BENT SOLENOID TUNING SIMULATIONS FOR THE COMET BEAMLINE.*

A. Kurup, Imperial College London, UK / FNAL, Batavia, USA

Abstract

The COMET experiment beamline uses bent superconducting solenoids for the muon transport and the spectrometer used to analyse the decay electrons from stopped muons. The bent solenoid includes not just a solenoid field but also a vertical dipole field. It is therefore important to have the ability to tune the field distribution. However, since the field distribution is mainly determined by the geometry it is difficult to adjust once the solenoids have been constructed. A cost effective method to provide tuning capability of the field distribution of the bent solenoids is proposed and the results of simulations presented.

INTRODUCTION

The COMET [1] experiment aims to investigate COherent Muon to Electron Transitions by nuclear capture. This requires having a very precisely controlled muon momentum spectrum on a target that will stop the muons and the electron momentum spectrum produced by coherent $\mu \rightarrow e$ transitions needs to be accurately measured. The COMET experiment utilises bent solenoids for the muon transport and the electron spectrometer. However, helical trajectories in a curved solenoid drift in the vertical direction. In order to compensate for this vertical drift an additional dipole field in the vertical direction is applied. In the COMET design this is done in a cost effective way by tilting the solenoids. The downside to using this method is that the relative magnitude of the vertical dipole field component is given by the geometry, which is fixed after the solenoid has been manufactured. It may be necessary to tune the magnitude of the vertical dipole component after manufacture to correct for manufacturing tolerances and thermal contraction due to cooling the magnets to superconducting operating temperatures.

This paper investigates the possibility of having some control over the vertical dipole component by powering alternate solenoids with a different current. The simulations presented aim to demonstrate whether this method could provide the ability to control the momentum distribution, vertical dispersion and composition of the beam at the stopping target. For these simulations, only the muon transport has been considered and only the simple scenario where all solenoids in the bent transport channel have identical geometries and only two different power supplies are used.

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G4BEAMLINE FIELD DISTRIBUTION

Initial simulations were done using G4Beamline [2] by taking the existing baseline design of the COMET beamline. The geometry was altered to include the tilt of the solenoids but all other parameters were kept the same. Figure 1 shows the model that was simulated and Figure 2 shows the tilt of the solenoids, which is $1.43°$.

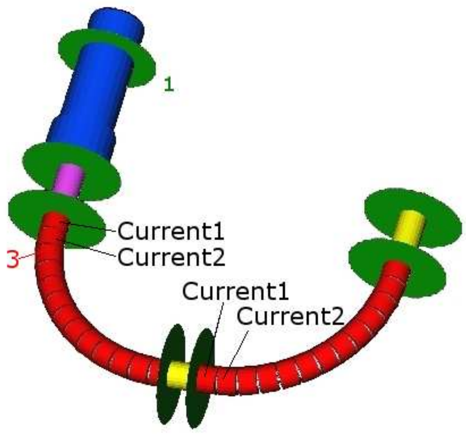

Figure 1: G4Beamline model of the muon transport channel. The blue solenoids are the pion capture channel, the red solenoids are the bent, tilted solenoids for pion decay and muon transport and the final yellow solenoids end just before the stopping target. The virtual detector (green circle) labelled 1 shows the position of the pion production target. Alternate solenoids in the transport channel (in red) were powered with a different current. Field measurements were made at the centre of the solenoid labelled 3.

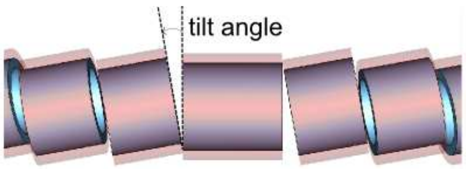

Figure 2: Drawing of the bent, tilted muon transport channel of the COMET beamline showing the tilt used to produced the vertical dipole field. The tilt angle shown here is exaggerated as the angle used in the simulations is $1.43°$.

All the solenoids in the G4Beamline simulations are ideal solenoids composed of infinitely-thin current sheets. Four different scenarios for powering the bent, tilted solenoids were investigated, see Table 1.

Figure 3 shows the B_x, B_y and B_z field components at

Table 1: Values for Current1 and Current2 used in the simulations. Current1 was applied to every other solenoid starting with the first one and Current2 was applied to the other solenoids, see Figure 1.

	Current1 (A)	Current2 (A)
1	631890	631890
2	758268	758268
3	631890	1263780
4	631890	315945

the centre of the third solenoid (labelled 3 in Figure 1) for the different powering schemes. The z direction is parallel to the axis of each solenoid and the x axis is in the plane of the bend. As can be seen, by supplying alternate solenoids with a different current it is possible to adjust, to some extent, the vertical dipole component (i.e. B_y) independently.

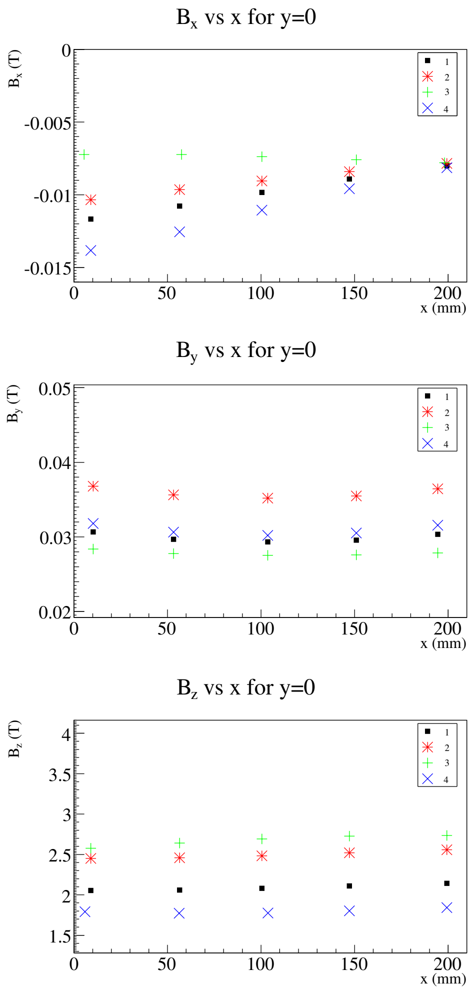

Figure 3: Results of the G4Beamline simulation. The plots show the B_x,B_y and B_z components as a function of x for the different powering schemes described in Table 1.

EM STUDIO FIELD DISTRIBUTION

To obtain a more accurate field distribution of the beamline, a 3-D magnetostatic simulation using EM Studio [3] was done. The geometry was kept the same as in the G4Beamline simulations. Preliminary designs of the superconducting solenoids have a non-magnetic steel wall inside the coils and an iron yoke outside. To obtain a comparison with the G4Bemaline model the iron yoke was not considered and the permeability of the steel was set to 1.

Figure 4 shows the B_x, B_y and B_z field distributions, for the same location as in the G4Beamline simulation, for the same four current scenarios listed in Table 1. The

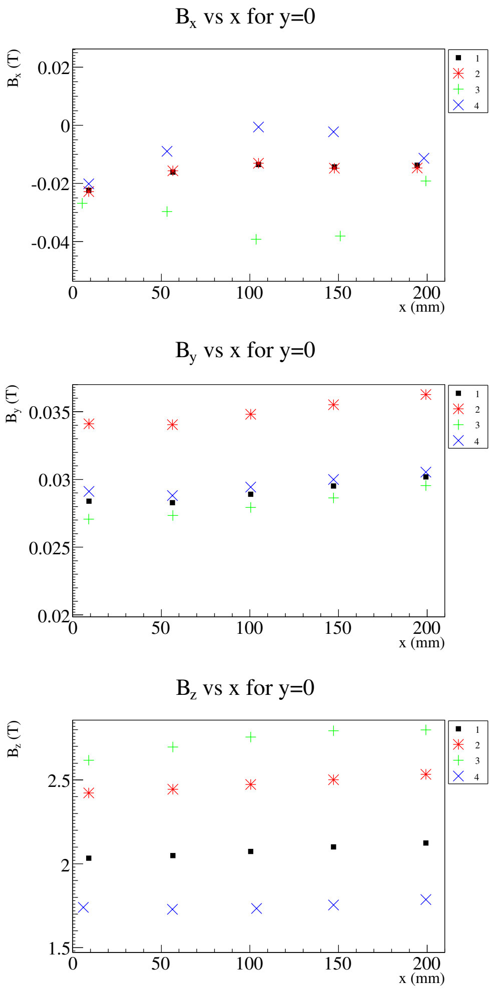

Figure 4: Results of the EM Studio simulation. The plots show the B_x,B_y and B_z components as a function of x for the different powering schemes described in Table 1.

B_y and B_z components show good agreement with the G4Beamline simulation but the B_x component shows significant differences, though the absolute magnitude of the differences are small. This is likely due to the way in which fringe fields are considered in G4Beamline. However, the fact that the B_x component in the EM Studio simulations does not follow the same trend as in the G4Beamline simulations will complicate tuning the beam transported by the channel.

PARTICLE TRACKING

To understand the effect of altering the field in the solenoids, some preliminary tracking studies have been done using the G4Beamline model of the muon transport channel. Initially, a simple muon beam was tracked through 90° of the bent solenoid. The input beam contained on-axis, parallel muons with a momentum range of 10–150 MeV/c. Figure 5 shows the momentum distribution as a function of the vertical position after the muons were tracked through half of the bent solenoid. This figure shows that it is possible to affect the vertical dispersion produced by the transport channel by powering alternate solenoids with a different current.

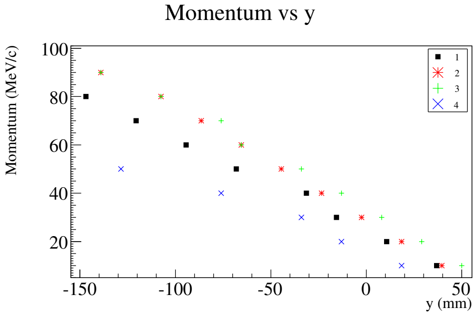

Figure 5: Momentum as a function of vertical position for an on-axis,parallel muon beam with a momentum range of 10–150 MeV.

Since the COMET experiment requires a very low background rate it is important to track particles using a realistic beam to determine to composition of the beam at the stopping target. An input beam produced by a MARS [4] simulation of 8 GeV/c protons on a graphite target was tracked through the whole G4Beamline model. Figure 6 shows the momentum distribution of muons and Table 2 shows the composition of the beam at the stopping target for the different current scenarios.

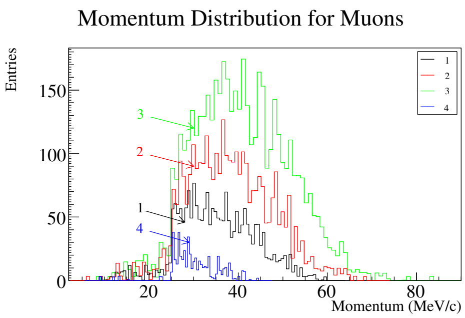

Figure 6: Momentum distribution of muons at the end of the muon transport channel for the different scenarios.

Table 2: Fractional beam composition at the stopping target for the four different scenarios.

	μ^-	μ^+	e^-	e^+	π^-	π^+	p^+
1	0.89	0.02	0.055	0.030	0	0	0.0024
2	0.89	0.011	0.072	0.029	0	0	0.001
3	0.91	0.014	0.063	0.009	0	0	0.0006
4	0.96	0.027	0	0	0.018	0	0

Although it is possible to affect the momentum distribution of muons at the stopping target by powering alternate solenoids with a different current, the change in the muon yield is quite significant. This may be detrimental if tuning the solenoid requires reducing the current.

CONCLUSIONS

By powering alternate solenoids with a different power supply it is possible to independently control the vertical dipole component of the bent, tilted solenoids. The simulations using EM Studio show deviations of the B_x component compared to the G4Beamline solenoid model. To make the model more accurate it will be necessary to include the iron yoke. The effect of this on the transport of particles will need to be investigated. Thus, tracking with a field map from the EM Studio simulations is essential.

It is also important to study the mechanical forces applied to the support structure of the solenoid as having significantly different currents in adjacent solenoids may put significant additional stress on the support structure.

As the next step, it will be useful to study the effect of thermal contraction on an optimised version of the muon transport channel, tuning of the momentum spectrum to obtain the best yield and apply this method to the electron spectrometer to allow tuning of the momentum selection.

REFERENCES

[1] The COMET Collaboration, “An Experimental Search for Lepton Flavor Violating $\mu^- \rightarrow e^-$ Conversion at Sensitivity of 10^{-16} with a Slow-Extracted Bunched Proton Beam”, http://j-parc.jp/NuclPart/pac_0801/pdf/Kuno.pdf

[2] Thomas J. Roberts $et al.$,”G4beamline Particle Tracking in Matter-Dominated Beam Lines”, EPAC’08, Genoa (2008), p. 2776.

[3] Computer Simulation Technology (CST) Electro-magnetic Studio, http://www.cst.com/Content/Products/EMS/Overview.aspx

[4] N.V. Mokhov, S.I. Striganov, “MARS15 Overview”, AIP Conf. Proc. **896** (2007), p. 50.