DOE/ER/40327--T6

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
Ernest Ma, Professor	Physics
Faculty Associates:	
John G. Layter, Adjunct Professor	Physics
Gordon VanDalen, Professor	Physics
Stephen J. Wimpenny, Asst. 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, Riverside.

In 1990, we will concentrate on analysis of LEP data from the OPAL detector. We expect to record 10^5 Z's by the end of 1989 and 10^6 in 1990. This data will be used to measure the number of quark-lepton families in the universe. In the second half of 1990 we will also be occupied with the installation of the D-Zero detector in the Tevatron Collider and the preparation of software for the 1991 run.

A new initiative made possible by generous university support is a laboratory for detector development at UCR. The focus will be on silicon strip tracking detectors both for the D-Zero upgrade and for SSC physics.

The theory program will pursue further various mass-generating radiative mechanisms for understanding small quark and lepton masses as well as some novel phenomenological aspects of supersymmetry.

DISCLAIMER

HIGH ENERGY PHYSICS AT UCR

Table of Contents

Experimental High Energy Physics

INTRODUCTION

The OPAL project is now entering into a most exciting phase. Many years of work on the design and construction have culminated in the successful completion of the OPAL detector. It has been installed in the underground experimental area at Point 6 of LEP. A short pilot run is scheduled for 3 to 5 days at the beginning of August, 1989. It will provide us the opportunity for the shake-down of the OPAL detector and the data acquisition system under real beam conditions. It will also give us several hundred Z events for an initial look at the physics. The first physics run will commence on August 20 for a total fall running of about six weeks. The tentative program consists of an energy scan around the Z and an extended run at the Z with about 100,000 Z's recorded. There will be about six months of running of LEP during 1990. It is expected that over one million Z's will be obtained for precision tests of the Standard Model and for the search for new physics beyond. The Riverside group is very active and playing a leading role in several areas of physics analysis.

The D-Zero detector will be installed in the Tevatron Collider during 1990. The UCR group will be especially concerned with the installation of the high voltage supply system and its associated control software. We will also be testing the trigger electronics and developing the off-line software for the muon detection system.

The turn-on of OPAL and the increasing volume of D-Zero computing necessitate a significant increase in our computing capability. We propose an upgrade staged over two years as follows: acquisition of 4

VAX workstations in 1990, followed by a 10 MIPS VAX/VMS host machine in 1991.

We are currently setting up on campus a laboratory devoted to development and evaluation of silicon strip tracking chambers and readout. This project is receiving generous funding from the university. Initially we will focus on R & D for a silicon strip vertex detector for the D-Zero upgrade. Concurrently we are planning a program of research oriented towards developing silicon detectors for SSC applications.

(1) HADRON COLLIDER PHYSICS

This program began with the study of proton-proton interactions at cm energy 60 GeV at the CERN-ISR in 1973. In 1978 we joined with eight other institutions to propose the UA1 experiment at the CERN SPS proton-antiproton collider. Now we are looking forward to continuing the study of parton-parton interactions at the 2 TeV frontier at Fermilab. We are also starting to plan for the SSC machine.

1a) 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 and 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.

UCR has now completed its work on experiment UA1 except for the thesis research of graduate students M. Lindgren and D. Joyce. A total of six UCR students have completed their Ph.D. research on the UA1 experiment, the most recent being M. Ikeda (June 1989) whose thesis topic was: "The D^* content of jets at the CERN Proton-Antiproton Collider". His results will be presented by him at the 1989 Proton-Antiproton Collider Conference and by S. Wimpenny at the 1989 EPS Conference Madrid.

The thesis research of M. Lindgren and D. Joyce is describe below:

Measurement of the strong coupling constant α_s from Intermediate Vector Bosons production (M. Lindgren)

The dominant production mode for intermediate vector bosons at CERN Collider energies is by the Drell-Yan mechanism of quark antiquark annihilation (Fig. 1a). These events form the majority of W events produced at the collider. If QCD corrections are taken into account there are several other production modes, the most important being the radiation of a gluon by either the incoming quark or antiquark.[1] This gives rise to one or more hadronic jets accompanying the W.(Fig. 1b). To first approximation the yield of W+1 jet events is proportional to the strong coupling constant α_s. A more precise value can be determined by looking at the one-jet to zero-jet ratio, R_{exp}, and comparing the experimental result with the QCD predicted value, R_{MC}, obtained from a Monte Carlo simulation of W production.

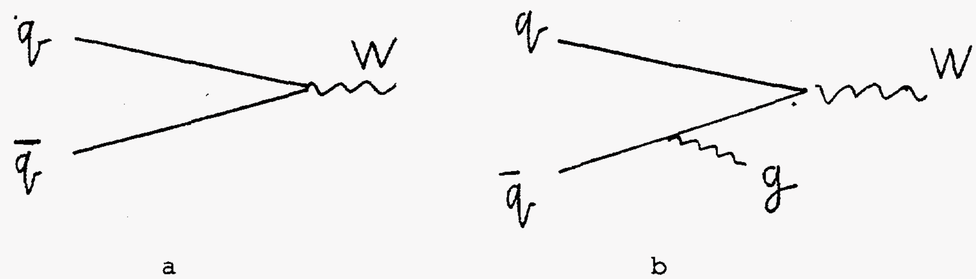


Figure 1

The UA1 jet algorithm has been used to look for jet activity in the W event sample. To reduce the systematic uncertainties in the jet energy measurement and to decrease the number of jets arising from the underlying event only jets with a $P_T > 10$ GeV/c and with $|\eta|$ less than 2.5 are retained. In the W sample 221 zero-jet events and 56 events with one jet are found giving

$$R_{exp} = \frac{\text{\# of W+1 jet events}}{\text{\# of W+0 jet events}} = .253 \pm .044$$

To determine α_s the ratio R_{exp} is compared with the predicted value R_{MC}, which is determined by a QCD simulation of W boson production. The Monte Carlo ratio is a function of as, which is then varied until $R_{MC}(\alpha_s) = R_{exp}$. R_{MC} is determined by using the most complete simulation of W production presently available, the EKS Monte Carlo[2], which incorporates the matrix elements of all tree level diagrams for W production up to order α_s^2. The work now in progress is the incorporation of the parton level events from EKS into the UA1 detector simulation software.

Finally to complete this work it will then be necessary to evaluate the considerable sources of systematic uncertainty, both experimental and theoretical. In brief, to search for possible systematic effects in the data analysis the jet definition algorithm will need to be varied, as well as changing the transverse energy threshold, and looking at the effect on α_s. Then there are the uncertainties in the absolute calibration of the calorimeter and especially it's response to low energy particle. One would also expect that there will also be some effect from the structure functions and fragmentation model which will have to be determined.

References

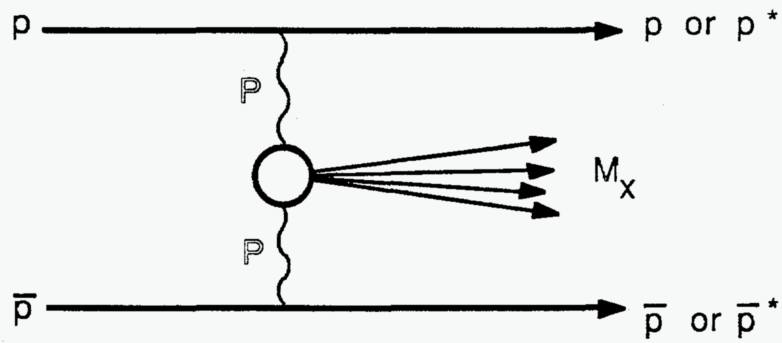
[1] W. J. Stirling, Jet Activity in $W^{\pm}, Z^0$ events-A theoretical analysis, Proceedings of the St. Vincent Workshop on $p\bar{p}$ physics (1985) 348

[2] S. D. Ellis, R. Kleiss, W. J. Stirling, Phys. Lett. **B154** (1985) 435; R. Kleiss and W. J. Stirling, Nucl. Phys. **B262** (1985) 235

Double Pomeron Exchange - Gluon-Gluon Interactions (D. Joyce)

The double pomeron (DPE) interaction in hadronic physics is the analogue of the two-photon interaction in e^+e^- interactions. In the DPE process the leading hadrons are connected by pomeron exchange to a central cluster of particles. Large rapidity gaps separate the central cluster from the leading particles.

In QCD the simplest representation of the pomeron is a pair of gluons. Because gluons are flavor neutral it has long been conjectured that the central cluster might be rich in heavy quarks.



Double Pomeron Exchange

A DPE trigger was implemented by UA1 in Fall 1985 in parallel with other triggers. A total of 43,000 events were recorded corresponding to an integrated luminosity of 132 nb^{-1}. The trigger relied on the absence of signal in the forward and very forward calorimeters ($|\eta| \geq 3$) and on the deposition of several GeV transverse energy in the central calorimeter. For this trigger the invariant mass M_x of the central cluster covers the range 5 - 40 GeV.

Many questions have been raised about the nature of the pomeron and of the central cluster. We plan a survey of the properties of the central cluster M_x including:

- charged particle multiplicity
- jet structure
- strangeness and charm component. Is the pomeron coupling flavor-independent as expected if it has a gluonic structure?

This survey will provide the first information on DPE production of massive clusters.

1b) D-ZERO - PROTON-ANTIPROTON INTERACTIONS AT 2 TeV

1. INTRODUCTION

Since Fall 1986 Riverside has played a major role in the development of the D-Zero detector at Fermilab. Our work spans three main areas: the design of the high voltage system; a feasibility study of a silicon microstrip detector for the first D-Zero upgrade and hardware/software development for the D-Zero muon detection system.

2. PHYSICS AND DETECTOR

D-Zero is a 4π non-magnetic hermetic detector designed for the Tevatron Collider at Fermilab. The evolution of the D-Zero design has benefitted substantially from the experience with the UA1 and UA2 detectors at CERN and the CDF detector at Fermilab. Additional input from the ongoing SSC R&D program has also proved valuable especially in the areas of readout and tracking designs for the projected Tevatron upgrades. In overall concept D-Zero has been designed to complement the strengths of the existing CDF 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.

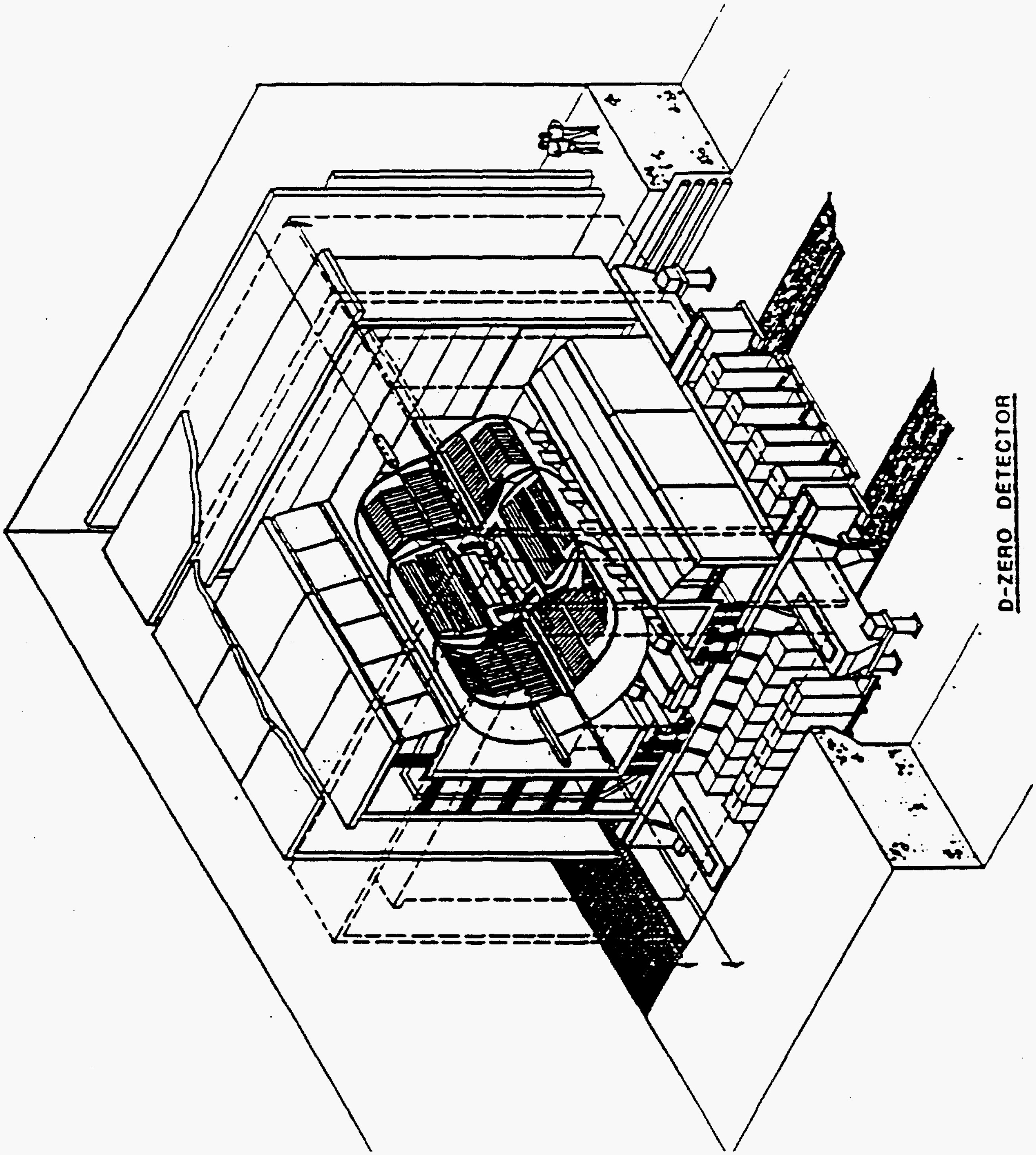
These physics issues dictated the basic design choices for D-Zero:

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 $\theta < 1^\circ$ ($\eta \geq 5$). 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 D-Zero detector. Tables 1 and 2 gives the performance goals for the detector.

The first run with the completed Detector is scheduled to commence in Spring of 1991. Prior to installation in the D-Zero experimental hall most elements of the detector will have been tested and debugged in test beams at Fermilab. The spring run, however, will be the first time the detector has been run so that we anticipate the first month or so will be spent debugging the readout and tuning the trigger system. The first data-taking for physics analyis run would then follow in the late Spring of 1991.



D-ZERO DETECTOR

Figure 1

TABLE 1

Performance Specifications

Tracking	
Spatial resolution in $r\Delta\phi$	50 μm (Vertex chamber)
	200 μm (Outer chambers)
Spatial resolution in z	10 mm (Vertex chamber)
	3 mm (Outer chambers)
Two track resolving power ($r\phi$)	1 mm (Vertex chamber)
	3 mm (Outer chambers)
Overlapped track rejection by dE/dx	50:1
Transition Radiation Detection	
e/π discrimination	50:1
Calorimetry	
Energy resolution - electromagnetic	$15\%/\sqrt{E}$(GeV)
- hadronic	$40\%/\sqrt{E}$(GeV)
Position resolution (EM)	2 cm/$\sqrt{E}$(GeV)
Isolated e/π resolving power	50:1
Muon Detection	
$\delta p/p$ (multiple scattering limit)	18%
3 σ sign determination	$p_T \leq 300$ GeV/c
Solid Angle Coverage	
Drift chambers	$\lvert\eta\rvert \leq 3.5$
Transition Radiation	$\lvert\eta\rvert \leq 1$
Calorimetry	$\lvert\eta\rvert \leq 5$
Muon detection	$\lvert\eta\rvert \leq 2.3$ ($\Delta\Omega$ =98%)

TABLE 2

Detector Specifications

Vertex Chamber	
Length	115 cm
Radial interval	3.7 to 16.2 cm
Number of supercell layers	3
Maximum drift distance	16 mm
Radial wire spacing	4.57 mm
Number of wires per supercell	8
Total number of wires	640
Total number of helical pad readouts	896
Total number of readout channels	2176
Transition Radiation Detector	
Length	165 cm
Radial interval	17.6 to 47 cm
Number of polypropylene/xenon chamber packages	3
Number of wire readouts per chamber	256
Number of helical pads per layer	256
Number of readout channels	1536
Central Drift Chamber	
Length	179.4 cm
Radial interval	51.8 to 71.9 cm
Number of supercells in radius	4
Number of wires per supercell	7
Number of delay lines per supercell	2
Maximum drift distance	7 cm
Number of wires	896
Number of delay lines	256
Total number of readout channels	1408
Forward-Backward Drift Chambers	
Theta modules:	
z intervals	104.8-111.2 and 128.8-135.2 cm
Radial interval	11 to 61 cm
Number of cells in radius	6
Number of wires per cell	8
Number delay lines per cell	1
Number of wires per end	384
Number of readout channels per end	480
Phi modules	
z interval	113.0 to 127.0 cm
Radial interval	11 to 61 cm
Number of wires in z	16
Number of wires per end	576
Number of readout channels per end	576
Total number readout per end	1056

Table 2 continued

Central Calorimeter	
Radial interval	33.25 to 86.01 in
Active length	102 in
Gross weight	740,000 lb
Total number of readout channels	14,592
Total absorption lengths	~ 7
Sampling gap	2 x 2.3 mm LAr
EM Section	
Absorber	3 mm U
Number of azimuthal modules	32
Longitudinal readout segmentation	4 times
Total radiation lengths	20.5
Transverse segmentation	$\Delta\eta=\Delta\phi=0.1$
layer 3:	$\Delta\eta=\Delta\phi=0.05$
Total number of readout channels	10,368
Fine Hadronic Section	
Absorber	6 mm U
Number of azimuthal modules	16
Longitudinal readout segmentation	3 times
Transverse segmentation	$\Delta\eta=\Delta\phi=0.1$
Total number of readout channels	3456
Coarse Hadronic Section	
Absorber	46.5 mm Cu
Number of azimuthal modules	16
Longitudinal readout segmentation	1 time
Transverse segmentation layers	$\Delta\eta=\Delta\phi=0.1$
Total number of readout channels	768

Table 2 continued

Endcap Calorimeter	
Number of Endcaps	2
Radial interval	1.7 to 88.2 in
Active length	85 in
Gross weight (each end)	500,000 lb
Total number of readout channels (each end)	15,968
Total absorption lengths	~ 9
Sampling gap	2 x 2.3 mm LAr
EM Section (per endcap)	
Absorber	3 mm U
Longitudinal readout segmentation	4 times
Total radiation lengths	20.5
Transverse segmentation	$\Delta\eta=\Delta\phi=0.1$
layer 3:	$\Delta\eta=\Delta\phi=0.05$
(approx. 2 x coarser for $\eta > 3.2$)	
Total number of readout channels	7488
Inner Hadronic (per endcap)	
Absorber	6 mm U/ 46.5 mm Cu
Longitudinal readout segmentation	4 times U/ 1 Cu
Transverse segmentation	$\Delta\eta=\Delta\phi=0.1$
(approx 2 x coarser for $\eta > 3.2$)	
Total number of readout channels	5856
Middle Hadronic (per endcap)	
Absorber	6 mm U/ 46.5 mm Cu
Number of modules in azimuth	16
Longitudinal readout segmentation	4 times U/ 1 Cu
Transverse segmentation	$\Delta\eta=\Delta\phi=0.1$
Total number of readout channels	1664
Outer Hadronic (per endcap)	
Absorber	46.5 mm Cu
Number of modules in azimuth	16
Typical longitudinal readout segmentation	2 times
Transverse segmentation	$\Delta\eta=\Delta\phi=0.1$
Total number of readout channels	960

Table 2 continued

Proportional Drift Tube Chambers	
Maximum length	228 in
Maximum width	100 in
Cathode pad pattern repeat length	24 in
Total number of wires	11,754
Total number cathode pads	23,508
Total number of readout channels	47,016
Total number of modules	176
Minimum angle covered	5 degrees
Central Region	
Toroid z interval	-149 to 149 in
Toroid perpendicular distance	125 to 167 in
Toroid weight	2300 tons
Mean field	1.9 T
Central Region chambers -- before toroid	
Number of wire layers	4
Number of modules	18
Number of wires	1728
Central Region chambers -- 2 stations outside toroid	
Number of wire layers	3 + 3
Number of modules	76
Number of wires	5016
End Region (each)	
Toroid z interval	176 to 236 in
Toroid perpendicular inner distance	36 to 164 in
Toroid weight (each)	900 tons
Mean field	1.9 T
End Region chambers -- before toroid	
Number of wire layers	4
Number of modules	18
Number of wires	1032
End Region chambers -- 2 stations outside toroid	
Number of wire layers	3 + 3
Number of modules	64
Number of wires	3978

3. RIVERSIDE ACTIVITIES

3.1 High Voltage System Design and Implementation

Since the start of 1987 the Riverside group has been responsible for the coordination of high voltage system for the D-Zero detector. This includes all aspects of both the power system itself and the associated distribution system. When completed this will be the largest integrated system of its kind in operation.

At the core of the design is a new computer controlled high voltage power supply which has a wide operating range in terms of both output voltage (0 to 5.6kV +ve and -ve) and current sensitivity (32nA to 1 mA). Also built into the design of the supply is fast trip circuitry to shut the supply down in a controlled manner in the event of a detector failure (eg. broken wire), monitoring computer failure, voltage regulation failure or the detection of a large current transient. The supply also has an external shutdown capability which can be interlocked to a safety system, daisy-chained to a neighboring supply (linked channel trip) or triggered by an external software instruction.

We have designed and tested 3 different prototypes at Fermilab and are now close to having a final design. The power supply module is a VME based unit which is 3 slots wide and 6U in height. Each of these contains 8 separate channels, giving 48 channels total per standard J1/J2 Eurosize crate. Each module consists of a digital motherboard and 8 mating analog daughterboards. The latter are fixed to either +ve or -ve polarity and operate either as a 1mA, 250V to 5.6kV supply or as a 3mA 0 to 2kV supply. Any combination of daughterboards can operate on the motherboard. Up to a maximum of 4 crates can be interconnected using

D-Zero designed interconnect modules, giving a sub-system size of 192 power supply channels. The full D-Zero design uses 7 such sub-systems.

The supplies are controlled by two Motorolla 68020 cpus which are resident in a VME controls crate (one per subsystem). These in turn are programmed and monitored by either a local AST 286 PC or remotely (via a tokenring connection) by one of the D-Zero VAX stations. We have designed, written and tested the control software which is resident in both the 68020's and the PC and this is now fully operational. The Host VAX software is designed and partially written. This will be completed in Fall 1989 with a first system test at the D-Zero hall sometime later in the year.

Between the power supplies and the detector is the power distribution system. This has been designed and prototyped and fabrication of the units will begin during Summer 1989. The system consists of a passive splitter system which is located either in the D-Zero mobile counting house (muon system and calorimeters) or on the detector platform (other detectors). Because of space restrictions we have developed a special 8-conductor cable/connector system which is both compact and very resilient. Both parts are custom designed to suit D-Zero but will eventually become available as commercial products. All of the cable has been fabricated, delivered and tested at Fermilab. The connectors went into production at Reynolds Industries at the end of April and the first parts are scheduled for delivery in June 1989.

Design of the counting room and platform layouts was completed in May and installation of hardware began in early June. If all goes well the full power system should be in place and tested by Fall 1990.

3.2 Muon Detection System

The D-Zero detector is distinguished by a very powerful muon detection system. It will be very important for W,Z and top physics. We are building up our effort in this area. As detailed below we are testing the Module Address Cards for the first level muon trigger and we are developing off-line reconstruction software for the muon system.

3.2.1 Muon Detector Electronics

The DØ muon detector is constructed in three layers; layer A just before the magnetized iron and two more layers (B and C) immediately after the magnetized iron. Figure 1 show the orientation of the three muon layers with respect to the calorimetry and the magnetized iron. Each layer consists of 4(3) decks for layers A(B,C) respectively. Each deck contains 24 proportional drift tubes (PDT's). As charge particles pass through the muon chambers they induce a charge on the vernier pads initiating a *pad latch* marking it as a hit PDT.

The MAC is a VME card designed to read pad latches from all decks of a muon layer. The MAC uses the pad latch information within a layer, along with a lookup table, to determine if a centroid is present. The centroid is a position calculated from a group of pad latches in adjacent decks. For example, in figure 1 the MAC would read three pad latches in layer B and output a centroid. There are two varieties of centroids calculated, coarse and fine, representing wide (3 half-tube widths) and narrow (one-half tube width) windows respectively in the drift direction.

The centroid information from the MAC's is sent to the Coarse Centroid Trigger (CCT) where a lookup table is used to determine if a trigger occurred. Figure 2 shows schematically how the CCT receives MAC information from layers A, B and C. The centroid information from 3 muon chambers (or MAC's) from layer A and 5 muon chambers each from layers B and C come together in the CCT where centroid information between layers can be compared. The trigger information from the CCT is then sent to the trigger processor.

The final modifications have been made to the MAC prototype and 220 circuit boards are in production. Figure 3 shows the schedule for producing and testing the Module Address Cards. We plan to stuff and test 5 of the MAC circuit boards at Fermilab by the end of September 1989. Graduate student Bazizi is working at Fermilab on the muon Module Address Card. Darrel Smith, along with Kamel Bazizi and undergraduate student Steve Jerger have assembled a VME test station at UCR to test the MAC's as they come off the assembly line. The test station at UCR includes an AST286 computer interfaced to a VME crate via a BIT-3 interface card. The MAC tests will include simulating real data (pad latches) as well as faking pad latches from our host computer through the VME bus. Kamel Bazizi is preparing a list of hardware and software tests at Fermilab to verify the quality of the MAC's as they are assembled. The MAC's will be shipped to UCR starting in mid-October. The hardware/software tests will be performed at UCR to check, debug, and repair the remaining cards (approximately 210). We expect the MAC testing to continue through March 1990. To meet this schedule we anticipate hiring as many as 3 part-time undergraduate students.

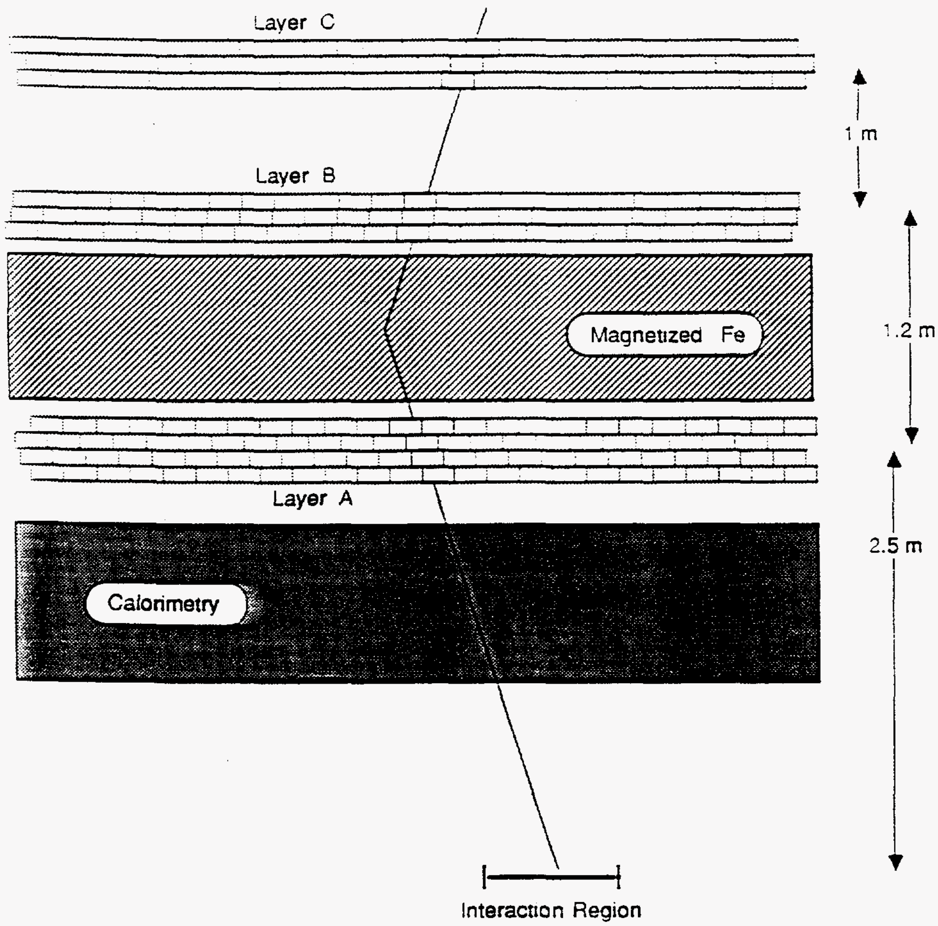


Figure 1

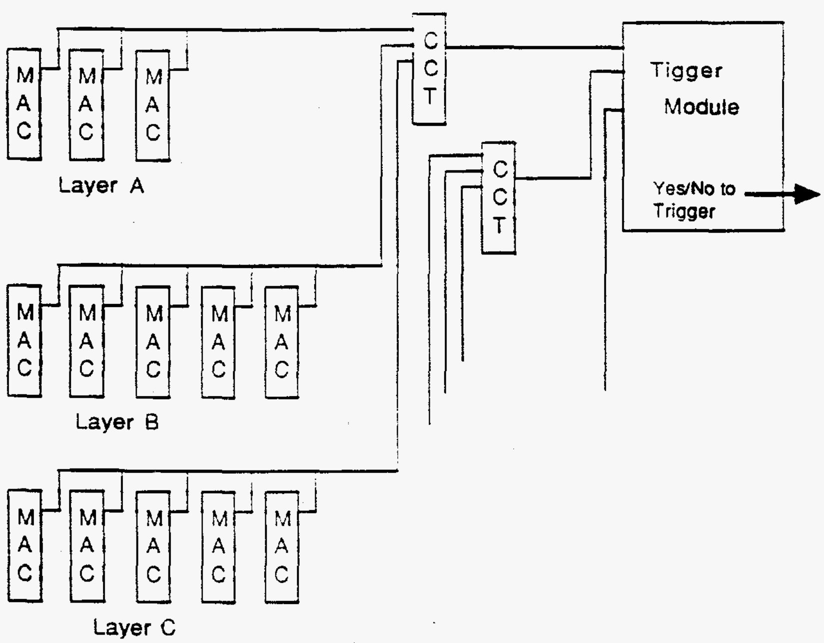


Figure 2

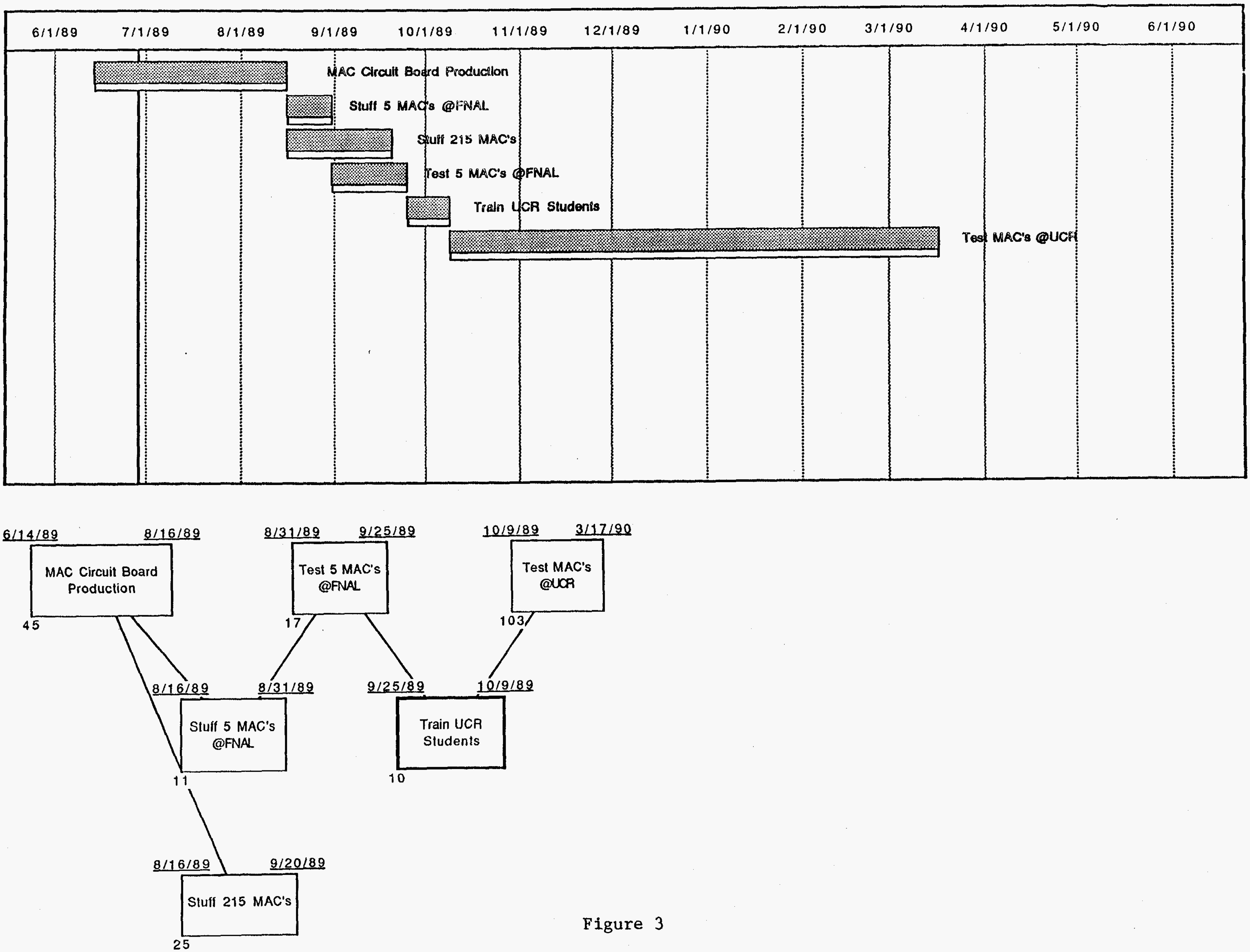

6/1/89
7/1/89
8/1/89
9/1/89
10/1/89
11/1/89
12/1/89
1/1/90
2/1/90
3/1/90
4/1/90
5/1/90
6/1/90
MAC Circuit Board Production
Stuff 5 MAC's @FNAL
Stuff 215 MAC's
Test 5 MAC's @FNAL
Train UCR Students
Test MAC's @UCR
6/14/89
8/16/89
MAC Circuit Board Production
45
8/31/89
9/25/89
Test 5 MAC's @FNAL
17
10/9/89
3/17/90
Test MAC's @UCR
103
8/16/89
8/31/89
Stuff 5 MAC's @FNAL
11
9/25/89
10/9/89
Train UCR Students
10
8/16/89
9/20/89
Stuff 215 MAC's
25

Figure 3

3.2.2 Muon Software

We are also working on the off-line software for muon track reconstruction. The magnetic field in the muon toroids has been calculated using the known currents circulating around the magnets and calculating the vector potentials from a computer program, POISSON[1]. The magnetic field maps have been entered into the standard D-Zero ZEBRA banks.

In the coming year we will develop the off-line software for track reconstruction through the muon detector.

3.3 Silicon Microvertex Detector

The D-Zero collaboration is planning a series of upgrades to match the increasing luminosity of the Tevatron collider and to enhance the physics capability of the detector. The UCR group has been assigned responsibility to investigate the design and physics potential of a silicon microstrip detector in the D-Zero apparatus. The unsurpassed position resolution of silicon detectors enables efficient tagging of events containing secondary vertices from b- and c- quarks. The capability of identifying b- and c-quarks will be particularly important for top quark studies.

The silicon microvertex detector envisaged would consist of four radial layers of silicon microstrips surrounding the beam pipe. The strips will run parallel to the beam pipe and each layer will provide a measurement of the track position in the transverse plane with a position resolution of approximately 10 μm [1]. This will result in an impact parameter error of < 15 μm for high momentum tracks.

We are in the process of carrying out simulation studies of the SMVD. Using the ISAJET program to generate events containing b-jets or gluon jets and using the GEANT program to track particles through the detector, we are testing various algorithms for identifying b-jets. A major challenge is that, since there is no central magnetic field in D0, low momentum tracks will have large impact parameters due to multiple scattering and therefore may simulate tracks from secondary vertices. To reject these tracks we focus on particles in the core of the jets, where tracks have predominantly high momentum. Candidate events containing b-jets can be selected by demanding that these core tracks have large impact parameters and form a secondary vertex. Preliminary analysis using this technique has shown that b- jets can be distinguished from gluon jets with an enhancement factor (b/gluon) of greater than 13 and corresponding efficiency of approximately 21% [2] (see figure 1).

Additional work has been carried out to study pattern recognition and track reconstruction in the silicon microvertex detector. An event reconstruction algorithm using only SMVD data has been implemented which achieves a track-finding efficiency of 77% for all tracks and 85% for tracks in the jet cores. Small impact parameter tracks were used to reconstruct the primary vertex position in the transverse plane with a resolution of 20 μm (see figure 2). This is a factor of at least 3 better than the primary vertex position determined from the nominal beam position.

We plan to generate a large sample of top quark production events in the mass range $100 < m_T < 150$ GeV with ISAJET/GEANT. In this mass range top decays to W + b. These events will be used to estimate the increased efficiency for top quark detection afforded by a silicon vertex detector. In particular we will investigate the ability of the MVSD to reject the background to top due to W production accompanied by gluon jets.

In addition to the simulation studies we propose to investigate aspects of the silicon detectors and readout electronics required to construct the detector. As well as being essential for the D0 silicon detector, we believe that such a program will be useful for progressing towards more advanced silicon detector systems such as those being proposed for the SSC [3]. Further details are given in section c: Detector Development.

References

1.) D. Joyce et al., "Silicon Detector Tests with the RAL Microplex Readout Chip", presented at the International Conference on Advanced Technology and Particle Physics, Como, Italy 13th-17th June 1988.

2.) D. Smith, "Identification of b-jets in D-Zero with a Barrel Silicon Vertex Detector", D-Zero Note no. 830, (1989).

3.) S.L. Shapiro et al., "Silicon PIN Diode Array Hybrids for Charged Particle Detection", Nucl. Instr. Meth. **A275**, 580, (1989).

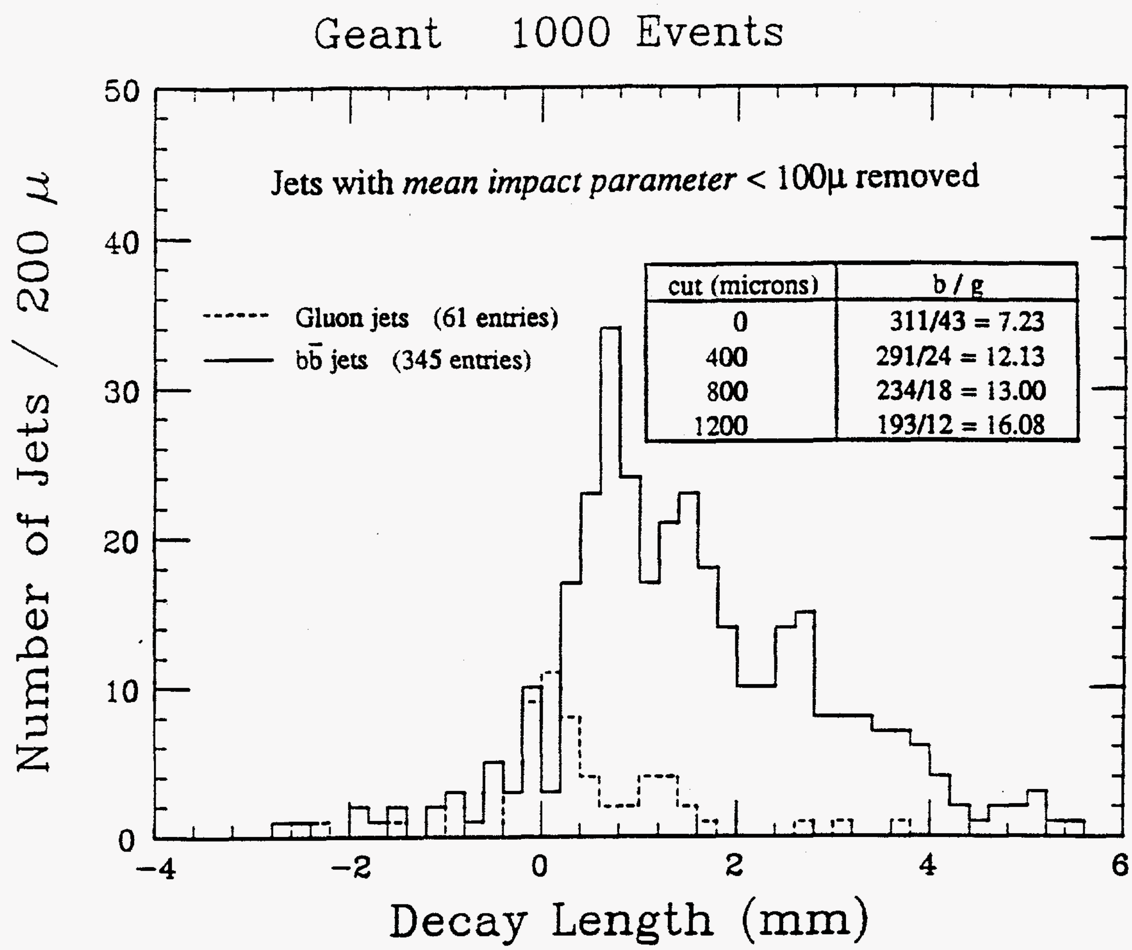


Figure 1

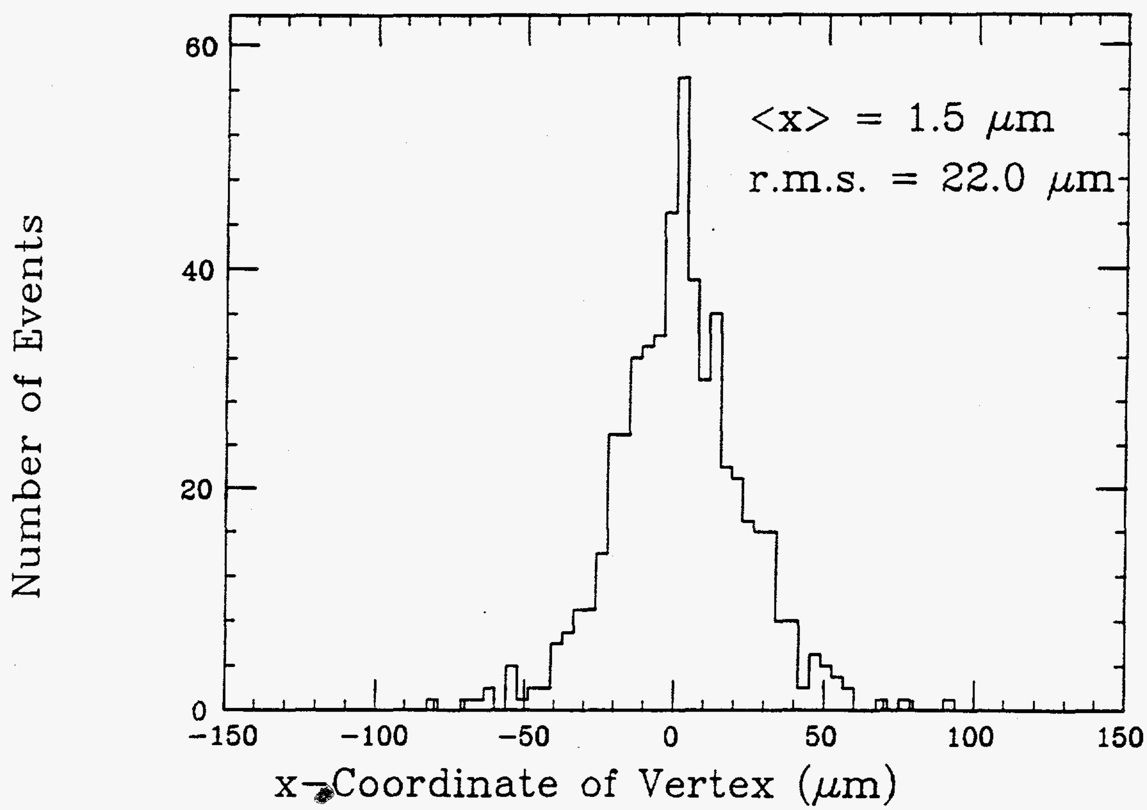


Figure 2

1c) DETECTOR DEVELOPMENT

We are currently setting up a laboratory at Riverside devoted to development and evaluation of high resolution tracking chambers and associated electronics for hadron colliders. Our first task will be to investigate aspects of silicon detectors and readout electronics required to construct a silicon strip vertex detector for D-Zero. In the longer term we plan to progress toward more advanced silicon detector systems for the SSC [1].

DZERO

We plan to evaluate the properties of several designs of silicon detectors, including their leakage currents and capacitance characteristics and the possibility of using capacitively coupled microstrips and devices with strips on both sides of the silicon [2]. These are state-of-the-art detectors and we have already started setting up some of the equipment necessary for their evaluation.

The readout chip for the detectors will require a high density of integration since a total of approximately 50000 strips at a pitch of 50 μm are anticipated for the whole D-Zero detector. This necessitates the use of a custom VLSI CMOS chip such as the Berkeley SVX or the Rutherford Lab MICROPLEX. Low power dissipation (< 2 mW / channel) is required together with, low noise (< 2000 electrons rms), high speed (integration time < 1 μsec), sparse data readout and good radiation hardness. We plan to set up a test bench for evaluation of currently available readout chips and, if necessary, to improve on the current designs to achieve our specifications.

Finally, we anticipate that a significant amount of work will be done to study mechanical support systems for the SMVD. A layer to layer hardware alignment of less than 25 μm in r,ϕ must be achieved and cooling of the heat dissipated by the electronics must be provided to avoid stress and movement of the silicon. Also, we will determine suitable low radiation length materials such as rohacell, carbon fiber, beryllium and aluminum to be used for the mechanical support.

SSC

To address a wide field of physics topics encompassing QCD studies, the Standard Model (and its minimal extensions) and new physics, a detector for the SSC will require a powerful tracking system. Such a system should have good momentum resolution, provide full charged-particle reconstruction for jets in the central region and have the ability to do precise vertex reconstruction.

One system under consideration might consist of a series of silicon detector layers placed around the interaction region together with an outer detector constructed from gaseous drift tubes. Silicon detectors offer extremely good positron and time resolution in addition to the excellent two-track resolution required to resolve particles in the high multiplicity TeV jets at the SSC.

Complimentary to our silicon microvertex detector project for D-Zero we plan to execute a program of research oriented towards developing silicon detectors for SSC applications. This will include studies of;

(a) Double-sided microstrip detectors with stereo strips for the measurement of the z-coordinate. Of particular interest is the overall performance of double-sided detectors (noise, efficiency, radiation hardness) and the resolution for the z measurement.

(b) Radiation hardness of double-sided silicon detectors and their associated readout electronics. This is of special importance at the SSC interaction regions due to the high radiation levels expected.

(c) Aspects of mechanical support structures and cooling for silicon detector systems. The experience which we will gain from the D-Zero SMVD will be carried over to the larger scale problem at the SSC.

(d) Monte Carlo studies of the performance of a tracking system incorporating silicon detectors. This will determine the overall performance of the silicon tracking system. Pattern recognition, momentum resolution, vertex reconstruction and the efficiency for linking of tracks to the outer detectors will be studied to allow optimization of the detector.

References

1.) S.L. Shapiro et al., "Silicon PIN Diode Array Hybrids for Charged Particle Detection", Nucl. Instr. Meth. **A275**, 580, (1989).

2.) P. Holl et al., "Double-sided Silicon Strip Detector with Capacitative Readout and a new Method of Integrated Bias Coupling", IEEE Trans. Nucl. Sci. **36**, 251, (1989).

1d) NUCLEON STRUCTURE FUNCTIONS

At the heart of all calculations of hard scattering cross-sections are parameterizations of the parton distributions functions $q(x,Q^2)$, $q(x,Q^2)$ and $g(x,Q^2)$. These, in turn, are derived from measurements of the Deep Inelastic Structure Functions $F_1(x,Q^2)$, $F_2(x,Q^2)$, and $F_3(x,Q^2)$ and it is on the reliability of these measurements on which the parton distribution functions depend.

In general the experimental data are in quite good agreement with the exception of the region of small Bjorken x ($x<0.2$) where significant discrepancies exist. This is particularly unfortunate as this is the most important kinematic region for calculations pertaining to cross-sections at the Tevatron and SSC.

As a part of an ongoing study of the deep inelastic data we are investigating two of the principal experimental datasets - those of the EMC and BCDMS Muon Collaborations at CERN. It is the inconsistencies between these two sets of data which give rise to some of the largest uncertainties in the parton distributions.

The EMC and BCDMS have published high precision measurements on the structure function $F_2(x,Q^2)$ measured using hydrogen [1,2], carbon [3] and iron targets [4]. Here we consider only the hydrogen data. The same basic problems are also present in the other datasets. The raw datasets are compared in Fig.1 from which it can be seen that, in terms of their broad characteristics, the data agree. The Q^2-dependence of $F_2(x)$ is the same for both experiments as can be seen in Fig.2 . The x-dependence, however is different and if we plot the ratio of the two sets of data at a fixed value of Q^2 (Fig.3) a clear difference becomes visible. This difference is inconsistent with the statistical and systematic errors quoted by the two groups.

A preliminary study of the analysis methods used by the two groups shows that there are few differences in terms of either theoretical input or method . The fact the the Q^2-dependences are the same makes the problem all the more difficult to understand. Further work in this direction is in progress.

We do however, have one more set of data with which we can compare these experiments and that is the electron data from the SLAC A and SLAC-MIT groups [5]. While there is little kinematical overlap with the two CERN groups the data do provide an independent measure of the x-dependence of F_2. We have re-analyzed the data from these two groups and the results are show in Fig.1. To make a proper comparison we need to Q^2-evolve the SLAC data into the EMC/BCDMS region using QCD. This has not yet been completed. Preliminary indications are, however, that the x-dependence of the SLAC data is similar to that seen in the EMC data and is not consistent with the BCDMS measurements.

We plan to continue this work with the aim of resolving some of the discrepancies in the data and producing a better set of parton distribution parameterizations for use in QCD calculations.

References

1.) J.J. Aubert et al., Nucl. Phys. **B259**, 189, (1985).
2.) A.C. Benvenutti et al., CERN-EP/89-06, (1989).
3.) A.C. Benvenutti et al., Phys. Lett. **195B**, 91, (1987).
4.) J.J. Aubert et al., Nucl. Phys. **B272**, 158, (1987).

5.) J.S. Poucher et al., Phys. Rev. Lett. **32**, 118, (1974).

A. Bodek et al., SLAC-PUB-132 , (1974).

A. Bodek et al., Phys. Rev. **D20**, 1471, (1979).

W.B. Atwood et al., Phys. Lett. **64B**, 479, (1976).

M.D. Mesatayer Ph.D Thesis, SLAC Report 124, (1978).

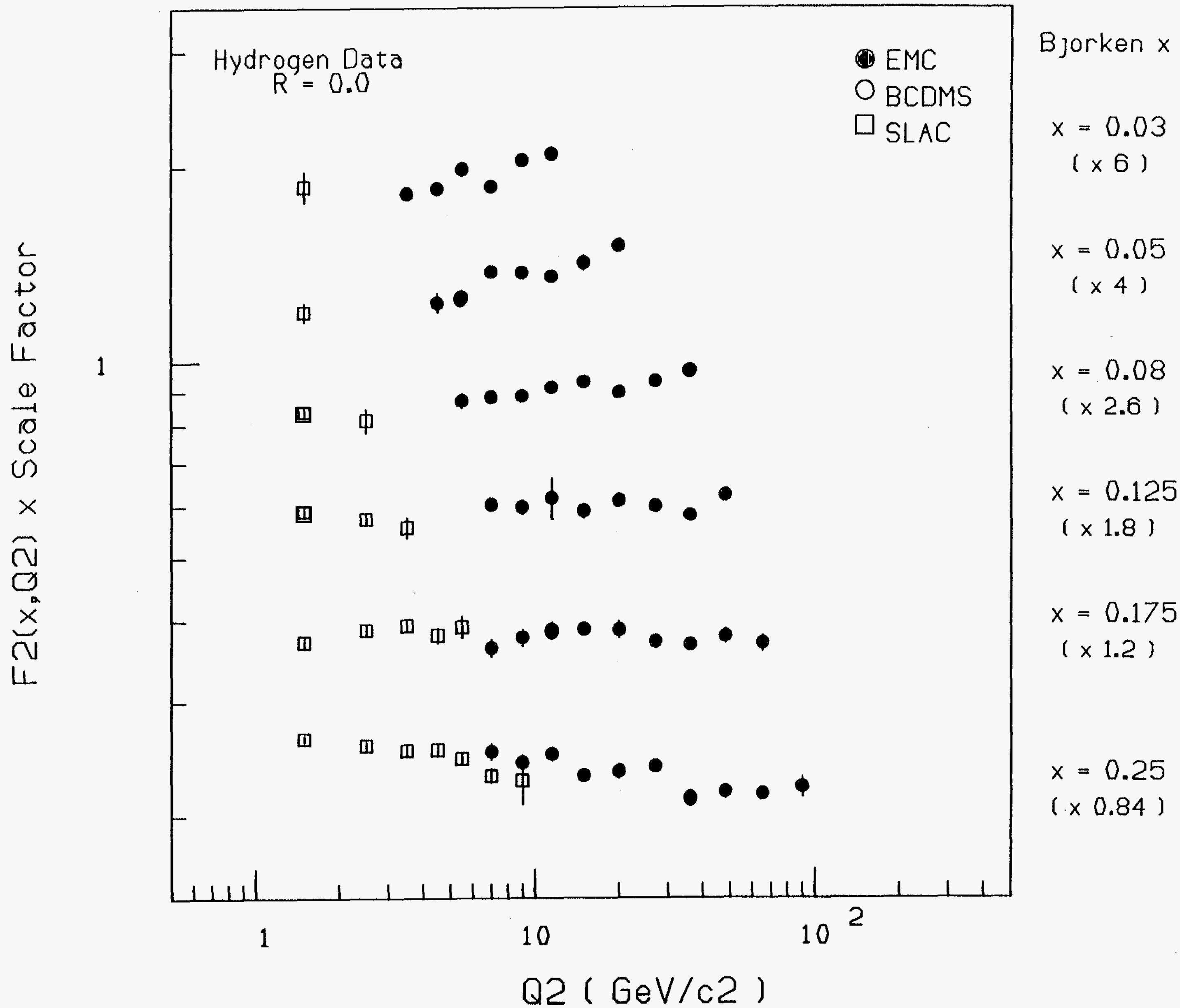

Hydrogen Data
R = 0.0
EMC
BCDMS
SLAC
Bjorken x
x = 0.03
(x 6)
x = 0.05
(x 4)
x = 0.08
(x 2.6)
x = 0.125
(x 1.8)
x = 0.175
(x 1.2)
x = 0.25
(x 0.84)
F2(x,Q2) x Scale Factor
1
1
10
10 2
Q2 (GeV/c2)

Figure 1

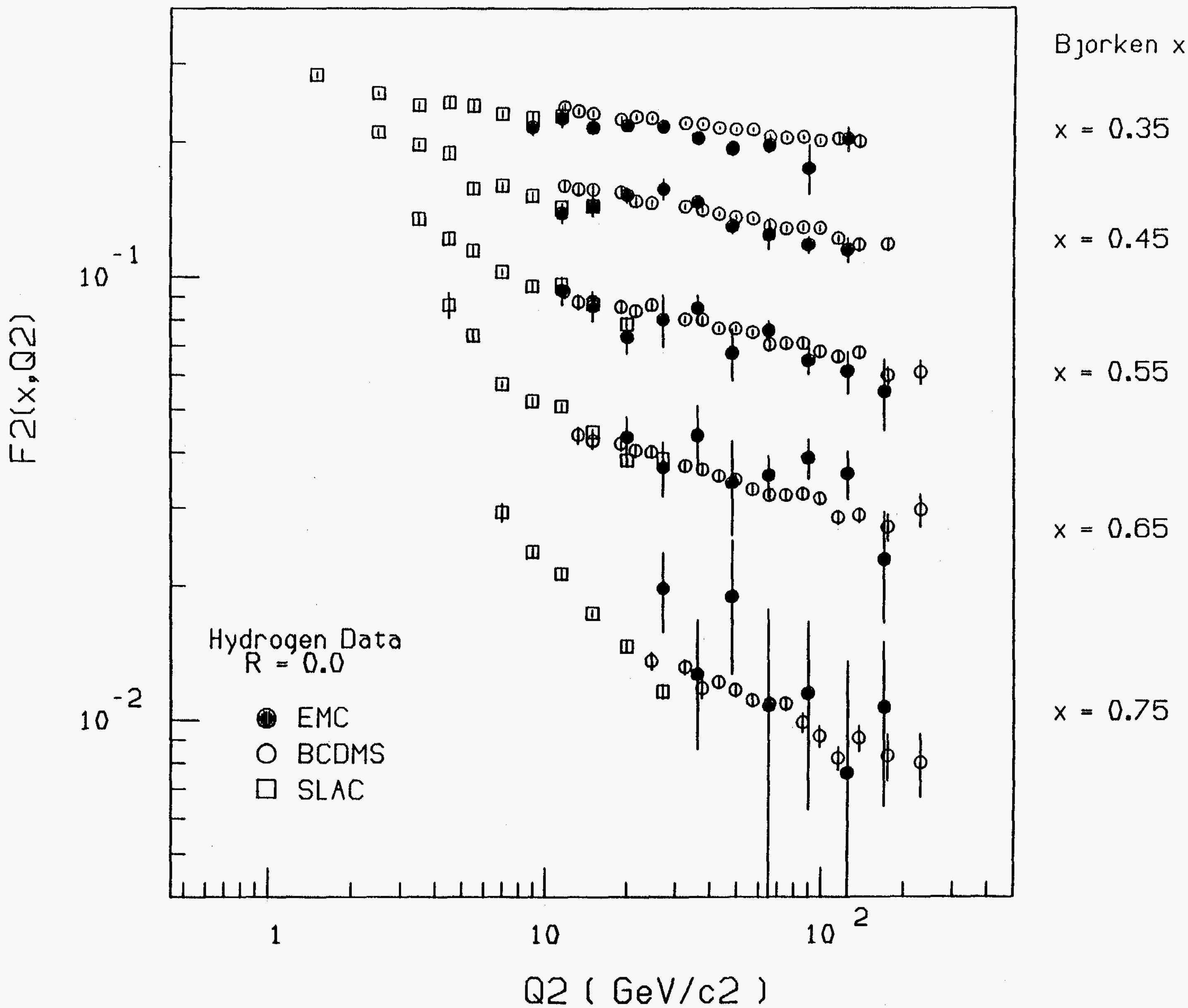


Figure 1 (cont.)

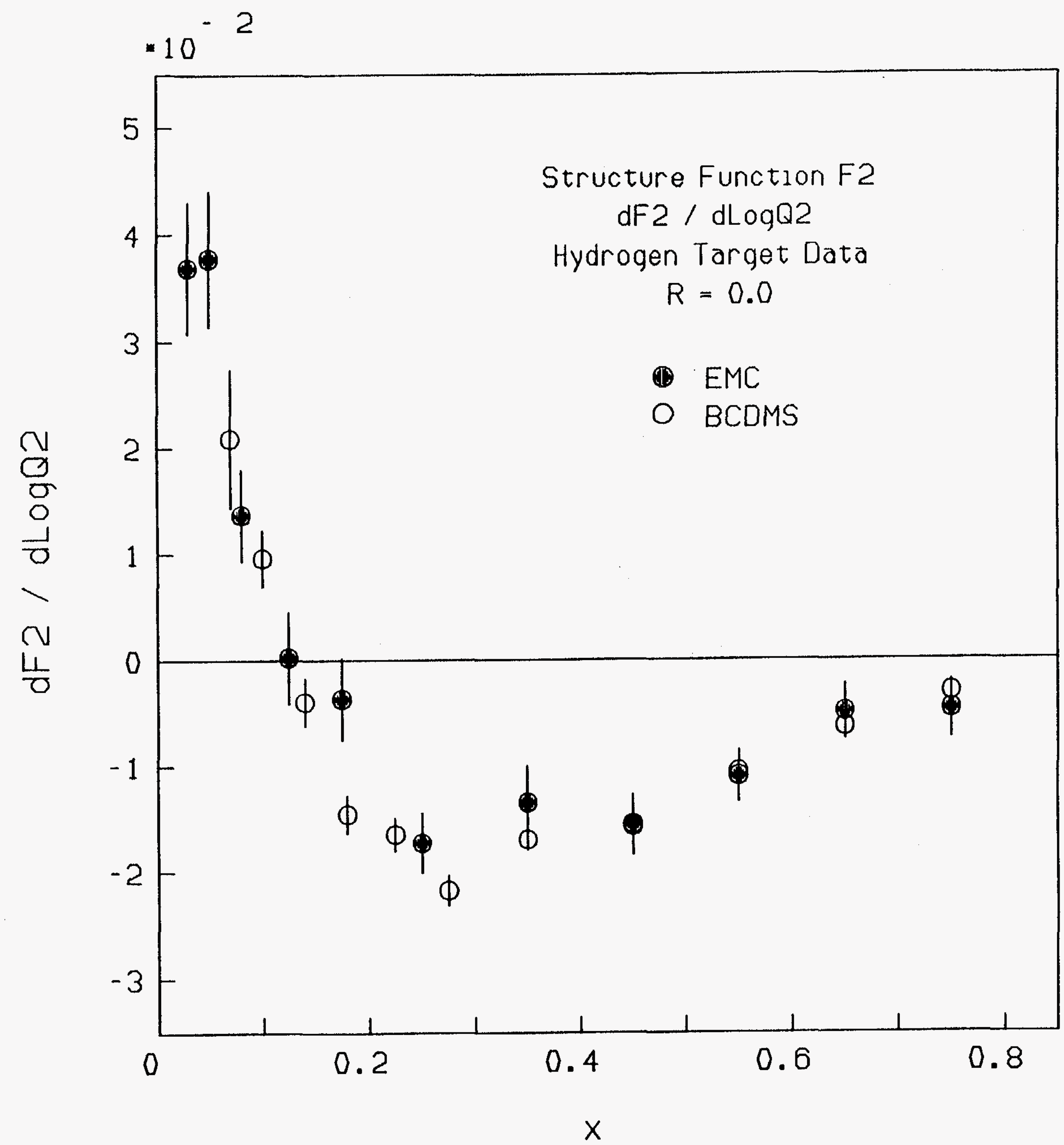

*10^- 2
Structure Function F2
dF2 / dLogQ2
Hydrogen Target Data
R = 0.0
EMC
BCDMS
dF2 / dLogQ2
5
4
3
2
1
0
-1
-2
-3
0
0.2
0.4
0.6
0.8
X

Figure 2

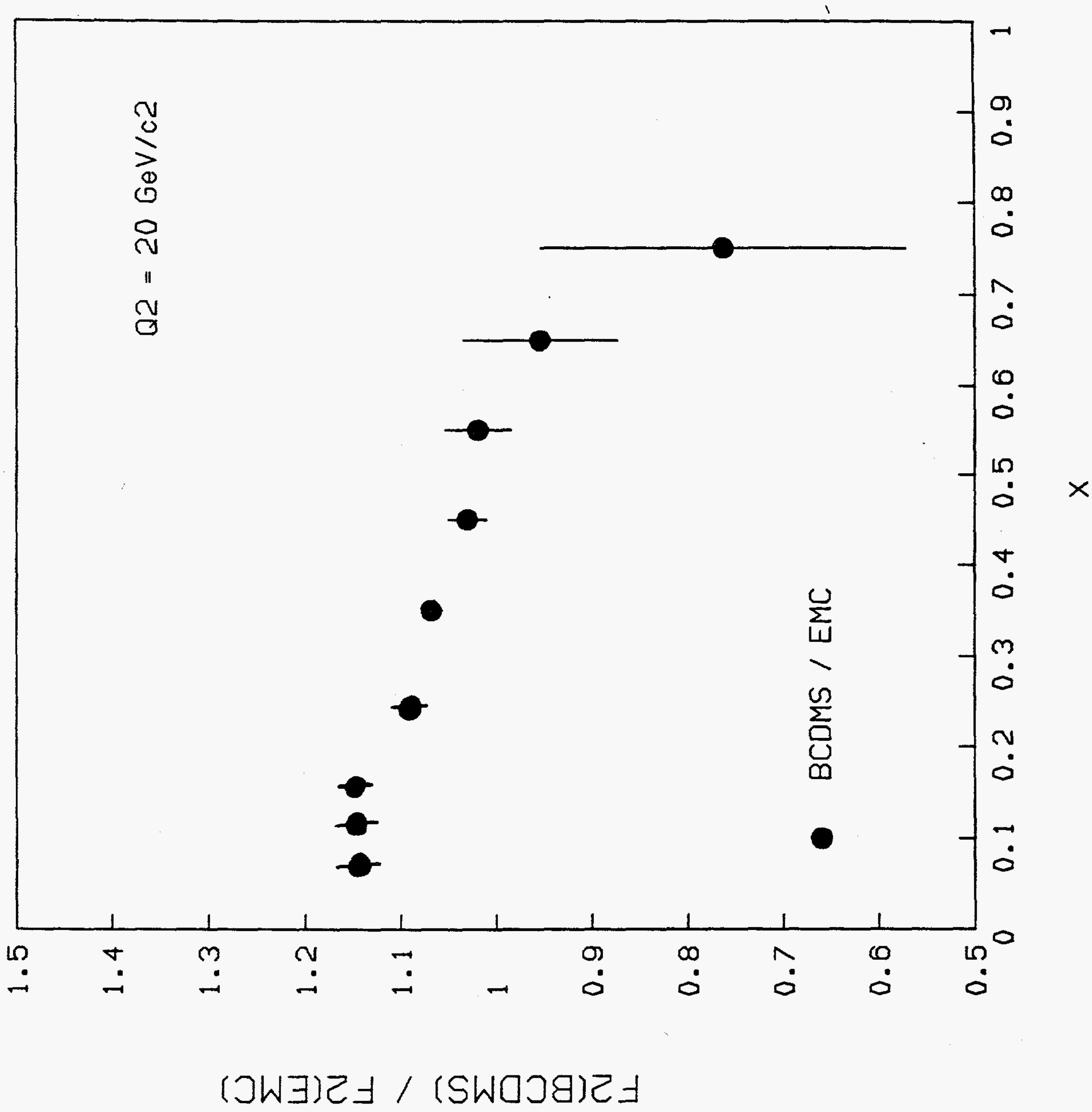

Q2 = 20 GeV/c2
BCDMS / EMC
F2(BCDMS) / F2(EMC)
X
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Figure 3

Personnel - Hadron Collider Physics

Ph.D.'s

J. Ellison	:	post graduate researcher
A. Kernan	:	professor
D. Smith	:	assoc. research physicist
S. Wimpenny	:	assistant professor
M.-J. Yang	:	post graduate researcher
To be named	:	post graduate researcher

Graduate Students

D-ZERO	UA1
K. Bazizi	D. Joyce
R. Hall	M. Lindgren
D. Franks	
K. McIlhenny	
T.P. Wu	

Undergraduate Students

T. Fahland

S. Jerger

C. Lietzke

(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. The TPC/Two-Gamma experiment has contributed significantly to our understanding of the annihilation and two-photon processes. Since 1984 we have been a member of the OPAL collaboration participating in the construction of the OPAL detector. The initial physics run at LEP is scheduled for the Fall of 1989 after a pilot run in early August. About one million Z^o events will be collected during 1990 for detailed studies of the Standard Model and the physics beyond. As the continuation of earlier work in neutrino oscillation, we have began participation in the preparation of a proposed experiment at Los Alamos. The first engineering run is expected to take place in 1992.

(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 excellent particle detection capabilities.

A total of 160 pb^{-1} of data has been collected during the first phase of operation. Three graduate students have already received their Ph.D's with this data. The detector, with upgraded inner tracking capabilities, has been used to collect about 20 pb^{-1} of data during the initial high luminosity operation of PEP during 1988-89.

The production of hadrons in two photon interactions is of considerable interest. In the point-like regime, hadron production proceeds via the production of a pair of quark and anti-quark. The production cross section is proportional to the 4th power of the quark charge. This is in contrast to the 2nd power dependence on the quark charge in the annihilation process. As a result, the relative contributions of the strange quark and the charm quark are quite different in these two processes. Willis Lin has carried out a detailed study of hadron production in two photon interactions. He will be completing his thesis during the 1989-90 contract period. A paper is being prepared for publication in Physical Review Letters.

It has been well-recognized that two photon interactions provide excellent opportunities to carry out experimental measurements of the radiative widths of meson with even charge conjugation parity. Mourad Daoudi has carried out a detailed study of the production of f'(1515) and its subsequent decay into two K^o's. He is also studying the K^+K^- final state for further comparison. He has reported the results of his work at the 1989 APS Spring Meeting in Baltimore. It is expected that he will complete his thesis during the 1989-90 academic year.

The high luminosity running at PEP began in the Fall of 1988. Due to the high priority of SLC, PEP operation has been very limited. During the 1988-89 running cycle, TPC/Two-Gamma accumulated only 20 pb^{-1} of data. It has been shown that with 250 pb^{-1} to 1000 pb^{-1} of data, TPC could provide interesting measurements on tau decays, quark fragmentation studies, and two photon physics. The plan for the next two years is (i) to test switching for the simultaneous running of SLC and PEP, (ii) to accumulate at least 50 pb^{-1} of data during 1989, and (iii) to accumulate an integrated luminosity of 300 pb^{-1} by the end of 1990. Since all hardware tasks have been completed, all efforts will be focused on data processing and physics analysis.

Personnel

The physicists who will continue to participate in this experiment are John Layter and Benjamin Shen. Graduate students Willis Lin and Mourad Daoudi are analyzing existing data and are approaching the completion of their Ph.D requirements. Two other students, Chili Ho and Heungmin Oh had been working on various aspects of the TPC/Two-Gamma experiment since 1988 anticipating to carry out their thesis research with the high luminosity data. However, since the accumulation of luminosity has been much slower than expected, they have been re-assigned to work on the OPAL experiment at CERN. When more data is taken at PEP another student may be assigned to the TPC/Two-Gamma experiment.

(b) OPAL Experiment at LEP

The OPAL Collaboration, comprising 22 institutions from 9 countries 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. LEP is scheduled for commissioning on July 15, 1989. A pilot run is scheduled for a duration of 3 to 5 days at the beginning of August. The first extended physics run of six weeks will begin in late August and yield several pb^{-1} of high quality data.

The OPAL Detector

The OPAL detector has been under development and construction for over six years and is now nearing completion in LEP at interaction region I6. During the past year all the elements of the detector have undergone final tests to fix their operating parameters and to determine their response. We include here an extensive report on the principal detector element, the central detector, and on the hadron calorimeter, on which the Riverside group has concentrated its hardware effort. Briefer updates on some of the other detector elements are also included.

The Central Detector

The central tracking chamber of the OPAL detector consists of three elements, a high resolution vertex chamber, a pictorial drift chamber of the "jet chamber" type, and the Z chambers. The vertex detector is used to identify decay vertices of short lived particles and to improve the momentum resolution. The jet chamber records the tracks of charged particles over nearly the entire solid angle and provides the principal measurement of momentum. Particle identification is done by multiple sampling of dE/dx energy loss. The measurement of up to 159 points per track and an excellent two-track resolution guarantee a high tracking efficiency. The Z chambers, mounted around the outer mechanical support of the jet chamber, are used to obtain a precise measurement of the z coordinate of the tracks, thereby enhancing the mass resolution.

The OPAL vertex detector is mounted immediately outside the carbon fiber beam pipe of 1.4mm thickness and is separated from the jet chamber by another carbon fiber pipe of the same thickness. The detector is a mini jet chamber, with eleven layers of axially oriented sense wires followed by five more stereo layers to provide a high precision measurement of the z position near the inner radius. Stand-alone tests with a mixture of equal volumes of argon and ethane (fast gas) resulted in resolutions of 55 microns while a mixture of four parts CO_2 to one of isobutane (slow gas) leads to resolutions on the order of 30 microns.

The jet chamber is designed to combine good space and double track resolution with particle identification for almost the full angular range. The sensitive volume of the jet chamber is a 4 m long 3.7 m, the inner one 0.5 m. The chamber is divided into 24 identical sectors, each containing a sense wire plane with 159 sense wires and two cathode wire planes which form the boundaries between adjacent sectors. All wire planes are oriented in radial direction. True three-dimensional coordinates (r, ϕ, z) are determined from the wire position, the drift time and from a charge division measure. The signal wires are staggered by 100 microns in order to resolve the left/right ambiguities. The chamber is operated with a three-component gas mixture of argon (88%), methane (9.4%) and isobutane (2.6%) at a pressure of 4 bar. Low noise preamplifiers are mounted on the end plates close to the points where the anode wires are attached. Signals are recorded with 100 MHz flash analog-to-digital converters (FADCs) and stored in fast memories 256 and

1024 samples deep to provide the necessary time range depending on the drift distance. The valid data from all 80 front end FADC crates is transferred to 20 microprocessors residing in two VME crates for further data reduction (Fig. 2.1).

The space resolution in the r-phi plane is shown in Fig. 2.2 as a function of the drift distance. The average resolution in r-ϕ is 120 microns. The efficiency to find two adjacent hits reaches 85% at 2 mm hit separation. The space resolution in the z-direction, as obtained from charge division, is 1% of the wire length. The overall momentum resolution has contributions from the measurement errors in r-ϕ, the multiple scattering, and systematic sagitta errors. The sagitta error for particles with momenta of 6 to 50 GeV/c is less than 30 microns, and the systematic error is less than 30 microns. At low momenta the resolution is limited by multiple scattering to 2%, whereas at high momenta the main limitation originates in systematic errors. The very successful tests with the laser calibration make it possible to reach a resolution of dp_T/p_T = 6% for p_T = 100 GeV/c. In Fig. 2.3 the energy loss dE/dx of electrons, pions, kaons, and protons is plotted as function of momentum together with the expected energy loss. Using the 159 measured samples per track a truncated mean is calculated providing a dE/dx resolution of 3.5%.

The OPAL Z chambers are arranged to form a barrel around the Jet chamber covering continuously the polar angle from 44° to 136° and 95% of the azimuthal angle. They are designed to make a precise measurement of the z coordinate of charged particles as these leave the central detector and thus to improve both the polar angle and mass resolution. The Z chambers consist of 24 drift chambers that are 4 meters long, 50 cm wide and 59 mm thick. Each chamber is divided into 8 bidirectional cells of 50 cm by 50 cm, so that the maximum drift is about 25 cm. The Z chambers use the same gas as the jet chamber. Each cell has six wires with 4 mm spacing and a stagger of 250

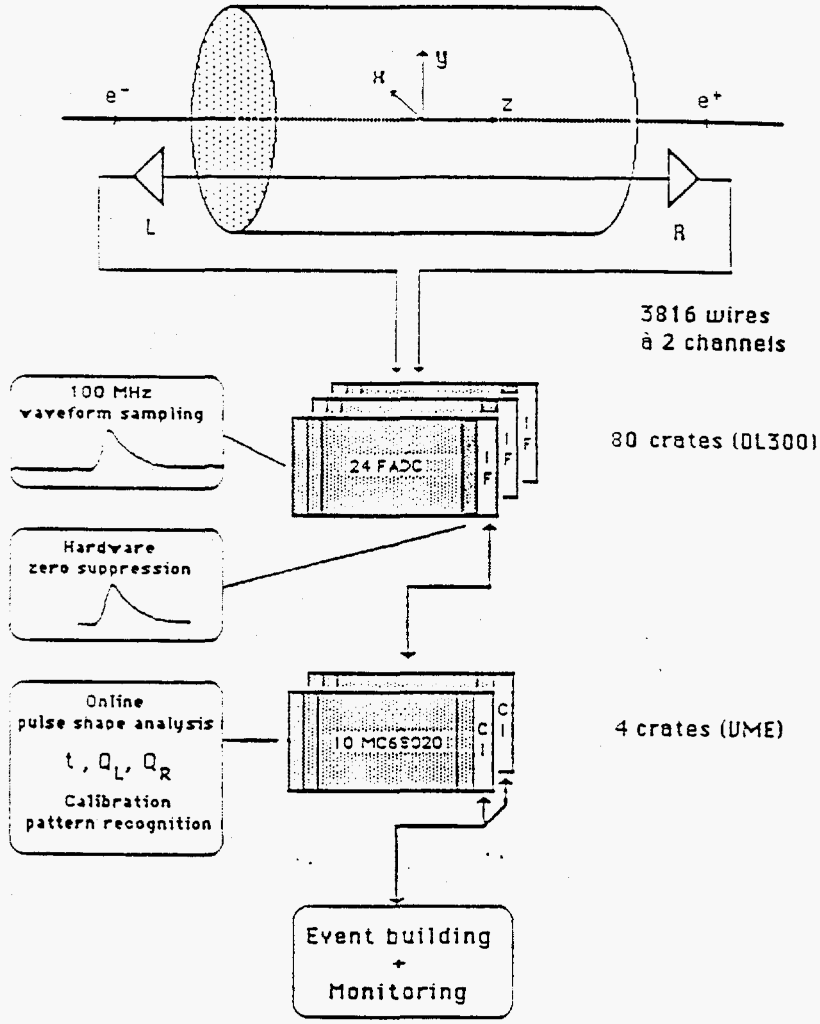


Fig. 2.1 OPAL Data Readout and Reduction

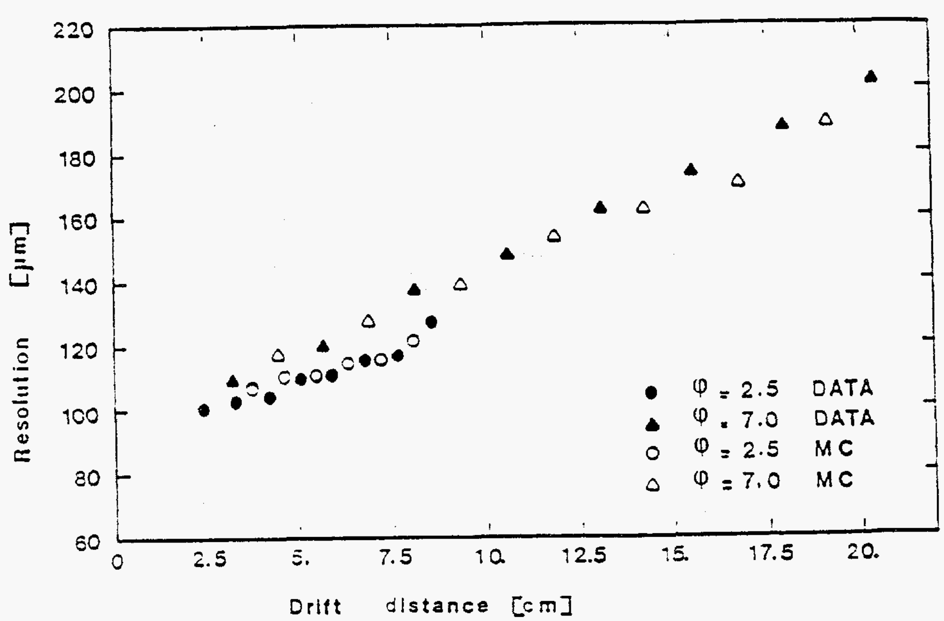


Fig. 2.2 Spatial Resolution of the Central Jet Chamber

microns to resolve the right/left ambiguity. The intrinsic z resolution, for minimum ionizing particles normal to the drift direction, varies from 100 microns to 200 microns the range of drift distances. The absolute resolution is determined by the precision of the surveying, and is expected to be around 300 microns.

A combined test of all three components of the central detector show the capability of these elements to make a consistent measurement of a track passing through all three of them, as shown in Fig. 2.4. Several thousand cosmic ray tracks recorded during this combined test at the beginning of the year are currently being used to adjust calibration constants and to fix relative detector positions.

The Hadron Calorimeter

The OPAL hadron calorimeter uses layers of streamer chambers to instrument the magnet return approximately one meter thick. This detects and measures the energy of hadrons emerging from the lead glass and also acts as a segmented muon filter. The solid angle covered by four or more interaction lengths is 97% of 4π. It is divided into barrel, endcap, and poletip sections as shown in Fig. 2.5. The poletip section has been developed by the Israeli groups and will not be discussed here.

The barrel consists of 24 "wedges" each covering 15° in ϕ. Each wedge weighs nearly 80 tons and consists of nine layers of chambers, alternating with eight iron slabs, each 10 cm thick. The barrel is closed at each end by doughnut shaped endcaps, where eight layers of chambers alternate with seven slabs of iron, also 10 cm thick. Since there is a high probability of hadronic interactions being initiated in the 2.2 interaction lengths of material in front of the calorimeter, the overall hadronic energy has to be determined by combining the lead glass and hadron calorimeter signals.

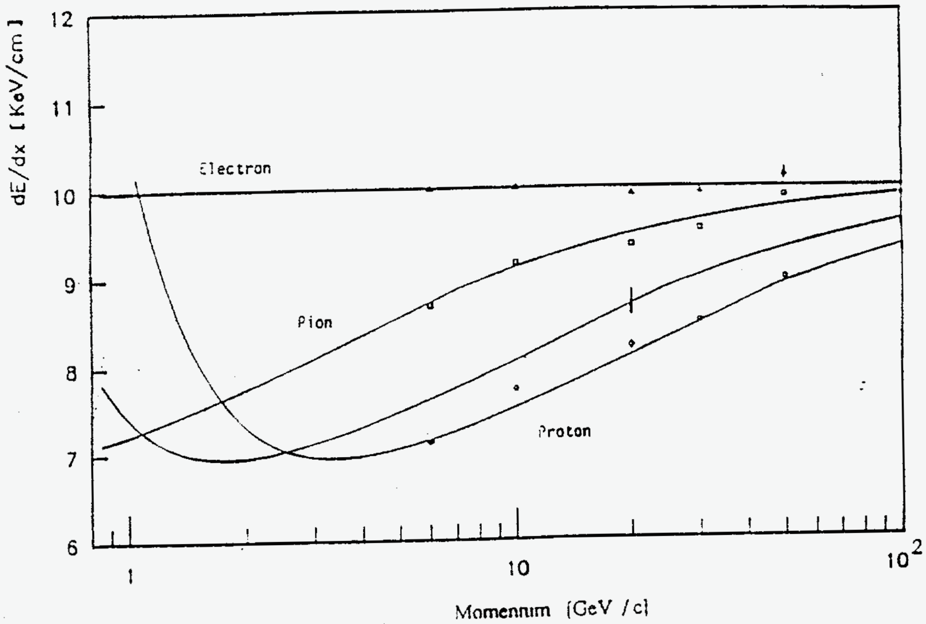


Fig. 2.3 dE/dx Measurements with the Central Jet Chamber

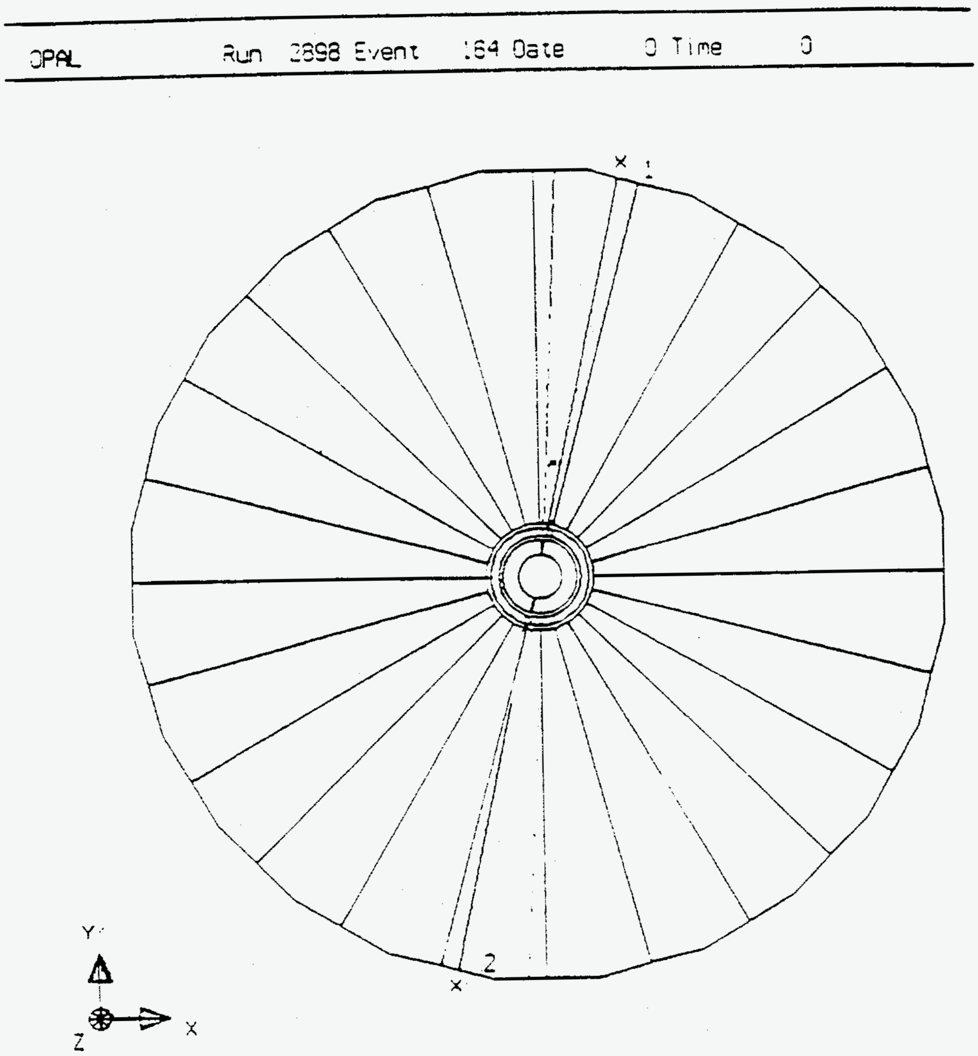


Fig. 2.4 Cosmic Ray Event Taken During the Central Detector Combined Test

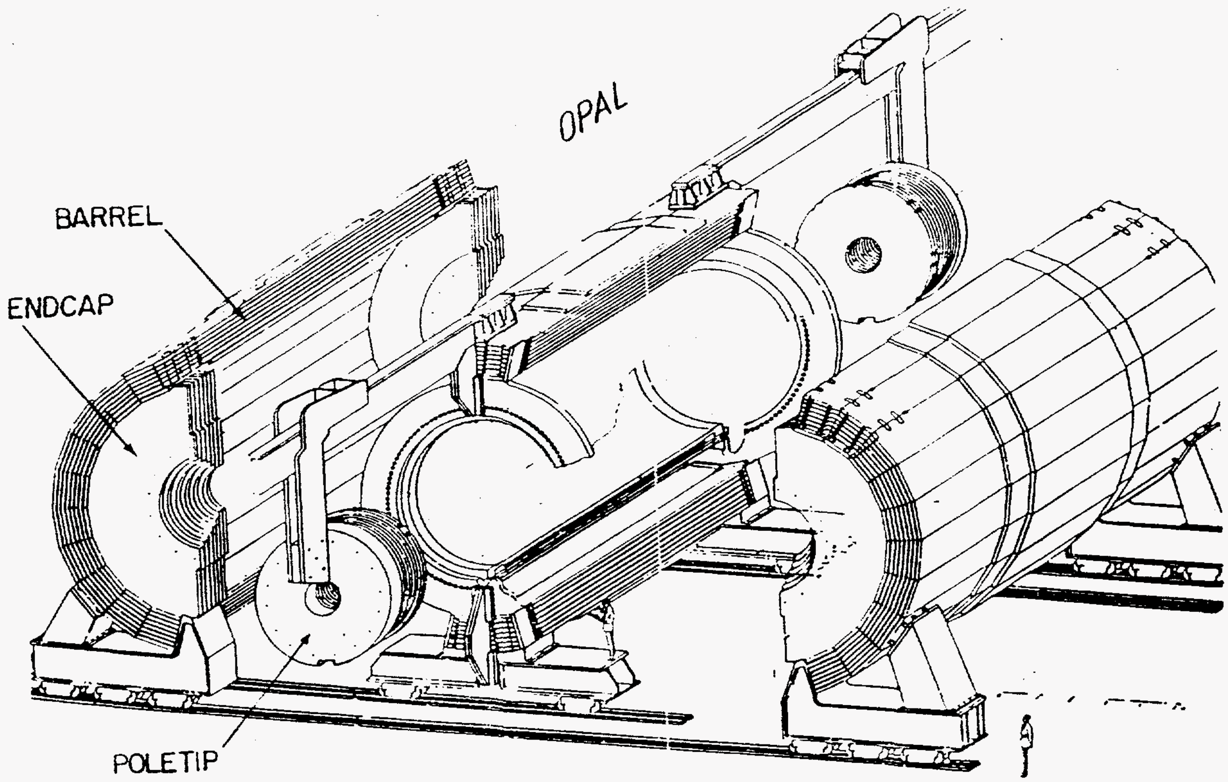


Fig. 2.5 OPAL Hadron Calorimeter

The multi-cell plastic chambers which form the active elements of the detector layers are based on the Iarocci design developed in INFN Frascati. The inside surfaces of each cathode cell are coated with emulsified graphite to produce a surface with a resistance in a range between 0.1 and 5 megohms per square. Subsequent treatment of the surface with BREOX, a polyalkylene glycol, was found to dramatically improve the stability of chamber operations with no deleterious side effects. A voltage of about 4.8 KV is applied to the anode wires. The chambers operate in a mixture of 75% isobutane, 25% argon.

Signals are read out capacitively through both upper and lower faces of the chambers. On the bottom, i.e., at the inner radius of the barrel, they are induced onto large area pads roughly 50 by 50 cm. On the top, they are induced through the gas envelope onto 4 mm wide aluminum strips which run down the full length of each cell and are centered over the wires. The pads are arranged to form projective towers, a total of 976, pointing to the interaction point. Locally mounted analog summing amplifiers add the signals induced on the separate layers of a tower. The resulting summed charge is a measure of the hadronic energy deposited in that element of solid angle. A typical hadronic shower initiated by a normally incident 10 GeV pion produces about 30 strip hits and generates a charge of about 900 pC. The charge from the innermost layer of each tower is recorded separately to assist in the interpretation of anomalously high signals in the lead glass.

There are approximately 56700 individual strips in both barrel and endcaps. Strip signals above a remotely adjustable threshold of about 6 mV are latched into a locally mounted 864 channel shift register. There are 72 such registers, and on receipt of a trigger signal, these simultaneously read their complement of strips into corresponding memories in their readout controllers in the electronics huts. After zero suppression, the memories are read sequentially into the memory of the local data acquisition microprocessor. The strip production and the design and implementation of the readout electronics have been carried out by members of the Riverside group.

During the past year, several calorimeter modules have been exposed to test beams to investigate and optimize the detector parameters and to develop simulation programs. In Fig. 2.6, the average response of a tower to a pion beam is given as a function of beam momentum, together with predictions of the Monte Carlo simulation. An energy resolution of $120\%/\sqrt{E}$ has been measured for both the strips and the towers. The muon finding capability of the strips is illustrated in Fig. 2.7. The two top panels of the figure are from a pion beam at 6 GeV/c. They show clear hadronic activity in the strips (although a muon has snuck into the left panel at the top). The bottom panels are from a 5 GeV/c run using a muon trigger. The left panel shows at least one muon, while the right panel indicates that the muon identification is questionable. Physicists from the Riverside group are using these test runs to tune this "clustering algorithm" in time for data taking.

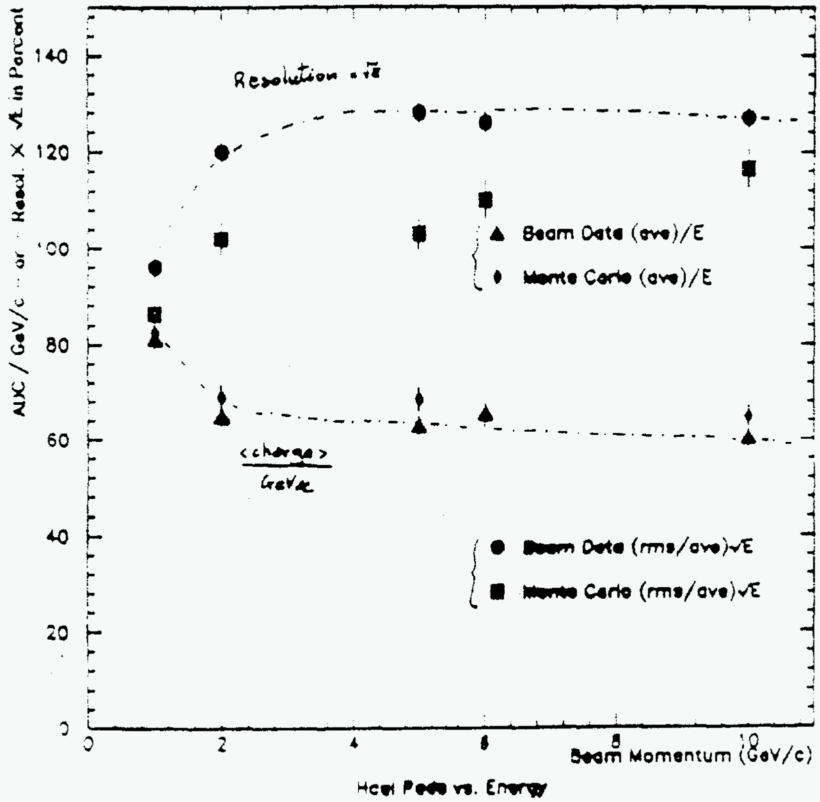


Fig. 2.6 Hadron Calorimeter Energy Resolution

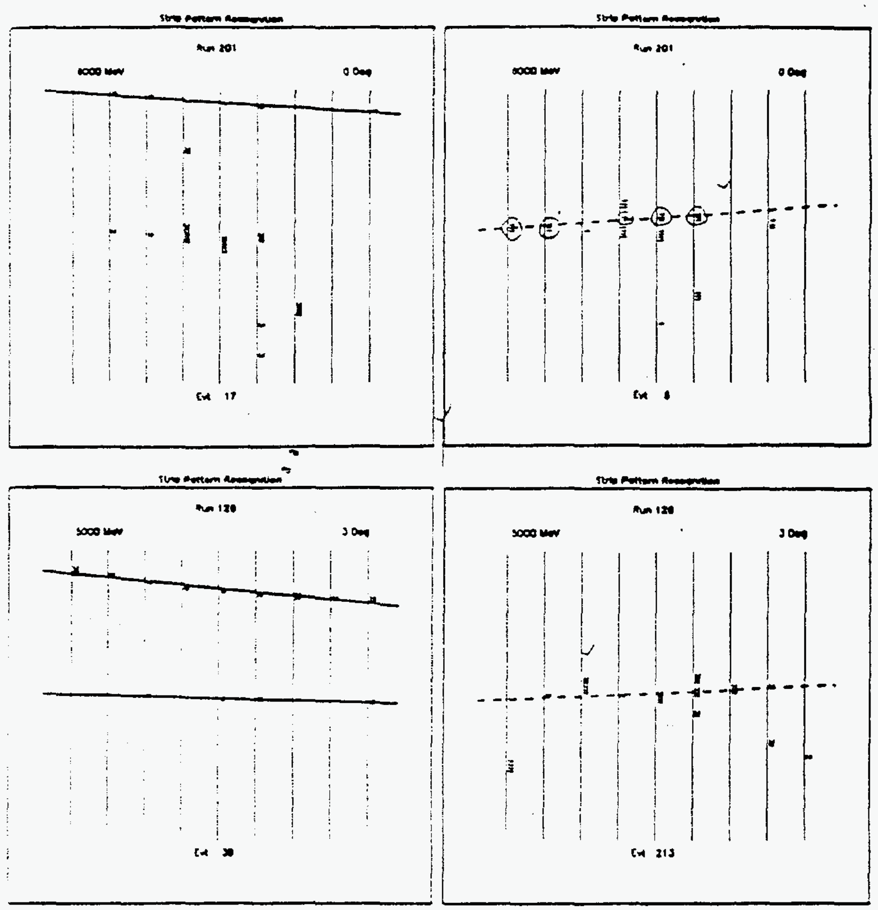


Fig. 2.7 Events from Fall '88 Beam Test. Strip event displays from test of HSCLMU and HSCLUS. Beam enters from left (layer 1). Hit strips are indicated by their cluster class number. "Clean" μ fits are shown as solid lines. "μ fits with too many nearby hits are shown as dashed lines.

Other Detector Elements

The barrel portion of the electromagnetic calorimeter, in charge of the Tokyo group, has been completed for several years and has been calibrated in test beams twice over a two year period. Last year's report discussed the long and short term stability of this system. During the past year the completed modules have been installed in the detector and the data acquisition system has been checked in cosmic ray runs and found to work well, as shown by the cosmic ray tracks fitted to block hits in Fig. 2.8.

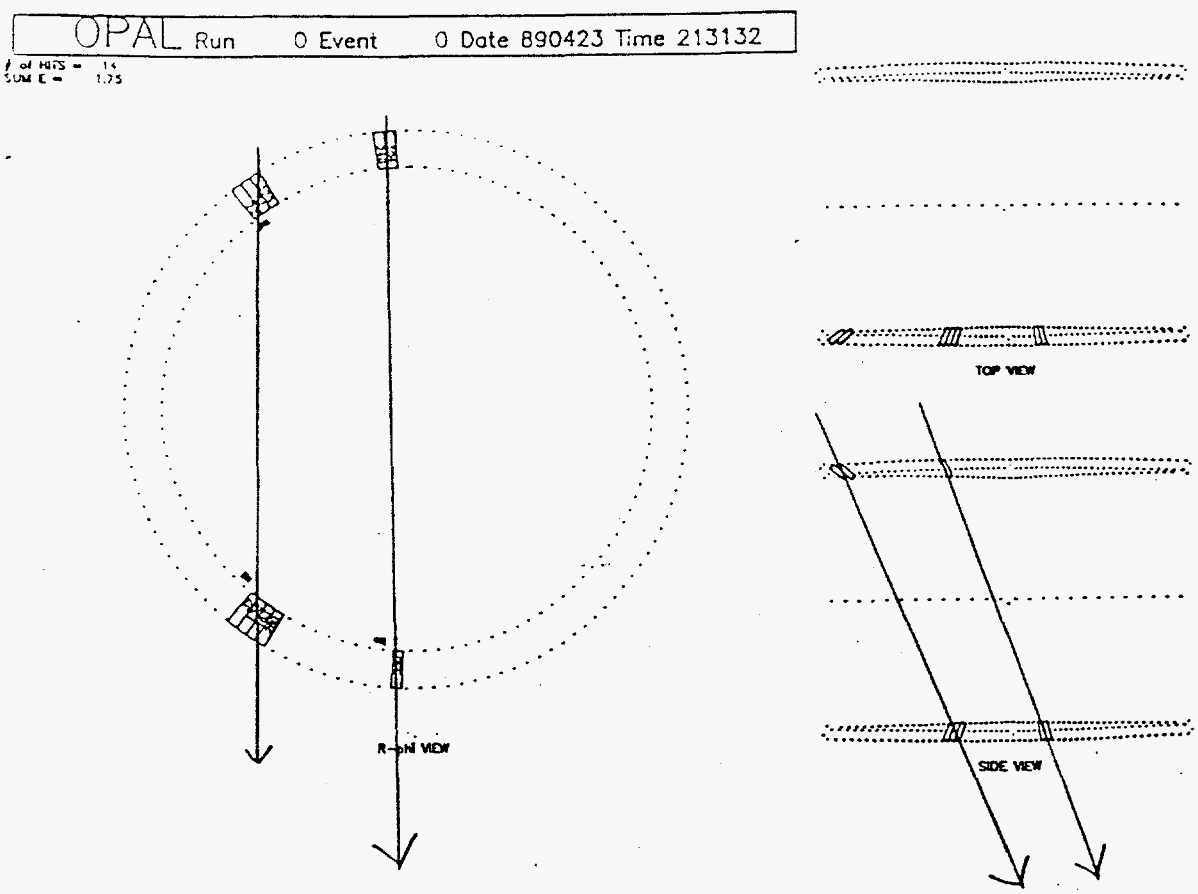


Fig. 2.8 Cosmic Ray Event in Lead Glass Barrel

The forward detector, involving a variety of tracking and calorimetric elements, has been completed, assembled, and tested in beams during the last several months. A very precise evaluation of the efficiency of the detector as a function of minimum angle has been obtained from these tests, and it seems that it will be possible to lower the estimates of the error on the luminosity measurement which this subsystem provides.

The OPAL Data Acquisition System

Data acquisition for detectors of the magnitude of those found at LEP constitutes a formidable problem. The general solution to the problem has been found in two basic principles of data acquisition architecture: distributed processing capability, and tree structured organization to take advantage of processing parallelism. To these OPAL has added a third principle of utilizing the industry standard VME bush structure.

An overall block diagram of the system is shown in Fig. 2.9, which indicates the 16 OPAL detector elements entering at the bottom. One such system is the hadron calorimeter strip readout, designed by William Gorn of the Riverside group. This system, shown in Fig. 2.10, is for the most part assembled from VME building blocks common to all detector elements. Its distinguishing element, the UCRCON module, handles the readout of the 57000 strips. Thirty-six of these modules, eighteen on each side of the detector, process the data coming in from the shift registers on the front end electronics on the 24 wedges of the barrel and the 8 quadrants of the endcaps. The zero-suppression function of the modules reduces this vast amount of data -- the largest number of channels of any OPAL detector element -- to the few hundred strips actually hit in any given event. Several error checking functions, built into the modules and called into play during breaks in data taking, ensure proper functions of the readout at all times.

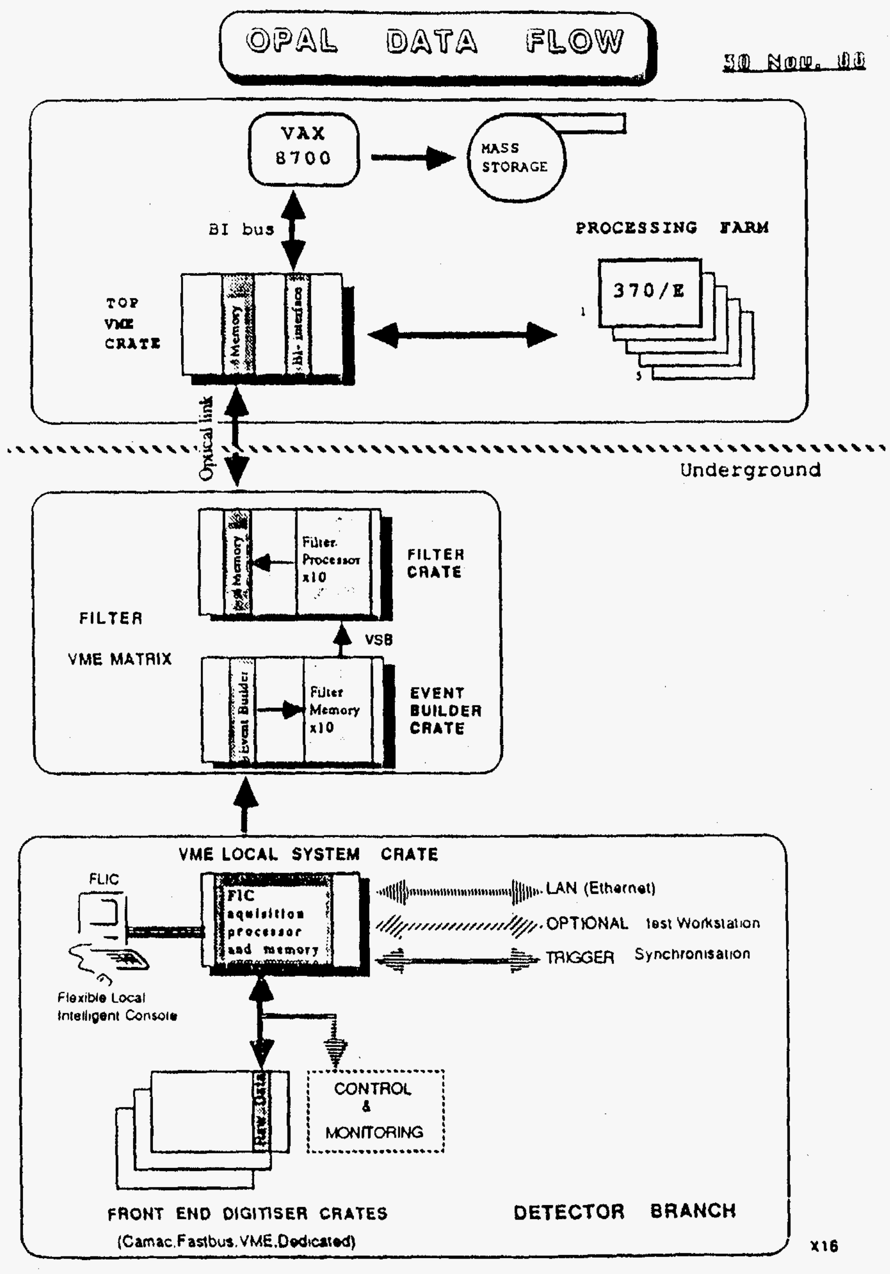


Fig. 2.9 Data Acquisition System Overall Structure

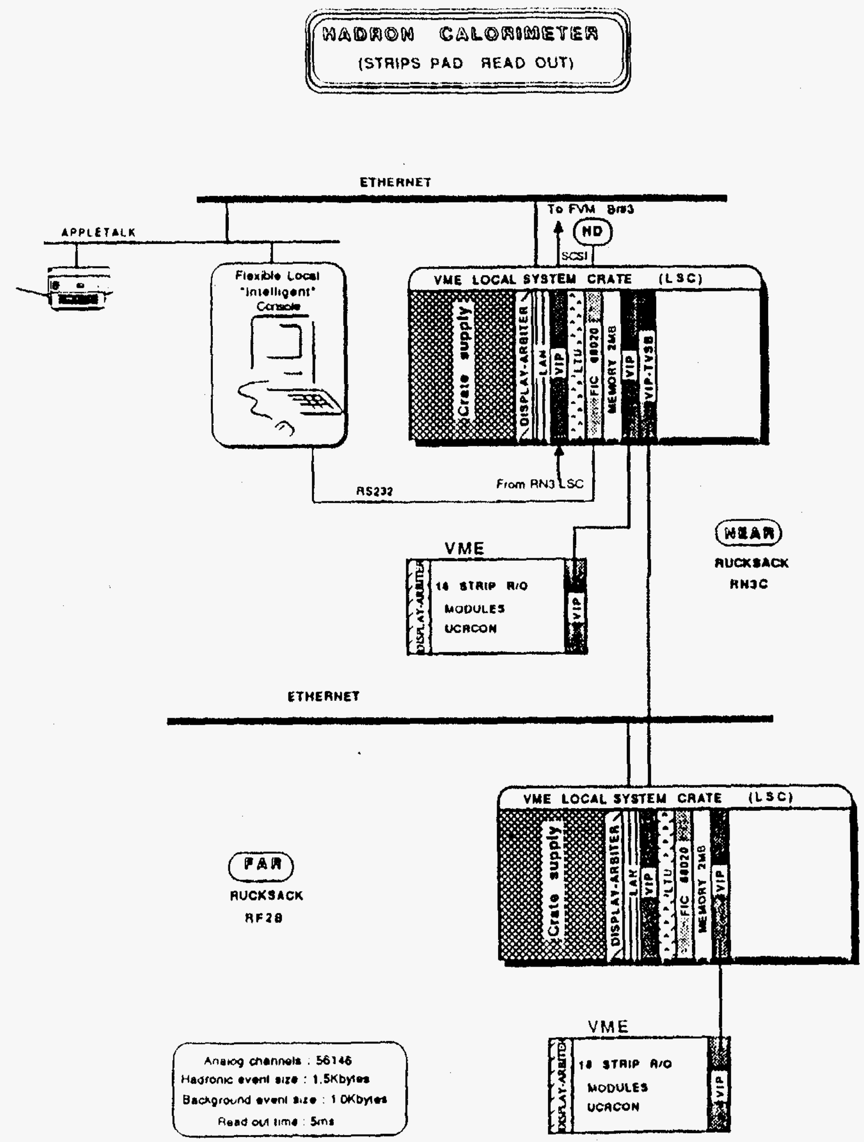


Fig. 2.10 Hadron Calorimeter Strip Readout

Following the data flow chain upwards from the parallel readout of the individual detectors, one reaches the event builder crate, shown in Fig. 2.11, which assembles coherent events from the information arriving from each of the 16 sources. The line continues through the event filter, which will flag several types of events of interest to facilitate their expeditious processing, and eventually discard junk events once its function has been proven by comparison with offline analysis. Michael Dittmar of the Riverside group has played a major role in the development of the filter concept and its software implementation.

The elements described up to this point reside in the underground experimental hall. The flagged and filtered events are then sent up over a 4 Mbyte/sec optical link to the surface control area where they are first parcelled out to the 370/E emulators for full or partial reconstruction before being recorded on tape cartridges. The data recording function is handled by the VAX 8700, provided to the Collaboration by the Riverside group. IBM-compatible 3480 cartridge drives have recently been added to VAX cluster, as shown in Fig. 2.12, since this medium has become the CERN standard during the past year. The 8700 also provides the experiment with all run control functions and assembles and maintains the calibration data base.

The software side of the data acquisition system represents as large an effort as the hardware elements described above. The OPAL strategy has been to rely as much as possible on the MODEL data acquisition system, developed by the CERN DD division to provide run control and data manipulation functions in the VAX environment, and on the OS9 operating system, a commercial product for VME based processors. Integrating all 16 detector systems into this overall data acquisition structure is currently the main focus of the OPAL group. Subsets of the full system have already operated harmoniously in tests, and additional functionality will be added incrementally in a continuous improvement effort.

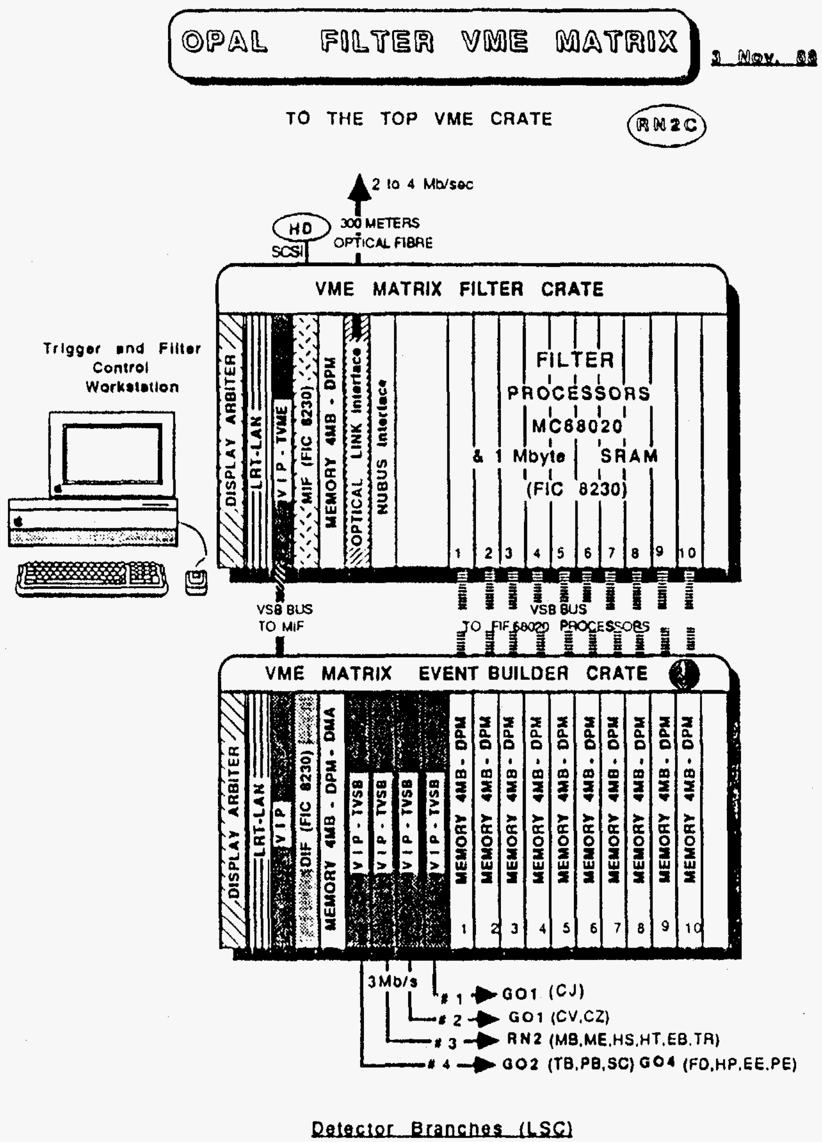


Fig. 2.11 Event Builder and Filter

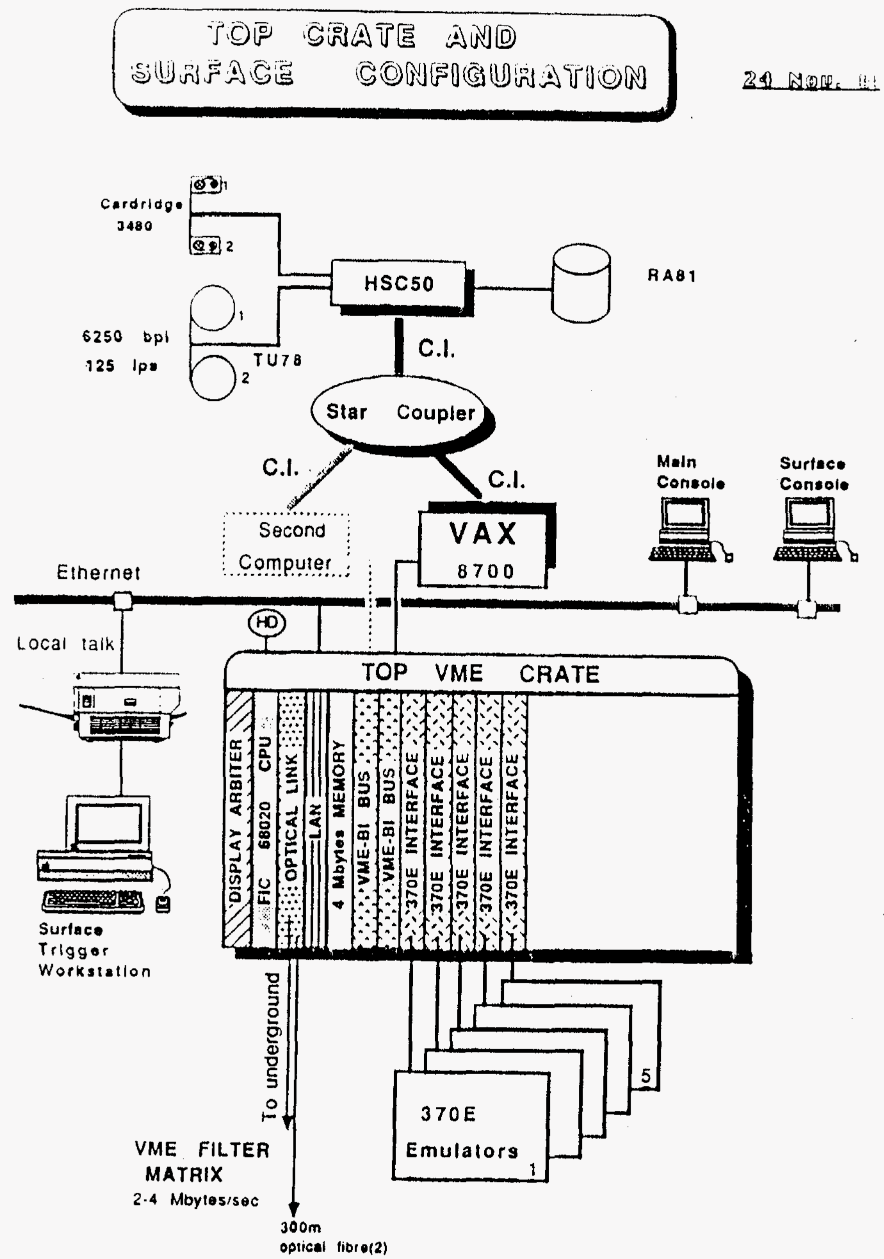


Fig. 2.12 Top Crate and Surface Configuration of Computers

OPAL Physics Analysis

(i) Overview:

OPAL Physics analysis efforts are focussed at present on the data sample expected from the August LEP Pilot Run and the main Fall 1989 data taking.

The pilot run sample may offer the first several hundred multihadronic decays seen by OPAL (luminosity of tens of nb^{-1}). These data are expected in early August 1989. The data will be analyzed for the multi-hadron cross section, leptonic branching fractions, and limits on new physics. The whole data acquisition, reconstruction and analysis system will be tested in "real time".

The main fall run, which will begin in late August or early September of this year, will consist of several pb^{-1} of data (up to 100,000 multihadron decays). The data will be taken while scanning the LEP energy around the Z peak with the highest c.m. energy at most 96 GeV. From this data we should be able to measure the mass and width of the Z to better than 70 MeV, to determine neutrino generations to half a generation, to measure tau polarization, and to search for a variety of new particles.

The OPAL collaboration has established a system of "Coordinators", who are responsible for four major areas of group effort: Installation and Running, Software, Physics, and UpGrade. Since January 1989 these coordinators have been actively organizing, evaluating, and directing the group's efforts.

The PHYSICS COORDINATOR (Albrecht Wagner of Heidelberg) and Deputy Coordinator (Gordon VanDalen of Riverside) have structured the 1989 data analysis around 15 "working groups":

1 total hadronic cross section
2 mu_ mu- final states
3 Bhabha scattering
4 Tau decay studies
5 Neutrino counting
6 Hadronic event shape

7 QCD related studies
8 c- and s-tagging
9 b-tagging
10 top search, b′ search
11 Heavy lepton search
12 Standard Higgs search
13 nonStandard Higgs search
14 Search for supersymmetric decays
15 Luminosity measurement

The working groups were activated following the "Second OPAL Physics Workshop" held in December 1988 [co-organizer M. Dittmar]. Conveners were selected by the OPAL Collaboration Board in early January, and OPAL Physicists were invited to join one or two of the Physics working group.

The approximate time scale of OPAL physics analysis activities is:

Sept 88	First data samples through Monte Carlo and Reconstruction 20,000 multihadrons (approx. 1pb-1) and equivalent samples of bhabhas, taupairs, mupairs, exotics.
Dec 88	Second OPAL Physics Workshop Report on results of "analysis" of Monte Carlo samples with feedback to analysis programmers and estimates of Physics potential for 89 data.
Jan 89	Appoint Physics Coordinator, select topics for 15 working groups.
Feb 89	Select working group conveners, organize groups.
Jan-May 89	LEP Physics Workshop (Altarelli) with four experiments and theoreticians represented.
Jan-Apr 89	Update OPAL Monte Carlo and Reconstruction with information from 2nd OPAL Physics Workshop and "final" data formats.
May 89	Second major Monte Carlo sample production.
June 89	Third OPAL Physics Workshop Analysis of new Monte Carlo samples, first draft papers.
Jun-Jul 89	Final preparation of Monte Carlo simulation and Reconstruction code. Product simulated data with mixture of generators and backgrounds.
Jul 89	Cosmic tests begin.
Aug 89	LEP Pilot Run
Sept 89	LEP first physics run.

Riverside is active in several Working Groups: #1- Multihadron [conveners G. VanDalen, and M. Dittmar], #4- Tau Studies [Dittmar, Layter, Riles, Ho, O'Neill], #5-Neutrino Counting [Dittmar, Layter, Riles, Shen, Larson, Heflin], and #11 - Heavy Lepton [Layter, Riles, Oh]. Activities in each of these areas will be discussed in more detail below.

(ii) The Measurement of the Total Hadronic Cross Section

The measurement of the total hadronic cross section and the determination of the mass and width of Z^0 are studied by Working Group #1 with VanDalen as convener and Dittmar as co-convener.

The mass can be measured quickly during the first data taking expected for early September with an accuracy of about 100 MeV (or a relative accuracy of 10^{-4}). This accuracy will be further improved once LEP is expected to reach its design parameters to values between 50 MeV and for the long term future a value of about 10 MeV is expected.

Figure 2.13 shows the expected hadronic cross section around the Z^0 pole. The expected number of events per day at the peak is of the order of 30000 using the LEP design parameters (about this number of hadronic events has been observed at PETRA/PEP in a year of very good machine running).

Already an early measurement of this cross section will provide a relatively precise measurement of the weak mixing angle ($\sin^2\theta_W$) of about 0.3%. This should be compared to values accurate to about 2-3% from other experiments,

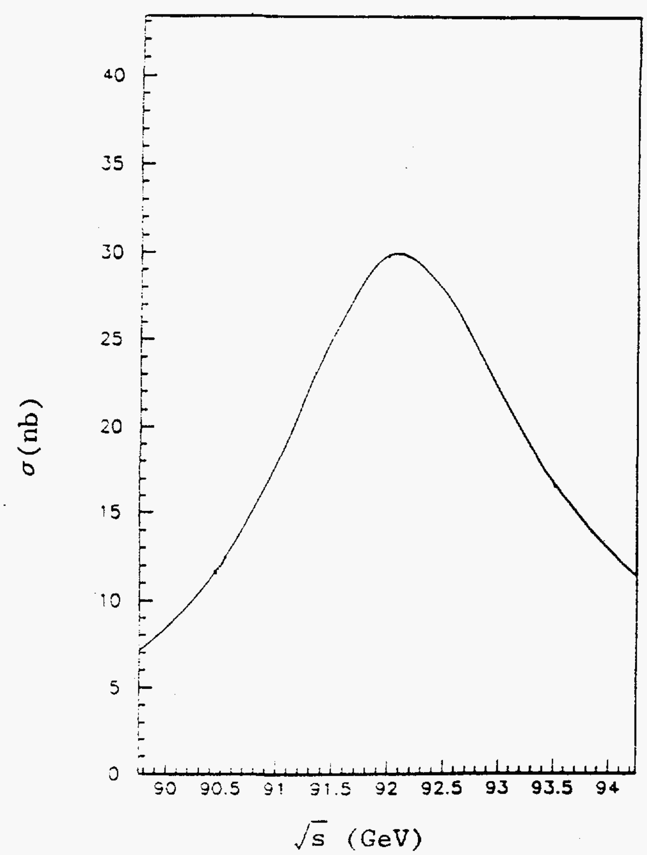


Fig. 2.13 Hadronic Cross Section

measured during the last years. Thus, the measurement of the Z^0 mass and width will be of major importance during this year.

However, to constrain the electroweak theory, additional measurements of this mixing angle have to be made. The promising measurement of the tau polarization at LEP, is expected to give a precision of finally about 1% (see below).

In addition, the hadronic cross section will provide an accurate measurement of the total Z^0 width which determines for the first time the number of massless neutrinos to a high accuracy in a laboratory experiment.

A good understanding of the detector response for hadronic events, essential for a precise cross section measurement, provides at the same time the possibility to look for new physics which is expected to show up often together with jets. A careful investigation of hadronic events gives us therefore a long term perspective on physics with OPAL for so called standard physics as well as the search for new physics.

The observed multihadron cross section is calculated from number of event candidates as:

$$\sigma(e+e- \Longrightarrow \text{hadrons}) = \frac{1}{\text{eff}} \frac{1}{L} (N_{had} - N_{bkgd})$$

where "L" is the measure integrated luminosity, "eff" is the hadronic event selection efficiency, "N_{had}" is the number of hadronic event candidates, and "N_{bkgd}" is the number of background events.

Luminosity

The luminosity is measured by the OPAL "Forward Detector". The forward detector measures electrons from small angle Bhabha's in the angular range from 40 mrad to 120 mrad. The effective cross section of the Lumi counters is 64 nb, giving about two tagged bhabha's per hadronic Z decay at the peak. The luminosity systematic error is estimated to be 7% at LEP start up, and as low as 3% after the '89 data have been analyzed.

Acceptance

The planned track and event cuts used to define the multihadron sample have been carefully studied [1].

The essential requirements are

At least 5 tracks from primary vertex with p_t>150MeV/c and | cost Theta | < 0.93

$E_{vis} = E_{tracks}$ + Ecal > xx% of the C.M. energy

At startup we will use low values of "xx%". A 50% cut gives 92% acceptance, whereas 25% cut gives 96% acceptance.

We have also studied the acceptance uncertainty dependence on fragmentation models, radiative corrections, backgrounds, and detector performance (trigger, resolutions, dead sections, etc.).

The uncertainties from varying fragmentation and QCD models is at most 1%. This error can be further reduced by using observed distributions in n-charged, sphericity, thrust, etc., to optimize the fragmentation parameters. Figure 2.14 shows the variation with several Lund parameters.

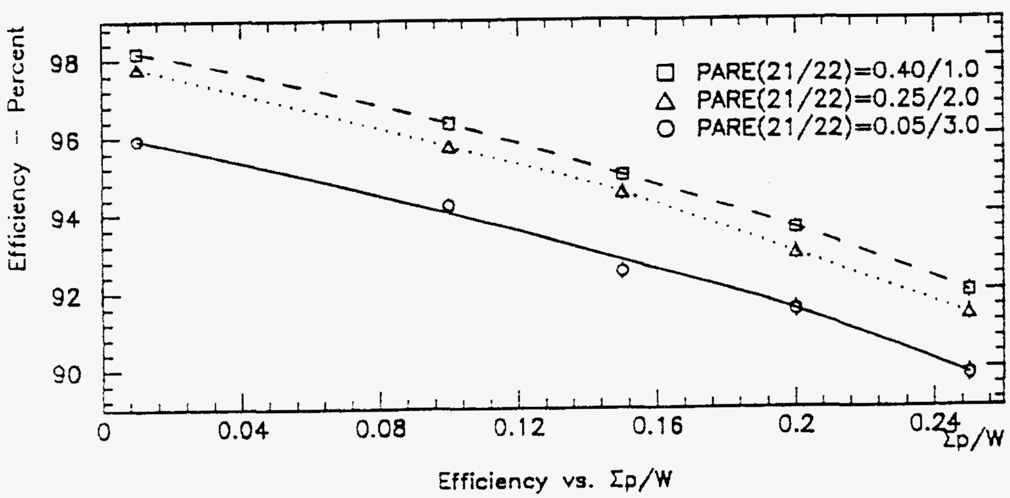


Fig. 2.14 Variation of Efficiency with QCD Λ, Q_o

Radiative effects on the acceptance have been studied with a variety of $0(\alpha)$, $0(\alpha^2)$ and exponentiated programs. Variations in the program cutoffs were used to estimate the maximum possible effects. The uncertainty from radiative corrections is less than 0.3%. The energy dependence of the radiative correction has also been checked for a variety of Z masses and widths. The acceptance is constant to within a few tenths of a percent in the likely Z scan range of ± 3 GeV.

Background from gamma-gamma interactions, tau-pairs, bhabhas (that shower in pipe), and beam/gas + off-momentum-beam/pipe interactions have been considered. With our selection criteria, background are less than 0.1% of the signal at the peak.

The efficiency dependence on (CJ) and lead glass performance has been studied with the GOPAL Monte Carlo, and by dropping out data structures in the analysis. Dropping 2 (of 24) CJ sectors lowers the acceptance by at most 0.4%. Uncertainty in lead glass calibration of 10% (we expect better than 1%), would change the acceptance by at most 1%.

Therefore, most of the uncertainty in the multihadron cross section measurement will come from the luminosity systematics.

Expected data samples, measurement precision

For a model data set of a first scan - 40 nb^{-1} per point, 5 points at 1 GeV spacing we get fit errors of

ΔM_Z = 50 MeV (+) 50 MeV (machine uncertainty)

$\Delta \Gamma_Z$ = 145 MeV

$\Delta \sigma$ = 11%

This measurement could be made in the first weeks of LEP running this fall.

The ultimate precision of a Fall 89 data sample (about 1 pb^{-1} total in scan) would be

ΔM_z = 30 MeV (+) 50 MeV (machine uncertainty)

$\Delta\Gamma_z$ = 60 MeV

$\Delta\sigma$ = 3%

Figure 2.15 shows confidence contours in σ_{peak} vs. Γ_z for a 1 pb^{-1} model data set. The sensitivity of the measurement to new Physics is indicated for a range of possible deviations from the "simple" Standard Model.

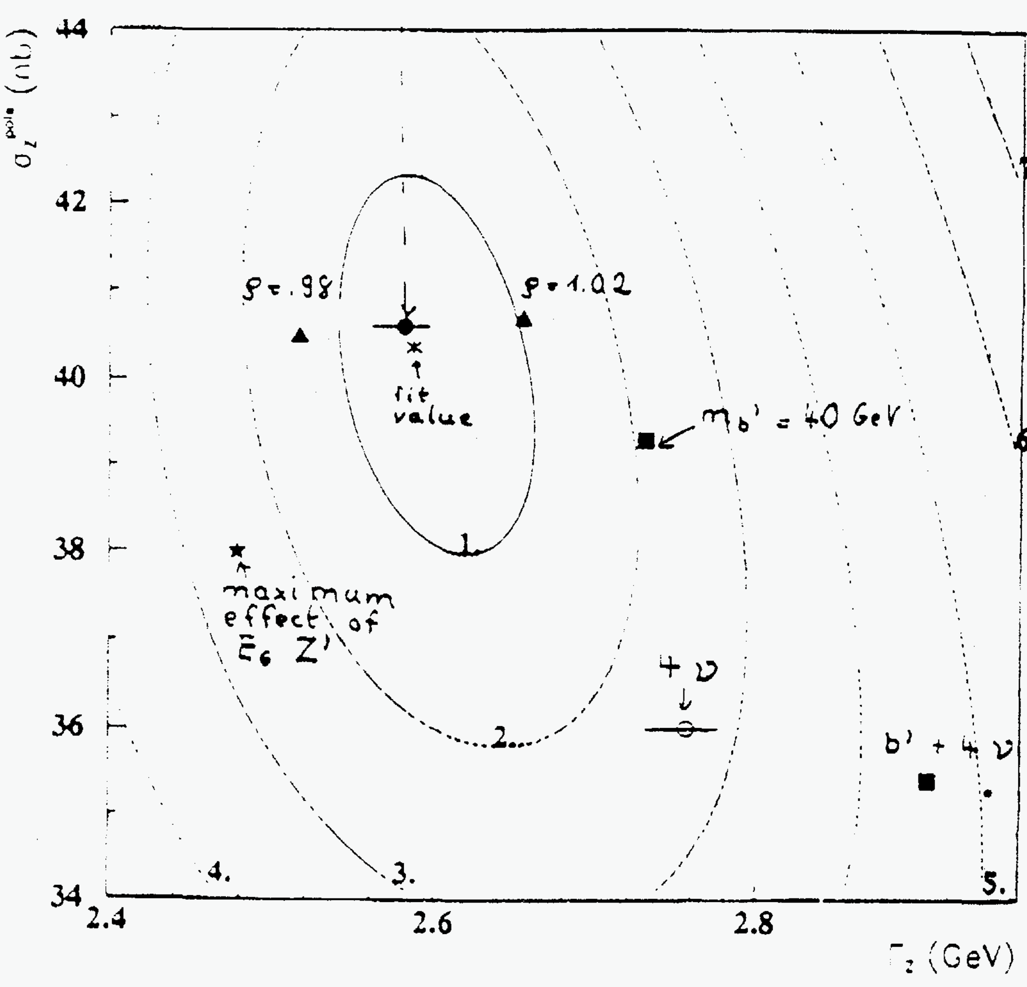


Fig. 2.15 Model independent Fit to Model/Generated Data of 1 pb^{-1}

$\sigma_z^{pole} = 40.2 \pm 2.2$ nb

$M_z = 92.01 \pm 0.03 \pm 0.05$ GeV

$\Gamma_z = 2.60 \pm 0.06$ GeV

Plans for Fall Running

The multihadron cross section working group meets at least weekly at CERN to extend our understanding of the detector, its potential, and our interpretation of the coming data. The present plan is three-stage physics analysis:

Pilot run:	One (or two energies), about 10 nb^{-1} of luminosity (few hundred events) Measure σ at one energy, measure leptonic to hadronic branching ratio to a few percent. Data in early August. Report at SLAC Lepton Photon Conference. First paper.
First Scan:	First scan to find the LEP "optimum Z" mass for subsequent fall running. Data in late August, early September. Preliminary analysis at Madrid-EPS Conference. Paper.
89 Scan:	Dedicated or continuous scan in fall. Precision measurements of mass and width of Z^o, search for new physics. Papers.

References

1. "Selection of Tracks and Events in the Multi-Hadron Sample", P. Maettig, D. Schaile, and G. VanDalen, UCR-OPAL-8902.
2. "The Properties of Z^o", OPAL Collaboration draft paper.
3. "Results from the First Scan with OPAL Detector".

(iii) Tau Polarization

The measurement of tau polarization is studied by Working Group #4 with participation of Dittmar, Layter, Riles and graduate students Chili Ho and Brendan O'Neill.

Tau polarization arises from the stronger coupling of Z^o to left-handed than to right-handed charged fermions; its strength is a direct measure of the Weinberg mixing angle[1-2]. The polarization (or average helicity) also provides a direct measure of the relative sign between the axial and vector coupling constants of the tau lepton. Although difficult to measure, tau polarization is large (16-25%, depending on the Weinberg angle) and is quite insensitive to radiative corrections. Figure 2.16 shows the polarization of the negatively-charged tau plotted vs. center-of-mass energy for a Z mass of 91 GeV and for various values of the Weinberg mixing angle. The dashed curve indicates the expected radiative correction [3].

By far the most powerful measure of tau polarization comes from the momentum spectrum of pions produced in the two-body decay of a charged tau to a charged pion and a neutrino. Non-zero tau polarization induces an asymmetry in the angular distribution of the pion in the rest frame of the tau w.r.t. the tau's direction of motion in the laboratory. The Lorentz boost of the tau transforms this angular asymmetry into an asymmetry in the pion's momentum spectrum. Neglecting detector efficiency and resolution effects, the slope of the resulting spectrum is directly proportional to the degree of tau polarization, where the slope has the same sign for both positive and negative charged pions. Figure 2.17 shows the expected spectrum, including momentum resolution effects, for 100,000 tau-to-pion decays, at one value of the Weinberg angle.

Since the degree of polarization is proportional to eight times the square of the sine of the Weinberg angle, the error on that angle is roughly one-eighth of the error on the polarization. This is in contrast to the forward-backward asymmetry, which is much less sensitive to the Weinberg angle and has large radiative corrections on the Z resonance that are difficult to calculate reliably. On the other hand, the main disadvantages of the tau polarization measurement are the necessarily large amount of data required and the potentially large systematic error due to contamination.

Keith Riles has performed a study to assess the feasibility of establishing a non-zero value for polarization from the data to be taken this fall. The study has two distinct aspects. The first is simply determining the minimum number of detected tau-to-pion decays necessary to prove a two sigma deviation from zero for the polarization. The result is that one needs

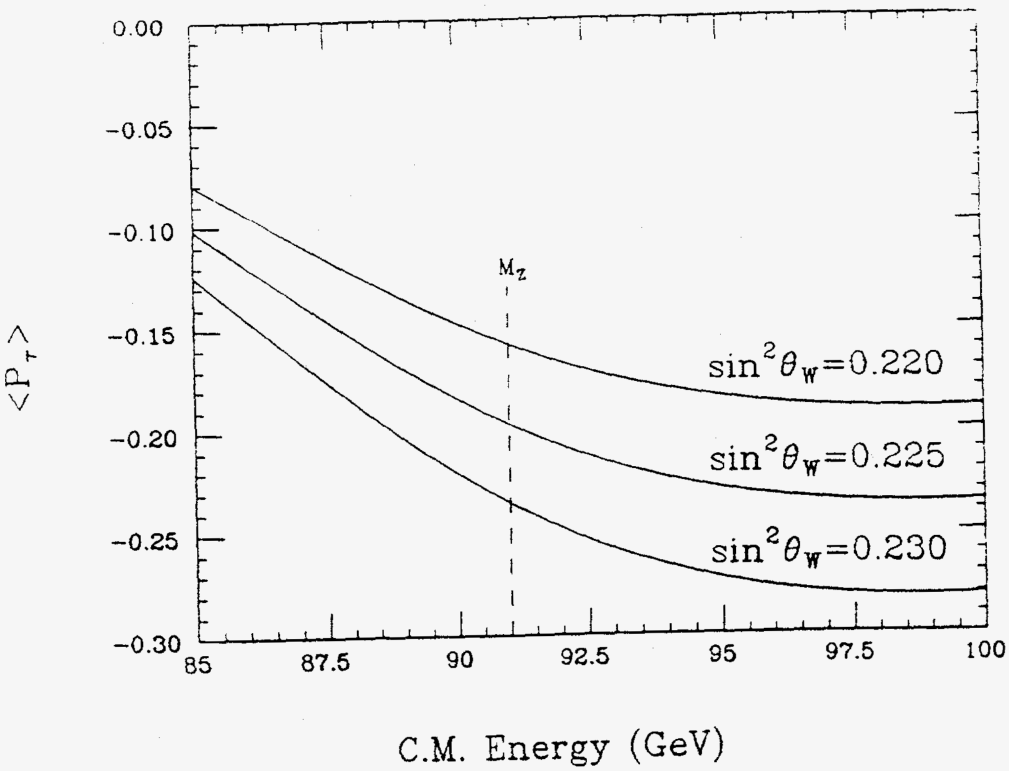


Fig. 2.16 Tau- polarization plotted vs. center-of-mass energy for various values of the Weinberg mixing angles.

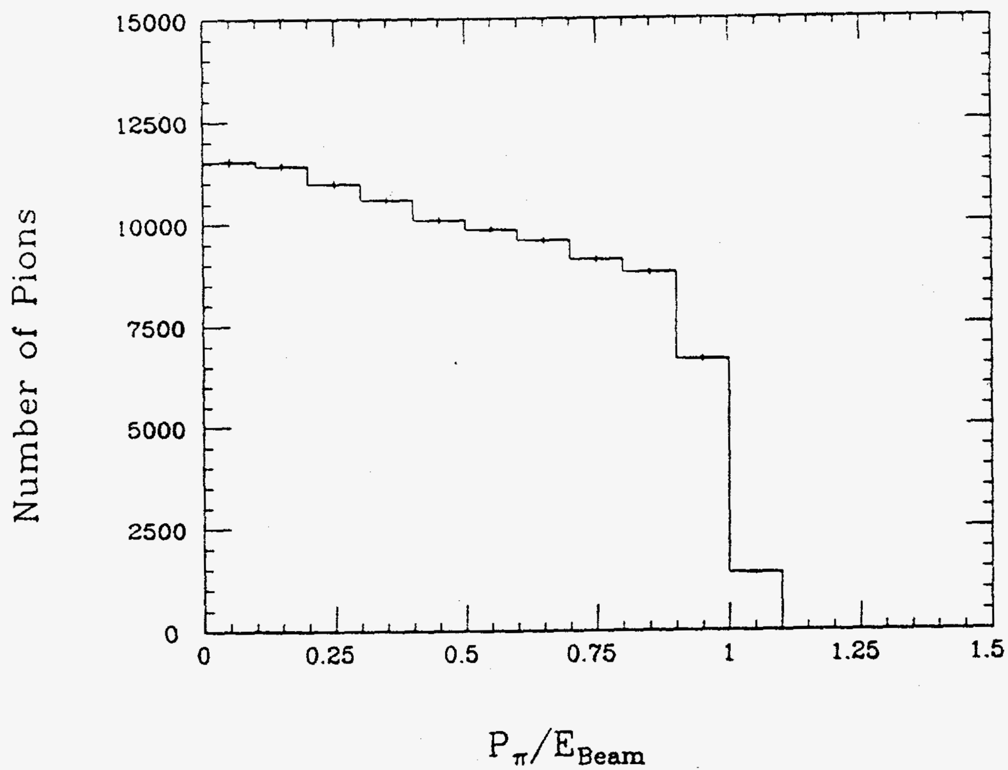


Fig. 2.17 Scaled momentum distribution of pions expected from polarized taus where realistic momentum resolution has been assumed.

approximately 500-600 well-measured decays if the Standard Model prediction is correct. To establish that the vector and axial coupling constants do not have their expected magnitudes, but with opposite signs would require only about 150 measured decays for the same two sigma significance. These estimates take into account the effects of detector resolution, but do not account for contamination of the pion sample. Figure 2.18 shows the estimated error on polarization plotted vs the number of well-measured $\tau \rightarrow \pi$ decays, where the polarization is obtained from a fit to the smeared pion momentum resolution.

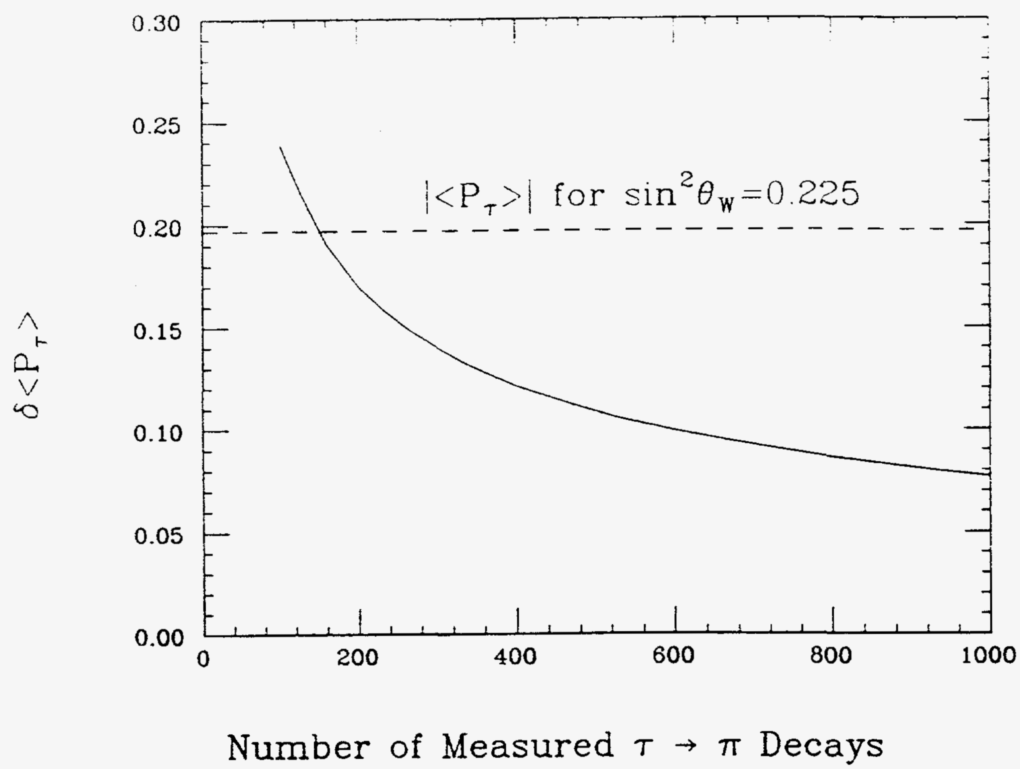


Fig. 2.18 Estimated error on measured tau polarization plotted vs the number of detected tau-to-pion decays.

The second part of the study addresses backgrounds. Contamination from processes other than τ-pair production through the Z should be negligible, except possibly at low momenta where two-photon production of τ-pairs could be a small background. The major concern is from contamination due to other τ decay channels. In particular, the muon and ρ backgrounds may be difficult to suppress. The muons would be difficult to remove at low momenta, where penetration in the hadron calorimeter would be limited, while ρ backgrounds can be difficult to remove at all momenta. When the ρ decays, a π^0 is produced along with the contaminating charged pion. In principle, the photons from the π^0 decay can be detected with the electromagnetic calorimeter. One might imagine requiring very small energy detected in the calorimeter near the charged pion candidate. Indeed, this does suppress the ρ background enormously. Unfortunately, this also suppresses the signal pions substantially too because of the large hadronic cross section for charged pions interacting in the lead-glass blocks. From Monte Carlo studies, one finds that requiring the charged pion be minimum-ionizing in the lead glass costs a factor of two to three in efficiency, hence requiring two to three times more integrated luminosity for a given error in the measured polarization.

Given these numbers, work is underway now to study the effectiveness of the presampler between the magnetic coil and the lead glass in identifying events with photons accompanying the charged pion. Since there are two radiation lengths preceding the presampler, photons have a high probability of showering, thereby inducing large pulse heights in the presampler. The pulse height from signal pions should be quite small, corresponding to that from a single, minimum-ionizing charged track. The concern at this stage lies in the reliability of Monte Carlo simulation of the presampler, particularly in its simulation of noise and possible beam-related backgrounds.

It will be impossible to remove completely the ρ background, since asymmetric decays in which the π^0 receives little energy would be indistinguishable from signal pion decays. Tau decays, however, are well understood at this level of precision, and it should be straightforward to correct for these effects once the reliability of the Monte Carlo detector simulation has been established. If contamination from ρ's and other backgrounds can be suppressed without too much loss in efficiency, we should be able to measure tau polarization to two-σ significance with as little as 4 pb^{-1}. This is greater than conservative estimates of expected integrated luminosity in the fall, but less than some optimistic estimates. We expect to have much more than this by the end of the spring run. Therefore prospects are very good for making this measurement within a year. Graduate students Ho and O'Neill are expected to concentrate on these studies in their thesis work.

References

1. G. Goggi, 1978 LEP Summer School, Les Houches, CERN-79-01, p. 483.
2. J. Augustin, 1978 LEP Summer School, Les Houches, CERN-79-01, p. 499.
3. T. Riemann and M. Sachwitz, Topical Seminar Devoted to e+e- Physics at LEP Energies, Moscow (1987) PHE-87-12.

(iv) Neutrino Counting

The determination of light-mass neutrino generations is studied by Working Group #5 with participation of Dittmar, Layter, Riles, Shen and graduate students Ed Heflin and Bill Larson.

Since the discovery of the muon, the question of the replication of particles with similar properties has been an intriguing one. With the discovery of yet a third generation and the parallelism between quarks and leptons, it has become urgent to know how far the procession of generations continues. Some indications are available from cosmological arguments, but they involve theoretical assumptions that many consider to be at least debatable if not altogether untenable. No single accelerator experiment has the statistical accuracy to answer the question, an analyses combining the data from different experiments suffer from uncertainties in systematics.

When high statistics running at the Z^0 becomes available, the question of the number of generations can be answered straightforwardly by measuring the Z^0 width. If one assumes only that the neutrinos of the next generation are light enough that they can be produced in pairs by Z^0 decay, one simply measures the Z^0 width and compares it to what is expected from couplings to known particles. There are two drawbacks to this method however. First, the fractional contribution of a new neutrino pair to the width is small, on the order of 6%, so that enough statistics must be accumulated to make possible a width measurement to about 50 MeV. Second, the method assumes only a new neutrino is making the contribution to any increased width, whereas a number of candidates can be suggested. Similar difficulties limit the effectiveness of other methods such as the so-called "invisible width" measurement.

These and other considerations led Ma and Okada [1] to suggest in 1978 that the ideal reaction for the determination of the number of neutrino generations would be radiative neutrino pair production, in which one of the beam particles radiates a gamma ray before annihilating to form a Z^0. The signature of the process is then a single gamma ray observed in the detector. One additional generation would then lead to a 33% increase in the rate over what would be expected from the three known generations. The method was popularized by Barbiellini, et al. [2], and is the measurement of choice at LEP to count the number of generations.

Of course there are also difficulties with this method. In the first place, any measurement which proposes the detection of just one of anything will have trouble with backgrounds. There is also the strategic problem of where to run the accelerator: ideally one would like to sit several GeV above the Z^0 peak, so that the radiated photons would be quite hard and so more easily separated from the backgrounds as illustrated in Figure 2.19. For many other reasons however, the accelerator may run at or very close to the Z^0 peak, where background separation is expected to be more difficult.

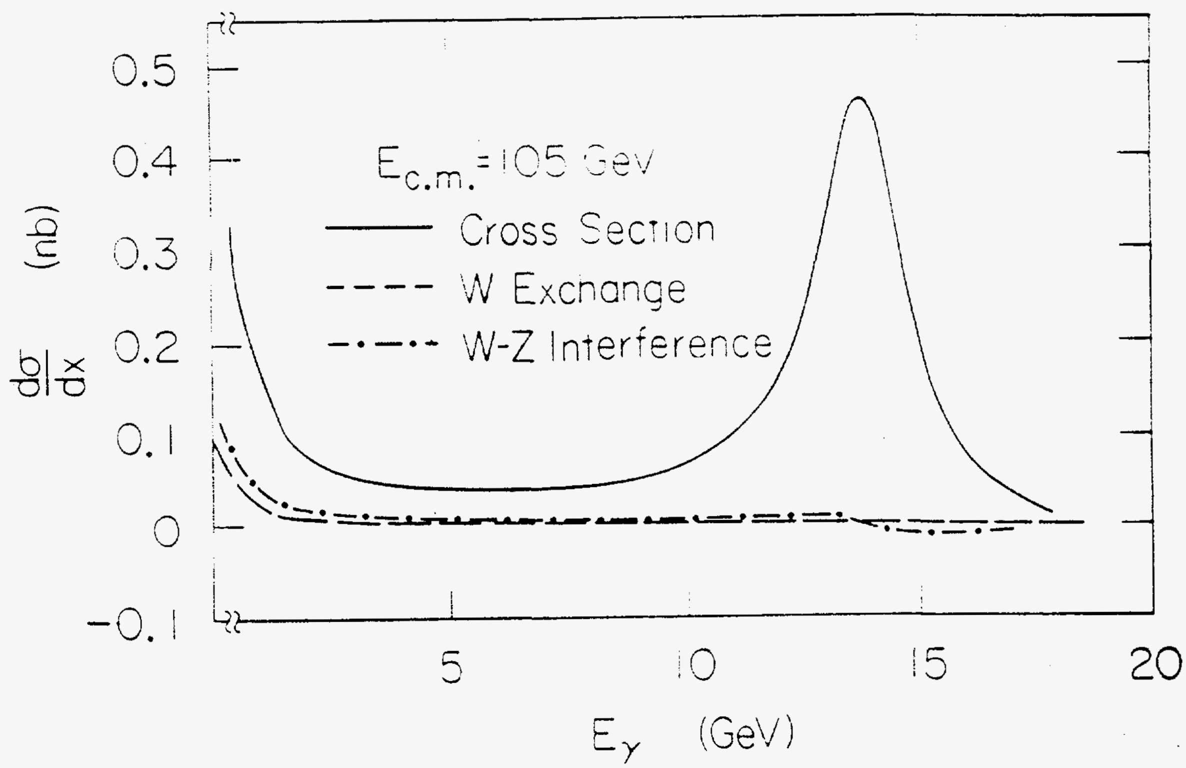


Fig. 2.19 Differential cross section versus the photon energy.

The OPAL Collaboration, with its extensive lead glass coverage and its capability of vetoing charged particles to very small angles, has long felt that this measurement is well within its capabilities. During the past year the Working Group has tried to bring more exact detector simulation studies to bear on the experimental difficulties. Much of this work was presented at a recent group workshop on LEP physics. Results of one such presentation are combined in Figure 2.20 which compares the error in N, the number of generations, when one applies several methods of extracting the signal from the background: i) background elimination, achieved by applying cuts on the transverse momentum of the gamma ray which at the same time reduces statistics of the signal, ii) background subtraction, which counts on being able to evaluate the background level accurately, and iii) a method of shape analysis which attempts to fit the energy and angle dependence of the signal and background. The conclusion of this study is that at least 5 pb^{-1} must be

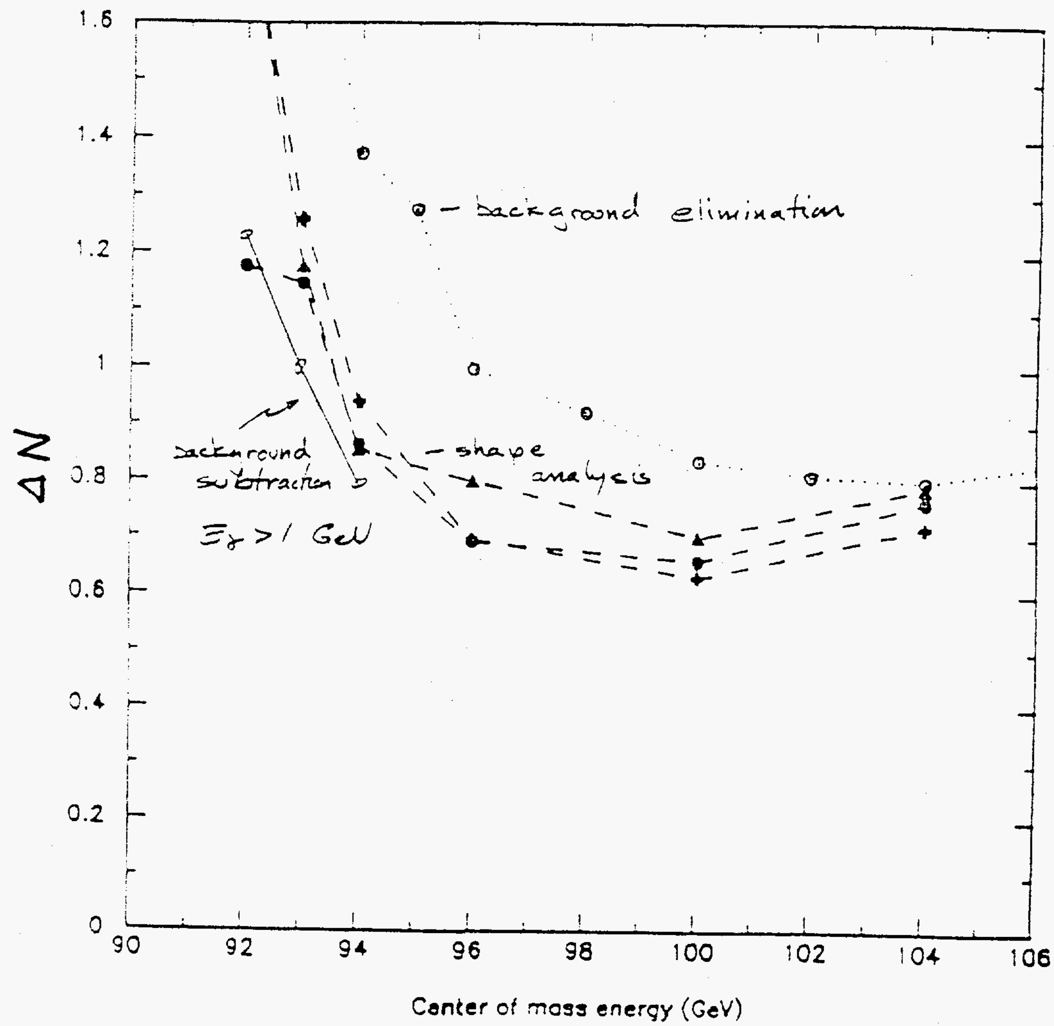


Fig. 2.20 Fit precision in number of neutrino generations as a function of $\sqrt{s}$ with 1 pb^{-1} of data at each energy

accumulated at an energy several GeV above the Z^0 to make a measurement whose uncertainty is less than half a generation.

The Riverside group has brought its experience with two-photon physics to this study by studying the background expected from the largest contributor to the background, the decay of the f_2 to two neutral pions [3]. The result of this study is that this source of background can become significant if one desires to increase statistics by lowering the trigger threshold. Another study has underlined the importance of triggering on single electron events to establish the trigger efficiency and to understand the lead glass and forward detector response. Another imaginative proposal seeks to use the precise timing of the time-of-flight counters to localize the point of origin of an observed single gamma ray to the region of the beam crossover. Such a trick would greatly reduce backgrounds coming from beam-pipe showers and from beam-gas interactions. The overall conclusion from the workshop is that the neutrino counting experiment can be done with data from first year of operation of LEP.

Graduate students Heflin and Larson will carry out their thesis work in this area.

References:

1. E. Ma and J. Okada, Phys. Rev. Letters 41, 287 (1978).
2. G. Barbiellini, B. Richter, and J.L. Siergrist, Physics Letters **106B**, 414(1981).
3. M. Daoudi, J.G. Layter, and B.C. Shen, UCR-OPAL-8915.

(v) Search of Heavy Leptons

The search of heavy leptons is studied by Working Group #11 with active participation of Layter, Riles and graduate student Heungmin Oh.

The large luminosities and high beam energies expected at LEP provide opportunities for new particle searches. One obvious possibility is a fourth generation heavy lepton doublet. We are participating actively in the OPAL heavy lepton Working Group, which will explore several different heavy lepton possibilities. The search drawing most effort is that for a sequential heavy charged lepton with a massless or very light neutrino partner, since this has been the pattern of the first three generations. We are contributing to this effort through studies of electron and muon identification, in addition to Monte Carlo work at the generator level.

A more general search, however, allows for the possibility of a massive neutrino partner [1,2]. Searches have been carried out recently at PEP experiments [3,4,5] for such a lepton doublet with negative results, but the relatively low center-of-mass energy (29 GeV) prevented searching for leptons with mass above 14 GeV. Figure 2.21 summarizes the current status of heavy sequential lepton searches [6]. Note that the UA1 limit of 41 GeV on standard charged leptons (with light neutrino partner) is more model-dependent than the limits from e+e- experiments.

For relatively light neutrino masses, the search strategy is identical to that for the standard case, but for very heavy neutrinos, events are characterized by large missing energy, which makes identification somewhat more difficult for two reasons. One is that two-photon backgrounds become important at very low visible energy; the other is that electron and muon identification suffer at low momenta. Muons are difficult to identify at momenta below 3 GeV, while calorimetry information is inadequate to distinguish electrons from pions at momenta below 1 GeV. If dE/dx measurements can be used, electron identification improves substantially, but it is not clear that dE/dx measurement will be well-calibrated in the first OPAL data-taking run.

We have concentrated our efforts on the more general search, with massive neutrinos. A heavy lepton Monte Carlo has been installed in the OPAL detector simulation program. The Monte Carlo, LULEPT[3,5], simulates the production of a heavy charged lepton, with both semi-hadronic and leptonic decays to a neutrino partner of arbitrary mass included. Unlike other heavy lepton Monte Carlos, for example the TIPTOP Monte Carlo by Jadach and Kuhn, LULEPT explicitly simulates correctly, exclusive semi-hadronic modes, such as $L^- \rightarrow L^0 \pi^-$, including full longitudinal and transverse spin-spin correlations between lepton and anti-lepton decay products. This is important for the very heavy neutrino case, where branching ratios are extremely sensitive to the

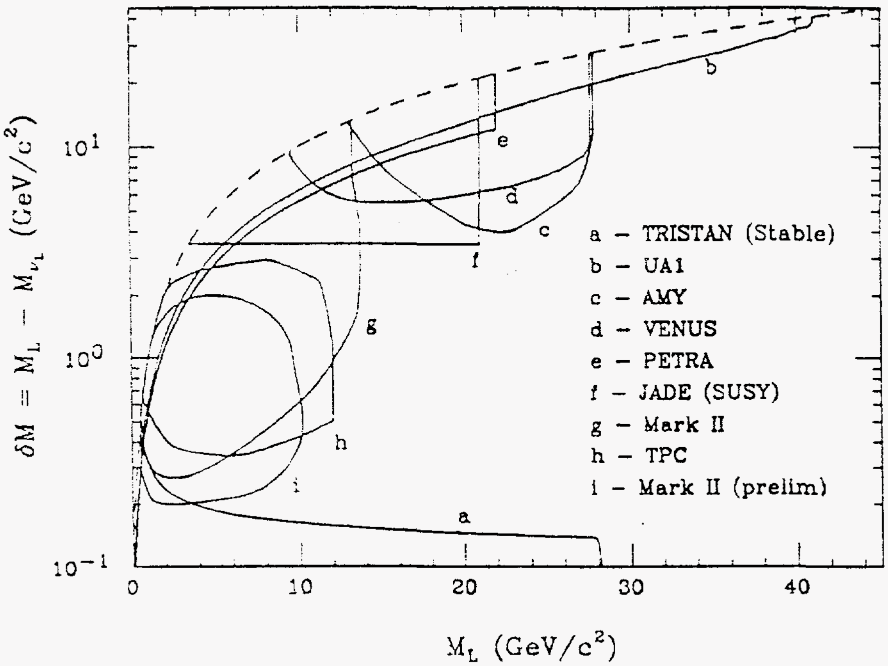


Fig. 2.21 Currently excluded regions in the plane of mass splitting vs charged lepton mass. The vertical axis is drawn logarithmically to emphasize the difficulty in exploring small mass splittings. The dashed curve corresponds to the standard sequential lepton doublet with a massless neutrino.

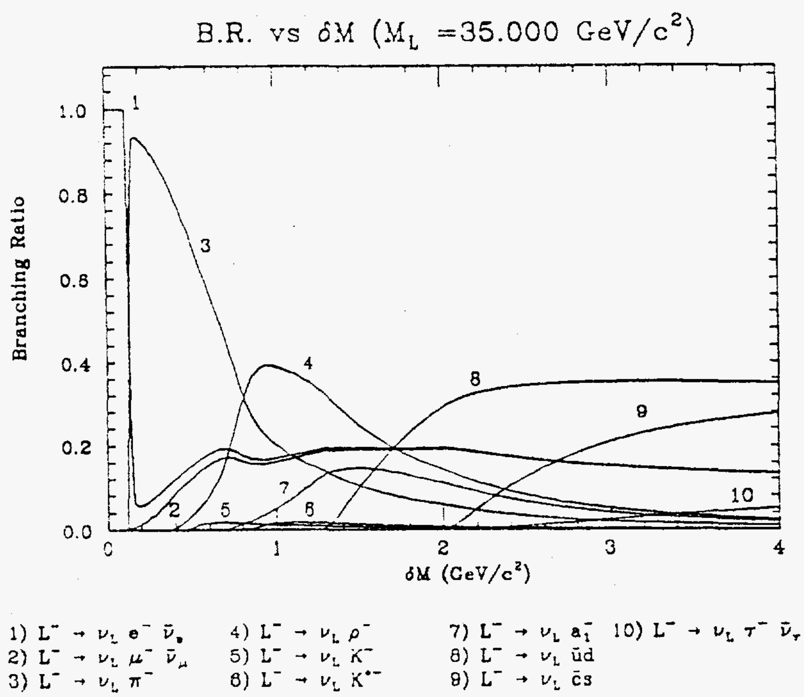


Fig. 2.22 Branching ratios calculated by LULEPT for small δ_M and a charged lepton mass of 35 GeV/c^2.

mass difference between the charged and neutral heavy leptons, as can be seen in Fig. 2.22. Spin-spin correlations become quite important for very heavy and therefore slow-moving charged leptons and should also be simulated properly.

To assess the sensitivity of OPAL to the general sequential lepton case, a study has been carried out at the 4-vector level [7], using simple assumptions concerning detector acceptance and efficiencies. Two variables found to be useful are **acoplanarity** in events with two charged particles and **jet mass** for events with an isolated lepton and three or more additional charged particles. Figure 2.23 shows the acoplanarity (acolinearity in the plane transverse to the beam direction) distribution of electron-muon events for several different neutrino mass values and a charged lepton mass of 35 GeV. Also shown is the distribution for tau pair events. Figure 2.24 shows the invariant mass of charged tracks opposite an isolated electron for the same heavy lepton masses and for the tau pair background. Although no detector simulation was included in the study, the results should be insensitive to resolution effects, except for very low mass splittings between the charged and neutral heavy leptons. The preliminary and conservative conclusions are that with 2 pb^{-1} of integrated luminosity this fall, it should be possible to exclude heavy lepton doublets with mass splittings as low as 3-5 GeV and charged lepton masses up to about 35 GeV. With 4 pb^{-1}, these limits improve to splittings of 1-2 GeV and charged masses of about 40 GeV. If dE/dx measurements are used, the sensitivity to low mass splittings will be improved considerably, allowing exclusions down to several hundred MeV. Our present study considered only decay topologies with at least one isolated electron or muon. Work is under way to examine the topology where both heavy charged leptons decay semi-hadronically. In addition, studies of detector efficiencies are being carried out. The heavy lepton Working Group is also working on searches for stable charged leptons and for heavy neutrinos that decay through

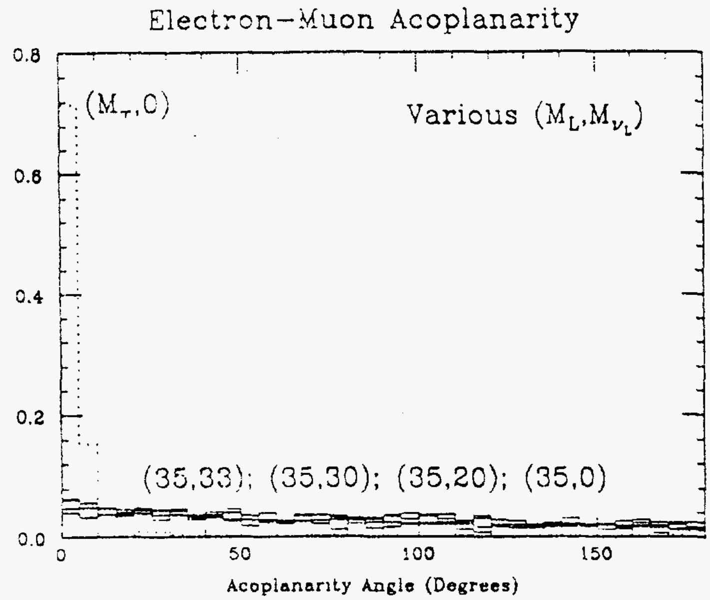


Fig. 2.23 Acoplanarity distribution of electron–muon events for $M_L = 35$ GeV/c^2 and for various values of M_{ν_L}. Also shown is the expected distribution from the tau pair background. Curves are normalized to the same areas.

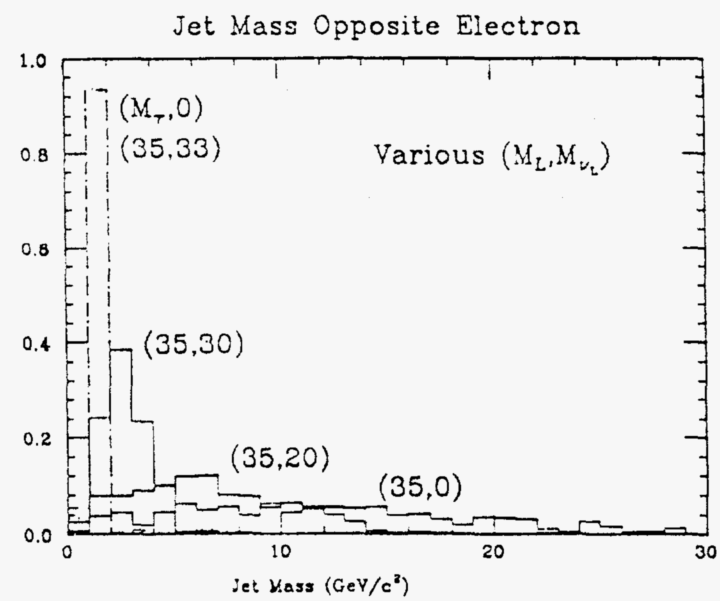


Fig. 2.24 Jet mass distribution for electron–jet events for $M_L = 35$ GeV/c^2 and various values of M_{ν_L}. Also shown is the distribution of the tau pair background(dotted), which is nearly indistinguishable in shape from the (M_L=35,M_{ν_L}=33) curve(dashed).

mixing to lighter generations, giving rise to events with multiple electrons, muons or jets. In both cases, the limitations of available Monte Carlo programs hamper progress. We plan to modify the LULEPT Monte Carlo to allow production of heavy neutrinos that decay into lighter but still heavy stable charged leptons. We will also modify LULEPT to generate charged or neutral heavy leptons that decay through mixing to conventional particles.

References

1. M.L. Perl, in Proceedings of the XXIII International Conference on High Energy Physics, p. 596, Berkeley, California, 1986.
2. S. Raby and G.B. West. Nuc. Phys. B292: 793 (1987).
3. D. Stoker, et al., Phys. Rev. D39: 1811 (1989).
4. H. Aihara, et al., submitted to Phys. Rev. D, LBL-27217 (1989).
5. K. Riles, Ph.D thesis, Stanford University, SLAC-342 (1989).
6. K. Riles, to appear in Proceedings of XXIV Recontres de Moriond: Electroweak Interactions and Unified Theories, Les Arcs, France, March 5-12, 1989.
7. K. Riles, OPAL heavy lepton working group note 89-05, UCR-OPAL-8920.

Personnel

The OPAL experiment at LEP is the major project of the e^+e^- physics group. The physicists participating in OPAL include Michael Dittmar, William Gorn, John Layter, Keith Riles, Benjamin Shen and Gordon VanDalen. Five graduate students have been working on various aspects of the experiment. They are Edward Heflin, Chili Ho, William Larson, Heungmin Oh, and Brendan O'Neill. It is expected that they will complete their Ph.D thesis work within the next two years. In addition, we have two visiting technical associates from Harbin Institute of Technology working with our group on the OPAL experiment.

(c) Neutrino Physics at LAMPF

The study of neutrino interactions has been a very important part of the development of elementary particle physics. The neutrino has been used as a probe to investigate a wide range of fundamental questions including electroweak interaction, lepton number conservation, and cosmology. Since 1982, several members of our group, notably William Gorn and Gordon VanDalen, have participated in an experiment at LAMPF which established significant limits in the search for neutrino oscillations [1]. As a follow-up of the previous work, we are participating in a proposed experiment to search for neutrino oscillations with high sensitivity at LAMPF.

The proposed experiment [2] will be carried out by a team of 29 physicists from LANL and five universities. The design of the detector is to be completed in 1989, the beam tests and construction of the detector to be carried out in 1990 and 1991. Data taking with complete detector will commence in 1992.

The Detector

The detector is similar to a large water Cherenkov device but with better angular, position, and energy resolutions due to more light and the higher index of refraction, longer radiation length, and lower density of liquid scintillator compared to water. The detector as shown in Fig. 2.25 consists of a cylindrical tank of liquid scintillator with 1000 10" photomultiplier tubes covering about 28% of the surface area of the tank. The tank is approximately 5 m in diameter by 8.5 m long, contains an active mass of 150 tons, and fits inside the existing E645 veto shield. The 10" tubes have excellent timing and single photoelectron separation and should give energy, position, and angular resolutions of $< 5\%$, < 25 cm, and $< 15^{\circ}$, respectively, for 45 MeV electrons. In addition, we obtain proton-electron identification from the fit to the Cherenkov cone. Neutrons can be identified from the

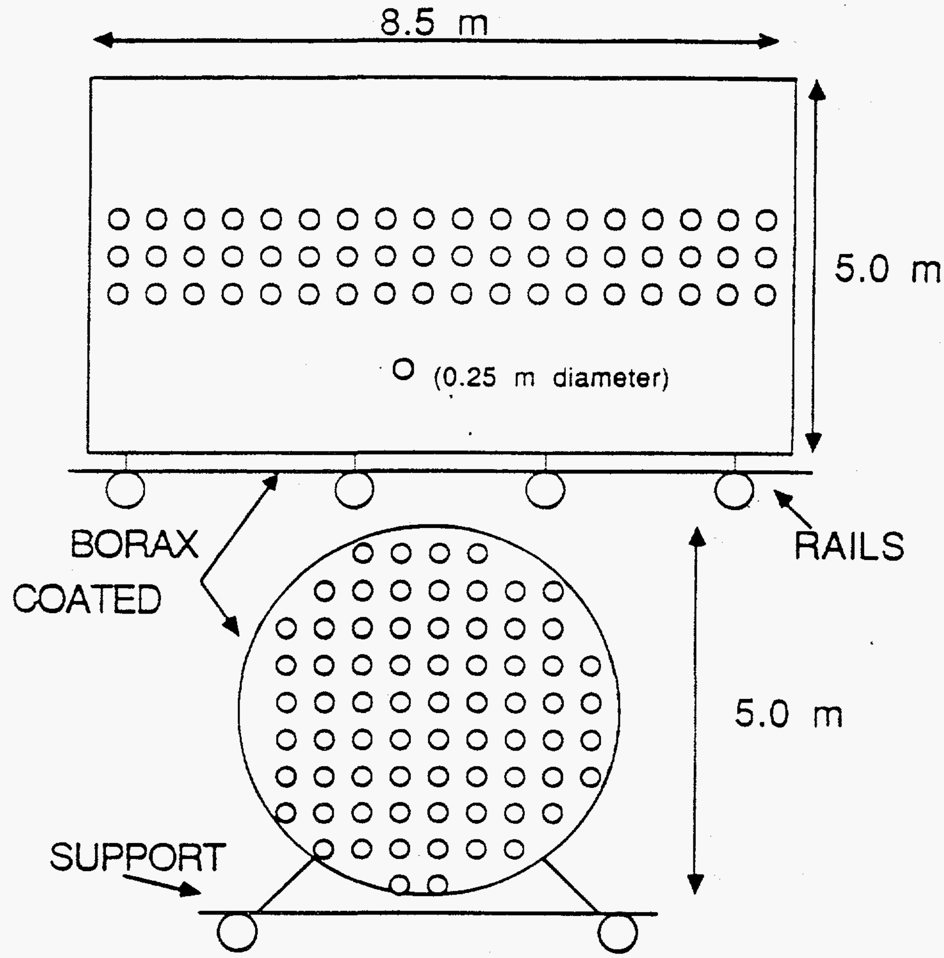


Fig. 2.25 A schematic view of the detector, consisting of a cylindrical tank of liquid scintillator with 1000 10" photomultiplier tubes covering about 28% of the surface area of the tank.

observation of the 2.2 MeV photon emitted from neutron absorption on a free proton. Finally, the superb event timing allows us to separate neutrino-induced events from pion decay-in-flight from other beam-induced and cosmic ray background due to the 200 MHz time structure of the LAMPF linac. The property of the liquid scintillator, used in the BNL E734 neutrino experiment are given in Table I.

Table 1. Properties of Liquid Scintillator

n	ρ	Composition	Decay Time	λ	Light Output
1.47	0.85 g/cm^3	CH_2	4 ns	10 m	4% of anthracene

Event Rates

An estimate of our event rates is shown in Table 2 for neutrinos from pion decay-at-rest and Table 3 for neutrinos from pion decay-in-flight.

Table 2. Event rates per 130 days for neutrinos from pion decay-at-rest

Process	Cross Section (cm^2)	Acceptance	Events	Comments
$\bar{\nu}_e p \to e^+ n$	1.3×10^{-40}	0.234	19,350	max-mix., $E_e > 37$ MeV
$\nu_e^{12}C \to e^{12}N$	1.46×10^{-41}	0.342	1588	$E_e > 10$ MeV
$\nu_e^{13}C \to e^{13}N$	1.09×10^{-40}	0.490	190	$E_e > 10$ MeV
$\nu e^- \to \nu e^-$	4.0×10^{-43}	0.331	340	$E_e > 10$ MeV
$\nu C \to \nu C^*$	7.5×10^{-42}	0.509	1215	C^* emits 15.11 MeV γ

Table 3. Event rates per 130 days for neutrinos from pion decay-in-flight

Process	Cross Section (cm^2)	Acceptance	Events	Comments
$\pi^o \to \nu\bar{\nu}$		0.509	$\sim 10^8$	for B.R.=1
$\eta \to \nu\bar{\nu}$		0.509	$\sim 10^4$	for B.R.=1
$\nu_\mu p \to \nu_\mu p$	4.5×10^{-40}	0.234	1970	$E_p > 20$ MeV
$\nu_e C \to e^- N$	3×10^{-39}	0.509	14,310	max-mix., $E_e > 60$ MeV
$\nu_\mu C \to \mu^- N$	6×10^{-40}	0.283	910	$E_\mu > 10$ MeV
$\bar{\nu}_\mu p \to \mu^+ n$	5×10^{-40}	0.283	300	$E_\mu > 10$ MeV
$\bar{\nu}_\mu C \to \mu^+ B$	1.5×10^{-40}	0.283	45	$E_\mu > 10$ MeV
$\nu_\mu C \to \nu_\mu C^*$	3.5×10^{-41}	0.509	170	C^* emits 15.11 MeV γ
$\nu_\mu e^- \to \nu_\mu e^-$	2.5×10^{-43}	0.509	9	$E_e > 10$ MeV

Figs. 2.26(a) and 2.26(b) show the neutrino energy distributions from decay-at-rest and decay-in-flight, respectively. At a distance of ~ 27 m from the beam stop, the neutrino flux is 5.39 x $10^{13} \nu_\mu/cm^2$ from pion decay-at-rest and an equal number of ν_e and $\bar{\nu}_\mu$ from muon decay-at-rest after 130 days of running at LAMPF (~ 3000 actual hours) or 8678 Coulombs. Using 5.9 X 10^{30} C nuclei, a cross section of 1.46 x 10^{-41} cm^2, and an acceptance of 0.342, we can estimate the number of $\nu_e C \rightarrow e^- N$ events to be

$$(5.39 \times 10^{13})(1.46 \times 10^{-41})(0.342)(5.2(\times 10^{30}) = 1588.$$

The 0.342 $\nu_e C \rightarrow e^- N$ acceptance is the product of the shield live time (74.3%), the 25 cm fiducial volume cut efficiency (76.2%), the electron identification efficiency (90%), and the fraction of events with $E_e > 10$ MeV (67%). Similarly, we estimate 340 $\nu e \rightarrow \nu e$ events and 1215 $\nu C \rightarrow \nu C^*$ events in one year from pion decay-at-rest. For maximal $\bar{\nu}_\mu$ - $\bar{\nu}_e$ mixing we would obtain 19,350 $\bar{\nu}_e p$ events with $E_e > 37.5$ MeV, and we get several high energy $\nu_e C \rightarrow e^-$ N scattering events for a 10^{-8} $\pi^o \rightarrow \nu\bar{\nu}$ branching ratio.

For pion decay-in-flight we estimate 1.59 x $10^{12} \nu_\mu/cm^2$ (3.18 x $10^{11} \bar{\nu}_\mu/cm^2$) for $E_\nu > 100$ MeV after 130 days of running at LAMPF. With the present A6 beam stop configuration and with the tank filled with liquid scintillator we then should detect 1970 νp elastic scattering events above a 10 MeV threshold (due to saturation effects in the scintillator, a 10 MeV threshold corresponds to a ~ 20 MeV proton energy), while many more events should be observed if a decay path is added to the beam stop. For νp elastic scattering we use a tighter 50 cm fiducial volume cut in order to reduce neutron-induced background. In addition, we should observe about 910 $\nu_\mu C \rightarrow \mu^-$ N charged current events and 14,310 $\nu_e C \rightarrow c^-$ N events for maximal ν_μ - ν_e mixing. Finally, a typical supernova in our galaxy will produce ~ 35 $\nu C \rightarrow \nu C^*$ (15.11 MeV γ) events in a 10 s interval.

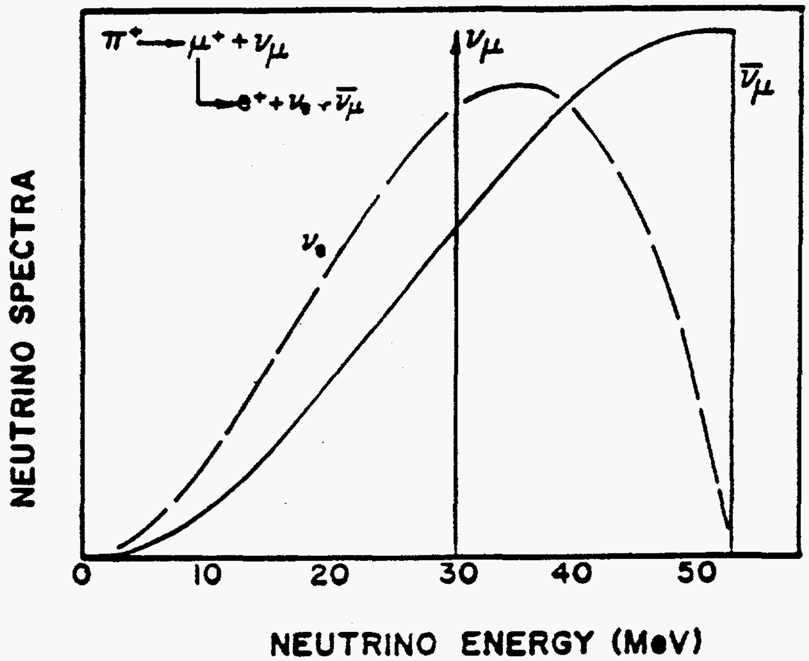


Fig. 2.26a Neutrino energy distributions from pion decay-at-rest

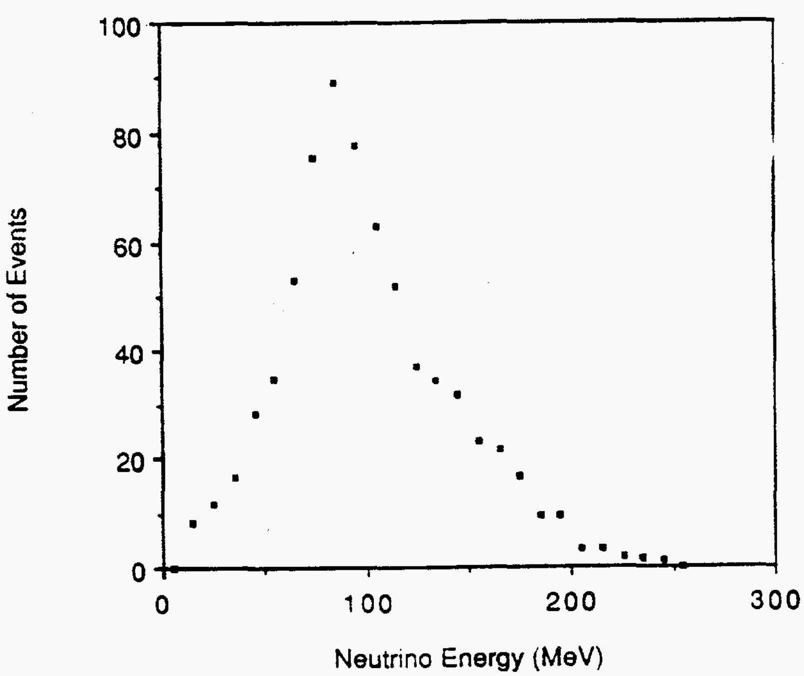


Fig. 2.26b Neutrino energy distribution from pion decay-in-flight.

Background

There are three potential backgrounds that can effect us: beam neutrino, beam neutron, and cosmic ray interactions. Fortunately with resolutions of the detector the backgrounds listed can be discriminated against. As far as the beam neutrino background is concerned, we should be able to separate the various types of neutrino interactions.

The A6 beam line has so much shielding, almost 9 m of Fe equivalent, that beam neutron interactions have not even been unambiguously identified in the E645 detector after more than one year of data collection. We expect the beam neutron interaction rate to be less than 100 events per LAMPF day (a LAMPF day or LD accounts for the 6% duty factor of the linac) in the energy region $E_n > 20$ MeV. Beam neutron interactions that do occur in the detector will be located usually near the edge of the tank and will have a much different dependence on distance from the beam stop than neutrino induced events. Thus, beam neutrons represent a small background which can be easily subtracted.

Cosmic muons can almost always be recognized by the veto shield which surrounds the detector. The estimated 3×10^{-6} veto inefficiency corresponds to less than one hundred unidentified cosmic muons per LD. As with beam neutrons, cosmic muon induced events will have a different position dependence than neutrino induced events and will not display the characteristic 200 MHz beam structure. Furthermore, we will do extensive beam off running so that the cosmic muon background subtraction can be quite precise. Therefore, cosmic muons should not be a serious background.

Expected Sensitivities and Limits

Table 4 lists the final limits and measurement errors that we expect after two years of data collection. Cross section measurement errors are generally expected to be ~ ±10%, while neutrino oscillation limits are estimated at the few x10^{-4} level. A range is given for the $\bar{\nu}_\mu$ - $\bar{\nu}_e$ oscillation limit, where the smaller number assumes that the recoil neutron from $\bar{\nu}_e p \rightarrow e^+ n$ can be reliably detected and the larger number assumes that the recoil neutron is not detected.

Table 4. Expected measurement errors and limits after two years of data collection.

Process	Measurement Error or Limit
$\bar{\nu}_\mu - \bar{\nu}_e$ Oscillations	$< 2.6 - 8.8 \times 10^{-4}$ at large Δm^2
$\nu_\mu - \nu_e$ Oscillations	$< 4.0 \times 10^{-4}$ at large Δm^2
$\pi^o \rightarrow \nu\bar{\nu}$	$< 10^{-8}$
$\eta \rightarrow \nu\bar{\nu}$	$< 10^{-4}$
$\nu e \rightarrow \nu e$	$\pm 10\%$
$\nu_e C \rightarrow e^- N$	$\pm 10\%$
$\nu C \rightarrow \nu C^*$	$\pm 10\%$
$\nu_\mu p \rightarrow \nu_\mu p$ (free protons)	$\pm 20\%$
$\nu_\mu p \rightarrow \nu_\mu p$ (free plus bound protons)	$\pm 10\%$
$\nu_\mu C \rightarrow \mu^- N$	$\pm 10 - 20\%$

Figure 2.27 shows the present ν_μ - ν_e oscillation limits together with our expected limits after two years of data taking. As can be seen readily, our expected limits obtained in both decay at rest (D.A.R.) and decay in flight (D.I.F.) experiments exceed the existing limits by orders of magnitude.

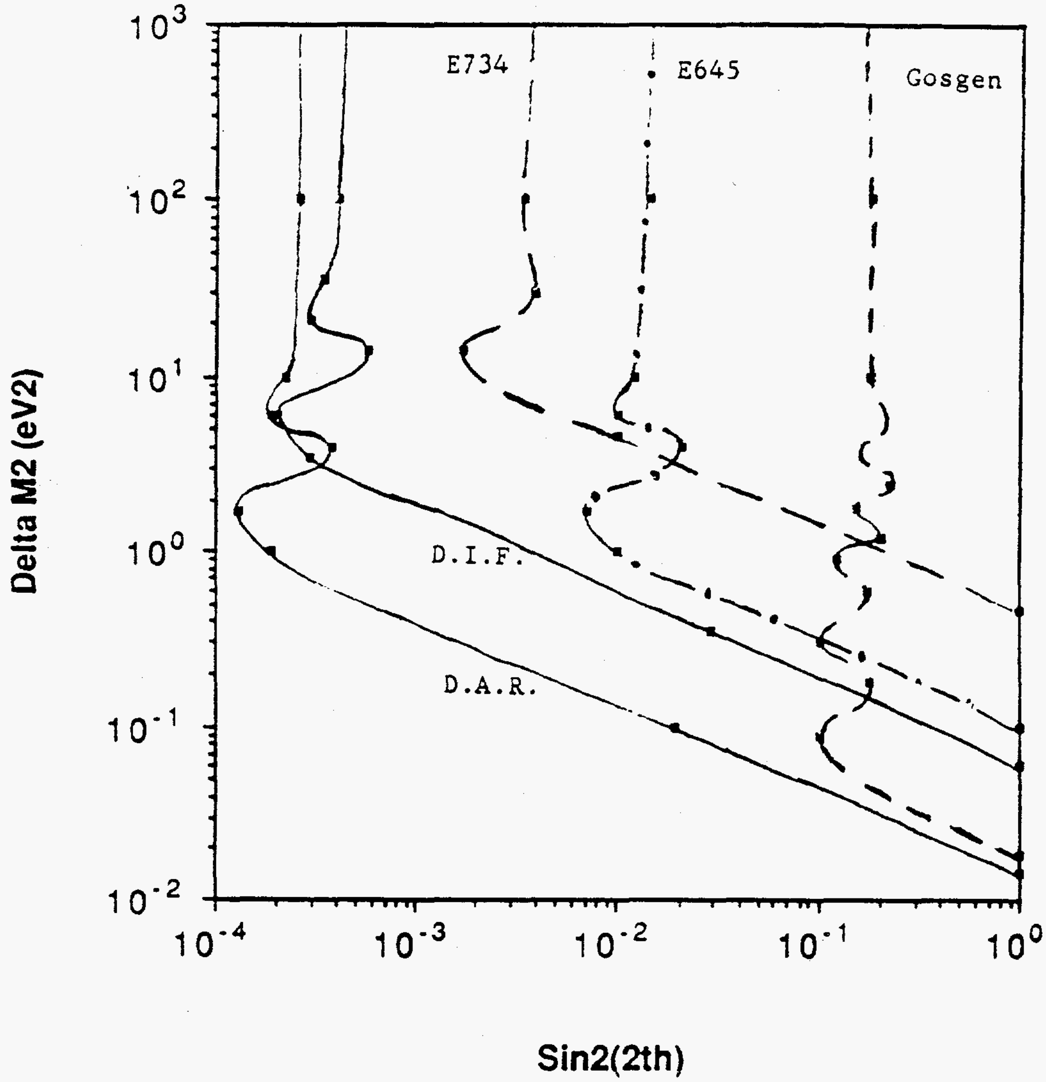


Fig. 2.27 The present ν_μ - ν_e oscillation limits together with our expected limits from decay-at-rest and decay-in-flight after two years of data collection.

Personnel

Relatively modest efforts from B.C. Shen and G.J. VanDalen will be devoted to this project until the construction phase of the experiment. A research associate and a student may be added to the project in 1990-1991.

References

1. D. Beavis, S.Y. Fung, W. Gorn, R.T. Poe, G.J. VanDalen, et al., Phys. Letters B194, 591 (1987).
2. X. Q. Lu, S.Y. Fung, J.H. Kang, B.C. Shen, G.J. VanDalen, et al., LAMPF proposal.

Task B: Theory

1. Introduction

The High-Energy Physics Theory Program at U.C. Riverside has had an even more successful year than the previous one. Since July 1988, there have been 26 completed papers (UCRHEP-T16 to UCRHEP-T41). They are listed under Publications (Sec. 3) together with those 8 papers which were listed in last year's report as yet to be published but are now published. Of the 28 papers with definite publication information, 10 are in letter journals: 3 in Phys. Rev. Lett., 2 in Phys. Lett. B, and 5 in Mod. Phys. Lett. A. This is certainly indicative of our quality as well as productivity.

The Theory Group consists mainly of E. Ma (Professor), S. Rajpoot (Visiting Assistant Professor), J. Pantaleone (Postgraduate Researcher), D. Ng and G. Wong (Graduate Student Research Assistants). This proposal (for the period February 1990 to January 1991) is to fund the research activities of Ma, Pantaleone, Ng, Wong, and a new Research Assistant (to be named) with the anticipated departure of Ng and Wong in September 1990 after they receive their Ph.D degrees.

In Sec. 2, the research activities of the Theory Group since July 1988, as well as some research plans for the immediate future, are discussed. In Sec. 3, there is a list of completed or published papers since July 1988. 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.

2. <u>Research Program</u>

Since July 1988, E. Ma has completed 14 papers for publication, including 4 which will appear in Conference Proceedings. They are described briefly below.

The main focus of Ma's research during the past year has been in mass-generating radiative mechanisms for light quarks and leptons in renormalizable gauge field theories. There are 8 papers in this category, including 2 (#23, #27 on list in Sec. 3) which will appear in the Proceedings of the Fourth Family Symposium and the Weak Interaction Workshop respectively. One paper (#13) is a follow-up on Ma's previously published work (#4) on the two-W mechanism for radiative Majorana neutrino masses in a minimal model. Some interesting phenomenological consequences of the mixing of a heavy 4th neutrino with the 3 known light neutrinos are discussed. In paper #28, the technical aspect of the two-W mechanism is further clarified in a nonminimal model. In papers #15 and #24, a simple model of radiative quark and lepton masses using the standard electroweak SU(2) X U(1) gauge group is proposed and developed without the need of nonstandard particle representations. In paper #21, a left-right model of radiative quark and lepton masses is presented which is comprehensive in its treatment of all light fermions including the very light neutrinos without using any discrete symmetry. Finally in paper #30, a brief review of recent developments in this area of research is given, as requested by the editors of Int. J. Mod. Phys. A.

The other papers by E. Ma deal with exotic baryon-number nonconservation (#9), e-μ-τ nonuniversality (#18), a supersymmetric left-right E_6 model (#12, #16), heavy Majorana neutrino production (#26), and τ as a nonleptonic superparticle (#34).

In the immediate future, the research plans of E. Ma include a detailed analysis of his proposed left-right model of radiative masses (#21), further consequences of identifying τ as a nonleptonic superparticle (#34), a detailed study of $\mu \rightarrow e\gamma$ looking for a possible theoretical lower bound from the requirement that e and μ have radiative masses, and incorporating supersymmetry to stabilize various mass-generating radiative mechanisms.

Since July 1988, S. Rajpoot has completed 8 papers for publication, including 2 which will appear in Conference Proceedings. They represent research on 2 fronts. One deals with his original work on supersymmetry generators with spin 3/2. Two papers (#19, #33) in this category were completed in collaboration with C. Pilot (Univ. of Tulsa). The other deals with various extensions of the standard model: 4th family (#25), Fritzsch mass matrices (#10), distinct hypercharge for quark and lepton (#20), gauged baryon and lepton number (#31), leptoquark matter (#32), and chiral color (#29).

Since September 1988 when he joined the Riverside Theory Group, J. Pantaleone has completed 6 papers for publication, including 1 Conference Proceedings and 1 long review article for Rev. Mod. Phys. He worked with Ma on 4 papers: consequences of a model of radiative neutrino masses (#13), e-μ-τ nonuniversality (#18), consequences of a model of radiative quark and lepton masses (#24), and heavy Majorana neutrino production (#26). He also collaborated with T.K. Kuo (Purdue Univ.) on 2 papers (#14, #22) dealing with neutrino oscillations in matter. The last 3 papers are described in more detail below.

Neutrino Oscillations in Matter (#14, #22) Nonzero neutrino masses would provide new, unique information on particle physics beyond the standard model. Neutrino flavor oscillations provide the most sensitive method for directly testing for small neutrino masses. When the oscillations occur in matter, a resonance can occur which dramatically enhances the flavor mixing and can lead to conversion from one neutrino flavor to another. This is an attractive solution to the long standing "solar neutrino problem" and consequently several new experiments to measure the solar neutrino flux are currently under construction. The emphasis of Pantaleone's research, in collaboration with T.K. Kuo, has been on improving the analytical description of neutrino oscillations in matter and extending the original analyses to include three neutrino flavors, as is observed in nature.

Heavy Majorana Neutrinos (#26) Many collider experiments place constraints on the possible masses and mixing angles of heavy neutrino's, usually assuming that the heavy neutrino is a Dirac fermion. However, since neutrinos are neutral they could instead be Majorana fermions. To aid the search for heavy neutrinos, the characteristics of Majorana neutrino production in collider experiments have been calculated.

Graduate students D. Ng and G. Wong participated in a paper (#24) on 1-loop induced fermion masses and the resulting exotic interactions in a standard-model context. Ng also worked with Ma on a supersymmetric left-right E_6 model (#12, #16).

3. Publications

The following list contains work published or completed by the Riverside Theory Group since July 1988.

1. UCRHEP-T6: "Supersymmetry with Vector-Spinor Generators," C. Pilot and S. Rajpoot, Mod. Phys. Lett. A 4, 303 (1988).

2. UCRHEP-T7: "Chirally Symmetric Strong and Electroweak Interactions," S. Rajpoot, Phys. Lett. B208, 483 (1988).

3. UCRHEP-T10: "Two-Body Radiative Gluino Decays," E. Ma and G.-G. Wong, Mod. Phys. Lett. A3, 1561 (1988).

4. UCRHEP-T11: "Natural Hierarchy of Radiatively Induced Majorana Neutrino Masses," K.S. Babu and E. Ma, Phys. Rev. Lett. 61, 674 (1988).

5. UCRHEP-T12: "Superalgebras with Fermionic Generators Other Than Spin 1/2," C. Pilot and S. Rajpoot, Mod. Phys. Lett. A4, 831 (1989).

6. UCRHEP-T13: "A BCS Quark Mass Matrix," P. Kaus and S. Meshkov, Mod. Phys. Lett. A3, 1251 (1988).

7. UCRHEP-T14: "Radiative Quark and Lepton Masses Through Soft Supersymmetry Breaking," E. Ma, Phys. Rev. D39, 1922 (1989).

8. UCRHEP-T15: "See-Saw Fermion Masses in the Standard Model," S. Rajpoot, Phys. Rev. D39, 351 (1989).

9. UCRHEP-T16: "Model of Exotic Baryon-Number Nonconservation at Moderate Energies," X.-G. He, G. Joshi, and E. Ma, Phys. Rev. D39, 1454 (1989).

10. UCRHEP-T17: "An SU(3) X SU(2) X U(1) Model with Fritzsch Mass Matrices," S. Rajpoot, Phys. Rev. D (in press).

11. UCRHEP-T18: "Purely Gluonic Soliton Solutions in the Leading-Logarithm Model," G. Xu and B.R. Desai, Phys. Rev. D (in press).

12. UCRHEP-T19: "Supersymmetric Left-Right E_6 Gauge Model: Flavor-Changing Interactions," E. Ma and D. Ng, Phys. Rev. D39, 1986 (1989).

13. UCRHEP-T20: "Model of Radiative Neutrino Masses: Mixing and a Possible Fourth Generation," K.S. Babu, E. Ma, and J. Pantaleone, Phys. Lett. B218, 233 (1989).

14. UCRHEP-T21: "Nonadiabatic Neutrino Oscillations in Matter," T.K. Kuo and J. Pantaleone, Phys. Rev. D39, 1930 (1989).

15. UCRHEP-T22: "Radiative Quark and Lepton Masses Induced by a Fourth Generation," E. Ma, Phys. Rev. Lett. 62, 1228 (1989).

16. UCRHEP-T23: "New Supersymmetric Left-Right Model and Rare Decays," E. Ma and D. Ng, in Proc. of the Rare Decay Symposium, to be published.

17. UCRHEP-T24: "Space-Time and Quantum Mechanics from Octonions," S.-Y. Chu.

18. UCRHEP-T25: "Is e-μ-τ Universality Violated?" E. Ma and J. Pantaleone, in Proc. of Beyond the Standard Model, to be published.

19. UCRHEP-T26: "Vector-Spinor Superalgebra and Goldstone Spin -3/2 Fermions," C. Pilot and S. Rajpoot, Int. J. Mod. Phys. A (in press).

20. UCRHEP-T27: "Distinct Hypercharge Sources for Quarks and Leptons," S. Rajpoot, in Proc. of Beyond the Standard Model, to be published.

21. UCRHEP-T28: "Radiative Quark and Lepton Masses in a Left-Right Gauge Model," E. Ma, submitted to Phys. Rev. Lett.

22. UCRHEP-T29: "Neutrino Oscillations in Matter," T.K. Kuo and J. Pantaleone, Rev. Mod. Phys. (in press).

23. UCRHEP-T30: "The Fourth Family as a Source of Radiative Masses for the First Two," E. Ma, in Proc. of the Second International Symposium on the 4th Family of Quarks and Leptons, to be published.

24. UCRHEP-T31: "One-Loop Induced Fermion Masses and Exotic Interactions in a Standard-Model Context," E. Ma, D. Ng, J. Pantaleone, and G.-G. Wong, Phys. Rev. D (in press).

25. UCRHEP-T32: "The τ-Lepton Lifetime Discrepancy as Evidence for the 4th Family," S. Rajpoot, in Proc. of the Second International Symposium on the 4th Family of Quarks and Leptons, to be published.

26. UCRHEP-T33: "Heavy Majorana Neutrino Production," E. Ma and J. Pantaleone, submitted to Phys. Rev. D.

27. UCRHEP-T34: "Radiative Quark and Lepton Masses," E. Ma, in Proc. of 12th International Workshop on Weak Interactions and Neutrinos, to be published.

28. UCRHEP-T35: "Radiative Hierarchy of Majorana Neutrino Masses," K.S. Babu and E. Ma, submitted to Phys. Lett. B.

29. UCRHEP-T36: "CP Violation in Models with Chiral Color," X.-G. He and S. Rajpoot, Phys. Rev. Lett. (in press).

30. UCRHEP-T37: "Radiative Mechanisms for Generating Quark and Lepton Masses: Some Recent Developments," K.S. Babu and E. Ma, Int. J. Mod. Phys. A, to be published.

31. UCRHEP-T38: "Electroweak Interactions with Gauged Baryon and Lepton Numbers," S. Rajpoot, Phys. Rev. D (in press).

32. UCRHEP-T39: "Lepto-Quark Matter," S. Rajpoot, submitted to Mod. Phys. Lett A.

33. UCRHEP-T40: "The Construction of Left and Right Handed Chiral Superfield with (1, 1/2) + (1/2, 1) SUSY," C. Pilot and S. Rajpoot, Mod. Phys. Lett. A (in press).

34. UCRHEP-T41: "Identifying τ as a Nonleptonic Superparticle," E. Ma and P. Roy, submitted to Phys. Rev. Lett.

4. Travel and Consultants

Since July 1988, members of the Theory Group have traveled to conferences and to give talks. Visitors also came to Riverside to give seminars and to collaborate. 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 24th International Conference on High Energy Physics (Munich, W. Germany) in August 1988 with funds provided by the University. He also gave a seminar at the Ecole Polytechnique

(Palaiseau, France). In February 1989, he attended the Fourth Family Symposium in Santa Monica, California and gave a talk. In April 1989, he attended the Weak Interaction Workshop (Ginosar, Israel) and gave a talk. In May 1989, he attended the e^+e^- Conference at KEK (Tsukuba, Japan) and also visited the Tata Institute (Bombay, India) and gave a talk there, with funds provided by the University. He also gave seminars at U.C. San Diego and Cal State Univ. at Los Angeles.

S. Rajpoot attended the "Beyond the Standard Model" Conference at Iowa State Univ. in November 1988 and gave a talk. He also attended the Fourth Family Symposium (Santa Monica) in February 1989 and gave a talk. In July 1989, he will attend a conference on Geometry in Physics at U.C. Davis and give a talk there.

J. Pantaleone attended the "Beyond the Standard Model" Conference at Iowa State Univ. in November 1988 and gave a talk. He also attended the Symposium on the Next Supernova in Santa Monica, California in February 1989. In July 1989, he will attend the SLAC Summer Institute and Topical Conference.

D. Ng attended the Rare Decay Symposium (Vancouver, Canada) in December 1988 and gave a talk. In June 1989, he attended the Collider Phenomenology Workshop at Argonne National Lab and then spent 4 weeks at the Theoretical Advanced Study Institute (TASI) in Boulder, Colorado.

G. Wong also spent 4 weeks at TASI in June 1989.

K. S. Babu (Univ. of Maryland) visited Riverside for about a week in March 1989 and gave a seminar. During his visit, a joint research project with Ma was started, resulting in a paper (#28 on Publication List in Sec. 3).

P. Roy (Tata Institute, Bombay) visited Riverside for 4 weeks in June 1989 and gave 3 seminars. Roy and Ma collaborated on a research project resulting in Paper #34 on Publication List in Sec. 3. His visit was supported by University funds.

Other visitors who gave high-energy theory seminars/colloquia include H. Cheng (MIT), W.R. Frazer (Univ. of California), G. Gelmini (SISSA, Trieste), R. Peccei (UCLA), J. Preskill (Caltech), A.I. Sanda (Rockefeller), M. Shin (U.C. Irvine), A. Soni (UCLA), T.N. Truong (Ecole Polytechnique, France), T. Weiler (Vanderbilt), and M. Wise (Caltech).

5. Personnel and Needs

As already mentioned in Sec. 1, the 2 Ph.D members covered by the present proposal are E. Ma (Professor), for whom 2-1/2 months of summer salary is requested, and J. Pantaleone (Postgraduate Researcher), for whom continuing support for the entire 12 months is requested. There are at present 3 graduate students doing research under Ma. Two (D. Ng and G. Wong) are Research Assistants and their continuing support is requested through August 1990. The other (R. Anderson) has an outside job and is self-supporting. With the anticipated completion of the Ph.D degree for Ng and Wong, a new Research Assistant is expected beginning July 1990.

Two foreign trips are planned, at about $2,250 each, to conferences such as the International High Energy Physics Conference in Singapore and the Neutrino Conference in Geneva, etc. Five domestic trips are planned, at about $1,250 each, to conferences such as the Particles and Fields Meeting in Houston, the International Conference on Particles and Nuclei in Cambridge, MA and various other conferences, workshops, and summer institutes yet to be announced. About $5,000 is requested for bringing in consultants to work on research projects of mutual interest.

With a growing Riverside campus, it is expected that the University will approve the addition of a junior faculty member to the Physics Department in the area of Theoretical High Energy Physics to begin July 1990. This will strengthen the research effort of the present Theory Group which has already a very strong record since the initial funding of DOE in February 1988. Continuing support by DOE and at a level compatible with the Group's activities is vital for its future success.

II. High Energy Physics Computing at UCR

As a university group we place a strong emphasis on data analysis and software activities in general. Thus for example a major activity at present is a simulation study for a silicon vertex detector for D-Zero. With the turn on of LEP in August 1989 and the first D-Zero run scheduled for early 1991, a substantial increase in computing power on campus becomes essential. When LEP is operating at design luminosity the OPAL detector will record 1,000,000 Z^o's per year. D-Zero is expected to record 10^7 interactions in its first run in 1991. Meanwhile we are starting a major effort to develop the offline muon reconstruction software at UCR. For the next few years we expect that a total of three faculty plus research staff (3-4) and graduate students (4-6) will be working on data analysis, simulations and software development at UCR. The necessary expansion of our computing resources is discussed in detail below. Briefly we plan to add four VAXStations in 1990 and a VAX-based machine capable of 10 MIPS in 1991.

The D-Zero/OPAL collaborations maintain extensive VAX/VAXClusters for both on-line data acquisition and off-line analysis. Software and data-bases are routinely updated and distributed using HEPnet/DECnet to institutes within the collaborations supporting VAX-based processing. The data from both experiments (including reconstruction tapes and DST's) will be available on ExaByte 8mm video tapes or IBM 3480 cartridges. Beyond this we also anticipate additional Monte Carlo studies in connection with the SSC sub-system R&D work.

At Riverside we have an existing VAX infrastructure both in the Physics Department, and the campus central computing facility. The Physics Department has a VAXCluster of a 3500 server/host and three VAXStations II's. The cluster includes four 9-track tape drives, two ExaByte 8mm video-digital tapes, and 4 GBytes of disk. The campus central facilities include a VAX8820 based cluster with 12.5 GBytes of disk, central management and operations support staff.

There is a need to expand beyond the present computing power provided by the Physics Department VAXCluster. The current 2.7 MIPS MicroVAX 3500 which can process only 1.8 events/hour is already limiting turnaround on ISAJET/GEANT programs and the anticipated OPAL/D-Zero data analysis will make this situation worse. The addition of VAXStation 3100's will provide computing power sufficient for program development and DST analysis, however, we will need more computing power (MIPS) starting in 1991. A machine with 10-15 MIPS in a VMS environment would meet the need. A possible solution would be to upgrade the existing MicroVAX 3500 to a VAXStation 3540 (Foxfire). This represents the highest expansion in the 3500 series giving 10 MIPS in a multiprocessor environment. At this time DEC is proposing new and higher powered systems to come out later this year (5 MIPS per CPU) but the pricing has not been fixed. We are waiting to see what they plan to offer as this might provide a better long-term solution.

We propose that the upgrade be spread out over two years as follows:

Year 1: 4 VAXStation 3100 systems (2 each for D-Zero and OPAL) including 12 MBytes of base memory and an RZ23 disk (104 MBytes).

Year 2: 1 VAX/VMS machine capable of providing at least 10 MIPS and capable of further expansion. Add two 8mm tape drives to the VAXStation 3100's.

For the first year this would:

- increase the available CPU power in the Physics cluster by a factor of four,
- add high-performance workstations for support of OPAL/D-Zero software, and
- offer additional host capacity for ExaByte tapes.

These systems would share the central disk capacity (4 GBytes), batch processing, and print services of the existing Physics Department VAXCluster. The VAXStation 3100 is chosen because it:

- offers the lowest price (i.e. price/performance) upgrade to the existing facility,
- allows transparent access to the D-Zero/OPAL VAXClusters via DECnet,

- offers high-performance windowing and graphics, and
- provides for future mass-storage upgrades.

The University of California has a standing purchasing agreement with Digital Equipment Corporation which offers excellent discounts on hardware, and very low cost software through the University Library plan.

Selected Systems for the 1st year: 4 of each

PV010-BC	VAXStation 3100 model 30 with 19" monochrome monitor, 8 MByte memory, keyboard, mouse, thin/thick ethernet adapter, VMS licenses.	$4,215.00
VS42D-DA	RZ23 disk subsystem including 104 MBytes capacity and SCSI port.	$3,180.00
	4 MByte memory upgrade (to bring each system to 12 MBytes).	$1,500.00
	Total/System	**$8,895.00**

Selected System for the 2nd year:

VS620-AA	Model 3520, 2 processors, VMS operating system, BA213, 19'' monitor	$13,121.00
	3520-to-3540 upgrade to 4 processors	$10,618.00
MS60-BA	8 MBytes ECC memory	$3,000.00
	2 ea. 8mm Tape Drives with SCSI Interface 2 x $6,000 each	$12,000.00
	Total	**$38,739.00**