

SECONDARY BEAMS FROM A HIGH ENERGY LINAC

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Viewing the particular linac, of which the parameters are given in the preceding report by V. W. Hughes, as a source of secondary beams, it was considered necessary, as part of the Yale Design Study of Linear Accelerators, to study the problem of secondary beam formation and targeting. This linear accelerator is projected as a machine in which the primary beam will be mainly used for the production of pion, muon and perhaps neutrino beams. The implication is that this accelerator should not be regarded as complete until a secondary beam handling system and experimental area is available.

An attempt was made to estimate the secondary beam intensities and characteristics in order to gain some insight in the sort of physics that could be done and further to obtain preliminary requirements for the necessary magnetic systems and shielding. For the sake of discussion, assume a machine with about 750 Mev primary energy and 1 ma average intensity. A sketch of a possible experimental area is shown in Fig. 1. This 1 ma primary beam, hitting any target to produce secondary beams, will result in a tremendous amount of background. Therefore, a permanent target room has been considered. Since this room will be exceedingly "hot", it will be well shielded and probably not too accessible at any time. Several experimental areas, such as a pion room, a muon room and possibly a neutron room, all with semi-permanent setups have been contemplated. An estimate has been made of the sort of beams one could get into these areas. A summary of this is given in Table 1. The values indicated refer to a primary beam of about 600 Mev. Resultant

TABLE I

SUMMARY OF SECONDARY BEAM INTENSITIES

$T_p = 650$  Mev.  $I_p \approx 1$  ma ( $6 \times 10^{15}$ /sec)

Intensities listed are for  $\pi^+$  beams and their decay products,  $\mu^+$  and anti-neutrino beams. Negative beam intensities are down by a factor of about 7 to 10 from the positive intensities listed.

(I).	<u><math>\pi^+</math> beams</u>							
	<u>Kinetic Energy</u>	<u>Intensity</u>	<u>Solid Angle</u>	<u>Target</u>	<u>Target Dissipation</u>	<u>Distance from Target</u>		
	300 Mev $\pm$ 1%	$10^7$ /sec	$10^{-4}$ ster.	6 gms/cm <sup>2</sup> Be	12k watts	75 ft.		
	200 Mev $\pm$ 5%	$3 \times 10^9$ /sec.	$10^{-3}$ ster.	25 gms/cm <sup>2</sup> Be	50k watts	75 ft.		
(II).	<u><math>\mu^+</math> beams</u>							
	<u>Kinetic Energy</u>	<u>Intensity</u>	<u>Angle to Decaying <math>\pi</math></u>	<u>Energy of Decaying <math>\pi</math> Beam</u>		<u>Distance from <math>\pi</math> Production target</u>		
	220 $\pm$ 2 Mev.	$1.4 \times 10^8$ /sec	$\pm 2^\circ$	200 Mev $\pm$ 5%		120 ft.		
	42 $\pm$ 1 Mev.	$10^8$ /sec.	$\pm 4^\circ$	100 Mev $\pm$ 5%		120 ft.		
(III).	<u>Neutrino beam from <math>\pi^+</math> decay in flight</u>							
	<u>Kinetic Energy</u>	<u>Intensity</u>	<u>Angle to Decaying <math>\pi</math></u>	<u>Energy of Decaying <math>\pi^+</math></u>		<u>Distance from <math>\pi^+</math> Production target</u>		
	172 $\pm$ 2 Mev.	$2 \times 10^8$ /sec.	$\pm 3^\circ$	300 Mev $\pm$ 5%		120 ft.		
(IV).	<u>Neutrino beam from <math>\pi^+</math> decay at rest</u>							
	<u>Kinetic Energy</u>	<u>Intensity</u>	<u>Solid Angle</u>	<u>Source of Beam</u>		<u>Target Dissipation</u>		
	29.8 Mev.	$10^7$ /sec.	$10^{-6}$ ster.	All protons and produced $\pi^+$ stopped in target.		600 k watts.		

values improve by increasing the energy to 750 Mev. At about 600 or 700 Mev, the peak pion intensity for nucleon-nucleon interactions comes at about 100 Mev in the nucleon-nucleon center-of-mass system\*. Increasing the energy of the primary proton beyond this point has as a consequence that the peak position rises somewhat in energy and intensity. The main effect, however, is a considerable broadening so that by going to energies much higher than 700 Mev, one really does not shift the peak position of the pions a great deal. A higher number of higher energy pions is obtained but the peak will still remain at about 100 Mev in the center-of-mass system. With a 750 Mev beam one finds a peak at around 200 Mev in the pion laboratory system, falling off by about a factor of 3 to 5, at around 400 Mev and hitting an end point around 450 to 475 Mev for p-p interaction. So with a 750 Mev primary beam, the maximum pion intensity will come at around 200 Mev and the maximum usable pion intensity probably around 400 Mev. Increasing the energy up to 850 Mev, for instance, does not result in many more 200 Mev pions, but one does get a few more 400 Mev pions. So 750 Mev is a reasonable figure to start with. The results of some experiments at Dubna,\*\* with 660 Mev, show a nucleon-nucleon cross section for  $\pi^+$  production of about 14 millibarns and also a dependence with nucleon mass of about  $A^{2/3}$ , up to aluminum.

Assuming something like a 6 mg carbon target or a 12 mg copper target, it is possible to obtain a good geometry beam of  $\Delta p/p \cong \pm 1\%$  into

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\* S.J. Lindenbaum, Ann. Rev. of Nucl. Sci. 7, 317 (1957).

\*\* A.G. Meshkovsky et al., JETP, 4, 842 (1957); 5, 1085 (1957), and 6, 463 (1958)

something like  $10^{-3}$  sterad.; for a primary target of about 1/4 inches in diameter, one can get  $\sim 4 \times 10^8$   $\pi^+$ 's at 200 Mev and  $\sim 2 \times 10^8$   $\pi^+$ 's at 400 Mev. These numbers are for a distance of 80 feet from the target area, taking into account the decay of pions.

There is some question about the optimum way of extracting  $\pi$  beams. Of course, the high intensity is in the forward direction, and at  $45^\circ$  it is down by a factor of  $\sim 2$ . However, forward direction pions suffer from a contamination of the primary protons. Therefore, the way to do this is to take the  $\pi$ 's off at an angle of something like  $45^\circ$ , with consequent losses being only approximately a factor of 2. The major limitations to the sort of intensities possible involve the desired geometric characteristics of the beam, i.e., how big a cross-sectional area the beam should have, what its convergence will be, and the thickness of the production target. For the targets mentioned above, namely,  $6 \text{ g/cm}^2$  carbon and  $12 \text{ g/cm}^2$  copper, the dissipation of the proton beam is something like 13 and 20 kilowatts, respectively. This is not considered to be a problem. Zucker at Oak Ridge reported a target dissipation of up to 75 kw. Something like 100 kw dissipation in the target will probably be about the maximum. Even if one could handle more than this, the geometric spread of proton and pion beams in the target and the degradation of the beam will be quite serious. The dissipation of 80 kw implies, for instance, a  $50 \text{ g/cm}^2$  copper target. By increasing the momentum dispersion to about 5%, it is feasible to increase the above mentioned good geometry estimates by probably a factor of 20. This would mean that at 300 Mev one could get approximately  $5 \times 10^9$   $\pi^+$  per second, approximately (by an order of magnitude)  $10^9$  per second at 400 Mev and for the  $\pi^-$  at 200 Mev, less by about a factor of 6 to 10. This

represents the upper limit that one could hope to get. These calculations have been compared with some of the experimental results obtained at Berkeley and at Chicago.

Considering now what can be done with the proton beam after the pions are produced, it should be possible, with a simple magnet system, to recover 1 to 2% for possible further usage. Therefore, a pion experiment and a proton experiment can be run simultaneously. Of course, as the proton beam goes through the production target, its energy is degraded. However, it seems quite feasible to recover here a 10 micro-ampere, 700 Mev beam with  $\Delta p/p \cong 1\%$ .

With a 400 Mev pion beam, after 80 feet, the  $\mu$  contamination, as pointed out by J.P. Blewett, is about 50%. Therefore, one of the more interesting uses of this machine will be  $\mu$  experiments. Starting out with a "bad" pion beam with a  $\pm 5\%$  energy spread, will result in a  $\mu$  beam produced isotropically in the center-of-mass system of the pions, varying in energy from about 420 Mev to 250 Mev. With a practical magnet system, it seems possible to focus the forward one-degree cone. At 400 Mev, this is about an  $18^\circ$  cone in the center-of-mass system, implying that something like 2% of the muons which decay along the line of flight of the pions can be focused. Consequently, it should be possible to obtain approximately  $10^8 \mu^+$  per second and probably  $10^7 \mu^-$  per second. At lower energies, the intensity of the  $\pi$  beams goes up and the decay length of the pions decreases. More muons would be available in the target area where the pions are going to be used. However, the forward peaking of the pion center-of-mass system in the laboratory system decreases so the muon intensities will probably remain roughly constant.

There has been a good deal of interest in neutrino experiments and the question of neutrino production has been considered here. The same number of neutrinos as muons is obtained from the  $\pi$  beam after a distance of 80 feet from the target. The neutrinos will have energies in the range of 150 Mev to 175 Mev. For experimental purposes, possibly with large spark chambers, it seems possible to get several counts per day. This intensity is high enough so that one could look at  $\mu$  production, for instance. Also, if it would be possible to dissipate the entire 1 ma proton beam in a target, then a reasonable amount of 30 Mev neutrinos could be obtained from the  $\pi$  decay. Making the reasonable assumption that one-hundred completely stopped protons yield one pion and each stopped pion yields one neutrino; further assuming that the stopping target is a  $4\pi$  solid angle neutrino source, then the neutrino intensities at 30 Mev are quite reasonable. Consequently, a low energy neutrino experimental area has been tentatively located behind the proton stopping target.

It should be stated that some of the  $\pi$  beam and the  $\mu$  beam intensities, mentioned in Table 1, are probably estimated rather conservatively and could be larger by a factor of 10.

#### Discussion

J.P. Blewett (BNL): What correction of the  $\pi$ - $\mu$  decay have you made in estimating the  $\pi$  beam?

W.A. Blanpied (Yale): At 400 Mev the half length is about 80 feet so that even though the cross-section is considerably increased at 200 Mev more  $\pi$ 's decay by the time they reach the counting area. It is possible to get about half of the 400 Mev  $\pi$ 's assuming a reasonable length to accommodate the shielding and magnet system.

J.P. Blewett (BNL): There will be a lot of  $\mu$  contamination?

W.A. Blanpied (Yale): There will be quite a lot, roughly 50% at 400 Mev, but, of course, most of these can be cleaned up by using differences in energies. However, the  $\mu$  contamination is not terribly important if you are looking at strong interactions. I think  $\pi$  contamination in  $\mu$  beams would be more serious.

V.W. Hughes (Yale): I guess it is fair to say that the secondary beam intensities seem to be a factor of a thousand more than obtainable from a synchrocyclotron; probably more like a factor of 10,000 because of the good geometry of the external beam.

W.A. Blanpied (Yale): I should emphasize the fact that in  $\pi$  experiments, sacrifices in geometry had to be made to obtain more  $\pi$ 's. But here the  $\pi$  intensity is high and it is possible to obtain  $10^{-4}$  steradian  $\pi$  beams, monochromatic to  $\pm 1\%$ . This is also true for the  $\mu$  beams. There are two things to consider, first the intensity obtainable as compared to that from existing facilities with this sort of geometry and second, the sort of experiments you can do that require a very good definition. In that sense, one will certainly do very well.

J.P. Blewett (BNL): Why is the available neutrino beam from the  $\pi$  decay, as mentioned, so small?

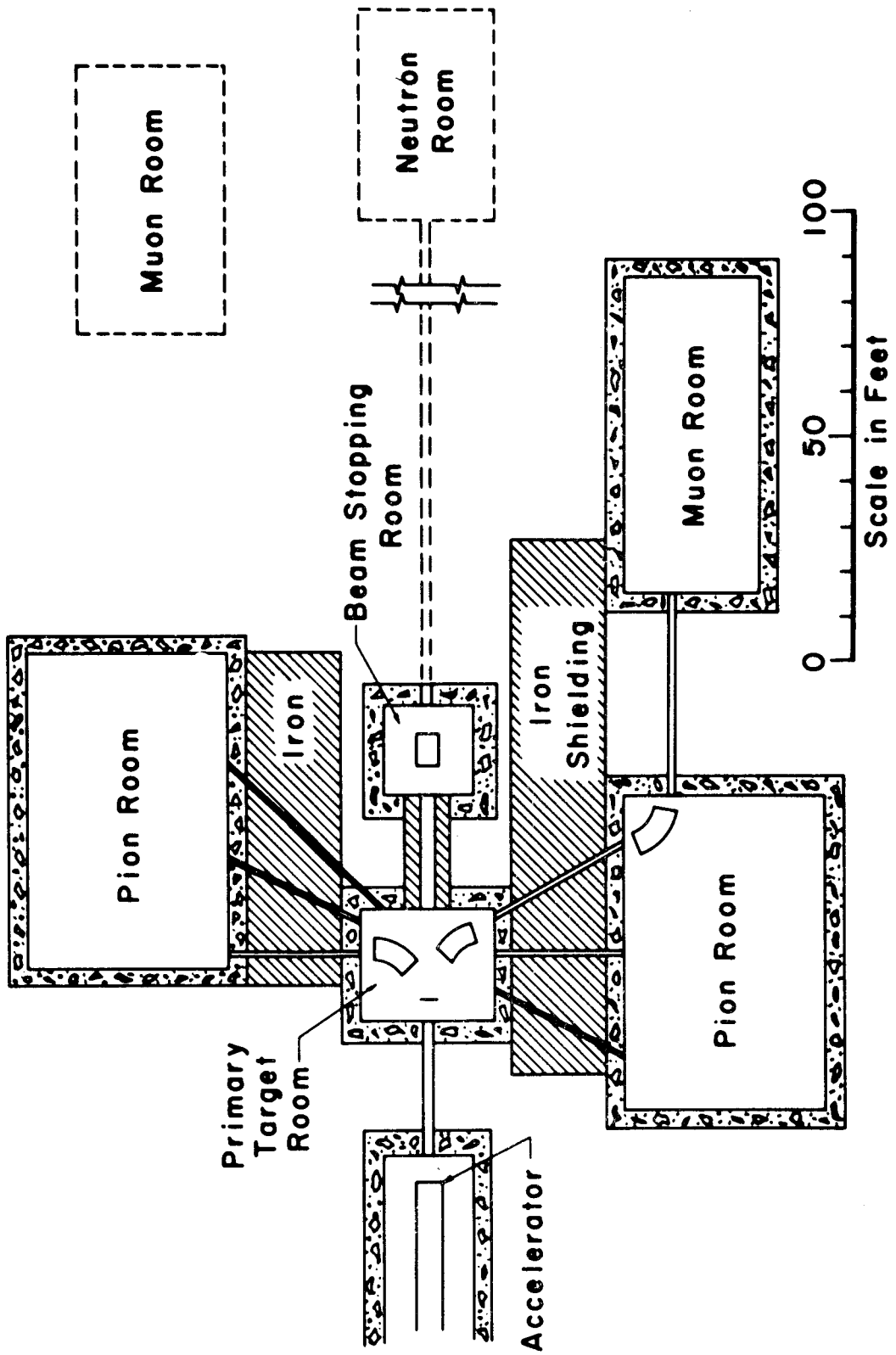
W.A. Blanpied (Yale): One would gain by raising the energy of the machine because more  $\pi$ 's are produced and the forward peaking of the neutrinos in the laboratory system is greater.

J.P. Blewett (BNL): With regard to the dissipation in the target, did you consider a moving target?

W.A. Blanpied (Yale): A metallic target can be constructed to dissipate up to 80 kw or so, but beyond that a thicker target might not do much good because the dissipation due to the multiple scattering in the target spreads the beam so much that it becomes difficult to handle with a magnet system.

P. Grand (Yale): I should like to make a comment about the target cooling. Some thought has been given to using alkali metals as a coolant, contained between carbon interfaces. Considering the thin target involved, I think lithium seems most promising at temperatures of about  $1,800^{\circ}$  C. However, the reaction C-Li has to be studied at these temperatures.





Schematic of Experimental Area

Fig. 1