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WITH MEDIUM-ENERGY PROBES

MASTER

Annual Progress Report

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1. INTRODUCTION

This is the progress report for our continuing program of experimental research in nuclear physics with medium energy probes for the preceeding twelve month period, August 1981 to August 1982. During this period we have made notable progress. An unusually large number of our experiments have received beam time and the runs have been successfully completed. Our researches have received wide recogniton. In the following pages we briefly review the progress of our program since the last progress report. We also present the highlights of the very exciting program of research we have planned for the coming year. We believe that the proposed program offers us oppourtunty of making several significant contributions in the study of strong interaction physics.

2. PROGRAM OF RESEARCH

The general outline of our program of research for the three year period, December 1980 - November 1983 was presented in detail in the original proposal. In the last year's progress report we described how we were making progress towards achieving our original program goals. In the same vein, in the following pages we will review the progress made since last year. For continuing programs we will indicate how they will proceed during the following year. There have been some altogether new and exciting physics developments. These we will describe in somewhat greater detail.

In Table I we summarize the beam time utilization by our experiments at LAMPF, Bates, and Saclay. As the table illustrates, an unusually large number (nine) of our experiments received beam time this year. Of these we have a collaborative role only in two experiments (LAMPF #518 and Saclay #95). For the other seven, involving ~1500 hours of running, we have the primary (and in most cases, the exclusive) responsibility. These statistics illustrate the fact that in the following year we expect that our major task will be the analysis of data and the preparation of publications.

We have an exciting series of experiments planned for the next year. We summarize these plans in Table II.

In the following pages we report on the three major components of our program: (I) Pion Induced Reactions, (II) Proton Induced Reactions, and (III) Electron Induced Reactions

TABLE 1. BEAM TIME UTILIZATION

Dates	Expt. #	Experiment Title*	Beam Time hrs	Comments
7/10-7/31	95	Study of π -He Interaction at Low Energy	~200 (Saclay)	completed
8/18-8/22	78-7	A Comprehensive Study of the $^{40}\text{Ca}(e,e')$ Reaction	128(Bates)	completed
9/1-9/10	508	Dibaryon Resonances in Pion Production	215 (HRS)	continuing
9/25-9/28	168	Measurements of the Relative Sign of Neutron and Proton Matrix Elements via (α,α') Reaction	50 (INDIANA)	completed
11/4-11/25	606	Tests of the (N-Z) Dependence of Pion Double Charge Exchange	476 (EPICS)	completed
5/19-5/24	504	Study of (p,π^-) Reaction on ^{12}C and ^{13}C	128 (HRS)	completed
7/11-7/26	671	Test of the Microscopic IBA Model via Pion-Nucleus Scattering on Palladium Isotopes	312 (EPICS)	completed
8/4-8/12	716	Pion Double Charge Exchange on Heavy Nuclei: ^{90}Zr and ^{88}Sr .	184 (EPICS)	completed
6/12-9/18	518	Polarized Beam and Target Experiments in the p-p System. A_{zz} and A_{xz} for the $d\pi^+$ Channel	1600 (BR)	continuing

* The spokesman for experiment #95 is B. Saghai. The spokesmen for experiment #518 are J. Simmons, J. Jarmer and L. Northcliffe. Northwestern group members are spokesmen for all other experiments.

TABLE 2. BEAM TIME APPROVED AND REQUESTED

Expt. #	Experiment Title (Spokesmen)	Beam Time (hrs)	Comments
605	A Dibaryon Search at EPICS	128 (EPICS)	9/27-10/3
---	Study of Nuclear Structure of ^{26}Mg by Electron Scattering	200 (NIKHEF)	10/8-11/30
533	The Asymmetry in the (p, π) Reaction on ^6Li at 800 MeV	120 (HRS)	approved
550	Excited State Spectra of the Exotic Nuclei, ^{18}C and ^{26}Ne by (π^-, π^+) Reactions	150 (EPICS)	approved
758	To Catch a Demon...	100 (HRS)	approved
139	Are Nucleons and Deltas Deformed? (Seth)	(SACLAY)	exploratory time granted
---	Are Nucleons and Deltas Deformed? (Seth)	300 (SLAC)	proposal in preparation

I. PION INDUCED REACTIONS

a) Pion Double Charge Exchange

The study of Pion Double Charge Exchange (DCX) Reactions has been a major part of our program from the beginning. We initiated this field of investigation at the EPICS channel at LAMPF with two parallel goals. The first and foremost objective is to study detailed properties of DCX reaction so as to understand its mechanism^{1,2} and hopefully to illuminate the central problem of pion-nucleus interaction. The second objective is to use the reaction, to study nuclei far from the valley of stability^{3,4}. During the past year we have made progress on both fronts.

In a preliminary study of the reaction $^{48}\text{Ca}(\pi^+, \pi^-)^{48}\text{Ti}$ we had noted that the ratio of the 5° analog cross sections:

$$R \equiv \frac{^{48}\text{Ca}(\pi^+, \pi^-)^{48}\text{Ti}(\Delta T = 0)}{^{42}\text{Ca}(\pi^+, \pi^-)^{42}\text{Ti}(\Delta T = 0)} < \sim 4 \quad (1)$$

instead of what is predicted by most simple theories and optical model calculations which have a single DCX form-factor proportional to $\rho(r)$,

$$R = \frac{[(N-Z)(N-Z-1)/A^{10/3}]_{48}}{[(N-Z)(N-Z-1)/A^{10/3}]_{42}} \approx 18 \quad (2)$$

-
1. "Angular Distributions for $^{18}\text{O}(\pi^+, \pi^-)^{18}\text{Ne}$ Reaction and Pion Double Charge Exchange Form Factors", K.K. Seth et al., Phys. Rev. Lett. 43 (1979) 1574; also 45 (1980) 147.
 2. "Pion Double Charge Exchange", K.K. Seth, review paper, Proc. Intern. Energy Nucl. Chem. Workshop. Los Alamos Conf. Rep. #LA-8835-C (1981) 250-312.
 3. "Mass of ^{18}C by Pion Double Charge Exchange", K.K. Seth, et al., Phys. Rev. Lett. 41 (1978) 1589.
 4. "Pionic Probes for Exotic Nuclei", K.K. Seth, review paper, Proc. 4th Internat. Conf. on Nuclei far from Stability, Helsingor, CERN Conf. Rep. # 81-09 (1981) 655-663.

In LAMPF proposal #606 we stated that if this observation were to be proven correct in a carefully done experiment, it would reaffirm our earlier conjecture¹ that $\rho^2(r)$ terms in the DCX form factor play an important part. We have now done the experiment #606. In this experiment we were successful (see Figs. 1 & 2) in observing both the analog transitions, ($\Delta T = 0$): $^{48}\text{Ca}(\pi^+, \pi^-)^{48}\text{Ti}(17.4 \text{ MeV})$ and $^{48}\text{Ti}(\pi^+, \pi^-)^{48}\text{Cr}(8.8 \text{ MeV})$, and the non-analog transitions, ($\Delta T = 2$): $^{48}\text{Ca}(\pi^+, \pi^-)^{48}\text{Ti}(\text{g.s.})$ and $^{48}\text{Ti}(\pi^+, \pi^-)^{48}\text{Cr}(\text{g.s.})$. We measured the 5° excitation functions for all these transitions. The measured ratio R for $^{48}\text{Ca}/^{42}\text{Ca}$ is illustrated in Fig. 3. It is indeed considerably less than 18 everywhere, the average value being $\sim 5 \pm 1$. We also notice that the data indicate that R is far from being constant. It is too early to state what the real implications of these data are, but it appears fairly certain that these data will force substantial modification of our current thinking about the mechanism of the DCX reaction.

Just two weeks ago we completed our experiment #716 whose primary purpose was to extend pion DCX to heavy nuclei, ^{88}Sr and ^{90}Zr , in order to study the variation of DCX cross sections with atomic weight. Fig. 4 shows the on-line data for ^{88}Sr and illustrates that the attempt to observe double analog transitions via pion DCX in these heavy nuclei was a great success. These results are particularly noteworthy because all previous attempts to observe double isobaric analog states ($T = T_z + 2$) in medium weight nuclei by conventional nuclear reactions have been uniformly unsuccessful.

As mentioned earlier, the second emphasis in our experiments on pion DCX has been to study nuclei far from stability. In an earlier experiment (LAMPF #460) on the study of the possible stability of ^7H via the reaction

Fig. 1. Composite missing mass spectrum for the DCX reaction $^{48}\text{Ca}(\pi^+, \pi^-)^{48}\text{Ti}$ at $\theta = 5^\circ$. The spectrum is the sum of four spectra at 130, 180, 235 and 292 MeV. Notice the clear excitation of the double analog state ($T = T_z + 2$) at 17.3 MeV.

Fig. 2. Composite missing mass spectrum for the DCX reaction $^{48}\text{Ti}(\pi^+, \pi^-)^{48}\text{Cr}$ at $\theta_L = 5^\circ$. The spectrum is the sum of the four spectra at 130, 180, 235 and 292 MeV. Notice the clear excitation of the double analog state ($T = T_Z + 2$) at 8.8 MeV.

Fig. 3. Ratio of 5° cross sections for the analog transition $^{48}\text{Ca}(\pi^+, \pi^-)^{48}\text{Ti}$ (17.3 MeV) and the $^{42}\text{Ca}(\pi^+, \pi^-)^{42}\text{Ti}$ (g.s.). Note that the ratio is everywhere different from ~ 18 which is predicted by the usual theories.

Fig. 4. On line results for the missing mass spectrum for the reaction $^{88}\text{Sr}(\pi^+, \pi^-)^{88}\text{Zr}$. Notice the clear excitation of the $T = 6$ double analog state at 17.35 excitation.

Fig. 5. The missing mass spectrum for the reaction $^{58}\text{Ni}(\pi^+, \pi^-)^{58}\text{Zn}$. Notice that the ground state is clearly excited. It leads to a mass excess of $-42.25(6) \text{ MeV}$ for ^{58}Zn .

${}^7\text{Li}(\pi^-, \pi^+)X$ it was found that the observed missing mass spectrum for π^+ did not show any enhancement corresponding to ${}^7\text{H}$. However it did fit the phase-space predicted for X consisting of three unbound heavy particles, e.g., $n + n + {}^5\text{H}$. This suggested the possible stability of ${}^5\text{H}$. To examine this conjecture experimentally we proposed (LAMPF expt. #604) to study the reaction ${}^6\text{Li}(\pi^-, p){}^5\text{H}$. The experiment was completed in Feb. '81. The first results of the analysis were presented in an invited paper at the 4th International Conference on Nuclei Far From Stability.⁴ No large enhancement corresponding to a near-bound ${}^5\text{H}$ were observed. The final analysis of the data is in progress.

During the course of our experiment #606 it became possible to make a brief attempt to study the reaction ${}^{58}\text{Ni}(\pi^+, \pi^-){}^{58}\text{Zn}$. A successful attempt was made at $T(\pi^+) = 299 \text{ MeV}$, $\theta = 5^\circ$. The observed spectrum is shown in Fig. 5. The atomic mass excess of ${}^{58}\text{Zn}$ was determined to be $-42.253(65) \text{ MeV}$.

Our work on study of exotic nuclei has received wide recognition. The principal investigator was invited to give review talks both at the 4th International Conference on Nuclei far from Stability at Helsingor and at the Annual meeting of the Division of Nuclear Physics, American Physical Society at Asilomar.

b) Pion Elastic and Inelastic Scattering

With our experiments on ${}^{18}\text{O}$ we pioneered the use of pion scattering to study isovector properties of nuclear states.⁵ Since then the study of π^+/π^- inelastic scattering for this purpose has become the accepted technique

5. "Neutron Deformation Parameter by Comparative Study of π^+ and π^- Inelastic Scattering", S.G. Iversen, et al., Phys. Rev. Lett. 40 (1978) 17, also Phys. Lett. 82B (1979) 51.

and many light nuclei have been studied. However, not many heavier nuclei have been so investigated. In contrast to light nuclei, the low lying collective states of heavy nuclei are expected to be mostly isoscalar. The neutron and proton matrix elements, M_n and M_p for these states are generally expected to be proportional to N and Z . This hydrodynamical expectation has been recently challenged by the IBA-2 (Interacting Boson Approximation-2) model which predicts large departures from the $M_n/M_p = N/Z$ rule. We have just made a study of π^+ and π^- scattering from the 2_1^+ states of the palladium isotopes, $^{104,106,108,110}\text{Pd}$ at $T(\pi) = 180$ and 270 MeV (LAMPF expt. #671) to determine M_n/M_p and thus submit the model to a critical test. The experiment was a success. As illustrated by Fig. 6, the 2_1^+ states were well resolved from elastic scattering and complete angular distributions were measured in the range $14^\circ < \theta_L < 50^\circ$. The data is being currently analyzed. We fully expect that it will have a decisive impact on the IBA-2 model.

At low energies ($T(\pi) < 50$ MeV) the isovector part of the pion optical potential is very poorly known. This is primarily due to the fact that almost no π^- elastic scattering data exists at these energies. To remedy this situation we did expt. #316 in which we measured low energy (20,30,40 and 50 MeV) π^- elastic scattering from a large number of nuclei, $^{12,13}\text{C}$, $^{16,18}\text{O}$, $^{40,48}\text{Ca}$, ^{58}Ni , ^{90}Zr and ^{208}Pb using a range spectrometer. Some of the preliminary results for 50 MeV are displayed in Fig. 7. However, more detailed analysis has revealed some problems with backgrounds. Work is continuing and it is hoped that a satisfactory resolution of the problem will be forthcoming soon.

Fig. 6. Typical π^+ scattering spectra from Pd isotopes at $E_{\pi^+} = 180$ MeV and $\theta_{\text{lab}} = 45^\circ$.

A paper describing the results of our experiment at Saclay on elastic scattering of 65 MeV pions on deuterium has been submitted for publication⁷. The data taking for low energy pion scattering on $^3,^4\text{He}$ has been finished. The data is being analyzed.

II. PROTON INDUCED REACTIONS

a) Pion Production Reactions

At the High Resolution Spectrometer (HRS), pion production studies constitute our major program.

Our studies of (p, π^+) reaction at 800 MeV on ^6Li , ^{10}B and ^{12}C have been completed and a detailed report was presented at the Workshop on Pion⁸ Production held at Bloomington, Indiana. We have also completed a study of the (p, π^-) reaction on ^{12}C and ^{13}C at 800 MeV (LAMPF experiment #405). This new data is being analyzed.

One of the main conclusions of our studies of (p, π^+) reaction on complex nuclei is that the reaction obviously proceeds in a very complicated manner. At low energies ($T_p \approx 150 - 200$ MeV) the reaction seems to exhibit simple, stripping-like behavior. No such simple behavior can be discerned at 800 MeV. No ℓ -transfer, or spectroscopic factor characteristics can be identified. These, rather disappointing conclusions, have made us concentrate more on the elementary pion production reactions rather than on production on complex nuclei. It is the basic premise of this approach that

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7. "Differential Cross Sections for $\pi^\pm$ -d Scattering at 65 MeV," B. Balestri, et al., Nucl. Phys. (submitted for publication). See Appendix A for copy.
 8. "The $(p, \pi^\pm)$ Reactions at 800 MeV", H. Nann, Proc. Workshop on Pion Production and Absorption in Nuclei, Bloomington, AIP Conference Proceedings #79 (1982) 219-228. See Appendix A for copy.

Fig. 7. Preliminary results of analysis for 50 MeV pion scattering from several nuclei (our experiment 316). The figure at the left is for π^+ , the figure at the right is for π^- .

an understanding of the elementary reactions

$$\vec{p} + \vec{p} \rightarrow d + \pi^+$$

and

$$\vec{p} + \vec{p} \rightarrow t + \pi^+$$

is prerequisite to any satisfactory theory of pion production on complex nuclei. Accordingly, we have concentrated on the above two reactions.

$\vec{p} + p \rightarrow d + \pi^+$: The Dibaryon Story

We first made a study of this reaction with an unpolarized 800 MeV beam. The precision differential cross sections measured in this experiment were published sometime ago.⁹ Since then we have measured $A_{y0}(\theta)$ with a polarized 800 MeV beam. These data, shown in Fig. 8, vividly illustrates the failure of all existing theories, including the so called 'unified theories', in providing a satisfactory explanation of this reaction. These data are at exactly the same c.m. energy ($\sqrt{s} = 2.24$ GeV) as the $iT_{11}(\theta)$ data of Bolger et al.,¹⁰ which is currently being explained in terms of dibaryon resonances. Our data raises serious questions about the validity of these interpretations. A paper describing our results has been submitted to Physics Letters.¹¹

We have completed our experiment (LAMPF experiment #508) on search for dibaryon resonances in the single pion production channel at 500, 550, 600, 650, 700 and 800 MeV. Only 750 MeV remains to be done. Our results for A_{y0} are displayed in Fig. 9. The quality of our data is much superior to that of the data in literature (Fig. 10). The data have been analyzed in terms of b-coefficients of the associated Legendre polynomials:

9. " $\vec{p} + p \rightarrow d + \pi^+$ Reaction at 0.8 GeV", H. Nann, et al., Phys. Lett. 85 (1979) 257.

10. "Evidence for a Dibaryon Signal in the Measurement of Elastic $\pi^+ + d_{pol}$ Scattering", Phys. Rev. Lett. 46 (1981) 167; also 48 (1982) 1667.

11. "Analyzing Power for the $\vec{p} + p \rightarrow d + \pi^+$ Reaction at 0.8 GeV and Effects of Dibaryon Admixtures", K.K. Seth, et al., Phys. Lett. (submitted for publication). See Appendix A.

Fig. 8. Measured analyzing power, $A_{y0}(\theta)$ for the reaction $\bar{p} + p \rightarrow d + \pi^+$ at $T_p = 793$ MeV. The curves refer to the various theoretical calculations, all without dibaryon resonances, as described in the text.

Fig. 9. $A_{y0}(\theta)$ for the reaction $\bar{p} + p \rightarrow d + \pi^+$ as measured in our experiment #508. The solid curves are due to Blankleider and Afnan. The dashed curves are due to Niskanen.

Fig. 10. $A_{y0}(\theta)$ data for the reaction $\bar{p} + p \rightarrow d + \pi^+$ from literature at the time of our proposal #508. The curves are due to Kamo and Watari.

Fig. 11. The energy variation of the b-coefficients of the analyzing power, $A_{y0}(\theta)$ of the reaction $\bar{p} + p \rightarrow d + \pi^+$. Result for the two energies shown by triangles are from SIN. The solid curves are due to Blankleider and Afnan. The dashed curves are due to Niskanen. Notice the unexpected resonance in the even coefficients b_2 and b_4 .

$$\sigma(\theta) \equiv \sigma_{00}(\theta) + \vec{p}_B \cdot \vec{n} \sigma_{y0}(\theta) ,$$

$$\sigma_{00} \equiv (4\pi)^{-1} \sum a_{2n} P_{2n}(\cos\theta) , \quad n = 0, 1, 2$$

$$\sigma_{y0} \equiv (4\pi)^{-1} \sum b_n P_n^1(\cos\theta) , \quad n = 1, 2, \dots$$

$$A_{y0} \equiv \sigma_{y0}(\theta)/\sigma_{00}(\theta)$$

The energy behavior of these coefficients is shown in Fig. 11. It is clear that once again none of the existing theories explain our results. In particular, we note that the behavior of the even coefficients, b_2 and b_4 , is qualitatively different from the predictions. Do these results indicate the need for dibaryon admixtures? The answer is not yet clear.

The results shown in Fig. 11 will be formally presented for the first time by Dr. A. Saha in his invited paper at the "Symposium on Pion-Induced Induced Nuclear Reactions and Pion Production with Light Ions" of the American Chemical Society. A paper for Physical Review Letters is in preparation.¹²

Measurement of A_{zz} and A_{zx} for the $\vec{pp} + d\pi^+$ Reaction

A natural extension of our measurements of $A_{y0}(\theta)$ for the $\vec{pp} + d\pi^+$ channel is to measure other spin-correlation parameters for this channel. For several years we have waited for the availability of a polarized proton target at the HRS, in order to do these experiments. Since this has not materialized, we have considered other alternatives. Recently we were invited by the collaboration at LAMPF experiment #518 at the EPB to join them in measuring A_{zz} and A_{zx} in the $pp + d\pi^+$ channel using the HERA

12. "Pion Production and Dibaryon Resonances", A. Saha, et al., Phys. Rev. Lett. (to be submitted).

polarized target. We have joined the collaboration and our graduate student, David Barlow has been assigned the problem for his Ph.D. dissertation.

The first experimental runs were done during LAMPF cycle #34. The experiment is to continue through the entire cycle #35.

$\bar{p} + d \rightarrow t + \pi^+$: Δ -Components in the Deuteron?

The deuteron is the 'first' nucleus. Our original motivation for studying pion production from deuterium was indeed to take the 'first' step towards complex nuclei. We measured differential cross sections at 800 MeV and $A_{Y0}(\theta)$ at $T(p) = 650$ and 800 MeV. An unexpected phenomenon was observed in $A_{Y0}(\theta)$ at 800 MeV. As shown in Fig. 12 there is a pronounced peak in A_{Y0} at $\sim 150^\circ$ at 800 MeV, whereas no such peak exists at 650 MeV. This led us to measure $A_{Y0}(\theta)$ in the back angle region at $T_p = 600$ and 700 MeV also. As shown in Fig. 12 the back-angle peak is non-existent at 600 MeV. At 700 MeV there are indications of its development. We do not yet have data at 750 MeV, but the existing data clearly indicate that the back-angle peak in $A_{Y0}(\theta)$ develops between 700 and 800 MeV. The differential cross sections at 800 MeV also show a bump in the same angular region. (Fig. 13) By plotting the data against the variable u , we find that this feature is connected with the exchange of a heavy particle. It is very tempting to attribute this to a Δ -exchange, arising out of Δ - Δ components in the deuteron.¹³ We are currently exploring this and other possible explanations quantitatively. One of the serious shortcomings of our data is that we are limited to $T_p = 800$ MeV. It would be extremely interesting to follow this back-angle peak to higher energies. Does it develop further or does it die out?

13. "Search for Evidence of a $\Delta(1236)$ - $\Delta(1236)$ Components of a Deuteron" C.P. Horne, et al., Phys. Rev. Lett. 33 (1974) 380.

Fig. 12. Analyzing power $A_{y0}(\theta)$ for the reaction $\bar{p} + d \rightarrow t + \pi^+$. The data points and the curve through them is for $T(p) = 800$ MeV. The other curves are tracings of the data at other energies. Notice the development of the bump at 150° .

Fig. 13. Differential cross sections for the $\vec{p} + d \rightarrow t + \pi^+$ reaction at 800 MeV. Note that the secondary bump occurs at approximately the same angle ($\sim 150^\circ$) as in the analyzing power $A_{y0}(\theta)$ of the preceding figure.

We are exploring the possibility of extending these measurements to higher energies at the Laboratoire National Saturne at Saclay.

A paper on these results was presented at the Washington meeting of the American Physical Society.

$d(\vec{p}, \pi^+)d^*$: Dibaryon Bandheads

MacGregor¹⁴ has noted that the proposed 1D_4 (2140 MeV), 3F_3 (2260 MeV) and 1G_4 (2430 MeV) dibaryons fall on a trajectory, which should therefore have 1S_0 band head at 2020 MeV and 3P_1 first resonances at 2060 MeV. These correspond to laboratory kinetic energies of 300 MeV and 390 MeV in pp collisions. Wainer and Lomon¹⁵ have showed that in order for these resonances to exist and yet to have escaped detection in existing pp experiments, their widths must be no greater than ~ 0.5 MeV. Thus a good resolution experiment is needed to detect these resonances, if they exist at all. We have measured the analyzing power, $A_{Y0}(18^\circ)$ as a function of the missing mass of the $d^* [= (n+p)^*]$ system in the reaction

$$d(\vec{p}, p')d^*$$

The results are shown in Fig. 14 as a function of the excitation energy of d^* . No statistically significant departures from a smooth behavior are observed anywhere. These data do not support McGregor's conjecture.

To Catch a Demon...

The evidence for anomalous mean-free path lengths for the first 10^{-10} second of the life of a projectile fragment in heavy-ion collisions seems

14. "Interpretation of p-p Dibaryon Resonances at 2140, 2260, and 2430 MeV", M.H. Mac Gregor, Phys. Rev. Lett. 42 (1979) 1724.

15. "Experimental Constraint on Widths of Postulated Low-Mass Dibaryons", J. Wainer and E.L. Lomon, Phys. Rev. D22 (1980) 1217.

to be quite firm now. Many proposals have been made to explain the phenomenon. One of the more provocative of these is due to Fredriksson and Jandel.¹⁶ These authors postulate the existence of a highly reactive six-quark state of $(I, S, J^\pi) = (0, 0, 0^-)$ which is made up of three di-quark clusters. They propose that this deuteron-like object, which they call the 'demon deuteron', or 'demon' for short, has a mass between that of the deuteron and $(m_n + m_p + m_\pi)$, and has a lifetime of $\sim 10^{-10}$ sec. We propose (LAMPF experiment #758) to search for the demon, δ in the reaction

$$\vec{p} + p \rightarrow \delta + \pi^+$$

by measuring the differential cross sections, $\sigma(\theta)$ and the analyzing power, $A_{yo}(\theta)$ as functions of the δ missing-mass.¹⁷

b) Proton Elastic and Inelastic Scattering

For the last several years, a large amount of work on elastic and inelastic scattering of 800 MeV protons has been done at LAMPF. The elastic scattering data has been analyzed to obtain $(r_n - r_p)$ for nuclei, with the assumption of the validity of the impulse approximation. If these claims are correct one should obtain the same results at other energies at which one has equal faith in the validity of the impulse approximation. With this goal in mind we measured (LAMPF experiment # 425/433) elastic and inelastic scattering of 500 MeV protons from ^{12}C , $^{40,48}\text{Ca}$, ^{90}Zr , and ^{208}Pb . The data for elastic scattering have been analyzed. It is found¹⁸ that one

16. "Diquark Deuteron", S. Fredriksson and M. Jandel, Phys. Rev. Lett. 48 (1982) 14.

17. "To Catch a Demon...", K.K. Seth, spokesman, LAMPF proposal #758 (1982). See Appendix C for copy.

18. "Elastic Scattering of 500 MeV Polarized Protons from $^{40,48}\text{Ca}$, ^{90}Zr and ^{208}Pb , and Breakdown of the Impulse Approximation at Small Momentum Transfer", G.W. Hoffmann, et al., Phys. Rev. Lett 47 (1981) 1436.

Fig. 14. $A_{y0}(18^\circ)$ for the reaction $D(p,p')\overline{PN}$. McGregor's resonances are predicted at 143 MeV and 183 MeV. No trace is observed.

has serious problems in fitting the data at 500 MeV and that the results obtained are in disagreement with those found at 800 MeV. It is claimed that a breakdown of the impulse approximation is the cause.

The inelastic data is in the final form. Various approaches for its interpretation are being tried.

III. ELECTRON INDUCED REACTIONS.

a) Electron Scattering from ^{40}Ca

This experiment is now complete. The transverse scattering data at $\theta = 160^\circ$ was taken in August, and is being analyzed. The analysis of the data at 45° and 90° has been finished. We are now trying to obtain model independent transition densities from these data.

b) Electron Scattering from ^{26}Mg

Like ^{40}Ca , the nucleus ^{26}Mg has been extensively studied with pions in (3,3) resonance region and with protons at 150 MeV and at 800 MeV. It is essential for the interpretation of these data that electron scattering data of excellent quality be obtained. Without such data it is impossible to interpret the proton data unambiguously. In order to provide these data we have proposed to study electron scattering from ^{26}Mg in the momentum transfer region from 0.2 fm^{-1} to 3.0 fm^{-1} at the Linear Accelerator at NIKHEF (Amsterdam), in collaboration with Dutch physicists¹⁹. The experiment has been approved and its first phase has been scheduled for running during October-November, 1982.

19. "A Study of the Nuclear Structure of ^{26}Mg by Inelastic Electron Scattering", K.K. Seth, H. deVries, J.F.A. Hienen, spokesmen. Proposal to NIKHEF, 1982. See Appendix C for copy.

c) Are Nucleons and Deltas Deformed

The quark-gluon picture of hadrons is now generally accepted, and strong interaction physics has to be understood in terms of this picture. Fundamental understanding of nucleon-nucleon force, dibaryon structures, baryonium, etc., is only possible in these terms²⁰. The two well known models of hadrons as bags of quarks and gluons are the so-called "MIT bag" model²¹ and the "Little bag" or the "Chiral bag" model²². Both model have achieved impressive successes in obtaining agreement with many well-known properties of hadrons, but their predictive powers essentially remain untested. The main difference between the two models concerns the role played by pions. The 'MIT' bag is a closed spherical object which communicates with other bags only when it 'overlaps' with them. The "Chiral" bag is dressed with a pion cloud outside it and can therefore interact with other bags without overlapping. The 'Chiral' bag has other appealing qualities also. It is of the utmost importance to find out which one of these models is closer to the reality.

There is one prediction in which the two bag models differ drastically. The MIT bag is spherical, whereas the Chiral bag is necessarily deformed because of the coupling of the pion-field to the spin of the nucleon. An immediate consequence of these differences in the predictions of the shape of a nucleon (and of its spin-isospin flip partner, the Δ -1232)

20. "The Nucleon Nucleon Force", R. Vinh-Man, Proc. 9th. ICOHEPANS, Nucl. Phys. A37 (1982) 3c-24c.

21. "The MIT Bag", K. Johnson, Acta Physica Psonica B6 (1975) 865.

22. "Quarks and Nuclei", G.E. Brown, Proc. 9th ICOHEPANS, Nucl. Phys. A374 (1982) 63c-72c.

partner, the $\Delta(1232)$ is that in the MIT-bag model the transition between N and Δ is pure M1. In the Chiral-bag model a quadrupole (C2 or E2) component is also expected. The presence of a resonance quadrupole part in the electroexcitation of $\Delta(1232)$ is therefore an unambiguous signal of the deformation of nucleons and deltas.

We propose to do a high precision Rosenbluth separation of the E2 part of the transition $p(e,e')\Delta(1232)$ in the four momentum transfer region $q^2 < 1 \text{ GeV}^2$. The proposed experiment has two parts. For $q^2 < 0.25 \text{ GeV}^2$ we propose to do the experiment at the ALS at Saclay. The two spectrometer facility at the ALS is ideally suited for the purpose. For $0.2 < q^2 (\text{GeV}^2) < 1.0$ we propose to do the experiment at SLAC. Once again the two spectrometer facility in end-station A at SLAC is ideally suited for the purpose.

The proposal²³ for the low energy part of the experiment was submitted to the Saclay PAC in December, 1981. Since questions of high precision are involved the committee has initially granted beam time for exploratory studies only. We expect that this time will be scheduled in early 1983.

The proposal for the high energy part of the experiment at SLAC is being prepared for submission to the SLAC PAC at its meeting in November 1982.

23. "Are Nucleons and Deltas Deformed", K.K. Seth, spokesman, Saclay Proposal #139 (1981). For copy see Appendix C.

IV. DATA ANALYSIS AND THE COMPUTER

As mentioned earlier, we have now completed a large number of experiments. Data analysis is of necessity a major part of our activity now. The primary tool for this presently is our PDP 11/60 computer and it is already proving to be the bottleneck.

Our PDP-11/60 has been in routine use for about three years now. It is used for an average of ~18 hours a day, primarily for data replay. While no serious problems with main-frame hardware or peripherals have been encountered and the system has performed very reliably, we are now severely limited by several features which are inherent in the basic architecture of the 11/60.

The main, and almost crippling, disadvantage of the 11/60 is its 128 K memory limitation. Not only does it mean that larger programs can not be run on the 11/60, it also means that despite the advertizements to the contrary, the 11/60 becomes effectively a single user computer when a large program like 'Q' is used. Since data replay has the highest priority, our 11/60 is essentially unavailable for any other calculation or program development. This means that we are unable to do essential physics calculations which must be done interactively, such as model-independent transition density analysis of our electron scattering data. We are of course not able to run programs like DW70 and ALLWORLD which are prohibitively expensive to run on university computers. We have carefully examined several proposed alternatives for remedying this situation and have come to the conclusion that the only viable solution is to move upto the next level of virtual memory computer. The obvious choice is a DEC computer of the VAX family.

Our 11/60 has a rather limited disc capacity (one CDC drive with 65 MB) also. This disc is also the System disc. Thus we have no room to even put one data tape on a disc. Replay can therefore not be done in an unattended mode. We have considered acquiring a large 128-256 MB disc, copying three to six data tapes on it and replaying from the disc. This would essentially increase our computer's usefulness by about 30%. Apart from the cost of such a disc system (~\$25,000), there is one serious problem. Such a disc system and controller for 11/60 is not compatible with one for VAX. Therefore the choice of the longer-term computer must be made first. These and similar considerations have prevented us in past from proposing any short-term improvements of our system, which will leave us with more peripherals which are likely to be incompatible with a VAX family computer.

We believe that there is now a serious need for a significant improvement in our data analysis capabilities. We believe that the need can only be met, with some reserve for future growth, by acquiring a VAX-750 computer as outlined below.

The minimum cost system based on a VAX 750 CPU consists of:

- a) VAX-750 CPU with 1 MB of memory
- b) VAX/VMS Operating System
- c) A Winchester-type 121 MB -134 MB Fixed-media disc.

This system would increase our CPU memory by a factor eight, and our disc memory by factor two, This system will increase our data-replay speed by a factor two to three. It will allow unattended replay from the large disc and enable us to increase the useful computer time by ~30%. Further it will equip us with a modern, well supported computer system which will

enable us to handle very large programs by virtue of its virtual memory architecture. The total cost of the system would be \$75,000.

We are separately submitting a revised budget request reflecting the proposed purchase of this system.

3. CONTRACT PERSONNEL

(9/1/81 - 9/1/82)

Principal Investigator: Kamal K. Seth

Research Associates: A. Saha

D. Kielczewska

Computing Assistant: D. Smith (terminated 11/81)

Research Assistants: M. Kaletka

D. Barlow

J. Stewart

L. Casey

Summer Students:

D. Godman

R. Seth

4. DISSEMINATION OF RESEARCH RESULTS

1. PUBLICATIONS AND PREPRINTS*

1. "Pionic Probes for Exotic Nuclei", Kamal K. Seth, invited paper, 4th International Conference on Nuclei Far From Stability, Helsingor CERN Publications (Geneva) CERN 81-09 (1981) 655-663.
2. "Elastic Scattering of 500 MeV Polarized Protons from $^{40,48}\text{Ca}$, ^{90}Zr , and ^{208}Pb , and Breakdown of the Impulse Approximation at Small Momentum Transfer", G.W. Hoffmann, L. Ray, M.L. Barlett, R. Fergerson, J. McGill, E.C. Milner, Kamal K. Seth, D. Barlow, M. Bosko, S. Iversen, M. Kaletka, A. Saha, and D. Smith, Phys. Rev. Lett 47 (1981) 1436-1440.
3. "Kaon Scattering and Charged Sigma Hyperon Production in K-p Interactions below 300 MeV/c", J. Ciborowski, J. Gwizdz, D. Kielczewska, R.J. Nowak, E. Rondio, J.A. Zakrzewski, M. Goossens, G. Wilquet, N.H. Bedford, D. Evans, G.P. Fleming, Y.A. Hamam, J.V. Major, J.H. Bartley, D.H. Davis, D.H. Miller, D.N. Tovee and T. Tymieniecka, J. Phys. G. Nucl. Phys. 8 (1982) 13-32.
4. "Characteristics of π^- Production in the Collisions of 4.2 GeV/c/Nucleon d, α and ^{12}C Beams with Tantalum", H.H. Agakisiev, N. Angelov, N. Ahababian, T. Baatar, A.M. Baldin, J. Bartke, J. Bogdanowicz, A.P. Cheplakov, L.A. Didenko, S.V. Dzhamukhadze, A.P. Gasparian, K.K. Gudima, N.S. Grigalashvili, V.G. Grishin, I.A. Ivanovskaja, L. Jenik, T. Kanarek, R.A. Kvatadze, E.N. Kladnitskaya, D.K. Kopylova, M. Kowalski, V.B. Lyubimov, R.R. Mehtiev, V.E. Nikitina, V.M. Popova, L.M. Shcheglova, A.I. Shkovskaya, L. Simic, A.N. Solomin, M.I. Soloviev, M.K. Sulejmanov, G.P. Toneeva, V.D. Toneev, O.B. Abdinov, S. Backovic, V. Damianovic, D. Krpic, D. Krmpotic, S. Drndarevic, E. Balea, O. Balea, V. Boldea, V. Hakman, T. Ponta, I.N. Erofeeva, V.S. Murzin, L.N. Smirnova, N.N. Melnikova, S.I. Lyutov, Z. Korbel, T. Trka, Ya. Trkova, L.D. Grekova, P. Kerachev, P. Markov, H. Semerdzhiev, B. Chandraa, D. Batmunh, R. Tegoo, D. Tuvdendorz, D. Armutlijsky, H. Kocznev, S. Prokopeva, H. Bialkowska, D. Kielczewska, K. Lang.
5. "The (p, $\pi^\pm$) Reactions at 800 MeV", H. Nann, invited paper, Proc. Workshop on Pion Production and Absorption in Nuclei, Bloomington, AIP Conference Proceedings (New York) 79 (1982) 219-228.
6. "Level Structure of ^{28}Si by the $^{27}\text{Al}(^3\text{He}, d)^{28}\text{Si}$ Reaction", H. Nann Nucl. Phys. A 376 (1982) 61-80.
7. "Measurement of the Relative Sign of Neutron and Proton Transition Matrix Elements of the 2^+ States in ^{30}Si ", A. Saha, K.K. Seth, D. Barlow, H. Nann and W.W. Jacobs, Phys. Lett. 114B (1982) 419-422.

8. "Systematics of Ground State (p,t) Transitions in Calcium Isotopes", A. Saha, K.K. Seth and H. Nann, Phys. Rev. C (in press).
9. "Analyzing Power for the $\bar{p} + p \rightarrow d + \pi^+$ Reaction at 0.8 GeV and Effects of Dibaryon Admixtures", Kamal K. Seth, A. Saha, D. Kielczewska, S.G. Iversen, M. Kaletka, D. Barlow and B. Hoistad, Phys. Lett. (submitted).
10. "Differential Cross Sections for Elastic $\pi^\pm$ -d Scattering at 65 MeV", B. Balestri, G. Fournier, A. Gerard, J. Miller, J. Morgenstern, J. Picard, B. Saghai, P. Vernin, P.Y. Bertin, B. Coupat, E.W.A. Lingeman and K.K. Seth, Nucl. Phys. (submitted).
11. "First Excited 0^+ States in the Germanium Isotopes via the $\text{Se}(d, {}^6\text{Li})$ Reaction", Van den Berg, R.V.F. Janssens, G.T. Emery, A. Saha, and R.H. Siemssen, Nucl. Phys., A379 (1982) 239-255.

* For copies see Appendix A

II. INVITED PAPERS AT CONFERENCES

1. "Pionic Probes for Exotic Nuclei", Kamal K. Seth, American Physical Society, Asilomar Meeting of the Division of Nuclear Physics, Oct. 30, 1981, Bull. Amer. Phys. Soc. 26 (1981) 1151.
2. "The (p,π) Reaction at 800 MeV", H. Nann, Workshop on Pion Production and Absorption in Nuclei, Bloomington, Oct. 23, 1981. AIP Conference Proceedings 79 (1981) 219-238.
3. "Pion Double Charge Exchange and Pion Nucleus Interaction", Kamal K. Seth, 1982 Congress-Canadian Association of Physicsts, Kingston, June 23, 1982. Bull. Canad. Assoc. of Phys. 38 (1982) 33.
4. "Nuclear Physics with 4 GeV Protons", Kamal K. Seth, LAMPF-II Workshop, Los Alamos, Feb. 1, 1982.
5. "Some Possibilities for Nuclear Physics at LAMPF-II", Kamal K. Seth, LAMPF-II Workshop Los Alamos, July 19-21, 1982.
6. "Pion Production and Dibaryon Resonances", A. Saha, American Chemical Society, Symposium on Pion Induced Nuclear Reactions an Pion Production with Light Ions. Kansas City, September 13, 1982.

III. PAPERS SUBMITTED AT CONFERENCES AND MEETINGS*

1. "Precision Studies of the $\bar{p} + p \rightarrow d + \pi^+$ Channel as Probe of Dibaryon Resonances", A. Saha, D. Kielczewska, S. Iversen, M. Kaletka, D. Barlow, M. Bosko, D. Smith and K.K. Seth, Bull. Amer. Phys. Soc. 26 (1981) 1149.
2. "Evidence for Δ - Δ Components in the Deuteron", Conference on Spin Excitations in Nuclei, Telluride, March 1982.
3. "Back Angle Anomaly in Pion Production in the Reaction $\bar{p} + d \rightarrow \pi^+ + t$ at Energies Between 600 MeV and 800 MeV", D. Kielczewska, A. Saha, M. Kaletka, D. Barlow and Kamal K. Seth, Bull. Amer. Phys. Soc. 27 (1982) 552.
4. "Dibaryon Rotational Band - a Test of MacGregor's Conjecture", Kamal K. Seth, D. Kielczewska, A. Saha, M. Kaletka and D. Barlow, Bull. Amer. Phys. Soc. 27 (1982) 552.
5. "Measurement of the Relative Sign of Neutron (M_0) and Proton (M_p) Transition Matrix Elements in the 2_2^+ State in ^{30}Si ", A. Saha, K.K. Seth, D. Barlow, H. Nann and W.W. Jacobs, Bull. Amer. Phys. Soc. 27 (1982) 559.
6. "Pion Production and Dibaryon Resonances", A. Saha, D. Kielczewska, D. Barlow, M. Kaletka, Kamal K. Seth, Symposium on Pion Induced Nuclear Reactions and Pion Production with Light Ions, Kansas City Meeting, American Chemical Society.
7. " $\pi^\pm$ -Elastic Scattering from Deuterons and Helium Isotopes below 70 MeV" B. Balestri, P.Y. Bertin, B. Coupat, G. Fournier, A. Gerard, E.W.A. Lingeman, J. Miller, J. Morgenstern, J. Picard, B. Saghai, K.K. Seth, and P. Vernin, International Summer School in Nuclear-Structure at Dronten, Netherlands, 16-28 August 1982.

* For copies see Appendix B.

IV. COLLOQUIA, SEMINARS

(Kamal K. Seth)

- December 10, 1981: University of Mainz (Germany)
"New Insights into Pion Nucleus
Interactions from Pion Double Charge Exchange"
- December 11, 1981: Max-Planck Institute fur Kernphysik,
Heidelberg (Germany)
"Pion Production in Elementary Collisions"
- December 14, 1981: National Instituut voor Kernfysics,
Amsterdam (Holland)
"Exotic Nuclei and Pion Double Charge Exchange"
- December 16, 1981: Centre de Recherche Nucleaires, Strasbourg
(France)
"Exotic Nuclei and Pion Double Charge Exchange"
- December 18, 1981: C.E.N de Saclay, Paris (France)
"Experimental Evidence for Dibaryons"
- February 18, 1981: SUNY at Stony Brook (N.Y.)
"Experimental Evidence for Deformation of the
Nucleon"
- March 4, 1982: Duke University, Durham (N.C.)
New Insights into Pion Nucleus Interactions
from Pion Double Charge Exchange"

5. SEMINARS AT NORTHWESTERN

DATE	NAME	TITLE
January	22 R. Segel	"M1 Transitions and Δ -hole pairs in Nuclei"
	29 K.K. Seth	"Pionic Probes for Exotic Nuclei"
February	5 P. Zupranski	"Experiments with Vector and Tensor Polarized ^7Li "
	12 A. Saha	"Measurement of Isovector Properties in Nuclei"
	26 T. S-H Lee	"Nuclear Structure Studies with Pions"
March	5 D. Kielczewska	"Experimental Search for Dibaryon Resonances"
	19 R. Holt	"Pion deuteron scattering, absorption, d-states dibaryons and all that!"
April	9 R. Segel	"Inclusive Proton Reactions"
	16 W. Weise	"Chiral Symmetry and Quark bags with surface"
	23 (Seth, Saha Kielczewska)	Washington APS: preview

6. PROPOSALS SUBMITTED

- LAMPF #671 (EPICS): "Test of the Microscopic IBA Model via Pion-Nucleus Scattering on Palladium Isotopes"
Requested: 260 hours
Approved: 280 hours
- *LAMPF #716 (EPICS): "Pion Double Charge Exchange on Heavy Nuclei"
Requested: 300 hours
Approved: 150 hours
- *LAMPF *758 (HRS): "To Catch a Demon..."
Requested: 100 hours
Approved: 100 hours
- LAMPF #759 (EPICS): "Isospin Mixing in ^4He "
Requested: 75 hours
Rejected
- *IKO #007: "A Study of the Nuclear Structure of ^{26}Mg by Inelastic Electron Scattering"
Requested: Phase I - 80 hours, Phase II - 160 hours
Approved: Phase I - 80 hours, Phase II - resubmit
- *SAC #139: "Are Nucleons and Deltas Deformed?"
Requested: True for Exploratory studies
Approved: to be scheduled in 1983

* For copies of new proposals see Appendix C