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Proposal
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Progress Report and Proposal

"Studies of Elementary Particles"

CONTRACT DE-AC02-76ER01112

Department of Physics
University of Michigan
Ann Arbor, Michigan 48109

Submitted to *Department of Energy*

DRDA-89-3072

Name and Address of Institution:

The Regents of The University of Michigan
Ann Arbor, MI 48109

Title of Proposed Research:

"Studies of Elementary Particles"

Desired Starting Date/Proposed Duration:

1 January 1990 (60 months)

Amount Requested:

$20,686,600	Operating Funds
3,243,600	Capital Equipment Funds
$23,930,200	

Submitted by:

J. Wehrley Chapman
Department of Physics
Project Director

Official Authorized to Sign for Institution:

FARRIS W. WOMACK, VICE PRESIDENT AND
CHIEF FINANCIAL OFFICER

DoE Contract Highlights

- Task B has **completed and successfully operated** 8 Michigan **muon array** patches for the UMC experiment. Data from the detector has already improved the limits on the ratio of gamma rays to hadrons in primary cosmic rays.
- The Task C built **luminosity monitor for the MarkII** detector is functioning well and fulfilling its key role in the determination of the **Z mass and width**.
- Major Task C contributions to the machine diagnostics, the beamstrahlung monitor and wire scanner, have provided critical tuning information for the SLC.
- Task E (γ^*) has recently reported the detection of 200 GeV γ-rays from the Crab Nebula with a statistical significance of 5.8 σ. This observation confirms the importance of imaging techniques for VHE γ-ray astronomy.
- The Michigan theory group (Task G) has focused on:
  - Working to understand the systematics of **gluon dynamics** in poorly understood **pseudoscalar meson decays**.
  - Exploring the consequences of **heavy Higgs boson** and/or a top quark more massive than the $W^{\pm}$ or Z.
  - Surveying the potentially attractive ways of experimentally **searching for the Higgs boson** of the minimal Standard Model or the spectrum of Higgs bosons to be expected in extensions of the Standard Model.
  - Calculating the **radiative corrections for** $W^+W^- \rightarrow W^+W^-$ as a precision test of the Standard Model, especially in its sensitivity to the Higgs sector.
  - Investigating the modifications of general relativity arising from **quantum fluctuations of matter**.
  - Exploring phenomenological test of **CP violation dynamics**.
  - Developing relations between the **strong CP** problem and **ElectroWeak CP** violation.
  - Investigating 4-Fermi interactions in Technicolor models.

- The new VAX computer (Task H) is functioning well along with the cluster of workstations and the expanding Departmental local area network.
- The electronic shop facility (Task H) is very active with UMC, SLC, MACRO, and SSC development projects. Its newly renovated area and "state of the art" CAD equipment make the shop an excellent resource for HEP.
- The first MACRO (Task I) supermodule is complete and a 90 day run has begun. Data from this run will serve as an evaluation platform for the various detectors and trigger schemes proposed for MACRO including the ERP trigger module built at Michigan. The ERP trigger is performing exceptionally well. The data from the 90 day run will provide a thesis topic for Cathy Smith, a Michigan graduate student.
- The Task K D0 group has grown to 5 physicists who have designed, built, and tested prototypes for the Inter-Cryostat Detector (ICD) and its associated electronics.

Future Plans

- Prototypes of a very large sparse array of electron and muon counters that would extend the UMC (Task B) energy range to 10^{20}eV are being studied, constructed, and evaluated as the next step for UHE gamma ray studies.
- A prototype SSC electron calorimeter module (Task C) and its attendant electronics is under construction. A pre-calorimeter stiff track triggering scheme is also being simulated by computer. Chambers and electronics will be fabricated and tested if the concept remains as promising as initial simulations indicate.
- A proposal has been submitted and mirror prototypes have been developed for a gamma ray imager to be located at Mt. Hopkins (Task E). This imager will, along with the existing unit at Hopkins, increases dramatically the sensitivity of searches for VHE gamma ray sources.
- A fiber optic connection to the NSFnet hub, located at Michigan, is to be installed in the summer of 1989. With this Task H addition we will have very high speed connection to the "center" of the nations academic network.
- Three supermodules for MACRO (Task I) will be fabricated and installed in the upcoming year. Three additional modules in the second year and the remaining six modules in the third year.
- A second generation Fermilab ACP system of 250 VAX equivalents will be attached to the VAX 6260 (Task H) and running in early 1990.
- In the upcoming five year period, Task K plans to complete and install the D0 Intercryostat Detector, further refine the central calorimeter databases, and be centrally involved in the analysis of data from the D0 experiment.

Work Completed in (1988-1989)

Overview

- 1988 marked the end of our participation in the running of the IMB detector. The processing of data will continue till the end of 1989. Publication of results should be possible the following year.
- The Michigan Array of muon detectors has operated well for about a year along with the Utah surface array. We are reporting limits on the flux of gamma rays with energies above 1 PeV from various sources; Cygnus X3, Hercules X1 and the Crab nebula.
- The area of buried muon counters has been increased to 1250 m^2 by the addition of four new patches.

Analysis of Data from the IMB Detector

Analysis of IMB data is in two steps: first, computer reconstruction of each event rejects those which are clearly incoming tracks. Then events retained by the program are individually scanned. Approximately ten events per live day, on average, are scanned with about one per day identified as originating within the fiducial volume and saved. This final sample is ultimately compared to the sample obtained independently by the University of California-Irvine group and the final data-summary tape is agreed upon.

Each data tape is analyzed twice by the above procedures, once for contained events with more than 70 photomultiplier hits and again for those events with between 20 and 70 hits. The first class of events will contain virtually all nucleon decay events should they occur. The second, "low energy" class has neutrino interactions near threshold such as those found from the supernova SN1987a. The processing of low-energy events requires modifications of the analysis software to eliminate many events which are caused by electronic noise and would cause the usual fitting routines to slow considerably. In the present configuration each class of events requires about the same amount of CPU time.

The computer reconstruction program requires about three CPU-hours per live day on the department VAX 6200 machine. This computer has six parallel CPU units so the actual time required is usually similar to the CPU time. Typically 2-3 tapes (1 tape $\sim$ 1 live day) are processed per calendar day, limited by available manpower. Since mid-1988 many runs have been preprocessed on-line at the experiment, which reduces the CPU time required per tape by about a factor of five.

The data sample that the Michigan group will analyze ends on 1 January 1989 and includes runs 2035 through 3635. For the class of events with more than 70 hits, essentially all have been computer processed and 80% have been scanned. Of the low-energy events, about 60% have been computer processed and 30% have been scanned.

This work has been carried out in 1988 by J. Matthews with M. Mudan (a graduate student at University College in London) along with undergraduate students at Michigan.

CONSTRUCTION OF THE MUON ARRAY

In 1988 we installed four more patches of muon counters thus completing the eight inner patches shown in Figure 1. Each patch contains 64 sheets of scintillator, each sheet is 2.5 m^2 in area and is viewed by a 5" photomultiplier tube. The sheets are buried beneath 3 meters of earth. A survey taken in November '88 showed that the rate of failure for the buried counters was about 1% per year. This low rate of failure vindicates our decision to reduce construction costs by burying the counters without regard for their subsequent replacement or repair.

Construction and installation of electrons has continued, keeping pace with the deployment of the muon detectors. In Fall '88 we completed the installation of Michigan built discriminators and high voltage systems for muon patches 5–8. In addition, we developed a rugged PMT pulse amplifier system to be used as signal repeaters for the outer muon patches. These were installed in muon patches 6–8.

We also implemented several incremental improvements in the electronics systems. We installed new WWVB and GOES clock CAMAC interfaces, providing us with redundant stable time bases for studying any periodic γ ray sources we might detect. These interfaces, designed by our DoE HEP electronics shop, latch the time of an event trigger and provide it both to CAMAC and an external connector. This latter feature is used to transmit the time information to the CASA data acquisition computer.

Networking is becoming a crucial part of modern experiments. During this past year we installed a connection from Dugway to the NSFnet and attached the Michigan and Chicago VAX computers. This provides reliable remote access to our VAX computers at Dugway from U. Utah, U. Chicago and the University of Michigan. We provided the gateway/router, while Chicago purchased the modems, and the University of Utah funded the leased line between Dugway and Salt Lake City. We use this NSFnet connection to transmit to Ann Arbor at the end of each data run diagnostic histograms to our laser printer and the Utah-Michigan array data to our VAX 6200 disks. The Chicago and Michigan VAXes are now linked via DECnet/Ethernet. Data is acquired in parallel by the CASA and Michigan computers, and periodically transferred over the Ethernet to the CASA VAX, where it is merged with the CASA data before transferring to tape.

STATUS OF AIR SHOWER DATA ANALYSIS

Michigan has the primary responsibility for analysis of data from the combined surface and subsurface elements of the Utah-Michigan array. The experiment records approximately 10^5 events per day, or about 1 per second. The time and pulse height of the surface array hits and the time of the buried muon array hits are used to reconstruct the direction, electron size, and muon size of the shower at the ground. All events which are successfully reconstructed (about three out of four) are retained with their fit results for later analyses such as source searches, distributions and dispersions of electron and muon sizes, etc.

To take advantage of the unique opportunities for cross-calibrations and measurements available at the Utah site, all events which triggered the array in coincidence with either of the Fly's Eyes or the Utah Cerenkov telescope are also retained. Those events coincident with Fly's Eye II Cerenkov Mode triggers are merged and saved with fit results obtained from our Utah collaborators.

Data is recorded on disk at the site and copied to 6250 BPI tapes about every two weeks by Fly's Eye staff and sent to Ann Arbor for analysis. Since late 1988, data has been automatically transferred via computer link and we envision using such a procedure routinely in the future. The reconstruction programs are run on the department VAX 6200 machine and process more than four events per second. The processing procedure is managed by J. Matthews with undergraduate students at Michigan; maintenance and development of the programs is done by J. Matthews, D. Nitz, J.C. van der Velde, and graduate students D. Ciampa and J. Kolodziejczak.

Data have been taken since 29 March 1988 with no serious interruptions. All data taken through October 1988 have been processed into data summary tapes. Data taken prior to September 1988 will probably be re-analyzed to utilize improvements in some fitting routines, but the changes are minor and the analyzed set is useful as it stands.

Preliminary results have been obtained on three- and six-month subsets of the data and have been reported at various conferences. Analysis for excess air showers from the directions of Cygnus X-3 and Hercules X-1, including searches for short term bursts have yielded null results. Studies of fluctuations in muon content have demonstrated our capacity to reject hadron showers at the level of 1/100 to 1/4000, depending on electron size. Cutting on muon poor showers has not resulted in an increased signal from Cyg X-3 or Her X-1. A search over the whole sky does not reveal any discrete sources, with or without cuts on muon content. We have improved the limits on the ratio of gamma rays to hadrons in primary cosmic rays to about 0.001, based on muon content.

Proposed Work for (1989-1990) and Beyond

Construction of the Michigan Array

We plan to lay the cables in conduit for all the outer patches (9 thru 16) by July '89 before the Chicago group installs the inner 500 modules of CASA and thereby presents the use of tricks in that area. In addition we will install two more patches, probably 9 and 10 in Figure 1, in July and August of '89. Our schedule calls for installing four more patches in 1990 and completing the project by installing the last two patches in early '91.

During the summer of '89 we will be constructing electronics for muon patches 9-16, replicating the high voltage distribution and discriminator systems that are in place for the first 8 patches. We will also be constructing pulse repeaters for these outer patches.

Several improvements to the electronics are also underway which we expect wil be completed by the end of the summer. We are designing a new version of the master trigger module that correlates muon triggers with Fly's Eye track triggers in hardware, rather than via software as it is currently performed. The new module also provides a LAM register that identifies the trigger class. This allows the VAX to efficiently read only sections of data that pertain to the trigger class of the event. These improvements will reduce our deadtime by a factor of 2 at a given event rate.

A new muon patch trigger is under development. This is used to provide information on the muon content of showers observed by the Fly's Eye detector. The current patch trigger equires $\geq$ 15 total muon counters to be hit in the inner 4 patches. The revised trigger will utilize the information from all 16 patches, generating a trigger if $\geq$ n patches have $\geq$ m counters hit each.

A new diagnostic scaler system is also under development which will be used for the outer 8 muon patches and replace the system currently used for the inner 8 patches. The new system will have an 8 times higher density and use significantly less power than the current system. This allows us to double the number of muon patches, while only increasing the rack space and power used by the electronics by 50%.

Work is underway on the software front in preparation for the operation of the 500 counter (1/2 CASA) array at the end of 1989. The data acquired by the Michigan VAX is now being routinely sent to the CASA VAX where it is merged with the data from the 49 counter CASA mini-array. The control of the CASA and Michigan arrays has not yet been merged, but is scheduled to be done during the next 6 months.

We plan to purchase the commercial electronics required to instrument muon patches 9–16 at the end of 1989. This includes low voltage supplies to power the Michigan built electronics, high voltage photo tube supplies, LeCroy 4290 TDC system components.

During the 1989–1990 time frame we will complete the integration of the data acquisition and control the software for the CASA and Michigan arrays. When the complete CASA array becomes operational in 1991, the trigger rate will severely tax the aging MicroVAX II workstation that we currently use. We will need at that time to upgrade the data acquisition computer to a more modern model that is $\gtrsim$ 5 times faster.

Analysis of IMB Data

The Michigan group plans to continue analysis of IMB data taken through the end of 1988, which marks the end of Michigan's involvement in data taking. This will require several months to complete, depending on the available manpower. It is the intention of the IMB collaboration to write substantial papers on the search for nucleon decay, characteristics of neutrino interactions, and other subjects using this data set. This will involve computer simulations, publication charges, etc. for the next two or three years.

Analysis of Data from the Michigan Array

It is our intention to continue the above analyses and publish results on searches for gamma showers from Cyg X-3, Her X-1, the Crab Nebula and Pulsar, and diffuse and discrete production of gamma rays in the galaxy. We plan as well to present these results at the 1990 International Cosmic Ray Conference in Adelaide, Australia.

A marked improvement in sensitivity will occur when we begin analysis of data taken jointly with the Chicago Air Shower Array. The first 500 units of CASA are anticipated to provide data beginning in the Fall of 1989.

Prototype Studies for a Very Large Array

Despite decades of study, the origin and nature of cosmic rays above 10^{17} eV remains entirely unknown. The "knee" in the spectrum around 10^{16} eV is not understood. Continuing argument takes place as to whether the primaries above the knee are "iron-rich" or "proton-rich". The paucity of our knowledge about these important questions is simply due to lack of good data. The problem is that the data rate is very low and the anisotropy and muon content of the showers caused by these primaries have never been well measured.

Based on our experience with the Michigan muon array we have begun some calculations of the parameters for a very large air-shower array. The goal of the device would be to measure the rate, muon content, electron content, and direction of cosmic ray primaries in the energy range 10^{17}–10^{20} eV.

The size of such an array would have to be > 100 km^2. It would record 10^6 events/yr above 10^{17} eV, with an integral rate which falls approximately as E^{-2}. Fortunately the electron size and muon size grow approximately linearly with E so that the elements of the array can be very widely spaced. Calculations indicate that a space of 700 m will suffice up to energies of 10^{19} eV. Above that the spacing can be increased in order to optimize rate vs. cost. About 250–500 "stations" would be needed to cover the entire range 10^{17} to 10^{20} eV.

Using stations that have four .25 m^2 electron counters our calculations show that appropriate triggers can be devised, and that the core location and electron content of such showers can be determined to an accuracy of 100 m and $\pm$ 10%, respectively. Each station would be equipped with $\sim$ 10 m^2 of underground muon counters for measuring composition and to provide independent estimates of shower direction. Station-to-station relative timing requirements are not severe because of the large spacing. Each station would be entirely self-supporting, with no cabling and a minimum electronics. All communication, calibration, and data transfer would be by radio.

During FY90 we would like to do prototype studies on the hardware for such an array. We estimate the cost at $\sim$ \$10,000.

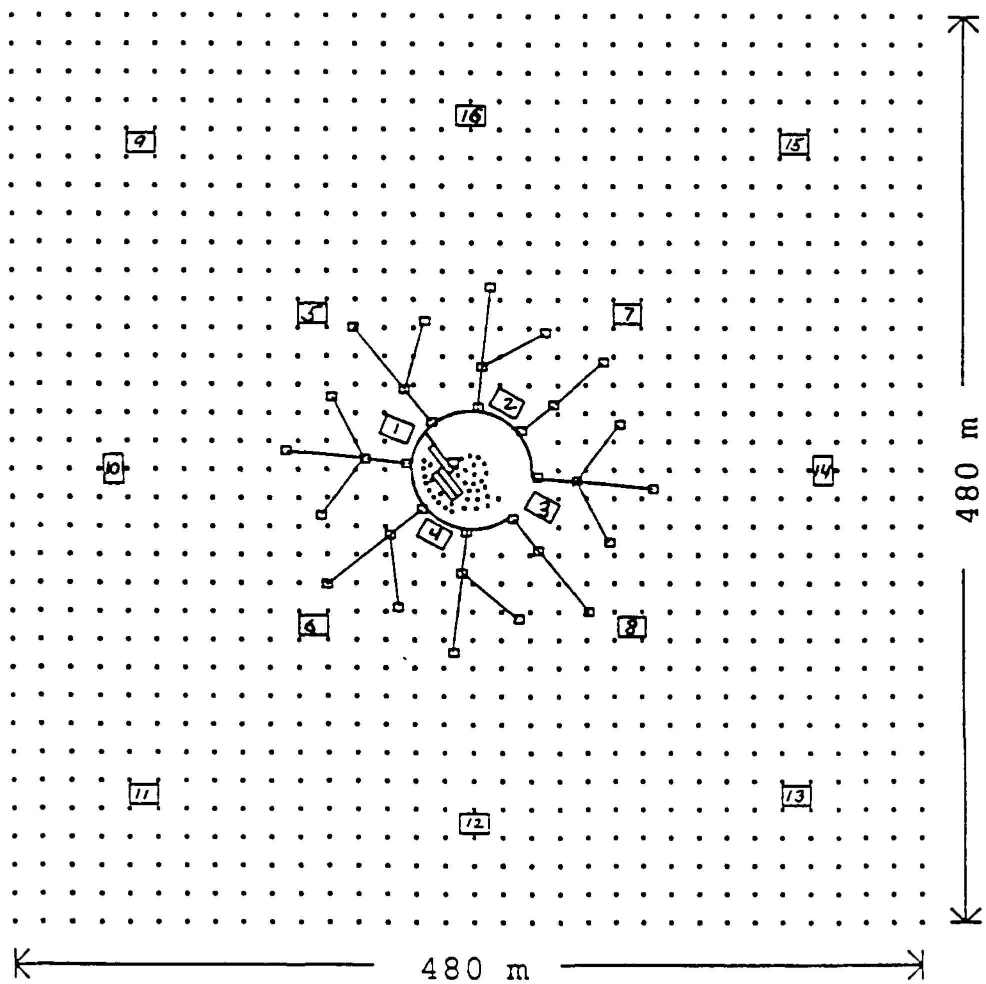


Fig. 1. Layout of Michigan muon array patches at the Fly's Eye site. Grid indicates the proposed CASA array. Muon patches 1–8 are operational; patches 9 and 10 will be installed in 1989.

Review of Research Activities (1988-1989)

Overview

The primary research activity of the members of Task C consists of participation in the MKII/SLC program with major contributions to the detector, physics planning and machine diagnostics. This activity has finally reached to point of successful SLC operation and MKII data taking. Our group is still involved in the completion of two analysis efforts using data accumulated by the HRS collaboration at PEP. We have also started looking to the future by initiating several major SSC-related activities.

Personnel

Task C supports faculty members J. Chapman and R. Thun, research fellows G. Bonvicini, R. Frey and W. Koska, and graduate students M. Chmeissani, E. Gero, S. Hong, M. Ken and M. Petradza. Bonvicini, Frey, Koska, Gero, Hong and Petradza continue to be resident at SLAC in support of the MKII/SLC effort. It is expected that Ken and Petradza will obtain their PhD degrees during 1989.

MKII/SLC Experiment

Our group takes great pride in having made major contributions to both the machine and detector components of the MKII/SLC program. Years of intense effort are now being rewarded with data at the Z°. Michigan contributions consist of the following:

a. **Beam-wire scanning, beam-beam deflections.**

W. Koska has worked full-time for nearly three years on the software for measuring beam profiles and beam positions using two techniques. One of these consists of flipping a thin carbon wire into the center of the beam pipe and scanning the SLC beams across the wire. The other technique obtains data on beam parameters by measuring the deflection when the two SLC beams pass closely to one another. These two kinds of measurements have been absolutely critical for successful SLC operation. Results are described in the attached papers.

b. **Beamstrahlung monitor.**

G. Bonvicini, E. Gero and R. Frey (in collaboration with C. Field of SLAC) have designed, built and brought into successful operation a monitor for detecting the hard electromagnetic radiation generated when the two intense SLC beams pass near each other. This monitor has also been used for sensing the radiation from the carbon-wire scanner. The beamstrahlung signal has been observed regularly and initial results are summarized in an attached paper. This effort represents one of the pioneering activities in the field of linear collider diagnostic methods. E. Gero plans to make beamstrahlung his thesis topic.

c. **Small-angle monitor (SAM)**

This tracking-calorimeter device consists of 1800 proportional-wire channels placed around the beam-pipes and is used for measure Bhabha scattering in the angular interval from 50 to 150 milliradian. The Bhabha event rate in this detector is slightly higher than the expected peak Z° event rate. The first few Bhabha and Z° events, obtained just recently, are shown in the attached figures. SAM will play a critical role in measuring the SLC luminosity. This luminosity measurement is essential for determining the Z° resonance shape and for finding the position of the peak. All members of the Michigan group have contributed to the SAM project. S. Hong has major responsibility for the analysis of SAM data and expects to make this his thesis topic.

d. **Muon upgrade**

J. Chapman and M. Chmeissani have recently completed the successful construction, installation, and testing of 800 channels of VME based preamplifer-TDC electronics that digitizes the forward muon chambers of the MKII. These chambers extend significantly the muon coverage of the detector and will be important for measuring semi-leptonic decays of quarks. The forward regions are particularly important for asymmetry measurements.

e. **Radiation corrections**

G. Bonvicini and R. Frey have participated in a major synthesis of radiation corrections with emphasis on Z° physics. Bonvicini has continued this work as outlined in an attached paper. He has organized a workshop on radiative corrections to be held in Ann Arbor on May 22-25. About forty experts in the field are expected to attend.

HRS analysis

We have two students. M. Ken and M. Petradza, who are analyzing HRS PEP data for their thesis work. Ken is doing a general study of D_s (F-meson) and K_0 production. Petradza is analyzing QED events with four final-state leptons. Her analysis includes both HRS and MKII data since the cross-section for hard-scattering processes are small in higher order. Initial results are generally consistent with the expectations of QED.

SSC studies

Both J. Chapman and R. Thun have been active participants in various SSC workshops and study groups. They have made contributions to detector radiation studies and to trigger investigations. J. Chapman presented a summary of Z coordinate options for straw tube tracking at the recent SSC meeting in Berkeley, CA. The paper from that presentation is attached. Work on triggering schemes for drift tubes is continuing.

Last year R. Thun began a study of proportional chamber gases with emphasis on fast drift velocities and immunity to spurious neutron-induced signals. This work is documented in two attached papers. The use of CF_4 or A-CO_2 mixtures leads to significantly faster drift times in small-diameter proportional tubes. Gases with low hydrogen content minimize neutron induced signals, as expected.

The work on proportional tubes is being extended to include the construction of a fine-grained electromagnetic calorimeter test module. The module is presently under construction and is financed from SSC Detector R&D funds. Part of the project consists of developing suitably fast electronics and this part of the effort is led by J. Chapman. It is expected that initial tests of the calorimeter will take place this fall in a Fermilab test beam.

Finally, R. Thun is voting for SSC with his feet by moving down to Texas for a one-year sabbatical leave with the new SSC organization.

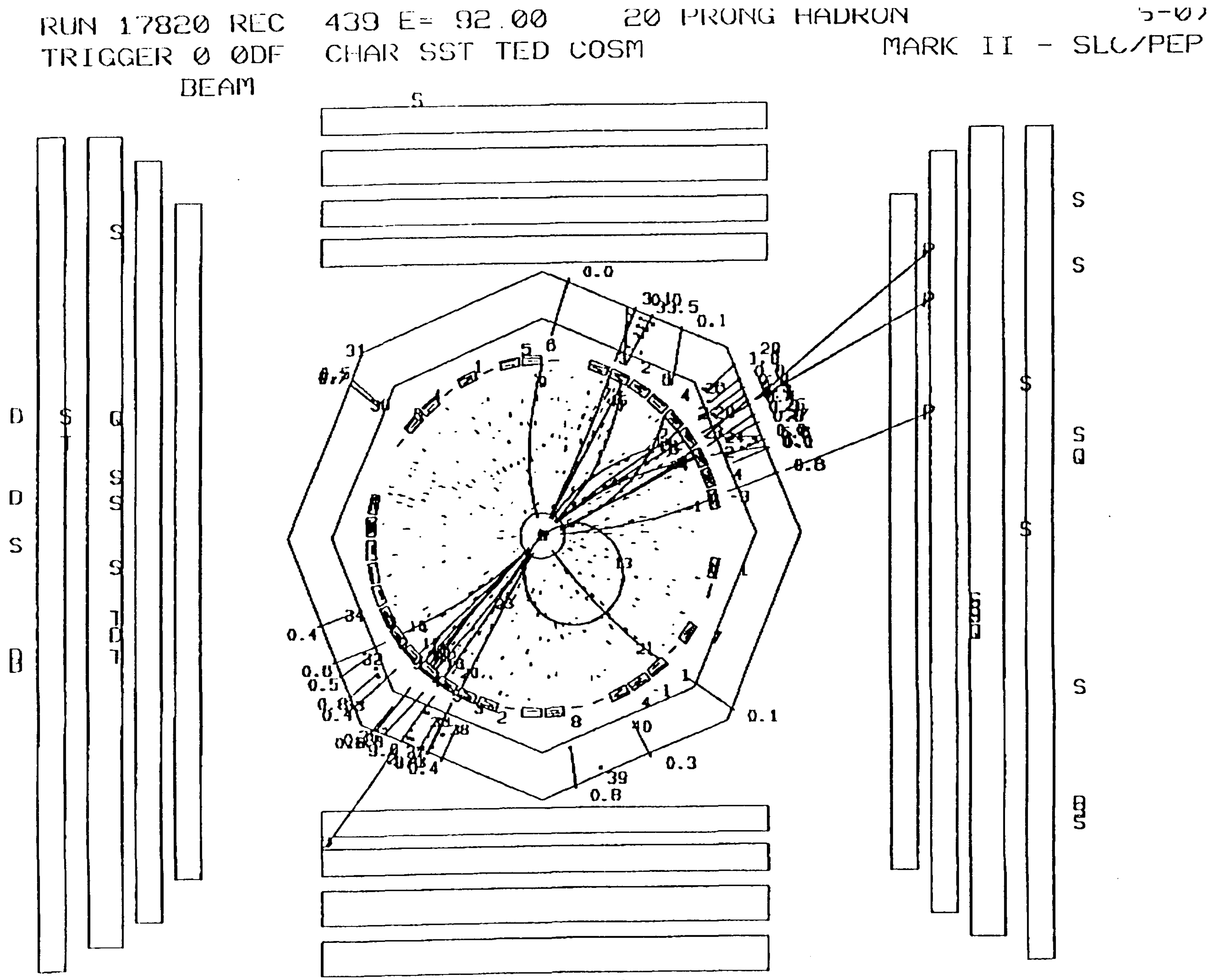
Budget

We have drawn up budgets both for next year and for the five-year period 1990-1994. These budgets assume that we will continue to participate in the MKII/SLC experiment at essentially the present level of activity for the next three years (two years of data-taking plus one additional year of analysis). After the MKII/SLC experiment we expect our main activity to consist of the preparation of a major SSC experiment. We do not preclude the possibility of participating in some other experiment prior to SSC start-up but have not made any definite plans to do so. The one-year and five-year budgets are shown in the attached tables.

Publications

1988

1. "Experimental Limits on Massive Neutrinos from e^+e^- Annihilations at 29 GeV," Phys. Rev. D37, 577-582 (1988) (C. Akerlof et al.).
2. "Measurement of the Inclusive K_s^o Branching Fraction in Tau Decay," Phys. Lett. B205, 407-410 (1988).
3. "Production of η Mesons in e^+e^- Annihilations at $\sqrt{s} = 20$ GeV," Phys. Lett. B205, 111-114 (1988).
4. "Measurement of the $D^o \rightarrow K^-\pi^+$ Branching Fraction," Phys. Lett. B205, 411-415 (1988) (S. Abachi et al.).
5. "Tests of Small Proportional Tubes with CF_4-HRS Gas Mixtures," Nucl. Inst. Meth. A273, 157-160 (1988) (R. Thun).
6. "Nuclear-Target Effects in J/ψ Production in 125 GeV/c Antiproton and π^- Interactions," Phys. Rev. Lett. 60, 2121-2124 (1988) (S. Katsanevas et al.).
7. "Production Cross Section and Electroweak Asymmetry of D^* and D Mesons Produced in e^+e^- Annihilations at 29 GeV," Phys. Lett. B206, 551-556 (1988) (P. Baringer et al.).
8. "High-Mass Dimuon Production in $\bar{p}N$ and π^-N Interactions at 125 GeV/c," Phys. Rev. D38, 1377-1403 (1988) (E. Anassontzis et al.).
9. "Measurements of Upper Limits for the Decay Widths of D^{*+} and D^{*o}," Phys. Lett. B212, 533-536 (1988) (S. Abachi et al.).
10. "Measurement of the D^o, D^+ and D_s^+ Meson Lifetime," Phys. Rev. D39, 123-137 (1988) (D. Averill et al.).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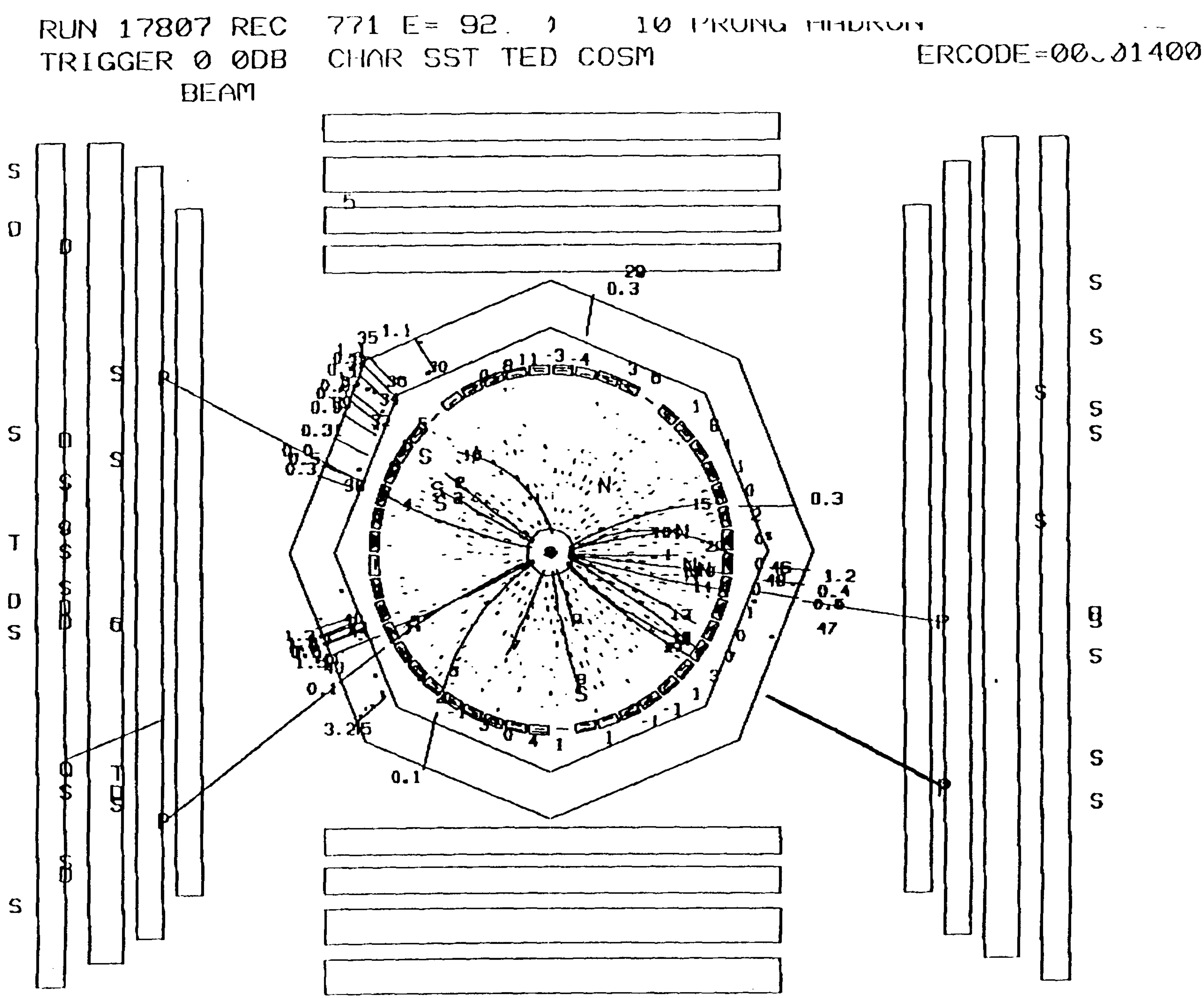
20 PRONG HADRON
TRIGGER 0 0DF CHAR SST TED COSM
BEAM
MARK II - SLC/PEP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BEAM

M

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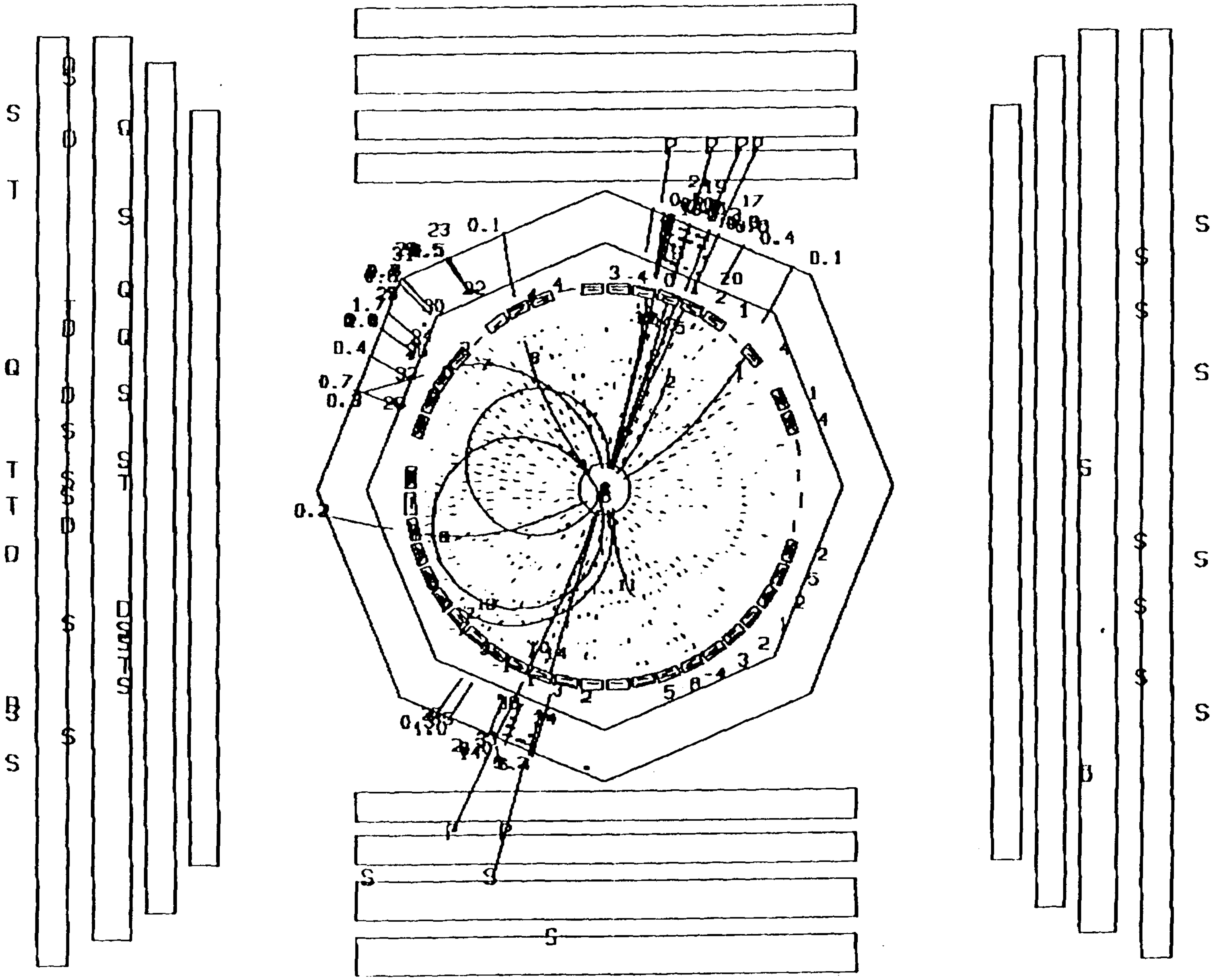
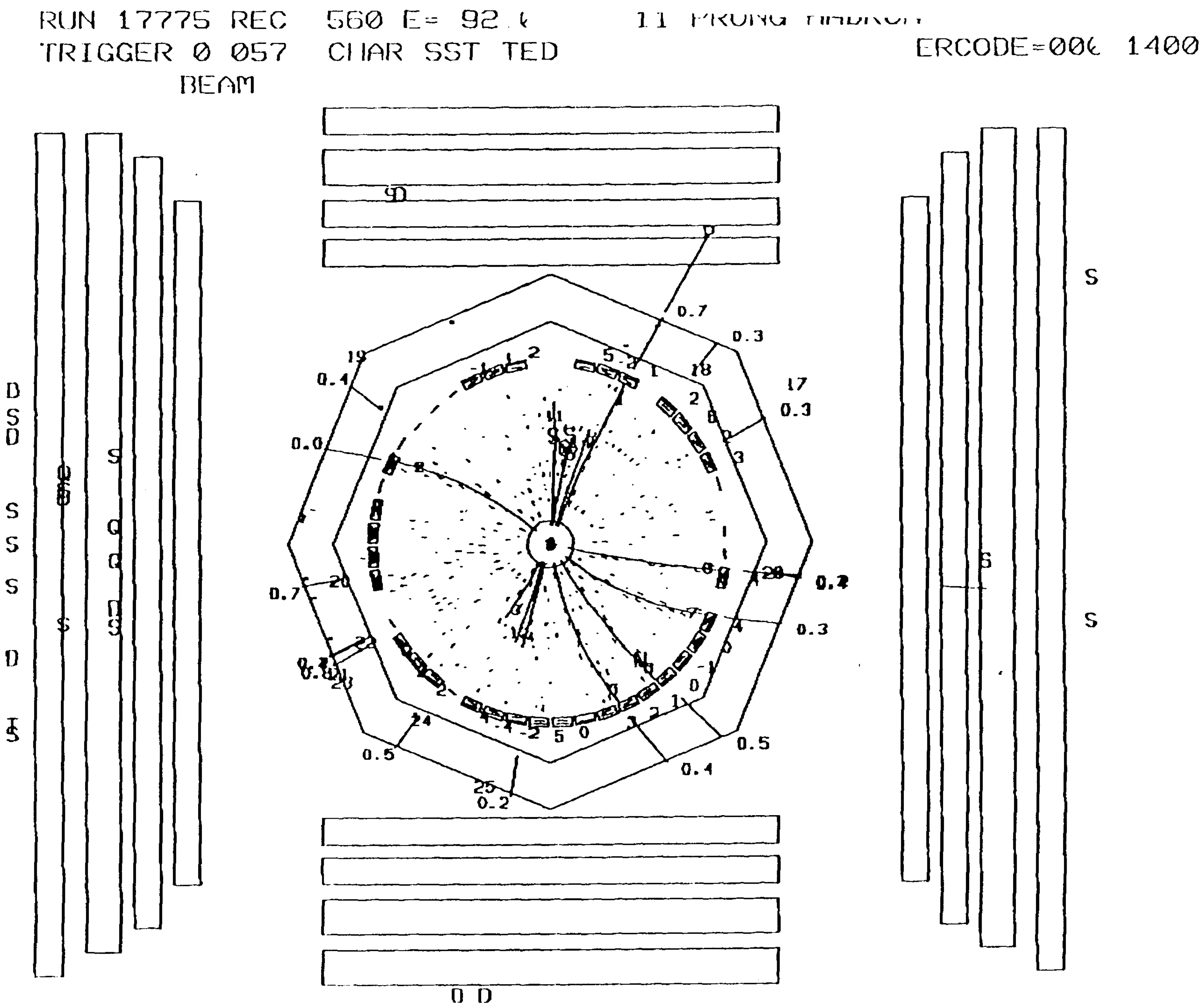
BEAM



2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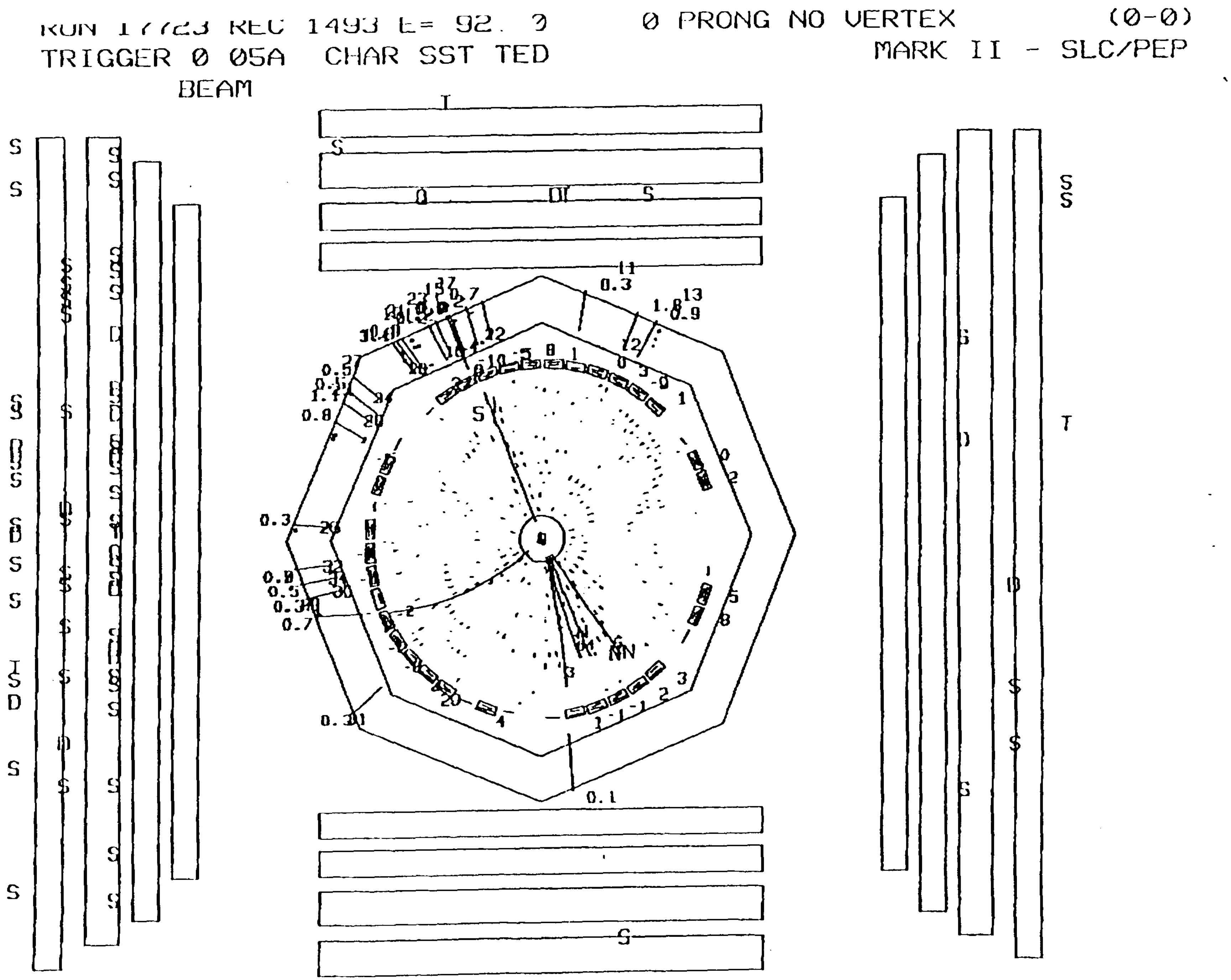
11 PRONG HADRON
TRIGGER 0 057 CHAR SST TED
ERCODE=006 1400
BEAM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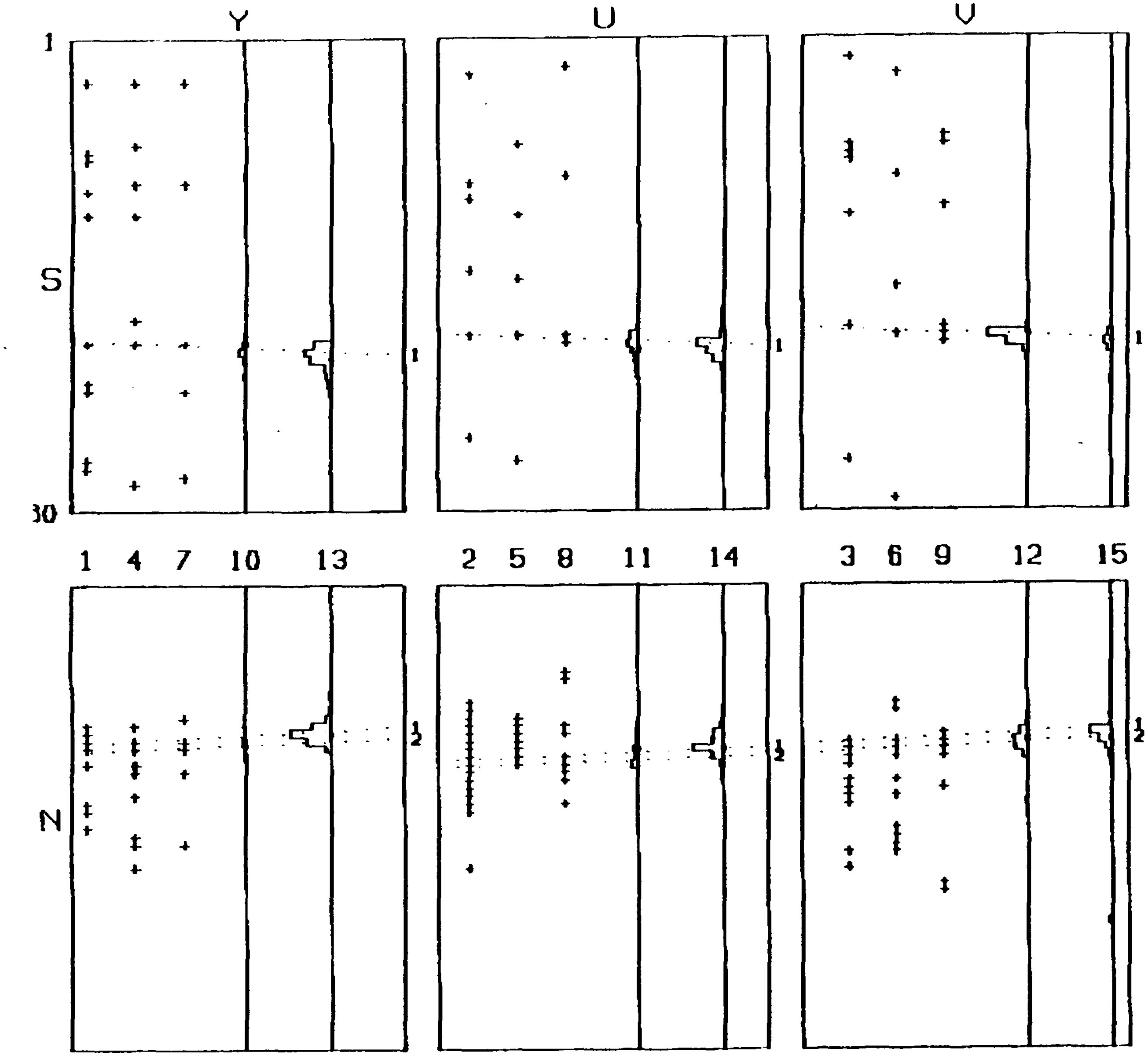
0 PRONG NO VERTEX
(0-0)
MARK II - SLC/PEP



RUN = 17677 EVENT = 1223 ES = 38.2GEV EN = 39.1GEV

* SAM TRIGGER : YES
* ENERGY SCALE
  ⊢—⊣ : 15.0 GEV

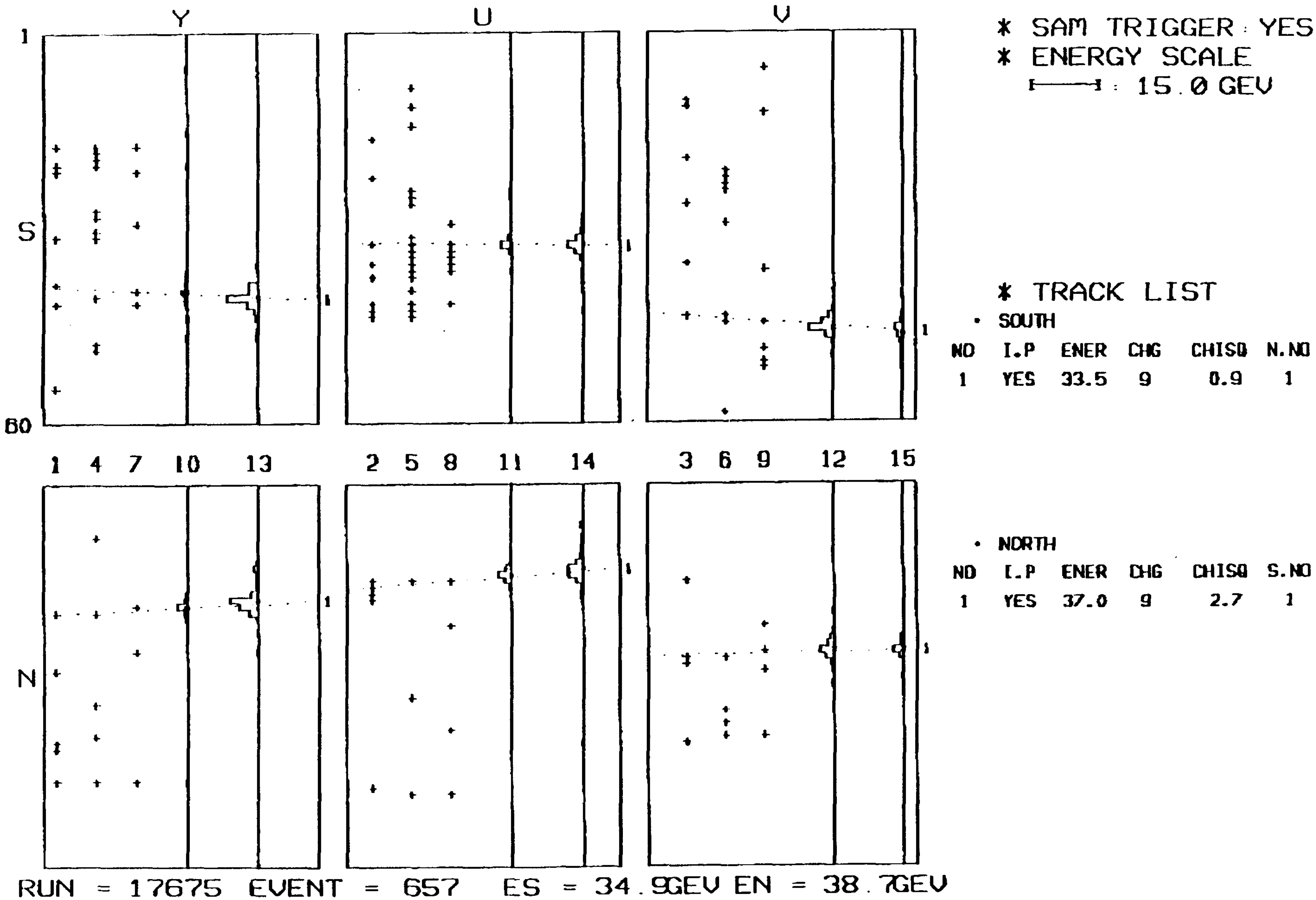
* TRACK LIST

• SOUTH

NO	I.P	ENER	CHG	CHISQ	N.NO
1	YES	37.1	9	7.1	1

• NORTH

NO	I.P	ENER	CHG	CHISQ	S.NO
1	YES	37.3	9	12.4	1
2	YES	0.0	NA	NA	NA



Y
U
V
1
S
60
1 4 7 10 13
2 5 8 11 14
3 6 9 12 15
N
* SAM TRIGGER : YES
* ENERGY SCALE
: 15.0 GEV
* TRACK LIST
• SOUTH
NO I.P ENER CHG CHISQ N.NO
1 YES 33.5 9 0.9 1
• NORTH
NO I.P ENER CHG CHISQ S.NO
1 YES 37.0 9 2.7 1
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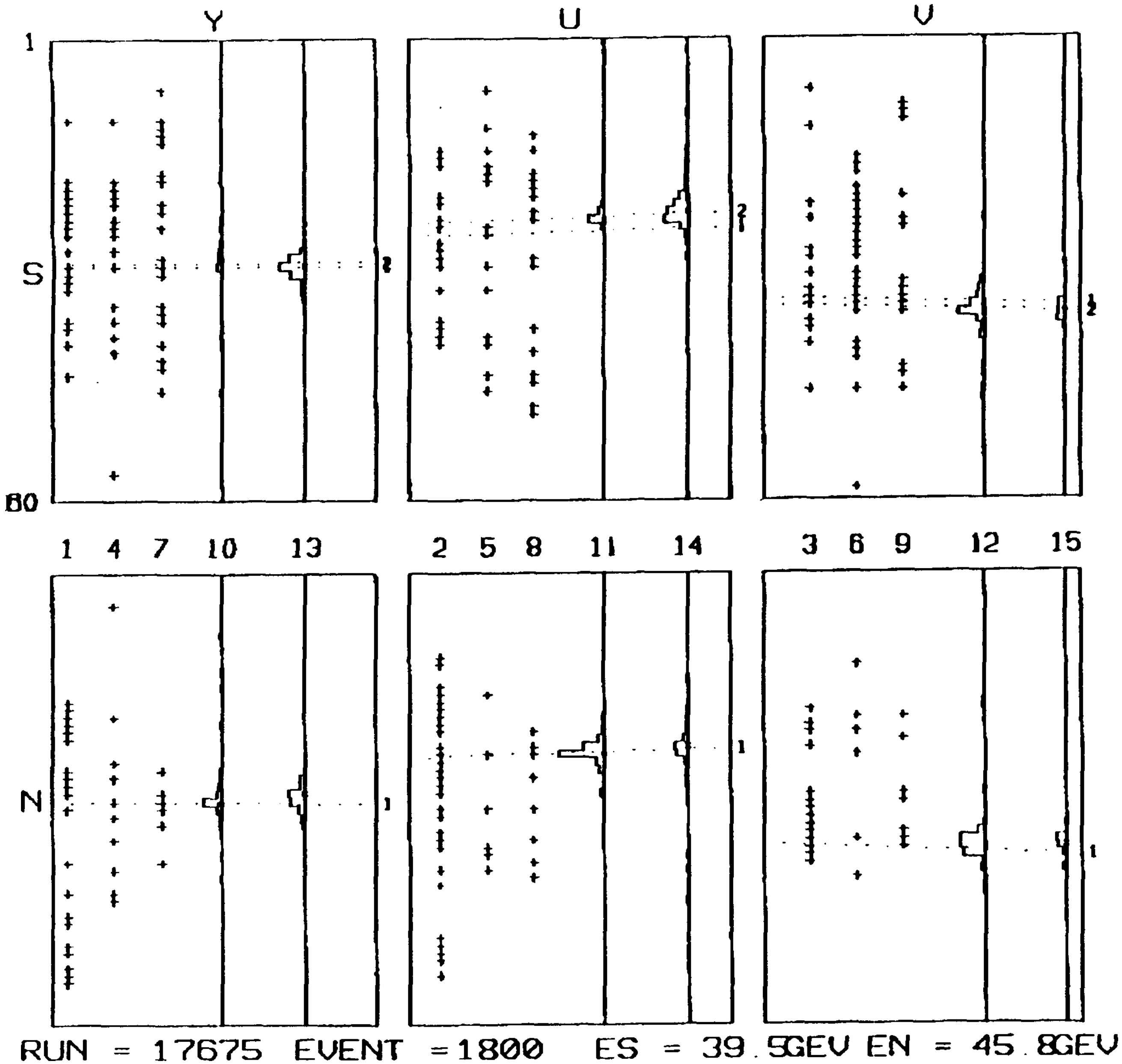

* SAM TRIGGER : YES
* ENERGY SCALE
|——| : 15.0 GEV

* TRACK LIST

• SOUTH

NO	I.P	ENER	CHG	CHISQ	N.NO
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• NORTH

NO	I.P	ENER	CHG	CHISQ	S.NO
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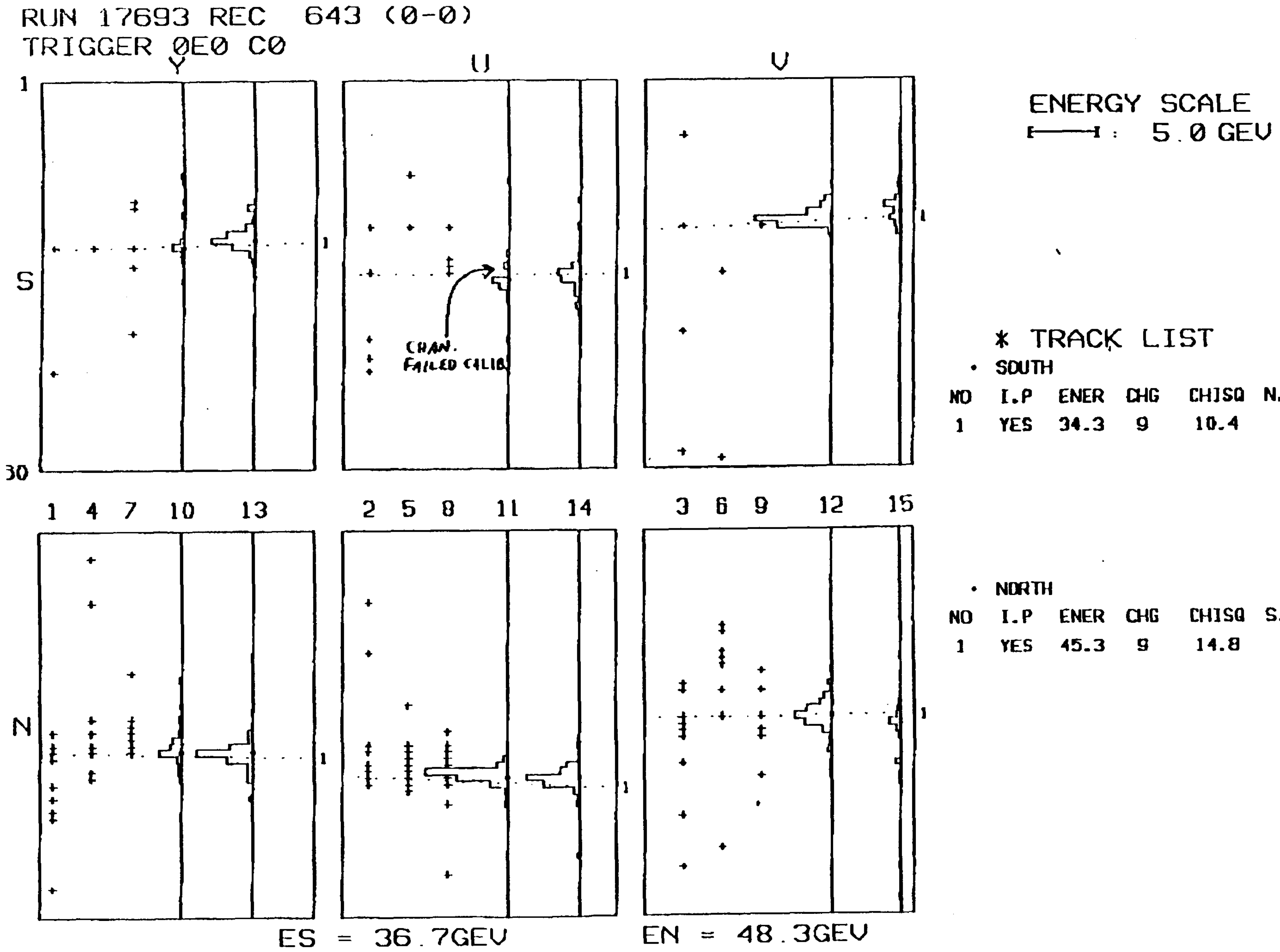

* TRACK LIST

• SOUTH

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• NORTH

NO	I.P	ENER	CHG	CHISQ	S.NO
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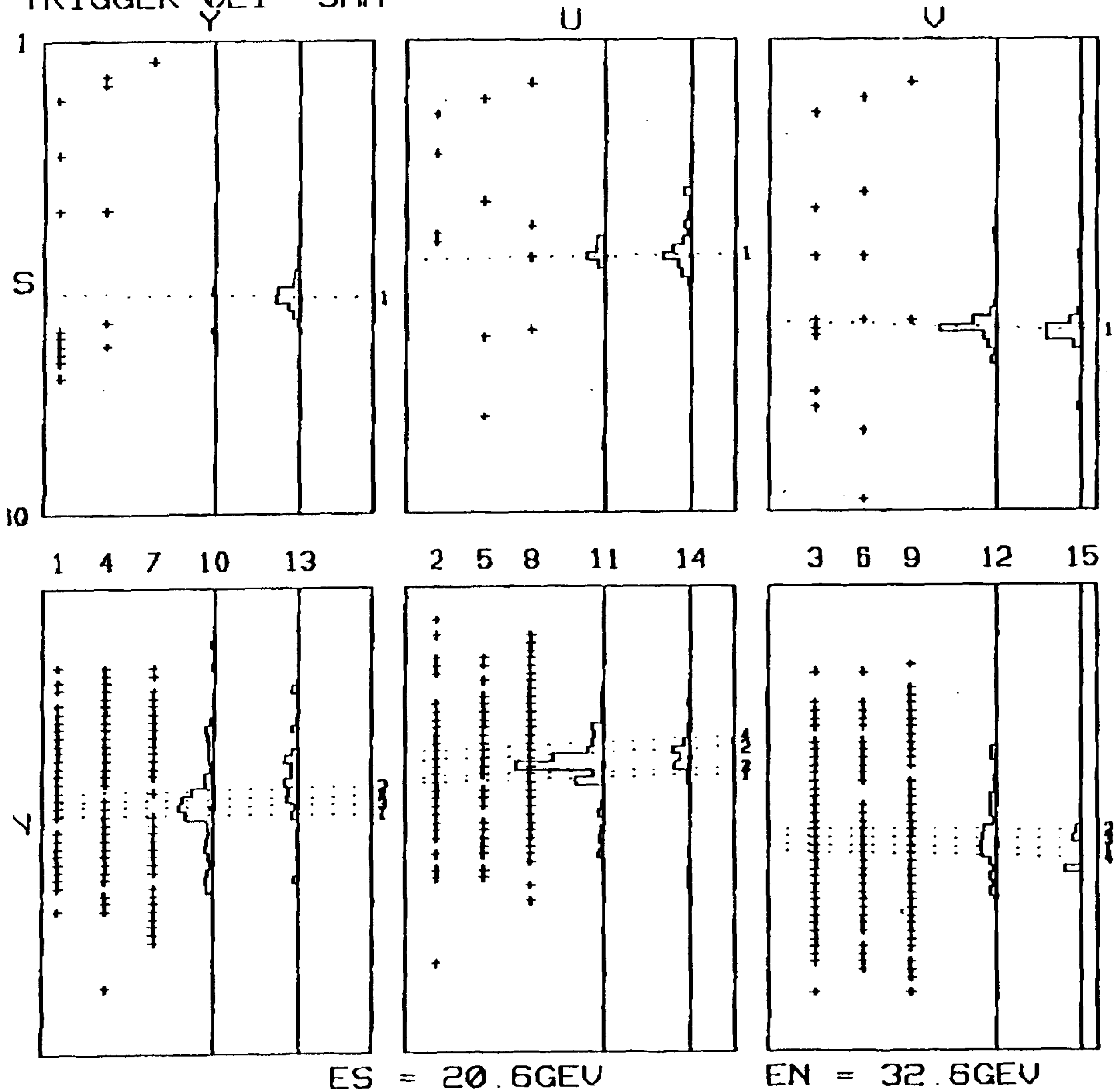
TRIGGER 0E1 SAM



ENERGY SCALE
|—| : 5.0 GEV

* TRACK LIST

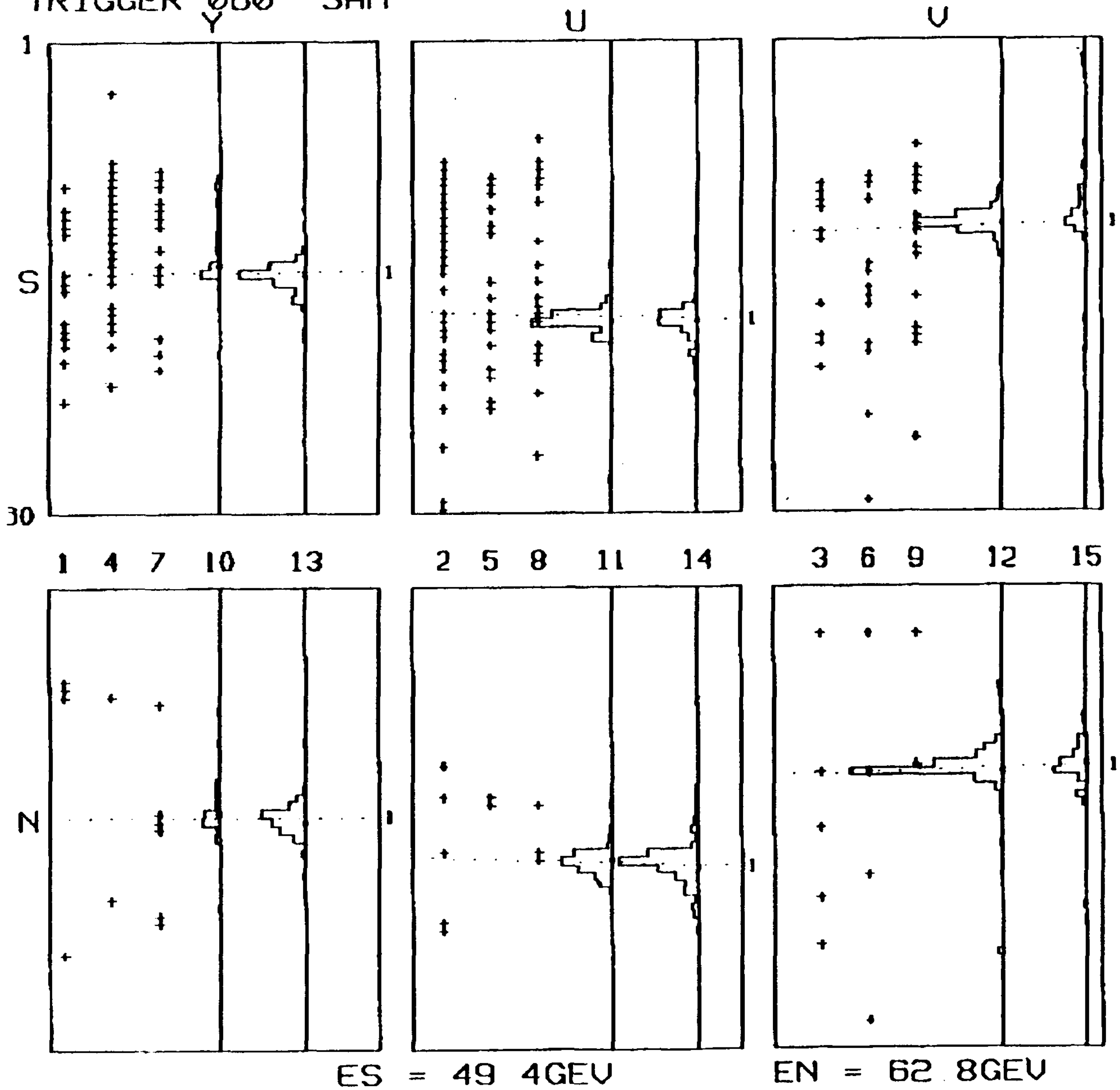
• SOUTH

NO	I.P	ENER	CHG	CHISQ	N.NO
1	YES	10.4	0	NA	NA

• NORTH

NO	I.P	ENER	CHG	CHISQ	S.NO
1	YES	10.6	9	17.2	NA
2	YES	0.0	NA	NA	NA
3	YES	0.0	NA	NA	NA
4	YES	0.0	NA	NA	NA

RUN 17731 REC 490 (0-0)
TRIGGER 060 SAM



ENERGY SCALE
5 0 GEV

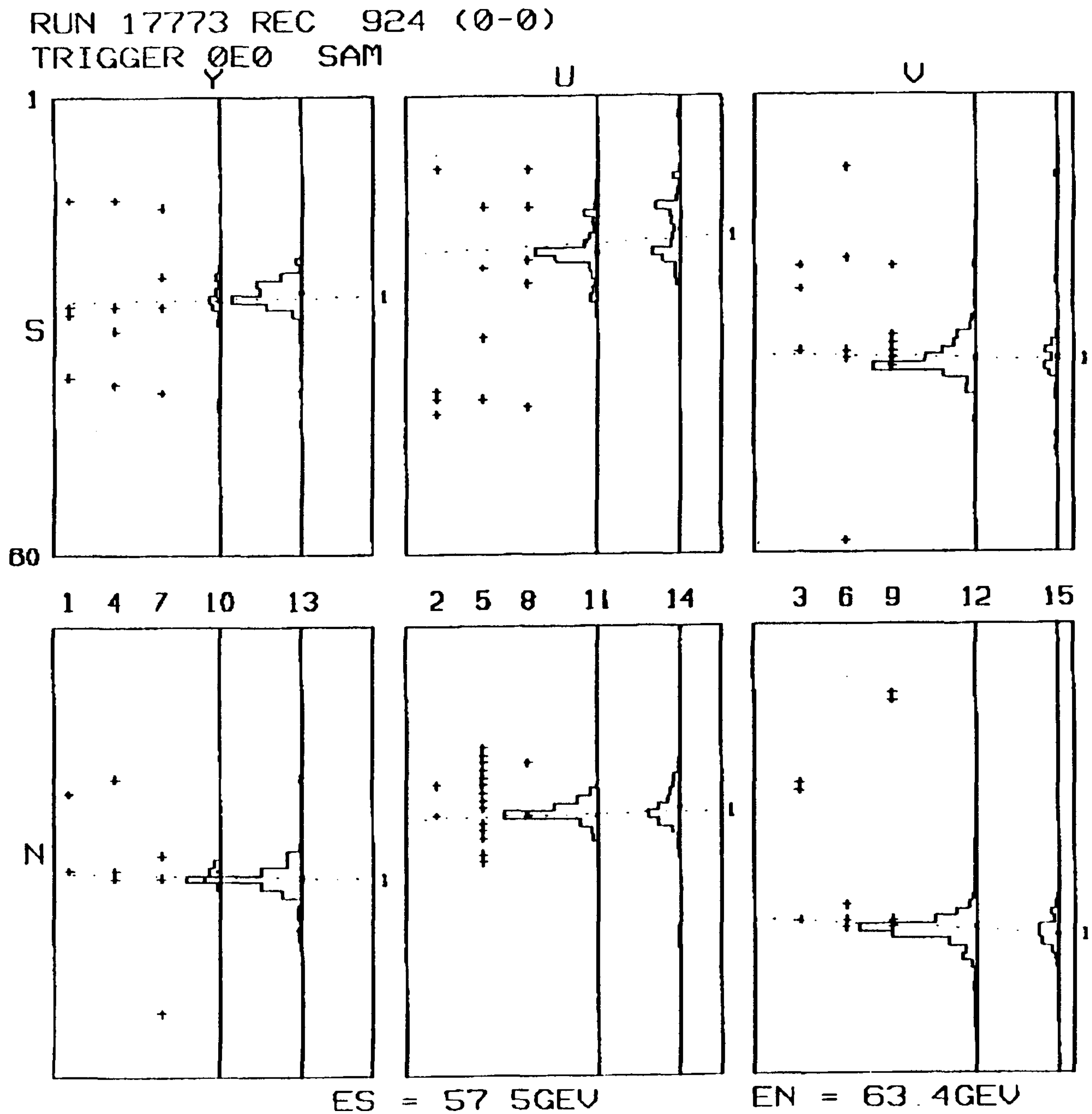
* TRACK LIST

• SOUTH

NO	I.P	ENER	CHG	CHISQ	N.NO
1	YES	46.6	9	6.1	1

• NORTH

NO	I.P	ENER	CHG	CHISQ	S.NO
1	YES	60.3	0	NA	1



ENERGY SCALE
⊢—⊣ : 5.0 GEV

* TRACK LIST

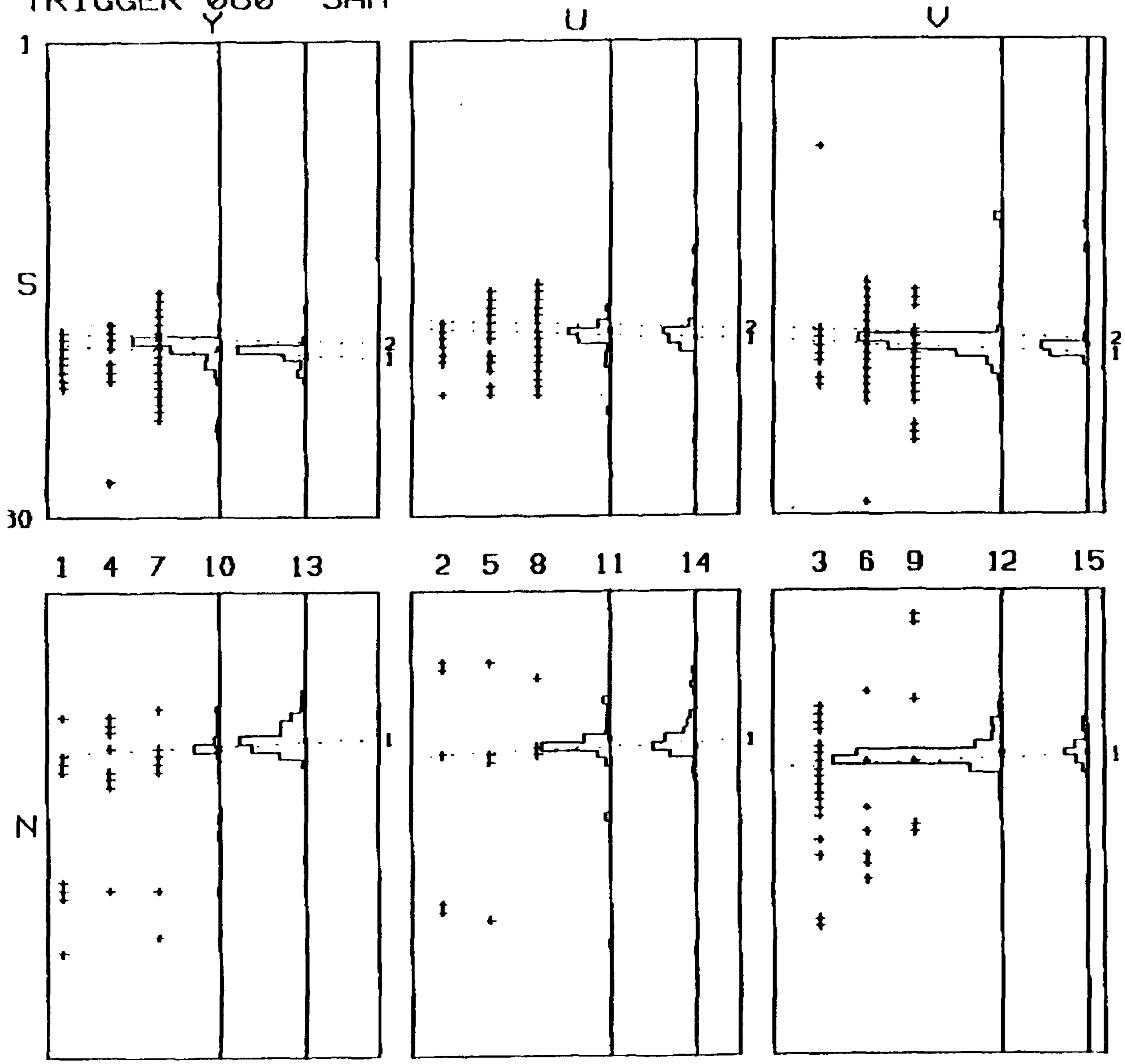
• SOUTH

NO	I.P	ENER	CHG	CHISQ	N.NO
1	YES	55.7	0	NA	1

• NORTH

NO	I.P	ENER	CHG	CHISQ	S.NO
1	YES	61.3	9	1.8	1

RUN 17784 REC 1290 (0-0)
TRIGGER 060 SAM



ENERGY SCALE
|—| 5.0 GEV

* TRACK LIST

• SOUTH

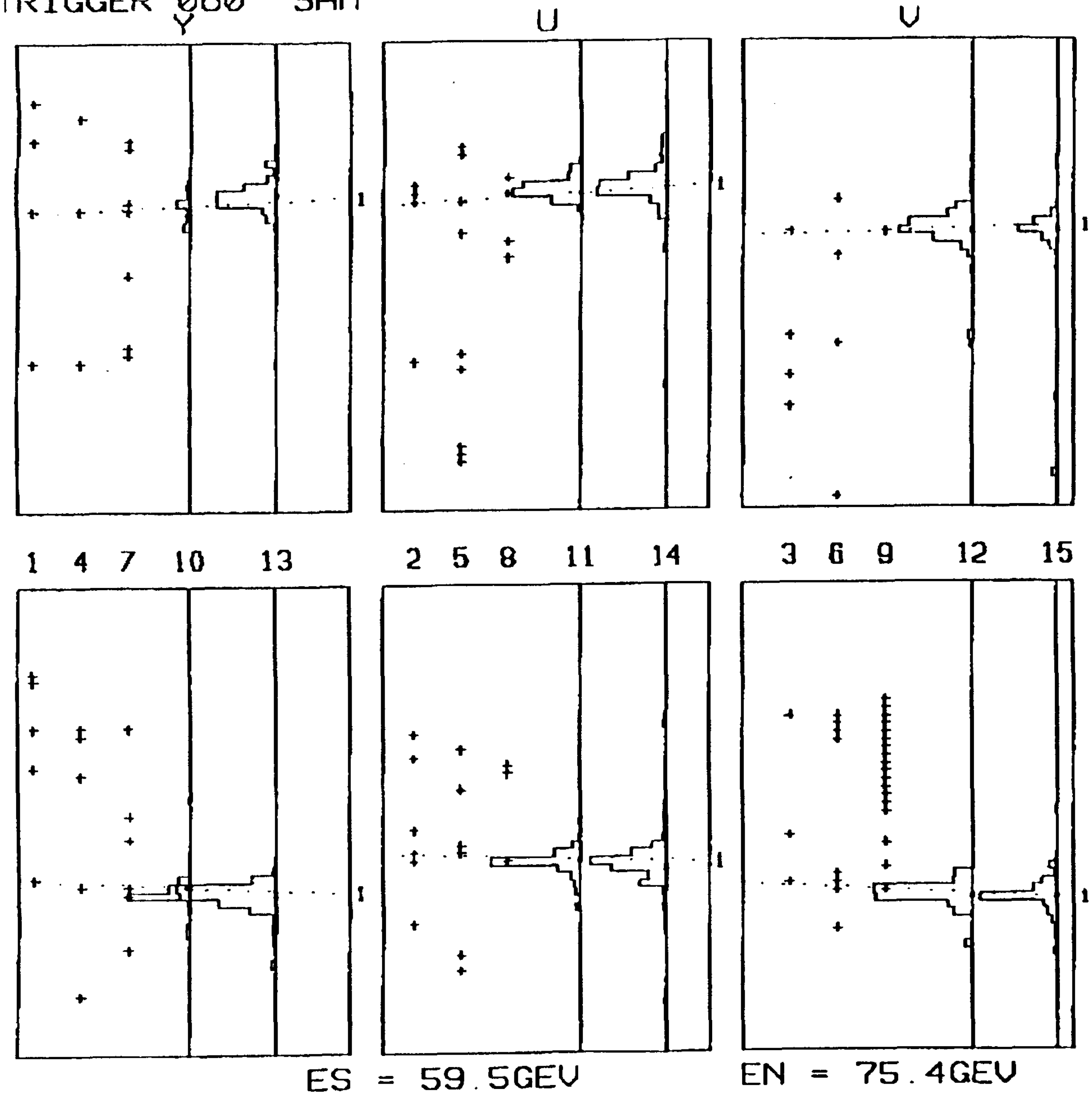
NO	I.P	ENER	CHG	CHISQ	N.NO
1	YES	52.1	9	9.2	1
2	YES	0.0	NA	NA	NA

• NORTH

NO	I.P	ENER	CHG	CHISQ	S.NO
1	YES	56.3	9	5.5	1

ES = 55.0GEV EN = 58.9GEV

RUN 17813 REC 1638 (0-0)
TRIGGER 060 SAM



ENERGY SCALE
⊢—I : 5.0 GEV

* TRACK LIST

• SOUTH

NO	I.P	ENER	CHG	CHISQ	N.NO
1	YES	57.4	9	4.7	1

• NORTH

NO	I.P	ENER	CHG	CHISQ	S.NO
1	YES	73.5	9	5.0	1

Review of Research Activities

Overview

During the last year the research effort of Task E has been divided between observations of 200 GeV γ-rays using the two large solar concentrators in Albuquerque, New Mexico and development of various components required by the GRANITE proposal submitted in collaboration with the Smithsonian Astrophysical Observatory and Iowa State University. These two activities have been synergistic; many of the techniques learned in Albuquerque will be incorporated in the design and operation of the new Čerenkov telescope on Mt. Hopkins.

γ^* Experiment

γ-ray observations from satellite instruments have shown that the Crab pulsar is one of the three most luminous stellar objects at energies above 1 GeV. With the additional knowledge of pulsar phase provided by radio measurments at Jodrell Bank, this source is an obvious first candidate for testing the efficacy of ground-based atmospheric Čerenkov detectors. The γ^* experiment has acquired data on the Crab pulsar and nebula for two years, first from November 1987 through February 1988 and, second, from October 1988 through December 1988. It was fervently hoped that with high statistics a sharp phase pulse could be detected similar to the observations of the COSB satellite. The data was analyzed using a γ-ray shower selection criterion similar to that developed by the Mt. Hopkins collaboration. Analysis of the first year's data indicated an on-off excess of events with a statistical significance greater than 4 σ but no evidence for phase structure with an event sample of approximately 300,000 events.

As the data was analyzed from the first year of operation, we became aware of several possible sources of systematic error which might lead to the false detection of a source. Several changes were made to subsequent data taking and data analysis procedures to eliminate these. During November 1988 about five times more data were taken on the Crab in a rapid cycling mode between on and off source. This was followed in December 1988 with the accumulation of 300,000 events while continuously staring at the Crab in an attempt to obtain a phase signal. The analysis of this data has just recently been completed. After applying a number of cuts to reduce the hadronic background we find a 5.8 σ DC signal. This is corroborated by a number of cross checks of the data. For example, there was some concern that ζ Tauri, a third magnitude star 1.1° from the Crab nebula, might generate just enough extra accidental background events to fake a real signal. To check this possibility, an equal exposure was obtained for a sky direction 1.1° from ζ Persei, a third magnitude star of the same spectral type. Comparison of the Čerenkov imaging distributions from on and off source showed a clear effect for the Crab and nothing for ζ Persei. The same dichotomy was observed when all data cuts were applied.

Figure 1 shows the on-off rate for the Crab nebula and pulsar on a run-by-run basis. The data is consistent with DC emission at a flux level of $1.69\times10^{-6} \pm 0.29\times10^{-6}\ \gamma/\mathrm{m}^2 - \mathrm{s}$. This result is plotted in figure 2 with data from other reported observations[1–7] of the Crab including the recent Mt. Hopkins measurement.[8] Our measurement at 200 GeV is consistent with a power law behavior of the γ-ray flux over the energy range from 10^8 eV to 10^{12} eV covering the satellite measurements of the COS-B collaboration[7] and the recent data point from Mt. Hopkins[8] at 700 GeV.

We have extensively searched for evidence of time modulation with periodicity near that of the pulsar and find no signal whatsoever. If we assume the period and phase are identical to the radio pulse, the pulsed fraction must be less than 3.8% of the DC flux or $6.4\times10^{-8}\ \gamma/\mathrm{m}^2 - \mathrm{s}$ averaged over the entire data sample. Secondly, each run was separately tested for evidence of such a signal with negative results. Finally, a frequency search was made from 29 to 30 Hertz and also from 14.5 to 15.5 Hertz. No significant signal was seen with an amplitude as large as 50% of the DC flux. This absence of a phased signal component is in agreement with the Mt. Hopkins measurements.[9] The lack of a phase pulse suggests that the origin of the γ-rays is the nebula, not the pulsar. The most likely mechanism is inverse Compton scattering of X-ray photons by energetic electrons[10,11] resulting in the transfer of a large fraction of the electron energy to the scattered photon. It remains something of a puzzle to understand why the pulsed component becomes so weak at these higher energies.

The development of the data analysis software has led to a number of insights into better ways of reducing the hadronic background. One interesting quantity is the apparent height of shower maximum determined by the intersection of the shower directions imaged by the two concentrators. This distribution is plotted in figure 3. The histogram shows that the apparent height for hadronic showers is approximately 10 kilometers corresponding to an atmospheric depth of 8 radiation lengths. By contrast, electromagnetic showers reach maximum at a median atmospheric depth of 5 radiation lengths at this energy. With the GRANITE detector, the angular accuracy will be five times better so that the atmospheric shower depth can be used to confirm if a signal from a stellar object is consistent with the effects of energetic γ-rays.

These results are a confirmation of the claims made in the GRANITE proposal for the advantages of a stereoscopic detector system. Although we are extremely limited by current funding, an attempt will be made to monitor Hercules X-1 during May and June 1989. The γ^* detector has been shown to have more than enough sensitivity to detect the bursts seen by Mt. Hopkins[12] and Haleakala[13] but nature has been extremely reluctant to exhibit any further examples of the bizarre behavior that reportedly occurred in the summer of 1986.

GRANITE

A proposal for the Gamma-Ray New Imaging Telescope (GRANITE) was submitted to DoE in December 1988. It incorporates many ideas and techniques learned from our close association with the Solar Thermal Test Facility at Sandia National Laboratories. D. Meyer has adapted a technique for making accurate second surface mirrors so that they may easily be fabricated by students here at the University of Michigan. The focal properties of these mirrors is superior to the slumped glass used more widely and the low weight simplifies the mechanical support structure considerably. We are now searching for the glass which will have the greatest transparency in the near UV while providing a sufficiently smooth surface to maintain a sharp focus.

The data acquisition electronics for GRANITE will require several custom circuits which are being designed here at Michigan. The most crucial is an amplifier-discriminator module which has been engineered by H. Levy, a visiting scientist from Israel. The printed circuit board layout is now almost complete with fabrication and assembly of a prototype to begin shortly. It is essential that this circuit be thoroughly tested and debugged before Levy leaves at the end of the summer.

Future Experimental Program

Assuming the GRANITE proposal is approved, we plan to spend a very busy year fabricating mirrors and electronics for the new detector. The γ^* group will also integrate the entire data acquisition system. This activity as well as mirror installation can only be performed at the Mt. Hopkins site. Such a program will preclude any opportunity to continue observations in New Mexico so all our equipment will be moved from Albuquerque to Tucson by the end of summer, 1989.

The experimental program with the two coupled detectors at Mt. Hopkins has been described in the GRANITE proposal. With the increased sensitivity of two telescopes in coincidence we expect to see a much larger number of objects with far better statistical certainty. The interest will center on the sources seen in the past such as the Crab, Her X-1, and Cyg X-3 as well as more exotic objects such as Geminga and 3C-273 that have been detected only from satellites. This program will require the assistance of one post-doctoral scholar and two graduate students.

By 1991 we should have enough data to show if γ-ray astronomy can be pushed to new levels of sensitivity with a larger array of optical concentrators. This would require a new proposal and ultimately an increase in manpower for our group.

Other Activities

C. Akerlof, J. Matthews, and J. van der Velde have begun organizing an international conference on γ-ray astronomy to be held in Ann Arbor in October 1990. By that time we expect to have new information from the GRANITE detector and the UMC array as well as several other new or upgraded detectors around the world. An organizing committee has been selected and a tentative program has been outlined. When planning is complete, a proposal will be submitted to DoE and NSF. Approximately $10,000 will be requested from each agency.

Budget

The budget for FY'90 is based on the assumption that the principal activity will be the construction and operation of the GRANITE detector at Mt. Hopkins. This will require one post-doctoral scholar and two graduate students. Travel expenses must increase over FY'89 to reflect higher air travel costs and the greater detector usage at the Mt. Hopkins site.

Data rates with the GRANITE detector may go higher than 50 Hertz as the energy threshold is pushed down to 100 GeV or below. Since the γ-ray component is a fraction of a percent of this rate, some online image processor would be highly desirable to reduce offline computation and data storage. The natural starting point for such a design is the trigger processor used on the HRS spectrometer at SLAC which took advantage of azimuthal symmetry to quickly distinguish radial tracks from cosmic rays which miss the interaction point. Clearly the same kind of symmetry is involved in distinguishing showers whose origin lies in the direction of the optical axis of the concentrator. The estimated cost of this project is $25,000 over a two-year period.

If the experimental program with GRANITE is as successful as hoped, a strong case can be made for building an extended array of Čerenkov telescopes to better sample the shower characteristics. With several imaging detectors operating in coincidence, the shower direction and transverse width can be more accurately determined and the hadronic background correspondingly reduced. The design of such a system should begin in 1991. An additional position of assistant scientist is included in the budget for 1992 to help carry out this program. It is difficult to estimate the capital costs of a large Čerenkov telescope array but $3.6 million is a reasonable guess based on our experience with the GRANITE proposal. The budgets for 1992-1994 assume that 25% of this amount is spent by the University of Michigan for electronics and optical components.

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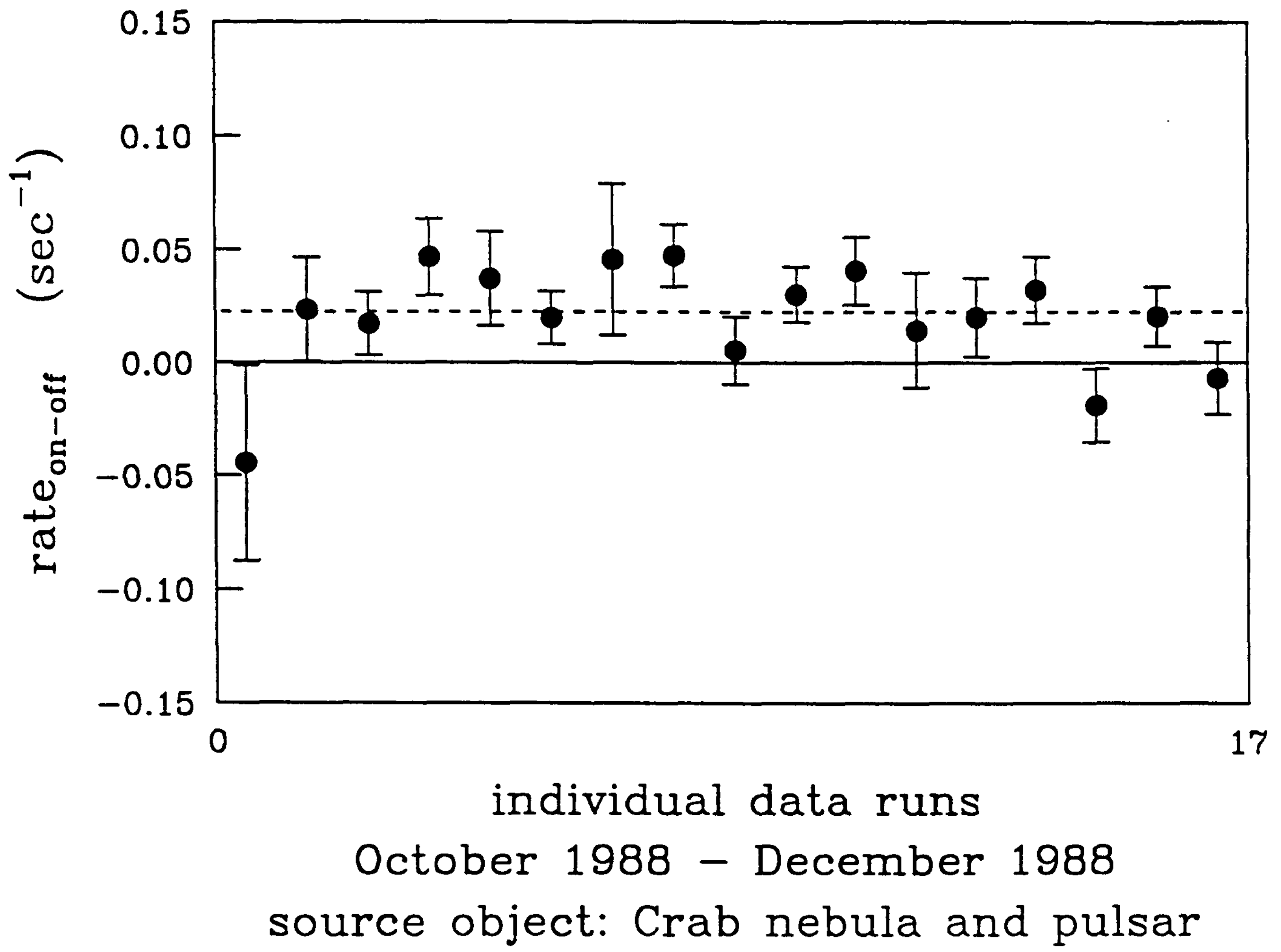
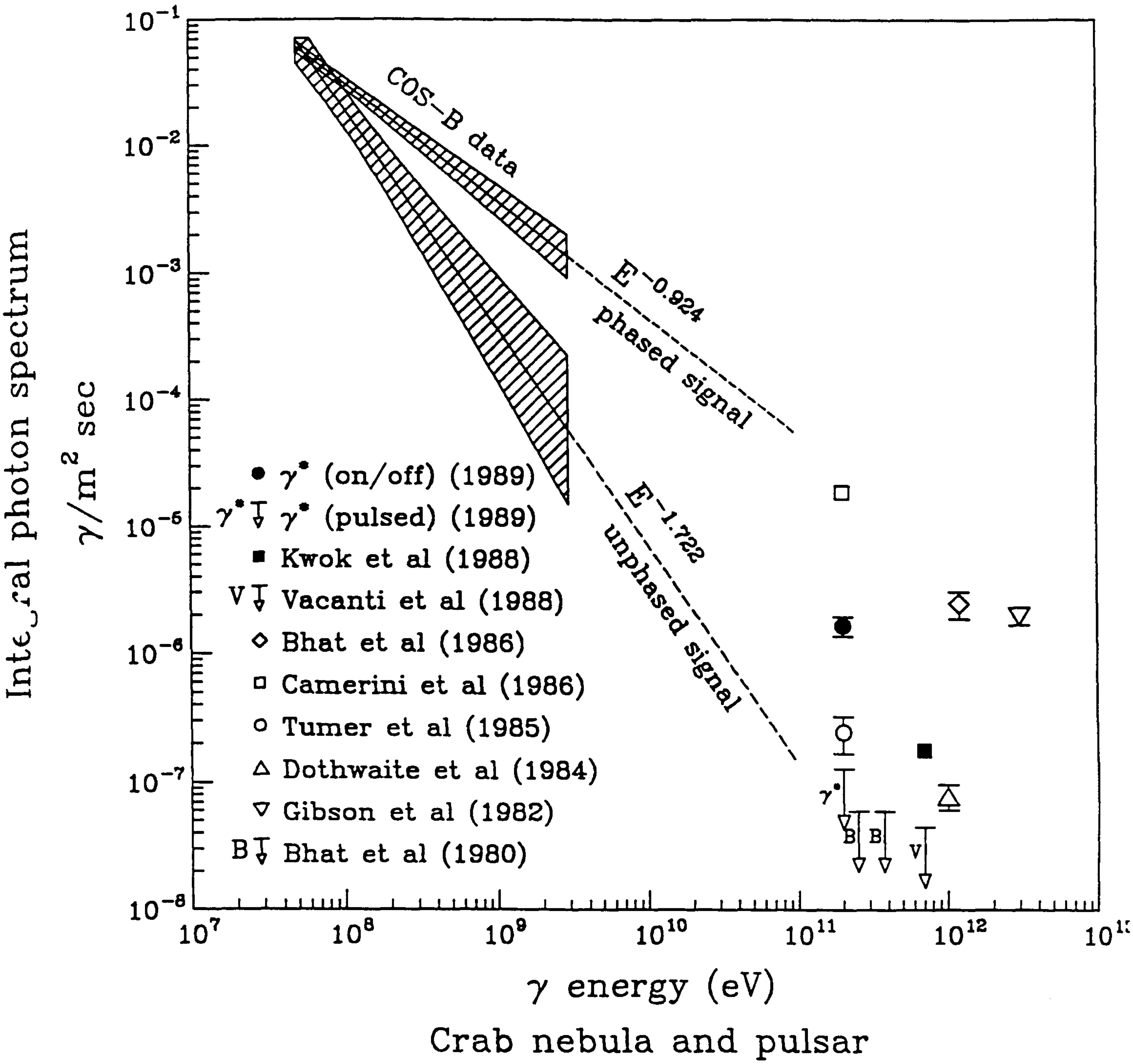


0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
rate$_{on-off}$ (sec^{-1})
0
17
individual data runs
October 1988 – December 1988
source object: Crab nebula and pulsar

Figure 1



COS-B data
$E^{-0.924}$
phased signal
$E^{-1.722}$
unphased signal
γ* (on/off) (1989)
γ* γ* (pulsed) (1989)
Kwok et al (1988)
V Vacanti et al (1988)
Bhat et al (1986)
Camerini et al (1986)
Tumer et al (1985)
Dothwaite et al (1984)
Gibson et al (1982)
B Bhat et al (1980)
γ*
B
B
V
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{7}
10^{8}
10^{9}
10^{10}
10^{11}
10^{12}
Integral photon spectrum
γ/m^2 sec
γ energy (eV)
Crab nebula and pulsar

Figure 2

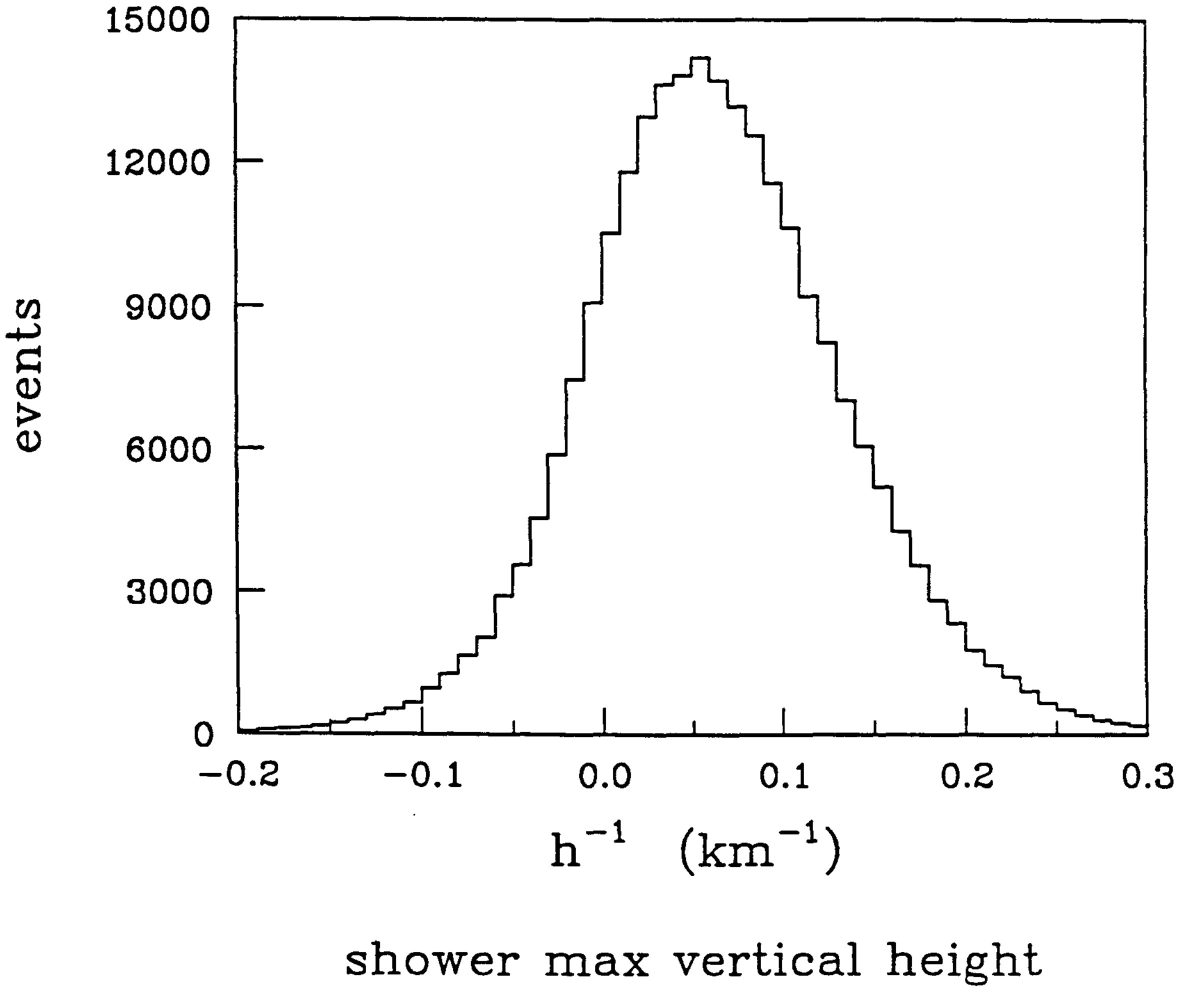

15000
12000
9000
6000
3000
0
events
−0.2
−0.1
0.0
0.1
0.2
0.3
h^{-1} (km^{-1})
shower max vertical height

Figure 3

Review of Research Activities

In this section, we summarize the recent research of the faculty, post-docs, and students.

Akhoury

Akhoury has been working in the past year on projects related Chiral Perturbation theory and on issues related to the low energy sector of the Standard Model for the case of a heavy Highs particle.

In Chiral Perturbation theory, with W.A. Bardeen, Akhoury has been investigating the implications of the decay of a Glueball into Pseudoscalar mesons. The aim was to explain why the possible glue state(ι) in J/Ψ radiative decays is seen to go more often to $KK\bar{\pi}$ rather than $\eta\pi\pi$ final states. The calculations which give this enhancement, contrary to phase space expectations, involve taking into account the coupling of Vector and Scalar mesons to the Pseudoscalar ones.

Another project involving Chiral Lagrangians, with M. Leurer, involved an explanation of the η' to $\eta\pi\pi$ decays based on the addition of suitable higher derivative terms in the Chiral lagrangians. Not only the total decay rate, but also the Dalitz plot parameters for this decay could be reproduced in agreement with experiment. Some radiative decays of the η and η' were also discussed. Akhoury gave a talk about this work at the Conference on the intersections of Nuclear and Particle Physics in 1988.

In the area of the heavy Higgs limit of the Standard Model, Akhoury, with J. Vidal, has obtained a model based on the Veneziano–Lovelace unitarized model to incorporate the possible vector boson bound states that could dominate longitudinal vector boson scattering at SSC energies. This model is an attempt to go beyond the so called minimal model of Chanowitz and Gaillard, and under the assumptions of the Reggeisation of the longitudinal vector boson scattering at high energies, has only one free parameter, which is the mass of the lowest lying resonance. (The analogue of the ρ in $\pi\pi$ scattering). If this lowest lying resonance is below 2 TEV, then there may be indications which are observable at SSC energies.

Einhorn

Einhorn and Wudka have completed their proof of a "Screening Theorem" for very heavy Higgs Bosons, viz., to the N-loop order, contributions to the vector boson propagators proportional to m_H^{2N} are not observable. This generalizes the previous observations at one-loop by Veltman and at two-loops by van der Bij and Veltman. The method of proof shows that the custodial SU_2^R symmetry is crucial for this result, together with the identification of these contributions as Higgs-field wave function renormalization.

Einhorn updated earlier work on possible spin correlations in the fragmentation of heavy (charm, bottom, top) quarks and pointed out some ways experimenters might search for them.

While in Aspen, Einhorn began a collaboration with Appelquist and Wijewardhana of the effects of four-fermion interactions in Technicolor models for the Higgs Boson. Recalling the classic work of Nambu and Jona-Lasinio, we point out that these effects can be surprisingly important in chiral symmetry breaking. They can significantly raise the masses of quarks and leptons without lowering the threshold for new physics commonly associated with Extended Technicolor interactions.

Einhorn has concluded a reprint volume for North-Holland entitled *The Standard Model Higgs Boson*. This volume included a critical overview of the properties and production of the Higgs Boson, together with reviews of its contributions to radiative corrections, the possibility of its being extremely heavy, and the consequences of Triviality for the Higgs mass. It is anticipated that this will be published by the end of the year.

Kane

Kane has made important progress in the past year in understanding how to study interactions of (longitudinal) W bosons in the TeV region at future colliders, as will be essential to understand the Higgs sector of the Standard Model. He has been carrying out a program toward this goal since 1983. The remaining problems to solve involved dealing with the large QCD + electroweak processes that could fake a signal. In collaboration with his student Yuan, two new approaches have been developed that he now believes have solved this background problem. The more interesting one relies on the color structure of the signal and backgrounds being very different, leading to large differences in multiplicity for the two types of processes; cuts on the multiplicity appear to reduce the background by about an order of magnitude, which gives signal/background > unity. It is also very important that this selection procedure does not bias the ability to study the polarization of the W's (most suggested procedures do cause such a bias), which is crucial since any Higgs physics should be associated with the longitudinal W's. This work was done as part of Yuan's thesis, but is being published in collaboration with several other people who also worked on it, especially at studies (Gunion, Seiden, Sadrozinski, Weinstein). Further improvements in analysis, based on Yuan's thesis, are being written up in a paper in preparation by Kane and Yuan.

With Yuan and Vidal, Kane performed an extensive analysis of ways to test the ZWW and γWW vertices of the non-Abelian gauge theory. It improved on previous work in several ways, for example, by not making ad hoc assumptions about some of the parameters. It studied what can be done at higher energy e^+e^- and upgraded hadron colliders as well; that hadron colliders could do as well as e^+e^- here was first pointed out by Kane in 1986 (and independently by Chanowitz).

Kane (with Castoldi and Frère) pointed out that the possibility existed to gain great insight into the origins of CP violation by studying semileptonic K decays. The most basic point is that the Standard Model at tree level predicts no CP violation should occur in semileptonic K decays, so any effect observed is necessarily due to new physics. While it turns out that this was known to some people, only one of the many reviews of the past five years mentions it, and no experimenters were aware of it. Based on our work, two groups have already shown interest in the experiments. The situation is actually much better upon looking in detail. It turns out that specific observables can be found that isolate CP violating contributions from different effective Lagrangians, so if effects are ever found it will be possible to quickly specify the kinds of physics that could contribute. Given the difficulty of interpreting measurements of ϵ and ϵ', and the long time scale before CP can be studied in heavy quark decays, this approach could turn out to be the main way to make progress in the next decade.

Tomozawa

Tomozawa continued to work on quantum effects on gravitational collapse and their application to astrophysical observations. The direction of the research is based on his work over the past few years: The solution of the quantum Einstein equation in a spherically symmetric and static metric indicates that the gravitational potential is repulsive at short distances. As a result, the gravitational collapse of a massive object into a black hole leads to a bounce back motion, and therefore leads to an oscillation, a black hole (BH) oscillation due to quantum effects. This is quite a novel concept and is verifiable by astrophysical observations. A BH oscillation yields repeated gravitational wave (GW) signals which can be tested by a sensitive GW detector. In fact, the room temperature GW detectors in Rome and Maryland had several coincidence signals at 4 1/2 hours before the explosion of supernova 87A. They are also in coincidence with the low energy neutrino signal (5 events) at the Mont Blanc detector. These data are ignored because 1) the statistics are poor, 2) the energy of the GW signals is too large for SN 87A and 3) there were no neutrino signals in the Kamiokande and IMB detectors at the time of the Mont Blanc data. Tomozawa has suggested that a BH oscillation can explain an apparent large energy for the GW signals by a resonance effect and the Mont Blanc data may be understood by the difference in the thresholds of the detectors and a possible cut off of high energy neutrinos due to large cross sections.

The emission of particles and radiation from an oscillating BH changes the scenario of gravitational collapse completely. The addition of infalling matter on a neutron star triggers a collapse to a BH, while the loss of masses from an oscillating BH due to the emission of particles may result in a neutron star. Therefore, the existence of a neutron star at a later stage in SN 87A does not preclude the existence of a BH at the time of the explosion. As is described above, the GW signals recorded by the Rome and Maryland detectors and the low energy neutrino events of Mont Blanc indicate such a possibility. A satellite measurement of cosmic background radiation (CBR) by the Japanese-Berkeley collaboration indicates a marked departure from the 3°K Planck distribution at higher frequencies. Tomozawa has presented a model which explains the data. The model considers the effects of galaxies which do not expand in the course of the universe expansion. In other words, the red shift of CBR which is caused by the universe expansion is exempted inside galaxies. This model seems to explain the data remarkably well. The above results were presented at the 5th Marcel Grossman Meeting on Gravity held in Perth, Australia, in 1988, as well as in several conferences and symposia on Supernova 87A, the Ginga satellite data, and airshowers held in Japan in 1988-1989. Tomozawa and Majumder have computed the initial chemical abundance of cosmic rays based on the existing observed data and the standard spallation model and compared the obtained result with the prediction of the BH oscillation model.

Veltman

Veltman is continuing his study of on problems relating to the Higgs sector. As an application, a presumably "definitive" paper on γ-matrices and the γ^5 problem was written. This paper contains a new prescription for handling of traces containing γ^5. The technique is needed in connection with problems under study.

With the latest in symbolic computer code (Schoonschip) Veltman was able to evaluate one-loop radiative corrections to WW scattering at high energies for a very large Higgs mass. This work was done together with F. Ynduráin (Madrid). A new idea involving additional particles coupled via the Higgs field was formulated and presented in that paper. Several very interesting subjects resulted from that.

Concerning graduate students:

– R. Bouamrane will soon finish his thesis on one-loop radiative corrections to WW scattering in the SM.
– C. Kyriasidou is investigating the impact of the above mentioned ideas on new particles in radiative corrections.
– L. De Wit is narrowing down to the problem of ambiguities in radiative corrections in the case of a heavy Higgs boson.

Yao

In the past years, one of Yao's interests has been to develop technique to evaluate effects of heavy particles. The formulation of a heavy theory with a Higgs and/or a heavy top quark is of both formal and phenomenological consequences.

For a heavy Higgs, an article by Yao and Akhoury, (Physical Review 25, 3361 (1982)) has received renewed interest. It has been shown here that all processes with longitudinal vector bosons can have only small one loop radiative effects. This agrees particularly with the exact calculations recently performed by Veltman and Ynduráin and by Dawson and Willenbrock.

As hinted at in the above paragraph, one theoretical simplification to analyze longitudinal vector boson physics is to connect it to the pseudo-Goldstone bosons. This is known as the equivalence theorem. The derivation of this theorem is through the Ward identities, which deal with Green's functions. Because of it, there are some ensuing technical problems, one being that we would like a theorem for the S-matrix elements. Yao (and Yuan) wrote an article which points out the modification necessary to account for this difference. Another problem of the theorem has to do with the high energy limit, which will be discussed in the Current and Future Research section.

For a heavy top quark, Yao (and Steger) have shown that $SU(2)$ symmetry is non-linearly realized in this kind of limit to split the 3rd family quark doublet. Several detailed papers are in preparation to follow up on their letter article. In view of the mounting evidence that the top quark is at least quite heavy, these papers should be of experimental interest. As a prelude to a larger program to include QCD in this kind of short distance physics, Yao (and Kaufman and Steger) have analyzed the $B^\circ - \bar{B}^\circ$ mixing problem. They found that the effects when $m_t \gg m_W$ are substantially different from those for $m_W \gg m_t$. Also, they performed the analysis in the off-shell $p_b^\mu = (m_b - \frac{\mu}{2} \sim O(\mu))$ and p_s or $p_d = (O(\mu), \vec{p} \sim 0(\mu))$ region, where μ is the binding energy of the B_s or B_d system. They have shown that the results are gauge invariant to the leading order.

Leurer

The following works have been completed in the last year:

(1) $\eta - \eta'$ physics:

R. Akhoury and I have written an effective Lagrangian for pions, kaons, the eta and the eta prime. Although this Lagrangian includes only leading terms in the chiral and $1/N$ expansions, we found that its predictions are in good agreement with experiment. We calculated the $\eta{-}\eta'$ mixing angle, and got the relatively high value (about 20 degrees) which have been advertised recently by various authors (amongst them Akhoury and Frère). We further calculated the decay rate of η and η' to three pions and to two photons. Both these decay rates are sensitive to the $\eta - \eta'$ mixing angle and we found that with the new, larger mixing angle value, the prediction of our Lagrangian is in a good agreement with experiment, while discrepancies occur for the older mixing angle value (about 10 degrees). A long standing problem in the chiral Lagrangian treatment of the $\eta - \eta'$ system was the $\eta' \to \eta\pi\pi$ decay rate. The chiral Lagrangian prediction was known to be smaller by two orders of magnitude than the experimental observation. We found out that this was due to the fact that in the chiral limit the *first order* chiral Lagrangian has an extra symmetry which does not exist in nature and which forbids η' decay to $\eta\pi\pi$. Certainly, this symmetry should be removed by adding the next to leading order terms in the chiral expansion. We showed that by adding such terms one gets the correct order of magnitude prediction for $\eta' \to \eta\pi\pi$ decay rate. We have also discussed the $\pi\gamma\gamma$ and $\pi\pi\gamma$ decay modes, the first of which seems to be in agreement with experiment and the second of which does not. The paper is to be published in Zeit. für Phyzik.

(2) CP violation in $K \to \pi l \nu$ decays.

The only test of CP conservation in $K \to \pi l \nu$ decay is the polarization of the lepton in the direction orthogonal to the decay plane. According to the standard model, this orthogonal polarization should vanish, as the process is CP conserving. Therefore if, in the future, a nonzero orthogonal polarization of the lepton will be seen, it will be a signal of some nonstandard physics. Motivated by this observation (which was mentioned to me by G. L. Kane), and by the prospects for K factories operating in the near future, I have studied the possible contributions of various nonstandard interactions to CP breaking in this process. Taking into account the effects of possible nonstandard intermediate vectors, scalars and leptoquarks, I showed that the intermediate vectors contribution to the orthogonal spin of the muon identically vanishes, and gave general expressions for the contributions of intermediate scalars and leptoquarks. In most theoretical models, the mass of leptoquarks is very high, and therefore their contribution to CP breaking in $K \to \pi l \nu$ is small and we do not expect any observable effect even in K factories. It is however possible that the CP violating effects of nonstandard scalars will be observed in the near future. In particular, it is known that observable CP breaking may be introduced by the scalars of the Weinberg model.

(3) Supernova 1987a and solar neutrinos.

Large magnetic moments or transition moments were advocated as possible explanations for the solar neutrino puzzle, which incorporate the attractive feature of correlations between sun spot activity and depletion of the neutrino flux. However, it was pointed out by several authors that the large magnetic moment of a Dirac neutrino, necessary to solve the solar neutrino problem, may be incompatible with the observation of the neutrino pulse from the 1987 supernova. In a recent work with J. Liu, I have shown that the analogous magnetic transition moments of Majorana neutrinos are not constrained by the supernova results. We have also discussed other laboratory, astrophysical and cosmological bounds on the transition moment.

Liu

During the last year, J. Liu has mainly been involved in working in the area of neutrino physics. The major interests have been the neutrino mass, neutrino mixing and its electromagnetic form factors. Their physical implications were the main subject of his research. Recently, he has been working with Geng and Ng (TRIUMF) to investigate the possible relations between the strong and weak CP contributions to the electric dipole moment of the neutron. Also, he is working in collaboration with Chang (Northwestern U.) and Kueng (U. of Illinois at Chicago) on the electric dipole moment of W.

Proposed Research

Akhoury

Akhoury has been working on several projects which should be completed during the coming academic year. In one of these, with a graduate student A. Alfakih, Akhoury is investigating some rare η decays. With the possibility of an η factory at Saclay, it has become possible to look for rare η decays, like $\eta \to \pi^0 e^+ e^-$, $\eta \to Ke\nu$ etc. Like the rare Kaon decay experiments, those with the η could also provide a window to search for new physics beyond the Standard Model. Akhoury and Alfakih are first computing the full Standard Model (SM) predictions up to one loop for the rare η decays. The aim is to get this SM prediction correct to within a few percent, so that comparison with experiment can be reliably made. These calculations are nearing completion, after which they will look for the contributions from non standard particles. Their analysis has also implications for $K^0 \to \pi^0 e^+ e^-$ which they aim to investigate.

Another student, S. Titard, has been investigating the validity of the Adler–Bardeen theorem for various γ_5 prescriptions. This investigation is aimed at clearing up some misunderstandings about which is the correct γ_5 prescription in gauge theories that yields unambiguously the correct higher order radiative corrections.

One project that Akhoury would like to work on in the future is to use the Wilson approach of effective Lagrangians to study the possibilities that one has if the SM Higgs is very heavy. In particular he would like to give a unique prescription to obtain the heavy Higgs limit in the SM and clarify the connection between the Linear and the Non-linear Sigma models.

In yet another project, Akhoury will attempt to compute the Standard Model radiative corrections relevant to LEP and SLC, for processes like $e^+e^- \to \mu^+\mu^-$ at the Z resonance. Some corrections, specially those of the soft bremsstrahlung, have not been properly taken into account in earlier studies, which were done away from the resonance. These corrections could be large.

Einhorn

Einhorn will continue the collaboration referred to previously with Appelquist et.al. We are currently investigating the role of four-fermion interactions on weak isospin breaking. Can they produce splittings as large as the bottom-top quark mass difference without creating difficuties with radiative corrections elsewhere, especially, in the ratio of charged to weak neutral current, often called the ρ-parameter?

Einhorn (together with a student Contoponagous) has continued to investigate the behavior of gauge field theories with infrared divergences such as QED or QCD with massless fermions. The Kinoshita-Lee-Nauenberg (KLN) theorem accounts for the cancellation of infrared divergences, but there remain paradoxical infrared-**finite** contributions which depend on the method used to regulate the infrared divergence. This observation has not been noticed before and is under investigation. They have nearly completed a demonstration in one case that observables are independent of the regulator method. They will try to demonstrate generally that certain finite parts are an artifact of the calculational method and will attempt to demonstrate that such contributions, like the infrared divergent terms, cancel out of observables. This seemingly formal point in fact has a variety of important applications: Certain estimates of the magnitude and relative importance of radiative corrections are either exaggerated or incorrect. It also bears on the existence of certain helicity dependent selection rules, such as chiral conservation in the limit of zero fermion mass. We hope to shed light on questions such as such as: (a) Is the KLN theorem valid for non-Abelian theories like QCD, a subject about which there is considerable dispute and misunderstanding? (b) Are radiative corrections to polarized Deep Inelastic scattering really as large as Standard calculations suggest? They are preparing a paper showing that the effects of so-called collinear singularities leads to interactions of a right-polarized electron with a left-handed current which do not vanish as the electron mass tends to zero. This surprising application may confuse the search for right-handed charged currents at HERA in polarized Deep Inelastic Scattering experiments. (c) Are the "higher-twist" corrections coming from light quarks to the asymptotic scaling behavior of QCD really as large as previous calculations indicate or are they overestimated because of incorrect enhancements for small quark masses?

Kane

Kane is emphasizing work in two areas. First, with a student and with Frère he is pursuing the study of CP violation in the semileptonic K decays in depth. Different ways to isolate a signal will be identified and related. Various models that produce CP violation will be examined and related to the observables.

Second, with two students he is pursuing his long program to understand how to observe the Higgs sector, emphasizing now the somewhat neglected area of intermediate mass Higgs bosons and the spectrum of scalars that would arise from a supersymmetric world. They are also examining how to measure and test the relevant masses and parameters if signals are ever seen.

Tomozawa

Tomozawa will pursue the direction which he has been developing in the area of gravitational collapse and astrophysics. The most important aspect of his research is that quantum effects on gravitational collapse may be verified by astrophysical observations and in fact, the data of the Rome and Maryland gravitational wave detectors may have offered such evidence already.

Tomozawa and Majumder will continue the calculation of the explosion of SN1987A based on the black hole oscillation model.

Veltman

Veltman's physics program remains strongly focused on the Higgs sector. Some real advances have been made. Further investigation is in progress.

Yao

Yao will continue his research on heavy particle effects. He and Steger will put QCD into the analysis for top quark physics. In the near future, they will have the complete effective Lagrangian to include all the one loop heavy top effects.

Some features of a strongly interacting Higgs are arresting. Because of the one loop results, Yao would like to see if it is a general rule that higher order Higgs effects are small for a Higgs mass of several TeV. He and a student (Kassa Adel) in fact have shown that the ratio of the width of Higgs to four longitudinal W to that of to two W becomes unity only when $m_H \sim 5$ TeV, which corresponds to a coupling strength of $\lambda \sim 140$. (A similar observation can be made of the ρ-parameter calculation by Veltman and van der Bij.)

In deriving the equivalence theorem, one needs to convert p^μ/m to $(\epsilon^\mu)_L$ for the vector bosons. A tacit assumption made here is that the transverse amplitudes do not have dominant high energy behavior, so that one can in fact equate $p^\mu/m = (\epsilon^\mu)_L$. There are processes in which this assumption does not apply. On the other hand, if one is interested in the leading strong interacting Higgs effects only, the theorem seems to hold again. Yao (and Yuan and two students, Adel and Lin) are investigating to see how this comes about. They intend to perform if necessary a two loop calculation to see if the equivalence theorem is a low energy theorem, true to all orders in strong Higgs effects, as claimed by some.

Leurer

(1) The possibility of neutrinos with nonstandard properties:

Standard model neutrinos are massless and do not mix, but in most beyond-standard theories the neutrinos gain masses and mixing angles. One unsettled issue is the character of the massive neutrinos, as they could be of Dirac or of Majorana type. Another subject of interest is their electromagnetic properties e.g., their electric or magnetic dipole moments. Large magnetic moments (or transition moments) were suggested as a solution to the solar neutrino puzzle which have the attractive feature of anticorrelation of neutrino flux with sun spot activity. In the next year I intend to study these subjects and in particular, look for nonstandard models which will provide the neutrinos with the large magnetic moment needed to solve the solar neutrino problem.

(2) CP breaking in K and B physics:

Until now, ϵ and possibly also ϵ' are the only CP breaking parameters which have been seen in the laboratory, and their values are in agreement with the predictions of the standard model. I have just completed a work on the possibility that a nonvanishing orthogonal spin of the muon will be seen in $K_{\mu 3}$ decays. Such an effect would signal nonstandard physics and could be hunted for in K factories. In the future I intend to study other CP breaking quantities, in and out of the standard model, that could be seen in K and B factories.

(3) The possible mass scale of a composite W:

In some composite models, weak $SU(2)$ is a global symmetry and the heavy W and Z vectors are composite particles. A study of bounds on the mass scale of such composite vectors is now in progress.

Liu

Working on neutrino physics will remain a major research activity for J. Liu during the coming year. Together with R. Akhoury, he will also study radiative τ lepton decays to explore the possibility of detecting new physics in high luminosity τ factories.

Haeri and Nash

Two new postdocs will be joining us in September, 1989. Both have worked on aspects of dynamical symmetry breaking.

Relation to Other Projects

Akhoury is co-organizer of the *Workshop on QED Structure Functions* to be held in Ann Arbor, May 22-25, 1989.

Einhorn recently served on the Kaon Subpanel of NSAC considering the question of whether the U.S. should participate in the construction of a KAON factory that Canadian physicists propose to build at TRIUMF. In April, he participated in the DoE Technical Review of Fermilab. Einhorn attended the 1988 Aspen Workshop on *Dynamical Models of Electroweak Symmetry Breaking* and has been invited to participate in the 1989 Aspen Workshop on *Issues in Electroweak Interactions*. Einhorn will spend two months during the coming year as CNRS visiting Professor at the Center for Theoretical Physics, CNRS, Marseille. He has been invited to go to the Santa Barbara Institute for Theoretical Physics to participate in the *Workshop on Physics Far Below the Planck Energy*, Jan. 1 — June 30, 1990.

Kane has given a number of invited talks at conferences. At the 1988 Snowmass study on the Particle Physics of the 1990's he was co-leader of the working group on "New Particles at Accelerators". He was a reviewer of the 1988 DoE Outstanding Junior Investigator program. He is on the SLAC Scientific Policy Committee, the Spanish-American Joint Committee for Scientific and Technological Cooperation, and the International Executive Committee of the SSC User's Organization.

Tomozawa will give an invited talk in the International Symposium on Supernova and High Energy Astrophysics to be held on Nov. 22-24, 1989 in Calcutta, India. He is spending the academic year, 1988-1989, as a visiting professor at the Research Institute for Fundamental Physics, Kyoto University.

Veltman is a member of the Program Committee at SLAC and of the "Fachbeirat" of the Max Planck Institute for Physics in München, Germany.

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Personnel

The presently supported faculty consist of Assistant Professor R. Akhoury, Professors M.B. Einhorn, G.L. Kane, Y. Tomozawa, M. Veltman and Y.-P. Yao. For AY1988-89, in order to repair our budget deficit, we have been operating at well below our traditional levels of research staff, having only 2 postdocs, M. Leurer and J. Liu. Beginning September, 1989, we will increase this to 3 postdocs, J. Liu, and two recent Ph.D.'s, D. Nash (Yale) and B. Haeri (UCLA).

Professors D.N. Williams, A.C.T. Wu, and P. Federbush (the last of the Department of Mathematics) have very close ties to our group. Williams is developing a program of lattice calculations and is partially supported by the Scientific Computing group at Michigan. Wu is a mathematical physicist who has been working on topological aspects of field theory, most recently investigating the CTP theorem in nonabelian gauge theories. Prof. Federbush is a mathematical physicist who is attempting to establish rigorously, within the framework of constructive field theory, the existence of Yang-Mills field theory. Currently, no non-trivial theory in 4 dimensions has been demonstrated to exist.

Budget Discussion

FY90:

We are fortunate that the Department has encouraged us to seek new faculty, and we hope that DoE will provide increased research support as circumstances change. Our budget for FY90 includes summer salary and research support for the likely addition of one Assistant Professor, J. J. van der Bij, in the fall of 1989.* In total then, our budget request includes summer salary support for 7 faculty plus full-year suport for 3 post-doctoral fellows.

In order to enable Einhorn to take advantage of an invitation to participate in the Santa Barbara Institute for Theoretical Physics "Workshop on Physics Far Below the Planck Scale," approximated 25% of his academic salary for the Winter Semester would be drawn from the contract, with 40% being provided by the Physics Dept. and the remainder being provided by the ITP. It is anticipated that Kane will also spend a portion of that Semester at the ITP under a similar arrangement.

Our budget request for graduate student support is for the equivalent of approximately one fully funded research assistant per faculty member. In fact, this will be spread among a larger group estimated to be about 11 graduate research assistants, 9 of whom are known definitely at this time. They are also supported through part-time teaching, and one

⋆ This should be known for sure well in advance of the contract year. Should he accept the position, we will submit detailed documentation supporting the proposed addition to our Task.

(Contopanagous) has been awarded a University Rackham Fellowship. Without financial support from DoE, they would be forced either to double their teaching loads, leaving little time to devote to research, or to seek research support from other groups in other fields of physics.

We would like to have a more active visitors program, but we have been restrained by budgetary pressures. Dr. J.-M. Frère of Universite Libré, Brussels, is a frequent Visiting Scientist, spending about 2 months each year with us. This has been a productive relationship, as he has collaborated with several members of our group. He and Yao share a NATO Grant which covers some of the expenses of exchanges between Ann Arbor and Brussels. Also, a young Italian physicist, Francesca Borzumati, has indicated her desire to visit next year. Her phenomenological interests overlap those of several people here, especially Kane's.

In addition, because there is a good possibility of making additional faculty appointments in subsequent years, we are inviting a number of distinguished young people to visit here. One such prospect is J. Bagger, Associate Professor at Harvard, who may be in residence one semester during AY89-90. The Department has an Outstanding Junior Visitors program to provide incentives for bringing such visitors, but requires that the research tasks bear 50% of the cost. This provides us with an opportunity to have an outstanding researcher in residence for only half the normal cost, so we have included in the budget 50% of his salary for one semester.

The substantial rise in air fares in recent times has put great strain on our seminar and visitor budgets. Unlike groups in large metropolitan areas on the East or West Coasts, we are not located very near other strong centers of theoretical research in our field. Consequently, to stay abreast and to foster collaboration is relatively more expensive here. We continue to be disappointed that DoE policy, while wisely supporting large visitor programs at National Laboratories, seems not to provide for adequate funds to University groups for visitors.

FY91:

We are currently interviewing two outstanding candidates for Assistant Professorships to begin in the fall of 1990. Even if they do not materialize, it is quite possible that our recruiting efforts would lead to other appointments by then, so we have included in our projection for FY91 summer salaries and research support for two additional faculty. With the then-total of 9 faculty supported by this contract, we would want to increase our number of postdoctoral fellows from 3 to 4 and, presumably, be in a position to support additional graduate research assistants as well.

FY92:

With 10 faculty in Elementary Particle Theory (9 of whom would be directly associated with this Task,) we would not anticipate additional faculty appointments for FY92, but we would like to restore to our Task an Assistant Research Scientist. From 1977 thru 1987, we had an Assistant Research Scientist associated with our task and found such a person to be an extremely productive addition to the staff. As with experimental groups, having a more experienced researcher who can devote full-time to research undistracted by teaching and administration can be enormously helpful in keeping up the momentum of a research project, thereby having a multiplier effect on the productivity of others in the group.

FY93-94:

These years are too far off with too many interim uncertainties to do other than request inflationary increases.

Contract Services

Administration

Task H contains a one semester research leave for J. Chapman as released time for administration of the DoE contract. This support represents a continuation of the Task H program. The work includes the general contract administration, proposal preparation, and communication with Washington DoE offices. Supervision of the services functions of Task H is also part of the work for which the released time is provided. The services include general computer support and electronics shop design and fabrication support.

VAX Computer

a. Upgrade

Installation of the new computer is essentially complete. We were indeed fortunate to receive a generous research grant from Digital Equipment Corporation that has permitted us to install an up to date multi-processor system exceeding our specification but not our budget. The commercial price of the system exceeds our $500K of DoE contract support by more than a factor of three. System reliability has been very good. The new VAX was available for users about 1 week after the old system was shutdown.

Our RFP and systematic evaluations have served as guides for several other DoE installations. Documentation of the process is contained in a "Computer Acquisition History" prepared for and sent to P.K. Williams of the DoE in late 1988. Additional copies are available on request.

b. Network

The Departmental computer network plan is shown in Figure 1. The network is composed of multiple Ethernet loops that connect the VAX 6200, the VAXstations, the SUN workstations, and the Apollo workstations. These Ethernet loops are operating currently as a single segment since they are merged at repeaters within the building. This is a temporary situation since the common connection results in all units contending for the bandwidth of a single cable.

The soon to be installed configuration of Figure 1 will make use of a University-supported, campus-wide computer interconnect. The location of Physics is shown in the network map of Figure 2. This network uses "smart" routers that suppress traffic that does not need to cross loop boundaries. The four independent loops at the Randall node are again shown in the VAX configuration of Figure 3. A minimal amount of hardware is proposed under Task H for this interconnect though we plan to be one of the first Local Area Networks to be gateway connected to the University system. The bulk of the cost for the connection will be born by the University since use of the system transcends High

Energy Physics. HEP will be able to use the new connection for local functions as well as for access to HEPnet and other nationwide networks. A University based connection to the nationwide HEPnet is proposed for installation as shown in Figure 4. The fiber for the University connection is already in place and the activation of the campus wide network is expected before summer.

c. ACP System

A version of the Fermilab ACP system is approved and funded for the University of Michigan by the NSF. This system will constitute the U.S. computational node for L3 and will be available to all L3 collaborators. The initial capacity of the ACP farm will be that of 18 R3000 MIPS processors or about 250-300 VAX 780s. The system will meet the L3 collaboration's anticipated local needs with about 1/3 left over for local use by the DoE High Energy community. The details of the Michigan ACP proposal are contained in Appendix A. The ACP farm will connect to the VAX cluster for I/O access as shown in Figure 5.

d. Personnel

The cost of computing remains with the individual tasks and the personnel performing the service functions are paid from the funds recovered from these tasks. The staff includes Sally vande Ven as 1/2 time network manager, Lisa Waits as 1/2 time user counselor, and Jon Geld as full time computer system manager. A VAX policy committee composed of B. Ball, J. Chapman, D. Nitz, J. Geld, and S. vande Ven directs the operation of the system. A graduate student in computer science is also supported by revenues from the VAX as part of our research agreement with Digital Equipment Corporation. This individual, Sumanta Guha, is responsible for coordinating efforts to utilize the parallel computational features of the 6200 and reporting the results to Digital.

e. System Use and Cost Recovery

The computational capability of the new computer and its attached VAXstations far exceeds that available in the older system and hence provides the users with a very responsive computer resource. The increase in capability is a multiple of about 20 and has, fortunately, not been fully consumed by increased demand. Table 1 lists our average operations cost broken down by category. Revenue from recharges to the research accounts must on the average cover these costs. In the past we have simply adjusted the recharge rate to balance the VAX costs and revenues. During periods when computing is resource limited, this is all that is necessary. Today we have unused CPU cycles and members of the HEP community who can effectively use those cycles. We cannot simply rescale the recharge rate without redistributing the cost of computing services among the HEP tasks. This is difficult to do in "tight money" situations.

The VAX committee has implemented a dual option cost recovery scheme that will, at least partially and equitably, provide for use of the available resource without distorting the distribution of costs year to year as computing needs shift with experiments. The new option permits HEP research groups to select a **guaranteed prepayment** plan for computer time at a reduced rate. The existing **standard** rate will remain an option for those who choose the "pay as you go" arrangement. The necessary revenues are assured by the prepayment plan since the amount recovered is independent of actual use. When the prepaid amount of computing is exhausted by a research group, charging will revert to the standard plan for that group. Prepayment intervals of 6 months are anticipated.

f. Future Plans and Budget Discussion

The future direction of computing in High Energy Physics at Michigan will depend on the direction taken in computing in the HEP community and at the University. A few things are clear. Our current LAN arrangement overloads the bandwidth of the single Ethernet port to the VAX. A second data path for workstations and X-window terminals will be necessary for effective operation of additional units. **A $3500 Ethernet interface is listed in the budget for the first year along with the final part of the VAX acquisition cost**. Many of our graphics terminals are approaching 15 years of use, are no longer manufactured, or maintained. We anticipate a steady replacement of them with Ethernet connected workstations or X-window terminals.

It is clear that conventional 6250 Bpi tapes are insufficient for data storage on the scale of new experiments. The LEP experiments are using the IBM 3480 format. Other experiments are using the 8mm format. We will need to acquire tape handling equipment compatible with that chosen by collaborative experiments as data becomes available. The most likely choice is the IBM 3480 format. **We have requested $60K in the second year for a tape and controller of this type and $18K for a BI expansion cabinet to accommodate the tape interface**. Should other formats be selected, we will modify our plans accordingly. **A $2500 CD Rom reader is also included in the second year request**. The device provides for complete online documentation. Distributed computer access from offices and labs makes online access attractive and less expensive via CD Rom than the proliferation of manuals throughout the Department. When combined with the network access, this capability permits computer based analysis to continue undiminished while away from one's home institution. Digital Equipment Corporation is likely to begin distributing program updates on CDs as well.

For the third year of the contract we propose to purchase $10K in X-window terminals or workstations to replace our aging terminals. In addition, we request $30K to add a second IBM 3480 drive or the alternate device chosen by the HEP community and $10K to increase the capacity of the ACP system for DoE research work.

The direction taken by computing in remaining two years depends on the success of the ACP project, on the upgrade possibilities of the VAX 6200, and on the alternate equipment available. Current projects underway at DEC make the prospect of significant board-swap enhancements of the 6200 a real possibility at moderate cost. **We request $50K in each of the 4th and 5th years to begin a 6200 upgrade.** We also propose to continue **terminal replacement at an annual cost of $10K.**

DoE Electronics Shop

The personnel for the shop includes two engineers, John Mann and Maher Siraj, and a chief technician, Elsie Ordinario. The shop work force includes numerous physicists, students, and technicians from the research groups. The number of persons utilizing the shop approaches 20 and as many as 10 people are simultaneously present at peak periods. A list of projects that have been completed or are in progress within the shop are listed below. The shop is operating in its new location in the West Engineering building and minimal future disruptions are anticipated. Some additional office space is planned when more of the building has been renovated.

a. Development Hardware

We propose to purchase additional test modules and fixtures each year. The number and quality of our test equipment is a serious limitation. We have utilized VME instrumentation in two experiments over the past year and consider that standard as clearly superior to the other options in price and performance. When the modules and fixtures of the current experiments are sent to their respective points of installation, we will have no local equipment for VME module testing. A VME crate, power supply, Q-Bus connection, a μVAX, and few modules are included in the first year of the proposal to provide this development base. Each subsequent year we propose to enhance this base with additional VME and NIM modules. We also request funds during the second year to add another fast scope.

b. CAD Facility

We are fortunate to have within the University an outstanding CAD software package called Mentor Graphics. This package is utilized in the Engineering School as a consequence of a donation by the manufacturer. The hardware to run this package is in place in our shop and we have produced PC layouts, surface mount hybrid designs, and custom integrated circuit designs with it. The software includes circuit simulations, auto trace routing, as well as artwork production. This equipment will be invaluable in the development of circuitry for the next generation of detectors. The CAD facility makes use of the campus backbone for access to software at the Engineering School.

c. 1989 Activity

- Maintenance and support of the SAM amplifiers for the MarkII.
- Fabrication and final testing of the muon upgrade electronics for the MarkII.
- Construction of 512 Phototube discriminators for the UMC muon detector.
- Construction of high voltage distribution circuits for the UMC muon detector.
- Design and construction of long line pulse repeaters for the UMC muon detector.
- Design and construction of long line pulse repeaters for the γ^* detector.
- Design and construction of a satellite clock interface for the UMC muon detector.
- Design and construction of a μ trigger system for the UMC muon detector.

- Design and construction of a scalar system for the UMC muon detector.
- Design and construction of the ERP trigger modules for the MACRO detector.
- Design and construction sample and hold modules for the MACRO detector.
- Design and construction of the readout modules for the MACRO detector.
- Design and construction of an oil level sensor for the MACRO detector.
- Design of a 32 channel scalar module for the γ^* experiment.
- Design of a pulse width sensing module for the γ^* experiment.
- Design of an 8 channel amplifier-discriminator module for the γ^* experiment.
- Design and construction of a DRV-11 to VME interface.

d. 1990 Activity

- Design of an inexpensive simplified trigger module for the MACRO detector.
- Design of fast gas tube electronics for potential SSC detectors.
- Design of a synchronizing clock system for the γ^* experiment.
- Development of Prototype electronics for the UMC very large array.
- Construction of high voltage circuits for the UMC very large array.
- Construction of the ERP trigger modules for the MACRO detector.
- Construction sample and hold modules for the MACRO detector.
- Construction of the readout modules for the MACRO detector.

e. 1991 Activity

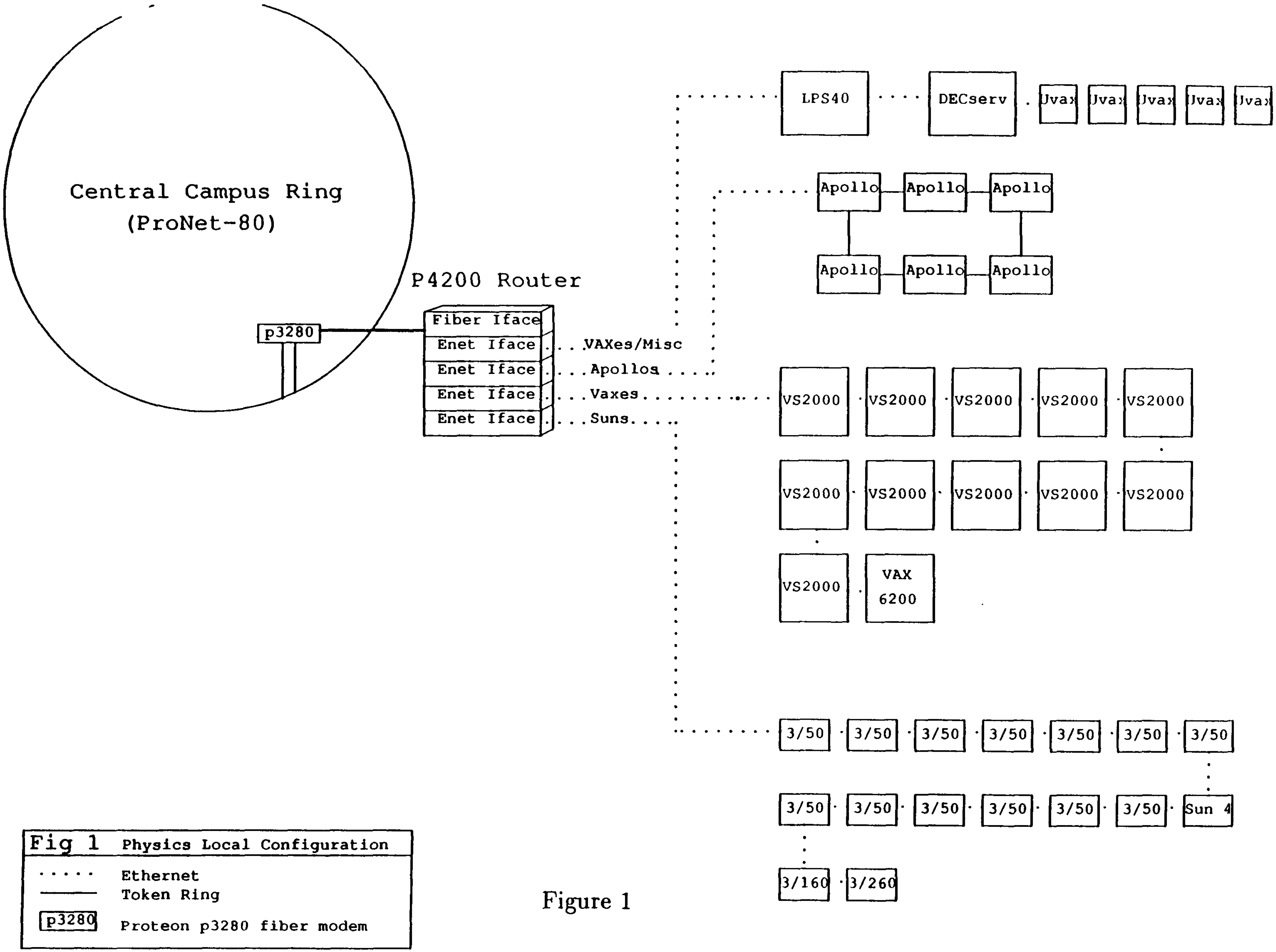
- Construction of UMC (very large array) electronics.
- Construction of electronics for prototype SSC detectors.
- Construction of γ^* electronics.

f. Future Plans and Budget Discussion

The future activity of the electronics shop is guaranteed for the next two years given the experiments already underway. Several members of the Department are active and funded for SSC detector research and development in the realm of electronics. This is expected to intensify as serious prototyping of detectors and trigger electronics is undertaken. **To facilitate this prototyping and testing a μVAX based test facility is proposed in the first year at a cost of $20K.** The electronics shop was assembled from the personnel and equipment of the various research groups. While this has provided an inventory base and some test equipment, there are no fast scopes not committed to experiments and subject to transport to various detectors around the world. **We propose a second year purchase of a modern fast scope at a cost of $10K.** This unit would be specifically for the engineering staff of the shop and remain within the shop area.

The proposed budget also includes $5K/year of test equipment in the form of VME modules. Maintenance on the CAD stations is also included at $3K/year increasing to $4.5K/year in the last two years. A decision has been made to standardize on VME format for test equipment and most small detector subsystems. This standard has the advantage of modern design and reduced cost as a result of its industrial popularity.

As SSC detector fabrication begins, we expect to need another CAD workstation. Other High Energy AstroPhysics experiments indicate increased need for CAD work as well. **We have requested $15K of University cost-sharing funds in the third year of the contract to address this need.** Any other items required by SSC research projects will have to be supported by SSC development money or by supplemental request since detail projections are not possible at this time.


Central Campus Ring
(ProNet-80)
P4200 Router
p3280
Fiber Iface
Enet Iface
Enet Iface
Enet Iface
Enet Iface
VAXes/Misc
Apollos
Vaxes
Suns
LPS40
DECserv
Jvax
Jvax
Jvax
Jvax
Jvax
Apollo
Apollo
Apollo
Apollo
Apollo
Apollo
VS2000
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Sun 4
3/160
3/260
Fig 1 Physics Local Configuration
Ethernet
Token Ring
p3280 Proteon p3280 fiber modem

Figure 1

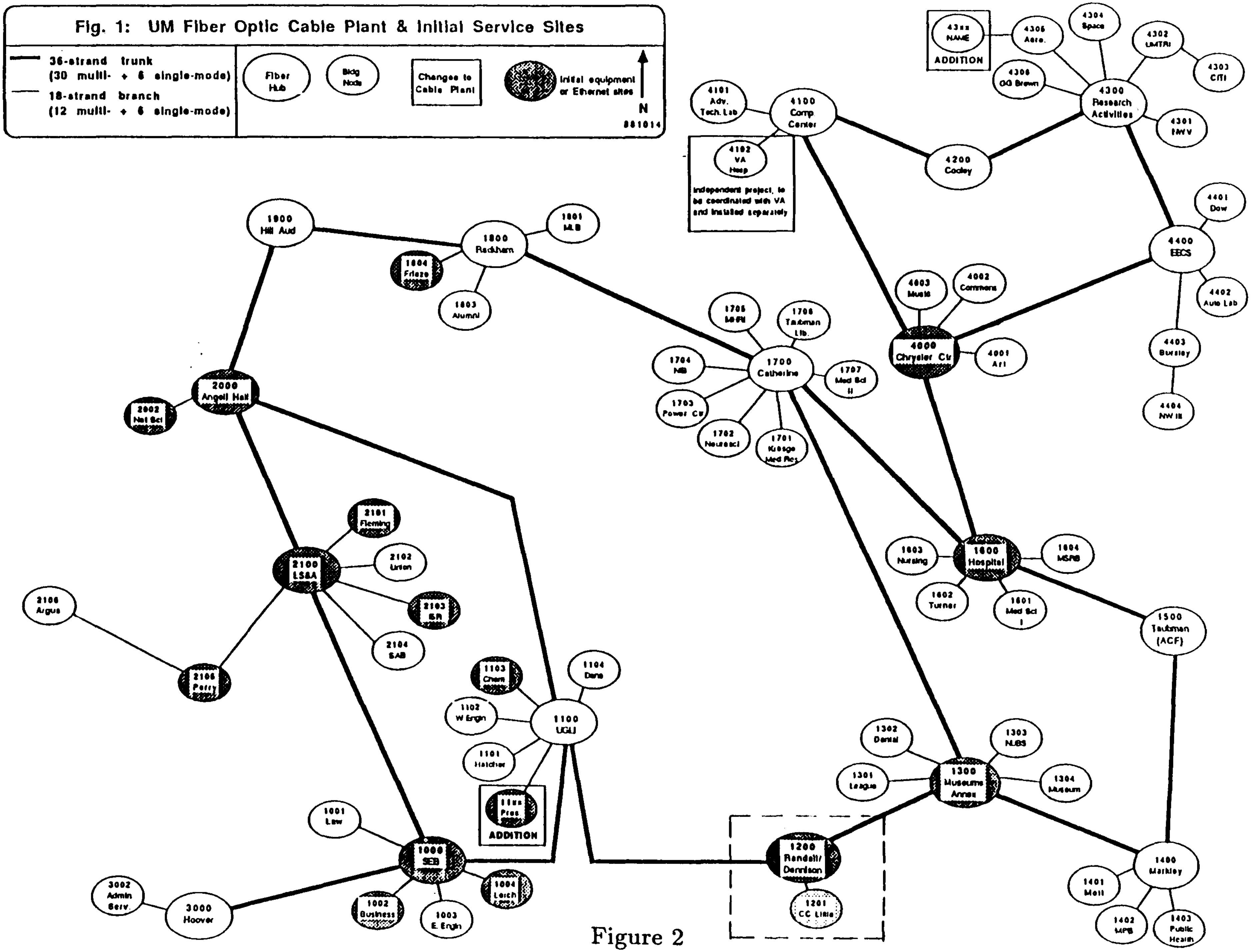
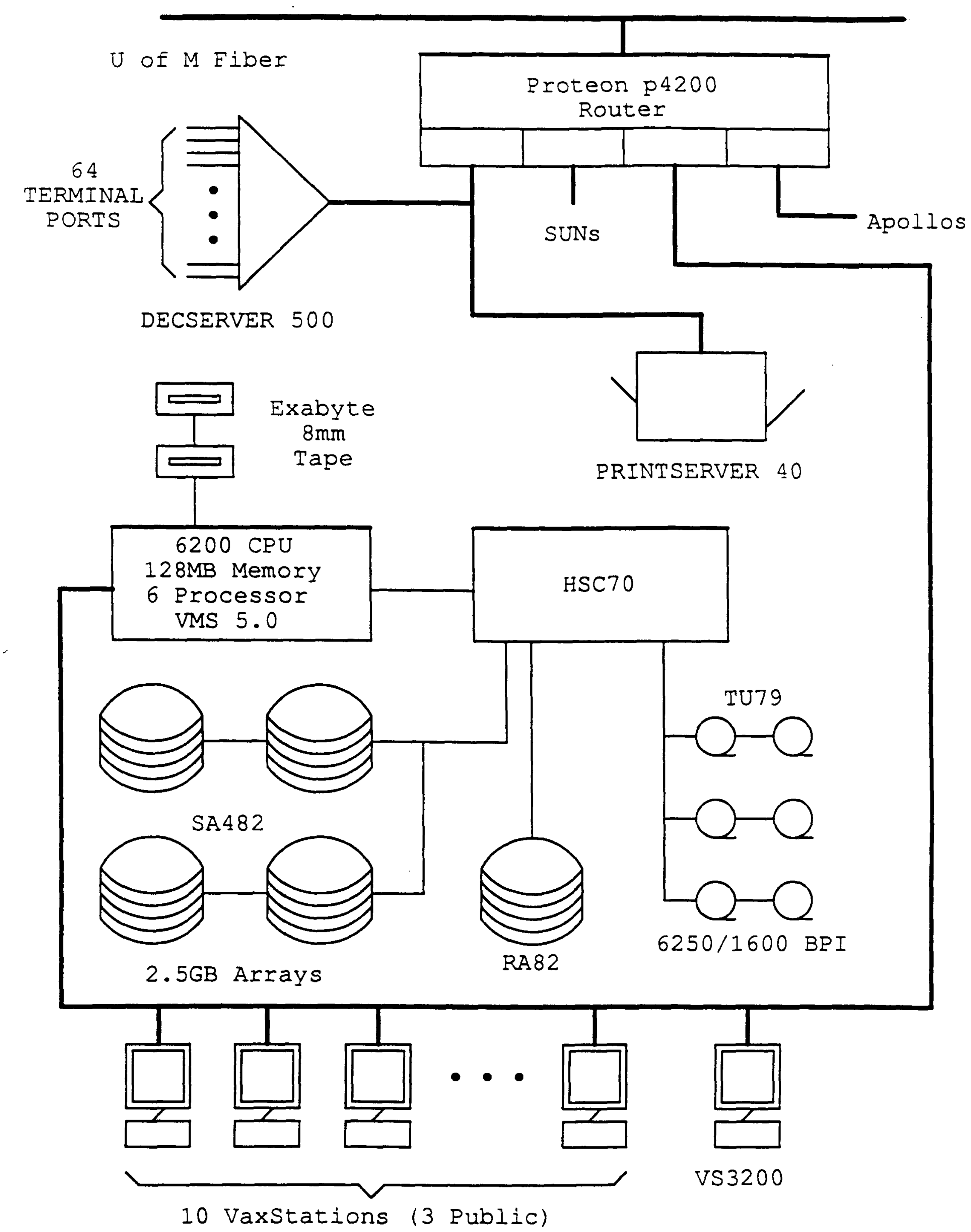


Fig. 1: UM Fiber Optic Cable Plant & Initial Service Sites
36-strand trunk (30 multi- + 6 single-mode)
18-strand branch (12 multi- + 6 single-mode)
Fiber Hub
Bldg Node
Changes to Cable Plant
Initial equipment or Ethernet sites
N
881014
43xx NAME
ADDITION
4306 Aero.
4304 Space
4302 UMTRI
4303 CITI
4308 OG Brown
4300 Research Activities
4301 NAVV
4101 Adv. Tech. Lab
4100 Comp Center
4102 VA Hosp
Independent project, to be coordinated with VA and installed separately
4200 Cooley
4401 Dow
4400 EECS
4402 Auto Lab
4403 Bursley
4404 NW II
4003 Music
4002 Commons
4000 Chrysler Ctr
4001 Art
1900 Hill Aud
1800 Rackham
1801 MLB
1804 Frieze
1803 Alumni
1705 MHRI
1706 Taubman Lib.
1704 NIB
1700 Catherine
1707 Med Sci II
1703 Power Ctr
1702 Neurosci
1701 Kresge Med Res
2000 Angell Hall
2002 Nat Sci
2101 Fleming
2100 LS&A
2102 Union
2103 ISR
2104 SAB
2106 Argus
2105 Perry
1603 Nursing
1600 Hospital
1604 MSRB
1602 Turner
1601 Med Sci I
1500 Taubman (ACF)
1103 Chem
1104 Dana
1102 W Engin
1100 UGLI
1101 Hatcher
11xx Pres
ADDITION
1302 Dental
1303 NUBS
1301 League
1300 Museums Annex
1304 Museum
1001 Law
1000 SEB
1004 Lorch
1002 Business
1003 E Engin
3002 Admin Serv.
3000 Hoover
1200 Randall/Dennison
1201 CC Little
1400 Markley
1401 Mott
1402 MPB
1403 Public Health

Figure 2



U of M Fiber
Proteon p4200
Router
64
TERMINAL
PORTS
SUNs
Apollos
DECSERVER 500
Exabyte
8mm
Tape
PRINTSERVER 40
6200 CPU
128MB Memory
6 Processor
VMS 5.0
HSC70
TU79
SA482
RA82
6250/1600 BPI
2.5GB Arrays
VS3200
10 VaxStations (3 Public)

Figure 3

U-M Campus DECnet
Proposed Connectivity and Addressing
DECnet Area Diagram

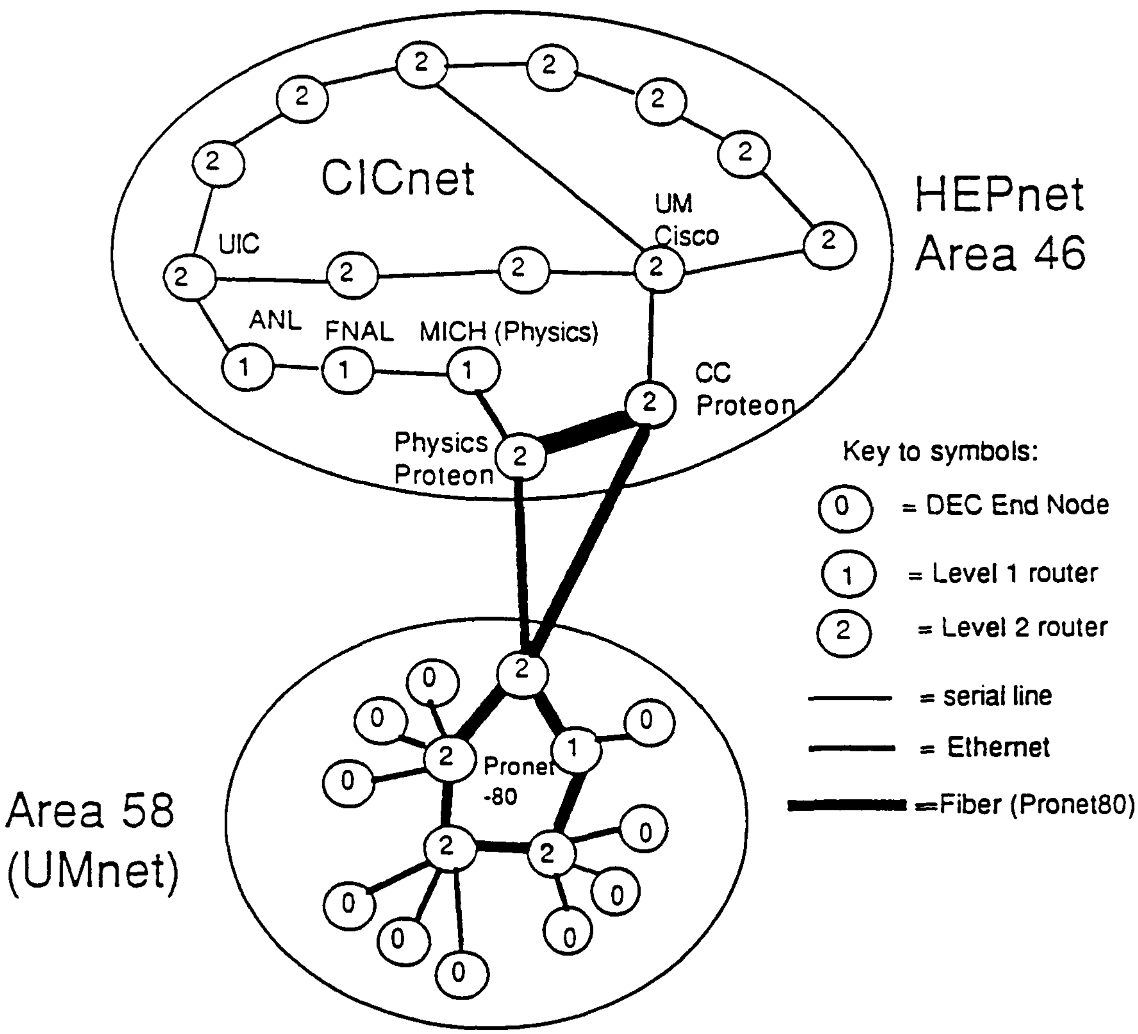
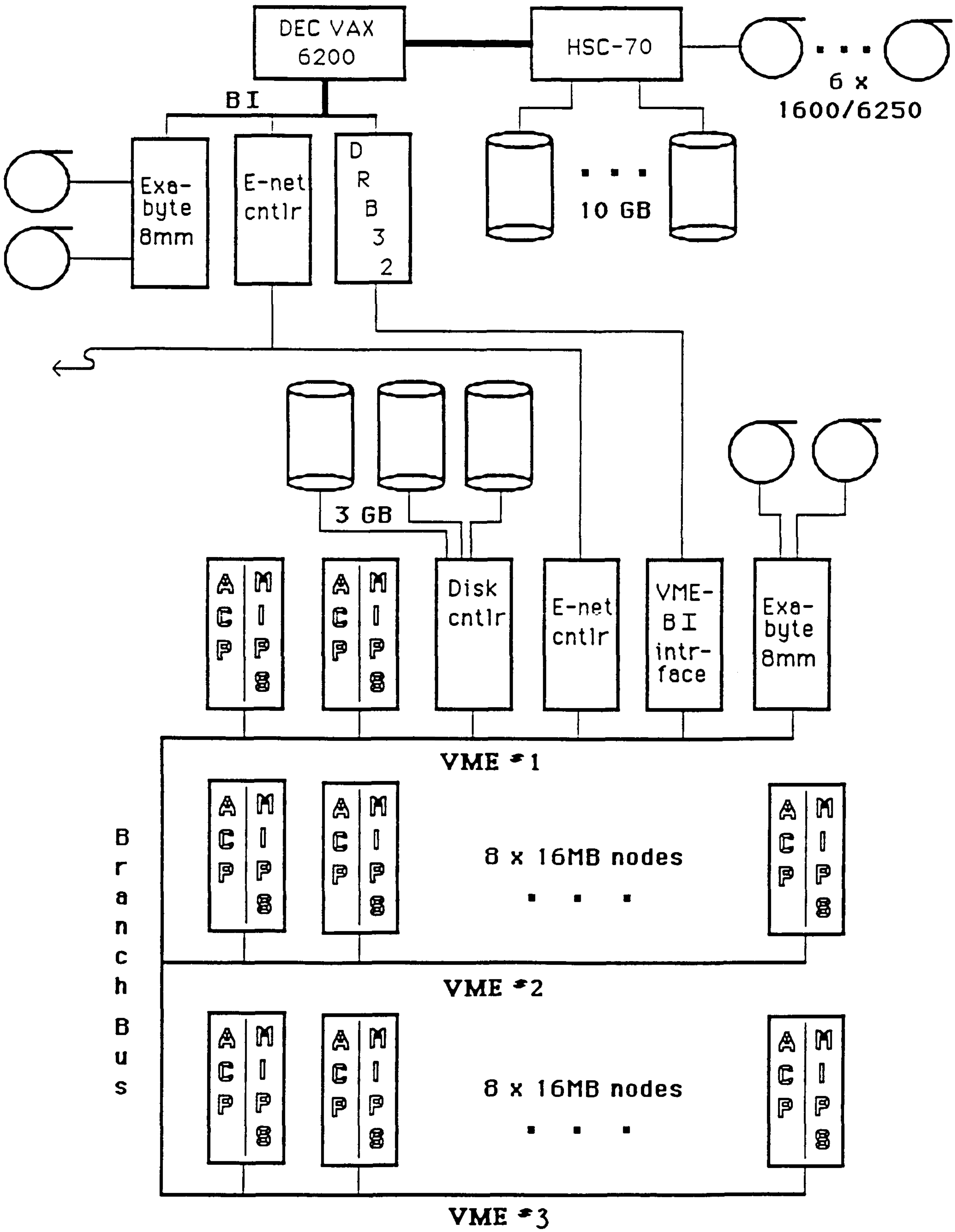


Figure 4



DEC VAX 6200
HSC-70
6 x 1600/6250
BI
Exa-byte 8mm
E-net cntlr
DRB32
10 GB
3 GB
ACP MIPS
Disk cntlr
E-net cntlr
VME-BI intr-face
Exa-byte 8mm
VME #1
Branch Bus
8 x 16MB nodes
VME #2
8 x 16MB nodes
VME #3

Figure 5

VAX Maintenance and Operation

	$ per month	Total / mon	$ per year	Total / yr
Hardware Maintenance				
VAX 6200	5,802.00		69624.00	
VAXstation 2000 (9x)	765.00		9,180.00	
VAXstation 3200	150.00		1,800.00	
		6.717.00		80,604.00
Software Maintenance				
VAX 6200	83.34		1,000.00	
VAXstation 2000 (9x)	292.50		3,510.00	
VAXstation 3200	54.17		650.00	
Joiner Associates (BITnet)	87.50		1,050.00	
VPA, LPS40, PSI	36.67	430.00	440.00	5,600.00
Supplies				
Paper	100.00		1,200.00	
Ribbons	3.42		41.00	
LPS40 Supply Kits	77.10		925.00	
Tapes	283.33	463.85	3,400.00	5,566.20
Miscellaneous				
Telephone (phones&modems)	150.00		1,800.00	
Mail	10.00		120.00	
tools, odds&ends *	100.00	260.00	1,200.00	3,320.00
Staff (includes benefits)				
1 Grad Student	956.25		11,475.00	
GS Tuition Waver	311.60		3,739.00	
1/2 F.T.E.	1,425.00		17,100.00	
1 F.T.E.	2,200.00	4,892.00	26,400.00	58,714.00
		12,762.85		153,804.00

* The odds & ends category is a catch-all for things like the phone bills, copying, books, radio shack and Wedemeyer small parts, etc. These are the $5 & $10 items purchased for general operation and too numerous to split up by machine type (VAX, SUN, Switch) so I have elected to stick them in with the VAX operations.

Table 1

Appendix A

Description of the Michigan Physics ACP Computing Facility

Byron P. Roe and Robert C. Ball

Introduction

The Michigan L3 group is building a computing facility at the University physics department with a planned initial scalar computing capacity of about 250 VAX MIPs. Expansion by a factor of up to eight should be possible. The system is expected to be in operation before the end of 1989. It consists of a collection of high speed MIPs R3000 processors interconnected by means of the Fermilab branchbus. The processors will be front ended by the Physics Department VAX 6200 computer. We at Michigan are concentrating on the user interface to the R3000s and on the process of converting existing large programs for execution on the system. The facitlty will be used as an adjunct to the central CERN facilities by the L3 group and especially the US contingent. One third of the R3000 resource will be available for general departmental use.

The Experimental Motivation

The CERN L3 experiment has been rated by the High Energy Physics Advisory Panel (HEPAP) as one of the most critical experiments to be performed in high energy physics in this decade and has been given its highest priority rating. Computing estimates for L3 show a need for a minimum of several hundred VAX 11/780 equivalent years of scalar computing power for each year of LEP running. By CERN rules, a substantial fraction of this power must be provided at laboratories off the CERN site. To attain this level of high performance computing we intend to build a second generation Fermilab ACP system (Advanced Computing Project) at the University of Michigan, for use by the entire L3 collaboration and especially by the US contingent. We will develop substantial enhancements to the basic ACP system to suit our requirements.

The computing needs of High Energy Physics are for scalar, not vector, cycles. Although there are ongoing efforts to vectorize the primary code used today for detector simulation, GEANT, these have not yet been successful, and are not expected to greatly improve the performance of the program in the near future. HEP as a whole needs large amounts of scalar computer power, available in a convenient fashion.

ACP PROJECT

The Fermilab ACP project was initiated because of the need for immense scalar computing power to analyze the data from the Fermilab collider (Tevatron) and other colliders in the world. The cost of commercially available processors was perceived as prohibitive to the analysis of the experimental data in anything like a timely fashion. The goal of the ACP group was therefore to produce a high performance system of inexpensive scalar processors which would allow the high energy physics community to continue to produce physics results in an affordable fashion.

The first generation ACP system consists of downloadable, attached processors built around the Motorola 68020, and resident in VME crates. Intercrate communications occur via the 20 MByte/sec, Fermilab developed branchbus. Two production systems of approximately 50 boards each are in use at Fermilab around the clock⋆ . Shortly a total of 500 nodes will be available at Fermilab. Other, smaller systems are in place around the country.

The second generation ACP system is much more advanced than the first generation† . The processor boards, which remain VME crate resident, are designed around the MIPS

⋆ The only serious difficulty encountered in using these "first generation" ACP systems has been in adapting large evolving reconstruction codes in the context of a large team effort, particularly when the effort is centered on a VMS development and file service environment. The commonly anticipated problem of parallelizing code has proven to be a non issue, being accomplished with relatively little effort.

† Commercial high performance technology trends in the areas of microprocessors, workstations, networks, operating systems, and compilers encourage a far more open environment in the Second Generation ACP Multiprocessor System now under development. The essence of the Second Generation philosophical goal is to attain a seamless merging of the commercially available workstation/Ethernet - Unix (or, when required, VMS) world at the physicists desk with extremely high performance multiprocessor superfarms at the back end. Software tools are being developed to provide the basic high energy physics block transfer capabilities (SEND, GET, BROADCAST,ACCUMULATE) between any Unix (or VMS) TCP/IP platform, specifically including workstations and individual, or classes of, back end processing nodes. More sophisticated capabilities such as remote procedure calls and queue management are also available. A key to the usability of the new environment for large experiment groups is the availability of powerful, easy to network, workstation/development systems with highly sophisticated compilers and debuggers on which application programs can be developed. The same

Computer Corp. R3000 chip set, which has been benchmarked at 12-17 MIPS. They occupy a single board and include 8MB of memory. For the Michigan system we are obtaining an additional 8 MB of memory per processor on a second board. Each of the processors in the system will run a full System V (BSD enhanced) Unix operating system. Remote subroutine calls and message passing between processes throughout the system will be supported. In addition ethernet based communications to other computers (eg, VAX or Amdahl computers) will allow those computers to fully participate in system operations.

MICHIGAN ACP ENHANCEMENTS

At Michigan we intend to incorporate several enhancements into this system. The VAX ethernet link is far too slow for large amounts of data transfer. We intend to use a BI to VME interface to speed up data flow between the Michigan 6200 and the ACP system. We wish to develop this link for full ACP communications with the VAX.

We will also work on the development of user friendly software. The Fermilab system as distributed will require a sufficient knowledge of Unix such that users must log in to the ACP system during their code development stage* , and also during the production stage. The first step in easing this restriction is to develop the necessary additions to the L3 PAMs to steer the creation of the necessary program versions for simulation, and then at a later date, reconstruction. At the same time work on a precompiler will progress. The precompiler will take a user's program and prepare from it the program versions needed to run a simple, multiprocess topology on the ACP system. VAX-based command procedures will augment this with the goal of completely insulating the casual user from the need to learn Unix on the ACP nodes. The initial Michigan ACP system will have 18 processors of which two will usually be dedicated to I/O operations.

The scalar power needed by the L3 experiment alone is as large as any of the current NSF vector-computer Centers can offer in their totality, even if we could afford to pay for the exclusive use of the Center. Thus the scalar power of a CRAY X/MP cpu is of the

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machine code executables will run, after being down loaded, on superfarm nodes based on the same silicon as in the workstation.

* Communication from Tom Nash, Dec, 1988.

order of 35-80 MIPS[‡] , at most one third of the capacity of the system we will build. The implementation of scalar machines at L3 collaborating institutions is therefore vital to the success of the experiment.

The ACP system to be built at Michigan will not only be a production system, but also a demonstration system, showing the ease of using such a powerful scalar system by many, non-expert, users. This user friendly, high performance, 250 MIP, scalar computing system is capable of expansion to at least a factor of 8 more in computation power over the level which we are planning simply by the addition of processor boards. New generations of faster processor boards will raise the computational ability ceiling even higher.

‡ See, for example, I.Y.Bucher and M.L.Simmons, "Performance Assessment of Supercomputers," LA-UR-85-1505, Los Alamos National Laboratory (1985). In a private communication with Ms. Bucher, she indicated this report was based on an earlier CRAY X/MP using a 9.5ns clock, and rated it on completely non-vectorizable code at 4.4 MFLOPS. This is to be compared to a rating of 0.2 MFLOPS for a VAX 780 which is commonly rated as 1 MIP. She further indicated that most code has some vectorizable portion and can run at as much as 10 MFLOPS. This is a debatable factor with HEP code where typically 1 of every 3 statements is a branch. In addition the current CRAY Y/MP processor uses a 6ns clock. These factors taken together give a single processor rating in the range of 35-80 MIPS, or 140-320 MIPS for a four processor machine.

Review of Research Activities

INTRODUCTION

MACRO (Monopole, Astrophysics and Cosmic Ray Observatory) is a large area underground detector that is being installed in the Gran Sasso Laboratory (GSL) in Italy. The first supermodule (a 12 m × 12 m × 4.5 m section of the detector) has been taking data on a continuous basis since the beginning of March this year even as installation of additional supermodules has continued. A collaboration of over 100 scientists from the USA and Italy is carrying out the project. The principal goals of the experiment are: 1) to perform a sensitive search for GUT magnetic monopoles and ultra-massive electrically charged particles below the astrophysical bounds, 2) to observe high energy (multi-TeV) neutrinos from astrophysical point sources such as Vela X-1 and LMC X-4 in an attempt to understand particle acceleration in these environments, 3) to observe low energy ($\sim$ 10 MeV) neutrinos from the gravitational collapse of stars within our Galaxy or the nearby Magellanic clouds that will likely occur within the expected MACRO lifetime and yield valuable data on neutrinos and collapsing stars, 4) to observe downward moving muons and multi-muon bundles, some coincident with the EASTOP extensive air shower array on top of the Gran Sasso mountain, that will reveal the composition of cosmic rays near the "knee" of the high energy spectrum, and 5) to measure neutrino oscillations employing the entire earth as a baseline.

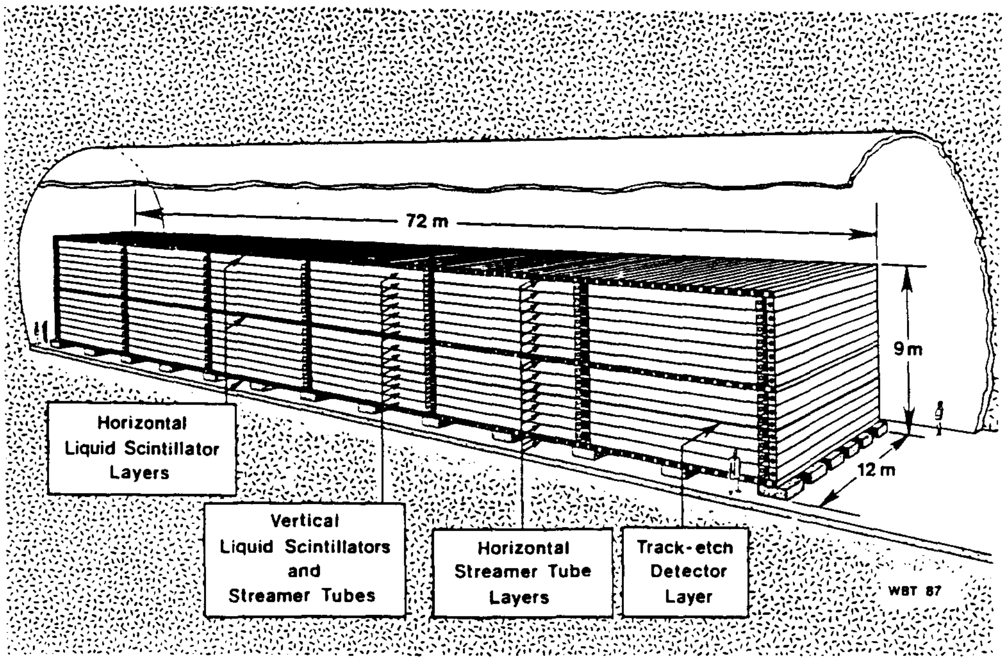

Fig. 1.

The MACRO experiment, shown schematically in Figure 1, consists of liquid scintillators, limited streamer tubes and passive absorbers. The final dimensions of the detector and the exact configuration of the upper half are still to be determined but a minimum length of 72 m is assured. Thick liquid scintillators provide a signature for slow particles by recording the waveform of their unusually long signals. In addition, accurate time of flight measurements distinguish upward moving muons produced by neutrino interactions in the rock below from downward moving atmospheric muons. Limited streamer tubes provide accurate trajectory information for these muons as well as identifying bare monopoles through monopole-induced level shifting in helium followed by ionization in n-pentane vtruction of the first three supermodules is now complete. The first supermodule has been filled with liquid scintillator; it is fully instrumented and is now taking data. Construction of three additional supermodules will start this May and instrumentation of the entire bottom layer of supermodules will take place within the next year.

The division of labor between the US and Italian groups is as follows: The Italians are primarily responsible for the streamer tube system and the mechanics while the US group is primarily responsible for the scintillator system. Barry Barish of Caltech and Enzo Iarocci from the University of Rome are the co-spokesmen for the project. Michigan's responsibilities for the construction of MACRO include the preparation and handling of liquid scintillator, the design and production of trigger and ADC/TDC electronics, and the construction of the vertical scintillation boxes. Gregory Tarlé is the task leader for the Michigan MACRO effort. He is also spokesman of the liquid scintillator group which includes Richard Heinz of Indiana University and Richard Steinberg of Drexel. Mike Longo, who joined the MACRO group in 1986 has assumed responsibility for building the 196 vertical (side) scintillator tanks for the detector at Michigan. The 288 horizontal tanks are being built at Caltech. Longo is also Chairman of the MACRO Technical Advisory Panel (TAP); the other members are S. Ahlen (Boston U.), R. Webb (Texas A. & M.), and R. Steinberg (Drexel). Jim Musser and Tarlé are also working on the MACRO trigger and acquisition electronics, an activity shared with B. Barish (Caltech) and L. Sulak (Boston U.).

A major activity of the scintillation group has been to set up a liquid scintillator preparation facility in Frascati. This facility is now complete. It has been used to produce the scintillator for the first supermodule and will ultimately produce over 1 million liters of high purity scintillator for the entire experiment. William Thompson, a Senior Engineering Technician from Michigan, has relocated to Italy and has constructed the facility and taken care of the day-to-day operations. At this facility ultra-high purity mineral oil is received and mixed with pseudocumene and other scintillator chemicals. Four 5000 gallon isotankers have been installed for the receipt of mineral oil. Another two isotankers are used to transport the mineral oil from the refinery in New Jersey to Italy by ocean-going freighter. These shipping isotankers are continuously shipped back and forth across the Atlantic. We have found that the difficulty involved in obtaining suitable isotankers on short notice and the problems involved in maintaining sterility dictate the use of dedicated shipping containers for the oil. A mobile mixing isotanker, mounted on a truck chassis and fitted with an industrial mixer, is used to mix the scintillator and transport it to the Gran Sasso Lab where it is transferred directly to the detector. Transfer from isotanker to isotanker and from mixing/transport isotanker to the detector is accomplished by pressurization with clean, dry compressed air. A quality assurance lab has been set up in Frascati to test incoming batches of mineral oil and other chemicals for transparency and purity prior to mixing. Mixed samples of scintillator can also be tested for pseudocumene content and light yield. A dual pipeline system has been installed under the MACRO detector to convey the mixed scintillator to the various supermodules. This pipeline will have to be extended as the next three supermodules are constructed.

The MACRO group at Michigan is also responsible for providing one third of the trigger and acquisition electronics for the MACRO scintillator system. We have focused our attention on providing a trigger and readout system that is sufficiently flexible to address a large number of the physics objectives of MACRO. MACRO is designed to address a broad range of astrophysically interesting topics, each associated with a unique event topology within the detector. The event types of interest can be classified into three basic categories. The first type is associated with the passage of a very heavy ionizing particle, such as a GUT monopole, through the detector. These particles are characterized by a combination of very low velocity and high ionization. The time development of the signal in the thick scintillator tanks, along with the detector traversal time form the basis for the trigger for this category of events. The second event type of interest is associated with the passage of one or more relativistic muons through the detector. Two approaches have been taken to the trigger for this event category. The first is based on the observation of coincident signals in any two faces of the detector within the detector traversal time for a relativistic particle. This simple approach works as long as the muon penetrates the detector completely and doesn't pass through one of the inevitable gaps in the detector geometry. An alternative approach, developed at the University of Michigan and described in more detail below, uses the photomultiplier signals obtained at the two ends of the scintillator tanks to reconstruct the amount of energy deposition and the traversal position in each tank. A trigger is generated if the energy deposition in any tank exceeds a preset threshold level. A large fraction of the total number of muons entering MACRO come to rest within the detector, and this trigger provides sensitivity to this potentially very interesting event topology, as well as eliminating inefficiencies associated with gaps in the detector geometry. The final event type is caused by the occurrence of a gravitational collapse event, generally associated with type II supernova within our galaxy. These events are characterized by the observation of a large number (~ 100) of low energy neutrino-induced reactions taking place within the scintillator tanks over a few second period. The trigger for this event type must be capable of distinguishing these neutrino-induced events from the high level radioactive background. The University of Michigan has taken the lead in developing this trigger.

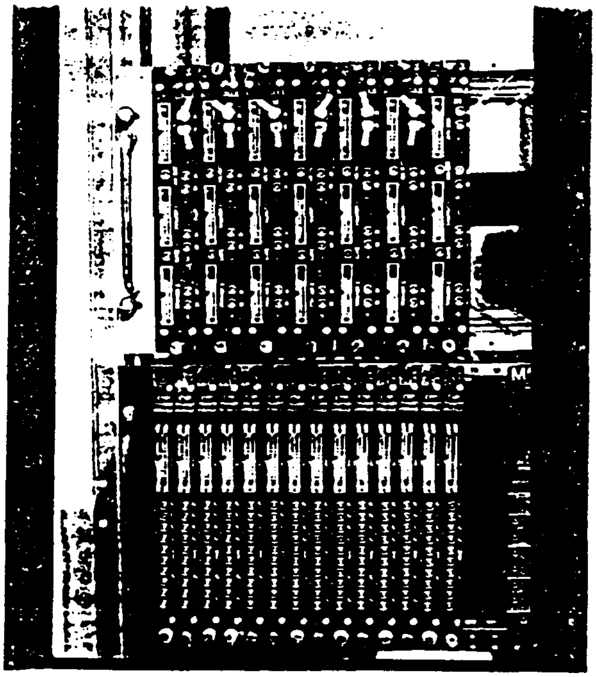

Fig. 2. The ERP System. The trigger processors and sample and hold modules shown are sufficient to instrument 32 counters.

Responsibility for the scintillation trigger electronics on MACRO is shared by Caltech, the University of Michigan, and Boston University. Caltech has concentrated their efforts on the development of a slow particle trigger. Boston University has developed a fast particle trigger based on the multi-face coincidence of simple discriminators, and has combined this with an ADC/TDC (Analog and Time to Digital Converter) readout system designed and implemented by the IMB proton decay collaboration at the University of Michigan. The MACRO group at the University of Michigan has focused attention on providing a trigger and readout system which is flexible enough to act both as the primary fast particle trigger and ADC-TDC readout system as well as providing sensitivity to bursts of very low energy events, such as would be associated with a gravitational collapse. The primary drawback of the simple discriminator-based fast particle trigger stems ultimately from the non-uniform response of the MACRO scintillator tanks. The light yield near a PMT is about a factor of 10 larger than the response at the far end of the tank. Consequently, a discriminator-based trigger has trouble distinguishing a low energy radioactive background event taking place near one of the PMTs from an interesting event at higher energy. The system we have developed, the ERP (Event Reconstruction Processor, shown in Fig. 2), is designed to make maximal use of the information contained in the PMT signals by combining it with the known position-dependent response of the the scintillator tanks to produce a trigger based on the amount of *energy deposition* in the tank. The heart of the ERP is a look-up table (LUT) which is constructed using the known tank response of each MACRO scintillator tank, and which contains the energy and position corresponding to every possible combination of PMT signal pairs, to six bits accuracy.

The ERP system consists of a trigger processor containing the LUT, a sample and hold unit which stores the amplitude and timing information for a scintillator module in the form of DC voltages, and a system supervisor, which converts the voltages stored in the sample and hold units to ADC/TDC values under control of the trigger processors, stores the ADC/TDC values in buffer memory, and issues event triggers. The basic operation of the ERP differs little from that of a standard ADC/TDC system, with a second level trigger based upon the LUT result. The two photomultiplier tube (PMT) signals from each scintillator tank are input to the sample and hold module. Low level discriminators in this module determine a coincidence between signals at the two ends of the tank, signaling a potentially interesting event and initiating activity in the trigger processor. The leading edges of these discriminator outputs are used to establish a relative time between all PMT signals observed in the detector. When a coincidence is obtained, a common system stop is generated and voltages proportional to the time between the leading edge of the discriminator outputs and the common stop time are stored in the sample and hold module. In addition, voltages proportional to the integrated PMT charges are stored. The latter are input to the trigger processor unit where they are digitized to six bit accuracy. The two corresponding six bit digital numbers are used to form an address within a 4K by 8 bit LUT stored in random access memory, which is loaded with the energy deposition and position corresponding to all possible combinations of these two six bit numbers. In the event of a positive trigger decision the supervisor module is notified, and the digitization of the amplitude and timing information stored in the sample and hold units for each tank hit is initiated. The trigger processors can issue two types of triggers to the supervisor. The first, associated with large energy depositions such as those obtained from muons, causes the supervisor to issue a trigger to the data acquisition system immediately after digitization. The second, associated with lower levels of energy deposition, causes the supervisor to store the ADC/TDC information in an onboard 1500 event buffer without triggering a readout by the data acquisition system. A readout trigger is generated when this buffer has filled, allowing offline searches for gravitational collapse events. The primary source of background in this search is caused by radioactivity in the rock surrounding the detector. The 'response flattening' behavior of the ERP allows us to set a much lower energy threshold at the trigger level than would otherwise be possible, and provides a more sensitive and bias-free gravitational collapse search. As indicated above, it also allows us to obtain a clean muon trigger from a single tank hit, that is, without requiring a coincidence between entry and exit faces. This allows for the possibility of studying several interesting classes of events which would otherwise not generate a trigger, such as upward going muons which stop in the detector, downward going neutrinos which interact in the detector, and downward going muons which stop in the detector.

Michigan's role in the construction of the vertical scintillation boxes dates back to the time when G. Tarlé and W. Thompson first thermoformed single 12 m long, Teflon lined, PVC sheets to make two prototype MACRO scintillation counters. A clear PVC window separated the liquid scintillator compartment from compartments at the ends which housed photomultiplier tubes (PMT's) and were filled with clear mineral oil. This construction technique is the same that has been adopted for the final MACRO scintillation detectors, both horizontal and vertical. When Longo joined MACRO, Barish at Caltech agreed to share the scintillator box construction task, with Longo building the vertical boxes. The overall design of the scintillator boxes was worked out in discussions with the Caltech group and other US groups. A width of 75 cm was chosen for the horizontal boxes with two 8 inch PMT's on each end. The vertical boxes are 23 cm wide and 50 cm high with one 8 inch PMT on each end. Light collecting cones have been used to improve light collection efficiency by a factor of about 2.5 over the prototype tanks. A facility for the construction of the vertical scintillator boxes has now been set up at Michigan. Sufficient vertical boxes for the first three supermodules have now been produced and have arrived in Italy. Installation of these boxes in the first three supermodules has been completed.

Work Completed Last Year

In the previous year the Liquid Scintillator Handling Facility at Frascati has been completed and put into operation. Two additional 5000 gallon receiving/storage isotankers have been placed in the hangar, bringing the total storage capacity of mineral oil to 20,000 gallons. After encountering delays and other problems trying to utilize non-dedicated isotankers to ship oil, we decided to lease two additional isotankers dedicated to shipping. These isotankers were sanitized by us at Frascati and shipped to Petroleum Specialties Corp. where they have been filled with mineral oil, pressurized with dry nitrogen, sealed and shipped to Italy. Transfer into the receiving isotankers has been accomplished, and these shipping isotankers have now been turned around twice at Petroleum Specialties. Two more isotankers have been ordered to add to the transit capacity. Ninety drums of pseudocumene and scintillator concentrate have been received from Drexel University and a mezzanine has been constructed in the hangar to accommodate these. A 500 gallon premix tank has been designed and is on order. This will enable the scintillator concentrate to be mixed with pure pseudocumene in a more carefully controlled manner. A dual pipeline system has been installed under the MACRO detector to conduct liquid scintillator down the hall from the mixing/transport isotanker to the detector boxes. In addition, a liquid scintillator delivery system has been constructed which contains all the flow control valves, meters, etc. and which allows simultaneous filling of two detector boxes at once.

Five isotankers (25000 gallons) of liquid scintillator have been mixed and delivered to the Gran Sasso Lab. This scintillator has turned out to have an attenuation length of over 12 m (see Fig. 3) and a light yield from the far end up by a factor of four from our best prototype counters. These spectacular results are largely due to the selection of greatly improved scintillator ingredients and the monitoring of the purity of these ingredients through all phases of the manufacturing process. This has been made possible through the use of special spectrophotometers constructed at Indiana and Drexel Universities. With these, we were able to determine that Britol 6NF-HP, made by Petroleum Specialties in New Jersey was the clearest mineral oil among dozens of oil samples obtained from all over the world. Similar analysis of pseudocumene, PPO, bis-MSB and BHT performed at Drexel identified materials with poorer attenuation length and helped determine the ideal scintillator mix for our detectors. Tests performed at Caltech, varying the concentration of this optimized concentrate permitted us to settle on a 3.5% concentration of pseudocumene as optimal.

To ensure proper quality control for all the scintillator that will be used in MACRO, a quality assurance laboratory has been set up at Frascati. Indiana University has constructed a duplicate of their spectrophotometer at this lab and a PC based CAMAC data acquisition system was supplied by Michigan. A variety of chemical analysis equipment to measure pseudocumene content, cloud point and other relevant information has been put into place in this lab. With this facility, we have been able to test the purity and attenuation length of the scintillator ingredients before committing to a large scale mix.

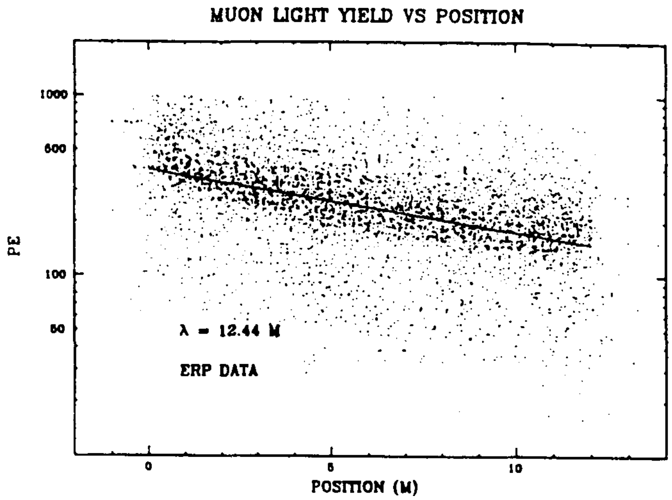

Fig. 3. The position-dependent response of the MACRO Horizontal counters, summed over all counters is the first supermodule. The line represents the response expected for a 12.44 meter attenuation length.

In June of the previous fiscal year, 64 channels of ERP electronics, sufficient to instrument the top and bottom layers of the first MACRO supermodule, were installed and tested at the Gran Sasso Laboratory. Work from that period until the first of this year was concentrated in getting the first supermodule ready for a shakedown run, which officially began on March 10, 1989. The purpose of this run is twofold. First, a MACRO supermodule is a large detector in it's own right, and several interesting physics results will be obtained from the run, which is scheduled to last 90 days. Second, it provides the experience needed to evaluate the various electronic systems, such as the ERP, which have been developed for MACRO.

All of the senior graduate students now working on MACRO have defined thesis topics, and could all potentially obtain degrees as a result of analysis of the data obtained during this 90 day run. Cathy Smith, the senior graduate student on MACRO from the University of Michigan, has taken up residence in Italy for the duration of run, and will be engaged in a study of events seen both in MACRO and in EASTOP, an extensive air shower array located on the top of the Gran Sasso mountain. Using the combined data from both detectors, it should be possible to obtain information concerning the composition of Cosmic Rays at high energy, since composition is known to affect both air shower development and muon multiplicity distributions seen in underground detectors.

Since the start of the run, attention here has concentrated on the development of data analysis software. A data reduction package called DREAM, which has been under development both in the U.S. and Italy, will ultimately be used by all MACRO experimenters for data analysis. The first stage in implementing DREAM will be to develop software modules which convert the raw data obtained from the detector into physically meaningful quantities. As an example, the raw ADC and TDC values read out of the ERP system will be converted to charge in picocoulombs and relative time in nanoseconds. The next step in the analysis chain will use the resulting charge values to obtain the energy deposition and position of energy deposition in each tank hit, and the time values to determine more accurately the trajectory of the particle and the sense of its motion (upward or downward going). This information, along with the trajectory obtained from the streamer tubes, is used in the final stage of data analysis to obtain the quantities of most importance, (*i.e.* the muon multiplicity, origin in siderial coordinates, etc.) and to classify each event according to physical content, such as upward going muon or muon bundle. Most of the software necessary to perform the first two stages of data analysis is now operational, and preliminary results are described below. Prior to the start of the spring run we had not made detailed measurements of the position dependent response of each of the scintillator tanks in the first supermodule. This required that a nominal tank response, obtained on a test tank at Caltech, be used to built the ERP LUTs initially. This results in some degradation in the preformance of the ERP system in the form of non-optimal energy thresholds. We have now, based on the muon data from the early part of the run, determined the true response of each tank. The result is shown in Figure 3. In this figure we show the light output as measured by the ERP system as a function of position for all tanks after normalizing each tank to the mean light yield for a muon at the tank center. Also shown on this plot is a line representing the light output expected for a 12.44 meter attenuation length. After properly normalizing the tank response, the energy deposition and position can be obtained. The raw energy spectrum for muon events is shown in Figure 4. Figure 5 shows the distribution of muon transit positions in the scintillator tanks summed over all tanks, obtained from the ERP ADCs. Figure 6 shows the same distribution as obtained by the ERP TDCs, and Figure 7 shows the correlation between the TDC and ADC - derived positions. The position resolution of the TDC and ADC measurements are both ≈ 0.4 meters at this time. Improvement in the TDC position measurement by a factor of two is expected as better values for the TDC calibration constants are obtained from the data. As stated above, transit times derived for the TDC values are used to obtain the trajectory of the muon through the detector, and its sense of motion. Figure 8 shows the distribution of muon points of origin in alt-azimuth coordinates for one day of muon data. Most of the structure evident in this plot is an artifact of the coarse scintillator detector segmentation, and would not appear on a plot in which the streamer tubes were used to determine the muon trajectory. More critical is the ability of the scintillator system to distinguish upward from downward going muons. The raw distribution of muon velocities obtained from the ERP TDC system is shown in Figure 9. Upward-going muons would appear on this plot at $\beta = -1$ at a level of $\approx 10^{-4}$ that of the downward-going muon flux. The total number of muons in this data sample is about 2700. Although this result does not represent a definitive demonstration of our ability to distinguish upward from downward-going particles at the required level, it is certainly encouraging that no apparent background is evident in the *raw* data at a level which is within a factor of three of the expected upward-going muon flux. The width of the velocity distribution is dominated at the present time by errors in the TDC calibration constants, which will be refined as more data becomes available; this will lead to a width about a factor of two narrower that that shown in Figure 9.

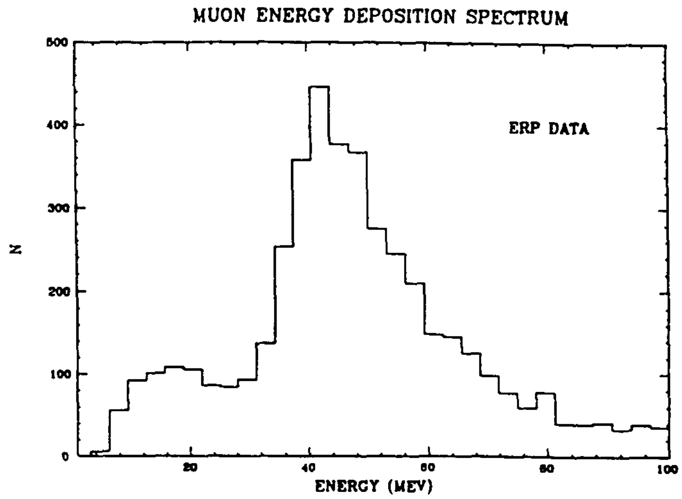

Fig. 4. The energy deposition distribution for muons triggering the ERP system.

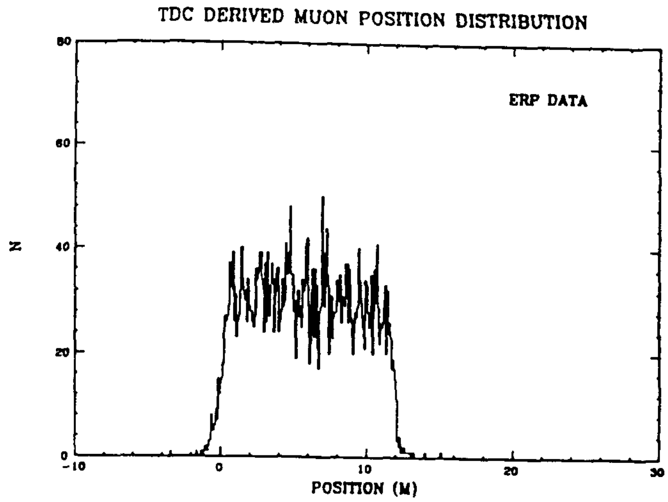

Fig. 6. The distribution of muon transit positions based on left-right timing differences.

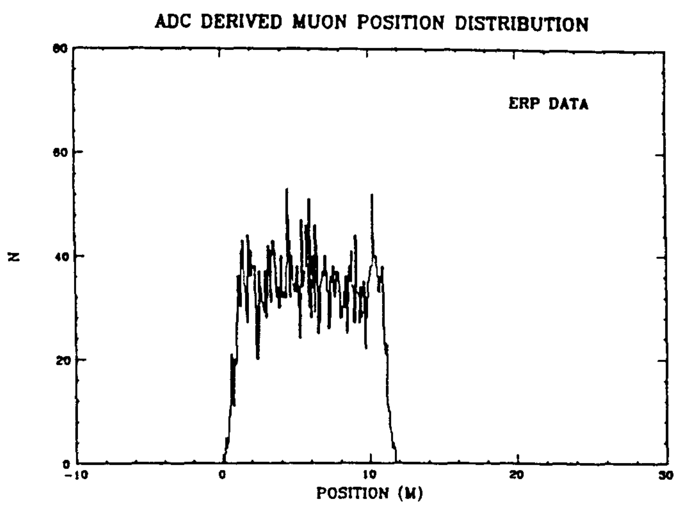

Fig. 5. The distribution of muon transit positions in the horizontal scintillator tanks for ERP triggers, based upon the left-right ADC difference.

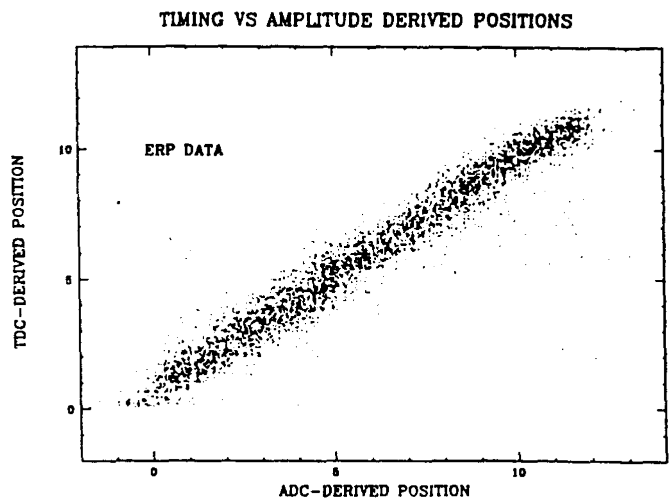

Fig. 7. The correlation between the ADC and TDC-delivered positions.

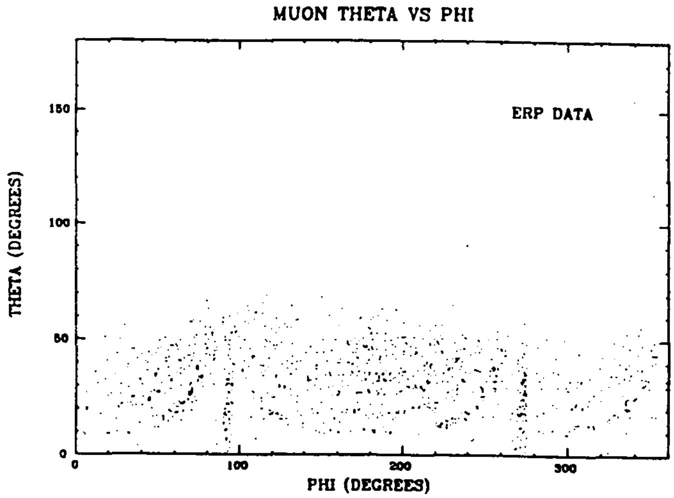

Fig. 8. The distribution of muon trajectories as determined by the MACRO scintillators. Theta is the zenith angle, and phi is the azimuthal angle.

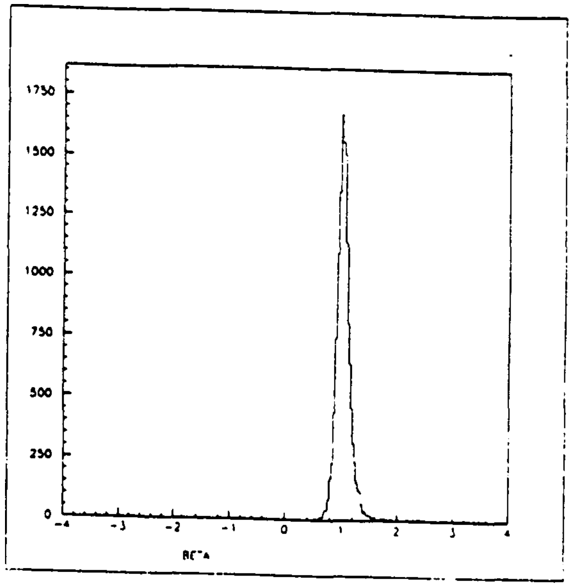

Fig. 9. The muon velocity distribution, as determined by the time of flight through the detector.

Studies of the efficiency and false trigger rate of the ERP muon trigger have been preformed by comparing the triggers generated by the ERP system with those given by the BU face coincidence system. The BU system is instrumented over all four faces of the supermodule which have scintillator coverage, while the ERP system is instrumented only over the top and bottom face. Since the vast majority of all BU triggers involve either the top or bottom face, the ERP should generate a trigger for every BU trigger, with the exception of events which pass through the two side planes of the detector. This is found to be the case, with less than 1% inefficiency derived for the ERP muon trigger. The false trigger rate is somewhat more difficult to determine, since the ERP system is sensitive to particles entering or exiting through the two sides of the supermodule not covered by scintillator tanks, which would not trigger the BU system, as well as particles which pass through a gap in the scintillator coverage on one of the instrumented planes. The trigger rate of the ERP system is about 30% higher than the coincidence rate obtained for the four planes instrumented by the BU system. This is consistent with the rate expected for the event topologies described above which would not trigger the BU system. An accurate false trigger rate for the ERP system can be determined by a study of the streamer tube data obtained from ERP triggers. This work is ongoing.

A complete Monte Carlo simulation of the neutrino-induced reactions which take place in the MACRO scintillation tanks as a result of a gravitational collapse event was developed here this year in order to obtain

realistic detection efficiencies for all reaction channels. Using this model we studied the possibility of observing the 2 MeV gamma produced when the neutron from the charged current reaction $\nu_e P \rightarrow Ne^+$ combines with a free proton to produce a deuteron, and found that $\approx 20\%$ of the gamma rays from this reaction deposit an observable amount of energy within 300 microseconds of the time of the prompt positron signal. This is four times larger than the chance coincidence probability within this time window, based upon the known ambient radioactive background rate above 2 MeV. One of the capabilities built into the ERP system is the ability to lower the trigger threshold in a tank for a preset time after an event, allowing for the possibility of detecting fusion gamma rays. An observed enhancement by a factor of four in the rate of very low energy events occurring within 300 microseconds of events within a burst would be a powerful confirmation of the observation of a gravitational collapse.

The first shipment of 22 vertical scintillation counters manufactured at Michigan arrived at the Gran Sasso Laboratory in March, 1988. These were tested for leaks before installation in the first supermodule by C. Weaverdyck and M. Longo. About 12 leaks were found, mostly around the lids, and repairs were made. The vertical counters were tested again for leaks after they were installed. By this time, due to severe leakage problems with the horizontal boxes, it had been decided to wait several months before filling the end (PMT) compartments with clear mineral oil. This meant that more stringent requirements for leakage around the clear windows were necessary. Several windows which leaked below liquid level were found and repaired by M. Longo, W. Thompson and H. Schick.

Feedback from the construction and testing of the first counters led to some refinements in the construction which should reduce leaks and result in generally sturdier counters. These include the use of thicker clear windows between the scintillator and PMT compartments, better welding techniques, and more effective leak testing before shipment.

There had not been an opportunity to build and fill a full sized vertical counter at Michigan, so the first test of a filled vertical counter occurred after the first supermodule was assembled at the Gran Sasso. Tests there with cosmic ray muons showed that the vertical counters gave approximately the same light output as the horizontal counters despite the fact that they have only one PMT at each end while the horizontal counters have two. As expected, the attenuation length for light is the same in both as it is governed by the scintillator itself rather than the efficiency of total internal reflection off the surface of the teflon liner.

The light collecting cones for the vertical counters are formed by hand from reflective Alzak sheet. Despite this simple design, tests at Michigan show that these cones give an enhancement of 2.5 times in the light collected.

The vertical counters are shipped completely assembled so that the only work that has to be done in Italy is leak testing and, after the counters are installed, the mounting of the PMT's and housings. This procedure minimizes the manpower needed at the Gran Sasso and has worked well.. On the other hand, the installation of the vertical counters is much more difficult than the horizontal ones, because the side counters have to be installed in steel boxes which are load-bearing parts of the detector superstructure. The installation therefore involves the removal of the steel covers which have hundreds of screws and which require several men to lift into place. As a result it was decided to have the installation done by the Polivar company which also handles the streamer tube installation.

All except one of the 14 vertical side counters on the first supermodule have been filled with liquid scintillator and have had PMT's installed. No problems with these counters have appeared in the first data run.

The second shipment of vertical counters arrived at the Gran Sasso Lab in March 1989. H. Schick and W. Thompson supervised the unloading, finished the leak testing of the first shipment and have leak tested the second. The installation of the vertical counters in supermodules 2 and 3 was completed in April and May 1989 with W. Thompson certifying their leak tightness. The installation of the north end wall vertical counters was also completed in May.

Work to be Performed in the Next Few Years

The development of data analysis software for MACRO is just now getting under way, and much of our effort over the next year will be extended in that direction. The development effort will be carried out within the context of obtaining publishable results from the spring run. Specifically, C. Smith will concentrate on developing the algorithms necessary to identify single and multiple muon events, determine their direction of origin, and search for coincidences between MACRO and EASTOP events. She will then determine the way in which the combined data can best be used to derive information concerning Cosmic Ray composition. For the ERP gravitational collapse system a process will be developed for scanning the data for event bursts as the data is acquired. It is quite important that the observation of a gravitational collapse be evaluated quickly, so that astronomers, and physicists at other underground facilities can be notified. The software gravitational collapse trigger process will first convert the raw ADC/TDC information obtained from the ERP system to energy depositions and positions. A running scan of the number of events as a function of energy within a few second time window will determine whether a gravitational collapse has occurred. In the event of the detection of a candidate, MACRO experimenters in the US will be notified instantly via a computer mail message generated by the trigger process. This message will contain all the information available about the event.

Following the 90 day spring run in which muon data is being emphasized, a dedicated monopole run will be preformed on the first MACRO supermodule in the summer, followed by a run in which the gravitational collapse systems are given priority. The implementation of the various trigger systems is being staged in this way to allow an evaluation of each in the simplest possible way. After the gravitational collapse shakedown run, a decision will be made as to the final makeup of the MACRO trigger and readout electronics. Assuming that this decision includes the implementation of the ERP system we will enter into a period in the fall of this year in which the final design modifications on the ERP are implemented. Immediately following this we will begin to produce units for installation. Our projected installation schedule calls for the complete instrumentation of three supermodules during this fiscal year, and the next three supermodules in the next fiscal year, and the remaining six supermodules in the third fiscal year.

When C. Smith returns from Italy sometime around December of this year the plan is to replace her in Italy with E. Diehl, a new graduate student, who will receive his PhD on some aspect of the data taken with the entire bottom layer of six supermodules. Diehl has already learned how to use detectors and instrumentation and is now learning all about the MACRO software.

We expect to continue operating the liquid scintillator facility to fill the remaining counters. Until now, our filling schedule has been limited only by construction progress. In the coming year, it is expected that two more shipping isotankers will have to be added to the transit fleet to keep up with demand. These have already been ordered. With nine isotankers—four for receiving and storage, four for shipping, and one for mixing and transport—our total on-site holding capacity will be 45,000 gallons.

The rate of construction of vertical counters averaged about one per week over the period March, 1988 to March, 1989. This rate was sufficient to stay ahead of the installation schedule for the first three supermodules. Approximately 40 more vertical counters are needed to complete the six supermodules in the bottom half of the detector; 112 will be needed for the upper half. If the schedule results in the full detector being completed at the middle of 1992, we will just barely be able to keep up with the present manpower.

Description of the Budget

Scientific personnel for FY89 will consist of G. Tarlé, M. Longo, J. Musser, C. Smith, and E. Diehl. The liquid scintillator and trigger electronics operation will continue with the same manpower requirements except for the addition of the new graduate student, E. Diehl. Counting Diehl plus raises and inflation for the existing manpower this part of the total operating budget comes to $353.1K, up from $305K in FY89. The big change in the budget comes from the vertical tank operation headed by M. Longo. For the past few years, this operation has been funded by Longo's NSF grant which will terminate in January, 1990. DoE support will be required thereafter. In FY90 this part of the operating budget comes to $167.7K for a total operating budget of $520.8K. This includes Longo's summer salary, the salaries of the two technicians, H. Schick and C. Weaverdyck and a new graduate student. The budget in future years reflects our needs to increase our scientific staff for data analysis while maintaining a tight construction schedule. In FY92 we have added two postdocs and one more graduate student and have carried these through in the remaining years.

The Capital Equipment part of the budget reflects the expenditures necessary to continue the construction of MACRO on schedule. The mineral oil budget of $170K per year for FY90, FY91 and FY92 assumes that the presently planned detector (six double-decker supermodules) will be completed in these years with half of the oil being purchased by Michigan, half by Indiana, and the scintillator concentrate by Drexel. Most of the $30K/year for scintillator handling represents the cost to rent the nine isotankers ($22.5K) with the rest for miscellaneous handling equipment. The cost for components for the ERP system assumes that we complete 500 channels of electronics at $600/channel over the next three years. The tank construction budget of $20K/year is for all the small parts and supplies needed for the tank construction. The PVC sheets and teflon has been purchased through Caltech.

It is difficult to project costs into FY93 and FY94 but to do this, we have assumed that MACRO will have an upgrade and that the operating and Capital Equipment needs will remain constant.

Task K - *(H.A. Neal and G. Snow) - D0 Experiment*

D0 Experiment

Overview

This is a request for support from the Department of Energy to fund the University of Michigan activities in the D0 experiment at Fermilab for a period of five years. This period corresponds to the completion and installation of the detector in the D0 collision area of the Tevatron Collider, the first data runs to study proton-antiproton collisions at center-of-mass energies near 2 TeV, and the extraction of first physics results. The initial physics analysis efforts will focus on the properties of the W and Z intermediate vector bosons, jet production, searches for the the top quark, and searches for heavy particles not predicted by the Standard Model.

During the past year, an accelerated schedule to complete the D0 detector for data taking beginning in early 1991 has been endorsed by Fermilab and the D0 collaboration. This decision was driven by the great success of the Tevatron Collider in achieving high luminosities and stable running conditions and by the desire to complement the physics results emerging from the CDF collaboration as quickly as possible in the early stages of exploring the exciting new energy regime near 2 TeV. The new timescale has revitalized and focussed the efforts of all collaborating groups in D0, and the University of Michigan group is organizing its activities accordingly.

The University of Michigan became a collaborating institution in the D0 experiment one year ago. During this period we have

1. Grown to a group of five physicists and three students
2. Established a laboratory for the developement and testing of the various components of the Inter-Cyrostat Detector (ICD) which comprises our main hardware responsibility in the experiment
3. Built and tested prototypes for the scintillator tiles, the associated electronics, and the laser calibration system to develop a final design for the ICD
4. Installed software on Michigan computers which allows us to perform large-scale simulations of physics processes and detector response for the experiment
5. Continued to develop the database software effort for the D0 central calorimeter

Progress in each of these areas will be summarized in greater detail below. In addition, the work of two of us (HN and TG) on analysis of data from the HRS experiment at SLAC will be described.

After these summaries, the budget is presented which covers the involvement of the Michigan group in D0 for the upcoming five-year period. During the first 18 months, we will focus our activities on the production, testing, and installation of the ICD system, as well as contribute to the test beam effort at Fermilab. As D0 enters the data-taking mode, we will participate in running the experiment and we will launch a major physics analysis effort at the University of Michigan. We are furthermore interested in upgrade efforts which will prepare the experiment for running at significantly increased Tevatron luminosities.

Facility Development

The D0 group at the University of Michigan has acquired and has renovated a number of rooms in the East Engineering building on the Ann Arbor campus for use as lab and office space. Currently these rooms house our equipment, workbenches, scintillator and electronics test facilities, computer/data acquisition system, calibration test setup, D0 Endcap Calorimeter mockup, library and offices. We will also use this space for production testing of the completed ICD boxes and phototubes. Since the Randall Lab building is nearby we take advantage of the support which the department can provide.

The Physics Department has recently upgraded the available computing power by acquiring a VAX 6260 mainframe computer (18 VAX-780 equivalents). The 6260 is linked to an extensive network of individual workstations in the department greatly enhancing the capabilities for computing (an additional 10 VAX equivalents). In addition this computer serves as a routing node to the HEPnet network of computers, facilitating communication among our colleagues based at various sites around the country and around the world. The Physics Department Computing Facility also manages the campus-wide Software Library. Members have access to a large selection of software products at a minimal cost.

The D0 group has its own VaxStation 3500 workstation used for data acquisition, analysis, Monte Carlo and general computing specifically relevant to D0 activities. This workstation is a node on HEPnet and is linked to the SPIRES database at SLAC via QSPIRES. The group subscribes to the Software Library. A clustered VaxStation 2000 is used primarily for D0 database work. A second VS2000 is used in the HRS analysis.

The Physics Department Instrument Shop affords the group access to sophisticated computer-driven milling machines which were used in producing the prototype ICD tile blanks. The means to polish the blanks and install the readout wavelength shifting material are available in our lab. The current best design for the ICD readout system was developed at Michigan. Other machine shops in the department allow our members to construct devices used in our research effort.

A cosmic ray telescope and proportional wire chamber system has been set up as an ICD tile test facility. This equipment allows pulse height and efficiency data from 12 test tiles to be taken simultaneously with a 1 square inch resolution. We are therefore able to assess the quality of all units to be installed in the ICD during the production phase.

The phototubes to be used in the ICD will be fully tested by us in our lab prior to their installation in the experiment. This test facility will determine high voltage setpoints and perform a long-term test to discover unsuitable tubes.

In order to study questions of mounting, packaging and cabling of the ICD we have constructed a mock-up of a quadrant of the Endcap Calorimeter cryostat in our lab. This also allows us to study, in conjunction with our colleagues at FNAL, possible conflicts in the limited space between the Central and Endcap calorimeters.

ICD Readout and Electronics

A Monte Carlo calculation carried out by Andy White of the University of Florida indicated that particles passing through the gap between the Central and Endcap calorimeter cryostats register less energy than they were given in the simulation. The reason for the discrepancy is the loss of energy in the uninstrumented walls of the cryostats. This study led to the proposal for instrumenting the inter-cryostat region with a detector capable of correcting for the deficiency. White also found that a correlation exists between the energy lost in the gap and the number of particles intersecting it.

The ICD is a scintillator-based detector which will correct for the lost energy by counting the number of through-going particles. It's segmentation matches that of the calorimeters. The design of such a system requires

- high uniformity of response to minimum ionizing particles
- high detection efficiency
- a dynamic range compatible with the expected population for a given cell

However the very restricted space between the heads of the calorimeter cryostats makes it also necessary to produce

- a very compact,
- robust,
- modular,
- simple,
- and compatible detector.

In our search for the optimal design for the ICD scintillator tile readout system we have designed, built and studied a number of unique prototypes. All the designs incorporated wavelength shifting materials (either bars or fibers) since significant light output could be had with little impact on the available space. We have developed the most uniform tile readout scheme using wavelength shifting optical fibers. These are embedded in grooves machined in the tile's top surface. Mean pulse heights vary typically less than 10 percent over the surface of the tile due to the fact that the fibers are distributed over the scintillator. The efficiency is high with light output adequate for the job. The results of our studies are summarized in D0 note #841 by Marcin, Neal, Gustafson and Snow. This work has also been presented at collaboration meetings by Marcin, Neal and Snow. We are currently working with our colleagues at the University of Florida in finalizing the tile development.

The ICD electronics will integrate this detector with the rest of the D0 calorimeter signal path. We have designed and are now testing shaping amplifiers which will transform the photomultiplier pulses into pulses which mimic the signals from the uranium/ liquid-argon calorimeter. We can thereby utilize the extra digitizing channels already built into the D0 system. We will be building shapers for the 768 channels of the ICD. These units will also include the capability of extracting the fast signals for possible use in a trigger.

We have designed, built and tested a photomultiplier base capable of driving three tubes simultaneously. In this way we reduce the heat load on the cryostats as well as power supply and cabling costs.

Software/GEANT and Analysis

During the past few months the official D0 software set has been installed on the departmental VAX system. This software includes the D0GEANT program for simulation of the D0 detector using the CERN GEANT program.

An earlier version of the program was used to begin to understand how to simulate the ICD within this framework. Some modifications to this understanding will have to be made with the official software distribution in place, but the overall program structure has not changed. An effort will begin shortly to write the code necessary for understanding the performance of the ICD, and how it can be used to better understand and measure the energy flow within the D0 detector. This experience with D0GEANT will lead to other large-scale simulations of physics processes the group is interested in. We plan to study the ability of the D0 detector to identify non-standard decays of a heavy top quark to, for example, charged Higgs particles and signatures from interactions between two or more intermediate vector bosons. The latter processes will be most relevant to the analysis of data taken at later stages of the experiment with higher Tevatron luminosities.

We plan to take advantage of the second generation ACP system (Advanced Computing Project) being developed in the department by the Michigan group participating in the L3 experiment at CERN. The facility has a planned initial scalar computing capacity of 250 VAX MIP's with several-fold expansion possible. It is expected to be operational by the end of 1989, and one third of the facility will be available for non-L3 use. The facility is being developed with attention paid to ease the conversion of existing large programs for use on the system. We intend to utilize the ACP for event-oriented large-scale simulations and analysis of D0 data.

Calorimeter Database

Over the past two years the University of Michigan group has been active in the development of a database system for the D0 central calorimeter, and in assisting other members of the collaboration in constructing databases for other components of the experiment.

The initial task was that of defining the parameters that needed to be recorded for each of the Uranium plates in the central calorimeter. This was worked out during the D0 Winter Workshop at Mohonk in 1987 by a group chaired by H. Neal. The results of this effort were published in D0 Note #549. Immediately thereafter a prototype database running on a PC was prepared and the data entry process was started, while work was underway designing a permanent VAX/VMS RdB database system. Upon the completion of the PLATE database using RdB, all data that had been enterered via PC files were then translated and transferred into the RdB database. At this point, the PLATE database is essentially complete, and contains details of the plate thickness profile, and weight for each of the twenty plates in each of the 36 modules of the central calorimeter. This data will be used, not only in the construction quality control process, but also in making detailed estimates of the calorimeter sampling fractions on a tower by tower basis.

As part of the effort to help acquaint other groups in the collaboration with database techniques, and especially the rather complicated RdB language, H. Neal published D0 Note #697, which illustrated the steps in creating RdB database definition programs, screen data entry programs with data integrity checks, and the importing and exporting of data. In addition, that note presented a utility program that interfaces between arbitrary databases and the CERN HBOOK plotting packages, permitting one to plot on the screen or in hardcopy the distribution of any database field variable under any set of logical constraints constructed from any of the field variables.

In February, 1989, we published D0 Note #819 which provides a status report on the Brookhaven calorimeter database, and presented distributions for several of the measurements pertinent to the calorimeter sampling fractions. During the course of the present academic year Neal presented two talks at the D0 Collaboration meetings on database issues, the last in April, 1989 in conjunction with Marcel Demarteau in which a detailed tower by tower sampling fraction analysis was reported. This analysis is continuing, and will provide input into the D0 Monte Carlo so that the real variations in Uranium plate thickness will actually be reflected in the Monte Carlo itself.

Finally, a project headed by H. Neal to compile and publish within the collaboration a compendium of all detector databases is underway. When completed, a member of the collaboration at one site should be able to query a database at another site that might contain the current parameters for any selected component of the detector. To upgrade our ability to query and display data from databases, efforts are underway to master the fourth generation database packages of RALLY and TEAMDATA. These packages are now resident on the Brookhaven cluster and the Michigan 6260.

HRS Inclusive Λ Production Studies

Over the past year Terry Geld and Homer Neal have worked on completing the analysis of strange particle data from the PEP High Resolution Spectrometer experiment. Their analysis has concentrated on inclusive Λ production, and an attempt to extract a refined measurement of the strange quark suppression parameter δ in $e^+ e^-$ collisions at 29 GeV.

The HRS experiment identified more inclusive Λ's events than all other competing electron-positron collider experiments combined. Though preliminary results have been presented based on portions of the data, an analysis based on the full 300 pb^{-1} has not been published; it is our goal to complete this project by Fall, 1989. A HRS Note summarizing our findings is now complete and is being reviewed by collaborators.

Λ's produced in the HRS are identified by reconstructing *vees* within a fiducial volume bounded by the drift chamber system of the detector. Cuts are applied to insure that the primary and secondary vertices are distinct and to minimize the reconstruction background. We have observed 2100 inclusive Λ and $\overline{\Lambda}$ events, and 7350 K^0's. With these events we are able, by utilizing data on the Λ_C branching ratio, to extract a best fit to the value of the diquark suppression parameter. This parameter describes just how much more difficult it is to produce a strange quark in a pair of quarks rather than singly.

Several analysis details were addressed to improve the extraction of real events from the background. Inasmuch as the inclusive Λ's are produced near threshold, the background subtraction process was problematic. Breit-Wigner plus polynomial fits to the data represented a particularly dangerous approach, since the signal is not a true Breit-Wigner and one risks removing a large fraction of the signal in such a subtraction process. Instead, a regression analysis focussing on the wings of the background was employed. The method used to determine the extent of the background in the correlation studies also required innovative analysis efforts.

Our inclusive Λ cross section analyses result in a value of δ=.31$\pm$.09. We are presently completing an analysis of correlations between Λ and $\overline{\Lambda}$'s in the same event, in an attempt to learn if such pairs are produced randomly or in association.

Additional details of our findings may be found in the attached HRS Note draft.

Budget Discussion

The five year budget request is presented in the accompanying table. The budget is developed with the intent of establishing a strong group that will be effective in carrying forward the D0 project in the years ahead.

We begin with the current effort consisting of two faculty, one full-time postdoc and three students, augmented with contributions from two NSF funded research scientists (R. Gustafson and R. Ball), and build to a stable effort of two full time faculty, one postdoc, one full time research scientist, an engineer/technician, and three students. In addition, we anticipate, but do not directly budget herein, the possible addition of one more faculty member to this effort.

In the faculty summer salary category over the next three years, we list only that of Gregory Snow, who is to receive 1 month of summer salary in 1990 and two months thereafter. The summer salary for H. Neal is a cost sharing contribution from the University, in the amount of two months per summer.

To continue the momentum of our efforts on the D0 ICD project, it is absolutely essential that we both retain our postdoctoral position occupied by M. Marcin, and that we augment that position by a research scientist. The primary responsibility of these individuals, and of the engineer and students listed, will be to oversee the day to day fabrication and testing of the tiles to be used in the ICD, to manufacture the electronics required for the ICD, and at the appropriate time, to assist with the running of the experiment and the subsequent data analysis.

The travel items were computed to take into account the need for attendance at collaboration meetings, travel to install the ICD modules, trips to Fermilab to participate in test beam activities, and trips to domestic and international conferences. In this category we would also support appropriate travel by Gustafson and Ball.

The other primary budget items are associated with required supplies and equipment, computer maintenance and use of the departmental VAX and ACP facilities. Funds in the laboratory budget will be used to pay for those expenses incurred by project members working on the ICD task at Fermilab.

reprints, preprints,
+ budget retained