

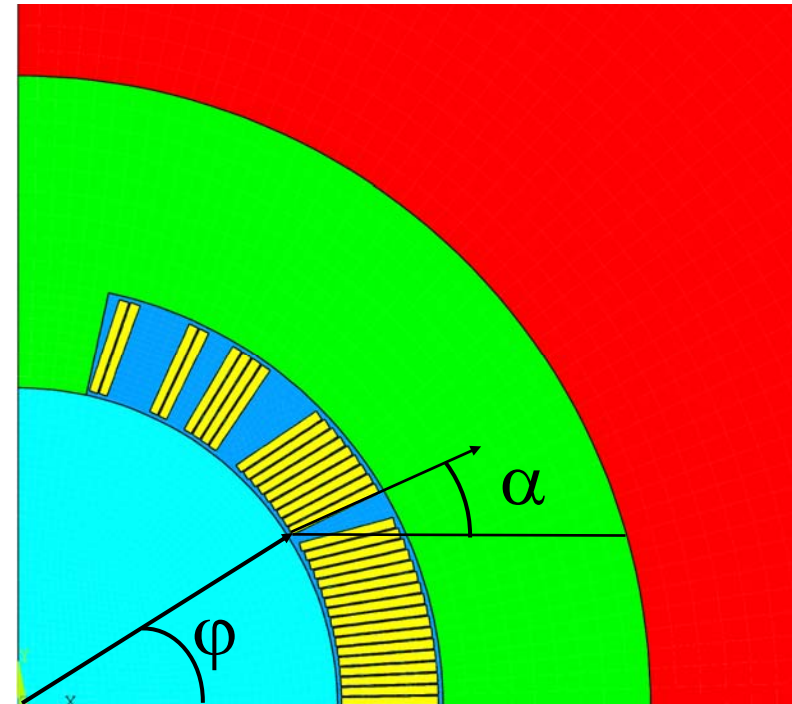
Mechanical 2D analysis

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DISCORAP Meeting
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Reference layout

collar thickness: 30 mm
 operative current: 8924 A
 Bpeak: 4.9 T
 b3 = 0.09 u. b5 = 0.10 u.
 b7 = 0.40 u. b9 = 0.48 u.
 b11= 0.95 u. b13= -1.14 u.
 temperature margin
 (Roxie) 0.98 K
 Lorentz forces:
 Fx=+0.68 MN
 Fy=-0.30 MN



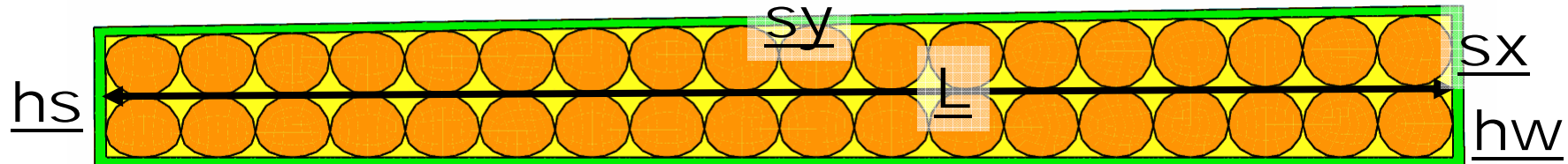
	block #1	block #2	block #3	block #4	block #5
φ	0.11459	32.0753	52.2079	62.5962	73.9214
α	0	25.9687	55.9759	64.0005	70.0001

Material properties

(from *An Introduction to Mechanical Design and Construction Methods* by Carl L. Goodzeit)

	Young modulus (GPa)	Thermal contraction (4.2 K to 295 K)
Stainless steel	192	$2.4 \cdot 10^{-3}$
Insulated conductor	7.5	$5.63 \cdot 10^{-3}$
Wedges (G11)	25.5	$2.47 \cdot 10^{-3}$
Kapton (ground insulation)	2.5	$9 \cdot 10^{-3}$

Conductor dimensions @ 50 MPa



bare conductor

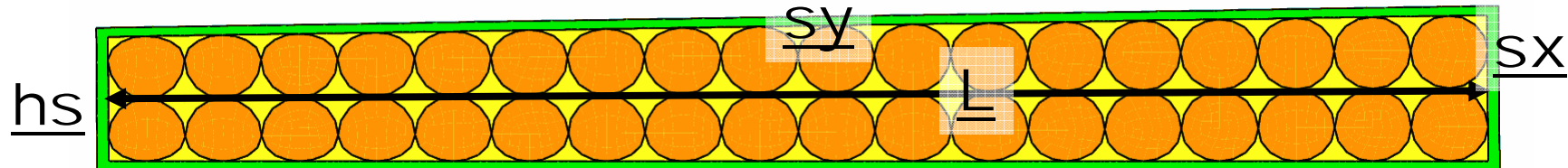
short side thickness (h_s)	1.362 mm
wide side thickness (h_w)	1.598 mm
width (L)	15.10 mm
keystoning angle (ϑ)	$0^\circ.4477$

insulation

radial thickness (s_x)	125 μm
azimuthal thickness (s_y)	98 μm
insulated average thickness (H_m)	1.676 mm

to perform a mechanical
analysis we need the
conductor dimension
@ 0 MPa

Conductor dimensions @ 0 MPa



assuming the same Young modulus for the conductor:

$$d(0 \text{ MPa}) = \frac{d(50 \text{ MPa})}{1 - \frac{50 \text{ MPa}}{E_{\text{cond.}}}}$$

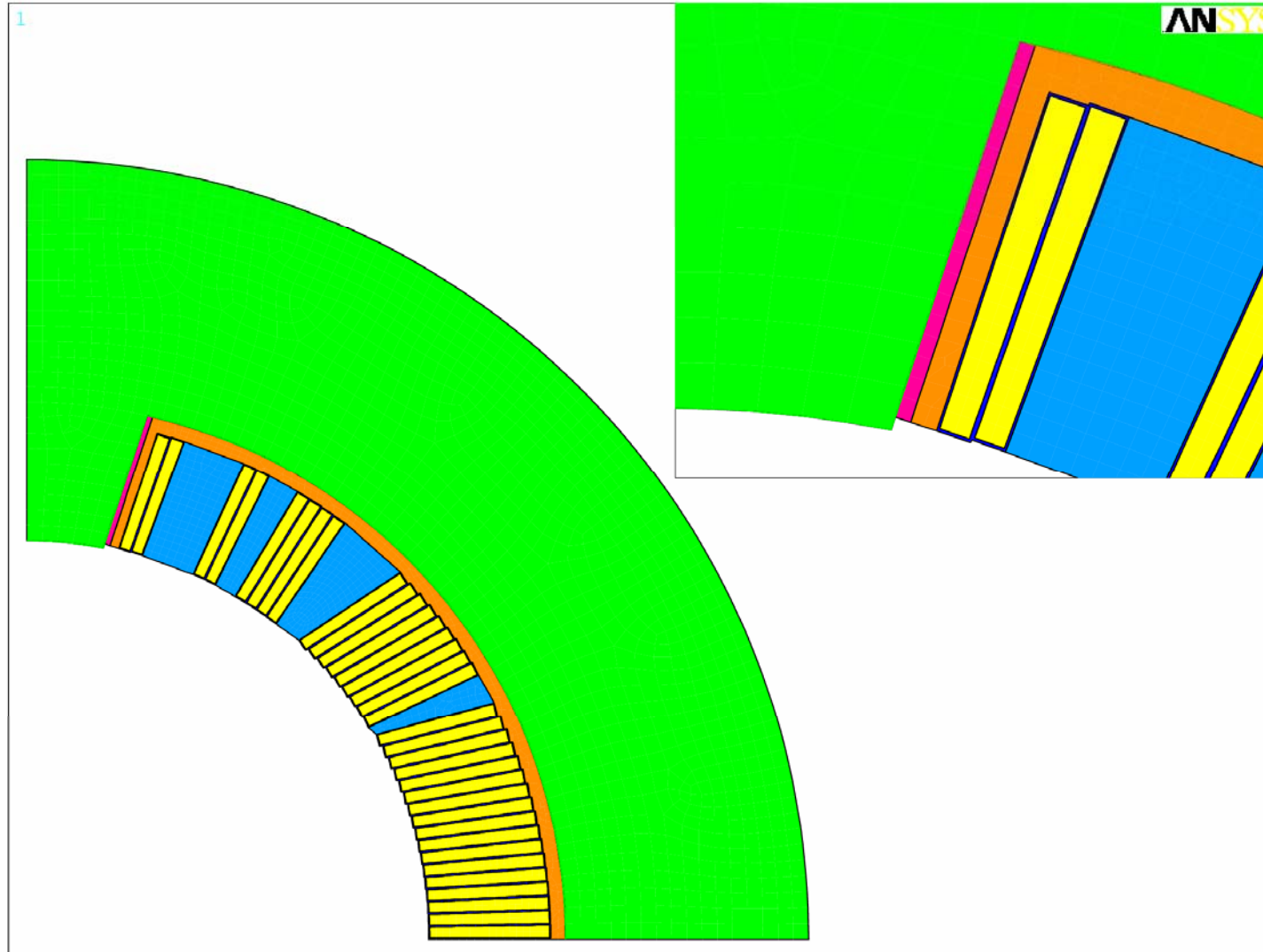
bare conductor

short side thickness (h_s)	1.371 mm
wide side thickness (h_w)	1.609 mm
width (L)	15.10 mm

insulation

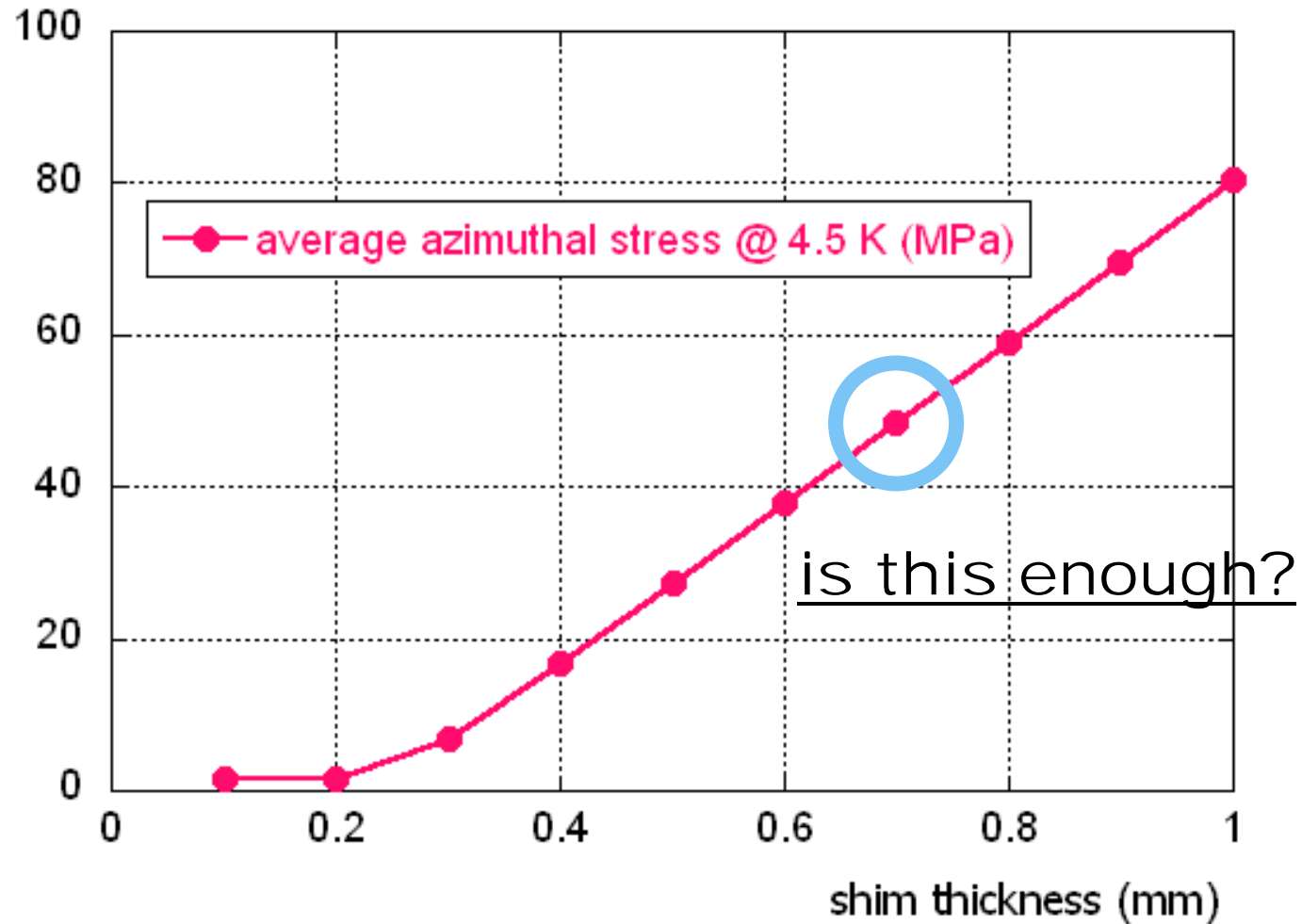
radial thickness (s_x)	125 μm
azimuthal thickness (s_y)	98.65 μm

Mechanical model of reference layout (30 mm thick stainless steel collar)



we choose a shim thickness
giving an average stress
inside the winding of 50 MPa

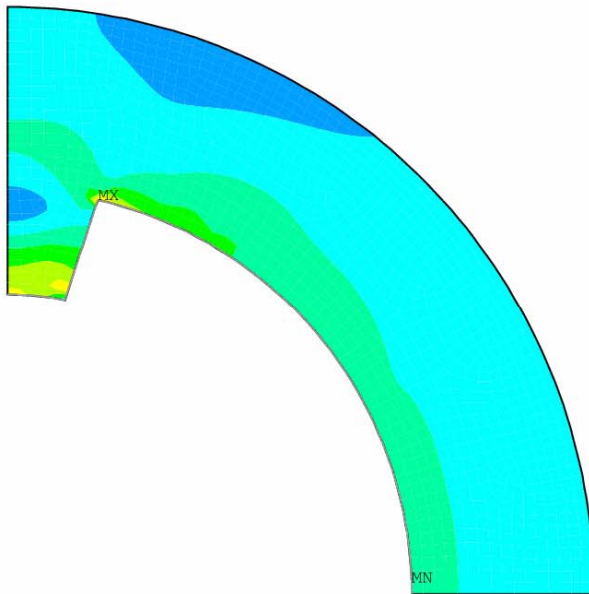
Determination of the shim thickness



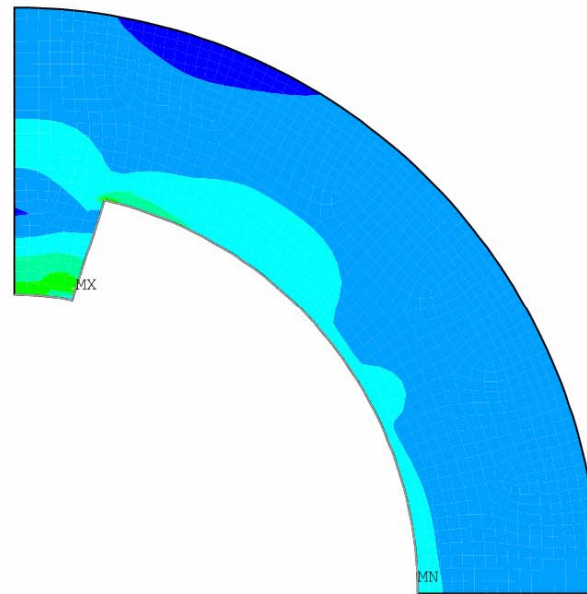
Von Mises stress in the collar

Nitronic40 has a yield stress of 900 MPa

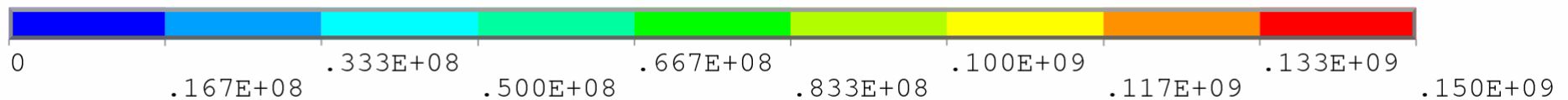
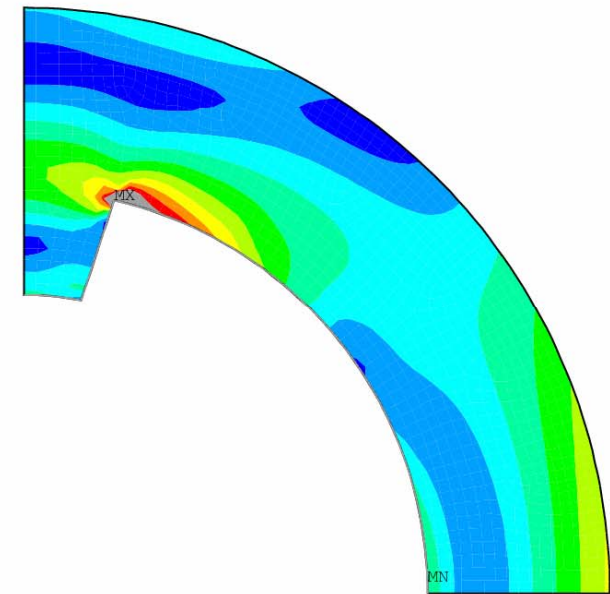
collaring



cool-down

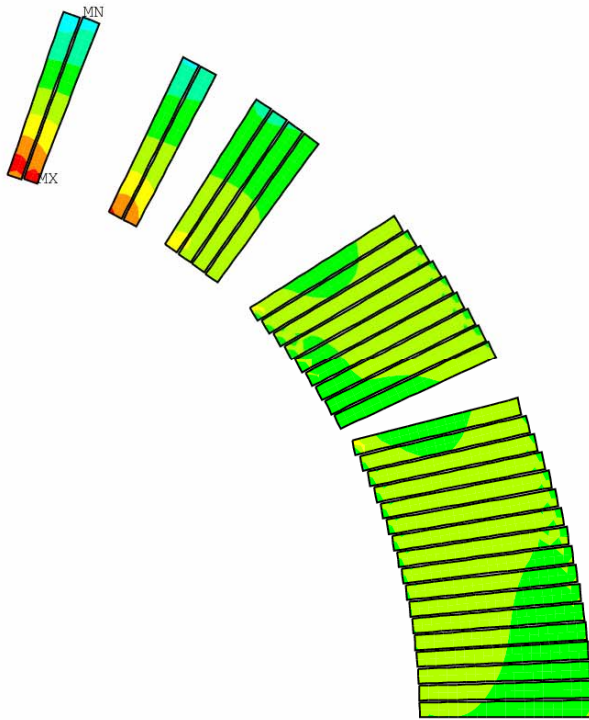


energization

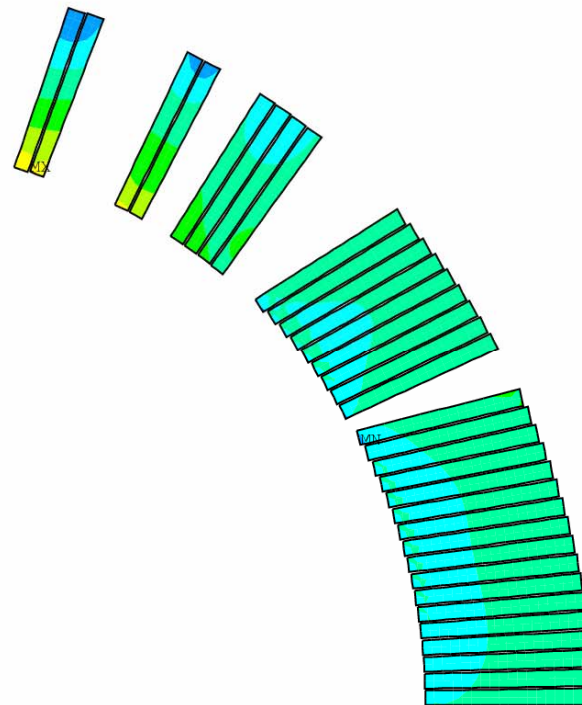


Von Mises stress in the winding

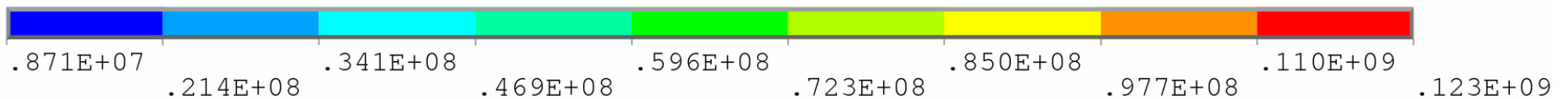
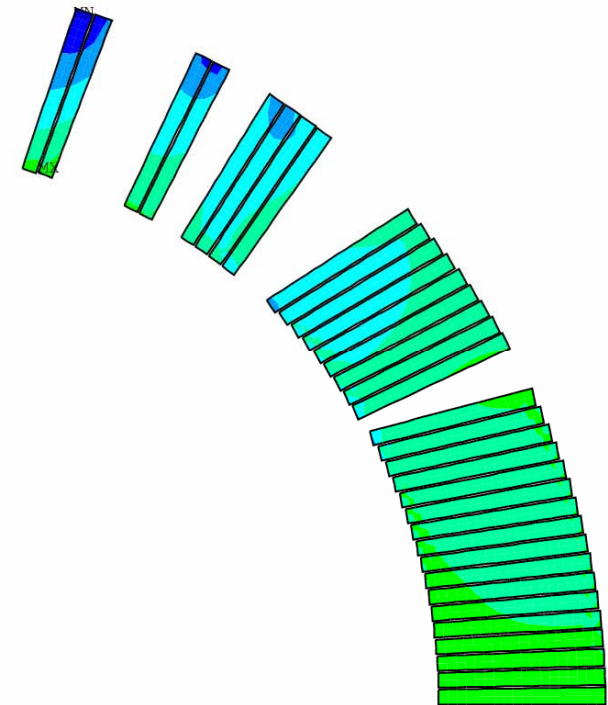
collaring
 $\sigma_{ave}=73$ MPa



cool-down
 $\sigma_{ave}=50$ MPa



energization
 $\sigma_{ave}=51.5$ MPa

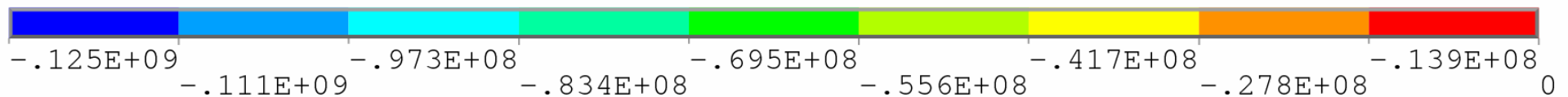
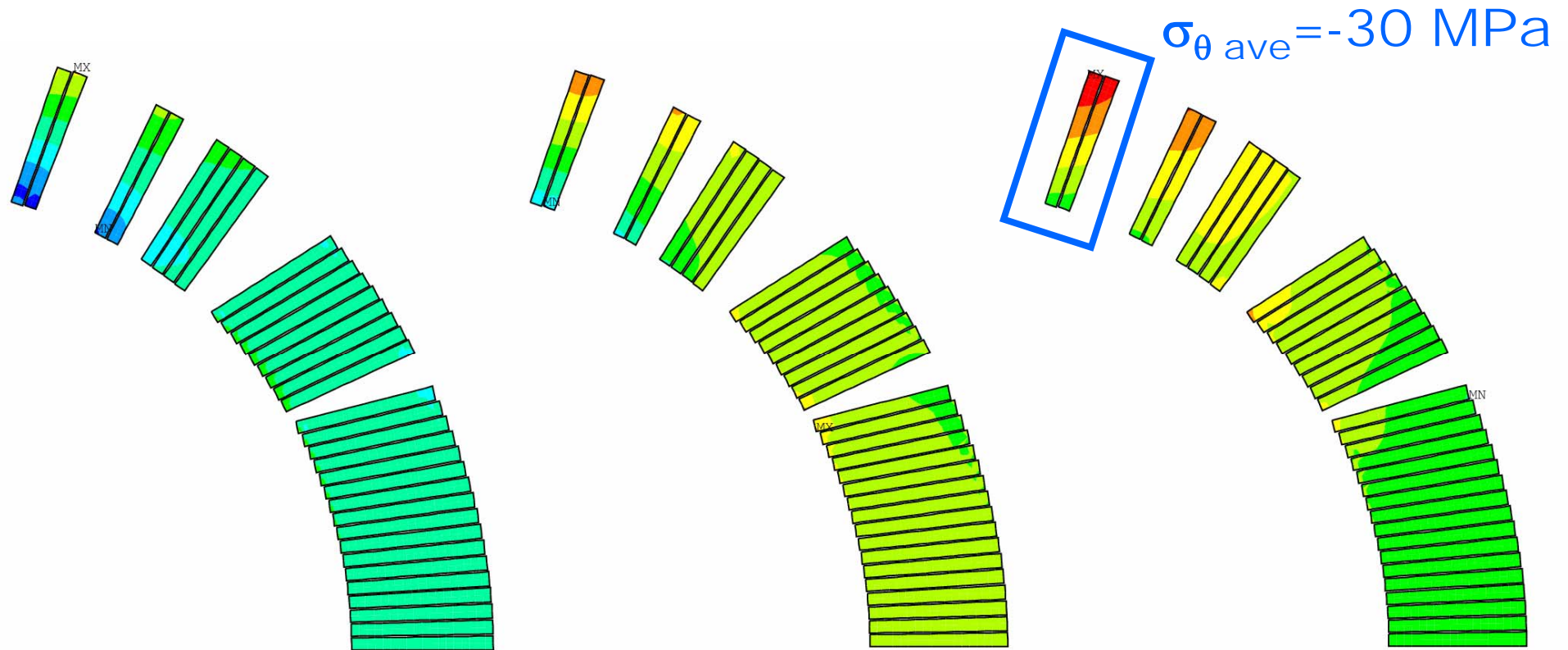


Azimuthal stress in the winding

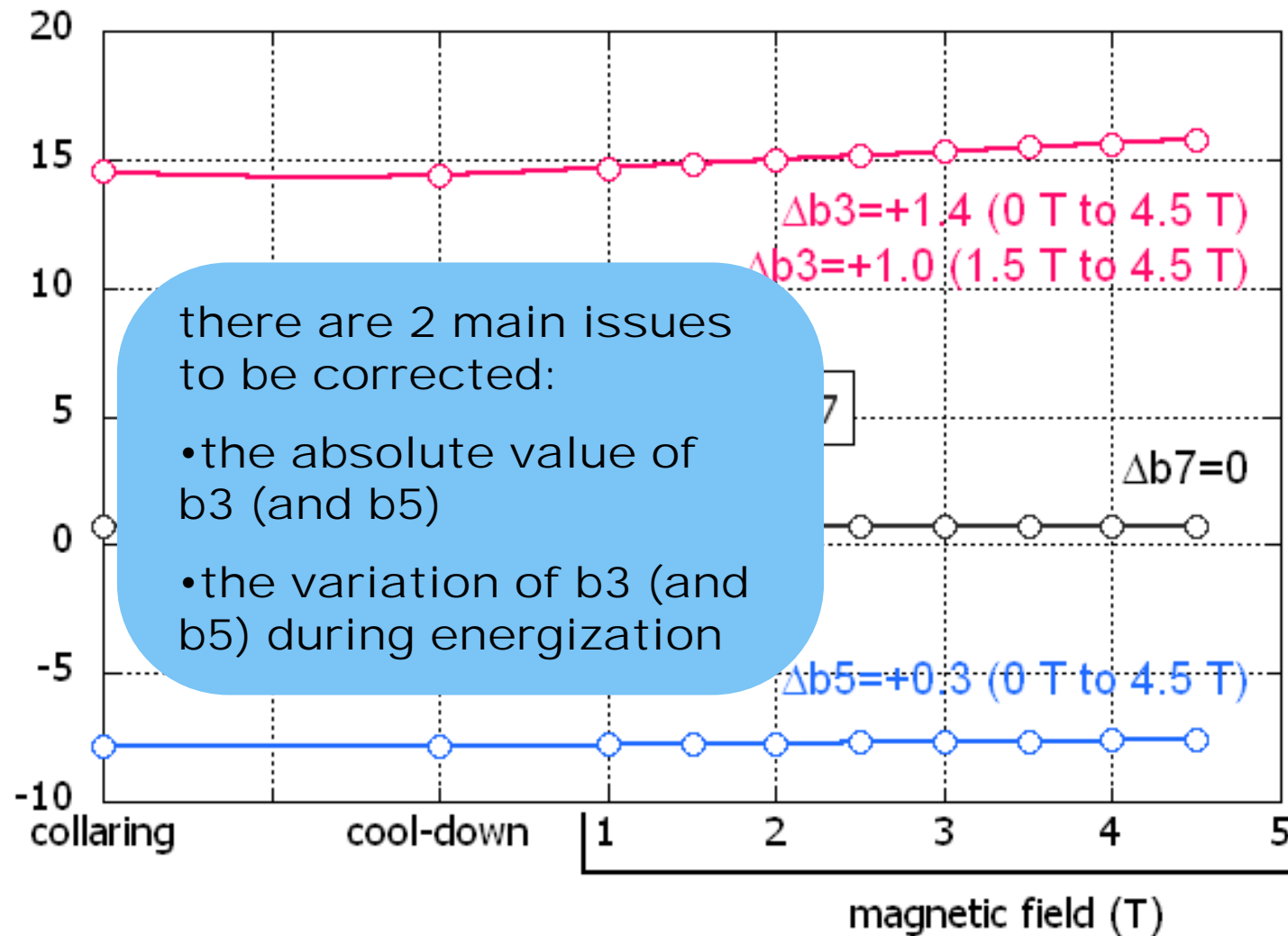
collaring

cool-down

energization



Resulting effect on harmonics



the large value of b_3 (~ 15) is (almost totally) due to the fact that the magnetic optimization is done using warm conductor dimensions

Effect of thermal contraction

- resulting conductor dimensions (@4.5K and 50 MPa)
 $h_s = 1.355 \text{ mm}$ $s_x = 124.37 \text{ }\mu\text{m}$
 $h_w = 1.590 \text{ mm}$ $s_y = 97.55 \text{ }\mu\text{m}$
 $L = 15.04 \text{ mm}$

the results have been averaged on all the conductors

Magnetic optimization

(using the conductor dimensions @ 4.5 K and 50 MPa)

	block #1	block #2	block #3	block #4	block #5
φ	0.1146	31.1083	52.4416	62.4008	73.5226
α	0	35.0680	54.1998	63.2798	74.4016

harmonics:

$$b_3=0.20$$

$$b_9=0.85$$

$$b_5=0.23$$

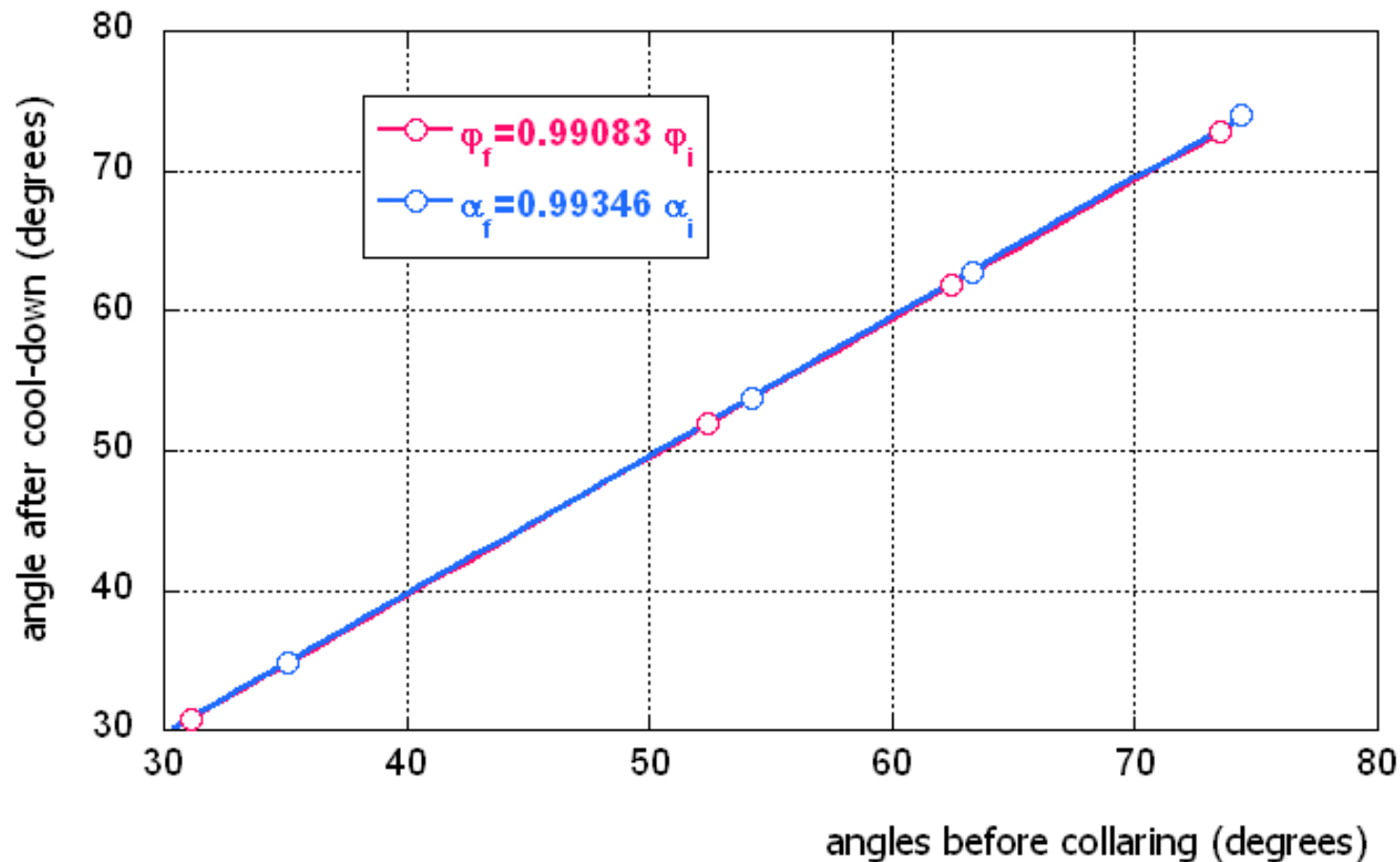
$$b_{11}=1.71$$

$$b_7=0.76$$

$$b_{13}=-1.17$$

we need to calculate the
"warm" angles to input in the
mechanical model

Transfer function between warm and collaring+cool-down



Recalculated warm angles ($F_\varphi=0.99083$, $F_\alpha=0.99346$)

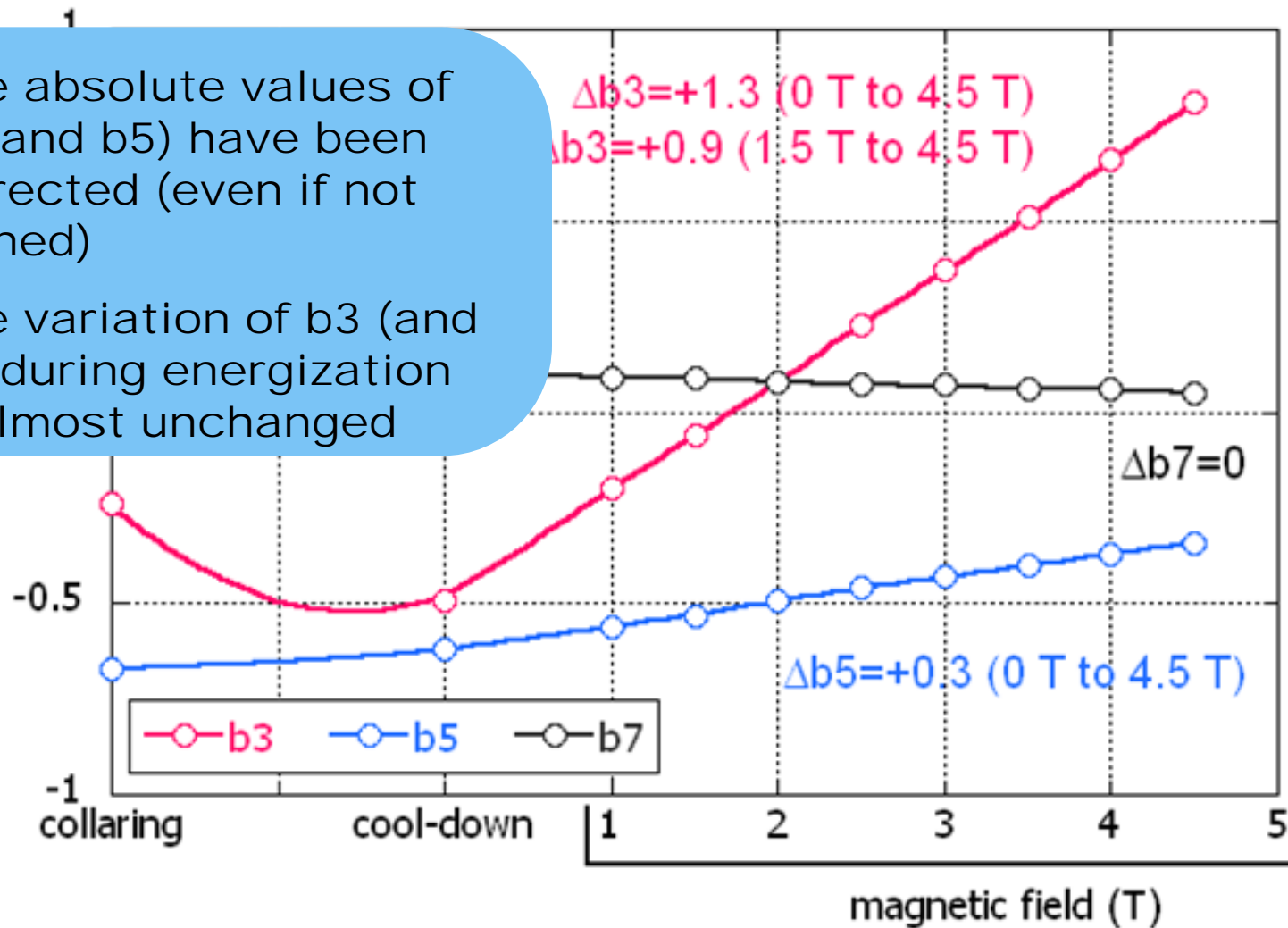
	block #1	block #2	block #3	block #4	block #5
φ	0.1146	31.3962	52.9269	62.9783	74.2030
α	0	35.2989	54.5566	63.6964	74.8914

harmonics @ 50 MPa, 4.5 K and 0 T:

$b_3=-0.49$ $b_9=0.97$
 $b_5=-0.62$ $b_{11}=1.79$
 $b_7=0.11$ $b_{13}=-1.13$

Resulting harmonics

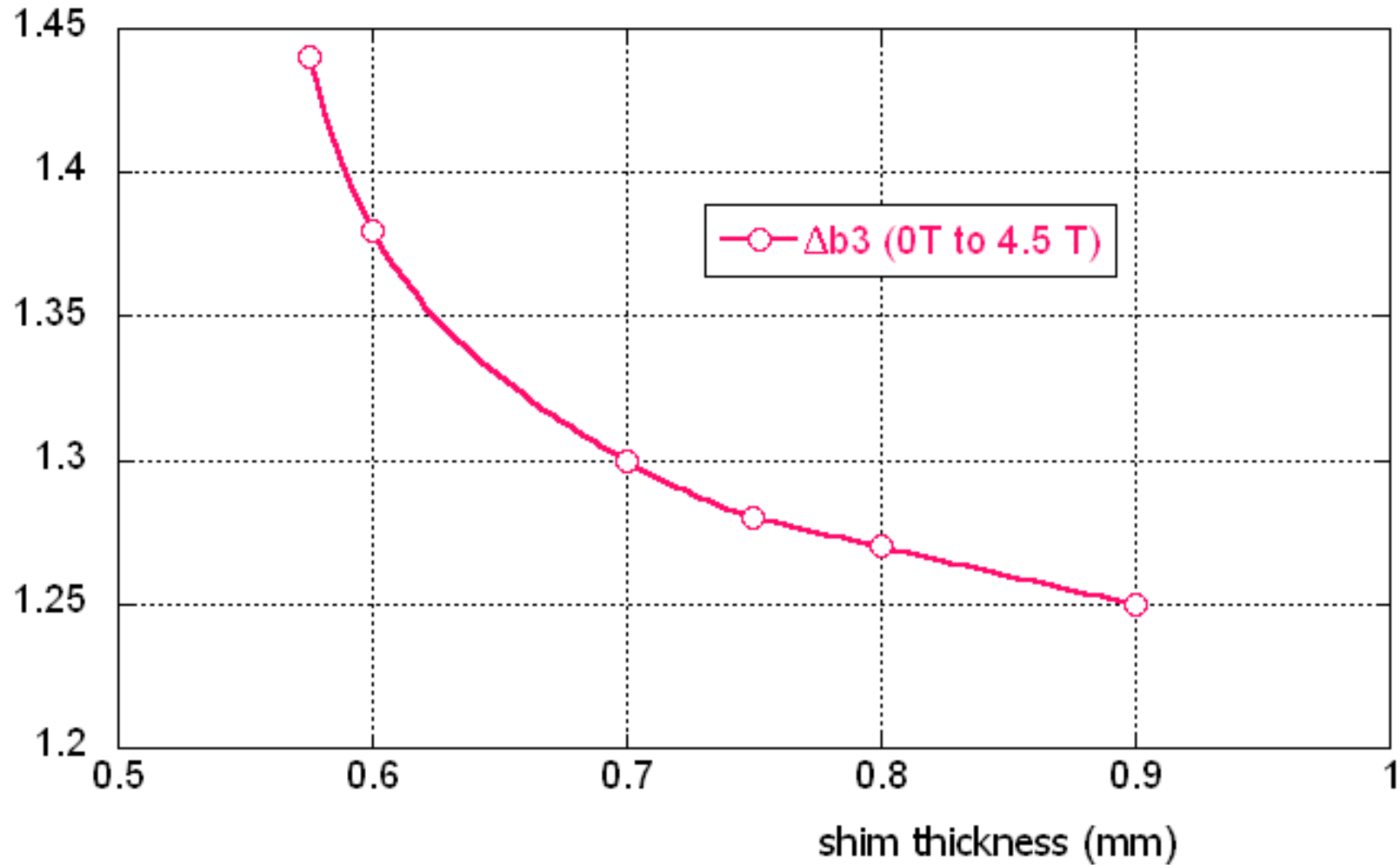
- the absolute values of b_3 (and b_5) have been corrected (even if not refined)
- the variation of b_3 (and b_5) during energization is almost unchanged



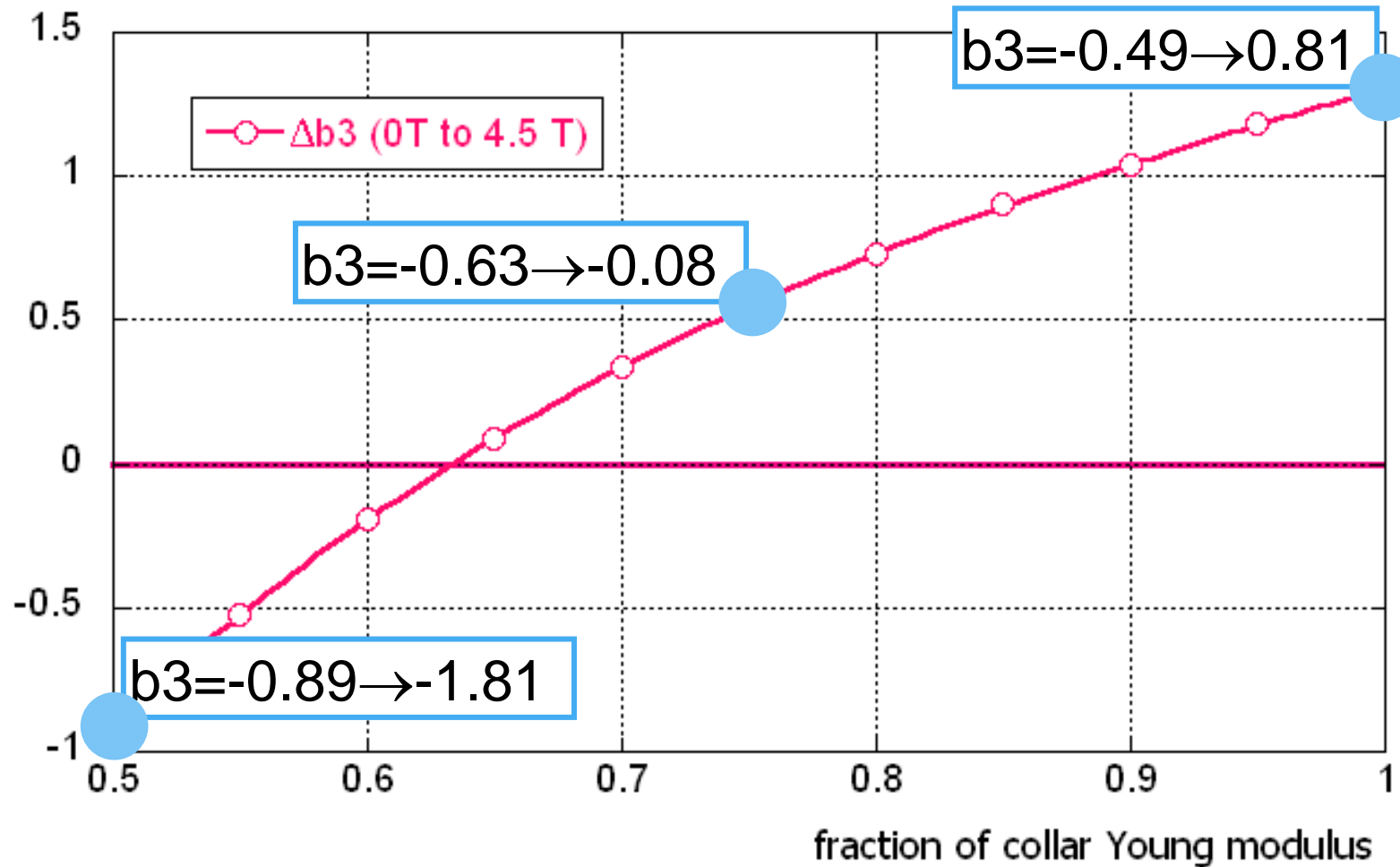
to understand the behavior of Δb_3 (and Δb_5) we can consider:

- ◆ the effect of the shim thickness
- ◆ the effect of the collar rigidity
- ◆ the effect of the collar thickness

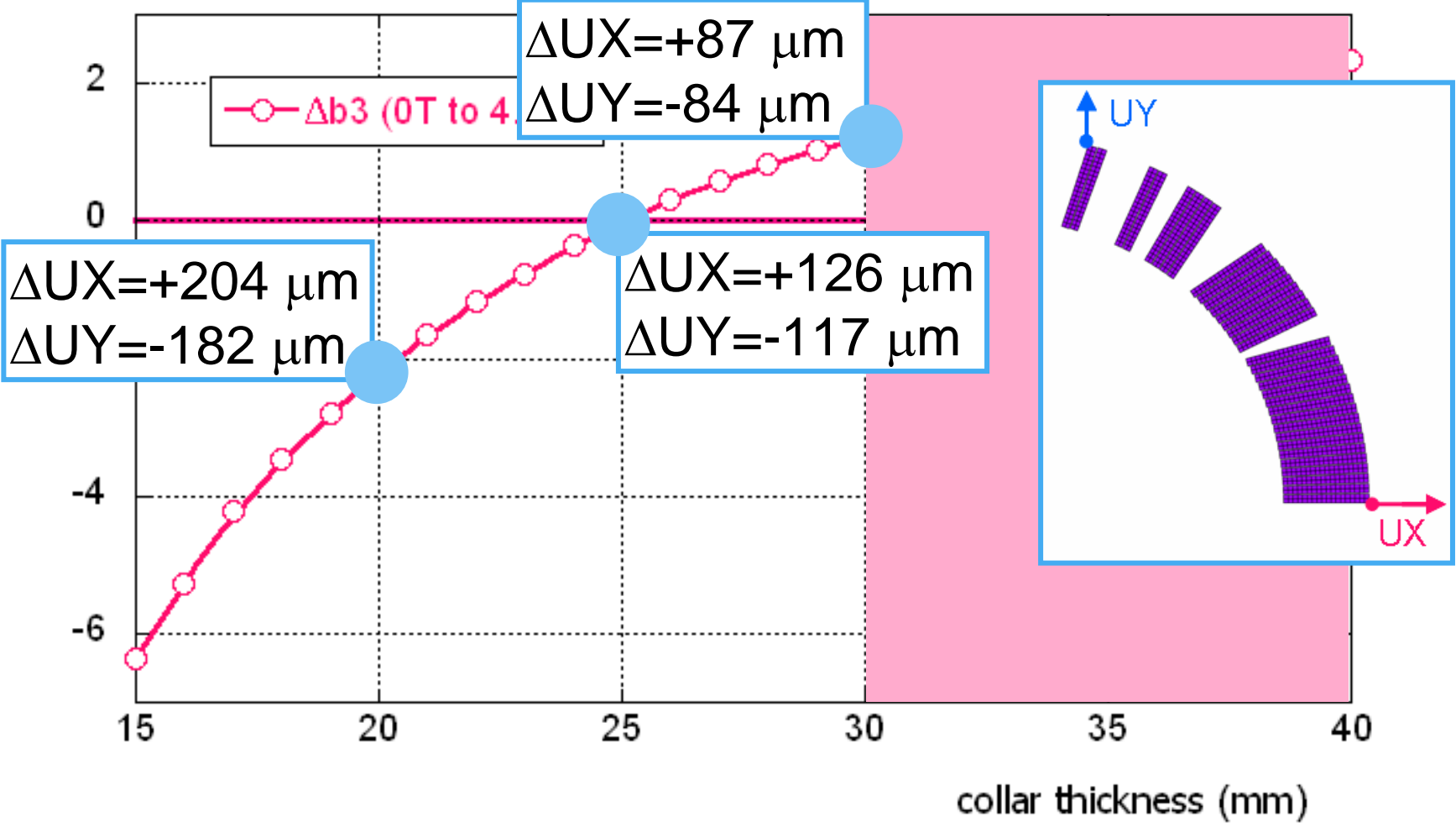
Variation of b_3 : effect of shim thickness



Variation of b_3 : effect of collar rigidity



Variation of b_3 : effect of collar thickness (keeping the same iron radius)



$U(1.5 T \rightarrow 4.5 T) \sim 2/3 U(0 T \rightarrow 4.5 T)$

- the best performance corresponds to a 25 mm thick collar

to gain further benefits, the internal radius of the iron yoke can be move correspondingly

Possible magnetic optimization (25 mm thick collar)

(using the conductor dimensions @ 4.5 K and 50 MPa)

	block #1	block #2	block #3	block #4	block #5
φ	0.1146	31.1016	52.3954	62.4748	73.3947
α	0	35.0614	54.1515	63.3538	74.2736

harmonics:

$$b_3=0.15$$

$$b_9=0.84$$

$$b_5=0.15$$

$$b_{11}=1.72$$

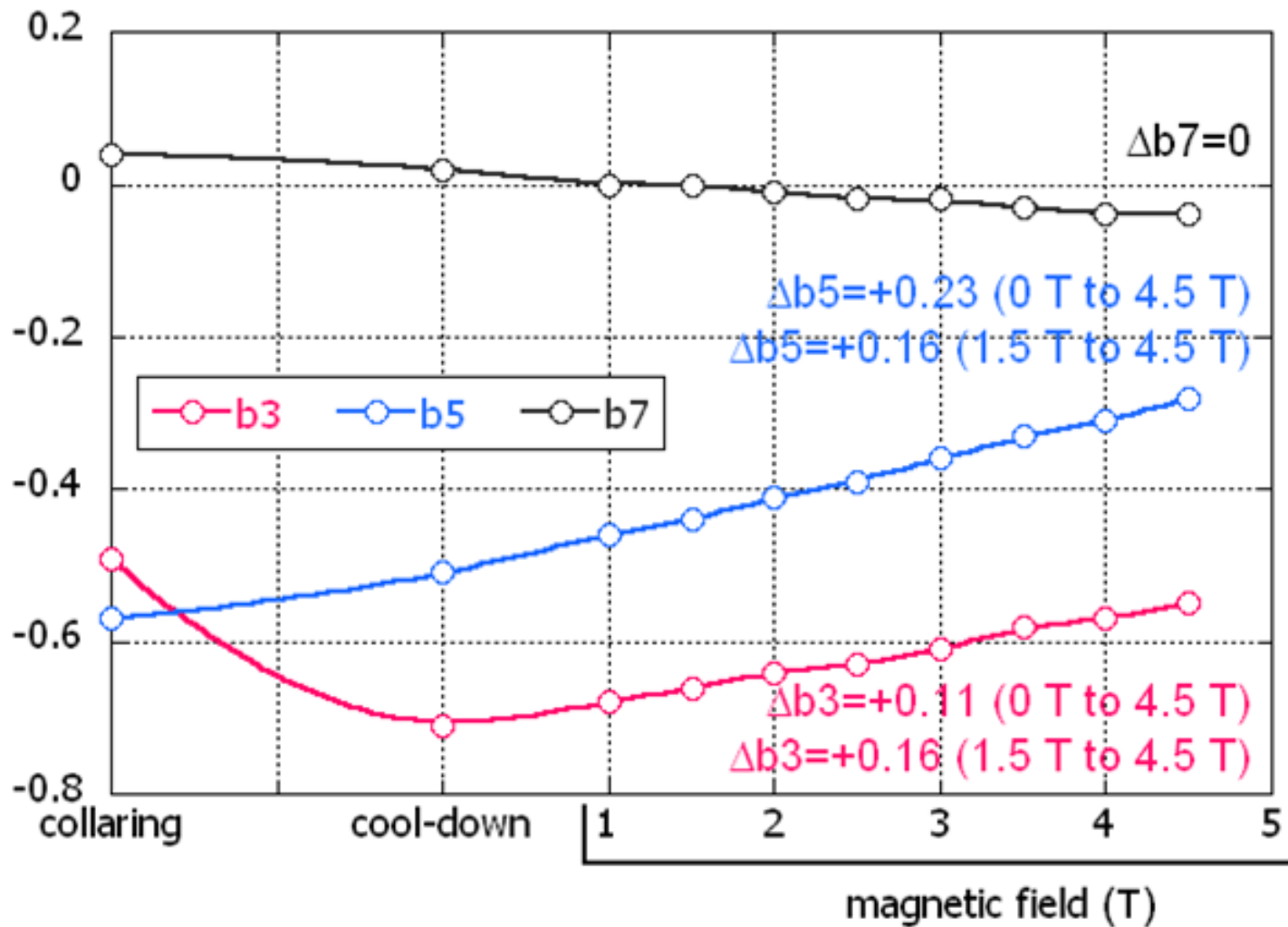
$$b_7=0.66$$

$$b_{13}=-1.22$$



$I=8653$ A (-3%), $B_{\text{peak}}=4.9$ T, $\Delta T(\text{roxie})=1.025$ K

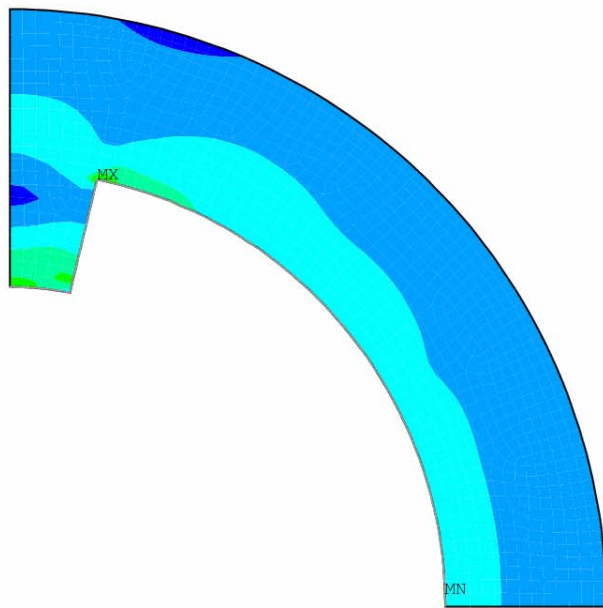
Resulting harmonics (after applying the transfer function)



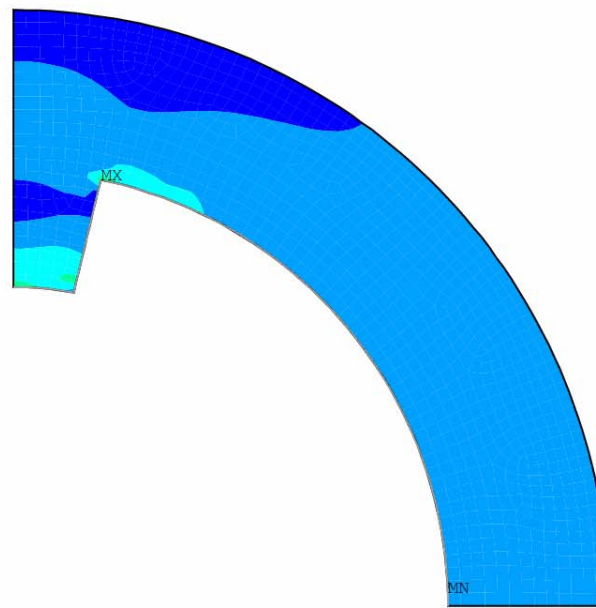
Von Mises stress in the collar (25 mm thick)

Nitronic40 has a yield stress of 900 MPa

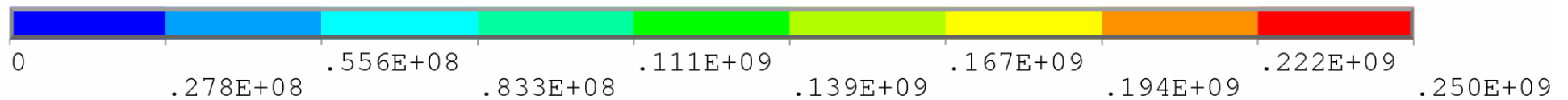
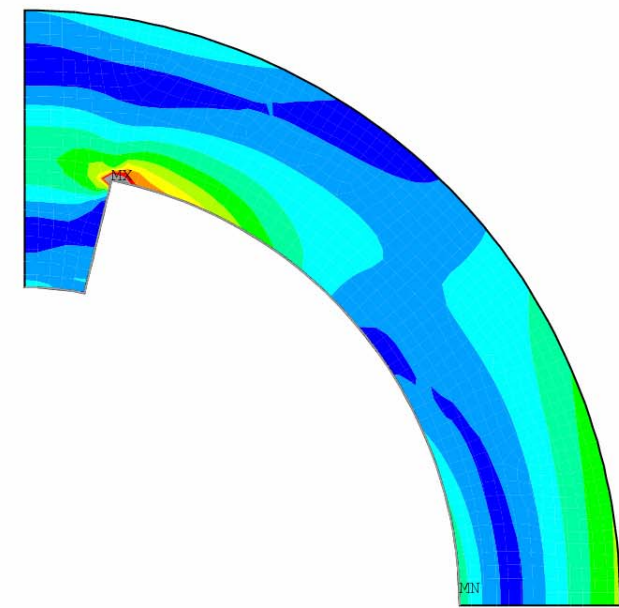
collaring



cool-down

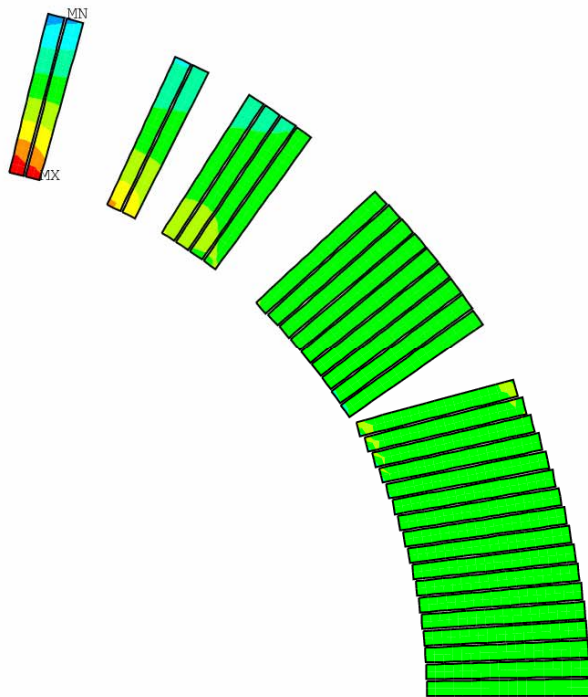


energization

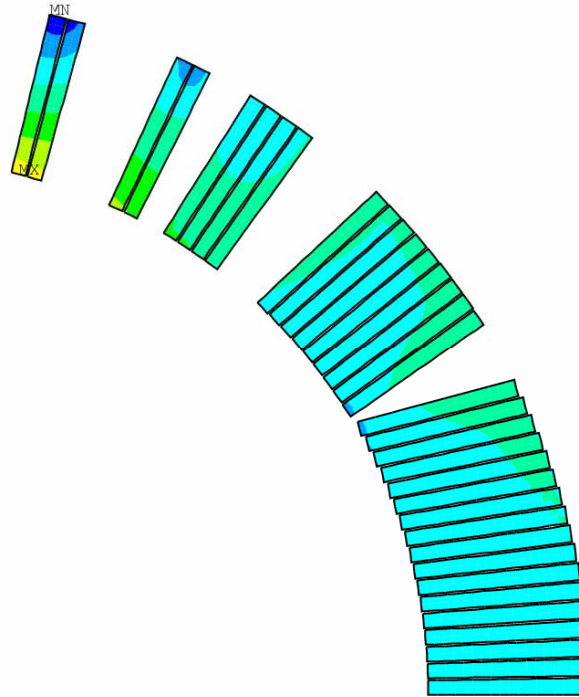


Von Mises stress in the winding (25 mm thick collar)

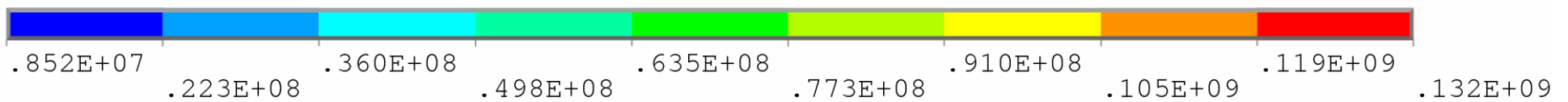
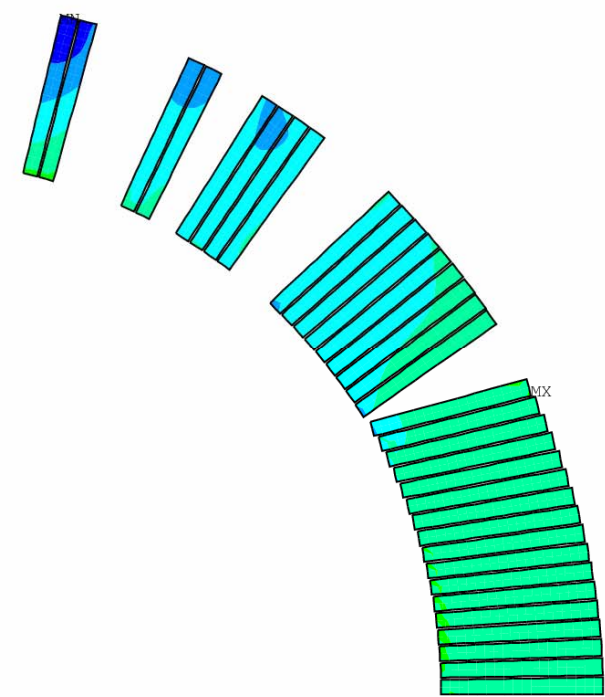
collaring
 $\sigma_{ave} = 72 \text{ MPa}$



cool-down
 $\sigma_{ave} = 49 \text{ MPa}$

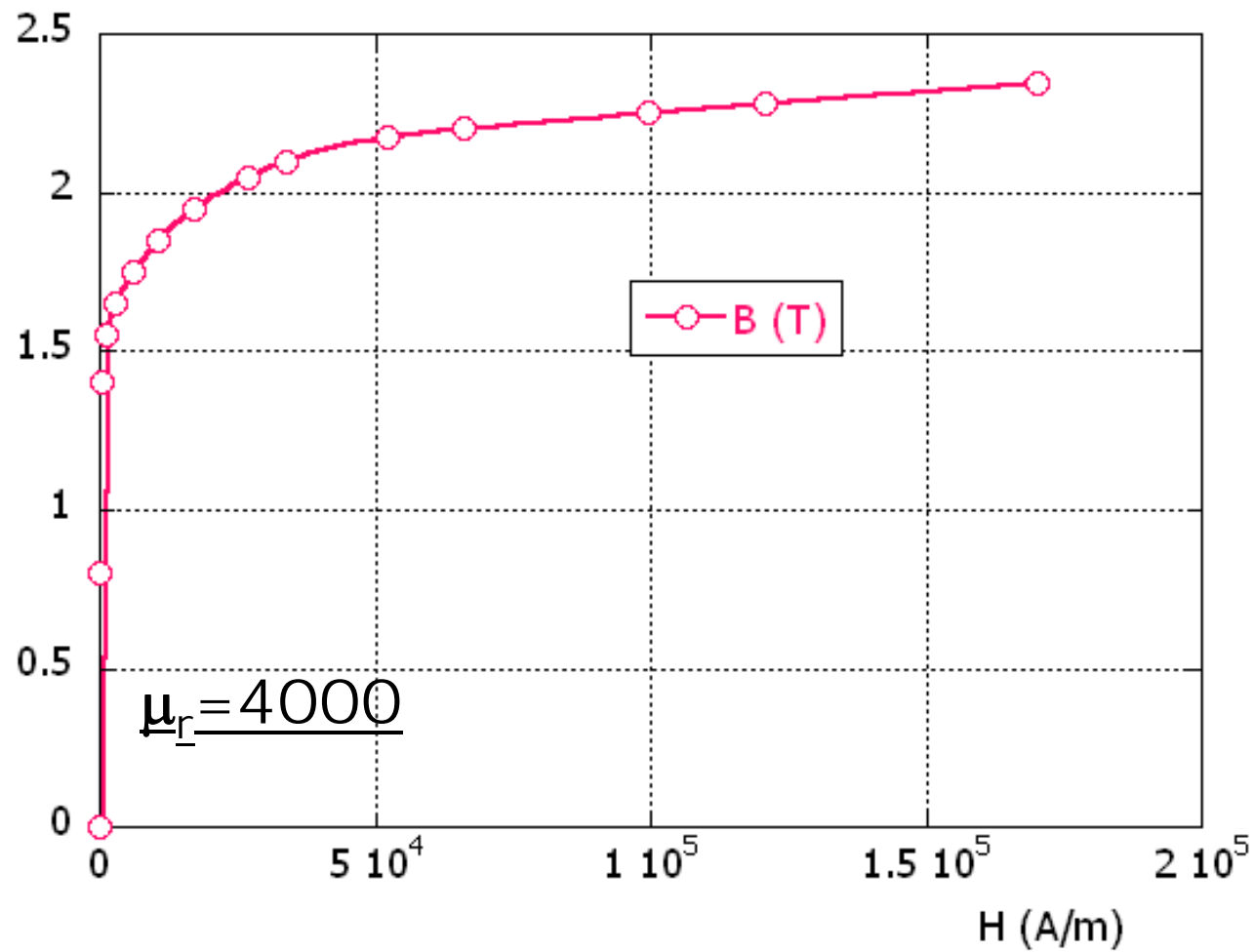


energization
 $\sigma_{ave} = 49 \text{ MPa}$

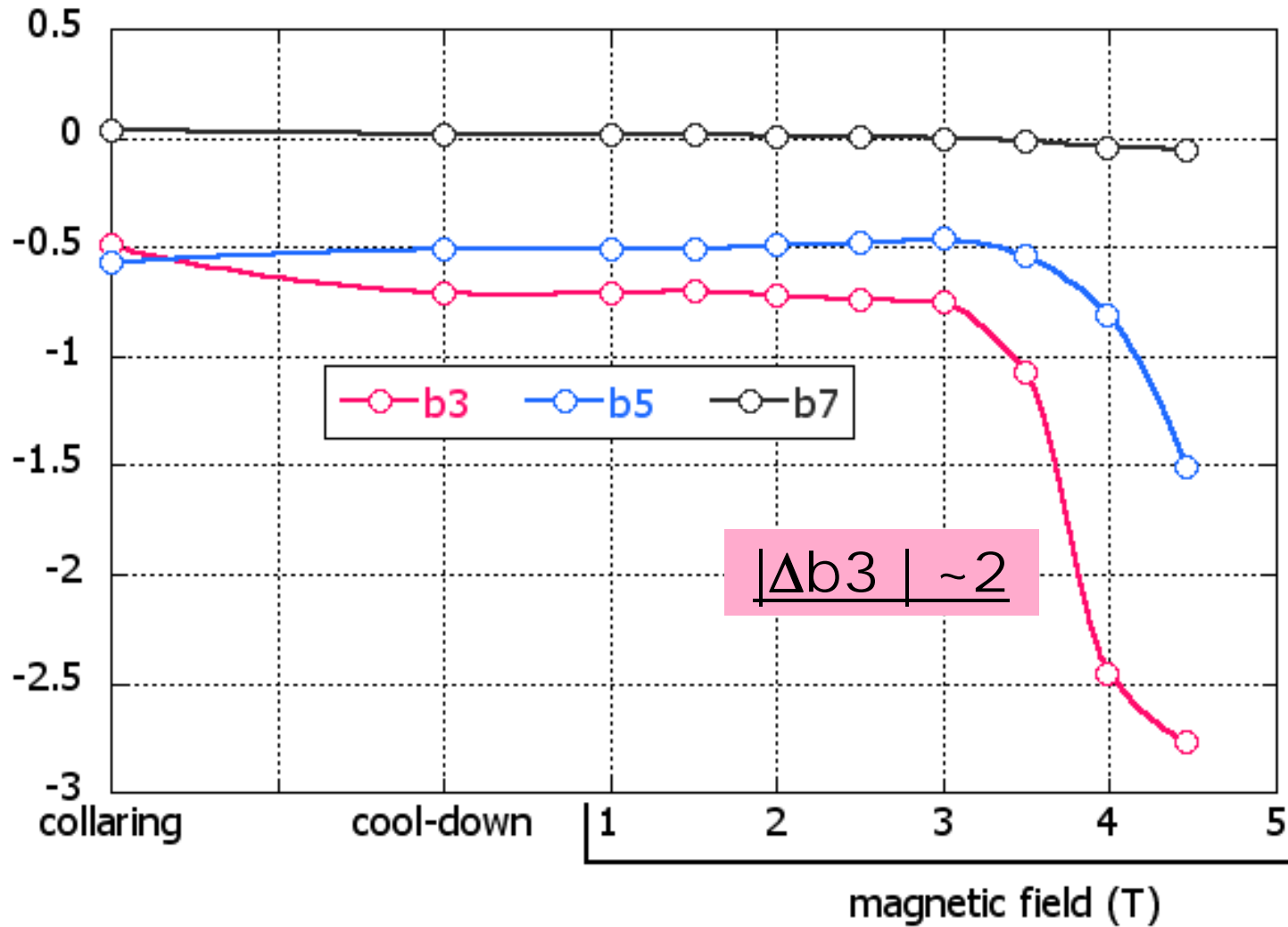


Some considerations on
non-linear iron

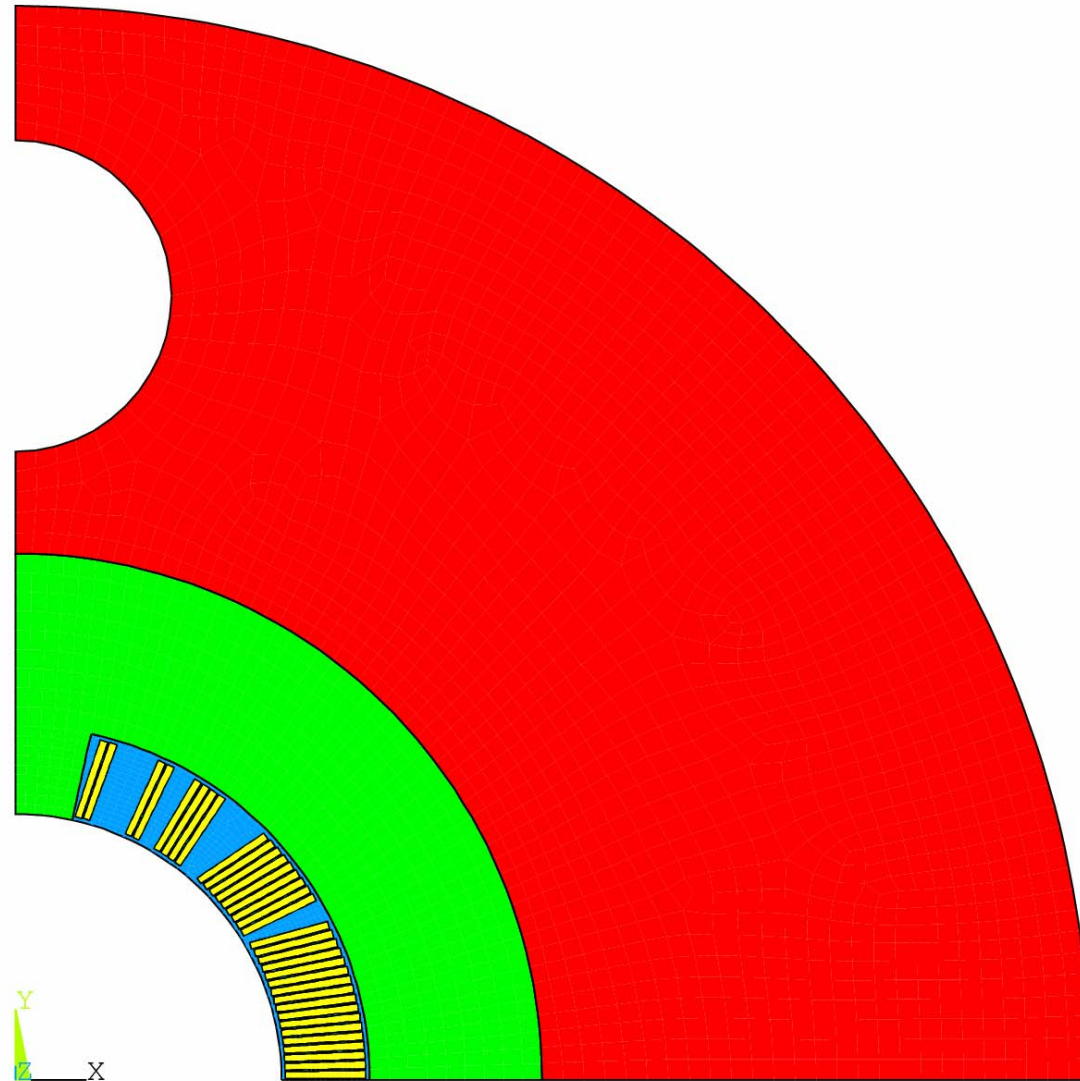
Non-linear BH curve from CMS iron



harmonics as function of field (no holes in the iron)



non linear iron with 1 hole (1/2 symmetry)



harmonics as function of field (hole height=150 mm, hole diameter=60 mm)

