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

COO-1428-382

ANNUAL PROGRESS REPORT

for the period

June 1, 1973 - May 31, 1974

DISCLAIMER

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I. INTRODUCTION

Considerable progress on several of our programs has been made during the past year. The most recent exposure in our large πN study at 13 GeV/c in the SLAC 82" bubble chamber consists of 500,000 $\pi^- p$ pictures. This film is currently being measured with our SMPs and is approximately 1/3 finished. Some recent topics of interest that have come out of the πN study are a partial wave analysis of the 3π system in the A_3 meson region, a study of the R meson from $\pi^+ p$ interactions regarding cross section and decay branching ratios, and a high statistics examination of the dynamics of the reaction $\pi^+ p \rightarrow (\rho^0, \omega)\Delta^{++}$. This work will go on for an appreciable period of time and we expect the prolific output of important information to continue. Current results will be reported at the International Conference in London.

The 9 GeV/c $K^+ d$ experiment in the ANL 80" bubble chamber has been finished for some time except that results continue to appear. Two abstracts have been submitted to the June 1974 American Physical Society meeting in Salt Lake City and there is a recent indication that we see our $K^*(1760)$ decay via the mode $K^* \omega$ (i.e. K, 4π). We intend to pursue our study of the $K^*(1760)$ by doubling our statistics with a new run of $K^+ d$ in the 80" BNL bubble chamber sometime during the coming fiscal year.

Our entry into the bubble chamber-hybrid technique has been twofold. During the Fall and Winter our 100 GeV $\pi^+ p$ run in the NAL 30" bubble chamber-wide-gap spark chamber system was accomplished which resulted in 180,000 pictures which we are sharing with the University of Wisconsin. Scanning, measuring and reconstruction of the events in this exposure are successfully underway. In March, 1974, we received approval for 100,000 pictures of a 300 GeV/c π^+ beam in the NAL 30" Hybrid bubble chamber system. We have also been participating in the development of the SLAC 40" bubble chamber-hybrid spectrometer. One of our research associates has spent the last several months at SLAC helping in this program and we were recently approved by SLAC for our first experiment with this system.

At Argonne National Laboratory we have been active this year in two outstanding endeavors with the ZGS. Our collaboration in the 12' bubble chamber neutrino experiment has already yielded exciting results -- the observation of neutrino-nucleon interactions via a neutral weak current. Considerable data are also accumulating which will shed new light on the axial-vector form factor of the nucleon. Also at the ZGS we have carried out the first phase of our experiment to measure backward $\pi^- p$ and $K^- p$ scattering via Δ^{++} exchange using counters and spark chambers. Our first results were recently reported at the Washington, D. C. APS meeting.

The analysis of data from our pp collaboration using the AGS-ARGO spectrometer (BNL Expt. 396) is continuing. The most noteworthy result so far is the fact that the multiplicity of charged secondaries increases with the momentum transfer in the reaction. This work will continue throughout the coming year.

Our measuring system utilizing five SMPs and two digitizing microscopes has performed exceptionally well this past year. Some 203,000 events were measured during calendar year 1973. While POLLY is still not ready for production measuring, all hardware components are finished. In particular the micropup digital controller is in operation and operational software is rapidly being implemented.

Finally it is worth remarking that about 8000 events from the SLAC 15" rapid cycling bubble chamber have been scanned, measured and reconstructed with our system during the past Fall and Winter. These are part of a π^+p experiment carried out by Earle Fowler and his SLAC, Indiana University and Vanderbilt University colleagues.

What follows is a more detailed discussion of the topics mentioned above.

II. BUBBLE CHAMBER EXPERIMENTS

A. Status of the 13 GeV/c πN Experiments

1. Introduction

For several years we have been involved in detailed studies of the production and decay of resonant states in pion nucleon interactions at 13 GeV/c. There are many interesting problems to be resolved in this energy region. These include looking for missing members of SU(3) multiplets, detailed comparisons of branching ratios to predictions and analysis of exchange mechanisms. We are endeavoring to push the sensitivity of our results to the practical limit set by conventional bubble chamber techniques. This has set a limit of $\sim 2 \times 10^6$ pictures and in order to maximize the information we can obtain this has been divided as follows:

π^+p	755 k pictures	35 events/μb
π^+d	200 k pictures	9 events/μb
π^-p	500 k pictures	25 events/μb.

This division allows detailed studies of resonant production in different charge states and enables one to isolate separate exchange contributions and resolve the complexity of the different backgrounds. These experiments form a unique set and have produced much interesting physics to date. We are now measuring the π^-p phase of this experiment which will complete the program. This is proceeding more slowly than expected because of the inability within our present budget to fully man our measuring system.

2. Measuring

Measurements of the 755,000 picture π^+p exposure of the SLAC 82" chamber were completed in July, 1973, with a total of more than 600,000 events. The π^+d experiment had been completed earlier. Our measuring system is now very efficient and we are operating in a true scanning-measuring mode because of the high event density. The geometry program TVGP operates in a real time mode online and gives instant feedback to the measurer. The kinematic fitting program, SQUAW, runs automatically as a background job. This system provides data ready for physics analysis immediately after measurement.

Measuring on the π^-p film began in July, 1973, when the machines were converted from 46 to 35 mm film format. Approximately 30% of this film will have been measured by July, 1974.

3. Experimental Results

3.1 Study of the R Meson[1]

The positively charged I=1 meson system in the 1.6 → 1.8 GeV region has been a continuous source of interest for us, because one expects that several resonances may exist in this mass region. Apart from the $\pi^+\pi^-$ decay mode of the 3^-g, the world data on resonances in this region is either meagre or the results are conflicting.

We have examined the two and four pion enhancements in the R region carefully and cross sections and branching ratios into two and three body modes were determined with a critical evaluation of the effect of realistic backgrounds. One very nice feature of the data is the very clear $\pi^+\omega$ decay mode and these data have given the best result to date on this decay mode. See fig. 1.

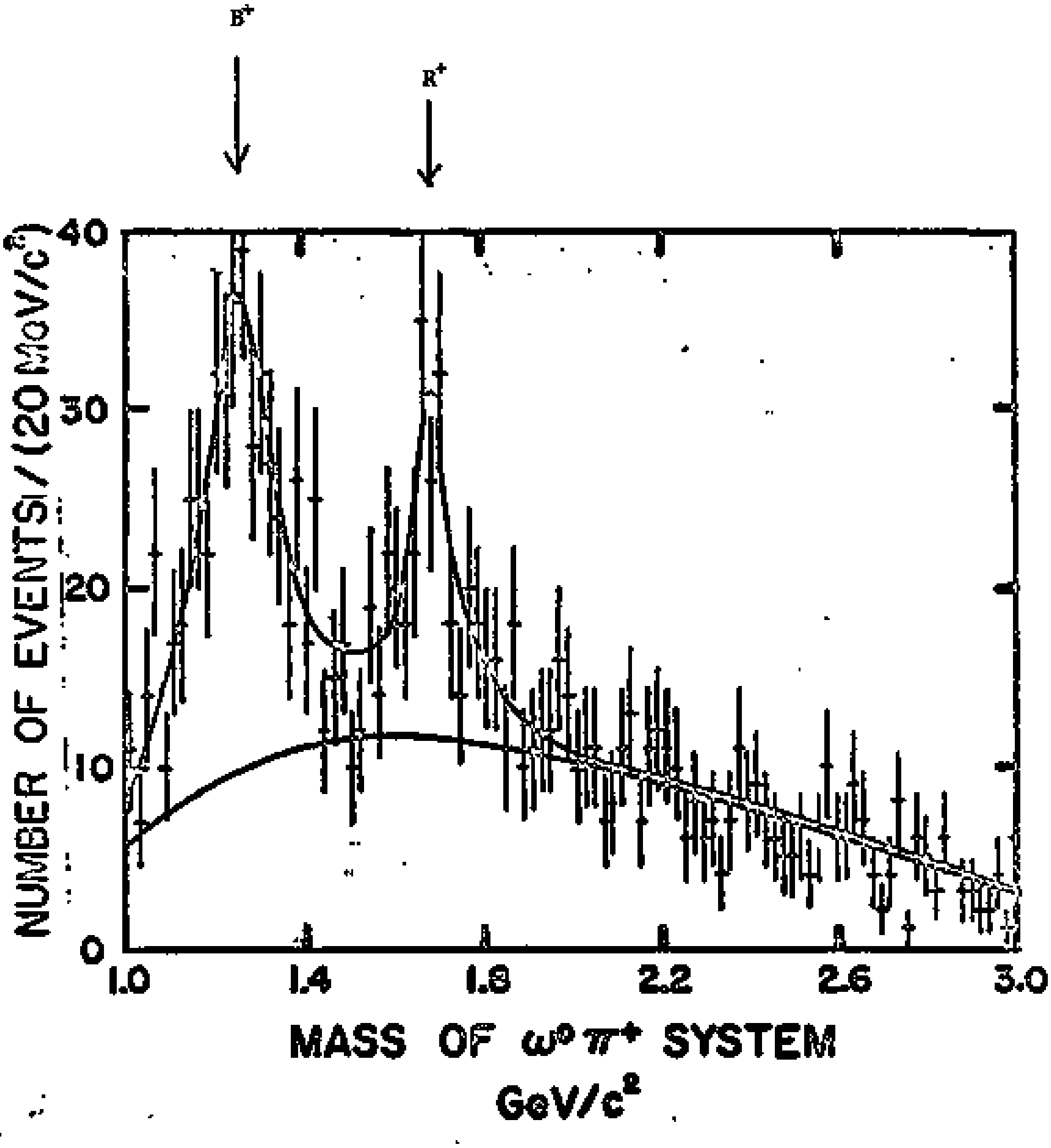
A comparison to spectrometer results in this mass region was also made as was a search for multiple structure in the R region.

3.2 Partial Wave Analysis of the 3π (A region)[2,3,4]

We have completed a detailed spin partiy analysis of the A region utilizing a sophisticated maximum-likelihood program using techniques developed by Ascoli and co-workers at Illinois. This partial wave decomposition confirmed that the A_1^+ (1^+) decay is dominantly rho-pi in an S-wave, that the A_2^+ (2^+) is a rho-pi D wave and the A_3^+ (2^-) is principally f-pi S-wave. This was the first such analysis of the A^+ region and yielded the interesting result that the A_3^+ amplitude undergoes a phase change through its mass width. This result is in conflict with results on the A_3^- system; however, our data contain a much cleaner A_3 signal than did the original bubble chamber compilation of Ascoli. See figs. 2 and 3.

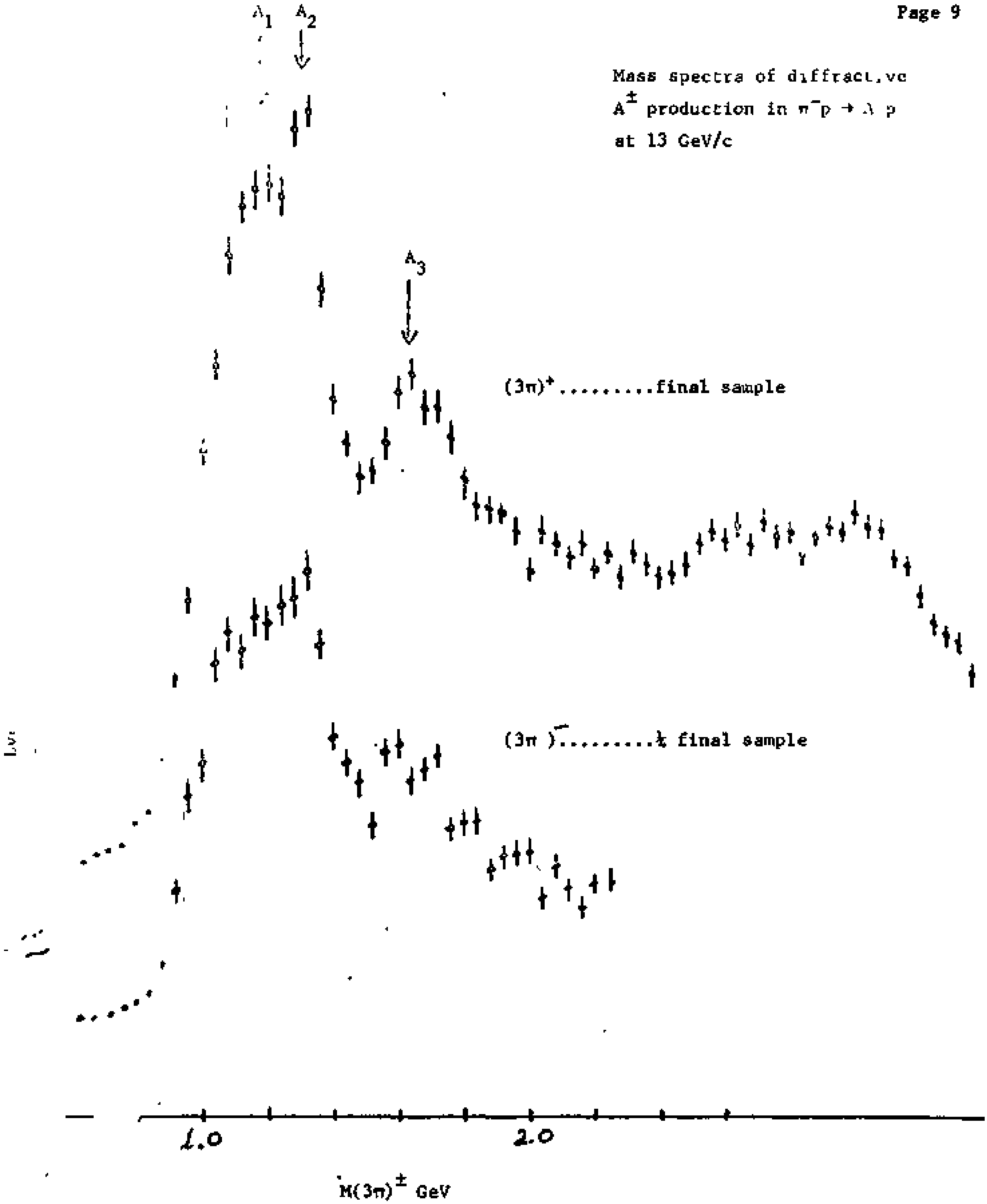
3.3 The Reaction $\pi^+p \rightarrow (\rho^0,\omega)\Delta^{++}$

Cross sections, density matrix elements and statistical tensors were determined and a discussion of the results in terms of particle exchanges, quark model constraints and the equal phase hypothesis were presented. See fig. 4. The existence of a helicity non-zero amplitude for the rho-delta channel in the forward direction was established and discussed.



B+
R+
NUMBER OF EVENTS / (20 MeV/c²)
0
10
20
30
40
1.0
1.4
1.8
2.2
2.6
3.0
MASS OF ω° π+ SYSTEM
GeV/c²

Fig. 1



A1
A2
A3
Mass spectra of diffractive
A± production in π⁻p → A p
at 13 GeV/c
(3π)⁺.........final sample
(3π)⁻.........½ final sample
1.0
2.0
M(3π)± GeV

Fig. 2

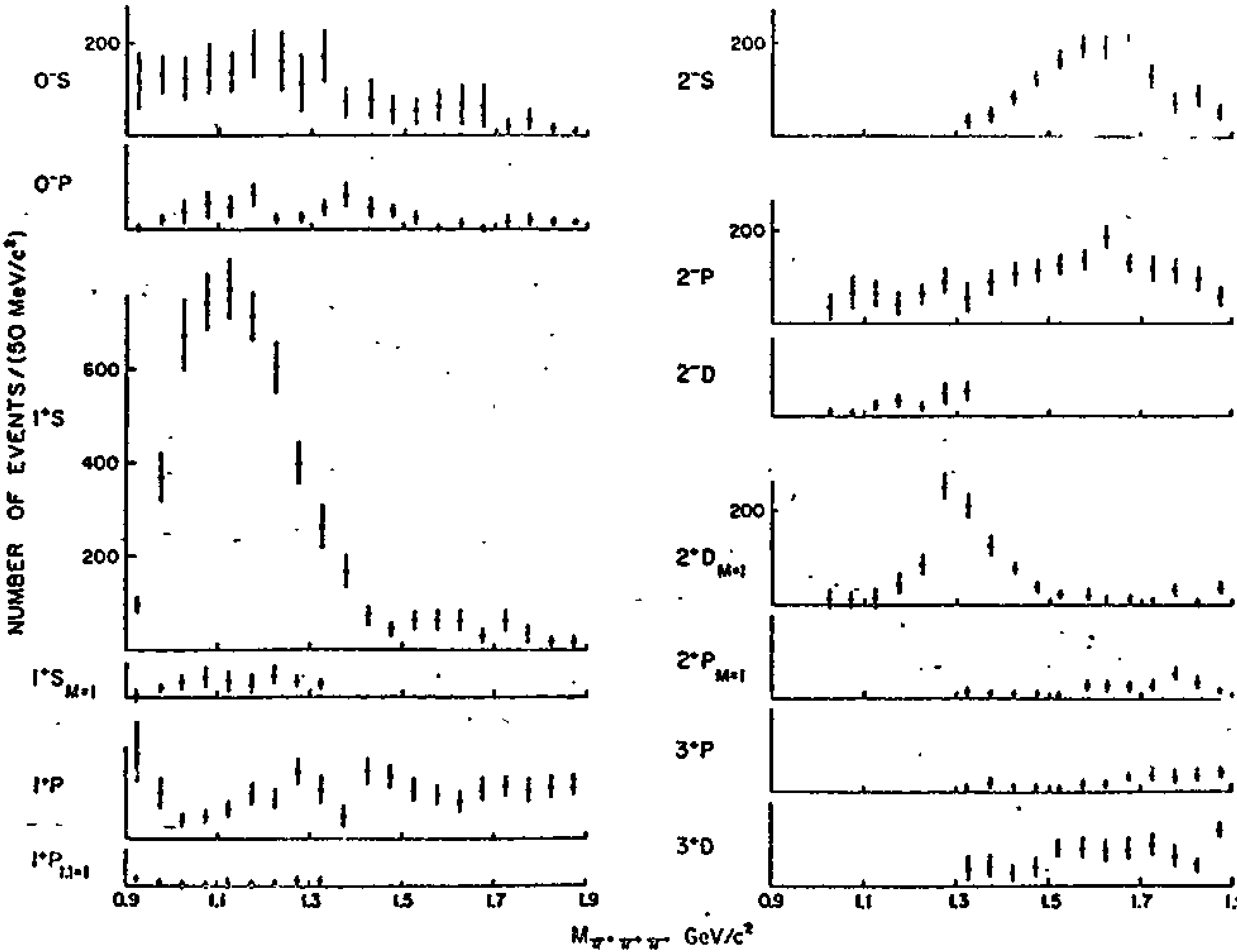
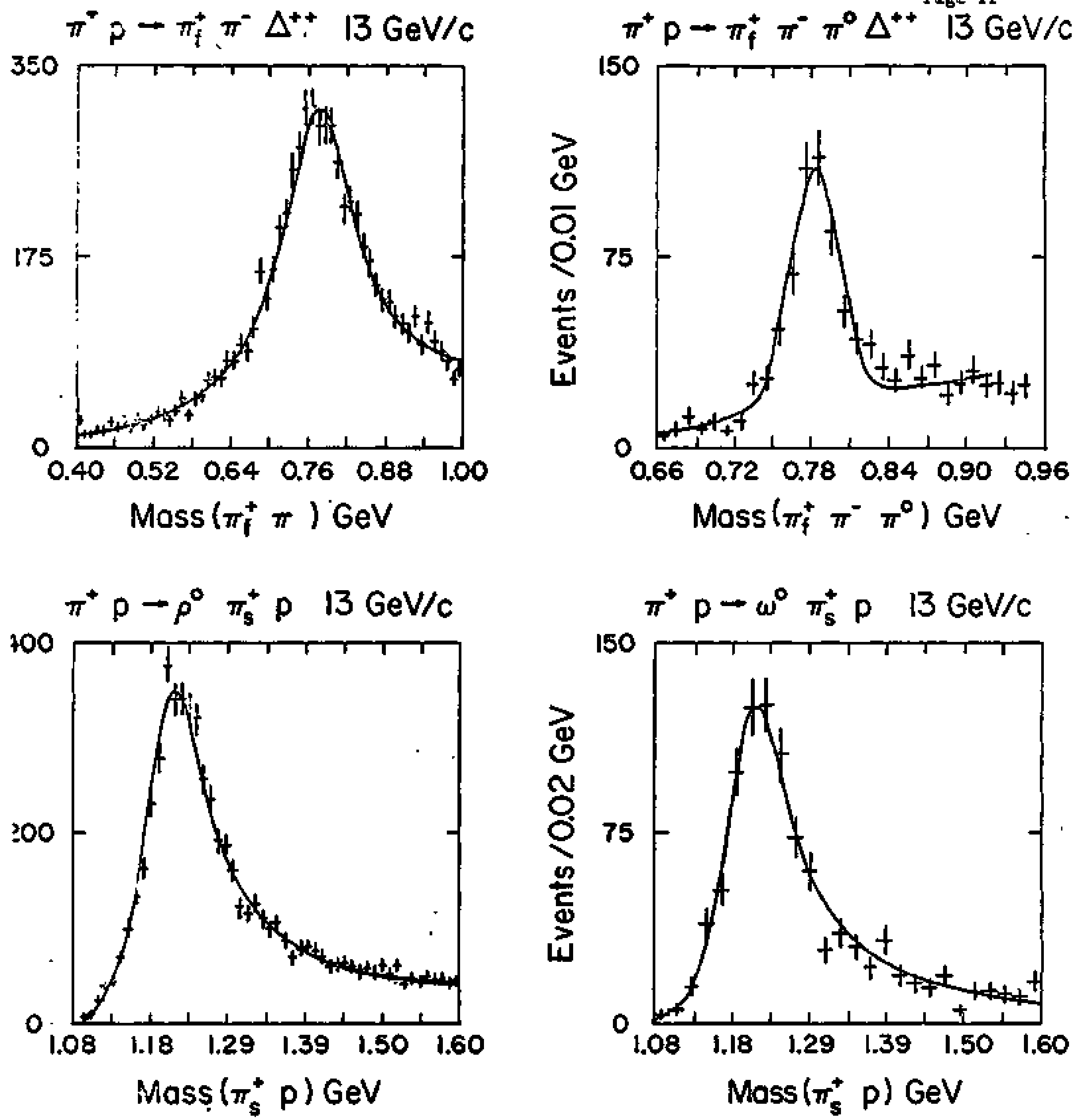

0⁻S
0⁻P
1⁺S
1⁺S M=1
1⁺P
1⁺P M=1
2⁻S
2⁻P
2⁻D
2⁺D M=1
2⁺P M=1
3⁺P
3⁺D
NUMBER OF EVENTS / (50 MeV/c²)
200
600
400
0.9
1.1
1.3
1.5
1.7
1.9
M π⁺π⁺π⁻ GeV/c²

Fig. 3



Quasi-two-body mass projections

Fig. 4

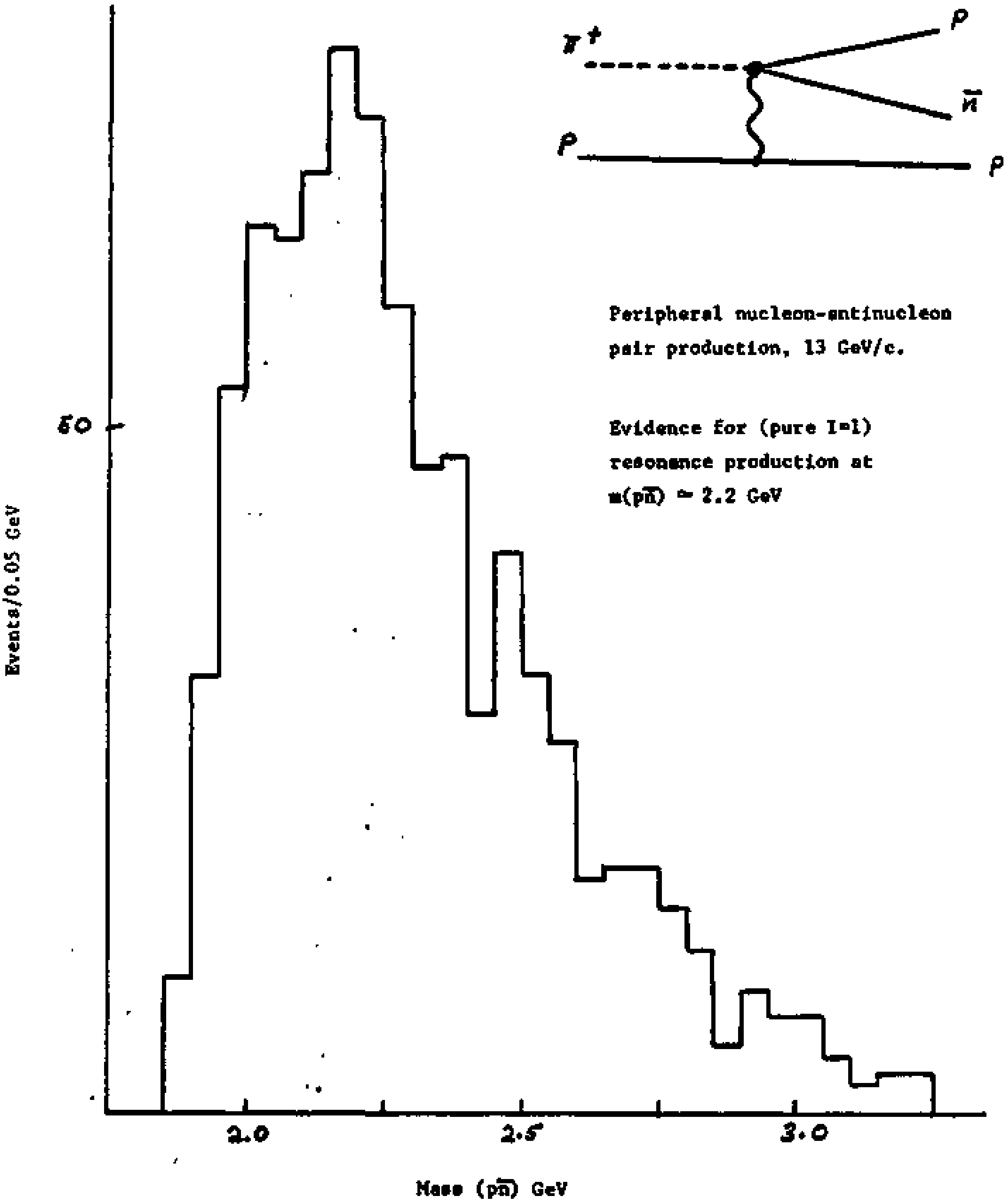

π+
p
n̄
p
p
Peripheral nucleon-antinucleon
pair production, 13 GeV/c.
Evidence for (pure I=1)
resonance production at
m(pn̄) ≃ 2.2 GeV
50
Events/0.05 GeV
2.0
2.5
3.0
Mass (pn̄) GeV

Fig. 5

3.4 Peripheral Nucleon-Antinucleon Production[6]

We have completed our data samples of the reactions $\pi^+ p \rightarrow (p\overline{n})p$ and $p\overline{p}\Delta^{++}$ and are now accumulating events in the $\pi^- p \rightarrow (\overline{p}n)p$ channel for comparative studies, fig. 5. There is evidence for complicated resonance production in the low mass I=1 states; these observations are consistent with the low energy annihilation studies. We also observe the antinucleon interactions for about 7% of the events.

4. The Six-Prong Pi-Plus Proton Reactions

The reactions $\pi^+ p \rightarrow 3\pi^+ 2\pi^- p$ and $\pi^+ p \rightarrow 3\pi^+ 2\pi^- \pi^0 p$ have been measured and analyzed. A detailed comparison with the predictions of a multi-peripheral model utilizing on-the-mass shell pion-nucleon and pion-pion scattering with vertex modifications has been carried out.

B. 9 GeV/c K^+d Experiment

We have measured and analyzed approximately 150,000 events from a 370,000 picture exposure of the BNL 80-inch deuterium-filled bubble chamber to a 9 GeV/c K^+ beam. Except for the measurement of the last few hundred five and six-prong events in early June, all of these events existed in final form on data summary tapes at the beginning of this period and a number of papers had already appeared (Phys. Rev. 4 1974 (1971), Phys. Rev. Letters 26 1505 (1971), Phys. Rev. Letters 27 1160 (1971), Proc. Bologna Conference (1971), and Nucl. Phys. B54 109 (1974)). Two Ph.D. theses also resulted from this experiment as well as numerous conference reports.

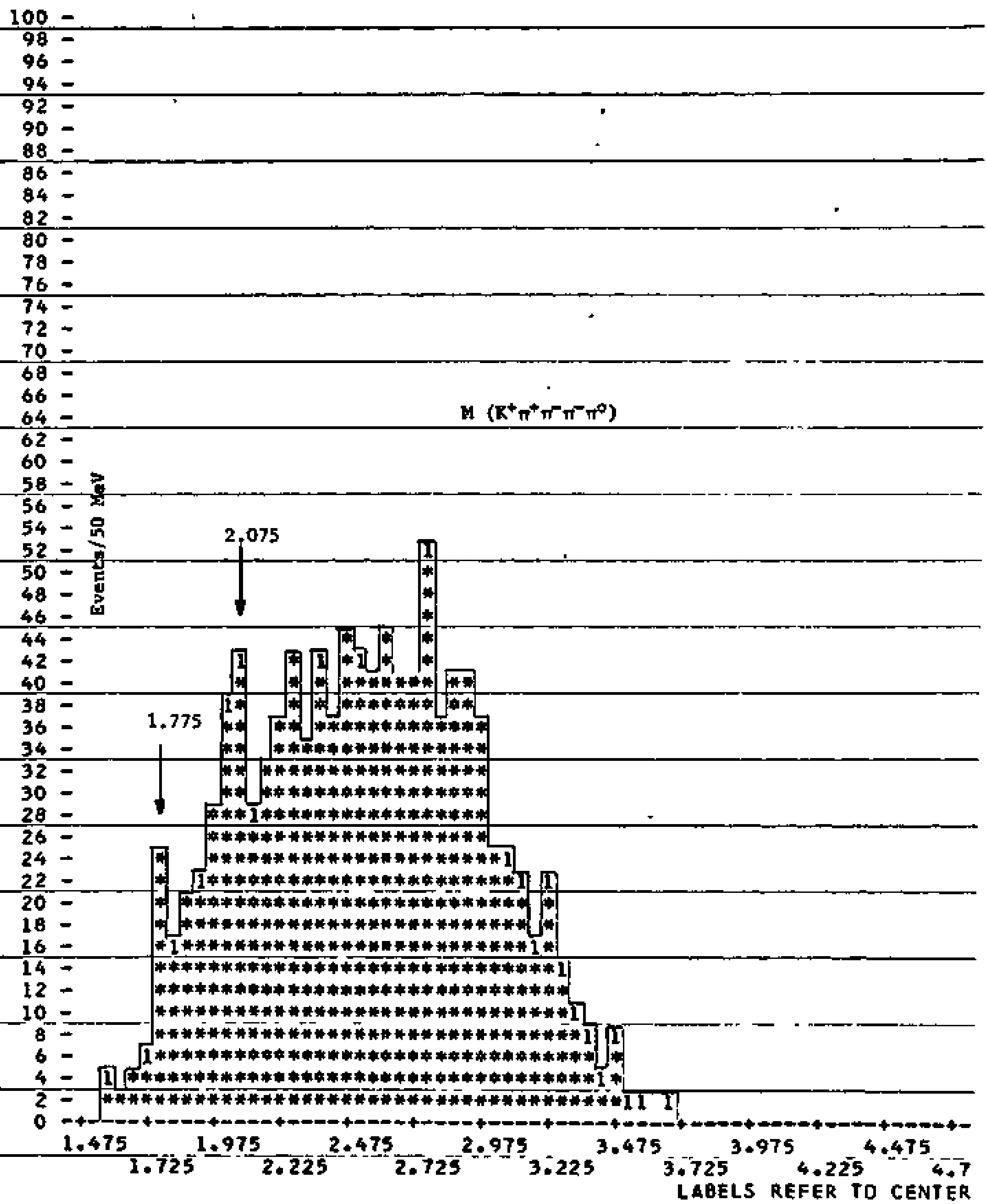
During the current year, the analysis of this experiment has continued even though all of the participants have also become deeply involved in other experiments. Dr. Carmony gave a review talk on the high mass K^*

resonances at the Division of Particles and Fields meeting in Berkeley in September. The $K_N(1760)$ which was discovered in the early part of this experiment is now firmly established and we have reported three standard deviation evidence for a spin parity assignment of 3^-. Strong production of $K_N(2100)$ has been found very recently in the final state $K^+\pi^+\pi^-\pi^-\pi^0$. (See fig. 6). Attempts are being made to establish the J^P and branching ratios of this resonance. The first evidence for $K^*\rho$ decay modes of these K^*'s was reported at Berkeley. Evidence for a $K^*\omega$ decay mode of the $K_N(1760)$ has been discovered, again in the $K^+\pi^+\pi^-\pi^-\pi^0$ final state. The new results on these two high mass K^*'s will be reported at the Salt Lake City APS meeting (June, 1974) and published in the near future. We have also studied the $p\pi$ low mass enhancement in the reaction $K^+n \rightarrow K^+p\pi^-$, using a double Regge Pole exchange model (Phys. Rev. 9 1210 (1974)). We are also submitting a "Comment" to Physical Review comparing our method of analyzing the moments of the $p\pi$ system to that of Lissauer et al. Furthermore, work is continuing to compare the branching ratios of the various members of the 3^- nonet to SU_3 predictions. Since this lab also has one of the biggest g-meson data samples it is appropriate that we make this comparison.

C. Neutrino Physics Using the Argonne National Laboratory 12-Foot Bubble Chamber

Neutrino physics is currently one of the most exciting areas of experimental research in particle physics. In the past, the study of neutrino interactions has been limited by the lack of high intensity beams and large detectors. This is no longer the case. Neutrinos are now being used as probes of the hadrons where one cannot only measure their weak elastic form factors but the nature of possible parton constituents as

HISTOGRAM NO. 25 EFFECTIVE MASS K-4PI IN 50 MEV BINS



TOTAL PTS.	UDFL. PTS.	OVFL. PTS.	PTS./STAR	LOWER
1048	2	0	2	

Fig. 6

well. These results are directly comparable to those from electron scattering from the same targets. On the other hand, studies of neutrino interactions measure the form of the weak interaction itself. In fact, recent evidence has been found[7] for weak neutral currents. The existence of these currents had been anticipated[8] by some bold theoretical proposals which unify the theories of weak and electromagnetic interactions.

In October of 1973, Professors Barnes, Carmony and Garfinkel joined the ANL bubble chamber group in its program of studying neutrino interactions with protons and neutrons in the 12-foot bubble chamber. Previous to that time, approximately 300,000 pictures had been taken in a single run in Hydrogen, and two runs of 300,000 pictures each had been made in Deuterium. Preliminary results[9] had been published on the reactions $\nu p \to \mu^- p \pi^+$ and $\nu n \to \mu^- p$.

We immediately converted three scanning machines to two-view 70 mm format appropriate to neutrino scanning. The machines used were obtained from Brookhaven as surplus. They have subsequently been mounted on high platforms to give a suitably large magnification for the 12-foot bubble chamber. We have recently converted a fourth machine from single strip to the new format.

We soon trained three regular scanning girls who began scanning film from the second deuterium run in addition to their measuring duties. In order to increase our scanning output, we attempted to use students under the work study program as scanners. In spite of having success in two or three cases the effort has not been profitable. The turnover was large with at least half the students quitting during or shortly after their training period. Even the students who stayed on were eventually forced to resign because of the limited term of their work study grants. We are currently scanning with approximately three full-time equivalent scanners.

Although the possible existence of weak neutral currents was foremost in our minds, our first results dealt with the charged current reaction $\nu p \to \mu^- p \pi^+$. Professor Garfinkel presented[10] the results to date on this reaction at the Chicago APS meeting. The reaction is saturated by Δ^{++} production. Several quantitative theories for this process exist and we were able to rule them all out except two. One of these,[11] a theory by S. Adler, predicted both the cross section and density matrix elements correctly, well before the data were taken. At the Washington meeting of the APS, Dr. Singer of ANL presented the results[12] to date on the quasi-elastic reaction $\nu n \to \mu^- p$ which allows us to measure the weak axial vector form factor. Each of the charged current events was looked at by a Physicist from ANL or Purdue.

During the past year, our main thrust was toward answering the neutral currents question. We were clearly sensitive to neutral currents if they existed and if the rates were as large as expected for the reactions $\nu p \to \nu n \pi^+$ and $\nu p \to \nu p \pi^0$. We scanned for such events and physicists looked at every event that might be a π^+ originating in the liquid or a proton with an associated electron-positron pair. Approximately 20 such events were found.

Having found a signal it was then necessary to determine the background level. Since the chief source of background was neutrons it was necessary to determine the number of events expected from the background process $np \to nn\pi^+$. Here we were able to make use of the full power of the bubble chamber technique by identifying events from the reaction $np \rightarrow pp\pi^-$. These events are readily identifiable in the bubble chamber (subject to a one constraint fit) and their number should equal that of the background reaction to which they are charge symmetric. The background reaction $np \rightarrow np\pi^0$ was related to the same calibrating reaction $np \rightarrow pp\pi^-$ by an auxiliary run of the bubble chamber exposed to a neutron beam.

Our total neutral current signal after all cuts were imposed was fourteen events and our measured background due to all sources was 2.38 ± 0.75 events. This was then a clear observation of the existence in nature of weak neutral currents. Our result was described in an invited talk[13] at the Washington APS meeting by Dr. S. Barish of ANL. It was received with great interest. This result and our results on charged currents were discussed at length at the Fourth International Conference on Neutrino Physics and Astrophysics which was attended by Professor Garfinkel. Our neutral current result has been submitted to Phys. Rev. Letters, and two papers concerning neutral currents have been submitted to the London International Conference.

Now that we have proved that neutral currents exist, we have the task of measuring their properties and finding out if they really correspond to those proposed by Weinberg and Salam.

III. BUBBLE CHAMBER-ELECTRONIC HYBRID EXPERIMENTS

A. 100 GeV π^+ and K^+ Interactions in the NAL Hybrid 30-Inch Bubble Chamber/Spark Chamber System

The performance of NAL in turning out bubble chamber photographs has taken a quantum jump for the better since our last progress report, and we are pleased to report that we (and our University of Wisconsin colleagues) completed taking our approved 80,000 hybrid pictures in February, 1974. Since then, several 100,000 picture exposures have been completed in one-week running periods. And we at Purdue have been approved to run 100,000 bubble chamber pictures of π^+ at 300 GeV, with the option of using the hybrid system.

The hybrid system performed as expected during the 100 GeV π^+ run, and for the last portion we triggered the spark chamber only on π^+ or K^+ beam interactions (our beam contained 50% protons), thereby enriching our sample of well-measured fast forward tracks from meson interactions. We have now measured over 4,000 events, about one-quarter of the total in our half of the film. Also, we and Wisconsin have measured all K^+ interactions, a total of a few hundred events from our hybrid run. We have also measured all tagged K^+ interactions (about 150 events) from the earlier 100 GeV π^+ run by the University of California Davis group. We operated the spark chambers in conjunction with that run. The optical tagging system which we built and installed with the spark chambers to store Cerenkov information about the interacting beam particle, worked well and has served to resolve occasional ambiguities occurring with the upstream beam tagging tape.

The people involved in this experiment in the last year are Professors Barnes, Carmony, Christian, and Garfinkel, Drs. T. Mulera, and K. Rangan, and Mr. W. Morse, and our colleagues at Wisconsin. Professor Barnes has attended the Gordon Conference on High Energy Multiparticle Production Processes in June, 1973, and the Fifth International Conference on High Energy Collisions at Stony Brook in August, 1973; both meetings were by invitation. Our first analysis will be completed shortly on the K^+ events.

We expect to present a general survey, within the limited statistics available, and will include much improved track momentum data for forward tracks which go into the spark chambers. This will be the first time that 100 GeV K^+p data will have been presented anywhere.

Our next analysis, to follow soon, will be low multiplicity π^+p events, up to six prongs, with forward tracks linked between the bubble chamber and the spark chambers. For events which trigger the spark chambers, we find that the great majority of bubble chamber tracks above 15 GeV hook up with tracks in the spark chamber (see Table I). This will permit three constraint fitting of some events, an improvement over the two constraint fits obtained by the NAL-Berkeley group in the 200 GeV π^-p bare bubble chamber experiment. See fig. 7 for a plot of $\delta P/P$ vs. P with and without the spark chambers. In addition, a fraction of events with π^0 present will be explicitly rejected by the presence of one or more showers seen in the fourth spark chamber, after two radiation lengths of lead. Thus we are studying in detail the low multiplicity channels which contain most of the diffractive dissociation cross section, plus other identifiable exclusive channels.

We are also studying inclusive distributions, and we now know that the spark chambers will improve the accuracy of charged tracks and provide unique and valuable information on neutral pions and their correlations.

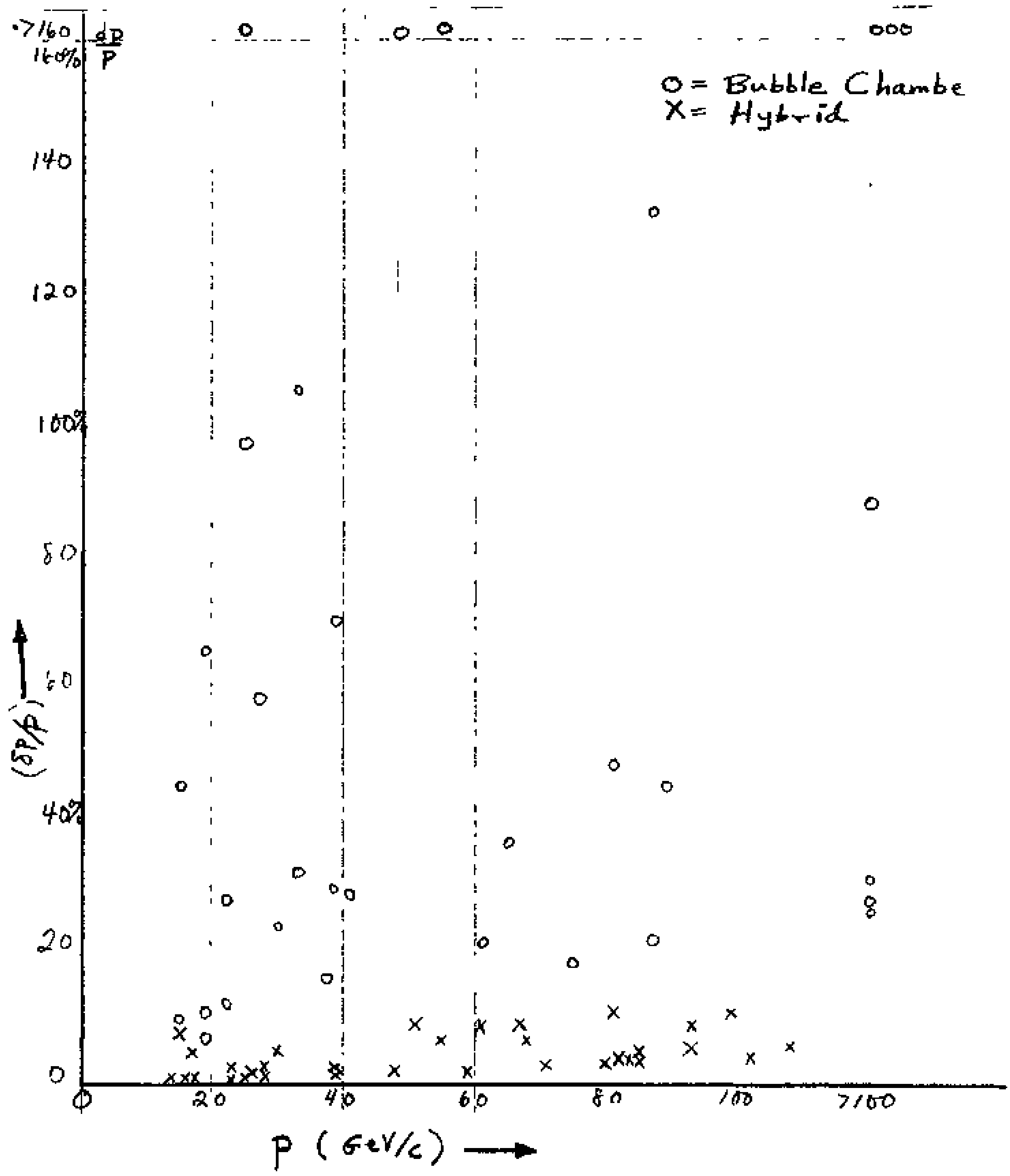
We are glad to be doing at last the wide range of exciting studies which we outlined in our 100 GeV π^+ proposal. Having all the data safely in house has done wonders for our morale.

TABLE I

Hybrid Hookup Rates (Per Track) for Bubble Chamber Events
Which Trigger the Spark Chamber

$P_{track} > 15$ GeV	78%
5 GeV $< P_{track} <$ 15 GeV	40%

Note that many tracks below 15 GeV (and some above) are not expected to pass through the spark chambers.



Track momentum errors with 30-inch bubble chamber only and with spark chamber hybrid hookup.

Fig. 7

IV. COUNTER-SPARK CHAMBER EXPERIMENTS

A. Backward $K^-p \rightarrow \Sigma^+\pi^-$ and $\pi^-p \rightarrow p\pi^-$ Reactions (ANL E-348)

We are pleased to report that our counter-spark chamber effort at the Argonne ZGS (E-348) has proceeded very much as we had outlined in last year's proposal. Installation of the equipment began in July, 1973, and was in a state of readiness when we received our first beam in mid-November, 1974. Approximately 35 shifts were used to tune the apparatus and serious data taking was begun in the first part of December. The data taken thus far comes from a month of running in December (3 GeV/c and two short runs at 4.5 and 5.5 GeV/c) and a month of running in March and the first part of April (5.1 GeV/c). Our preliminary results at 3, 4.5, and 5.5 GeV/c have been presented;[14,15,16] the 5.1 GeV/c data are still in the analysis stage. We expect to complete the data taking stage of E-348 in the fall of 1974 with about one more month of beam time.

The experiment is designed to measure the backward reactions $\pi^-p \rightarrow (mm)^+\pi^-$ and $K^-p \rightarrow (mm)^+\pi^-$ by analyzing a slow π^- in a magnetic recoil spectrometer and calculating the missing mass (mm) for the forward-going baryon. One specific goal of the experiment is to measure $K^-p \rightarrow \Sigma^+\pi^-$ and π^-p backward elastic scattering, for which SU(3) predicts equal cross sections and polarizations. Although we are not measuring the π^-p backward elastic scattering polarization, we are measuring the polarization of the Σ^+ in $K^-p \rightarrow \Sigma^+\pi^-$ by measuring the direction of the decay proton from the Σ^+ decay. In addition, we will test SU(3) predictions for the cross sections of the backward reactions $\pi^-p \rightarrow \Delta^+(1236)\pi^-$ and $K^-p \rightarrow Y^*(1385)\pi^-$.

The floor plan of the apparatus as it is presently installed in the Meson Area of the Argonne ZGS is shown in fig. 8. A high intensity 3 to

PURDUE / ANL RECOIL
SPECTROMETER
E-348

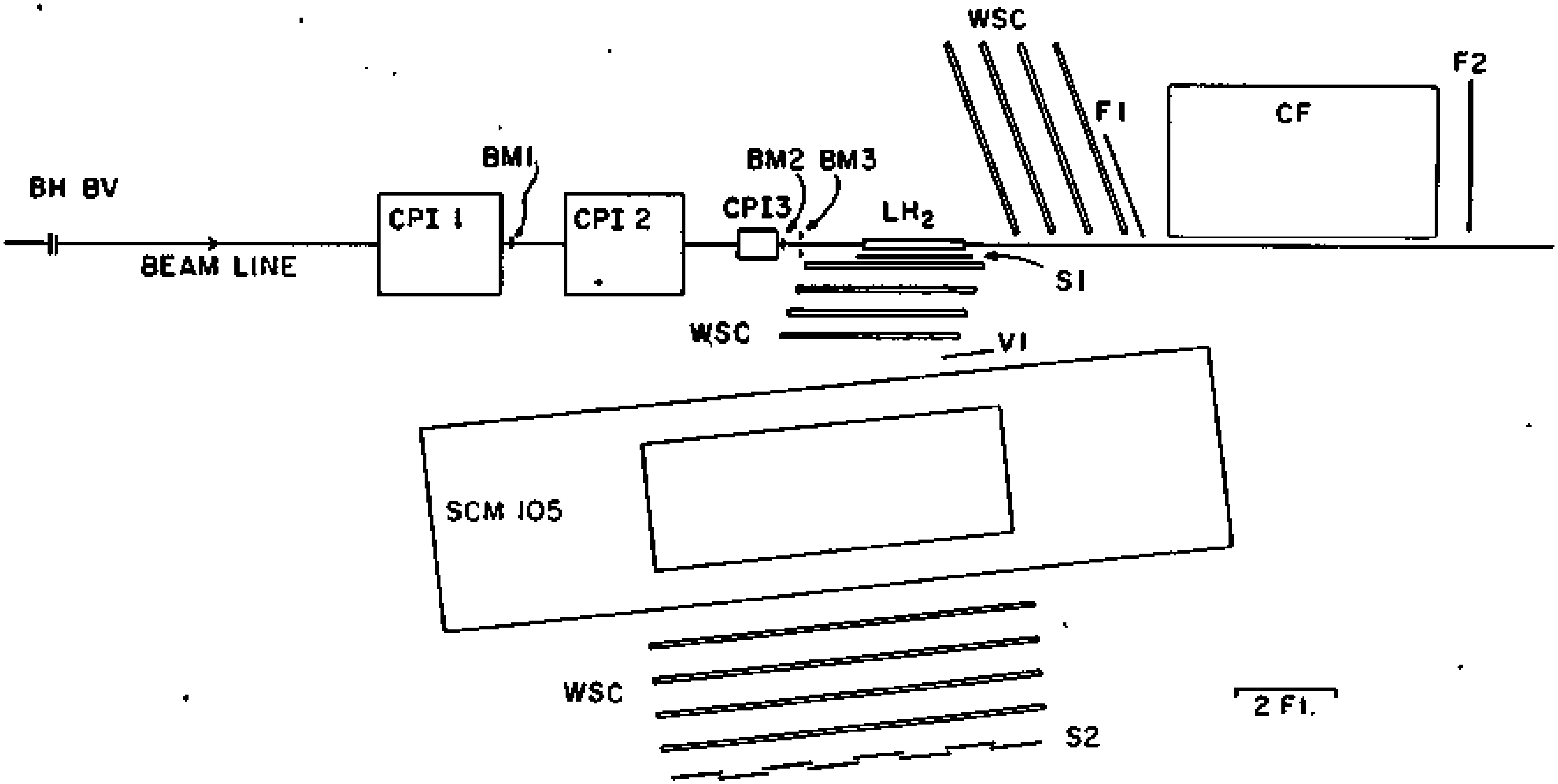


Fig. 8

6 GeV/c negative beam (2.5 x $10^6 \pi^-$, 2 x $10^4 K^-$, and 8 x $10^3 \bar{p}$ per burst) is derived from the M4 internal target. Three beam hodoscopes are used to determine the incident particle angles and to subdivide the 2.5% momentum interval. A differential Cerenkov counter set to count K's and three threshold Cerenkov counters set to count π's are used to identify the π's, K's and $\bar{p}$'s in the beam. The hydrogen target is 24" long with a 2" diameter.

Recoil π^-'s are momentum analyzed in a magnetic spectrometer consisting of wire spark chambers with magnetostrictive readout before and after an SCM-105 bending magnet with an 84" horizontal by 26" vertical aperture. A ¼" thick scintillation counter (S1) alongside the hydrogen target and an eight-counter hodoscope (S2) at the back of the spectrometer are used in the fast electronic trigger. This spectrometer measures π^- recoil angles between 70^o and 140^o in the laboratory system.

In the forward direction a set of four wire spark chambers is used to measure the direction of protons from the $p\pi^0$ decay mode of the Σ^+ in $K^- p \to \Sigma^+ \pi^-$. From the decay parameters of the Σ^+ we can determine the Σ^+ polarization. An additional Cerenkov counter set to count π's is placed immediately downstream of these chambers in order that the $\pi^- p$ backward scattering data may be enriched by vetoing fast forward pions in one of our possible triggers.

The fast electronics defines three particles of interest: the beam particle, a particle passing through the recoil spectrometer, and a pion passing through the forward set of chambers. Coincidences between various combinations of these gives six triggers for the apparatus.

An EMR-6050 computer (32K of 24-bit words, supplied by Argonne) is used online to record data on magnetic tapes, monitor the equipment, select triggers, and to reconstruct events. This computer is also being used for the offline reconstruction of events.

Thus far, the bulk of our running has been at 3 and 5.1 GeV/c, and a few shifts were used to take $\pi^- p$ backward elastic scattering data at 4.5 and 5.5 GeV/c. Table II summarizes the data taken. In addition we have a number of triggers which have a positive particle in the recoil arm. These positive recoil events will be analyzed later (we feel that we can distinguish π^+'s from p's in the recoil arm since we have recorded dE/dx information from the S1 counter; for $K^- p \rightarrow \Sigma^- \pi^+$, kinematics alone should be sufficient).

In fig. 9 we show the missing mass spectra for the reactions $K^- p \rightarrow (mm)\pi^-$ and $\pi^- p \rightarrow (mm)\pi^-$ at 3 GeV/c. The peaks at the Σ^+ and p masses appear with only a small background. It is also clear that we see the $Y^*(1385)$ and $\Delta^+(1236)$, and possibly additional structure higher in mass. Presently we have about 1300 Σ^+'s at 3 GeV/c and about 1000 at 5.1 GeV/c.

Fig. 10 shows preliminary differential cross sections for $K^- p \rightarrow \Sigma^+ \pi^-$ and $\pi^- p$ backward elastic scattering at 3 GeV/c. Although some further analysis is required, at this time we can say that the two differential cross sections agree remarkably well in shape and magnitude as SU(3) predicts.

A surprising feature of the data is the striking change in the shape of the differential cross section between 3 and 4.5 GeV/c (see fig. 10). It appears that the transition from s-channel resonance effects to "asymptopia" occurs very rapidly and perhaps at a very low energy when compared to the forward scattering reactions.

TABLE II

Summary of Data Taken in December 1973
and March 1974 (E-348)

Beam Energy	3.0	4.5	5.1	5.5
Total π flux	5.0×10^9	7.9×10^9	7.0×10^9	2.1×10^9
Total K flux	1.0×10^9	0	3.5×10^9	0
Total triggers recorded	1.9×10^6	0.6×10^6	5.3×10^6	0.3×10^6
Total number of reconstructed events (negative only)	130×10^3	83×10^3	240×10^3	23×10^3
Total number of $\pi^- p \to p\pi^-$ elastic events	4500	2100	2400	350
Total number $K^- p \to \Sigma^+ \pi^-$ events	1300	0	1100	0

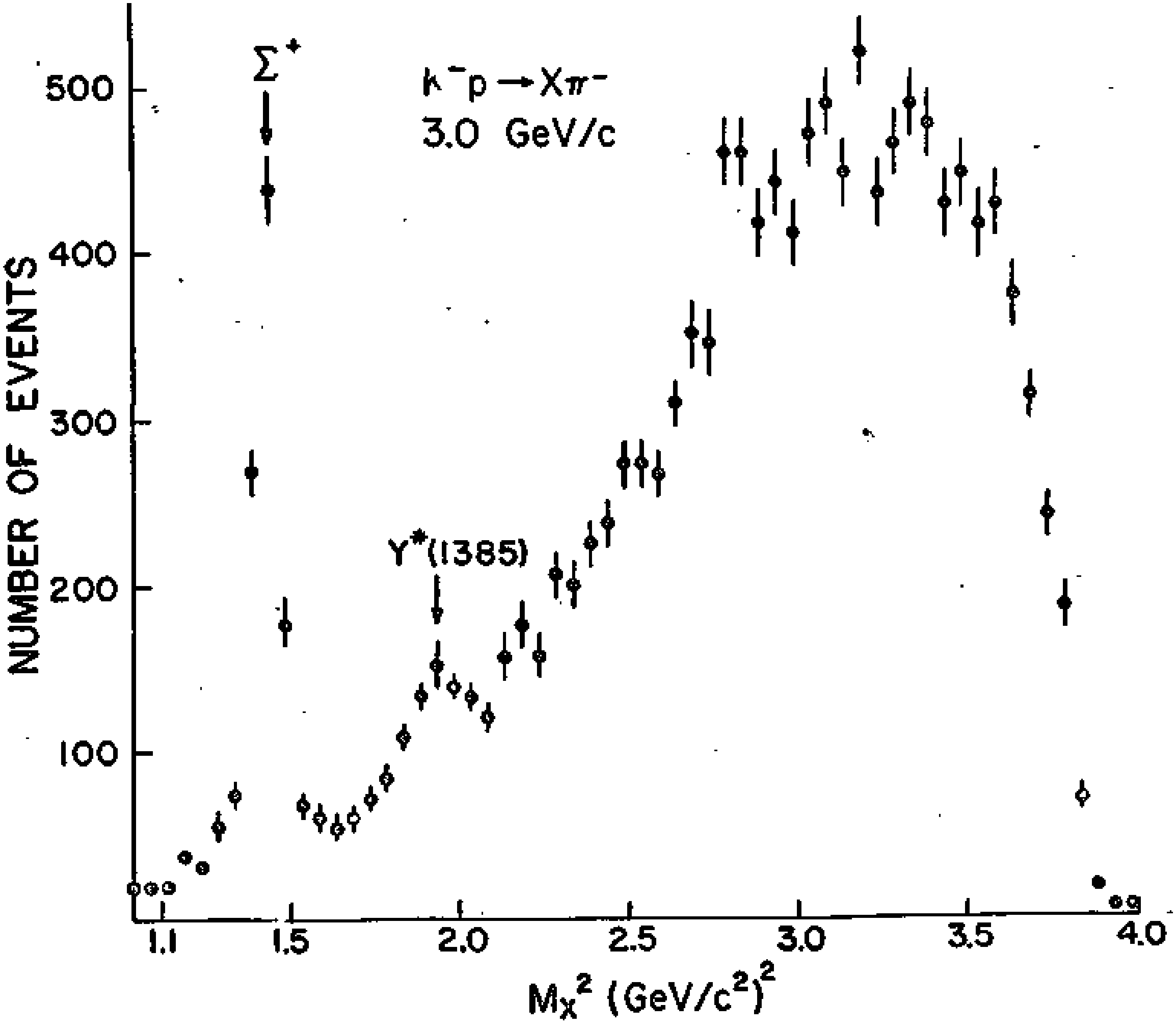
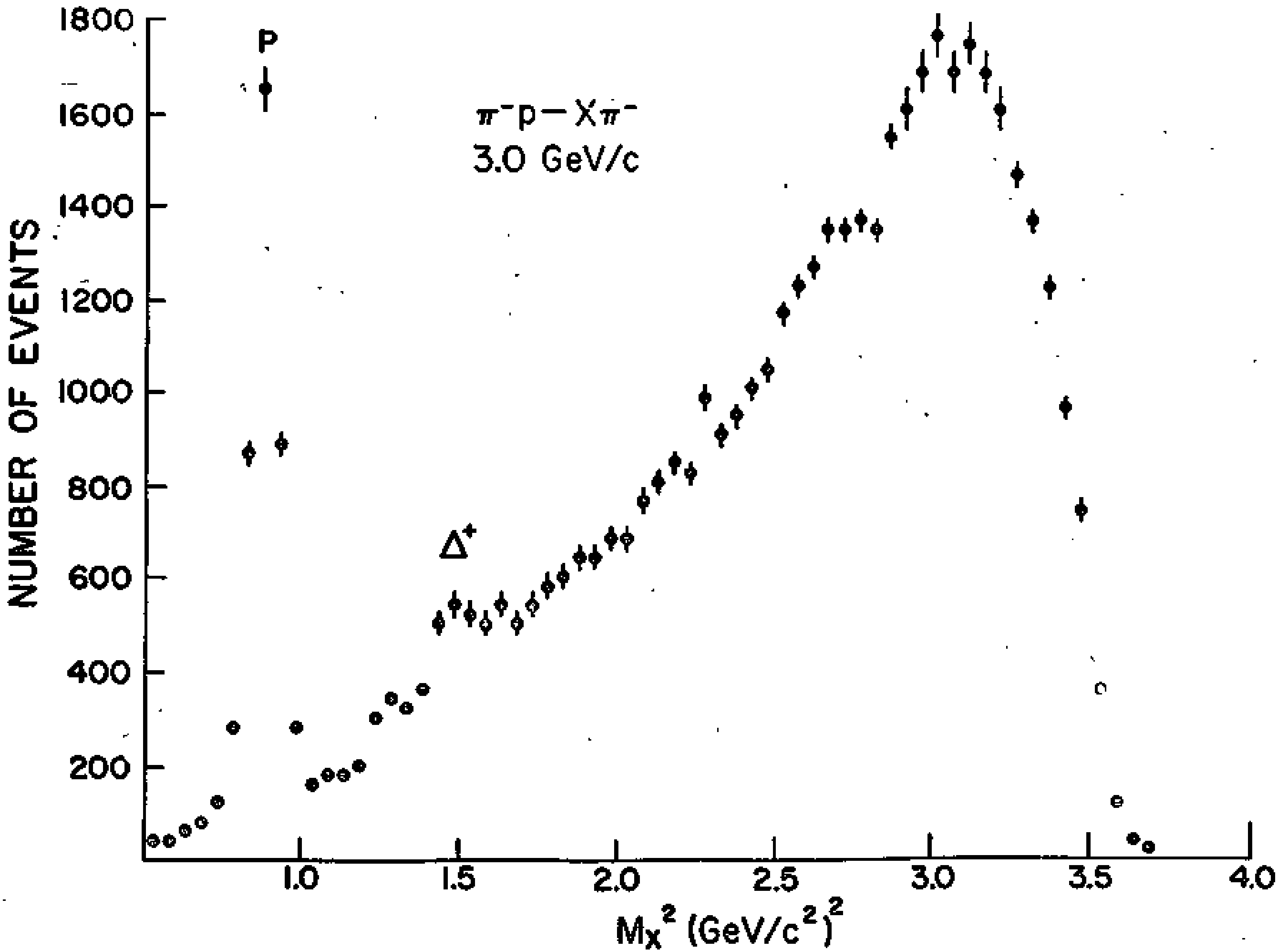
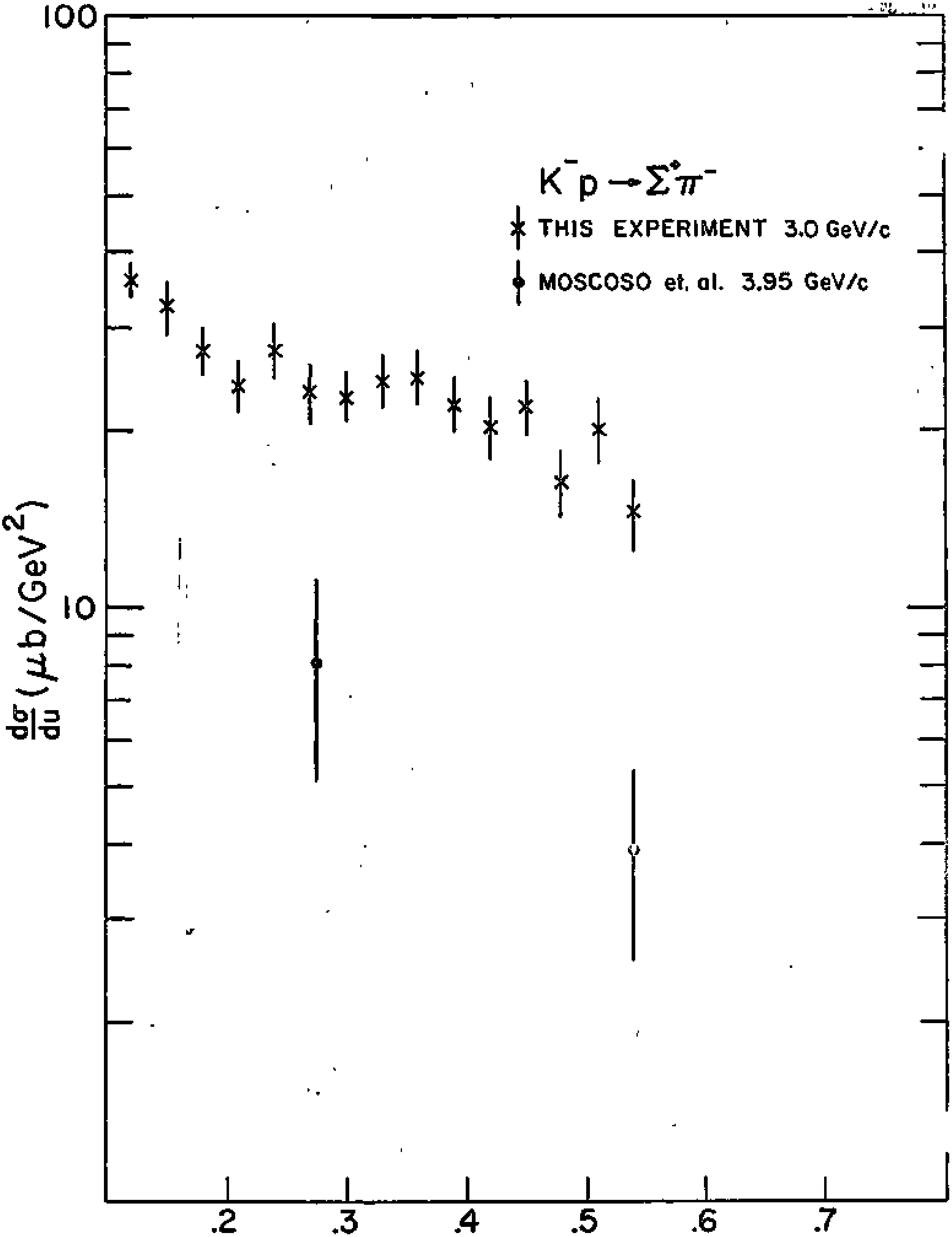

Σ⁺
K⁻p → Xπ⁻
3.0 GeV/c
Y*(1385)
NUMBER OF EVENTS
500
400
300
200
100
1.1
1.5
2.0
2.5
3.0
3.5
4.0
Mx² (GeV/c²)²

Fig. 9a

Fig. 9b



P
π⁻p → Xπ⁻
3.0 GeV/c
Δ⁺
NUMBER OF EVENTS
1800
1600
1400
1200
1000
800
600
400
200
1.0
1.5
2.0
2.5
3.0
3.5
4.0
M_X^2 $(GeV/c^2)^2$



$K^- p \to \Sigma^{*} \pi^-$
THIS EXPERIMENT 3.0 GeV/c
MOSCOSO et. al. 3.95 GeV/c
$\frac{d\sigma}{du}$ (μb/GeV^2)
100
10
.2
.3
.4
.5
.6
.7

Fig. 10a

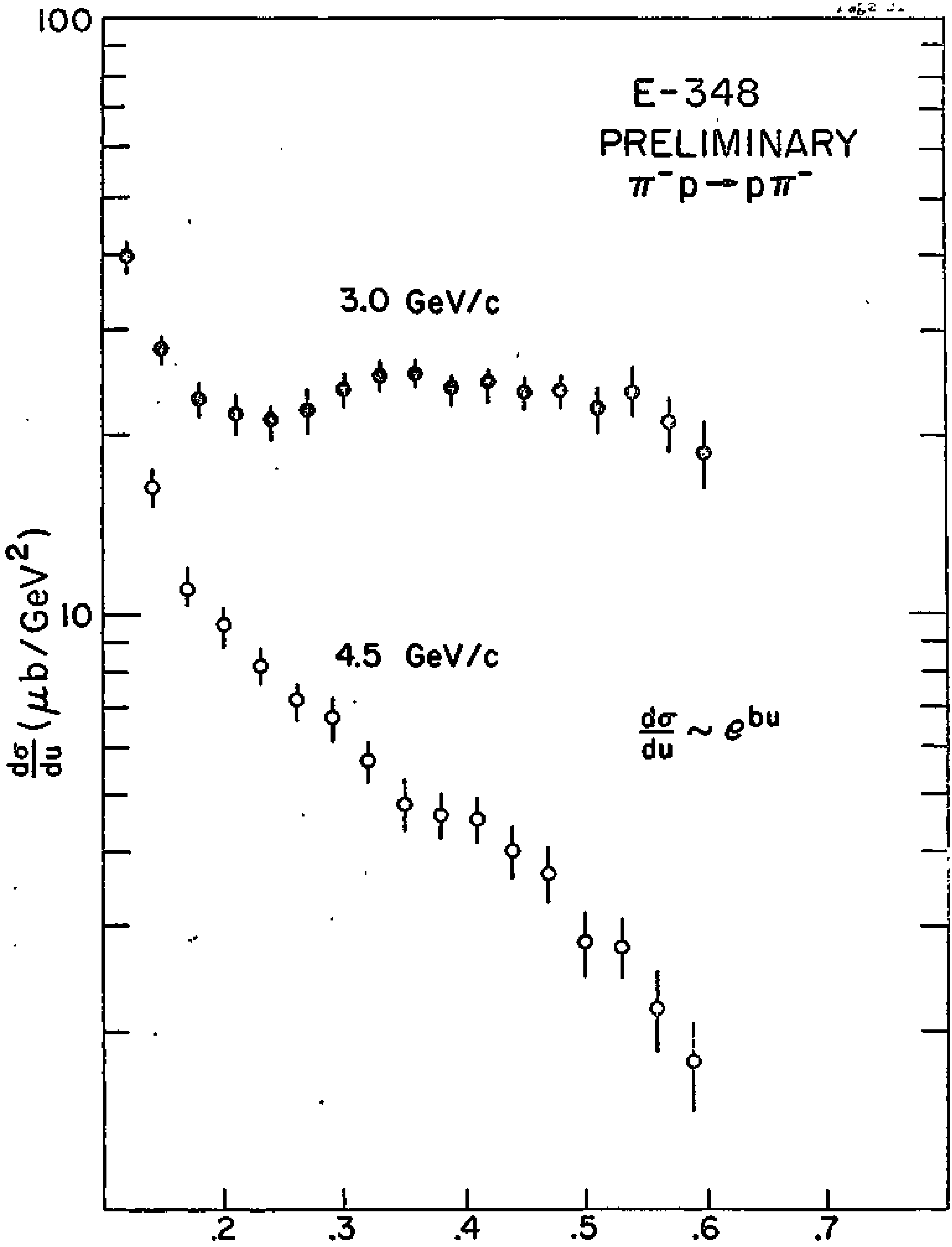

E-348
PRELIMINARY
π⁻p → pπ⁻
3.0 GeV/c
4.5 GeV/c
dσ/du ~ e^bu
dσ/du (μb/GeV²)
100
10
.2
.3
.4
.5
.6
.7

Fig. 10b

In conclusion, we should like to note that this is the first counter-spark chamber experiment attempted by the Purdue group on a stand-alone basis at one of the National Laboratories. The effort has been successful in that in a little over one year we have proposed the experiment, built the apparatus, set up the equipment and taken data. In addition, first results were presented at the Washington APS meeting. We believe that the experiment is generally viewed as a very successful one and feel that the counter spark chamber effort at Purdue is therefore worthy of continued and vigorous support.

B. BNL-Purdue Study of Interactions at 28.5 GeV/c

1. Physics Goal and Layout of the Experiment

By now, it is commonly accepted that the hadronic structure of the proton is the central question of strong interactions. To the credit of this collaboration it has to be emphasized that we initiated an experimental program to study this problem at a time when resonance physics was at the zenith of its popularity.

In what follows we describe how we attained the above goal. This is the point of view of the author of this report and not necessarily of all members of the collaboration.

In our thinking we were influenced by two historical precedents. The power of high momentum transfer collision, to probe the innermost structure of matter, was demonstrated by Rutherford in discovering the nuclear constituents of atoms. The truly fundamental nature of the information that is embodied in the momentum distribution of multiparticle systems was illustrated by Plank's discovery of Planck's constant h in black body radiation. These ideas determined the design of the apparatus, the data taking, and analysis of the data.

In order to ensure the detection of all charged particles in a multiparticle final state the target was surrounded by cylindrical spark chambers immersed in a 10 kg magnetic field. A magnetic spectrometer, downstream from the vertex detector, ensured that only those multiparticle events were recorded where a large momentum transfer was transmitted by the scattered projectile. The apparatus is shown in fig. 11.

2. An Approach to Study the Structure of the Proton in the Reaction $p + p \to p + X^+$

It is a consequence of the exponential fall off of elastic differential cross sections, that high momentum transfer events (large angle scattering) arise from several small momentum transfer events (several small angle scatterings). Thus the importance of multi-scattering (rescattering) effects increases with increasing momentum transfer. In particular if n particles are produced in a single scattering, then kn particles are produced in k scatterings. As a result the average multiplicity $\langle n \rangle$ must rise with increasing momentum transfer.[17] If the proton has a finite size, rescattering will take place and thus $\langle n \rangle$ is an increasing function of the momentum transfer. We looked for this effect and found a dramatic rise.[18] Some more data have been analyzed since the publication of the original results. They are plotted in fig. 12. It is, of course, tempting to interpret our results in the less general but more glamorous term of quarks. One may assume that protons are built of three quarks and the number of scattering steps that takes the scattered proton out to a given t value can be calculated.[19] It is also possible that the opening of a yet unobserved exotic particle production $I^G J^P = 0^+ 1^-$, via P-wave pomeron - f coupling, results in the rise of multiplicity.[20]

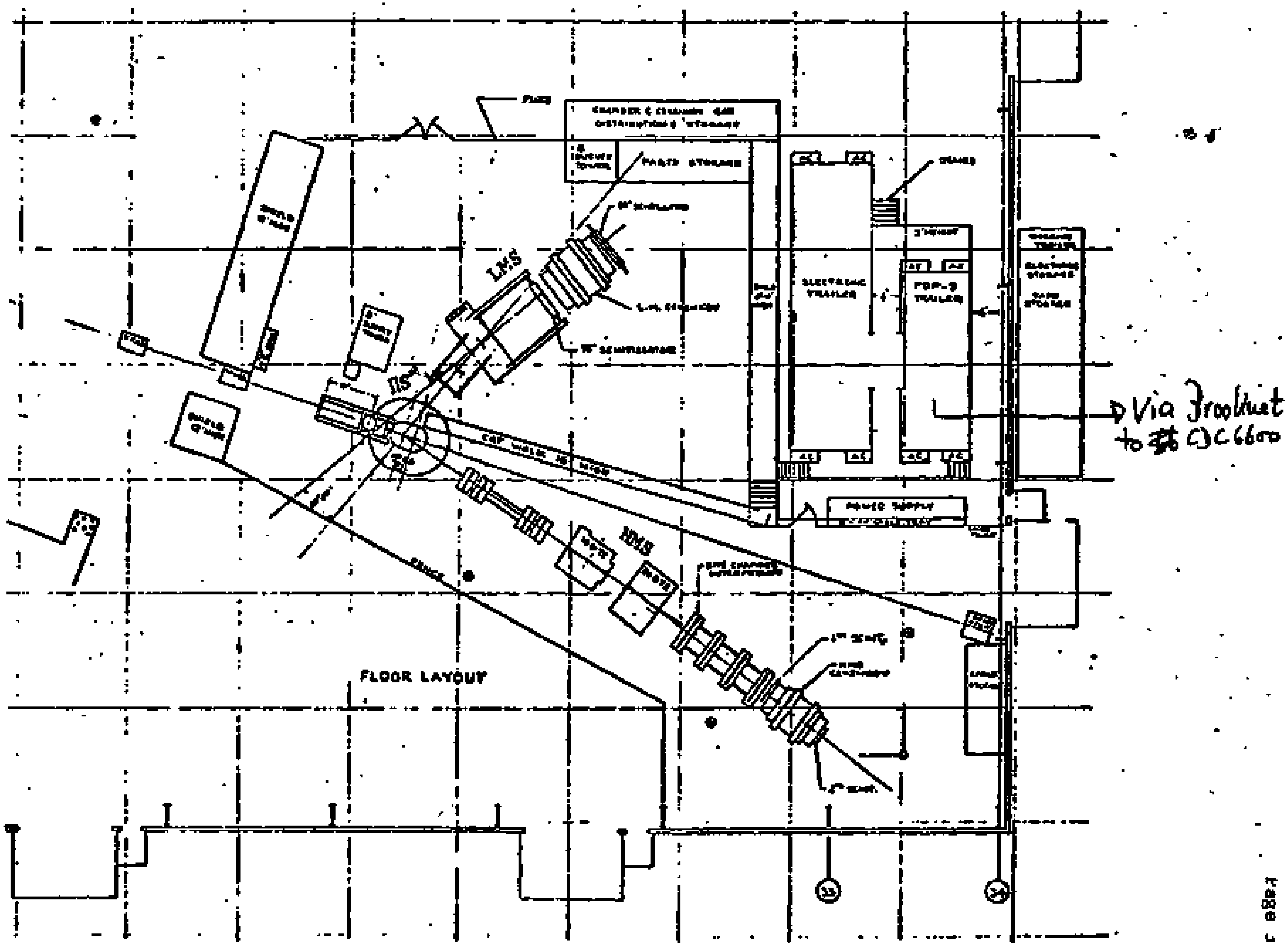

PARTS STORAGE
ELECTRONIC TRAILER
PDP-9 TRAILER
POWER SUPPLY
LMS
HMS
FLOOR LAYOUT

Fig. 11

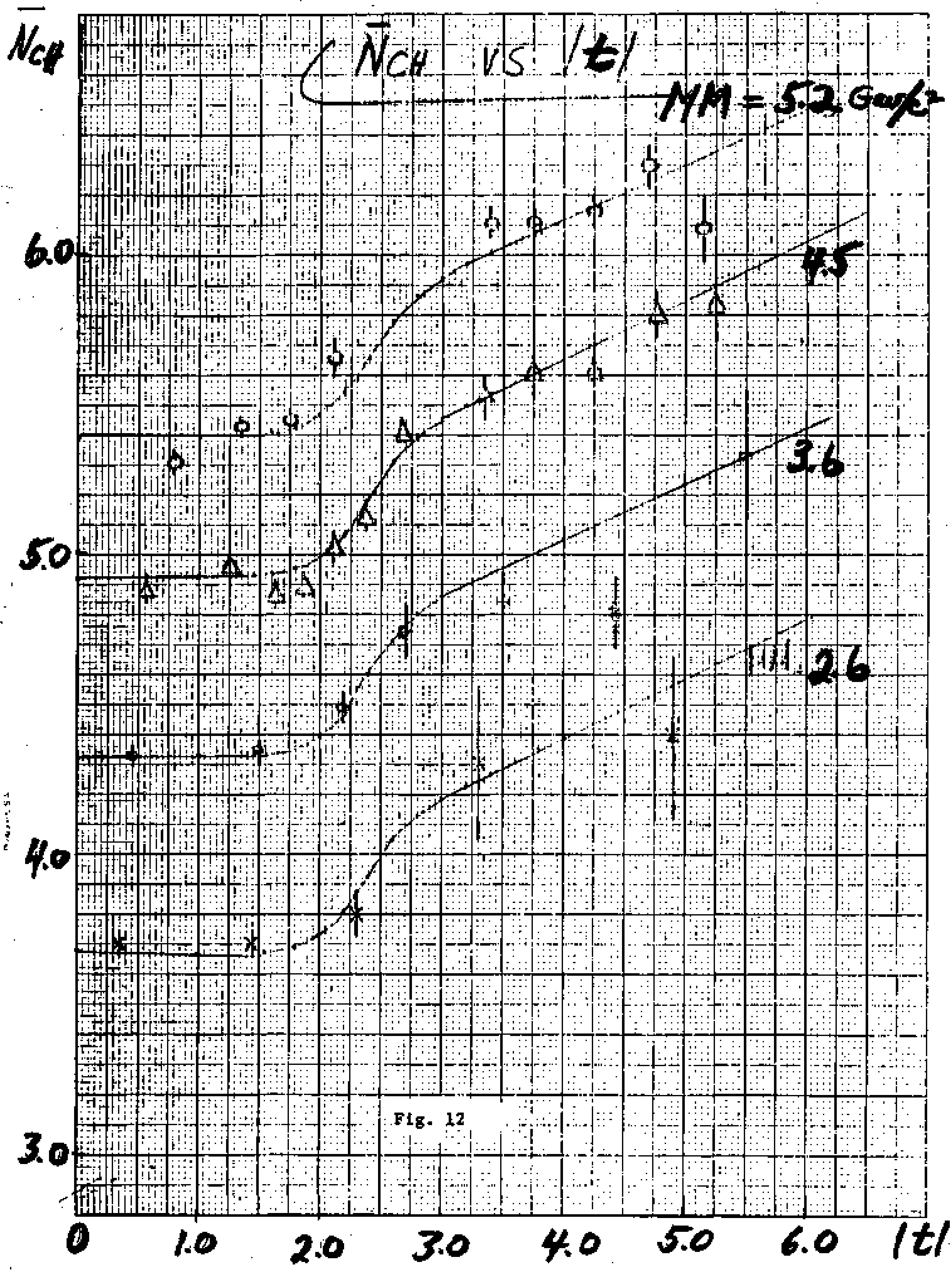

$\bar{N}_{CH}$
$\bar{N}_{CH}$ VS |t|
MM = 5.2 Gev/c²
6.0
5.0
4.0
3.0
4.5
3.6
2.6
0
1.0
2.0
3.0
4.0
5.0
6.0
|t|

Fig. 12

3. Observation of Azimuthal Correlation in Semi-Inclusive Spectra

One of the puzzling features of the reaction

$$p + p \rightarrow p + X^{+} \qquad (1)$$

is the presence of a dominantly smooth low mass X^{+} mass distribution. Up to the present only bubble chamber information exists on multiparticle reactions. Because of the lack of statistics very little is known about the details of the X^{+} production mechanism, even when X^{+} represents a fitted final state. There is nothing known about the production mechanism for the unfitted reaction 1 when X^{+} decays into more than one neutral particle. The main reason is that no theoretical technique has been developed to utilize the information contained in the angular distribution of unfitted nonresonant multiparticle final states where momentum information -- but no mass identification -- exists.

We noted that both the production normal and transverse momentum are Lorenz invariant, if the Lorenz transformation is along the missing momentum with respect to the fast forward proton. Thus the angle between the production normal and the transverse momentum is also Lorentz invariant, and happens to be the azimuthal angle of the X^{+} decay products in a suitably chosen coordinate system in the X^{+} rest frame. With this convention we plotted the azimuthal decay distribution of X^{+} and found a clear $\sin 2\varphi$ distribution[21] reminiscent of coherent $T = 0$ exchange production[22] of $K^{*}(890)$. Since apart from π exchange the proton-meson-proton coupling is dominated by ω exchange, we identify the exchange object with ω^{o}. The t dependence of the effect is consistent with the net helicity flip zero-absorption model of Ross et al.[23] and the dual absorption model of Harari.[24]

4. Pattern Recognition Software Developments

At Purdue we have developed an interactive display system utilizing the POLLY display scope. The resolution of this system is not adequate for our purpose and we will use it as a temporary solution. We hope to obtain a Hewlett Packard display primarily for our use. There is also a problem with the disc space, which is not big enough to accommodate the size of the work file that is economical for a steady use of the display.

The pattern recognition program π-track has been adopted for our IBM 360/40 system. If the program is the sole user of the computer we can bring the program into operation. We are also able to phase it and fit it into the computer in a multiprogramming mode with the bubble chamber measuring system as far as the size is concerned. The running is hindered by a peculiarity of the linkage editor. There are several subroutines recurring in distinct phases, and the linkage editor remembers the location only of the subroutine in the first phase. Solution of this problem is underway.

At Brookhaven our research associate (A. Laasanen) has completed the geometrical reconstruction and kinematical fitting programs for multi-particle final states, recorded in the vertex detector.

5. The Status of ππ Interactions

At the XVth International Conference and at the Tallahassee Conference a new "amplitude analysis" of ρ^0 production was presented. In contrast to our earlier work, the CERN phenomenologists claimed to have shown phase incoherence between the helicity zero and helicity one P-wave amplitudes. In spite of the prestige and influence of CERN we have challenged their result in a public debate. (G. Kane in his summary talk just preceeding our public debate, judged the CERN result the most significant development in the field). In front of the conference participants we have demolished the phase incoherent result.[25,26]

V. PURDUE MEASURING AND DATA PROCESSING SYSTEM

A. A total of 204,000 events were measured during calendar year 1973, and the current measuring rate is approximately 5000 events per week. This represents a 10% improvement over the previous year. Much of the difference is the fact that there was not a budgetary shutdown of the measuring system during calendar 1973. Considerable measuring time was lost during 1973 to unsuccessful attempts to measure the 15" RCBC film on SMP's, and to calibration, lens-changes, and debugging for the NAL 30" film and for debugging measurements of the wide-gap spark chamber film associated with the NAL 30" chamber. Many small software changes were made to facilitate measurement of the NAL film.

B. The POLLY system is in an advanced state of development . . .

1. Hardware

All system components have been constructed and largely debugged. The final film positioning system requires some work. We plan to use the CRT under control of the MPUP to detect the frame marker on the fly. When the MPUP finds the correct frame it will signal the capstan drive circuit which will then advance the film by a programmed distance and stop.

An address stop circuit under control of the Supernova has been added to the MPUP hardware. This provides either a stop signal or a scope sync when the MPUP address bus is compared with an address provided by the Supernova. This has proved extremely useful for debugging.

2. Software

Considerable progress has been made with fiducial-measuring, track finding, and track-following routines. Repeatability of data readings is on the order of 1.5 microns for intersected fiducials relative to each other. The most recent work has been in bringing the full MPUP programming into operation. A simple cross-assembler permits relatively easy writing of code for the MPUP, and we are in the process of bringing the MPUP hardware and software up together. We already have clear indications that the gain in speed anticipated from use of the MPUP (between a factor of five and ten) will be obtained. As soon as MPUP operation is reliable, and the hardware changes (new transistors in the DACs and non-zero quiescent current in the CRT) have been made to give stability of operation, we expect to do absolute calibration and then force events through measurement.

The FORTRAN compiler for our Supernova, previously advertised as under construction, is operational. It generates interpretive code, making use of functional subroutines stored in fast memory.

C. Interactive Graphic Display

The spark chamber experiment at BNL (Exp. #396) requires considerable manual fix-up of failing events. Programs have been developed to provide a display of these events on the POLLY display system. There will not be enough time available when POLLY starts measuring; so work has been started on a display system attached to the 360/40. We will use a Tektronix storage scope, which we have, or possibly a new Hewlett Packard scope, for the display. A track ball has been constructed and a teletype keyboard adapted for data input. Most of the circuit cards have been constructed, but the system must still be put together and tested.

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VII. PUBLICATIONS AND INVITED TALKS - June 1, 1973 - May 31, 1974

1. Phase Coherence of P-Wave Single Pion Production Amplitudes; L. J. Gutay and K. V. Vasavada, Physics Letters 46B, 88 (1973).

2. Study of the R Meson Produced in 13 GeV/c π^+p Interactions; G. Thompson, J. A. Gaidos, R. L. McIlwain, D. H. Miller, T. A. Mulera, and R. B. Willmann, Nuclear Physics B69, 220 (1974).

3. Partial Wave Analysis of the $(\pi^+\pi^+\pi^-)$ System Through the Region of the A_3 Meson; G. Thompson, R. C. Badewitz, J. A. Gaidos, R. L. McIlwain, K. Paler and R. B. Willmann, Nuclear Physics B69, 381 (1974).

4. ρ^o Production Density Matrix Elements, Phase Coherence and Smoothness of the Ball Amplitudes; L. J. Gutay and K. V. Vasavada. Submitted to Physical Review D, to appear in May, 1974.

5. Rapid Multiplicity Rise as Function of Momentum Transfer in Multicomponent Models; L. J. Gutay and P. Suranyi. Submitted to Physical Review D, to appear in May, 1974.

6. Review of Evidence for High Mass K^* States; D. D. Carmony. Paper given at APS-DPF Meeting, Berkeley, 1973.

7. The Current Status of Meson Spectroscopy; D. H. Miller (while at CERN). Lecture notes to be published in Proceedings of "The 1973 International School of Subnuclear Physics," held in Erice, Sicily.

8. Observation of Increasing Charged Multiplicity as a Function of Transverse Momentum in 28.5 GeV/c pp Interactions; L. J. Gutay, A. Lassanen, K. Stanfield and R. B. Willmann, Phys. Rev. Letters 31, 1371 (1973).

9. A Study of the Reactions $\pi^+p \to (\rho^o,\omega)\Delta^{++}$ at 13 GeV/c; J. A. Gaidos, A. A. Hirata, R. J. DeBonte, T. A. Mulera, G. Thompson, and R. B. Willmann. Submitted to Nuclear Physics B, to appear in June, 1974.

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14. Partial-Wave Analysis of the Low-Mass ($\pi^+\pi^+\pi^-$) System Produced by Incident π^+ Mesons at 13 GeV/c; G. Thompson, J. A. Gaidos, R. L. McIlwain, and R. B. Willmann, Phys. Rev. D, 560 (1974).

15. A Programmed Controller for a CRT Film Scanner; R. L. McIlwain (to be published in Proceedings of the Oxford Conference on Computer Scanning, Oxford, England, 1974).

16. 1974 Status of the Purdue POLLY; R. L. McIlwain, T. R. Palfrey, Jr., L. K. Rangan, A. C. Ammann, R. E. Buten, M. J. Baggett, D. F. Olive, and M. W. Shrimplin (to be published in Proceedings of the Oxford Conference on Computer Scanning, Oxford, England, 1974).

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18. One-Pion-Exchange Model Analysis of the $\Delta^{++}(1236)$-Region and of the $n\pi^+$ Low-Mass Enhancement in the Reaction $pp \to p\pi^+n$; V. Blobel, D. D. Carmony, H. Fesefeldt, H. Franz, B. Hellwig, P. Kobe, D. Mönkemeyer, W. Schrankel, B. Schwarz, F. Selonke, J. Seyerlein, F. Wagner, B. Wessels, accepted for publication in Nuclear Physics B.

Invited Talks During 1973-74

Two invited talks were given during the year in the field of Meson Resonances. The first was a series of three lectures given at the International School of Subnuclear Physics, Erice, Sicily, under the title of 'The Current Status of Meson Spectroscopy.' The second, entitled 'Recent Results of Meson Resonances, and Possible Experiments at High Energy,' was given at the IXth Rencontre De Moriond, Meribel-Les-Allves, France, in 1974. Both of these will be published in the proceedings and in addition, the first was also distributed as a report CERN/D.Ph.II/Phys. 73-22. Both talks were given by David H. Miller.