed the maximum rate of interest permitted and any costs of collection, including reasonable attorneys' fees. As to all partially manufactured goods, BURLE may, at its option complete their manufacture, and hold Customer responsible for their price. Upon recovery of the price, goods shall become the property of the Customer.

14. CUSTOMER'S RIGHT TO SPECIFIC PERFORMANCE

In the event of any failure by BURLE to deliver the goods covered hereby, the Customer shall have the right to such specific performance only after diligent efforts to obtain substitute goods.

15. GENERAL

(A) No addition to, deletion from, or modification of any of the provisions of these Terms and Conditions of Sale shall be binding upon BURLE, unless made in writing and signed by a duly authorized signer of BURLE. Oral statements, warranties, or representations made by any agent or employee or representative of BURLE are not authorized by BURLE and shall be of no force or effect.

(B) These Terms and Conditions of Sale are the final, complete and exclusive statement of the terms of the agreement between BURLE and the Customer. ANY DIFFERENT OR ADDITIONAL TERMS PROPOSED BY CUSTOMER ARE OBJECTED TO AND HEREBY REJECTED.

(C) A waiver by BURLE of any default by the Customer or of any of these Terms and Conditions of Sale shall not be deemed to be a continuing waiver or a waiver of any other default or of any other of these Terms and Conditions of Sale, but shall apply solely to the instance to which the waiver is directed.

(D) This agreement may not be assigned by Customer without BURLE's written consent.

(E) These Terms and Conditions of Sale shall be construed in accordance with the laws of the Commonwealth of Pennsylvania, USA, including where otherwise applicable the United Nations Convention on Contracts for the International Sale of Goods. In the event of any inconsistency between the terms hereof and the provisions of such Convention, the terms hereof shall prevail.

(F) Any claims arising hereunder by either party shall be brought in an appropriate court of general jurisdiction in the Commonwealth of Pennsylvania, USA, and the Customer irrevocably accepts the jurisdiction of such courts and consents to service of process by registered or certified mail at its address as it appears on the reverse side hereof or any attachment hereto.

16. TRANSPORTATION FOR NORTH AMERICAN ORDERS

(A) All sales are made F.O.B. at BURLE's plant in Lancaster, Pennsylvania, USA, transportation at Customer's expense, with title and risk of loss passing to the Customer at the plant.

(B) In the event BURLE pays transportation and insurance beyond the point of shipment to the destination specified by the Customer, all such costs will be billed as a separate item on the invoice.

17. TRANSPORTATION FOR INTERNATIONAL ORDERS

(A) The terms "F.O.B.", "F.A.S.", "C.I.F." and/or "C&F", as used herein or on the reverse side hereof or any attachment hereto, shall be defined in accordance with "Incoterms" published by the International Chamber of Commerce.

(B) All sales are F.O.B. Lancaster, Pennsylvania, USA. Transportation from this point and consular and brokers' fees shall be at Customer's expense. Title to and risk of loss of the items included in each shipment will pass to the Customer upon delivery to the carrier at the plant.

(C) All shipments normally will be made via the most economical method and routing consistent with service requirements as selected by BURLE.

(D) In the event BURLE pays transportation and insurance beyond the point of shipment to the destination specified by the Customer, all such costs will be billed as a separate item on the invoice.

18. PAYMENT TERMS FOR INTERNATIONAL ORDERS

Payment for the products specified by the Customer's order shall be made in U.S. Dollars, through the medium of an irrevocable Letter of Credit in favor of BURLE, 1000 New Holland Avenue, Lancaster, PA 17601-5688, USA, Attn: Credit Department, confirmed by a bank located in the United States acceptable to BURLE. Unless otherwise agreed, such Letter of Credit shall be valid for a period of time sufficient to enable BURLE to receive payment in full plus thirty days, shall be for the total price of the product, including any applicable transportation and insurance costs, and in a form acceptable to BURLE, and shall authorize partial payments against partial deliveries. The Letter of Credit shall provide for payment(s) to BURLE at sight upon presentation to the confirming bank of BURLE's sight draft(s) on the confirming bank for one hundred percent of the invoice value of each delivery, accompanied by commercial invoice(s) or by shipping documents.

The Letter of Credit shall permit shipment and shall permit presentation of non-negotiable copies of bills of lading provided they are accompanied by BURLE's declaration that the originals have been mailed directly to the opening bank. All bank charges in connection with said Letter of Credit including those of the confirming bank, shall be for the account of the Customer.

Other payment terms may be negotiated between BURLE and the Customer, in which case such special payment terms shall be specified in writing and become a part of the sale agreement.

19. UNITED STATES EXPORT LAWS

(A) BURLE's obligations are subject to the export administration and control laws and regulations of the United States. The Customer shall comply fully with such laws and regulations in the export, resale or disposition of products.

(B) Quotations or proposals made, and any orders accepted by BURLE from customers outside the United States are with the understanding that the ultimate destination of the product is the country indicated therein. Diversion of the product to any other destination contrary to United States law is prohibited. Accordingly, if the foregoing understanding is incorrect or if the Customers intend to divert the product to any other destination, the Customer shall immediately inform BURLE of the correct ultimate destination.

EOI materials