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PROGRESS REPORT

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BUBBLE CHAMBER GROUP

(Professor Schneps, Assistant Professors Canter, Dao and Mann, Drs. Katsoufis and Tompkins, Messrs. Gelfand, Truxton and Wald)

In the past year the Bubble Chamber Group has been involved in a wide range of activities in experimental high energy physics. We have used beam momenta varying from 2.9 GeV/c to 300 GeV/c; bubble chambers including the FNAL 30-inch, BNL 80-inch, ANL 12-foot and FNAL 15-foot; targets which include hydrogen, deuterium, hydrogen with downstream plate, and deuterium with downstream spark chambers; beam particles including K^-, $\bar{p}$ and p -- we are still waiting for neutrinos. We have searched for exotic particles and charmed particles, continued to study strange baryons and mesons, probed the dimensions of the "fireball", and studied multiplicities and correlations in high energy collisions. In the following we summarize progress in each of the activities which have taken place.

A. Ξ^* Resonances in K^-p Interactions at 2.87 GeV/c

In 1974-5 we instituted a complete reanalysis of $K^-p \rightarrow \Xi^*$ data from the Brandeis-Maryland-Syracuse-Tufts collaboration, and in addition included K^-p data from the BMST K^-d experiment. The results were summarized in our progress report last year. Since then we undertook a very careful analysis of backgrounds and ambiguities in various channels to ascertain their validity. This has now been completed without causing substantial changes. A paper has been drafted which we expect to submit for publication shortly.

B. Resonance Production and Search for Exotic Hyperons in $K^-n \rightarrow \Sigma^-\pi^-\pi^+(\pi^\circ)$ Reactions at 2.87 GeV/c

Within the next two months we will submit to Physical Review a study of the final states $\Sigma^-\pi^-\pi^+$ and $\Sigma^-\pi^-\pi^+\pi^\circ$ resulting from K^-n interactions with beam momentum of 2.87 GeV/c. The reactions were obtained using a 10.2 event/μb portion of a million picture exposure of the 31-inch deuterium-filled bubble chamber at Brookhaven National Laboratory. Work was carried out in collaboration with Brandeis University.

Although substantial analysis and a first draft of this study had been completed a year ago, we found that further work was needed to eliminate contamination from $\Sigma^-K^+K^-(\pi^\circ)$ backgrounds and to minimize the number of $\Sigma^-\pi^-\pi^+\pi^\circ$ candidates which possessed two acceptable kinematic fits having significantly different Σ^- momenta. These problems have now been resolved by refitting our candidate samples to the background hypotheses and by requiring that all acceptable fits be compatible with track ionizations as evaluated on the scan table by physicists.

It has been pointed out[1] that two component duality with factorization requires the existence of exotic hadrons such as $qq\bar{q}\bar{q}$ for mesons and $qqqq\bar{q}$ for baryons, and that dual resonance models will not be tenable if such resonances are not found. The lowest lying exotic baryons have been predicted to occur with masses $\sim$1.9 GeV/c^2; exotic hyperons are expected to be more massive, perhaps by $\sim$0.150 GeV/c^2 per strange quark.[2] On the other hand, color-flavor quark models of hadrons where the quarks are bound by an octet of color gluons, provide a natural description of saturation at the $q\bar{q}$ level for mesons and the qqq level for baryons.[3] Exotic states are not predicted.

In this experiment upper limits at 90 percent confidence level are established for the decay of exotic I = 2 hyperons having $\Gamma < 0.08$ GeV/c^2 and decaying into $\Sigma^-\pi^-(\pi^\circ)$ channels. In the

$\Sigma^-\pi^-\pi^+$ channel we find $\sigma < 8$ μb for $1.50 < M(\Sigma^-\pi^-) < 2.40$ GeV/c^2. In $\Sigma^-\pi^-\pi^+\pi^\circ$ we find $\sigma < 10$ μb for $1.4 < M(\Sigma^-\pi^-) < 2.1$ GeV/c^2 and $\sigma < 5$ μb for $1.8 < M(\Sigma^-\pi^-\pi^\circ) < 2.4$ GeV/c^2.

Cross sections for $\Sigma^-\rho^\circ$, $\Sigma^-\omega$, $\Sigma^\circ(1385)\pi^-$, $\Lambda^\circ(1520)\pi^-$, $\Sigma^-\eta'$ and other processes have been determined. Density matrix elements for $\Sigma^-\rho^\circ$ and $\Sigma^-\omega$ production, measured as functions of cos θ^* over the forward center of mass hemisphere, indicate dominance of natural parity exchanges in these channels.

[1] P.G.O. Freund, in Baryon Resonances-73, edited by E.C. Fowler, Purdue, West Lafayette, Indiana (1973) p.121.

[2] Ibid., p. 129.

[3] H.J. Lipkin, Phys. Lett. 45B, 267 (1973).

C. Study of the Reactions $K^-p \rightarrow V^\circ$ + Neutrals at 6.5 GeV/c in the Argonne 12-foot Bubble Chamber (ANL E-292)

A consortium of five bubble chamber groups (Argonne, Michigan State, Kansas, Brussels and Tufts) has been conducting a high statistics K^-p experiment in the ANL 12-foot hydrogen bubble chamber exposed to a 6.5 GeV/c K^- beam. During March 1976 a very productive run of this experiment was accomplished by double-pulsing the bubble chamber and by running with high primary beam intensity. Running with this configuration yielded 700,000 pictures within four weeks, thus raising the total number of usable photographs to 1,050,000 which corresponds to about 75 events/μb for the entire experiment.

The Tufts group is concentrating on the 0-prong plus Vee topology:

$$K^-p \rightarrow \Lambda^\circ/\Sigma^\circ + \text{neutrals}$$
$$K^-p \rightarrow K^\circ + \text{neutrals}.$$

Our initial goal is to obtain high statistics samples of quasi-two-body reactions containing narrow-width neutral mesons produced with Λ hyperons; the mesons can be detected as spikes in the distribution of missing masses recoiling from the Λ°'s:

$$K^{-} + p \rightarrow \Lambda + (mm = \pi^{\circ}, \omega, \eta', \phi, f', h^{\circ}....?).$$

In these final states the distributions in t, u and in lambda polarization will enable investigation of Regge exchanges and SU(3) predictions. We are, of course, hopeful that new I = 0 mesons may be detectable in this way in the missing mass regime above 1.7 GeV.[1]

During April and May of this year the consortium worked together in a study of inclusive K° and Λ° production in 6.5 GeV/c $K^{-}p$ interactions for the purpose of delineating how inclusive distributions are built up from semi-inclusive processes (primarily 0-prong Vee, 2-prong Vee, and 4-prong Vee topologies). A paper describing preliminary results was submitted to the July 1976 Conference in Tblisi, U.S.S.R.

Trends exhibited by the data are as follows:

i) Suppression of backward K° production is found in all topologies; K° production becomes more central as the charged prong multiplicity increases.

ii) The 0 and two-prong contributions to inclusive Λ° production show more target-like than beam-like production, while in the 4-prong topology the Λ's are more centrally produced.

iii) As observed in other experiments at neighboring energies, the t' distribution for Λ production contains two components with distinct shapes; the slope at low t' decreases with increasing charged multiplicity.

iv) Peaking is observed in u' distributions which correspond to forward Λ production, with the sharpest effect being seen in 0-prong plus Λ events. This effect indicates the presence of nucleon exchange.

A peak at small u' is seen in the two-prong plus K° contribution to the total K° production, indicating that target fragmentation into K° + nucleon, or K^{*-} exchange processes, are occurring.

Scanning and measuring of 0-prong plus Vee events has proceeded at a low pace at Tufts during the past year, since higher priority was given to our Fermilab experiments. However, we anticipate the devotion of a large portion of our facilities to this experiment during the fall and winter as processing for our other experiments draws to a close. Last year the University of Brussels group joined us in this experiment and agreed to contribute to the scanning of this topology. Since that time it has become clear that the groups at Kansas and Argonne could add the 0-prong Vee topology to their existing scanning effort with little additional burden. Hence there is now a four group collaboration on this topology which should greatly shorten the time scale required for completion of the project. We have also been joined recently in this investigation by our former student Elias Katsoufis (University of Patras, Greece), who is contributing significantly to the development of the collaboration's DST and to analysis programs.

[1] For indications of unresolved meson structure above 1.7 GeV in lower energy K^-p data, see D.R. Hodge, Ph.D. Thesis, University of Wisconsin (1968), unpublished.

D. Search for Charmed Particles in 14.75 GeV/c $\bar{p}p$ Interactions

1) Hadronic Decay Modes

We have searched for narrow resonances above 1.5 GeV in $\bar{p}p$ interactions through the following reaction channels:

$$\bar{p}p \rightarrow V^\circ + n\pi^\pm + \text{anything}, \quad n < 8$$

where V° is a neutral strange particle, either K_s°, Λ°, or $\bar{\Lambda}^\circ$. The data came from an 80,000 picture exposure of the BNL 80-inch bubble chamber. Tohoku University in Japan and Michigan State University have been collaborating with Tufts on this film. Measurements have been completed and a final data summary tape will be available as soon as ionization work is completed. We expect to find more than 4200 events of the above mentioned reaction.

The search for high-mass narrow resonances entailed looking at the invariant mass combinations of many final states such as $K_s^\circ\pi^\pm$, $K_s^\circ\pi^+\pi^-$, $K^\circ 3\pi$, $\Lambda^\circ\pi^\pm$, $\Lambda^\circ 2\pi$, $\bar{\Lambda}^\circ 3\pi$ etc. In our preliminary analysis we have looked at many plots and observed well known resonances such as $K^*(890)$ in the $K_s^\circ\pi^\pm$ mass combinations and $Y^*(1385)$ in the $\Lambda^\circ\pi^+$ and $\bar{\Lambda}^\circ\pi^-$ combinations. There are several 2 to 3 standard deviation mass peaks (above 1.5 GeV) observed in some of the mass combinations. Of particular interest are a mass peak at $\sim$2.50 GeV in $(K_S^\circ 3\pi)^\pm$ which is enhanced by a selection of high momentum K_S°, and a peak in $\Lambda\pi^+\pi^+\pi^-$ at 2.45 GeV/c enhanced by a cut on the Λ center of mass momentum. We intend to do further analysis on these mass peaks.

Preliminary analyses of these searches for narrow resonances were presented by E. Gelfand, (a Ph.D. candidate in our group) at the APS meeting in Washington in April, and by J. Schneps at the Neutrino Conference in Aachen.[1] The results will appear in the Proceedings of that conference. Because of the current interest in charmed particles, we have devoted much time to the analysis of this experiment. We expect to have the data in final form within two months.

2. <u>Semi-Leptonic Decay Modes</u>

We have searched for the semi-leptonic decay modes of charmed particles through the reaction channel:

$$\bar{p}p \rightarrow V^\circ + e^\pm + \text{anything}$$

where V° is a neutral strange particle, either K°_S, Λ° or $\bar{\Lambda}^\circ$. The lepton candidates were detected either from their curvature and ionization in the chamber or from the conversion showers at the downstream tantalum plate. This work is being carried out independently at Tufts, Tohoku and Michigan State. At Tufts, we have found ten $K^\circ_s e^\pm$ and three $\Lambda e^\pm$ candidates. In a comparable number of non-Vee events we find only two electrons which indicates the amount of background in our sample, and points out the correlation of $e^\pm$ with Vees, particularly K°_s. We also considered various other backgrounds. Electrons from Dalitz decays of π° mesons were eliminated by an appropriate cut and backgrounds due to short K_{e3} decays and $\Lambda(\Sigma^\circ) \rightarrow ne^\pm\nu$ were shown to be very small (< 0.2 events). Based on our observed number of candidates, we have computed the following ratio:

$$\frac{K^\circ_s e^\pm}{\pi^\pm} \sim 0.7 \times 10^{-4} \text{ or } \sigma(K^\circ_s e^\pm \sim 9\ \mu b).$$

This is in rough agreement with the ratio $e^\pm/\pi^\pm$ determined from pp interactions over a wide range of incident momentum.[2.3]

A preliminary analysis based on the Tufts events was reported at the Neutrino Conference in Aachen in June of this year.[1] Our collaborators are expected to complete their independent analysis of leptonic events soon. After cross-checking, we intend to publish our results.

[1] Search for Charmed Particles in 14.75 GeV/c $\bar{p}p$ Interactions, to appear in Proceedings of the Neutrino Conference, 1976, Aachen, West Germany, (June 1976).

[2] L. Baum et al., Phys. Lett. <u>B60</u>, 485 (1976).

[3] I. Hinchliffe and C.H. Llewellyn-Smith, Phys. Lett. <u>B61</u>, 472 (1976).

E. Study of π° and Total Multiplicity Distributions in $\bar{p}p$ Interactions at 15 GeV/c

A unique feature in the 80-inch BNL chamber is the presence of a downstream tantalum plate which has two radiation lengths for γ conversion. A program to study the π° and total particle multiplicity distributions in this film was started at Fermilab two years ago. It was continued at Tufts and nine rolls of film have now been scanned for γ conversions at the plate. We feel the present statistics are sufficient for a determination of the neutral and total multiplicity. In many ways, hadron production in $\bar{p}p$ interactions differs from that in other interactions. The multiplicity distributions may give important clues as to this difference. In our study we also try to isolate the non-annihilation and annihilation components.

The analysis of this data is underway and we expect to complete it within a few months.

F. Investigation of Inelastic Collisions Using Principal Axis Variables

Classical geometrical ideas about high energy collisions of hadrons suggest that produced particle momenta may tend to lie in a preferred plane. In 15 GeV/c $\bar{p}p$ collisions for example, a beam-target collision having impact parameter R of one fermi could produce an excited state having high angular momentum:

$$L = \sqrt{\ell(\ell+1)}\ \hbar \simeq p\ R \rightarrow \ell \simeq 76.$$

As a consequence of the high angular momentum of the excited blob, final state momenta may tend to lie in a plane perpendicular to L, coming off like fragments from a disintegrating pinwheel.

A "natural" coordinate frame for investigating planarity and other properties of multiparticle production has recently been revived, called the Principal Axis System.[1] We are at present exploring the utility of variables defined in this system using 2, 4, 6, and 8 prong plus Vee event samples from our $\bar{p}p$ film. For each event, analysis proceeds by constructing a "solid body" in momentum space using the CM 3-momenta of all produced particles in an event. A final state "inertial tensor" is defined

$$Q^{\alpha\beta} = \sum_{i=1}^{N} p_i^{\alpha} \; p_i^{\beta}$$

where α,β label the x, y, z momentum components and i is summed over all N particles observed in the final state. The principal axis coordinate system is defined by the three orthogonal eigenvectors of Q; the overall "shape" in momentum space of the multiparticle final state is then described by the relative magnitudes of the eigenvalues of Q, e.g.:

$\lambda_1 \simeq \lambda_2 \simeq \lambda_3 \rightarrow$ isotropic particle production;

$\lambda_1 >> \lambda_2, \lambda_3 \rightarrow$ jet structure;

$\lambda_1 > \lambda_2 \simeq \lambda_3 \rightarrow$ planarity.

Our preliminary study has encountered two difficulties in application of these intuitively appealing variables to real data: (i) the inertial tensor is only well-defined for events in which all or nearly all of the final state particles are detected. In our data - as in most experiments - only a small fraction of the events actually have negligible unobserved missing mass. (ii) In our high charged multiplicity events, a mild planarity effect may be present; we observe $\lambda_1 > \lambda_2 \gtrsim \lambda_3$. However, any real planarity effect must be untangled from the ordering of the eigenvalues which is imposed merely by the definition of the principal axes.

More work will be required in our $\bar{p}p$ data to surmount these difficulties.

[1]M.J. Counihan, Physics Letters 59B, 367 (1975).

G. Determination of Fireball Dimensions from Interference Correlations in pp Interactions at 28.5 GeV/c

Our research interests in determining the dimensions of the region from which pions are emitted (commonly called the "fireball") were aroused by theoretical studies of Kopylov, Podgoretsky and Cocconi, who predicted that like-charged pions will show strong interference correlations due to their Bose-Einstein statistics. From a data sample of 48,000 events taken with the Argo Multiparticle Spectrometer System (in which the low momentum proton was triggered) our group at Tufts in collaboration with researchers from BNL, Purdue and VPI has determined an average interaction radius of $R = 1.3 \pm 0.1$ fermi and $\tau = (1.2 \pm 0.8) \times 10^{-24}$ sec. These results will be published soon in Nuclear Physics B. The interference correlation was initially studied by comparing the production cross sections of like-charged and unlike-charged pion pairs, $\sigma^{\ell}(q_T, q_o)$ and $\sigma^{u}(q_T, q_o)$. Further considerations based on $\pi\pi$ correlations and the size of the data sample needed to probe the shape of the fireball, rather than just the average radius, suggested to us the reaction channel

$$p + p \rightarrow n\pi^- + X, \quad n > 2.$$

The interference pattern is studied by comparing the production cross section of the negative pion pairs from the same event and from neighboring events (normalized at the same total cross section), $\sigma^{S}(q_T, q_o)$ and $\sigma^{N}(q_T, q_o)$. The data sample in this analysis is at least four times that of the previous one.

Most of the analysis was carried out on the Purdue computer with participation from various members of the Tufts group.

H. Neutron Dissociation in 300 GeV/c pd Interactions (Fermilab Experiment # E-209)

This experiment was completed last October and a total number of 100K pictures was taken from the Fermilab 30-inch deuterium-filled bubble chamber together with the downstream wide-gap spark chamber spectrometer. The experiment has been a continued collaboration among the following institutions: Tufts, Iowa State, Vanderbilt and Caltech. Most of the scanning work in the second phase of the experiment was done at Tufts, while Iowa State provided the downstream spark chamber film measurements.

The physics goals of this experiment are a detailed study of target neutron dissociation and a comparison of double diffraction dissociation processes in np and pp interactions. The second phase of the experiment will provide enough statistics to augment what we have learned previously in the first phase. In the New York meeting of the American Physical Society this year[1] we presented a paper on the dissociation of the target neutron into $p\pi^-$ states and the spin structure analysis of the diffractively excited states. We plan to finish our analysis on the neutron dissociation and submit the work for publication soon.

The scanning and measuring work in the second phase has been interrupted by our search for charmed particles in the 15 GeV/c $\bar{p}p$ film and in measuring the neutral pion correlations in the 300 GeV/c pp film. We hope to complete the remaining load in a reasonable amount of time, in close conjunction with the downstream spark chamber measurements of Iowa State. These measurements will be necessary for a detailed study of double diffraction processes.

[1] E.W. Anderson et al., New York APS Meeting, Bull. APS 24, 28(1976).

I. Study of π°, K°, $\Lambda^\circ/\overline{\Lambda}^\circ$ Production from pp Interactions at 300 GeV/c in the 15-foot Bubble Chamber (FERMILAB E-343)

During January 1976 the E-343 collaboration (physicists from ANL, University of Kansas, SUNY at Stony Brook, and Tufts) obtained 21,000 photographs of the hydrogen-filled 15-foot bubble chamber exposed to 300 GeV/c protons. This run brought the total number of usable photographs for E-343 to 25,000 pictures, thus finishing the picture-taking phase of this experiment.

Our major physics objectives remain as described in our Progress Report of last year. Briefly, these include:

1. Study of the dependence of π°, K°, $\Lambda^\circ/\overline{\Lambda}^\circ$ production on charged particle multiplicity in both diffractive and non-diffractive processes.

2. Determination of the integrated Mueller correlation parameters for neutral pions (f_2^{oo} and $f_2^{\pm o}$) in 300 GeV/c pp collisions.

3. Measurement of f_2^{oo} as a function of $n_{charged}$. Theoretical interest in $f_2^{oo}(n_{ch})$ is keen, since these parameters discriminate among choices of isospin composition which are possible for cluster models of high energy multiparticle production.[1]

4. Observation of production of prompt leptons in hadron-hadron collisions has received considerable attention since the effect suggests the creation of particles possessing new degrees of freedom for strong interactions. However, calculation of how much of the prompt $e^\pm$ and $\mu^\pm$ signals is really anomalous has been hindered by uncertainties in the knowledge of contributions coming from known mesons. In particular, it has been speculated that the recent discovery of abundant e^+e^- pair production at low transverse momentum[2] may merely be detecting Dalitz decays of abundantly produced η°'s. Since the branching ratio of η° into $\gamma\gamma$ is 38%, we expect in this experiment to measure or to put significant limits on inclusive η° production in the Fermilab energy regime.

At the February 1976 APS meeting in New York, the E-343 collaboration presented results based upon 4000 frames obtained during a two-day run in 1975. Total and differential cross sections for the inclusive processes $p + p \rightarrow (\gamma, \pi^\circ, K^\circ, \Lambda^\circ, \overline{\Lambda}^\circ) + X$ were reported; good agreement is found with published results obtained in the 30-inch bubble chamber at this momentum. For the integrated Mueller moment f_2^{oo} we reported the value $+3.4 \pm 1.7$. It is of interest that our preliminary result suggests a positive f_2^{oo} value; previous measurements had suggested a zero or negative correlation among π°'s:

69 GeV/c pp : -2 ± 1 [3]

205 GeV/c pp : -0.2 ± 2.9 [4].

A negative f_2^{oo} value would be very difficult to understand from the viewpoint of most multiparticle production models.

The scanning and measuring load has been divided equally among the three university groups. Data processing at Tufts and at the other institutions is nearing completion; the entire film sample has been double-scanned, a portion has been third-scanned, and over half the film has undergone three measurement passes. The collaboration intends to undertake final analysis throughout the fall. We plan to present new results at the 15-foot Bubble Chamber Workshop at Sonoma, California, on October 22, 1976.

[1] G.H. Thomas, Private Communication. See P. Grossberger and H.L. Mietonen, Nucl. Phys. B89, 109 (1975) and references therein.

[2] L. Baum et al., Phys. Lett. B60, 485 (1976).

[3] G. Blumenfeld et al., Phys. Lett. 45B, 525 (1973).

[4] K. Jaeger et al., Phys. Rev. D11, 2405 (1975).

J. Preparation for Running with the External Muon Identifier in the ν-Deuterium Experiment at Fermilab (Fermilab E-227)

It is crucial to bubble chamber neutrino experiments such as our ν_μ-Deuterium exposure that the capability exists to distinguish charged current, neutral current, and di-lepton final states on an event-by-event basis. For this reason the External Muon Identifier which has been developed for the 15-foot bubble chamber by physicists from the University of Hawaii and Lawrence Berkeley Laboratory, is a valuable tool for neutrino research. To gain experience in working with this device, two members of the Tufts group (W. Mann and J. Schneps) attended the "EMI School" conducted at Fermilab from October 27 through 29, 1975. Subsequently, in December 1975 one of us participated in a ν_μ-H_2 run (E-45) which utilized the EMI.

Among the presentations at the EMI School were discussions of off-line computer programs required to reconstruct hits in the EMI's proportional chambers and to match them with tracks extrapolated from the bubble chamber. The software chain developed by the Berkeley group was of particular interest to us since their programs are compatible with TVGP and SQUAW, and we had already worked with the latter programs in reconstructing and fitting 15-foot bubble chamber events in E-343. During March 1976, the Berkeley group provided us with their complete off-line software package, suitable for operation on a CDC-7600 computer.

During the summer substantial progress was made toward conversion of the EMI programs for operation on the Tufts PDP-10 computer. All of the Fortran routines have been compiled and double-precision coding has been inserted in appropriate routines; re-writing of some MACRO subroutines and revision of coding which requires CDC utility routines remains to be done before tests can be made using real data.

As the Fermilab program for the 15-foot chamber firmed up during the past year it became clear that deuterium running would be delayed. However, we now have a firm commitment that the next running period of the chamber will be devoted to deuterium. Officially the date for this is August 1977, but in practice this may slip a couple of months. Some advantages in the delay are the possibilities of running at 500 GeV/c and of an improved version of the EMI.

K. Multiparticle Production in 400 GeV/c p-Ne and p-H_2 Collisions Using a Light Ne-H_2 Mixture in the Fermilab 15-foot Bubble Chamber (Fermilab Proposal #291)

As indicated in last year's Progress Report, the Tufts bubble chamber group, together with physicists from Kansas University and Michigan State University, had proposed to take two exposures in the FNAL 15-foot bubble chamber with a light neon-hydrogen fill (∿20% mole neon). The specific request was for 25,000 pictures with 400 GeV/c protons and 25,000 pictures with a 100 GeV/c Cerenkov-tagged secondary beam of protons and π^+'s.

It is a pleasure to report here that we have been approved for a run of 25,000 pictures at 400 GeV/c incident proton momentum. At this time, we anticipate some delay in the scheduling of our exposure due to the high priority assigned to other liquid fills for the 15-foot bubble chamber as determined by the neutrino physics program.

Originally, our primary physics goal was to undertake a quantitative examination of the space-time structure of hadronic interactions at high energy. We proposed to measure charged and neutral particle multiplicities, single particle inclusive spectra and multiparticle correlations in hadron-neon interactions. By comparison of this data with analogous distributions obtained with hydrogen targets, the nature of multiparticle production in proton-nucleon collisions can be probed for small space-time intervals.

The experimental situation in this area has been changing rapidly, and interesting results are appearing in the literature[1]. Since models such as Gottfried's energy flux cascade[2] will require data using a variety of incident hadrons, momenta, and target nuclei, we believe that distributions from 400 GeV/c p + neon interactions would still be a significant contribution. However, consideration is being given to other possible investigations, such as measurement of prompt $e^{\pm}$ production at low $p_{\perp}$ and searches for charmed particles.

We note that a beautiful extension of our study of π° inclusives from 300 GeV/c p + H_2 collisions (E-343) may be possible with Ne-H_2 film. By selection of events which have even-numbered charge multiplicity and an absence of nuclear stubs, a sample of "hydrogen-like" collisions can be isolated. The high gamma conversion efficiency afforded by this exposure should enable counting of π°'s from these events with much more reliability than is possible in pure hydrogen exposures (i.e. the conversion weights on observed gammas will be greatly reduced). In this way accurate determination of $f_2^{oo}(n_{ch})$ for high charged-particle multiplicities (n_{ch} > 10 prongs) should be possible. It is precisely these values for f_2^{oo} which can distinguish among various choices of dominant isospin which can be made in cluster models of multiparticle production.

[1]See for example, J.R. Elliott et al., Phys. Rev. Lett 34, 607(1975); W. Busza et al., Phys. Rev. Lett. 34, 836(1975).
[2]K. Gottfried, Phys. Rev. Lett. 32, 957 (1974).

L. Characteristics of Multiparticle Production in High Energy Collisions

With the increasing amount of data on multiparticle-production from hadron-hadron collisions, we have studied the problem of whether the produced particles are highly correlated and if so, in what part of phase space correlations occur. In particular we have used the independent emission model to study the hadron pair production process:

$$\begin{matrix}\pi \\ p\end{matrix} + p \rightarrow h_1 + h_2 + \text{anything}$$

where h_1, and h_2 are any of the charged hadrons p, $\bar{p}$, π^+, π^-, K^+ and K^-. Comparing our model analysis with available pBe data at 28 GeV[1] we concluded that there is not much correlation between hadron pairs except at very small invariant mass and possibly at large invariant mass. A paper on this study was published in Physical Review Letters.[2] It is also noted that an extensive Monte Carlo program has been written based on the independent particle emission model. This program can be useful in planning future experiments.

Another study has been made to increase our understanding of the semi-inclusive processes:

$$p + p \rightarrow h + n \text{ charged particles}$$

where h is a charged hadron. Based on a single Regge exchange model, we found that the inclusive and semi-inclusive data on π^+,π^-, K^+ and p production can be related to low energy total and topological cross sections over a wide range of incident proton energies and a large kinematic region of produced particles. On the other hand, we noted that our scheme does not work if the produced particles require exotic exchanges, i.e. K^- and $\bar{p}$. Presently we are working on reanalyzing some of the data and a revised version of the paper on this subject. This work is being done with Prof. G. Goldstein.

[1] J. Aubert et al., Phys. Rev. Lett. 35, 639 (1975).

[2] F.T. Dao and D.J. Quinn, Phys. Rev. Lett. 36, 991 (1976).

M. Hardware Acquisition and Development

1. On-Line Measuring System

The on-line measuring system (OLMS), consisting of two Data Tech image-plane digitizers and two Vanguard film plane digitizers connected to a PDP-8 computer system, has operated in the past year with virtually no downtime due to computer or encoder/electronics failures. This is significant in that all maintenance work, including that on the computer, has been done "in-house".

Last year we acquired a third Vanguard digitizer from the Brandeis group. We have constructed new electronics for it so that we may bring it on-line in a short time if this should be required. Currently it is being used as a high-magnification scanning machine for 15-foot chamber film.

2. Scanning Equipment

In addition, we have acquired two machines from the Syracuse group. One is an NRI film plane digitizer equipped with a detent stage. It is similar in design to our Micrometrics table and should make an excellent scanning table. It was a working measuring machine at Syracuse and in the future could be interfaced to our OLMS.

The second machine is a Vanguard scanning machine that is unique in that it has a servo-controlled lens mount in one view. We intend to convert this view to 100X magnification, as we did with several of our other scanning tables, for precision scanning of high energy film.

Both machines have been installed in place of two Prevost tables and will prove a valuable addition to our facilities.

3. PDP-1 Computer

The PDP-1 which has not been on service contract for several years, is still operational. It is used to edit and separate tapes from the on-line measuring system.

4. Terminals

Virtually all of our computing is done on the Tufts University PDP-10 computer. Together with the High Energy Photon Group, we have three KSR-33 teletypes with modems and dedicated university extensions used as terminals to the PDP-10. These terminals have suffered substantial "down-time" in the past year and we are considering alternatives.

COMMUNICATIONS -- BUBBLE CHAMBER GROUP

FALL 1975 - FALL 1976

I. Papers presented at meetings:

1. "Neutron Dissociation in 300 GeV/c pd Interactions", Iowa State, Tufts, Vanderbilt, Cal. Tech., Bull. Amer. Phys. Soc. 21, 52 (1976).

2. "Production of Neutral Particles in 300 GeV/c pp Collisions in the 15-Foot Bubble Chamber", SUNY at Stony Brook, ANL, Kansas, Tufts; Bull. Amer. Phys. Soc. 21, 87 (1976).

3. "Study of Resonance States Involving K°/Λ° in 15 GeV/c pp Interactions", Tufts, Michigan State, Fermilab, Bull. Amer. Phys. Soc. 21, 646 (1976).

4. "Search for Charmed Particles in 14.75 GeV/c $\bar{p}p$ Interactions", Tufts, Michigan State, Tohoku, Fermilab. Paper presented and the Neutrino Conference in Aachen, West Germany, June (1976); Paper presented at the Third European Symposium on Antinucleon-Nucleon Interactions, Stockholm, Sweden, July (1976).

5. "Inclusive V°-Production in K^-p Interactions at 6.5 GeV/c", ANL, Brussels, Kansas, Michigan State, Tufts; International High Energy Physics Conference at Tblisi, U.S.S.R., July (1976).

II. Publications:

1. "Search for Ξ^* Resonances in 2.87 GeV/c K^-n Interactions", E. Briefel, S.A. Gourevitch, L. Kirsch, P. Schmidt, (Brandeis); C.Y. Chang, R. Staab, G.B.Yodh, (Maryland); R. Fernow, P. Gauthier, G.C. Moneti, M. Goldberg (Syracuse); J. Canter, W.A. Mann, J. Schneps, J. Tompkins and G. Wolsky (Tufts), Phys. Rev. 12D, 1859 (1975).

2. "Recent Developments in Inclusive Reactions", F.T. Dao, Proceedings of the Conference on the Experimental and Phenomenological Multiparticle Production, Budapest, Hungary, Oct. 9-10 (1975).

II. Publications (Cont'd):

3. "Production of Hadron Pairs in High-Energy Collisions", F.T. Dao and D.J. Quinn, Phys. Rev. Lett. 36, 991 (1976).

4. "Search for Charmed Particles in 14.75 GeV/c $\bar{p}p$ Interactions", J. Canter, F.T. Dao, E. Gelfand, W.A. Mann, J. Schneps (Tufts); B.Y. Oh, M. Pratap, G.A. Smith, J. Whitmore (Michigan State); T. Kitagaki (Tohoku); J. Lach (Fermilab); Proceedings of the Neutrino Conference at Aachen, West Germany, June 1976.

5. Quantitative Proton Tomography: Preliminary Experiments, A.M. Cormack and A. Koehler, Phys. Med. Biol. Vol. 21, 560 (1976).

III. Accepted for Publication:

1. "Observation of Bose-Einstein Statistical Correlations in pp Interactions at 28.5 GeV/c," J. Canter, F.T.Dao, J.R. Ficenec, L.J. Gutay, E. Lazarus, W.A. Mann, J. Schneps, W.N. Schreiner, P. Schubelin and F. Turkot, Nuclear Physics B, (1976).

(Professor Milburn, Assistant Professors Rutherfoord and Quinn, Drs. Stottlemyer, Oliver* and Thornton, Messrs. Mroczkowski, Shupe, Hossain and Jawahery.)

A. Summary

During this reporting period the Photon Group has seen the completion of the analysis of its major experiment on large-angle Compton scattering of photons on protons at high energies, using the Cornell Electron Synchrotron. The termination of this phase of the Photon Group's work has been accompanied by an almost complete turn-over of the professional and student research staff, and by a concomittant initiation of new lines of experimental high energy research based upon the Group's new resources and expertise. These include preparation of proposals to SLAC for a streamer chamber study of phi-meson and K^-+electron production by π^+ on protons at 15 GeV, and for a back-scattered laser beam at SPEAR to measure the expected electron polarization and to serve as a feasibility demonstration for a possible high-repetition-rate "laser beam" facility at PEP or PETRA. The recent arrival of Dr. William Oliver as Research Associate provides, in addition, the immediate involvement of the Group in a continuing hadron-jet experimental collaboration at Fermilab.

B. Personnel Changes

Aside from the almost total concentration on expermental and analytical work related to the Cornell Compton scattering experiment during the first 8 months of 1976, the activities of the group have been strongly affected by major changes in research personnel. In chronological order:

Dr. Alan Stottlemyer resigned in April to join Computer Sciences Corp., Silver Spring, Maryland, to work, as we understand, in the area of space sciences. Prior to his departure, he was able to complete and document his improvements in the programs relating to the Pb-glass hodoscope used in our Compton experiment, and this to such a level of perfection that no further alterations were required. We wish him well in a new job which should similarly challenge his talents and which offers him new levels of administrative responsibility.

Assistant Professor Quinn resigned at the end of May to join S.R.I., in Menlo Park, California, to work on a variety of projects related to decision analysis and to energy resources. We are sorry

*Expected arrival before 11/76

that he could not see the conclusion of the Compton experiment, to which he made important contributions, especially in the realm of proton-arm ray-tracing, and in establishment of the overall experimental geometry. However, we appreciate his growing interest in public energy-related problems, through recent years, and his leaping into this work full time, when an excellent opportunity showed itself.

On August 1, Dr. Ronald K. Thornton, whose vita is appended to this report, joined the photon group as Research Associate. He received his Ph.D. this past June from Brown University, where his dissertation research was on an experimental study of proton-anti-proton reactions at 1.862 GeV leading to the production of pairs of neutral pseudoscalar mesons. These were observed in a shower-sensitive optical spark chamber at BNL. During the brief period he has been with us he has taken advantage of this experience and is already deep into a Monte-Carlo study of various geometries which might enable us to utilize our segmented Pb-glass Cerenkov hodoscope for effective separation of electron/positron signals as small as 10^{-4} from large pionic backgrounds. (This is discussed further, below).

On September 1, Assistant Professor Rutherfoord took up his new duties working for the University of Washington, Seattle, in their high energy experimental group at Fermilab. Dr. Rutherfoord's participation in our group's work since 1968 has had a major impact on our program over this period. Indeed, in the just-concluded Compton scattering experiment and in the earlier Pi-0 photoproduction experiment at Cornell he was literally the prime mover. His continuing intense interest in photon-hadron interactions, at both experimental and theoretical levels, as much as anything made "photon group" a legitimate nickname for us. We expect to hear of his continuing impact on high energy physics in the future.

Dr. William P. Oliver, Ph.D. Berkeley (1969), joined us on September 7 as Research Associate. His vita is also appended to this Report. He comes from the University of Washington and has most recently been working on a hadron jet experiment at Fermilab (further described below). His extensive experience in both hardware and software systems at Fermilab, SLAC, and LBL includes work covering both weak and strong interaction physics, and also the unique collimated coherent bremsstrahlung beam at SLAC whose high polarizations and intensities we had considered applying to eta-meson photoproduction. We expect Dr. Oliver to play a major role in our planning of future lines of research, as well as by contributing his talents to the solution of day to day problems.

Dr. Oliver expects during the immediate future to continue his collaboration with the Fermilab hadron-jet experiment in the development and construction of which he has already made a large professional investment. This will be described further below.

The completion by Mr. Shupe of all Ph.D. requirements this past August and his appointment as Research Associate at the University of Illinois, Urbana, takes from the group a Research Assistant who had developed into a mature collaborator. Dr. Mroczkowski's Research Assistantship terminated at the beginning of the year, when he left to join Honeywell Radiation Labs., in Lexington, and no replacement was available at that time. This fall we will have two beginning graduate research assistants, with Mr. Jawahery starting in September. As the group embarks upon its new program we expect them to develop the necessary new skills to make substantial contributions.

C. High Energy Compton Scattering on Protons at Large Angles

(Professors Milburn, Quinn and Rutherfoord, Dr. Stottlemyer, Mr. Shupe; in collaboration with Profs. M. Deutsch of M.I.T., R. Siemann of Cornell, and S. Hertzbach, R. Kofler and M. Rabin of U.Mass., and their students.)

Data from this experiment cover the primary photon energy range of 2-6 GeV and invariant momentum transfers (squared) between -0.71 and -4.29 $(GeV/c)^2$, in 15 separate data points distributed throughout this hitherto almost entirely unexplored region. Nearly the entire effort of the Photon Group through August 1976 was devoted to the analysis of the nearly 7 million events recorded on about 300 tightly-packed data tapes recorded at Cornell during the early fall of 1975 (see the 1975 PROGRESS REPORT). This analysis was planned and executed almost entirely at Tufts, while benefitting from frequent consultations with our colleagues at M.I.T., Cornell and U. of Mass. The programs used to analyze on-line the event-by-event data during the experimental runs at Cornell were heavily overhauled in order to handle the unexpectedly large volume of recorded data both efficiently and accurately, and to reflect the experience gained during the preliminary analysis.

Specific developments include:

i) conversion to an analysis system based upon a multi-tape data source (rather than sampled on-line data) and to be executed in an efficient interactive mode using Tufts DEC-10 in a time-sharing environment. Nine-track tapes were copied from the prime logging tapes, kept at Cornell for security, and 2/3 of them were converted to PDP-10 7-track format at the Smithsonian Astrophysical Observatory CDC-6400 using an efficient routine (less than $7.00 per tape). The remaining third was converted using the same routine at the U. Mass. CDC-6600 (charged to U. Mass.). Special routines were developed for the DEC-10 to permit the accumulation of event data summaries during a series of computing sessions, and to facilitate editing these accumulations to compensate for bad tapes, computer crashes and other inevitable occurrences. These edited summary/backup files ultimately served as the sources for the final fitting and graphing routines required to extract cross-section results. They also made it possible to analyze the vast majority of the data tapes each in only a single pass through the computer, with repeat runs only required for the occasional defective tape copy or system failure. In retrospect, this facility turned out to be vital both for the completion of the analysis within a tight time schedule, and within the limits of the groups' funds available for computing.

ii) Major revisions were made to the scattered photon analysis program ("GAMARM"). Dr. Stottlemyer carefully reviewed the experience with the on-line analysis of actual data at Cornell and identified unanticipated sources of background, in particular that represented by "events" in which signals were generated by tracks through the light pipes connecting the main Cerenkov radiators with the corresponding photomultipliers. He also modified the algorithm for extracting the azimuthal angular measurement of the scattered photon and thereby improved the corresponding angular resolution. Besides making these improvements in the acceptance criteria for individual photons Dr. Stottlemyer installed an additional routine to yield a measurement of the energy-dependent efficiency with which the Cerenkov hodoscope detected the scattered-Compton or Pi-0 photons. This efficiency is essential to the estimation of absolute cross sections.

iii) The proton-arm ("CLASP") routines were also revised to include a modification of the retracing algorithms (tracking the Compton-recoiling proton through the CLASP spectrometer) which accounted for the effects of multiple scattering, and also to permit a more accurate evaluation of the efficiencies of this subsystem for the detection of protons. In addition, timing data from the various trigger counters in the CLASP arm were examined to verify the efficiency of and the substantial absence of background in the proton detection system. Ms. M. White, an M.I.T. graduate student, assisted in the latter studies.

The actual conditions of operation at Cornell involved much higher background rates than had been anticipated and consequently, to avoid the dangers inherent in attempting to exclude background events by restrictive triggering, 4-5 times as many event candidates were recorded as had been expected. This large excess of raw data, coupled with the limited time and computing budget available for analysis required that extraordinarily close attention be paid to maximizing the efficiency of the production analysis programs and to minimizing both operating costs (proportional to the product of actual core usage and processor time) and total computing time. The main programs were reorganized, and rewritten where necessary, to optimize core usage and computational speed. With the cooperation of the Tufts Computing Center staff, we were able to exploit fully the program overlay, and especially the virtual memory, features of their DEC-10/KI-11 system, to monitor actual operating costs in their dependence on overall system usage, and to schedule our production work at the most efficient times.

The actual cost/analyzed event was a little less than 1/5-cent. Our colleagues at U. Mass. have adapted a version of our final program to their CDC-6600 system and achieved operating speeds with real taped data which, were they to charge us at the approximate $200/CPU hour rate available at the ERDA CDC-6600 at BNL, would yield event costs almost identical to those at our Tufts DEC-10. This confirms for our class of event analysis the adequacy of the "6-to-1" DEC-10/CDC-6600 comparison algorithm we have been using as based upon an earlier study here using bubble chamber programs as benchmarks. We have further established using the 6600/6400 relative processing speed comparison established in 9-to-7 track tape conversion, and the present Smithsonian pricing schedule for government contract users, that use of the latters CDC-6400 would also have cost about the same, per event, as the Tufts DEC-10, albeit with the much greater real time and inconvenience associated with a low-priority large-program batch entry operation at a remote site. We believe, in conclusion, that the Tufts DEC-10 has shown itself to have now developed to the point of being competitive with regard to cost and convenience in almost any kind of computing we might need. We have also found it possible to transfer data and programs efficiently and rapidly among a wide variety of computing systems over a variety of media, and so are able, should special hardware resources and/or machine-dependant programs make it necessary, also to exploit external computing facilities economically.

The analysis of the bulk of our data tapes entered its production phase in mid-May 1976, and was concluded by mid-August. This work was almost entirely done late at night and over weekends, when time-sharing usage of the DEC-10 was at a minimum and several tape drives could be set aside for our use. The previous organization of the analyzing program system, with its interactive control by a teletype terminal and its periodic backup filing of accumulated data, permitted these operations to settle into a routine during which Mr. Shupe, who was primarily responsible for them, was able to organize and type most of his dissertation.

The overall analysis of the experiment was based upon the generation by Monte-Carlo techniques of simulated Pi-0 photoproduction and Compton scattering events as would be generated in our hydrogen target by bremsstrahlung coming from primary electrons in a radiator. The outgoing "particles" from these simulated events were then propagated into the known geometrical apertures of their respective detectors, having been subjected to appropriate multiple scattering. This procedure generated blocks of simulated "event" data identical in essential format to the large array of Cerenkov pulse heights, MWPC wire addresses, and counter latch bits present on the real data tapes. These data were then passed through the same analysis program as the real data, to yield the angular and energy distributions to be expected from the pure Compton and Pi-0 components of the observed process, and as modified by the very complex angular and energy acceptance functions of our system. Examination of the Pi-0 Monte Carlo distributions in comparison with the real data showed that only the single-Pi-0 background needed to be considered. Comparison of the Compton and the Pi-0 Monte Carlo azimuthal angle distributions with those of the real data permitted the ratio of the Pi-0 to the Compton differential cross sections to be extracted directly, a measurement minimizing the effects of uncertainties in detector acceptances and inefficiencies, and in the accuracy of primary photon beam monitoring. Inclusion of information recorded from the latter monitor yielded absolute cross sections for each process.

The Monte Carlo programs to generate simulated Compton and Pi-0 events were developed by Dr. Rutherfoord on the group's PDP-11. The Compton events were actually generated on the PDP-11, stored up overnight on the PDP-11's disk, and shipped in the morning, via routines the group has developed for a dedicated 2400 baud link, to the Tufts DEC-10 for analysis by the main program (often via intermediate storage on the DEC-10's disks or tapes). Time pressures, and the disproportionately large number of "events" required for the Pi-0 background analysis, necessitated use of the relatively fast (and to us "free") CDC-6600 at U. of Mass.. Following a series of translations, from PDP-11 to DEC-10 to the SAO CDC-6400, a program operable at U. Mass. was created and, with the assistance of our colleagues at that institution, was rapidly executed to yield a simulated "Pi-0" data tape for each of our data points. These were then returned to Tufts and analyzed by the master system.

vii) By mid-summer Dr. Rutherfoord and Mr. Shupe began bringing together the summary files of the actual event data for each data point, along with the corresponding Compton and Pi-0 Monte-Carlo simulations. These data were brought down from the DEC-10, where they were stored on tape, over the dedicated 2400-baud link to the PDP-11 where they were combined in a special routine which fitted analytically the relative proportions of Compton and Pi-0 events to the actual azimuthal angle ("coplanarity") distribution. After corrections for various inefficiencies, and inclusion of primary beam flux information, the final cross sections and ratios were obtained.

The essential results from this experiment - the Compton scattering cross sections - are summarized for this present report in the accompanying figure. This is taken from Mr. Shupe's Ph.D. Dissertation, Proton Compton Scattering at Large Angles (Tufts University, August 1976, 284 pp) in whose text and several appendices the many details of the analysis outlined above are documented thoroughly. We include here also tables of both our measured Compton and Pi-0 differential photoproduction cross sections, and of the ratio of the two. This last is expected, as mentioned, to be relatively free of systematic errors from beam-flux monitoring and absolute acceptance determination. A paper for Physical Review Letters is currently in preparation to present these results formally and to offer interpretation in the light of current theoretical conceptions. We note in this present report that our Compton scattering results appear to join smoothly with DESY data taken at lower momentum transfers, and that in our new, previously unexplored region the cross sections fall off regularly with both t and s and with a decreasing slope in t above 2.5 $(GeV/c)^2$. It was found that current vector dominance models were inadequate to account for this behavior. The energy dependence of the Compton cross section at fixed center-of-mass angle was found to be approximately s^{-6}, as predicted by a quark model with dimensional-counting arguments. Our measurements of the Pi-0 cross section were in addition, found to be consistent with comparable SLAC measurements of the same quantity (at 4 and 5 GeV, R.L. Anderson et al., SLAC Pub. 1707, 1976). This lends credence to our overall observational and analysis procedures,

FIGURE VI-1.

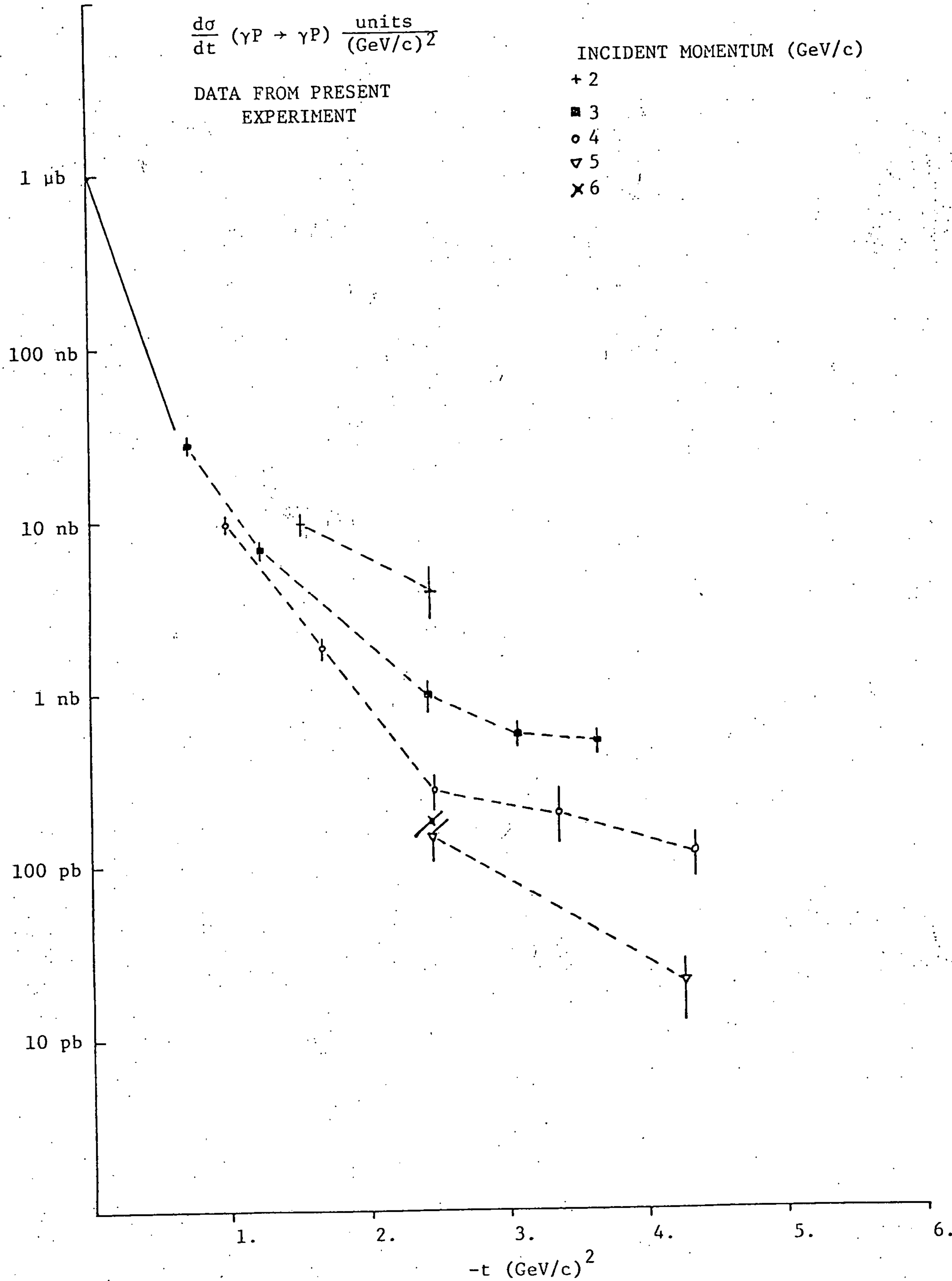
$\frac{d\sigma}{dt}$ (γP → γP) $\frac{\text{units}}{(\text{GeV/c})^2}$
DATA FROM PRESENT EXPERIMENT
INCIDENT MOMENTUM (GeV/c)
+ 2
■ 3
o 4
▽ 5
× 6
1 μb
100 nb
10 nb
1 nb
100 pb
10 pb
1.
2.
3.
4.
5.
6.
-t (GeV/c)^2

TABLE VI-1.

DIFFERENTIAL CROSS SECTION
FOR PROTON COMPTON SCATTERING

k	t	$\frac{d\sigma}{dt}(\gamma P \to \gamma P)$	Δk(rms)	Δt(rms)
2.0	-1.52	9.474 ± 1.551	.233	.188
2.0	-2.45	3.960 ± 1.320	.239	.335
3.0	-.71	27.50 ± 2.22	.381	.076
3.0	-1.22	6.881 ± 1.059	.365	.126
3.0	-2.43	.9670 ± .1934	.345	.260
3.0	-3.06	.5521 ± .1104	.338	.348
3.0	-3.65	.5060 ± .1020	.355	.469
4.0	-.98	9.427 ± 1.015	.471	.084
4.0	-1.68	1.812 ± .315	.471	.149
4.0	-2.49	.2647 ± .0618	.446	.224
4.0	-3.36	.1972 ± .0604	.442	.326
4.0	-4.23	.1144 ± .0309	.451	.470
5.0	-2.45	.1416 ± .0405	.582	.208
5.0	-4.29	.02037 ± .00866	.549	.397
6.0	-2.45	.1744 ± .0245	.614	.161

Errors are statistical only.

Units are GeV, GeV^2, Degrees, nb/GeV^2.

Δk(rms) and Δt(rms) are the first moments of the data about the mean values of k and t.

TABLE VI-2.

DIFFERENTIAL CROSS SECTION
FOR PIZERO PHOTOPRODUCTION
AND CROSS SECTION RATIO

k	t	θ^*	$\frac{d\sigma}{dt}(\gamma P \to \pi^\circ P)$	R
2.0	-1.52	90	756.5 ± 60.2	.0125 ± .0027
2.0	-2.45	127.8	733.9 ± 29.5	.00540 ± .0020
3.0	-.71	45	560 ± 15	.0491 ± .0054
3.0	-1.22	60	468 ± 7	.0147 ± .0025
3.0	-2.43	90	62.8 ± 1.7	.0154 ± .0035
3.0	-3.06	105	35.42 ± 1.07	.0156 ± .0035
3.0	-3.65	120	12.81 ± .39	.0395 ± .0010
4.0	-.98	45	307 ± 5	.0307 ± .0038
4.0	-1.68	60	98.58 ± 1.84	.0184 ± .0035
4.0	-2.49	75	9.95 ± .28	.0266 ± .0069
4.0	-3.36	90	7.29 ± .26	.0271 ± .0092
4.0	-4.23	105	7.64 ± .29	.0150 ± .0046
5.0	-2.45	64.62	3.88 ± .11	.0365 ± .0114
5.0	-4.29	90	1.458 ± .044	.0140 ± .0064
6.0	-2.45	57.95	3.656 ± .084	.0477 ± .0077

Errors are statistical only.

Units are GeV, GeV^2, Degrees, nb/GeV^2.

and since the Compton Pi-0 cross section ratio is relatively insensitive to the details of geometry and efficiency of our apparatus, to our final Compton cross sections.

In summary, the Compton scattering experiment is essentially finished, except for the formal writing up of the results for publication. This last is now in progress, and hopefully will be completed well before the end of the year.

D. Studies of Strange Particle Data Tapes at 9.3 GeV: Charm Search

(Professor Milburn, Assistant Professor Quinn)

The principal development, up to this writing has been the preparation and acceptance for publication in the Physical Review of an article reporting in detail the quantitative limits established by our search for photoproduced charmed mesons and baryons at this near-threshold energy (cf. our 1975 PROGRESS REPORT). Further work, as proposed, on the inclusive polarized photoproduction of $K^{*}(890)$ and $\Sigma^{*}(1385)$ states detected in the charm search has been delayed, in part by the departure of Prof. Quinn at the beginning of the summer (see above). It has, however, been established that the SLAC-IBM data summary tapes on which this study is to be based can be read satisfactorily at Tufts DEC-10. It is hoped that, with the aid of one of our two new Graduate Research Assistants, the program transfer from the SAO CDC-6400 to Tufts can be effected and this relatively straightforward and inexpensive study will get underway this fall.

E. High Average Power Laser Development for A SLAC Laser Beam

(Professor Milburn, Mr. Mroczkowski)

The primary development, to this writing, has been the completion of the Ph.D. dissertation by Mr. Mroczkowski in November, 1975, in which his development of a novel efficient high-repetition-rate lamp pulsing system, involving a pre-triggering, arc-stabilization scheme, was written up in detail.

He also, as part of his dissertation, developed in conjunction with Prof. M. Randic, then of the Tufts Chemistry Department, a new crystal field analysis of Nd^{3+} states in YAG. A draft of the latter work has been prepared by Mr. Mroczkowski for early publication, and a technical paper on the efficient flash lamp triggering system is anticipated in due course.

As left by Mr. Mroczkowski when he took up his new job in January of this year, the YALO system was primarily limited in average power output by the DC power supply, which could produce no more than 5 amperes, or at most 3 KW at the system's operating voltage. Budget limitations, reinforced by unexpectedly high computing costs for the Compton experiment, precluded purchase of another supply. This past summer we were fortunate to obtain through the assistance of Dr. Arthur Uhlir, Dean of Engineering, two very sturdy 700 volt, 5 amp DC supplies which, we understand, had been rendered surplus from the U.S. ABM program by the SALT talks. These appear to be ideally suited for our application, and are presently being adapted for the purpose. These supplies, plus the anticipated arrival of a second graduate research assistant and the cessation of the great pressure to complete the Compton scattering analysis should make it possible to continue this modest technical development this fall. The goal continues to be the determination of the optimum configuration for and capability of high repetition rate laser systems suitable for backscattered laser beam production at the SLAC linac.

In this connection, Professor Milburn delivered an invited contribution to the ZGS Symposium on High Energy Physics using Polarized Beams and Targets, Argonne National Laboratory, 22-27 August 1976. In a paper on "Laser Beams in High Energy Physics" (to be published in the Proceedings) he established that the present state-of-the-art in Nd-YAG, and possibly also in flash-pumped dye, laser systems was already adequate to rebuild the "laser beam" at SLAC into a form suitable for upwards of 100 Hz operation of a streamer chamber in highly polarized, nearly monochromatic photon beams to about 12 GeV, or even to about 30 GeV, given the proposed SLAC energy doubling (SLED). The anticipated cost would be about $250-300K, assuming use of present-day commercially advertized laser components and a specially built rotating mirror commutator to combine sequentially the outputs of individual laser heads operating at about 20 Hz.

F. Study of Hadron Jets at Fermilab

(Dr. William Oliver, in collaboration with Drs. Hicks, Mockett, Rothberg, Young and Williams of the University of Washington, Seattle, and Drs. Limon, Mantsch, Orr, and Pruss of Fermilab)

Dr. Oliver begins his appointment at Tufts midway during the runs of a major Fermilab experiment (E-236A) to measure the properties of back-to-back hadron jets generated at large transverse momenta by 200 GeV/c particles incident on hydrogen. Since Dr. Oliver expects to continue to work on this experiment, in the development and construction of which he has played a central role, and to see it through to its conclusion, it becomes immediately a very significant element in the present and future program of the Tufts group. Since we have not previously described this hadron jet experiment, we shall devote a few paragraphs to a summary of its features and current status. This will be followed by a description of Dr. Oliver's planned work during the remainder of 1976.

The experiment consists of two large-solid-angle arms, oriented back-to-back in the center-of-mass frame of a 200 GeV/c momentum beam particle. One arm is a single-magnet, one-steradian-acceptance spectrometer. Trajectories entering and exiting the magnet are measured by multiwire proportional chambers. The particle species is identified by a series of three threshold gas Cerenkov counters downstream of the magnet. The other arm is a 3-steradian-acceptance calorimeter. The calorimeter is sectioned to distinguish π°'s from other hadrons. A 9-radiation-length lead section is followed by a 5-1/2-interaction-length steel section. Proportional chambers are located in front of the calorimeter to measure more accurately the trajectories of incident charged particles.

The two arms were designed to complement one another. The magnet arm was triggered on charged single particles having transverse (to the beam direction) momentum greater than 2 GeV/c. The acceptance of the magnet arm was made large enough (based on preliminary ISR data) so that we could look for jet structure in the correlation between the trigger particle and its nearest neighbor. The calorimeter was designed so that it could be triggered on the aggregate transverse momentum possessed by all particles incident upon it. The calorimeter is sensitive to all particles, charged or neutral, hadronic or electromagnetic, so is an ideal detector with which to search for jet structure.

The experiment is set up in the Ml beam line in the Meson Laboratory at Fermilab. A long data run was performed during June and July of 1976. Data were taken mostly for a beam momentum of 200 GeV/c. The beam particle species (π, K, or p) was identified by a series of three differential Cerenkov counters. Both arms were triggered by a trigger in either arm. The experiment was sensitive to a total of 2 x 10^{10} beam particles during the June-July run. 450 tapes were written.

The first goal of the analysis is to extract from the magnet-arm data inclusive cross sections for the production of $\pi^{\pm}$, $K^{\pm}$, p, $\overline{p}$ by $\pi^{\pm}$, $K^{\pm}$ beam particles. Our data is the first measurement of these cross sections for particles having transverse momentum greater than $\sim$1 GeV/c. The second goal of the analysis is to look for a coplanarity signal in the calorimeter for magnet-arm triggers. The observation of this signal will be very strong evidence that collisions in which large momentum is transferred proceed by a single hard scattering (presumably a collision between hard constituents).

A further goal is to look for jet structure in the correlations between the various particles entering the calorimeter. If jets are seen, we will extract the cross sections for their production and compare for the various beam particles and various beam momenta.

The final goal will be to study the correlations between the jets seen in the two arms to learn something about the dynamics of the constituent-constituent scattering process.

Dr. Oliver's immediate effort during the remainder of 1976 is to study the systematics of the single particle high-p_T trigger in the magnet arm. He will use data taken (especially for this purpose) with the current in the magnet set to $\sim$1/3 of the usual value. The copiously-produced low p_T particles provide a very strong signal with which to map out the geometric acceptance of the trigger. The absolute efficiency of the trigger will be measured by using events triggered on the calorimeter arm. Proportional chamber information will be used to determine which trigger counters should be present and hence measure their efficiencies.

He will then use this information in a Monte Carlo program to calculate the acceptance of the magnet arm trigger. This acceptance will be folded into the yield of high p_T particles (as determined by the analysis effort in Seattle) to calculate inclusive production cross sections.

Next Dr. Oliver will turn his attention to the general problem of pattern recognition in the proportional chambers in front of the calorimeter as well as the chambers upstream of the magnet. These chambers are busy and will probably require special treatment. He plans to devise a technique for coherently solving the pattern recognition problem by using all the information at once.

The acceptance calculation will involve only about 5-10 data tapes and probably not more than about ten hours of CDC-6400 computer time. The calculation of the acceptance will probably be completed this fall, 1976. The pattern recognition problem is less straightforward and harder to estimate. Dr. Oliver plans only to develop the technique at Tufts. If the technique is successful he would then arrange for production computer runs at Fermilab or elsewhere which would either be free or paid for by the University of Washington High Energy budget. He plans to develop the pattern recognition program on the PDP-10, hopefully using interactive graphics. A very crude estimate of the computer time required would be about 5 hours.

The hadron jet experiment is scheduled to run again in January, 1977. Dr. Oliver's presence at Fermilab will probably be required for about six-seven weeks. This breaks down as about three weeks preparation time at the end of 1976, to bring up the proportional chamber system to a state of full readiness and reliability, and a three to four week run in 1977.

Dr. Oliver is also considering accepting an invitation to participate in an approved Fermilab experiment (E-439) to study, with very large acceptance, di-muon production by 400 GeV protons in steel. This would be in collaboration with groups from U. of Washington and from Northeastern University.

G. High Energy Eta Photoproduction Using A Linearly Polarized Photon Beam

As described in the Photon Group's 1975 PROPOSAL and 1975 PROGRESS REPORT, the execution of our authorized SLAC feasibility run (E-108) was held up by competing experiments in the SLAC A-Beam area. With completion of our interim Cornell Compton scattering experiment, reported above, we had expected to press for our SLAC run. However, the recent personnel changes in our group, combined with the realignment of our co-proposers at the University of Massachusetts (Drs. Hertzbach, Kofler and Rabin) into other groups would make it difficult to execute the proposed feasibility demonstration and initial experimental run adequately. We have consequently asked that E-108 be removed from the current list of approved SLAC experiments, while retaining the option to resubmit it again should a sufficient collaboration become interested in prosecuting it. We note that the physics of the proposed experiment, though presently overshadowed by the deluge of new particle discoveries, remains of fundamental interest for the systematic understanding of medium-energy particle production dynamics. This is emphasized by a recent paper from Daresbury at 2.5 - 3.0 GeV which shows little contribution from unnatural parity exchange in any Regge model of polarized eta photoproduction, in contradiction with present theories.[1] Our proposal at 6, 10, and 14 GeV promised to elucidate this question over a much larger energy range. Since it seems unlikely, using known techniques, that these measurements can be made except at SLAC by the means we proposed, we hope that it may prove logistically feasible to return to this experiment in the not too distant future.

[1] The Polarized Beam Asymmetry in Photoproduction of Eta Mesons From Protons at 2.5 and 3.0 GeV. P.J. Bussey et al., Phys. Letters 61B, 479 (1976).

H. Planning and Proposals for New Experiments

In addition to the continuing work stemming from Dr. Oliver's association with Fermilab (see Sect. F, above) the Photon Group hopes to embark on two new experimental studies, both related to the interest, experience and equipment resources of the Tufts groups. These are:

1. Proposal to Study Phi-Meson Production Mechanisms and the K^- Associated Lepton-to-Pion Ratio in π^+-p Interactions at 15 GeV/c.

The experiment would utilize the SLAC streamer chamber and external pion beam. The proposal is in collaboration with Prof. Z. Ming Ma of Michigan State University, and with Profs. Dao, Mann, and Schneps of our Bubble Chamber Group. A copy of the theoretical justification for this proposal, SLAC-E-125, is included as an appendix to this Report.

In essence, the experiment would detect negative kaons emerging at relatively large p_T from the primary interaction to flag an interaction in which a phi-meson could have been produced and to trigger the streamer chamber. The resulting photograph would show the primary interactions charged products with almost 4π acceptance. The K^- trigger would be based upon a momentum-selecting array of picket fence scintillation counters in anti-coincidence with a large gas Cerenkov counter with threshold set to detect pions efficiently. The picket fence would be built at Michigan State; the Cerenkov detector would preferably be borrowed. A suitable high pressure counter is, we understand, available from storage at LBL. Alternatively, an atmospheric pressure counter, based upon the dense gas isobutane, might be constructed relatively inexpensively. Besides having the capacity to resolve and study phi-mesons, through fitting events seen in the streamer chamber, the experiment proposes to tag those outgoing positive particles of known momentum which are electrons. This is to be done through the combination of a simple atmospheric pressure Cerenkov detector, to be built, combined with the Tufts Pb-Glass Cerenkov hodoscope reconfigured slightly for the new application. In addition, an existing Pb-scintillator sandwich counter available to us from the ZGS, would be used to backstop the Pb-glass array and maximize the energy resolution of the system.

The goal of the electron detection system is to resolve with a maximum of confidence electron signals as small as 10^{-4} from an expected heavy background of positive pions, some of which can simulate electrons through charge-exchanges on nuclei. This separation of electrons from pions is a problem to many recent experiments studying the occurrence of large p_T lepton production in hadronic reactions, especially in those involving electron (SPEAR, PEP) and proton (ISR) storage rings. The essential technique is to utilize the differences in shower development structure associated with pion- and electron-induced electromagnetic cascades. Counter systems reported in the literature generally use only the longitudinal differences. These differences result essentially from the fact that the pion generally penetrates deeply before it charge exchanges and showers and because the produced π° generally does not contain all the energy of the incident pion. The Tufts 60-element Pb-glass Cerenkov hodoscope, possibly augmented by another 20 elements from University of Mass., would permit additional resolution, and therefore pion rejection, to be obtained from use of an X-Y configuration to sense the lateral as well as the longitudinal shower development. One would expect the π°-induced showers to be broader than electron showers due to the divergence of the two gamma rays. Two different proven Monte Carlo programs for electromagnetic shower development have been acquired - one from Prof. Ma and one from Prof. M. Rabin of U. Mass.

These are being modified to make them fit the various geometric configurations we wish to examine, and to permit comparisons between their somewhat different modelling algorithms. The goal of this development is to devise an optimum configuration of the two different kinds of Cerenkov counter element available to us for the purpose of maximizing the rejection of pions, consistent with the acceptance of electrons in the same momentum spectrum and with as large as possible an entrance aperture. We note that in addition to its application to our proposed SLAC experiment, this study will be of potential value to other similar applications of our counters, and to the art of Cerenkov counter usage in general.

The streamer chamber proposal was presented to the SLAC Program Advisory Committee on 14 September. At that time questions were raised concerning the predictions in our proposal of the expected overall rate of phi production in the primary 15 GeV reaction. At this time no published data on inclusive phi meson or K^--meson production in 15 GeV π^+p exists, and our assumed cross section of 200 microbarns had to be based upon what appeared to be physically reasonable extrapolations from closely related reactions in other channels and at other energies. Just before the above PAC meeting we, and Committee members, became aware of unpublished data from the CERN OMEGA collaboration which purports to indicate that phi production in 16 and 19 GeV π^-p reactions (a different but analogous process to the π^+p we propose) may actually be suppressed by a factor of ten or more from the 200 microbarns we require to get the desired yield of upwards of 10^4 phi's. Unfortunately, the OMEGA data were obtained in a very complex detection system and, in the absence of detailed published information on the acceptance of their triggering arrangement for inclusive phi production, we can neither evaluate nor challenge directly the adverse implications with respect to our proposal. Fortunately, the Columbia group under Dr. C. Baltay (a PAC member) does have data tapes containing about 750,000 measured events from an earlier 15 GeV bubble chamber exposure to π^+p. Although he did not examine his data specifically for inclusive phi production, it should be possible to establish from a study of plus-minus pairs in his data tapes whether a phi signal comparable to that expected from a 100 or more microbarn phi cross section exists, in the presence of a heavy pi-pair background. Dr. Baltay has informed Dr. Ma that he will study this as soon as possible this fall - a matter of rerunning a lesser or greater number of data tapes on his computer. We are hoping that Dr. Baltay's data will provide an empirical confirmation of our predicted phi rates, and this in time for re-submission of our streamer chamber proposal to the SLAC PAC in December.

2. Electron Polarization Measurement and PEP/PETRA CW Laser Beam Feasibility Test at SPEAR

In recent years considerable theoretical concern has been expressed over the question of polarization of the electrons and positrons in storage rings such as SPEAR,[1] PEP,[2] and PETRA.[3] If the beams are or can be polarized the possibility of forming thereby a unique angular momentum state in the annihilation collision would give a very useful additional definition to the ensuing reactions, in both angular distributions and polarizations of the products.[4] On the other hand, should the beams be assumed erroneously to be unpolarized but actually have an unknown and possibly variable polarization component, then serious interference with the interpretation of observed reactions could occur. The uncertainty of the situation has been emphasized by Chao and Schwitters' recent calculations showing the dependency of the beam depolarization processes on the details of orbit resonances, field perturbations and beam sizes.[5]

It has been recognized for some time, therefore, that a rapid (order of 1 minute) measurement of electron and positron beam polarizations would be highly desirable for these storage rings. Of the various methods proposed for this[6] the use of spin dependence in electron Compton scattering, as realized in back-scattered laser beam technique, is one of the cleanest and most direct.[1-3] For this, essentially, a transverse polarization component of the electron (positron) spin produces an up-down asymmetry in the scattering of circularly polarized photons, the azimuthal dependence of the rate having a term proportional to cos ψ where ψ is the angle between the normal to the electron-photon scattering plane and electron polarization.

Although proposals were formulated a few years ago to test these concepts for SPEAR[1,7] and brief studies have been made in relation to PEP[2] and PETRA[3], no actual experiment has yet been mounted to prove the method (an incidentally to measure the SPEAR polarization) in practice. The basic method is essentially a variant of that used successfully by Tufts to inject a laser beam tangentially into the CEA synchrotron[8], coupled with an additional rather delicate and precise photon detecting scheme to measure the up-down symmetry of the backscattered photon beam within a few microradians of angular resolution. An additional variant proposed depends upon the recent commercial availablility of moderate power cavity-dumped Argon-ion lasers whose pulse lengths of a few nanoseconds and repetition rates of a few MHz are extraordinarily well matched to the bunch lengths and orbital periods of SPEAR, PEP and PETRA. This last compatibility results in high backscattered photon yields and consequently rapid measurement of the electron or positron polarizations (if any) within a short time period.

In addition, it has very recently been calculated[9] that by using the most powerful forms of commercially available Ar-ion laser one might not only measure, say, the PEP beam polarization (possibly only to ensure that it is zero!) but at the same time ~~to~~ use the peak portion of the photon energy spectrum (5-6 GeV) as a highly polarized, 415 kHz repetition rate photon beam for a triggered streamer or other continuously sensitive electronic track chamber. Photon beam intensities of as much as 10^6 Hz might be expected in such a beam, effectively a CW source which arises in an effectively negligible (and with polarization measurement useful) perturbation on the stored beams. Such a facility would enable a track chamber or multiparticle spectrometer group to embark on a detailed study of the photoproduction dynamics of even the relatively rare channels formed in such reactions at up to 3.4 GeV in the center of mass.

These considerations, together with the long-standing interest and experience of the Photon Group with the necessary technique and evidence of mounting interest at SLAC to see some action with regard to SPEAR (and PEP) polarization measurements, have motivated us to become seriously involved in this project. We intend to prepare, in collaboration with Dr. C.K. Sinclair and possibly other interested SLAC scientists, a proposal for a simultaneous electron beam polarization measurement and a PEP/PETRA laser-beam feasibility demonstration, using the circulating SPEAR electron beam and a detector set up in the SSRP tangent beam area. It is planned to spend much of the remainder of 1976 in the formulation of this proposal, in close consultation with SLAC colleagues.

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I PHYSICS JUSTIFICATION

(a) Production Mechanisms for ϕ-meson.

Since the discovery of ψ/J (3095) at BNL[1] and SLAC[2] there has been renewed interest in the assumption of a fourth quark, called the charmed quark (c for short). By now, there is strong credibility that the ψ/J (3095) is an orthocharmonium state[3] with other higher mass enhancements being identified as excited states in this $c\bar{c}$ bound state picture. To complete this picture, it is absolutely necessary [4] that mesons and baryons with a non-zero charm quantum number exist. Experimental searches for these charmed particles in hadronic reactions thus far have not turned up convincing evidence.[5-8]

In as much as ϕ (1019) is almost a pure $s\bar{s}$ state, it is very likely that production mechanisms for ϕ (1019) and ψ/J (3095) share many common features. Empirical rules governing ϕ (1019), such as Zweig's Rule, which was proposed to explain the suppression of ϕ decay into the $\rho\pi$ state may be applicable to ψ/J (3095). Although applicability of Zweig's Rule to production processes has not been unambiguously demonstrated, available experimental evidence seems to support such a notion, at least qualitatively. For example, in the reaction

$$\pi^- p \to \phi n \qquad (1)$$

Ayres[9] observed that the reaction is suppressed relative to the reaction

$$\pi^- p \to \rho n \qquad (2)$$

by a factor of some 280. This is expected according to Zweig's Rule. Except for the ϕ meson, none of the other participants in the reaction carries a significant amount of the strange quark in its wave function. Therefore in terms of the standard particle exchange picture, the strange and the antistrange quark lines must terminate on themselves as is shown in

Figure 1 (a). This mechanism is suppressed according to Zweig's rule. For reaction (2) no such effect is expected. Furthermore, a comparison of the production cross-sections (see Figure 2) for reactions (1) and (2) enhances one's impression that these two reactions may indeed be governed by different mechanisms. The cross-sections for ϕ production exhibit a very steep drop-off ($\sigma \sim P_L^{-3.5}$) following a rapid rise from threshold. This is characteristic of Fermi's statistical model or a Regge cut model. In comparison, the ρ production cross-sections fall slowly with energies ($\sigma \sim P_L^{-1.89\pm.09}$).

Suggestions have been made[10] that Zweig's rule is strictly observed for ideally mixed vector and tensor meson states. The apparent violations such as reaction (1) are due to the mixing effect in the physical particles. It therefore, follows that the cross section ratio, R, is given by

$$R \equiv \frac{\sigma(\pi^- p \to \phi n)}{\sigma(\pi^- p \to \omega n)} = g^2_{\phi\rho\pi}/g^2_{\omega\rho\pi} \approx 1/225 \qquad (3)$$

The cross section ratio is expected to be a constant. Although the cross section for the reaction

$$\pi^- p \to \omega n \qquad (4)$$

is poorly known, considerations of allowed exchange mechanisms would lead one to expect that reaction (4) (via ρ exchange) should have a slower energy-dependent fall off in cross sections than reaction (2) (via π exchange). Taking this factor into consideration, one would conclude that the cross section ratio R decreases rapidly with increasing momentum, therefore, in-consistent with equation (3). Similar results have been reported by a Liverpool group[11] in a comparison of the reactions

$$\bar{p}p \to K^+K^-\omega^o \qquad (5)$$

and

$$\bar{p}p \to K^+K^-\phi \qquad (6)$$

at 3.6 GeV/c. Here the observed rate based on 12 events for reaction (6) is an order of magnitude higher than would be expected from the measured rate for reaction (5).

Recently, a theoretical attempt to understand reaction (1) in terms of a double Regge pole exchange picture was advanced by Berger and Sorensen.[12] Figure 1 (b) shows the proposed exchange mechanism. The precipitous drop-off in the production cross sections is explained in terms of a cancellation effect by K (890) and K (1420) in the intermediate state. Although the model can account for the shape of the cross section drop-off, it fails to predict its experimental magnitude by a factor of 3. In addition, the model predicts a turn over in the t-distribution which is not observed experimentally.

On the constructive side, it was first pointed out by Sivers[13] that one might expect to observe production of a pair of strange particles in association with the ϕ meson (Figure 3(a)). An example of this mechanism (Figure 3 (b)) would be

$$\pi^- p \rightarrow K^o \phi \Lambda^o \tag{7}$$

where the s and $\bar{s}$ quarks from the ϕ meson terminate on the neighboring K^o and Λ^o respectively. Experimental data relevent to this question are quite limited. In $\bar{p}p$ interaction at 3.6 GeV/c, the cross section ratio is reported to be

$$\sigma(\bar{p}p \rightarrow \phi\pi^+\pi^-)/\sigma(\bar{p}p \rightarrow \phi K^+K^-) = 0.7 \pm .3 \tag{8}$$

based upon a total of 24 ± 4 ϕ events. An unpublished piece of information from the OMEGA Spectrometer group indicated[14] that in the $\pi^- p$ interaction at 19 GeV/c, the cross section ratio is

$$\sigma(\pi^- p \rightarrow \phi\pi^+\pi^-\pi^- p)/\sigma(\pi^- p \rightarrow \phi K^+K^-\pi^- p) = 1.4 \pm .3 \tag{9}$$

based on a total of 120 ϕ events. In both cases, the ratios are consistent with being one. However, in both experiments, ϕ events represent a larger fraction of the final states when an additional pair of kaons are involved.

H. Lipkin[10] has argued that the proper interpretation for experimental data such as (8) and (9) is complicated by the fact that it is difficult to produce a kaon pair in any reaction. Therefore, cross section ratios (8) and (9) merely indicate the relative difficulties for Zweig's rule violations as compared with producing an extra pair of charged kaons. Available data, therefore, seem to support the notion that these two processes are comparable in magnitude.

In summary, experimental facts on Zweig's rule are virtually nonexistent and our understanding of the dynamic origin of Zweig's rule is very limited. A careful study of ϕ producing reactions can not only shed light on the mechanism for producing a bound state of a pair of identical quarks, such as ϕ, f' (1520), ψ/J (3095), etc. in hadronic interaction, but also can provide a basis for understanaing the dynamic origin of Zweig's rule. Furthermore, since ϕ production cross sections are of the order of 10^2 μb, it makes sense to test dynamic models such as the associated production picture of Sivers (e.g. ϕ production in association with a pair of strange particles and ψ/J production in association with a pair of charmed particles) using the ϕ-meson before embarking on a massive search for charmed particles using ψ/J or ψ' mesons.

A survey of currently existing data indicates that except for reaction (1), data are virtually non-existent for exclusive ϕ production reactions where Zweig's rule may play an important role. In this experiment, we propose to use the trigger

$$\pi^+ p \rightarrow K^- + X \qquad (10)$$

to obtain a large sample of ϕ events at a level of 144 to 436 events/μb. This includes an acceptance of 5.7 to 17.2%.

(b) Search for New High Mass $K\bar{K}$ States

An effective K^- trigger will also make possible a high statistics search for new high mass $K\bar{K}$ states. One such state that is of particular interest here is the ϕ', the missing member of the $J^P = 3^-$ nonet.[15] It is expected that ϕ' should have a mass between 1800 and 1900 MeV/c^2 and has an appreciable decay rate into $K\bar{K}$ states. The triggering efficiency as a function of the $K\bar{K}$ mass is given in Figure 4. Here the $K\bar{K}$ pair is assumed to be isotropicly produced. At a mass of 1800 MeV/c^2, it is expected that a 120 to 360 event/μb sensitivity can be achieved.

(c) Measurement of $R(e^+/\pi^+)$ with an Accompanying K^-

The subject of direct lepton production[16] has been of interest for over ten years. Although specific emphasis has been shifting over the years, its general motivation is always to search for new particles, such as the intermediate vector boson $W^{\pm}$, recently discovered ψ/J (3095) and these elusive charmed particles.

Recent results from ISR[17,18], BNL[19] and Fermilab[20-24] indicate that in proton-nucleon or proton-nucleus interactions,

(i) the ratio $R(\mu/\pi) \simeq R(e/\pi)$ to a 40% accuracy.

(ii) the lepton to pion ratio $R(\ell/\pi)$ is $\sim 10^{-4}$ for $P_\perp > 1.5$ GeV/c.

(iii) for the lower $p_\perp$ region, the ratio $R(\ell/\pi)$ rises to $\sim 4 \times 10^{-4}$ as $P_\perp \to 0$.

(iv) the lepton charge symmetry is good to a 10-20% level.

Taking all existing data into consideration, Lederman[16] concluded that such large lepton to pion ratios cannot be explained by the production of known particles. The approximate equality of muon and electron production and the lepton charge symmetry seem to indicate that the source of these leptons is a vector meson. If such were the case the mass of such a vector meson will have to be between 0.7 and 1 GeV/c^2 to be consistent with existing data. Another possible explanation would be due to the semileptonic decay of new unknown particles, such as the charmed mesons or baryons.

Theoretical estimates[4,25] for the leptonic and semileptonic branching ratios for a charmed particle range from 5 to 20%. Assuming that the charm quantum number is conserved in strong interaction, the D meson (the pseudo scaler charmed meson) must be produced either in a pair or in association with a charmed baryon, e.g., C. In either case, one would expect leptonic charge symmetry in the final state. Since dominant decay modes of charmed particles involve a strange particle in the final state, one would expect the lepton to pion ratio to be substantially higher than 10^{-4} when the lepton is accompanied by a kaon.

Experimental evidence for anomalous direct lepton production in association with strange particles has been reported in neutrino-proton[26] and $\bar{p}p$[27] interactions. In a bubble chamber experiment, Canter <u>et al</u>.[27] have reported the observation of 10 $K_S^o\ e^{\pm}$ candidate events in $\bar{p}p$ interaction at 15 GeV/c. A total of 9 of these events are identified by an e^+ or e^- shower behind a 2 radiation lengths tantalum plate placed in the BNL 80-inch hydrogen bubble chamber. The remaining candidate shows a characteristic e^- spiral in the bubble chamber. Background calculations indicate that only 1.5 events can be accounted for by hadronic showers and accidental correlations. These results come from a scan of 921 $K_S^o \rightarrow \pi^+\pi^-$ events. This corresponds to a production cross section $\sigma(K_S^o\ e^{\pm})$ of 13 μb and ratios of

$$R(K_S^o\ e^{\pm}/\pi^{\pm}) = 1.2 \times 10^{-4} \quad (11)$$

and

$$R(K_S^o\ e^{\pm}/K_S^o) = 9.3 \times 10^{-3} \quad (12)$$

Assuming equal participations of all kaon charge states, one has

$$R(K\ e^{\pm}/\pi^{\pm}) = 4.8 \times 10^{-4} \quad (13)$$

An interesting question would be to ask whether or not charmed or charm-like particle production is responsible for the anomalously large lepton to pion ratio. If charmed particles are at the source of this effect, one would expect to see a similar effect in π^+p interaction. Therefore, a measurement of the K^-e^+/π^+ ratio in π^+p interaction can confirm the large $K_S^o\ e^\pm$ effect in $\bar{p}p$ interaction. With a larger sample of Ke events, it will be possible to study the final state composition of these events.

Assuming equal production of K_S^o and K_L^o, one may expect

$$R(K^-e^+/K^-) = 4.7 \times 10^{-3} \tag{14}$$

in this experiment.

(d) Search for Charmed Particle Production in π^+p Interaction

Experimental effort in search for charmed particles has been largely in e^+e^- and nucleon-nucleon interactions. Recently, a narrow enhancement has been reported by the LBL-SLAC collaboration using SPEAR.[28,29] The structure is observed at a mass of 1.87 GeV/c^2 and has a width between 10 and 20 MeV/c^2. Neutral decay modes of this particle have been seen in the $K\pi$ and $K3\pi$ states[28] and hints of charged states in the $K2\pi$ mode are also reported.[29] If these effects are indeed due to charmed particles, one would expect to detect copious production of these states in hadronic interactions.

Previous searches for hadronic production of charmed states in exclusive channels

$$\pi^+p \rightarrow \pi^+p\ D^o\ \bar{D}^o \qquad (15)$$

$$\pi^+p \rightarrow C^{++}\ \bar{D}^o \qquad (16)$$

have been reported.[6,8] In a bubble chamber experiment, the upper limit for reaction (15) with π^+ and p in the Δ^{++} state is reported to be 2.6 μb for a 95% confidence level. The corresponding upper limit for reaction (16) is set at 3.0 μb. In both cases, a K^o_S or a Λ^o in the final state is required. An inclusive search for two body decay modes of neutral charmed states has been carried out by an MIT-BNL group[5]. A small acceptance two arm spectrometer is used to look for structures in two body states from pBe interaction at 30 GeV/c. The upper limits[30] for the product σ.B are of the order of 118 nb for observing a 3 standard deviation effect in the $K^+\pi^-$ state at 1.87 GeV/c^2.

It is a well-known fact that meson production is far more copious in the meson-nucleon interaction than it is in the nucleon-nucleon interaction.[31] Threshold reactions such as reactions (15), (16) and

$$\pi^+ p \to \pi^+ p F^+ F^- \tag{17}$$

where $C^{++} \to \pi^+ p\ D^\circ$

$$D^\circ \to K^- \pi^+, \quad \bar{D}^\circ \to K^+ \pi^-,$$
$$\bar{K}^\circ \pi^\circ, \quad K^\circ \pi^\circ,$$
$$K^- \pi^+ \pi^\circ, \quad K^+ \pi^- \pi^\circ,$$
$$\bar{K}^\circ \pi^+ \pi^-, \quad K^\circ \pi^+ \pi^-,$$
$$K^- \pi^+ \pi^+ \pi^-, \quad K^+ \pi^- \pi^+ \pi^-,$$
$$\bar{K}^\circ \pi^+ \pi^- \pi^\circ, \quad K^\circ \pi^+ \pi^- \pi^0$$

and $F^\pm \to K^\pm K_S^\circ$

$$K^+ K^- \pi^\pm \tag{18}$$

are possible candidates for the discovery of these charmed mesons and baryons.

The value of detecting charmed particle production in exclusive channels is clear. Ability to identify other participants in a given reaction not only can reduce the combinatorial problem in mass plots, but also allows one to study the dynamic mechanisms governing the production of these states. From available data, it is obvious that for three or more body decay modes, there is substantial ground for improvement. An ideal detector for such a search must have a large solid angle coverage, be triggerable and have a demostrated multi-track handling capability. We believe that our proposed experiment with a K^- trigger in the streamer chamber is a natural vehicle for such a search.

Theoretical estimates for associated charmed production cross sections have been made by Field and Quigg[32] and Barger and Phillips[33] separately using Regge pole models. For two body reactions, cross sections of the order of a nanobarn are predicted. Lee, Gaillard and Rosner[4] argued that $D\bar{D}$ and $C\bar{D}$ pairs can result from the decays of high mass meson and baryon clusters respectively. Since these clusters may be produced diffractively in π^+p interaction, cross sections for the reaction

$$\pi^+ p \rightarrow M + \ldots\ldots\ldots\ldots\ldots \qquad (19)$$
$$\quad\ |\!\rightarrow D^o\bar{D}^o$$

or

$$\pi^+ p \rightarrow N^{*\,++} + \ldots\ldots\ldots\ldots \qquad (20)$$
$$\quad\ |\!\rightarrow C_1^{++}\ \bar{D}^o$$

may be of the order of microbarns. Currently no positive information exists for charmed particle production in hadronic interactions. It is therefore, not possible to predict with confidence the energy dependence of cross sections for the production. However, one can argue that in general, cross sections for reactions requiring a quantum number exchange fall with increasing c.m. energy. On the other hand, the suppression due to large t_{min} or small available phase space near threshold would suggest that the production cross section should peak near but above the threshold energy. Furthermore, experimental evidence[31] seems to support the notion that mesons tend to be produced more copiously with a meson beam than with a baryon beam. Therefore, our proposed experiment should provide an interesting ground for charmed particle searches.

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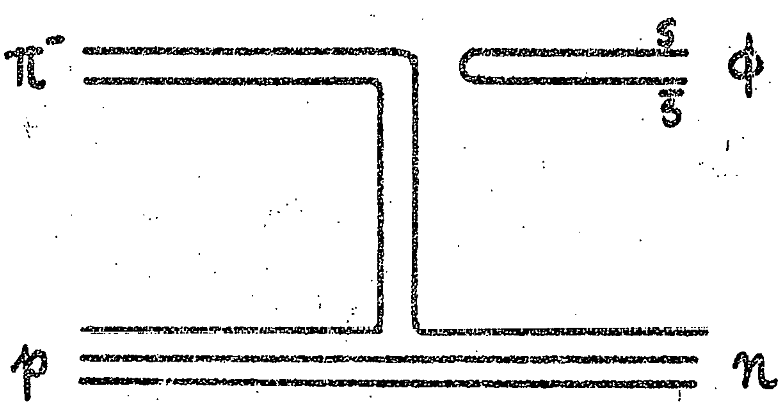
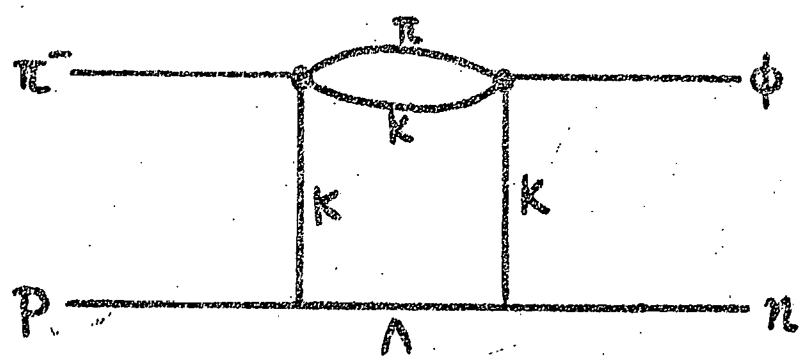


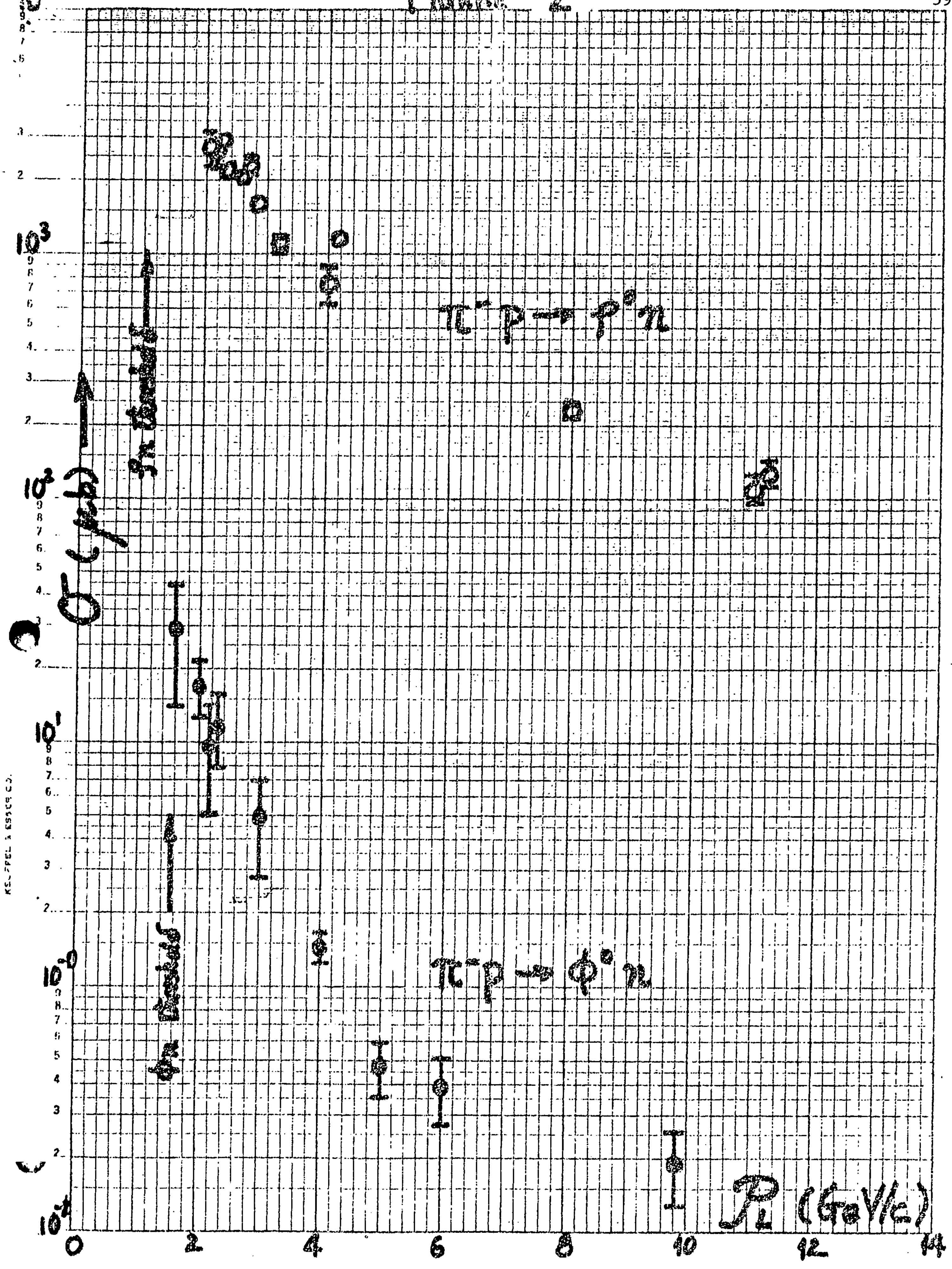
(a)

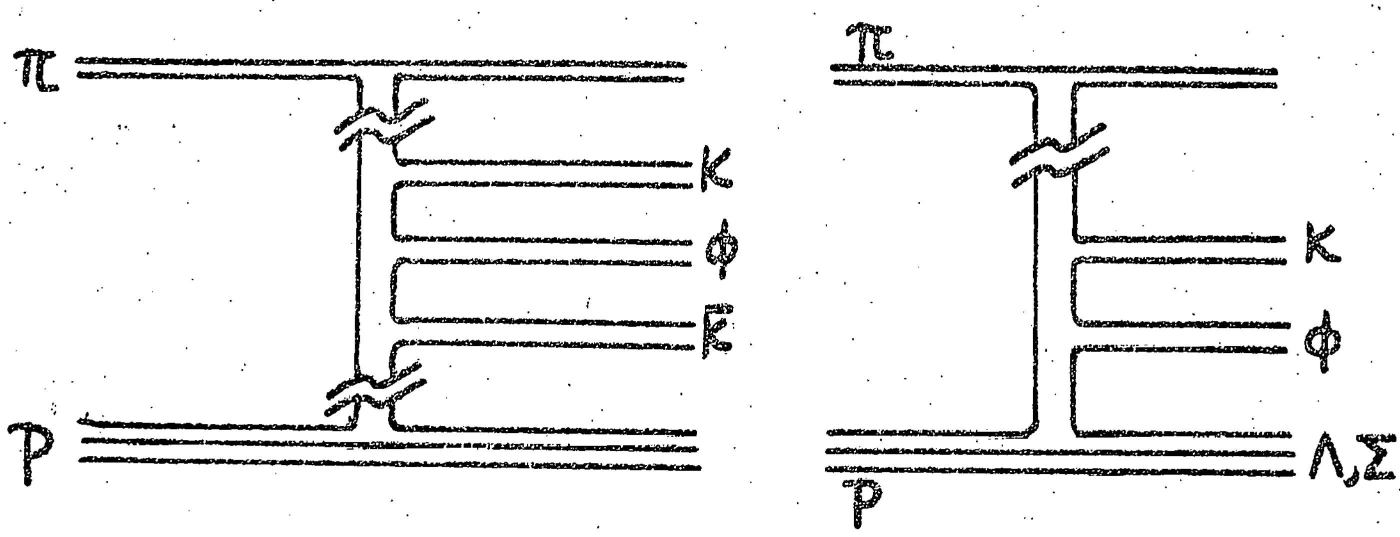


(b)

FIGURE 1

FIGURE 2





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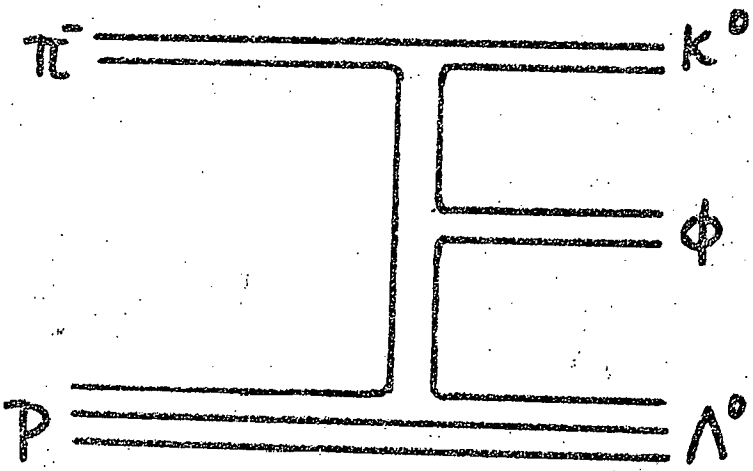

(b)

FIGURE 3

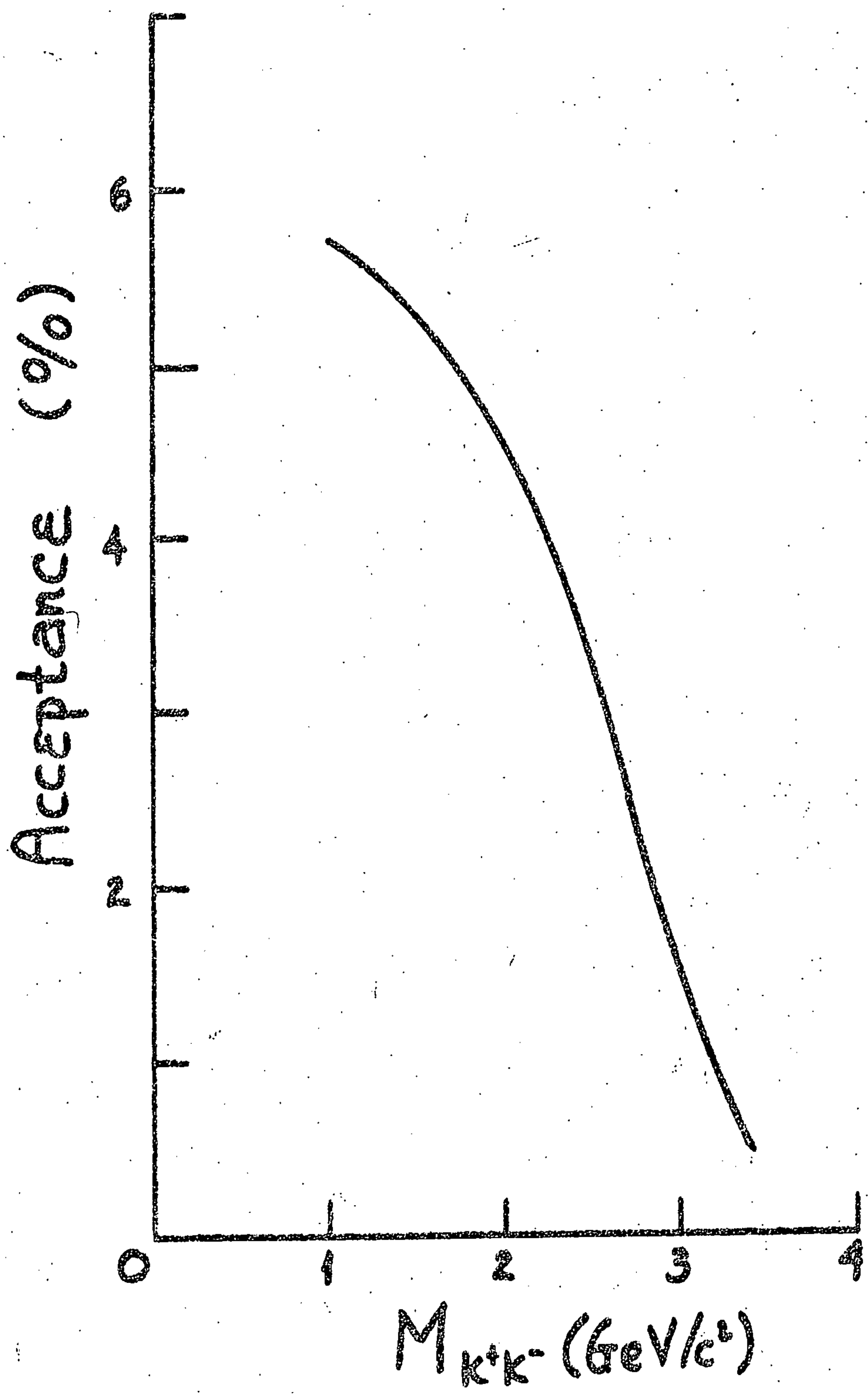

FIGURE 4

PUBLICATIONS - PHOTON GROUP 1976

Journal Articles Published

1. Production of Hadron Pairs in High Energy Collisions, F.T.Dao and D.J. Quinn, Phys. Rev. Letters 36, 991 (1976). (Also listed under Bubble Chamber Group Publications)

2. Search for the Associated Production of Charmed Baryon and Meson States by a 9.3 GeV Photon Beam, D.J. Quinn and R.H. Milburn. Accepted for publication in The Physical Review.

3. Laser Beams in High Energy Physics, R.H. Milburn. Invited paper presented to the Symposium on High Energy Physics with Polarized Beams and Targets, August 23-27, 1976, Argonne National Laboratory, and to be published in American Institute of Physics Conference Series, Vol. 35.

Reports, Presentations, etc.

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1. An Experimental Test of Position Resolution of a Lead Glass Array. R.H. Milburn, D.J. Quinn, J.P. Rutherfoord, M.A. Shupe, and A.R. Stottlemyer (with authors from Cornell, M.I.T., and Univ. of Mass.-Amherst). Nucl. Inst. and Methods 129, 427-435 (1975).

2. Semi-Local Duality in π° Photoproduction, J.P. Rutherfoord with H.K. Armenian, Gary R. Goldstein, and D.L. Weaver, of Tufts; Phys. Rev. D12, 1278 (1975).