Muon Beams from Beam Dumps*

Lawrence W. Jones†
University of Michigan, Ann Arbor, MI 48109

For some time we have been conducting a prompt neutrino experiment (E613) at Fermilab using a beam dump target. Our greatest background has been from muons from the target, in spite of 10 m of magnetized iron and about 16 m of passive iron shielding. It was natural to wonder if a prompt source of muons might make possible a high quality, high intensity muon beam, as an alternative to the typical π-μ decay channel beam. Such a solution could be relatively inexpensive and also quite compact. The considerations we have on this subject fall into two classes: the muon source problem, and novel muon focussing devices.

Prompt Muon Fluxes

In the course of developing Monte Carlo simulations for muon production and evolution through prompt neutrino beam dump targets and active shield, M. Peters and others have developed muon production cross section models which fit our observed muon fluxes quite well at 400 GeV. The ratio $\mu^\pm$ prompt/ $\pi^\pm$ is 10^{-4}-10^{-5} and depends on E, target A, Feynman x, and p_T. From a real target a significant fraction of the muons is from K decay and even π decay in addition to the prompt muons.

An ideal prompt muon beam of several TeV (from a 10-20 TeV accelerator) might be made from a heavy target (W,Ta) made of plates spaced by 2-5 times the plate thickness. A target 3λ thick might then extend over a meter in length.

A π-μ decay drift space for a conventional muon beam of the same energy might be ~3 km. If E_π=7 TeV, γ_π=5×10^4, so that in 3 km only 7.7×10^{-3} of the pions will decay. At the same time, the prompt muon yield increases with energy, both because of the increase in the cross section for charm production with E and because of the Drell-Yan process energy dependence.

While it appears that the π-μ decay beam may still have a greater absolute intensity, it seems appropriate to make a detailed calculation, which has not been done, except by Mori in the Diablerets ICFA study. He, however, did not appear to consider σ (charm) vs. E, the effect of a thick target, or the A^1-dependence of charm production.

One advantage of a prompt beam would be its relatively small source spot size. It thus appears possible to maintain a good optical envelope and focus of such a beam using short focal length magnetic focusing elements.

A specific candidate for a prompt beam of the sort discussed here would be a site filler accelerator at Fermilab. To make a conventional muon beam would require bending the protons in a radius smaller than the machine radius, hence of a lower energy. This is because the only long path for such a beam would be inside the ring. Alternatively, a proton beam of full energy could be brought out tangent to the ring and to a dump target a short distance from the extraction point. The beam optics and experiments would fit comfortably on the site in a corner outside the site filler ring.

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Muon Focusing Elements

In dealing with hadron and electron beams, we are accustomed to transport through air or vacuum; any significant material in the beam destroys it through nuclear interactions or bremsstrahlung. In this case the only kind of focusing must be alternating gradient, or "strong" focusing. Maxwell's equations require $\partial Bx/\partial y = \partial By/\partial x$ in free space so that a lens which is horizontally focusing must be vertically defocusing, etc.

Muon beams permit us to relax these conditions as high energy muons may pass through materials with only multiple Coulomb scattering and weak (virtual photon) coupling to nuclei. Hence muons can pass through several g/cm^2 of absorber with almost no effect. If we can put conductor in the beam we can build a lens with simultaneous focusing in both dimensions, i.e. a lens much stronger than "strong focusing".

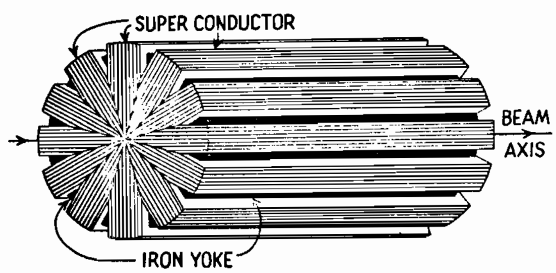
There are two possible super-strong lenses which occur to us. There is an old notion called the plasma lens wherein a uniform current density J with axial symmetry is colinear with a beam over a path length L. The resulting field is characterized by

$$B = B_\phi = kr, \quad k = 2\pi J$$

and the focal length of this lens for particles of momentum p is

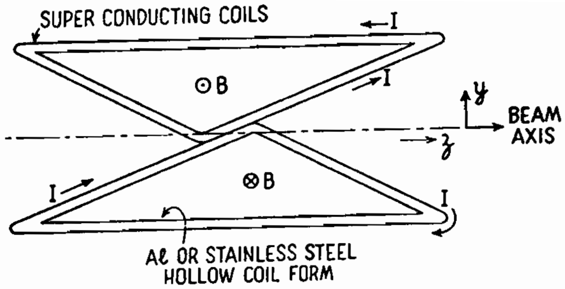
$$f = p/0.3\ kL.$$

If, rather than a current-carrying plasma, a bundle of superconducting wires is used, very high current densities may be achieved, and a muon lens of quite short focal length could be realized.



It may be that this much material (meters of solid Nb-Ti in Cu) might produce too much multiple Coulomb scattering for the beams. If so, the alternative below may be superior.

The objective is to make $\int B_\phi dz=kr$. The lens described above had B_ϕ=kr and $\int dz$=L for all r. Alternatively one could make B_ϕ constant in r but over a length z proportional to r. This could be done in principal using windings on the surface of a cone, however there is a problem at r=0 due to the finite conductor size. It appears more satisfactory to separate x and y so that in one lens, $\int By dz=kx$, and $Bx\equiv0$ while in a second $\int Bx dz=ky$ and $By\equiv0$. This can be achieved with coils wound as illustrated:



VERTICAL SECTION (NOT A FIGURE OF REVOLUTION)

The illustration is a vertical focusing lens, $B_x=-ky$, $B_y=0$. The coils can be superconductor on a stainless steel form; an iron box around the assembly would carry the return flux. A radial lens would logically be combined with a bending magnet with only one tapered "pole" in the beam. The return yokes would then function as muon spoilers.

No numbers are presented here, however it seems that higher momentum muon beams with very large apertures from a dump target should be possible.