PILAC: A PION LINAC FACILITY FOR 1-GEV PION PHYSICS AT LAMPF

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Abstract

A design study for a Pion Linac (PILAC) at LAMPF is underway at Los Alamos. We present here a reference design for a system of pion source, linac, and high-resolution beam line and spectrometer that will provide 10^9 pions per second on target and 200-keV resolution for the (π^+,K^+) reaction at 0.92 GeV. A general-purpose beam line that delivers both positive and negative pions in the energy range 0.4-1.1 GeV is included, thus opening up the possibility of a broad experimental program as is discussed in this report. A kicker-based beam sharing system allows delivery of beam to both beamlines simultaneously with independent sign and energy control. Because the pion linac acts like an rf particle separator, all beams produced by PILAC will be free of electron (or positron) and proton contamination.

1. The Nuclear Physics Program of PILAC

There are five classes of experiments that require pions of energies up to 1.1 GeV [1]. These classes are:

1.) Λ-hypernuclear physics via the (π,K) reaction;

2.) Λ-nucleon scattering at threshold;

3.) rare decays of π and η;

4.) pion-nucleus elastic and inelastic scattering with 0.4-1.1 GeV pions; and

5.) baryon resonances.

2. PILAC Concept

A concept for the reference facility is shown in Figure 1. The reference PILAC facility requires the following items [2]:

1.) proton buncher;

2.) new target cell for zero-degree pion production;

3.) 0.38-0.53-GeV pion injection beamline;

4.) 0.38-0.92-GeV, 12.5 MeV/m gradient superconducting pion linac;

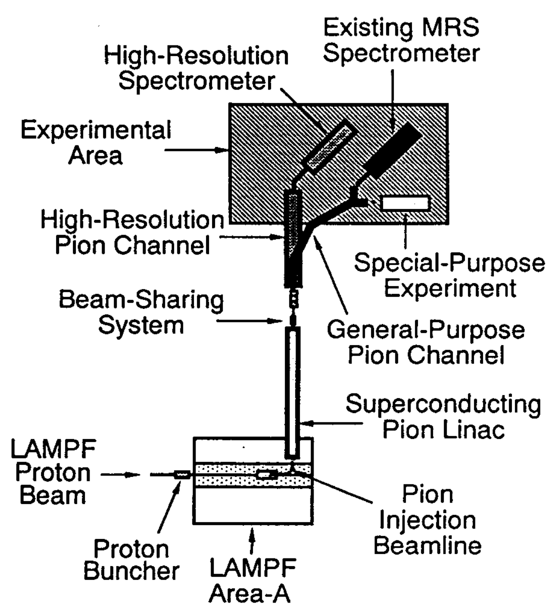

Figure 1. Concept for PILAC facility at LAMPF.

5.) kicker-based beam-sharing system;
6.) 1.1-GeV high-resolution dispersed beam line and spectrometer;
7.) general-purpose beam line with dispersed mode for existing MRS spectrometer; and
8.) experimental area and related civil engineering.

3. Proposed Development Plan for Superconducting Cavities for PILAC

The reference design requires 12.5 MeV/m cavity gradient and has negligible beam loading. We believe that this large gradient can best be achieved by use of titanium heat-treated niobium cavities [3]. In order to establish the gradient and Q that will be achieved in the PILAC cavities, it is necessary to scale up the technology to the larger, lower-frequency cavities needed and to test several prototype cavities. This requires new, larger facilities at Los Alamos. To save time, we propose to develop the heat-treatment technology in a parallel effort using existing equipment at 3 GHz. We will also take an existing 805-MHz single-cell cavity and heat-treat it in the Cornell oven.

4. Injection Beam Line

The injection beam line proposed for PILAC consists of a matching section based on a strong quadrupole doublet placed as close as possible to the pion-production target followed by a second-order achromat. Sextupoles and octupoles correct all detrimental second- and third-order aberrations. This beam line has a solid angle of 10 msr, a momentum acceptance of 6.6%, and a transverse phase-space output of 225 π mm-mrad. In the reference version of this beam line design, 82% of the output beam is contained within the specified phase space.

We are also considering a possible design of the injection beam line that will deliver both π^+ and π^- simultaneously s is shown in Figure 2. This version of the injection line has not yet been studied thoroughly.

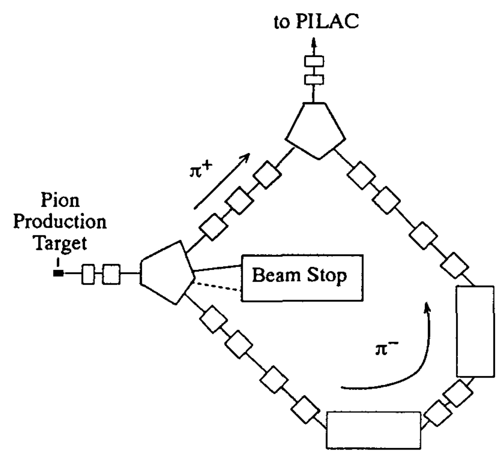

Figure 2. Possible design for simultaneous π^+ and π^- injection line for PILAC.

5. Choice of Operating Frequency for PILAC

A series of linac designs was studied to determine the optimum operating frequency for PILAC. The highest frequency that is a harmonic of the LAMPF injector and is also compatible with the required transverse phase space acceptance of 225 π mm-mrad is 805 MHz. This frequency has been chosen for the reference design.

6. Reference Linac Design

The reference linac design is based on a study maximizing the pion intensity in the desired output phase space. A conceptual layout of this design is shown in Figure 3. The beam intensity is the product of longitudinal acceptance and pion survival in the linac. A total phase space rotation of $3\pi/4$ in the longitudinal plane maximizes the acceptancewhile minimizing the energy spread of the output beam. The layout of the linac minimizes pion decay. The number of cells per cavity was chosen to give the largest cavity that can be handled comfortably in the existing superconducting cavity lab. This results in a choice of seven cells per cavity. A total of 40 cavities is required to accelerate from 0.38-0.92 GeV. By raising the injection energy and rephasing the linac, energies up to 1.1 GeV can be provided, but at reduced intensity. Quadrupole doublets are required after each five cavities in order to contain the transverse phase space in the cavity bore. Five cavities will be mounted in a single cryostat as a module. Nine modules are combined to make the full linac. The total length of the linac is approximately 100 meters.

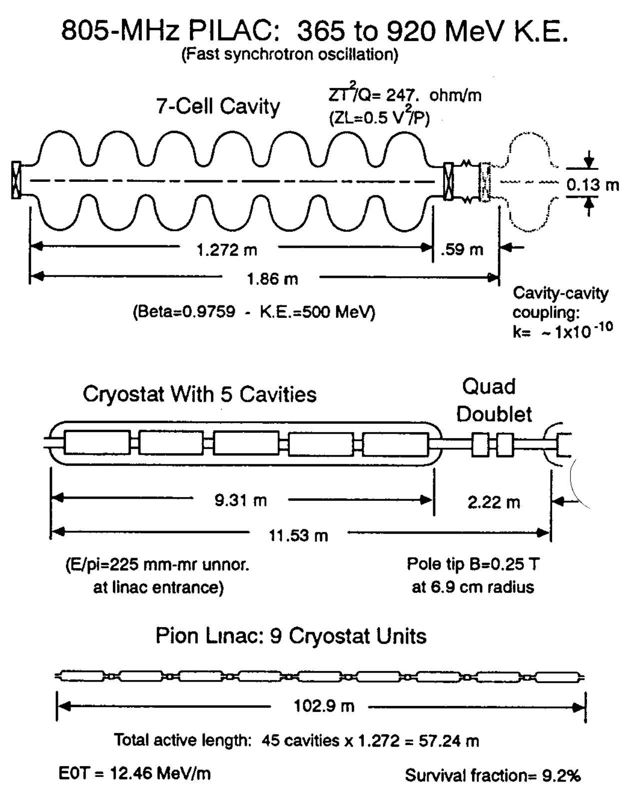

Figure 3. Reference design of pion linac.

7. High-Resolution Beam Line and Spectrometer

A high-resolution beam line has been designed using program MOTER [4]. This beam line, a QQQQMDMDMDMDM design with vertical bends, has a momentum dispersion of 25 cm/% and a horizontal divergence of 5 mrad full width in the horizontal planeand is shown in Figure 4. The full size of the beam spot will be 40-cm high by 10-cm wide. The momentum resolution of the high-resolution beam line calculated by MOTER is one part in 10^4 when second- and third-order optical corrections are introduced on the dipole entrance and exit faces.

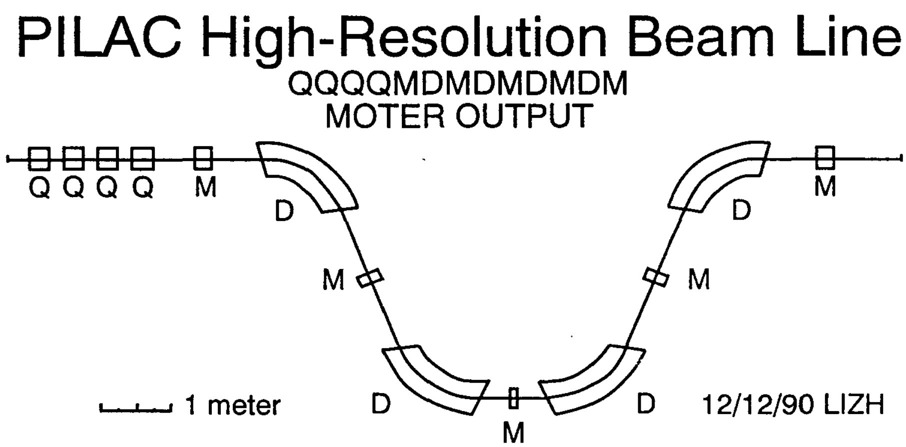

Figure 4. High resolution beam line for PILAC.

A spectrometer with acceptance matched to this beam line has also been designed and is shown in Figure 5. The design is very similar to that of the existing EPICS spectrometer at LAMPF except that the bending magnet has been made from a single unit in order to minimize the flight path of kaons in the spectrometer. By using iron-dominated superconducting quadrupole magnets similar to those planned for the Hall-C spectrometer at CEBAF, the acceptance of the spectrometer has been increased by almost a factor of six compared with that of the existing EPICS spectrometer. The acceptance of the proposed spectrometer is 27 millisteradians for the 10-cm x 40-cm beam size of the high-resolution beam line.

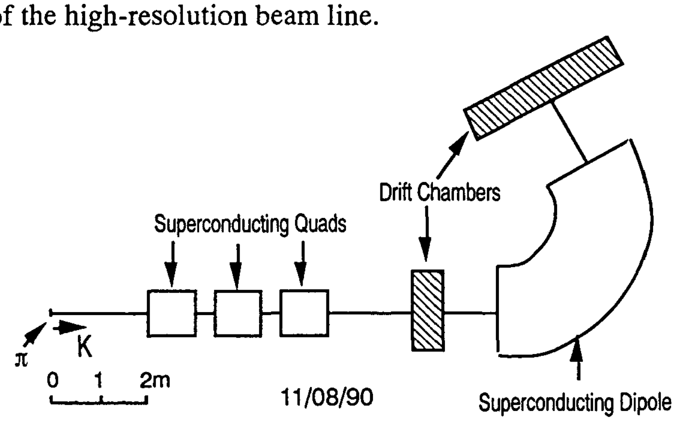

Figure 5. High Resolution Spectrometer for PILAC.

8. General-Purpose Beam Line

A beam line capable of providing an achromatic beam spot and also 2-3 cm/% horizontal dispersion (for use with the existing MRS spectrometer) is being designed. The conceptual layout for this line is shown in Fig. 6. The output beam spot and divergence in the achromatic mode will be 5-mm radius by 25 mrad (half widths). The output beam spot will be tuneable over a wide range. This line will be fabricated with laminated -iron magnets so as to make possible rapid changes in energy. We are also studying a second port for the output of this line. In addition to providing beam for experimenters, the new general-purpose line will serve as a pion injector for a future linac extending the energy range of PILAC to 1600 MeV.

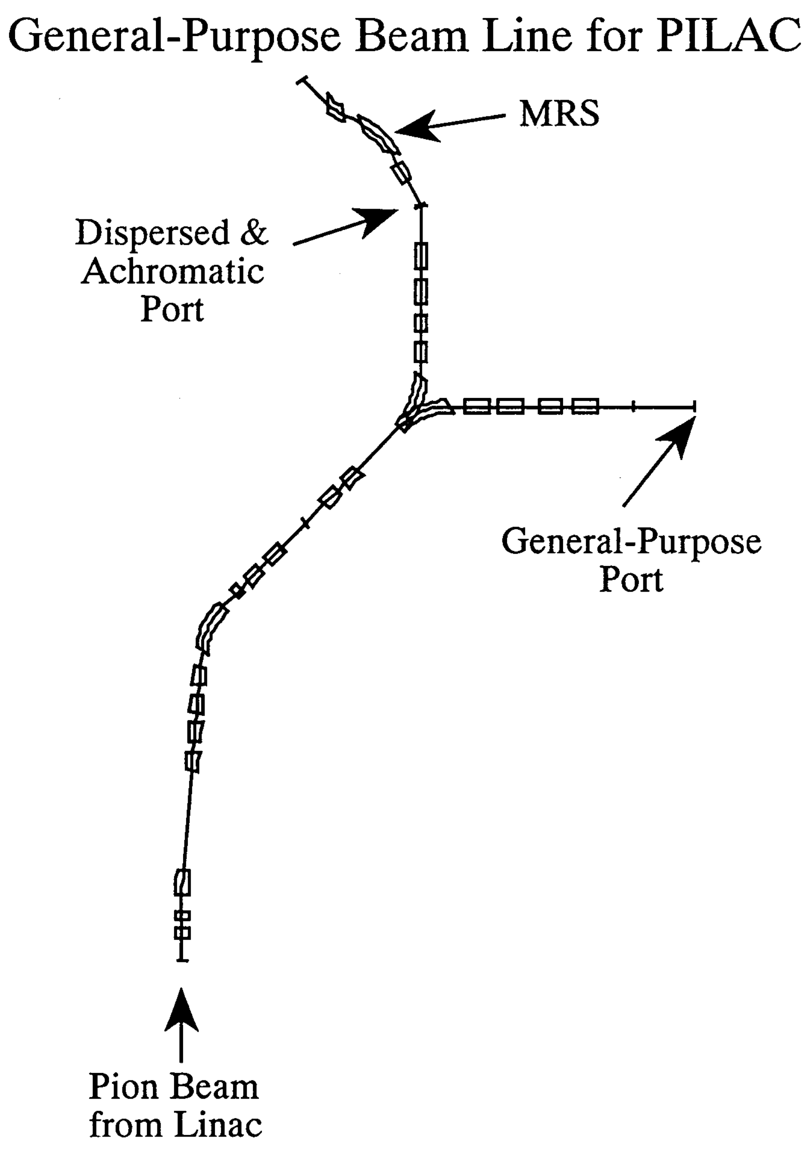

Figure 6. Proposed Layout of General-Purpose Beam Line for PILAC.

9. Beam Sharing in PILAC

A kicker-based beam sharing system is envisaged for PILAC. With the kicker magnet off, the pion beam from the linac goes straight ahead into the high-resolution beam line. With kicker magnet on, the beam is deflected into the general-purpose line. The basic idea is that the kicker rise time will be comparable to the time required to switch the phase program of the linac cavities. Then the phase program and the kicker can be switched simultaneously. With simultaneous injection of π^+ and π^- into the linac, it will be possible to have independent control of the pion sign and energy delivered to each of the two beam lines.

10. PILAC Pion Yield

The pion yield expected from PILAC is $1.2\pm0.6\text{x}10^9$ π^+ per second at 0.92 GeV. This yield is comparable to that which can be achieved in the same phase space at the proposed KAON facility and is more than an order-of-magnitude larger than can be achieved at the Brookhaven AGS with the new booster operating, as is shown in Figure 7. In this figure, the yield of PILAC is shown as a function of the cavity gradient. A design value of 12.5 MeV/m has been chosen for the Reference Design.

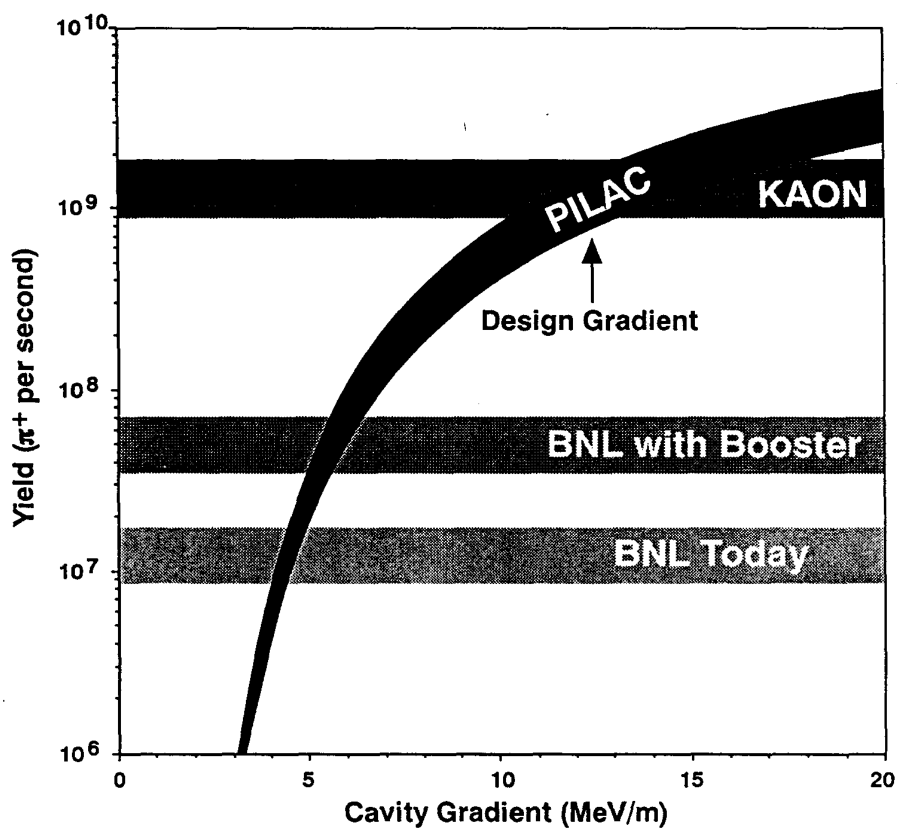

Figure 7. Estimated π^+ Yield of PILAC vs. cavity gradient. For comparison purposes, the yield of π^+ in the same phase space at KAON, BNL with the new booster, and BNL today are shown.

11. Program MOTER

The program used for raytracing calculations of the high-resolution beam line and spectrometer is MOTER (Morris Klein's Optimized Tracing of Enge's rays). This program was written at Los Alamos in the early 1970s [4]. MOTER is being updated to include rf cavities in order to make possible a precision study of the optics of PILAC in a single computer program.

12. Summary and Conclusions

PILAC is being designed to provide a beam of 10^9 pions per second at 0.92 GeV, with a future upgrade to 1.6 GeV. We have demonstrated that the system resolution of 200 keV can be achieved in a high-resolution beam line and spectrometer. In order to provide the necessary flux, the linac requires superconducting cavities that achieve a gradient of 12.5 MeV/meter. Although no linac presently operates at this high gradient, tests at laboratories around the world have shown that this gradient can be achieved by titanium heat treatment of the cavities. An R&D program is proposed to scale up the results from single-cell 1.5-3-GHz cavities to the necessary 7-cell 805-MHz cavities.

PILAC will provide an energy of 0.92 GeV with operation possible up to 1.1 GeV at reduced intensity. This energy is sufficient to optimize the yield of the (π^+,K^+) reaction and to access a broad range of interesting physics. The PILAC energy resolution, 200 keV, is more than an order-of-magnitude better than that which is available today and will give access to a wealth of information on hypernuclear physics. The PILAC beam-sharing system will allow simultaneous operation of two or more line with independent sign and energy control. The PILAC beams will be of unprecedented purity since the linac acts as a high-resolution rf separator. PILAC is cost-effective since it is by far the least expensive upgrade to LAMPF that gives access to this physics. The new superconducting cavities represent a new technology that will open up applications in other fields. Finally, PILAC is feasible only at LAMPF, since only LAMPF has the necessary tightly bunched proton beam to produce pions that can then be accelerated in a superconducting linac.

XIII. References

[1] "Physics with PILAC," Los Alamos Report, to be published.

[2] PILAC Technical Notes 1-25, Los Alamos, 1990-91 and other contributions to this conference.

[3] H. Padamsee, IEEE Cat. No. 87CH2387-9, 1691 (1987).

[4] H. A. Thiessen and M. M. Klein, Proceedings of the 4th International Conference on Magnet Technology, Brookhaven, N.Y., pp. 8-17 (1972).