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ANTHONY R BARKER, JOHN P. CUMALAT, SENARATH P. DE ALWIS,
THOMAS A. DEGRAND, WILLIAM T. FORD*, K. T. MAHANTHAPPA,
URIEL NAUENBERG*, PATRICIA RANKIN, AND JAMES G. SMITH

*Department of Physics, University of Colorado
Boulder, Colorado 80309,0390*

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MASTER

* Principal Investigator

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

Experimental Group I

*Gregory Baranko, Anthony Barker, Bruce Broomer, Eric Erdos,
David Fillmore, Mariano Goluboff, Charles Griffis, Joshua Howie,
Nety Krishna, Peter Mikelsons, Eric Phipps, Uriel Nauenberg
Jin-Yuan Wu, Philip Zercher*

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1. OVERVIEW

TASK A1 PROJECTS

Here we describe the research activities in task A1; these are the Fermilab Kaon Program (E799 and KTeV), the SLD program, the finalization of the detector development program associated with the SSC, the B-Factory, and the NLC Study Group. We also present briefly all our responsibilities as members of the High Energy Physics community.

The KTeV Program. 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 $K_L \rightarrow \pi^0 e^+ e^-$. 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. Among the nine papers published to date by the E-799 group are two reporting the best current limits on the decays $K_L \rightarrow \pi^0 e^+ e^-$ and $K_L \rightarrow \pi^0 \mu^+ \mu^-$, both of which are expected to have significant CP-violating amplitudes. Prof. Barker and Eric Phipps, a Colorado undergraduate, are working on the extraction of a branching ratio for the rare decay $K_L \rightarrow \pi^+ \pi^- e^+ e^-$ from the E799 data.

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 built. 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, more accurate 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 April 1996.

The KTeV Collaboration consists of ten institutions, including the University of Colorado at Boulder. The lead person on this effort at Boulder is Prof. Anthony Barker; he is joined in the KTeV project by Prof. Uriel Nauenberg. In addition, Dr.

Jin-Yuan Wu joined the group in January 1995 as a postdoctoral Research Associate. Two Colorado graduate students, Peter Mikelsons and David Fillmore, have chosen to do their thesis research on the KTeV experiments, and four undergraduate students, Charles Griffis, Joshua Howie, Eric Phipps, and Philip Zercher are also participating in the ongoing detector design and construction efforts. Bruce Broomer, our electrical engineer, is working primarily on KTeV electronics design, and Eric Erdos is helping to coordinate the KTeV detector assembly work underway in Boulder.

The Colorado group has important responsibilities in the construction of the KTeV apparatus, which are discussed in detail below. We have designed and will have finished by this summer the construction of a system of four large lead/scintillator calorimeters which will be used to detect photons that miss KTeV's primary electromagnetic calorimeter. Events with undetected photons were an important source of background in previous kaon experiments at Fermilab, and these new detectors will minimize such backgrounds in both KTeV experiments. Most of the calorimeter modules are now assembled, and some early test results are discussed below.

We also have major responsibilities for the design and operation of the KTeV trigger systems. The Colorado group designed the fast trigger logic for KTeV (trigger levels 0 and 1), and will work with the University of Chicago on the assembly and testing of the fast trigger starting this summer. We are also working on the design of a specialized trigger processor which will be an important component of KTeV's level 2 trigger. This processor is designed to identify and count "in-time" charged tracks within about one microsecond. The KTeV section of this proposal includes a discussion of the aims of the experiment and the resources which are necessary in order for Colorado to successfully discharge these responsibilities.

The SLD Program. The SLD program is now engaged in a major four year run to collect 500 K or more Z's with electrons having approximately an 80% longitudinal polarization at the interaction point. We have just terminated a long run in which we collected upwards of 100 K Z's with an 80% electron longitudinal

polarization. This good data sample will produce excellent physics results. The measurement of the left-right asymmetry will lead to the most accurate single measurement of $\sin^2\theta_w$ to date (± 0.0005). As discussed below, we already have obtained a result, using the 1993 data, with an error of ± 0.0009 . In addition, because of the large longitudinal polarization we will get excellent measurements of the polarized forward backward asymmetries which will lead to quite accurate values of A_f for the b and c flavors. We have obtained such results with the 1993 data using exclusive channels.

A new vertex detector will be installed this fall. This state of the art detector coupled with statistics of 500 K or more Z's, the high longitudinal polarization, and the use of micron size beams will allow us to carry out unique measurements in the b sector. For example, it will allow us to carry out a unique measurement of B_s mixing that should determine one of the legs of the now famous CP triangle in the b-quark sector. In addition, the large forward-backward asymmetry of b-quarks due to the longitudinal polarization will provide a clear signal for the direction of the quark versus the anti-quark, enhancing the efficiency of our mixing measurement. All these measurements are leading to stringent comparisons with the LEP results. In addition, we have carried out a measurement of the $Z^0 \rightarrow b\bar{b}$ branching fraction, and various QCD measurements which are sensitive to the electron longitudinal polarization.

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 50K polarized Z's with an average polarization of 62%. This year the polarization has improved with the use of upgraded strained Gallium Arsenide sources which has provided longitudinal electron polarizations of $\approx 80\%$ at the interaction point. In addition the machine luminosity has improved markedly; SLC has already achieved maximum luminosities of 70 Z's/hour and average luminosities of 35-45 Z's/hour. Areas of improvements are the reduction of the beam jitter which has now been observed because of the reduction of the beam sizes to the sub-micron level in the

y direction. Such improvements have already occurred. Beam studies attempting to increase the luminosity at the interaction point took place during the last week of the 1995 run. These studies are being examined now.

Two of our students have finished their data analysis and presented their results at conferences. They have received their degrees. Jan Lauber was a CERN fellow and is now a member of the Oxford group at CERN and Cheng Gang Fan will receive a masters in computer science this spring and will become a member of our industrial force. We are actively recruiting new students to work in the future data analysis.

Our major analysis effort, led by Gregory Baranko, is now being prepared for publication. We have uncovered a technique by which we can measure directly A_e^2 directly using the full hadronic sample without needing to know the value of the longitudinal polarization. This is a very powerful technique since most systematic errors inherent in this type of measurement cancel out. Therefore, in the limit of large statistics this can lead to a very accurate measurement of $\sin^2\theta_w$. The details of this measurement are included as an Appendix. This analysis will continue as more data is collected.

Detector Development Activities. We are terminating our detector development activities associated with the SSC. We are assembling a full wave rectified Cockroft Walton photomultiplier base with an amplifier discriminator system attached in order to test our design. We have done a first order design of the trigger card for the muon system that was supposed to be associated with the GEM detector and is now part of the ATLAS detector. This was done in collaboration with the Brookhaven group. This effort will terminate this summer. We are beginning to consider the development of cathode strip chambers to be used for tracking in the forward and backward directions of a typical linear electron collider detector. Because of their high segmentation we expect that these chambers should have high tracking efficiency in the presence of high backgrounds. Such devices could be the appropriate choice for the NLC type detectors. A drawback, because of the

high segmentation possibilities, is the large number of electronic components.

The B-Factory. The BaBar/B Factory is the next logical step in our study of CP violation. It will allow us to examine the phenomena of CP violation in the b-quark sector. We will measure the magnitude of the sides of the CP triangle in the b sector of the CKM matrix.

We have joined the trigger, data acquisition group of the Babar detector, in particular associated with the calorimeter effort. We plan to contribute to the design of the electronics associated with this part of the detector. In addition we have proposed to be a site for the assembly of the Cesium Iodide (CSI) calorimeter crystal modules. This summer a member of our group will be at SLAC participating in the software development of the calorimeter aspects of the BaBar detector. In particular, we will be participating in the development of the calorimeter description using the GEANT simulation package.

The NLC Project. A group of us at SLAC have begun a task force to study the physics to be learned from the NLC and the detector design in view of the associated backgrounds surrounding it. This effort has just started and we describe the status of this program below.

Other Efforts. Our group has contributed greatly to the community: Uriel Nauenberg is the chairman of the SLAC Users Organization. He was a DOE consultant for the 1994 Brookhaven Annual Review and has done so again in 1995. He is on the Advisory Board and the Physics Committee of the SLD collaboration. He served for the second year as the chairman of the Nominating Committee for Members of the Executive Board of the Division of Particles and Fields. He was a member of the Local Program Committee for the 1994 DPF meeting in Albuquerque. He received a Faculty Fellowship for the 1994-1995 Academic Year, which will allow him to fully dedicate himself to research. He gave a colloquium at the University of Colorado on the SLD results, as well as an invited talk at the 1995 Aspen Winter Physics Conference, and another at the Italian National Laboratory in Frascati.

Anthony Barker received a Sloan Research Fellowship in 1993 which will end this September. In addition, he received a Young Investigator award from the National Science Foundation which began in the fall of 1994. He delivered a presentation on the kaon physics program at Fermilab for the 1994 Fermilab Users' Meeting, and gave a colloquium on the KTeV Project at Colorado State University. He is the Trigger System Manager for the KTeV Project, coordinating trigger design and development efforts underway at a number of collaborating institutions. He also represents the University of Colorado on the KTeV Collaboration Council.

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

Gregory Baranko, Cheng Gang Fan, Mariano Goluboff, Nety Krishna, Uriel Nauenberg; in collaboration with members of the SLD group.

The SLD detector is now embarking in an exciting major new four year run which will attempt to collect upwards of 500K Z 's produced in e^+e^- annihilations with an 80% longitudinally polarized electron beam and with an improved, larger, and more efficient vertex detector. This sample of data will allow us to carry out the most accurate single measurement of $\sin^2\theta_w$ and other measurements that likely can only be done at SLAC with the SLC/SLD equipment. This is due to the special properties of the SLC beams; namely the large longitudinal electron polarization and the micron-like beam size in conjunction with the unique vertex measuring elements of the SLD detector.

The measurements that will be obtained with this data when placed together with the final results from LEP will provide a very stringent test of the overall consistency of the Electroweak Model. Already with the present data, as described below, the tests show agreement with the Standard Model at the sub 1% level.

We describe below the improvements that have been carried out to the SLC and improvements that have occurred and are being planned for the SLD. We discuss the present status of the physics results and the prospects for the future; we describe what analysis the Colorado group has and is contributing to and where it plans to contribute in the future physics analysis activities. We also discuss our detector maintenance and improvement activities as part of our responsibilities.

2.1) Improvements to the SLC, The Electron Polarization, and the SLD.

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 has just finished its third physics run. In the run that just terminated we have collected over 100K Z 's with an electron longitudinal polarization of $\approx 80\%$. We ran at peak luminosities of 70 Z 's/hour and averages more like 35-45 Z 's/hour. This is a marked improvement over our 1993 run where the polarization

was 63% and the average luminosity was $\approx 20\text{-}25$ Z's/hour. We do not expect further improvements in the polarization but we need further improvements in the luminosity ($\times 2$) if we are to reach our goals of 500K Z's given the proposed running schedule of 22 weeks per year for the next 3 years. The SLC accelerator group is investigating the emittance growth problems which have hampered the needed luminosity levels. As mentioned in the introduction some of the effects inducing beam jitter have been controlled but more has to be accomplished. The new cooling ring vacuum jacket did remove the major beam instability, but another, smaller one, appeared. This new instability does not have a major effect on the beam running conditions. The improvements in the final focus to remove aberrations have been carried out and beam spots are as expected. Even with all these improvements another factor of two is needed before we reach the necessary luminosity levels.

The major improvement in the polarization are the result of the discovery that a mechanically strained Gallium Arsenide source can in principle emit electrons with almost 100% longitudinal polarization. This has led to the present polarization of 80% at the interaction point. This level of polarization probably can not be improved on very much.

All detector elements are operational. We are still improving their signal characteristics and only a few are still being debugged. The major new development in the present version of the SLD detector is the improvement in the particle ID (CRID) software to the point where we can now do particle identification. Analysis of the data with this particle ID included has been shown to be very powerful in b physics. It will lead to more accurate asymmetry measurements and will lead to substantial improvements in all sorts of physics measurements involving the b quark sector. The agreement between the data and the Montecarlo in the spectrum of particles whose particle ID has been determined is quite good.

The SLD detector will install this fall a new, larger, vertex detector to improve our vertexing capabilities. This device is being built and should be ready for installation this fall. This improvement, added to our improved particle ID capabilities

will greatly enhance our b physics capabilities specially in our B_d and B_s mixing studies.

There is now an SLD wide group developing the software to bring up the forward tracking system. We have made some improvements in the software recently to increase our track reconstruction efficiency and developed a global track fit that associates the tracks found in each drift chamber with the interaction point. We expect the forward system software to be operational by the time the next run starts.

2.2) The SLD Physics Analysis Effort. The study of Z^0 decays concentrates on the determination of the basic parameters of the Standard Model and their implication on the top and Higgs masses as determined from the radiative corrections to the minimal 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 (80%), the small size of the beam ($0.7 \mu\text{m}$ in y by $2.5 \mu\text{m}$ in x in the 1994-1995 run), and the unique 3-D vertex detector. As a result of these, some of the measurements that can be carried out with the SLC/SLD likely will result in highly accurate determinations of the parameters of the Standard model. We have already carried out a very accurate measurement of the Glashow-Weinberg angle by means of a measurement of the left right asymmetry. The new result based on the latest 100 K run will be announced this summer. 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 their direction of motion. The results from the 1993 run have already been published.^[2]

At present there is a 2.3σ discrepancy between the LEP and our results on the value of $\sin^2\theta_w$. Whether this discrepancy is real or only a statistical fluctuation will be clarified when we finish the analysis of our data collected in our present run. Because of our higher polarization and increased number of events, we will

have a much smaller error leading to a clear statement of whether we agree with the average of the LEP results or not. The present results have implications on the top quark mass determined from radiative corrections of the minimal electroweak model. The SLD predicted mass is 245 GeV about 2σ from the CDF/D0 results.

The final error in the left-right asymmetry is given by:

$$\delta A_{LR} = \{A_{LR}^2(\delta P/P)^2 + \frac{1}{P^2} \frac{[1 - (PA_{LR})^2]}{N_z}\}^{1/2}$$

For the present run we carried out a series of improvements in the Compton measurements that determine the value of the electron polarization at the target. The aim of these improvements is to reduce the contribution to the uncertainty due to the polarization measurement error. These improvements consist of the installation of a higher rep. rate, stabilized YAG laser, a new upgraded light transport and light polarization measurement system, a refurbished scattered electron detector (Čerenkov Counter), and a linearity monitoring system. We have now reached a 1% error level in the determination of the electron longitudinal polarization. This is now small enough that it will not affect significantly the error in A_{LR} even when we reach our final aim of 500K Zs.

One of the characteristics of the A_{LR} measurements is that it is very sensitive to the value of $\sin^2\theta_w$. In fact the error in this fundamental electroweak parameter is given by

$$\delta \sin^2\theta_w = 1/7.86 \delta A_{LR}$$

In Fig. 1 we show the final expected error as a function of the observed number of Zs given the predicted 1994 error in the polarization measurement.

ERROR IN $\sin^2 \theta_w$ VERSUS NUMBER OF Zs

FIG. 1

The SLD collaboration has now analyzed the 1993 data and a large number of papers have been published. The bibliography, which is attached shows the breath of this work. The Colorado group has contributed to this data analysis. Gregory Baranko, a member of the Colorado group, has pointed out an unique way to measure the value of $\sin^2\theta_w$ without knowing the value of the electron longitudinal polarization and with many limiting systematic errors canceling out. It essentially depends on measuring both the unpolarized and polarization-enhanced, flavor inclusive, forward backward charge asymmetry and also use the measured difference in the Z^0 production rate for the different polarization states of the electron. The details of the measurement is presented as an appendix where we present the various preliminary results with the present sample of 70 K events (1992-1993 combined data) where the tracks were reconstructed by the drift chambers. Although the errors are still large, because of the statistical limitation of the present data, the technique will lead to an excellent determination using the 1994 sample of data because many systematics cancel out and the polarization measurement is not needed. This work will be one of the main future efforts of the Colorado group. As shown in the appendix, this work has led to the following preliminary value of $\sin^2\theta_w$:

$$\sin^2\theta_w = 0.2300 \pm 0.0028(stat.) \pm 0.0010(syst.)$$

Over the next four years the collaboration will continue to improve on the analysis carried out so far. We will carry out improved analyses in the b quark sector because of the improved particle ID and the improved vertex detector. We will have a major new effort in the study of particle mixing, specially in B_s mixing. The Colorado group is participating in the B-particle mixing and will also participate in the b quark asymmetries using particular exclusive decay channels to improve the b quark identification. Initial results using the 1993 data show that this is a powerful particle identification technique.

2.3) The End Cap Drift Chambers. The University of Colorado group built the End-Cap Drift Chambers and has the responsibility to keep them operational.

These were installed in 1990 and we have been debugging them with the associated electronics since that time. They are now fully operational and working well. Because of the large backgrounds in the forward and backward directions we have had difficulty with track reconstruction. The latest beam conditions and reduction in the amount of material in the forward and backward direction have led to a reduction in beam related backgrounds. As a result we are now reconstructing tracks. A group of SLD members have been brought together to improve the tracking with the aim of having an operational software package by the beginning of the next run. The Colorado group has generated the first order time to distance relation using cosmic rays. A spatial resolution of $125\ \mu\text{m}$ is observed. Cosmic ray resolutions are expected to be worse than for Z induced tracks because of the poorer trigger timing in the cosmic ray case. The reconstruction efficiency of the cosmic ray tracks is higher than 90%. We also have used these cosmic rays to determine the relative alignment of the inner and outer end-cap drift chambers. Our contribution to this effort will continue; our principal aim is to provide the drift time to distance calibration of the chambers.

2.4) Equipment Request. We now have an operational DEC-ALPHA VMS system in Colorado. We have used it extensively to do the analysis to determine $\sin^2\theta_w$ from the forward backward asymmetries discussed previously. We have also used it in our other effort to determine the time to distance relation for the end cap drift chambers. The disk storage capacity which we acquired in 1993, 5.8 GB, 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. Hence we are requesting funds to acquire an additional 8.5 GB of disk at the end of 1995. We are requesting funds for another ALPHA UNIX station so that we can carry out an analysis effort here in Colorado. The SLD analysis effort is being moved to the UNIX platform. This UNIX station will also be used in the study of the BaBar detector design with the GEANT Monte-carlo. The ALPHA VMS station will concentrate on running Montecarlo events.

As seen from the budget table the University is contributing matching funds for this effort. Our X-terminals have not kept up with our needs to do the analysis with our collaborators at SLAC. We would like to upgrade our X-terminals here and at SLAC to be compatible with those of our collaborators. We are requesting funds for 4 NCD X-Window terminals, 2 to remain here and two to be located at SLAC. These are to be used by the research associates and students. We are also requesting a postscript laser printer to be able to produce the overheads for presentation at meetings. We are also requesting the purchase of modems that will allow us to communicate directly with the ALPHA from our homes.

2.5) The Budget Justification. Our budget request remains as before. Prof. Nauenberg has ended his Fellowship year and will go back to teaching the regular 50% time.

We are requesting funds for the rest of the personnel that is already associated with SLD including two graduate students. Recent funding cuts has required that we reduce our student group by one. Because of the large data sample being generated by SLD, the particular analysis being carried out at Colorado, and our responsibilities in the maintenance of the end cap drift chambers, we would like to increase our group to the original level of two students.

We are requesting funds to maintain our computing systems. We have removed our dedicated phone line to SLAC because of funding constraints. Telenet communications with SLAC are very poor and this loss has made it quite difficult to do analysis with our collaborators. Nevertheless, we will continue to attempt to improve this avenue of communication.

Our travel funds request is the same as last year even though travel costs have increased due to the fact that our starting point is the new Denver International airport and gate fees are more expensive.

3. The KTeV Project: Studies of CP Violation

Anthony Barker, Bruce Broomer, Eric Erdos, David Fillmore, Peter Mikelsons, Uriel Nauenberg, Jin-Yuan Wu, with undergraduates Charles Griffis, Joshua Howie, Eric Phipps and Philip Zercher

3.1 Introduction

The University of Colorado joined the KTeV Collaboration when Anthony Barker joined the faculty, during the summer of 1992. At that time, Prof. Uriel Nauenberg also joined KTeV. The Colorado collaborators now include Profs. Barker and Nauenberg plus two graduate students, David Fillmore and Peter Mikelsons, and a new postdoctoral Research Associate, Dr. Jin-Yuan Wu. The undergraduates are contributing to the construction of various parts of the detector and to data analysis as described below.

The KTeV Project is a new fixed-target experiment at Fermilab. As the name suggests, KTeV will study the decays of neutral K mesons using the TeVatron beam. Two KTeV experiments are approved: E799 Phase II, a search for a variety of rare K_L decays with a single-event sensitivity goal of a few times 10^{-11} , and E832, a next-generation effort to measure, more accurately, the direct CP Violation parameter $\text{Re}(\epsilon'/\epsilon)$. Analysis effort in E799-II will be particularly focussed on those K_L decays with implications for CP Violation, including $K_L \rightarrow \pi^0 e^+ e^-$, $K_L \rightarrow \pi^0 \mu^+ \mu^-$, and $K_L \rightarrow \pi^0 \nu \bar{\nu}$. E832 plans to measure $\text{Re}(\epsilon'/\epsilon)$ to a combined statistical and systematic uncertainty of 1×10^{-4} , a factor six to seven smaller than the errors on the best current results.

KTeV requires a new Experimental Hall and an entirely new spectrometer. Upon joining the group, Colorado was given responsibility in two primary areas: Trigger Electronics and the Spectrometer Anti Calorimeters. Colorado will design, commission, and maintain much of the KTeV Trigger Logic. Some of the trigger

electronics will be purchased from commercial vendors like LeCroy, but other systems will use custom boards to be designed and tested at collaborating institutions. The Colorado group is working on the design of a system of special-purpose TDC's which will be used as part of KTeV's Level 2 Trigger. The Spectrometer Anti's are a set of four large lead/scintillator calorimeters which will cover areas outside the acceptance of KTeV's CsI Calorimeter. Their principal purpose will be to detect photons and charged particles that might otherwise have escaped the detector unnoticed. However, they are true calorimeters, 16 radiations lengths deep, and having coarse transverse segmentation. The Colorado group will be responsible for their calibration and operation during the data taking. Each of these projects is described in more detail below.

Before proceeding to a detailed discussion of the ongoing KTeV-related activities at Colorado, we first review the motivation for the study of CP Violation, which is the principal goal of both KTeV experiments.

3.2 Physics Motivation for the Study of CP Violation

The origin of CP Violation is one of the central questions in elementary particle physics. The striking fact that everything in the observable universe seems to be made of matter, and nothing of antimatter, is incontrovertible evidence for the critical role CP Violation played in the early universe: clearly an understanding of this phenomenon must be a fundamental goal of high-energy physics. The importance of CP Violation as a clue to new physics was demonstrated by the work of Kobayashi and Maskawa^[22] in the early 1970's: Their attempt to incorporate CP-Violating processes in what has become the Standard Model of Electroweak Interactions provided the first clue that a third generation of quarks and leptons might exist, since the Standard Model can explain CP Violation only if the unitary quark mixing matrix is 3×3 or larger.

While the Standard Model can explain the existence of CP Violation, it would be surprising if this first guess at its origin is the whole story. Theorists disagree about whether Standard Model CP Violation can be strong enough to explain the dominance of matter over antimatter in the universe.^[23] Extensions to the Standard Model (Left-Right Symmetric Theories,^[24] the Weinberg Model,^[25] and Supersymmetry,^[26] for example) often lead naturally to CP Violating effects. The challenge is to learn enough about CP Violation from experiments to be able to distinguish among the theories that might explain its origin.

Unfortunately, nearly 30 years of experimental work has so far identified only a single CP-Violating effect: the fact that the mass eigenstates K_S and K_L are mixtures of the CP-even K_1 and CP-odd K_2 , where:

$$|K_1\rangle \equiv \frac{1}{\sqrt{2}} (|K^0\rangle + |\bar{K}^0\rangle)$$

and

$$|K_2\rangle \equiv \frac{1}{\sqrt{2}} (|K^0\rangle - |\bar{K}^0\rangle).$$

All known CP-Violating phenomena, including the asymmetry in semileptonic K_L decays and interference in $K_{L,S} \rightarrow \pi\pi$ decays, can be understood as a consequence

of the single $\Delta S = 2$ matrix element responsible for this mixing. Indeed, so-called Superweak models^[27] posit that CP violation arises from a new interaction of strength G_F^2 , in which the fundamental coupling changes Strangeness by two units. If this is so, the mixing of different CP eigenstates in the K^0 mass matrix could well be the only observable manifestation of CP Violation. More generally, the range of models that can be adjusted to agree with measurements of a single amplitude is vast; so in order to make progress experimenters must measure other, independent manifestations of CP Violation.

The decay $K_L \rightarrow \pi\pi$ occurs primarily (or perhaps entirely) as a result of what is called *indirect* CP Violation. Recall that the mass eigenstate K_L is nearly identical to the CP-odd eigenstate K_2 , but has a small admixture of the CP-even state K_1 , where the amount of K_1 is parametrised by the CP-Violation parameter ϵ ($K_L = K_2 + \epsilon K_1$). Since K_1 is CP-even, it is allowed to decay to two pions. The admixture of K_1 in the K_L therefore results indirectly in the decay $K_L \rightarrow \pi\pi$.

The classic example of a second manifestation of CP Violation would be observation of the so-called *direct* CP-Violating decay $K_2 \rightarrow \pi\pi$. In contrast to the indirect case, direct CP Violation would result from a $\Delta S = 1$ amplitude coupling a K_2 directly to $\pi\pi$. The rate for such direct decays depends on a second CP Violation parameter, ϵ' . The mixture of $\pi^+\pi^-$ and $\pi^0\pi^0$ decays resulting from a direct CP-Violating amplitude will be different^[28] from that produced by indirect CP Violation. The indirect CP Violation charged-to-neutral ratio is just the ratio observed in K_S decays (since K_S is dominantly K_1), so the signature of direct CP Violation in $K \rightarrow \pi\pi$ would be a slight difference between the charged-to-neutral partial width ratio for the K_L and that for the K_S . The double ratio R of these partial widths is related simply to $\text{Re}(\epsilon'/\epsilon)$ by the equation

$$R \equiv \frac{\Gamma(K_L \rightarrow \pi^0\pi^0)/\Gamma(K_L \rightarrow \pi^+\pi^-)}{\Gamma(K_S \rightarrow \pi^0\pi^0)/\Gamma(K_S \rightarrow \pi^+\pi^-)} = 1 - 6 \text{Re}(\epsilon'/\epsilon).$$

In the Standard Model, one recent theoretical calculation^[29] of values for this “ratio of ratios” R yields values ranging from 0.994 to 1.001, depending on the top quark

mass and hadronic matrix elements as well as on V_{td} , the far off-diagonal CKM matrix element. In particular, a real CKM matrix necessarily predicts $\epsilon' = 0$ and $R = 1$ exactly.

Several efforts have been made to measure ϵ'/ϵ since the original discovery of CP Violation in 1964. The most recent are those of NA31 at CERN and E731 at Fermilab. NA31 collected data in 1986, 1988, and 1989. Their published 1986 result^[30] was $\text{Re}(\epsilon'/\epsilon) = (33 \pm 11) \times 10^{-4}$, the first significantly non-zero value measured for ϵ'/ϵ . They have since published^[31] the results of analysis on their 1988 and 1989 data, yielding an average measurement of $(23 \pm 7) \times 10^{-4}$. The Fermilab experiment, E731, has recently published^[32] the final result from data collected in 1987-88; they find $\text{Re}(\epsilon'/\epsilon) = (7.4 \pm 5.2 \pm 2.9) \times 10^{-4}$, only slightly more than one standard deviation above zero. So, although the statistical significance of the difference between the two results is only 1.7σ , the conclusions that have been drawn from the two numbers are quite different: NA31 claim that direct CP Violation has been shown to occur, and that theirs is the first measurement of a new CP Violation parameter; the FNAL group says the results are still inconclusive, and that the Superweak Model, which predicts $\epsilon' = 0$, is still viable.

The unsettled experimental situation can be cleared up in just one way: new experiments must be performed to measure $\text{Re}(\epsilon'/\epsilon)$ with improved precision. It is this that E832, one of the two KTeV experiments, proposes to do.

The other KTeV experiment is E799-II, the second part of a rare K_L decay search that was to be spread over two FNAL fixed-target runs. The apparatus needed for a rare K_L decay search shares many features with one designed for a measurement of ϵ'/ϵ , including good acceptance for events with final-state multiplicities as high as six (or even eight) particles, efficient identification of particles escaping the geometrical acceptance of the primary calorimeter to reduce backgrounds, and the ability to cope with a high-rate environment with minimal deadtime. It is therefore natural to combine a rare decay search with an ϵ'/ϵ measurement for purely practical reasons.

But the connections between CP Violation in $K_L \rightarrow \pi\pi$ decays and the rates of several rare K decays go much deeper than that. In the Standard Model, direct CP Violation arises largely as a consequence of so-called Penguin diagrams which describe an effective flavour-changing neutral current at second order in the Weak Interaction. Penguins lead to processes like $b \rightarrow s\gamma$ and $s \rightarrow dg$. The first of these processes, $b \rightarrow s\gamma$, is the dominant mechanism for the decay $B \rightarrow K^*\gamma$, which has recently been observed by the CLEO group.^[33] This is an example of an Electroweak Penguin, so-called because an electroweak quantum (in this case a photon) is radiated from the virtual t (or c or u) quark line in the loop.

When the top quark was thought to be lighter than the Z^0 , the dominant contribution to ϵ'/ϵ was believed to come from Strong Penguins, in which the up-type quark couples instead to a gluon — for example, the process $s \rightarrow dg$ mentioned above. This leads to fairly large predictions^[34] for the value of ϵ'/ϵ , which are inconsistent with current data. However, it turned out that for large m_t , the contributions of Electroweak Penguins are comparable to those of Strong Penguins and interfere destructively with them, making ϵ'/ϵ smaller (and harder to measure).

But there is a silver lining to this otherwise unfortunate phenomenon, namely that the same Electroweak Penguins that suppress ϵ'/ϵ in the Standard Model lead to interesting rare decays of the form $K_L \rightarrow \pi^0 l\bar{l}$. The lepton pair in the final state results from the internal conversion of a virtual photon or Z^0 radiated in the transition $s \rightarrow d\gamma^*$ or $s \rightarrow dZ^*$. These decays are otherwise highly suppressed, so that the direct CP-Violating contribution to the overall rate may be large (possibly greater than 50% of the amplitude). Indeed, in the case of the decay $K_L \rightarrow \pi^0 \nu\bar{\nu}$, the process must be due almost entirely to direct CP Violation if it occurs within the Standard Model.

A search for these rare K_L decays is thus actually *complementary* to a measurement of ϵ'/ϵ in $K_{L,S} \rightarrow \pi\pi$. As m_t increases and ϵ'/ϵ becomes smaller and harder to measure, the rate for the rare decays $K_L \rightarrow \pi^0 l\bar{l}$ rise approximately

quadratically with m_t ,^[35] making them easier to observe. Unfortunately the Standard Model predictions for these rare decays are so small that even with a large top quark mass, the expected branching ratios are below 10^{-10} for the $\pi^0 e^+ e^-$ and $\pi^0 \mu^+ \mu^-$ modes, and below 10^{-9} for $\pi^0 \nu \bar{\nu}$. Analysis of the modes with charged leptons is also complicated by contributions from CP-conserving amplitudes and from indirect CP Violation.

Rare decay searches must proceed by stages in order to gradually understand backgrounds and detector limitations. It is unlikely for searches to leap ahead in sensitivity by many orders of magnitude in a single run: incremental improvements are the rule. Results have been published^[36] from the first phase of E799; they report $B(K_L \rightarrow \pi^0 e^+ e^-) < 4.2 \times 10^{-9}$ and $B(K_L \rightarrow \pi^0 \mu^+ \mu^-) < 5.1 \times 10^{-9}$ at the 90% confidence level, so we are now perhaps two orders of magnitude away from the Standard Model region. The second KTeV experiment, E799-II, proposes to cover much of the remaining territory, reaching single-event sensitivities of a few times 10^{-11} for the $\pi^0 e^+ e^-$ and $\pi^0 \mu^+ \mu^-$ modes. At this level, background from radiative Dalitz decays, $K_L \rightarrow e^+ e^- \gamma \gamma$, will be a serious concern^[37]; the excellent energy resolution of the CsI calorimeter will help us to fight this background, because it will make the region of $\gamma \gamma$ invariant masses consistent with the decay $\pi^0 \rightarrow \gamma \gamma$ as narrow as possible.

In rare decay searches, there is always the exciting possibility of discovering an anomalously high rate for a rare mode, signaling the presence of new physics. This is of course the motivation for the searches for lepton-flavour-number-violating modes, particularly $K_L \rightarrow \mu^\pm e^\mp$ and $K^+ \rightarrow \pi^+ \mu^+ e^-$ that have been carried out, including the recent Brookhaven experiments E791^[38] and E777.^[39] At KTeV, we will be able to search for the related decay $K_L \rightarrow \pi^0 \mu^\pm e^\mp$, as well as for a wide variety of other decays. The general-purpose design and high typical acceptance of the KTeV apparatus is a key advantage here, since one never knows which mode will hold the surprise.

A bonus of E799-II is that the common decay $K_L \rightarrow \pi^0 \pi^0 \pi^0$ results in a

huge flux of π^0 mesons whose rare decays can be studied in parallel with those of the K_L . This has already been demonstrated in E799-I, where the first published result^[40] was a new measurement of the somewhat controversial decay $\pi^0 \rightarrow e^+e^-$:

$$BR(\pi^0 \rightarrow e^+e^-) = (7.6^{+3.9}_{-2.8} \pm 0.5) \times 10^{-8}.$$

This result agrees with theoretical predictions and with a contemporary measurement by Brookhaven E777^[41] using π^0 's produced in K^+ decays. It is consistent with the most stringent published upper limit,^[42] and does not support the anomalously large central values measured by two earlier experiments.^[43,44] The signal-to-background ratio in the statistics-limited E799 measurement was 8:1, a testimony to the promise of this technique for studying π^0 decays in E799-II.

3.3 Background and Overview of the KTeV Project

The KTeV collaboration currently includes ten institutions and about 60 physicists. Many of the participants were involved in previous generations of Kaon experiments at Fermilab, including E617, E731, E773, and E799-I. Anthony Barker, now at the University of Colorado at Boulder, was a collaborator on E731, E773, and E799-I when he was a McCormick Postdoctoral Fellow at the University of Chicago.

The KTeV Project includes modifications to the New Muon (NM) beamline at Fermilab, a new target and sweeping magnets, construction of a new Experimental Hall, and design, construction, and commissioning of a new detector. The new Experimental Hall is currently under construction, and will be ready for occupancy by KTeV at the end of July 1995. The current best estimate is that the next fixed-target run, in which the KTeV experiments will collect data, will begin in April 1996, and will last about 18 months, with at least 12 months of good data-taking time, to be divided between E799-II and E832.

Work has been underway for nearly four years on the detailed design and construction of the KTeV Detector. The design of the detector is similar in spirit to that of the detector for the previous e'/e experiment, E731. However, all elements of the detector and associated electronics will be new, with the exception of the drift chamber system, which will be reused but is undergoing extensive refurbishment at Rice University. The design of other elements of the detector, including the electromagnetic calorimeter, the analysis magnet, the photon veto system, and the particle identification system are based on previous experience and reflect evolutionary changes based on the group's extensive experience in doing kaon physics at TeVatron energies.

This section of our Proposal reviews the overall design of the KTeV Detector and the status of the Project as of April 1995. A more detailed description of the KTeV Project, including discussions of Physics Goals and Sensitivity and Beamline Design, as well as plans for the Detector, can be found in the KTeV Design

Report.^[45] It should be noted, however, that there have been a number of changes in the Detector design since the Design Report was submitted in January 1992.

The most costly element of the new detector will be a CsI electromagnetic calorimeter. This array of 3100 pure CsI crystals, each 27 radiation lengths long, will give us superb energy and position resolution. Equally important for the ϵ'/ϵ analysis, the radiation hardness and low light absorption of pure CsI compared to lead-glass (the calorimeter material used in E731) will allow drastic reductions in the systematic error on ϵ'/ϵ , which must be reduced by a factor of four from E731 if we are to achieve our goal of measuring $\text{Re}(\epsilon'/\epsilon)$ to a precision of 1×10^{-4} in E832.

Another important element of the new detector is the Photon Veto system. This is essentially a set of lead/scintillator sampling calorimeters that cover solid angles beyond the acceptance of the CsI Calorimeter. They serve to detect photons and charged particles that would otherwise escape the detector, thereby drastically reducing the background to $K_L \rightarrow \pi^0 \pi^0$ that arises from the much more common decay $K_L \rightarrow \pi^0 \pi^0 \pi^0$ as well as reducing a wide variety of backgrounds to various rare decay modes (the Photon Vetoes are particularly important in the search for $K_L \rightarrow \pi^0 \nu \bar{\nu}$).

There are to be altogether nine calorimeter stands in the Photon Veto System, which will be placed at approximately equal intervals along the vacuum decay region and the spectrometer. The first five of these detectors, called Ring Counters because of their circular outer perimeter, will be located within and supported by the large vacuum tank. These detectors are being designed and built at Fermilab. The last four Vetoes will surround the apertures of Drift Chambers 2, 3, and 4 as well as the CsI Calorimeter. These large, free-standing detectors will be called SA2, SA3, SA4, and CIA, respectively. They have been designed, and are currently being built by the University of Colorado group. We will also be responsible for the calibration and maintenance of these devices during the running of the experiments. All of the Photon Vetoes will be fully-functional lead/scintillator

calorimeters, which can be used either to veto events as part of the Level 1 Trigger (hence their name) or as calorimeters which will collect data that can be analysed offline.

A schematic of the KTeV Detector is shown in Figure 2. The four drift chambers are labelled *C1*, *C2*, *C3*, and *C4*. The Vacuum Vetoes are labelled RC6 through RC10. Note that the first five Vacuum Vetoes, RC1 through RC5, have been deleted from the Detector as an economy measure. Their principal purpose was to reduce background to the rare decay $K_L \rightarrow \pi^0 \nu \bar{\nu}$, and eliminating them will reduce our sensitivity to that decay by roughly a factor of two. The Spectrometer Anti Detectors are labelled SA2, SA3, SA4, and CsI Anti in Figure 2. They are just in front of the drift chambers and the CsI, and cover solid angles just beyond the apertures of those detectors.

Both E832 and E799-II require the greatest possible beam intensity. In the case of E832, this is necessary because the statistical error on ϵ'/ϵ must be limited to 7×10^{-5} , requiring approximately 50 times more $K \rightarrow \pi\pi$ events than were collected by E731 in a run of similar length. In rare decay searches like E799, the sensitivity is directly proportional to the number of K_L decays to which the detector is exposed, so the greater the intensity the better, as long as backgrounds can be controlled.

High intensity necessarily leads to high trigger rates and a large volume of data that must be acquired, processed, and stored. This makes the design of the Trigger and Data Acquisition systems for KTeV a critical issue. The Trigger will have multiple levels, each level making a decision which is in general slower but more sophisticated than that made at the previous level.

Level 0 is the name given to local logic applied to prompt signals produced by individual detectors. For example, a Photon Veto detector might have 32 modules, each with its own photomultiplier tube. Each of the 32 signals would be discriminated and the Level 0 logic would just form the OR of the 32 signals. The Level 1 Trigger is the logic that correlates prompt signals from various detectors.

KTeV Spectrometer

(PLAN VIEW)

ANALYSIS MAGNET

METERS
FIG. 2

It produces a new decision for every 19 ns RF bucket. One of the goals in the design of KTeV detectors is to ensure that activity in one bucket will always produce trigger signals for that bucket and that bucket only. To this end, we have selected the fastest suitable scintillator and phototubes, and we will use pulse-shaping and edge-detection circuitry where necessary.

The Colorado group is responsible for the overall design and operation of the Level 0, Level 1, and Level 2 Triggers. To reduce the amount of design and debugging effort necessary, it has been decided that the logic for the Level 0 and Level 1 Trigger, in which the logic to be performed is relatively simple, should be assembled from commercially available CAMAC and NIM modules. Prof. Barker and Peter Mikelsons, one of Colorado's KTeV Graduate Research Assistants, have written documents^[48] describing the detailed design of KTeV's Level 0 and Level 1 Triggers, as well as the Level 2 trigger control logic.

At Level 2, events selected by the Level 1 Trigger are subjected to further processing which is done by custom electronics. There will be two or three such processors. One is the Hardware Cluster Counter (HCC), a device which will determine how many separate energy clusters above a programmable threshold are present in the CsI Calorimeter. The University of Chicago is responsible for the HCC. The University of Chicago is also developing a system of Transition Radiation Detectors which will be used to improve e/π separation in KTeV analyses. Another Level 2 processor being designed by the University of Virginia's KTeV group will look for evidence of electrons in the TRD's so that we can select or veto events with electrons at the trigger level during E799-II data taking.

The last Level 2 processor looks at signals coming from the Drift Chamber system. Electronics developed for E773 searched for hit patterns characteristic of $K^0 \rightarrow \pi^+\pi^-$ events, using logical OR's of drift chamber wires covering swaths about 10 cm wide. In the rare decay experiment, E799, different logic was used to count the number of hits in each drift chamber plane; this allowed a cut to be made on the charged multiplicity as part of the Level 2 Trigger. These selection

criteria based on drift chamber activity become less effective as intensity increases, because chamber hits from tracks many RF buckets before or after the bucket in which the Level 1 Trigger was satisfied can count toward satisfying the trigger criterion. By definition, the "event of interest" occurs in the bucket in which the Level 1 Trigger fires, and we are interested only in particles in that bucket. As the probability of "out-of-time" tracks rises with intensity, the number of "accidental" triggers resulting from out-of-time hits not associated with the event of interest rises as well, and the rejection power of the charged Level 2 Trigger falls.

Since E832 and E799-II must run at the highest possible intensity, it was necessary to design an improved charged Level 2 Trigger in order to obtain adequate rejection power. We therefore plan to install a system of "Trigger TDC's", the purpose of which is to identify drift chamber hits left by out-of-time tracks by using timing information from two wires in complementary drift chamber planes. The complementary planes are adjacent planes in a single chamber, offset by half a cell width, which are used to resolve the left-right ambiguity. Only in-time hits will "count", and accidental triggers due to out-of-time tracks will be eliminated.

The new electronics are called TDC's because they measure the drift time for each hit in the Drift Chamber system using synchronous counters running at 625 MHz, corresponding to a least-significant-bit time of 1.6 ns. After a Common Stop signal is received, the pair of times measured for two complementary wires will address a memory-lookup table. The memory will have been loaded with all possible time-pairs that can correspond to hits produced by in-time tracks. If the time-pair presented falls within the allowed region, the signals will be allowed to pass on to the Level 2 logic that counts charged multiplicity and looks for hit patterns characteristic of $K^0 \rightarrow \pi^+\pi^-$ decays. If the time-pair does not fall in this region, the hits will be blocked and will not be able to contribute towards satisfying the Level 2 Trigger requirements. This system of Trigger TDC's will be fitted to Drift Chambers 1 and 2, and is currently being designed at the University of Colorado. We will also design simpler "hit-counting" electronics to look at signals from Chambers 3 and 4; these boards will count hits within a gate, but will

not attempt to make cuts dependent on hit timing.

Colorado is also responsible for the Global Level 2 Trigger logic, which will receive results from Level 1, coordinate the various Level 2 Processors, and distribute the necessary control signals to the front-end electronics and data acquisition system.

Events satisfying the requirements of the Level 2 Trigger will be read out by a fast, parallel Data Acquisition System utilising a memory-matrix scheme in which data flows in on perhaps four parallel readout paths to the matrix, and is then distributed along "orthogonal" paths to four computers. These computers will perform online reconstruction of the data, and will then impose additional software cuts before writing selected events to magnetic tape. This online filtering process is often referred to as the Level 3 Trigger.

We anticipate that the rate of Level 1 Triggers may be as high as 150 kHz. If deadtime is 33%, the Level 2 processors will receive 100 kHz of incoming events, and must reduce this to 10 kHz or less, since this is the maximum rate at which data can be transferred to the memory matrix. Of the 250,000 events per spill processed by the online computers at this rate, only about 25,000 will be selected for storage on magnetic tape for later offline analysis. Thus Level 2 and Level 3 must each provide about a factor of 10 reduction between input and output.

The total number of events recorded for E832 in 130,000 such spills would be over three billion, or about 30 terabytes of data. The Collaboration is currently considering how best to analyse this fairly formidable quantity of data offline. Much of the initial stage of processing will likely be done at Fermilab, either on the KTeV Data Acquisition processors, or on the lab's UNIX processor farm, or (most likely) on a combination of the two. However, the Colorado group is proposing to acquire a computer similar to those in the KTeV DAQ, and with this machine, we would plan to contribute to the first pass of data processing. Data summary tapes will be distributed to collaborating institutions for further analysis to take place on local workstations. It is essential that the Colorado group be prepared for the

heavy load of data analysis tasks that will face us when data begin to arrive here in 1996. In the meantime, considerable processing power will be needed to work on Monte Carlo simulations of the detector needed to get reconstruction and analysis software running.

For this purpose, we are requesting funding this year for a Silicon Graphics Challenge computer. This is the same computer that is being used for the KTeV Data Acquisition System, which will ensure that we can easily use the same code, libraries, and calibration files that will be used online. We initially plan to buy a Challenge with one R8000 processor. Later, we can add additional processors up to a maximum of six. The Colorado high energy theory group is active in the area of lattice gauge calculations, which also requires large amounts of computing power. The SGI Challenge is a "superscalar" machine, which is well-suited to the programs they use for lattice gauge calculations. We are therefore requesting this machine jointly with the theory group, and plan to share it with them.

If the current schedule holds, and E799-II and E832 collect data starting in early or mid-1996 and continuing through the end of 1997, analysis should be in full swing by late 1996. We tentatively plan to have a "fast-track" analysis of about 10% of the data in order to better understand the detector and to get a preliminary result fairly soon after the data are collected, perhaps by 1997. The final ϵ'/ϵ result will likely be one of the last to appear, because of the extensive systematic checks that are required in that analysis, but we hope that thorough planning of offline analysis code and procedures will allow us to report a value of $\text{Re}(\epsilon'/\epsilon)$ to a precision of 1×10^{-4} in 1998 or 1999.

3.4 KTeV Activities at the University of Colorado

In the previous section, Colorado's KTeV responsibilities were placed in the context of the overall KTeV Project. Here we discuss the actual activities underway in Boulder, paying particular attention to their relation to particular requests in the proposed budget.

Design work on the Spectrometer Anti (SA) System (the Photon Vetoes not in the vacuum vessel) has been underway since January 1993. Most of the detailed mechanical design work was done by our mechanical engineer, Gerhard Schultz, who retired at the end of April 1995. Both Profs. Barker and Nauenberg were also involved in conceptual design work for the SA's, with considerable effort having gone into documentation and preparation of specifications for bidding and vendor selection. A detailed discussion of the geometry and design of the Spectrometer Anti System has been written,^[46] and was submitted to the Fermilab PAC during a 1993 review of the KTeV Vacuum and Veto Systems. In total Colorado has received \$ 303,200 in equipment funding from Fermilab for the construction of the Spectrometer Anti's. However, the Memorandum of Understanding between Fermilab and the Colorado group specifies that costs of infrastructure and personnel must be paid out of our DOE grant.

Figure 3 shows the conceptual design for an SA detector. As was mentioned in the preceding section, there will be four detectors; the Figures here show SA3, the largest of the four and the one that is being built first. Each detector consists of a number of modules attached to a large (5 m $\times$ 5 m) frame, which rests on two supports bolted to the floor of the Experimental Hall. The stand is built from steel I-beams, and employs an "A-frame" design for stability. Because the SA's must be placed immediately in front of the drift chambers in order to detect photons that would otherwise be lost in the dead material of the chamber frames, the SA stands will also be used to support Drift Chambers 2, 3, and 4.

FIG. 3

FIG. 4

The arrangement of SA modules on the frame is shown in Figure 4 for SA3, which has 36 modules weighing up to approximately 700 pounds each. An important feature to note here is that the edges of the modules are beveled at an angle of approximately 13° with respect to the direction of the beams. This greatly complicates the design, since it makes all the layers of the lead/scintillator stack different; however, it ensures that no photon will be able to sneak down an inter-module crack in an SA detector. This is necessary in order to maintain uniformly high efficiency for photon detection over the entire active area of the SA.

Each module starts with an aluminum end plate that bolts onto aluminum front and back plates. Three precision-ground stainless steel dowel pins support the stack of absorber plates within the module housing; two smaller dowel pins support the scintillator panels. Each of the 32 violet scintillator panels is machined with grooves spaced at intervals of approximately 2.5 cm. Blue scintillating fibers placed in these grooves collect scintillation light and direct it to a two-inch Thorn-EMI photomultiplier tube mounted at end of the module. The total number of 1 mm fibers per tube will range from 230 to 460, depending on the width of the module.

The photomultiplier tube is mounted inside of a μ -metal magnetic shield, which is mounted in turn inside of a soft iron tube that provides additional magnetic shielding. The tube is attached to a circular aluminum flange bolted to the end of the module. Large 1-inch stainless steel bolts passing through this flange secure the module to the detector frame. An additional bolt at the back of the module serves to relieve stress on the end-plate bolts: this is particularly important for the left and right modules which will exert a large torque on the end-plate bolts due to their sideways orientation.

During the past year, we have ordered and received the materials needed for the assembly of the 124 SA modules. This includes 4,337 lead absorber plates in 237 different sizes, as well as 3,968 scintillator panels in 416 different designs. Lengths of scintillating fiber are inserted into grooves machined into the scintillator

panels, and the absorber plates and scintillator panels are then assembled into the aluminum module housing. The preparation of materials for, and assembly of, each module require about 20 man-hours of labour which has largely been supplied by undergraduate students employed by our group.

As of 1 May 1995, we have completed the assembly of 105 of the 124 SA modules, and we expect that all modules will be assembled by the end of June. We have been measuring the performance of the assembled modules using cosmic rays, and we are obtaining light yields of approximately 100 photoelectrons per minimum-ionizing particle at the phototubes. Figure 5 shows a histogram of the digitised pulse heights due to a minimum ionizing cosmic ray muon for one of the SA modules we have tested.

Our Instrument Maker, Eric Erdos, has designed a module installation fixture which is used to install the heavy assembled modules onto the detector frame. This fixture is basically a large, adjustable counterweight that bolts onto the front face of a module. The counterweight must be adjustable due to the variety of different module weights. We have recently begun using this fixture to install modules on the frames (some must be installed several meters off the ground), and it has worked very well. We are currently developing detailed plans for the installation and alignment of the SA detectors in the new Experimental Hall.

One of the Colorado graduate students, Peter Mikelsons, has worked together with Prof. Barker on the detailed design of the KTeV Level 0 and Level 1 trigger logic, including a timing analysis.^[48] The timing data is a critical input needed in the design of other parts of the KTeV detector, notably the CsI Total-Energy Trigger electronics being designed at UCSD. The Level 1 timing information is also needed in order to determine how long delay cables need to be for various systems. The fast trigger logic is currently being assembled at Fermilab according to our design. During the summer of 1995, Mikelsons will move to Fermilab, where he will work closely with the University of Chicago physicists now working on the staging of the fast trigger. Mikelsons will remain at Fermilab during the run, and will serve as a

trigger expert on call during data taking.

FIG. 5

During the past year, extensive work has been done on the design of Level 2 trigger processor electronics at Colorado. Two FASTBUS modules are being designed. One will be used to analyze data from drift chambers 3 and 4 (the more downstream chambers); it counts charged multiplicity within a timing window chosen to contain all "in-time" activity. This module will also be used as an essential component of another Level 2 trigger processor being designed at the University of Virginia, which will look at TRD data in order to identify electrons at the trigger level in E799-II.

The second, more complex module being designed at Colorado is a so-called Trigger TDC module that uses timing information to determine which chamber hits are from "in-time" tracks, and which are not. This is done by quickly digitising hit times for all hits in a broad time window. Each pair of hit times for two hits on adjacent wires in complementary chamber planes addresses a memory lookup table, which is loaded with a map of all the possible time-pairs corresponding to in-time tracks. The output of the memory lookup determines whether or not each hit "counts" toward the total charged multiplicity.

The electrical engineer at Colorado, Bruce Broomer, is working closely with Barker, Wu, and the two graduate students on the design of the Level 2 processor modules. The schematic design of the simpler modules is complete, and we are currently working on the physical layout. We plan to order this "Hit-Counting" module during the summer of 1995 and to deliver modules to Fermilab by the fall. The schematic design of the Trigger TDC module is still underway. In order to accommodate the number of parts required, the Trigger TDC module has had to be split into a Mother-Daughter board pair, with the high-speed timing circuits on the daughter board, and I/O and bus interface circuitry on the Mother board. We plan to complete this design and order the Trigger TDC boards during the summer of 1995 as well.

We have received a total of \$ 330,900 from Fermilab in equipment funding for the trigger electronics described here. As in the case of the SA funding, the

Memorandum of Understanding specifies that costs for infrastructure and personnel are to be paid from our DOE grant.

Installation of the KTeV detector, including the systems being designed at Colorado, will begin in the fall of 1995. We plan to have all our construction work and testing in Boulder completed by the end of 1995. The Spectrometer Anti detectors will be shipped to Fermilab as they are completed and reassembled in the new Experimental Hall. When installation at Fermilab begins in earnest, we plan to have at least two Colorado personnel present at the lab. This presence should continue through the run, since we will be responsible for assuring correct operation of the trigger systems we are designing. We are requesting funding for an additional postdoctoral Research Associate to work on KTeV, who would also be resident at the lab during the run, and who would be responsible for debugging and repairing Colorado's Level 2 processor electronics and the installation, calibration and maintenance of the SA's.

We currently expect that the KTeV run will extend to about the end of this three-year grant period. However, we hope to begin analysis of rare decay data before the end of data-taking, provided adequate computing resources are available at Fermilab to do the first-pass reconstruction. After data summary tapes are available, analysis will begin in Boulder. At present, we plan to concentrate our efforts on the rare decay experiment.

5. Detector Development Activities

Bruce Broomer, Mark Christoph, Eric Erdos, Uriel Nauenberg, Gerhard Schultz

As part of our SSC involvement we have been developing a full-wave rectified Cockroft-Walton photomultiplier tube base with an Amplifier-Discriminator module.

The standard photomultiplier base consists of resistors and Zener diodes which dissipate approximately 20 watts. An external high voltage must be applied to the base to achieve the inter-dynode voltages. This high voltage supply is expensive and the heat generated by the high wattage being dissipated in the resistor chain creates a fire hazard. These problems are solved by the development of this device. We have completed the construction of the unit in addition to an amplifier discriminator unit installed in the photomultiplier base. A report (CU-HEP-358) has been published and submitted to the SSC for final disposition.

We have designed the electronics for the muon trigger associated with cathode strip chambers. This design has not been implemented as yet with the necessary electronics chips since it was not part of the deliverables. The complete design was presented in a report (CU-HEP-359) that was submitted to the SSC.

We are beginning to consider a new design for tracking in the forward direction of detectors like the SLD detector or a future NLC detector. We are considering the use of cathode strip chambers which have been developed at Brookhaven National Laboratories for proton collider detectors. These chambers are highly segmented and should be able to operate more effectively in the background atmosphere that is prevalent in e^+e^- Linear Colliders like the SLC and the future higher energy Linear Colliders. The drawback is that these detectors provide more material in the path of these particles which leads to deterioration in the resolution and increase in the background due to photon conversions. One of our efforts this year will be to study how to reduce the amount of material present. We may want to construct a few simple chambers to determine their structural integrity as a function of material.

5. The B-Factory Program

Anthony Barker, Bruce Broomer, Eric Erdos, Mariano Goluboff, Uriel Nauenberg in addition to future post-doctoral research associates.

CP violation remains one of the unresolved phenomena in particle physics. It appears as one of the central issues in the development of the universe into matter instead of anti-matter. In the Standard Model CP violation appears in the Cabibbo-Kobayashi-Maskawa (CKM) matrix that describes the mixing of the quarks and their interactions. We have no evidence that this is the sole source of the observed CP violation. The standard model predicts large, measurable, CP violating processes in B^0 decays into CP eigenstates. The presence of CP violation in the CKM matrix is reflected in the unitarity triangle of the b sector. Observation of the magnitude of the legs of this triangle which imply that some of the CKM parameters must be complex are clear evidence for the presence of CP violating amplitudes in the CKM matrix. It is the purpose of the BaBar/B-Factory project to make these measurements.

We are participating in the activities of the electronics group, the software development group, and the calorimeter assembly activities. We expect that our electronics development activities will be associated with the calorimeter trigger and data acquisition. The exact areas where we will contribute still are not decided waiting for our English collaborators to define their contribution.

This summer we will have some members of our group at SLAC helping with the calorimeter software. Our main area of activities is planned to be in the development of the exact GEANT geometry description of the calorimeter section of the detector. This activity will then continue from Colorado during the Fall and continuing into next year. We propose to use our ALPHA UNIX being requested to continue the development of the software .

The construction of the calorimeter, meaning the assembly of the various pieces associated with the Cesium Iodide crystals, is now planned to take place at SLAC. We propose to have members of our group associated with this activity.

6. The NLC Activities.

Anthony Barker, Uriel Nauenberg in collaboration with the NLC Study Group

A group of experimentalists and theorists across the U.S. are beginning an effort in understanding the physics associated with e^+e^- annihilations at 0.5 to 1.5 TeV. This is the energy regime of the Next Linear Collider (NLC). Our aim is to understand this topic by the time of SNOMASS '96, a meeting of the High Energy Physics Community to understand what activities will take place during the next decade. We expect that this group in association with SLAC's Accelerator division will prepare a proposal within a few years.

With this aim in mind, we are hosting a 3 day workshop in Estes Park, Colorado, on June 21-23, 1995 . We expect to assemble a large group of physicists to begin to organize the physics studies to be carried out. Uriel Nauenberg, in collaboration with Bob Hollebeek and Steve Olsen, will lead the study associated with the search for Supersymmetric particles in the 100-300 GeV mass regime.

In Colorado we have installed in our VMS ALPHA the ISAJET Montecarlo programs that will study the relevant processes for the production of Supersymmetric particles. We have collaborated with Howard Baer from Florida State University in these activities. One of the aspects of linear colliders that is showing great promise in this study is the fact that the electrons are going to be highly linearly polarized. As a result of this fact it seems that the major background signals will be highly suppressed in this environment. Further studies into these production mechanisms will continue at Colorado during the next year. In this regard the requested ALPHA UNIX computer is necessary to develop and run the Montecarlo programs.

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APPENDIX

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