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A NOVEL FOCUSSING ELEMENT FOR INCREASING THE FLUX IN THE FERMILAB ELECTRON BEAM

R. J. Morrison and F. V. Murphy
Physics Department, University of California
Santa Barbara, California

ABSTRACT

A desire to increase the flux in the Fermilab electron beam has led us to consider a beam element which, under rather special circumstances, focusses in one plane only. This element, called MQ for brevity, depends for its operation on the fact that the Fermilab beam, unlike most others, transforms neutral flux into charged flux.

The Fermilab electron beam[1] begins with an intense flux of neutral particles--mostly photons and neutrons--produced at zero degrees by the primary external proton beam in a thick beryllium target. Electrons produced by the photons striking a converter are transported to a momentum-dispersed focus, then to a final focus, by a more-or-less conventional array of dipoles and quadrupoles. The designers attempted to maximize the flux by maximizing the phase-space acceptance.[2] The usual constraints were present: power, expense, muon background, spot size, and divergence requirements, etc., but utmost importance was also placed on minimizing losses in the second stage which might produce halo. The design succeeded, and the beam provides the predicted flux and acceptable halo. However, the utility of more electron flux, which would reduce the running time of the present experimental program and which also would allow the exploration of small photoproduction cross sections at higher energies, has become more obvious.

As in most beams, the particles in the Fermilab electron beam are focussed by quadrupole doublets with the usual result that the angular acceptances are quite asymmetrical: $\Delta\theta = \pm 1.2$ mrad, $\Delta\phi = \pm 0.5$ mrad. Therefore, the small $\Delta\phi$ seemed a promising point of attack. We needed a magnetic focussing element which when placed between the converter and the first quadrupole pair, would gather the lost ϕ cone without losing the θ cone. A quadrupole clearly violates the latter condition. The other commonly used focussing technique, a magnet boundary inclined at an angle β to the plane normal to the beam, while promising at first sight, would in fact have a quadrupole-like defocussing action in the θ direction. Such a boundary has the matrix[3]

$$\begin{matrix} 1 & 0 & 0 & 0 \\ -\tan\dfrac{\beta - s}{\rho} & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & +\tan\dfrac{\beta}{\rho} & 1 \end{matrix}$$

where s is much less than β, and ρ is the radius of curvature of a trajectory inside the field. This defocussing action is a consequence of the fringe fields and is unavoidable for any real magnet.

Peculiar to the Fermilab electron beam, however, is the fact that the electrons themselves, while retaining the phase-space characteristic of the photons produced at the primary target, do not exist, and are therefore unaffected by magnetic fields until materialized in the converter. Therefore, electrons produced in a converter inside a uniform magnetic field wil ave as if they suddenly entered a field region with no fringe-field effects whatsoever. If such a converter is inclined at an angle β to the plane normal to the beam, the beam can be focussed (or defocussed) in one plane, unaffected in the other. Figure 1 illustrates this. A photon emitted from the source S with angle ϕ produces an electron in the converter C-C' in the first field region B. The slope of the converter correlates ϕ with the electron's path length in the field, and therefore with its bend, producing focussing. The second magnet, -B, merely cancels the average bend and its momentum dispersion, leaving a small net offset, d. The focal length of such an element (and of the corresponding inclined magnet boundary) is $f = \rho/\tan(\beta)$. The corresponding matrix is

$$\begin{matrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & \tan\frac{(\beta)}{\rho} & 1 \end{matrix}$$

Some TRANSPORT and TURTLE calculations[3] verify the relevance of such focussing to the Fermilab electron beam. The initial design approach was to adjust the focal length of the MQ so the beam envelope had equal maximum size in both directions in the first quadrupole doublet, for $\Delta\theta = \Delta\phi = \pm 1.2$ mrad, then adjust the quadrupole for an intermediate momentum-dispersed focus as before. A straightforward design puts the MQ just downstream of the target box, about 12 m from the target. For 300 GeV the new magnetic element is 1.2 m long, and contains a copper converter 0.04 cm thick, inclined at an angle of 88.5 degrees to the beam. The compensating magnet which follows is only 0.6 m long. Both magnets run at 15 kG but need only very small field volumes. The offset is 0.2 cm. The same design works at other energies if the magnetic fields are scaled; alternately, a higher field strength or lower energies allow the magnet length and converter inclination to be reduced. To obtain even larger acceptance, the converter could, in principle, be placed in the proton dumping magnet inside the target box. Of course, phase space conservation demands that the beam be larger than the unmodified beam where the angular divergence is small, but in fact the beam size at the critical positions was dominated by the quadrupole chromatic aberrations, which are almost unaffected by the MQ, so the net effect on crucial beam sizes is small and acceptable. The effect on the beam envelope is shown in Fig. 2.

The actual flux gained by the addition of such an MQ is somewhat complicated to predict. To a crude approximation the neutral pions which define the phase space of the photons are produced with transverse momenta limited to about 200 MeV. Thus the angular distribution of electrons of, for example, 50 GeV, which come from photons of say 100 GeV, which in turn come from neutral pions of say 200 GeV, should extend to at least 1 mrad. Then the expected gain in flux at 50 GeV would follow the increase in angular acceptance at least to 1 mrad. At higher secondary energies the forward peaking of the production will be sharper and the expected gain somewhat less. However, because the proton beam is focussed rather strongly onto the target, the production appears smeared over a range comparable to 1 mrad. This is consistent with apparent production angle distributions measured near 100 GeV electron energy. The flux gain, therefore, will be at least a factor of two around 100 GeV and significant at even the highest energies.

As mentioned above, using this technique causes a small offset at the front of the beam and a surprisingly small increase in beam size, both of which seem acceptable. The increase in vertical beam size at the first focus, however, degrades the pion rejection. This is irrelevant for tagged-photon experiments which benefit from the almost perfect pion rejection in the tagging process but will be a serious drawback for electroproduction.

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REFERENCES

[1] The Fermilab electron beam as built resembles quite closely that described in Halliwell et al., Nucl. Instr. and Methods 102, 51 (1972).

[2] The theory and limitations of this optimization have been discussed in G. Brianti et al., Proceedings of the 1973 International Conference on Instrumentation for High Energy Physics, Frascati, Ed. S. Stipcich, p. 655.

[3] We use the notation and programs of K. L. Brown and S. K. Howry, TRANSPORT, SLAC Report 91, and D. C. Carey, TURTLE, Fermilab Report NAL-64. Note that β is a negative quantity for the case of interest.

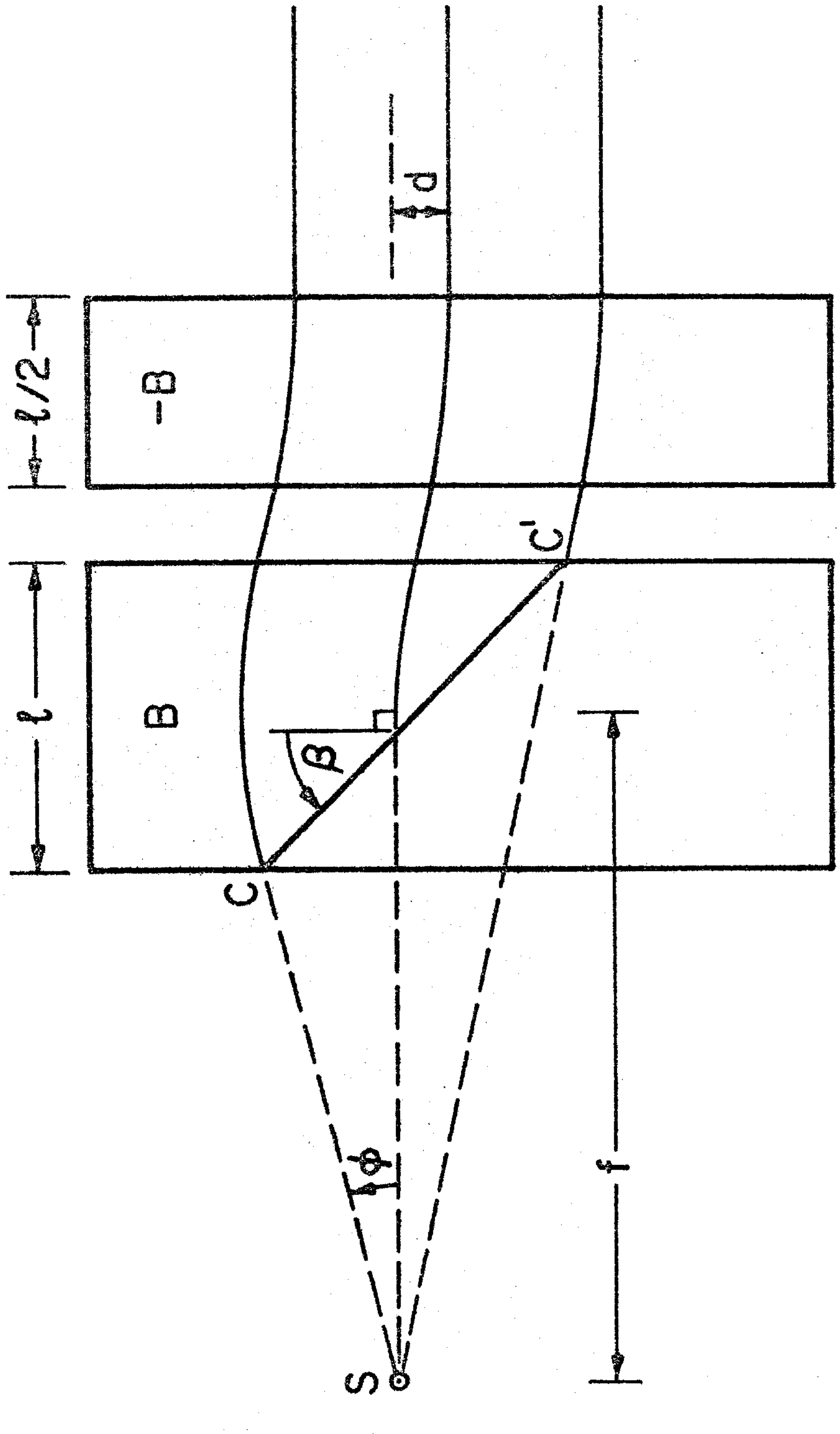

Fig. 1. Operation of the MQ with focal length, f.

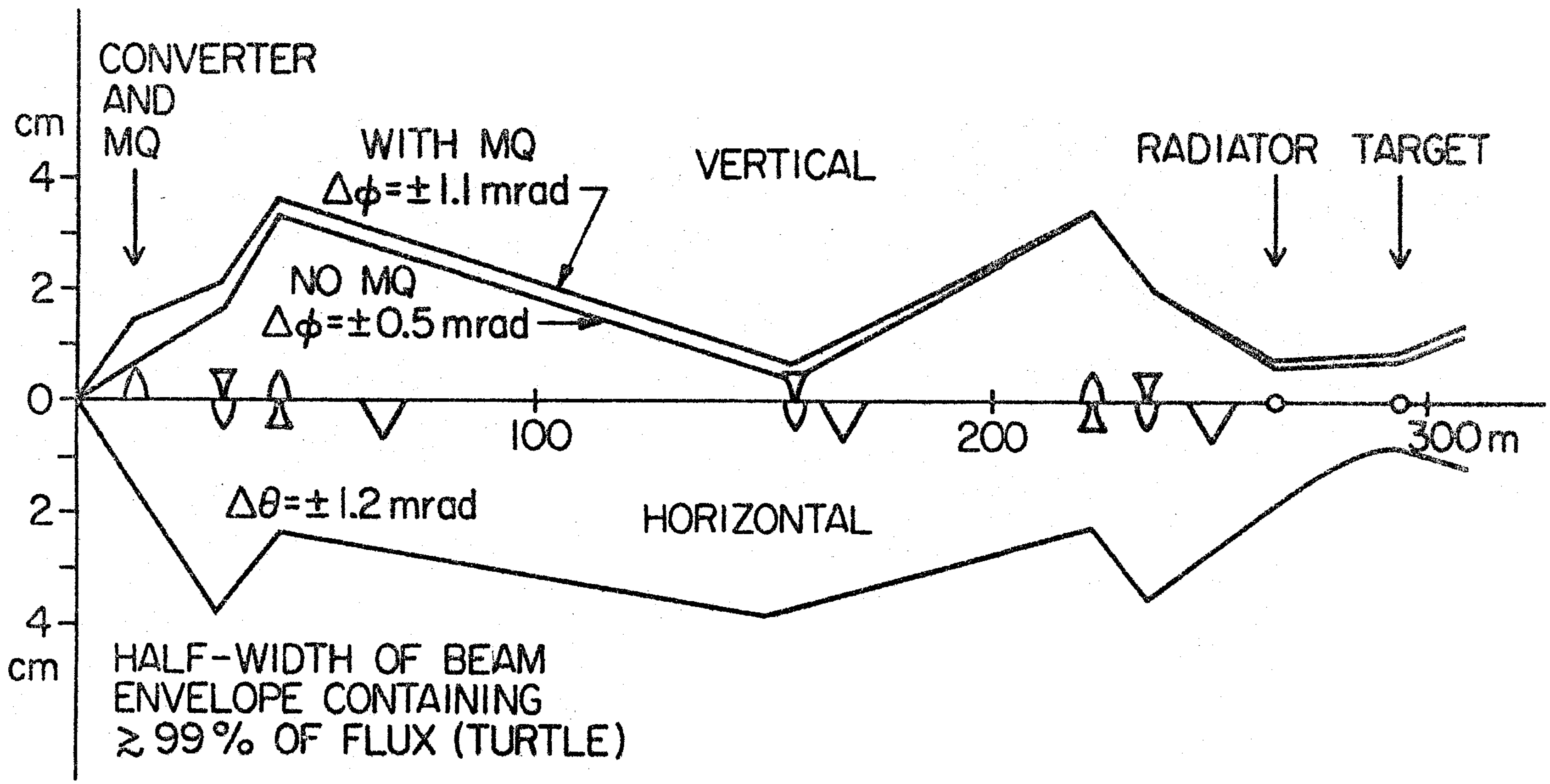

Fig. 2. Effect of the MQ on the envelope of the Fermilab electron beam.