Cosine-theta: electromagnetic design

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Outline:

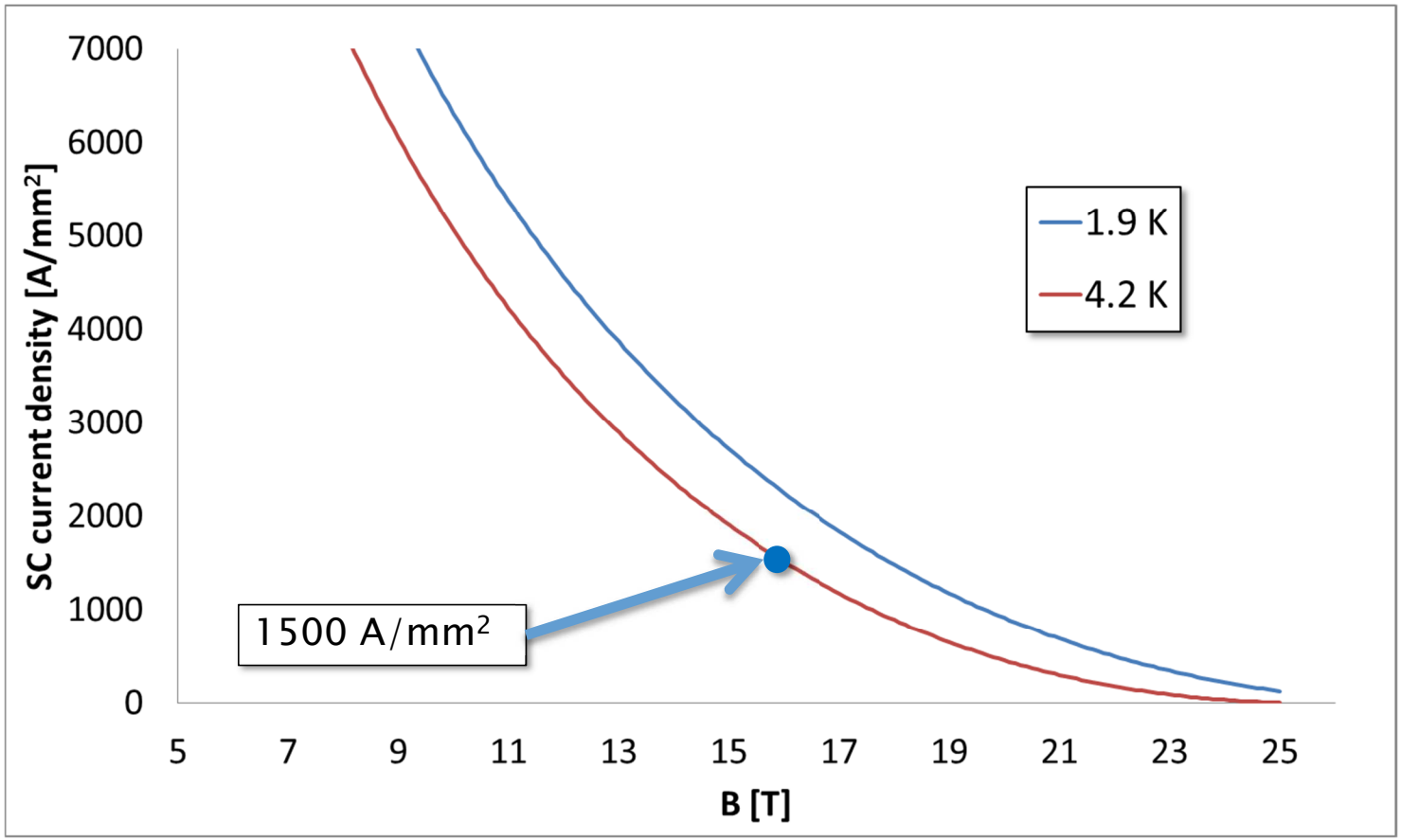
1. Design parameters
2. Baseline layout
3. Alternative layouts and ideas
4. Conclusions and perspectives

1.1 Main design parameters

Constraints for the magnet design	
Bore inner diameter	50 mm
Beam distance	204 mm
Material	Nb_3Sn
Bore nominal field	16 T
Operating temperature	1.9 K
Operation on the load line	86 %
Maximum strand number per cable	40
Cable insulation thickness	0.15 mm
Cu/NCu	≥ 0.85
Field harmonics (geometric/saturation)	≤ 3/10 units
Yoke outer radius	300 mm

- Magnetic design for a **double aperture** magnet (LHC-style)

1.2 Critical current



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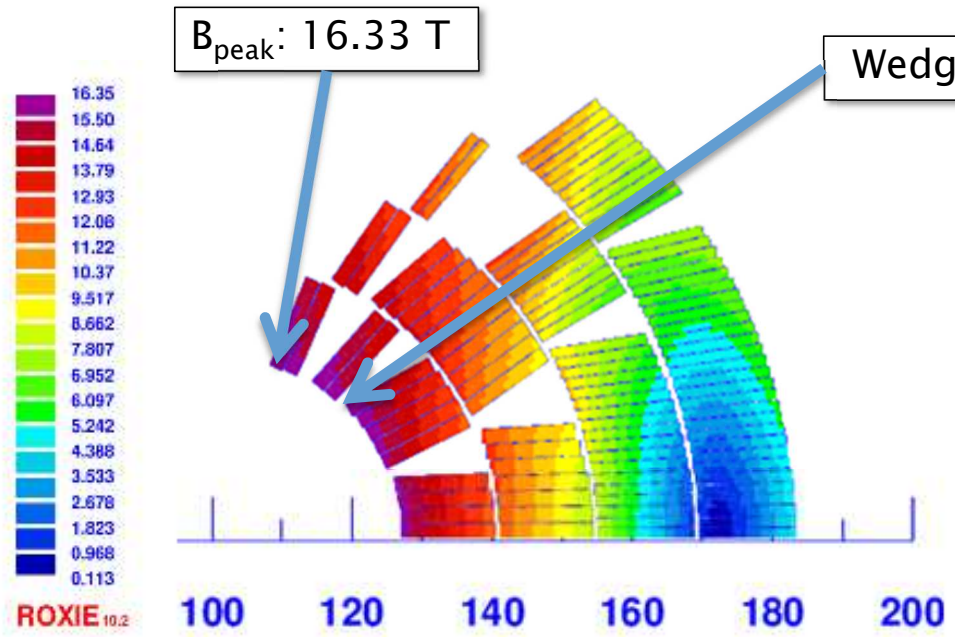
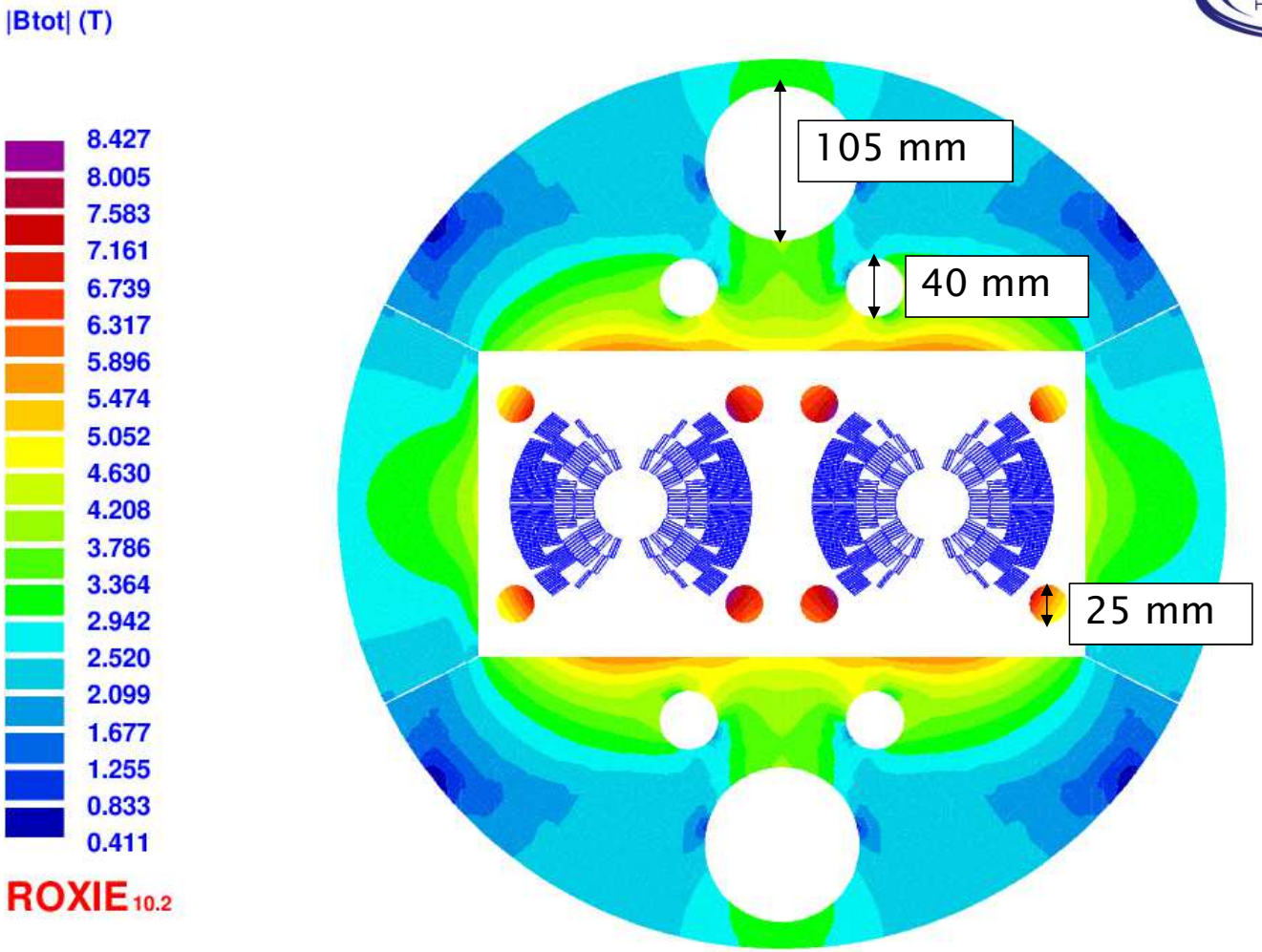
2.1 Cross section layout



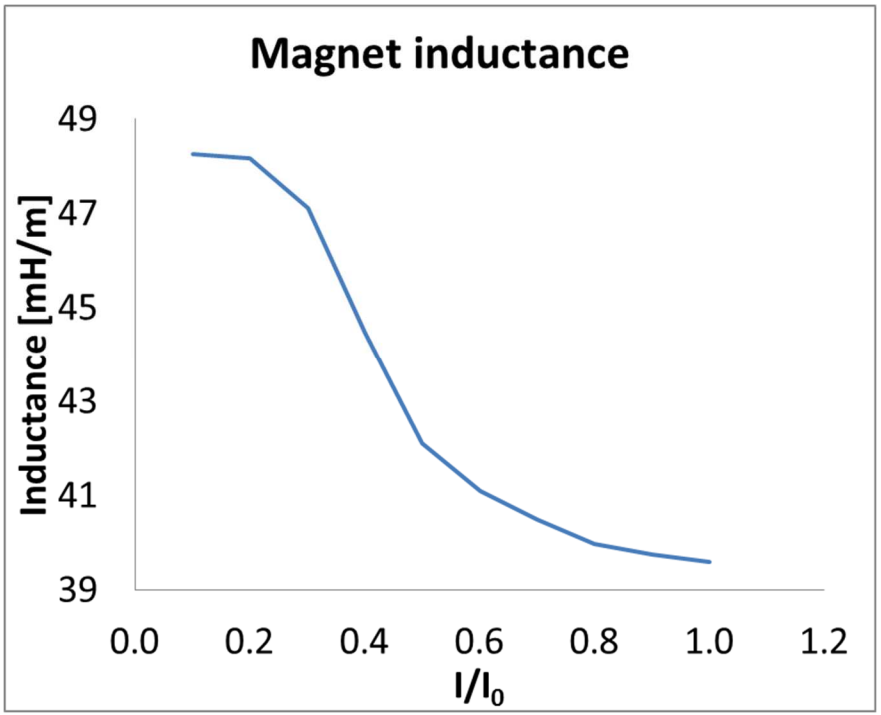
Number of turns:
Layer 1: 13
Layer 2: 19
Layer 3: 29
Layer 4: 39
Tot: 200/ap.

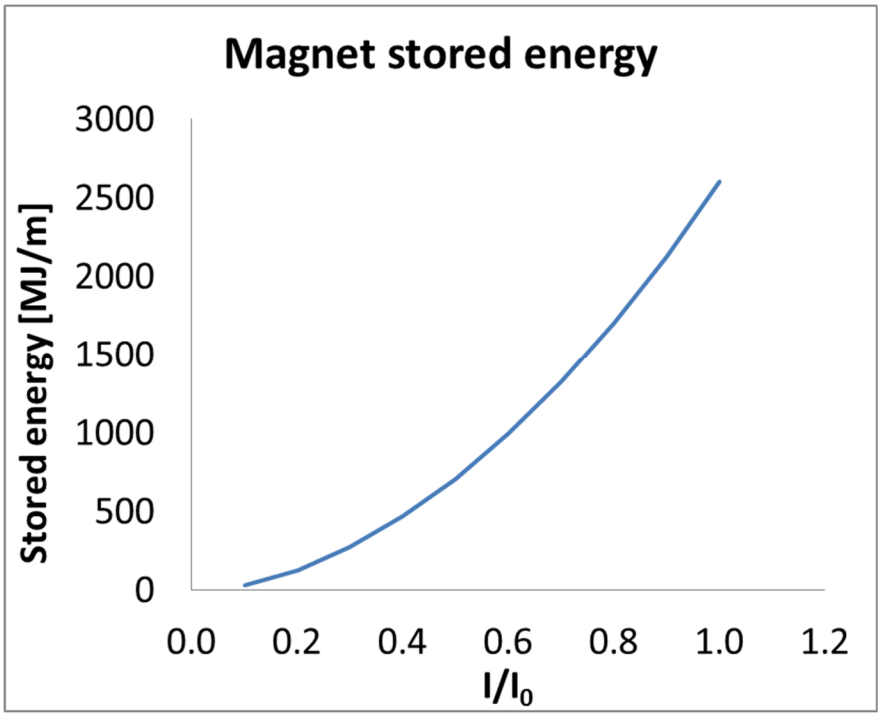
	HF Cable (inner)	LF Cable (outer)
Strand number	22	37
Strand diameter	1.1 mm	0.7 mm
Bare width	13.2 mm	13.65mm
Bare inner thickness	1.892 mm	1.204 mm
Bare outer thickness	2.007 mm	1.3231 mm
Insulation	0.15 mm	0.15 mm
Keystone angle	0.5°	0.5°
Cu/NCu	0.85	2.2
Operating current	11240 A	11240 A
Operating point on LL (1.9 K)	86 %	86 %

2.2 Iron yoke


|Btot| (T)
8.427
8.005
7.583
7.161
6.739
6.317
5.896
5.474
5.052
4.630
4.208
3.786
3.364
2.942
2.520
2.099
1.677
1.255
0.833
0.411
ROXIE 10.2
105 mm
40 mm
25 mm

2.3 Inductance and Stored energy

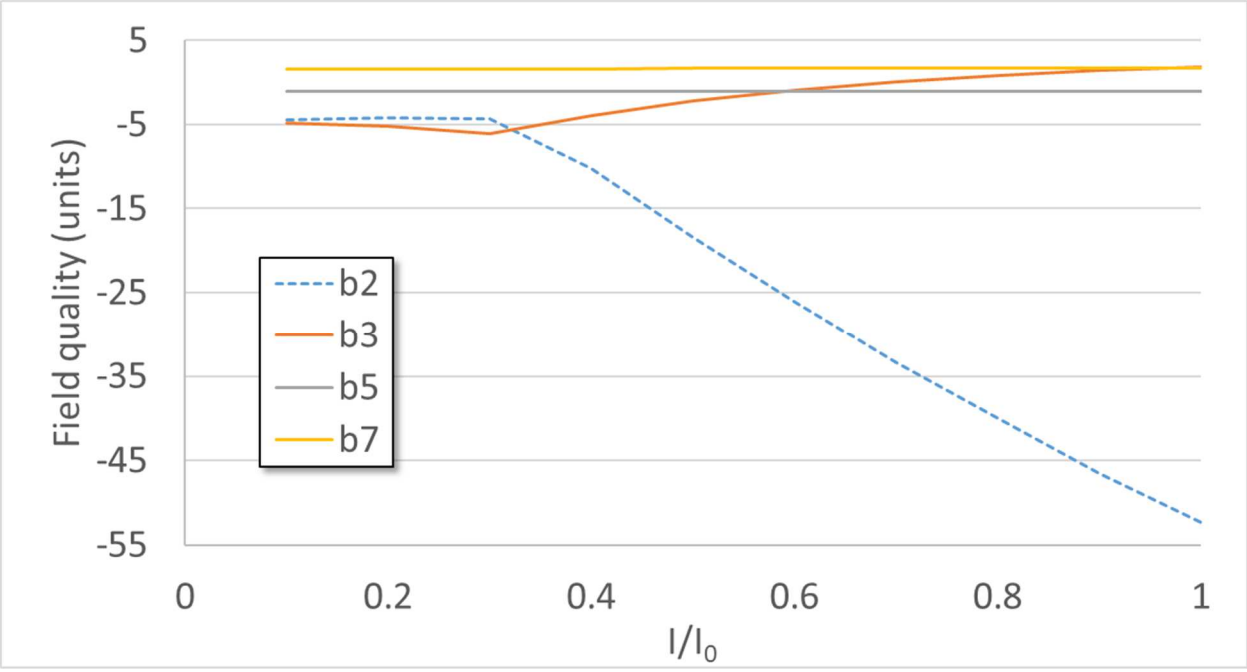




@I_{op}: L=39.6 mH/m, U=2.6 MJ/m

2.4 Field quality

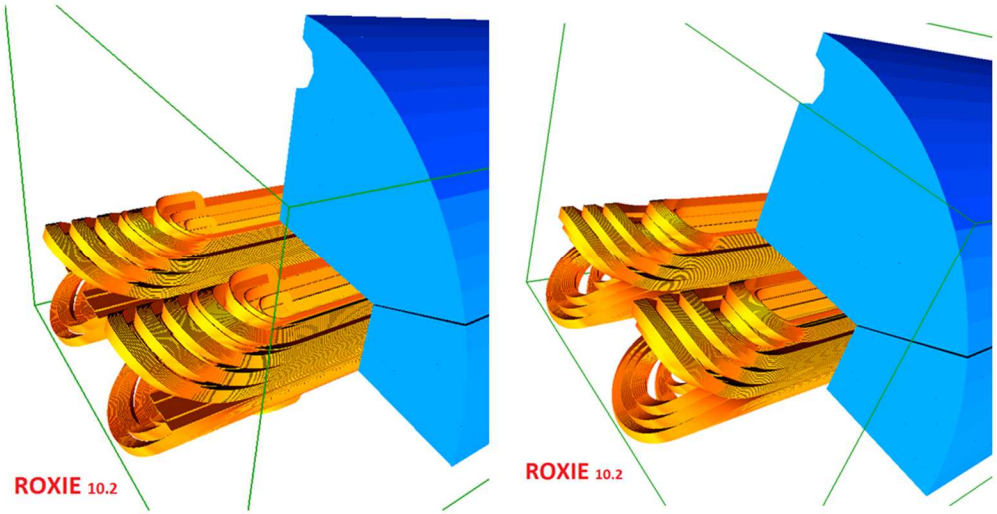
High-order harmonics at 16 T						
b2	b3	b5	b7	b9	b11	b13
-52.3	1.8	-1.15	1.7	1.4	1.0	-0.2



- All harmonics are **within constraints**
- b2 optimization **not yet** performed
- **Persistent currents** not considered

2.5 3D coil ends design

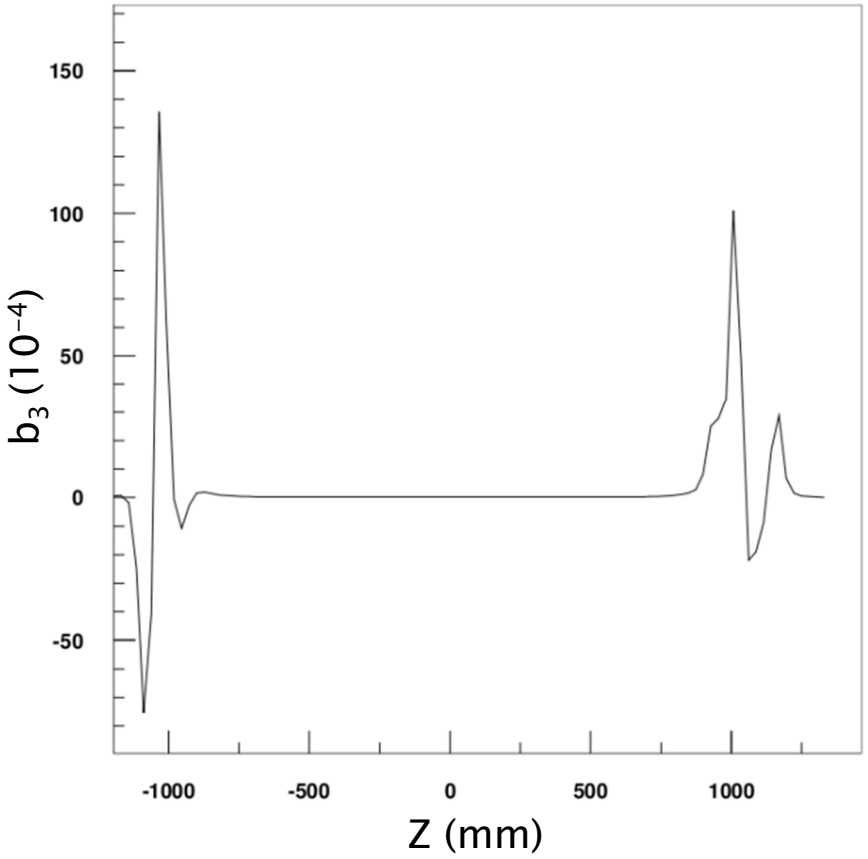
Integrated harmonics at 16 T				
b2	b3	b7	b9	a1
-57.9	3.4	2.0	1.4	-4.8

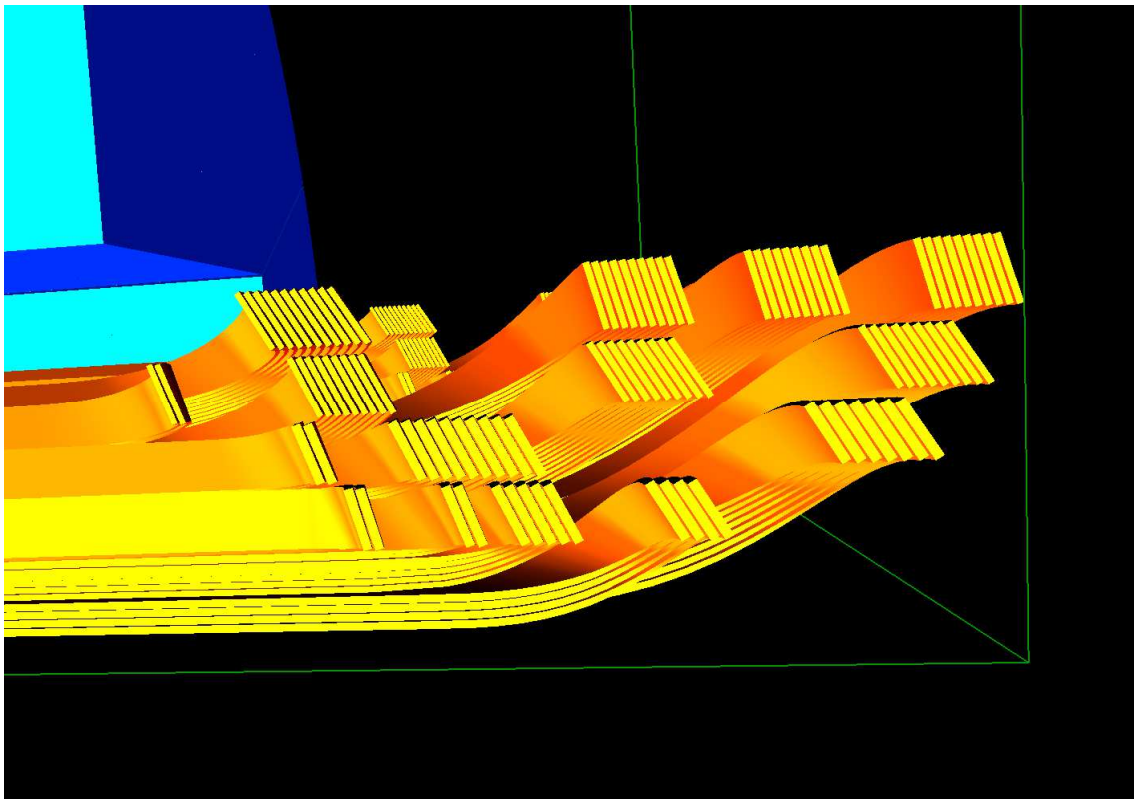


Coil ends main parameters:

- Magnetic length = 2084 mm
- Iron length = 1780 mm
- Physical length = 2230 mm

2.6 Coil end cross section





2.7 Amount of conductor

HF Conductor

- 22 strands
- ∅ = 1.1 mm
- Cu/NCu = 0.85
- J_{cu} = 1170 A/mm^2
- Strand Area = 26.8 cm^2/apert.
- Weight (FCC) = 3.05 ktons

LF Conductor

- 37 strands
- ∅ = 0.7 mm
- Cu/NCu = 2.2
- J_{cu} = 1140 A/mm^2
- Strand Area= 38.7 cm^2/apert.
- Weight (FCC) = 4.41 ktons

COND. AREA (double ap.): = 131 cm^2

FCC dipoles extrapolation:

➢ COND. MASS: = 7.46 ktons

Data for FCC extrapolation	
Number of dipole units	4578
Dipole lenght	14.3 m
Conductor density	8.7 kg/dm^3

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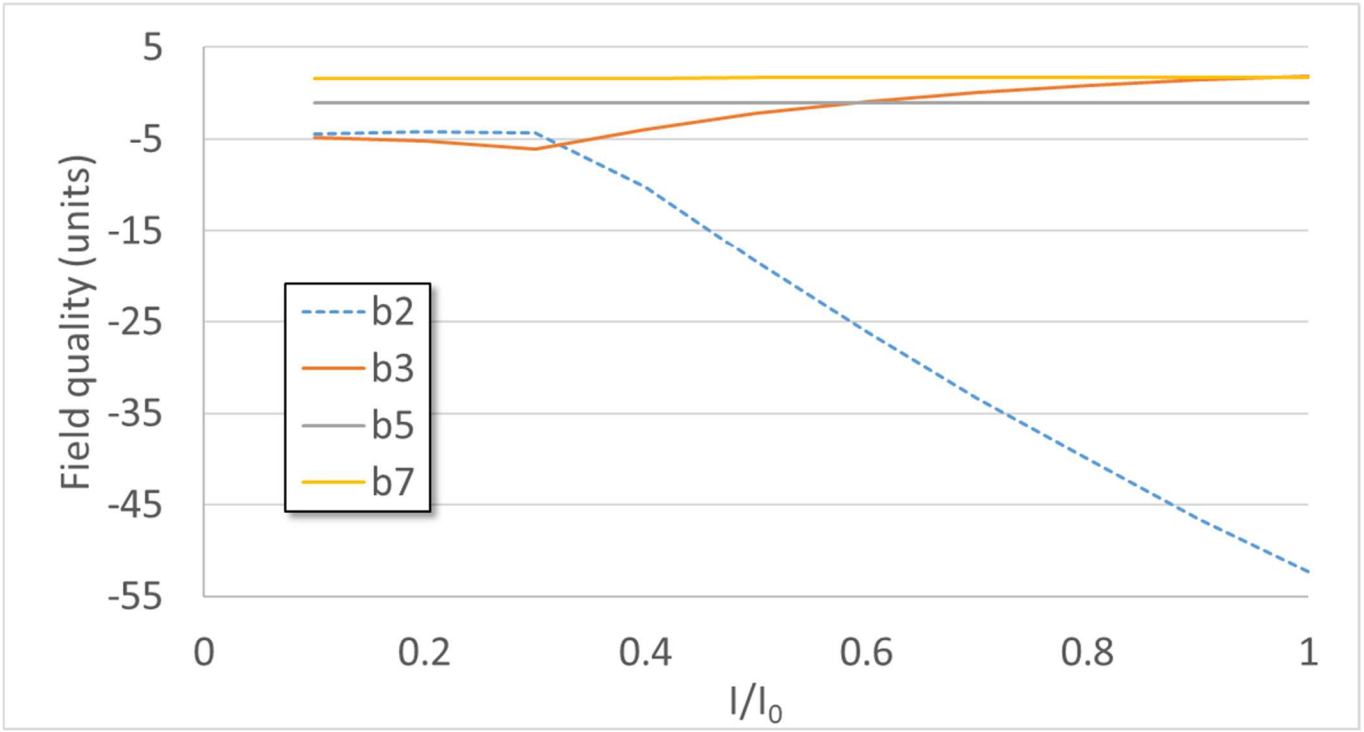
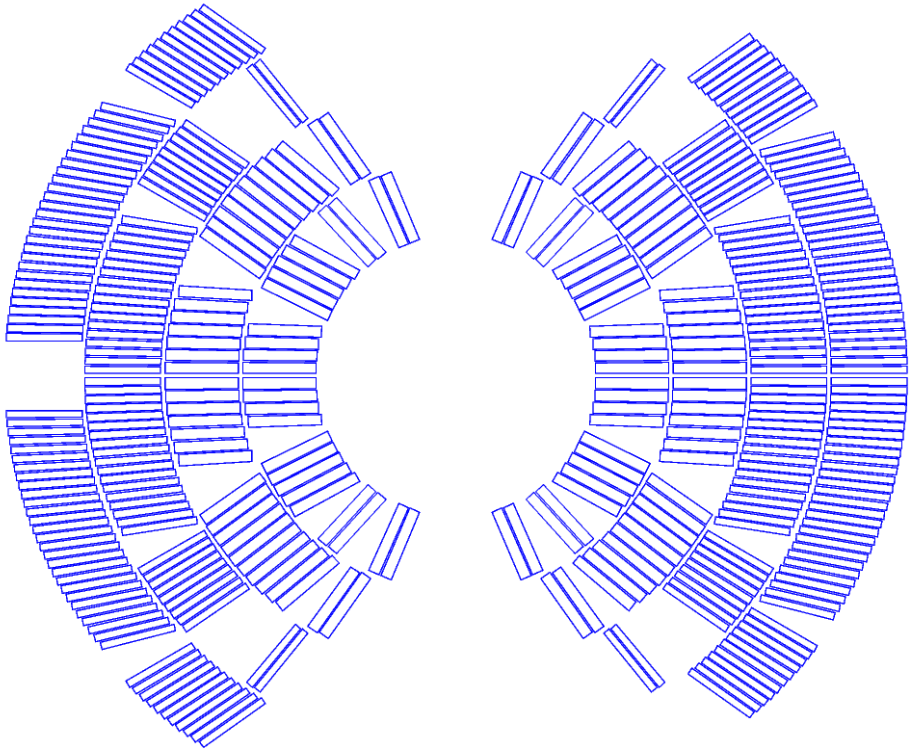
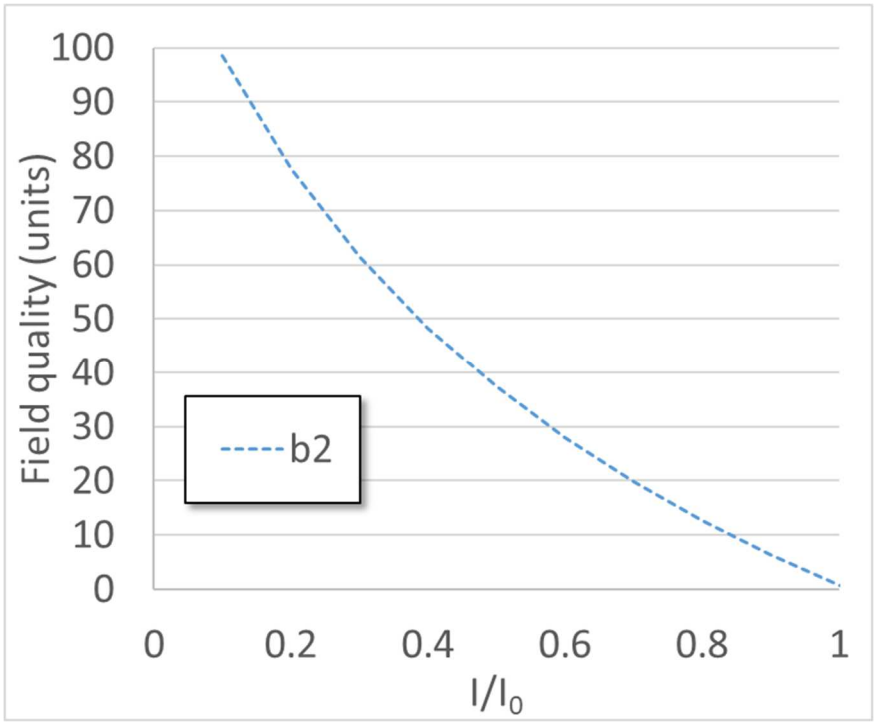
3.1 Large b2 at nominal current



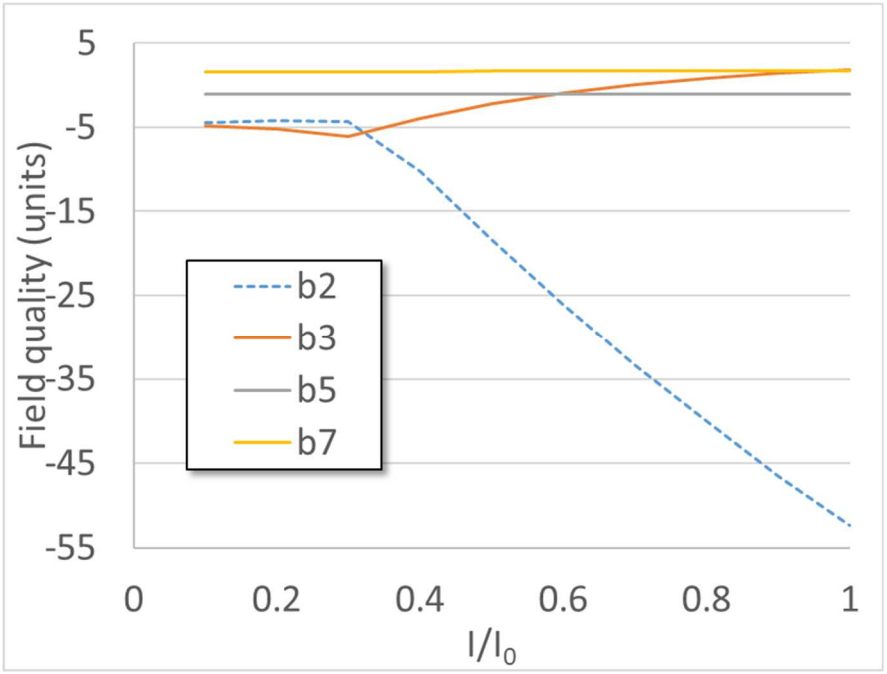
3.2 b2 optimization with asymmetry?

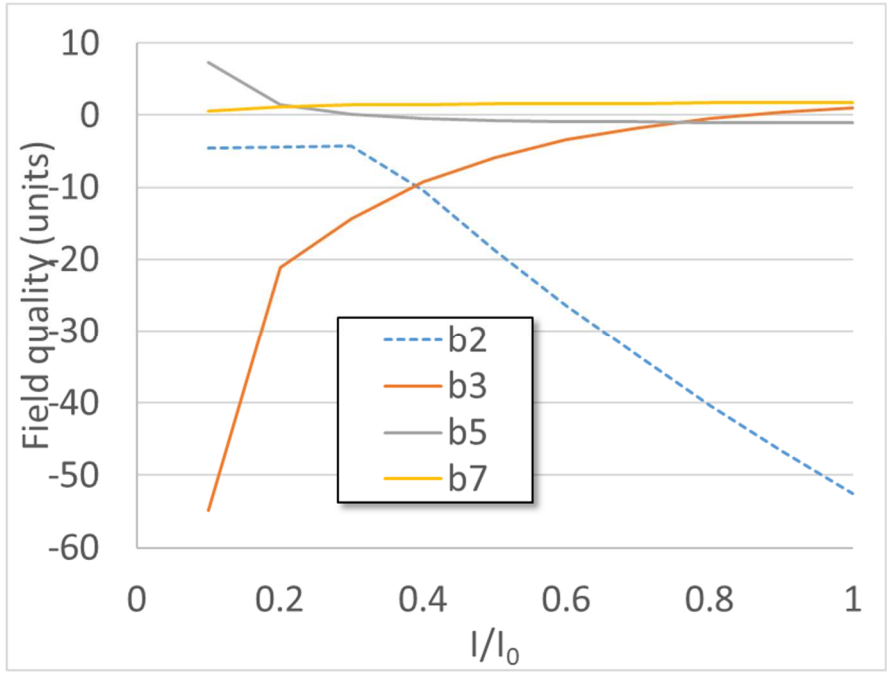




Warning: design with no accelerator field quality!

3.3 Persistent currents effect

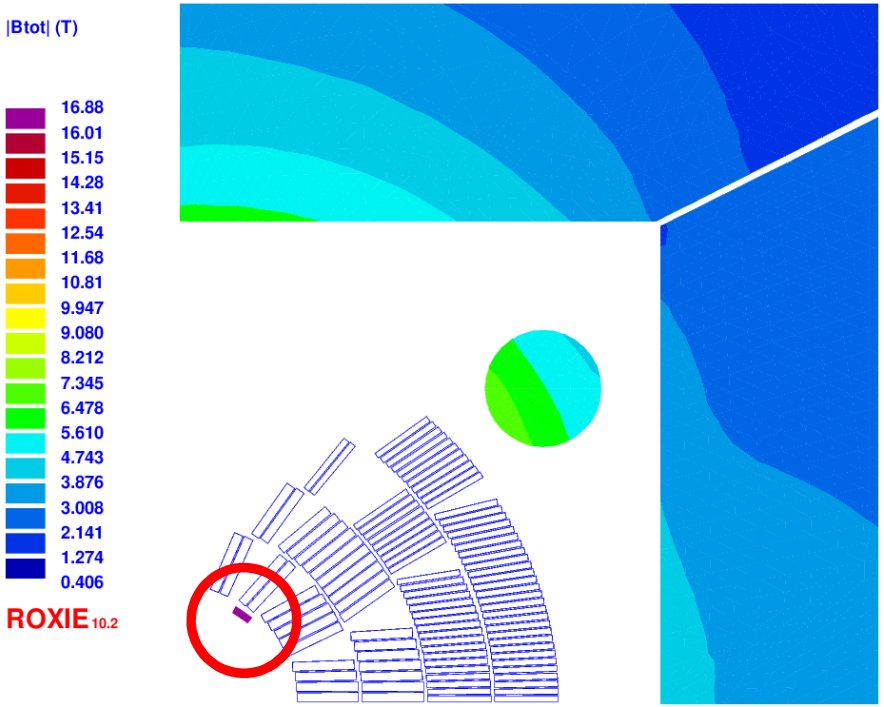


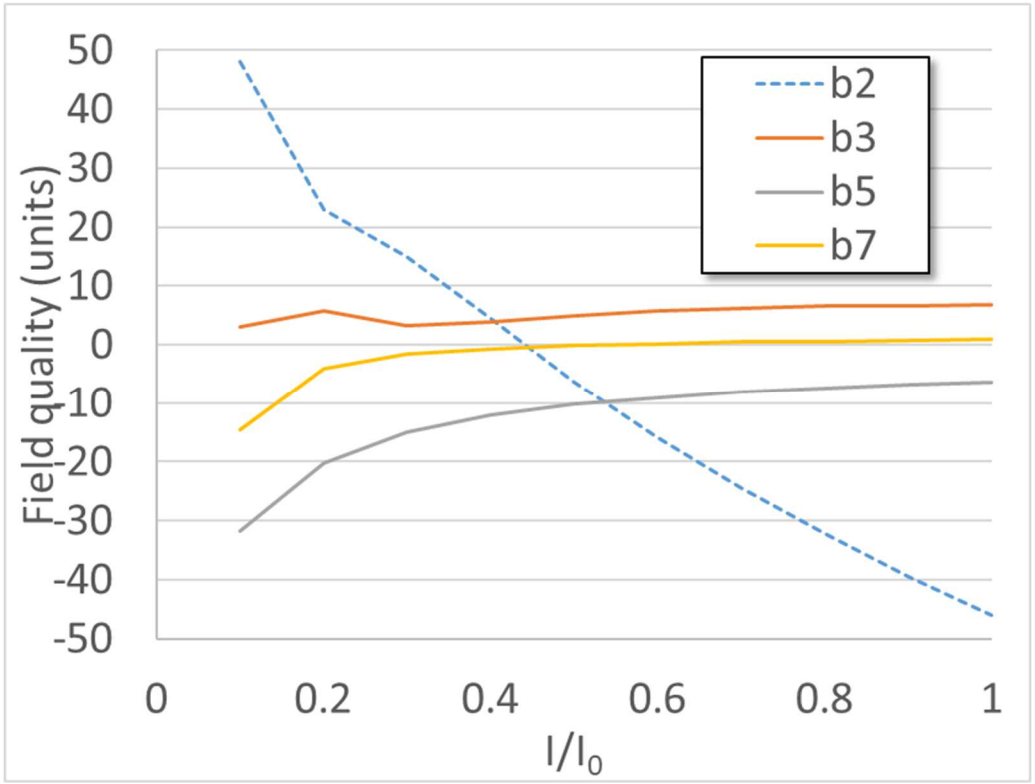


- 50 μm filament diameter
- −50 units on b3 at injection
- +8 units on b5 at injection
- No effect on b2
- Negligible effect at operation current

3.4 Persistent currents optimization

Possible solution: iron on the beam pipe?





Field quality to be optimized

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4.1 Conclusions and perspectives

- Baseline cosine-theta solution: a **4 layer** dipole (two double pan-cakes) which accomplishes the **EuroCirCol** constraints:
  - Able to produce **16 T** bore field
  - Margin on the load-line is **86%** at 1.9 K
  - **Good** field quality (2D and 3D)
  - **Competitive** amount of conductor (**7.46 ktons**)

- We are working and developing new ideas to optimize furthermore the magnet:
  - b2 optimization
  - Persistent currents
  - 3D peak field

Thank you!