Current tolerances

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Current Tolerances

- Seek to understand what are the tolerances to current variations in MICE cooling channel magnets
- Seek to consider three tolerance parameters
  - Change in optical beta function vs coil current
  - Change in particle projection as a function of coil current
  - Field uniformity in the tracker as a function of coil current
- Thinking about
  - Changes run-by-run
  - Changes during a single run (power supply fluctuations)
- Other considerations
  - I assume ideal cylindrical block conductors
  - No iron, no hysteresis, no misalignment
  - No concept of solenoid time constant (L/R)

Settings

- Geometry as per note 464
- No material, magnets only
- Solenoid mode – tolerance may be different in flip mode
  - Match1 current = 248.39
  - Match2 current = 231.75
  - Focus current = 107.80
  - End1 current = 234.0
  - Centre current = 274.0
  - End2 current = 253.0
- I treat FC coils with one parameter
- I treat SS coils with one parameter each (incl. End coils)

Optics tolerance requirement

- Require change in emittance < 1 %
- Recall the emittance change formula

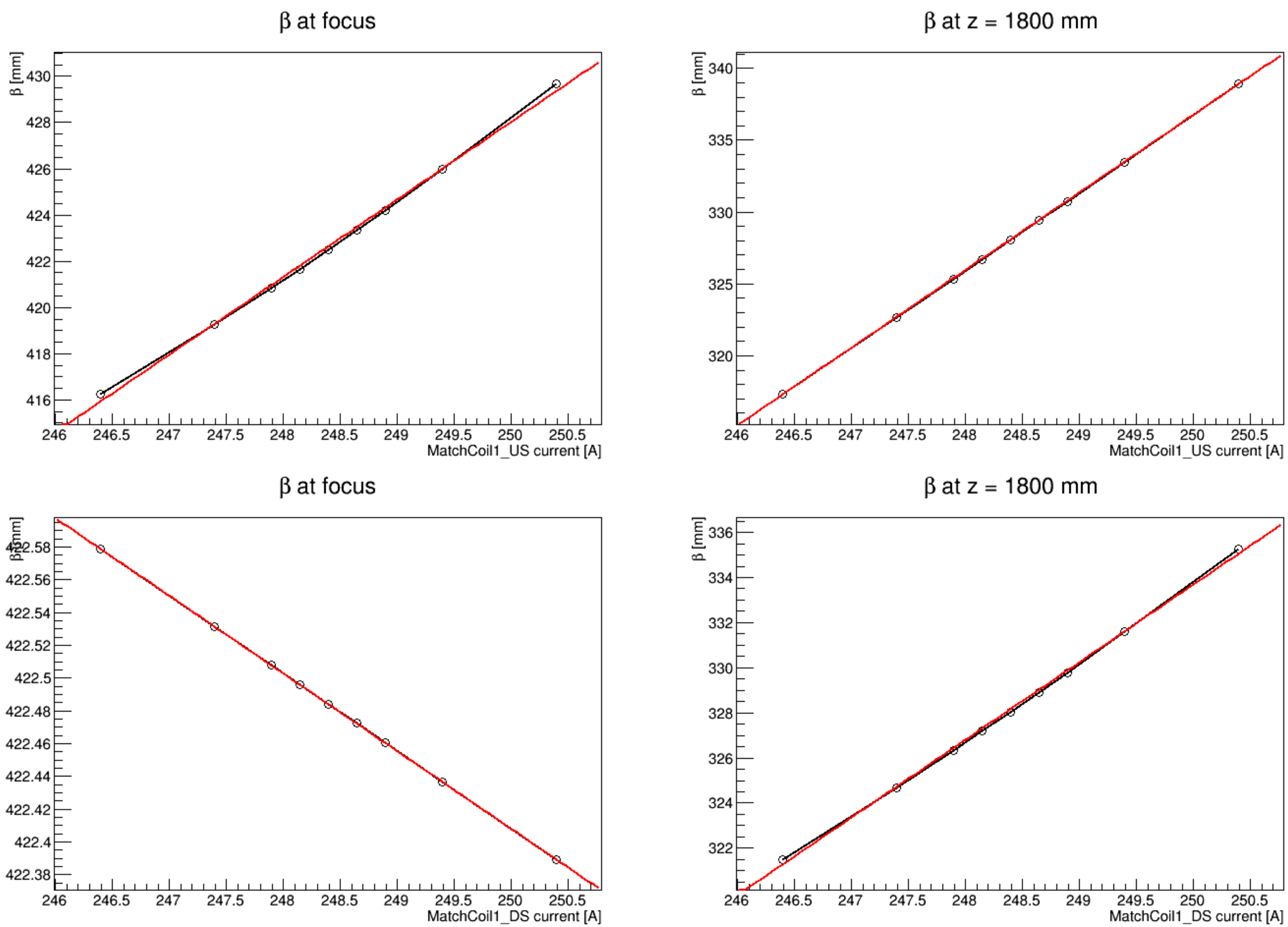
$$\frac{d\epsilon_n}{dz} \approx \frac{1}{E}\left\langle\frac{dE}{dz}\right\rangle \epsilon_n + \frac{1}{2m}\frac{13.6^2}{L_R}\frac{\beta_\perp}{\beta_{rel}^3 E}.$$

- Equilibrium emittance formula

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

- If we want emittance at 1 % level, require beta stable at 1 % level (0.1 % level?) at the absorber
- In linear approx, stability of downstream coils does not affect cooling
- But it is probably sensible to keep an eye on them
- Consider stability of beta at TKD also at 1 % / 0.1 % level

E.g. Match1 Tolerance

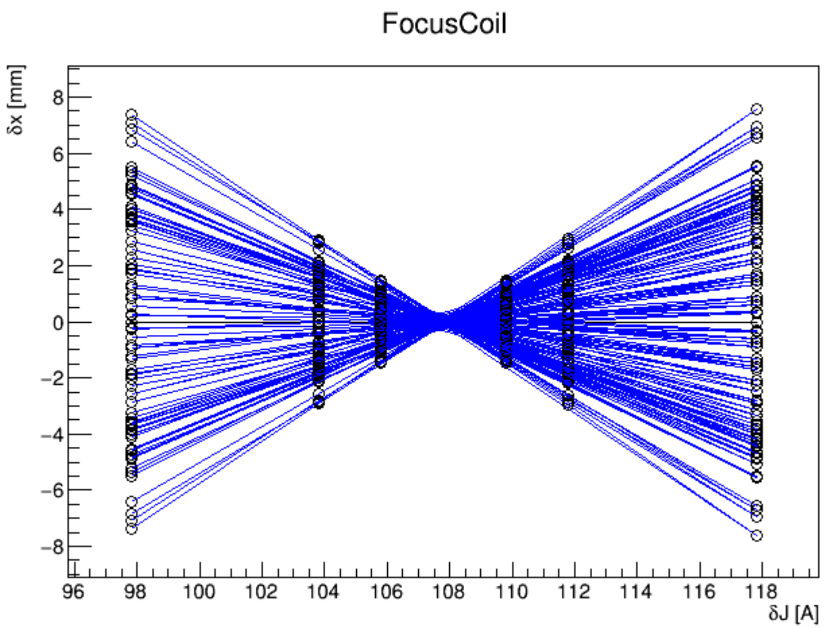


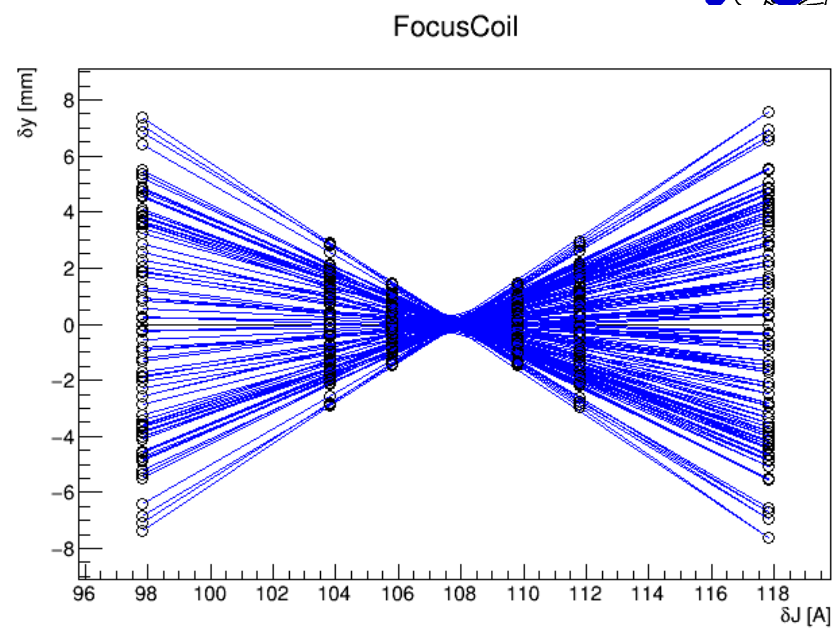
Summary – beta vs coil current

Beta at FC | Beta at TKD

Name	dβ/dI (FC) [mm/A]	I(1%) [A]	I(0.1%) [A]	dβ/dI (TKD) [mm/A]	I(1%) [A]	I(0.1%) [A]
EndCoil2_US	0.006	720.942	72.094	0.009	489.942	48.994
CenterCoil_US	-0.769	-5.495	-0.549	0.291	14.496	1.45
EndCoil1_US	-0.591	-7.148	-0.715	-0.503	-8.402	-0.84
MatchCoil2_US	3.005	1.406	0.141	0.59	7.161	0.716
MatchCoil1_US	3.357	1.259	0.126	5.399	0.783	0.078
FocusCoil	-8.541	-0.495	-0.049	-5.77	-0.732	-0.073
MatchCoil1_DS	-0.047	-89.125	-8.913	3.443	1.227	0.123
MatchCoil2_DS	-0.008	-507.857	-50.786	-1.095	-3.858	-0.386
EndCoil1_DS	-0.009	-493.211	-49.321	-1.468	-2.878	-0.288
CenterCoil_DS	-0.005	-917.996	-91.8	-0.698	-6.05	-0.605
EndCoil2_DS	0	23679607	2367960.68	-0.008	-509.759	-50.976

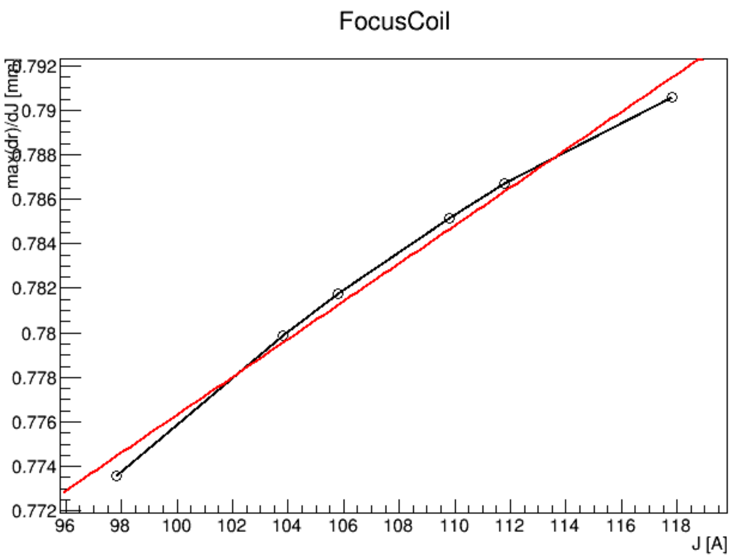
Stability of Particle Trajectory

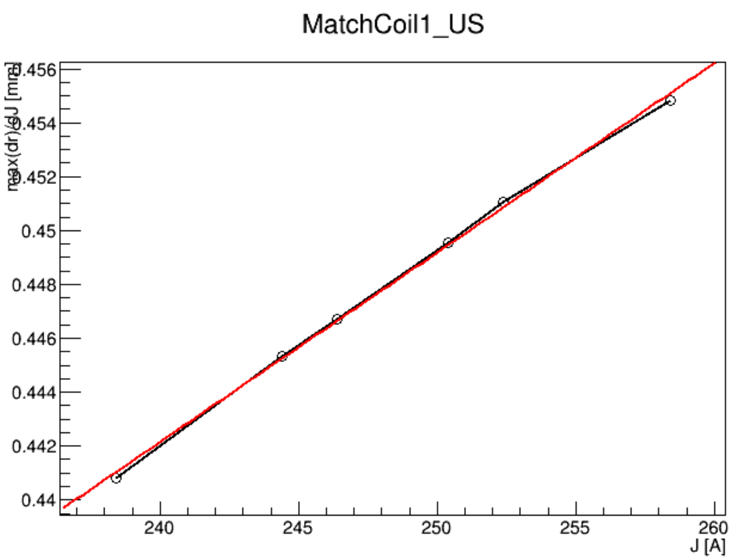




- Require stability in measured particle trajectory
  - Say, trajectory should not move by more than 1 sigma due to current variations
  - This is already generous...
  - For canonical 24 mm shell of particles

Stability of Particle Trajectory





Coil	**J(dr=0.661 mm) [A]**
EndCoil2_US	309.06
CenterCoil_US	4.18
EndCoil1_US	3.15
MatchCoil2_US	3.52
MatchCoil1_US	1.48
FocusCoil	0.84
MatchCoil1_DS	1.04
MatchCoil2_DS	1.74
EndCoil1_DS	3.38
CenterCoil_DS	5.77
EndCoil2_DS	209.83

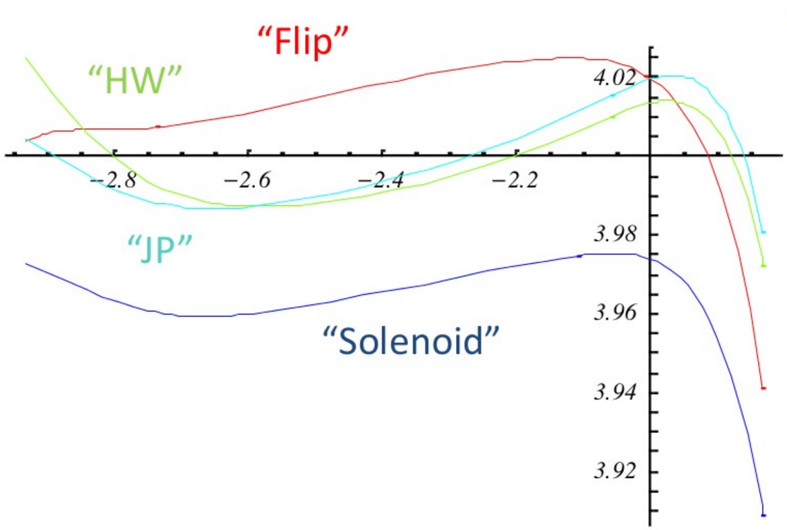
Field deviations

- Require field quality should not degrade too much
  - Calculate $dB_z/B_z = abs(B_z - <B_z(reference)>)/<B_z(reference)>$
  - Where $<B_z(reference)>$ is the mean B field on axis with nominal currents
  - Look at maximum value of dB_z/B_z
  - Look at mean value of dB_z/B_z
  - Mean of B_z calculated by sum of 1 mm z-steps across the tracker volume
  - Look at worst case of upstream or downstream for each coil
- Consider “Solenoid” mode and “JP” mode

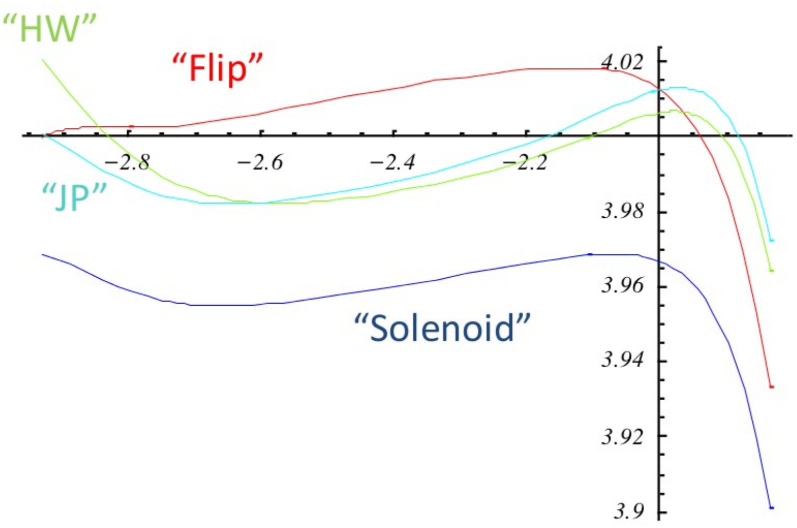
Imperial College London

SS fields at Step IV in tracking volume (SSU)

Solenoid mode



Flip mode

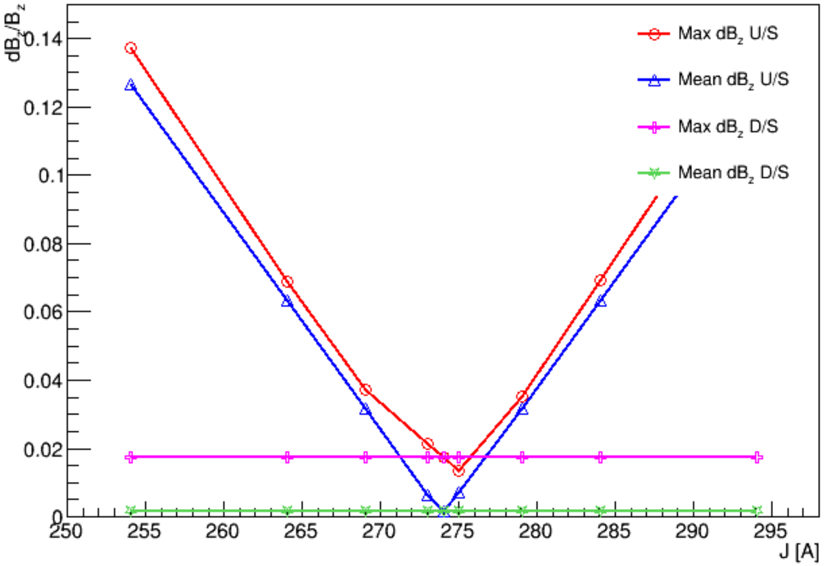


- Setting corresponds to 200 MeV/c symmetric solenoid
- ...Then I just flip the polarity without changing |Js| (bit incorrect)
- The effect of field non-uniformity are being evaluated (C. Hunt).

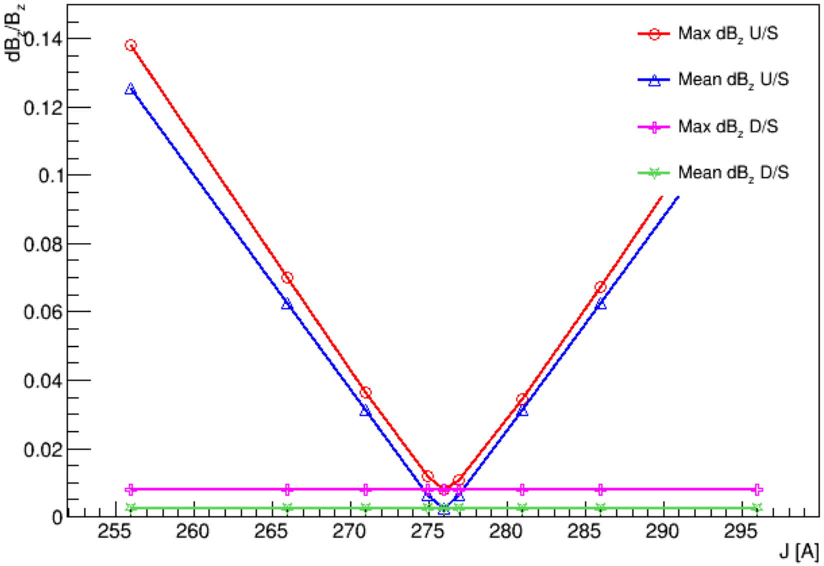
J Pasternak, CM42

E.g. Center Coil

“Solenoid” CenterCoil_US



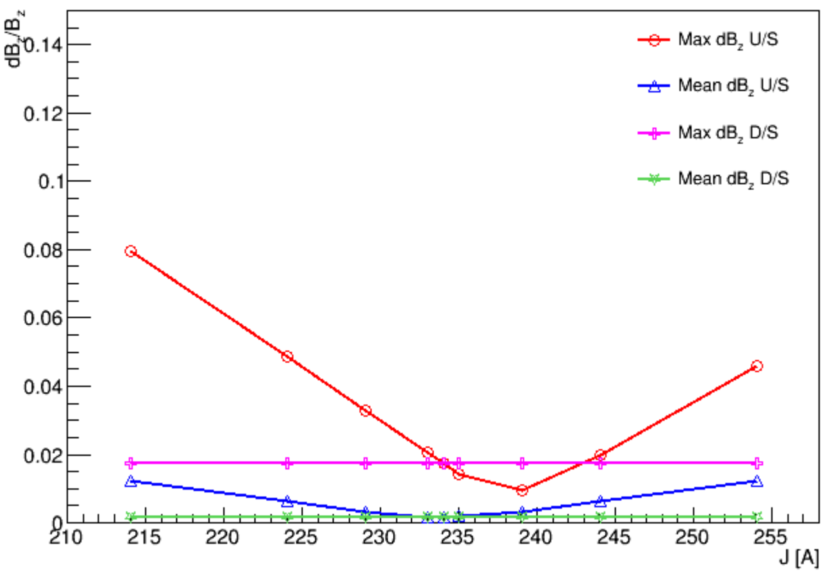
“JP” CenterCoil_US



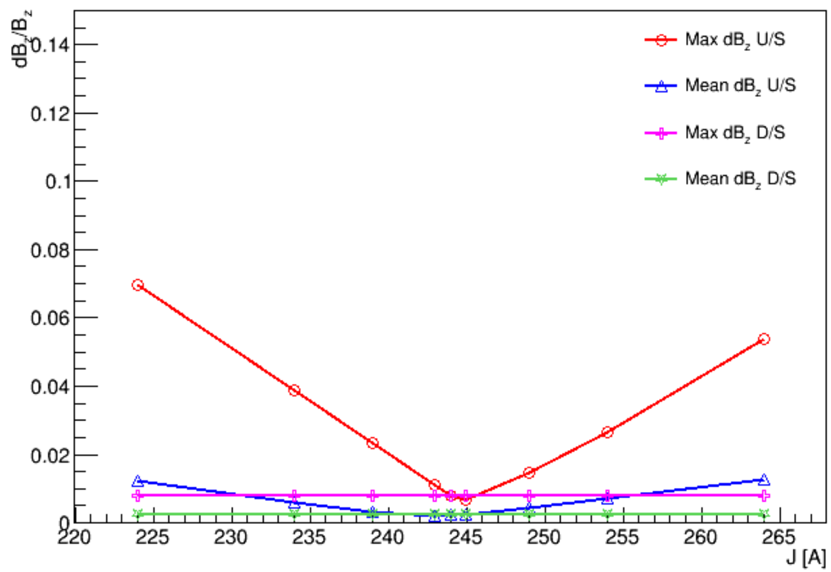
- For “Solenoid” mode, max value of dB_z is hidden by generally poor field quality
- “JP” mode looks much better
- Use worst case of Max dB_z U/S or D/S to define tolerances

E.g. End Coil

“Solenoid” EndCoil1_US



“JP” EndCoil1_US



- More obvious effect in end coil

Tolerances

Coil Name	Tolerance (dBz/Bz < 1%)	Tolerance (dBz/Bz < 0.1 %)
EndCoil2_US	16.19	10.62
CenterCoil_US	2.83	1.18
EndCoil1_US	8.22	1.32
MatchCoil2_US	20	7.55
MatchCoil1_US	20	18.05
FocusCoil	20	18.19
MatchCoil1_DS	20	18.03
MatchCoil2_DS	20	7.55
EndCoil1_DS	8.22	1.32
CenterCoil_DS	2.84	1.18
EndCoil2_DS	16.18	10.62

Tolerances in “Solenoid” mode

Coil Name	Tolerance (dBz/Bz < 1%)	Tolerance (dBz/Bz < 0.1 %)
EndCoil2_US	16.25	4.64
CenterCoil_US	2.66	0.38
EndCoil1_US	8.25	1.32
MatchCoil2_US	20	7.57
MatchCoil1_US	20	18.12
FocusCoil	20	18.27
MatchCoil1_DS	20	18.11
MatchCoil2_DS	20	7.57
EndCoil1_DS	8.25	1.32
CenterCoil_DS	2.66	0.39
EndCoil2_DS	16.24	5.62

Tolerances in “JP” mode

Current Tolerances - Summary

Name	1.00%	0.10%	Source
EndCoil2_US	16.2	4.64	Field quality
CenterCoil_US	2.66	0.38	Field quality
EndCoil1_US	7.15	0.715	optics
MatchCoil2_US	1.406	0.141	optics
MatchCoil1_US	1.259	0.126	optics
FocusCoil	0.495	0.049	optics
MatchCoil1_DS	1.04	0.123	tracking/optics
MatchCoil2_DS	1.74	0.386	tracking/optics
EndCoil1_DS	2.878	0.288	optics
CenterCoil_DS	2.66	0.38	Field quality
EndCoil2_DS	16.24	5.62	Field quality

- Summarised in MICE Note 474