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RESEARCH OBJECTIVES

1. APPLICANT ORGANIZATION: The Regents of The University of California
University of California, Riverside
Riverside, California 92521

2. NAME, OFFICIAL TITLE AND DEPARTMENT OF ALL PROFESSIONAL PERSONNEL ENGAGED ON PROJECT, BEGINNING WITH PRINCIPAL INVESTIGATOR:

Name and Title:	Department:
Principal Investigators:	
Anne Kernan, Professor	Physics
Benjamin C. Shen, Professor	Physics
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Faculty Associates:	
John G. Layter, Adjunct Professor	Physics
Gordon VanDalen, Assoc. Professor	Physics

3. TITLE OF PROJECT:

High Energy Physics

4. ABSTRACT OF PROPOSED RESEARCH: (Outline Objectives and Methods in 200 Words or Less)

This proposal is for the continuation of the High Energy Physics program at the University of California at Riverside.

In hadron collider physics we will complete our transition from experiment UA1 at CERN to the DZERO experiment at Fermilab. On experiment UA1 our effort will concentrate on data analysis at Riverside. At Fermilab we will coordinate the high voltage system for all detector elements. We will also carry out hardware/software development for the DØ muon detector.

The TPC/Two-Gamma experiment has completed its present phase of data-taking after accumulating 160 pb^{-1} of luminosity. The UC Riverside group will continue data and physics analysis and make minor hardware improvement for the high luminosity run. The UC Riverside group is participating in design and implementation of the data acquisition system for the OPAL experiment at LEP. Mechanical and electronics construction of the OPAL hadron calorimeter strip readout system is proceeding on schedule. Data analysis and Monte Carlo detector simulation efforts are proceeding in preparation for the first physics run when IEP operation comenses in fall 1989.

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I. Introduction

The experimental high energy physics group is working at the frontier of e^+e^- and $p\bar{p}$ colliders. Currently we are in transition from TPC/Two-Gamma at PEP to OPAL at LEP, and from UA1 at CERN to D-zero at Fermilab.

One notes the obvious complementarity of the two programs. While the intermediate vector bosons were discovered at the CERN $p\bar{p}$ collider the definitive exploration of their properties awaits SLC and LEP. And while the Fermilab collider experiments will be the first to explore the several hundred GeV mass range, LEP II in the mid-nineties will produce WW states in abundance and will have the best chance of observing the Higgs if its mass is less than 80 GeV.

Approximately two thirds of our group are stationed at accelerator sites. During 1988, the two graduate students on UA1 will complete their hardware work on the U/TMP calorimeter and the silicon vertex detector at CERN. At Fermilab, two research physicists and a graduate student will implement the high voltage system of DØ. D. Smith and a graduate student will be at Fermilab in connection with testing the DØ muon trigger electronics. At SLAC, four graduate students will participate in the data-taking of the TPC/Two-Gamma experiment during high luminosity PEP running. At OPAL, J. Layter, two research physicists, two graduate students and a technical associate will work on all aspects of the experiment from hadron calorimeter to physics analysis. G. VanDalen will be spending the 88-89 academic year on sabbatical leave at CERN to devote his full effort to OPAL.

The University has continued its strong support to the high energy physics group. A junior faculty position has been assigned to experimental particle physics in hadron collisions to be filled in the

88-89 academic year. In addition, the support of a junior level research associate has been made available for e^+e^- experiments. The high energy computing facility in the Department has been upgraded to a cluster with a microVAX3500 and several microVAXes with funds from the University. The Physics Department has acquired a core system of ACP for data analysis and Monte Carlo work.

The theoretical high energy physics program has had a very successful year since the appointment of Ernest Ma on the faculty. Of the 15 completed papers since September, 1987, 10 have already been published in refereed journals and the remainder have been submitted for publication. The University also provided Professor Ma with considerable amount of start-up funds in supporting a visiting assistant professor, several graduate students, computing and research travel.

The Riverside campus of the University of California has entered a period of rapid growth. Enrollment has increased at the rate of 14% per year during the past two years. With the newly established school of engineering accepting students in fall 1989, enrollment will grow at a higher rate. Along with this rapid growth the Physics Department expects to appoint several more faculty members in particle physics in the next three years.

II. PHYSICS

A. Experiments

(1) Hadron Collider Collider Physics

(a) Experimental UA1-Proton-Antiproton Interactions at 600 GeV

UC Riverside was one of the nine institutions which proposed the UA1 experiment in early 1978. The goal of the experiment was to find the W and Z bosons. These were discovered in 1983. In addition the UA1 experiment has verified in considerable detail a range of important predictions of the Standard Electroweak/QCD theory.

A total of five UCR students have completed their Ph. D. research on the UA1 detector. Currently three additional Ph. D. students are working on the UA1 experiment. With the completion of their thesis research UCR participation in the UA1 experiment will come to an end.

Graduate student M. Ikeda is testing QCD by a measurement of the rate for "gluon splitting" into a pair of charm-anticharm quarks. This work should be completed in 1989.

Graduate student D. Joyce has recently completed the construction and testing of a 5-element silicon strip telescope with CMOS MICROPLEX readout. This work, which was presented at the 1988 Proton-Antiproton Conference at Fermilab, is part of a feasibility study for a UA1 silicon vertex detector. A NIM publication is in preparation. D. Joyce will shortly begin physics analysis and expects to complete his Ph. D. thesis in 1989.

Finally graduate student M. Lindgren is working on the new Uranium-TMP calorimeter with special responsibility for measurements of the conductivity and other properties of the TMP liquid. He will begin physics analysis in 1989.

All hardware activities by the UCR group will terminate at the end of 1988.

(b) The DØ Experiment - Proton-Antiproton Interactions at 2 TeV

INTRODUCTION

We joined the DØ collaboration in November 1986. The hadron collider program at Fermilab forms a natural continuation of our work at the CERN $Sp\bar{p}S$ collider.

At Fermilab postgraduate researchers, S.J. Wimpenny , K.Roberts and M-J. Yang have designed and are testing a High Voltage system capable of running the full DØ detector. At UCR testing of the trigger electronics for the DØ muon system will be carried out by D. Smith and graduate students. Development of offline software for the muon system will also be carried out on campus.

PHYSICS AND DETECTOR

The DØ Experiment

DØ is a 4π hermetic detector designed for the Tevatron Collider at Fermilab. The evolution of the DØ design has benefitted from the experience with the UA1 and UA2 detectors at CERN. Since the CDF detector for the Tevatron Collider had already been designed at the inception of DØ particular attention was given to achieving a complementary set of strengths for the second detector.

The dominant areas for new physics at the Tevatron are by no means so clear as for the $Sp\bar{p}S$, where the W and Z searches provided the focus. A large variety of potentially new phenomena has been discussed for the design values of $\sqrt{s}$ = 2 TeV and L = 10^{30} cm^{-2} sec^{-1}. The plan to upgrade the

Tevatron luminosity to 5 x 10^{31} cm^{-2} sec^{-1} will further increase the physics reach of the experiments. The general themes of the Tevatron program include: (i) precision measurements of W and Z properties (mass differences, decay widths, production mechanisms, rare decays, decay asymmetries, study of trilinear boson couplings); (ii) tests of QCD at very large q^2 (jet topological cross sections, searches for parton compositeness, direct photon studies, searches for quark-gluon phase transitions, measurement of fragmentation functions); (iii) searches for new states which could direct the extension and evolution of the standard model (manifestations of supersymmetry - squarks, gluinos, winos, zinos, sleptons), technicolor particles, new quarks (top and beyond), heavy leptons, additional gauge bosons, or massive quasistable objects; (iv) measurement of the characteristics of the large cross-section, low p_T processes (multiplicity distributions, multiparton collisions, emergences of some new phenomena glimpsed in cosmic ray experiments); and (v) sensitivity to qualitatively new phenomena in the heretofore unexplored high energy, large q^2 domain.

These physics issues dictated the basic design choices for DØ:

i) No central magnetic field is provided. Since the relevant particles to be detected are jets (partons), leptons and non-interacting secondaries (neutrinos, photinos etc.) at large momentum, calorimetric measurement of energies are superior to momentum determination by track curvature. Moreover, a non-magnetic tracking system can be compressed, giving the opportunity for enhanced calorimetry and muon detection.

ii) Lepton identification is of fundamental importance in searching for most high mass states, due to the relative cleanliness of leptonic decay modes of W,Z and heavy quarks. Measurement of both electrons and muons over the fullest possible solid angle is highly desirable; electron and muon measurements have quite different systematics so confirmation of new effects in both channels is beneficial. Electron channels are superior for precision mass measurements, while muons offer the possibility of seeing a lepton within a jet.

iii) Measurement of the missing transverse energy in an event is crucial for many studies, and achievement of the best possible E_T resolution is a dominant goal. It is of particular importance to prevent unknown large fluctuations in measured event E_T, particularly far out in the tails of the distribution, in order to avoid having common event types simulate new physics. Good missing E_T resolution involves optimization of several features of the detector. Calorimeter coverage should cover the full solid angle with minimal cracks or hot spots. Holes for beam entrance and exit should be limited to $\theta < 1^o$ ($\eta \geq 5$). Good energy resolution helps control the rms width of the E_T distribution; of more importance here is the near equality of response to electrons and hadrons so that fluctuations in hadron shower composition are of minimal importance. Figure 1 is a schematic of the DØ detector. Table 1 gives the performance goals for the detector.

The commissioning of the DØ Detector is scheduled to commence in Fall of 1990, with the aim of having a first physics run in 1991 at which time the detector is expected to be fully operational. Prior to installation in the DØ experimental hall most of the elements of the detector will have been

tested and debugged in test beams at Fermilab. However, for some detectors such as the forward calorimeters and the main trigger framework only a partial pre-installation checkout is possible and these will have to be debugged in situ. If all goes well it is hoped to make a smooth transition from commissioning to data taking in the early part of 1991. In the longer term a new Small Angle MUon Spectrometer (SAMUS), is being developed by collaborators from Serpukhov. This will extend the forward arms of the muon system down to within ±4.25 degrees of the beam pipe and will be added to the detector in the shutdown following the 1990/91 run.

RIVERSIDE ACTIVITIES

High Voltage System -- Status and Plans

Since the beginning of 1987 two Riverside physicists have been based at Fermilab working on the development of the DØ detector with responsibility for coordinating the design of the high voltage power system to be used for the full DØ detector. This includes both hardware and control software designs.

In order to do the range of physics discussed in section 2 it is necessary to maintain a very tight control on the calibration and monitoring of all parts of the detector. An important requirement is that the high voltage system which powers the detector must be both flexible and capable of responding quickly to changes in detector. It must also be protected against damaging the detector in case of hardware failures such as broken wires inside tracking chambers or gas leaks. With all of these points in

mind we have designed and are in the process of testing an integrated high voltage system for DØ.

There are approximately 3650 different high voltage connections at the detector which are divided up between eight different types of detector. These range in complexity from simple photomultiplier tubes in the Level 0 Trigger Hodoscopes through large Uranium / Liquid Argon Calorimeters to the high resolution wire chambers which form the heart of the detector. This results in the requirement of a computer controlled high voltage power system which is capable of operating over a wide dynamic range in both output voltage (100V to 7 kV - negative and positive polarity) and current draw (20 nA to 1 mA) with a monitoring sensitivity of better than 1%. Other considerations are that the system be as compact as possible and have a response time of around 100 μseconds per channel .

The DØ system as currently designed is a VMEbus based system consisting of 3 unit wide standard size modules (6U x 160 mm) each of which contains eight discrete high voltage power supplies (Fig A1.1). Six of these modules are housed in a VME crate together with a vertical interconnect module (which allows the extension of the data bus beyond a single crate) and a 68000 microprocessor which controls the modules. Voltage and trip settings can be downloaded to the 68000's in the same manner as for the other control parameters in DØ [1] via a vertical interconnect from a VME control crate. Local power supply monitoring can be done using an IBM PC which is connected directly into the controls crate. Under normal running conditions however this task will be performed remotely on one of the DØ

MicroVAXes via a Token Ring connection to the same crate. This is shown schematically in Figs. A1.2 and A1.3.

The power supplies are a new 'in house' Fermilab design built to DØ specifications. A first prototype was tested in April of this year and found to satisfy most of the DØ requirements. Subsequently some small design changes were made to improve stability and reduce noise in the monitoring circuitry; we hope to have a second prototype ready for testing in late August. If this proves to be acceptable then these supplies will manufactured by a commercial vendor starting early in 1989.

In parallel with the power supply development we have been working on the design and implementation of the software required for the control systems. Starting at the lowest level the microcode design for the 68000's is now complete and coding is in progress. The IBM PC software design is well under way and the first part - the implementation of an interactive color graphics display - is nearly finished. The communication protocol between the PC and/or the remote MicroVAX system is nearly finalised and once completed will allow us to code the remainder of the PC program. The MicroVAX program is a longer term project and although a lot of design work has been done coding will not start until the Fall. We currently anticipate being able to produce a first test version of the PC control software by October 1989 and that development work will continue into 1989. For the MicroVAX system the corresponding timescale is for a first version in early 1989 with continued development extending up until the end of the year.

Returning to the hardware once more, in addition to the power supplies we have designed a distribution system employing an average fan-out factor

of four between the supplies and the detector. This reduces the number of power supplies needed to around 800 thus substantially reducing the overall system cost. The cables and connectors needed have been selected and ordered. Prototype fanout modules in a variety of different configurations have been designed and are being built at Fermilab. These will be available for testing within a few months.

In the coming months we forsee that the UCR group will continue to oversee the production, installation and testing the high voltage system hardware and software. By 1989 most of this effort will be directed towards installation planning and the completion of the control software. Our current timescale requires the completed high voltage system to be in place in the DØ experimental hall by the spring of 1990 and to have a partial system available for test beam usage by June 1989.

Muon Detector Work

The DØ experiment is distinguished by a very powerful muon detector. It will be extremely important for W,Z and heavy quark physics. We expect to have a major involvement in bringing up the muon system. In 1989 we will be testing the trigger electronics for the muon detector. We will also begin the design and implementation of off-line reconstruction software for the muon system.

Muon Detector Electronics

The DØ muon detector is under construction at FNAL. It consists of tracking chambers before and after a toroidal magnetic field with $\int B \cdot dl$ of 2 Tesla-meters. The three planar chambers are made of three layers of staggered proportional drift tubes, except for the innermost chamber which contains four layers. The tracking chambers provide trigger as well as track information. The expected muon momentum resolution, $\delta p/p$, is 18%.

Construction and assembly of all the modules should be completed by summer 1989. Currently the muon group is developing readout electronics and testing them with cosmic rays. One of the critical pieces is a VME-based, triple-height (9U) card called the Module Address Card (MAC). The MAC is being prototyped at Fermilab. Once the prototype is complete, a production run of 200 MAC's on high density circuit boards will begin.

At UCR we are setting up a VME test station to test the Module Address Cards as they come off the assembly line. By simulating different patterns of proportional drift tube (PDT) hits from the muon chamber, we will verify the operational quality of the MAC boards. The test station includes an AST286 microcomputer which acts as a master to a VME crate containing the MAC boards plus other muon-related electronics. Communication between the AST286 and the VME crate is performed by a BIT-3 interface card. Test programs for the MAC's are being written in Turbo Pascal.

The production of the MAC boards will begin in November 1988. We expect to run the VME test station for about one year, matching the production of MAC's.

Muon Detector Software

The DØ software is maintained on the BNL VAX cluster using the CMS (Code Management System) program. The program library (DØLIBRARY) is frequently updated, using HEPnet, to all collaboration sites. This permits all DØ institutions to have access to the same software. At UCR, the DØLIBRARY is maintained on our physics department MicroVAX cluster [sec. III].

The DØ detector software is built around GEANT, a software package developed and supported by the DD Division at CERN. Each detector group is responsible for maintaining software for their respective detectors; for the tracking chambers, this includes track-finding and track-fitting programs. In the last year, we wrote track-fitting software as part of a feasibility study for a silicon vertex detector. This code is now maintained in the DØLIBRARY at Brookhaven.

We are continuing our work in reconstruction software by writing track-finding and track-fitting routines for the muon chambers. During the next year, as discussed in detail below, we plan to (i) incorporate a precise toroidal magnetic field for the muon detector, (ii) develop a track-fitting routine for the muon detector, and (iii) develop software for matching tracks between detector elements.

The following tasks lie ahead:

(i) The current analysis program assumes a constant magnetic field in the toroids. A more precise field calculation needs to be implemented to reproduce the inhomogeneities in the iron absorber.

(ii) The existing software uses a simple track fitting algorithm; the muon chambers are positioned on both sides of the magnetized absorber and reconstructed tracks from both sides are extrapolated, using a straight line, to a point in the middle of the absorber. This procedure also assumes a homogenous magnetic field, as described above. We plan to replace the naive track fitting procedure with one that takes into account the continuous curvature of muons through the iron absorber. We will use the Evans & Sutherland PS 390 graphics workstation [sec. III] to aid us in the fine tuning of the track-fitting algorithm. The improved reconstruction software will be added to the DØLIBRARY.

(iii) Next we will develop the software needed to track the muons through the drift chambers to the vertex of origin.

Monte Carlo Studies of Beauty Physics

Our interest in heavy quark physics at the hadron collider was evident by the large UCR contribution to the Beauty Physics Workshop at Fermilab last November. The principal line of study was to use dimuon events and to use kinematic correlations of the two tracks to separate the underlying beauty quark production mechanisms.

For this study ISAJET was used to generate $b\bar{b}$ quark pairs at center-of-mass energy of 2 TeV. Following fragmentation into a beauty meson pair, a muonic decay was forced for both tracks and they were then fed through a simulation of the DØ muon trigger. At the quark level, two distinct

mechanisms can be identified: *flavor creation*, an order α_s^2 process in which the $b\bar{b}$ pair results from either quark or gluon annihilation and *gluon splitting* which is an order α_s^3 process in which the $b\bar{b}$ pair comes direction from gluon splitting. At the quark level the two mechanisms give rise to two completely different geometrical signatures.

In principal, the observed correlations between the decay muons should reflect the quark level mechanisms and signatures, however, the differences are diluted to some extent by the effects of fragmentation, hadronization and the muonic decay of the beauty mesons. Our experience on UA1 has shown that these problems can be sorted out and that high p_T muons represent a relatively clean signature for the presence of heavy flavors.

If we assume a first run of DØ collecting an integrated luminosity of 1 pb^{-1}, we would expect approximately 1000 dimuon events from $b\bar{b}$ jets with $p_T >$ 40 GeV/c. With reasonable statistics it would be possible to use the muonic decay tagging and dimuon correlations to study different QCD production mechanisms described above. In the coming months we will refine our results by including a better version of GEANT with upgrades to the muon software.

Fabrication Costs -- DØ Hardware

The budget contains several equipment items:

(i) $14,000 to complete the installation of the muon electronics test station.

(ii) $7,150 for items needed for the DØ High Voltage system

(iii) $27,800 to provide a hard disc for DØ data storage and miscellaneous terminals and software to enhance our efficiency.

(iv) $16,500 to continue the development of the ACP farm donated by the University.

Personnel

The UCR physicists participating in DØ include Anne Kernan, Darrel Smith, Steve Wimpenny, and Ming-Jen Yang. Two graduate students are working on various aspects of the experiment; they are Kamel Bazizi and Raymond Hall.

References

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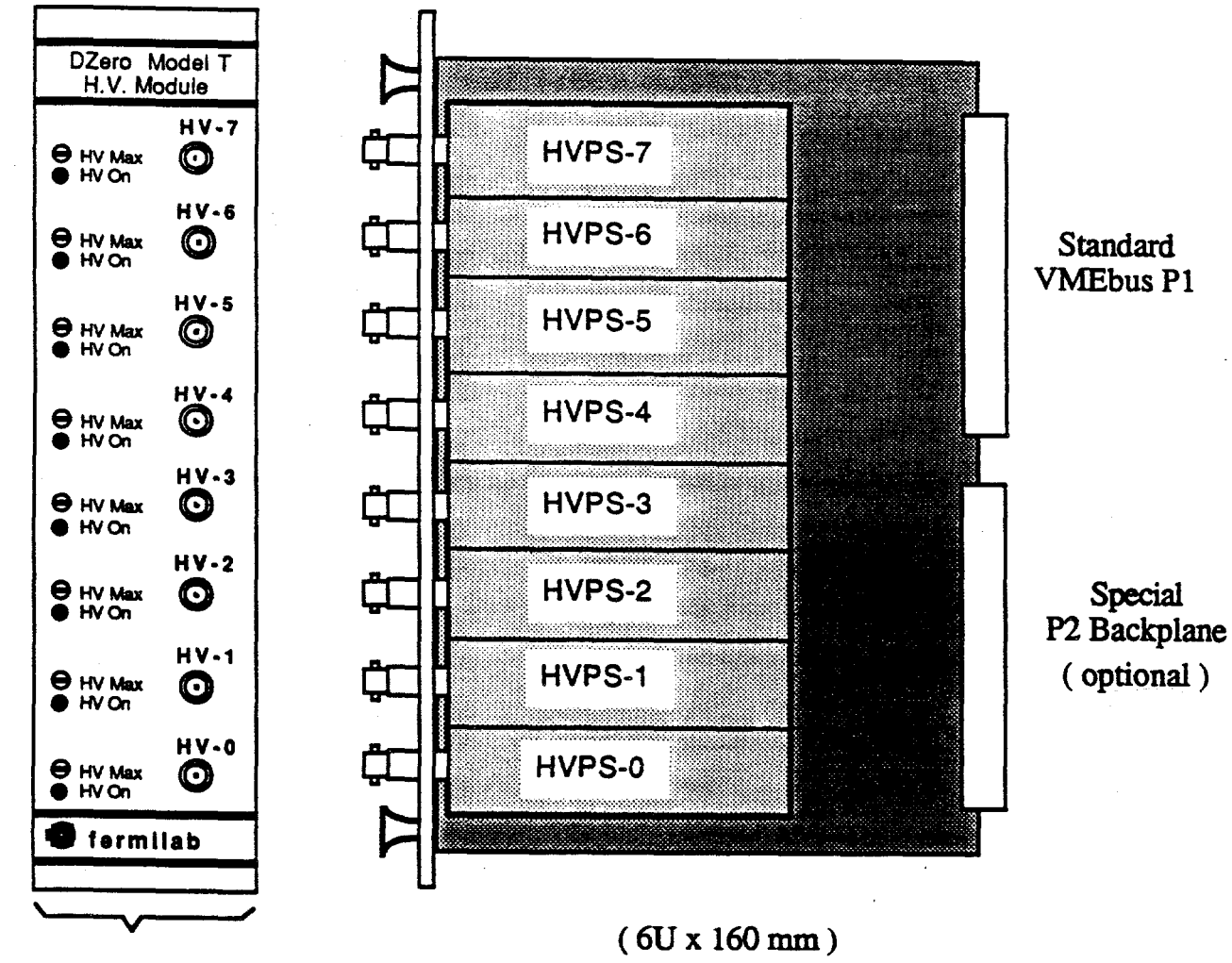


Fig. A1.1 VME-based High Voltage System

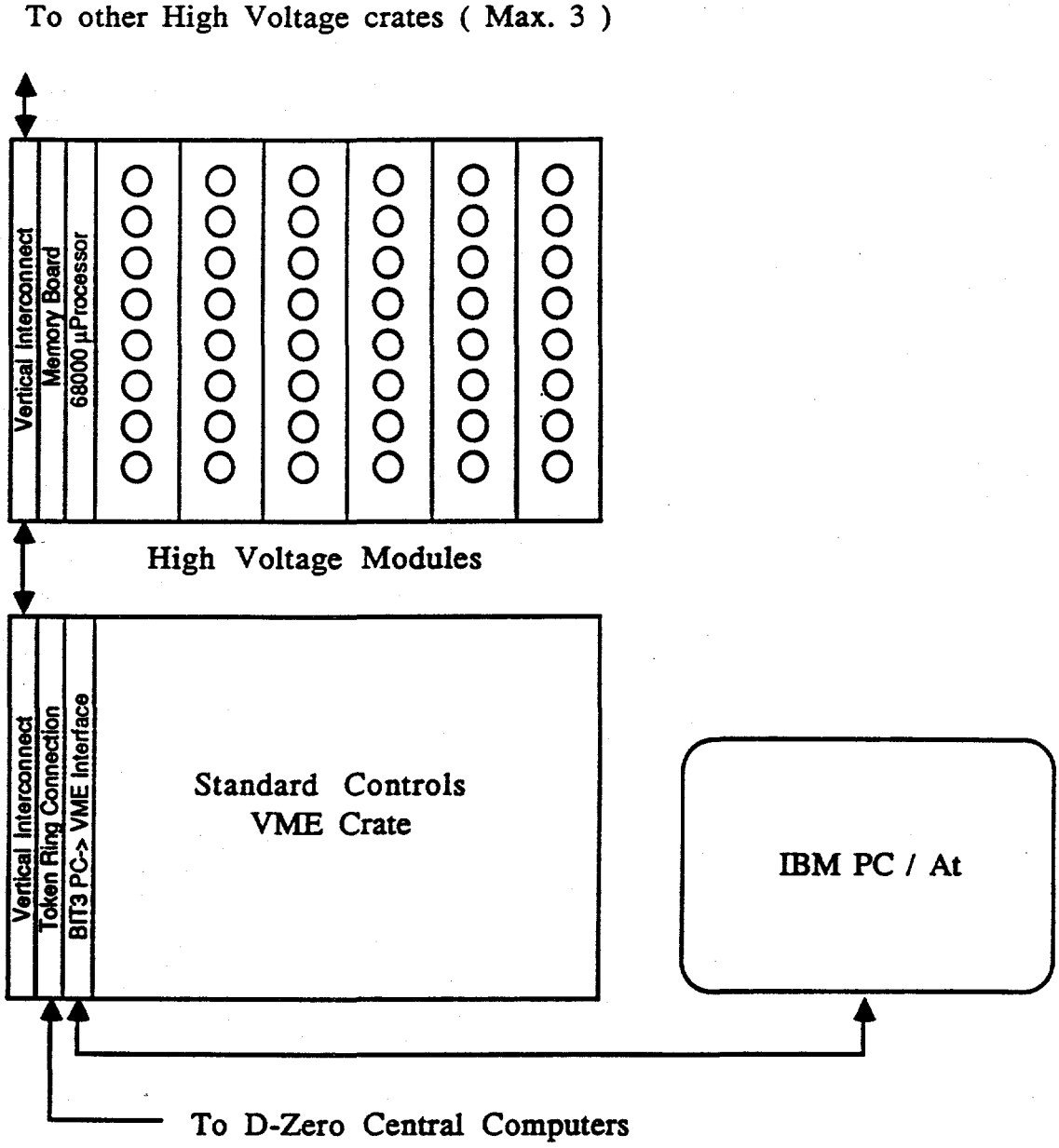
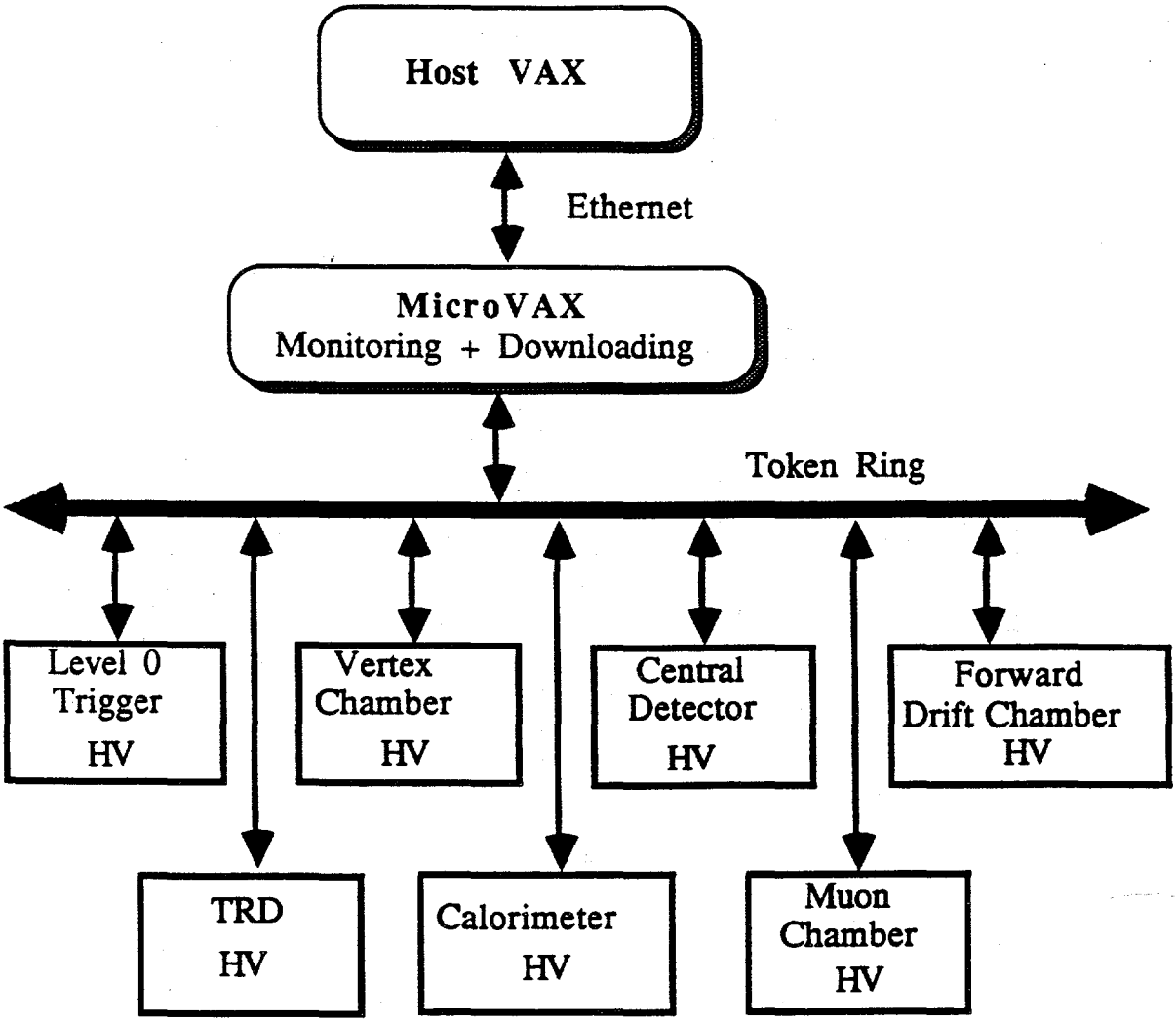


Fig. A1.2 High Voltage Control Crate



High Voltage Dataway Connections to the Central Host VAX

Fig. A1.3 High Voltage Dataway

(c) Nucleon Structure Functions

The prediction of hard scattering cross-sections for the current and future generation of colliding beam machines relies heavily on the use of perturbative QCD calculations. In the absence of sufficiently advance lattice calculations these in turn rely on the input of the parameterizations of the shape of the quark ($q(x,Q^2)$ and gluon ($g(x,Q^2)$) distribution functions at some fixed value of Q^2. QCD can then evolve these distributions to the hard scattering (Q^2) scale relevant to the process being studied.

The parton distributions cannot be measured directly in an experiment and must be derived from the measurements of the deep inelastic structure functions $F_1(x,Q^2)$, $F_2(x,Q^2)$ and $F_3(x,Q^2)$. Over the last 20 years fixed target electron, muon and neutrino scattering experiments at SLAC, CERN and Fermilab have performed detailed measurements of these quantities for a typical scale of $Q^2 \sim 10\text{-}20$ GeV/c^2. The data are in fairly good agreement over most of the kinematic range studied with the exception of the small x region ($x \leq 0.2$) where there are discrepancies at the level of 10-15% [1,2]. This is somewhat unfortunate as this is the kinematic region most relevant for the collider calculations and this uncertainty becomes the limiting uncertainty for many physics studies. A good example is the collider limit on the number of neutrino species, N_ν, where the conclusions vary substantially depending upon which parton distributions are used [3,4].

The largest discrepancy in the data is in the $F_2(x,Q^2)$ results from the EMC [5] and the BCDMS [6] collaboration muon experiments at CERN which differ at small values of x by around 10-15%. In the absence of a running experiment which can resolve this difference we propose to try to re-examine

the data and look to see if the differences can be understood in terms of differences in either physics corrections or apparatus effects. One of us (S.J. Wimpenny) was heavily involved in the original EMC analyses and has a good understanding of the processes and difficulties involved. A preliminary look [7] suggests that the problems may well lie in the treatment of some of the physics corrections which were applied to the data. However much work remains to be done before any conclusions can be drawn.

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(2) e^+e^- Collider Physics

The high energy physics group at UCR has pursued a systematic experimental program studying e^+e^- interactions since the mid-seventies. As an original member institution in the TPC collaboration, we participated in the building of the time projection chamber facility at PEP. The analysis of the data taken in the early-eighties has yielded a wealth of information which contributed significantly to the understanding of the Standard Model. In continuing our study of e^+e^- interactions at higher energies, we began participation as a member of the OPAL collaboration at LEP in 1984. We are taking part in the building of a multifaceted detector for detailed studies of physics at the Z^0 when LEP begins operation in the fall of 1989.

(a) TPC/Two-Gamma Experiment at PEP

The TPC/Two-Gamma Collaboration, comprising 12 institutions, has been engaged in systematic studies of e^+e^- interactions at 29 GeV at PEP. The detector facility consists of the PEP-4 TPC as the central detector and the PEP-9 Two-Gamma spectrometer at forward angles. As a result, it has a large solid angle coverage and the most complete particle detection capabilities among the operating detectors at e^+e^- colliders.

During the first phase of operation up to 1986, we have collected a total of 160 pb^{-1} of data. The detector has been upgraded with a vertex chamber and other improvements for the second phase of operation. Data-taking for high luminosity PEP running is scheduled to begin in September, 1988.

Three graduate students have already received Ph.D's with physics analysis of data taken during the first phase of operation. Four

additional students are currently associated with this experiment. Willis Lin and Mourad Daoudi have been analyzing existing data and are expected to receive their Ph.D's within the next year. Chili Ho and Heungmin Oh are participating in the high luminosity running and will be analyzing the new data.

Progress to Date

Much of the hardware and software work has been carried out by our graduate students. Improvements to the outer drift chamber system has been completed by Willis Lin. Chamber performance has been checked out with data from a recent cosmic ray run. The operation, monitoring and maintenance during the forthcoming high luminosity running will be the responsibility of Heungmin Oh. Chili Ho has participated in the installation and testing of the new vertex chamber. His initial analysis of the cosmic ray data yielded a spatial resolution approaching 50 microns. Mourad Daoudi has made considerable progress in the new trigger Monte Carlo detector simulation integrating the TPC and Two-Gamma trigger elements. Willy Langeveld has provided the day-to-day on-site supervision and guidance for these students.

Willis Lin has been studying particle fractions of hadronic events in photon photon interactions. In the point-like regime, hadron production in photon photon interactions proceeds via the production of a pair of quark and anti-quark. With the exchange of a quark, the cross section of the process is proportional to the 4th power of the charge of the quark exchanged or produced. This is in contrast to the annihilation process where the cross section is proportional to the 2nd power of the charge of the quark produced. This difference will be reflected in the particle

fractions of the one photon and the two photon processes. Of particular interests are the suppression of $s\bar{s}$ production and the threshold of $c\bar{c}$ production. Preliminary results had been reported by Lin at the April APS meeting in Baltimore, and by Layter at the International Workshop on Photon Photon Collisions in Israel in May 1988.

Mourad Daoudi has studied the six particle final state of the two photon event sample from the existing data. A summary of the analysis is being prepared. He has chosen to concentrate on the study of the K^0K^0 reaction for his thesis research. From this analysis, he will be able to determine the radiative decay width of f'(1515) and to search for scalar mesons near threshold. The only results in this area were reported by TASSO from an analysis performed on a smaller data sample several years ago. Considerable progress has been made by Daoudi in selecting a clean sample of K^0K^0 events. Detailed analysis is in progress.

Program for the Coming Year

The first high luminosity running is scheduled to begin on September 6, 1988. The goal of the first running period is twofold: to achieve a procedure for compatible running of PEP and SLC with minimum interference and to collect a sizeable data sample for physics analysis. The ultimate goal is to accumulate a integrated luminosity of 1 fb^{-1} after one year's running. To achieve this goal, several different technical improvements must be accomplished. Members of the UCR team will be participating in this effort.

We will continue the analysis efforts in the trigger Monte Carlo and in the calibration of the vertex chamber. Willis Lin will carry out detailed Monte Carlo acceptance calculations which are essential for the

study of the production of $s\bar{s}$ and $c\bar{c}$ in two photon reactions. Mourad Daoudi will analyze the K^0K^0 reaction and determine the radiative width of f'(1515). They are expected to finish their analyses and complete their Ph.D requirements during 1989.

Heungmin Oh has already begun analyzing the $KK\pi\pi$ final state in the existing data to study the production of K^*K^*. He will continue this analysis on data sample from the new run. Chili Ho is interested in making a precision measurement of the lifetime of the tau lepton. The present world average is three standard deviations longer than that predicted by the Standard Model. If this should be confirmed in a single high statistics precision measurement, it would be evidence for physics beyond the Standard Model.

Personnel

The physicists who will continue to participate in this experiment include John Layter, Benjamin Shen and Gordon VanDalen. Since there are no more hardware commitments, our efforts will be mainly in working with graduate students on the physics analysis projects mentioned above. The two students, Willis Lin and Mourad Daoudi, are analyzing existing data and are approaching the completion of their Ph.D requirements. Heungmin Oh and Chili Ho will carry out their analysis work on the new data from high luminosity running. UCR's participation in the TPC/Two-Gamma experiment will continue until all students have completed their thesis work.

(b) OPAL Experiment at LEP

The OPAL Collaboration, comprising 22 institutions from 9 countries and currently counting 157 physicists, is constructing the Omni-Purpose Apparatus for LEP, a multifaceted detector whose goal is the optimal reconstruction of events at LEP I and LEP II, the initial and ultimate high-energy phases of e^+e^- collider. OPAL proposes to achieve this goal by stressing high-resolution momentum and energy measurements, together with good particle identification, over a large solid angle. all elements of the detector involve proven technologies, so that OPAL should be fully functional from the beginning of LEP data-taking in the fall of 1989.

OPAL Detector

The principal components of the OPAL detector (Fig. A2.1), together with performance figures achieved either with prototypes or segments of the actual detector, are as follows:

The Central Detector is a drift chamber of the configuration known as a jet chamber, successfully employed by the JADE Collaboration at DESY, many of whose members are now in OPAL and are responsible for its construction and utilization. Two sectors of the eventual 24 sectors have been tested with cosmic rays and yield a position resolution of close to 100 microns over most of the drift length. This is equivalent to a momentum resolution of 0.002p. Charge identification should be possible down to 20 degrees. The central detector will operate in an Ar-CH_4-C_4H_{10} environment at a pressure of 3.5 atmospheres and will give a dE/dx resolution of 3.0% for tracks crossing all 159 wires in a given sector.

The Vertex Detector is a miniaturized version of the jet chamber which incorporates several layers of stereo wires in addition to its

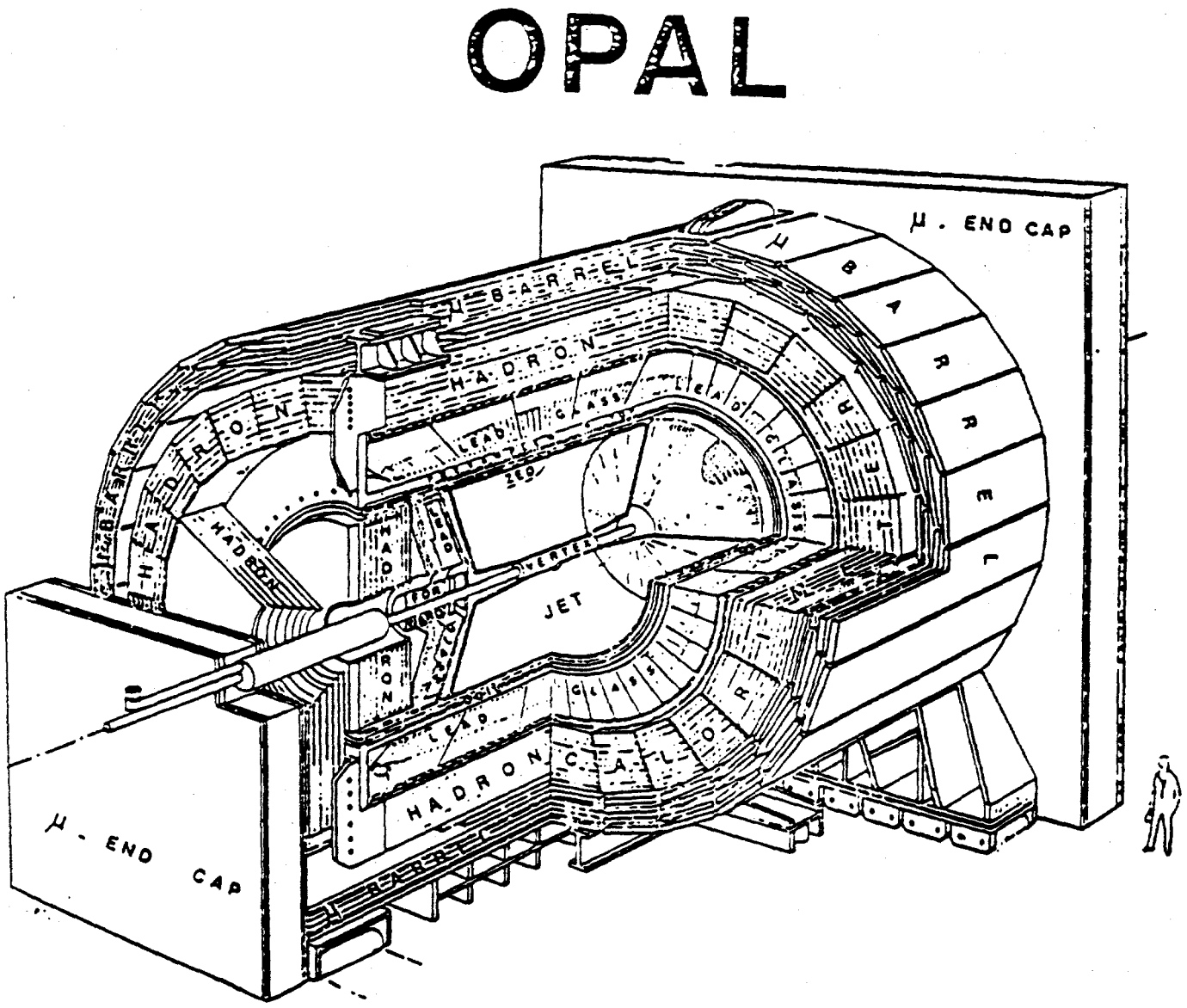

Fig. A2.1 The OPAL Detector

axially oriented wires to give 500 micron resolution along the beam direction. The vertex detector has achieved ap position resolution in the bending plane of 30 microns using slow gas (CO_2-C_4H_{10}). This implies an error of 20 microns or less in the event-by-event determination of the vertex position.

Electromagnetic Calorimetry in OPAL is done with lead glass blocks. In the barrel region, the geometry is pointing, while in the endcaps all blocks are axially oriented. The endcap blocks are read out with facuum phototriodes which retain their gain in magnetic fields up to 1 tesla. The barrel blocks are outside the field and are viewed with conventional PM tubes. When used in conjunction with presamplers to correct for showering in material preceding the blocks, both barrel and endcaps have achieved a resolution of $6\%/\sqrt{E}$ and a position resolution of 15 mrad. Both parts of the detector have been calibrated repeatedly in test beams and show good long term stability and excellent correlation with LED calibration systems.

The Hadron Calorimeter of OPAL incorporates limited streamer (Iarocci) tubes interspersed throughout an iron absorber (Fig. A2.2). The absorber is also the magnetic flux return, and field uniformity considerations have enforced a non-optimal sampling interval which leads to an energy resolution of $120\%/\sqrt{E}$. The addition of the strip readout, carried out by the UCR group, makes the calorimeter a powerful tool for muon identification, both by itself and in conjunction with specialized muon chambers at the outer extremities of the detector.

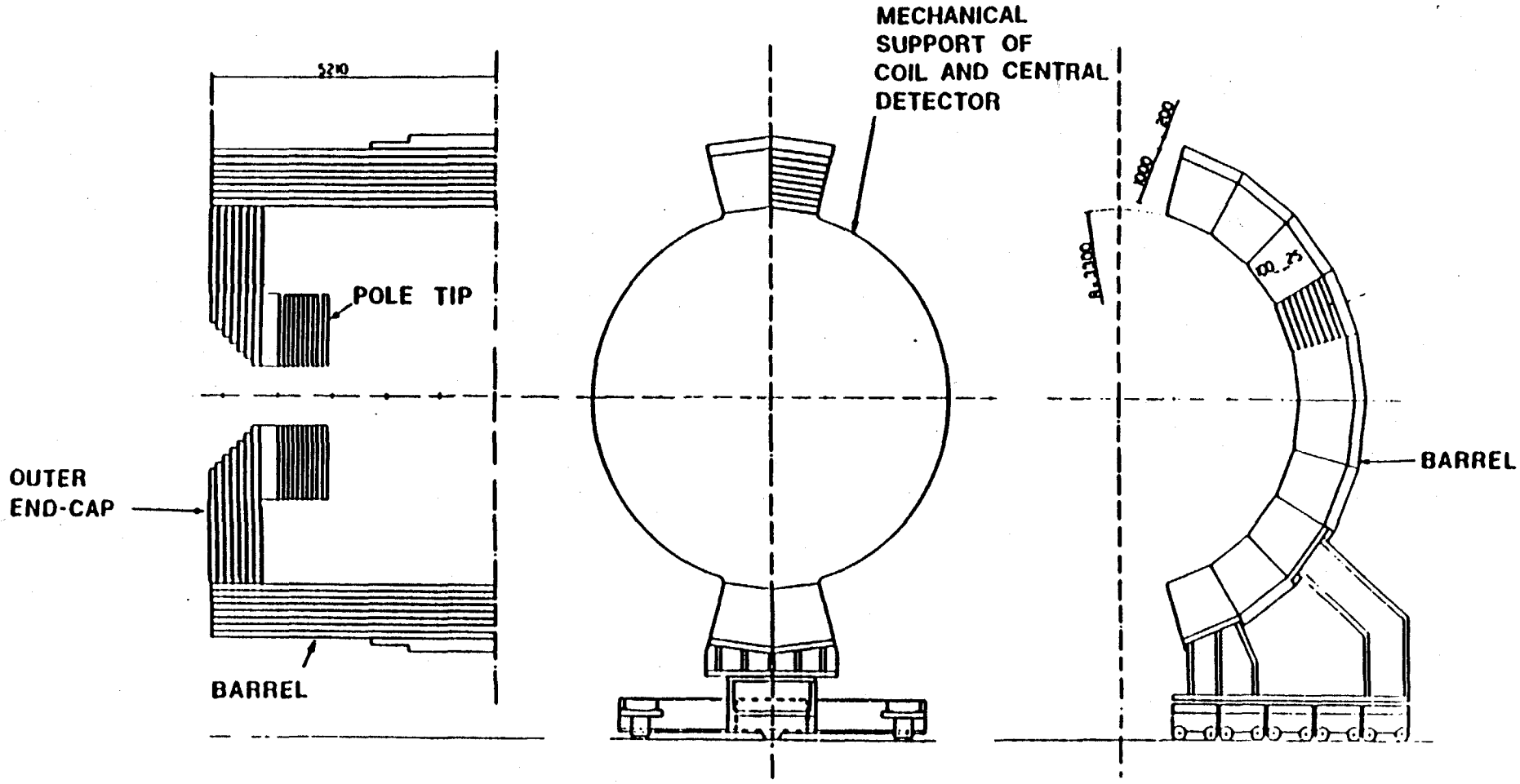

Fig. A2.2 Side and end views of OPAL Hadron Calorimeter

Progress to Date

Most of the detector elements described above are either completed or in final phases of construction. This section will discuss in detail the progress on the aspects of the detector for which the UCR group has primary responsibility.

During the past two years, the UCR group, assisted by two visitors from the Harbin Institutes of Technology in China, have completed the production of all the strip material needed for the barrel and endcap portions of the calorimeter, and in conjunction with teams from Bologna and Maryland have installed all the streamer tubes, equipped with strips and pad towers, in the 24 iron wedges that make up the calorimeter. In addition, strip material prepared by a team working at UCR has been incorporated in "cans" or subassemblies, nearly all of which are now installed in the endcap iron.

The modular electronics scheme involving "mother" and "daughter" boards designed by William Gorn of UCR has been described in detail in last year's report. Activity during this past year has centered on their completion, testing, and installation. Four hundred thirty (430) mother boards and nearly 8000 daughter boards have been fabricated, and nearly all of these boards have been thoroughly tested by the UCR team. A low voltage power supply system has been assembled, and auxiliary boards for distributing power, threshold levels and test pulse signals have also been completed and tested. All 24 wedges have been checked for HV stability, and the 14 wedges with readout electronics installed have been checked for signal continuity using the test pulse system.

In addition, several of the wedges have been studied with cosmic rays before their installation. The objectives of these tests were to confirm

the correctness of the cabling and readout ordering, to examine the uniformity of the wedges, and to confirm the choice of threshold settings. The test results showed that the readout ordering is well understood, that the wedges are quite uniform, and that an operating point exists at which the chambers produce clean tracks with an efficiency that approaches the geometrical efficiency of the streamer tubes.

A prototype readout control unit was built at the end of the year which operated in the environment of the PILS online data acquisition system. This prototype unit was used for the wedge tests described above. In the meantime, the data acquisition group have decided that the OS9 system is superior to PILS and have adopted it throughout the data acquisition chain. This step has necessitated a significant redesign of the readout control unit to make it respond to OS9 protocols, and this work is still in progress.

In addition to hardware responsibilities, members of the UCR group have undertaken the simulation of the OPAL trigger. By representing the functions of all the trigger elements in a Monte Carlo program, one can evaluate the strengths and weaknesses of the trigger in responding to classes of events that are of physics interest and in rejecting those which can be considered uninteresting. The trigger simulation is essential for a proper understanding of detector efficiency, and it is expected that the elaboration and refinement of this program will be a continuing activity of the UCR group.

Trigger simulation studies lead to a related question, that of event filtering. Events will be partially or completely reconstructed in the microcomputers and emulators operating in the data acquisition chain. The additional information provided by the reconstruction, including such

items as multiplicity, energy deposition, vertex location, etc., make possible a more stringent event selection and classification, leading eventually to more stringent event selection and classification, leading eventually to channeling of chosen events to "express lines" for expedited processing. Initially the filter program will simply try to verify the hardware trigger. UCR personnel are involved in the design of the filter program.

A critical analysis of selection criteria for hadronic events used by other e^+e^- experiments has been undertaken by UCR group members as the first step in defining such a strategy to be used by the OPAL experiment on the first data that will become available in the fall of 1989. This work forms part of the UCR contribution to the OPAL Physics Workshop discussed below.

Program for the Coming Year

The coming year will see the completion of the hardware construction the installation of OPAL detector and the initial phase of data-taking. The main focus of UCR activity will thus turn to software and physics analysis.

Remaining items of hardware installation are the mounting of readout electronics for 10 of the 24 wedges and for all the endcaps. This work has necessarily been postponed until the entire calorimeter is assembled in the experimental area I6, since the space for mounting the pieces exists only when everything is assembled. This work should be done before the end of the summer if there are no major difficulties in getting access to the equipment in the crowded I6 environment. Finishing the revisions

of the readout control box for the OS9 system is the other major hardware project remaining to be done.

The online program is the point of contact between the front end data gathering electronics and the high level event builders, filters, and processors. The program must carry out essential functions such as data formatting and buffering, assembling of histograms for performance monitoring, processing overall run control signals, updating database information, and communicating status and error conditions to the central control programs. Additionally it may be possible to execute simple clustering algorithms and flag possible muon candidates before sending the data on to the high level elements. Much of this work will involve building on basic skeleton programs provided by the OPAL online data acquisition group, and although much work remains to be done, no serious problems are foreseen in this area.

A beam test of a calorimeter wedge mockup is scheduled for this coming fall. The mockup will be quite similar to the prototype calorimeter tested three years ago, but the electronics will be the final versions for both the strips and pads. The main aim of the test is to understand the angular dependence of the pad response and to determine an initial calibration for both strips and pads. The test will furthermore provide an opportunity to exercise many of the online data taking programs in a beam environment.

UCR has acceded to requested from the OPAL Collaboration to provide system management expertise in the running of the principal data acquisition computer, the VAX 8700, provided earlier to the experiment by UCR. Gordon VanDalen, who will spend a sabbatical year at CERN, will devote some fraction of his time to this task. Work will also continue on

trigger simulation and filtering tasks as discussed above. Further effort is also required in the program for reconstruction of OPAL events, known as ROPE, particularly in the area of the use of the strips in clustering and muon identification.

The Collaboration has organized a Physics Workshop, to take place at the time of the December round of OPAL meetings, with the intention of arriving at analysis strategies in the following areas: Z^0 mass and width, new particles (t, SUSY, Higgs, etc.), measurement of Standard Model coupling constants, QCD tests and fragmentation. Among the goals of the Workshop will be the assessment of the readiness of the software tools available for the effort, and the setting of priorities for remedying perceived insufficiencies. Michael Dittmar of UCR is one of the two organizers of the Workshop.

The UCR group members are focussing their efforts in three main area of physics analysis. The determination of the Z^0 mass and width using the hadronic part of the cross section will be one of the highest priority items for all groups, and a clear understanding of backgrounds, cuts, and efficiencies is essential to be able to make use of the first available data. Generation counting by looking at radiative decays of the Z^0 to two neutrinos is an idea put forward over ten years ago by Ernest Ma, who has recently joined the UCR Theory Group. Accordingly, UCR physicists have begun working on this topic, examining in particular the effects of higher order corrections to the observable signal. The muon identification capabilities of the hadron calorimeter can be used in a search for supersymmetric particles, in particular smuon paris which will decay to muons plus missing momentum.

Personnel

The physicists participating in OPAL include Michael Dittmar, William Gorn, John Layter, Benjamin Shen and Gordon VanDalen. Three graduate students have begun working on various aspects of the experiment. They are William Larson, Brendan O'Neill and Edward Heflin. In addition, we have a visiting technical associate from Harbin Institute of Technology.

B. Theory

(a) Introduction

The High-Energy Physics Theory Program at U.C. Riverside has had a very successful year. In the Fall of 1987, E. Ma joined the Riverside Physics Department and was fortunate to be awarded funding from the U.S. Department of Energy beginning on February 15, 1988. The University of California, Riverside also recognizes the importance of this research effort and as part of Ma's initial complement, is funding a Visiting Assistant Professor (S. Rajpoot) until June 1989. In addition, the University is also providing support for 2 graduate students per year as research assistants until June 1990. At present, there are 3 graduate students at Riverside doing research in theoretical high-energy physics (2 under E. Ma, and 1 under B.R. Desai). There is also some funding for travel and equipment until June 1989. Meanwhile, DOE funding in the present contract year is used to support a postgraduate researcher (J. Pantaleone) beginning September 1988, and a graduate student beginning July 1988. Since the University's explicit contribution to this research program will be ending soon (although the implicit contributions such as support staff, computer time, faculty research time during the academic year, sabbatical leaves, office space and facilities, etc., are still very sizeable), DOE is being asked to increase its present level of funding to this task in order to maintain its viability, quality, and vitality.

The Riverside High Energy Physics Theory Group has been very productive in the last year. There have been 15 completed papers since September 1987 (see Sec. 3: Publications), 3 of which have already appeared in Phys. Rev. Lett., 2 in Phys. Rev. D, 1 to be published in Phys. Lett. B, 3 in Mod. Phys. Lett. A, 1 in the proceedings of a

conference, and the others are under consideration for publication in various refereed journals. This extraordinary degree of activity is due in no small measure to S. Rajpoot who came to Riverside in January 1988 (from Oklahoma State Univ.) as Visiting Assistant Professor funded by the University until June 1989, as mentioned earlier. In the budget request for this task (see Sec. 6), it is proposed that Rajpoot continue his association with Riverside, after his present University appointment, as Assistant Research Physicist supported by the contract.

In Sec. 2, the research activities of the Riverside High Energy Physics Theory Group since September 1987, as well as some research plans for the immediate future, are discussed. In Sec. 3, there is a list of completed papers since September 1987. In Sec. 4, the travel activities of various members of the group are described and visitors who gave talks or came to collaborate on research are noted. In Sec. 5, there is a list of personnel and a statement concerning their needs. In Sec. 6, the budget is given. In Sec. 7, the vitae of S. Rajpoot and J. Pantaleone are submitted.

(b) Research Program

Since September 1987, E. Ma has completed 7 papers for publication. They are described as follows.

UCRHEP-T1: "D^o - $\bar{D}^o$ Mixing in the New Left-Right Model," Mod. Phys. Lett. A3, 319 (1988). In the newly proposed supersymmetric left-right model with E_6 particle content (E. Ma, Phys. Rev. D36, 274 (1987); K.S. Babu, X.-G. He, and E. Ma, Phys. Rev. D36, 878 (1987)), D^o - $\bar{D}^o$ mixing can occur through W_R couplings of the c and u quarks to the exotic h quarks. It is found that for a wide range of reasonable values of the parameters,

this mixing is well above that predicted by the standard model and close to the present experimental upper limit.

UCRHEP-T2: "Gauge Model of Generation Nonuniversality Revisited," Phys. Rev. Lett. 60, 495 (1988). In 1981, Li and Ma proposed a gauge model where generations transform under different SU(2) gauge groups (Phys. Rev. Lett. 47, 1788 (1981)) and made a number of experimentally verifiable predictions. Two of them appear now to have experimental support: (1) The τ-lepton lifetime is longer than predicted by the standard model, and (2) B^o - $\bar{B}^o$ mixing is greater than predicted by the standard model. An updated and improved analysis of the model is given in this paper with Li and Tuan. In particular, a plausible branching fraction of the order 10^{-4} is predicted for $b \to s\ell^+\ell^-$, just below the present experimental limit and well above the standard-model expectation of 10^{-6}.

UCRHEP-T3: "Exotic Baryon-Number Nonconservation: Another E_6 Superstring Variation," Phys. Rev. Lett. 60, 1363 (1988). Using a single, simple Z_2 discrete symmetry to classify all supersymmetric SU(3) x SU(2) x U(1) x U(1)' gauge models based on E_6 particle content as the possible low-energy limit of superstring theory, all models previously proposed are found. In addition, a new model is discovered which conserves lepton number but not baryon number. The proton is stable because no physical final state having zero lepton number is available for this decay. However, neutron-antineutron oscillations are possible and the experimental limit of about 3 years on this lifetime serves to constrain some of the parameters of this model. Neutrinos are massless and left-handed as in the standard model or one is massless and left-handed while the other

two are massive Dirac particles. Neutral fermions exist which can decay into qqq and $\overline{qqq}$.

UCRHEP-T4: "Gauge and Higgs Bosons in a Model of Generation Nonuniversality," Phys. Rev. D38, 304 (1988). This work was done in collaboration with graduate student D. Ng. It is a follow-up of UCRHEP-T2. Many details of the gauge and Higgs bosons of that model are given in this paper. In particular, an approximate global SU(2) symmetry is identified and a likely scenario is presented in which two triplets and two singlets of Higgs bosons have masses significantly below 100 GeV and should be accessible to experimental discovery in the near future.

UCRHEP-T10: "Two-Body Radiative Gluino Decays," submitted to Mod. Phys. Lett. A. This work was done in collaboration with graduate student G.-G. Wong. It deals with the decay of a gluino into a gluon plus a color-singlet neutral fermion $\tilde{\chi}$. It is found that if $\tilde{\chi}$ is not the photino but a linear combination which contains the Higgs fermion which couples to the t quark, then the ratio of this two-body decay to the usual three-body decay of quark-antiquark-$\tilde{\chi}$ can be quite significant even though the two-body decay is a higher-order loop process. In the experimental search for gluinos, one should thus also book for events with one jet + missing energy.

UCRHEP-T11: "Natural Hierarchy of Radiatively Induced Majorana Neutrino Masses," submitted to Phys. Rev. Lett. This work was done in collaboration with K.S. Babu (Univ. of Rochester). The idea of generating neutrino masses radiatively has been around for some time, but there is a recent surge of papers on this subject. All models proposed so far require a host of new particles and in many cases new discrete symmetries as well. In this paper, it is pointed out that only a fourth neutrino is

needed as long as it has both Dirac and Majorana masses. Then the other 3 known neutrinos can pick up radiative Majorana masses through the exchange of 2 W bosons. Typical masses of the order 10^{-8} eV, 10^{-3} eV, and 10^{2} eV are obtained.

UCRHEP-T14: "Radiative Quark and Lepton Masses through Soft Supersymmetry Breaking," submitted to Phys. Rev. Lett. A supersymmetric extension of the standard strong and electroweak gauge model is presented with the property that light quarks and leptons acquire radiative masses as the result of the breaking of a chiral symmetry by soft supersymmetry-breaking terms. This radiative mechanism is then extended to include all known quarks and leptons in the context of a supersymmetric SU(3) x SU(2) x U(1) x U(1)' gauge model based on E_6 particle content as the possible low-energy limit of a superstring theory.

In the immediate future, the research plans of E. Ma include a study of how the baryon asymmetry of the universe can be generated in his model of exotic baryon-number nonconservation (UCRHEP-T3: Phys. Rev. Lett. 60, 1363 (1988)). There are several novel features in this model not found in other models, such as the spontaneous nature of the baryon-number nonconservation, the low energy-scale of this breaking, the fact that the decaying particle which generates the asymmetry is a fermion and not a boson, and the importance of massive final states. This work is being pursued together with X.-G. He (Univ. of Melbourne).

Another research topic under study is the role of flavor-changing interactions in E_6 superstring models. Since there are 3 sets of 2 Higgs doublets and 1 singlet in such models, flavor-changing neutral currents are in general present. In the new left-right model proposed by Ma (Phys. Rev. D36, 274; 878 (1987)), one can apply a discrete symmetry and get rid

of all direct flavor-changing quark couplings to neutral particles as well as lepton couplings in the e-μ sector. Various phenomenological consequences, especially those involving the τ lepton, will be pursued together with graduate student D. Ng.

P. Kaus continued his collaboration with Fishbane (Univ. of Virginia) and Gasiorowicz (Univ. of Minnesota), and jointly published "Zero-Point Energy in Flux-Tube Confinement," Phys. Rev. D37, 2623 (1988). They discuss the zero-point energy associated with a heavy-quark-antiquark system confined to a cylindrical cavity through the dielectric vacuum picture of confinement. The correction to the string tension and the universal Coulomb-type behavior produced by the Casimir forces are treated.

Kaus and Meshkov (Caltech and National Bureau of Standards) also wrote "A BCS Quark Mass Matrix," which has been accepted for publication in Mod. Phys. Lett. A. They study the quark mass gap and quark mass hierarchy by introducing a BCS interaction among ur-quarks, yielding in lowest order one heavy quark and two almost massless quarks for each charge sector. The physical mass splittings between the two lightest quarks come from higher-order corrections and are obtained by fitting the Kobayashi-Maskawa matrix.

B. Desai and Xu, Graduate Student - A purely gluonic soliton solution in the leading logarithm model. The possibility of obtaining a purely gluonic soliton solution is presented in the leading logarithm model which approximates many properties of QCD, e.g., confinement and asymptotic freedom.

The Lagrangian density, without sources, in this model corresponds to

$$L = \frac{b_o F}{8} \ln \left(\frac{F}{ek^2}\right)$$

where $F = F^{\mu\nu} F_{\mu\nu} = \vec{E}^a \vec{E}^a - \vec{B}^a \vec{B}^a$

$$k^2 = \frac{\mu^4}{e} \exp \left(-\frac{4}{b_o g^2}\right)$$

and $b_o = 11n/24\pi^2$ where n corresponds to the SU(n) of the gauge potential, the mass μ is the renormalization point and g^2 is the value of the running coupling constant at $F = \mu^4$.

Identifying the dielectric constant as

$$\epsilon = \frac{b_o}{8} \ln \left(\frac{F}{ek^2}\right)$$

it is shown that to obtain a non-vacuum soliton solution both $\epsilon > 0$ and $\epsilon < 0$ domains must exist within the same space with ϵ changing sign from one domain to another without going through $\epsilon = 0$.

Confining to a two-dimensional space, a possible soliton solution is presented consistent with the asymptotic conditions.

S. Rajpoot contributed 7 items to the list of publications in Sec. 3. In the following 2 subsections, 2 of his main areas of research are described.

Chiral Colour

It is conceivable that the underlying gauge symmetry of strong interactions is larger than SU(3). Frampton and Glashow[1] have revived the old idea that colour is chiral.[2] The minimal gauge symmetry required to entertain this idea is $SU(3)_L \times SU(3)_R$. The observed SU(3) of colour is the diagonal sum of $SU(3)_L$ and $SU(3)_R$ which is accomplished

through the Higgs mechanism of spontaneous symmetry breaking. With the extension of colour to chiral colour, the elegance of the standard model is lost. Firstly, the Adler, Bell, Jackiw anomalies no longer cancel since left-handed (right-handed) quarks couple to $SU(3)_L$ [$SU(3)_R$]. This requires additional fermions to cancel the anomalies. Frampton and Glashow considered exotic quarks in the [(6,1) + (1,6)], and $(3,\bar{3})$ representations of $SU(3)_L \times SU(3)_R$. Their model predicted five generations of conventional quarks and leptons for anomalies to cancel. This looked like a model dependent prediction to me. I considered $SU(3)_L \times SU(3)_R$ representations like (8,1) + (1,8) and (10,1) + (1,10) in addition to their representations.[3] I found that it was possible to construct anomaly free chiral colour models with only three generations of conventional quarks and leptons. This work is published as a rapid communication in Phys. Rev. D (ref. 3). This work is based heavily on the simple requirements that a chiral colour model should satisfy for elegance;

(i) the model contains no fermions with exotic electric charges other than $\pm$ 2/3e and $\pm$ 1/3e.

(ii) GIM cancellation[4] of flavour changing neutral currents is implemented in a natural way a la Glashow and Weinberg.[5]

Further work still remains to be done in this direction. The projects on that I have in mind include

Embedded $SU(3)_L \times SU(3)_R \times SU(2)_L \times U(1)$ in simple groups like SU(N) and look for a minimal model of chiral colour based on a simple group. This work will be on par with embedding SU(3) x SU(2) x U(1) in SU(5) and in SU(N) which was done by Georgi[6] and Frampton[7]. Some of the questions that need answering are to do with predictions for the weak

mixing angle $Sin^2\theta_w$ and for proton decay. I will be looking at these and related issues.

The second feature of extending the standard model to include chiral colour is that one needs a fairly elaborate Higgs structure to break $SU(3)_L \times SU(3)_R \times SU(2)_L \times U(1)$ to $SU(3) \times U(1)$ and give masses to the quarks and leptons of the model. Looking at the work of Frampton and Glashow[1] this again looked like very model dependent. In their model they needed scalars like $(3,\bar{3},2,1)$, $(3,\bar{3},2,-1)$, $(1,1,2,1)$ and more to give masses to the fermions and break the gauge symmetry. I presented a model of chiral[8] colour which in many respects is economical. The model is also based on the gauge group $SU(3)_L \times SU(3)_R \times SU(2) \times U(1)$. It has only two Higgs representations, the conventional doublet $(1,1,2,1)$ and nonet $(3,\bar{3},1,1)$. To cancel anomalies, I added exotic fermions that are singlets of the weak interaction group $SU(2)_L$. The quarks and leptons acquire masses through the see-saw mechanism of Gell-Mann, Ramond and Slansky that was first generalized by me[9] to include all quarks and leptons. This work on chiral colour is published in Phys. Rev. Letters (ref. 8). Further work remains to be done on this model. The weak isosinglet fermions that are responsible for the see-saw mechanism to work have no weak charged current interactions. These fermions have only neutral current interactions. Signatures of these "see-saw" fermions need to be spelled out. In particular what can one unravel at the hadronic collider like the SSC and the TEVATRON? A signature of axigluons at the PP or the $P\bar{P}$ collider is the production of four jets with large transverse momentum P_T. The axigluons[10] couple to $(3,\bar{3},1,0)$ scalars which decay into $q\bar{q}$ states giving the four jet signature alluded to. Work needs to be done to

establish whether the four jet signature is stronger than the conventional QCD signal.

If QCD is mediated by chiral colour gluons then it is natural to consider the flavour group to be chirally symmetric also. The minimal gauge group of chirally symmetric[11] strong and electroweak interactions is $SU(3)_L \times SU(3)_R \times SU(2)_L \times SU(2)_R \times U(1)$. I have presented a model with this structure and is to be published in Phys. Lett. B. In this model all conventional fermion masses again have see-saw masses. The mass scale responsible for the see-saw mechanism is the scale at which chiral QCD becomes conventional QCD, i.e., $SU(3)_L \times SU(3)_R \rightarrow SU(3)_{L+R}$. This scale need not be the GUT scale so one gets conventional quark masses with the see-saw fermion masses in the 100 GeV range. Further work needs to be done to look for a GUT theory that contains chirally symmetric strong and electroweak interactions. Since everything is chirally symmetric, SO(2N) groups with $N \geq 7$ are suggestive. I will be looking at this problem.

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Extra Neutral Gauge Bosons

Inspite of the successes of the standard model[1] in describing well the strong and the electroweak interactions, there are several issues which suggest that the standard model may just be a low energy manifestation of a larger gauge symmetry. In the past the electroweak symmetry of the standard model has been extended to $SU(2)_L \times SU(2)_R \times U(1)$[2] and also to $SU(2)_L \times U(1) \times U(\tilde{1})$ where $U(\tilde{1})$ unifies one conventional generation to its mirror fermion[3] generation. Such a scheme arises naturally if one seeks three generations of conventional fermions out of GUT groups[4] like $SO(4N+2)$ with $N > 2$.

I considered extending the electroweak sector of the standard model from a different view point. My point was that quark matter is distinct from leptonic matter. Leptons have no strong interactions and carry integer changes while quarks have strong interactions and carry fractional changes. This led me to propose distinct hypercharge sources[5] for the quarks and the leptons. Thus the electroweak gauge symmetry of the standard model is extended from $SU(2)_L \times U(1)$ to $SU(2)_L \times U(1)_y^q \times U(1)_y^\ell$ where q = quarks and ℓ = leptons. In this model, depending on the specific choice of the higgs sector to break the symmetry $SU(2)_L \times U(1)_y^q \times U(1)_y^\ell$ to U(1)-electromagnetism, the extra neutral gauge boson can be either below M_{Z_o} or above it where M_{Z_o} is the mass of the standard neutral boson (M_{Z_o} = 90 GeV). In my previous work, I only considered constraints coming from neutrino neutral current interactions and the measurements of

the change asymmetry in the reaction $e^+e^- \rightarrow \mu^+\mu^-$. I would like to make a thorough study of this model taking into consideration all the available data on neutral currents like e-D scattering atomic parity violations, $p\bar{p}$ collider production of Z^o and its mixing with the extra neutral boson.[6]

I also noticed that although the $SU(2)_L \times U(1)_y^q \times U(1)_y^\ell$ model looks quite complicated in the hypercharge sector, things start to simplify if I make the structure more symmetric. For instance if one takes the view that electroweak interactions are left-right symmetric then the minimal extension of $SU(2)_L \times U(1)_y^q \times U(1)_y^\ell$ is to $SU(2)_L \times SU(2)_R \times U(1)^q \times U(1)^\ell$. One finds that $U(1)^q$ is the generator of Baryon number and $U(1)^\ell$ is the generator of lepton number.[7] There is more work that needs to be done. The gauge symmetry $SU(2)_L \times SU(2)_R \times U(1)^q \times U(1)^\ell$ is anomalous. Anomaly cancellation will predict new exotic fermions and the number of generations. This model will have three neutral gauge bosons one of them is the neutral boson of the standard model. By using all the available data on neutral currents I will be able to obtain bounds on the masses of the extra gauge bosons. I would also like to study GUT schemes based on SU(N) or SO (4N+2) groups that can accommodate the desired gauge symmetry $SU(3) \times SU(2)_L \times SU(2)_R \times U(1)^q \times U(1)^\ell$.

This work may point in the direction of the correct underlying structure of the electroweak interactions.

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(e) Publications

The following list contains work completed by the Riverside group since September, 1987.

1. UCRHEP-T1: "D^0 - $\bar{D}^0$ Mixing in the New Left-Right Model," E. Ma, Mod. Phys. Lett. A3, 319 (1988).

2. UCRHEP-T2: "Gauge Model of Generation Nonuniversality Revisited," E. Ma, X. Li, and S.F. Tuan, Phys. Rev. Lett. 60, 495 (1988).

3. UCRHEP-T3: "Exotic Baryon-Number Nonconservation: Another E_6 Superstring Variation," E. Ma, Phys. Rev. Lett. 60, 1363 (1988).

4. UCRHEP-T4: "Gauge and Higgs Bosons in a Model of Generation Nonuniversality," E. Ma and D. Ng, Phys. Rev. D38, 304 (1988).

5. UCRHEP-T5: "Chiral Color Model with Simple Higgs Structure," S. Rajpoot, Phys. Rev. Lett. 60, 2003 (1988).

6. UCRHEP-T6: "Supersymmetry with Vector-Spinor Generators," C. Pilot and S. Rajpoot, Mod. Phys. Lett. A (to be published).

7. UCRHEP-T7: "Chirally Symmetric Strong and Electroweak Interactions," S. Rajpoot, Phys. Lett. B (to be published).

8. UCRHEP-T8: "Three-Generation Models with Chiral Color Interactions," S. Rajpoot, Phys. Rev. D38, 417 (1988).

9. UCRHEP-T9: "The Irreducible Representations of a Spin (1, 1/2) + (1/2, 1) Superspace," C. Pilot and S. Rajpoot, in Proc. of 4th Annual Conf. on Applied Mathematics, Central State Univ., Edmond, Oklahoma (April, 1988).

10. UCRHEP-T10: "Two-Body Radiative Gluino Decays," E. Ma and G.-G. Wong, submitted to Mod. Phys. Lett. A.

11. UCRHEP-T11: "Natural Hierarchy of Radiatively Induced Majorana Neutrino Masses," K. S. Babu and E. Ma, submitted to Phys. Rev. Lett.

12. UCRHEP-T12: "Superalgebras with Fermionic Generators Other Than Spin 1/2," C. Pilot and S. Rajpoot, submitted to Phys. Lett. B.

13. UCRHEP-T13: "A BCS Quark Mass Matrix," P. Kaus and S. Meshkov, Mod. Phys. Lett. A (to be published).

14. UCRHEP-T14: "Radiative Quark and Lepton Masses Through Soft Supersymmetry Breaking," E. Ma, submitted to Phys. Rev. Lett.

15. UCRHEP-T15: "See-Saw Fermion Masses in the Standard Model," S. Rajpoot, submitted to Phys. Rev. Lett.

(d) Travel and Consultants

Since September, 1987, the Riverside High-Energy Physics Theory Group has had the opportunity to travel to conferences, give talks, and to invite physicists to come to give seminars and work on joint projects. This funding comes partly from the University as part of Ma's initial complement, with the remainder coming from the Contract.

E. Ma attended the 8th Vanderbilt High Energy Physics Conference (Nashville, TN) in October 1987. Later that month, he gave an invited seminar on his model of generation nonuniversality (Phys. Rev. Lett. 60, 495 (1988) and Phys. Rev. Lett. 47, 1788 (1981)) at the University of California, Irvine. He spent 2 weeks at the University of Melbourne in Australia in March 1988. He gave 2 seminars there, the one already mentioned plus another one on his new supersymmetric left-right model (Phys. Rev. D36, 274, 878 (1987)). This travel was paid for by the University of Melbourne. In April 1988, he attended the 8th International Workshop on Photon-Photon Collisions in Israel, with funds provided by the University. He will attend the 24th International Conference on High Energy Physics (Munich, W. Germany) in August, again with funds provided by the University.

P. Kaus attended the Aspen Winter Conference on Elementary Particle Physics (Aspen, Colorado) in January, 1988. He was chairman and organizer of the Conference and gave a talk.

D. Ng (graduate student working with E. Ma) attended a Physics Workshop on Higgs bosons (University of California, Davis) in January

1988. He also attended the 3rd Asia Pacific Physics Conference (Hong Kong) in June 1988 and gave a talk based on his work with E. Ma (Phys. Rev. D38, 304 (1988)). This trip was supported only to the extent that the registration fee came from University funds.

G.-H. Xu (graduate student working with B.R. Desai) attended the Theoretical Advanced Study Institute in Elementary Particle Physics (TASI 88) at Brown Univ. (Providence, RI) in June 1988.

G.-G. Wong (graduate student working with E. Ma) attended the 16th SLAC Summer Institute on Elementary Particle Physics (Stanford, CA) in July 1988.

S. Rajpoot came from Oklahoma State University (Stillwater, OK) to give a seminar in January 1988 before joining Riverside. He attended the 13th International Conference on Neutrino Physics and Astrophysics (Boston, MA) in June 1988.

J. Pantaleone came from Purdue University (West Lafayette, IN) to give a seminar in May 1988. He will join Riverside as Postgraduate Researcher in September 1988.

X.-G. He (Univ. of Melbourne) visited Riverside for 1 week in June 1988 and gave a seminar. He and Ma are working on a project concerning the baryon asymmetry of the universe in the context of an exotic model of baryon-number nonconservation recently proposed by Ma (Phys. Rev. Lett. 60, 1363 (1988)).

C. Pilot (University of Tulsa) visited Riverside for 2 weeks in May 1988 and worked with Rajpoot.

Other visitors who gave high-energy theory seminars/colloquia include M. Bander (U.C. Irvine), V. Barger (Wisconsin), K. Choi (Johns Hopkins), N.G. Deshpande (Oregon), J.L. Hewett (Iowa State), G. Hou (Max-Planck

Inst.) S. Meshkov (Caltech/NBS), K. Tanaka (Ohio State), and L. Wolfenstein (Caltech/Carnegie-Mellon).

(e) Personnel and Needs

The present Ph.D members of the Riverside High Energy Physics Theory Group are:

S.-Y. Chu, Visiting Assistant Professor.

B.R. Desai, Professor.

P. Kaus, Professor.

E. Ma, Professor.

J. Pantaleone, Postgraduate Researcher, beginning September 1988 (DOE support).

S. Rajpoot, Visiting Assistant Professor.

Graduate students who have passed their comprehensive examinations and are doing research in theoretical high-energy physics are:

R. Anderson, beginning September 1988 (own support).

D.Y.M. Ng (University support).

G.-G. Wong (University support).

G.-H. Xu (DOE support).

Of the above faculty members, Desai, Kaus, and Ma are tenured professors in the Physics Department. Kaus is on phased retirement and is currently taking up only 2/3 of a full position. Chu and Rajpoot have visiting appointments until June 1989. Pantaleone will come aboard this Fall, supported entirely by the present Contract, and his continued support during the next contract year is requested in this renewal proposal. In addition, summer salaries are requested for Ma (1 mo.) and Rajpoot (2.5 mos.). Graduate research assistantships are requested for Xu

(until September 1989) and for Ng (beginning July 1989). With the growing size of the group and the desire for all personnel (including the graduate students) to have the opportunity to attend conferences and workshops, the travel budget needs an increase as well. Two foreign trips are planned, at about $2,250 each, to conferences such as the International Europhysics Conference on High Energy Physics (September 1989) in Spain, the 12th International Workshop on Weak Interactions and Neutrinos (April 1989) in Israel, and others of similar nature. Six domestic trips are planned, at about $1,000 each, to conferences such as the 1989 International Symposium on Lepton and Photon Interactions at High Energies at Stanford, California, the 1989 International Symposium on Heavy Quark Physics at Ithaca, New York, the Conference on Beyond the Standard Model at Ames, Iowa, and various other conferences, workshops, and summer institutes yet to be announced. About $1,500 is set aside for visitors and consultants. The University's contribution to supplies and expenses will end in June 1989, and funds in this category are needed for the next contract year. In addition, funds are being requested specifically for the support of S. Rajpoot as Assistant Research Physicist. The appointment will start October 1988, hence only 4 months are covered by the contract year ending on January 31, 1989. The continued support of this position after that date will be requested.

III. HIGH ENERGY PHYSICS COMPUTING AT UCR

The UCR High Energy Physics Group has developed a computing facility designed to meet the needs of physics analysis within large collaborations. The computing facility has evolved through the period of the UA1 and PEP4/TPC experiments to its present form consisting of a MicroVAX 3500, recently purchased by the University, clustered with three other MicroVAX II workstations. The processors in the MicroVAX cluster also share 3.2 GBytes of common disk storage, and four high-density high-speed tape drives. The computing facility also operates 2 high resolution color-graphics workstations (described below). Each graduate student, postdoc, and faculty member has a graphics terminal, and in some cases, access to PC's.

At present the MicroVAX cluster forms the communications and data-storage hub of a system of dedicated services including: (i) 1 ACP farm, (ii) high-resolution color graphics stations -- Megatek 7555 and Evans & Sutherland PS390, (iii) disk and tape drives, (iv) job-entry node for the SDSC (San Diego Supercomputer) and (v) world-wide networking access. The system will evolve over the next several years to include a second ACP farm as well as VHS video cassette tape drives.

Two high quality, 3-D color graphics workstations are connected to the MicroVAX cluster: (i) an Evans & Sutherland PS390, the graphics device chosen as the DØ standard, and (ii) a Megatek 7555. The Evans & Sutherland is supported on the Local Area Network (LAN / Ethernet) and is a bona fide HEPnet node (UCRPH8). The Evans & Sutherland graphics workstation is supported by a DI3000 device driver, allowing easy access to the industry standard GSR's (Graphics Support Routines). The Megatek 7555 is also supported locally using another DI3000 device driver.

We have recently installed a five-node ACP (Advanced Computer Program) farm. Each node consists of a Motorola 68020 (16 MHz) microprocessor along with 6 MBytes of memory. The ACP farm was purchased by our physics department as an upgrade to the existing MicroVAX cluster. The ACP represents a major advance in parallel computing due to its size, speed (80% of a VAX 780 per node), cost per CPU, and maintenance.

Large scale processing will be accomplished on one of two ACP farms. Analysis and Monte Carlo software for the ACP's are being developed within both the DØ and OPAL collaborations, and similar systems are planned at other member institutions. The standard GEANT Monte Carlo system is being used by both OPAL and DØ for detailed detector simulation at this stage of detector development. The full range of available physics generators, including ISAJET, LUND and others, are also available in ACP standard code. Each ACP farm will ultimately consist of 8 to 20 processors. As more advanced processors become available the performance of the ACP farm will be increased. The initial configuration of the ACP farm is primarily funded by the University of California.

Data analysis by the physicists requires a range of workstations for final data analysis and presentation. We have installed three MicroVAX workstations, the Evans & Sutherland and Megatek workstations described above, and a number of PC's -- including MacIntosh and IBM PC/AT. All of these systems are being integrated to the central MicroVAX cluster as communications and file storage server. All remote network links for the High Energy Physics group are maintained by the UCR Computing and Data Communications, and the University-wide Office of Telecommunications and Information Systems. UCR has a 56 Kbaud line to UCSD providing: (i) HEPnet/DECnet access, (ii) BITnet

access, (iii) access to the NSF Supercomputer centers. The line will soon be upgraded, at University expense, to a T1 (1.544 Mbit/second) rate line.

From our offices we can log in on (i) local computing in the physics department and on campus, (ii) computers at our experiment sites (FNAL, CERN, SLAC) to use central computers, and (iii) to the NSF Supercomputer centers including the CRAY XMP/48's at San Diego and Illinois. Standard program and database distributions (e.g DEC supported CMS) are made by means of the network and much of the collaboration business is transacted by electronic mail.

In summary we use computers for four broad areas:

(i) Data reduction. The processing of raw data through to data summary form is primarily done on large central computer facilities at the host labs -- FNAL, CERN, SLAC. UCR physicists access this data reduction stage via the available networking.

(ii) Data Simulation/Monte Carlo. This area has grown well past the capacity of central lab computers. The burden of Monte Carlo work will increasingly fall on member institutions including UCR. Our ACP farm systems together with network access to super computing centers should place us in a leadership role within both the DØ and OPAL groups.

(iii) Data Analysis/Presentation. The UCR collection of workstations linked by the MicroVAX cluster should offer an excellent tool for data analysis to extract the physics.

(iv) Communications/Documents. The UCR workstations and PC's will allow us to use the best available software for network communications and text processing.

The planned evolution of the UCR High Energy Physics computing facilities is motivated by the need for more processing power while not significantly increasing computer related operating expenses. Specialized processors and enhanced graphics are necessary to address the demands of physics analysis in the increasingly complex experiments we are now preparing (DØ and OPAL). Even with these improvements, mostly supported by the University, we can supply only a fraction of the anticipated computing needs of the new experiments at this time. Our system configuration allows us to expand, in the next several years, by adding more microprocessor-based nodes at small incremental cost.