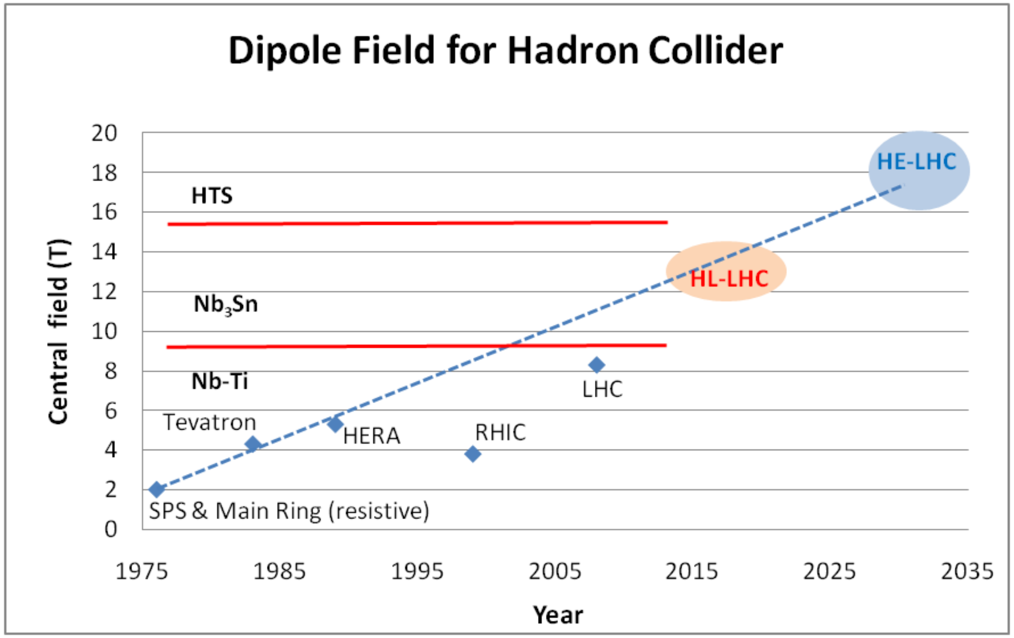
EuCARD 2012 Collaboration Meeting
Warsaw University of Technology
22th April 2012

WP-7 / Task 4
Very high field magnet

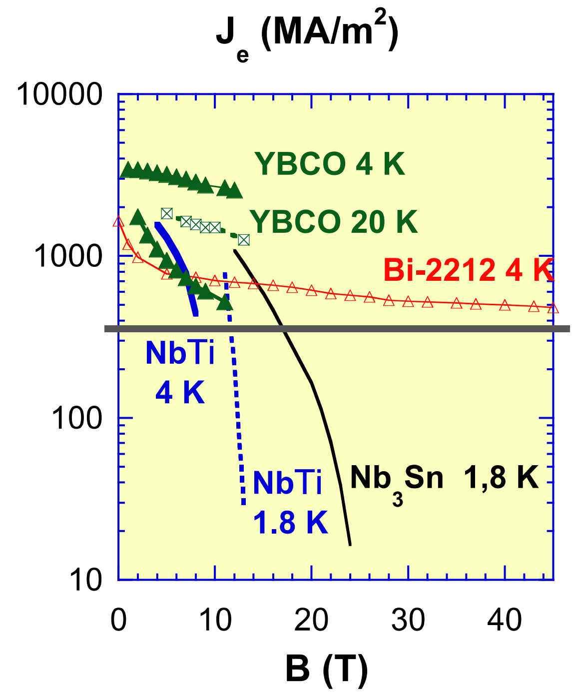
- **Introduction/objectives/partners**
- **Works done**
  - ✓ **HTS conductors (Bi-2212 & YBCO coated) - characterization**
  - ✓ **HTS solenoids**
  - ✓ **HTS insert design and first implementations**
- **Conclusions & work still to do**

Objective, introduction

Motivation: quest for higher fields



Courtesy L. Rossi



Construction of an HTS dipole insert (6 T) within a Nb_3Sn dipole magnet (13 T)

Partners

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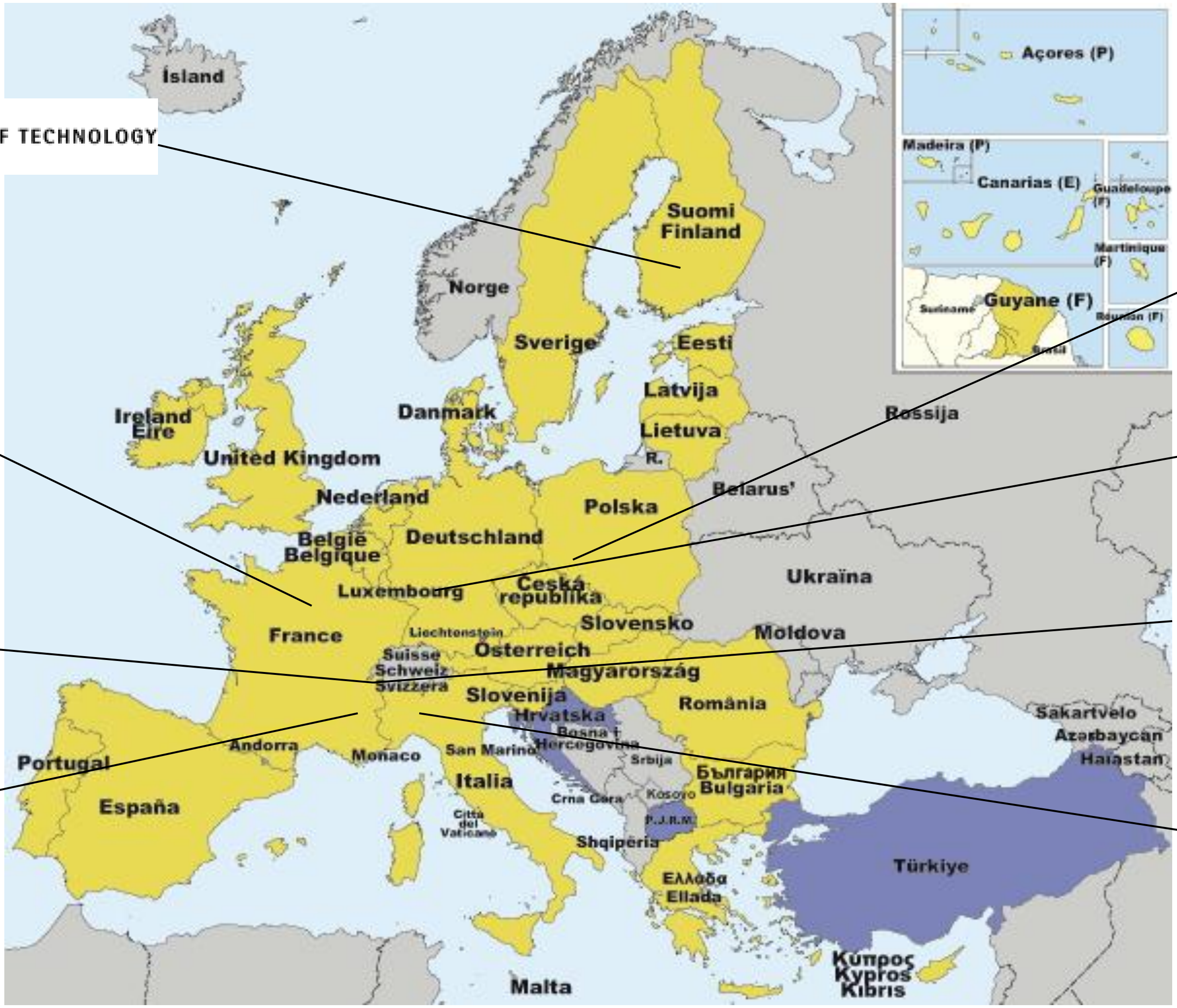
Irfu

cea

saclay

CERN

cnrs



Wroclaw University of Technology

KIT
Karlsruhe Institute of Technology

UNIVERSITÉ DE GENÈVE

INFN
LASA

EuCARD

Objective, introduction

Three subtasks:

- Specification, characterization and quench modelling
- Design, construction and test of solenoid insert coils
- Design, construction and test of dipole insert coils

Deliverable:

- **A HTS dipole insert coil constructed (D - M48)**

Milestones:

- HTS conductor specifications for insert coils (R - M12)
- Two HTS solenoid insert coils (D - M24)

Done

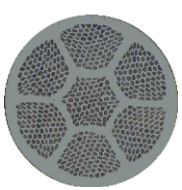
Works done

- HTS conductors (Bi-2212 & YBCO coated)
  - Comparison within the context (high J_c & σ)
  - Characterizations
- Technological implementation
  - Solenoid coils & connexions
- Protection modelling and protection proposal
- HTS insert design
  - Electromagnetic and mechanical designs
  - Conductor design and first realization
  - Some mechanical implementation

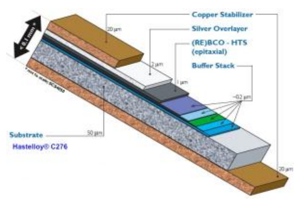
HTS materials

HTS conductors: two competitors

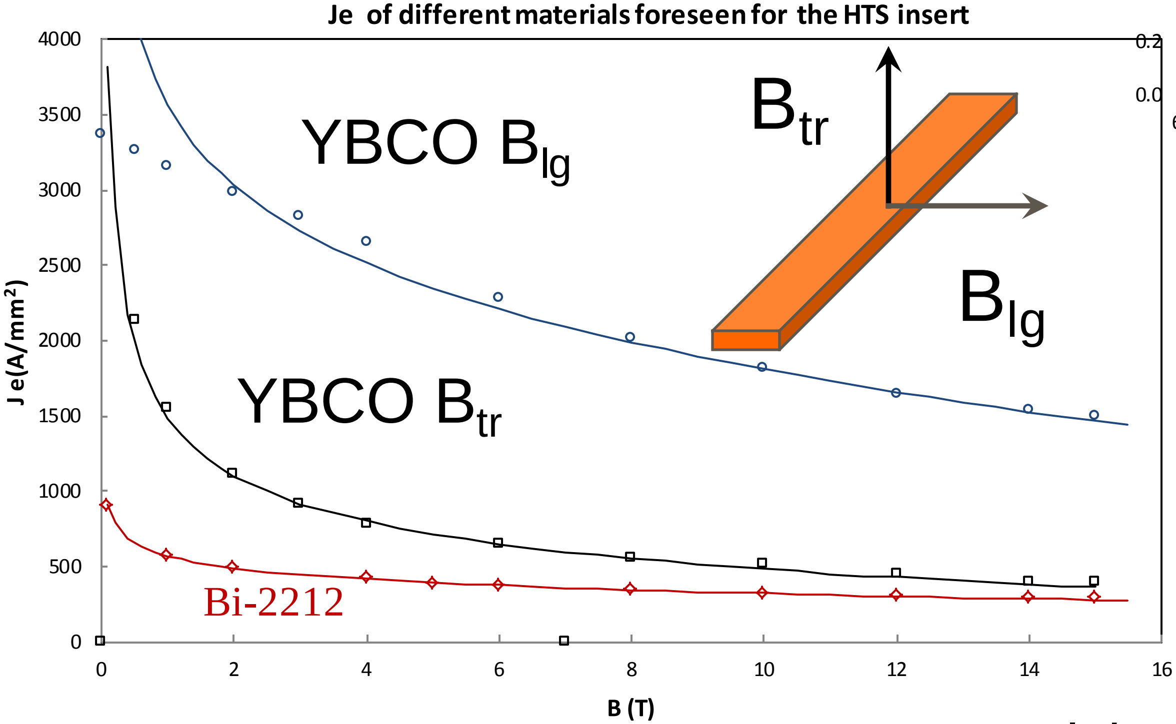
	Bi-2212 **(round wire)**	**YBCO** **(coated conductor)**
	**Round isotropic wire** (Ø = 0.8 mm) High current cable (Rutherford) Bending radius (W & R)	Conductor of future with low cost **Performances** **J_c & intrinsic mechanics (700 MPa)** Great attention to delamination
	Mechanical performances (100 MPa) Defect free lengths Niche conductor	Thin tape (4 x 0.1 mm^2) Lengths & defect free lengths Large field anisotropy
	**Thermal treatment** Cost	**High current cable** Cost, cost, **delamination (trans.)**



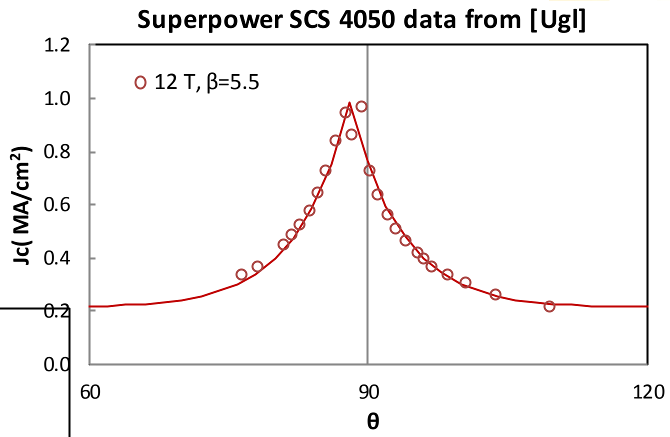
Nexans

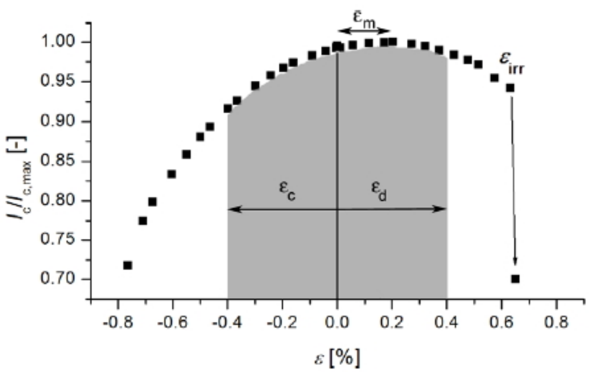


The competitors: YBCO



Courtesy J. Fleiter



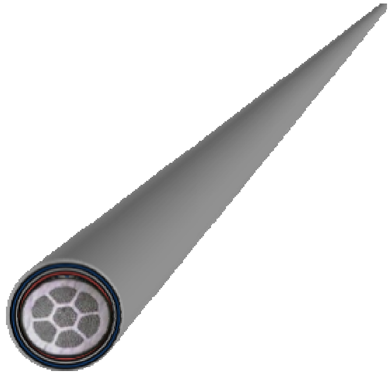


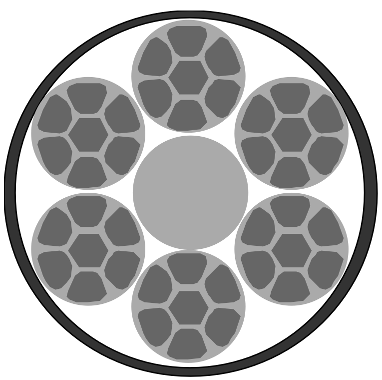
van der Laan

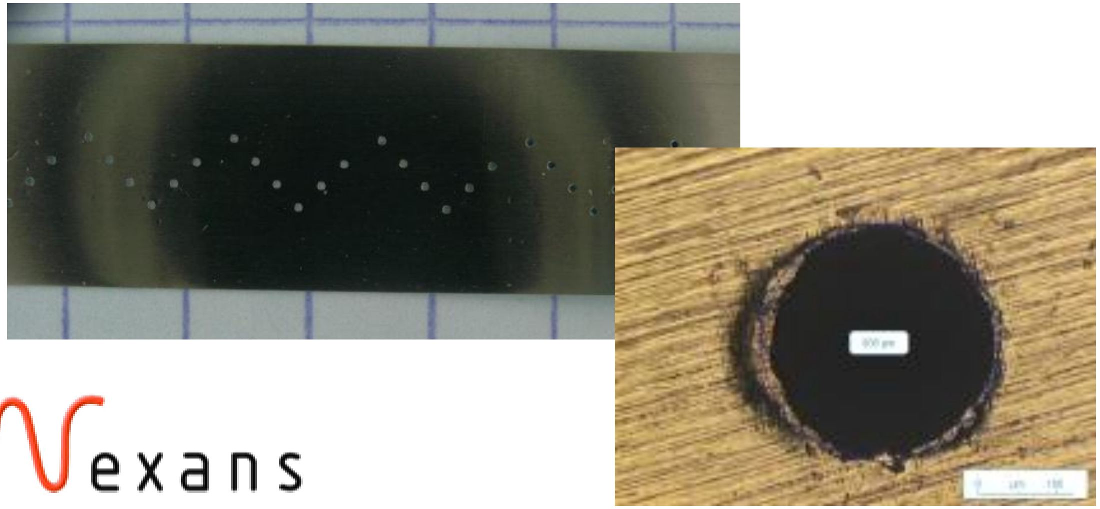
Delamination is an issue with YBCO

The competitors: Bi-2212 reinforcement (W & R)

Bi-2212 strand: $\sigma_c \approx 80$ MPa



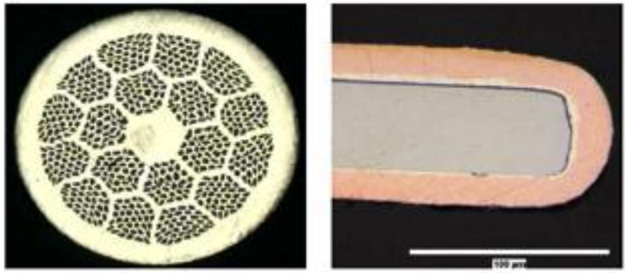


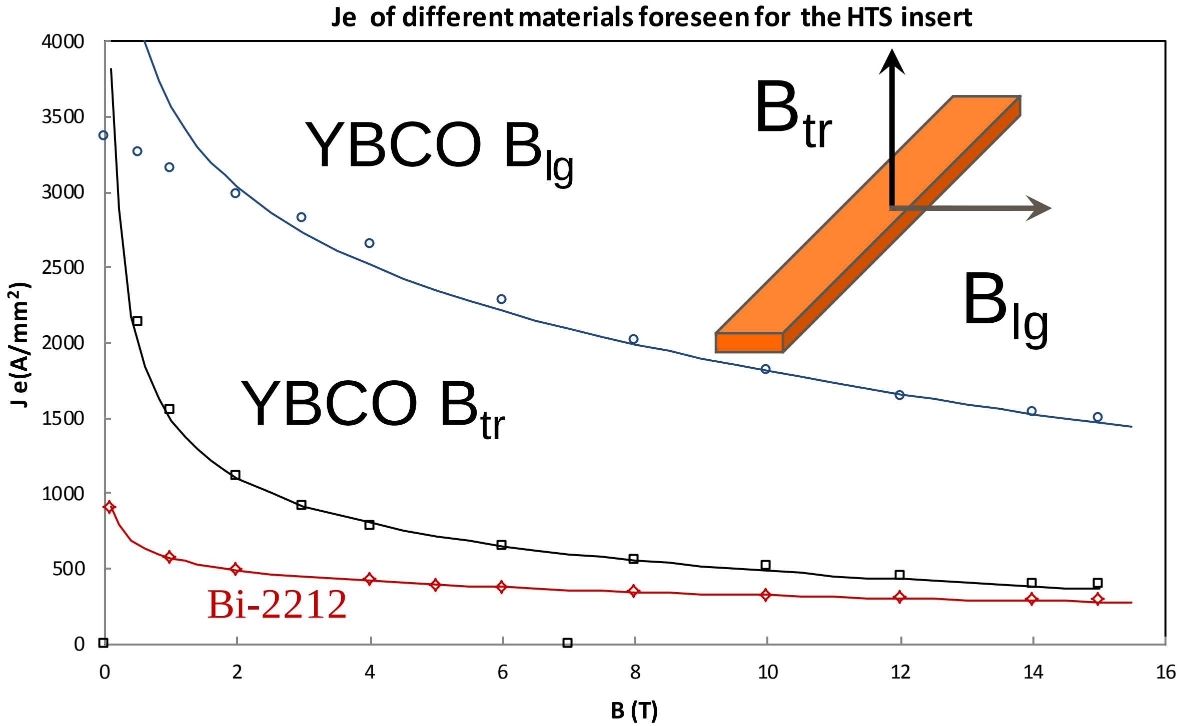


- Holes : 300 µm
- Thickness : 50 / 100 µm

Reinforced conductor $\sigma_c \approx 200$ MPa (Inconel: 540 MPa (0,2 %))

Characterizations





Courtesy J. Fleiter

J_c parameterization

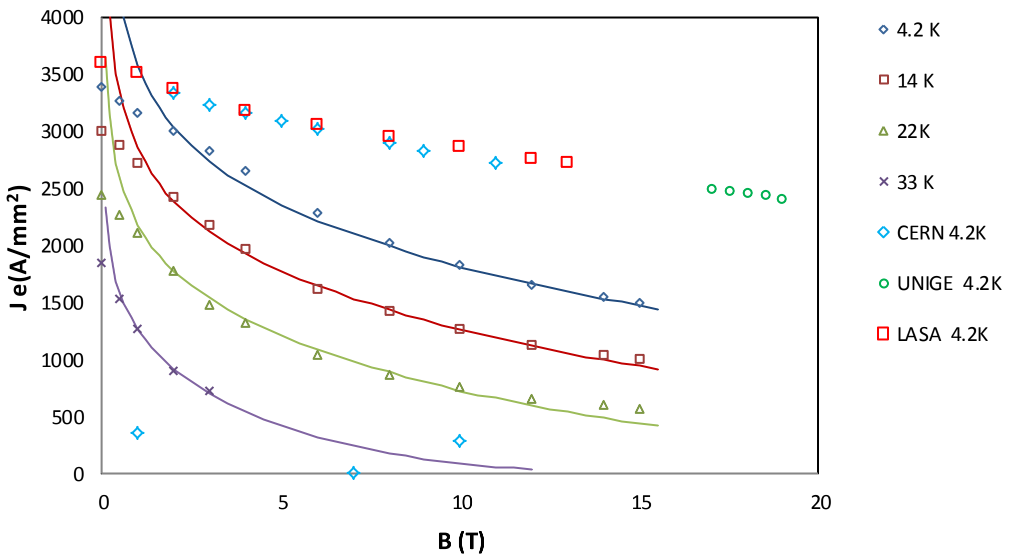
The most appropriate fit to describe critical surface of Bi-2212, Bi-2223, Y-123 and MgB_2 is the one based on flux creep theory:

$$J_c(B,T) = \frac{C_0}{B} \cdot B_{irr}^m \cdot b^p (1-b)^q$$

Where

$$B_{irr}(T) = B_{irr,0}(1-t)^n$$

$$b = \frac{B}{B_{irr}} \qquad t = \frac{T}{T_c} \qquad C_0 = cste$$



Protection

Quench propagation: the critical issue of HTS materials

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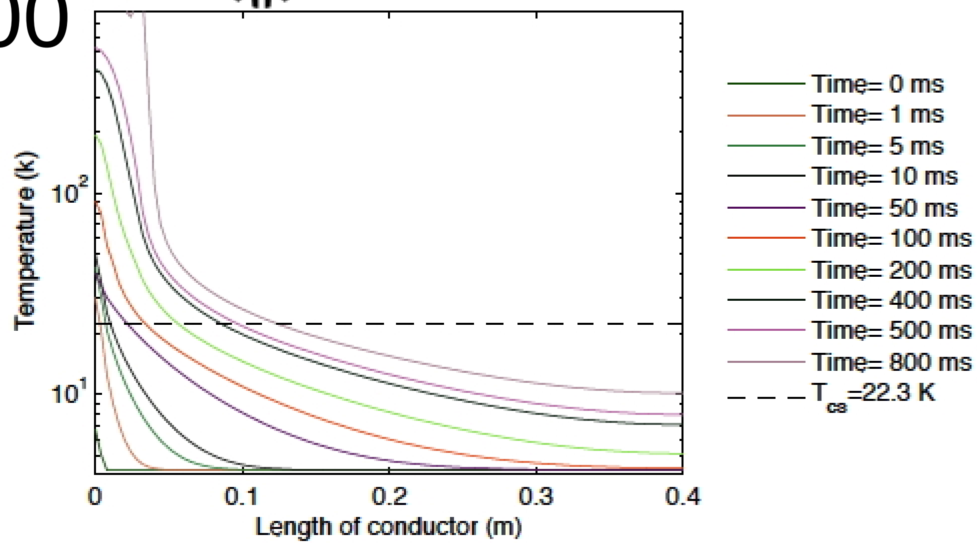


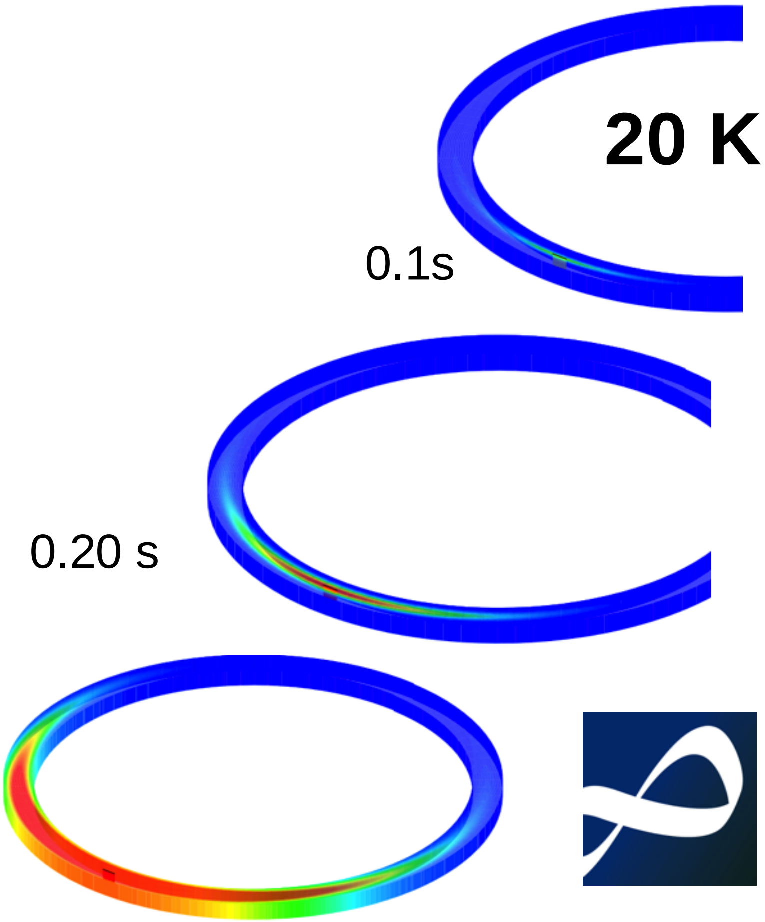
Courtesy A. Stenvall

20 K

0.1s

0.20 s

0.5 s



Pancake

30 series turns

365 MA/m² (Ø ≈ 100 mm)

0.3 J in 100 ms

250 K

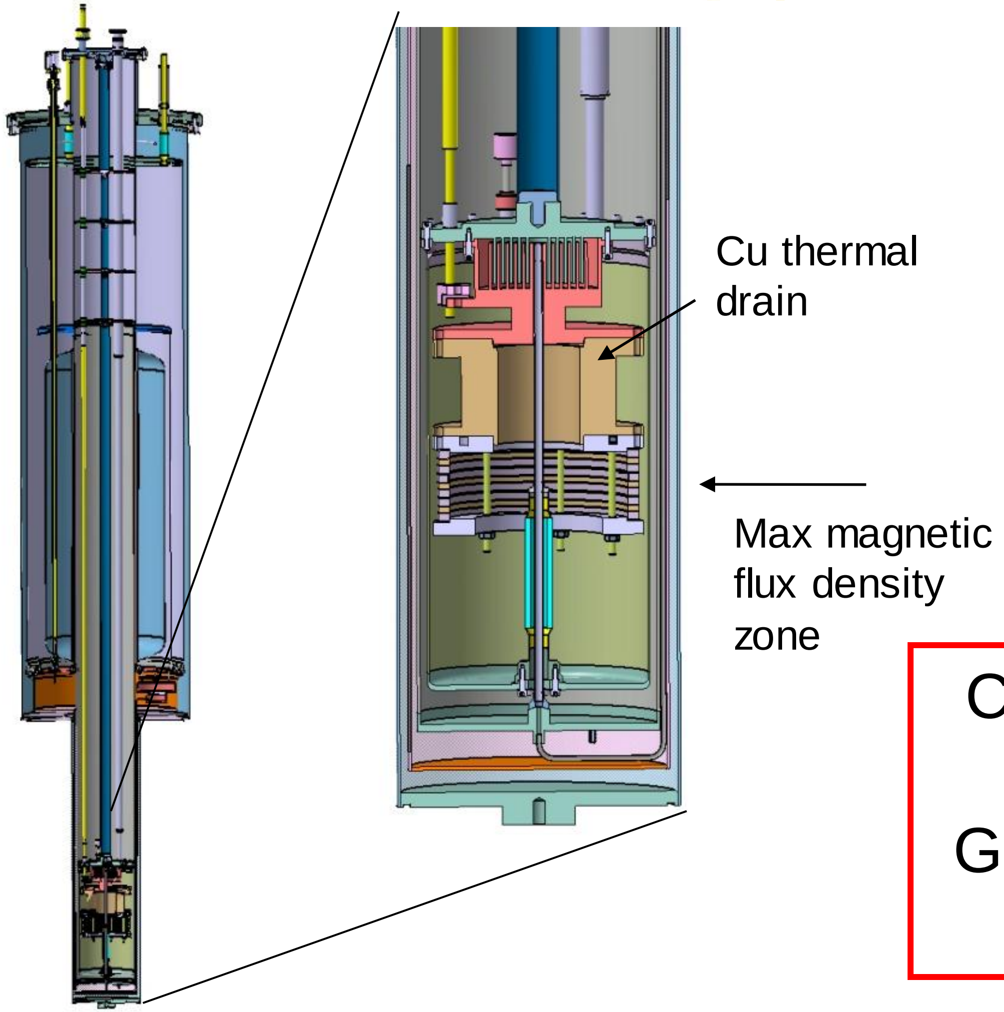
Courtesy T. Lecrevisse

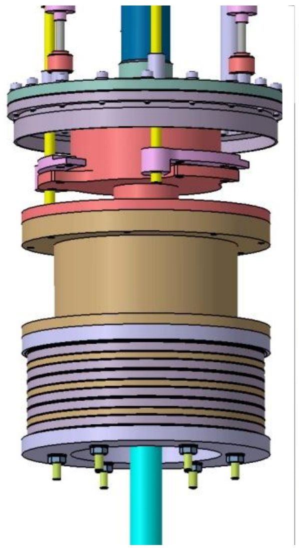
Solenoid prototypes:

Development, test stand…

And blow up !

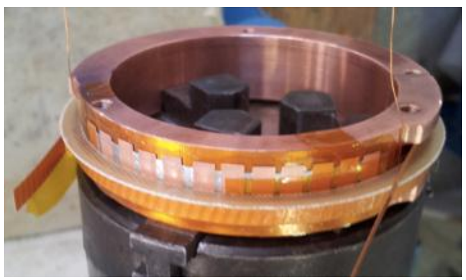
CEA coils in the Grenoble cryostat

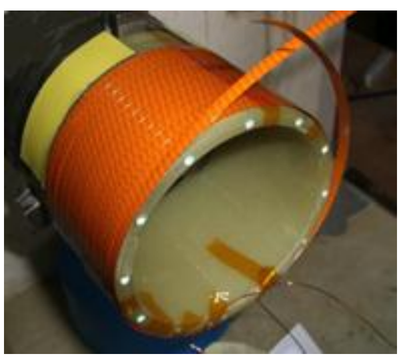


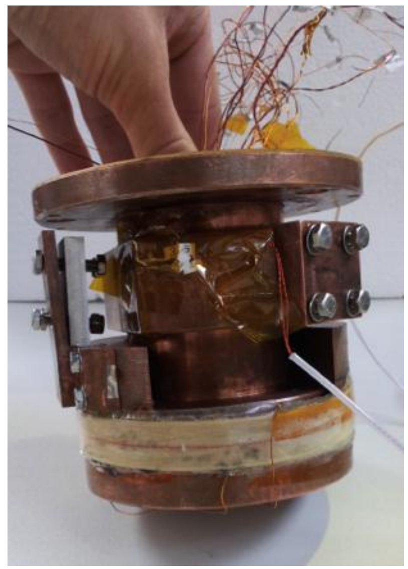


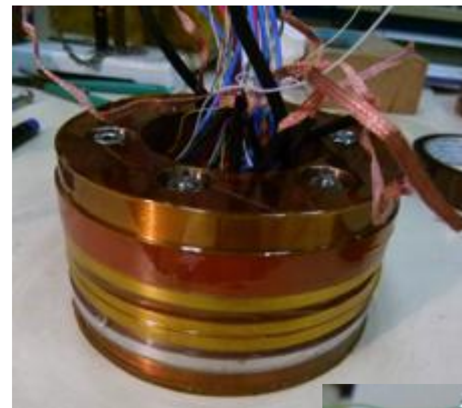
Coil should be finished today and tested in Grenoble this week and next week

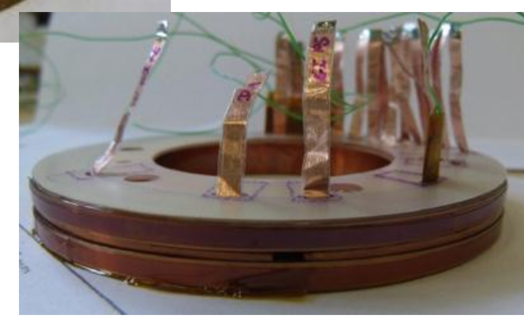
Solenoids realized





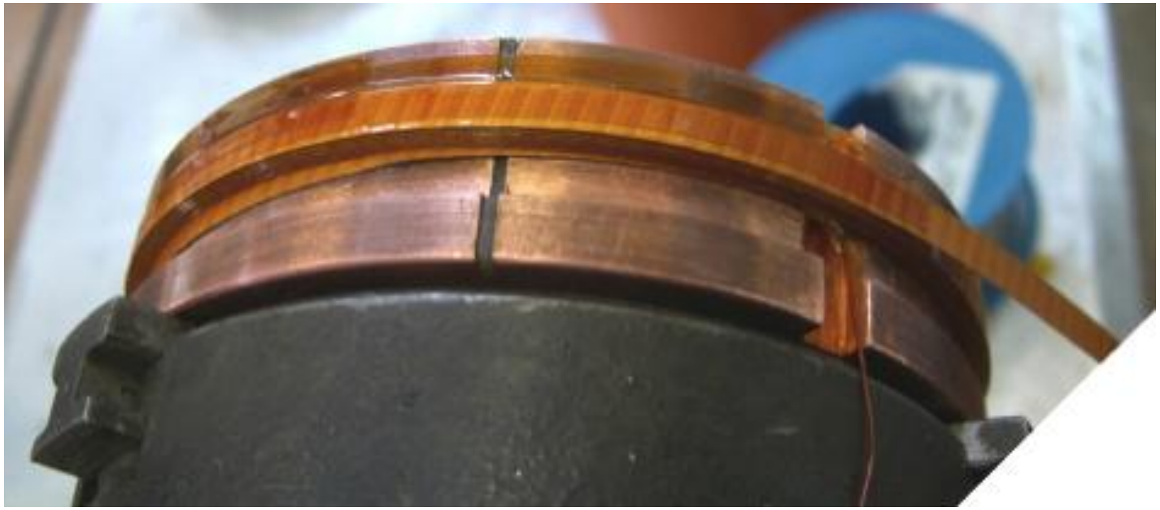


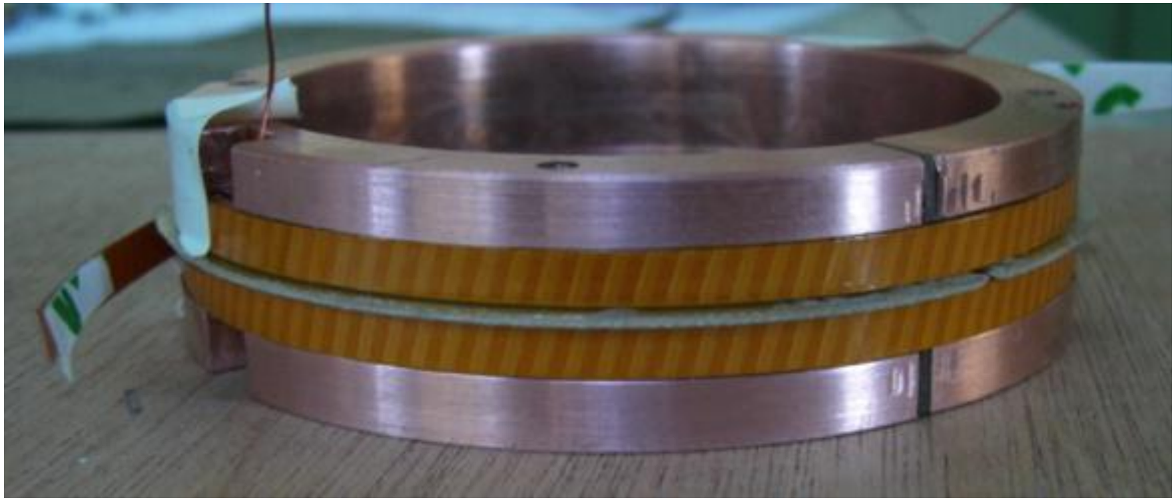




Coil strongly instrumented
(heaters, voltages tapes,Cernox®, …)

Double pancake

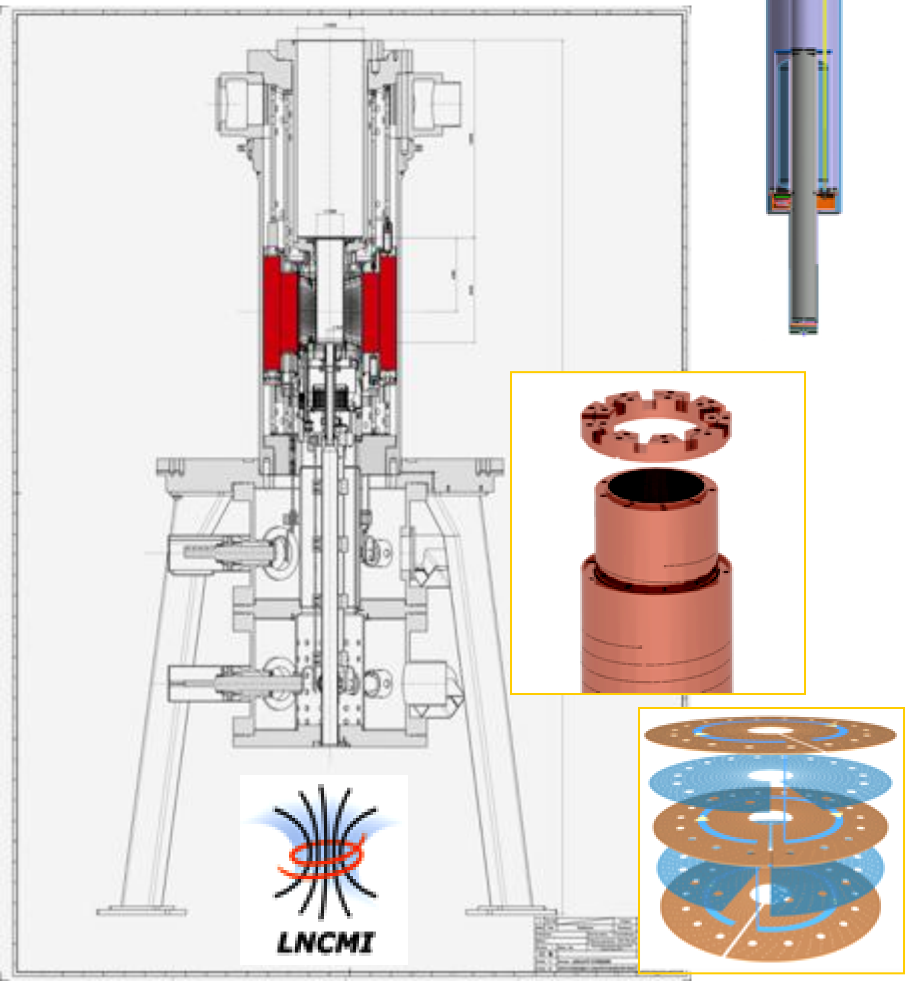




Double pancake without connexion between the two pancakes
Cu mandrel (conduction cooling)
$Ø_i = 75$ mm

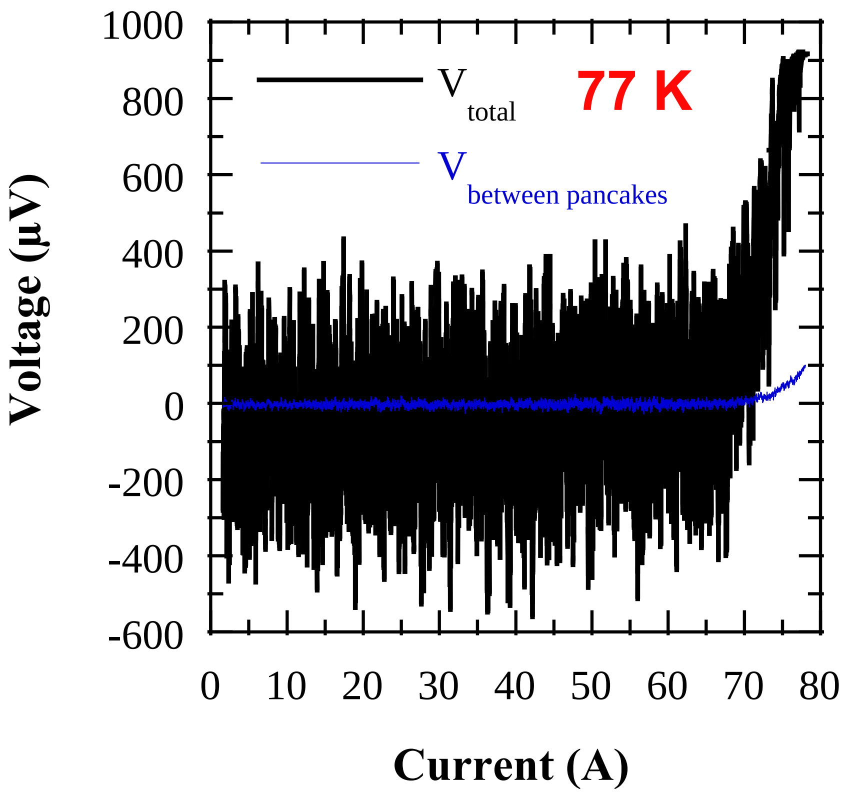
Tape 4 mm SuperPower® SCS 4050 tape
Kapton®

Solenoid test bench



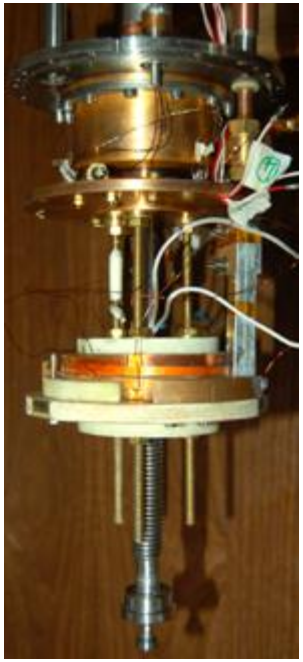
20 T facility

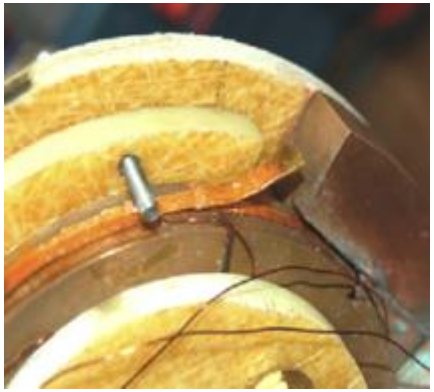
Double pancake



Test 4.2 K:

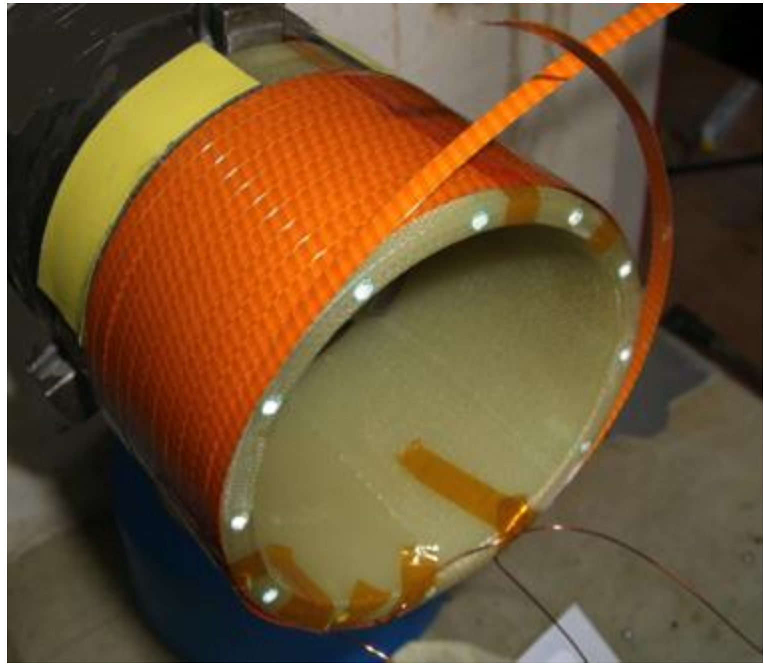
- 18 T
- 400 A (1000 MA/m^2)
- 700 MPa (JBR)

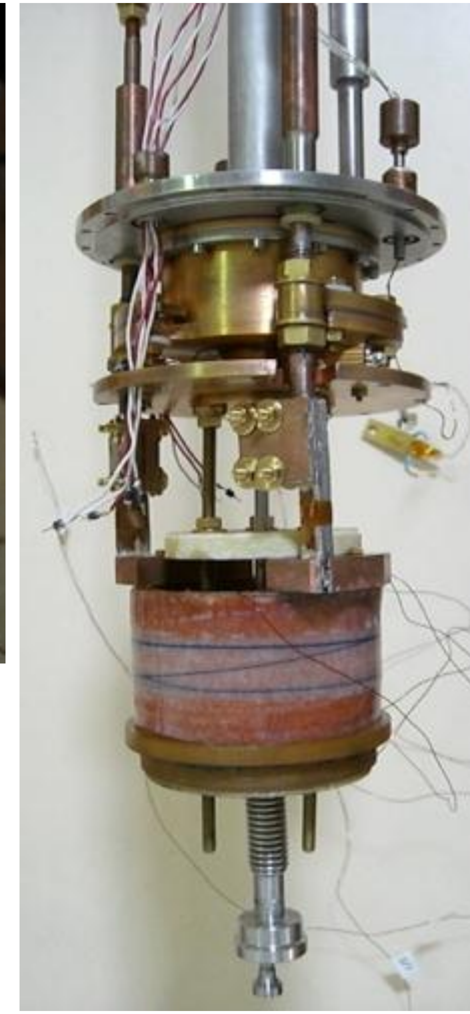




Layer coil

- 4 layers
- 10 serie turns per layer

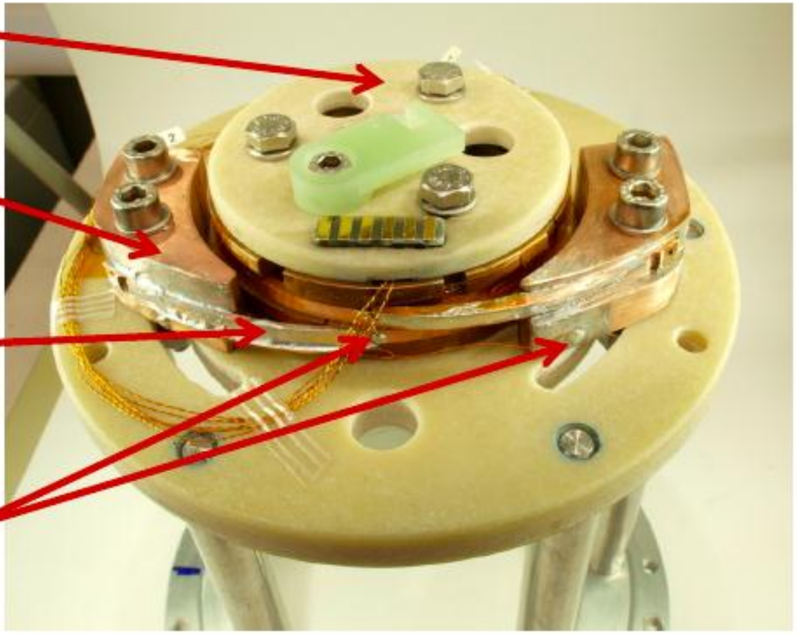




Test 4.2 K:
- 16 T
- 400 A (1000 MA/m^2)

CNRS double pancake sent to KIT

- **Fixing of DP with top cover**
- **Current terminals made of copper**
- **Curved tape guiding made of copper**
- **Voltage taps placed at current terminals and at cc-tape directly after tape guiding**
- **Additional fixing by impregnation with beeswax**



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CNRS double pancake sent to KIT

- **15 T configuration of HOMER I**
  - **14.5 T / Ø 160 mm**
  - sample current up to **800 A**
  - sample cooled in He-bath (1.8 K - **4.2 K** (here))
  - sample quench detection

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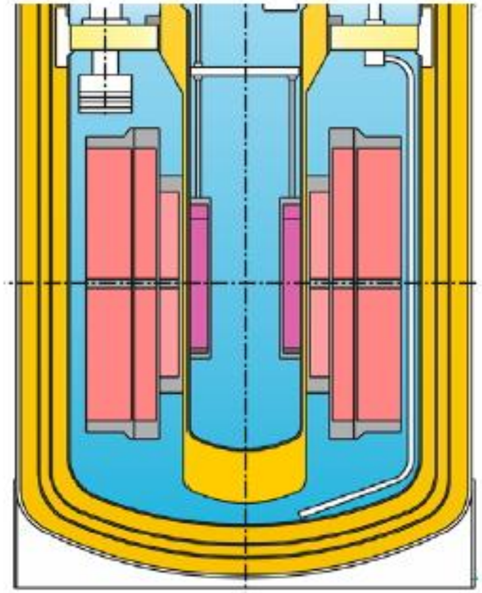


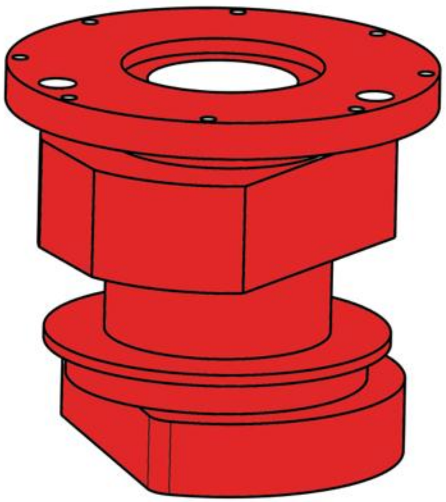
15 T configuration

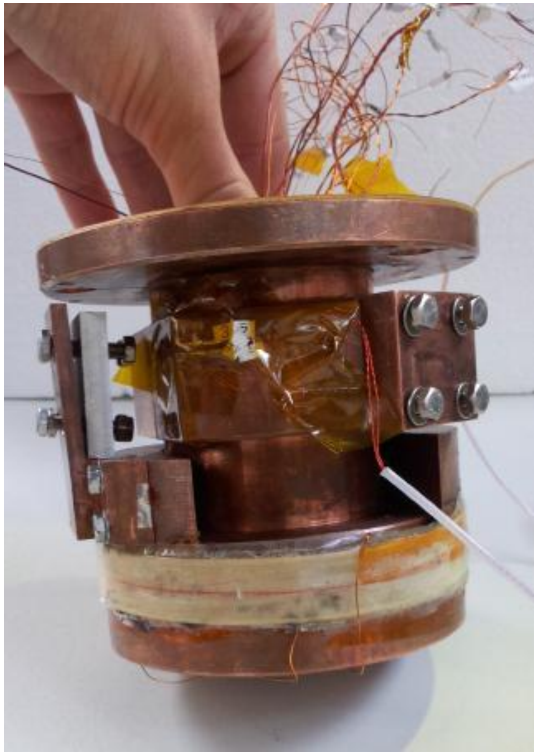
Results (4.2 K)

- 400 A up to 12 T
- 698 A at 10 T
  - Wire broken (730 MPa)

Same results / Grenoble

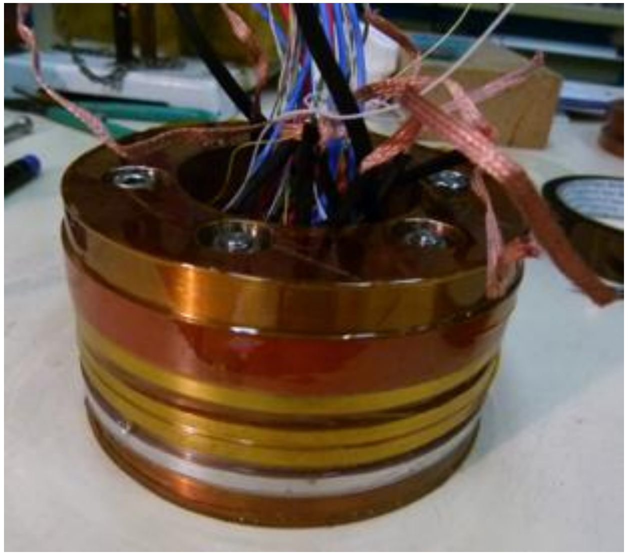
Instrumented double pancake

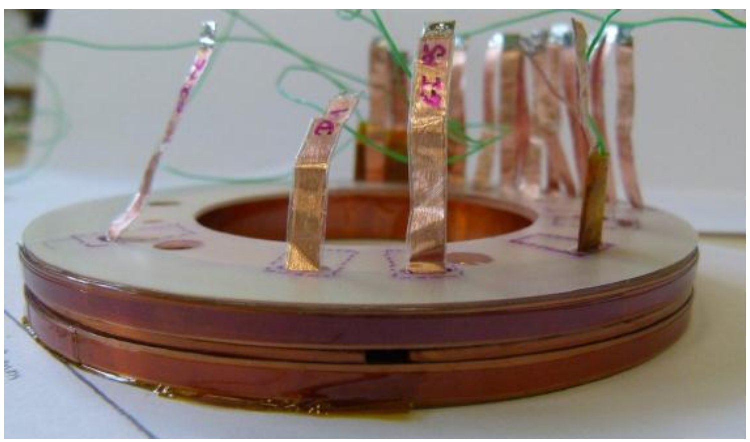


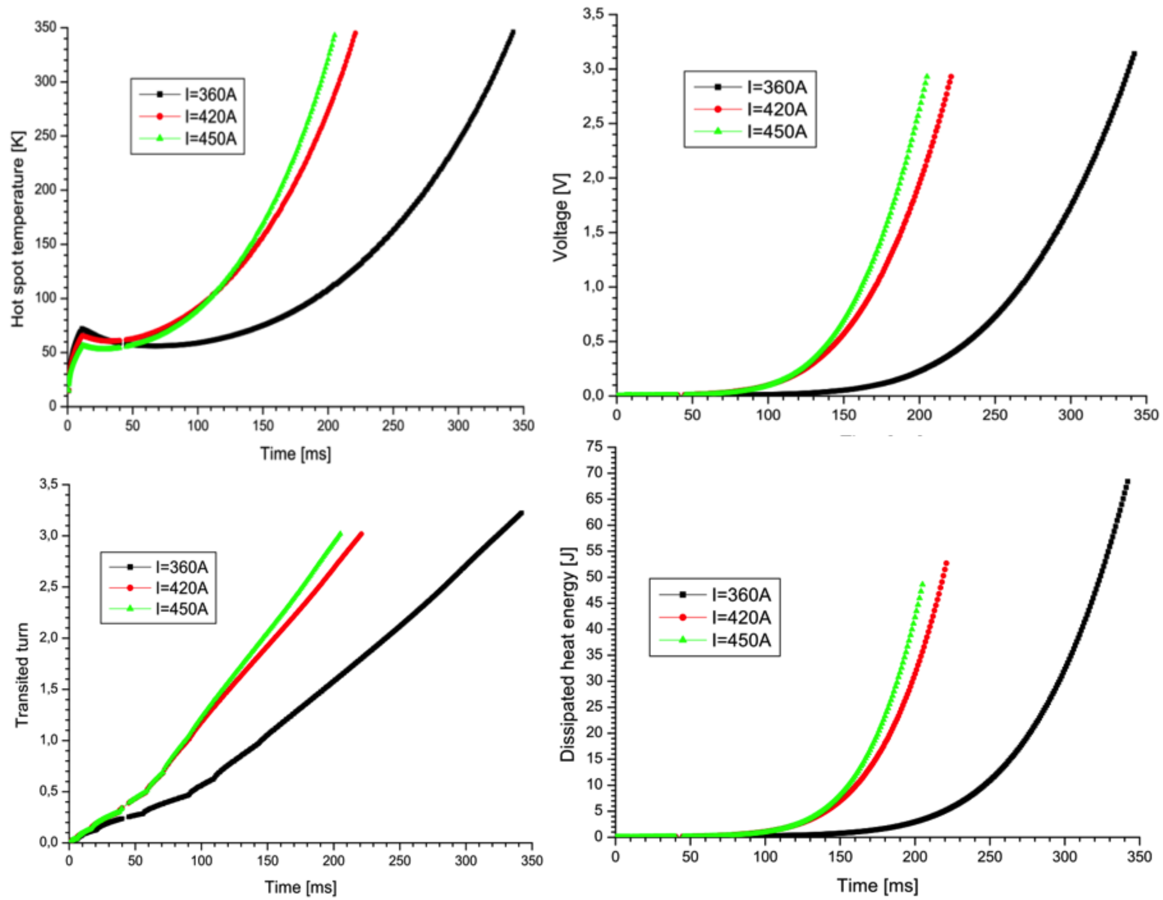


- Heater inside one pancake
- Numerous voltages taps

Multi pancake instrumented coil





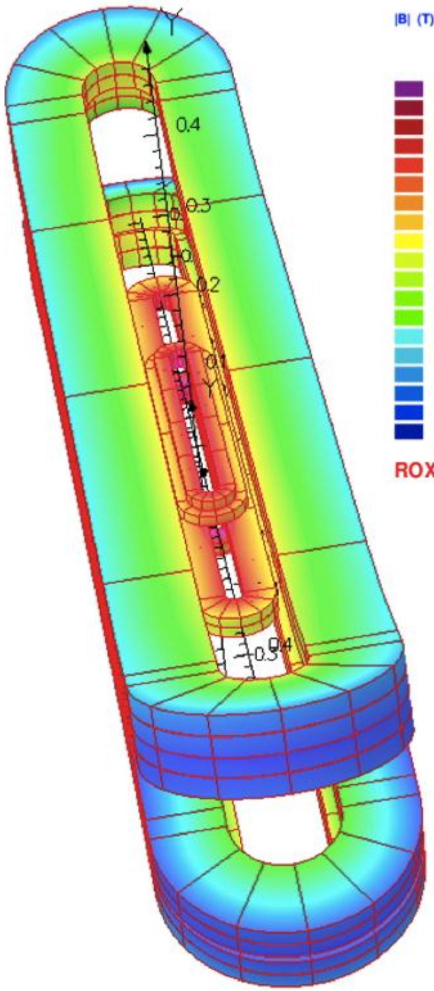


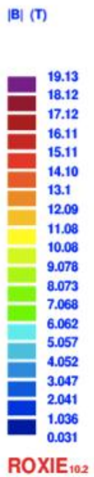
Quench simulations

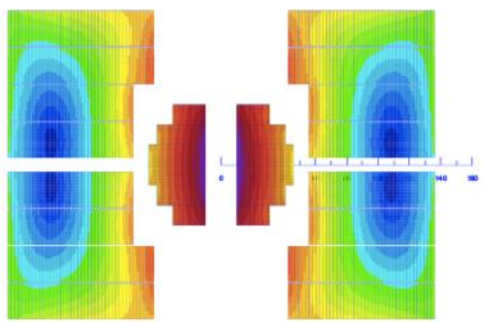
Dipole insert design

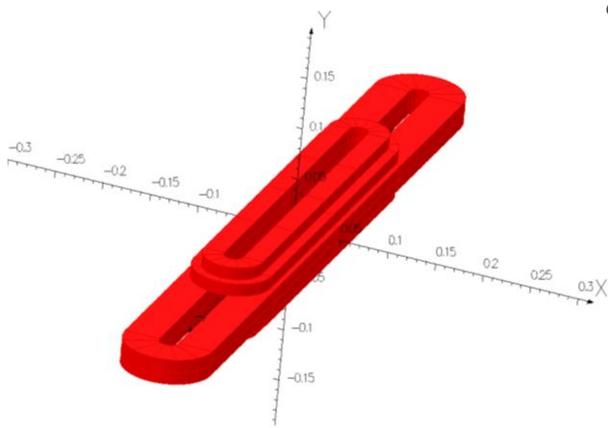
Field computation, conductor development, mechanical structure and assembly scheme

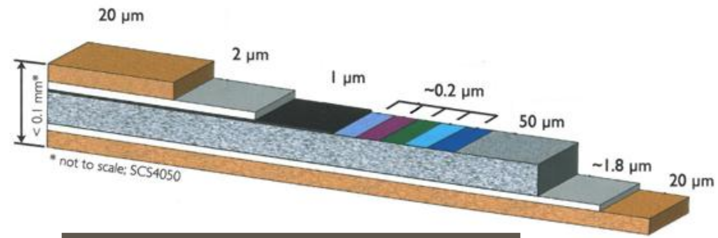
Insert electromagnetic design

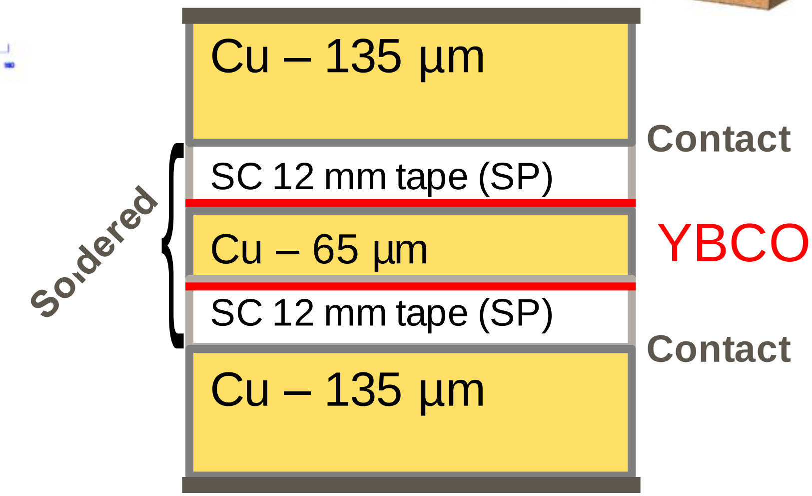


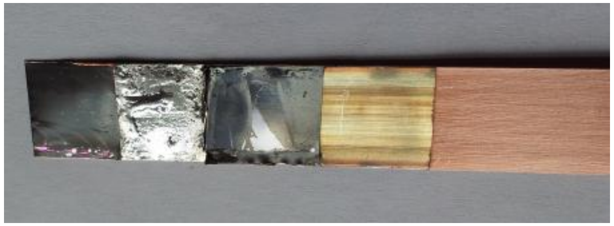




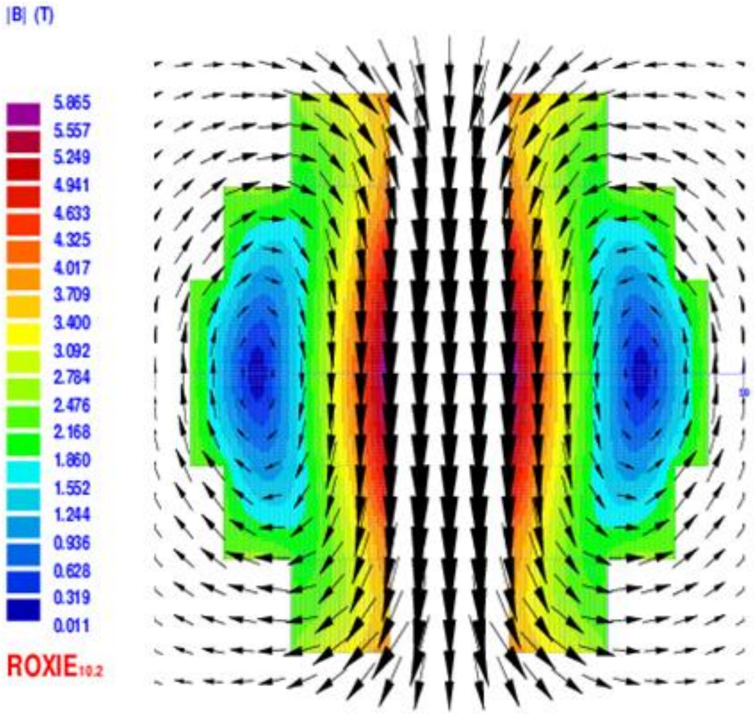








Magnetic design



B0 = 6 T

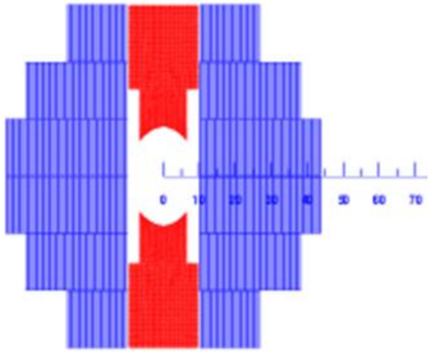
Bpeak= 5, 87 T

Je= 250 MA/mm^2

IRON POLE : **is it an advantage or not ?**

Iron pole : 2 D consideration

CEA - Saclay



- 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

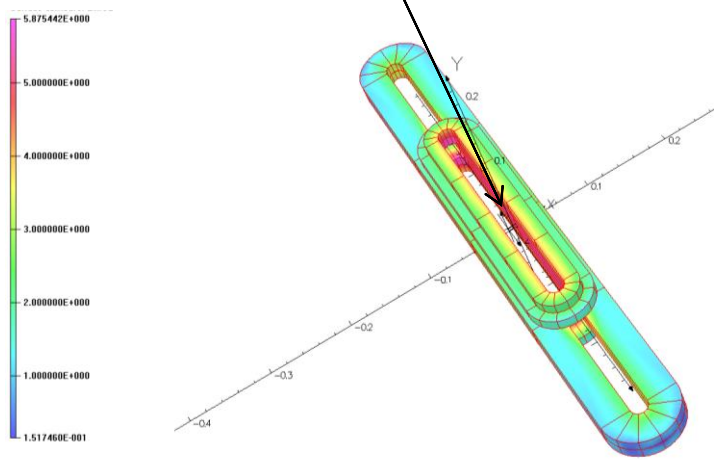
- + : The pole increases the central field of 10%
- - : It increases also the peak field of 10% in the straight section

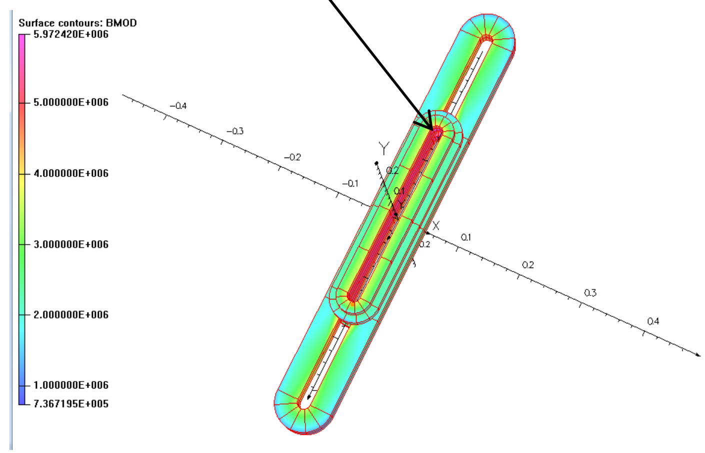
→

3D 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	250A/mm²	250A/mm²
B0	6,09 T	5,52 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



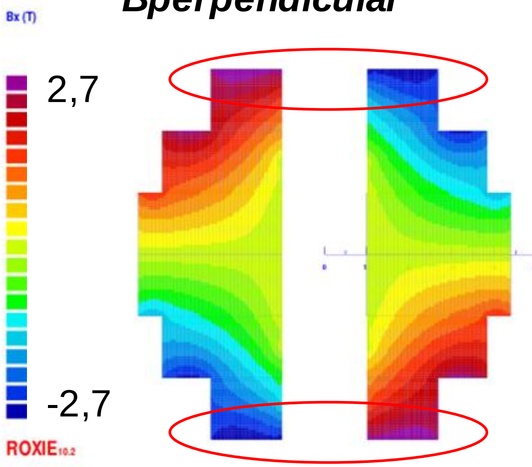


- The iron pole concentrates the field lines and reduces field in the heads

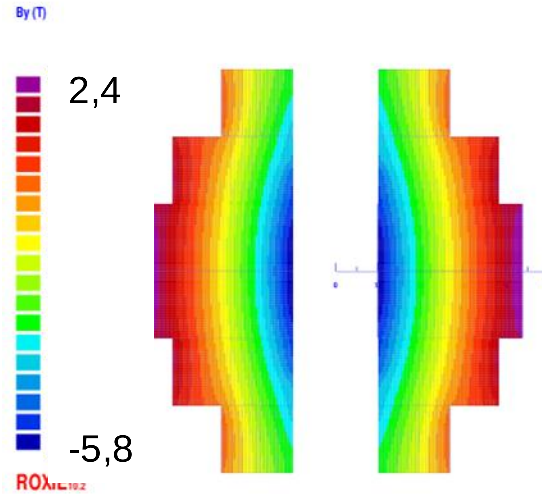
3D design : Estimation of the transverse field (1/2)

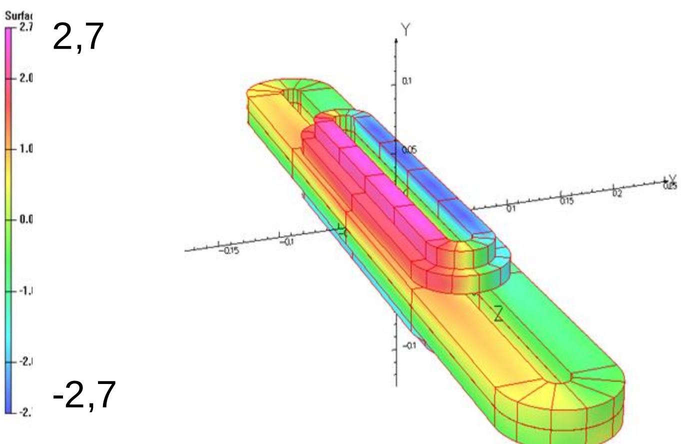
- Determination of perpendicular and parallel fields to determine the critical points of the coil (case with iron pole)

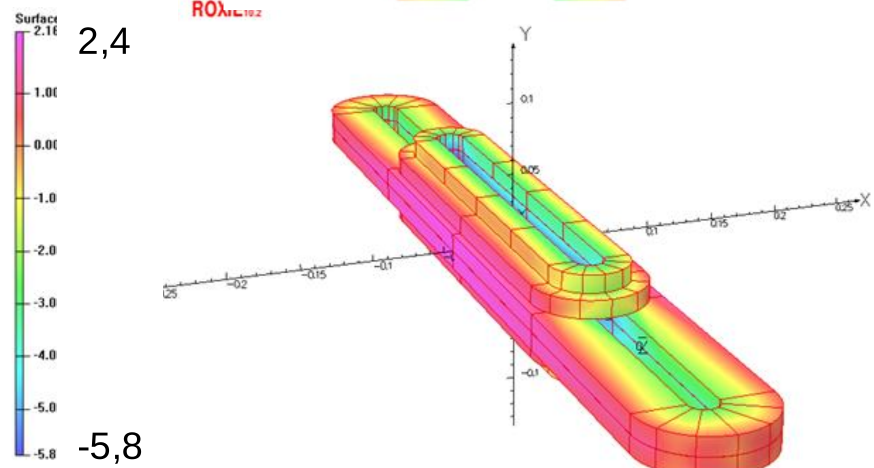
Bperpendicular



B//







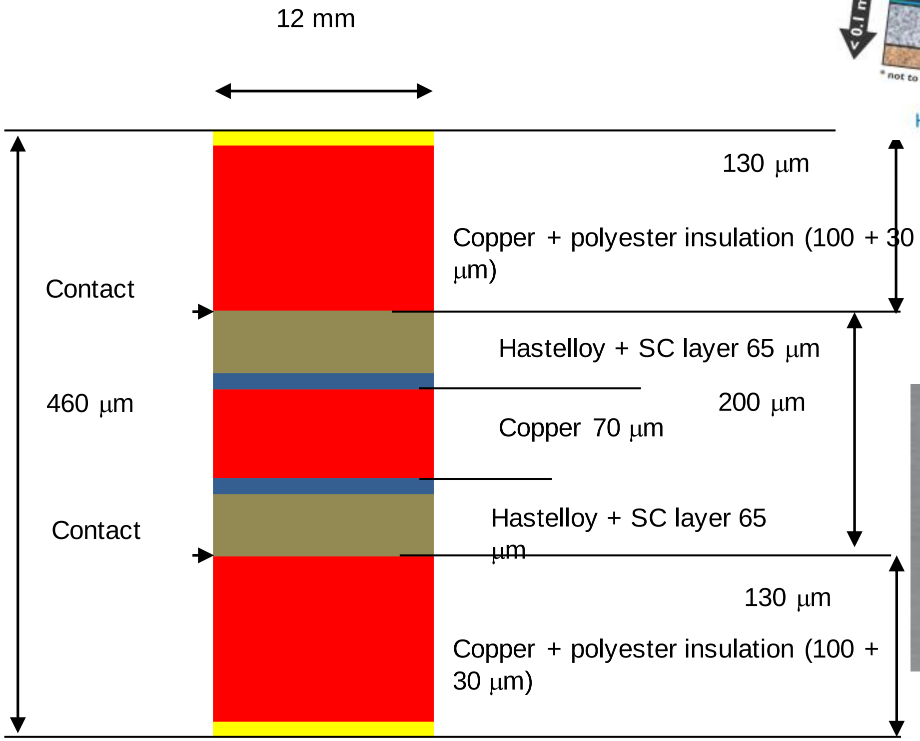
3D design : Estimation of the transverse field (2/2)

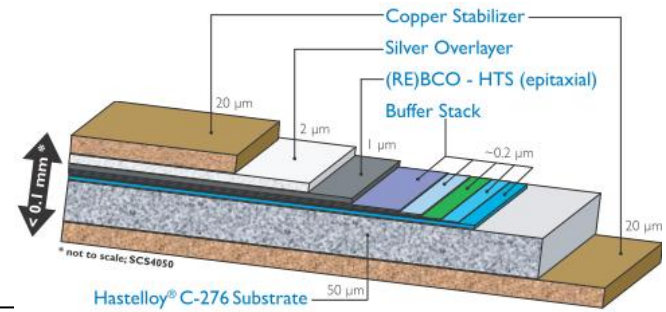
- Study of the two cases: with or without the iron pole

	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
- **The transverse field is the critical issue of the design**

Conductor





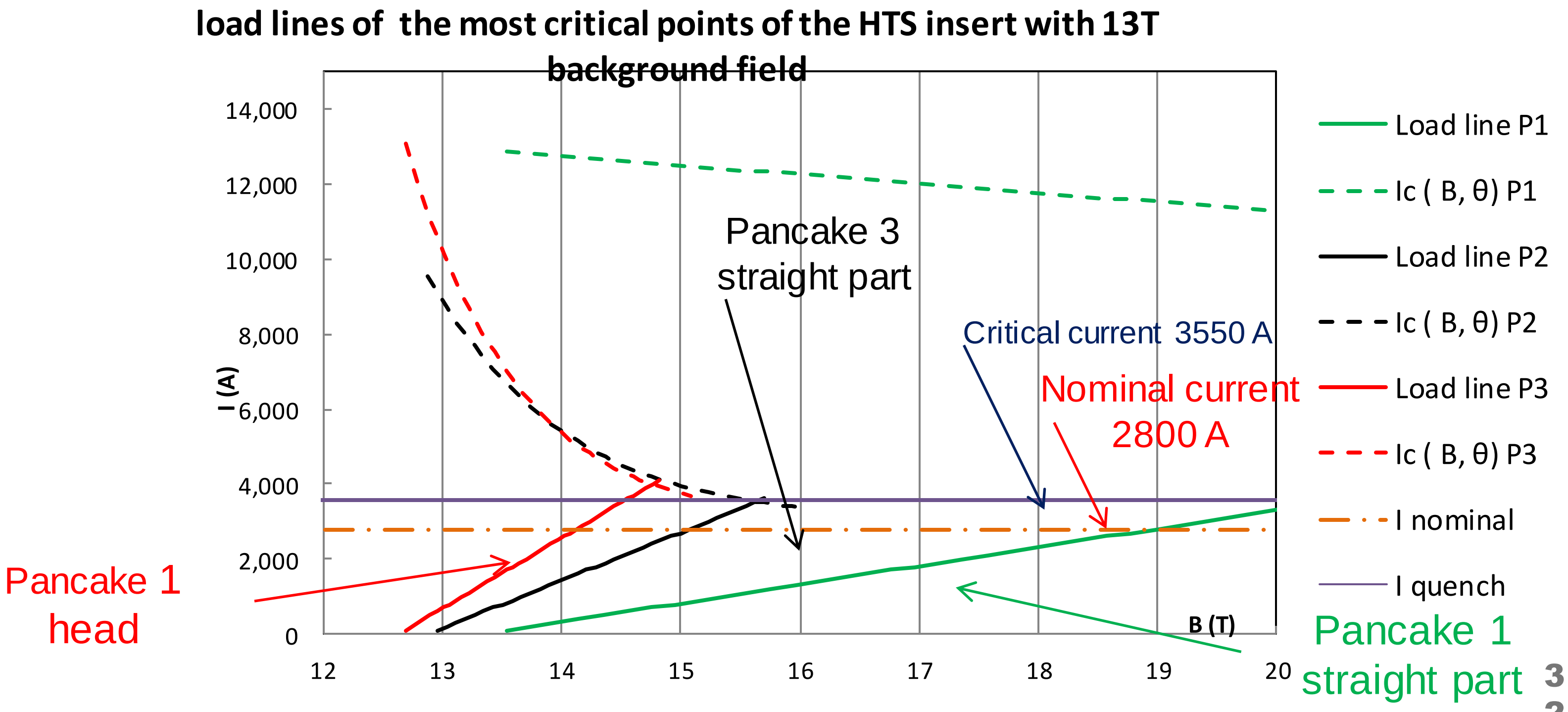
Superpower SCS 12050

- Conductor:
  - 4 * 12 mm wide YBCO ribbons (thickness: 0,1mm)
  - Isolation: 0,25 µm kapton per face

Study of the load line

HTS under a field of 19 T

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



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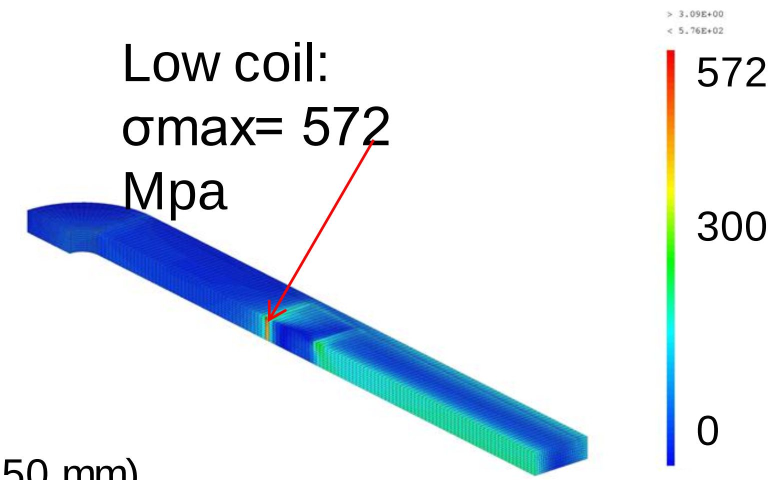
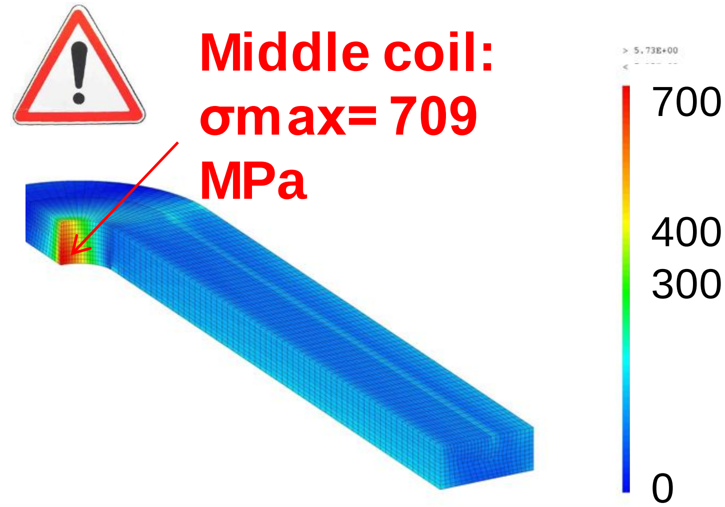
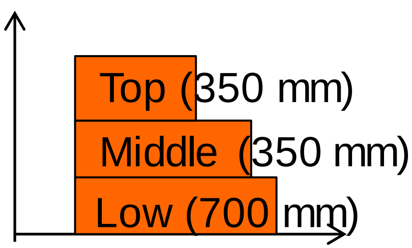
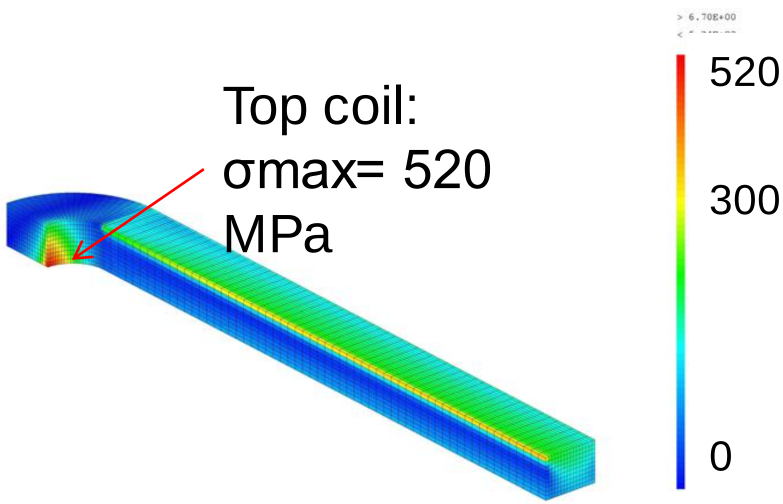
Study of the stresses over the coils





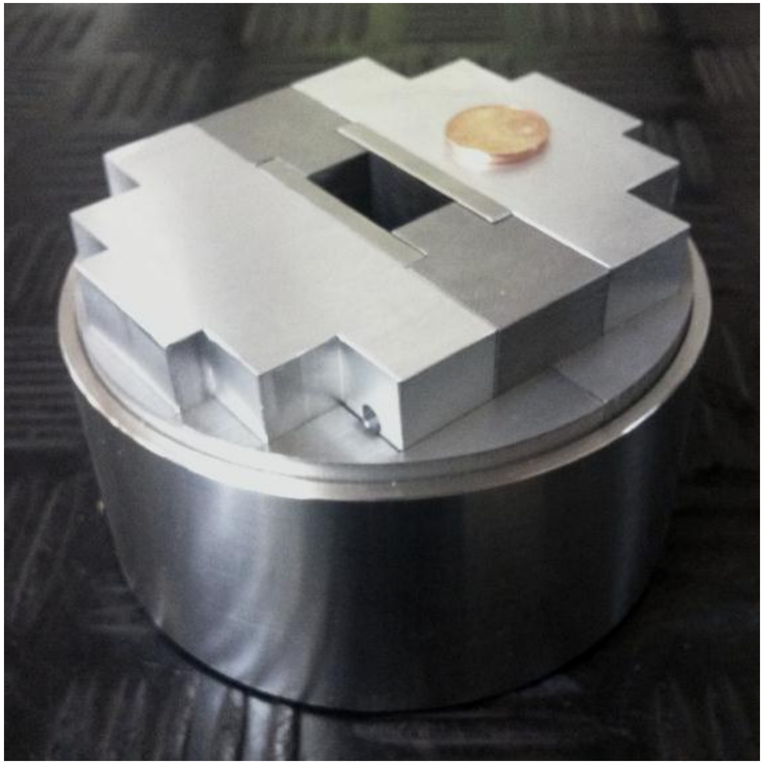


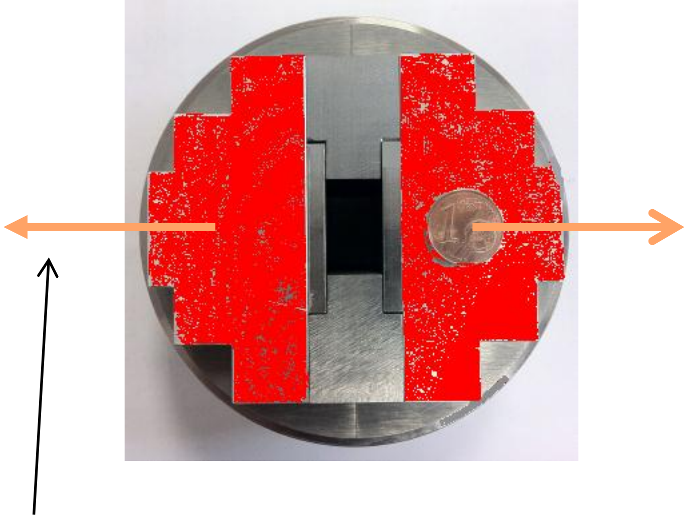


- Maximum stress allowed on the ribbon : **400 Mpa**
- Local maximal stresses in the heads of the middle top **over the admissible value**

- New calculation will be done with a shortened top coil to reduce the stress concentration on the head

Insert mechanical design

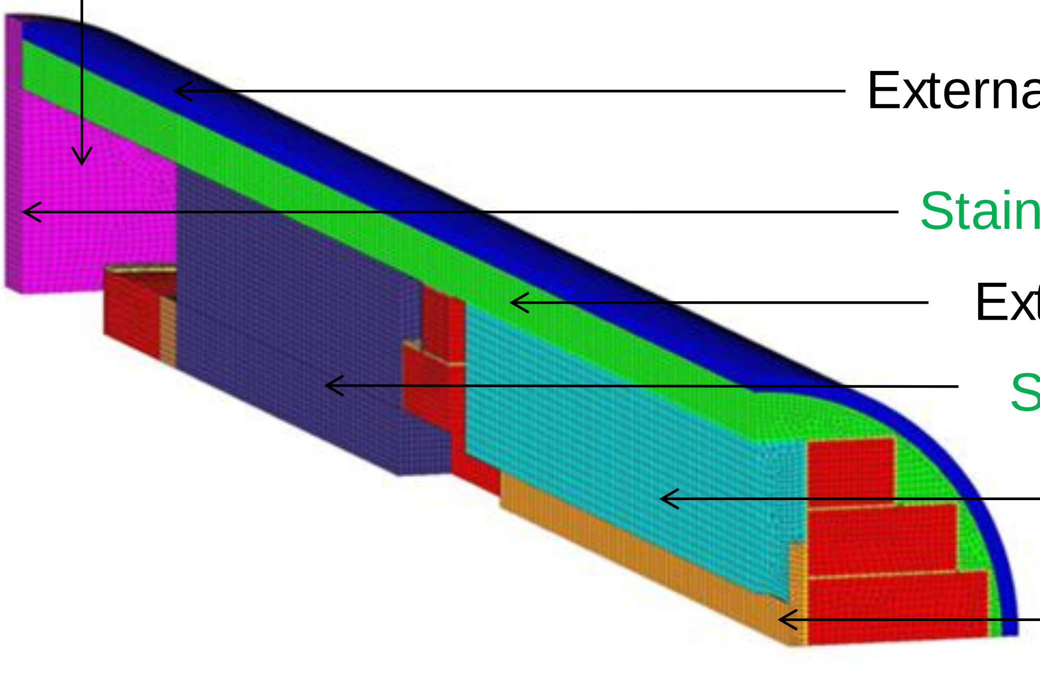




Around 1000 t/m
(or 10^7 N/m)

Structure

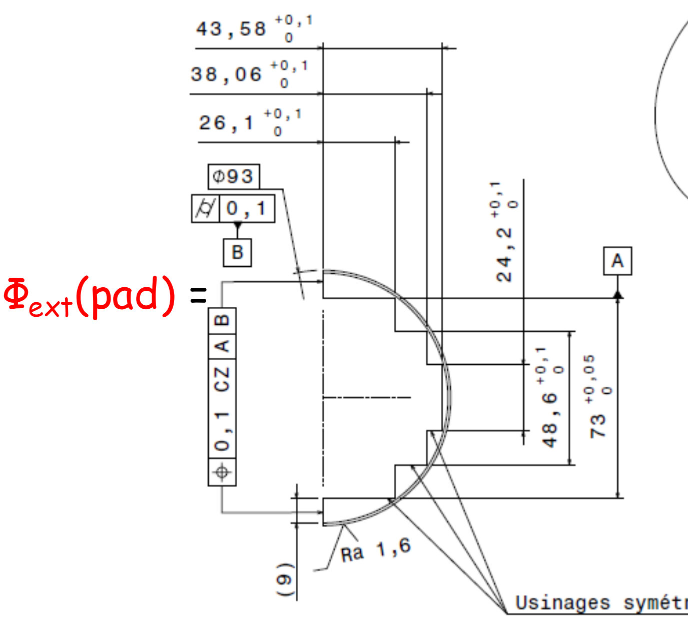
1/8 geometry

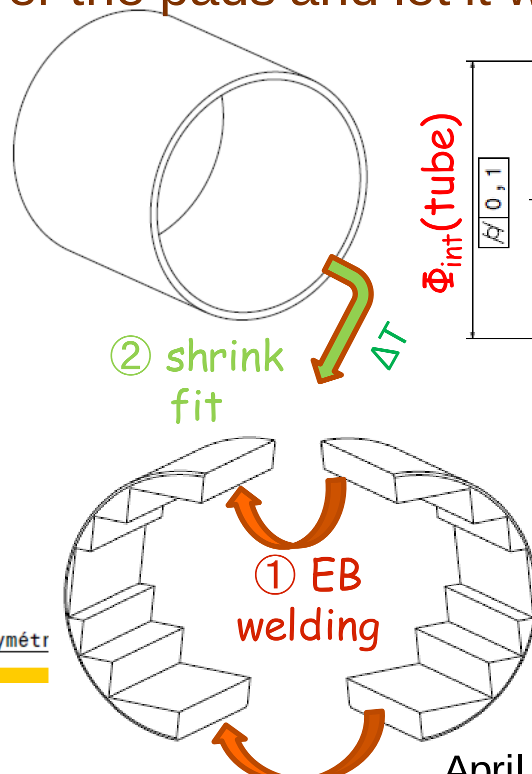


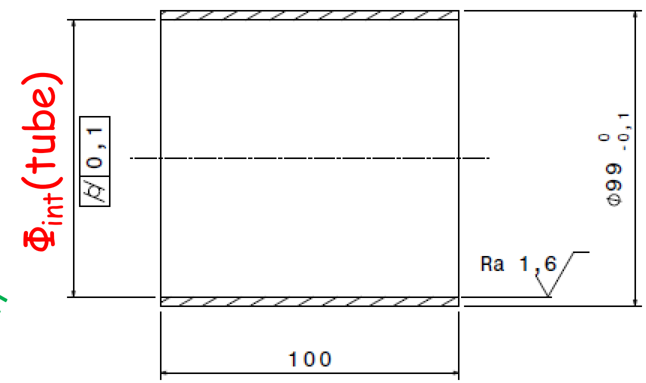
In green, pieces to detailled

Structure assembling by thermal shrinkage

- Thermally shrinked tube over the pads
  - Aim: define the nominal cotation
  - Studied sheme:
    - Cooling the pads with nitrogen after welding (77 K)
    - Or heating the tube (500 K?)
    - Slide the tube over the pads and let it warm







Conclusions

- Advances in many fields for HTS inserts
  - Characterizations and scaling laws
  - Better understanding of the conductors and their implementation
  - Successful HTS coils with high performances
  - A lot of progress about quench modelling
  - Conductor proposal
  - Insert design

Thank you for your kind attention