Task 4 :
Electromagnetic and mechanical design

M. Devaux

Summary

- Design contrains
  - Fresca 2
  - Aim of 6T
  - Conductor
- Magnetic design
  - Influence of the iron pole
  - Study of the transverse field
  - Influence on Fresca 2
- Mechanical structure
  - Component details
  - Influence on Fresca 2
- Conclusion

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DESIGN CONSTRAINS

- Fresca 2
- Aim of 6T
- Conductor

Design contrains from Fresca 2

- Fully dismountable from Fresca 2, without the need of disassembling it.

- Not transfer any load on Fresca 2 during operation

→ All the magnetic loads and deformations have to be self-supported by the insert.

- Inner bore of Fresca 2 = 100 mm

→ Outer diameter of the HTS insert = 99 mm

- Located in the straight section of Fresca 2

→ Length = 700 mm.

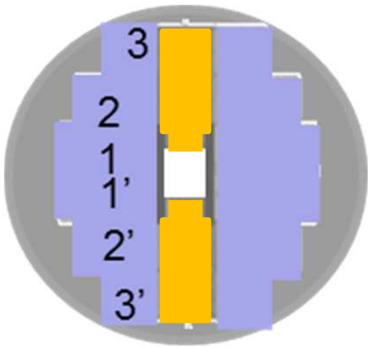
- Necessity to optimise the space

→ Inner bore = 10 mm (space for a Hall probe for the magnetic field measurement during testing)

Design contrains from the aim of 6T

- Aim = 6T
  - 3 double pancakes : the mid-plane pancake is longer than the other ones to reduce the peak field problems at the edges.
  - A ground and inter-pancake of 0.2 mm (G10 foils) between each coils to insulate them between them.

Coil number and Location	Number of turns	Length (mm), heads included
1-1' mid plane	73	700
2-2' medium	61	350
3-3' external	35	326



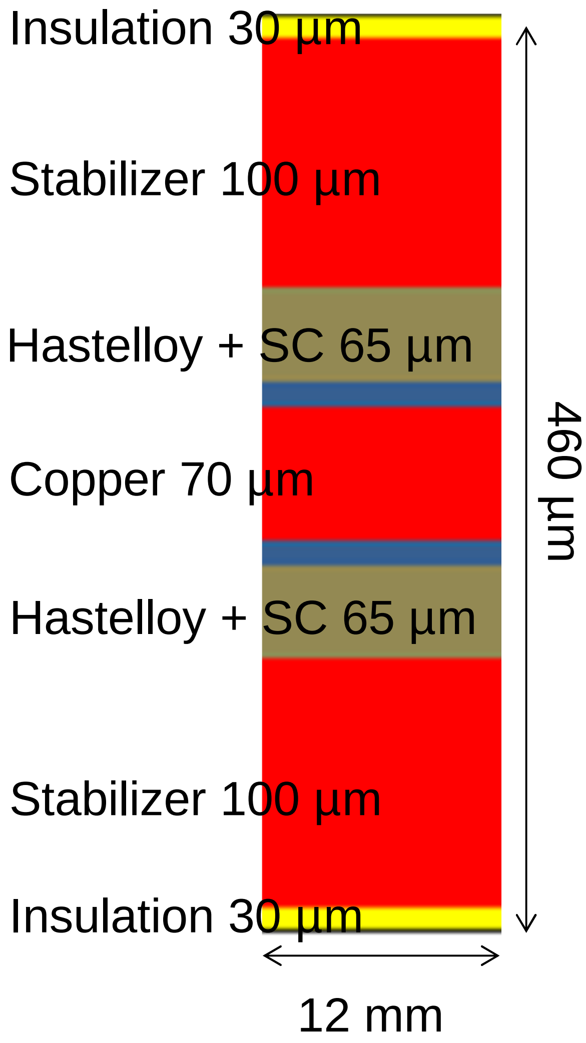
- Iron pole to increase the field

Design contrains from the conductor

- Presentation of J. Fleiter

- Requirements for the conductor
  - High current capacity
  - Flexibility in the winding
  - SC close to the neutral axis to limit stress in the coil ends
  - Good mechanical resistance
  - Low resistance connections

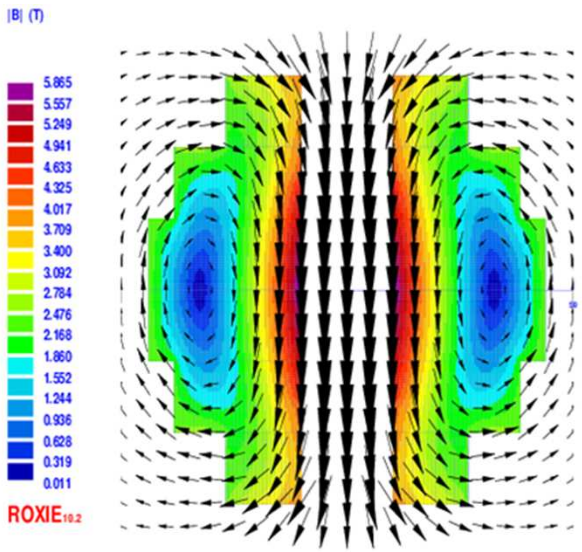
- YBaCuO tape
  - Block technique
  - Height of 12 mm: imposes the height of the pancakes
  - Ends are designed as a half circle of 10 mm



MAGNETIC DESIGN

- Iron pole
- Transverse field
- Load line
- On Fresca 2?

Magnetic design



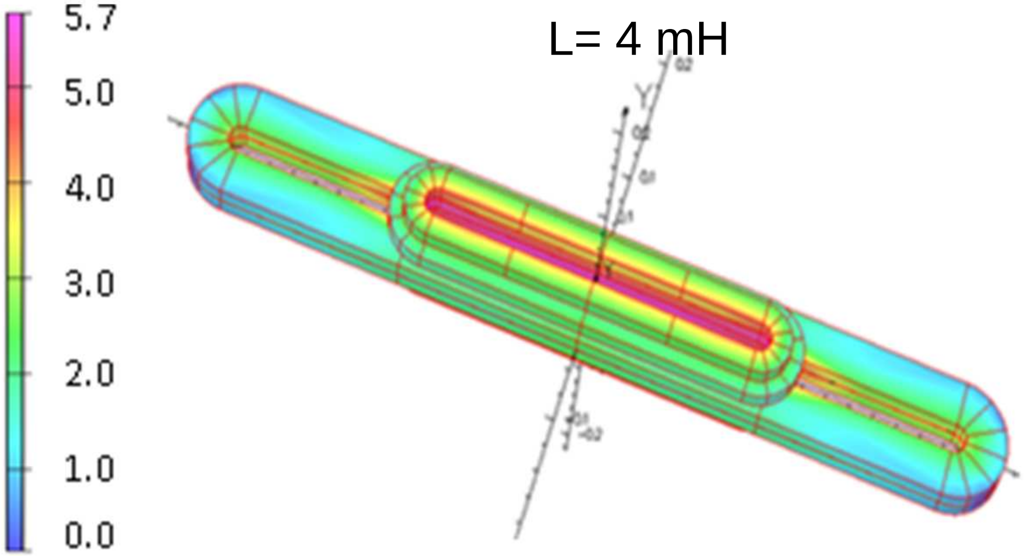
B0 = 6 T

Bpeak= 5, 87 T

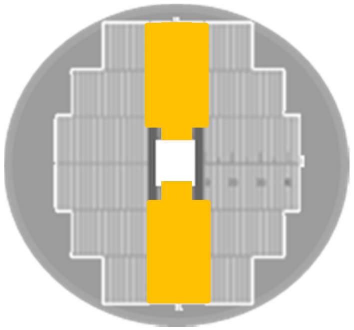
Je= 250 A/mm^2

E= 15,7 kJ

L= 4 mH



Iron pole : 2 D consideration



- A comparison is done between case with iron pole/ case without iron pole
- Pole in magnetil (saturation for a field over 2,12 T)

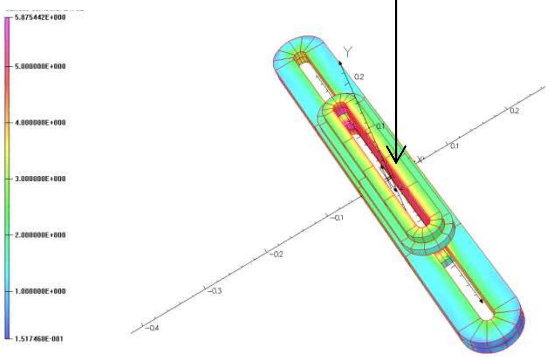
	WITH IRON POLE	WITHOUT IRON POLE
B0	6,1 T ☺	5,5 T ☹
Bpeak	5,9 T ☹	5,6 T ☺

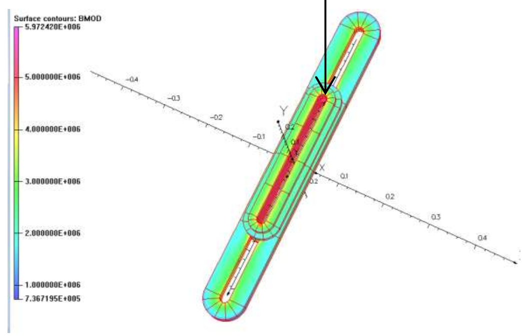
- ☺ : The pole increases the central field of 10%
- ☹ : It increases also the peak field of 10% in the straight section

Study needed to evaluate the field in the heads, especially the transverse field

Iron pole : 3 D consideration

	WITH IRON POLE	WITHOUT IRON POLE
Pole	All along the straight section up to the heads of the two upper blocks	-
Je	250 A/mm^2	250 A/mm^2
B0	6,1 T ☺	5,5 T ☹
Bpeak	5,9 T	6 T
Localisation of the Bpeak	First coil in the middle of the straight section	Heads of the second block





- The iron pole concentrates the field lines and limits the peak field in the heads
- Validation of the necessity of the iron pole

3D design : Estimation of the transverse field

- High field orientation dependance on the critical current
- Determination of transverse and parallel fields to determine the critical points of the coil

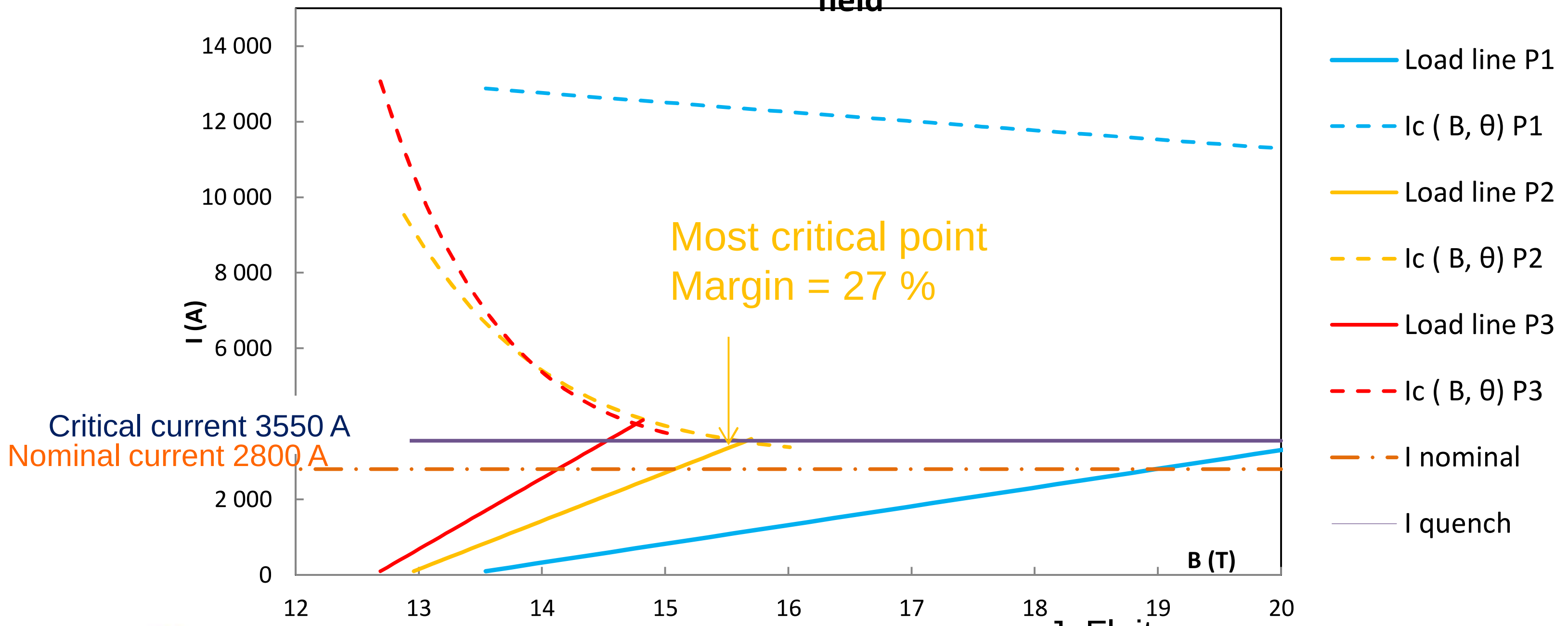
	B_{perp} max	B total	$B_{//}$ at this point
In the straight section (Roxie and TOSCA calculation)			
WITH IRON POLE	2,7	3,15	1,62
WITHOUT IRON POLE	2,5	3,11	1,85
In the heads (TOSCA)			
WITH IRON POLE	1,63	2,82	2,23
WITHOUT IRON POLE	2,05	2,45	1,36

- The transverse field is similar with or without iron pole
- It has to be considered carefully as it equals 2,7 T for a total field of 3,15 T in the straight section
- However, the insert will be not tested alone in its nominal configuration
- Study under the field of 19 T required

Study of the load line under 19 T

	Pancake number	B_{tot} (T)	$B_{//}$ (T)	$B_{\perp}$ (T)
Btot max	1 (straight part)	18.98	18.98	0
$B_{\perp}$ (T) in the heads	1	14.12	14	1.89
$B_{\perp}$ (T) in the straight part	3	14.99	14.72	2.86

Load lines of the most critical points of the HTS insert with 13T background field



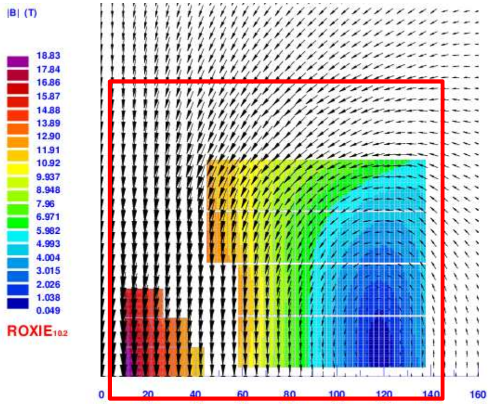
J. Fleiter

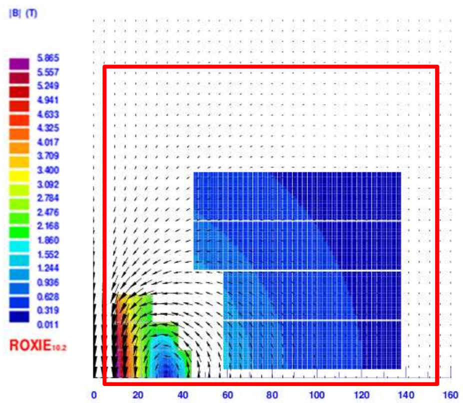
On Fresca 2 ??

- Magnetic calculations in 2D and 3D have been done with the two magnets.
- The iron of the insert participes to the main field of Fresca 2 (0,6 T) :

Fresca 2 alone **(Inom)**	Fresca 2 (I nom) with the insert (0 A)	Fresca 2 (I nom) with the insert (inom)
13 T	13,6 T	19,6 T

- Field vector maps with current or not in Fresca 2:



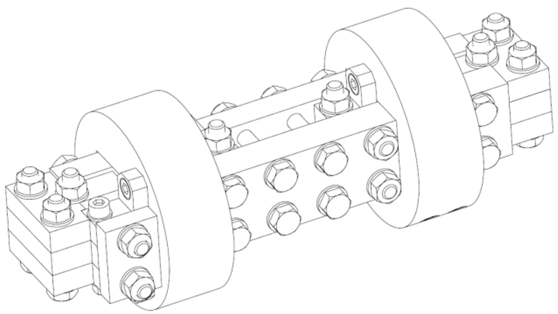


- In Fresca 2, the magnetic flux due to the insert is opposite to the one due to Fresca 2: This contributes to reduce the peak field of Fresca 2

Conclusion about magnetic design

- 6T can be reached
- Iron pole
- Due to the anisotropy of the superconducting properties of YBCO the lowest critical current margin is not located at the peak field value.
- The critical current margin has been evaluated to 27 %

A pancake of few turns will be tested at LNCMI-Grenoble in different field orientation to evaluate the dependence of the critical current with the field orientation.



MECHANICAL DESIGN

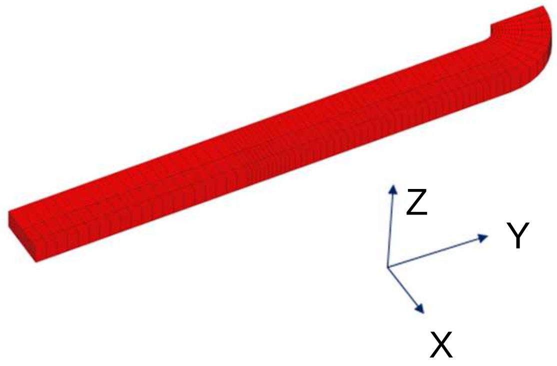
- Structure
- Details of the components
- On Fresca 2?

Mechanical datas

- Constrains due to Fresca 2:
  - The insert is mechanically self-supported
  - Displacement < 0,5 mm

- Calculations of the applied forces on the coils in the worst configuration (field of 19 T)

	Straight section (t/m)			Ends (t)		
	Fx	Fy	Fz	Fx	Fy	Fz
Coil 1	139,5	0	-7,4	3,65	3,65	-0,38
Coil 2	120	0	-11,6	2,9	3	-0,27
Coil 3	72,5	0	-11	1,34	13,5	-0,2
Total	332	0	30	-	-	-



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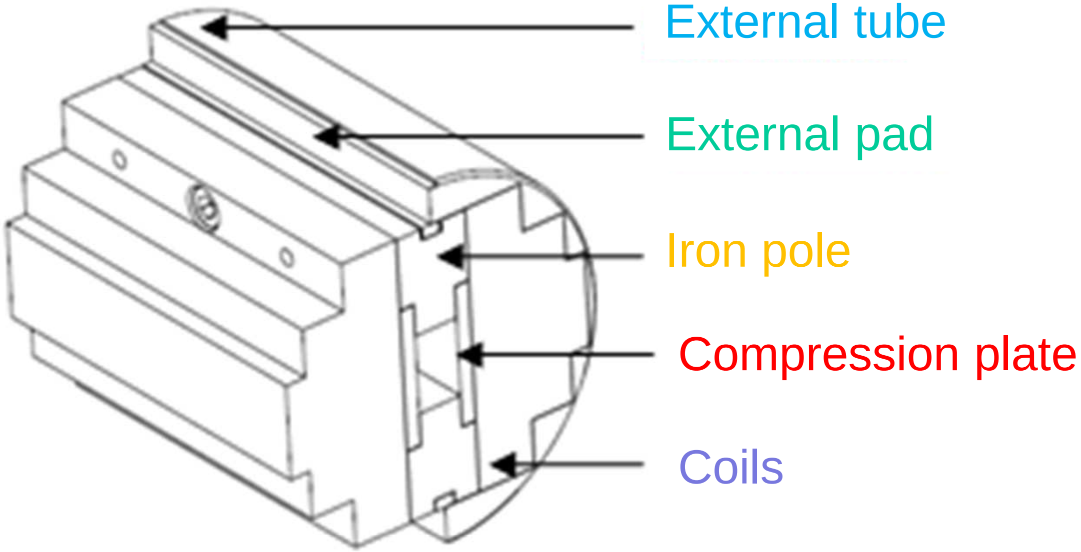
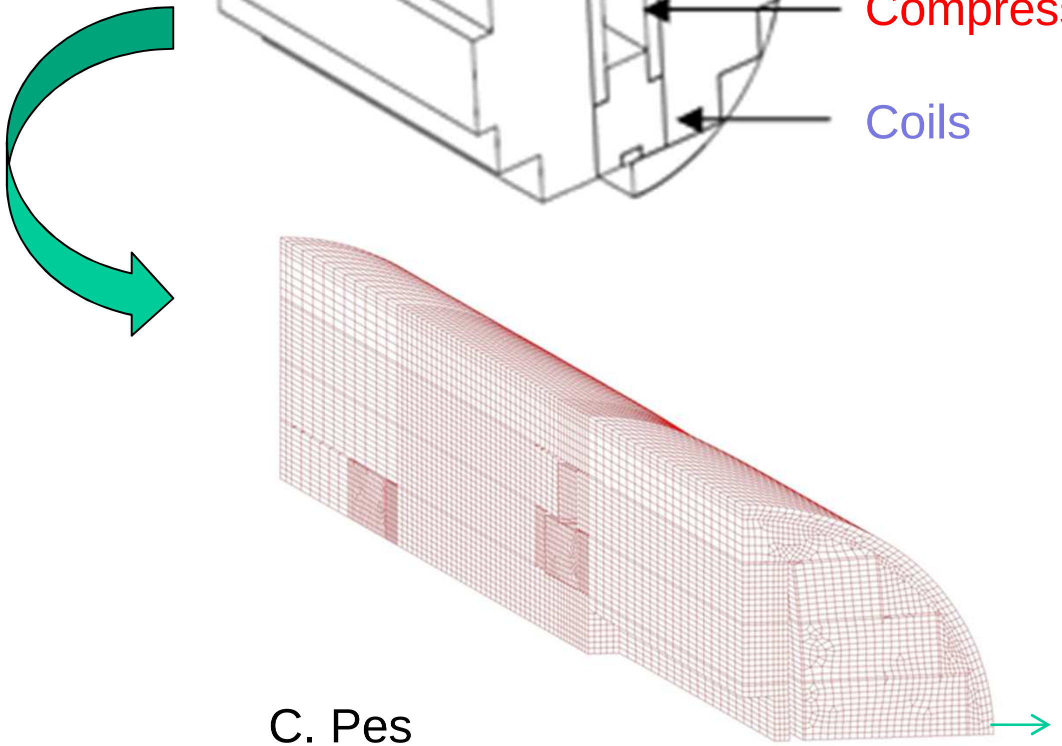
Data to take into account in the choice of the mechanical structure

Mechanical structure





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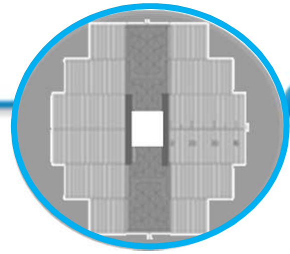
Ux = 0.14 mm < 0,5 mm

External tube



- Carries the resulting load and limits the deformation.
- Due to the magnetic forces it will become ovoid.
- Optimization of its thickness

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Tube thickness (mm)	Coil winding cross section (mm²)	Maximum field on axis (T)	Maximum stress (MPa)
2	985.5	18.56	1071
3	942	18.4	824
4	893	18.21	649

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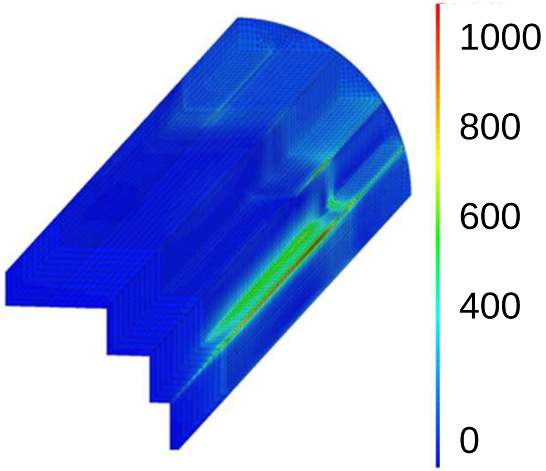
- Last calculations : 530 MPa

- The material will be Nitronic® alloy high elastic limit.

External pads, Compression plates and Pole

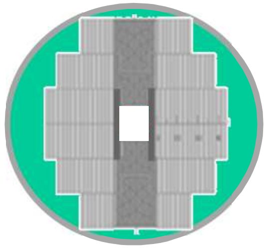
- *External pad:*



Apply uniformly the load from the coil winding to the external tube.

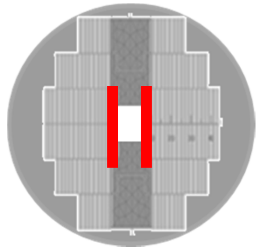
Von Mises stresses up to 800 MPa on some critical points.

304 stainless steel (high elastic limit)



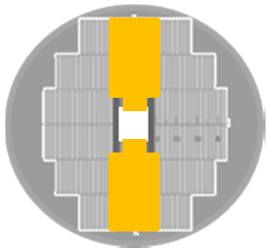
- *Compression plate:*

Reduce the oval shape induced by the magnetic loads by keeping the compression stiffness in the Y direction

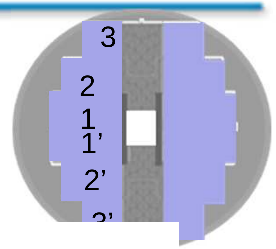


- *Pole*

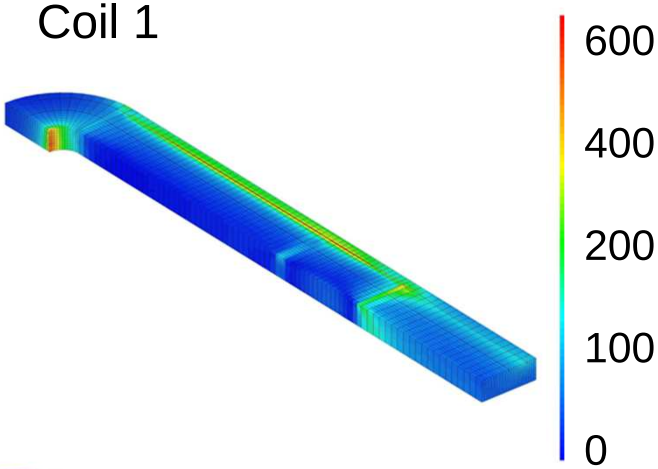
Ensure the compression stiffness in the Y direction by applying load on the compression plates.
Iron (magnetic contribution)



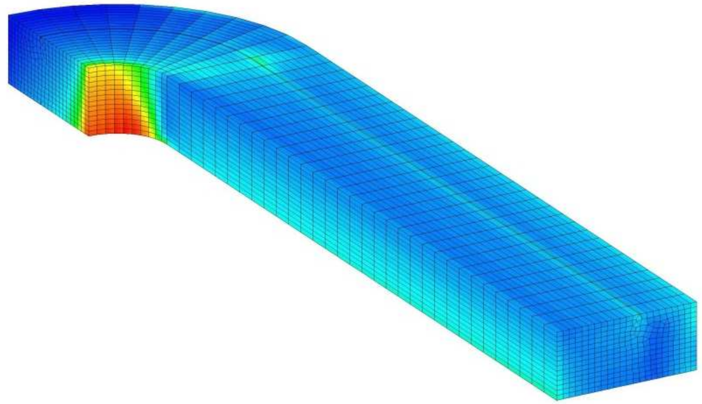
Stresses on the coils

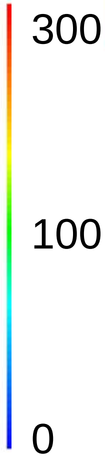


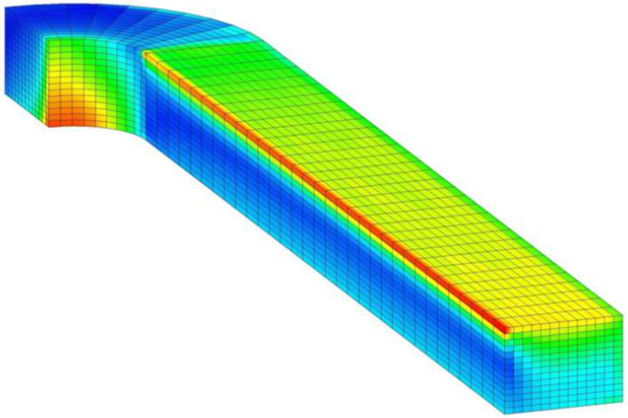
Coil 1



Coil 2







Coil 3

Maximal stress on the winding is 600 MPa

Development of a conductor able to support it

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Conductor

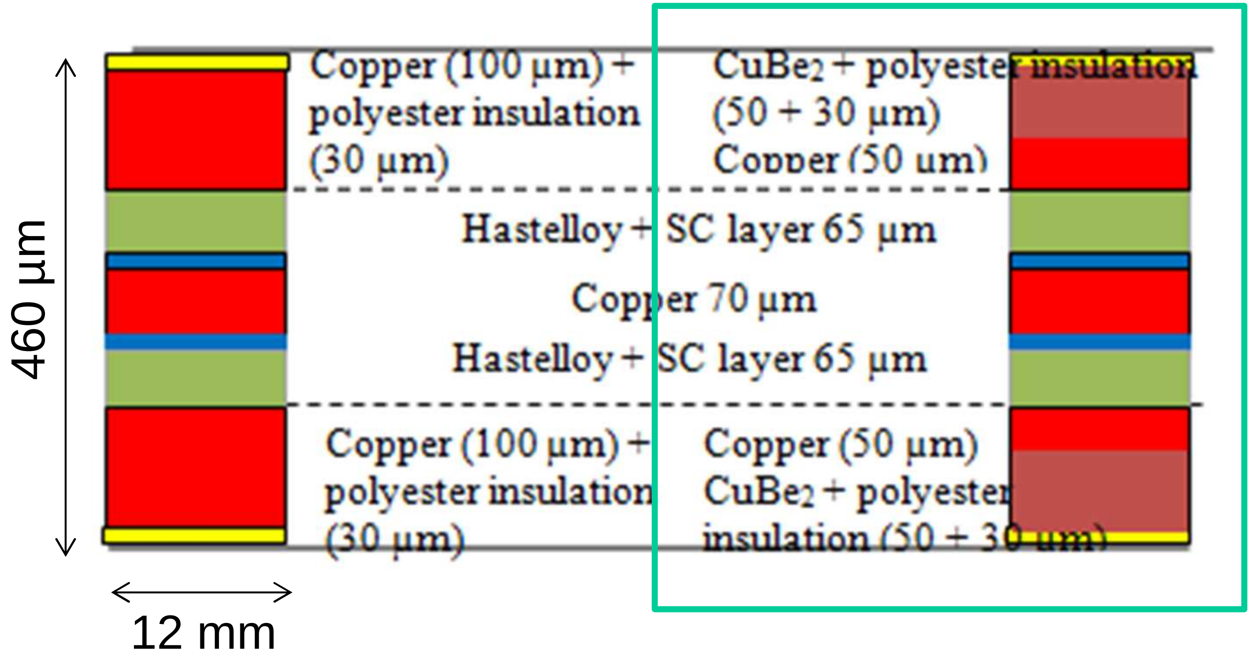
- Need to developp a conductor which supports a stress over 400 MPa

- First idea : reinforcement and stabilization with copper

Cannot support over 300 MPa

- Adding $CuBe_2$: compromise between stabilization and reinforcement

Stress around 600 MPa



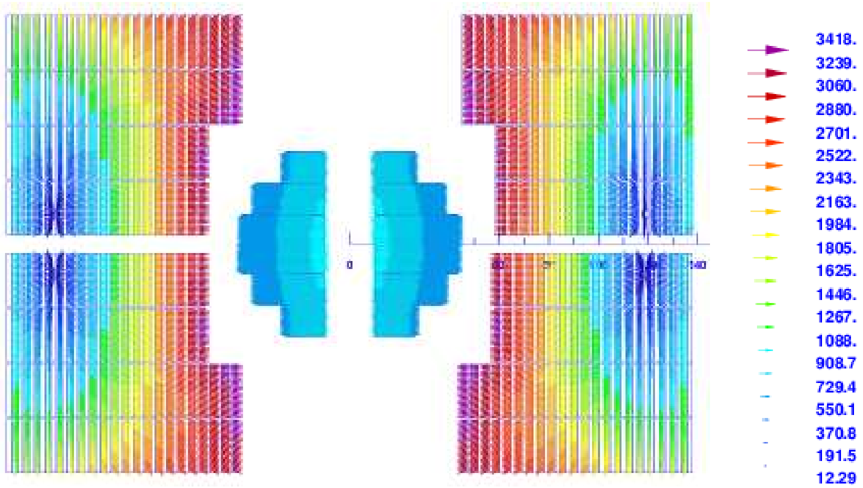
On Fresca 2?

- Influence of the forces of the insert on Fresca 2 ?

Forces on Fresca2 (per quadrant)	Alone @4,2 K (13T)	Alone @1,9 K (15 T)	With the insert @ 4,2 K (19T)
Fx (MN/m)	7.7	9,7	7.3
Fy (MN/m)	-3.81	-5,4	-4.3

Mechanics of Fresca 2 is designed for 15 T

<u>The influence of the insert on the forces of Fresca 2 is negligible comparing to the case « 15 T ».</u>



On Fresca 2 ?

- If the insert is not centered in Fresca 2?

- Worst configuration: decentering of 1 mm (only 0,5 mm is possible)

	X= 1 mm, Y= 0 mm	X= 0 mm, Y= 1 mm
$\Sigma Fx_{(insert)}$ (N/m)	1400	0
$\Sigma Fy_{(insert)}$ (N/m)	0	-2660
$\Sigma Fx_{(Fresca\ 2)}$ (N/m)	-4000	0
$\Sigma Fy_{(Fresca\ 2)}$ (N/m)	0	7160

Forces resultants on the whole system {dipole + insert} is not null because the forces on the other magnetic circuits (yoke, poles and pads) have been not calculated

- Force resultants created by the misalignment of the insert are negligent comparing to global forces

Conclusion on the mechanical design

- Stresses on the components are reasonable

- High stresses on the conductor have been solved by adding $CuBe_2$

- No influence on the mechanics of Fresca 2

- New developments will be needed to assemble the components
  - Cutting the pads by electroerosion at LNCMI-Grenoble
  - Fixation of the pads by electron-beam welding at Cern
  - Insertion of the tube by thermal shrinkage
  - Deposit of Cu on $CuBe_2$ for the conductor

Presentation of J-M Rey

Conclusion

• Electromagnetic and mechanical designs are finished

• Next steps :

– Conception of the components and assembly report are in progress

Presentation of M. Durante

– Winding of the pancake prototype

– Test in different field orientation

THANKS FOR YOUR ATTENTION !