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# EXPERIMENTAL PROGRAM AT THE STANFORD LINEAR ACCELERATOR CENTER $^{\ast}$

by

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# ABSTRACT

The present status of the experimental high-energy physics program at SLAC is discussed. The experimental arrangements are described, together with those preliminary results already obtained.

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#### I. INTRODUCTION

An electron beam was first taken the entire length of the machine, through the Beam Switchyard and into End Station A in September 1966. The initial beam survey experiments were done before Christmas 1966, but for the most part the main experimental programs didn't really start collecting data until just a few months ago. For this reason nearly all the results presented here must be considered as preliminary in nature.

The linear accelerator delivers 360 pulses/sec, each of duration ~ 1.5  $\mu$ sec. This results in a duty factor, defined as the ratio of beam-on time to real time of about 1/2000 at 360 pulses/sec; frequently the beam is shared between experiments by means of pulsed magnets in the Beam Switchyard and the duty factor for a particular experiment becomes correspondingly worse. Many types of counter-spark chamber experiments become very difficult or impossible because of the duty factor.

The maximum beam intensity is quite high, however, being typically

30 milliamps instantaneous =  $3 \times 10^{11}$  electrons/pulse =  $10^{14}$  electrons/sec.

Note that such beams have a considerable amount of power, a few tenths of a megawatt, making collimator and beam stopper design difficult.

The natural momentum spread of the electron beam has a full width of about 1/2%; this can be sharpened by closing momentum-defining slits in the Beam Switchyard and throwing away those electrons outside the desired momentum interval. The beam has a very small phase space, spot sizes of 1- or 2-mm diameter, and angles of 10<sup>-5</sup> radian being typical.

Although electrons have been accelerated to more than 20 GeV, such energies are not practically feasible over long periods of time and the experiments have run with electron beam energies of 18 GeV and under.

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# **II.** LEPTON-PROTON SCATTERING EXPERIMENTS

#### Experiment 1

# e p Elastic Scattering

B. Barish, M. Breidenbach, D. Coward, H. DeStaebler, R. Early,
J. Friedman, H. Kendall, P. Kirk, J. Litt, J. Mar, A. Minten,
L. Mo, W.K.H. Panofsky, J. Pine, and R. Taylor.

The process  $e^{-}p - e^{-}p^{-}$  is being studied by a collaboration between SLAC, MIT, and Cal Tech. They observe the scattered electron in the 8-GeV SLAC spectrometer. This spectrometer uses two large bending magnets to bend the particles in the vertical direction and three quadrupoles to give a point-to-point focus in the vertical direction and a line-to-point focus in the horizontal. The resolution, acceptance, and other interesting quantities are given in Table I, together with those of the 1.6- and 20-GeV spectrometers. The fact that SLAC has been able to produce results this quickly is in large measure a tribute to the sophistication of these spectrometer systems.

#### TABLE I

Maximum Momentum (GeV/c)		1.6	8	20
Resolution	( <sup>o</sup> p/p (%)	± 0.1	± 0.1	± 0.1
	$\sigma_{\theta}$ (mrad)	± 1.0	± 1.5	± 0.3
Acceptance	∫ Δp/p (%)	5%	<b>4</b> %	<b>3.</b> 5%
	$\Delta \Omega$ (msr)	3	0.8	0.1
Weight	Magnets (tops)	70	300	250
	Shielding	150	850	1400
Power	(megawatts)	1.5	3.5	5.0

# Spectrometer Characteristics

The particle position in the focal plane is determined with two sets of hodoscopes, 55 counters measuring  $\theta$  and 41 measuring p. The electrons are identified using a shower counter made of alternating layers of lead and Plexiglass.

Thus far the group has measured the cross section at several values of t, the four-momentum transfer to the proton, between 0.7 and 25  $\text{GeV}^2$ , the results being shown in Fig. 1. Most of the points were taken with the momentum of the scattered electron at 8 GeV/c, t being varied by appropriately changing the incident energy and angle of the scattered electron; this procedure gave the maximum counting rate. The cross sections measured range from  $\sim 10^{-31}$  to  $2 \times 10^{-39}$  cm<sup>2</sup>. The highest t point shown in Fig. 1 represents 7 counts obtained in 24 hours with a 200-kilowatt beam. Such a low counting rate means that this value of t will not be much exceeded in measurements of this type until beams of higher energy are available. If one assumes that only one-photon-exchange diagrams are important there are two form factors to be determined,  $G_{E}(t)$  and  $G_{M}(t)$ , and in principle one must make at least two measurements at each value of t in order to separate the two form factors. At these high values of t the  $G_E$  contribution is suppressed by kinematic factors, and if one makes the reasonable assumption that  $G_{\rm E} \approx G_{\rm M}/\mu$ , the  $G_E$  term contributes only  $\lesssim 3\%$  above t = 5 GeV<sup>2</sup>, and the values of  $G_M^{/\mu}$ shown in the figure are calculated under this assumption.

As indicated in Fig. 1, the new data continue to lie along the dipole curve given by

$$G_{M}/\mu = \frac{1}{(1 + t/0.71)^2}$$

for t in  $\text{GeV}^2$ . Although it is hard to see deviations of the experimental points from the dipole curve when plotted on the multicycle semilog paper, Fig. 2 shows some deviation of the ratio of the experimental cross section (proportional to  $\text{G}^2$ ) to that given by the dipole fit. These deviations from the dipole curve seem to be

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real, but I don't think that too much weight can be ascribed to them since nobody really understands the dipole curve anyway. In the next few months this group will obtain data to study the Rosenbluth plot for t in the region 3 to 6 GeV<sup>2</sup> in order to determine  $G_{\rm F}$ .

# **Experiment** 2

Positron to Electron Elastic Scattering Ratio

B. Barish et al.

The ratio

$$R = \frac{\frac{d\sigma}{d\Omega} (e^+ p - e^+ p)}{\frac{d\sigma}{d\Omega} (e^- p - e^- p)}$$

is being studied by the collaboration doing Experiment 1, again with the 8-GeV/c spectrometer. This ratio is sensitive to the two-photon-exchange amplitudes shown in Fig. 3:

$$R \approx 1 + \frac{4 \text{Re}(\text{B} + \text{C})}{A}$$

Various people have also suggested such experiments as a tool for observing certain meson exchanges.

The positron beam is obtained in a manner similar to that used at other linear accelerators. Electrons are accelerated the first third of the machine and then made to produce showers in a few-radiation-lengths target. Low-energy electrons and positrons are produced as shower products and the positrons are focused and reaccelerated. This gives beams of typically a few times  $10^9 e^+$  per pulse  $\approx 10^{12} e^+$ /sec in a 1/2 % momentum band with maximum energy about 12 GeV.

The first run was a few days in August, which has already given results up to  $t = 5 \text{ GeV}^2$ , as shown in Fig. 4. The values of R shown in the figure have

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been corrected for radiative corrections (<4%). It appears that the best bet at the moment is that R is unity to within a few percent for the regions studied thus far.

Although one cannot go much higher in t, further runs are being made to obtain ratios in other regions of the energy-angle plane.

#### Experiment 3

# Inelastic Electron Scattering

# B. Barish et al.

This experiment is just now getting under way on the 20-GeV/c spectrometer; again the electron scattering group of Experiments 1 and 2 are involved. They will observe only the scattered electron in the reaction

# $e^{-}p \longrightarrow e^{-}N^{*+}$ ,

where  $N^{*+}$  denotes any and all systems with Q = +1, S = 0, B = 1. This is a first, exploratory experiment and they plan to look for bumps in the  $N^{*}$  mass distribution as a function of t, as well as making probes into the deep inelastic regions. Such data can be used to test various sum rules, e.g., that of Bjorken based on a quark model, which states that at a fixed  $q^{2}$  the total e-p cross section should add up to give the point-like cross section.

# Experiment 4

Elastic and Inelastic Muon Scattering

A. Barna, J. Cox, B. Dieterle, W. Lakin, F. Martin, M. Perl, W. Toner, and T. Zipf

The SLAC muon beam is obtained by allowing the incident electron beam to develop showers in a thick copper target. A few high-energy photons in this shower produce  $\mu^{\pm}$  pairs instead of the more mundane  $e^{\pm}$  pairs. Unwanted particles are filtered out by 18 ft of beryllium, and a beam transport system then delivers the  $\mu$ 's to the experimeter. At the moment the beam is limited to less

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than 13 GeV/c by the beam transport system and delivers  $\sim 10^5 \mu^{\pm}$ /sec in an interval  $\Delta p/p = \pm 1.5\%$ ; this beam has a diameter of  $\sim 7$  cm and angles of  $\pm 5$  mrad. A factor of  $\sim 3$  increase could be obtained by redesigning the target to take more power (heating problems).

The system shown in Fig. 5 has just recently been assembled and will be used to study  $\mu$  scattering, both elastic and inelastic, in the 2-meter-long liquid hydrogen target. Recoil protons will be detected by the thin-plate chambers under the target and other spark chambers (all visual) will be used to track the scattered  $\mu$  through a large bending magnet. Thick-plate chambers behind the magnet will allow rejection of pions and other background.

The group hopes to measure elastic  $\mu^{\pm}p$  cross sections up to  $t = 2 \text{ GeV}^2$  as well as obtaining data on the inelastic scattering up to  $4 \text{ GeV}^2$ . Muons have an advantage over electrons in that they don't give a large amount of low-energy bremsstrahlung. A second reason for doing experiments with muons is the hope of eventually finding the long-awaited difference between muons and electrons.

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# III. QUANTUM ELECTRODYNAMICS EXPERIMENTS

#### Experiment 5

# Asymmetric Mu Pair Photoproduction

Most QED experiments being done at other laboratories are coincidence experiments which have to watch instantaneous counting rates and dead times of electronics rather closely, even with duty factors far better than that at SLAC. Various experiments have been discussed at SLAC, but the only one at the moment which is definitely being planned is the asymmetric  $\mu$  pair experiment.

The electron scattering group of Experiments 1-3 will use the 20-GeV spectrometer to detect muons having an energy very close to the tip of the bremsstrahlung spectrum. Of the two diagrams shown in Fig. 6, diagram B has a

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reasonably large four-momentum transfer  $t \approx 2 \text{ m}_{\mu}^{k}$ . Since it accounts for roughly half the cross section (Beware! This statement is not gauge invariant.), a test of QED can be made concerning the muon propagator.

# **IV.** PHOTOPRODUCTION EXPERIMENTS

# Experiment 6

High-Energy Photoproduction in the Forward Direction

# A. Boyarski, F. Bulos, W. Busza, R. Diebold, S. Ecklund, G. Fischer, J. Rees, and B. Richter

Since this is the experiment upon which I have been working, I will explore it in somewhat more detail than the others; much of the material presented here was reported by Richter in his rapporteur talk at the recent Stanford Conference. This experiment studied the reactions

$$\begin{array}{c} \gamma p \longrightarrow \pi^+ n \\ K^+ \Lambda \\ K^+ \Sigma^{o} \end{array}$$

in the region of photon energies from 5 to 16 GeV and momentum transfers from  $2 \times 10^{-4}$  to 2 GeV<sup>2</sup>. The SLAC 20-GeV/c spectrometer was used to detect the positive mesons from angles very close to  $0^{\circ}$  out to  $13^{\circ}$  in the laboratory.

A schematic of the detection system is shown in Fig. 7. In addition to the momentum (P) and angle ( $\theta$ ) hodoscopes, two other hodoscopes are used (X and  $\phi$ ). Information from the P and  $\phi$  hodoscopes is used to determine a particle's momentum and angle in the vertical plane, the vertical angle being determined to a resolution of 1.5 millirad. Information from the X and  $\theta$  hodoscopes is used to determine the horizontal production angle and to reject particles which have come from the magnet poles.

A coincidence between the three trigger counters generates a fast gate which allows passage of the counter information to an SDS 9300 computer which is used

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on-line for the spectrometer experiments. The range in the iron together with pulse height in the shower counter is used to separate the strongly-interacting particles from background muons and electrons. The differential Cerenkov counter pulse heights are used to separate members of the strongly-interacting group into p, K, or  $\pi$ .

In order to determine the yield of a particular reaction, the spectrometer momentum was set to correspond to that of particles produced by photons of the maximum energy in the photon beam. The hodoscope information was used to compute the missing mass of each event assuming the photon energy to be equal to the bremsstrahlung maximum. If the laboratory cross section does not vary significantly over the few-percent momentum acceptance of the spectrometer, the missing mass distribution has the same shape as the bremsstrahlung spectrum folded with the overall resolution of the system. The missing mass distribution was therefore fitted with a step function suitably smeared out to approximate the resolution effects. A polynomial in missing mass, beginning at the threshold for production of threebody final states, was used to represent background from other processes. Figure 8 shows the data and a fitted curve for  $\pi^+$  production, while Fig. 9 shows the data and fitted curve for  $K^+$  production.

The  $\pi^+$  results are shown in Fig. 10. The data show two striking features: a sharp rise at very small momentum transfers, and very similar shapes for each distribution from 5 to 16 GeV. For  $t \ge 0.04 \text{ GeV}^2$ , the higher energy curves seem to fall as  $e^{-2t}$  up to ~ 0.7 GeV<sup>2</sup> and then somewhat faster as  $e^{-3t}$ .

The fall-off at  $t \ge 0.04 \text{ GeV}^2$  is more gentle than that of the usual forward peak found at high energies, for which the coefficient of t in the exponential tends to be in the range 6 to 10 GeV<sup>-2</sup>. The very forward peak seen here is fantastically steep; although the exponential form probably doesn't have much significance in this region, it is amusing to note that in the steepest part of the peak the cross section falls roughly as  $e^{-80t}$ .

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It is convenient to expand the very forward region by using as the abscissa  $\sqrt{t}$  which is proportional to  $\theta$ ; this is done in Fig. 11. By plotting  $(S - M^2)^2 (d\sigma/dt)$  the data tend to have only a small variation with photon energy and the contribution from the electric Born terms (Fig. 12) is independent of energy. The Born approximation gives about the right cross sections in the very forward direction, although the 5- and 8-GeV data seem to rise even faster. For  $\sqrt{t} \ge 0.15$  GeV, the Born curve rises in contrast to the experimental date which levels off and then falls. By absorbing out some of the low partial waves, the data at  $\sqrt{t} \ge 0.2$  GeV is reproduced qualitatively, but the agreement in the forward direction becomes worse.

A different description is given by the Regge theorists. A number of these theorists have recently shown that unless one has conspiring trajectories (or cuts), all t-channel exchanges give a dip in the forward direction. Without conspiracy the term which falls the least slowly goes as

$$\cos^2 \theta_{t} \approx \frac{\sin^2 \theta}{\left(1 - \beta \cos \theta\right)^2}$$

As with the lower energy data from DESY, additional terms are clearly required. To the experimentalist the simplest solution to the dilemma would seem to be to invoke the s-channel Born term shown in Fig. 12b. The true believers of Regge theory find this to be heresy, however, and they prefer to invoke a "conspiracy" between trajectories. This means that in the small t region one must have certain relationships between various trajectories, some of which haven't been seen as real particles. Such a conspiracy allows the arbitrary Regge function  $\beta(t)$  to vary wildly and give a forward peak. The Regge picture is further complicated by the behavior of the Regge function  $\alpha(t)$  determined by comparing  $d\sigma/dt$  at different values of s with the relationship

$$\frac{\mathrm{d}\sigma}{\mathrm{d}t} = \beta(t) \ \mathrm{s}^{2\alpha(t)-2}$$

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As shown in Fig. 13,  $\alpha(t)$  remains close to zero instead of falling off with increasing |t|. However, Regge theorists have conquered nonshrinking reactions before and may well do it again. It is amusing to note that the simple Born theory gives  $\alpha = 0$ .

Although the experiment does not cover the full range of angles from  $0^{\circ}$  to  $180^{\circ}$ , reasonable estimates of the total cross section for the process  $\gamma p \rightarrow \pi^+ n$  can be obtained by integrating the region measured. The backward data of Ritson <u>et al.</u> (Experiment 7) can be used to reassure us that such a procedure is probably reasonable. The results are shown in Fig. 14, together with the lower energy data available. The crosses above k = 1.5 GeV show the result of integrating the DESY data, using the relation

$$\sigma \approx \int_{0}^{t_{\text{max}}} Ae^{-Bt} dt \approx A/B.$$

A 5% increase has been made for the forward peak. The wide angle data of Osborne at  $\theta_{\rm CM} \approx 80^{\circ}$  can be used to verify that large errors are not being made by this approximation. The data above the third resonance appears to fall in a smooth manner, a reasonable approximation being  $\sigma = 20\mu b/k^2$  for k in GeV.

The K- $\Lambda$  data are shown in Fig. 15. The small-angle K<sup>+</sup> data are quite different from the  $\pi^+$  data in that the K- $\Lambda$  cross section has a distinct dip near zero degrees rather than the rise shown by the  $\pi^+$  cross section. This difference between  $\pi^+$  and K<sup>+</sup> photoproduction was one of the most surprising results of the experiment and puts another constraint on any theory purporting to explain pseudoscalar meson production. At small momentum transfers the s-dependence of the cross section is such that  $d\sigma/dt$  decreases with s more rapidly than s<sup>-2</sup> between 5 and 8 GeV and decreases about as s<sup>-2</sup> thereafter. The same effect was shown in the  $\pi^+$  data.

The t-dependence of the points with momentum transfer greater than about  $0.5(\text{GeV/c})^2$  are well described by the same  $e^{-3t}$  dependence shown for the  $\pi^+$  data.

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Figure 16 expands the very forward region. At each energy the left-most point corresponds very nearly to  $0^{\circ}$  production,  $\sqrt{t_{\min}}$  being noticeably different from 0, due to the  $p - \Lambda$  mass difference.

Figure 17 shows the function  $\alpha(t)$  for  $K^{\dagger}\Lambda$  calculated as for  $\pi^{\dagger}n$ . Again,  $\alpha$  stays fairly close to 0.

Figure 18 shows the ratio  $K^+ \Sigma^0$  to  $K^+ \Lambda^0$  cross sections. The errors in the determination of the K- $\Sigma$  cross section are considerably larger than for the K- $\Lambda$  cross section, but the data show that the  $\Sigma^0 / \Lambda^0$  cross-section ratio is about unity. The measurements of Elings <u>et al.</u> at CEA also show a  $\Sigma / \Lambda$  ratio of around 1 for a photon energy of 3.4 GeV. At 5 and 8 GeV the  $\Sigma / \Lambda$  ratio seems to decrease at small momentum transfers. Except for this region the  $\Sigma / \Lambda$  ratios clearly do not agree with the quark-SU6 prediction of 1/27 in the forward direction and smaller than 1/3 elsewhere. This ratio also presents additional problems to the Born enthusiasts since one would expect  $\Sigma / \Lambda \propto g_{K^+p\Sigma}^2 / g_{K^+p\Lambda}^2$ . The latter ratio was found to be of the order of 1/10 in a recent analysis by Kim.

The K-A, K- $\Sigma$  and  $\pi$ -N cross sections can be used to test SU3 symmetry. Unbroken SU3 symmetry predicts a relation between the photoproduction amplitudes given by

$$\sqrt{2} A(\pi^+ n) = -\sqrt{3} A(K^+ \Lambda) - A(K^+ \Sigma^0)$$

With only cross-section data available, this can be written as

$$2\sigma(\pi^{+}n) = \left[ \left[ 3\sigma(K^{+}\Lambda) \right]^{1/2} + \left[ \sigma(K^{+}\Sigma) \right]^{1/2} e^{i\phi} \right]^{2},$$

where the introduction of the phase angle  $\phi$  reflects our lack of knowledge of the relative phase of the KA and K $\Sigma$  amplitudes. SU3 symmetry is not violated if  $|\cos \phi|$  evaluated from the expression above is  $\leq 1$ .

Figure 19 shows  $\cos \phi$  versus t as calculated from the SLAC data. SU3 symmetry is violated at momentum transfers of less than 0.1 (GeV/c)<sup>2</sup> and is

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unbroken at larger momentum transfers. The data of Elings et al. at 3.4 GeV for  $|t| \ge 0.2$  also show SU3 symmetry to be unbroken in agreement with the SLAC data at higher energies.

This breakdown of the SU3 prediction is in the region where one might expect a breakdown due to the difference in meson masses, namely,  $t \leq M_i^2$  where  $M_i$ is the  $\pi$  or K mass. The reason for the violation, of course, is simply related to the fact that the  $\pi$  data shoot up at low momentum transfer while the K data fall off.

#### Experiment 7

#### Meson Photoproduction at Backward Angles

# R. Anderson, D. Gustavson, J. Johnson, G. Jones, D. Kreinick, R. Prepost, D. Ritson, and R. Weinstein

This experiment is being done as a collaboration between Stanford and Cal Tech using the 1.6-GeV spectrometer with its large acceptance to observe low momenta  $\pi^{\pm}$ ,  $K^{\pm}$ , and protons coming from various photoproduction processes. Backward peaks (small values of u) in reactions such as  $\gamma p - \pi^{+}n$  can thus be studied, as well as the near-forward region (t > 0.1 GeV<sup>2</sup>) for  $\gamma p - p\pi^{0}$ . In fact, it appears that this is the only way in which the small t region for the latter process is likely to be studied for some time at SLAC.

Preliminary results on the process  $\gamma p - \pi^+ n$  were presented at the Stanford Conference for the region 3 to 10 GeV and u, the four-momentum transfer squared in the crossed channel, from about 0 to 0.6 GeV<sup>2</sup>; these results are shown in Fig. 20. The data seem to become somewhat more strongly peaked as the photon energy increases. The magnitude of the backward peak is down roughly 2 orders of magnitude from the forward photoproduction peak and 3 orders of magnitude from the backward  $\pi$ -p peak.

In the near future data will be obtained by detecting the low-energy, recoiling proton associated with a fast, forward-going  $\pi^0$ ,  $\eta^0$ ,  $\rho^0$  ... Each new

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meson should show up as a step at the kinematic condition corresponding to the meson being produced by a photon at the tip of the bremsstrahlung spectrum. As the mass (and width ) of the meson increases, it will become harder and harder to pick out the step on top of the background produced by the lower-mass mesons and the multibody final states.

# Experiment 8

Backward Neutral Meson Photoproduction

R. Anderson, B. Gittelman, J. Litt, A. Minten, D. Tomkins, B. Wiik, and D. Yount

This experiment will use the 20-GeV spectrometer to observe the very high momentum protons near  $0^{\circ}$ . The protons from  $\pi^{\circ}$  production can be studied at  $0^{\circ}$  since these protons have ~400 MeV/c more momentum than the incident  $\gamma$  ray, and by working near the bremsstrahlung tip the proton momentum is higher than that of the electrons, the major problem at  $0^{\circ}$ .

The spectrometer does not have sufficient resolution to separate single  $\pi^{0}$  production from two-pion production, and the experiment depends on the two-pion cross section not being too large for low  $\pi\pi$  masses. As with Experiment 7, the higher mass neutral mesons will also be studied where possible.

Data will be obtained this coming winter.

#### Experiment 9

Photoproduction Using a Two-Meter Streamer Chamber

M. Davier, I. Derado, D. Drickey, D. Fries, R. Mozley, A. Odian, F. Villa, and D. Yount

A streamer chamber is much like a wide-gap spark chamber, except that the high voltage pulse is cut short before the spark has a chance to develop beyond the streamer stage. For reasonable light intensity, the high voltage pulse must be

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very large, but very short. Using the fastest film available, streamers of  $\sim 1/2$  cm can be photographed at f/2; the depth of field problem is minimized by using a large demagnification ( $\sim 70$  in this case). (See report SLAC-74 for further details.) Watching events in a streamer chamber is a remarkable aesthetic experience, and I recommend it highly.

Since the tracks do not have to pass through the plates or be within certain angles as with other types of spark chambers, the system rather resembles a large bubble chamber, but with the advantage of being triggerable on events of interest.

The experimental arrangement of the streamer-chamber photoproduction experiment is shown in Fig. 21. The high voltage pulse is generated by a Marx generator and shaped with a Blumlein system giving a 600-kV pulse, 10 nsec wide, some 500 nsec after an interaction takes place. The chamber acts as a transmission line, with the median plane pulsed to high voltage and the top and bottom planes grounded; resistors at the far end terminate the line. The sensitive volume is 150 cm wide, 230 cm long, and  $2 \times 30$  cm deep (a region above and below the median plane). The hydrogen target is a hollow Mylar tube 12 mm in diameter with 0.05-mm thick walls; the hydrogen gas is at room temperature and 3 or 4 atmospheres pressure. The chambers are placed in a large magnet having a gap 2 meters in diameter and 1 meter high; stereo photos are taken by three cameras through the open top pole. The magnet is capable of 16 kG, but power supply troubles have kept the field down to 4 and 8 kG during the initial runs.

A very well-collimated bremsstrahlung beam, 3 mm in diameter and containing ~ 150 equivalent quanta/pulse, is passed through the hydrogen target; the reaction products are detected by counter telescopes downstream. To avoid triggering on the many  $e^{\pm}$  pairs, the counters are pulled back 4 inches from the horizontal plane containing the beam.

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A recent run yielded 120,000 pictures having about 12,000 events. Thus far, the triggering logic has been rather loose in order to avoid biases. Requiring only the presence of at least one non-electron particle in the counter telescopes gives a good event every 10 triggers. After some experience has been gained, more elaborate trigger logic will be used to enhance particular classes of events.

#### Experiment 10

# $\rho^{\mathbf{0}}$ Photoproduction

M. Benniston, A. Boyarski, F. Bulos, W. Busza, R. Diebold,
S. Ecklund, R. Giese, L. Kaufman, R. Larsen, D. Leith,
V. Perez-Mendez, B. Richter, A. Stetz, S. Williams

A sketch of this experiment is shown in Fig. 22. The annihilation photon beam produces  $\pi^{\pm}$  pairs in a target and then is stopped in a block of tungsten. The forward-going pions pass through a large bending magnet having a gap 100 cm wide by 35 cm high and 120 cm long. The pion momenta and production angle are measured with a set of wire chambers having magnetostrictive readout. An IBM 1800 computer is used to log the data on magnetic disks and to give some on-line displays.

The annihilation photon beam is produced by passing positrons through a hydrogen target to give the reaction

 $e^+e^- \rightarrow \gamma_1 \gamma_2$  .

Since there is a two-body final state, the  $\gamma$  rays from this process have a unique energy-angle relationship. The rate for this process falls more slowly with angle than does that of the background bremsstrahlung produced in the hydrogen. The number of bremsstrahlung photons above 1 GeV is calculated to be twice the number of 10-GeV annihilation photons for 12-GeV incident e<sup>+</sup>. This represents about the maximum energy of the beam.

Figure 23 shows an earlyphoton spectrum obtained from 10.2-GeV positrons. The photon energies were measured using the magnet-wire chamber system as a pair spectrometer.

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The photoproduction of  $\rho^{0}$ 's from various elements will be studied in runs this fall. Searches will also be made for higher mass resonances decaying into  $\pi^{+}\pi^{-}$ , and if backgrounds permit,  $\phi^{0} \rightarrow K^{+}K^{-}$  will be studied.

Having a monochromatic (almost) beam allows one to make a 1 constraint fit (the recoil is not detected) and various backgrounds can be rejected. If the backgrounds prove manageable, the reactions will be studied up to 18 GeV, using a bremsstrahlung beam.

#### Experiment 11

Photoproduction in the SLAC 40-Inch Hydrogen Bubble Chamber

G. Chadwick et al.

The bubble chamber was first cooled down in May 1967, and engineering pictures taken. These pictures look quite good and the first real production run of 500,000 photos is scheduled for this fall with the annihilation beam described in Experiment 10.

The chamber is 40 inches in diameter and 20 inches deep with a magnetic field of 26 kG, having < 5% variation over the visible volume.

# V. EXPERIMENTS WITH SECONDARY BEAMS

# Experiments 12a-d

# Beam Surveys

Four separate experiments have been performed to measure the fluxes of  $\pi^{\pm}$ ,  $K^{\pm}$ , and  $p^{\pm}$  from beryllium targets (0.3- to 1.8-radiation-lengths long) struck by high-energy electrons. The first three experiments were done nearly a year ago and the results are published in Phys. Rev. Letters <u>18</u>, 360-369 (1967). Each of these three experiments was done in a limited angular range; the fourth experiment was run last spring from 0<sup>°</sup> to 10<sup>°</sup> in the laboratory.

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(a) A. Barna, J. Cox, F. Martin, M.L. Perl, T. H. Tan, W. T. Toner, T. F. Zipf, and E. H. Bellamy

This group used the muon beam transport system to study the production near  $0^{\circ}$  from a 1.8-radiation-length Be target. The thick beryllium absorber was removed from the beam so as not to lose the strongly interacting particles, and the electron background was greatly reduced by inserting 3 radiation lengths of lead at a strategic focus. The K<sup>-</sup> results of this survey were recently compared with the K<sup>-</sup> fluxes from the process  $\gamma A \longrightarrow \phi^{\circ} A$  calculated by Y.S. Tsai (Sect. D.3, <u>SLAC Users Handbook</u>). An upper limit of 0.6  $\pm$  0.2  $\mu$ b was found for diffraction photoproduction of  $\phi$ 's from protons in the region 9 to 15 GeV.

(b) A. Boyarski, F. Bulos, W. Busza, D. Coward, R. Diebold, J. Litt, A. Minten, R. Richter, and R. Taylor

One leg of the Beam Switchyard was used as a spectrometer to study  $\pi^{\pm}$  produced at laboratory angles  $0.2^{\circ}$  to  $1.1^{\circ}$  from a 0.6-radiation-length Be target. This experiment gave a first hint that the pion production does not fall off at  $0^{\circ}$  as predicted theoretically.

# (c) S. M. Flatté, R. A. Gearhart, T. Hauser, L. H. Johnston, P. R. Klein, J. J. Murray, R. Morgado, M. Peters, and S. G. Wojcicki

This group studied secondary particle production at 2° and 3° from a 0.3radiation-length beryllium target. Their beam transport system gave a small, wellfocused beam, and they used a set of tiny, elegant, gas-filled Cerenkov counters to separate the hadrons. Compared with many of the other experiments at SLAC, their equipment seemed like models, much as small boys have model railway systems--we referred to this experiment as being in HO gauge. The experiment also used rf-gated photomultiplier tubes (known as DCFEM = dynamic crossed-field emission multipliers) to show that the electron rf bunches have a width of less than 10° of the rf cycle  $\approx 10^{-11}$  sec.

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 (d) A. Boyarski, F. Bulos, W. Busza, R. Diebold, S. Ecklund, G. Fischer, B. Gittelman, J. Rees, and B. Richter

A comprehensive survey of secondary particles produced by an 18 GeV electron beam incident on a 0.3-radiation-length Be target was made using the 20-GeV spectrometer system. Secondary momenta from 2.5 to 16 GeV/c and lab angles from  $0^{\circ}$  to  $10^{\circ}$  were studied.

The pion yields have roughly the order of magnitude predicted by Tsai, using  $\rho^0$  diffraction production and the Drell mechanism; the  $\pi^-$  and  $\pi^+$  yields were the same to within ~30%. The angular distributions, however, were found to be somewhat different than these models would predict, in particular the data did not fall off at very small angles, but did fall faster than expected at large angles. An empirical expression was found to fit the pion yields, generally to within 30%:

$$Y = (E_{e^{-}} - p)^{2} \frac{1.5 \times 10^{-5}}{4 + e^{p \sin \theta / 0.16}} \pi / (\text{incident } e^{-}) / \text{GeV/c/ster},$$

where  $E_{a^{-}}$  and p are in GeV/c.

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The  $K^+$  yields are down from the  $\pi$  yields by roughly a factor of 10 at the smaller angles; since the K angular distribution is somewhat broader than the  $\pi$  distribution, this becomes a factor of ~ 3 for the region 5° to 10°. The K<sup>-</sup> yields are consistently lower than the K<sup>+</sup> yields, especially at higher momenta. At 10 GeV, 3°, for example,  $K^-/K^+ \approx 1/3$ . The Drell and  $\phi \rightarrow K^+K^-$  mechanisms give  $K^-/K^+$  close to unity. This ratio may indicate that a mechanism suggested by Tsai is playing an important role here, namely, that many of the pions produced by the Drell or  $\rho^{\circ}$  mechanism interact before escaping from the nucleus and these interactions produce K's.

The proton yields tend to be somewhat less than the  $K^{+}$  yields, although this depends on the momentum. The antiproton yields are the smallest, being typically 1% of the pion yields.

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Table II shows the number of 10 GeV/c particles which should be obtained per pulse in a 50-meter-long beam at  $1^{\circ}$  having  $10^{-4}$  steradian,  $\Delta p/p = 2\%$ , and using a 1-radiation-length beryllium target struck by  $2 \times 10^{11}$  electrons of 18 GeV per pulse.

# TABLE II

# Number of Particles per Pulse Expected for "Typical" Beam

$\pi^+$	4800	к <sup>+</sup>	140	ą	120	
π_	4400	к	80	q	12	

# Experiment 13

# Search for New Particles

The muon group of Experiment 4 inserted two differential Cerenkov counters into the  $\mu$  beam to search for new charged particles not having strong interactions, but with a lifetime greater than  $10^{-8}$  sec. Assuming that the particles couple to the electromagnetic field a la QED, one can calculate the cross section for photoproducing pairs of these particles. No such particles were found with masses

and

$$0.52 < M < 0.86$$
 GeV.

The gap between 0.46 and 0.52 GeV had some  $K^{\pm}$  background. This experiment has an advantage over many types of searches since with the known production mechanism one can say that particles with these characteristics simply don't exist.

The same group has also searched for particles which charge between 0.04 and 0.7 times the electron charge. Again it is assumed that the pair photoproduction of such particles is just that given by QED with no form factor effect and no anomalous magnetic moment, etc. The muon beam line was tuned to a momentum greater than that of the incident beam. No fractionally charged particles were seen. The lower limit thus obtained for such particles depends on the assumed lifetime and whether or not they have strong interactions (see Table III).

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# TABLE III

Lifetime	Stable	10 <sup>-10</sup> sec	Stable
Strong (25 mb/nuclear) Interactions?	No	No	Yes
Q = e/25	0.2	0.1	
e/10	0.5	0.35	0.15
e/3	1.0	0.75	0.50
2e/3	1.5	1.1	0.75

# Lower Mass Limit (GeV) Obtained for Fractionally Charged Particles (95% Confidence)

# Experiment 14

 $K_2^0$  Decay Asymmetry

D. Dorfan, J. Enstrom, D. H. Miller, M. Paciotti, D. Raymond, M. Schwartz, and S. Wojcicki

The ratio

$$\mathbf{R} = \frac{\text{rate } (\mathbf{K}_2^{\mathbf{O}} \rightarrow \pi^- \mu^+ \nu)}{\text{rate } (\mathbf{K}_2^{\mathbf{O}} \rightarrow \pi^+ \mu^- \overline{\nu})}$$

was measured and has been reported in Phys. Rev. Letters <u>19</u>, 987 (1967). A  $3^{\circ}$  neutral beam was used and the yield of  $K_2^{\circ}$ 's produced by showers in the beryllium target was found to be consistent with the average of the  $K^+$  and  $K^-$  yields measured in the beam surveys. The beam had considerably fewer neutrons than the usual neutral beam, the ratio being ~ 3 neutrons/ $K_2^{\circ}$ .

The apparatus is shown in Fig. 24. The  $K_2^0$ 's decay in the helium bag. At least 2 of the 8 hodoscope counters immediately following the decay region are required to trigger the system. The bending magnet has sufficient strength to bend 96% of the particles enough to cause the particle to pass through the appropriate half of the last set of hodoscopes. The pions have interactions and are stopped in the lead while the muons continue through and count in the last set of hodoscopes, which

consists of 8 pairs of counters separated by 1 inch of wood to eliminate coincidences caused by low-energy  $\gamma$  rays. The bending magnet polarity was changed frequently and the information from each of the 8 pairs of counters can be considered as a separate experiment measuring R.

The spark chambers were used on a sampling basis to check for proper operation of the system and to study systematic errors. About 14,000 photos were taken out of ~ 0.8 × 10<sup>6</sup> events total. Many types of systematic errors have been studied, the largest of which is the production of  $K^+$  in the front hodoscope with its subsequent decay yielding  $\mu^+$ , resulting in a correction of 0.0017 ± 0.0006.

The results from each of the 8 pairs of counters behind the stopper were all quite consistent with one another and gave an average value

$$\mathbf{R} = \mathbf{1.0081} \pm \mathbf{0.0027},$$

a three-standard deviation CP-violation effect. This value is consistent with the results of a recent experiment at Brookhaven which studied the decays  $K_2^0 - \pi^{\pm} e^{\mp} \nu$ . The ratio R can be related to the real part of  $\epsilon$  where  $\epsilon$  is the quantity used in the definition

$$K_2^{o} = \frac{(1 + \epsilon) K^{o} - (1 - \epsilon) K^{o}}{\text{normalization}}$$

For small  $\epsilon$ , and assuming the validity of the  $\Delta S = \Delta Q$  rule,

$$\mathbf{R} = \mathbf{1} + 4 \operatorname{Re}(\epsilon).$$

The experimental result thus gives

Re (
$$\epsilon$$
) = 0.0020 ± 0.0007,

which strongly favors the so-called "large" solution for  $\epsilon$ .

#### **Experiment 15**

The 82-inch Hydrogen Bubble Chamber

S. M. Flatté, J. J. Murray, P. R. Klein, et al.

The 72-inch Alvarez bubble chamber has undergone considerable modification; in particular, the expansion system has been modified so that it can pulse 1 or 2 times per second instead of the previous once every 6 seconds. Also, the visible length has been changed from 72 inches to 82 inches.

The chamber is already at SLAC and runs are planned for this winter. The initial beam will be capable of 4- to 14-GeV pions and rf separation for  $K^+$ 's near 12 GeV. At the moment, the  $K^-$  yield appears to be slightly too low to be of interest.

An old idea put forth by R. Milburn several years ago has been recently revived by Murray and Klein who propose to backscatter a laser beam from the electron beam. The laser beam would intersect the electron beam at an angle of  $\sim 3$  milliradians  $\approx 0.2^{\circ}$ . Those photons which are Compton-scattered into a small cone about the incident electron direction would pass into the 82-inch bubble chamber and cause photoproduction reactions. Very good collimation of the scattered photons is required,  $\sim 10^{-5}$  radian; the small phase space of the SLAC electron beam is also a necessary factor.

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By polarizing the laser beam, the backscattered beam can be made nearly 100% polarized, either linearly or circularly. Furthermore, the energy spread of the beam would be ~2% at 1 GeV and ~ 15% at the highest energy of 10 GeV.

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Fig. 1



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(c)

(a)

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(b) Fig. 3

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FIG. 13--SCHEMATIC LAYOUT OF  $\mu$ -p EXPERIMENT (ELEVATION)



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Fig. 6



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(a)

Fig. 12

















Fig. 19





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Fig. 21

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![](_page_48_Figure_3.jpeg)

K\* BEAM LAYOUT