Magnetic measurement on PSB dipoles

MAIN and INJECTION type

(PSB Upgrade - LIU Project)

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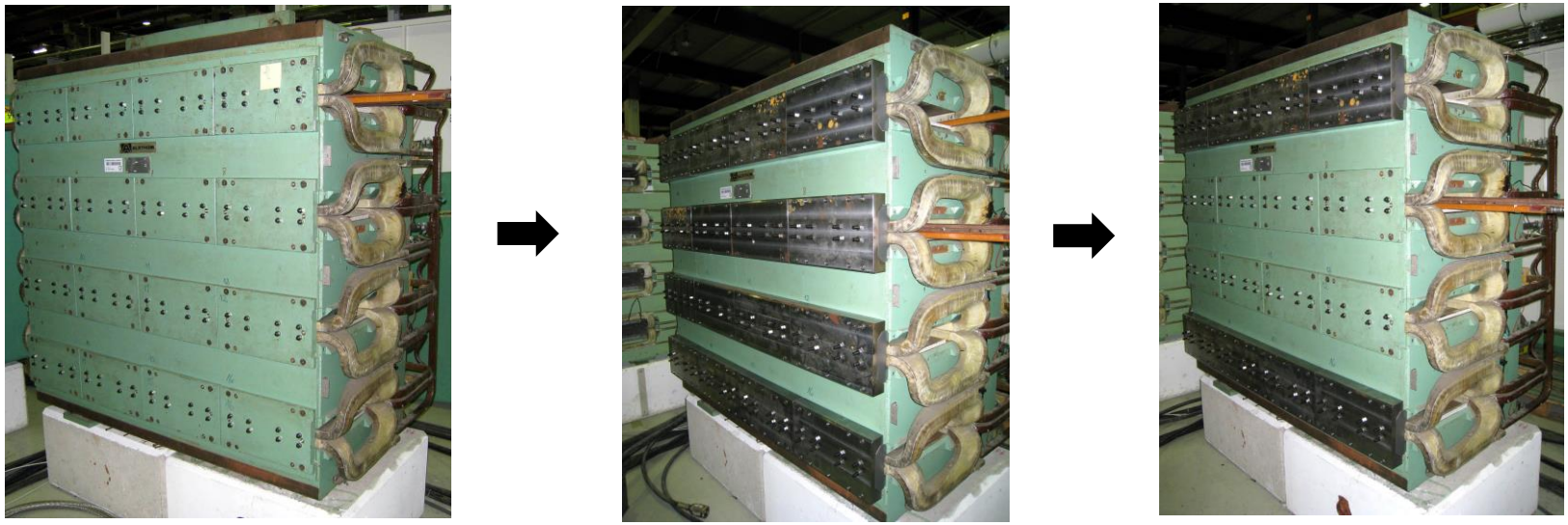
1 – Measurements on a PSB MAIN dipole

Measurements setup

- Two 6000 A power converters: one for inner apertures, one for outer apertures
- Integrated field measured in pulsed mode with 2.5 meters long coil + ADC acquisition
- Different side plates configurations for the MAIN dipole



Measurements

1 - Determining the currents for the two converters to achieve simultaneously the same integrated field level in both inner and outer gaps for 1.4 and 2.0 GeV with the original side plates.

Repeat the measurements with new side plates in order to quantify how much they reduce the difference between currents for inner and outer apertures → defining the requirements for the Q-trims

2 - Equivalent length of the four apertures with respect to the different side plates configurations

3 - Excitation curves up to 5500 A

4 - Eddy currents effects

Results for the integrated field balancing in all gaps for 1.4 and 2 GeV (1.40 and 1.824 Tm) with respect to the side plates configurations

Original side plates for all apertures	Equivalent current difference between inner and outer apertures
1.4 GeV	29 [A] - **0.71** [%]
2.0 GeV	188 [A] - **3.44** [%]
New side plates for all apertures	Equivalent current difference between inner and outer apertures
1.4 GeV	8 [A] - **0.20** [%]
2.0 GeV	74 [A] - **1.38** [%]
Original side plates for inner apertures **New side plates** for outer apertures	Equivalent current difference between inner and outer apertures
1.4 GeV	6 [A] - **0.15** [%]
2.0 GeV	67 [A] - **1.25** [%]

As new side plates decrease the saturations effects for all apertures, a third measurement was done with mixed plates only (new plates for outer apertures only), to reduce the difference in saturation.

→ Current difference decreased by almost a factor of 3 at 2 GeV with mixed plates

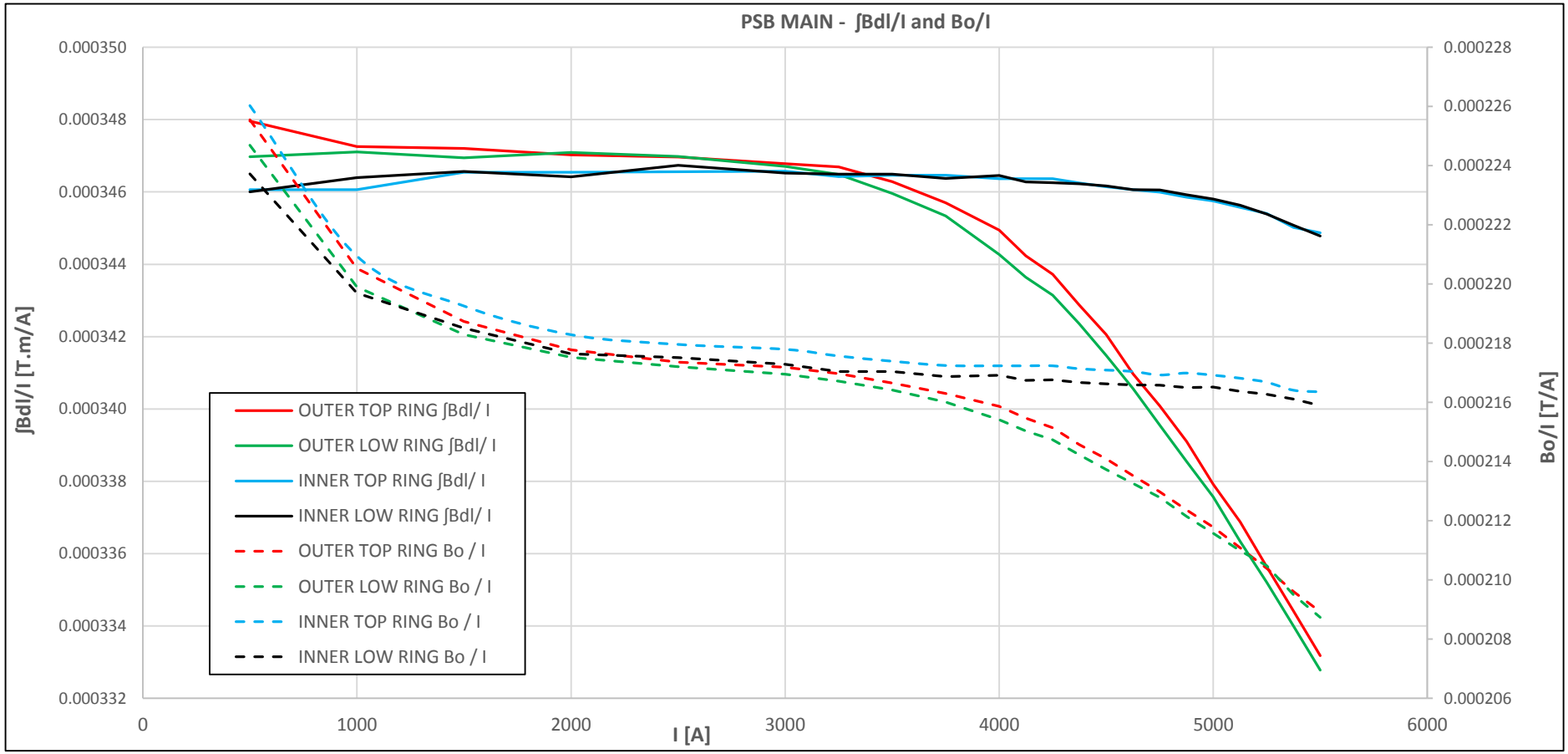
Magnetic lengths at 1.4 and 2 GeV with respect of the different side plates configuration:

The magnetic length is a parameter that concerns the extrapolation of field integral from central values, and as such is relevant only for B-train operation (more stable magnetic length -> more accurate measurement of the constant of integration with the NMR

	Aperture	**Original side plates**	**New side plates**	**Mixed side plates**
1.4 GeV	Outer top	1.597 [m]	1.602 [m]	1.600 [m]
	Inner top	1.597 [m]	1.600 [m]	1.598 [m]
	Inner bottom	1.597 [m]	1.600 [m]	1.598 [m]
	Outer bottom	1.597 [m]	1.602 [m]	1.601 [m]
2 GeV	Outer top	1.595 [m]	1.600 [m]	1.599 [m]
	Inner top	1.597 [m]	1.600 [m]	1.599 [m]
	Inner bottom	1.596 [m]	1.600 [m]	1.600 [m]
	Outer bottom	1.595 [m]	1.600 [m]	1.600 [m]

→ Slight increase of the equivalent length with the mixed side plates compare to original ones. Better balancing at 2 GeV and lower at 1.4 GeV concerning magnetic length

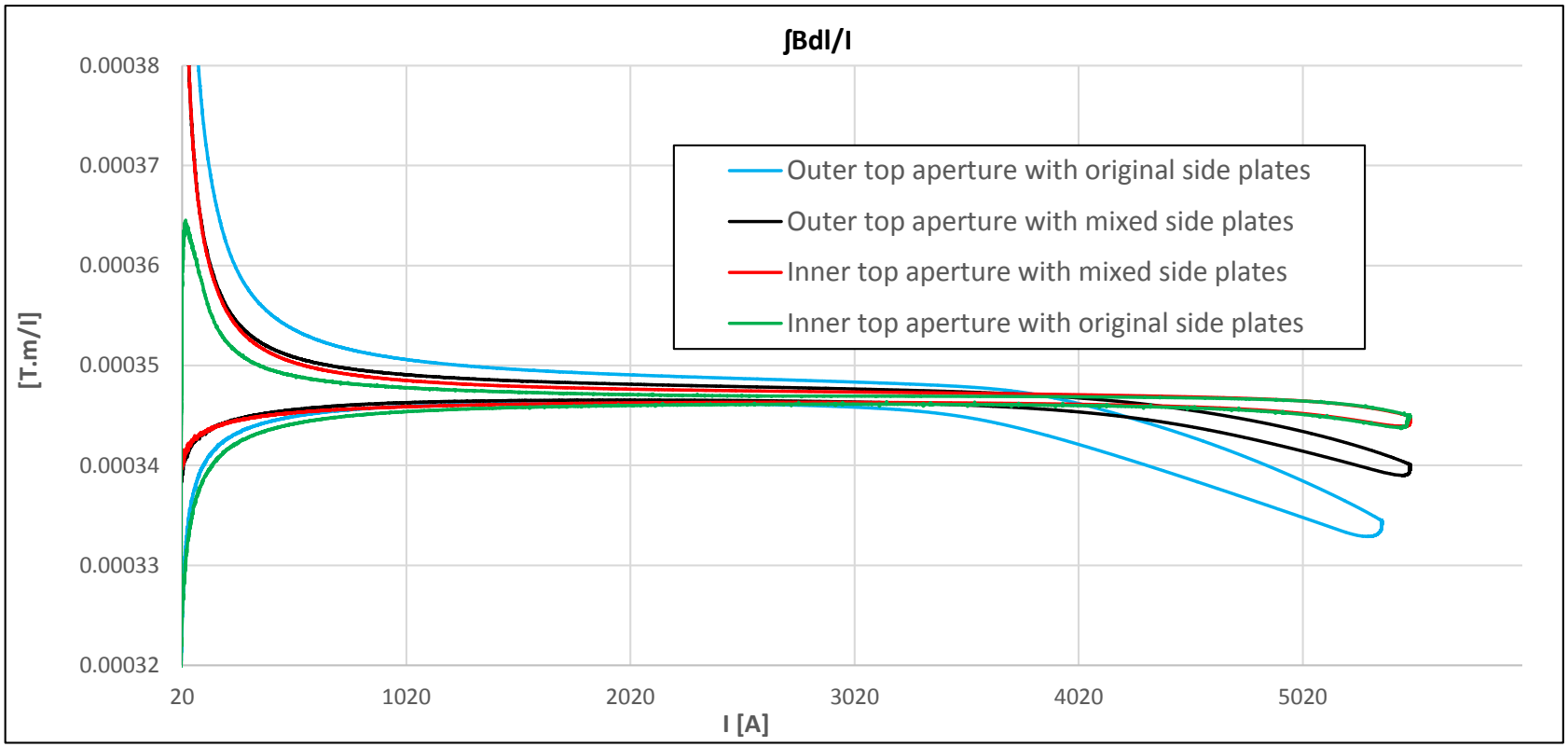
Excitation curves for integrated and center field with original side plates:



→ As expected, saturation is higher in outer apertures and in the integral

(due to the magnet ends being typically more saturated due to end effects)

Dynamic excitation curves with original plates and mixed side plates



→ View of the saturation effects during a full current cycle, including eddy current losses (larger area inside the cycle)

Eddy currents effects and influence of the different side plates configurations

Side plates configuration	Aperture	di/dt [kA/sec]	Flat top current for 2 GeV [A]	Time constant [ms]	Amplitude [%]
New plates on all apertures	Outer	20	5349	125	0.42
	Inner	20	5275	110	0.10
Mixed plates	Outer	20	5349	120	0.37
	Inner	20	5282	115	0.22

Side plates configuration	Aperture	di/dt [kA/sec]	Flat top current for 1.4 GeV [A]	Time constant [ms]	Amplitude [%]
New plates on all apertures	Outer	20	4049	120	0.15
	Inner	20	4041	80	0.12
Mixed plates	Outer	20	4049	115	0.15
	Inner	20	4043	85	0.13

→ The new plates (laminated) seem to reduce the amplitude of the eddy currents, while the time constant is not significantly affected. (NB these values are not directly comparable to those reported in 2011 due to different test conditions)”

1 – Measurements on a PSB INJECTION dipole

1 - Determining the currents for the two converters to achieve simultaneously the same integrated field level in both inner and outer gaps for 1.4 and 2.0 GeV

2 - Equivalent length of the four apertures

3 - Excitation curves up to 5500 A

4 - Integral field quality in all apertures

5 - Eddy currents effects

6 - Field profile in Z direction for both inner and outer gaps at 1.4 and 2.0 GeV

INJECTION DIPOLE

Results for integrated field balancing in all apertures for 1.4 and 2 GeV :

Current values for integrated field balancing	Equivalent current difference between inner and outer apertures
1.4 GeV	**Δ I**
4076 [A]	14 [A] - **0.34** [%]
4062 [A]	
2 GeV	**Δ I**
5429 [A]	128 [A] - **2.36** [%]
5301 [A]	

→ The INJECTION dipole has a smaller current difference between apertures than the MAIN dipole with original side plates

Integrated field difference between the two outer apertures and the two inner apertures

	MAIN DIPOLE	MAIN DIPOLE	INJECTION DIPOLE
	Original side plates	Mixed side plates	
∫Bdl difference between inner apertures at 1.4 GeV [‰]	-0.31	0.27	0.47
∫Bdl difference between outer apertures at 1.4 GeV [‰]	1.89	0.45	0.98
∫Bdl difference between inner apertures at 2 GeV [‰]	-0.14	0.26	0.13
∫Bdl difference between outer apertures at 2 GeV [‰]	1.35	1.03	1.17

→ Mixed side plates decrease the current difference at 2 GeV

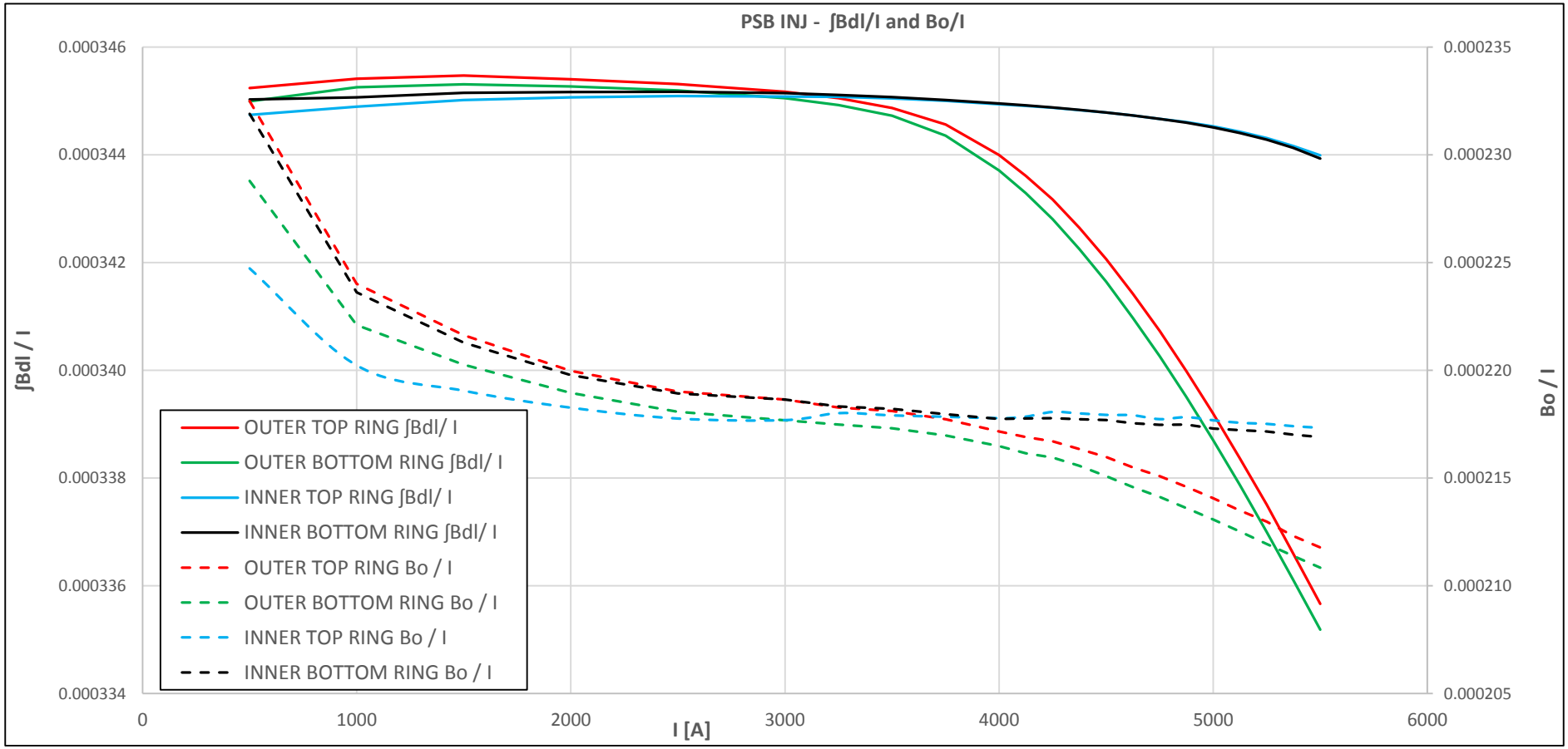
→ We may be able to trim the difference between the two inners and two outers with extra shims

Magnetic length at 1.4 and 2 GeV

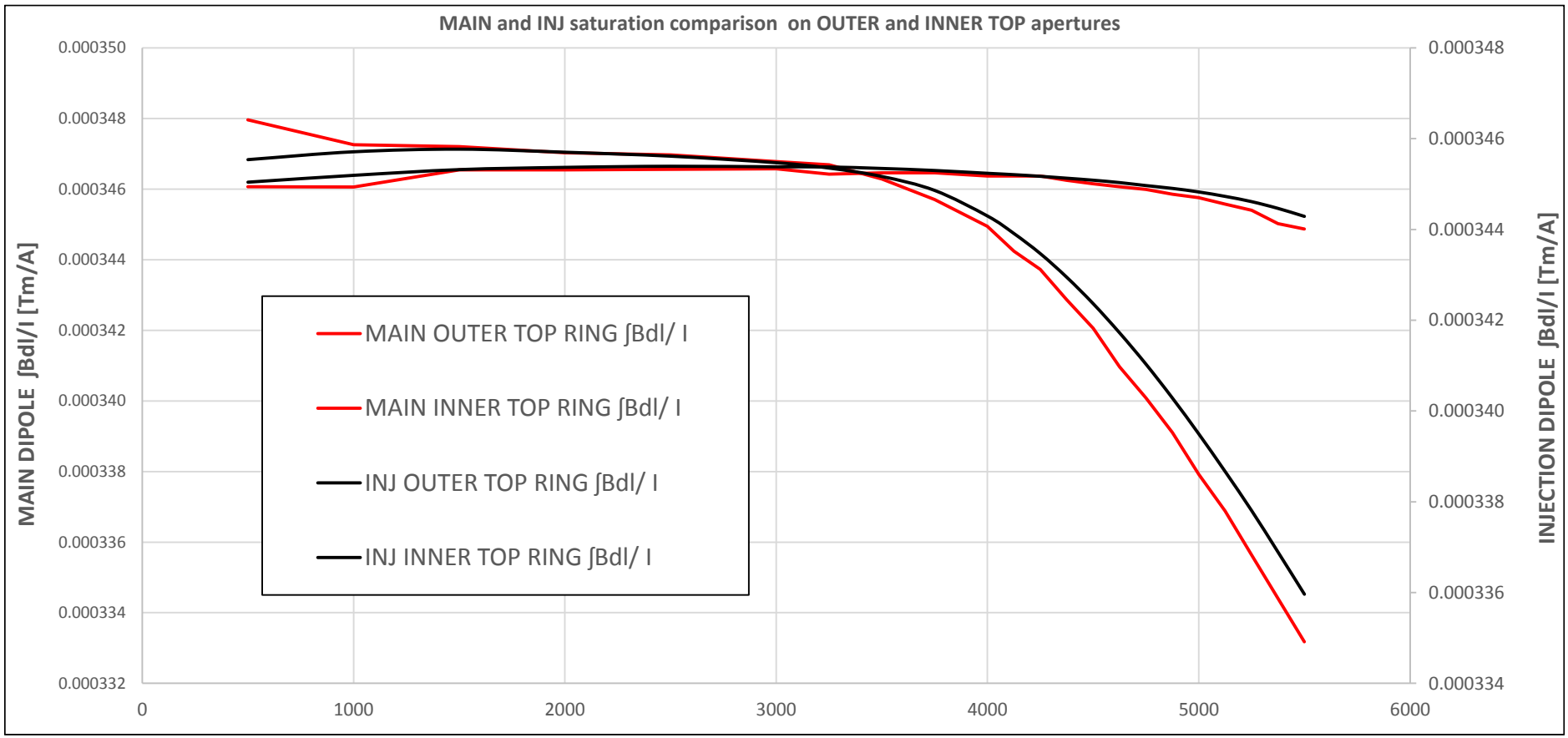
	Aperture	Magnetic length [m]
1.4 GeV	Outer top	1.588
	Inner top	1.587
	Inner bottom	1.586
	Outer bottom	1.586
2 GeV	Outer top	1.590
	Inner top	1.586
	Inner bottom	1.585
	Outer bottom	1.590

→ Difference between inner and outer aperture slightly increase with the current

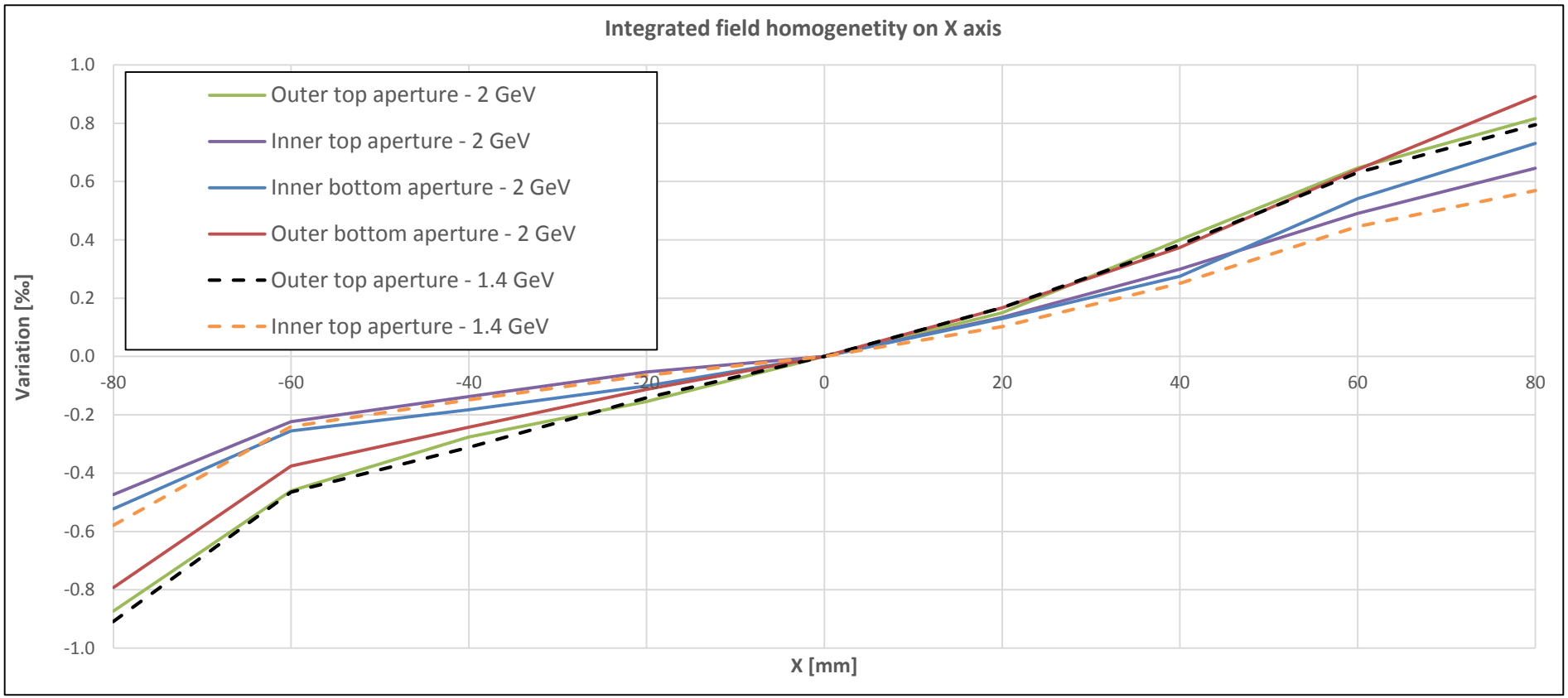
Excitation curves for integrated and center field:



Graphical comparison for saturation behavior between MAIN and INJECTION type dipole



Integrated field quality:



→ Presence of a field gradient, but homogeneity better than ±1 ‰ on ± 80 mm

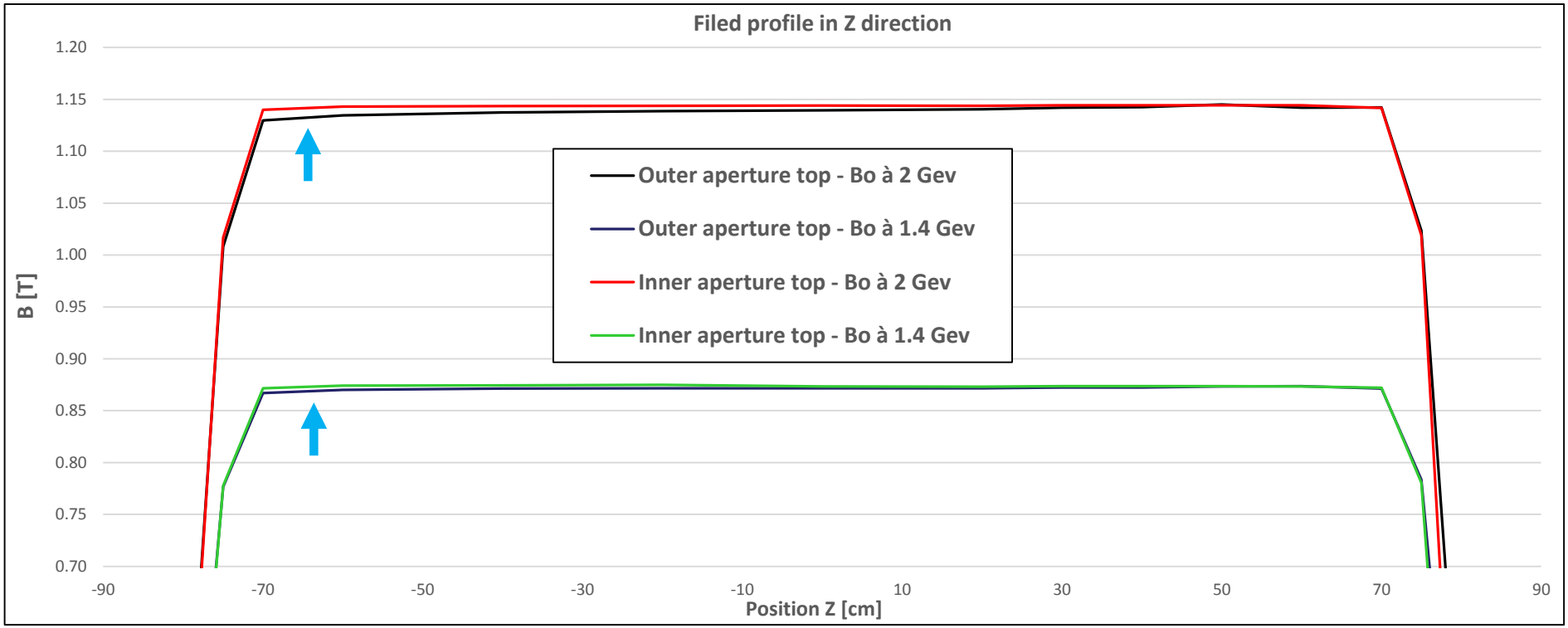
Eddy currents effects

Aperture	di/dt	Flat top current for 2 GeV	Time constant	Amplitude
Outer	20 [kA/sec]	5429 [A]	150 [ms]	0.29 [%]
Inner	20 [kA/sec]	5301 [A]	130 [ms]	0.10 [%]

Aperture	di/dt	Flat top current for 1.4 GeV	Time constant	Amplitude
Outer	20 [kA/sec]	4076 [A]	145 [ms]	0.23 [%]
Inner	20 [kA/sec]	4062 [A]	80 [ms]	0.09 [%]

→ Behavior very similar to MAIN dipole

Field profile in Z direction



→ The measurements confirm the simulations, with the presence of a field attenuation on the magnet side where the injection beam pipe goes across the yoke, as expected due to more saturation in this area

Conclusion

→ New sides plates (mixed configuration) reduce integrated differences between outer apertures at 2 GeV

→ New sides plates (mixed configuration) reduce the behaviour disparity between MAIN and INJECTION magnets at high currents

→ New sides plates (mixed configuration) reduces the current requirements for the two MPC (From 188 to 67 A at 2 GeV) and subsequently the requirements for the QF trims.