NUCLEAR PHYSICS STUDIES WITH MEDIUM ENERGY PROBES

Contract Period: 1989-92
Progress Report, Aug. 1989 - Aug. 1990
Budget, Dec. 1, 1990 - Nov. 30, 1990

Principal Investigator:
Kamal K. Seth

submitted to the
UNITED STATES DEPARTMENT OF ENERGY

NORTHWESTERN UNIVERSITY

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

CONTENTS

I. INTRODUCTION	3
II. RESEARCH PROGRAMS	4
III. DATA ANALYSIS AND COMPUTERS	13
IV. PERSONNEL	14
V. PUBLICATIONS	15
VI. INVITED PAPERS	16
VII. CONTRIBUTED PAPERS	16
VIII. OTHER ACTIVITIES	17
IX. BUDGET FOR 1990-91	18

(Preprints removed and cycled separately)

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

I. INTRODUCTION

This progress report refers to the period August 1989 to August 1990 which includes the first year of the three year period December 1, 1990 - November 30, 1992 of our existing research contract. The budget proposal for the year 1990-1991, as originally approved, is also presented.

During the last year the major achievement of our research program was the successful start-up of our Fermilab experiment E760 on antiproton production of charmonium and the study of $p\bar{p}$ scattering between 4 and 9 GeV/c. A report on the progress of this experiment, which will continue into the next two years, is presented. Progress report of our research programs at LAMPF, Bates and NIKHEF, and plans for the development and continuation of these programs, are also presented.

II. RESEARCH PROGRAMS

II.A THE QUARK-QUARK INTERACTION - Fermilab Experiment E760

The understanding of the quark-quark and quark-antiquark interaction is the most fundamental and the most important problem in strong interaction physics. Until the time when lattice-gauge calculations are able to provide some insight into the problem, phenomenological potential models must lead. Fortunately, according to QCD, the quark-quark interaction is flavor-independent. In principle, it can be studied equally well between systems of any two quarks (or antiquarks). Unfortunately, relativistic corrections make the study of $q\bar{q}$ interactions between the light 'up', 'down' and 'strange' quarks very difficult. One must go to at least the charmed quarks to obtain meaningful answers. It is the objective of the Fermilab E760 experiment to make precision measurements of the energies, widths, branching ratios and other observables related to the wave functions of the charmonium ($c\bar{c}$) states in order to obtain an understanding of the $q\bar{q}$ interaction.

In order to meet its objectives, in the E760 experiment the charmonium states are populated directly by the annihilation of protons and antiprotons. This makes all the states with $J^\pi = 0^\pm, 1^\pm, 2^\pm$, and 3^- accessible, in contrast to the e^+e^- experiments in which only $J = 1^-$ states are directly produced. This makes E760 absolutely unique in its capabilities and it has been hailed as inaugurating "a new era in charmonium physics" (Jaffe[1]).

Since in the E760 experiment charmonium states are produced in $p\bar{p}$ collisions, it offers a rare opportunity to study forward angle $p\bar{p}$ scattering in the 3 GeV/c $\rightarrow$ 9 GeV/c region at the same time as the charmonium measurements. Such measurements are extremely important if the nucleon-nucleon and the nucleon-antinucleon interactions are to be simultaneously understood at a fundamental (quark-gluon) level.

The E760 experiment is located in the Fermilab antiproton accumulator in the middle of a straight section as marked in Fig. 1. The gas-jet target crossing the stochastically cooled beam and the surrounding detector system are located in a special pit-area constructed for the experiment.

Fig. 1 Schematic lay-out of the antiproton source (the production target, the debuncher ring, and the accumulator ring) at the Fermilab. The location of the E760 experiment is indicated by the large dot on the accumulator ring.

The main detector consists of an annular detector system which covers a nearly 2π solid angle around the beam/gas-jet intersection point. Its components are shown schematically in Fig. 2. In brief, the various components of the system (and the main collaboration group responsible for each) are as follows:

1. Scintillation Counters: Thin scintillation counters H1 and H2 provide fast triggers in conjunction with the gas threshold Cerenkov counter. (*University of Torino*)
2. Cerenkov Counter: This is a very light-walled threshold Cerenkov counter divided azimuthally into 8 identical segments. Each segment has two separate chambers with two different gases, CO_2 in the forward chamber and Freon 13 in the back chamber. (*University of Torino*)
3. Central Calorimeter: This is the most important part of the detector system. It consists of 64 identical wedges, each consisting of 20 lead-glass blocks, forming a cylindrical barrel which covers 10° to 70° in θ , and 360° in ϕ . The angle $\Delta\theta$ subtended at the interaction point by an individual lead block (16.4 to 12.5 radiation lengths) varies from $\sim 1^\circ$ in the forward direction to $\sim 5^\circ$ in the most backward direction. The rather fine grained segmentation of this detector and the pointed geometry is meant to provide accurate determination of the centroids of the electromagnetic showers. This ability, coupled with the ability to detect γ -rays down to $\sim 30\text{MeV}$ energy, enables a high level of rejection of the background γ 's from π^0 decays. (*Fermilab, Northwestern University, University of California (Irvine)*)
4. Forward Calorimeter: The angular region, $\theta = 2^\circ - 10^\circ$, not covered by the central calorimeter, is covered by this counter. It consists of a 12×12 array of scintillation-glass and lead sandwich counters, each $10\text{ cm} \times 10\text{ cm} \times 48\text{ cm}$ deep. (*Penn. State University*)
5. Charged-Particle Counters: The purpose of these counters is to provide accurate tracking of charged particles. This is done at three different levels inside the volume of the central calorimeter. Nearest to the beam pipe are two rings of straw drift-tube detectors. Farthest away are two layers of larocci-tube detectors. In between is the so-called inner tracking detector which consists of a radial projection chamber surrounded by a multiwire proportional counter. Finally, there is an annular forward tracking chamber, consisting of three layers of multiwire proportional counters which provide

Fig. 2 Schematic representation of the E760 detector system.

charged particle tracking in the $\theta = 10^\circ$ to 19° region. (*University of Genoa, University of Ferrara*)

6. Luminosity Monitor: This consists of a telescopic assembly in which protons recoiling at $\theta = 80^\circ$ to 90° are detected in eight solid-state detectors. Of these eight detectors, two fixed detectors (500μ each) constitute the luminosity monitor. The other six detectors (500μ , 3000μ), which are mounted on a movable carriage, are used for the small - t elastic scattering measurements. (*Northwestern University*)

All items of the detector except the lead-glass central calorimeter were tested in a 1-1/2 month run in Feb.-March 1990. The central calorimeter was completed at the end of May 1990 and the entire system put in the beam on June 4. We have been running the experiment with antiprotons continuously since then. The present run is scheduled to end on Aug. 28. The next three-four month run is expected to start near the end of November, 1990.

As noted above, our group had the responsibility for the assembly and testing of the lead-glass central calorimeter. This responsibility was shared with colleagues from University of California (Irvine) and Fermilab. Our students, Steve Trokenheim and Camille Ginsburg were responsible for designing the equipment and testing the spectral sensitivity of each of the 1280 lead glass blocks. They also participated in the assembly of the lead glass blocks into 64 wedges, light leak testing and calibration. The project was successfully completed (with only one poorly performing tube out of 1280 at the end of the assembly).

Since $p\bar{p}$ forward angle scattering measurements were the special interest of our group we became 100%-responsible for the design, construction, testing and operation of the luminosity monitor. As described before, the luminosity monitor consists of an array of solid state detectors which 'look' at recoil protons at angles between 82° and 90° . The detectors (each 1 cm x 5 cm x 500μ - 3000μ) are located in a pan at ~ 1.5 meters from the interaction point. The system comprises of two fixed detectors at 3.5° and 4.5° and six detectors located at $\sim 1^\circ$ intervals on a movable carriage (see Fig. 3). The pan is open to the vacuum of the accelerator ($\sim 10^{-10}$ torr). With the gas-jet on, the ambient pressure at the detectors is usually $\sim 10^{-8}$ torr. A remotely insertable ^{244}Cm sources is mounted at ~ 1 meter from

Fig. 3 A photograph of the Luminosity Monitor pan showing the two fixed detectors (left) and the movable carriage containing up to eight detectors (right). The high voltage and signal feed-thrus are mounted on the two flanges on the lower right hand side. The other fixtures are for the motion of the carriage and its position measurement.

the detectors. It is used to monitor the performance of the detectors at regular intervals.

In the initial tests some deterioration of the solid state detectors was observed in the high vacuum and radiation conditions prevailing in the luminosity monitor. Fortunately, only some detectors were affected. These were replaced. Since then no significant loss in performance has been observed for the eight detectors which have been in continuous use for about three months. Typical spectra from two detectors are shown in Fig. 4.

II.A1 $p\bar{p}$ FORWARD SCATTERING

As mentioned earlier, the movable detectors in the luminosity monitor have been installed for the express purpose of measuring small t behavior of $p\bar{p}$ elastic scattering in the $T(\bar{p}) = 3 - 8$ GeV region. The present run has enabled us to take substantial amount of data at 3.23 GeV (J/ψ), 4.64 GeV (χ_1), 4.86 GeV (χ_2) and 5.36 GeV (ψ'). On-line analysis of these data has already given results which are much superior to those in the published literature and have also revealed certain problems. The most vexing problem concerns the large amount of low energy noise (< 1 MeV), as already seen in the bottom part of Fig. 4. This limits the smallest angle at which we can resolve the recoil peak with precision to $\sim 1.5^\circ$ or $t \approx 1.5 \times 10^{-3} (\text{GeV}/c)^2$. This falls somewhat short of the t -value for maximum Coulomb-nuclear interference, $t \approx 1.1 \times 10^{-3} (\text{GeV}/c)^2$ and therefore introduces additional uncertainties in analysis. Nevertheless, even our preliminary results are considerably better than the best available in the literature. For example, at 5.72 GeV/c (χ_2) from the measurements shown in Fig. 5 we get:

$$\sigma_T = 62.06(25)\text{mb} \quad b = 13.48(33) \quad , \quad \rho = 0.032(13)$$

The best previous work in this vicinity is due to Jenni et al.[2] at 6.00 GeV/c. They obtained:

$$\sigma_T = 61.30(60)\text{mb} \quad b = 13.50(90) \quad , \quad \rho = +0.040(60)$$

Our errors are almost uniformly a factor three smaller. We expect that we will similarly obtain results of high quality at other energies between 3 GeV and 8 GeV. This should help clear up the controversies about the low energy behavior of ρ , the ratio of the real part of the forward scattering amplitude to the imaginary part.

II.A2 CHARMONIUM SPECTROSCOPY

As stated earlier, the full detector became operational in early June and we have been

Fig. 4 Typical spectra for the solid state detectors. Notice that while the detector at 3.250° (top) has very little background, the detector at 1.625° (bottom) has an appreciable background contribution. The width and the shape of the recoil proton peak is determined entirely by the size and shape of the intersection volume of the antiproton beam and the hydrogen gas-jet target.

Fig. 5 Preliminary results for $p\bar{p}$ small- t elastic scattering at 5.725 GeV/c. The gap in the data in the region $t = 0.01 - 0.02$ is due to the malfunction of one detector.

testing, calibrating and studying various trigger schemes since. In the three months running we have verified that the design goals of the experiment are fully achievable.

In normal operation we can stack antiprotons at the rate of $\sim 1 - 1.5$ ma/hr. A day's filling of the accumulator yields 20-25 mA of 9 GeV/c circulating beam. This is decelerated to the required momentum in 2-4 hours. With the typical operation of the gas-jet a luminosity of $0.5 - 0.7 \times 10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$ is obtained and the beam lifetime ($1/e$) is about 40 hours.

The ideal place to test and calibrate the system is obviously the J/ψ (3097). A typical scan across the J/ψ ($\Gamma = 68 \text{ keV}$) is shown in Fig. 6. The measured full width at half maximum is 400 keV. This is more than a factor two better than the best achieved in any experiment (including the best of e^+e^-) so far. The absolute energy calibration, based on the orbit length and circulation frequency measurements was found to be within 140 keV (corresponding to orbit length error of 1mm out of a circumference of 475 m) of that corresponding to the known J/ψ mass. The orbit length was calibrated at this point and used for all other energy measurements. It was found that the energy repeatability was better than $\pm 50 \text{ keV}$.

In Fig. 7 we show the results of the ψ' (3686) scan. The measured peak width leads to $\Gamma(\psi') = 236 \pm 60 \text{ keV}$, which is in agreement with the known width of $243 \pm 43 \text{ keV}$.

In Figs. 8 and 9 we present the χ_1 (3510) and the χ_2 (3555) scans. In these two cases we already have new results. These very preliminary results illustrate the capabilities of E760 rather dramatically. The improvement in absolute energies is about a factor of five and the determination of the widths is all new.

<u>Particle</u>	<u>1990 Particle Data Book</u>		<u>E760 - Preliminary</u>	
	Mass(MeV)	Width(MeV)	Mass(MeV)	Width(MeV)
$\chi_1 (1^{++})$	3610.60(50)	<1.3	3510.42(10)	0.84(10)
$\chi_2 (2^{++})$	3556.30(40)	2.6 ± 1.2	3556.00(10)	1.80(15)

We have not yet had time to digest even a fraction of the data already taken. However, it is already clear that we are indeed poised to inaugurate "the new era in charmonium

Fig. 6 A typical excitation function for the J/ψ (3097 MeV) resonance. The measured FWHM ≈ 400 keV is due to the experimental energy resolution.

Fig 7 A typical excitation function for the ψ' (3686 MeV) resonance.

Fig. 8 A typical excitation function measurement for the x_1 (3510 MeV) resonance. The open circles represent data uncorrected for beam momentum spread. The triangles represent the corresponding theoretical values when a Breit-Wigner resonance, with the parameters given in the inset, is corrected for beam momentum spread.

Fig. 9 A typical excitation function measurement for the x_2 (3555 MeV) resonance. The open circles represent data uncorrected for beam momentum spread. The triangles represent the corresponding theoretical values when a Breit-Wigner resonance, with the parameters given in the inset, is corrected for beam momentum spread.

spectroscopy". We intend to go after the difficult 1P_1 and η_c, η_c' searches in the next 3-4 month run scheduled to start in Nov. - Dec. 1990.

II.B. EXPERIMENTS WITH QCD OVERTONES

II.B1 EXOTIC BARYONIC SYSTEMS

In this proposed experiment, which is ideally suited for existing heavy-ion beams at the SPS at CERN, we wish to study the stability of single- and double-lambda hypernuclei, sigma hypernuclei, cascade hypernuclei and even omega minus-neutron systems. The proposal is still under development. We are at present exploring the possibility of a joint project between GSI, Heidelberg and Northwestern. If we are successful in forming this collaboration a formal proposal will be submitted to CERN this year.

II.B2 DEFORMATION OF NUCLEONS AND ISOBARS

We submitted our revised proposal NE 6 to measure the longitudinal component in the electroexcitation of the delta to the NPAS Program Advisory Committee in February 1990. Unfortunately, because of serious limitations on available beam time at SLAC the committee approved only one proposal. We were among the five unsuccessful ones.

We believe that there is little, if any, probability of getting beam-time for this proposal at SLAC. We plan to modify the proposal for submission at CEBAF during the coming year.

II.B3 BOUND STATES OF REAL PIONS

The possibility of bound states of real pions and nucleons has been discussed and debated for a long time. In particular, it was predicted[3] that the $T = 2$ state of a pion and two nucleons is bound. Earlier experiments at LAMPF had suggested that indeed the π^-nn and π^+pp $T = 2$ states exist with production cross sections of ~ 15 nb/sr in pion DCX experiments.[4] In our experiment, LAMPF 981 we were successful in showing that there is no evidence for the existence of the π^-nn $T = 2$ state even at the level of ~ 1 nb/sr. The paper reporting these results was published in Phys. Rev. Letters.[5]

II.B4 DIBARYONS

Over the last several years we have had an extensive program of searching for dibaryons.

We have recently completed the final analysis of our high resolution, high statistics study of the $\vec{p} + d \rightarrow p' + X$ reaction at $T(\vec{p}) = 800$ MeV (LAMPF 851) and shown that there is no evidence for the existence of any dibaryons in the mass range 1875-2200 MeV. The results were presented at the PANIC XII Conference [6]. A paper describing our results (see Fig. 10) is being readied for submission to the Physical Review Letters.

II.C. NUCLEAR STRUCTURE EXPERIMENTS

II.C1 PION DOUBLE CHARGE EXCHANGE

Our program of pion double charge exchange experiments at LAMPF continues to be as active as ever. Among the recent activities of the program are the following.

- a. We have finished the final analysis of our angular distribution measurements for the $^{42}\text{Ca}(\pi^+, \pi^-)^{42}\text{Ti}$ reaction at 50 MeV (LAMPF 1068). The results are summarized in Fig. 11. A paper describing these results is in preparation.
- b. It is well known that the DCX cross sections for the reaction $^{48}\text{Ca}(\pi^+, \pi^-)^{48}\text{Ti}$ (analog) at 50 MeV are quenched. A previous experiment[7] established an upper limit of 4 $\mu\text{b/sr}$ for the $\theta = 40^\circ$ production cross section for this transition. In a two week run of our experiment LAMPF 1112 during June - July 1990 we attempted to determine just how strong the quenching is. On-line analysis of the data yields $\sigma(40^\circ) \leq 0.4 \mu\text{b/sr}$, i.e., more than an order of magnitude lower than previously estimated. It is expected that the results of this experiment will have a strong impact on the theoretical models for this quenching and its relation to two-body correlations in ^{48}Ca .
- c. Auerbach et al.[8] have recently proposed that the effect of two-body correlations enters the DCX reactions in a very simply way. For nuclei which have low-lying states of good seniority zero, the predictions become extremely simple and transparent. The model was developed to explain certain observations in nuclei of the $1f_{7/2}$ shell and has not been tested for any other nuclei. Our proposal to (LAMPF 1198) to test this model of DCX reactions with nickel isotopes has been approved. We hope that it will be scheduled for running in the coming year.

Fig.10.(Top) Measured Double differential cross sections for the reaction $\bar{p} + d \rightarrow p + X^+$ at $T_p = 798$ MeV and $\theta(\text{lab}) = 15.1^\circ$. The statistical errors ($\sim \pm 1\% \rightarrow 2\%$ per 0.4 MeV bin) are smaller than the size of the points. (Bottom) Details of data and polynomial fits to $\sigma(\theta)$ (0.4 MeV bins) and $A_{\nu 0}(\theta)$ (1.0 MeV bins) in three selected regions of missing mass. The positions of 'claimed' dibaryons are marked by vertical lines in each panel.

Fig. 11 LAMPF 1068 results for pion DCX and elastic scattering from ^{42}Ca at $T(\pi^+) = 50 \text{ MeV}$. The theoretical curves are preliminary.

II.C2 EXOTIC NUCLEI

Our studies of the light exotic nuclei by means of pion double charge exchange reactions continue to be very fruitful.

- a. In our study of the ${}^6\text{Li}(\pi^-, \pi^+)X$ reaction at 220 MeV ($\theta = 30^\circ$) we have been able to show that there is no evidence for the formation of ${}^6\text{H}$ at the level of $d\sigma/d\Omega \leq 2$ nb/sr. This is in direct contradiction to the claims made by two Soviet groups using heavy-ion reactions.[9] A paper describing our results has been submitted to the Physics Letters.[10]
- b. We have submitted a proposal to the National Superconducting Cyclotron Laboratory to repeat the Soviet heavy-ion experiment, ${}^7\text{Li} + {}^7\text{Li} \rightarrow {}^8\text{B} + X$ to verify the Soviet claim for ${}^6\text{H}$. The proposal[11] will be heard at the next meeting of the PAC.
- c. In our study of the continuum spectra associated with (π^-, π^+) and (π^-, p) reactions leading to extremely neutron-rich systems we have found dramatic evidence for the existence of 'dinuetrons' as a composite system. We describe these exciting new results in a submission to the Physical Review Letters.[12] We are also preparing a proposal for further experimental studies bearing on this very provocative idea.

II.C3 HIGH RESOLUTION ELECTRON SCATTERING

Some of the results of our experiments at NIKHEF on high resolution electron scattering from ${}^{26}\text{Mg}$ were described in our last progress report. The analysis of the data has now been completed for 75 states up to an excitation of 9 MeV. Form-factors and model independent transition densities have been obtained for all the transitions. The results constitute a remarkable confirmation of the s-d shell model calculations of Brown and Wildenthal.[13] The preliminary results were presented at the PANIC XII conference. Two papers describing the detailed results are under preparation.

II.C4 DEEP INELASTIC ELECTRON SCATTERING

In this Bates experiment data was taken at energies between 400 and 850 MeV on targets of ${}^{40}\text{Ca}$, ${}^{48}\text{Ca}$ and ${}^{238}\text{U}$. Analysis of the data is in progress, mainly at Bates, under the supervision of Dr. C. Williamson.

REFERENCES

1. R.L. Jaffe, *Proc. 1st Workshop on Antimatter Physics at Low Energies*, Fermilab, 1986, edited by B.E. Bonner and L.S. Pinsky, 1986.
2. P. Jenni *et al.*, Nucl. Phys. B129 (1977) 232.
3. H. Garcilazo, *Phys. Rev. C* 26 (1982) 2685, *ibid.*, C34 (1986) 1425.
4. D. Ashery *et al.*, *Phys. Lett. B* 215 (1988) 41.
5. B. Parker, Kamal K. Seth, C.M. Ginsburg, B. O'Reilly, M. Sarmiento, R. Soundranayagam, and S. Trokenheim, *Phys. Rev. Lett.* 63 (1989) 1570.
6. Kamal K. Seth, B. Parker, C.M. Ginsburg, and R. Soundranayagam, *PANIC XII* (1990), abstr. XVI-13.
7. H.W. Baer *et al.*, *Phys. Rev. C* 35 (1987) 1425.
8. N. Auerbauch *et al.*, *Phys. Rev. Lett.* 59 (1987) 1076; *Phys. Rev. C* 38 (1988) 1277.
9. D.V. Aleksandrov *et al.* *Sov. J. Nucl. Phys.* 39 (1984) 323; A.V. Belozyorev *et al.*, *Nucl. Phys. A* 460 (1986) 352.
10. B. Parker, Kamal K. Seth, and R. Soundranayagam, *Phys. Lett.* (submitted).
11. "Does ^6He Really Exist", a proposal submitted to the National Superconducting Cyclotron Laboratory, *spokesman*: Kamal K. Seth.
12. Kamal K. Seth and B. Parker, *Phys. Rev. Lett.* (submitted).
13. B.A. Brown, R. Radhi, and B.H. Wildenthal, *Phys. Rep.* 101 (1983) 313; also priv. comm. (1990).

III. DATA ANALYSIS AND COMPUTERS

Our VAX-750 computer system is essentially obsolete now. Repair parts are not easily available and cost exorbitantly. The maintenance contracts cost approximately \$10,000/yr. We have therefore begun a progressive phase-out of this system. As a first step we have acquired a Vaxstation 3520 system with a Wren disc drive. During the coming year we propose to acquire a tape controller and another disc for the 3520 and remove the 750 mainframe and the RA81 disc system from the maintenance contract. We hope that LAMPF will soon standardize in favor of the 8 mm tape system, as FERMILAB already has. We will then remove all the remaining components of the 750 system from maintenance and dispose of it. The much cheaper Vaxstation 3520 is approximately six times faster than the old VAX-750.

IV. PERSONNEL
(August 1989 - August 1990)

Kamal K. Seth
Principal Investigator

Brett L. Parker
Rayappu Soundranayagam
Miguel Sarimento
Research Associates

Steve W. Trokenhiem
Camille M. Ginsburg
Atul K. Mody
Graduate Students

V. PUBLICATIONS

(August 1989 - August 1990)

1. "Neutron-Rich Exotic Nuclei" in section on Nuclear Physics in *McGraw-Hill Encyclopedia of Science and Technology*, edited by D. Bromley (McGraw-Hill Publishers), in press.
2. "Search for a $T=2$ Dibaryon." B. Parker, Kamal K. Seth, C.M. Ginsburg, B. O'Reilly, M. Sarmiento, R. Soundranayagam, and S. Trokenheim, *Phys. Rev. Lett.* 63 (1989) 1570.
3. "Negative Pion - Nucleus Elastic Scattering at 30 and 50 MeV." Kamal K. Seth, et al., *Phys. Rev. C* 41 (1990) 2800.
4. "Nuclear Structure Studies with Electrons." Kamal K. Seth, *Proc. Int. Symp. on Weak and Electromagnetic Interaction in Nuclei - WEIN 89*, edited by P. Depommier (Editions Frontiers, Gif-sur-Yvette, France, 1989) pp. 425-461.
5. "DCX and Neutron-rich Nuclei." Kamal K. Seth, *Proc. Second LAMPF Inte. Workshop on Pion Double Couple Charge Exchange*, Los Alamos 1989, edited by W. Gibbs (World Scientific, Singapore), in press.
6. "High Resolution Charmonium Spectroscopy with an Internal Gas-Jet Target", *Proc. Topical Conf. on Electronuclear Phys. with Internal Targets*, Stanford 1989, edited by R.G. Arnold (World Scientific, Singapore, 1990) pp. 211-228.
7. "Search for Superheavy Hydrogen-6", B. Parker, Kamal K. Seth, and R. Soundranayagan, *Phys. Lett.* (submitted). *accepted*
8. "Dineutrons in Extremely Neutron Rich Nuclei", Kamal K. Seth and B. Parker, *Phys. Rev. Lett.* (submitted).

VI. INVITED PAPERS

1. "Inelastic Electron Scattering from ^{26}Mg ," R. Soundranayagam, Kamal K. Seth, A. Saha, C.W. de Jager, H. de Vries, H. Blok, G. van der Steenhoven, B.A. Brown, and B.H. Wildenthal, 1989. *Int. Nucl. Phys. Conference*, Sao Paulo (Brazil), 1989.
2. "Study of Light Nuclei by Pionic Reactions," Kamal K. Seth, Invited Paper, *Int. School - Seminar on Heavy Ion Physics*, Dubna, (U.S.S.R.) 1989.
3. "Do the Neutron Rich Nuclei have a Halo". Invited Paper, Seventh International School of Intermediate Energy Nuclear Physics, L'Aquila (Italy), 1990.

VII. CONTRIBUTED PAPERS

1. "M3 Quenching in Magnesium-26," Kamal K. Seth, et al. 1989 *Int. Nucl. Phys. Conf.*, Sao Paulo (Brazil).
2. "M3 Quenching in Magnesium 26", K.K. Seth et al., PANIC XII (1990), abstr. I-54.
3. "Electron Scattering from ^{26}Mg : How Good is the s-d Shell Model", R. Soundranayagam, et al., PANIC XII (1990), abstr. I-55.
4. "A High Resolution Search for $T = 0$ and $T = 1$ Dibaryons", K.K. Seth et al., PANIC XII (1990), abstr. XVI-13.

VIII. OTHER ACTIVITIES (Kamal K. Seth)

- Convenor, Antiproton Physics Section, KACN Factory Workshop, TRIUMF (Canada) July, 1990.
- Invited Speaker, Rheinfels Workshop 1990 on 'Hadron Mass Spectrum', St. Goar on the Rhine, Sept., 1990
- Invited Speaker, 8th Int. Conf. on Atomic Masses and Fundamental Constants, Jerusalem (Israel), Sept., 1990.
- Invited Speaker, 10th Int. Seminar on High Energy Physics Problems, Relativistic Nuclear Physics and Quantum Chromodynamics, Dubna (U.S.S.R.), Sept., 1990. (REFUSED)
- Invited Speaker, Workshop on Antiproton Physics--Annual Meeting of the Nuclear Physics Division, Urbana-Champaign, Oct., 1990.
- Invited to write review on "LIBARYONS" for *Reviews of Modern Physics* (AIP).
- Invited to write review on "PION PHYSICS" for *Progress in Nuclear and Particle Physics* (Pergamon Press).

IX. BUDGET (1990-91)

We reproduce below the budget for the contract period December 1, 1990 - November 30, 1991, as approved in our three year (1989-1992) renewal last year. No changes are projected.

NORTHWESTERN UNIVERSITY
Contract No. DE AC02-76ER02706
December 1, 1990 - November 30, 1991

A-II(a) REIMBURSABLE COST-SHARING PORTION

		Cumulative Totals
1. <u>Salaries and Wages</u>		
(a) Principal Investigator:		
Kamal K. Seth, Professor	\$17,000	\$ 17,000
2 summer months - 100% time		
(b) Research Associates (3, each 12 months):	78,000	95,000
(c) Research Assistants (3, each 12 months):	28,000	123,000
(d) Two Work-Study Students	1,370	124,370
2. <u>Employee Benefits:</u> 18.5% of salaries and wages	23,008	147,378
3. <u>Supplies and Materials:</u> Targets, computer and electronic supplies, miscellaneous supplies.	9,472	156,850
4. <u>Publications and Communications</u>	3,000	159,850
5. <u>Travel</u>		
(a) <u>Domestic:</u> Expenses for travel to national laboratories to do experiment, national meeting sand conferences. Negotiated per diem for technical personnel.	20,000	179,850
(b) <u>Foreign:</u> Travel to NIKHEF, CERN, and other foreign laboratories for collaborative expts. Participation in international conferences.	10,000	189,850

6. <u>Other:</u>		
Computer maintenance contracts	7,000	196,850
7. <u>Equipment*</u> : Detectors, and electronic components	10,000	206,850
8. <u>Total Direct Costs</u>		
9. <u>Indirect Costs:</u> Off campus rate, 27% of \$188,976	53,150	260,000
10. <u>Total Project Costs</u>		260,000
11. <u>Sponsor Cost</u>		260,000

* Northwestern University hereby certifies that the equipment requested for purchase is not reasonably available within our Institution.

A-II(b) ITEMS EXCLUDED FROM COST SHARING TO BE FURNISHED BY
UNIVERSITY: None

A-II(c) UNIVERSITY CONTRIBUTION OF PRINCIPAL INVESTIGATOR, Kamal
K. Seth, 5% time for 9 months during academic year.

-END-

DATE FILMED

11 / 28 / 90