# USE OF A 10 GeV HIGH-INTENSITY ACCELERATOR AS A PION FACTORY(*)

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(Presented by F.T. Cole)

A study has been made of the use of a 10 GeV high intensity proton accelerator for the production of pion beams of energy below 500 MeV. The specific comparison is between the proposed MURA high intensity accelerator[1], which produces a time-average intensity of 30 $\mu$A at 10 GeV, and an 800 MeV proton acceleraotr of 100 $\mu$A time-average intensity.

Pion yields from the 10 GeV accelerator are estimated from the statistical model. This model is in good agreement with experiment for 10 GeV protons in the range tested, down to pion energies of 1 GeV. It is also in good agreement with experiment for pion yields from 400 MeV to 2.8 GeV produced by 6.2 GeV protons in the Bevatron. The statistical model can, therefore, be expected to give an accurate estimate of the expected pion yield. Yields for the 800 MeV accelerator are taken from the Oak Ridge Study[2]. The yields for the two accelerators are shown in Fig. 1 for a 10 cm carbon target, production angle of 45°, solid angle of $4.5 \times 10^{-3}$ sr and energy spread of 2 MeV. The $\pi^-$ intensities for the low-energy accelerator are obtained by multiplying the $\pi^+$ intensities by 1/7. There is no such difference between $\pi^+$ and $\pi^-$ for the high-energy accelerator, because at 10 GeV a large number of reactions contribute to pion production.

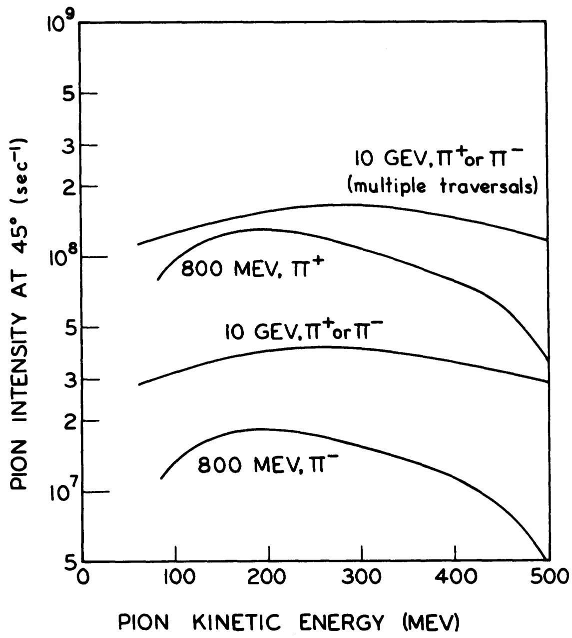


Fig. 1 Yields calculated for 800 MeV isochronous cyclotron and for 10 GeV FFAG accelerator.

Also shown is the $\pi^+$ or $\pi^-$ yield from the high-energy accelerator for multiple traversals of a thin internal target. In this case the effective target thickness with respect to production is infinite, but pion loss due to scattering and absorption is negligible. This ability to use a thin target is one of the advantages of the high-energy accelerator.

The 10 GeV FFAG accelerator has also the advantage of flexibility in duty factor,

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which cannot be approached by an isochronous cyclotron or linear accelerator. This makes it possible to match the output of the accelerator to widely varying detectors. Further, pion experiments in this low-energy range can be carried on simultaneously with the high-energy experiments which can be performed with this accelerator, because the low-energy pions can be produced at larger angles. Secondary particles from an internal target in the proposed MURA accelerator pass through essentially no fringing field and their orbits are therefore not distorted.

The conclusion of this study is that a 10 GeV accelerator produces low-energy pion beams of intensities comparable to those from pion factories. Because of the advantages discussed above (large $\pi^-$ flux, flexibility of duty factor, etc.) and because of its simultaneous utility at higher energy, the 10 GeV accelerator forms an attractive alternative.

## References

1. MURA Staff, Proceedings of the International Conference on High Energy Accelerators (U.S. Atomic Energy Commission, Washington, D.C.) 1961, p 57.
2. The Mc[2] Isochronous Cyclotron, A Status Report, ORNL Report 3324, June 15, 1962, p 2.3 (unpublished).

## DISCUSSION

HADDOCK : First, concerning the use of a thin target in the FFAG whereby very little energy is lost in the target in the production of pion beams. This is not an important effect in the producing of high-intensity pion beams for the simple reason that you are producing a spectrum of particles and you do not care, within reason, what the energy spread in the primary beam is. For the case given in Fig. 1, 10 gr/cm$^2$ target in the FFAG, this corresponds to about 25 MeV energy loss; it is about a fraction of a geometrical cross-section for carbon. In making intense beams you could conceivably use one to two geometrical mean free paths.
Second concerning your point that with high-energy accelerators, the low-energy beams do not depend much on angle. This is not true for the cyclotron pion factories, in this case low energy is something below 100 MeV and you would be somewhat independent of angle; however, for medium energy pion beams between about 200 and 400 MeV, you are very angle dependent. If you plot from the only known data on pion yields, that at 660 MeV from the Dubna machine, and that at 450 MeV from the Chicago machine, the pion production at 20°, you obtain numbers which are two to three times larger than the infinite traversal case

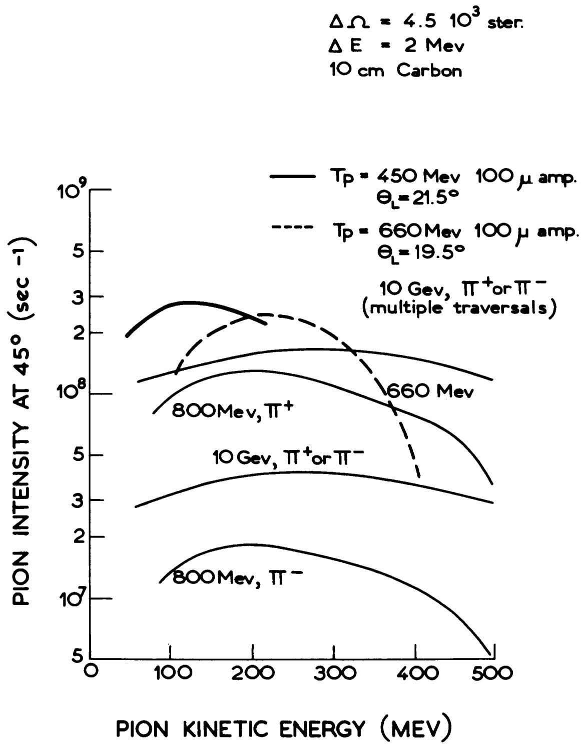


Fig. 2 A version of Fig. 1, as suggested by Haddock, see discussion.

that was shown.
I would like to thank F.T. Cole for showing me a preprint of this talk; I have taken the opportunity to sketch on his drawing the $\pi^+$ yields at 450 MeV and 660 MeV mentioned above. The conditions are the same as for Fig. 1 with the exception that production is from a carbon target at angles near $20^\circ$ in the laboratory. I would like to enter this figure into the Proceedings, see Fig. 2.
It is true that the $\pi^-$ intensities are anywhere between a fourth to a twentieth less in the cyclotron pion factories than in the higher energy machines. When all factors are added together, however, I believe they will turn out to be equivalent to several times the intensities estimated above at the higher energies for the multiple traversal case and correspondingly higher yields of $\pi^+$s, say, 20 - 40 higher. Such factors may be introduced because the meson factories are being estimated at 500 $\mu$A these days instead of 100 or 50 $\mu$A, and by moving to forward angles you will gain considerably in the energy spectra between 200 and 400 MeV.
We believe that there is sufficient research potential connected with medium energy protons, neutrons, pions, muons and neutrino physics to justify an experimental area of at least 60,000 square feet. This is about two football fields and represents a large commitment of space, time, and equipment at any accelerator.

COLE : My comment about thin targets may have been poorly phrased; what I meant to say was only that this gives an advantage in production for the higher energy accelerator. The 10 GeV accelerator also has a few safety factors in intensity!

BLASER : Would you comment on the extraction efficiency of FFAG, especially on how extraction efficiency is correlated to beam stacking?

COLE : At MURA we have extracted a beam from one of our accelerators in a single turn; the efficiency was in this case limited by improper design of the deflector magnet and was something like 80%. This could easily be made 100% in our next accelerator, which we expect to have ready within a month or so. This is again single-turn extraction. We have done a fair amount of orbit computing for extraction in 10 to 20 turns, but only for the question of using the accelerator as an injector for some higher energy machine. Regarding extraction over long periods of time, which would be the thing of most interest for experimental work, we have done very little work on this. We have several schemes but we have not done the amount of orbit computation necessary, or tried anything experimental. As far as its relation to beam stacking is concerned, I think there is probably very little to worry about. The spread in radius due to the spread in energy of the stacked beam is not very large and I do not think this would cause a particular problem. The ideal would be to pick things out of the beam at the same time as you are adding to it, which is what we do with an internal target, but we simply have done no work in that line yet.

BLASER : Does this really mean that a stacked beam could be extracted with similar extraction efficiencies?

COLE : I do not really know.

RICHARDSON : I should just like to repeat what I said in my paper, that a reasonable value for the long-term extraction efficiency, at least on the present situation, is somewhat between 30 and 50%.

COLE : I should have to be convinced very firmly, that anything that can be done in a cyclotron cannot be done in an FFAG. I think that if higher extraction efficiencies can be reached in cyclotrons, we can also do them in FFAG.

RICHARDSON : I was assigning the same energy gain per turn to the FM cyclotron and the FFAG. When you get to something like the $Mc^2$ cyclotron where you have a large increase in radius per turn, then I think you are better off.

COLE : As you may know, some work has been done by Terwilliger, reported in the 1959 CERN Symposium, which shows that we can increase greatly the radial spread by properly chosen orbit perturbation. So I think that one can improve this situation very much.

LIVINGSTON : What would the current be if you were to deflect 100% of the beam in the single-turn case that you mentioned for this machine?

COLE : It would be 30 $\mu$A.