MAGNETIZED IRON MUON SHIELDS

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ABSTRACT

A magnetic shield in the form of a gapless "H" magnet of length 6 to 10 meters is proposed as a muon shield as an alternative to a range shield. This particular geometry has the advantage that the high-flux, low-momentum portion of the muon flux is confined to a relatively small angular cone. Applications to both low-intensity beams and neutrino beams are discussed.

The extremely long shields required to range out high-energy muons are a serious design constraint for experiments with a 200-GeV accelerator. For many cases, it might be more reasonable, both from the experimental and the economic point of view, to sweep the muons out magnetically. This can be accomplished at modest cost in space and dollars by magnetizing the 6 to 10 meters of iron required for hadronic shielding.

The most obvious application of this method would be cases where the muons represent an experimental shielding problem but not a biological one, such as tertiary beams or beams running on low primary proton fluxes. But with careful attention to design it might be possible to apply this technique to a neutrino beam. The resulting gain in neutrino intensity and collimation as well as saving in cost might be considerable.

The optics of a shield of this type are illustrated schematically in Fig. 1. A central region is magnetized to saturation. This sweeps a central region free of muons. For 7-m length, 25 kG field, the muon-free cone is 25 mrad to either side of the beam for 200-GeV muons. Lower energy muons are deflected further, until an energy is reached beyond which the muons pass through the coil. By designing the return path to have a lower field than the central region, the reverse bend in this region can be controlled to produce a beam of muons with little divergence. A crude calculation with a central region one meter wide gives the results shown in the figure; muons emerging with from 190 down to 30 GeV clear the coil. Muons from 5 to 30 GeV/c emerge approximately parallel at an angle of 0.15 radians, by making the return path field one-half the central field. Lower energy muons clearly have more complex orbits, but can be ranged out by following this shield with a passive one of modest length. Clearly, a careful design study is necessary to optimize this magnet. An end view of the magnet is given in Fig. 2.

The magnetic design of the magnet should be straightforward; 50,000 to 100,000 ampere-turns could drive the iron to saturation (μ = 25). At this excitation, total gaps of up to an inch due to crudeness of machining could be tolerated or deliberate gaps could be used to provide field shaping. Thus this represents a conservative design. It might be possible to provide such a modest excitation be means of an uncooled copper coil, minimizing maintenance problems. With a one-meter central region, the magnet would weigh about 400 tons, which gives a cost in the neighborhood of \$120,000. This is considerably less than the cost of any range shield. The cost of copper is negligible even at current densities that permit an uncooled coil, and the machining of the magnet can be very crude.

For low-intensity beams, the magnet could be run with deflection in a vertical plane; μ^+ could be deflected into the ground, and the less abundant μ^- would be too high off the ground to present a serious problem by the time they cleared the area set aside for the experiment.

For neutrino beams, a somewhat larger magnet is desirable. A magnet about 10 meters long with a central region about 2 meters square, weighing 1600 tons, should suffice. (For the magnet to work, its central region must envelop the muon beam.) It could be followed by a short section of ferroconcrete or earth to range out low-energy muons with "exotic" orbits, as shown in Fig. 3. By 20 meters from the front face, the muon-free region would be over 2 meters wide. Prudence would dictate that the experimental area be unoccupied by personnel while the beam is on, and probably also that the beam spill be interlocked to stop if the magnet fails.

Clearly, a detailed computer study is called for to optimize the design of this magnet, in which alternative field configurations must be considered.

Another advantage of this type of shield for neutrinos is that the "equilibrium" muons from neutrino interactions are greatly reduced in number, since only muons produced in the last few meters of the magnet avoid being swept out of the beam.

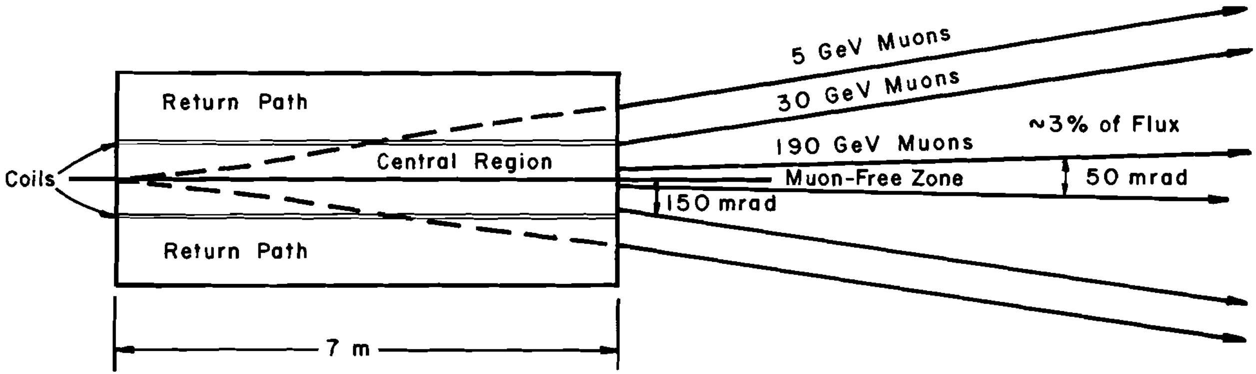

Fig. 1. Effect of muon trajectories of magnetized iron shield, showing reverse deflections in the magnetic return path.

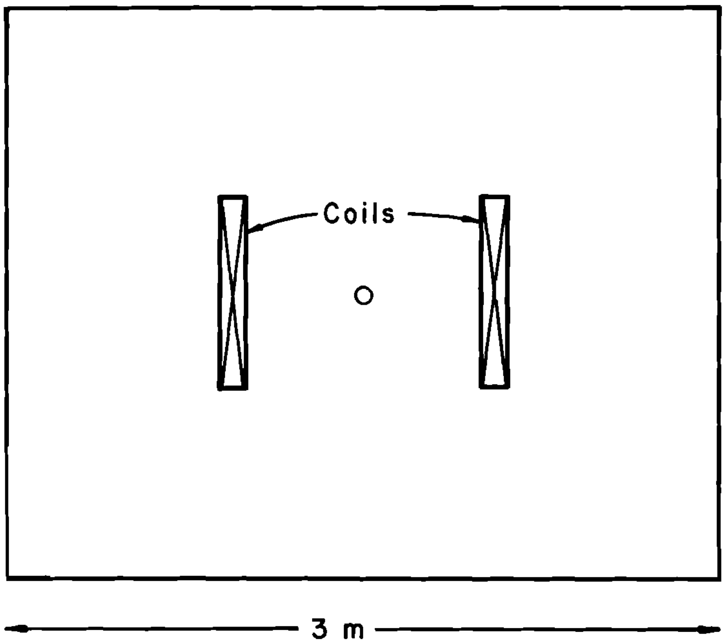

Fig. 2. Cross section of solid iron magnetic shield, showing location of beam axis.

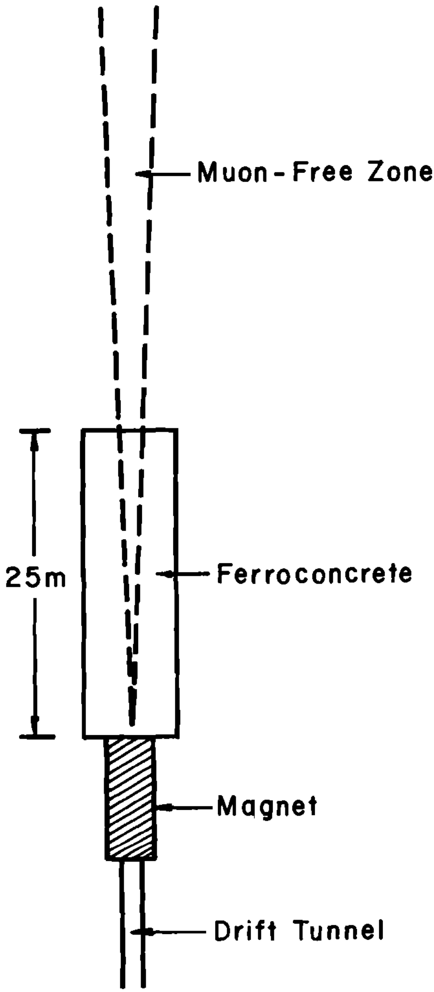

Fig. 3. Downstream end of neutrino beam, showing replacement of thick iron by magnetized iron and concrete.