**STRONG INTERACTIONS STUDIES WITH
MEDIUM ENERGY PROBES**

**PROGRESS REPORT
1993-1994**

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I. INTRODUCTION

This progress report refers to the period August 1993 to September 1994, which includes the second year of the three year period December 1, 1992 - November 30, 1995 of our existing research contract. The budget proposal for the third year, December 1, 1994 to November 30, 1995, as originally approved, is also presented.

As anticipated in our 1992-95 proposal, Fermilab E760/E835 on high precision charmonium spectroscopy has remained a major part of our preoccupation and commitment during the last year, and it will remain so in the forthcoming year. In early 1994 we joined the collaboration of the Brookhaven experiment E852 on the spectroscopy of states with exotic quantum numbers. The first successful three month run of E852 was completed on July 31 and preliminary data analysis has been started. Some new commitments have resulted from this collaboration and a separate proposal for supplemental financial support is being prepared for them. At Los Alamos our experiment #1274 on search of extremely neutron rich exotic nuclei by pion absorption (a joint experiment with physicists from Moscow Engineering Physics Institute) began making initial measurements a month ago and is expected to take data during the period October 15-November 30, 1994.

In addition to the above on-going programs, our Bates proposal (94-01) for a definitive measurement of the quenching of the longitudinal response in quasi-free scattering of electrons from nuclei has been approved with high priority for 600 hours of beam time, and we expect to start the experiment in late 1995.

The year 1993-1994 has been very productive in the dissemination of the results of our research. Several papers have been published and several invited presentations have been at international conferences.

II. RESEARCH PROGRAMS

In the following we describe the progress made in our various research programs during the year 1993-94, and our plans for the three year 1994-95.

II.A. THE QCD-RELATED PROGRAM

This part of our program used to be exclusively based on our Fermilab experiment E760 which did not receive beam time in 1993-94. In 1994 we added a strong new component to this program. We joined the collaboration of Brookhaven experiment E852, which received its first beam during the three month period May, June and July 1994. Progress and plans for both these programs are described below.

II.A.1. CHARMONIUM SPECTROSCOPY

Phase I of this project, under the designation E760, received beam time in 1990 and 1991. The period 1992-93 was devoted to extensive data analysis, and a large number of papers describing the results from E760 were published[1-9]. In 1993 phase II of this project was started as Fermilab experiment E835. It was approved for 15-18 months of beam time during the period 1995-96. An extensive program of source and detector improvements was undertaken and we describe them briefly.

Antiproton source:

During the operation of E760 stacked beam intensity was ≤ 40 mA and σ_p/p was typically 2×10^{-4} . Because of the new LINAC and improvements in the $\bar{p}$ source, during E835 operation stacked beam intensity of as much as 120 mA is expected at $\sigma_p/p \leq 3 \times 10^{-4}$.

Gas-jet Target:

The hydrogen gas jet target used in E760 operated at liquid nitrogen temperature (77°K). In order to obtain increased gas jet density a new target, which can operate in

20°K–30°K region, has been designed. It is expected that a density increase of a factor 2-3 will be achieved at these lower temperatures. This means that together with the factor 2 to 3 increase in the stacked antiproton beam, an overall increase of a factor 6 ± 2 is expected in the instantaneous luminosity. This anticipation has motivated a large number of improvements in the detectors, electronics and the data acquisition system.

Central Calorimeter

The lead-glass calorimeter essentially remains unchanged. However improvements in electronics are being investigated to allow the operation of the calorimeter with lower energy thresholds. This should enable us to achieve better S/N in all neutral channels like $\eta_c \rightarrow \gamma\gamma$. Improvements in electronics are also planned to avoid increase pile-up rates which would result from expected with the luminosity increase.

Charged Particle Detectors

Major improvements are planned for charged particle detection. These consist of

- a) A new two layer straw tube drift chamber
- b) A new 24-fold scintillator hodoscope (H2')
- c) A 4,608 pixel silicon strip barrel detector
- d) A 1000 element scintillating fiber barrel detector

Luminosity Monitor

The E760 luminosity monitor, which was built and operated by the Northwestern group, operated flawlessly. In addition to providing luminosity measurements with very small errors, $\pm 0.8\%$ (statistical) and $\pm 2\%$ (systematic), it also provided gas-jet density profile measurements, beam displacement measurements and forward scattering parameter measurements.

An article describing the design and performance of the luminosity monitor has been accepted for publication in NIM[10].

No major changes in the design of the luminosity monitor are planned. It has however been disassembled and is being refurbished to accommodate new cabling and

detectors. Several of the old detectors suffered radiation damage or became otherwise inoperative. These are being replaced.

Electronics and the Data Acquisition System

The factor 5-7 increase expected in instantaneous luminosity has made it necessary to reduce pulse lengths from the central calorimeter (at the ADC, TDC levels) from the present ~ 700 ns to ~ 70 ns by clipping, allowing for a much shorter time gate. Commensurate improvements in the follow-up electronics require the replacement of the present CAMAC based TDC's and latches by new units which permit fast read-out over their ECL ports. Similarly, the existing smart create controllers are being replaced by faster units designed by Fermilab. Event building and data filtering is also being upgraded by using Motorola MVME167 processors and a Silicon Graphic Challenge computer with 4 CPU's (400 MIPS). An overall throughput rate of 5Mb/sec will then become possible. This is judged to be adequate for E835.

The physics objectives of the next run of E835 are:

- a. Identify η'_c and measure its resonance parameters.
- b. Measure the width and other parameters of $h_c(^1P_1)$ discovered by E760.
- c. Measure the total widths of χ_o and η_c
- d. Search for D-states of charmonium

II.A.2 SPECTROSCOPY OF THE QCD EXOTICS

QCD predicts that color neutral objects other than $q\bar{q}$ mesons and qqq baryons should exist. In the mesonic sector these can be hybrids ($q\bar{q}g$), glueballs (gg, ggg) for four quark states ($q\bar{q}q\bar{q}$). These constructs go to the heart of the non-Abelian nature of QCD. It is necessary for our belief in QCD to find them, or to find very good reasons for their non-existence. The E852 experiment at Brookhaven is devoted to the search of these exotic objects which can have very distinctive quantum numbers not allowed for $q\bar{q}$ mesons.

E852 attempts to identify QCD exotics in the interaction of a 18 GeV π^- beam with a liquid hydrogen target. The experiment is designed to be able to look at both charged and neutral final states. In this dual capability E852 is unique. The schematic lay-out of the experiment is shown in Fig. 1. The charged particle detection capability comes from a much improved MPS spectrometer at Brookhaven. Excellent photon detection capability has been added to the MPS in terms of a 3053 element lead glass wall.

The first run with the apparatus in Fig. 1 took place during the three month period, May, June, July 1994. The run was generally successful and data analysis is presently in progress.

The next three month run of E852 is currently scheduled to start in January 1995.

Fig. 1 Schematic of E852 Detector at Brookhaven

II.B. THE NUCLEAR PHYSICS RELATED PROGRAM

II.B1 HIGH RESOLUTION ELECTRON SCATTERING

This project has been completed with the submission of two papers for publication to the Phys. Rev. Letters and the Phys. Rev. C[11,12]. Their first pages are reproduced in Appendix I.

II.B2 QUASI-FREE ELECTRON SCATTERING (Bates 94-01)

Earlier this year we submitted a proposal to make precision measurements of quasi-free scattering of electrons from a series of nuclei in order to settle the long-standing controversy between Bates results and Saclay results about possible quenching of the longitudinal response. The proposal was accepted for 600 hours of beam time and was given a B priority. This gives us a good chance for some beam time during the coming year. Before that, however, considerable amount of work has to be done to improve the BIGBITE spectrometer which is to be used in the experiment.

III.B3 SPECTROSCOPY OF LIGHT EXOTIC NUCLEI (LAMPF 1274)

This experiment, proposed in collaboration with physicists from MEPHI (Moscow Engineering Physics Institute), is currently taking data at the LEP channel at LAMPF. Data taking is expected to last until Nov. 31, 1994, when the beam is shut-off for the year.

In this experiment we detect in coincidence two heavy particles resulting from the absorption of negative pions on light nuclei (^{11}B , ^{14}C). It is hoped to discover very neutron rich nuclei, such as ^6H , ^{10}He and ^{12}Li .

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9. T.A. Armstrong et al., Phys. Lett., B307 (1993) 397.
10. S. Trokenheim et al., Nucl. Instr. Methods (in press)
11. K.K. Seth, et al., submitted to Phys. Rev. Lett.
12. R. Soundranayagam et al., Phys. Rev. C (submitted).

III. DISSEMINATION OF RESEARCH RESULTS

A. PAPERS PUBLISHED

1. "Study of the Angular Distribution of the Reaction $p\bar{p} \rightarrow \chi_2 \rightarrow J/\psi + \gamma \rightarrow e^+e^-\gamma$ ", T. Armstrong et al., Phys. Rev. D48 (1993) 3037.
2. "Longitudinal Response Functions for ^{40}Ca from Quasi-elastic Electron Scattering", T.C. Yates et al., Phys. Lett. B312 (1993) 382.
3. "Charmonium Revisited: Outstanding Problems in Charmonium Physics", Kamal K. Seth, Proc. Third Workshop on Tau-Charm Factory (Marbella), edited by J. Kirkby and R. Kirby (Edition Frontieres, Gif-sur-Yvette, 1994) pp. 461-486.
4. "Charmonium Physics: A Status Report", Kamal K. Seth, Proc. 23rd International Symposium Multiparticle Dynamics (Aspen), edited by M.M. Block and A.R. White (World Scientific, Singapore, 1994) pp. 460-475.
5. "Negative Pion-Nucleus Elastic Scattering at 20 and 40 MeV", G. Burleson et al., Phys. Rev. C49 (1994) 2226.
6. " $p\bar{p}$ Forward Scattering Parameters-Results from Fermilab E760", S. Trokenheim, Proc. 5th Blois International Conf. on Elastic and Diffractive Scattering (Providence), edited by H.M. Fried et al. (World Scientific, Singapore 1994) pp. 64-67.
7. "Form Factors in the Timelike Region", Kamal K. Seth, International Workshop on Exclusive Processes (Elba), edited by C. Carlson et al., (World Scientific, Singapore 1994) pp. 70-84.
8. "Outstanding Problems in Charmonium Physics", Kamal K. Seth, Proc. Lake Louise Winter Institute on Particle Physics and Cosmology, edited by A. Astbury et al., (World Scientific 1994) - in press.

9. "Absence of M3 Quenching in ^{26}Mg ", Kamal K. Seth et al., Phys. Rev. Lett (submitted).
10. "High Resolution Charmonium Spectroscopy by Antiproton Annihilation - Fermilab E760 and Beyond" Kamal K. Seth, Proc. 14th International Conf. on Few Body Problems in Physics (Williamsburg), edited by F. Gross (Amer. Inst. Phys., New York, 1994) - in press.
11. "A $p\bar{p}$ Luminosity Monitor for Fermilab Experiment E760", S. Trokenheim et al., Nucl. Instr. Methods, 1994 - in press.

B. INVITED TALKS

1. "Charmonium Revisited: Outstanding Problems in Charmonium Physics", Kamal K. Seth, Third Workshop on Tau-Charm Factory (Marbella).
2. "Charmonium Physics: A Status Report", Kamal K. Seth 23rd International Symposium Multiparticle Dynamics (Aspen).
3. " $p\bar{p}$ Forward Scattering Parameters-Results from Fermilab E760", S. Trokenheim, 5th Blois International Conf. on Elastic and Diffractive Scattering (Providence),.
4. "Form Factors in the Timelike Region", Kamal K. Seth, International Workshop on Exclusive Processes (Elba), (World Scientific, Singapore 1994) pp. 70-84.
5. "Outstanding Problems in Charmonium Physics", Kamal K. Seth, Lake Louise Winter Institute on Particle Physics and Cosmology.
6. "High Resolution Charmonium Spectroscopy by Antiproton Annihilation - Fermilab E760 and Beyond" Kamal K. Seth, 14th International Conf. on Few Body Problems in Physics (Williamsburg).

(The principal investigator was requested to present invited talks at following conferences, but had to decline because of pressure of time.

7. Russian Academy of Science Conference on "The Physics of Fundamental Interactions" at Moscow (4-7 April, 1994).
8. International Conf. on "Mesons and Nuclei at Intermediate Energies" at Dubna (Russia) (3-7 May, 1994)
9. International Symposium on Medium Energy Physics at Beijing (China) 22-26 Aug. 1994.
10. XIIth International Seminar on "High Energy Physics Problems" at Dubna 912-17 Sept. 1994)

C. LECTURES AND SEMINARS (Kamal K. Seth)

1. "High Resolution Charmonium Spectroscopy"
Brookhaven National Laboratory (Oct. '93)
2. "QCD and Charmonium"
Moscow Engineering Physics Institute, Moscow Russia, (Dec '93)
3. "New Results from Fermilab E760"
Institute of High Energy Physics, Protvino Russia (Dec '93)
4. "Charmonium Spectroscopy by Proton Antiproton Annihilation"
Institute of Theoretical and Experimental Physics, Moscow Russia (Dec '93).
5. "Charmonium-in and out of the Nucleus"
University of Connecticut, Storrs, (Sept. '94)
6. "The Physics of Tau-Charm Factories"
Argonne National Laboratory, Argonne (Sept. '94).

IV. PERSONNEL

Principal Investigator

Kamal K. Seth

Post Doctoral Research Associates

Miguel Sarmiento (term 4/94)

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John Wise (6/94-)

David Brown (7/94-)

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NORTHWESTERN UNIVERSITY EQUIPMENT REQUEST FORM

Party Requesting Disposition

Name K. K. SETH	Date 8/12
Department Physics	Location of Equipment Tech 2376

List of Equipment

Tag #	Description (manufacturer, model, serial #, etc.)
30251	DEC, Model VAX 11/750 Computer
28295	DEC, Model 28295 Disc Drive
25851	DEC, Decwriter II

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ASRSP <i>Kurt Helms</i>	Date <i>26 Sept 94</i>	☒ Yes This equipment is NU titled ☐ No without government restrictions.			

APPENDIX 1

Absence of M3 quenching in Magnesium-26

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Abstract

In a high-resolution electron scattering experiment ten 3^+ states in ^{26}Mg have been identified, increasing the world data on $M3$ transitions several-fold. Differential cross sections have been measured and magnetization current densities and form factors have been deduced. It is found that while the level of agreement of the $B(M3)$ values with shell-model predictions varies from state to state, the summed $B(M3)$ strengths are in good agreement. No overall quenching of the $M3$ strength is found; and it is concluded that no renormalization of the free nucleon g -factors is needed.

High resolution electron inelastic scattering from ^{26}Mg

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Abstract

Electron inelastic scattering from ^{26}Mg has been measured over a momentum transfer range of 0.4 to 3.0 fm⁻¹ with scattering angles ranging from 33° to 154°. Squares of form factors have been obtained for 74 levels up to 10.33 MeV excitation. These data permit unambiguous identification of unnatural parity states, most of them for the first time, because of the pure transverse nature of their form factors. New spin and parity assignments have been made for 34 states by combining the present data with the results of other experiments.

Model-independent analysis of the measured form factor has been done to obtain charge and current densities for most of the transitions. Among the new results of the present experiment are the unambiguous demonstration of the need for $2\hbar\omega$ components in the excitation of 0^+ states, the detection of substantial transverse strength in 4^+ excitations, and the identification of seven 3^+ states which were not identified previously. The form factors, transition charge and current densities and reduced transition probabilities obtained in the present experiment for the positive parity states have been compared with detailed s-d shell shell-model calculations. In general excellent agreement between theory and experiment is found for all but the 0^+ states. There is no evidence for unusual quenching of any multipole, including the $M3$.

A $p\bar{p}$ Luminosity Monitor for Fermilab Experiment E760 *

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The design and performance of the luminosity monitor for Fermilab experiment E760, in which the circulating antiproton beam in the FNAL antiproton accumulator intersects a hydrogen gas-jet target, is described. Absolute luminosity monitoring at the level of $\pm 0.8\%$ (statistical) $\pm 2.1\%$ (systematic) is achieved. The luminosity monitor also enables forward scattering parameters to be measured for momenta in the 3-8 GeV range with greater precision than achieved before.

1. Introduction

The E760 experiment at Fermilab is dedicated to the study of charmonium ($c\bar{c}$) spectroscopy through the direct production of charmonium states ($c\bar{c}_R$) in $p\bar{p}$ annihilations:

$$p\bar{p} \rightarrow (c\bar{c})_R \rightarrow \text{electromagnetic final states.} \quad (1)$$

The experiment is located at the Fermilab Antiproton Source. The stochastically cooled circulating antiproton beam (momentum 3.5 – 8.8 GeV) in the antiproton accumulator traverses a hydrogen gas cluster-jet target to produce $p\bar{p}$ collisions with a typical luminosity of $\sim 10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$. A schematic of the E760 detector is shown in Fig. 1. It is described in detail elsewhere[1].

E760 requires a measurement of the luminosity with errors less than two to three percent. In this paper we describe the luminosity monitor (also shown in Fig. 1) which has been designed for this purpose. The monitor is based on the principle of measuring recoil protons corresponding to forward angle elastic scattering of antiprotons.

In principle if $p\bar{p}$ elastic scattering cross sections can be accurately measured at an extremely small angle ($0.1^\circ < \theta < 0.2^\circ$), Coulomb normalization can lead to luminosity determinations with the required precision. This was judged to be not possible in the geometry of the E760 experiment. Measurement of the relative cross section at a forward angle which is large enough so that the cross section is dominantly diffractive (exponentially varying with momentum transfer) can also lead to accurate luminosity measurements if the parameters of diffractive scattering are known with accuracy. This is not the case at all energies and for all the parameters. It was therefore deemed necessary to design a luminosity monitor which can measure relative differential cross

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HIGH RESOLUTION CHARMONIUM SPECTROSCOPY BY ANTIPROTON ANNIHILATION - FERMILAB E760, AND BEYOND*

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Abstract

Fermilab experiment E760 is devoted to the study of charmonium spectroscopy by resonant formation of charmonium states in proton-antiproton annihilations. Unprecedented mass resolution has been achieved in the collision of a stochastically cooled circulating antiproton beam in the Fermilab antiproton accumulator and an internal hydrogen gas cluster-jet target. Significant improvements have been made in the knowledge of the resonance parameters of nearly all bound states of charmonium. Simultaneously, new measurements have been made of the proton electromagnetic form factor in the time-like region up to 13 GeV^2 , the $\bar{p}p$ forward scattering ρ -parameter has been measured with greatly-improved precision, and several new light quark resonances have been identified.

1. INTRODUCTION

The $SU(3) \times SU(2) \times U(1)$ 'Standard Model' unifies the $SU(2) \times U(1)$ electroweak theory with the gauge field theory of strong interactions which goes by the name of Quantum Chromodynamics (QCD). The electroweak sector of the Standard Model is now well established, and no significant departures from its predictions have so far been found experimentally. This is not true of the QCD sector. The non-Abelian field theory of QCD is not analytically calculable. Putting aside the lattice-gauge calculations in which some major breakthroughs may now be taking place, as described by Lepage at this conference [1], QCD calculations can only be made in the perturbative domain of very large momentum transfers, Q^2 . In this domain a number of predictions have been made and they have been largely verified experimentally. The situation is quite different in the small Q^2 domain in which most of our universe resides. In this domain perturbative calculations lose their validity, and the best one can do is to try to live with QCD-based models; viz., potential models, QCD sum-rule models, etc. As always, models have limitations, sometimes serious limitations.

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