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**A 1-2 GeV/c Beam Line for
Hypernuclear and Kaon Research**

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Abstract

A kaon beam line operating in the range from 1.0 to 2.0 GeV/c is proposed. The line is meant for kaon and pion research in a region hitherto inaccessible to experimenters. Topics in hypernuclear and kaon physics of high current interest include the investigation of doubly strange nuclear systems with the K^-, K^+ reaction, searching for dibaryon resonances, hyperon-nucleon interactions, hypernuclear γ rays, and associated production of excited hypernuclei. The beam line would provide separated beams of momentum analyzed kaons at intensities greater than 10^6 particles per spill with a momentum determined to one part in a thousand. This intensity is an order of magnitude greater than that currently available.

Preface

This document was prepared with the intention of proposing a facility for hypernuclear research and describing its justification. A brief historical overview of the field is given, with a special emphasis on the contributions of the collaboration using the Brookhaven National Laboratory Alternating Gradient Synchrotron (BNL AGS). After a brief description of presently existing facilities for hypernuclear research, a broad outline of possible future experiments is developed. Finally, a separated kaon beam facility capable of executing those possible experiments is described.

This proposal has been assembled with important contributions and advice from several sources. The development of the beam line design of Section V is due to Philip Pile of Brookhaven and Harald Enge of MIT. However, the design represents the culmination of several years of informal discussions among various individuals. These discussions have included D. Lazarus, ENL; H. A. Thiessen, LANL; E. Hungerford, Houston; P. D. Barnes, CMU; D. Lobb and J. Doornbos, TRIUMF; A. Kusumegi, KEK; and many others.

The discussion of Section IV on the future research possibilities has drawn heavily on the ideas of E. V. Hungerford, P. D. Barnes, A. T. M. Aerts, C. B. Dover, M. V. Hynes, and B. Povh, and their co-workers.

The author would like to stress that the achievements described in the historical survey of Section I have depended on the close and stimulating collaboration among the intermediate energy group at BNL and groups from Carnegie-Melon University, the University of Houston, Massachusetts Institute of Technology, Los Alamos National Laboratory, the University of New Mexico, Brandeis, Vassar, New York University, Rutgers, Florida State, the University of Torino, Princeton, William and Mary, Florida State, and the University of Texas.

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I. Description of Hypernuclear Research

I.1. What are hypernuclei and why are they interesting?

The study of hypernuclei started a little more than 30 years ago, when the first evidence for stable hypernuclear formation was discovered by Danysz and Pniewski.¹ Yet today, hypernuclei are still considered a "frontier area" of nuclear physics and worthy of study. The rate of progress through these three decades has been relatively slow, compared to other fields of research, and this slow rate is largely attributable to the lack of suitably intense beams for producing strange particles.

The study of hypernuclei—that is, nuclei in which one or more of the nucleons have been replaced by hyperons—allows us to study the effective interaction between baryons and how that interaction is influenced by the additional strangeness degrees of freedom that hyperons possess.

The difference between nucleon-nucleon and nucleon-hyperon forces must be explainable in terms of the meson exchange forces between those objects and ultimately perhaps in terms of the quark makeup of the baryons. While the nucleon-nucleon interaction has been thoroughly examined over the past years, a unique description in terms of a specific boson exchange model has not been achievable. It is probable that the quark structure of the nucleon may play an important role in the theoretical description of these strongly interacting systems, and that one must consider quark and gluon contributions to the boson exchanges.

To distinguish the roles of quarks and boson exchanges one might conceivably make use of the different quark flavors; the only one which is readily available, in addition to the up and down flavors of ordinary nucleons, is that of strangeness. The mass difference between the heavier strange quark and the other quarks affects the dynamics of the hyperon-nucleon interaction.

It is thus of interest to compare the interaction of strange and non-strange baryons and arrive at a more fundamental understanding of hadronic forces.

At the present time, the research in hypernuclei is at a critical phase, one in which decisions affecting its future must be taken. During the seventies and early eighties kaon beam lines for hypernuclear studies were created at the CERN PS (1973) and the BNL AGS (1978). At the beginning of the present decade, a kaon line at the 12 GeV KEK accelerator was commissioned (1980), and a low momentum line at CERN was tested (1980). Because of conflicting priorities among particle and nuclear physics programs, the CERN program has been terminated and only the BNL AGS line and the KEK K-2 line remain active. Thus very limited facilities exist for hypernuclear research. One may legitimately conclude that there is a mismatch between the facilities capable of performing this research, and the interest in it.

I.2. Fundamentals and Early Work

Let us consider the Λ hyperon with $Q=0$, $I=1/2$, $T=0$. With a strangeness of $S=-1$ it is the lightest of the hyperons, and by virtue of strangeness conservation in strong interactions, it can decay only by the weak interaction:

$$\Lambda \rightarrow p + \pi^- \approx 64\%$$

$$\text{or } \Lambda \rightarrow n + \pi^0 \approx 36\%$$

Its properties can be compared to that of the nuclear analog, the neutron,

	Λ	n
charge	0	0
mass	1115.6 MeV	939.57 MeV
spin	1/2	1/2
isospin	0	1/2
lifetime*	2.6×10^{-10} s	925 s
strangeness	-1	0

*mean life

The 260×10^{-12} sec is to be compared to the lifetime of a nuclear state. For example a nuclear state at an excitation of $\sim 7-8$ MeV has a decay width in the order of 1 eV, and by the uncertainty principle

$$\Delta E \Delta t \sim h \sim 6.6 \times 10^{-16} \text{ eV-sec},$$

this corresponds to a lifetime, Δt , of about 10^{-15} seconds. Thus the Λ hyperon lives for about a thousand nuclear lifetimes.

If, in the reaction

we replace the nuclear neutron by a Λ , the object so produced lives long enough to partake of nuclear motions. We call the resulting nucleus a "hyper-nucleus", a name suggested originally by Maurice Goldhaber².

In the quark picture the Λ hyperon differs from a proton and neutron in its possession of the strange s quark. The crucial questions of the study of hypernuclei focus on the issue: How do nuclear systems containing a strange hyperon differ from ordinary nuclei? What do these differences tell us about the fundamental nuclear force?

The discovery of a hypernucleus occurred in 1953, with a report by Danysz and Pniewski,¹ of the observation of the decay process such as is illustrated in a nuclear emulsion (Fig. I-1)³. A high energy particle produced a recoil hypernucleus, $\Lambda^7\text{Li}$, which after slowing down, a process requiring at least 10^{-12} sec, subsequently decayed with the emission of charged pions and nucleons.

For about 20 years our knowledge of hypernuclei was obtained through emulsions or bubble chambers, and they were identified by the characteristic decay through fragmentation. From a measurement of the decay products of light nuclei, a consistent picture of the binding energy of the hypernucleus in its ground state could be obtained. The hypernuclear binding energy shows

Fig. I-1. The formation and decay of $\Lambda^7\text{Li}$ through the (K^-, π^-) reaction on ^{16}O (from ref. 3).

a smooth dependence on A , and contrasts sharply with the neutron binding energy behavior, which looks wildly erratic, but is in fact related to the shell structure of the nucleus⁴ (Fig. I-2). This illustrates one very important difference between hypernuclei and ordinary nuclei. Since the Λ hyperon carries a strangeness quantum number of -1 , it is uninhibited by the Pauli principle and may occupy any nuclear orbit, whether filled with other nucleons or not. Thus in any hypernucleus, the ground state is one in which the Λ is found in the lowest, or $1s$ shell. The Λ separation energy will reflect only the depth of the nuclear well and will not depend at all on the extent of filling of the orbitals by other nucleons.

From emulsion data a value of 30 MeV is obtained for the single particle Λ potential well depth⁵, V_0 . This value of 30 MeV is significantly smaller than for the nuclear case, where $V_0 \approx 50$ MeV for low energy neutrons, and provided the first evidence that the Λ -nucleon interaction is significantly different from the nucleon-nucleon interaction. Except for some additional separation energy values measured since that time, the above information was all that was known about hypernuclei up to the 1970's.

At that time more intense beams of K-mesons became available to experimenters so that sophisticated counter experiments could be done to widen our knowledge of hypernuclei. Almost all of the experimental work in this area has been done at the CERN proton synchrotron and the Brookhaven AGS. These beams make it possible to exploit the characteristics of the reaction mechanism by which the Λ is formed:

Figure I-3 shows results obtained at CERN⁶ on the (K,π) reaction on Be and C showing the recoilless production of substitutional states, wherein the deposited hyperon assumes the quantum numbers of the nucleon it replaces. In the last decade there were three major advances in technique which allowed us to develop the spectroscopy of hypernuclei:

- 1) The use of recoilless production via the (K,π) reaction, as developed at CERN through the leadership of the Heidelberg Group.
- 2) The exploitation of angular distributions using the BNL "Moby Dick" spectrometer.
- 3) The successful observation of electromagnetic transitions in coincidence with the (K,π) reaction.

These techniques have allowed us to establish a sound basis for the understanding of the nuclear structure of light hypernuclei^{7,8}.

I.3. The AGS Program in Hypernuclear Research

A summary review of the PNL-AGS program is offered here with the intent of placing the beam line construction request in its proper context of a coherent, developing research field. It should be emphasized that these experiments were made possible by a close collaboration of a number of user groups from universities and national laboratories. These user groups have made essential contributions to the development of the hypernuclear spectrometer and to the evolution of the research in this area. The appendix to this document lists the experiments performed up to now with this facility, the spokesmen and their collaborators, and the resulting publications.

I.3.a. $^{12}\text{C}(K^-, \pi^-)_{\Lambda}^{12}\text{C}$ (AGS Exp. 646)

The AGS program produced its first results in an experiment on the study of the (K^-, π^-) reaction on ^{12}C , in which double-differential cross sections

Fig. I-2. Neutron (x) and lambda (•) separation energies compared.

Fig. I-3. Λ - and Σ -hypernuclear states formed by (K^-, π^-) on Be and C.

for the excitation of excited states in $\Lambda^{12}\text{C}$ were obtained⁹. They were the first experiment done anywhere in which the various multipole components in the reaction cross section leading to the formation of hypernuclear levels could be separated and they clearly showed the importance of obtaining the angular distributions for the outgoing pion. These angular distributions are shown in Fig. I-4. The data were very successfully analyzed with a DWIA calculation by Dover et al.¹⁰ for particle-hole excitations of the type $(s_{1/2}, p^{-1}_{3/2})_{\Lambda n}$, $(p_{3/2}, p^{-1}_{3/2})_{\Lambda n}$, $(p_{1/2}, p^{-1}_{3/2})_{\Lambda n}$, and $(s_{1/2}, s^{-1}_{1/2})_{\Lambda n}$. The contribution of each of these configurations to the observed cross section is a strong function of the momentum transfer, q . For example, the excitation of the ground state $(s_{1/2}, p^{-1}_{3/2})_{\Lambda n}$ configuration requires $\Delta L=1$, and consequently is small near 0° , and large near 15° . The states $(p_{3/2}, p^{-1}_{3/2})_{\Lambda n}$ and $(p_{1/2}, p^{-1}_{3/2})_{\Lambda n}$ contribute to a multiplet of $0^+, 2^+, 2^+$ excitations which lie very close together and are unresolvable with the magnetic spectrometer. However the 0^+ and 2^+ are strong functions of q (or θ). The 2^+ components produce a marked shoulder in the angular distribution from 10 to 20° , which is apparent from experiment. The energy and the width of the $0^+, 2^+, 2^+$ complex as compared to the 1^- ground state showed no discernable variation with angle and this fact places constraints on the spin-dependent Λ nucleus interactions.

I.3.b. $\underline{{}^{13}\text{C}(K^-, \pi^-){}^{13}_{\Lambda}\text{C}}$ (AGS Exp. 746)

This experiment produced the most complex set of hypernuclear levels yet examined and provided grounds for a fully consistent spectroscopic analysis in terms of a sophisticated shell model treatment with a general ΛN force⁷. The experiment provided a direct measure of the weakness of the Λ -nucleus spin-orbit potential. The spectra obtained in the experiment¹¹ (Fig. I-6) bear a

Fig. I-4. Angular distributions and nuclear structure for low-lying states of ^{12}C .

Fig. I-5. The spectrum of (K^-, π) -on ^{13}C compared to proton pick-up reaction on ^{13}C .

Fig. I-6. Low-lying levels of $\Lambda^{13}\text{C}$. The size and spacing of the peaks and their variation with scattering angle helps determine the nature of the residual Λ -N interaction.

resemblance to the neutron pickup reaction $^{13}\text{C}(p,d)^{12}\text{C}$; in the weak-coupling limit, the spectra could be reconstructed by superposing the neutron pick-up spectra shifted by the 11 MeV p to s Λ shell spacings observed in the $\Lambda^{12}\text{C}$ case (Fig. I-5). At 0° the spectrum consists largely of a p-shell Λ coupled to core excited states; at 15° it has a large component of an s-shell Λ coupled to those states. Yet there are significant differences with the pick-up reaction and these differences can be related to the Λ -nucleon residual potential. The analysis of the $\Lambda^{13}\text{C}$ data at angles of 0° and 15° (Fig. I-6) by the BNL Theory Group⁷ indicates that all measured energy splittings can be satisfied by a value for the Slater integral $F(2)$, a measure of the quadrupole-quadrupole effective interaction, $V_{\text{eff}} = F(2)Q_\Lambda \cdot Q_n$, with,

$$-3.4 < F(2) < -3.0 \text{ MeV},$$

and, for the spin-orbit splitting,

$$\Delta E(p_{1/2} - p_{3/2}) = 0.5 \text{ MeV}.$$

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These values are much smaller than the corresponding nuclear values of -10 and 6 MeV , respectively. These differences reflect the presence of the strange quark. In the naive quark model of Pirner, the spin-orbit coupling of the Λ , Σ , N , or Δ in the nucleus is just the sum of the individual spin-orbit couplings of the u and d quarks of the baryon to the nuclear core. This model yields a vanishing spin-orbit potential for the Λ . Meson exchange models also yield small Λ spin-orbit forces.

I.3.c. Electromagnetic Hypernuclear Transitions (AGS Exps. 760 and 781)

The fact that the spin-dependent Λ -nuclear interactions appear to be small places severe demands on the magnetic resolving power of hypernuclear spectrometers. In fact it does not appear to be practical to construct instruments, operating with available beam intensities, capable of resolving hypernuclear multiplets. Electromagnetic transitions detected in coincidence with the (K, π) reaction, however, allow the separation of specifically selected final states in a hypernuclear system whose initial state is reasonably well defined by the spectrometer. These $(K^-, \pi^+ \gamma)$ experiments were made possible at BNL by a modification of the original Moby Dick spectrometer, which allow kaon intensities of up to 10^5 kaon/spill on target.

The $(K^-, \pi^+ \gamma)$ technique made possible a complete characterization of the Λ -N effective 2-body interaction in the p-shell. In p-shell hypernuclei there are only a relatively few bound states which qualify for γ -emission and so the spectra are relatively simple. Most of the excitations available for study belong to the configuration $\{(1S)^4_N (1P)^{A-5}_N (1S)_\Lambda\}$; that is, the Λ is present in the s-shell, and the reaction proceeds via an orbital angular momentum transfer, $\Delta L=1$.

The γ -ray transitions can be divided into two classes, depending on the role of the Λ :

1) spin-flip doublet transitions - These are M1 transitions connecting the members of the hypernuclear doublet built on a core state. In this type the Λ spin is flipped with respect to the core spin.

2) core transitions - In this type the γ -ray transition connects core states, and the Λ plays the role of a spectator (whose presence, however, perturbs the core states).

Dalitz and Gal¹², and more recently Millener et al.⁸, have performed a phenomenological analysis using a Λ -N potential model to determine a set of four $P_N S_\Lambda$ two-body matrix elements to describe the spin-dependent ΛN interaction in the p-shell. The two-body interaction can be expressed as follows:

$$V_{\Lambda N} = V_0(r) + V_\sigma(r) \underline{S}_N \cdot \underline{S}_\Lambda + V_\Lambda(r) \underline{l}_{N\Lambda} \cdot \underline{S}_\Lambda + V_{N\Lambda} \underline{l}_{N\Lambda} \cdot \underline{S}_N + V_T(r) S_{12} \quad (5)$$

with $\underline{l}_{N\Lambda}$ the relative orbital angular momentum, and

$$S_{12} = 3(\underline{\sigma}_\Lambda \cdot \hat{r})(\underline{\sigma}_N \cdot \hat{r}) - \underline{\sigma}_N \cdot \underline{\sigma}_\Lambda; \quad r = |\underline{r}_N - \underline{r}_\Lambda|.$$

The potential parameters are referred to as the overall central potential V , the spin-spin term Δ , the Λ spin orbit S_Λ , the induced nuclear spin-orbit S_N , and the tensor T . These parameters are assumed constant across the p-shell. The average central interaction has no effect on spectra, while the S_N (induced spin orbit) affects the spacing of the core states.

As can be seen from eq. 5, measurements of several hypernuclei ranging across the p-shell can serve to fix these parameters unambiguously. The Λ spin-orbit parameter S_Λ is known to be small and negative from previous

(K, π) results of CERN¹³ and Brookhaven¹¹. The most uncertain parameter is T, which has been estimated by Millener et al.⁸ to be small and positive. As Dalitz and Gal¹² have previously observed, the most promising test for T comes from measuring hypernuclear doublet separations in the heavier p-shell hypernuclei, where the coefficient of T in the expression above is the largest.

In AGS experiment 760 core transitions (type 2 above) were observed for the first time in the (K⁻, π γ) reaction with an array of NaI detectors in $\Lambda^7\text{Li}$ and $\Lambda^9\text{Be}$ hypernuclei¹⁴. The spectra are illustrated in Figs. I-7 and I-8. These clearly show the 2.04 MeV γ ray (related to the $3^+ \rightarrow 1^+$ ^6Li core transition) and the 3.05 MeV γ ray (related to the $2^+ \rightarrow 0^+$ ^8Be core transition). The 1.1 MeV γ rays are attributed to the $\Lambda=4$ hypernuclear system¹⁵.

The close doublet spacing implied by the smallness of the Λ -nucleus spin dependent interactions means that the M-1 spin flip transitions connecting members of the doublet are low in energy. The detection of these γ rays was accomplished for the first time with a Ge-detector array in AGS experiment 781.^{16,17} Ground state doublet transitions were observed for $\Lambda^{10}\text{B}$ and $\Lambda^{16}\text{O}$, and the former case is illustrated in Fig. I-9.¹⁸

The results for these two experiments have provided important constraints on the p-shell Λ -nuclear effective interaction and offer hope that in the future, heavier hypernuclei might be examined with these techniques. The principal limitation, obvious from Fig. I-9, is counting rate. Clearly future advances in applying these techniques depend on access to kaon beams of improved intensity and purity.

I.3.d. Associated Production of Hypernuclei

It has been pointed out that in the exoergic (K⁻, π^-) reaction, the kinematics allow zero momentum transfer to the recoiling hypernucleus near $P_K = 530$ MeV/c. However, over quite a range of P_K from 500 to over 1000

Fig. I-7. Hypernuclear γ -ray spectra from ${}^7\text{Li}$, at various excitation energies from the ground state to 34 MeV. In these spectra, one may discern the 2.04 MeV hypernuclear transition (2), the 3.50 MeV nuclear γ ray from ${}^6\text{Li}$, and the 1.1 MeV γ rays from ${}^4\text{H}$ and ${}^4\text{He}$ (5,6).

Fig. I-8. Hypernuclear γ -ray spectra from $\Lambda^9\text{Be}$. The decays of the doublet near 3.05 MeV can be seen in spectrum (2). This doublet is much more closely spaced than is shown on the level scheme (ref. 12), and cannot be resolved in the spectrum.

MeV/c, the momentum transfer is small compared to the Fermi momentum characteristic of nucleons in the nucleus. High spin states formed of "stretched" configurations, in which the particle and hole coupling have maximum angular momentum, are of considerable interest in medium and heavy nuclei. These states are not easily formed in (K^-, π^-) reactions at small angles because of momentum matching considerations. It is of some interest, therefore, to explore the use of alternative reaction mechanisms.

One such alternative reaction involves the associated production of hyperons, namely the (π^+, K^+) reaction. The kinematics of (π^+, K^+) is compared to the complementary (K^-, π^-) reaction in Fig. I-10 for a ^{48}Ca target nucleus. One sees immediately that the momentum transfer is much higher over the whole incident momentum range from threshold, ≈ 700 MeV/c, to 1500 MeV/c. The figure shows the momentum match to states of various angular momenta, J . It is clear that the (π^+, K^+) preferentially produces states of higher spin than is the case for (K^-, π^-) .

The use of the (π^+, K^+) reaction to form hypernuclei was tested recently at the AGS in experiment 758 on ^{12}C .¹⁹ This nucleus was chosen since it had been well studied at Brookhaven with the (K^-, π^-) reaction. In that reaction, two peaks are clearly seen; the lower excitation peak is identified as the 1^- gs , produced by a $\Delta L=1$ transition which transforms a $p_{3/2}$ neutron into an $s_{1/2}$ Λ . Near 11 MeV is seen a peak which consists of several unresolved contributions with spins 0^+ and 2^+ arising from the components $[n^{-1}(p_{3/2}), \Lambda(p_{3/2})]$ and $[n^{-1}(p_{3/2}), \Lambda(p_{1/2})]$. The smallness of the Λ -nucleus spin-orbit interaction causes this complex of states to be nearly degenerate in energy. In using the (π^+, K^+) reaction to investigate $^{12}_\Lambda\text{C}$ one would expect to populate more effectively the higher spin members of the multiplet components.

Fig. I-9. Evidence for a spin-flip M1 transition in ^{10}B drawn from the recent AGS experiment #781.

Fig. I-10. Zero degree momentum transfers from the (K^-, π^-) and (π^+, K^+) reactions on ^{48}Ca compared.

The experiment was performed at 1050 MeV/c incident pion momentum to take advantage of the maximum in the elementary cross section for $\pi^+ + n \rightarrow K^+ + \Lambda$.

Data were recorded at spectrometer settings of 5° , 10° , and 15° . The data are shown for these angles as binned into 1 MeV excitation energy regions, in Fig. I-11. An examination of these the presence of at least two peaks together with a broad distribution characteristic of the quasi-free $\pi^+ + n \rightarrow \Lambda + K^+$ process. The two peaks observed are reminiscent of the peaks observed for carbon in the complementary (K^-, π^-) reaction.

Plots of the angular distributions obtained from the present experiment compared to DWBA calculations²⁰ are shown in Fig. I-12. A good agreement is evident after the DWBA predicted cross sections have been reduced by a factor of two to account for Fermi broadening.

These results confirm the feasibility of the (π^+, K^+) reaction as a spectroscopic tool for investigating hypernuclei. The overall running times for the accumulation of these spectra are roughly the same as those experienced for (K^-, π^-) . It is evident that the inherently lower cross sections have been compensated by the higher particle flux, and that the background components induced by the higher flux are manageable. In view of the recent successful detection of electromagnetic radiation for p-shell hypernuclei, it is natural to consider the extension of the present experiment to $(\pi^+, K^+ \gamma)$ reactions. Thus possibilities for a much more expanded field of hypernuclear research have been opened up. A beam line in the range of 1 to 2 GeV/c pion momentum, and a flux up to 10^7 particles/spill would allow the effective exploitation of this tool.

Fig. I-11. Excitation spectra for $_{\Lambda}^{12}\text{C}$ derived from the (π^+, K^+) reaction.

Fig. I-12. Predicted and measured differential cross sections for the (π^+, K^+) reaction on ^{12}C .

I.3.e. The Lifetime of the Λ Hyperon in Nuclear Matter (Exp. 759)

In the absence of nuclear matter, a Λ hyperon decays to a nucleon with a mean life of 263 ps, via the emission of a pion. The presence of nuclear matter introduces a competitive decay mode, the non-mesonic decay mode. The four branches are as follows:

$$\begin{array}{ll}
 \text{mesonic} & \Lambda \rightarrow \begin{cases} p + \pi^- + 36 \text{ MeV} \\ n + \pi^0 + 36 \text{ MeV} \end{cases} \\
 \text{non-mesonic} & \begin{cases} \Lambda + p \rightarrow n + p + 176 \text{ MeV} \\ \Lambda + n \rightarrow n + n + 176 \text{ MeV} \end{cases}
 \end{array}$$

The non-mesonic decay mode is of special interest because it affords the opportunity to study the weak component of the baryon-baryon interactions, or the four fermion weak interaction. This issue is closely related to the parity-violating processes in ordinary nuclei. Calculations of the decay rates have been carried out in the framework of mesonic exchange by McKellar and Gibson, and in terms of a two-baryon, 6 quark model, by Kisslinger et al.²¹ These calculations have offered a range of lifetimes between $\tau=1/3$ and $\tau=3 \tau_{\text{free}}$. Lifetime measurements from nuclear emulsion have been limited to light hypernuclei, and are too crude to shed much light on the four fermion weak interaction (Fig. I-13).

At BNL, the group led by scientists from Carnegie-Mellon University have demonstrated the feasibility of a direct measurement of the decay of the hypernucleus, in the case of $\Lambda^{12}\text{C}$.²²

The decay protons have been detected in a scintillation hodoscope situated near the ^{12}C target. A digital wire chamber forms part of the detector package and allows the proton trajectory to be reconstructed so that an accurate flight-time correction can be made.

The result of the experiment is shown in Fig. I-14. The time response function of the scintillation hodoscope has been measured with the (π^-, px) reaction and is shown to be Gaussian with a standard deviation, σ , of 140 ps. The time distribution from decay protons following hypernuclear formation via the (K^-, π^-) reaction, is shown on the figure for 270 analyzed decay events. The deduced lifetime is about 200 picoseconds with an error of about 10%.

The application of this technique has been proposed for the light systems, $\Lambda^4\text{He}$ and $\Lambda^5\text{He}$, with some improvements in this counter array which will allow measurement of the neutron and proton branching ratios. For these light systems it should be possible to extract the spin-isospin dependence of the four fermion weak interaction by using accurate nucleon wave functions.

I.3.f. Experimental Observation of Σ -Hypernuclei

Since the first observation of narrow Σ -hypernuclear states in the (K^-, π^-) reaction on ^9Be , there has been intense theoretical interest in the properties of such states, especially on their widths and spacings. The outstanding question on the Σ -widths is to explain their narrowness. Since the Σ is capable of strong decay to the Λ in the presence of nuclear matter, the very existence of narrow Σ states appears difficult to justify. Various mechanisms have been proposed^{23, 24, 51}, the selectivity mechanism results from the fact that Σ - Λ conversion proceeds mainly through a relative $J=1$, $T=1/2$ spin-isospin state, the other channels being suppressed.

Some support for this mechanism has arisen from the observation of Piekarz et al.²⁵ of a narrow state, at high excitation ($\approx 22\text{MeV}$) which appears in $\Sigma^6\text{H}$ ($\Sigma^- + ^5\text{He}$), formed by the (K^-, π^+) reaction on ^6Li (Fig. I-15). This state is attributed to an $S_N \rightarrow S_\Lambda$ substitutional excitation which is expected to be narrow according to the selectivity idea of Dover and Gal^{23, 51}.

Lifetime and Branching Ratio for Λ Hypernuclear Decay

Fig. I-13. Lifetime measurements for Λ hypernuclei.

Fig. I-14. A direct lifetime measurement for $\Lambda^{12}\text{C}$. The decay curve is consistent with a lifetime of ≈ 200 picoseconds.

The other outstanding issue for Σ -states is in the effective 2-body force between Σ and nucleon. Experimental data now exist for $\Sigma^{12}\text{C}$ and $\Sigma^{16}\text{O}$, and the several peaks visible in these spectra are interpreted to provide evidence for the Σ spin-orbit force in size and sign. A comparison between the Σ -N and Λ -N spin-orbit potentials (known to be small) might provide an interesting insight into the origin of the nuclear spin-orbit force. Indeed, predictions of naive quark models and meson exchange theories differ considerably.

Recent unpublished calculations by Gal indicate the ${}^7\text{Li}$ is a particularly favorable target for the extraction of the spin-orbit couplings. The determination is based on the difference between the $p_{3/2}$ and $p_{1/2}$ Σ contributions at reaction angles of 0° and 15° . An experiment (Exp 774) is in progress to determine the Σ -nucleus spin-orbit splitting for this case.

1.3.g. Dibaryon Resonances

The subject of quarks in nuclei is receiving increased theoretical attention. Are there any observable nuclear phenomena which would require an explanation in terms of a quark-bag model? Experiment 773 has addressed this question by examining the (K^-, π^-) reaction on deuterium.

Quark-bag models predict the existence of 6 quark states or dibaryon resonances interacting via gluon exchange, rather than separated color singlets interacting via mesons²⁶. Non-strange dibaryons may be difficult to detect because of their broadness caused by pionic decay channels. Strange dibaryons couple to ΛN or ΣN channels and lie closer to baryon-baryon thresholds than do their $S=0$ analogs. The lowest $S = -1$ resonance predicted lies near the 2.13 GeV Σ -N threshold and decays by $\ell=1$ particle emission²⁶. Cross sections for the formation of the dibaryon in the $(K^-\pi^-)$ reaction on deuterium have been estimated by Aerts and Dover²⁶, who have also argued that these states are very narrow. Indeed data taken with stopped kaons and

in-flight kaons indicate a rather poor fit to the threshold cusp known to exist at this energy²⁷ and a broader peak and a shoulder in the data indicate the possible presence of a resonance (Fig. I-16).

The ΣN system responsible for this cusp would be produced in the 1^3S state and thus the dependence of the cusp on momentum transfer would be different from the proposed dibaryon resonance. A key technique which is being exploited in this experiment is the positioning of a three-layered scintillation counter hodoscope around the deuterium target. This hodoscope is used to distinguish between the energetic protons or charged pions produced in the weak decay of a resonance, and the slow spectator proton produced by the quasi-free reaction transforming a target neutron into a Λ . The Λ quasi-free production background is an important and undesirable component of the background on which the presumed resonance sits.

This experiment is currently under analysis, and interesting structure in the region of the threshold cusp has been observed. This experiment, as well as the γ -ray studies, are examples of two-armed spectrometer studies, which in general produce much cleaner and informative spectra than the more inclusive single-arm studies. They are a part of "second generation" hypernuclear studies which require a coincidence with several existing particles and therefore need a much greater incident flux.

I.4. Future Directions for Research

It is apparent that we have made only a modest beginning on extracting the wealth of information potentially available from hypernuclei. Research possibilities may be divided into several categories: a) extension of present measurements to more nuclear targets for Λ hypernuclear studies; b) more detailed studies of Σ states through (K^-, π^-) and (K^-, π^+) reactions and their intercomparison; c) production of $S=-2$ hypernuclei including double Λ and

Fig. I-15. Σ -hypernuclear states in $\Sigma^- {}^6\text{H}$, derived from the (K^-, π^+) reaction on ${}^6\text{Li}$.

Fig. I-16. The region of the threshold cusp (on the right) for (K^-, π^-) on ${}^2\text{H}$. The structure on the right of the cusp is under investigation as a possible $S = -1$ dibaryon resonance (Exp. 773).

cascade hypernuclei; d) an exploitation of the (π^+, K^+) reaction for studies of states with high momentum components, e) studies of excited states of hyperons, such as the Y^* resonances and their decay modes; and f) the study of $S=-1$ and $S=-2$ dibaryon resonances and their relation to the exciting and challenging aspects of the role of quarks in nuclear models and the testing of various quark bag model calculations. Because of thresholds, cross sections, and reaction kinematics, a complete program of research on strange systems requires several different momentum ranges.

I.4.a. "Medium" Momentum Region 700-800 MeV/c

Conventional Λ -hypernuclear spectroscopy has been applied almost exclusively to the lightest nuclear systems. Further improvements in beam line and spectrometer design are required to explore heavier hypernuclei such as those in the s - d shell. For reasons of compromise among the conflicting factors of cross section, kaon flux, kaon decay, pion-kaon separation, and minimum momentum transfer, the optimum beam momentum for Λ hypernuclear studies is in the region 700-800 MeV/c. While the present LESB-1 beam line at the AGS may be adequate for such studies, clearly the present hypernuclear spectrometer does not have sufficient resolution to broaden the range of hypernuclear studies. A high-resolution, multi-gap spectrometer is desirable with a resolution of at least 0.05%. Furthermore sufficient beam time for hypernuclear work is unlikely to be available in the foreseeable future because of demands on this line for other experiments.

I.4.b. "Low" Momentum Region 400-600 MeV/c

The discovery of narrow Σ -states raises the possibility of a Σ -hypernuclear spectroscopy paralleling the Λ -hypernuclear effort. Of high current interest is the comparison of the Σ and Λ -nuclear spin-orbit interactions and their explanation in terms of relativistic mean-field or quark models.

Experimental data on Σ -states so far obtained has been rather limited--at CERN because of low flux, and at BNL because of too high a beam momentum and consequently too high a quasi-free background. The low momentum region 400-600 MeV/c will be ideal for Σ -hypernuclear research. A beam line for this momentum range does not currently exist. A very fine facility at the CERN PS (K-26) was discontinued in 1983; however a Heidelberg-KEK collaboration intends to carry out the construction of a facility for Σ -hypernuclear research at KEK.

1.4.c. "High" Momentum Region 1.0-2.0 GeV/c

Hypernuclear physics has so far been devoted to strange nuclei with $S=-1$. At momenta above about 1.1 GeV, strangeness changing reactions such as (K^-, K^+) which can produce nuclei with $S=-2$ become feasible. Such nuclei might contain a cascade particle (Ξ) or two Λ 's. There is meager evidence for both of these from nuclear emulsion experiments. There is much theoretical interest in dibaryon resonances and their relationship with quark-bag models. Dibaryon resonances with various strangeness quantum numbers have been predicted; perhaps the most interesting, however, is the H-particle proposed by Jaffe²⁸, which contains 6 quarks in an SU(3) flavor singlet. The H has $S=-2$ and might, for example, be produced in a (K^-, K^+) reaction on ^3He . Aerts and Dover have recently proposed²⁹ such an experiment in which the (K^-, K^+) reaction on a proton produces a cascade particle Ξ^- , which subsequently fuses with a second proton to form the H. The H could also be formed from a atomic state, for instance, in the process $\Xi^- + d \rightarrow H + n$ ²⁹.

These experiments with $S=-2$ nuclei require a beam line with a higher momentum than is currently available. The cross section for Ξ^- production on the free proton lies above 1 GeV/c; hence a line covering the range from 1-2 GeV would be optimal for exploitation of the (K^-, K^+) reaction. At the same

time, such a line would be suitable as a source of pions for the (π^+, K^+) and $(\pi^+, K^+ \gamma)$ studies.

In view of the existence of LESB-1, and the opportunities offered at KEK, it is our feeling that best way to improve hypernuclear research facilities is to construct a line offering separated kaons and pions in the 1.0 to 2.0 GeV/c region. This would complement existing facilities and help to offer a full range of options to the experimenter. It would play a decisive role in continuing hypernuclear research until the time when a next generation kaon factory is available.

II. Existing Facilities for Hypernuclear Research

II.1. The LESB1 Kaon Line at BNL/AGS

The LESB1 kaon beam line at the AGS was constructed circa 1970 and first used for hypernuclear physics in 1978³⁰. At that time a rotatable spectrometer consisting of a symmetric ($Q_1=8Q24$, $Q_2=12Q30$, $D=18D36$) $Q_1Q_2DQ_2Q_1$ sequence was placed before, and an identical $Q_1Q_2DQ_2Q_1$ placed after, the target position. The first spectrometer measures the incoming, the second the outgoing particle momentum. Figure II-1 shows the spectrometer configuration as it existed in the years 1978 through 1981. The target missing mass spectrum is reconstructed from the momentum difference measurements. The spectrometer was instrumented with a) multi-wire proportional counters at the spectrometer entrance, up and downstream of the target, and at the rear of the spectrometer; b) with a kaon differential Cerenkov counter at the spectrometer entrance and a pion veto Cerenkov counter near the target; and c) with timing scintillators at the entrance, target, and exit positions. The instruments b) and c) give excellent particle discrimination at an incident kaon momentum of 800 MeV/c, since the K, π flight time difference along the spectrometer path is more than 5 ns in each leg.

The important beam line and spectrometer parameters are given in Table II-1. The distance from the production target to the spectrometer target was about 22 meters. As can be seen from the table, about 6000 K^- per 10^{12} protons can be transmitted to the target; typically 3×10^{12} protons are put on the production target, yielding about 18000 kaons/sec. This rate was adequate for the initial hypernuclear experiments at the AGS; however for the measurement of partial cross sections involving coincident detection of multiple particles or photons it was inadequate (as were all other kaon lines).

Table II-1

A Comparison of the LESBL/Hypernuclear Spectrometer Parameters

pmax	<u>Pre-1982</u>	<u>Present</u>
beam line	1.1 GeV/c	1.1 GeV/c
spectrometer	0.9 GeV/c	1.1 GeV/c
$\Delta p/p$	$\pm 2\%$	$\pm 2\%$
Beam Length	22 m	15.2 m
Separation Ratio (800 MeV/c)	$10\pi^-/K^-$	$10\pi^-/K^-$
	$3\pi^+/K^+$	$3.5\pi^+/K^+$
Rates/ 10^{12} Proton	$6 \times 10^3 (K^-)$	$45 \times 10^3 (K^-)$
Rates (typical)	$18 \times 10^3 (K^-)$	$135 \times 10^3 (K^-)$
Spectrometer Resolution	0.1%	0.1%
$\Delta p/p$ Spectrometer Momentum Bite	6%	13%
Spectrometer Rotation	0-45°	-5-45°
$\Delta\Omega$	12msr	20msr

The spectrometer is mounted on a large motor driven rotatable platform called "Moby Dick" obtained originally from the Cambridge Electron Accelerator. The mount is capable of swinging from -5 to 45° , although no experiments have been done for lab angles greater than 30° .

An upgrading program was begun in 1981 and completed in 1983. The spectrometer was shortened by about 8 meters and the eight-inch diameter quadrupoles in the QQDQQ spectrometer sequence were replaced by 12-inch quads. The effect is to increase kaon flux on target (by reduced decay length), to increase the usable solid angle, and to increase the available momentum bite in the missing mass spectrum. The shortening is accomplished by incorporating the kaon analysis in the last dipole, D_3 , in the beam line, and by placing instrumentation for particle detection at the mass slit of the beam separator (Fig. II-2). For this purpose it was necessary to replace the MWPC counters by high rate, high spatial resolution drift chambers. The high spatial resolution is necessary since the magnification from the mass slit to the target has been decreased by a factor of three. The new detectors are capable of handling 10^6 particles/sec/wire and have a spatial resolution, σ , of about 200 microns. The parameters for the improved spectrometer are given also in Table II-1. Only through this upgrading has it become possible to do experiments such as the $(K, \pi\gamma)$. These experiments are not feasible either at KEK or at the old CERN beam lines.

Fig. II-1. The original "Moby Dick" spectrometer, first used at the AGS in 1977.

Fig. II-2. The modified LESBl-Moby Dick system used for hypernuclear studies after 1981. Only the elements following the LESBl separator are shown.

II.2. K2 and K3 Beam Lines at KEK

Two low-energy beam lines are in operation at the Japanese National High Energy Physics Laboratory, KEK³¹. The floor layout for these lines is depicted in Fig. II-3,4. The 12 GeV primary proton beam, under slow extraction, is split 3 ways vertically by a system which consists of an electrostatic splitter and two Lambertson-type magnets. Two beams are transported to the K2 and K3 targets for kaon experiments; the third is used for experiments with primary protons.

The K2 beam is designed to provide antiprotons and kaons in the momentum range 1-2 GeV/c, while the K3 beam is meant to provide such particles in the momentum range below 1 GeV/c. The attached tables (II.2 and II.3) provides the major specifications for lines K2 and K3, and the figures show the floor layouts for these lines.

Line K3 exists in two versions, K3-S and K3-L, the former optimized for low-momentum performance and the latter for higher momentum performance. The K3-S line is used primarily for the study of rare K^+ decay modes, while the K3-L line has been used for hypernuclear experiments with stopped K^- beams.

One crucial feature in the operation of those beam lines is the use of a unique separator design due to Yamamoto, Maki, and Kusumegi³². Unlike conventional separators, the KEK design has high voltage supplies mounted directly within the vacuum envelope of the separator. Thus the stored energy in the capacitance of cables and feedthroughs in the conventional design is avoided, and the damage due to occasional sparking is minimized. Operational gradients between the anodized aluminum and stainless steel plates of the separator of 75 kV/cm have been achieved. At these high fields, it becomes inadvisable to incorporate the magnetic field in the same spatial region as the electric field; the magnetic field induces a greater probability of discharge due to

Fig. II-3. The K-2 beam line at KEK.

Fig. II-4. The K-3 beam line at KEK.

Table II.2. Beam Characteristics for K2

	K2
Momentum range	1.0 - 2.1 GeV/c
Target	6 mm diam. 60 mm long Pt
Central production angle	0°
Beam length	28.9 m
Solid angle acceptance	1.02 msr
Horizontal acceptance	±50 mr
Vertical acceptance	±6.5 mr
Momentum bite	±3%
Solid angle momentum acceptance	6.25 msr% $\Delta P/P$
Electrostatic separator	6.0 m long, 10 cm gap, 60-70 kV/cm
Characteristics at beam end	
Horizontal magnification	2.4
Dispersion	0.0
Vertical magnification fwhm	2.6
Horizontal image size	22 mm
Vertical image size fwhm	23 mm
Horizontal divergence	27 mr
Vertical divergence	3.6 mr
Yields measured for 10 ¹² PPP	
2.1 GeV/c K ⁺	5 x 10 ⁵
K ⁻	1 x 10 ⁵
P	1.5 x 10 ⁴

Table II.3. Beam Characteristics for K-3

Mode	M3-S	K3-L
Momentum range	0.5 - 1.1 GeV/c	
Target	3 mm diam. 60 mm Pt.	3 mm diam. 40 mm Pt.
Central production angle	0°	0°
Beam length	14.45 m	16.3 m
Solid angle acceptance	7.2 msr	3.0 msr
Horizontal acceptance	±200 mr	±90 mr
Vertical acceptance	±11.5 mr	±10.5 mr
Momentum bite ($\Delta p/p$)	±3.0%	±1.8%
Solid angle momentum acceptance	48.4 msr $\Delta p/p$	13.3 msr $\Delta p/p$
Electrostatic separator	1.88 m long, 15 cm gap, 50 kV/cm	
Characteristics at mass slit		
Horizontal magnification	-9.58	-3.40
Dispersion	4.25 cm/%	3.45 cm/%
Vertical magnification	-0.424	-0.345
Separation(cm)/ image-size(cm)	5.5/1.9	5.8/2.1
Tilt angle of mass slit	K- π , 0.8 GeV/c 67.0°	K- π , 0.8 GeV/c 70.0°
Momentum resolution		±0.15%
Characteristics at beam end		
Horizontal magnification	2.06	2.00
Dispersion	-0.168 cm/%	0.0 cm/%
Vertical magnification	0.85	0.50
Horizontal image size (2 σ)	1.06 cm	0.86 cm
Vertical image size (2 σ)	1.50 cm	0.76 cm
Horizontal divergence	±100 mr	±52 mr
Vertical divergence	±17.8 mr	±24.5 mr
Yields expected for 10 ¹² PPP		
0.6 GeV/c K ⁺ /K ⁻	1.1 × 10 ⁵ /2 × 10 ⁴ (K ⁺ /K ⁻)	3.8 × 10 ⁴ /7 × 10 ³ (K ⁺ /K ⁻)
0.8 GeV/c K ⁺ /K ⁻	5.7 × 10 ⁵ /1.1 × 10 ⁵ (K ⁺ /K ⁻)	2.1 × 10 ⁵ /4.2 × 10 ⁴
0.8 GeV/c $\bar{p}$	8.1 × 10 ³	3.5 × 10 ³
1.0 GeV/c $\bar{p}$	3.6 × 10 ⁴	1.1 × 10 ⁴
Yields measured for 10 ¹² PPP		
0.5 GeV/c	2 × 10 ⁴ K ⁺	
0.6 GeV/c	5.2 × 10 ⁴ K ⁺	
0.8 GeV/c $\bar{p}$	3.5 × 10 ³	3.5 × 10 ³
1.0 GeV/c $\bar{p}$	1.1 × 10 ⁴	1.1 × 10 ⁴

the Penning effect. The KEK design uses separate magnets before and after the separator to provide the desired magnetic displacement force.

II.3. Needs for Improved Facilities

While the KEK beam lines represent a high degree of skillful innovation, they are incapable of approaching the performance required for advanced hyper-nuclear research. For example, the exploitation of the double-strangeness and charge exchanging (K^- , K^+) reactions require particle rates in excess of 10^6 per second. Because of the limitation in production rates imposed by the 12 GeV KEK primary proton energy, such levels are not achievable at KEK. For this region, there appears to be no existing alternative to the Brookhaven AGS.

At the low momentum region, particularly suitable for the population of Σ -hypernuclei, or the study of Y^* hyperons through resonance formation, the KEK facilities may be more suitable. Recently several interesting experiments on Σ -hypernuclei have been reported by Yamazaki et al., with a beam of stopped kaons derived from K3. There has also been a proposal to adapt the CERN K-26 beam design of Birien to a new line at KEK--the so-called KEK 26 beam³³. The use of combined function superconducting magnets allows the building of a line less than 10 meters long, compared to the CERN K-26 length of 11.5 meters. The resulting shortening allows a smaller decay factor which compensates the production difference between the CERN 24 GeV primary beam and the KEK 12 GeV beam.

III. Research with a 1-2 GeV Kaon Beam

In this section we consider some of the motivating research goals which have led us to propose a beam line in this momentum range, and describe some features of future proposed experiments.

III.1. Extension of Present Research to the 1-2 GeV/c Region

III.1.a. Λ Hypernuclei

The present (K^-, π^-) experiments on Λ hypernuclei are severely limited by intensity factors, by the effects of nuclear absorption on the reaction projectiles and products, and by limitations in momentum transfer. The intensity limitations become critical in coincidence experiments where several reaction products are measured simultaneously. Examples of these are the ($K^-, \pi^- \gamma$) experiments (Exps. 760 and 781), the dibaryon resonance search (Exp. 773), and Λ lifetimes in hypernuclei (Exp. 759). Absorption and momentum transfer limitations become crucial as one moves to measurements of hypernuclei heavier than the p-shell. The higher-spin bound states characteristic of s-d shell hypernuclei require higher momentum transfer for optimum matching. These limitations can be alleviated by the use of a higher momentum beam line. Figure III-1 suggests that there are two useful ranges of Λ hypernuclear production--from 700 to 900 MeV/c and from 1500 to 1800 MeV/c. The former area has been exploited by the LESB-1/Moby Dick combination in the experiments described in Section I.3. The second range, near 1.7 GeV/c would prove interesting for the studies of heavier Λ -hypernuclei and states of higher spin. In this region, beam intensities of about an order-of-magnitude higher than those available at 800 MeV/c are possible with an optimized beam line design. The possibility of performing γ -ray studies of s-d shell hypernuclei would be opened up by such a line.

Fig. III-1. The 0° production cross section for Λ (—) compared to the momentum transfer (---) for the (K^-, π^-) reaction.

Fig. III-2. The production of cascade Ξ particles as a function of incident momentum in the (K^-, K^+) reaction.

III.1.b. Associated Production of Hypernuclei

The use of the (π^+, K^+) reaction to probe hypernuclear excitations was demonstrated to be feasible in Exp. 758. Here the problem is not one of intensity, since copious amounts of pions are available. However the LESB-1 line is incapable of operation above 1.1 GeV/c, which is close to the maximum of the peak in the elementary cross section in the reaction $\pi^+ + n \rightarrow \Lambda + K^+$. At that momentum, the beam line quadrupoles are operating at their maximum field values. Increasing the π^+ and K^+ momenta above 1.1 GeV/c increases the mean free path and decreases distortion effects. Thus the optimum momentum for the (π^+, K^+) reaction, especially for heavier nuclei, lies somewhat above 1 GeV/c. The availability of a 1-2 GeV/c beam line would be welcomed for (π^+, K^+) studies. Furthermore, the feasibility of coincident γ -ray studies in the $(\pi^+, K^+ \gamma)$ reactions would be improved for such a line, and this avenue offers exciting possibilities for photon studies for heavier hypernuclei.

III.1.c. The Double Strangeness and Charge Exchange Reaction (K^-, K^+)

The feasibility of studying $S=-2$ objects such as hypernuclei depends largely on intensity considerations. It is known from emulsion work that such cascade and double Λ -hypernuclei exist with reasonably long lifetimes. From the experience we have gained from the studies on Λ and Σ levels, we can expect that bound levels of such $S=-2$ systems exist with reasonably sharp level widths. An examination of Fig. III-2 showing the total cross section for cascade particle production via the (K^-, K^+) (K^-, K^0) reactions suggest that the optimum momentum range lies between 1.4 and 1.8 GeV/c. Basic information on the reaction amplitudes for (K^-, K^+) needs to be developed and the potential uses of such reactions explored.

In the following sections, studies on doubly strange nuclear systems are considered in more detail.

III.2. Strange Dibaryons

Perhaps the most interesting problems for nuclear science to resolve are the issues of quark confinement and the related one of the quark structure of nuclei. Although at the present time it is not known how to directly attack these problems, the development of experiments and experimental techniques that involve the introduction of at least one distinguishable quark into the nuclear medium should prove extremely important. Historically, the Λ hypernuclear spectra observed by the single strangeness exchange reaction are beginning to provide insights to these questions⁶. For example, measurements of the hyperon-nucleus spin orbit force can be compared to a single quark³⁴ and meson exchange models³⁵. Both models predict similar results for the Λ but differ for a Σ hyperon. Most meson exchange models predict a Σ spin-orbit potential of about the same size, but somewhat larger than that of the Λ . The additive quark model predicts a large Σ spin orbit term (Table I). Although quark model calculations are still rather primitive, the results are suggestive and encourage further investigation of all baryon-baryon interactions. Therefore, the formation of $S=-2,-3$, and even charmed hypernuclei is eagerly anticipated³⁶.

Doubly strange systems ($S=-2$) can be produced by the double strangeness exchange reaction,^{37,38} (K^-, K^+), which gives a large momentum transfer to the recoiling system and consequently favors higher spin final states. In all cases the cross section maxima are between 1.2 and 1.9 GeV/c and are low in magnitude requiring intense beams of K^- particles. No suitable beam line is now available anywhere to pursue these studies.

Table 1. Relative Baryon-Nucleus Spin Orbit Potential from a Simple Quark Model.

	$\underline{N}$	$\underline{\Delta}$	$\underline{\Lambda}$	$\underline{\Sigma}$
	1	1	0	4/3

In 1977 Jaffe²⁸ made predictions about the spectrum of strange 6 quark objects using the MIT bag model. His calculations indicated a dibaryon state, H , with strangeness -2 and $J^\pi=0^+$ at a mass of 2150 MeV. This mass is about 80 MeV lower than the $\Lambda\Lambda$ threshold and, the H would be therefore stable against strong and electromagnetic decay. Subsequently, there have been both experimental³⁹ and further theoretical²⁶ examinations of the six quark system. However, there is no experimental evidence to confirm the theoretical predictions, and, in addition, the observation of a $\Lambda\Lambda$ hypernucleus⁴⁰ suggests that an H , into which a bound $\Lambda\Lambda$ system would decay via the strong interaction, may not be a physically significant concept.

Notwithstanding the above doubts, the dibaryon problem remains an interesting and important question in the overlap area of particle and nuclear physics. On the one hand, particle physics has had great success treating the baryon and meson spectrum with the concept of quarks interacting via QCD⁴¹. On the other hand, there is yet no clear way to expand these ideas to incorporate a system of interacting baryons, or to isolate observable effects of quark degrees of freedom, such as dibaryons, within the nuclear system.

Positive evidence of six quark structures would indicate that the present theoretical approach to this problem is proceeding in the right direction. Therefore, a great amount of effort has been expended in searches for such states. In strangeness zero systems there is no conclusive evidence for narrow dibaryon resonances⁴². In $S=1$ systems, there is a suggestion of unusual behavior in the Λp missing mass near the ΣN threshold. An experiment has been undertaken at the AGS (experiment 773) to investigate this region. However, of all the predicted dibaryons, the H (if particle stable) would provide the cleanest signature, and the most positive identification of such structures. In view of the importance of this problem for future directions in intermediate energy physics, further experimentation is clearly needed.

Several mechanisms have been proposed to produce the H particle:

- a) $p+p \rightarrow K^+ + K^+ + H$
- b) $K^- + (pp) \rightarrow K^+ + H$
- c) $\Xi^- + (px) \rightarrow X + H$

Predictions of H production cross sections are speculative because they depend on model assumptions for the baryon-baryon to H particle fusion process. However, a calculation²⁹ by Aerts and Dover for process b) using ^3He as the source for the $S=0$, (pp) target suggests cross sections of the order of $0.5 \mu\text{b/sr}$. In this reaction the neutron is a spectator and may be left undetected, or if detected, to help discriminate against background events. The reaction mechanism is indicated in Fig. III-3.

Based on these calculations, an experiment⁴² was outlined for a LAMPF II type kaon facility. The experimenters suggest that with a K^- flux of $4 \times 10^5/\text{s}$ approximately $7.8 \text{ events (nb-/sr)}^2/100$ days could be accumulated if detection of the neutron is required, and more than an order of magnitude greater statistics if the neutron can be left undetected. It is suggested that the production cross section follows the $KN \rightarrow K\Xi$ cross section which peaks between 1.4 and 1.8 GeV/c incident beam momentum. Because of momentum transfer considerations, the peak in the predicted H formation cross section lies at the high momentum end of this range. The experiment should be undertaken at or near 0° .

The required spectrometer resolution varies with the binding energy of the H and the expected background. Aside from a statement that better energy resolution is generally desirable, it would appear that structure in the $^3\text{He}(K^-, K^+)X$ missing mass spectrum with a width less than a few MeV would be extremely exciting. If this structure lies below the $\Lambda\Lambda$ threshold there is little else it could be other than an H. Above that threshold any structure

Two Body S = -2 States

Fig. III-3. Energy-level diagram of S = -2 states and their decays.

Below, a possible mechanism for H formation in the (K^-, K^+) reaction.

is likely to be at least several MeV wide. Therefore, there seems little compelling reason to require a spectrometer resolution better than a few MeV.

III.3. Double- Λ Hypernuclei

The double strangeness exchange reaction (DSE) can also produce $\Lambda\Lambda$ hypernuclei, which in many instances will be bound. Examples of such nuclei have been extracted from emulsion data⁴⁰. The $\Lambda\Lambda^6\text{He}$ event of Prowse⁴⁰ is particularly well defined. In the analysis of this event, the $\Lambda\Lambda$ interaction energy was estimated to be 4.6 MeV. The hypernucleus decayed via $\Lambda\Lambda^6\text{He}$ and subsequently by $^5\text{He} + \pi^- + p + ^4\text{He}$, while the formation most probably occurred through the reaction $\Xi^- + ^{12}\text{C} \rightarrow ^7\text{Li} + \Lambda\Lambda^6\text{He}$. The track length of the $\Lambda\Lambda^6\text{He}$ shows that the hypernucleus formed a bound system.

In the production of $\Lambda\Lambda$ hypernuclei through the (K^-, K^+) double strangeness and charge exchange reaction, high spin states are favored due to the large momentum transfer of the reaction. Electromagnetic transitions should rapidly occur so that, except for isomeric states, the two Λ 's will reside in the 1s shell before decay via the weak interaction. In all but the lightest hypernuclei the decay should be predominantly through $\Lambda N \rightarrow \pi N$.

Estimates of cross sections to bound levels are very low due to the large momentum transfer required and the fact that the DSE reaction must be a two-step process in this case. Cross sections of about ten nanobarns/sr to high spin states of light hypernuclei are predicted³⁷. The cross section peaks in the range of 1.2-1.4 GeV/c incident momentum.

Given the expected narrow hypernuclear structure, precise energy resolution for the final state is important. However, the extremely low cross section probably excludes the operation of spectrometers with less than several MeV resolution, due to the required target thickness. Unfortunately, it is also probably not possible to observe electromagnetic transitions in

coincidence with the hypernuclear formation to more precisely define the level structure.

A count rate estimate yields 25 events/nb/sr-100 days for $10^6 K^-/\text{sec}$ incident, a 5 gm/cm^2 target, and a typical 20 msr spectrometer acceptance. Because of this extremely low rate it would be desirable to use a hybrid spectrometer-bubble chamber or spectrometer-TPC to reduce background by the observation of the hypernuclear decay in coincidence with its formation. In the same way $\Lambda\Lambda$ hypernuclei might be observed through the fragmentation decay of Ξ hypernuclei or Ξ -nucleus interactions as in the emulsion events. In these cases the spectrometer would be used only to provide a tagged beam of Ξ particles.

The reaction $K^-p \rightarrow K^+\Xi$ is backward peaked in the center of mass indicating strong u channel exchange⁴⁴. In the laboratory the cross section is forward peaked, though somewhat oscillatory, with a 0° cross section of about 40 $\mu\text{b/sr}$. Using a hydrogen target and a 1.7 GeV/c K^- beam of $10^6 K^-/\text{s}$ intensity one could expect a tagged secondary beam of as many as 25 Ξ^-/sec . This secondary beam of Ξ might be used for the injection of two strange quarks into a nucleus, in particular, fragmentation to produce a $\Lambda\Lambda$ hypernucleus. Such a reaction coupled to a spectrometer hybrid system as previously mentioned may provide the best method for detailed study of these hypernuclei. Alternatively, these Ξ may be brought to rest and used for atomic or stopping experiments.

Although the cross sections for formation of $\Lambda\Lambda$ systems are very low, these experiments are the only way to attack the Λ - Λ interaction. Furthermore, the injection of two strange particles into the nucleus is likely to be as fruitful a study as the Λ and Ξ hypernuclear experiments have been.

Table III-1. Binding Energies of Ξ Hypernuclei from Emulsion.

Hypernucleus	B_{Ξ}	Reference
Ξ ^8He	5.9 ± 1.2	Wilkinson et al. ⁴⁵
Ξ ^{11}B	9.2 ± 2.2	Catala et al. ⁴⁶
Ξ ^{13}C	18.1 ± 3.2	Mondal et al. ⁴⁷
Ξ ^{15}C	16.0 ± 4.7	Bechdolff et al. ⁴⁸
Ξ ^{17}O	16.0 ± 5.5	Bechdolff et al. ⁴⁸
Ξ ^{28}Al	23.2 ± 6.8	Bechdolff et al. ⁴⁸
Ξ $^{29,30}\text{Mg}$	2.4 ± 6.3	Bechdolff et al. ⁴⁸

III.4. Cascade Hypernuclei

It has been proposed that the DSE reaction may lead to the formation of Ξ hypernuclei⁴⁴. Examples of such hypernuclei have been previously observed in emulsions. A summary of binding energies is given in Table III-1, but the interpretation of these data as Ξ hypernuclei is not unique. For example, the event observed by Wilkinson et al. cannot decay via $\Xi^8\text{He} \rightarrow \Lambda^4\text{H} + \Lambda^4\text{H}$, leaving both hyperfragments in ground states, if it is a 1s Ξ hypernucleus, although the decay would be possible if one of the fragments was left in the spin-flipped excited state. In addition the ΞMg event appears to have an

anomalously low binding energy, but it too could decay from or into an excited state. The formation reactions in these cases would not have given sufficient impetus to the recoil hypernucleus for it to have moved appreciably before decay, thus no lifetime could be associated with the system although decay did presumably occur after the strong reaction process $\pi N \rightarrow \Lambda \Lambda$.

In the DSE reaction the momentum transfer is rather large compared to the Fermi momentum, which favors the formation of high spin states. The situation is somewhat similar to the (π^+, K^+) reaction where predictions²⁰ and measurements⁴⁹ show that the populated hypernuclear states have the stretched configurations. As an aside, the use of the $K^- p \rightarrow K^+ \Xi^*(1530)$ reaction to provide a relatively slow Ξ^- from the $\Xi^* \rightarrow \pi \Xi$ decay has not been determined to be useful⁴⁴, but could be important for Ξ stopping experiments.

To produce observable spectra without overlapping levels the high spin selection should be sufficiently restrictive to populate a few reasonably widely-separated levels. Whether this will also sufficiently discriminate against quasi-free processes is not clear, especially since the expected levels and the breakup threshold lie rather close in energy.

Within the nucleus the Ξ hypernucleus can undergo reactions of the type $\Xi p \rightarrow \Lambda \Lambda$. The free cross section for this process is about 20 mb averaged over the momentum interval 0.8-2.2 GeV/c.⁴⁵ This cross section has not been measured for the lower momentum of interest here. Theoretical estimates range from 60 mb⁴⁴ to 12 mb⁵⁰. The reaction is also apparently quite spin-isospin selective. Using the Born approximation estimate of 60 mb and the nuclear matter limit for the damping width of the Ξ an estimate of 5-10 MeV width for these hypernuclear levels is predicted⁴⁴. One should recall that similar estimates were made for Σ hypernuclei⁵¹, and these indicated that widths can be much smaller than predicted from the naive optical model limit. For

example, isospin-spin selectivity might quench these decay reactions considerably, particularly for the s shell⁵¹.

Thus it is important to investigate these systems to further explore the hyperon-nucleon interaction, and the behavior of a nucleus containing two strange quarks. Quite a lot of information can be obtained even if the Ξ hypernucleus contains no narrow structure, but clearly one would hope to see several narrow states as is the case for Λ hypernuclei. This, coupled with the fact that these Ξ hypernuclei are formed with the largest cross section of all the DSE reactions, makes these experiments very exciting.

The forward $p(K^-, K^+) \Xi$ cross section peaks at about 1.8 GeV/c incident momentum and provides cross sections to selected states of up to ≈ 1.4 $\mu\text{b}/\text{sr}$. Ground state excitations are typically 1/3-1/2 of the stretched state values. Using a K^- beam of 1.8 GeV/c with intensity of $10^6 K^-/\text{s}$, a target of 5 gm/cm^2 , and a spectrometer with 20 msr acceptance one would expect 18 events/ μb -day. Thus this experiment is certainly feasible.

Spectrometer resolution of several MeV is adequate since the expected natural line widths are of this magnitude. However, the spin-orbit splittings are predicted to be small and will be difficult to observe experimentally.

III.4. Exotic Atoms

The technique of using a tagged beam of Σ^- , which are then stopped in a target composed of laminated sheets of a high-Z material immersed in a liquid hydrogen both may be used for other hyperons as well. By this method the hyperon would be produced and tagged through the $p(K^-, K^+) Y$ reaction with the recoil ranging out in a sheet of high-Z material. The subsequent atomic capture and cascade process provides the atomic X-rays for detection and

analysis. This method has been recently used at BNL to measure the magnetic moment of the Σ^- ,⁵² where the incident K^- beam was brought to rest in the liquid hydrogen-high-Z target. For other hyperons the reaction threshold would require hyperon production in flight.

An outline of the possible physics is given in ref. 53. While not all of the proposed experiments would be feasible with a 1-2 GeV/c separated K^- beam, a number might be possible. Such a beam line meets several of the requirements suggested in ref. 52 for a new series of studies with exotic atoms. These are, for example:

- a) higher K^- flux;
- b) better π/K ratios; and
- c) better beam definition.

The interaction of Ξ^- and Ω^- hyperons with nuclei is almost completely unexplored and awaits inventive experimentation.

III.5. Hyperon-Nucleon Interaction^{54,55}

The familiar nucleon-nucleon force of nuclear physics has been successfully described in terms of boson exchange models employing pseudoscalar, scalar and vector mesons. The accommodation of this picture to the QCD description of nucleons as extended structures comprised of quarks and gluons is the central issue of modern nuclear physics. Experimental data are needed to decide whether the QCD picture is necessary to explain some new aspects of the force which are not adequately treated by boson exchange.

The "typical" quark phenomena start to manifest themselves at momentum transfers of 1 GeV/c and more. At low energies which are important for nuclear properties we cannot expect to see characteristic quark behavior even if the whole job of the NN interaction is mediated by quarks and gluons. At 1 fm and more, typical for internucleon distances in nuclei, the interaction is

averaged over the constituents of the nucleon. The only feasible way to establish the role of quark exchange in the NN interaction is to use the quark flavor as a monitor of its effect. The only practically accessible flavor is strangeness. Because of the larger mass of the strange quark, the dynamics of the Y-N interaction process will be affected. Thus, we propose studying the Y-N interaction and comparing it to the NN interaction. In this sense the use of strangeness as a flavor "tag" is analogous to the use of radiochemical tracers in chemistry, medicine, or biology.

The role of the strange quark has already been invoked to explain the spin-orbit coupling of the Λ and the Σ in hypernuclei. Although these spin-orbit phenomena can be discussed in terms of meson exchange, their description in terms of quark degrees of freedom is more fundamental.

Although hypernuclear data are available, they still represent an ensemble average over individual nucleons. Needed are more elementary data on Σ , Λ , Ξ , and Ω scattering on protons. There exist a limited amount of data on hyperon-nucleon interactions. This interaction has been studied so far only at very low energies where the s-wave scattering dominates and at very high energies. The central problem of the hyperon-nucleon experiments lies in the preparation of hyperons with well-determined kinematical conditions which are needed for such investigations. Available kaon fluxes have limited studies to Λ and Σ -nucleon interactions. It has been suggested by Bruckner et al.⁵⁴ at CERN, and by M. V. Hynes at Los Alamos⁵⁵, that high intensity kaon beams near 1.5 GeV/c can profitably be coupled with detector arrays similar to those at colliding-beam experiments and applied to these reactions. Although Hynes made his estimates for an accelerator in the LAMPF-II intensity range, it is

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demonstrated below that practical hyperon interaction studies can be carried out with the proposed 1-2 GeV/c line at the AGS. In the following section, the proposals of Bruckner et al. and of Hynes, have been used extensively as source materials.

The following reactions for $S=-2$ systems which are of interest and are feasible are displayed in Fig. 1.1-4 along with the corresponding quark-gluon exchange and boson exchange diagrams. It seems reasonable to restrict these studies to 2 GeV/c and below because of two considerations:

- 1) The hadronic interactions are best described in terms of potential models, which lose their validity at relativistic energies, and,
- 2) The number of partial waves involved in the interaction is not excessively large.

The Ξ^- particles in the (K^-, K^+) reaction on hydrogen are produced highly polarized perpendicular to the production plane. Thus spin-averaged reaction amplitudes and spin flip amplitudes are obtainable. It is unlikely that the alternative boson exchange and quark exchange models can simultaneously reproduce both types of amplitudes.

A simplified experimental arrangement taken from the proposal of Bruckner et al.⁵⁴ is shown in Fig. III-5. The Ξ^- are produced by the (K^-, K^+) reaction on a liquid hydrogen target. The K^+ is used as a simple kinematic tag for the Ξ production; for K^+ ranging from 500 MeV/c to 800 MeV/c, the Ξ^- are produced in the range 800 to 1400 MeV/c, going mainly in the forward direction. The hydrogen target is surrounded by a 4π detector for charged particles and neutrals, and is placed in a solenoidal magnetic field. The secondary Ξ^-p interaction in the target can be reconstructed, using reasonably good spatial and energy resolution:

Fig. III-4. Quark-gluon exchange diagrams for $\bar{K}$ -N interactions.

Fig. III-5. A solenoidal-field detector configuration for studying $\bar{K}$ -N interactions.

a) $(PE^-)_{in} = P_{K^-} - P_{K^+}$, and

b) $(PE^-)_{out}$ from the decay $\Xi^- \rightarrow \Lambda \pi^-$, $\Lambda \rightarrow p \pi^-$

Similarly for the neutral reaction products of Fig. III-5 a reconstruction is possible provided that the photons and π^0 can be detected.

Counting rates for the reactions above and practical detector systems (such as the JADE type) have been estimated by Bruckner⁵⁴ and Hynes⁵⁵. The latter estimates that for elastic Ξ^- scattering with a flux of 10^5 K^- /sec, an accumulation time of 14,000 hours is required to produce 1000 counts in each of 10 momentum bins, 100 MeV/c wide from 800 to 1800 MeV/c, at 10 scattering angles. For the expected K^- intensity of the proposed AGS line, 1400 hours is projected, given a nominal 2×10^{12} proton/pulse share of the AGS primary proton intensity. This is within the feasible range for AGS experiments.

In summary, a study of the 2-body (Ξ^-p) interactions is interesting for a number of reasons. There has been no systematic study of these reactions up to now. Since the reactions involve strangeness exchange, the baryon-baryon force is "tagged" with flavor and a possible distinction between quark and boson exchange models is possible. Because the Ξ^- are polarized, both spin-averaged and spin-flip amplitudes can be determined, leading to stronger model tests. The K^+ detection provides a clean signature for $S=-2$ production, and inhibits many background sources present in Σ or Λ interactions. The elastic scattering of the Ξ^- will interfere with Coulomb scattering at small angles and the sign of the scattering length is thereby determined. Finally, final state $S=-2$ dibaryons corresponding to the bag model predictions can be detected. The momentum range for 1-2 GeV/c contains the Ξ^- production maximum (1.8 GeV/c), yet the potential model and effective range approximations are still valid, and only 2-body final states at these low momenta need be considered.

IV. A Proposed Beam Line in the Range from 1 to 2 GeV/c

The general considerations applicable to optimizing kaon beam line design are reviewed in this section. Based on the application of these considerations to the AGS environment, a practical beam line design is presented. This line is capable of separating kaons from pions in the momentum range from 1 to 2 GeV, with optimum performance at 1.8 GeV/c. The design incorporates two electrostatic separators with two mass slits and corrections for second and third order aberrations. These corrections are effected by introducing sextupole and octupole components in selected quadrupole fields.

IV.1. Design Principles

The following set of design principles follow closely an analysis due to H. Enge⁵⁶. Kaon and pion separation is accomplished by introducing a velocity filter in the line. The filter incorporates electric and magnetic fields in its structure. The effect of the magnetic field is identical for particles of the same momentum p . The radius of curvature is thus

$$R = mv^2/qE = p\beta c/qE \quad (1)$$

In traveling a distance $d\ell$ in the separator field E , the deflection angle ϕ_s is given by

$$d\phi_s = 1/R d\ell = qE/p\beta c d\ell \quad (2)$$

This deflection angle is related to the image size by the transport matrix element $(y/\phi)_{21}$ (see Fig. IV-1).

Fig. IV-1. An optical analog diagram for the beam optics involved in optimum separator design. The S_y principal trajectory is shown, arising at the object point (the production target) and culminating at the image point (the mass slit of the separator). The beam is shown deflected through an angle ϕ by the action of the separator field. The lenses represent the quadrupole focussing system.

$$dy_1 = (y/\phi)_{\lambda 1} d\phi, \quad (3)$$

where the transfer matrix element $(y/\phi)_{\lambda 1}$ is taken to the mass slit image point from a local point in the separator. This matrix element may be expressed in terms of (y/y) , the y magnification of the system from the object to the mass slit, and $(y/\phi)_\lambda$, the transfer matrix element from the object point to a local point in the separator:

$$(y/\phi)_{\lambda 1} = - (y/y) (y/\phi)_\lambda \quad (4)$$

These expressions may now be combined and integrated over the distance traveled in the separator field,

$$y_i = \frac{-q(y/y)}{p\beta c} \int (y/\phi)_L EdL \quad (5)$$

Denoting the total width of the beam in the separator by Δy_L , it follows that $(y/\phi)_L$ is given, in terms of the total ϕ acceptance angle at the object, $(\Delta\phi)$, by

$$\Delta y_L = (y/\phi)_L \Delta\phi \quad (6)$$

and thus

$$y_i = \frac{-q(y/y)}{p\beta c\Delta\phi} \int \Delta y_L EdL \quad (7)$$

The separation between pions and kaons may be written down from (7) assuming that their momenta and phase spaces are the same

$$(y_i)_K - (y_i)_\pi = \Delta y_i = \frac{-q(y/y)}{pc\Delta\phi} (\beta_K^{-1} - \beta_\pi^{-1}) \int \Delta y_L EdL \quad (8)$$

It is convenient to define a separation factor S as the ratio between the centroid separation for K 's and π 's at the mass slit to the image size, $(y/y)\Delta y$, where Δy is the object size

$$S = \left| \frac{\Delta y_i}{(y/y)\Delta y} \right| \quad (9)$$

In any practical design, the beam width will be kept constant through the separator, and close to the plate spacing d . The separator plate voltage, V , is Ed . Using the approximation $\beta^{-1} \approx 1 + 1/2 (mc/p)^2$, one gets for S

$$S = \frac{qVL}{2(pc)^3 \Delta y \Delta \phi} [(m_K c^2)^2 - (m_\pi c^2)^2] \quad (10)$$

The kaon flux after travelling a length L will be reduced by the kaon decay factor $\exp\{-L/L_K\}$, where L_K is the characteristic decay length. For a desired separation S , and for a fixed momentum and horizontal angular acceptance, the intensity is,

$$N_K \propto (\Delta \phi) (e^{-L/L_K})$$

or,

(11)

$$N_K \propto L e^{-L/L_K}.$$

Eq. 11 has a maximum for $L=L_K$, for a constant $L/\Delta \phi$. With this optimization, eq. (10) can be rewritten to give an expression for the desired aperture of the line at the production target, using $L_K = c\tau_0(pc/m_K)$,

$$\Delta \phi = \frac{qVc\tau}{2(pc)^2 m_K c^2 S \Delta y} [(m_K c^2)^2 - (m_\pi c^2)^2] \quad (12)$$

This consideration shows that the optimum separator length depends on the momentum p . For practical reasons the rest of the beam line scales in length with p . An examination of existing beam lines shows that the typical total length is about $3 L_K$.

Finally an expression for the optimized beam line intensity can be derived by assuming an empirical expression derived from the Sanford-Wang parameterization for the negative kaon production rates,

$$d^2N/d\Omega dp = 0.055(\text{pc})/\text{sr/GeV/per interacting proton.} \quad (13)$$

The following expression obtains:

$$N = \frac{4.6 \times 10^{-3} V \Delta\theta}{S \Delta y} (e^{-L_{TOT}/L_K}) \frac{\Delta p}{p} \quad (14)$$

where N is the kaon intensity per interacting proton in the target,

V is the separator potential in megavolts,

L_{TOT} is the total beam line length,

$\Delta\theta$ is the horizontal acceptance at the production target,

S is the separation factor

Using the formula given by (14) above, it is reasonable to assume that a line offering an intensity above 10^6 can be practically realized at the AGS. For example, if we take the following parameters:

$$V = 0.6 \text{ Megavolts}$$

$$L_{TOT} = 30 \text{ meters}$$

$$L_K = 15 \text{ meters (2 GeV)}$$

$$\Delta\theta = 0.1 \text{ rad}$$

$$S = 2$$

$$\Delta y = 0.3 \text{ cm}$$

$$\Delta p/p = 0.04 (\pm 2\%).$$

The result is $N_K = 2.49 \times 10^{-6}$ per interacting proton, or 5×10^6 kaons for 2×10^{12} primary proton interactions.

IV.2. Description of Proposed Beam Line at the AGS^{57, 58}

An optical design using the principles laid out above is presented in this section. The derivation of the relations presented in the previous section is based on first-order beam optics. Experience with practical magnetic spectrometer design, however, shows that for the large acceptance angles such as those involved here, both second and third-order aberrations need to be considered. A beam line incorporating these corrections has been formulated using the program RAYTRACE⁶³.

A layout drawing of the line is shown in Fig. IV-2. The line has been optimized for a momentum of 1.8 GeV. The line incorporates two mass slits--as suggested originally by D. Lazarus⁵⁹--with vertical waists of the beam at both slits. One important argument for using the two slits is that the effective source size for pions at the production target is larger than the beam cross section, apparently because of secondary production from hyperons decaying near the primary source⁶⁰. The first mass slit then represents a well defined source for the second velocity filter.

The basic system is approximately symmetric about mass slit #1 because for such a system many aberration coefficients are automatically zero. The two dipoles each deflect the beam 30 degrees in the same direction. The total effective length of the velocity filters is 9m.

This length is shorter than the 14 meters suggested by the optimization procedure of the previous section, for a momentum of 1.8 GeV/c. However, it should be borne in mind that this line is meant for use in a number of experiments requiring kaons in the range of 1 to 2 GeV/c. Fortunately the relative number of kaons changes slowly with separator length, as is shown in Fig. IV-3.

Fig IV-2. A floor layout of the proposed 1-2 GeV/c beam line. The design is based on the modified, but otherwise standard, magnets in use at the AGS. The separators E1 and E2 are based on KEK designs.

Fig. IV-3. Relative kaon flux as a function of separator length, L , for a fixed separation quality factor, S .

Fig. IV-4. First order vertical and horizontal beam envelopes, and dispersions for the proposed beam line.

The relative kaon flux has been calculated from eq. 11 of Section IV.1 for a fixed separation factor S . Since the line will be used for experiments over a range of momenta, it is necessary to consider decay losses which become increasingly severe as the momentum is reduced. The selected 9 meter separator length results in only a 10% loss over the optimum length at the designed operating point of 1.8 GeV/c due to its shorter length. Another advantage from a shorter separator length is realized from the smaller vertical acceptance required. The strict optimization procedure of Section IV.1 assumes that the vertical acceptance scales linearly with the separator length; therefore a 14 meter separator will require 50% more vertical acceptance than a 9 meter separator. Studies with RAYTRACE have shown that above a vertical acceptance of 8-10 msr, the image size at the mass slit grows as the cube of the angle ϕ . From the standpoint of minimizing corrections for high order aberrations, it is obvious that the vertical acceptance, and consequently separator length, must be kept reasonably small.

Figure IV-4 shows the beam envelopes in the horizontal and vertical planes, and the horizontal dispersion. The desired momentum band can be approximately selected at the first mass slit where the dispersion is 4.3 cm/percent. The dispersion at the second mass slit is about 0.4%, and is not zero because of the asymmetry in the position of the kaon production target and the experimental target relative to D1 and D2, respectively.

In order to attain the best possible K- π separation, vertical aberrations have been minimized by introduction of higher-order multipole distortions in seven of the eight quadrupoles. Table IV.1 shows the most important characteristics of the beam elements. The maximum distortion of any quadrupole amounts to about 5 percent of the quadrupole field. This can easily be produced simply by displacing the pole pieces slightly.

The most important optical characteristics of the kaon beam line are given in Table IV.2. The spot sizes Δx and Δy quoted represent full width at the base of a peak and are due only to aberrations. They are to be folded in with the first-order contributions from the source size. For comparison, the spot sizes generated by aberrations without higher order corrections in the quadrupoles are shown. The corrections were, of course, made to improve the mass resolution, i.e., the vertical spot size. There is very little difference between the "corrected" and "uncorrected" horizontal spot size.

Tables IV.3 through IV.5 list the 1.8 GeV/c RAYTRACE outputs for the positions of mass slit 1, mass slit 2, and target positions, respectively.

An essential ingredient in this design is the high electric fields required in the separators. These are based on a design developed at KEK by Yamamoto, Maki, and Kusumegi³². In conventional separators, external high voltage supplies are used and feedthrough insulators are required. The capacitance of cables and feedthroughs is considerable and the stored energy released in a discharge can be quite damaging. In the KEK design high-voltage supplies are mounted directly in the vacuum vessel of the separator. The separator plates are made of stainless steel and anodized aluminum. Typical operational gradients of 75 kV/cm are routinely achieved, and in the latest Mark II separators 100 kV/cm has been achieved.

The KEK type separators do not include a magnetic field in the separator volume, as this has shown to cause high-voltage breakdowns in the residual gas of the vacuum chamber through electron spiralling. The separated-function-position correcting magnets CM1 through CM4 are shown to provide the compensation necessary to cancel beam displacement caused by the separator electric field.

Table IV.2. Characteristics of the Enge-Pile Kaon Beam Line

<u>Mass Slit 1</u>					
Momentum	-2%	-1%	0	1%	2%
Central position (cm)	-8.80	-4.43	0	4.46	8.89
Central ray direction (mr)	-0.3	-.07	0	.10	.12
Horizontal magnification	-6.93	-6.90	-6.82	-6.69	-6.51
Vertical magnification	-0.88	-0.86	-0.84	-0.83	-0.81
Δy no sextupole or octupole (cm)	1.04	0.59	0.29	0.24	0.45
Δy (sextupoles only) (cm)	0.52	0.38	0.26	0.24	0.45
Δy (sextupoles + octupoles) (cm)	0.17	0.16	0.15	0.14	0.14
K- π separation at 75 KV/cm and 1.8 GeV/c = 0.34 cm					
<u>Mass Slit 2</u>					
Momentum	-2%	-1%	0	1%	2%
Vertical magnification	.96	.97	.97	.97	.96
Δy no sextupole octupole (cm)	2.16	1.03	0.50	0.77	1.21
Δy sextupoles only (cm)	0.77	0.54	0.37	0.28	0.55
Δy sextupoles + octupoles (cm)	0.10	0.10	0.09	0.11	0.15
K- π separation at 75 KV/cm and 1.8 GeV/c = 0.80 cm					
<u>Target (Mass Slit 2 + 90 cm)</u>					
Momentum	-2%	-1%	0	1%	2%
Central ray position (cm)	-.78	-.38	0	.40	.77
Central ray direction (mr)	.05	.82	.03	-.94	-.79
Horizontal magnification					
Δx no sextupoles or octupoles	2.93	1.90	0.94	0.30	0.75
Δx sextupoles + octupoles	2.66	1.63	0.70	0.32	0.87
Δy no sextupoles or octupoles	3.99	2.66	1.60	0.85	0.51
Δy sextupoles + octupoles	1.65	1.64	1.57	1.51	1.51

Table IV.3. 2.8 GeV/c Beamline, Symmetric, 1-12-85, to Mass Slit # 1
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	-3X	-2X	-1X	0	1X	2X	3X
Energy (MEV) =	1320.800	1338.130	1355.460	1372.790	1390.120	1407.450	1424.780
XOR (CM) =	-13.048	-8.796	-4.431	0.001	4.456	8.890	13.262
YOR (CM) =	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ZOR (CM) =	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TH (MR) =	0.235	-0.027	-0.073	0.000	0.097	0.124	-0.018
PHI (MR) =	0.000	0.000	0.000	0.000	0.000	0.000	0.000
IXMAX1 (CM) =	8.525	6.178	3.888	2.786	2.329	3.767	5.108
ZIYMAX1 (CM) =	0.199	0.167	0.156	0.147	0.141	0.141	0.151
X/TH =	-0.694	-0.454	-0.222	-0.002	0.200	0.380	0.535
T/TH =	-0.155	-0.152	-0.149	-0.147	-0.146	-0.148	-0.154
Y/PH =	-0.016	-0.010	-0.004	-0.000	0.004	0.005	-0.000
P/PH =	-1.109	-1.133	-1.157	-1.182	-1.206	-1.232	-1.259
X/TH**2 =	-5.210	-6.095	-6.943	-7.763	-8.561	-9.338	-10.092
X/PH**2 =	-6.438	-4.295	-2.015	0.276	2.450	4.364	5.837
T/TH**2 =	-0.043	-0.070	-0.090	-0.106	-0.110	-0.126	-0.130
T/PH**2 =	-2.556	-2.540	-2.509	-2.496	-2.532	-2.657	-2.920
Y/TH*PH =	1.425	0.875	0.415	0.029	-0.323	-0.697	-1.179
P/TH*PH =	-0.635	-0.844	-1.041	-1.231	-1.421	-1.627	-1.872
X/TH**3 =	-43.753	-47.838	-51.426	-54.167	-55.679	-55.508	-53.070
X/TH*PH**2 =	166.263	193.253	218.253	238.528	252.462	257.739	251.002
X/TH**3 =	-0.725	-1.156	-1.321	-1.212	-0.808	-0.071	1.055
T/TH**3*PH**2 =	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Y/PH**3 =	-1511.413	-1470.220	-1454.277	-1440.244	-1437.353	-1447.660	-1474.563
Y/TH**2*PH =	41.513	47.976	53.943	59.484	64.584	69.152	72.963
P/PH**3 =	-132.678	-129.991	-129.180	-130.456	-134.170	-140.926	-151.638
P/TH**2*PH =	9.904	10.705	11.428	12.090	12.685	13.185	13.524
X/TH**4 =	52.949	35.424	23.822	17.236	15.340	18.314	26.978
X/TH**2*PH**2 =	310.659	209.097	111.757	11.935	-95.858	-219.295	-372.777
X/PH**4 =	6888.187	6053.287	5207.071	4379.143	3550.178	2741.408	1918.710
T/TH**4 =	1.076	-0.752	-1.185	-0.456	1.379	4.416	8.941
T/TH**2*PH**2 =	6.418	2.213	-2.629	-9.525	-19.600	-34.646	-58.402
T/PH**4 =	1175.814	1130.413	1069.782	1001.75	928.196	850.810	763.906
Y/TH**3*PH =	303.944	290.734	277.169	267.703	266.428	278.406	311.359
Y/TH*PH**3 =	-2861.413	-2920.653	-3087.893	-3375.035	-3811.556	-4452.242	-5402.755
P/TH**3*PH =	72.756	72.767	72.512	73.267	76.151	82.561	94.645
P/TH*PH**3 =	-458.212	-430.460	-456.054	-484.281	-561.044	-691.294	-902.772
X/TH**5 =	-7798.999	-7042.030	-6103.471	-5316.988	-4532.037	-3926.070	-3622.317
X/TH**3*PH**2 =	-11768.244	-11627.986	-11207.965	-10501.654	-9433.267	-7850.877	-5400.594
X/TH*PH**4 =	-112917.455	-112507.126	-112199.000	-111902.203	-111772.230	-112285.477	-114480.088
T/TH**5 =	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T/TH**3*PH**2 =	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T/TH*PH**4 =	0.000	0.000	0.000	0.000	0.000	0.000	0.000
X/T**3+T**2*X/T**4 =	-5.078	-6.007	-6.883	-7.720	-8.523	-9.292	-10.025
X/T**3+T**2*X/T**5 =	-63.250	-65.443	-66.185	-67.460	-67.009	-65.325	-62.125

Table IV.4. 1.8 GeV/c Beamline, Symmetric, 1-20-85, to Mass Slit #2
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	-3Z	-2Z	-1Z	0	1Z	2Z	3Z
Energy (MEV) =	1320.800	1338.130	1355.460	1372.790	1390.120	1407.450	1424.780
XOR (CM) =	0.887	-0.775	-0.452	0.006	0.481	0.840	0.944
YOR (CM) =	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ZOR (CM) =	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TH (MR) =	-3.651	0.050	0.823	0.032	-0.939	-0.786	1.623
PHI (MR) =	0.000	0.000	0.006	0.000	0.000	0.000	0.000
1XMAX1 (CM) =	2.912	4.232	5.119	5.678	6.051	6.423	6.988
21YMAX1 (CM) =	0.185	0.100	0.099	0.091	0.105	0.153	0.184
X/TH =	-0.393	-0.505	-0.575	-0.616	-0.649	-0.698	-0.758
T/TH =	0.739	0.742	0.700	0.661	0.618	0.594	0.588
Y/PH =	-0.140	-0.133	-0.141	-0.152	-0.159	-0.162	-0.163
P/PH =	0.980	0.976	0.970	0.964	0.964	0.969	0.969
X/TH**2 =	0.804	0.107	0.416	-0.677	-0.638	-0.312	0.101
X/PH**2 =	-13.930	-15.896	-17.632	-19.168	-20.735	-22.735	-25.211
T/TH**2 =	-0.468	0.510	1.092	1.353	1.350	1.110	0.890
T/PH**2 =	24.308	23.957	22.913	21.653	20.667	20.416	21.300
Y/TH*PH =	-2.345	-0.391	0.148	0.016	-0.167	-0.003	0.839
P/TH*PH =	1.855	2.126	2.083	1.929	1.828	1.887	2.195
X/TH**3 =	58.158	54.586	50.749	49.005	52.252	62.134	79.992
X/TH*PH**2 =	103.602	90.664	69.158	43.244	12.301	-28.244	-83.744
X/TH**3 =	-3.434	7.790	14.967	17.544	15.789	10.281	1.814
T/TH**3*PH**2 =	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Y/PH**3 =	2387.814	2394.629	2381.345	2371.587	2385.467	2438.004	2545.721
Y/TH**2*PH =	53.386	55.666	38.579	11.661	-14.656	-33.157	-40.021
P/PH**3 =	602.144	587.900	569.065	552.765	544.842	549.558	571.200
P/TH**2*PH =	8.467	10.528	7.400	1.770	-4.009	-8.071	-9.369
X/TH**4 =	121.340	104.003	74.593	30.818	-8.171	-27.720	-31.626
X/TH**2*PH**2 =	2227.126	2415.283	2334.148	2125.099	1917.475	1785.811	1796.224
X/PH**4 =	-4026.082	-3504.245	-3337.570	-3403.234	3692.8538	-4339.242	-5602.802
T/TH**4 =	-209.117	-119.557	-48.051	-1.658	24.153	37.379	44.274
T/TH**2*PH**2 =	-15.385	167.497	218.263	205.278	180.177	160.886	148.460
T/PH**4 =	6078.870	4994.661	4049.850	3390.128	3145.157	3439.362	4428.458
Y/TH**3*PH =	-837.006	-313.965	-1.100	75.567	3.651	-137.178	-329.143
Y/TH*PH**3 =	12565.562	13922.457	13819.449	13387.397	13461.040	14516.098	17045.958
P/TH**3*PH =	-188.405	-57.432	17.360	29.827	1.623	-47.663	-113.496
P/PH**3*PH**3 =	4158.913	4263.260	4043.378	3794.576	3732.415	3982.727	4678.101
X/TH**5 =	-6949.339	-8576.694	-10103.167	-11742.897	-13517.661	-15515.993	-17997.626
X/TH**3*PH**2 =	156.921	6700.252	10317.014	11589.179	12827.5317	15707.345	21057.583
X/TH*PH**4 =	67737.087	60355.263	44951.982	30201.646	19634.145	11726.095	3499.553
T/TH**5 =	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T/TH**3*PH**2 =	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T/TH*PH**4 =	0.000	0.000	0.000	0.000	0.000	0.000	0.000
X/TH**2+T2*X/TH**4 =	1.107	0.367	-0.210	-0.600	-0.659	-0.382	0.227
X/TH**3+T2*X/TH**5 =	40.784	33.144	25.491	19.730	18.458	23.344	34.998

Table IV.5. 1.8 GeV/c Beamline, Symmetric, 1-20-85, to MS#2+90CM
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	-3%	-2%	-1%	0	1%	2%	3%
Energy (MEV)	1320.800	1338.130	1355.460	1372.790	1390.120	1407.450	1424.780
XOR (CM)	-1.215	-0.771	-0.370	0.000	0.397	6.770	1.090
YOR (CM)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ZOR (CM)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TH (MR)	-3.651	0.050	0.823	0.032	-0.939	-0.786	1.623
PHI (MR)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
IXMAXI (CM)	3.703	2.660	1.631	0.697	0.319	0.870	1.506
ZIYMAXI (CM)	1.564	1.655	1.639	1.569	1.511	1.505	1.575
X/TH	0.292	0.183	0.084	0.000	-0.072	-0.142	-0.228
T/TH	0.739	0.742	0.708	0.661	0.618	0.594	0.686
Y/PH	0.742	0.745	0.722	0.716	0.703	0.710	0.721
P/PH	0.980	0.976	0.970	0.964	0.964	0.969	0.980
X/TH**2	0.303	0.566	0.567	0.560	0.577	0.687	0.885
Y/PH**2	7.947	5.666	2.950	0.319	-2.134	-4.361	-6.496
T/TH**2	-0.468	0.510	1.092	1.353	1.350	1.110	0.643
T/PH**2	24.808	23.957	22.913	21.653	20.667	20.416	21.300
Y/TH*PH	-0.675	1.522	2.033	1.752	1.478	1.695	2.815
P/TH*PH	1.855	2.126	2.083	1.929	1.828	1.887	2.195
X/TH**3	16.222	20.122	21.876	22.795	24.803	29.430	37.993
X/TH*PH**2	102.581	94.960	68.184	37.416	11.269	-8.194	-22.052
X/TH**3	-3.434	7.790	14.467	17.544	15.789	10.281	1.814
T/TH**3*PH**2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Y/PH**3	2930.094	2924.081	2869.463	2876.400	2876.148	2932.933	3060.142
Y/TH**2*PH	61.249	65.391	45.541	17.455	-18.090	-40.261	-48.291
P/PH**3	602.144	587.900	569.065	552.765	544.052	549.558	571.200
P/TH**2*PH	8.467	10.528	7.480	1.770	-4.009	-8.071	-9.169
X/TH**4	-67.406	-3.524	31.833	29.950	14.140	6.356	8.479
X/TH**2*PH**2	2225.217	2578.166	2541.331	2318.739	2087.047	1936.338	1936.878
X/PH**4	1445.300	991.294	307.595	-351.868	-861.9968	-1243.603	-1617.003
T/TH**4	-209.117	-119.557	-48.051	-1.658	24.153	37.379	44.274
T/TH**2*PH**2	-15.385	167.497	218.263	205.278	180.177	160.886	148.450
T/PH**4	6078.870	4994.661	3049.850	3390.128	3145.153	3439.362	4428.458
Y/TH**3*PH	-1006.999	-365.014	15.752	107.765	6.331	-179.031	-430.564
Y/TH**3*PH	16332.608	17785.082	17482.348	16823.334	16838.642	16118.206	21275.736
P/TH**3*PH	-188.405	-57.432	17.360	29.827	1.623	-47.600	-113.496
P/TH**3*PH	4158.913	4263.268	4043.378	3794.576	3732.415	3982.727	4678.101
X/TH**5	5519.083	4738.314	3488.722	1761.909	-156.992	2065.243	-4013.731
X/TH**3*PH**2	-4140.063	6499.321	12139.276	13125.479	12111.2507	11105.122	11198.680
X/TH**3*PH**2	139078.503	132745.928	110872.928	87894.647	71462.378	62934.853	62579.313
T/TH**5	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T/TH**3*PH**2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T/TH**3*PH**2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
X/T**2:T2*X/T**4	0.214	0.557	0.646	0.615	0.612	0.703	0.906
X/T**3:T2*X/T**5	30.019	31.968	30.598	27.200	24.411	24.267	27.958

Finally, it is desirable to take the secondary particle beam close to zero degrees. For this purpose a standard AGS C-magnet (18C72) must be modified to allow the primary beam to emerge without striking into coils or yoke. This element is labeled D1 on the beam line layouts. All of the elements in this line are based on standard AGS magnets. The separators are based on existing KEK designs for which blueprints already exist. Thus no extensive design or developmental costs are envisaged.

A practical intensity estimate for the proposed AGS 1-2 GeV/c beam line can be obtained by scaling the observed kaon intensities obtained at the KEK K-2 line, as tabulated in Table II.2. It is assumed that the K^- production cross sections scale linearly with primary proton momentum, so that one may compare KEK and AGS production rates for a similar 6cm tungsten target. This factor is therefore (30/13).

With this assumption, one can write

$$\begin{aligned}
 N_K &= (K^- \text{ rate at KEK}) \times \frac{(\text{BNL primary momentum})}{(\text{KEK primary momentum})} \\
 &\times \frac{\text{BNL (protons on target)}}{\text{KEK (protons on target)}} \times \frac{(\Delta\Omega\Delta p(\text{BNL}))}{(\Delta\Omega\Delta p(\text{KEK}))} \times \frac{(\text{Decay Factor BNL})}{(\text{Decay Factor KEK})} \\
 &= 10^5 \times \left(\frac{30}{13}\right) \times \left(\frac{4 \times 10^{12}}{1 \times 10^{12}}\right) \times \left(\frac{8}{6.25}\right) \times \left(\frac{7.9}{6.8}\right) = 1.4 \times 10^6 \text{ kaons/spill}
 \end{aligned}$$

An alternate intensity estimate is derived by assuming the Sanford-Wang calculation production rates. At 30 GeV/c protons, and for a secondary K^- momentum of 2 GeV/c, the Sanford-Wang estimate gives ≈ 0.1 kaons/sr/GeV/c/-interacting primary proton. The interacting proton fraction for the 6cm W target is ≈ 0.5 . Thus the Sanford-Wang flux estimate is given by,

$$\begin{aligned}
N_K &= 0.1 \times (0.008 \text{ sr-}\%) \times (0.02 \text{ GeV}\%) \times (4 \times 10^{12} \text{ protons}) \\
&\quad \times (0.5 \text{ interaction fraction}) \times (7.9)^{-1} \text{ decay fraction} \\
N_K &= 4 \times 10^6 \text{ kaons/spill}
\end{aligned}$$

These two alternative estimates give a reasonably consistent estimate, at least as to order-of-magnitude. These estimates are also reasonably close to the optimum flux predicted by Enge. It thus appears practical to achieve our design goal of a flux in excess of 10^6 kaons/spill, which is the physics requirement demanded by the experiments outlined in Section IV.

Table IV.6 summarizes the relevant parameters for the proposed AGS beam line.

IV.3. Spectrometer Design Considerations

Many of the proposed uses for the 1-2 GeV/c separated beam line will involve the addition of a particle spectrometer to measure the exiting particles in a reaction, for example the K^+ particles in a (K^-, K^+) reaction.

As in the current use of LESBl for hypernuclear research studies, the second half of the beam line can be used as an incident particle spectrometer. This will necessitate placing hodoscopes between the two mass slits, where the particle intensity will be at the $10^7/\text{sec}$ level. This is practical with modern instrumentation⁶¹.

The first order transport equation from drift chamber D1 to scintillation hodoscope H1 of Fig. IV-2 is as follows:

Table IV.6. Proposed AGS Beamline Design Parameters

Momentum Range	1-2 Gev/c
Target	6 cm platinum
Central Production Angle	5°
Beam Length	31.1 m
Horizontal Acceptance	±50 mr
Vertical Acceptance	±8 mr
Momentum Acceptance	±3%
Solid Angle Momentum Acceptance	8 msr %
Particle Yields	
4 x 10 ¹² , 30 Gev/c protons	
Sanford-Wang est.	4 x 10 ⁶ K ⁻
Scaling from K2	1.4 x 10 ⁶ K ⁻ } at 2 Gev/c

$$x_{H1} = -4.28 x_{D1} + 0.01 \theta_{D1} - 5.94 \delta p$$

It is relatively easy to achieve 0.5 mm resolution in D1 and a 2mm resolution in scintillation hodoscope H1. The resulting first order kaon momentum resolution at 1 GeV/c will therefore be about 0.9 MeV/c, FWHM.

A spectrometer to measure the exiting particles in a reaction (for example, the K^+ of a (K, K^+) reaction) will be placed at the exit of the beam line. The QQDQQ spectrometer currently in use at LESB1, Moby Dick, is mounted on a rotatable platform, and could be used for the first experiments on cascade hypernuclei, where the outgoing K^+ particles have momenta less than 1 GeV/c. An improvement in the present Moby Dick spectrometer could be obtained by introducing higher order corrections in the spectrometer quadrupoles, as was done for the beam line. An improved version of the present Moby Dick spectrometer has been suggested by H. Enge, and would be suitable for reaction products up to 1.8 GeV/c.

Most of the important aberrations have been minimized in this design except x/θ^2 , the second-order chromatic aberration in the dispersive plane. This term is too large to correct with sextupoles, or rather, the sextupole term would introduce too many other aberrations. It is assumed that this chromatic aberration can be corrected by using two detector planes.

Table IV.7 shows the most important characteristics of the Enge reaction product spectrometer elements and Table IV.8 shows the output characteristics. Table IV.9 gives the RAYTRACE output data for this spectrometer design.

This modification of the Moby Dick spectrometer is not presented as part of the beam-line proposal. It is described here to indicate one of many possible designs for high-quality spectrometers for cascade hypernuclear spectroscopy. Other experiments, such as, for example, the hyperon-nucleus

Table IV.7. Spectrometer Elements for $P_0 = 1.8 \text{ GeV/c}$

<u>Q1:</u>	L = 70 cm
	R = 15.24 cm
	BQ = -16.46 kG
	BH = 80 Gauss
	BO = 700 Gauss
	BD = -40 Gauss
	BDD = -190 Gauss
<u>Q2:</u>	L = 70 cm
	R = 20.32 (special elliptic chamber)
	BQ = 11.797 kG
	BH = -10 Gauss
	BO = 110 Gauss
	BD = 2 Gauss
	BDD = 20 Gauss
<u>Dipole:</u>	R = 300 cm
	$\phi = 23^\circ$
	$\alpha = \beta = 11.5^\circ$
	B = 20 kG
<u>Q3:</u>	L = 70 cm
	R = 20.32 cm
	BQ = 11.797 kG
	BO = 100 Gauss
<u>Q4:</u>	L = 70 cm
	R = 15.24 cm
	BQ = -16.47 kG

Table IV.8. Output Characteristics of the Reaction Product Spectrometer

Momentum	-8%	-4%	0	+4%	+8%
Central ray pos. (cm)	-15.19	-7.37	0	6.93	13.46
Central ray dir. (mr)	-61.66	-29.74	0	27.62	53.23
Δx (cm)	15.62	7.35	.14	6.59	12.42
Δy (cm)	10.82	5.26	1.58	1.04	2.67
Hor. magnif.	.57	.74	1.00	1.45	2.38
Vert. magnif.	.53	.70	1.00	1.56	3.03

Table IV.9. Reaction Product Spectrometer

	-8%	-4%	1.8GeV/c	+4%	+8%
ENERGY(MEV)	= 1268.600	1320.600	1372.600	1424.600	1476.600
XOR (CM)	= -15.189	-7.367	-0.001	6.931	13.456
YOR (CM)	= 0.000	0.000	0.000	0.000	0.000
ZOR (CM)	= 0.000	0.000	0.000	0.000	0.000
TH (MR)	= -61.658	-29.744	-0.006	27.622	53.232
PHI (MR)	= 0.000	0.000	0.000	0.000	0.000
!XMAX!(CM)	= 15.618	7.347	0.140	6.594	12.417
2!YMAX!(CM)	= 10.821	5.259	1.578	1.043	2.669
X/TH	= -1.864	-0.880	0.001	0.788	1.490
T/TH	= -1.753	-1.354	-1.000	-0.690	-0.420
Y/PH	= 0.461	0.197	0.001	-0.137	-0.227
P/PH	= 1.903	1.421	1.003	0.642	0.330
X/TH**2	= -0.589	-0.159	0.000	-0.099	-0.416
X/PH**2	= 1.995	0.546	-0.021	-0.099	0.054
T/TH**2	= -0.028	0.080	0.037	-0.147	-0.448
T/PH**2	= 1.194	0.318	-0.041	-0.111	-0.045
Y/TH*PH	= 0.613	0.342	0.191	0.100	0.049
P/TH*PH	= 0.828	0.417	0.165	0.015	-0.062
X/TH**3	= -7.733	-2.119	0.111	0.995	1.947
X/TH*PH**2	= -63.929	-28.661	2.934	29.051	49.343
T/TH**3	= 8.589	9.828	10.316	10.310	10.081
T/TH*PH**2	= 0.000	0.000	0.000	0.000	0.000
Y/PH**3	= 63.566	36.497	22.810	14.659	8.845
Y/TH**2*PH	= -20.788	-18.641	-16.506	-13.866	-11.279
P/PH**3	= 102.506	88.613	80.354	74.378	69.390
P/TH**2*PH	= -239.217	-222.399	-207.202	-192.878	-179.394
X/TH**4	= -192.728	-105.144	-7.451	98.369	210.145
X/TH**2*PH**2	= -568.691	-206.880	-1.325	81.957	78.742
X/PH**4	= 107.086	50.285	-4.710	-43.511	-61.668
T/TH**4	= -87.548	-48.303	-4.295	43.204	93.056
T/TH**2*PH**2	= -328.474	-107.726	15.619	64.578	61.399
T/PH**4	= 76.550	33.757	-2.068	-25.715	-36.114
Y/TH**3*PH	= 22.155	23.414	45.706	62.399	47.188
Y/TH*PH**3	= -671.968	-278.091	-101.285	-24.874	14.755
P/TH**3*PH	= 315.475	290.982	286.078	288.832	285.633
P/TH*PH**3	= -970.741	-781.692	-684.567	-630.928	-592.145
X/TH**5	= 226.768	919.797	2181.589	3443.465	4377.834
X/TH**3*PH**2	= 5288.333	1617.206	-1779.963	-4726.785	-7079.457
X/TH*PH**4	= -5471.393	-3585.065	-1975.880	-398.442	1104.429
T/H**5	= 0.000	0.000	0.000	0.000	0.000
T/H**3*PH**2	= 0.000	0.000	0.000	0.000	0.000
T/TH*PH**4	= 0.000	0.000	0.000	0.000	0.000
X/T**2+T2*X/T**4	= -0.898	-0.327	-0.012	0.059	-0.079
X/T**3+T2*X/T**5	= -7.370	-0.648	3.601	6.505	8.952
PSI	= 0.000				
N	= 1	2	3	4	
X/D**N	= 1.886	-1.508	0.767	0.148	
X/T*D**N	= 0.000	0.000	0.000	0.000	
X/T**2*D**N	= 6.701E-01	-8.999E+01	8.302E+01	4.397E+02	
X/T**3*D**N	= 3.352E+01	-4.504E+02	5.289E+03	-1.267E+04	
X/T**4*D**N	= 2.695E+03	2.837E+03	-6.364E+03	-3.819E+03	
X/T**5*D**N	= 3.528E+04	-6.971E+03	-1.374E+06	4.878E+06	

interaction studies described in Section IV, will require quite different spectrometer facilities at the end of the beam line.

IV.4. Preliminary Cost Estimates for a 1-2 GeV/c Kaon Beam Line

The table (IV.10) presented in this section offers a preliminary cost estimate⁶³ based on the design presented in section IV.2.

As noted previously, the separators are a standard design, built and operated at KEK, Japan. These have high-voltage supplies, available commercially from Nichikon, built into the separator vacuum tank to minimize the destructive effects of high voltage breakdowns. These designs require a separate magnetic field. The separator plates are formed from anodized aluminum, rather than the glass used in AGS designs.

The power supply costs quoted here are preliminary and are somewhat dependent on final magnet parameters and momentum range.

The quadrupole magnets Q2 through Q7 require shimming to provide 2nd and 3rd order aberration corrections.

Any building or area modifications required for the installation of this line are not included.

Table IV.10. Cost Estimates

1. <u>Separators</u>	205 meter units required, each consisting of a pair of 2.5 meter tank units, costing $\$120 \times 10^3$ apiece.		
Cost:	tanks	$4 \times 120 \times 10^3 = 480 \times 10^3$	
	magnets	$2 \times 75 \times 10^3 = 140 \times 10^3$	
	Separator power supplies (4)	$4 \times 50 \times 10^3 = 200 \times 10^3$	
	and controls	$2 \times 70 \times 10^3 = 140 \times 10^3$	
Total Separator Cost: $\$970 \times 10^3$			
2. <u>Magnets</u>	2-dipoles; 20 KG, 4 inch gap		
Cost:	dipoles	$(2) \times 50 \times 10^3 = 100 \times 10^3$	
	power supplies	$(2) \times 50 \times 10^3 = 100 \times 10^3$	
	fixture costs for above	30×10^3	
	dipole cost	subtotal	230×10^3
	quadrupoles	$(8) \times 40 \times 10^3 = 320 \times 10^3$	
	power supplies	$(8) \times 30 \times 10^3 = 240 \times 10^3$	
	fixture costs for above	50×10^3	
	quadrupole cost	subtotal	610×10^3
3. <u>Beam Hardware</u>	Cost:	vacuum pipe, straight sections, 400 ft.	4×10^3
		12 beam pipe flanges and bellows	12×10^3
		dipole vacuum boxes, two needed	30×10^3
		pumping stations $(2) \times 12 \times 10^3$	24×10^3
		(roughing and turbo pumps included in above)	
		mass slit controls and readouts $(2) \times 20 \times 10^3$	40×10^3
		subtotal	110×10^3
4. <u>Production Target Station</u>	Cost:	instrument package, storage vault,	
		target handling equipment	60×10^3
5. <u>Diagnostic Instrumentation</u>	Cost:	counter telescope	
		single wire ion chambers	
		secondary emission monitor	
		beam loss monitor	25×10^3
6. <u>Setup Labor Cost</u>	Cost:	200×10^3	
total \$			2205×10^3

V. Appendices and Bibliography
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58. The modifications of the Enge-Kowalski design necessary to develop a practical version at the AGS are due to Philip Pile
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60. D. E. Lobb, ref. 56, p. 859; J. Doornbos, ref. 57, p. 819
61. P. Pile, ref. 56, p. 875

62. RAYTRACE is a program developed by H. Enge and S. B. Kowalski
63. R. E. Chrien, memorandum, 2/21/84

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APPENDIX

List of AGS Hypernuclear Proposals and Experiments

Hypernuclear Physics Experiments at the AGS

Experiment #646 Hypernuclear spectroscopy of states formed by the coherent interaction of K⁻ nuclei

Collaborators: H. Palevsky, R.E. Chrien, R. Sutter, M. May - BNL
R. Chester, C.M. Hoffman, G.H. Sanders, A.J.S. Smith - Princeton
M. Deutsch - MIT
E.V. Hungerford - U. Houston
R.L. Stearns - Vassar
D. Marlow, S. Dytman, R. Takeutchi, P. Barnes, R. Eisenstein - Carnegie-Mellon

Spokesman: H. Palevsky - BNL

Experimental Runs: December, 1978, March-June, 1979
844 hours

Publications: R.E. Chrien, M. May, H. Palevsky, R. Sutter, R. Cester, M. Deutsch, S. Bart, E. Hungerford, T.M. Williams, L.S. Pinsky, B.W. Mayes, R.L. Stearns, P. Barnes, S. Dytman, D. Marlow, and F. Takeutchi States of $^{12}\Lambda\text{C}$ formed in the reaction $^{12}\text{C}(\text{K}^-, \pi^-)$, Phys. Lett. 89B (1979). 31-35.

M. May Hypernucleus physics research at AGS. Invited paper, Annual Meeting of the American Physical Society, January 29-February 1, 1979, New York, New York; Bull. Am. Phys. Soc. 24, 69(1979).

M. May (K, π) reaction at Brookhaven. Invited paper, Proc. of the 2nd Conf. on Meson-Nuclear Physics, March 5-9, 1979, Houston, Texas, p. 658.

M. May Physics for a new kaon facility at the AGS. Invited paper, Proc. of Kaon Factory Workshop, August 13-14, 1979, University of British Columbia, Vancouver, Canada, p. 111.

M. May Hypernuclear physics research at Brookhaven. Invited paper, Proc. of the 1979 International Conf. on Hypernuclear and Low Energy Kaon Physics, Sept. 11-14, 1979, Jablonna, Poland.

Status: Completed

Experiment #692 Measurement of the $K^{\pm}$ elastic scattering from selected nuclei at 800 MeV/c.

Collaborators: P. Barnes, S. Dytman, R. Eisenstein, D. Marlow, F. Takeutchi, W. Wharton - Carnegie-Mellon
S. Bart, E. Hungerford, B. Mayes, L. Pinsky, T. Williams - U. Houston
R. Chrien, M. May, H. Palevsky, R. Sutter - BNL

Spokesman: P. Barnes - Carnegie-Mellon

Experimental Runs: December 14, 1978 to January 21, 1979, February 16 to March 6, 1979

Publications: D. Marlow, P.D. Barnes, N.J. Colella, S.A. Dytman, R.A. Eisenstein, R. Grace, F. Takeutchi, W.R. Wharton, S. Bart, D. Hancock, R. Hackenberg, E. Hungerford, W. Mayes, L. Pinsky, T. Williams, R. Chrien, H. Palevsky, R. Sutter. Kaon scattering from C and Ca at 800 MeV/c. Phys. Rev. C 25 2619 (1982).

D. Marlow, P.D. Barnes, N.J. Colella, S.A. Dytman, R.A. Eisenstein, R. Grace, F. Takeutchi, W.R. Wharton, S. Bart, D. Hancock, R. Hackenberg, E. Hungerford, W. Mayes, L. Pinsky, T. Williams, R. Chrien, H. Palevsky, R. Sutter. Pion scattering from C and Ca at 800 MeV/c. Phys. Rev. C30, 1662 (1984)

Status: Completed

Experiment #728 Search for Zn bound states

Collaborators: H. Palevsky, R.E. Chrien, R. Sutter, M. May - BNL
R. Chester, C.M. Hoffman, G.H. Sanders, A.J.S. Sanders - Princeton
M. Deutsch - MIT
E.V. Hungerford - U. Houston
R.L. Stearns - Vassar
D. Marlow, S. Dytman, F. Takeutchi, P. Barnes, R. Eisenstein - Carnegie-Mellon

Spokesman: H. Palevsky - BNL

Experimental Runs: August, 1978, October to November, 1978

Publications: M. May (K, π) reaction at Brookhaven. Invited paper, Proc. of the 2nd Conf. on Meson-Nuclear Physics, March 5-9, 1979, Houston, Texas, p. 658.

M. May, R.E. Chrien, H. Palevsky, R. Sutter, S. Dytman, D. Marlow, P. Pile, R. Takeutchi, M. Deutsch, R. Cester, S. Bart, E. Hungerford, T.M. Williams, L.S. Pinsky, B.W. Mayes, and R.L. Stearns
Experimental study of the Σ -nucleon system through the reaction $H(K,\pi)\Sigma N$, Phys. Rev. C25, 1079 (1982).

Status: Completed

Experiment #746 Spin and isospin effects in light hypernuclei

Collaborators: R.E. Chrien, M. May, H. Palevsky, R. Sutter - BNL
R. Cester - U. Torino
M. Deutsch - MIT
S. Bart, E.V. Hungerford, B. Mayes, L. Pinsky - U. Houston
R.L. Stearns - Vassar
P. Barnes, S. Dytman, R. Eisenstein, D. Marlow, F. Takeutchi,
R. Wharton - Carnegie-Mellon

Spokesman: H. Palevsky - BNL

Experimental Runs: March to August, 1980

Publications: M. May, H. Piekarz, R.E. Chrien, S. Chen, D. Maurizio, H. Palevsky, R. Sutter, R. Xu, P. Barnes, B. Bassalleck, N.J. Colella, R. Eisenstein, R. Grace, P. Pile, F. Takeutchi, W. Wharton, M. Deutsch, J. Piekarz, S. Bart, R. Hackenburg, E.V. Hungerford, B. Mayes, L. Pinsky, R. Cester, and R.L. Stearns Observation of levels in $\Lambda^{13}\text{C}$, $\Lambda^{14}\text{N}$, and $\Lambda^{18}\text{O}$ hypernuclei, Phys. Rev. Lett. 47, 1106 (1981).

Status: Completed

Experiment #752 A Search for Σ Hypernuclear Levels in ^{16}O in the (K^-, π) Reaction

Collaborators: S. Bart, D. Hancock, R. Hackenburg, E. Hungerford, B. Mayes, L. Pinsky, T. Williams - U. of Houston
R. Chrien, M. May, H. Palevsky, R. Sutter - BNL
P. Barnes, R. Eisenstein, W. Wharton, F. Takeutchi - Carnegie-Mellon
R. Stearns - Vassar

Spokesman: E. Hungerford - U. of Houston

Experimental Runs: November to December, 1980, May 1981

Publications: H. Piekarz, S. Bart, R. Hackenburg, A.D. Hancock, E.V. Hungerford, B. Mayes, K. Sekharan, J. Piekarz, M. Deutsch, R.E. Chrien, S. Chen, M. Levine, D. Maurizio, M. May, H. Palevsky, Y. Xu, P.D. Barnes, B. Bassalleck, R. Eisenstein, R. Grace, C. Maher, P. Pile, and R.L. Stearns Experimental observation of the Σ hypernuclei, $\Sigma^0\text{H}$ and $\Sigma^{16}\text{C}$, Phys. Lett. 110B, 428 (1982).

Status: Completed

Exp. #758: The (π^+ , K^+) Reaction, a New Tool for the Study of Hypernuclear Structure

Collaborators: J. Amann, T. Carey, N. King, T. Kozlowski, C. Morris, R. Mischke, J. Moss, R. Silbar, H. A. Thiessen - LANL; R. Chrien, R. Sutter, P. Pile, S. Bart - BNL; H. Plendl - Florida State U.; E. Hungerford, L. S. Pinsky, E. W. Mayes - U. of Houston; C. Glashausser - Rutgers; R. L. Stearns - Vassar; H. Funsten - William and Mary

Spokesman: H. A. Thiessen - LANL

Exp. Runs: Completed January-February, 1983

Status: Complete

Publication: Milner, C., Barlett, M., Hoffmann, G. W., Thiessen, H. A., Amann, J. F., Bhatia, T. S., Silbar, R., Peng, J. C., Kozlowski, T., Chrien, R. E., Pile, P., Bart, S., McGill, J. A., Glashausser, C., Barnes, P. D., Franklin, G. B., Grace, R., Hungerford, E. V., Hackenburg, R., Plendl, H., and Stearns, R. L. Observation of Λ -hypernuclei in the $^{12}\text{C}(\pi^+, K^+)\Lambda^{12}\text{C}$ reaction. Tenth Intern. Conf. on Particles and Nuclei, Heidelberg, July 30-Aug. 3, 1984 (submitted, Phys. Rev. Lett., December 1984).

Exp. #759: The Weak Decay Modes of Hypernuclei

Collaborators: P. D. Barnes, B. Bassalleck, R. A. Eisenstein, R. Grace, R. Rieder, W. R. Wharton - CMU; R. Chrien, P. Pile - BNL

Spokesman: P. D. Barnes - CMU

Exp. Runs: Completed March-April 1983

Status: Complete

Publication: Grace, R., Barnes, P. D., Eisenstein, R., Franklin, G., Maher, C., Rieder, R., Seydoux, J., Szymanski, J., Wharton, W., Bart, S., Chrien, R. E., Pile, P., Hungerford, E. V., Hackenburg, R., Bassalleck, B., and Stearns, R. L. The four-fermion weak interaction and the decay of $\Lambda^{12}\text{C}$. Tenth Intern. Conf. on Particles and Nuclei, Heidelberg, July 30-Aug. 3, 1984 (to be submitted to Phys. Rev. Lett.).

Exp. #760: Spin Dependence of the Lambda Nucleus Interaction Determined by Observation of Hypernuclear Gamma Rays

Collaborators: M. Deutsch, J. Piekarz - MIT; R. Chrien, M. May, R. Sutter - BNL; R. Cester - Torino; S. Bart, E. V. Hungerford, B. Mayes, L. Pinsky, H. Piekarz - U. Houston; B. Budick - NYU; R. L. Stearns - Vassar; Y. Xu - Peking

Spokesman: M. Deutsch - MIT

Exp. Runs: May-June, 1982

Publication: May, M., Bart, S., Chen, S., Chrien, R. E., Maurizio, D., Pile, P., Xu, Y., Hackenburg, R., Hungerford, E., Piekarz, H., Yue, Y., Deutsch, M., Piekarz, J., Barnes, P. D., Franklin, G., Grace, R., Maher, C., Rieder, R., Szymanski, J., Wharton, W., Stearns, R. L., Bassalleck, B., and Budick, B., Observation of hypernuclear gamma-ray transitions in ^7Li and ^9Be . Phys. Rev. Lett. 51 (1983) 2085

Exp. #773: Investigation of Possible Strange Dibaryon States with AP Missing Mass Region above the ΣN Threshold

Collaborators: E. V. Hungerford, B. W. Mayes, H. Piekarz, L. S. Pinsky - U. Houston; M. Deutsch, J. Piekarz - MIT; R. Chrien, P. Pile - BNL; B. Bassalleck - U. New Mexico; R. Stearns - Vassar

Exp. Runs: April-May 1984

Extension: 750 hours approved February/March 1985

Status: Experiment in progress

Exp. #774: Search for Σ -Hypernuclear Levels in the ${}^4\text{He}$

Collaborators: E. Hungerford, L. S. Pinsky, B. W. Mayes, H. Piekarz - U. of Houston; S. Bart, R. E. Chrien, P. Pile - BNL; B. Barralleck - U. of New Mexico; R. Stearns - Vassar

Spokesman: E. V. Hungerford - U. Houston

Exp. Runs: Scheduled for April 1985

Status: Approved for 100 hours initially; Extension approved for 400 hours to study "Narrow Σ -Hypernuclear States in Boron Carbon Targets"

Exp. #781: Spin Dependence of the Lambda Nucleus Interaction Determined by Observation of Hypernuclear Gamma Rays

Collaborators: R. E. Chrien, M. May, P. Pile, S. Bart - BNL; M. Deutsch - MIT; E. V. Hungerford, B. Mayes, L. Pinsky - U. of Houston, R. L. Stearns - Vassar; B. Budick - NYU

Spokesmen: M. Deutsch - MIT; M. May - BNL

Exp. Runs: February-March 1984

Status: Data Reduction in progress; Extension for 100 hours approved

Extension Topic: The Feasibility of a Direct Measurement of the P to S State γ Emission in ${}^{13}\text{C}$

Publications:

Chrien, R. E. Hypernuclear research at the AGS. Invited Talk. Intern. Symp. on Nuclear Spectroscopy and Nuclear Interactions, Osaka, March 21-24, 1984.

Chrien, R. E. The gamma-ray spectroscopy of hypernuclei. Invited talk at the Intern. Symp. on In-beam Nuclear Spectroscopy, Debrecen, Hungary, May 14-18, 1984.

Chrien, R. E. Detecting gamma rays from hypernuclei. Invited talk at the Conference on the Intersections between Particle and Nuclear Physics, Steamboat Springs, Colorado, May 23-30, 1984 (submitted).

May, M., Barlett, M., Barnes, P. D., Bassalleck, B., Chrien, R. E., Chu, C. Civelekoglu, Y., Derderian, J., Deutsch, M., Eisenstein, R., Franklin, G., Fukuda, T., Grace, R., Hackenburg, R., Hungerford, E., Kishimoto, T., Marlow, Milner, E. C., Pile, P., Prater, J. K., Rieder, R., Seydoux, J., Stearns, R. L Sutter, R., Szymanski, J., and Wharton, W. Hypernuclear gamma rays due to Λ spin-flip. Abstract. Tenth Intern. Conf. on Particles and Nuclei, Heidelberg July 30-Aug. 3, 1984 (submitted).

Exp. #788: The Four Fermion Weak Interaction and the Decay of $\Lambda^4\text{He}$ and $\Lambda^5\text{He}$

Collaborators: P. D. Barnes, R. Eisenstein, G. Franklin, R. Grace, D. Hertzog, C. Maher, D. Marlow, R. Rieder, J. Seydoux, J. Szymanski, W. Wharton, R. Chrien, P. Pile, E. V. Hungerford, B. Bassalleck, M. Deutsch, R. L. Stearns

Spokesmen: P. D. Barnes and G. Franklin

Status: Approved for 650 hours and scheduled for May-June, 1985

Exp. #796: The Study of Strangeness in Nuclei by Using the (π^+, K^+) Reaction

Collaborators: S. Bart, R. E. Chrien, P. Pile, R. J. Sutter, P. D. Barnes, G. Diebold, G. B. Franklin, R. Grace, D. Hertzog, J. Seydoux, J. Szymanski, H. Plendl, E. V. Hungerford, T. Kishimoto, J. F. Amann, J. A. McGill, J. C. Peng, R. Silbar, T. S. Bhatia, H. A. Thiessen, C. Glasshauser, R. Fergerson, M. Barlett, G. W. Hoffman, E. C. Milner, R. L. Stearns

Spokesmen: P. Pile and J. C. Peng

Status: Approved for 600 hours and scheduled for 1986