EuCARD WP-7-T3 & T4 ESAC meeting
CEA – Saclay
February 2013

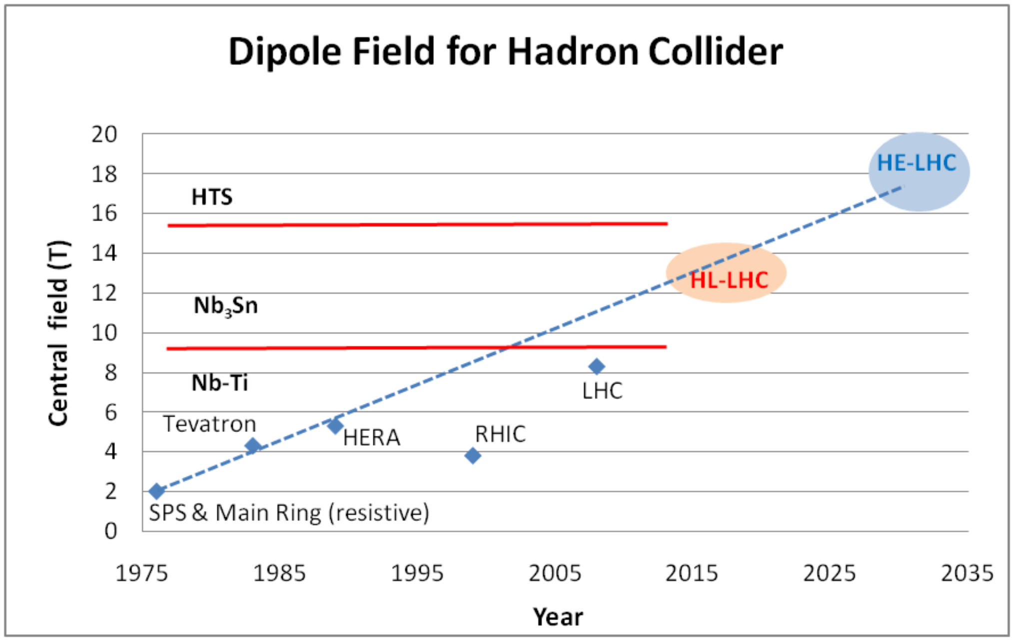
WP-7 / Task 4
Very high field magnet
General description of the insert task

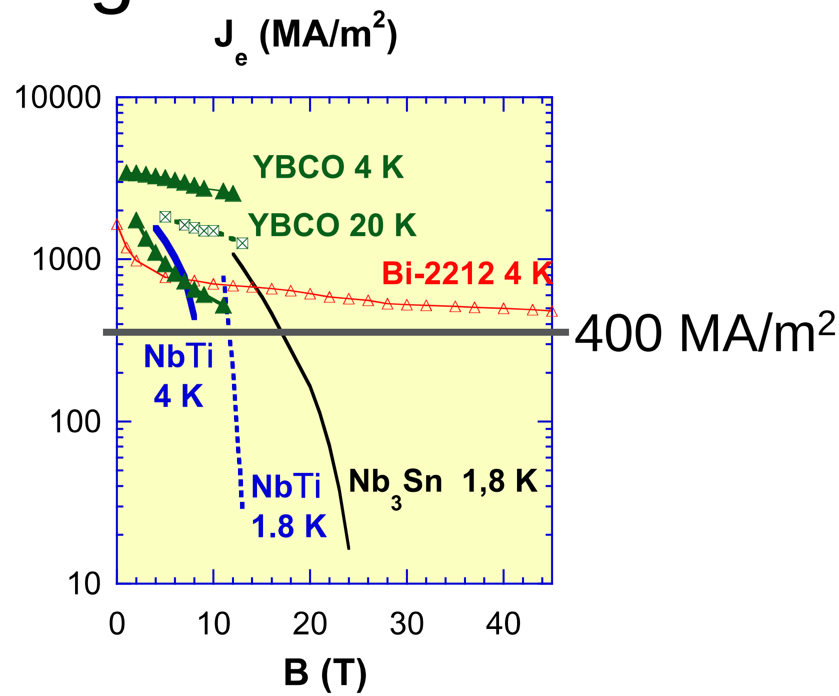
Pascal Tixador
(Grenoble INP / Néel-G2Elab)
For all the contributors to this task

ESAC: External Scientific Advisory Committee

Introduction, objectives

Motivation: quest for higher fields





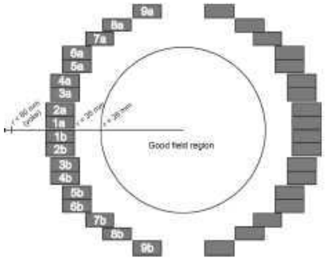
Courtesy L. Rossi

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

Existing inserts

A lot of HTS solenoids, a few HTS dipoles

B_o (T)	T (K)	J_e (MA/m²)	HTS	Group
1.1	4.2	50	Bi-2212	Berkeley
1.3	45	86	Bi-2223	SEI
1.9	4.2	75	Bi-2223	HEP Russia
2.2	17	200 A	Bi-2223	HTS 110 (NZ)
2.6	20 K	330	YBCO	DIT-Danfysik



N. Zangenberg et al., IEEE ASC

Task "HTS insert": objectives, DOW

Three subtasks:

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

Milestones:

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

Done

Deliverable:

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

Delayed

WP7 – task 4 partners

TAMPERE UNIVERSITY OF TECHNOLOGY

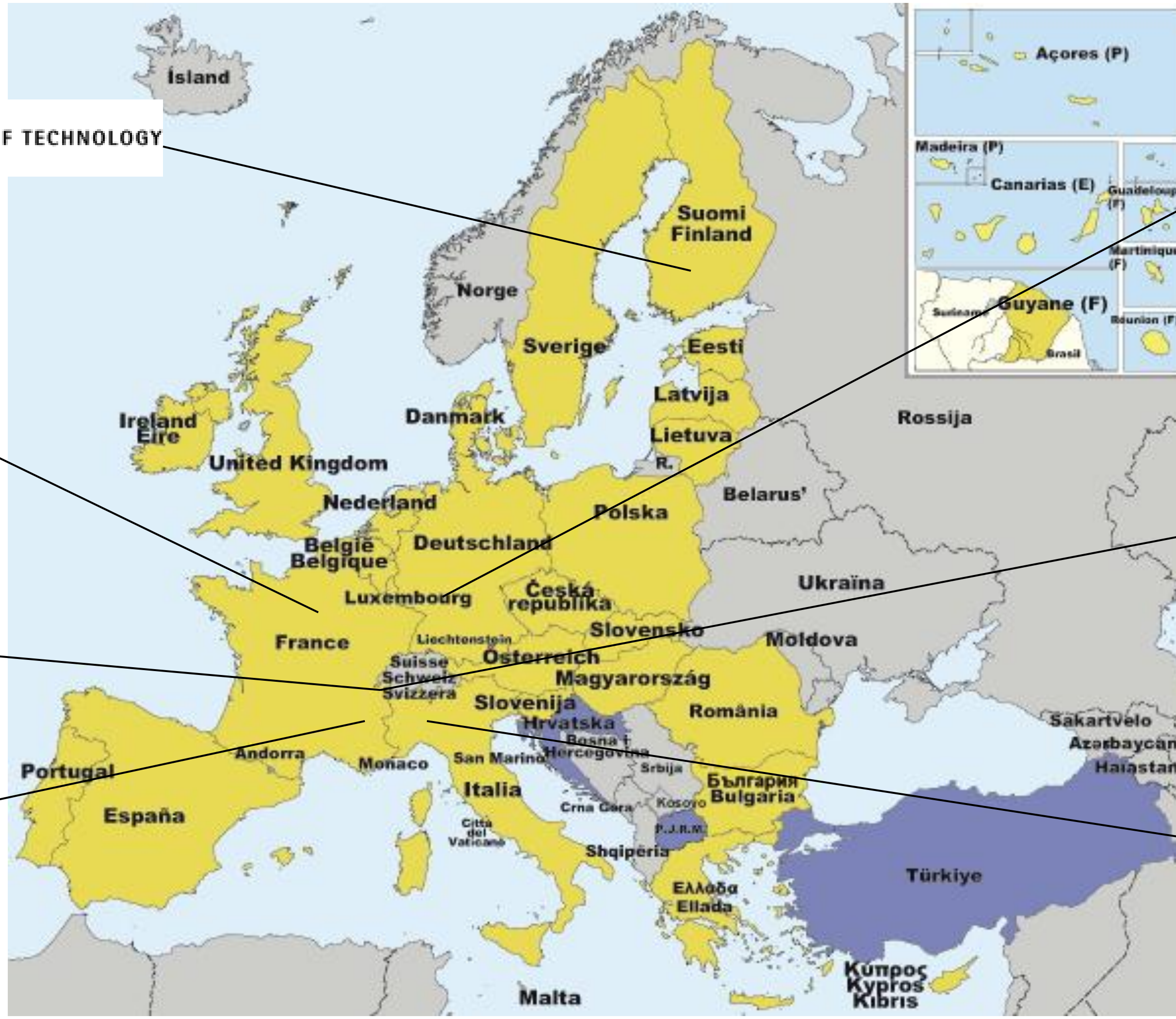
Irfu

cea

saclay

CERN

cnrs



KIT
Karlsruhe Institute of Technology

UNIVERSITÉ DE GENÈVE

INFN

LASA

Works done – Outline of the presentation

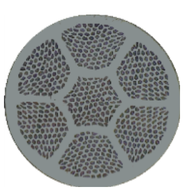
- HTS conductors (Bi-2212 & YBCO coated conductor)
  - Comparison within the context (high J_{ce} & σ)
- HTS insert solenoids
  - Technological implementations
- Protection modelling and protection proposal
  - Numerical tools
  - Protection studies
- HTS insert design
  - Electromagnetic and mechanical designs
  - Conductor design and first realization
  - HTS preliminary tests
- Conclusions and works to be done

Agenda of the task 4 review

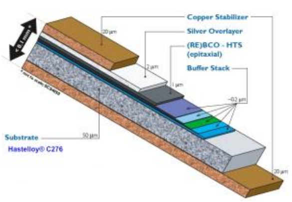
- General description of the insert task, P. Tixador
- Electromagnetic and mechanical design, M. Devaux
- Technology development for the insert, J.M. Rey
- Study of the HTS insert quench protection, M. Sorbi
- Past and future tests for the inserts, F. Debray
- HTS conductor for the insert, J. Fleiter
- Manufacturing planning, M. Durante

HTS conductors

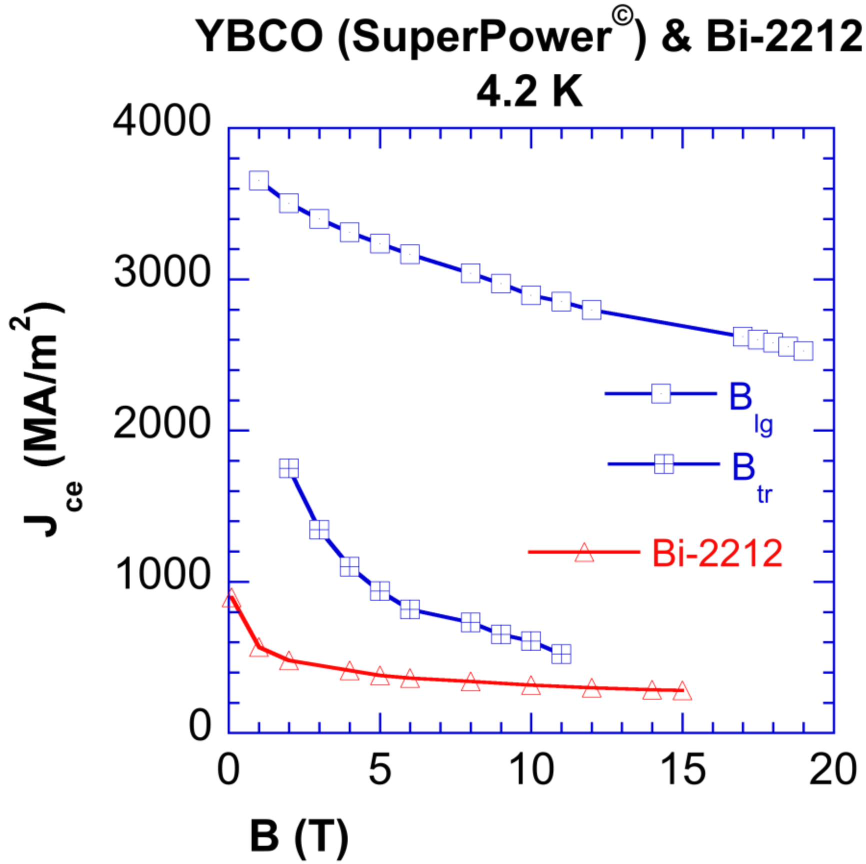
	Bi-2212 **(round wire)**	**YBCO** **(coated conductor)**
	**Round isotropic wire** (Ø = 0.8 mm) High current cable (Rutherford) Bending radius (W & R)	Conductor of future with low cost **Performances** **J_c & mechanics (1000 MPa)**
	Mechanical performances (100 MPa) Defect free lengths Niche conductor	Thin tape (4 x 0.1 mm^2) Lengths & defect free lengths Large field anisotropy
	**Thermal treatment** Cost	**High current cable** Cost, cost **Delamination of YBCO (trans.)**

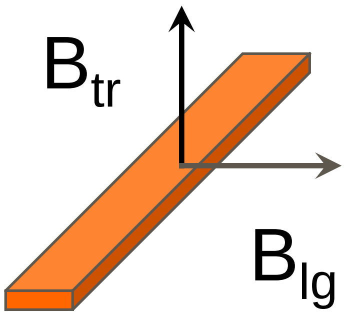


Nexans



HTS conductors

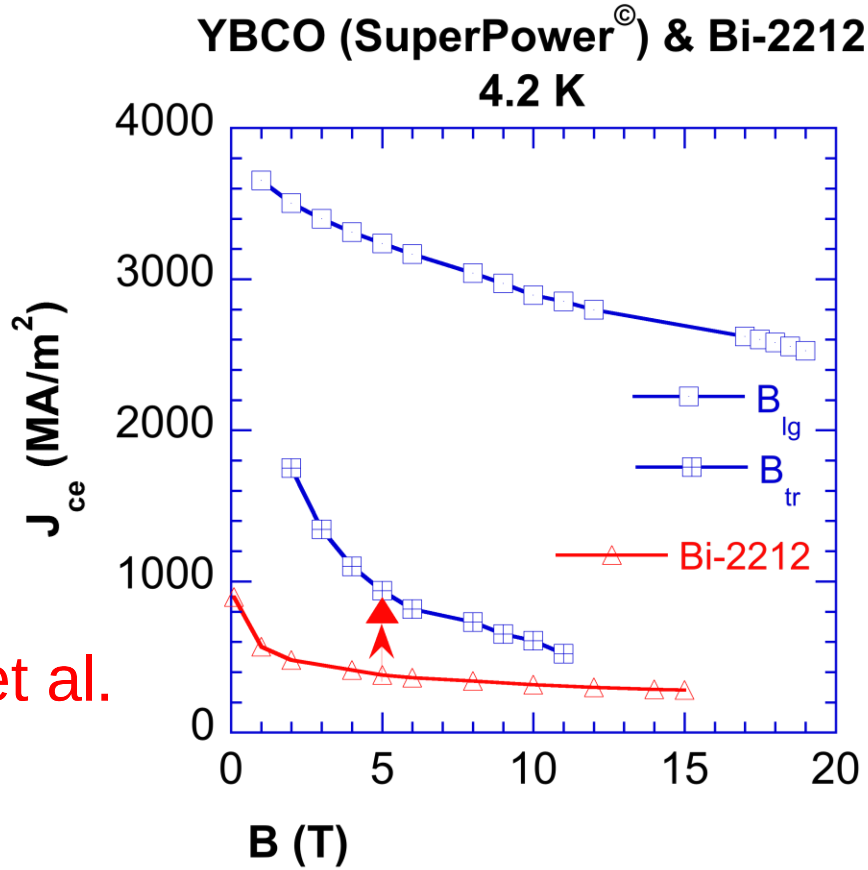




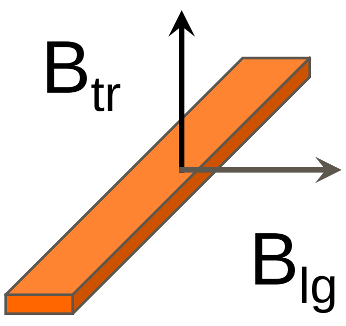
Courtesy J. Fleiter

Parametrization: I_c (T, B, θ)

HTS conductors



UNIVERSITÉ DE GENÈVE

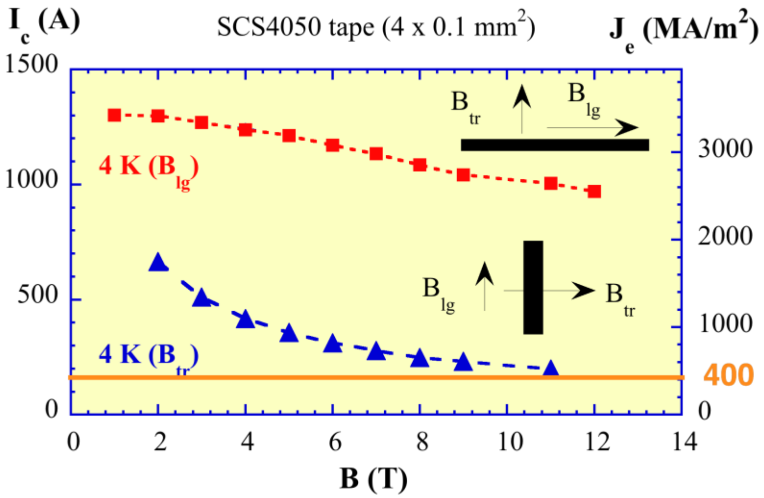


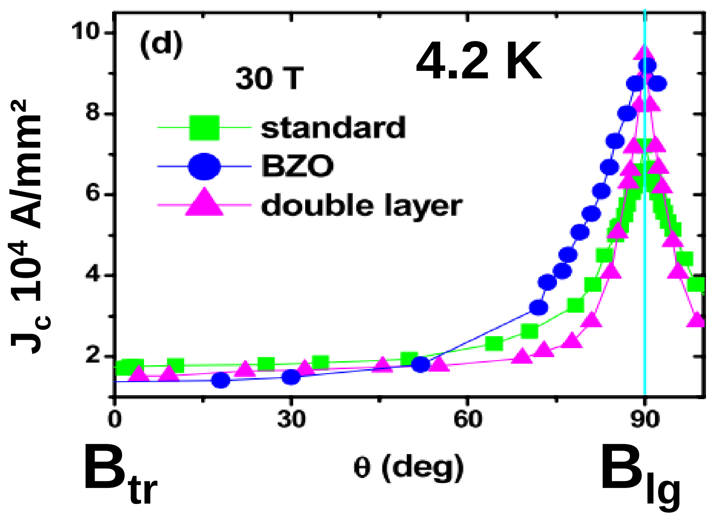
J. Jiang et al.

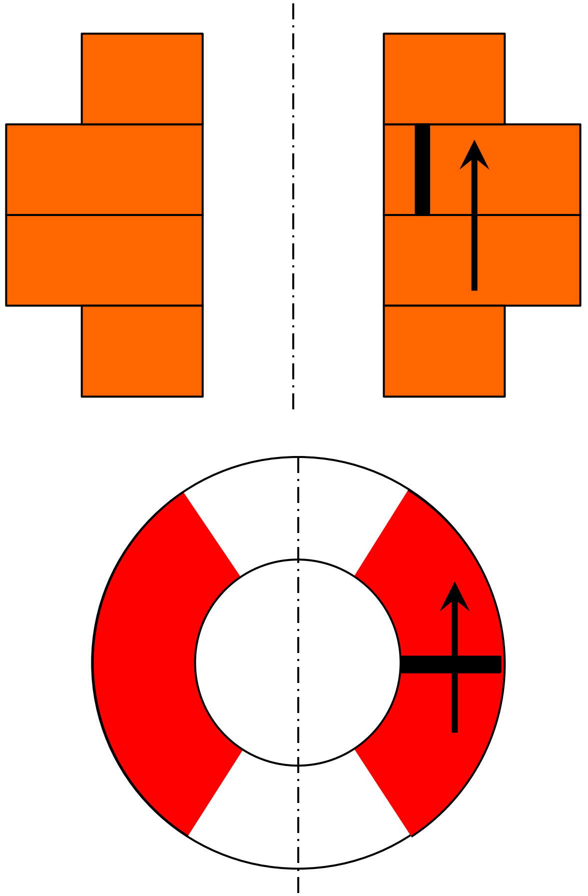
Courtesy J. Fleiter

Parametrization: I_c (T, B, θ)

YBCO insert





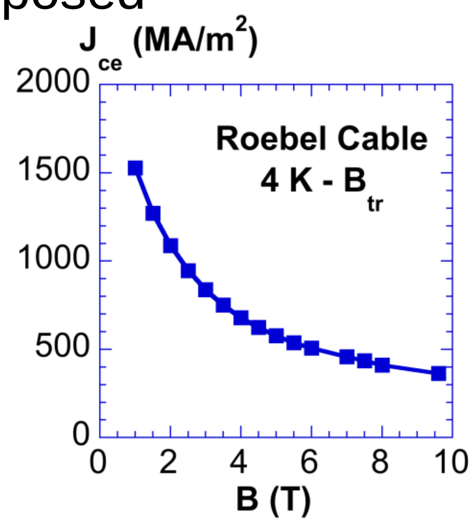


YBCO => Block coils

YBCO high current cables: elect. machines

Roebel cable

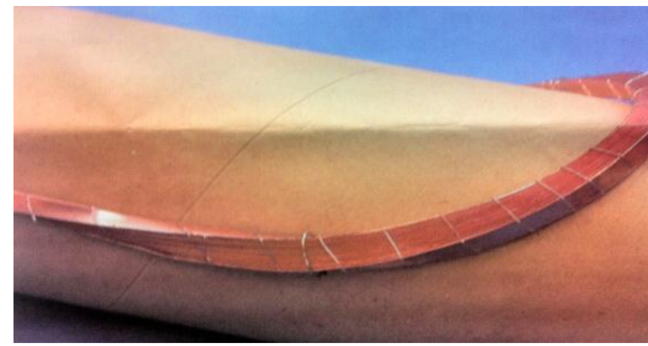
- Fully transposed
- Cost
- Delicate



Courtesy J. Fleiter

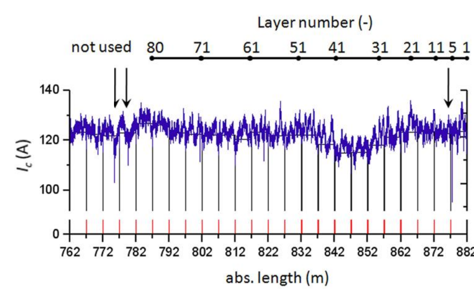
Stack of tapes

Transposition in the coil head



ASC 2012 – MIT?

Transverse field issue

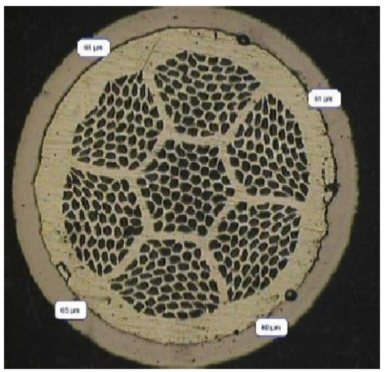


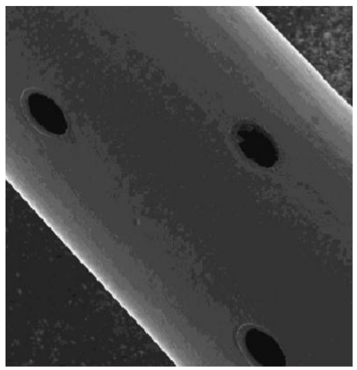
Stack of double tapes

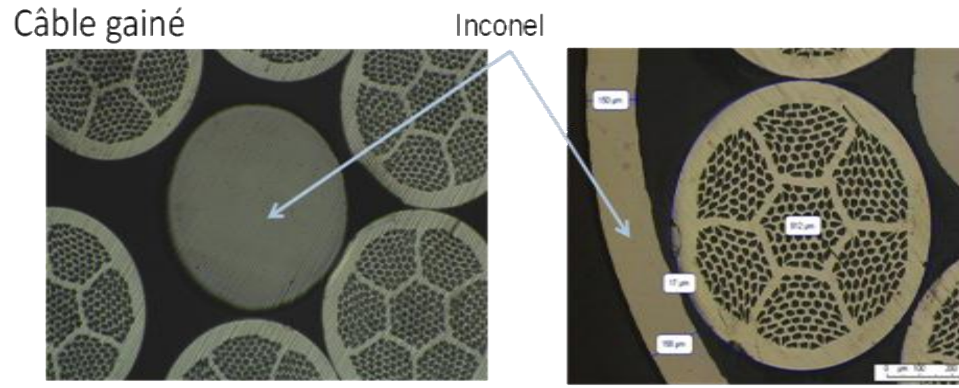
Works on Bi-2212

Bi-2212 strand: $\sigma_c \approx 80$ MPa => too low

Mechanical reinforcement by external shealth







- Holes : 300 µm
- Shealth thickness : 50 / 100 µm

Reinforced conductor $\sigma_c \approx 200$ MPa (Inconel: 540 MPa (0.2 %))

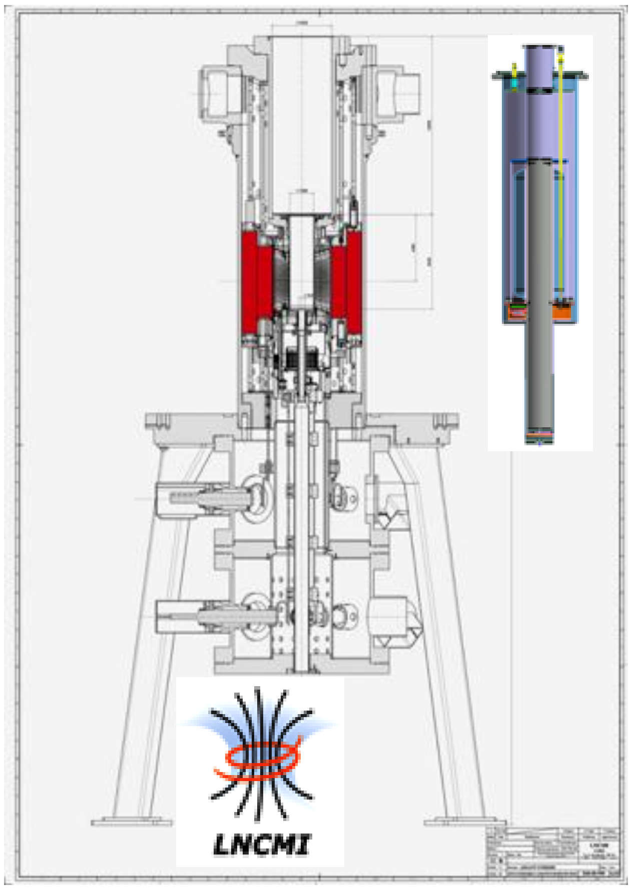
No strong I_c degradation after reinforcement

WP-7 / Task 4
Very high field magnet

- HTS insert Solenoids
  - Technological implementation
  - Experiment for validation of simulation tool

Insert solenoid test bench

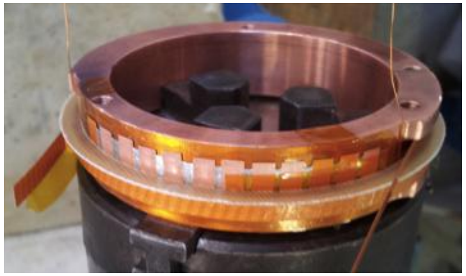
Background field

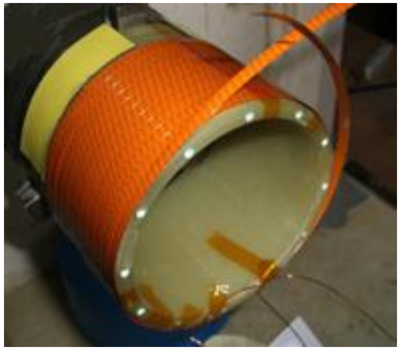


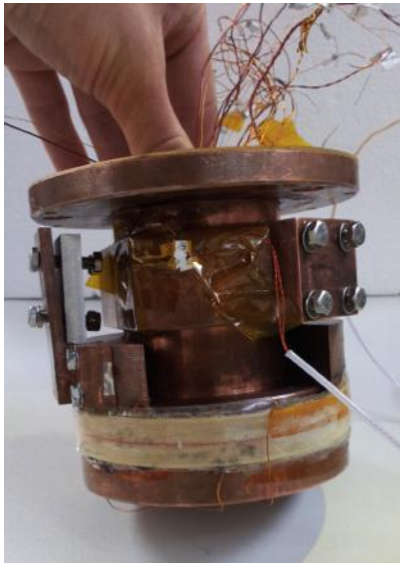
20 T facility

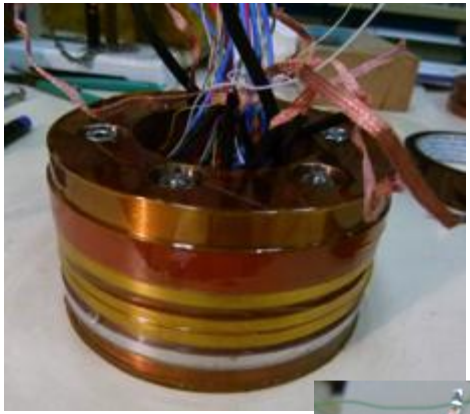
18 T (120 mm)

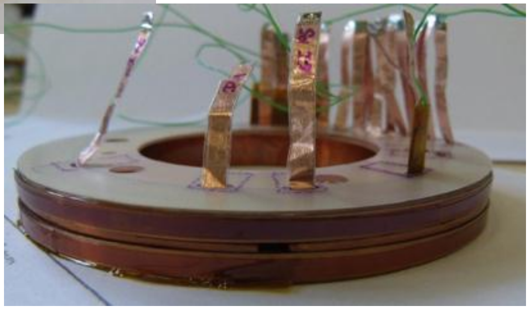
Solenoids realized





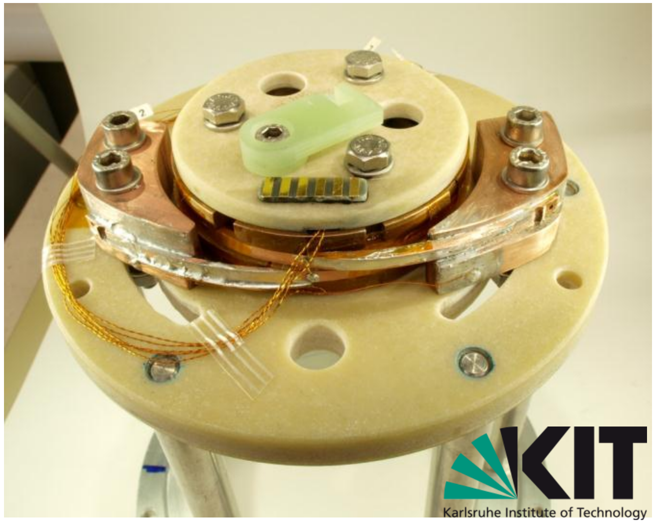






Coil strongly instrumented
(heaters, voltages tapes, Cernox®, …)

Double pancake



124 tests
- 250 < J < 550 (MA/m^2)
- 10 < B < 17 (T)
- 100 < σ < 374 (MPa)

Destruction: 950 MA/m^2, 17 T, 646 MPa

Results (4.2 K)
- 400 A up to 12 T
- 698 A under 10 T
  - Failure (730 MPa)

1200 MPa in Hastelloy (mix law)

+ Works about connexions
(process, solder, …)
(20 $n\Omega cm^2 \leq Rs \leq$ 600 $n\Omega cm^2$ (lap joint))

Presentation of F. Debray

WP-7 / Task 4
Very high field magnet

- Protection modelling and scenario
  - Numerical tools
  - Protection studies

Numerical tools

Very important to have tools to design, to optimise (MQE, MQZ, Vp, F(T_{max})) and to protect the magnet.

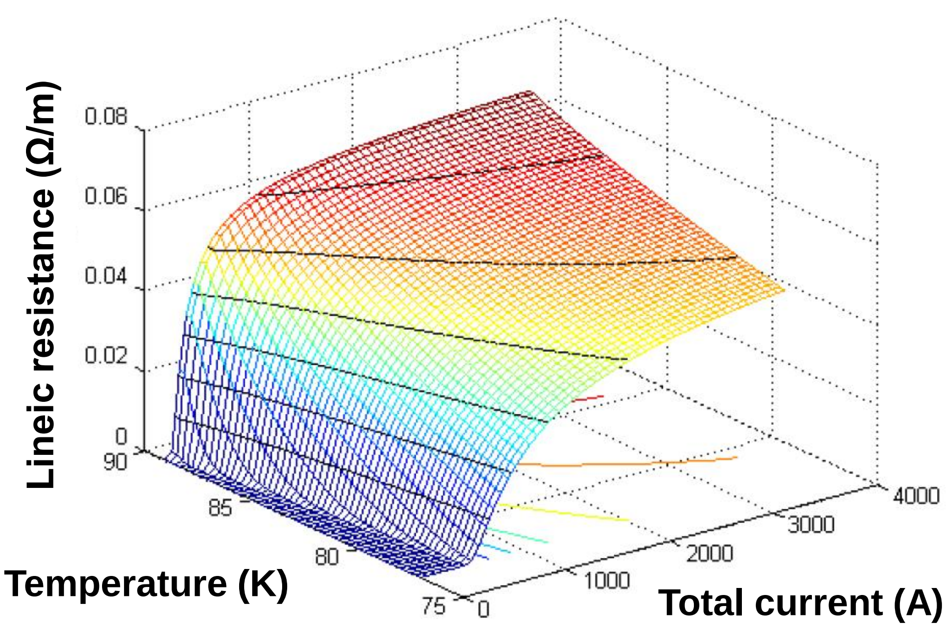
Three different codes

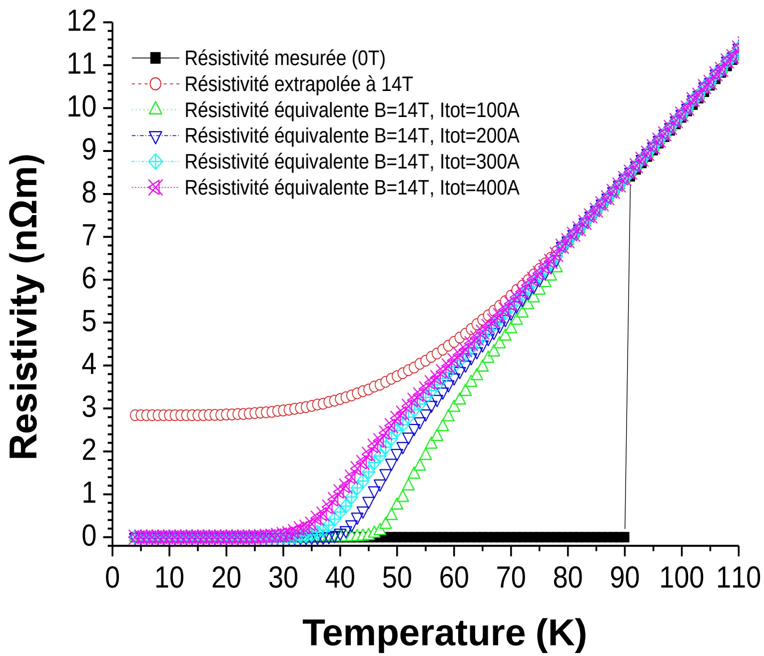
- Tampere (FEM)
- LASA (propagation velocities (Wilson))
- CEA (FEM)

Numerical tools: CEA code

Works carried out by CEA (T. Lecrevisse PhD) using CASTEM where the « CNRS » model (power law for SC and shunt in //) was implemented.

ρ(T, i)



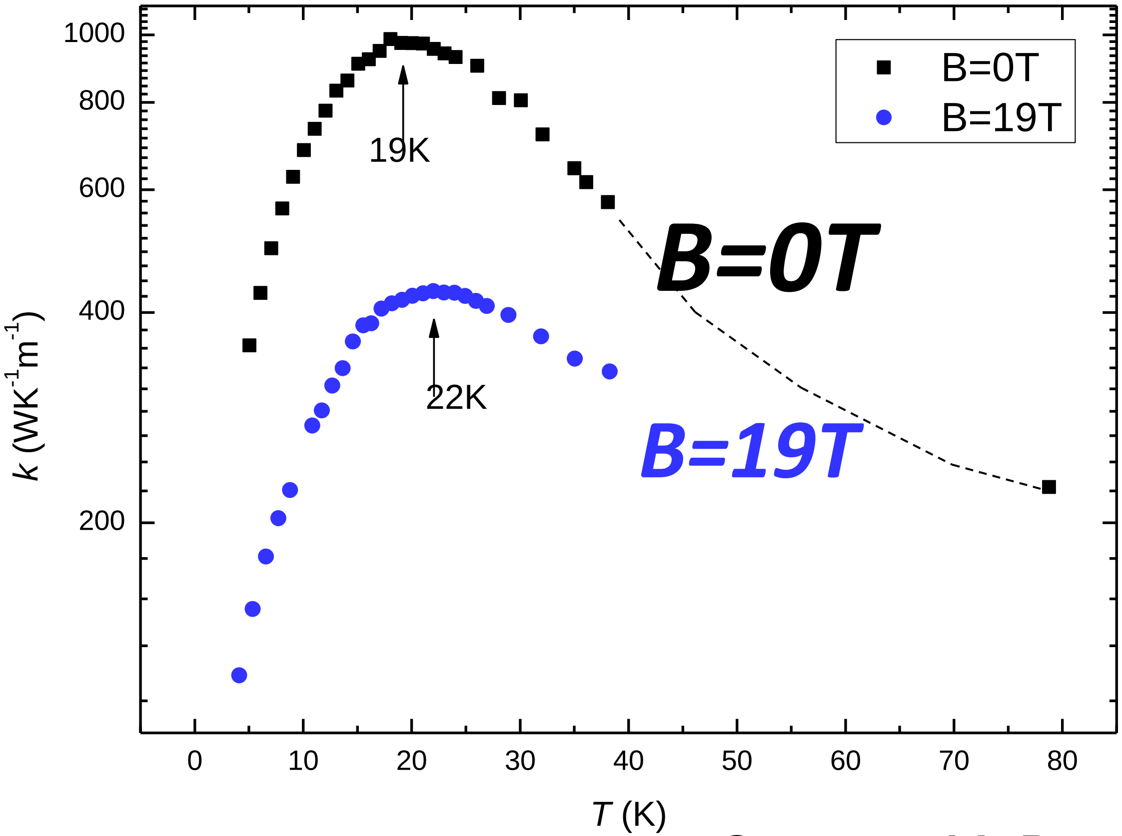


Needs:

- Material properties
- I_c (T, B, Θ)

Conductor properties

Field-Induced Variations at ***19T***

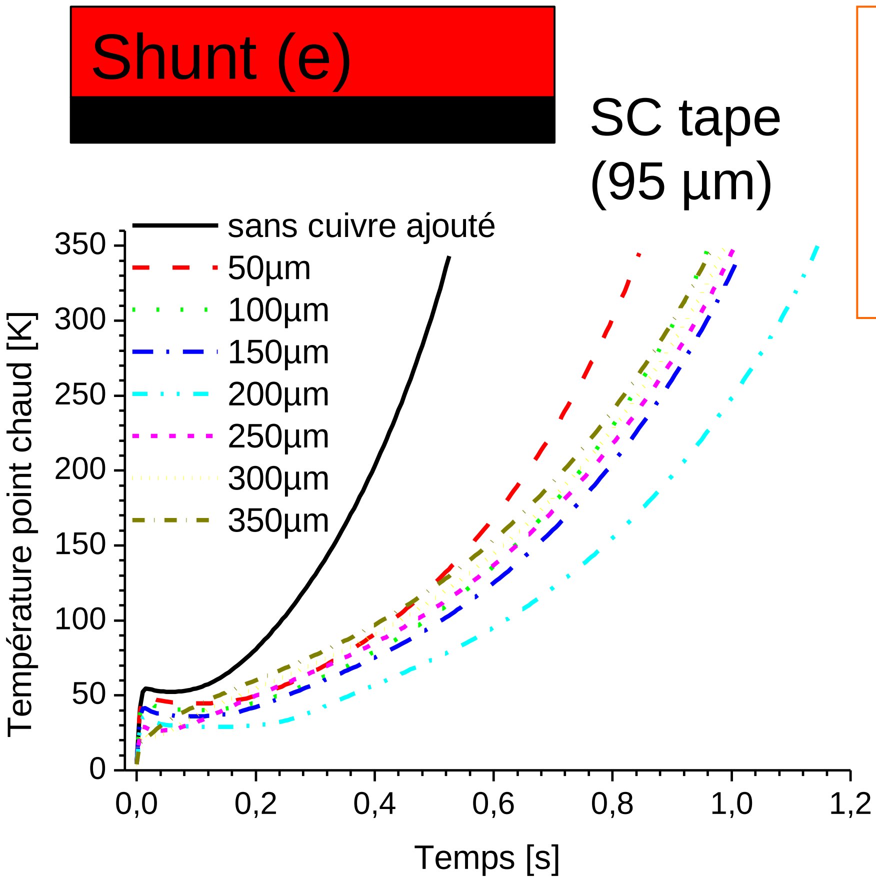


Shift of the $k(T)$ maximum on applying the field

Field-induced k reduction $k_{max}(0T)/k_{max}(19T)=2.2$

Courtesy M. Bonura

Simulation tool: optimization example



Same J_e (340 MA/m^2)

130 A (0 µm) < I < 600 A (350 µm)

I_c = 880 A

Competition between:

- I/I_c
- Propagation velocity
- Enthalpic stabilization

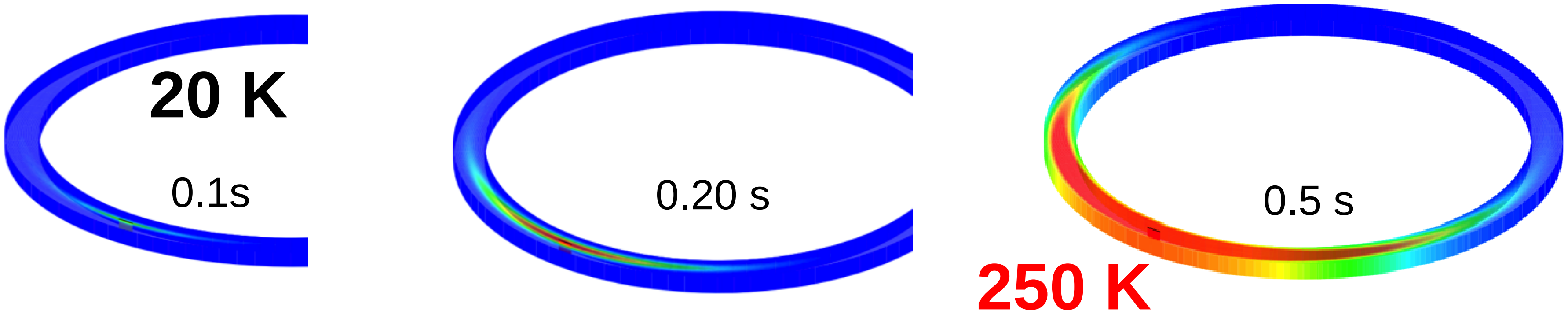
MQE max (40 mJ)
for 100/150 µm

Courtesy T. Lecrevisse

Simulation tool: quench develpment

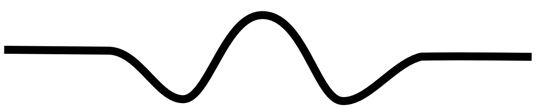
Pancake: 30 series turns (365 MA/m² (Ø ≈ 100 mm))

0.3 J in 100 ms



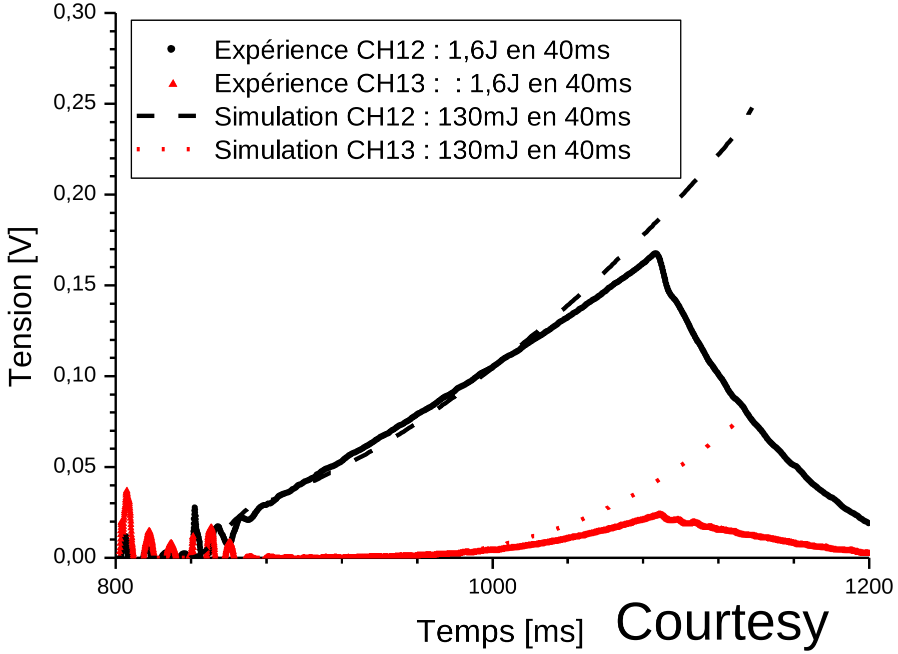
Courtesy T. Lecrevisse

CNRS©

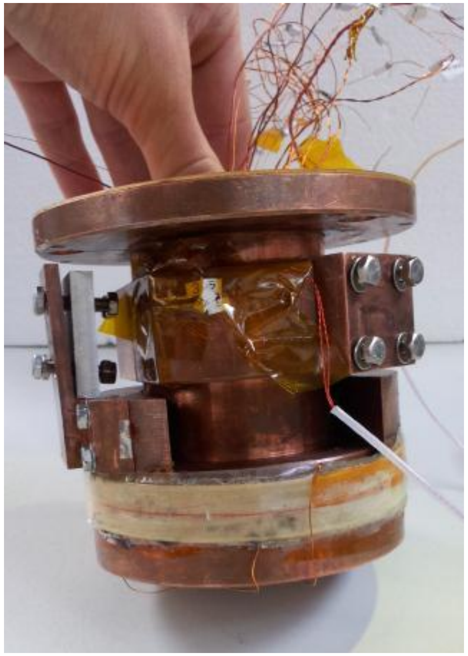


Differential dilatation
high stresses

Code validation



Courtesy
T. Lecrevisse



Ajustable parameters
→ Deposited energy
→ Cooling
→ Length

Protection

TAMPERE UNIVERSITY OF TECHNOLOGY

INFN

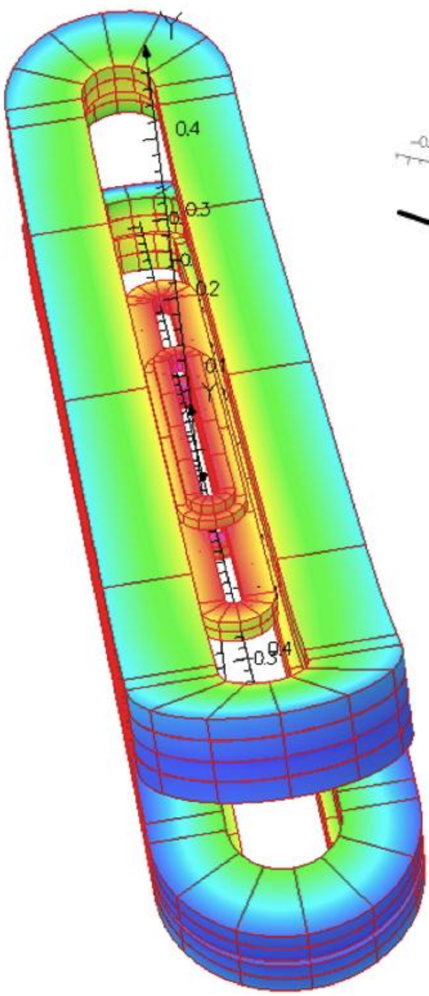
Scenario	Insert $T_{hot\ spot}$ (K)	Remark
Insert quench **No** Fresca discharge	77 K	$V_{fresca\ p.s.}$ = - 19 V **ΔI_{fresca} = + 255 A**
Insert quench Fresca discharge	77 K	ΔI_{fresca} = + 67 A
Quench Fresca No insert discharge	85 K	**$V_{insert\ p.s.}$ = - 78 V** **ΔI_{Insert} = + 260 A**
Quench Fresca Insert discharge	< 70 K	ΔI_{fresca} = + 67 A

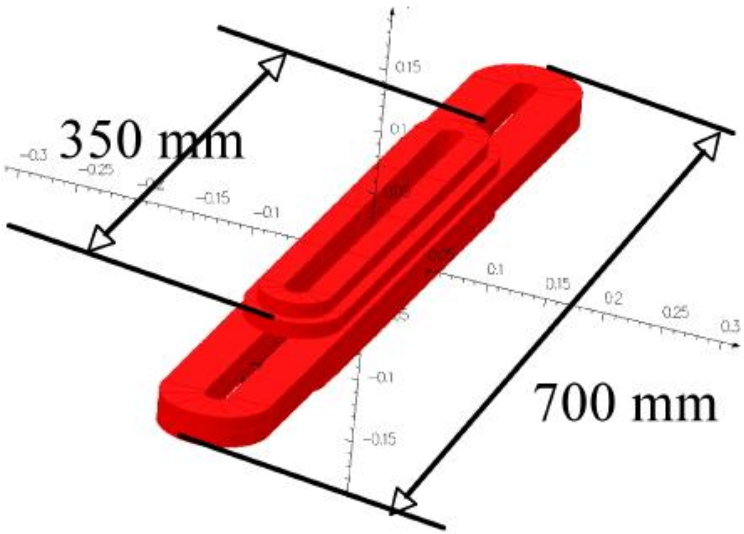
Courtesy, M. Sorbi & A. Stenvall => presentation M. Sorbi

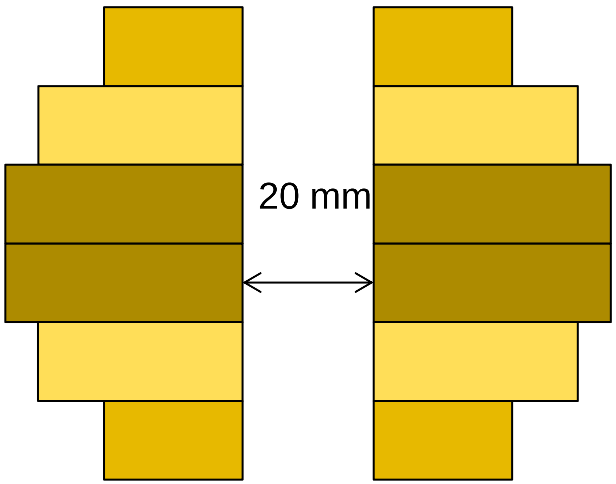
WP-7 / Task 4
Very high field magnet

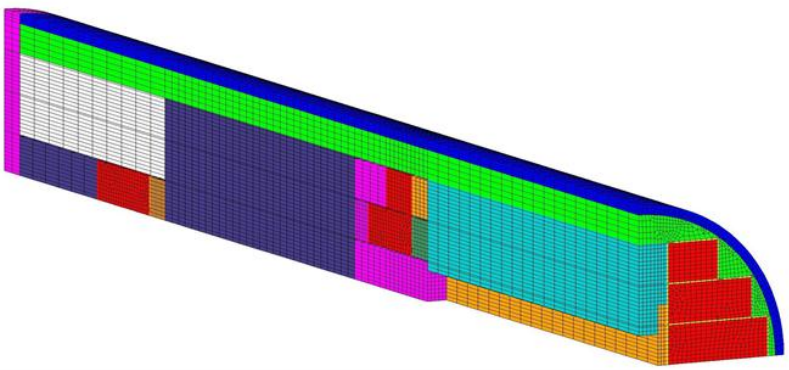
- HTS insert design
  - Electromagnetic and mechanical designs
  - Conductor design and development
  - First test specific set-up

YBCO 6 T Insert









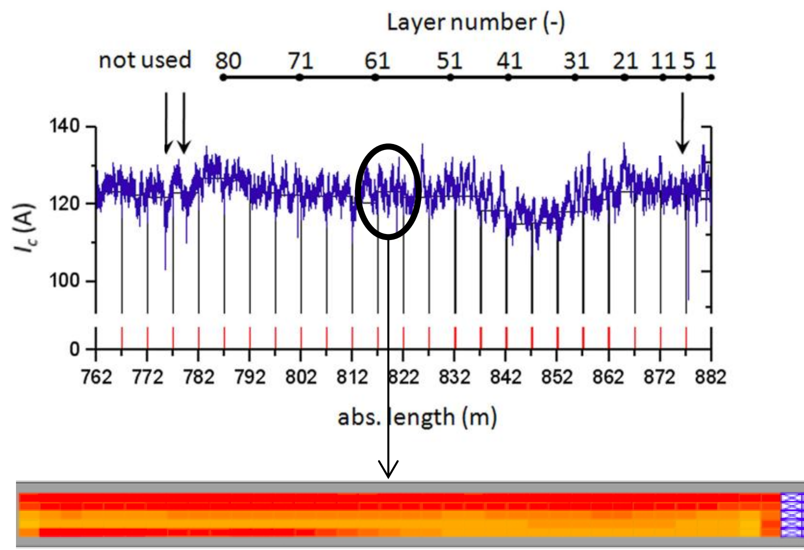
Presentations of M. Devaux and J.M. Rey

Insert YBCO conductor

Required specifications

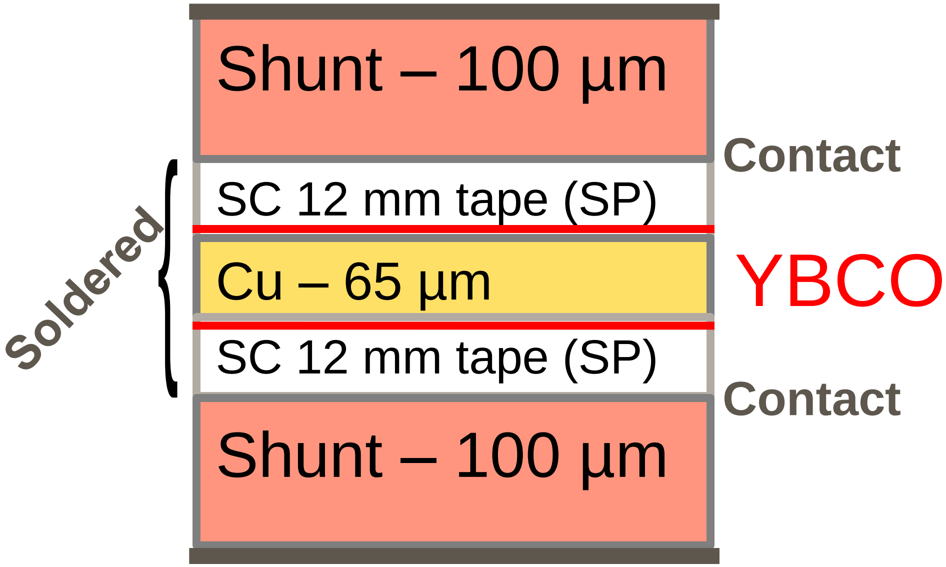
- High current density
- High mechanical strength
- Current redistribution

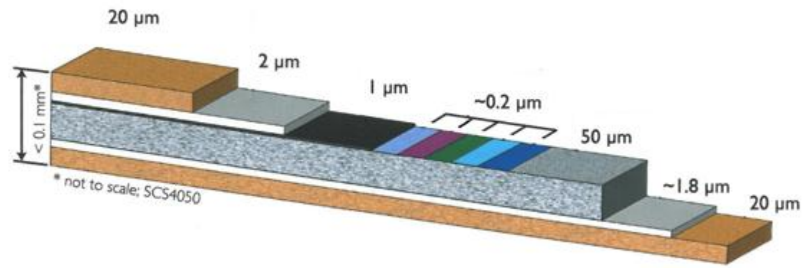
- High current (protection)
- Low AC losses (Field quality)

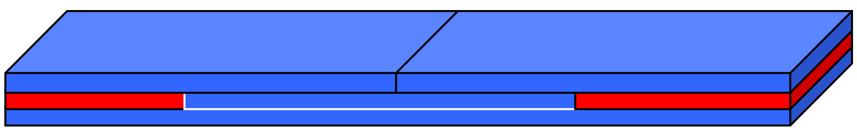


$\Delta J_c \approx 30$ % (Cryoscan)
J_c => 3.2 MA/cm^2

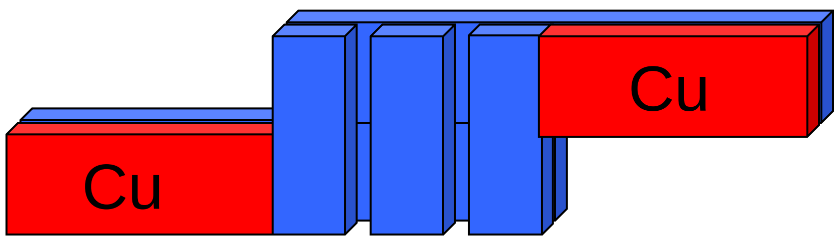
Insert YBCO conductor







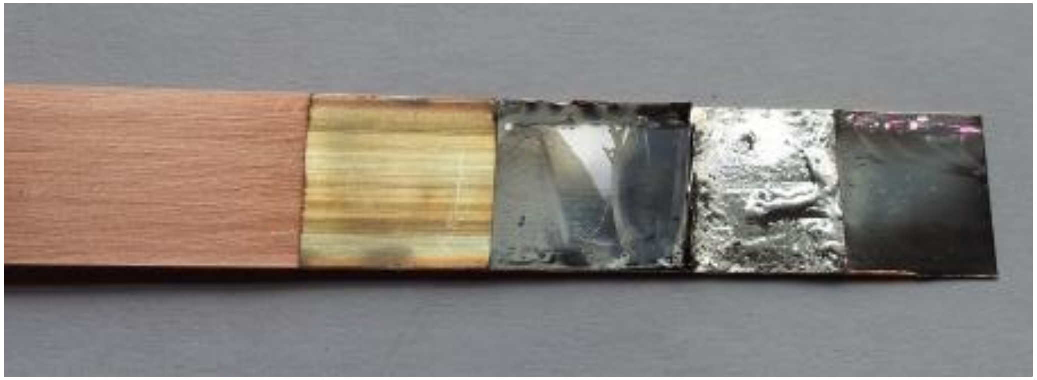
Connexions within pancake



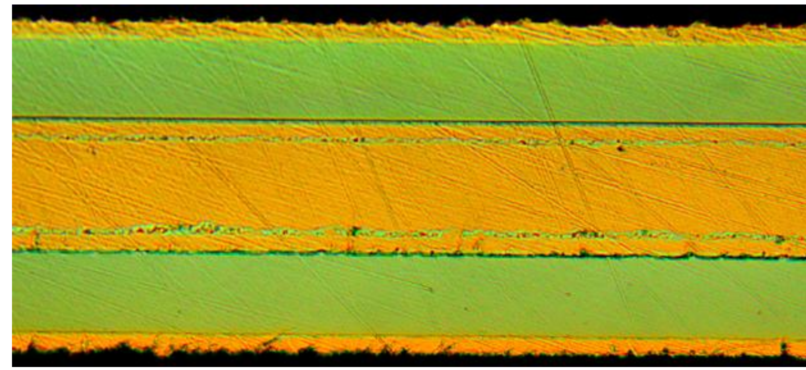
Connexions between pancake

- Stabilization
- Easy connexions
  - within and between pancake
- YBCO close to neutral axis
- AC losses

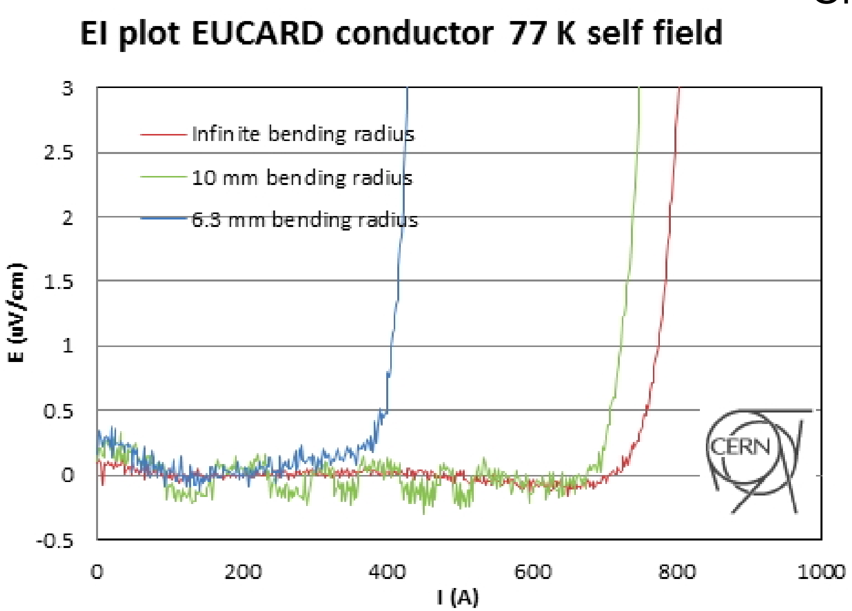
EuCARD insert YBCO conductor



CNRS©

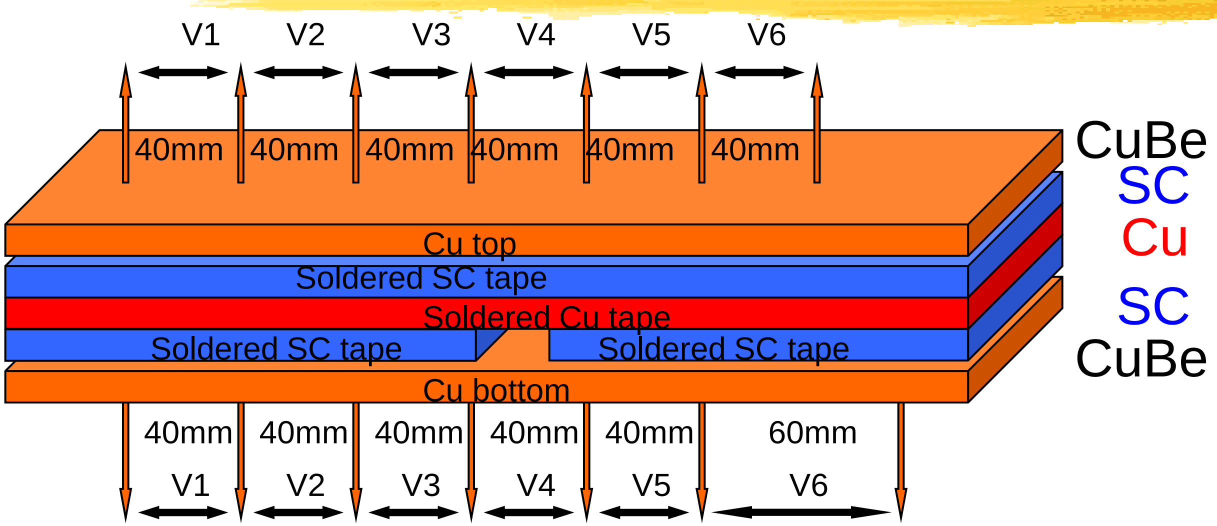


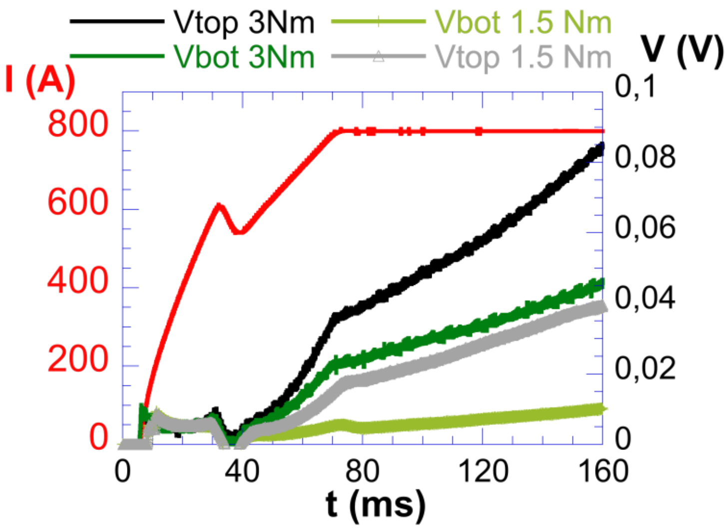
CERN©

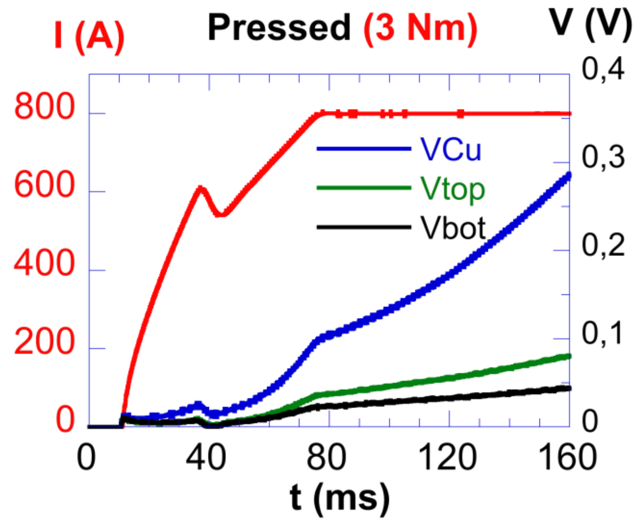


Courtesy J. Fleiter

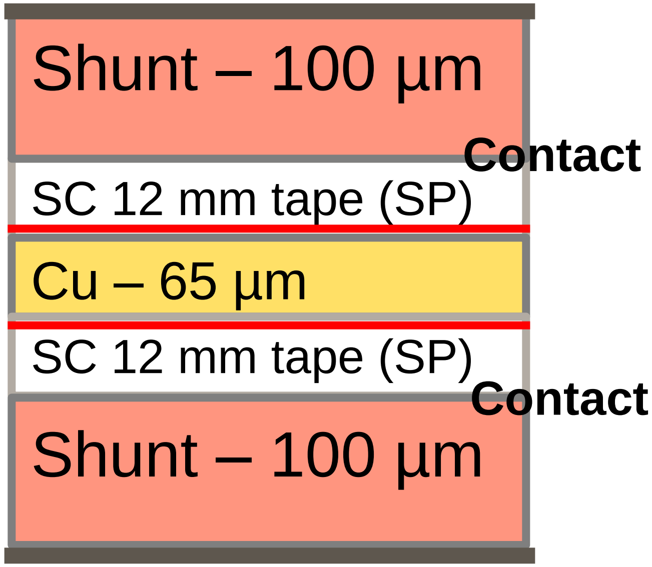
Conductor – current distribution







Shunt



Shunt specifications:

- Good mechanical properties (stresses)

$$\sigma = \sum \alpha_k \sigma_k = \alpha_{Hast} 1200 + \alpha_{Shunt} \sigma_{Shunt} \quad [MPa]$$

- Good electrical conductivity (protection)

$$\int_{T_o}^{T_{\max}} \frac{c_p}{\rho} dT = F(T_{\max}) = J_o^2 \left[\frac{W_{mag}}{V_{\max} I_o} + t_{\det} \right]$$

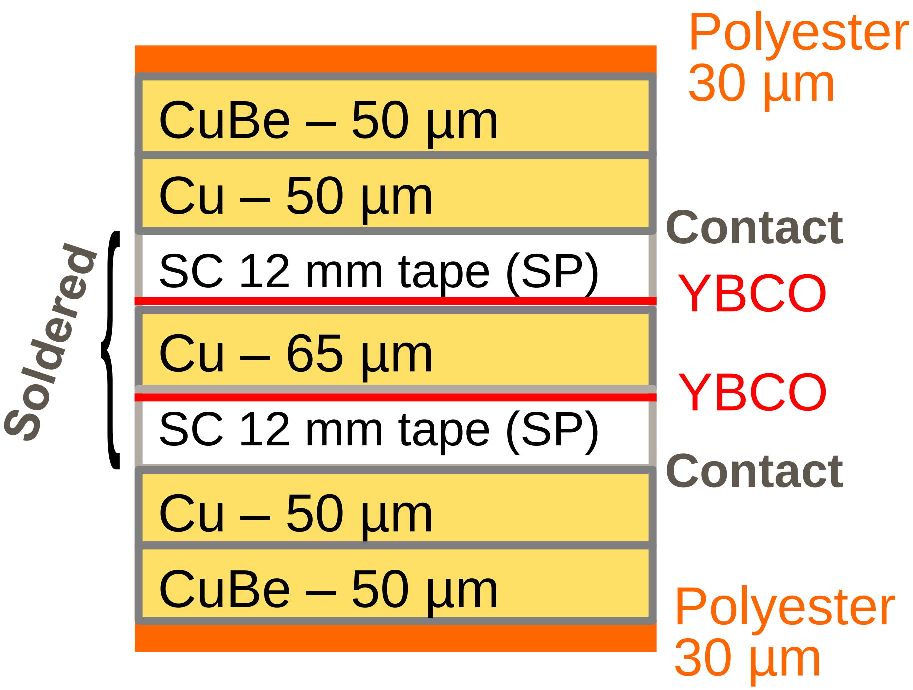
CuBe	Without heat treatment		With heat treatment	
	300 K	77 K	300 K	77 K
ρ (10^{-8} Ωm)	8.73	6.94	6.84	5.4
σ_{lim} (MPa)	570	750	950	**1280**

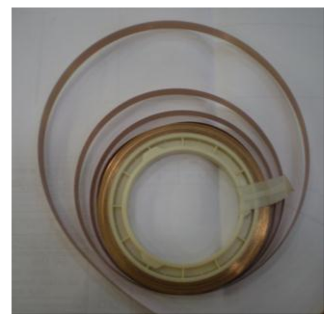
Measurements: CEA & Grenoble

Hastelloy®
- 125 10^{-8} Ωm
- 1200 MPa

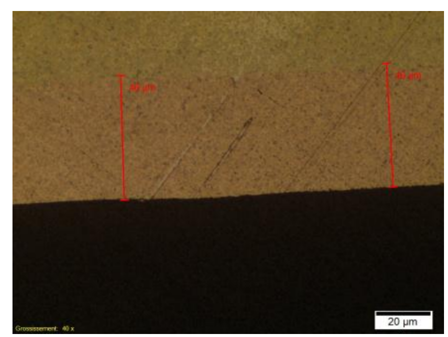
Shunt

Shunt	Cu	Hastelloy	CuBe	Cu/CuBe
σ (MPa)	300	900	900	500
F (300 K)(MA^2/m^4 s)	50 730	13 580	18 570	30 100





Polyester coating (30 µm)



Cu deposition on CuBe Nexans

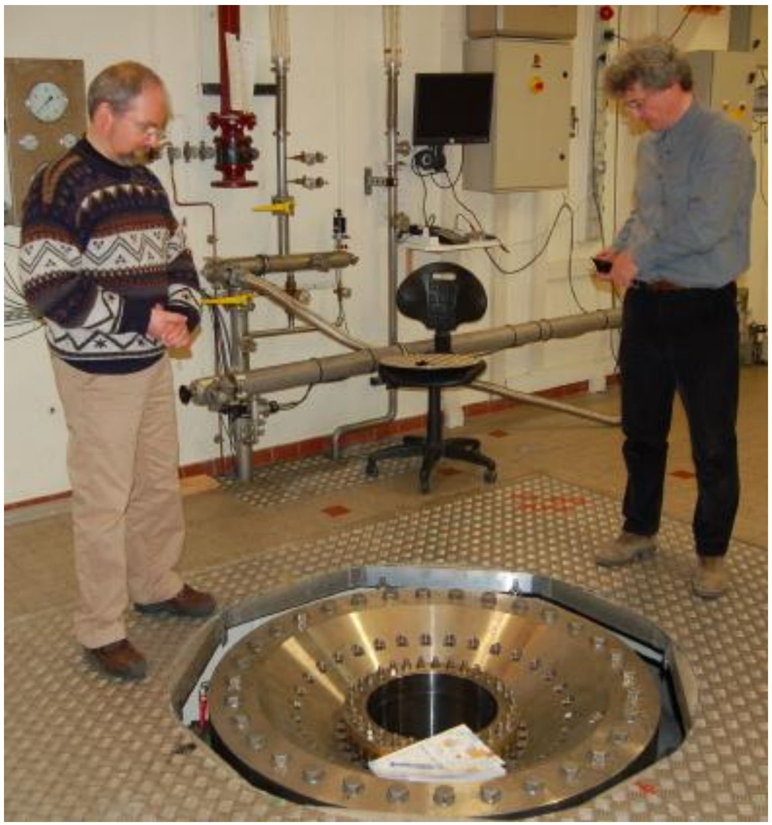
EuCARD WP-7-T3 & T4 ESAC meeting
CEA – Saclay
February 2013

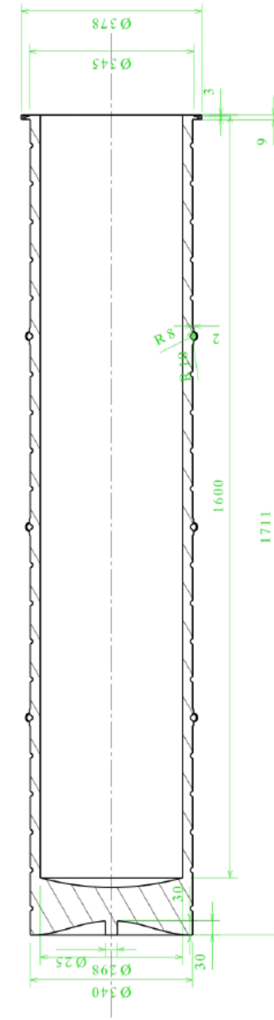
WP-7 / Task 4
Very high field magnet

- HTS pancake preliminary test

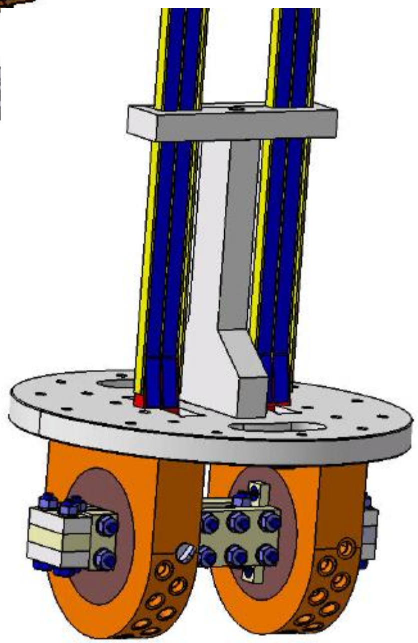
Preliminary tests for EuCARD pancake

Use of the LNCMI large bore 10 T magnet (M10)





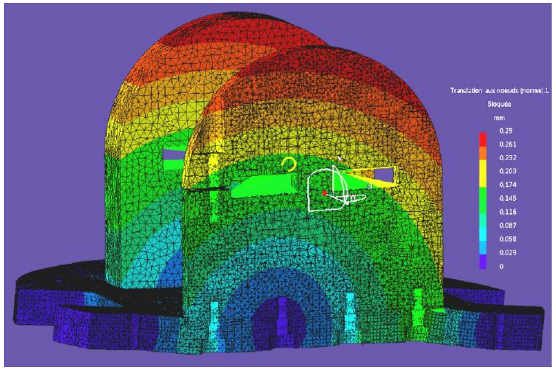
Specific set up for HTS pancake



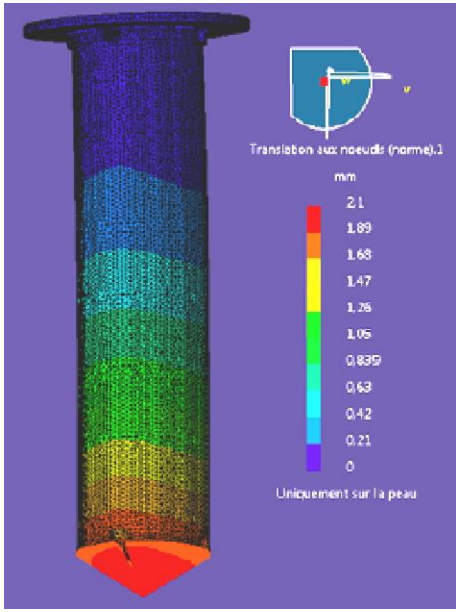
Pancake
(260 mm long)

B$_e$

Deformations

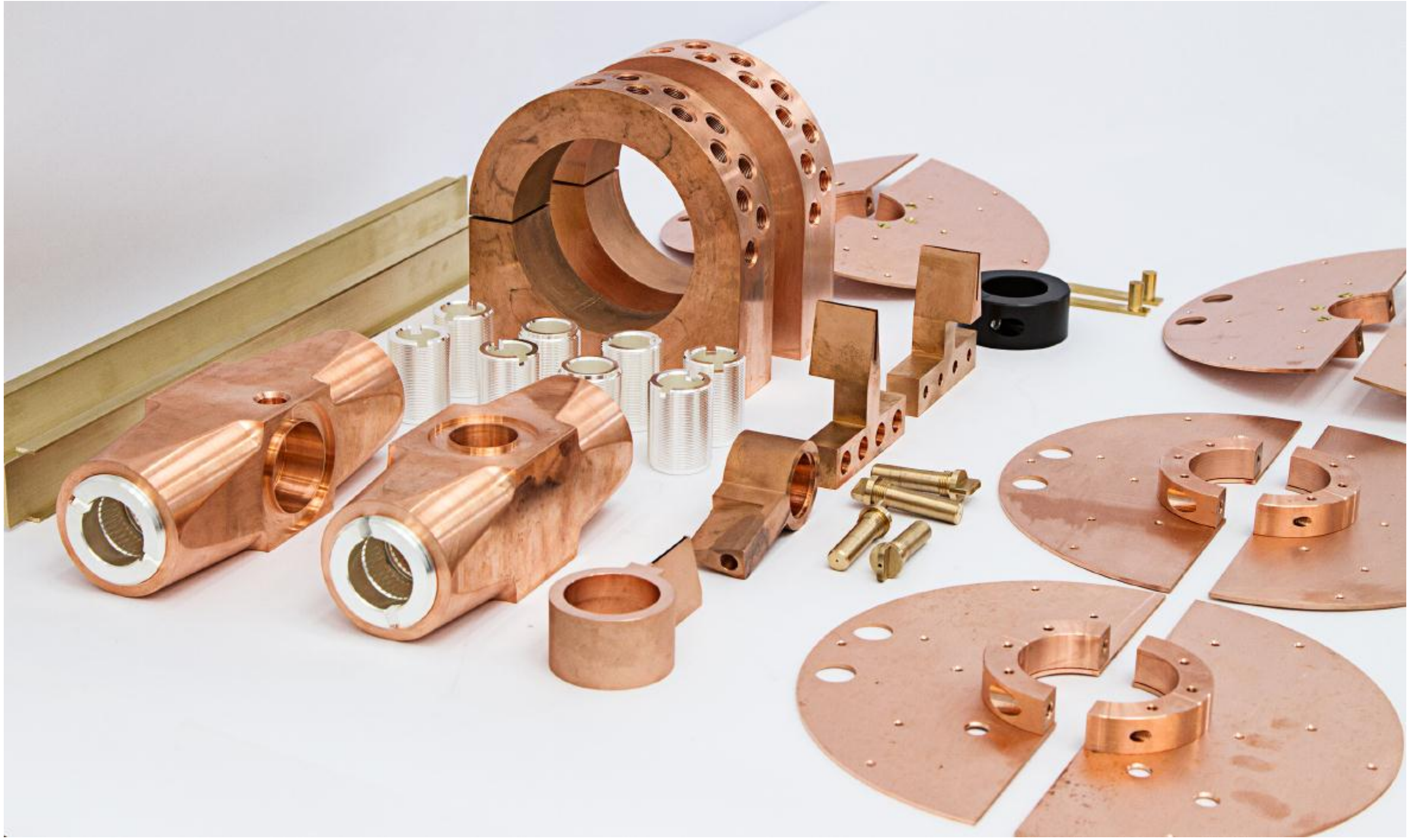


Courtesy P. Jeantet



- Design finished
- Under realization
- Tests spring 2013

Specific set up for HTS pancake



WP-7 / Task 4
Very high field magnet

- Conclusions & works to be done

Conclusions

- Advances in many fields for HTS inserts
  - Better understanding of the conductors and their implementation (connexions, …)
  - A lot of progresses about simulation tools and quench modelling
  - Successful HTS solenoids with high performances
  - HTS insert fully designed
  - Dedicated conductor with preliminary tests

Works to be done (short term)

- Complete tests of the YBCO 2 tape conductor
  - At 4.2 K in Fresca (CERN)
- Manufacturing & assembling of the set-up for the pancake test under 10 T
- Pancake windings (CEA)
- First pancake tests under 10 T (2013)
- Insert manufacturing and final tests in Fresca II

Works to be done

- Mechanics in simulation tools
- **High current YBCO cables**
- Coil ends
- Quality of field (AC losses)

N. Zangenberg et al., IEEE ASC

=> EuCARD II

Thank you for your kind attention

and many thanks to all the people who have participated to these works