EuroCircol – Cosine Theta

Design and protection of the EuroCirCol costheta bending dipole for the Future Circular Collider

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EuroCirCol A key to New Physics

INFN Istituto Nazionale di Fisica Nucleare

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Outline:

1. Main design parameters
2. 2D Magnetic design
3. 3D coil ends
4. Protection
5. Conclusions

1.1 Main design parameters

Constraints for the magnet design	
Bore inner diameter	50 mm
Beam distance	**204 mm**
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
Peak temperature (105 % of operating current)	≤ 350 K
Yoke outer radius	400 mm

- Magnetic design for a **double aperture** magnet

Why is beam distance **204 mm**?

- It is an **advantage** in terms of electromagnetic design
  - Bore field increase
  - More copper in conductors

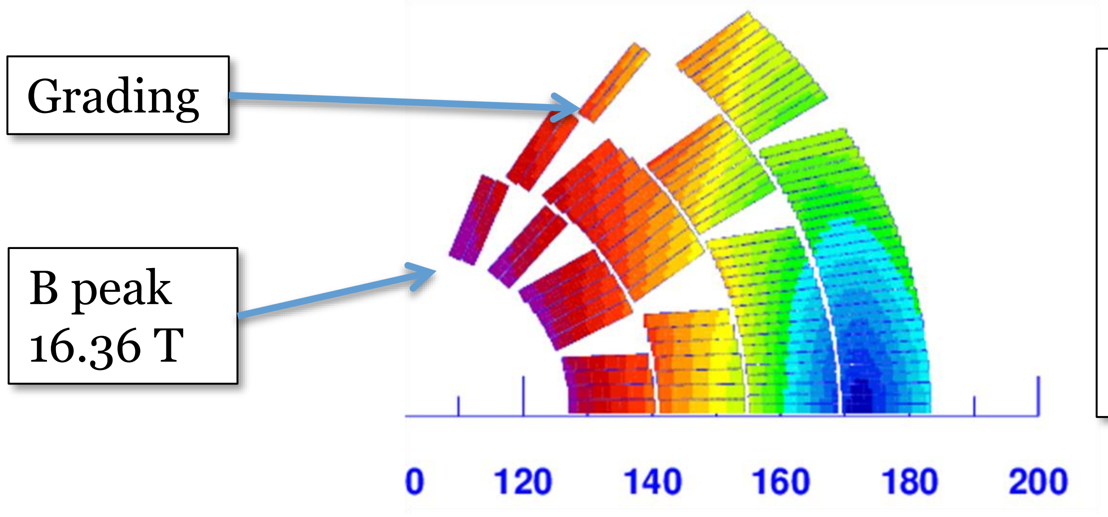
- It is an advantage in terms of mechanics
  - More **symmetric**
  - More efficient
  - Details in the talk on mechanics (B. Caiffi, this morning)

- It is lees far from hypothetic compatibility of the magnet with **HE-LHC** (194 mm)

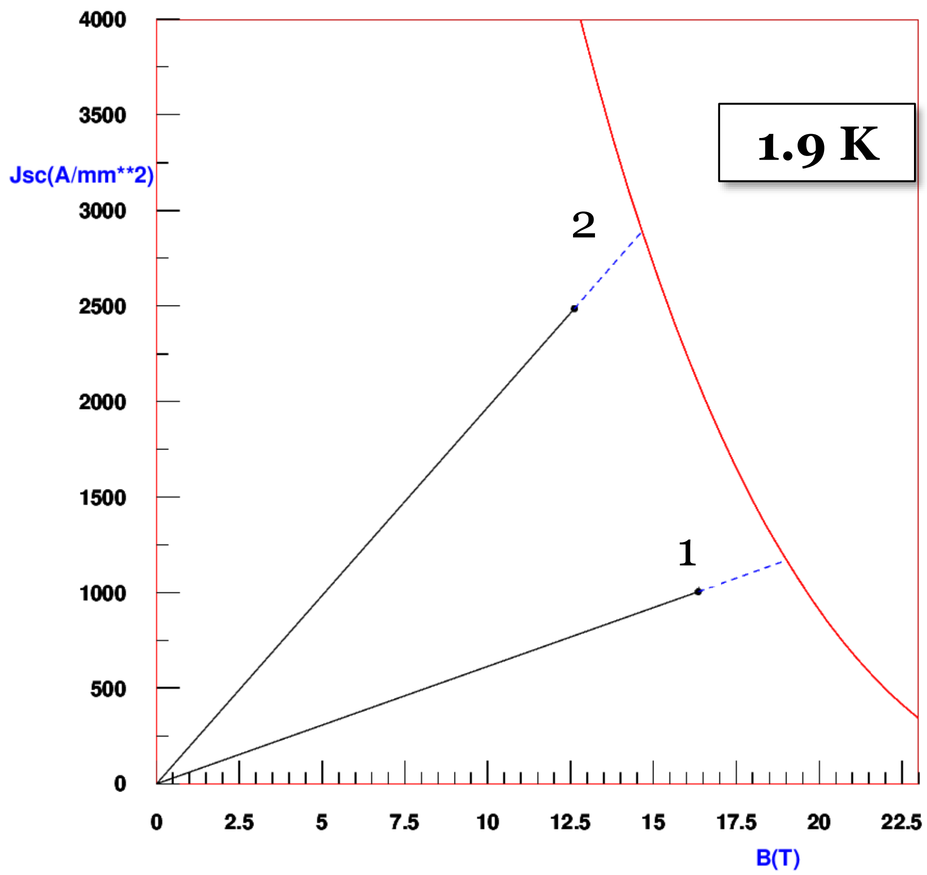
Design strategy

- Design as **compact** as possible
  - Reduce amount of conductor
  - Reduce complexity of the magnet
- Maintain the feasibility of the protection
  - HST < **350 K**
- Consider the possible construction issues
  - **Wedges**
  - Connections

2.1 2D Magnetic design – cross section



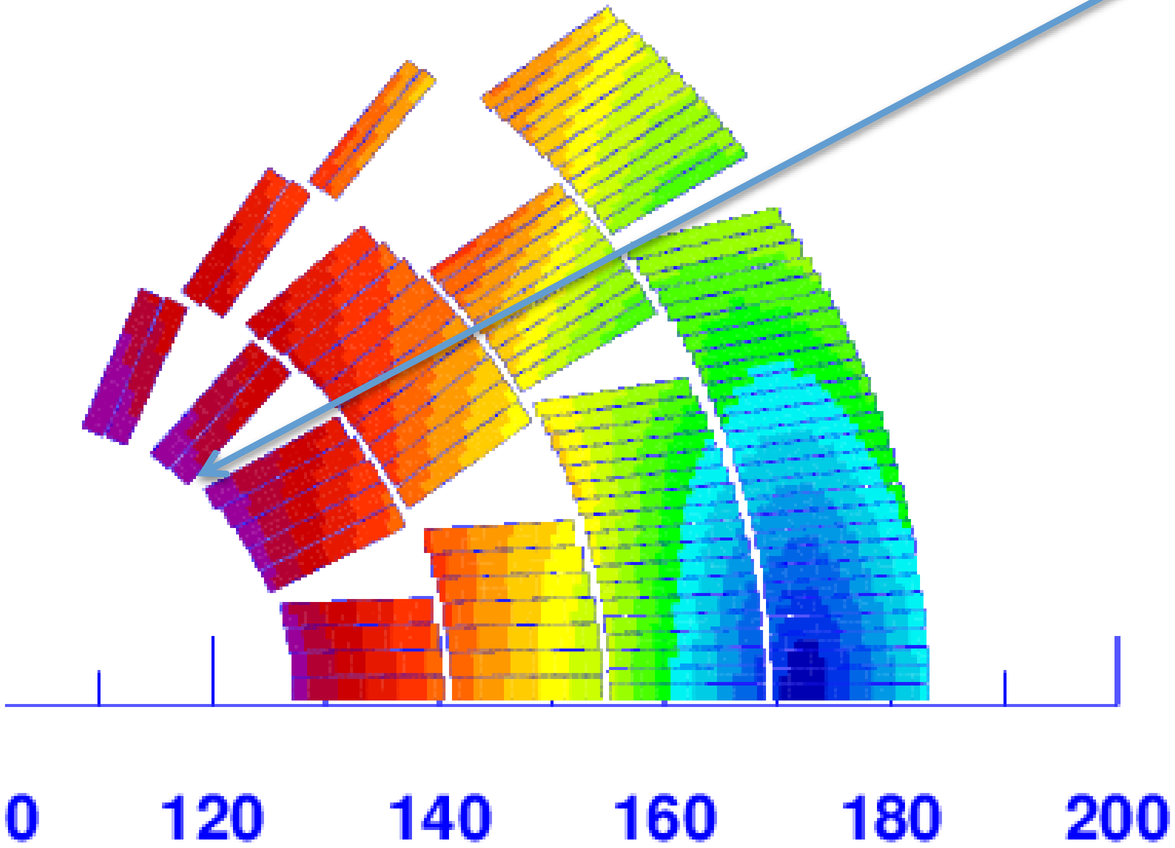
Number of turns:
Layer 1: 13
Layer 2: 19
Layer 3: 29
Layer 4: 39
Tot: 200/ap.



	Cable 1 (inner)	Cable 2 (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	2.072 mm	1.3231 mm
Insulation	0.15 mm	0.15 mm
Keystone angle	0.5°	0.5°
Cu/NCu	0.9	2.2
Operating current	11060 A	11060 A
Operating point on LL (1.9 K)	86 %	86 %

All the parameters are within the **design constraints**

2.2 2D Magnetic design – wedges

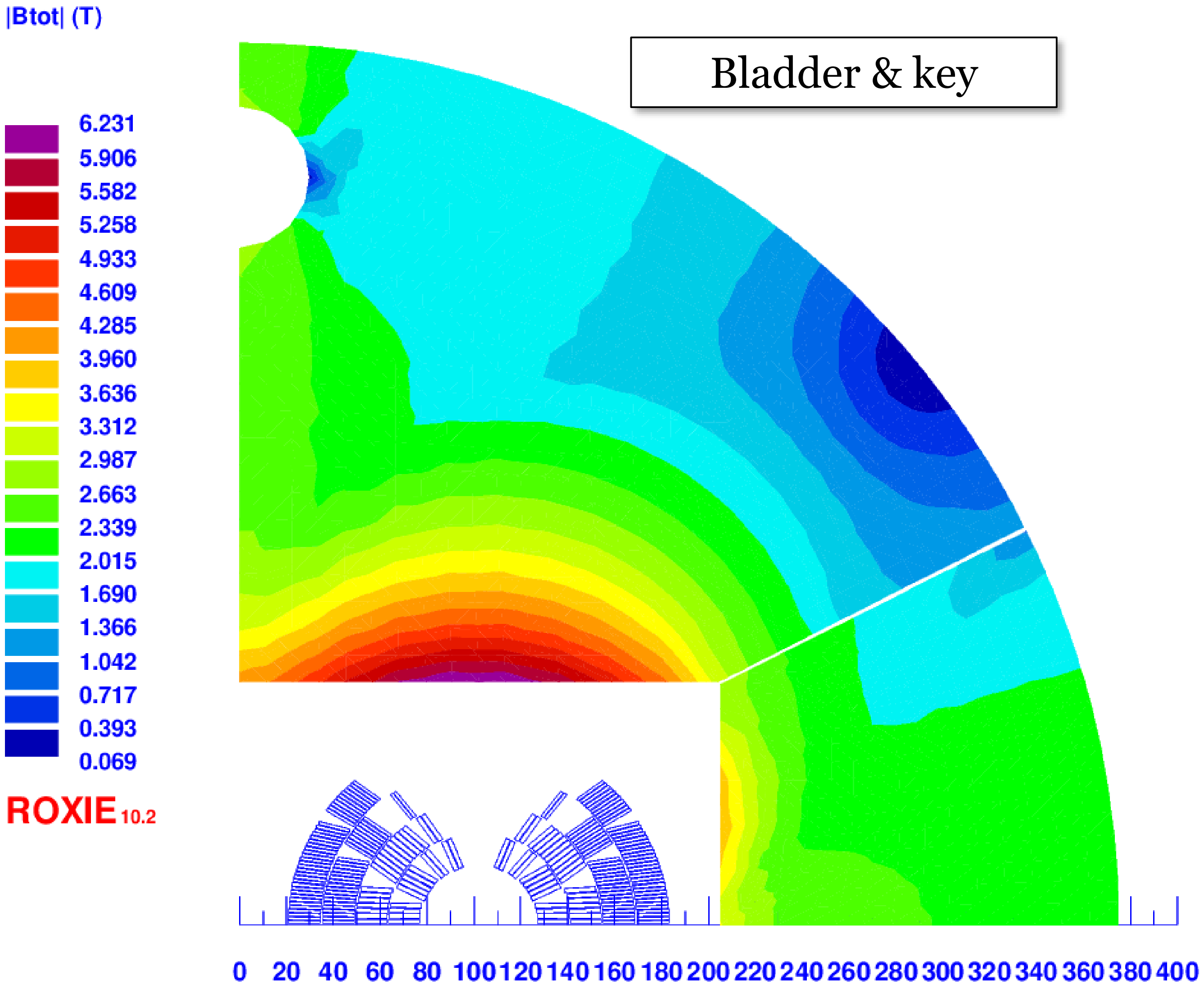


- Minimum wedge thickness: 0.86 mm
- In LHC main dipole: 0.7 mm

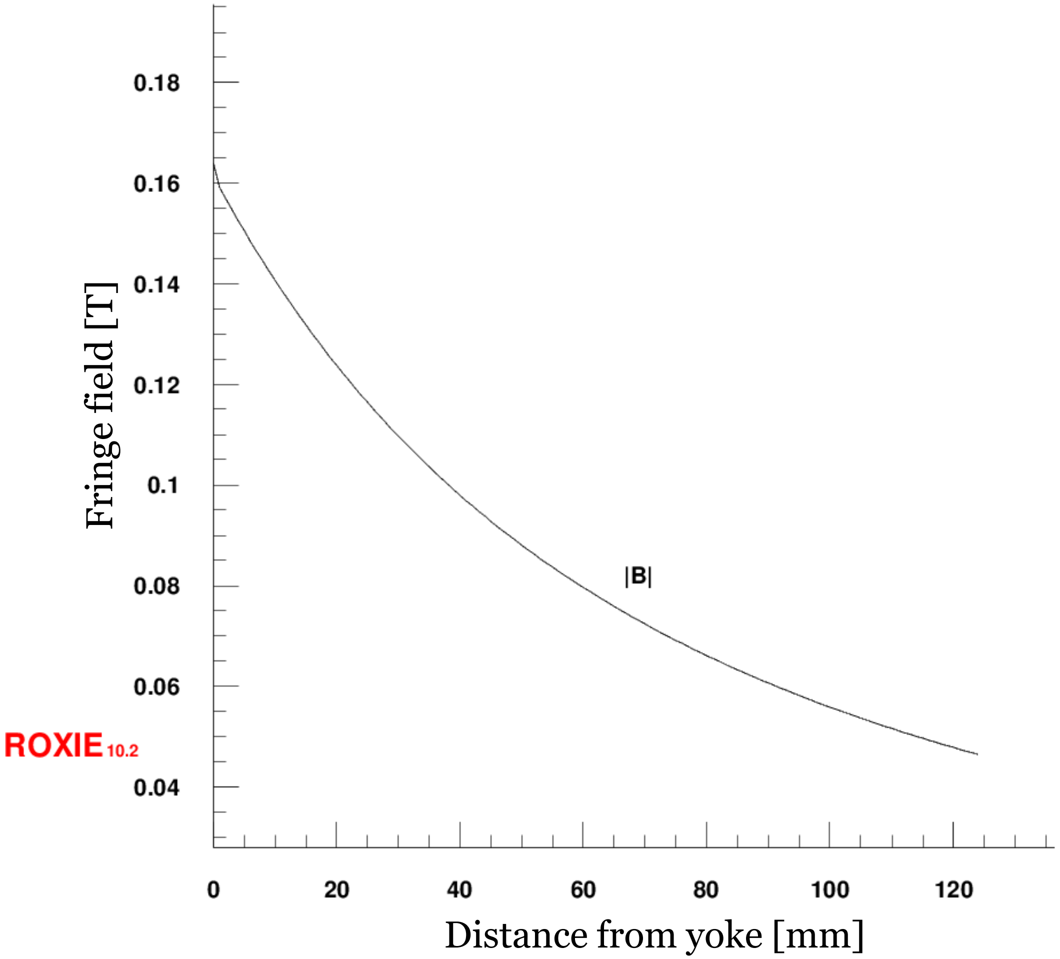
- Number of wedges: 8
- In LHC main dipole: 4 (with one half of layers)

Design comparable with LHC main dipole

2.3 2D Magnetic design – iron yoke



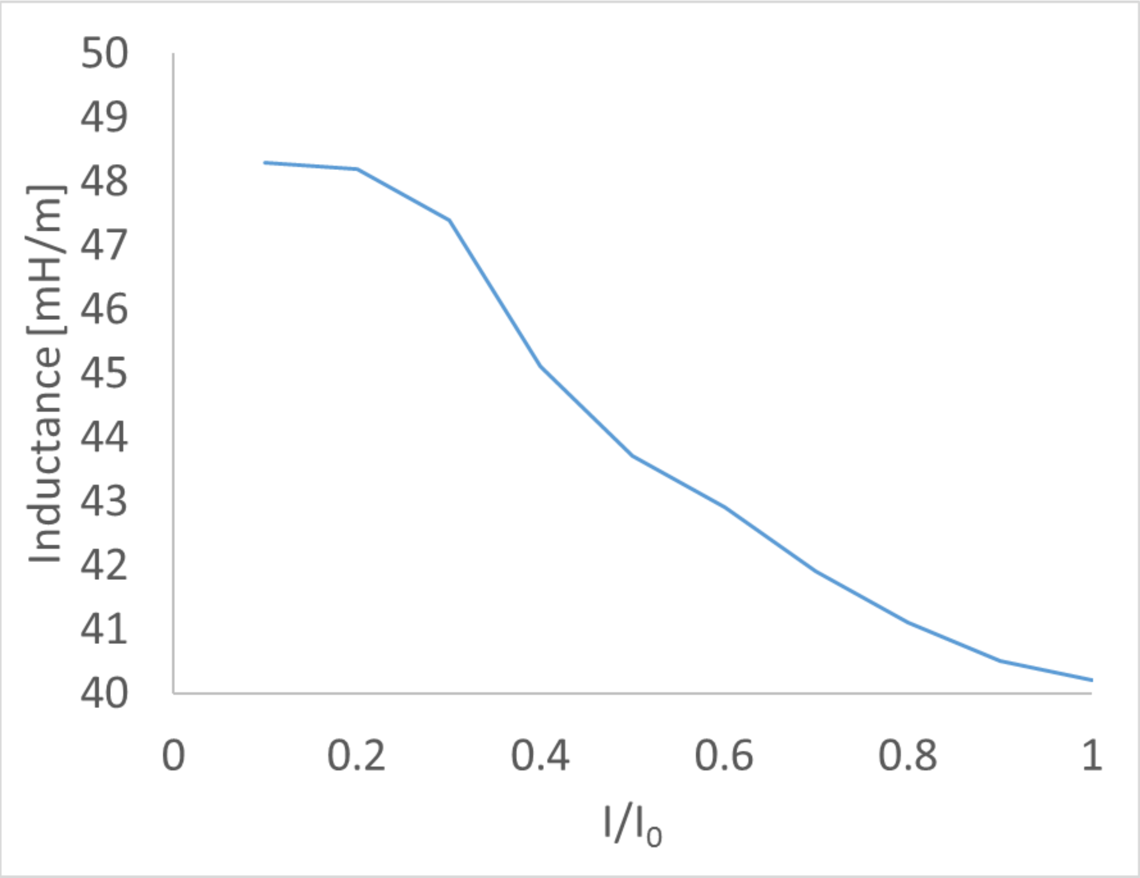
- Outer radius: 375 mm
- Fringe field: 0.1 T at 410 mm

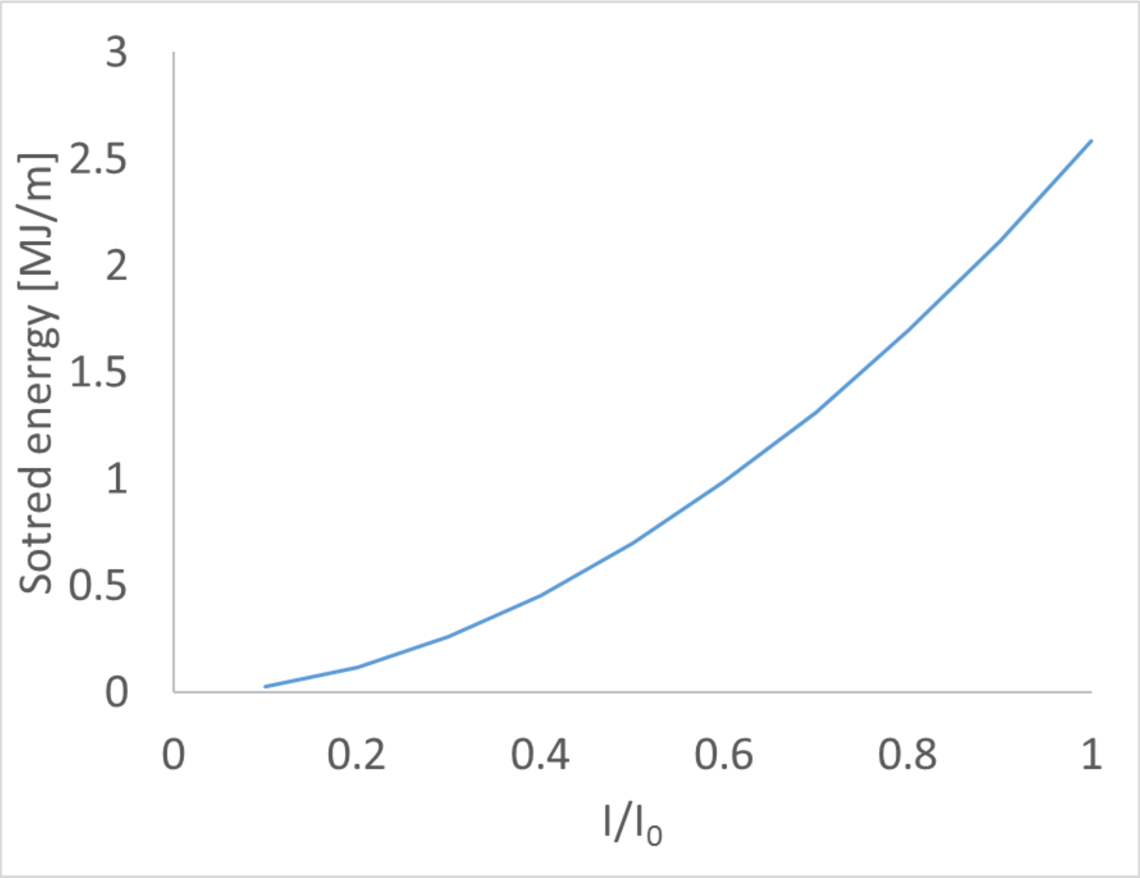


➢ More details in the talk on the mechanics (B. Caiffi, this morning)

2.4 2D Magnetic design – inductance and energy

Double aperture





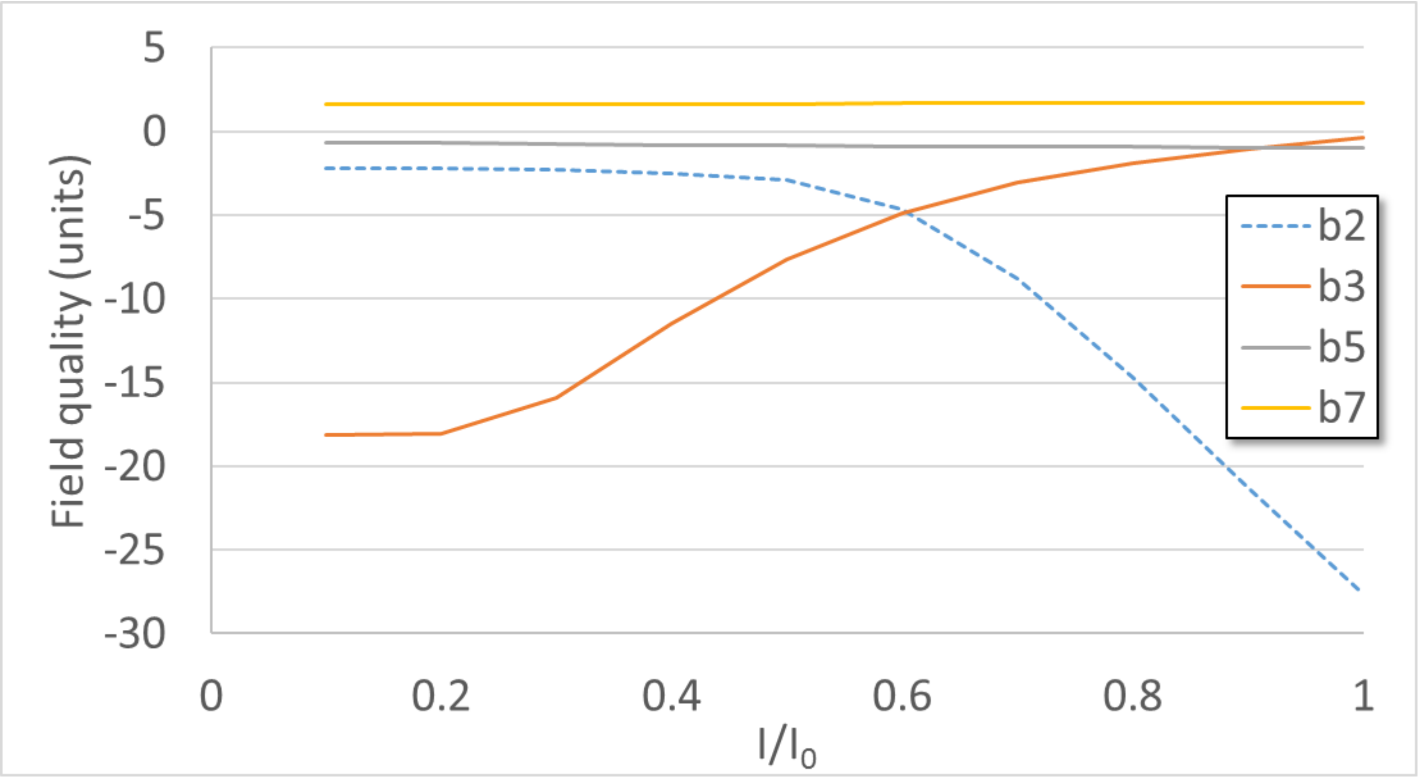
Inductance @ I_{op}	Stored energy @ I_{op}
40.2 mH/m	2.6 MJ/m

2.5 2D Magnetic design – field quality

NORMAL RELATIVE MULTIPOLES @ 16 T:

b 1: 10000	b 2: -27.6	**b 3: -0.41**
b 4: -0.69	**b 5: 0.99**	b 6: -0.01
b 7: 1.72	b 8: -0.00	b 9: 1.4
b10: 0.00	b11: 1.03	b12: 0.00
b13: -0.18	b14: 0.00	b15: 0.01

- b2 optimization not yet performed
- b3 saturation to be contained
- Persistent currents **not** considered

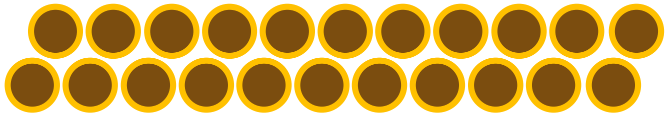


Acceptable field quality

2.6 2D Magnetic design – strand area

Conductor 1:

- 22 strands
- ∅ = 1.1 mm
- Cu/NCu = 0.9
- J_{cu} = 1116 A/mm²
- Strand Area = 26.8 cm²/apert.
- Weight (FCC) = 3.05 ktons



COND. AREA (double ap.): = 131 cm²

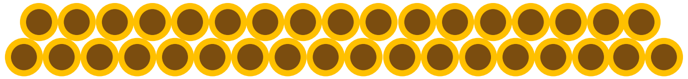
FCC dipoles extrapolation:

➢ **COND. MASS: = 7.46 ktons**

Conductor 2

- 37 strands
- ∅ = 0.7 mm
- Cu/NCu = 2.2
- J_{cu} = 1129 A/mm²
- Strand Area= 38.7 cm²/apert.
- Weight (FCC) = 4.41 ktons

High Cu content for protection reasons!



Data for FCC extrapolation	
Number of dipole units	4578
Dipole lenght	14.3 m
Conductor density	8.7 kg/dm³

2.7 2D Magnetic design – alternatives

Same design can be proposed with 250 mm beam-beam distance, but with:

- More current
- Less copper
- More difficult to protect
- Extreme IL conductor

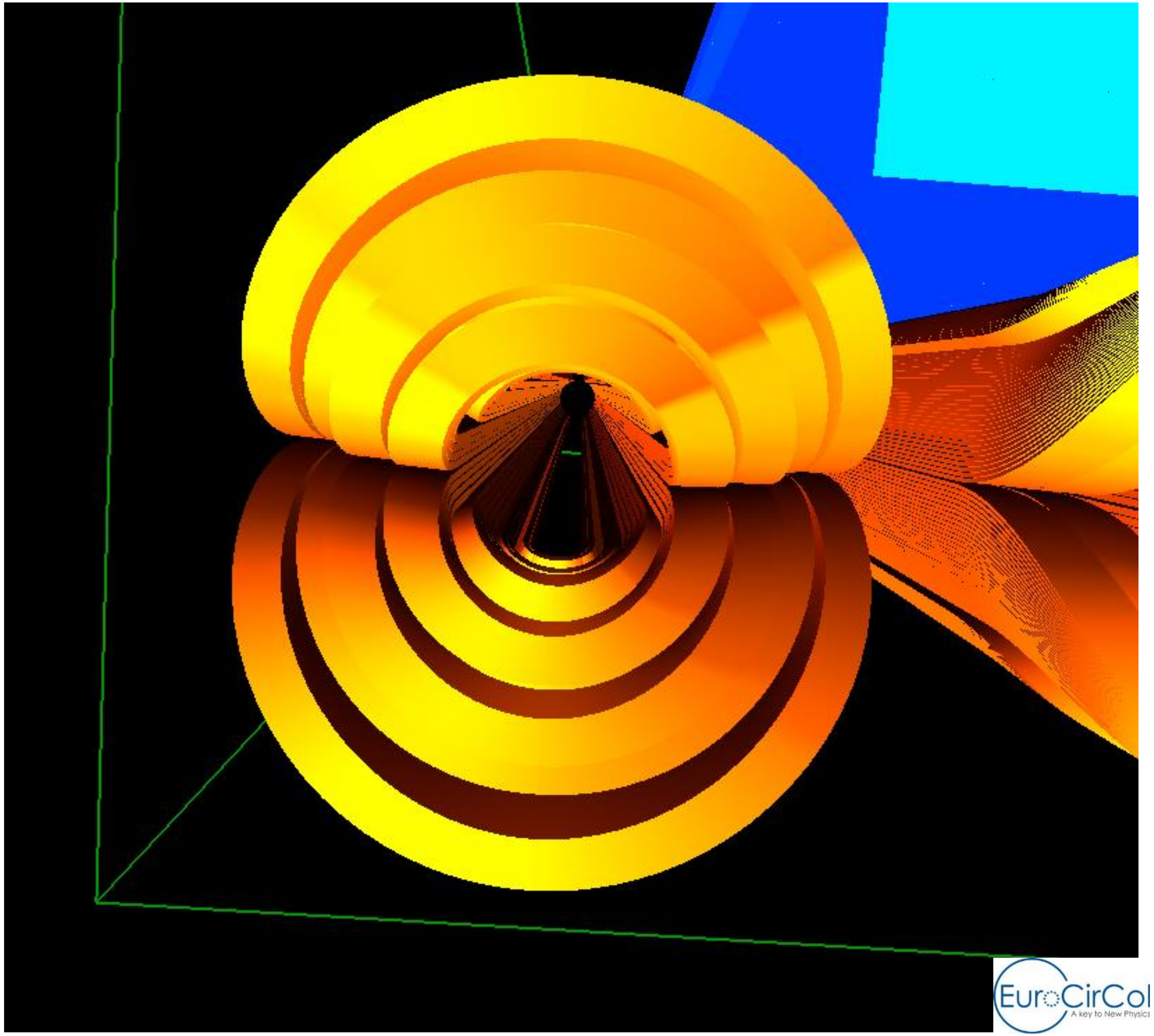
Same design can be proposed with iron pad, leading to advantages such as:

- Less current
- More copper
- Easier to protect
- “Standard” IL conductor

➢ To be understood if iron pad can sustain mechanical stresses

3.1 3D coil ends – layout

Designed by A.M. Ricci, INFN-Genova

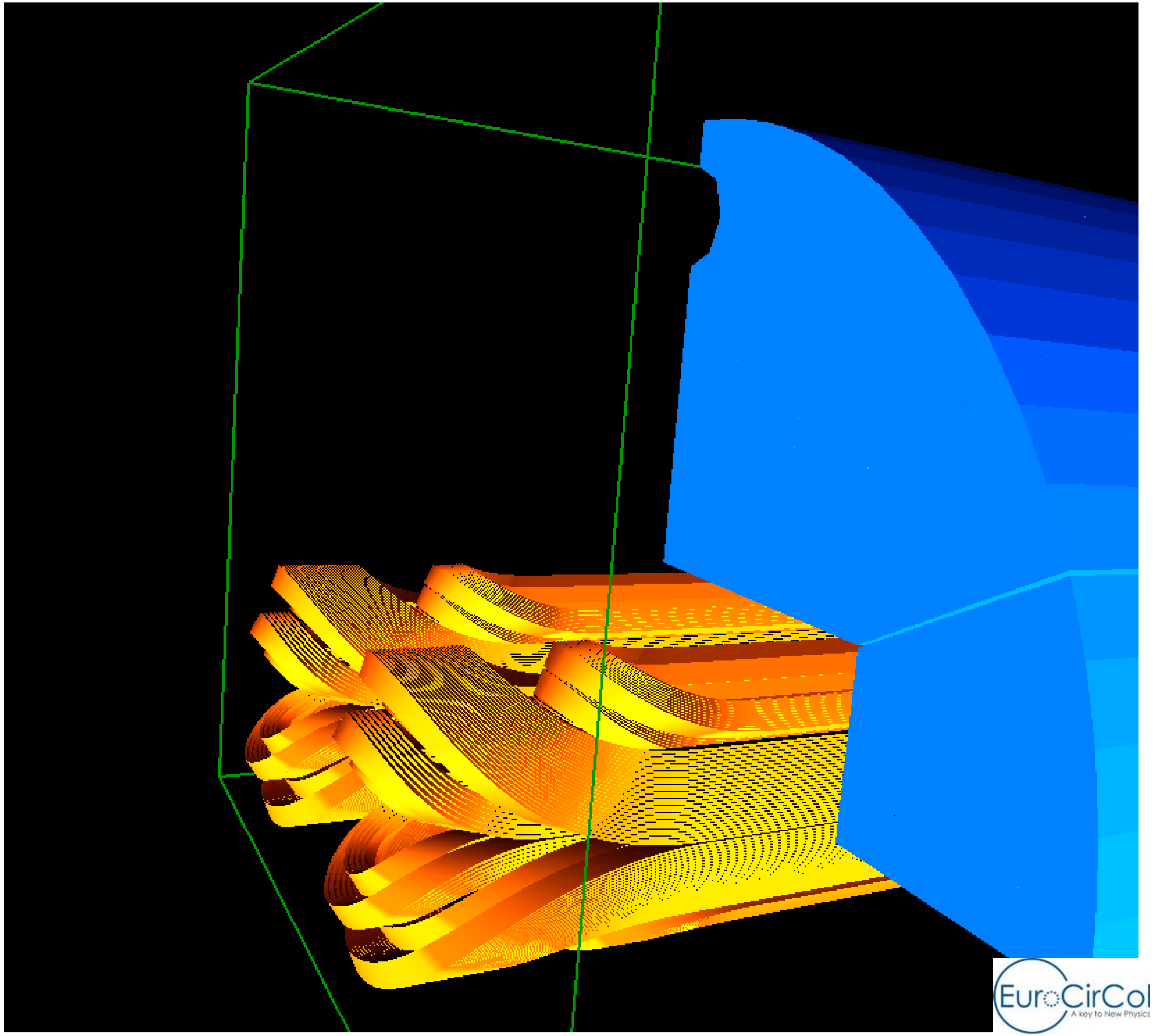


- Work in progress
- Based on a two double pan-cakes configuration
- Harmonic analysis performed
- Peak field to be computed yet

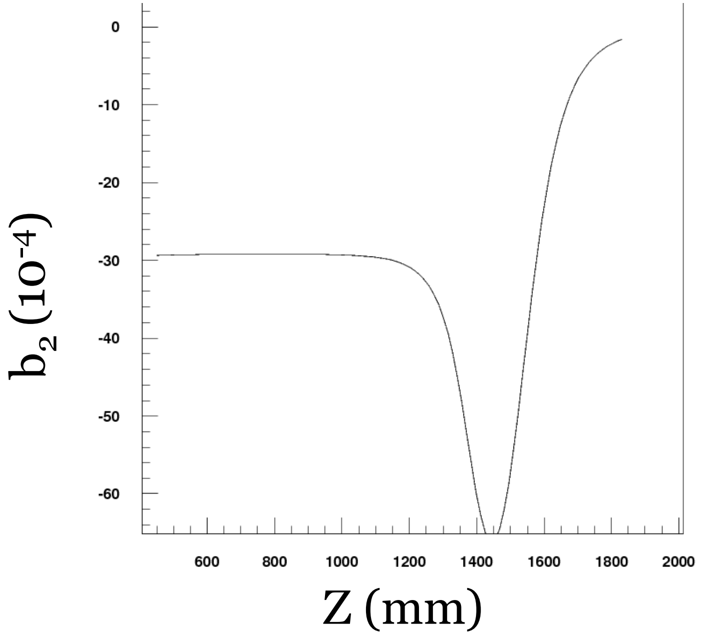
3.2 3D coil ends – field quality (opposite connections)

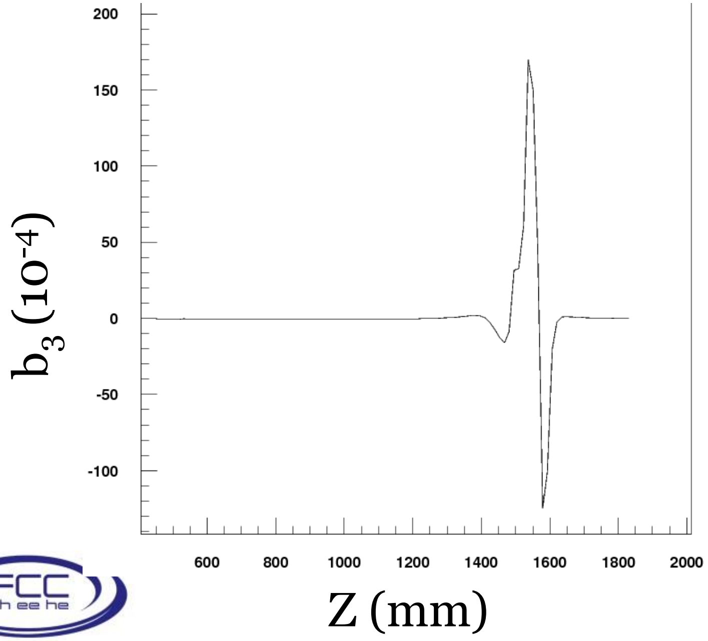
NORMAL 3D INTEGRAL RELATIVE MULTIPOLES (10^{-4})

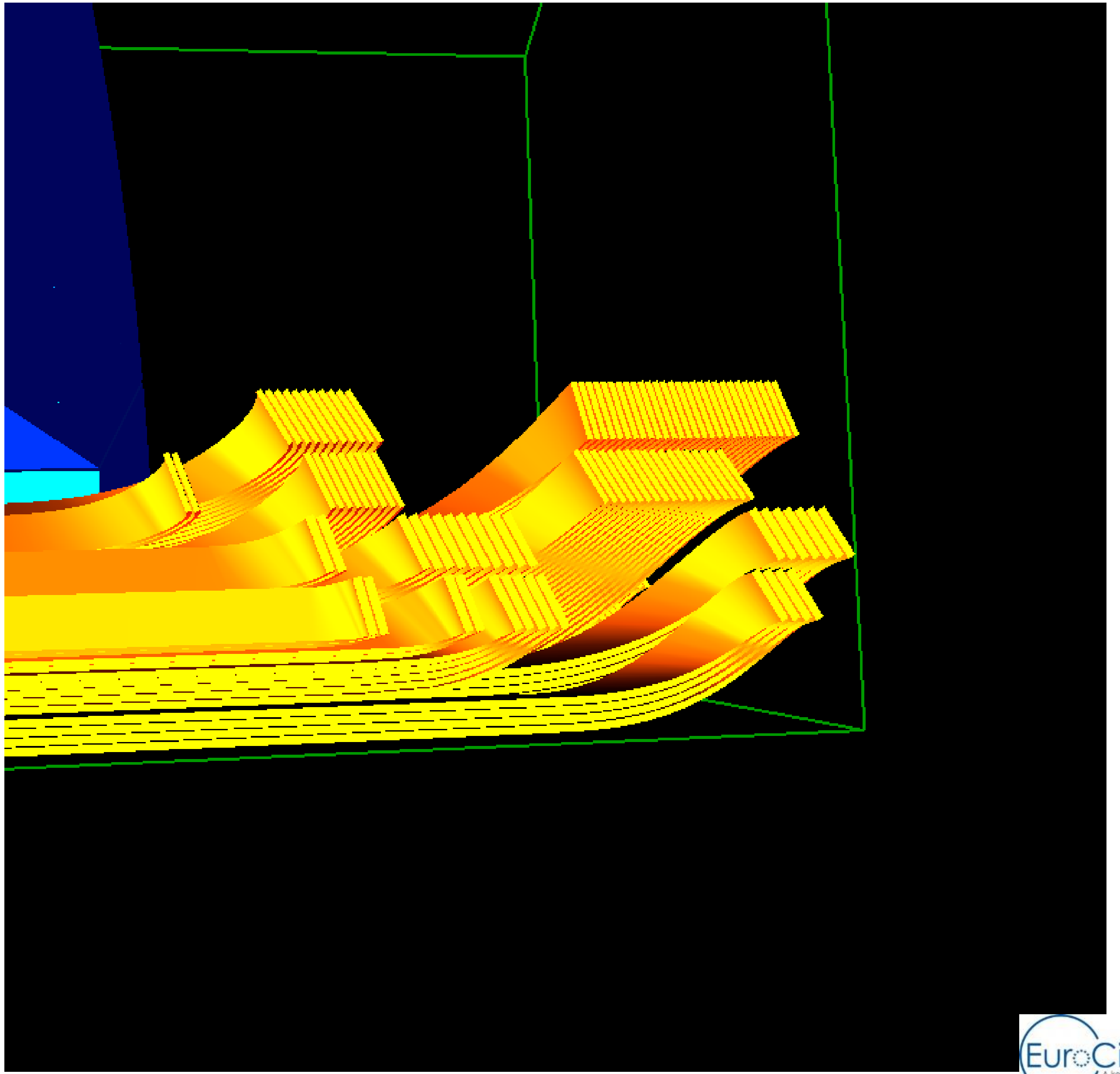
b1 = 10000.00
b2 = - 39.36
b3 = 2.59
b7 = 1.96
b9 = 1.39
Others < 1



3.3 3D coil ends – field quality (opposite connections)



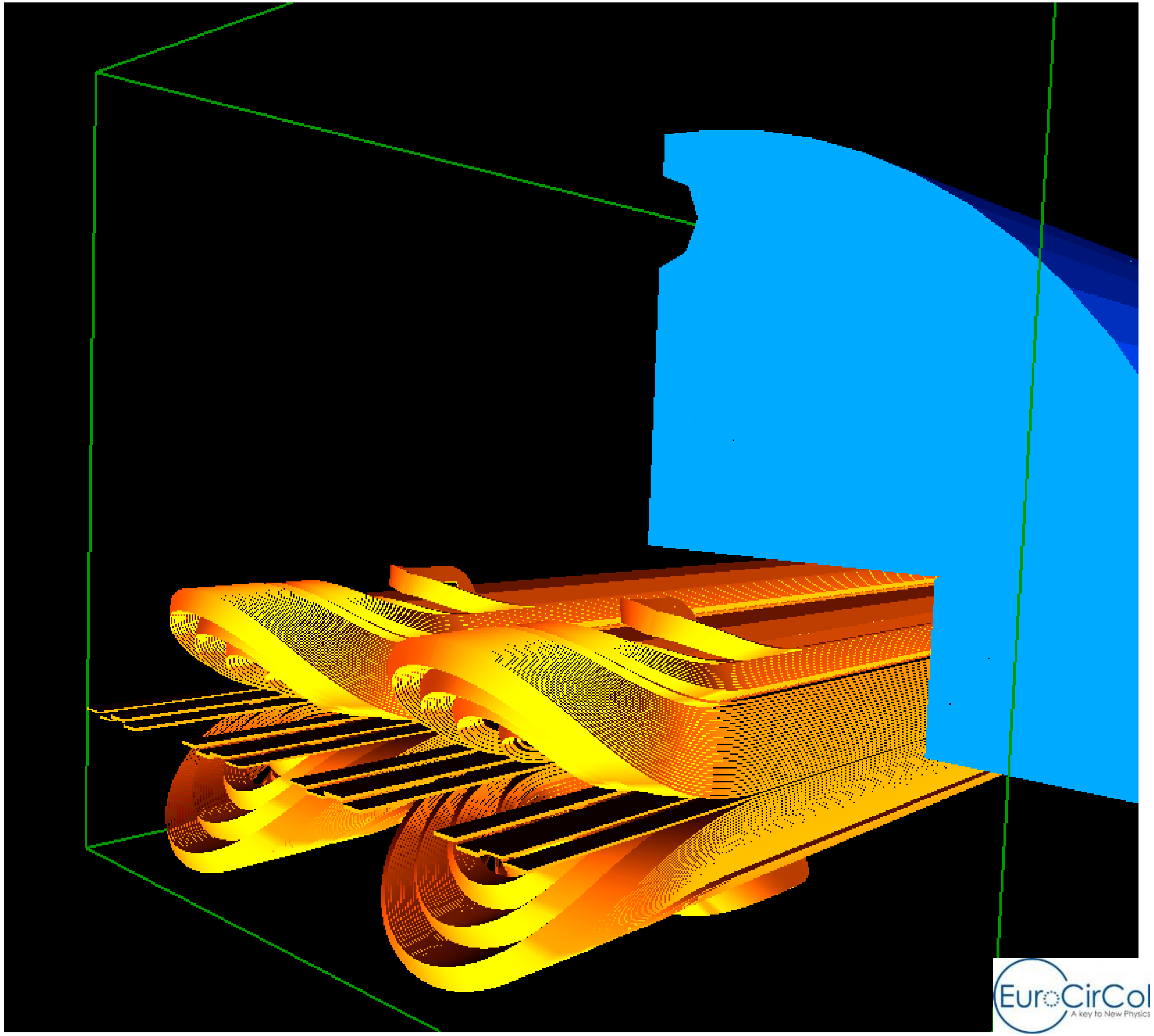




3.4 3D coil ends – field quality (connection side)

NORMAL 3D INTEGRAL RELATIVE MULTIPOLES (10^{-4})

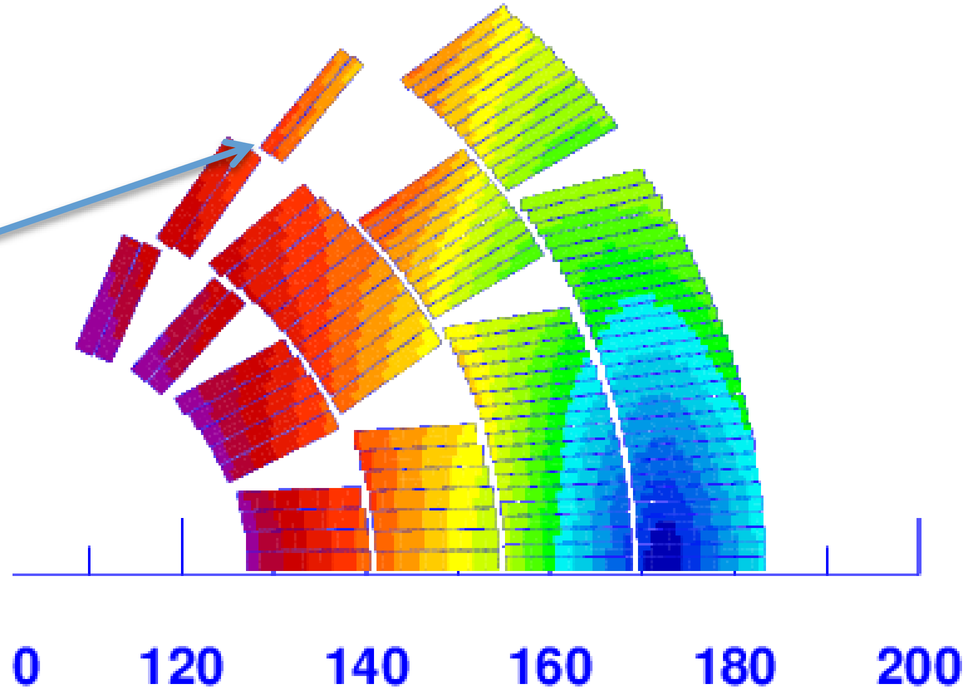
b1 = 10000.00
b2 = -42.85
b3 = 5.45
b5 = -2.76
b7 = 2.08
b9 = 1.49
Others < 1



4.1 Protection

- Main assumptions:
    - **No** energy extraction
    - Quench induced in the whole magnet **40 ms** after initial quench start
    - Inductance dependence on the current
    - Material properties from **MATPRO**

- Result (**105 %** of I_{op}):
    - Hot spot temperature: **~340 K**



More detailed **quench protection studies** in the Tiina Salmi talk (this morning)

5.1 Conclusions

- The presented 16 T cosine-theta **accomplishes** the **EuroCirCol** design constraints
  - Able to produce **16 T** bore field
  - Margin on the load-line is **86%** at 1.9 K
  - **Good** field quality
  - Hot spot temperature **below 350 K** @ 105% I_{op}
  - Possibility of using **iron pad** to improve the magnet is under exploration
  - Possibility of adapting the magnet for **HE-LHC?**

- We have began the design of 3D coil ends
  - Two **double-pancakes** (well-known technology)
  - **Acceptable** field quality
  - Peak field to be computed