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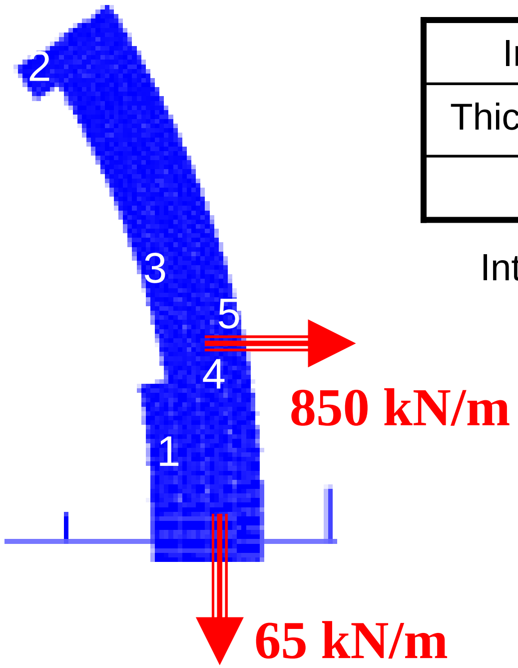
Design ideas for a cos(2θ) magnet

Magnetic design

The proposal technology comes from accelerator magnet => high current

- A previous 2D study gives a compact solution with 2200 Amps in 2 layers

The need for a low current leads to a new solution with 950 Amps but 4 layers.



Insulation	Insulated conductor (Rutherford type)		
Thickness (mm)	Keystone (°)	Height (mm)	Width (mm)
0.125	0.22	7.3	0.99 - 1.03

Internal coil radius : 250 mm

Stack	1	2	3	4	5
Number of conductors	44	10	146	151	155

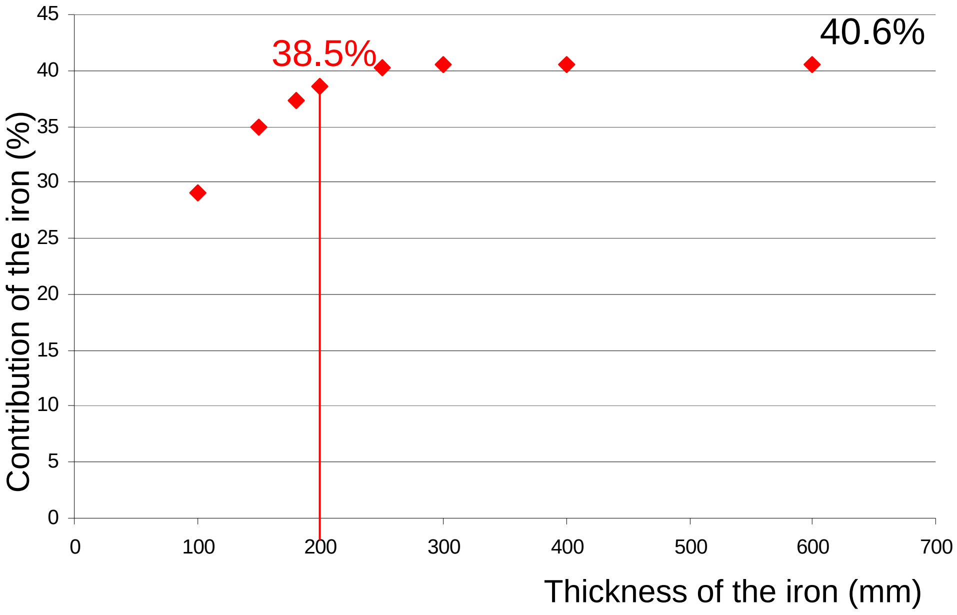
506 turns

G =14.2 T/m (length of the straight section=845 mm)

Iron yoke influence

Yoke is situated at 3 mm from the outer coil : maximal contribution on the field

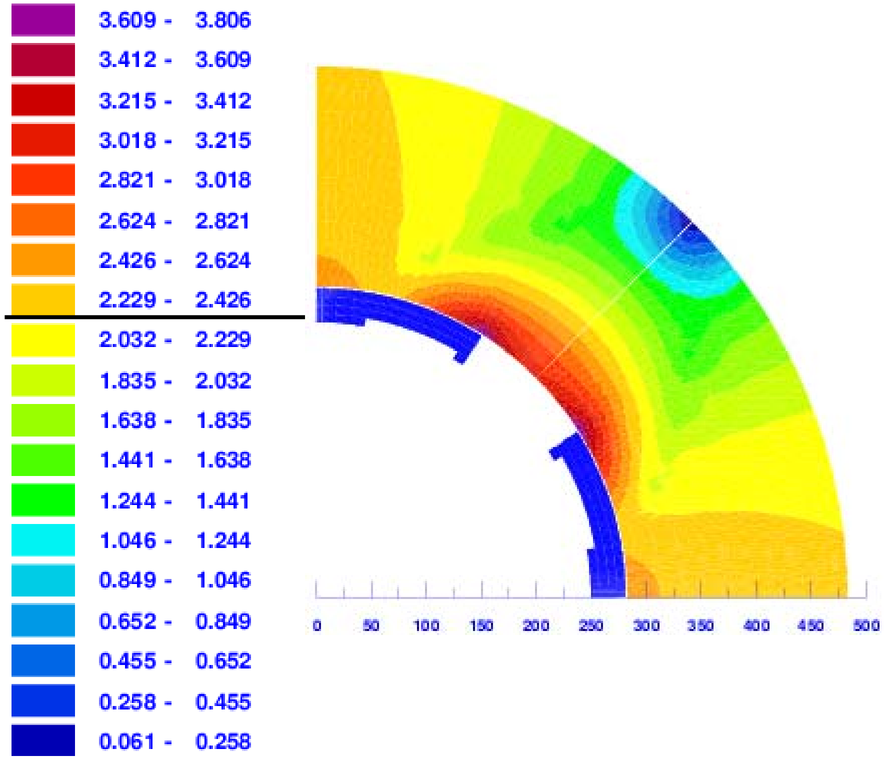
- Iron thickness versus yoke contribution to the main field (G = 14.2 T/m)



With a thickness of iron of 200 mm, we are closed to the maximal contribution of the yoke : 40 %

- Yoke saturation:

Yoke in mild steel (saturation at 2.12 T)



Harmonic studies

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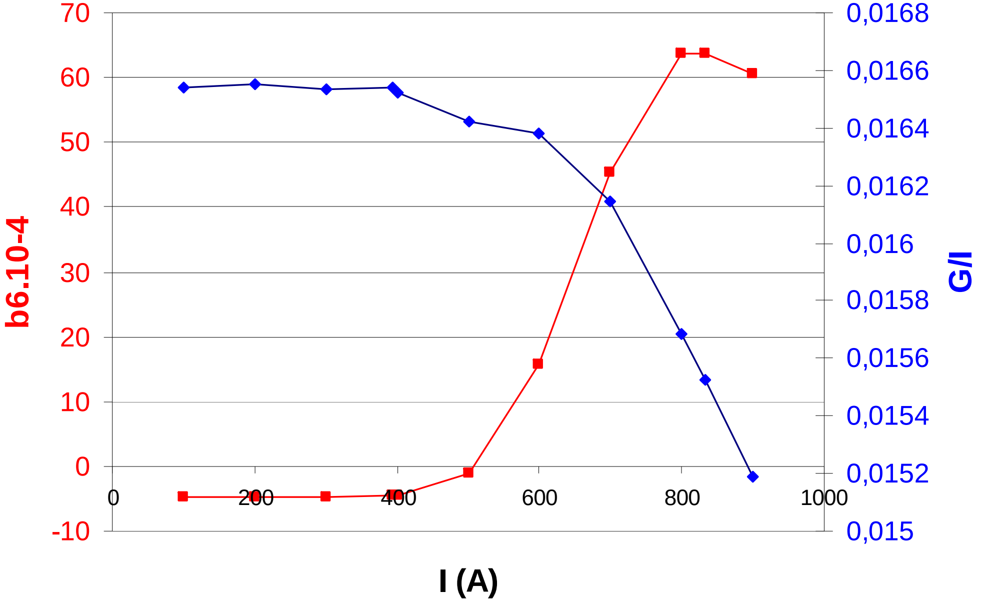
• Harmonics (10^{-4}):
Optimization has been done at low field (6.5 T/m).

G (T/m)	I (A)	b6	b10	b14	Spec
1	61	-4.48	-4.97	22.4	< ± 8
6.5	393	-4.28	-4.93	22.4	< ± 5
14.2	950	57.2	-3.59	20.8	< ± 60

• Main field linearity: $\frac{G}{I} = f(I)$ and $b6 = f(I)$



⇨ Except b14 at 1 and 6.5 T/m, all harmonics respect the specifications

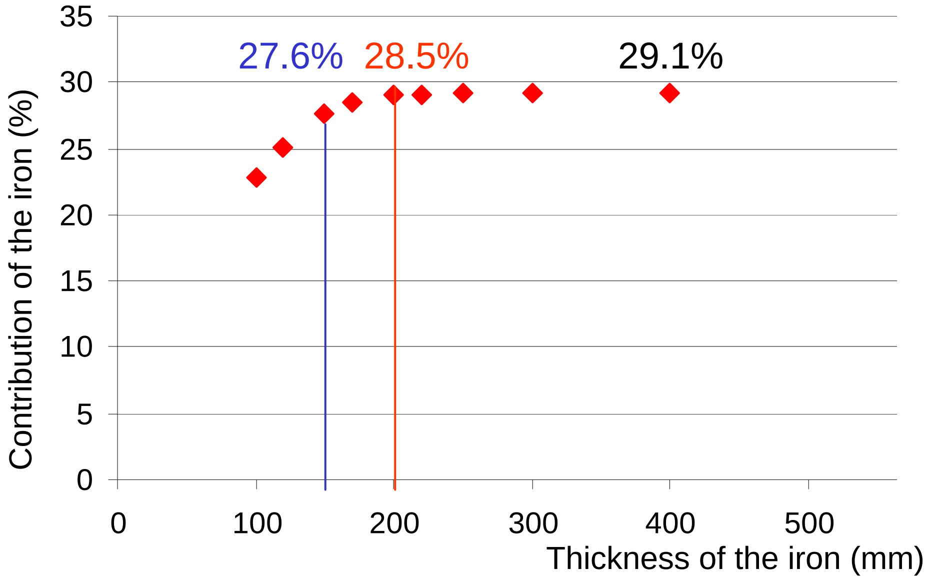
Over 450A, loss of field linearity (saturation of the yoke)

To avoid yoke saturation and to optimize harmonics, study of a case with a yoke at 50 mm from the outer coil

Alternative solutions: yoke at 50 mm from the outer coil

(Coils are re-optimized to have good harmonics)

• Iron thickness versus yoke contribution to the main field (G = 14.2 T/m)



Reduction of the yoke contribution :
Raise of the current

• Study with a thickness of 200 mm: comparison with the previous case

• Study with a thickness of 150 mm:

Quasi same contribution of the iron yoke

And diminution of the iron volume

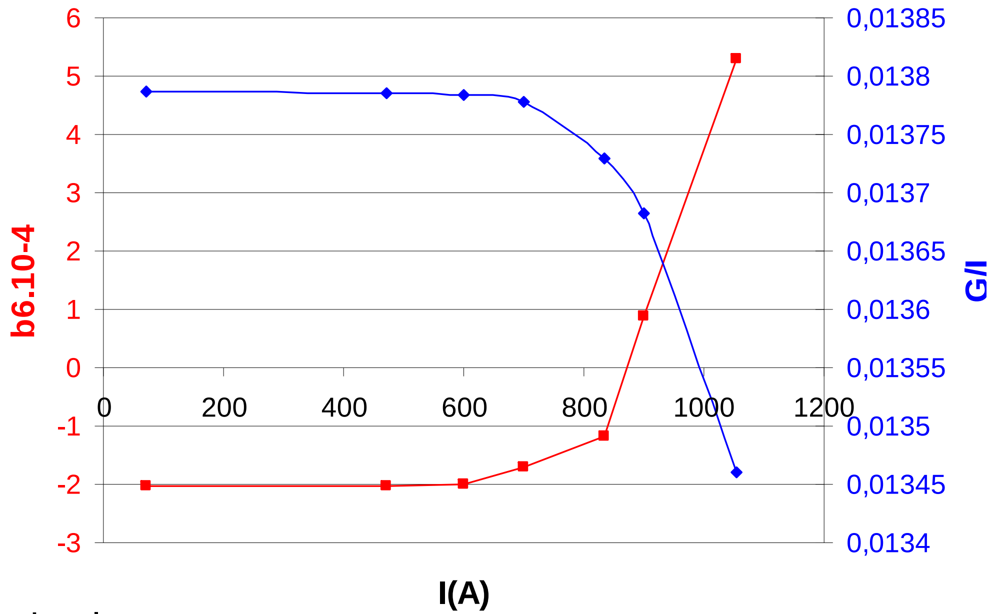
Yoke at 50 mm from the outer coil (thickness of 200 mm)

- Harmonics (10^{-4}):

Optimization has been done at low field (6.5 T/m).

G (T/m)	I (A)	b6	b10	b14
1	72	-2.02	-0.86	11.73
6.5	472	-2.02	-0.86	11.73
14.2	1055	5.3	-2.11	6.97

- Main field linearity and b6: $\frac{G}{I} = f(I)$ and $b6 = f(I)$



Improvement of the harmonics and their tolerances

⇨ Improvement of field linearity (saturation of the yoke at 600 A against 450 A previously)

BUT

Raise of the current (1055A against 950 A previously)

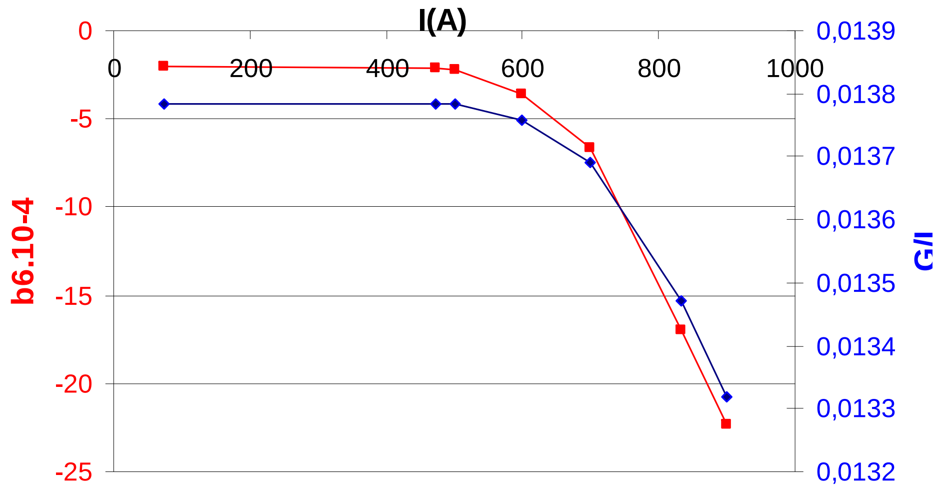
Yoke at 50 mm from the outer coil (thickness of 150 mm)

- Harmonics (10^{-4}):

Optimization has been done at low field (6.5 T/m).

G (T/m)	I (A)	b6	b10	b14
1	73	-2.07	-0.85	11.73
6.5	472	-2.14	-0.86	11.73
14.2	1105	-27	-3.11	-7.3

- Main field linearity and b6: $\frac{G}{I} = f(I)$ and $b6 = f(I)$



Same harmonics as the previous case with less iron

⇨ BUT

Raise of the current (1105A)

⇨ A compromise should be done

Solution without iron?

Mechanical studies

The main aspects of this preliminary study are :

- to decrease the size and then the weight of the magnet
  - => decrease the internal radius of the coil and its size
  - => use a minimum of iron with a maximum of efficiency : cold iron
  - => limit the volume of helium : indirect cooling

- to sustain the very high forces on the coil : 1600 kN/m in radial (2 half poles)
  - => use the iron collars

- to ease the integration process
  - => keep the magnet in horizontal position : table for integration

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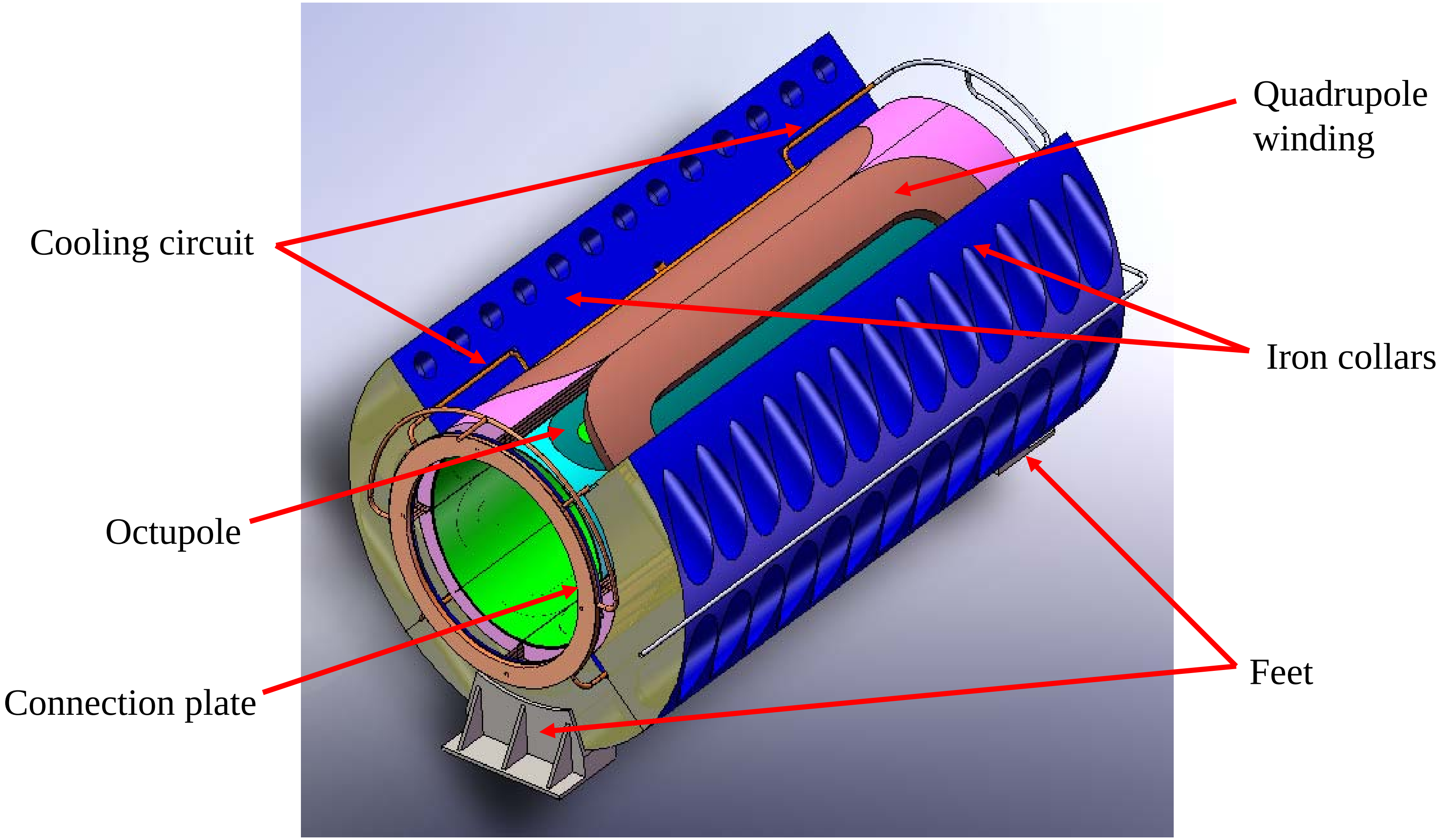
Preliminary design

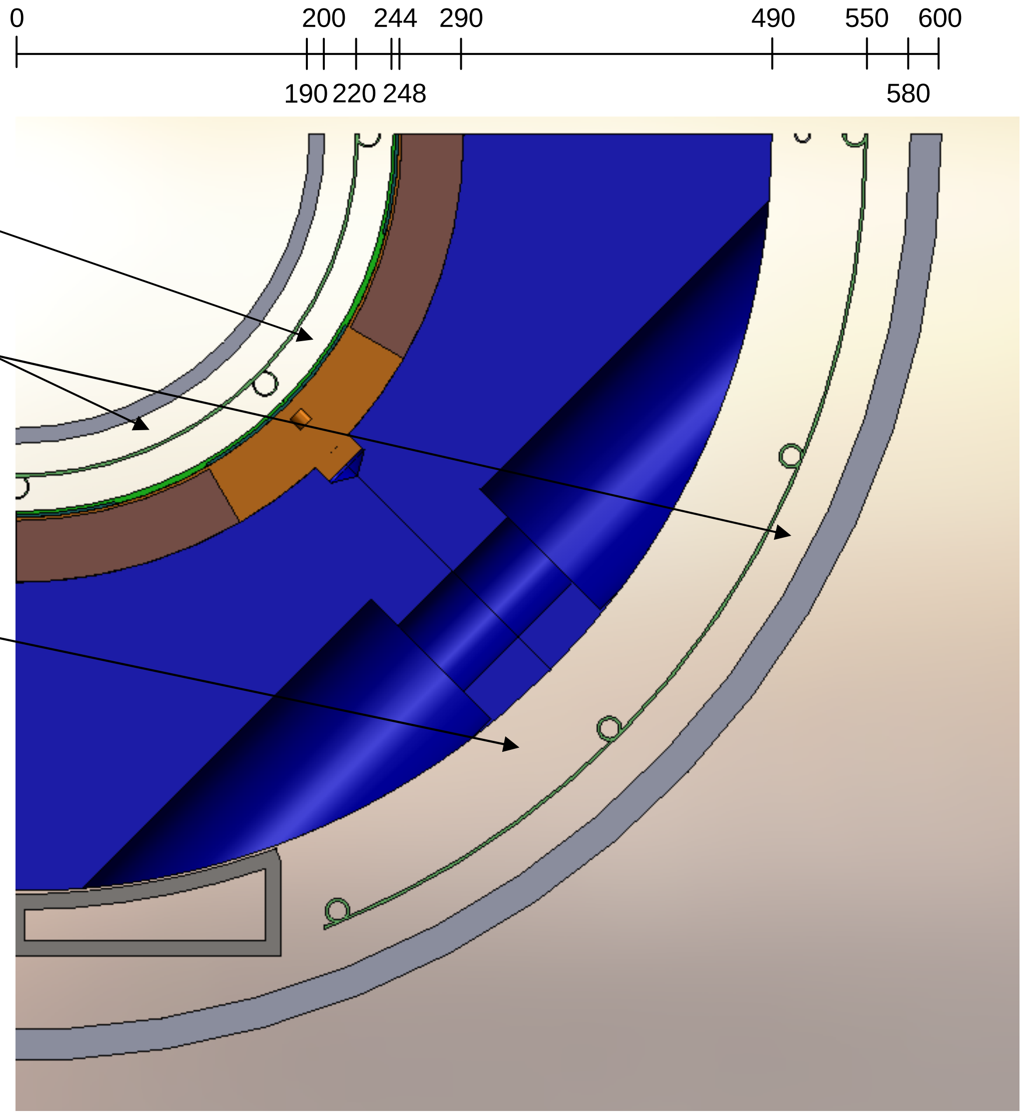


Space budget

Space needed for shield cooling circuit

Space needed for superinsulation

Space needed for connection between the quadrupoles



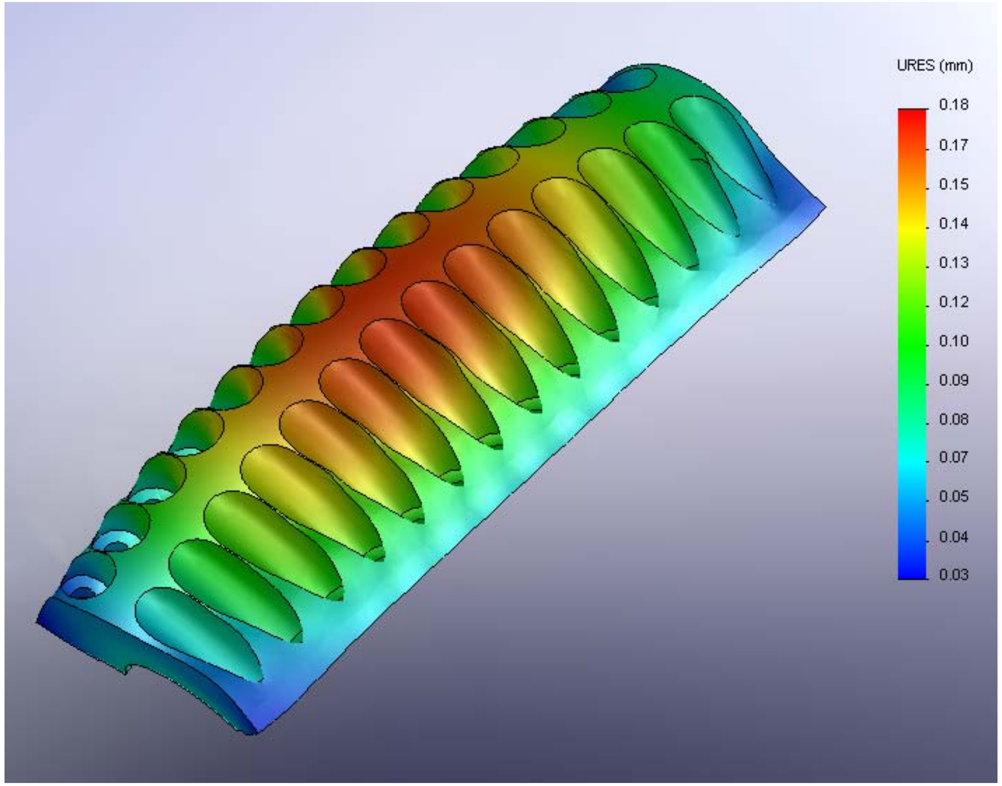
Collar deformation

Radial pressure : 7 MPa

2x14 bolts M56

→ 165 kN (87 MPa)

Maximum radial displacement : 0.18 mm, without bolt pre-stress



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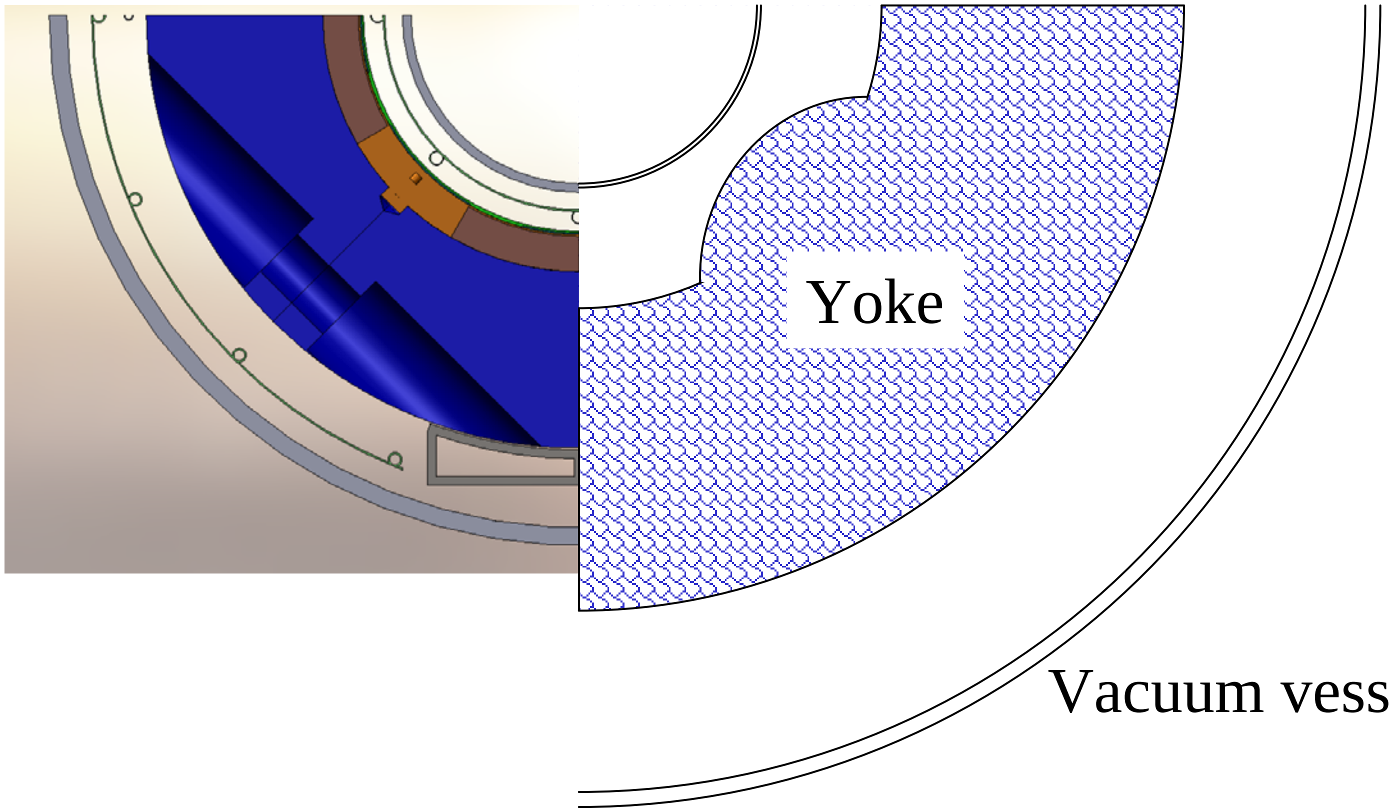
Comparison with Toshiba design



Comparison with Toshiba design

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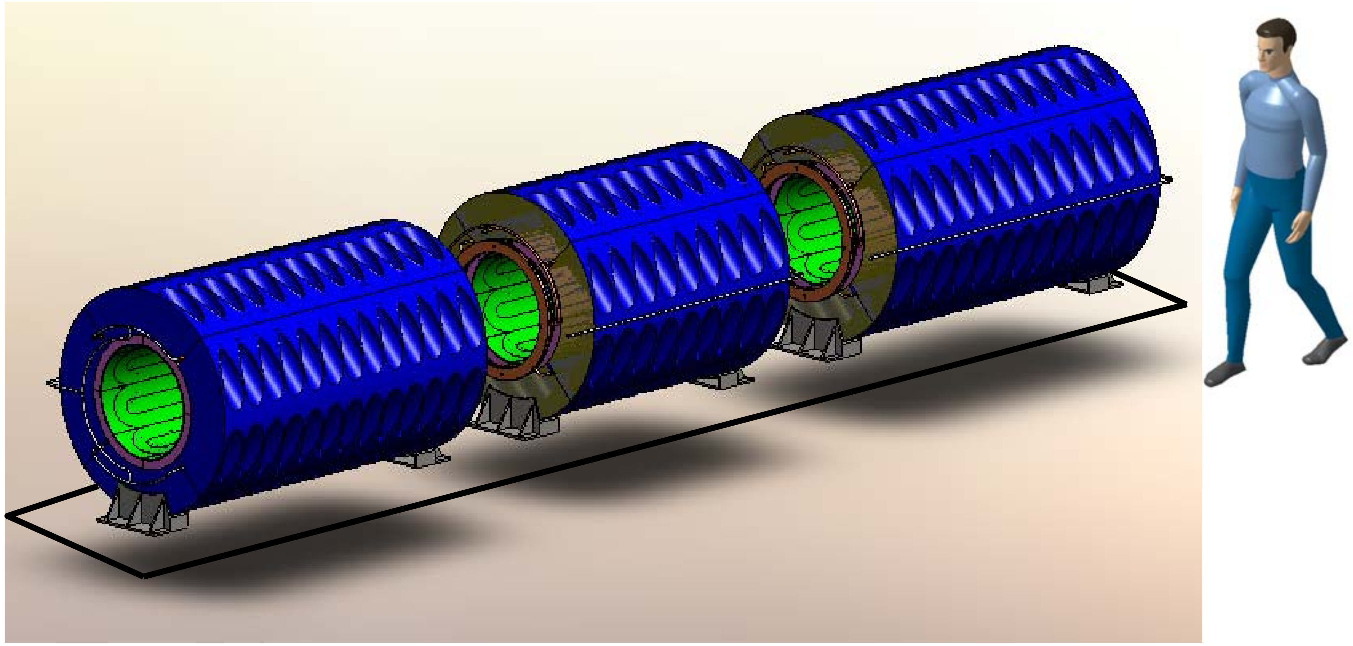
	11/03/2009 Cos(2θ) (Saclay)	TDR 12/2007 Superferric (Toshiba)
Magnetic length [m]	1,2	1,2
Current [A]	950	292
Number of turns	545	1250
Ampere-turns	517750	365000
Mean turn length for one pole [m]	2,7	3,375
Non insulated conductor height for one pole [mm]	7,050	1,9
Non insulated conductor width for one pole [mm]	0,755	0,9
Non insulated conductor surface for one pole [mm²]	5,323	1,710
Insulation thickness (mm)	0,125	0,04
Insulated conductor surface for one pole [mm²]	7,34	1,94
Surface of one pole [mm²]	7997	5500
Current density (A/mm²)	129	133
Conductor volume for one pole [dm³]	7,8	7,2
Cu/Sc ratio	6,4	3,5
SC volume for one pole [dm³]	1,06	1,60
Iron mass [ton]	4,6	12
Lineic stored energy [kJ/m]	470	754
Lineic inductance [H/m]	1,35	13,6
Margin on the load line [%]	30	41
Lineic azimutal forces (between two half poles) [kN/m]	588	222
Lineic radial forces (one pole) [kN/m]	1604	1191
Discharge voltage (V)	300	1163
Vacuum vessel inner diameter (m)	0,38	0,38
Vacuum vessel outer diameter (m)	1,2	1,72

Multiplet assembly



The cold mass assembly could be done on an horizontal table …

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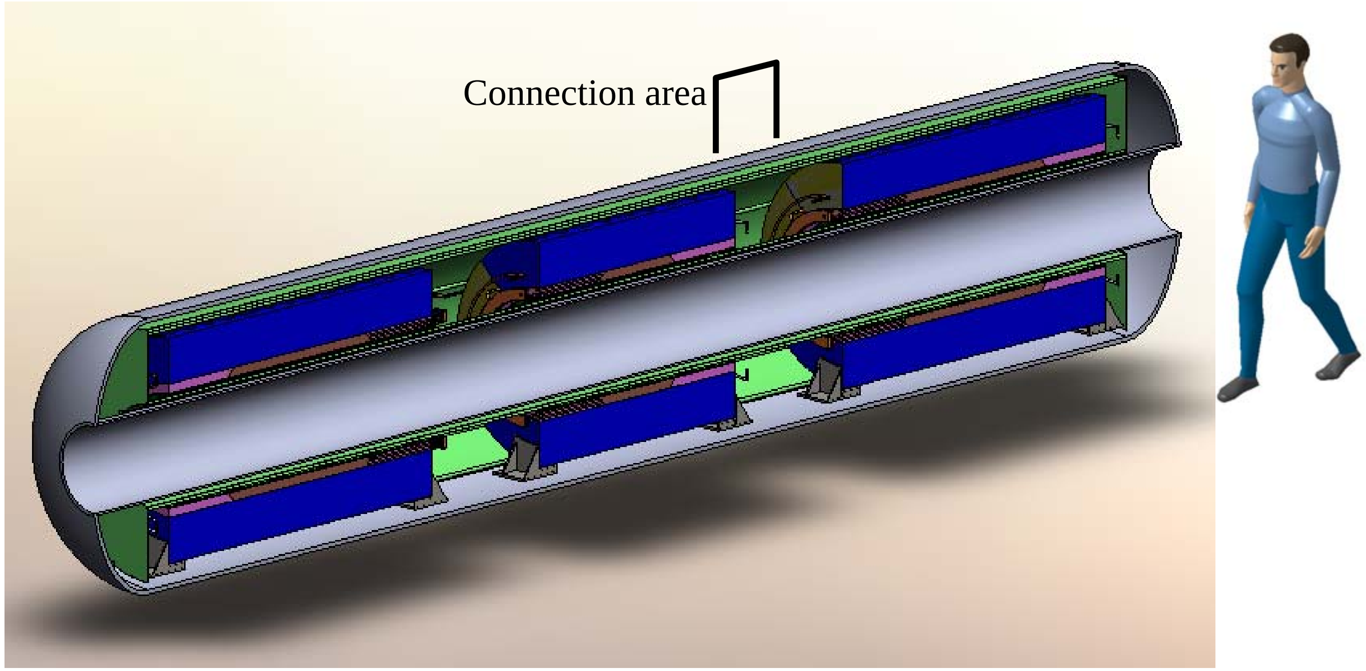
Multiplet assembly



… then introduced horizontally into the cryostat and connected to the external feedbox.

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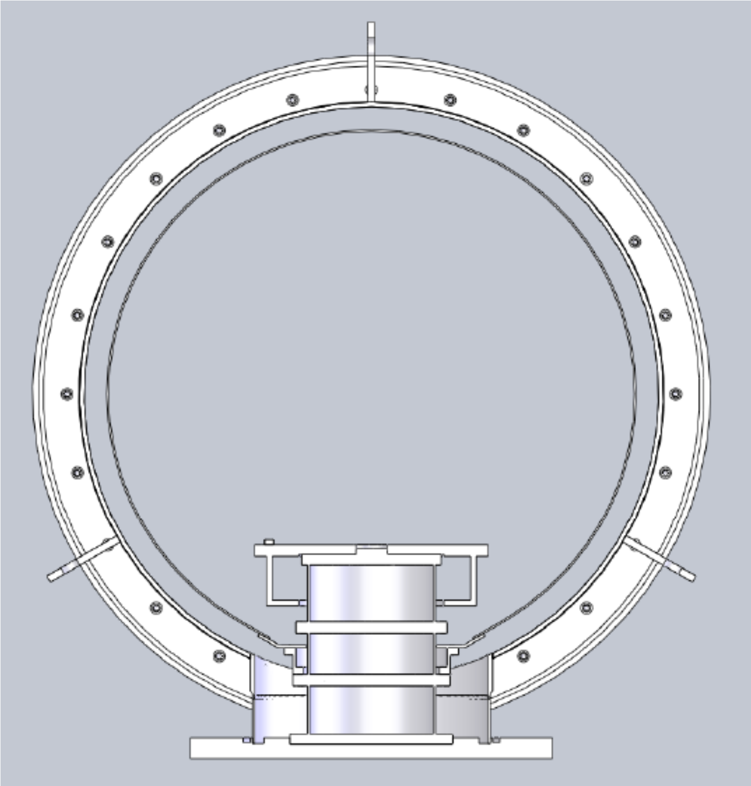
Table principle



The link to the cryostat (shield and vacuum vessel) is done by composite tubes.

Cryogenic aspects

- The indirect cooling avoid a great quantity of liquid helium storage (9 m^3 in the Toshiba proposal).
- It is very interesting in case of quench.
- It is probably enough to absorb the deposited loads on the coil
- The cool-down probably need additional circuit
- The thermal link with the correction coils (mainly the octupole) is to study

Further studies

- Magnetism:
  - 3D computation with heads : optimization of magnet length and gradient
  - Cycle losses
  - Sensibility to the location defects
  - Iron or not? Optimization of the iron thickness
  - Raise of the Jc (Cu/Sc = 6.4)
- Mechanism:
  - Space optimization (mainly internal radius of the coil)
  - Mandrel computation
  - Vacuum vessel sizing
  - Design with a better quench protection
- Cryogenics:
  - Static thermal map
  - Cool-down studies (additional pipes needed)

Next steps

- **Choice of a solution**
- Task sharing