PLANS FOR LAMPF II

by

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ABSTRACT

A high-intensity 16- to 32-GeV proton accelerator is proposed. Several major areas of physics would benefit, including muons, neutrino physics, rare kaon decays, hypernuclei, and antiproton physics. The possibilities for constructing such a machine on the Los Alamos site and a preliminary cost estimate are discussed.

Introduction

During the past year, we have been discussing the possibilities for a major upgrade of LAMPF to serve the medium-energy physics community during the decade of the 1990's. Most of our effort has gone into the physics that will be performed, with smaller efforts devoted to conceptual design of a possible set of experiments, and planning of the accelerator and experimental areas. The meeting July 19-22, 1982, in the Los Alamos Study Center is the first opportunity for a large group of users to discuss with us our plans and to provide their input.

Several physics working groups have been set up. These working groups include:

Nuclear Physics	N. Stein, secretary
CP Violation	C. Hoffman, secretary
Rare K decays	R. Mischke, secretary
Hyperons	R. Mischke, secretary
Nucleon/Anti-Nucleon	B. Bonner, chairman
Neutrinos	R. Carlini, secretary
Nuclear Chemistry	B. Dropesky, secretary
Exotic Atoms	M. Leon, secretary
Muons	R. Heffner, secretary

The working groups will meet here at the Study Center, again at the Users meeting in November, and several times during the winter and spring. From July 18 to July 29, 1983, there will be a LAMPF II workshop at the Los Alamos Study Center. During this longer workshop, it will be possible to become more involved in the detailed planning for the LAMPF II Experimental Areas and facilities.

The goal of this series of meetings is the preparation of a proposal for LAMPF II. This will be done in two steps. First, in the fall of 1982, we will write a report that identifies the physics we want to study. We expect that this physics report will be available in time for the LAMPF Users Group meeting in November. During the next year, we hope to develop our plans to the point where it will be possible to make a detailed proposal for the complete facility, including meaningful cost estimates. The working groups will be particularly helpful in defining the beam lines and general purpose detectors that will be required. A small design group is being established to make plans for the accelerator and experimental areas. If all goes well, we anticipate that a complete proposal will be ready in the fall of 1983.

Possibilities For LAMPF II Beams

Most of the physics we have discussed to date requires high-intensity secondary beams. Our basic goal is to provide fluxes on the order of 100 times those presently available at the CERN PS or the Brookhaven AGS. A year ago, the Los Alamos/TRIUMF/Rome/CERN collaboration[1] ran an experiment on secondary particle production at the CERN PS. This experiment used an existing beam line and measured the yield as a function of the energy of the primary beam. A sample result is shown in Fig. 1. For negative pions and kaons, the yield is roughly proportional to the energy of the primary beam. If LAMPF II were to operate at 16 GeV, 60 Hz and 10^{13} protons per pulse, it would produce 100 times as many kaons and pions as the CERN PS operating at 24 GeV and 10^{13} protons each 2.4 seconds. Compared with the Brookhaven AGS operating at 30 GeV and 10^{13} protons each 2.4 seconds, LAMPF II would produce 75 times as many kaons. In these comparisons, it is assumed that the same factors for beam sharing, target efficiency, and beam-line acceptance are applicable at each machine.

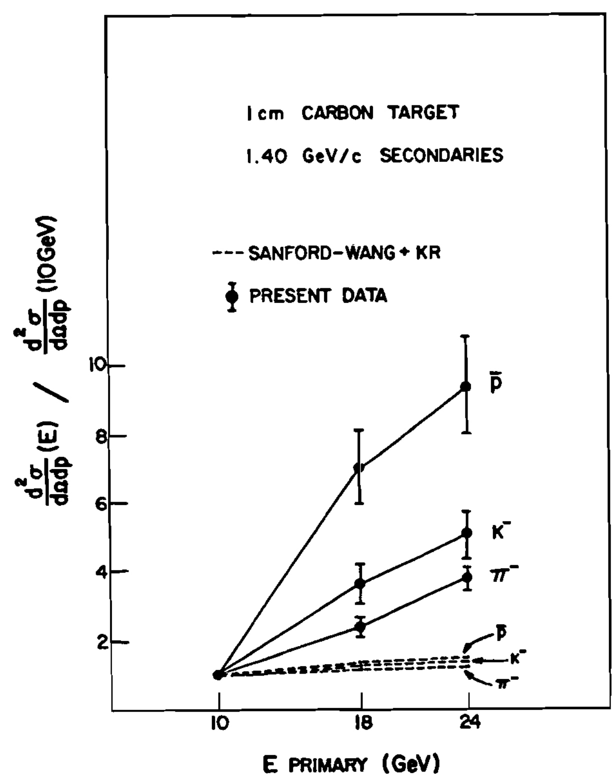

Fig. 1
Energy dependence of production cross sections on 1-cm carbon target normalized to 10-GeV cross section.

The antiproton yield varies more rapidly with primary beam energy. We expect that at the peak of the antiproton yield, the cross section for antiproton production at 16 GeV will be approximately one-half that obtained at 24 GeV and one-fifth that at 30 GeV. Thus, at LAMPF II, operating at 16 GeV we expect a fiftyfold increase in the antiproton flux compared with CERN, and 20 times that of Brookhaven. In a later improvement, we will raise the energy of LAMPF II to 32 GeV. At this higher proton energy, the antiproton flux will be 100 times that of Brookhaven and 200 times that of CERN. The yield of kaons and other secondary particles will be more than doubled in this upgrade.

There are two important cases of tertiary beams at LAMPF II, namely, muons and hyperons. Muon beams result from pion decay, hence are proportional to the pion yield. In most cases, the pions of interest are very low in energy and no data exist. If we make the assumption that the yield of low-energy pions is proportional to the power deposited in a target, then LAMPF II muon beams will be about 10 times more intense than those at LAMPF. In the special case of negative muons resulting from a decay channel, it will be possible to improve on the technology of the channel by including a superconducting solenoid. In this case, an improvement of 100 times the flux of the present stopped muon channel is possible. We must check these estimates by measuring the flux of low-energy pions and especially the yield of surface muons at CERN or Brookhaven. The contamination of the low-energy muon and pion beams by electrons and positrons will be much worse than at LAMPF, but properly designed separators can eliminate this problem. We therefore expect that LAMPF II will be a better muon factory than LAMPF.

Some thought has been given to using K^- beams to produce hyperons. It may be possible to use the (K,π) reaction to produce a tagged beam of hyperons. Recent experience at Brookhaven[2] shows that a significant improvement in the signal to noise in a Σ x-ray experiment can be obtained by tagging--the only feasible method of producing excited states of hyperons because of their short lifetimes. Thus LAMPF II will be the only available source of excited hyperons. It may also be possible to produce a tagged antihyperon beam by using the antiproton beam. This possibility has not yet received serious study.

A neutrino beam is one of the most important products of LAMPF II. The calculated flux of neutrinos as a function of proton energy is shown in Fig. 2, and was presented by Herb Chen at the February workshop. Improved estimates will be discussed at the neutrino working group meeting. I would like to direct your attention to the solid curve, that of neutrino flux divided by proton energy, or neutrinos per unit beam power on target. This has a plateau above 3 GeV. The average energy of neutrinos produced is slowly varying with proton energy, with the result that, for a neutrino-electron scattering experiment, the yield of events will be approximately a factor of 1000 larger at 16 GeV than at LAMPF for the same current on target. If a neutrino horn can be operated at 60 Hz, then it is reasonable to assume that the full 100-μA LAMPF II current can be put on a carbon target for the fraction of the year that neutrino experiments operate. Flux is not the whole issue, because backgrounds and event definition are important issues. However, it appears that LAMPF II will be a substantially better neutrino source than LAMPF with the proton storage ring in operation.

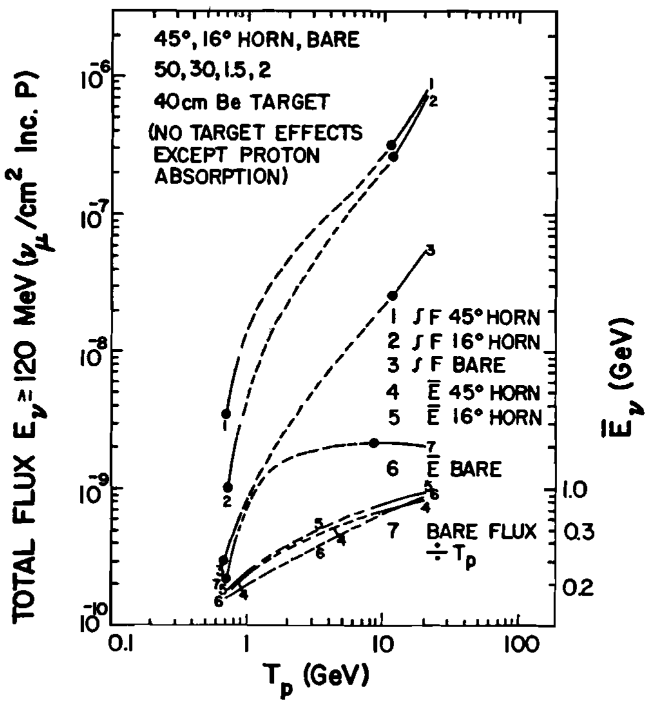

Fig. 2
Yield of neutrinos and average neutrino energy vs proton energy for a decay tunnel of 30-m length.

Some comments on the duty factor of LAMPF II are in order. For slow extracted beams, we propose to build a separate stretcher ring that will make possible a duty factor of at least 70%. A microstructure will be imposed on this beam, and we expect to have 1-ns pulses each 20 ns (50-MHz rf system). For experiments desiring a short duty factor, it will be possible to extract the whole beam in a single turn, which will result in a pulse length of 3 μs. It will also be possible to extract the beam in 10 batches, resulting in 10 pulses of 300 ns each separated by the order of 100 μs. The latter mode will be particularly useful for experiments involving the decay of muons, because it will be possible to load an apparatus with muons and then look for their decay between beam bursts. It will be particularly attractive to build a muon beam viewing the neutrino target because both classes of experiment benefit from the short duty factor mode.

Polarized beams of protons from LAMPF II will be possible. There is a compatibility problem with such beams. Most users of the polarized beam insist on high duty factor with variable energy. To provide this beam during routine operation, it would be necessary to have a separate stretcher ring and separate switchyard. A possible option remains. If the neutrino facility is operated for a fraction of the year using essentially all of the beam, as is the case at Brookhaven, then it may be possible to divert occasional pulses of polarized beam to the stretcher ring. The stretcher ring could be dedicated to low-energy operation, hence variable energy would be possible. This mode places severe constraints on the polarized source and on the flexibility of operation of the accelerator because the polarized beam pulses would require a substantially different tune of the accelerator. Further study is required in order to know if this mode is possible, including a study of the feasibility of a 60-Hz neutrino horn.

Hypernuclear Physics at LAMPF II

The strangeness exchange reaction, $K^- + n \rightarrow \pi^- + \Lambda$, makes possible the transfer of strangeness to the nucleus. On the quark level, a d quark from the neutron is exchanged with an s quark from the kaon, normally without spin flip. Because the reaction is exothermic, there exists a "magic" momentum of the kaon which results in a Λ produced at rest in the laboratory. Momenta close to the magic momentum have been exploited to produce low-spin hypernuclear states. The Heidelberg/Saclay collaboration working at CERN has come to the startling conclusion that the spin orbit force between the Λ and the nucleus is nearly 0 (Ref. 3). This result has been confirmed by the group working at Brookhaven.[4] A simple quark model has been proposed to explain this phenomenon.[5] This model predicts that the Σ nucleon spin orbit force will be very large.

Sigma hypernuclei may be produced by the (K^-,π^-) reaction. The magic momentum is lower, approximately 300 MeV/c compared with 550 MeV/c for the Λ case. Sigma hypernuclei should have short lifetimes and the states will be noticeably broadened because of the rapid conversion process, $\Sigma + N \rightarrow \Lambda + N$, which occurs in nuclei. Spectroscopic arguments can affect the rate of conversion, and at least a few states have been observed that have a width narrower than the present experimental resolution. The new Σ data were discussed at a recent meeting in Heidelberg.[6] The statistics of these data are poor, and the interpretation is crude. Preliminary indications are that the Σ nucleus spin orbit force will turn out to be large.

All of the experiments to date suffer from poor statistics by comparison with normal practice in nuclear physics. The high intensity of LAMPF II will make possible a major improvement in this field. Intensity is not the only problem. Present kaon beams have pion contaminations of 10-50 pions per kaon in the beam spot on target under normal operating conditions. A simple increase of the flux would raise the pion rate to an intolerable level. Also, the present resolution under normal operating conditions is on the order of 3 MeV or worse. In most cases, the low counting rates have led to the necessity of thick targets, which dominate the resolution. It will be necessary to use some of the increased flux of LAMPF II for increased beam purity and for improved resolution. It appears possible to improve the beam purity by incorporating an additional stage in the beam line to clean up the halos in the image of the target. The simplest form of beam-line improvement is to include an additional crossover upstream of the separator. The question remains whether a two-dimensional achromatic image is required, or whether a one-dimensional image will be sufficient. A design for a dispersed beam line with an additional crossover appears in the January 1981 workshop at Los Alamos. This design would allow approximately 10^{-7} negative kaons with 300-KeV resolution at 700 MeV/c. The beam flux should be compared with present fluxes of 10^4-10^5 at 3-Mev resolution. The improved flux and resolution should allow studies to extend to states and regions of the periodic table that cannot be reached today. Sigma hypernuclei require a lower momentum beam line. The beam line proposed by Don Lobb at the February 1982 workshop might be suitable for this purpose.

In addition to the basic improvement in flux and resolution, LAMPF II should be able to provide the first possibility of experiments in the doubly strange nuclei, either double Λ or cascade hypernuclei produced in the (K^-,K^+) reaction. The present world sample of such reactions consists of a few cases observed in emulsion.[7] A few binding energies are known. The high fluxes of LAMPF II will allow the first systematic direct measurements of such processes in a dedicated experiment.

It is possible to reach the hypernuclei by using the (π^+,K^+) reaction. The momentum transfer to the nucleus cannot be made small in this reaction. However, it is possible to obtain momentum transfer on the order of 250 MeV/c that is matched to the high-spin "stretched" states which should exist in many nuclei.[8] The momentum transfer at zero degrees is plotted as a function of the beam momentum in Fig. 3. The (π^+,K^+) reaction should not be viewed as a replacement for (K^-,π^-), but rather as an additional tool for reaching high-spin states which should show selectivity for different states. There are several important experimental advantages to the (π^+,K^+) reaction. First, the beam flux can be 100 to 1000 times larger. A dispersed beam line without detectors, such as the EPICS beam line, would be possible. The two-body reaction has a forward differential cross section which is about 10 times smaller than (K^-,π^-),

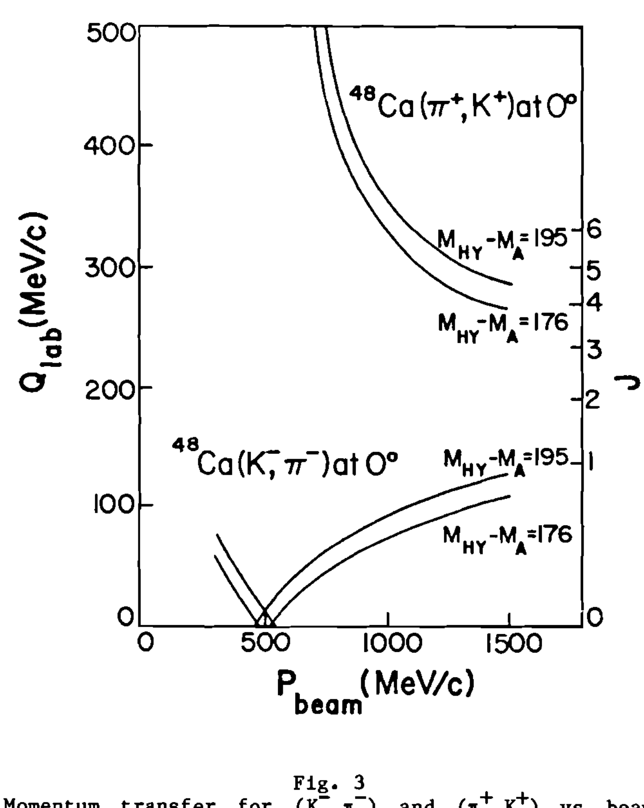

Fig. 3
Momentum transfer for (K^-,π^-) and (π^+,K^+) vs beam momentum at 0°. The target is ^{48}Ca. The scale at the right shows the most probable momentum component of states of various J.

leaving a net gain of 10 to 100 fold. Detection of the kaons is simpler, since the detector that identifies the reaction product needs to be at the focal plane of the spectrometer, which means that it will not interfere with the momentum resolution. It is thus feasible to do cleaner experiments at large momentum transfer than in (K^-,π^-) by using (π^+,K^+). The first experiment to measure this reaction with sufficient resolution to identify specific nuclear states will be performed by a Los Alamos-led collaboration at Brookhaven in the spring of 1983.

Scattering of Kaons and Pions From Nuclei

Pion scattering from nuclei can be studied at EPICS at energies up to 290 MeV. The most interesting areas studied have included inelastic scattering to high-spin unnatural parity states, and double charge exchange. LAMPF II offers the possibility to increase the range of energy available to include the 600-MeV/c and 900-MeV/c pion-nucleon resonances. There are several important advantages of the higher energy, including a much longer mean free path of the pion in nuclear matter and a different spin-isospin structure of the pion-nucleon interaction. A rather detailed calculation has been performed by Jim Carr of Florida State and was reported at the February 1982 workshop. His paper appears in this volume. The basic conclusion is that at 600 MeV/c, the role of the π^+ and π^- in exciting neutron or proton states is reversed from the situation at 180 MeV. The π^+ will preferentially excite neutrons, while the π^- will excite protons. Because of a fortunate cancellation among the amplitudes, the sensitivity ratio is even larger than the 9:1 expected at 180 MeV and indeed, the ratio can be nearly infinite. LAMPF II offers the possibility to build a high-resolution system at 0^o pion production angle with the result that the apparent target size is much smaller than for 35^o as at EPICS. The result is that it should be possible to construct a system that has substantially better resolution than EPICS. Because of the near equality of π^+ and π^- produced by 16-GeV protons, the beam intensity can be between 10 and 100 times larger for π^- than at EPICS, and it is normally the π^- runs that dominate the running time requirements at EPICS.

The double-charge-exchange reactions, (π^+,π^-) and (π^-,π^+), have been the source of the most surprising results from EPICS. Double isobaric analog transitions increase in strength dramatically at the highest available energies at EPICS. Near the P_{33} resonance, there is a surprising dominance of the non-analog transitions and a need to do more experiments with negative pion beams. Mass measurements have turned out to be particularly clean, and EPICS already has significant advantages compared with heavy-ion double charge exchange. EPICS is the only system anywhere in the world with sufficient counting rate and resolution to tackle these problems. The rates at EPICS are extremely low. The increase in energy of pions and the increase in flux of negative pions that will be possible at LAMPF II will make a major increase in the number of cases that can be studied. A high-intensity pion channel and spectrometer at LAMPF II working in the 200- to 600-MeV region would be an extremely useful tool for pion scattering and double-charge-exchange experiments. It may be possible to use the existing HRS spectrometer with a newly constructed dispersed pion beam for these experiments.

Kaon nucleus scattering has some extremely interesting possibilities, because the K^+ has the longest mean free path in nuclear matter of all the hadronic probes. To date, the counting rate and resolution available have not been high enough to make use of the kaon as a nuclear probe. The best experiment is that of the Carnegie-Mellon group at Brookhaven.[9] The resolution achieved was barely sufficient to study elastic scattering from carbon. The counting rate and geometrical constraints at Brookhaven prevented extending the angular distribution beyond 30^o. These data are presently being analyzed by the University of Texas at Austin group.[10] Their initial reports indicate that it is necessary to use a KMT type of multiple-scattering theory with input specialized to kaons. When this is done, the results are in much better agreement with the data then has ever been observed for pions at EPICS or 800-MeV protons at HRS, verifying the usefulness of kaons as a precision probe of nuclear matter. For inelastic scattering, the K^+ will emphasize natural parity transitions because no spin flip is involved in the basic kaon-nucleon interaction.[10] Much remains to be worked out in the details of the reaction mechanism, but it is already clear that a kaon channel and spectrometer operating at approximately 700 MeV/c would be a very useful device. It is likely that the same beam line could be used for (K^-,π^-) and kaon scattering. The existing EPICS spectrometer might be used for both of these experiments.

Other Nuclear Physics At LAMPF II

In a talk such as this, it is not possible to consider all of the possibilities with any detail. One of the more interesting possibilities I can only mention is the study of the propagation of resonances in nuclear matter. The Δ resonance (1238 MeV) is essentially the only case that can be studied in detail at LAMPF. Only after some years of work has it been possible to clearly identify its effect on nuclear processes.[11] One of the reasons for this difficulty is the large width of the Δ. The Y*(1520) can be excited by negative kaons, and its narrow width and low threshold makes it an extremely interesting case to study. The higher N* resonances should also be observable, and the higher energy of the LAMPF II beams will be required to reach them.

Two classes of experiment are good tests of quark models, and these models are similar enough to shell models of the light nuclei that they can be considered nuclear physics problems. These classes are the study of the decays of the hyperons, especially the electromagnetic decays, and the pion- and kaon-nucleon scattering problems. Hyperon decays can be used to obtain the quark shell model wave functions of the hyperons. The field of excited hyperon decays is extremely rich, and there are strong selection rules on the allowed decays that will be sensitive tests of the small components of the quark wave functions (for example, admixtures of 4-quark antiquark in dominantly 3-quark states). Low-energy kaon-nucleon scattering requires high intensity and a special short beam line because of the short lifetime of the charged kaon. The kaon-nucleon scattering problem at low energy is waiting for good data, and both the pion and kaon-nucleon scattering above 500 MeV/c require better data to clearly establish the phase shifts, which are normally compared with quark models.

Muons At LAMPF II

Muon beams should be the easiest beams to produce at LAMPF II. Typically, surface beams are obtained at large angles to the proton beam, which makes it possible to share a production target with a kaon or antiproton beam line. It is also possible to share the production target with a neutrino beam; thus 1 can have a choice of duty factors, either near 1 or near 0. Indeed, the fast extracted beam could be broken into 10 micropulses on the order of 300 ns in duration with 10-100 μs between bursts. Because a typical neutrino horn has a pulse length of more than 1 ms, this mode of operation could be obtained without compromising the neutrino program. Indeed, this mode would even be preferred for a "beam stop experiment" using the electron neutrinos from muon decay. The combination of higher flux, better duty factor, and more beam ports for muons makes LAMPF II a superb muon factory.

The experiments that will be done with muons at LAMPF II span a very wide field. Among the most interesting are the rare decays. The decay $\mu \to e^+\gamma$ was measured at all of the meson factories; the best upper limit, 1.7×10^{-10}, was obtained at LAMPF.[12] A second generation experiment will be performed at LAMPF using the "crystal box" now under construction. A limit of 10^{-12} is expected. Using the higher intensity 100% duty factor beam of LAMPF II, a limit of 10^{-14} is possible.

The measurement of the hyperfine structure of muonium has been the subject of experiments for several decades. The precision of the results has increased steadily. With one more factor of 10 improvement, it will be possible to see directly the weak interaction contribution. This is an important test of the unification of the weak and electromagnetic interactions which has resulted from the Weinberg-Salam-Glashow theory.[13]

Muon capture experiments should be able to take the maximum advantage of the flux of LAMPF II, because negative muons are required. Experiments range from muon capture on hydrogen to muon capture on heavy elements. Tests of nuclear structure and of the muon capture matrix element are possible.

The muon (g-2) experiment was performed at CERN some years ago. Because of the time dilation factor, higher energy muons than are available at LAMPF are the best choice for such an experiment. The theory has been improved by Kinoshita to the point where a 10 times better measurement would be useful. The 100 times increase in the muon flux available at LAMPF II coupled with modern superconducting magnet technology should make such a measurement possible. Vernon Hughes and his group are developing a proposal for a 10 times improved (g-2) experiment at LAMPF II.[14]

We have considered the possibilities for muonic x-ray measurements at LAMPF II. To date, we have not been able to see any real advantages in using the higher flux or duty factor. The semiconducting germanium detector is still the detector of choice. Higher intensity will not significantly improve the experiments because of radiation damage in the detector. Crystal spectrometers do not have adequate efficiency for most applications. Thus we do not expect that LAMPF II will have a significant effect, except that there may be a higher availability of muon beams for this work.

The muon spin rotation field is particularly active at this time. However, the 100% duty factor beams that will be available at SIN and the fast-pulse KEK Boom facility in Japan will soon leave the U.S. no effective way to compete. LAMPF II will make possible competitive beams. If a dedicated muon beam line for μSR is possible, then we will be able to again have a world-class facility. In the interim, while we are waiting for LAMPF II to come on line, we are considering the possibility of a pulsed muon facility at PSR.

A particularly good muon workshop was held at Los Alamos in March 1982, and proceedings are available which document the case for muon physics at LAMPF II and PSR.[15]

Rare Kaon Decays At LAMPF II

The field of kaon decays has been an active field of study for several decades. One of the reasons for this interest is the extreme richness of decays available for study. Recently, the interest in grand unified theories has brought forth the idea that investigation of decay modes that violate various conservation laws could be extremely productive. In particular, there are now reasons why lepton number might not be conserved at a low level. An example of such a decay is $K \to \mu + e$, or the related decay $K \to \pi + \mu + e$, which can be studied more cleanly. The present limit for $K \to \pi + \mu + e$ is 5×10^{-9}. If such an experiment were to be performed at LAMPF II, the ultimate statistical limit would be less than 10^{-12}. It should be noted that at Brookhaven the Zeller group has proposed an experiment that can approach 10^{-11}. If one talks about the result in terms of a limit on the mass of a horizontal generation changing boson, then a 10^{-12} limit would imply that the mass of this object is greater than 140 TeV. It is clear that the study of rare processes such as this can make a significant impact in Glashow's "Great Desert."[16]

Another class of decay that shows the potential for further study of rare kaon decays is $K \to \pi$ + missing neutrals. Working near the end point of the pion spectrum, one is sensitive to light particles such as neutrino-antineutrino pairs. Tom Sanford suggested that this might be a measurement of the number of neutrino types in the universe, since the phase space for the decay is proportional to the number of states available for decay. Bob Shrock has pointed out that this argument is circular, because additional neutrinos would bring with them additional unknown quark-neutrino couplings and the problem cannot be unscrambled. He also points out that for reasonable assumptions, another class of decay could dominate the observed result, namely the case of decay into photino-antiphotino pairs (the photino is the spin 1/2 supersymmetric partner of the photon). Another possibility is axions. It is clear that regardless of the outcome of the discussion, a measurement should be made at the level of 10^{-9}, which is the result of a second-order weak interaction calculation for three flavors of massless neutrinos. At a minimum, this checks Weinberg-Salam, which is a renormalizable theory, and this decay should be accurately calculable. If a significant deviation is found, it will be exciting regardless of the origin of the discrepancy.

There are many other examples of important kaon decays. We had a good talk by Laurence Littenberg at the February workshop and another is scheduled by Henry Lubatti at this workshop.

CP Violation Experiments

CP violation is a very well-studied problem. Experiments in this field are difficult and are useful only if they achieve very impressive limits. The key problem is to discover the underlying mechanism. The superweak theory was invented to allow CP violation at a low level without affecting in any other way our body of physics knowledge. If this theory is correct, we may never find any other process in which effects are seen. However, other alternative proposals have been advanced, such as the Kobayashi-Maskawa mixing matrix theory. To sort out some of these possibilities, it is necessary to study as many different processes as possible. One example is the search for polarization of the muon in the decay $K^+ \rightarrow \pi^0 + \mu^+ +$ neutrino. This experiment was recently performed by Adair et al. at Brookhaven[17] with an observed effect of $(4.2 \pm 6.7) \times 10^{-3}$. A limit less than 10^{-3} is desired. The same apparatus could be put in a high-intensity kaon beam free of major contaminants at LAMPF II and would achieve a limit of less than 0.5×10^{-3}. Another possibility is to look for a different direction of polarization of the muon, namely, $p_K \cdot (p_\mu \times j_\mu)$ as opposed to $p_\pi \cdot (p_\mu \times j_\mu)$. The availability of 100% polarized muon beams at LAMPF II will be an invaluable aide to the development of detectors for this process.

There are numerous other experiments that can be repeated with higher sensitivity. Detailed consideration is required before it will be clear about which should be done first. However, all of the present limits are statistical in nature and not due to systematics. It is clear that the high intensity of LAMPF II will be important in the next generation of experiments. We expect that Jim Cronin and the CP Violation working group will have a lot more to say about this subject.[18]

Neutrinos At LAMPF II

There has recently been a proposal by Los Alamos for a neutrino program at PSR.[19] This proposal calls for the construction of a decay channel neutrino source and a large detector. I view this proposal, which is constrained to 800-MeV protons by the realities of existing facilities at Los Alamos, as the first step in a long-term program which will lead to experiments at LAMPF II. The reason for this statement is clear from Fig. 2. The flux of neutrinos is a very strong function of the primary proton energy. (This is an obsolete figure; a more accurate calculation will be discussed by the Irvine group at the neutrino working group meeting.) If event rate is the only criterion, then the highest proton energy should be chosen. In designing the accelerator, one should consider the neutrinos delivered per watt of beam power. This curve is also shown, and indicates that the flux per watt is constant above the 1- to 2-GeV knee region. The average neutrino energy varies slowly with the proton energy, and varies from 200 MeV for 800-MeV protons to 700 MeV for 16-GeV protons. For neutrino oscillation experiments, flux divided by energy is the figure of merit, hence a low-proton energy should be chosen. This is the reason that I have pointed out that LAMPF II could be run at a lower energy with a higher repetition rate (for example 400 μA at 4 GeV might be possible with a machine that runs at 100 μA and 16 GeV). It is quite clear that for oscillation experiments either the PSR proposal or a low-energy mode of LAMPF II are optimum. The limits on neutrino oscillations that may be obtained at LAMPF II are impressive. A mass squared limit of 5×10^{-4} $(\text{eV})^2$ is obtainable, and a mixing angle limit $\sin^2(\theta)$ of 10^{-5} are within the statistical possibilities.[20]

The most important neutrino experiment that will be done at LAMPF II is neutrino-electron scattering. To date, only total cross sections have been measured. What is needed is an experiment measuring the angular distribution with sufficient accuracy to be a significant test of the Weinberg-Salam theory. The angular distribution may be parameterized in the following form,

$$\sigma(y) = A + B(1 - y) + C(1 - y)^2 \quad .$$

The B term is predicted to be 0. I believe that an experiment can be designed that will measure B with sufficient accuracy to have an important impact on our understanding of the weak interaction. I would like to request that the community of physicists who are interested in neutrino experiments design such an experiment. This experiment is so important that I am prepared to change the specifications of the LAMPF II accelerator to optimize the experiment. The problem is that I must understand the important factors. Please help us with this problem.

There are numerous other neutrino experiments which can be done at LAMPF II. Two among these stand out. The first is neutrino-proton scattering and neutrino-neutron scattering. We should determine the spin-isospin structure of the weak neutral current (WNC) between neutrinos and quarks. This is best done at small momentum transfer, and a triggered bubble chamber might be the appropriate technique. The second class of experiment is neutrino-nucleus scattering, especially to specific inelastic final states. An example is scattering to the 15.11-MeV level of ^{12}C with detection of the decay γ from the excited state. No such experiment has been designed, but the high flux of LAMPF II may make these possible. In general, one expects that the high flux will be used for experiments that are not now possible, to do experiments with narrow-band beams where only broad-band experiments are presently possible, and to reduce detector size and running time in order to significantly increase the physics output in the area of neutrino physics. Every effort will be made to optimize the accelerator parameters to match the needs of the neutrino physics program.

Hyperon Physics At LAMPF II

LAMPF II will be a superb source of hyperons, especially of excited hyperons which are not long lived and hence cannot be produced by the techniques presently in use at FNAL or the SPS at CERN. We are considering tagged beams produced as tertiary beams from kaon interactions in a hydrogen or other target. Only the ballpark of available fluxes have been considered, and this is interesting enough for further study. The assumptions are that a clean kaon beam of 10^8 per second interacts in a one-interaction length target and that a detector and tagging apparatus can be designed with 4π acceptance. Then the following reactions lead to hyperon fluxes as shown:

$K^- + p \rightarrow \pi^0 + \Lambda$	10^7 Λ per second
$k^- + p \rightarrow \pi^- + \Sigma$	10^6 Σ per second
$K^- + p \rightarrow K^+ + \Xi$	10^5 Ξ per second
$K^- + p \rightarrow K^+ + K^0 + \Omega^-$	10^3 Ω^- per second.

Of course, one will have to allow for the kinematics of the reaction and for less than 100% detection efficiency.

The experiments that might be done with such beams include hyperon-nucleon scattering near threshold, measurement of the properties of the hyperons including the quadrupole moment of the Ω^-, and measurements of the hyperon decays including the decays of the excited states of hyperons. The most interesting of these appears to be the measurement of the quadrupole moment of the Ω^-, perhaps by exotic atom techniques. Such a measurement would be an important test of the quark model. Experimentally, the tagging could be very clean because of the rapid decay of the K short into two charged pions. As mentioned earlier, the decays of the excited hyperons could lead to a determination of the wave functions of the constituent quarks. We are at the stage of developing ideas into practical proposals. Detector developments are crucial. Something equivalent to the vertex detectors of the colliders is required. A 2π geometry π^0 detector would be useful for the problem of tagging neutral hyperons. All new ideas are welcome.

Possibilities For Antiproton Physics

The recent rebirth of interest in antiproton physics surrounding the LEAR proposal at CERN is very clear. The issue for LAMPF II is to define a portion of the physics that will still be exciting in a decade. In my mind this is not a problem because the physics possibilities are too broad to be accomplished with the available running time and the announced flux of LEAR even in a decade of operation. The real issue is then to find a set of technical advantages for LAMPF II that are so great that LEAR will not be able to compete. There are two areas that come to mind. The first is producing beams of higher energy than the maximum available at LEAR. The second is to provide a polarized beam of higher intensity than the unpolarized beam of LEAR. A final possibility is to provide a higher intensity beam in an energy region not available at LEAR, either higher or lower in energy.

Two approaches should be kept in mind. One can provide secondary beams of a conventional design, or cooled beams. It turns out that after some literature searching, one finds that most of the antiproton beams that have been used to date were either designed as kaon beams or were minor modifications to existing kaon beams. Because the antiproton is long lived, there is no technical reason why long multiple-stage separated beams should not be used. Thus reports of high pion contamination limiting the experiments need not concern us. A good separated beam can be built which has no pions. There is no doubt on this point. Another possibility has been discussed many times by Kalogeropoulos.[21] He suggests a time-separated beam so long that the antiproton energy can be obtained by time of flight in the channel. This allows a very large momentum acceptance channel to be used, perhaps 10 times that of the antiproton channel for the antiproton accumulator at CERN. Thus a 1000-times increase in the antiproton flux (100 times for proton current) is straightforward. Perhaps these numbers should be increased by an additional factor of 10 because LEAR has been promised 10% of the available antiproton flux at CERN. Such beams can be built for costs comparable to that of other secondary beams. The physics payoff is clear. Experiments such as $\bar{p} + p \rightarrow e^+ + e^-$ are flux limited in the high-momentum transfer region, which is in the region above LEAR. LAMPF II will have a dedicated secondary beam line for antiprotons. The antiproton working group need only specify the performance desired.

Cooled antiprotons are difficult and expensive. The cost of an antiproton accumulator and a LEAR ring probably exceeds the cost of the LAMPF II synchrotron and stretcher. There will be staffing problems as well, since it is not likely that we will have adequate people to build an antiproton system and an accelerator simultaneously. I don't want to discourage thought, as the payoff is great enough to warrant solving these problems. Rather, I'd like to suggest that we start with a conventional antiproton beam line (or TSB) and later add cooling. We should be looking for a major technological breakthrough on which we might base a proposal for a second-generation antiproton proposal. Indeed, the combination of additional flux for neutrinos and the fivefold increase in antiproton production have led me to propose that the energy of choice for LAMPF II is 32 GeV or higher.

Cooling was given some attention at the February accelerator workshop. Jim Simpson considered the application of the technology proposed for the FNAL cooler to LAMPF II.[22] Briefly, his conclusion is that we can produce a cooled beam at least three times more intense than the antiproton accumulator at CERN using one 16-GeV LAMPF II pulse in six. This means a thirtyfold improvement over LEAR while simultaneously providing beam to all of the other users of LAMPF II (note that full-power AA operation at CERN shuts down all other users). Using more protons on target at LAMPF II would not help, because these could not be cooled except by building multiple cooling rings, a solution distasteful to me because of its brute force nature. We have also considered electron cooling and have come to a similar conclusion. The factor of 30 over LEAR is soft, since later it may turn out that a larger fraction of all available antiprotons is devoted to LEAR. I think that we should continue to look for a higher intensity solution, especially a scheme that provides polarized antiprotons. In this regard, I suggest that we consider scattering the antiprotons before cooling, which would allow us to take advantage of the higher flux of LAMPF II. Hopefully, other more elegant and more efficient techniques for polarizing the antiprotons will appear. I'd like to turn this problem over to the antiproton working group.

Polarized Protons and Heavy Ions

The reason for lumping these two rather unlikely bedfellows together is that the ultimate system for both is probably some sort of colliding beam facility. For polarized protons, the new physics would consist of colliding a beam of arbitrary polarization with another of arbitrarily selected polarization direction. If the colliding beam facility were made with superconducting magnets that could be ramped slowly, then upwards of 100 GeV per beam could be installed on the LAMPF site. Heavy ions could share such a facility. At the February workshop, Don Swenson pointed out that the modifications to LAMPF necessary to allow heavy-ion acceleration to 800 MeV per nucleon are small compared with the cost of a colliding beam facility.[23] If the storage time could be made as large as 24 hours, then it is feasible to consider devoting a few hours a day to heavy-ion acceleration to refill the collider, then returning LAMPF and the LAMPF II accelerators to production for the remainder of the day for high-intensity proton operation. At the present time, proposals have been made for heavy-ion collisions at Isabelle, and the Berkeley group is revising the proposal for Venus. It is prudent to keep the heavy-ion option open and to prepare a rough proposal. It will surely be cost effective to build a collider at LAMPF II, but the Isabelle proposal would be the best. We will take a low-key approach while we wait to see what happens at Brookhaven and Berkeley.

Another class of physics is low-energy polarized proton scattering in the 0.8- to 4-GeV region as has been emphasized by E. Lomon.[24] I frankly hesitate to spend a large amount of money for this because both Brookhaven and Saclay will be operating in this region in the next year. In order to make available a variable-energy polarized beam with large duty factor, the LAMPF II stretcher must be dedicated 100% to this operation. A separate switchyard and experimental areas are required to serve such a program simultaneously with the 16-GeV program. One possibility for modest-cost polarized beam remains. It may be cost effective to run the neutrino program for a fraction of the year as at Brookhaven, with the slow extracted beam operating the remainder. The stretcher is not needed for neutrino (fast-extraction) experiments. It may be possible to store an occasional pulse of polarized beam in the stretcher at a low energy while putting most of the power on the neutrino target. The power bill for operating the stretcher would be very small because only a fraction of the magnet current is required. The same switchyard could be used, also at low power. This puts a very high premium on the polarized source current, but perhaps this problem will be solved in the next few years. It appears that our best strategy is to plan to use this mode for polarized proton physics at low energy, and that we not plan additional facilities for such use. We must build into the accelerator and stretcher the capability of preserving the proton polarization. And of course we must watch the developments at Brookhaven and Saclay to see if there are signs of exciting physics that would justify larger expenditures.

LAMPF II Accelerator

For some time, we have used 16 GeV as the nominal goal of the LAMPF II project. Considering future possibilities for an antiproton cooler and the probable need for the highest possible flux for neutrino experiments, I propose that our goals be 16 GeV at turnon time with enhancement to 32 GeV at a later date. The most likely changes required to increase the energy are doubling the bend magnet field from 8 to 16 kG by adding additional power supplies and doubling the rf power by adding additional cavities in drift spaces reserved for this purpose.

Our reference design is that of Rees and Cooper.[25] The parameters of this machine are listed below.

Rees and Cooper Proposal

16 GeV
60-Hz repetition rate
10^{13} protons per pulse
100 μA (6×10^{14} protons per second)
10 MV per turn rf
40.25-48 MHz tuning range
140-m average radius
27.7 betatron tune
19 transition γ
10-kG bending field
0.25-ns pulse width at extraction
8 5-m straight sections for rf

We will construct a stretcher ring in the same tunnel as the accelerator, probably with a similar lattice. The stretcher ring will be used to provide a nearly continuous slow extracted beam. Additional bunching may be provided in the stretcher ring if required.

The basic idea of the Rees and Cooper proposal is that by arranging that the ring operate slightly below transition, tight bunching of the beam will be easiest to obtain. This is important because we require less than 1-ns bunches separated by 20 ns or more for use in time-of-flight measurements of low-energy secondary beams. A secondary advantage is that transition is avoided altogether, hence there will be no danger of beam losses in crossing transition, and many complications are avoided. I suggest that we keep this philosophy for initial operation. To go to 32-GeV operation, we will have to learn how to cross transition without beam loss. Because the bending-magnet field is quite low, it is likely that we can come up with a similar design slightly larger and which operates at 16 kG or less.

The technical problems that must be solved include providing the large amount of rf power and minimizing beam losses. The rf can be provided by using a large number of Fermilab-type cavities. The straight section space can be increased to a much larger amount if necessary. The transition energy will be raised slightly by this change. Present-day machines have losses on the order of 10%. We will have to reduce these to 0.1%, or provide collimators which concentrate the losses in limited regions designed for remote handling. The latter approach is sure to succeed if the aperture of the magnets is sufficiently generous. There is some doubt about the maximum field of the bending magnets. A preliminary look at the specifications of the existing rapid-cycling machines indicates that 10 kG is the maximum field achieved to date. Further study and a prototype are required before we can be sure about the maximum energy that can be obtained.

Siting Considerations

The LAMPF site is a long narrow mesa. Approximately 2 km of space remains to the east of the present experimental areas. This space to the east should be used for new experimental areas. Two reasonable locations for the accelerator are available. The first is under the downstream one-third of the LAMPF linac. The second is east of the experimental areas. Both locations will accommodate a ring approximately 1 km in circumference. I prefer the location under the LAMPF linac because the maximum amount of space will be available for experimental areas and because we have the option to make use of the existing experimental areas. A sketch of this location is shown in Fig. 4. It should be emphasized that this is essentially the same figure used at the LAMPF Users meeting in November 1981. We have not yet made a detailed study and in particular, we have not considered the option of building entirely new experimental areas.

Figure 4 also shows the possible layout of a switchyard serving the present experimental areas A, B, and C. The accelerator would be approximately 10 m below the existing linac, and compound bends are required to return to beam elevation. The target cell for Area C is assumed to be located underground, with a new vertical dispersed beam serving the existing HRS spectrometer.

A more detailed experimental area plan is shown in Fig. 5. We shall discuss the beam lines in clockwise order starting from Area C. As indicated earlier, Area C could be used for a high resolution pion or kaon beam and might utilize the existing HRS spectrometer. Area B is rather small for a 16-GeV

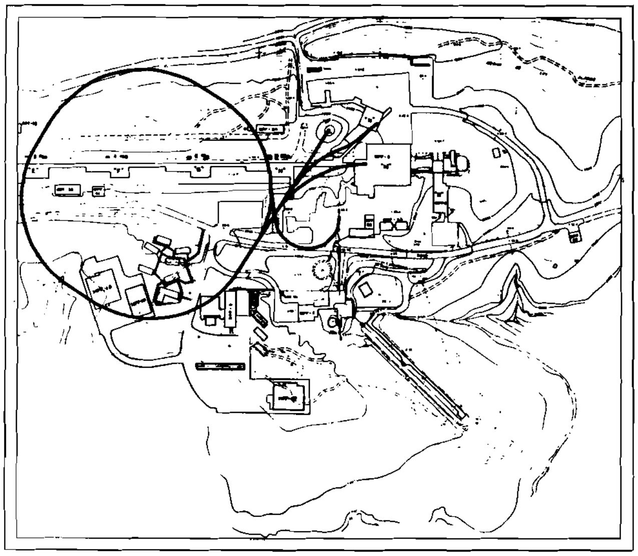

Fig. 4
Possible location of a 145-m average radius accelerator at LAMPF. An artist's conception of a switchyard providing beam to the existing experimental areas is shown.

experimental area, but could be used for a low-energy short kaon beam. The beam line shown is the beam line proposed by Don Lobb at the February workshop with an additional output leg. A long time-separated antiproton beam is indicated starting from a target cell at the northeast corner of Area B.

In Area A we have shown a new high-resolution kaon beam line at the present location of EPICS. This is in fact the beam I proposed at the January 1980 workshop at Los Alamos. The existing EPICS spectrometer can be used with the new kaon beam to study hypernuclei and kaon scattering at momenta up to 700 MeV/c. Moving downstream, a new high-energy kaon beam might share a target with the existing P^3 beam, a K^0 beam, and a new superconducting muon channel. The high-energy kaon beam is a scaled-down version of the Brookhaven MESB and is assumed to operate at momenta up to 5 GeV/c. The new K^0 beam is shown at 20^o, which is probably too large an angle to be reasonable. It may be possible to locate a K^0 beam at 5^o if it heads to the south side of the proton beam. Area A-East including the present beam stop and Biomed are assumed to be abandoned. Two muon beams are shown to the south. The upstream beam is imagined to be a surface muon beam, optimized for rare muon decays and μSR. The downstream muon beam is a version of the new SIN superconducting muon lines.

There are several important conclusions resulting from this sketch. The first is that we can provide the beams required by our physics program with approximately the same number of beam lines as exist at LAMPF today. This implies that the number of users and support personnel will not be grossly larger than at present. A number of investments can be preserved, including the two spectrometers, EPICS and HRS. A three-way split of the primary beam is reasonable. Thus we may consider 50 μA in Area A and 25 μA each in Areas B and C. Finally, the H^- injection line is a branch of Line D split off by a pulsed magnet. The repetition rate of LAMPF II, 60 Hz, implies that half the linac beam, or 500 μA, is available for PSR, thus exceeding our long-term commitment to this important facility. The space available is marginal for high-energy experiments. A plan for new experimental areas, not yet considered, could solve this problem.

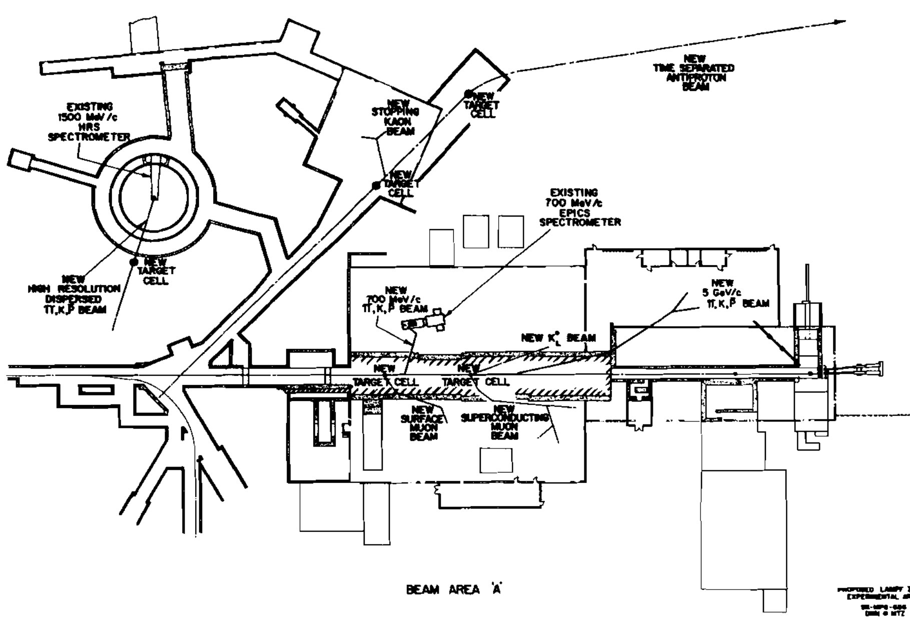

Fig. 5
A possible layout of the LAMPF experimental areas for use with 16-GeV protons.

The neutrino facility is not shown on the drawings. It is likely that a fast extracted variable-energy beam could be provided heading west. Sufficient space for a neutrino and pulsed muon facility is available either north or south of the linac. Laboratory land is available as far as 8 km in the westerly direction which seems reasonable for any presently conceived neutrino oscillation experiment. Immediately to the west of the ring there is another wide region of the mesa. This wide spot is big enough for a colliding beam facility with 1-km circumference, and also for an antiproton accumulator. If one wishes to look further into the future, a several-kilometer diameter ring can be accommodated at an elevation approximately 50 m below the proposed ring. The Los Alamos site is larger than that at any other major accelerator laboratory.

Cost and Schedule

It is still too early to make a precise estimate of the costs involved in constructing LAMPF II. Some estimates are available by scaling from Fermilab. We estimate $75 $\times 10^6$ for the accelerator, including $45 $\times 10^6$ for the 60-Hz accelerator, $20 $\times 10^6$ for the stretcher, and $10 $\times 10^6$ for tunnels. Experimental areas are estimated at $75 $\times 10^6$, which allows approximately $5 $\times 10^6$ for each secondary beam line, each spectrometer, and each switchyard branch. All numbers are given in 1981 dollars. These numbers are at best guesses, but are not out of line with those which have been quoted by various consultants including Lee Teng in the 1981 workshop and Russ Huson in the February 1982 accelerator workshop.

A schedule of important milestones is shown below.

LAMPF II Schedule

1982	Physics Proposal
1983	Facility Proposal
1984-5	Detailed Design
1986	Start of construction
1990	First Beam

It will be recognized that this is an optimistic schedule. There is no allowance for a delay while we wait for funding. This is the most likely source of a long delay. It is also not clear that we will be able to write a complete facility proposal within one year. We have requested enough funds from the Los Alamos Institutional Supporting Research funds, but it is not clear that we will receive enough funding or whether it will be possible to find sufficient help to make such a proposal in one year. From the enthusiastic response at this workshop, it is clear that our first milestone, that of writing a physics proposal, will be completed on time.

We should also discuss the construction schedule and possible interference with the operation of LAMPF. The injection line for LAMPF II is likely to be a branch of Line D that serves WNR and PSR. Our experience with the PSR construction shows that we can construct such a branch and connect it to the existing line during the normal long shutdowns of LAMPF which have been scheduled each year in recent history. Thus there will be no interference whatsoever with the WNR and PSR programs. The main ring construction will not interfere with LAMPF operation because it will be far enough underground. If we adopt the plan of reutilizing the existing experimental areas, then a long shutdown of these areas, perhaps two years, is required. Louis Rosen has suggested that a better plan is to construct new experimental areas. This would minimize the interference with LAMPF operation and would eliminate the need for any shutdown of LAMPF. When we begin to study the question of experimental-area design in more detail later this year, we will first address this question. At the present, our plans represent only the opinion of one person, namely myself, and significant changes can be expected as we begin to work on the details.

Competing Projects

There are three major laboratories working on proposals for projects whose physics goals overlap with those of LAMPF II. These are TRIUMF in Vancouver, Canada, SIN in Villigen, Switzerland, and Brookhaven. TRIUMF will soon propose a 10- to 20-GeV 100-μA proton accelerator as a kaon factory. This machine may be either a synchrotron or a cyclotron, depending on a solution to the injection problem. SIN is working on a design for a 2-GeV 2000-μA proton cyclotron, with the possibility of 500 μA of pulsed beam. Both of these projects will be discussed at this workshop. It should be noted that SIN has nearly completed construction of a new 2000-μA injector cyclotron, and an improvement program for their experimental areas to handle the higher intensity beam is under way. Thus by 1987, when the SIN upgrade is complete, higher intensity beams will be available at SIN than at LAMPF.

At Snowmass, N. Samios discussed the several design projects now under way at Brookhaven. Most of these are schemes for reducing the cost of Isabelle and are not directly relevant to our discussion here. One project competes directly: a group headed by Y. Y. Lee is studying a booster/storage ring for injection into the AGS. Initially, this ring will be used as a storage ring to increase the intensity of the polarized beam. In a later stage, it may be possible to use this ring as a 2-GeV accelerator to raise the space-charge limit in the AGS by a factor of 5 to 20. This project will be difficult, because it will be necessary to reduce the beam losses in the AGS by a corresponding factor while increasing the phase space of the injected beam. It will also bring to Brookhaven the requirement of remote handling in the target areas and perhaps elsewhere in the beam transport systems. It would not make sense for Brookhaven to take on this task at the same time as Isabelle construction. There are so many unknowns in the prospects for this and the other projects that the Los Alamos response will be to proceed to make the best possible plan for development of LAMPF and leave for a later date the decision on which project should be funded.

Summary and Conclusions

We have seen how LAMPF II is a straightforward improvement of LAMPF. The physics is an exciting extension of the present LAMPF experimental program. The LAMPF II experimental program is designed to serve the needs of the present LAMPF users for the decade of the 1990's. The accelerator we propose is feasible to construct, although some challenging problems must be solved before it becomes a reality. The cost of our proposal is modest by the standards of high-energy physics, and it amounts to the same cost in today's dollars as was experienced for the Brookhaven AGS upgrade during the early 1970's. When completed, LAMPF II will have many of the attributes of LAMPF; that is, it will serve both the nuclear physics and the high-energy physics communities, it will keep all of our commitments to the WNR and PSR facilities, and it will be a superb place to train students during the decade of the 1990's. I believe that the medium-energy physics community needs a project like this if our field is to maintain its vitality, and I sense the enthusiasm which many of you have for our goals. It is time to get busy and do the hard work necessary to create at Los Alamos the world's premier medium-energy facility of the 1990's.

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