The deliverable would consist of:

- Conceptual design layouts that result from the design and analysis efforts.
- Requirements, specification, and procedures developed as part of the effort.
- Conceptual and preliminary engineering analysis, summaries, and conclusions that result from finite element and classical analyses.
- Input to a final report.

Present anticipated funding for fiscal year 1991 for the above effort is $591K.

Travel	$ 26.0K
Designer	$ 35.2K
Meetings, Reports, Etc. Designer Sr. Level	$ 88.7K
Engineering Design	$441.5K

Since this program is in its early stages and many unknowns still remain, this Statement of Work and its associated deliverables and estimated costs must be considered on a level of effort basis. It is believed, that based on an engineering appraisement, that the deliverables can be achieved within the projected costs.

APPENDIX IX

STATEMENT OF WORK FOR WESTINGHOUSE CALORIMETER SUBSYSTEM ELECTRONIC SIGNAL PROCESSING FY91 TASKS

Task 1 Fiber Optic Link Design - to be proposed at a later date

The large number of elements within the scintillator tile-fiber calorimeter, the high interaction rate, and the calorimeter environment pose severe challenges for extracting data from the calorimeter front-end electronics. Digital transmission of data over optical fiber offers significant advantages in terms of noise immunity, electrical isolation, and high speeds.

The objective of this task is to specify, design, and develop a high speed fiber optic data link between the calorimeter front-end electronics (analog storage and digital conversion) and the global data-handling system. Specific subtasks include:

1.1 Complete a functional design specfication for the fiber optic data link based upon the capabilities of the front-end data storage and conversion ronics, the proposed triggering schemes, and the availability of economical fiber optic components.

1.2 Complete the design of a fiber optic link which meets the specfication requirements.

1.3 Fabricate, test and debug a prototype fiber optic link.

1.4 Assist in the evaluation of the fiber optic link using the FY91 test beam calorimeter electronics.

Task 2 Instrumentation for EM Prototypes

The electronic collaborators for the scintillator tile-fiber calorimeter subsystem have identified three front-end systems which will be evaluated during the FY91 test beam. The three electronic systems include: 1) a "standard" system consisting of existing commercial modules; 2) analog storage and conversion electronics being develop at ANL; and 3) the use of analog storage devices being developed at LBL.

The objective of this task is to complete the design, development, and fabrication of an analog storage instrumentation module which uses the LBL switched capacitor storage chip. In addition, assistance will be provided in the test of the instrumentation module during the calorimeter beam tests during FY91. Specific subtasks include:

2.1 Complete the design of an analog storage module utilizing the LBL integrated circuit.

2.2 Fabricate, test, and debug a prototype instrumentation module.

2.3 Assist in the test and evaluation of the performance of the instrumentation electronics.

6 September 1990

Progress Report on Work Done in FY90 and Request for FY91 Funding for Research and Development of a Liquid Argon Calorimeter Collaboration for the SSC

G.S. Abrams,[8] K. Amako,[7] A.R. Baden,[10] J. Bakken,[9] T. Bowen,[1] T. Burnett,[17] V. Cook,[17] L. Cremaldi,[12] R. Davisson,[17] N. DiGiacomo,[9] P. Draper,[14] J. Faust,[6] T. Ferbel,[14] D. Fong,[10] G. Forden,[1] T.A. Gabriel,[13] J. Goodman,[10] H.A. Gordon,[2*] D.E. Groom,[8] N. Hadley,[10] T. Handler,[15] J. Hauptman,[6] D. Hitlin,[3] O. Inaba,[7] E. Jenkins,[1] K. Johns,[1] F. Kirsten,[8] T. Kondo,[7] S. Kunori,[10] M. Levi,[8] F. Lobkowicz,[14] H. Ma,[2] L. Mason,[9] P. Mockett,[17] G.T. Mulholland,[4] M.J. Murtagh,[2] M. Pang,[6] V. Radeka,[2] D. Rahm,[2] J. Reidy,[12] S. Rescia,[2] J. Rothberg,[17] J. Rutherfoord,[1] M. Shupe,[1] J. Siegrist,[8] A. Skuja,[10] R.V. Steiner,[18] D. Summers,[12] Y. Watanabe,[16] H. Weerts,[11] R.W. Williams,[17] J. Womersley[5]

[1] University of Arizona, Tucson, AZ 85721
[2] Brookhaven National Laboratory, Upton, NY 11973
[3] California Institute of Technology, Pasadena, CA 91125
[4] Fermilab, Batavia, IL 60510
[5] Florida State University, Tallahassee, FL 32306-3016
[6] Iowa State University, Ames, IA 50011
[7] KEK, Tsukuba-shi, Ibaraki-Ken, Japan
[8] Lawrence Berkeley Laboratory, Berkeley, CA 94720
[9] Martin Marietta Astonautics, Denver, CO 80201
[10] University of Maryland, College Park, MD 20742
[11] Michigan State University, East Lansing, MI 48824-1116
[12] University of Mississippi, University, MS 38677
[13] Oak Ridge National Laboratory, Oak Ridge, TN 37831-6369
[14] University of Rochester, Rochester, NY 14627
[15] University of Tennessee, Knoxville, TN 37996-1200
[16] Tokyo Institute of Technology, Tokyo 152, JAPAN
[17] University of Washington, Seattle, WA 98195
[18] Adelphi University, NY

* Contact - 516-282-3740, bnlcl6::gordonh, gordonh@bnlcl1, FAX 516-282-5568

Brookhaven National Laboratory - Progress Report FY90
(H.A. Gordon, H. Ma, M.J. Murtagh, V. Radeka, D. Rahm, S. Rescia)

This work is building on the data and experience of the NA34(HELIOS) calorimeter which measured $e/\pi \sim 1.1$ with uranium absorber and 100 ns shaping time. For an SSC detector, the use of uranium may prove to be too costly, so it would be useful to make an accurate measurement of the performance of a lead liquid argon calorimeter. Some EGS studies by our collaborators from the University of Washington have suggested that e/π will more nearly equal one if a 12 mm lead plate is used instead of a 6 mm plate. We have designed a stack 100 cm × 100 cm with a depth of 7.5 λ following closely the HELIOS design. The stack is segmented transversely into 40 (2.5 cm) X strips alternated with 40 (2.5 cm) Y strips and divided longitudinally into 3 sections. Each unit cell will consist of 1 lead plate followed by a 2 mm argon gap followed by a 1.6 mm G10 printed circuit signal board and then another 2 mm argon gap. The interleaving of the X and Y strips in depth provides information about the transverse profile of the shower and a direct measurement of the sampling fluctuations. The connection scheme will follow closely the HELIOS method of achieving low-inductance charge transfer to the preamplifiers. The preamplifiers will be the same type that were used in HELIOS which operated in the liquid argon.

Although we followed the HELIOS design, many details needed to be changed. We tried to keep all aspects of the design under control so that the measurement of e/π would not have contributions of more than 1% from any systematics. For example we needed an array of 16 tie rods to hold the stack together. We calculated that with the diameter of rods required, the energy loss in the dead regions of the tie rods would not affect the total energy. The printed circuit boards that gang the strips together longitudinally were longer than in the HELIOS case and we needed to calculate that this would not introduce any timing problems. We worked closely with our collaborators from the University of Washington who are building the cryostat into which these modules will be placed. We have designed and will fabricate the structure that will move the modules into the cryostat as well as the mounting of the cryostat in the AGS hall. We need to be able to move the cryostat transversely to the beam. We designed and will procure all the necessary cryogenic plumbing for the cryostat including the cooling, filling and control systems, as well as the purity monitoring.

We will expose the stack to a beam of electrons and π's at the AGS with momentum in the range from 0.5 GeV/c to > 20 GeV/c. The intensity of the beam can be as high as 10^7 particles/sec. This will allow the study of pileup effects directly. We plan to do these beam tests in 1991. We requested a beam from the AGS which would allow this measurement. We were assigned the A3 line. An enormous amount of work is in progress in changing this beam line from a neutral K^0 line to a charged particle beam. We have coordinated this effort.

The electronics external to the cryostat also follows the HELIOS chain however in almost every case a new design was done for this SSC project. First there is an intermediate amplifier attached to the outside wall of the cryostat, very close to the signal feedthroughs. A good electrical and mechanical connection between the vessel and the intermediate amplifier housing defines a Faraday cage. The output of the intermediate amplifier drives a balanced line using a transformer which connects to a variable gain amplifier. These amplifiers are adjusted to a fraction of a percent using the results of the calibration system. Each channel can be adjusted separately so that the contribution to an analog energy sum is equalized. Each channel can also be turned off to measure the cross-talk. These variable gain amplifiers were realized by designing the largest hybrid circuit ever made at BNL. This hybrid has been prototyped and tested and is now in production. Fast sums of all the channels are made with separate shaping amplifiers. These will be built with shaping times of 50, 100, and 200 ns in order to measure the variation of e/π as a function shaping time.

In addition, we are pursuing extensions and modifications to the HELIOS scheme. This is needed for the colliding beam environment since one needs to put modules together with as little dead space as possible. However, the HELIOS scheme achieves the low inductance longitudinal ganging in the space at the side of the stack. This is fine for a fixed target experiment like HELIOS, but would lead to severe problems in an SSC experiment. We have participated with Annecy, CERN, Orsay, and Milan in the test of a novel structure of electrodes called the "accordion." This idea allows a more natural way for the longitudinal summing of the signal in the calorimeter while preserving the low inductance. It also offers the possibility of a fully active calorimeter with minimal cracks. A successful beam test of this structure was done at CERN this summer. Only preliminary "on-line" results are available now and although they may improve, we quote two numbers to show how promising this technique is. The electromagnetic resolution ($\frac{\sigma}{E}$) measured for 125 GeV e's is 1%. The signal to noise for minimum ionizing tracks is 30 : 1.

Brookhaven Plans for FY91

We need to continue the establishment of the A3 line as a charged particle beam. Funds are needed for rigging, carpentry, electrical and mechanical work to install two new quadrupoles as well as the shielding for the beam ($80k).

We need funds for the support of the operating costs of the beam: the liquid argon, the liquid nitrogen, tapes etc. ($50k).

In our SSC Major Subsystem Proposal of Oct. 2, 1989, we proposed to study e/π for several configurations of lead stacks. We have done EGS studies which show that cladding the lead with thin iron sheets should suppress e/π even further. We will build such a stack keeping the same overall dimensions as the current stack to allow the summing boards, preamps and cables. We will build this so that a quick switch of the stacks can be made during the 1991 run($150k).

We propose to continue the study of details of how to make a liquid argon calorimeter for the SSC. For example we will study in a detailed engineering design an idea for making modules which have no projective cracks and so have excellent hermeticity($75K). We will continue our collaboration with our European colleagues from CERN-Orsay-Annecy-Milan in the development of the accordion calorimeter ($20k). We will provide electrical and mechanical engineering support for the Martin Marietta work on cooling preamps in the liquid argon as well as the development of signal feedthroughs($70K).

There are many elements of the BNL generic SSC detector R&D program which will now naturally be included in this subsystem proposal. First we will support the continued development of the ISAJET Monte Carlo program especially as it relates to calorimeter problems($100k). We will study the radiation damage to components used in liquid argon calorimeters - especially the electronics ($100k). Some studies of radiation effects are suggested in the subsystem project on Front End Electronics.

We will continue the productive research into the readout methods for fast calorimetry ($86k). This includes a study of all the questions related to the charge transfer from the electrodes into the preamplifier, electrode configurations and their effect on the time dispersion of the signal. This effort includes also the collaboration with the University of Pittsburgh (W. Cleland's group) in the studies of pileup and optimum pulse shaping.

Some specific circuit development work (preamplifiers, summing and pulse shaping amplifiers, calibration) are part of the subsystems project on Front End Electronics for SSC Detectors. The efforts in these two projects are complementary.

University of Rochester - Progress Report FY90

(Drs. F. Lobkowicz, J. Ftacnik; Messrs. G. Osborne, I. Horvath)

The task is to prove (or disprove) the suitability of Liquid Argon Calorimetry (LAC) as a medium of choice for any SSC general detector, whether with magnetic field inner tracking or not.

One of the outstanding problems is the achievable energy resolution at high energies, which is governed by the "e/h ratio". We are participating in the preparation of a lead-LAr test calorimeter to study this problem and will participate also in the data taking and analysis next fiscal year. We are also supplying some of the components. Comparison of this test detector with the HELIOS detector, which uses U-LAr, will determine how far one can trust Monte Carlo predictions of calorimeter behavior. The test stack is being built at BNL, and our group is actively engaged in the construction and assembly. This requires frequent trips to BNL by F.L., and we have two Rochester graduate student working on the design and assembly during the summer.

Another problem being investigated at Rochester is how to achieve a fast readout of the LAr signals. Intrinsically LAr is a slow device; it takes 400 nsec to collect the whole charge in a 2 mm gap. A fast readout requires transformer coupling of the signal and amplifiers inside the cold liquid. One has to take great care to minimize inductances, so that the accumulated charge can be brought out in a few tens of nsec. Up to the transformer, impedances are of the order of a 1–2 Ω, and care has to be taken to minimize stray inductances. From the transformer to the charge sensitive amplifier the apparent detector capacitance is reduced by a factor N^2 (N=transformer secondary/primary ratio) and the typical impedances are of the order of a few hundred ohms. Nevertheless, the charge integrating preamplifiers should be near the electrodes (inside the liquid argon); otherwise the capacitance of the line after the transformer will increase the overall noise.

The HELIOS experiment provides an existence proof that such a fast readout of a LAr calorimeter with "cold" preamplifiers is possible. However, its readout units are strips which extend to the edge of the detector, and so all connections, transformers, amplifiers, etc., can be at the side of the module where there is plenty of space. In a 4π calorimeter the gaps between the modules should be minimized and the amplifiers have to be behind the calorimeter modules (or possibly in front). One has to design — and build prototypes of — a readout scheme for a pad structure which satisfies the conditions that

(i) it has a low impedance of a few ohms;

(ii) it takes up a minimum of space;

(iii) it can be mass produced reliably and at reasonable cost.

At this stage it is too early to decide how to arrange the whole stack of absorber, pads, LAr, etc., of a single tower; we assume for the moment an average tower size of $\Delta\eta\Delta\phi = 0.03 \times 0.03$, and a LAr gap size of 2.0 mm. If uranium is used, there are likely to be 2 such gaps for each 4 mm uranium layer, with the readout pads being G-10. If lead is to be used, a reasonable arrangement is a single 2.0 mm gap for each 6 mm of absorber material. Since we cannot yet know which system is the best, we have to study the readout scheme in a way which will accommodate all these options. Indeed, it may well be that the electrical characteristics will make one scheme preferable to another.

We have built room temperature table-top "models" of several fundamental types of towers, designing and testing the readout characteristics. The "ionization current" in such a setup can be simulated by injecting the current using a CMOS FET. Electrically, such a model should be an exact replica of a section of the actual detector. We are comparing measured rise times and ringing amplitudes with calculations (SPICE) using the assumed circuit characteristics. We have found that one has to be very careful in including all connector and other stray inductances if one wants to reproduce the measured values. We are by now beginning to get agreement between calculations and experiment.

Ferrite transformers saturate and become useless in a magnetic field ($> 0.02\,T$). Thus one also has to investigate whether and how one can shield the transformers in the neighborhood of a coil which has a central field of 2 Tesla. The Rochester group has studied and tested various shielding systems, and checked the behavior of transformers and shields at low temperatures. The conclusion so far is that one can shield transformers against an ambient field of 0.7 Tesla and maybe a bit more, but that it is impossible to shield against an ambient field above 1 Tesla. The reason is that magnetic shielding material (of high permeability) not only shunts the fieldlines around an inside cavity, but also attracts field lines on the outside; thus the field at the surface of an iron cylinder in a transverse field will be twice the field at infinity.

This shielding is adequate for the SDC calorimeter if the "short coil option" of a 2 T central field is chosen for the tracking solenoid. Such a coil — essentially a free standing coil with the return flux yoke very far away — has a large leakage field. Nevertheless, with the present SDC design the field is $< 0.7\,T$ everywhere where there are calorimeter modules, and the field exceeds 0.5 T only in a very small region of the Electromagnetic section of the forward calorimeter. A detailed report of these studies is being prepared for the SDC collaboration meeting.

The problem of transformer shielding becomes easier if one can build smaller transformers. We have tested various pulse transformer materials and built prototype transformers of varying sizes. The original HELIOS transformers were wound on 0.5″ diameter toroids out of a PHILIPS 3D3 material (a MnZn ferrite material): we have not found any material which is better if one asks for high permeability at low temperatures and good high frequency behavior. We have succeeded in building adequate transformers on slightly smaller cores (0.375″); however, the smaller the transformer, the higher are the inductive losses due to wiring size and other "imperfections"; we are by now convinced that 0.35″ or so is the ultimate lower limit for building low loss transformers. One should note that any transformer imperfection either makes the transformer look inductive (thus introducing ringing or lengthening rise times) and/or increases the transformer associated noise (stray capacitance, eddy currents etc have such effects).

Even with cold preamplifiers in the LAr one requires signal feedthrus which match the output impedance of the preamplifiers. Some 1.6×10^5 50Ω or 100Ω signals will have to be led out the LAr into room temperature lines for the central detector alone. Let us assume for the moment that these signals are to be fed 2000 at a time through a 17-cm inside diameter tube as described in the Martin-Marietta design study. (We disregard here for the moment that with the proposed $\Delta\eta\Delta\phi = 0.04 \times 0.04$ transverse segmentation, with only two depth segmentations, the capacitance/channel may be too large.) The number of channels thus may have to increase from the number assumed in the Martin-Marietta design.

Originally Rochester committed itself to working on the feedthru problem, and to design and possibly build a prototype, as well as to study its electrical and heat transfer properties. This part of the overall project had to be abandoned when our funding was cut way below our initial request.

In summary, our experience in E706 and D0 has convinced us that LAr calorimetry is a good candidate for both a magnetic (SDC) and a non-magnetic (EMPACT) general detector at the SSC. In collaboration with BNL and other universities we are proceeding to develop and test prototypes. One of the crucial problems — that of shielding transformers in an ambient field — has been solved. Another one — how to design modules for a fast readout with minimum loss in hermeticity — is quite far along. The third main problem — the e/h ratio — awaits tests to be done next fiscal year.

Our plans for next year are basically continuing and finishing the present studies. One of the main jobs will be the test calorimeter whose performance will have to be measured and analyzed during next fiscal year. But there are further studies to be made on transformer design as well as on designing a calorimeter module arrangement which will allow fast readout. One should note that the following problems in designing a module are closely interconnected and must all be solved simultaneously:

(i) mechanical problems of supporting absorber and readout planes, transformers, preamplifiers etc., including allowing sufficient mechanical tolerances;
(ii) electrical problems in that very low impedances must connect the individual pad to the transformer – this requires specially designed connectors;
(iii) transformer design and transformer shielding in a magnetic field – the magnetic field problem;
(iv) cooling the preamplifier and "cryogenic shielding" of the actual calorimeter module from possible bubbles created by heat dissipation of the preamplifiers;
(v) cable arrangement from the preamplifiers to the outside world;
(vi) distribution of power, calibration signals, etc.

BUDGET FOR FY 1991 - U. of Rochester

This is the present plan for Rochester R&D for next year:	
Salaries – 1 graduate student	
+1 Postdoc ((J. FTACNIK COMING IN JANUARY)	$39.9 k
Fringe benefits	5.2
Travel	13
Subcontracts (Housing at BNL, shop BNL)	8.4
Postage, publications, duplication	2.3
Telephone	0.6
Materials and supplies	3.0
Indirect cost	17.6
Shop services #	40
Capital equipment - Apparatus #	50
# means no indirect assessed	
Total	$180.0 k

Justification for the individual items:

1) The postdoc and the graduate student would be working on the beam test and its analysis. The test would be the thesis subject of the student.
2) Travel and housing (subcontract) will be needed for me and the two other physicists
3) Capital equipment: In order to evaluate transformer manufacture, readout schemes for SSC calorimetry, etc, we need some better equipment than what is presently at our disposal.
   (i) a good LCR measurement device (including losses, frequency dependence)
   A Hewlett-Packard unit costs $28 k
   (ii) A frequency analyzer approx $12 k
   (iii) readout board prototypes $10 k (these are counted as cap. equipment)
4) Shop services will be needed to design, build and test readout prototypes for pad structures, as well as real transformer shields. The rest are small matters - the price which I have to pay for operating within the DOE contract.

University of Maryland - Progress Report FY90

(Professors N. Hadley, A. Skuja, J. Goodman, A.R. Baden, Dr. D. Fong, and one undergraduate)

Maryland is responsible for providing instrumentation for the test beam. This instrumentation includes Cerenkov counters for particle identification as well as scintillator (or scintillating fiber) hodoscopes and veto counters for triggering and beam definition. We are also responsible for the data acquisition system and the setup of the trigger electronics and logic along with BNL and Iowa State.

To date this year, we have acquired on loan one ancient Cerenkov counter which we are modifying and refurbishing for the needs of the beam test. We have designed an extension to the counter so that the length of the radiator will be three meters. We are currently engineering new beam exit and entrance windows for this counter. Within the next two months, we hope to borrow yet another counter and to start modifying it as well. We note that both counters must operate at reduced pressure in order to give good e/π separation at the higher (10 GeV) beam momenta. We have acquired samples of scintillating fibers and tested their light output and attenuation length. From our experience in similar test beams for the *DØ* experiment good beamline instrumentation is essential for understanding calorimeter performance.

We have acquired the necessary data acquisition software from Fermilab and are in the process of installing it on a μVAX located at Maryland. We specified the computer needed for data acquisition and it has been ordered by Brookhaven National Laboratory. We have secured a loan of a Jorway branch driver from Professor Zeller's group at Yale University and it is now in transit to Maryland. We plan to bring up the DAQ system here on the microvax here at Maryland and then to transfer it to the dedicated DAQ computer at BNL in the fall.

In the coming year we will complete the construction or acquisition of the beam hodoscopes and veto counters. We will complete the beam Cerenkov counters and ship them to BNL. We plan to participate actively in the setup of the testbeam at BNL and in the analysis of the test beam data, as we have done for test beam data from the *DØ* liquid argon calorimeter. We are requesting $45,000 in operating funds for technicians to complete the construction of the beamline instrumentation and to install it and the trigger system at Brookhaven. These funds will also cover our travel to Brookhaven both during beam setup and data taking. We are also requesting $15,000 in construction funds to pay for the beam hodoscopes, shop time for refurbishing the Cerenkov counters and the necessary phototubes, flanges and gas system.

BUDGET FOR EQUIPMENT FUNDS for FY91 - U. of Maryland

Equipment to construct beam line hodoscopes and refurbish Cerenkov counters includes camacs, phototubes, scintillator and mechanical parts	$15,000

BUDGET FOR OPERATING FUNDS for FY91

1 Salary Items	
1 Part-Time Technician and	$30,000
1 Part-Time Engineer	
Travel for Installation of the Beamline	$15,000
Instrumentation and Data Acquisition System at	
the Brookhaven National Lab and travel for data taking	
Indirect Costs (46% on Campus)	$20,700
Total	$65,700

Lawrence Berkeley Laboratory - Progress Report FY90

(G. Abrams, D. Groom, C. Hearty, M. Levi)

I. Progress and Results in FY90

With the funds allocated in FY90, our goals had to be curtailed severely to allow significant progress. With the SSC schedule in mind, we chose to push the demonstration of fast signal readout from a LAr chamber ganged as an electrostatic transformer. Using cosmic rays, we wished to establish a proof-of-principle measurement that provided convincing evidence that the method does indeed work, and that the electrostatic transformer is a viable alternative to the more conventional magnetic transformer.

The first part of our task was to assemble a low noise front end, amplifier and data acquisition system. The low noise preamp selected, the AMPTEK A250 with a 2SK147 FET, was a suitable choice. Fig. 1 shows the characteristic impedance of the preamp as function of frequency. It may be seen that the preamp acts like 50 ohms in the frequency range of interest. This preamp can thus be used as proper termination to 50Ω cable.

We next proceeded to demonstrate that a fast signal can be collected from a detector of reasonably large capacitance, even if a long cable hangs between the capacitor and the preamp. Fig. 2 shows the A250 response to a step function input, with the charge injected by a pulse generator onto a 400 pF capacitor and driven through 105′ of 50 Ω cable. The RC response of this system is expected to be

$$\tau = Z_{\text{cable}} \times C_{\text{Det}} = 20 \text{ ns}.$$

The 35–40 ns rise time indicated by Fig. 2 is consistent with this analysis. The small glitch seen several hundred ns after the leading edge is due to the imperfect match of the impedances of the cable and preamp.

With these ingredients in place, we proceeded to demonstrate that a minimum ionizing signal could be measured with suitably low noise and with fast shaping. A tower electrically connected as an $n = 5$ electrostatic transformer was built and tested in a LAr dewar using cosmic rays to deposit minimum ionizing energy uniformly through the stack. We were able to establish (to the ±20% level) that the charge collected in fast shaping (170 ns was the fastest peaking time that our electronics allowed) is consistent with that expected. The data in Fig. 3 show a large enough signal-to-noise ratio to establish convincingly the soundness of the electrostatic transformer principle.

For our purposes at the SSC, the noise performance of the system assembled is by no means adequate. The figure of merit for the noise performance, R_s, the equivalent series noise resistance, is related to the "equivalent noise charge" (ENC) by the expression

$$\overline{ENC^2} \propto kTR_s ,$$

where k is the Boltzman constant and T is temperature.

In our tests to date, we have achieved a value of 1 Ω for R_s by massively paralleling FETs at the front end of the A250. Explicitly, 11 2SK152 transistors were stacked (in parallel), and a step pulse injected: the width of the observed distribution (amplified by an Ortec 450 shaper integrating for 100 ns) was consistent with our desired low noise. This is an obviously kludged solution, but one which indicates that our goal is realizable.

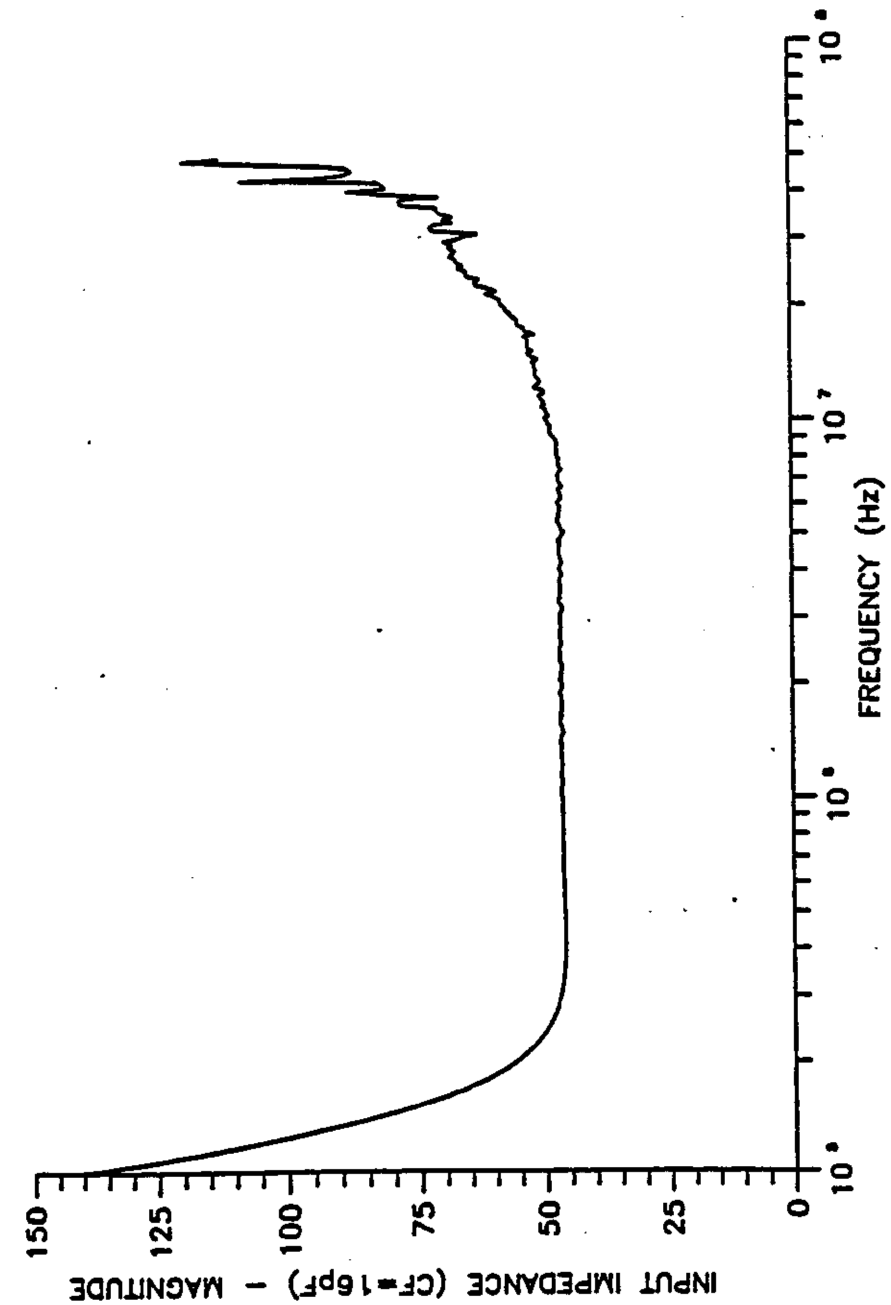
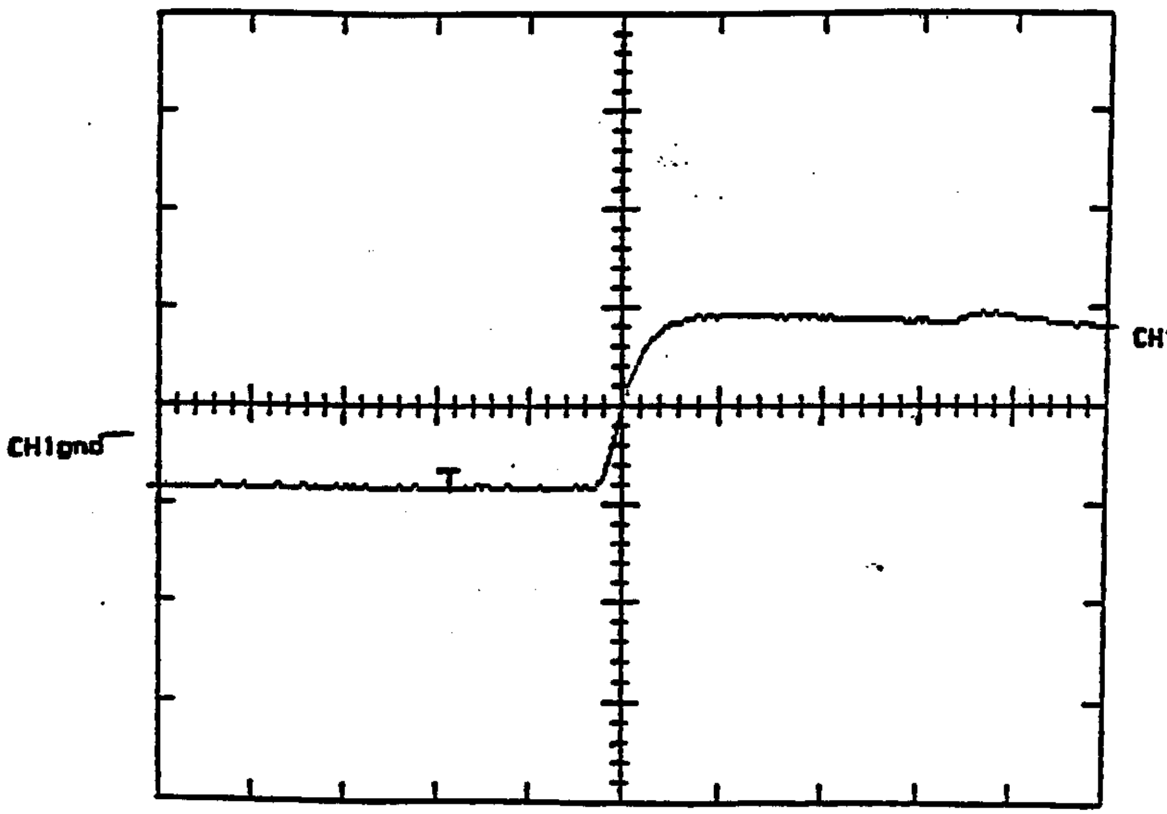


Fig. 1 Impedance of preamp as a function of frequency

Rise-time response for
Capacitive load of 390 pF
105' of 50Ω cable
Preamp (≈) terminated in 50Ω

500 mV/div



100 ns/div

Fig. 2 Response of A250 preamp to a step function via a long cable (see text).

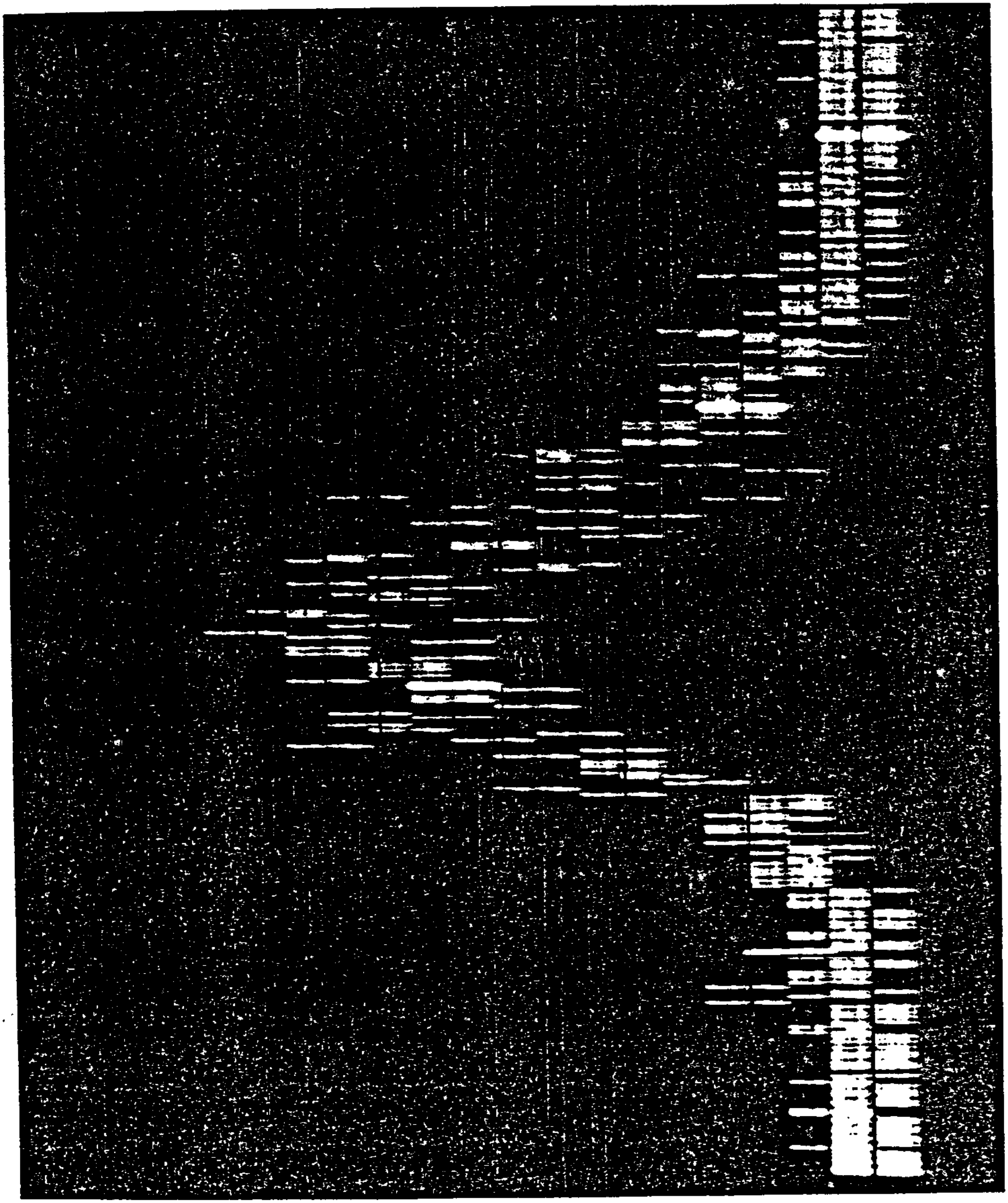


Fig. 3 Signal from minimum ionizing particle through stack.

II. Test Beam Prototype Module

We propose to continue the R&D path leading to a fast readout of the Liquid Argon signals via the electrostatic transformer. At this time there is still no viable way to read out a fast, low-noise signal in the presence of a magnetic field larger than 0.7 T. In larger fields, such as those encountered in the endcap region of the Solenoidal Detector, magnetic transformers (even if shielded) saturate and are rendered useless. The electrostatic transformer conceptually can realize the desired fast readout; however the concept needs a realistic proof-of-principle test in a beam to establish that the real-life degradation of the system performance can be held to an acceptable minimum.

The overall goal in FY91 is the production and testing (in an electron beam) of a prototype SSC Calorimeter. This prototype is expected to deal with the signal-to-noise (and speed of response) issues at a level to satisfy SDC requirements. Since compensation and related hadronic response issues will be addressed in the BNL beam test of Spring, 1991, the prototype will be built to fully contain an electromagnetic shower. With such a unit, speed of response, energy resolution, cross-talk, uniformity, *etc.* will be measured. It will be designed so that it fits into the Univ. of Washington cryostat being built for the BNL beam test. The goal is to test this prototype in conjunction with the BNL test module during the Spring cycle.

For definiteness the channels will be chosen to be typical of the size desired for the innermost hadronic modules : one interaction length deep and 12 cm by 12 cm wide, with nine such channels placed in a square array. The preamps (see above) will be mounted outside the cryostat, connected to the stack *via* a 4 m cable (probably 50 Ω). The signals then enter the same data stream (amplifiers, DAQ) as for the BNL beam test module.

III. Electronics R&D

At LBL we wish to continue to pursue an electrical design which allows the low level electronics (the preamps) to be located outside of the LAr cryostat (see above). A complementary program of preamp development is required to realize the low noise specifications for the SSC.

Several steps must be taken to make this low noise solution practical. Preamp development to take advantage of possible large power input and large physical size (both allowed if the preamp is not constrained to be in the LAr) is necessary. Further, the removal of the preamps to the outside also allows a solution that is no longer constrained to be radiation hardened. We must also push the technology to as low an R_s as possible, to gain not only a safety margin but also the ability to reduce the shaping time of the amplifier (so that pileup is reduced).

The goal is to produce a sufficient number (≈ 12) of low noise preamps (specified to have $R_s < 0.5\,\Omega$) so that the test beam prototype described above is read out by a realistic system that matches SSC specifications.

Funding Requirements (Equipment $) for FY91 - LBL

Item	Amount
1/4 ME	27K
1/4 Mech Designer	19
1 EE	103
1 Elec Tech	59
Layout time	15
Hybrid fab	20
Commercial NIM units, crate	16
P.C. board fab	10
Parts and supplies	45
Shops	50
Total	364K

Expected effort level (physicists) for FY91 :

G. Abrams	0.8
C. Hearty	0.6
M.Levi	0.05

Oak Ridge National Laboratory - Progress Report FY90

(R.G. Alsmiller, Jr.*, C.Y. Fu, and T.A. Gabriel*)

University of Tennessee - Progress Report FY90

(T. Handler)

University of Mississippi - Progress Report FY90

(L. Cremaldi, J. Reidy)

ABSTRACT

During the past several months, Tennessee, Mississippi, and the Oak Ridge National Laboratory have been coordinating efforts to benchmark the CALOR89 code system against the *D0* and HELIOS prototype calorimeter data, and to use the CALOR89 system to generate currently needed data for radiation damage studies, signal collection time, and compensation characteristics of various calorimeter designs. This report describes these results and gives our plans and projected budgets for the following year.

I. Introduction

A strong experimental Superconducting Super Collider (SSC) calorimeter development program must involve a substantial calculational analysis of the proposed detector system. The CALOR89[1] code system offers a solid approach for investigating all facets of calorimeter systems. Due to financial constraints, only a few prototypes can be built and tested. The remainder of the studies must be analytical. Once the calculated results have been shown to agree with the test data, a much wider variation of the design can be investigated. This approach is being followed in our subsystem research.

* Coordinators

During these several months, Tennessee, Mississippi, and the Oak Ridge National Laboratory have been coordinating efforts to benchmark the CALOR89 code system against the *DØ*[2] and HELIOS[3] prototype calorimeter data, and to use the CALOR89 system to generate currently needed data for radiation damage studies, signal collection time, and compensation characteristics of various calorimeter designs. Even though the total benchmarking of the *DØ* and HELIOS data has not been completed, the current caliber of the code is such that preliminary data generated will certainly be adequate for initial design studies. This report describes current progress and gives our plans and projected budgets for the following year.

II. The CALOR89 Code System

A flow diagram of the CALOR89 code system is given in Fig. 4. The transport codes that comprise this system include HETC88[4], the high energy hadronic transport code, EGS4[5], the electron, positron, and gamma ray transport code, MORSE[6], and MICAP[7], the low energy ($\leq$ 20MeV) neutron transport codes. Source gamma rays and electrons for EGS4 and neutrons for MORSE are obtained from the data generated in HETC88. The remainder of the codes are for analysis (SPECT and ANALYSIS), cross-section generation (PEGS), and signal reduction due to saturation/recombination effects (LIGHT). The major changes in CALOR and the main reasons for the additional benchmarking are an improved high energy collision model following the methods used in FLUKA87[4] and a new low energy neutron transport code, MICAP. To prevent too many changes at once, the code will be benchmarked against the new high energy model using the MORSE code and will be followed by additional benchmarking using the MICAP code.

III. *DØ*-Benchmark Calculations

In a recent paper, experimental results were presented on the hadronic and electronic response of a uranium-liquid argon calorimeter module.[2] The module used was a hadronic section of the *DØ* calorimeter and the quantities measured were the energy resolution, the electromagnetic to hadronic response ratio (e/π) and the longitudinal hadronic shower development. Experimental data was presented for incident particle energies of 25 to 150 GeV. Work is in progress to obtain comparisons between this experimental data and calculated results obtained with the CALOR89 computer code system.

The dimensions of the calorimeter module are given in detail in Ref. 2 and will not be repeated here. The calorimeter module is basically 6 mm uranium plates separated by 5.7 mm of liquid argon and G10 signal board. At the back of the module, the uranium is replaced by stainless steel. In the calculations, the module was modeled in rather complete detail using the combinatorial geometry routine included in CALOR89.

In Fig. 5, the calculated and measured integrated longitudinal shower containment for 25 GeV incident pions are compared as a function of thickness.[2] The circles are taken from Ref. 2 and is the prediction of a parameterization of Bock, et al[8]. In the figure, both the calculated and experimental data have been normalized to agree with the parameterization at the largest thickness shown.

In Figs. 6a and 6b, the measured fractional resolution is shown as a function of incident energy for electrons and pions. The solid curves are fits to the experimental data taken from Ref. 2. Calculated values for 25 GeV incident pions and electrons are also shown. The two calculated values for incident pions corresponding to integration times of 50 ns and

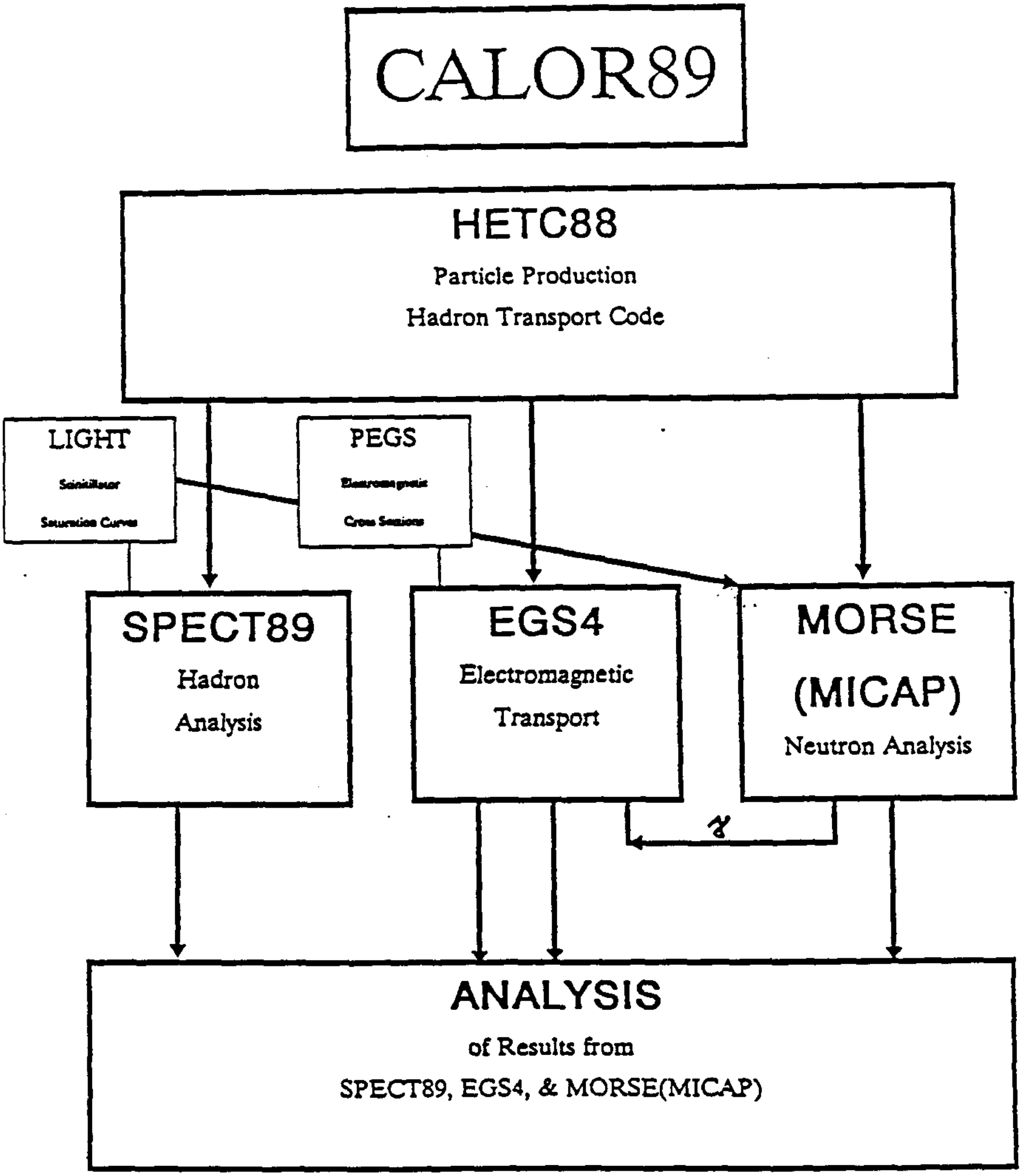


Fig. 4 The CALOR89 Code System

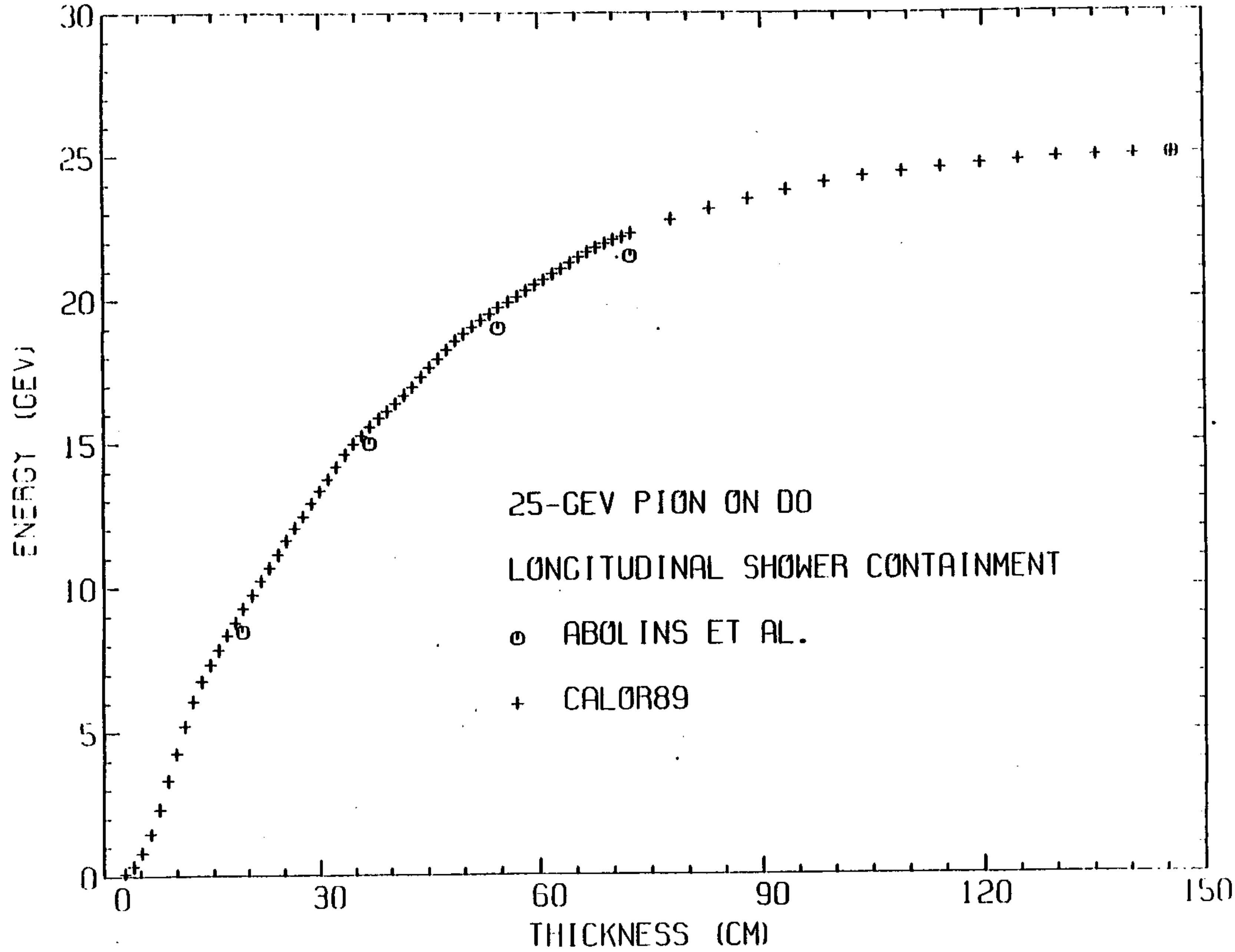


Fig. 5 ... shower containment for the DO calorimeter

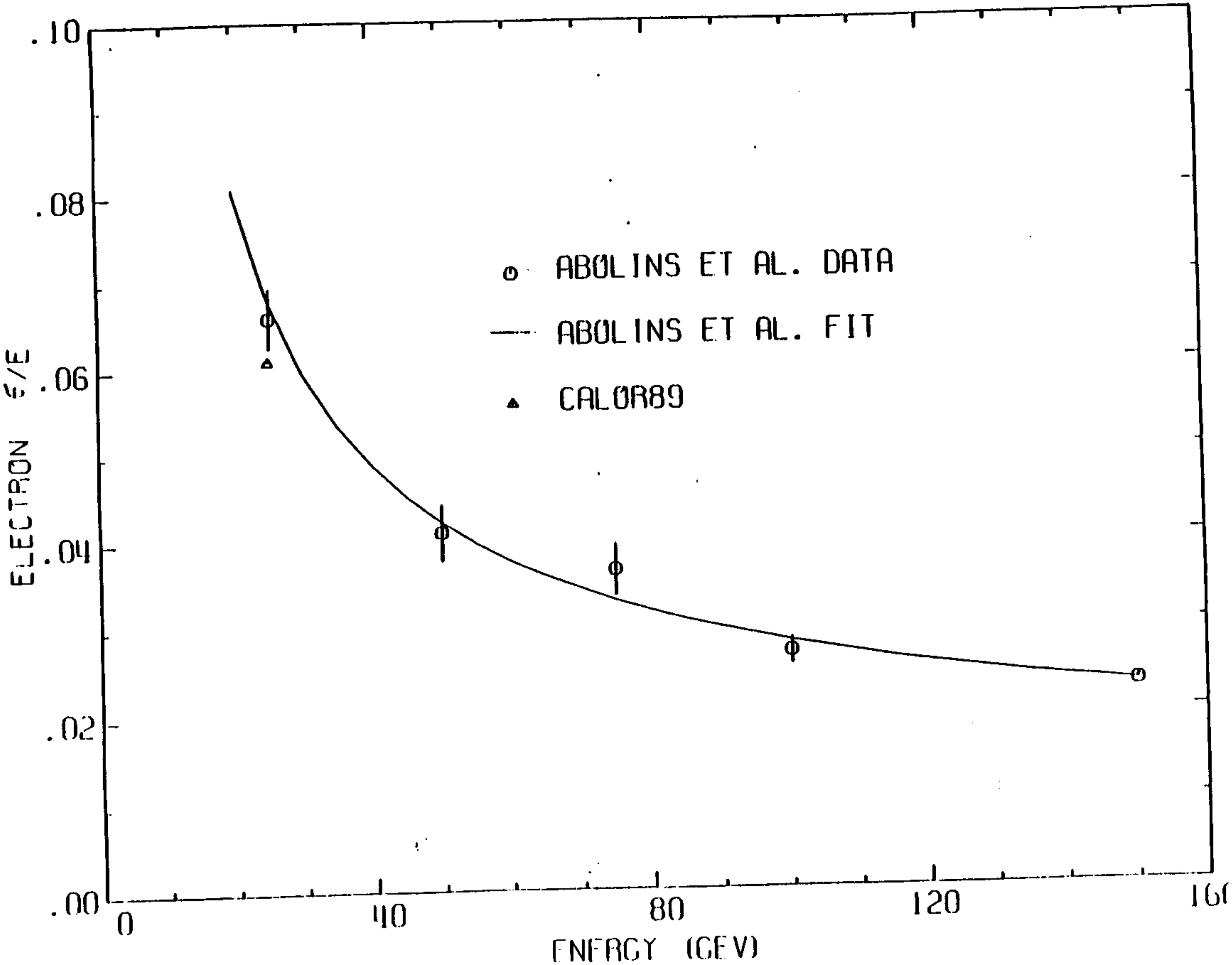
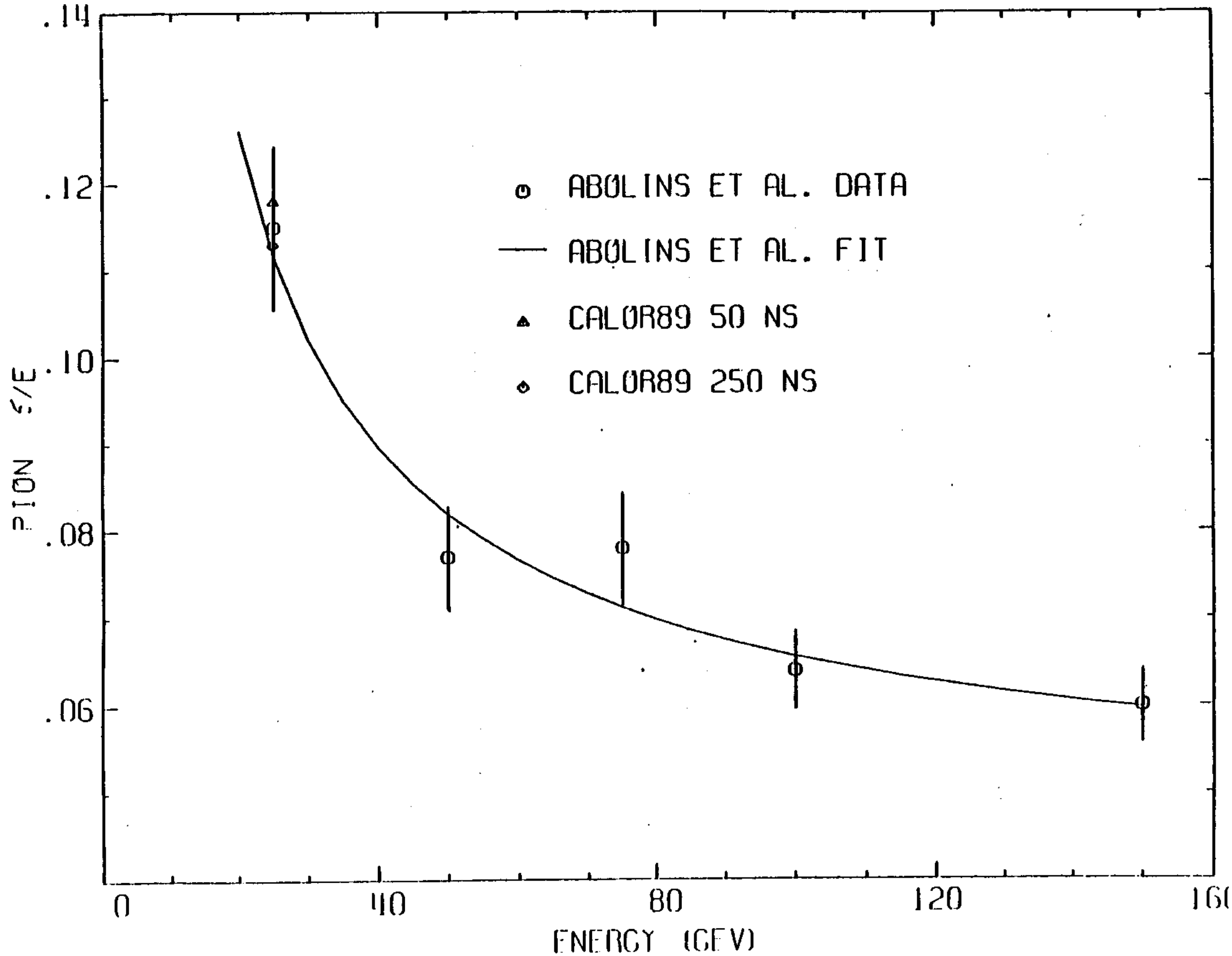


Fig. 6a Electron energy resolution for the DO calorimeter.



F b Pion energy resolution for the DO calorimeter.

250 ns. The experimental values contain a correction for noise, and this same correction has been added to the calculated values for comparison purposes. The agreement between the calculated and experimental data is quite satisfactorily.

In Fig. 7, the measured hadronic-to-electromagnetic energy deposition ratio (e/π) is shown as a function of incident particle energy. Also shown are the calculated values for integration times of 50 ns and 250 ns. There is a noticeable difference between the results for the two integrations times and the longer time gives the better agreement with the experimental data. Comparison at the higher incident energies are in progress.

IV. HELIOS-Benchmark Calculations

Progress has been made in benchmarking CALOR89 with the HELIOS[3] experiment. HELIOS is a Uranium/Liquid Argon calorimeter and was tested with electrons and pions, and protons at energies from 17 GeV to 450 GeV. The geometry for the calorimeter has been generated and the LIGHT program used to generate saturation/recombination curves for liquid argon. The 17 GeV π^- and e^- cases have been almost completely processed through the CALOR system. Only MORSE output remains to be generated. Five hundred histories 17 GeV π^- and 300 for 17 GeV e^- are being analyzed. Preliminary analysis of the 45 GeV data has been started.

During the first parts of the benchmarking, HETC crashed consistently due to "out-of-detector" particles. A modification to the JOM9 routine was made which has eliminated the problem while still producing results that are constant with the previous runs.

V. Anticipated Progress for FY91

During FY91, the calculations to aid in the design of the SSC Liquid Argon Calorimeter will be started. Benchmark calculations on *D0* and HELIOS which were started during FY90 will be completed and the calculated data which can be compared with experimental data will be further analyzed. Differences between experimental and calculated results will be determined and the differences resolved. Additional calculations as needed for the prototype will be started. Improvements in the CALOR system as it relates to liquid argon calorimetry will be continued.

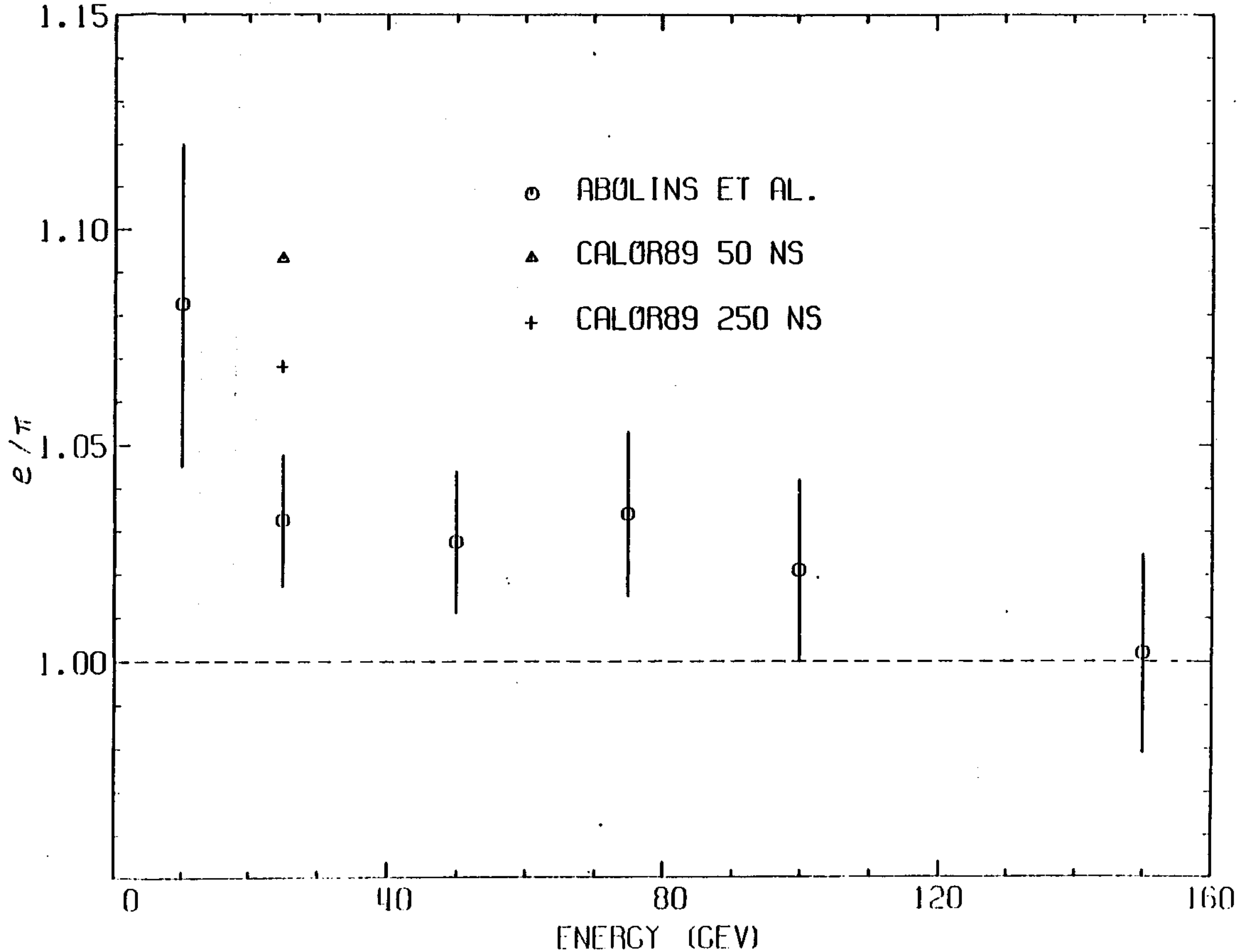


Fig. 7 Compensation characteristics of the DO calorimeter.

VI. Budgets for FY91 (See overall budget sheet for breakdown)

University of Tennessee	Summer Salary	$ 5000
	Travel	$ 3500
	Equipment	$21500
		$30000

The equipment money is for a high end work station such that the CALOR89 code system can be off loaded from the main computer center system which is heavily loaded. Currently work stations such as the IBM system 6000 RISC can be obtained that give equivalent computing power to the University's IBM 3090/200. This would have the advantage that the turnaround on simulation runs would be vastly improved

University of Mississippi	Postdoc incl. fringe (1/2 time)	$18300
	Programmer support	$15000
	Students	$ 6000
	Travel	$ 6000
	Computer fee	$ 5000
	Communication	$ 2000
	Sub-total	$52300
	Overhead(44% less students)	$20372
	TOTAL	$72672

Keeping in mind that ORNL is also contributing to this effort our budget is an attempt to weigh their contribution and at the same time give a realistic estimate on what we need to make a significant contribution to the program. We plan to acquire about 200-250 MIPS of parallel processing capability within the next few months for simulation. In addition, the University is installing a CRAY XMP this fall which we can use for a nominal base charge of $5K. In addition, we are hoping to hire a research scientist who will spend fulltime on simulations - some of it on LAr. This is less than we requested last year and we are in a position to do more. For the $10K we received we were able to do much less than was needed so I hope the SSC can be convinced that more is necessary this year.

Oak Ridge National Laboratory		$75K*

*Will be supplemented by Oak Ridge Detector Center funds. This request is for software support - i.e., professionals.

VII. References

1. T.A. Gabriel, et al., "CALOR87: HETC87, MICAP, EGS4, and SPECT, A Code System for Analyzing Detectors for Use in High Energy Physics Experiments," Proceedings of the Workshop on Detector Simulation for the SSC, Argonne National Laboratory (Aug. 1987) and T.A. Gabriel, et al., "CALOR89, A Monte Carlo Program Package for the Design and Analysis of Calorimeter Systems," Oak Ridge National Laboratory, ORNL/TM-11185, (in press).
2. M. Abolins, et al., "Hadron and Electron Response of Uranium/Liquid Argon Calorimeter Modules for the *D0* Detector," Nucl. Ins. & Methods in PHys. Res. A280, (1987) 36.
3. H. Gordon, et al., "Preliminary Performance Results of the HELIOS Uranium/Liquid Argon Hadron Calorimeter,: CERN Report ________, (August 1, 1988).
4. R.G. Alsmiller, Jr., F.S. Alsmiller, and O.W. Hermann, "The High Energy Transport Code - HETC88 and Comparison with Experimental Data," submitted to Nuclear Instruments and Methods.
5. W.R. Nelson, et al., SLAC-265, Stanford Linear Accelerator Center (1985).
6. M.B. Emmett, ORNL-4972, Oak Ridge National Laboratory (1975).
7. J.O. Johnson and T.A. Gabriel, ORNL/TM-10196, Oak-Ridge National Laboratory (1987).
8. R.K. Bock, et al., Nucl. Ins. & Methods 180 (1987) 533.

University of Washington - Progress Report for FY90

(T. Burnett, V. Cook, R. Davisson, P. Mockett, J. Rothberg, R.W. Williams)

Liquid Argon Test Dewar Design and Fabrication

The University of Washington has designed and engineered, according to the ASME Boiler Code Section 8 specifications, a large liquid argon dewar for the test program of the LAr Subsystem Group. We are currently in the construction phase of the project. We have acquired all major components and materials and these are undergoing fabrication in the UW shop. We expect to begin testing the dewar in early October. It will then be shipped to BNL and set up in the A3 line for our test program. A special requirement that the calorimeter could be placed into the dewar with minimum crane coverage necessitated that we devise a roll-in scheme for the loading operation. We also wanted to keep the cabling connected during loading so a special cabling arrangement was invented that allowed the calorimeter signal lines to remain hooked up during the loading. We have employed the highly tested signal feedthrus used by MKII and SLD to assure the safe operation of these highly critical elements.

Following the completion of the testing at UW we will ship the dewar to BNL where we will assemble it in the A3 line. We will need travel and operating funds to help with the beam tests and are requesting \$41K for FY91 including indirect costs of \$14K.

Composite Steel Lead Calorimeter Plates

Some time ago we suggested that the e/π ratio in a lead plate LAr calorimeter could be further improved if the lead plates were clad with millimeter thick steel plates. This suggestion was based on detailed EGS studies we did concerning the sampling efficiency of lead LAr calorimeters. We plan to construct in the UW shop a new calorimeter, identical to the one presently under construction, except that the plates are a sandwich of lead and stainless steel. This will be constructed in time for it to be tested in the BNL test beam next year. We budget this at $150K based on the costs of the first calorimeter, although the funding will come through BNL, UW will take the major role in the fabrication of the clad plates.

Calorimeter Segmentation

We plan to move to the next stage of development work that was begun with University of Washington generic funding. This work was to demonstrate using bench tests the feasibility of a new calorimeter segmentation scheme we dubbed BRITE PADS. This scheme would provide the accuracy of cm scale segmentation but with a factor of twenty fewer channels. Our bench tests have shown the technique works with very fast pulses (50 ns peaking time) and it is appropriate that we now demonstrate the technique with a real calorimeter. To this end we propose to build a small electromagnetic calorimeter and dewar for use in the BNL test beam. We budget this at $92K including $7K indirect costs. In this budget we assume we can borrow the amplifiers from the LAr Subgroup.

We also plan to continue the refinement of the electrode structures in both cost and ease of construction. We budget this work at $9K including $3K indirect costs.

Budget Summary for FY91 - U. of Washington

LAr BEAM TESTS		
Travel	$ 12K	
Operations	15K	
Indirect	14K	
Total		$ 41K
Fe-Pb CALORIMETER		
Engineering	$ 10K	
M&S	112K	
Shop	10K	
Travel	10K	
Operations	2K	
Indirect	6K	
Total (included in BNL request)		($150K)

CALORIMETER SEGMENTATION		
Engineering	$ 10K	
Pb/G10 Stack	20K	
Test Dewar	25K	
Shop	4K	
Technician	2K	
8mm Tape Drive	10K	
Travel	7K	
Operations	7K	
Segmentation	6K	
Indirect	10K	
Total		$101K

Florida State University - Progress Report FY90
(Prof. J. Womersley)

FSU has yet to make a significant contribution to the project, this being due to the very late arrival of FY90 funds. For FY91 we anticipate a greater involvement, including simulation work and running shifts at the BNL beam tests. We request continued funding at the same level as FY90, that is $10,000 (operating) to cover travel and miscellaneous expenses. Computer time and facilities for simulation will be provided by FSU at no cost to the subsystem proposal.

Michigan State University - Progress report FY90
(Prof. H. Weerts and technical staff: R. Richards and M. Nila)

The responsibility of this group is the production of the signal collecting boards for the first load of the test calorimeter at BNL and R&D on other readout structures. The calorimeter stack which will be tested at BNL is described under the section covering the activities of Brookhaven National Lab.

MSU is producing the charge collecting X and Y strip boards for the first test stack. The patterns for the strips are machined into a single and double Cu-clad G10 sheet (.031″ thick). After cutting the strip boards from the large sheets (three per sheet), the single and double clad boards are laminated together, so that the charge sensitive strips are on the inside of the lamination and thereby capacitavely couple to the liquid. The patterns on the outside, which are "identical" to the inside, serve as the high voltage plane. To decouple the individual strips the high voltage is supplied through a resistive layer which connects each strip to the HV bus. This layer is screen printed and machined in such a way before the lamination step, that the resistance between HV bus and each strip is on the order of $2.5M\Omega$. A total of 90 boards are being produced for the first load. At the writing of this the first ten production boards have been shipped to BNL.

We have also investigated the feasibility of laminating finite size thickness tiles (Cu or Pb) between sheets of G10. As a glue, standard B-stage sheet epoxy is used. Two test laminations were done: one consisting of 6 small Pb tiles ($1'' \times 2''$ and $1/4''$ thick) and one consisting of 20 Cu tiles (10″ × 5″ and 1/4″ thick). Both laminations were very strong and successfully survived many cryogenic cycles (> 20). At this point we feel that the lamination technique is understood and works well for cryogenic applications.

The MSU contribution to the LAr subsystem proposal for the next year will consist of two parts:

1) Produce another set of X, Y strip boards for the second stack to be tested at BNL. This stack will use a Fe-Pb-Fe sandwich as absorber instead of 12mm Pb. If possible we also intend to fabricate the Fe-Pb-Fe sandwich with the same lamination technique as used for the tiles.
2) Further R&D work on readout structures consisting of tiles sandwiched between G10. The problems to be solved are the following:
   - Try to laminate uranium tiles
   - Determine what is the best way to isolate the tiles within the sandwich and keep the capacitance between them to a minimum. One also wants to be able to pump out the regions between the tiles and have no air bubbles trapped, which could damage the lamination under vacuum.
   - Implement a connection scheme to the tiles. A reliable connection scheme which satisfies the electronics constraints (low inductance) and works at cryogenic temperatures has to be developed. It has to be combined with the lamination technique, to be shown to work and being able to be used on an industrial scale.

FY91 Budget - Michigan State University

Cost:	-fabrication of signal boards (second set)	\$10K
	-R&D operating/equipment cost , estimate	\$25K
	TOTAL	\$35K

Martin Marietta - Progress Report FY90

(J. Bakken, N. DiGiacomo, L. Mason)

INTRODUCTION

Although LAC technology is widely used in high energy physics and is generally considered well understood there remain many difficult engineering issues unique to the SSC. One of the more challenging issues involves the uncontrolled formation of argon gas within sensing elements where performance is degraded by the resulting density fluctuations and high voltage arcing. This is not a new problem for LAr but it is complicated by the extraordinary size and speed requirements of an SSC LAC. Signal to noise will be optimal when a preamplifier for each channel is placed near the submerged charge collection plates perhaps within the module support structure. However, preamplifiers are active devices that produce heat and even at the modest power level of 50 milliwatts per channel they can dissipate upwards of 15 kilowatts of heat within the LAC cryostats. Techniques exist for preventing the evolution of gas within critical areas but such solutions tend to increase design complexity and degrade hermeticity.

New solutions, beyond the traditional approach of using conservative gross thermal effect calculations and prototyping and testing are needed for the SSC. The ability to quickly and inexpensively investigate new engineering solutions is absolutely essential to producing an optimized design. To this end we have undertaken to develop an analysis capability that will allow confident exploration of alternative design solutions with minimal dependence on tests and prototypes. A report* is being prepared which presents the results of our analysis and corroborative test conducted on a simulated LAC module electronics section. We also discuss the feasibility of extending the analysis tool and process to the design of a full scale SSC LAC.

Our objective is to demonstrate the capability to confidently predict thermal and fluid conditions within the electronics section of a simulated LAC module for several module orientations and preamplifier power ratings. Our approach is based on using a commercially available, state of the art, computer code to perform 2 and 3 dimensional coupled thermal and fluid analyses and on conducting tests to obtain data for subsequent validation of the analyses.

SIMULATED LAC ELECTRONICS TEST

The main objective of the test is to obtain data on conductive and convective heat transfer from a group of discrete heat sources to a surrounding bath of liquid argon. These data are used for benchmark verification of two and three dimensional analytical models developed for use with a coupled thermal and fluid analysis computer code. The validated steady state and transient modeling and analysis approaches can then be used in the detector design process with an established level of confidence. A second objective is to obtain relevant data on LAC preamplifier thermal conditions. To this end every attempt has been made to remain faithful to the predicted envelope of critical parameter values for a SSC LAC such as power density, flow channel geometry and LAr depth.

The details of the tests performed in FY90, an analysis of the data and comparison with the simulation code will be available in the next month.

REQUEST FOR FY91

Preamble - it is unlikely that there are enough funds to do all these tasks, however we list the work that the collaboration believes should be done. It is in priority order.

TASKS:

1. Argon Electronics Heat Management Concept Development

Each preamplifier for the liquid argon calorimeter will dissipate 70 to 200 mW. The preamplifiers will most likely be immersed in the liquid argon between the EM and the hadronic calorimetry. There are approximately 90,000 preamplifier channels per barrel or endcap calorimeter assembly, so it will be necessary to extract 7 to 20 kW of thermal energy from each of the calorimeter assemblies to prevent argon boiling. Candidate preamp cooling concepts include: natural convection; forced convection; LN_2- or liquid argon-cooled preamp mounting boxes (the liquid argon could come from the calorimeter argon volume) where the cooling media could be allowed to flash and the gases extracted from the calorimeter. We propose the following tasks for selection of the electronics cooling method:

- Develop preamplifier cooling design concepts

---

* T. Adams, N.J. DiGiacomo, B. Easom, L. Mason, and R. Leitch, *Test and Modeling of Heat Transport in Liquid Argon* (to be published).

- Create coarse models and perform thermal/structural analyses.
- Develop fabrication methodology to insure reliability/feasibility
- Identify the most promising candidates
- Develop CAE models and fabrication sketches
- Fabricate test specimens (if tests are necessary)
- Develop pre-test performance predictions
- Test in liquid nitrogen and argon
- Perform post-test data analysis
- Generate prototype design/s
- Recommend cooling method

2. Signal and High Voltage Feedthrough Development

The calorimeter is highly segmented in the η, ϕ and depth directions which results in large electronic channel counts. Approximately 90,000 channels of electronics emerge from each of the three calorimeter segments, (barrel and two endcaps). The 270,000 signal wires are routed out of the calorimeter before the signals are multiplexed. Each wire constitutes a leak path between the argon and vacuum, between the vacuum and ambient air and as a heat transfer path from ambient to the argon environment. A reliably sealed, low-heat-leak feedthrough will be developed during this study.

- Define requirements for feedthroughs
- Perform literature search
- Develop feedthrough design concepts
- Coarse screen concepts for design, manufacturing, operation, etc. feasibility
- Model candidate concepts and analyze
- Develop test model design
- Pre-test predictions
- Build and test candidate feedthrough methods
- Evaluate test results
- Develop prototype feedthrough design.

3. Hermeticity and Containment Study

Construct and maintain LAC solid models for calorimeters with solenoid and/or toroid magnets as defined by the evolution of module/vessel concepts, then analyze the models to ensure that the configuration and technology improvements do enhance the LAC hermeticity and containment. It is anticipated that the models will evolve in detail as the module requirements are better defined and as the electronics cooling and electronic feedthrough concepts are established. The tasks are:

- Develop and maintain current configuration models for liquid argon calorimeters
- Optimize vessel shapes based on module design and materials
- Evaluate models for hermeticity and containment in both η and ϕ.

4. Material Compatibility and Testing

In order to keep the argon and vacuum vessel walls as thin as possible to maximize hermeticity and to minimize the inactive material in front of and between active calorimeter elements, it is necessary to shape the vessel heads to react the fluid and structural loads while minimizing material thicknesses. In optimizing the vessels for hermeticity, it was found during prior studies that portions of the argon vessel heads between adjacent calorimeter vessels should be shaped. Preliminary analysis using aerospace methods indicate that vessels with elliptical shapes can be designed to meet the stress requirements of the ASME code, and are stable, but the analysis method for ensuring structural integrity of these vessels, and provides the bases for a Code Case submittal to ASME.

- Evaluate LAC vessel shape vs ASME compliance
- Verify evaluation method with scaled tests
- Review materials of construction and determine qualification methods for candidate materials not currently qualified
- Develop ASME Code Case for establishing evaluation methods for shaped heads on argon and vacuum vessels to assure compliance with ASME code.

5. Sensor Positioning Tolerances Study

The primary function of this study is to define the effects of thermal, stress, creep, and soil rebound on the performance of the calorimeter and central tracker over a specified time period and to characterize the design, fabrication, assembly, checkout and operation procedures to minimize these effects.

- Develop thermal/structural liquid Argon calorimeter model for analysis
- Optimize critical elements/system to obtain structurally stable LAC
- Perform analysis for thermal cycle shift of structure
- Model module attachment techniques and analyze for thermal and structural stability
- Monitor module development, model module designs and analyze for stability in thermal and mechanical load conditions
- Develop alignment plan for all phases of LAC (i.e., Design, fabrication, build, assemble, checkout and operational verification).

6. Radiation Hardness

Candidate materials for calorimeter construction will be screened for compatibility with the anticipated radiation levels and for environmental effects, fatigue and creep to ensure integrity of the calorimeter for the life of the experiment.

- Monitor selection of candidate liquid Argon calorimeter materials
- Conduct literature search on candidate materials
- Evaluate candidate materials for structural/mechanical performance
- Recommend materials for test.

Budget - Martin Marietta Astronautics

$\sim 10K$/man month

	TASK	MM	START	FIN.	"1990"					"1991"						
					NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
1	Argon electronic heat mgt.															
	Research literature	4					xxxxxxxx									
	Dev. preamp cooling concept	4						xxxxxxxx								
	Create coarse models	3							xxx							
	Analyze models, struct/thermal	5								xxxxxx						
	Evaluate feasibility of candidates	1.5								xx						
	Recommend promising candidates	0.5									xx					
	Dev. CAE and designs	7									xxx					
	Fabr. test items	9										xxxxxxxxx				
	Pre-test predictions	4										x	x	x	x	
	Test	12											xxxxxxxxxxxxxxx			
	Post test analysis	1											x	x	x	x
	Generate prototype designs															
	Recommend cooling method															
	TOTAL=	51														
2	Feedthroughs															
	Define req'ts of feedthroughs	1.5					xxxx									
	Research lit., feedthrough concepts	2					xxxxxxxx									
	Concept development	3						xxxxxxxxx								
	Coarse screen concepts	5							xxxxxxx							
	Model and anal. candidates	6									xxxxxxx					
	Detailed anal. of best concepts	6										xxxxxxxx			xxxxxx	
	Design and fab	16											xxxxxxxxxxxxxxx			
	Test	12													xx	xx
	Evaluate test results	2													xx	xx
	Develop prototype design/spec.	0														
	TOTAL=	53.5														
3	Hermeticity and containment															
	Maintain model configuration	8					xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx									
	Follow module development	4														
	repackage barrel and endcap	4														
	Resize vessel walls	6						xxx				xxx			xxx	
	Evaluate model for hermeticity	3							xxx				xxx			xxx
	Evaluate module designs vs phi	4							xxxxxxxxxxxxxxxx							
	TOTAL=	29														
4	ASME compatibility study															
	Work with ASME rep.	0.5					x									
	Involve college participation	0.5					x	x								
	Conduct litr. search, stabiliy	2					x	x	x							
	Establish Baseline configs.	0						xxxxxxxxxxxxxxxxxxxxx								
	Config. vessel heads	2														
	Consider manuf. feasibility	0.5														
	Titanimum strap	0.5														
	Endcap stanchions	2														
	Est. stability anal. methods	2							xx	xx	xx	xx				
	Select test verific. approach	2								xx						
	Fab and test scale models	16									xxxxxxxxxxxxxxxxxx					
	Eval. test results	3										xxxxxxxxxxxxxxxxxxxxx				
	Vadidate design/anal. approach	2													xxxxxxxx	
	Prepare ASME Code Case	0														
	TOTAL=	33														
5	Sensor position tolerance study															
	Dev. thermal/ structural model	3								xx						
	Monitor concept development	0.5								xx			x			x
	Preform thermal stability anal.	5									xxx		x			x
	Preform struct. stability anal.	4									xxx		x			x
	Review matl. effects on stab.	1										x		x		x
	Predict deflection	1										x		x		x
	Evaluate creep	3										x		x		x
	Evaluate effects of cyclic cond.	5											xxx			xx
	Dev. alignment plan for LAC	1.5														x
	TOTAL=	24														
6	Radiation hardness															
	Monitor concept development	1						x		x		x		x		x
	Conduct literature search	2							x		x		x		x	
	Assess materials for rad. hard	2.5							xx		xx		xx		xx	
	Recommend materials for test	1.5													xxxxxxxx	
	Provide radiation level map	1.5							xxxx							
	TOTAL=	8.5														

Adelphi University - Budget FY91
(R.V. Steiner)

This requests the involvement of Adelphi University in the upcoming calorimeter beam testing at Brookhaven being conducted under the SSC Subsystem Proposal. With five years of experience on the design, construction and simulation of the SLD Liquid Argon Calorimeter, conducted first as a post-doc at Columbia's Nevis Laboratories and now as an Assistant Professor at Adelphi, I believe I can contribute substantially to this effort. In addition, Adelphi's physical proximity to Brookhaven means that it should be possible for Adelphi to contribute in a meaningful way throughout the period of data acquisition and analysis.

I believe that my involvement in the calorimetry of both the SLD and EMPACT collaborations gives Adelphi a unique opportunity to contribute to the development of SSC calorimetry. I am currently responsible for SLD's calorimeter noise simulation and have a particular interest in this area. In addition, I am interested in such vital issues as hermeticity, speed, pileup, energy resolution, e/π separation and so on.

In order to support the costs of travel, student support, the analysis effort and contingency, I am requesting $15,000 in support of these efforts.

University of Arizona - Progress report FY90
(T. Bowen, G. Forden, E. Jenkins, K. Johns, J. Rutherfoord, and M. Shupe)

We just received $10,000 in August from the DOE for travel to Brookhaven to assist in test beam work, both set-up and running and for travel to planning meetings. We have not used any of that money yet. In the mean time we have been working on LAC simulations and preparing for studies of pad geometries and their effects on read-out timing.

Budget - University of Arizona

Travel to test beam site	$15,000
Simulation work (part-time student programmer)	$ 8,000
Half-time equivalent grad student	$ 7,000
Total subject to overhead	$30,000
Overhead at off-campus rate of 25%	$ 7,500
Total request for LAC major subsystem work	$37,500

Iowa State University - Progress Report FY90
(J. Faust, J. Hauptman, and M. Pang)

For several months, we have been solving problems related to the design of big solenoidal detectors for the SSC. A series of internal group reports, some presented to the FAST collaboration and some to the SDE (Trilling) collaboration, before these groups joined together, have been written.* These assessments were based on absolute rate calculations

* "Hermeticity Studies in CCFR data," M. Pang, J. Hauptman, SDC-89-11 note, 1989; "Hadronic Shower Shapes in Depth," J. Hauptman, SDC-89-20 note, 1989; "Fake Missing E_T Trigger Rates due to non-Hermeticity, Finite Depth, and Finite Resolution," M. Pang,

derived from CCFR data taken at Fermilab, and are directly applicable to the dead spaces in cryostats and supports of the liquid argon modules.

In addition, two papers related to the ability of calorimeters of different geometries to do physics at the SSC were written.† The first paper applied the methods developed to study hermeticity and dead spaces to a specific problem of coil geometry. The second paper discussed calorimeter geometries and $W_L W_L$ scattering, and noted several physical selections which may result in the ability to separate this final state, $W^+W^- \rightarrow \ell\nu + q\bar{q} \rightarrow \ell\nu + 2$ jets, from the expected enormous $t\bar{t} \rightarrow bW^+\bar{b}W^-$ background.

(This work was performed by two graduate students and one faculty member, and roughly breaks down into six months of graduate student salary support split among M. Pang and S. DeBoer, plus one trip to the "Workshop on Solenoidal Detectors for the SSC.")

Proposed Work (to be done)

Myungyun Pang (graduate student) will be resident at BNL to assume a portion of the work on the liquid argon stack and work on data acquisition software. He will stay for the beam testing of this stack at the AGS, and participate fully in the analysis and understanding of this device. This work may be done partly at BNL and partly at ISU. We may also perform some calculations, although not extensive ones, on the performance of different radiator materials in the liquid argon stack using CALOR89.

Scott DeBoer (graduate student) will commute to BNL for the data taking runs, participate in electronics testing, and analysis of beam data after the tests.

Alexander Zinchenko (postdoc) will participate in the preparations for the run, data taking, and analysis of the test beam data.

Work at Iowa State University will proceed whenever students are available in Ames on the problem of the detection of the Higgs through its decay to WW, and the subsequent leptonic decay of one W, and the hadronic decay ($Wq\bar{q}$) of the other W. If the Higgs has a high mass, its production mechanism is likely to be through the fusion of two W bosons, which were radiated by quarks within the colliding protons. This process in general leaves the two radiating quarks at some large transverse momenta with respect to the colliding beams, and these momenta, if properly measured, can indicate the production of the Higgs boson. Such a capability would be very important for any high p_T 4π detector, and their solutions may have substantial impact on the design and performance criteria expected of a liquid argon device.

Budget - Iowa State University FY91

A sensible budget for FY91 might be about $30K for graduate student salaries, three months of post doc salary, and enough travel for Ames ↔ BNL trips. Generally, this small

J. Hauptman, SDC-90-45 note, Dec. 1989; "Beyond $\eta = 3$," J. Hauptman, SDC-89-6 note, Sept. 1989; "Lateral Segmentation," J. Hauptman, SDC-89-19 note, Aug. 1989; and a table of "Calorimeter Requirements," generally distributed. J. Hauptman is chairman of the calorimeter requirements subgroup for SDC.

† "Coil Effects on the Calorimeter," J. Hauptman, and "$\eta > 3$ Calorimeters and $W_L W_L$ Scattering," J. Hauptman, "Proceedings of the International Workshop on Solenoidal Detectors for the SSC," KEK, Tsukuba, Japan, April 23–25, 1990.

group always has 1–2 students working on instrumentation problems, and this would be partial support for them.

Request Budget for Liquid Argon Subsystem in FY91 by Task

Institution	Task	Budget in $1000
BNL	Completion of A3 Beam Line	80.00
	Operation of Test Beam	50.00
	Fabrication of steel/lead stack	150.00
	Engineering Support for Hermetic Modules	75.00
	Support of Accordion Tests	20.00
	Engineering Support for Feedthroughs	75.00
	Support of ISAJET	100.00
	Radiation Damage to Components used in calorimetry	100.00
Rochester	Support of test beam	62.00
	Support for Shielding Transformer and Compact Low Inductance Connections in Modules	180.00
Maryland	Fabrication of items for beam test	15.00
	Support for beam test	65.70
LBL	Test Beam EM Module with Electrostatic Transformer Electronics R&D	364.00
ORNL	Support for Simulation	75.00
Tennessee	Support for Simulation	30.00
Mississippi	Support for Simulation	72.67
Washington	Support for Beam Tests	41.00
	Development of Calorimeter Segmentation based on Brite Pads	101.00
Florida State U.	Support of Beam Tests	10.00
Michigan State U.	Fabrication of Signal Boards	10.00
	R&D on Tiles	25.00

Martin Marietta	Engineering on Cooling Preamps in Liquid Argon	510.00
	Engineering on Feedthroughs	535.00
	Engineering on Hermetic Modules	290.00
	Engineering on Material Compatibility and Testing	330.00
	Engineering on Sensor Positioning Tolerances Study	240.00
	Engineering on Radiation Hardness	85.00
Adelphi U.	Support of Beam Test	15.00
Iowa State	Support of Beam Test and Simulation	30.00
Arizona	Support of Beam Test and Simulation	37.50
Total		3773.87

Requested Budget for Liquid Argon Subsystem in FY91 by Institution

Institution	Total
BNL	650.00
Rochester	242.00
Maryland	80.70
LBL	364.00
ORNL	75.00
Tennessee	30.00
Mississippi	72.67
Washington	142.00
Florida State	10.00
Michigan St.	35.00
Martin Marietta	2025.00
Adelphi U.	15.00
Iowa State	30.00
Arizona	37.50
Total	3808.87

WARM LIQUID CALORIMETRY
LARGE SUBSYSTEM R&D
PROGRESS REPORT

September 1, 1990

J. Busenitz, D. DiBitonto, M. Timko
University of Alabama

B. Aubert, J. Colas, P. Ghez, J. -C. Lacotte, J. -C. Lemarec, and P. Petitpas
Laboratoire d'Annecy-le-Vieux de Physique des Particules

J. Bensinger
Brandeis University

A. Ciocio, M. Hoff, J. Kadyk, P. Limon, M. Pripstein*,
M. Strovink, W. Thur, T. Weber, W. A. Wenzel
University of California, Berkeley and Lawrence Berkeley Laboratory

L. Dobrzynski, D. Kryn, J.P. Mendiburu, and P. Salin
Laboratoire de Physique Corpusculaire du Collége de France

J. Womersley
Florida State University

G. Brandenburg, A. Daw(st), S. Geer, J. Oliver, and E. Sadowski
Harvard University

R. Kikuchi
Kyoto University

K. Miyano
Niigata University

M. Gregory(st), R. Hollebeek, M. Newcomer, and Cen Yi(st)
University of Pennsylvania

Ph. Lavocat, B. Mansoulié, S. Palanque, and J. Teiger
CEN Saclay

K. Matsuda
Saitama College of Health

K. Abe, K. Hasegawa, F. Suekane, H. Yuta
Tohoku University

M. Higuchi, Y. Hoshi
Tohoku Gakuin University

* Contact person
(st) student

Table of Contents

I. Summary

In our Large Subsystem Proposal we outlined an R&D program to investigate the use of warm-liquid calorimetry in an SSC detector. We requested funds for the U.S. share of the first year of a proposed two-year international collaboration to contribute to an informed choice of calorimeter technology, consistent with major SSC detector schedules.

We received funding for most -- though not all -- of our first year's plan. With the help of our Japanese and European colleagues, our vigorous pursuit of that program has significantly advanced the understanding of warm-liquid calorimetry, and we remain on schedule for the work ahead.

This report informs you of our progress so far, and requests funds for the U.S. share in the efficient and timely completion of the project. Our European and Japanese collaborators continue aggressively to pursue their part of the research program.

One year ago we planned the following approach:

- *A beam test to verify the principles of warm-liquid calorimetry and electron-hadron compensation.* (WALIC)*
- *The design, fabrication, and test of a large prototype swimming-pool calorimeter of a design easily extrapolated to a realistic SSC calorimeter.* (TBM)
- *Continuation of R&D at all collaborating institutions to determine material compatibility, speed of response, and other issues.**
- *Design and engineering studies to show how a warm-liquid calorimeter would fit into an SSC detector.*

* *Continuation of work begun under the auspices of the generic R&D program*

We received funds to pursue the first three items on our list, and we have made significant progress. We are in the midst of the WALIC beam test at Fermilab. We have completed the design and parts procurement for the TBM. We have advanced our knowledge of material compatibility. We have developed a practical "electrostatic transformer" readout for liquid ionization detectors. We have assembled and operated a small prototype of a "swimming-pool" calorimeter module.

We received no funds to pursue engineering studies, an unfortunate circumstance in light of the considerable work done in the previous year in collaboration with EG&G. We hope to re-start that engineering work in the coming months.

In summary, we have made gratifying progress, and we remain on-track to achieve our original goals on schedule.

II. The Critical Issues for Warm-liquid Calorimetry

Warm-liquid calorimetry is a promising technology that could result in a reliable, hermetic, fine-grained, compensating calorimeter with excellent resolution for SSC detectors. Newly developed, it requires some additional research, particularly in its systems aspects, in order to be confident that a successful and reliable detector can be built. Considerable progress has been made in the last few years in understanding the principles of warm-liquid calorimetry, and an extensive R&D program is underway world wide to deepen that understanding. In our view, the R&D program is designed to address the critical uncertainties of the warm-liquid technology.

A. The critical issues for warm-liquid calorimetry are:

A.1. To successfully test a realistic proof-of-principle module.
A.2. To understand the material compatibility issues.
A.3. To attain adequate speed of response and signal-to-noise.

B. Less critical, but nevertheless important are:

B.1. Electron-hadron signal compensation (e/h).
B.2. Purification, cleanliness, and long-term stability.
B.3. Radiation resistance.
B.4. Engineering studies of a real detector calorimeter.

III. Review of the Large Subsystem Proposal

The R&D program is progressing along several tracks and at several institutions to attack the challenges listed above. It includes small-scale experiments and measurements as well as extensive beam tests. The central feature of the program is the construction and testing of a large proof-of-principle module.
The major goals can be put into three categories:

A. Completion of the WALIC beam test at Fermilab.
B. Construction and test of the Test-Beam Module (TBM).
C. Continued R&D at various collaborating institutions.

The tasks necessary to complete the goals of the program have been distributed among each of the U.S. and foreign collaborators to take advantage of the manpower and talent at each institution, as well as the scientific interests of the people involved. Table 1 indicates which institutions are responsible for each part of the work for both fiscal years 1990 and 1991. Our European colleagues have been particularly active in the WALIC tests at Fermilab and have recently accelerated their program of material compatibility investigations. Lawrence Berkeley Laboratory is the leader of the WALIC effort, and has taken on the major responsibility for the mechanical design of the Test Beam Module. The other U.S. collaborators are taking the responsibility for the electronics design and fabrication for the TBM. In addition, Harvard University is building a swimming-pool EM calorimeter and the University of Pennsylvania is studying purification and compatibility of TMS. Table 2 is a listing of the fund distribution the occurred in fiscal year 1990 for each of the U.S. institutions involved in the collaboration. It should be noted that both LBL and Penn received significant funding through the Generic R&D program in fiscal year 1990.

Table 1
Division of R&D Effort for FY 1990 & FY 1991

R&D Item	Responsibility by institution
WALIC beam tests	Alabama, LBL, Penn, Harvard, LAPP, Col. de France, Saclay, Kyoto U., Tohoku Gakuin U.
Engineering design and construction of the EM swimming-pool calorimeter	Harvard, LBL
Engineering design and construction of the hadronic swimming-pool calorimeter (TBM)	LBL, EG&G*
Design and test prototypes of stacks for swimming-pool module	Harvard, LBL, Penn, Col. de France, LAPP
Materials compatibility studies	LBL, Penn, Col. de France, all Japanese groups
Fast readout R&D and electronics for TBM	Alabama, Harvard, Penn., LBL, Saclay, LAPP
R&D on other promising liquids	Harvard, all Japanese groups

* Industrial contractor

Table 2
Warm-Liquid Calorimetry R&D
U.S. Budget for FY 1990

	LBL (K$)	Hvrd Brnd (K$)	Penn (K$)	Alabama (K$)	Total (K$)
I. WALIC Calorimeter Experiment	170	25		50	245
II. Test Beam Module					
A. Engineering design and construction					
1. Mech. Engin. & Design	160				160
2. Elect. Engin. & Design	80				80
3. Constr. & Fabrication	120				120
Subtotal	360	0	0	0	360
B. Verification of Stacks for TBM					
1. Engineering	20	25			45
2. Technicians	10	15			25
3. Materials & Assembly	20	25			45
Subtotal	50	65	0	0	115
C. Mat. Compat. Verification for TBM					
1. Fab. & Maintenance of Cells	30		40		70
2. Experimental Program	40		65		105
Subtotal	70	0	105	0	175
D. Electronics for TBM Test					
1. Fast Readout Electronics			40	20	60
2. Other Electr. & Test Equip.			0	0	0
Subtotal	0	0	40	20	60
E. Purchase of TMP	0				0
Subtotal for TBM Design & Fabrication	480	65	145	20	710
Travel	25	10	5	5	45
Total (Large Subsystem Proposal)	675	100	150	75	1000
[Generic Funding for Warm-liquids*	343		70		413]
Grand Total (incl. Generic R&D)	1018	100	220	75	1413

* These are 1990 Generic R&D funds that were specifically intended for use in the Warm-liquid R&D program.

IV. Progress Report on the 1990 R&D Program

A. The WALIC tests.

The WALIC beam test (E-795) presently being carried out at Fermilab has, as its main goal, the understanding of the behavior of calorimeters. This is information that is long overdue in the field, and will be of use to anyone designing a calorimeter, regardless of type. Because the medium chosen for this research is warm-liquids, the tests have special relevance to that technology.

A.1. The WALIC Segmented Calorimeter

The apparatus consists of thin sealed boxes of stainless steel containing tetramethyl pentane (TMP) and electrodes, inserted between sheets of radiators and absorbers. This design was chosen to make it easy to change the configuration of the calorimeter to facilitate the study of a wide range of questions, such as shower development, resolution, and electron-hadron compensation (e/h), as a function of absorber thickness and material. The TMP boxes were manufactured commercially in the U.S., and then cleaned, filled, and tested in Europe, and then shipped to Fermilab. The European part of the collaboration also designed and built the electronics and wrote much of the software. The radiators and absorbers were designed and fabricated at LBL, and the whole hangs freely by means of independent hangers, suspended from parallel steel bars on a movable frame, also designed and fabricated at LBL (figure 1). The configuration of boxes and absorber plates can be easily modified. The entire array is surrounded by a perforated aluminum Faraday cage, which reduces the electrical noise by a factor of 50,000.

The experiment (E-795) has recently begun running in the MT6 beam line at Fermilab, and will continue to the end of the second part of the present fixed-target running expected in April or May of 1991. The calorimeter is presently instrumented to 6.5 interaction lengths, about half its ultimate depth. So far the results are very encouraging.

The first phase of the experiment, completed at the end of June 1990, consisted of the array set up in an electromagnetic calorimeter configuration and taking data with electron beams at nine momenta from 2.5 to 175 GeV/c. This set-up consisted of a 0.25 inch lead plate (1.13 Xo) followed by a TMP box (0.07 Xo), repeated 26 times, for a total of 31 radiation lengths. The signal from each of the four electrodes in each TMP box was read out and recorded. The raw data are very clean and the preliminary results agree quite well with predictions. These results were reported at the Singapore Conference in August 1990. Figure 2 shows the raw pulse height distribution from electrons and muons/pions in the beam. These are raw data with no corrections applied (such as gain, 3% beam momentum spread, etc.). Figure 3(a) shows the pedestal distribution and figure 3(b) the signal from the 26 boxes for muons and non-interacting pions, indicating a signal-to-noise of 3.5 for the 26 plates. This result can be extrapolated to a full depth hadronic SSC calorimeter with a short 100 ns signal shaping time, yielding a minimum-ionizing-particle (MIP) signal-to-noise of about six-to-one.

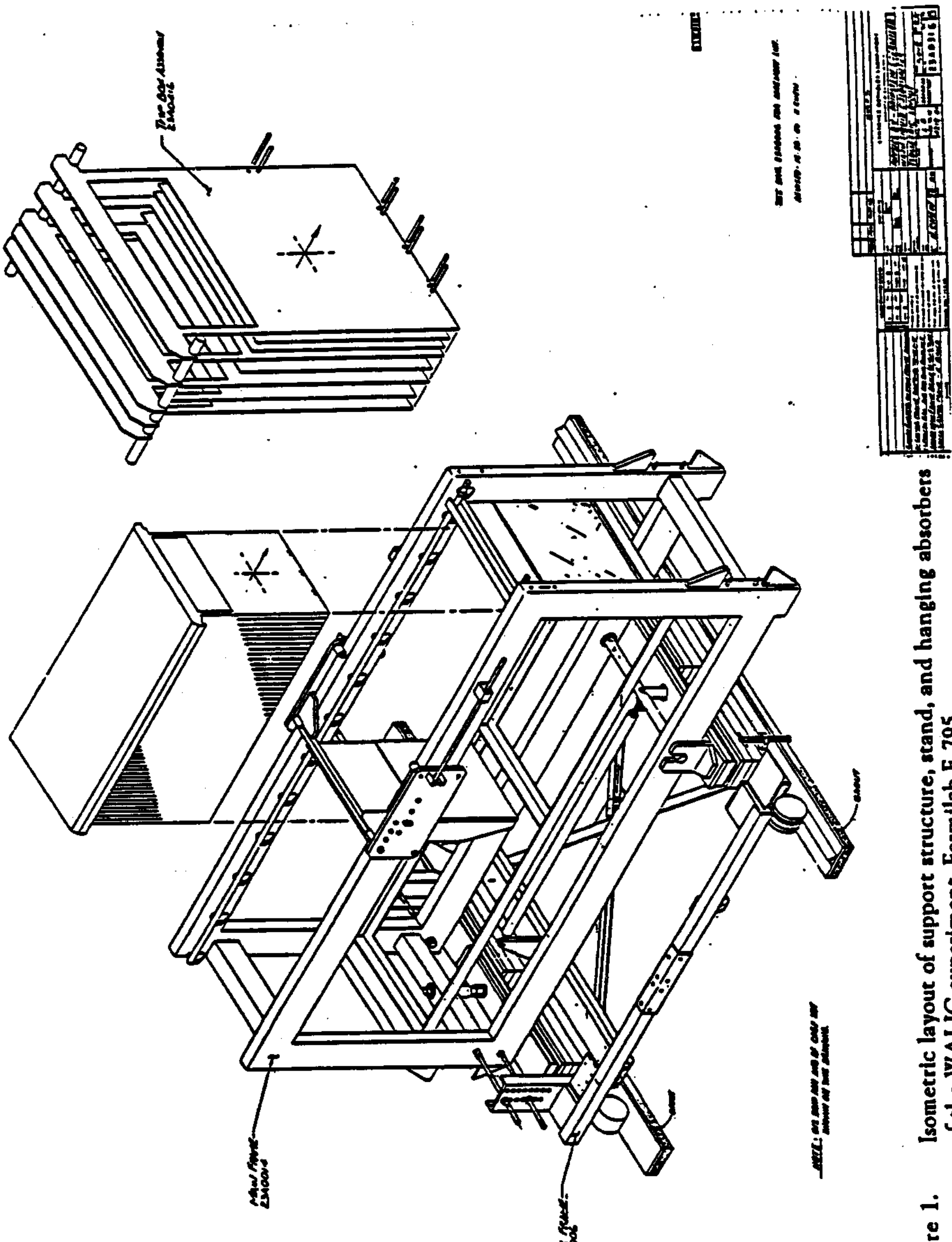


Figure 1. Isometric layout of support structure, stand, and hanging absorbers of the WALIC experiment, Fermilab E-795.

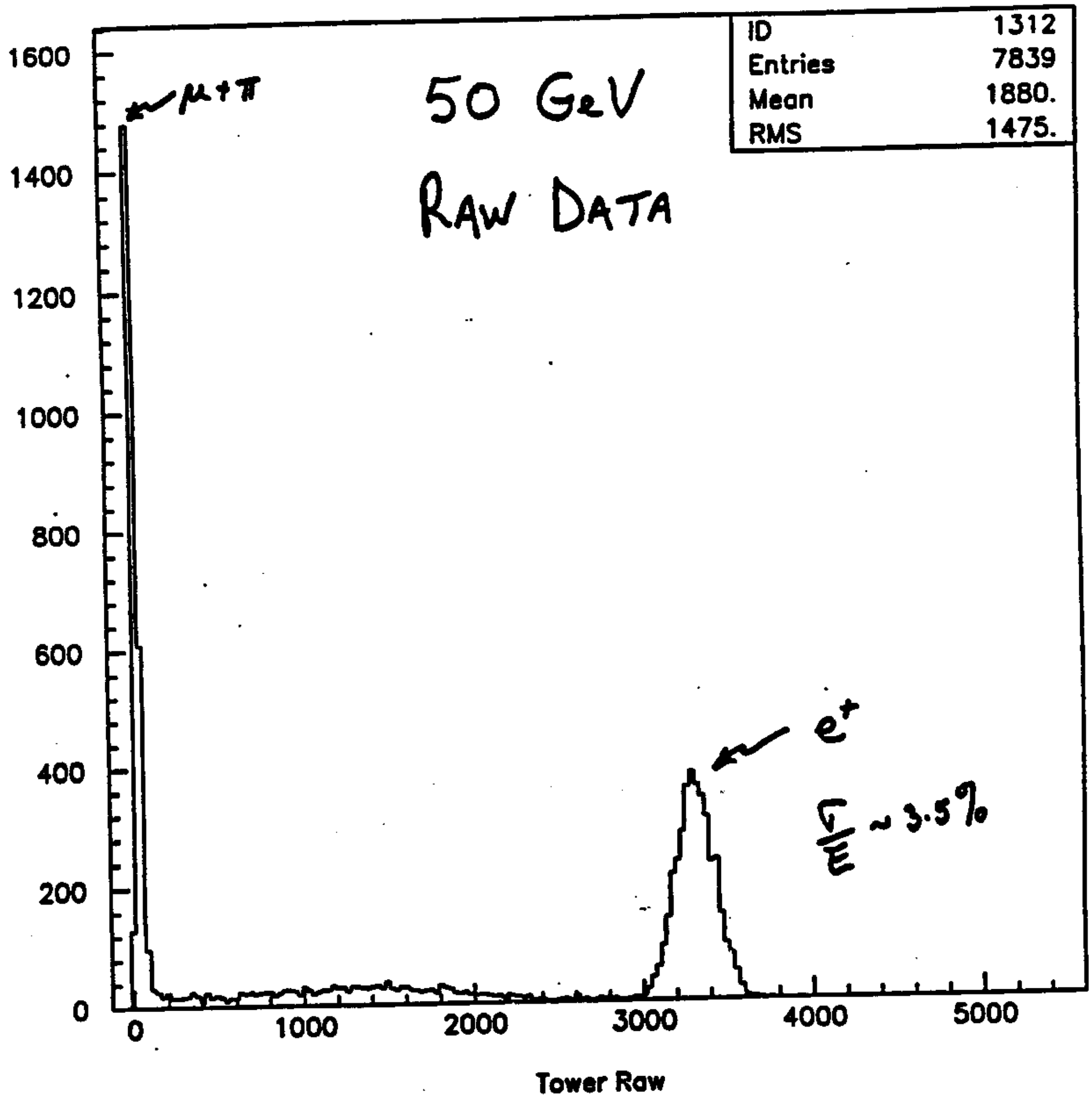


Figure 2. Raw data in the WALIC calorimeter of 50 GeV electrons with 26 Pb plates and 26 TMP boxes.

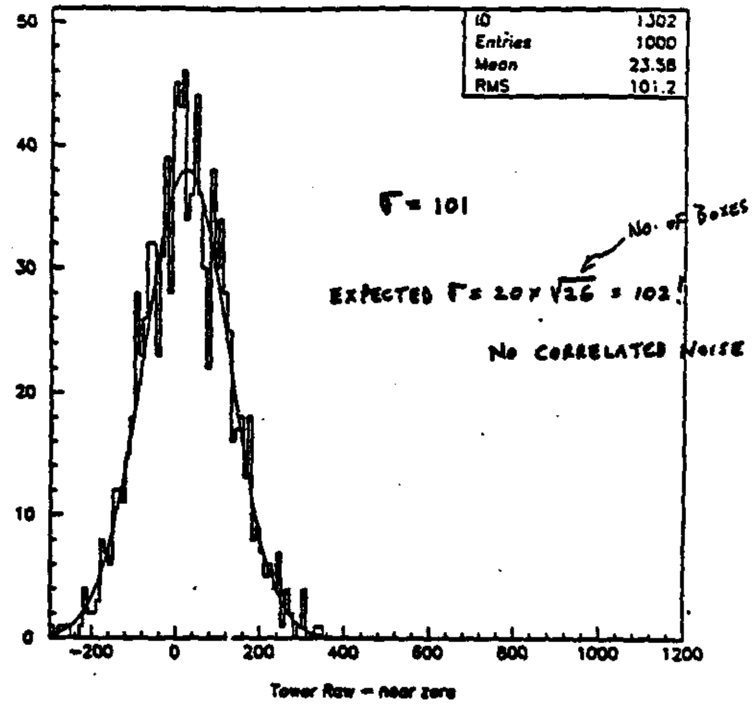


Figure 3(a). Raw, uncorrected data of pedestals in the same conditions as figure 2.

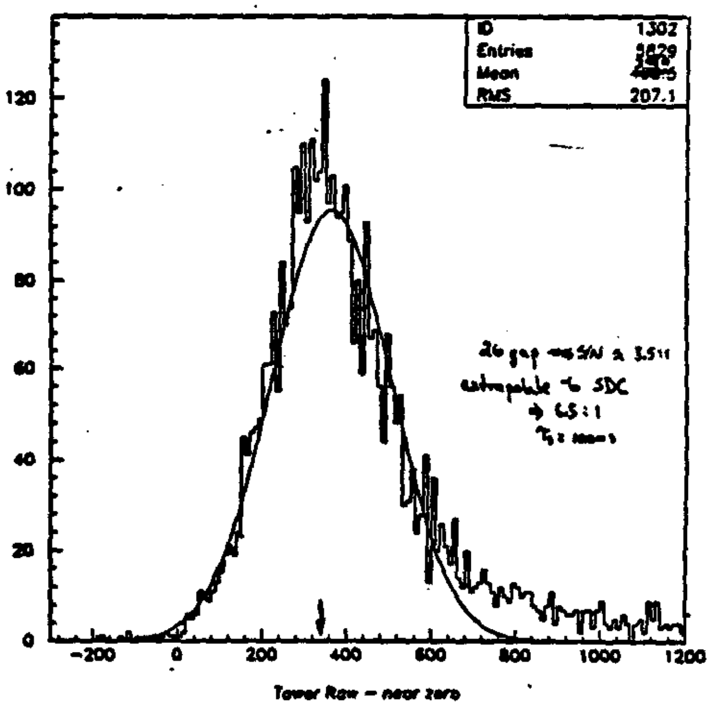


Figure 3(b). Raw, uncorrected data of muons and pions (i.e. minimum ionizing) on the same scale as the pedestals in figure 3(a).

Figure 4 are electron shower depth profiles at three different energies. The data agree very well with Monte-Carlo simulations, with both the peak energy deposition position and penetration of the shower growing very slowly with energy. Figure 5(a) displays the linearity of signal response versus energy and figure 5(b) the resolution, σ/E, versus $E^{-1/2}$. The preliminary fit to the raw, uncorrected data yields a resolution of $\sigma/E \approx 0.16\ E^{-1/2} + 1\%$. We are very encouraged by these preliminary results.

The second phase of the experiment, which was just concluded at the end of August, consisted of setting up 68 TMP boxes in a hadronic configuration of Pb - TMP, covering 6.5 interaction lengths. The 68 boxes represent about half the ultimate number of 140 TMP boxes to be installed by November 1990. Because only one-half of the 13 interaction length calorimeter was instrumented, this phase of the run used only low energy hadron and electron beams, 50 GeV/c or less, to avoid large leakage effects that would be present at higher energies. Several configuration of Pb and TMP were tried. Enough data under various conditions were obtained to provide us with the necessary information to optimize the run plan and configuration for the third and last phase of this experiment, beginning in December 1990. We are now embarked on an extensive data analysis effort with the goal of providing some preliminary results on the hadron calorimetry configurations at the October Fort Worth meeting.

These tests will answer many questions about warm-liquid calorimetry, not the least of which is can it work in a moderately large system. The present design of the WALIC hadronic array does not readily extrapolate to a colliding beam detector, however, and so does not test the systems issues relevant to an SSC calorimeter. A swimming-pool EM module with 20 radiation lengths of tungsten plates and TMP will be added to the front of the hadronic array for the second half of this run. This will be the first test of a warm-liquid calorimeter in the swimming-pool configuration. The issues of operating a large system in a realistic configuration, await the next step in the R&D program – the Test Beam Module.

A.2. Electromagnetic Swimming Pool Prototype

A small Electromagnetic "Swimming Pool" type calorimeter has been designed and is being built by the Harvard group with help from others, and will be added to the WALIC tests for the second part of the run, to begin in January, 1991. Although not as large as the Test Beam Module described below, this prototype incorporates many essential features. It is a complete EM calorimeter segment, and as such will be our first swimming-pool type calorimeter to undergo beam tests. It is possible that we will use this device together with the larger hadronic Test Beam Module in a complete warm liquid system test.

The EM swimming pool consists of thirty layers of tungsten plates and TMP gaps, as shown in figure 6. The tungsten radiator plates are 3 mm (approximately one radiation length) thick and the TMP gaps are double 1.5 mm gaps separated by thin stainless steel collector plates. The transverse dimensions of the test calorimeter are 20 cm by 20 cm, divided into sixteen 5 cm by 5 cm towers. The entire assembly of towers is enclosed in a stainless steel box which serves as the containment vessel for the TMP.

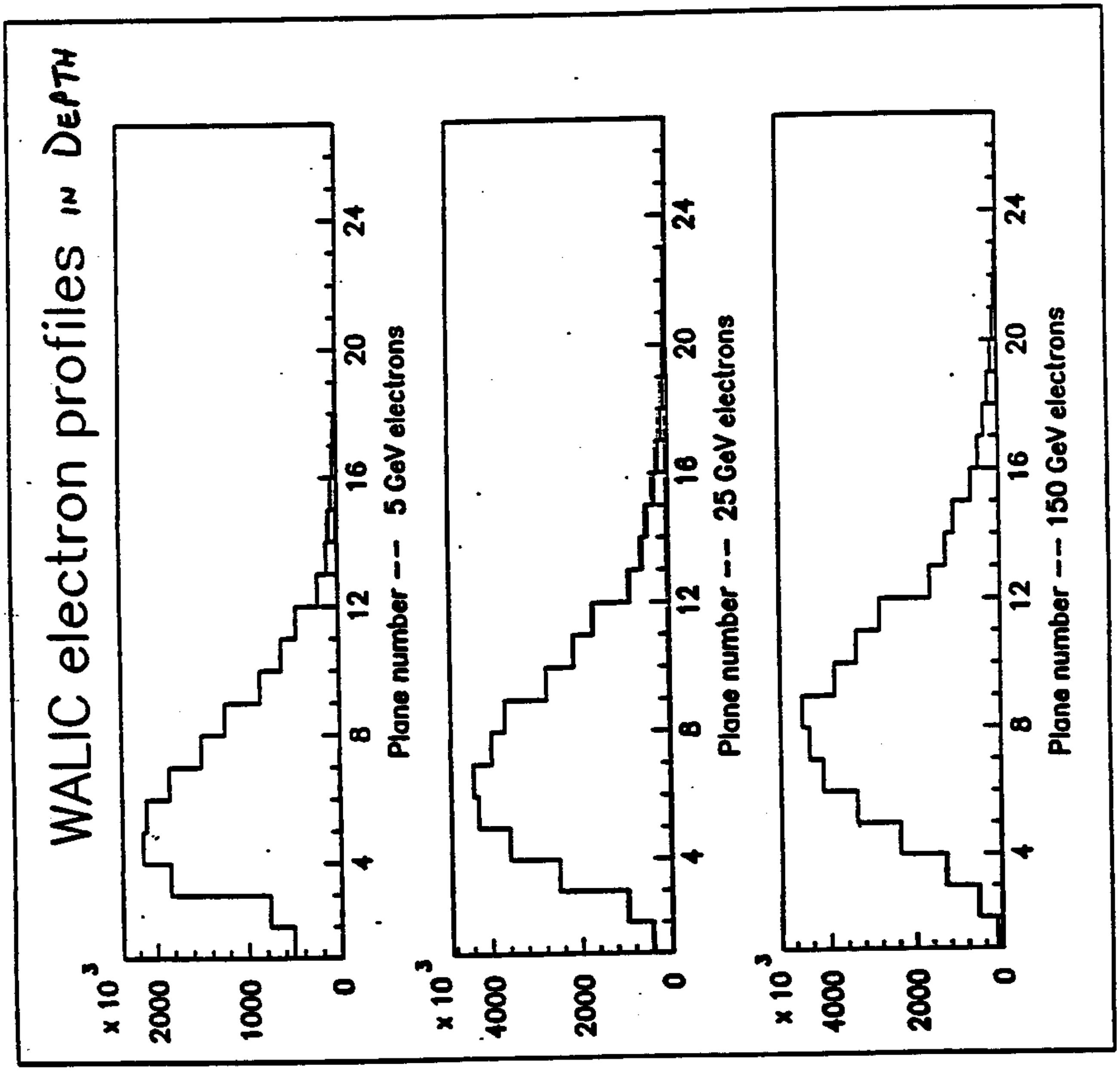


Figure 4. Depth profile histograms at three different electron energies in the WALIC experiment set up with 26 gaps.

Resolution

$$\sigma/E = \alpha/\sqrt{E} + \beta$$

$\alpha = 16.1 \pm 2.\%$

$\beta = 1.3 \pm 2.\%$

Geant Monte Carlo $\alpha = 18.2 \pm 7.\%$

$\beta = 0.4 \pm 2\ \%$

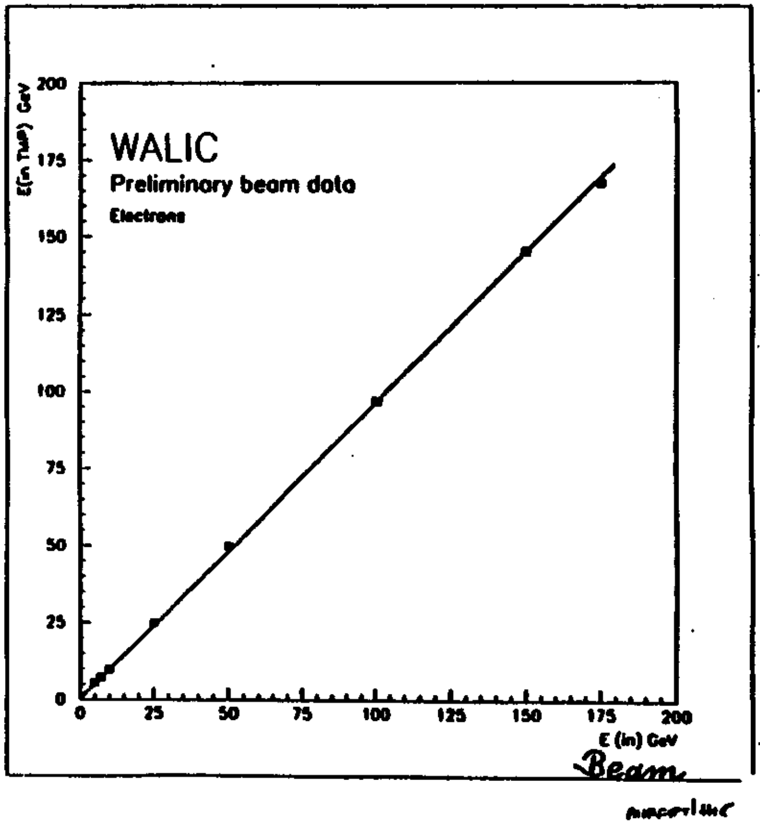


Figure 5(a). Electron energy from the 26 gap WALIC calorimeter vs. beam energy.

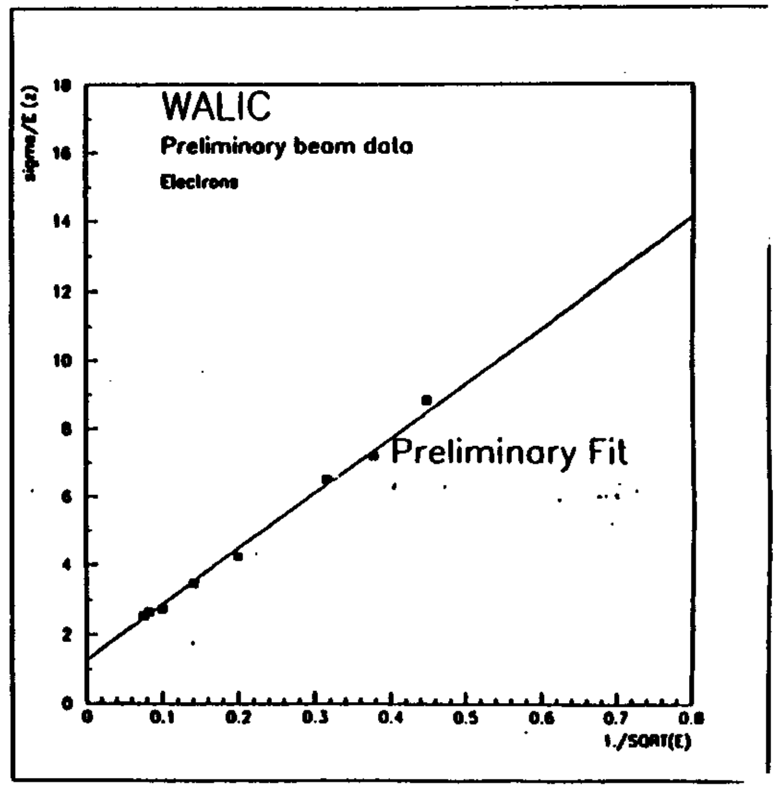


Figure 5(b). Electron energy resolution vs. beam energy for the WALIC calorimeter.

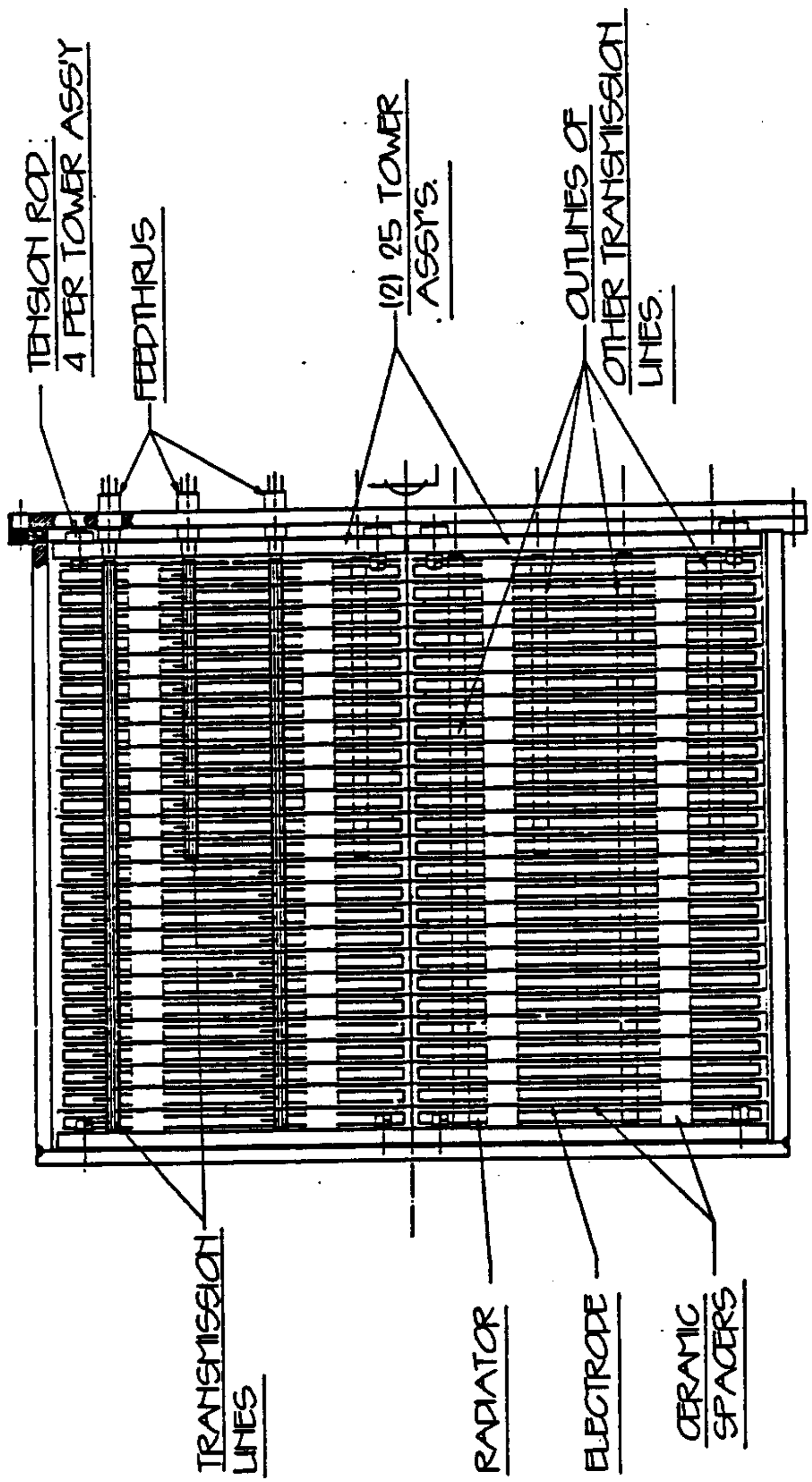


Figure 6. Drawing of the EM swimming-pool stack of tungsten plates.

Much of the design of this calorimeter has focussed on the development of the necessary electrodes, feed-throughs, spacers, and other structural elements, all of which are fabricated from ceramics and stainless steel. Attention has also been paid to extracting the signal from each tower in the fastest possible way. However, the greatest amount of time has been spent on producing radiator plates which can be immersed in the TMP without contaminating it.

The initial plan was to use stainless steel clad plates of depleted uranium. These plates were successfully produced, but difficulties arose when it came time to clean them, a process which had to include a high temperature bakeout. At the same time, as a contingency plan, tungsten plates were being produced, and after several iterations a cleaning procedure has been found for them. Although it has lower Z, tungsten has a similar density to uranium, and if it can be procured for a reasonable cost would allow for a very compact EM calorimeter section in an SSC experiment.

The final assembly of this prototype is underway at Harvard. The filling and initial testing (with cosmic rays) will occur at LBL this fall, whence it will be shipped to Fermilab for beam tests.

B. The Test Beam Module.

The primary goal of the warm-liquid calorimetry R&D program is to design, fabricate, and test a calorimeter module that will serve as a "proof of principle" of the warm-liquid technology's relevance to a large colliding beam detector. This Test-Beam Module (TBM) is designed in a "swimming-pool" configuration (i.e., the absorbers inside a liquid volume), that meets safety, hermeticity, hadronic compensation, resolution, and time response requirements for an SSC detector. Furthermore, it is possible to extrapolate this design to a real SDC calorimeter module (and probably for other experiments, as well) without major conceptual changes.

The design of the TBM utilizes many of the features that we envision being used in an actual calorimeter for an SSC detector, such as the "electrostatic transformer" readout, fine transverse segmentation in a tower configuration, and materials that lend themselves to efficient mass production techniques. The most time consuming part of the design phase of the TBM has been creating a module that uses only materials we are sure will be compatible with TMP. It has also been a challenge to eliminate any volumes that would trap air, since oxygen is very electro-negative and its presence would decrease the free-electron lifetime in TMP. We believe that we have overcome these constraints and have a design that fulfills all the requirements.

The conceptual and technical design phases of the TBM are now complete, and detailed fabrication drawings are being finished. Each of the modules is about five interaction lengths deep, and 60 cm on each transverse side, comprising a five by five array of 12 cm square towers. The towers are read out in the electrostatic transformer configuration, summed so that there are four depths for the total of ten interaction lengths. An interesting feature of the design is that each layer of ten gaps is assembled from prefabricated, self-contained one-by-five arrays. A conceptual assembly drawing is shown in figure 7, and a detail of the tie-rod and insulator interface is in figure 8. Each unit of this ten-gap building block has one signal plate in the center that collects the signal from two "electrostatic transformers" with a "turns ratio" of five. The advantage of this construction technique is that a one-by-five is small enough and sufficiently self contained that it can be built, cleaned, and tested independently of the final assembly of the large modules.

EG&G is doing the final drawings and analysis of the containers for an electromagnetic and two identical hadron modules. At this time we are not sure whether we will be able to use the EM module being built for the present WALIC test (described above), or whether we will have to construct a new one. Design of handling fixtures and shipping containers is beginning. We expect the TBM to be in place and ready for a beam test in June, 1991.

Some long lead items, such as ceramic insulators, tooling for the lead plates, and the lead plates themselves are in the bid and procurement cycle. We have performed tests on the ceramic insulators to see that they are strong enough to support the lead, and have built a one-by-one module and are in the process of building a one-by-two module at this time. The one-by-one has begun testing, and its performance is described elsewhere in this report. The sub-assembly and parts tests are continuing. A high voltage test fixture for the insulators and Kapton has recently been completed and will be used to test the electrical design and obtain information about the proper test procedures to use during fabrication and assembly of the TBM.

C. Supporting R&D

Much of the R&D performed up to now has concentrated on the fundamental properties of warm liquids. The primary goal of the R&D to be performed in the future is to understand the system-related issues of warm-liquid calorimetry and how it fits into and influences a detector and its physics performance. Nevertheless, it is necessary to continue some level of small-scale R&D in support of the construction and test of the TBM and the possible construction of a warm-liquid SSC calorimeter. These R&D projects are being done at essentially all of the collaborating institutions, and because of their importance and difficulty, some of them are being done in parallel at more than one institution.

C.1. Liquid purity, material compatibility, and long-term stability

Much progress has been made in the production of high-purity warm-liquids, particularly TMP (C_9H_{20}) and TMS ($(CH_3)_4Si$). The ionization electron lifetime in the liquid is very sensitive to impurities. For signal collection to be insensitive to modest changes in the liquid purity, one would like purities corresponding to ionization electron drift lifetimes of better than roughly ten times the signal shaping time of 50 to 100 ns, that is, better than about 0.5 to 1 µs. In this collaboration, the LBL and Saclay groups have achieved lifetimes in TMP of better than 100 µs. Collège de France has attained lifetimes in TMS of about 100 µs. The University of Pennsylvania and our Japanese collaborators, deliberately using modest and very simple cleaning procedures, have gotten lifetimes in TMS of about one microsecond. The latter results can be easily improved. The LBL purification and filling system is designed to handle TMS as well as TMP, and the

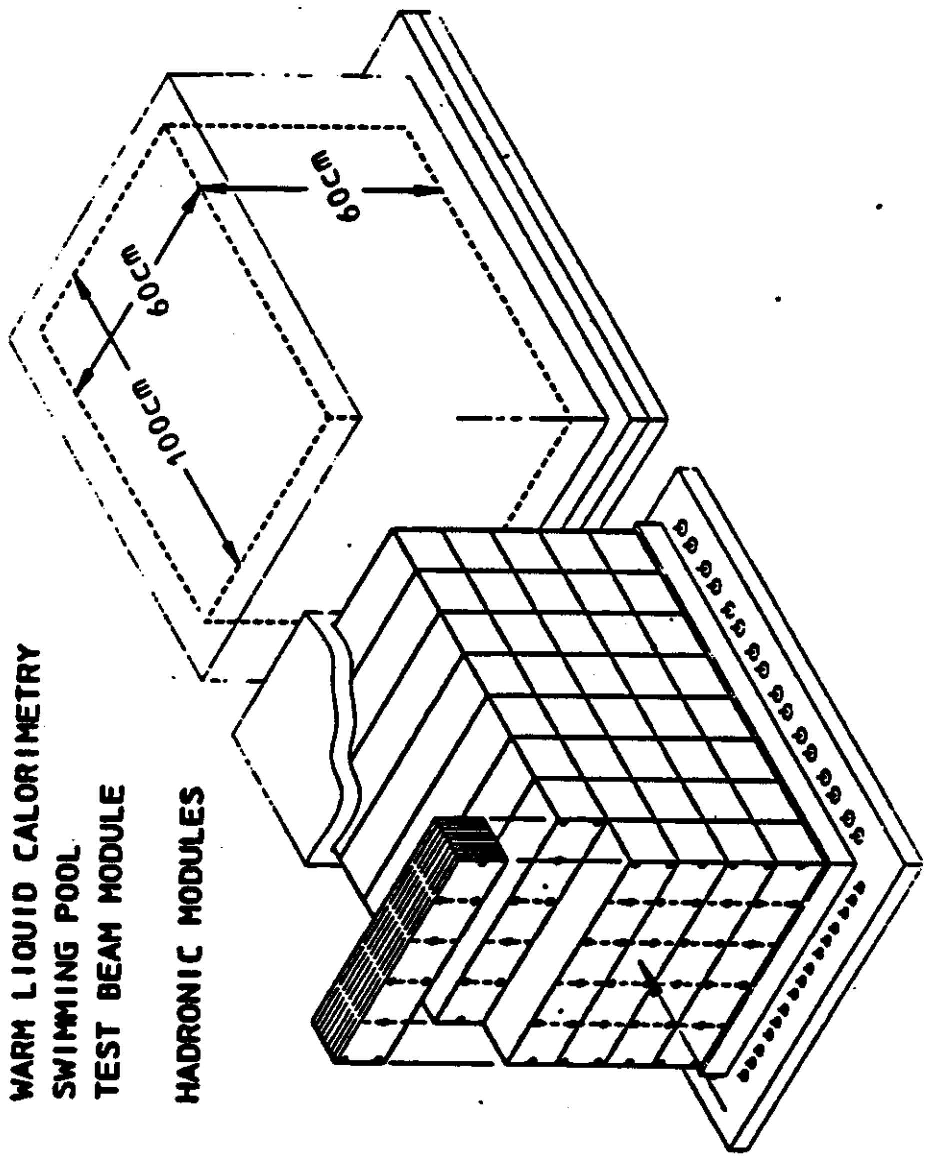


Figure 7. A conceptual drawing of one TBM module showing how a one-by-five preassembled module is assembled into the stack.

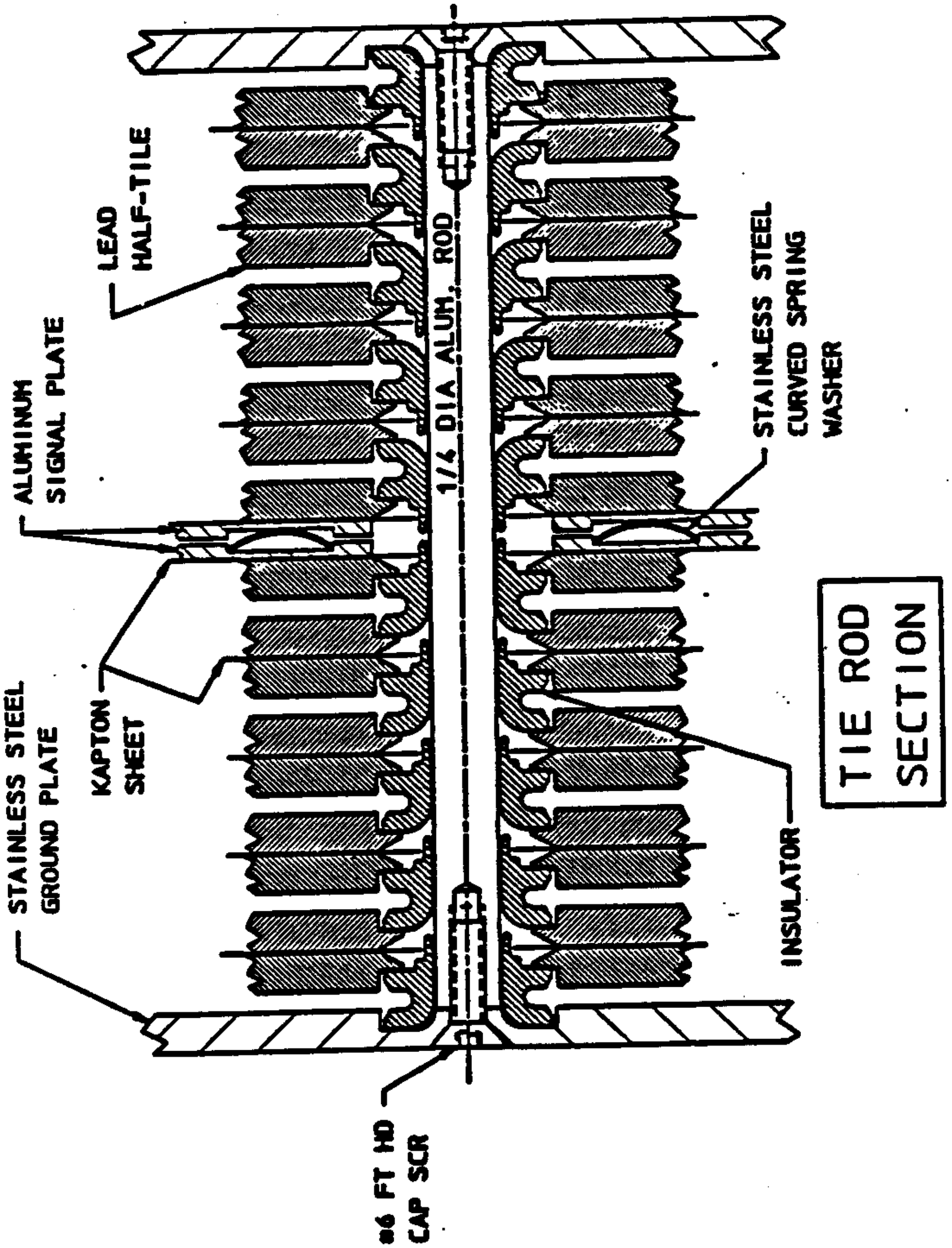


Figure 8. Detail of the ceramic insulator - lead tile interface of the TBM.

Saclay group system can be adapted for TMS, if necessary. The Penn system is capable of purifying almost any liquid ionization medium in addition to TMS.

Materials compatibility is one of the most important issues, since it has a profound impact on the design and cost of large warm-liquid calorimeters, and has, in fact, already had considerable influence on the design of the TBM. There are two approaches to studying compatibility: tests of individual materials in small test cells, and tests of mock-ups or prototypes of calorimeter modules including all of the materials that are intended to be used in the final device. Both of these techniques are being used by the collaboration.

We have learned that properly cleaned stainless steel, copper, lead, aluminum, ceramic (alumina), and Kapton can be in long-term contact with TMP (or TMS) without affecting the free-electron lifetime. Figure 9 is a check-off of the materials that have been tested by at least one member of the collaboration. Much more needs to be known about the compatibility of various materials (and their surface treatment) in contact with warm liquids in order to be able to reduce the cost of a very large calorimeter. Foremost among these materials are moldable plastics for insulators and structural members, and cements and other glues for inexpensive assembly.

Two particularly interesting tests have recently started. At Collège de France, a sample of Kapton and lead, glued together with Kerimid 500 shows no decrease in the free-electron lifetime of better than 50 μs. This is particularly interesting because it raises the possibility of using glues as part of the calorimeter assembly process. Gluing together multiple layers of Kapton, for example, will largely eliminate high-voltage punch-through due to weak spots or pin holes in single layers. Tests of Kapton laminates using glues and cements particularly designed for Kapton, and chosen to be non-electro-negative are starting at LBL.

The other recent test of particular interest is the operation using cosmic rays of a ten gap stack with lead and ceramic insulators at the University of Pennsylvania. This stack was cleaned with normal chemical processes and assembled, put into their test apparatus, pumped down, and filled with TMS. It has now been running long enough to convince us that a practical system with lead in contact with TMS will work. The free-electron yield as a function of immersion time in TMS is shown in figure 10. More recently, a stack with lead plates separated by Kapton sheets and supported by ceramic insulators has started to be tested. This device was fabricated and cleaned at LBL, shipped to Penn, assembled there, and put into their test apparatus. The results are very preliminary, but it appears that the device did not decrease the free-electron lifetime in the TMS.

C.2. Fast Signal Response and Signal-to-Noise.

A critical issue for any liquid-ionization calorimeter used at the SSC, whether liquid argon or warm liquid, is to develop a fast signal response with good signal-to-noise. It is one of the most important parameters of a calorimeter, and one of the most difficult challenges for the warm-liquid R&D.

material	LBL	Japan	PENN	Saclay	College de France	UA1
Stainless Steel	◉	◉	◉	◉	◉	◉
Indium		○				
Copper	◉	◉			◉	
Teflon		○				
Viton		○	○			
Macor		○				
Lead	○	○	◉		◉	
Aluminium	◉					
G10						
Kapton	○					
CERAMIC	◉			◉	◉	◉
Vespel					○	
Peek					○	
TUNGSTEN					◉	

◉ : good

○ : tests underway but not completed yet. Preliminary results look promising.

Figure 9. A check list of the test done to date on material compatibility.

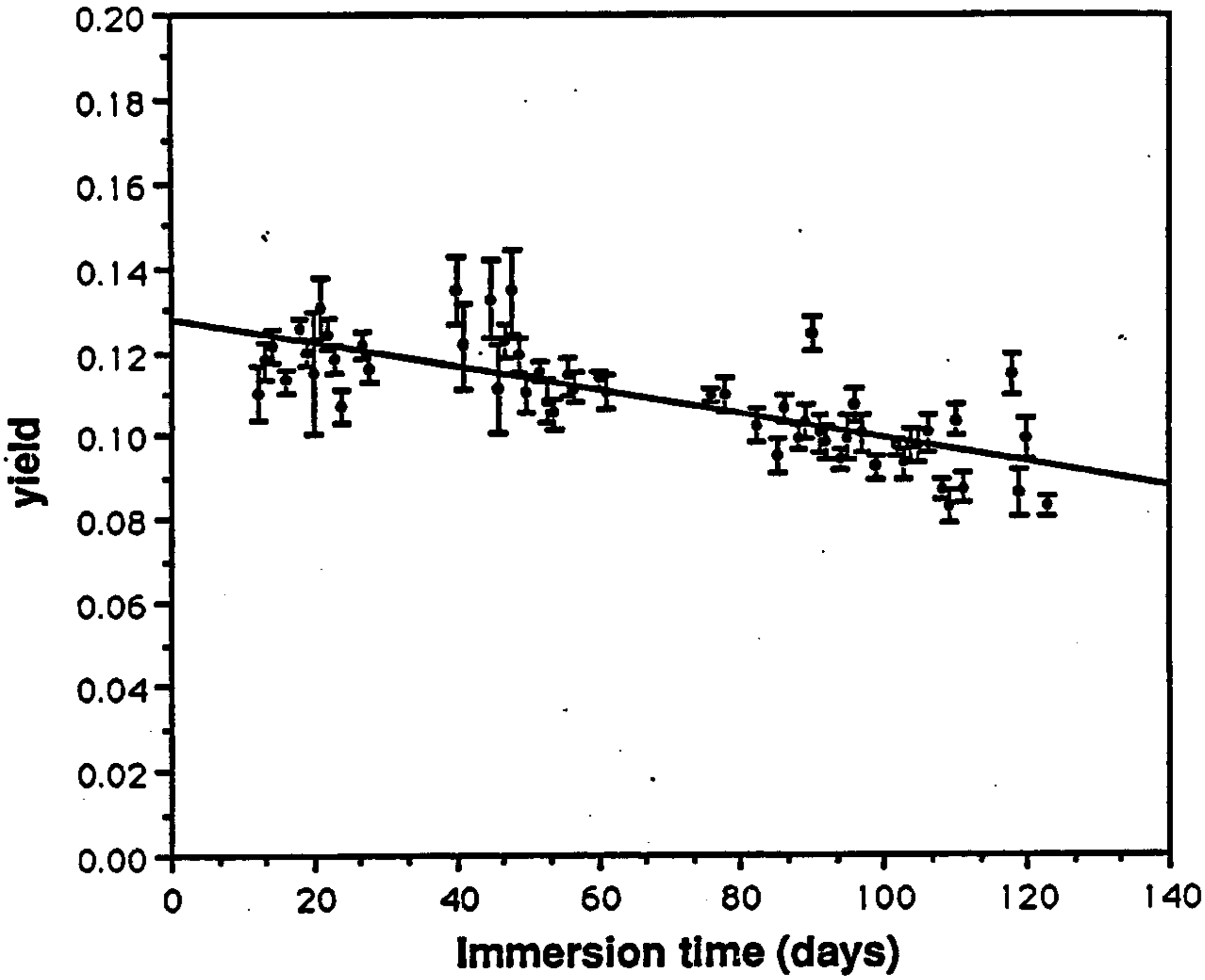


Figure 10. Free electron yield as a function of immersion time in a multi-plate lead and TMS detector.

A large fraction of the Generic R&D effort has been devoted to improving the response time of the warm-liquid designs. We have had considerable success in two methods of reducing the response time and increasing the signal-to-noise: using higher gap voltages, and reducing the effective capacitance by the use of the "electrostatic transformer."

Unlike liquid argon, the velocity of free electrons in warm liquids does not saturate at low fields. Since the signal-to-noise depends on the peak current, faster drift velocities help. We have attempted to design the TBM to operate at 50 kV/cm instead of the nominal 25 kV/cm, in order to test this and the system consequences of high voltage operation. Furthermore, although TMP has been the primary warm liquid used in the R&D, because it is easier and safer to handle, the drift velocity in TMS is much faster. The safety issues of TMS must be studied.

The charge transfer time depends on the tower impedance, as well as the length and impedance of the connecting cable. To minimize this, it is essential to reduce considerably the tower gap capacitance, C_d. We have developed and tested a novel approach of ganging tower electrodes in a combination of series and parallel connections to reduce the overall tower capacitance substantially. The arrangement would then act as an electrostatic transformer (EST), so-called because it behaves from the preamplifier point of view very much the same as a ferrite core transformer. Unlike the ferrite transformer, the operation of the EST is unaffected in the presence of a strong magnetic field. Thus, liquid ionization calorimeters with EST matching of tower and pre-amp capacitances are especially advantageous in a strong magnetic field.

One of the questions that we have investigated this year is the amount of cross-talk to neighboring towers. This issue is exacerbated by the EST design relative to the straightforward parallel hookup. A three-by-three aluminum model shown in figure 11(a) was constructed and tested with injected pulses at LBL. The results shown in figure 11(b) indicate that cross-talk will not be a major problem.

Both the warm liquid R&D and the liquid argon R&D groups have had considerable success with simulations, mock-ups, and small calorimeter tests of electro-static transformers, and both groups continue to study them. Nevertheless, signal-to-noise remains one of the major questions for liquid ionization detectors and we are energetically studying the issues. Figure 13 shows the results of a simple model calculation that compares the multi-gap signal-to-noise of liquid argon, TMP, and TMS for various shaping times, under the particular assumptions of fixed liquid depth of 10 cm and area of 0.01 m^2 per plate.

The TBM hadronic modules are constructed as electrostatic transformers and will provide the first large scale beam test of the design.

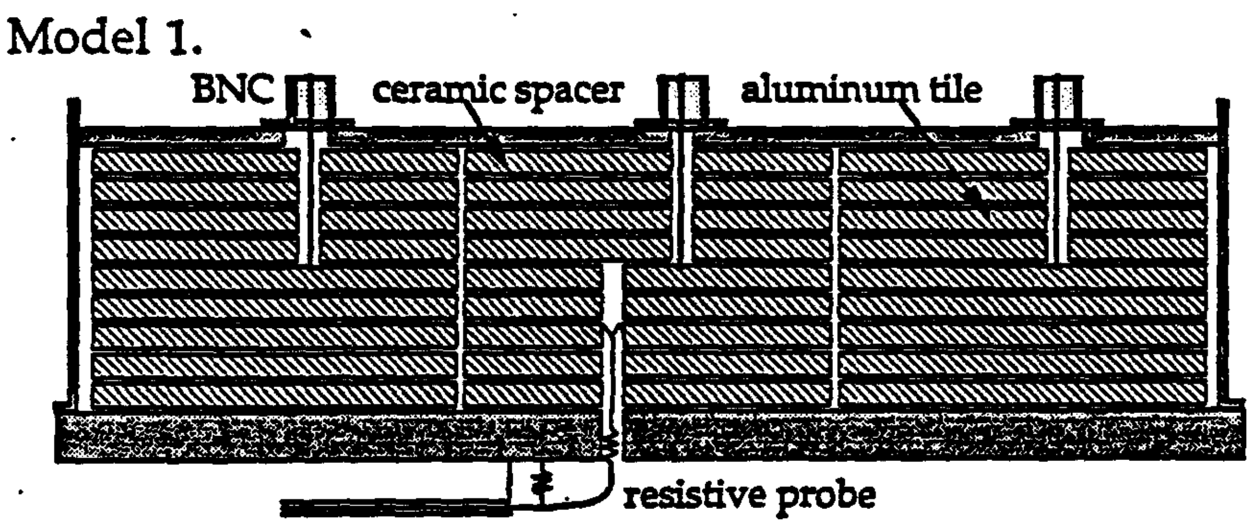


Figure 11(a). A 3-by-3 aluminum mock-up of an elestrostatic transformer readout used to test charge transfer time and cross-talk. The resistive probe injects charge, and the signal is read out through the BNC connection.

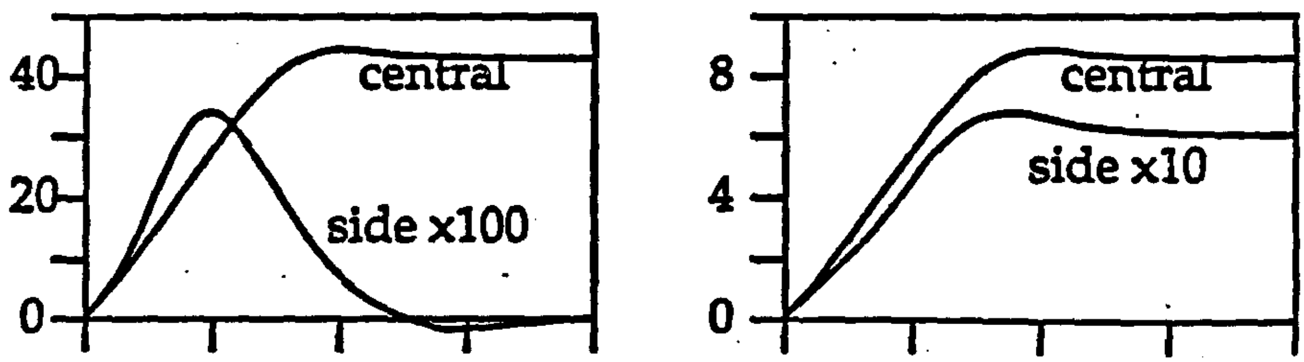


Figure 11(b). The central tower signal vs. time for an transformer ratio S = 4 EST readout plotted along with the cross talk signal. The value M is the number of plates that have charge injected onto them. Note that the cross talk signal is multiplied by a large factor to make it appear on the same scale.

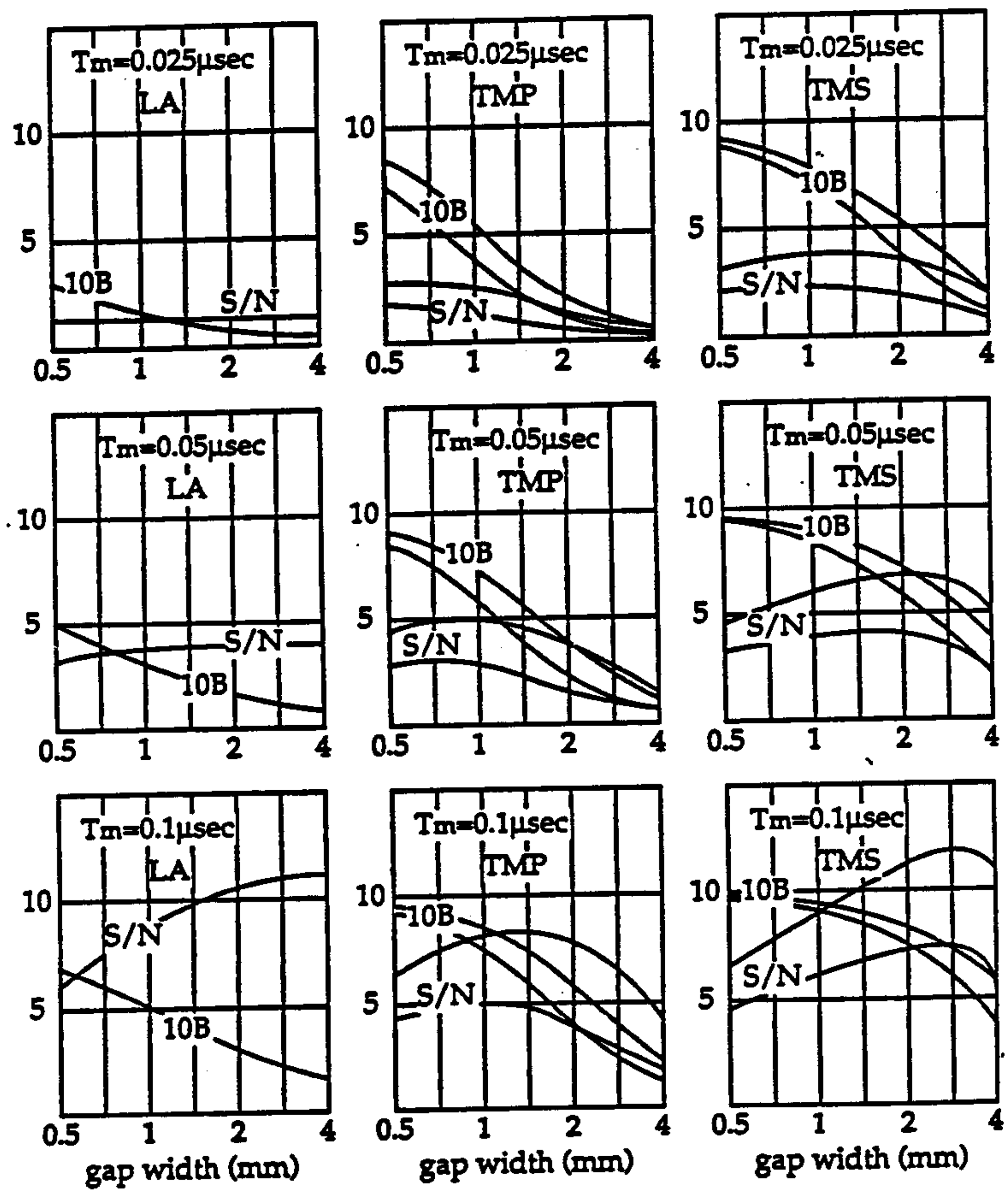


Figure 12. Signal -to-noise (S/N) and pile-up sensitivity (B) for liquid argon, TMP, and TMS, for various shaping times, T_m. Small values of B indicate greater relative sensitivity to pile-up. The assumptions are multi-gaps with a total liquid depth of 10 cm, and a plate area of 0.01 m^2.

V. Plans for the Fiscal Year 1991 R&D Program

The major goals of the 1991 plan are:

A. Completion of the WALIC beam tests.
B. Fabricate and commence testing of the TBM.
C. Continue material compatibility studies related to the TBM and to a practical SSC calorimeter module.

We discuss these briefly, and submit the budget request for the U.S. part of the program.

A. Completion of the WALIC beam tests.

During the fall of 1990 we will complete the the installation of the WALIC calorimeter to its ultimate depth of 13 interaction lengths. We will then be prepared to make a more rigorous study of the electron/hadron compensation and the general question of resolution and shower development. We also intend to do a study of the behavior of the calorimeter with steel radiator in place of the lead. This is of particular interest because if such calorimeters work well and are compensated, they are much easier to design and less expensive to build than calorimeters with almost any other radiator material.

The next phase of the experiment starts in January, and continues to the end of the fixed-target operation at Fermilab, in May or June, 1991.

B. Fabrication and test of the TBM

We are presently in the procurement and fabrication phase of the TBM. We expect to have the TBM completely assembled at LBL and ready for shipment in the late spring of 1991. The only design work that still remains (aside from surprises) is shipping containers and liquid handing equipment. If, as we presently expect, the tests will be at CERN, the modules will hopefully be filled at CERN, using the UA-1 equipment, and only a small amount of additional equipment would then be necessary. If the tests are at Fermilab, we will fill the modules from containers that are themselves filled either at CERN, Saclay, or possibly at Wiley Organics, Inc., the supplier of the liquid. In this case, we will need to design and build extra liquid handling equipment for use at Fermilab.

It would be most convenient and efficient for us to perform these measurements in the same test beam (MT6, at Fermilab) as we are using in experiment E-795, but it appears that our already aggressive schedule will not overlap with available Fermilab beam. As a result, we will soon begin negotiations with CERN for a test beam starting in June, 1991. We expect that the first phase of the run, a "proof-of-principle," will require about three months. Improvements and further tests might take another three months, resulting in completion in the late fall of 1991.

The beam requirements for the TBM test are rather modest, except for the energy range required of a high-energy beam. The most troubling requirement is the schedule. It appears that there may be no available high-energy beams in the United States during the relevant test period.

Table 3
Test Beam Requirements for
Warm-liquid R&D

Intensity	low	a few to a few thousand per pulse
Highest energy	200 GeV	
Lowest energy	5 GeV	
Other Requirements:	The beam must have an efficient electron tagging system. The beam must contain electrons as well as hadrons at all energies.	

C. Basic supporting R&D

The supporting R&D is mostly concerned with material compatibility, although there are a few other issues that should be studied related to a design for a realistic SSC detector calorimeter.

C.1. Material purity and compatibility

The major goal is to continue studies related to the TBM. Although the design is essentially frozen, there are still some details that need to be tested, and a few design options still possible. Among the details are the type of glue used to make Kapton laminates and tests of the actual type of commercially purchased feed-throughs, ceramics, and resistors. Among the design options are the choice and verification of cleaning procedures and the possibility of gluing lead plates in preassembly. Of course, the more information and understanding we have of the compatibility issues, the more likely we are to be able to design and build a successful SSC calorimeter. It is interesting that most of the admittedly limited set of materials that have been so far tested have turned out to be acceptable if properly processed. We intend to continue and even upgrade the material investigations in the U.S., particularly at Penn and LBL.

C.2. Radiation Resistance

It is very attractive to build a forward calorimeter ($\eta > 3$) using warm-liquid technology. It appears unlikely that so;lid scintillator will survive the radiation exposure. The cryostat required for liquid argon, a problem in any calorimeter, is a particularly difficult one for the forward piece. As a result of these considerations, it is important to resume the studies of the radiation resistance of warm-liquids.

The most comprehensive study in TMP and TMS to date has been performed by R.A. Holroyd of BNL,[1] in which he exposed the liquids to radiation from an intense Cobalt-60 source, up to doses of 10^5 Grays (i.e. 10^7 Rads). Even for this maximum dose, only about 1% of the liquid suffers from radiolysis decomposition. The conversion products are predominantly other saturated and unsaturated hydrocarbons or silanes, which do not attach electrons, and, therefore, do not significantly decrease the free-electron lifetime. Hydrogen and other gasses released by radiolysis are easily vented. Holroyd estimates that the effect of radiation damage from neutrons to be equal to or less than gamma rays. This needs to be verified empirically and we will do so by exposing TMP to large doses of neutron radiation. It is likely that warm liquids will perform very well, even at the most intense radiation levels expected at the SSC.

D. Milestones, responsibilities, and plan changes for fiscal year 1991

The milestones are as follows:

1.	Completion of WALIC test	May, 1991
2.	Complete fabrication of TBM	May, 1991
3.	Start TBM beam test	July, 1991

The responsibilities of the collaborating institutions are essentially the same as they were in fiscal year 1990, and are shown in Table 1.

We do not envision any changes in our basic plan from that stated in the Large Subsystem Proposal. We have made good progress, and the plan has proved to be both relevant and realistic.

Table 4
Warm-Liquid Calorimetry R&D
U.S. Budget for FY 1991

Overhead not included	LBL (K$)	Hvd (K$)	Penn (K$)	Alabama (K$)	Total (K$)
I. WALIC Calorimeter Experiment	120	20	10	30	180
II. Test Beam Module					
A. Engineering design and construction					
1. Mech. Engin. & Design	100				100
2. Elect. Engin. & Design	30	20	5		55
3. Constr. & Fab. Labor	150	10	10		170
4. Component & outside Costs	250				250
5. Shipping containers	25				25
6. TMP purch. & shipping	90				90
7. TMP Filling Equipment	30				30
8. Clean room upgrade	20				20
9. Contingency	100				100
Subtotal	795	30	15	0	840
B. Verification of Stacks for TBM					
1. Engineering					0
2. Technicians			10		10
3. Materials & Assembly			20		20
Subtotal	0	0	30	0	30
C. Mat. Compat. Verification for TBM					
1. Fab. & Maintenance of Cells	20		50		70
2. Experimental Program	60		20		80
Subtotal	80	0	70	0	150
D. Electronics for TBM Test					
1. Fast Readout Electronics	0	25	25	10	60
2. Other Electr. & Test Equip.	0	0	0	0	0
Subtotal	0	25	25	10	60
E. TBM Test at CERN					
1. Test expenses	50	20	20	20	110
2. Travel & living at CERN	45	10	10	10	75
3. TBM shipping	25	0	0	0	25
Subtotal	120	30	30	30	210
Subtotal for TBM Fabrication & Test	995	85	140	40	1260
III. Travel (not incl. TBM test)	15	5	5	5	30
Total	1130	110	185	75	1500

---

1 R. A. Holroyd, Radiation Effects in the SSC, M.G.D. Gilchriese, ed., SSC-SR-1035