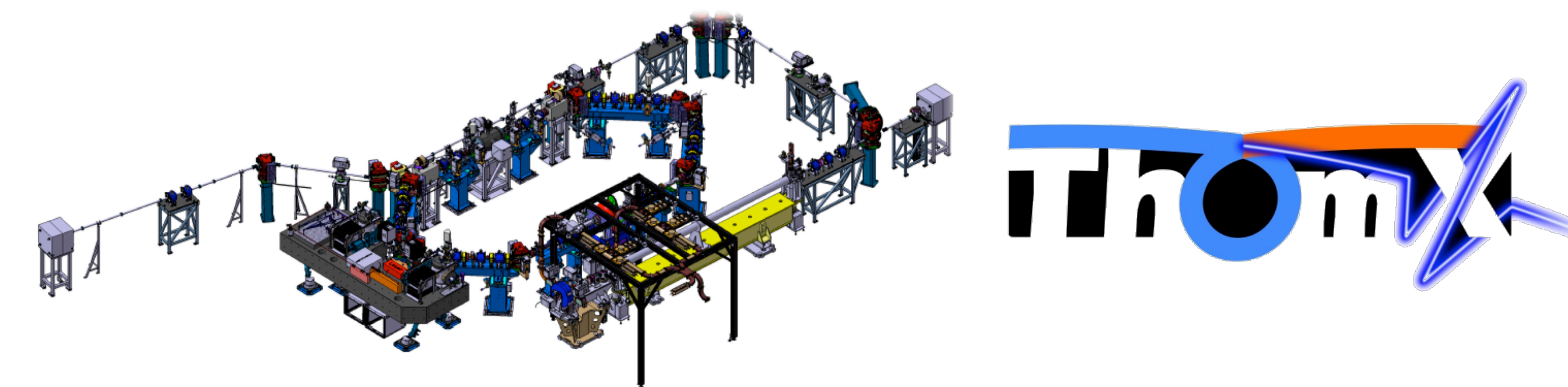


Simulations, measurements and sorting of THOMX ring bending magnets

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Background

The THOMX facility is a compact X-ray source based on Compton Back Scattering (CBS), under construction at LAL in Orsay (France). Due to high constraints as its compactness (18 meters long storage ring), the low electron energies (ranging from 50 to 70 MeV), the non-linear beam dynamics, the limited beam storage period (60 ns per turn), THOMX storage ring has to face many technical challenges. One of them concerns particularly ring dipole magnets, having small curvature radius, which have to be designed to ensure a large dynamic aperture preserving the machine performances.

Objectives - Requirements

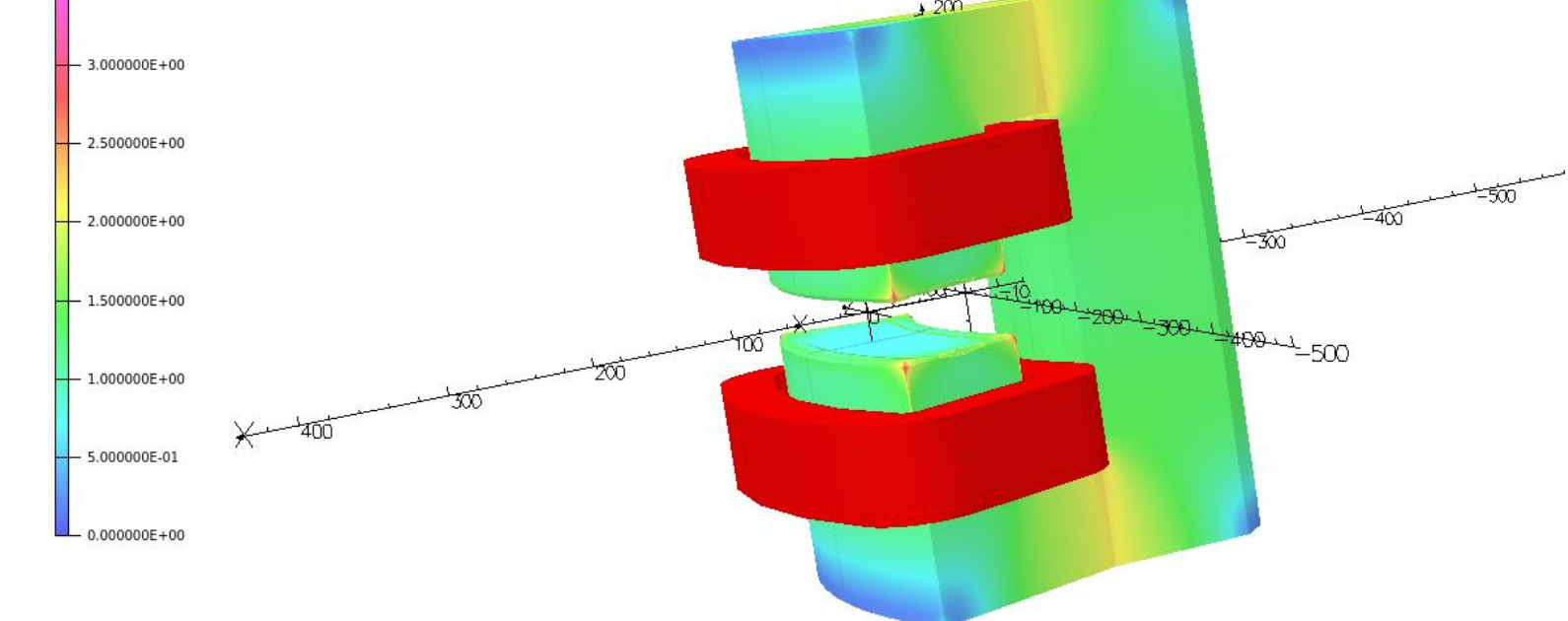
- ❖ Iron length shorter than 300 mm due to the compactness of the ring. Indeed, ThomX facility has ben designed to not exceed 70 m² on the floor.
- ❖ C-shape dipole due to the interaction point configuration.
- ❖ Integrated field as homogeneous as possible from one dipole to other due to the use of an unique power supply for the ring.
- ❖ Tolerances for multipolar components lower than 1.10^{-3} for sextupolar components, 1.10^{-4} for octupolar components, 5.10^{-4} for decapolar components to ensure the stability of the beam in the ring.
- ❖ Same dipoles for all parts of accelerator to have a larger choice for the sorting: 15 dipoles in total and 8 for the storage ring.

Conclusion

- ❖ All dipoles are manufactured by Sigmaphi. The comparison of simulated and measured magnetic field of ThomX dipole shows very good agreement.
- ❖ Simulated and measured field values differ by a value of 47 G, i.e 0.71% of $B_y(0,0,0)$ in the center of dipole at 275 A. This value was expected and came from a better quality for iron than simulated iron.
- ❖ Simulated and measured multipolar components are similar.
- ❖ From magnetic measurements and sorting, ThomX dipoles are now positioned and aligned on the girders.

Magnetic design

TOSCA Model

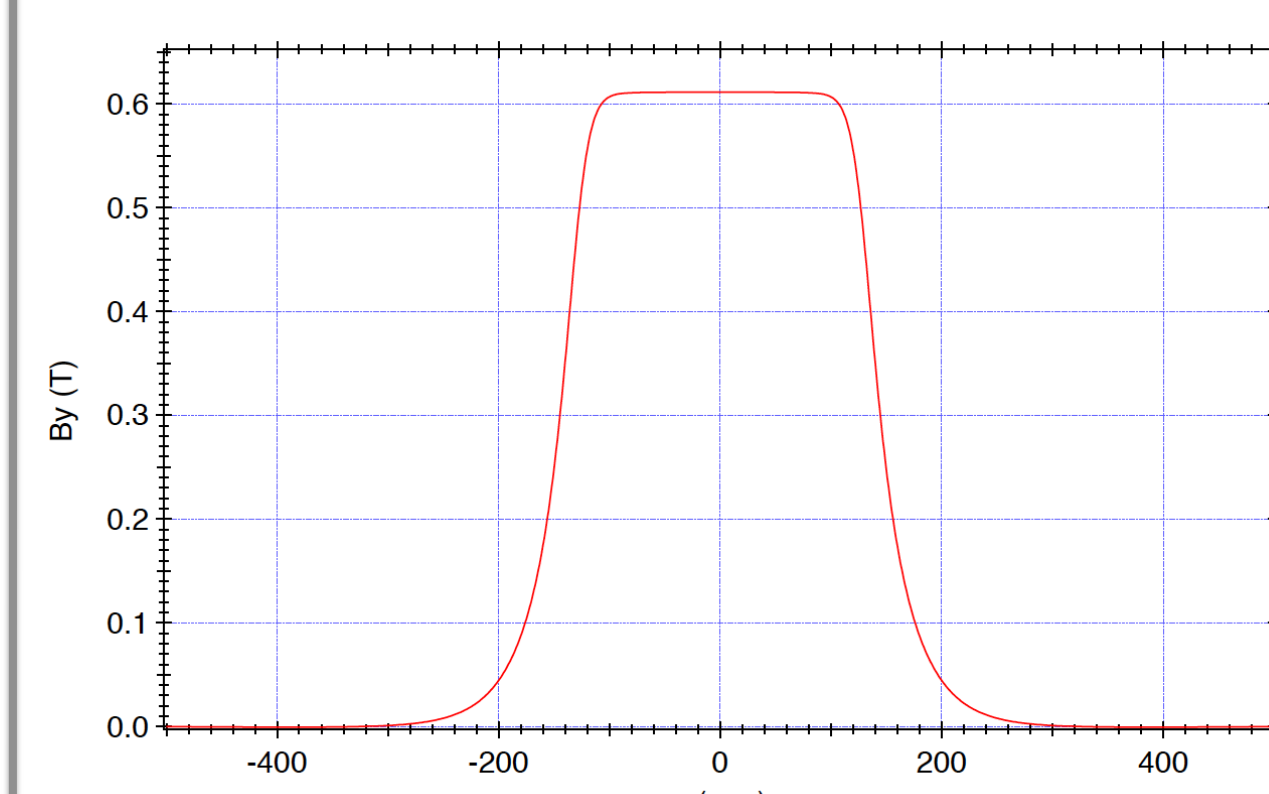


The magnetic design was mainly based on :

- the width of the pole to prevent saturation,
- the end pole chamfer to adjust the magnetic length in the good field region and
- the add-ons of shims to obtain flat field and ensure its homogeneity.

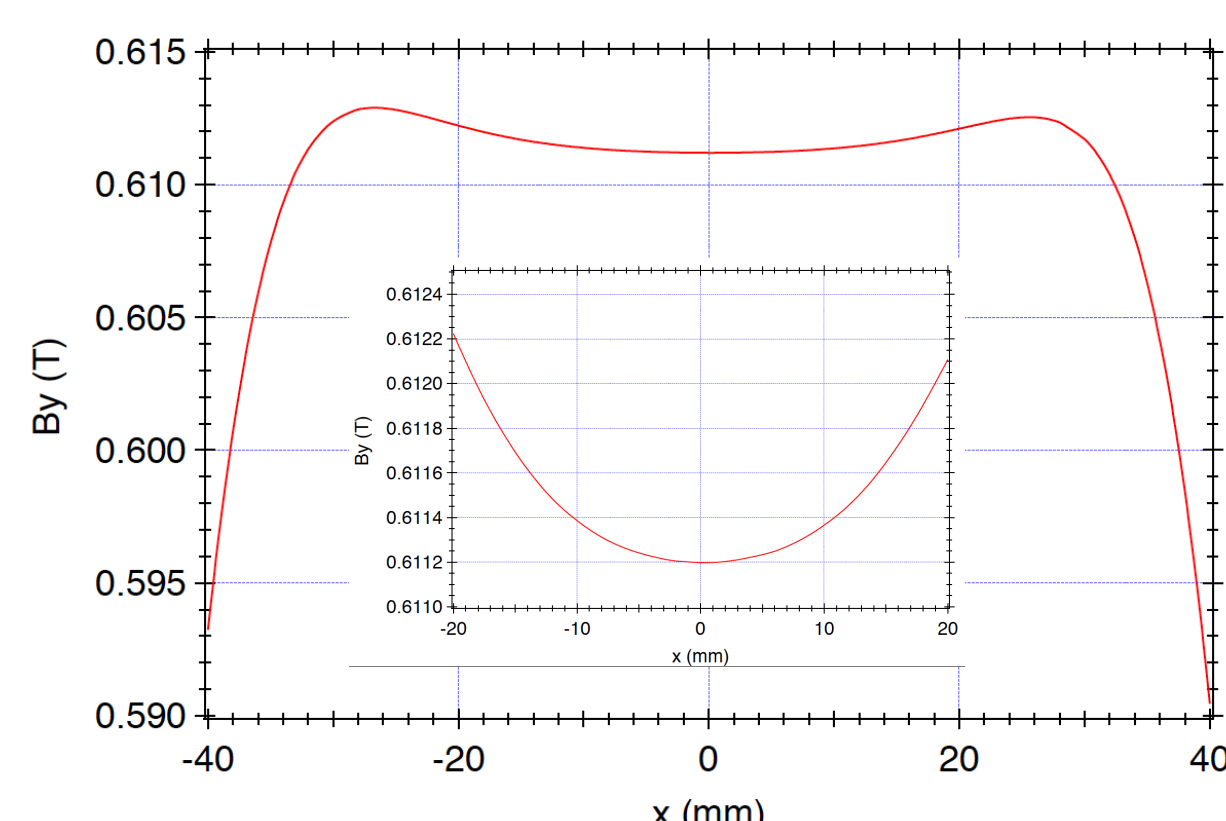
Due to the compactness of the ring, involving a length of magnet lower than 400 mm, it is observed a saturation of 21.5% for 275 A

Distribution of $B_y(0,0,z)$ & $B_y(x,0,0)$

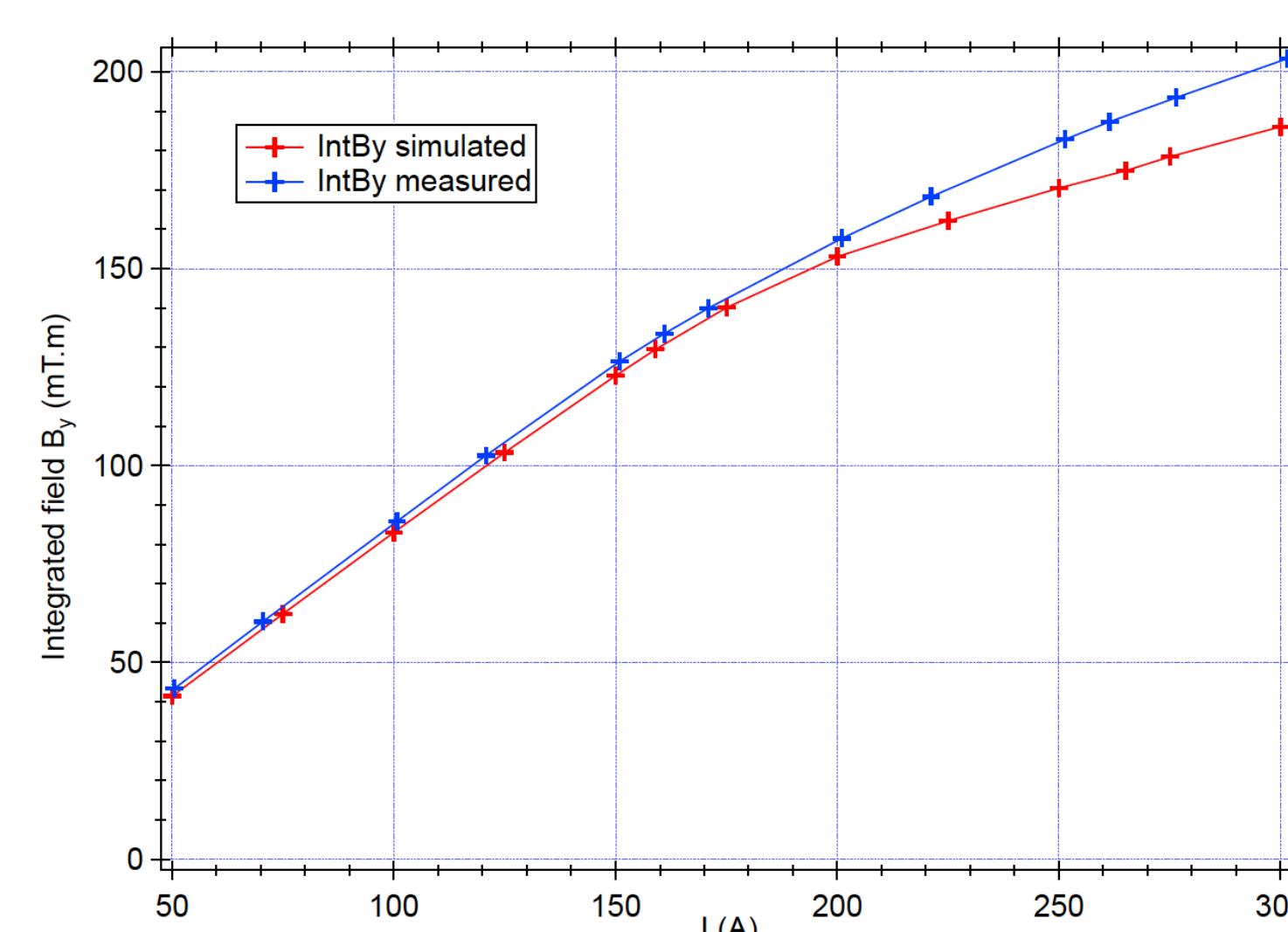


$B_y(0,0,0) = 0.6112$ T for 13200 A.t (**275 A**)
Fringe field = 10.3 G @ $z = \pm 300$ mm

The **field homogeneity** is **$1.7 \cdot 10^{-3}$ at 275 A**
The field distribution is as flat in the middle as required.



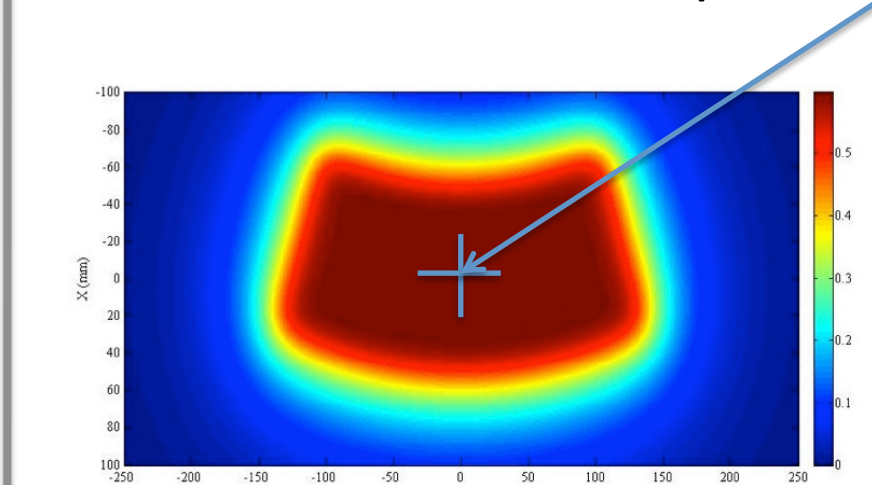
Vertical field integral



For 50 MeV beam energy :
Vertical field integral = 0.1289T.m for a 45° deviation
=> I = 159.29 A

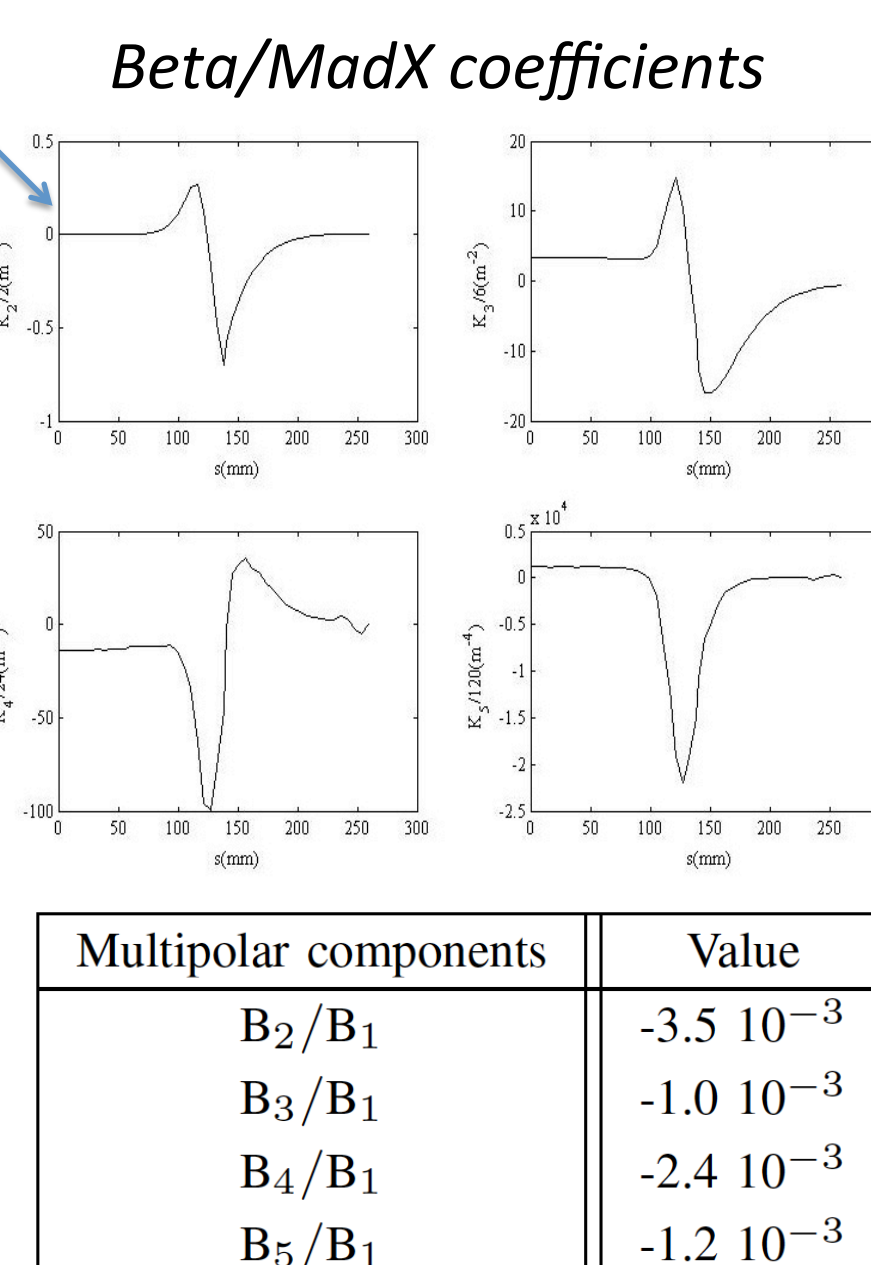
Multipoles

Distribution of B_y with Matlab in the midplane



Analysis is carried out in the midplane, where $y = 0$.
The center of the magnet is then identified by $x = z = s = 0$

$$B_y(x,z) \cdot L = B_1 \cdot \rho \left(\frac{L}{\rho} + \frac{B_2 \cdot x^2 \cdot L}{B_1 \cdot \rho} + \frac{B_3 \cdot x^2 \cdot L}{B_1 \cdot \rho} + \dots + \frac{B_n \cdot x^{n-1} \cdot L}{B_1 \cdot \rho} \right)$$

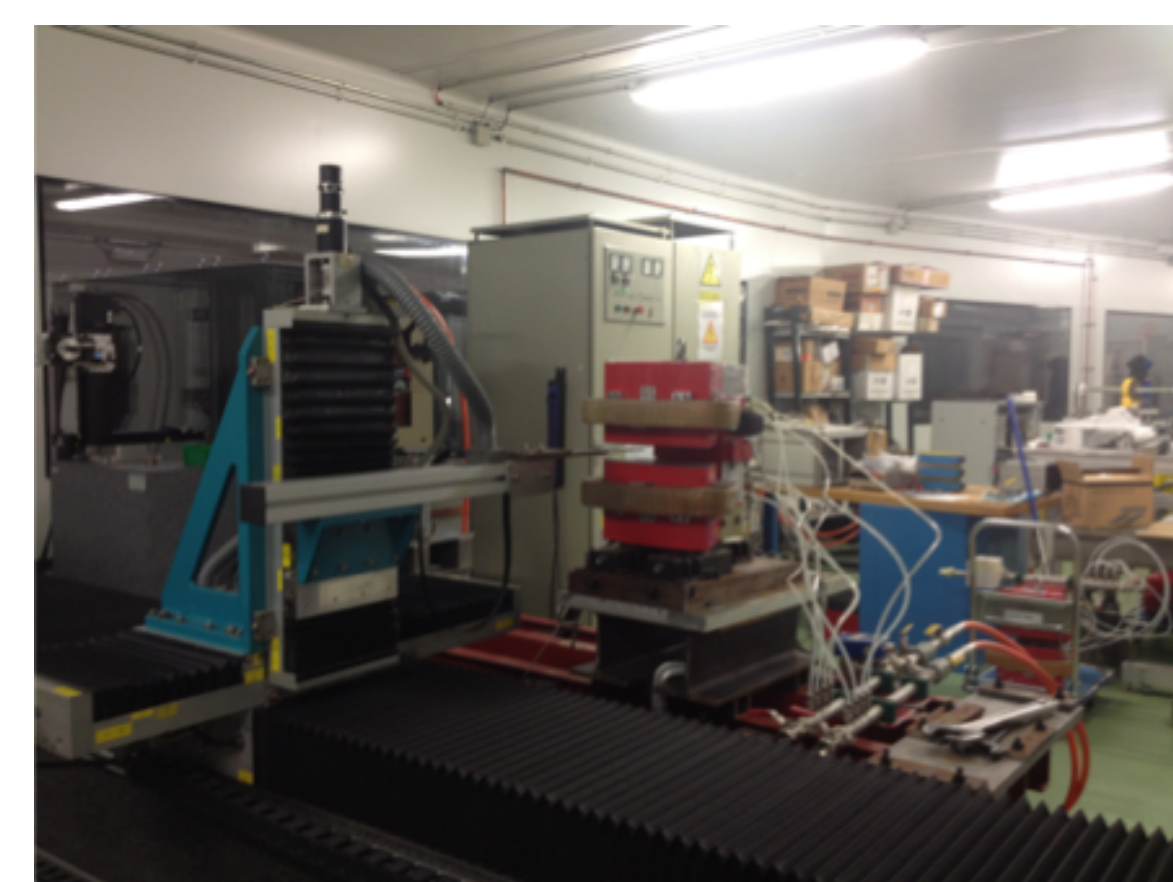


Features



Parameter	Value
Quantity	14+1 (pre-series)
Radius of curvature	352 mm
Main field B_0	0.611 T
Gap	42mm
Good field region	± 20 mm
Field integral $B \cdot dl$	0.1289 T.m @ 159 A
Ampereturns	12624 A.t
Operating Current	159 A @ 50 MeV
Coil Voltage	9.4 V
Power	2471 W
Inductance	12.54 mH @ 159 A
Diff. Pressure	7 bars
Diff. Temperature	9.5°
Total weight	200 kg
Overall Dimensions (H x W x L)	35*40*40 cm ³

Layout at ALBA



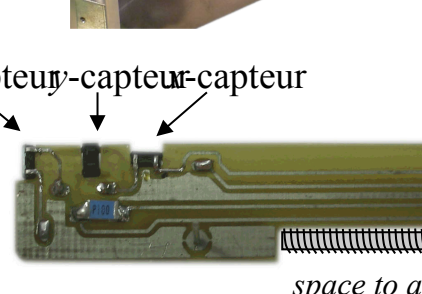
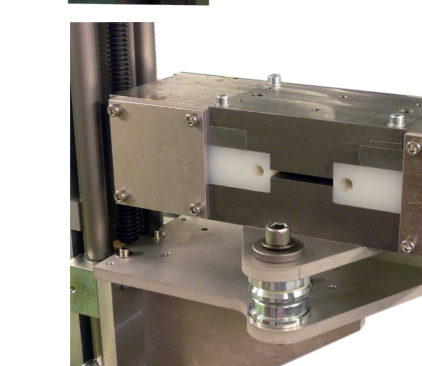
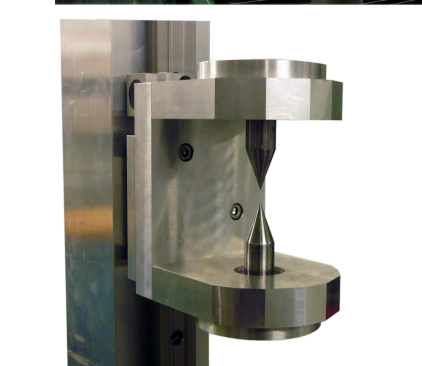
1) Calibration of the three hall probes with 5 probes RMN and new calibration method based on modeling of the response of the probe to an external field.

2) Determination of hall probe offset with a double layer mu metal chamber.

3) Determination of relative positions between sensors with a magnetic needle tool inspired from SLAC design.

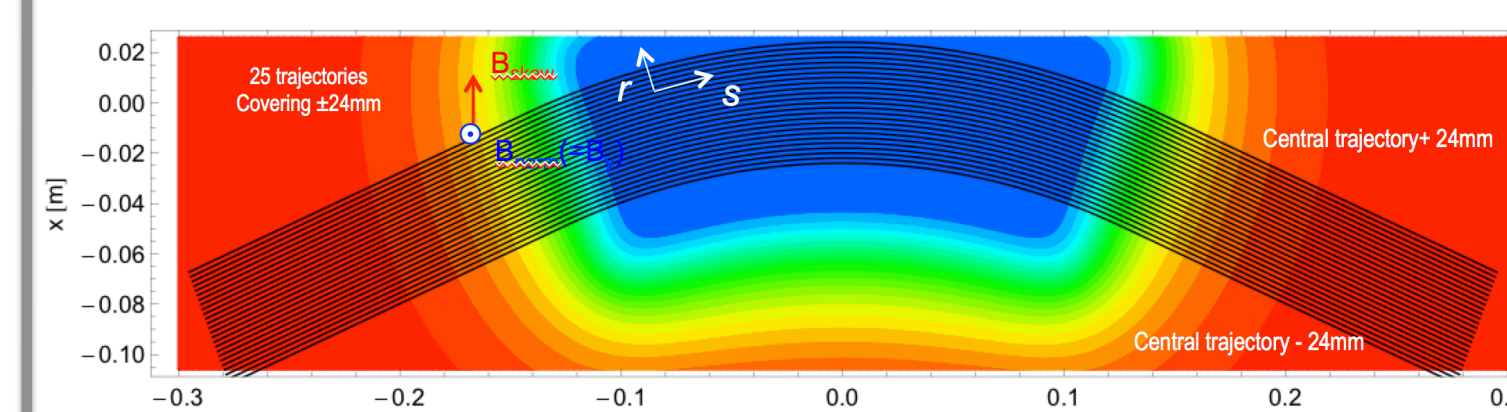
4) Determination of default angle errors of the 3D Hall probe by the mean of a very accurate permanent magnet dipole.

5) Control of the temperature probe with a temperature sensor and a manganine heater, in combination with a PID controller at 0.05 °C.

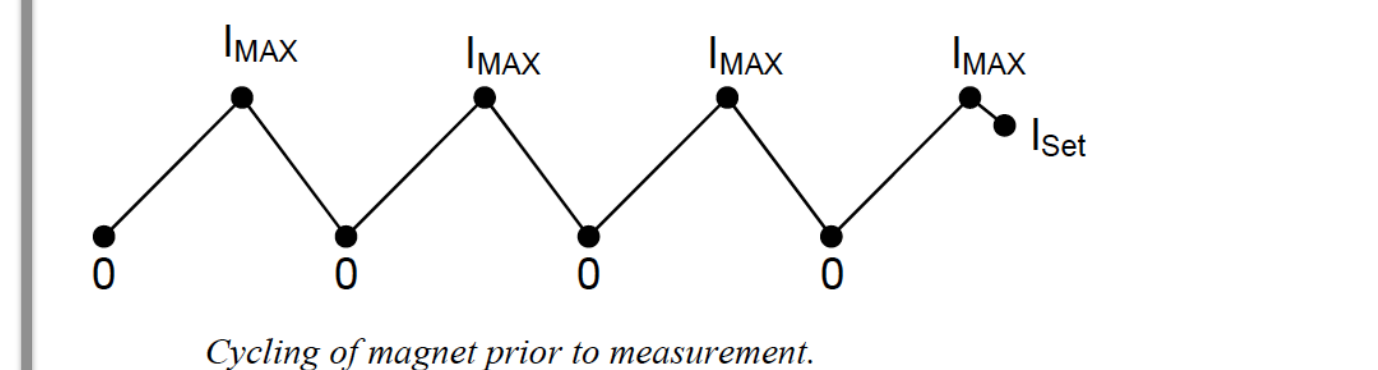


Method

Fieldmap measurements have been done on a squared horizontal grid containing the nominal trajectory and :
- for 0 A to 300 A, by 10 A step for the first bending magnet (measurement at 275 A has been repeated twice to check the cycling procedure),
- for 100 A (≈ 0.25 T), 200 A (≈ 0.50 T), 275 A (≈ 0.70 T)

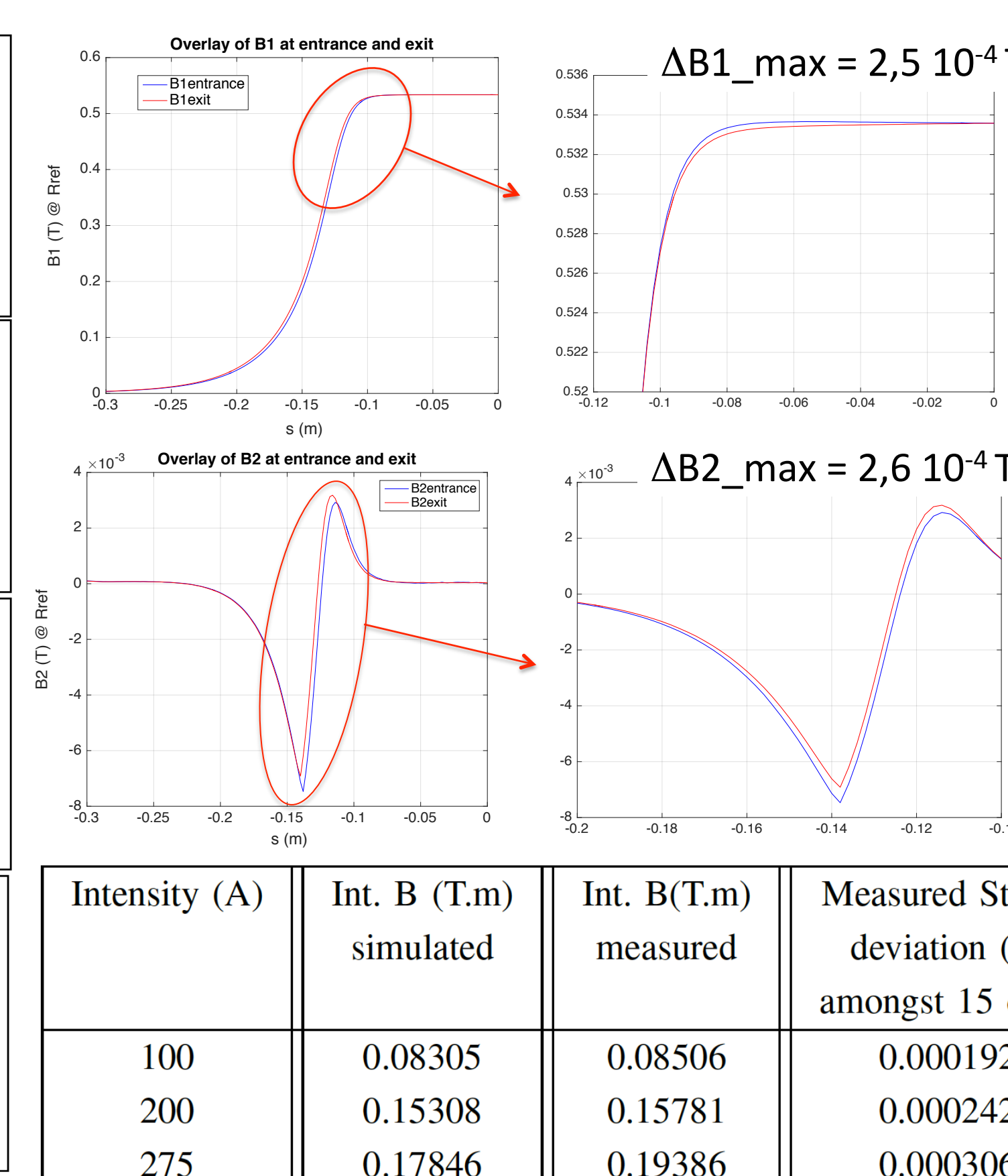
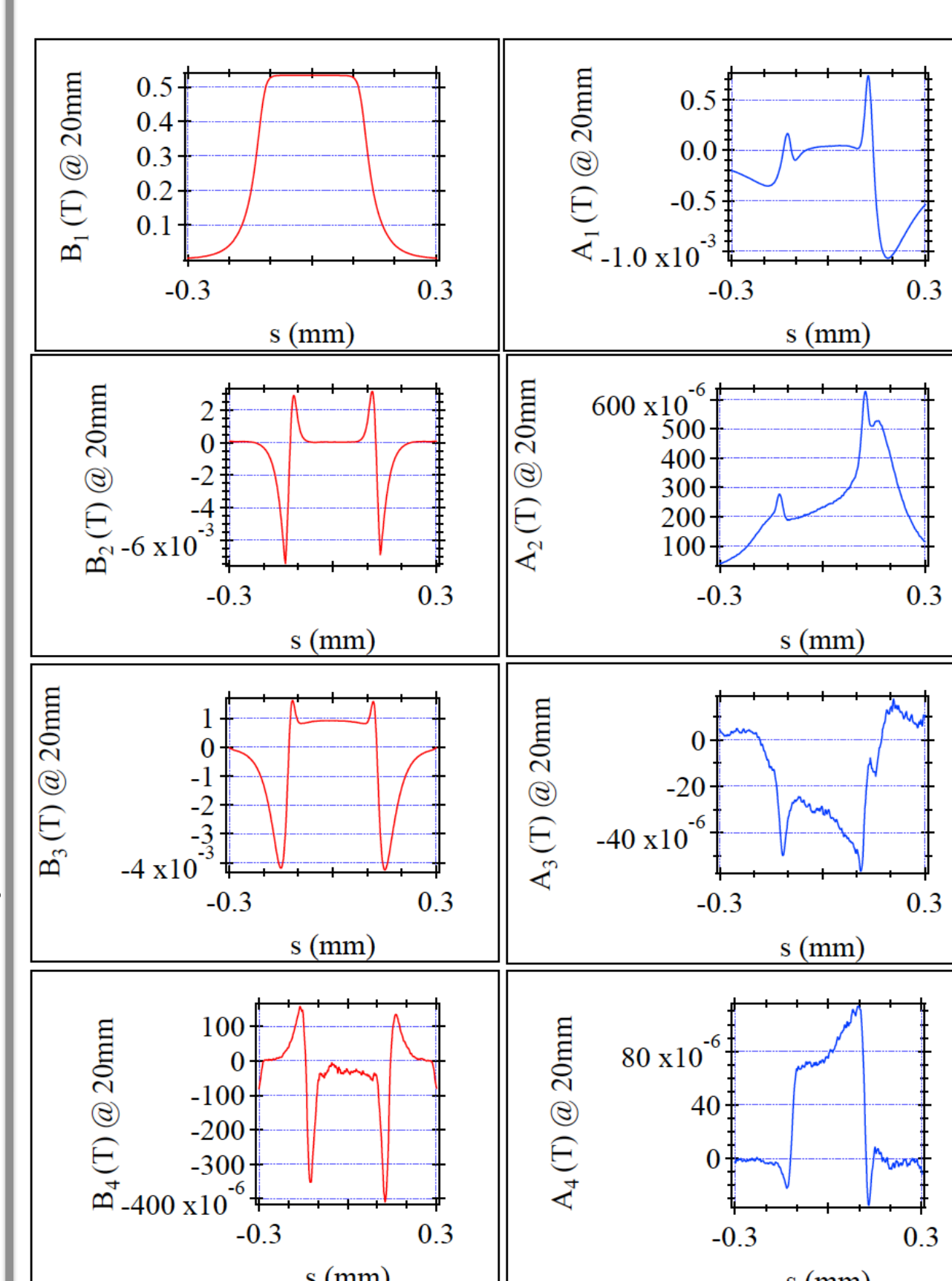


All magnets have been cycled in the same way to assure the same initial condition for all measurements.



Total cycling time: **~ 20 min**
so ~ 3 min for 0 to I_{\max} and the same for I_{\max} to 0.
Waiting time at I_{\max} & $I=0$ **~ 30 sec.**

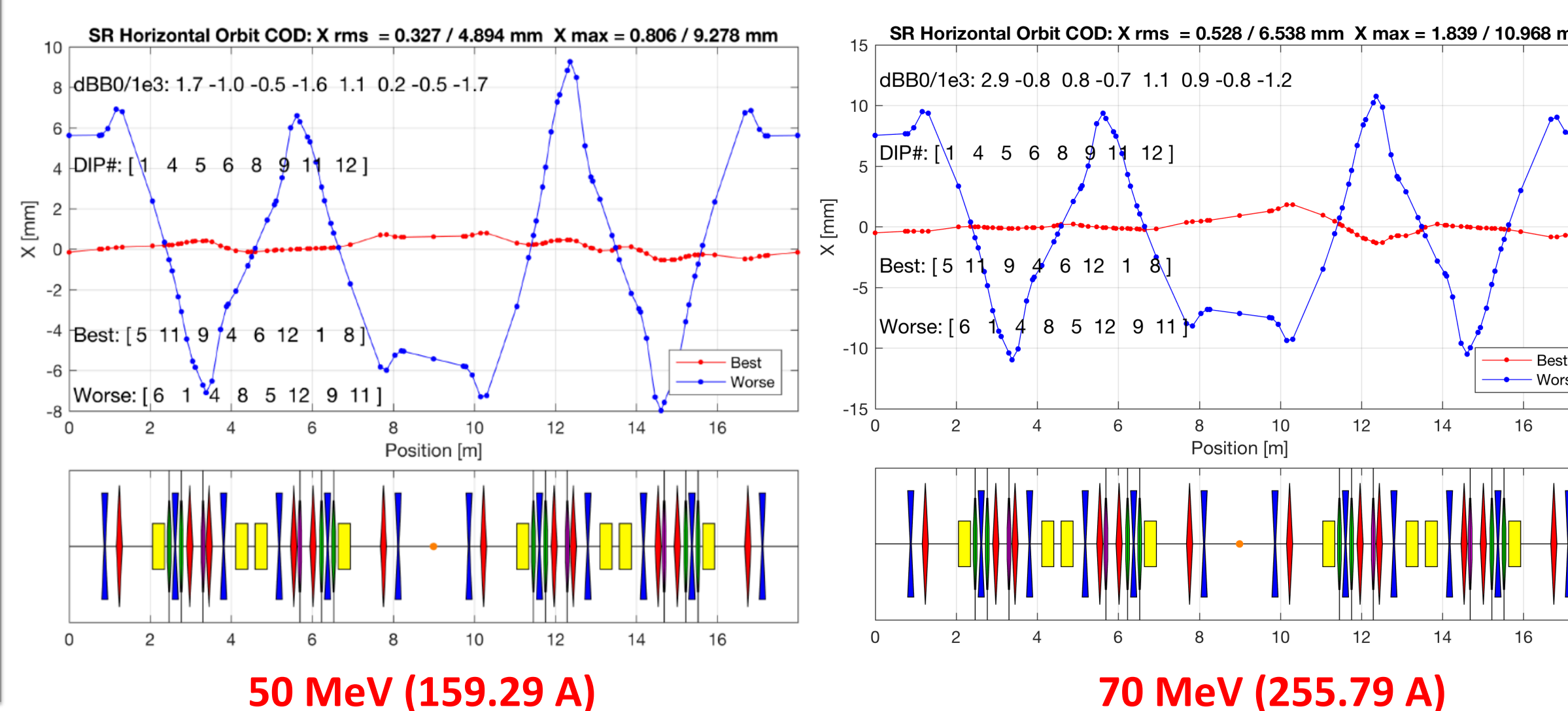
Magnetic measurements



Sorting

To minimize the Closed Orbit Distortion (COD) caused by dipole field errors, the sorting was f:

- 1) based on the minimization of the COD according to the measured field errors expressed as the normalized deviations of the integral field strength from its mean value and then
- 2) based on a method of simulated annealing to find the 8 best dipoles for the Storage Ring, by using a maximum of the COD as a cost function to compare different permutations of the measured error set.



Results

Parameter	Value
Model	GH-700
Nominal current	5mA
Magnetic sensitivity	1V/T
Max. linearity error ($\pm 1T$ esla)	$\pm 2\%$
Temperature coefficient	-0.07 %/C
Absolute accuracy	± 0.05 mT
Repeatability between different scans	± 0.5 Gauss rms