Fermilab

Doc Number: MI-0216
Version: 1.1

Can Magnetic Fields Assist in Radiation Shielding for 8 GeV Proton Beams?

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8/15/97

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*Operated by the Universities Research Association under contract with the U. S. Department of Energy

Abstract

Here are a few thoughts on using magnetic fields to control radiation produced by an 8 GeV proton beam. Basic result is that the transverse kick $p\theta$ available within a nuclear cascade is of order $.3B\lambda_i$ which takes a value of about 20 MeV for a 0.4 T field in iron. Since this is to be compared to a typical hadronic transverse momentum of 300 MeV in the nuclear interactions, it is clear that a rather specialized application would be the only purpose in modifying a cascade using such low fields. I will pass this along in hopes that it sparks a useful idea for someone or perhaps saves someone from further time lost.

1 Introduction

Since I occupy an office which is directly above the Booster L3 extraction area, I have a direct interest in shielding the 8 GeV transfers. Discussions of the problem occur near my office so I have some familiarity with the problem, and I was asked what could be done with permanent magnets to bend the particles produced by the protons which are lost in the extraction process. Here are some thoughts. But remember, I have never done a shielding calculation nor have I really simulated a nuclear shower.

2 Bending in a Nuclear Cascade

We assume that we are into the high energy regime where one can characterize a shower by a nuclear interaction length, a typical multiplicity or secondary momentum and a characteristic transverse momentum ($\approx$ 300 MeV). If we produce the shower in iron, the characteristic interaction length is 17 cm. For 8 GeV protons, the typical secondary pion or kaon has a momentum of a few hundred MeV and thereby typical angles of up to a radian. I don't know what the inelasticity of the initial collision is so I don't know what momentum the incident proton maintains.

The magnetic field as perhaps provide one of the following functions: trapping, deflection, or focusing.

- Trapping requires a field of radius ρ which has a magnetic field of

$$B = \frac{2\pi p}{.3\rho} \tag{1}$$

where B is the field in Tesla, p is the particle momentum in GeV/c, and ρ is in meters. Only very low momentum particles can be trapped in the space we are considering for additional shielding.

- Deflection is characterized by the transverse momentum imparted by the field before the next nuclear interaction. If λ_i is the nuclear interaction length, we can create a transverse kick of $p\theta$

  $$p\theta = .3B\lambda_i \tag{2}$$

  Using 0.4 T and 0.17 m for B and λ_i we get a kick of only 0.02 GeV.

- I don't have a handy formula to estimate the focusing possibilities.

At this point, we are not encouraged to believe we can do great things with magnetic fields.

3 Geometries Available for Solid Iron Permanent Magnets

Creating magnetic fields with solid iron is quite easy with coils of wire. Fields near iron saturation are easily achieved at relatively low power. Such systems have been widely studied in the context of shielding for neutrino experiments. I am writing this note in view of the possibility that the flexibility of mixing geometries in ways which are only sensible using permanent magnets to drive the fields may provide advantages which haven't been recognized until now. The low energy combined with the recent availability of permanent magnet materials may provide new options. In a simple iron circuit with no gap, driven by ferrite or other CSEM materials, one can estimate the field as simply that given by the B_r of the material. This will be reduced by $\int H dl$ through the iron (assume $H = H_c$ where $\mu_0 H_c \approx 3 \times 10^{-4}$ T.). Compare the integral through the iron to the integral of B through the CSEM. Some factor of enhancement can be obtained geometrically by flux concentration. Typical available CSEM (Current Sheet Equivalent Materials) materials are shown in this table.

B_r	$< .4$	$< .9$	< 1.2
Material	Ferrite	$SmCo_5$	$NdFeB$

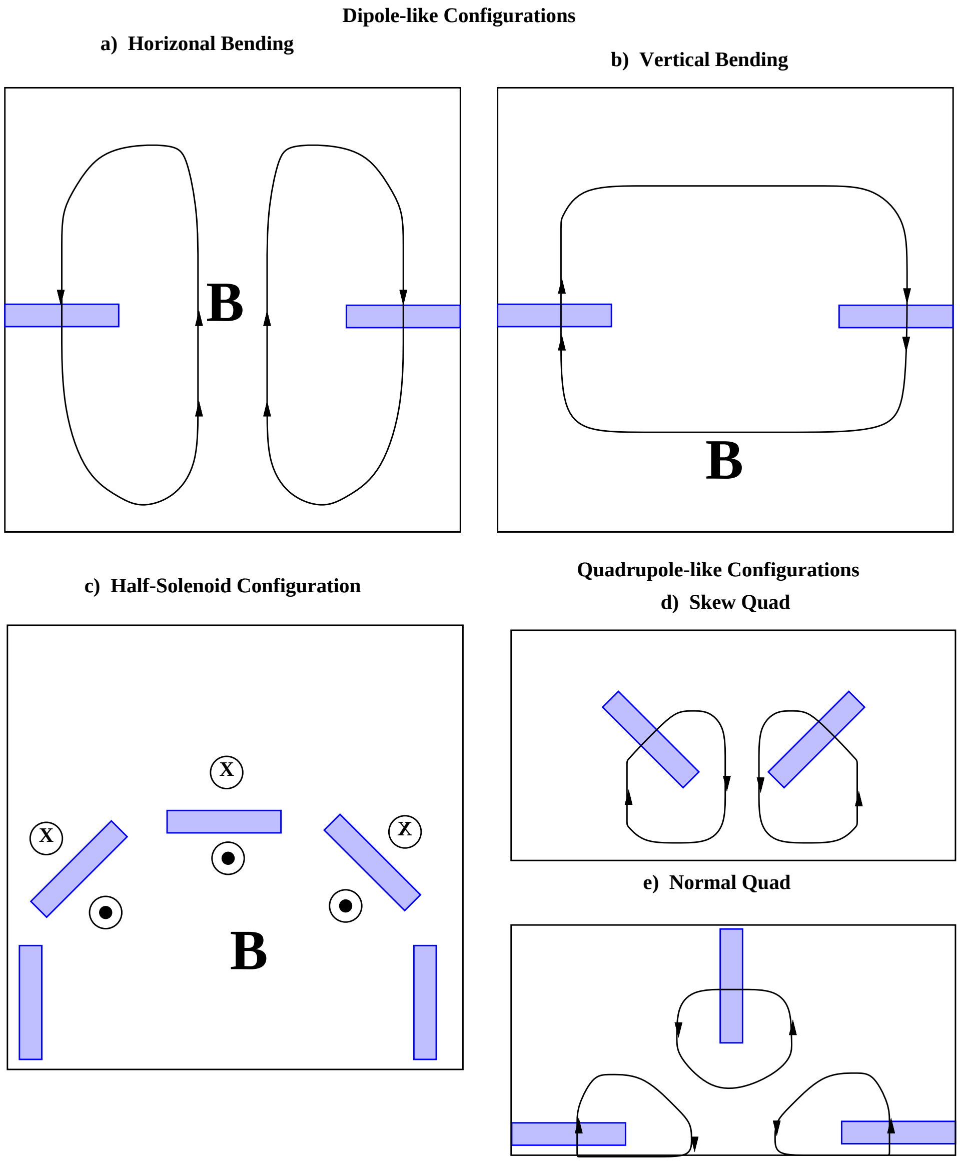

Figure 1: Some field shapes available with CSEM and Iron.

A few interesting configurations for ferrite-driven iron magnets are shown in Figure 1. Initially, I imagine all of these shapes as end views as viewed from a beam particle. Here are some configurations for discussion:

1. Using the bending magnet b), one can deflect positive particles back down.

2. Alternatively, one can use it to get the positive particles high enough to follow it with magnets of configuration a) which will then provide a side deflection.

3. Perhaps one can use the half-quad configurations to provide a focusing channel?? The solenoidal configuration can also provide focusing.

4. Finally, note that configuration b) can be rotated by 90^o (so as to have $\vec{B}$ parallel to the direction of the beam to be shielded) to provide a horizontal deflection to all particles which have a finite vertical component. Here, we can build a flexible modular design with ferrite at about 0.4 T field but can also build a fairly simple structure with copper driving coils which would easily provide ~ 2 T.

4 Summary

I conclude that there are different and intriguing configurations which would employ CSEM material to add magnetic effects to the shielding for an 8 GeV beam. Simple arguments suggest that the fundamental effects are not large. Only a detailed understanding of the real source of the critical background particles could provide an opportunity to actually help.

Since hadronic cross sections fall with energy until the multi-GeV region is reached, the mean path length at lower energies will tend to be shorter than 17 cm.

It is noted however, that an iron shield which is magnetized with a large $B_z \approx 2$T can spread the beam with a transverse kick of about 100 MeV per interaction length for vertical particles, dropping to 100 $\sin\theta$ where θ is the angle between the field and the particle under consideration. This is still not comparable to the 300 MeV which characterizes a typical hadronic interaction but may usefully modify a marginal situation.