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PHYSICS
Semiannual Report
May through October 1967

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PHYSICS
Semiannual Report

May through October 1967

November 1967

David L. Judd, Director, Physics Division

LAWRENCE RADIATION LABORATORY
University of California
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PHYSICS DIVISION SEMIANNUAL REPORT*

May through October 1967

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Physics Research

THEORETICAL PHYSICS

Geoffrey F. Chew, Group Leader

DYNAMICS BASED ON RISING REGGE TRAJECTORIES

Stanley Mandelstam

A dynamical scheme based on rising Regge trajectories is outlined. The fundamental approximation is that the scattering amplitude can be approximated by the contribution of a finite number of Regge poles. An additional simplifying assumption is that the Regge trajectories are straight lines or, equivalently, that the scattering amplitude is dominated by narrow resonances. Unitarity is introduced by means of the Cheng-Sharp equations but, in the narrow-resonance approximation, we adopt a very trivial solution of these equations. Crossing is introduced by means of the generalized superconvergence relations of Igi and Horn and Schmid. Levinson's theorem is not used; the bootstrap condition is the absence of Kronecker-delta singularities in the J plane.

It is hoped that this scheme avoids some of the disadvantages of conventional schemes. In the narrow-resonance approximation one has to solve numerical equations, not integral equations. The scheme is applied to the pseudoscalar, vector, and axial-vector nonets considered as bound states of the $N\bar{N}$ system. As only one channel is being examined we have to introduce certain parameters from experiment, but we obtain reasonable values for the other parameters.

A DYNAMICAL SCHEME BASED ON TWO-BODY UNITARITY AND CONTINUOUSLY RISING REGGE TRAJECTORIES

Richard Slansky

Investigations of various dynamical schemes based on two-body unitarity were begun. Generalizations of the Cheng-Sharp equations which accounted for many two-body channels were derived. Various forms of the Regge-residue functions were studied in a model in which a single Regge trajectory increased linearly with the energy squared. Further dynamical schemes based on continuously rising Regge trajectories that utilized full two-body unitarity were examined. Work is in progress to incorporate the finite energy sum rules into two-body unitarity, but no definite conclusions have been reached.

CONNECTION BETWEEN EXCHANGED REGGE POLES AND DIRECT-CHANNEL RESONANCES

Christoph Schmid

We extrapolate the ρ-Regge amplitude in πN charge exchange down to intermediate energies ($W = 1688$ to 2420 MeV, respectively, $p_L = 1.0$ to 2.6 GeV/c), where we partial-wave analyze it. Preliminary calculations indicate a surprising connection between the Regge exchange amplitude and direct-channel resonances. The partial-wave amplitudes from the Regge term describe semicircles on the Argand diagram. This has its origin in three new features of our analysis: (i) We use the Regge connection between real and imaginary parts, while other authors analyzed purely imaginary diffraction peaks. (ii) Our Regge amplitude contains the zeros at $\alpha = 0, -1, -2$. (iii) We carry out the analysis at intermediate energies at which the secondary peak is still important.

SIMPLIFIED MULTI-REGGE CALCULATION OF HIGH-ENERGY COLLISION CROSS SECTIONS

Naren F. Bali, Geoffrey F. Chew, and Alberto Pignotti

The multi-Regge-pole hypothesis is used to construct a model for high-energy production processes. Only contributions of one or several Pomeranchuk Regge pole exchanges are considered, and with the help of some approximations the integration over phase space is performed analytically. The parameters in the model are related to physical quantities

such as masses, couplings, widths of momentum transfer distributions, and the slope of the Pomeranchuk trajectory. A determination of the parameters is achieved by fitting the high-energy data for p-p collisions.

WIDE-ANGLE PROTON-PROTON SCATTERING AND REGGE POLES

Christoph Schmid

At fixed t the wide-angle (60 to 120 deg) proton-proton differential cross-section data fall on straight lines on a log-log plot, i.e. they show Regge-type behavior. In contrast, if one first decomposes the data at fixed s into a forward and a backward peak, and then plots the forward peak alone at fixed t, one does not find Regge-type behavior between 60 and 120 deg. This experimental result is also expected theoretically: By including a forward and a backward Regge term one would commit double counting.

Using one Regge term $\beta(t)s^{\alpha(t)}$ to represent the data between 60 and 120 deg leads to severe restrictions on the form of $\beta(t)$ and $\alpha(t)$ from the requirement of Fermi statistics. The Regge amplitude therefore reduces to a function which depends on only two numbers, and is essentially the same as Allaby's $C \exp(-A\sigma)$, where σ is the "magic" variable $G = s \sin \Theta$, which was found by Allaby et al.[1] by trial and error.

REGGE-POLE ANALYSIS OF THREE-PARTICLE PRODUCTION PROCESSES

Edmond L. Berger*

The application of a double Regge-pole exchange model to peripheral processes involving three particles in the final state is under investigation. Thus far, momentum transfer and mass distributions have been obtained from a model in which the Regge pole hypothesis is adopted for the absolute square of the invariant amplitude summed over final spins and averaged over initial spins. The resulting mass distribution for the $\pi\rho$ final state in the reaction $\pi p \to \pi\rho p$ shows significantly increased peaking in the A_1 region over that obtained by using an elementary exchange model. Detailed analysis of data on the reaction $pp \to \pi^- \Delta^{++} p$ at proton lab momentum 6.6 BeV/c, obtained by Gerald Smith et al. (Alvarez group), is proceeding; preliminary results indicate that the large enhancement observed at mass $(\pi\Delta) = 1.43\ (\mathrm{BeV})^2$ is adequately explained by the Regge pole exchange model but cannot be understood on the basis of an elementary exchange model without introducing a $\pi\Delta$ resonance.

1. J. V. Allaby, G. Cocconi, A. N. Diddens, A. Klovning, G. Matthiae, E. J. Sacharidis, and A. M. Wetherell, Phys. Letters 25 B, 156 (1967).

*Visiting scientist from Dartmouth College, Hanover, New Hampshire.

EFFECTS OF THRESHOLD AND PSEUDOTHRESHOLD CONSTRAINTS ON REGGE FITS

Robert D. Mathews

The practical importance of threshold and pseudothreshold constraints for Regge formulas is being investigated. In some reactions, the pseudothreshold may be very close to the physical region of the crossed channel and the pseudothreshold constraints on helicity amplitudes may be important for understanding the density matrix elements and differential cross section. It has already been shown by J. D. Jackson that these constraints are required in order to eliminate certain rapidly varying factors in the differential cross section. In particular the reaction $\pi N \to \pi\Delta$ is being studied. After experience is gained with this reaction it will, one hopes, be possible to extend the investigation to other quasi-two-body final states.

FEYNMAN GRAPHS FOR REGGE POLES

John Harte†

We assume that the lines in a Feynman graph correspond to Regge poles so that an "off-shell" line with four-momentum p_μ has spin $\alpha(p^2)$. Integrations over closed loops, such as those which occur in the normally divergent calculations of mass and coupling constant renormalizations, can be shown to be convergent, provided that the unrenormalized trajectories approach negative values as $p^2 \to \infty$. The effect of higher mass intermediate states in the mass-renormalization bubble graphs is to generate renormalized trajectories, which rise faster and turn over at higher energies than the unrenormalized ones.

LARGE-ANGLE ep AND pp SCATTERING

John Harte†

Recent proton form factor data from SLAC

†AEC Postdoctoral Fellow under contract No. AT(11-1)-34.

that extend up to t = -25 BeV^2 are compared with the behavior $F(t) \sim e^{-a|t|}$, predicted from a crossing symmetric bootstrap model. The data can be well described by a sum of two exponentials, thus indicating the presence of a discontinuity. Within the experimental errors, this discontinuity is located at the same value of t as the "break" in the 90-deg pp differential cross section. The origin of this striking similarity is under investigation.

REGGE-POLE FORMALISM FOR HIGH-ENERGY SCATTERING $\pi^+ d \to pp$

Huan Lee

The reaction $\pi^+ d \to pp$ at high energy is under investigation in the Regge model. It is found that the anomalous threshold singularities associated with the deuteron can be ignored. The kinematical singularities are obtained by constructing the invariant amplitudes explicitly. We have found that the differential cross section may have a dip near the momentum transfer at which the neutron trajectory passes through -1/2. Comparison with experimental data is still in progress.

RHO TRAJECTORY AND POLARIZATION IN $\pi^- p \to \pi^0 n$

Marco Toller[‡] and Luigi Sertorio[§]

It is suggested that the polarization in the process $\pi^- p \to \pi^0 n$ is due to a ρ' trajectory which has the same quantum numbers as the ρ trajectory, but belongs to a family of trajectories in which the phenomenon of parity doubling appears. Also the B trajectory should belong to this family. This hypothesis is being tested by means of a fit of the experimental data, taking into account a dispersion-theoretical sum rule.

0(2, 1) EXPANSION OF SCATTERING AMPLITUDE

Marco Toller[‡]

The connection between the representations of the groups 0(3) and 0(2, 1) including reflections has been investigated and used to clarify the connection between the Watson-Sommerfeld formula and the 0(2, 1) expansion. Some phenomena, which appear in the Regge theory (i.e., the ghost problem, twin trajectories, compensating trajectories), have been reformulated in the 0(2, 1) formalism. Similar features have been found in the 0(3, 1) expansion of the forward scattering amplitude. However, in this last case it has been observed that the ghost problem has a natural solution. This solution is being translated in the 0(2, 1) language and in the Regge language, giving rise to well-defined mechanisms which kill ghosts with vanishing mass. It is hoped the same mechanisms operate also for negative t.

[‡]CERN, Geneva 23, Switzerland.
[§]Iowa State University, Ames, Iowa.

ON SUBALGEBRAS THAT SURVIVE CONTRACTION

Gabor Domokos[#] and Graham L. Tindle[**]

We prove that if a subalgebra $\underset{\sim}{B}$ of $\underset{\sim}{G}$ is spanned by root vectors and X is a regular element of $\underset{\sim}{G}$, the limit lim Ad exp[tX($\underset{\sim}{B}$)] exists and is isomorphic with $\underset{\sim}{B}$, i.e., $\underset{\sim}{B}$ "survives" contraction with X. The algebra $\underset{\sim}{SL}(2C)$ is considered as an example, and it is shown that $\underset{\sim}{SL}(2C)$ itself may survive contraction. Applications to relativistic scattering theory are indicated.

ON THE ALGEBRAIC CLASSIFICATION OF REGGE POLES

Gabor Domokos[#] and Graham L. Tindle[**]

Starting from the Lorentz invariance and usual on-mass-shell analyticity properties of scattering amplitudes, we prove that (a) massless "particles," transforming according to infinite spin representations of the two-dimensional Euclidean group, are necessarily "elementary," corresponding to Kronecker-delta singularities in the j plane; (b) the classification algebra of Regge poles, at vanishing invariant mass, is necessarily the Lie algebra of the homogeneous Lorentz group, SL(2C). We calculate the contributions of Regge poles to scattering amplitudes of particles with arbitrary finite mass and spin, at vanishing momentum transfer, taking into account the conspiracy of Regge poles, arising from their classification according to SL(2C). The Regge contributions are indeed found to have the required analyticity properties and therefore a uniform asymptotic behavior at large energies.

INVESTIGATION OF THE ρ BOOTSTRAP AND THE DETERMINANTAL APPROXIMATION

D. Atkinson and Kwok Maw Ong

The ρ bootstrap is considered critically

[#]On leave of absence from the Central Research Institute for Physics, Budapest, Hungary.
[**]NATO Fellow.

by comparing the results of a δ function and a Breit-Wigner exchange. It is found that the self-consistent solution that exists for the δ-function case is not reproduced by the Breit-Wigner input. The reason for this is traced to an abnormally large repulsive long-range contribution in the δ-function case that is absent in the Breit-Wigner exchange. It is concluded that the ρ bootstrap is in serious trouble.

MESON BOOTSTRAP WITH FINITE-ENERGY SUM RULES

C. Schmid

By applying finite-energy sum rules to the $\pi\pi$ system we calculate the Regge poles in the crossed channel from the low-energy resonances in the direct channel. Since both channels contain the same particles, bootstrap conditions are found. In particular we calculate the ρ trajectory and an effective P trajectory (representing P and P'), and find, particularly for the ρ, very good agreement with experiment. The intriguing question of elementarity versus compositeness is answered in the sense that the dominant contributions must come from moving Regge poles of a slope $d\alpha/dt$ of approximately 1 GeV^{-2}. We discuss in detail the assumption of resonance saturation of the low-energy integral and the assumption of one-Regge-pole dominance of the high-energy expression, and show how these approximations are affected by changes in the cutoff energy and in the momentum transfer.

SINGLE-CHANNEL APPROACH TO MULTICHANNEL SCATTERING

Kwok Maw Ong

An iteration scheme is proposed whereby one may solve the multichannel N/D equations by means of single-channel techniques of Omnes and of Froissart. The technique will be applied to the coupled channels $\pi N \rightarrow \pi N$; $\pi N \rightarrow \pi N^*$; $\pi N^* \rightarrow \pi N^*$. It is our goal to obtain the desired shape of the πN phase shift in the P state.

POLARIZED BEAM PHOTOPRODUCTION AS A PROBE OF EXCHANGE MECHANISMS

Robert L. Thews

High-energy photoproduction of single mesons of arbitrary spin by polarized beams is studied. It is shown that for linear beam polarization, a study of the dependence of the differential cross section and the diagonal elements of the spin density matrix on the azimuthal production angle gives information on the quantum numbers exchanged in the crossed channel. For example, the dependence of $\rho_{00}\, d\sigma/dt$ in vector meson photoproduction gives the relative contribution of Pomeranchon exchange and pseudoscalar meson exchange.

SUM RULES FOR SPIN DENSITY MATRIX ELEMENTS

Gordon A. Ringland[††] and Robert L. Thews

The spin structure of amplitudes for the production of a single baryon or meson resonance of arbitrary spin in a quasi-two-body final state resulting from a pion- or kaon-nucleon interaction has been investigated. If the reaction is dominated by the exchange of a single set of quantum numbers in the crossed channel, the spin density matrix elements are shown to satisfy bilinear sum rules. It is suggested that the breaking of these sum rules is a good test for the presence of two or more exchange amplitudes. Comparison with data presently available yields results in agreement with general views on the most important mechanisms in well-studied reactions, and also some new results on some more obscure reactions.

PHASE CONTOURS, ZEROS, AND HIGH-ENERGY BEHAVIOR

Charles B. Chiu, Richard J. Eden, and Chung-I Tan

We define phase contours as curves along which the phase of an invariant scattering amplitude is a constant. These curves are sections of a complex surface, which we take either in the real (s, t) plane or in the complex plane of one of the variables. The relation between phase contours, zeros of the amplitude, and high-energy behavior is discussed. Characteristic features of phase contours are investigated in a variety of special models, and it is seen that basic assumptions about high energy behavior can readily be expressed in terms of the topology of the phase contours. Specific illustrations of phase contours are given for pion-nucleon scattering based on phase-shift solutions at low and medium energies and on an extrapolation from Regge solutions at high energies.

[††]Miller Fellow.

KINEMATIC SINGULARITIES AND THRESHOLD RELATIONS OF HELICITY AMPLITUDES

J. D. Jackson

The kinematic singularities of helicity amplitudes have been extensively studied by Hara, Wang, Stapp, Cohen-Tannoudji, Morel, and Navelet among others. Less well known are the concomitant relations between different helicity amplitudes at the normal and pseudo thresholds, e.g., $t = (m_a \pm m_c)^2$, $(m_b \pm m_d)^2$. Careful consideration of these relations is necessary in any model of peripheral processes. Otherwise the physical cross section in the s channel possesses spurious apparent poles in t at these threshold points. Although such thresholds lie outside the physical region, some of them (the pseudo thresholds) are near enough to give a totally false t dependence to the cross section. In addition to eliminating spurious poles, the threshold relations among the amplitudes imply restrictions on the decay density matrix elements of resonances.

A systematic method of determining the threshold kinematic singularities, as well as the threshold relations, has been developed by using orbital angular momentum and Russell-Saunders coupling of nonrelativistic quantum theory. No appeal to the singularity structure of the Trueman-Wick crossing matrix is necessary. A paper based on this work is in preparation. It is being written in collaboration with Dr. G. E. Hite, University of Illinois, where the research was begun.

DISCONTINUITY FORMULAS FOR THE REGION BELOW THE FOUR-PARTICLE THRESHOLD

Joseph Coster

Discontinuity formulas have been derived for all direct and crossed-channel normal thresholds occurring in the part of the physical region lying below the four-particle threshold of the channel in question.

A STUDY OF SUPERCONVERGENCE RELATIONS AND FINITE-ENERGY SUM RULES

Michael DerSarkissian[##]

Superconvergence relations and finite-energy sum rules have been studied. The former have been studied in connection with the nucleon electromagnetic form factors. The latter are presently being studied for $\pi^{\pm}p \to \pi^{\pm}p$ elastic scattering near the backward direction. The reaction $\pi^+p \to \pi^+p$ has a dip in the differential cross section near the backward direction but no dip structure is known for the reaction $\pi^-p \to \pi^-p$. A search for these features using finite-energy sum rules is now in progress.

[##]Visiting Scientist, Temple University, Philadelphia, Pennsylvania.

SINGULARITIES OF MULTIPARTICLE AMPLITUDES

David I. Olive[‡‡]

Studies have been made of various recent works on physical region singularities of many-particle scattering amplitudes. Particular attention was given to simplifying proofs that the positive α areas of Landau curves were what mathematicians called "manifold" and therefore possessed unambiguous "$i\epsilon$ prescriptions."

S-MATRIX SINGULARITY STRUCTURE

M. J. W. Bloxham,[§§] David I. Olive,[‡‡] and J. C. Polkinghorne[‡‡]

Unitarity compels physical amplitudes to have certain singularities. A general argument was found deriving all such singularities and the associated discontinuities. At present the last of four papers describing this work is being written.

FINITE-ENERGY SUM RULE AND BACKWARD πN SCATTERING

Charles Chiu, Michael DerSarkissian, and Jerome Finkelstein

The general formalism for the finite-energy sum rule near the backward direction for πN scattering has been investigated. We studied the experimental situation for the first-moment sum rule for the B amplitude in the u channel in detail. We find there is a sign change in Im B (I = 1/2) near $u = -0.15\ (\mathrm{GeV}/c)^2$ which could be associated with the expected asymptotic behavior at this position when α_N passes through -1/2. We do not observe the sign change in the Im B (I = 3/2) for the first-

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moment sum rule. At this stage, since the $I = 3/2$ first-moment sum rule is more sensitive to the cutoff energy, we do not associate the obtained sum-rule results with the asymptotic behavior.

REGGE PARAMETERS AND SUPERCONVERGENCE RELATIONS

J. Finkelstein

Several questions concerning superconvergence relations, both in their exact form and also in the resonance approximation, have been studied. Among the points studied are the constraints placed on scattering amplitudes by superconvergence relations imposed over a range of momentum transfer, and the information that can be obtained about Regge parameters from these relations.

CONSTRUCTION OF SOLUTIONS TO SUPERCONVERGENCE RELATIONS

D. Atkinson and M. B. Halpern

Superconvergence relations with a finite number of external one-particle states (and for all $t < 0$) are studied in the one-tower approximation, and a simple method for their solution is introduced. In general we find that, given a mass spectrum and one solution for the couplings, an infinite number of other solutions can be constructed. In simple cases, we also construct the first solution.

PERTURBATIVE APPROACH TO SUPERCONVERGENCE RELATIONS AND CURRENT ALGEBRA

K. Bardakci, M. B. Halpern, and G. Segrè

Using unitary representations of the Lorentz group, we introduce a perturbative approach, in powers of mass splitting, to the representation of current algebra and superconvergence relations.

PION ELECTROMAGNETIC MASS SPLITTING

William Weisberger

The calculation of the pion electromagnetic mass splitting by Das et al. [Phys. Rev. Letters 18, 759 (1967)] has been pursued to see whether the contribution proportional to m_π^2 is convergent or logarithmically divergent. The generalized WARD identities of current algebra do not give sufficient information to decide this question. Adler's sum pole has been used by Bjorkin to derive a lower bound on high-energy electroproduction cross sections. The possibility of fixed poles in the angular momentum plane invalidating the derivation of these results is under investigation.

REACTION $\gamma N \to \pi\Delta$ AND POLARIZED PHOTON EXPERIMENTS

Douglas Beder and P. Söding
[of Alvarez Group]

The reaction $\gamma N \to \pi\Delta$ was studied with regard to the value of polarized photon experiments for untangling the properties of baryon resonances. Both circular and linear polarized photons are found to be useful for determining parities and relative magnitudes and phases of transitions to resonant states. The role of one-pion exchange can also be clarified by using linearly polarized photons.

DECAY RATE FOR $K_L^0 \to \pi^0\gamma\gamma$

Thomas Walsh

A brief study of the rate and spectrum for the CP-conserving decay $K_L^0 \to \pi^0\gamma\gamma$ has been carried out. A more systematic investigation of two-photon decays, using current algebra, is under way.

VECTOR-DOMINANCE MODEL OF $\eta \to \pi\pi\gamma$

Douglas Beder and S. Flatté
[of Alvarez Group]

A Monte Carlo phase-space programme ("OWL") was modified to calculate absolute decay rates into n particles, and used to calculate $\eta \to \pi\pi\gamma$ with a vector-dominance model of the interaction. Results indicate substantial rates in this mode for $\eta'(960)$ but minuscule rates for $\eta(550)$.

LOW-ENERGY THEOREMS FOR COMPTON SCATTERING

Daniel Z. Freedman

Low-energy theorems for Compton scattering have been studied. The object was a synthesis of two very recently proposed ideas on the subject. The first is the realization[2] that such theorems could be derived for helicity amplitudes in S-matrix theory without reference to gauge invariance on any field-theoretic concept. The second is a theorem due to Pais[3] that low-energy theorems can be written for

all the 2j electromagnetic moments of a spin-j hadron. We hope to obtain a uniform treatment of the Compton scattering from targets of arbitrary spin using only S-matrix theory. Work is still in progress. Concrete results at present include the deduction of the kinematic singularities of s-channel helicity amplitudes for Compton scattering from targets of all spins.

IRREDUCIBLE REPRESENTATIONS OF SU_n

Ivan Kramer

The determination of the dimensionality of the irreducible representations of SU_n was pursued. The correspondence between the basis tensors of a given mixed symmetry in indices (upper and lower, with the usual tracelessness requirement) and the dimensionality represented by the basis was determined. Particular attention was paid to the reduction of products of irreducible representations of mixed symmetry into a sum of irreducible representations of the group. With the aforementioned formalism all the SU_6 particle algebra was worked out for the physically interesting representations, e.g., the representations having values 35, 56, and 70.

BEHAVIOR OF RELATIVISTIC S MATRIX IN LEFT-HAND λ PLANE

Hung Cheng

The asymptotic form of the relativistic S matrix for large angular momentum in the left-hand plane is investigated. For inelastic scattering, we found that the S matrix does not approach $e^{2i\lambda\pi}$. We then studied the coupled Schrödinger equation with two channels. Preliminary results showed that

$$\left.\begin{array}{l} S_{11}(\lambda) \to e^{2i\pi\lambda} \\ S_{12}(\lambda) \text{ vanishes rapidly} \end{array}\right\} \operatorname{Re} \lambda \to -\infty.$$

If the above conclusion is correct, we would have an extremely powerful tool, based on Regge-pole representation for the dynamical calculation of the S matrix.

The one-channel Dirac equation and Klein-Gordan equation are also studied. The asymptotic form $e^{2i\lambda\pi}$ is confirmed in both cases.

2. M. L. Goldberger (Princeton), private communication.
3. A. Pais (Rockefeller University), private communication.

OPTICAL-MODEL ANALYSIS OF PION-NUCLEUS INTERACTIONS

C. Thomas Mottershead

Optical-model analysis of π^- mesic atom level-shift data, and of He^4 scattering data taken in the pion form-factor experiment, is continuing. A generalization to relativistic kinematics of the usual reduced-mass formalism has been derived and applied to the analysis. It amounts to a small but significant correction. A program is in operation that fits the scattering data with logarithmic derivatives of the pion wave function at the nuclear surface. Formulas have been derived giving the shift in these logarithmic derivatives due to changing the sign of the Coulomb potential. It is hoped that this method will allow a relatively model-independent measurement of the pion charge radius. The interpretation of the logarithmic derivatives obtained from data fitting is aided by some new formulas expressing them as certain weighted integrals of the nuclear potentials.

SEPARABLE POTENTIAL FITS TO NUCLEON-NUCLEON SCATTERING DATA

Thomas R. Mongan

We have made separable potential fits, with three different functional forms, to nucleon-nucleon scattering between 0 and 400 MeV. The energy-shell transition amplitudes derived from our potentials have singularities only for real negative energies, as well as the usual unitarity cut. We have ensured the presence of the deuteron pole and the singlet antibound-state pole in our amplitudes. A thesis is being prepared on this work.

NUMERICAL BETHE-SALPETER EQUATION CALCULATIONS

William B. Kaufmann

The unequal-mass ϕ^3-type Bethe-Salpeter equation has been studied. Current efforts include the calculation of composite form factors, the inclusion of exchange potentials, and the calculation of elastic phase shifts. Phase shifts for the ϕ^4 equation (using a cutoff) have also been obtained.

NUCLEON-NUCLEON SCATTERING POTENTIAL

Judith Binstock

An equivalent potential is being calculated

for nucleon-nucleon scattering in the elastic scattering region. The input for this model is a set of bosons, with their masses and coupling constants, which communicate with the nucleon-antinucleon channels. The equivalent potential is constructed as outlined in Ref. 4. It yields a spin-singlet amplitude which corresponds to a sum of ladder diagrams. The output is compared with the data in order to determine what the best input coupling constants are. The I-spin zero scalar "sigma" is not included as a possible boson, but is assumed to be a crude parameterization of the effect of two-pion exchange, which is included.

AVERAGE NUCLEAR PROPERTIES

W. D. Myers and W. J. Swiatecki

We are continuing the program, mentioned in the preceding semiannual report, of systematically working out a large number of average nuclear properties by using a nuclear Thomas-Fermi equation.[5] The relevant integral equation has been solved (in closed form) for nuclear matter and, numerically, for semi-infinite nuclear matter, for finite nuclei without Coulomb energy, and for finite nuclei with Coulomb energy. The results provide, among other things, an estimate of the nuclear compressibility coefficient, an estimate of the binding of neutron matter, details of the fall-off through the surface of the neutron and proton densities, the size of the neutron skin thickness, the central depression in the proton density due to the Coulomb repulsion, and the dependence of the nuclear surface tension on the curvature of the surface and on the neutron/proton ratio. Some of these effects, as revealed by the numerical solutions, have been analyzed in detail, others are still under study.

ATTEMPTS TO MAKE SUPERHEAVY ELEMENTS

W. J. Swiatecki

Several theoretical investigations of the past few years have given indications that there may exist "islands of stability" beyond the end of the periodic table of elements. Until relatively recently the relevant magic numbers of neutrons and protons were assumed to be N = 184, Z = 126, but more realistic calculations of single-particle levels are now fairly unanimous in suggesting that Z = 114 is a better candidate than Z = 126. (Also N = 180 may be as good as N = 184.) This led to the realization that one is in a position, with existing heavy-ion accelerators, to make an attempt to form superheavy nuclei. A program along these lines, involving several workers in the Nuclear Chemistry group, was started 3 months ago. A beam of argon ions was used to bombard targets of ^{248}Cm (or ^{244}Cm), with the hope of observing the reaction

$$^{40}\mathrm{Ar} + {}^{248}\mathrm{Cm} = {}^{288}114 \rightarrow {}^{284}114 + 4n.$$

The 114 nuclei, knocked out of the target, would be caught on a foil, and fission fragments expected from their disintegrations would be observed in a mica detector. In the absence of experimental information on reactions induced by heavy ions in heavy targets, the planning of the experiments has to rely heavily on theoretical estimates of cross sections, optimum energies, disintegration lifetimes, etc. The half dozen runs on the Hilac that have been carried out so far indicate cross sections for the formation of element 114 in the above reaction of less than or equal to about 10^{-33} cm^2. Experiments are planned with heavier targets (^{252}Cf) and heavier projectiles (^{50}Ti) that might give a better chance for the formation and survival of the 114 nuclei.

EQUILIBRIUM CONFIGURATIONS OF A CHARGED CONDUCTING DROP

W. J. Swiatecki and C. F. Tsang

Work is continuing on the theory of fission of a charged conducting drop. This was started in connection with experimental work in the Chemistry Division on the disintegration of charged droplets. The experiments and theory together will serve as an analog study of nuclear fission. (See preceding semiannual report.) The stage reached at present is that the saddle-point configurations of a charged drop (the critical configurations defining the fission barrier) have been worked out in three degrees of approximation, which indicate reasonable convergence and which will be further improved. A computer program has been developed that automatically finds the saddle-point configuration for any intensity of electrification of the drop. Various properties of these shapes will be compared with the nuclear saddle-point configurations (corresponding to a volume electrification) in order to establish

4. Jerome Finkelstein, Equivalent-Potential Method for Relativistic Scattering, UCRL-17311 (1967).
5. W. D. Myers and W. J. Swiatecki, Average Nuclear Properties, UCRL-17724, Aug. 1967; also talk at Nuclear Structure Conference, Tokyo, Japan, September 7-14, 1967.

the degree of analogy between the macroscopic and nuclear droplets.

THE STABILITY OF THE OUTER RADIATION ZONE

C. S. Liu

The long-term stability of the outer radiation zone against low-frequency electrostatic perturbations has been studied. The quiet-time outer zone is found to be stable except near the auroral zone ($L \approx 6$), where the flux of the quiet-time ring-current belt is peaked. The quiet-time ring-current belt is stable by itself and supports a negative-energy wave propagating azimuthally. This wave, however, can resonate with the Davis and Williamson particles when the phase velocity is equal to the drift velocity of the particles. The wave loses energy to the particle as $(\partial F/\partial L)_{\mu J} > 0$ for Davis particles, and the wave grows. This overstability can explain the quiet auroral arcs. During the storm time, the ring-current belt has sharp density gradient. The outer edge of the ring-current belt is found to be unstable by itself as the density gradient reaches certain limits. This purely growing mode can account for the auroral substorm.

ATTEMPT AT A FLUID DESCRIPTION OF THE WEIBEL-KAHN INSTABILITY

Norman Albright

Ron Davidson has shown[6] that the firehose instability ($p_{\parallel} - p_{\perp} > B^2/8\pi$) may be described by the fluid equations. The firehose and Weibel-Kahn instabilities are both low-frequency transverse-wave instabilities. However, the Weibel-Kahn instability ($p_x \neq p_y, p_z$; $B = 0$) cannot be described by the fluid equations. Attempts to do so yield the correct region of instability, but the wrong growth rate. In the firehose instability all electrons participate, whereas the Weibel-Kahn instability is essentially a resonance phenomenon. A fraction of the electrons with velocity near zero resonate with the purely growing disturbance.

200 GeV STUDY

Lloyd Smith

Serious design work on the 200 GeV accelerator started in Chicago at the end of June, and still continues. We are participating in this work, partly in Berkeley and partly in Chicago. The main parameters have been selected, and are as follows: radius--one kilometer; energy--200 GeV, extendible to 400 GeV by increased magnet excitation; injector--10 GeV synchrotron cycling at the rate of 15 pulses per second; preinjector--200 MeV, 200 MHz Alvarez-type linear accelerator; main ring aperture--about 5×12 cm^2; repetition time--4 seconds, with 1 second flat-top.

NORMAL MODES FOR A BOUNDED COLLECTION OF CHARGED PARTICLES

Frank Sacherer

The normal modes of a bounded one-dimensional group of charged particles with uniform charge density in an external parabolic potential have been found. In addition the nonlinear envelope equation of such a system has been studied, and the limits of motion have been found when an external driving force is present.

CLEARING ELECTRODES AND THE LENGTH OF BUNCHES IN ELECTRON STORAGE RINGS

L. Jackson Laslett and A. M. Sessler

The effect of various clearing electrode structures, including their electrical termination, upon the longitudinal shape of bunches in a storage ring is under study. This investigation was initiated in the hope of understanding the anomalous lengthening of high-intensity bunches which has been observed in ACO (Orsay). Preliminary work would seem to offer the possibility of explaining the observations.

COLLECTIVE ION ACCELERATOR

A. M. Sessler

Following receipt of the report on the Soviet work at Dubna, theoretical studies were initiated to obtain a better understanding of the proposed accelerator. Preliminary investigation has been encouraging; i.e., it appears to support the Soviet enthusiasm for the device. In collaboration with others, the form of a possible LRL experimental-theoretical program is being investigated.

6. Ron Davidson (University of California), private communication.

INCOHERENT BEAM-BEAM INTERACTIONS

E. Keil (CERN), C. Pellegrini (Frascati), P. Morton (SLAC), and A. M. Sessler

A combined theoretical-computational attack has been launched on the problem of the incoherent beam-beam limit of colliding-beam devices. The dependence of the limit upon beam shape, accelerator parameters such as crossing angle and β at the crossing point, and compensating nonlinear lenses is being studied computationally. A simplified theoretical model has been developed and is now being evaluated analytically; it is subsequently to be compared with the computational results, and then (one hopes) to be employed to give insight into the phenomenon.

RESONANCES IN CIRCULAR ACCELERATORS AND EXTERNAL FEEDBACK LOOPS

E. D. Courant (BNL), C. Pellegrini (Frascati), M. Lee (BNL), and A. M. Sessler

Prompted by observations of anomalous behavior at the ZGS (Argonne), a theory of coupling resonances in the presence of a damping electrode has been evolved. Numerical evaluation is now in progress. It is possible that, quite generally, appropriate feedback loops could be helpful in crossing resonances--a possibility that is presently under investigation.

PASSIVE COMPENSATION OF LONGITUDINAL SPACE-CHARGE EFFECTS IN CIRCULAR ACCELERATORS: THE HELIX

A. M. Sessler and V. G. Vaccaro (CERN)

The longitudinal electric field associated with a particle beam having azimuthal variation in charge density and moving within a helix that is surrounded by a conducting sheath is investigated theoretically. It is shown that, for density variations having a wavelength long compared with the helix radius, the magnitude and sign of the electric field may be set to any desired value by appropriate choice of the helix and wall parameters. In particular, conditions on the parameters of a helical insert of short circumferential length are given, for which there is complete compensation of the longitudinal space-charge forces at one particle energy. Such a device should permit acceleration of a large line density through phase transition, in an alternating-gradient accelerator, without a decrease in longitudinal phase-space density.

BYPASS-STORAGE-RING OPTION FOR NAL

E. D. Courant (BNL), L. W. Jones (Michigan), B. W. Montague (CERN), E. M. Rowe (Wisconsin PSL), and A. M. Sessler

A bypass-storage-ring system is explored in the context of its addition to the NAL accelerator. It is shown that colliding-beam center-of-mass energies of 140 to 280 GeV, as much as 4.5 times those of the CERN ISR, are feasible with this system. Superconducting magnets for the storage ring seem a natural development. Luminosities in the range of 10^{32} cm^{-2} sec^{-1}, or well above the CERN ISR design values, would be expected. The geometry of a bypass-storage-ring system is studied, and four self-consistent options are considered. Of these, two wherein the bypass is on the outside of the main ring are preferred. On comparing with a totally separate intersecting storage-ring system, it is noted that the cost and size of the bypass-storage-ring option are quite modest relative to its gain in energy, and that consequently the threshold of interest in a separate, intersecting storage-ring system is forced up to energies of the order of a TeV.

This work will be published as a National Accelerator Laboratory Report (NAL-5).

SPACE-CHARGE CONTRIBUTIONS TO INTENSITY LIMITS IN CIRCULAR PARTICLE ACCELERATORS

L. Jackson Laslett

Recently additional attention has been given to analysis of the defocusing effect of the dc component of magnetic field that arises from an intense particle beam in a circular accelerator. The effects of such fields, especially in influencing the frequency of coherent oscillations, were summarized in a paper presented at the 1967 International Conference on High Energy Accelerators.[7] At present work is in progress to study the effect of d.c. magnetic images in "picture-frame" magnets, or, more generally, in magnets in which a ferromagnetic

7. L. Jackson Laslett and L. Resegotti (CERN), The Space-Charge Intensity Limit Imposed by Coherent Oscillation of a Bunched Synchrotron Beam, in Proceedings of the VI International Conference on High Energy Accelerators, Cambridge, Massachusetts, September 1967.

yoke entirely surrounds the beam.

CLOSED-ORBIT CONTROL

L. Jackson Laslett, G. R. Lambertson (Bevatron), and J. E. Braley (Special Projects)

Results of a computational investigation of methods for controlling the closed orbit in a large alternating-gradient synchrotron were presented at the 1967 International Conference on High Energy Accelerators, held in Cambridge, Massachusetts.[8] It is intended to resume investigation of this problem with reference to the projected national accelerator planned for Weston, Illinois.

ERROR ANALYSIS FOR SURVEY NETWORKS APPLICABLE TO THE NAL ACCELERATOR

L. Jackson Laslett and J. E. Braley (Special Projects)

As a result of discussions with personnel at the National Accelerator Laboratory (Oakbrook, Illinois), certain specific survey networks of possible utility for surveying the magnet elements of the projected national accelerator have been conceived. As a sequel to similar work undertaken in connection with the LRL 200-BeV Design Study, studies are being resumed to examine the effect of surveying errors on the figure formed by elements of the magnet ring and on the deviation of the closed orbit from the center line of the vacuum chamber.

COMPUTATIONS CONCERNING NONLINEAR, AREA-PRESERVING ALGEBRAIC EQUATIONS

L. Jackson Laslett

Computations were performed (usually with the CDC-6600 computer in double-precision arithmetic) to examine the characteristics of phase-plane diagrams (stability, fixed points, etc.) for algebraic transformations chosen either (i) to simulate one-degree-of-freedom motion in particle accelerators or (ii) to emphasize certain theoretical features of mathematical interest. The results of this work have been summarized in informal notes circulated to other members of the Laboratory who had an interest in the problem, and some of the data served to illustrate the special behavior of a class of transformations discussed by E. M. McMillan.[9]

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9. Edwin M. McMillan (Lawrence Radiation Laboratory), private communication.

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29. F. Landis Markley, A Physical Interpretation of Static Model Parameters (UCRL-17502 Rev., June 1967), Phys. Rev., Dec. 25, 1967.
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EXPERIMENTAL PHYSICS

Luis W. Alvarez in charge

SUMMARY OF EXPERIMENTS IN PROGRESS

This brief summary lists (and in some cases abstracts) the articles appearing on the following pages.

I. Bubble Chamber Experiments

A. Associated Production Experiment. Between mid-1960 and mid-1961, the 72-inch hydrogen bubble chamber was exposed to π^+ and π^- beams at six laboratory-system momenta from 1.030 to 1.325 BeV/c. About 1 000 000 pictures were taken, of which 3/4 have been analyzed at Berkeley and the remainder at the Universities of Wisconsin and Purdue, Johns Hopkins, and Duke Universities. Numerous results from this experiment have been published. In late 1964 an additional 110 000 pictures of π^- incident at five different momenta from 0.910 to 1.030 BeV/c were taken for analysis at Berkeley.

B. π63 Experiment. The 72-inch hydrogen bubble chamber was exposed to π^- in the momentum range of 1.5 to 4.2 BeV/c; all together 30 000 events/mb of film were taken between mid-1963 and early 1965. Many papers have been published or submitted for publication, and the analysis is now in its final stages.

C. K63 Experiment. An exposure of the 72-inch hydrogen bubble chamber to a K^- beam having laboratory-system momenta of 1.7, 2.1, 2.45, 2.58, 2.63, and 2.70 BeV/c was made, totaling 30 000 events/mb. Exposures with deuterium were taken at 2.1 and 2.7 BeV/c, and a run was made at 2.1 BeV/c with a Pb plate in the chamber to convert γ rays, and thus detect neutrals. The film was taken between mid-1963 and early 1965, and as of September 1967 nearly 300 000 events had been measured.

D. K65 Experiment. During the period from August 1965 to October 1967 the 25-inch hydrogen bubble chamber was exposed to a K^- beam of about 400 MeV/c. Roughly 1.4 million pictures were taken, 60 000 of which were in deuterium. The average track density was about 6 K^- per picture. More than 90% of the film has been scanned once, yielding 490 000 events, and about 25% of the film has been rescanned. A total of 240 000 events have been measured; of these approximately 180 000 have been measured on the Spiral Reader. All the events have been processed on the CDC 6600 computer, and the analysis is in progress.

E. π66 Experiment. Between February and August 1966, 665 000 pictures of π^- incident on deuterium in the 72-inch hydrogen bubble chamber were taken. The momenta ranged from 1.1 to 4.2 BeV/c.

F. BP66 Experiment. A 72 000-picture pp exposure was made in the Brookhaven National Laboratory 80-inch hydrogen bubble chamber in November 1966. Incident beam momenta were 13, 18, 21, 24, and 28.5 GeV/c; roughly equal amounts of film were exposed at each of the five momenta.

G. $\bar{P}$67 Experiment. The BNL 31-inch hydrogen bubble chamber was recently used to obtain 125 000 pictures of $\bar{p}p$ interactions in the range 1.5 to 1.95 BeV/c.

H. D66 Experiment. Approximately 210 000 pictures were exposed in the 72-inch deuterium-filled bubble chamber of an incident deuteron beam at about 4.5 BeV/c. To get information on the effects of proton background in the beam, about 20 000 pictures were taken with the chamber exposed to a proton beam at the same momentum, and about 3 500 pictures with a proton beam at one-half this momentum. All the film was taken in the spring of 1966.

J. P65 Experiment. An exposure of the 72-inch hydrogen bubble chamber to protons at 5.5 and 6.6 GeV/c was made in 1965.

K. LRL-SLAC Experiment. A study of the π^-p interactions between 0.5 and 1.5 BeV/c is being carried out. A quarter-million pictures have been taken at Argonne, and 350 000 more are scheduled at Argonne and Berkeley.

L. K68 Experiment. A 3 000 000-picture exposure of the 82-inch bubble chamber at SLAC to K^+, π^+, and π^- around 12 GeV/c is planned for 1968.

II. Other Experiments Supported by the AEC

A. Spark Chamber Experimental Program. In collaboration with some members of the Moyer-Helmholz Group at LRL, a series of spark-chamber experiments at the Bevatron to study various neutral final states produced in $\pi^- p$ interactions is being prepared.

B. Deuteron Missing-Mass Experiment. An experiment to measure the momentum spectrum of deuterons produced in pp interactions has been placed on the Bevatron schedule starting in January 1968.

C. Particle Yields and Secondary Beams at SLAC.

III. High-Altitude Particle Physics Experimental Facility

IV. Flux Amplifier

V. Data Reduction Operations

VI. Spiral Reader Development

VII. Programming Effort

VIII. UCRL-8030

IX. Publications and UCRL Reports

I. Bubble Chamber Experiments

A. ASSOCIATED PRODUCTION EXPERIMENT

Hyperon Production and Decay

Frank S. Crawford, Jr., and Joseph C. Doyle

Study of the reaction $\pi^- p \rightarrow \Sigma^- K^+$ at incident pion momentum of 1.17 GeV/c has been completed.[1] Study of $\pi^- p \rightarrow \Lambda^0 K^0$ at the same momentum has continued, as has study of this same reaction at momenta below 1.03 GeV/c (the threshold for Σ production).

Search for $\eta \rightarrow \pi^+\pi^-\pi^0\gamma$ and $\eta \rightarrow \pi^+\pi^-\gamma\gamma$

LeRoy R. Price and Frank S. Crawford, Jr.

We have completed our search for the decay modes $\eta \rightarrow \pi^+\pi^-\pi^0\gamma$ and $\eta \rightarrow \pi^+\pi^-\gamma\gamma$, where the η were produced in the reactions $\pi^\pm p \rightarrow \pi^\pm p\eta$ with incident pion momenta 1170 and 1030 MeV/c. We have found no events of either type. We have published[2] upper limits on these two decay modes.

Leptonic Decays of η Mesons

LeRoy R. Price and Frank S. Crawford, Jr.

We are looking for the decay modes $\eta \rightarrow e^+e^-$, $\mu^+\mu^-$, $e^+e^-e^+e^-$, $e^+e^-\mu^+\mu^-$, and $\mu^+\mu^-\mu^+\mu^-$. The η are produced in the reaction $\pi^\pm p \rightarrow \pi^\pm p\eta$ at pion momenta 1170 and 1030 MeV/c. The analysis is in the preliminary stage and no results are yet available.

Analysis of $\eta \rightarrow \pi^+\pi^-\pi^0$ and the Branching Ratio $\eta \rightarrow (3\pi^0)/(\pi^+\pi^-\pi^0)$

LeRoy R. Price and Frank S. Crawford, Jr.

We have completed an analysis of the $\eta \rightarrow \pi^+\pi^-\pi^0$ Dalitz plot, using a power series expansion. In contrast to other analyses, we find that a low branching ratio $\eta \rightarrow (3\pi^0)$ is completely consistent with the Dalitz plot if one assumes the three pions to be in only the pure T = 1 state.[3]

Radiative Pion Production

LeRoy R. Price, Ronald A. Grossman, and Frank S. Crawford, Jr.

We are continuing our study of the two-prong, four-prong, and six-prong events in πp interactions. We are now primarily using events in which the γ ray has materialized in the hydrogen, although events with kinematically determined γ rays are still being analyzed. Our analysis has also been extended to cover many more energy intervals (pion beam momentum from 900 to 1200 MeV/c).

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1. J. C. Doyle, F. S. Crawford, and J. A. Anderson, Study of $\pi^- p \rightarrow \Sigma^- K^+$ at 1170 MeV/c, UCRL-17703, July 1967.

2. L. R. Price and F. S. Crawford, Phys. Rev. Letters 18, 1207 (1967).

3. L. R. Price and F. S. Crawford, Three-Pion Decay Modes of the η Meson: Is T = 3 Necessary?, submitted to Phys. Rev.

Production of η Mesons

Ronald A. Grossman, LeRoy R. Price, and Frank S. Crawford, Jr.

A detailed study of the angular distributions and absolute cross sections for η produced via $\pi^{\pm}p \rightarrow \pi^{\pm}p\eta$ at incident pion momenta from 900 to 1200 MeV/c is being continued. The final pion-proton system is found to have a large admixture of $N^*(1238)$. In addition there is a significant amount of I = 1/2 amplitude present.

B. π63 EXPERIMENT

Strange-Particle Production in π^-p Interactions from 1.5 to 4.2 GeV/c. I. Three- and More-Body Final States

Orin I. Dahl, Janos Kirz, and Donald H. Miller

We have investigated π^-p interactions from 1.5 to 4.2 GeV/c in the Lawrence Radiation Laboratory's 72-inch hydrogen bubble chamber. This report describes the procedures for identifying and analyzing the reactions involving strange-particle production, and the results obtained on three- and more-body final states. The analysis is based on 890 000 photographs, on which 50 000 strange-particle events were found. Cross sections for the constrained final states are presented as a function of the beam momentum. The peripheral production of low-lying resonances is found to be the outstanding feature of the reactions. Dalitz plots and their projections are shown for the three-body final states. Production of $Y_0^*(1405)$, $Y_0^*(1520)$, $Y_0^*(1815)$, $Y_1^*(1385)$, $K^*(890)$, and $K^*(1440)$ is observed, as well as the $K\bar{K}$ decays of the A_2 and the ϕ meson. Cross sections and angular distributions for production and decay of these resonances are presented. The results concerning the $K^*(890)$ are compared with absorption-model predictions. Effective-mass distributions for particle pairs and triplets are given for the four-body final states. In these states the D and E meson and simultaneous Y^*K^* production are also seen. Evidence concerning the quantum numbers of the A_2, the D, the E, and the $K^*(1440)$ is discussed. The behavior of the $K\bar{K}$ system near threshold is examined. A small amount of Ξ production is observed, and the $\Xi^*(1530)$ is also seen. [Abstract from Orin I. Dahl, Lyndon M. Hardy, Richard I. Hess, Janos Kirz, and Donald H. Miller, Phys. Rev. 163, 1377 (1967).]

Strange-Particle Production in π^-p Interactions from 1.5 to 4.2 GeV/c. II. Two-Body Final States

Orin I. Dahl, Janos Kirz, and Donald H. Miller

The reaction $\pi^-p \rightarrow \Lambda K^0$, Σ^0K^0, and Σ^-K^+ in the 1.5- to 4.2-GeV/c momentum range were studied in the Lawrence Radiation Laboratory's 72-inch hydrogen bubble chamber. The total cross sections for the three reactions decrease as $E_{c.m.}^{-3.6}$, $E_{c.m.}^{-3.3}$, and $E_{c.m.}^{-9.3}$, respectively. The differential cross sections are presented at 11 beam momenta. A peripheral peak is the dominant feature of the reactions $\pi^-p \rightarrow \Lambda K^0$ and Σ^0K^0, for which K^* exchange is allowed, but no such peaking is seen in $\pi^-p \rightarrow \Sigma^-K^+$. An exponential fit to the momentum-transfer distributions in the peripheral region yields slope parameters in the 6- to 10-$(GeV/c)^{-2}$ range. The differential cross sections for $\pi^-p \rightarrow \Lambda K^0$ and Σ^-K^+ show peaking for forward production of hyperons in the c.m. system, to which baryon exchange is expected to contribute. The angular distribution of the Λ polarization in $\pi^-p \rightarrow \Lambda K^0$ is presented (in an article in Phys. Rev.). [Abstract from Orin I. Dahl, Lyndon M. Hardy, Richard I. Hess, Janos Kirz, Donald H. Miller, and Joseph A. Schwartz, Phys. Rev. 163, 1430 (1967).]

Multipion Final States from π^-p Interactions at 3.2 and 4.2 GeV/c

Orin I. Dahl, Janos Kirz, and Donald H. Miller

We have analyzed approximately 30 000 four-prong events at π^- beam momenta of 3.2 and 4.2 GeV/c, obtained with the 72-inch hydrogen bubble chamber at the Lawrence Radiation Laboratory. We present all the effective-mass distributions obtainable from the final states $p\pi^+\pi^-\pi^-$, $p\pi^+\pi^0\pi^-\pi^-$, and $n\pi^+\pi^+\pi^-\pi^-$, as well as the cross sections of these final states. In addition, we present the results of our study of the quasi-three-body final states $N^{*++}(1238)\pi^-\pi^-$, $p\pi^-\rho^0$, $p\pi^-\omega$, and $p\pi^-\eta$. We have given particular emphasis to the production and decay of the A_1, A_2, and B enhancements; the A_1 and B enhancements observed in our data are consistent with the interpretations as kinematic enhancements, although the possibility exists that what we observe at our energies is an admixture of resonant states and kinematic enhancements. On the other hand, the A_2 enhancement can be interpreted only as a genuine resonant state. From the study of the decay angular correlations in the A_2 region as well as the control regions, we have determined

that the lowest possible quantum numbers of the A_2 are $J^P = 2^+$. [Abstract from Suh Urk Chung, Orin I. Dahl, Janos Kirz, and Donald H. Miller (UCRL-16881 Rev., May 1967, Phys. Rev., Feb. 1968.]

C. K63 EXPERIMENT

Production and Decay of Cascade Hyperons

Phil Dauber

A systematic study of production and decay of Ξ^- and Ξ^0 is being undertaken using K^-p film at incident momenta 1.7 and 2.1 to 2.7 GeV/c. The sample of about 3 200 Ξ^- and 1 000 Ξ^0 represents roughly half the world supply of analyzed cascade events. All well-constrained reactions with up to four bodies in the final state are included; total cross sections for each reaction as a function of energy are being determined, as well as partial cross sections for resonant intermediate states. Differential cross sections and polarizations are being measured for Ξ^-K^+ and Ξ^0K^0 production, and a partial-wave analysis of Ξ^-K^+ will be performed in collaboration with the UCLA group (data for incident K^- momentum 1.8 to 2.0 GeV/c are on record at UCLA). A study of resonance production is in progress, including a spin-parity determination of $\Xi^*(1530)$ by means of an improved method that uses the complete decay sequence $\Xi^* \to \Xi \to \Lambda \to p$.

An analysis of the normal $\Lambda\pi^0$ decay of Ξ^0 is under way, including determination of lifetime and decay asymmetry parameters. Preliminary values of $\tau_{\Xi^-} = 1.60 \pm 0.05$ and $\tau_{\Xi^0} = 2.90^{+0.30}_{-0.20}$ have been obtained. These values agree within one standard deviation with the $\Delta I = 1/2$ prediction $\tau_{\Xi^0} = 2\tau_{\Xi^-}$. The asymmetry parameter determination should greatly improve the precision to which the Ξ^0 parameters are known, thus providing another check of the $\Delta I = 1/2$ rule. Some 1000 previously unanalyzed Ξ^- events produced at 2.0 GeV/c (UCLA film) are also being included in the asymmetry parameter determination.

A search for leptonic and $\Delta S = 2$ decay modes is also in progress. This search has yielded two unambiguous examples of $\Xi^- \to \Lambda^0 e^- \bar{\nu}$. These events will enable us to quote a better value for the rate for this mode than has been possible previously because the previous world total of 2 or 3 events was scattered among many small experiments. Probably no clear-cut examples of other unusual Ξ decays will be found, but improved upper limits can be quoted for several possible modes.

A brief letter describing measurement of the ratio ($\Xi^- \to \Lambda e^- \bar{\nu}$/all Ξ) will shortly be submitted to Physical Review Letters because of current theoretical interest in this quantity with respect to SU(3) models relating leptonic decay rates. Results of the general cascade analysis will be presented in a paper to be submitted to Physical Review. Results of the partial-wave analysis of Ξ^-K^+ and of a study of the Ξ^* production mechanism will be published separately.

Study of Reaction $K^-p \to \Sigma^\pm\pi^\mp$

Angela Barbaro-Galtieri and Phil Dauber

An analysis of charged $\Sigma\pi$ production by K^- on protons from 2.1 to 2.7 GeV/c is in progress. Total and differential cross sections as well as Σ^+ are being measured. The data will be fitted to a model including S-channel production of resonances and Regge poles in the t and u channels. The model will be extended below 2.1 GeV/c by use of data at LRL and UCLA.

The Reactions $K^-p \to \bar{K}^0 n$ and $K^-p \to \pi^0\Lambda$

Angela Barbaro-Galtieri, Stanley M. Flatté, Robert D. Tripp, and Charles G. Wohl

The process of cleaning up V zero-prong events by comparing and resolving discrepancies between two film scans and remeasuring failing events has been completed at the momenta we are concentrating on (2.1, 2.45, and 2.7 GeV/c). This cleaning up has been necessary in order to reduce systematic effects to within the good statistical error limits on cross-section determinations. Semifinal results give hope that we may be able to determine spins and parities of the higher Y^* resonances seen in the total cross section measurements by Cool et al. [Abstract from Phys. Rev. Letters 16, 1228 (1966).]

Production of Σ's in K^-p Interactions

Philippe Eberhard and Morris Pripstein

This study has led to the unambiguous determination of the spin parity of the $Y^*(1660)$ (it was found to be $3/2^-$) and some determination of the widths of $Y^*(1660)$ and $Y^*(1405)$. Two papers have been written [P. Eberhard, M. Pripstein, F. T. Shively, U. E. Kruse, and W. P. Swanson, Phys. Rev. 163, (1967), and P. Eberhard and M. Pripstein, Model for the Decay $\Sigma(1660) \to \Sigma\pi\pi$, UCRL-17682, July 1967]. A third paper is in preparation.

The measurements have been finished and we are now in the process of making a meaningful study of resonance production in the reactions $K^-p \rightarrow \Sigma + \pi + \pi$.

The Reactions $K^-p \rightarrow \Lambda\pi^+\pi^0\pi^-$ and $K^-p \rightarrow \Lambda\pi^+\pi^-$

Daniel M. Siegel and Ronald R. Ross

Experimental studies of differential production cross sections and resonance decay characteristics (angular distributions and density matrix elements) for $K^-p \rightarrow Y_1^*(1385)^+\rho^-$ and $K^-p \rightarrow Y_1^*(1385)^+\pi^-$ have been completed. Other charge states of Y^* and ρ production have also been studied. The results are being written up as a thesis and a probable publication. The results will be compared with absorption-model calculations.

The Reactions $K^-p \rightarrow p\bar{K}^0\pi^0\pi^-$ and $K^-p \rightarrow n\bar{K}^0\pi^+\pi^-$

Jerome H. Friedman and Ronald R. Ross

The reactions $K^-p \rightarrow p\bar{K}^0\pi^0\pi^-$ and $K^-p \rightarrow n\bar{K}^0\pi^+\pi^-$ have been studied in detail for incident K^- beam momentum 2.1 to 2.7 GeV/c. Cross sections for the production of the well-known resonances have been measured as a function of center-of-mass energy. The associated resonance production of $K_{1/2}^*(892)$ - $N_{3/2}^*(1238)$ has been studied, and the total cross section, differential cross section, and multiple decay correlation parameters have been measured. These measurements are currently being compared with the predictions according to the peripheral model with absorptive corrections and with those according to a Regge pole model.

The investigation of the $K\pi\pi$ enhancements in the first reaction is still in progress.

K^- Interactions in Deuterium

Angela Barbaro-Galtieri, Maxine Matison, and Alan Rittenberg

The deuterium film of path length 5 events per μb, equally divided between 2.1 and 2.64 GeV/c, has been scanned. Measurements have been made on Franckensteins and the spiral reader of 50 000 events of the following topologies: three- or four-prongs with or without a secondary decay, and one- to four-prongs with a vee. During this period special emphasis has been placed on measuring the three- and four-prong with-a-vee events; these measurements are now completed. All ambiguities have been looked at on the scanning table, and the data are now in the final analysis stage.

Search for a charged meson at 960 MeV

No evidence for this meson has been detected, and an upper limit for its production at 2.1 and 2.64 GeV/c is placed at $[K^-n \rightarrow \Lambda\delta^-, \delta^- \rightarrow N(\pi)] < 5$ microbarns. In addition, the isospin of the $\eta'(960)$, obtained from data for hydrogen decay into $\eta\pi\pi$ and $\pi\pi\gamma$, is confirmed to be zero.

Search for a T = 2 hyperon resonance

This part of the experiment is being done in collaboration with SLAC (Chadwick, Guiragossian, and Pickup). No evidence for T = 2 resonances in the $\Sigma^-\pi^-$ and $\Sigma^-\pi^-\pi^0$ final states has appeared in the present data. The reaction $K^-n \rightarrow \Sigma^-(\pi^+\pi^0\pi^-)$ suggests the presence of the H meson at 990 MeV. The enhancement in the 3π spectrum at this mass is of the order of a two-standard-deviation effect.

Search for T = 3/2 resonances in the $K\pi$ system

Here, too, the evidence for a higher-isospin state is negative. The other mass combinations in three- and four-prong states are now being studied to search for production of other resonances.

D. K65 EXPERIMENT

Study of Σ Decay Parameters

Robert D. Tripp, Frank T. Solmitz, and Roger O. Bangerter

In order to measure the decay parameters γ_+^+, γ_-^-, β_+^+, and β_-^- we have scanned and measured roughly 70% of our film for the reactions $\Sigma^\pm \rightarrow \pi^\pm n$ followed by $np \rightarrow np$. β and γ are determined by the left-right asymmetry in the n-p scattering. We have analyzed about 2000 events of the above sequence of reactions.

We have also analyzed the up-down asymmetry of about 100 000 Σ decays in order to determine the decay parameters α_+^+, α_0^+, and α_-^-.

Σ Interactions and Decays

Lawrence K. Gershwin

Σ^- Leptonic decay

From the measurement of about 50 000 Σ^-

decays, 39 have been found that are $\Sigma^- \to ne^-\bar{\nu}$. From the correlation of the direction of the electron with respect to the polarization of the Σ^-, one can determine the relative values of the axial and vector coupling constants. This has an important bearing on the validity of the Cabibbo hypothesis. We expect another 10 events from current and future measurements.

Σ^- capture in hydrogen

When Σ^- comes to rest in hydrogen, the reaction $\Sigma^- p \to \Sigma^0 n$ or $\Sigma^- p \to \Lambda n$ occurs. One can investigate the form of the matrix element for $\Sigma^- p \to \Lambda n$ by investigating the correlation of the Λ polarization with respect to the Σ^- polarization. About 700 such events have been analyzed; another 300 are expected.

Σ^- and Σ^+ interactions

We can study $\Sigma^- p$ and $\Sigma^+ p$ interactions from 100 to 600 MeV/c incident Σ momentum. Because of the scarcity of events, probably only cross sections can be obtained. About 150 $\Sigma^- p \to \Sigma^0 n$ and $\Sigma^- p \to \Lambda n$ have been analyzed; another 50 are expected. $\Sigma^- p \to \Sigma^- p$ and $\Sigma^+ p \to \Sigma^+ p$ have not yet been measured; about 100 of each are present in our film.

Σ^- and Σ^+ radiative decays

By studying the branching ratios of $\Sigma^\pm \to n\pi^\pm\gamma$ one can obtain information on the "which-is-which" question of S- and P-wave decays of $\Sigma^\pm \to n\pi^\pm$. We have about 60 $\Sigma^- \to n\pi^-\gamma$ events already measured; another 20 are expected. About 20 $\Sigma^+ \to n\pi^+\gamma$ have been measured; another 20 are expected.

$\Sigma^+ \to p\gamma$

About 30 events $\Sigma^+ \to p\gamma$ have been found. Another 20 are expected. One can examine the decay asymmetry of the proton and hence get some information on the form of the interaction. Also, the rate itself is of interest.

Σ^+ Magnetic Moment

Terry S. Mast and Lawrence K. Gershwin

From an analysis of 13 500 decays of the type $\Sigma^+ \to p\pi^0$ we have made a preliminary determination of the Σ^+ magnetic moment of $\mu_\Sigma = 2.35 \pm 1.00$. More events are being measured, and a final value will be published shortly.

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

Robert D. Tripp and Terry S. Mast

After measurement of most of the events of this type and a remeasurement of many events with unsatisfactory fits, we have a sample of 7000 events. The events have been weighted to correct for scanning biases and escape loss, and analysis of the amplitudes contributing to this reaction has begun.

Twenty-four thousand Λ-missing-mass events have been measured and weights for scanning bias and escape loss have been determined. The polarization and angular distributions of the $\Lambda\pi^0$ part and those of the $\Sigma^0\pi^0$ part have been determined. The $\Lambda\pi^0$ channel is of particular interest, since it is a pure I = 1 state.

Study of the Neutral K Meson

Margaret Alston-Garnjost, Frank S. Crawford, Jr., and Bryan R. Webber

A study of the time distribution of 281 leptonic neutral K decays is nearing completion. This will provide information on the validity of the ΔS and ΔQ rule and CP conservation in these processes. In 170 of the events, the charge of the lepton has been identified. At least 100 more events should be available from film that remains to be measured.

The time distribution of 55 three-pion events is also being studied for signs of CP nonconservation.

Charge-Exchange ($K^- p \to \bar{K}^0 N$) and Elastic ($K^- p \to K^- p$) Reactions

Angela Barbaro-Galtieri, Terry S. Mast, Robert D. Tripp, and Alain Verglas

The momentum range of the incident K^- has been extended up to 430 MeV/c.

1. About 17 000 charge-exchange events have been measured with the spiral reader and processed through the programs SIOUX-ARROW.

The production angular distribution has been analyzed in terms of Legendre polynomial coefficients (A_ℓ/A_0). An accurate measurement of the cross section ($\approx A_0$ term) will

be available after remeasurement of the failing events.

In order to solve the remaining ambiguities resulting from the study of the differential cross section alone, the polarization of the outgoing neutron has to be measured. Half of the total sample has been scanned for the recoiling protons of the reaction np → np.

Some events have been processed in order to check the behavior of the different programs involved.

2. The elastic events are necessary in order to compute the amplitudes of the two isospin channels.

Five thousand events of this type have been measured and processed. Their analysis is progressing.

E. π66 EXPERIMENT

π^+d Interactions from 2.8 to 4.2 GeV/c

Maris A. Abolins, Orin I. Dahl, Jerome S. Danburg, Paul L. Hoch, Janos Kirz, and Donald H. Miller

More than 21 000 events involving a visible Λ^0 or K_1^0 decay produced by π^+ in the range 2.8 to 4.2 GeV/c colliding with deuterons have been measured and processed through the Alvarez group programs. Ionization selection criteria have been used to determine correct hypotheses. For the events measured on the spiral reader this information was obtained directly from pulse heights; the Franckenstein-measured events were each individually inspected by trained technicians and physicists.

Attention is presently being turned on events with ΛK^0 or ΣK^0 pairs with or without additional pions in order to study possible final-state interactions in these systems.

π^+d Interactions from 1.1 to 2.3 GeV/c

Maris A. Abolins, Don Davies, Orin I. Dahl, Janos Kirz, Donald H. Miller, and Robert K. Rader

The motivation for the 1.1- to 2.3-GeV/c experiment was the desire to study the production and decay of the I = 0 mesons η, ω, η', and ϕ as a function of momentum near threshold; thus the major measuring effort has been directed at events that presumably involve π^+ neutron interactions, with the proton acting as a "spectator." To this end we have measured ≈50 000 four-prong events, 1300 five- and six-prong events, and ≈1500 events with neutrally decaying strange particles. A preliminary report on the production cross section and angular distribution of isoscalar mesons with mass < 1 GeV has been prepared, and was delivered (by Janos Kirz) at the Heidelberg Conference on Elementary Particles. A more comprehensive publication is being prepared.

F. BP66 EXPERIMENT

Jared A. Anderson, Orin I. Dahl, Jerome H. Friedman, Janos Kirz, Dennis B. Smith, Lawrence H. Smith, Robert J. Sprafka, and Michael Wahlig

First and second scans for all topologies (except two-prongs, which we are ignoring) are completed. A third of our film was scanned for a beam track count: six rolls of this portion of the film remain to have the conflicts resolved.

Measuring has been concentrated on four-prongs. From the preliminary scan of approximately one-third of the film we expect 30 000 four-prongs (6000 at each momentum). Of these, roughly 21 000 have been measured (4000 on SR I and SR II; the remainder on MP II B and MP II D). Using production SIOUX (adapted and updated for the BNL 80-inch bubble chamber), we have 16 000 of the four-prong events on data summary tapes.

Work in progress or about to be done:
(i) From the event scan and beam track count, we expect to soon have a survey of cross sections of n-prong topologies at our five incident momenta.
(ii) We are using our data summary tapes to determine our ability to successfully fit four-prongs (by looking at χ^2 and missing-mass distributions corresponding to fits). Then we expect to analyze our data for fitted cross sections and experimentally test production models (e.g., multiperipheral models).

G. $\bar{P}$67 EXPERIMENT

Maris A. Abolins, Alan Rittenberg, and Gerald A. Smith

At present ≈50 000 pictures have been fully scanned, and preparations are being made to begin measurements on the spiral reader. Initial analysis will be directed at the study of

resonance production in the s channel with subsequent pionic decay modes. This will be done by investigating the total and differential $\bar{p}p$ cross-sectional dependence on the incident momentum.

H. D66 EXPERIMENT

Philippe Eberhard, Gerald R. Lynch, Morris Pripstein, and Phil Dauber

The scanning of all the film has been completed. The events are being measured on the spiral reader and the measurement data then processed on the CDC 6600 by use of the new set of Alvarez group programs (TVGP, SQUAW, ARROW). We have virtually completed a first-measurement pass on a sample of about 146 000 events, of which about 90 000 have been measured in the last 6 months. We are in the midst of an intensive analysis of the results of these measurements. The analysis is complicated by the presence of biases which are inherent in a study of dd interactions in a bubble chamber. We have made substantial progress in analyzing these unique biases and isolating their effects, and we will soon be reporting results on some dd interactions.

J. P65 EXPERIMENT

P65 Strange Particles

A. Barry Wicklund and Gerald A. Smith

We have analyzed 8000 strange-particle production events in pp collisions (5.5 and 6.6 GeV). A short letter on $pp \rightarrow \Lambda p K^+$ is being expanded into a comprehensive report on all reactions $pp \rightarrow YNK$.

Although the one-pion-exchange model gives a good description of these reactions, we have isolated asymmetries in the Treiman-Yang distributions and have developed a general procedure for using these asymmetries to detect non-OPE features in the data, such as alternative exchange mechanisms and multi-Regge behavior.

We have also measured the cross sections for $pp \rightarrow Y^*NK$, $N^*K\Lambda$, and $K^*N\Lambda$, taking account of the manifestly peripheral nature of the background. The principal conclusion is that the $I = 1/2$ and $I = 3/2$ amplitudes for Y^*K production are both nearly equal, and have the same dependence on the Y^*K invariant mass.

P65 Nonstrange Particles

Eugene Gellert and Gerald A. Smith

At a momentum of 6.6 GeV/c, we have measured 32 000 two-prongs (using the spiral reader), 61 000 four-prongs, and several thousand six-prongs. Although this is only a fraction of the events on our film, no more measurements are planned at this time.

The fitting of the four-prong events is essentially complete. We have fitted about 9000 reactions $pp \rightarrow pp\pi^+\pi^-$ with less than a 5% contamination, 8100 reactions $pp \rightarrow pp\pi^+\pi^-\pi^0$, and 10 000 reactions $pp \rightarrow pn\pi^+\pi^+\pi^-$ with a contamination of about 10% each, after ionization. The other reactions have been difficult to fit uniquely. A second scan has also been completed so that more accurate cross sections should be available in about two weeks.

We have continued our study of the events $pp \rightarrow p\pi^-\Delta^{++}(1238)\Delta^{++} \rightarrow p\pi^+$. A plot of a special function of one of the Treiman-Yang angles shows that the 1400-MeV phenomenon in the $\Delta^{++}\pi^-$ channel is more likely to be a resonance than simple pion exchange. (This function was suggested by A. B. Wicklund, who also used it in his strange-particle analysis.) Therefore, in collaboration with Edmond L. Berger (of Dartmouth College), we are calculating this distribution, as well as the mass and other angular distributions, from a model based on the exchange of Regge poles rather than simple pion exchange. Ed Berger is to present this work at the Chicago APS meeting in January 1968.

An enhancement in the masses $p\pi^+\pi^+\pi^-$ of the reaction $pp \rightarrow pn\pi^+\pi^+\pi^-$, first seen by Chinowsky et al., is confirmed.

The two-prong events should be fitted in the next month, and we will then examine the various πN mass combinations for the 1400-MeV phenomenon.

K. LRL-SLAC EXPERIMENT ON π^-p INELASTIC REACTIONS

LeRoy R. Price, Arthur H. Rosenfeld, and Paul Söding

The number of events measured on existing 72-inch film was 20 000. We ran at ANL, taking 250 000 pictures in the Mura 30-inch hydrogen bubble chamber at π^- beam momenta between 660 and 1470 MeV/c. This run yielded 70 000 two-prong events, all of which have been measured.

Preliminary results were presented by A. D. Brody (SLAC) at the Boulder 1967 Summer School.

L. K68 EXPERIMENT

Stanley M. Flatté, Margaret Alston-Garnjost, Gerald R. Lynch, Monroe Rabin, and Frank T. Solmitz

A beam has been constructed at SLAC under the direction of Stanley Flatté (LRL), Paul Klein (SLAC), and Joseph Murray (SLAC). It is now capable of providing $\pi^{\pm}$ mesons between 5 and 14 GeV/c, and when the rf separator is added in January 1968, it will provide between 5 and 10 K^+ mesons per pulse at 12 GeV/c. A counter-control system will assure beam purities above 99%, and a momentum resolution of ± 0.25%.

The 82-inch bubble chamber will be ready to take pictures by January 1968, and preparations are now being made for the exposure and analysis over the next year of 3 000 000 pictures (1 000 000 each of π^+, π^-, and K^+ around 12 GeV/c).

II. Other Experiments Supported by the AEC

A. SPARK CHAMBER EXPERIMENTAL PROGRAM

Neutral Decay Modes of the η Meson*

Orin I. Dahl, Morris Pripstein, and Michael Wahlig

We plan to measure the branching ratios of the various neutral decay modes of the η meson in a study of the reaction $\pi^- p \rightarrow n\eta$ just above threshold, where the cross section for this reaction is maximum. The reaction will be identified by detecting all the final-state particles. The detection equipment will consist of a set of very large spark chambers to detect γ rays and a set of neutron counters to measure the neutron time of flight from the liquid hydrogen target. The 20 neutron counters will be mounted in a ring at a polar lab angle of about 20 deg. The spark chambers are between seven and eight radiation lengths thick, and form five of the six faces of a cube with the target at the center so that the solid angle, for detection of γ rays from the decay of the η meson, is large.

The spark chamber pictures will be scanned and measured by the SASS device developed at LRL.

According to the present Bevatron schedule, the setup of the equipment at the accelerator is to begin in January and the experiment to start 2 months later.

Neutral Diboson Experiment*

Orin I. Dahl, Morris Pripstein, and Michael Wahlig

With the same personnel and much of the same equipment as in the preceding experiment, we are also preparing for an experiment at the Bevatron to study the reaction $\pi^- p \rightarrow n\pi^0\pi^0$ between 1.5 and 2.5 GeV/c. A completely different beam from the one used in the η experiment has been designed. The principal purpose of the experiment is to analyze the $\pi^0\pi^0$ system in a search for scalar mesons and to measure the π-π phase shifts.

We now expect to run this experiment at the Bevatron immediately after the η experiment is finished. Twenty-five periods of Bevatron time have been allotted for tune-up and forty periods for data-taking. In this running time we expect to collect about 8 000 events of the desired type to study the peripheral production of the diboson $\pi^0\pi^0$ system.

B. DEUTERON MISSING-MASS EXPERIMENT

Maris A. Abolins, Gerald S. Smith, and Lawrence H. Smith

We hope to measure the mesonic spectrum recoiling against the deuteron from 0 to ≈1.8 GeV. This will be done at a variety of incident proton momenta. Our intention is also to study the $pp \rightarrow d\pi$ cross section as a function of incident momentum.

The detection apparatus--which consists of scintillators, wire spark chambers with magnetostrictive readout, and a Cerenkov counter--has been fabricated. A PDP-5 computer interfaced to the detection system has been built and is undergoing final tests.

*Collaborative experiment with the Moyer-Helmholz Physics Group.

C. PARTICLE YIELDS AND SECONDARY BEAMS AT SLAC

Stanley M. Flatté

Particle yields at SLAC have been analyzed by a LRL-Purdue-Stanford-SLAC collaboration, from data gathered in November and December of 1966, culminating in a paper (Stanley M. Flatté, Joseph J. Murray, Paul R. Klein, Lawrence H. Johnston, and Stanley G. Wojcicki, Particle Yields at SLAC and the Photon-Nucleus Interaction in the 5-18-GeV Region, UCRL-17687, July 1967), to be published in Physical Review.

A beam has been built at SLAC which will provide $\pi^{\pm}$ between 5 and 14 GeV/c and K^{+} at 12 GeV/c to the 82-inch hydrogen bubble chamber. The beam has been tested and will provide particles with contamination below the 1% level, thanks to a counter system that will be used to trigger the bubble-chamber camera.

III. High Altitude Particle Physics Experimental Facility

Luis W. Alvarez, Philip M. Dauber, Lester J. Lloyd, Lawrence H. Smith,* and Michael A. Wahlig

This program, led by L. W. Alvarez, is funded by NASA, through a contract with the Space Sciences Laboratory of the University of California. The above-named LRL and SSL staff members are contributing to the project, together with a group of physicists at the NASA Manned Spacecraft Center at Houston. Because this program is currently benefiting from the availability of LRL facilities and working space, the following account is presented here.

The present objective of the program is to develop a balloon-borne momentum-analysis system to measure the spectra of cosmic ray particles; the high energy protons ($\gtrsim$100 GeV) will subsequently be used in the study of high energy interactions. Presently work is continuing on the development of both the momentum-analysis system and the flight capability of the balloon-borne gondola.

The momentum analysis system employs spark chambers and emulsions to determine the incident and exit trajectories of particles passing through the field of a superconducting magnet. This magnet, which is one of the world's largest, with an integrated field strength of 12 kilogauss-meters and a 40-in.-diameter open center bore, has been designed and wound at LRL's Livermore Site and is being assembled for testing. The large emulsion plates, with emulsions 200 microns thick poured on both sides of 35-in.-diameter pieces of Herculite glass, are being provided by Eastman Kodak. Several test emulsion plates have already been provided by their Rochester research laboratory, and the results are very encouraging. The feasibility of the technique of using spark chambers to locate near-vertical tracks in emulsions has been proven by a series of test runs. Even with the poor resolution in these tests, tracks in the emulsions were found in their predicted locations in $\approx$ 75% of the cases. A massive granite stage is under construction, to be used for rapid high-precision measurement of the large emulsion plates. Laser interferometers having an accuracy better than 1μ over 20 in. have been mounted on the axes; the modified-microscope optical system is being designed and assembled, and interface electronics for computer control are under construction.

A new type of balloon-launch system, necessary because of the weight and size of the experimental gondola (8500 lb and 50 ft tall), was developed and tested in April. A full-sized test flight was then made in August from Chico, California, for engineering and operational purposes. Included in this flight, for check-out, were a large Cerenkov counter (20 ft high, 8 ft in diameter, using Freon gas), some scintillation counters, and a spark chamber, but only a dummy magnet. This flight was only partially successful. The engineering data and counting rates, including pulse-height analysis on one of the scintillators, were successfully telemetered. However, during the parachute descent a coupling between the gondola and parachutes evidently failed; the gondola free-fell into the ocean and was not recovered. The descent system is currently being redesigned, and further tests are planned.

IV. Flux Amplifier

Philippe Eberhard

The construction of the flux amplifier has been continued. Mechanical switches with superconducting properties have been realized. The sensitivity of the apparatus achieved so far corresponds to the detection of energies of the order of 10^{-15} joule.

*Space Sciences Laboratory, University of California, Berkeley.

V. Data-Reduction Operations

Personnel

The assembled effort figures for this period, given in FTE's, are as follows

	Effort	
	Gross	Net
May	87.1	77.5
June	87.7	78.8
July	94.9	81.4
August	82.7	72.1
September	80.0	64.6
October	75.6	67.6
Average	84.7	73.7

The difference between average gross effort and average net effort (i.e., sick leave, vacation, holidays, etc.) amounted to 13.0%. This compares with 11.7% for the last report period.

Our average net effort showed a decrease of 2.7% below last report period. The effort will be allowed to continue to decrease until we are able to arrive at our prescribed fiscal level.

Scanning

General Summary

The bulk of scanning effort during the period covered by this report was devoted to finishing our two largest experiments, K63/D66 and π66. Consequently, the scanning output of these two experiments is comprised mainly of ambiguities, conflicts, cross-section scans, and other special scans. The other three experiments, K65, P65/$\bar{P}$67, and APE, carried on normal first and second scanning as well as lesser amounts of special scanning. First and second production scanning will resume their former pace as soon as film is received from the first experiment in the 82-inch bubble chamber at SLAC.

APE

The Associated Production Experiment received 18.1% of the group's scanning and measuring effort. Their scanning was apportioned among first, second, and special scans as follows:

	Number of rolls	
First scan		
π^- Film: Four- and six-prongs and γ-conversion events	187	
π^+ Film: Four- and six-prongs and γ-conversion events	227	
Subtotal		414
Second scan		
π^- Film: Four- and six-prongs and γ-conversion events	28	
π^+ Film: Four- and six-prongs and γ-conversion events	15	
Subtotal		43
Special scans		
Conflicts, all film	43	
Gamma-conversion source scans	445	
Training scans	42	
Subtotal		530
Total rolls scanned by APE's		987

K63/D66

The K63/D66 effort has decreased sharply; the combined experiments received 23.2% of the total scanning and measuring effort. The experiments are coming to a close, with only miscellaneous special scans left to be done and a few events remaining to be measured. Production information for May 1 through October 31:

	Number of rolls	
Second scan		
Experiment 12: All event types	435	
Tau scan (three-prongs)	186	
Experiment 14: Tau scan (three-prongs)	40	
Subtotal		661
Special scans		
Experiment 14: Cross-section scan	5	
Total rolls scanned by K63/D66		666

π66

The π66 effort began to taper off in September and October, giving the experiment 26.7% of the group's scanning and measuring effort. Special scanning dominates the scanning output, since all three of the constituent experiments are being wrapped up at this time.

	Number of rolls	
First scan		
Experiment 18: All π^- vee'd events	18	
Experiment 25: All vee'd events	38	
Experiment 26: All except two-prongs	58	
Subtotal		114
Second scan		
Experiment 18: All π^- vee'd events	25	
All π^+ vee'd events	50	
Experiment 25: All vee'd events	331	
Experiment 26: All events except two-prongs	62	
All event types	20	
Subtotal		488
Special scans		
Experiment 18: Cross section	14	
Conflict	180	
First measurement ambiguities	520	
Second measurement ambiguities	205	
Operator-rejected events	545	
Twice-failing events	40	
"20010"-failing events	545	
Experiment 25: One-, two-prongs	9	
Conflict scan (vee'd events only)	247	
Ambiguities	75	
Operator rejects	361	
Experiment 26: Cross-section scan (second scan)	20	
Conflict cross section	30	
Conflict (all except two-prongs)	74	
Subtotal		2865
Total rolls scanned by π66		3467

P65/$\overline{P}$67

The P65/$\overline{P}$67 combined experiment received 14.1% of the group's scanning and measuring effort. Scanning effort was applied mainly to the completion of P65 and the first scan of the $\overline{P}$67 Brightfield film from the 30-inch BNL chamber. Though the number of rolls scanned for $\overline{P}$67 is small, each roll is equivalent to approximately three rolls of 72-inch bubble chamber film in terms of the number of exposures.

	Number of rolls	
First scan		
Experiment 17: Two-prongs	34	
Experiment 28: All primary event types	29	
Subtotal		63
Second scan		
Experiment 17: Two-prongs	20	
Four-prongs	9	
Four- and six-prongs	25	
Subtotal		54
Special scans		
Experiment 17: Conflict (two-prongs)	20	
Conflict (four- and six-prongs)	33	
Ionization scan (four- and six-prongs)	295	
Subtotal		348
Total rolls scanned by P65/$\overline{P}$67		465

K65

K65 received 17.9% of the group's scanning and measuring effort. Routine scanning constituted the majority of the output for K65. The film used is from the LRL 25-inch bubble chamber, and each roll is equivalent to about two rolls of 72-inch bubble chamber film in terms of number of exposures.

	Number of rolls	
First scan		
All event types	27	
All event types (except two-prongs)	77	
Subtotal		104
Second scan		
All event types	7	
All event types (except two-prongs)	49	

	Subtotal		56
Special scans			
Conflict scan		150	
	Subtotal		150
Total rolls scanned by K65			310

Measuring

With both spiral readers operational, the total number of events measured in this period is 24.9% higher than the number measured during the preceding semiannual report period. MP II's B, C, and D were used far more intensively than they have previously been, but MP II A's utilization suffered due to lack of events to be measured. Spiral Reader II became operational early in June, so its full effect is not evidenced in this report period; likewise, the effect of Spiral Reader I is somewhat lessened, since it was disassembled for approximately one month while being moved to Building 50B. Consequently, our extrapolated annual rate is somewhat lower than expected. However, barring further periods of extended down time for the spiral readers, we should achieve the one-million-event-per-year milestone during the current fiscal year.

Machine	Events	Measuring hours
II A	14 478	1 563
II B	30 497	3 511
II C	31 056	3 395
II D	32 159	3 841
All MP II's	108 190	12 310
SR I	204 228	2 609
SR II	153 060	2 216
Both SR's	357 288	4 825
Total	465 478	17 135

The vertex-oriented nature of the spiral readers dictates the necessity of adding the number of vertices measured:

Machine	Vertices measured
SR I	255 085
SR II	172 850
Total	427 935

VI. Spiral Reader Development

Lester J. Lloyd, Norman R. Andersen, Frank D. Neu, Bud Antuna, James H. Burkhard, Gerald R. Lynch, Frank T. Solmitz, and Joseph E. Strople

Spiral Reader I was disassembled, moved to Building 50B, reassembled, and put back into operation. The three-reel film drive system was put into operation; it worked fairly well. Some further development was carried out to make it advance film more rapidly and stop more reliably.

Development of Spiral Reader II was completed at the beginning of this 6-month period. An improved and simplified magnetic tape channel was designed and built. A preliminary test of the "large-radius scan" (scanning a 4-in.-diameter area on the film, instead of the current 2-in.) was made.

VII. Programming Effort

The computer programs described in this report involve the programming efforts of the following persons:

Robert J. Harvey
(Supervisor of the Alvarez Programming Group)

G. T. Armstrong	M. S. Hutchinson
J. N. Baldridge	D. L. Iverson
J. P. Berge	W. O. Koellner
J. H. Burkhard	M. Leavitt
R. E. Carlson	A. J. Lee
R. W. Casey	M. I. Nelsen
B. J. Cottrell	E. A. Romascan
O. I. Dahl	N. K. Ruiz
C. T. Draper	T. R. Tonisson
N. L. Gould	J. J. Wilson

Introduction

From April through October 1967 the Alvarez Programming Group has been primarily concerned with the generalization and modification of existing programs to use the CDC 6600 computer as efficiently as possible. We have maintained close contact with the Mathematics and Computing Group and have assisted in the evaluation of new systems.

Most of the effort of the group is directed towards maintenance and development of bubble chamber data processing. However, in the past 6 months work has begun on two spark chamber experiments, and work has continued on the analysis of data from the high-altitude particle physics experiment (HAPPE).

General Information

Alvarez Group programs may be divided roughly into the following six general classifications:

1. Data-Editing Programs, designed to prepare (i.e. select, order, sort, etc.) data from various measuring devices for processing through the physics programs.

2. Data-Analysis Programs, designed to analyze (e.g. reconstruct, fit, plot, etc.) data for purposes of extracting their scientific content.

3. Library-Function Programs, designed to serialize, manipulate, and keep track of data for reference purposes.

4. Support Programs, routines which perform miscellaneous functions in support of the programs in the above categories.

5. Spiral Reader Programs, codes associated with the control, operation, and support of the spiral reader. (See also Alvarez Data Reduction Development.)

6. Non-Bubble-Chamber Applications, programs associated with spark chamber and high altitude particle physics experiments (HAPPE).

The following annotations summarize the work of the Alvarez Group Programming Staff in each of the above areas for May through October 1967:

1. Data-Editing Programs

MATCH is a program to match corresponding track images from three stereo views of a bubble chamber interaction, and is being generalized to handle all topologies of events. This program is essential to processing high-multiplicity events at high energies.

PANAL orders and sorts events via experiment, roll, frame, and beam track. Modifications were made to the 7044/94 PANAL versions. The CDC 6600 version is being completed.

MRGSEL is used to extract or merge subsets of events from output tapes produced by any of the various analysis programs. It has been modified to increase its speed of operation, and is currently being tested under the SCOPE system.

2. Data-Analysis Programs

SOUCI is the 6600 combined three-view geometry and kinematic fitting program. An addition has been made whereby a different set of track parameters is used to define stopping, neutral, and two-point charged nonstopping tracks. Documentation of this program, which is being used by several laboratories, is nearing completion.

ARROW is the CDC 6600 program for processing SOUCI output. It has been speeded up and core size has been reduced.

3. Library Function Programs

LYRIC III is the CDC 6600 version of the main library program. Development of new features for LYRIC has been tabled pending installation of the IBM mass-store system. However, routine maintenance and user assistance have continued.

4. Support Programs

ALAC is the Alvarez Group computer time-accounting program. Portions of it have been rewritten to operate more efficiently.

ASEM is a program to assemble programs on the CDC 6600 for the PDP-4 computer.

IORTN is the generalized input-output package used by most production programs; has been written to increase both speed and efficiency.

MAXIME is a new function-maximizing routine that has been begun.

5. Spiral Reader Programs

ACORN is the PDP-4 control program for the spiral readers. Program development includes the modifications necessary to handle several types of film format, different chambers, and new devices. Program development on ACORN has been halted.

OAK will be the successor to ACORN as the control program for the spiral reader. Its benefits will include faster operation through parallel processing and the ability to handle larger amounts of data.

POOH is the filtering and pattern-recognition CDC 6600 program for the spiral reader. The major modifications have been the gener-

alization of the program to accept data from both spiral readers currently in operation and the inclusion of spiral reader constants as parameters.

6. Non-Bubble-Chamber Applications

SPARK CHAMBERS. A PDP-5 program is being connected to an experiment using magnetostrictive-readout wire chambers. The computer will monitor the data and provide real-time calculations to enable the experimenter to determine the progress of the experiment. In another spark chamber experiment, the data from the photographs will be scanned automatically by use of a modified version of the SASS system (Donald H. Zurlinden, Computer-Controlled Data Reduction of Spark Chamber Film, UCRL-17695, Aug. 1967).

HAPPE--high-altitude particle physics experiment. Programming support for the HAPPE project has continued for the past 6 months. The major effort has been a spark chamber optical calibration program. The real-time program to handle telemetered data from the experiment worked successfully.

VIII. UCRL-8030: Data on Particles and Resonant States

Arthur H. Rosenfeld,
Angela Barbaro-Galtieri,
Naomi Barash-Schmidt, LeRoy Price,
and Paul Söding

A summer edition was produced just before the Heidelberg Conference. A total of 2000 copies of the report and 6000 copies of the wallet sets was distributed. (Half were printed at CERN, half at LRL.)

IX. Publications and Reports

1. R. O. Bangerter, M. Alston-Garnjost, A. Barbaro-Galtieri, L. K. Gershwin, T. S. Mast, F. T. Solmitz, M. L. Stevenson, R. D. Tripp, A. J. Verglas, and B. R. Webber, Decay Parameters for $\Sigma^{\pm} \rightarrow n\pi^{\pm}$, UCRL-17781, Aug. 1967.
2. S. U. Chung, O. I. Dahl, J. Kirz, and D. H. Miller, Multipion Final States from $\pi^- p$ Interactions at 3.2 and 4.2 GeV/c, UCRL-16881 Rev., May 1967.
3. J. C. Doyle, F. S. Crawford, and J. A. Anderson, Study of $\pi^- p \rightarrow \Sigma^- K^+$ at 1170 MeV/c, UCRL-17703, July 1967.
4. P. Eberhard, M. Pripstein, F. T. Shively, U. E. Kruse, and W. P. Swanson, A Determination of the Spin and Parity of the $Y^*(1660)$ (UCRL-17590 Rev., June 1967), Phys. Rev. 163, 1446 (1967).
5. P. Eberhard and M. Pripstein, Model for the Decay $\Sigma(1660) \rightarrow \Sigma\pi\pi$, UCRL-17682, July 1967.
6. S. M. Flatté, Search for $\eta \rightarrow \pi^+\pi^-\pi^0\gamma$, Phys. Rev. Letters 18, 976 (1967).
7. S. M. Flatté, J. J. Murray, P. R. Klein, L. H. Johnston, and S. G. Wojcicki, Particle Yields at SLAC and the Photon-Nucleus Interaction in the 5-18-GeV/c Region (UCRL-17687, July 1967), Phys. Rev. (to be published).
8. A. Barbaro-Galtieri, M. Matison, and A. Rittenberg, Search for a Charged Meson in the Mass Region of 960 MeV, UCRL-17914, Nov. 1967.
9. L. K. Gershwin, M. Alston-Garnjost, R. O. Bangerter, A. Barbaro-Galtieri, T. S. Mast, J. J. Murray, F. T. Solmitz, M. L. Stevenson, R. D. Tripp, A. J. Verglas, and B. R. Webber, Measurement of the Electron-Asymmetry Parameter of $\Sigma^- \rightarrow n + e^- + \bar{\nu}$, UCRL-17740, Aug. 1967.
10. T. S. Mast, M. Alston-Garnjost, R. O. Bangerter, A. Barbaro-Galtieri, L. K. Gershwin, J. J. Murray, F. T. Solmitz, M. L. Stevenson, R. D. Tripp, A. J. Verglas, and B. R. Webber, Measurement of the Σ^+ Magnetic Moment, UCRL-17746, Aug. 1967.
11. L. R. Price and F. S. Crawford, Jr., Search for Decay Modes of $\eta \rightarrow \pi^+\pi^-\pi^0\gamma$ and $\eta \rightarrow \pi^+\pi^-\gamma\gamma$, Phys. Rev. Letters 18, 1207 (1967).
12. L. R. Price and F. S. Crawford, Jr., Three-Pion Decay Modes of the η Meson: Is T = 3 Necessary? UCRL-17629, June 1967.

NUCLEAR EMULSION GROUP

Harry H. Heckman in charge

TRAPPED PROTONS AT LOW SATELLITE ALTITUDES

Harry H. Heckman

Analysis and interpretation of data pertaining to energetic geomagnetically trapped protons collected during the recent period of solar minimum has been our principal effort this report period. We have examined how our data are systematically affected by errors in geomagnetic field models, atmospheric density profiles, and background estimates. We find that, quantitatively, the final results have various degrees of sensitivity to these sources of errors. The overall interpretation of the data, as outlined in our previous report, is not altered, however.

Scanning and measuring of six emulsion packages recovered between 8/66 and 6/67 after 4 to 7 days in polar orbit are nearing completion. Although the results from these experiments are preliminary, it appears that we have observed the first evidence for intensity changes in the inner-belt protons, most probably due to solar-cycle changes in the atmosphere.

B-L SPACE AND GEOMAGNETIC FIELD MODELS

Peter J. Lindstrom (Space Sciences Laboratory) and Harry H. Heckman

This work has been completed and submitted for publication. Three field models were selected for intercomparison in B-L space, $0.20 \leq B \leq 0.24$ gauss and $1.2 \leq L \leq 1.8$ R_e (earth radii), because of their general usage in the analysis of trapped radiation data: Jensen and Whitaker (512 coefficient); Jensen and Cain (48 coefficient); GSFC (9/65)(99 coefficient). These models were compared with the GSFC (12/66) field model (121 coefficient). The geographic coordinates of constant B-L trajectories were computed by using the GSFC (12/66) field in both the southern and northern hemispheres. At each geographical point along the trajectories thus defined, B and L values were recalculated by using different geomagnetic field models. We find that variations in B-L space of the 48- and 512-coefficient models with respect to the 121-coefficient model are great enough to cause significant ambiguities in flux contours of the trapped radiation. We also have examined the effects of temporal variations of the geomagnetic field on B-L space. The uncertainties in the proton flux contours in B-L space caused by errors in the field models and time variations of the geomagnetic field demonstrate the need for careful reevaluation of existing data that pertain to possible time variations of inner-belt protons.

STOPPING-POWER DIFFERENCES OF $\pi^{\pm}$ MESONS

Harry H. Heckman

Scanning on this experiment continues, and is approximately 50% complete. The ratio of grain densities of π^- and π^+ mesons gives evidence for $dE/dx(\pi^-) < dE/dx(\pi^+)$ for ranges less than 30 μ. The effect is small, and is statistically significant at this time for ranges < 10 μ only, where $g_{\pi^-}/g_{\pi^+} \approx 0.95$.

HIGH-ENERGY NEUTRON SPECTRUM MEASUREMENTS

Harry H. Heckman and H. Wade Patterson

Description of this work appears under the report by the Health Physics Group.

PUBLICATIONS AND PAPERS

H. H. Heckman, Note on the Magnetic-Moment Adiabatic Invariant for Particle Motion in a Dipole Magnetic Field, J. Geophys. Res. 72, 4016 (1967).

P. J. Lindstrom and H. H. Heckman, B-L Space and Geomagnetic Field Models, UCRL-17492, Sept. 1967.

EXPERIMENTAL PHYSICS

Edward J. Lofgren in charge

NUCLEON ISOBAR PRODUCTION IN PROTON-PROTON COLLISIONS FROM 3 TO 7 GeV/c

Charles M. Ankenbrandt, Alan R. Clark, Bruce Cork, Tom Elioff, Leroy T. Kerth, and W. A. Wenzel

The experiment is concerned with isobar production at high momentum transfer, and it therefore can provide a test of the statistical model of nuclear interactions. The analysis of the data is now complete, and a paper is being prepared that will be submitted to the Physical Review in the very near future.

DIBOSON PRODUCTION BY 2- TO 5-GeV/c PIONS

Alan R. Clark, Bruce Cork, Tom Elioff, Leroy T. Kerth, T. N. Rangaswamy, and W. A. Wenzel

The automatic system SASS has performed successfully, and $\approx 3 \times 10^6$ frames have now been scanned and measured. Programs for the reconstruction and analysis of the data are nearly complete.

MEASUREMENT OF THE $(K^+ \rightarrow e^+\nu)/(K^+ \rightarrow u^+\nu)$ BRANCHING RATIO

Charles M. Ankenbrandt, Alan R. Clark, Bruce Cork, Tom Elioff, Denis Keefe, Leroy T. Kerth, John F. McReynolds, David Newton, and W. A. Wenzel

The experiment is now set up at the Bevatron and the beam has been tested. It yields a stopping K^+ flux of $\approx 1.5 \times 10^3$ per pulse with a pion (and muon) background of about five per kaon. The spark chambers and counters are installed inside the magnetic spectrometer, and these, together with the optical system, are under test. In addition to the primary goal of the experiment other experimental branching ratios may be accessible to the technique employed here. We are studying the feasibility of measuring or setting limits to the modes $K^+ \rightarrow e^+\nu\gamma$, $K^+ \rightarrow u^+\nu\gamma$, $K^+ \rightarrow \pi^+\gamma\gamma$, $K^+ \rightarrow \pi^+\nu\nu$, etc. We also will be able to measure rather accurately the branching ratio $(K^+ \rightarrow \pi^+\pi^0)/(K^+ \rightarrow u^+\nu)$.

NEUTRAL LEPTONIC CURRENTS

Charles M. Ankenbrandt, Alan R. Clark, Bruce Cork, Tom Elioff, Henry J. Frisch, Rolland P. Johnson, Denis Keefe, Leroy T. Kerth, David Newton, and W. A. Wenzel

The proposed experiment was approved by the Bevatron Scheduling Committee in June 1967. The design of the neutral beam and of the detection system is under way. A test magnetostrictive wire chamber using fine aluminum and stainless steel wire is being constructed. Integrated circuit elements will be employed in a very large coincidence matrix for use in the spark chamber trigger logic. Progress has been made in the development of a rapid-cycling spark gap, which may increase the data rate significantly.

NUCLEON-NUCLEON TRIPLE SCATTERING

Charles M. Ankenbrandt, David Cheng,* Leroy T. Kerth, K. C. Leung, Burns Macdonald,† and Pamela Surko

The experiment to measure the Wolfenstein parameters D, R, and R' for the pp, np, and pn systems is scheduled for February at the 184-inch cyclotron. The experiment uses a polarized neutron beam of well-defined energy produced by scattering the cyclotron external proton beam on a deuterium target (or a proton beam on a hydrogen target) at 15 to 30 deg in the laboratory system. This produces a polarized beam with kinetic energies in the range of 510 to 670 MeV.

A superconducting solenoid 1 m long and with a 4-in. bore, operating at 40 000 gauss, is used to rotate the polarization of the nucleons through ±90 deg. The nucleons impinge on a hydrogen or deuterium target and the

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†Visitor from Virginia Polytechnic Institute, Blacksburg, Virginia.

polarization of the recoil particles is analyzed by a further scattering in carbon. The detection of the final scattering in carbon uses spark chambers with a magnetostrictive readout system. The superconducting solenoid is presently being constructed. The magnetostrictive spark chambers are being tested.

This experiment will also be the first test of the on-line connection to the 6600 computer, located in Building 50. This link is not critical to the experiment, but will be very useful to the experiment when it works; and conversely, this experiment is ideal for a first trial of this new experimental facility.

TOTAL CROSS SECTIONS AT COSMIC-RAY ENERGIES

Bruce Cork

An experiment supported by the National Science Foundation to measure the total cross section of cosmic-ray protons is nearly assembled at Echo Lake, Colorado. The first measurements will be with a carbon (graphite) absorber. The interactions will be detected with the aid of spark chambers; the energy of the incident protons will be detected with a large iron-plate calorimeter.

PUBLICATIONS AND PAPERS

"A Search for Massive Particles in Cosmic Rays," issued jointly by University of Michigan, University of Wisconsin, Lawrence Radiation Laboratory, and others, has been accepted for publication in the Physical Review.

A document by L. W. Jones, F. E. Mills, and Bruce Cork, "Proposal for an Ultrahigh-Energy Cosmic Ray Facility," has been submitted to the National Science Foundation.

EXPERIMENTAL PHYSICS

Burton J. Moyer and A. Carl Helmholz in charge

$K_L^0 \rightarrow \pi^0\pi^0$

A. Carl Helmholz, Robert W. Kenney, Ivan R. Linscott, Burton J. Moyer, William P. Oliver, Sherwood Parker, Charles A. Rey, Robert Cence,* B. Jones,* V. Peterson,* and V. Stenger*

A substantial amount of running has been completed, and a small part of these data has now been analyzed. Data have been taken in four modes of operation:

(a) free decay, trigger on neutral decays,
(b) free decay, trigger on charged decays,
(c) dense regenerator, trigger on neutral decays,
(d) dense regenerator, trigger on charged decays.

Carbon and beryllium slabs have been used as regenerators.

Data from the carbon regenerator run have been almost completely analyzed. Some of the conclusions from data taken in about 3 days of running are that $2\pi^0$ decays are seen with the expected efficiency and resolution, that spark counting is a useful tool in the analysis of the data, and that the background (in this case from neutron + carbon $\rightarrow 2\pi^0$ + other collision products) is not serious. Not enough $2\pi^0$ free decay data have yet been analyzed to give a value for the branching ratio; however, preliminary indications that the background will not be serious remain unchanged, even if a value as small as Cronin's revised one is correct.

Free-decay events show 7-6-5-4-3 showers in the ratios 3%-59%-29%-7.5%-1.5% respectively. The high ratio of the 5+6 shower to the 4 shower, and an improvement in accuracy in measuring and reconstructing events, are mainly responsible for the low background. Spark counting has yet to be used in a systematic way on all the data.

Measurements should start soon on the regenerator events with charged-mode triggering. These will be used in an attempt to measure directly the product of beam flux and regeneration amplitude with the same beam and equipment as is used for the neutral decays. Finally, $K_1^0 \rightarrow \pi^+\pi^-\pi^0$ events will be analyzed in an attempt to determine the K flux and energy spectrum, the gamma-detection efficiency and energy resolution, and the angular accuracy of the measured gamma directions.

*University of Hawaii.

COMPARISON OF THE LIFETIMES OF POSITIVE AND NEGATIVE PIONS

David S. Ayres, David O. Caldwell, Allan W. Cormack, Virgil Elings, Arthur J. Greenberg, William Hesse, Robert W. Kenney, and Rollin J. Morrison

The completed setup has been extensively proof-tested for time stability, and adverse systematic effects have been searched for and eliminated when found. Present running is directed toward collection of final data. The preliminary observed ratio of lifetimes, τ_+/τ_-, remains greater than unity by 1.2 standard deviations, with good χ^2. Essential corrections to this observed ratio have neither been calculated nor applied, even if known. No preliminary numerical result will be quoted here because of the importance to CPT conservation. Final uncertainty in the ratio will probably be of the order of 0.15%. Final results should be available within 2 months.

A SEARCH FOR EXCITED LEVELS OF ^{15}N PRODUCED BY μ^- CAPTURE IN ^{16}O

Selig N. Kaplan, Robert V. Pyle, and Lewis E. Temple

Preliminary analysis of approximately 2×10^8 μ^- stoppings in H_2O indicates $1.8 \pm 1.2\%$ of the stoppings produce the 6.3-MeV γ ray corresponding to the transition from $3/2^-$ excited level of ^{15}N to the ground state. This is to be compared with theoretical predictions of 5.5 to 7.5% based on a giant dipole model of μ^- capture. An experimental run under conditions of higher beam intensity and lower background is planned this winter. [Reported in Selig N. Kaplan, Robert V. Pyle, and Lewis E. Temple, ^{15}N Excitation by μ^- Capture in ^{16}O (UCRL-17889 Abst., Oct. 1967), Bull. Am. Phys. Soc. 12, 1143 (1967)].

η^0 DECAY AND $\pi^0\pi^0$n EXPERIMENTS

Thomas B. Risser

Both these experiments are to be collaborations with several members of the Alvarez group. They are designed to study neutral final states comprised of γ rays and neutrons and produced in the reactions $\pi^- p \rightarrow \eta^0 n$ (710 MeV/c) and $\pi^- p \rightarrow \pi^0\pi^0 n$ (1.5 to 2.5 BeV/c) respectively.

In each experiment the γ rays will be detected by a five-sided cube of lead plate spark chambers currently in use by the Moyer-Helmholz group for their $K_2^0 \rightarrow \pi^0\pi^0$ experiment at the Bevatron. The neutrons will be detected by 20 large scintillation counters, and the entire system will be triggered by neutrons with the desired time of flight.

Of the two experiments, the first to be performed will be a study of the neutral decay modes of the η^0 meson. The second will study the $\pi^0\pi^0$ system in the $\pi^0\pi^0$n final state.

The intent is to use the existing spark chamber array without rearrangement. The η^0 experiment also uses the existing beam elements, and will consequently be the first to be performed. It is scheduled to begin in March 1968, after several months of setting up. The $\pi^0\pi^0$n experiment will follow once the η^0 experiment has been completed, a new pion beam constructed, and the neutron counters reoriented.

K_{e4} EXPERIMENT

Brownlee Gauld, Victor Perez-Mendez, R. Cence,* R. Gaiduk,* R. Morgado,* and V. Peterson*

This experiment is now scheduled to run at the Bevatron beginning March 1968. It has been considerably redesigned since a previous report. The K momentum will be 1500 ± 50 MeV/c. An M5 magnet will be used as an analyzer of the decay particles; the K's will enter from the side, perpendicular to the magnetic field, and each of the three charged decay particles will be detected by separate sets of counters and planar wire spark chambers.

The e^+ counters are at such a wide angle as to eliminate the possibility of detecting π's from τ decay. The π^- counter includes a gas Cerenkov counter in anticoincidence to preclude detection of e^- particles from $K_{\pi 2}$ decay with Dalitz decay of the π^0. The π^+ counters will also include a gas Cerenkov counter in anticoincidence. Along with a wide-angle e^- counter this will enable us to search for the $\Delta S = -\Delta Q$ mode of decay simultaneously with the $\Delta S = +\Delta Q$ mode. The π^+ Cerenkov counter again eliminates $K_{\pi 2}$ decays.

The spark chambers are now under construction. The design of the Cerenkov counters is near completion, and construction will begin shortly.

MEASUREMENTS OF THE D, R, AND R' PARAMETERS IN THE NN SYSTEM BETWEEN 500 AND 700 MeV

Charles A. Ankenbrandt, David Cheng, Rolland P. Johnson, Leroy T. Kerth, Kwok-Chu Leung, Burns Macdonald, and Pamela T. Surko

Preparations for this experiment continue.

Approximately one-half of the spark chambers are built. The cryostat for the superconducting solenoid is being built, and the coil is being tested. The setup date is presently expected in late December.

MEASUREMENT OF np → γd ANGULAR DISTRIBUTION AS A DIRECT TEST OF TIME REVERSAL IN THE ELECTROMAGNETIC INTERACTION

David Cheng, Victor Perez-Mendez, Johnie M. Sperinde, R. P. Haddock,† J. A. Helland,† B. L. Schrock,† M. J. Longo,‡ S. S. Wilson,‡ and K. K. Young‡

We are currently taking data at the 184-inch cyclotron. Approximately 0.5 million events have been collected in the first 400 hours of beam time. The separation of np → γd events and the np → π^0d background is relatively clean. Approximately 5 to 10% of all the triggered events are γd events.

As a by-product, the angular distribution of np → π^0d will also be measured in the energy range 300 to 730 MeV incident-neutron kinetic energy, and these data will contribute to another test of isotopic-spin conservation.

It is expected that the data taking will be completed by late November.

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†University of California–Los Angeles.
‡University of Michigan.

p-He SCATTERING EXPERIMENT

Albert W. Stetz, Victor Perez-Mendez, and Johnie Sperinde

We have completed an experiment at the 184-inch cyclotron to study the effectiveness of helium for polarization analysis for 70- and 80-MeV protons. Using the low-energy proton beam described in a previous report, we have photographed 500 000 prospective p-He events. About 1 in 50 of these frames contains useful elastic scattering events. These events are being measured on the TRAMP scanning and measuring tables. Approximately one-half the film has been scanned and measured to date. Eventually 5000 events at 70 and 80 MeV will be measured and analyzed by programs which have been written to calculate the polarization and differential cross section as a function of angle from TRAMP output.

PHOTOPRODUCTION OF ρ_0, ϕ_0, f_0 (SLAC Experiment)

A. Boyarski,[§] F. Bulos,[§] R. Delold,[§] R. Larsen,[§] D. Leith,[§] B. Richter,[§] Leon Kaufman, Victor Perez-Mendez, Albert W. Stetz, and Stephen H. Williams

The spectrometer for measuring the momenta of the π pairs produced from vector meson decays was assembled and connected on-line to the IBM 1800.

Initial measurements with this setup were done on the SLAC "monochromatic" photon beam (e^+ annihilation in flight) to determine the energy spread of this beam. The energy distribution of the monochromatic beam is found to be $\pm 2\%$, which compares well with the $\pm 1.5\%$ calculated by Tsai.

Sources of background from the end station were found and eliminated, and the experimental setup, magnet, spark chambers, and computer are now ready for data taking on vector mesons.

MAGNETOSTRICTIVE READOUT DEVELOPMENT FOR SPARK CHAMBERS

Victor Perez-Mendez, Ronald L. Grove, Gerald L. Stoker, and T. Droege[**]

During this period we studied the possibility of using torsional pulses for readouts of large spark chambers. Torsional pulses are generated in the same configuration as for longitudinal pulses when the readout wire is polarized azimuthally by a dc electric current (Weideman effect). The torsional pulses have the advantage that they are completely nondispersive in the lowest mode and their velocity is ≈ 0.6 of the longitudinal velocity.

Further work on the use of piezoelectric detectors and spark-induced longitudinal waves on nonmagnetic wires has brought the use of this combination for readout of chambers in magnetic fields to the point where it can now supersede the standard magnetostrictive-wire-pickup-coil combination.

The following papers have been issued on this and previous work during this period:

1. R. Grove and V. Perez-Mendez, Magnetostrictive Readout for Spark Chambers using Torsional Pulses, UCRL-17637 (paper given at APS Meeting, Seattle, September 1967).
2. R. L. Van Tuyl, V. Perez-Mendez, K. Lee, and R. Grove, Delay-Line Multiplexing Method for Storage and Display of Information from Magnetostrictive Spark Chambers (paper to be presented at Nuclear Science Symposium, Los Angeles, November 1967).
3. R. L. Van Tuyl, K. Lee, and V. Perez-Mendez, Electrical Pulsing and Operating Characteristics of Large Wire Spark Chambers with Magnetostrictive Readout, UCID-3099, Sept. 1967.

$\pi^-{}^4$He INTERACTIONS

Leon Kaufman, Victor Perez-Mendez, Brownlee Gauld, Johnie Sperinde, and Stephen Williams

The thesis by Leon Kaufman, π^-–He^4 Inelastic and Capture Reactions Leading to Excited and Multineutron Final States, UCRL-17605, July 1967, was completed and approved in June.

We find a level of the α particle with an excitation energy of 32 MeV and an intrinsic width smaller than our 1-MeV resolution. We find that our data on the four-neutron final state is best fitted by considering two neutrons interacting through a $^1S_0$ potential and the other two as spectators. We observe, too, that the proton spectrum shows a stronger than expected interaction between the three neutrons in the final state.

Lower limits for the production of a trineutron and a tetraneutron are set. Parameters on the magnetostrictive readout chamber's performance are given in the thesis. We presented a paper on our results to the APS meeting held in Seattle last August, and a summary of our results (UCRL-17846) has been sent to Phys. Letters.

[§]Stanford Linear Accelerator Center.
[**]Summer visitor from University of Michigan.

$\pi^- {}^3He$, $\pi^- {}^4He$ INTERACTIONS

Johnie Sperinde, Leon Kaufman,
Victor Perez-Mendez, and Ben Smith

A 184-inch cyclotron experiment is being planned for next spring. We intend to look for possible excited levels with T = 1/2 or 3/2 in ^3He and T = 0 or 1 in ^4He, and to study the energy and angular dependence of π^- elastic and inelastic scattering on both ^3He and ^4He. We also expect to learn more about the 3n system from double charge exchange on $^3He(\pi^- {}^3He \rightarrow \pi^+ 3n)$.

EXPERIMENTAL PHYSICS

Wilson M. Powell and Robert W. Birge in charge

$K^-p \rightarrow \Lambda\pi\pi$

Robert P. Ely and Jack S. Sahouria

The investigation of the reaction $K^-p \rightarrow \Lambda\pi\pi$ near 1 GeV/c is continuing. A paper giving preliminary results was presented to the APS meeting in Seattle Aug.-Sept. 2, 1967.[1] At present program VARMIT is being used to fit the data (angular distributions and Dalitz-Plot distribution) to a set of partial waves with angular momenta 3/2, 5/2, 7/2. Preliminary results show that angular momenta of 1/2 or >5/2 are not likely to be present [we assume a $Y_1^*(1385)$ as intermediate state]. Since there are two isotopic-spin states present in the above reaction, one needs a large number of parameters in order accommodate a representative number of partial waves (at present we are considering seven waves: DS3, PP3, DD3, DD5, FP5, FF5, and FF7 and their interference terms). Thus our effort is now devoted to finding a computer solution for this large number of parameters.

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

Robert P. Ely and James Louie

In the study of the above reaction near 1 BeV/c, a model consisting of direct-channel Y_1^* resonant amplitudes with contributions from background t- and u-exchange terms is being constructed. Experimental angular distributions, polarizations, and total cross sections are being compared with the predictions according to the model, which uses 12 parameters. These parameters consist of two coupling constants in the t channel, one product of coupling constants in the u channel, the branching ratios of the resonances, the mass and width of the $Y_1^*(1770)$, and the phases of the various amplitudes relative to the 1770. A χ^2 minimizing procedure (VARMIT) is being used in this problem.

1. Jack S. Sahouria and R. P. Ely, Investigation of the Reaction $K^-p \rightarrow \Lambda\pi\pi$ Near 1 GeV/c, Bull. APS 12, 916 (1967).

π^+p INTERACTIONS IN THE MOMENTUM INTERVAL 2.9 TO 4.3 BeV/c

David G. Brown, Robert W. Birge, George Gidal, and Giovanni Borreani

We are making a detailed analysis of π^+p two-prong and four-prong interactions between 3 and 4 BeV/c incident π^+ momentum[2] (in collaboration with University of California–Riverside). Of particular interest are $N^{*++}\rho^0$, $N^{*++}\omega^0$, and other quasi-two-body final states. At these energies t-channel effects seem to dominate, as shown by the momentum-transfer distribution's exponential shape. The $N^*\rho^0$ shows shrinkage with incident pion momentum. The rate of shrinkage and magnitude of the $N^*\rho$ differential cross section are approximately those predicted by OPE models, with the finite widths of the ρ and N^* taken into account, but form factors are necessary because of the steepness of the forward peak. The t dependence of the density matrix elements seems in basic agreement with peripheral-model predictions. The $N^*\omega$ and $N^*\eta$ momentum-transfer distributions are much shallower, and the $N^+\omega$ shows evidence for a dip at t = -0.8 and a backward peak. The cross sections for these reactions are being studied and means sought to identify s-channel effects, especially from the T = 3/2 nuclear resonance, $N^*(2850)$.

The decays of higher-mass N^*'s into $N^*(1238) + \pi$ have been observed. A phase-shift analysis[3] (in collaboration with UCLA) of the final-state $N^*\pi^+\pi^-$ gives confirming evidence for an S-wave $\pi\pi$ resonance near 730 MeV mass. A search, with known sensitivity, for this resonance in the missing-mass spectrum is in progress. Automatic ionization measurements on the FSD measuring machine

2. David Brown, George Gidal, Robert W. Birge, Robert Bacastow, Sun Yiu Fung, Warren Jackson, and Robert Pu, Phys. Rev. Letters 19, 664 (1967).
3. E. Malamud, P. Schlein, G. Gidal, and D. Brown, Heidelberg Conference Report, Phys. Rev. Letters 19, 1056 (1967).

enable us to identify the large number of events involved.

K^-d AND K^-n ELASTIC SCATTERING

George E. Kalmus and Nathan Jew

K^-d and K^-n elastic scattering scanning and measuring for the "long proton" two-prong events in the K-25 films has essentially been completed. The purpose of these efforts is to extract the K^-d and K^-n elastic cross sections from the breakup reaction $K^-d \rightarrow K^-pn$. Analysis on this reaction is proceeding.

The analysis of the K^-d elastic events is in progress.

IONIZATION MEASUREMENT WITH THE FSD

Giovanni Borreani

The ionization information coming from the measurement of bubble chamber events on the flying-spot digitizer is being used to resolve ambiguities left after the kinematical fit in four-pronged events from π^+p interaction at 1.35, 1.43, and 1.68 GeV/c in the 72-inch bubble chamber. In order to make the information usable, a calibration has been necessary to correct for differences due to nonuniformity of bubble chamber sensitivity and illumination. Correction factors have been determined statistically by using events with nonambiguous four-constraint kinematical fit. It is found that the corrections vary from one exposure to another, and that best resolution is to be expected if the minimum ionization is kept not above 15 bubbles per mm on the film.

MEASUREMENT OF ELECTRONS IN HEAVY-LIQUID BUBBLE CHAMBERS

George E. Kalmus and Daniel F. Kane

A program ELTRAK has been developed (described in the preceding semiannual report, p. 56) to generate and measure electron tracks in heavy liquids. We have used this program to improve techniques for measuring electron tracks. A UCRL report on this work is being prepared.

K67 BEAM DESIGN

Powell-Birge Group
(In association with Trilling-Goldhaber Group)

Some new techniques for optimizing beam parameters have been developed and incorporated into a program package TRAMTIK. A user's manual is now being prepared. By using this the K67 beam has been optimized between 1 and 2 BeV/c. The solid angle varies from 4 msr for the former to 0.7 msr for the latter. Magnet measurement and shimming for this beam are virtually complete. The beam is scheduled for operation about 1 January 1968.

ON-LINE SYSTEM

Robert W. Birge and P. Wes Weber

During this period the "Cobweb" on-line system has come into initial operation. Two measuring machines are now operating (one measuring microscope and one Franckenstein); the first Trilling-Goldhaber machine is scheduled for operation the second week in November and our third machine is scheduled several weeks later. The IBM 7044 computer is devoted exclusively to this application 16 hours per day, five days per week. The operation of the machines has far exceeded our most optimistic estimates in that we have maintained measurement rates of 20 events per hour over a week's period, and 30 events per hour for short periods on simple two-prong events. The current error rate is only about 1%, and consists mainly of cases in which the operator interchanges tracks in different views. The success of the system is due to many factors, but the speed seems to be mainly related to accurate computer control of the stage motion, so that little or no manual setting is needed. Because the next two machines to go on-line have added mechanical features and better film-handling mechanisms, we expect even better results. The low error rate and freedom from need for further filtering make this system nearly competitive economically with other more highly automated measuring systems, while offering at the same time the possibility of measuring difficult events and those rejected or impossible to measure elsewhere.

25-INCH HYDROGEN BUBBLE CHAMBER

Wilson M. Powell and Glenn J. Eckman

The chamber was off at the start of the report period while Bevatron generators were being repaired. The bubble chamber crew helped with packing and shipping the 82-inch bubble chamber to SLAC. New hydrogen and deuterium supply lines were installed over the EPB (external proton beam) building.

The chamber resumed operation with hydro-

gen for the Alvarez-Murray-Tripp K65 run on July 6. The Trilling-Goldhaber-Kadyk K^- experiment was run from July 25 to August 28. The K65 experiment was then continued, switching to deuterium on October 11.

A total of 195 rolls of film was taken for the Alvarez-Murray-Tripp experiment and 124 rolls for the Trilling-Goldhaber-Kadyk experiment. A total of 5.13×10^5 pictures was taken during the report period.

The chamber has been disassembled to be cleaned and repaired for moving into the EPB location for the Powell-Birge, Alvarez, Leith, and Trilling-Goldhaber experiments.

THE REACTIONS $K^-n \rightarrow \Lambda\pi^-$ AND $K^-p \rightarrow \Lambda\pi^0$

Robert P. Ely and Wesley M. Smart

We have extended the partial-wave analysis from our data in the energy region 1660 to 1900 MeV[4] to the data at higher energies (1900 to 2200 MeV).[5-7] This analysis has established the resonant nature of $Y_1^*(1910)$ and measured its spin and parity as $J^P = 5/2^+$. The earlier assignment $J^P = 7/2^+$ for $Y_1^*(2030)$ has been confirmed.[2] The mass, width, and $\Lambda\pi$ branching ratio were measured as 1902 ± 11 MeV, 52 ± 25 MeV, and 0.08 ± 0.04 for $Y_1^*(1910)$, and as 2032 ± 6 MeV, 160 ± 16, and 0.41 ± 0.03 for $Y_1^*(2030)$. In addition we found a suggestion for the existence of a $J^P = 1/2^+$ resonance at 1880 MeV with a width of 220 MeV.

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4. W. M. Smart, A. Kernan, G. E. Kalmus, and R. P. Ely, Jr., Phys. Rev. Letters 17, 556 (1966).
5. C. G. Wohl, F. T. Solmitz, and M. L. Stevenson, Phys. Rev. Letters 17, 107 (1966).
6. W. Peter Trower, Ph.D. Thesis, University of Illinois, 1966.
7. Philip M. Dauber, Ph.D. Thesis, University of California-Los Angeles, 1966.

DATA REDUCTION

Robert W. Birge and P. Wes Weber

With an average of 25 (full-time equivalent) visual-measurement personnel, the following data reduction was accomplished in the past six months:

Scanning

Experiment	Bubble chamber	Beam	Number of frames
Conventional system			
32	25-inch hydrogen	850–1150-MeV/c K^-	320 586
34	25-inch deuterium	850–1150-MeV/c K^-	398 689
35	1.1-meter CERN (C_2F_5Cl)	Stopping K^+	614
36-41	72-inch hydrogen	3.3–4.1-BeV/c π^+	1 799
42-44	72-inch hydrogen	1.35–1.68-BeV/c π^+	124 161
		Subtotal	845 849
FSD system			
36-41	72-inch hydrogen	3.3–4.1-BeV/c π^+	101 409
	72-inch hydrogen	1.35–1.68-BeV/c π^+	22 298
		Subtotal	123 707
		Total	969 556

Measuring

	Measuring hours	Number of events	Events per measuring hour
Conventional system			
(2 measuring microscopes, 2 MP1-type Franckensteins)[a]	3 693	20 413	5.5
FSD system			
(2 SP5B-type image plane digitizers)	4 465	98 500	22.1
Total	8 158	118 913	14.6

a. One microscope and one Franckenstein working in COBWEB (on-line computer controlled) mode for ≈2 months.

NOTE: Approximately 7000 events were reduced on the COBWEB system with less than 1% reconstruction error. The faster rate of measurement, with essentially no reconstruction errors, constitutes a factor-of-3 increase in useful events.

EXPERIMENTAL PHYSICS

Emilio Segrè and Owen M. Chamberlain in charge

MEASUREMENT OF FORM FACTOR RATIO ξ IN $K_{\mu 3}$ DECAY

David Cutts, Rae F. Stiening, Clyde Wiegand, and M. Deutsch*

Our Bevatron spark chamber experiment is in the final stage of analysis. We have obtained 3300 examples of the decay $K^+ \rightarrow \pi^0 \nu \mu^+$ in which all kinematical variables have been determined. From an analysis of the muon polarization in these events we have measured $f_-/f_+ = \xi$. A preliminary analysis of the data indicates no evidence of time-reversal invariance violation. If we assume the Im $\xi = 0$, we find Re $\xi = -0.8 \pm 0.3$. Our result for Re ξ is in disagreement with previously published values. For a compilation, see, for example, T. D. Lee and C. S. Wu.[1]

We find no evidence of a momentum-transfer dependence for ξ.

SEARCH FOR THE DIRECT DECAY $K^+ \rightarrow \pi^+ \gamma\gamma$ [2]

Min Chen, David Cutts, Peter K. Kijewski, Rae F. Stiening, Clyde Wiegand, and M. Deutsch*

As a part of our Bevatron spark chamber study of K^+ decays at rest we have searched through our data for examples of the direct decay $K^+ \rightarrow \pi^+ \gamma\gamma$. No events were found. Candidates were recognized by the relation of the conversion points of two γ rays to the momentum of a charged particle. The charged particle was assumed to be a pion. Its momentum was determined from its range in an aluminum-plate spark chamber. Our apparatus was sensitive to pions having a kinetic energy between 60 and 90 MeV. The γ rays were detected by a lead-plate spark chamber. If we assume the hypothetical direct decay process $K^+ \rightarrow \pi^+ \gamma\gamma$ to be distributed according to a phase-space model, we can set an upper limit for the branching ratio of the K^+ into this channel of 1.1×10^{-4}. Following the suggestion of Fujii,[3] we have interpreted our result as a limit on the off-the-mass shell variation of the $K^+ \rightarrow \pi^+ \pi^0$ amplitude. If this amplitude is assumed to be of the form

$$M(q^2) = M(m^2_{\pi^0}) \left(1 - \xi \frac{q^2 - m^{-2}_{\pi^0}}{m^2_{\pi^0}} \right)$$

our result requires that $|\xi| < 30$. In this expression q is the invariant mass of the two γ rays. Our results are incompatible with the suggestion of Lapidus[4] that the $K^+ \rightarrow \pi^+ \gamma\gamma$ mode may be related to the $\eta \rightarrow \pi^0 \gamma\gamma$ mode through a σ-meson intermediate-state model. The rate of $K^+ \rightarrow \pi^+ \gamma\gamma$ predicted by Lapidus is more than an order of magnitude greater than what we obtain from our upper limit of the branching ratio. We note, however, that this conclusion depends on the presently reported value[5] of the branching ratio of $\eta \rightarrow \pi^0 \gamma\gamma$ decay.

NUCLEON-NUCLEON INTERACTIONS

William Chinowsky, William R. Gage, Robert R. Kinsey,† Stanley L. Klein, Mark A. Mandelkern, and Peter E. Schmidt

Analysis of the interactions of 6-BeV/c protons in the 72-inch hydrogen bubble chamber is essentially completed. Results on

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*Massachusetts Institute of Technology, Cambridge, Massachusetts.

1. T. D. Lee and C. S. Wu, Ann. Rev. Nucl. Sci. 16, 486 (1966).
2. Submitted for publication in Phys. Rev. Letters.
3. Y. Fujii, Phys. Rev. Letters 17, 613 (1966).
4. I. Lapidus, Nuovo Cimento 46, 668 (1966).
5. A. H. Rosenfeld, A. Barbaro-Galtieri, W. J. Podolsky, L. R. Price, P. Söding, C. G. Wohl, M. Roos, and B. H. Willis, Rev. Mod. Phys. 39, 1 (1967).

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strange-particle production in three-body states have been reported.[6] A paper describing the observation of $N^*\rho$ and Y^*K decay modes of a T = 3/2 nucleon isobar, produced in the quasi-two-body reaction $pp \rightarrow N^*n$, is in preparation. The existence of the state has been clearly demonstrated, but the interpretation as the well-established $N^*(1950)$ is not completely certain. If these events do represent alternative decay modes of $N^*(1950)$, then the branching ratio is of the order of 5% for each mode. Some 5500 examples of the three-body reaction $pp \rightarrow pp\pi^0$ and 12 500 of $pp \rightarrow pn\pi^+$ have been identified. These are being analyzed to determine rates for $N^*(1450)$ production and decay in the elastic channel to compare with the corresponding rates for the three-body decays produced in the final-state $pp\pi^+\pi^-$. We find no sharp peaks in the mass distributions of $n\pi^+$, $p\pi^0$, or $p\pi^+\pi^-$, but some excess of events in all three at masses below ≈ 1500 MeV/c^2. Conclusions about the branching ratios are awaiting a better evaluation of the shape of the background distribution.

The study of four- and five-particle nonstrange final states is being completed, and a paper will be written in the near future. The outstanding feature is the strong evidence for nearly 100% quasi-two-body final states NN^* and N^*N^*. The four-body strange-particle data show strong $Y^*(1385)$ production. It is presently being analyzed in terms of the one-pion-exchange model.

Analysis of interactions on deuterium at 6 and 8 GeV/c incident momentum is continuing. No results are available yet.

LOW-ENERGY π^-p INTERACTIONS

William Chinowsky, William R. Gage, Robert R. Kinsey,† Stanley L. Klein, Mark A. Mandelkern, and Peter E. Schmidt

Analysis of an exposure of some 300 000 photos of interactions of π^- with protons in the Saclay 81-cm chamber, obtained at the Rutherford Laboratory, has just begun. Incident momenta in this experiment were 450, 500, and 550 MeV/c. This film is being scanned and measured also at the Nuclear Physics Laboratory at Oxford University. Of particular interest are studies of $\pi\pi$ final-state interactions and determinations of the π-nucleon interaction parameters revealed in the energy and angle distribution of particles produced in the inelastic channels $\pi^+\pi^-n$ and $pp\pi^0$. The state of the analysis is still primitive, and results may not be expected for some months.

6. W. Chinowsky, R. P. Kinsey, S. L. Klein, M. Mandelkern, J. Schultz, F. Martin, M. L. Perl, and T. H. Tan, Production of K Mesons in Three-Body States in Proton-Proton Interactions at 6 BeV/c, Phys. Rev., Jan. 25, 1968.

ANTIPROTON-PROTON ANNIHILATIONS

William Chinowsky, William R. Gage, Robert R. Kinsey,† Stanley L. Klein, Mark A. Mandelkern, and Peter E. Schmidt

An exposure of the BNL 30-inch liquid hydrogen chamber to $\bar{p}$ of incident momenta 700 to 1150 MeV/c has just been completed. The 220 000 photos obtained will be analyzed at Berkeley and at Irvine. Special effort will be made to identify quasi-two-body reactions yielding resonances among the final-state particles, with particular attention to the energy dependence of production cross sections. The utility of this approach for the understanding of many two-body final states has been demonstrated by Morrison. A number of higher-mass resonances decaying into pions has been found by Maglić et al., and it may be possible to determine some of their quantum numbers and decay modes, as well as production rates.

PIONIC ATOMS

Arthur R. Kunselman and Georges-André Grin

The measurements of pionic atom x rays from the cyclotron run in May have been analyzed (A. R. K.). The measured high-energy portions of the radiative yields of the elements agree with values calculated from the processes affecting the pion cascade. The measured capture ratios on chloride compounds agree with capture ratios in muonic atoms.

Preparations are being made for a continuation of previous experiments on pionic atoms with the emphasis on chemical effects on the intensity of the x-ray lines.

POLARIZATION IN π^+p AND π^-p ELASTIC SCATTERING FROM 250 TO 410 MeV

William Gorn, Charles C. Morehouse, Thomas M. Powell, Peter R. Robrish, Stephen Rock, Stephen R. Shannon, Herbert M. Steiner, and Howard L. Weisberg

Data taking, using the polarized proton target, was completed in mid-April 1967. The data are being analyzed to find the polarization parameter at four energies for the angular region $70 \lesssim \theta_{c.m.} \lesssim 180$ deg. Subsequent

analysis will determine phase-shift solutions in this energy region, one hopes unambiguously. An attempt will be made to use the solution(s) thus found to reduce the number of solutions found at higher (Bevatron) energies.[7]

A preliminary phase-shift analysis at 310 MeV allowed us to choose unambiguously between the existing solutions. The measured polarization parameter for π^+p elastic scattering is in good agreement with the Lovelace-Bareyre phase-shift predictions, but a few degrees change in these solutions is required to obtain agreement with the measured π^-p polarization parameters.

PHASE-SHIFT ANALYSIS OF $\pi^{\pm}p$ ELASTIC SCATTERING EXPERIMENTS

Claiborne H. Johnson, Jr.,
Owen Chamberlain, Richard D. Field, Jr.,
and Herbert M. Steiner

The phase-shift analysis is proceeding. Uniqueness is not yet established in the framework of a theoretical approach with minimum assumptions, namely unitarity, charge independence, and forward dispersion relations. A new solution has been found that extends from low energy (300 MeV) to 1100 MeV. Although it has not yet been checked in every respect, it confirms our suspicion that more information is needed.

In the near future new results from the Rutherford Laboratory will be included in the data set, and direct comparisons of data and solutions will be made with other groups active on this problem. The new solution will be further studied and extended, if possible, to higher energy.

POLARIZATION IN π^+p AND π^-p ELASTIC SCATTERING EXPERIMENT FROM 250 TO 410 MeV

Claiborne H. Johnson, Jr.,
Owen Chamberlain, Richard D. Field, Jr.,
and Herbert M. Steiner

Analysis of this work is still in progress. Preliminary results are available but the final analysis is not completed.

7. See Claiborne H. Johnson, Jr., Measurement of the Polarization Parameter in π^+p Scattering from 750 to 3750 MeV/c (Ph. D. Thesis), UCRL-17683, Aug. 1967.

SEARCH FOR T VIOLATION IN INELASTIC ep SCATTERING

Owen Chamberlain, Gilbert Shapiro,
Herbert M. Steiner, Howard L. Weisberg,
Charles C. Morehouse, Thomas M. Powell,
Peter R. Robrish, Stephen Rock,
Stephen Shannon, Richard Taylor, ‡
Luke Mo, ‡ Elliot Bloom, ‡ John Litt, ‡
Henry Kendall, § and Jerome Friedman §

A proposal has been submitted to the Stanford Linear Accelerator to search for evidence for violation of time-reversal invariance in the inelastic scattering of ≈12-GeV electrons from polarized protons.

It was first suggested by Bernstein, Feinberg, and Lee[8] that the CP-violating decay of K_L^0 could be explained by the existence of a T-violating coupling between photons and hadrons, and the existence of such a coupling is consistent with all experiments thus far performed. Christ and Lee[9] then suggested the presently proposed experiment as a situation in which such an effect might manifest itself. The experiment consists in scattering electrons from a target containing polarized protons. One thus sums over recoil baryon states having a given (range of) invariant mass and momentum transfer. In the one-photon approximation, any difference in the rate of this reaction when the sense of the target polarization normal to the scattering plane is reversed would be evidence for T violation in electromagnetic interactions.

The polarization reversal is effected by a 0.3% change in the frequency of the microwaves irradiating the target, without any change in the experimental setup--not magnetic field strengths nor counter positions nor counting logic. This reversal can take place as often as once per minute. It is never necessary to measure absolute rates. This type of experiment is thus remarkable for its relative freedom from systematic errors.

Construction has begun on a magnet and cryostat suitable for polarizing the protons (in an ethanol-water-porphyrexide solution) along a vertical axis. The experiment is expected to be ready next spring.

‡Stanford Linear Accelerator Center, Stanford University, Stanford, California.
§Massachusetts Institute of Technology, Cambridge, Massachusetts.

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POLARIZED PROTON TARGET IMPROVEMENTS

Owen Chamberlain, William Gorn, Charles C. Morehouse, Thomas M. Powell, Peter R. Robrish, Stephen Rock, Stephen R. Shannon, Gilbert Shapiro, Herbert M. Steiner, and Howard L. Weisberg

An alcohol target has been successfully polarized, though we have not yet reliably reached 35% polarization, as should be expected from results at CERN (Borghini). We have a reliable measurement at 20%, and we believe that we can routinely achieve at least this level of polarization.

The new readout scheme (the "1260" system) has been successfully tested at 79 MHz nuclear magnetic resonance frequency. It shows great promise of giving improved accuracy in measuring the target polarization. One measurement takes 8 seconds at present; soon this time may be reduced to less than 1 sec. Formerly 5 min was required. The reproducibility of one measurement seems to be within about 2%. Formerly the accuracy was within about 4%, with rather large fluctuations being encountered on some occasions.

On the basis of the successful test of the 1260 system Bill Miller is being asked to design and construct a form of the system suitable for the alcohol target (105 MHz) to supplement the existing lanthanum magnesium nitrate (LMN) form (at 79 MHz). Considerable housekeeping must be done on the interface with the PDP-5 computer before the 1260 system will be ready for routine use.

In connection with our proposal submitted to SLAC (Stanford Linear Accelerator Center) for a measurement of asymmetry in inelastic electron-proton scattering from a polarized target, we have started tests on an (ethyl) alcohol target, and have made a study of its resistance to radiation damage. A 13-MeV electron accelerator was loaned to us for a period of 10 days by the LRL-Livermore Laboratory. With energetic help from George MacFarlane, Bill Nordendahl, and others from the Livermore Laboratory, we have determined the extent to which radiation causes deterioration in an alcohol target. The polarization is reduced to 70% of its initial value by exposure of the target to 4.5×10^{14} electrons per cm^2. This indicates that the alcohol target is suitable for the experiment at SLAC.

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ATOMIC BEAM GROUP

Howard A. Shugart in charge

ATOMIC BEAM GROUP

The Atomic Beam Group continues to devote the major portion of its effort toward the systematic measurement of atomic and nuclear properties of radioactive isotopes. This research furnishes knowledge of parameters such as the nuclear spin, the electronic angular momentum, the nuclear multipole moments, the electronic g_J factor, the hyperfine interaction energy between the nucleus and electrons, and other more intricate interactions. In the long run these properties are used as input information in the evaluation of atomic and nuclear theories, and also provide valuable starting points for nuclear spectroscopic studies. All the techniques employed in this work involve systems in which the atom is essentially unperturbed by neighbors, as in the atomic beam method; or the atom is subjected to infrequent collisions, as in the optical pumping or electron-impact excitation methods.

Owing to the relative simplicity of the system under study, interpretation of results assumes a particularly unambiguous form. This, coupled with the sensitivity of these methods, makes studies of rare radioactive species a productive endeavor.

Beyond the measurement efforts, the group explores new techniques which hold promise of revealing better understanding of physical laws and tries new applications of our standard methods.

The activity of the group during the past six months can be indicated by an enumeration of papers that have appeared in the literature or as reports.

PUBLICATIONS AND PAPERS

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8. Stephen G. Schmelling and Howard A. Shugart, Nuclear Spin, Hyperfine Structure, and Nuclear Magnetic Moment of ^{163}Tm, Bull. Am. Phys. Soc. 12, 1046 (1967).
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Invited Talks

1. Eugene D. Commins, Precise Test of Time-Reversal Invariance and Allowed Beta Decay, Bull. Am. Phys. Soc. 12, 661 (1967).
2. Tetsuo Hadeishi, Magnetic Resonance of Ground State of Neutral and Ionized Atoms Observed Through Collision-Induced Coupling with Metastable-State Neutral Atoms, Bull. Am. Phys. Soc. 12, 900 (1967).

Papers

1. Roger C. Barrett, S. J. Brodsky, G. W. Erickson, and M. H. Goldhaber, Corrections of Muonic x Rays and a Possible Proton Halo (SLAC-335, Aug. 1967), submitted to Phys. Rev.
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3. Vernon J. Ehlers, Thomas R. Fowler, and Howard A. Shugart, Nuclear Magnetic Moment of ^{85}Rb: Resolving a Discrepancy, UCRL-17792, Sept. 1967.
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1. Frank Paul Calaprice, The Nuclear Magnetic Moment and Beta-Decay Asymmetry of Argon-35, UCRL-17551, May 1967.
2. Berken Chang, Optical Pumping in Atomic Lead, UCRL-17765, Aug. 1967.
3. Chung-Heng Liu, Magnetic Resonance of the Ionic Ground State of Atoms Through Exchange Collisions with the Metastable State; and Intensity Beats Due to Coherent Excitation, UCRL-17697, July 1967.
4. Carl Alvin Kocher, Polarization Correlation of Photons Emitted in an Atomic Cascade, UCRL-17587, May 1967.
5. Gerald Lee Wick, Test of Time-Reversal Invariance in Beta Decay of Neon-19 and Beta Decay Asymmetries, UCRL-17708, July 1967.

EXPERIMENTAL PHYSICS

George H. Trilling and Gerson Goldhaber in charge

K_2^0 DECAYS AND INTERACTIONS

John A. Kadyk and Jonathan Chan

An analysis was made to determine the energy dependence of the form factor for K_{e3}^0 decay, based upon 531 events. The result was consistent with there being no energy dependence, and is still the most precise published result. The analysis, representing only 20% of the total data available, was presented at the Washington APS Meeting in April, and has been subsequently published in Physical Review Letters. It is hoped that the rest of the K_2^0 decays will be analyzed soon, with the FSD used as the measurement device.

Analysis of the reaction $K_2^0 p \rightarrow K^+ n$ was undertaken, with the collaboration of Jae K. Kim of Harvard. The entire set of data has been collected, consisting of about 300 events, and work is in progress toward an improved determination of the I = 0, S = +1 scattering length.

BEAM DESIGN AND CONSTRUCTION

John A. Kadyk, Donald Coyne, Roger W. Bland, Faysal Hamzeh, and Gloria Fang

The design for the new beam to be used with the 25-inch bubble chamber has been completed. This has been a collaborative effort with the Powell-Birge group. Magnet testing and beam setup have now begun. This beam will become operational early in 1968, and should supply separated beams of K^+ or K^- from about 1.0 to 2.0 BeV/c, and π^+, π^-, or p up to about 3.2 GeV/c. It will be possible to take two, and possibly even three, photographs on each Bevatron cycle. Other features should include a beam destroyer, to precisely define the number of beam tracks, and a beam stepper (kW-momentum only), to make the beam more uniform.

K^+d INTERACTIONS FROM 860 TO 1580 MeV/c

Allan A. Hirata, Sulamith Goldhaber,* Gerson Goldhaber, George H. Trilling, Roger W. Bland, John A. Kadyk, Charles Wohl, Benjamin C. Shen,† Bertram M. Schwarzschild,‡ and Victor Seeger

We are continuing our investigation of K^+d interactions in the region from 860 to 1580 MeV/c. We have film, taken in the 25-inch deuterium-filled bubble chamber, at 860, 960, 1200, 1360, and 1580 MeV/c. These momenta span the region of the peaks observed by Cool et al.[1]--one in the I = 1 K^+p total cross section at 1250 MeV/c and one in the I = 0 total cross section (obtained from K^+p and K^+d measurements) at 1150 MeV/c.

Our present analysis is concentrated on charge-exchange scattering,

$$K^+d \rightarrow K^0pp, \qquad (1)$$

and inelastic processes such as

$$\begin{aligned} K^+d &\rightarrow K^+\pi^-pp \\ &\rightarrow K^0\pi^0pp \\ &\rightarrow K^0\pi^+np. \end{aligned} \qquad (2)$$

We are now completing a rescan of our film for such events in an effort to reduce the residual systematic biases. We hope to have final total and differential cross-section measurements for these reactions shortly. It is hoped that these data will lead to clarification of the nature of the observed peaks.

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*Deceased.

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‡Present address: Imperial College, London, England.

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π^+p INTERACTION AT 3.7 GeV/c

Donald G. Coyne, W. Ralph Butler,
Peter Gaposchkin, and Jimmy McNaughton

Analysis of the 180 000 pictures (π^+p at $\approx$3.7 BeV/c in the 72-inch H_2 chamber) taken in December 1966 is continuing. At present slightly more than 1/3 of the pictures have been prepared for the FSD (i.e., roadmade) and about 14 000 events of all types have been completely processed and accepted. Work has been initiated to permit logical selection of good events by utilizing FSD ionization measurements, rather than by physicist inspection, whenever possible.

The presently accumulated data are of the same order as those of a previous experiment of this group in the 20-inch BNL chamber (1963). It is hoped that we will gain further insight into the A, H, B and other effects once a substantially greater sample has been collected.

K^+p INTERACTIONS AT 9 GeV/c

Alex Firestone, Benjamin C. Shen, †
and Gerson Goldhaber

We have continued the study of 100 000 stereo exposures of K^+p interactions at 9 BeV/c. The film was taken with the Berkeley cameras in October 1966 at the Brookhaven National Laboratory 80-inch hydrogen bubble chamber exposed to an rf-separated K^+ beam.

In a study of the four-body final states $K^+p\pi^+\pi^-$ and $K^0p\pi^+\pi^0$ we have observed a new resonance in the $K\pi\pi$ system; the $K^*(1250)$ of width 50 MeV and probably spin 1+. This resonance decays primarily into the final state $K^*(890)\pi$, but $K\rho$ and $K\pi\pi$ are also present. We have resolved the large $K\pi\pi$ enhancement in the region 1.1 to 1.5 GeV into three resonances: the $K^*(1250)$, mentioned above; the $K^*(1320)$ observed earlier by this group[2] at a slightly different mass in a K^+p experiment at 4.6 BeV/c; and the well-known $K^*(1420)$ resonance. The results of this study have been published.[3]

Twelve charged anticascade hyperons which correspond to a cross section of 5.3 μb have been observed in this sample of film. The results of a study of the production mechanism of these events have been published.[4]

We have used the hydrogen bubble chamber as a missing-mass spectrometer for those events in which the recoil proton stops in the bubble chamber, and confirm the existence of the L meson of mass M = 1740 MeV and width Γ = 120 MeV. The results of this study have been presented to the Heidelberg International Conference on Elementary Particles, September 1967.

At present we are studying the three-body and five-body final states in an effort to investigate: (i) the branching ratios and spin of the $K^*(1420)$, (ii) possible two-meson decay modes of the L meson and higher resonances, and (iii) possible higher resonances that may decay into $K^*(1250)$, $K^*(1320)$, $K^*(1420)$, or L mesons by a cascade process involving the emission of pions.

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EXPERIMENTAL PHYSICS

PION FORM FACTOR

Kenneth M. Crowe, Anthony Parsons, and Anthony Fainberg

We have measured the differential elastic scattering cross section for $\pi^{\pm}$ ^{4}He at several energies between 50 and 90 MeV. The aim of the experiment is to measure the electromagnetic form factor of the pion by extracting, from the difference between the π^+ and π^- cross section, details of the Coulomb interaction.

The experiment was run at the 184-inch cyclotron, and used an array of counter telescopes to detect the elastic pions. The reduction of the data is complete, and we are now evaluating an optical-model description of the π ^{4}He nuclear interaction, which is needed for a full understanding of the difference between the π^+ and π^- cross section.

As by-products, the experiment yielded some interesting data on pion capture on ^{4}He, as well as $\pi^{\pm}p$ data obtained in checking the apparatus.

K_2^0 CHARGE ASYMMETRY

Donald H. Miller and Michael Paciotti

The experiment to measure the charge asymmetry in the muonic decay of the K_2^0 was completed in the early part of the summer. The data have been reduced and the results published in Phys. Rev. Letters 19, 987 (1967). A research progress meeting concerning this work was given by Stan Wojcicki. The data are now being further analyzed; information can be obtained about the production of K^0 at 3 deg by 15-GeV/c electrons in 1 foot of Be.

K^+ DECAY ANALYSIS

Kenneth M. Crowe, Mike Zeller, and Ned Dairiki

An experiment to measure the parameters of the K^+ three-body leptonic decays is in the final stages of analysis. The experiment was performed at the Bevatron in the early part of 1965 by use of a system of wire chambers and a range spark chamber in conjunction with a magnetic spectrometer having momentum acceptance between 130 and 240 MeV/c.

From invariance arguments and the assumptions of locality and the universal Fermi interaction for the leptons, the $K_{\ell 3}$ decay matrix elements can be written

$$M = \{f_+(p_\alpha + q_\alpha) + f_-(p_\alpha - q_\alpha)\} \times [\bar{u}_\ell(P)\gamma_\alpha(1+\gamma_5)u_\nu(Q)],$$

where $\ell = \mu$ or e, and p, q, P, and Q are the four-momenta of the K^+, π^0, lepton, and neutrino, respectively.

Theoretical interest lies in the measurement of the form factors $f_+(q^2)$ and $f_-(q^2)$, since here the strong-interaction effects become evident. Previous determinations of branching ratios, performed mainly in heavy-liquid chambers, have resulted in values of $\xi = f_-/f_+$ which show inconsistency with $K_{\mu 3}$ polarization data. This experiment was performed for further clarification.

Branching-ratio measurements comprising some 20 000 events, yielding approximately 300 events each in the $K_{\mu 3}$ and K_{e3} modes, are being planned. These measurements will be used to determine an estimate for the form-factor ratio ξ, and also to reduce the uncertainty in the $K_{\mu 2}/K_{\pi 2}$ ratio.

HEALTH PHYSICS

H. Wade Patterson in charge

DOSIMETRIC CALCULATIONS

Gerald M. Litton, Palmer G. Steward, and Roger W. Wallace

The penetration of heavy ions and the shape of the resulting Bragg peak for ions with Z as high as 92 and energies up to 500 MeV/amu in a variety of targets have been calculated, with nuclear interactions, multiple scattering, energy straggling, and initial energy and angular spread of the beam taken into consideration. This work has been reported.[1]

A beginning has been made on examining the details of the inelastic nuclear collisions between heavy ions and heavy nuclei. An incompressible liquid drop model has been used, and changes in surface and volume have been used to identify the various products formed and their energies. These data on inelastic events have been added to the Bragg-peak calculations, and the effect of the secondaries on the width and height of the peak has been evaluated along with the effect of the side scattering on a beam of finite width.

OPERATION HENRE

A. Jerry Miller, Joseph B. McCaslin, Alan R. Smith, Lloyd D. Stephens, H. Wade Patterson, and Harold A. Wollenberg, Jr.

Nuclear emulsions, moderated gold foils, and a U-fission track plate were used to measure neutron spectra, neutron air attenuation, and the neutron yield of monoenergetic 14-MeV neutrons produced 1125 feet above ground elevation. The source of neutrons was the Oak Ridge-designed D-T accelerator operated at NTS.

The nuclear emulsion data indicate that at distances of 1125 feet or greater, there are very few uncollided neutrons. The air attenuation data provided experimental verification of calculated attenuation lengths. The results of the fission-track plate agreed within a few percent with the published yield supplied by the HENRE Operations Group.

Similar measurements are planned with accelerator operation at 27 feet above ground elevation.

PHOTOPEAK ANALYSIS OF SEMICONDUCTOR γ-RAY SPECTRA BY COMPUTER

Jorma T. Routti and Stanley G. Prussin

Development of a method of analysis by computer of γ-ray spectra measured with Ge(Li) systems was continued. The computer code has been used on the CDC-6600 to perform complete analysis of data from both routine activation and accurate spectroscopic measurements. Methods and results were discussed in a paper presented at the Pacific Conference on Chemistry and Spectroscopy, Anaheim, California, October 30-31, November 1, 1967. A report describes this work more fully.[2]

FISSION TRACK DETECTOR DEVELOPMENT

Harold Wollenberg, Lowell Kleppe, and Dean Knight

Mica and Lexan were evaluated as detecting media in conjunction with U and Th foils exposed to various sources of neutrons: (a) a Pu-Be neutron source at LRL, (b) 14-MeV neutrons at the HENRE accelerator, NTS, and (3) broad-spectrum exposures in the lazy susan and exposure room facilities at the UC Campus's TRIGA reactor. Tracks are easiest to recognize in mica, and etching time appears to have little effect on track fading in mica.

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1. Gerald M. Litton, Program BRAGG: a Fortran-IV Program for Calculating Bragg Curves and Flux Distributions, UCRL-17391, Feb. 1967; Gerald M. Litton, Bragg and Flux Curves and Energy Spectra Due to the Penetration of High Energy Heavy Ions, Including Effects Due to Multiple Scattering, Nuclear Interactions, Straggling, and Energy and Angular Distribution in the Initial Beam (Ph. D. Thesis), UCRL-17392, Aug. 1967.

2. Jorma T. Routti and Stanley G. Prussin, Photopeak Analysis of Semiconductor γ-Ray Spectra by Computer, UCRL-17672, Dec. 1967.

Exchange of data and cooperation with people at NRDL is continuing to better establish parameters of the TRIGA's exposure room for forthcoming dosimetry and radiogeology experiments.

NEUTRON-ACTIVATED SAFETY SYSTEM AT THE 88-INCH CYCLOTRON

Henry S. Dakin and William W. Wadman III

A safety interlock system using a fast-counting BF_3 detector in a moderator has been built and is installed for use at the 88-inch cyclotron. The system will trigger an rf grounding crowbar at a neutron dose rate of 100 mrem/hr or greater. Whenever a man is required to be in the vault while various components of the accelerator are operative and the safety chain is temporarily modified, this system is activated, along with other safety precautions. Shutdown occurs in a period of time inversely proportional to the dose rate. The fastest time theoretically possible is 2×10^{-6} sec. The total dose to a person accidentally irradiated during accelerator testing with this system in operation is about 10 mrem of neutrons and 1 to 2 mrem of gamma radiation. The system is described in detail in a report.[3]

RADIOGEOLOGY

Harold A. Wollenberg, Jr., and Alan R. Smith

Evaluation of radiometric data from Eocene formations of the western Sierra Nevada indicates regional variations in relative abundances of U, Th, and K, and reveals Th concentrations > 100 ppm in some dark sands of ancient beach placers. Sampling and field radiometry of Precambrian and Paleozoic rocks of the eastern Sierra Nevada, Inyo, and White Mountains suggests a possible trans-Sierran east-to-west radioactivity gradient in pregranitic geosynclinal rocks. Fission-track analyses of Th and U in accessory minerals indicates a variation of Th content over three orders of magnitude in the mineral sphene from a suite of Sierran granitic rocks.

3. Henry S. Dakin and William W. Wadman III, Rapid Beam Cutoff for 88-Inch Cyclotron, UCRL-17728, May 1967.

BEAM EXTRACTOR MONITOR

Lloyd D. Stephens, Joseph B. McCaslin, Robert W. Allison, Jr., Kenneth C. Crebbin, and Tom Elioff

The spallation reaction Au → ^{149}Tb has been used as a high-energy threshold monitor for the Bevatron resonance beam-extractor system in order to determine beam profiles and intensities in the M1-Q1 and M2-Q2 areas.

^{149}Tb is a 3.95-MeV α-emitter which has a 4.1-hour half-life. The reaction threshold is about 600 MeV. Prior experience[4] on a system to concentrate and extract ^{149}Tb from Hg provided the instrumentation and capability for this work.

NEUTRON SHIELDING STUDIES FOR THE 88-INCH CYCLOTRON

William W. Wadman III and Alvin J. Miller

Results from shielding studies of forward-directed neutrons from a thick tantalum target bombarded by 50-MeV protons, 55-MeV deuterons, and 110-MeV α particles are being reduced from data acquired recently. The shielding configurations were: All concrete, 12-in. iron-faced concrete, and 12-in. depleted-uranium-faced concrete. The preliminary results are as follows:

Tenth-value layers measured in the concrete

Bombarding particles	All concrete (in.)	12 in. Fe (in.)	12 in. U, depl. (in.)
50-MeV p^+	11.75	9.5	9.4
55-MeV d^+	14.0	8.8	9.4
110-MeV α	13.2	10.0	10.4

Threshold detector activities were measured and will be used to derive the neutron spectra at 3-in. intervals through the concrete, as well as the effects of the heavy material on the high-energy neutrons in the spectra.

4. Joseph B. McCaslin and Lloyd D. Stephens, High-Sensitivity Neutron and Proton Flux Detector With a Practical Threshold Near 600 MeV, Using Hg(Spallation)^{149}Tb, UCRL-17505, April 1967.

NEUTRON STARS IN EMULSIONS

Harry H. Heckman and H. Wade Patterson

It was found by René Remy that there is a relationship between the number of gray prongs per star and the energy of the neutron that initiates the star. This work was previously reported.[5] Due to an oversight, emulsions were not previously processed identically, thus leaving open to question the exact definition of what proton energy gave rise to a gray prong. The possible application of this technique to neutron spectroscopy around accelerators and in space is interesting enough that we felt this should be redetermined on the basis of measured range rather than estimates of ionization. The first exposure was made at the 88-inch cyclotron to neutrons produced by 55-MeV stripped deuterons. About 0.5% of the stars produced showed a gray prong; range 1.9 mm, $E_p > 20$ MeV.

CERN SHIELDING STUDY

William S. Gilbert, Joseph B. McCaslin, H. Wade Patterson, Alan R. Smith, and Lloyd D. Stephens

All experimental data collected at the CERN proton synchrotron during September, October, and November 1967 have been analyzed, and a computer program has been written that successfully predicts the measured neutron fluxes found in the PS tunnel and in the earth shielding. All chapters of the report of this study have been written in at least first-draft form, and completion of the report is scheduled for January 1968. Preliminary results were presented at the Sixth International Conference on High Energy Accelerators, September 1967.[6]

AUTOMATIC DATA PROCESSING OF FILM BADGE EXPOSURE RECORDS

Lloyd D. Stephens, Olga M. Fekula, Michael Brock, Jr., and Gerald M. Litton

A film-badge exposure data-processing program has been run successfully, providing a calendar listing of both gamma and neutron exposures. This will be the usual output form, although several choices are available. Basic input information is provided by both tape and punched cards. An additional subprogram had to be written to deal with these two basic input forms. The four-digit film badge number and the six-digit personnel number create a basic difficulty which will cease only when an improved film perforator becomes available.

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5. René Remy, Neutron Spectroscopy by the Use of Nuclear Stars from 20 to 300 MeV (M.S. Thesis), UCRL-16325, Aug. 1965.

6. William S. Gilbert, Beam Loss and Shielding Experiments Relevant to High-Energy Proton Synchrotrons, UCRL-17797, Sept. 1967.

Computing and Data Handling

MATHEMATICS AND COMPUTING

James A. Baker in charge

INTRODUCTION

During the period of this report (May through October 1967), members of the Mathematics and Computing Services Group performed programming and mathematical tasks for the Laboratory research groups. These tasks may be divided roughly into the following eight general classifications:

1. Physics Applications Programming
2. Nuclear Chemistry
3. Accelerator and Magnet Design
4. Biomedical Applications
5. Miscellaneous
6. Systems Programming
7. Research in Mathematics and Computer Science
8. Computer Operations

The following summarizes the work of this Group in the above areas.

1. APPLICATIONS PROGRAMMING

A. PHYSICS

Powell-Birge Group

Herbert C. Albrecht, Esther H. Coleman, Harold Hanerfeld, Myron H. Myers, Joan R. Tyson, and John Visser, Jr.

The COBWEB[1] Project, a computer-controlled bubble chamber film measuring system, has been in production since June 9, 1967. Both measuring and scanning procedures have been implemented on the IBM 7044. The three devices now being utilized are a Franckenstein, a measuring microscope, and a scan table. Another Franckenstein is expected to be operational by November 15 of this year, with three more Franckensteins to be connected on-line in 1968. Editing programs have been completed on the CDC 6600 to transform measured COBWEB output to formats compatible with the SIOUX[2] and FOG bubble chamber data-analysis systems. These editing programs also separate scanned COBWEB output. In addition, a tape can be produced by these CDC 6600 programs which includes event, measuring machine, and measurer statistics. Approximately 10 000 events have been measured, with less than 1% of these events failing in the reconstruction phase of the FOG System. The IBM 7044 COBWEB program continues to be improved in the areas of physics data checks, ease of computer operation, measuring speed, and flexibility.

The bookkeeping programs LIBRO[3] and BOOKIE[4] have been changed to handle different input tape formats and to aid in the study of scanning efficiency.

Improvements were made to several programs, TABS,[5] VBTABS, and LOGFILE, which deal with scanning-and-measuring machine utilization, measurers' work rates, etc. These changes include program conversion to the CDC 6600, different input tape formats, and expansion in order to generate meaningful statistics concerning the COBWEB system.

The SUMX[6]-type selection and display routines, MODULES, have been organized into functional packages. Extensive write-ups were completed on the organization and use of each package. Several control programs were written to utilize these routines.

A program, HIGH,[7] was written which generates high energy (100 BeV/c) events of the types

1. Eugene P. Binnall and Myron H. Myers, COBWEB: IBM 7044/On-Line Bubble Chamber Film Measuring Machines, UCRL-17136, Sept. 1966.
2. Physics Division Semiannual Report (henceforth abbreviated "PDSR"), UCRL-16511, Nov. 1965, p. 25.
3. PDSR, UCRL-17544, May 1967, p. 36.
4. PDSR, UCRL-16863, May 1966, p. 32.
5. PDSR, UCRL-11132, Nov. 1963, p. 71.
6. Max Leavitt, SUMX6600, Alvarez Programming Notes P-135 and P-137, April 14, 1966.
7. PDSR, UCRL-17544, May 1967, p. 37.

$$K^- p \rightarrow \Sigma^+ \begin{cases} \pi^- \pi^0 \\ \pi^- \end{cases}$$
$$\hookrightarrow \begin{cases} p\pi^0 \\ \pi^+ n \end{cases}$$

HIGH, in conjunction with the kinematics program BISE,[8] is being used to study the effects of high energies on the analysis of bubble chamber events.

The input to HIGH specifies the event hypothesis to be generated. The momentum, dip angle, and azimuth angle for each particle are generated. Normally, distributed errors are introduced for the "measured variables." The "measured variables" are read into BISE, which tries to kinematically fit these "measurements" to each of the four interpretations.

Some initial results are already indicated. Events generated with an extra π^0 at the production origin do not fit the hypothesis without the extra π^0. Events generated without the extra π^0 at the production origin do not fit the wrong decay hypothesis. A discussion of the results as they relate to the other hypotheses would be too long for the purposes of this report, and will be presented elsewhere. Analysis of this early work is still continuing.

Further studies will be made with HIGH. The effects of large errors (poor measurements) on the measured variable will be examined for effects on the fits.

Trilling-Goldhaber Group

Nick Armstrong, Emmett R. Burns, Jr., Bronwyn H. Hall, Daniel P. Lamb, and James G. Miller

The conversion of all production programs to the CDC 6600 computers was completed; all new experiments are being processed with 6600 versions. Some of the older experiments still require occasional processing on the IBM machines.

The program TGIF[9] has been converted from the IBM 7044 to the CDC 6600. In the process of converting it, the program was made more efficient by reducing its core size and improving its execution speed. Several special options were added which made it easier to locate problems with certain events.

8. Harold Hanerfeld, BISE: A Two-Vertex Kinematics Program, UCRL-17473, March 1967.
9. A. D. Johnson, Preliminary Trilling-Goldhaber Memo No. P-118 (not for distribution outside Laboratory).

A new summary, which enables the physicists and scanners to locate problems sooner, is now available after each run. Modifications were made in the vertex routine in order to decrease the reject rate for certain classes of events.

Experiment-dependent constants and event types have been added to SIOUX for three additional experiments now being processed with it. Work has also continued on decreasing the reject rate for classes of events that give trouble. Preliminary work has started on the problem of incorporating the film-plane vertex reconstruction into TVGP.[10]

Logical and card-select routines have been incorporated in ARROW[11] for the current experiments.

The programs PANAL,[12] PACKAGE,[13] EXAMIN,[14] and SELECT[15] have been modified and maintained in order to complete the experiments started with this system.

The program CHAOS[16] has been reduced in core size and improved in running time. Some CRT routines have been added and additional work is being done to give CHAOS both CRT options and access to the express mode of the CDC 6600.

The Franckenstein library program FLIB[17] has been completed and is being used for production. Planned future additions will enable the user to process TGIF and PANAL data.

Debugging of PHONY[18] has progressed so that various modes of operation now work satisfactorily. Debugging of the routines by introducing multiple-scattering and film-setting errors is currently in progress. Future work is planned for decreasing the running time and adding other options.

10. A. D. Johnson and T. B. Day, Three-View Geometry Program, Alvarez Programming Note P-117, June 8, 1965; PDSR, UCRL-16511, Nov. 1965, p. 24.
11. E. A. Romascan, R. W. Casey, T. R. Tonisson, and O. I. Dahl, 6600 ARROW System, Alvarez Programming Note P-147.
12. M. Hutchinson, PANAL, Alvarez Programming Note 358 Rev., Feb. 1, 1963.
13. Barrie Pardoe, PACKAGE, Alvarez Programming Notes P-27, Jan. 30, 1963, and P-40, April 22, 1963.
14. Dave Johnson, EXAMIN, Alvarez Programming Note P-271, Dec. 1, 1961.
15. PDSR, UCRL-11776, Nov. 1964, p. 26.
16. PDSR, UCRL-11132, Nov. 1963, p. 51 (or see Derik Armstrong, Mathematics and Computing).
17. PDSR, UCRL-17544, May 1967, p. 37.
18. PDSR, UCRL-17544, May 1967, p. 37.

The subroutine XGRAPH[19] has been rewritten for the CDC 6600. Some new features were added at the same time.

A program using VARMIT[20] is being used to fit mass histograms at various reaction energies to an expression involving Breit-Wigner and background terms. Gerson Goldhaber's program to do phase-shift analysis by use of VARMIT was modified to fit data from more than one reaction energy at the same time.

Spark Chambers

Eric R. Beals, William H. Benson, Leslie D. Wilson, and Donald H. Zurlinden

The programs DCGLOP and SHOWER were written for analysis of the Schrock np → γd cyclotron experiment. The first reduces data from four wire chamber modules to points in space and then determines particle momentum by using standard orbit codes; the second determines shower vertices in the γ chambers from film measurements automatically scanned by the PDP-5 Vidicon system.

DDP-24

Film scanning programs for the DIBOSON[21] experiment were completed and the remaining film (containing approximately 10^6 events) was scanned.

Work was begun on preparing film scanning programs for Bevatron experiment #67, the K_{e2} branching experiment. The experiment will utilize linear and circular-gap spark chambers, and will contain shower as well as straight track data. The program FTIC[22] was generalized to scan side chambers, as well as the circular chamber, and new setup programs were designed and coded.

19. The original writeup is available, if necessary, from Judith Lawrence, Bldg. 50B, Rm. 1237A, Ext. 5529.
20. Laboratory Computer Center writeups Z0 E0 Z013 and Z0 E0 Z014 are available from Judith Lawrence, Computer Center Library (Bldg. 50B, Rm. 1237A, Ext. 5529).
21. D. H. Zurlinden, Computer-Controlled Reduction of Spark Chamber Film, UCRL-17695, Aug. 1967; and PDSR, UCRL-16511, Nov. 1965, p. 27.
22. PDSR, UCRL-16511, Nov. 1965, p. 27.

B. NUCLEAR CHEMISTRY

Esther H. Coleman, Ruth L. Hinkins, David W. Jenson, Gerald M. Litton, and Claudette E. Rugge

A program DAMGARD was written to compute radial integrals between atomic levels for the purposes of calculating Stark effects and oscillator strengths. The Bates-Damgaard method was used.[23]

A set of programs named EDEN has been written to calculate operator equivalent factors and crystal field matrix elements for intermediate coupled wave functions for f^n configurations.

In the study of fission fragment angular distributions, the standard Halpern-Strutinskii theory was reparameterized to include known optical-model transmission coefficients. Program KNOTTY was written to determine the parameter K_0^2, which is the standard deviation of the assumed Gaussian distribution of the total angular momentum component on the nuclear elongated axis. The input to the program is corrected from an average position on a rectangular scan of mica, which is used to detect the fission fragments, to an average angle within the circular mica chamber, and then converted to the center-of-mass system.

Program KNOTTY is presently fitting measured 29- to 50-MeV helium-ion-induced fission fragments from targets of ^{206}Pb and ^{207}Pb.

Program TEASE was written to aid in the analysis of x-ray–γ-ray spontaneous fission fragment events as they were collected on tape from a Nuclear Data 1024-channel pulse-height analyzer. The program distinguishes, under input control, up to nine event types with as many as four recording dimensions and as many as four nonstabilizing events. Distributions are formed, saved, and accumulated from tape to tape on all specified event types and their associated dimensions, and the nonstabilizing coincidence events are sorted and compressed on tape for future processing according to fission-fragment mass and energy.

23. D. R. Bates and A. Damgaard, The Calculation of the Absolute Strengths of Special Lines, Phil. Trans. Roy. Soc. (London) A 242, 101 (1949).

Nonlinear least-square programs FELSPAR and TAILSIG were written to analyze photoelectron and x-ray–γ-ray coincidence fission product spectra, respectively, using a sum of Gaussians with two different fitting functions. The user has the option of fixing area ratios among as many as four peaks while fitting mean values, area, standard deviations, and exponential tailing constants.

A program SPECT30 was written to utilize the VISTA system to process and analyze γ-ray spectra. The routine permits background specification by means of the light pen. It also allows the user to specify boundaries of peaks in the spectrum.

Two types of spectra are analyzed: standards and unknowns. The standards are used to calibrate the channels of the spectral analyzer. On-line override of the calibration is a feature of the program.

The final calibration is then used to identify peaks in an unknown spectrum. The user specifies the peak limits and draws in the background with the light pen, and the program then calculates the energy and other pertinent information related to the peaks.

A programming system is being written to handle data on-line from a Bevatron experiment. The hardware consists of a PDP-8, an Ampex TM-7 tape unit, a Data Disk M-6 disk, a CRT display operating directly from the disk, an experimenter's control console, and possibly a CalComp plotter and equipment to control the experiment from the computer. Data are accepted from an ADC and a multiplexer. The data that arrive during the 1-sec Bevatron beam burst consists of up to 1000 events characterized by four 12-bit words each. These data are placed on magnetic tape and the results of the preliminary analysis of the data are sent to the disk. In between beam bursts the data are analyzed further and used to update and display a number of histograms on the CRT.

C. ACCELERATOR AND MAGNET DESIGN

Richard G. Ahlstrand, Robert A. Belshe, Victor O. Brady, Bruce R. Burkhart, Thomas P. Clements, Elon R. Close, John S. Colonias, Robert N. Healey, Ardith S. Kenney, Barbara S. Levine, Bob M. Powell, Steven J. Sackett, Edna E. Williams, and Jonathan D. Young

Magnet Design

Program LINDA,[24] a two-dimensional magnetostatic program, has become operational and is used for both the National Accelerator Laboratory and the AGS Study Group.

Program TRIM[25] is being revised and updated to increase its accuracy and speed. An IBM 360/75 version of TRIM has been completed and is operational at SLAC and at Argonne National Laboratory.

Program TAMI,[26] a general-purpose code for the solution of three-dimensional magnetostatic problems with variable μ, is 60% completed.

A new version of TRIM called POISSON has been completed. This version is considerably faster than TRIM, and includes the calculations of axially symmetric fields.

Program SMIRT has been completed to solve electrostatic problems.

Orbit Studies

Program OPTIK[27] has been converted for use on the CDC 6600. This program has been adopted for on-line graphic output, and allows the experimenter to view the results and interact with the program via a teletype and a light pen.

A simplified version (PDP8OPT) of the OPTIK beam-analysis program has been written for the PDP-8 Computer.

Program SYNCH[28] has been reorganized and partially rewritten to allow easy conversion to other machines. Machine-dependent coding is concentrated in a few utility routines; a version with unpacked data storage has been

24. PDSR, UCRL-16863, May 1966, p. 31.
25. J. S. Colonias and J. Dorst, Magnet Design Applications of the Magnetostatic Program Called TRIM, UCRL-16382, Sept. 1964.
26. Steven Sackett, A Computer Code (TAMI) for Magnetic Fields in 3-D Space with Magnetic Materials Present, ENA66-371, Jan. 3, 1967.
27. Thomas J. Devlin, OPTIK: An IBM 709 Computer Program for Optics of High-Energy Particle Beams, UCRL-9727, Sept. 1961.
28. A. A. Garren and J. W. Eusebio, SYNCH--A Computer System for Synchrotron Design and Orbit Analysis, April 1965.

prepared. Also, a version of SYNCH with on-line graphic input-output facilities has been prepared to allow on-line interaction.

Program SOTRM,[29] a beam transport program, has been completed. This program calculates the first- and second-order transfer matrices associated with any magnetic element for which a field configuration can be furnished.

Special Projects

MIM66, a program to do digital simulation of analog solution to differential equations, is being modified (from the program MIMIC[30]), and additional features are being added such as teletype communication and graphic display output.

Work on the 184-inch cyclotron improvement project is continuing. An attempt is being made to improve the operation of the present regenerator system, and computation of the extraction efficiency of the cyclotron has been started.

Because the long-term behavior of solutions of nonlinear algebraic equations with periodic coefficients is of interest in connection with the study of stability of proton beams in a storage ring, the behavior of several nonlinear transformations is being extensively investigated.

The computer code, PYRMI, is an extensive modification of the Linear Accelerator Design Code, PARMILA.[31] The latter was written in FORTRAN II by T. Swenson. The modification was written in CHIPPEWA FORTRAN for the CDC 6600. While retaining all the computational features of the original code, it provides, in addition, for the omission or arbitrary assignment of strength and polarity for any of the cell quadrupoles and for the insertion of complex magnetic systems consisting of quadrupoles and bending magnets with wedge angles in the pre-, inter-, and posttank spaces.

In PARMILA, linac design is the fundamental function of the code. Particle tracking is performed after the design phase; hence, the tracking feature is not useful for a linac already designed and in use. PYRMI provides optionally for the design parameters to be specified by data rather than being computed. This feature makes particle orbit computation possible for an existing accelerator (such as the Bevatron linac) whose parameters are known.

The code, BYRMI, is a streamlined reduced-array-dimension version of PYRMI written for the Bevatron linac. This code uses much less memory space and less computer time. In addition to output plots of PARMILA, BYRMI provides for the construction of histograms for variables of interest.

29. PDSR, UCRL-17544, May 1967, p. 39.
30. PDSR, UCRL-17544, May 1967, p. 39.
31. PDSR, UCRL-17544, May 1967, p. 39.

D. BIOMEDICAL APPLICATIONS

Esther H. Coleman, William D. Hogan, Mark W. Horovitz, Gerald M. Litton, Thomas F. Mahan, Marjory C. Simmons, and Kenneth G. Wiley

Data Processing

Our computer processing system for medical data has been demonstrated to Donner Laboratory physicians and is now in routine use. The system includes a program MEDPIC, which enables the user to request, via a VISTA console, the production of on-line CRT displays and off-line plots on microfilm or on a CalComp plotter. Program TAPEUP was written to permit changes to be made on MEDPIC input tapes.

A program DOSIT was written for the Health Physics Group to be used in conjunction with the existing program PEDRO. DOSIT provides tabulations of cumulative radiation exposures of LRL personnel.

A study of clinical trials has been completed and reported.[32, 33]

Radiation Effects

The VISTA section of program TELLY[34] has been rewritten and improved. Program MAGMAP was written to draw contour plots of ionization intensity in the vicinity of a cyclotron beam. A radiation dose-planning program DOSMAP1 was written to calculate depth-dose distributions within a homogeneous body. The program can be used for any number of confocal, coplanar beams or to simulate rotational doses. The contour of the body is approximated by a polygon and the ionization produced by each beam is adjusted according to the depth of material penetrated.

32. William Hogan, On Clinical Trials, UCRL-17582 Rev., May 1967.
33. William Hogan, Bibliographical Note on Controlled Clinical Trials, UCRL-17698, July 1967.
34. PDSR, UCRL-17544, May 1967, p. 41.

An ALGOL program which computes depth-dose distributions has been translated into the FORTRAN program KALNAES. This program carries out calculations for coplanar, confocal beams applied to convex bodies that may be inhomogeneous. An analytic expression is used for the depth-dose function.

Program BRAGG[35] was modified to permit the calculation of an energy spectrum at any chosen depth in the target and to give a greater variety of plotting options. The program was adapted for use in conjunction with program IONPIE.[36] BRAGG was extended to include effects of secondary particles and to permit its use for calculations with low-energy heavy ions.

Kinetic Models

A large amount of iron kinetics data has been processed by use of program IRK[37] in order to determine ranges of values for the parameters of a model.

A program FINDR has been written to solve Volterra integral equations representing processes of erythro-kinetics.[38] This method is simpler than an approach which had been used previously.

Program BURDEN was written to determine the amount of radioactivity in an object at any time. This quantity is computed by using an absorption function and a retention function, both of which are dependent on time.

Several programs have been written to determine the parameters of models of amino acid metabolism by least-squares fitting. Data used by the programs are obtained from $^{14}CO_2$ breath analyzers.

Program STEM was written to study some ordinary differential-equation models of the regulation of hematological stem cell kinetics. Solutions can be observed and parameter values entered on-line at a VISTA console.

Instrumentation

Programs have been written to read, correct, store, and analyze data punched on paper tape by an X-Y scanner at the 184-inch cyclotron. Assistance has been given on programs which read data and carry out Fourier analysis of NMR spectra. Some fast Fourier transform programs have been tested.

Imaging properties of scintillation cameras were studied. Formulas for the response to some simple test patterns were derived.

E. MISCELLANEOUS

Mannie L. Clinnick, Esther H. Coleman, Thomas F. Mahan, and Deanna A. Wilber

Work has continued on PUZZLE,[39] and a new version is currently being used for production runs. An improved input procedure is the major modification in the new version. Because of the increased use of dual in-line packages on printed circuits, a simple code input has been implemented for both 14- and 16-pin packages. An engineering note[40] has been issued which gives a fairly detailed users' manual, as well as a brief history of the code. A writeup of the current working version is available.[41]

Work has started on a PDP-5 programming system for a computer-controlled rapid magnet mapper. "PDP-5 Rapid Magnet Mapper" project is intended to supplement, and later, perhaps, replace, the two existing rapid mappers now in use. The present mappers include what are essentially special-purpose digital computers, which collect data used to construct field-strength maps for large magnets. With a general-purpose computer in the system, a large gain in flexibility will be realized, as well as a potential increase in speed of measurement--perhaps as much as fivefold.

The program QUAD was written to compute ion trajectories in the quadrupole mass spectrometer by the numerical integration of Mathieu's equation. The resultant paths are displayed in plots produced by the CalComp plotter: deviations in the x or y direction versus time, axial plots of the x solution versus the y solution, and perspective plots of the x and y solutions combined versus time.

The program GUESS, which used electrostatic and spin-orbit parameters to calculate

35. Gerry Litton, Program BRAGG, a Fortran IV Program for Calculating Bragg Curves and Flux Distributions, UCRL-17391, Feb. 1967.
36. PDSR, UCRL-16511, Nov. 1965, p. 30.
37. PDSR, UCRL-16511, Nov. 1965, p. 31.
38. Grove C. Nooney, Iron Kinetics and Erythron Development, UCRL-11879 Rev. 1, May 1965.
39. PDSR, UCRL-16511, Nov. 1965, p. 30.
40. Deanna Wilber and Ron Zane, Development of "PUZZLE": A Program to Aid in Printed Circuit Layout Design, EE-1215, July 28, 1967.
41. Ronald Zane and Deanna Wilber, PUZZLE: A Program for Computer-Aided Design of Printed-Circuit Artwork, UCRL-17814, Sept. 1967.

energy levels, eigenvalues, and g-values for f^n configurations, was converted from the 7094 to the 6600.

An EDP filing system for drawings and blueprints has been created for the Mechanical Engineering Department. Computer programs were written to create files for each major project (Program HANDLE), and to update such files (NUMFIX, CATFIX). Programs PRNTNM and PRNTCT produce printed copies of the files in a convenient format.

F. SYSTEMS PROGRAMMING

Eric R. Beals, William H. Benson, Robert A. Belshe, Jerry T. Borges, Douglas N. Brainard, Penny A. Collom, William F. Dempster, Robert L. Fink, John Garratt, Judy E. Glasner, Walter H. Hutchinson, Joyce P. Johnston, Jeremy A. Knight, David J. Moss, Samuel J. Penny, David F. Stevens, and Robert E. Tracy

PDP-5/8

Further refinements of the PDP-8 disk system programs have been made by improving the disk input-output routines and the tape-to-disk-to-tape editor.

The PDP-5/8 floating-point package has been improved by decreasing execution time of these routines and by reducing the amount of core used. Several new functions have been added. Complete description is available.

Preliminary work on a data-acquisition compiler for the PDP-8 will allow a user to prepare data-handling programs in a FORTRAN-like language.

PDP-7

A time-sharing system for a real-time processing environment is being written for Nuclear Chemistry's PDP-7. Planning and design of the system are almost completed.

Data collected during an experiment are entered directly into memory from one or more ADC's through the data-break facility of the computer. Communication between the user at the site of his experiment and his program in the computer is available through a number of CRT display scopes and associated remote-control consoles.

The 8K computer memory can be variably divided to contain up to eight user programs, each protected from any core modifications by any other user program currently residing in memory. The executive system cycles control of the processing unit between the user programs and handles all input-output operations.

6411

ASOP was extended to provide system input-output facilities to both 6600's; this service results in a 30% reduction in the number of 6600 disc requests. The ability to "attach" a teletype or 210 console to a program executing on a 6600 was provided. Two job status inquiry features were provided: one giving the status of a specified job, the other a listing of all jobs since the previous dead start. The 210 console driver was modified to permit the sharing of a single PPU with the DD60 driver.

PDP-5 Link

Read-and-write drivers, designed to make the link available through standard FORTRAN input-output statements, have been written; final checkout is awaiting the availability of the hardware. When complete, the link will permit nearly on-line processing by the 6600 of sample data from Bevatron or cyclotron experiments.

Mass Storage System

Preliminary external specifications have been prepared and released as Mathematics and Computing Memo #302; internal specifications are in preparation and coding has begun on some sections.

6600

Improved facilities for saving and restoring the contents of a 6600 were implemented. This is useful both for "running down" a computer prior to preventative maintenance (PM) time and for reducing time loss resulting from hardware malfunction.

An improved method of disk track allocation and control was implemented; job scheduling was modified to provide better service for high-priority jobs; a means for the automatic, periodic rerunning of certain (accounting and maintenance) jobs was instituted. A new dynamic priority-assignment algorithm has been prepared and is being evaluated.

The program library was made accessible (from both 6600's) from the disk pack or the data cell.

The investigation into methods of evaluation-systems performance ended when Charles Symons returned to CERN. It was determined

that PPU (peripheral processing unit) resident monitoring routines can easily provide much information which can be gained in other ways only with great difficulty, if at all. Such routines formed the basis of a comparison between the BKY 30 system and CDC's standard SCOPE 3.0 system; they indicated that BKY 30 is superior in input-output bound situations, while SCOPE 3.0 showed better overall throughput.

The microfilm driver was rewritten to write in direct mode, providing a factor-of-15 improvement in speed.

2. RESEARCH IN MATHEMATICS AND COMPUTER SCIENCE

Paul Concus, Daniel Drake, David W. Jenson, Loren P. Meissner, Grove C. Nooney, Leo S. Vardas, and Jonathan D. Young

Transient Diffusion in a Composite Slab

Work was completed on a paper (Paul Concus and D. R. Olander, Transient Diffusion in a Composite Slab, UCRL-17607, June 1967) in which the solution of the diffusion equation for two slabs of different materials of finite thickness in contact at a plane interface was obtained numerically by using a truncated eigenfunction-series technique. The paper will appear later in the International Journal of Heat and Mass Transfer. Supplementary tables required for the solution were also prepared, and appear in the report: Paul Concus, Table of the Solutions of $a \cdot \tan(\pi x) = -b \cdot \tan(a \pi x)$, UCRL-17608, June 1967.

Heat Transfer Through a Rotating Nuclear Target

The approximate periodic, steady-state temperature of a rotating nuclear target system was found by solving the equations for a one-dimensional model of the system by a method similar to the one above. A report describing the work is being prepared.

Numerical Solution of the Two-Dimensional Laplace Equation

A library program, D3-BKY-LAPL, was written to numerically solve the Laplace equation in a two-dimensional simply connected bounded domain subject to boundary conditions of the first, second, or third kind. The program obtains the solution by approximating the given boundary values in the least-squares sense with a linear combination of harmonic polynomials.

Nonlinear Block-Successive Overrelaxation

Work was begun in formulating a nonlinear block-successive overrelaxation method to solve two-dimensional elliptic quasi-linear partial differential equations. Preliminary results for the magnetostatic-field equation have indicated the method to be a promising one.

Error-Propagation Analysis for Iterated Algebraic Transformations Based on Affine Matrices

For a computation which consists of a simple algebraic transformation on two variables, iterated many thousands of times, a method was developed for analyzing the propagation of errors, including perturbations of the initial values of the variables, as well as round-off errors that occur during the iteration.

The first phase in this development was the programming of a set of multiple-precision floating-point interval arithmetic routines, which were collectively named DIABLO (A1 BKY DIABLO: available from the Computer Center Library). These routines are capable of performing addition, subtraction, and multiplication of variables with any specified precision up to a maximum of about 600 decimal digits. Each variable represents an interval; the left (most negative) end of the interval is stored in multiple precision, and the width of the interval is stored in single precision. The basic method used was suggested by Professor R. J. De Vogelaere of the Mathematics Department, University of California, Berkeley.

When these multiple-precision routines were applied to the iteration, it was found that the interval width did not provide a suitably close error estimate. The second phase was initiated, which consisted of the implementation and testing of a method of error-propagation analysis based on the matrix representation of an affine transformation (that is, a linear transformation combined with a translation). The linear transformation corresponds to the usual perturbation matrix (the Jacobi matrix of the transformation), while the translation corresponds to round-off. The iteration is performed by using the multiple-precision routines with the interval width set to zero; some excess precision is used in the calculation so that a very close estimate of the round-off can be obtained. After each iteration, the variables are rounded and the error thus induced is entered as the translation part of an affine matrix which applies to that step, and the linear part of the same matrix is formed by the perturbation effect intro-

duced at the same step. The cumulative product of all these affine matrices gives an overall affine matrix, which provides an estimate of the accumulated error that is valid for small perturbations of the initial values provided that the cumulative round-off error never gets so large as to invalidate the first-order perturbation theory.

Cubic Spline Fitting

Cubic spline fitting has been applied to a set of points

$$(t_i, x_i);\ i + 1, I \quad \text{with } I \geq 3$$

to obtain

(i) a computational definition of a smooth curve (segmented cubic)

$$x(t);\ t_1 \leq t \leq t_I$$

such that

$$x(t_i) = x_i$$

and that

$$x'(t) \text{ and } x''(t) \text{ are continuous};\ t_1 \leq t \leq t_I;$$

(ii) the values for

$$x'(t_i);\ i = 1, I$$

which, together with the x_i, determine the function $x(t)$, which is a segmented cubic;

(iii) the values for

$$x''(t_i);\ i = 1, I$$

which, together with the x_i, determine the curvature of $x(t)$ at the t_i;

(iv) interpolated values of

$$x(t^*),\ x'(t^*),\ x''(t^*), \text{ and } x'''(t^*)$$

for any t^*; $t_1 < t^* < t_I$.

The computer subroutine, SPLYND, has been written in Chippewa FORTRAN for the CDC 6600 to perform the functions (i) and (ii) above. The report, Jonathan D. Young, Approximate Differentiation by Cubic Spline Fitting, UCRL-17659, June 1967, was written to describe the process in more detail. The report, Jonathan D. Young, Numerical Applications of Cubic Spline Functions, UCRL-17742, Aug. 1967, discusses higher-order differentiation, numerical integration, and interpolation by means of the cubic spline fit. An article also entitled "Numerical Applications of Cubic Spline Functions," combining and condensing the material of the two reports, is to appear in the December 1967 issue of the Logistics Review.

Stability of Stem-Cell Populations

Mathematical analysis shows that stable control of stochastic proliferation of stem cells may be based on the probability distribution governing their differentiation and on a desired or optimal size of the stem-cell population. Such control has a simple biological interpretation that includes the assumption of stem-cell avidity for a mediating substance.

Information in Biological Systems

A lecture with the foregoing title was delivered at a seminar of the Biology Department, University of California, Santa Barbara. The thesis of the lecture was that transmitted genetic information cannot include an explicit description of an organism, but may include data with instructions defining how physical law is to operate on the data. A parallel with stored-program computers was suggested, as well as the connection between the development of an organism and the internal modification of instructions.

Miscellaneous

BLIMP (Bit and LIst Manipulating Processor) is a 6600 version of L^6 which has been modified to provide FORTRAN compatibility in the sense of subroutine linkages and COMMON-DIMENSION statements. Block pointers; that is, L^6 "bugs," and field definitions are stored in FORTRAN-like variables. Thus, unlike L^6, field names are not restricted to single characters and concatenation is represented by a series of field names separated by blanks. Compile-time-defined fields which result in a faster-running object code have been added to BLIMP.

The BLIMP compiler has been written in BLIMP (1960 cards) and hand-translated into ASCENTF (7200 cards). The object code produced by BLIMP is also ASCENTF in order to achieve FORTRAN compatibility under the Chippewa Operating System. The hand-coded version of BLIMP will translate the BLIMP compiler in about 11.5 seconds, or better than 10 000 cards per minute.

3. COMPUTER OPERATIONS

Paul A. Rhodes and F. Marvin Atchley

On July 4, 1967, a second CDC 6600 was delivered to the Laboratory. This CDC 6600 configuration consisted of one 6600 main frame, one 6602 console, three 6603 disk files, two 854 disk pack drives, eight 607 tape drives, two 501 printers and controllers, and one 405 card reader and controller.

The system was installed and power was turned on exactly at noon on Thursday, July 6, 1967. Control Data Corporation installation personnel started debug runs on July 7, 1967. On July 18, 1967, the Laboratory started acceptance tests on this machine. These tests were completed on August 17, 1967, with a result of 99% up time during the 30-day acceptance period. The utilization of both CDC 6600's in terms of the number of jobs run per month is as follows: May, 15 991; June, 16 327; July, 18 712; August, 27 119; and September, 23 409.

In August, Computer Operations began full-time operation of the CDC 6411 (ASOP) program, controlling the input and output of our two CDC 6600 Computers. In addition to decreasing turn-around time, ASOP allows job-status inquiries from remote consoles. Five DD-10 consoles and four teletypes allow job-status inquiry and direct user-program communication from remote locations.

The Computer Center Magnetic Tape Library now contains more than 16 000 reels of tape and has a monthly fetch rate in excess of 10 000 reels.

Plans were completed and work has begun on the site for the IBM Photoscopic Chip Storage device. This device will be delivered during the first quarter of calendar year 1968. When delivered, it will be installed in Building 50B as an on-line storage device connected to the CDC 6600's.

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1. Paul Concus and D. R. Olander, Transient Diffusion in a Composite Slab, UCRL-17607, June 2, 1967.
2. Paul Concus, Table of the Solutions of $a \tan(\pi x) = -b \tan(a\pi x)$, UCRL-17608, June 2, 1967.
3. Paul Concus, Numerical Solution of the Minimal Surface Equation, Math. Comp. 21, 340-350 (1967).
4. Harold Hanerfeld, BISE--A Two-Vertex Kinematic Program, UCRL-17473, March 28, 1967.
5. Gerald M. Litton, Program BRAGG--A FORTRAN-IV Program for Calculating Bragg Curves and Flux Distributions, UCRL-17391, February 24, 1967.
6. Gerald M. Litton, Penetration of High-Energy Heavy Ions, With the Inclusion of Coulomb, Nuclear, and Other Stochastic Processes (Ph. D. Thesis), UCRL-17392, August 1967.
7. Deanna Wilber and Ron Zane, Development of "PUZZLE": A Program to Aid in Printed Circuit Layout Design, UCID-3079, July 28, 1967.
8. Ronald Zane and Deanna A. Wilber, PUZZLE: A Program for Computer-Aided Design of Printed-Circuit Artwork, UCRL-17814, September 12, 1967.
9. Jonathan D. Young, Approximate Differentiation by Cubic Spline Fitting, UCRL-17659, June 12, 1967
10. Jonathan D. Young, Numerical Applications of Cubic Spline Functions UCRL-17742, August 1967), Logistics Rev. 3[14], 9 (1967).

DATA HANDLING

Howard S. White in charge

COMPUTER PROGRAM DEVELOPMENT

Dennis Hall, editor

HAZE: Semiautomatic Event Measurement

Carol Osborne, Joyce Crawford, James Greene, and Priscilla Davis

The real-time HAZE program (420) continued in routine production operation. Substantial increases in the amount of available computer time brought the event measurement rate up to 14 400 events per week by the end of October. This weekly rate corresponds to a yearly rate of 750 000 events per year, and represents nearly the full capacity of a single FSD. The addition of a tandem FSD unit would increase this capacity to approximately 1.5 million events per year.

A sixth scanning table (SPVB) was completed and the appropriate changes to the HAZE programs were inserted. The full scanning capacity of the six SPVB tables is 900 000 events per year. Modifications to the programs to allow processing of data scanned at the Riverside campus were completed, and a test sample of 6 500 events from Riverside was processed. This experiment is being done in collaboration with the Powell-Birge Group.

A special-purpose scan-tape editing program for the Segrè-Chamberlain Group was written and debugged.

FOG: Geometry and Space Reconstruction

Joan Franz and Frank Windorski

The FOG three-view geometry program (140) continued in routine production operation. Minor modifications for processing stopping incoming tracks were made.

Program 137B continued in routine production operation, with occasional minor modifications to handle special cases arising in various experiments, and addition of new adjustable constants to handle new subexperiments as required. An option to accept FSD fiducials instead of Franckenstein fiducials was added in order to make 137B compatible with COBWEB data.

CLOUDY: Kinematical Analysis

Vivian Morgan and Ray Sanchez

Routine production operation of the CLOUDY programs continued. The problem of simultaneous two-vertex kinematical constraints of Σ decays continued to be studied.

FAIR: Data Display

Loren Shalz and Donna Chrisler

The FAIR system of programs continued to operate in routine production operation. Development was almost entirely in the area of special calculations for the Powell-Birge Group. Two procedures for utilizing ionization information from the FSD for identifying mass hypotheses were developed and partially coded.

The FAIR master dictionary was brought up to date and prepared for distribution.

Program 437 was modified to produce fixed-record-length tapes for input to the less flexible CDC 6600 system.

TRIST: System Monitor

Carol Osborne and Priscilla Davis

The tape-handling subroutines were reassembled, resulting in a shortening of the space required as well as an increase in flexibility. The TRIST restart procedure also was rewritten and incorporated into the operating systems. Debugging of B-level logic, essential to the economic operation of DAPR, continued.

Documentation of all systems subroutines was completed, and changes to allow for additional system disk storage were implemented.

Event Accounting

Shirley Buckman, Carol Osborne, and Priscilla Davis

Subroutines were added to the FOG programs so that event-accounting source records are now written during FOG production runs.

A subroutine to produce event-accounting source (EAS) records during 432 production runs was written, and should be in production soon.

Range information is now carried on the event-accounting tapes. As many as four tracks per event can be named as being range tracks.

Experiments 03, 04, 05, 06, and 07 have been added to the list of experiments for which event-accounting master tapes are being kept.

Considerable analysis preceded the decision to express the vertex points in centimeters in real space at the top glass plane (usually z = 0.0) as seen by camera 1. The vertex point is calculated at several levels of processing from scanning through FOG. Since in event accounting the vertex is a part of the identification of an event, it is essential that the scanned vertex match the FSD vertex and the FOG (space) vertex, within a reasonable tolerance.

There are two routines that generate the vertex point. One is a subroutine, to be used in programs 422, 435, 442, 432, 516, and 137B. It calculates from scan-table least counts or from microns on film to the real space expression. (This subroutine will be modified to produce the camera 1 expression given camera 2 or camera 3 input.) The other routine calculates the top glass coordinate from x, y, and z in space as is available in FOG. The results from these two routines have been checked for all chambers, and agree well within the 3-cm tolerance that we are currently using.

Program 442 was written and debugged. This program will replace Programs 438 and 435, and will both merge scan-tape data and (or) produce an event-accounting source tape. Program 443 was written as a diagnostic aid. It dumps event-accounting source tapes in a "readable" form.

DAPR: Fully Automatic Event Scanning and Measurement

Joyce Crawford, Howard White, Dennis Hall, Joan Franz, Barbara Britton, and Nan Jontulovic

A thorough study was made of Programs 511, the real-time track-segment-finding programs. Tuning of constants and thresholds produced considerable improvement in the quality of track initiation and following.

Debugging of the track-joining and -linking portions of Program 512 was essentially completed. A weighting function for extrapolating beyond the ends of a given segment was added to the joining program and also, where applicable, to linking. A diagnostic package was written and debugged for use with Program 512, providing a graphical display of "goodness of fit" between specified segments. Used in conjunction with Program 515, these diagnostics provide a good check on the performance of joining and linking in Program 512, and are very helpful in studying special and difficult situations in joining and linking in detail. An extensive updating of documentation is in progress, and a clean assembly is in preparation. Work remains to be done on the resolution of ambiguities in join-link, and occasional modifications of procedures are expected as experience is obtained with larger sets of data.

The production version of the vertex-finding, vertex-matching, and track-matching program (513) was essentially debugged and ready for a final tuneup of thresholds and constants. The program successfully identifies physical events and prepares a data abstract tape (DAT) for input to the automatic scanning program (516).

Program 516 was flow-charted, coded, and nearly debugged. This program performs a function analogous to the human scanner. The DAT tape is a digital abstraction of the film. Program 516 "sees" the film by reading the DAT tape.

The program operates in two stages. In the first stage, each vertex is identified with a list of qualities (e.g., produced by a beam track, inside fiducial volume, etc.). In the second stage, chained vertices are identified and compared with the scanning criteria supplied by the physicist.

When an event is selected, the program assigns event types, assigns mass codes, orders and labels the tracks, catalogs the event, and outputs it on a standard HAZE

library. From here the event is immediately accessible to the geometry and kinematics programs and thus to the physicist.

The ability to read a scan tape was also added to the program in order to check its efficiency against that of a human scanner.

The diagnostic display program (515) was modified to include track identification codes and also to indicate the vertices found by Program 513.

Coding of the off-line quality monitor (514) was completed, and debugging was started. Program 514 provides quality control information in statistical form.

PUBLICATIONS AND PAPERS

Howard S. White, DAPR--Digital Automatic Pattern Recognition for Bubble Chambers, UCRL-17589, May 1967. A paper presented at the Symposium on Automatic Photointerpretation, Washington, D. C., May 31-June 2, 1967.

Howard S. White, Pattern Recognition in Bubble Chambers, UCRL-17635, June 1967. A paper presented at the Seminar on Computerized Imaging Techniques, Washington, D.C., June 26-27, 1967.

DATA-PROCESSING OPERATIONS

The following table summarizes the processing of events measured on Franckenstein and FSD. An event is the entire collection of related vertices measured in a bubble chamber picture. New measurements are counted separately, but the effect of any reprocessing has been eliminated from the totals.

EVENT MEASUREMENTS ANALYZED

Experiment	Chamber (and Laboratory, if other than LRL)	Beam	Group	Number of events
Franckenstein Measurements				
32	25-inch hydrogen	0.8–1.2-GeV/c K^-	Powell-Birge	9 464
34	25-inch deuterium	0.9–1.2-GeV/c K^-	Powell-Birge	13 287
35	100-cm propane-freon (CERN)	Stopping K^+	Powell-Birge	67
36	72-inch hydrogen	3.3-GeV/c π^+p	Powell-Birge	2 082
37	72-inch hydrogen	3.7-GeV/c π^+p	Powell-Birge	201
40	72-inch hydrogen	3.9-GeV/c π^+p	Powell-Birge	214
43	72-inch hydrogen	1.43-GeV/c π^+	Powell-Birge	250
44	72-inch hydrogen	1.35-GeV/c π^+	Powell-Birge	416
				25 981
FSD Measurements				
05	25-inch hydrogen	1.0-GeV/c K^+	Trilling-Goldhaber	1 525
11	25-inch hydrogen	300-MeV/c K_2^0	Trilling-Goldhaber	2 017
12	25-inch hydrogen	1820-MeV/c K^+	Trilling-Goldhaber	2 151
17	25-inch deuterium	860-MeV/c K^+	Trilling-Goldhaber	1 520
36	72-inch hydrogen	3.3-GeV/c π^+	Powell-Birge	552
38	72-inch hydrogen	3.5-GeV/c π^+	Powell-Birge	17 483
39	72-inch hydrogen	2.9-GeV/c	Powell-Birge	8 144
40	72-inch hydrogen	3.9-GeV/c π^+	Powell-Birge	18 291
42	72-inch hydrogen	1.54-GeV/c π^+	Powell-Birge	18 992
43	72-inch hydrogen	1.4-GeV/c π^+	Powell-Birge	25 036
44	72-inch hydrogen	1.35-GeV/c π^+	Powell-Birge	619
71	72-inch deuterium	5.9-GeV/c p^+	Segrè-Chamberlain	41 934
90	80-inch hydrogen (BNL)	9.0-GeV/c K^+	Trilling-Goldhaber	38 309
91	72-inch hydrogen	3.5-GeV/c π^+	Trilling-Goldhaber	36 308
				212 881
			Total events analyzed	238 862

Accelerator Operation and Development

ACCELERATOR STUDY GROUP

Edward J. Lofgren in charge

STUDY GROUP ACTIVITIES

The LRL Accelerator Study Group has continued to play an active role in support of the National Accelerator Laboratory (NAL) accelerator project. Eighteen members of the LRL group participated in the summer study held by NAL at Oak Brook, Illinois. Design and development work continued at LRL on certain phases of the accelerator in cooperation with the design group at NAL.

Synchrotron Magnet Design

A 6-ft-long model and a full-scale 20-ft-long iron core for a main synchrotron magnet of LRL design were constructed in order to investigate mechanical fabrication problems associated with long laminated magnets. The magnetic properties of bending magnet and quadrupole magnet designs proposed by NAL for the main synchrotron have been calculated with two-dimensional computer programs. Development of a three-dimensional computer program for magnets is continuing.

Synchrotron rf Systems

Design of the rf accelerating cavities for the 200 GeV synchrotron and the injector synchrotron is continuing.

The mode spectrum is being explored in the model of the rf accelerating cavity for the main synchrotron and the transmission line between the cavity and the rf houses outside the tunnel. A low-voltage sheet metal model of the rf accelerating cavity for the injector synchrotron was constructed. A program of testing small rings of different types of ferrite is continuing in order to select several ferrites for use in tests of the full-size ferrite rings to be used for varying the frequency of rf cavities.

Injector Synchrotron

The LRL group collaborated with the design group at NAL in the selection of parameters and a magnet lattice for the injector synchrotron. Development of a synchrotron vacuum chamber made of alumina ceramic sprayed onto a metal foil was initiated.

Fast Kicker Magnets

Design work on kicker magnets for use for (a) extraction of the beam from the injector synchrotron, (b) injection of the beam into the main synchrotron, and (c) fast extraction of the beam from the main synchrotron emphasized production of the desired beam deflection with a short length of magnet and with a low voltage pulse. A model of a transmission-line-type magnet with a shorted output was built and tested. The model produced a magnetic field pulse of 270 gauss ± 1% with a rise time of 15 nsec. The voltage required on the magnet was 25 kV.

Tunnel Design and Remote Handling

A report indicating that it is feasible to precast a concrete tunnel for the 200 GeV synchrotron at Weston, Illinois, was submitted by Lin, Kulka, and Yang, consultants to LRL. Models were built and tested of quick-disconnect systems for joints in vacuum systems, water piping, and magnet bus bars that are located in high radiation areas.

Superconducting Beam-Transport Magnets

A program to develop superconducting magnets was initiated in order to explore the possibility of using them in the experimental area of the 200 GeV facility. A horizontal superconducting solenoid, 36 in. long, was built,

and a superconducting bending magnet and a superconducting quadrupole magnet were designed. An investigation of the use of iron superconducting magnets to reduce the current requirement and provide magnetic shielding was completed.

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M. A. Green, Cost Optimization of Storage Ring Magnet Systems, UCRL-17354, June 1967.

J. A. Satti, Bus Bar Quick Disconnect Proposed for the 200 GeV Accelerator, UCRL-17661, July 1967.

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W. S. Gilbert, Beam Loss and Shielding Experiments Relevant to High Energy Proton Synchrotrons, UCRL-17797, Sept. 1967.

J. M. Peterson, On the Selection of Injector Systems, UCRL-17798, Sept. 1967.

A. A. Garren and E. L. Hubbard, A Criterion for Designing Synchrotrons Without Alternating-Gradient Focusing, Sept. 1967 (not yet issued as a UCRL report).

BEVATRON

Edward J. Lofgren in charge

OPERATIONS

On December 19, 1966, during a routine shutdown for inspection of the Bevatron and associated equipment, a fracture was discovered in a rotor pole of one of the Bevatron motor-generator sets. Subsequent inspection revealed fractures in other rotor poles. It was decided on that day to remain shut down and to replace all the field poles of the two 46-MW generators. The shutdown ended on June 3, 1967.

Westinghouse Electric Corporation provided the supervision and labor for the installation of the new pole pieces and all jobs required to put the machines back in operation. The installation, alignment, balancing, and testing was completed by June 3, 1967. Many planned construction and modification projects to the Bevatron and to related experimental areas were carried out during the shutdown. Bevatron magnet pulsing and beam tune-up were started on June 3. On June 4 beam control was turned over to the Moyer Group to continue their study of K_2^0 decay modes.

During the period covered by this report we provided beam for four primary experiments and four secondary experiments. Three of the primary experiments were completed during this period:

(i) the Alvarez-Murray Group's study of $K^0K_2^0$ interference and other K^-p reactions near 400 MeV/c;

(ii) the Trilling-Goldhaber Group's study of K^-p reactions at 250 MeV/c. This and the preceding experiment used a separated K^- beam from an internal target in Quadrant III of the Bevatron. The experiments were done in the 25-inch hydrogen bubble chamber;

(iii) the University of Washington Group's study of the magnetic moment of the Ξ^- cascade particle. This experiment was done with spark chambers in a 1.8-BeV/c separated K^- beam from an internal target in the Bevatron near the exit of Quadrant II.

After operation started in June, the maximum allowed peak beam intensity was raised from 3×10^{12} to 4×10^{12} protons per pulse. This increased level was not achieved immediately. In the middle of July the operations crews were encouraged to try to increase the operating beam intensity to the new maximum allowed operating level. On August 4 the crews reached an operating intensity of 4×10^{12} protons per pulse and were able to operate at this intensity whenever the experiments could use the full beam.

Work continued on the two-channel external proton beam facility. The 72-inch hydrogen bubble chamber building was removed. Utility tunnels in the new external proton beam (EPB) hall were dug and concrete was poured. The foundation for the shielding wall was finished and the heavy-duty floors poured in the new building. The beam transport system and shielding were completed to the second focus in the west channel. A temporary shielding backstop was installed downstream from the second focus to allow us to operate with beam to this area. The Lofgren Group's experiment to study the K_{e2} branching ratio was installed at this second focus. Preliminary tests were made to check the extraction efficiency and beam quality of the external proton beam, using the new resonant extraction magnet. During the first tests, beam was extracted by using an energy-loss target. The extraction efficiency was the same as before, about 35%. The beam quality, however, was not quite so good as before, probably because of the temporary elimination of the quadrupole near the first extraction magnet. (The quadrupole was left out for the time being because of space limitations.) Beam quality, however, was adequate for the scheduled experiments.

Preliminary tests on the new resonant extraction system were made. Most of the Bevatron study periods were devoted to measuring the dimensions of the internal beam, measuring the radial ν value as a function of radius, and building and testing diagnostic equipment. Preliminary extraction tests were made. The results are in satisfactory agreement with the calculations. Resonant extraction studies will continue.

Overhead sprinkler systems were installed on the ceilings of the Bevatron Main Ring Building and the Motor Generator Building. Heat detectors are mounted on the ceiling. If one of the heat detectors is triggered, a valve will open automatically and fill the pipes with water. Water will spray out only where heat

has melted the fusible links in the sprinkler heads. This system provides fire protection for the roof area but at the same time is designed to prevent unnecessary water from being sprayed on the Bevatron and associated equipment.

The curved-bridge crane was installed in the new EPB hall. Final testing was under way at the end of October, and final acceptance at an early date is hoped for, so that the crane can be used for the installation of the EPB shielding in the backstop area.

A five-day shutdown was scheduled to start on September 25 to provide routine maintenance on the main motor-generator sets. The shutdown started a day early when a generator field-pole connection on the east main Bevatron generator failed. "Zyglo" examination of all of these connections detected cracks in five more joints. These were all new joints installed about 3 months prior to this time, and were under warranty by the Westinghouse Electric Corporation. Their field engineers were called in immediately and an investigation of the cause of failure was begun. After a week of study and tests, the connections were all rebrazed. All brazing was completed by the evening of October 9. Operation for physics experiments was resumed on October 11.

More complete details of Bevatron operation for this period are given in the reports, Bevatron Operation and Development, No. 54 and No. 55.[1]

PUBLICATIONS AND PAPERS

Yves M. Baconnier and Glen R. Lambertson, Resonant Extraction Studies for the Bevatron, UCRL-17604, Sept. 1967, presented at Sixth International Conference on High Energy Accelerators, Cambridge, Massachusetts, September 11-15, 1967.

1. Kenneth C. Crebbin and Robert Frias, Bevatron Operation and Development, UCRL-17931, Nov. 1967; 55, UCRL-17932, Nov. 1967.

184-INCH CYCLOTRON

James T. Vale in charge

HALF-SCALE RADIO-FREQUENCY MODEL

James T. Vale

The main item of interest this period involves the half-scale radio-frequency model for improvement of the 184-inch cyclotron. Most of the problems have been solved. The one exception is the cavity mode. However, this problem exists in the present machine, and it is controlled here by nulling it through balancing the top to bottom excitation. The aim, of course, is to eliminate this mode in the new system, but if it cannot be eliminated, it fairly certainly can be controlled as in the existing system.

This work has been done by Leal Kanstein and Seth Shepard with the consultation of Dr. Kenneth MacKenzie of UCLA. A report by the first two people follows.

Increasing the beam repetition rate is the most direct way of increasing the average beam of an accelerator. With this in mind, and rf study was begun to develop a modification proposal for the 184-inch cyclotron at Berkeley. The full-scale design criteria were:

(i) an rf swept frequency of 36 to 19 MHz;
(ii) an fm system capable of producing beam pulses at 300 Hz;
(iii) 40-kV dee voltage;
(iv) lowest rf drive power.

The half-scale design achieved is illustrated in Figs. 1 and 2. The frequency is modulated by twin capacitors incorporating horizontally mounted, 3-ft-diameter rotors, each having 20 sets of 13 teeth. Each stator has 4 sets of 14 teeth which mesh with the rotor teeth. The stators are connected to the dee by means of a tapered transmission line. The capacitor gap was made 1/8 in., corresponding to a conservative full-scale no-spark condition.

The dee is cut back as much as the beam second-harmonic considerations will permit, in order to minimize the system capacity. Parallel 304 vacuum tubes drive the dee through plate and cathode transmission lines.

The outstanding difference between this system and other rf schemes is in the twin horizontal rotors. This is a departure from convention which has the following advantages:

(i) Cross modes may be well separated

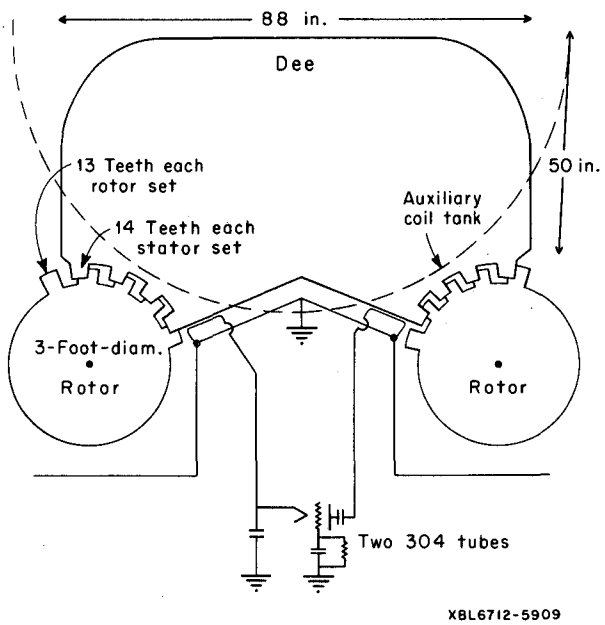

Fig. 1. Half-scale model for 184-inch cyclotron.

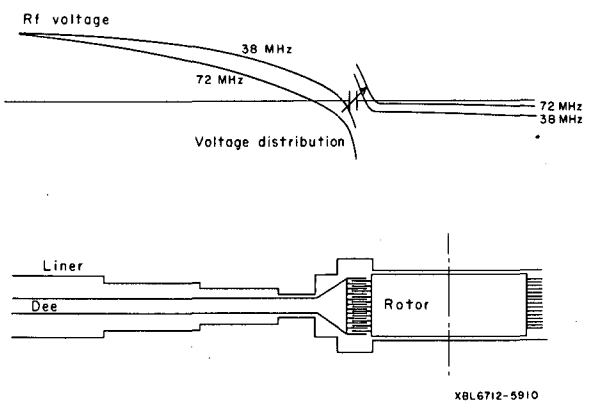

Fig. 2. Profile of half-scale model of 184-inch cyclotron.

from the main mode by adjustment of the dee inductance between the rotor-stator capacitors.

(ii) All dee-charging current flows through the rotating capacitors; hence minimum capacitor voltage requires as large a capacity as possible. However, the maximum size of each set of teeth, and group of sets, is limited by spurious resonances within the teeth and their assemblies. Thus larger total capacity, without interference from internal modes, is achieved with two capacitors.

(iii) Horizontal mounting of the rotor-stator assembly allows simple adjustment of the inductance between the dee and the stator teeth, hence producing lower and more uniform tooth gap voltage.

(iv) The system is more "streamlined" to rf current flow, with lower losses. Magnetic measurements on the 184-inch cyclotron and preliminary calculations indicate that eddy-current losses in the rotors can be kept within reason.

By suitable adjustment of liner-to-dee spacing (see Fig. 2) and stator geometry, the rotor-to-stator gap voltage was held to about 1.5 times the dee voltage at the highest frequency. The model has been swept through the necessary frequency range without complications of spurious modes other than cavity resonance of the main tank liner assembly (Fig. 3). Presumably, the coupling to this resonance can be balanced out as is done in the present 184-inch rf system. Rough and conservative power measurements indicate that about a megawatt will be necessary for 40 kV dee voltage on the full-scale system.

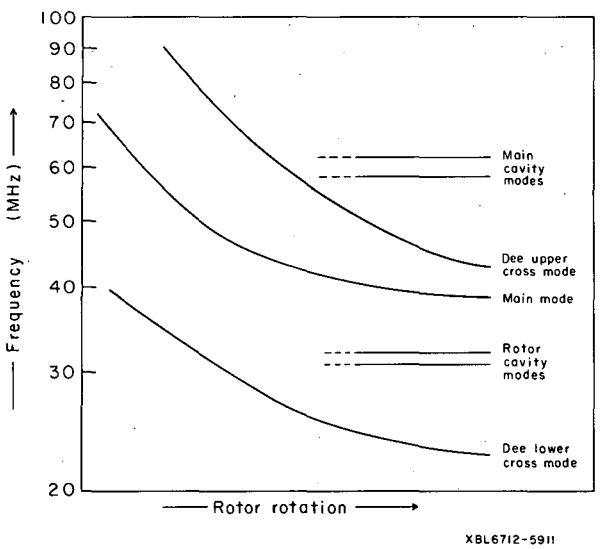

Fig. 3. Modes of oscillation of half-scale model.

184-INCH REGENERATOR STUDIES

Arthur C. Paul

Improvement of the extraction efficiency of the 184-inch cyclotron should accompany an increase in internal current if the machine activation is to be held close to the present value. The behavior of the regenerative extraction system has been under computer study for the last half year in an attempt to understand the mechanisms of particle loss and to evaluate the effectiveness of several modifications directed at improvement of the extraction efficiency. The study can be logically divided into several phases, as follows.

Present Operation of the Extraction System

Some 1500 particles have been tracked in the magnetic field of the 184-inch cyclotron. Five distinct modes of particle loss have been identified (see Fig. 4):

Mode 1: axial growth and subsequent vertical loss of the low-energy beam penetrating into the regenerator field, but not deep enough for the onset of regeneration;

Mode 2: resumption of radial precession during regeneration, resulting in vertical loss of the beam or exit from the magnetic field at the wrong azimuth;

Mode 3: failure of successfully regenerated beam to pass through the magnetic channel aperature;

Mode 4: vertical loss of the successfully regenerated beam by overfocusing in the last several turns in the rapidly falling fringing field of the cyclotron (peeler field); and

Mode 5: mismatch between the phase-space acceptance of the external beam and the emittance of the beam leaving the cyclotron. The relative importance of the various modes of loss depends on the betatron oscillation amplitudes, and hence is determined by considering the quality of beam incident on the regenerator.

Experimental Programs

Certain experimental programs have been undertaken to correlate the computer studies with the operation of the 184-inch cyclotron. The most important has been a measurement of the radial and vertical particle density just before the particles encounter the regenerator field. This measurement allows evaluation of the relative importance of each of the above modes of loss.

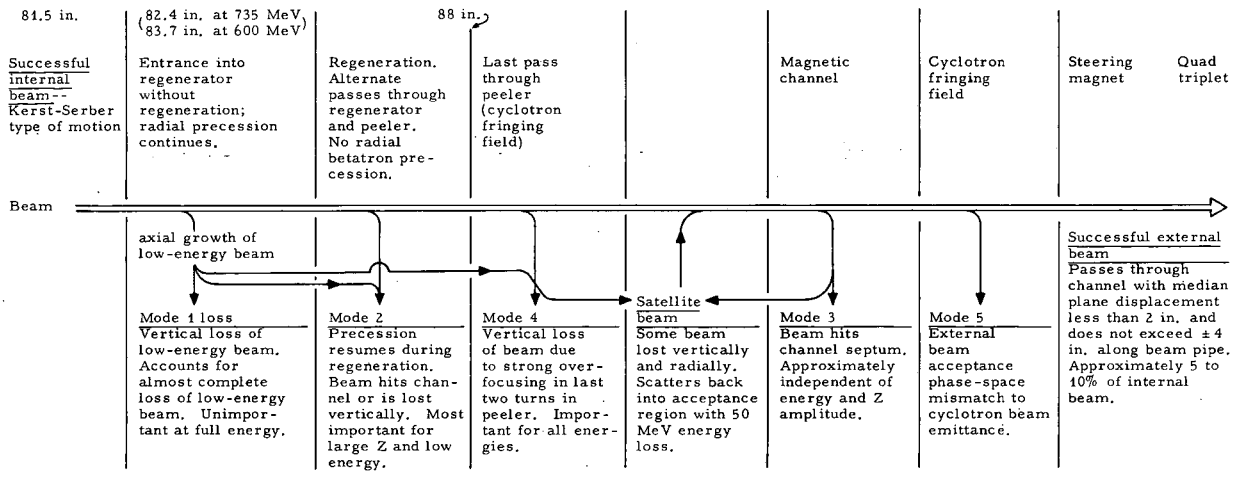

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Fig. 4. Loss mechanisms of the extraction system for the 184-inch synchrocyclotron.

Hogilation

A means of improvement in the extraction efficiency has been studied by use of a time-varying magnetic perturbation (locally called a Hogilator) to off-center the orbits so as to prevent entry of low-energy particles (large radial oscillation amplitudes) into the regenerator. The study indicates that the number of particles lost by low-energy penetration into the regenerator for the measured particle distributions is relatively small, so that use of the Hogilator would not significantly improve the extraction efficiency. Moreover, the installation of a Hogilator that would eliminate Mode 1 loss for a particle distribution of sufficiently large betatron amplitude to incur a significant loss of particles would drive them through the n = 0.2 resonance. The avoidance of this resonance would require reshimming a large sector of the 184-inch magnet--a very difficult task. It is therefore concluded that a Hogilator does not represent a very promising method of improving the extraction efficiency.

Improvement of Channel Transmission

The most significant modes of particle loss are Modes 3 and 4, which occur on the last turn after regeneration is complete. Study is now under way of the improvement of channel transmission by the installation of a horizontally focusing region in front of the existing channel. At present, this "prechannel" appears to be a promising means of increasing the extraction efficiency. Simultaneously, the feasibility of installing this prechannel into the cyclotron is being studied by the mechanical engineers.

PERMUTED KEYWORD INDEX

The following pages are an alphabetical permuted index of the material in this report. Author's names are included. The index was prepared by the IBM-1401 computer using the key-word-plus-title program KWPT. All significant words are indexed; insignificant words have been automatically rejected by the computer.

In some cases, the titles have been edited slightly to ensure proper word combination during automatic indexing and to provide maximum meaningful information. For most sections covering multiple subjects in detail but not having subtitles, the editor has provided appropriate titles for adequate indexing of each subject.

Indexed terms are alphabetized and displayed in the left column of the index. The middle column shows the complete title and authors. The page number is given in the right column. Following the word index is the number index, which treats numbers as key words.

Your comments about the usefulness of this index and possible improvements are invited. Address such comments to Miss Gloria Smith, who is responsible for the automated indexing, or to the editor, Charlotte E. Mauk.

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