LINEAR ACCELERATOR FOR UNSTABLE PARTICLES*

D. E. Nagle
University of California, Los Alamos Scientific Laboratory
Los Alamos, New Mexico

The idea of accelerating mesons or other beta-unstable particles[1-3] heretofore seemed unattractive for several reasons. First, accelerators like the large proton synchrotrons do produce reasonably intense secondary beams of π and K mesons at reasonably high energies, and the beams available at lower energy have not been of sufficiently high intensity to warrant injection into another accelerator. Second, the loss by beta decay in conventional accelerators is severe for μ, π or K mesons. Third, the cost of such accelerators is considerable.

It is now possible, however, to consider a design which answers these objections wholly or substantially. First, high-intensity beams will become available from "meson factories." Second, new structures[4] such as the shaped biperiodic $\pi/2$-mode structures and new techniques[5] such as superconducting cavities are now being developed to produce economically larger accelerating electric fields, and hence reduce the loss from beta decay. We take up this second point: Imagine particles accelerated under the conditions specified in Table I.

Table I
Acceleration Parameters

	Initial	Final
Total Energy	γmc^2	$\gamma' mc^2$
Momentum	ηmc^2	$\eta' mc^2$
Mean Life for β Decay	τ	τ
Accelerating Gradient	E_o	E_o

The fraction f of particles which survive beta decay during the acceleration is $(\gamma + \eta)^\alpha / (\gamma' + \eta')^\alpha$ where $\alpha = m_o c^2/E_o c\tau$ is the rest energy divided by the energy gained in a decay length. For $\alpha = 1$, E_o is 0.16 MeV/m for muons, 18 MeV/m for pions, and 13 GeV/m for $K^\pm$! The acceleration of muons is therefore relatively easy, pions still possible, and K's far beyond present technology. For comparison the SLAC electron linac has accelerating gradients of $\sim$ 6.6 MeV/m; in experiments with superconducting cavities at Stanford a gradient of 5.6 MeV/m is reported,[6] and in same room temperature experiments at Varian Associates 12 MeV/m was attained.[7]

As an example, I have chosen a linac designed to accelerate pions from an external pion beam of a meson factory. The design parameters are given in Table II. Note that the power required at room temperature is of the order of 350 MW. At 12% duty, the cost of the rf installation is prohibitive; however, if an improvement in losses of a factor of 10^6 or better is achieved by going to a superconducting cavity, the rf costs are trivial and the refrigeration load is quite reasonable.

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Table II
Pion Linac Design Parameters

Initial Kinetic Energy	400 MeV
Final Kinetic Energy	1200 MeV
Frequency	402.5 MHz
Aperture	8 cm radius
Acceleration Rate	10 MeV/m
Number of Tanks	8
Focusing	7 Quad doublets between tanks
Quad Gradients	4.1-7.9 Kg/cm
RF Power (room temperature)	350 MW
f	0.19

Figure 1 is an E,φ acceptance diagram and Fig. 2 the emittance at 1.2 GeV. The criterion for a particle to be "lost" was that it fall 100 MeV behind the "synchronous" energy. Many such particles would get through the linac. It is also true that less than one phase oscillation is executed in the linac, and that some particles within the acceptance area would be "lost" if the linac were continued beyond 1200 MeV. In any case the momentum acceptance is ample, since the pion channels will have 10% or less acceptance. Figures 3 and 4 give the transverse acceptance, about 60 mr-cm, and the transverse emittance.

A 300-MeV pion beam for the Los Alamos pion factory linac was designed by Butler and Jakobson.[8] They compute an output flux of $5 \times 10^{10} \pi$/sec within 10% momentum acceptance and 80 mr-cm transverse acceptance. Allowing a factor of 2 reduction in intensity for a 400-MeV channel, we obtain of the order of 2×10^9 pions/sec at 1200 MeV, a truly impressive intensity. A pion linac starting at 300 MeV has also been computed, with somewhat similar results.

The pion beam could be used directly by experimenters, or it could produce the heavier mesons given in Table III.

Table III
Thresholds for the Reaction $\pi + P \rightarrow$ Boson + P

Boson	Threshold Energy
σ (?)	350
η	560
ϵ (?)	820
ρ	915
ω	966

The (?) indicates existence questionable. The reactions $\pi + P \rightarrow \Lambda + K$ and $\pi + P \rightarrow \Sigma + K$ are also accessible. A large number of experimenters are using the π beams at high energy installations, attesting to the utility of such beams.

Acknowledgment

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References

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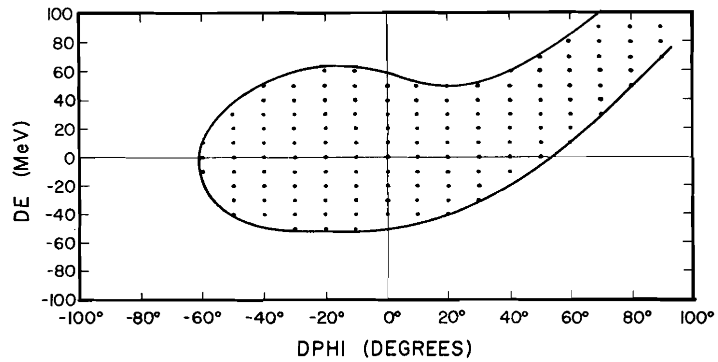

Fig. 1. Energy phase acceptance at 400 MeV for pion linac.

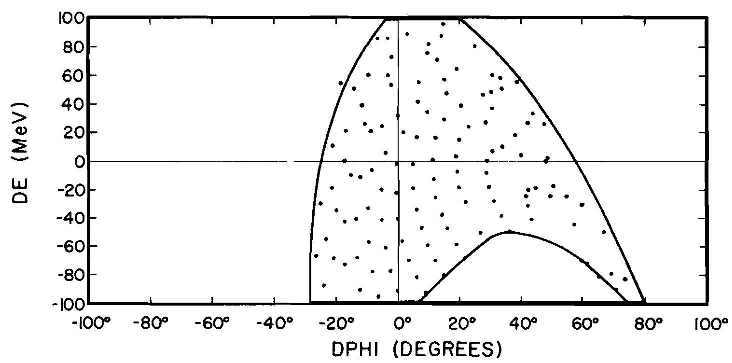

Fig. 2. Energy phase emittance at 1.2 GeV.

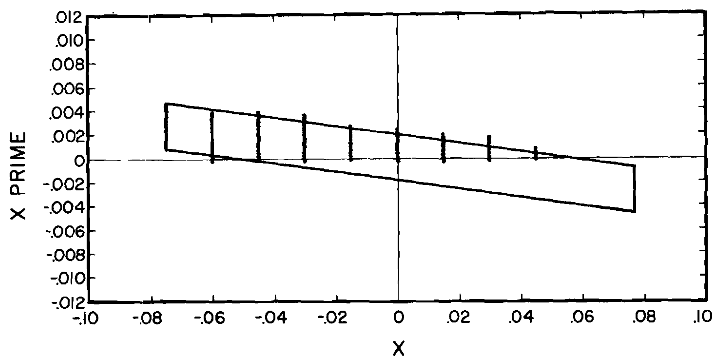

Fig. 3. Transverse acceptance of pion linac. The diagram is symmetric with respect to the origin.

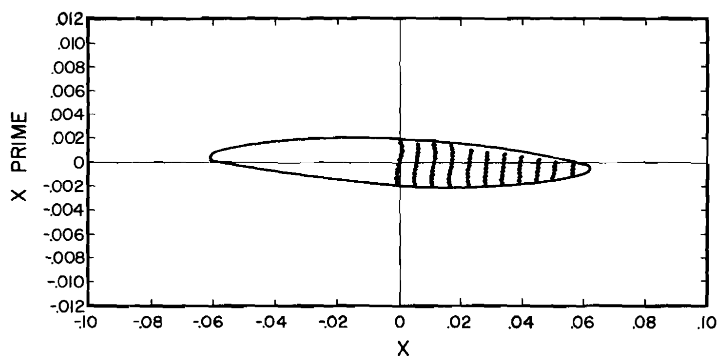

Fig. 4. Transverse emittance of pion linac at 1.2 GeV.