

Purdue University
Contract AT(11-1)-1428 Task A

*all Reports
Reviewed*

ANNUAL PROGRESS REPORT FOR THE PERIOD

June 1, 1970 - May 31, 1971

MASTER

I. Introduction and General Summary

During the year 1970-71 the Purdue High Energy Physics Group has continued bubble chamber experiments already begun; extended physics analysis of old data; extended bubble chamber runs on the basis of interesting current data; begun work towards extending current studies by use of spectrometer and hybrid apparatus at BNL, NAL and SLAC; made important progress in upgrading our present measuring system; and moved to new quarters in the Physics building. Publications, talks, proposals, and theses resulting from this effort are noted in section V of this report.

The 230,000 picture 13.1 GeV/c π^+p experiment in the SLAC 82" HBC was extended by 250,000 pictures while publications continued to emerge from the first data. An additional 250,000 (total of 750,000) have been approved for next fall. The 360,000 picture π^+d run at the same momentum in the same chamber has been measured, and publications are appearing. The 150,000 picture K^+d run in the BNL 80" chamber was extended by 250,000 pictures; measurement on some topologies is now complete for the entire sample; and publications are continuing to appear. New results from 5- and 6-prong topologies in old 3 GeV/c π^+d film from the LRL 72" chamber is being published, as have been further results from our old K^+d experiment at 4.5 GeV/c in the ANL 30" chamber. Publication continues from our study of pion-pion interactions, based on still older Purdue data. This material is reported in section II of this report.

Purdue staff have taken part in several experiments or in the preparation for them at BNL, ANL, and NAL. These collaborations are reported in section III. In each case these collaborations are related to, or are extensions of, work

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already done here on K-nucleon or π -nucleon physics. One of these, the collaboration on the 30" NAL hybrid bubble chamber experiment, will give us a valuable opportunity to extend our π^+p data to high energy.

Considerable change was experienced in house. The laboratory moved to expanded quarters (15,000 square feet, two-thirds of it in the new addition to the Physics building). Our computing facility was moved in one day, from turn-off to successful program execution. Our measuring equipment was moved, cleaned up, reinstalled, and retuned during the month of August. Scanning and measuring staff was furloughed without pay for that month, as an accepted alternative to further staff attrition. The measuring system was brought on the air the first work day of September. Other changes in the measuring and computing system are noted in section IV of this report. During the year good progress was made on the vital development of the Purdue version of a POLLY-type measuring machine, and is reported in the same section.

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II. In-house Experimental Physics Program

A. 13.1 GeV/c π^+p Experiment

The results described below have been obtained from a 230,000 picture exposure taken at SLAC in 1968. Measurements on another 250,000 picture exposure taken in 1970 were begun in May 1971. Approval for a third run has been obtained, and it is expected that this will take place in October 1971.

1) Four-prongs.

We have continued our investigations of quasi-two and three body production processes available in the reaction $\pi^+p \rightarrow \pi^+\pi^-\pi^+p$ and in the considerably rarer modes $\rightarrow \pi^+pK^+K^-$, $\rightarrow \pi^+p\bar{p}$.

The reaction $\pi^+p \rightarrow \rho^0\Delta^{++}$ was shown¹ to be mediated by Reggeized pion exchange with small absorptive corrections given by a Regge-cut contribution. This model predicts a rise in the differential cross section at small values of $t' = t - t_{\min}$ consistent with the data and in contrast to a dip required by vertex factorization and conspiracy. The production of transverse rho states was shown to be in good agreement with $\pi\Delta$ photoproduction as predicted by vector dominance arguments. With increased statistics, we hope to study this reaction in more detail, especially the S-wave dipion substructure. The small absorption and lack of π^+ interchange ambiguities at 13 GeV/c is especially helpful.

The $f^0\Delta^{++}$ channel was studied² and interpreted in a way similar to the $\rho^0\Delta^{++}$ state. In addition a background subtracted distribution of the Jackson angle in the f^0 decay clearly exhibited the spin (2) character of the f^0 , a result not clearly obtained in previous experiments. With a substantial increase of data, we intend to study the background structure in the f^0 region; at present, very little is known in this area.

The $\pi^+\rho^0p$ channel was dominated by diffractive production of the A_1 region corresponding to low ηp mass values. The data for this reaction were presented

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and discussed in terms of a double Regge-pole exchange mechanism consistent with duality.^{3, 4} There was evidence in the mass spectrum for A_2 production but no clear indication of fine structure in the regions reported in some experiments with less data. A spin-parity analysis has been made, demonstrating the dominance of a 1^+J^P state and yielding a sharp 2^+ peak at the A_2 ; these results will be published soon.

A similar study of the π^+f^0p reaction⁵ (A_3 region) was presented in terms of a double exchange model. When more data is accumulated in this channel, a spin-parity analysis will be made as well as detailed comparisons with the coherent A_3 production off deuterium (which is being studied at the same energy in our lab.).

The πpp and πf^0p channels are formed by diffractive production off the proton; in addition, we have studied the $\pi^+\pi^-\Delta^+$ reaction⁶ which goes by diffractive production off the pion. The data for this reaction was presented and discussed within the framework of a dual double Regge exchange model.

The $\pi^+pK^+K^-$ reaction⁷ was shown to consist mostly of $\Delta^+K^+K^-$ and pK^-K^{*0} three body production which was consistent with an interpretation in terms of the double exchange model. Little or no ϕ production was evident in the K^+K^- spectrum.

An examination of the $\pi^+pp\bar{p}$ ⁷ channel (a fair fraction of the available data at high energies) yielded strong evidence against the existence of a $\bar{p}p$ resonance reported in a small statistics experiment at lower energy.

We have also reported and published⁸ the production of an $N^*(1720)$ and its subsequent decay to $\Delta(1236)\pi$.

Our analysis of the final state $p\pi^+\pi^+\pi^-\pi^0$ has been delayed because the fitting program, SQUAW, was losing a large fraction of these events. Revisions were made to the program, and likely candidates have been re-fitted to recover the lost events. A final step in the selection process, checking the ionization, is in progress.

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2) Six-prongs

Approximately 30,000 events with six charged particles in the final state were measured during the year, completing the total sample of 40,000 events. Events consistent with the reaction $\pi^+p \rightarrow p 3(\pi^+) 2(\pi^-)$ have been selected, and are being examined for resonance production, and quasi-two and three body final states.

3) Four-prongs + vees

The entire sample of 4,000 events with four charged particles plus a visible K^0 or Λ in the final state have been measured. These events will be used to determine associated production cross sections, and to search for resonance production.

4) Two-prongs

The last year has been concerned with the analysis of 63,248 two prong events and $\sim 3,000$ two prong events with strange particles. These were measured in the 1969-1970 contract year.

The two prongs of the type $\pi^+p \rightarrow p\pi^+MM$ is $\pi\pi^0$ ($n = 1, 2, \dots$) show definite structures in the π^+MM spectrum. These have been interpreted by us as meson states confirming in part the observations of the CERN Boson Spectrometer group.^{9, 10} An initial paper was published in the Proceedings of the International Conference on Meson Resonances at Philadelphia, p.457. This initial report was followed by a letter¹¹ specifically on the states observed in the $p\pi^+\pi^0$ final state. These data and results are shown in Figs. 1 and 2. These results on meson states are of great importance and we are in the process of quadrupling our statistics with an approved 500,000 picture extension from SLAC already being measured. We are waiting for at least part of this new data before publishing further.

The other important paper now nearly finished is on the $\pi^+p \rightarrow \pi^0\Delta^{++}$ final state. This contains the density matrix elements, cross section and $d\sigma/dt$ which

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are compared to current Regge-pole models. This data is very valuable in this energy region and particularly with the increase in data will provide accurate parameters for the reaction.

The number of strange particle events does not allow us as yet to do much more than classify them into partial channels. We will eventually use them particularly to set limits on the decays of meson states to strange particles. One result is the measurement of the ΛK^+ branching ratio of the $N^*(1700)$ which we find to be significantly lower than other experimenters' indications. Other possible N^*_8 may contribute in their data.

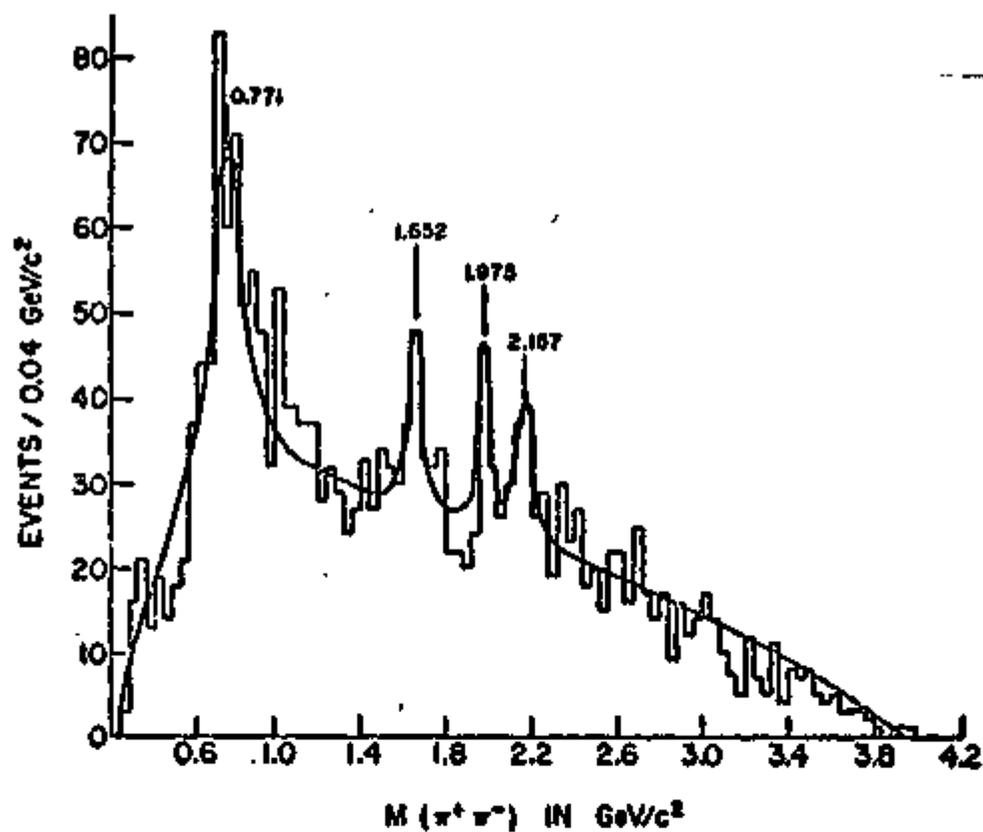
The above data was presented at Kiev in several talks in the parallel sessions.

B. 13 GeV/c π^+d Experiment

This experiment is a 10 event/ μb exposure which we completed measuring with 80k events in February 1971.

1) $\pi^+\pi^-$ and $\pi^+\pi^-\pi^+\pi^-$ final states

Of primary interest in our initial analysis were the states $\pi^+\pi^-$ (3700 events) and $\pi^+\pi^-\pi^+\pi^-$ (4500 events) and the decays of neutral bosons. A preliminary analysis shows little structure in the $(4\pi)^0$ but some in $(2\pi)^0$. A comparison was made to our π^+p experiment at the same energy, since if one pion exchange dominated meson production, the reaction $\pi^+n \rightarrow pX^0$ has a cross section twice that for $\pi^+p \rightarrow pX^+$. In an invited paper given at the Bologna Meson Conference it was clearly shown that O.P.E. is small even in the g region (1.6 - 1.8 GeV). This analysis is now being carried out more quantitatively. In the $\pi^+\pi^-$ final state there is strong ρ^0 and f production together with interesting structure above 1.6 GeV. We have been determining density matrix elements, cross sections, and $d\sigma/dt$ up through the f in order to make comparisons with theory and the $\Delta^+\pi^+\pi^-$ final state from our π^+p film. In particular we have studied the cross section for the production of transversely polarized ρ^0 mesons



STATE OBSERVED	MASS IN GeV/c^2	Γ_{obs} IN GeV/c^2	Γ_{phys} IN GeV/c^2	CROSS SECTION IN μb
P^*	0.771 ± 0.025	0.188 ± 0.030	0.145 ± 0.038	54.0 ± 10.3
R_1^*	1.652 ± 0.015	0.061 ± 0.020	0.040 ± 0.032	8.7 ± 2.3
S^*	1.975 ± 0.012	0.045 ± 0.020	≤ 0.052 AT 90% C.L.	6.5 ± 1.8
T^*	2.157 ± 0.010	0.078 ± 0.018	0.068 ± 0.022	10.5 ± 3.2

FIGURE 1.

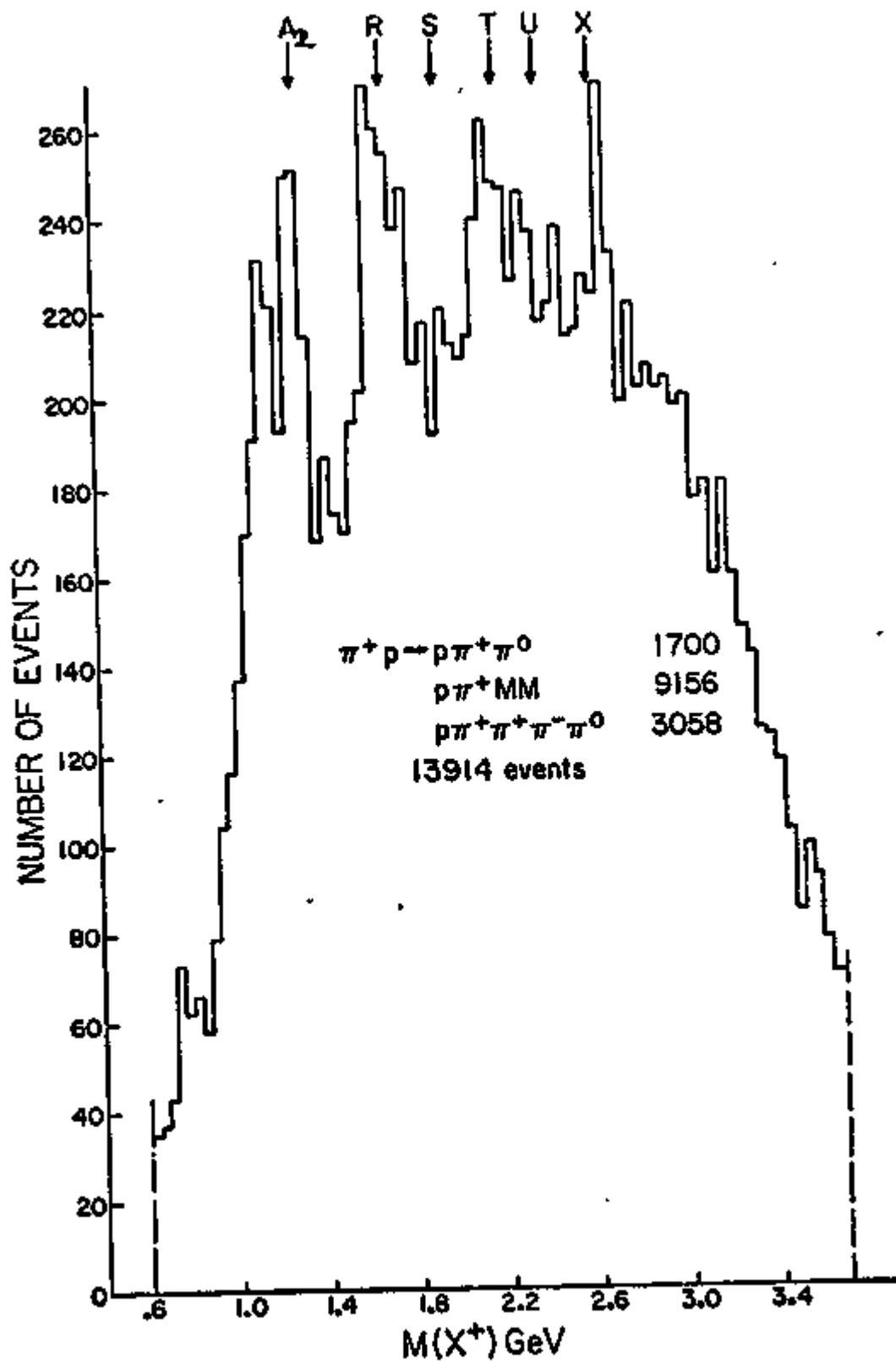


FIGURE 2

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as a function of momentum transfer, i.e. $p_{11} d\sigma/dt$ where p_{11} is the density matrix element. We have adequate statistics in the interval $-0.01 > -0.3$ $(\text{GeV}/c)^2$ to study the behavior of the density matrix elements. The assumption of vector meson dominance predicts that our cross section should show the same t dependence as photoproduction data. By direct comparison of experiments we find that our cross section is too small by more than a factor of 2. This disagreement with vector meson dominance is due to the small value of our density matrix element ρ_{11}^H for t values near $t = 0.02$. These conclusions are obtained after taking account of s -wave background produced with the ρ mesons and the final results will be published shortly.

2) $d\pi^+\pi^+\pi^-$ final state

From the analysis of the four-prong events we have obtained a sample of 2016 $\pi^+d \rightarrow d\pi^+\pi^+\pi^-$ events. To our knowledge this is the largest sample of $\pi^+d \rightarrow d\pi^+\pi^+\pi^-$ to date. The physics being pursued at present is:

- (i) Study of mass spectra and angular correlations. In particular, a study of the A_3 meson region. This is the first experiment to observe a clear signal of diffractively produced A_3 mesons. This work is accepted for publication.¹²
- (ii) Calculation of a dual diffractive amplitude and application to this reaction. This model gives detailed predictions of mass spectra, general angular correlations and decay distributions of meson states produced in this reaction, i.e. the ρ^0 and f^0 mesons. This work was presented at the Washington APS meeting.
- (iii) An investigation of the spin-parity states present in the 3π meson system as a function of 3π mass. Preliminary results are in agreement with those obtained at Illinois.
- (iv) A detailed comparison of this reaction and the reaction $\pi^+p \rightarrow p\pi^+\pi^+\pi^-$

also at 13 GeV/c has just started and should lead to a better understanding of the non-diffractive meson states produced in $\pi^+p \rightarrow p\pi^+\pi^+\pi^-$.

(v) There is also preliminary evidence for ρ - ω interference in the $\pi^+\pi^-$ spectrum which is being analyzed.

3) The reaction $\pi^+d \rightarrow (p_g) p\pi^+\pi^-\pi^0$

From the analysis of the three and four-prong events we hope to obtain a high statistics sample of $\pi^+n \rightarrow p\pi^+\pi^-\pi^0$ events. At present only a preliminary physics analysis on a partial sample has been done and published.¹³ This reaction is badly contaminated from other channels and work is progressing on its separation from these channels.

Preliminary investigations show a very rich structure in the $\pi^+\pi^-\pi^0$ effective mass spectra especially in the high mass region previously unavailable to lower energy experiments. There is also strong diffractive production of nucleon isobars which decay into $p\pi^-\pi^0$. This reaction is particularly suitable for studying ρ -exchange, the only exchange consistent with g -parity restrictions at the meson vertex.

C. Many Body Final States from π^+d Interactions near 3 GeV/c.

An extensive study of multiparticle final states in π^+d interactions near 3 GeV/c has been recently completed. Some of the most interesting recent results have involved systems decaying to five pions in which several resonances have been observed. In particular the $\eta'(958)$, $D(1285)$, $E(1422)$ and $f'(1514)$ have all been observed to decay to $\eta\pi^+\pi^-$ (with $\eta \rightarrow \pi^+\pi^-\pi^0$). These states appear as prominent (greater than four standard deviations) signals in the $M(\eta\pi\pi)$ spectrum and represent the first clear-cut observation of this decay mode for the E and f' . Spin and parity analyses were attempted for the η' , D and E mesons and the statistically favored assignments were $J^P = 0^-, 2^+$, and 1^+ respectively. These

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are not firm results, however, due to the paucity of events. Also a determination of the SU-3 mixing angle for η and η' was made. The result, $-24^\circ \pm 3^\circ$, is in excellent agreement with the Linear Mass Formula prediction. Two reports for Physical Review Letters and an article for Physical Review are currently being prepared.

D. 4.5 GeV/c K^-d Experiment

In the past year we have continued the analysis of 400,000 pictures taken in the 30" deuterium bubble chamber at ANL. A summary article on the final states with one and two prongs plus \bar{K}^0 was published,¹⁴ and an article on the three prong plus \bar{K}^0 final states which compares the data to the Reggeized multi-peripheral model of Plahte and Roberts has been submitted for publication.¹⁵ The properties of the A_2 meson as produced in $K^-n \rightarrow \Lambda A_2$ reactions has been studied¹⁶ and were also reported on at the Duke Conference on Hyperons.¹⁷ Evidence against a recently reported $n\pi^-\pi^-$ enhancement has been presented¹⁸ at nearly the same energy and with twice as much data as the original report. A Ph.D. thesis¹⁹ was written on the three prong plus Λ^0 final state and a shortened version will be submitted for publication. Two additional publications,^{20, 21} on the impulse model and on an application of the Veneziano model have appeared this year using the K^-d data.

E. 9 GeV/c K^-d Experiment

In addition to the 150,000 pictures obtained in 1969, an additional 220,000 were taken in May 1970. This was the first bright field illumination bubble chamber film taken by this group, and minor modifications to the measuring machines (SMP's) were necessary. In addition, for the first time, picture quality and film development were optimized during the run. This was accomplished with a portable version of the SMP track digitization electronics. In contrast to the initial film, most of the scanning of the new film has been done at the Purdue-

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Indianapolis branch and at the University of California at Davis. All of the measuring is, however, being done here. We have measured approximately 85,000 events mostly of the three and four prong topology (about 10% of the events have an associated Vee). Initial experimental results were presented at the Kiev Conference.^{22, 23, 24} Analysis of $K\pi$ scattering²⁵ and the Q region²⁶ (or low mass $K\pi$ system) were presented at the New York APS meeting (January 1971). Further analysis of $K\pi$ scattering, particularly in the $K^*(1420)$ region²⁷ and evidence for higher mass strange mesons²⁸ were presented at the Washington APS meeting (April 1971). A letter confirming two structures in the Q region has been accepted for publication by Physical Review Letters,²⁹ and was reported on at the Bologna Conference.³⁰ A manuscript on charge exchange production of $K^*(890)$ is nearly completed.³¹ Abstracts for three papers^{32, 33, 34} to be presented at the Amsterdam Conference on Elementary Particles have been submitted. Several additional articles and two theses are in preparation.

III. External Experimental Physics Program

A. Collaboration with BNL ARGO Spectrometer Group

During the latter part of 1970 and the early part of 1971, two of our senior physicists (Gutay and Miller) together with a Research Associate spent several months at BNL working with the Collins group. This was the first stage in an effort to continue our π nucleon experiment to the 600 event/ μ b level using a spectrometer system. During this period we were helping the Collins group prepare their apparatus for their pp multiparticle experiment and studying their apparatus for the feasibility of running pions. We will participate in the p p experiment to be run starting in September, supplying two senior physicists (Gutay and Stanfield).

During the summer Gutay and Miller will spend 5 weeks each at BNL doing a detailed simulation of a π nucleon experiment in the ARGO spectrometer and the proposed MORA spectrometer. This will form the basis of a proposal to be submitted this summer. Our bubble chamber data will be an invaluable guide in these studies.

B. Neutral Meson Missing Mass Spectrometer Experiment

A group including Professors R. C. Lamb and F. C. Peterson, Dr. D. L. Cheshire and Mr. R. W. Jacobel from Iowa State University, Dr. E. W. Hoffman from Argonne National Laboratory, and Professor A. F. Garfinkel from Purdue University are in the process of taking data on experiment E-238 at Argonne. In this scintillation counter experiment, neutral mesons M^0 created in the reaction $\pi^- p \rightarrow M^0 n$ are observed in the missing mass mode by measuring the momentum of the neutron.

The neutrons were detected by a set of 20 plastic scintillators located at an angle of 1° to 5° with respect to the incident beam. These neutrons

correspond to mesons emitted near 0° or near 180° in the center of mass. The charged particle decay products of M are detected by an array of 35 scintillation counters subtending a solid angle of nearly 4π steradians around the hydrogen target. With one quarter of the run complete, we have accumulated 460,000 events in the mass range of 500 to 1400 MeV/c². Forward production cross sections for the η^0 , ω^0 , ρ^0 , and f^0 and backward cross sections for the η^0 , and ω^0 have been obtained. The remainder of the run will concentrate on a search for new high mass neutral bosons as well as neutral components of the reported R , S , and T states. Preliminary results were reported at the Washington Meeting of the A.P.S.

C. 3.9, 4.6 and 5.0 GeV K^-p Experiment (BNL Collaboration)

Results were published with Purdue co-authorship (V. E. Barnes) on a variety of hyperon and meson states as part of a continuing study of K^-p interactions in the BNL 80" bubble chamber at 3.9, 4.6, and 5.0 GeV/c.

a) The existence of two $\Sigma(1670)$ resonances was confirmed.³⁵ Y^{*+} states of mass 1670 MeV are seen to decay into $\Lambda(1405)\pi^+$ and $\Sigma^0\pi^+$. The former decay mode is seen only for peripherally produced $\Sigma^+(1670)$: the interval $\cos \theta^*(p, \Sigma^+(1670))$ between $[0.7, 1.0]$ contains 100% of the signal. Conversely, only 42% of the $\Sigma^+(1670)$ signal in the $\Sigma^0\pi^+$ decay mode occurs in the above $\cos \theta^*$ interval. This is only possible if two distinct $\Sigma^+(1670)$ resonances are present, one of which is less peripherally produced than the other.

b) The $L(1745)$ meson was observed³⁶ in the reaction $K^-p \rightarrow K^-\pi^+\pi^-p$ as a relatively narrow enhancement in the $K\pi\pi$ mass spectrum: $M = 1745 \pm 20$ MeV, $\Gamma = 100 \pm 50$ MeV. Although $K^*(1420)\pi$ is observed to be an important decay mode of the L , $20 \pm 20\%$ in our data, a substantial fraction is seen to decay into either uncorrelated $K\pi\pi$ or into $K^-\rho^0$. No significant evidence is found

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for decay of the L into $K(890)\pi$, $K\omega$, $K\phi$, or $K\eta^0$, and the data show no evidence for $K\pi\pi$ threshold enhancements for arbitrary $K\pi$ mass selections. Hence, we support the early interpretation of the L(1745) as a genuine resonance and we do not agree with the suggestion of the LRL group that the L is a moving kinematical enhancement.

c) Evidence was reported³⁷ for the existence of a surprising new meson, call the M(953), with mass 953 ± 2 MeV and width $\Gamma < 10$ MeV, produced in the final state $K^-p \rightarrow pK^-M^0$. The M is remarkably similar in mass, width, and $\eta\pi\pi$ decay mode to the $\eta'(958)$ which is also seen in our data in the final state $K^-p \rightarrow p\eta'$. But the $M^0 \rightarrow \pi^+\pi^-\gamma$ decay mode shows no ρ^0 enhancement in the $\pi^+\pi^-$ spectrum, in sharp distinction to the 100% $\rho^0\gamma$ fraction of the decay $\eta' \rightarrow \pi^+\pi^-\gamma$ as seen in our data and in the world data.

d) New values of the branching ratio of the K(1420) meson were reported³⁸. The $K(890)\pi/K\pi$ ratio differs from the world average and agrees with that predicted by an SU(3) analysis of the 2^+ meson nonet. In addition to improved statistics, the K(1420) is observed in final states $K^-p \rightarrow K^0(1420)n$ where the absence of the Q enhancement allows an unambiguous determination of the branching ratios.

e) The reaction $K^-p \rightarrow K^0(890)n$ was investigated³⁹ down to very small values of momentum transfer, $t \sim \frac{1}{2} m_\pi^2$. The absolute predictions of the one pion exchange model with absorption describe very well the production and decay properties of the $K^0(890)$, suggesting the need for Regge cuts in addition to Regge poles to explain the data.

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D. NAL 30" Hybrid Bubble Chamber Experiment

As of this writing a Purdue group is collaborating in the construction and initial operation of the NAL 30" hybrid HBC, with a view to studying π^+p interactions at very high energy with Professor A. Erwin of Wisconsin. We are very pleased to have this opportunity. Our membership in this collaboration arose gradually out of the following sequence of events.

In June of 1970 we submitted NAL Proposal number 41, "Very High Energy Proton-Proton Interactions: Exploratory Survey in a Bubble Chamber", correspondent V. E. Barnes, in which we stated that if a smaller chamber were available sooner, near NAL turn-on time, we would like the exposure in that chamber. When plans were announced to move the ANL MURA 30" hydrogen bubble chamber to NAL, we considered possible hybrid spectrometer systems downstream from the bubble chamber, to aid primarily in determining high momentum tracks. And we considered equipment upstream to refine knowledge of beam angles and momenta and to provide mass tagging of π 's, K's, and protons. J. Lamsa, D. Carmony, and V. Barnes, studied muon contamination of the proposed beam to the chamber⁴⁰. V. Barnes considered possible admixtures of K^- and \bar{p} in a predominantly π^- beam, and found them promising for significant K^- and \bar{p} studies as a byproduct of a π^- exposure at 130 GeV.

As an outgrowth of these studies, of our proposals NAL no. 41 and NAL no. 40, we submitted in April 1971 a proposal NAL no. 126 "Multiparticle π^+p Interactions at 130 GeV and at the Highest Energy" for the 30" chamber with a supplementary downstream spectrometer consisting of wide gap optical spark chambers with or without an external bending magnet. This hardware arrangement was adopted by a number of groups who submitted proposals for a coordinated set of

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particles and energies. Suitable beam defining equipment was also specified to exploit the anticipated 7000 \bar{p} and 2000 K^- interactions at 130 GeV. Exposures of 200,000 pictures at each energy were requested.

As a follow-up of the above proposal, we also submitted in April 1971 a proposal NAL no. 131 " K^-p and $\bar{p}p$ Interactions at 200 GeV", correspondent D. H. Miller, for the 30" hybrid chamber.

Barnes, Garfinkel, and Lamsa participated actively in a 15-foot bubble chamber workshop at NAL in March, 1971, where specific recommendations were made to the NAL management concerning: Bubble chamber beams and particle yields (also for the 30-inch chamber), optics for the 15-foot chamber, Track Sensitive Targets, ν beams, and μ detectors.

At Purdue small-scale development and testing of multiwire proportional chambers is being carried on. Spatial resolution will be tested using a beam from the Purdue 14 MeV Tandem Van de Graaff. We hope to apply the experience thus gained toward better instrumentation for the NAL hadron beam to the bubble chamber.

IV. Measuring-Computing System

A summary of our bubble chamber event processing is given in Fig. 3 for 1970 and Fig. 4 for 1971. These figures show both the weekly measuring rate and the cumulative totals for events accepted by the geometry program TVGP. There is roughly a 15% decline in the 1971 rate as compared to the same period in 1970. This decline is due to the measurement of more complicated events (mostly four- and six-prongs and two-vertex events) and to a 15.5% reduction in scheduled measuring for financial reasons. On a tracks per hour basis our measuring shows substantial improvement.

A) SMP Operation and Development

The SMP's and the computers were moved into their new quarters in the new physics wing in August 1970. The new area is much more spacious and allows for more efficient operation. Scanning and measuring are now in adjacent areas rather than on separate floors. Convenient access to the computers, multiplexer and particularly the 360/40 to 360/44 interface has improved their duty cycle. Last year we began a project of replacing the old transistor track centering circuits with analog integrated circuits. This project has now been completed and further small changes were made so that the SMP's can handle both conventional and bright field illumination. We are now able to digitize over a much wider range of track quality and to switch from bright to dark field film in less than one hour. New computer programs were developed for calibration of the SMP's and for diagnostic check-up. These programs have reduced the SMP down time significantly. In anticipation of the completion of POLLY in the near future, further major changes to the SMP hardware are not anticipated.

B) Time-sharing Data Processing and Program Development

In the last year, the programming staff has done significant program development, and maintenance of measuring and batch-job software. The

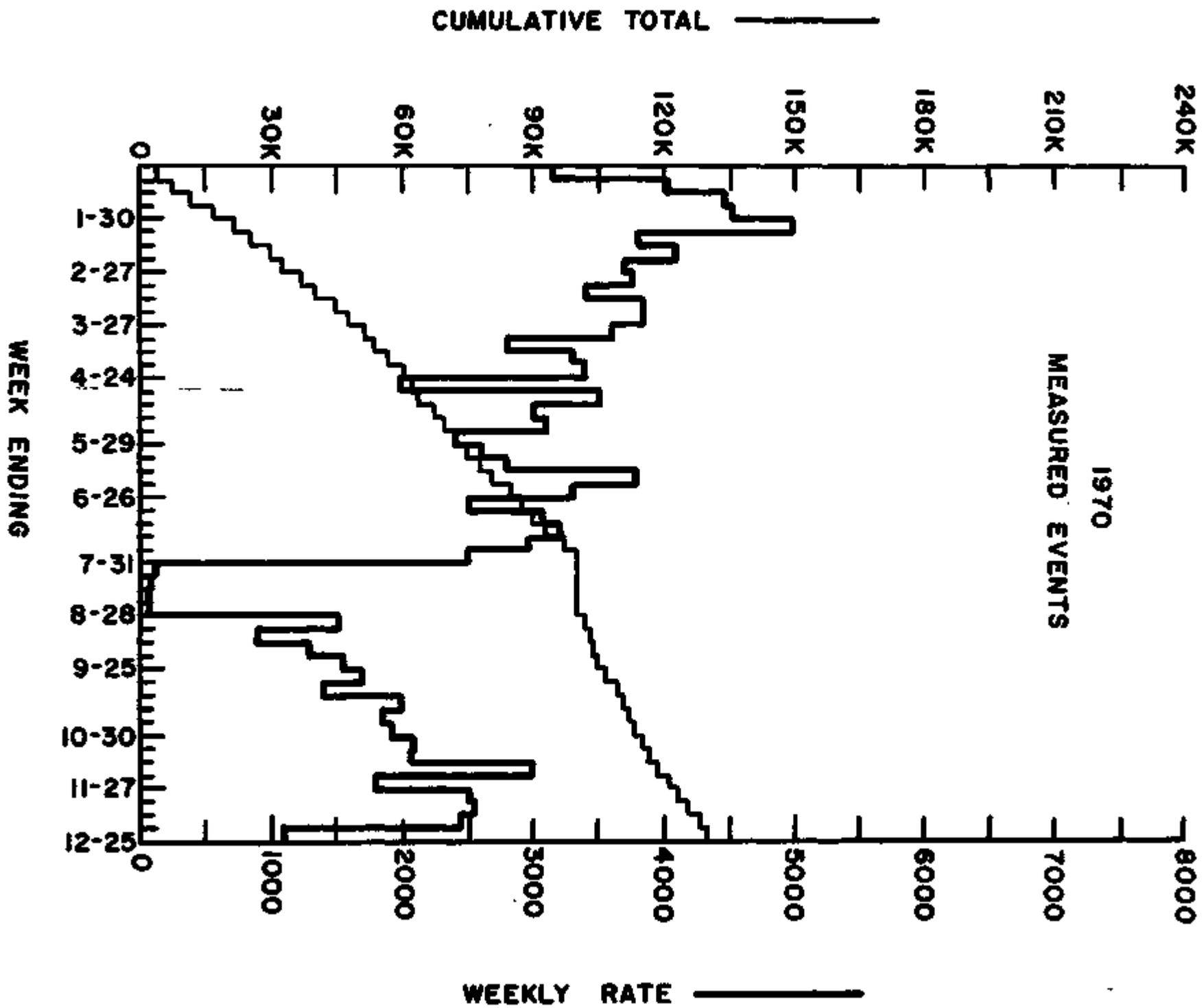


FIGURE 3

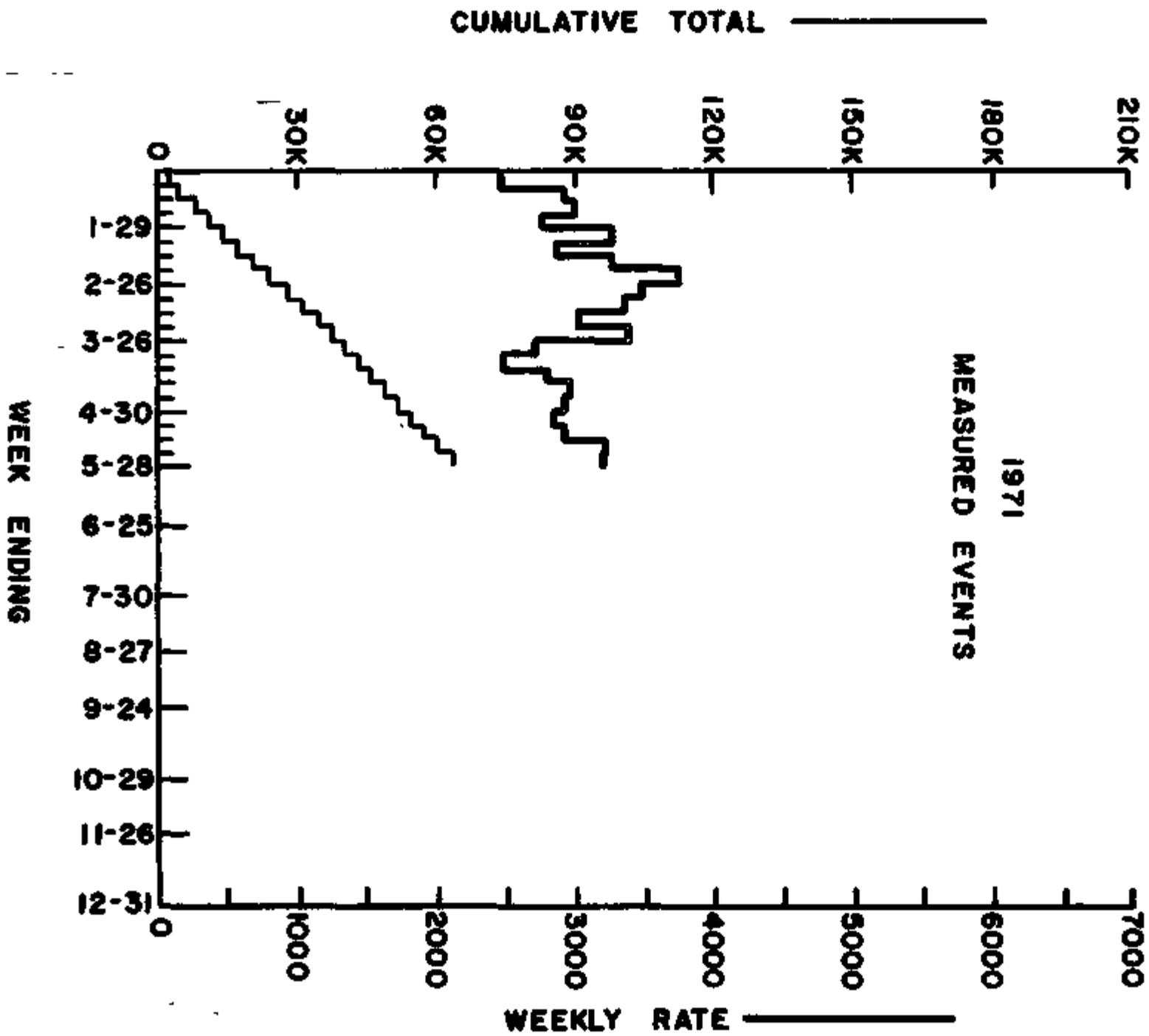


FIGURE 4

following is a list of the major programming improvements:

1. Conversion of the measuring-event file system from the /40 to the /44. This increases the speed and reliability of the measuring process and ease of updating the file.
2. Development of the on-line scanning, or scanning-measuring, capability for the SMP measuring system. As of June 1 we will be using the SMP's as Scanning and Measuring Projectors for the first time -- a change made necessary by reduction of scanning staff.
3. Development of a specialized monitor system for the /40 to support the current measuring effort with reduced overhead, easier operating procedures, and full disk-format compatibility with the /44. This increased available disk storage for both computers and led to other advantages described below.
4. Development of programs and procedures, when combined with (3) above, that permit all /40 program development and maintenance to be done in the /44 batch job stream. This change greatly reduces the time required to modify /40 programs. This change increases the usefulness of the /40 vis-a-vis POLLY development.
5. Development of benchmark and test programs to provide information used in the eventual selection of the minicomputer for POLLY.
6. Development of /44-based assembler, linkage-editor, and simulator to provide for Supernova program development and maintenance. This will prevent the problems from occurring in the Supernova which were just overcome in the /40 by (4) above.
7. Conversion of the /44 system to use the second high-speed data channel in such a way to minimize interference between measuring and batch jobs. Without this change our computing system would now be over-saturated.
8. In conjunction with the SHARE Model 44 Project, continued improvement of the Purdue-developed 44 MFT system. These changes are shared between the

other 44MFT users and ourselves. (At the present time, there are eleven full-time 44MFT users, including three in physics research and five in other areas of higher education.)

C. POLLY Progress

Designs from ANL POLLY II and POLLY III and from Illinois DOLLY are incorporated in the Purdue POLLY and adapted to take advantage of our situation.

1. The Computers

The first decision made was the type of computer to use to run the POLLY. A large amount of computation is required to filter out the noise and to obtain the parameters which describe tracks and fiducial marks. These computations are made many times in the course of following the tracks, and they are the limit in the speed of the POLLY. Thus, the computer used at this level must be dedicated. We looked carefully at selected portions of the Argonne code and decided that most of the calculations could be performed in 16-bits and that a modest amount of double precision code would do it all.

The Purdue High Energy Physics group has an IBM 360 model 44 and model 40 which can be used on a time-shared basis for file management, occasional floating point computations and program storage. Using a fast 360 data channel it is possible to transfer 32,000 16-bit words in less than 20 msec. A careful study of the amount of code and data actually required at one time in the mini-computer indicated that 16k 16-bit words would probably be enough. The computer was actually purchased with 20k.

All of the available 16-bit computers with cycle times of about 1 μ sec or less were studied for possible purchase. Short, but crucial, sections of code from the Argonne programs were coded for each candidate. A modest effort was made to optimize the code for each machine. Specified instruction times were then used to compute the time to execute the programs. The Data General Supernova (800nsec

cycle) and the Varian 620f (750 nsec cycle) were far superior to other computers and had code times within 10% of each other from one section of code to another. The 620f was slightly superior. We made the decision to purchase the Supernova when we learned that it was to have 300 nsec semiconductor memory instead of 800 nsec core.

2. Computer Interface

To use the Supernova it is necessary to have a high speed data channel to the 360/40 or 360/44. For convenience in testing we will initially connect to the 360/40 since more time is available on it. The 360 interfaces are all designed to the same specifications, so the channel works with either machine. The interface connects between the high-speed data channel on the Supernova and either a selector channel or a multiplexor channel on the 360. The interface contains circuits for fetching commands, data address, and word count from the Supernova memory and stores them in counters or registers. Using these registers it fetches or stores data words into Supernova memory, converts them from 16-bits to 8-bits (or vice-versa), and generates the control signals required to activate the standard 360 interface. To the programmer the Supernova side of the interface looks very similar to the 360 side. The same method of reporting status is used in each, and they have about the same capabilities and limitations.

We have designed and constructed this interface and connected it between the Supernova and the 360/40. It is now under test.

3. Precision CRT and Scan Circuits

We plan to borrow heavily from the Argonne and Illinois designs for the CRT circuits. We will only make changes required for interfacing to the Supernova, etc. We plan to use the Illinois digital slice scan circuits because we feel they offer more flexibility at a comparable or lower cost than an analog sweep. The precision DAC's are being constructed for us now at the University of

Illinois, and the digital circuitry will be built here. With this system the programmer has control of the main deflection, the length, width, direction, and curvature (parabolic approximation) of the slice, and the direction of the sweep line which need not be perpendicular to the direction of the slice. For each slice we must compute a starting point, direction, and curvature. The curvature is needed because it contains a rough correction for the pin-cushion distortion of the CRT. With a small additional complication it can also contain track curvature.

4. Operator Display (CRT)

The operator interacts through an optical display of the frame, a CRT display (computer generated) of selected portions of the frame as programmed or requested, a track ball for positioning a reticle on either the visual display or the CRT, a button board under computer control to indicate which of several possible options should be tried, and an alphanumeric keyboard for more complicated situations (getting a dump, reloading, etc.).

The CRT display will display points, vectors, or alphanumeric characters of variable sizes. Rather than displaying from the computer memory we will use a large scale integrated circuit shift register to give an automatic refresh. We have enough of these circuits to contain about 4000 points. The CRT display itself is now starting testing, and the shift register refresh circuitry is in an advanced state of design.

5. Optical and Mechanical Hardware

The POLLY mainframe is installed in place. It is designed to accommodate a second POLLY bay, but no other hardware implementation of the second bay has started. The main optical bench for the precision CRT and the precision lens (the same 1:1 lens used in the Illinois DOLLY) is built. Lens, CRT, focussing and deflection coils are ordered or have been delivered. Mounting and positioning parts have mostly been machined. Design is complete, and most parts have

been ordered or built for the optical display system. Film advance and platen modules are in an advanced state of construction. (The first module is being built for SLAC 46 mm single-strip format; other modules will be built as needed.) Track ball (x-y control) and angle digitizers have been purchased and are ready for installation. Of the major components, only the console "buttonboard" has not been ordered, and the Supernova's teletype will perform as keyboard for test purposes until the buttonboard has been designed and built.

6. POLLY Software

Some of the POLLY software has already been mentioned in section IV B of this report. Three sorts of code are under development or have been written:

a) Support for the Supernova, permitting assemblies, linkage edits, and code simulations to be done in the batch job stream of the 360/44. This code is functioning nicely at present.

b) Interface code, permitting loading of code prepared in the 360/44 job stream directly into the Supernova via the Supernova-360/40 interface and /44-/40 shared disks. A rudimentary system exists for this now, and it is being refined to give maximum flexibility for future debugging and POLLY operator control.

c) POLLY code. The Supernova "operating system" for POLLY has been written and debugged. Device routines have been written for the 360 interface and for the CRT display. Device routines for driving the slice scan and analyzing slice scans are under design. Other device routines (film advance, button board, etc.) are yet to be attacked.

However, it has already become clear that use of the simulator permits the debugging of device routines prior to the operation of the hardware. This has already been our experience with the display and interface hardware. We anticipate little delay at the device-routine level for software development. Last, and most important in the POLLY, is the overall control logic -- track recognition, track

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following, fiducial measuring, etc. This code has not yet been written, but it is our plan to lean very heavily on Argonne ideas and algorithms as well as on our own SMP filtering experience in designing and writing this code, the major effort for which will begin next fall, prior to completion of hardware or digital circuitry.

V. Summary of Publications, Papers, and Proposals

Three additional publications^{41,42,43} not directly mentioned in the text of this report have come out during the year. Papers published between June 1, 1970 and May 31, 1971, are marked in the footnotes with an asterisk(*).

A. Publications

During the year 19 papers appeared in the journals Physical Review Letters(7), Physical Review D (4), Nuclear Physics B (6), and Physics Letters (2). Seven additional papers have been submitted to these journals, and two are scheduled for June publication in Physical Review Letters. Conference papers have been published during the year from the Cambridge (Data Handling) the Duke (Hyperon Resonances), the Philadelphia (Meson Resonances) and the last Ohio University conference (Vol. 1 of Particles and Nuclei). Six additional papers are under preparation for Physical Review Letters and Physical Review D.

B. Conference Papers (unpublished)

Eighteen papers were submitted to the XVth International Conference at Kiev. Four of these were permitted oral presentation at the conference, and fifteen were referenced by rapporteurs.

Two papers, one invited, and the other submitted and presented orally, were given at the Bologna conference (Meson Resonances).

Four papers have been submitted to the European High Energy Conference at Amsterdam.

Nineteen contributed papers were presented at the Austin, New York, and Washington meetings of the APS.

C. Doctoral Theses

The following three theses have been accepted during the year. Their authors are situated, respectively, at BNL, at Purdue, and at ANL.

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W. Miller, "Many Body Final States From Interactions near 3 GeV",

A. Ammann, "Study of Λ and Σ^0 Final States Produced by the Interaction of K^- Mesons on Deuterium at 4.5 GeV/c".

S. Kramer, "A Study of the Reactions with Two Charged Final State Particles in π^+ - Proton Interactions at 13.1 GeV/c".

D. Scientific Proposals Submitted

During the year the following proposals were submitted: they are appended to the total annual report and renewal request.

Proposal	Spokesman
NAL No. 40 (π^-p in 14' Chamber)	Barnes
NAL No. 41 (pp in 14' or Smaller Chamber)	Williamson
NAL No. 42 (Neutrino Interactions in 14' D + Ne Chamber)	Garfinkel ✓
NAL No. 43 (Meson Production at 50,100 GeV)	Miller
NAL No. 126 (π^-p in 30" Hybrid)	Barnes ✓
NAL No. 131 (K^-p and $\bar{p}p$ in 30" Hybrid)	Miller ✓
SLAC (π^-p at 13.1 GeV/c in 82" HBC)	Miller ✓
SLAC (Run in 15" Rapid-cycling HBC)	Fowler

REFERENCES

- * 1. Reaction $\pi^+ p \rightarrow \rho^0 \Delta^{++}$ at 13.1 GeV/c; J. A. Gaidos, R. B. Willmann, J. W. Lamsa, C. R. Ezell and F. T. Meiere, Phys. Rev. D1, 3190 (1970).
- * 2. The Reaction $\pi^+ p \rightarrow f^0 \Delta^{++}$ at 13.1 GeV/c; J. A. Gaidos, C. R. Ezell, J. W. Lamsa, R. B. Willmann, Nuclear Physics B26, 225 (1971).
- * 3. Double-Regge Analysis of the Reaction $\pi^+ p \rightarrow \pi^+ \rho^0 p$ at 13.1 GeV/c; J. W. Lamsa, J. A. Gaidos, R. B. Willmann, and C. Ezell, Phys. Rev. D1, 3091(1970) (June 1).
- * 4. Double-Regge-Pole Analysis of $\pi^+ p \rightarrow \pi^+ \rho^0 p$ at 13.1 GeV/c; J. A. Gaidos, C. R. Ezell, J. W. Lamsa, R. B. Willmann, Phys. Rev. D2, 1226(1970).
- * 5. Double-Regge-Pole Analysis of $\pi^+ p \rightarrow \pi^+ f^0 p$ at 13.1 GeV/c; J. A. Gaidos, C. R. Ezell, J. W. Lamsa, and R. B. Willmann, Nuclear Physics B26, 109(1971). (1 October)
- * 6. Double-Regge-Pole Analysis of $\pi^+ p \rightarrow \pi^+ \pi^- \Delta^{++}$ at 13.1 GeV/c; J. A. Gaidos, C. R. Ezell, J. W. Lamsa, R. B. Willmann, Nuclear Phys. B23, 84(1970).
- 7. Production of $K^+ K^-$ and $p\bar{p}$ Pairs in Four-body Reactions at 13.1 GeV/c; J. A. Gaidos, T. A. Mulera, C. R. Ezell, J. W. Lamsa, R. B. Willmann, (submitted to Nuclear Physics).
- * 8. Observation of $N^*(1720)$ Decay to $\Delta(1236)\pi$ from $\pi^+ p$ Interactions at 13.1 GeV/c; R. B. Willmann, J. W. Lamsa, J. A. Gaidos, and C. R. Ezell, Phys. Rev. Letters 24, 1260(1970).
- * 9. Comparison of the CERN Boson Spectrometer Results with a $\pi^+ p$ Experiment at 13 GeV/c in a Bubble Chamber. Invited talk given at the International Conference on Meson Resonances, Philadelphia 1970. Published in book form by Columbia University Press as "Experimental Meson Spectroscopy".
- * 10. Study of High Mass Boson Structures $\pi^+ p$ Interactions at 13.1; Kramer et al., Particles and Nuclei 1, 131(1970).

- * 11. Decay of Some High Mass Bosons to $\pi^+\pi^0$ S.L. Kramer, H.R. Barton, Jr., L.J. Gutay, S. Lichtman, D.H. Miller, J.H. Scharenguivel, Phys. Rev. Lett. 3396(1970)
- 12. Coherent Production of High-Mass Meson States in π^+d Collisions at 13 GeV/c; K. Paler, et al., to appear in Phys. Rev. Letters June 28, 1971.
- * 13. A Multiperipheral Analysis of the Reaction $\pi^+d \rightarrow p_s p \pi^+ \pi^- \pi^0$ at 13 GeV/c; H. R. Barton, Jr., et al., Particles and Nuclei 1, 198 (1970).
- * 14. Final States with One or Two Charged Particles and a Visible \bar{K}^0 from K^-d Interactions at 4.5 GeV/c; D. D. Carmony, R. L. Eisner, A. C. Ammann, A. F. Garfinkel, L. J. Gutay, D. H. Miller, L. K. Rangan and W. L. Yen, Phys. Rev. D2, 30-45 (1970).
- 15. Final States with Three Charged Particles and a Visible \bar{K}^0 from K^-d Interactions at 4.5 GeV/c; W. L. Yen, A. C. Ammann, D. D. Carmony, A. F. Garfinkel, L. J. Gutay, D. H. Miller and K. Paler (submitted to Nuclear Physics).
- * 16. A_2 Meson Production in K^-d Reactions; A. F. Garfinkel, A. C. Ammann, D. D. Carmony and W. L. Yen, Phys. Letters 33B, 536-540 (1970).
- * 17. Comments on the $\Sigma(1620)$; A. F. Garfinkel, Hyperon Resonances (1970 Duke Conference) pp. 301-303.
- * 18. Evidence Against an $n\bar{\pi}^-\pi^+$ Enhancement at a Mass of 1.627 GeV/c² in $K^-d \rightarrow p_s \pi^+ \pi^- \pi^- n \bar{K}^0$ at 4.48 GeV/c; A. C. Ammann, D. D. Carmony, A. F. Garfinkel, L. J. Gutay, D. H. Miller and W. L. Yen, Phys. Letters 34B, 533-534 (1971).
- 19. Study of Λ and Σ^0 Final States Produced by the Interaction of K^- Mesons on Deuterium at 4.5 GeV/c; A. C. Ammann, Ph.D. Thesis, Purdue University, (1970).
- * 20. Study of Impulse Model in Reaction $K^-d \rightarrow p/\bar{\pi}^- + \text{neutrals}$; J. Tebes, D. D. Carmony, A. F. Garfinkel, L. J. Gutay, and D. H. Miller, Nuc. Phys. B20, 565 (1970).

- * 21. Application of the Generalized Veneziano Model to the Reaction $K^- n \rightarrow K^{*-} \pi^+ p$ at 4.5 GeV/c; K. Paler et al., Nuc. Phys. B21, 407 (1970).
22. $K(498)^0$, $K^*(890)^0$, and $K^{**}(1420)^0$ Production in $K^+ n$ Interactions at 9.0 GeV/c; H. W. Clopp, D. D. Carmony, D. Cords, A. F. Garfinkel, R. F. Holland, F. J. Loeffler, L. K. Rangan, and R. L. Lander, D. E. Pellett, P. M. Yager, Kiev Meeting of the XV International Conference on High Energy Physics, August, 1970.
23. Q Meson Production in $K^+ d$ Interactions at 9 GeV/c; R. F. Holland, D. D. Carmony, H. W. Clopp, D. Cords, A. F. Garfinkel, F. J. Loeffler, L. K. Rangan, and R. L. Lander, D. E. Pellett, P. M. Yager, Kiev Meeting of The XV International Conference on High Energy Physics, August, 1970.
24. Z^* Production in $K^+ d$ Interactions at 9 GeV/c; L. K. Rangan, D. D. Carmony, D. Cords, H. W. Clopp, A. F. Garfinkel, F. J. Loeffler, and R. L. Lander, D. E. Pellett, P. M. Yager, Kiev Meeting of The XV International Conference on High Energy Physics, August 1970.
25. Investigation of $K\pi$ Scattering in $K^+ d$ Interactions at 9 GeV/c; D. Cords, D. D. Carmony, H. W. Clopp, A. F. Garfinkel, R. F. Holland, F. J. Loeffler, H. B. Mathis, L. K. Rangan, J. Erwin, R. L. Lander, D. E. Pellett, P. M. Yager, Bulletin American Physical Society 16, 91 (1971).
26. Structure in the Low Mass $K\pi\pi$ System from $K^+ d$ Interactions at 9 GeV/c; R. F. Holland, D. D. Carmony, H. W. Clopp, D. Cords, A. F. Garfinkel, F. J. Loeffler, L. K. Rangan, R. L. Lander, D. E. Pellett, P. M. Yager, Bulletin American Physical Society 16, 112 (1971).
27. Charge Exchange Production of K^{*+} 's and $K\pi$ Scattering in the Mass Region 1000 - 1500 MeV/c² from $K^+ n$ Interactions at 9.0 GeV/c; H. W. Clopp,

- D. D. Carmony, D. Cords, A. F. Garfinkel, R. F. Holland, F. J. Loeffler, H. B. Mathis, L. K. Rangan, J. Erwin, R. L. Lander, D. E. Pellett, P. M. Yager, Bulletin American Physical Society 16, 547 (1971).
28. Search for High Mass K^* Resonances in K^+d Interactions at 9 GeV/c;
H. B. Mathis, D. Cords, D. D. Carmony, H. W. Clopp, A. F. Garfinkel, R. F. Holland, F. J. Loeffler, L. K. Rangan, J. Erwin, R. L. Lander, D. E. Pellett, P. M. Yager, Bulletin American Physical Society 16, 525 (1971).
29. Evidence for Splitting in the Q Region of $K^+\pi^+\pi^-$ Mass; A. F. Garfinkel, R. F. Holland, H. W. Clopp, D. Cords, F. J. Loeffler, L. K. Rangan, R. L. Lander, D. E. Pellett, P. M. Yager, (accepted for Phys. Rev. Letters).
30. New Evidence for Splitting in the Q Region of $K^+\pi^+\pi^-$ Mass; A. F. Garfinkel, R. F. Holland, H. W. Clopp, D. Cords, F. J. Loeffler, L. K. Rangan, R. L. Lander, D. E. Pellett, P. M. Yager, International Conference on Meson Resonances, Bologna, April 14 -16, 1971.
31. $K^*(890)$ Production in the Charge Exchange Reaction $K^+n \rightarrow K^+\pi^-p$ at 9.1 GeV:
D. Cords, D. D. Carmony, H. W. Clopp, A. F. Garfinkel, R. F. Holland, F. J. Loeffler, H. B. Mathis, L. K. Rangan, J. Erwin, R. L. Lander, D. E. Pellett, P. M. Yager, W. L. Yen, (to be published).
32. Evidence for Splitting in the Q Region of $K^+\pi^+\pi^-$ Mass; A. F. Garfinkel, R. F. Holland, H. W. Clopp, D. Cords, F. J. Loeffler, L. K. Rangan, R. L. Lander, D. E. Pellett, P. M. Yager, paper submitted to the International Conference on Elementary Particles, Amsterdam, June 30-July 6, (1971).

33. Evidence for a $K\pi$ Resonance near $1750 \text{ MeV}/c^2$; H. B. Mathis, D. D. Carmony, H. W. Clopp, D. Cords, A. F. Garfinkel, R. F. Holland, F. J. Loeffler, L. K. Rangan, J. Erwin, R. L. Lander, D. E. Pellett, P. M. Yager, W. L. Yen, paper submitted to the International Conference on Elementary Particles, Amsterdam, June 30 - July 6, 1971.
34. $K^*(890)$ Production in the Charge Exchange Reaction $K^+n - K^+\pi^-p$ at 9.1 GeV; D. Cords, D. D. Carmony, H. W. Clopp, A. F. Garfinkel, R. F. Holland, F. J. Loeffler, H. B. Mathis, L. K. Rangan, J. Erwin, R. L. Lander, D. E. Pellett, P. M. Yager, W. L. Yen, paper submitted to the International Conference on Elementary Particles, Amsterdam, June 30 - July 6, 1971.
- * 35. Observation of Σ Resonances in the 1670 MeV Mass Region; M. Aguilar-Benitez, V. E. Barnes, D. Bassano, S. U. Chung, R. L. Eisner, E. Flaminio, J. B. Kinson, N. P. Samios, K. Jaeger, Phys. Rev. Letters 25, 58 (1970).
- * 36. Production of the Λ Meson in the Final State $K^-p - K^-\pi^+\pi^-p$ at 4.6 GeV/c; M. Aguilar-Benitez, V. E. Barnes, D. Bassano, S. U. Chung, R. L. Eisner, E. Flaminio, J. B. Kinson, R. B. Palmer, N. P. Samios, Phys. Rev. Letters, 25, 54 (1970).
- * 37. Evidence for the Existence of a New Meson in the 955 MeV Mass Region; M. Aguilar-Benitez, D. Bassano, R. L. Eisner, J. B. Kinson, D. Pandoulas, N. P. Samios, V. E. Barnes, Phys. Rev. Letters 25, 1635 (1970).
- * 38. Branching Ratios of the $K(1420)$ Meson; M. Aguilar-Benitez, D. Bassano, R. L. Eisner, J. B. Kinson, N. P. Samios, V. E. Barnes, Phys. Rev. Letters 25, 1362 (1970).
- * 39. Investigation of the Forward Structure in Charge-Exchange $K^{*0}(890)$ Production; M. Aguilar-Benitez, V. E. Barnes, D. Bassano, R. L. Eisner, J. B. Kinson, N. P. Samios, Phys. Rev. Letters 26, 466 (1971).

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40. "Muon Contamination of Hadron Beams in the Neutrino Area", J. W. Lamsa, V. E. Barnes, and D. D. Carmony, Purdue University, March 22, 1971.
(unpublished.)
- * 41. Review of $S = -1$ Baryon States as Observed in Production Experiments. Invited Talk given at the International Conference on Hyperon Resonances, Duke University. D. H. Miller. Published in book form by Moore Publishing as "Hyperon Resonances - 70".
- * 42. Experimental Determination of the Low Mass $I = 0$ S-wave $\pi\pi$ Phase Shift Using a Method which is Consistent with the Off-Mass-Shell Dependence of Current Algebra, J. H. Scharenguivel, L. J. Gutay, D. H. Miller, F. T. Meiere, S. Marateck, Nuclear Physics B22, 16 (1970).
- * 43. R. L. McIlwain, F. J. Loeffler, and T. R. Palfrey, Jr., "Status and Performance of the Purdue SMP System", Xth International Conference on Data Handling Systems in High Energy Physics (Cambridge, England), p. 261, CERN Report 70-21, Geneva (1970).