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PROGRESS REPORT OF A RESEARCH PROGRAM IN EXPERIMENTAL AND THEORETICAL HIGH ENERGY PHYSICS

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For the Research Period
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NOTICE

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I. INTRODUCTION

This report covers the work accomplished during the preceeding five month period in the high energy physics program in the Department of Physics at Brown University.

The program is organized into several Tasks. Two of the Tasks are in theoretical physics (A and D) and two are in experimental physics (B and C). There is an Outstanding Junior Investigator Award in experiment (J). A final Task (S) comprises the technical support for the experimental tasks. (There is also a Task E which is for an SSC sub-system but is not supported by this office.)

II. PROGRAM IN THEORETICAL PHYSICS

A. TASK A

Progress Report for a Research Program in Theoretical High–Energy Physics

The High–Energy Theory Group (Task A) of Brown University has been carrying out a research program in theoretical high energy physics with the support of DOE. Currently, Professors Robert Brandenberger, Herbert M. Fried, Antal Jevicki, Kyungsik Kang and Chung-I Tan are Principal Investigators of the Theory Group (with Antal Jevicki serving as the Person–in–Charge from July 1991 to June 1992). The Group includes, in addition, one Assistant Professor (Research), one Research Associate, Graduate Research Assistants and Visiting Research Faculty. This report serves to summarize the progress which has been made since 1 January 1992 when the DOE contract was replaced by the Grant. The report for Task A is divided into three sections.

1. Individual Physics Research Contributions
2. Theoretical Papers Issued Since 30 June 1991
3. Scientific Personal Associated with the Theoretical Program

The research activities of the high energy theory group at Brown University have always covered a broad spectrum of topics in the theory of elementary particles and fields commensurate with the research specialties of its personnel. The Group has continued to produce a significant output of important papers with new ideas and calculational techniques in topics of high interest. All of our regular staff have continued to actively work in a variety of research projects of interest and importance, with considerable impact on their evolution and development.

1. Individual Physics Research Contributions

Prof. Brandenberger's research in 1991/92 has focused on topics at the interface between particle physics, quantum field theory, gravitation and cosmology. In particular, his students, collaborators and he have been studying electroweak baryogenesis, topological defects, structure formation with global textures, cosmological perturbations, nonequilibrium entropy and new higher derivative gravity theories without singularities.

Anne Davis (Cambridge) and Prof. Brandenberger have been studying electroweak baryogenesis. They proved [6] the inequivalence of the three recently proposed baryogenesis mechanisms. They were also able to find a mechanism by which one can generate a net baryon number at the electroweak scale in models with a second order phase transition[19]. Their mechanism uses electroweak strings as the locus where the baryon number violating processes occur out of thermal equilibrium. In further work they explored general mass bounds on particle physics models containing stable high mass particles or defects.[7] They also discussed new constraints on models with superconducting cosmic strings[9].

Prof. Brandenberger with his students, Tomislav Prokopec and Andrew Sornborger, have been studying aspects of global textures. They performed a careful numerical analysis of the dynamics of textures.[10] They showed that spatial gradient terms are very important in the evolution of textures.[15] His senior thesis student Stephen Ramsey and Prof. Brandenberger started an analysis of new statistics for large-scale structure. Their work shows that the texture model is ruled out since it produces the wrong topology of large-scale structure. The standard CDM model and two variants of the cosmic string theory with hot dark matter produce results within the statistical error bars of the data.

Slava Mukhanov (Moscow), Hume Feldman and Prof. Brandenberger completed their long review article on the classical and quantum theory of cosmological perturbations [1,2,3]. The review is currently in press in Physics Reports. Their analysis allows a consistent description of the generation and evolution of perturbations in inflationary Universe models. Prof. Brandenberger has been invited to present our results at a couple of international conferences.[13,18] As a further application of this theory, Tomislav Prokopec, Slava Mukhanov and Prof. Brandenberger discussed a new nonequilibrium definition of entropy. They demonstrated that on the scales of galaxies and clusters, this entropy dominates over the entropy of the cosmic microwave background on these scales.[16,17]

Slava Mukhanov, Andrew Sornborger and Prof. Brandenberger have been working on a new higher derivative theory of gravity in which they hope no singularities will appear. So far they have verified[12] that all homogeneous and isotropic solutions are nonsingular. Thus, there is neither a Big Bang nor a Big Crunch singularity in this model. Their model has many consequences for particle physics and quantum gravity. Black hole radiation will turn off once the hole shrinks to some minimal radius. There is no loss of quantum coherence, and global charge is not violated.

Prof. Fried's research efforts during the past academic year have concentrated on two main topics, the first an approximate, infrared (IR) approach to a class of nonlinear differential equations; and the second the current topic, an analytic approach to confinement in four-dimensional QCD. In addition some approximate solutions have been found for the intense, crossed-laser problem in QED.

The first method, developed in conjunction with Dr. J-D Fournier of the Observatoire de Nice, represents a steady progression and application of previous IR techniques applied to the more complicated case of a nonlinear Duffing equation with damping; in this study, an expected limit-cycle behavior was reproduced by the approximations of the IR Method.

The second topic, and the subject to which all attention is now being paid rewrites the full QCD gauge theory in the form of a "modified" QED for field strengths, rather than vector potentials, and generates in a resonable "Gaussian" approximation an effective gluon propagator (EGP), which displays confinement about a flux-tube structure, as well as finite expectation values for the gauge-dependent $g < A >$ and the gauge-independent $g^2 < F^2 >$. This EGP is acausal, permissible for confined gluons, and contains a matrix-valued mass so that the value of the "gluon's mass" depends upon which process one is describing. An extension of the formalism to include quarks is underway.

During the past year **Prof. Antal Jevicki** has concentrated his attention on formulating and investigating basic symmetries of low dimensional string theories. In collaboration with J. Avan, a large W_∞ symmetry was discovered as a space–time symmetry of collective string field theory[20]. A related symmetry algebra was subsequently found in the conformal approach by Witten and Klebanov and Polyakov[21]. It is expected that these symmetries are of fundamental importance. Continuing their collaboration, Prof. Jevicki and Dr. Avan have proceeded to extend their work in two different direction. In the first (HET-839) starting from W_∞ they address the question of general field theoretic representations. Using the coadjoint orbit method they show that the collective field theory follows but also exhibit a sequence of much larger theories. In HET-847 Avan and Jevicki study systematically algebraic theories with W_∞ as a spectrum generating algebra. In addition to the critical oscillator potential which was well known in matrix models a new potential of singular type was also discovered, its relevance might come in connection with a black hole type classical background.

Professor Kyungsik Kang has continued to study two main topics (1) the new threshold model that he proposed, in collaboration with Dr. A. R. White of Argonne National Laboratory, to explain high energy elastic and diffractive scattering and its consequences, and (2) the quark flavor mixings. The new threshold model was proposed to explain the large UA4 result for the real part of the elastic $p\bar{p}$ forward scattering amplitude and the low E710 results for the total cross–section at the Fermilab Tevatron. The more recent E710 result on the real part of the forward elastic scattering amplitude and the preliminary CDF results on the total cross–section strengthen, if any, the validity of the new threshold model[23], suggesting a very likely possibility to find a new physics effect beyond the standard model in the high–energy elastic scattering, a non–perturbative domain of QCD. In HET-837 the new threshold model is compared to the Odderon model in confronting the high–energy data on the real part of the forward amplitude and the total cross–sections. In HET-838, Kang and White discussed a possible origin of the new physical threshold. They suggest that a short–lived axion–like particle "η_6" with mass around 30 GeV must be produced diffractively at the hadron colliders. Just like the mini–centauros and

Geminions in Cosmic Ray experiments. It is argued that η_6 is the lightest particle belonging to a new color–sextet quark sector of QCD, which could be responsible for dynamical symmetry breaking of the electroweak interaction. Properties of η_6 are discussed to suggest how η_6 can be found. In HET-833, Professor Kang made a comprehensive and focussed review of the current status of high– energy elastic scattering.

In HET-843, Professor Kang, in collaboration with the Dortmund group headed by Dr. E. Paschos, made a careful comparison between the experiments as the predictions for the flavor–mixing matrix elements from the Fritzsch–type mass matrix by making use the multiple parameter function minimization program MINUIT from the CERN computer library. All parameters of the mass matrix are varied so as to find the best parameter set that gives the minimum χ^2–value. Our results show among other things that the Fritzsch mass matrix Ansatz can be consistent with experiments but the strange quark mass must be around 99 MeV, somewhat lower than the commonly quoted values, and the top quark mass is predicted to be about 109 GeV.

Prof. Chung-I Tan has been studying matrix models intensively as possible models for nonperturbative string theories. These models arise as a simplified discrete approximation to the full functional integral over metrices in 2-D quantum gravity. One of the more intriguing features of these studies is their connection with integrable hierarchies. For instance, it was first recognized that a "double– scaling" limit near a critical point of a Hermitian one–matrix model, in which one sums over contributions from all general, leads to a specific heat which satisfies the Painleve–I equation. Other higher multicritical points have been shown to be related to the KdV hierarchy. In spite of these dramatic advances, many questions, both technical and conceptual, remain to be answered and explored. It is therefore worthwhile having many solvable models available, each not only providing a testing ground for checking various working hypotheses such as universality but also possible revealing new nonperturbative structures. In this spirit, Prof. Tan has carried out extensive studies using various types of one–matrix models. For instance, in collaboration with K. Demeterfi[24] they have studied general nonperturbative solutions of one–matrix model based on unitary matrices. They have shown that a unitary matrix models contains a richer scaling structure that the corresponding Hermitian models. In particular, depending on how the double–scaling is taken, it is possible to recover the KdV hierarchy within the framework of unitary–matrix models. Prof. Tan has also examined other matrix models, in particular the generalized Penner models where the matrix potentials are non–polynomial, containing logarithmic terms[25]. One finds that the topological expansion for the free energy develops a logarithmic singularity already at the sphere level, corresponding to having a scaling violation. The model was initially introduced for calculating the Euler characteristic of the moduli space of Riemann surface at a fixed genus and punctures. It is intriguing that the basic model also recovers certain features of the $c = 1$ string compactified at the self–dual radius. By treating these as conventional matrix–models, Prof. Tan was able to clarify many puzzles surrounding these models. Further generalizations of these works are currently being investigated.

Dr. Jean Avan has concentrated on various aspects of the theory of classical and quantum integrable models. He has constructed integrable generalization of the Toda and Volterra lattice models, the continuum limit of which generalizes the well–known Korteweg–de Vries hierarchy.[27] Dr. Avan has investigated the quantum Neumann model (harmonic forces on a point particle constrained to stay on a n-sphere): the Uhlenbeck–Moser quantum commuting observables are shown to arise directly from a new 2×2 Lax operator formulation obeying a linear commutation relation, instead of a quadratic relation á la Sklyanin. This work was done in collaboration with M. Talon (LPTHE Paris 6, France).[28]

In collaboration with A. Jevicki, Dr. Avan has established the classical integrability of the one–dimensional string collective field theory of Jevicki and Das, explicitly constructing commuting conserved quantities which, moreover, are identified as the Cartan algebra of a W_∞–linear Poisson algebra. Background independence was shown to hold for a x^2-external potential.[26] They then established the quantum integrability of this same model, constructing a complete non–abelian W_∞ algebra of eigen–operators for the full Hamiltonian with x^2– potential.[29] They finally showed that such a complete construction was possible only for very few polynomial and rational potentials, in particular only for x^2 as a monomial. Another integrable case, $v(x) = x^2 + \frac{g}{x^2}$, yields a different but related algebra of eigen–operators known as $W_\infty(c)$ or Racah–Wigner algebra of SU(1,1).[31] They also used the W_∞ algebra structure naturally underlying the collective theory to construct natural integrable generalizations of it by means of the coadjoint orbit construction and the Adler–Kostant–Symes scheme.[30]

Dr. Paul Mende has been investigating QCD (the heavy quark limit) and string theory (high energy properties and non-perturbative effects). The large mass limit of QCD uncovers symmetries that are not present in the QCD lagrangian. Heavy mesons play a prominent role in our understanding of fundamental processes. From their weak decays we may extract fundamental parameters of thestandard model of electroweak interactions. Rare decays are sensitive to the presence of new fundamental forces, and they offer the exciting possibility of observing for the first time violation of CP invariance in a decay process. Straightforward interpretation of measured lifetimes and branching fractions is marred by the difficulties that strong interactions present for practical calculations. Monte-Carlo simulations of lattice QCD may eventually furnish accurate calculations of the matrix elements that are relevant to these processes. An alternative approach is furnished by the heavy quark effective theory (HQET) formalism, in which approximate spin and flavor symmetries are made explicit. The symmetries become exact in the limiting case of infinitely massive heavy quarks. In this regard it is of paramount importance to determine the accuracy of the large-mass approximation since in reality the charm and bottom quark masses are both only factors of a few larger than, say, the ρ-meson mass. Unfortunately, this issue involves non-perturbative matrix elements and is therefore hard to pin down. Dr. Mende, in collaboration with B. Grinstein (SSC), has investigated these issues using two-dimensional QCD in the $1/N$ expansion as a model of the strong interactions. In this exactly solvable model, one can explicitly compute the precise approach to the large quark-mass limit and test the validity of the approximations in the heavy quark effective field theory. It is found that the large-mass approximation is good, even at the charm mass, for the form factors, but it breaks down for the pseudoscalar decay constant.

In string theory, the principal challenge is to understand how gravity and quantum mechanics are reconciled in a consistent theory. Dr. Mende has examined interactions of energetic strings in compact spaces, where new behavior emerges: amplitudes are exponentially enhanced compared to typical high-energy processes. This is likely to have applications to string thermodynamics and cosmology, where the evolution of small-radius compactified dimensions is of critical importance. On another front, he has examined non-perturbative behavior of the non-critical 1+1 dimensional string field theory, and tentatively identified tunneling solutions in the semiclassical limit. These are likely to be important in making contact with the eigenvalue behavior of the matrix model approach, in understand non-perturbative symmetry break, and perhaps in elucidating the physics of the black hole solution which has been best viewed in the conformal field theory approach.

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2. Theoretical Papers Issued since 30 June 1991

HET-821	"Progress Report" 1990-1991"
HET-822	"Renewal Proposal"
HET-823	"The Effect of Topology on the Thermodynamic Limit for a String Gas", N. Deo, S. Jain, O. Narayan and C. I Tan.
HET-824	"Quantum Integrability and Exact Eigenstates of the Collective String Field Theory", J. Avan and A. Jevicki - *Phys. Lett.* **272** (1991) 17.
HET-825	"Vortices in Helium 3: An analog to Cosmic Strings in the Early Universe", R. H. Brandenberger. **Physica B**
HET-826	"Physics of the Very Early Universe", R. Brandenberger.
TA-470	"Proceedings
HET-827	"A Note on Electroweak Baryogenesis", R. Brandenberger and A. C. Davis. submitted to *Phys. Lett. B*
HET-828	"Cosmological Limits on Stable Particle Production at High Energy", R. Brandenberger and A. C. Davis. *Phys. Lett. B*(in press) 1992.
HET-829	"Topology of Large–Scale Structure in a Cosmic String Wake Model", J. Gerber and R. Brandenberger.
HET-830	"Superconducting Cosmic Strings and Primordial Magnetic Fields", R. Brandenberger, A. C. Davis and A. Matheson, submitted *Phys. Rev. D*
HET-831	"Nontopological Clobal Field Dynamics", L. Perivolaropoulos. submitted to *Phys. Rev. D*
HET-832	Give This Number To Next Conference
TA-471	
HET-833	"The Current Status of High Energy Elastic Scattering", M. M. Block, K. Kang and A. R. White, **Submitted Review of Modern Physics.**
HET-834	"BRST Cohomology and Physical States in 2D Supergravity Coupled to $\hat{c} \leq 1$ Matter", K. Itoh and N. Ohta.**Nuc. Phys. B**
HET-835	"Exact Results in Collective String Field Theory", A. Jevicki.
TA-472	"Proceedings of the XXth International Conference on Differential Geometric Methods in Theoretical Physics, Baruch College, New York, June 1991.
HET-836	"Logarithmic Scaling Violation in One-Matrix Models", C- I Tan
TA-473	"*Proc. of Particles and Fields '91*, Vancover, Aug. 1991, (World Scientific).
HET-837	"The Odderson Versus a New Threshold", K. Kang and A. R. White.,
TA-474	Proceedings of the Joint International Lepton-Photon Symposium and Europhysics Conference on High Energy Physics, Geneva, Switzerland, 25 July - August 1991.
HET-838	"η_6 Production", K. Kang and A. R. White.

TA-475	Proceedings of the Joint International Lepton-Photon Symposium and Europhysics Conference on High Energy Physics, Geneva, Switzerland, 25 July - 1 August 1991.
HET-839	"String Field Action From W_∞", J. Avan and A. Jevicki. *Mod. Phys. Lett.* **A7**, (1992) 357-370.
HET-840	"Texture Collapse", T. Prokopec, A.Sornborger and R. Brandenberger. **Phys. Rev. D**
HET-841	"Topological Defects and Structure Formation", R. Brandenberger.
TA-476	Proceeding of the 10th Seminar on Relativistic Astrophysics and Gravitation, Potsdam, Germany, October 21-26, 1991.
HET-842	"A Nonsingular Universe", V. Mukhanov and R. Brandenberger. *Phys. Rev. Lett.* **68** (1969) 1992.
HET-843	"Numerical Analysis of the Fritzsch Type Mass Matrices", K. Kang, J. Flanz and E. Paschos.
HET-844	"Spectrum of Two Dimensional (Super) Gravity", K. Itoh and N. Ohta.
HET-845	" Gauge Invariant Cosmological Perturbations", R. Brandenberger, Proceedings (Wiley Eastern Ltd.), New Delhi 1992. H. Feldman and V. Mukhanov.
TA-477	
HET-846	"Large-Scale Structure Models: Status and Problems", R. H. Brandenberger.
HET-847	"Integrable Collective Field Theories", J. Avan, A. Jevicki. to appear in *Comm. Math. Phys.* (1992).
HET-848	"Comment on: Are Textures Natural", R. Brandenberger, T. Prokopec and A. Sornborger.
HET-849	"Entropy of Gravitational Perturbations", R. Brandenberger, V. Mukhanov and T. Prokopec.
HET-850	"String Collisions in Compact Space", P. Mende.
HET-851	"Heavy Mesons in Two Dimensions", B. Grensten and P. Mende.
HET-852	"Dynamical Simulations of Semilocal Strings", A. Achucarro, K. Kuijken, L. Perivolaropoulos and T. Vachaspati.
HET-853	"Large Scale Structure by Global Monopoles and Cold Dark Matter", L. Perivolaropoulos.
HET-854	"On the Stability of Electroweak Strings", L. Perivolarpoulos and T. Vachaspati.
HET-855	"W_∞ Currents in 3-Dimensional Toda Theory", J. Avan.
HET-856	"On Shell Effective Field Theory and Off-Shell Matrix Elements in Two Dimensions", P. Mende.
HET-857	"Final Report for all Tasks - 1959-1991 "
HET-858	"Two-Dimensional Quantum Gravity, Matrix Models and String Theory" , K. Demeterfi.

3. Scientific Personnel Associated with the Theoretical Program: 1 January - 31 October 1992

H. M. Fried – Professor

A. Jevicki – Professor

K. Kang – Professor

C-I Tan – Professor

R. Brandenberger – Associate Professor

P. Mende – Assistant Professor (Research)

J. Avan – Research Associate

M. Li – Assistant Professor (Research) – As of 1 September 1992

K. Demeterfi – Graduate Research Assistant – Until 31 August 1992

J. Lee – Graduate Research Assistant

T. Prokopec – Graduate Research Assistant

A. Sornborger – Graduate Research Assistant

B. Urosevic – Graduate Research Assistant

K. Orginos – Graduate Research Assistant – As of 1 September 1992

N. Deo – Visiting Research Associate

L. Perivolaropoulos – Visiting Scientist

K. Itoh – Visiting Research Associate – Until 30 April 1992

N. Ganoulis – Visiting Associate Professor (Research – Until 30 June 1992

A. vanTonder – Visiting Assistant Professor (Research) – As of 1 September 1992

S. Mukhanov – Visiting Assistant Professor (Research) – Until 30 December 1991

B. Sazdovic – Visiting Scientist – Until 1 March 1992

B. TASK D

1. Progress Report for a Research Program in Computational Physics

The Monte Carlo method for calculation of Green's functions in high energy theory is more than a decade old. Initially the possibility of an actual numerical solution of quantum field theory seemed plausible and many of us worked very hard to produce these solutions. The group that I founded (the so called Los Alamos group) initially used codes and algorithms developed in large part by Warnock Zemach and myself was very successful in studies of a wide range of problems in the quenched approximation with the initial forays into small lattices with dynamical fermions. Initial calculations suggested that these methods produced results that were at least in the rough range of experiment. In order to do better in dynamical as well as quenched calculations, a whole series of very compute intensive calculations were undertaken and still continue. These are very labor and machine intensive and of necessity must have many participants. In my opinion, despite excellent physicists, the results of these collaborations have been somewhat dissapointing. Even with terraflop performance machines, I think that it is unlikely that we will see any important physics insights using Monte Carlo related methods. This is not surprising. The method is basically a very course one and subject to well know limitations.

For this reason I and my students have been developing a deterministic numerical evaluation scheme for Lattice QCD.This "Source Galerkin method" has a similar treatment of boson and fermion fields and incorporates the symmetries of the theory under study from the beginning of the calculation. The ideas involved are particularly straightforward. A source for every field is placed in the action of the quantum field theory being studied. Then, either using the operator equations of motion, or equivalently the path integral representation on a lattice, equations are derived for the vacuum-vacuum matrix element Z. The result is a set of coupled linear differential equations in the discretized sources. Differentiation with respect to the sources produces the lattice Green's function equations. These, of course, have the sam "problem" as the continuum equations in that no finite subset of them closes. An N point Greens function is associated with Green's functions of more as well as fewer than N points. Except for their large number, the equations for Z, in themselves are nothing at all unusual mathematically. We must solve them as any other set of linear differential equations is solved. They must be made manageable through some expansion scheme. The fact that at the end of the calculation the sources are set to zero suggests that Z be expanded in a Taylor series (or other set of complete functions) in these sources. We approximate this expansion by limiting the number of the set of functions allowed in this expansion. By doing this we obtain a finite set of linear equations accurate within the limits of the approximation. The Gakerkin part of the name of this method comes from the techniques we use to make this set of linear equations internally consistent and has been discussed in last years proposal. This year has resulted in so many significant breakthroughs for this method that I no longer regard it as speculative. It will play a part in particle physics. We, however, do not yet know for sure if we can work four dimensional space time problems on large lattices. We have achieved the following progress in this year. 1. The very subtle problems in discovering and applying the boundary conditions on this huge set of differential equations has been understood. As a spinoff we have obtained significant insights into the solutions of cannonical quantum field theory besides the very limited set specified by the path integral formulation. 2. We have learned how to handle and catalog set of complete functions of a huge number of independent variables. This is regarded as a non-trivial mathematical problem. 3. We have successfully solved one dimensional fermionic field theories on a huge number of sites (essentially unlimited) and have solved two dimensional fermionic quantum field theories on a few sites. We believe that even without further development of our methods we can now solve problems of interest to condensed matter theory. 4. We can solve one dimensional field theory problems (quantum mechanics) on essentially any size lattice in very short times on a workstation. This method is orders of magnitude faster and more accurate than any numerical method we know of for the fairly wide class of problems we have examined. It is likely that there are significant quantum mechanical problems which can be examined with Source Galerkin. 5. We now know how to control the number of variables to manageable numbers on lattices of significant size in four dimensions.

Because of this, we believe we can examine interesting quantum field theories in the next year.

This year has resulted in significant success for my students. Andrew Sohnenschein (an undergraduate) wrote the best undergraduate thesis that I have ever seen on these ideas. He has done much that will be published when we start releasing papers.

Santiago Garcia has presumably (no official notification yet) been awarded an NSF Postdoctoral Research Associateship in Computational Science and Engineering. The award of this small number of fellowships is to help "increase expertise in the development of innovative methods and software for applying high performance computers". This award pays only part of the cost of the postdoc. The rest will be paid by Brown and DOE. However, there will be no cost to DOE beyond what it would have cost for Garcia to stay on as a Graduate student.

III. PROGRAM IN EXPERIMENTAL PHYSICS

A. INTERACTIONS OF LEPTONS AND HADRONS FROM ACCELERATOR AND ASTROPHYSICAL SOURCES TASK B

1. Data Analysis In Progress

1.1. Lepton Interactions in Freon

(1) Muon–Neutrino Studies at Tevatron Energies Using the Tohoku One–Meter High–Resolution Freon Bubble Chamber as Target (E745)

(2) Muon Interactions in a Hybrid System With the Tohoku High–Resolution Freon Bubble Chamber (E782).

The layouts of the hybrid systems used in the 1985 and 1987 muon neutrino runs (E745) are shown in Figs. 1.1 and 1.2, respectively. The total number of pictures obtained included 188,900 in 1985 and 364,951 in 1987. In last year's Progress Report we gave a preliminary analysis of strange particle production, first comparing the 1985 and 1987 data and then combining the two data sets with appropriate weights.[1] A more complete DST of the 1987 run with remeasurements will add to the total number of events and the data analysis will continue, on strange particle production and on nuclear effects in particular.

The run of E782, with the upgraded hybrid system shown in Fig. 1.3 exposed in a beam of 200 GeV/c muons, ended in August 1990 with about 350,000 pictures. Mukunda Aryal, then a member of the Brown group, was responsible for upgrading the data acquisition and on–line monitoring software for the new hybrid system, and contributed greatly to the success of the run.

Film analysis has been proceeding at Tohoku and Tennessee, with events found in one of every five pictures. Brown is not participating in the film analysis, as our own scanning–measuring facility was dismantled years ago, and the splendid FNAL facility which we had used for E745 film was shut down in 1990. The Tohoku group itself will probably discontinue measuring after mid–1993. Meanwhile, a group from India which has been trying to get funding to join E782 since 1988, well before the run, has now succeeded. It is too late for the run, of course, but it has been agreed that two physicists of this group will visit Tennessee and Tohoku in July, to become familiar with the film scanning requirements. Their help with scanning will be very useful, and will allow the measuring to proceed more efficiently at Tennessee and Tohoku. In the interest of concentrating on the most useful part of the data, measuring will be done only on events with apparent high momentum transfers, as evidenced by the emission of at least one fast hadron.

The results of measurements are being monitored by comparing Tennessee and Tohoku results, and also comparing various kinematic quantities to predictions of the Lund model.[2,3] Mukunda did considerable work on the application of the Lund model to E782 before he left Brown, and still takes an interest!

As of December 1991, about 85,000 frames had been scanned, and about 800 events had been measured. Of particular interest at Brown at this time is the strange particle population. V^0's are seen in events with energy transfer $\nu_1 > 1$ GeV, and the rate is strongly dependent on ν_1. In a sample of 772 events with $\nu_1 > 1$ GeV, 39 K/Λ's were seen in all.

Figure 1.4 shows the percentage of K/Λ events as a function of ν_1.[4] (In general, the energy transfer ν is defined as

$$\nu = E^{\mu}_{\text{inc}} - E^{\mu}_{\text{Scatt}} \approx P^{\mu}_{\text{inc}} - P^{\mu}_{\text{Scatt}}.$$

However, since $P\mu(E^{\mu})$ is too high (~ 200 GeV) to determine in the bubble chamber, we use ν_1, derived from the momentum of the visible hadrons.)

We hope to be able eventually to make a significant comparison of strange particle production by muons and muon neutrinos.

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3. K. Tamae and T. Kitagahi, E782 Note 92-04, February 5, 1992.

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1.2. STUDIES OF HADRON INTERACTIONS WITH HYDROGEN AND HEAVIER NUCLEI.

The following experiments are all in the stage of physics analysis, all film analysis having been completed, and many publications have already been produced from these data, as reported in previous and current progress reports.

(1) High Statistics Study of Particle Production and Dynamics and Their Dependence on Incident Quantum Number (FNAL Experiment 570).

(2) A Study of the Detailed Characteristics of Hadron–Nucleus Collisions using the Fermilab Spectrometer (FNAL Experiment 565).

(3) Studies of $\pi^{\pm}p, K^{+}p$ and pp Interactions at 147 GeV/c (FNAL Experiment 299 and of $\pi^{-}p$ Interactions at 147 GeV/c (FNAL Experiment 154) using the Proportional Wire Chamber Hybrid System at Fermilab.

The first two experiments listed above provide data for a study of the dynamics of hadron production in hydrogen and in heavy targets, using four incident hadron beams: $\pi^{\pm}, K^{+}$ and p, all at a momentum of 200 GeV/c.

The experimental run, completed in mid–1982, resulted in a total of about one million pictures which, because of the low–systematic– error nature of the experiment, continue to yield physics results of interest.

The experiments were done using as the visible target the 30–inch bubble chamber filled with hydrogen and containing near its upstream boundary thin foils of magnesium, silver, and gold (two thicknesses of each to allow for correction for multiple interactions in a foil). The beam was tagged by means of Cerenkov counters in the portion of the spectrometer upstream of the target. The downstream spectrometer included CRISIS for the identification of charged secondary particles, as well as proportional wire chambers and drift chambers to record their trajectories, and a lead glass detector (FGD) for the detection of forward-going gamma rays. The experimental arrangement provides for the simultaneous detection and analysis in the same exposure, using the full power of the visible target and the spectrometer, of events produced in the hydrogen and in three heavy nuclei. Data were obtained simultaneously for all the positive beam particles and all the targets, and there was no change in the apparatus when a negative beam was used. The system was run in an untriggered mode, so systematic biases were minimal

Of the approximately 1×10^6 pictures taken, about 218,000 were taken with a negative beam (mostly π^-) and the remainder with a positive beam. The positive beam composition varied somewhat during the run, and averaged approximately 49% pions, 36% protons and 15% K mesons.

Data analysis has concentrated on the study of interactions as a function of A and of incident particle, for which the bubble chamber vertex detector provides unique data. Analysis of some aspects of these interactions has been reported earlier – for example a general study of multipion production in the interactions of 200 GeV/c protons and π^+ and K^+ mesons with nuclei of gold, silver, and magnesium,[1] and a study of rapidities and rapidity correlations, emphasizing the dependence on the number of projectile collisions[2]. Previous results on the general topic of rapidities in hadron–nucleus collisions have been reviewed by Fredricksson et al.[3] and by Busza and Ledoux[4]. As said above, a notable feature of our experiment is that we have four different incident beam types and four different targets, thereby providing twelve reactions all analyzed in an identical manner.

Most recently our collaboration has completed an analysis of neutral strange particle production in 200 GeV/c $p/\pi^+/K^+$ interactions in Au, Ag and Mg.[5] There have been very few previous studies of strange particle production in hadron–nucleus collisions at high energy. The NA5 and NA35 streamer chamber experiments at CERN have reported interesting results[6–8] with p and $\bar{p}$ beams at 200 and at 600 GeV/c, but these experiments did not include meson beams. Pion beam experiments[9–11] have produced very limited information on strange particle production, and we know of no K^+–nucleus results.

Table 1.1 shows the inclusive cross sections for the production of K^0, Λ and $\bar{\Lambda}$ together with the results for 147 GeV/c $p/\pi^+/K^+$ interactions on hydrogen from a previous FNAL hybrid experiment (E299).

Table 1.2 shows the average multiplicities per event in the heavy nuclei.

We show the A-dependence of neutral strange–particle production cross sections by plotting our data in Fig. 1.5, along with other results[6–8] at 200 GeV/c, and our hydrogen–target values[12] at 147 GeV/c. We have fit the results to the form $\sigma_{hA} = \sigma_{hp} A^{\alpha}$, where the subscripts hA and hp refer to hadron–nucleus and hadron–proton reactions respectively, and A is the mass number of the nucleus. The best fits are shown in the Figure separately for each beam type, and the fitted values of the exponent α are given in Table 1.3. Note that our values of α are significantly greater than the geometrical value of 2/3, so there is only a limited amount of shadowing. It is also interesting that for the proton beam the values of α for K^0 and Λ production are consistent with being equal to each other, and the same is true for the π beam. Furthermore, the values for the two beams are also consistent with each other. However, these observations do not seem to extend so clearly to the K^+ beam, for which we have the least statistics.

The data have been analyzed in terms of the number ν_p of projectile collisions in the nucleus, and also in terms of ν_s, the number of secondary collisions. We find that the average multiplicities of K^0 and Λ increase with ν_p similarly for each subsample of beam and target, but of course ν_s increases also with ν_p. When the ν_s dependence is separated out, the trend for K^0 is rather similar to that found for charged pions,[1,2] exhibiting an initial increase but then a levelling–off as ν_s increases, suggesting that rescattering is not a significant source of K^0 production. By contrast, the Λ multiplicity increases linearly over the whole range of ν_S, so there is evidence that secondary collisions are enhancing Λ production. A sensitive way to strengthen this conclusion is to inspect the ratio of Λ to K^0 production rates as functions of ν_p

TABLE 1.1. Total inclusive cross sections for K^0, Λ, and $\bar{\Lambda}$ production. The values for proton targets are from experiment E299 which was at 147 GeV/c beam momentum, compared to 200 GeV/c for this experiment.

	σ_{K^0} (mb)	σ_{Λ} (mb)	$\sigma_{\bar{\Lambda}}$ (mb)
p-Au	1256±316	613±156	102±76
p-Ag	1186±235	418±91	56±24
p-Mg	168±68	123±46	---
p-p *	10.0±0.4	4.2±0.2	0.8±0.2
π^+-Au	1049±235	442±109	41±28
π^+-Ag	360±106	120±38	---
π^+-Mg	101±54	16±11	16±13
π^+-p *	8.0±0.6	1.8±0.2	0.7±0.1
K^+-Au	1112±349	531±158	66±51
K^+-Ag	281±118	230±93	58±46
K^+-Mg	127±84	26±27	---
K^+-p *	11.8±2.0	1.4±0.4	0.5±0.2

* Reference 12

TABLE 1.2. Mean multiplicities of neutral strange- particles, fully corrected for all detection efficiencies and unseen decay modes. The K^0 multiplicity includes $(K^0 + \bar{K}^0)$.

	$\langle n_{K^0} \rangle$	$\langle n_\Lambda \rangle$	$\langle n_{\bar{\Lambda}} \rangle$
p-Au	0.86±0.14	0.42±0.07	0.07±0.05
p-Ag	1.05±0.14	0.37±0.06	0.05±0.02
p-Mg	0.41±0.14	0.30±0.09	---
π^+-Au	0.76±0.12	0.32±0.06	0.03±0.02
π^+-Ag	0.60±0.10	0.20±0.04	---
π^+-Mg	0.63±0.20	0.10±0.05	0.10±0.07
K^+-Au	0.67±0.18	0.32±0.08	0.04±0.03
K^+-Ag	0.39±0.13	0.32±0.10	0.08±0.06
K^+-Mg	0.49±0.28	0.10±0.10	---

TABLE 1.3. Exponent α characterizing the A– dependence of K^0 and Λ production cross sections by proton, π^+, and K^+ beams.

Beam	$\alpha(K^0)$	$\alpha(\Lambda)$
p	0.92±0.02	0.94±0.02
π^+	0.86±0.04	0.92±0.05
K^+	0.74±0.06	1.10±0.05

and ν_s, and this ratio is found to be clearly increasing with both variables, thereby indicating that Λ's are enhanced by some additional means that are not applicable to K^0's. This is consistent with the argument of Nikolaev[13] that intranuclear cascading causes Λ enhancement, and the so-called Λ- retention property prevents any significant absorption of Λ's inside the nucleus.

It is interesting to note that our much earlier data of E299, the third experiment listed,[12] continues to be useful in new contexts, as well as in comparisons such as described above. For instance, in the mid to late 1980's Bialas and Peschanski[14] suggested searching for ultra-short-range fluctuations in rapidity distributions of both hadronic collisions and cosmic rays. They essentially suggested choosing a given phase-space region, such as a rapidity interval Δy, then dividing it into m small bins of equal size $\delta y = \frac{\Delta y}{M}$ and calculating for each bin the expression

$$F_q^m = \frac{\langle k_m(k_m-1)\cdots(k_m-q+1)\rangle}{\langle k_m\rangle^q},$$

where k_m is the number of tracks falling into the m^{th} bin, q is a positive integer and the $\langle\rangle$ indicate the average value taken over the whole event sample.

They have shown that if non-statistical self-similar fluctuations take place, as δy gets small one finds that the power-law dependence

$$\langle F_q^m\rangle \propto \left(\frac{\Delta y}{\delta y}\right)^{f_q}, f_q > 0 \tag{1.1}$$

holds, up to the threshold of the correlation-length between particles. Such an effect has been called *intermittency*. Should the fluctuations be of purely statistical character, the moments F_q^m would become independent of the bin width δy.

Many studies of this kind have been carried out and reported in the literature since 1989 on hadron-hadron, nucleus-nucleus, and hadron-nucleus interactions, as well as on leptoproduction and e^+e^- annihilation. Our E299 data confirm the presence of the intermittency effect in hadronic collisions at $\sqrt{s} = 16.7$ GeV CMS energy, the effect being intermediate between the effects observed in e^+e^- annihilations and nucleus-nucleus interactions.

A publication is being prepared on this work (Section 5, Number 445). It would be of interest to pursue this study in the data of E565 and E570 as well. The pursuit of this and other topics of interest in these well understood data sets is limited by the pressure of time and understaffing, but we intend not to lose sight of these topics for which we have excellent relevant data.

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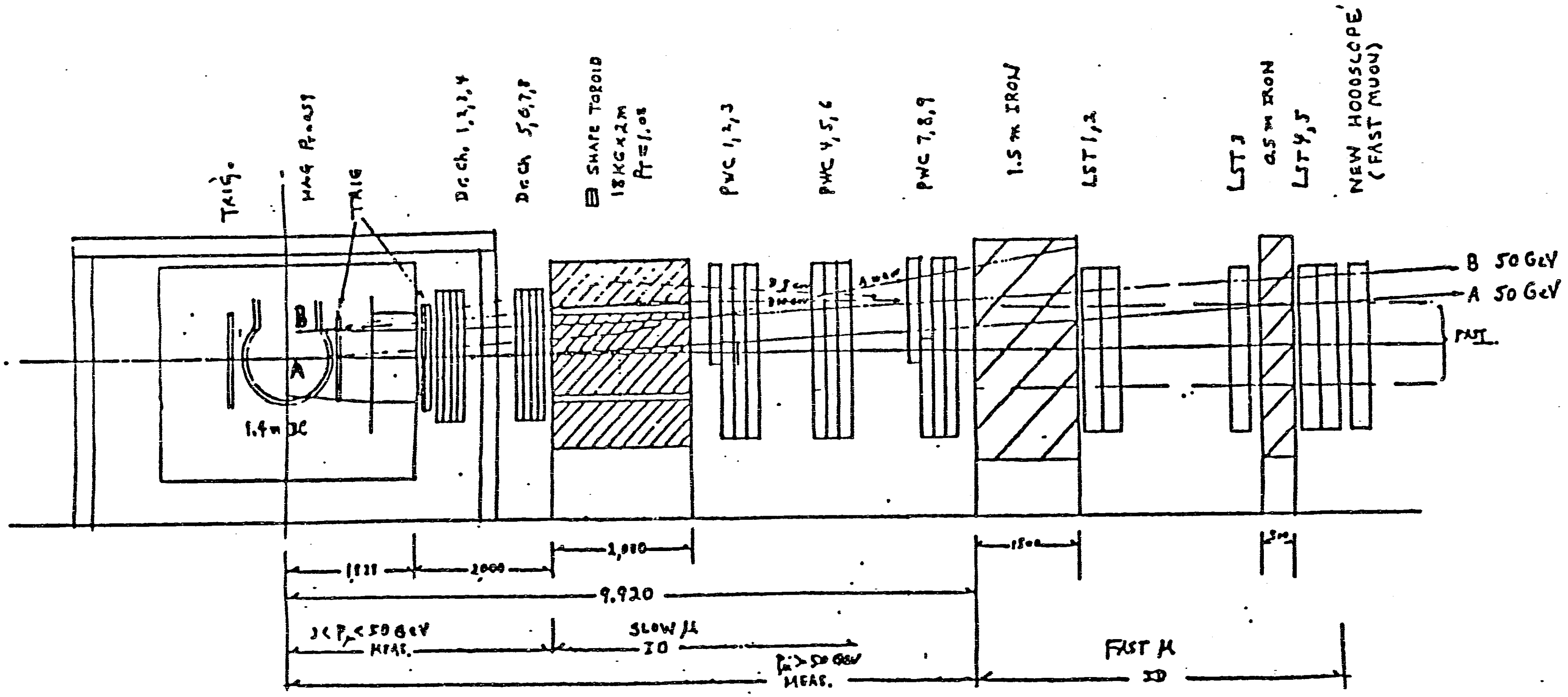
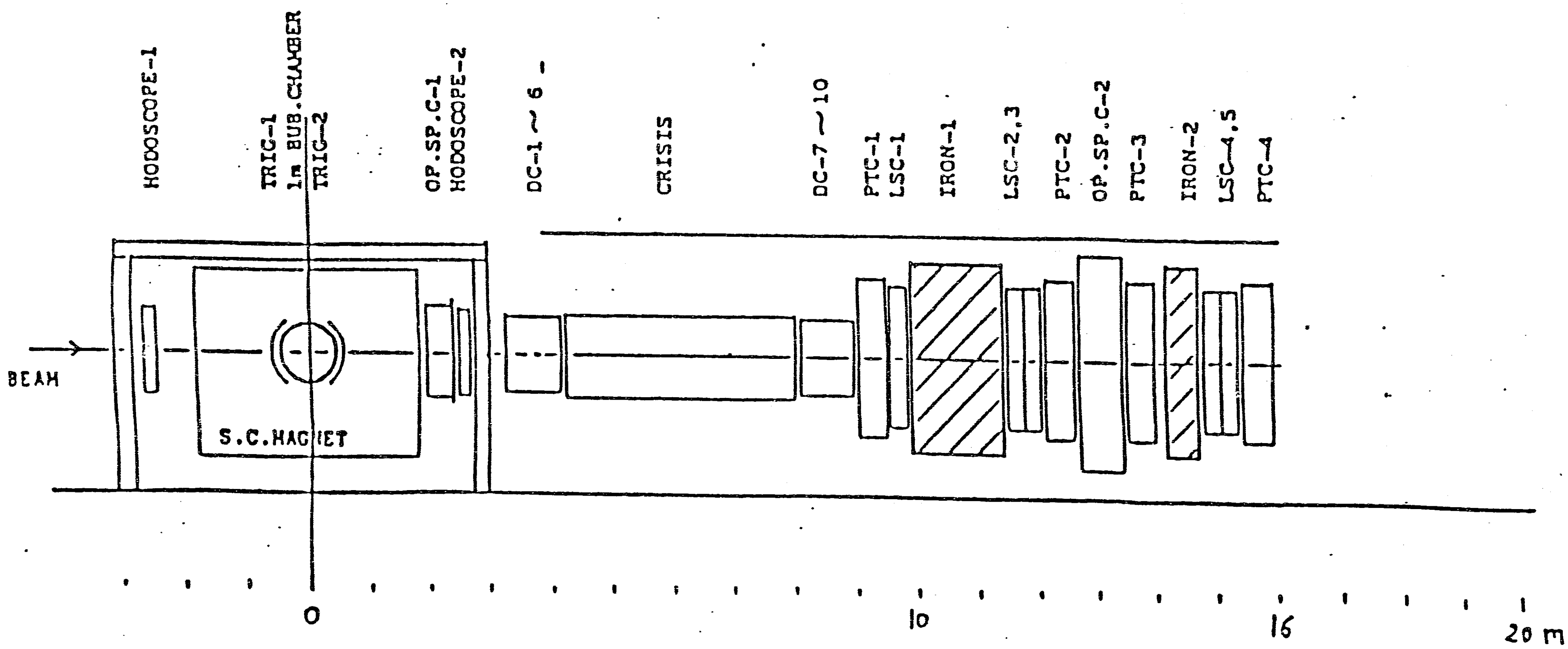
1.3. Large Volume Detector at Gran Sasso

Analysis has begun on the initial data from LVD. As this is still to be regarded as an engineering run, the results are given in Section 2.1.



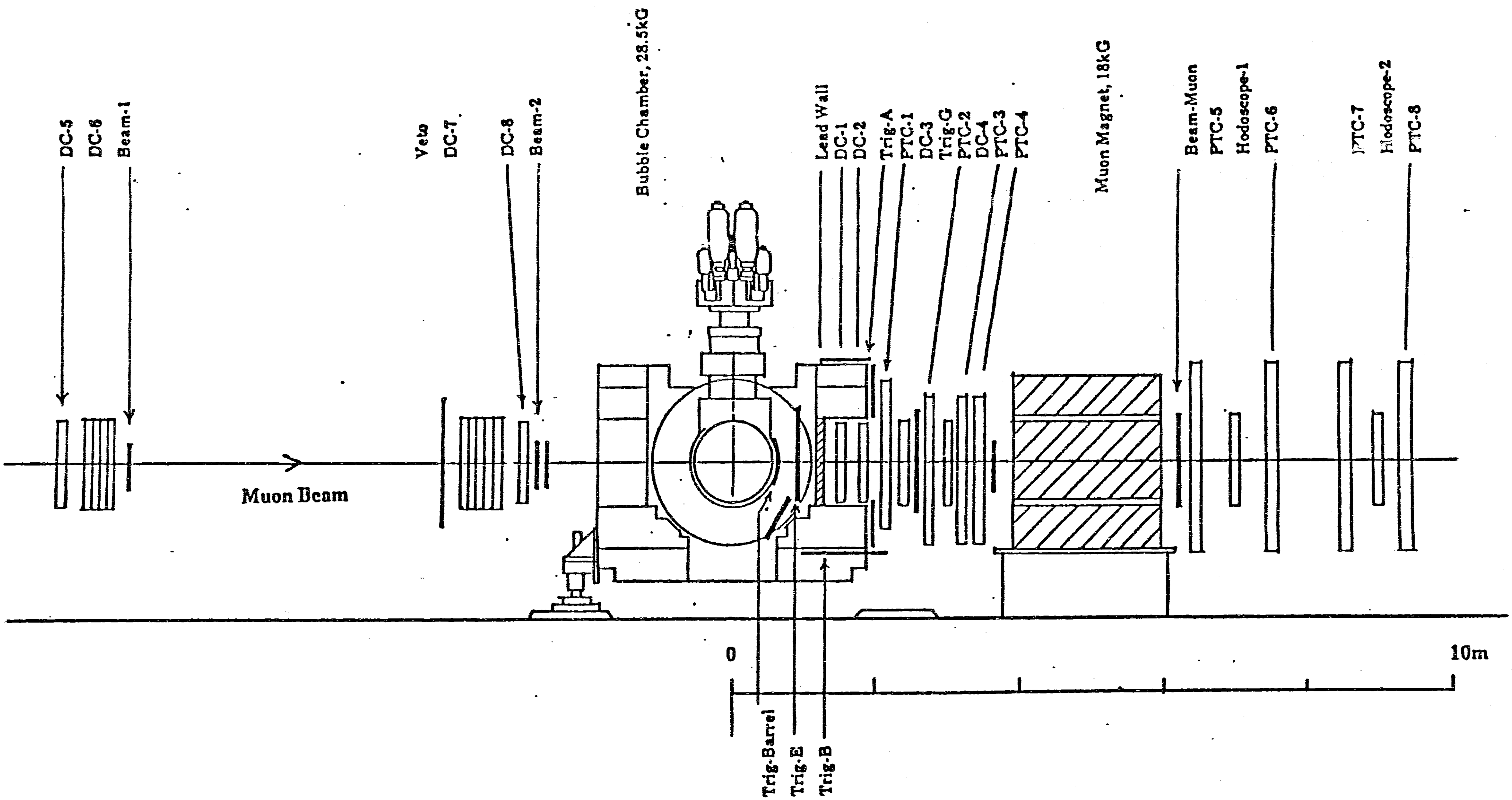
Layout Of Detector System For E745, 1987 Run

FIGURE 1.1



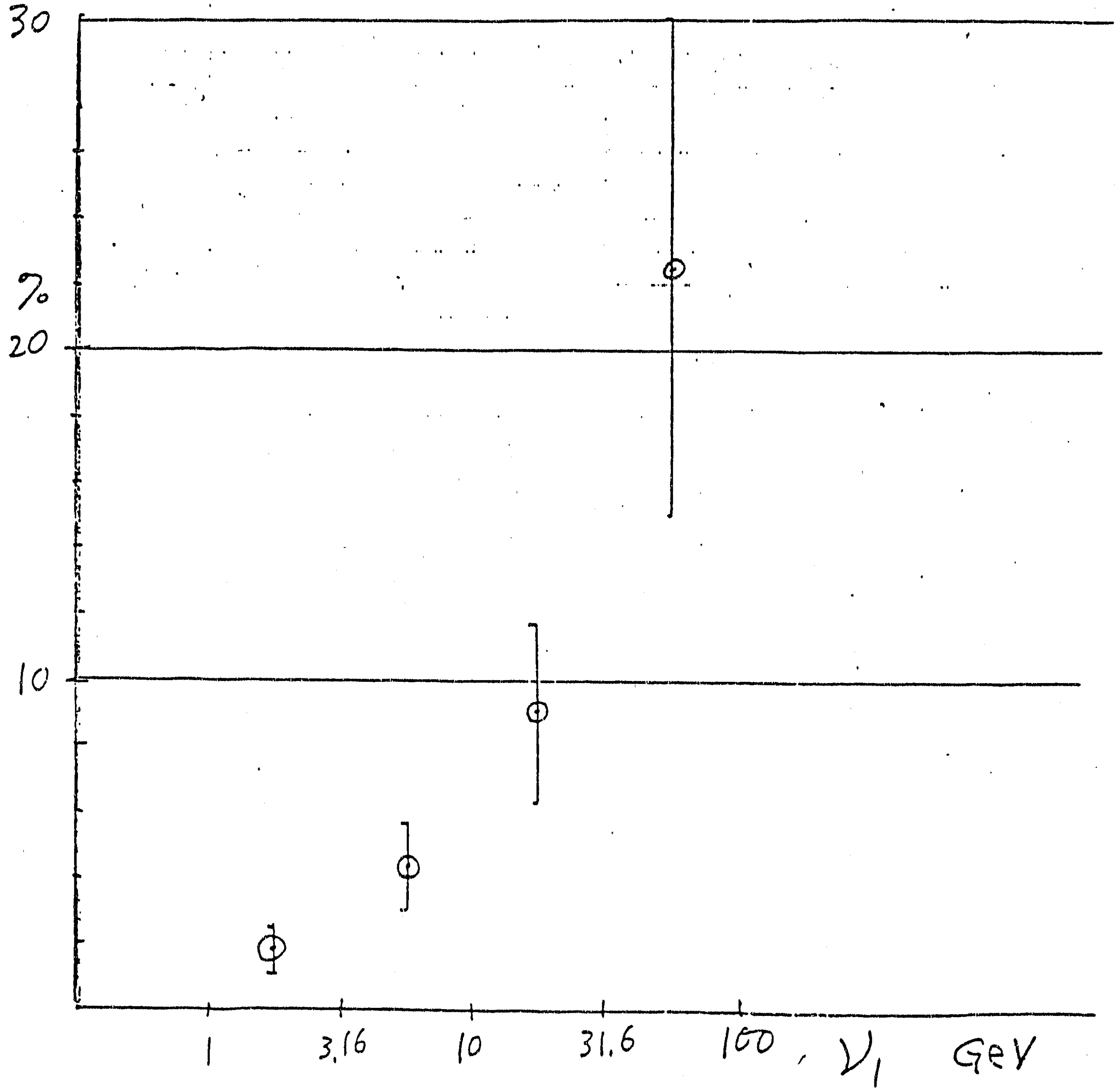
Layout Of Detector System For E745, 1985 Run

FIGURE 1.2



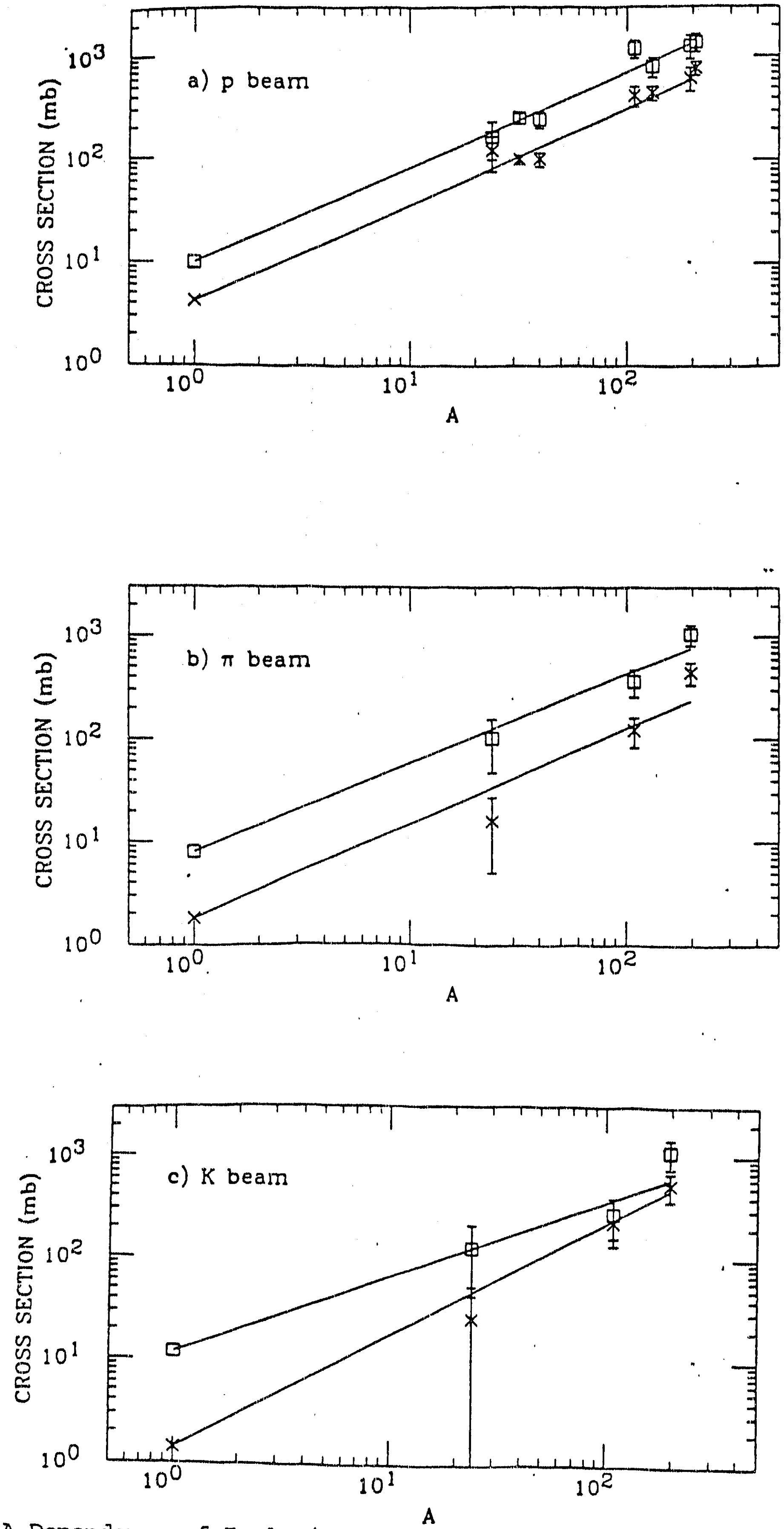
Layout Of Detector System For E782

FIGURE 1.3



FRACTION OF STRANGE EVENTS VS. ν_1

FIGURE 1.4



A-Dependence of Inclusive Cross Sections for the Production of K^0 (squares) and Λ (crosses). The Lines Represent Best Power-law Fits, Constrained to Pass Through the Values for Hydrogen Targets Obtained from Ref. 12.

FIGURE 1.5

2. Experimental Runs in Progress and Preparation

2.1. High Energy Physics and Astrophysics Underground; Large Volume Detector at the Gran Sasso Laboratory

The major purpose of this experiment is to study muons and neutrinos from astrophysical sources. Such studies provide information on particle properties and interactions at energies beyond the scope of accelerators, while at the same time they contribute to our understanding of these sources. The physics topics of interest include neutrino oscillations, muons and neutrinos from discrete sources, muon bundles, neutrinos from stellar collapse, proton decay, monopoles, dark matter and exotic particles. Some of these are described in some detail in the accompanying proposal.

The detector which we have designed and begun to build, LVD or Large Volume Detector, consists of a large volume of liquid scintillator divided into modules surrounded by planes of limited streamer chambers (LST's), all organized into five towers. An overview of the whole detector is shown in Fig. 2.1, together with detail of the modules, and an end view is shown in Fig. 2.2. The modular design has allowed us to begin data taking with part of the detector, while the rest is being assembled.

The present status of LVD is:

- The first tower is installed.
- Construction of the second tower has started.
- Data–taking is in progress in Tower 1, using microvaxes of the DAQ system.
- Off–line track reconstruction and analysis are in progress.

Each of the five towers will contain 38 modules and each of these consists of a portatank containing eight liquid scintillation counters, each $1.0m \times 1.0m \times 1.5m$ and each viewed by three photomultipliers, totalling 9.6 tons of liquid scintillator and 6.7 tons of steel. Each portatank, covered on its bottom and one side by two layers of limited streamer chambers, constitutes a module 6.3 m long, 2.0 or 2.5 m wide and 1.0 m high. When the modules are stacked in the support structure, the horizontal and vertical tracking planes of the LVD detector (shown in Fig. 2.2) are formed from the layers of streamer chambers fastened to the base and one vertical side of each portatank.

A summary of detector characteristics is given in Table 2.1. The streamer chambers form an omni–directional tracking system with high spatial and angular resolution for charged particles, while the scintillation counters provide good energy resolution and sensitivity to $\nu(\bar{\nu})$ interactions. The large size of LVD coupled with its relatively fine granularity, sensitive tracking and energy resolution, give this detector the ability to perform some definitive measurements in high energy physics and astrophysics. Brown's major responsibilities in this experiment are in the read–out electronics[1,2] for the LST's, and in data acquisition. Fig. 2.3 is a schematic of the LVD Data Aquisition hardware for one tower, and Fig. 2.4 is a schematic of the array of Microvax computers for the data acquisition tasks of the DAQ cluster. As shown, each of the 5 satellite nodes (one for each tower of LVD) will be connected to a thick–wire ethernet cable which leads to a sixth computer, a VAXstation II/GPX which acts as a boot node. This node, in addition to having a disk, also has one TK50 and one TU81+tape drive. The primary recording device is, for the moment, the TU81+tape drive. The data stream at the satellite node and at the boot node are shown in Figs. 2.5 and 2.6 respectively. Data are also being transferred to the external laboratory, 10 km away.

The hardware for the first satellite node (LVDGS2) is in place in Hall A of the Gran Sasso Laboratory, as is the boot node (LVDGS1). It is on these two nodes that a set of data acquisition programs has been developed and tested by Asoka, who continues to play a leading part in data acquisition.

The general acquisition system has been described previously.[3] Asoka has been working on software for this system, and has documented his work in LVD Note 105[4] and LVD Note 106.[5] LVD Note 105 describes GRAND 4.01, a collection of data acquisition programs for LVD which have been developed since September 1990 using MODEL, a CERN data acquisition package. With this package of building blocks, one has the flexibility to put together a data acquisition software package that is unique to each experiment and which can run in a distributed environment. Presently most

TABLE 2.1	
Main Characteristics of LVD	
Detector Properties	
Size	13.135 × 39.304 × 11.96 m^3
Volume	6174 m^3
Geometric Acceptance	7184 m^2- steradian
Mass	3.6 kilotons (metric)
Scintillator Elements:	
Size	0.992 × 1.492 × .992 m^3
Number	1520
Total Volume	2232 m^3
Total Mass	1.8 kilotons (metric)
Acceptance (≥ 0 MeV)	6089 ± 158 m^2 - steradian
Acceptance (≥ 3 Mev)	5983 ± 157 m^2 - steradian
△ E	20% / $\sqrt{E(MeV)}$
$E_{threshold}$	7 MeV (outer layer)
	5 MeV (inner layers)
	0.8 MeV (within gate)
Tracking Chambers:	
Gas Cell Size	0.9 × 614.6 × 0.97 cm^3
Total Cells	109,440
Total Volume	58.72 m^2
Sense Strip Width	4 cm
Number	155,040
$\triangle\Theta$	1 mrad (≥ 3 plane-pairs)
	2 mrad (2 plane pairs)
	67 mrad (1 plane-pair)

of the MODEL products are installed on the DAQ cluster which has VMS 5.4-2 as its operating system. MODEL itself has been extensively documented in a large number of CERN reports, a list of which appears in Reference 4.

Currently GRAND Version 4.01 is running on the LVD data acquisition cluster of microvaxes in Hall A of the Gran Sasso Laboratory, on the data from Tower 1. The function of GRAND is to integrate all the MODEL products and to provide an environment for work on the data acquisition software. GRAND was designed for a full five tower LVD experiment and as a complete back–end data acquisition software package.

The philosophy behind the human interface part of GRAND is to make the data acquisition system as simple as possible for the operator, even at the expense of very specific and detailed programming to produce this state of affairs.

Asoka DeSilva has been making great contributions to the progress of the experiment during the past 2 1/2 years. The great achievements of the past year are the completion of Tower 1, the beginning of data taking in Tower 1, and the beginning of off– line track reconstruction. Figures 2.7 and 2.8 show two examples of reconstructed single muon tracks in Tower 1 in three views–the bars show streamer tube read–out strips struck, and the boxes show scintillation counters struck. The numbers in each box encode the energy lost in that counter. In Figure 2.9, we show the zenith angle distribution of muons detected in Tower 1, comparing the data with the prediction for LVD at Gran Sasso.[6] In Figure 2.10 the comparison between Tower 1 data for the muon azimuthal angle distribution and the prediction is shown. Figure 2.11 illustrates the distribution in energy detected per scintillator tank. Tower 1, with 365 tons of liquid scintillator, is ready for neutrinos from a super nova.

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6. "Muon Studies with the LVD Tracking System", B. Jeckelmann, LVD Note 15, September 1987.

2.2. GEM Collaboration at SSC

As mentioned in last year's Progress Report,[1] we decided after the disapproval of the L* Expression of Interest to join the new detector effort which was just being initiated last June. We consider it essential that SSC have two major complementary multipurpose detectors in addition to smaller more specific ones. This second major detector is, of course, in addition to the SDC detector. In the intervening time, considerable progress has been made in the design of this second detector, named GEM for Gammas, Electrons, Muons to indicate its major focus. The GEM LOI was submitted on November 30, 1991, and various R and D projects are under way and subsystems are being evaluated in order to reach a final design within the scheduled time for review.

We have joined the muon group, and are particularly interested in the design and implementation of the muon trigger. A small subgroup including MIT, LLNL, Tennessee, Indiana and Brown has proposed an R&D project to evaluate resistive plate counters (RPC)'s for this purpose. If RPC's can satisfy the requirements of time resolution and efficiency, they would provide an economical, rugged and relatively simple solution for the trigger. We have submitted a proposal to the Texas National Research Laboratory Commission (TNRLC) for funding for this project, and expect that this will be awarded soon, thus permitting us to work on this during the summer of 1992.

The RPC's would be used in the barrel component of the GEM muon subsystem to perform the following functions:

- Furnish the beam crossing tag
- Furnish the first level trigger
- Supply the z–coordinate for the muon tracks
- Establish muon tracking roads for the precision tracking elements of the system,

and also, furnish both an anticoincidence signal to veto cosmic rays and a cosmic ray coincidence trigger to test GEM subsystems.

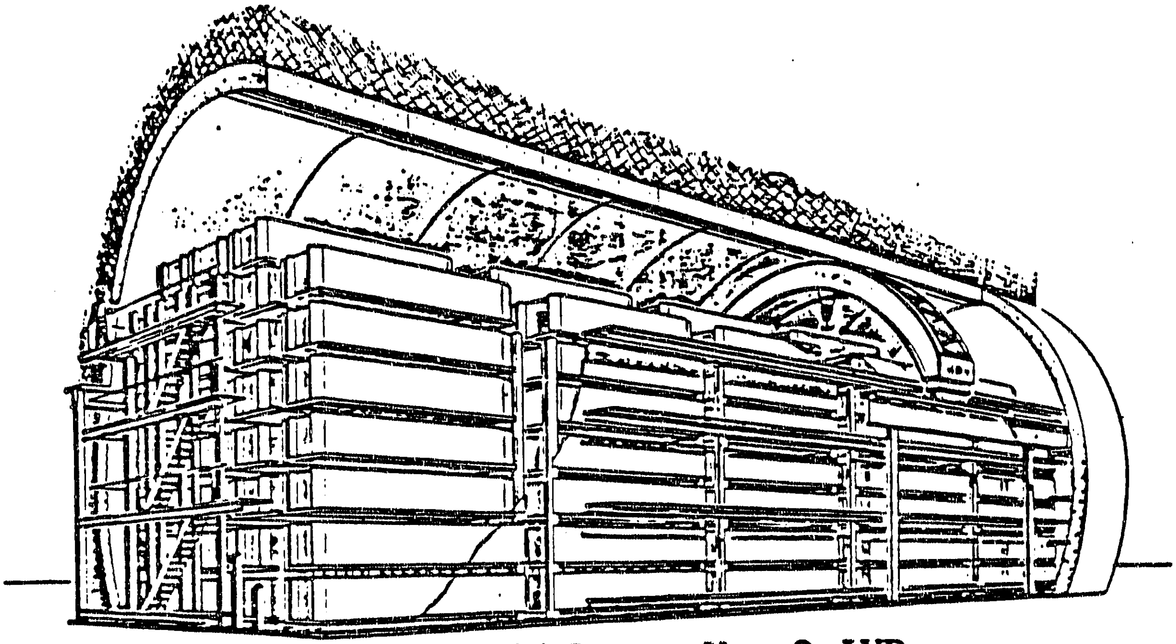
We propose to set up a test facility (at MIT) to measure the following RPC properties:

1. Pulse rise time jitter
2. Maximum counting rate
3. Efficiency
4. Life time

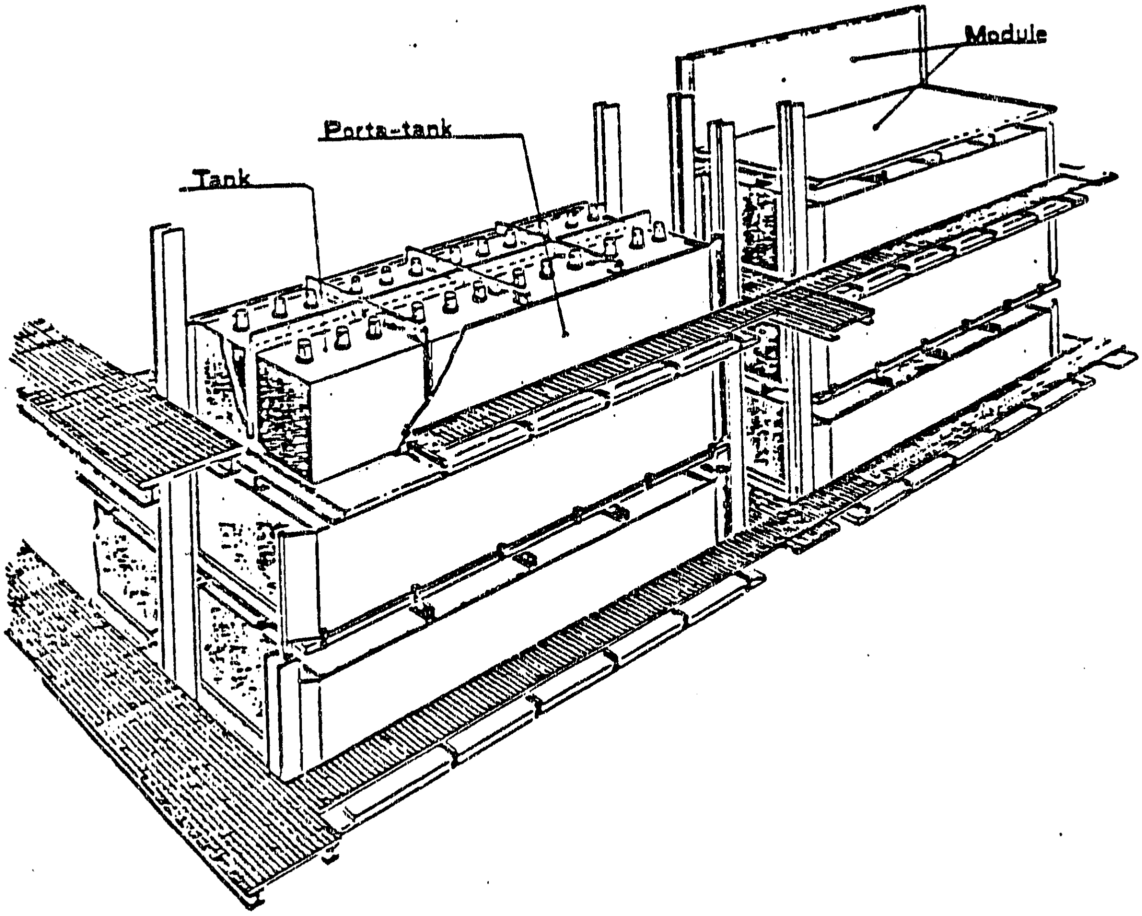
We have obtained on loan from Professor Santonico of Rome II University a $1m^2$ RPC for testing. Brown will supply hodoscopes to establish a time zero, Tennessee will supply drift chambers to provide spatial resolution and Indiana will supply the gas system for the RPC. LLNL will build a new large RPC for testing by late fall 1992. Further details of the suggested trigger are given in the accompanying Proposal.

References for Section 2.2

1. "Progress Report of a Research Program in Experimental High Energy Physics", Mildred Widgoff, DOE/ER/3130-TB270, July 1, 1991.

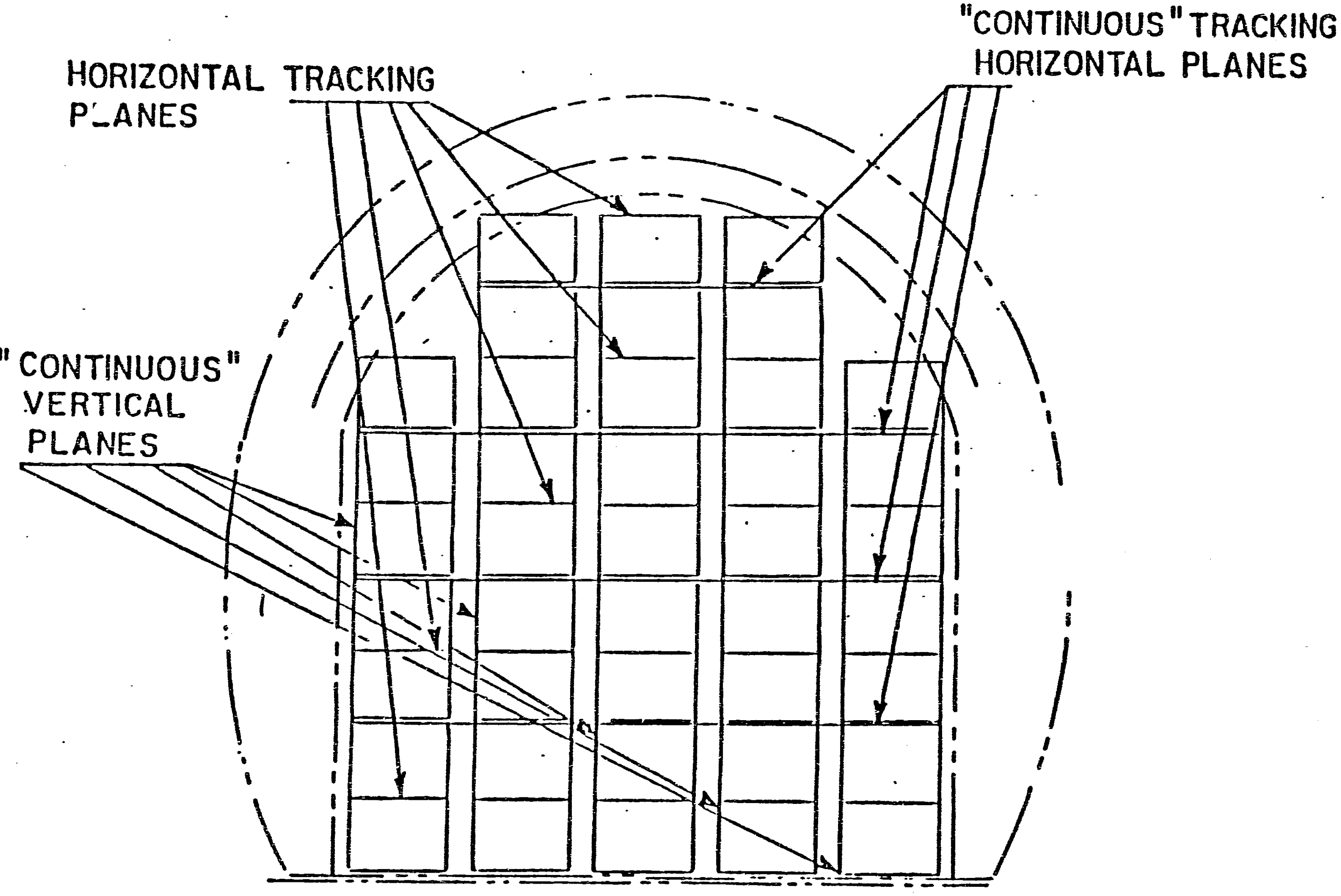


(A) General View Of LVD



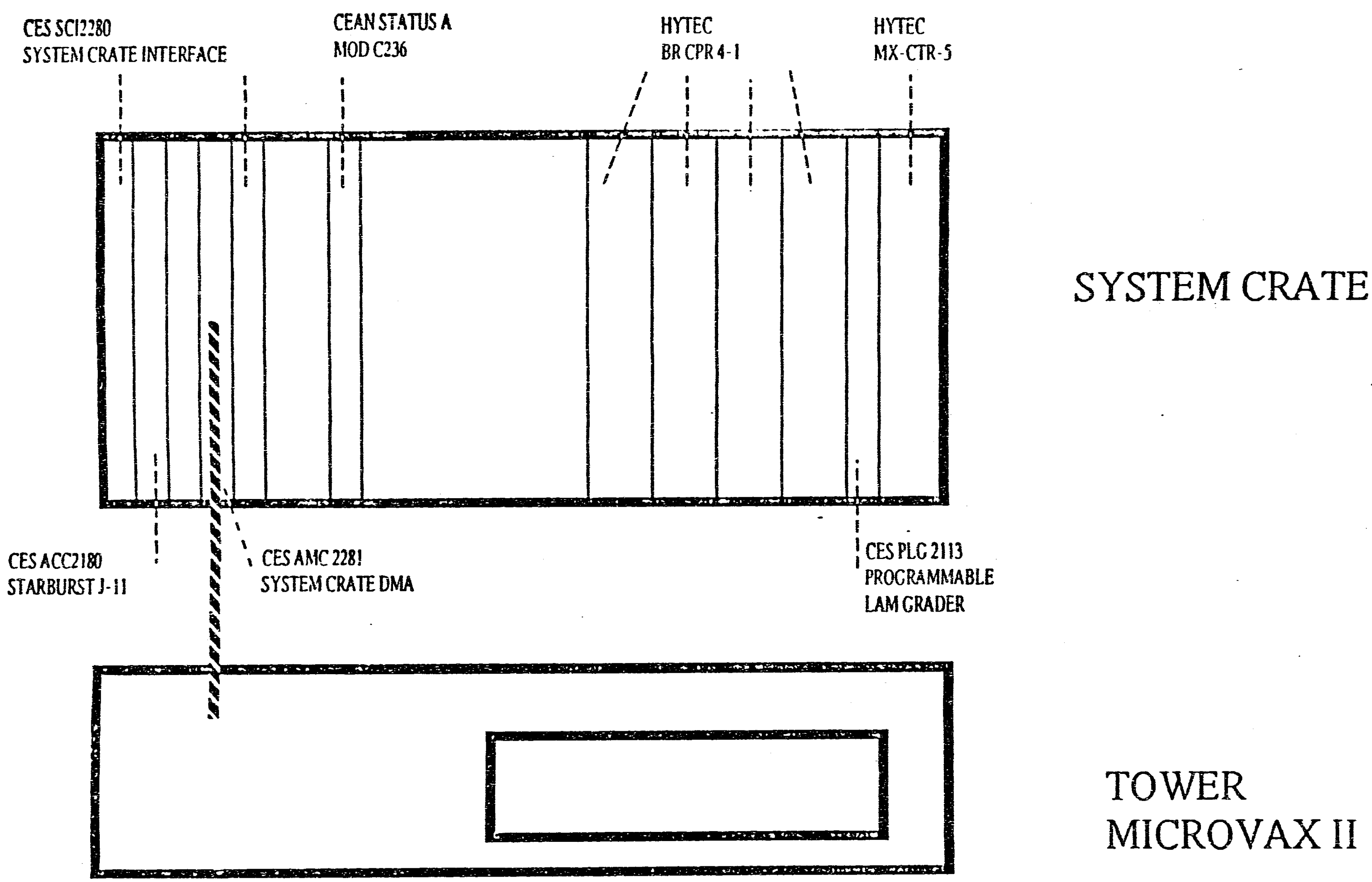
(B) Detail of LVD Assembly System

FIGURE 2.1



End View of LVD, Showing Tracking Planes

FIGURE 2.2



LVD Tower Data Acquisition Hardware

FIGURE 2.3

LVD Local Area Vax Cluster and Communication Network

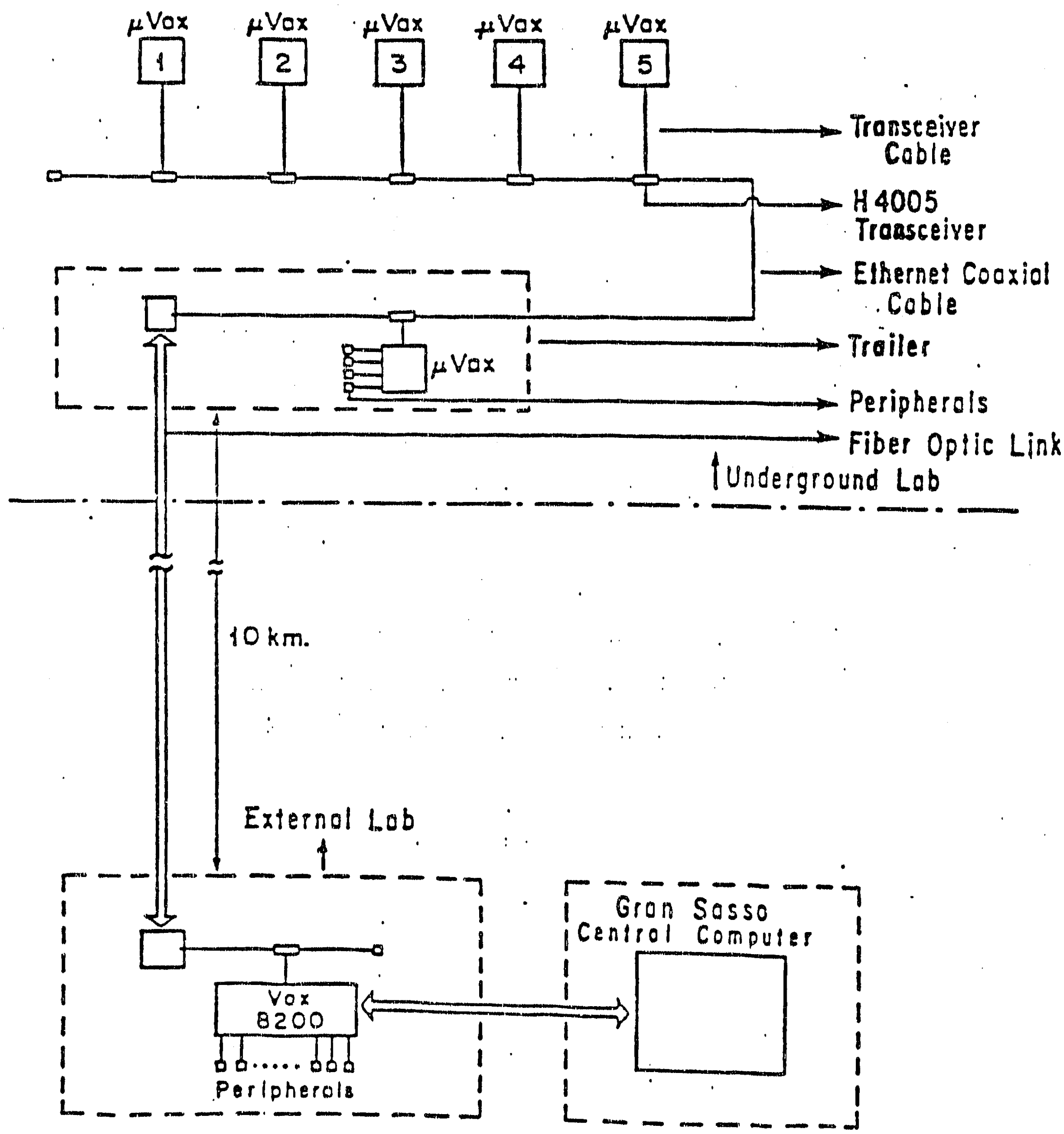
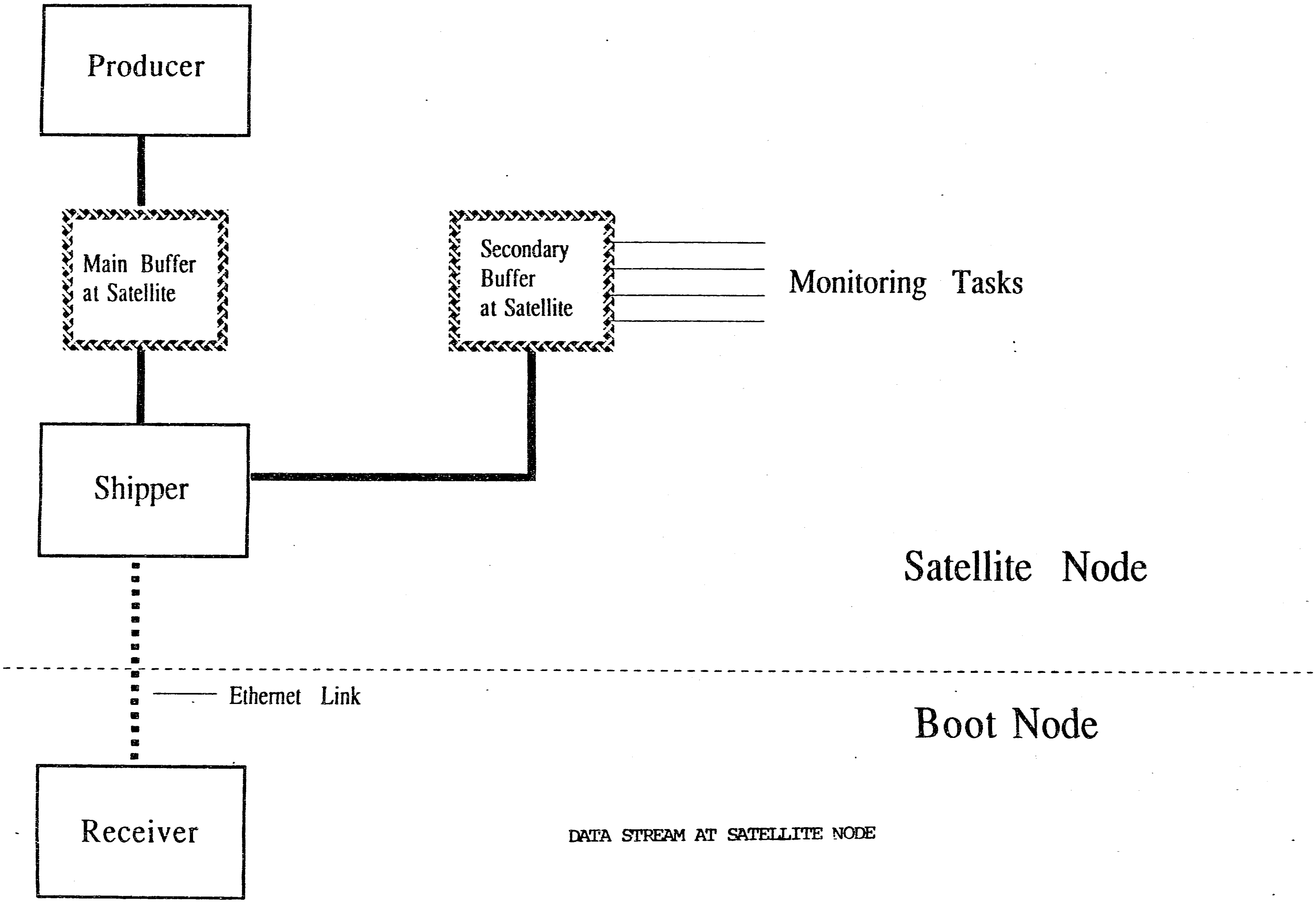
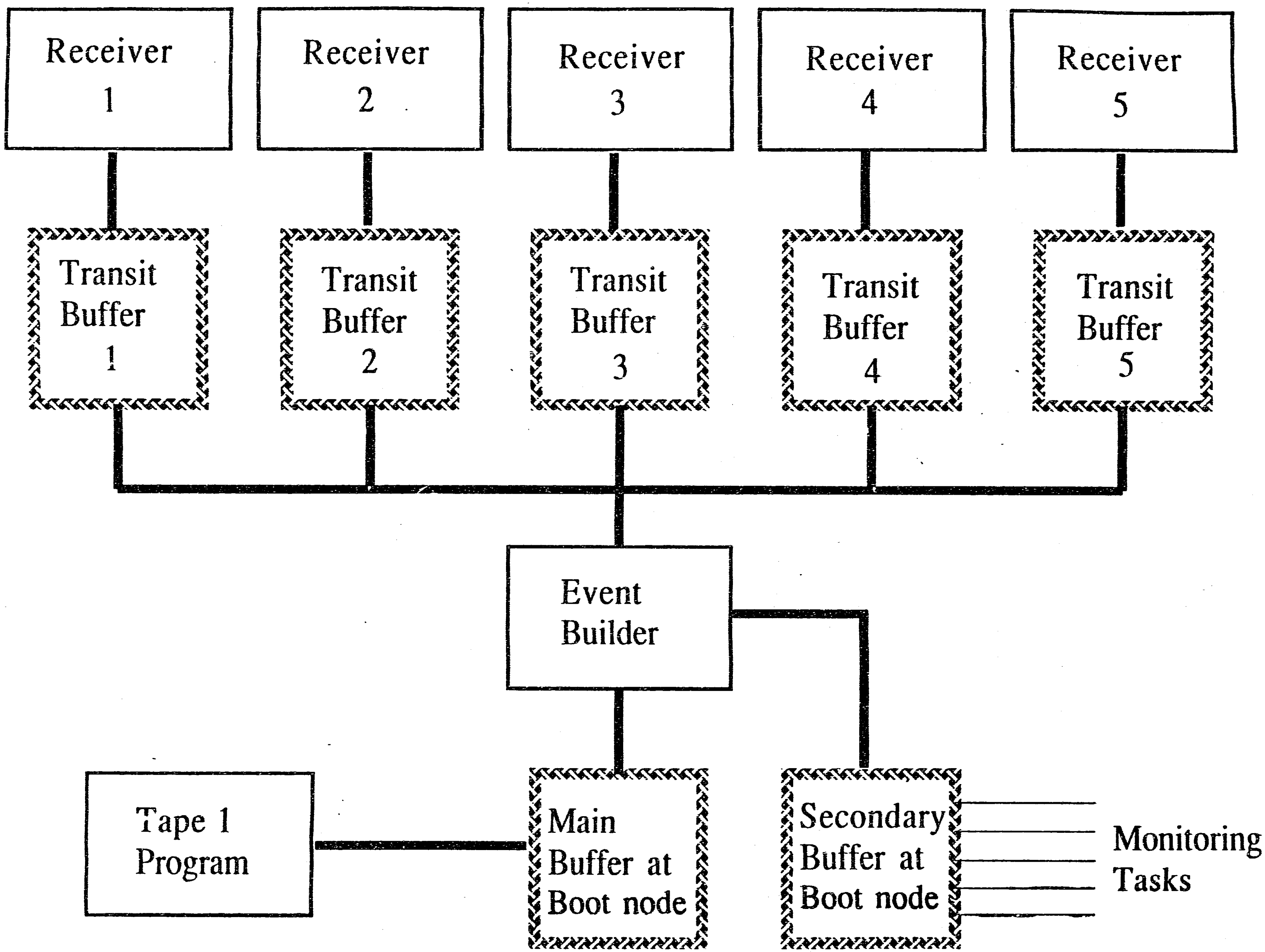


FIGURE 2.4



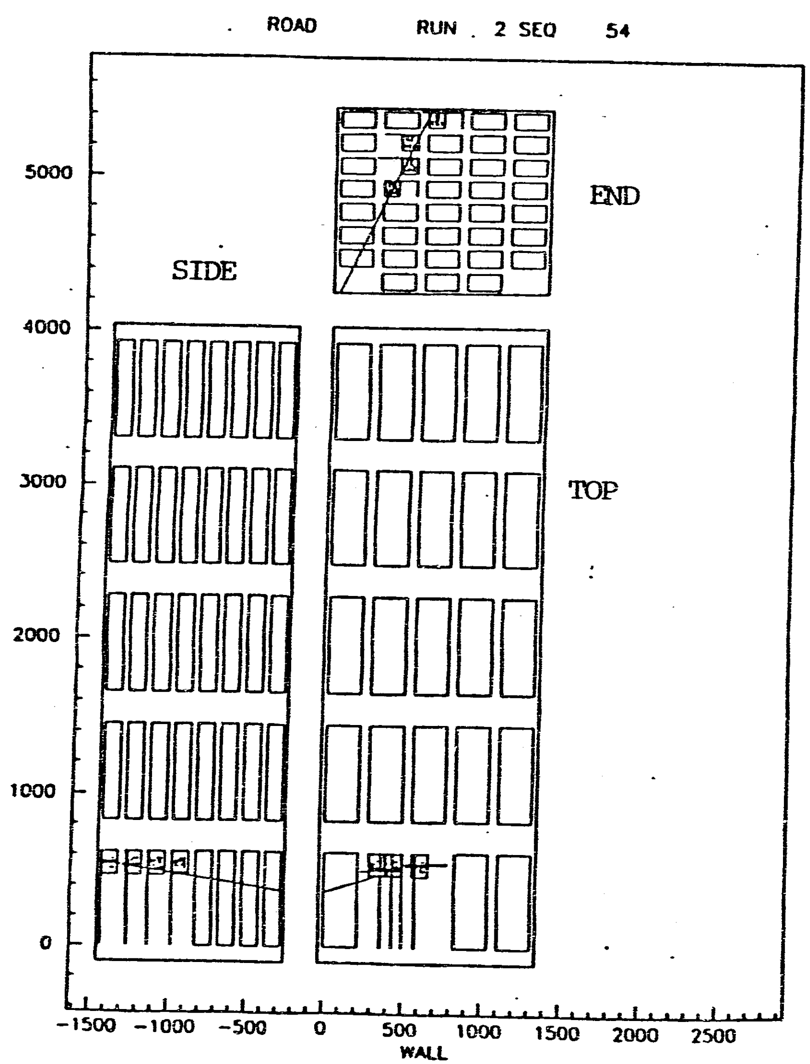
DATA STREAM AT SATELLITE NODE

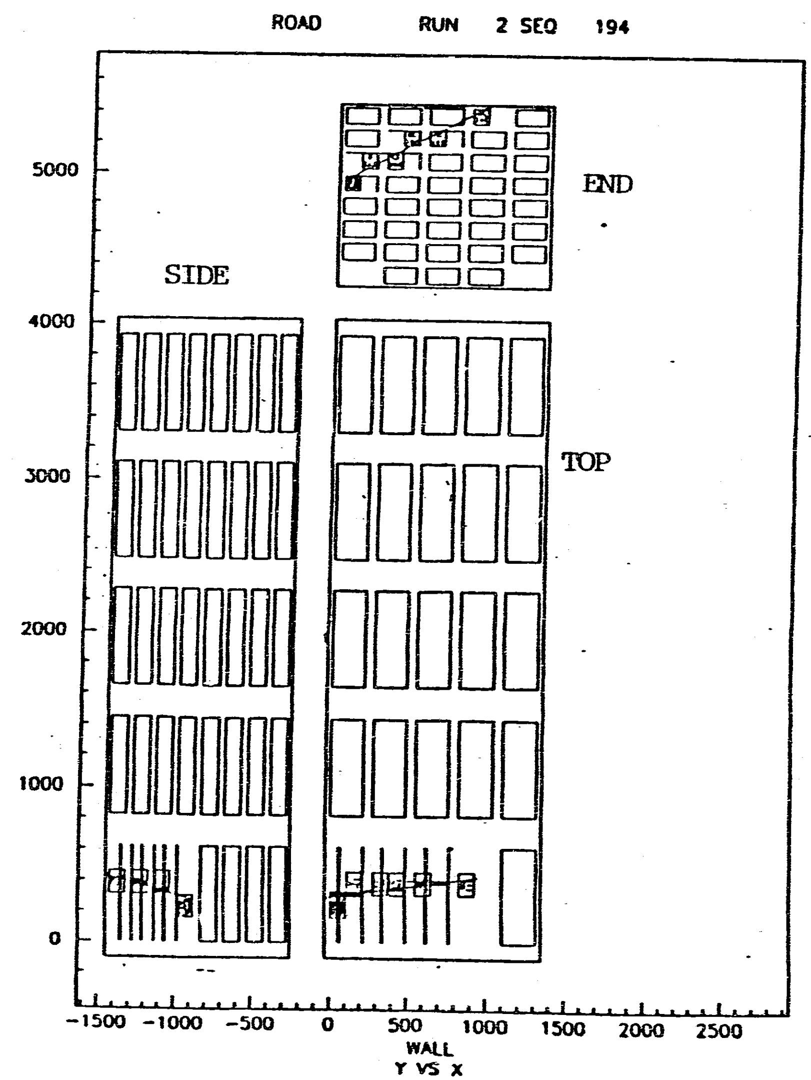
FIGURE 2.5



DATA STREAM AT BOOT NODE

FIGURE 2.6

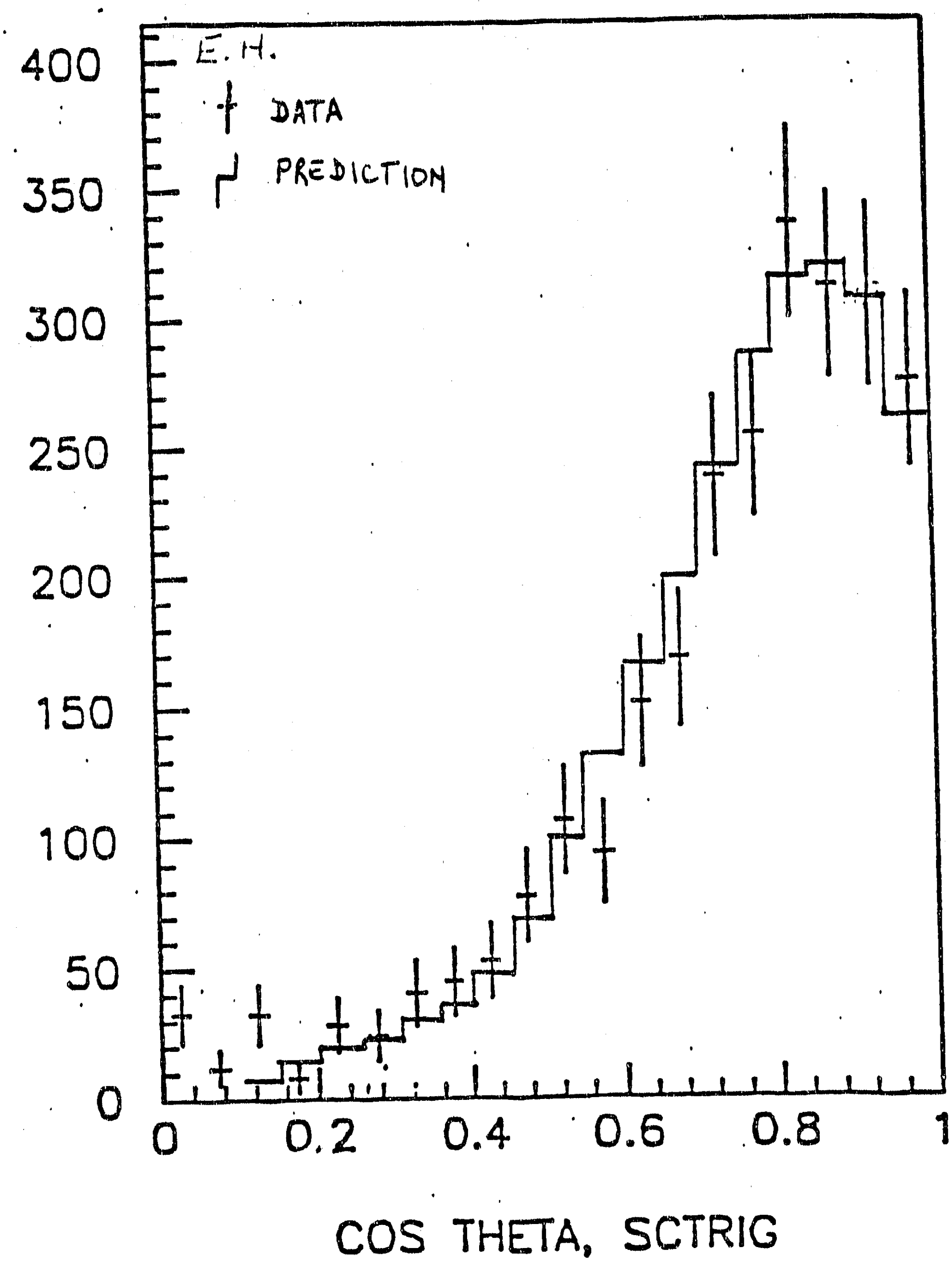




RECONSTRUCTED TRACKS IN LVD

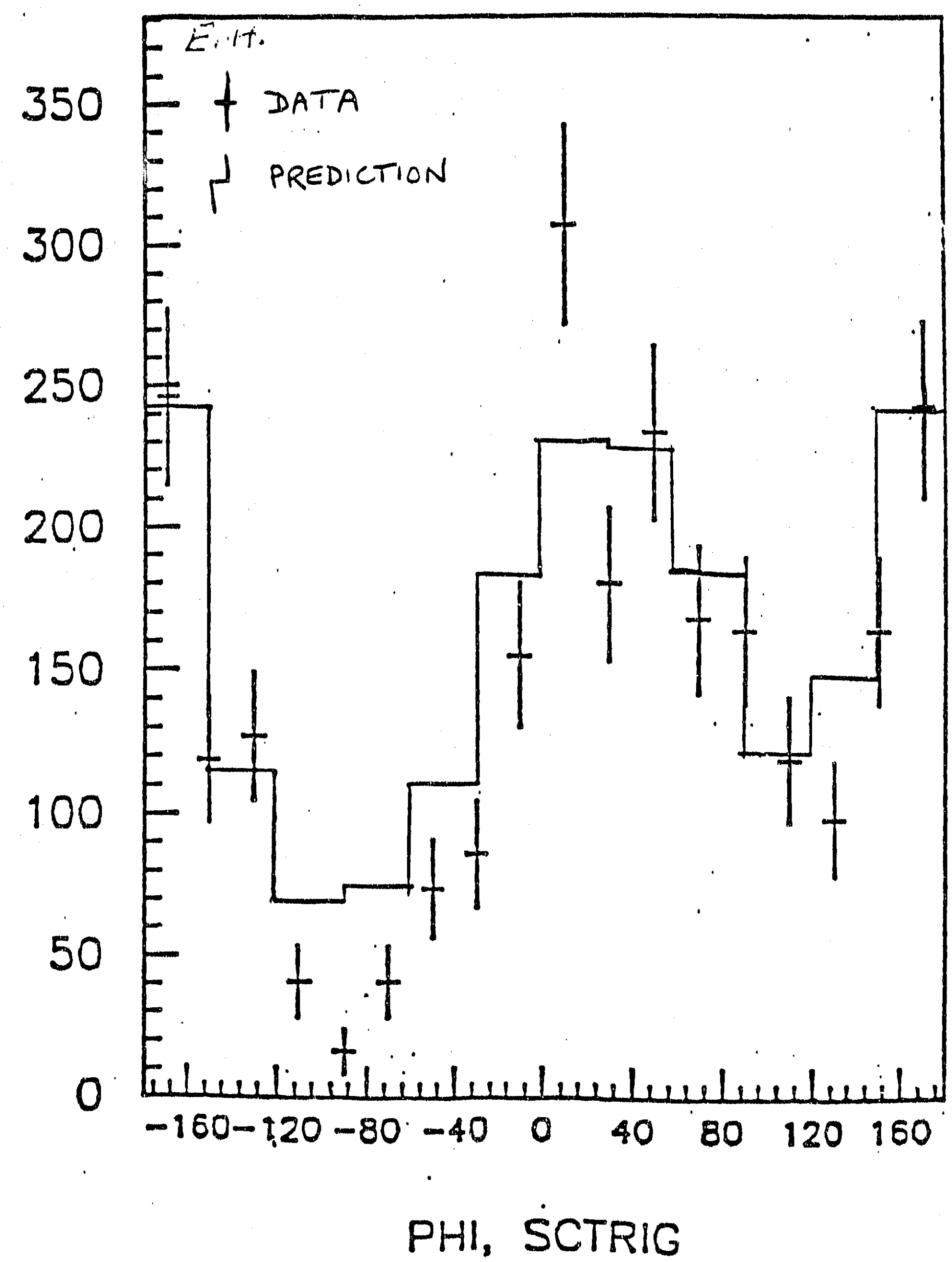
FIGURE 2.7

FIGURE 2.8



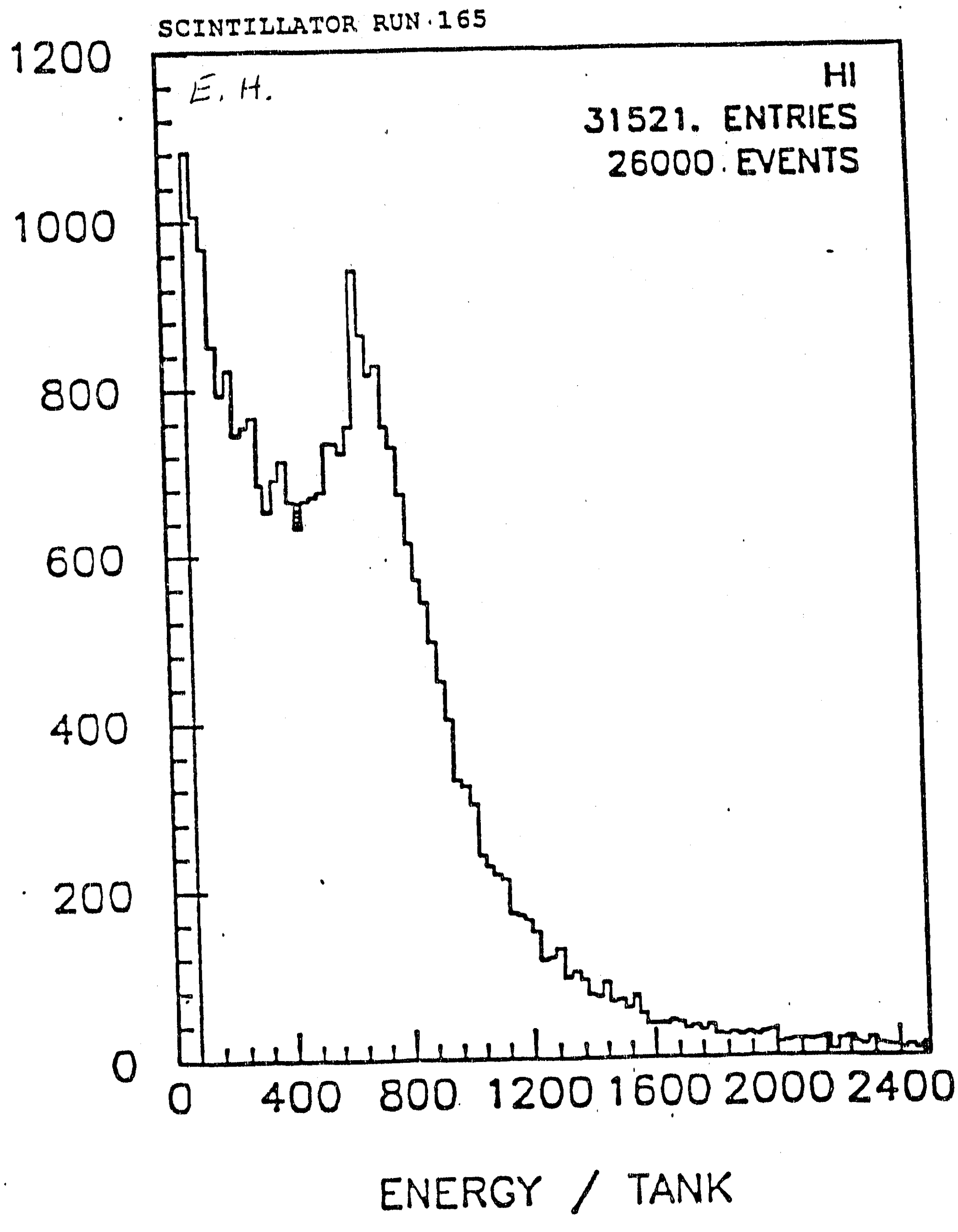
MUON ZENITH ANGLE DISTRIBUTION

FIGURE 2.9



MUON AZIMUTHAL ANGLE DISTRIBUTION

FIGURE 2.10



ENERGY IN SCINTILLATOR TANKS

FIGURE 2.11

3. Associated Matters

Asoka De Silva will do his Ph.D. Thesis on the early data of LVD, now being collected in Tower 1. The most likely subject will relate to muon fluxes e.g. muon bundles, though this has not been settled. Asoka has spent most of the past two and a half years at Gran Sasso, doing outstanding work on data acquisition, as well as streamer tube readout electronics. In addition, he has assisted wherever needed in the assembly of LVD modules, and in the organization of the running of the experiment. He is an invaluable member of the LVD collaboration.

Although Brown is not participating in the film analysis of E782, which completed its run in a 200 GeV/c muon beam at FNAL in 1990, scanning and measuring of the events is proceeding at Tohoku and at the University of Tennessee, and we are looking forward to the data analysis. These data will be compared with the muon neutrino interaction data of E745, which ran at Fermilab in 1985 and 1987.

E782 is the last in a series of experiments using hybrid systems, with their advantage of a visible, 4π target, to study hadron and lepton interactions. Although the runs are over, these experiments continue to yield results of physics interest.

The past year saw the inauguration of the GEM collaboration to build a detector at the SSC. We have joined this collaboration and expect to work on muon detection and the muon trigger.

Professor Widgoff and Asoka De Silva have been invited to the Neutrino 92 Conference to be held in Spain in June 1992, and Asoka will attend. Professor Widgoff has been invited also to the 26^{th} International Conference on High Energy Physics scheduled in August 1992 in Dallas, and plans to attend.

4. Scientific Personnel Associated With Task B

Mildred Widgoff – Professor of Physics, Principal Investigator

Anatole M. Shapiro – Adjunct Prof. of Research (Visiting), Professor Emeritus

Asoka De Silva – Graduate Research Assistant

Nadeem Hamidi – Graduate Research Assistant, starting June 1, 1992.

David Rossi – Senior Research Technician, part–time, through Support Task S which was inaugurated in January, 1991.

5. Papers and Reports Published and in Preparation

*440. "Grand", Asoka De Silva, LVD Note 105, July, 1991, revised February 1992.

442. "The LVD Data Acquisition and Processing Environment", A De Silva, G. C. Trinchero and P. Haridas, LVD Note 103, April 1991.

443. "Network Data Transfer Rates", Asoka De Silva, LVD Note 106, July 1991.

444. "Neutral Strange Particle Production in 200 GeV/c $p/\pi^+/K$ Interactions on Au, Ag and Mg", D. H. Brick and M. Widgoff with IHSC Collaboration, *Phys. Rev.* **D45**, 734 (1992).

445. "Study of Intermittency in Hadron–Hadron Collisions at $\sqrt{s} = 16.7$ GeV", M. Widgoff with IHSC Collaboration, in preparation.

446. "Progress Report of a Program in Experimental High Energy Physics – Task B", M. Widgoff, May 1992, DOE-FG02-91ER40688TB1.

* Previously listed as in preparation.

B. HADRON COLLIDER AND NEUTRINO PHYSICS (TASKS C AND J)

1. Task C

The major emphasis of Task C at present is the DØ ("D-ZERO") experiment at Fermilab's TeVatron Collider, where the first data run is just now underway. In this report, we will review progress related to the installation, commisioning, and first collider data taking with the DØ detector.

An additional project involving Task C personnel builds upon our earlier neutrino program at BNL by developing and testing new cryogenic methods for neutrino physics. We will discuss recent progress in this effort.

1.1. THE DØ EXPERIMENT

The DØ experiment has been the principal focus of this Task since the completion of the neutrino program (E734) at Brookhaven. We have been part of the DØ collaboration from its inception, and have carried as our primary responsibility the design, development, and installation of the Level-2/data acquisition system. This work is coordinated by Professor Cutts, and will be described below. Professor Partridge is responsibile for DØ's Level-0/interaction trigger system; this work is described in the accompaning Task J report.

The DØ Detector is the premier new facility in high energy physics. Just completed and installed at the world's highest energy accelerator, DØ provides a next generation detector to enhance the physics potential of the Fermilab 2 TeV Collider. Important features of DØ include excellent identification and measurement of letpons and jets, based on tracking (including a TRD), fine-grained U-liquid argon calorimetry, and full muon chamber coverage, over nearly the entire solid angle. A wide range of important and exciting physics is now available; some major areas are top searches, electroweak, W/Z, and QCD studies as well as searches for exotics like SUSY- or techni-particles.

Progress these last few months has been very exciting. The completed DØ Detector was moved early in February into the collision hall. Figure 1-1 shows it bedecked with flags at this time. We all have been very busy since then working with the detector and bringing systems fully online, while the Collider commissioning is underway. At the present time we have taken some data at very low luminosity (figure 1-2 shows a sample 2-jet event) but both the accelerator and the collider detectors are still in tune-up phase.

As mentioned above, the Level-2/data acquisition system for DØ is the responsibility of Brown's Task C. This system encompases the hardware and associated control software for the complete data path - from buffer boards in the 79 VME crates which accept the raw data that has been digitized, through to a special high speed link in the host cluster. The heart of the data acquisition system is a farm of 50 VAXstations (currently model VS4000/60s), each of which receives a complete event, performs a software filter, and transmits accepted events to the host.

The readout from the digitizing crates into the Level-2 farm is controlled by two systems, the Supervisor and Sequencer. The Level-1 trigger interrupts the Supervisor with the trigger-pattern and event number, at the time it passes an event, and then initiates full digitization. After selecting a node appropriate to the trigger, the Supervisor interrupts the Sequencer system via a special high speed bus. The Sequencer system includes custom readout sequencing hardware, one per each of the eight separate high speed datapaths corresponding to separate groups of VME digitizing crates. The Sequencer creates a 32-bit token for each readout board, which routes it repeatedly through the digitizing crates on its data cable. (The token includes both the crate numbers to be readout plus the event number, used to insure synchronization of data blocks). A custom VME buffer board collects blocks within each crate and outputs on its data cable in response to an appropriate token.

During the last year, we spent a great deal of effort integrating this sophisticated readout scheme into an operating Level-2 system at DØ. At present, the data flow control is working well, with enormous flexibility of collecting data from specific crates and routing them to a specific node (or nodes), all keyed on the pattern of Level-2 trigger bits. As one example, routing of events to "shadow" as well as "regular" Level-2 nodes has proven to be a useful method of testing new analysis filters.

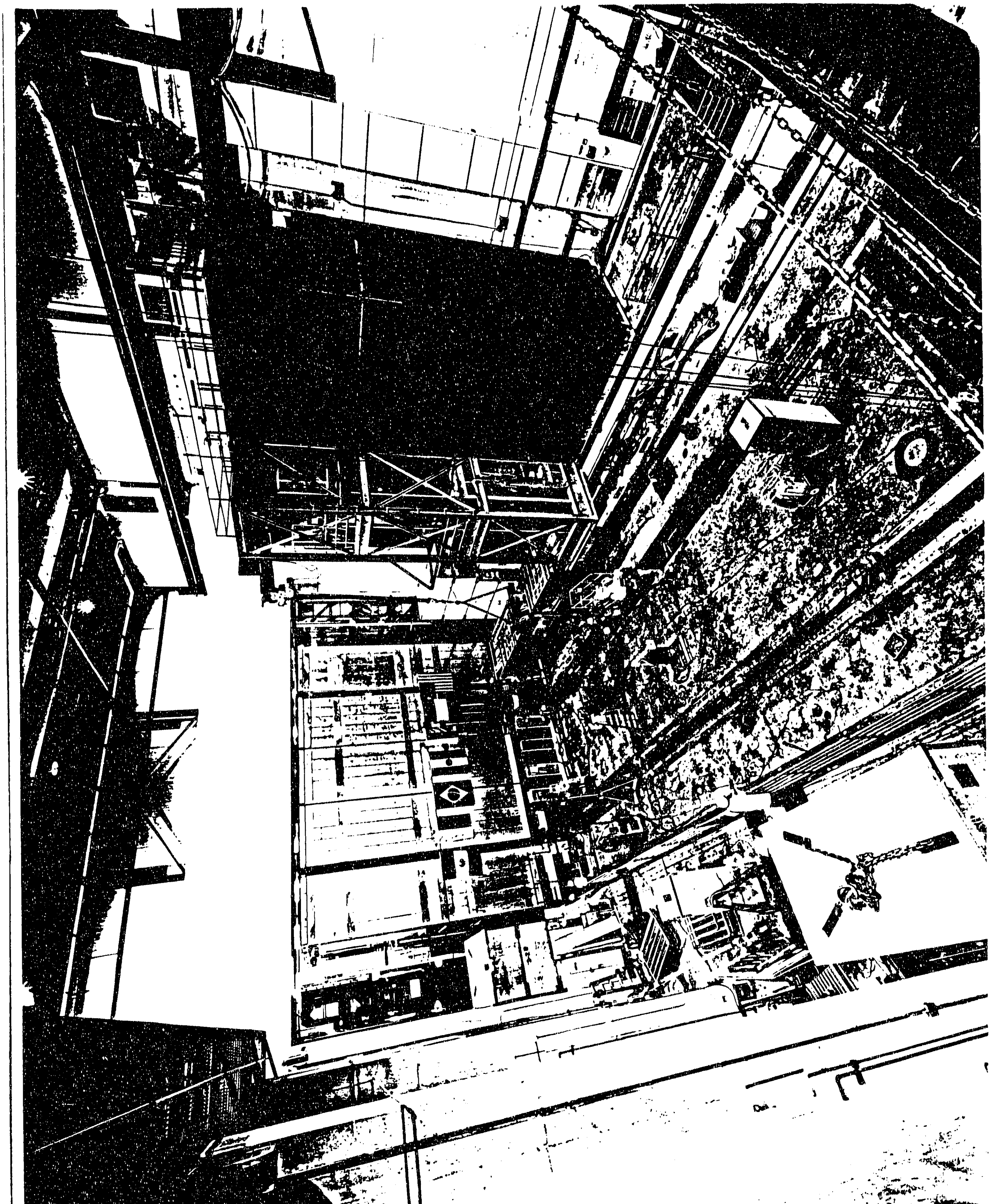


Figure 1.1

The DØ Detector Shown After Rollin to the Collision Hall
Prior to the Restacking of the Shielding Wall
February 1992

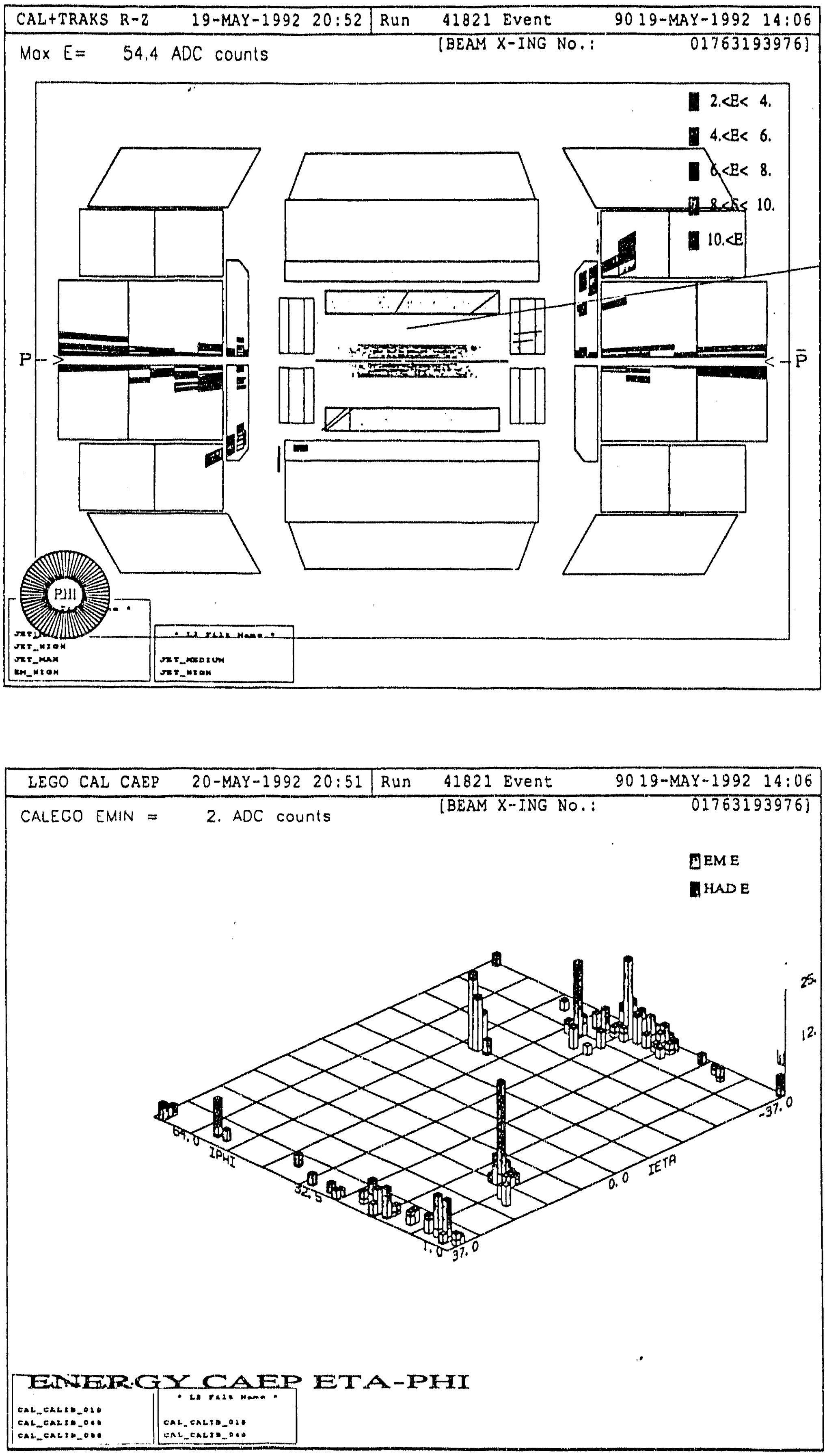


Figure 1.2

A 2-jet Collider Event in the DØ Detector, Collected in Tune-up May 1992

Currently the readout from the digitization crates into a Level-2 node is limited to of order 100 Hz by the time taken in the Sequencer system in responding to event interrupts and forming readout tokens. We are working at this moment on the integration of a new generation of sequencer boards into the data acquisition control system. These boards have onboard list processors to automatically create the tokens; with these and other functions moved to hardware the readout control time required per event will be reduced by an order of magnitude, to bring our overall input capability into Level-2 to the design range of 200-400 Hz.

Each of the Level-2 nodes consists of a standard, upgradeable VAXstation system (currently a VS4000-60) connected via a bus adaptor to a VME crate which includes 8 channels of multiported memory, a buffer memory for the output channel, and slots for coprocessor(s) and additional multiport memory channels. Data for an event flows from the 8 sections of the detector in parallel (at 320 MBytes/sec aggregate speed) into the multiport memory which is mapped to the FORTRAN COMMON of the ZEBRA memory management package. The data therefore is made readily available to the filter routines as standard ZEBRA banks. An elaborate filter framework coordinates the event analysis.

Until early this year we were using an earlier generation of Level-2 nodes, consisting of MicroVAX boards together with dualported memory boards in Q-BUS crates. The move to the long-planned VAXstation plus VME-based multiported memory (MPM) boards was a major upgrade, and brought the increased functionality of the MPMs together with an order of magnitude processor improvement. There were a number of upgrades in the control systems and in the Level-2 software but these were to take advantage of new hardware features; in general the Level-2 filter framework ported directly to the new VAXstations as it has through 3 generations of systems. On the control side we developed a new interface to couple the Supervisor and the Level-2 nodes, which also allow a new control system (the Surveyor) to monitor the Level-2 nodes' status. A major milestone achieved in the Level-2 code was the mapping of ZEBRA banks onto multiport memory, so that the event data is not moved from the 8 MPM channels.

Figure 1-3 shows the first 16 nodes of the new Level-2 system. as installed in February. The crate near the floor, on the left, houses termination/repeaters which

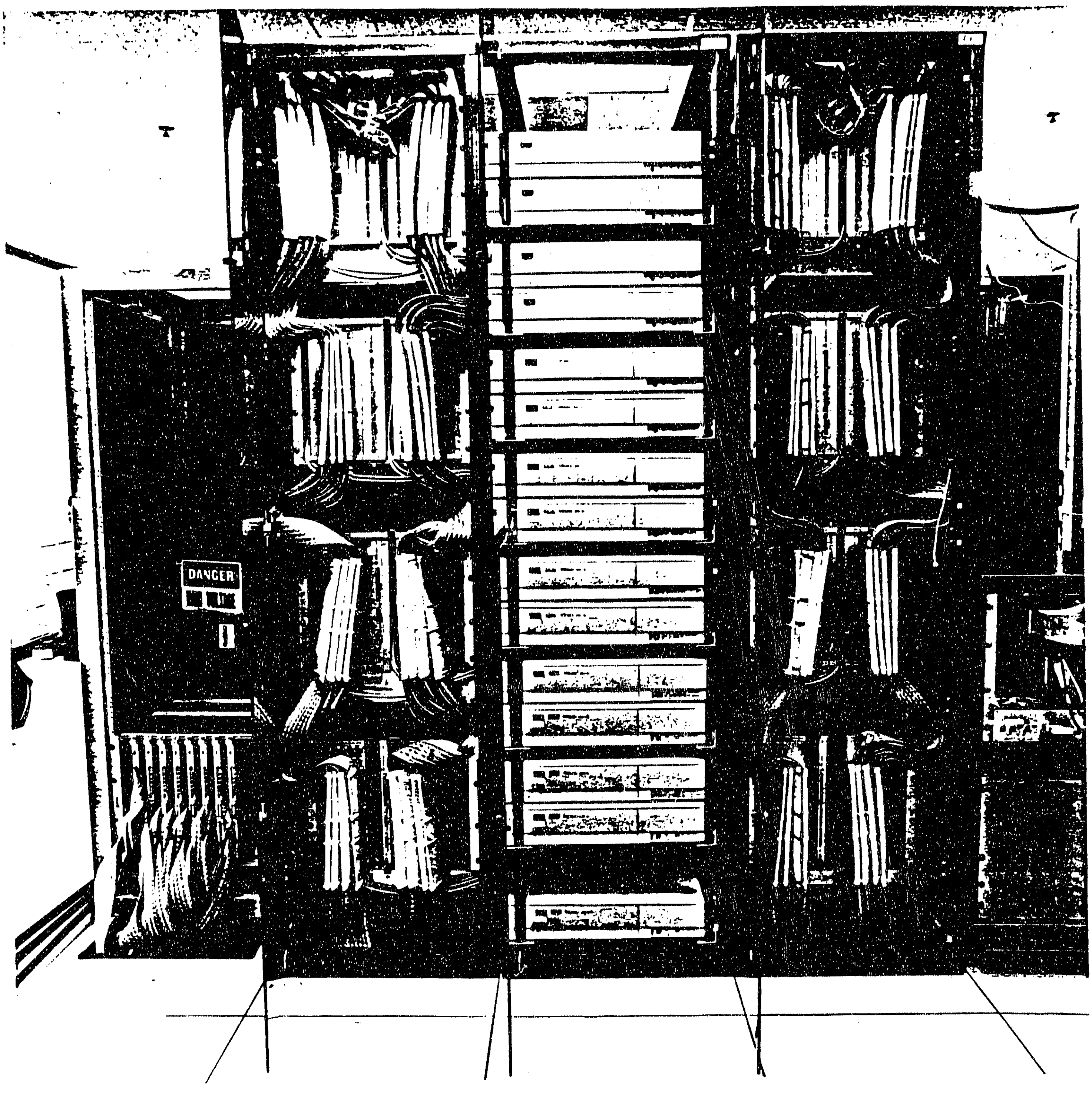


Figure 1.3

The DØ Level-2 System: as Installed
February 1992

are the end of the "long-haul" data cables from the digitizing crates. The middle rack contains the Level-2 processor systems, which are flanked on either side by VME crates containing the bus adaptors, MPMs, and output buffers. The Supervisor and Surveyor systems are in the single crate partly shown on the right. (The Sequencer is at the far end of the long-haul data cables, in the moving counting house with the digitizing crates.)

As the detector and collider are tuning up, over the next few months, we have several items beyond the new Sequencer boards to install at DØ. At present we have 32 Level-2 systems, and in the next month will deliver and integrate the final 18. Further, although the present ethernet connection is capable of the design 1-2 Hz output of filtered events from the Level-2 to the host, we have long planned to use a Level-2 output datapath similiar to the input : with buffer memories in each node sharing a datacable which dumps (at 40 MBy/sec) to a MPM associated with the host. We will install this system, which uses a DEC XMI/VME adaptor on the online host system, in the near future.

In addition to our Level-2 work, Task C personnel are participating strongly in the startup detector operation, manning shifts and working intensively with other experts to bring the entire data gathering operation to a smooth dependability. We also have been working with physics analysis groups undertaking among other things, studies of W-Z events (and generating a large sample for the general collaboration pool on systems at Brown) and exploring calorimeter response for QCD projects. Similar activities will naturally grow to be a major focus as our installation/operation work is completed and as DØ begins collecting long-awaited collider events.

1.2. Neutrino Calorimetry

The goal of this project is to develop a cryogenic technique suitable for detecting low energy neutrinos and, if successful, to carry out one or more of several experiments on solar neutrinos, neutrino properties or dark matter.

Our principal motivation has been the need to detect the interaction of low energy neutrinos (< 1 MeV) in real time in large targets. For example, to be sensitive to solar neutrinos reaching the earth from the two low energy, dominant branches – $p-p$

and $Be-7$ in the energy generation cycle of the sun. Other applications requiring similar detection properties are experiments to search for weak neutral current coherent scattering, neutrino magnetic moment measurements or searches for particle–like dark matter.

The difficulty is to extract in real time the small amount of energy deposited by the interaction from the considerable mass of the detector, and to find a material for the detector medium which has very low radioactivity because the signal rates are in general quite small.

Our proposed solution has been to use superfluid liquid as the detecting medium and to extract the energy via the carriers known as rotons – a special class of phonons in helium. This would yield several attractive features if it can be done; among them are the extreme purity of the superfluid and the very large number of energy carriers. The former promising low background and the latter low threshold and good resolution.

Although all of the basic physical phenomena needed to make this possible have been known for some time, no one had attempted to couple them in this way. Nor have each of the phenomena been fully explored. The technical challenges are great: developing the detecting elements, dealing with the ubiquitous superfluid film, demonstrating an existence proof for the coupling sequence of the necessary phenomena for detection, refining our understanding of the basic processes as needed for these applications, and studying possible sources of background.

Funding for the construction and operation of a prototype R.& D. detector has been obtained from the office of the Nuclear Physics of the D.o.E. No Task C person receives any funds from that grant; however, Task C personnel (R. Lanou is P.I.) are actively participating in the project.

In previous Progress Reports we have discussed the design and construction of the apparatus. The apparatus consists of a dilution refrigerator (500 microwatts at 100m K), a two liter test cell, a "film burner", sources, detectors and associated electronics/data acquisition.

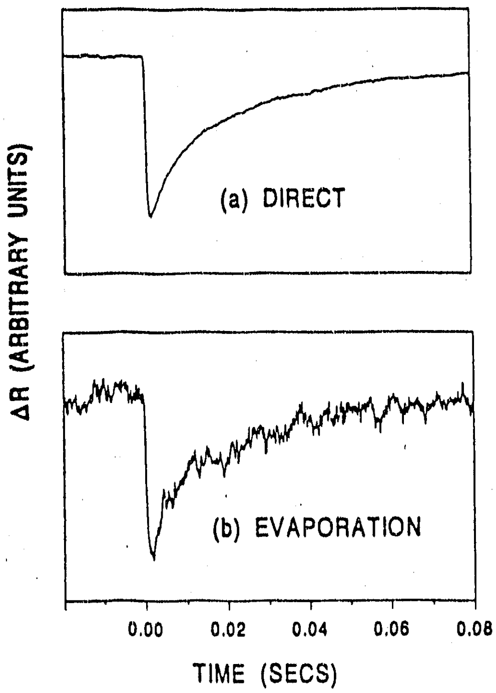
In the past year we have made important progress. We have developed and successfully operated (for long periods of a month or more) a so– called "film burner".

This device is crucial if we are to achieve adequate sensitivity. This novel and original device as well as its performance characteristics are discussed in a Review of Scientific Instruments article which we published in January.

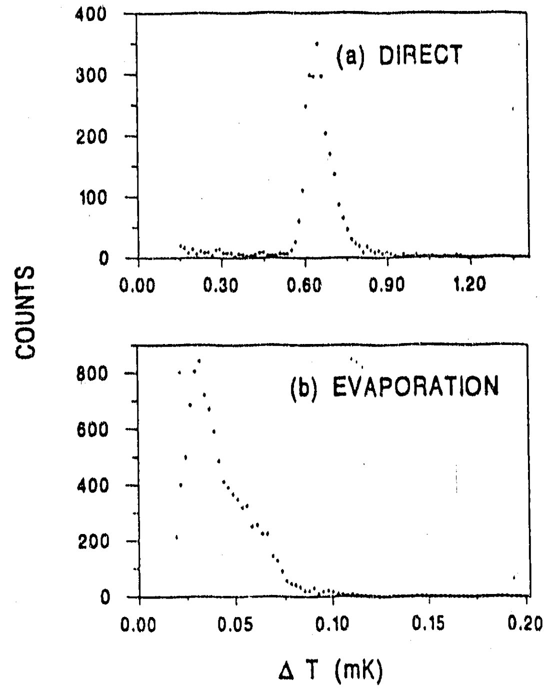
A second important results was the detection, by the process proposed, of individual 5-6 MeV α–particle events in the helium resulting from decays in an Americium-241 source mounted internal to the cell. The sensitivity was not yet good enough to detect individual, single compton recoil electrons from 550 keV gamma rays (Cesium-137). However, a collimated flux from an external source was detectable and permitted a spatial scan which effectively "x-rayed" the volume of helium. These results were recently published in the 20 April volume of Physical Review Letters. The figures on the following page illustrate these results.

Thus we have established at least two of the minimal conditions for this technique to work. Much work remains to refine the measurements, improve the sensitivity and establish the remaining properties required to scale a device up to a useful size.

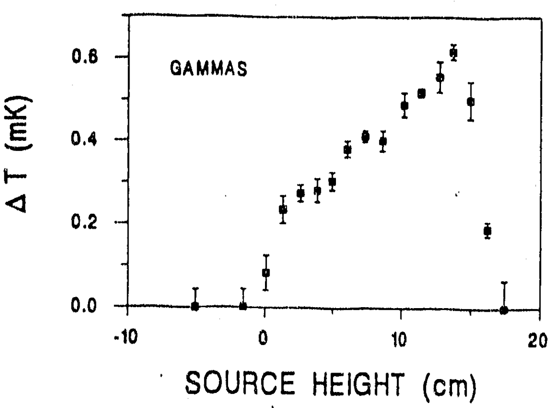
Plans to pursue these latter points are discussed in the accompanying continuation proposal.



Change in resistance of the bolometer detector (a) when the α hits the wafer directly and (b) when the α scatters in the superfluid helium bath and the wafer is heated by evaporated helium atoms.



Pulse-height distribution, expressed in terms of temperature rise, (a) for α particles hitting the bare wafer directly (T_{wafer} = 84 mK) and (b) for α particles stopped in the superfluid helium bath (T_{wafer} = 50 mK).



The steady-state temperature rise of the bolometer on the silicon wafer as a function of height of the γ source. The bottom of the cell is at 0 cm, the liquid is at 14 cm, and the wafer is at 15 cm.

1.3 Papers Produced in Past Year

1. J. Hoftun, " DØ Data Acquisition: Handling Events at High Rates", DØ Note 1298 (December 1991).
2. D. Cullen-Vidal, D. Cutts, "Shower Studies in the DØ Calorimeter Using Neural Networks", DØ Note 1394 (January 1992).
3. D. Cutts, J. Hoftun, M. Mattson, D. Nesic, "Simulation of the DØ/Level-2 Data Acquisition System", presented by D. Nesic, *Workshop on Data Acquisition and Trigger Systems Simulation for High Energy Physics*, Dallas (April 1992).
4. M. Mattson "DØ Level-2 Data Acquisition Simulation", Senior Thesis (May, 1992).
5. R. Torii, S. Bandler, T. More, F. Porter, R. Lanou, H. Maris, G. Seidel, "Removal of Superfluid Films from Surfaces Below 0.1K.", *Rev. Sci. Instruments* **63**, 230 (1992).
6. S. Bandler, R. Lanou, H. Maris, T. More, F. Porter, G. Seidel, R. Torii, "Particle Detection by Evaporation from Superfluid Helium", *Phys. Rev. Lett.* **68**, 2429 (1992).

1.4 Scientific Personnel in Task C

David Cutts	Professor of Physics
Robert E. Lanou	Professor of Physics
Richard A. Partridge*	Assistant Professor of Physics
Jan S. Hoftun	Research Assistant Professor of Physics
Dusan Nesic	Research Associate
David Cullen-Vidal	Graduate Research Assistant
Thomas Fahland	Graduate Research Assistant
Freedy Nang	Graduate Research Assistant
Hoawei Xue	Graduate Research Assistant

* Also on Task J

2. Task J

Outstanding Junior Investigator Award in Experimental Particle Physics

Task J is an Outstanding Junior Investigator Award to Richard Partridge for a program in experimental particle physics. The principle activity supported during the past year has been the completion of construction, testing, and installation of the Level 0 trigger components for the DØ experiment at Fermilab. In addition, Task J supported an investigation of physics processes relevant to the upcoming data run with DØ and various activities related to the SSC. This section summarizes the progress in these areas during the past year.

The Level 0 trigger is the first level in a multi-level trigger scheme being developed for DØ. It consists of two arrays of scintillation counters placed near the collider beam pipe on opposite ends of the detector and features precise time-of-flight measurement for particles striking the detectors. The goals for the Level 0 trigger include identifying interactions, determining the position of the interaction point within the luminous region, detecting multiple interactions in a single beam crossing, and measuring the luminosity of the collider. The progress in completing construction, testing, and installation of the scintillation counters, readout and trigger electronics, and the laser calibration system are described below.

The scintillation counters were designed, constructed, tested using cosmic rays, and installed on the DØ detector under an earlier contract between Brown University and DOE. The performance of these counters was found to be quite good, with time resolutions of 100-150 ps in cosmic ray tests. We are currently beginning the first data run for DØ and are in the process of getting readout and timing established for the counter readout. All counters are functional, but we do not yet have performance results for the Level 0 counters under actual beam conditions.

Considerable progress has been made in the development, testing, construction, and installation of the various electronic components in DØ. The analog front end electronics consists of custom QTAC modules take the PMT signals and perform Time to Analog Conversion (TAC) and integrate the charge of the PMT signals.

These modules had previously been built and tested at Brown and were installed on the detector along with various commercial NIM modules and interface devices built at Brown. The analog outputs of the front end electronics are brought to the Moving Counting House (MCH) where VME electronics digitizes the signals, forms vertex and multiple interaction signals, and provides readout to the DAQ system. Three different VME boards were built for Level 0:

- The L0ADC board digitizes the analog signals, incorporates luminosity scalers, and calculates statistical information for vertex finding
- The L0VTX board uses the results of the L0ADC boards to calculate the position of the interaction vertex and detect the presence of multiple interactions
- The L0CTRL board controls the event readout and generates various timing signals needed by Level 0 electronics

These boards have had their design, printed circuit layout, fabrication, and testing completed during the past year. The engineering and technician resources for this work were provided by the support staff from Task S, with some of the design and testing done by graduate and undergraduate students supported by task C and supervision by Prof. Partridge under Task J. These electronics are now being brought into operation at Fermilab.

A laser calibration system has been designed to calibrate and monitor the Level 0 counters. The light from a pulsed UV laser is waveshifted by a piece of scintillator and distributed to each counter by fiber optics. The laser and fiber optics have been installed at Fermilab; a small amount of work remains to be done on the wavelenght shifter, photodiode monitoring of the laser pulse, and triggering of the laser to complete this system.

In addition to construction of the detector, effort has been made to study physics topics using Monte Carlo simulations of DØ. Task J has supervised a triggering study of $W \to q\bar{q}$, which is the planned thesis topic of Freedy Nang, a Brown graduate student. Task J has also provided supervision for studies of top quark decays into two like-sign muons by Elain Fu, a Brown undergraduate student, and Haowei Xu, a Brown graduate student. Elain Fu wrote up her work as a senior thesis and Haowei

Xu has done a variety of preliminary studies in preparation for doing his Ph.D. thesis on this topic.

The final area of progress is studies of physics and detector issues at the SSC. A study of the ability of the SDC detector to find $H \to \gamma\gamma$ was done and included in the SDC technical proposal. The conclusion of this work was that at the nominal detector resolution, observation of this decay of the Higgs was possible for $M_H \approx 150$ GeV and by modifying the detector design to improve the electromagnetic calorimeter resolution lower Higgs masses could be resolved. Detector studies focused on the SDC data acquisition system, where simulation studies were made to understand the global properties of large data acquisition systems. This work was supported by Task E, which is a grant administered by the OSSC and is not part of the present progress report. Prof. Partridge has also served as co-leader of the SDC data acquisition group and spent the spring semester on leave through the auspices of an SSC fellowship.

2.1. Publications and Reports During the Reporting Period

1. Assessment of Level 0 Trigger Electronics at D0, senior thesis by Kevin A. Epstein (unpublished).
2. Analysis of the Like-Sign Muon Decay of the Top Quark, senior thesis by Elain S. Fu (unpublished).

3. Task S

This Task's mission is to provide technical support to the experimental Tasks B, C & J. This support is dominantly in the area of electronics at present.

This year the technical staff (technicians and engineers) has been primarily occupied in work on the D–Zero project (Tasks C & J) with lesser effort devoted to LVD (Task B) and SSC (Task E) projects.

The details of each of these projects are contained in the sections of this Report related to Tasks B, C & J.

3.1. Personnel in Task C

David Rossi	Senior Electronic Technician
Jack Fowler	Electronic Technician
Richard Hlustick	Electronic Technician
Lang Wang	Electronic Engineer

(P.I.'s: R. Lanou (Contact Person), D. Cutts, R. Partridge, M. Widgoff)

END

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