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Progress Report for FY93
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Elementary Particle Physics and High Energy Phenomena

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Document Organization

This progress report for FY93 for work under Grant DE-FG02-91ER40672 is presented in the three attached sections:

- Experimental Group I (Tasks A1, D1, and R): U. Nauenberg, A. Barker, co-investigators.
- Experimental Group II (Tasks A2, D2, and J): John P. Cumalat, William T. Ford, Patricia Rankin, and James G. Smith, co-investigators.
- Theory Group (Tasks B and T): Senarath P. de Alwis, Thomas A. DeGrand, and K. T. Mahanthappa, co-investigators.

PROGRESS REPORT
TASK A1 AND RMCHEP PROJECTS

Here we describe the research activities included in tasks A1 and D1, including the Fermilab Kaon Program (E799 and KTeV), the SLD Program, and the SDC Muon R&D Program. The activities of the Rocky Mountain Consortium for High Energy Physics are also described.

Fermilab Experiment 799 collected data between October 1991 and January 1992. This was the first phase of a two-part experiment designed to search for a number of rare kaon decays, particularly $K_L \to \pi^0 e^+ e^-$. The University of Colorado is one of eight institutions in the E799 Collaboration, represented by Prof. Anthony Barker, who is currently participating in the analysis of these data. The first result from E799, a new measurement of the branching ratio for the rare electromagnetic decay $\pi^0 \to e^+ e^-$ based on π^0 mesons tagged in $K_L \to \pi^0 \pi^0 \pi^0$ decays, has been accepted for publication in Physical Review Letters.

The KTeV Project is a major new initiative at Fermilab. It encompasses two new fixed-target experiments devoted to the study of the neutral kaon system, both utilizing a new detector facility which is currently being designed. The first experiment will be a continuation of E799, with improved sensitivity and background rejection capabilities; the second experiment, E832, will be devoted to a new measurement of the important CP Violation parameter, ϵ'/ϵ. Both experiments plan to collect data during Fermilab's next fixed-target run, currently scheduled to begin in 1995.

The KTeV Collaboration consists of nine institutions, including the University of Colorado. The lead person on this effort at Boulder is Prof. Anthony Barker; he is joined in the KTeV project by Prof. Uriel Nauenberg. We expect to have 2 graduate students join the experiment during the summer of 1993.

The Colorado group has important responsibilities in the construction of the KTeV apparatus, which are discussed in detail below. Briefly, we are designing and will build a system of four large lead/scintillator calorimeters which will be used to detect photons that miss KTeV's primary electromagnetic calorimeter: these detectors will allow us to identify such photons, which would otherwise produce sizeable backgrounds. We are responsible for the design and operation of the bulk of KTeV's trigger electronics, including a major upgrade to the Level 2 Trigger which will digitize drift chamber hits in real time.

The SLD has made major strides towards increasing both the polarization of the electron beam and the number of Z's acquired on tape. Both the machine and the detector are working well and improving steadily. Last year SLD acquired over 10K polarized Z's with an average polarization of 22%. This year the polarization has improved with the use of a new strained Gallium Arsenide source which has provided longitudinal electron polarizations of more than 70%, which becomes 60 64% at the interaction point. In addition the machine luminosity has improved markedly: SLC has now achieved maximum luminosities of 50 Z's/hour and average luminosities of 30–35 Z's/hour. SLD has already collected over 20 K Z's, and the experiment is well on its way to reaching its goal of 60 K Z's for the present run.

Improvements to the SLC scheduled to be installed during the fall of 1993, should increase the luminosity by a factor of four over present levels. Hence we expect to collect upwards of 100 K Z's during the 1994 run. Because of the achieved high polarization values and high luminosity this sample of data will lead to significant physics measurements which can not be accomplished at any other machine.

The SDC detector effort is continuing. The C.U. SDC Muon Group has carried out a large number of measurements to study the elastic properties of the 90 tungsten wire to be used in the muon tubes. We have developed a computer controlled tensioning device that can tense the sense wire to the desired value in a period of 10 seconds. We have also taken on the task of developing a Cockroft-Walton photomultiplier base and the associated amplifier and discriminator electronics to be used with the scintillator counters.

The Rocky Mountain Consortium for High Energy Physics (RMCHEP) is continuing in its program of faculty acquisition. Anthony Barker joined the Univer sity of Colorado. Colorado State University has begun its program of high energy physics; it has two outstanding high energy physicists as faculty members in Walter Toki and Robert Wilson. Prof. Neville W. Reay and the other members of his group from Ohio State will move to Kansas State University this summer to start a new program in High Energy Physics with the support of the RMCHEP. The University of Kansas has acquired two excellent junior faculty, David Beeson and Alice Bean. The University of Nebraska should be able to start its High Energy Physics program soon with the appointment of a senior faculty person. The University of Arizona plans to appoint a junior faculty member this year.

Our group has contributed greatly to the community:

1. Uriel Nauenberg is a member of SLAC's PAC; is on the Advisory Board and the Physics Committee of the SLD collaboration; he is the chairman of the nominating committee for the election of the Members of the Executive Board of the Division of Particles and Fields; he is also on the Board of Governors of the HSSC, where he is the chairman of the Education Committee and a member of the Program Committee. This year, at the San Francisco meeting, we will host approximately 60 high school students to learn about the SSC as a machine and to learn about the physics we plan to carry out with it. He is also the chair of the RMCHEP. This year he gave an invited lecture at the Washington APS meeting representing the SLD collaboration.

2. Anthony Barker received a Sloan fellowship which is a great honor for the High Energy Physics group and the University of Colorado. In addition he is the Manager of the Trigger and Data Acquisition Group of the KTeV experiment and is a member of the KTeV Collaboration Council as the representative of the University of Colorado. He has been invited to give a review talk on Precision Experiments with Strange Particles at the XIIIth International Conference on Physics in Collision this summer.

1. The Study of the Properties of the Z^0 with the SLD Detector

Gregory Baranko, Eric Erdos, Cheng Gang Fan, Nety Krishna, Mark Christoph, Uriel Nauenberg, Gerhard Schultz, Victor Slonim; in collaboration with the members of the SLD group.

The SLD experiment observed its first Z^0 events in June, 1991. Since then the polarization of the electrons and the machine luminosity have increased markedly. The SLD is now in its second major physics run. We are running with an electron longitudinal polarization, at the interaction point, of 60-64% and a luminosity averaging 30 Z's/hour (max. of 50 Z's/hour) when running and 2,000 Z's/week average. These, when compared with the polarization of our initial run, 22%, and the integrated number of Z's for the run, 11,000, indicate the level of improvement that has has occurred during the last six months. We have already collected 22,000 Z's at this early date in the current run. This new luminosity will allow us to reach the goal of 60,000 Z's by the end of the run in the fall. All detector elements are operational; we are still improving their signal characteristics and only a few are still being debugged.

The major improvement in the luminosity was the result of using flat beams (0.7 μm in y by 2.5 μm in x). Not only did this running mode increase the luminosity, but also, just as important, decreased the background in the detector due to beam bremsstrahlung. The background reduction has led to a major improvement in the track reconstruction efficiency in the forward detectors. Also these cleaner beam condition has reduced the background contribution to our Z^0 signal to the point where it no longer contributes to the systematic error in the analysis.

The major improvement in the polarization is the result of the discovery that a mechanically strained Gallium Arsenide source can in principle emit electrons with almost 100% longitudinal polarization. The mechanical strain is achieved by depositing the Gallium Arsenide on a substrate of Gallium Arsenide Phosphide. The different lattice sizes of the two materials leads to this strain. These new sources were used in the new target installation. The new multi-source system was installed in the target area at the start of the run. It contained a variety of cathodes of which two were of the strained lattice variety. These strained cathodes were shown to produce very high (> 80%) polarization. In the thick targets that we are using presently this value is reduced because the electrons become depolarized by scattering while they are coming out of the target. At the start of the run the polarization at the interaction point, measured with the Compton Polarimeter, was already higher than our goal of 40%. This value improved slowly as we learned to steer the beam in the arcs. The polarization reached 52%. This polarization depends on the wavelength of the laser that impinges on the cathode (Gallium Arsenide) surface. Recently we increased the wavelength of the laser with a resultant increase in the electron longitudinal polarization, at the interaction point, to 60-64% which reflects our present running condition. We expect that by developing a thinner, larger area strained Gallium Arsenide source this polarization could increase to about 72%.

The measurements that can be carried out with this beam are unique, incisive, and can not be carried out anywhere else. We should be able to carry out a very accurate measurement of the value of the Glashow-Weinberg angle by means of a measurement of the left right asymmetry. This consists of counting the difference in the number of Z's produced with the electrons polarized in the direction parallel and anti-parallel to the direction of motion. We have already made a measurement of this asymmetry using last year's data.[1] The value of the Glashow-Weinberg angle we obtained is:

$$sin^2\theta_W = 0.2378 \pm 0.0057(stat.) \pm 0.0005(syst.)$$

Because of our improved running conditions this year, this result will become far more accurate. With the events collected in this year's run we expect to achieve a statistical error of about 0.0009. This comes close to our present systematic error limit. As a result we are making improvements to reduce the systematic error which is due mainly to our imprecise knowledge of the laser polarization being used in the Compton polarimeter. This polarimeter measures the electron polarization near the interaction point. This work is going on now and we expect this systematic error to be reduced by a factor of 2.

1. The End Cap Drift Chambers.

The University of Colorado group built the End-Cap Drift Chambers. These were installed in 1990 and we have been debugging them with the associated electronics since that time. The track resolution obtained with cosmic rays is shown in Fig. 1 as a function of the drift distance. A nominal resolution of 200 μm is observed. Cosmic ray resolutions are expected to be worse that for real tracks because of the poor trigger resolution. Hence the better timing of real events should lead us to expect a better track resolution. The reconstruction efficiency of the cosmic ray tracks was found to be better than 90%.

The reconstruction efficiency in the 1992 data was greatly affected by the high beam related backgrounds. The use of flat beams in the 1993 run has reduced this background by about 30%. This reduction has significantly improved the track reconstruction efficiency. We reconstruct tracks that are directionally associated with the signals produced in the end-cap calorimeters. In Figs. 2-4 we show the tracks associated with large angle Bhabhas. The directional association with the calorimeter signals is clearly evident. We are now beginning to observe the differences in the fitted directions of background tracks and of tracks associated with Z's. The background tracks (those tracks that are reconstructed when the event is a $Z \to e^+e^-$ into the barrel region) point in all directions while the real tracks point towards the interaction point. This indicates that most reconstructed background tracks are due to accidental concidences of track segments. This observation will allow us to further remove the background from the real signal.

We have made a comparison of the number of good fitted tracks in the data ("good" tracks exclude the expected background tracks) with the expected number from Monte Carlo. The agreement is good. In the South Inner End Cap we observe on the average 2.4 ± 0.2 real tracks added to a background of 0.9 ± 0.1 while the Monte Carlo predicts 2.7 real tracks. Similarly in the South Outer End Cap we observe 4.0 ± 0.3 added to a background of 2.2 ± 0.3 background tracks while we expect 3.8 good tracks.

We are now in the process of determining the best drift constants to use that will lead to the best resolution and track reconstruction efficiency.

In the present run all four End-Cap (two on each end) Drift Chambers were operational. Each End Cap consists of three Superlayers (U-X-V) that determine a particle's direction. Since then one of the superlayers in the North Outer End Cap began to draw excessive current (indicative of maybe a broken wire) and had to be turned off. We are waiting for an access to try to fix this problem. The other three Drift Chambers and the two remaining superlayers are working well.

2. Physics Analysis Effort.

The study of Z^0 decays concentrates on the determination of the basic parameters of the Standard Model. The collisions produced by the SLC and recorded by the SLD detector have particular characteristics not associated with any other accelerator. These are the high longitudinal polarization of the electrons, the small size of the beam, and the unique vertex detector. As a result of these we can carry out some unique and very accurate measurements.

The most important initial measurement we are carrying out is the left-right asymmetry which we discussed in the previous pages. In addition we have and will continue to carry out a series of measurements of importance to the field of High Energy Physics.

Our two graduate students in the SLD effort, Jan Lauber and Cheng-Gang Fan, have been working on SLD for several years. They have carried out a series of successfull QCD measurements with last years data. This work will be published soon.

Jan Lauber completed his thesis in the Spring Semester of 1993. He is presently a CERN fellow working at LEP. The topic of his work was the determination of the QCD coupling α_s.[2] This is obtained from a measurement of the number of multiple jets as a function of particle pair mass, a cut used to determine which particles belonged to a given jet. In Fig. 5 we show how the coupling constant depends on the scale factor at which we calculate it. This is due to the fact that the theoretical calculation of the dependence of the number of jets on the coupling constant has been calculated to only a few orders in the coupling constant. The value of α_s we obtained was:

$$\alpha_s(M_{Z^0}) = 0.131^{+0.007}_{-0.006} \qquad at \;\; (Q^2 = M^2_{Z^0})$$

Cheng-Gang Fan thesis topic is the determination of the vector character of the gluon. This is accomplished by measuring the distribution of the angle between jets and the energy distribution of the jets.[3] This work should be completed this semester. He will then try observe various angular orientations of jets that could be related to the presence of longitudinally polarized electrons. These are QCD effects, both Parity-Conserving and Parity-Violating. The 60,000 Z's produced with the polarized electrons is a unique sample in which to look for these new QCD effects. The determination of whether these terms are present cannot be done anywhere else.

We have determined whether the strong coupling constant described above is flavor independent. This work is continuing in order to reduce the uncertainty. At present we have determined that the ratio of the strong interaction coupling constant associated with b quarks to that for the other flavors, as well as the ratio of the strong coupling constant for the $u,d,$ and s quarks to that for the c and b quarks:[4]

$$\frac{\alpha_s(b)}{\alpha_s(u,d,s,c)} = 1.058 \pm 0.078(stat.) \pm 0.013(syst.)$$

$$\frac{\alpha_s(u,d,s)}{\alpha_s(c,b)} = 0.983 \pm 0.080(stat.) \pm 0.022(syst.)$$

We have also determined the branching ratio for $Z \rightarrow b\bar{b}$ quarks. We are continuing to improve on the uncertainty of this measurement. This measurement is important because it is quite sensitive to the mass of the top quark alone. This is due to the fact that the branching ratio has vertex corrections that are large and depend on the mass of the top quark. In Fig. 6 we show the dependence of the branching ratio on the top quark mass. We have carried out this measurement using global characteristics of mesons and baryons that are made up of b quarks. This is different from past methods used at LEP that make use of the high transverse momentum of the leptons from semi-leptonic decays of B mesons. These global charateristics are:

1. Particles with B quarks have a larger number of secondary particles with large impact parameters that other particle decays.
2. Particles that come from B meson or baryon and those from secondary decays form a larger number of secondary vertices than particles coming from lower mass meson or baryon decays.

We believe that these global methods are less susceptible to systematic errors that other methods used and will allow us to reach the best levels of accuracy and hence allow us to make a separate determination of the top quark mass.

With last years data we have determined the branching ratio to be:[9]

1. Using the Impact Parameter Method:

$$R_b = 0.214 \pm 0.010(stat.) \pm 0.025(syst.)$$

2. Using the Secondary Vertex Method:

$$R_b = 0.201 \pm 0.011(stat.) \pm 0.030(syst.)$$

We have begun to measure the lifetime of the τ lepton. Because of the three dimensional tracking characteristic and high resolution of our vertex detector we are capable of measuring the decay length of this particle and of other particles containing heavy quark with high accuracy. This should lead to a measurement with low systematic errors and should improve on the results from LEP. This work will increase markedly in the present year.

We will begin to study the forward backward asymmetry of the heavy quarks and in particular of the b quark. This is another result that is useful in determining the Glashow-Weinberg angle. Because of the longitudinal polarization of the electrons we can also measure the "modified" forward backward asymmetry. This consists of measuring the forward backward asymmetry for electrons polarized in one direction and add it to the backward forward asymmetry when the electrons are polarized in the other direction. This quantity depends only on the asymmetry parameter A_{FB} of the final state particle and the magnitude of the longitudinal polarization. The Colorado group intends to work on this effort in collaboration with Prof. Robert Wilson from Colorado State University.

3. Computing.

For the last few years the SLD group has been doing their computing work using mostly the Colorado VAX-8800. Because of the large increase in the number of Z's being logged now the VAX-8800 has become unable to provide enough CPU power to keep up. As a result of this state of computing we made a request to purchase ALPHAs, the latest VMS workstations being produced by DEC. The rating of these is 108 specmarks which we can compare with the 12 specmark rating of the VAX-8800. Hence the acquisition of 2 ALPHAS, our present plan, leads to a factor of 18 increase in the computing capacity for our effort. This should be sufficient for the near future.

The disk storage capacity which will become available in 1993 is not sufficient to replay "raw" data samples in the range of 10 K events. These data samples are necessary to calibrate the time to distance relation in the End Cap Drift Chambers. An average SLD event is 1 MB of data, so 1 GB of disk is required to store 1 K events.

2. Fixed-Target K-Decay Experiments The KTeV Project

Anthony Barker, Bruce Broomer, Eric Erdos, Mark Johnson, Uriel Nauenberg, Peter Mikelsons, and Gerhard Sch[illegible]z; in Collaboration with the University of California, Los Angeles, the University of California, San Diego, The University of Chicago, Elmhurst College, the Fermi National Accelerator Laboratory, Osaka University, Rice University, and Rutgers University.

Last year the high-energy group at the University of Colorado at Boulder began work on a new research effort in experimental high-energy physics. We are collaborating in a series of fixed-target experiments at the Fermilab Tevatron which are performing high-precision, high-sensitivity studies of the neutral K-meson system. Anthony Barker, who joined the Colorado faculty as an Assistant Professor in July, 1992, has collaborated in three experiments which were part of this program, and which have already run at Fermilab: E731, E773, and E799-I.

The first of these was designed to measure the CP violation parameter ϵ'/ϵ, and collected data in 1987–88. The second, E773, ran from July to September of 1991, and was designed to measure another parameter of CP violation in the K^0 system, the difference in the phases of the CP-violating decay amplitudes, $\phi_{00} - \phi_{+-}$. The third experiment, E799-I, which collected data from October, 1991 to January, 1992, is the first part of a two-phase experiment dedicated to the study of rare K_L decays, especially $K_L \rightarrow \pi^0 e^+ e^-$. Analysis of E773 and E799-I data is underway, and Barker will be active in this effort, particularly in the search for rare decays.

The final result from E731 on ϵ'/ϵ was published in Physical Review Letters in February of 1993; the value reported[6] was $\mathrm{Re}(\epsilon'/\epsilon) = (7.4 \pm 5.2\,[\mathrm{Stat.}] \pm 2.9\,[\mathrm{Syst.}]) \times 10^{-4}$, slightly more than one standard deviation above zero. This is in contrast to the result of the other high-precision experiment, NA31 at CERN, which has reported[7] a preliminary result based on three years' running: $\mathrm{Re}(\epsilon'/\epsilon) = (23 \pm 7\,[\mathrm{Combined}]) \times 10^{-4}$. In order to resolve the question of whether ϵ' is non-zero, as the Standard Model predicts, a new, higher-precision experiment has been proposed. This experiment, E832, will run just after the second, higher-sensitivity phase of the rare decay experiment, E799-II. Both experiments are approved at Fermilab, and both will utilise a new beamline and detector facility. The new project, which encompasses both E799-II and E832, is called KTeV (Kaons at the TeVatron). The KTeV experiments plan to collect data during the next Fermilab fixed-target run, which is currently scheduled to begin in early 1995.

The University of Colorado is part of the KTeV collaboration, which currently includes nine institutions and about 40 physicists. The Collaboration has prepared a Technical Design Report[8] (TDR) which describes the physics motivation of both experiments. It discusses the expected precision of the E832 ϵ'/ϵ measurement and estimates the sensitivity of various E799-II rare decay searches. The KTeV TDR also includes a fairly detailed description of the proposed detector, including cost estimates.

The anticipated activities of the University of Colorado group in the analysis of data from the 1991–1992 experiments are discussed in more detail in the next subsection of this progress report. The following subsection describes Colorado's responsibilities in the construction and operation of the KTeV facility.

1. Analysis of Rare Decay Data from E799-I.

With startup funds provided to Prof. Barker by the university, we have acquired a DEC 5000/240 workstation with various peripheral equipment, which is being used to analyse rare decay data collected during E799-I. We will be particularly involved in the search for four-charged particle decays of the K_L. We have evidence already for the decay $K_L \rightarrow \pi^+\pi^-e^+e^-$, which has not previously been observed. It is expected that there will be CP-violating asymmetries in the angular distributions of the final-state particles in this decay. While the number of events reconstructed in this first observation will be too small to measure these asymmetries, our measurement of the branching ratio for this mode will make it clear how much improvement in sensitivity will be required in order for the KTeV rare decay experiment, E799-II, to detect the asymmetry.

The $\pi^+\pi^-e^+e^-$ decay mode is also sensitive to the K^0 charge radius, through the radiative transition $K_2 \to K_1\gamma^*$, where γ^* is a longitudinal virtual photon. This process is expected to contribute only about 1% of the total $K_L \to \pi^+\pi^-e^+e^-$ decay rate, but the experimental acceptance for this component of the decay is enhanced because it tends to result in large e^+e^- invariant masses due to the supression of amplitudes involving a longitudinal photon at small q^2. With the greatly improved sensitivity expected in E799-II, a measurement of the radiative $K_2 - K_1$ transition rate may yield a value for the K^0 charge radius with an accuracy competitive with the existing measurement based on electron–K^0 scattering, and with different systematic uncertainties.

Other four-track decays we will search for include the electromagnetic decays $K_L \to e^+e^-e^+e^-$ and $K_L \to e^+e^-\mu^+\mu^-$. The first of these, K_L Double Dalitz decay, has been observed recently by Brookhaven E777 (six events) and CERN NA31 (two events). We have evidence for this decay from E799-I, and expect ultimately to reconstruct about 20 events. The angular correlations in this decay are sensitive to the presence of CP-violating components in the decay amplitude for $K_L \to \gamma\gamma$. The $e^+e^-\mu^+\mu^-$ mode has not been seen; it is expected to be suppressed by a factor of about 30 relative to the $e^+e^-e^+e^-$ decay. At this level, it would be just at the limit of sensitivity in E799-I. However, the presence of CP-violating couplings could conceivably enhance the rate for this decay considerably relative to that for $K_L \to e^+e^-e^+e^-$.

Finally, we expect to reconstruct perhaps 800 examples of the π^0 Double Dalitz decay, which was used by Samios 30 years ago to determine the parity of the π^0. We plan to do this by using the copious $K_L \to \pi^0\pi^0\pi^0$ mode to tag π^0 decays. E799-I will likely be the first experiment to substantially expand the world sample of $\pi^0 \to e^+e^-e^+e^-$ events beyond the 162 examples found by Samios in bubble chamber photographs. A precise measurement of the matrix element for this decay is needed to improve the prediction for the rate of the interesting decay $\pi^0 \to e^+e^-$.

Indeed, the first result to be published from E799-I will be a new measurement of $\pi^0 \to e^+e^-$ based on π^0 mesons tagged in $K_L \to \pi^0\pi^0\pi^0$ decays. This important result, $BR(\pi^0 \to e^+e^-) = (8.4^{+4.1}_{-2.9} \pm 0.5) \times 10^{-8}$, has been accepted for publication in Physical Review Letters this spring. It represents an improvement over the upper limit previously reported by the SINDRUM Collaboration[10] and helps to resolve controversy regarding previous reports[11,12] of an anomalously high rate for this decay.

2. KTeV Facility Design and Construction.

The Colorado group is committed to three major projects in the construction of the KTeV detector: first, we will design, assemble, and test a 2000-channel system of special-purpose TDC's which will be an integral part of the Level 2 Trigger for KTeV; second, we will construct four large lead/scintillator photon detectors, the "Spectrometer Veto System"; and third, we will be responsible for the design, installation, and commissioning of the Level 0 and Level 1 Trigger systems for KTeV.

Part of the Level 2 Trigger system for E773 and E799-I consisted of a processor which counted hits in each of two views in the four drift chambers in order to estimate the charged multiplicity for the trigger, and, using this information, identified hit topologies characteristic of $K \to \pi^+\pi^-$ decays. The effectiveness of this system was compromised by the fact that all hits within a long timing window whose length was determined by the maximum drift time counted towards satisfying the trigger requirements for an event, even though many of these hits were produced by out-of-time tracks, that is, tracks not synchronous with the scintillator signals used to generate the Level 1 Trigger. The number of such "accidental" hits would be drastically reduced if we could identify and reject for trigger purposes hits which were produced by out-of-time tracks. We plan to do this by requiring that the signal times from two adjacent wires in the X, X' or Y, Y' planes of a chamber be consistent with the hypothesis that both hits were produced by the passage of an in-time charged particle. In effect, this is a digital mean-timing scheme.

At Colorado, we are designing circuit boards which will contain 32 channels of Common-Stop TDC's. Each TDC channel will consist simply of a synchronous counter clocking at 500 MHz, so that one least-significant bit will correspond to 2 ns. When the Common Stop signal arrives, all counters will stop counting. The counts from each pair of adjacent wires will address look-up table memories, which will be loaded in advance with patterns indicating what pairs of times correspond to in-time track hits. With this design, a timing cut can be imposed on the drift chamber hits with essentially no increase in the dead time imposed by the Level 2 Trigger. The use of look-up tables not only makes the system very fast, but also gives us great flexibility to compensate for differences in cable lengths, changes in drift speed, and non-linearities in the time-to-distance relationship. Prof. Barker and an undergraduate student, Hans Rikhof, are currently working on Monte Carlo simulations of the Trigger TDC system in order to study efficiencies, rejection power, and other characteristics of the Trigger TDC's for various design options.

Equipment costs for the Trigger TDC system will be supplied through Fermilab, as part of the KTeV Project. However, to give an idea of the scale of the undertaking, the current Trigger TDC budget is shown below. A substantial design and engineering effort will be required to develop and test this system at the University of Colorado. During the past several months, we have completed negotiations with the Mentor Graphics Corporation for the donation by MGC of Electronics CAD software valued at somewhat more than $ 380,000 to the High Energy Group at Colorado. This gift will give us the capability to do schematic design, logic and thermal simulation, and physical layout and routing of complex printed circuit board designs. In addition, it will improve our ability to share information with our collaborators at The University of Chicago, which has a similar system. A Hewlett-Packard 720 workstation was purchased for use with this CAD system with University-supplied funding of about $ 11,000 together with a $ 10,000 contribution from the Rocky Mountain Consortium for High-Energy Physics.

Prof. Barker worked closely with Bruce Broomer, our group's Electrical Engineer, in order to obtain the Mentor Graphics donation. In addition, Broomer is playing a key role in the conceptual design and planning for circuit prototyping which in currently in progress at C.U. Because KTeV is making significant demands on Broomer's time, which are expected to increase in the coming months, we are requesting that the Department of Energy support 50% of Broomer's salary, which is currently funded on tirely by the Texas National Laboratory Research Commission (TNLRC) through the Rocky Mountain Consortium for High-Energy Physics, which supports SSC-directed research.

It is important in both the ϵ'/ϵ and Rare Decay experiments to be able to identify events in which one or more particles are produced at large engles to the beam and so miss the drift chambers and electromagnetic calorimeter. In E832, photons missed in this way result in a background from $K_L \rightarrow \pi^0\pi^0\pi^0$ decays contaminating the $K_{L,S} \rightarrow \pi^0\pi^0$ samples. In E799-II, escaping particles can lead to a wide variety of backgrounds to rare decay processes. For example, $K_L \rightarrow \pi^+\pi^-\pi^0(\pi^0 \rightarrow e^+e^-\gamma)$ is the source of the dominant background to a search for $K_L \rightarrow \pi^+\pi^-e^+e^-$. The background arises from events in which the photon produced in the π^0 Dalitz decay is not detected and carries little transverse momentum. This can happen if the photon is soft and is emitted at a relatively large angle to the beam, so that it misses the CsI calorimeter.

In order to detect such particles, a system of lead/scintillator Veto detectors has been designed for KTeV. There will be altogether nine of these detectors, surrounding the decay volume and detector with "Rings" at different locations along the beam direction. The first five Ring Counters will be located inside the vacuum decay volume; the last four, the Spectrometer Vetoes, will surround three of the four drift chambers and the CsI calorimeter itself. The Colorado group is responsible for the construction of these Spectrometer Vetoes and has been working on the design of these devices.

Each Veto will be a large (approximately 2.5 m by 2.5 m) rectangular array of lead/scintillator sandwiches with a rectangular hole in the center matching the active area of the detector element it surrounds. In order that the detectors efficiently identify photons whose energies may be as low as 100 to 200 MeV, the sandwiches will consist of 32 layers of violet scintillator separated by 33 layers of lead/steel absorber laminate, each layer being one-half of a radiation length thick. Light will be extracted from the scintillator via blue optical fibers, and two-inch photomultiplier tubes viewing the light guides or fibers will generate fast signals to be used in the

KTeV Level 1 Trigger, and later in offline analysis. Each of the four Vetoes will consist of 28 to 36 modules, each weighing between 250 and 700 pounds. Module edges will be beveled at an angle of 13.4° so that photons cannot escape through inter-module cracks. Representative engineering drawings of the Spectrometer Anti design are shown in Figures 7 and 8.

As these details and the drawings indicate, the design of these detectors is well along already. Indeed, the scintillator sheets and scintillating fibers for the entire SA system have already been ordered by Fermilab. The detector design, has been presented to the KTeV Collaboration and has been shown to Fermilab management and the FNAL PAC. Details of the geometry of the detectors, their design and the budget have been described in a KTeV memorandum[13].

Most of the detailed design work on the SA detectors has been done by our Mechanical Engineer, Gerhard Schultz. His work has been carried out in our recently acquired AutoCAD design hardware. This effort is represented in a few of the typical drawings shown in Figures 7 and 8.

The third Colorado responsibility, the design, installation, and commissioning of the Level 0 and Level 1 Trigger systems for KTeV, is an important item, but not an expensive one. These systems will be constructed from commercial electronics to be supplied by Fermilab. The electronics will be installed and tested in the experimental hall at Fermilab.

3. The R&D Program for the Muon System The SDC Detector.

Greg Baranko, Bruce Broomer, Mark Christoph, Mourad Daoudi, Greg Dobbs, Eric Erdos, Justin Lee, Uriel Nauenberg, Gerhard Schultz, Victor Slonim, Quenten Van Egeren; in collaboration with the SDC Muon Group.

Our group has carried out three major efforts in the SDC collaboration:

1. We have continued our efforts to study the construction of the muon tubes. We have finished a detailed study of the sense wire properties of the muon tubes. We have constructed a tensioning device that is reliable and simple to use.

2. We have continued our effort in the electronics. We have finished the card design for the Cockroft-Walton photomultiplier base. We have finished the design for the amplifier discriminator card Both these layouts have gone out to industry for construction.

3. We have continued our effort in the software. This effort consists in the implementation of the pattern recognition software algorithms and the study of its efficiency in the presence of the background levels expected at a luminosity of about 10^{33} cm^{-2}sec^{-1}. We also compared CALOR and GEISHA for neutron and photon backgrounds after a piece of material. In addition we wrote the software that adds the background events from beam crossings separated by intervals of 16 nsec from the nominal event time.

1. Wire Studies

In Colorado we have a device that can measure the position of a marker on a wire to $\pm 12.5\mu$, the accuracy of our measuring device. We used this to determine the elastic properties of the gold plated tunsten wire to be installed as the sense wire in the muon drift tubes.

We measured the elongation of 1 meter of wire under a hanging mass that was varied in exact incremental steps of 100 gm in the region where the wire was known to be elastic (linear) and of 10 gm in the non elastic region. While the elongation of the wire in the linear region was quite constant over the various wire pieces we tested, the value of the hanging mass at which the wire began to show a non-linear behavior was quite varied; anywhere from 960 to 1310 gm .[14] We carried out these measurements for about 14 samples of wires. Some typical results are shown in Fig. 9.

We also determined whether the range of the linear region could be extended by stretching the wire initially past its preliminary maximum value, then releasing the tension and then carrying out the measurement. The results of this study are shown in Fig. 10. It clearly shows that the linear region can be extended from a maximum of 980 gm to 1260 gm. This will likely be the procedure that will be followed when the wire is to be installed in the muon tubes.

Finally, we studied a new tensioning device that allows us to set the tension quickly and easily in a fail-safe manner. This is necessary to avoid making mistakes in the construction of over 60 K muon tubes. The device consists of a a tensioning wheel with a clutch that is controlled by a computer feedback system connected to a tension sensor. The desired tension is stored in the controller by means of a simple touch panel. This device is shown in Fig. 11. The controller engages the clutch and the tension on the wire is increased until the sensor detects that the wire has the desired tension. At that point the clutch is disengaged and the tension maintained. The time it takes for the tension to be set to 980 gm. once you tell the system to start is 6.1 seconds. This is important because of the need to produce a large number of tubes every day. The tension on the wire is measured by the well known resonant frequency method in which the wire is set to oscillate at the natural frequency determined by the tension on the wire and the linear density of the wire.

We have set the tension in a 1.5 meter sample of wire over 20 times to determine the reliability of the system. In all cases the measured frequency was within 0.1% of the expected value which implies a tension variation of 0.2% at worst.

2. The Design of Electronics

We have taken on the responsibility of designing a new Cockroft-Walton photomultiplier base and an amplifier-discriminator circuit that will amplify, shape, and discriminate the photomultiplier pulse.

The standard photomultiplier base is constructed with resistors and Zener diodes dissipating approximately 2 watts. An external high voltage must be applied to the base for dynode biasing. This high voltage supply is expensive and creates a potential safety problem.

The Cockroft-Walton base being designed and constructed at the University of Colorado at Boulder consists of a high frequency oscillator driving a step-up transformer. The high frequency power is used to drive a full wave Cockroft-Walton circuit. It consists of a chain of rectifiers and capacitors which produce the desired voltage for the different dynodes of the photomultiplier tube. Since the voltage chain consists of capacitors and diodes there is very little energy loss. The output voltage is fed back to the input to regulate the high voltage. The output voltage is remotely adjustable over a limited range to maximize the photomultiplier performance.

The usual present day Cockroft-Walton devices are only half-wave circuits. They suffer from the following problems:

1. They have a slow response time to changing loads (poor voltage regulation).
2. They have a higher ripple content than standard high voltage resistor divider bases.
3. They have a slow response time in charging the last stages of capacitors.
4. They have noise pickup from the high frequency signal that is applied to the diode capacitor circuit.
5. The voltage distribution is in fixed multiples of input voltage and cannot be linearly changed as in the resistor divider technique.

The full wave Cockroft-Walton base being built solves most of these difficulties:

1. The response time to changing loads is reduced by a factor greater than 3.

2. The higher ripple content is reduced by at least a factor of 11.

3. The response time in charging the last stages of capacitors is reduced by a factor greater than 3.

4. The noise pickup from the high frequency signals is reduced by a better shielding and ground layout.

The photomultiplier we will be using to test this circuit is a Burle 8578 12-stage tube. The high frequency power consists of a square wave with a frequency of 100 khz. The transformer is driven by a push-pull circuit. The circuit is shown in Fig. 9.

The input signal to the amplifier discriminator is the output of the anode of the photomultiplier tube. The signal is a negative pulse having a rise time of 2 nsec and output of − 2 volts. The pulse then decays exponentially in about 16 nsec. The signal is terminated into 50 ohms. This signal is amplified by a video amplifier and fed into a ECL comparator and buffer circuit. The output signal is standard 10K ECL logic. A test circuit will be used to test the and calibrate the amplifier-discriminator module. The threshold on the tripping point of the comparator is controlled by an outside voltage source. The electronics diagram is shown in Fig. 10

3. Software Development

We have carried out a range of software activities. We have made a comparison of the neutron and photon background rates produced by the computer simulation packages GEISHA and CALOR. We simulated hadron incident on 10 and 12 interaction lengths of material and analyzed the remaining background. We observed that the energy distribution of the neutrons and photons between the two simulations was quite different. The energy of the neutrons in CALOR is usually much lower. Moreover the rates of these particles were different. For example, in the case of lead, CALOR predicts about seven times as many neutrons as GEISHA. In iron, the results agree better. The CALOR simulation seems to give results more in agreement with experimental results at lower energies. We therefore plan to incorporate the CALOR package into SDCSIM for further usage.

At the same time we have written a simulation of the background due to off-time events with the punch-through included. This is a detailed representation of the background from minimum-bias events offset in time by a multiple of 16 nsec to represent interactions that occurred in different time buckets, but still within the drift time of the muon tubes. This program will be incorporated into SDCSIM.

We have done a detailed pattern recognition efficiency study in the forward direction for muons in the presence of background. The background considered was bremsstrahlung (EM) from the muons traversing the calorimeter and the magnetized toroids; punch-through background from off-time events (MB) and random hits due to low energy neutrons (RN). In Table 1 below we show the resulting efficiency and momentum resolution. It is quite clear that at high momentum the efficiency and resolution degrades due to the bremsstrahlung associated with the muon itself. The pattern recognition efficiency drops to 82-85%. In Table 2 we show the effect of increasing the stereo angle of some of the drift tubes and the effect of adding another set of modules between the toroids. The result of the study shows that increasing the stereo angle does not help but the introduction of a set of drift chambers between the two toroids reduces markedly the number of poorly measured tracks at low momentum where the effect of large scatters is the greatest.

TABLE 1

TRACK RECONSTRUCTION EFFICIENCY

PT_{gen}	TYPE	RN	N_{accept}	CPU(s)	N_{lost}	N_{bad}	N_{ghost}	EFF(%)	PT_{res}(%)
100	NB	0	400	35	0	22	0	98	13.9
250	NB	0	400	37	0	14	0	99	14.6
500	NB	0	400	37	0	14	0	99	18.2
100	EM	0	400	117	12	19	7	97	11.1
250	EM	0	400	231	30	41	10	92	15.9
500	EM	0	600	756	50	58	14	89	20.6
500	EM	0	1000	1212	43	61	18	89	20.7
250	EM+RN	10	1000	4777	36	35	9	92	16.2
500	EM+RN	1	1000	1520	43	93	12	86	20.8
500	EM+RN	5	1000	2437	42	107	22	85	20.8
500	EM+RN	17	1000	15456	45	130	24	82	21.1
100	EM+MB	0	1000	421	11	30	4	96	11.1
500	EM+MB	0	1000	1398	44	91	18	86	20.7

TABLE 2

TRACK RECONSTRUCTION EFFICIENCY

The stereo angle is 15 degrees

PT_{gen}	TYPE	RN	N_{accept}	CPU(s)	N_{lost}	N_{bad}	N_{ghost}	EFF(%)	PT_{res}(%)
500	EM	0	1000	1217	41	57	17	90	20.4

The intertoroidal chamber FW3 is included

PT_{gen}	TYPE	RN	N_{accept}	CPU(s)	N_{lost}	N_{bad}	N_{ghost}	EFF(%)	PT_{res}(%)
100	EM+MB	0	1000	476	11	13	3	97	13.1
500	EM+MB	0	1000	1438	43	76	13	88	20.2

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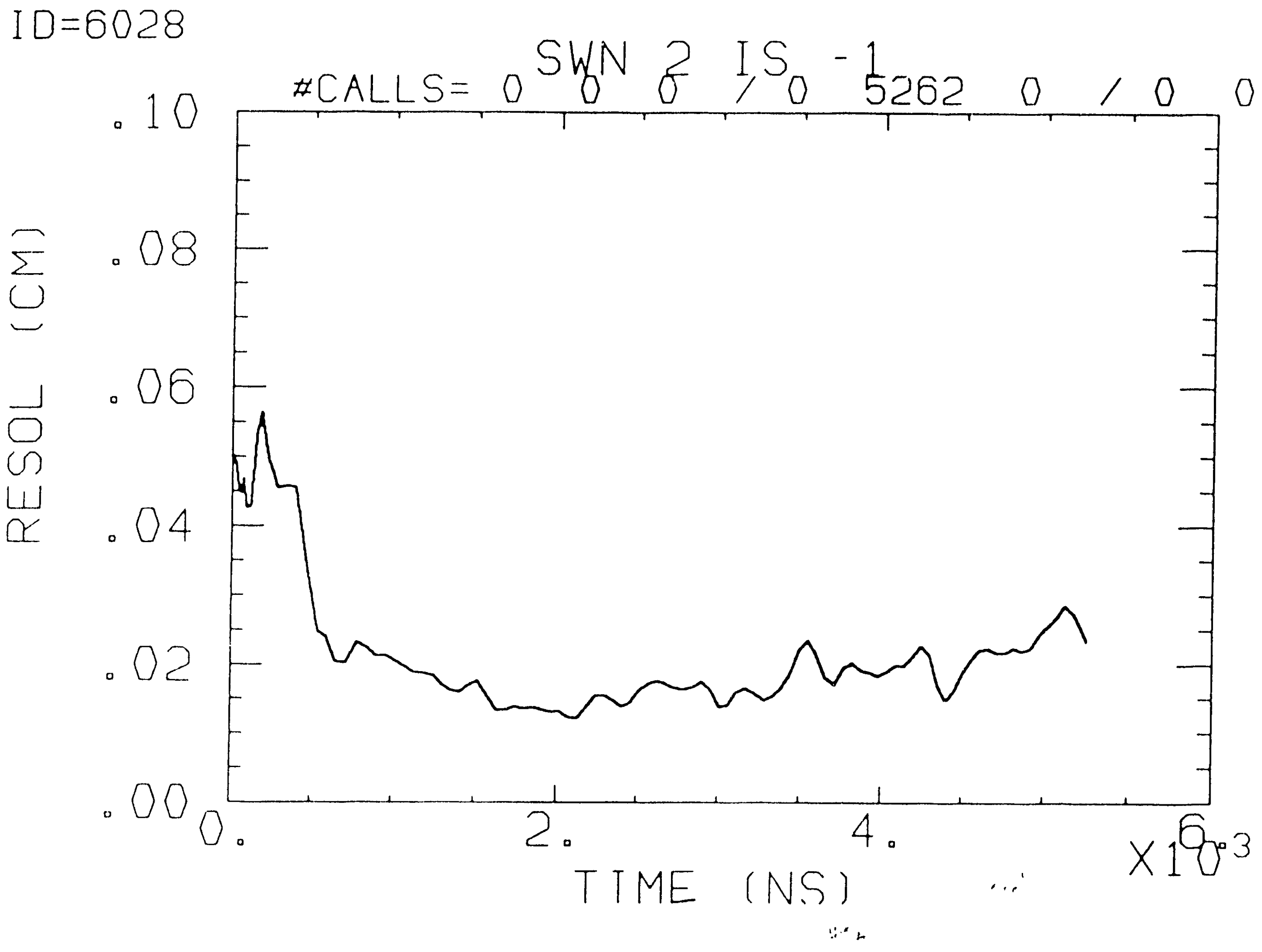
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2.
4.
6.
X10^3
TIME (NS)

Figure 1

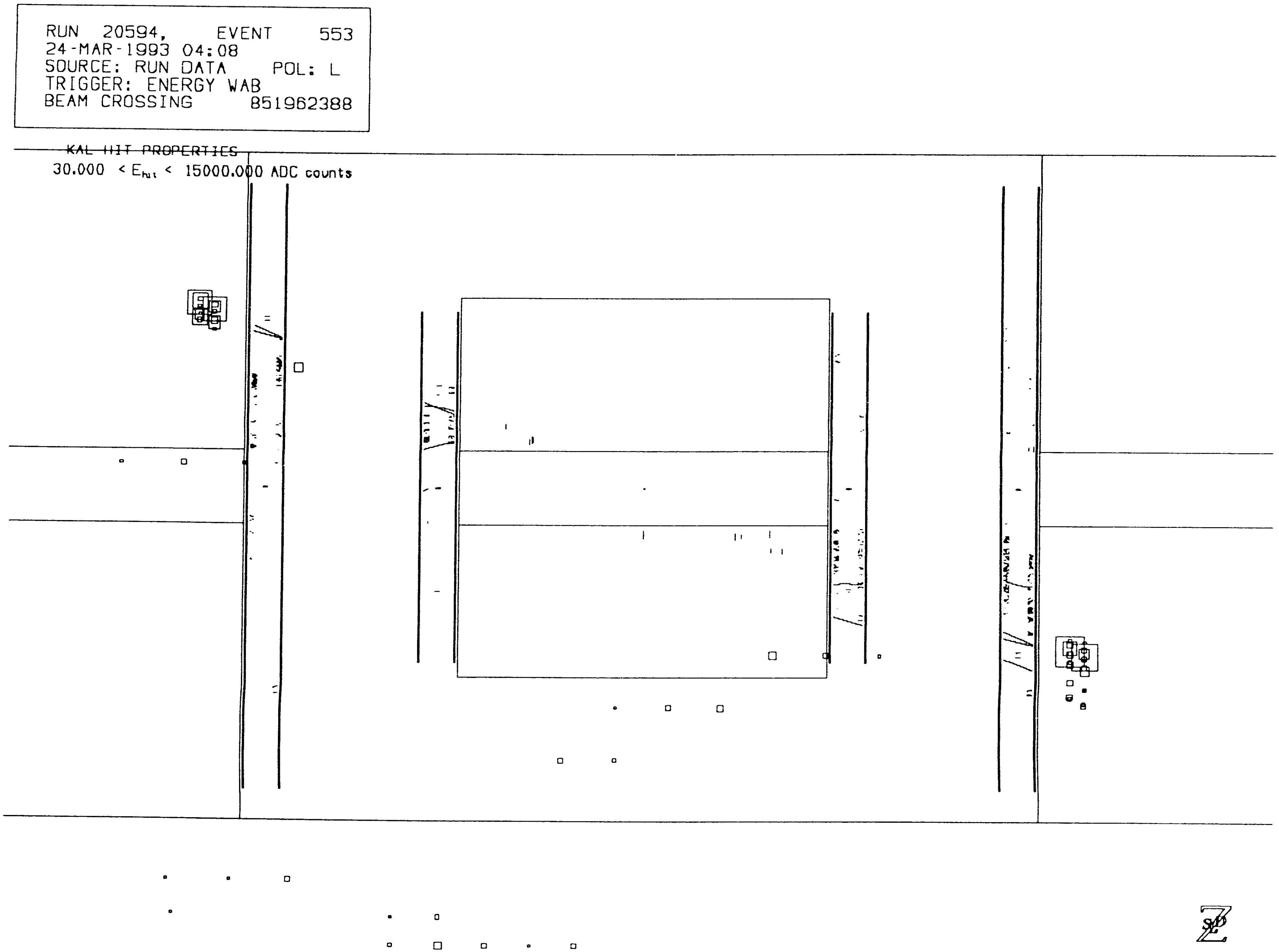
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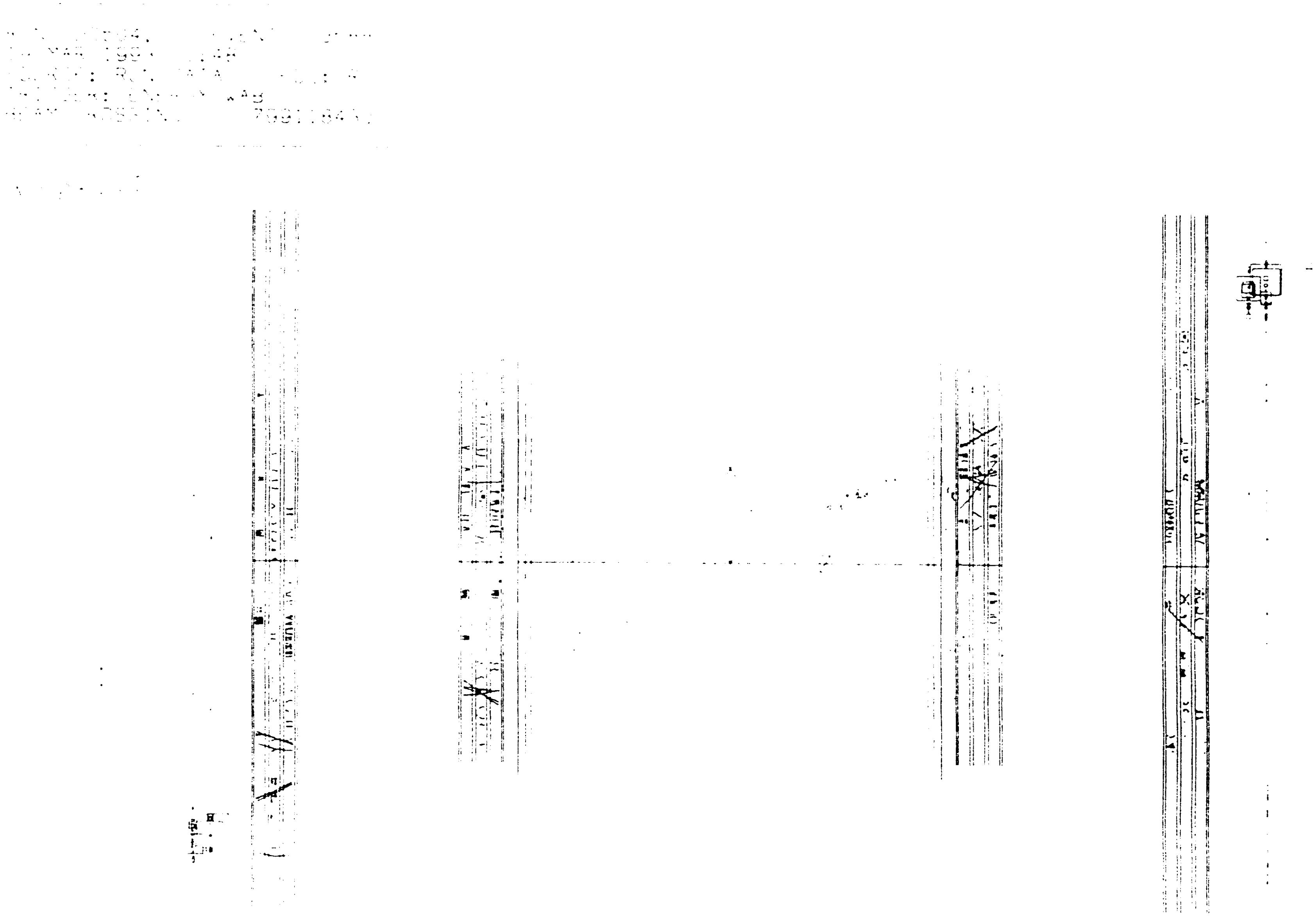
Figure 2



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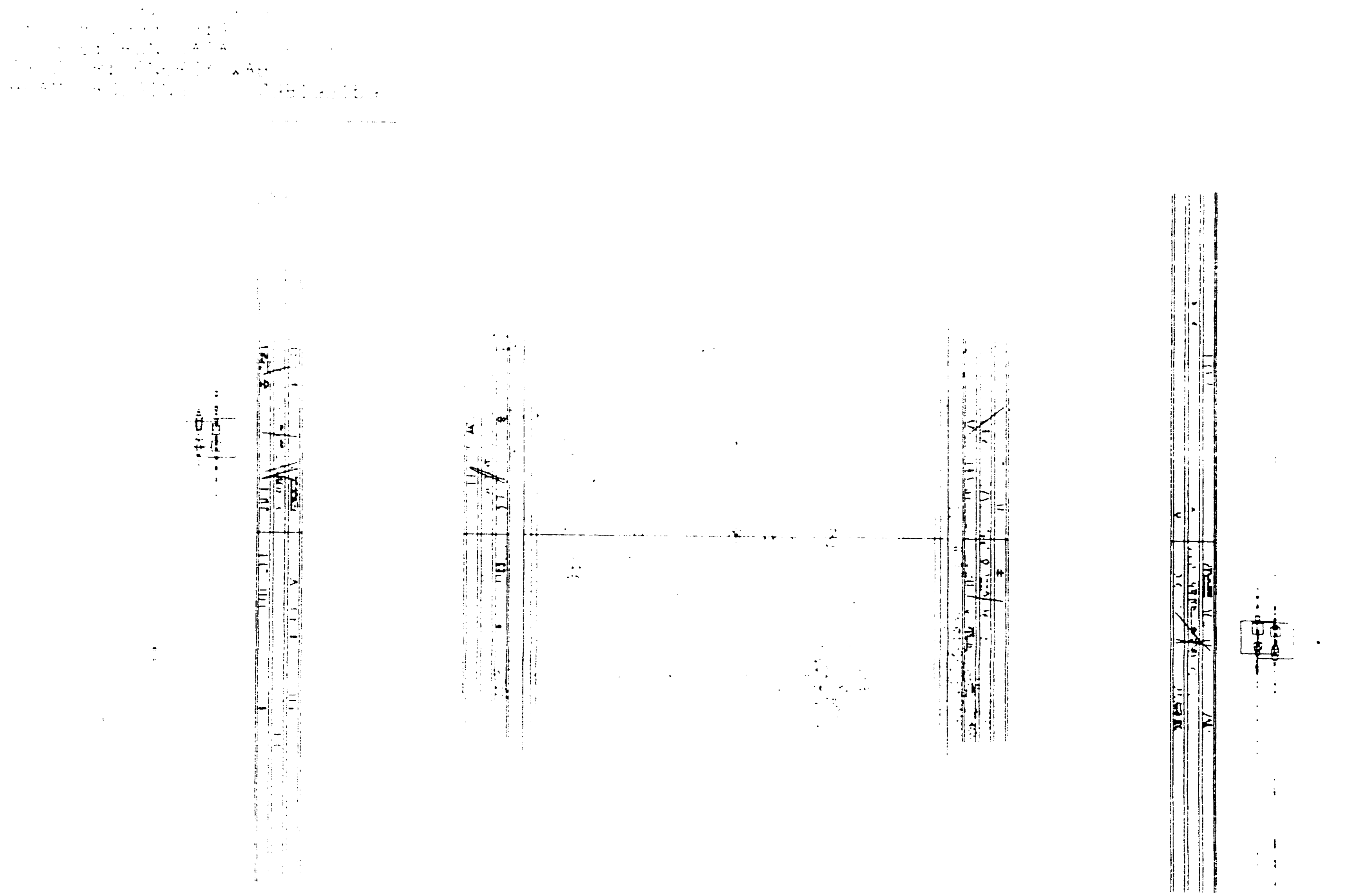

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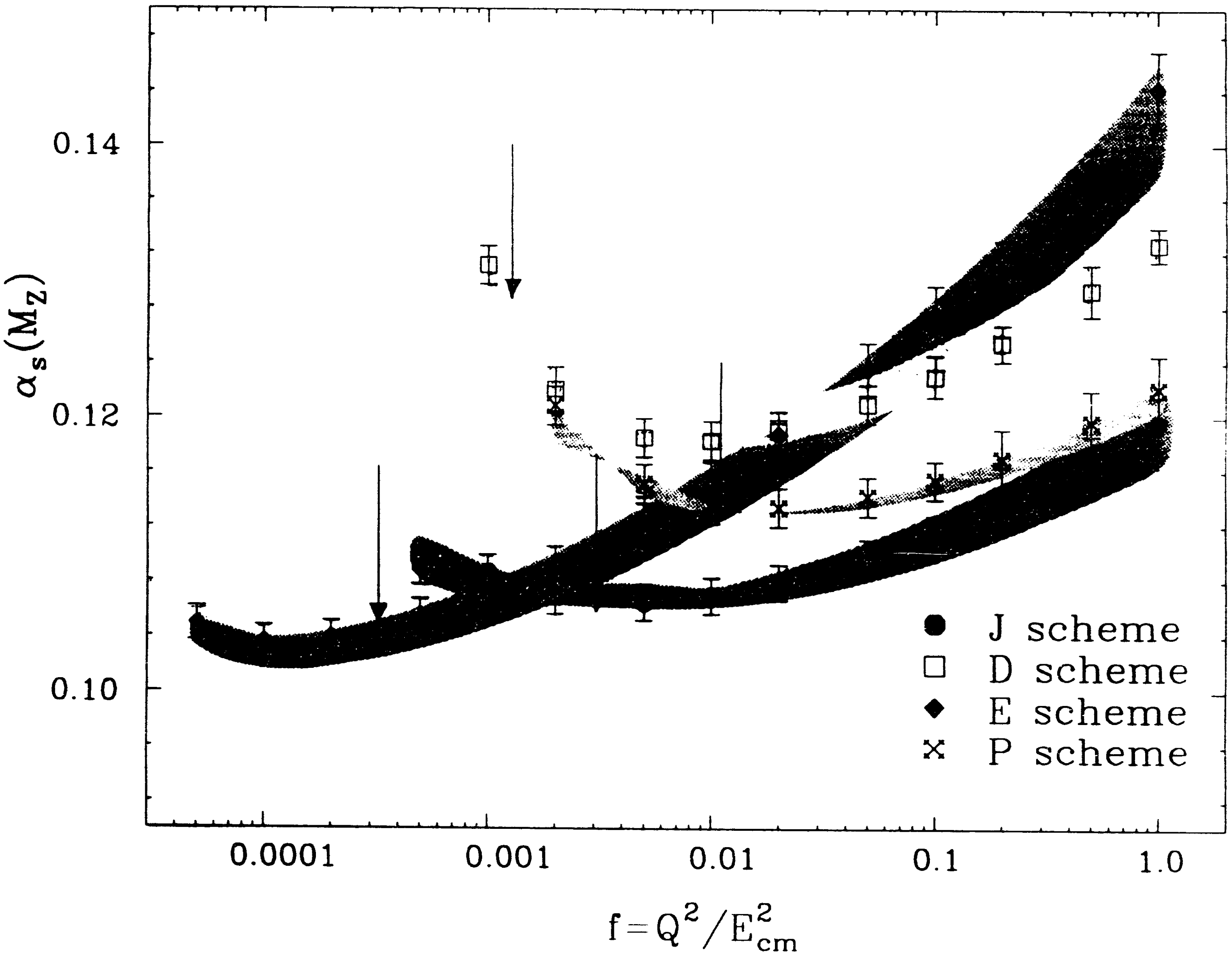
0.14
0.12
0.10
$\alpha_s(M_Z)$
0.0001
0.001
0.01
0.1
1.0
$f = Q^2/E_{cm}^2$
J scheme
D scheme
E scheme
P scheme

Figure 5

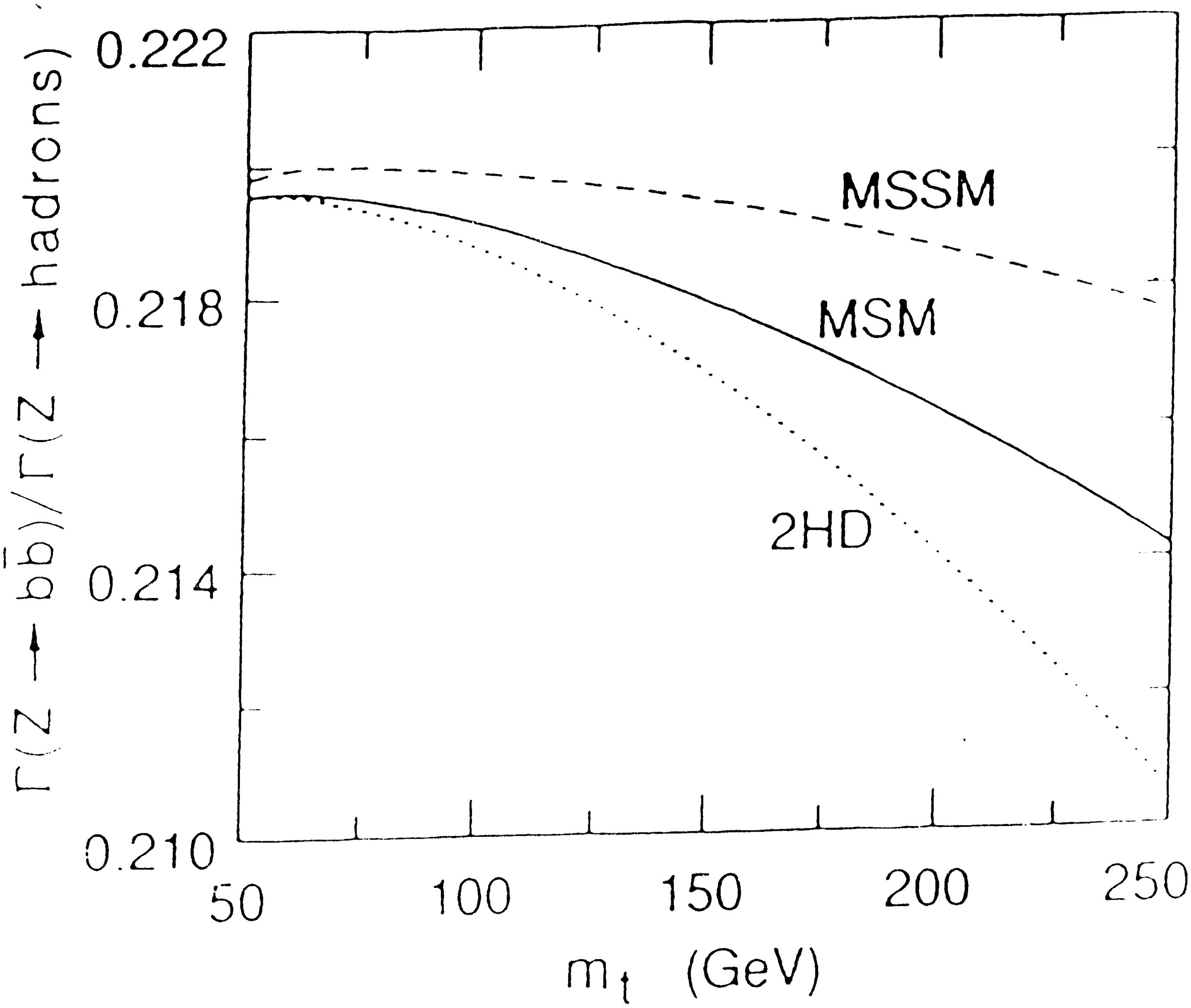
0.222
0.218
0.214
0.210
50
100
150
200
250
MSSM
MSM
2HD
m_t (GeV)
Γ(Z → b$\bar{b}$)/Γ(Z → hadrons)

Figure 6

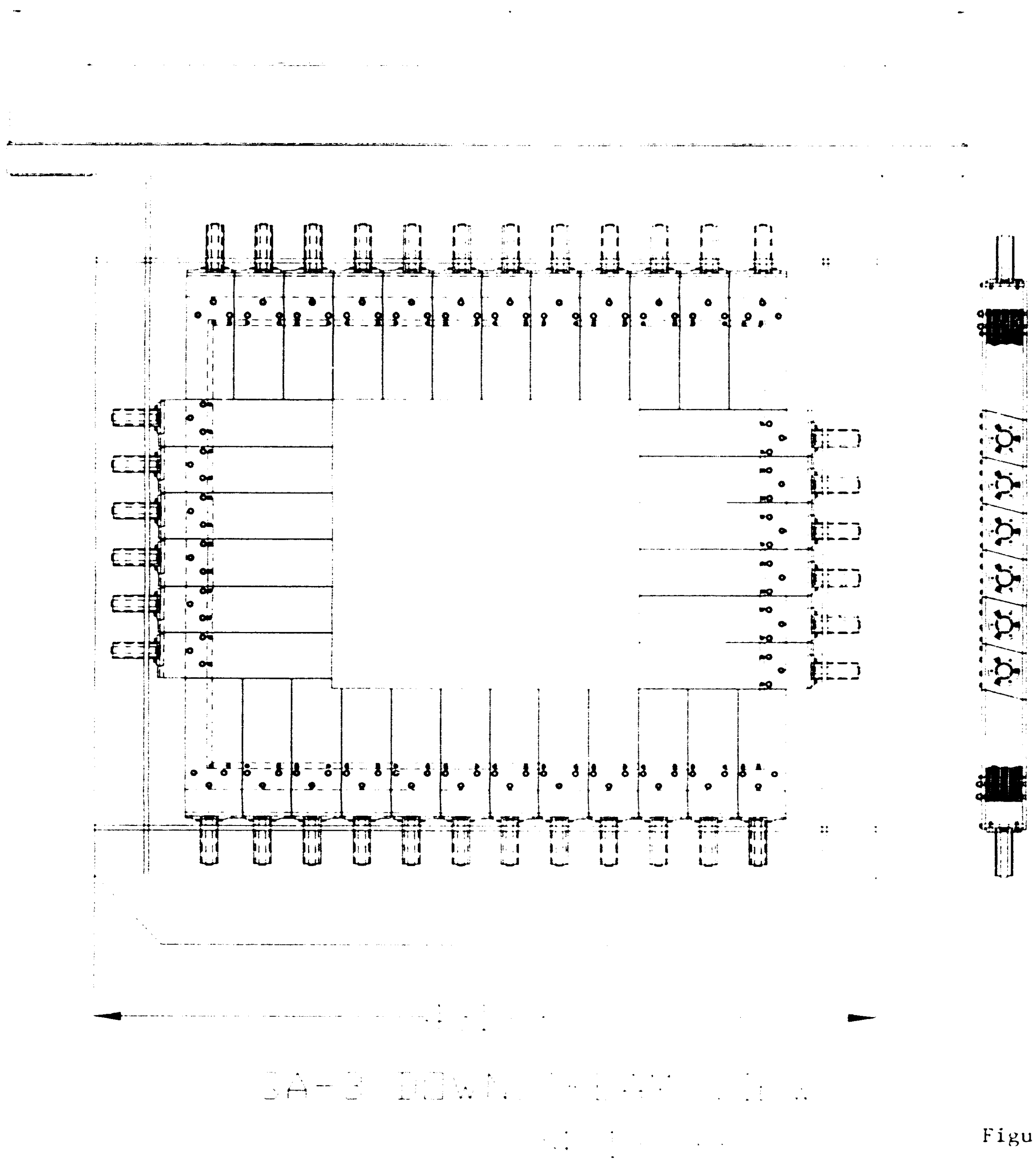

Figure 7

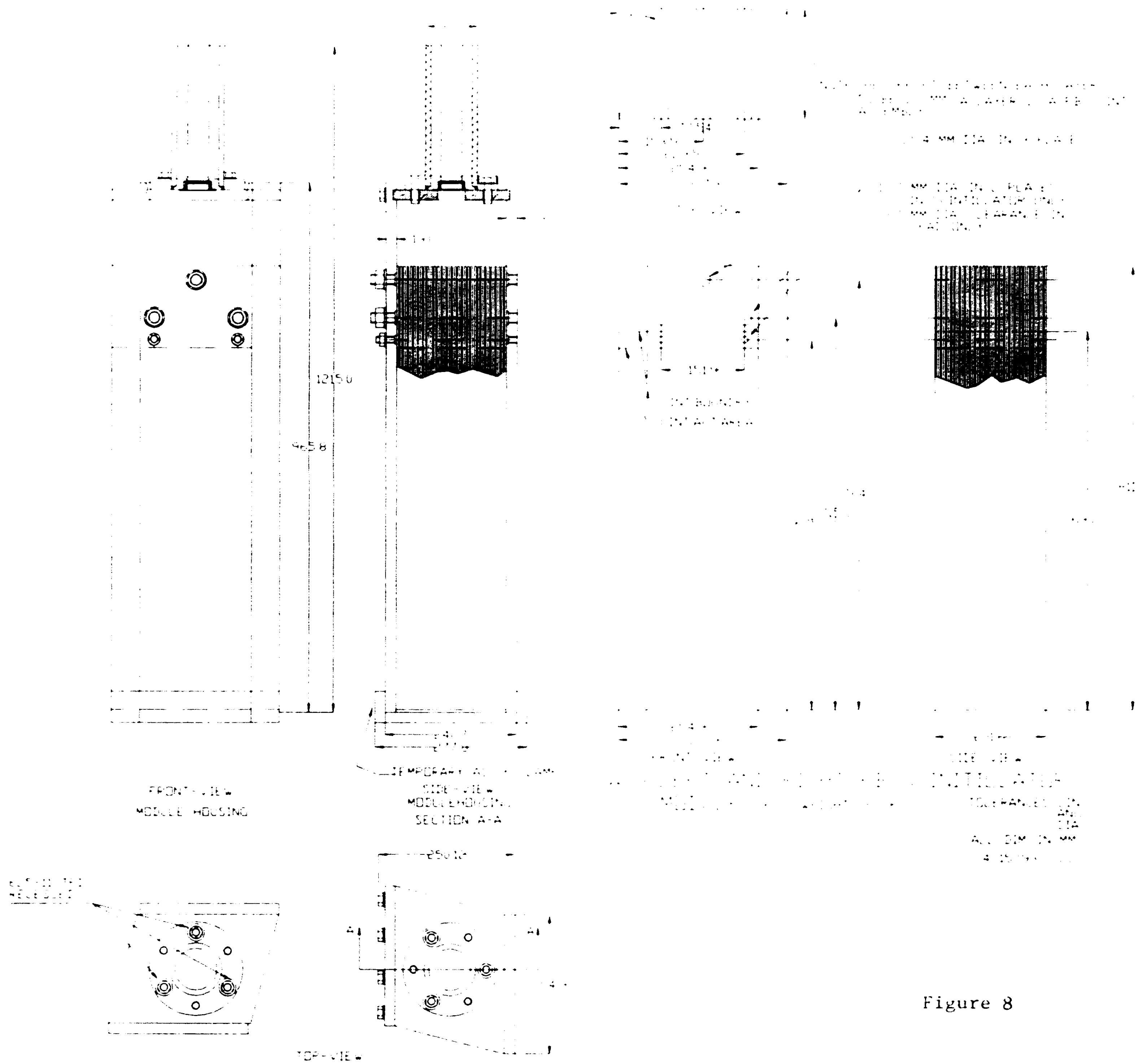
1215.0
965.8
FRONT VIEW
MODULE HOUSING
SIDE VIEW
MODULE HOUSING
SECTION A-A
TOP VIEW
ALL DIM IN MM

Figure 8

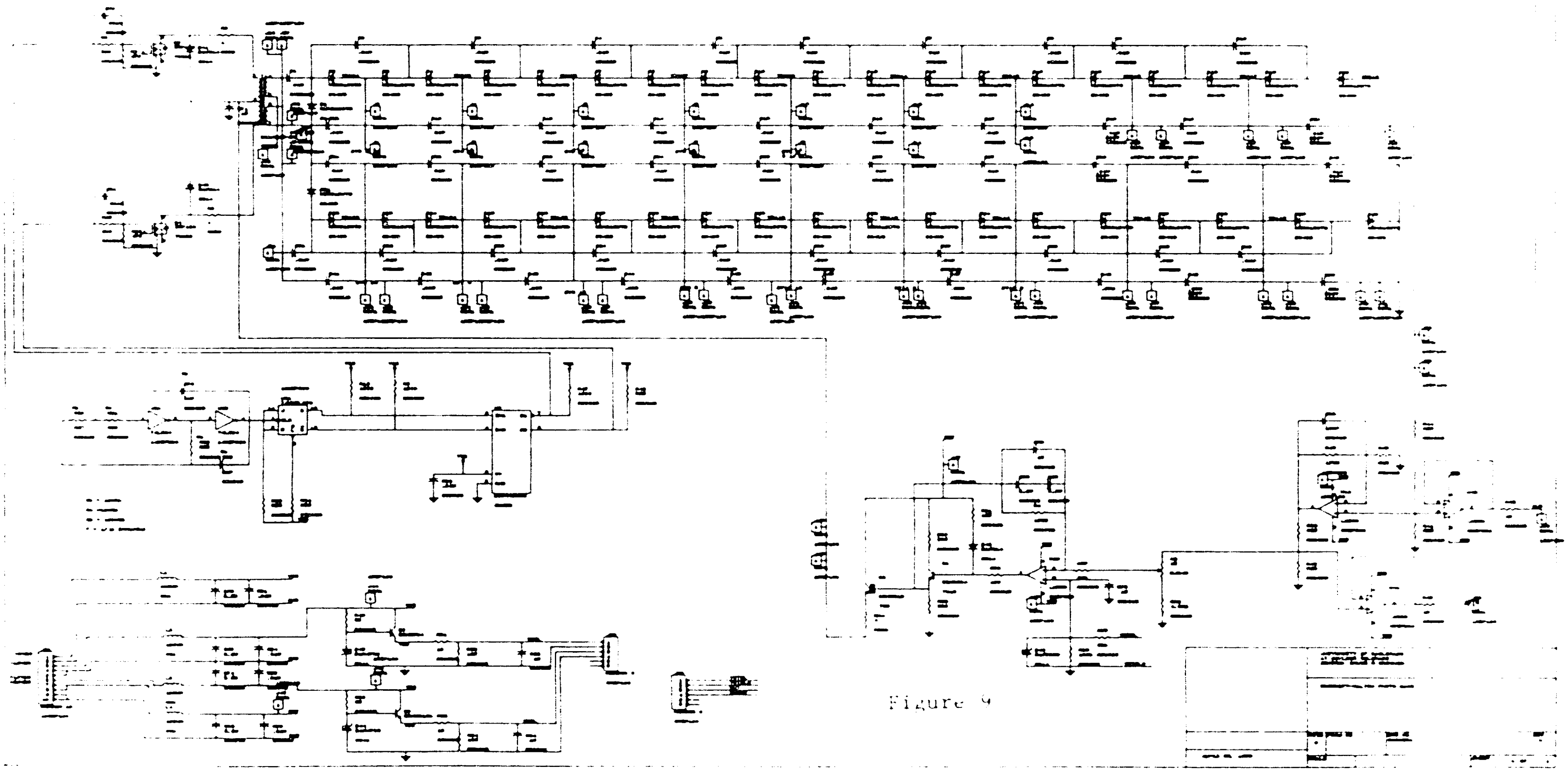

Figure 4

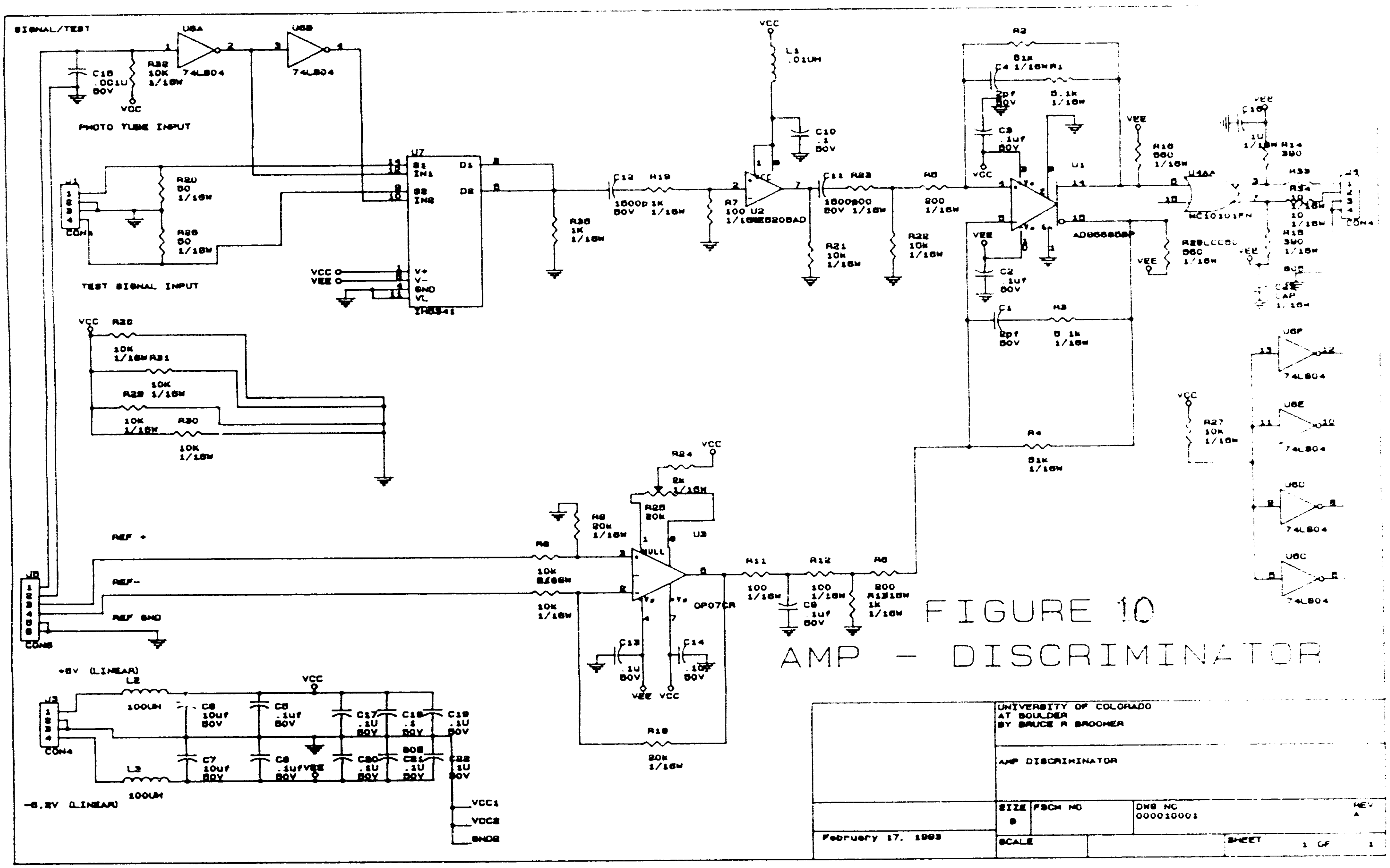

FIGURE 1C
AMP - DISCRIMINATOR

Experimental Group II

John P. Cumalat, William T. Ford,
Patricia Rankin, and James G. Smith

TABLE OF CONTENTS

I. Overview

The experimentalists in this group participate in photoproduction experiment E687 at Fermilab and the preparation of its successor E831, in CLEO II at Cornell/CESR, its planned major upgrade, and a proposal to build a B-Factory at Cornell, and in the SDC collaboration embarking on construction of a very large detector to run at SSCL.

There are four faculty participants in this group: John Cumalat, Bill Ford, Tricia Rankin, and Jim Smith.

Postdoctoral Research Associates are Vicki Greene (working on E687 and the SDC tracking system), Doug Johnson (CLEO, SDC tracking), Mourad Daoudi (CLEO, SDC muon system), Karen Lingel (CLEO), Harry Cheung and John Ginkel (E687).

We have presently eight graduate students. Derrell Durrett received his PhD this spring, having completed a thesis with data from the Mark II detector at PEP. Russell Balest, Kihyeon Cho, Steve Culy, Carlo Dallapiccola, Will Johns, Martin Lohner, Matt Nehring and Clara Campbell are continuing in their thesis research. David Craig is contributing to the SDC tracking system R&D and construction. Another Colorado student, Xian-Ping Lu, is working at Fermilab in accelerator related research; his funding is not covered by this grant.

Among individual external responsibilities and recognition of note: John Cumalat is the co-spokesman of E687 and E831 and presented Fermilab's fixed target heavy flavor program to DOE review panels. William Ford serves on the SDC Technical Board as chair of the steering committee for tracking; he is institutional representative to the Rocky Mountain Consortium steering committee. Patricia Rankin is a Sloan Fellow and a DOE Outstanding Junior Investigator. Vicki Greene is an SSC Fellow.

II. High Energy Photoproduction of States Containing Heavy Quarks

A. E-687

Harry Cheung, Steve Culy, John Cumalat, Carlo Dallapiccola, Eric Erdos, John Ginkel, Vicki Greene, William Johns, Matt Nehring, and Gerhardt Schultz in collaboration with the University of Illinois at Urbana-Champaign; Fermilab; Northwestern University; Notre Dame University; University of California at Davis; University of Northern Kentucky; University of Puerto Rico; University of South Carolina; University of Tennessee; Vanderbilt University; Korea University; Dipartimento di Fisica and Istituto Nazionale di Fisica Nucleare, Universita di Bologna; Dipartmento di Fisica, Universita di Milano; Istituto Nationale di Fisica Nucleare, Milano; and Dipartimento di Fisica Nucleare e Teorica, Universita di Pavia.

Experiment E687 is an experiment studying the production and decay of charm in perhaps the most highly segmented and instrumented fixed target experiment to date. The spectrometer has 300 threshold Cerenkov cells, a 10 meter neutral Vee decay volume, excellent gamma and pizero identification, electron and muon identification, a large charged particle acceptance covering the entire forward hemisphere, and most importantly, 12 microstrip planes with a total of 8256 pulse height analyzed strips.

The E687 Collaboration has had 3 data-taking periods. The first occurred from December 1987- February 1988. During this period a total of 60 million triggers were written on tape. The second running period was from March 1990 until August 1990. During this period 300 million events were acummulated. We had expected to resume running in November, 1990, but the startup schedule slipped continuously making planning near impossible. The third running period began in June 1991 and lasted until January 1992. During this third running period we accumulated another 200 million triggers giving the experiment a total of 510 million triggers for the 1990-1991 running period. From March 1990 until January 1992 our group ran shifts and maintained the spectrometer. The Colorado group was extremely active in upgrading the beam, the spectrometer, and in participating in the analysis. The analysis work will be described later in this section. The Colorado group moved all personnel back to Boulder in February, 1992.

The major hardware effort at Colorado for the E687 spectrometer was to build and install an electromagnetic calorimeter. The design was based on a then new fiber optics technology and consists of 100 alternating layers of scintillator fiber sheets and lead. The highly compact size of this calorimeter significantly reduces the hadronic background, and gives cleaner pattern recognition, higher hadron rejection, better spatial resolution and better π^0 identification than a solid scintillator-lead sandwich design. Harry Cheung, Carlo Dallapiccola, Will Johns, and John Ginkel worked full-time on this project. The detector was delivered to Fermilab in November, 1989, fully cabled by February, and readout by March, 1990.

The calorimeter consists of 100 sheets of lead $54'' \times 90'' \times .055''$ with 0.75 mm diameter scintillating fibers sandwiched between each sheet of lead. Fermilab supplied the scintillator and Colorado did all the assembly. The total number of tubes used was 716 for the calorimeter and 156 for the tiebreakers. The detector is divided (longitudinally) into three modules. The most upstream (front) module consists of 20 layers of lead, (10 layers of scintillating fibers in each of two views). The middle and back modules each have 40 layers of lead. This gives a total of 25 radiation lengths and 1.0 interaction lengths, (5 radiation lengths in the front module and 10 radiation lengths in each of the other two modules).

The modules have one layer of scintillating fiber sandwiched between each sheet of lead, and the layers of scintillating fibers are arranged horizontally or vertically in an alternating order. The width (tranverse to the beam) of each strip is 25.4 mm for all strips in the front and middle modules and 50.8mm in the back module. There are also two tie-breaker modules, the front tie-breaker is sandwiched between the front and middle calorimeter modules and the back tie-breaker is between the middle and back calorimeter modules. The tie-breakers consist of scintillators of width 50 mm and thickness 10 mm. The two tie-breakers contain 156 PM tubes and light guides.

A major effort in the project has been to develop the software necessary to reconstruct π^0's and gammas. To accomplish this goal several steps were necessary. Carlo Dallapiccola and John Ginkel monitored changes in the pedestals of the ADC's. Carlo Dallapiccola used straight-thru muons to determine the attenuation values for each counter. Will Johns has worked on measuring the non-linearity of the ADC-phototube-base system for each counter and the hardware and software associated with the laser calibration system. John Ginkel has created the parameter files necessary to perform the energy and pattern recognition. Finally, Harry Cheung has written the pattern recognition for photon identification and performed the electron energy calibration.

The University of Colorado has been a leader in the collaboration in analysis of the E687 data. The analysis effort (after data taking) involves several steps. These steps include initial reconstruction of all the data, skimming at Fermilab into three data streams, sub-skimming at home institutions, and physics analysis. Colorado's contribution will be described for each step.

The initial reconstruction of the data is called PASS1. In this reconstruction the particles are traced through the silicon microstrip, magnets, and proportional wire chambers. The momentum, particle type, and energy deposition for each charged particle is recorded. Neutral Vees, Ξ^-'s and Ω^-'s are reconstructed and from results of the tracking, Σ's are found. Also included is the formation of neutral showers using calorimetry information and the π^0 analysis. Colorado played a major role in PASS1. John Cumalat contributed heavily to the particle tracking routine. Carlo Dallapiccola worked on Λ, Ξ^-, and Ω^- reconstruction. Harry Cheung wrote the inner electromagnetic shower finder and π^0 reconstruction routine. John Ginkel was instrumental in modifying and bringing to fruition the outer electromagnetic calorimeter shower finder and it's π^0 reconstruction routine.

The PASS1 reconstruction was performed at Fermilab using the Unix farms. The Unix Farms include four farms of IBM nodes and 3 farms of SGI nodes. The farms have to be continually monitored and physicists are required to carry pagers and be on call 24 hours per day. From Colorado, graduate student Matt Nehring was one of the 6 PASS1 managers.

The first stage skimming was also performed at Fermilab. The University of Colorado participated in writing and debugging this skim program, but the skimming was performed by Fermilab physicists and data aids.

Second Stage skimming is performed at home institutions. Fermilab does not have the resources to allow us to accomplish these skims. At Colorado we have managed to build up a small, but very powerful Unix system. While we need more computing power, tape drives, and disk, we have managed to accomplish many skims. As part of these skims we have allowed other groups in our collaboration to copy our tapes.

The University of Colorado has been involved in several analysis efforts. The efforts involve studies of decays containing π^0s and kaons (Harry Cheung), Λ_c^+ decays to p$K^-\pi^+$ (Harry Cheung), semileptonic decays (Steve Culy, Will Johns, and Matt Nehring), charm decays to K_s^0 (John Ginkel), and charm baryon decays to Λ^0's, Ξ^-'s, and Ω^-'s(Carlo Dallapiccola). Vicki Greene is examining the possibility of using π^0's and γ's from D^{+*} and D^{0*} to isolate D^+ and D^0 decays, while John Cumalat is pursuing the fully leptonic decays of the Charm mesons.

Harry Cheung has studied the decay of the $\Lambda_c^+ \rightarrow pK^-\pi^+$. The goals of his analysis are to better determine the Λ_c^+ lifetime, identify the Σ_c^{++} and Σ_c^0 masses and production rate, and to search for new charm baryon states. His Λ_c^+ signals are presented in figure 1. These results[4] have recently been published and represent the best measurement of the Λ_c^+ lifetime.

Will Johns has been studying the semileptonic decays of the $D^0 \rightarrow K^-l^+\nu$ using the small Q value in the $D^{+*} \rightarrow D^0\pi^+$ decay. In figure 2 is presented the

$D^0 \rightarrow K^- l^+ \nu$ decay. The semileptonic decay channel can be used to isolate the $|V_{cs}|$ CKM matrix element and to determine the form factor of the decay. Will Johns first results were presented at the 1992 APS Division of Particles and Fields Meeting held at Fermilab. Also shown in figure 2 is $D^0 \rightarrow K^- \pi^+$ decay which is used for normalization. Will Johns has further observed the Cabibbo supressed channel $D^0 \rightarrow \pi^- l^+ \nu$ and he is studying the possibility of isolating $D^0 \rightarrow \rho^- l^+ \nu$, $D^+ \rightarrow \omega^0 l^+ \nu$, $D^+ \rightarrow \rho^0 l^+ \nu$, and $D_s^+ \rightarrow \eta^0 l^+ \nu$. As part of this analysis he can also measure the $D^0 \rightarrow K^{*-} l^+ \nu$ branching fraction. With the above branching fractions measured it will be possible to compare these rates with the total rate semileptonic rate calculated from the lifetime. Will Johns is concentrating on the muon decays, while Matt Nehring will study the electron decays. The first preliminary results from the electron channel $D^0 \rightarrow K^- e^+ \nu$ were presented by Matt Nehring at the Washington, DC APS meeting in April, 1993. The signal based on 40% of the data is shown in figure 3. The results are already competitive with the best available results.

Carlo Dallapiccola has studied Charm Baryon States decaying to Ξ^-'s and Ω^-'s. Figure 4 displays the Ξ^- and Ω^- mass plots used in the analysis. Carlo has managed to observe signals in $\Xi_c^0 \rightarrow \Xi^- \pi^+$ (Figure 5), $\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+$ (Figure 6), and $\Omega_c^0 \rightarrow \Omega^- \pi^+$(Figure 7). He has further measured the lifetimes of the $\Xi_c^0 \rightarrow \Xi^- \pi^+$ and $\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+$. Both the Ξ_c^+ results[5] and the Ξ_c^0 results[6] have recently been published. The first observation[7] $\Omega_c^0 \rightarrow \Omega^- \pi^+$ has also been published. Unfortunately we were unable to measure a lifetime for the state.

The E687 has made the most accurate measurements for the lifetimes for the charmed baryons. There are two main competing theoretical models for the lifetimes. Guberina *et al.*[8] predict $\tau(\Omega_c^0) \approx \tau(\Xi_c^0) < \tau(\Lambda_c^+) < \tau(\Xi_c^+)$, whereas Voloshin and Shifman[9] predict $\tau(\Omega_c^0) < \tau(\Xi_c^0) < \tau(\Lambda_c^+) \approx \tau(\Xi_c^+)$ (each inequality represents a factor of about 1.5). Both predictions use the c-quark decay spectator model with W-exchange and QCD light quark interference effects. Theory can now use the E687 measurements to extract the contributions from each of these effects.

John Ginkel has studied states involving K_s^0 particles. He has also made a measurement placing a limit on Direct CP violation for the decay $D^0 \rightarrow K^-\pi^+$. His results have been presented at the Washington DC APS meeting and are being readied for publication. Figures 8 and 9 display John Ginkel's signals of the D^0 channels $K_s^0 K_s^0$, $K_s^0 K_s^0 K_s^0$, and $K_s^0 \pi^+\pi^-$. The $K_s^0 K_s^0$ decay channel is important to measure accurately as the channel is only occurs via final state interactions.

Vicki Greene has investigated $D^{*+} \rightarrow D^+\pi^0$ and $D^{*+} \rightarrow D^+\pi^0$ decays. The main purposes of the project are to identify better techniques for isolating signals and to better understand the electromagnetic calorimeters. Figure 10 presents Vicki's signals of $D^* - D$ mass differences. It turns out that E687 has close to the best measurements of these mass differences just from this study. As a result of this study Vicki has been able to accurately determine the geometry of the electromagnetic calorimeters.

The Colorado Group has also been instrumental in initiating new projects within our collaboration. First, Gary Grim, a graduate student from UC Davis is working on an effort to identify D^0's decaying to states with one neutral particle missing. The missing particle could be a π^0, K^0, η, or a ν. The technique uses the small D^{*+}-D^0 mass difference and the well measured secondary and primary vertex positions. The project grew out of the semileptonic analysis and looks extremely promising. The first results were presented at the 1993 Washington DC APS meeting. Second, Dr. Barbara Caccianiga, a postdoc from INFN in Milan, is investigating the semileptonic decays of the Λ_c^+ decaying into $pK^-\mu^+\nu$ and $\Lambda^0\mu^+\nu$. Thus far the skimming and the analysis of these decay channels have been done at Colorado. Again, this project grew out of Colorado's semileptonic analysis. Third, Byung Gu Cheon from Korea University has been working with Harry Cheung and John Cumalat on the analysis of the decay $\Lambda_c^+ \rightarrow \Sigma^+\pi^+\pi^-$. Together, John Cumalat and Harry Cheung wrote most of the reconstruction code for the Σ^+ decays. This Σ^+ collaborative effort has been beneficial as a cooperative science agreement between the University of Colorado - Korea University has been initiated thru the National Science Foundation. In addition the E687 group submitted 2 abstracts to the Korean Physical Society. Byung Gu Cheon also presented our results at the Washington APS meeting.

B. P-831

Harry Cheung, John Cumalat, Eric Erdos, John Ginkel, Vicki Greene, and Gerhardt Schultz in collaboration with the University of Illinois at Urbana-Champaign; Fermilab; Notre Dame University; University of California at Davis; University of Northern Kentucky; University of Puerto Rico; Dipartimento di Fisica and Istituto Nazionale di Fisica Nucleare, Universita di Bologna; Dipartmento di Fisica, Universita di Milano; Istituto Nationale di Fisica Nucleare, Milano; and Dipartimento di Fisica Nucleare e Teorica, Universita di Pavia.

The E687 broadband photon group has participated in submitting a new proposal to further increase the sample of charm particles. Colorado is actively involved in both the design of the beamline and the spectrometer. A study of the feasibility of the experiment was conducted at the Snowmass 1990 meeting. John Cumalat made the presentation for the group to the Fermilab PAC. A second presentation was presented at the January Fermilab PAC and the experiment received approval. In the April, 1993 PAC meeting the experiment was recommended second stage approval. Final negotiations on the Fermilab memorandum of understanding are now being completed.

The new experiment will run at 5 times the present photon flux. This increase in flux will be attained by reducing the secondary electron (positron) energy from 350 GeV to 250 GeV, running both positron and electron beams simultaneously, and by increasing the incident proton intensity. Another factor of two increase in events to tape will come from a reduction in the experiment's deadtime and from improved spectrometer efficiency.

The spectrometer requires several upgrades to handle the increased rate. The proportional tubes in the experiment need to be changed to scintillators. The

Iarocci tubes used for the calorimeter will also be changed to scintillator. The Proportional Wire Chambers will be changed to have lower gain and less noise and the amplifiers in the silicon microstrip system will be speeded up. The greatest change will be in the upstairs electronics. New ADC's and TDC's will be required.

The University of Colorado is involved in several of these detector upgrades. The memorandum of understanding calls for the University of Colorado to install scintillating tiles in the inner electromagnetic calorimeter and to aid in improving the target tracking.

C. Electron-positron physics with the Mark II detector at SLC

William Ford, Derrell Durrett, Patricia Rankin, and James Smith, in collaboration with Caltech, U. C. Santa Cruz, Hawaii, Indiana, Johns Hopkins, LBL, Michigan and SLAC.

Our measurement of the charged multiplicity of $b\bar{b}$ events from Z^0 decays appeared in ***Phys. Rev. D***.[11] Derrell Durrett completed his PhD thesis,[12] a study of D_S and D^+ meson production and decay into final states containing K^* or ϕ. This included measurements of the fraction of c quarks that fragment to D^+ and to D_S, and a limit on the $\phi\ell\nu$ to $\phi\pi$ ratio of branching fractions for D_S.

III. Electron-positron physics with the CLEO II detector at CESR

Russ Balest, Clara Campbell, Kihyeon Cho, Mourad Daoudi, William Ford, Doug Johnson, Karen Lingel, Martin Lohner, Patricia Rankin, and James Smith in collaboration with Caltech, Carleton, U. C. San Diego, U. C. Santa Barbara, Carnegie Mellon, Cornell, Florida, Harvard, Illinois, Ithaca College, Kansas, Minnesota, McGill, SUNY Albany, Ohio State, Oklahoma, Purdue, Rochester, Southern Methodist, Syracuse, and Vanderbilt.

The CLEO II experiment at the Cornell accelerator CESR principally studies the decays of B mesons, charmed particles, and taus. We are currently using an analysis data sample of about $2.1 fb^{-1}$ taken at and around the $\Upsilon(4S)$ and are continuing to accrue data fairly steadily. Over the last year we have published over fifteen papers on topics including precise tau branching ratio measurements, shape studies of quark jets, isospin mass splittings, and $\Upsilon(3S)$ decays. We expect to continue this level of productivity or even exceed it; about thirty results were presented in parallel sessions at the recent Washington APS conference. We have just announced the first observation of the decay $B \to K^*\gamma$, an electromagnetic penguin decay, and we hope that other rare decays will soon follow. The Colorado group is very active in the current CLEO physics program; we are also involved in the future plans of the collaboration. The most significant improvement in the CLEO II detector compared to CLEO I was the installation of a CsI electromagnetic calorimeter. Since we intend to keep this, and the changes needed to the machine configuration are incompatible with the current tracking devices, our plans for an improved, high luminosity detector are focused on the inner detector. We are aiming to improve upon the current particle identification without loss of track momentum resolution.

One of the Colorado group's main physics efforts has been in the area of charmless, non-leptonic B decays. We have worked with a group from Cornell led by Jim Alexander. Fig. 11 shows that the decays $B^\circ \to \pi^+\pi^-$ and $B^\circ \to K^+\pi^-$ can proceed either via a tree diagram with a $b \to u$ transition, involving the Cabibbo-Kobayashi-Maskawa matrix element V_{ub}, or via penguin diagrams involving $b \to d$

and $b \to s$ transitions. The branching ratio for $B^\circ \to \pi^+\pi^-$ is predicted to be 1.2×10^{-5} for $V_{ub}/V_{cb} = 0.07$[51] and recent estimates for $B^\circ \to K^+\pi^-$ are close to 10^{-5}.[52]

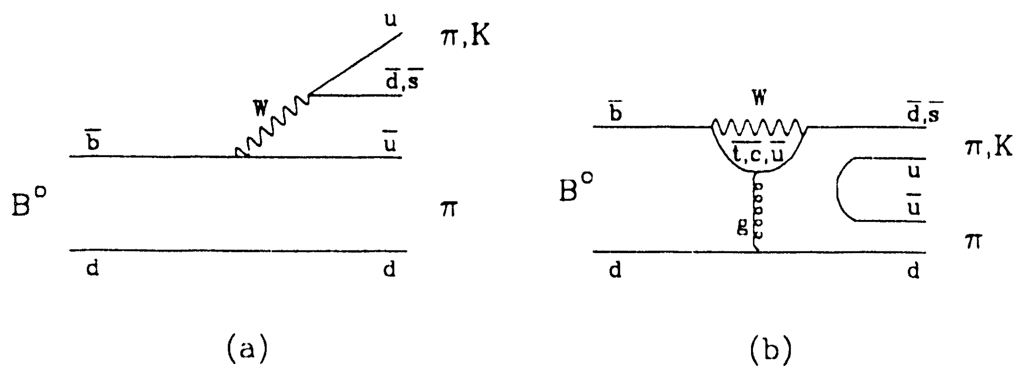

Fig. 11. Spectator (a) and penguin (b) diagrams for the decay modes mentioned in the text.

Our analysis of the decays $B^\circ \to \pi^+\pi^-$ and $B^\circ \to K^+\pi^-$ is now nearly complete and should be published this summer. We reported new results at this years Moriond meeting and at the Washington APS meeting. We have improved our sensitivity by a factor of two with a maximum likelihood fit involving the input variables: m_{12}, E_{12}, x_F, dE/dx_1 and dE/dx_2, where the subscripts 1 and 2 refer to the candidate tracks and x_F is a variable incorporating the shape information of the event into a "Fisher discriminant". We began by using neural network techniques to reject backgrounds on the basis of shape information. It turned out that the Fisher approach of using linear combinations of shape inputs performed just as well and was much simpler and faster.

The result of the analysis is summarized in Fig. 12. There is a 2.8σ excess in the $K\pi$ mode and a 2.3σ excess in the $\pi\pi$ mode. A fit to the total number of $\pi\pi$ and $K\pi$ events is able to exclude zero at more than 4σ after inclusion of systematic errors. We find at the 90% confidence level, upper limits of 3×10^{-5} for the branching fraction of both modes.

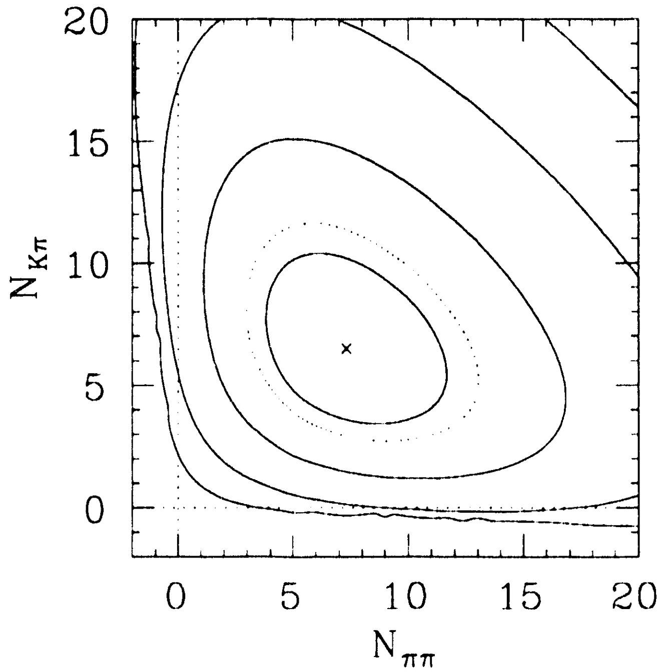

Fig. 12. Plot of likelihood contours for the fit to $N_{\pi\pi}$ and $N_{K\pi}$. The solid lines represent 1, 2, 3 and 4 sigma contours while the dotted line is for 1.28σ.

We recently expanded the analysis to include quasi-two body decays such as $B \to K^*\pi$, $B \to K\rho$, $B \to \pi\rho$. Because of the helicities of the particles involved, each decay involves a low momentum track or π^0 which gives additional combinatoric background. This background is somewhat reduced by helicity and resonance mass cuts. Further reduction has been achieved with event shape cuts via the Fisher discriminant as in the $K^+\pi^-$ and $\pi^+\pi^-$ modes described above. The low momentum tracks also present problems of particle ID in momentum regions where there is crossover in the dE/dx signals and hence no K/π separation. There is so far no evidence for any signals, and we expect to have useful new limits on many of these modes before the summer.

Our group also has a considerable involvement in tau physics. With the latest precise measurements of the tau mass at BES and the electronic branching ratio at CLEO, a 1% measurement of the tau lifetime is needed in order to resolve the tau decay puzzle. With the large data sample available at CLEO ($\sim 2fb^{-1}$)

such a measurement is feasible. We have chosen a method using the 1-1 topology and extracting the tau lifetime from the correlation between the impact parameter difference of the two charged tracks and their acoplanarity. This "impact parameter difference method" offers several advantages over other methods: it is independent of the knowledge of the tau direction, and is less sensitive to tracking resolution and uncertainties in the beam size depend on and beam position. However, although uncertainties in the beam size are less significant the overall beam size is important; the large CLEO beam size contributes doubly in the statistical error.

We are also measuring the branching fraction for the decay $\tau \rightarrow 3\pi^{\pm}\nu_{\tau}$ using events in which both taus decay to three charged tracks. With the use of the Fisher-discriminant techniques discussed above, we have reduced hadronic backgrounds to less than 10%. We expect to be able to measure the branching ratio for $\tau \rightarrow 3\pi^{\pm}\nu_{\tau}$ at a level of about 2%, about four times better than has been achieved previously. This benefits from a factor of two reduction in errors since the number of events in the 3-3 sample is proportional to the square of the above branching ratio. With the recently published CLEO II precise measurement of the branching ratio for $\tau \rightarrow \pi^{\pm}\pi^{0}\pi^{0}\nu_{\tau}$, the expected equivalence of the two 3π charge states would be tested precisely for the first time. This equivalence is expected since both states arise from the decay of the a_1.

We also plan to measure the tau lifetime using the 3-3 sample. In contrast with the method mentioned above, this method is totally independent of beam size since one simply measures the distance between the two 3-prong vertices. With the data samples expected by the end of 1994, we should be able to measure the tau lifetime with this technique with a precision of $\sim 2\%$. Though this will likely be less precise than other measurements from LEP and even CLEO, it would be the first measurement using the vertex separation of 3-3 events and would have somewhat different systematics from other measurements.

One of the other physics topics which we have been working on is the use of $D^{*} \rightarrow D\pi$ decays to study the decays of D particles to CP eigenstates. These decay modes include K^+K^-, $K_s\pi^0$ and $K\phi$. The large number of charm decays recorded by the CLEO detector means that we can significantly improve upon existing limits on the amount of CP violation in the charm system, and our neutral particle detection capability allows us to add new modes. Although the amount of CP violation is expected to be small, it is possible that it could be increased substantially by the contributions of "new physics". Preliminary measurements of the asymmetries between the D^0 and $\bar{D}^0$ decay modes were announced at the recent Washington APS meeting. Our results are tabulated below; the lowest 90% confidence level upper limit attained was for the $K_s\pi^0$ decay mode where the upper limit is 0.066. This is the first measurement made of the asymmetry for this channel. We will continue to work on these limits and we plan to consider in addition the decay modes $\pi^+\pi^-$, $K^{*0}\pi^0$, $K_S\rho^0$ and $K_S\omega$. We also plan to measure the absolute KK branching fraction both for the charged and the neutral decay modes.

Channel	N in D^0	$\bar{N}$ in $\bar{D}^0$	Asymmetry	UL (90%CL)
ϕK_S	95.53±10.12	95.08±10.16	0.002 ± 0.075	0.125
$\pi^0 K_S$	385.43±21.04	389.92±21.07	0.006 ± 0.038	0.066
K^+K^-	167.99±16.33	165.64±16.17	0.007 ± 0.069	0.118

Our group has also been involved in the study of charmed baryons for the past 9 months. The main emphasis of this work has been in the search for the Ω_c. The decay modes of current interest are those where the Ω_c decays to an Ω^- plus some number of π's. The Ω^-'s are detected by their decay to ΛK^- where the Λ then decays to $p\pi$. Detection of this decay chain is complicated by the fact that both the Ω^- and the Λ travel finite distances in the CLEO detector and therefore two detached vertices must be reconstructed. Also, we have found that the Λ baryon finding efficiency is low in general. We have identified a potential problem in the area of track finding which may be responsible for this and which, if we can fix it, will greatly improve our ability to reconstruct these modes and many others.

In spite of these complications, it is expected that with CLEO's large data set and neutral particle detection capabilities the Ω_c^+ should be observable in both the $\Omega^-\pi^+$ and the $\Omega^-\pi^+\pi^0$ modes.

A longer term study is focused on developing a set of criteria which would enable us to use K_L decays in addition to K_S decays. This would enhance both the CLEO physics program and any B-factory program, since weak interactions result in the K^0 becoming a fifty-fifty mixture of K_S, which live for a short-time and usually decay in the drift-chamber, and K_L which have a long lifetime and are usually described as undetectable. In an attempt to develop such a set of criteria we have begun a study of the use of kinematic constraints to predict the direction taken by K_L particles in the decay chain $D^* \to D\pi$ where the D decays to $K_L\phi$. This decay chain can be selected by looking at the invariant mass of the $\phi\pi$ combination and it seems clean enough for us to be able to isolate a usable event sample. We have shown that the K_L particles are constrained to lie on a cone in the lab frame and are using this constraint to select calorimeter showers which could indicate a K_L interaction. We are in the process of studying the characteristics of this sample and its purity. Related to this work is a study of whether we can identify decays of the type $B \to \psi K_L$, and how big the background to this channel could be. If such decays can be used they will enable important cross checks to be made on the decay channel $B \to \psi K_S$ and also reduce the statistics needed to observe CP violation at a B-factory.

The CLEO Inner Detector Task Force (IDTF) is responsible for designing an upgrade to the CLEO detector, which will serve the needs of both the CESR Phase III upgrade design, and the proposed asymmetric B factory design. The IDTF is designing both a tracking system and a particle ID system. The goal for the tracking device(s) is to maintain or improve upon the excellent resolution properties of the current CLEO II detector. However, since we will require particle identification on tracks up to 4.5 GeV in an asymmetric B factory, we have had to sacrifice some space inside the CsI crystals for an advanced particle ID device. The reduced lever arm in the tracking device will degrade the momentum resolution.

To compensate for this, we are planning to reduce the amount of material in the tracking device (thus reducing multiple Coulomb scattering). We have also included a silicon microstrip device, with excellent resolution in both r and ϕ generally enhancing our physics abilities. The current design includes 4 layers of double-sided silicon-microstrip detectors inside 20 cm, and a drift chamber from 20 cm to 80 cm.

As members of this group we have been particularly involved in computer studies of the new detector, performing simulations of various physics processes to make sure that the tracking devices work together as envisioned to give mass resolutions, et cetera, as good as or better than the current CLEO II detector. We also have worked on track finding and fitting techniques more suitable for tracking systems with silicon devices. As an example; if there are only 4 layers inside 20 cm, one must optimize the number of hits required for a track to be fit so as to optimize the efficiency for low momentum tracks. In addition there are fitting techniques (Kalman Filter, which is also termed Billoir Fitting) which better take into account the uncertainty due to multiple scattering than the fitting method currently in use by CLEO II. These techniques become especially important where there are hard scatterers such as Si layers in the tracking volume.

In the area of service work, we have a variety of responsibilities. We are involved in software maintenance, tracking, particle identification (dE/dx), and in developing the data acquisition system for the vertex detector. We are also active participants in the experiment in general, serving on many committees and being a site for large scale Monte Carlo generation.

In order to take advantage of the large CLEO II data samples, it is necessary to generate huge (by e^+e^- standards) Monte Carlo samples. We have generated a sample of 2 million tau-pair Monte Carlo events using our farm of DECstations at Colorado. We also have generated large samples of 4S resonance and continuum Monte Carlo as well as signal Monte Carloes for the rare B decay analysis and our charm studies.

During the past year, Colorado has begun to have a significant involvement in the silicon vertex detector being built for CLEO II. This device will be installed at a radius of 2 cm from the beam in the Spring of 1994. Our group has taken responsibility for the construction and testing of a few of the readout boards needed in this system. In addition, we have taken on a major share of the responsibility for the data acquisition code for the readout of the silicon.

Particle identification is very important for much of the physics we are interested in and for most of the CLEO physics program. We have a commitment to working on the analysis of data from the current dE/dx system in order to optimize the resolution over the full momentum range. We expect to expand our role in this work.

IV. Outstanding Junior Investigator (P. Rankin) – Task J

This is only a brief report on my activities, the work done under this task has now transferred over to tasks A2 and D2 and more details can be found in those sections. My research activities this year have ranged from searches for CP violation in charm decays using data from the current CLEO detector, through studies of the uses of neural nets in particle physics, to investigations of how to do physics at a higher luminosity symmetric 10 GeV machine and at a B-factory.

One of the physics topics that I have been working on recently is the use of $D^* \rightarrow D\pi$ decays to study the decays of D particles to CP eigenstates. These decay modes include K^+K^-, $K_s\pi^0$ and $K\phi$. The large number of charm decays recorded by the CLEO detector means that we can significantly improve upon existing limits on the amount of CP violation in the charm system, and our neutral particle detection capability allows us to add new modes. Although the amount of CP violation is expected to be small, it is possible that it could be increased substantially by the contributions of "new physics". Preliminary measurements of the asymmetries between the D^0 and $\bar{D}^0$ decay modes were announced at the recent Washington APS meeting by Kihyeon Cho. The results are tabulated below; the lowest 90% confidence level upper limit attained was for the $K_s\pi^0$ decay mode where the upper limit is 0.066. This is the first measurement made of the asymmetry for this channel. We will continue to work on these limits and we plan to consider in addition the decay modes $\pi^+\pi^-$, $K^{*0}\pi^0$, $K_S\rho^0$ and $K_S\omega$. We also plan to measure the absolute KK branching fraction both for the charged and the neutral decay modes.

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The long term project in high energy physics is the SSC to which I have made a 20% time commitment for the next few years. I worked with Brenda Corliss an undergraduate honors student on building a test facility to evaluate the pulse shaper cards which will be used in the straw chamber readout. We also worked on the analysis of noise pickup problems with the cards using the analysis program PSPICE. She showed that the problems seen were consistent with the hypothesis that the broadcasts of a local radio station were causing interference.

I am also pursuing studies in the field of neural networks, as they promise to be an important future tool for use in high energy physics in general. The comment which best sums up the field of neural nets for me is that "neural nets may not be the best way of doing anything but they are the second best solution for just about anything"(Denker). Supervised networks hold promise for event classification problems since unlike code optimised for a specific pattern recognition problem (which may well be better at that specific task), once a network has been set-up in software it can be used to sort any group of events out from any background. It is unsupervised networks which have the greatest potential however. Unsupervised networks do not require a learning set. Instead they are used to extract features from data sets, that is they organise the data into groups or patterns. Essentially the net is supplied with a set of constraints and a function to minimize while obeying these constraints. A common application of such networks is to solve the "travelling salesman problem". The constraints in this case are the number of cities to visit and the number of visits; the aim is to minimize the distance travelled. The equations governing the net are mathematically equivalent to those arising in the Ising model of spin systems and are often termed energy functions.

Last summer I worked with a summer student on a study to determine if an unsupervised neural net could be used to organise the hits from a set of tracking detectors into particle tracks. This is a computer-time intensive problem if more traditional techniques are used. There is a good possibility that the computer time needed to fully reconstruct events can be reduced by the use of neural net algorithms. In this case the constraints applied are the characteristics which define a track, such as uniform curvatures. The initial results were promising and I am continuing to pursue this approach with an undergraduate student this summer. We are working on an 'elastic arms' algorithm approach which uses Hough transforms and which has been pioneered by Carsten Peterson. Also, although this work is centered on the SDC detector, if a working neural net track finder can be implemented in software it may also be possible to implement such a network as a hardware processor. Such dedicated processing devices will be a very efficient way of dealing with the large amounts of data we expect to get from both the SSC and from a B-factory detector.

Finally, I am working on two projects associated with future B physics work, both at a symmetric machine and, longer term at a B-factory. Karen Lingel and I are members of the CLEO Inner Detector Task Force (IDTF) which is responsible for designing an upgrade to the CLEO detector, which will serve the needs of both the CESR Phase III upgrade design, and the proposed asymmetric B factory design. The IDTF is designing both a tracking system and a particle ID system. The goal for the tracking device(s) is to maintain or improve upon the excellent resolution properties of the current CLEO II detector so we can continue our current physics program. However, since we will require particle identification on tracks up to 4.5 GeV in an asymmetric B factory, we have had to sacrifice some space inside the CsI crystals for an advanced particle ID device. The reduced lever arm in the tracking device will degrade the momentum resolution. To compensate for this, we are planning to reduce the amount of material in the tracking devices (thus reducing multiple Coulomb scattering). We have also included a silicon microstrip device, with excellent resolution in both r and ϕ generally enhancing our physics abilities. The current design includes 4 layers of double-sided silicon-microstrip detectors inside 20 cm, and a drift chamber from 20 cm to 80 cm. Karen has been particularly involved in computer studies of the new detector, performing simulations of various physics processes to make sure that the tracking devices work together as envisioned to give mass resolutions, etc., as good as or better than the current CLEO II detector. She has also worked on track finding and fitting techniques more suitable for tracking systems with silicon devices. As an example, where there are only 4 layers inside 20 cm, one must optimize the number of hits required for a track to be fit so as to optimize the efficiency for low momentum tracks. In addition, there are fitting techniques (Kalman Filter, also known as Billoir Fitting) which better take into account the uncertainty due to multiple scattering than the fitting method currently in use by CLEO II. These are more important in situations where there are hard scatterers (as in the Si layers).

I am also very involved in studies aimed at determining how well CP violation in the B system can be measured at a B-factory. As part of this work, I am working on developing a set of criteria which would enable us to use K_L decays in addition to K_S decays. This would enhance both the CLEO physics program and any B-factory program, since weak interactions result in the K^0 becoming a fifty-fifty mixture of K_s which live for a short-time and usually decay in the drift-chamber, and K_L which have a long lifetime and are usually described as undetectable. In an attempt to develop such a set of criteria we have begun a study into the use of kinematic constraints to predict the direction taken by K_L particles in the decay chain $D^* \rightarrow D\pi$ where the D decays to $K_L\phi$. This decay chain can be selected by looking at the invariant mass of the $\phi\pi$ combination and it seems clean enough for us to be able to isolate a usable event sample. We have shown that the K_L particles are constrained to lie on a cone in the lab frame and are using this constraint to select calorimeter showers which could indicate a K_L interaction. We are in the process of studying the characteristics of this sample and its purity. Related to this work is a study of whether we can identify decays of the type $B \rightarrow \psi K_L$, and how big the background to this channel could be. If such decays can be used they will enable important cross checks to be made on the decay channel $B \rightarrow \psi K_S$ and also reduce the statistics needed to observe CP violation at a B-factory.

V. SDC at SSC, Central Tracking

Bruce Broomer, Brenda Corliss, David Craig, Eric Erdos, William T. Ford, Senta V. Greene, Douglas R. Johnson, Will Kinney, Patricia Rankin, Gerhard Schultz, James G. Smith, Andrew Winningham, and Charles Zuelchner, in collaboration with approximately 900 physicists and engineers from 100 institutions worldwide.

The Solenoidal Detector Collaboration (SDC) is constructing a general purpose detector to study electroweak symmetry breaking, top quark properties, gauge boson production, possible supersymmetry, compositeness, etc. in proton-proton collisions at 40 TeV.[55] The detector consists of a large magnetic spectrometer surrounded by calorimeters and muon tracking detectors. It is optimized to be sensitive to unexpected physics as well as to make the crucial tests of the standard model symmetry breaking mechanism. The charged particle tracking system provides a complete view of the event structure, accurate momentum measurement and charge sign determination for charged hadrons, electrons and muons. The calorimeters measure hadron jet directions and energies and identify electrons. The external tracking devices, linked with the central tracking, identify muons and provide a confirming momentum measurement by bending of the tracks in toroids. All of these systems play an important role in the formation of the experiment trigger, and will be robust enough to operate in the presence of the expected high backgrounds.

Our group is working on the central charged particle tracking system, inside the solenoid, shown in Fig. 13. It consists of silicon strip detectors near the interaction point, surrounded by arrays of cylindrical tube (straw) wire chambers. Gas microstrip detectors cover the intermediate angle region. Our effort is devoted to development, design, and fabrication of the straw tube subsystem, and to coordination and evaluation of the tracking system.

The straw tracker contains five cylindrical superlayers of average radii between 80 and 160 cm arranged in two 4 m long sections placed end to end. Each superlayer is 6-8 detector layers thick, and is assembled from modules (Fig. 14). A module contains 160-200 straws having a total cross section of about 12 by 3 cm. Each module is a complete working unit contained in a low mass rigid structural shell. This subsystem is the responsibility of our group, in close collaboration with with physicists from Colorado State, Duke, and Indiana Universities, the Universities of Michigan and Pennsylvania, and the KEK Laboratory, and with engineers from Oak Ridge National Laboratory and Westinghouse Corporation.

We have made progress during the last year in building our first prototype straw modules, preparing for making long modules for a beam test, refining endplate designs toward a suitable production version, building and testing front end electronics boards, designing and testing connections to the readout electronics, measuring position and time resolution of prototype detectors operated with the custom electronics, and in modelling the detector system performance.

1. Front End Electronics Design, Fabrication, and Testing

We designed and built 25 16-channel front end boards (A-S-D8/T4) to read out prototype straw modules. This version incorporates eight-channel custom IC chips designed by our collaborators at the University of Pennsylvania and produced by the Tektronix SHPi high speed bipolar process. This is implemented as surface-mount packaged chips. The front end boards are connected to the prototype modules via micro-coaxial cables built into routing boards that attach permanently to the gas cap endplate. These have the decoupling capacitors mounted in-line perpendicular to the board on the same lattice as the wires. We have designed and built these in versions for 159 channel (stereo) and 212 channel (trigger) modules. We also designed and produced 16 ECL level translator boards for use in conjunction with the A-S-D8 boards to drive our FASTBUS TDCs.

We succeeded in establishing clean operation of the custom A-S-D8 boards at $V_{threshold}$ = 0.6 V (2.5 fC charge sensitivity). This entailed building a Faraday cage to contain the prototype 1-foot straw chamber and front end electronics, and powering them with batteries inside the shield. Subsequently we achieved the same operating conditions with low-noise power supplies and an AC isolation transformer.

The Penn group have designed and fabricated a higher density version of the A-S-D board, containing 160 channels in smaller EPIC packages. Besides achieving approximately the compact configuration needed to fit in SDC, these boards permit connections that avoid the cables believed to cause noise and crosstalk in the earlier prototypes. At Colorado we attached the HV supply board and blocking capacitor array and have performed tests on a 1 m prototype chamber. We find clean operation with $V_{\text{threshold}} = 0.6$ V, observing Fe^{55}pulses from a single channel on the oscilloscope. More extensive multi-channel operation will require a transition board to interface via our ECL level translator boards to the FASTBUS TDC's. We have completed the schematic and wirelist and are doing the layout. The data aquisition software, including an online event display, has been updated to accommodate the new readout system. We will begin tests of the full system using cosmic rays upon completion of the transition board.

We prepared drawings and specifications for feasibility quotes on hybrid packaging of A-S-D chips in 32- or 64- channel units. These were sent to a number of vendors, whose responses so far do not show great promise for this option. We have done some work on a concept for a high density front-end board.[57,58] The substrate is kapton, allowing for flexible links between raw signals and the ASD, and between these and the digital circuitry.

2. Development of a Removable HV/Signal Connection Board

We have designed a new interface to the front-end electronics that will allow plug-and-socket like removal of the active component substrate. It is a custom version of a Cinch product (CIN::APSE technology) meant for making interconnections between parallel joined boards. Decoupling capacitors are encased in the Cinch inline block with spring loaded contacts. A separate circuit board carries the protection resistors and traces for HV supply to the wires. The capacitor block will be clamped between the HV board and ASD readout board. A double pogo stick connector bridges from the taper pins on the module to the HV board. Thus all components are readly removable from the module for servicing and testing.

We made the sample boards in two options: with and without ground-cathode connections. This will permit us to evaluate the effectiveness of the ground connections for minimizing crosstalk and noise, and will provide some insurance in case the version with grounds leads to high voltage breakdown problems. One of the options is a kapton rigid/flexible board to permit folding to fit into the available space in SDC. We now have all parts needed for HV supply and FEB connection to our 1 m prototype modules, and are awaiting a slightly modified version of the 160-channel FEB from Penn.

We completed a report[63] of a measurement of the radiation length of sample blocking capacitors, based upon an undergraduate project conducted earlier. The measurements confirm that the capacitors contain high-Z material, an undesirable property for the tracking system, although other sources contribute significantly to material as well. We prepared a specification for HV capacitors that includes a figure of merit for the radiation length contribution, to aid in evaluating options from the vendors. To date we have not identified any dielectrics with significantly lower radiation length.

3. Prototype Design and Fabrication

We designed and have procured injection-molded plastic double vee wire supports to locate the wire in each straw at 80 cm intervals, for use in the various prototypes being built here and at collaborating institutions. Measuring the vee locations in a clamped array of straws with wire supports, we find about 30-35 microns each for error contributions of wire placement in the vee and vee placement relative to the lattice.[59] This is acceptable but larger than we want. We are investigating modifications to tighten the vee aperture for future orders.[64]

We have worked with our colleagues at Colorado State University (CSU) to produce a pair of 1 meter prototype 159-cell straw modules. For this version we redesigned the Indiana University endplate and designed and fabricated new solder clips. Indiana and Duke collaborators provided the 1 m graphite epoxy module shells, straws, some of the tooling, and wire. We made the straw bundle with double vee wire supports, encased it in the shell and endplates, and have placed a fraction of the wires. The second prototype is being assembled at CSU, and will feature individual cathode connections to clusters of four cells. We plan to test noise and crosstalk comparing the two prototypes to establish the feasibility and need for the cathode connections.

In preparation for 4 meter module assembly we cleared out and partitioned the lab space and installed long optical tables. We plan to set up for the large scale production of straw modules in space in the recently refurbished Nuclear Physics Lab high bay. We have a layout for the clean room and are seeking vendor quotes.

In collaboration with groups from Indiana and Duke, we have been very active in planning module assembly procedures. Given the large number of modules required for the complete tracking system, it is necessary to develop construction methods that will ensure a uniform and high performance of the individual modules while keeping to the stringent production schedule.

4. Endplate Design

We have worked with Duke, CSU, and Indiana on a new endplate designed for better handling of the gas flow and wire anchoring functions. A single G10 part now serves for both. The parts are being machined in our shop. Variations remain among the institutions in schemes for wire anchoring, but seem to be converging on a taper pin approach, with several options for the electrical contacts.

6. Pattern Recognition and Simulation

We have continued our effort on simulation of straw tracker performance and segment reconstruction, including a measurement of the false rate, improved occupancy calculation, incorporation of straw inefficiency in the model, yields of low energy photons,[65] and an updated measurement of the segment finding efficiency.[66]

We started a program to investigate the use of neural net strategies for track pattern recognition. We coded one of these in detail[62] and found good performance for the high resolution silicon detector. More work is needed to provide enough constraints to cope with the less precise straw layers.

We made stand-alone calculations of occupancy, segment reconstruction efficiency, and trigger efficiency in the SDC straws as function of particle rate, which verify the full simulation (SDCSIM) results.[69].

We have adapted the University of Michigan trigger simulation code to SDCSIM format, so that studies can be made combining information from the tracking, calorimeter, and muon systems to establish rates and efficiencies for the full SDC trigger.

7. Organization and Management

We mention here a number of activities related to collaboration, project, and workshop organization. We co-hosted a session on Tracking for Advanced Colliders at the Boulder Rocky Mountain Consortium for High Energy Physics (RMCHEP) summer workshops, and contributed talks on SDC Tracking[61] and Neural Net Algorithm[62] at the High Luminosity and Tracking sessions of the workshop.

We contributed to planning and preparation for DOE Review of SDC (November, 1992), including a presentation there on the scope of the straw tracker. We

Our current design for wire attachment and connections allows for conductive plating of the full endplate surface, for grounding and shielding. We are getting parts made in preparation for building modules for the summer beam test.

5. Detector Prototype Testing

With cosmic rays we have studied point measurement resolution in the one foot prototype equipped with our custom A-S-D8/T4 front end boards. We collected cosmic ray data with several HV settings and two gas mixtures. A measurement of the distance-time relation, resolution and residuals as a function of high voltage (at $V_{\mathrm{threshold}} = 0.6$ V) is described in Ref. 60. With CF_4-isobutane (80-20), our best observed resolution is about 160 microns (140 micron residual), at 1800 volts. This compares with 100 microns for the slower $Ar - C_2H_5$ $(50 - 50)$ gas mixture. We observe apparent crosstalk at higher voltage. These results are in reasonable agreement with observations by other members of the collaboration.

From a number of tests to measure crosstalk in the front end and interconnections to the prototype detectors we measure about 1.5-1.8% crosstalk between neighboring straws. We find consistency between values measured with Fe^{55} signals from the straws and those involving the interconnections alone. This level is still high enough to limit operation below the streamer onset voltage of the chamber. We anticipate improvement with the more compact connections to the readout that we are developing.

We also have measured the A-S-D8 output pulse width as function of input pulse charge.[68] This information is important for assessing dead time losses at high rate. With a combination of Fe^{55} and cosmic ray data we find values between about 15 and 50 ns over a wide range of input charge. The growth is slow for large pulse heights. These results confirm the 40 ns deadtime used in the simulations, allowing for the variation with pulse height over the full dynamic range anticipated.

helped plan the construction schedule and budget of the straw tracking system, prepared a Memorandum of Understanding with SSCL, and set up accounting and reporting procedures for the project. We developed plans for a joint production line with Colorado State University, and are coordinating the endplate development and a test beam run for summer, 1993. We also helped with organization of the SDC review by the Technical Board selection of the outer tracker technologies, and contributed to the preparation of a report for this process.[67] We hosted meetings of the module assembly committee and the endplate design committee for the SDC straw detector group and are currently organizing two meetings to prepare for the test beam run at BNL.

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FIGURE CAPTIONS

1) Λ_c^+ signals for various cuts on CLD(confidence level of the $PK\pi$ vertex), CL1 and CL2 (isolation cuts), and l/σ.

2) Mass difference plots for $D^{*+} - D^0$ for $D^0 \rightarrow K^-\pi^+$ and $D^0 \rightarrow K^-\mu^+\nu$.

3) Mass difference plots for $D^{*+} - D^0$ for $D^0 \rightarrow K^-e^+\nu$.

4) $\Lambda^0\pi^-$ and Λ^0K^- invariant mass distributions from E687.

5) $\Xi_c^0 \rightarrow \Xi^-\pi^+$ invariant mass distribution

6) $\Xi_c^+ \rightarrow \Xi^-\pi^+\pi^+$ invariant mass distribution

7) $\Omega_c^0 \rightarrow \Omega^-\pi^+$ invariant mass distribution

8) $K_s^0K_s^0$ invariant mass distribution

9) $K_s^0K_s^0K_s^0$ invariant mass distribution

10) $D^{*0} - D^0$ mass distributions for various cuts of l/σ.

13) The central part of the SDC detector, showing the calorimeters, solenoid coil, and tracking system, including silicon strip, straw tube, and gas microstrip detectors.

14) End view of a portion of an axial straw superlayer, showing three modules.

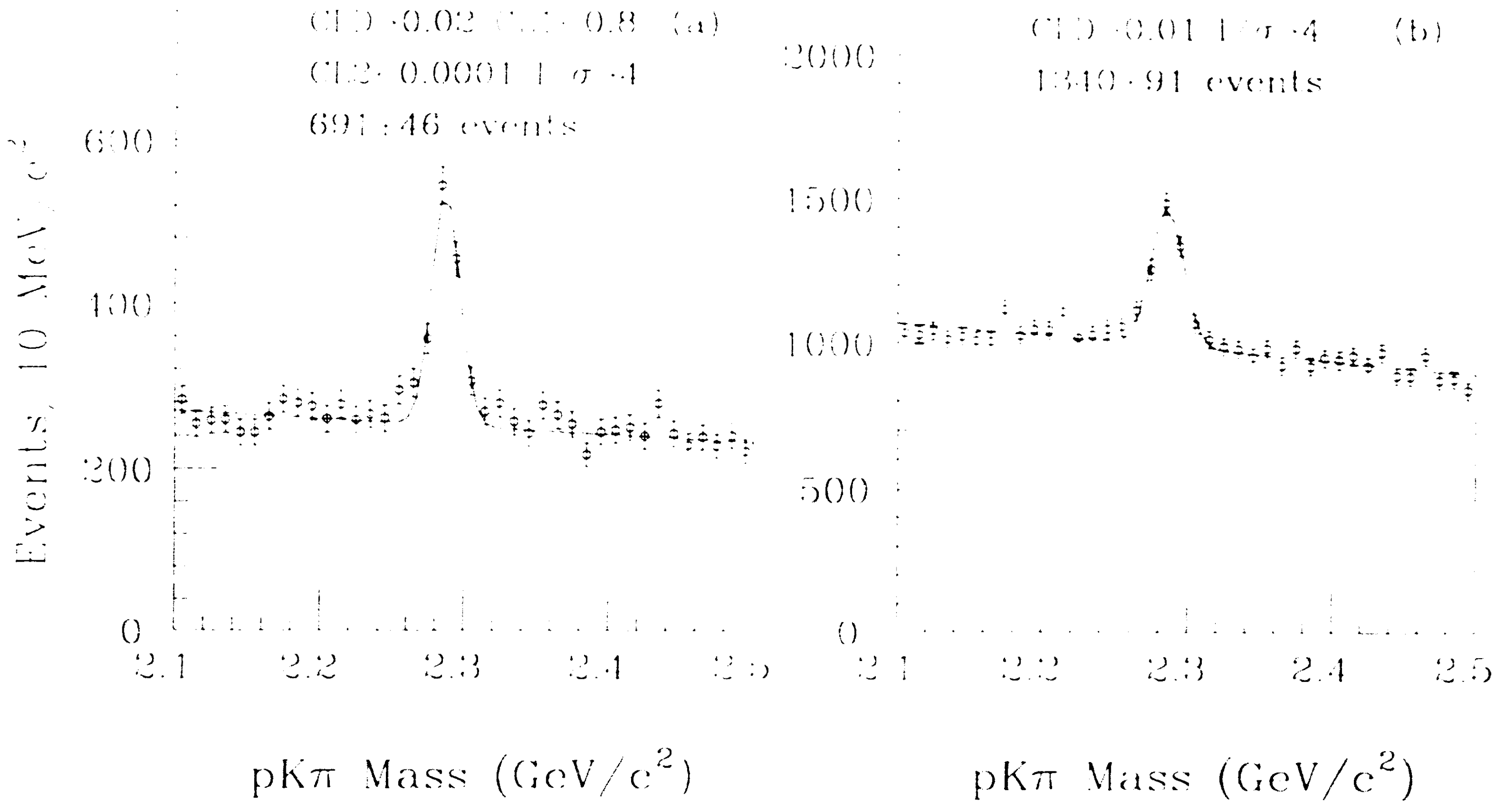
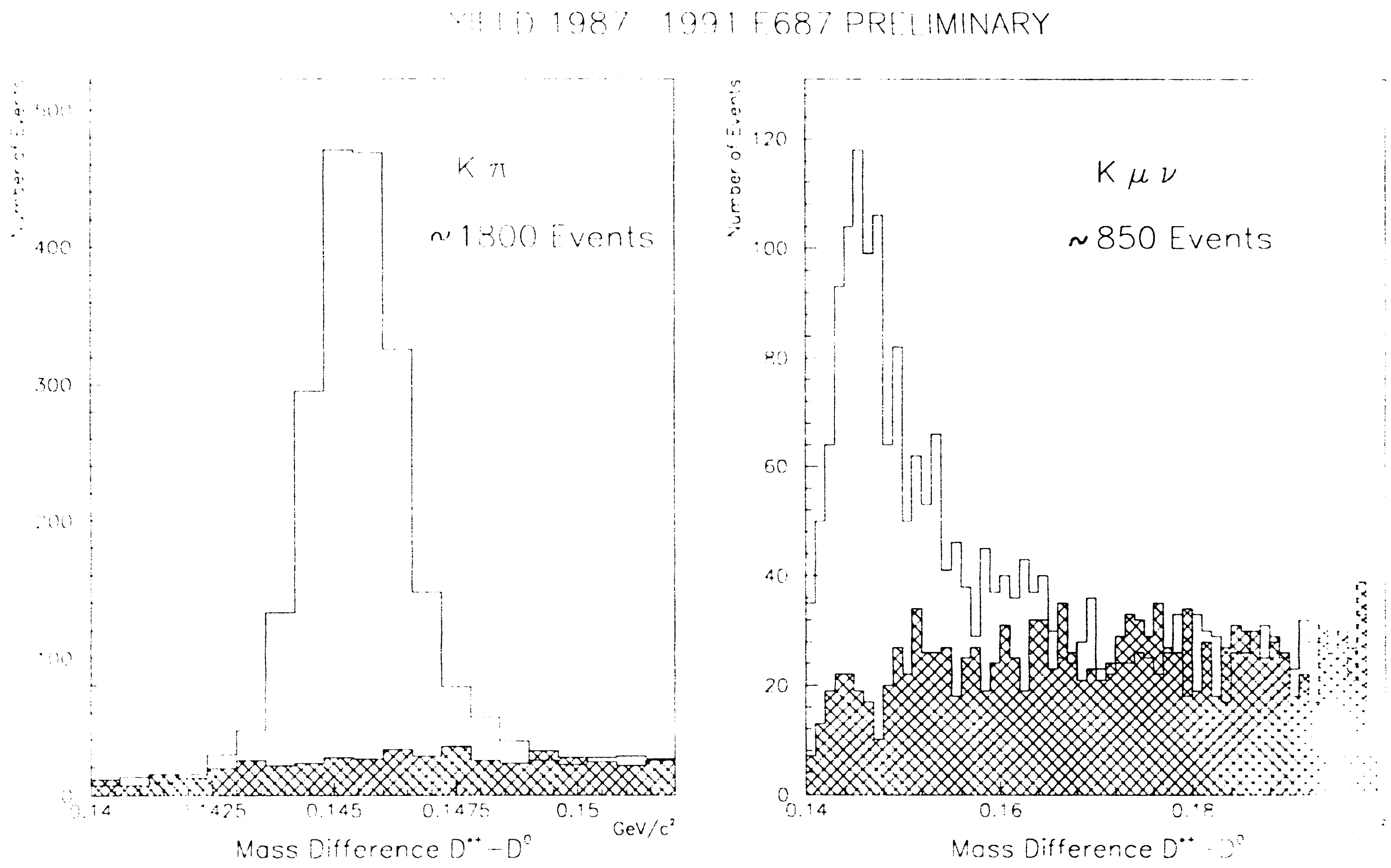

(a)
691±46 events
(b)
1340±91 events
Events/10 MeV/c²
pKπ Mass (GeV/c²)
pKπ Mass (GeV/c²)

Fig. 1



1991 E687 PRELIMINARY
Number of Events
$K\pi$
~1800 Events
0.14
0.145
0.1475
0.15
GeV/c²
Mass Difference D*+ − D⁰
Number of Events
$K\mu\nu$
~850 Events
120
100
80
60
40
20
0
0.14
0.16
0.18
Mass Difference D*+ − D⁰

Fig. 2

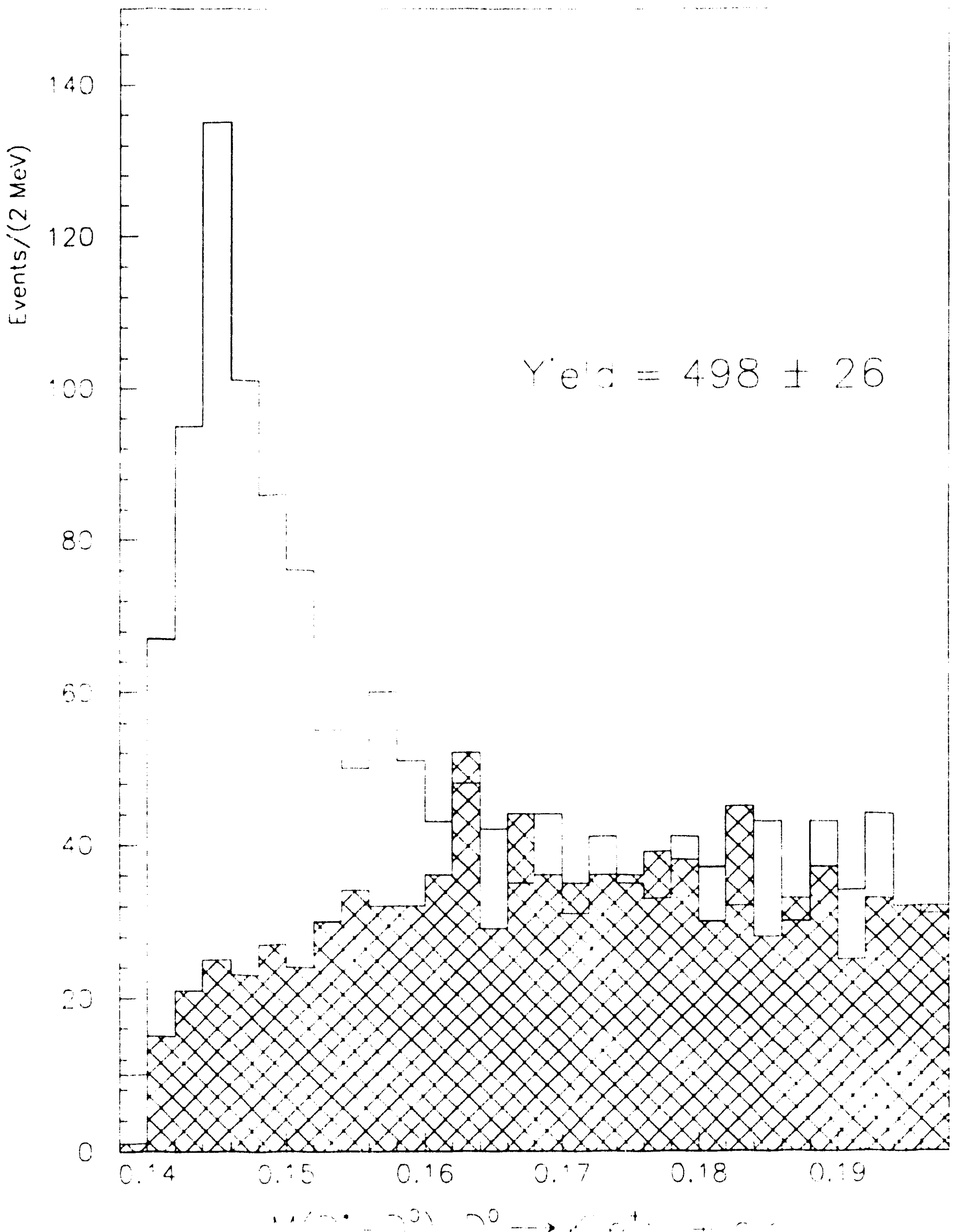

Events/(2 MeV)
Yield = 498 ± 26
140
120
100
80
60
40
20
0
0.14
0.15
0.16
0.17
0.18
0.19

Fig. 3

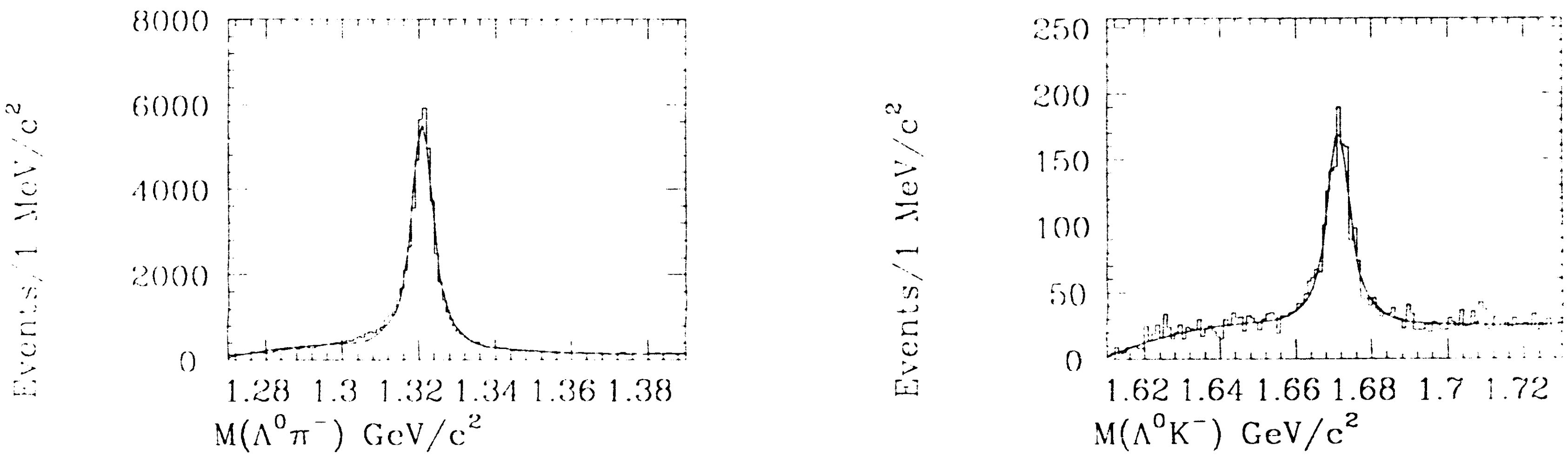

Events/1 MeV/c²
8000
6000
4000
2000
0
1.28 1.3 1.32 1.34 1.36 1.38
M(Λ⁰π⁻) GeV/c²
Events/1 MeV/c²
250
200
150
100
50
0
1.62 1.64 1.66 1.68 1.7 1.72
M(Λ⁰K⁻) GeV/c²

Fig. 4

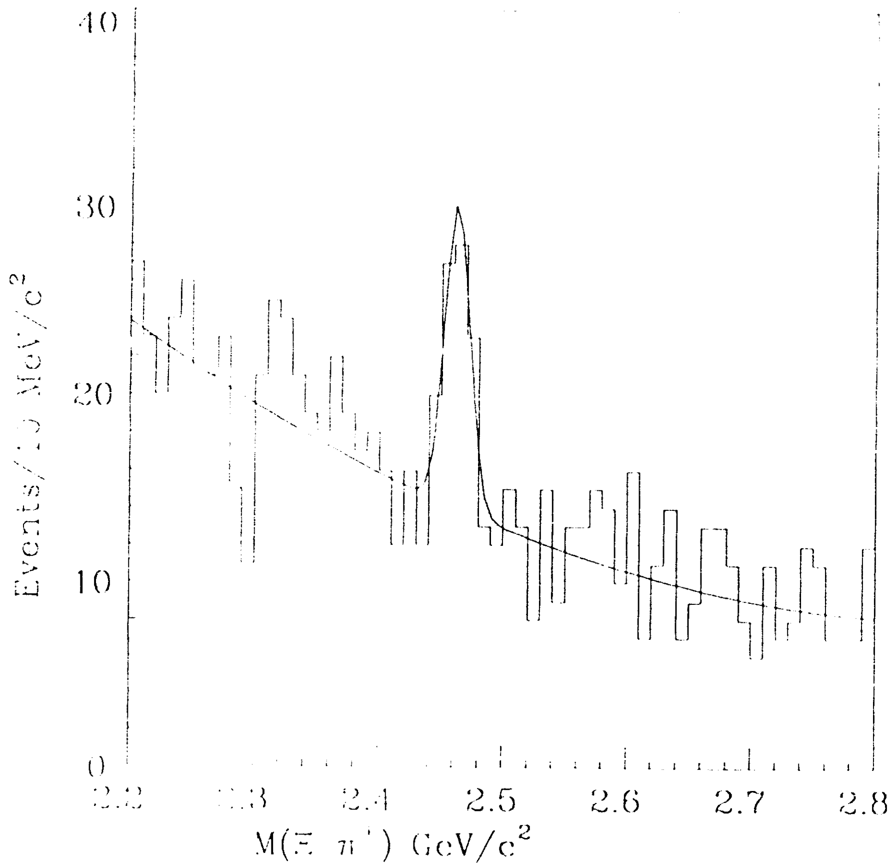


Fig. 5

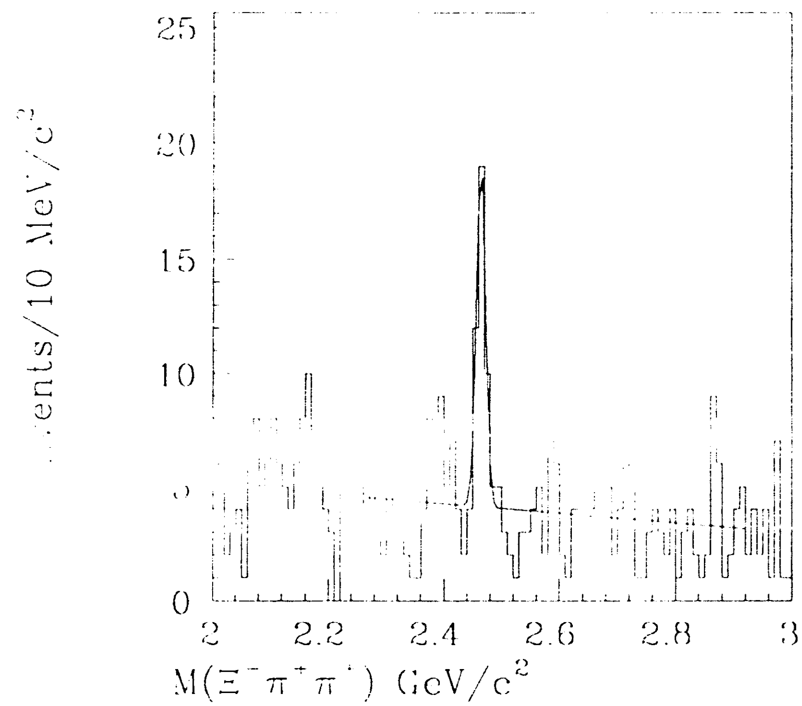


Fig. 6

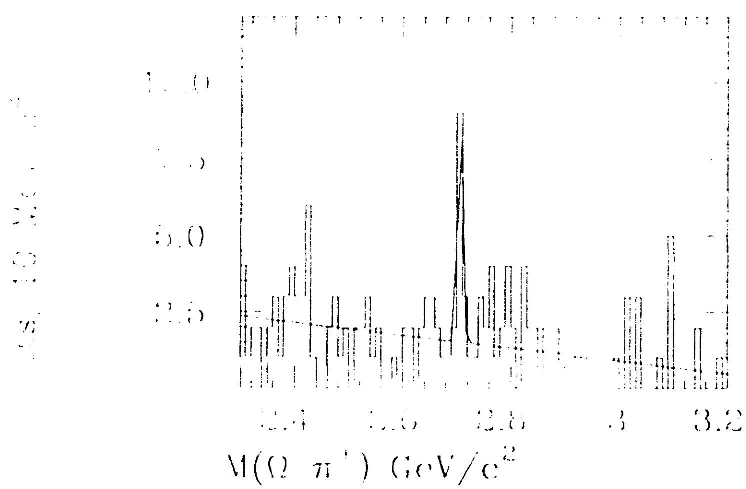


Fig. 7

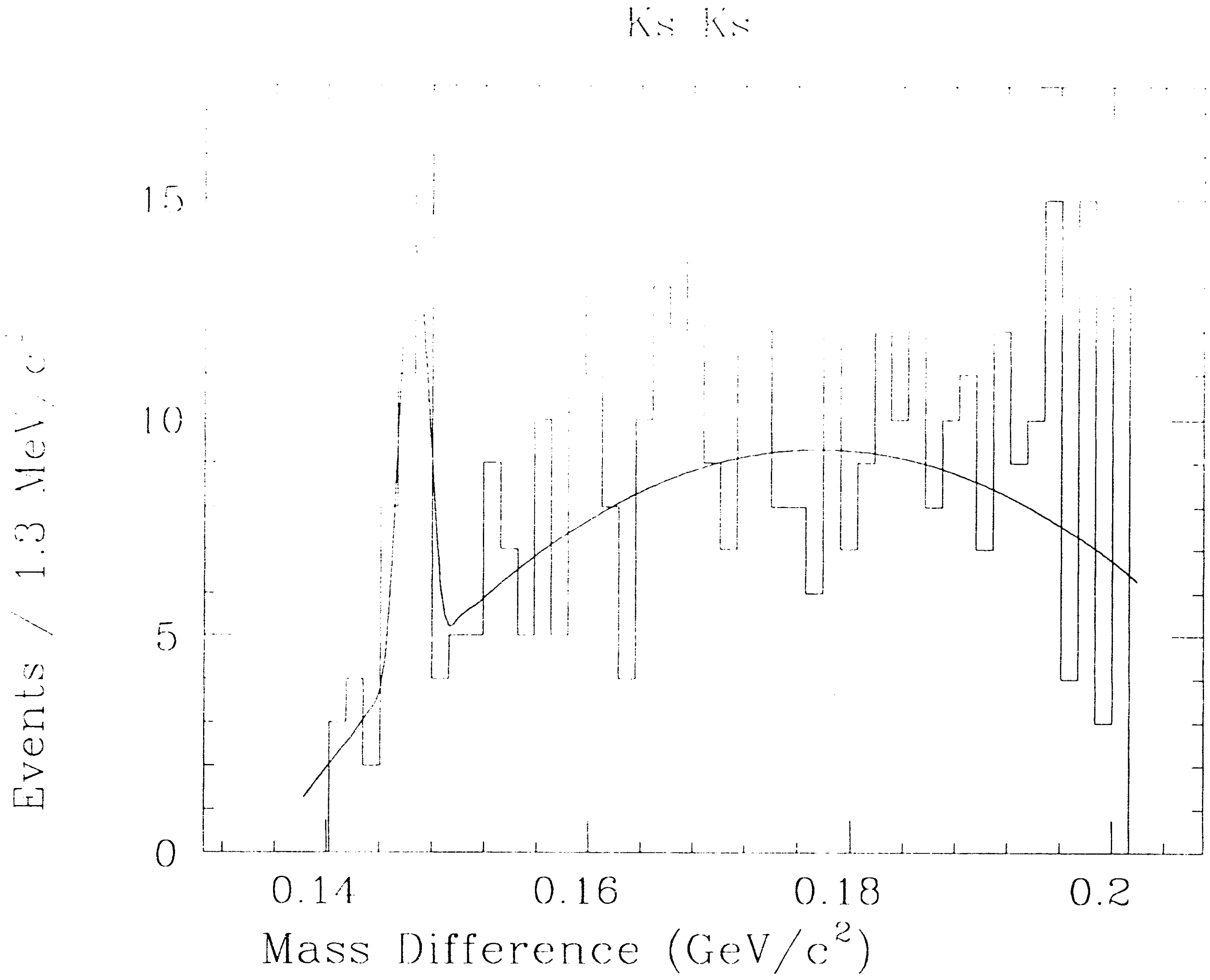

Ks Ks
Events / 1.3 MeV/c²
15
10
5
0
0.14
0.16
0.18
0.2
Mass Difference (GeV/c²)

Fig. 8

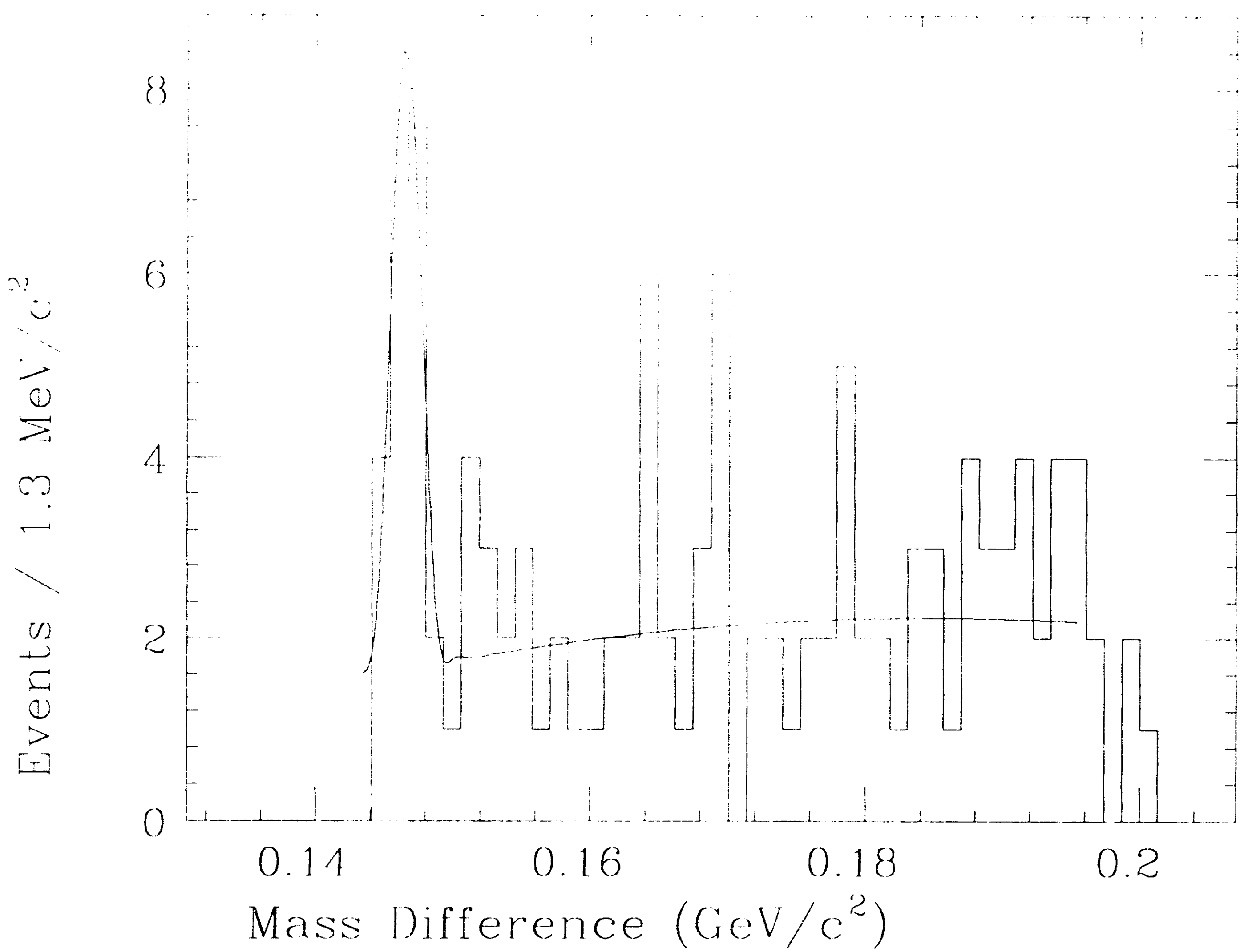
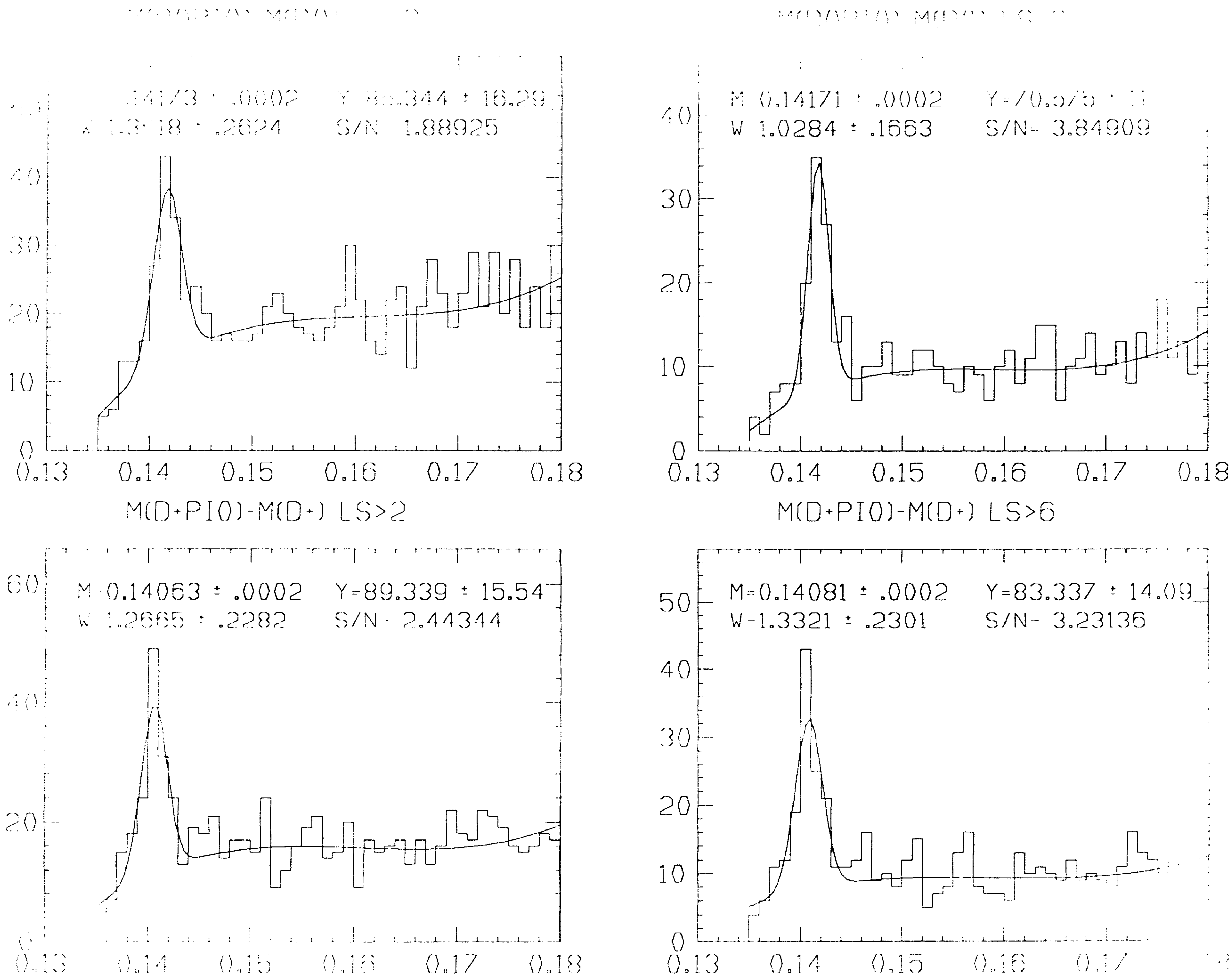
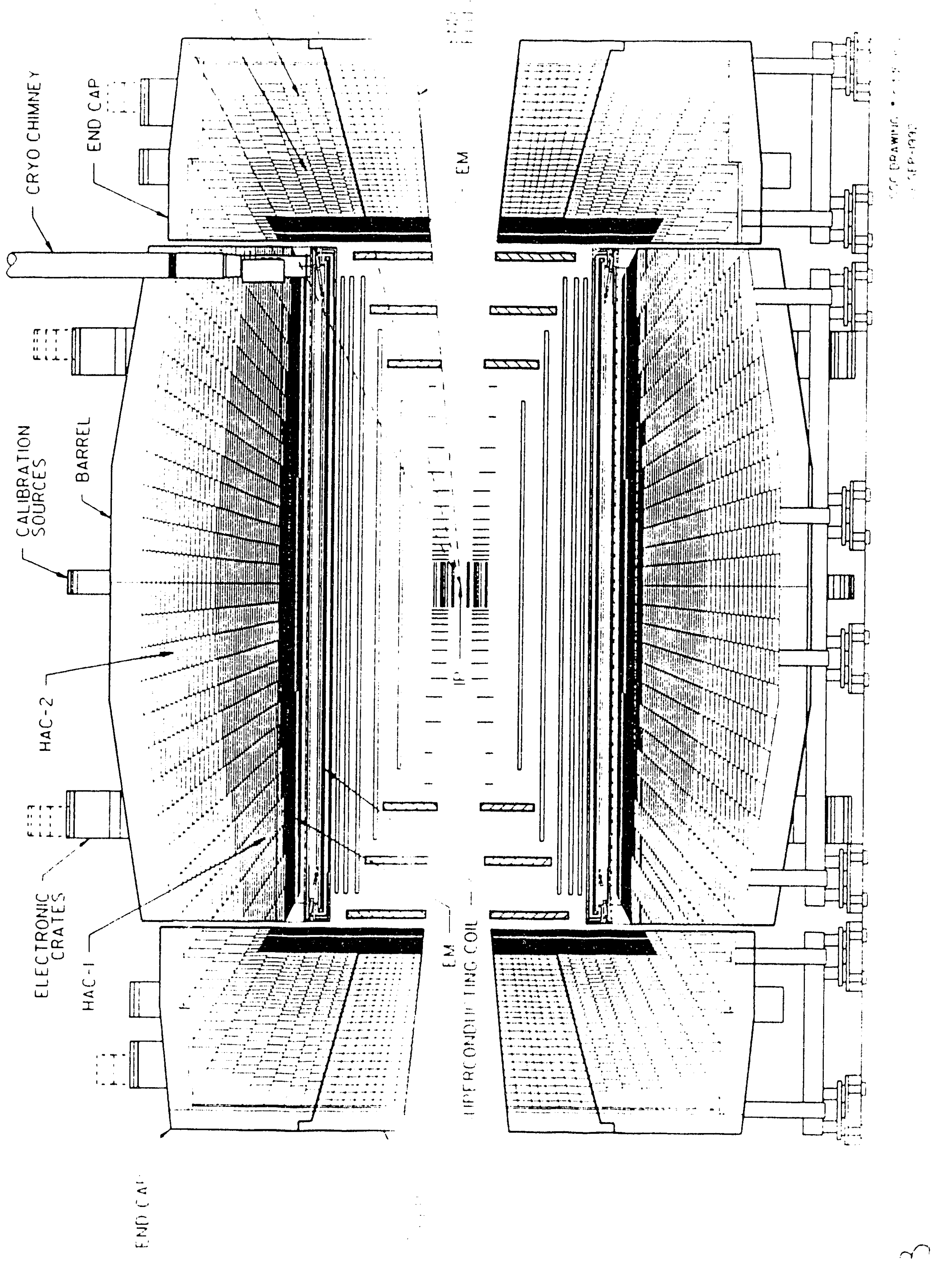


Fig. 9



M 0.14063 ± .0002
Y=89.339 ± 15.54
W 1.2665 ± .2282
S/N 2.44344
M(D+PI0)-M(D+) LS>2
M 0.14171 ± .0002
W 1.0284 ± .1663
S/N 3.84909
M(D+PI0)-M(D+) LS>6
M=0.14081 ± .0002
Y=83.337 ± 14.09
W-1.3321 ± .2301
S/N- 3.23136

Fig. 10


CRYO CHIMNEY
END CAP
CALIBRATION SOURCES
BARREL
HAC-2
ELECTRONIC CRATES
HAC-1
EM
IP
EM

SDT-000010.F

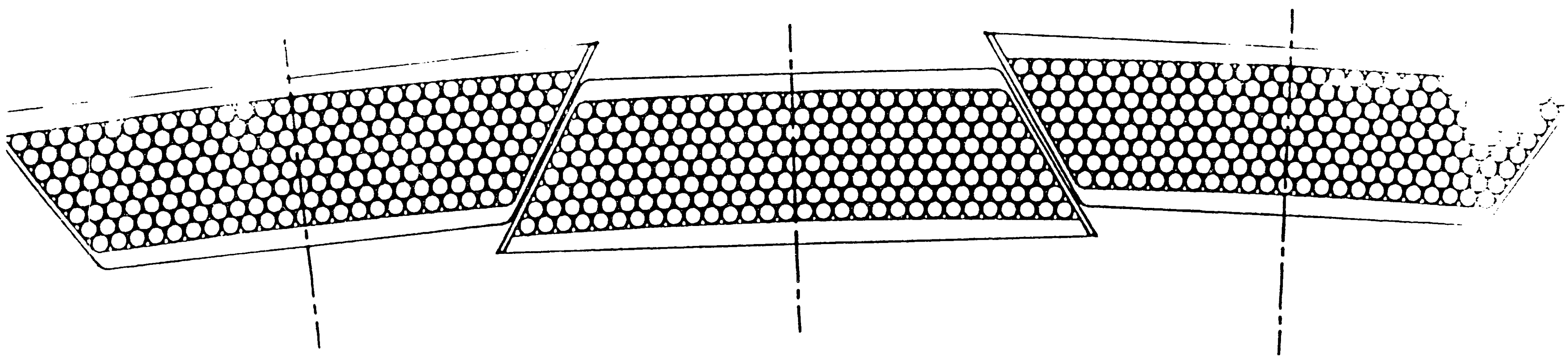


Fig. 14

1. Theoretical Particle Physics – Task B

The theoretical high energy physics group consists of three faculty members, S. P. de Alwis, T. DeGrand and K. T. Mahanthappa; two postdoctoral research associates, C. Baillie and P. K. Mohapatra, and three students, M. Wingate, H-S. Li, and W. Kinney. Li has just defended his Ph. D. thesis and will remain with us until June 1993. He will be replaced by K. Sato. Mohapatra and Baillie will be leaving in August 1993 and will be replaced by S. Balakrishna (presently supported on A. Hasenfratz's contract through Arizona) and Doug Macintyre (University of California, Santa Cruz). Finally, Ben Svetitsky, a theoretical physicist from Tel Aviv University on sabbatical leave, will visit us for a year starting in September 1993.

1.1 Mostly Lattice QCD (T. DeGrand)

"Grand Challenge" Spectroscopy I am a member of the High Energy Monte Carlo Grand Challenge (HEMCGC). Members of this collaboration include Khalil M. Bitar, R. Edwards, U. M. Heller, A. D. Kennedy, (SCRI, Florida State University), Thomas A. DeGrand (University of Colorado), Steven Gottlieb, A. Krasnitz (Indiana University), J. B. Kogut (University of Illinois), Weiqiang Liu (Thinking Machines, Inc.), R. L. Renken (University of Central Florida), Michael C. Ogilvie, (Washington University), D. K. Sinclair, K. C. Wang (Argonne National Lab), R. L. Sugar (University of California, Santa Barbara), Michael Teper (Oxford University), D. Toussaint (University of Arizona). We have been carrying out simulations of full QCD on the Connection Machine CM-II at the Supercomputations Research Institute at Florida State University. The goal of the collaboration is to study spectroscopy and simple matrix elements of full QCD on the largest lattice sizes and smallest masses practicable. This year I completed a paper on simple matrix elements using valence Wilson quarks and two flavors of staggered sea quarks, which shows that the presence of sea quarks is a small effect compared to other lattice systematics, at the parameter values we studied. We are presently working on an analysis of spectroscopy and matrix elements with two flavors of dynamical Wilson fermions at $6/g^2 = 5.3$, which will hopefully be finished before the end of the year.

1. HEMCGC collaboration, Simple Hadronic Matrix Elements with Wilson Valence Quarks and Dynamical Staggered Fermions at $6/g^2 = 5.6$, COLO-HEP-304, submitted to Phys. Rev. D.

2. HEMCGC collaboration, Hadron spectroscopy with dynamical Wilson fermions at $\beta = 5.3$, to appear in the proceedings of Lattice '92.

Multiple Instruction Lattice Collaboration Projects This collaboration includes Claude Bernard (Washington University, St. Louis), Thomas A. DeGrand (University of Colorado), Carleton DeTar (University of Utah), Steven Gottlieb (Indiana University), R.L. Sugar (University of California, Santa Barbara), and D. Toussaint (University of Arizona). We are carrying out QCD simulations on MIMD supercomputers, mainly arrays of Intel i860's at the San Diego Supercomputer Center, with additional running at the Pittsburgh Supercomputing Center, and the National Center for Supercomputer Applications. We are also members of a computational Grand Challenge project by the DOE's component of the Presidential Initiative in High Performance Computing and Communications (HPCC) at Oak Ridge National Laboratory.

We have worked on several topics in the past year:

Our first project on the iPSC/860 was to extend and complete the studies of the thermodynamics of Kogut-Susskind quarks on lattices with six time slices. We completed a study of the high temperature crossover with a quark mass $am_q = 0.025$, and extended this to quark mass $am_q = 0.0125$. In agreement with other recent simulations, our results are consistent with a rapid crossover, as opposed to a true phase transition. When coupled with the spectrum calculations described below, this study enabled us to significantly improve our previous estimate of the crossover temperature for this lattice spacing in physical units.

While studying the location and nature of the phase transition we have also measured quantities which shed light on the nature of the high temperature plasma. Of particular interest to phenomenology is knowledge of the large-scale organization of the plasma. Studies of the energy density, baryon number susceptibility and hadron screening lengths yield results which are consistent with a plasma of weakly interacting quarks and gluons. We used the iPSC/860 to explore the spatial structure of the screening of color singlet sources. We found that even in the high temperature regime the positions of the quark and antiquark in the meson propagators were strongly correlated, as were the positions of the quarks in the nucleon propagators. These results are very different from what one would expect from a free or weakly interacting quark plasma. To further explore the properties of the plasma we have recently measured the distribution of quarks in the vicinity of a fixed test quark at temperatures above, below and near the crossover temperature, T_c. At low temperature one expects that the test charge will be screened at short distances by a dynamical antiquark or by two quarks. We find that to be the case, with a significant baryonic component already at a temperature of $0.75T_c$. The screening decreases dramatically as one approaches the crossover temperature, and at $1.25T_c$ the total induced charge is two orders of magnitude less than at $0.75T_c$. These results are consistent with a weakly correlated high temperature plasma,and give no support to the hypothesis of small color singlet clusters in the plasma. It is clear that further detailed studies are needed to fully determine the structure of the plasma.

In addition to our work with Kogut-Susskind quarks, we have been investigating high temperature QCD with Wilson quarks. We have recently completed a study on $12^3 \times 6$ lattices with two flavors of Wilson quarks using hopping parameters of κ=0.16, 0.17 and 0.18. We have determined the location of the crossover between the high and low temperature states for these hopping parameters, and have carried out spectrum calculations for the same hopping parameters on $12^3 \times 24$ lattices in order to determine the critical value of the gauge coupling, that is, the value for which the pion and quark masses vanish. For $\kappa = 0.16$ we found a smooth crossover between the low and high temperature regimes similar to that found for Kogut-Susskind quarks. However, at the two largest values of κ we found coexistence between low and high temperature regimes indicative of a possible first order phase transition. In work still in progress, we have extended our study to $\kappa = 0.19$ and 0.20 finding similar results. The discontinuity in the plaquette and the chiral order parameter between the two regimes grows with increasing κ. Recently, in collaboration with A. Hasenfratz, we have begun a study of the quark mass, as measured by means of the axial vector current Ward identity, on finite temperature lattices with both four and six time slices. We have identified three regimes: low and high temperature ones in which the quark mass is positive, and a high temperature "unphysical" regime in which the quark mass is negative. For $N_t = 4$ we find smooth crossovers between these regimes. The possible first order transition observed for large values of κ at $N_t = 6$ is between the low temperature regime and the "unphysical" negative quark mass one. We hope that this project will help to clarify the phase structure of QCD with Wilson quarks. However, to separate out the affects of lattice artifacts from continuum physics requires work at smaller lattice spacings.

We have carried out a series of high statistics spectrum calculations with two flavors of Kogut-Susskind quarks on lattices ranging in size from $8^3 \times 24$ to $16^3 \times 24$. These studies were made with quark masses $am_q = 0.025$ and 0.0125 at gauge couplings corresponding to the finite temperature crossover for $N_t = 6$. These calculations allowed us to set an energy scale for the $N_t = 6$ Kogut-Susskind thermodynamics calculations described above, and therefore to make an estimate of the transition temperature. However, our primary objective was to study the effects of finite box size on spectrum calculations. It has long been recognized that such effects can be substantial if the spatial volume of the simulation is small. By working at relatively large lattice spacings we were able to encompass a wider range of lattice sizes than in previous studies, and also work at relatively small values of m_π/m_ρ. Our hope is to set the limits for the physical size of the lattice for calculations at weaker coupling for which such experiments would be very costly. Using the ρ meson to set the scale our lattices had box sizes ranging from 1.8 to 3.6 fm, and we found significant effects on the spectrum only on the lower half of that range.

For the future we are planning several projects.

First, we are planning a large scale study of the decay constants of heavy-light mesons at a very small value of the lattice spacing, $1/a = 3$ GeV. This is quite a bit smaller than present day simulations. The apparent disagreement observed at stronger coupling between static ($M_{\text{heavy}} \rightarrow \infty$) and conventional (propagating heavy quarks, with extrapolation up in mass) results seems to be considerably reduced in the new calculations. However, the signal-to-noise ratio on our present data set is not good enough to make the comparison in a definitive way. We therefore plan to increase the statistics by a large factor. We plan to make a still more definitive test by going to weaker coupling and checking that the size of the discrepancy continues to decrease. This project is expected to be carried out at Oak Ridge as part of our DoE Grand Challenge.

Second, we will use the SDSC Paragon to carry out a set of quenched spectrum calculations at a gauge coupling of $6/g^2 = 6.0$ on $16^3 \times 48$ and $24^3 \times 72$ lattices. We have several objectives in this project. First, with the very interesting recent work of Weingarten and collaborators on the quenched spectrum with Wilson quarks, quenched spectrum calculations with Kogut-Susskind quarks now lag significantly behind those with Wilson quarks. We therefore propose to carry out a series of quenched Kogut-Susskind calculations on these lattices with quark masses in the range $.0005 \leq am_q \leq 0.025$. We are particularly interested in understanding the differences that have been previously observed in quenched spectrum calculations using Kogut-Susskind and Wilson quarks. We also plan to investigate the effects of lattice volume, and quark mass on the masses of the lightest hadrons. A high statistics calculation at this lattice spacing would be a significant contribution to the study of the Kogut-Susskind spectrum.

In addition to calculating the masses of the lightest hadrons, we plan to use the lattices to begin a program of computing masses of orbitally excited states and simple matrix elements using Wilson valence quarks. Our aim in some of these calculations is to obtain quantitative results that can be compared with experiment, and in others to obtain a qualitative understanding of QCD bound states.

A number of groups have carried out calculations of the masses of P-wave states in the quenched approximation. We propose to extend the program begun by me to use sophisticated interpolating fields for this purpose. The experimental situation for orbitally excited mesons made up of light quarks is particularly confusing, and even a modest improvement in spectrum calculations might elucidate the data. A significant amount of data on orbital excitations of charmed mesons has recently appeared. Some lattice calculations have been done on these states, but more work is certainly called for. The prototypical matrix element of a P-wave system is the decay constant of the a_1 meson, f_{a_1}, defined by

$$\langle 0|\bar{\psi}\gamma_\mu\gamma_5\psi|a_1^\nu\rangle = f_{a_1} m_{a_1}^2 g^{\mu\nu}$$

This matrix element is measured in the decay $\tau \to a_1\nu$, and is known experimentally to about eight per cent accuracy. It is a difficult quantity to compute in the quark model since it vanishes in the nonrelativistic limit. However, the calculation is accessible on the lattice, the technology being identical to that used to obtain f_π, f_K, and f_D. In addition, it will apparently be possible to extract decay constants of strange mesons from τ decay data in the next few years. The relevant lattice calculations will be no harder than for the a_1.

On a more qualitative level, we would like to investigate the properties of the wave functions of the quarks within hadrons. In particular, we would like to determine whether there is evidence within lattice calculations for a pion cloud around hadrons which is well separated from the valence quark degrees of freedom. The main qualitative feature of quark wave functions is that the size of the wave function is much smaller than the size indicated by form factor measurements. This suggests that if there is a quark model which these lattice results reproduce, it is not a conventional quark model but the "little bag model" of Brown and co-workers in which the confinement region of the quarks is small, and the outer regions of the hadron are occupied by a pion cloud. In this model the hadron charge radius has little direct connection with the size of the bound state. About half the pion or proton charge radius comes from vector dominance and the remainder from the intrinsic size of the valence quark wave function. These ideas can be tested by measuring quantities such as

$$O(x,y) = \sum_{x} \bar{\chi}\chi(x) q(x+y) \bar{q}(x+z),$$

where q and $\bar{q}$ create a valence quark and antiquark, and $\bar{\chi}\chi$ is the pion condensate. There is a similar expression for baryons. This can also be viewed as a study of the effect of the valence quarks on the local QCD vacuum—can we see them confined inside a bag? It would extremely interesting if lattice Monte Carlo calculations could identify a specific quark model for QCD.

1. MILC collaboration, QCD thermodynamics with two flavors at $N_t = 6$, Phys. Rev. D45, 3854, 1992.

2. MILC collaboration, Finite-Size Effects and T_c for $\beta = 5.445$ with Two Staggered Flavors, Nuclear Phys. B (Proc. Suppl.), 26, 262, 1992.

3. MILC collaboration, QCD Thermodynamics with Two Flavors of Quarks, Nuclear Phys. B (Proc. Suppl.), 26, 305, 1992.

4. MILC collaboration, QCD thermodynamics with two flavors of Wilson quarks at $N_t = 6$, Phys. Rev. D46, 4741, 1992.

5. MILC collaboration, Finite Size Effects on the QCD Spectrum Revisited, Nucl. Phys., B [Proc. Suppl.] 30, 369, 1993.

6. MILC collaboration, Baryon Density Correlations in the Quark Plasma, Nucl. Phys., B [Proc. Suppl.] 30, 319, 1993.

Heavy Dynamical Fermions in Lattice QCD It is expected that the only effect of heavy dynamical fermions in QCD is to renormalize the gauge coupling. A. Hasenfratz (Colorado) and I derived a simple expression for the shift in the gauge coupling induced by N_f flavors of heavy fermions. We compared this formula to the shift in the gauge coupling at which the confinement-deconfinement phase transition occurs (at fixed lattice size) from numerical simulations as a function of quark mass and N_f. We found remarkable agreement with our expression down to a fairly light quark mass. However, simulations with eight heavy flavors and two light flavors showed that the eight flavors do more than just shift the gauge coupling. We also observed confinement-deconfinement transitions at $\beta = 0$ induced by a large number of heavy quarks.

1. A. Hasenfratz and T. DeGrand, Heavy Dynamical Fermions in Lattice QCD, COLO-HEP-311, submitted to Phys. Rev. D, April 1993.

1.2 SUMMARY OF RECENT RESEARCH AND FUTURE PLANS - S. P. DE ALWIS

Matrix models, and black holes In a paper published about a year and a half ago, (paper 49 in my C. V.) my collaborator (R. Brustein) and I constructed a generally covariant version of the collective field theory coming from matrix models. In particular it was shown that there must be an additional target space curvature term in the effective action. This action is the natural setting for discussing (at low energies) the properties of two dimensional black holes coming from string theory. Work on this project is continuing and we have been able to relate the black hole metric to a matrix model potential. We point out that general covariance is needed to resolve an ambiguity in the identification of the potential.

1. R. Brustein and S. P. de Alwis, Matrix models for black holes, paper in preparation.

Quantum Black Holes Most of my research in the past year [1,2,3,4] has been on quantum black holes in two dimensional dilaton-gravity . In [1] I have shown that general covariance requires that the theory be a (quantum) conformal field theory, and that therefore the classical Lagrangian (proposed in [5]) needs modification. Furthermore it turns out that these modified Lagrangians can be written as Liouville-like theories and are exactly solvable even at the semi-classical level. In the second paper [2] these solutions and their implications for Hawking radiation are discussed. In the third paper it is shown that regardless of the number of matter fields the quantum theory can be defined. This gives us, in two dimensions, a non-trivial solvable theory of quantum gravity (with black holes at the classical level). The taming of classical singularities by quantum effects can also be explicitly demonstrated and Hawking radiation can be calculated with back reaction taken into account. In [4] I have shown that the expression for the ADM and Bondi masses that have been used in the literature need to be modified, and that the new expression satisfies a positive energy theorem.

1. S. P. de Alwis, Quantization of a Theory of Dilaton Gravity, Phys. Lett. **B289** (1992) 278.
2. S. P. de Alwis, Black Hole Physics and Liouville Theory, Phys. Lett.**B300** (1993) 330.
3. S. P. de Alwis, Quantum Black holes in Two Dimensions, Phys. Rev. D **46** (1992) 5429.
4. S. P. de Alwis, Two dimensional quantum dilaton gravity and the positivity of energy, COLO-HEP-309, February 1993.
5. C.G. Callan, S.B. Giddings, J.A. Harvey, and A. Strominger, Phys. Rev. D **45** R1005 (1992).

Future plans My future research plans include the continuation of the above investigations in string theory, quantum gravity and black hole physics. In particular since one now has a non-trivial theory of quantum gravity which is solvable at the quantum level in two dimensions, one can hope to clarify some puzzling issues, such as the origin of time, without having to deal with the technical complications of four dimensional gravity. This investigation is being actively pursued now. Also I would like to understand the implications for four dimensional physics (for instance in spherically symmetric situations) that follow from the theory of quantum dilaton gravity discussed above. In addition I hope to pursue some ideas, which are still in the formative stages, in cosmological structure formation.

1. S. P. de Alwis, The problem of time in two dimensional quantum dilaton gravity, paper in preparation.

1.3 Research Work of K. T. Mahanthappa and Collaborators

During the past year K. T. Mahanthappa has been investigating (i) ultraviolet behavior of supersymmetric nonlinear sigma models in 1/N expansion, (ii) one- and two-loop corrections to the gauge coupling constant function in string effective field theories and its holomorphicity property and (iii) induced gauge non-linear sigma models.

K. T. Mahanthappa was invited to talk on the earlier work on renormalizability of (2+1)-dimensional supersymmetric nolinear sigma at the Annual Meeting of the Physical Society of Japan at Sendai, March 29-April 1, 1993. He also gave an invited review talk at the Fifth Asia Pacific Physics conference, August 10-15, 1992, Kuala Lumpur, Malaysia.

Ultraviolet Behavior of Supersymmetric Nonlinear Sigma in 1/N Expansion

Our earlier work has shown that the (2+1)-dimensional $N(Q) = 1$ supersymmetric non-linear sigma model (SSNSM) is renormalizable in 1/N expansion. We are continuing our investigation of the ultraviolet behavior of SSNSM with $N(Q) > 1$. In particular we are interested in proving in 1/N expansion the analogues of some of the results gotten in perturbative coupling constant expansion. For example, N(Q) = 2 perturbation theory implies finiteness of N(Q) = 4 models on hyper-Kahler spaces; the demonstration of this result involves the use of Yau's theorem for hyper-Kahler manifolds. We have preliminary results indicating similar behavior in 1/N expansion. We are also exploring theories in higher than (2+1)-dimensions.

1. K. T. Mahanthappa, "Dynamical Mass Generation and Renormalization in a Supersymmetric Sigma Model," invited Plenary talk in the Proceedings of the Second International Symposium on Particles, Strings and Cosmology, March 25-30, 1991 Boston (World Scientific, Singapore, 1992) p. 263-283.
2. K. T. Mahanthappa, "1/N Expansion and Renormalizability of a Supersymmetric Nonlinear Sigma Model," invited Plenary talk in the Proceedings of the 1991 Summer Workshop on High Energy Physics and Cosmology held at the International Center for Theoretical Physics, Trieste (Italy), (World Scientific, Singapore 1992), p. 601-622.
3. V. G. Koures and K. T. Mahanthappa, "1/N Expansion and Renormalizability of a (2+1)-Dimensional Supersymmetric Nonlinear Sigma Model," invited talk in the Proceedings of the Meeting of Division of Particles and Fields of the American Physical Society, August 18-22, 1991, Vancouver, Canada (World Scientific, 1992) p. 825-828.

Holomorphicity of the Gauge Coupling Function in String Effective Theories

This work is done with the doctoral student Hesheng Li.

During the past eighteen months we have been investigating the holomorphic property of corrections to the gauge coupling constant function f in supergauge. (Earlier we have studied one-loop corrections to the coupling of the antisymmetric tensor field and the Chern-Simons terms in string theory, and the results have been published in Physical Review D.)

Earlier investigators have claimed that one-loop corrections to gauge coupling constant function $f = 1/g^2 + \Theta/8\pi^2$ in supersymmetric gauge theories are non-holomorphic because of infrared divergence. We have investigated both one-loop and two-loop corrections with an emphasis on the dependence of corrections on the mass matrix. We find that the holomorphic property of f very much depends on the allowed representations of the mass matrix subje to the constraint of gauge invariance. We have three distinct cases depending on the property of the mass matrix: (i) massive mass matrix which has all eigenvalues nonzero; (ii) pseudo massive mass matrix which can have zero eigenvalues but still could be used as an infrared regulator without violating gauge invariance and (iii) intrinsically massless mass matrix which has zero eigenvalues and cannot be used as an infrared regulator. We have shown that at one- and two-loop levels both massive and pseudo-massive cases yield holomorphic f, whereas the intinsically massless case gives non-holomorphic f. These results form the thesis of Hesheng Li, and we are preparing manuscripts for publication.

Even though the above results are shown to be true at one- and two-loop levels, it is likely they are true at higher loops also. We are at present investigating the possibilty of showing the validity of these results to all loops using Slavnov-Taylor identities.

1. H. S. Li and K. T. Mahanthappa, "One-loop Threshold Correction to the Coupling of Antisymmetric Tensor Field and the Chern-Simons Term in String Theory", Phys. Rev. D46, 3663 (1992).

Induced Gauge Fields from Grassmannian This work is being done in collaboration with postdoctoral research associate Dr. S. Balakrishna.

It is well known that CP^1 models have a U(1)-gauge field in their excitations. But what is not so well known is that these models could be extended to Grassmannians (or Grasmann manifolds) wherein non-abelian gauge fields arise as excitations. Field theories based on these extensions naturally lead to extentions of nonlinear sigma models; the gauge fields are essentially composites of scalar fields. Such induced gauge theories are worth studying from two points of view: (i) they could be candidates for a more fundamental theory and (ii) they could provide a solution for symmetry breaking which leads to massive gauge bosons. At present we are pursuing the latter aspect. There are many phases in such a model wherein there are both massless and massive gauge fields. We are trying to understand the nature of symmetry breaking in these phases. Renormalizability of such a class of models is another aspect we are interested in exploring.

1.4 Spin Models and Dynamically Triangulated Random Surfaces (C. Baillie)

Over the past year I have been working on the three topics outlined below.

Dynamically Triangulated Random Surfaces with Novel Actions

There has been considerable recent interest in the theory and simulation of random surfaces, inspired both by string theory and the study of membranes in solid state physics. The Polyakov partition function for a string embedded in euclidean space with a fixed intrinsic area worldsheet discretizes to

$$Z = \sum_{T} \int \prod_{i=1}^{N-1} dX_i^{\mu} \exp(-S_g), \tag{1.1}$$

where $\sum_T$ is a sum over different triangulations of the worldsheet with the same number of nodes N which is the discrete analog of the path integration over the intrinsic metric in the continuum. The discretized action, S_g, is just a simple Gaussian

$$S_g = \frac{1}{2} \sum_{<ij>} (X_i^{\mu} - X_j^{\mu})^2, \tag{1.2}$$

where the variables X_i live on the nodes of the triangulation and the sum $< ij >$ runs over its edges. To a solid state physicist this would be the action for a fluid (because of the sum over triangulations) membrane with Gaussian interactions and no self-avoidance. The difficulties encountered in analytical calculations for string theories in physical dimensions are mirrored in simulations of Eqn. ((1.1)) which generate very crumpled surfaces from which it is impossible to take a continuum limit.

The addition of an extrinsic curvature term, or "stiffness", to the Gaussian action which originally arose in the context of biological membranes and QCD has been mooted as a possible resolution of these problems. One discretization of this has shown particular promise,

$$S_e = \sum_{\Delta_i, \Delta_j} (1 - n_i \cdot n_j), \tag{1.3}$$

where the normals n_i, n_j are on adjacent triangles Δ_i, Δ_j. The strategy is to examine the phase structure of the Gaussian plus extrinsic curvature action $S_g + \lambda S_e$ (henceforward GPEC) as the coupling λ is varied to see if any continuous transitions are present at which one might define a non-trivial continuum theory. The case of fixed, or "tethered", surfaces where there is no sum over triangulations offers some hope because there does appear to be a second order transition between a low λ crumpled phase and a large λ smooth phase. Initial work on dynamical surfaces with modestly sized meshes tended to support a similar picture, with a peak in the specific heat that grew with mesh size. More recent simulations with higher statistics and larger meshes have cast doubt on this because the increase in the peak height tails off with increasing mesh size. This is not in itself worrying since it is possible that the string tension and mass gap may still scale in such a way as to give a non trivial continuum limit, even at a higher order transition.

This rather confused picture for GPEC actions naturally prompts the question of whether discrete models with more clearly cut phase transitions exist. Ambartzumian *et al* suggested that an action based on the modified Steiner functional might be a suitable alternative candidate as it possessed the nice geometrical property of being subdivision invariant as well as retaining a desirable stiffening effect on the surfaces. The action was

$$S_{steiner} = \frac{1}{2} \sum_{<ij>} |X_i^\mu - X_j^\mu| \theta(\alpha_{ij}), \tag{1.4}$$

where $\theta(\alpha_{ij}) = |\pi - \alpha_{ij}|$ and α_{ij} is the angle between the embedded neighbouring triangles with common link $< ij >$. We performed the first numerical simulation of this.

Later Durhuus and Jonsson observed that an action of this form ran into problems with the entropy of vertices in smooth configurations and failed to give a well-defined grand canonical partition function. Our *microcanonical* simulation of this action had shown that it produced smooth surfaces but in this case of course it is not clear how to obtain the continuum limit, where the problems would presumably resurface.

We had observed that varying the coupling λ in an action of the form

$$S_1 = \frac{1}{2} \sum_{<ij>} |X_i^\mu - X_j^\mu| + \lambda \sum_{<ij>} |X_i^\mu - X_j^\mu| \theta(\alpha_{ij}) \tag{1.5}$$

would allow one to employ the approach used in our earlier simulations of GPEC actions, namely hunting for continuous transitions at which to define the continuum theory. We chose the first, edge-length, term in S_1 because of its simplicity and similarity to the second Steiner term. Durhuus and Jonsson pointed out that a subdivision invariant action of the form

$$S_2 = \sum_{\Delta} |\Delta| + \lambda \sum_{<ij>} |X_i^\mu - X_j^\mu| \theta(\alpha_{ij}), \tag{1.6}$$

where $|\Delta|$ is the area of a triangle, might cure the entropy problems of $S_{steiner}$ by virtue of the first term being coercive enough to compete with the entropy of smooth surfaces. If we do not insist on subdivision invariance we could also envisage combining a Gaussian term with $S_{steiner}$

$$S_3 = \frac{1}{2} \sum_{<ij>} (X_i - X_j)^2 + \lambda \sum_{<ij>} |X_i^\mu - X_j^\mu| \theta(\alpha_{ij}). \tag{1.7}$$

Therefore we have also simulated the novel actions S_1, S_2, S_3.

Finally, we investigated a further possibility for a random surface action which, like the Steiner term, is a natural object to consider from a geometrical point of view. For a curve C embedded in three dimensions it was shown by Fenchel that

$$\frac{1}{\pi}\int_C |\kappa| ds \geq 2 \tag{1.8}$$

where κ is the curvature and the equality holds when C is a plane convex curve. For a surface M imbedded in three dimensions the Gauss-Bonnet theorem tells us that

$$\frac{1}{2\pi}\int_M K dS = \chi(M) \tag{1.9}$$

where K is now the Gaussian curvature of the surface and χ is the Euler characteristic. As this is a topological invariant it tells us nothing about the configuration of the surface. To get the equivalent of Fenchel's Eqn. ((1.8)) we take a modulus sign in Eqn. ((1.9)) and find

$$\frac{1}{2\pi}\int_M |K| dS \geq 4 - \chi(M) \tag{1.10}$$

with the equality holding when the surface is imbedded as a convex surface in three dimensional space. This term discretizes to

$$S_{tight} = \sum_i |2\pi - \sum_{j(i)} \phi_{ij}| \tag{1.11}$$

where the outer sum is over all the vertices of the triangulation and the inner sum is round the neighbors j of a node i. ϕ_{ij} is the angle subtended by the jth triangle at the ith vertex.

1. C. F. Baillie and D. A. Johnston, A Modified Steiner Functional String Action, Phys. Rev. **D45**, 3326 (1992)

2. C. F. Baillie, D. Espriu and D. A. Johnston, Steiner Variations on Random Surfaces, Submitted to Phys. Lett. **B** (1993)

3. C. F. Baillie and D. A. Johnston, Smooth Random Surfaces from Tight Immersions?, Submitted to Phys. Rev. D (1993)

Dynamically Triangulated Random Surfaces with Self-Avoidance Dynamically triangulated random surfaces provide convenient discretizations of bosonic strings that can be simulated numerically using Monte Carlo techniques. In addition they provide a simple model of a fluid membrane. This is because the varying triangulation means that there is no fixed reference frame, which is precisely what one would expect of a fluid where the molecules at two different points could interchange and still leave the membrane intact. However, in order to describe a realistic fluid membrane which does not pass through itself, or self-intersect, one must add some form of "self-avoidance" to the simulations. It turns out that there are two ways to do this - "weak" and "strong" - and we have simulated both. For the case of weak self-avoidance we found essentially no difference from the simulations without any self-avoidance. However, for strong self-avoidance the results were dramatic: the nature of the crumpling transition changes completely - the "crumpled phase" is actually larger than the "smooth phase" due to the fact that the surface becomes a branched polymer which is extended in one direction. We have completed this work by investigating the cross-over between weak and strong self-avoidance.

1. C. F. Baillie and D. A. Johnston, Crossover Between Weakly and Strongly Self-avoiding Random Surfaces, Phys. Lett. **B295**, 249 (1992)

Spin Models coupled to Quantum Gravity Simulations of dynamically triangulated random surface models of bosonic strings yield very crumpled surfaces unless an extrinsic curvature term is added. The reason for this is that the central charge of these models, $c = d$, the embedding dimension, is greater than 1. For $c \leq 1$ things are well-behaved and there are analytic expressions for quantities like critical exponents. An alternative way to cure the pathological nature of the surfaces is to put spin models on them. The result of this is in fact a simulation of matter coupled to quantum gravity in two dimensions. Following our investigations of Potts models, we looked at the XY model. In two-dimensions this displays a "Kosterlitz-Thouless" (KT) phase transition. We found that coupling it to quantum gravity gives results consistent with the persistence of this KT type phase transition.

1. C. F. Baillie and D. A. Johnston, The XY Model Coupled to Two - Dimensional Quantum Gravity, Phys. Lett. **B291**, 233 (1992)

1.5 RESEARCH OF P. MOHAPATRA

The Solar Neutrino Puzzle I have investigated the possibility of spin(-flavor) precession combined with short wavelength vacuum oscillation as a solution for the solar neutrino puzzle. A large frozen-in magnetic field inside the sun with a neutrino magnetic moment of the order of 10^{-10} Bohr magneton can completely depolarize the ν_{eL} resulting in a factor of half of the emitted number. With a short wavelength vacuum oscillation and maximal mixing, the number of ν_{eL}'s reaching the earth is reduced by another factor of half; this explains the Homestake chlorine experiment. The difference between the Homestake and the Kamiokande-II experiments can be attributed to the contribution to the Cherenkov radiation in the latter through the neutral current and electromagnetic interactions of the components which are inert in the former.

This in combination with MSW can explain the present exprimental data on solar neutrinos but with a different region of the parameter space than the regular MSW alone. In this scenario there is a larger region of parameter space allowed. There is a large strip of parameter space corresponding to adiabatic solution and no solution for large mixing angle region. The non-adiabatic region still remains as a solution but shifted and larger relative to the regular MSW.

1. Spin(-Flavor) Precession And Short Wavelength Vacuum Oscillation As A Solution For The Solar Neutrino Puzzle, Mod. Phys. Lett. A6, 3467, 1991,

Presented at the workshop on The Many Aspects of Neutrino Physics, Fermilab, Nov 14-17, 1991(unpublished); Presented at the Beyond the Standard Model III, June 22-24, 1992, Ottawa (to be published in the proceedings).

2. How unique are the MSW parameters?, submitted to Phys. Lett. B for publication.

Flavor tagging in Future Colliders: I have proposed a way to differentiate between various extra $U(1)$ models using flavor tagging in the decay modes $Z' \rightarrow q\bar{q}$ once the extra Z' is observed at future colliders in the lepton channel. A generalization of the R parameter, namely, one for charge 1/3 and one for charge 2/3 quark, gives a two parameter test for the various models. Flavor tagging eliminates the uncertainty because of extra fermions and can reduce the QCD background at SSC/LHC dramatically. For E_6 and $SO(10)$ based models the former is always 3. This seems to be a very good way to eliminate certain models.

Using Pythia5.6 I have been able to show that the flavor tagging and use of suitable cuts in the parameters can reduce the background to noise ratio from a number of the order of 10^5 to something like 8. That is in fact a tremendous improvement and is very useful not only in extra Z physics but also has far reaching implications at future hadron colliders for any kind of jet-jet events. In the SSC Physics Symposium at Madison this was very well received and is the main theme of the working group on "New Phenomena" of which I am an active participant. I plan to work in this general direction in the future.

1. Flavor Tagging as a Way of Differentiating Various Extra Z''s at Future Colliders, Presented at the Beyond the Standard Model III, June 22-24, 1992, Ottawa (to be published in the proceedings); To be published in Mod. Phys. Lett. A; Presented at the SSC Physics Symposium, Mar 29-31, 1993 Madison; To present at the Workshop on Physics and Experiments at Linear e^+e^- Colliders, Apr 26-30,1993, Waikoloa.

1.6 Research Activities of Doug MacIntyre

I have been studying discrete symmetries, and in particular, discrete gauge anomalies in string theory models. Discrete symmetries are vital to model building, and discrete gauge symmetries have some interesting and powerful features. In general, in string theory models, these discrete gauge symmetries are anomalous, but in all the string theory models checked to date, there is a mechanism that can cancel these anomalies. Whether or not it is always possible to cancel discrete gauge anomalies in all string theory models is a question I have been studying. If it is true, then this would indicate some new, deeper consistency in string theory. If there exists string theory models for which this is not the case, then the cancellability of discrete gauge anomalies may provide us with a criterion for selecting realistic models among the multitude of string theory models. I have searched through two types of models- orbifold compactifications of the heterotic string, and Type II models- and plan to check other types of models: Calabi-Yau and covariant lattice formulations in particular. In addition to searching through models, I plan to spend some time searching for proofs of the cancellability of these discrete gauge anomalies.

I also plan to begin working on the two-dimensional black hole and topics in quantum gravity, collaborating with Prof. de Alwis. The two-dimensional black hole has generated much excitment in the last two years. It has provided a simple model that has been used to study some difficult problems in four-dimensional black-hole physics, in particular the question of information loss in Hawking radiation. This issue has not yet been resolved and I plan to help continue this research.

1.7 RESEARCH OF S. BALAKRISHNA

Double scaling limit of scalar theories on the lattice   An important but highly nontrivial problem is to know what theories arise in the continuum from a lattice regularization. One does not know even for simple scalar models on the lattice what these theories are. In this work, a scalar model with a potential is studied on the lattice in a certain limit. The limit involved here is called double scaling that first arose in the context of matrix models. Here, a coupling in the model is taken to its critical value in a suitable way as a parameter N is taken to infinity. It is found that the model goes to the continuum in this limit for a class of critical behaviors labeled by an integer $m > 2$. The theory one reaches is that of a massless scalar with only a $m + 1$ point interaction, but in the presence of a constant source. It is of interest to see whether this method of going to the continuum limit is applicable to some other lattice models.

1. Double scaling limit of scalar theories on the lattice, preprint COLO-HEP/295, AZPH-TH/92-43, submitted for publication.

Difficulties in inducing a gauge theory at large N Recently, there was an attempt to induce large N QCD by V. Kazakov and A. Migdal. They constructed a lattice gauge model based on SU(N) involving an adjoint scalar in the absence of any kinetic term for the gauge variables. They hoped that the induced gauge theory obtained by integrating away the scalars may be nontrivial and may agree with QCD. They solved the model exactly at large N and claimed that to be the long-sought exact solution of large N QCD. Subsequently, various problems were discovered in this approach. In this work, it is found that the model can not be a solution of large N QCD, for it is trivial as an induced gauge theory at least in the strong coupling regime of interest. It remains to see whether there are any extensions of the model that are realistic.

1. Difficulties in inducing a gauge theory at large N, preprint COLO-HEP/303, AZPH-TH/93-01, submitted for publication.

Anomaly matching for the QCD string It is a long held belief that QCD has a string formulation. It is thus important to look for any common threads in the two pictures. Because of asymptotic freedom, this is easier to handle in the ultraviolet regime. We know that QCD stress tensor has a trace anomaly. Any string formulation if extendible to the ultraviolet regime is required to exhibit this anomaly. In this work, it is found that the well known trace anomaly of the string is related to this anomaly. It is further found that the two anomalies agree both in magnitude and sign for pure SU(2) QCD. The agreement in sign is a pleasant surprise since the QCD trace anomaly is sensitive to asymptotic freedom. There are lots of things that need to be clarified in this field. The success for SU(2) suggests that a suitable extension of this approach might give agreement for the relevant case of SU(3) as well.

1. Anomaly matching for the QCD string, preprint COLO-HEP/313, AZPH-TH/93-10, submitted for publication.

2. TASK T

2.1 Theoretical Advanced Study Institute (TASI) in Elementary Particle Physics-Task T

K. T. Mahanthappa of the University of Colorado at Boulder, and Stuart Raby and Terrence Walker of the Ohio State University are the co-directors of TASI-93 (June 7 - July 2, 1993). There will be 60 students and 70 lectures by 17 lecturers plus theoretical and experimental seminars to be arranged. The theme of TASI-93 is "THE BUILDING BLOCKS OF CREATION - from Microfermis to Megaparsecs". Particle physics with emphasis on energies in TeV range and astroparticle physics are being covered.

A list of names of the lecturers and topics is given below. The lecture notes will be published by the World Scientific in the early winter of 1994.

COURSE TITLES AND LECTURERS

Particle Physics

- Standard Model (SM) - W. Marciano (Brookhaven National Lab)
- Effective Field Theory in SM - A. Cohen (Boston University)
- Quark Masses and Mixing Angles - J. F. Donoghue (University of Massachusetts) and M. Neubert (SLAC)
- Theories of Fermion Masses - L. Hall (Berkeley)
- Introduction to SUSY - D.R.T. Jones (Liverpool)
- Minimal SUSY SM and GUTs - P. Nilles (Munich)
- Technicolor and Extended Technicolor - K. Lane (Boston University)
- Lattice Gauge Theory - P. Lepage (Cornell)

Astroparticle Physics:

- Standard Cosmological Model - J. A. Freiman (FNAL)
- Phase Transitions in the Early Universe - N. Turok (Imperial College and Princeton)
- Galaxy Formation/LSS - R. J. Scherrer (OSU)
- Theory of Neutrino Oscillations - S. P. Rosen (UT, Arlington)
- Big Bang Nucleosyntesis: Theory/Abundances, - D. N. Schramm (Chicago)
- Observational Cosmology - R. Kirshner (Harvard)
- Underground Detectors - Beier (Univ. of Pennsylvania)

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3. T. DeGrand and M. W. Hecht, Wave functions and their use in spectroscopy and phenomenology, to appear in the proceedings of Lattice '92.

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15. S. P. de Alwis, Black Hole Physics and Liouville Theory, Phys. Lett.**B300** (1993) 330.

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25. S. Balakrishna, Difficulties in inducing a gauge theory at large N, preprint COLO-HEP/303, AZPH-TH/93-01, submitted for publication.

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