

Final Close-out Report to the US Department of Energy

for **DOE/ER/40858--3**

Selected Problems in Nuclear/High Energy Physics:

**Experimental Hypernuclear Physics, Muon Rare Decay,
and Development of New Detector system applicable to
Nuclear/High Energy Physics Experiments**

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1. Project Title

Selected Problems in Nuclear/High Energy Physics:

Experimental Hypernuclear Physics, Muon Rare Decay,
and Development of New Detector system applicable to
Nuclear/High Energy Physics Experiments

Total Budget Funded: **\$149,000**

Budget Period: **Three Years (June 1st of 1994 - May 31st of 1997)**

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3. Project Background

The requested funding was to support the experimental nuclear / particle physics program, "Selected Problems in Nuclear/High Energy Physics (SPINHEP)", established at Hampton University in the spring of 1992. This program has been one of the four major research components of the Nuclear/High Energy Physics (NuHEP) Center of Excellence at Hampton University which is funded under the NSF Minority Research Center of Excellence Program. The research projects in this program provided excellent research opportunities for student education and training in forefront physics problems. They also provided a solid support to the goal of the NuHEP Center, that is to increase the pipeline of under- represented minority scientists to the nation. In a complementary way, the great support from the center has made the SPINHEP research program possible. Important support from the center includes a strong outreach program for student recruiting, organized coordination in the center's research efforts and focus, computer systems, and laboratory space.

The supported medium energy physics research project includes (1) establishment and preparation of the approved hypernuclear experiments at the Thomas Jefferson National Accelerator Facility (Jlab); (2) continuation of our support to and participation in the hypernuclear experiments at Brookhaven National Laboratory (BNL) and at the Laboratory for High Energy Physics of Japan (KEK); (3) continuation of support to complete the Muon Electron Gamma Rare Decay (MEGA) experiment at LAMPF; and (4) construction of a Total Internal Reflective Cherenkov detector to separate kaons from proton background for the hypernuclear experiments in Hall C at CEBAF. Our effort also includes development of new experimental technique and equipment which will be applied to these experiments and may be applicable to future new experiments at JLAB, BNL, and KEK (and future JAP50).

The thrust of the work is to explore the limits of conventional models of nuclear and particle physics. The research program is designed to: (1) investigate forefront problems in experimental nuclear / particle physics; (2) educate students in this field of research, especially encouraging minority students seeking higher education and research careers; and (3) establish a high quality experimental instrumentation laboratory to provide a study and training base for students and to develop the instrumentation necessary to undertake experimental programs at JLAB and other laboratories.

4. Project Summary

Under this DOE funding, the experimental program described in this report now consists of two major approved experiments at Jlab: "Investigation of the Spin Dependence of the Effective NN Interaction in p Shell" (E89-009) which is tentatively scheduled to be completed in the fall of 1999 and "Direct Measurement of the Lifetime of the Heavy Λ -Hypernuclei at CEBAF" (E95-002) which will be run in parasitic mode with E89-009. Also, a new experiment (E97-008) which attempts a directly observation of the spin-orbital splitting in the higher orbits with medium heavy targets was proposed and conditionally approved by Jlab PAC-12 in 1997. The condition for this experiment is simply to run E89-009 first and study the best possible energy resolution. Our experimental group at Hampton University has played a leadership role in the development and preparation of these experiments. The Principal Investigator (PI) of this grant is spokesperson and acting program coordinator for all three experiments. Establishment of Jlab experiments is our group's main focus.

Our group has also supported and participated in several other hypernuclear physics experiments or approved proposals at BNL Alternate Gradient Synchrotron (AGS) and KEK. Detailed justifications for these experimental programs are contained in proposals to both accelerator advisory panels. The PI of this grant was invited to join a newly-formed (1996) U.S.-Japan Joint International Collaboration on Hypernuclear Physics which involves 10 U.S. and 8 Japanese scientists both in theory and experiment in this field. The goals of this collaboration are: (1) to utilize the unique characteristics of each of three different reaction mechanisms (K, π), (π, K), and ($e, e'K$), in probing different hypernuclear structures with high precision (resolution better than 2 MeV); and (2) to attack the unresolved issues in a joint and more complete manner, such as spin-spin and spin-orbital interaction strength and the charge symmetry breaking of the YN interaction.

In addition as originally proposed in the grant proposal, our group also contributed in completing the MEGA experiment at LAMPF.

Our detector development program established in the NuHEP Center has successfully constructed a large active area Lucite detector which uses a total internal reflection technique as a part of the kaon identification system for the Jlab Hall C SOS spectrometer. Its application in the first two experiments using the ($e, e'K$) reaction, E91-16 and E93-18 in 1996, has proved its effectiveness to reject the proton background both on-line and off-line. We continued the program to develop new techniques and equipment associated with our Jlab experiments and possible future experiments at different national laboratories. This new work included developing: (1) a fission fragment detector with excellent timing and position resolution for the lifetime measurement of heavy hypernuclei and (2) new spectrometer systems for strangeness $S = -1$ or -2 hypernuclear programs at either hadronic facilities such as BNL and KEK (or JHF-50 the new Japanese 50 GeV proton accelerator) or electron facility (mainly CEBAF). The fission chamber has been built and tested by source in lab and it is now under beam test. The optical design of the S2S spectrometer was presented in AGS-2000 Workshop (1996) and recently in JHF98 International Conference.

Under the support of this grant, the new DOE grant, and our Center funded by NSF, our group has developed to include one PI, one research associate (postdoc), three Ph.D. graduate students. One graduate student is working on her thesis and the other two will have their thesis experiments done in 1999. Undergraduate students were also involved in our research work during summer as part of our outreach and science education programs.

Generally, the goal of this research is to probe the limits of conventional models of elementary interactions or models where these interactions are imbedded within the nuclear medium. The nucleus is used as a strongly interactive rich hadronic many body system. The inserted "impurity", a strange particle or quark, is the probe to explore the perturbation of a known interaction by this environment. This is termed as "Hypernuclear Physics", in which models of higher order interaction forces (such as multi-pion exchange) or of quark and gluon substructure, may be explored more clearly. Such phenomena are usually described dominantly by a lower order single pion exchange picture in conventional nuclear physics. High quality experiments and data are needed in this research area such as the hypernuclear experiments at Jlab which are our main effort. The instrumentation program is designed to apply new techniques to improve experimental results. It also serve as a student training base to enhance and enrich their experimental research capabilities and technical skills for career development.

5. Accomplishments (Funding Cycle 6/1/94 - 5/31/97)

During this cycle, the HU group has accomplishments in all the proposed projects:

I. Hypernuclear Physics Program at Jlab

E89-009: Investigation of the Spin Dependence of the ΛN Effective Interaction in the p Shell (L. Tang, co-spokesperson) Approved with B⁺ priority

The general goal of this hypernuclear experimental program is to investigate the properties of the Λ hyperon and the perturbation of its environment when it is embedded in a nucleus. This will be accomplished with the highest currently achievable energy resolution in the spectroscopy study. The initial studies are designed to extract the effective Λ -N interaction for p shell hypernuclei, helping to resolve the Λ -N interaction mechanism. In particular, this will illuminate the importance of ΛN - ΣN coupling in nuclei. Eventually, we anticipate using the Λ as a probe of the nuclear interior by extending the study to heavier hypernuclear systems.

Due to the absence of one pion exchange (OPE) mechanisms, the Λ -N interaction is short ranged. Therefore, in the nuclear medium, the coupling of a lambda to a sigma, $\Lambda N \rightarrow \Sigma N$, and the three body ΛNN interaction (which all may be substantially equivalent) are important in determining the properties of a hypernuclear system. In addition, the strangeness degree of freedom allows the particles to rearrange themselves in order to maximize the nuclear binding energy. Thus, the studies of hypernuclear systems can emphasize different fundamental physics from conventional nuclear studies. For example, the hyperon spin-orbit interaction is smaller, and charge-symmetry-breaking is larger, than in a similar purely nucleonic system. Systematic studies comparing spectra from different reaction mechanisms are needed to understand the open questions. Furthermore, precise measurements of the properties of heavy hypernuclei can provide information about the interior of a nuclear system that is quite difficult to obtain by other means.

The features of E89-009 include: (1) resolution of about 600 keV FWHM (a factor of three better than any previous measurements); (2) spectra from the $(e, e' K^+)$ reaction which have never been obtained previously; (3) spectra which include the excitation of the unnatural parity (spin flip) states due to the unique properties of the electro- or photo-production mechanism; and (4) production of isospin mirror-pair hypernuclei complementary to those produced by the (K^-, π^-) and (π^+, K^+) reactions for the charge symmetry breaking studies. Experimentally, E89-009 has a unique design which is the best way to study hypernuclear spectroscopy using the high quality, high intensity, and 100% duty factor electron beam at JLAB. Cross-section is maximized by tagging on 0° scattered electrons ($Q^2 \approx 0$), so a low beam energy can be used.

It has been well recognized that it is the strong HU group effort that has made this experiment possible. As one of the "major Installation" experiments at Jlab, the experiment

is tentatively scheduled to be carried out in 1999. Number of students (graduate, undergraduate, and summer outreach program students) has involved in preparing this experiment. At least one Hampton University graduate student will utilize this experiment for his or her Ph.D. Thesis.

Our accomplishments include:

(1) The group has finalized the design of the Hypernuclear Spectrometer System (HNSS) for the Jlab experiment E89-009 (see Fig.1). The newly revised design will significantly reduce the experimental installation and dismount cost (from over \$200K down to \$100K) and time (from over 45 days to 35 days). This revision maintains all the features of the original proposed experiment. A detailed revision report was submitted to the Jlab Nuclear Physics Experiment Scheduling Committee. A complete and systematic study of the HNSS optics was done and demonstrated the optimized way to operate the Hall C SOS spectrometer for the best resolution. The results show that E89-009 can reach an energy resolution of about 650 keV which is significantly better than the original proposed resolution (1-2 MeV) in the first phase of the experiment. This result and our methods of a systematic study of a spectrometer system were published in a NIM paper. Our suggestion was accepted by Hall C and a vacuum extension which reaches as close as the first tracking drift chamber was built and installed before the two $(e,e'K^+)$ experiments, E91-016 and E93-018. We completed a raytrace simulation of the sieve slit calibration and compared it with the real experimental sieve slit data. A sieve slit is a collimator made of a thick heavy metal with series of small opening holes to define a set of specific angular distribution of particle rays for the spectrometer optical calibration and commissioning. The comparison shows a good match except that the simulation did not include the detector phase space volume limitation. This means that the SOS optical properties have reached its design. From this study we have generated a reconstruction code based on raytrace for SOS. It is used in the data analyses for the two $(e,e'K)$ experiments (E91-016 and E93-018) and obtained the best up-to-date resolution. Our student is now using the newest sieve slit data to find the best description of the SOS optics in order to generate a finalized momentum reconstruction code. This effort is to make E89-009 capable to reach 650 keV resolution and to obtain the data with the best quality which is extremely difficult to obtain by other facilities.

(2) As we have proposed, the group has led the collaboration and played central role in completing the preparation of E89-009. We have completed the preparation of the Hypernuclear Spectrometer System (HNSS), which is our responsibility. This includes (a) refurbishing and modifying the 65 tons Split-pole spectrometer done completely by our group; (b) redesigning and building the new pole pieces for the Splitter magnet which we obtained from LBL; (c) completing the magnet test and mapping; (d) completing the Split-pole spectrometer support platform design and construction; (e) completing the Splitter magnet support foundation design and construction; and (f) completing the preparation of the vacuum system. Thus, we have made the HNSS system ready to be assembled for the experiment. We also coordinated the preparation of all the other required key elements which were responsible by the rest of the collaboration.

TOP VIEW OF EXP89-009 APPARATUS

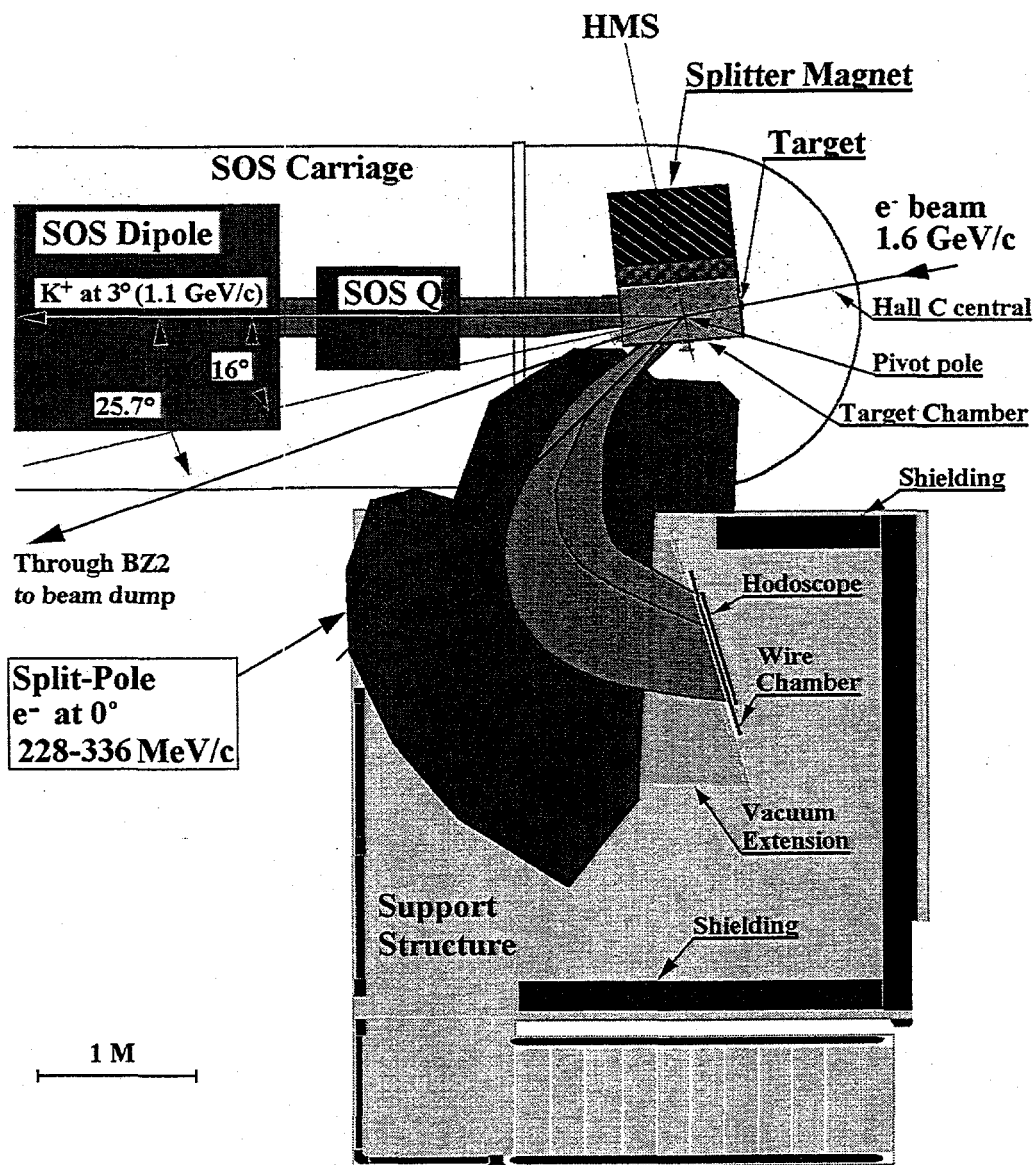


Fig. 1. The top view of the experimental layout of the Jlab Hall C E89-009.

(3) The group has also worked closely with our collaborators and contributed in testing the rate capability of the high rate Multi-wire Proportional Chamber (MWPC) built by the University of Houston group. This chamber was originally planned to be used as the focal plane position detector for the electron arm of HNSS. We then led the effort to investigate the possibility and advantages of using the Silicon Strip Detector (SSD) instead of the MWPC in the high particle rate environment and estimate the radiation damage problem. Such an investigation eventually convinced the collaboration to build such detector. This SSD is currently under construction by the Tohoku University group in Japan and University of Houston group.

(4) During the past funding years (June 1994 - May 1997), we have developed a large area Lucite total internally reflective Cherenkov detector for the Jlab Hall C SOS spectrometer. This detector has been mounted and applied successfully in the first two ($e, e'K$) experiments as part of the kaon identification system. Since the SOS detector package does not have on line kaon-proton separation capability, the kaon experiments must write an overwhelmingly large amount of proton background events on disk. It is even tough in off-line analysis to remove this background by TOF. This causes a very slow analysis speed. The Lucite detector has worked well in rejecting 90% of the protons at on-line level while still maintaining high kaon detection efficiency (about 99% level). Fig. 3 (a) shows the kaon detection efficiency and proton rejection rate; and (b) shows the number of photoelectrons as a function of the particle velocity. A strong threshold effect can be seen from the data. This detector is ready to use again in E89-009.

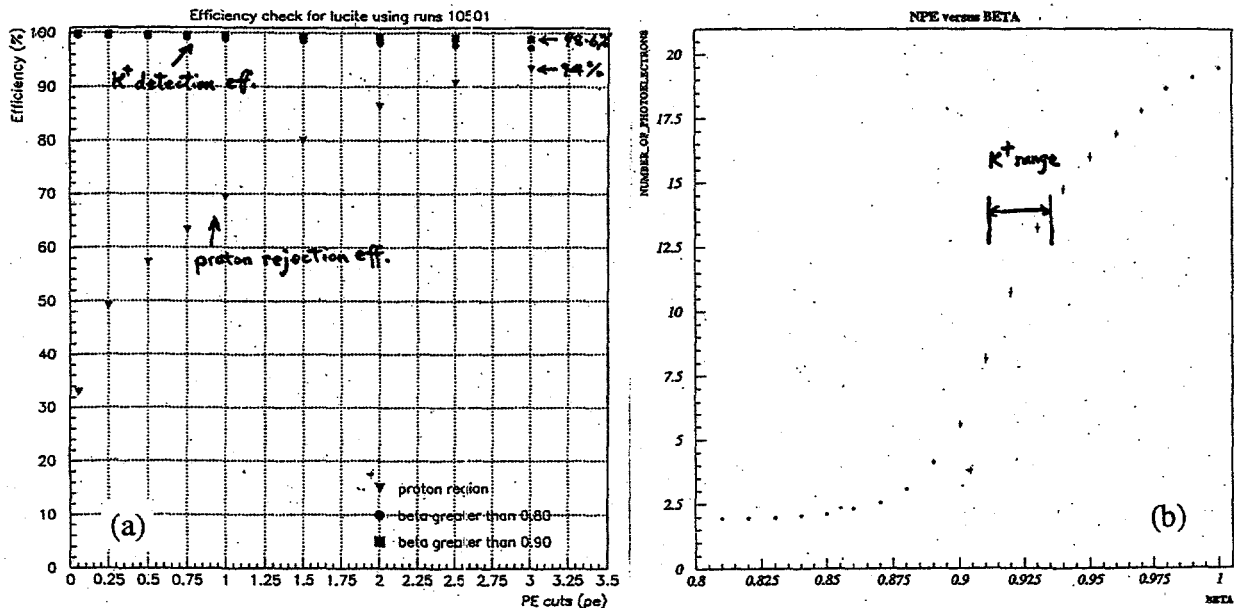


Fig. 3. (a) Kaon detection efficiency and proton rejection rate of the Lucite total internally reflective Cherenkov detector and (b) number of photoelectrons as a function of the relative velocity β . Data is from the JLAB experiment, E91-016.

(5) The group has also led the effort of monitoring the beam stability in terms of energy and position drift in Hall C and developed a correction method. The drifting problem could effect the quality of E89-009.

The group is now leading the collaboration in preparing the final readiness review. More detailed information about this experiment can be found in our proposal to DOE for the next funding cycle.

E95-002: Direct Measurement of the Lifetime of the Heavy Hypernuclei at CEBAF
(L. Tang, co-spokesperson) Approved with B priority

We proposed a new Jlab hypernuclear experiment, i.e. E95-002. It was approved and the collaboration was established during this funding cycle. Our group are leading and coordinating the collaboration in preparing this new experiment.

The lifetime of heavy Λ hypernuclei is an especially interesting subject from the viewpoint of the weak decay mechanism of the Λ in a nucleus. High precision measurements of hypernuclear lifetimes and their A dependence will provide valuable constraints in attempts to understand many fundamental issues in hypernuclear physics. Such open issues are the effective YN interaction range; $\Lambda N \rightarrow \Sigma N$ conversion; and the ΛNN three body interaction. At the quark level, Pauli blocking may lead to an observable deviation from the expected A dependence of the hypernuclear lifetime as calculated by conventional hadronic models, especially in the very high A ($A > 100$) region.

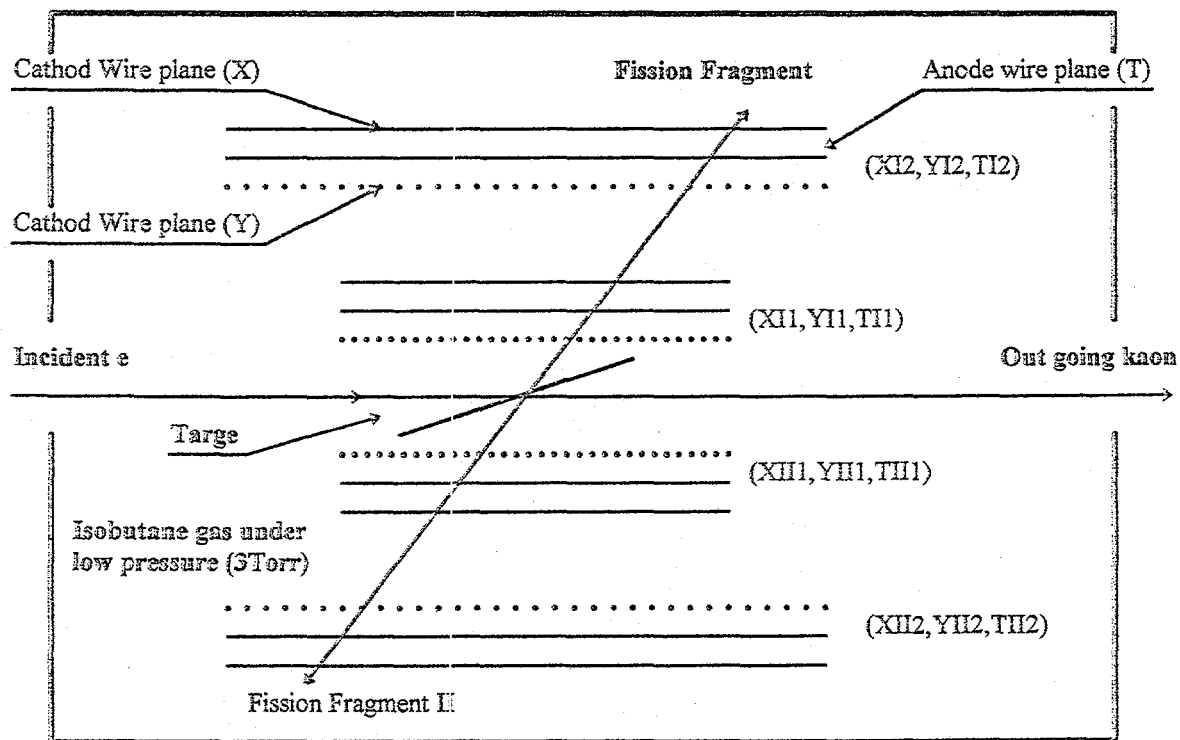
It is commonly believed that only the lifetimes of very light Λ hypernuclei are dominantly determined by the mesonic decay, $\Lambda \rightarrow \pi + N$ (+40 MeV). As the mass of the hypernucleus increases, the rate of the nonmesonic decay, $\Lambda N \rightarrow N + N$ (+176 MeV) increases while that of mesonic decay decreases rapidly because of Pauli suppression of low momentum final state nucleons. Thus, it is generally believed that the lifetime of Λ hypernuclei is a decreasing function of mass number A . However, the effective YN interaction range may change this description, i.e. additional nucleons may appear to have no effect upon the lifetime of hypernuclei as A reaches a certain level.

In very heavy hypernuclei, partial deconfinement may require that the u and d quarks in the Λ be antisymmetrized with the nonstrange quarks in the neighboring nucleons so that observable effects, such as isospin mixing in hypernuclei or modification of the mesonic decay rate in the nuclear medium, may occur. The partial widths of different decay modes, as well as the A dependence, are subjects of many theoretical investigations.

A high precision hypernuclear lifetime measurement for various masses, especially in the heavy region, is necessary and important. However, the presently available data are scarce, extremely poor in quality (about 100% relative error in most of cases), and no data are available for $A > 16$.

E95-002 is designed to carry out a direct measurement of the lifetime of heavy Λ hypernuclei by fully utilizing the unique features of the CEBAF beam (2 ns beam bunch spacing and 1.67 ps bunch width) and fission fragment detection techniques. Since the hypernuclei will be produced by $(e,e'K^+)$ reactions, this experiment is designed to ensure Λ hypernuclear production once a kaon has been detected by the SOS spectrometer. Since the nonmesonic decay of the Λ dominantly determines the lifetime of the Λ hypernuclei and since this releases a large amount of energy (176 MeV), the probability of a time-delayed fission ($\sim 10^{-10}$ sec) due to Λ hypernuclear decay is more than two orders of magnitude higher than that of prompt fission due to other sources. Thus, coincident detection of a kaon and delayed fission will select the decay of a Λ hypernucleus.

The fission fragments will be detected by a low pressure MWPC chamber system (LPMWPC) mounted around the target (see Fig.4). The detected kaon will be used to select the event and, more importantly, to reconstruct the correct beam bucket during which the



- * Kaon timing (resolution of 300 ps FWHM) points the correct beam bench (1.7 ps bench width)
- * Fragments timing (T1, T2 with resolution of 150 ps FWHM) points a delayed time to a beam bench (< 2 ns)
- * Coincidence of detection of kaon and FF with 2 ns signals a hypernuclear decay
- * Decay time measured by delayed time of FF with respect to pointed beam bench
- * Under low pressure the device senses only to the high Z particles

Fig. 3 The concept of the proposed fission fragment detection device for the heavy hypernuclei lifetime measurement experiment, E95-002.

hypernucleus was produced. The SOS system has demonstrated excellent beam bucket reconstruction capability with a timing resolution of about 150 ps. Since the beam bunch width is only 1.67 ps, the reconstructed beam bucket provides an absolute zero time for the production of a Λ hypernucleus. The LPMWPC is a well known technique commonly applied in nuclear fission experiments. It has excellent position and timing resolution (200 μm and 130 ps FWHM, respectively), is sensitive only to the desired Z range of fragments, and has 100% detection efficiency. With high count rate capability and radiation resistance, the position and timing information provided by a double plane system will allow reconstruction of actual decay time with respect to the production beam pulse. Overall timing resolution for the decay time spectrum will be about 200 ps FWHM. Furthermore, the prompt fission time spectra from various channels are measured simultaneously, providing an accurate determination of the prompt background line shape parameters and an accurate absolute time-zero shift correction due to possible systematic errors. With an overall timing resolution of 200 ps FWHM and statistics from more than a total of 1000 events, the lifetime extraction accuracy can be about ± 7 ps. With an assumption of 200 ps lifetime, the relative error stays the same in the region of lifetimes greater than 100 ps.

This experiment combines the features of CEBAF beam and the fission detection technique to measure the lifetime of Λ hypernuclei with an accuracy unachievable by any other means. High quality data will be provided in the heavy mass region. One Hampton University graduate student will use the first phase of this experiment for a Ph.D. thesis.

The HU group has led the collaboration in investigating this low pressure MWPC technique. The group has designed and constructed the full size chamber for the experiment after the prototype study. The chamber is now fully constructed and tested by Cf-252 fission source in laboratory. Currently, it is installed inside Hall C and undergoing beam environment test. We have obtained the best features of this kind of chamber with the size that was used. The tested result was submitted to NIM for publication recently.

E97-008: Study of Lambda Hypernuclear Spectroscopy Beyond P Shell
(L. Tang, co-spokesperson) Conditionally Approved with B priority

This new hypernuclear spectroscopy experiment is a natural extension of E89-009. It is to utilize the accuracy which is established by the HU group built Lab Hall C HNSS system to study more directly the spin-orbital interaction in the effective AN interaction in the higher orbits. At such orbit, the splitting is predicted large enough so that the HNSS accuracy may be able to carry out a direct observation. The establishment of this new experiment is a result of our effort in working closely with other scientists in the world in the same field to promote a joint effort (see next section). The experiment was conditionally approved with a condition of completing E89-009 first in order to study and understand the HNSS system well.

II. A Joint U.S. and Japan Collaboration of Hypernuclear Physics

The PI has been actively involved in both the AGS and KEK hypernuclear programs in the past years. This effort was to support a more unified hypernuclear research collaboration and

to push a greater success in the field. Now a joint research collaboration between U.S. and Japan was formed and a major research group has joined our E89-009 collaboration. This has significantly strengthened the collaboration of E89-009. The joint U.S. and Japan Collaboration of Hypernuclear Physics was formed in 1996. It includes 10 U.S. and 8 Japanese scientists currently active in this field both in theory and experiment. The PI of this proposal was invited to the collaboration to represent the Jlab hypernuclear collaborations. The joint collaboration will attack the unresolved issues in a coordinated manner. It will both support the ongoing and create the future experiments at KEK, BNL, Jlab, and JHF50. Table 1 lists the completed and approved hypernuclear experiments which the Hampton group has led or is involved in by the end of the funding cycle. All the KEK experiments are completed now and currently under analysis.

Table 1. Hampton group led or involved hypernuclear experimental programs

Jlab E89-009	$(e, e'K)$ Hypernuclear Spectroscopy in p Shell	Co-spokesperson
Jlab E95-002	Lifetime of Heavy Hypernuclei	Co-spokesperson
Jlab E97-008	$(e, e'K)$ Hypernuclear Spectroscopy beyond p Shell	Co-spokesperson
AGS E907	(K^-_{stop}, π^0) Hypernuclear Spectroscopy Collaborator	Collaborator
AGS E930	High Precision γ Spectroscopy	Collaborator
KEK E336	(π^+, K^+) Hypernuclear Spectroscopy (Light)	Collaborator
KEK E369	(π^+, K^+) Hypernuclear Spectroscopy (Heavy)	Collaborator
KEK E419	High Precision γ Spectroscopy	Collaborator

III. Strangeness and Hypernuclear Experiments at BNL (AGS) and KEK

The HU group has participated in all the completed experiments (AGS E907, KEK E336, 369, and 419). The PI has contributed about two to three weeks per year to participate in running the BNL (AGS) strangeness and hypernuclear experiments as described in the previous section during the funding cycle. These included E873 (K^+ nucleus elastic scattering), E887 (high statistical search for the narrow Σ -hypernuclei), and E907 (high precision Λ -hypernuclear spectroscopy using (K^-_{stop}, π^0) reaction). In 1996, the PI also contributed three weeks to participate in running the KEK E336 (high precision and systematic investigation on the Λ -hypernuclear spectroscopy using (π^+, K^+) reaction). During E336, the PI was invited to visit Tohoku University and its electron accelerator facility, the Laboratory for the Nuclear Science, and gave a talk about Jlab and its hypernuclear programs. Students and postdoc of our group has involved only in the AGS experiments at BNL due to the limited funding.

The PI also participated in proposing new experiments at both AGS and KEK, such as the approved AGS E930 and KEK E419.

IV. MEGA Experiment at LAMPF

The PI of this proposal has contributed approximately three weeks per year in support of running this experiment; as a commitment in the proposal for the funding cycle. This

included the MEGA photon chamber electronics construction, chamber preparation, setup and installation, cosmic ray test, and actual data taking. We contributed in construction of the photon chamber electronics in the Hampton University Lab and maintenance of these electronics at the experiment. Two publications were done about the MEGA photon chamber and its electronic trigger system.

V. Detector Development Program

We have completed our development of the Lucite total internal reflective Cherenkov detector. The prototype was tested using AGS test beam in January of 1995 and the full sized detector was built and installed in the SOS for the first two (e,e^+K^-) experiments, E91-016 and E93-018, in 1996. It consists of 8 segments with 16 3" photomultipliers. It provides a total active area of 130 cm x 45 cm. Its application has proved its effectiveness in rejecting proton background at both on-line and off-line level with high kaon detection efficiency (about 99%). The detector is now part of the standard SOS kaon identification system and will be used again when E89-009 starts in 1999.

VI. Involvement in the Other Experimental Programs

As an institution closely tied with Jlab, the group has actively participated in Hall C commissioning and most of the Jlab Hall C experiments which have so far been completed. Our students have developed their expertise and provided their support of running Hall C experiments. As a part of the NuHEP Center at Hampton University, we have involved in the first two (e,e^+K^-) experiments in Hall C, E91-016 and E93-018. Both experiments are led by Hampton faculty - Dr. O.K. Baker (Kaon Form Factor) and adjunct faculty - Dr. Ben Zeidman (S shell Light Hypernuclei). The Lucite detector constructed by our group and Temple group was used as part of the kaon identification system for rejecting proton background. It is worthwhile to mention that, during these two experiments, two days of beam time (about total of 30 hours of beam on target) was dedicated to our group for a feasibility test in producing the heavier hypernuclei.

This dedicated test run is extremely useful in testing the kaon identification system, signal to background ratio, and quasifree production in the (e,e^+K^-) reaction. The running conditions and SOS optics were examined and data obtained successfully. The data is under detailed analysis. There is evidence for at least two possible sharp peaks in the 11 MeV bound region below Λ threshold. These two possible peaks appear to be at the expected binding energies for the spin flip 2^- ground state and the 3^+ substitutional state just below threshold. There might be a third excited state in between these two. The width of peaks agrees with the overall resolution (about 2 MeV) for the experimental setup (not optimized like E89-009). It is too early at this point to show the preliminary spectrum since there are several calibrations to be done first. However, this test run may provide valuable information on the unnatural parity states which have never been seen and can only be seen at Jlab. Also, the 2^- ground state is the spin flip mirror pair of the 1^- ground state seen for the $^{12}_{\Lambda}\text{C}$ system. The data obtained from Al target will be used to study the quasi-free kaon production

systematically in comparison to C. One of our students is studying these data for her Ph.D. thesis.

A more complete list of participated experiments other than those mentioned above can be found in the section of "BIBLIOGRAPHY".

VII. Students

We have involved a number of graduate and undergraduate students in the projects of preparing the HNSS for E89-009 and the study and construction of the Lucite detector. These include (1) the Split-pole spectrometer refurbishing, re-assembling, and test; (2) the splitter magnet re-assembling and field mapping; (3) the Lucite detector study and partial construction at Hampton University Lab; and (4) AGS beam test of the Lucite detector. Our graduate student participated in writing the data acquisition and analysis code for this detector and data analysis. During the experiments, E91-016 and E93-018, two days of beam time (total of 30 hours of beam on target) was dedicated to one of our graduate students to carry out an important feasibility test for carrying out our E89-009. This test has produced the $^{12}_{\Lambda}B$ hypernuclear spectrum for the first time with a resolution of about 2-3 MeV. She is analyzing the data for her Ph.D. thesis. This test will give us valuable information about carrying out a high precision hypernuclear experiment at JLAB and we are searching for the evidence of the expected as well as the new unexpected hypernuclear structures. We are expecting her graduation in the spring of 1998 and we are proud of that she will be the first African-American female Ph.D. in the experimental nuclear physics.

In summary, we have achieved the goal that we have planned and completed the commitment that we have proposed in the previous funding cycle. We also created new programs, attracted new collaborations, and broadened our effort to increase the depth and strength of our research and created opportunities to educate and train our students.

6. Publications and Technical Reports During the Funding Cycle

- (1) "K⁺ Elastic Scattering from C and ⁶Li at 715 MeV/c", R. Michael, M.B. Barakat, S. Bart, R.E. Chrien, B.C. Clark, D.J. Ernst, S. Hama, K.H. Hicks, Wendy Hinton, E.V. Hungerford, M.F. Jiang, T. Kishimoto, C.M. Kormanyos, L.J. Kurth, L. Lee, B. Mayes, R.J. Peterson, L. Pinsky, R. Sawafta, R. Sutter, L. Tang, J.E. Wise, Phys. Lett. B382, 29-34 (1996); Nucl. Phys. A585, 121c (1995).
- (2) "Revised Geometry of the experiment E89-009", L. Tang and Ed.V. Hungerford, special report to Jlab large experiment review Committee, 1996
- (3) "Architecture of the MEGA Detector Trigger", Y.K.Chen, M.D. Cooper, P.S. Cooper, M. Dziedzic, C.A. Gagliardi, G.E. Hogan, E.V. Hungerford, G.J. Kim, J.E. Knott, K.J. Lan, F. Liu, B.W. Mayes, R.E. Mischke, R. Phelps, L.S. Pinsky, K.M. Stantz, J.J. Szymanski, L.G. Tang, R.E. Tribble, X.L. Tu, Van Ausdein, W. Von Witsch, C.S. Wright, Nucl. Instr. and Meth. A372, 195-206 (1996).
- (4) "Systematic Resolution Study of the CEBAF Hall C Spectrometers - HMS and SOS", L. Tang, C. Yan, Ed.V. Hungerford, Nuclear Instr. and Meth. in Physics Research A366, 259-262 (1995).
- (5) "Do Narrow Σ Hypernuclear States Exist?", K. Baker, M. Barakat, S. Bart, R.E. Chrien, W. Franklin, T. Fukuda, K. Gross, R.S. Hayano, K. Hicks, E.V. Hungerford, B. Mayes, R. Michael, T. Nagae, W. Naing, I. Omata, S. Wissink, R. Sawafta, Y. Shimizu, L.G. Tang, L.J. Zhu, Nucl. Phys. A585, 103c (1995).
- (6) "MEGA: A Search for the Decay $\mu \rightarrow e\gamma$ ", J.J. Szymanski, J.F. Amann, K. Baker, D. Barlow, K. Black, R.D. Bolton, M. Brooks, S. Carius, Y. Chen, M.D. Cooper, P.S. Cooper, J. Crocker, M. Dziedzic, R.J. Fisk, J. Flick, W. Foreman, C.A. Hogan, E.B. Hughes, E.V. Hungerford III, K. Johnston, C. Jui, G.J. Kim, J.E. Knott, D.D. Koetke, M.A. Kroupa, T. Kozlowski, K. Lan, D. Lee, F. Liu, R. Manweiler, R. Marshall, B.W. Mayes II, R.E. Mischke, F.J. Naivar, B.M.K. Nefkens, J. Novak, M.A. Oothoudt, J.N. Otis, R. Phelps, L.E. Piilonen, C. Pillai, L. Pinsky, J. Price, M.W. Ritter, S. Schilling, T.D.S. Stanislaus, K.M. Stantz, W. Stephens, J. Sturrock, L.G. Tang, B. Tippens, R.E. Tribble, X.L. Tu, L.A. Van Ausdein, W. von Witsch, D. Whitehouse, C. Wilkinson, B. Wright, S.C. Wright, Y. Zhang, W. Zhou, X.G. Zhou, and K.O.H. Ziock, Conference Proceedings, AIP Conference Proceedings 338, 289(1995).
- (7) "Construction of MEGA Photon Detector", M. Barakat, Y. Chen, S. Conrad, M. Cooper, M. Dziedzic, J.A. Flick, C. Gagliardi, E.V. Hungerford, K. Johnston, G.J. Kim, K. Lan, F. Liu, Y.C. Lu, B.W. Mayes, R. Mischke, R. Phelps, L.S. Pinsky, D. Semon, R.E. Tribble, L.G. Tang, X.L. Tu, L. van Ausdein, W. Von Witsch, H.Z. Wang, X. Yao, W. Yi, Nucl. Instr. and Meth. A349, 118-137 (1994).

- (8) "A possible incorporation of the MRS spectrometer or its modified high resolution version to the new AGS 1-2 GeV/c separated beam line for hypernuclear physics experiment at BNL", L. Tang, C. Yan, P.H. Pile, and H.A. Thiessen, CEBAF Tech. Note, TN-94-050, (1994).
- (9) "High Resolution Short-Orbit-Spectrometer - A Modified Version of SOS", L. Tang and C. Yan, CEBAF Tech. Note, TN-94-015, (1994).

7. Talks and Poster Presentations

- (1) Tohoku University and the Laboratory for Nuclear Science in Japan, June 1996, "CEBAF and its Hypernuclear programs".
- (2) BNL AGS Year 2000 Workshop, BNL, NY, May 1996, "A Superconducting Circular Dipole Spectrometer, S2S, for S=-1 and -2 hypernuclear experiments at D line of AGS".
- (3) JLAB PAC meeting, program defense, January 1996, "Direct Measurement of the Lifetime of the Heavy Hypernuclei at CEBAF".
- (4) International Nuclear Physics Conference of 1995, Beijing, P.R. China, August 1995, "High Resolution Hypernuclear Spectroscopy Program Using (e,e'K) Reaction at CEBAF Hall C". (Poster)
- (5) Louisiana Tech University, Ruston, LA, December 1994, "Concepts of Hypernuclear Physics and CEBAF experiment".
- (7) Los Alamos Meson Physics Facility, Los Alamos, NM, August 1994, "Optical and Resolution Study report on the AGS 2 GeV/c beam line and MRS spectrometer".
- (8) BNL Hypernuclear Experimental Collaboration meeting, during 1994 International Conference on Hypernuclear and Strangeness Particle Physics, Vancouver, Canada, July 1994, "MRS and its modified version for the AGS new 2 GeV/c beam line".

8. Students

I. Conferences Attended and Presentations Given by Supervised Students

APS Spring Meeting at Washington DC, April, 1997. Presentation: "Feasibility test run result on electroproduction of hypernuclei".

National Alliance Research Centers of Excellence, March, 1996. Presentation: "Monte Carlo study of the energy resolution for the HNSS system used in the hypernuclear experiment at Jlab".

National Alliance Research Centers of Excellence, March, 1995. Poster.

National Conference of Black Physics Student, February, 1995. Attended.

"Diversity in the Scientific and Technological Workforce", National Science Foundation, September, 1994. Presentation: "Magnetic field mapping for the CEBAF Hall C SOS spectrometer".

National Alliance Research Centers of Excellence, March, 1994. Presentation: "Wavelength shifter technique for the total internal reflective Cherenkov detector".

"Diversity in the Scientific and Technological Workforce", National Science Foundation, October, 1993. Presentation: "Possible new readout technique for the total internal reflective Cherenkov detector".

National Alliance Research Centers of Excellence, March, 1993. Presentation: "Total internal reflective Cherenkov detector".

II. Graduate Students Advised

As Principal Advisor

- (1) Wendy Hinton, Ph.D. candidate
Dissertation: Electroproduction of Λ -hypernuclei using $^{12}\text{C}(e, e'K^+)^{12}\Lambda\text{B}$ reaction.
- (2) Jinseok Cha, M.S. degree
Research topic: Optical simulation of the SOS momentum reconstruction method and resolution.
- (3) Win Tun, Ph.D. candidate
Dissertation: High resolution electroproduction of Λ -hypernuclei in p shell.

As Assisting Advisor

- (1) Jinseok Cha, Ph.D. candidate
Dissertation: Electroproduction of kaons and light hypernuclei in s shell.
- (2) Win Naing, Ph.D. candidate
Dissertation: Search for narrow states in the ${}^6_{\Sigma}\text{Li}$ hypernuclear system.

III. Undergraduate Students Advised

- (1) Mr. Bonapate, (in the SEMS program)
Project: Construction of the MEGA electronics
- (2) Mr. McCloud, (in SEMS program)
Project: Construction of the MEGA electronics
- (3) Ms Leslie Simpson, (in the UNIPHY program)
Project: Magnetic spectrometer field test
- (4) Mr. Kenneth Williams, (in the UNIPHY program)
Project: Magnetic spectrometer field test
- (5) Mr. Tege Marques (Physics Major)
Project: Construction of the Low Pressure Multi-wire Proportional Chamber
- (6) Mr. Nyuiawodze Adover (Physics Major)
Project: Construction of the Low Pressure Multi-wire Proportional Chamber

BIBLIOGRAPHY

Resume of
LIGUANG TANG

EDUCATION

- Ph.D. 1987, Physics, University of Houston, Houston TX
M. S. 1981, Physics, High Energy Physics Institute of the Chinese Academy of Science and Technology, Beijing, P.R.China.
B. S. 1976, Mechanical Engineering, Beijing Polytechnic University, Beijing, P.R.China.

EXPERIENCE

ASSISTANT PROFESSOR OF PHYSICS, Hampton University, Hampton, VA
STAFF PHYSICIST, Physics Division, JLAB, Newport News, VA
(1/92-present)

Courses taught:

Physics 201	Introductory Physics
Physics 217	Modern Physics Lab
Physics 312	Thermodynamics
Physics 400	Seminar for Physics Seniors
Physics 501	Electrodynamics I
Physics 502	Electrodynamics II
Physics 526	Introductory Particle Physics
Physics 607	Electromagnetic Theory I
Physics 608	Electromagnetic Theory II

Research Project: Experimental hypernuclear and strangeness physics at JLAB, BNL (AGS), and KEK. Muon rare decay experiment at LANL. JLAB Hall C Hypernuclear Spectrometer System (HNSS) design for hypernuclear experiment. Magnetic spectrometer and beam optics. Experimental technique and instrumentation, such as wire chamber, Cherenkov detector (JLAB Hall C SOS Lucite detector), and the Low Pressure Multiwire Proportional (or Step) Chamber for fission fragment detection.

Experiments Lead or Involved:

- (1) Investigation of the spin dependence of the AN effective interaction in the p shell, E89-009, JLAB (Co-spokesperson)
- (2) Direct Measurement of the Lifetime of the Heavy Hypernuclei at CEBAF, E95-002, JLAB (Co-spokesperson)
- (3) K^+ - nucleus Elastic Scattering, E873, BNL (completed)
- (4) Search for Narrow Σ -Hypernuclear States, E887, BNL (completed)

- (5) Search for lepton number violate μ electromagnetic rare decay, MEGA, LANL (completed)
- (6) Investigation of Light Hypernuclei Using (K^-_{stop}, π^0) Reaction, E907, BNL
- (7) Systematic Study of Light Hypernuclei Using (π^+, K^+) Reaction, E336, KEK, Japan
- (8) Electroproduction of K^+ and Light Hypernuclei, E91-016, JLAB (completed)
- (7) L/T Cross Section Separation in $p(e,e'K^+)\Lambda(\Sigma)$, E93-018, JLAB (completed)
- (8) The Energy Dependence of Nucleon Propagation in Nuclei, E91-013, JLAB (completed)
- (9) Photodisintegration of the Deuteron, E89-012, JLAB (completed)
- (10) The Electric and Magnetic Form Factors of Neutron, E93-038, JLAB
- (11) The Charge Pion Form Factor, E93-021, JLAB
- (12) ($e, e'p$) cross section in the Δ resonance region, conditional approved, JLAB

Funded Research Grant

Department of Energy	(1994-1995)	\$50,000
Department of Energy	(1995-1996)	\$47,000
Department of Energy	(1996-1997)	\$52,000

Professional Service: UNV 101 (Freshman Study) Breakout Instructor, (present).

Program Planning Council of the School of Sciences,
(9/93 - present).

Ph.D. Qualifier Committee, (93-94, 96-97).

Modern Physics Lab Committee, (Chairman, 95-present).

Experimental Physics Lab Committee, (95-present).

Mentor of UNIPHY program of NuHEP, (summer of 95 and 97).

Proctor of the Ph.D. qualify examination

Ph.D. Dissertation Committees (5), (present).

Supervisor of the undergraduate student research from the SEMS program (94).

Department representative in the Center for Teaching Excellence

RESEARCH SCIENTIST AND

POSTDOCTORAL RESEARCH, University of Houston, Houston, TX

(6/87-12/91)

Experimental hypernuclear and strangeness physics at BNL (AGS). Lepton number violating muon rare decay experiment (MEGA) at LANL. Development of the proposal for the high resolution hypernuclear experiment at JLAB (E89-009) and design of the high resolution spectrometer. MEGA Photon chamber design and construction. MEAG photon chamber electronics. Scintillation barrier counter design and construction for BNL hypernuclear experiment. Monte Carlo study of the streamer tube detector.

RESEARCH ASSISTANT, University of Houston, Houston, TX

(6/83-5/87)

Search for narrow structures in the Σ -nucleus system above the production threshold on ^{12}C and ^7Li target using (K^-, π^+) reaction. Target hodoscope design and construction for Σ -

hypernuclear experiment. Experiment to measure Antineutron-proton total and annihilation cross section. Low mass and large area drift chamber construction.

TEACHING ASSISTANT, University of Houston, Houston, TX
(9/82-5/83)

Teaching assistant for PHY 201-202, 101-102. Physics and Mathematics tutor.

RESEARCH ASSISTANT, High Energy Physics Institute of China, Beijing, PRC
(9/78-5/81)

Heavy leptons and evidence of gluon search in e^-e^+ collision at PETRA, DESY, Hamburg, Germany. Muon chamber construction and test for e^-e^+ experiment. Mark-J detector system survey for e^-e^+ experiment.

Conferences Attended and Presentations Given by Supervised Students

National Alliance Research Centers of Excellence, March, 1996. Presentation: "Monte Carlo study of the energy resolution for the HNSS system used in the hypernuclear experiment at JLAB".

National Alliance Research Centers of Excellence, March, 1995. Poster.

National Conference of Black Physics Student, February, 1995. Attended.

"Diversity in the Scientific and Technological Workforce", National Science Foundation, September, 1994. Presentation: "Magnetic field mapping for the CEBAF Hall C SOS spectrometer".

National Alliance Research Centers of Excellence, March, 1994. Presentation: "Wavelength shifter technique for the total internal reflective Cherenkov detector".

"Diversity in the Scientific and Technological Workforce", National Science Foundation, October, 1993. Presentation: "Possible new readout technique for the total internal reflective Cherenkov detector".

National Alliance Research Centers of Excellence, March, 1993. Presentation: "Total internal reflective Cherenkov detector".

Graduate Students Advised or Being Advised

As Principal Advisor

(1) Wendy Hinton, Ph.D. candidate

Dissertation: Electroproduction of Λ -hypernuclei using $^{12}\text{C}(e,e'K^+)^{12}\Lambda\text{B}$ reaction.

(2) Jinseok Cha, M.S. degree

Research topic: Optical simulation of the SOS momentum reconstruction method and resolution.

(3) Win Tun, Ph.D. candidate

Dissertation: High resolution electroproduction of Λ -hypernuclei in p shell.

As Assisting Advisor

(1) Jinseok Cha, Ph.D. candidate

- Dissertation: Electroproduction of kaons and light hypernuclei in s shell.
- (2) Win Naing, Ph.D. candidate
Dissertation: Search for narrow states in the $^{12}_{\Sigma}\text{C}$ hypernuclear system.

Undergraduate Students Advised or Being Advised

- (1) Mr. Bonapate, (in the SEMS program)
Project: Construction of the MEGA electronics
- (2) Mr. McCloud, (in SEMS program)
Project: Construction of the MEGA electronics
- (3) Ms Leslie Simpson, (in the UNIPHY program)
Project: Magnetic spectrometer field test
- (4) Mr. Kenneth Williams, (in the UNIPHY program)
Project: Magnetic spectrometer field test
- (5) Mr. Tege Marques (Physics Major)
Project: Construction of the Low Pressure Multi-wire Proportional Chamber
- (6) Mr. Nyuiawodze Alover (Physics Major)
Project: Construction of the Low Pressure Multi-wire Proportional Chamber

PUBLICATIONS AND TECHNICAL REPORTS

- (1) "K⁺ Elastic Scattering from C and ⁶Li at 715 MeV/c", R. Michael, M.B. Barakat, S. Bart, R.E. Chrien, B.C. Clark, D.J. Ernst, S. Hama, K.H. Hicks, Wendy Hinton, E.V. Hungerford, M.F. Jiang, T. Kishimoto, C.M. Kormanyos, L.J. Kurth, L. Lee, B. Mayes, R.J. Peterson, L. Pinsky, R. Sawafta, R. Sutter, L. Tang, J.E. Wise, Phys. Lett. B382, 29-34 (1996); Nucl. Phys. A585, 121c (1995).
- (2) "Revised Geometry of the experiment E89-009", L. Tang and Ed.V. Hungerford, special report to JLAB large experiment review Committee, 1996
- (3) "Architecture of the MEGA Detector Trigger", Y.K.Chen, M.D. Cooper, P.S. Cooper, M. Dzemidzic, C.A. Gagliardi, G.E. Hogan, E.V. Hungerford, G.J. Kim, J.E. Knott, K.J. Lan, F. Liu, B.W. Mayes, R.E. Mischke, R. Phelps, L.S. Pinsky, K.M. Stantz, J.J. Szymanski, L.G. Tang, R.E. Tribble, X.L. Tu, Van Ausdeln, W. Von Witsch, C.S. Wright, Nucl. Instr. and Meth. A372, 195-206 (1996).
- (4) "Systematic Resolution Study of the CEBAF Hall C Spectrometers - HMS and SOS", L. Tang, C. Yan, Ed.V. Hungerford, Nuclear Instr. and Meth. in Physics Research A366, 259-262 (1995).
- (5) "Do Narrow Σ Hypernuclear States Exist?", K. Baker, M. Barakat, S. Bart, R.E. Chrien, W. Franklin, T. Fukuda, K. Gross, R.S. Hayano, K. Hicks, E.V. Hungerford, B. Mayes, R. Michael, T. Nagae, W. Naing, I. Omata, S. Wissink, R. Sawafta, Y. Shimizu, L.G. Tang, I.J. Zhu, Nucl. Phys. A585, 103c (1995).
- (6) "MEGA: A Search for the Decay $\mu \rightarrow e\gamma$ ", J.J. Szymanski, J.F. Amann, K. Baker, D. Barlow, K. Black, R.D. Bolton, M. Brooks, S. Carius, Y. Chen, M.D. Cooper, P.S. Cooper, J. Crocker, M. Dzemidzic, R.J. Fisk, J. Flick, W. Foreman, C.A. Hogan, E.B. Hughes, E.V. Hungerford III, K. Johnston, C. Jui, G.J. Kim, J.E. Knott, D.D. Koetke, M.A. Kroupa, T. Kozlowski, K. Lan, D. Lee, F. Liu, R. Manweiler, R. Marshall, B.W. Mayes II, R.E. Mischke, F.J. Naivar, B.M.K. Nefkens, J. Novak, M.A. Oothoudt, J.N. Otis, R. Phelps, L.E. Piilonen, C. Pillai, L. Pinsky, J. Price, M.W. Ritter, S. Schilling, T.D.S. Stanislaus, K.M. Stantz, W. Stephens, J. Sturrock, L.G. Tang, B. Tippens, R.E. Tribble, X.L. Tu, L.A. Van Ausdeln, W. von Witsch, D. Whitehouse, C. Wilkinson, B. Wright, S.C. Wright, Y. Zhang, W. Zhou, X.G. Zhou, and K.O.H. Ziock, Conference Proceedings, AIP Conference Proceedings 338, 289(1995).
- (7) "Construction of MEGA Photon Detector", M. Barakat, Y. Chen, S. Conrad, M. Cooper, M. Dzemidzic, J.A. Flick, C. Gagliardi, E.V. Hungerford, K. Johnston, G.J. Kim, K. Lan, F. Liu, Y.C. Lu, B.W. Mayes, R. Mischke, R. Phelps, L.S. Pinsky, D. Semon, R.E. Tribble, L.G. Tang, X.L. Tu, L. van Ausdeln, W. Von Witsch, H.Z. Wang, X. Yao, W. Yi, Nucl. Instr. and Meth. A349, 118-137 (1994).

- (8) "A possible incorporation of the MRS spectrometer or its modified high resolution version to the new AGS 1-2 GeV/c separated beam line for hypernuclear physics experiment at BNL", L. Tang, C. Yan, P.H. Pile, and H.A. Thiessen, CEBAF Tech. Note, TN-94-050, (1994).
- (9) "High Resolution Short-Orbit-Spectrometer - A Modified Version of SOS", L. Tang and C. Yan, CEBAF Tech. Note, TN-94-015, (1994).
- (10) "Search for a strangeness -1 dibaryon below the ΣN threshold", K. Johnston, E.V. Hungerford, T. Kishimoto, B.W. Mayes, L.G. Tang, S. Bart, R.E. Chrien, L. Lee, P.H. Pile, R. Sutter, K. Hicks, T. Fukuda, R. Krauss, D.R. Gill, R. Stearns, and H. Seyfarth, Phys. Rev. C46, R1573-1576 (1992).
- (11) "Hypernuclear Spectrometer System (HNSS) at CEBAF, L.Tang, American Institute of Physics, Conference proceedings No. 51, 269 (1992).
- (12) "Hypernuclear Physics Program at CEBAF and the Spectrometer System (HNSS) Design Report on the Electron Spectrometer", L.Tang, program review report sent to National Science Foundation, (April, 1992).
- (13) "Study of Hypernuclei by Associated Production", P.H. Pile, S. Bart, R.E. Chrien, D.J. Millener, R.J. Sutter, N. Tsoupas, J.-C. Peng, C.S. Mishra, E.V. Hungerford, T. Kishimoto, L.-G. Tang, W.von Witsch, Z. Xu, K. Maeda, D. Gill, R. McCrady, B. Quinn, J. Seydoux, J.W. Sleight, R.L. Stearns, H. Plendl, A. Rafatian, and J. Reidy, Phys. Rev. Lett. 66, 2585(1991).
- (14) "Nonleptonic weak decay of ^4He and ^{12}C ", J.J.Szymanski, P.D. Barnes, G.E. Diebold, A. Eisenstein, G.B. Franklin, R. Grace, D.W. Hertzog, C.J. Maher, B.P. Quinn, R. Rieder, J. Seydoux, and W.R. Wharton, S. Bart, R.E. Chrien, P. Pile, R. Sutter, and Y. Xu, R. Hackenburg, E.V. Hungerford, T. Kishimoto, and L.G. Tang, B. Bassalleck, R.L. Stearns, Phys. Rev. C43, 849-862 (1991).
- (15) "A Monte Carlo Study of the Resolution Limits in a Lead-Streamer Tube Photon Shower Counter", L.G. Tang and E.V. Hungerford, Nucl. Instr. and Meth. A287, 407-412(1990).
- (16) "Observations of hyperon-nucleus system produced on ^{12}C and ^7Li targets using the (K^-, π^+) reaction at 715 MeV/c", L. Tang, E. Hungerford, T. Kishimoto, B. Mayes, and L. Pinsky, S. Bart, R. Chrien, P. Pile, and R. Sutter, P. Barnes, G. Diebold, G. Franklin, D. Hertzog, B. Quinn, J. Seydoux, and J. Szymanski, T. Fukda, R. Stearns, Phys. Rev. C38, 846 (1988).
- (17) "A search for Narrow States in the Antineutron-Proton Total and Annihilation Cross Sections Near NN Threshold", T. Armstrong, C. Chu, J. Clement, C. Elinon, M. Furic, K. Hartman, A. Hicks, E. Hungerford, T. Kishimoto, J. Kruk, R. Lewis, D. Lowenstein, W.

Lochstet, B. Mayes, B. Moss, G. Mutchler, L. Pinsky, G.A. Smith, L. Tang, W. von Witsch and Y. Xue, Phys. Lett. B175, 383(1986).

- (18) "Experimental Study of Heavy Charged Leptons and Search for Scalar Partners of Muons At PETRA (12 GeV \sqrt{s} < 36.7 GeV)", D.P. Barber, U. Becker, G.D. Bei, G. Berghoff, A. Boehm, J.G. Branson, D. Buikman, J.D. Burger, M. Capell, C.C. Chang, H.S. Chen, M. Chen, C.P. Cheng, Y.S. Chu, R. Clare, P. Duinker, G.Y. Fang, Z.Y. Feng, H.S. Fesefeldt, D. Fong, M. Fukushima, J.C. Guo, A. Hariri, G. Herten, M.C. Ho, T.T. Hsu, D.Z. Jiang, R.W. Kadel, W. Krenz, J. Li, Q.Z. Li, D. Luckey, E.J. Luit, C.M. Ma, D.A. Ma, G.G.G. Massaro, T.Matsuda, H. Hewman, M. Pohl, F.P. Poschmann, J.P. Revol, M. Rohde, H. Rykaczewski, I. Schulz, K. Sinram, M. Steuer, H.W. Tang, L.G. Tang, D. Teuchert, Samuel C.C. Ting, K.L. Tung, F. Vannucci, X.R. Wang, Y.X. Wang, J. Warnock, M. White, G.H. Wu, S.X. Wu, T.W. Wu, P.C. Yang, C.C. Yu, N.L. Zhang, and R.Y. Zhu, Phys. Rev. Lett. 45, 1905(1980).
- (19) "Unique Solution for the Weak Neutral Current Coupling Constants in Purely Leptonic Interactions", D.P. Barber, U. Becker, G. Berghoff, A. Boehm, J.G. Branson, J. Bron, D. Buikman, J.D. Burger, C.C. Chang, H.S. Chen, M. Chen, C.P. Cheng, Y.S. Chu, R. Clare, P. Duinker, G.Y. Fang, H.S. Fesefeldt, D. Fong, M. Fukushima, J.C. Guo, A. Hariri, G. Herten, M.C. Ho, H.K. Hsu, T.T. Hsu, R.W. Kadel, W. Krenz, J. Li, Q.Z. Li, M. Lu, D. Luckey, C.M. Ma, D.A. Ma, G.G.G. Massaro, T.Matsuda, H. Hewman, M. Pohl, F.P. Poschmann, J.P. Revol, M. Rohde, H. Rykaczewski, K. Sinram, H.W. Tang, L.G. Tang, D. Teuchert, Samuel C.C. Ting, K.L. Tung, F. Vannucci, X.R. Wang, J. Warnock, P.S. Wei, M. White, G.H. Wu, T.W. Wu, J.P. Xi, P.C. Yang, C.C. Yu, X.H. Yu, N.L. Zhang, and R.Y. Zhu, Phys. Lett. B95, 149(1980).
- (20) "Search for the Production of a New Quark Flavor at the c.m.-System Energy Between 33 and 35.8 GeV", D.P. Barber, U. Becker, H. Benda, A. Boehm, J.G. Branson, J. Bron, D. Buikman, J.D. Burger, C.C. Chang, H.S. Chen, M. Chen, C.P. Cheng, Y.S. Chu, R. Clare, P. Duinker, G.Y. Fang, H.S. Fesefeldt, D. Fong, M. Fukushima, J.C. Guo, A. Hariri, G. Herten, M.C. Ho, H.K. Hsu, T.T. Hsu, R.W. Kadel, W. Krenz, J. Li, Q.Z. Li, M. Lu, D. Luckey, C.M. Ma, D.A. Ma, G.G.G. Massaro, T.Matsuda, H. Hewman, M. Pohl, F.P. Poschmann, J.P. Revol, M. Rohde, H. Rykaczewski, K. Sinram, H.W. Tang, L.G. Tang, Samuel C.C. Ting, K.L. Tung, F. Vannucci, X.R. Wang, P.S. Wei, M. White, G.H. Wu, T.W. Wu, J.P. Xi, P.C. Yang, C.C. Yu, X.H. Yu, N.L. Zhang, and R.Y. Zhu, Phys. Rev. Lett. 44, 1722(1980).
- (21) "Tests of Quantum Chromodynamics and a Direct Measurement of the Strong Coupling Constant α_s at $\sqrt{s} = 30$ GeV", D.P. Barber, U. Becker, H. Benda, A. Boehm, J.G. Branson, J. Bron, D. Buikman, J.D. Burger, C.C. Chang, H.S. Chen, M. Chen, C.P. Cheng, Y.S. Chu, R. Clare, P. Duinker, G.Y. Fang, H.S. Fesefeldt, D. Fong, M. Fukushima, J.C. Guo, A. Hariri, G. Herten, M.C. Ho, H.K. Hsu, T.T. Hsu, R.W. Kadel, W. Krenz, J. Li, Q.Z. Li, M. Lu, D. Luckey, C.M. Ma, D.A. Ma, G.G.G. Massaro, T.Matsuda, H. Hewman, M. Pohl, F.P. Poschmann, J.P. Revol, M. Rohde, H. Rykaczewski, K. Sinram, H.W. Tang, L.G. Tang, Samuel C.C. Ting, K.L. Tung, F.

Vannucci, X.R. Wang, P.S. Wei, M. White, G.H. Wu, T.W. Wu, J.P. Xi, P.C. Yang, X.H. Yu, N.L. Zhang, and R.Y. Zhu, Phys. Lett. B89, 139(1979).

- (22) "Test of Universality of Charged Leptons", D.P. Barber, U. Becker, H. Benda, A. Boehm, J.G. Branson, J. Bron, D. Buikman, J.D. Burger, C.C. Chang, H.S. Chen, M. Chen, C.P. Cheng, Y.S. Chu, R. Clare, P. Duinker, G.Y. Fang, H.S. Fesefeldt, D. Fong, M. Fukushima, J.C. Guo, A. Hariri, G. Herten, M.C. Ho, H.K. Hsu, T.T. Hsu, R.W. Kadel, W. Krenz, J. Li, Q.Z. Li, M. Lu, D. Luckey, D.A. Ma, C.M. Ma, G.G.G. Massaro, T. Matsuda, H. Hewman, J. Paradiso, F.P. Poschmann, J.P. Revol, M. Rohde, H. Rykaczewski, K. Sinram, H.W. Tang, L.G. Tang, Samuel C.C. Ting, K.L. Tung, F. Vannucci, X.R. Wang, P.S. Wei, M. White, G.H. Wu, T.W. Wu, J.P. Xi, P.C. Yang, X.H. Yu, N.L. Zhang, and R.Y. Zhu, Phys. Rev. Lett. 43, 1915(1979).
- (23) "Discovery of Three-Jet Events and a Test of Quantum Chromodynamics at PETRA", D.P. Barber, U. Becker, H. Benda, A. Boehm, J.G. Branson, J. Bron, D. Buikman, J.D. Burger, C.C. Chang, H.S. Chen, M. Chen, C.P. Cheng, Y.S. Chu, R. Clare, P. Duinker, G.Y. Fang, H.S. Fesefeldt, D. Fong, M. Fukushima, J.C. Guo, A. Hariri, G. Herten, M.C. Ho, H.K. Hsu, T.T. Hsu, R.W. Kadel, W. Krenz, J. Li, Q.Z. Li, M. Lu, D. Luckey, D.A. Ma, C.M. Ma, G.G.G. Massaro, T. Matsuda, H. Hewman, J. Paradiso, F.P. Poschmann, J.P. Revol, M. Rohde, H. Rykaczewski, K. Sinram, H.W. Tang, L.G. Tang, Samuel C.C. Ting, K.L. Tung, F. Vannucci, X.R. Wang, P.S. Wei, M. White, G.H. Wu, T.W. Wu, J.P. Xi, P.C. Yang, X.H. Yu, N.L. Zhang, and R.Y. Zhu, Phys. Rev. Lett. 43, 830(1979).
- (24) "Study of Electron-Positron Collisions at the Highest PETRA Energy", D.P. Barber, U. Becker, H. Benda, A. Boehm, J.G. Branson, J. Bron, D. Buikman, J.D. Burger, C.C. Chang, H.S. Chen, M. Chen, C.P. Cheng, Y.S. Chu, R. Clare, P. Duinker, G.Y. Fang, H.S. Fesefeldt, D. Fong, M. Fukushima, J.C. Guo, G. Herten, M.C. Ho, K.K. Hsu, T.T. Hsu, R.W. Kadel, W. Krenz, J. Li, Q.Z. Li, M. Lu, D. Luckey, D.A. Ma, C.M. Ma, G.G.G. Massaro, T. Matsuda, H. Hewman, J. Paradiso, F.P. Poschmann, J.P. Revol, M. Rohde, H. Rykaczewski, K. Sinram, H.W. Tang, L.G. Tang, Samuel C.C. Ting, K.L. Tung, F. Vannucci, X.R. Wang, P.S. Wei, M. White, G.H. Wu, T.W. Wu, J.P. Xi, P.C. Yang, X.H. Yu, N.L. Zhang, and R.Y. Zhu, Phys. Lett. B85, 463(1979).

INVITED TALKS AND POSTER PRESENTATIONS

- (1) Tohoku University and the Laboratory for Nuclear Science in Japan, June 1996, "CEBAF and its Hypernuclear programs".
- (2) BNL AGS Year 2000 Workshop, BNL, NY, May 1996, "A Superconducting Circular Dipole Spectrometer, S2S, for S=-1 and -2 hypernuclear experiments at D line of AGS".
- (3) JLAB PAC meeting, program defense, January 1996, "Direct Measurement of the Lifetime of the Heavy Hypernuclei at CEBAF".

- (4) International Nuclear Physics Conference of 1995, Beijing, P.R. China, August 1995, "High Resolution Hypernuclear Spectroscopy Program Using (e,e'K) Reaction at CEBAF Hall C". (Poster)
- (5) Louisiana Tech University, Ruston, LA, December 1994, "Concepts of Hypernuclear Physics and CEBAF experiment".
- (7) Los Alamos Meson Physics Facility, Los Alamos, NM, August 1994, "Optical and Resolution Study report on the AGS 2 GeV/c beam line and MRS spectrometer".
- (8) BNL Hypernuclear Experimental Collaboration meeting, during 1994 International Conference on Hypernuclear and Strangeness Particle Physics, Vancouver, Canada, July 1994, "MRS and its modified version for the AGS new 2 GeV/c beam line".
- (9) Brookhaven National Laboratory, Upton, NY, May 1994, "Possible Modification on the MRS Spectrometer Build at LAMPF for Higher Resolution Experiment at AGS of BNL".
- (10) Hampton University, Hampton, VA, May 1994, "CEBAF Hall C Hypernuclear Physics Program".
- (11) Continuous Electron Beam Accelerator Facility, Newport News, VA, March 1994, "Preparation process for the Hall C Hypernuclear Experiment".
- (12) Continuous Electron Beam Accelerator Facility, Newport News, VA, January 1993, "Design of the CEBAF Hall C Hypernuclear Experiment and Preparation".
- (13) Continuous Electron Beam Accelerator Facility, Newport News, VA, January 1993, "CEBAF Hall C Hypernuclear Spectrometer System and Its Detector System".
- (14) Continuous Electron Beam Accelerator Facility, Newport News, VA, November 1992, "Hypernuclear Spectrometer Design and Construction Plan".
- (15) Hampton University, Hampton, VA, October 1992, "Experimental Research Programs on Strangeness Particle and Hypernuclear Physics at NuHEP Center of Excellence of Hampton University".
- (16) Continuous Electron Beam Accelerator Facility, Newport News, VA, June 1992, "Progress Report on E89-009 Design".
- (18) Hampton University, Hampton, VA, April 1992, "Hypernuclear Physics and the Experimental Research Program at CEBAF Hall C".
- (19) Continuous Electron Beam Accelerator Facility, Newport News, VA, January 1992, "Conceptual Design of A Spectrometer System for CEBAF Hall C E89-009".

- (20) Continuous Electron Beam Accelerator Facility, Newport News, VA, August 1990, "Future of the Hypernuclear Physics: CEBAF".
- (21) Continuous Electron Beam Accelerator Facility, Newport News, VA, August 1990, "MEGA experiment at LAMPF and its Detector System".
- (22) APS Fall Meeting of Nuclear Physics Division, Houston, TX, October 1988, "Lead-Streamer Tube Photon Detector".
- (23) Continuous Electron Beam Accelerator Facility, Newport News, VA, June 1988, "Design of Aerogel Cherenkov Detector".
- (24) University of Houston, Houston, TX, March 1987, "Search for Possible Narrow Σ -Hypernuclear States above Production Threshold at AGS of BNL".
- (25) Brookhaven National Laboratory, Upton, NY, March 1985, "Target Hodoscope for Decay π^0 Tagging in the Final State for Σ -nucleus System".