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PHYSICS DIVISION SEMIANNUAL REPORT
May through October 1961

Berkeley, California

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UNIVERSITY OF CALIFORNIA

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GENERAL PHYSICS RESEARCH

PHYSICS RESEARCH

Luis W. Alvarez in charge

RESEARCH WITH BUBBLE CHAMBERS

The K72 Experiment

During this report period a large fraction of the group's physics research activity has been devoted to the design, construction, and operation of a new separated K^- beam at the Bevatron for use in conjunction with the 72-inch bubble chamber. This new system and the numerous experiments associated with it are often referred to collectively as the "K72 experiment."

A production rate, for events with a cross section of 1 millibarn, of about 5000 per 30 half-days is realized at 1.55 Bev/c at a Bevatron intensity of 10^{11} protons/pulse. The yield of the entire K72 experiment is expected to be about 20,000 such 1-mb events. This is in striking comparison with the 1958 1.15-Bev/c K^- run with the 15-inch bubble chamber, in which the total yield was 50 1-mb events.

The beam was designed to operate at momenta between 1.25 and 1.85 Bev/c, with momenta in the chamber as low as 1.0 Bev/c through the use of absorber. Fluxes of about 2, 5, and 10 K's in the chamber per 10^{11} Bevatron protons on target are obtained at momenta of 1.25, 1.55, and 1.85 Bev/c, respectively, with backgrounds of about 10% muons and 1% pions. The K72 facility constitutes a major extension of the group's continuing program for study of K^--nucleon reactions, both in its reach to higher momenta and in the vastly increased rate of production of useful reactions resulting from the high, well-separated K flux and long path length in the 72-inch chamber.

K^- separation is achieved by the now conventional technique of two-stage separation with static electromagnetic velocity spectrometers. The two 20-foot-long parallel-plate separators are equipped with glass cathodes which, with average plate spacings of about 2.25 in., can be operated at 450 kv. The plate spacing is tapered to conform to the actual beam height in order to minimize the flux of pions striking the plates and thereby to minimize the amount of scattered pion background. Whether or not the total pion background is reduced significantly as a result of this procedure is not known.

The chief innovation in beam design which contributed to the high K flux and purity of the beam was the use of bending magnets with fields carefully shaped by mechanical and electrical shimming to provide the specialized vertical focusing necessary to eliminate chromatic aberrations over relatively wide momentum intervals of $\pm 3\%$ at all operating momenta. The vertical image widths at the mass-resolving slits are typically 2 mm.

Another special feature of the beam is a steering magnet within the Bevatron magnet yoke designed to modify the Bevatron fringe field so that, in conjunction with a target mechanism allowing azimuthal adjustment of target position, a 0° target angle and $\pm 3\%$ momentum acceptance can be obtained at all operating momenta. The geometrical acceptance of the beam at 1.25 Bev/c is about 0.3 millisteradian.

By the end of this report period about 80,000 pictures (about 1000 1-mb events or about 5% of the total yield expected for all momenta combined) had been obtained at 1.25 Bev/c and 13,000 each at 1.05 and 1.11 Bev/c. That amount of 1.25-Bev/c data has yielded $30\ \Xi^-$, $4\ \Xi^0$, $1400\ Y_1^*$, $250\ K^*$, and about 30 events among the type $K^- + p \rightarrow \Lambda + \pi^+ + \pi^- + \pi^0$ which can be interpreted as examples of η production, viz: $K^- + p \rightarrow \Lambda + \eta$, $(\eta \rightarrow \pi^+ + \pi^- + \pi^0)$.

Programming for Data Analysis

Concurrently with the development of the K72 facility the existing PANG-KICK-EXAMIN system of programs was extended in both directions, so as to be able to process and analyze from beginning to end about 100,000 events per year--and thereby to cope with the flood of new data from the K72 experiments. A pre-PANG program, PANAL, has been written to edit and catalog event measurements from the several measuring engines of the Alvarez group. This program is described in Alvarez group memo 358. The geometrical construction code, PANG, has been extensively modified and has been combined with KICK to form a single very large geometrical reconstruction and kinematical analysis program PACKAGE. A post-EXAMIN program SUMMEX also came into operation. SUMMEX selects, lists, summarizes, and correlates data on binary data summary tapes. Thus in the analysis of the ω meson it was possible to study about 200,000 quantities calculated from about 2000 measured antiproton annihilations.

In collaboration with J. N. Snyder, of Illinois, coding was started on G-Heck, the eventual successor to KICK. "FAKE," a Monte Carlo program to test our system for biases and to help design experiments, was started.

Construction was commenced on an electronic system to perform kinematical analysis of interaction vertices, that is, an analysis equivalent to a least-squares fit subject to the constraints of momentum and energy conservation. It is a fully transistorized electronic analog system incorporating the main features of its digital-computer counterpart, GUTS. The primary goal is to provide an hypothesis-testing system with immediate feedback to facilitate human-assisted analysis of misfits and nonroutine event types.

Other Work With the 72-Inch Hydrogen Bubble Chamber

1.61-Bev/c Antiproton Experiment

The study of the effective mass distribution of 2-, 3-, 4-, and 5-pion combinations from the reaction $\bar{p} + p \rightarrow n\pi$ has given the following results.

1. The discovery of a neutral meson (called the ω) that decays into three pions. The mass and width are $M_\omega = 787$ and $\Gamma\omega/2 = 12$ Mev from the analysis of the 4-prong annihilation and $M_\omega = 780$, $\Gamma\omega/2 = 18$ Mev from the analysis of the 6-prong annihilation.

The spin, parity, and G parity have been determined to be 1, (-), and (-) respectively (the particle is a vector meson, 1^{--} with the necessary quantum numbers to account in part for the electromagnetic structure of the nucleons).

2. Confirmation of the existence of the ρ Meson (1^{-+}) of mass $M_\rho = 767$ Mev and width $\Gamma_\rho = 110$ Mev.

Antiproton Polarization Experiment

Double scattering of antiprotons of momentum 1.61 Bev/c has been studied in the 72-inch hydrogen bubble chamber. Methods for the determination of antiproton polarization and of the antiproton magnetic moment have been applied in the analysis of 300 events with double scattering. An average polarization of 0.50 ± 0.10 was obtained in the angular region from 6 to 25 deg. The value of the antiproton magnetic moment was determined to be -1.9 ± 1.4 nuclear magnetons.

In addition, an experiment was performed to determine whether or not annihilations of antiprotons show azimuthal anisotropies due to polarization of the initial antiprotons. Secondary events yielding four charged pions after an initial polarizing antiproton-proton scattering were analyzed. A possible asymmetry is indicated by the values $1.19 \pm .09$ found for the left/right ratio for π^+ mesons in the plane scattering of the antiproton. This result was obtained with 145 events.

Associated-Production Run With 72-Inch Hydrogen Chamber

Cusps in Associated Production

Preliminary results based on 1200 events 72-inch chamber associated production run have been published.[1] It was shown that the $\Sigma^- - K^+$ and $\Sigma^0 - K^0$

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[1]Wolf, Schmitz, Lloyd, Laskar, Crawford, Button, Anderson, and Alexander, Revs. Modern Phys. 33, 439 (1961).

thresholds are resolvable, and that the rise from threshold of each is con-
sistent with pure S wave. It was also found that Λ - K^0 production contains
terms in $(\cos \theta)^3$, so that at least D waves are present. This complicates
the cusp analysis because of the "Minami ambiguity." However, Nauenberg
and Pais have shown that the ambiguity can be resolved, for many of the
possible angular momentum states.[2] A sample of about 5000 associated
productions is now almost completely "passing" (through the kinematical
analysis programs). A Nauenberg-Pais type of analysis will be applied.

A second sample of about 5000 associated productions, taken with a
thinner bubble chamber window—to improve the resolution of the two thres-
holds—is about three-fourths measured. This sample will be treated as an
independent experiment.

Scattering of Lambdas by Protons

In the course of a study of the associated-production process

$$\pi^- + p \to \Lambda + K^0$$

we have examined subsequent lambda interactions of the types

$$\Lambda + p \to \Lambda + p,$$

$$\Lambda + p \to \Sigma^0 + p, \text{ and}$$

$$\Lambda + p \to \Sigma^+ + n.$$
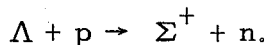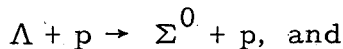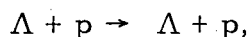
A sample of 5000 Λ productions has been examined systematically for these
reactions. The results are published.[3] We find remarkably good agreement
with the predictions made on the bases of global symmetry and of doublet
symmetry. The statistics are limited—a total of 17 Λ interactions. A second
sample of 5000 Λ productions from the same run is being processed now.

Lepton Decays of K_1^0 and K_2^0

The double vees in the first sample of 5000 associated productions
are being carefully examined for events of the type

[2] Nauenberg and Pais, Phys. Rev. 123, 1058 (1961).

[3] Alexander, Anderson, Crawford, Laskar, and Lloyd, Phys. Rev. Letters 7,
348 (1961).

$$\pi^- + p \rightarrow \Lambda + K^0,$$

$$\Lambda \rightarrow p + \pi^-,$$

$$K^0 \rightarrow \pi^\pm + \mu^{\mp} + \nu,$$

$$K^0 \rightarrow \pi^\pm + e^{\mp} + \nu,$$

$$K^0 \rightarrow \pi^+ + \pi^- + \pi^0, \text{ and } \pi^0 + \pi^0 + \pi^0.$$
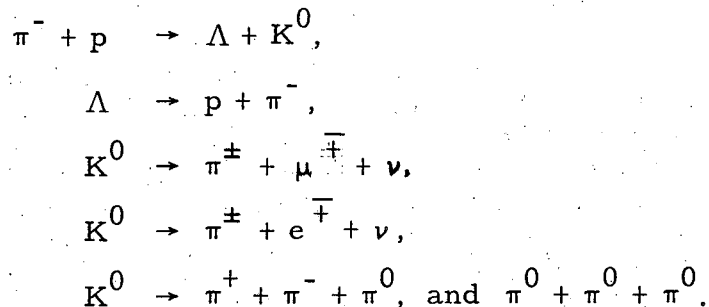
About 30 such events have been identified so far. By looking at the absolute rate for times much longer than the K_1^0 mean life we can obtain the K_2^0 mean decay rate. By looking at the overall time dependence we can compare the leptonic decay rate for K_1^0 and K_2^0 and thus check the predictions of the rule "$\Delta S/\Delta Q = +1$." (In a recent experiment, Ely et al. state that the rule is not valid.) Because of the possibility that a small fraction of the much more numerous $\pi^+\pi^-$ decays can fake a leptonic decay, through such mechanisms as, for example, a single Coulomb scattering on one of the decay pions, the sample must be examined carefully for possible biases. Scanning efficiencies for "long" vees must also be well known, of course. The experiment on the first sample is in this final stage.

$\pi^+ + p \rightarrow \Sigma^+ + K^+$ Near Threshold

About 400 events have been found and analyzed between threshold (1021 Mev/c) and 1060 Mev/c. Preliminary results have been presented.[4] In the first 20 Mev/c above threshold p-waves (as well as s-waves) are present already. There is no evidence for higher than p-waves. These results will be combined with the threshold dependence of $\pi^- p \rightarrow \Sigma^0 K^0$ and $\pi^- p \rightarrow \Sigma^- K^+$ to look at the question of charge independence near threshold. (For instance, discussed by Dalitz in his notes —Summer 1961).

$\pi^+ + p \rightarrow \Sigma^+ + K^+$ at 1170 Mev/c

This reaction has been studied in the range 1155 to 1185 Mev/c. Analysis of about 400 events indicates the presence of s, p, and d waves in the production. Preliminary results are being presented at the Washington Meeting of the American Physical Society in April 1962.[5]

$\pi^- + p \rightarrow \Sigma^- + K^+$ and $\Sigma^0 + K^0$ at 1170 Mev/c

This film is being scanned and measured. Results will be compared with $\pi^+ + p \rightarrow \Sigma^+ + K^+$ at the same momentum (now nearly completed), in order to check charge independence.

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[4]F. Grard and G. Smith, American Physical Society Meeting, New York, Jan. 1962.

[5]G. Smith, F. Grard, and F. Crawford, Abstract.

Evidence for Spin of the ρ Meson

The reactions $\pi^{\mp} + p \to \pi^{\mp} + p + \pi^0$ were studied at pion momenta of 1.25 Bev/c. At this momentum evidence was found for a strong pion-pion resonance at about 725 Mev (total energy of two pions). The effect was evident in the "physical region"—extrapolation was not necessary. Hence it was possible to look at angular distributions. (Extrapolation demands much more data—angular distributions have not been so far feasible where extrapolations are required). The angular distributions show a striking behavior and provide good evidence for angular momentum of 1 for this resonance. These results are published.[6]

Pion-Pion Interactions

Extrapolation techniques, applied to $\pi^- + p \to \pi^- + p + \pi^0$ at incident pion momentum of 1030 Mev/c, have given evidence for a pion-pion resonance in a p state at a total pion-pion energy of about 700 Mev. At this momentum it was not possible to see any effect in the "physical region," but only by extrapolation. This work is published.[7,8]

Evidence That the η Meson Has I-Spin Zero

If the η meson had I-spin 1 its charged members would be produced via the reactions $\pi^{\pm} + p \to + p + \eta^{\pm}$. The only η that has been observed is the η^0 (discovered by Pevsner et al.[9] in the π^--deuterium film from the 72-inch chamber associated-production run, loaned to John Hopkins University). From charge independence one can calculate from the results of Pevsner et al. a lower limit to the number of charged η's that should be produced in the above reactions by pions in hydrogen. The charged η should then decay to a charged pion plus two neutral pions. By examining the spectrum of events of the type $\pi^{\pm} + p \to p + \pi^{\pm} + $ neutrals, one can look for a peak at the η mass of 550 Mev. No such peak is found. The observed effect is only about one-fifth the predicted lower limit, so that I-spin of 1 seems to be ruled out. This work is published.[10]

$\pi^+ + p \to \pi^+ + \pi^+ + n$ at an Incoming π^+ Momentum of 474 Mev/c

This experiment was performed to determine the I = 2 low-energy S-wave π-π scattering length. Film was obtained with the beam apparatus setup for the 1.23-Bev/c π^- experiment in the 72-inch hydrogen chamber.

[6]Carmony and Van de Walle, Phys. Rev. Letters **8**, 72 (1962).

[7]Anderson, Bang, Burke, Carmony, and Schmitz, Revs. Modern Phys. **33**, 431 (1961).

[8]Anderson, Bang, Burke, Carmony, and Schmitz, Phys. Rev. Letters **6**, 365 (1961).

[9]Pevsner and others, Phys. Rev. Letters **7**, 421 (1961).

[10]Carmony, Rosenfeld, and Van de Walle, Phys. Rev. Letters **8**, 116 (1962).

The reaction was selected by use of ionization criteria on the scanning table, and this enriched sample was measured and fitted by the KICK program.

The 200 events identified were compared with phase-space expectations. A Chew-Low extrapolation was also performed.

Since neither of these methods gave indication of π-π interaction, an upper limit of $a_2 = 0.15 \, \lambda_\pi$ was assigned.

72-Inch Deuterium Bubble Chamber

1.23-Bev/c Deuterium Experiment

A test of the charge symmetry of K^+ and K^0 mesons has been made by comparing π^- and π^+ interactions at 1.23 Bev/c in the 72-inch bubble chamber filled with deuterium instead of hydrogen, but with all other conditions unchanged. About 250 events of the type

$$\pi^+ + d \rightarrow K^+ + (\Lambda \text{ or } \Sigma^0) + p$$
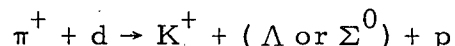
and approximately 500 events of the type

$$\pi^- + d \rightarrow K^0 + (\Lambda \text{ or } \Sigma^0) + n$$
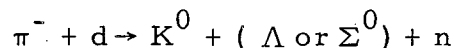
were compared. Total cross sections, angular distributions, momentum spectra, and Λ-decay asymmetries showed no deviations from charge symmetry.

The charge-symmetry experiment was a collaboration among LRL, Johns Hopkins University, and the Block group at Northwestern University.

This same experiment provided the data for the discovery of the η meson by the Johns Hopkins group in the reaction

$$\pi^+ + d \rightarrow \eta + p + p.$$
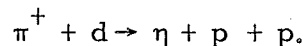
The data will be further used in the study of $\Sigma^\pm$ decay and final-state K-hyperon interactions.

15-Inch Hydrogen Bubble Chamber

η Production by 760-Mev/c K^- on Protons

At K^- momentum 760 Mev/c, strong peaking in the effective mass distribution of the three pions (missing mass for neutrals) at 548 Mev in the reaction $K^- + p \rightarrow \Lambda + \pi^+ + \pi^- + \pi^0$ (or Λ + neutrals) has been observed and is interpreted as evidence for η production in the reaction $K^- + p \rightarrow \Lambda + \eta$. The 548 Mev is the mass found for the η by Pevsner et al. Widths of the mass peaks are the same as our experimental resolution, implying $\Gamma_\eta < 7$ Mev for the η. The cross section for η production was found to be 0.63 ± 0.11 mb, yet,

disconcertingly, at K^- momentum of 850 Mev/c there is no evidence
at all for η production. At 760 Mev/c the branching ratio
$(\eta \rightarrow \pi^+ + \pi^- + \pi^0)/(\eta \rightarrow$ neutrals) was found to be 0.31±.11. The Dalitz
distribution for the 27 decays $\eta \rightarrow \pi^+ + \pi^- + \pi^0$ is most easily reconciled
if the η is a 0^{-+} meson, that is, if it has spin 0, odd parity and even g
parity.

Low-Momentum K^--p Interactions

An investigation of K^--p interaction in the vicinity of 400 Mev/c
incident K^- momentum has been completed. The study was carried out by
using the 15-inch hydrogen bubble chamber in a separated K^- beam. A
total of 10,000 K^- interactions was measured and fitted.

Results of the study have been

(a) the establishment of the existence of an excited hyperon of mass 1520
Mev and half width $\Gamma/2$ = 8 Mev,

(b) the determination that the relative $KN\Sigma$ parity is odd. The excited state
was found to have isotopic spin 0, spin 3/2, even parity with respect to K^-p
and a $\overline{K}N$: $\Sigma\pi$: $\Lambda 2\pi$ branching ratio of 3:5:1.

Also, an analysis of about 3500 K^--p interactions at rest and
about 950 in flight obtained in the K^--p exposures made in 1958 is complete.
Analysis of approximately 250 Σ^--p interactions (about 10% in flight) from
the same exposures is in progress.

Elastic scattering and charged-hyperon-production events from
low-energy K^--p exposures taken in 1960 (about 3,000 events) are being
measured and analyzed. Measurements are 75% complete on this sample.
Data will be used to improve statistics on in-flight cross sections in order
to give a better determination of the S-wave zero-effective-range parameters,
and to attempt nonzero range fits to the data.

Theoretical Study

A Two-Parameter Statistical Model

A statistical model has been developed which empirically relates
the volume (characterized by λ_i) associated with each particle to its mass
(M_i). The functional dependence used is $m_i^{\alpha}\lambda_i$ = constant, where α is
some constant. The two parameters λ_π and α, in addition to the masses
m_i, determine all the other λ_i. The model is applied to antiproton-proton
annihilation at low and moderate energies. The annihilation is assumed to
proceed through all possible intermediate states consisting of all combinations
of the five mesons, π, K (or $\overline{K}$), K^*(or $\overline{K}^*$), ρ, and ω. The experimental mul-
tiplicities and fraction of $K-\overline{K}$ π states to be 4.0±.4 and 1.94±.06 respectively.
These values of λ_π and α determine the two parameters λ_π and α_Λ predict

the extent to which the K^* (or $\bar{K}^*$), ρ, and ω take part in the annihilation. These predictions are found to be in reasonable agreement with recent experimental data on the role of K^* (or $\bar{K}^*$), ρ, and ω in $\bar{p}$-p annihilations. The η meson is also considered.

DATA REDUCTION

Margaret Alston and James Donald Gow

Franckenstein System

The period of May to October 1961 was marked by the addition of three more measuring projectors to the data-reduction facilities. MP ID, our third small Franckenstein-type measuring projector, was completed and brought into operation. This measuring projector is designed to measure 35-mm film pictures taken by the 15-inch liquid hydrogen bubble chamber. Like all our Franckensteins, this projector can semiautomatically follow photographed tracks of nuclear events while recording the orthogonal coordinates of selected points on the tracks. Its accuracy is $\pm 1.5 \mu$ or $\pm .00006$ in. MP IIC and IID, two large Franckenstein-type measuring projectors designed to handle 46-mm film from the 72-inch liquid hydrogen bubble chamber, were brought into operation.

New concepts in these machines include transistorized pulse-width-modulated power amplifiers for driving the main servo motors; a high-speed automatic picture-number-finding film drive; analog memory of approximate fiducial locations to speed up fiducial measurement; and automatic sequencing of the logical steps in the measuring procedure. The operation of this system was dependent on the existence of IBM control cards, which are produced in the film-scanning phase of the data processing.

Two of our existing scanning tables were connected to IBM card-punching machines. The projectors were modified so that a "grid" could be projected on the screen along with the bubble chamber pictures. This grid and the numerical control panels enable the scanning machine operator to record on IBM cards the film roll number, picture number, and event location and information on the type. The cards are subsequently used to generate control cards for the automatic measuring projectors as well as producing primary input to the library or data-control system.

The new equipment has already produced a noticeable increase in our data-processing rate. When sufficient experience has been gained with the new system, the older nonautomated measuring projectors will be modernized by addition of the features mentioned above.

Spiral Reader

Work has continued on the spiral reader, a high-speed combined scanning and measuring device intended primarily for single-vertex events.

During this report period the machine was mechanically and electronically completed. Debugging of the system and efforts to complete the necessary additions and modifications to our data-processing computer programs are in progress.

SMP System

During the summer a study was made of the possible designs for a bubble chamber data-analysis system based on a scanning and measuring projector, SMP, proposed by Alvarez.[11] This study was made by Professor James N. Snyder[12] and Professor Robert I. Hulsizer. The essence of the proposal resulting from the study is that the inherent simplicity of the SMP machine lends itself to exploitation as the extra-computer element of an on-line scanning-measuring-analysis system. In such a system the scanning, measuring, and data-analysis operations would be programmed in a high-speed computer with a direct-data connection, e.g., the IBM 709, 7090, or the CDC 1604. Whenever the analysis needed information from the film, the program would present a request to the operator of the SMP to provide the information, e.g., frame number, event type, a measurement of a track. If, in this way, the computer can do most of the labeling, ordering, and processing of data, then the external machine can be kept simple enough that its use for the slow process of scanning can be justified; a complicated measuring machine cannot be kept idle during the scanning operations and scanning must be done on separate, simpler machines. If scanning and measuring can be done on the same machine, considerable film and data handling can be eliminated. If, at the same time, the machine is on-line to a computer with analysis programs in it, immediate feedback to the operator of requests for corrections and remeasurements to allow successful completion of the analysis will further reduce film and data-handling operations.

The construction of a simple model of the SMP to handle film from the 15-inch bubble chamber was completed, and preliminary tests indicate a measuring accuracy of a fraction of a bubble diameter. It was connected to the direct-data channel of the IBM 709 and measurements were read into the computer and reconstructed on the cathode-ray-tube display.

Work was started on the design of programs to process the measurements and get them into a form suitable for input to the Alvarez group programs for bubble chamber data analysis.

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[11] L. W. Alvarez, A Proposed Device for the Rapid Measurement of Bubble Chamber Film, Physics Memo 223, Oct. 9, 1960, and A. J. Schwemin and Ronald Zane, SMP Data-Reduction System, UCRL-10109 (to be issued).

[12] James Snyder, Some Remarks on a Data Analysis System Based Upon the Scanning Measuring Projector, Physics Memo 326, Aug. 25, 1961.

Data-Reduction Operations

Personnel

The total effort in "full-Time Equivalents" (FTE) rose from 44 in May to 54 in October. The summer effort peaked at 74 FTE's when many of the part-time data analysts were working full time.

Scanning

During this 6-month period, the following scanning of 72-inch bubble chamber film was done:

Associated-Production Experiment 1st scan	= 176 rolls
Associated-Production Experiment rescan	= 205 rolls
K72 Production Experiment 1st scan	= 150 rolls
K72 Production Experiment rescan	= 30 rolls
Total scanning	= 561 rolls

Scanning of 15-inch bubble chamber film consisted mostly of remeasurements and some rescanning to determine operator efficiencies.

Measuring

The following is a summary of the measuring activity during this half year:

Measuring Projector	Bubble Chamber	Measuring time (hr)	Instrument time (hr)	Miscellaneous time (hr)	Number of events
IA	15-inch	2105	29	8	11,744
ID (and/or B)	15-inch	1609	47	7	12,505
Total		3714	76	15	24,249
IIA	72-inch	2710	140	63	12,662
IIB	72-inch	2388	177	41	11,717
Total		5098	317	104	24,379

BUBBLE CHAMBER OPERATION AND DEVELOPMENT

James Donald Gow

72-Inch Chamber Operation

From May 1 to June 11 the 72-inch chamber continued to operate for the associated-production experiment begun one year earlier. Upon completion of this run, the chamber was moved to a location between the chamber building and the Bevatron building, a position meeting the stringent requirements necessary for optimization of the intended operation in a high-energy K$^-$ beam. This required the installation of a heavy concrete support pad, extensive shielding, and modification of plumbing and control systems to permit remote operation. By the end of August the installation was complete and awaiting beam. Actual operation began on September 20. Approximately 100,000 pictures had been obtained by October 30. The high-energy K$^-$ experiment will continue to at least April 1962.

Because of the heavy operational schedule no modifications to the chamber or associated apparatus have been made.

25-Inch Chamber Design

As a result of discussions with potential users of the 25-inch chamber, it was decided to include operation with helium, as well as hydrogen and deuterium, as a design goal. Present plans call for initial operation only on H$_2$ and D$_2$, with provisions for conversion to helium without major modifications.

Operation with helium will require improved insulation, a driven expansion system, and refrigeration at helium temperature. The expansion system used with helium will drive the chamber because of the low chamber pressure. The present expansion system is simply a latching mechanism with the driving energy required to move the upper part of the chamber supplied by the liquid hydrogen. Helium operation requires that the temperature gradient on the liquid nitrogen shield be reduced. It may also be necessary to use low thermal conducting sapphire windows on the LN shield to reduce the radiation heat loss. The optical system design was modified slightly to provide a compatible system for helium and hydrogen.

The dimensions of the magnet, vacuum tank, nitrogen shields, and chamber were fixed during this period. The design calculations of the main bellows and the inflatable gasket were completed and work started on the chamber bellows test fixture.

In October a general meeting was held with interested physicists to review the general design from the point of view of the experimentalist. The 25-inch Bubble Chamber is scheduled to be ready for operation in early 1963 when the Bevatron comes on again after its major modification shutdown.

25-Inch Chamber Development

The primary chamber development effort has been directed toward engineering tests of critical components of the 25-inch chamber design.

A low-temperature fatigue test facility for life tests of the 25-inch chamber expansion bellows has been designed and constructed and optical models of the proposed illumination system are in preparation.

Superconductivity Development

The Superconductivity Studies Group has been active in the development of all currently available materials for high-field magnet fabrication. The prime effort of the group has been directed toward the measurement of short samples of promising materials in transverse fields, toward the development of satisfactory measurement techniques and criteria, and toward the solution of the engineering problems posed by superconducting-magnet fabrication and operation. The measurement of short samples was done by the transverse field-resistive transition method, as this gives results appropriate to the field-current relationship obtaining in a magnet. Details of this work are available in the references cited at the conclusion of this section.

Nb_3Sn-cored wire was the first material investigated. Techniques for making samples and reliable high-current contacts to normal metals have been worked out. Measurements of the wire in fields up to 93.5 kilogauss indicate that the wire is relatively insensitive to the activation sintering schedule, but that core continuity and, hence, wire performance is quite sensitive to the reduction process, drawing being the most favorable.

Two small test solenoids, wound bare on stainless spools and sintered in situ, have been constructed. The larger, made from 200 ft of wire purchased from the Kawecki Chemical Co., made a field of 12 kilogauss at 25 amp. The coil was "insulated" by quenching the Nb wire sheath in an external field. The rise time of the coil field was about 3 hr, emphasizing the necessity for better insulation. This work was not pursued further because of the diversion of effort to NbZr alloy.

Extensive transverse and parallel field measurements of Nb-Zr alloy wire (25 to 35 at % Zr) as well as studies of some factors affecting the critical current density have been undertaken. This work suggests a plateauing of the desirable effect of cold work in excess of 99% area reduction for the wire. The affect of short heat treatment on the wire is promising: the critical current density for fields below 40 kilogauss can be enhanced more than 100% (800°C, 60 min) but with strong degradation at higher field values. This effect is presumably related to the precipitation of a second phase along grain boundaries; its effect, we hope, be retained through subsequent cold work to restore the high field properties. J. Wong of Wah Chang is preparing samples of wire given intermediate heat treatment for our examination.

Several small NbZr solenoids have been wound: the largest, made from 1 lb of 10-mil-diam Nb-25 a/o Zr wire, developed a field of 35 kilogauss at 18 amp. This low value of the critical current is typical of all coils wound here or by other workers. The "20-amp catastrophe" is an effect whereby the critical current density for 10-mil wire is reduced by a factor of from 2 to 5 when it is wound into a tightly packed coil. We have shown that this effect is not a "length" effect but is solely related to turn proximity, that it is not therewith a thermal effect, nor is it a layer-to-layer capacitively

coupled rf triggering effect. We are continuing an extensive study of this problem because of its obvious impact on magnet economics.

Short lengths of Nb_3Sn-coated wire, developed by RCA, have also been examined both in dc and in pulsed fields. The dc result was comparable with that of the cored wire ($J_c = 1.05 \times 10^5$ amp/cm^2 at 93.5 kilogauss, 4.2°1C). The pulsed-field measurement, of a more preliminary nature, showed that the wire retained its superconductivity at 160 kilogauss with $J_c \approx 2.10^4$ amp/cm^2. These results were reported in a joint paper with J. J. Hanak and G. D. Cody of RCA at the High Magnetic Field Conference in Cambridge, Mass., November 4, 1961.

The coated wire is very fragile, shows evidence of submicroscopic damage in handling, and will probably not be useful, at least in its present form. We understand RCA will develop tape and cylindrical sheet forms to try to minimize this difficulty.

A small Nb_3Sn tube was made by powder-metallurgical techniques preliminary to making a superconducting flux concentrator. This trapped a field of 10 kilogauss with an average solenoidal current density of 2.10^4 amp/cm^2. We plan to try boosting this value by better fabrication and by suitably shaping the tube ends to relieve diamagnetic field stresses.

The group strength is presently nine men. Its work was summarized in a paper by Paul R. Aron, H. Paul Hernandez, and Harley C. Hitchcock, Recent Superconductivity Tests and Studies (UCRL-9819, Aug. 1961), presented to the Accelerator Conference in November. Other reports include Engineering Notes, EN4312-03 M30, 4322-03 M1-7.

Paul R. Aron and Harley C. Hitchcock, Superconductivity of Nb-25 a/o Alloy in High dc Magnetic Fields, UCRL-9790, July, 1961;

Paul R. Aron and Harley C. Hitchcock, Pulsed-Current Measurements of Superconducting Nb-25 a/o Zr wire in High dc Magnetic Fields, Physics Memo 319, Aug. 1961;

Paul R. Aron and Harley C. Hitchcock, Superconductivity of Vapor Deposit Nb_3Sn, Physics Memo 324, Aug. 1961.

PHYSICS RESEARCH
Walter H. Barkas in Charge

I. PION RESEARCH

A. Mean Life of Neutral π Meson

Hla Shwe, Frances M. Smith, and Walter H. Barkas

We have analyzed 3600 interactions of 3.5-Bev π^- in Ilford K.5 nuclear emulsion. Among these we found a total of 103 neutral pions which decayed by the Dalitz mode $\pi^0 \rightarrow \gamma + (e^+ + e^-)$. The distance s traversed by the neutral pion before decaying was measured. We have assumed the momentum spectrum of the neutral pions to be the same as that of the secondary charged pions (which we measured by multiple scattering). Using a statistical approach, our current estimate of the mean life of the neutral pions is $1.9^{+0.7}_{-0.4} \times 10^{-16}$ sec. The mean transverse momentum of the secondary charged pions is 274 ± 10 Mev/c. This new method for determination of the π^0 mean life takes advantage of the relativistic flight-path dilation of the high-velocity neutral pions.

B. 16-Bev Pion Interactions

Walter H. Barkas, Arthur G. Barkow, Piyare L. Jain, Gabriel Kane,
Zachary O'Friel, Hla Shwe, and Frances M. Smith

In November 1960, through the cooperation of the CERN emulsion group, we exposed a stack of K.5 emulsion to a beam of 16-Bev negative pions produced by the CERN proton-synchrotron machine. Interactions were found in this emulsion by along-the-track scanning. The multiplicities, angles, and energies of the secondary particles were measured. The "white" stars, those consisting only of near-minimum tracks and those with only one dark prong, were given special attention. A large fraction of these are produced in collisions with free protons in the emulsion. By analysis practically pure samples of hydrogen events can be found.

For the hydrogen-like events, the distribution of transverse momentum , P_T, was fitted by a function proportional to $p_T \exp (- P_T/135.7)$. The mean value, $\langle P_T \rangle$, was 271 Mev/c, and the maximum found was 1.1 Bev/c. The frequency distribution of shower particles was studied for increasing numbers of heavily ionizing secondaries. A definite positive correlation between numbers of heavily ionizing secondaries and shower particles was found.

When either the Duller-Walker or the Castagnoli method of analysis is applied to the white star secondaries, the center-of-mass velocity of the

system indicates that the effective target is lighter than a nucleon.

II.   STRANGE-PARTICLE RESEARCH

A.   Precision Energy Measurements

Harry H. Heckman, John N. Dyer, and Walter Barkas

In earlier work we found an apparent anomaly in the energy-momentum balance of the reaction $K^- + p \to \Sigma^- + \pi^+$. A very thorough investigation of the masses involved, and the determination of the kinetic energies of the products of this reaction, is under way.

A large stack of emulsion was exposed to a beam of K^- mesons which stopped in the middle of the stack. About 150 events consisting of the capture of a K^- meson by a free proton have been found, and the pion and hyperon ranges are both measured because the stack is sufficiently large to contain all the secondaries.

The following ranges are measured: the proton from $\Sigma^+ \to p + \pi^0$; the pion from $\Sigma^- \to n + \pi^-$; and both the pion and hyperon from $K^- + p \to \Sigma^\pm + \pi^\mp$. Some decay-in-flight pions from $\Sigma^- \to n + \pi^-$ are also favorable for measurement and aid in establishing the Σ^- mass.

These measurements greatly overdetermine the energies, so that an overall check is provided of the masses and range-energy relations involved. A new investigation of the range-velocity relation has also been undertaken. The work is considered important because the masses and reaction energies are needed for the kinematic analysis of all strange-particle processes.

B.   K$^-$-Meson Reactions in Complex Nuclei

A. Barbaro Galtieri, W. Zack Osborne, Jack W. Patrick,
Frances M. Smith, and Walter H. Barkas

The analysis of K^--meson interactions at rest in K.5 emulsion, referred to in the previous semiannual report, has been virtually completed. The ranges of some 300 π mesons from stars exhibiting no visible strangeness were measured. Height in the emulsion and angle of inclination to the plane of the emulsion were also measured to aid in bias elimination.

By range measurement very good resolution is obtained, an energy measurement being reliable to 1 Mev or so. This circumstance has led us to look for Σ^0-hyperon-pion resonant state. Those events consisting of $\Sigma^\pm + \pi^+$ prongs are carefully measured. The "invariant" mass of the Σ-π system is then calculated from the equation

$$M_Y{}^{*2} = (M_\Sigma + M_\pi + T_\Sigma + T_\pi)^2 - (\vec{p}_\Sigma + \vec{p}_\pi)^2.$$

Our most recent results are based on 187 cases in which the incident K^- was at rest and 21 in which the K^- was in flight.

The distributions of the invariant mass show a strong peaking at approx 1405 Mev for mesons at rest, and also apparently when in flight, but more statistics are needed to confirm the "in-flight" result. We are gathering more data for the in-flight reactions to determine the stability of this peak. We are also making calculations based on impulse models to see if the peaking can be understood without invoking a resonance state.

III. HEAVY-ION RESEARCH

A. Neutrons Produced in Heavy-Ion Interactions

William G. Simon and Harry H. Heckman

Emulsion exposures to determine $d\sigma/d\Omega dE$ for neutrons from heavy-ion-induced reactions were made in the previous reporting period. The recoil protons from n-p reactions are being measured with an IBM punchcard readout microscope. Preliminary results for the neutrons spectra produced by the bombardment of gold targets by 167-Mev O^{16} ions at laboratory-system angles of 0°, 45°, 105° have been obtained.

B. Charged-Particle Spectra in Heavy-Ion Interactions

Donald V. Reames

Analysis of the energy spectra of light charged particles produced at 0° to the O^{16} beam from thick targets is continuing. The p, d, t, a, and He^3 spectra for 167-Mev O^{16} on Ni and 142-Mev O^{16} on Al are essentially complete. Preliminary comparisons with the previously determined spectra (167-Mev O^{16} on Au and Al) show a smaller α/p ratio for Ni than the other targets. Also comparison of the two sets of Al data show approximately equal numbers of α particles produced by O^{16} in the energy region 142 to 167 Mev and in the region 30 to 142 Mev. Such is not the case for protons, for which approximately twice as many are produced in the interval 142 to 167 Mev as in the energy interval 30 to 142 Mev.

C. Electronic Charge Distributions for Heavy Ions

Harry H. Heckman

The reduction of all data relative to the equilibrium charge distributions for C^{12}, N^{14}, O^{16}, and Ne^{20} in zapon foils at velocities β between 0.0582 and 0.148 has been completed. We have attempted to interpret these data following the phenomenological theory proposed by Dmitriev.[1] The principal assumption in Dmitriev's theory which we chose to test is that the equilibrium charge distribution, ϕ_i, for a system of n electrons can be determined from a set of n statistically independent probability functions, M_i. It was found that such functions do exist and that they form continuous, monotonically decreasing functions of velocity. All the derived probability functions were satisfactorily represented empirically by a function of the type $M_i = (1 + a)/[1 + a(\exp k\beta^m)]$, where a, k, and m are constants and β is the ion's velocity. A good fit to all known data for N^{14} ions is obtained for velocities above $\beta = 0.39$, in addition to the data of this experiment. We have also found that the ratio of loss to capture cross-sections for the ith electron can be represented by a universal function of the form.

$$\frac{\sigma_\ell (i - 1 \to i)}{\sigma_c (i \to i - 1)} = \frac{\phi_i}{\phi_{i-1}} = f \left[\frac{137\beta}{(i - 0.62)^{0.7}} \right] ,$$

where ϕ_i is the observed fraction of the total beam carrying charge i. When the $(\phi_i/\phi_{i-1}) = (\sigma_\ell/\sigma_c)$ data are plotted vs $137 \beta/(i- 0.62)^{0.7}$, our experimental data for C, N, O, and Ne ions are reduced to three universal curves--one each for the 1K, 2K, and 1L electrons.

IV. SPACE RESEARCH

Harry H. Heckman

The measurements of the energy spectrum of protons in the inner Van Allen radiation belt between 12 and 650 Mev were completed. The nuclear track emulsions were irradiated during the flight of an Atlas missile from Cape Canaveral to Ascension Island. Above 100 Mev the spectrum is in good agreement with the albedo-neutron hypothesis. When compared with our previous measurements, the shape of the spectrum for $E \geqslant 80$ Mev appears to be stable over a period of a year. Below 80 Mev, the spectrum deviates markedly from the present theoretical calculations of the spectrum.

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[1] I. S. Dmitriev, Soviet Phys. JETP 5, 473 (1957).

Instead of monotonically increasing with decreasing energy, the observed spectrum reaches a maximum at about 35 Mev with a minimum indicated near 20 Mev. Mass measurements were carried out on 783 tracks with residual results are now being prepared for publication.

V. ANALYSIS OF PARTICLE TRACKS

A. Theory of Track Structure

Walter H. Barkas

It is very important to be able to determine from a segment of particle track the identity and velocity of the particle that produced it. Exact theory relating the measurable features of the track structure has been developed; this greatly increases the amount of information derivable from a segment of track. It is found that if both the mean gap length and the mean blob length are determined, for practical purposes the information content of the linear structure of the track is exhausted. This work was published: Phys. Rev. 124, 897 (1961).

B. Video Track Analyzer

Harry H. Heckman and Walter H. Barkas

In order to obtain particle velocities rapidly and objectively, a television track-analyzing system has been specified and is under construction. It provides 0.1 micron resolution.

For each segment of track, which may be dipping as much as 50° in unprocessed emulsion, the following information is displayed and also punched into IBM cards: number of blobs or gaps, mean gap length, mean blob length, mean track width, track dip angle, distribution of either blob lengths or gap lengths in ten channels.

Analysis of the data will be made with IBM programs based on the theory mentioned above.

C. The Grain Density of Emulsion Tracks

Jack W. Patrick and Walter H. Barkas

Measurements of the true grain density of emulsion tracks were made by several methods on the tracks of electrons, pions, K mesons, protons, Σ hyperons, and α particles. The curve of grain density versus

velocity in K.5 emulsion was obtained. The results found by different objective methods and by different observers were in agreement. Owing to the finite density of silver halide crystals in the emulsion, the grain density saturates. The nature of the saturation effect was studied. A decomposition of the grain density into primary and secondary components was made. Even at the minimum of grain density, some 25% of the grains are of secondary origin. Since only the primary grains are affected by the relativistic rise of the grain density, the interpretation of the ratio of plateau to minimum grain density is affected. Special observations of the grain density in the relativistic region were made, taking precautions to avoid temperature, fading, and development-difference effects. A rise to the plateau of 18% in the primary grain density was found. This implies a mean excitation potential for AgBr of 442 eV. Indices that measure emulsion quality were suggested. The results of this work have been reported in a paper[*] that is to appear shortly in the Nuovo cimento Supplement.

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[*] Jack W. Patrick and Walter H. Barkas, The Grain Density of Emulsion Tracks, UCRL-9692, UCRL-9692, June 1961.

THEORETICAL GROUP

David L. Judd

Material for this section had not been received at the time of publication.

PHYSICS RESEARCH

Edward J. Lofgren in Charge

K-NUCLEON INTERACTIONS

Victor Cook, Jr., Bruce Cork, William R. Holley, Denis Keefe,
Leroy T. Kerth, Paul G. Murphy, William A. Wenzel, and Theodore F. Zipf

The analysis of data and scanning of film from two previous experiments have been continued. Final results on the cross sections of K^+-p and K^+-n interactions in the momentum region 0.77 Bev/c to 2.83 Bev/c were obtained and published. Both σ_n and σ_p for K^+ mesons appear to be remarkably similar in this high-energy region--first a gradual increase with momentum until a little above 1 Bev/c, followed by a plateau value of about 17.5 mb, in each case. Apart from resolving some disagreements among earlier works on these cross sections, the experiment shows further the near equality of the $I = 0$ and $I = 1$ components of the interaction in this momentum region.

Scanning has been completed on the film taken during the same run in which parallel-plate spark chambers were used to study large-angle K^+-p scattering, and a scintillation counter hodoscope for the forward scattering. These data were obtained at momenta of 0.95, 1.17, and 1.95 Bev/c, and a phase shift analysis is in progress. At the moment only the qualitative result that the distributions are anisotropic and that rather large absorptive amplitudes are required can be stated.

Two interesting by-products of this experiment were the following. Firstly, by running parasitically in a low beam, some of the group, together with certain members of the University of Michigan group, were able to acquire spark chamber film of π^+-p elastic scattering. The scanning of this has been completed and the analysis is in progress. Secondly, the highly selective methane gas Cerenkov counters used to define the K-meson beam were tuned (by varying the pressure and timing) to select particles of various masses intermediate between those of the established particles. There have been several reports of particles with masses about 500 or 1400 electron masses; this experiment set upper limits for the proportion of positively charged secondary particles produced at the Bevatron of 6×10^{-8} for the mass region 420 m_e and 3×10^{-6} for masses between 1200 and 1600 m_e.

The analysis has been completed of the results of a counter experiment on the total cross section of K^- mesons on protons and neutrons by three members of the group in collaboration with the Chamberlain and Thornton groups. The beam used had a very small momentum spread and considerable attention was paid to the calibration of the momentum. The results of the final analysis show what the preliminary numbers had suggested, viz., a strong peaking, or resonance, in the K^--p cross section at 1 Bev/c. The absence of any similar strong effect in the neutron cross section leads one to ascribe it almost completely to the $T = 0$ channel, while magnitude of the peak is compatible with an angular momentum state $J \geqslant 3/2$.

POLARIZATION IN π^--p SCATTERING BETWEEN 500 AND 940 Mev

Edgar F. Beall, Bruce Cork, C. M. P. Johnson,
Louis J. Koester, Jr., Paul G. Murphy, and William A. Wenzel

Analysis was completed on spark chamber film taken in a parasitic π^- beam last year. The asymmetry in the scattering in carbon of the recoil proton from elastic π-p scatterings gives a measure of the polarization. The relation of the polarization measurements to the elastic scattering angular measurements by other groups in is still being examined.

ASYMMETRY PARAMETERS IN HYPERON DECAY

Edgar F. Beall, Bruce Cork, Denis Keefe,
Paul G. Murphy, and William A. Wenzel

An experiment to measure the polarization of the protons arising in the hyperon decay modes $\Sigma^+ \to p + \pi^0$ and $\Lambda^0 \to p + \pi^-$ has been completed and the data analyzed. The hyperons were created in associated production with a K^+ meson by an intense π^+ beam. A small thin-foil spark chamber recorded the direction of emission of the K^+ meson, and a water Cerenkov counter detected its decay product. A large spark chamber containing 40 carbon plates each 2 by 2 ft by 2.5 in. recorded the proton secondary from the hyperon decay. By studying the asymmetry in the elastic scattering from the carbon plates the polarization was estimated. The experiment determined the helicity $(-a_0)$ of the proton from $\Sigma^+ \to p + \pi^0$ decay to be $-0.78^{+0.12}_{-0.18}$, and the helicity $(-a_\Lambda)$ of the proton from decay as $+0.67^{+0.18}_{-0.24}$. Thus it serves to distinguish between the two groups of theoretical predictions, one demanding $a_\Lambda \approx -a_0$, the other $a_\Lambda \approx a_0$. In addition it indicates that $|a_0|$ is probably not unity and $|a_\Lambda|$ almost certainly not unity. Finally, the results on the Λ decay were sufficient to determine the ratio of p-wave to s-wave amplitude in the decay interaction as 0.4; this answer, taken together with observations and calculations on the H^4_Λ hyperfragments, determines the $K\Lambda N$ parity to be odd.

LOW-ENERGY $\bar{p}$-p INTERACTION CROSS SECTIONS

Bruce Cork, Armin G. Tenner, and Ching L. Wang

In collaboration with some members of the Alvarez group, Bruce Cork, C. L. Wang, and a visiting physicist from Amsterdam, A. G. Tenner, completed the scanning and analysis of film taken during an antiproton run in the 15-inch hydrogen bubble chamber.

The total, elastic, annihilation, and charge-exchange cross sections, as well as the elastic scattering differential cross sections at 45, 90, 145,

and 245 Mev, were obtained.

LIQUID HYDROGEN CERENKOV COUNTER AND β DECAY OF THE Σ HYPERON

Theodore F. Zipf

The design development and construction of a liquid hydrogen Cerenkov counter were continued by T. F. Zipf in collaboration with other physicists from the Glaser and Chamberlain groups and from UCLA. In spite of the many technical problems, the device was shown to be feasible. It is intended to utilize this counter in a forthcoming experiment as a target in which K⁻ mesons will come to rest and be captured. Liquid hydrogen has a low refractive index (1.10974) suitable for detecting electrons from the β decay of hyperons while remaining insensitive to the other fast particles produced in K⁻ capture. The design and construction of the rest of the apparatus needed in the experiment was also continued.

SPARK CHAMBER DEVELOPMENT AND NEW EXPERIMENTS

Bruce Cork, Richard Crolius, William R. Holley, Denis Keefe, Leroy T. Kerth
John J. Thresher, Ching L. Wang, and William A. Wenzel

The development of spark chamber techniques during this time was largely dictated by the requirements of two forthcoming experiments in which both novel geometric arrangements and very large chamber arrays were envisaged. For one of these experiments—on K⁻-p interactions in the momentum region 700 to 1300 Mev/c—various forms of cylindrical chamber were constructed and tested. The final design of a ten-gap chamber with 0.010-in. aluminum plates which was 20 in. o.d., 12 in. i.d., and 18 in. deep proved very satisfactory; such a chamber will be used to surround a liquid hydrogen target and record both the ingoing K⁻-meson and the outgoing interaction products. The problem of sterophotography of a cylindrical chamber was solved by using a mirror behind the chamber composed of many almost radial segments each tilted at a slight angle. Thus on a photograph a track appeared double, and measurements on the separation between the original sparks and their images gave information on the depth and dip of the tracks.

A large semicylindrical chamber was designed to be place downstream of the cylindrical chamber so that the range and polarization of certain of the reaction products could be measured. This is to contain twelve 1-in. carbon absorber plates and nine 0.5-in. steel plates. Two gaps Sealed semicylindrical chambers with two gaps each have been designed to fit between the absorbers.

In view of the proposed increase in the capacitance of the chamber, faster and more powerful methods of pulsing were explored. Triggered

spark gaps of different geometrical configuration were studied; a design
having the trigger electrode co-axial with the low-voltage ball seemed the
most suitable. A hard-tube (4PR60A) pulser to drive the trigger electrode
in the spark gap was developed; this has the advantage of faster response
than the earlier thyratron circuits.

BERKELEY 5-Mev ELECTRON LINAC OPERATIONS

William L. Everette

Continued operation of the 5-Mev electron linear accelerator at this
Laboratory has satisfactorily met the growing demand in the fields of chemistry,
nutrition, soils and plants, and bio-organic chemistry for a high-intensity
radiation source. One may consider momentarily that a 50-ma pulse of 5-Mev
electrons, pulse duration 6 μsec, delivers to the target 250 kw peak power.
At 240 pps the average power is 360 watts. In radiation dose units,

$$360 \text{ watts} = 3.6 \times 10^9 \frac{\text{ergs}}{\text{sec}} = 3.6 \times 10^7 \frac{\text{gram-rads}}{\text{sec}} ,$$

which is enough to cook anyone's goose! At 5 Mev all this energy except about
8% is absorbed by the sample through ionization and excitation collisions. The
8% escapes in the form of γ rays.

Usage of the machine over the specified period amounted to 40% beam
time, a figure which is lower than that for the period October to May. Utili-
zation breaks down as follows: physical chemistry, 30%; bio-organic chem-
istry, 35%; soils and plants, 15%; nutrition, 5%; materials testing, dosimetry,
and special applications, 15%.

Programs of research studies to which the linac has been an instru-
ment are reported briefly. Dr. Amos Newton, (Physical Chemistry) irra-
diated hydrocarbons, both liquid and vapor form, for studies of reaction
kinetics, polymerization, and free radical states. Dr. Jolly, University of
California Chemistry Department, irradiated volatile hydrides, a study in
germanium compound synthesis. From Dr. Calvin's group, Dr. Chris
Palm, visitor from Heidelberg University, completed his program of radiation
effects on primitive atmosphere gas samples. Dr. Lemmon, also from the
Bio-Organic Group, continued his studies of the radiation effects on choline
chloride and choline bromide.

The program of radiation sterilization of soils and plant foods was
continued by Dr. McLaren of the University of California Soil Science
Department. Fruit pasteurization studies by radiation were conducted by
Dr. Maxie and Dr. Romani, from the Department of Pomology, Davis Campus.
For specific details on the above work one should communicate with the person
making the study.

Materials in the form of electronic components and insulators have been irradiated with electrons at the 10^9-rad level by the Bevatron development group. Nuclear particle detectors were tested in the electron field for calibration purposes and in one case to determine the efficiency of a cosmic-ray detector in a radiation field approximating the Van Allen Belt fields. Obviously, this instrument was intended for space vehicle usage, and I might add that additional work along this line has been requested by people working for NASA.

Use of the machine for dosimetry studies was mentioned. Perhaps a few words about our methods are warranted. The nature of the sample to be irradiated dictates the method to be used. In certain applications, such as irradiation of fruits, soils, plants, etc., a specified beam field is established, usually by foil and air scattering or by a scanning magnet, or both. Absorbed doses at points of interest are then determined by cobalt glass dosimeters. These dosimeters are calibrated to 2% accuracy by means of the cobalt-60 source and Fricke dosimetry. In other irradiations such as gases, liquids, and certain solids which require sealed containers, absorbed-dose measurements are difficult. Usually exposure-dose measurements are difficult. Usually exposure-dose measurements are adequate and are made by measuring beam current and energy. Beam current can be monitored to 5% accuracy by using a current pulse transformer housed within the vacuum tank preceding the output window. The transformer signal is calibrated against a Faraday cup and electrometer system for each particular beam and output window condition. Beam energies are determined by spectrometer measurements either during a bombardment or for a voltage condition to be used for the bombardment. Ionization chambers are used to monitor irradiations made with γ rays.

As mentioned, operations are generally satisfactory. This is certainly true for experiments in chemistry in which the electron penetrating power, 2.5 g/cm^2, is acceptable. However, there are some complaints. An increase in penetration is certainly in order for sterilization and pasteurization work. With higher energy, polarization studies of gamma rays from thin foils can be made more efficiently and certain neutron-reaction studies are possible, e.g., fission-foil dosimetry of interest to Health Physics.

Steps are being taken to increase the beam energy. Presently the accelerator uses about 1.5 Mw pulsed rf power supplied by a VA-87 C klystron. The beam energy at this power level is 4.7 Mev. A 5-Mw klystron, VA-820, has been purchased and will be installed sometime this winter. The new tube should give us a factor-of-three increase in energy without further modification. Sufficient power is available from our present power supply. Klystron focus coils and pulse transformer are available from the Livermore Laboratory.

τ^+ DECAY ANALYSIS[*]

Thomas O'Halloran and Sulamith Goldhaber

As part of the study of properties of the K^+ meson,[1,2] an analysis has been undertaken of the K^+ decay into three charged particles. In particular we have concentrated on the film taken at K momentum of 220 Mev/c. At this momentum approximately 60% of the decays occur at rest, giving a fitted resolution of pion energy of about 1 Mev.

The detector used was the Alvarez 15-inch hydrogen and deuterium bubble chamber.

To date 2574 events have been found which were kinematically fitted by the KICK program to the τ mode of decay. An examination of the spectrum of the pion kinetic energy revealed a linear departure from phase space. The ratio Y of the number of events per volume of phase space can be represented as a linear function of the kinetic energy of the pion.
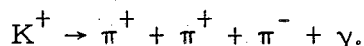
A least-squares fit to the data gives

$$Y_{\pi^+} = (1.141 \pm 0.047) - (0.00563 \pm 0.00168)\, T_{\pi^+},$$

$$Y_{\pi^-} = (0.700 \pm 0.042) - (0.0116 \pm 0.016)\, T_{\pi^-}.$$

This fit is consistent with that found in an earlier analysis of 899 τ-meson decays.[3]

In the analysis of the events one event has been found which fits the radiative decay mode

$$K^+ \rightarrow \pi^+ + \pi^+ + \pi^- + \gamma.$$

The energy of the γ ray is $E_\gamma = 32.6 \pm 1.0$ Mev. It is interesting to note that this value is consistent with the only other known example of a radiative decay.[4]

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[*]This work was done in cooperation with Gerson Goldhaber and Wonyong Lee of the Segrè Group.

[1]G. Goldhaber, S. Goldhaber, J. Kadyk, T. Stubbs, D. Stork, and H. Ticho, Separated K^+ Beams, Bev-483, 1960.

[2]Sulamith Goldhaber, K^+ Scattering Experiment in Hydrogen and Deuterium, Bev-513, 1960.

[3]S. McKenna, S. Natalie, M. O'Connell, J. Tietge, and N. C. Varshneya, A Study of 540 Tau-Meson Decays, Nuovo cimento 10, 763 (1958).

[4]R. Daniel and Y. Pal, An Abnormal Tau-Meson Decay, Proc. Indian. Acad. Sci. 40, 114 (1954).

STRANGE-PARTICLE PRODUCTION IN $\bar{p}$-p ANNIHILATIONS[*]

Sulamith Goldhaber and Thomas O'Halloran

We have examined 4250 annihilation events observed in the Lawrence Radiation Laboratory 15-inch bubble chamber[1] for strange-particle production events. The $\bar{p}$-p annihilations occur at a $\bar{p}$ momentum ranging from rest up to 740 Mev/c. In this sample we have identified by their decay mode or characteristic interaction 98 K^0 mesons, 25 K^+ mesons, and 28 K^- mesons.

We find the predominant mode of annihilation involving strange-particle pairs to occur with two charged pions. To obtain the percentage of strange-particle production, corrections for geometric cutoffs as well as detection efficiency have still to be made.

A study of possible strong K-K-π and K-π-π interactions is now being made.

K^+-H INTERACTIONS IN THE 15-INCH LRL BUBBLE CHAMBER[†]

Sulamith Goldhaber

We have continued the investigations of K^+ interactions in hydrogen and deuterium described in earlier reports.[1,2] We have determined the total and differential cross sections at average momenta of 355 and 520 Mev/c. (The respective half widths at half maximum for the two momenta is 20 and 15 Mev/c. At these momenta the interaction is a purely elastic one. A phase shift analysis of the data gives an excellent fit with pure S-wave scattering which leads to a δ_1 phase shift of

$$\delta_1 \ (355 \ \text{Mev/c}) = -20.0^\circ \pm 1.3^\circ$$

$$\delta_1 \ (520 \ \text{Mev/c}) = -29.3^\circ \pm 1.7^\circ$$

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[*] This work has been carried out in conjunction with William Chinowsky, Gerson Goldhaber, and Wonyong Lee of the Segrè Group.

[1] Low-Energy $\bar{p}$-p Interaction Cross Sections, this report, p. 24.

[†] This work was done in cooperation with William Chinowsky, Gerson Goldhaber, and Wonyong Lee of the Segrè Group, and Harold K. Ticho, William Slater, and Donald M. Stork, UCLA.

[1] T. F. Stubbs, H. Bradner, W. Chinowsky, S. Goldhaber, W. Slater, D. Stork, and H. K. Ticho, K^+-p Interaction at 455 Mev, Phys. Rev. Letters 7, 188 (1961).

[2] W. Slater, D. H. Stork, H. K. Ticho, W. Lee, W. Chinowsky, G. Goldhaber, S. Goldhaber, and T. O'Halloran, K^+-d Charge-Exchange Reaction from 52 to 456 Mev, Phys. Rev. Letters 7, 378 (1961).

We thus obtain a nuclear cross section of

$$\sigma_{nucl} \, (355 \text{ Mev/c}) \; = \; 11.6 \pm 1.3 \text{ mb}$$

$$\sigma_{nucl} \, (520 \text{ Mev/c}) \; = \; 12.2 \pm 1.3 \text{ mb}$$

The data at 520 Mev/c is appreciably lower than obtained in earlier measurements[3] and can be fitted with a potential consisting of a repulsive core followed by an attractive well.

PAPERS PUBLISHED

1. E. F. Beall, B. Cork, P. G. Murphy, and W. A. Wenzel, Properties of a Spark Chamber, Nuovo cimento 20, 502 (1961).

2. V. Cook, Bruce Cork, T. F. Hoang, D. Keefe, L. T. Kerth, W. A. Wenzel, and T. F. Zipf, K^--p and K^--n Cross Sections in the Momentum Range 1-4 Bev/c, Phys. Rev. 123, 320 (1961).

3. L. T. Kerth, K-Nucleon Interaction, Revs. Modern Phys. 33, 389 (1961).

4. V. Cook, D. Keefe, L. T. Kerth, P. G. Murphy, W. A. Wenzel, and T. F. Zipf, Search for Positive Particles of Masses about 500 m_e and 1400 m_e, Phys. Rev. 123, 655 (1961).

5. V. Cook, D. Keefe, L. T. Kerth, P. G. Murphy, W. A. Wenzel, and T. F. Zipf, Total Cross-Section Measurements of K^+-p and K^+-n Interactions in the Momentum Region 0.77 to 2.83 Bev/c, Phys. Rev. Letters 7, 182 (1961).

6. E. F. Beall, Bruce Cork, D. Keefe, P. G. Murphy, and W. A. Wenzel, Asymmetry Parameters in the Decays $\Sigma^+ \to p + \pi^0$ and $\Lambda^0 \to p + \pi^-$, Phys. Rev. Letters 7, 285 (1961).

7. Theodore F. Stubbs, Hugh Bradner, William Chinowsky, and Sulamith Goldhaber and William Slater, Donald Stork, and Harold K. Ticho, K^+-p Interaction at 455 Mev, Phys. Rev. Letters 7, 188 (1961).

8. William Slater, Donald H. Stork, and Harold K. Ticho, Wonyong Lee, William Chinowsky, Gerson Goldhaber, Sulamith Goldhaber, and Thomas O'Halloran, K^+-d Charge-Exchange Reaction from 52 to 456 Mev, Phys. Rev. Letters 7, 378 (1961).

9. Sulamith Goldhaber, Gerson Goldhaber, and Thomas A. O'Halloran, Pion-Pion Correlation in Tau Decay, Bull. Am. Phys. Soc. 6, 509(1961).

[3] T. F. Kycia, L. T. Kerth, and R. G. Baender, Phys. Rev. 118, 553 (1960)

10.   Sulamith Goldhaber, H. F. Fisk, W. S. Slater, D. H. Stork, and
       H. K. Ticho, W. Chinowsky, and Gerson Goldhaber, Production of
       Pions by Positive K. Mesons, Bull. Am. Phys. Soc. 6, 510 (1961).

11.   Sulamith Goldhaber, Wonyong Lee, William Chinowsky, and Gerson
       Goldhaber, Pion-Pion Correlations in $\bar{p}$-p Annihilations at Rest,
       Bull. Am. Phys. Soc. 6, 522 (1961).

12.   T. Stubbs, S. Goldhaber, H. Bradner, W. Chinowsky, G. Goldhaber,
       W. Kee, T. O'Halloran, W. Slater, D. Stork, and H. K. Ticho,
       K^+ Proton Interactions Below 100 Mev, Bull. Am. Phys. 6, 291 (1961).

PHYSICS RESEARCH

Burton J. Moyer and A. C. Helmholz in charge

Material for this section had not been received at the time of publication.

PHYSICS RESEARCH

Wilson M. Powell and Robert W. Birge in charge

BUBBLE CHAMBER OPERATIONS

Operation
Wilson M. Powell

Between June and September 281,000 pictures were taken in the Lawrence Radiation Laboratory 30-inch heavy liquid chamber of K^- mesons stopping in a mixture of Freon B-13 (CF_3Br) and propane (74%: 26% by weight). The optimum operating condition was found to be a temperature of $37^\circ C$ and a pressure of 287 lb/in.^{2} The lower temperature (relative to operation with pure propane) reduced the optical turbulence due to temperature gradients in the supporting oil. All the lights were used without diffusing shields, which allowed the power to the lights to be reduced and the apertures of the cameras to be stopped down to 7/32 in. The bubble density was maintained consistently at 8 to 10 bubbles per centimeter by an improved method for controlling the expansion ratio.

Seventy thousand pictures from the above run are being reproduced for University College, London.

The Weak Decays of Hyperons
Wilson M. Powell, George Gidal, Robert P. Ely, and William J. Singleton

The film for stopping K^- is being scanned for the weak decays

$$\Lambda \rightarrow p + e^- + \nu, \tag{a}$$

$$\Lambda \rightarrow p + \mu^- + \nu, \tag{b}$$

$$\Sigma^\pm \rightarrow n + e^\pm + \nu, \tag{c}$$

$$\Sigma^\pm \rightarrow \Lambda + e^\pm + \nu. \tag{d}$$

The few examples of (a), (b), and (c) reported in the literature indicate that the rates are less by an order of magnitude than the predictions of the universal Fermi interaction.[1]

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1. L. Okum, Strange Particles, Ann. Rev. Nuclear Sci. 9, 61 (1959).

No examples of (d) have been seen, and Okum[1] estimates a branching of ratio of approximately 10^{-4}.

On the basis of a preliminary scan, 450,000 Λ, 50,000 Σ^+, and 25,000 Σ^- hyperons were produced either by K^- interacting at rest or from interactions in flight (the K^- entered the chamber at 450 Mev/c). Twenty examples of the electronic decay of the Λ have been tentatively identified, but no estimate of the branching ratio has been made. No examples of the other decays have been observed. The University College, London, is participating in the scanning.

Bubble Density in Heavy-Liquid Bubble Chambers

George Gidal

Hahn[2] has reported a relativistic rise in bubble density in a Freon bubble chamber of approximately 30% from minimum ionization ($\gamma = 6$) to $\gamma = 100$ for pions and protons. We have investigated this effect in a 74% 26% mixture (by weight) of Freon (CF_3Br) and propane for electrons from γ-ray pairs, and we find an average increase in bubble density of 25% over a range of γ from 50 to 750. The measurements were made both by bubble counting on scan tables and by constructing integral gap-length curves using a projection microscope. More accurate measurements are planned.

K^- Interactions in Propane at 1.11 Bev/c

Robert Ely, George Gidal, Sun Yiu Fung, Yu Li Pan, and Wilson M. Powell

The T-1, 1380-Mev π-Λ resonance (Y^*) has been observed in the reaction

$$K^- + p \rightarrow \Lambda + \pi^+ + \pi^- \qquad (a)$$

Values of the mass and width are:

	No. of events	M (Mev)	$\Gamma/2$ (Mev)
Y^{*+}	154	1376 ± 3	24 ± 4
Y^{*-}	224	1376 ± 3	33 ± 5

The interactions on free protons were separated from those on carbon with 95% confidence by the kinematic fitting programs of the FOG-CLOUDY-FAIR data analysis systems.

2. B. Hahn and others, in Proceedings of an International Conference on Instrumentation for High-Energy Physics, (Interscience Publishers, Inc., New York, 1960), p. 143.

The production angular distributions contain significant contributions from d waves, and consequently the number of Y^*'s at production angles pertinent to Adair's spin-analysis procedure was not sufficient to give a significant result. However, there exists an anisotropy in the distribution of the Λ with respect to the Y^* production plane which is statistically significant and which indicates that the Y^* spin is greater than 1/2.[3] The forward-backward asymmetry parameters of the Y^* decay are smaller than those found at incident K^- momentum of 850 Mev/c by Berge et al.[4] This indicates that the Bose symmetrization interference effects described by Dalitz and Miller[5] are reduced, as predicted, at our energy.

Currently we are analyzing the data from the reaction

$$K^- + n \rightarrow \Lambda + \pi^- + \pi^0,$$ (b)

in which the K^--n system is in a T-1 state. By comparing Y^* production in reactions (b) and (a), we hope to separate the T = 0 and T = 1 Y^*-production amplitudes at this energy.

All the reactions in which Σ hyperons are produced are under study to determine the production cross sections and the degree of polarization of the Σ^+, and to examine the $\Sigma - \pi$ system for the resonances.

K^+- p Elastic Scattering

Warner Hirsch

From the interaction of 900-Mev/c K^+ in propane, 5000 K^+-p elastic scatterings have been measured and are being analyzed. About 1500 events with second scatterings are being considered in order to determine the polarization of the scattered protons and hence resolve the ambiguities in the phase-shift analysis.

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3. Henry P. Stapp, On the Identification of Spin-3/2 Resonances, Lawrence Radiation Laboratory Report UCRL-9526, Dec. 1960.

4. J. P. Berge and others, Phys. Rev. Letters 6, 557 (1961).

5. R. H. Dalitz and D. H. Miller, Phys. Rev. Letters 6, 562 (1961).
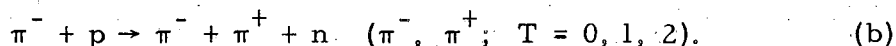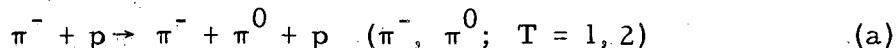
Elastic π^+- p Scattering

Peter Newcomb

The measurement and computer analysis have been completed for 2400 π^+-p elastic scatterings from the interaction of 730-Mev/c π^+ in the 15-inch hydrogen chamber. Bias corrections for the total cross sections and a phase-shift analysis are currently being considered.

π - π Interactions in 3-Bev π^- - Nucleon Interactions

Zavon Guiragossian

From the interactions of 3.0-Bev π^- mesons in the Lawrence Radiation Laboratory 72-inch hydrogen bubble chamber we have measured and analyzed with the FOG-CLOUDY-FAIR data-reduction system 1200 events of the types

$$\pi^- + p \rightarrow \pi^- + \pi^0 + p \quad (\pi^-, \pi^0; \ T = 1, 2) \qquad \text{(a)}$$

$$\pi^- + p \rightarrow \pi^- + \pi^+ + n \quad (\pi^-, \pi^+; \ T = 0, 1, 2). \qquad \text{(b)}$$

These are being analyzed both by the Chew-Low extrapolation procedure and by comparison of the invariant mass ($s = w^2/\mu^2$) of the μ-μ system with phase space. The range momentum transfer have been accepted. The distributions in s for both (a) and (b) show peaks corresponding to the T = 1 ρ particle at s = 27. The possibility of a T = 0 resonance is being investigated by comparing the s spectrum in Reaction (b) with that of (a).

DATA ANALYSIS FOR THE 30-INCH PROPANE BUBBLE CHAMBER

Howard S. White

Operations of FOG-CLOUDY-FAIR Programming System

During this 6-month period the FOG-CLOUDY-FAIR (FCF) program has processed about 35,000 events, which is an increase of 5,000 events over the preceding 6-month period. The table shows the distribution, by experiment, of FOG processing.

Experiment number	Vertices measured	Vertices processed
16	15894	12701
18	44	50
19	2333	5971
20	5037	5036
21, 22	641	2850
23	7876	8536
Total	31825	35144

The CLOUDY IV program reached maximum efficiency during this period, being limited only by measuring capacity and computer time availability. The 27,000 chains of related vertices processed by CLOUDY represented 40 different individual experiments. This figure may be compared with 8,000 chains processed during the preceding 6-month period.

The FAIR output summary system came into operation during the last part of the period of this report. Approximately 40,000 chains have been analyzed by use of this new techniques, which is more fully described in the section on Program Development.

FOG-CLOUDY-FAIR Program Development

FOG V, a spatial reconstruction program using 3- and 4-view measurements, has been assembled and debugged. This new program includes the most advanced tape-handling routines and is designed to maximize input-output efficiency in conjunction with calculations on the IBM 7090. It is written to be suitable for calculations with data from chambers using hydrogen, or propane or other heavy liquids. Sample data from the Brookhaven 20-inch hydrogen chamber and the CERN 30-cm hydrogen chamber as well as from the Berkeley 72-inch hydrogen chamber have been processed by this program.

A few minor FOG programs have been written and debugged during the period of this report. They are as follows.

(a) 119A. This program automatically assigns mass codes and assignment designators according to experiment, subexperiment, and vertex number to data contained in the FOG library. This procedure allows most categories of data to be entered into the FCF system without input additional to the microscope measurements.

(b) 123A.. This program produces mass codes and assignment designators in a form suitable for FOG IV or FOG V from input consisting of a sample event and a list of picture numbers. This procedure allows great flexibility for distinguishing different types of events in one experiment on the basis of identifications made at the scan tables.

(c) 124A. This program collates input tapes for the FCF system, and is designed to take advantage of the greater number of tapes available with the 7090 computer.

The CLOUDY program has been revised and extended to handle topological variations of events and to allow inclusion of several categories of kinematically different events on the same library. This program contains a special subroutine to deal better with constraints having zero degrees of freedom, and the revised tape-handling routine.

The FAIR output analysis programs were written and put into operation during this period. These programs permit a physicist, in a compiler-like language, to specify (a) categories of events that should be included in the summarization, (b) parameters of interest, and (c) operations to be performed upon these parameters for more convenient assessment of the information content of the data. Specification of events to be included is by describing ranges of parameters or describing numerical relationships between several mass permutations of a chain, or identifying those events desired by picture number. Parameters included in the abstraction from the CLOUDY library may be drawn from those already calculated and available on the CLOUDY library tape, or may be directly calculated within the FAIR abstraction program. It is intended that standard kinematical calculations will be performed within the CLOUDY program and their results stored on the library tape. Those calculations particular to individual experiments--e.g., angular correlations useful for polarization studies--are more suitably handled in the FAIR system. The result of an abstraction and calculation pass of the CLOUDY-to-FAIR library program is a very much abbreviated FAIR library tape containing only the physically useful parameters describing the accepted events.

To facilitate assessment of the data by the physicist, the FAIR system provides automatically generated lists of parameters of selected categories and graphical displays in the form of CRT histograms automatically generated and normalized for the generation of two-parameter scatter diagrams, and weighted histograms, and for the overlay of normalized theoretical curves on the display of the histogram and weighted histogram.

A further planned addition to the FAIR system will allow the assignment of selected events to the other groupings of data for further kinematical calculations within the CLOUDY system.

FLYING-SPOT DIGITIZER DEVELOPMENT

Jack V. Franck, Jerome A. G. Russell, and Howard S. White

A factor limiting high-energy physics research has been the diffi-
culty of measuring the large number of stereo photographs that can be obtained
with a major bubble chamber. Previous developments at Berkeley and else-
where have automated readout, provided semiautomatic track-following
abilities, and improved operator convenience for manually operated measuring
devices in order to increase the measurement rate. The further improvement
of these systems appears to be limited by the requirement of a continuous
chain of human guidance decisions necessary for manual control, with the
attendant loss of speed and possibility of errors.

The initial development at CERN by Paul Hough and Brian Powell[1]
of a measuring device suitable for use under automatic control gave promise
of overcoming many of these obstacles. This Hough-Powell Device (HPD) is
based upon a mechanically generated flying spot (formed by projecting light
from a mercury vapor arc lamp through the aperture formed at the intersection
of two crossed slits, one fixed and one mounted upon a rotating disc) in
optical contact with the film. The image of the spot is directed along two or
more optical axes, so that one image sweeps across a precision grating as
the other scans the film. By measuring the position of the spot on this grating
at the time the companion spot is centered upon a track, the position of the
track can be very accurately determined. In this way a bubble chamber
photograph is scanned along the image of the fixed slit. The motion of the
precision stage upon which the film is mounted separates consecutive scan
lines by predetermined amounts (usually two track widths) and causes the
photograph to be digitized over its entire area. The results are transmitted
as coordinates of the scan lines together with coordinates of track intersections
with the scan lines.

A series of informal meetings at Berkeley and at Brookhaven during
the latter part of 1960 was attended by representatives from Brookhaven
National Laboratory (BNL), the European Organization for Nuclear Research
(CERN), and Lawrence Radiation Laboratory. These meetings marked the
beginning of a collaboration between the three laboratories to share the devel-
opment effort, and served to explore the various ways in which the HPD could
be incorporated into a bubble chamber measurement system of large capacity.

It became clear that the best utilization of this device was as a part
of an equipment complex also containing a large digital computer capable of
concurrent kinematical analysis of the events being measured. Such a computer
could provide the guidance and control needed by the measurement device, and
would allow the simplest electronic design. Because of the extremely large

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[1] P. V. C. Hough and B. W. Powell, A Method for Faster Analysis of Bubble
Chamber Photographs, in Proceedings of an International Conference on
Instrumentation for High-Energy Physics, Berkeley, 1960 (Interscience
Publishers, Inc., New York, 1961).

amount of information contained in a bubble chamber photograph, the transfer of data from the measuring device to the computer should take the path of greatest efficiency. On-line operation of the HPD can achieve a much greater and more reliable information transfer rate than could be accomplished by using magnetic tapes, and also can allow direct and immediate computer control of the measurement process. For this purpose, a programmer from BNL and a second from CERN joined the LRL programming effort in May and August, respectively.

The HPD was thus seen as an instrument for automatically performing precision measurements of photographs under computer control. However, it is not desirable to eliminate manual scanning processes in the early stages of system development. Initial search of the film for events for interest would continue to be done on scanning projectors in a manner similar to that employed with Franckenstein and microscope measuring systems. Therefore, a means was required of conveniently describing to the computer control program which tracks of which pictures should be measured. Such a description can be obtained by digitizing, to low precision, three points on each track in each view. These rough coordinates are sufficient to allow the computer to define areas (roads) of the picture containing the tracks of interest.

By the beginning of the period of this report, a prototype measuring device had been fabricated at CERN and was connected to an IBM 709 computer. During the visit to CERN in May by three members of the Lawrence Radiation Laboratory staff (Jack Franck, Jerome Russell, and Howard White), this prototype HPD was first operated. A report of this series of measurements of various bubble chamber films has been published elsewhere.[2] It is pertinent to this report to note that these tests of the prototype HPD conclusively demonstrated its ability to measure film with a precision better than that normally obtained with other measuring devices. The tests further demonstrated the practicability of transmitting all coordinates to the computer by use of its direct data connection, and then reducing them by application of digital gating and filtering techniques. Other results obtained from these tests include evidence that adequate ionization measurements can be routinely made as a part of the measurement of track positions.

Satisfactory outcome of the CERN tests justified the decision to fabricate a production HPD at Berkeley. Certain reasons for building the hardware somewhat differently than BNL and CERN became apparent:

(a) The LRL film format having all views on one physical film is unlike that of the other laboratories and causes differences in the design;

(b) a vast store of experience in designing and building instruments of this precision and complexity is available at LRL and can best be utilized by detailed design here;

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[2] M. Benot, T. Lingjaerde, G. W. Moorhead, B. W. Powell, P. V. C. Hough, R. B. Palmer, J. A. G. Russell, H. S. White, and D. Lord, An Analysis of Results from the Prototype H. P. D., CERN 61-31 (Data Handling Division), 1961.

(c). A multilevel computer program capable of (i) concurrently controlling the HPD, (ii) receiving gating and filtering input coordinates from the HPD, (iii) collating the data from the several views, and (iv) performing the usual stereoscopic reconstruction and kinematical analysis. This program operate on a priority interrupt basis to maximize first computer and then HPD efficiency.

The object of the gating and filtering program is to exclude nonpertinent data received from the HPD. The gating program eliminates from further consideration digitizings exterior to the roads. The filtering program evaluates digitizings within the roads to recognize the existence of one or more tracks in the presence of random digitizations, and attempts to identify the one track entirely contained within a road. Normal points are formed from all digitizings of this track and stored for subsequent use by FOG. It is noted that these correspond to the result of setting upon a track with a line element, as is done by Franckenstein systems. However, since individual bubbles are probed by the flying spot, it is possible with this hardware and program to determine relative ionization by gap-length analysis with the expenditure of only a small additional amount of computer time.

In order to be able to test design modifications, program development, and other improvements to the FSD system, it is very desirable to have a minimum system in operation at the earliest possible date. At the end of the period of this report, the greatest effort is being concentrated upon operation of this minimum system in February 1962. Subsequent developments will complete the HPD to the level of complete system capability, and produce the digitized scan table, as well as complete the computer programming. The operational system is expected to be complete and useful for physics research by June 1962.

Continued development of the FSD system is expected to evolve smoothly into a system for the automatic scanning as well as automatic measuring of bubble chamber film. It is also noted that film of media such as spark chambers is approaching a volume and complexity sufficient to suggest application of this type of automatic analysis.

PHYSICS RESEARCH

Emilio Segrè in charge

π-p SCATTERING AND PHASE-SHIFT ANALYSIS AT 310 Mev

Hugo R. Rugge and Olav T. Vik

We have completed measurement of the differential and total cross sections for π^--p scattering at 310 Mev. A measurement of the polarization of the recoil proton has also been made. A total of 28 differential cross section points with approximately 3% counting statistics and four polarization points with errors of from .05 to .11 was obtained.

The experiment was performed in the "meson cave" of the 184-inch synchrocyclotron.

By use of these data as well as π^+-p scattering data obtained earlier by members of this group, a phase-shift analysis was performed.

The analysis for SPD waves is now complete. Two sets of phase shifts that fit the data have been found. With the inclusion of other available data, one of these sets is strongly preferred.

The analysis for SPD waves is still in progress. At this time two sets of phase shifts have also been obtained with the data measured by this group. Inclusion of other available data indicates a strong preference for one of these sets.

SPD Wave Fits

Set A		Set B	
$S_{1,1} = -5.4^\circ$	$S_{3,1} = -19.4^\circ$	$S_{1,1} = -6.9^\circ$	$S_{3,1} = -18.7^\circ$
$P_{1,1} = -2.4^\circ$	$P_{3,1} = -5.7^\circ$	$P_{1,1} = 25.6^\circ$	$P_{3,1} = -4.9^\circ$
$P_{1,3} = 2.6^\circ$	$P_{3,3} = 135.2^\circ$	$P_{1,3} = 7.8^\circ$	$P_{3,3} = 135.1^\circ$
$D_{1,3} = -4.7^\circ$	$D_{3,3} = 1.3^\circ$	$D_{1,3} = 3.1^\circ$	$D_{3,3} = 1.7^\circ$
$D_{1,5} = 14.1^\circ$	$D_{3,5} = 3.5^\circ$	$D_{1,5} = -0.4^\circ$	$D_{3,5} = -4.1^\circ$

Set A is the preferred set. The first subscript is 2I and the second 2J, where I is the isotopic spin and J is the total angular momentum.

SINGLE MESON PRODUCTION IN π + p COLLISIONS

Thomas Ypsilantis, Clyde E. Wiegand, Leonard B. Auerbach,
Tom Elioff, William B. Johnson, and Joseph Lach

In 1961 we performed an experiment at the Bevatron to study the reactions

$$\pi^- + p \rightarrow \pi^- + \pi^+ + n,$$

$$\pi^+ + p \rightarrow \pi^+ + \pi^+ + n$$

at incident pion momenta of 0.75, 1.25, and 1.75 Bev/c (lab).

Scintillation counters were used to detect particles. A time-of-flight criterion was imposed on the detected neutrons. A neutron could fall into any one of seven time bins. The neutron-detection efficiency of the counters and the energy resolution of each time bin were measured at the 184-inch cyclotron.[1] (UCRL-9986). The total range of neutron energy as defined by these bins was from 5 to 60 Mev.

Considering the incident beam direction as polar axis, those neutrons which fell in the annular interval $4^\circ \leq \theta \leq 60^\circ$ were studied if they satisfied the time-of-flight criterion. Pi mesons were measured in the annular interval $4^\circ \leq \theta \leq 140^\circ$.

A scattering event was defined by

(a) an incident pion scattered in the hydrogen target as determined by a coincidence of counters in the beam upstream from the target and an anticoincidence with a counter in the beam downstream from the target, and

(b) the creation of two fast particles and a slow particle (as defined above).

The θ and ϕ co-ordinates of all three particles and the time of flight of the neutron were stored in a magnetic-core memory unit and were transferred onto magnetic tape after ten scattering events had occurred. There were, on the average, 40 to 50 events per Bevatron pulse.

The events on these tapes were then subjected to a kinematic fit analysis on the IBM 709 computer. The fit analysis has now been completed for the incident momenta 1.25 and 1.75 Bev/c.

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[1] Clyde E. Wiegand, Tom Elioff, William B. Johnson, Leonard B. Auerbach, Joseph Lach, and Thomas Ypsilantis, Detection Efficiency of Plastic Scintillator for Neutron Energies 4 to 76 Mev, UCRL-9986, Dec. 1961.

Of those events which were found to satisfy the kinematics for the reaction, there were approximately

$$12,000 \quad \pi^- + p \text{ at } 1.75 \text{ Bev/c},$$

$$5,000 \quad \pi^+ + p \text{ at } 1.75 \text{ Bev/c},$$

$$7,000 \quad \pi^- + p \text{ at } 1.25 \text{ Bev/c, and}$$

$$4,000 \quad \pi^+ + p \text{ at } 1.25 \text{ Bev/c}.$$

The events were then sorted on the basis of the invariant momentum transfer Δ^2 to the neutron and the invariant barycentric energy ω of the two pions.

It is hoped that when the double distributions $d^2\sigma/ d\Delta^2 d\omega^2$ are obtained (this phase of the analysis is now nearing completion) the total cross sections for pion-pion scattering can be obtained over a wide range of ω^2 by use of a method suggested by Geoffrey Chew and F. E. Low, Phys. Rev. 113, 6 (1959).

The distribution $d\sigma/d(\frac{\omega^2}{\mu^2})$ for $\pi^\pm + p \to n + \pi^+ + \pi^\pm$ have been obtained for 1.75 Bev/c (Fig. 1). It is seen that the $\pi^+\pi^+$ state, which is pure isotopic spin 2, is very much lower than $\pi^+\pi^-$ --which is a mixture of $1,$spin states 0, 1, and 2--and that the $\pi^+\pi^-$ distribution is peaked at $\omega^2/\mu^2 \approx 28.$

SINGLE MESON PRODUCTION IN p + p COLLISIONS

Thomas Ypsilantis, Clyde E. Wiegand, Joseph Lach,
William B. Johnson, Tom Elioff, and Leonard B. Auerbach

An experiment was performed in 1961 to study the reaction

$$p + p \to n + p + \pi^+$$
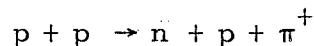
This experiment utilized the same apparatus as the experiment performed to study single-meson production in pion-proton collisions described in the preceding report. We were primarily interested in events in which the neutron was left with low laboratory-system kinetic energy and could be considered as a spectator to the scattering of the incident proton with a positive pion in its meson cloud.

At an incident proton momentum (lab) of 2.5 Bev/c, approximately 30,000 events were recorded which fitted the kinematics of the above reaction. However, before the data analysis can be finished a number of systematic corrections due to the detection apparatus must be completed. These are as follows.
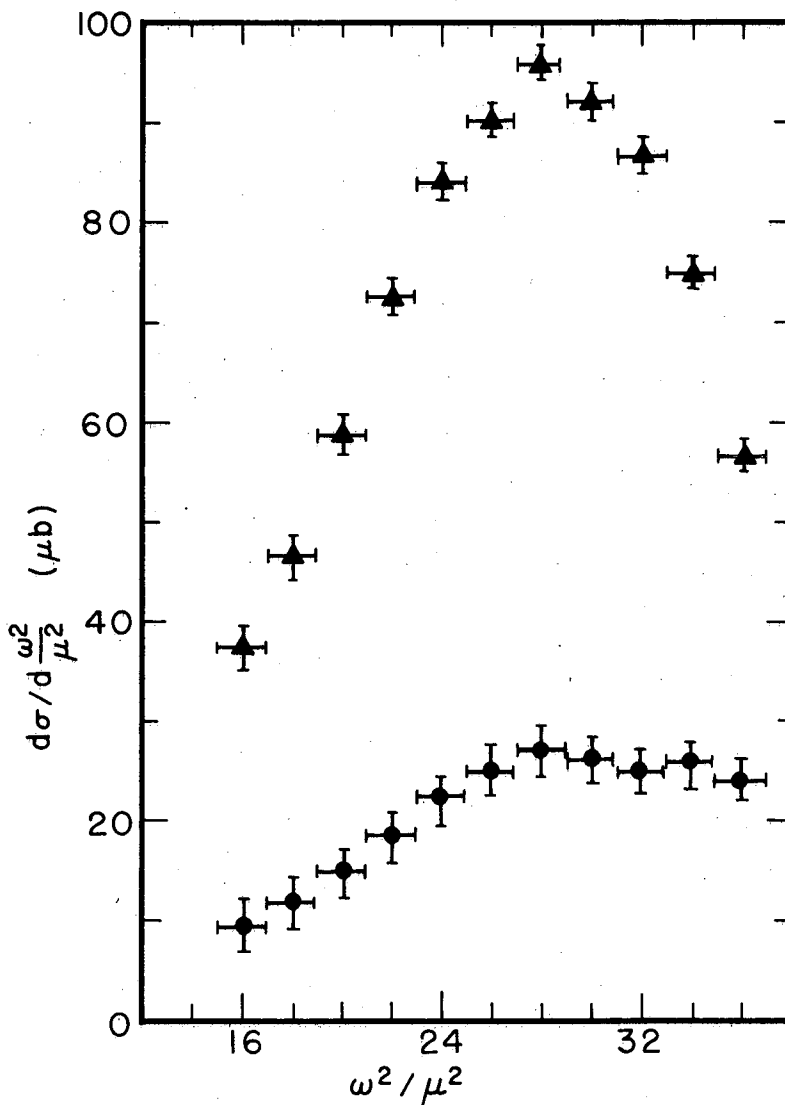
MU-26244

Fig. 1. Distributions $d\sigma/d\left(\dfrac{\omega^2}{\mu^2}\right)$ for

▲ $\pi^- + p \to n + \pi^- + \pi^+$ and

● $\pi^+ + p \to n + \pi^+ + \pi^+$, at 1.75 Bev/c.

1. A correction due to the neutron efficiency of the scintillation counters. This efficiency was measured at the 184-inch cyclotron for the seven time bins, and the results are available elsewhere. The average neutron-detection efficiency from 5 to 60 Mev is about 25%.

2. A correction due to the angular acceptance of the charged-particle counters. The charged-particle detectors covered a θ interval from 4 to 140 degrees, and the full 360 deg in ϕ. An appreciable number of events was lost because one of the charged particles escaped through the 4-deg hole in the array. Although this hole correction is for each event a function of the neutron angle and energy, it corresponds to an average loss of about 25% of the events for neutrons from 4 to 60 deg and from 5 to 60 Mev.

3. A correction due to the indistinguishability of the two charged particles. Although by measuring the neutron energy and the angular coordinates of all the final-state particles we have overdetermined the kinematics, the resolution of the apparatus is good enough to distinguish the pion from the proton in only 70% of the events. When one transforms into the center-of-mass frame of the final-state pion and proton, this manifests itself as an ambiguity in the pion-proton scattering angles.

The ranges of measurable neutron energies and of proton-incident momenta were chosen so that the nonspectator proton and pion would have energies near the 3/2 - 3/2 resonance in pion-proton elastic scattering. This should prove a valuable check of the Chew-Low extrapolation process for total and differential cross sections, since in this case the results are well known from the elastic pion-proton scattering data. The detailed analysis of the angle and momenta distribution of the neutrons, as well as the angular distribution of the nonspectator particles in their center-of-mass system, is still in progress.

DOUBLE MESON PRODUCTION IN p + d COLLISIONS

Roger Hill, Norman E. Booth, and Ernest H. Rogers

A further run on the measurement of the spectra of He^3 and H^3 produced in high-energy p + d collisions has been completed in collaboration with Alexander Abashian.

The new data confirm the presence of an anomalous bump in the He^3 spectra, and are being analyzed together with the data of previous runs. Figure 2 shows the I-spin zero part of the He^3 spectrum obtained at a laboratory-system angle of 11.8°. The dashed curve is the result of a simple phase-space calculation fitted to the points below 1300 Mev/c. The solid curve is the phase-space volume multiplied by the pion-pion enhancement factor for a scattering length of 2.8 pion Compton wavelengths.

With the new data it will be possible to perform a more complete analysis and to test critically the interpretation in terms of a strong pion-pion interaction.
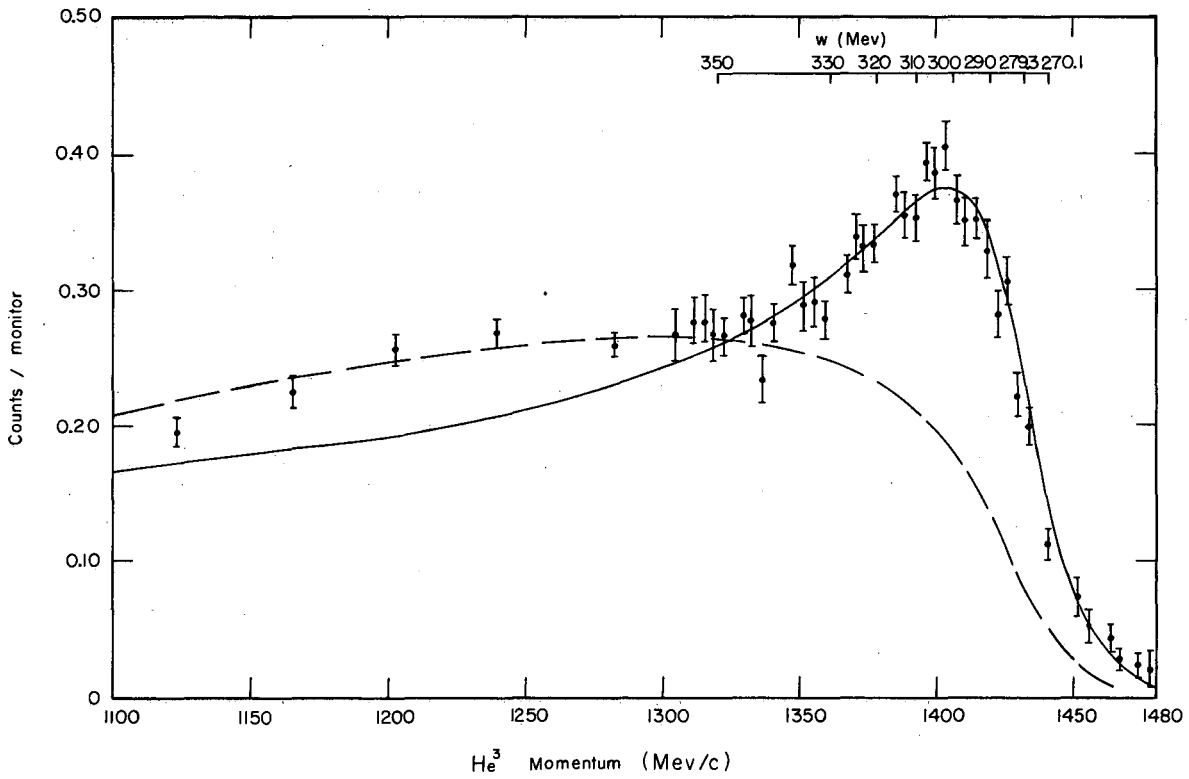
Fig. 2. He^3 spectrum for I-spin 0 at 11.8° (lab).

$\pi^+ \to \pi^0 + e^+ + \nu$ BRANCHING RATIO

Robert Bacastow, Tom Elioff, Rudolf Larsen,
Clyde Wiegand, and Tom Ypsilantis

Exploratory runs on the detection of the $\pi^+ \to \pi^0 + e^+ + \nu$ (pion beta decay)(10^{-8} theoretical branching ratio) have been completed at the 184-inch cyclotron. Pions from a 200-Mev/c positive beam consisting of 60% π's, 20% μ's, and 20% e^+'s were stopped in a liquid scintillation counter 2 by 2 in. thick. The stopping π intensity is approx 10^5/sec.

A source of background caused by the arrival of pions in adjacent rf pulses (approx 50 nsec apart), one of which stops whereas the other charge-exchanges in the pion telescope, has been uncovered. This will be eliminated electronically.

Preliminary measurements indicate an efficiency (including solid angle) for detecting the π^0 ranging between 10% and 25%, depending on chosen conditions. The detector consists of nine pairs of scintillator-lead sandwich counters arranged about the pion stopper. Whenever a pion stops and is followed within 40 nsec by a possible π^0, all counters are interrogated and the data stored on magnetic tape. In addition, other counter pulses are simultaneously photographed to reveal the presence of the e^+ and its annihilation radiation (detected in NaI).

POLARIZATION OF THE NEUTRON
IN $\pi^- + p$ CHARGE-EXCHANGE SCATTERING

Norman E. Booth, Roger Hill, N. H. Lipman, Hugo R. Rugge,
and Olav T. Vik

A liquid helium polarization analyzer is being constructed to measure the polarization of the recoil neutron from the reaction $\pi^- + p \to \pi^0 + n$ at an incident pion energy of 310 Mev. This analyzer will allow measurement of recoil neutron polarization in the angular region $30^\circ < \theta_{c.m.} < 45^\circ$ (neutron energy range 10 to 40 Mev) and thus augment existing recoil proton polarization data in the angular region $114^\circ < \theta_{c.m.} < 145^\circ$. It is hoped that this measurement will resolve the phase-shift ambiguity mentioned in the above article ($\pi - p$ Scattering and Phase-Shift Analysis at 310 Mev).

CORRELATIONS IN THE K^0-π^+ P STATE[*]

William Chinowsky, Gerson Goldhaber, and Theodore F. Stubbs

Measurements of the cross section for the reactions

$$K^+ + p + \pi^0, \tag{1}$$

$$K^+ + p \rightarrow K^+ + n + \pi^+, \tag{2}$$

$$K^0 + p + \pi^+. \tag{3}$$

at an incident K^+ energy of 455 Mev have already been reported.[1] Further work on the correlations in energy and angle between pairs of particles in the three-body final states has now been completed. The distributions in angle are all consistent, within the limited statistics, with isotropy. The most illuminating correlations are observed in the distributions in M*, the total energy of a pair of particles in the center-of-mass system of that pair of particles. In the events of Reaction (3) a peak in the distribution of M* of K^0 and p is found at 1480 Mev, of width approx 30 Mev. Other distributions are consistent with phase space, or reflect this K^0-p peak. An interpretation of this peak as an indication of a resonant K-p interaction in the T = 0, S = +1 state appears to be excluded in view of the small observed cross sections for the process $K^+ + n \rightarrow K^0 + p$.[2]

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[1]T. Stubbs, H. Bradner, W. Chinowsky, G. Goldhaber, S. Goldhaber, W. Slater, D. Stork, and H. Ticho, Phys. Rev. Letters 7, 188 (1961).

[2]W. Slater, D. Stork, H. Ticho, W. Lee, W. Chinowsky, G. Goldhaber, S. Goldhaber, and T. O'Halloran, Phys. Rev. Letters 7, 378 (1961).

ANTIPROTON ANNIHILATIONS IN DEUTERIUM[*]

William Chinowsky, Gerson Goldhaber, and Wonyong Lee

Scanning of the photographs of p in deuterium in the 15-inch bubble chamber has been completed. Geometrical and efficiency corrections are still to be made. Subject to small modifications for such effects, we find, in the 2444 observed annihilations, 1435 proton annihilations and 1009 neutron annihilations. The ratio of proton to neutron annihilations, $1.42\pm.06$, is consistent with a statistical model. The average number of charged prongs in the $\bar{p}$-p annihilations is 3.01; in the $\bar{p}$-n annihilations it is 3.09. Again the multiplicity distributions agree with a statistical model. In 68 annihilations at least one K meson was observed; of these, 31 had a neutral K_1^0 decay. Analysis of the K-meson production events is continuing.

PION-PION CORRELATIONS IN $\bar{p}$-p ANNIHILATIONS AT REST[**]

Gerson Goldhaber and Wonyong Lee

In a study of antiproton annihilations at 1.05 Bev/c it was shown that a marked difference exists between angular correlations of like and unlike pion pairs in the $\bar{p}$-p c.m. system.[1] This effect was attributed principally to Bose statistics.[2] More recently the appearance of a forward and backward charge asymmetry in $\bar{p}$-p annihilations at 1.67 Bev/c was observed,[3] which influences the pion-pion correlations and thus makes one question the dominance of the Bose effect. To check this point we have studied a sample of $\bar{p}$-p annihilations at rest where the forward-backward asymmetry effect cannot occur in the Lawrence Radiation Laboratory 15-inch hydrogen bubble chamber. We find for annihilation events into five pions, $p + p \rightarrow 2\pi^+ + 2\pi^- + \pi^0$, the ratio γ of the number of pion-pair angles greater than 90 deg to those less than 90 deg to be $\gamma_{unlike} = 2.26\pm.15$ and $\gamma_{like} = 1.14\pm.10$. This demonstrates that the effect attributed to Bose statistics[1,2] persists and is clearly independent of the forward-backward asymmetry effect.[3] The question whether π-π resonances also play a role in the observed effect cannot be decided as yet.

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[1]Goldhaber, Fowler, Goldhaber, Hoang, Kalogeropoulos, and Powell, Phys. Rev. Letters 3, 181 (1959).

[2]Goldhaber, Goldhaber, Lee, and Pais, Phys. Rev. 120, 300 (1960).

[3]Maglic, Kalbfleisch, and Stevenson, Phys. Rev. Letters 7, 137 (1961).

Publications: T. Stubbs, H. Bradner, W. Chinowsky, G. Goldhaber, S. Goldhaber, W. Slater, D. Stork, and H. Ticho, Phys. Rev. Letters 7, 188 (1961).

W. Slater, D. Stork, H. Ticho, W. Lee, W. Chinowsky, G. Goldhaber, S. Goldhaber, and T. O'Halloran, Phys. Rev. Letters 7, 373 (1961).

We also find a definite difference in the distribution of the invariant mass $Q_{\pi\pi}$ of the two-pion system for like and unlike pairs. Low values of $Q_{\pi\pi}$ are enhanced for like pion pairs.

ACCELERATOR OPERATION AND DEVELOPMENT

BEVATRON

Edward J. Lofgren in charge

The report for May through July 1961 has been issued as "Bevatron Operation and Development. XXX," UCRL-9981, Jan. 1962.

184-INCH CYCLOTRON

R. L. Thornton in charge

Reported by James T. Vale

Material for this section had not been received at the time of publication.

88-INCH CYCLOTRON

Elmer L. Kelly in charge

Work done at the 88-inch cyclotron will be described in a number
of reports to be presented at a conference on sector-focused cyclotrons,
April 17-20, 1962, at University of California at Los Angeles, to be published
in Nuclear Instruments and Methods.

60-INCH CYCLOTRON
W. B. Jones in charge

OPERATION

Summary of Usage

Summary of usage as prepared by Peter McWalters for this 6-month period:

Alpha bombardments		1,913.4 hr
Proton bombardments		564.9 hr
Deuteron bombardments		339.0 hr
Experimental bombardments		265.4 hr
	Operations total	3,082.7 hr
Outage		295.8 hr
	Available time	3,378.5 hr
Shutdown		965.5 hr
Holidays		72.0 hr
	Total Time	4,416.0 hr

An operating efficiency of 91.2% was maintained throughout this 6-month period.

HEAVY-ION LINEAR ACCELERATOR
Chester M. Van Atta in charge

Reported by Edward L. Hubbard

Material for this section had not been received at the time of publication.