MAGNET ALIGNMENT REVISITED

Subject arose at last CM; some confusion

I have revisited this

Chris Rogers searched the literature:

Four previous studies in MICE notes 64, 77, 202, 229

Some confusion about alignment of trackers and / or spectrometer solenoids

Alignment of the trackers *cannot* affect the emittance of the beam
- **but can (obviously) affect the measurement of it**
- **must be known well enough**

Alignment of S/C magnets can affect:

a) Performance of channel (emittance reduction)
b) Alignment studies & commissioning studies

Previous studies concentrated on (a); I concentrate on (b)

Work almost complete, MICE note 3 / 4 written

PHYSICS OVERVIEW

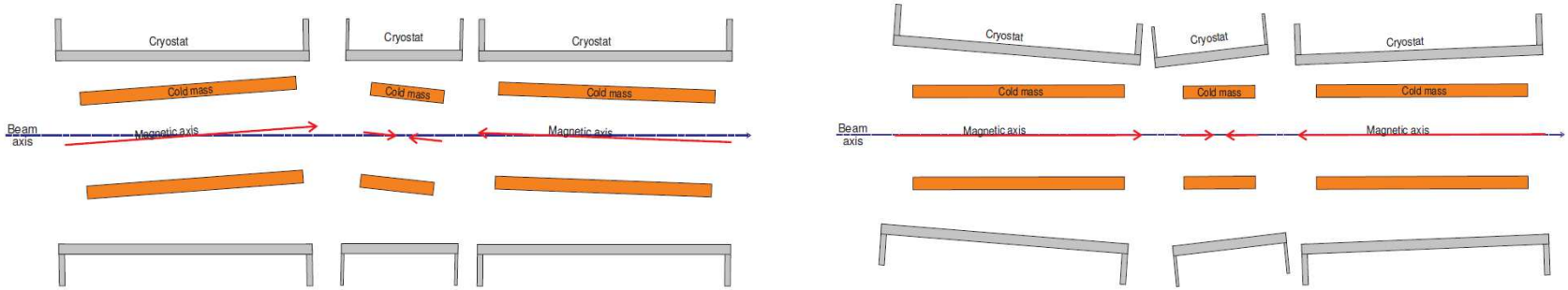


Figure 1: Misaligned modules in Step IV, much exaggerated.

Undesirable **Desirable**

Modules whose magnetic axes are offset & tilted wrt beam axis will give *pt* kicks to muons

Small kicks will move CoG of beam but will not change its emittance : CoG in *x, px,* &c are subtrcated

Movement of CoG of beam, especially if momentum dependent, will make alignment & commissioning v. difficult to understand.

PREVIOUS STUDIES

MICE note	Tilt ψ (mr)	Offset d (mm)	Criterion	Comment
64	< 2.4	< 1.8	Reduce 15% $\Delta\epsilon/\epsilon$ to 14%	MC study; tolerances deduced from offsetting only one coil of one FC in Step VI
77	< 6.0 (rms)	3.0 (rms)	$< 0.1\%$ systematic increase in emittance	Extensive MC study of Step VI with random offsets and tilts of coils
202	< 10	< 2	'$< 1\%$ of 10%'	MC study of Step VI; beam started in centre of upstream SS ($z = -4.7$ m) (ψ deduced as $\langle p_t \rangle / p_z = 2/200 = 0.01$)
229	< 1	< 3	1% error on $\Delta\epsilon/\epsilon$	MC study; refers to *tracker* alignment; fields not shifted (?)

Table 1: Summary of previous alignment studies. In all cases the beam was started inside the upstream spectrometer solenoid.

In all cases simulated beam started at ~ mid point of SSU

None considered what happens to a reference muon entering from outside

The alignment tolerance was derived as "2mm – 2 mr" from dEps/Eps

EXPLORE WHAT HAPPENS TO REF. MUON

Simple tracking code in magnetic field

3D field model based on Bz on axis
- **gives error fields due to tilted & offset coil**
- **more than adequate for small tilts and paraxial muons**
- **details in MICE note**

Fast to run so I can play with it & get feedback

➔ **Plenty of sanity checks**

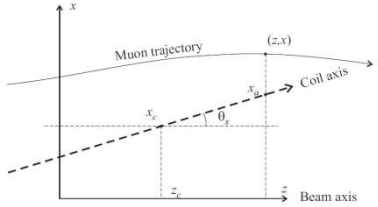


Figure 18: Geometry used for field calculation. Angles and offsets are small. z is the beam axis, θ_x is a small rotation around the y axis.

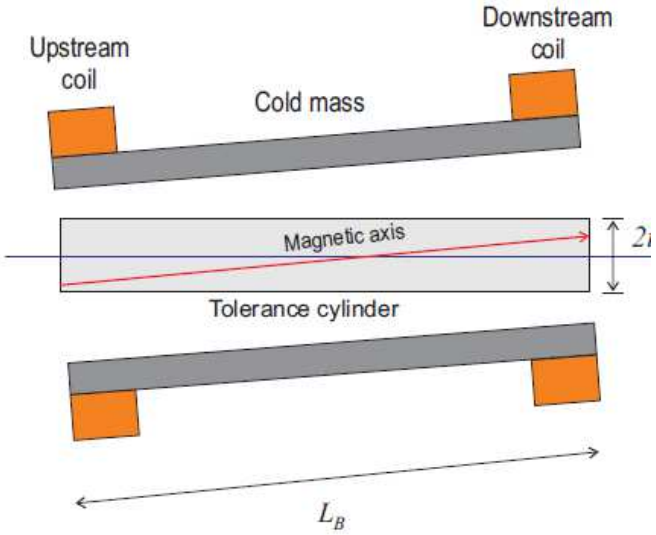
The coils are divided radially into coaxial cylindrical current sheets; all current sheets in a coil have the same tilts and offsets in x and y. In the beamline system the centre of a coil is at (x_c, y_c, z_c) where x_c and y_c are small offsets from zero. The x component of the magnetic field experienced by a muon at (x, y, z) is

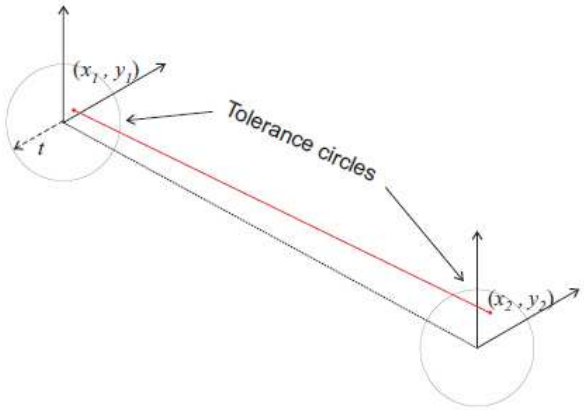
$$B_x = \sum_{\text{sheets}} \left(B_z \theta_x - \frac{(x - x_a)}{2} \frac{\partial B_z}{\partial z} \right)$$

where θ_x is a small rotation around the y axis in the $x - z$ plane and $x_a = x_c + (z - z_c)\theta_x$ is the x coordinate of the axis of the coil at z; the geometry is sketched in figure 18.

B_z is the z component of the field on the axis of a current sheet. The sum is taken over all sheets in all coils. The first term in the expression for B_x is simply the component of the axial field of the sheet resolved in the x direction; the second follows from $\nabla \cdot \mathbf{B} = 0$.

Tolerance Definition





"*x* mm – *y* mr" definition per coil hard to interpret for coils on common bobbin

Practical definition – easy to use / give to surveyors:

Bobbin axis must lie within a *t* mm radius cylinder of beam axis

➔ Translates to circles at ends of modules (flange faces)

Following studies use bobbins rather than individual coils

All for STEP VI 200 MeV/*c* Flip mode, empty channel

***Aligned but offset channel*:**

All magnetic axes parallel but offset from beam axis by 2 mm in *x*

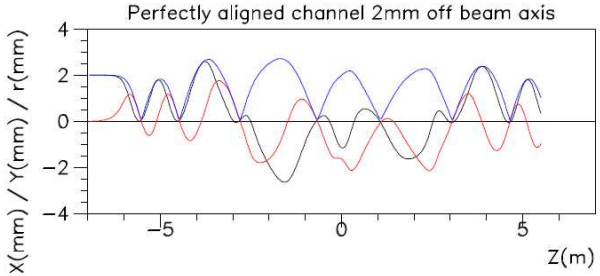
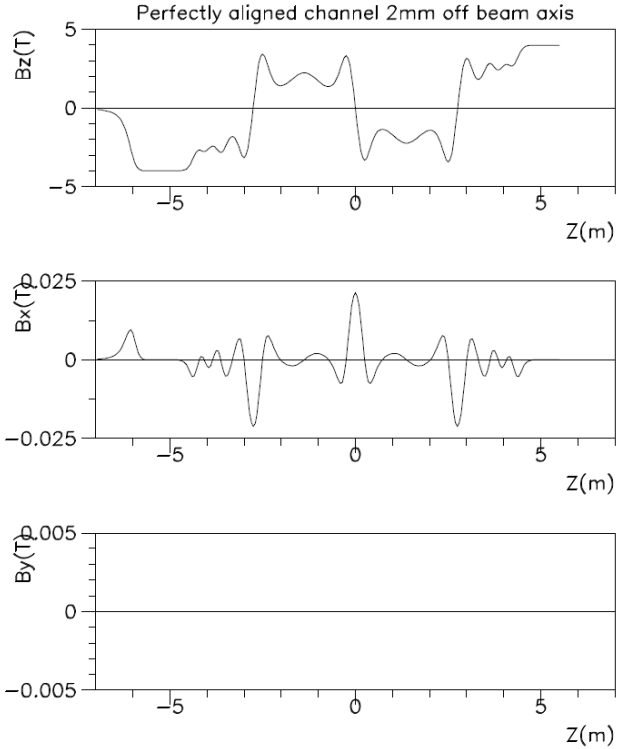
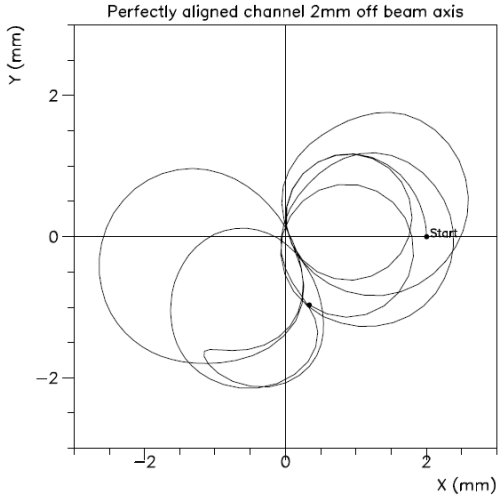


Figure 4: Trajectory of a 200 MeV/c reference muon, x-z (black), y-z (red) and r (blue), for channel axis offset by 2 mm in x.



200 MeV/*c*



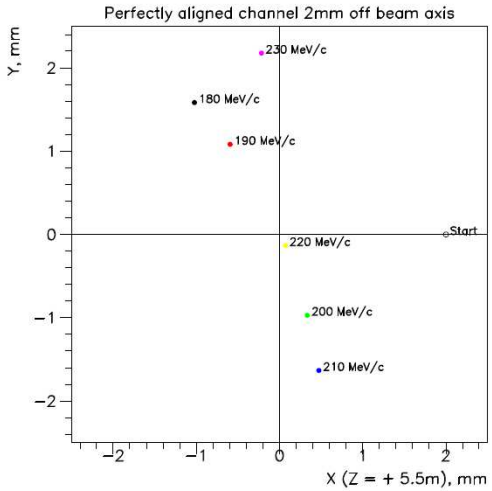
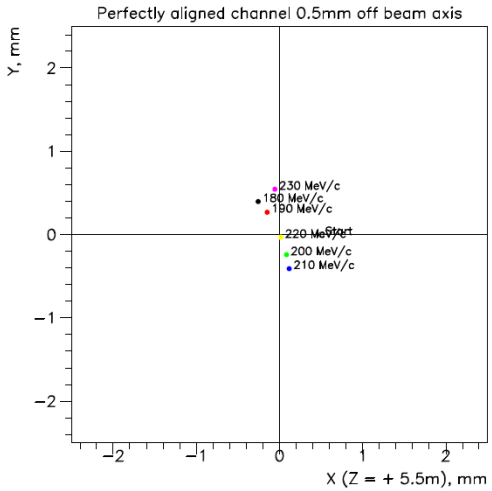


Figure 6: x - y with respect to magnetic axis at $z = 5.5\,\mathrm{m}$ of reference muons of different momenta for channel axis offset by 2 mm in x.



There is dispersion (expected)

Starting position (z = -7.0 m) is (2,0)

At z = 5.5 m (~ centre SSD) position varies with pz within ~ 2mm radius ➔ "4mm problem"

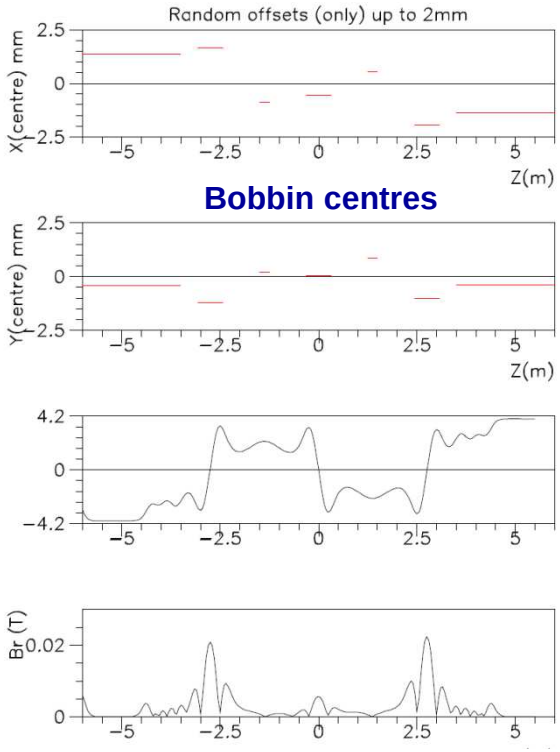
With 0.5 mm common offset problem becomes 1 mm

Not at all unexpected after a few moments thought.

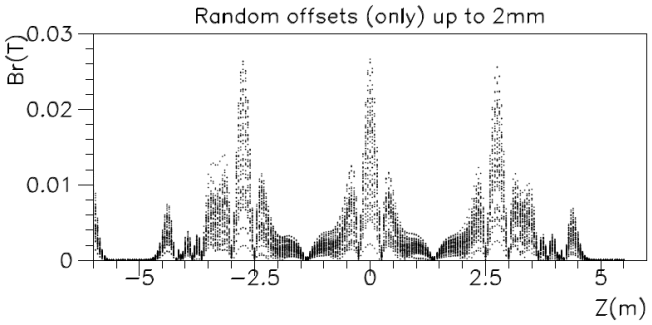
➔ 2 mm is too much

Random offsets, no tilts

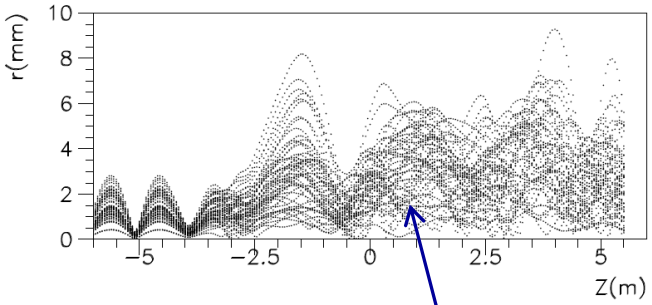
Shift bobbins randomly within *t* = 2mm cylinders, no tilt



Bobbin centres



Radial B



Radius (mm)

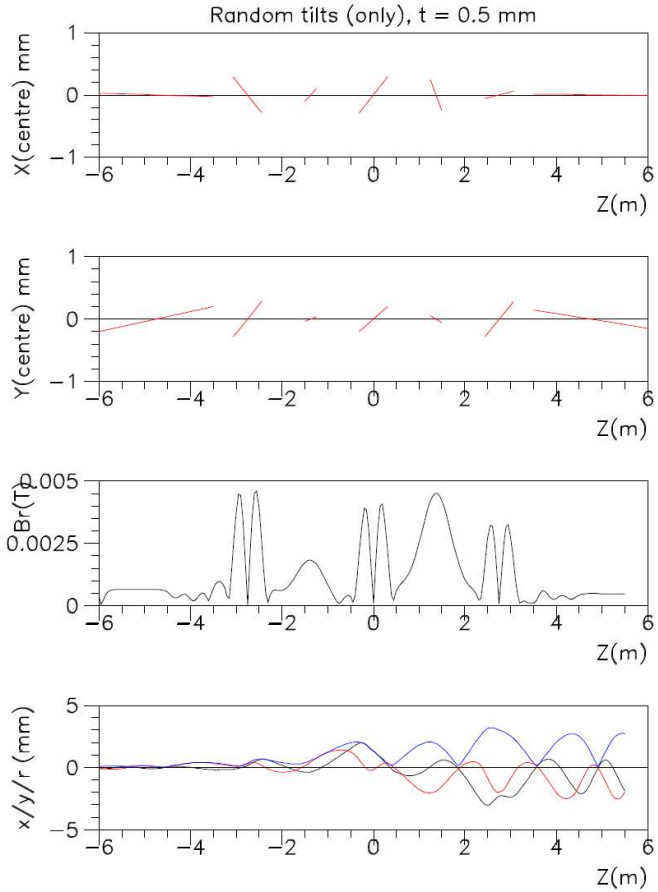
Too much

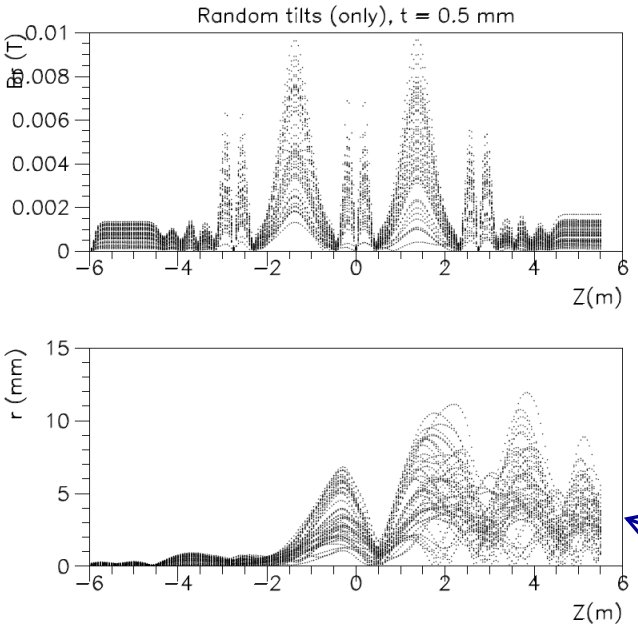
One **set of offsets**

Reference trajectories for 50 random sets of offsets

Reducing *t* 0.5 mm reduces spread by ~ 4

Random tilts, *no* offsets, *t* = 0.5 mm





Radial B

Radius (mm)

Too much

One **set of tilts**

Reference trajectories for 50 random sets of tilts

TODAY'S CONCLUSION

Misalignment (tilt) of CC is big problem

Probably have to align axis of CC bobbin to < 0.15mm at each end

Looking like ~ 0.5 mm OK for FCs and SSs

Work in progress

Will be finished & documented in a few days