# SIMULTANEOUS BEAMS OF DIFFERENT ENERGY FROM LAMPF*

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## Summary

The linac of the Clinton P. Anderson Meson Physics Facility (LAMPF) was designed to simultaneously accelerate $H^+$ and $H^-$ beams to energies up to a maximum of 800 MeV. To allow more flexibility in the experimental program, it is desirable to find an operating mode such that the $H^-$ beam may be accelerated to a lower output energy than the $H^+$ beam. There are two possible approaches for doing this. In one approach, the beams could time-share the rf pulses, with the radio frequency adjusted to provide the desired energy for each beam separately. In the other approach, which will be the one discussed in this paper, both beams use all of the rf pulses, and the $H^-$ beam is kicked out of the accelerating bucket when the desired lower energy is reached. This paper discusses a possible method of separating the $H^-$ and $H^+$ beams in longitudinal phase space (energy -phase), and summarizes dynamics calculations for various proposed schemes for kicking the $H^-$ beam out of the bucket.

## Introduction

The LAMPF accelerator provides an intense $H^+$ beam, used primarily for meson production, and an $H^-$ beam used for nucleon-nucleon and nucleon-nucleus studies. Users of the mesons coming from the $H^+$ beam generally prefer as high an energy proton beam as possible, because the meson flux in most cases increases with energy. This variation in meson flux with energy is very strong if mesons near the kinematic energy limit are in use; conversely, the variation is relatively weak if low-energy mesons are desired. Typically, for intermediate energies, the flux will drop by a factor of two if the proton energy is reduced from 800 to 650 MeV. The users of the $H^-$ beam prefer a variable energy beam permitting their measurements to be carried out as a function of energy. For most experiments, energy variation in 50-MeV steps is adequate. The energy range of most interest is from 400 to 800 MeV, giving an adequate overlap with the energies available from other accelerators.

The work reported in this paper is a preliminary feasiblity study of one possible way of modifying and operating the LAMPF accelerator to obtain an $H^+$ beam of 800 MeV and a simultaneous $H^-$ beam of lower energy. The method discussed here involves separating the H+ bunches in the longitudinal (energy-phase) plane and then dumping the $H^-$ bunch from the accelerating bucket. Both beams would be produced at the full duty factor of the accelerator.

The LAMPF accelerator has three types of components: 750-kV dc injectors, drift-tube linac tanks operated at 201.25 MHz and side-coupled linac modules operated at 805 MHz. The simultaneous beams of different energy would be produced in the 805-MHz linac portion, which accelerates the beam from 100 MeV. The method discussed here involves a separator region in the early part of the 805-MHz linac, and a dumper region (in longitudinal space) further downstream in the linac.

The purpose of the separator region is to introduce, or amplify, a deliberate oscillation of the $H^-$ bunch in longitudinal space, yet maintain a normal $H^+$ bunch. This would be done by inserting special rf cavities at appropriate points between the 805-MHz linac modules. These special cavities would be operated at a subharmonic of the module frequency, and phased such that the $H^+$ bunch passes through them at or near a zero-crossing of the rf. When 201.25 MHz is used for the special cavities, the $H^-$ beam arrives at the special cavities 135 degrees away from the $H^+$, and thus receives an energy kick from these cavities. Assuming that 20-kW peak drive power to a cavity can produce an effective gap voltage of 350 kV, one sees that each special cavity could shift the $H^-$ energy by 0.25 MeV.

The purpose of the dumper region is to evict the $H^-$ bunch from the accelerating bucket while retaining the $H^+$ bunch. This might be done by reducing the rf amplitude for a series of tanks, reducing the stable region (or fish) to fit snugly around the $H^+$ bunch , or by moving the rf phase of a series of tanks thus shifting the fish to leave the $H^+$ inside but leave the $H^-$ bunch outside , or by some combination of these strategies.

There are four aspects of the problem:

(1) effect of separator region on $H^-$ bunch,
(2) effect of separator region on $H^+$ bunch,
(3) effect of dumper region on $H^-$ bunch and
(4) effect of dumper region on $H^+$ bunch.

Aspect (2) has not yet been studied. Because the extent in phase of the $H^+$ beam is about ±10 degrees at 805 MHz, it would be only ±2.5 degrees at 201.25 MHz, and the degradation of the $H^+$ beam by the special cavities should be very small. The other aspects are discussed below.

## Separator Strategies

With any separation strategy, one attempts to get a large enough $H^-$ oscillation to permit a choice of points downstream along the linac

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where the $H^-$ can be dumped. But it is not desirable to make the $H^-$ oscillation so large that the $H^-$ bunch is badly distorted, producing a long tail in energy-phase space. The more the $H^-$ bunch is drawn out, the more difficult it becomes to dump all the $H^-$ particles without dumping any of the $H^+$ particles.

### Special Cavities Alone

The special cavities of the separator region may be used both to initiate an oscillation of the $H^-$ bunch in energy-phase and to amplify that oscillation. The calculation reported here assumes that special cavities may be placed only between modules, because of space limitations. For any special cavity, one has the choice between having it add or subtract from the energy of the $H^-$ beam. Because the longitudinal wavelength is only approximately equal to four modules, the spacing of the special cavities along the linac is irregular to achieve the most $H^-$ to $H^+$ separation per cavity. Unfortunately, it appears that a large number of special cavities (over 12) would be required to both initiate and amplify an $H^-$ oscillation. The capital cost of installing the scheme varies directly with the number of special cavities, and of course it is desirable to keep this number small.

### Initial Oscillation Plus Special Cavities

The $H^+$ and $H^-$ beams take separate paths through the transition region between the 201.25-MHz and 805-MHz linacs, and it is possible to start the $H^-$ beam into the 805-MHz linac with an offset in phase. If such an offset is used, the $H^-$ beam will oscillate in energy-phase space, and the special cavities might be used to amplify this oscillation. Fewer special cavities are needed this way to achieve a given amplitude of oscillation. Calculations indicate that eight special cavities are sufficient to fully separate the $H^+$ and $H^-$ bunches.

## Dumper Strategies

In contrast to the separator region, which has special cavities and occupies a fixed region of the linac, the dumper region has no special equipment and varies in position along the linac according to the energy at which the $H^-$ beam is to be dumped.

### Reduced Amplitude

One way of evicting the $H^-$ bunch from the accelerating bucket after the $H^-$ particles have achieved a desired energy, is to shrink the fish such that the $H^+$ particles are still inside but the $H^-$ ones are not. This may be done by reducing the rf amplitude. One adjusts the design phase $\phi$, such that although the field E is smaller, $E \cos \phi$ is the same. Some exploratory calculations were made for the dumper region using this strategy. Small changes in the dumper entrance energy or phase produced large changes in output energy for the dumped particles. For example, a change in entrance phase of two degrees might produce a change of over 15 MeV in output energy.

After about five modules from the start of the dumper region, the $H^-$ particles are far behind in energy from the $H^+$ particles, and it makes little difference to the $H^-$ bunch whether or not the amplitude for subsequent modules is increased.

### Shifted Phase

Another way of dumping the $H^-$ bunch is to pick a position along the linac where the $H^-$ bunch lies to the left (at reduced phase) of the $H^+$ bunch, and then to shift rf phase so that the left side of the fish is between the bunches (Fig. 1). For the next few modules, this will leave the $H^-$ bunch outside and the $H^+$ bunch off center but inside. The $H^-$ bunch will soon be left behind in energy (Fig. 2). After the $H^+$ bunch has made one oscillation, the rf phase may again be shifted to stop or at least reduce the oscillation (Fig. 3). This process introduces an additional but tolerable energy spread into the $H^+$ beam.

Because the dumper region must begin where the $H^-$ bunch is to the left of the $H^+$ bunch, there are only certain points where the dumper region may be placed. The peaks in the oscillations of the $H^-$ bunch are about 80 MeV apart. However, by starting the $H^-$ oscillation with a phase offset of the opposite sign and operating the special cavities with the phase shifted 180 degrees, one obtains an oscillation with peaks midway between those obtained before, and dumper regions may begin there. Thus the available $H^-$ output beam energies are roughly 40 MeV apart.

Exploratory calculations for the dumper region alone suggested that there may be regions

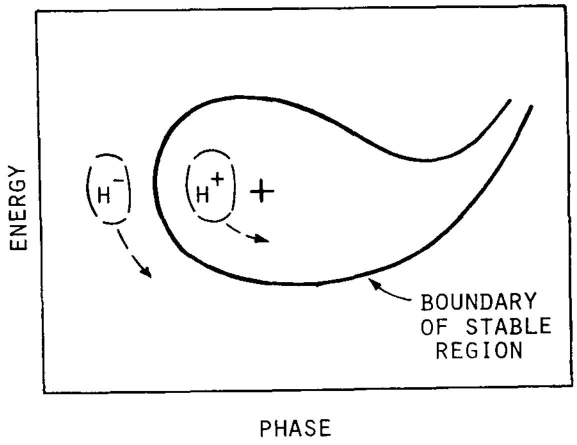
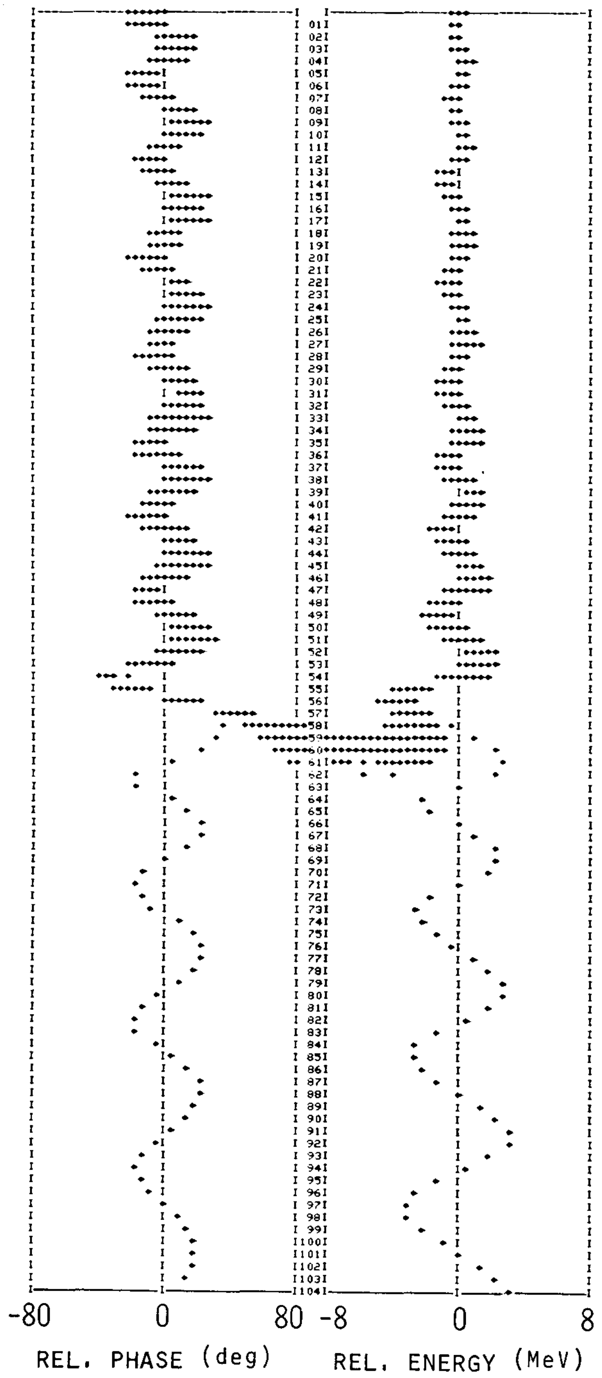


Fig. 1. Stable region (fish), shifted to the right, leaving the $H^-$ bunch outside.



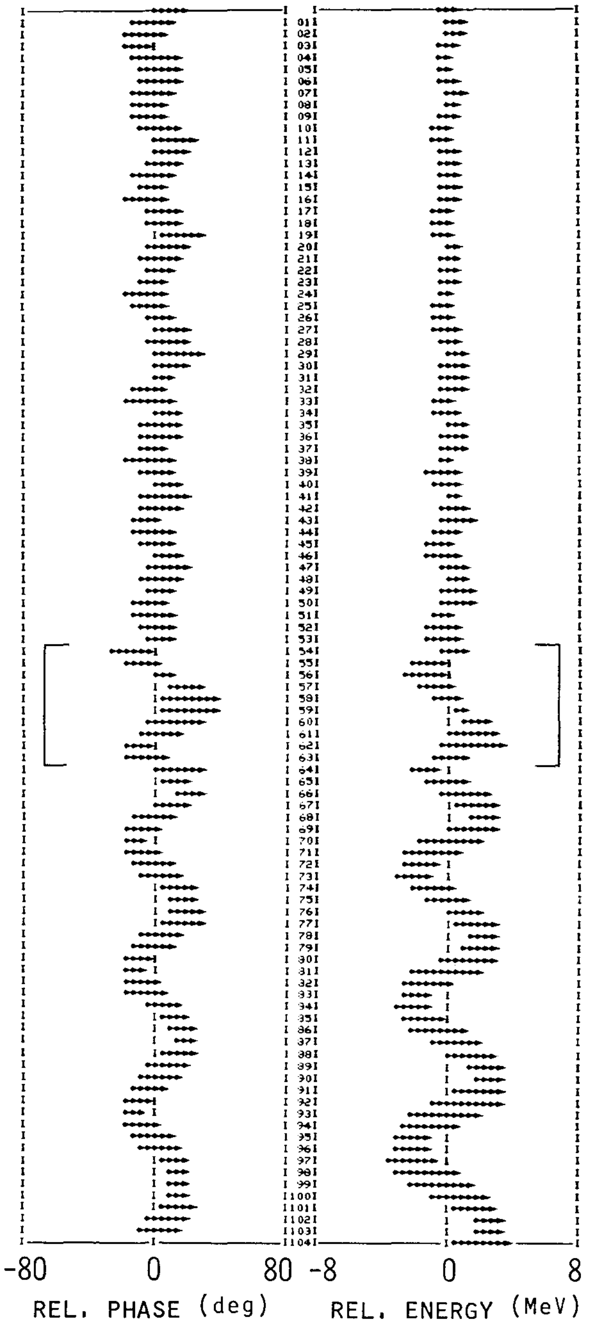


Fig. 2. Phase and energy profiles (relative to a design particle) for the 805-MHz linac for the $H^-$ beam. The particle continuing past the dumper region was a reference particle not affected by the separator region.

Fig. 3. Phase and energy profiles (relative to a design particle) for the 805-MHz linac for the $H^+$ beam. The dumper region is indicated by brackets.

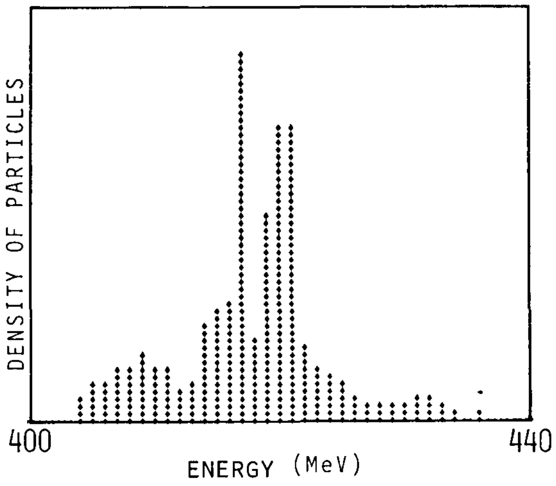


Fig. 4. Energy distribution for $H^-$ beam at exit of linac.

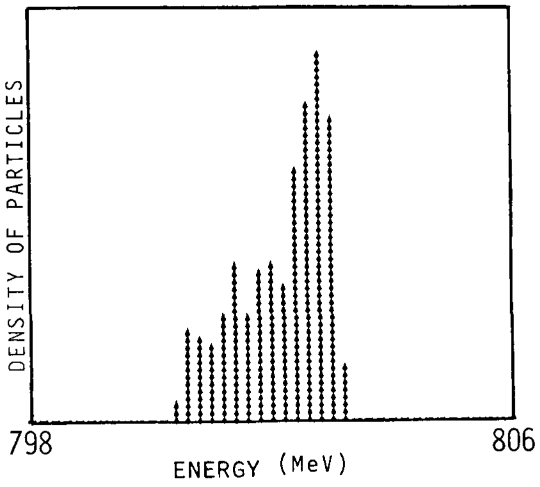


Fig. 5. Energy distribution for $H^+$ beam at exit of linac.

in entrance energy-phase space that give lower spread in output energy for the shifted-phase scheme than for the reduced-amplitude scheme. It is not clear if one scheme is better than the other for the limited separations of $H^-$ from $H^+$ that appear plausible with eight, or fewer, special cavities in the separator region.

Whole-linac calculations, as in Figs. 2 and 3, give distributions of $H^-$ or $H^+$ particles versus energy as shown in Figs. 4 and 5. The case shown in Figs. 2 and 4 produced an $H^-$ beam with an output energy near 420 MeV. By placing the dumper region at other places, and using adjustments discussed below under Additional Refinements, it was possible to calculate cases with $H^-$ beam output energies near 450, 490, 525, and 585 MeV. It is not certain whether $H^-$ beam energies higher than this could be obtained, because it becomes increasingly difficult to maintain $H^+$ - $H^-$ separation as the distance between separator and dumper regions is increased.

## Other Strategies

Other dumper strategies are possible. One might begin as in the shifted-phase scheme, but after the $H^+$ beam has made half an oscillation (bringing the bunch back near design energy), reduce the rf amplitude to shrink the fish.

## Additional Refinements

As one takes the $H^-$ beam further down the linac, it becomes more and more difficult to dump all the $H^-$ particles without dumping any of the $H^+$. The following schemes permit one to make small gains in $H^+$ - $H^-$ separation.

Initial $H^+$ Oscillation. One may introduce a longitudinal oscillation of the $H^+$ bunch by starting the $H^+$ bunch in the 805-MHz linac with a phase offset. If the $H^+$ phase offset is opposite in sign from the initial $H^-$ phase offset, the separation is improved. Because longitudinal oscillations are significantly damped in the early part of the linac, the maximum change in phase in the dumper regions is only about one-quarter of the initial phase offset. Thus the improvement in separation with this scheme is limited to a few degrees in phase.

Adjustment of Longitudinal Wavelength. It may be advantageous to slightly change the longitudinal wavelength so that the peak of an oscillation of the $H^-$ bunch falls exactly at the start of a dumper region. This may be done by adjusting the rf amplitude along the linac (maintaining $E \cos \phi$ constant) between the separator and dumper regions; increasing the rf amplitude shortens the wavelength.

## Conclusions

The preliminary studies suggest that by adding a series of eight low-frequency cavities, it would be possible to accelerate simultaneous $H^+$ and $H^-$ beams to different energies at LAMPF. The $H^-$ beams thus obtained are likely to have a broad energy spread; the utility of an $H^-$ beam with this large an energy spread is still under evaluation. However, it appears that it may be difficult to achieve enough separation of the $H^+$ and $H^-$ bunches along the linac such that all the $H^-$ particles can be dumped from the accelerating bucket without dumping any of the $H^+$ particles.