Magnetic design of the large aperture HTS superconducting dipoles for the accelerator ring of the Muon Collider

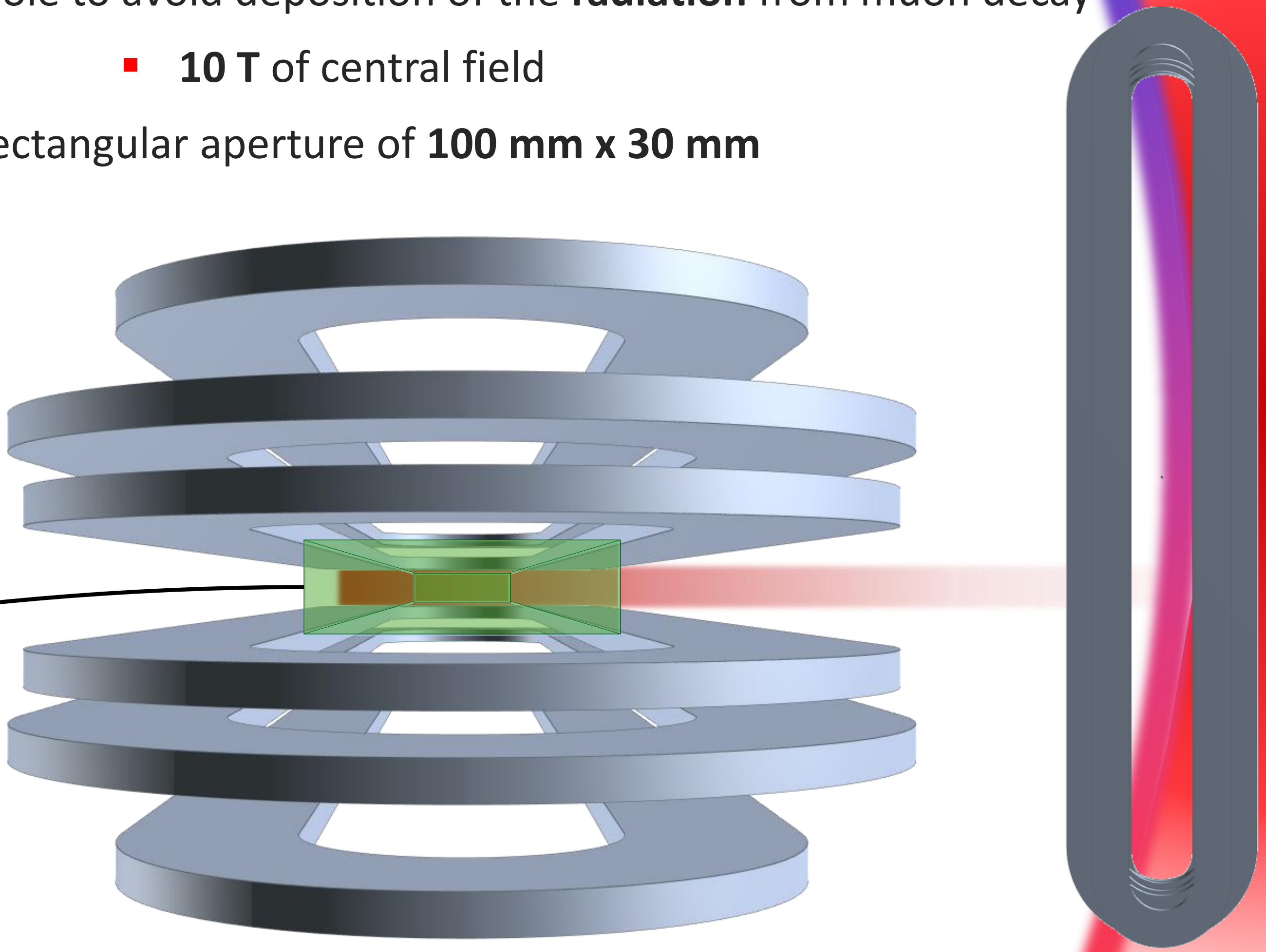
T. Maiello[1,4,5], L. Alfonso[1], L. Balconi[2,6], A. Bersani[1], L. Bottura[4], B. Caiffi[1], S. Fabbri[4], S. Farinon[1], A. Gagno[1,5], F. Levi[1], F. Mariani[2,6], S. Mariotto[2,3], D. Novelli[1,6], A. Pampaloni[1], D. Rinaldoni [4], C. Santini[2], S. Sorti[2,3], M. Statera[2] , G. Vernassa[2]

[1] INFN – Genova, [2] INFN LASA – Milano, [3] University of Milan, [4] CERN, [5] Università degli Studi di Genova, [6] Sapienza Università di Roma

REQUIREMENTS FOR THE SC DIPOLES

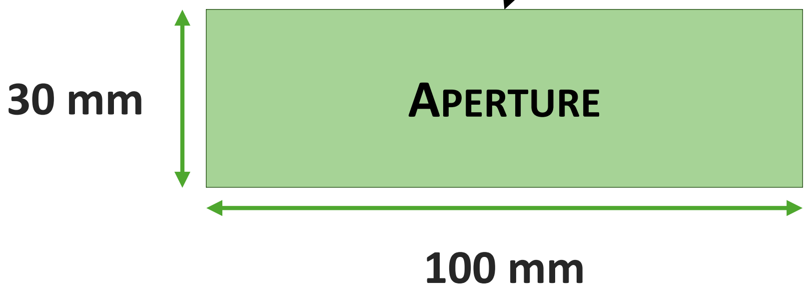
Main characteristics:

- **Open midplane** dipole to avoid deposition of the **radiation** from muon decay
- **10 T** of central field
- Rectangular aperture of **100 mm x 30 mm**



Proposed solution:

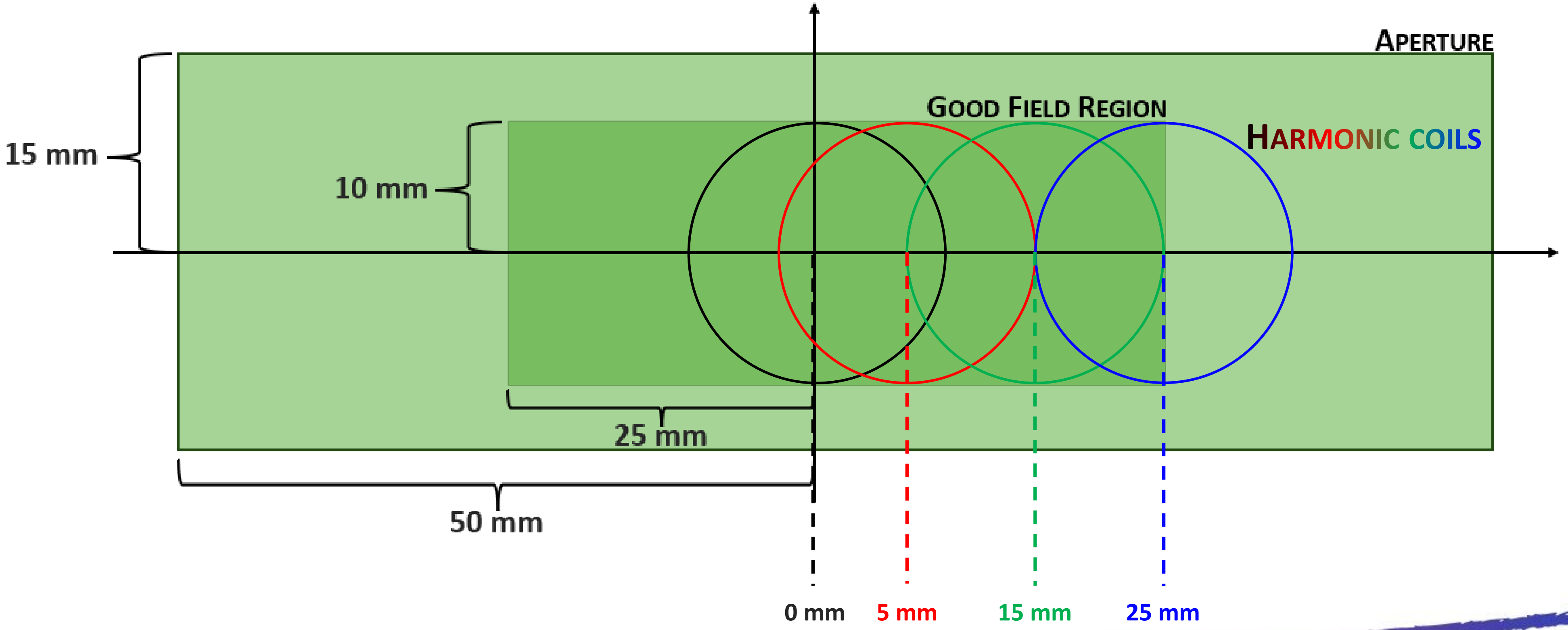
Magnet design based on **metal insulated HTS racetracks**



Requirements for the SC dipoles

Field quality requirements:

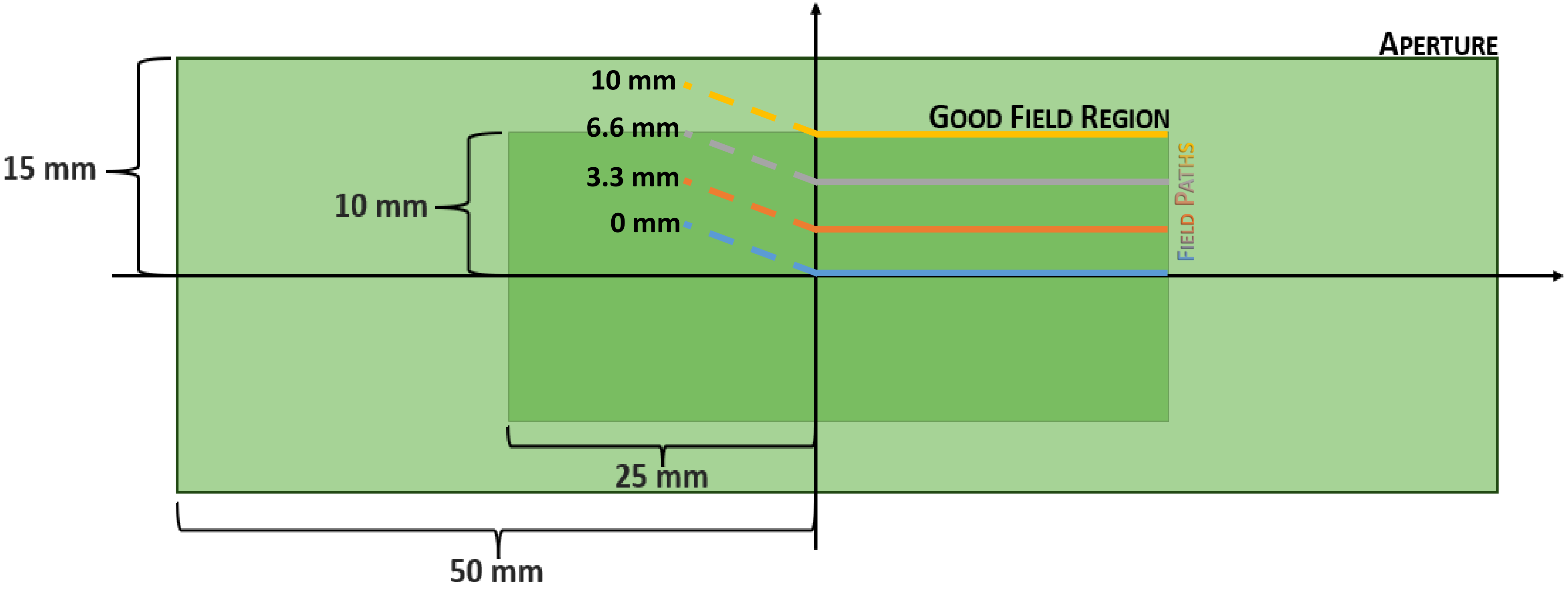
- Rectangular aperture of **100 mm x 30 mm**
- Rectangular good field region of **50 mm x 20 mm** → First question: are these numbers confirmed, or can they be reduced?
- Field **quality**: $b_n < 10$ units in beam radius of **10 mm**



REQUIREMENTS FOR THE SC DIPOLES

Field quality requirements:

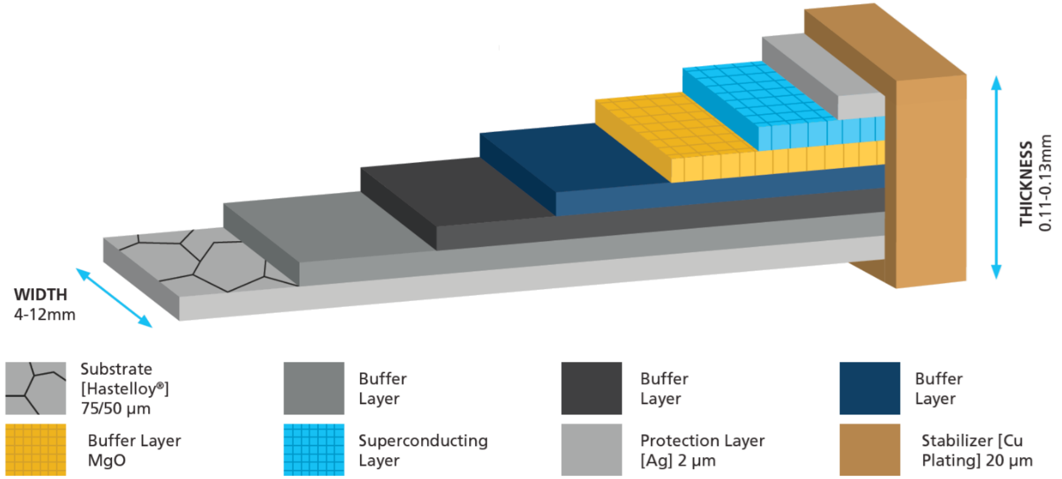
- Rectangular aperture of **100 mm x 30 mm**
- Rectangular good field region of **50 mm x 20 mm** → First question: are these numbers confirmed, or can they be reduced?
- Field **homogeneity** ≤ 1% in the good field region



HTS Cable Assumptions

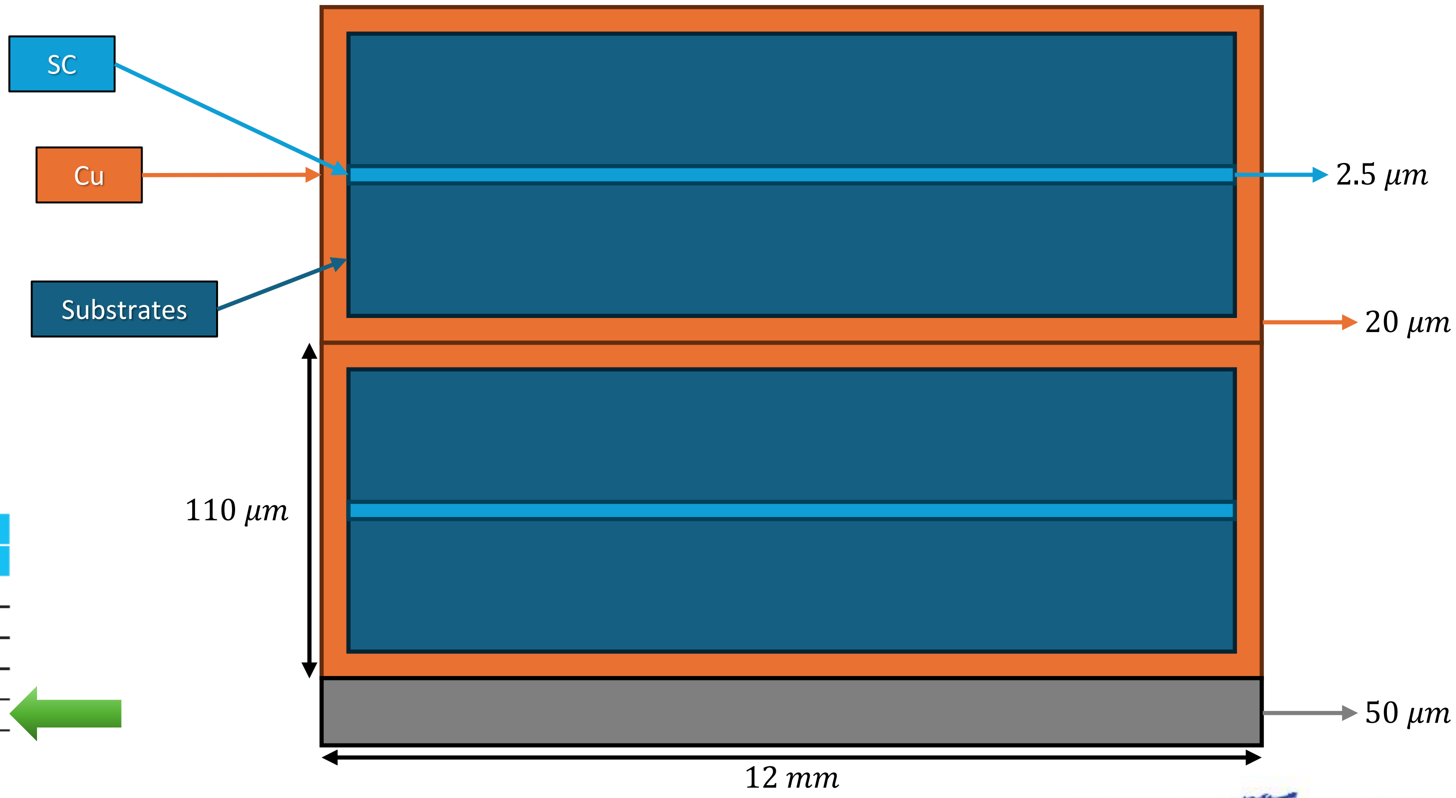
- The **conductor** consists of **two tapes** and **one** $50\ \mu m$ **SS strip**.
- The **SC** is based on a commercial **YBCO** tape from **Fujikura**

→ Same assumption as for the **collider** studies



Products	Width (mm)	Thickness (mm)	Substrate (µm)	Stabilizer (µm)	Critical Current (A)	
					77K, S.F.	20K, 5T*3
FYSC-SCH04	4	0.13	75	20	≥165	368
FYSC-SCH12	12	0.13	75	20	≥550	-
FYSC-512 * 1	12	0.08	75	-	≥550	-
FESC-SCH04 * 2	4	0.11	50	20	≥85	514
FESC-SCH12 * 2	12	0.11	50	20	≥250	-

*1 HTS wire without copper stabilizer is available in only 12mm wide for current lead applications.
*2 Artificial pinning specification for use at low temperature and high magnetic field
*3 Ic@20K, ST is a reference value and no guarantee of the actual performance.

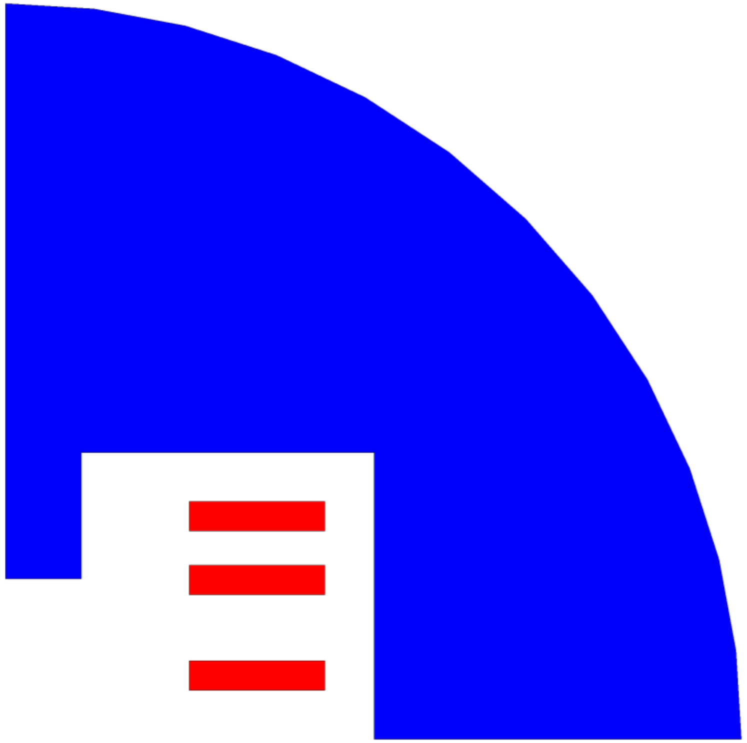


$A_{tot} = 3.24\ mm^2 \quad A_{SC} = 0.0598\ mm^2 \quad A_{Cu} = 0.9656\ mm^2$

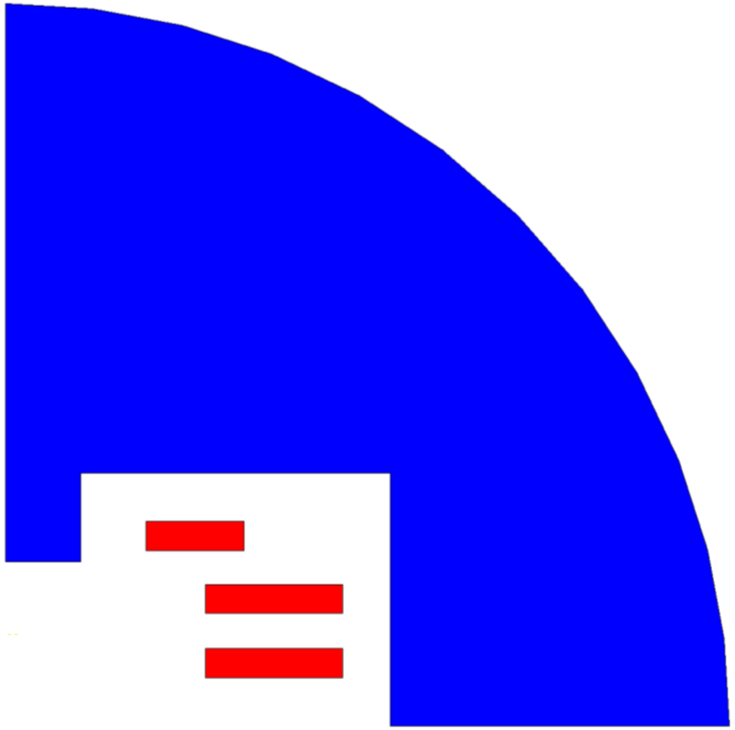
CONFIGURATIONS

Several configurations were found to meet various magnetic requirements. Since 3 racetracks are required, the possibilities are:

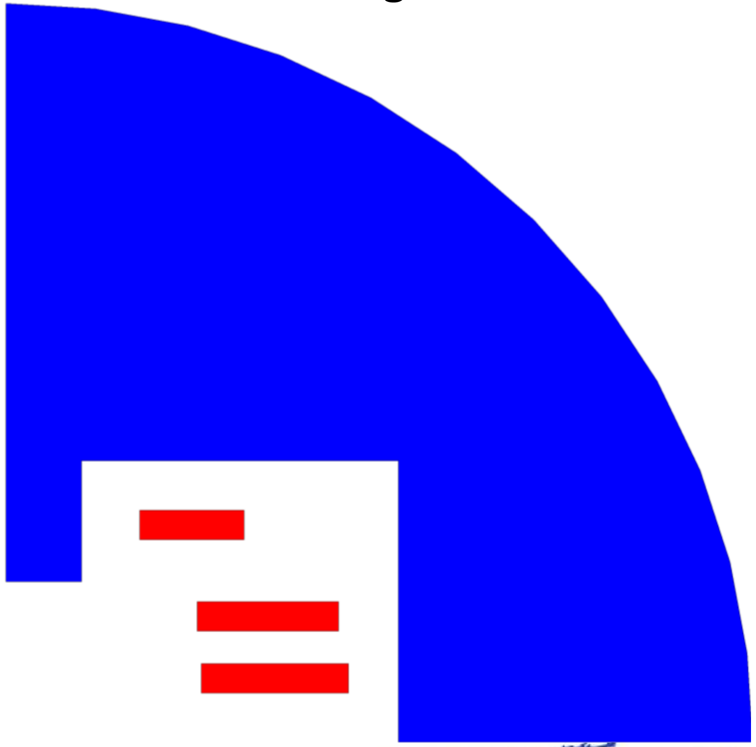
3 aligned



2 aligned



no aligned



3 Aligned Magnetic Design

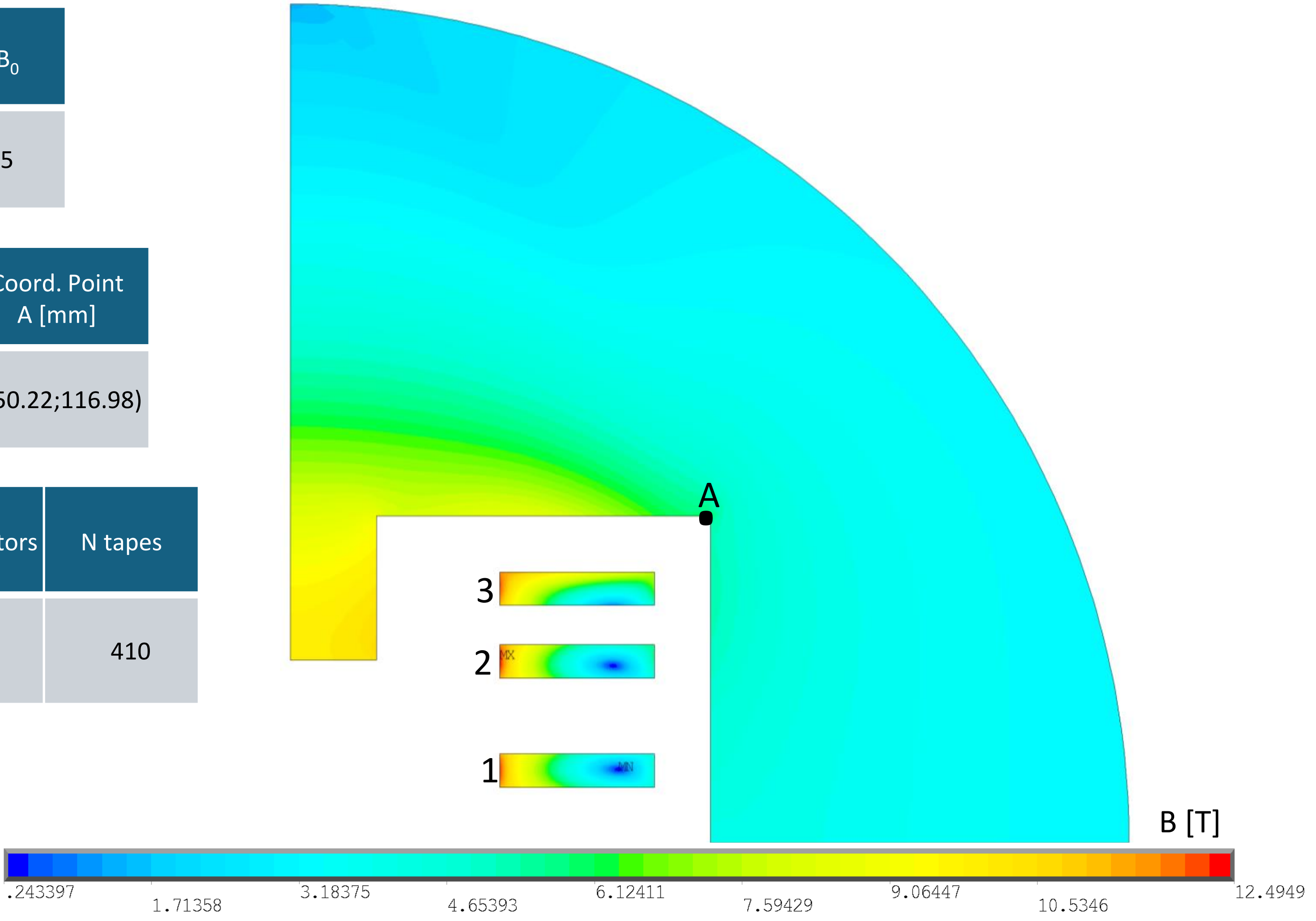
I [A]	J_{eng} [A/mm²]	B_0 [T]	B_p [T]	B_p/B_0
2336.12	721.02	10.00	12.49	1.25

T_{op} [K]	T margin [K]	Mag Length [m]	Mec Length [m]	Yoke radius [m]	Coord. Point A [mm]
20	>2.5	~1.3	~1.6	0.3	(150.22;116.98)

Racetrack 1	N conductors	N tapes
	205	410

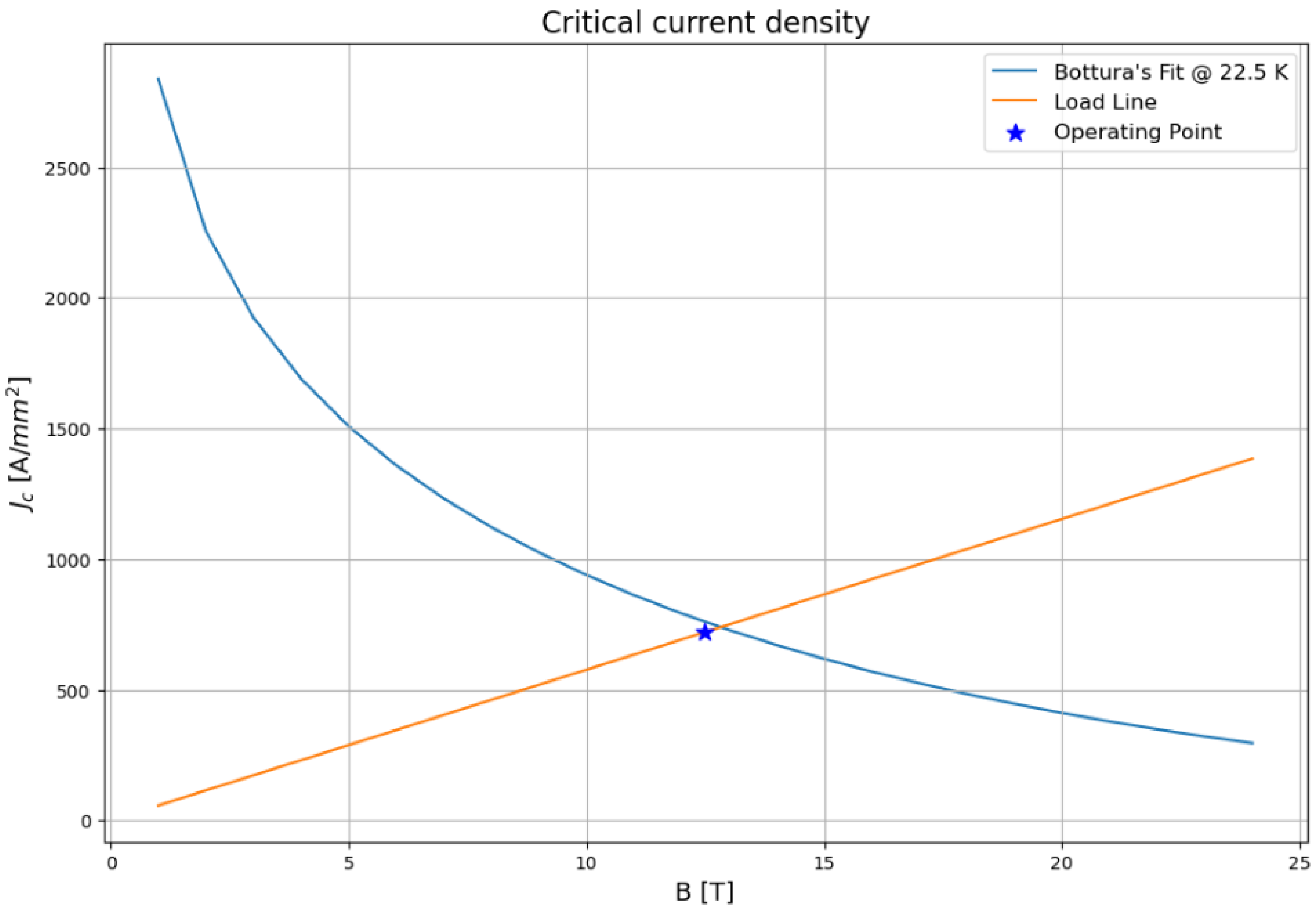
Racetrack 2	N conductors	N tapes
	205	410

Racetrack 3	N conductors	N tapes
	205	410



3 ALIGNED MAGNETIC DESIGN

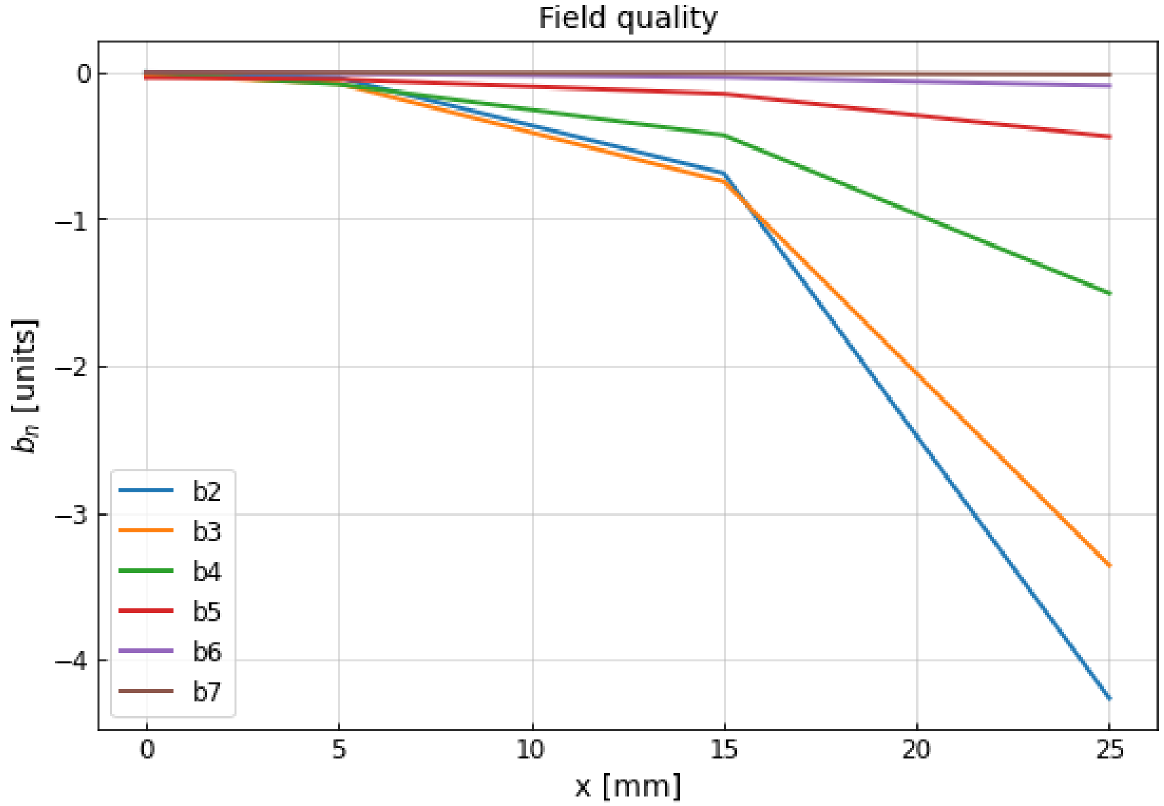
Margin in temperature

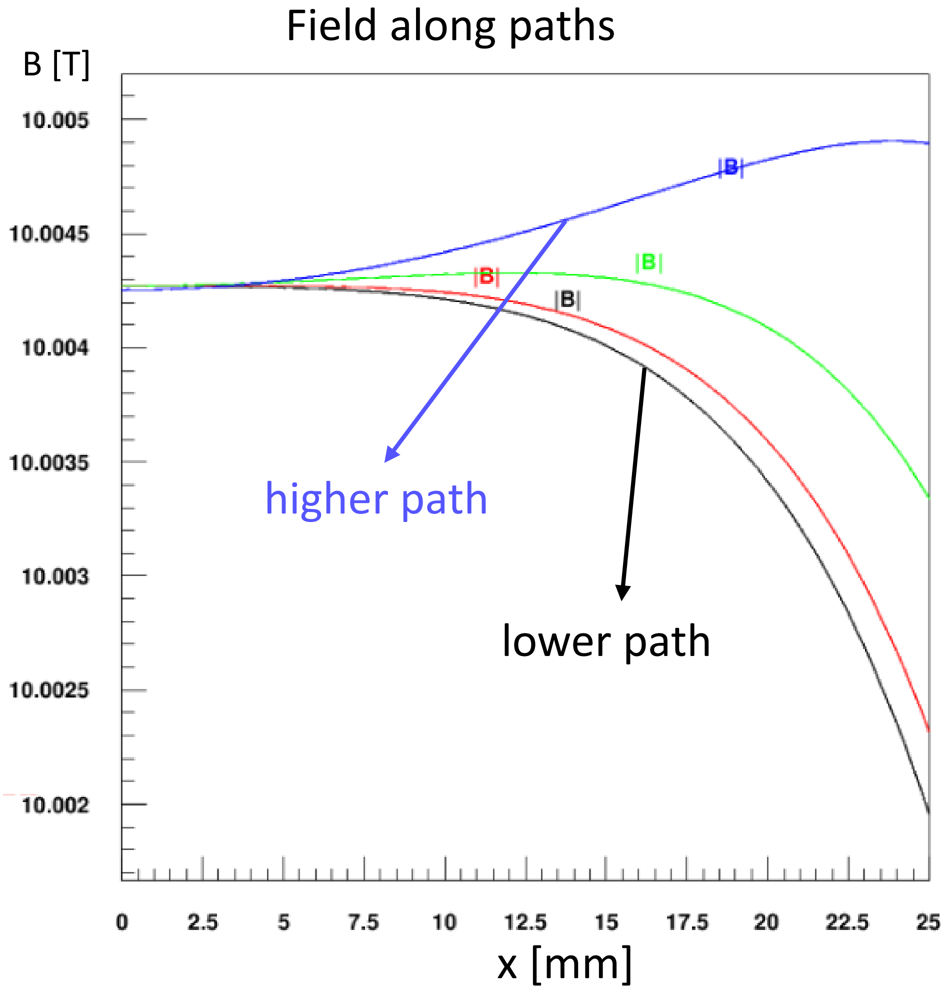


3 Aligned Magnetic Design

Results:

- All harmonics **greatly less** then **10 units**
- The harmonics higher than the 7th order are **negligible** (less than 0.003 units)
- The field **homogeneity** evaluated at x = 25 mm is about **0.029%**





2 Aligned Magnetic Design

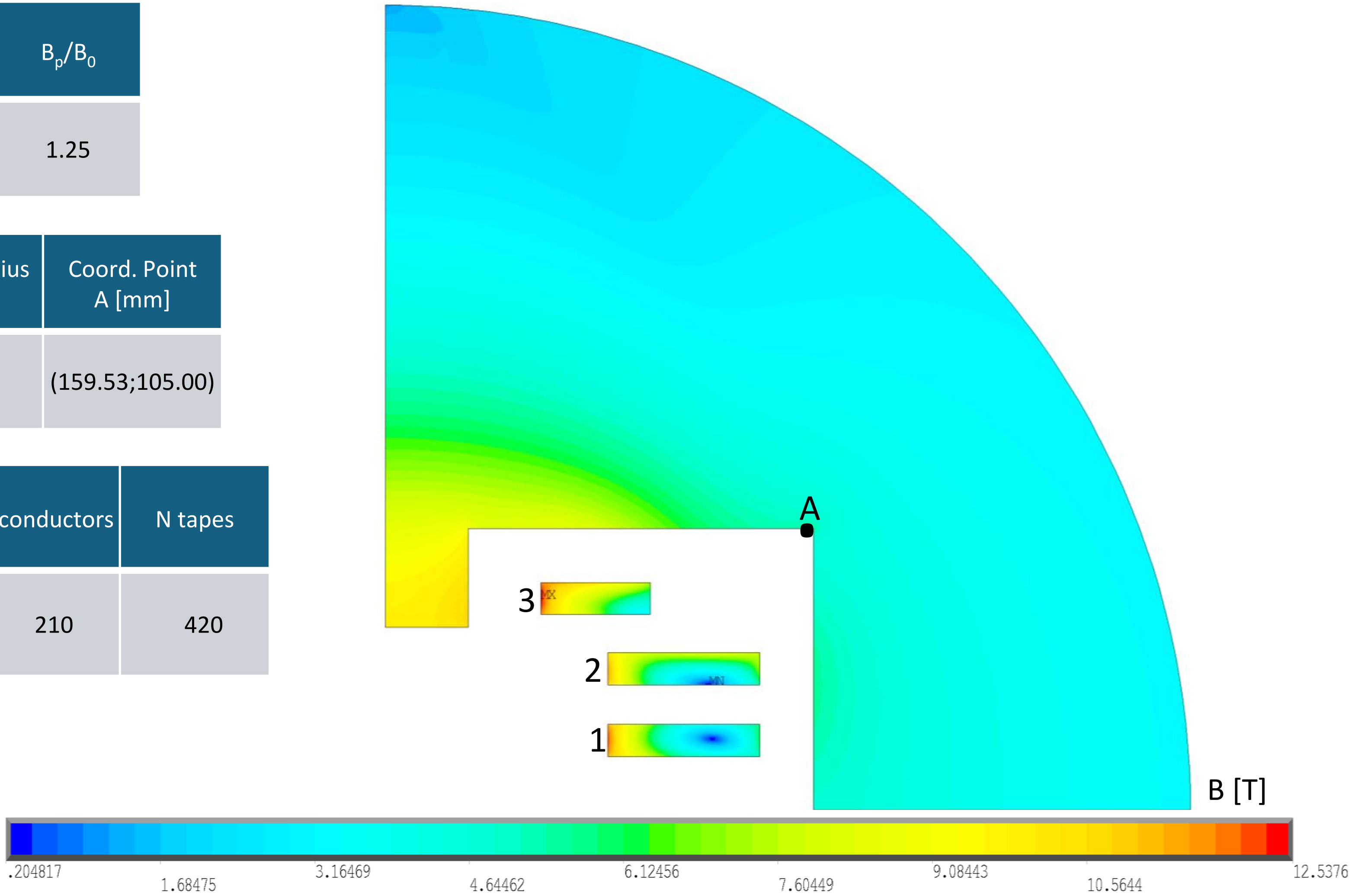
I [A]	J_{eng} [A/mm²]	B_0 [T]	B_p [T]	B_p/B_0
2392.00	738.27	10	12.54	1.25

T_{op} [K]	T margin [K]	Mag Length [m]	Mec Length [m]	Yoke radius [m]	Coord. Point A [mm]
20	>2.5	~1.3	~1.6	0.3	(159.53;105.00)

Racetrack 1	N conductors	N tapes
	210	420

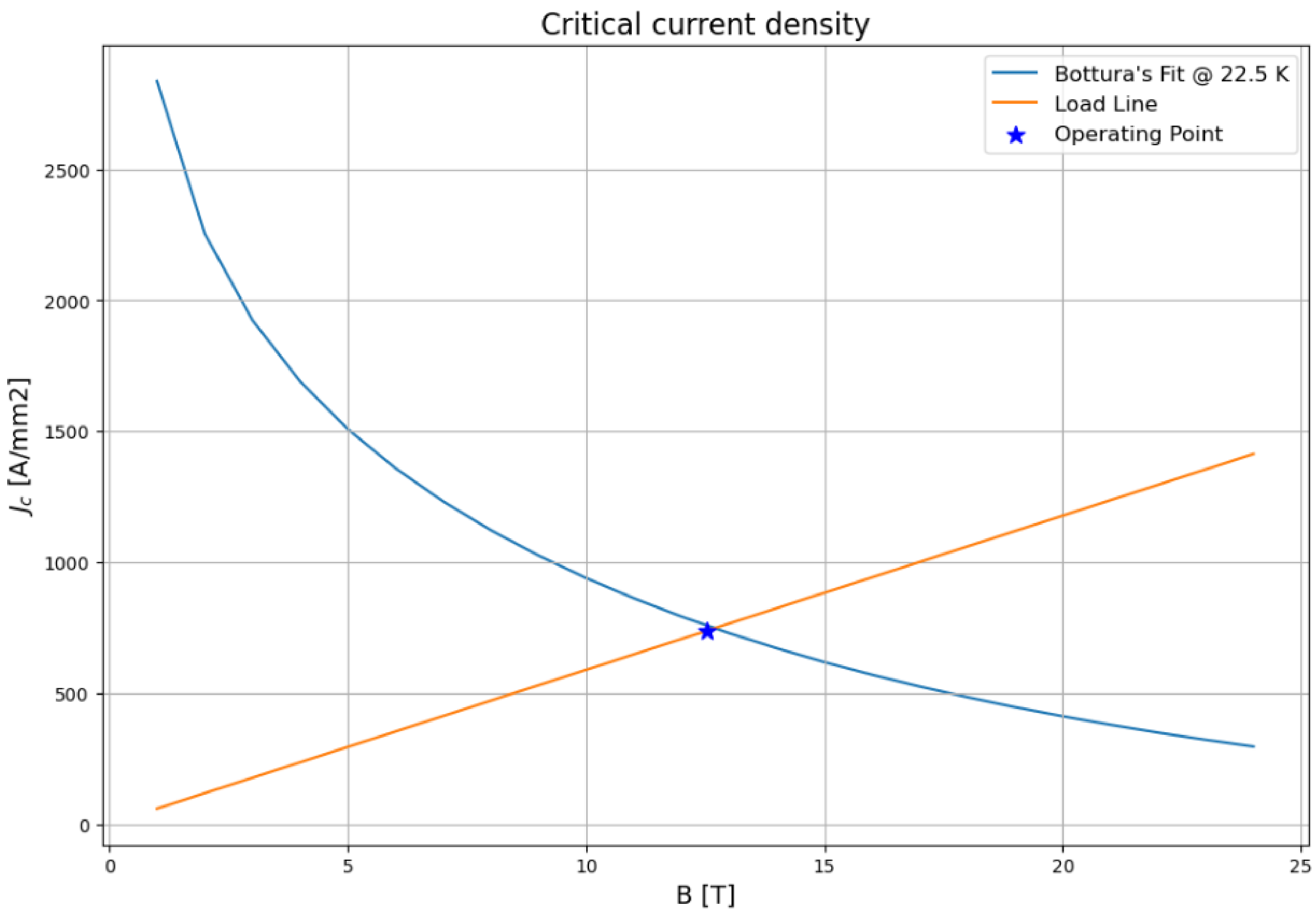
Racetrack 2	N conductors	N tapes
	210	420

Racetrack 3	N conductors	N tapes
	151	302



2 Aligned Magnetic Design

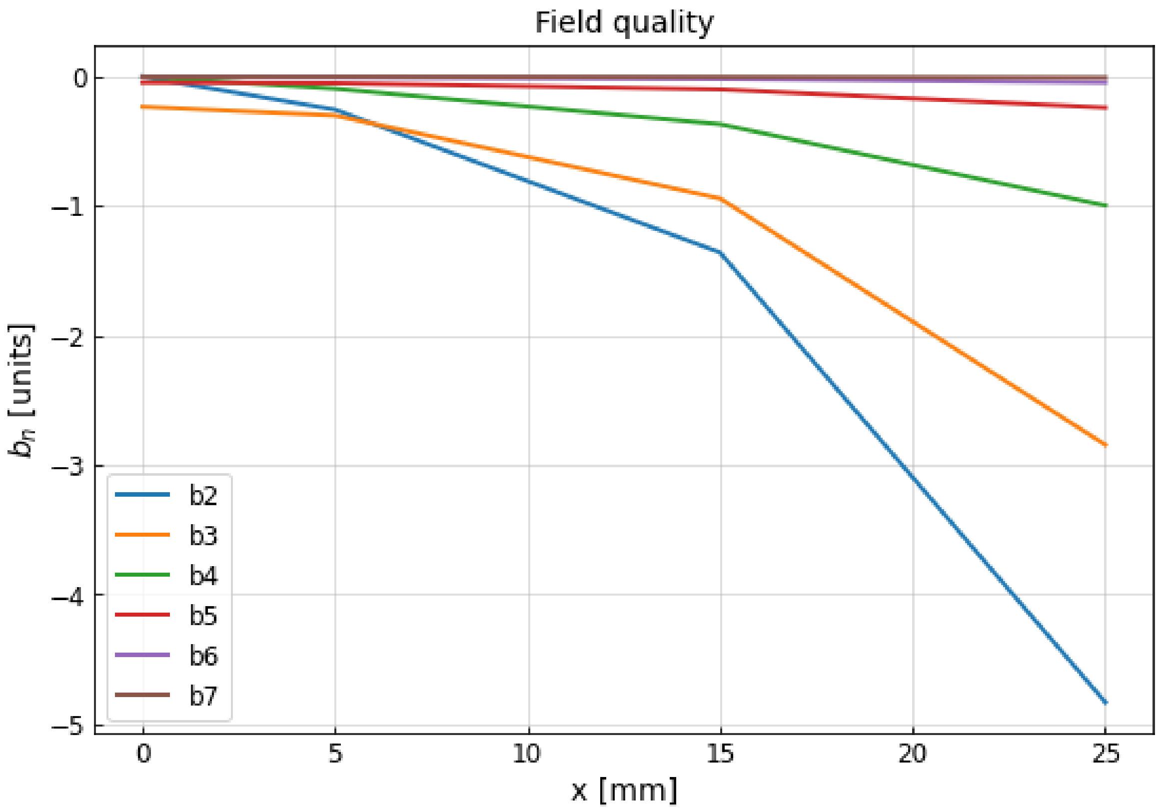
Margin in temperature

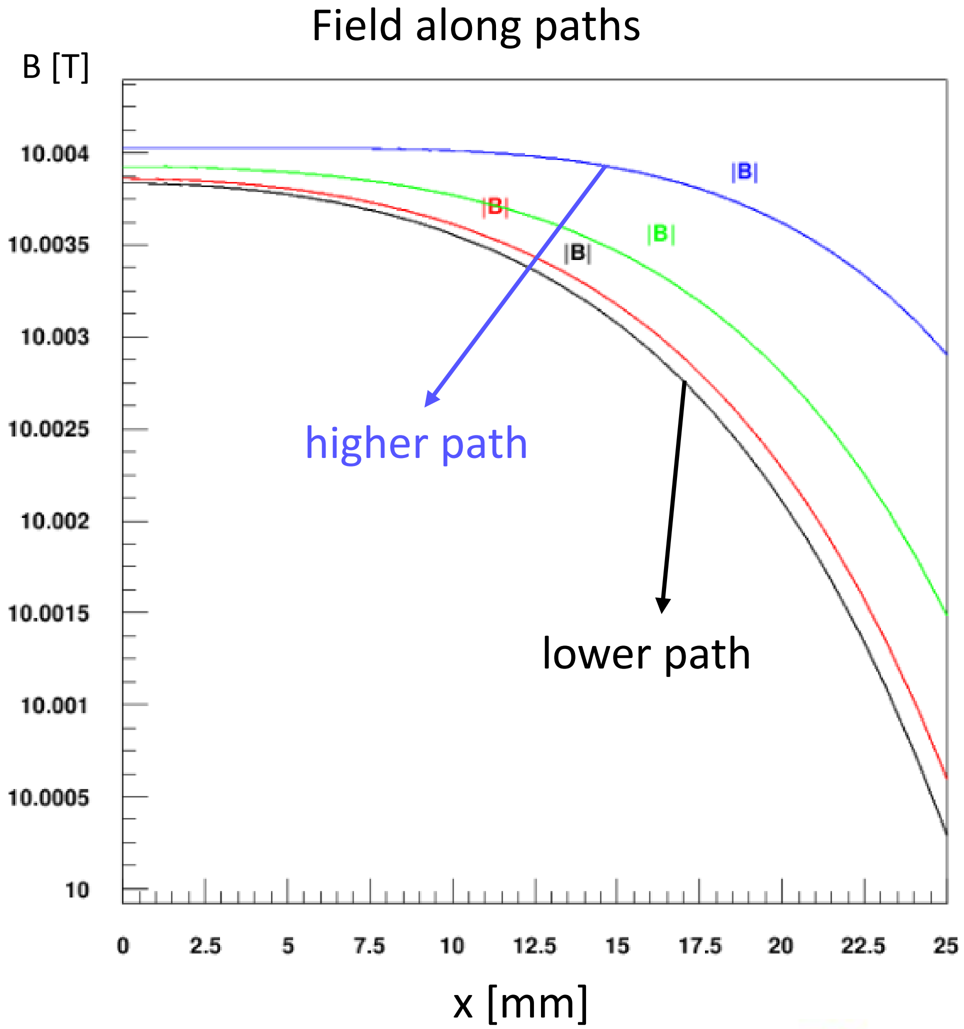


2 Aligned Magnetic Design

Results:

- All harmonics **greatly less** then **10 units**
- The harmonics higher than the 7th order are **negligible** (less than 0.003 units)
- The field **homogeneity** evaluated at x = 25 mm is about **0.033%**





0 Aligned Magnetic Design

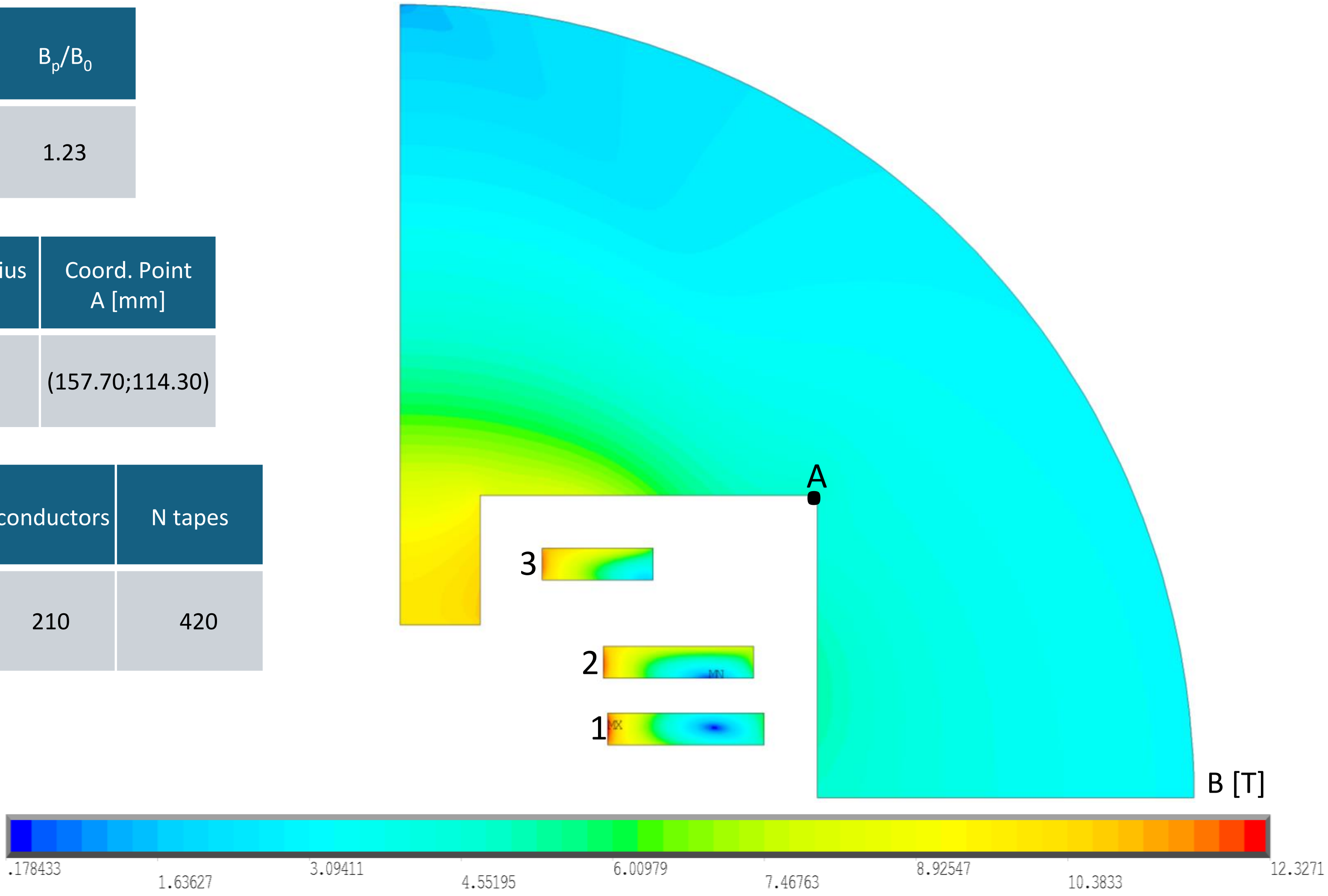
I [A]	J_{eng} [A/mm²]	B_0 [T]	B_p [T]	B_p/B_0
2347.61	724.47	10	12.33	1.23

T_{op} [K]	T margin [K]	Mag Length [m]	Mec Length [m]	Yoke radius [m]	Coord. Point A [mm]
20	>2.5	~1.3	~1.6	0.3	(157.70;114.30)

Racetrack 1	N conductors	N tapes
	219	438

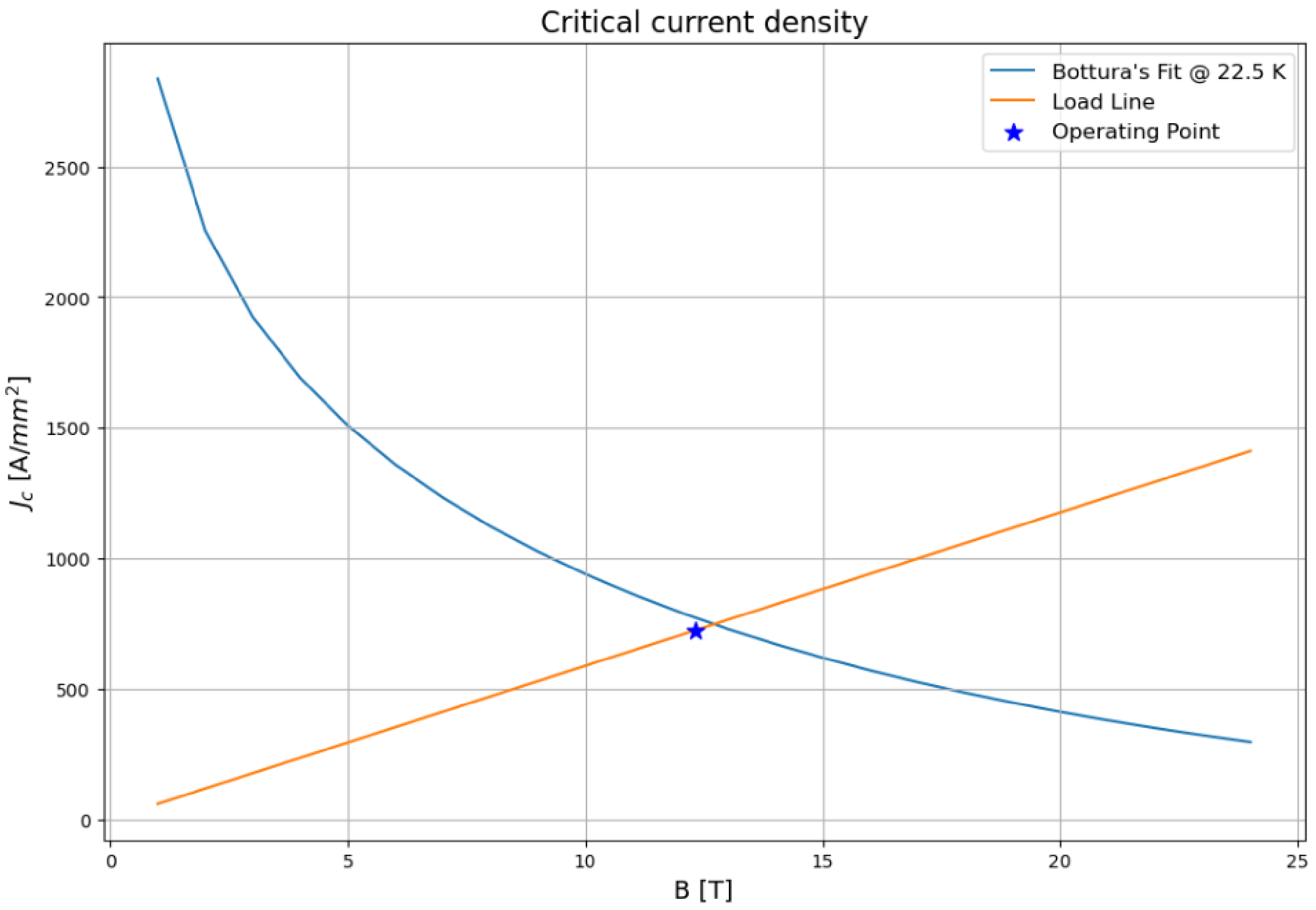
Racetrack 2	N conductors	N tapes
	210	420

Racetrack 3	N conductors	N tapes
	155	310



0 ALIGNED MAGNETIC DESIGN

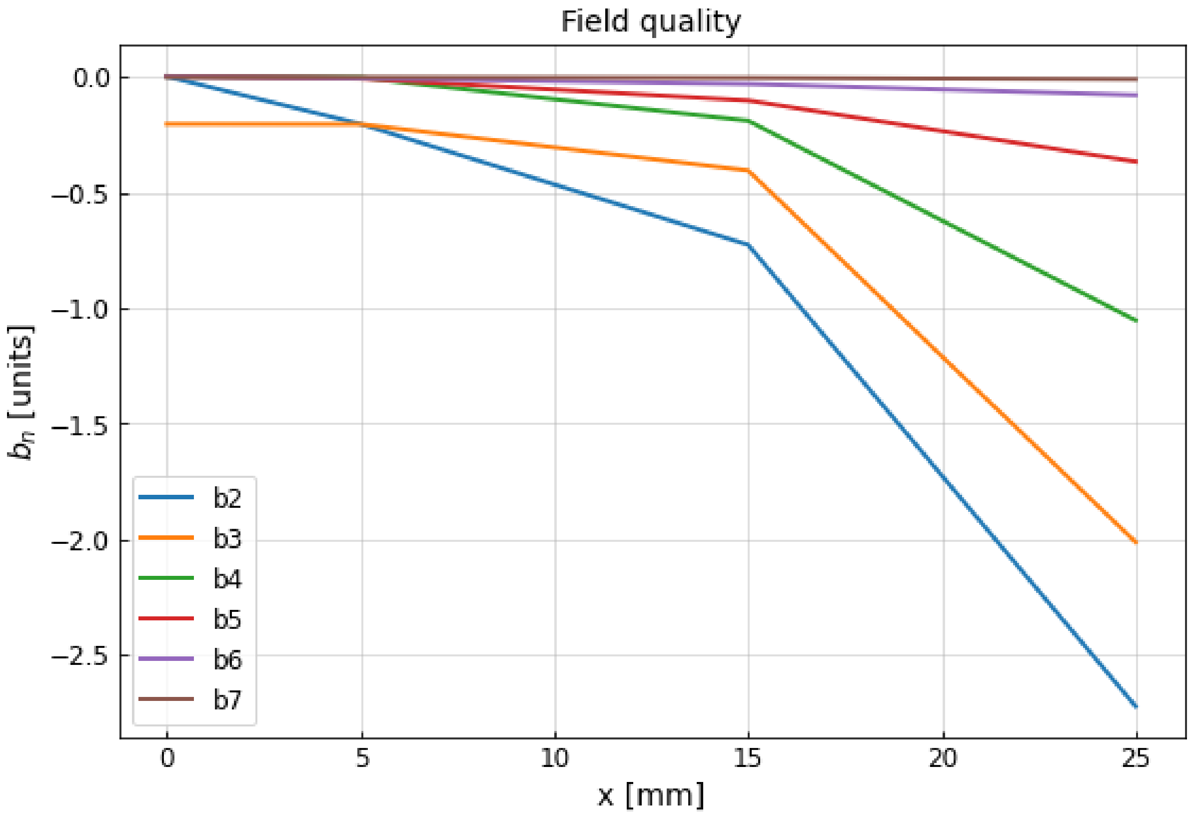
Margin in temperature

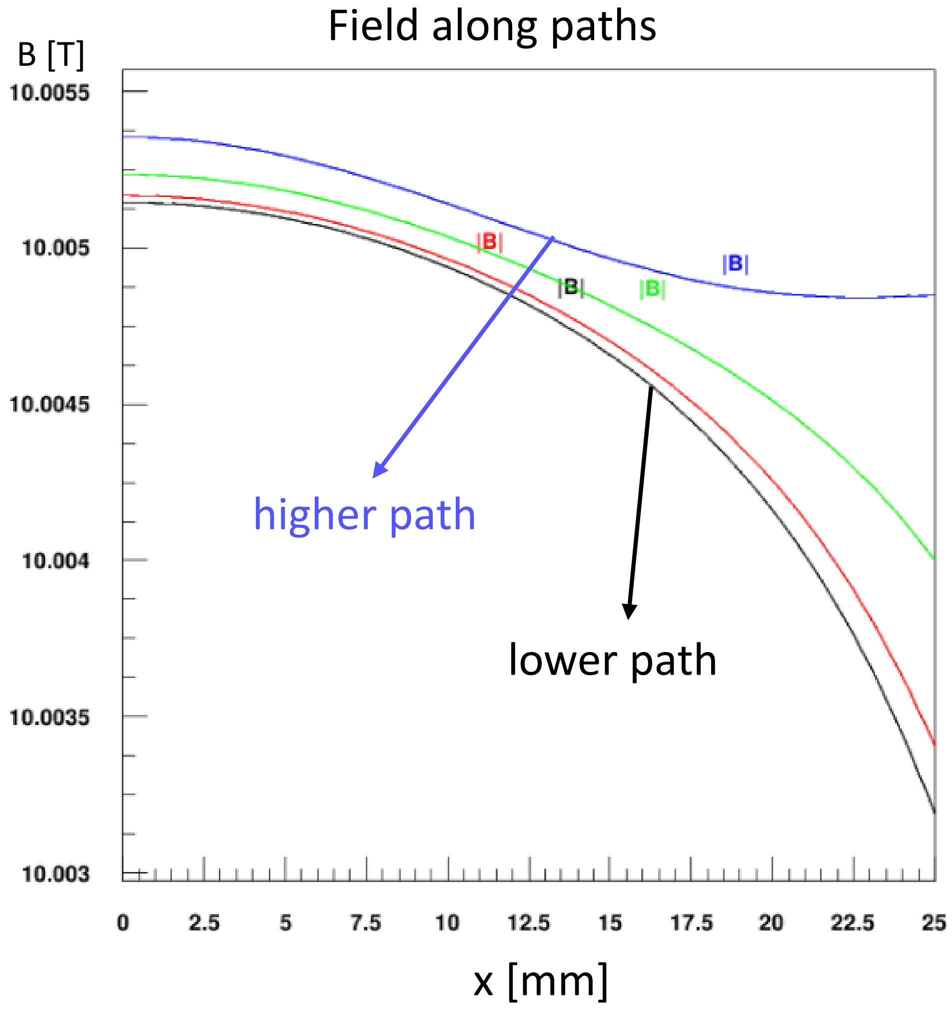


0 ALIGNED MAGNETIC DESIGN

Results:

- All harmonics **greatly less** then **10 units**
- The harmonics higher than the 7th order are **negligible** (less than 0.003 units)
- The field **homogeneity** evaluated at x = 25 mm is about **0.016%**



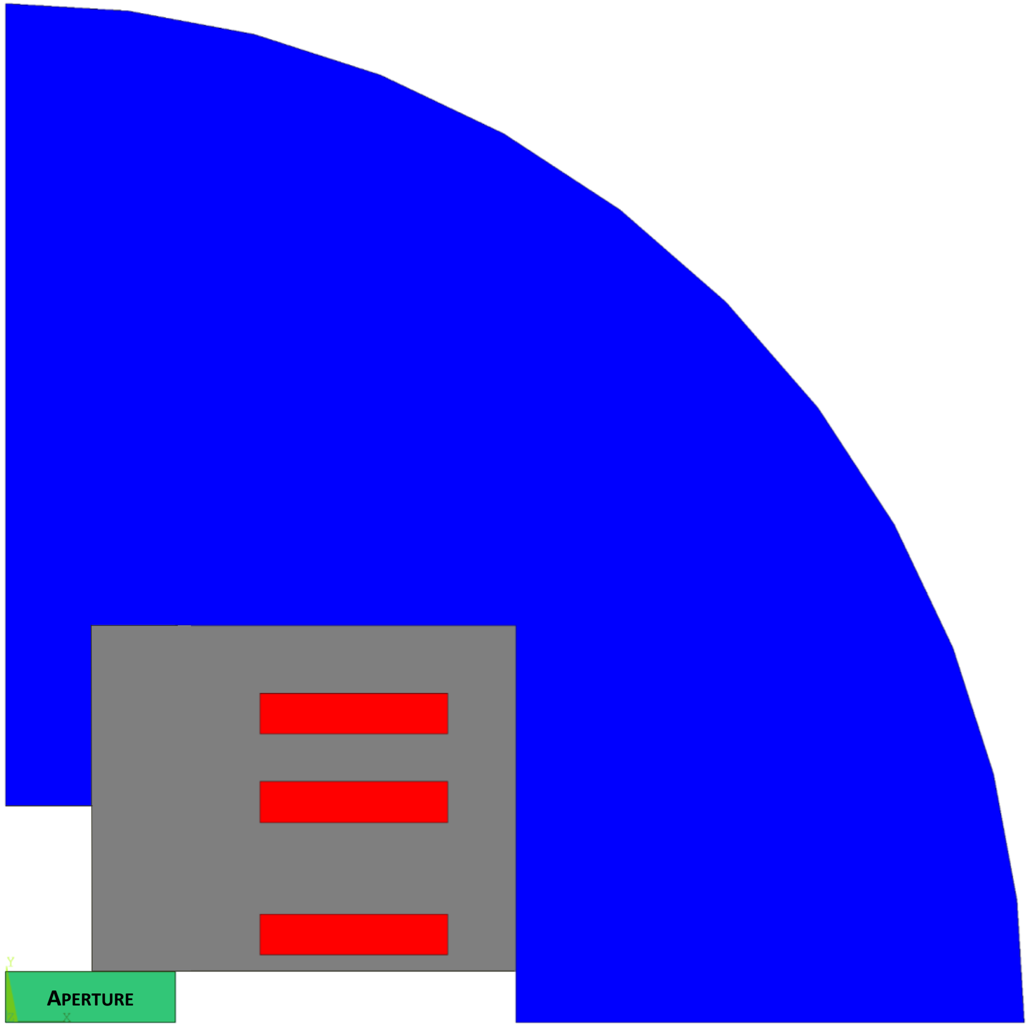


PRELIMINARY COST MODEL

Costs hypothesis:

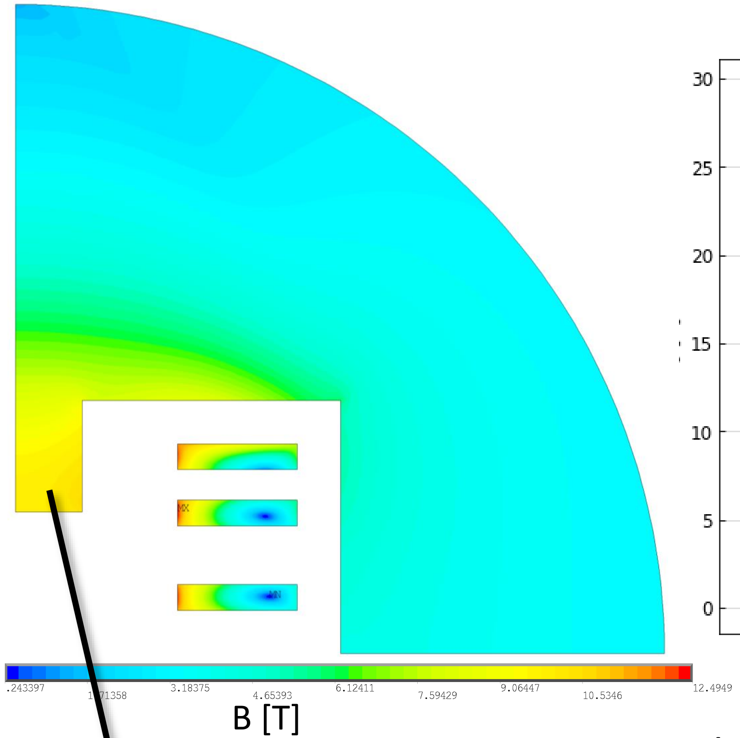
- 2500 €/kg of YBCO superconductor.
- 8 €/kg of iron.
- 10 €/kg of SS for mechanical structure and conservative configuration (total space filling)

Conductor	160 k€/m
Iron yoke	14 k€/m
Mechanical structure	3 k€/m
Assembly	20 k€/m
Total cost	197 k€/m

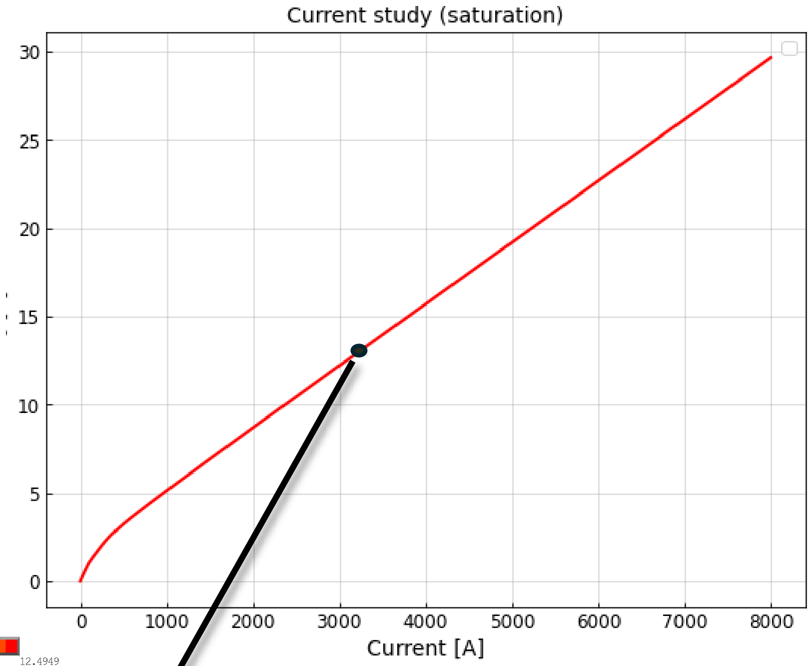


FUTURE STUDIES

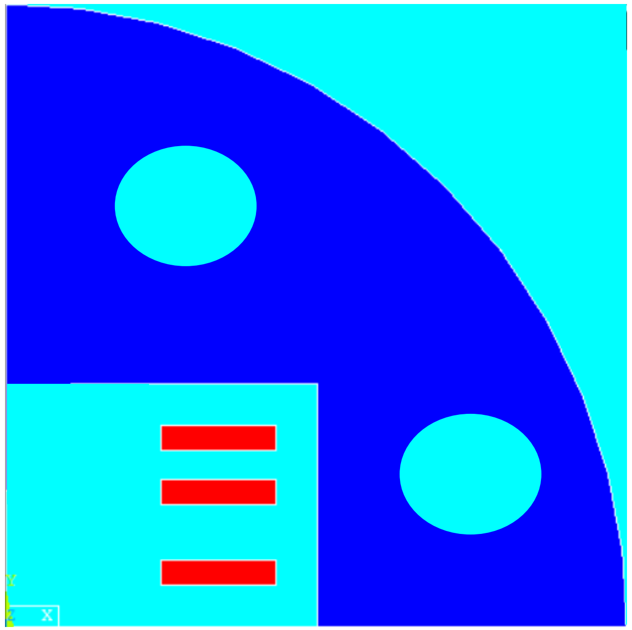
Since the iron pole is practically saturated, a future magnetic analysis involves studying various configurations by removing the pole and inserting holes inside the yoke to manage its saturation.



~9.3 [T]



Nominal current: 2336.12 A



Thanks for your attention

T. Maiello[1,4,5], L. Alfonso[1], L. Balconi[2,6], A. Bersani[1], L. Bottura[4], B. Caiffi[1], S. Fabbri[4], S. Farinon[1], A. Gagno[1,5], F. Levi[1], F. Mariani[2,6], S. Mariotto[2,3], D. Novelli[1,6], A. Pampaloni[1], D. Rinaldoni [4], C. Santini[2], S. Sorti[2,3], M. Statera[2] , G. Vernassa[2]

[1] INFN – Genova, [2] INFN LASA – Milano, [3] University of Milan, [4] CERN, [5] Università degli Studi di Genova, [6] Sapienza Università di Roma