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Electron Beam Deflection by Permanent Magnet

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1 Summary

The proposed scheme for beam containment in the Hall D line [1] places a permanent magnet in the photon beam following the tagger magnet as a fail-safe mechanism to ensure that the primary electron beam does not accidentally get dumped into the experimental area. Here we give a more quantitative estimate of the space needed in the tagger building to implement this beam containment proposal. We conclude that the tagger building must extend 13 m from the front of one permanent magnet to deflect the primary beam by 20 cm into a concrete absorber. This distance is sufficient to separate the electron from the photon beam pipe so that it can be contained downstream of the tagger building.

Table 1: Moliere radii for carbon, iron and typical shielding concrete mixture [2] ($\overline{Z}$ ~9).

Material	X_0(cm)	E_c(MeV)	E_s/E_c	R_M(cm)
Carbon	18.8	84.2	0.25	4.7
Concrete	10.7	59.6	0.35	3.7
Iron	1.76	22.4	0.94	1.7

2 Shower containment

The transverse shower containment is determined by the distance measured in Molière radii (R_M) [2]:

$$R_M = X_0 \; E_s/E_c \tag{1}$$

Where X_0 is the radiation length, E_s = 21 MeV, and E_c is the critical energy which can be approximated by

$$E_c = \frac{610 \; MeV}{Z + 1.24} \tag{2}$$

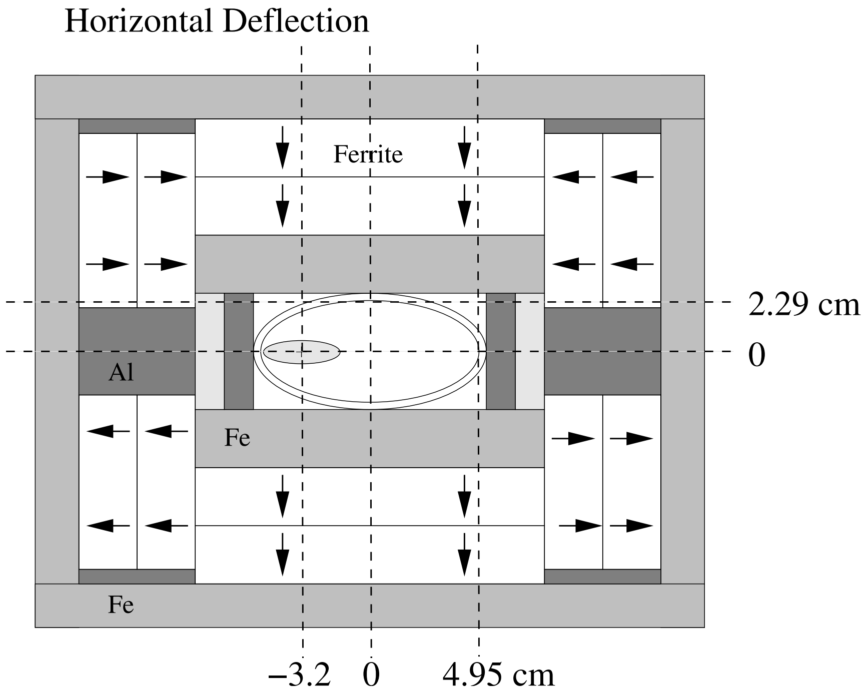

Figure 1: Schematic view of the permanent magnet assembly indicating nominal dimensions for horizontal deflection. The 10σ envelope of the electron beam at the radiator (σ_x=3.5 mm, σ_y=1.1 mm) is also shown for scale. The nominal beam center is shown offset horizontally from the center of the magnet by 3.2 cm to provide adequate bending aperture for the accidental dumping of the electron beam into the photon line. The inner dimensions of the elliptical beam pipe are 1.8" x 3.9".

Using the above formulas, we can compute the Molière radii for some typical materials which are given in Table 1. For concrete we use the PDG composition for shielding concrete to obtain R_M(concrete) $\sim$ 3.7 cm. Approximately 99% of the shower lies inside 3.5R_M, beyond which the scaling with R_M fails. We require that the impact of the electron beam be 4R_M from the 10-cm photon beam pipe, or 19.8 cm from the photon beamline. The containment distance for a 15-cm beampipe is 22.3 cm for concrete. If iron absorber is used instead, the distance from the beamline would be 11.8 cm for a 10-cm beampipe and 14.3 cm for a 15-cm beampipe.

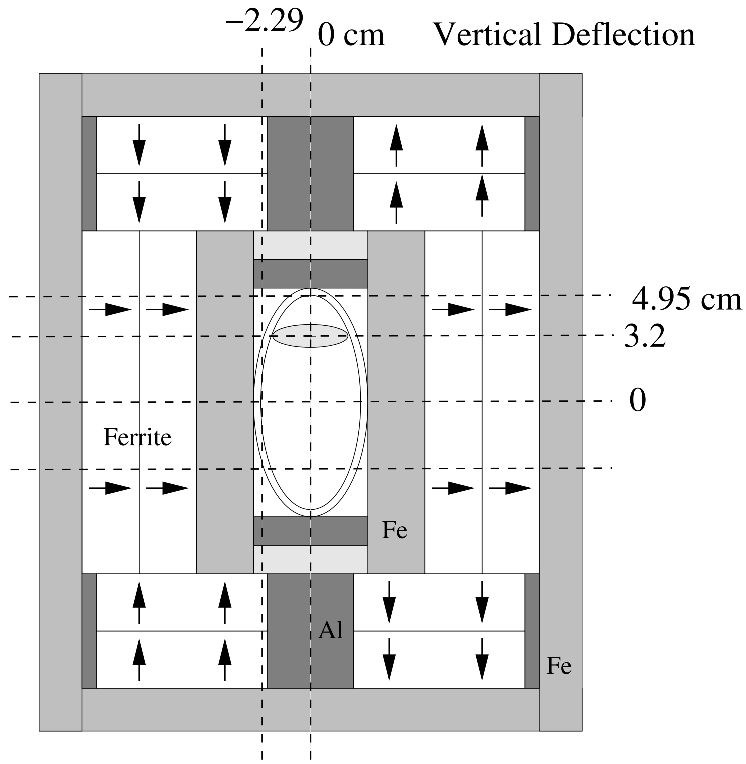

Figure 2: Schematic view of the permanent magnet assembly indicating nominal dimensions for vertical deflection. The 10σ envelope of the electron beam at the radiator (σ_x=3.5 mm, σ_y=1.1 mm) is also shown for scale. The nominal beam center is shown offset vertically from the center of the magnet by 3.2 cm to provide adequate bending aperture for the accidental dumping of the electron beam into the photon line. The inner dimensions of the elliptical beam pipe are 1.8" x 3.9".

3 Beam Trajectory

Three permanent magnets were obtained as surplus from Fermilab. They are "vertical bend dipole" (PDV) permanent magnets which were constructed for the Fermilab 8 GeV Booster for the Main Injector [3] and are available for use in the Hall D line. A schematic view of the cross section of one magnet is shown in Figs. 1 and 2, which were scaled from Figure 3.1A-6 and dimensions specified in Ref. [3]. Also shown on the figure is the 10σ envelope of the electron beam at the radiator to show that there is sufficient room for the photon beam to fit comfortably through the aperture. The physical length of the magnet is 368.3 cm and the magnetic length is 355.6 cm with an integrated strength of 0.8221 T-m, corresponding to a 0.23 T field in the gap. In order to allow for the maximum deflection within the gap, the nominal photon beam axis is taken to be 3.2 cm from the center of the magnet.

The trajectories of a 12-GeV and 6-GeV beam are shown in Fig. 3. They show that the 12-GeV beam cleanly exits the magnet and the 6-GeV beam might scrape at the exit. There are no present plans for use of the facility at 6 GeV, but accidental dumping of the beam at these energies would need to be investigated in more detail. The angle of the 12-GeV beam at the exit of the magnet is 20 mrad with an impact point 20 cm from the photon beam axis 13 m downstream of the entrance to the magnet. This is the required distance for a 10-cm beampipe if concrete is used to dump the beam. For a 15-cm beampipe one needs a unobstructed path length of 14.4 m. Corresponding numbers for iron absorber are 9 m (10-cm beampipe) and 10.3 m (15-cm beampipe).

It appears that a vertical or horizontal bend of the beam would be feasible. In the case of vertical deflection, the larger emittance of the beam in the horizontal plane does not limit the aperture available for deflection of the outgoing beam.

References

[1] L. Keller, E.S. Smith and E. Wolin "Hall D Beam Containment Proposal," GlueX-doc-32, June, 2000.

[2] Particle Data Group, Handbook Sections 27.4.3 and 27.5, 2004.

[3] Fermilab Booster Technical Design Handbook, Chapter 3, February 1997.

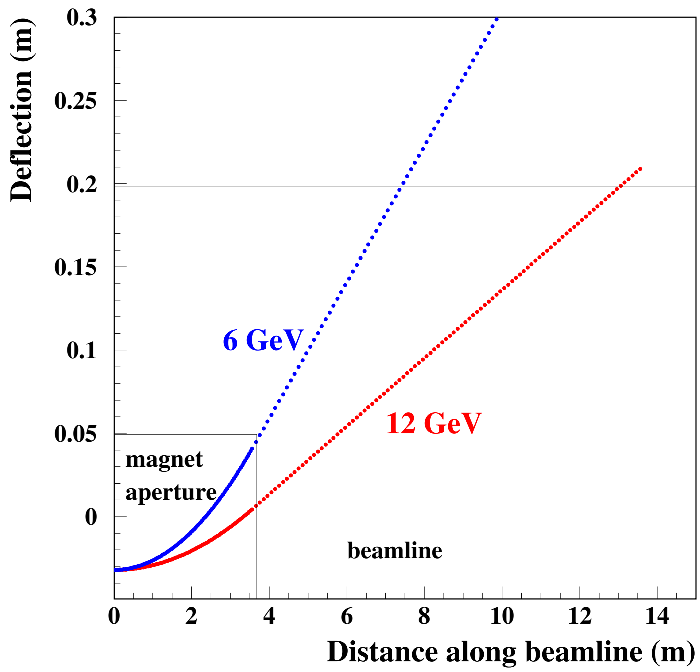

Figure 3: Trajectories of a 12 GeV and 6 GeV beam through the aperture of the permanent magnet showing the separation of the impact point from the beamline at a distance of 13 m.