

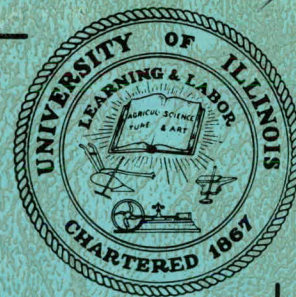
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MASTER

ANNUAL PROGRESS REPORT

to

UNITED STATES
DEPARTMENT OF ENERGY



Contract No. EY-76-C-02-1195

Department of Physics
University of Illinois
at Urbana-Champaign
Urbana, Illinois

Key Personnel: A. Wattenberg
R. O. Simmons

Submitted March 1979

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
DEPARTMENT OF PHYSICS
URBANA, ILLINOIS 61801

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

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I. SUMMARY OF SCOPE AND PURPOSE OF THE PROJECT

The University of Illinois programs in Elementary Particle Physics are carried out at various high energy particle accelerators and at the Urbana Campus. As mentioned in earlier progress reports, we are moving towards experiments at increasingly higher energies, including the use of colliding beam facilities. We are collaborating with groups from SLAC, Santa Cruz, and Seattle in the development of the Mark III detector to be used at SPEAR to study charmed particles and τ leptons. We are also involved with the colliding beam detector for Fermilab. Plans are also being developed for the future for higher energy neutrino experiments at Fermilab as we are now terminating the neutrino program at Brookhaven. Analysis of the neutrino experiments is still in progress and we are also analyzing the results of neutral beam experiments at Fermilab and production of states containing charmed quarks at Fermilab. Currently photoproduction experiments at Fermilab are continuing. We are also involved in a search for the η_c at Brookhaven and during the forthcoming year, we are scheduled to have new runs on the pion production experiments at Fermilab.

As in previous years, we find the most concise way to summarize our program is in the form of two lists of activities, one for the present program and one for the future program. These follow.

Highlights of the Program in FY79

1. We are analyzing data from the $\pi^- p$ run, Experiment 369 at Fermilab, and we are observing the χ_c state decaying to $\gamma + \psi$.
2. We are building new detectors for an improved study of these states in Experiment 610 at Fermilab.
3. A search for long-lived massive states (associated with the T) set a limit of about 10^{-8} seconds for the lifetime of more massive particles.
4. We are collaborating on a short experiment, BNL732, to look for the production of η_c by pions.
5. Data from the photoproduction of multi-hadron states (Fermilab E87A) is being analyzed. The results on the photoproduction of charmed mesons are consistent with the theoretical estimate of the photoproduction cross-section being about 500 nb.

6. In the photoproduction data from E87A at Fermilab, we are seeing the production of states that were supposed to be suppressed by Zweig's rule. We are not seeing theoretically proposed four-quark (exotic) mesons.
7. We are currently running (E401 at Fermilab) a high intensity photoproduction experiment, mainly studying the production of two-body states.
8. The neutrino experiment at BNL studied the neutrino reactions from a beam-dump. Our result is that we find no anomalous events.
9. We have joined the collaboration on the Mark III detecting facility at SPEAR.

Highlights of the Program in FY80

1. We will be taking data on the pion production of the charmed meson χ_c^3 states (χ_c) at Fermilab in Experiment 610.
2. We will be continuing the program of high intensity, high energy photoproduction at Fermilab using the broad band neutral beam. We will also be analyzing the data obtained in the runs currently in progress.
3. We will be completing the analysis of the neutrino experiments previously run at Brookhaven National Laboratory.
4. We will be beginning to plan future high energy neutrino experiments at Fermilab.
5. We will be building, testing, and installing the muon detector for the Mark III facility at SPEAR.
6. We will be joining a collaboration to design and build a detector for colliding beams at Fermilab.

II. PERSONNEL

In this section are listed the names of Senior Staff members and graduate students who are or will be involved in the Elementary Particle Physics Program at the University of Illinois in Urbana-Champaign.

Personnel who are or will be actively engaged in physics experiments in this program are:

1) Faculty members with the rank of Assistant Professor or higher:

Ascoli, G.	Kruse, U. E.
Brown, R. M.	O'Halloran, T. A.
Eisenstein, B.	Sard, R. D.
Gladding, G.	Thaler, J. J.
Holloway, L.	Wattenberg, A.
Koester, L. J.	

2) Senior Staff members holding research or professional appointments: (Research Associates, Research Assistant Professors, Research Physicists, or Engineers)

Bross, A.	Kohlmeier, J.
Butler, J.	Shupe, M.
Cooper, S.	Simaitis, J.
Cooper, J.	Wiss, J.
Downing, R.	Wray, J.
Elliott, J.	

3) Graduate Students (part time Research Assistants, Fellows, and Programmers):

Alverson, G.	Garren, L.	Nienaber, P.
Avery, P.	Goodman, M.	Olszewski, C.
Becker, J.	Graff, T.	Richardson, D.
Bender, D.	Hahn, S.	Russell, J. J.
Budd, H.	Lamm, M.	Schoessow, P.
Callahan, P.	Lesny, D.	Smith, E.
Fuess, S.	Lufkin, J.	Spadafora, A.
	MacKay, W.	Virkus, R.
		Wroblecka, W.

4) There are theoretical physicists at the University of Illinois whose main area of interest is Elementary Particle Physics. The interaction of these physicists with the experimentalists is of great value to the High Energy Physics Experimental Program. Members of this group are:

Bodwin, G. T.	Schult, R.
Chang, S. J.	Stack, J.
Jones, L. M.	Sullivan, J.
Kogut, J.	Weiss, N.
Ravenhall, D.	Wright, J.
	Wyld, H. W.

A. Technical Accomplishments During This YearA.1. Charm Search, ψ Production, and Pion Dissociation Using 215 GeV Pions

(G. Ascoli, J. Cooper, L. Holloway, L. J. Koester, U. E. Kruse, R. D. Sard, M. Shupe, G. Alverson, D. Bender, H. Budd, S. Hahn, W. MacKay, E. Smith, in collaboration with Harvard University, Oxford University and Tufts University physicists)

During Fiscal Year 1979 the analysis of FNAL 369 continued and results on the production of $\mu^+\mu^-$ with γ rays were submitted for publication. During the year the various programs for analyzing charged particles and identifying μ mesons were combined with programs analyzing γ rays in the lead glass detector. A peak in the $\mu^+\mu^-$ spectrum corresponding to ψ decay was found and γ rays associated with these ψ 's were then studied. A peak above background in the χ region for $\psi\gamma$ masses was found and analyzed. The results, reported in the thesis of G. O. Alverson and submitted for publication in Physical Review Letters, suggest that a large fraction of the ψ 's are produced through the process $\pi^-p \rightarrow \chi$ with subsequent radiative decay of $\chi \rightarrow \psi\gamma$ to form the ψ 's. Because of the limitations in statistics in FNAL 369, a new proposal was submitted to extend the data sample. This new experiment was approved as FNAL 610 (see B.1.).

The other data of FNAL 369 are still being analyzed with special emphasis on the search for charm production. To this end we are studying the results from the Cerenkov counters (looking for K^+ and K^-) and the charged particles (looking for K^0 decays).

In preparing for FNAL 610, major revisions in the experimental equipment are anticipated and design or construction work has taken place for new multiwire proportional chambers, lead glass γ ray detectors, and an improved Cerenkov counter array. The first new multiwire proportional chamber was assembled and tested. In the central region, the chamber was found to be working very well but difficulties were found at the edges. The first chamber has therefore been modified with new guard wires at the edges and will be tested in February 1979. A winding machine on loan from Harvard University was modified and assembled at the University of Illinois and the frames for two more chambers have been wound. In order to increase the detection efficiency and improve the γ ray resolution, the lead glass detector was redesigned and the new components have been ordered. Prototypes of proportional detectors to be used with the new lead glass array are being tested. It is hoped that these proportional detector arrays will give improved spatial resolution for the γ rays. The Cerenkov counter will be

lengthened for FNAL 610 to improve the detection of charged K mesons. The new size has been fixed and tests of the new optics are being carried out. While these improvements are being carried out at the University of Illinois, our collaborators at Fermilab are modifying the 80 cm x 80 cm multiwire proportional chambers to give improved efficiency and spatial resolution and are also building new drift chambers to replace the spark chambers used in FNAL 369.

A.2. AGS Experiment 732: Search for the η_c

(J. Thaler and L. Garren, with collaborators from Princeton University and Brookhaven National Laboratory)

The η_c remains the greatest single enigma in the realm of $c\bar{c}$ spectroscopy. If it has been seen, it has a much lower mass than expected. We are performing an experiment to search for the process $\pi^- p \rightarrow \eta_c n (\eta_c \rightarrow \gamma\gamma)$. This complements the searches performed at e^+e^- storage rings, being sensitive to a greater range of masses and lifetimes but depending on a specific production mechanism. This experiment was proposed in October 1978, and approved in November. Data taking began in February 1979, and lasted until the AGS shutdown in March. The Illinois group provided a photon veto array of lead-scintillator shower counters to reject background from $\pi^- p \rightarrow \pi^0 \pi^0 n$. We also provided an LSI-11 computer for CAMAC diagnostics and communication with the OLDF PDP-10 at the AGS.

Whether more data taking is needed in FY80 depends on the results of the February run now being analyzed. If all goes well, additional data will not be needed.

A.3. Fermilab Experiment 469: A Search for Long Lived Heavy Particles

(J. Butler, in collaboration with physicists from Brown University, Fermilab, Istituto di Fisica and Istituto Nazionale di Fisica Nucleare in Bari, Italy, Massachusetts Institute of Technology, and the Institute of Nuclear Research in Warsaw, Poland)

This experiment searched for new long-lived (lifetime $> 5 \times 10^{-8}$ sec) particles with masses between 4 and 8 GeV/c^2 using time-of-flight and Cerenkov counter technique. While this kind of search has been performed at high energies before, this particular one was the first to achieve sensitivities comparable to the cross sections expected for the new family of particles associated with the recently discovered T (9.4). The experiment produced information on the stability of these particles with respect to the weak interaction.

Our failure to observe these particles has been widely interpreted as evidence that they decay by the weak interactions to normal elementary particles.

Such decays are neither forbidden nor required by weak interaction theory.

From a technical standpoint this search represented an improvement of a factor of ~ 1000 over previous searches of this kind. In addition to the search aspect, we simultaneously studied the production in high energy collisions of the following nuclei and anti-nuclei: deuterons, anti-deuterons, tritons, anti-tritons, helium 3, helium 4, and anti-helium 3.

A proposal has been submitted to Fermilab (E497) to try to improve the lifetime limit. Such data would be useful in evaluating the generalization of Cabibbo angles to heavier quarks. (As for example in the theory of Kobayashi and Maskawa, Prog. Theor. Phys. 49, 652 (1972).)

A.4. A Study of Reactions Producing a Fast Forward Neutron in $\pi^- p \rightarrow nX^0$ at 8 GeV/c
(B. Eisenstein, J. Elliott, W. T. Wroblecka, in collaboration with the University of Chicago)

The University of Illinois-Argonne National Laboratory streamer chamber facility was originally developed for a series of experimental studies of baryon exchange processes. The analysis of the data on the last studied reaction, $\pi^- p \rightarrow nX^0$, is now essentially completed.

FY79 saw the publication of the data on the reaction $\pi^- p \rightarrow n\pi^+\pi^-$, ^{1/} in which we analyzed the final states $n\rho^0$, nf^0 , and $\Delta^-\pi^+$. This was the first published data on this reaction at an energy significantly above the resonance region.

Work continued on several other reactions. The study of the final state $n\pi^+\pi^-\pi^0$ was abandoned because the experimental resolution was inadequate to cleanly separate these ("0-constraint") events from others with a neutron and two charged particles. Similarly, we terminated the study of events fitting the final state $n\pi^+\pi^+\pi^-\pi^-\pi^0$ because of the virtual impossibility of extracting information about various final state channels.

Our effort was concentrated on completing the study of $\pi^- p \rightarrow n\pi^+\pi^+\pi^-\pi^-$, which was found to represent a mixture of many channels including, for example, $N^*\pi^+\pi^-$, $\Delta^0\pi^+\pi^-$, $n\pi^+\pi^-\rho^0$, $\Delta^-\pi^+$, and others. The multiplicity of final states, combined with the kinematic overlap between 2- and 3-body meson and/or baryon resonances, has made the untangling of these various channels difficult and

^{1/}B. Eisenstein, J. Elliott, W. T. Wroblecka, et al., Backward Resonance Production in $\pi^- p \rightarrow n\pi^+\pi^-$ at 8 GeV/c, Phys. Rev. D18, 1370 (1978)

tedious. Some qualitative results have been presented.^{2/}

A.5. Proportional Hybrid Bubble Chamber Experiments

(R. D. Sard, J. W. Cooper, R. L. Plumer, in collaboration with the International Hybrid Spectrometer Consortium - Brown University, Johns Hopkins University, Illinois Institute of Technology, University of Illinois, Massachusetts Institute of Technology, Indiana University, Rutgers/Stevens, Tennessee/Oak Ridge, Yale/Fermilab, plus the Universities of Nijmegen/Cambridge/Mons/Padua/Pavia/Trieste/Rome/CERN, and Tel-Aviv/Technion/Weizmann)

The results of the erstwhile bubble chamber collaboration are now being published.

A.6. Hadron Induced Dimuon Production at Fermilab

(J. Thaler, in collaboration with groups from the University of Chicago and Princeton University)

In the past year Fermilab Experiment 444 was completed. We obtained measurements of the high mass dimuon continuum production and ψ production by 225 GeV π^+ , π^- , p^- , and K^+ beams. We also obtained limits for T production.

The production of non-resonant dimuons constitutes a test of the QCD theory of hadronic structure in the context of the Drell-Yan model. The measurement of the ratios of π^+ to π^- and p to π^- induced cross-sections, the x_F dependence of the cross-sections, and the helicity angle distributions are all in agreement with the theory. On the basis of this agreement, we have extracted from the data the first measurement of the distribution of the quark inside the negative pions.

The high statistics measurement of ψ production (10^5 events) confirms the hadronic nature of the ψ . Isotopic spin is conserved and there is only a small t -channel polarization.

We saw no evidence for T production above the Drell-Yan dimuon continuum. This result is not in disagreement with other measurements at 200 GeV.

^{2/} B. Eisenstein, J. Elliott, W. T. Wroblecka, et al., Baryon Resonance Production via Positive Virtual Baryon Exchange; to appear in Proceedings of IV European Antiproton Symposium, Strasbourg, France, June 1978.

The results of this experiment have been published in three Physical Review Letters papers; Nuclear Instruments and Methods articles describing some features of the electronics have been submitted; and a comprehensive paper describing the whole experiment is in preparation.

A.7. Multi-Hadron Events Produced by High Energy Photons at Fermilab

(J. Butler, G. Gladding, T. O'Halloran, A. Wattenberg, J. Wiss, P. Avery, M. Goodman, J. Russell, in collaboration with groups from Columbia University and Fermilab)

Data taking for Experiment 87A was completed during May 1978. This experiment used the broad-band photon beam at Fermilab to study the photoproduction of multi-hadronic events, with an emphasis on production of charmed states. The apparatus, previously described, provided large aperture tracking and momentum analysis, kaon and photon identification and reconstruction as well as muon identification.

The emphasis of the data analysis effort of FY79 was on finding or establishing upper limits for the photoproduction of charmed meson and baryon states. The baryon analysis consisted of looking for the $\Lambda\pi^+$, $\Lambda\pi^+\pi^-\pi^+$, $p K_S^0$, and $p K^-\pi^+$, decay modes of the expected lowest-lying charmed baryon, the Λ_c^+ (2.26). Preliminary results on this search were reported at the 1978 Tokyo conference. Work is in progress to improve our V^0 identification algorithm, which should improve our acceptance for these states.

Our search for the photoproduction of charmed mesons has concentrated on the $K^-\pi^+$, $K_S^0\pi^+\pi^-$ decays of the D^0 (1863) and the $K^-\pi^+\pi^+$, $K_S^0\pi^+$ decays of the D^+ (1868). In order to reduce the data to a manageable size, we have restricted our analysis to events with two oppositely charged kaons, identified by the Cherenkov counters, or events with a single charged K and a K_S^0 . Such a procedure is justified if D mesons are photoproduced in pairs. Preliminary analysis based on the possible observation of a signal in the $K^-\pi^+$ decay mode indicates that charmed mesons are produced at roughly the .5 mb level, in approximate agreement with theoretical expectation.

We have begun processing the larger data sample consisting of events with a single K_S^0 or charged K in order to search for D mesons in a purely inclusive manner. The observation of D's without the requirement of another kaon in the event would greatly strengthen our results and make the cross section estimates less model dependent.

Finally, we have begun to develop the capabilities of the lead glass

shower detector array and the longitudinally segmented active target. Both devices have proved useful in cleaning up our diffractive data sample, allowing us to cleanly observe diffractive photoproduction of the ρ' (1600) decaying into $\pi^+\pi^-\pi^+\pi^-$ and $\pi^+\pi^-$. For the ρ' study, the shower detector is used to veto events containing excess neutral energy, while the active target is pulse height analyzed in order to veto events with secondary interactions or with additional wide angle tracks escaping detection in the spectrometer. In addition, we have used the lead glass shower array to observe production on states decaying into neutrals. These include: diffractive production of the ω and ϕ decaying into $\pi^+\pi^-\pi^0$, inclusive production of $\Sigma^0 \rightarrow \Lambda$ and $\eta \rightarrow \pi^+\pi^-\pi^0$. We have also set preliminary upper limits on η_c production via photoproduction of $\psi(3095)$ with a subsequent decay, $\psi \rightarrow \gamma \eta_c$ with $\eta_c \rightarrow 4\pi$ 6π .

A.8. Photoproduction of Two Particle States at Fermilab

(J. Butler, G. Gladding, A. Wattenberg, P. Callahan, in collaboration with a group from Fermilab)

In FY79, we have installed all the additional detectors to the Experiment 87A spectrometer which are necessary in order to perform Experiment 401.

In order to improve our knowledge of the interactions the target, we have installed a 44 scintillation counter hodoscope which is capable of measuring the vertical (bend-plane) coordinate of particles emerging from the target, to 1 mm, and a recoil detector consisting of 30 scintillation counters and 12 Lucite Cherenkov counters which detect particles emerging from the liquid target at large angles. We have also added an array of 16 scintillation counters immediately downstream of the large gas Cherenkov counter in order to allow us to trigger on heavy particles (p and K) in the "inner detector" (i.e., which accepts particles passing through all 5 MWPC planes and both analyzing magnets).

In order to improve our "outer detector" (i.e., which accepts particles passing through only the first analyzing magnet and the first 3 MWPC planes), we have installed a bank of 6 scintillation counters which will be used to trigger on outer tracks and a 14 element lead-scintillator electromagnetic shower detecting array which will be used to identify those outer tracks which are electrons.

We are currently in a "startup" phase of the experiment which includes testing and calibration of the detectors as well as preliminary trigger studies. We hope to complete the low mass vector meson (ρ , ω , ϕ) photoproduction studies from hydrogen as well as our running on the other hadronic final states (e.g., $\bar{p}p$, $K\bar{K}$, $K\pi$, etc.) before the scheduled three-week shutdown in March 1979. We expect to return, then, either in the spring or summer of 1979 to complete the high intensity phase of our experiment which concentrates on $\mu\mu$, ee , and μe

final states.

A.9. Production of States Containing ϕ Mesons

(M. Goodman, J. Butler, G. Gladding, T. O'Halloran, A. Wattenberg, J. Wiss, P. Avery, J. Russell, in collaboration with groups from Columbia University and Fermilab)

The Zweig rule (OZI rule) or the "continuity of quark lines" played a very important role in explaining the decay of the ϕ meson, the ψ meson, and the associated states of the $c\bar{c}$ system. When first proposed, it was an ad hoc assumption. It is now being looked at more carefully by theorists and there are very important connections between Regge exchanges and/or models which include gluon exchanges. There is a great deal of interest in better experimental information on the applicability of the rule. Okubo has pointed out a series of states coupled to photons which should be depressed in their production because of the Zweig rule. These are states containing ϕ mesons.

We are in an excellent position to study the production of states containing ϕ 's and KK mesons in the photoproduction experiments at Fermilab due to the existence of two Cherenkov detectors with good discrimination capabilities. We have been using the data from the 87A runs to obtain ratios of states such as $\phi\pi\pi$, KK, $\pi\pi$, $\omega\pi\pi$, and similar states also containing π^0 mesons. We are able to experimentally establish that the observed events are directly produced by photons; they are diffractively produced with no other particles present. In several cases we are finding that the suppression of meson states accompanied by ϕ 's, instead of being a factor of 100 as expected from Zweig's rule, are only about a factor of 3. The analysis is still in progress and it should be completed this summer. The implications of these results will be of value in predicting the production of mixed states involving more massive quarks.

There has been renewed theoretical interest in regard to the existence of exotic meson states, as, for example, those containing two quarks and two anti-quarks. In some cases the models, such as that of Lipkin and Close, predict a significant production by photons of four quark states that have not previously been looked for or observed. Specifically, it is expected that one of these exotic states would decay a reasonable fraction of the time into a ϕ and π^0 . We have looked for this state and have normalized our data to ω production. We find that the ratio we are obtaining (a few background events) relative to what was predicted is down by a factor of at least 100. A report on this will be given at the APS meeting in Washington.

A.10. Neutrino Interactions

(A. Bross, R. M. Brown, T. O'Halloran, S. Fuess, P. Nienaber, R. Virkus,
in collaboration with Columbia University and Brookhaven National Laboratory)

The primary goal of this experiment is the study of neutrino induced neutral current interactions in the elastic and single pion channels. Data taking concluded in May 1978, and we are now in the data processing stage of the experiment.

The experiment consists of twenty-two 6 ft x 6 ft thin plate optical chambers interspersed with twenty planes of plastic scintillator. The fiducial volume was five tons. The fiducial volume was followed by a muon identifier consisting of iron toroids and 8 ft x 8 ft aluminum spark chambers. No trigger was utilized and a picture was taken each pulse. Each frame is automatically digitized using the University of Illinois DOLLY system. The procedure has been compared with manually scanned film and is completely reliable. The digitized data then pass through a pattern recognition program which has been compared with manually scanned film and has also been found to be completely reliable. The film load consists of 700K $\bar{\nu}$ pictures (1.4M pulses) and 500K ν pictures. The processing of the $\bar{\nu}$ film through the physicists scan will be finished by mid-April 1979, and the ν film will be processed by mid-summer 1979. The final analysis will conclude during FY80.

In addition to the analysis for elastic and single pions, a beam dump experiment was conducted using the apparatus described earlier. The running consisted of two modes: a bare target mode and a beam dump mode. The bare target mode consists of a 15cm x 30cm x 30cm Cu target approximately 60m upstream of the usual iron shield. The flux incident on the apparatus consists of ν 's and $\bar{\nu}$'s originating from π and K meson decays. The second mode is the beam dump mode where the target is placed at the iron shield and if there are short lived sources of neutrinos, they will be a significant source of the beam. The experiment was done with 4.7×10^{18} protons incident on the beam dump and 1.9×10^{17} incident on the bare target. The conclusions of the experiment consist of a comparison between the bare target and beam dump data and are summarized below:

- a) There is no significant increase in the ratio of neutral current to charge current interactions.
- b) There is no significant change in the ratio between ν_{μ} and $\bar{\nu}_{\mu}$ induced events in the beam,
- c) There is no enhancement of ν_e or $\bar{\nu}_e$ induced events.
- d) There is no γ signal in the data.

The first 3 results indicate that we have not seen charm production in this data and reinforce the conclusion reached by CERN at higher energies. The final result would put a limit on axion production of $\sigma_{\text{prod}} \cdot \sigma_{\text{int}} \leq 5 \times 10^{-68} \text{ cm}^4$ at

the 90% confidence level.

We have concluded our running at the AGS. At the present time we are in the midst of preliminary calculations for a proposed instrumented beam dump experiment which will search for new types of neutrinos. It is anticipated that the proposal will be submitted to Fermilab, but the plans are too preliminary to warrant a detailed discussion at this time (February 1979).

A.11. Inclusive Hadron Production by Neutrinos at Fermilab

(B. Eisenstein, L. Holloway, and others, in collaboration with Harvard University, University of Chicago, and University of Michigan)

Our original proposal to study neutrino induced neutral current interactions at Fermilab using an iron/liquid argon calorimeter was repropoed as a Tevatron neutrino experiment studying both charged and neutral currents. The apparatus was reconfigured as a set of iron/liquid argon calorimeters, each of which was followed by a magnetic spectrometer for muon momentum measurement. When Fermilab decided not to support any such experiments at this time, we felt that it would be appropriate to wait until funding for fixed target physics with the Tevatron was better defined and to then reconsider resubmitting a proposal. In the interim we are continuing to upgrade the design of the apparatus.

A.12. Iron/Liquid Argon Calorimeter Development

(B. Eisenstein, L. Holloway, W. T. Wroblecka, in collaboration with Fermilab, Harvard University, and the University of Chicago)

We have built and tested an iron/liquid argon calorimeter. The device was intended as a prototype for a very large one to be used in a neutrino experiment at Fermilab. The future of that experiment is at best uncertain at the current time.

The calorimeter had transverse dimensions of 0.6m x 0.6m and an effective thickness of $\sim 680 \text{ gm/cm}^2$. Signals were read out from 2cm x 0.6m x 0.3cm iron strips that composed the plates of the calorimeter, premitting detailed studies of the longitudinal and transverse energy deposition in a shower.

The performance of the calorimeter was studied in tests in negative beams of 10, 20, 30, and 36 GeV in the Meson Laboratory at Fermilab. Our emphasis was on hadron-induced showers, but some data corresponded to μ^- and e^- in the beam. Detailed results on the energy and angle resolution of the calorimeter have been

submitted for publication^{1/} and represent the first such studies made for energies above a few GeV.

The measured resolutions proved to be adequate for the originally proposed neutrino experiment.

A.13. Mark III Project at SPEAR

(B. Eisenstein, G. Gladding, J. Thaler, A. Wattenberg, J. Becker, A. Spadafora, plus others, in collaboration with groups from SLAC, the University of California at Santa Cruz, and the University of Washington)

Enormous advances have been made in understanding the quark structure of hadrons from the discovery of the ψ and the D mesons, and more recently, the T. From the mass values obtained, one has been able to confirm theoretical predictions of a quark model that has forces resembling those due to electromagnetism. Much better calculation of the masses of the previously known particles have been made. An enormous amount of knowledge can be gained by more precise and new data on the decay modes of the charmed particles and the τ leptons. Specifically, there are the following questions:

- a) What is the Cabibbo angle for the decays of heavier particles?
- b) What is the Cabibbo angle for the τ decays?
- c) What is the origin of the strong interaction form factors that couple to the intermediate vector bosons?
- d) Does the $\Delta I = 1$ selection rule hold for the hadronic decays of more massive particles?
- e) What are the masses of the strange-charmed quark combinations?
- f) What are the masses of the multiply charmed particles?
- g) What is the mixing in the $D^0 + \bar{D}^0$ system, and is there any CP violation if such mixing exists?
- h) Will previously unobserved decay modes of the D mesons account for present discrepancy in the total decay rate?
- i) What are the branching ratios of the decay modes of charmed baryons?

In order to study these things, one needs a good source of charmed particles and τ leptons. The best sources are from e^+e^- colliding beams in the energy range 3-7 GeV, namely at SPEAR. For this reason, SLAC has approved the construction of a new detector at SPEAR which is based on some of the components

^{1/}B. Eisenstein, L. Holloway, W. T. Wroblecka, et al., The Segmented Calorimeter: A Study of Hadron Shower Structure, submitted to Nuclear Instruments & Methods.

that already exist from earlier detectors. It is anticipated that this facility (Mark III) will continue to take data for a number of years. To answer the above questions, the detector must have high efficiency and resolution for photons, must reliably distinguish between K's and other particles, and should subtend a large solid angle. Appreciably better statistics are needed than those that exist or are being obtained. The University of Illinois group has joined this collaboration in the current year. We have undertaken the responsibility of producing the muon detector that is needed. It is estimated that this detector will cost on the order of \$200,000. In the current year, prototypes are being studied; the design of the steel for the muon detector must be completed and part of the steel must be installed before summer in order for magnet tests to be carried out on schedule.

Although our main responsibility is the muon detector, we are involved in many other aspects of the Mark III project. Specifically, we are involved in Monte Carlo studies, in the setting up of the long-range analysis system, in the development of a fast programmable trigger system, and in the design of electronics for other components of the detector. However, as of the present moment, almost no funds are available for other than design work and programming.

A.14. Colliding Beam Studies at FNAL

(B. Eisenstein, L. Holloway, U. Kruse, in collaboration with the FNAL Colliding Detector Facilities Group)

At Fermilab, both $\bar{p}p$ and pp colliding beams have been proposed and are now under active design and consideration. The expected luminosity is in the range of 10^{30} - 10^{31} $\text{cm}^{-2} \text{sec}^{-1}$, and the center of mass energy will be between 700-2,000 GeV. These beams are suitable both for studying strong interactions where the expected cross-section is $\gtrsim 60 \times 10^{-27}$ cm^2 and searching for the production and decay of intermediate vector bosons (production $\sim 10^{-32}$ - 10^{-33} cm^2).

A detector design incorporating a large superconducting solenoid magnet has been selected as the most promising for colliding beam physics. A phased approach using the constituent calorimeter modules in a non-magnetic configuration is thought to be a practical solution to the financial and technical difficulties in bringing the ultimate detector on line.

B. Experiments Planned for Coming Years

B.1. χ Production in 270 GeV/s Proton-Proton Interactions

(G. Ascoli, J. Cooper, L. Holloway, L. J. Koester, U. E. Kruse, R. D. Sard, M. Shupe, D. Bender, H. Budd, T. Graff, S. Hahn, W. MacKay, P. Schoessow, E. Smith, in collaboration with Fermilab and Tufts University physicists)

Our primary effort in FY80 will be data taking for E610 at Fermilab. In E610 we plan a precise measurement of $\chi(3.42)$, $\chi(3.51)$, $\chi(3.56)$ production in pp interactions at 270 GeV/c. This experiment has been approved for 1000 hours of data with the tentative schedule calling for a test run in the fall of 1979 and a data run beginning in early 1980. Our experience indicates that completion of the test and data runs will require most of FY80.

In E610 we plan to use the Chicago Cyclotron Magnet Spectrometer (CCMS) at Fermilab to detect χ production via the decay $\chi \rightarrow \psi + \gamma + \mu \mu \gamma$. We (Illinois, Tufts University) will have upgraded the E369 lead glass γ detector, increasing the size of the array by a factor of 4 and improving the resolution by a factor of 2 in position and by a factor of 5 in energy. We (Illinois, Fermilab) will also have upgraded the CCMS with new multiwire proportional chambers and drift chambers to improve the momentum resolution and rate capabilities of the apparatus. With the better γ detector we will be able to resolve the various χ states and address questions concerning the basic charmonium production mechanism in hadronic interactions. E610 is designed to give a χ yield of at least two orders of magnitude greater than E369, obtaining ~ 2000 events. We will also look for as yet undiscovered higher mass charmonium levels decaying into $\psi + \gamma$ and for associated bare charm production, $\psi + D + \bar{D}$.

Based on our experiences with the E369 analysis, our goal is to have a working analysis package installed on the Fermilab CYBER computer at the beginning of E610. We hope to produce first order results on χ production concurrently with the data run, thus the first results will be produced in FY80. Further analysis during FY80 will be done using the University of Illinois CYBER system and the HEPG PDP-10.

B.2. High Energy Photon Experiments at Fermilab

(J. Butler, G. Gladding, T. O'Halloran, A. Wattenberg, J. Wiss, P. Avery, M. Goodman, M. Lamm, C. Olszewski, J. Russell, in collaboration with groups from Columbia University and Fermilab)

In the multi-hadron states from 87A, we should be able to analyze more difficult or rarer decay modes based on the experience we have gained this year.

In the initial analysis, we tried to choose the most promising states for analysis. We will look for other decay modes of charmed particles. If we obtain a good ratio of charmed particles to background in some decay mode, we have the capability of obtaining information on the lifetime of the charmed particles. Our original target was segmented for this purpose.

E458 is a continuation of the photoproduction experiments. The additional equipment required for 458 will be influenced by the results of the analysis of E87A and E401.

In FY80, we expect to complete the analysis of the data taken in Experiment 401. From the hydrogen running, we expect to observe 10^6 $\rho \rightarrow \pi\pi$ events and $5(10^5)$ $\phi \rightarrow KK$ events produced from photons > 25 GeV. This should allow an accurate measurement of the s-dependence of these fundamental cross-sections.

From the deuterium running on hadronic final states, we expect to observe 100 $\psi \rightarrow \bar{p}p$ events. This is calculated on the basis of an assumed σ_B of 0.15 nb. An essentially identical sensitivity will be obtained for K^+K^- final states having a mass of 2 GeV. Consequently, we are confident that we will be reasonably sensitive to whatever new phenomena may be present in these heavy particle final states.

From the high intensity deuterium running on leptonic final states, we expect to observe 10,000 $\psi \rightarrow e^+e^-$ or $\psi \rightarrow \mu^+\mu^-$ events. This should allow an accurate measure of the s-dependence of the production cross-section for energies > 40 GeV. We also expect to observe 200-400 events of the type $\psi' \rightarrow \psi\pi\pi$.
 $\downarrow \rightarrow \mu$
 From these events, we should be able to extract a reasonable measurement of the ψ' -nucleon cross-section. Finally, we hope to have enough data to make a sensitive survey of high-mass dilepton final states. In particular, we would expect to observe 60 events coming from the decay of 5 GeV object if its B_0 were 1% of that of the ψ .

In FY81 the program from the continuation of the above will be influenced by the results obtained from the present E401 experiment.

B.3. Neutrino Interactions

(R. M. Brown, T. O'Halloran, S. Fuess, P. Nienaber, in collaboration with Columbia University and Brookhaven National Laboratory)

It is anticipated that the final analysis of the data taken with the BNL detector will be finished during FY80. Assuming that the proposal now being prepared for Fermilab is submitted, we will begin modular construction of the apparatus intended for the instrumented beam dump experiment at Fermilab. While we do not intend to begin running during FY80, our preliminary plans indicate that some test runs will be necessary before the design can be completed.

B.4. Inclusive Hadron Production by Neutrinos at Fermilab

(B. Eisenstein, L. Holloway, and others, in collaboration with Harvard University, University of Chicago, and the University of Michigan)

We expect that FY80 will bring a much clearer understanding of budgets and laboratory priorities at Fermilab. Should there be a possibility of neutrino physics at the Tevatron, we intend to resubmit an updated proposal to study inclusive charged- and neutral-current processes.

Contingent on an approved experiment, we would expect to begin construction of apparatus in early FY81.

B.5. Mark III Project at SPEAR

(B. Eisenstein, G. Gladding, J. Thaler, A. Wattenberg, J. Becker, A. Spadafora, plus others, in collaboration with groups from SLAC, the University of California at Santa Cruz, and the University of Washington)

During FY80 the installation of the Mark III detector at SPEAR is scheduled for completion. This means that all of the components that fit into the pit into which the detector is installed need to be completed. The Illinois group is responsible for the fabrication of the muon detector components, including testing, shipping, and installation. With funds not being available until FY80, it is going to be an exceedingly tight schedule. It is estimated that when all of the extrusions and other parts are available at the University of Illinois, there will be still at least six months of assembly work and additional months of testing before the detector can be shipped to SPEAR. The present plans envision about 1400 proportional counters. Some positional information will be obtained by charge division, which will require about 2800 amplifiers and charge-sensitive detectors. Our electronics shops will also need about six months to build these components. All of the steel for the muon detector must be obtained during this same period and installed. In the latter part of FY80, we anticipate having three senior staff members at SPEAR as well as several graduate students.

During FY81 the first runs are scheduled for the Mark III detector. This means that all of the electronics installation must be completed, so that the initial runs to check the apparatus are performed with the system which will be used to obtain data.

It is anticipated that the first data taking runs will be at the 3.77 resonance to study the decay properties of the D mesons. Very good statistics are needed to obtain a measure of the Cabibbo angle for the D meson decays. We also need very good statistics to obtain the form factors for the semi-leptonic decays.

The advantage of the D mesons in studying the hadron vertex that ties to the intermediate vector boson is that there is a much larger momentum transfer than existed for the decays of strange particles. In the case of strange particles, we only obtained a linear term for the form factors. However, the D mesons should display an appreciable curvature and therefore make possible the measurement of a much more precise value of the form factors involved. With an appreciably larger sample of D meson decays and the improved ability to observe π^0 's, we hope we can remove or establish the discrepancy between the total cross section and the sum of the observed exclusive decays.

During FY81 the analysis programs should be functioning so that the data we are obtaining in the first runs can at least go through an initial analysis.

In the subsequent years, we plan to study the decay of the τ lepton and to look for the production of charmed baryons. It is hoped that we will be able to obtain much more data than now exists on the decay of charmed baryons. Obviously, the program for later years will depend on the information obtained from earlier data.

B.6. Colliding Beam Studies at FNAL

(B. Eisenstein, L. Holloway, U. Kruse, in collaboration with the FNAL Colliding Detector Facilities Group)

Testing of prototype calorimeter modules should be completed by the start of FY80, and acquisition of components and construction should begin. The detailed allocation of responsibilities among the CDF member institutions has not yet been made. It is likely, however, that the University of Illinois group will construct and test some of the scintillation counter hodoscopes. Additional responsibilities are expected.

IV. OPERATIONS AND DEVELOPMENT OF COMMON FACILITIES

A. Technical Accomplishments During This Year

A.1. Data Acquisition Systems

(R. Brown, R. Downing, J. Kohlmeier, V. Simaitis, J. Wray, R. Barth, D. Lesny, J. Lufkin)

The DOLLY/CSX precision film measuring system continues in very heavy use during this period, exclusively on spark chamber film from the neutrino experiment work (BNL Experiment 693). Over 400,000 frames will have been measured in FY78 at speeds averaging approximately 175 frames per hour. Initial work on the experiment has involved measurement made in a completely automatic mode, with minimal operator intervention; consequently, it has been possible for the DOLLY operators to combine DOLLY monitoring with manual film scanning for special events. In addition, the DOLLY system has been in use for manually guided measurement of events (e.g., showers) difficult for automatic extraction.

A.2. Computer Operations

(R. Brown, J. Wray, R. Barth, D. Lesny, J. Lufkin, D. Richardson, J. Scaman)

In FY79 the PDP-10 computing system was operational and available for time-sharing and batch use for approximately 8,000 hours. For most of the time, the system has been actively connected to the CSX-1 computer for on-line processing of DOLLY-measured events and CSX-1 program development. In addition, up to 24 time-sharing terminals (teletypes or CRT terminals) were connected to the system. Total CPU time is projected to exceed 3500 hours. A number of additions and improvements have been made to this system:

- Teletype-emulating connections have been made between the PDP-10 system and various DEC LSI-11 mini-processors located within the laboratory facilities. This connection, made via the University of Illinois black box system connected to the PDP-10, permits downloading of programs from the PDP-10 disk systems to the various LSI-11's which serve as equipment monitors and data acquisition systems. In addition, transfer of data back to the PDP-10 for more involved processing is available.
- A modem connection for dial-in phone lines has been provided for coupling to external terminals and to experimental sites remote from the building. Work is in progress to enable a "WILBUR-type" terminal connection to SLAC for communication with the Mark III programs. This work will be expanded to facilitate communications between the PDP-10 and other computers

(e.g., the CYBER 175 at the University of Illinois and Fermilab) in the near future.

- Preliminary designs and experiments are underway for using LSI-11 computers which share memory with the PDP-10, to be programmed as "parasitic processors" capable of undertaking sizeable tasks in parallel with normal PDP-10 execution. Notable, we hope to explore the use of such simple systems for some of the data reduction generated by data-acquisition systems in the large array experiments. Although the LSI-11 computer is too slow for effective production work, this pilot study will guide us in the development of faster and more powerful parasitic processors.

A.3. Engineering Systems

(A. Bross, R. Brown, R. Downing, J. Kohlmeier, V. Simaitis)

We have developed and tested a system of charge-coupled imagers capable of recording optical spark chamber data. The system consists of eight RCA 52501 CCD area imagers. Each device contains 512 x 320 elements of cell size 30 μm x 30 μm . Approximately 1.3 million cells (photosites) are therefore used to cover the image plane. The video output from each imager is sent to a separate video processor which performs filtering, dark level subtraction and sample and hold functions. The signals are then sent to 6 bit ADC's. The ADC information is sent to eight buffer memories where the data (X,Y,Z) for an individual cell are stored if the ADC output (Z) for that cell is above a computer set threshold. After the CCD readout is completed, information in the buffer memories is read onto magnetic tape under the control of an LSI-11 computer.

This system was incorporated into an experimental setup used in the neutrino program at Brookhaven National Laboratory. The CCD's were operated in parallel with an existing 70mm film system used to photograph the spark chambers and were thus constrained to work within the optical arrangement used for the film. In order to do this, image plane dissectors using fiber optic image conduits were employed in the CCD system.

During August and September 1978 a test run was performed at BNL using the CCD's in parallel with film. A twenty-five thousand frame exposure was taken using a cosmic ray trigger. Overall sensitivity of the CCD'S was found to be equivalent to a film speed of \sim ASA 1600. Comparisons were made between the CCD output and that obtained when the film was automatically digitized on the University of Illinois DOLLY system. CCD spark recording efficiency, relative to that for film, was between 75 and 90%. However, the overall performance of the CCD system meets or exceeds that of the automatically digitized film system.

Although the CCD spark efficiency was lower, it can be improved by using smaller memory threshold values and/or smaller f stop values. CCD accuracy is better than that for the film system and spark resolution is also improved. Large image formats can be accommodated by the use of multiple CCD imagers. The CCD system has essentially no background noise as compared to the film system which can pick up dust and scratches as sparks. Track finding is thus facilitated. Finally, the CCD system gives real time digitization of spark chamber data and thus eliminates the time (2-4 months) needed to measure the photographic film exposed during a typical accelerator run.

Design is proceeding on an 8-ported memory system to add on to the PDP-10 system. This will allow at least 1 M-word additional memory. A 1/2 M-word block is being implemented with 16K chips.

The additional 4 ports on this memory system will facilitate connections of the distributed processing system being designed with LSI-11's.

Work is continuing on new ultra-high speed modules for use in front-end trigger logic. New designs are implemented in 100K ECL logic.

B. Plans for Facilities for Coming Years

B.1. Data Acquisition Systems

(R. Brown, R. Downing, J. Kohlmeier, V. Simaitis, J. Wray, D. Lesny, J. Lufkin)

Subsequent to FY79, the continued use of the DOLLY/CSX-1 system is expected for clean-up of manual measurements and automatic re-measurements of neutrino spark chamber film from Experiment BNL693. Since there are no further experiments planned using film data acquisition, it is expected that the DOLLY system will be put on stand-by basis during FY80.

B.2. Computer Operations

(R. Brown, J. Wray, D. Lesny, J. Lufkin, D. Richardson, J. Scaman)

The use of the PDP-10 system will level off to a value set by the saturation of facilities. Total CPU use is predicted within the range of 3500-4000 hours. The programming staff is expected to work in the following support areas:

- Normal programming development for data analysis and new experimental design.
- Continued development of on-line graphics techniques and displays for data analysis and computer-aided scanning.
- Improved software and hardware techniques coupling the PDP-10 to experimental assembly sites in the Physics Building for assistance in the preparation and check-out of apparatus.
- Continued development of parasitic processing to permit simple short word length computers operating out of the PDP-10 memory to perform high volume, low complexity data reduction calculations.

B.3. Engineering Systems

(R. Brown, R. Downing, J. Kohlmeier, V. Simaitis)

R. Downing is a member of the "Fast System Design Group" sponsored by the U. S. NIM Committee. This group has the task of designing a new high-speed data acquisition system, to be called FASTBUS. Mr. Downing is a member of the "Tri-Group" and is currently on leave at SLAC to work full time on the design of this system.

The engineering group at the University of Illinois has already studied some of the problems associated with high-speed ECL buses, and has developed several readout systems utilizing these buses. We anticipate designing new systems in FASTBUS as soon as the standard is specified.

Work on high-speed logic modules for fast trigger decisions will continue. We will also start examining the use of fiber-optic cabling for high-speed data acquisition systems.

V. PUBLICATIONS SUBMITTED OR PUBLISHED AND PAPERS
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Thesis

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