PROGRESS REPORT

November 1, 1991 to October 31, 1992

for

**EXPERIMENTAL PARTICLE PHYSICS AT THE
UNIVERSITY OF PITTSBURGH**

by

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April 1992

Prepared for

U. S. Department of Energy

Grant No. DE FG02 91ER40646

MASTER

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ABSTRACT

During the past year Task A completed the HELIOS single and pair electron analyses and found no anomalous production or multiplicity dependence. The HELIOS electron-muon pair analysis continued in its search for lepton physics beyond the expected charm yields. Data taking began at the CMD2 detector at Novosibirsk. Measurements of the U. V. reflectivity and photomultiplier tests for the first Cerenkov counter to be used in the E865 experiment at BNL were carried out, along with the development of a general ray-tracing code. The design of the Cerenkov counter for E865 along with development of light mirror fabrication techniques were a major part of the Task A program.

The principal efforts of Task B, the Fermilab program, have been the completion of the analysis of the 1987-88 data with resulting publications, completion of the 1990-91 data run, and the beginning of the analysis of the 1990-91 data. In addition, the Task B group is taking a leadership role in developing a proposal to Fermilab for the upgrade of the CDF silicon vertex detector in preparation for the 1995 data run. This proposal is to be presented to the laboratory management in time for the fall Fermilab Program Advisory Committee meeting.

Task C has recently submitted results of its fractionally charged particle searches, placing new upper limits on the abundance of naturally-occurring fractionally-charged particles in various materials. This group has recently been approved by the Brookhaven management for an exposure of their p-i-n diodes in a high intensity proton beam. This measurement, along with its subsequent analysis, will complete the program.

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1. INTRODUCTION

The experimental high energy physics program at the University of Pittsburgh was started in 1970. Before that time, the Department had been a strong research center in several areas of physics, the strongest experimental fields being atomic, atmospheric, and nuclear physics. In the late sixties the University was awarded an NSF Science Development Grant, of which \$1.4 million went to the Physics Department. This grant was used to carry out a departmental expansion plan, which included the founding of two new groups--astrophysics and experimental high energy physics--as well as the expansion of several existing research groups. Included in the faculty appointments made as a result of this expansion are all of the faculty involved in the present experimental high energy physics program: Cleland and Engels in 1970; Coon (hired as a particle theorist) in 1971; Thompson in 1972; and Shepard in 1974. The most recent appointment in this area has been T. Humanic, who joined the faculty in 1988.

We describe briefly here the past activities of the high energy physics group at the University of Pittsburgh before the establishment of our present DOE contract. In broad terms, our interests include hadronic physics, weak interactions, electromagnetic properties of hadrons, semiconductor device physics, and instrumentation. In addition to the work carried out in our laboratories at the University, we have carried out experiments at three major high energy physics laboratories: BNL, CERN, and FNAL.

Our first experiment, a study of the phase and amplitude for coherent K_S^0 regeneration in hydrogen and deuterium was carried out in an existing apparatus at the AGS which had been built to study CP-violation. The data were taken in 1970, and our results were published in 1975 [1]. This experiment was done in collaboration with the University of Massachusetts, McGill University, and Northwestern University, with spokesperson E. Engels of Pittsburgh.

Our next efforts were centered on the AGS hyperon beam, where we first joined the Yale-FNAL collaboration in Experiment 571 to study Y^* production for $-t < 0.03 \text{ (GeV/c)}^2$, the results of which were published in 1974 [2]. In a new experiment (Experiment 583, Pitt-UMass-BNL collaboration, spokesperson E. Engels), we studied the production of hyperon resonances for $-t < 1.0 \text{ (GeV/c)}^2$. Because good acceptance was essential, a large aperture double magnetic spectrometer was constructed, mostly with resources from the University of Pittsburgh. Production of the $\Sigma(1385P_{13})$ by incident Σ was observed for the first time, and production cross sections were obtained for several nuclear targets as well as hydrogen. An upper limit for the partial width for the U-spin violating decay $\Sigma(1385P_{13}) \rightarrow \Sigma + \gamma$ was obtained from these data as well. The results of this experiment were published in 1977 [3].

After the completion of the hyperon resonance experiment, the apparatus of Experiment 583 was modified with the addition of a gas Cerenkov counter in order to study the leptonic decays $\Sigma \rightarrow \Lambda e \nu$ and $\Xi \rightarrow \Lambda e \nu$ (Experiment 618, Pitt-BNL collaboration, spokesperson J. Thompson). An optical spark chamber was installed to permit detection of the decay $\Xi \rightarrow \Sigma^0 e \nu$. From two data runs carried out in 1974-76, we obtained samples of the Σ^- and Ξ^- beta decays into $\Lambda e \nu$, comparable to the previous total world samples. We measured the asymmetry parameter in the normal decay of the Ξ^- and set upper limits on the branching ratios for the decays $\Xi^- \rightarrow \Sigma^0 e \nu$ and $\Xi^- \rightarrow \Lambda^0 \mu \nu$. An initial paper reporting our main results was published in 1978 [4], and the final results of these experiments were published in the Physical Review in 1980 [5, 6].

Concurrently with the leptonic hyperon beam experiments, Shepard participated in an experiment at FNAL to measure the pion form factor through the scattering of high energy pions from atomic electrons. This experiment (E216, UCLA - Notre Dame - Pittsburgh - FNAL - Dubna collaboration, spokesperson D. Drickey, later D. Stork) represented a substantial improvement over an earlier experiment carried out at Serpukhov, an effort in which Shepard was also a collaborator. E216 ran in 1975 and the first results were published in November, 1977 [7, 8, 9]. Subsequently, an experiment to measure the kaon form factor through K-e scattering (E-456) was performed by modifying the apparatus. This experiment was run in 1976-77, and the results were published in 1980 [10].

In the fall of 1976, Cleland spent a sabbatical year at the University of Geneva, where he worked on an experiment at the SPS to study K^* production and related problems in hadronic physics. Data from this experiment were collected during 1977 and 1978. This experiment (Experiment WA10, Geneva-Lausanne-Pittsburgh-Durham collaboration, spokesperson M. Martin) led to the discovery of several new resonant states, some of which were anticipated (such as the $a_4(2040)$ and the $a_6(2450)$) [11, 12] and others which were not (high mass broad resonances decaying into Λp the $N\Lambda(2300)$ and the $N\Lambda(2500)$). [13, 14] A study of N^* decaying into ΛK [15] and a search for narrow resonances in the pp and πpp systems [16] was also carried out by this group in the same apparatus.

As a result of Cleland's experience with WA10 and Thompson's participation in several ISABELLE summer studies [17], they became interested in combining new optoelectronics technology with optical data processing ideas to test the feasibility of. Starting with a small ISABELLE development grant, then a DOE Instrumentation contract, this group developed a simple optical processor which was tested in June, 1982, in experiment 702 at BNL. Thompson, on sabbatical leave during 1980-81, had been previously

participating in this experiment. The experiment was intended to measure the asymmetry in the decay $\Sigma \rightarrow p + \gamma$, but due to inadequate K beam flux for the proposed measurement, instead studied π^0 production at small angles and asymmetries in the normal decays. The optical processor performed according to expectations, in particular showing no signs of difficulty at high rates. This test established the viability of an optical processor in a high energy physics experiment and indicated a number of possible improvements in concept, technique, and construction. These studies were published in 1983 [18, 19].

During the year 1976-77, a significant discovery was made at Pitt by Coon and his students. In experimental research with silicon p-i-n diodes at low temperatures, they found that charge could be stored in shallow localized states in semiconductors for an arbitrarily long time and that its presence could be detected in a very short time by quantum mechanical field ionization. The discovery of this "cryogenic charge storage" effect was first reported in 1978 [20, 21], and it led to further theoretical and experimental studies under an NSF supported research program on applications, such as infrared detectors. Cryogenic charge storage together with later work formed the basis for two efforts subsequently pursued by this group--the high sensitivity search for fractional charge particles (such as quarks) and the development of a high resolution cryogenic semiconductor particle detector.

Also in 1976-77, Engels, Shepard, and Thompson joined a collaboration to search for short-lived particles produced by neutrinos. This experiment (E553, Cornell-FNAL-Lund-Pittsburgh-York collaboration, spokesperson L. Hand, followed by E. Engels, W. Frisken and P. Shepard) relied upon the position resolution obtainable in nuclear emulsion to see the track topology indicative of the production and decay of charm particles. It required a novel technique to locate the position of the events in the emulsion in order to reduce the scanning time to a manageable level. The technique developed by this group involved a new type of spark chamber, one of whose electrodes was a gold film on a glass plate, mounted rigidly to the emulsion stack. The sparks produced by ionizing tracks evaporated small regions of the gold, and these "holes" were then used to trace back to vertices in the emulsion. This target was incorporated into a large apparatus containing a magnetic spectrometer and a flash tube calorimeter. During the first running period (1978-79) the apparatus was debugged and an initial set of data were taken. It became clear from this set of data that, in order to carry out a competitive measurement, the apparatus would need to be improved, which required an expansion of the collaboration. Although groups from Rome, Turin, and Brussels were added to the collaboration and the approval for a second

round was given by FNAL, one of the key collaborators lost his support for continued work on this experiment. This led to a reconsideration by all of the collaborators, the end result being that the experiment was discontinued.

The experience gained from E553 has been valuable. Our group's interest in high resolution semiconductor detectors is a direct outgrowth of the difficulties experienced in working with photographic emulsions. It stimulated the interest in using cryogenic charge storage in microstrip detectors as a way to reduce the large number of readout channels. This work, involving the concept of an electronic emulsion consisting of lightly doped silicon was a collaboration between Shepard, Engels, and Coon. Initial tests were made to detect radiation from a radioactive source with commercial diodes. Later, the diodes were tested in a 40 GeV/c pion beam at FNAL. These tests were successful, and the results were reported at two detector workshops (at FNAL and BNL) in 1981 [22, 23] and were the subject of an invited talk at the Nuclear Science Symposium held in San Francisco in October, 1981 [24].

A second use of cryogenic charge storage was pursued by Coon, who developed a sensitive novel optoelectronic, nonmechanical technique to search for fractional charge particles in semiconductors. This work had its origins in theoretical calculations of energy levels and field ionization rates for fractional charge impurities in semiconductors. These calculations were published by Coon and his coworkers in October 1980 [25]. The concept of hydrogenic levels associated with fractional charge impurities was introduced along with suggested means of detection. Ground state field ionization is capable of providing a sensitive experimental probe while infrared photoexcitation and field ionization of excited states provide a detailed spectroscopic signature.

Until 1982, the federal funding for our activities had been from a number of NSF grants, with the exception of the optical processor work, which was supported for two years under an instrumentation contract from DOE. In 1982 DOE agreed to support a multitask particle physics program, which began on June 1 of that year. The new initiatives undertaken in June 1982 were: (1) participation in R807/808 (Direct Photon Production at the ISR) at CERN, leading to participation in NA34/HELIOS (Lepton Production and Relativistic Heavy Ion Collisions), (2) participation in E706 (Direct Photon Production at the Tevatron) at FNAL, including the fabrication of both room temperature and cryogenic silicon strip detectors, and (3) a search for fractional charge particles in semiconductors. The optical processor work, having reached the point where a test instrument had been built and evaluated and the results published, was discontinued.

During the years 1984-1986 this group has requested funds from both the University Capital Fund Drive and the Ben Franklin Partnership Program of the State of Pennsylvania to equip a laboratory and carry out research in the area of semiconductor devices. More than \$200K has been invested in new equipment associated with the establishment of the Applied Technology Laboratory. Coon was manager of this laboratory and was also principal investigator on a Small Business Innovation Research contract for semiconductor detectors. These activities have contributed to making Pittsburgh into an active center for semiconductor detectors. The establishment of this laboratory and a strong semiconductor device program enhances our ability to carry out detector-related research relevant to DOE supported high energy physics research.

We state below the responsibilities of each of the tasks in our contract in broad terms. More detailed recent history of each of these efforts is given in their respective sections.

Task A started as support of the Pitt contingent of the Axial Field Spectrometer Collaboration, performing experiment R807/808 at CERN, which probed several topics related to high P_T phenomena [26, 27, 28]. A measurement of the e/π ratio at low p_T [29, 30], is the basis for the present understanding that the low p_T excess seen depends quadratically on multiplicity, indicating an origin in the intermediate stage of the collision.

Our own analysis contributions to R807/808 were primarily on those aspects involving photons in the final state, both at high p_t [31, 32, 33, 34, 35], and at low p_t , in different reactions (pp compared with $\alpha\alpha$) and in high E_T triggers [36, 37, 38]; and inclusive η production at low p_T [39].

Following from the developing interest in the low p_t photon physics, in 1984 Cleland and Thompson joined the HELIOS collaboration (NA34), to perform an experiment at the CERN SPS to study lepton production in p-Be collisions. The second phase of this experiment was a general study of relativistic heavy ion collisions. The Pitt group accepted responsibility for the organization of the triggering system early in the experiment as well as the development of the trigger for the electron spectrometer.

Results from the HELIOS/2 (heavy ion) mode show both that events with large transverse energy are seen, so that high energy densities may be studied in these collisions and that high multiplicities may be as successful as high transverse energy as a trigger for central collisions. This is important to learn since the high multiplicity trigger is generally simpler to implement than a trigger based on topological

considerations. Data with sulfur incident on a platinum active target was the thesis of our student M. Murray, who extended the transverse energy distributions about 50 GeV beyond data taken with the solid disk target [40], and studied fluctuations in E_t through the method of correlated moments, seeing a stronger correlation in peripheral data than in data at medium E_t (the plateau region).

An initial run on electron production was made in 1986, accumulating a sample of about 2000 final single electron candidates, and a small sample of about 100 e^+e^- pairs useful for checking for systematic uncertainties in the singles analysis. These data were thesis study of M. Clemen. A nearly final analysis [41] shows an excess of order a factor of two in some regions, for both singles and pairs, with systematic errors of order 25-30% for the singles and 40% for the pairs. The multiplicity dependence is consistent with a linear relationship to pion multiplicity, but does not rule out the quadratic effect seen by the AFS experiment [29, 30].

The final data-taking run for HELIOS/1 was in 1989. These data yield $\approx 13,000$ muon pairs and ≈ 2000 -3000 electron pairs in the low m_T region of interest. A limit on new physics with missing energy at $\approx 1/2$ the level of the charm cross section was also set. Pitt continued analysis of the electron pair data with investigation of data from a silver target taken in 1989, with the result that, to within a factor of two, the electron pair production from the silver target can be explained by the electron pair production from a Beryllium target -- i.e., no unusual effects for heavy targets. Another responsibility is the thesis project of Paula Pomianowski: the study of the $e-\mu$ pair data, and comparison of that sample to the ee and $\mu\mu$ data.

A continuing low level collaboration with the Institute of Nuclear Physics in Novosibirsk on their present electron collider at the energy of the Φ and their plans for a high luminosity Φ factory has grown out of Thompson's recent NAS exchange visit to Novosibirsk. A high luminosity Φ factory such as the one the Novosibirsk group plans (10^{33} /cm²/sec) would allow a measurement of ϵ'/ϵ of order $.2 \cdot 10^{-3}$, competitive with the large next generation experiments. Even with the luminosity of the collider now coming into operation, new limits can be put on K_S and Φ decays, as well as some studies of K_L decays important to the success of the larger Φ project.

An official agreement to collaborate has been signed by INP and the University of Pittsburgh. Present investigations at Pittsburgh focus on two projects: separation of $\pi/\mu/e$ by patterns of ionization deposit in the electromagnetic calorimeter planned for the Φ detector; and studies of analysis strategies for

separating the decay $\Phi \rightarrow \pi\pi\gamma$, important because of its link to the $K K \gamma$ decay mode, a potential background to the CP violation measurements.

The major new effort of Task A is E865 at BNL, a search for $K^+ \rightarrow \pi e \nu$, a lepton-family number violating decay which could only be facilitated by some mechanism beyond the standard model -- such as technicolor particles or a horizontal gauge boson. The Pittsburgh responsibilities in this experiment, together with the University of New Mexico, are the design, construction, testing and installation of the two Cerenkov counters for this experiment.

Task B is the Fermilab part of the high energy physics program. E706 is the study of direct photon production in πp and pp collisions at the Tevatron. This experiment was approved by the Fermilab directorate in 1981 and began its first data run in June of 1987. All components of the experiment were successfully commissioned by the end of the summer of 1987 and the experiment completed its first data run in February, 1988. The analysis of these data is nearly complete and two publications are about to be published in PRL and Phys. Rev. D, respectively. One student, D. Weerasundara, is writing his thesis on the analysis of the data from this run and is expected to finish his Ph.D. work sometime during the summer of 1992. The primary hardware responsibility of the Pitt group has consisted of providing the silicon microstrip detector system [42, 43, 44, 45] which together with a large dipole magnet and a system of proportional wire chambers, constitutes the charged particle spectrometer. The silicon system was upgraded before the second run which started in February, 1990. The first half of this run ended in August, 1990, a liquid hydrogen target was installed and the second half of the run was completed in January of 1992. Two graduate students from the University of Pittsburgh, D. W. H. Chung, and S. Blusk will write their theses on the data from this second run of E706. In August, 1990 Engels and Shepard joined the CDF collaboration. Initially they along with a postdoc and one graduate student will focus on the upgrade of the silicon vertex detector SVX for the 1995 collider run. As the E706 work is completed they expect to increase their level of involvement in CDF as their major research commitment.

Task C is the search for fractional charge in semiconductors. Although the physics goals of this experiment are removed from those of the other tasks, there has been a mutually beneficial technical overlap with Task B, due to the common use of semiconductor detectors. The major effort under Task C has been development of a new experimental technique which combines field ionization and low background infrared spectroscopy using a liquid helium cooled monochromator and a computer controlled data acquisition system. Hardware development and tests with integer charge impurities proceeded

successfully and on schedule. Now that the IR4 beam line of the Brookhaven NSLS is in operation, full scale fractional charge search runs are being carried out at that facility. The runs have gone very well and the work has benefited greatly from the cooperation of Gwyn William's group at the NSLS. A new technique for shuttering the infrared beam has been successfully incorporated into the data acquisition system. A smaller but important parallel effort under Task C has been the analysis of the incorporation and detectability of fractional charge impurities in silicon. Work has been done on (a) the incorporation of fractional Z elements [46] involving quarks bound to nuclei and (b) the incorporation of pointlike fractional charge particles, i.e. quarks not bound to nuclei [47]. This work revealed a dramatic shallow-to-deep transition as a function of pointlike impurity charge.

Measurements using the low background infrared spectroscopic apparatus have confirmed a mechanism proposed to explain an unusual mode of infrared detection which requires no electronic amplification. Another unconventional mode of detecting infrared using interfacial workfunctions based on classical photoelectric effect has been observed. Infrared response from about 20 microns up to about 220 microns was obtained employing these interfacial workfunctions in different Si and Ge p-i-n diodes. The work could thus have a spinoff benefit in the area of infrared detectors [48, 49]. This work has led to interesting results on nonlinear dynamics in semiconductor devices [50] and has led to some new concepts for implementation of neural networks [51]. Although this is in the area of a spinoff benefit, it has stimulated some thought on our part about the possible utility of emerging adaptive network technology for pattern recognition problems in high energy physics. Another development involves our observation of single photon events in silicon devices in a mode which is similar to work at Rockwell. It is too early to see where this work will lead, but it is possible that there could be applications in high energy particle detectors.

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Progress Report

TASK A

1 Task A – Overview

This task started in 1982 as a collaboration with first the AFS experiment at the CERN ISR and later the NA34 (HELIOS) experiment at the CERN SPS on the subject of direct photon production, and, extrapolating to lower transverse momenta, the possibility of a related directly produced component of lepton pairs and the associated spectra of single leptons. The production of such lepton pairs and low transverse momentum photons is of interest in itself if anomalies are found even in p-p or p-light nuclei collisions. But the lepton and photon production in p-p or p-light nuclei also serves as an important calibration point for comparison of such collisions to relativistic heavy ion collisions, where their presence may signal the production of a quark-gluon plasma phase of matter.

A workshop on this general question (the Pittsburgh Workshop on Soft Photon and Lepton Pair Production) was held in Pittsburgh, hosted by this task, in September of 1990. The proceedings were published in spring, 1992.

The experimental work from NA34 is now drawing to an end. Substantial data sets were taken in both the di-electron and di-muon channels, and first results of the analyses of the full data sets were presented at the Lepton-Photon Conference in Geneva in July, 1991. Pittsburgh's analysis responsibilities for the comparison of electron pairs from silver and beryllium targets and for the study of single electrons from a beryllium target ended in winter 1991. A draft has been written on the single electron results and is now in circulation among the collaboration members. The remaining Pittsburgh analysis topic, a study of electron-muon pairs, is the thesis of Pitt graduate student P. Pomianowski.

With the conclusion of the work on NA34, and after a 6-month stay of Thompson at the Institute of Physics in Novosibirsk, USSR, the focus of the task has shifted to studies of kaon decays. There are two aspects to this work.

The first aspect of the rare kaon decay work is that because of Thompson's long stay at INP, there is a possibility to make a contribution to that work through continued communication and consultation but without a large equipment investment, since the detector and accelerator are already either constructed or with definite plans for construction. This work is in progress and one student is working on aspects of the planned measurement (in the CMD2 detector at $VEPP - 2M$), of the process $\Phi \rightarrow S^* \rightarrow \pi\pi\gamma$. This process is of interest for S^* quark composition studies and important for understanding a possible CP-odd background to the proposed Φ -Factory measurements of ϵ'/ϵ from the CP-violating decays of the $K\bar{K}$ final state. The definite agreement for this collaboration includes continuing work on the CMD2 detector at the $VEPP - 2M$ accelerator and possible later work at a Φ -Factory project planned at INP, depending on our experience with the present collaboration. These activities require only minimal support but nevertheless make a substantial contribution to the $VEPP - 2M$ work.

The second aspect of the rare kaon decay work is participation in E865 at BNL, a search for $K^+ \rightarrow \pi^+\mu^+e^-$, a lepton number violating process. As reflected in the budget in the proposal, E865 will become the major activity of this task as the NA34 analysis is completed. E865 builds on the work of the previous experiment, E777, which

set the current limit for this decay mode (of $2. \times 10^{10}$). E865, through a combination of a redesigned beam, larger acceptance apparatus, and longer running time, hopes to push the limit for this decay down by another factor of 70, and at the same time collect a sample of $K^+ \rightarrow \pi^+ ee$ decays for study, and study the asymmetries in the decays of K^+ and K^- to three charged pions, also of interest in the Φ - Factory work.

Pittsburgh's responsibilities for the preparation of the experiment are in the design and construction of the Cerenkov counters. Senior physicist D. Kraus has become interested in this work, particularly the problem of fabrication of light mirrors for Cerenkov counters, and efficient collection of Cerenkov light. Work on this project began at Pitt in February, 1991. The activities of the past year have been in optical simulation and design studies and preparation for construction of the first Cerenkov counter C_1 .

2 HELIOS

2.1 Final Data

In 1987 the full pair trigger, over the full experimental solid angle, was operational. The thesis of Y.M. Park [1] used this data for a preliminary study of lepton pairs using the complete solid angle of the experiment, and checking the efficiency of different parts of the trigger.

The 6-month long lepton pair run from July 1989, to December 1989, yielded the main data sample for the HELIOS analysis. The electron pair trigger was commissioned by a Pittsburgh team including J. Thompson, M. Clemen, Y.M. Park, P. Pomianowski, H. Kalechofsky, and L. Weber, in collaboration with the Moscow group working on the TRD and other experts in other parts of the experiment. The experiment operated rather smoothly during this run. The Pittsburgh group helped in running, checking, calibrations, and general simulation work for apparatus efficiency determinations, and P. Pomianowski was in charge of electron trigger checks. In addition, the group took on analysis responsibility for two topics: 1) the sample of electron-muon pair data taken (thesis of P. Pomianowski) and 2) the sample of data taken on a silver target to allow some crude checks of target dependence of the electron pair yields.

2.2 Lepton Results: Singles

An initial run on electron production was made in 1986, accumulating a sample of about 2000 final single electron candidates, and a small sample of about 100 e^+e^- pairs useful for checking for systematic uncertainties in the singles analysis. These data, from a limited part of the solid angle, grew from a trigger-checking run and were the thesis study of M. Clemen [2]. The completed analysis shows no evidence for an excess within the systematic errors of order 25-30% for the singles and 40% for the pairs. The data do not show a faster than linear multiplicity dependence on accompanying event multiplicity, in this data sample [3]. However the HELIOS singles electron sample is more sensitive to low mass sources, while the AFS experiment was more sensitive to the higher mass sources, having nominally removed any electron recognized as coming

from a pair with mass below $100 \text{ MeV}/c^2$. Therefore, these results, while not showing either an excess or a quadratic dependence on the associated multiplicity, also are not inconsistent with the previous AFS experiment observation of such a quadratic multiplicity dependence. [4,5]. However, if the multiplicity effect seen by the AFS is real and not an artifact of statistical fluctuations or some systematic errors, the HELIOS data show that the effect does not continue to grow as the mass reaches down below the pion mass.

A side product of Clemen's thesis work was conversion of the HELIOS code to run on the CRAY-XMP and CRAY-YMP at the Pittsburgh Supercomputing Center. All Clemen's analysis was done on the Pittsburgh CRAY system, and for a few years the Pittsburgh computing contribution was approximately 20% of the total HELIOS computing. Some early scalar code converted very well to the CRAY, with a vectorization speedup of about 20 (overall factor 42 between the CRAY XMP and the VAX 8650). However, later versions of the code, optimized and much faster on scalar machines, did not show as large an improvement on the CRAY. Our overall conclusions from these exercises was that when machine compatibility is important it is difficult to obtain large speed-up factors on parallel architecture machines, and it may be preferable to use truly parallel processing (i.e., different processors for different events).

2.3 Lepton Results: Pairs

The 6-month long lepton pair run from July 1989, to December 1989, yielded 13,000 muon pairs and 2000-3000 electron pairs in the low m_T region of interest. A limit on new physics with missing energy at 1/2 the level of the charm cross section was also set from 1988 data [6].

The large electron-pair and muon-pair samples have been analyzed at CERN, with responsibility for the final analyses resting on R. Veenhof and P. Nevski, but with each of these final analyses resting on many individual calibration, analysis, and simulation results provided by different members of the collaboration. As already seen in the Pittsburgh Workshop on Soft Photon and Lepton Pair Production in September, 1990, the final yields seen by this experiment, with its ability to measure the η in the same experiment as the pairs, are less anomalous than those seen in previous experiments.

For the muons, the statistical errors are small compared to the systematic errors. The dominant systematic errors are: 1) the acceptance determination; 2) the determination of the η production (particularly in the shower finding efficiency in the uranium liquid argon calorimeter for the photon from the decay $\eta \rightarrow e e \gamma$); 3) the effect of the form factor for η and ω decays; and 4) the subtraction of correlated like-sign backgrounds from pion decays, for example from the decay $\rho \rightarrow \pi\pi \rightarrow \mu\mu$. The final systematic errors are in the range 20 – 30%, if added in quadrature.

For the electrons, the statistics are more closely matched to the systematic uncertainties. The factors mentioned above for the muons also enter for the electron pairs, except for the correlated unlike sign backgrounds from $\rho \rightarrow \pi\pi \rightarrow \mu\mu$. The shower finding efficiencies for the photon in the decay $\eta \rightarrow e e \gamma$ are more delicate for the electron pairs than for the corresponding muon decay case, because of the three close-lying showers in the ULAC. This source of error alone is estimated to be above 25%, and

may dominate the systematic errors.

Results from these analyses were presented at the summer '91 Lepton-Photon Conference in July, in Geneva [7], indicating agreement between the observed pairs and expectations, with systematic errors of order 30%. Thus this large statistics experiment has substantially laid to rest, at least in this center of mass energy range around $29 \text{ GeV}/c^2$, the earlier, generally statistically marginal, indications of large excesses in the pair spectra. The key to the understanding of the spectra was large statistics for the study of systematic problems, and observations of the identified η decays in the same apparatus.

The Pittsburgh analysis from the silver-target data from 1989 are consistent with the analysis of the main body of HELIOS lepton pair data. A rough comparison of results from Be and Ag targets for electron pairs (a Pitt analysis, carried out by postdoc A. Vanyashin) showed no new physics within a factor of two, limited by the statistics in the Ag data sample.

2.4 Electron-Muon Pair Studies for Charm Decay Rates

The inclusion of the electron-muon trigger in the running had an important consequence for our group, in that this topic has become the thesis work of P. Pomianowski, graduate student in our group.

The physics result of her thesis will be a comparison of the $e\text{-}\mu$ pair mass and missing energy spectra, comparing the data with expectations from charm. A background to the charm signal of interest is events from other decays, for example pairs of kaon decays. The drift chamber quality cuts remove some such events, but some remain. The remaining task of Pomianowski's thesis work will be the completion of the calculation of uninteresting backgrounds and comparison of the remaining events with the expected charm signal.

Present status of data analysis. In fall 1990 and the early months of 1991 she transferred this analysis to Pittsburgh, installing the CERN libraries and HELIOS analysis code on the Pittsburgh Supercomputing Center CRAY/YMP, discovering in the process a number of small errors in the code, typically mistypings which resulted in operations with undefined variables. Many of the errors had only a small effect, but some were substantial. The ULAC shower-finding for the electron candidates was redone, and other errors were important for the data taken at the end of the run and for the high multiplicity silver data. Corrections based on her studies have now been included in the main HELIOS code, and the silver data was rerun completely to include these corrections.

She has completed the selection of her data sets ($e\text{-}e$ pairs, $\mu\text{-}\mu$ pairs, and $e\text{-}\mu$ pairs), including some studies of drift chamber track quality cuts as a way to remove spurious events resulting from low quality tracks in high multiplicity events.

The mass plots for the $\mu\mu$ and ee pairs are shown in Figure 1.

COMPLETE 1989 MM2FILT DATA

COMPLETE 1989 MM2FILT DATA

COMPLETE 1989 EE2FILT DATA

Figure 1: Effective mass plots for dimuons and dielectrons

In Figure 1a and b the $\mu\mu$ mass plots are shown, on both a logarithmic and linear scale, showing clearly the ρ , ϕ , and J/ψ mass peaks. In Figure 1c the ee mass plot is shown. Because of the lower electron statistics, only the ρ mass peak is clearly visible. The rho-omega peak in the $\mu\mu$ sample has 320 events and the rho-omega peak in the ee sample has 66 events. For both the muon and electron pair samples the signal to noise in the rho-omega region is approximately 4:1. The size of the rho signal is consistent with other collaboration analyses. The signal to noise in other electron pair analyses is somewhat higher, probably due to a difference in the way the trigger compatibility checks are imposed.

The effective mass spectrum of the $e\mu$ pairs is shown in Figure 2. The signal after like-sign subtraction is 91 ± 32 , with a signal to noise of 0.21. Her statistics are comparable to a previous analysis [8], but her mass spectrum is centered at somewhat higher masses, perhaps indicating a higher fraction of charm events in her sample.

COMPLETE 1989 EM2FILT DATA - CUTS, REQUIRE DC1,2,3

EFF MASS, UNLI

EFF MASS, LIKE

EFF MASS, SUB

Figure 2: Effective mass plots for electron-muon pairs

A simple Monte Carlo program for charm production was developed at CERN, based on PYTHIA, and offers a reasonable first approximation to the charm production. Pomianowski and her undergraduate helper Craig Valine have used this generator to study events arising from charm, from minimum bias interactions, and from kaon decays. The triggering and analysis cuts are applied to the generated events. Further work on overlap of minimum bias events to get reasonable background spectra is being carried out, but some comparisons can already be made. Figure 3 shows the Monte Carlo mass spectra for events from minimum bias interactions, kaon decays, and charm decays. The events from minimum bias interactions and kaon decays have almost no events with mass greater than about $0.9 \text{ GeV}/c^2$, while about $1/6$ of the charm events and about $1/5$ of the data (a signal of 24 ± 15) are in this region.

Figure 3: Effective mass plots for simulated electron-muon pairs

Figure 4 shows the Monte Carlo missing energy distributions, with missing energy of about 3.6 GeV in events with one electron arising from a kaon decay, and 4.5 GeV in events with a muon from a kaon decay. Events with charm have a substantially higher missing energy, about 23 GeV. The Monte Carlo vint sample is not shown but has approximately zero missing energy.

MISSING ENERGY FOR KAON EVENTS

EMISS FOR SINGLE MUON EVENT

MISSING ENERGY FOR KAON EVENTS

EMISS FOR SINGLE ELEC EVENT

MISSING ENERGY

Figure 4: Missing energy for simulated events

These Monte Carlo results for missing energy can be compared with the data, shown in Figure 5. The zero for the missing energy plot has not been carefully adjusted with respect to minimum bias interaction events, but the comparison between the $\mu\mu$ pairs and the ee pairs (each with missing energy about -4 GeV) and the $e\mu$ pairs, which have missing energy about 12 GeV, is clear. This trend for the $e\mu$ pairs becomes even more pronounced when the sample of $e\mu$ pairs above a mass of about $400 MeV c^2$ are taken. For this set of data (not shown in an explicit figure) the missing energy is about 25 GeV/ c^2 .

COMPLETE 1989 MM2FILT DATA - NO EXTRA CUTS

COMPLETE 1989 EE2FILT DATA - NO EXTRA CUTS

COMPLETE 1989 EM2FILT DATA - CUTS, REQUIRE DC1,2,3

Figure 5: Missing energy for data

Because of the low statistics the precision of the conclusions which can be drawn is rather limited, but the data certainly seem enriched in events arising from charm. To complete the analysis the rho acceptance must be compared via the Monte Carlo to the charm acceptance, and the relative composition of charm and background events in the data must be estimated.

It has been pointed out by S. Mayburov of the Lebedev Institute, Moscow, that LUND underestimates the muon yields from charm by about 30%, because it does not include muons from the Λ_c decay, found to be more important than previously expected. Mayburov will visit Pittsburgh in summer, 1992, to test the consequences of his model.

Judging from the present status, the limits on any other physics besides charm will be of order of 100% of the data observed. This can be compared with a limit from this same experiment from missing energy only of approximately 1/2 the expected charm contribution [6]

2.5 Collaboration with P. Lichard

During the visit of Lichard to Pittsburgh in fall 1990, (in conjunction with his attendance at the Pittsburgh Soft Photon and Lepton Pair Workshop) calculations comparing the modified soft annihilation model of Lichard to the data of relevant experiments were completed, and the results of that work have been published in Phys. Rev. D [9].

Also during Lichard's stay, a calculation of the dilepton-gamma continuum expected from his soft annihilation model were compared to experimental limits and found to be below realistic reliable experimental limits, both previously published and contemplated, by about a factor of 10 (published in Physics Letters,[10]).

During a brief visit in November, 1991, he estimated the Bremsstrahlung production backgrounds to the single electron data, and in so doing discovered some errors in commonly used Bremsstrahlung descriptions [11]. During a return trip to Pittsburgh in summer, 1992, he expects to write up his Bremsstrahlung studies. He is also interested in the kaon decay work at Novosibirsk, described below.

3 K Decays and CP Violation at INP, Novosibirsk

3.1 General

Recent ideas in accelerator physics make the construction of a Φ -factory of luminosity of order $10^{32} - 10^{33} \text{ cm}^{-2} \text{ sec}^{-1}$ feasible. Such a facility would allow substantial advances in the study of K_S decays and measurements of various CP-violation parameters, including the direct CP-violation parameter ϵ'/ϵ , important in the standard theory of elementary particle interactions. Two such facilities are in the construction stage: one at Frascati, Italy, and one at the Institute of Nuclear Physics at Novosibirsk. Both " Φ -factories" are planned to begin operation in approximately 1995.

In the short term, a lower luminosity machine, the upgraded VEPP-2M at Novosibirsk, of expected luminosity 10^{31} will allow preliminary studies of the interesting

physics as well as a test of suggested analysis strategies for the full luminosity machines. The CMD2 detector, a general detector with a high precision drift chamber inside an axial magnetic field, and barrel (CsI) and endcap (BGO) calorimeters, has been prepared for use at VEPP-2M.

A collaboration between J.A. Thompson and the INP was begun during an NAS exchange of Thompson at INP in 1989-90.

The University of Pittsburgh group is closely involved in the thinking and planning of two projects: a) study of the $\phi \rightarrow S^* \gamma$, and b) studies of the channel: $\phi \rightarrow K^0 K^0 \rightarrow \pi^+ \pi^- \pi^+ \pi^-$. The $S^* \gamma$ channel gives information about the structure of the S^* , and the final state $\pi \pi \gamma$ gives information about a possible background to the planned ϵ'/ϵ measurement at future Φ factories. The study of the four charged pion final state gives information on predicted quantum mechanical correlations in the evolution of the two neutral kaons, including the so-called Einstein-Podolsky-Rosen zero for equal decay lengths. Comparing the signal events to backgrounds from semileptonic decays of the long-lived neutral kaon, simulation and identification of pions, muons, and electrons will be studied in order to refine current estimates of such events and their separation at planned future Φ -factories. Once the successful separation of the four pion final state is shown, more careful estimates of the kaon decay physics accessible at VEPP-2M can be made.

3.2 Status of Accelerator and Detector

In the VEPP-2M accelerator, beam-beam collisions have been achieved. The electron current stored in the BEP booster is 1 A., the conversion coefficient from electrons to positrons is 4 times higher than previously, and the injection from the BEP booster into VEPP-2M is close to 100%. The circulating positron and electron beams have reached 30 mA x 30 mA with the introduction of a wiggler, which increases the maximum machine luminosity to 3-4 10^{30} . The causes of this low luminosity (a factor of 3-5 below design luminosity) are being studied while preliminary data is being taken. One clue may be the asymmetry in luminosity (by a factor of 3-5) between the luminosities in the two intersection regions. Various checks have been made: switching luminosity monitors to check identical performance, checking the beam current luminosity monitors with Bhabba event reconstruction, and checking that the luminosity is not affected by the detector magnetic field. Presently runs with different kinds of triggers are underway, and separate luminosity measurements will be done with only the DC or CsI calorimeter in the trigger. Naturally, intensive machine studies are also underway to resolve this puzzle.

The CMD2 detector has been fully assembled, except for the BGO endcaps which have now only two radial strips of crystals installed, in order to study Bhabba scattering, backgrounds, and trigger rate questions. One important problem found in preliminary running in December, 1991, was inadequate shielding of photomultipliers in the calorimeter. Our student, C. Yang, helped in the shielding of the tubes and in calibration after the shielding was complete.

Although the CMD2 detector is situated in the intersection region with the lower luminosity, with average luminosity $0.2 - 0.5 \cdot 10^{31}$, and only briefly luminosities as high

as $2 \cdot 10^{31}$, data are now being taken at the Φ for studies of the standard decays. While the luminosity and quality of the data are still in a preliminary stage, these data are useful generally to calibrate the equipment and begin the exercise of the trigger, data acquisition, and reconstruction programs and will also be useful for our preparations to study the mode $\Phi \rightarrow S^* \gamma$, important both for quark structure studies and as a possible background to the planned ϵ'/ϵ measurements at future phi factories. About 100 inverse nanobarns of data have been collected and the first excitation curve of the Φ has been shown in both the $K_L K_s$ and three pion modes.

In 1989 a Decstation 5000 system was taken to Novosibirsk (Budker-INP), and has proved useful in bulk data processing, allowing a 70Hz throughput of events. In 1992-93 we expect to continue to exploit the system of data processing now set up at Budker-INP, and for our student, C.H. Yang to participate in data taking for CMD2. We also expect to install the analysis programs at Pittsburgh, to have a parallel analysis effort. Until the reconstruction programs are well defined, full reconstruction would occur at Novosibirsk, with activities at Pittsburgh primarily in simulation (already established at Pitt) and analysis studies of already reconstructed data. With respect to the analysis work at the University of Pittsburgh, we hope to have help from visitors from Budker-INP, both in setting up and in fully exploiting the code.

The present data acquisition system is adequate for the early data runs, but it is expected that to take full advantage of the increased luminosity, it will be desirable to increase the speed of the data acquisition process. The use of transputers for this process has been proposed by the group at INP [12]. During Thompson's December 1991 visit to INP, she brought several transputers with associated memory and connectors, and a basic transputer toolkit for evaluation and study by the Novosibirsk group.

In April, 1991, a B008 motherboard and an associated B404 module containing a T800 transputer chip had been brought to Novosibirsk by Thompson for evaluation and tests, on a temporary export license. They were installed in a PC, and the Whetstone test was run. Compared to the INP AP32 special processor (which is equivalent to an IBM 370) a factor of 1.5 in speed was seen.

Using the transputers brought in December 1991, the transputer team, under G. Aksenov of B-INP, has:

1. constructed two computers with 2 MB memory as PC accelerators. These computers have demonstrated a speed like that of a microVAX 3500 for programs written in C and F77, and three times faster for test programs written in OCCAM. These computers are now intensively used by several groups of physicists. Existing software is being studied and exercised, and several bugs in standard transputer software have been found.
2. designed a computer with 8 MB memory, which will be adequate to install and use the CERN software such as PAW, ZEBRA, KERNLIB, etc. Production of this accelerator is expected within about two months, using the memory chips to be brought by Thompson in May.
3. designed two VME standard modules, one with two transputers and 2MB memory and one with 1 transputer and 4MB memory. Expect production of these modules also within the next few months.

CERN software for the transputers is expected from Germany in the next month or two. Once the CERN software is available, the CMD2 reconstruction software can be installed. This step is important for our goal of using the transputers as part of a high level trigger using online reconstruction results. After some experience with the initial VME modules, the group plans to design VME modules to connect to the present CMD digitizing system as a first step in moving toward a VME-based data acquisition system.

The transputers taken so far have been selected in consultation with M. Dudziak, formerly of INMOS-THOMSON. Dudziak will travel with Thompson to Novosibirsk in May, 1991, to consult on the further evolution of transputer use in the present VEPP-2M data acquisition system as a testing ground, to study the possibility of a transputer-based system for the larger Φ -Factory project (with expected data rates of 20 Mbytes/sec) now in the planning and construction stage at Novosibirsk. Such a transputer based system may also be of interest for use at other large future experiments, since the transputer chips offer a cost-effective alternative to RISC workstations. Such a system was considered for E865, and there were some preliminary discussions of collaboration by the INP group on such a system. However, for E865, the data burden is small enough (only about 2-3 Mbytes/sec) that the more conventional solution of a RISC workstation farm seems adequate, and preferable as being further developed presently.

3.3 Plans for study of $\phi \rightarrow S^* \gamma \rightarrow \pi \pi \gamma$

During the past year, Pittsburgh student C.H. Yang, under the direction of S. Eidelman at INP, has continued to study measurement problems for the decay $\phi \rightarrow S^* \gamma$. Their work is summarized in more detail in Appendix I. The S^* measurement, Yang's thesis project, is important both for studies of the structure of the S^* [13,14] and for understanding of possible backgrounds to the Φ -Factory ϵ'/ϵ -measurements.

An important background to the resonant S^* process is the contribution from continuum processes and radiative corrections. Calculations of these by Eidelman and Kuraev at INP, described in last year's progress report and used in the work in Appendix I, indicate that these effects will give a $\pi \pi \gamma$ contribution about 4 times the upper limit expected from the S^* decay. In this case the interference between the two modes will be important and may be a useful method in the separation of the $S^* \rightarrow \pi \pi$ decay. Other methods for circumventing the Bremsstrahlung and radiative correction effects are to use the neutral two pion decay mode rather than the charge mode, or to go further away from the beam line, where Bremsstrahlung effects will be smaller.

With the expected luminosity of this detector, one can hope to put a limit of order 10^{-5} to 10^{-4} for the branching ratio of this mode. The present limit is 10^{-3} . This mode is important because it is related to the potentially problematic mode $K \bar{K} \gamma$, proceeding through the intermediate state $S^* \gamma$, with subsequent two body decay of the S^* either to pions or kaons. The kaon decay mode would give a CP-even background to the detected final state kaons, and would require decay volume cuts to give a clean CP-odd sample such as is needed for the CP-violating decay studies. This decay mode was earlier thought to be possibly as large as 10^{-3} [15] but is now thought to be less

than 10^{-5} [13,16]. A measurement of the more copious $\pi\pi\gamma$ mode allows a check of the theory, interesting in itself, since a measurement of this decay mode at the 10^{-4} - 10^{-5} level allows a test of the quark content of these resonances.[13]

There is presently no measurement for either the $\pi\pi\gamma$ mode or the $S^*\gamma$ mode. By comparison of the effective mass plots under different selection criteria for the accompanying photon energy and the opening angle of the charged pions, we hope to make limits (or measurements) of the two decays separately. The Table in CPITT-20 (Appendix I) shows the fraction of different processes leading to an apparent $\pi\pi\gamma$ final state, under a standard set of cuts on the energy of the final state gamma, and on the angle between the two charged pions.

Given the expected luminosity of the refurbished VEPP-2M (of a few times $10^{31} \text{cm}^{-2} \text{sec}^{-1}$), one can hope to accumulate about 4 million Φ 's per day. With predicted branching ratios for the $S^*\gamma$ mode ranging from 10^{-5} to a few times 10^{-4} , one would then hope to accumulate and reconstruct (in the nearly hermetic calorimeter) of order hundreds of these decays per day. If the direct $\pi\pi\gamma$ mode appeared at its presently observed limit, this mode would contribute up to 30 times as many events as the cascade $\Phi \rightarrow S^*\gamma \rightarrow \pi\pi\gamma$, but in the region of the $S^*\gamma$, the background will be only several times the expected $S^*\gamma$ signal. The tail of the ρ and the underlying continuum processes also may give a contribution to this final state. For that reason, in planning the experiment one must be sure to accumulate data at points off-resonance energy to see the effect of the Φ resonance shape on any observed signal. An efficient run of 10-20 days seems to be desirable for this measurement. The data taken now is very preliminary, and in particular we expect the final data to be taken with the BGO endcap calorimeter installed, to allow more complete angular studies of any apparent signal.

4 Rare K Decays in E865 at BNL

This experiment is replacing the HELIOS work as the major activity of this task.

Figure 6: Layout for BNL E865, search for $K^+ \rightarrow \pi^+ \mu^+ e^-$

Figure 6 shows the layout for E865, very similar in design to that of its forerunner, E777.

The upstream Cerenkov counter, for which Pittsburgh has nearly finalized the design, requires a mirror of very light construction, and must also accommodate particle trajectories bending in a magnetic field.

4.1 Ray Tracing

The geometrical Monte Carlo program used by E777, the fore-runner of E865, was modified at Yale by M. Zeller for use in E865, and installed by Thompson at Pittsburgh. It was used here for detailed tracing of particle trajectories in order to understand the requirements for the Cerenkov counter design. The code used in E777 was modified at Pittsburgh, by Thompson to allow tracking of Cerenkov photons emitted in the magnetic field volume, and by T. Stever to include the angle of emission of the Cerenkov light with respect to the particle (about 17 mrad for an electron in hydrogen).

The optical ray-tracing code developed can handle several different kinds of optical elements: spheres, cylinders, arrays of cylindrical "slats", planes, parabolas, ellipses, and the element expected to be used for the collector: an elliptical "wall" collector, of elliptical walls in one dimension and flat tilted walls in the other dimension.

Still to be included are the effects of angle dependence and polarization dependence of reflectivity.

Figures 7 and 8 show positions of photon hits on optical elements, outlining the optical elements. Some sample trajectories are also shown.

Figure 8: Photon trajectories: x-z

Figure 7: Photon trajectories: y-z

The light collection system which has been developed uses two arrays of cylindrical slats per quadrant, an "inside" array reaching to 100 cm from the beam horizontally, and an "outside" array reaching from 100 to 150 cm, the edge of the magnet. The photons reflect first from the primary mirrors in the center of the magnet, back to an intermediate reflector (also a set of cylindrical slats), then up to the collectors, funnelling down through the collectors to the photomultipliers. This configuration has been chosen for the simple mechanical construction which it allows and the apparently optimum position of the PMT's in the magnetic field (from TOSCA simulations, only 100-200 Gauss, oriented perpendicular the PMT axis). The intermediate reflectors are required to deflect the photons approximately through a right angle, upward to the PMT position. Although the intermediate reflectors introduce an extra bounce for all photons, they also simplify the design compared to previous possibilities, and give on balance only about 0.75 bounces more than solutions without the intermediate reflector. From the computer results, the average number of bounces seen by photons from the "Dalitz" decay mode ($K \rightarrow \pi^+ \pi^0$ with subsequent decay $\pi^0 \rightarrow e^+ e^- \gamma$) is 2.8 (comparable to the 2.7 seen in E777) and only about 6% of photons lost and (assuming an average of 6 photoelectrons on the methane side seen by the positive particles) only about 1.1% of positrons from this decay not observed. For the rare decay of interest, only 4% of the photons are lost, but the lower number of photoelectrons (estimated 3 on average) gives an estimate of about 6.5% inefficiency. The average number of photoelectrons assumed is the same as seen in E777, but our pathlength for particles making Cerenkov light is somewhat longer than in E777 (146-160cm in this design, compared to 105-135 cm in E777).

The optical design has also been used to study light collection from Cerenkov photons produced by delta rays. An early estimate by D. Kraus had indicated that trapping of deltas from beam particles in the magnet might give a large accidentals rate in the Cerenkov counter. This question is still under study, but the preliminary results from deltas generated by Jim Lowe and passed through the optical collection system seem to indicate that the trapping is less severe than originally suspected (most particles complete only a few orbits before exiting the magnet). The collection efficiency for the Cerenkov photons from these deltas is only about 10 %, as approximately expected, since the light collection system is designed for Cerenkov photons which closely follow the trajectories of particles from the initial kaon decay.

4.2 Low Mass Mirrors

Besides the ray-tracing discussed above and the integrated design questions discussed in the proposal, our activities for the past several months have been in understanding techniques for fabrication of light mirrors. A test setup is being constructed by E. Shunko, K. McNair, M. Gach, and D. Kraus, which will allow us to test the stability of the mirrors and also serve as an analog computer test of the optical system which has been produced by the computer simulation work.

The mirrors are expected to be of thin acrylic plate (0.8 mm) covered with evaporated aluminum. A backing of rohacell was chosen to help constrain the mirrors to keep their shape. Rohacell has the advantage of strength combined with light mass.

However, it is sensitive to expansion when exposed either to temperature or humidity changes.

A first mirror was made by attaching the acrylic to the rohacell at approximately three points. The mirror initially showed good freedom from distortion, showing a pattern of reflected rays consistent with a good cylindrical shape, tested by the dispersion of the spot of a reflected laser (He-Ne) beam directed from the imaged mirror axis. In the investigations of the cylindrical mirror, the screen for studying the behaviour of the reflected beam spot was placed in the same point as the light source, and the maximum dispersion of the spot on the screen was approximately 1.5 cm for a mirror radius of 301.5 cm, (corresponding to a variation of radius of curvature of less than 10 cm). However, the mirror changed its apparent curvature (by about 10 cm in the radius) for different temperatures and different humidity conditions. Further investigation indicated that the distortion was due to a differential expansion of the rohacell and acrylic. As a result, it was decided to glue the acrylic plate to the rohacell ribs only in one point (at the center of the mirror) and only to allow the acrylic to move along the (stable geometrical) figure of the rohacell, rather than to bond particular points of the acrylic to particular points of the rohacell. The acrylic was attached by special nylon filaments. This configuration enables one to maintain the mirror radius as long as the rohacell ribs are not changing their radii. The stability of the rohacell itself seems adequate as measured through the observation of radii of curvature of specially cut and monitored rohacell cylindrical curves, and also through measurements of the mirror made with the special nylon tethering configuration described above. Stability for changes of the room temperature approximately 10 degrees C, was achieved over an observational period of about two weeks. The special mirror fabrication facility is prepared and mirror production, first for the prototype quadrant to be used for an analog test of the ray tracing, and then for the production of all the optical system components, will begin in May.

4.3 Gas Seal Tests and Prototype

Because of the more detailed safety review requirements recently instituted in the various national labs under DOE supervision, it was not sufficient to refer to the acceptance of the Cerenkov counter gas containment measures of E777. Accordingly, a prototype was built to demonstrate the gas containment methods proposed, and tests of various sealing techniques were carried out by Pitt undergraduate D. Willow, under the supervision of D. Kraus.

In particular, tests were made of secure seals of mylar t-joints. One substance tested was RTV silicon sealant, made by GE. Typical amounts of RTV used ranged from 7 mm to 1 cm per side of the triangles of RTV used to bond each side of the t-joint. These bonds held between 10 and 15 kg for over 24 hours. One such joint held 12 kg for 8 days. All the samples were 2 inches wide, and for 2 in mylar held in the t-joint so the spanning part of the T hangs at an angle of 10 deg from the horizontal, failure occurs at about 33 lb/linear inch. The RTV did not fracture, but it did fail. At the place where the weighted piece of mylar met the spanning piece of mylar (the clamped piece) the RTV would separate, and a small hole appeared across the 2 inch sample.

This failure was judged unacceptable.

The PRC polyurethanes, PR 1564 and PR 1538, had been used in the E777 Cerenkov counter sealing with success. After conducting similar T-joint tests to those with RTV, we were sure that both PR1538 and PR1564 bonded well to the mylar (with the application of a primer, PR420) and that the urethanes are very strong and can hold more weight than specified by BNL's safety committee. PR1564 was emphasised because it is not as hard as PR1538, which makes it a better gasketing material.

The curing time for PR1564 is 16 hours at 180 degrees F, and this product reaches a shore a hardness of 65. For PR1538 the curing schedule is the same, for a shore a hardness of 80.

As stated before, results from T- joint tests show that PR1564 has more than sufficient strength to hold the mylar in this manner. Using approximately 1 cm of PR1564 to a side of the triangle making the mylar-mylar bond, a sample held 17 kg for 8 days, which is slightly higher than the failure of mylar. The mylar stretched a very small amount over that period of time, but no failure occurred in the polyurethane. Other samples were tested with the same weight with the same results, but not for as long. Tests were also done to see how reproducible our results were with respect to hardness for PR1564. The hardness values we attained varied between 62.5 and 63.4 shore A hardness, compared to the expected value of 65. We also tested the shore hardness of a part of the gasketing polyurethane used by U. Washington and came up with an average value of 66.0. Tests were then done to see how PR1564 behaves under compression. After creating a device made of thick acrylic to see how the polyurethane behaved as it was compressed, we were convinced it is a good gasketing material by the way it conformed to the surface of the acrylic and by the way in which the polyurethane did not relax under the compression needed to uniformly compress along the acrylic. The thickness of the sample tested along where it was compressed decreased by 0.18 mm at its maximum. After these tests, the mylar and kevlar, which also bonds well to PR1564, were pulled on as the urethane they were imbedded in was compressed. After pulling a sample measuring 2.5" wide with 252 lb, the load relaxed to 232 lb after 3 days due to some slippage in the clamps which held the urethane as well as the creeping of the polyurethane. Thereafter, the clamps were adjusted and the polyurethane in the sample was pushed to failure well above 250 lb, the exact number not known due to the upper limit on the scale of the apparatus used.

This kevlar-mylar-PRC bond was chosen to be used in the Cerenkov counter, with the mylar-PRC bond serving as the gas seal and the kevlar serving as an outer restraining barrier.

4.4 Reflectivity Tests

During the past year, Stefan Van den Brink, under the supervision of D. Kraus, has made reflectivity measurements at wavelengths from 628nm (the usual He-Ne laser) down to about 185 nm, using a combination of LED's and Hg and D2 arc excitation sources, and a spectrometer system to select the appropriate wavelength. Besides the He-Ne laser at 628 nm, the sources used were:

1. green light emitting diode at 540 nm;

2. Hg lamp with most of the light at 250 nm;
3. Hg lamp with most of the light at 350 nm;
4. D2 lamp with a continuum of light below 250 nm.

Measurements with the approximately monochromatic sources were made in two ways: using plastic or glass filters to block lower wavelength components to allow separate measurements of all light and the higher wavelength components. The lower wavelength components were then found by subtraction, correcting for the reflectance from the filter, calculated from the known indices of refraction. Measurements with the D2 lamp were done only with the spectrometer. The spectrometer was calibrated using the HeNe laser at 628 nm and checked with the Hg source at 250 nm. For the D2 measurements, it was desirable to purge with nitrogen to remove oxygen (which is strongly absorbing for wavelengths below 180nm, and with a tail extending upward). The nitrogen purging also reduced the level of ozone production, an important health benefit to the experimenter, since the level of ozone before the purging was noticeably unpleasant in the respiratory system.

This reflectivity test setup was used to test various candidates for mirror materials. A standard mirror, and microscope glass were used to calibrate the system, indicating systematic uncertainties in the absolute reflectance of about 10% of the measured reflectance for the low (4%) reflectivity from the microscope glass, and somewhat better (about 5% of the reflectance) for the higher reflectivity glass mirror at 628 nm, where the reflectivity is about 90%.

Figure 9 and the accompanying table summarize these measurements.

REFLECTIVITY VS WAVELENGTH

APRIL29-1992

Figure 9: Reflectivity measurements

NOTES FOR THE REFLECTIVITY GRAPH

REFLECTING SAMPLES :

ADICO

UNMORE DC551, DC662, DC990, DC21300

STANDARD GLASS MIRROR

LIGHT SOURCES :

RED-NE LASER (630 NM)

GREEN LED (540 NM)

HG LAMP (250 NM + VISIBLE)

HG "BLACK" LAMP (350 NM)

DEUTERIUM/D2 LAMP (250 NM AND BELOW)

DETECTOR :

HAMAMATSU PHOTODIODE

OTHER APPARATUS :

SPECTROMETER

NO	REFLECTOR	SOURCE	SPECT	WAVELENGTH (NM)	REFLECTIVITY (%)	UNCERTAINTY (%)
1	GLASS MIRROR	LASER	NO	630	89.2	1.3
2		LED	NO	540	90.0	1.0
3		HG	NO	250	47.4	1.0
4		HG	YES	250	46.9	1.0
5	(3,4 COMBINED)			250	47.2	0.7
6	MADICO	LASER	NO	630	89.0	2.0
7		HG	NO	250	90.6	3.0
8		HG	YES	250	88.8	1.0
9		D2	YES	250	89.3	1.0
10		D2	YES	200	75.5	1.0
11		D2	YES	190	65.3	2.0
12	(7,8,9 COMBINED)			250	89.1	0.7
13	DC551	LASER	NO	630	88.7	1.3
14		HG	NO	350	93.9	1.0
15		HG	NO	250	84.7	1.0
16		HG	YES	250	83.1	1.0
17		D2	YES	250	86.1	2.0
18		D2	YES	200	67.8	5.0
19	(WITH N2)	D2	YES	200	72.5	1.0
20	(WITH N2)	D2	YES	190	71.4	3.0
21	(15,16,17 COM)			250	84.6	0.7
22	(18,19 COM)			200	71.7	0.9
23	DC662	HG	NO	250	91.2	1.0
24		HG	YES	250	80.5	1.0
25	DC21300	HG	NO	250	86.9	1.0
26		HG	YES	250	82.3	1.2
27	(25,26 COM)			250	84.8	0.7
28	DC990	HG	NO	250	13.1	1.0

xxvib

The MADICO samples show a very interesting high reflectivity, still close to 5% down at 190 nm. However, our present plan is to fabricate the mirrors from acrylic flycut to half thickness, with a standard aluminization with MgF₂ overcoating. We will flycut the acrylic here but have the aluminization and overcoating done commercially.

4.5 Photomultiplier tests

The knowledge of the parameters of the photomultiplier tubes one uses is essential to understanding the Cerenkov counter performance. One would like both quartz windows for good transmission down into the U.V. (for efficient collection of Cerenkov radiation) and high first dynode gain so that one can reliably separate noise from the one photoelectron signal. Unfortunately, the only tube with a reliable high first dynode gain (the RCA 8854) does not have a quartz window, but only U.V.-transmitting glass. We tested an EMI tube and a Hamamatsu tube with a quartz window and a high first dynode gain (about 20, like the RCA 8854) leaving the factory. However, we found that the gain deteriorated by a factor of two over a period of 6 months. The high initial gain was a surprise, since the method of making the Hamamatsu first dynode was described as the same as that of other tubes with first dynode gains more like 8-10. Thus, our present plan is to use RCA 8854's.

Van den Brink, again under Kraus's supervision, is now setting up a PMT-testing facility at Pitt. The goal of this facility is to make measurements of absolute quantum efficiency as a function of wavelength, extending down to 180 nm, and also to test the first dynode and overall gain. For the moment, first results are from an LED light source in the green, at 540nm. The LED light is measured with a Hamamatsu photodiode with well known absolute quantum efficiency, close to the LED. Then the light is attenuated by placing the photomultiplier a known distance away from the LED. The quantum efficiency can then be counted from a comparison of photomultiplier counts per second (with more than one photoelectron) with the known flux of incident photons calculated from the photodiode flux measurements. The overall gain can be calculated from the charge in the first photoelectron pulse (measured both with a QVT and by integrating the photomultiplier pulse), and the first dynode gain can be measured in a similar way using the output directly from the first dynode. Preliminary results for the EMI 9954B tube show reasonable agreement (quantum efficiency of about 8% at 540 nm) between quantum efficiency measured in this way and quantum efficiency measured by manufacturers using the PMT as a diode. We will also check the quantum efficiency at other wavelengths, including the peak wavelength (expected 26% at approximately 350 nm) but it seems likely that the manufacturer's specifications can be used for design purposes.

Figure 10 shows the discriminator curve taken with the LED on and off, and Figure 11 shows the pulseheight spectrum obtained from the differentiated curve, again with the LED on and off. The absolute correspondence to the QVT was obtained by taking a QVT spectrum gated by the photomultiplier output, as shown in Figure 12. These results seem to show that a reasonable threshold, set well above PMT noise, of something like 50-75 mV, loses only about 10% of the true one photoelectron signal, at least in the absence of a magnetic field.

Figure 12: QVT spectrum gated on photomultiplier output.

APR28-1992 using green LED ON, SCALER
PMT SET AT A DISTANCE OF 10 FT FROM LED

APR29-1992 using green LED OFF, SCALER
PMT SET AT A DISTANCE OF 10 FT FROM LED

Figure 11: Photomultiplier pulse height spectrum vs discriminator settings, for LED on and off.

APR29-1992 using green LED ON, SCALER
PMT SET AT A DISTANCE OF 10 FT FROM LED

APR28-1992 using green LED OFF, SCALER
PMT SET AT A DISTANCE OF 10 FT FROM LED

Figure 10: Photomultiplier counts vs discriminator settings, for LED on and off.

The planned calibration system will allow this conclusion to be checked in the actual environment of the photomultiplier in the experiment. While the final design and construction of the calibration system will be done by the New Mexico group, the plan is for it to be modelled on the successful E814 calibration system.

5 List of Publications from this Task

Below the list of publications from the past year for this task are given, including the (new) invited talk given by Thompson at the Hadron '91 conference in Czechoslovakia in September 1991, and several other articles for which the publication references were not available in previous years.

1. "The Transverse-Energy Distributions of ^{32}S -Nucleus Collisions at 200 GeV per nucleon", Phys. Lett. **B252**,303 (1991).
2. "A Search for Weakly Interacting Neutral Particles in Missing Energy Events in 450 GeV/c Collisions", T. Akesson, et al., (HELIOS Collaboration), Z. Phys.C **52**,219(1991).
3. "Single electron production in p-Be collisions at 400 GeV/c incident beam energy", J.A. Thompson, invited talk at the Hadron '91 conference in the High Tatras, Czechoslovakia, September, 1991.
4. "The modified soft annihilation model of anomalous dilepton and photon production and its comparison with data", P. Lichard and J. Thompson, Physical Review **D44**,668,(1991).
5. "Production of a dilepton-gamma continuum by the modified soft annihilation model", P. Lichard and J. Thompson, Physics Lett. **B261**,141 (1991).
6. "Plans to Study $K^0 K^0 \rightarrow \pi^+ \pi^- \pi^+ \pi^-$ at VEPP-2M", R. Demina, V. Savinov, and J.A. Thompson, p. 515, Proceedings of the Workshop on Physics and Detectors for DAΦNE, Frascati, Italy, April, 1991.
7. "Plan to Search for Φ Decay to $S^* \gamma$ at VEPP-2M", S. Eidelman, J.A. Thompson, and C.H. Yang, p. 437, Proceedings of the Workshop on Physics and Detectors for DAΦNE, Frascati, Italy, April, 1991.
8. "Plans for the Novosibirsk phi factory", S. Eidelman, E. Solodov and J. Thompson, Nuclear Physics **B(Proc. Suppl.)24A**,174(1991).
9. "Phi Factory Detector Requirements", K. Arisaka et al. (prepared by J. A. Thompson, presenter for the detector working subgroup), Nuclear Physics **B(Proc. Suppl.)24A**,236 (1991).
10. **Soft Lepton Pair and Photon Production**, ed. J.A. Thompson, Nova Science Publishers, Inc., including two contributions from the Pittsburgh group: "Single Electron Production in 450 GeV/c p-Be Collisions for Transverse momenta 50-400 MeV/c", by M. Clemen, et al., p. 139; and "Summary of Experimental Results", by J. Boehm, J. Schukraft, and J.A. Thompson, p. 281.

6 List of Appendices

1. "Monte-Carlo Simulation of $e^+e^- \rightarrow \pi^+\pi^-\gamma$ ", *CP - PITT - 20*, April 8, 1992, *S. Eidelman and C. Yang*.
2. "Monte-Carlo Simulation of $e^+e^- \rightarrow \pi^+\pi^-\gamma$, Part II", *CP - PITT - 21*, April 9, 1992, *S. Eidelman*.

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- [3] J.A. Thompson (HELIOS Collaboration), presentation at HADRON '91, High Tatras, Czechoslovakia, September, 1991.
- [4] T. Akesson et al., Physics Letters, **152B**, 411, (1985).
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Monte-Carlo Simulation of $e^+e^- \rightarrow \pi^+\pi^-\gamma$

To have an idea of the feasibility of measuring the branching ratio of the decay mode

$$\Phi \rightarrow S^*\gamma \rightarrow \pi^+\pi^-\gamma \quad (1)$$

a simple geometrical Monte-Carlo simulation has been performed. The CMD-2 detector was described as a cylinder with complete azimuthal coverage and polar angle coverage including the end-cap BGO calorimeter ($19^\circ < \theta < 161^\circ$). Charged particles were considered as detected if their transverse momenta were greater than 90 Mev corresponding to the magnetic field of 1T and the DC radius of 0.3M. A threshold for photon detection was 20 Mev. No smearing of the particle momenta or angles was included, i.e. influence of finite resolution was neglected.

Processes considered included $\Phi \rightarrow \pi^+\pi^-\pi^0$ ($\pi^0 \rightarrow \gamma\gamma$), $\Phi \rightarrow \eta\gamma$ ($\eta \rightarrow \pi^+\pi^-\pi^0$, or $\pi^+\pi^-\gamma$). Although the final state for them has more than one photon, they can imitate (1) if only one of the photons is detected or two photons merge into one (this way roughly taken into account by considering γ s with an angle between them less than 15 degrees as one γ). There are also two Bremsstrahlung processes when a photon is radiated either by an initial electron or a final pion in the reaction

$$e^+e^- \rightarrow \pi^+\pi^- \quad (2)$$

These reactions are non-resonant, i.e. their cross section has smooth energy dependence, however the value of the cross section is very big. Formula for the differential cross section were written in the soft photon approximation and their simulation was performed with input cuts of $E_\gamma > 10$ Mev and $10^\circ < \theta < 170^\circ$ corresponding to the "total" cross section of 10.7 nb and 1.26 nb, respectively.

Not yet considered was a decay mode $\Phi \rightarrow \rho\pi \rightarrow \pi^+\pi^-\gamma$ with the same final state and $\Phi \rightarrow K_S K_L$ in which K_S decays into $\pi^+\pi^-$ and K_L gives a signal in the calorimeter due to its decay or, more probably, due to its nuclear interaction. Finally, a serious background can come from process (2) where pions are acollinear due to finite resolution or a soft photon escaping detection and a signal in the calorimeter imitating a photon due to pion interaction

Appendix 1-2

with the calorimeter material. However, one can hardly rely on the results of the Monte-Carlo for nuclear interaction of pions and especially of neutral kaons since experimental uncertainties for these processes are large and their description in the existing code is rather poor. One will probably use experimental data from CMD-2 itself to understand this using tagged pions and kaons.

After simulation of the described reactions we tried different cuts to suppress background not influencing strongly the signal - $S^*\gamma$. The obvious cut is missing energy. Selecting events with $E_{\text{miss}} < 40$ Mev (rough estimate gives 20 Mev for a standard deviation) we can rather efficiently suppress the background due to Φ decays into 3 pions and $\eta\gamma$ since in this case there is always at least one photon escaping detection and carrying away some energy. Further suppression of these decay modes is obtained when one imposes a cut over the angle between two pions $\omega > 150^\circ$ thus selecting events with a small pion acollinearity typical of $S^*\gamma$ production. The final set of the cuts also included $E_\gamma < 160$ Mev and $30^\circ < \theta(\gamma) < 150^\circ$ to suppress the Bremsstrahlung processes not influenced by previous cuts. The resulting cross sections are presented in the table. One can see that at the maximum expected branching of $\Phi \rightarrow S^*\gamma$ equal to $2.5 \cdot 10^{-4}$ its cross section is only 4 times smaller than that of the Bremsstrahlung by initial electrons.

The correct calculation should of course take into account the interference of the all processes with the same final state ($\Phi \rightarrow S^*\gamma$, $\Phi \rightarrow \rho\pi \rightarrow \pi^+\pi^-\gamma$, two Bremsstrahlung reactions) and one can hope that at smaller branching ratios of $S^*\gamma$ it can, nevertheless, be observed by ~~arising~~ ^{the} pion asymmetry due to different charge parity of the dipion system.

Appendix 1-3

Process	2C + 1 γ		2C+1 γ , E _{miss} <40MeV		2C + 1 γ E _{miss} <40MeV $\omega_{\pi^+\pi^-} > 150^\circ$		2C + 1 γ E _{miss} <40MeV $\omega_{\pi^+\pi^-} > 150^\circ$ E γ < 160 MeV $\theta\gamma > 30^\circ$	
	ϵ	σ_{det} (cm ²)	ϵ	σ_{det} (cm ²)	ϵ	σ_{det} (cm ²)	ϵ	σ_{det} (cm ²)
$\Phi \rightarrow S^*\gamma$, $S^* \rightarrow \pi^+\pi^-$	0.838	$8.4 \cdot 10^{-34}$	0.838	$8.4 \cdot 10^{-34}$	0.62	$6.2 \cdot 10^{-34}$	0.458	$4.6 \cdot 10^{-34}$
$\Phi \rightarrow \pi^+\pi^-\pi^0$, $\pi^0 \rightarrow \gamma\gamma$	0.112	$6.6 \cdot 10^{-32}$	0.035	$2.1 \cdot 10^{-32}$	0.011	$6.3 \cdot 10^{-33}$	$6 \cdot 10^{-5}$	$3.6 \cdot 10^{-35}$
$\Phi \rightarrow \eta\gamma$, $\eta \rightarrow \pi^+\pi^-\gamma$	0.077	$2.0 \cdot 10^{-34}$	0.014	$3.5 \cdot 10^{-35}$	0.000 2	$5.1 \cdot 10^{-37}$	-	-
$\Phi \rightarrow \eta\gamma$, $\eta \rightarrow \pi^+\pi^-\pi^0$, $\pi^0 \rightarrow \gamma\gamma$	0.003	$3.7 \cdot 10^{-35}$	0	0	0	0	-	-
$e^+e^- \rightarrow \pi^+\pi^-\gamma$ (Bremsstrahlung, initial)	-	-	-	-	-	-	0.173	$1.8 \cdot 10^{-33}$
$e^+e^- \rightarrow \pi^+\pi^-\gamma$ (Bremsstrahlung, final)	-	-	-	-	-	-	0.260	$3.2 \cdot 10^{-34}$

$$\sigma_{\phi^{(0)}} = 4 \cdot 10^{-30}$$

$$\sigma_{3\pi^{(0)}} = 5.86 \cdot 10^{-31}$$

$$\sigma_{\eta\gamma^{(0)}} = 2.54 \cdot 10^{-33}$$

$$\eta \rightarrow \pi^+\pi^-\gamma$$

$$\sigma_{\eta\gamma^{(0)}} = 1.22 \cdot 10^{-32}$$

$$\eta \rightarrow \pi^+\pi^-\pi^0, \pi^0 \rightarrow \gamma\gamma$$

$$\sigma_{S^*\gamma^{(0)}} = 10^{-33}$$

$$S^* \rightarrow \pi^+\pi^-$$

$$\sigma^{(0)}_{e^+e^- \rightarrow \pi^+\pi^-\gamma} = 1.07 \cdot 10^{-32}$$

$$(\text{Bremsstrahlung, initial})^*$$

$$\sigma^{(0)}_{e^+e^- \rightarrow \pi^+\pi^-\gamma} = 1.26 \cdot 10^{-33}$$

$$(\text{Bremsstrahlung, final})^*$$

$$* \text{ With input cuts } E_{\gamma_{\text{min}}} = 10 \text{ MeV}$$

$$\text{Angle}_{\text{min}} = 10^\circ$$

$$E_{\text{total}} = 1.02 \text{ GeV}$$

Progress Report

TASK B

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1 TASK B – FERMILAB PROGRAM

The major goals of task B are as follows: 1) the analysis of the E706 data taken during the 1987-88 and 1990-91 fixed target runs at Fermilab and 2) the continuation of our work within the SVX group of the CDF collaboration. The E706 part of our program will involve our continuing emphasis on the physics emerging from the charged particle tracker of which the silicon microstrip detector system, constructed by the Pittsburgh group, is a part. We are currently supporting three graduate students at Fermilab as our part of the E706 collaboration although one of the students (Weerasundara) is expected to finish his thesis work during the summer of 1992 and this slot will then be shifted to our effort on CDF. The CDF program involves a dedicated effort towards the design of a silicon vertex detector upgrade, SVX II, to be accomplished by the time of the 1995-96 collider run, and in addition we are participating in the 1992-93 collider run.

1.1 E706 - Direct Photon Production at the Tevatron

1.1.1 Introduction

Fermilab experiment E706 is designed to measure direct photon yields in the p_t range 5 -10 GeV/c with incident π/p beams between 500 - 1000 GeV/c and to study the associated jets produced in such reactions. The experiment will also measure the production of high mass ($m > 3\text{GeV}$) e^+e^- and $\gamma\gamma$ states. The experiment is being carried out by a collaboration which includes Delhi University, Fermilab, Penn State University, Michigan State University, the University of Minnesota, Northeastern University, the University of Pittsburgh, Rochester University, and more recently the University of Oklahoma and the University of California at Davis.

Figure 1 is a plan view of the elements of the E706 spectrometer located in the Meson West Laboratory. The apparatus for E706 consists of an array of silicon strip detectors (SSD's) before and after a production target, a set of proportional chambers (PWC's) and straw tube chambers located after the analysis magnet, a large liquid argon calorimeter (LAC), and a small steel/plastic scintillator forward calorimeter. The forward calorimeter is followed by a muon system provided by E672 (not shown) utilizing a toroidal magnet in conjunction with PWC's to identify muons. The LAC [2] measures the position and energy of both photons/electrons and hadrons. It has a central hole of 40 cm. diameter; this area is covered by the forward calorimeter. The SSD's together with the PWC's and straw tubes after the analysis magnet constitute a magnetic spectrometer designed to measure the momenta of charged particles in hadronic jets associated with high p_t photons. In addition the SSD's serve as a vertex detector which accurately locates the position of primary and secondary interactions in the segmented target. One major contribution of the Pittsburgh group to E706 has been the design, construction and operation of the SSD system [3].

1.1.2 Discussion of the 1987–88 Data Run

The results of the 1987–88 data run have been accepted for publication [4,5]. Weerasundara is currently finishing his thesis on the study of $\gamma + \text{jet}$ production using the 1987–88 data. A large part of the Pitt effort on E706 has been the study of the recoiling jet in direct photon production.

Figure 2 is a sketch of an E706 event viewed in the center-of-mass system of the interacting particles. The high p_t photon intercepted by the LAC provides the trigger, and this photon may be a direct photon emitted by the interacting partons or it may be a decay photon from either a π^0 or η decay in which case it is viewed as being part of a "trigger jet". Balancing transverse momentum opposite the trigger jet is a "recoil jet". In the case of both the trigger and recoil jets, the momentum of the particles assigned to those jets by a simple algorithm are summed to form the total jet momentum vectors shown in Fig. 2. The angles θ_{i1} , θ_{i2} and θ_{i3} are the space angles between the i th particle and the three candidate jet axes. The i th particle is assigned to that jet for which θ_i has the smallest value. The fragmentation variable z is defined as

$$z = \frac{\vec{p}_i \cdot \vec{P}_{jet}}{|\vec{p}_i| |\vec{P}_{jet}|}.$$

Figure 3 is a plot of the fragmentation function $(1/N)dn/dz$ for the recoil jet associated with both direct photon and π^0 production. The direct photon data are compared with predictions of the ISAJET and Pythia Monte Carlo programs [6], [7]. The π^0 data are not compared with Monte Carlo programs, the reason being that the number of Monte Carlo events that must be generated in order to achieve a high p_t photon decaying from a π^0 , the π^0 itself having fragmented from a parent trigger jet, is simply prohibitive. For the direct photon data, the agreement with the Monte Carlo programs is good and these data will be presented in a paper now in preparation.

Remaining to be accomplished in the jet analysis of the 1987–88 data is the triple differential cross section taken with respect to the p_t and rapidity of the direct photon, and the rapidity of the recoil jet. This work is well underway and constitutes Weerasundara's thesis.

1.1.3 Discussion of the 1990–91 Data Run

The 1990–91 data run represented a significant upgrade of the E706 spectrometer system and this upgrade is described in some detail in the previous DOE progress report submitted by our group which represents the period November 1, 1990 through October 31, 1991. The target used for the latter half of the run is represented in Fig. 4. Shown in this figure is the distribution of interaction vertices originating in the various parts of the production target located along the beam. Apparent are peaks corresponding to interactions in the pairs of SSD's upstream and downstream of the target proper, with the prominent peaks being located in the copper targets just upstream of the liquid hydrogen target and the beryllium

target just downstream of the liquid hydrogen. The data yield from liquid hydrogen is a small fraction of the total yield but is deemed essential when comparing production on nuclear targets with comparable production in hadron collider experiments or other fixed target experiments using liquid hydrogen.

Table 1 shows the amount of data that has been taken to date by the E706 collaboration.

E706 RUN SUMMARY		
1988 Run		
INTERACTION	EVENTS	SENSITIVITY
π -Be @ 500 GeV/c	2×10^6	0.5 events/picobarn
(p, π^+) Be @ 500 GeV/c	3×10^6	0.75 events/picobarn
1990 Run		
π -Be @ 530 GeV/c	30×10^6	8.6 events/picobarn
1991 Run		
p-Be @ 800 GeV/c	23×10^6	7.3 events/picobarn
p-H @ 800 GeV/c	23×10^6	1.5 events/picobarn
(p, π^+) Be @ 530 GeV/c	14×10^6	6.4 events/picobarn
(p, π^+) H @ 530 GeV/c	14×10^6	1.3 events/picobarn
π -Be @ 530 GeV/c	4×10^6	1.4 events/picobarn
π -H @ 530 GeV/c	4×10^6	0.3 events/picobarn
Total Number of Events = 76×10^6		

Table 1: Summary of the data taken by E706 during the 1988, 1990 and 1991 runs.

Apparent is that the quantity of data taken during the 1990-91 run is about 15 times the amount of data taken during the 1987-88 run. The University of Pittsburgh group has been active in all aspects of data taking and many aspects of the ongoing data analysis of the 1990-91 data. Included in the activities of the group have the upgrade and maintenance of the SSD hardware, the development of the charged particle tracking code and the development of Monte Carlo simulation programs against which to compare the data.

1.2 CDF

During the past year the group from the University of Pittsburgh working on CDF has consisted of Shepard, Ping Hu, Prem Singh and part of Eugene Engels who has worked principally on E706 during this period. Our activities have concentrated on the following topics:

- Detector R&D on AC-coupled silicon detectors for the SVX prime upgrade of the initial SVX detector.
- Conceptual design studies for the SVX II upgrade. This has focused primarily on physics simulation.
- Design studies and some prototype work for the SVX II readout chip.

1.2.1 Preparations for SVX prime

The SVX detector which has been installed in the B0 collision hall for the 1992 collider run (run Ia) is too radiation soft to last for both run Ia and Ib. The inner two layers (there are four altogether) will probably fail by the end of run Ia for two reasons: (1) The leakage currents are DC coupled into the readout chips and will saturate the amplifiers by the end of run Ia; (2) the readout chip SVXD is a radiation soft version and will become excessively noisy by the end of the run. To correct these problems the collaboration plans to replace the inner two layers during the break between runs Ia and Ib. The plan is to use AC coupled detectors for the inner two layers along with a radiation hard version of the readout chip. The outer two layers would remain the same because they can be expected to withstand the integrated radiation damage from both runs Ia and Ib.

We have been working to help evaluate critical features of the AC-coupled detectors from Micron Semiconductor which are going to be used for this upgrade. The principle concern is the radiation hardness of the biasing scheme for the detectors. We worked both by ourselves and with others in the collaboration to perform radiation hardness tests of the prototype CDF detectors using a Cs^{137} source located in the medical school of the University of Pittsburgh. Although there are some follow up activities still in progress, that work has been completed. We have submitted a paper in collaboration with Mikko Laakso at Fermilab to the recent silicon detector conference in Milano, Italy in February, 1992. [8] That paper will appear in Nuclear Instruments and Methods, and is included with this report. There is also a CDF note (1584) which is still in preparation which contains some additional results on similar detectors being used by the OPAL collaboration at CERN.

The work outlined above has many results of interest from the point of view of detector science, but the principal concern from the perspective of the collaboration was the viability of the detectors for run Ib. The answers were all positive. The FOXFET biasing scheme employed by these detectors can be expected to stand up to the rather significant radiation exposure of run Ib.

1.2.2 Physics Simulation Studies for SVX II

During the past year the University of Pittsburgh has taken a leading role within the CDF collaboration in organizing a conceptual design study to determine exactly what kind of silicon vertex detector CDF should propose to the laboratory for run II and beyond. The

effort has focused primarily around a set of physics simulation studies of possible detector geometries. A number of elements have had to be developed. First the Monte Carlo software tools within the collaboration were not initially suited for this task and required extensive modification. In some cases the tools were completely inadequate and new tools had to be developed. Once appropriate tools had been developed and tested, several promising geometries were decided upon. Finally a specific set of physics bench marks were picked. This work has been Ping Hu's principal activity since last summer. The intent of these activities was to generate a concrete proposal to the PAC. At this point we (Pittsburgh, University of New Mexico, Johns Hopkins, Rochester, Fermilab, Pisa) have just finished a draft of an initial report to the collaboration which will be reviewed by five CDF godparents on May 1, 1992. This is expected to lead to a progress report to the PAC in June with a full proposal in the fall.

Among the questions being investigated were issues concerning the length of the detector, single versus double-sided detectors (i.e. 2D versus 3D tracking), forward tracking in addition to central tracking, and the physics reach of the proposed detector. In order to investigate these questions five geometries were studied and they are as follows:

- G1 The present SVX geometry, with measurement of the ϕ -coordinate only. The active silicon covers a total length in z of 51 cm. There is a gap in the coverage at $z=0$ to allow for support and cable access.
- G2 A barrel geometry with 4 layers, similar to the presents SVX, but with a total z coverage of 102 cm. This geometry again has measurement of the ϕ -coordinate only.
- G3 As (G2) with both ϕ and z information.
- G4 Geometry (G2) with a forward tracking upgrade using 5 radial discs equally spaced in z from ± 55 to ± 155 cm and each extending out to 27 cm in radius.
- G5 Geometry (G3) with the same disc arrangement as (G4).

Several physics benchmarks were used to evaluate the five detector geometries. The modes were selected both as generic measurements for a vertex tracking device as well as being modes of physics interest. We have generated the following physics processes with ISAJET:

1. Top events with $m_t = 130 \text{ GeV}/c^2$ and $200 \text{ GeV}/c^2$ for the $t\bar{t}$ decays. This sample was used to study the B tagging efficiency for top events.
2. $B^0 \rightarrow \psi K_s^0$ and $B_s \rightarrow \phi\psi$ exclusive decays. These samples were used to study B reconstruction, geometric acceptance, and mass resolution.
3. $B_s \rightarrow \ell\nu D_s$; $D_s \rightarrow \ell\nu\phi\pi$ semi-inclusive semi-leptonic decays with a lepton tag on the away-side. This sample was used to study B_s mixing.

4. Exclusive $B_s \rightarrow D_s 3\pi$; $D_s \rightarrow \phi\pi$, with a lepton tag on the away-side. This sample was used for B_s mixing studies as well.
5. $B\bar{B} \rightarrow \psi K_s l X$. This sample was used for CP violating asymmetry studies and lepton tagging in B events.

The top quark potential of the detector and its ability to do B physics were the principal concerns of the study which is not yet finished. In the case of B physics the design group has concentrated principally on B_s mixing and the CP studies are only just starting. Much more work is required here. We summarize briefly some of the results of the top study and the B_s mixing study below.¹

B tagging for top decay was studied for top masses of 130 GeV/c² and 200 GeV/c². For each top mass 1000 $t\bar{t}$ events were generated for each of the three geometries, G1 thru G3. In addition the top sample at 130 GeV/c² was studied for the geometry G5. The p_t of each top quark was required to be greater than 5 GeV/c². The B tagging algorithm consisted of three cuts: (a) at least three candidate tracks within an R cone less than 0.4 of the generated B direction,² (b) $\frac{D}{\sigma_D} > 3$, (c) track $p_t > 1$ GeV/c. D is the impact parameter. In the case of the double-sided geometries G3 and G5, the impact parameter cut was replaced by a 3D displaced track cut $\sqrt{(D/\sigma_D)^2 + (Z/\sigma_Z)^2} \geq 3$. Any events which passed all three cuts were taken as B tagged. The effect of these three cuts is shown in Figs. 5-7 which plot the R, D/σ_D , and p_t distributions respectively for both tracks originating from B decay or B decay daughters and for tracks with non- B decay origins. The G2 geometry was used for these plots. Before the cuts the ratio of the number of tracks from B decay to the number of tracks with a non- B -decay origin is ≈ 0.1 . The cumulative effect of the three cuts is to change this ratio to ≈ 50 , a relative enhancement of signal to background of ≈ 500 .

The results for the B tagging efficiency are shown in Table 2. The three columns labelled ϵ_1 , ϵ_2 , and ϵ_3 respectively correspond to the tagging efficiencies under the following conditions: (ϵ_1) any track can be used provided it passes the three cuts, (ϵ_2) all three tracks must have a B -decay origin, (ϵ_3) the same as (ϵ_1) but the Monte Carlo B direction is not used in making the R cut. The point here is that the cone cut was with respect to the Monte Carlo B direction in the case of ϵ_1 and ϵ_2 , but for the case of ϵ_3 the B direction is ignored, and any three tracks with R less than 0.4 of each other are accepted. Only the last column (ϵ_3) corresponds to the experimentally realistic situation. The small differences between the three cases are an indication of the effect of background tracks and of the uncertainty of not knowing the direction of the B .

We investigated the background by looking at the 130 GeV/c² top sample with the B lifetime set to zero (but not the charm lifetime), and by studying a sample of $W + 4$ jet

¹The top analysis was done by Ping Hu and later confirmed by John Matthews from the Univ. of New Mexico. The B_s mixing analysis was done by John Skarha from Johns Hopkins and Ping Hu working independently and together.

²We also studied the case of any three tracks within an R cone of 0.4 of each other disregarding any information about the B direction (see the ϵ_3 column of Table 2.)

$m_t = 130 \text{ GeV}/c^2$			
Model	$\epsilon_1(\%)$	$\epsilon_2(\%)$	$\epsilon_3(\%)$
G1	27	27	30
G2	46	44	50
G3	57	55	63
G4			
G5			67
$m_t = 200 \text{ GeV}/c^2$			
Model	$\epsilon_1(\%)$	$\epsilon_2(\%)$	$\epsilon_3(\%)$
G1	41	41	45
G2	60	58	64
G3	68	66	73
G4			
G5			

Table 2: B tagging efficiencies for $m_t = 130$ and $200 \text{ GeV}/c^2$. The efficiencies have a statistical uncertainty of 1.5%

events. For G1, 5% of the events are tagged with the B lifetime set to zero. Since 27% of the events produced a B tag originally, this simple test suggests a background rejection of about five to one. For the $W + 4$ jet sample the tagging efficiency is 0.2% but this is artificially low because there is no bottom or charm generated. The minimum jet p_t is $8 \text{ GeV}/c$ and for a gluon jet an estimate of the gluon splitting into a $c\bar{c}$ pair is $\approx 3\%$ [9]. If we assume 3 gluons jets per event, then 9% of the events have charm and we can expect to tag 5% of these or 0.45%. This give a rejection factor of ≈ 60 .

For the models studied the biggest increase in B tagging efficiency comes from doubling the length. The effect of going to double sided detectors is less. The increase depends on the top mass. For a top mass of $130 \text{ GeV}/c^2$ the B tagging efficiency increased by a factor of 1.6 in going from G1 to G2 and by a factor of 1.3 in going from G2 to G3. The corresponding factors for a top mass of $200 \text{ GeV}/c^2$ are 1.4 and 1.1 respectively. It should be pointed out that we have not fully investigated all of the advantages of double-sided detectors. For example, in the case of 3D tracks it is possible to form vertices with two tracks which are true vertices, whereas, this is impossible with 2D tracks. This needs further investigation. Finally the addition of disks is not useful for top B tagging.

In studying B_s mixing two approaches were considered in determining the optimal decay mode of the B_s for this measurement. The most promising for a first look at X_s is requiring the semileptonic decay of both the B_s and the other B :

$$B_s \rightarrow l\nu D_s, D_s \rightarrow \phi + X; B \rightarrow l\nu + X. \quad (1)$$

This has the advantage of being able to trigger on the two leptons at low p_T and thus forces the other B to be within the detector acceptance. For this high-rate decay mode, we initially search for the ϕ near the lepton and use it to tag the presence of a B_s . Depending on the p_T and multiplicity of the D_s decay, the ϕ direction could be combined with the lepton direction to yield a good measure of B_s transverse decay length. A sample of Isajet events containing oscillating B_s mesons with $p_T(b) > 10$ GeV/c was used. The resolution on the ϕ - l transverse decay length is 86 microns in geometry G1, which is almost identical to the result obtained if the D_s is fully reconstructed in the decay $D_s \rightarrow \phi\pi$. Additional pions associated with the ϕ vertex would also be included in order to fully or more completely reconstruct the D_s . The limiting factor in a semileptonic B_s decay mode is the uncertainty in the B_s momentum since the B_s is only partially reconstructed due to the missing neutrino or the lack of a fully reconstructed D_s . On average the neutrino takes 3.4 GeV/c p_T in a semileptonic B_s decay. The missing p_T can be corrected for on average from Monte Carlo simulation and Figure 8 shows the oscillation frequency plot for $X_s = 5.0$ with a perfect B_s tag. A clean oscillation structure is seen with only ≈ 4000 events. Work continues to determine the rates and X_s reach for the semileptonic B_s decay mode.

It is anticipated that the semileptonic mode will have a limited X_s reach due to the momentum uncertainty in the partial reconstruction of the B_s decay. For this reason, a simulation of a fully reconstructable B_s decay is also being studied. The disadvantages are that the event rate will be very small because all exclusive B_s decay modes have very small branching fractions and the reconstruction efficiency will also be lower.

We are studying $B_s \rightarrow D_s\pi\pi\pi$. The branching fraction of this mode is estimated to be 1.1%. The D_s has a 2.7% branching ratio decaying to $\phi\pi$, and half of the ϕ 's will decay to K^+K^- . This kind of event will have three tracks from the B_s vertex and three tracks from D_s vertex. Since CDF does not have a secondary vertex trigger for this decay mode at this time, we have assumed that these events come from the inclusive lepton trigger, in which the lepton comes from the other B and also provides the flavor tagging.

We generated $b\bar{b}$ events from ISAJET, and selected those events with trigger B lepton $P_T > 5$ GeV/c and a B_s with the above decay mode. In order to be able to reconstruct the events, we also required all π 's and K 's to have $P_T > 0.35$ GeV/c. This decay can be reconstructed by looking for ϕ 's with displaced vertices in the event, then reconstructing D_s with the tracks coming from the ϕ vertex, and finally reconstructing the B_s with tracks from the other 3-prong vertex.

Our current study is to find out what X_s range we can explore. The key in any X_s analysis is the resolution of the measured B decay time, which in turn is decided by the B vertex and B momentum resolution. The resolution in the proper time distribution, and the X_s measurement is essentially the same in the 2D and 3D analyses. Figure 9 shows the reconstructed time-dependent oscillation plot with $X_s = 20$ for 2845 reconstructed and tagged B_s decays in this mode.

These analyses do not include sources of mis-tagging due to the mixing of the other B (if B_d or B_s) or from semileptonic charm decay, which will reduce the amplitude of the

observed oscillations. For the fully reconstructed exclusive mode, the background is expected to be very small. For the inclusive mode, the background for example from the semileptonic B-decays other than B_s into modes containing ϕ , could shift or skew the distribution in Figure 9, but will not affect the frequency or the amplitude of the oscillations.

These analyses are on-going. We will include the effects of mis-tagging and study the improvements with the extended rapidity coverage of the disc system. Since this analysis requires tagging from the other B, we expect a significant improvement in acceptance when the disk system is added. Finally, we will estimate the maximum X_s measureable as a function of luminosity. The present results suggest that initially, the lower values of X_s can be studied using semi-inclusive modes, and that at higher luminosity X_s of at least 20 can be reached with exclusive modes.

It is expected that over the next few months many of the preliminary conclusions that are beginning to emerge from this work will be hardened and that a full proposal for the SVX II detector will be submitted to the laboratory.

1.2.3 Design studies for the readout chip for SVX II

Part of the effort in the SVX II conceptual design study group has been to identify some of the design issues for the SVX II readout chip. The analysis below was made by Shepard.

The readout electronics for the SVXII detector has to satisfy a number of demanding constraints. They include:

- Good signal to noise which should not degrade after one fb^{-1} to less than 12:1 for detector capacitance in the range 20 to 40 pF.
- Radiation hard to the level of 1.0 Mrad which corresponds to an integrated luminosity in excess of 2 fb^{-1} .
- Risetime and shaping times compatible with Main Injector luminosities of the order $10^{32} \text{ cm}^{-2}\text{sec}^{-1}$ and bunch separations as short as 132 ns.
- Multi-event pipelining of 1.2 μs duration for formation of the level 1 trigger.
- Rapid sparsification, digitization and readout of data ($< 5\mu\text{s}$) for use in level 2 vertex/trigger processors.
- Power dissipation constraints imposed by mechanical and cooling design limits.
- A minimum number of control signals involving high speed clocks which can produce noise in other parts of the detector. The exception would be fiber optic control signals.

We discuss their implications for the design of the SVX II readout chip located on the detector ladders (either barrels or disks). The discussion is intended to be generic and not to fix a specific design.

Tevatron Parameters and Design Implications

The RF bunch structure expected for the Main Injector era is shown in Table 3. The

Quantity	Value
Circumference	6.283185(3) km
Single-turn period	20.9586 μ s
Number of RF buckets	1113
RF period	18.831 ns
RF frequency	53.105 MHz
99-Bunch Collider Operation	
Number of super groups of populated bunches	3
Populated bunches per super group	33
Number of groups per super group	3
Populated bunches per group	11
Interval between populated bunches	7 RF periods = 131.8 ns
Interval between groups	21 RF periods = 395.4 ns
Length of populated group	70 RF periods = 1318 ns
Length of populated super group	3×70 RF periods + 2×21 RF periods = 252 RF periods = 4745 ns
Length of empty interval	119 RF periods = 2241 ns

Table 3: Tevatron parameters governing timing of bunch crossings

interval between RF bunches will be 132 ns. The filled ring consists of 3 equally spaced super groups. Each super group is composed of 33 filled RF bunches, and there are three groups of eleven within each super group. The bunches within each group of eleven are seven RF bunches or 132 ns apart. Between each group of eleven are two empty slots resulting in an interval of 395 ns between beam crossings from one group of eleven and the next within a super group. Below we explore the demands of this RF structure on the design of the front end electronics for the SVX II detector at luminosities of $L = 2 \times 10^{31} \text{ cm}^{-2}\text{sec}^{-1}$ and $L = 1 \times 10^{32} \text{ cm}^{-2}\text{sec}^{-1}$.

A key parameter in defining the design of the front end electronics is the occupancy of the SVX. The discussion given here is based on an occupancy of 2% per interaction at layer one for the present SVX. Since there are considerable uncertainties in estimating this number, it should be determined for the present SVX as soon as possible. Our estimates are based

on studies of track multiplicity in the CTC for jets with $p_t > 20$ GeV/c. These jets have an average multiplicity of 60 charged tracks visible in the CTC. At layer one there are 12 wedges with 256 strips/wedge or 3072 strips which gives an occupancy of $60/3072 \approx 0.02$. There are many corrections to this simple calculation, but it can be argued that they roughly cancel. First there are two barrels so we should divide by two, but the SVX sees many more high η tracks so we take this as a canceling effect. The average interaction is not as hard as the sample studied again by roughly a factor of two, but we have not included any factors for loopers or clustering. Again this a canceling effect. We assume an occupancy of 2% for this discussion, and it is relatively easy to reevaluate the results of the discussion with a different occupancy.

The contamination of the analogue signals from pile-up effects due to luminosity and occupancy at $L = 2 \times 10^{31} \text{ cm}^{-2}\text{sec}^{-1}$ and $1 \times 10^{32} \text{ cm}^{-2}\text{sec}^{-1}$ respectively are shown in Table 4. The second column indicates the fraction of the time there are zero, one, two, etc. beam crossings between events as given in column one. In the case of the lower luminosity the average number of beam crossings between interactions is five, while for the higher luminosity it is one. The third column gives the product of the second column and the expected occupancy (0.02). Thus, the third column represents the fraction of the time a strip from the current interaction would have been occupied from a previous interaction where the previous interaction occurred a number of beam crossing before as given in column one. The seriousness of these overlaps depends on the shaping characteristics of the front end electronics. If we assume semi-gaussian shaping of the form $CR - RC^4$ with a peaking time of 250 ns, the fourth column gives the amount of tail from a shaped pulse in % for a previous hit where the previous pulse occurred earlier by the number of beam crossings shown in column one. We have assumed that all pulses have the same amplitude. As one can see the effect of any tail is less than 1% after five beam crossings. The last column summarizes the information in columns three and four. These pulse overlap effects appear not to be serious at the lower luminosity. Only 1/2% of the tracks have analogue contaminations of 10% or more from previous interactions or 99.5% of the tracks have contaminations of less than 4%. The situation at the higher luminosity is degraded, but it is probably acceptable. Two percent of the tracks have contaminations greater than 10% while 98% of the tracks have contaminations less than 4%. The higher luminosity is at the edge of a range of luminosities where the overlap between events is dominated by the net occupancy per crossing which in turn will be determined by the number of interactions/crossing.

SVX II Chip Architecture

An overview of a possible design architecture for the SVX II readout chip is shown in Fig. 10. The electronics for each channel has three principle elements: (1) An input amplifier/shaper; (2) an analogue pipeline to hold the analog information during the formation of a level zero trigger; and (3) a comparator/ADC/latch stage to digitize the data for subsequent sparse readout. Some possibilities for implementing these elements are discussed below in more detail. Here we discuss some general requirements. A brief list of these requirements is also shown in Fig. 10.

$L = 2.0 \times 10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$				
Crossing	Fraction	Contaminated Fraction	% (n=4) Contamination	Summary
0	0.007	1.4×10^{-4}	100	
1	0.034	6.8×10^{-4}	70	$\approx \frac{1}{10}\%$ of tracks have $> 70\%$ contamination
2	0.084	1.7×10^{-3}	30	$\approx \frac{1}{4}\%$ of tracks have $> 30\%$ contamination
3	0.14	2.8×10^{-3}	10	$\approx \frac{1}{2}\%$ of tracks have $> 10\%$ contamination
4	0.18	3.6×10^{-3}	4	$\approx 99.5\%$ of tracks have $< 4\%$ contamination
5	0.18	3.6×10^{-3}	< 1	$\approx 99.1\%$ of tracks have $< 1\%$ contamination
6	0.15	3.0×10^{-3}		
7	0.10	2.0×10^{-3}		
8	0.065	1.3×10^{-3}		
$L = 1.0 \times 10^{32} \text{ cm}^{-2} \text{ sec}^{-1}$				
0	0.37	7.4×10^{-3}	100	
1	0.37	7.4×10^{-3}	70	$\approx 1.5\%$ of tracks have $> 70\%$ contamination
2	0.18	3.7×10^{-3}	30	$\approx 1.9\%$ of tracks have $> 30\%$ contamination
3	0.061	1.2×10^{-3}	10	$\approx 2\%$ of tracks have $> 10\%$ contamination
4	0.015	3.0×10^{-4}	4	$\approx 98\%$ of tracks have $< 4\%$ contamination
5	0.003	6.0×10^{-5}	< 1	

Table 4: Analogue contamination from earlier interactions at two luminosities

The chip should have 128 channels/chip, a feature of the present SVX chips. It should accommodate AC coupled detectors with a strip pitch of 50 microns. Ultimately a rad hard implementation is required. An approximate power consumption per channel of < 4 mW is desirable as this is within the capability of the cooling technology used for the present SVX detector. The SVX II chip should be able to support a level two trigger processor. At present concepts for a level two secondary vertex trigger are being pursued. These approaches require that digitized data be available to a level two processor within $5 \mu\text{s}$. For this reason the SVX II architecture has an ADC on every channel. Eight bit precision should accommodate a dynamic range of ten minimum ionizing particles and not limit the signal to noise of the input amplifier. Although difficult to achieve, a signal to noise ratio of twenty to one is a desirable design goal. Such a signal to noise ratio can be achieved with an input capacitance of 20 pF and a rise time adequate for a four pole shaper with a peaking time of 250 ns (see below). In any case the signal to noise should not degrade to less than 12:1 for integrated

luminosities in excess of one fb^{-1} .

A good signal to noise ratio and a suitably fast risetime depends on the front end amplifier having an input transistor with a large transconductance. Although various design options are possible we present the results of a spice simulation for a continuous time amplifier and shaper. The input capacitance was taken to be 20 pF and the charge sensitive input amplifier had an input transconductance $g_m = 5\text{mS}$ followed by a four pole semi-Gaussian shaper with pole zero cancellation. A schematic of this approach is shown in Figure 11 along with the simulated signal from the input amplifier and the signal at the output of the shaper. Assuming that the flicker noise is not excessive, the theoretical equivalent noise charge from this amplifier-shaper is less than 1000 electrons.

An important question is the additional noise contributed by the leakage currents in the silicon detectors which continue to grow due to bulk radiation damage to the silicon. If we assume measured damage coefficients for silicon and that one fb^{-1} corresponds to approximately 0.4 Mrads of high energy charged hadrons at layer one, then a 17 cm silicon strip (two SVX detectors) from a 300 micron thick detector with a 50 micron pitch will develop a leakage current of approximately $1.2\text{ }\mu\text{A}$ after an integrated luminosity of one fb^{-1} . This will increase the equivalent noise charge of the amplifier-shaper described above to ≈ 1300 electrons which is acceptable.

During the past year we have continued to pursue the development of electronic prototypes using the MOSIS service in California. Fig. 12 shows the layout of a simple folded cascode continuous time amplifier which we have been studying and which forms the basis of part of the discussion given above. We are continuing to pursue this design. We have also been looking at possible alternatives to analog pipelining (see Fig. 10). One possibility is to digitize the data immediately after the shaper and then use a digital pipeline. This would require a flash ADC and we have been looking at this possibility. A layout of a 4-bit flash ADC is shown in Figs. 13 and 14. We have received our first chips from MOSIS and their evaluation is in progress.

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E706 Spectrometer

Figure 1: A Plan View of the E706 Spectrometer

Figure 2: A sketch of a photon + jet event in the center-of-mass system of the interacting hadrons.

Fragmentation Functions

Figure 3: The fragmentation function $1/N \, dn/dz$ plotted as a function of the variable z . (a) and (b) show the data for direct photon production and (c) and (d) show the data for π^0 production. The photon data are compared with ISAJET and Pythia Monte Carlo predictions.

Figure 4: A plot of the vertex distribution along the beam line of the events produced in the target region.

Figure 5: Distribution of ΔR with respect to the B direction for tracks from B decay and B daughter decay (solid) and non- B decay (dashed).

Figure 6: D/σ_D distribution for tracks from B decay and B daughter decay (solid) and non- B decay (dashed).

Figure 7: Transverse momenta distribtuion for tracks from B decay and B daughter decay (solid) and non- B decay (dashed).

Figure 8: Oscillation plot for semileptonic B_s decay with $X_s = 5.0$.

Figure 9: Oscillation plot for $B_s \rightarrow \pi\pi\pi D_s$, $D_s \rightarrow \phi\pi$ decay with $X_s = 20.0$.

SIMPLIFIED SVXII BLOCK DIAGRAM

POSSIBLE SINGLE CHANNEL ARCHITECTURE FOR 95-97 RUNS

DESIGN GOALS

* 128 CHANNELS/CHIP	* DYNAMIC RANGE 10 MIPS
* 4 MW/CHANNEL	* DIGITIZED DATA AVAILABLE FOR LEVEL 2
* RAD HARD	* DATA SPARSIFICATION
* 250 NS PEAKING TIME	* 50 MICRON PITCH
* DETECTOR CAPACITANCE 20 PF AC COUPLED	* SIN = 20:1

Figure 10: Design architecture of the SVX II readout chip

Figure 11: Front end amplifier and shaper

Figure 12: Layout of front end amplifier under study for use in SVX II upgrade.

Figure 13: Tiny chip layout of a 4-bit flash ADC. The chip has two channels.

Figure 14: Enlargement of one cell of the ADC.

Appendix

TASK B

*papers removed and
cycled separately -*

END

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