Effect Of Iron Partial Return Yoke on the MICE Beam

Change History

Version	Changes	Author	Date
1	First draft	C.Rogers	23/01/2013

Project Summary

Project Title	Effect Of Iron Partial Return Yoke on the MICE Beam
Main Issue	#1161
Subtask Issues	
Project Lead	C. Rogers
Project Supervisor(s)	H. Witte
Associated Manpower	

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Motivation and Overview

It has been known that field leakage of the magnetic field from MICE can have detrimental effects on hardware in the MICE hall. Attempts to move or shield sensitive elements have been planned, but recent studies have shown that they may not be successful. An alternative solution may be to provide shielding around MICE magnets themselves and thus contain the field near to the solenoids. This can potentially cause some change to the field on the axis of the beamline that can potentially cause detrimental affects to the beam and hence affect the physics goals of MICE. Here we examine that effect.

We note that a plan was in place already to provide shielding for elements external to the MICE hall such as the ISIS control room. A study of the effect of that shielding on the MICE beam is described in MICE Note 244.

Magnetic Shielding Geometry and Field

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Tracking Simulation in MAUS

The field map as described above was implemented in a MAUS geometry and used for tracking. For this study all physics processes were disabled and there was no material in the beamline. Tracking was performed using MAUS-v0.4.3. A step size of 10 mm was chosen for most tracking except where stated.

The field was implemented as a field map containing the effects only of iron on the beam and this was added to a field map with real coil geometries implemented using the usual MAUS solenoid field routine. The error field was generated from a 3D field map with rectangular grid size 10 mm and trilinear interpolation. The standard solenoid field was generated using default parameters.

Coil	**Length [mm]**	**Inner Radius [mm[**	**Radial Thickness [mm]**	**Current Density [A/mm^2]**	**Z-Position at Centre [mm]**
End2	110.6	258	66.0	-135.18	-5951.00
Centre	1314.3	258	21.3	-152.44	-5201.05
End1	110.6	258	59.6	-127.37	-4451.00
Match2	199.5	258	29.8	-137.13	-4051.05
Match1	201.2	258	44.7	-118.56	-3611.00
Focus	210	263	84.0	-113.95	-2955.00
Focus	210	263	84.0	-113.95	-2545.00
Match1	201.2	258	44.7	-118.56	-1889.40
Match2	199.5	258	29.8	-137.13	-1449.25
End1	110.6	258	59.6	-127.37	-1055.10
Centre	1314.3	258	21.3	-152.44	-298.85
End2	110.6	258	66.0	-135.18	452.00

Table 1: Coil geometry and currents as simulated.

Field on Axis in MAUS

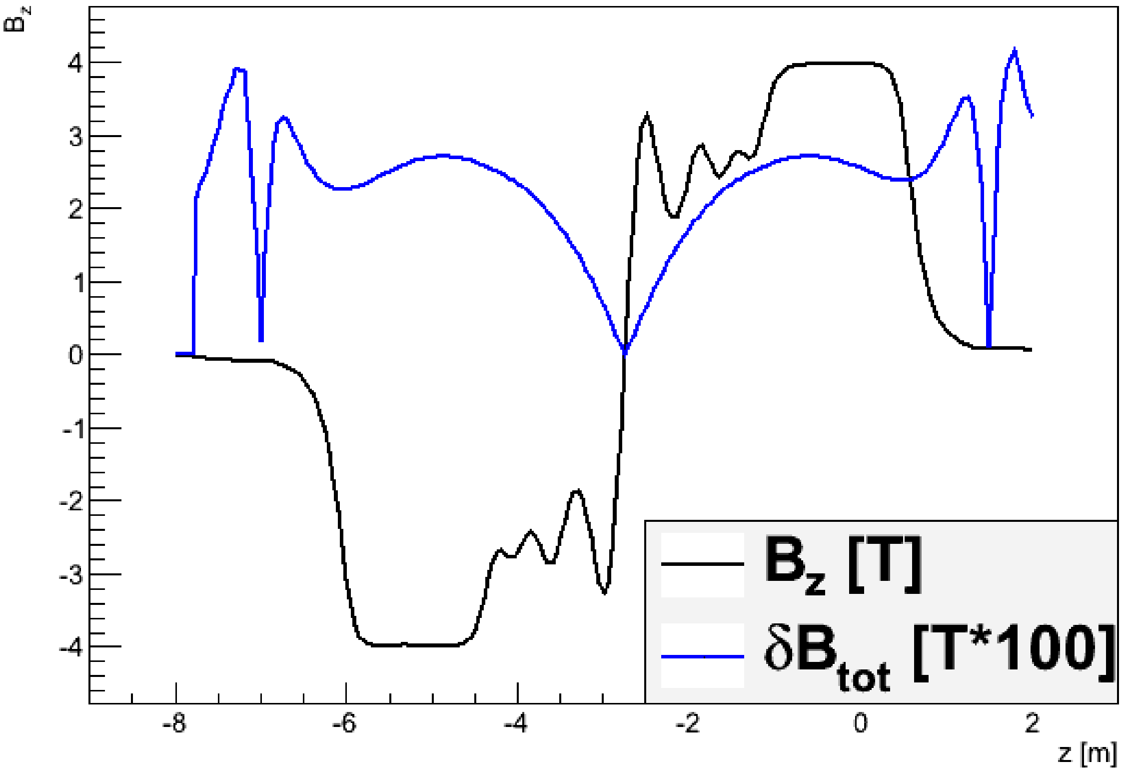

Figure 1: The simulated field is shown. (Black) Field in the absence of coils (Blue) amplitude of the difference between B-field vectors in the iron and no-iron case.

The coil geometry as simulated in MAUS is described in Table 1. The resultant field on axis as simulated in MAUS is shown in Figure 1 for both the no-iron case and the difference between iron and no-iron cases. The maximum discrepancy between the two cases is 41.5 mT.

Reference Particle Simulation

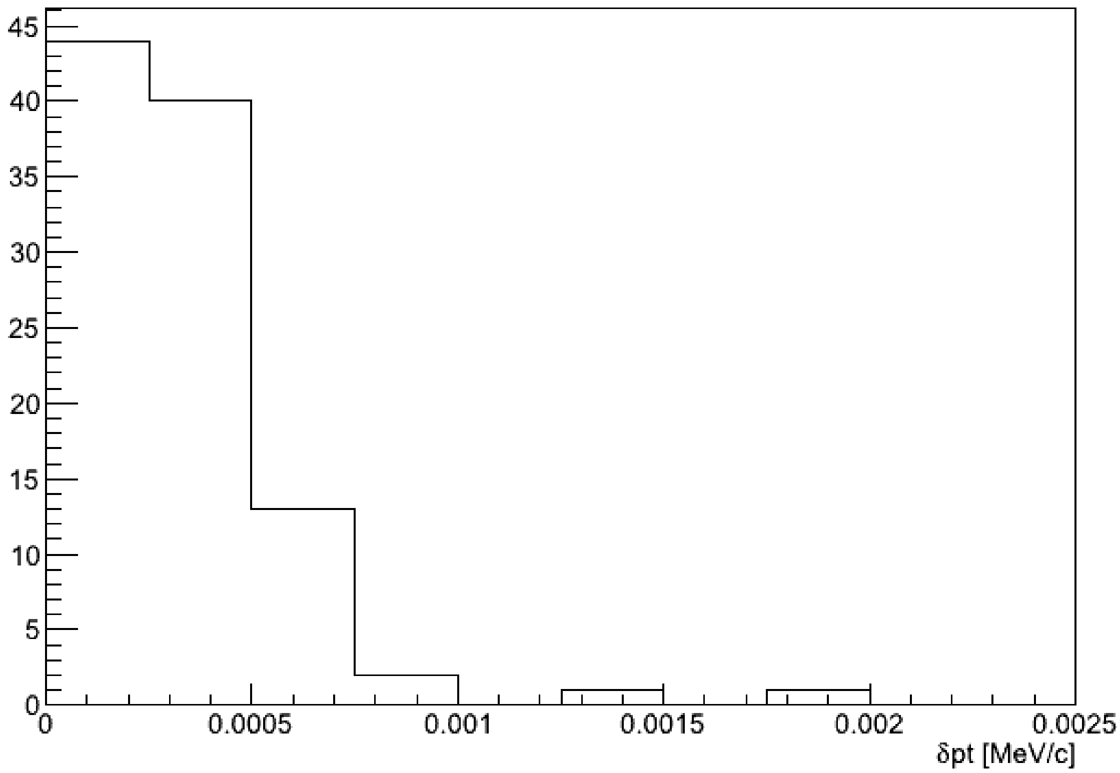

Figure 2: Residual stepping error, found as the magnitude of the difference between transverse momentum vectors for stepping with a 10 mm and 1 mm step size. Residuals are plotted at the final output plane, downstream of the downstream spectrometer solenoid.

Before any tracking modelling, we checked that the absolute error on tracking was small. In order to make this check we tracked a beam through the field, with iron, for the nominal step size of 10 mm and a smaller step size of 1 mm. The residual of the momentum for these two runs for a small sample of 100 muons is shown in Figure 2. A residual stepping error of order keV/c can be seen from the choice of step size. As we shall see, this is quite small compared to the beam misalignment induced by the iron.

The reference trajectory was tracked in the presence of iron in order to understand the significance of beam misalignments that might be induced by the magnetic shielding walls. For this study a reference mu+ was considered with a total energy of 226 MeV travelling initially in the positive z direction. The particle was injected at the centre of the upstream spectrometer coil, z=-5201.05 mm. The results are shown in Figure 3. Misalignments of order 10 microns are observed at the downstream tracker, growing to of order 100 microns in the fringe field of the downstream spectrometer solenoid. Angular divergence is of order 30 keV/c, 0.01 %.

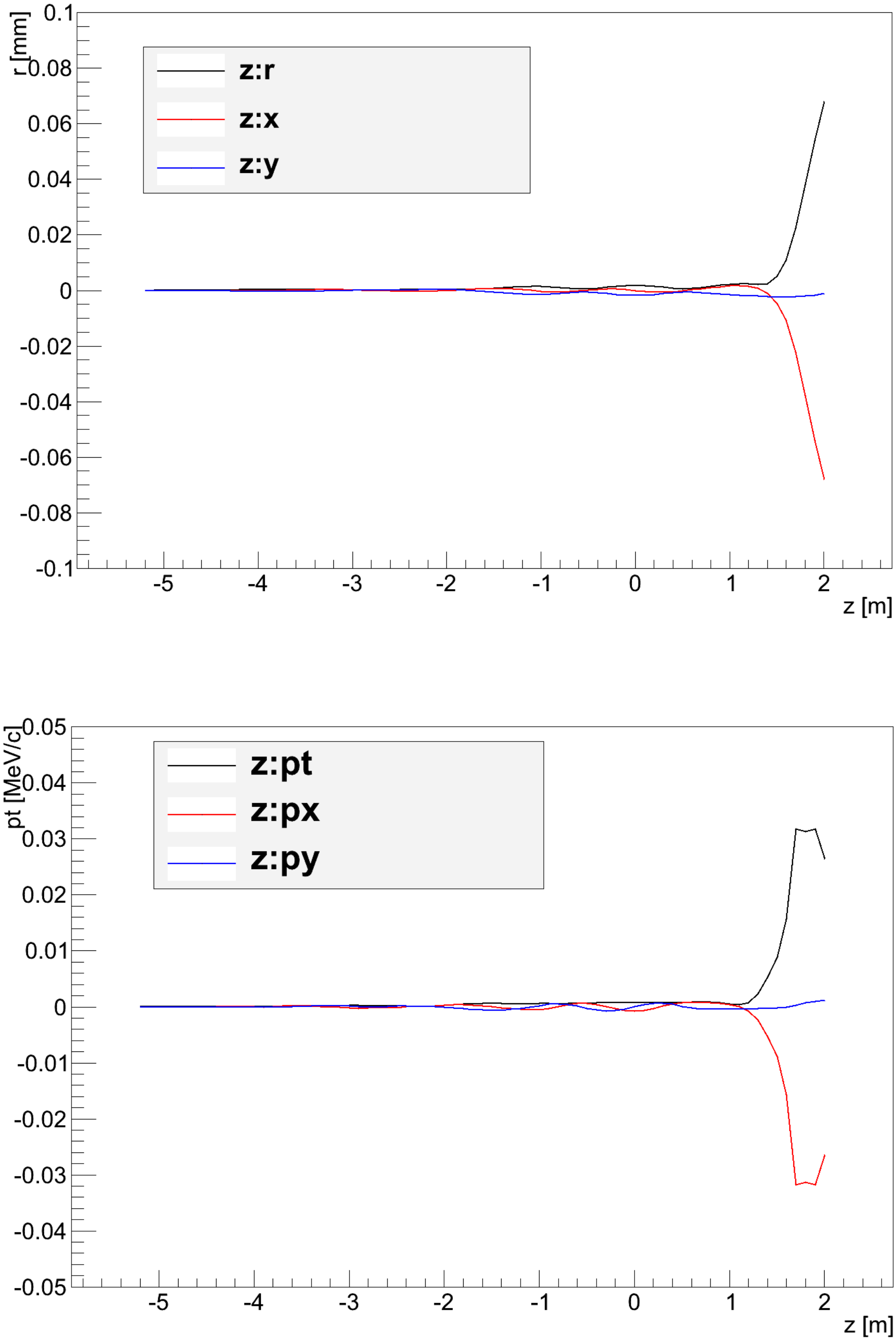

Figure 3: (Top) Transverse position (bottom) transverse momentum of the reference trajectory in the presence of iron.

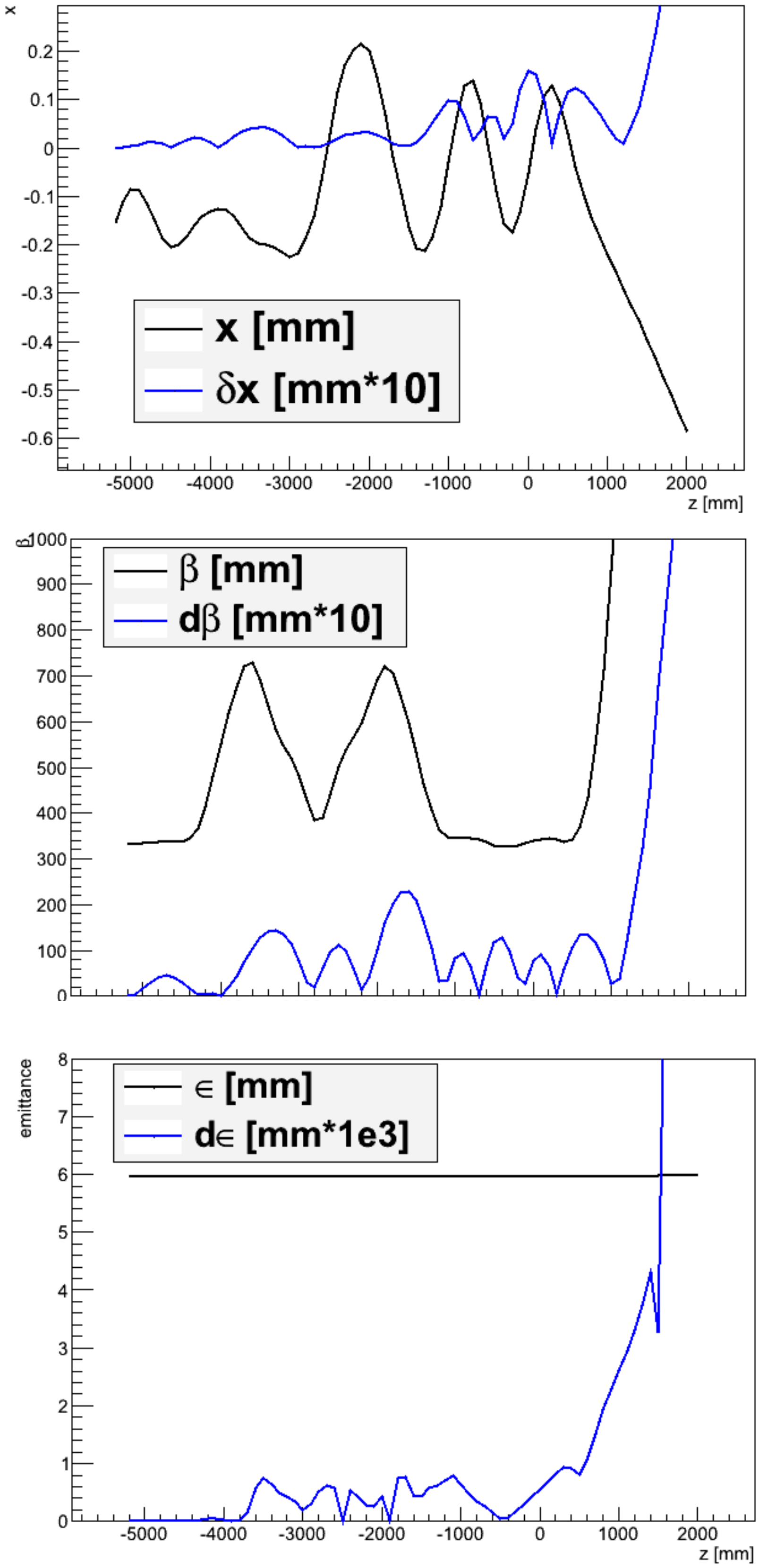

Figure 4: (Top) Mean x (Middle) optical beta function (Bottom) emittance value and residuals as a function of z [mm].

Beam Simulation

A beam of 100,000 muons was passed through the simulation. The beam was chosen to be matched to a field of -4 T with initial emittance of 6 mm, with all particles having initially 199.78 MeV/c (corresponding to a reference energy of 226 MeV). The beam was inserted at the midpoint of the upstream spectrometer solenoid, z=-5201.05 mm. The same random seed was used to generate beams for both simulations.

The discrepancy between beam mean position by the downstream spectrometer is of order 100 microns. The discrepancy between beta functions is roughly 10 mm and the discrepancy between emittance is about 1 micron.

Analysis

By way of analysis we should recall the nominal resolution of the experiment:

- 400 micron position
- 2 MeV/c transverse momentum
- 2 micron emittance (0.1% of the equilibrium emittance at 420 mm)

Additionally we should recall the alignment tolerance of the magnets is 1 mm/1 mrad.

Misalignments discussed above are significantly smaller than the measurement resolutions and tolerances. The only significant discrepancy is in beta function. Recall the standard equation for equilibrium emittance in an ionisation cooling channel,

$$\epsilon_n(equilibrium) = \frac{1}{2m}\frac{13.6^2}{L_R}\frac{\beta_\perp}{\beta_{rel} < \frac{dE}{dz} >}$$

The iron introduces a discrepancy of around 2 % in transverse beta function at the absorber, which we might expect to introduce a roughly 2 % discrepancy in equilibrium emittance. This should be measurable.

Conclusions

We conclude

- The magnetic shielding as arranged above has a barely measurable effect on the beam travelling through MICE
- The main effect is to introduce a slight misfocus to the beam, introducing a slight change in the cooling power of the channel.
- We note that this misalignment is considerably smaller than the effect of the iron shielding walls as studied in MICE note 244. Indeed, the shielding described above probably serves to protect the beamline from the effect of the shielding walls and so probably has an improved effect.
- There is no reason, from a beam dynamics perspective, not to implement a shielding wall as described herein.