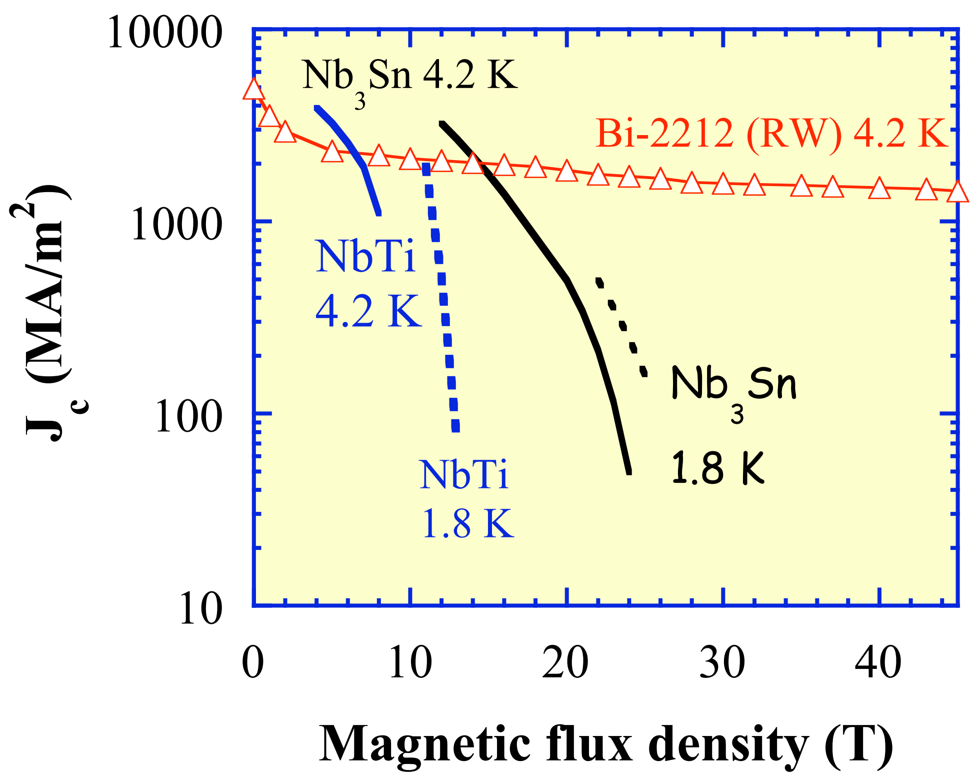
EuCARD 2010 Annual Meeting
STFC Rutherford Appleton Lab.
14th - 16th April 2010.

Task 4:
Very high field HTS dipole insert

P. Tixador (G-INP)

Motivation: quest for higher fields



LTS:
Limit ≈ 23 T

HTS:
Attractive
No $J_c(B)$ limit

Introduction: task 4 objective

Construction of an 6 T HTS dipole insert within the 14 T Nb_3Sn 100 mm dipole magnet (20 T)

Three subtasks defined:

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

Particular constraints:
- high mechanical stress
- conductor bending radius

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State of the art: HTS dipoles

- Many HTS solenoids (5.4 T (Bi) - 9.8 T (Y))
- Only a few HTS dipoles

T
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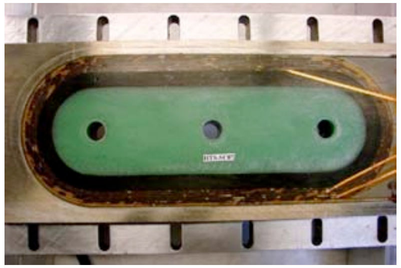
t



LBL

- 2x6 turn Racetrack, Impregnated
- 17 wire Bi-2212 Rutherford Cable
- W & R at 890° in pure O_2
- 1.11 T @ 4.2 K (1.48 T designed)

Design

Danish Technolog. Institute InnovAcc

- 18 YBCO coils
- T_o = 20 K
- I_o = 167 A (80% load line)
- Aperture field: 3.6 T (Ø = 52 mm)

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Challenge!

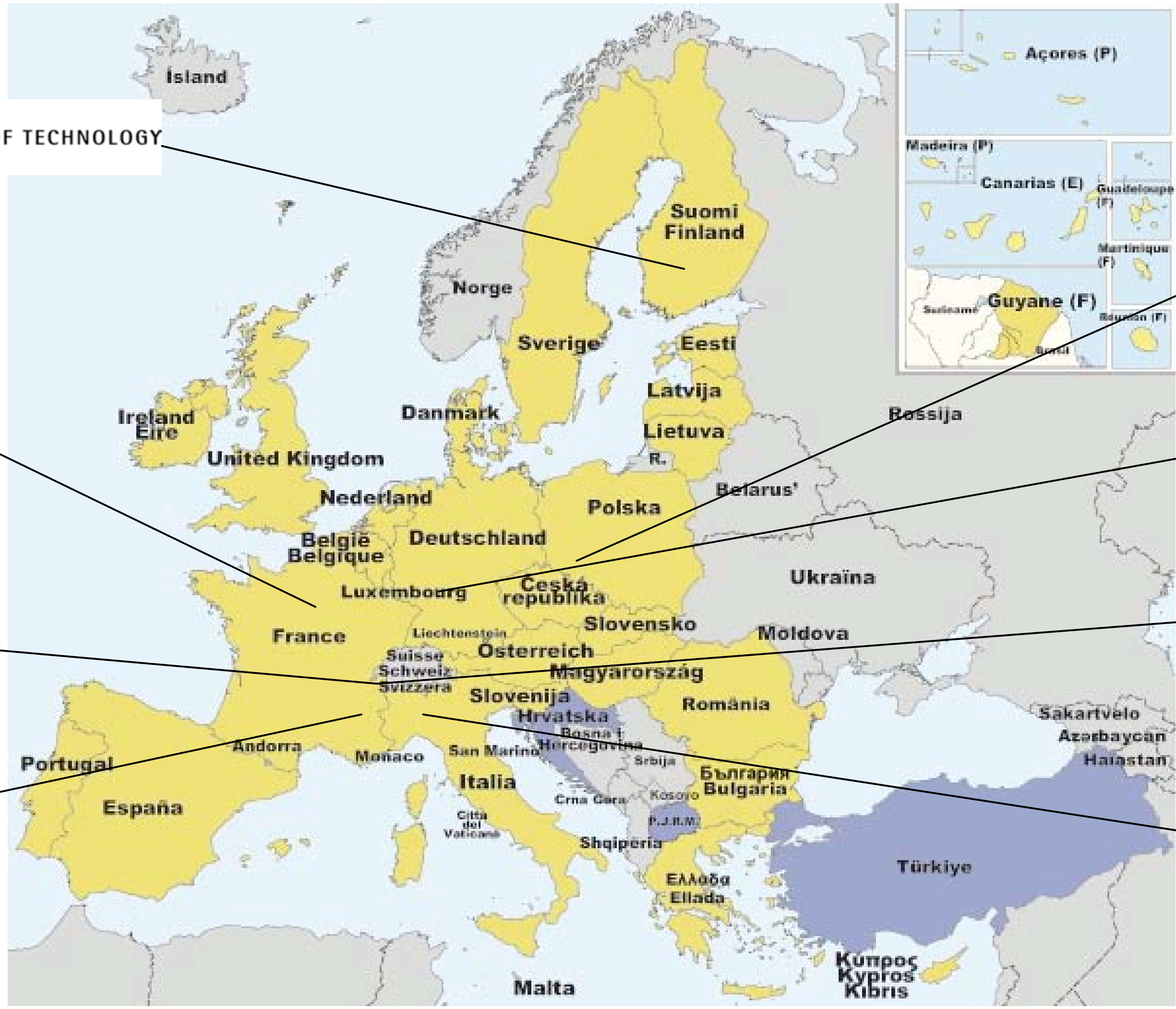
WP7 task 4 partners

TAMPERE UNIVERSITY OF TECHNOLOGY

Irfu
cea
saclay

CERN

cnrs



Wroclaw University of Technology

KIT
Karlsruhe Institute of Technology

UNIVERSITÉ DE GENÈVE

INFN
LASA

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Outline

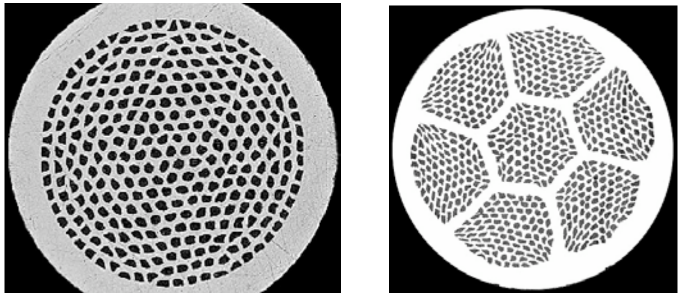
- HTS wire/conductor
- New characterization equipment
- Modelling works and protection
- Preliminary magnet designs & construction
- Conclusion and future works

HTS wire / conductor for high field dipole

Bi-2212 (1G) / YBaCuO (2G)

1 G (BiSrCaCuO)

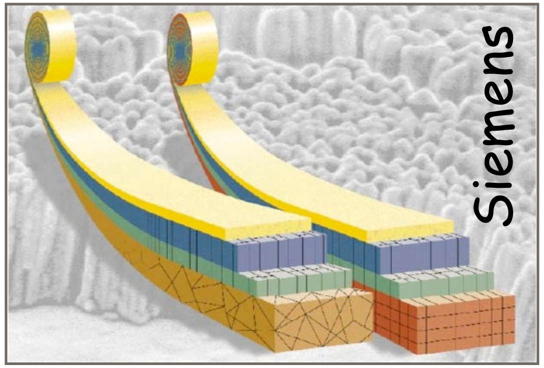
PIT round wires



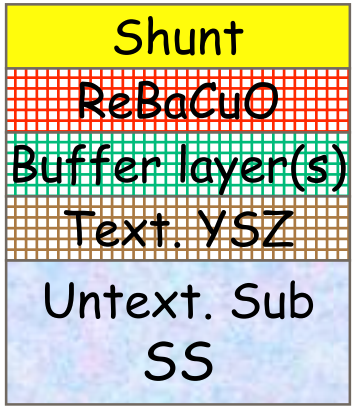
Metallurgical process
- R & W
- W & R

2 G (YBaCuO)

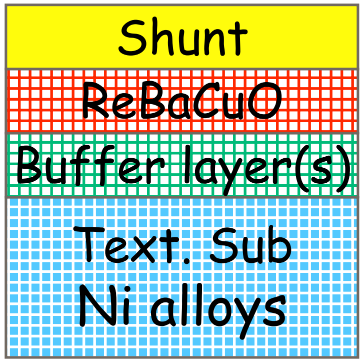
Coated Conductors / tapes



Thin film technology
- IBAD
- RABiTS



Ion Beam Assisted Deposition



Rolling Assisted Biaxially Textured Substrates

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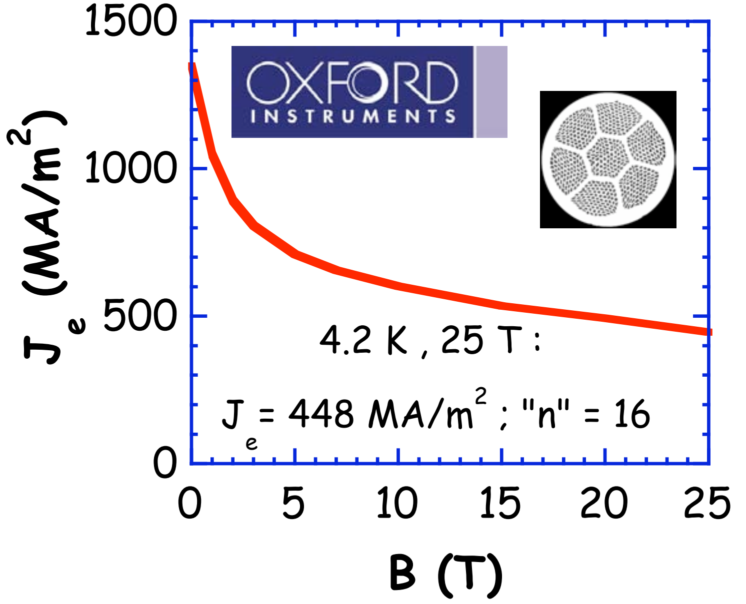
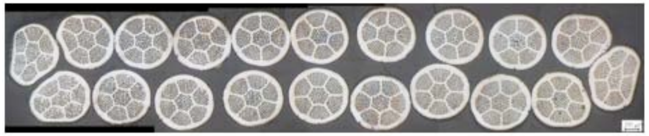
Bi-2212 : OST

OST 2212 Wire (Billet PMM030224)
Ø = 0.8 mm, SC : 28 %



A. Vostner
(EFDA meeting, Barcelona 8-9 May 2007)



20 strand Rutherford cable
I_c > 3 000 A @ 4.2 K

30 strand Rutherford cable
I_c > 4 000 A @ 4.2 K

Nexans Korea
Courtesy A. Allais

But: J_e = 200 MA/m² (15 T, 4.2 K)
(Bi-2212 purchased by CERN for EuCARD)

But large degradations
LBL: 2.6 T => 1.48 T

Bi-2212 heat treatment: a challenge!

One of the major issues for Bi-2212

- Accurate temperature profile (ΔT: a few K)
- Temperature homogeneity over the conductor volume
  - Not a real issue for sample/Vamas
  - Difficult for a coil (furnace dimensions)
- Sensitive to C, C contaminations, …
- Oxygenation is a key part
- Relative brittleness after reaction (less / Nb_3Sn)
- Degradations after treatments (LBL: 1.48 T => 1.11 T)

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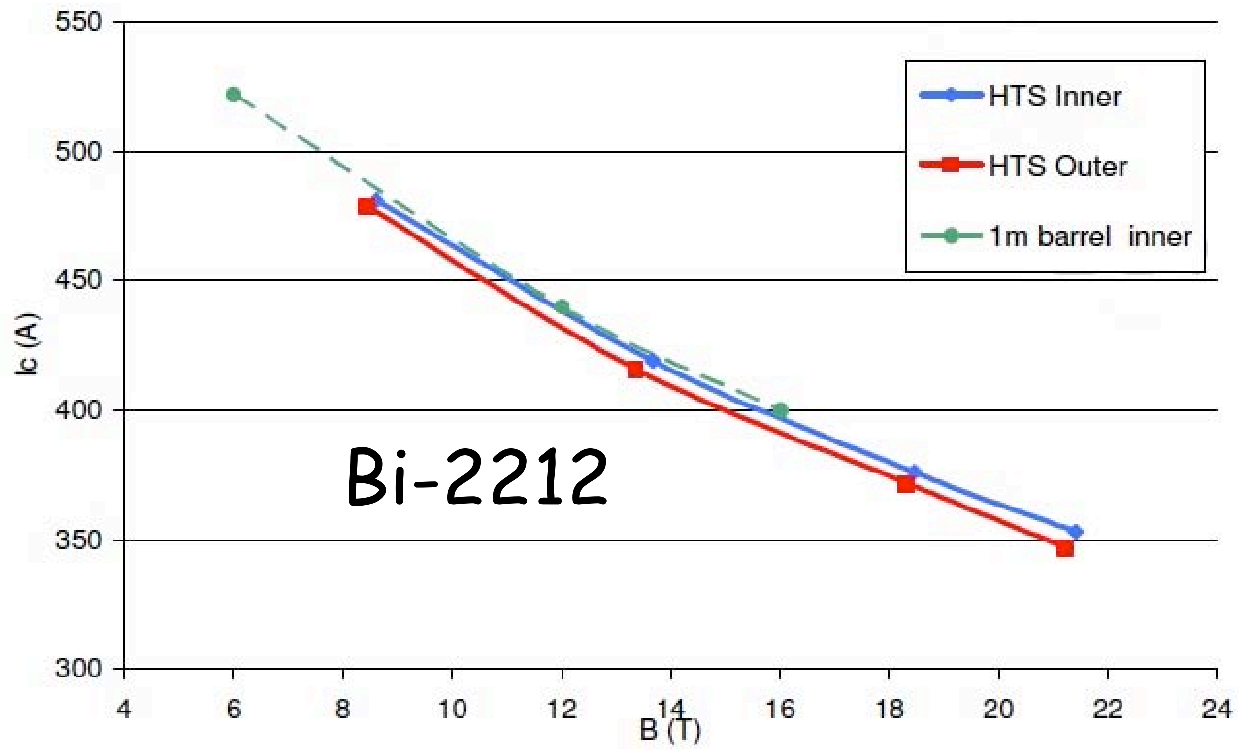
Bi-2212 Heat treatment

- OST has achieved progress in heat treat†



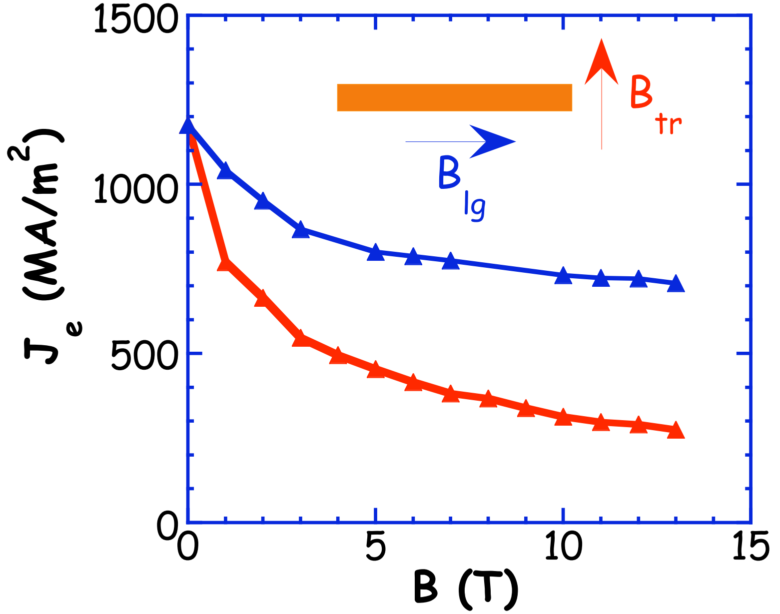
CEC-ICMC 2009

Heat treatment: task in itself!

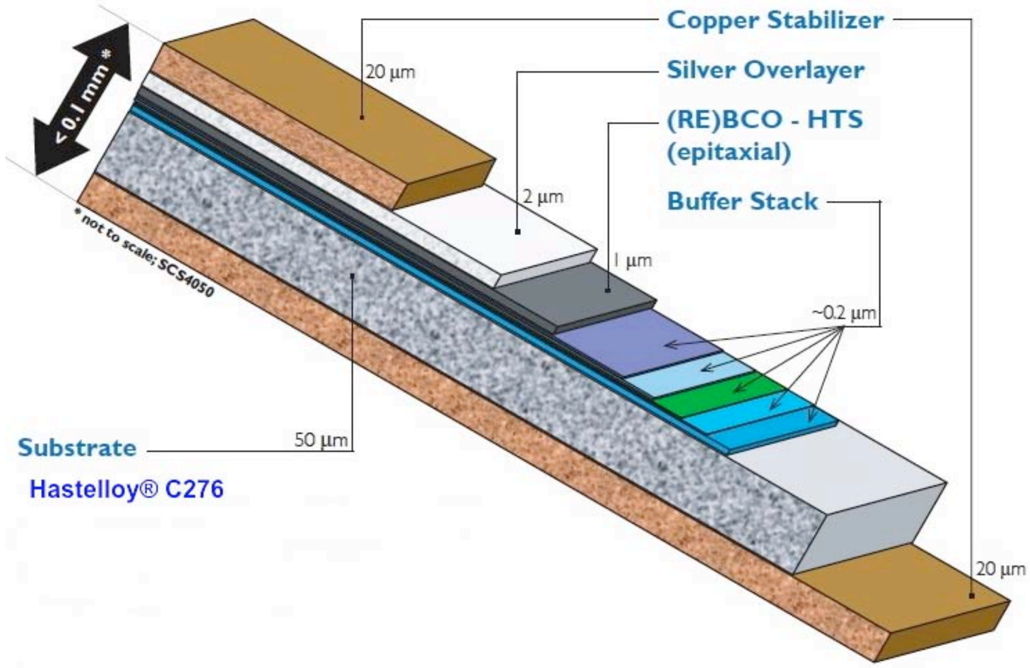
OST agrees to help and make

YBCO Coated conductor

YBaCuO coated conductor @ 4.2 K
Super Power - 4.1 mm x 0.095 mm



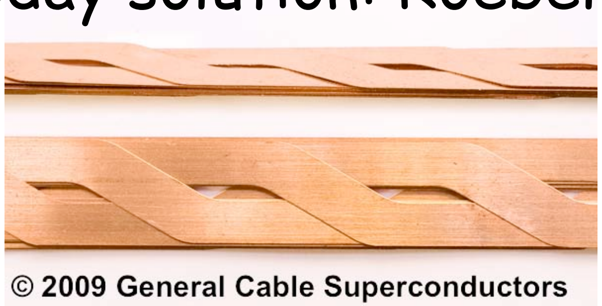
Measured data (LNCMI)



IBAD route (σ = 550 MPa)
2 x 20 µm Cu stabilizer layers

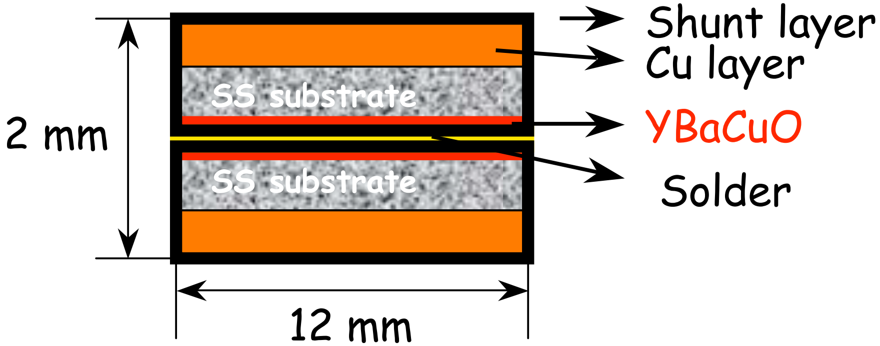
YBCO Coated conductor cable

Today solution: Roebel bar



- Transposed
- Expensive (29 k€ 10 m 3000 A (15T 4K))
- Some I_c degradation

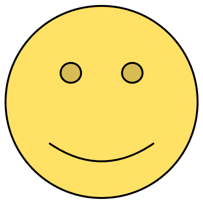
Possible alternative:
double YBaCuO tape conductor



YBaCuO:
- close to the neutral fibre/axis
- low AC losses (no transposition)

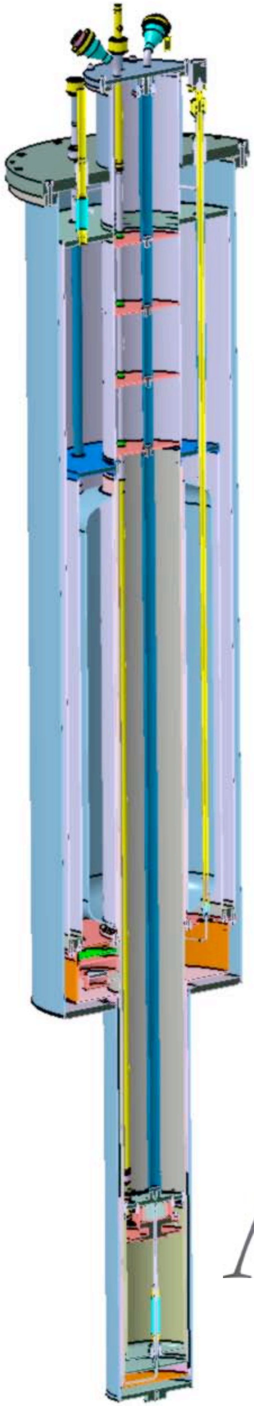
2 x this conductor
Conductor transposition pole to pole
=> ≈ 4 x 700 = 2800 A (15 T 4K)
2.4 k€ 10 m (59 $/m)

Bi-2212 versus YBCO: summary

	Bi-2212	YBaCuO
	High current cable (Rutheford cable) Isotropic	**W & O** Material of the future Perf. (J_c & stress (IBAD))
	**Heat treatment (R & W)** Mechanical performances Long lengths without defect	**High current cable** Lengths **Coil ends** **Anisotropic**

New charaterization equipment
Solenoid test station

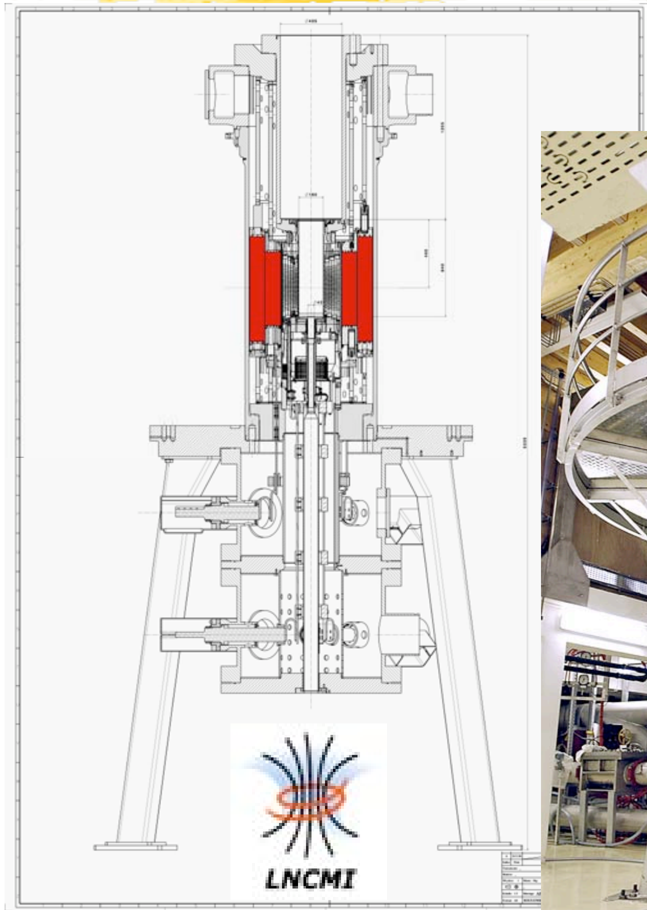
Solenoid test bench



Variable temperature cryostat
(4.2 K - 80 K)

- Gas cooling
- Conduction cooling

$\varnothing_e$ = 130 mm



20 T facility

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Modelling works
Benchmark of quench programs
Results for NbTi test winding

TUT (Tampere University of Technology)

LASA (Lab. for Accelerators and Applied Supercond.)

Quench programs

- TUT:
  - heat diffusion equations
- LASA:
  - propagation velocities

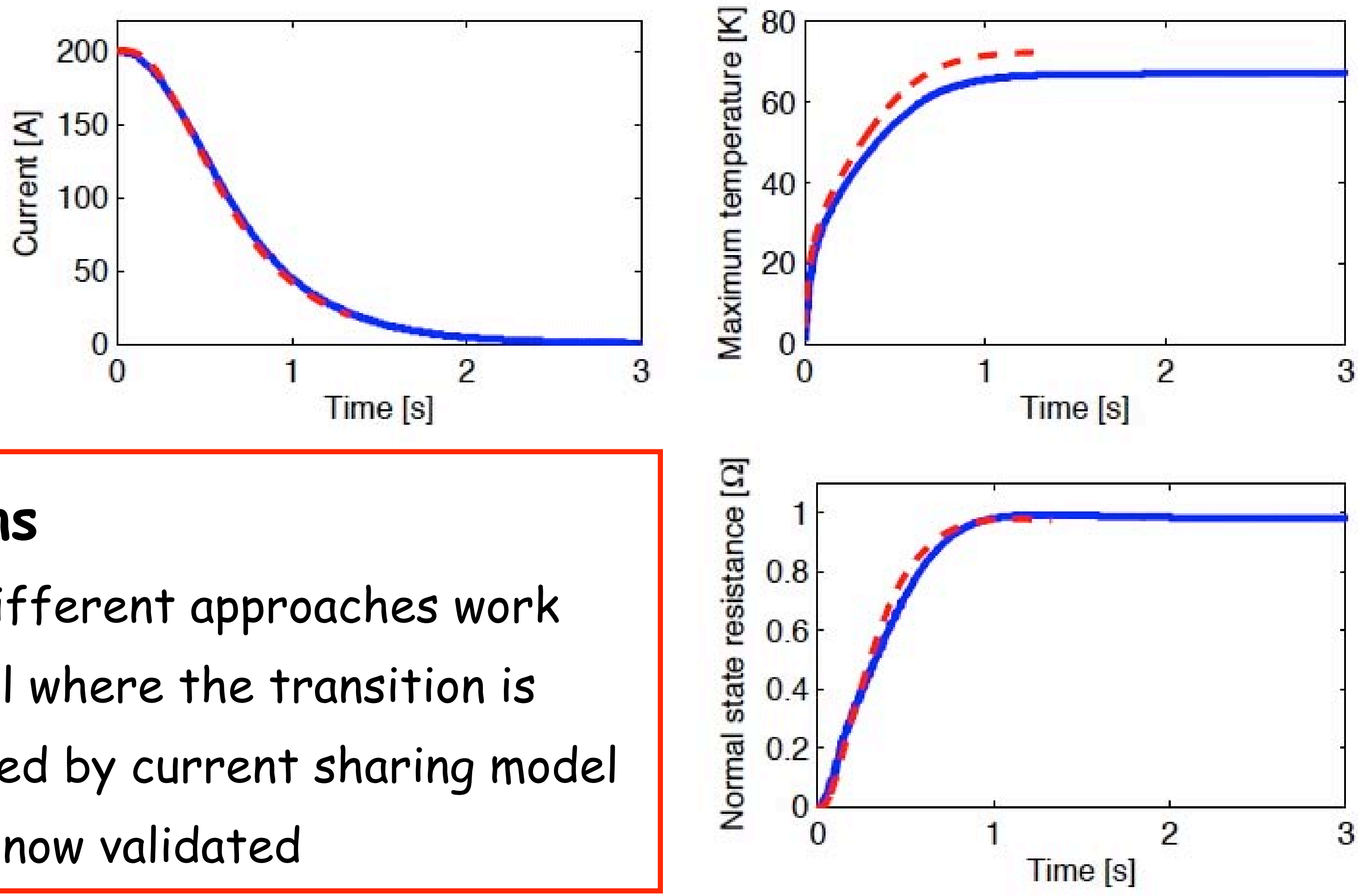
Bench mark problem:
NbTi solenoid
Result comparisons

$Ø_e$ / $Ø_i$ (mm)	25/50
h (mm)	200
Radial layers	26
Turn per layer	182
I_o	200 A
T_o	4.2 K
SC	NbTi
SC:Cu ratio	2
$Ø_e$ isolated (mm)	1.1
rrr	170

Benchmark results: comparisons 1/2

Red: TUT

Blue: INFN



Conclusions

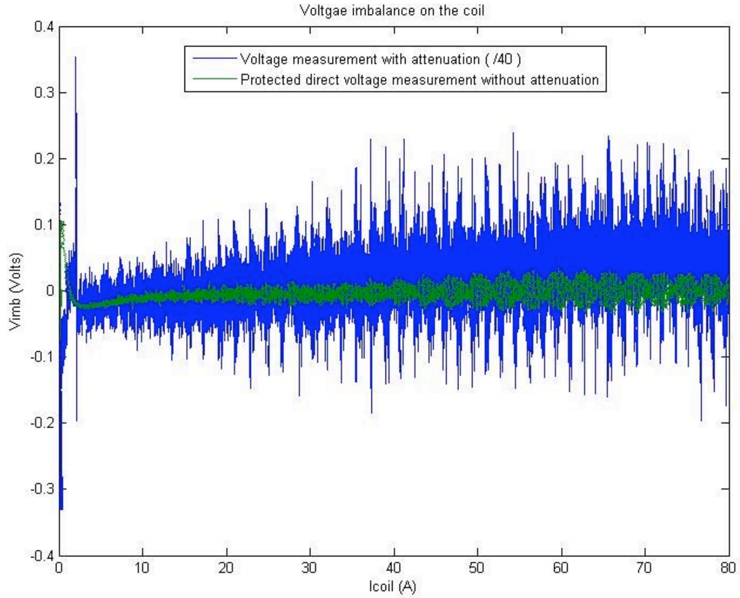
• The two different approaches work well on a coil where the transition is characterized by current sharing model

• Codes are now validated

Quench: HTS magnet issue

HTS:

- Operation far from T_c
- Low propagation velocities
- Concentred quench

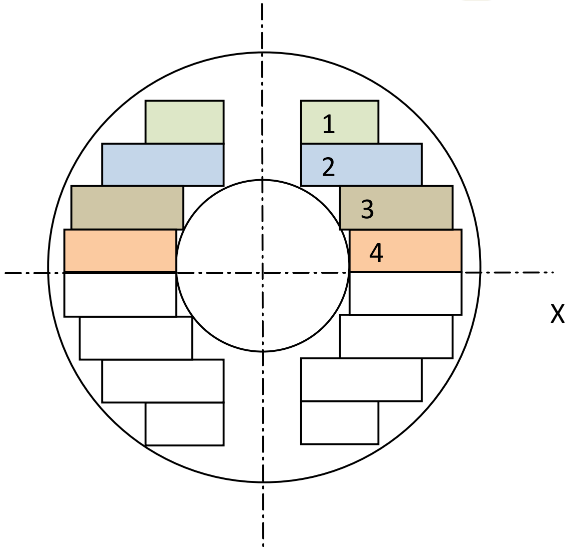


Improved detection (patented)

Preliminary magnet designs & construction

- Dipole
- Solenoid

Dipole design with blocks

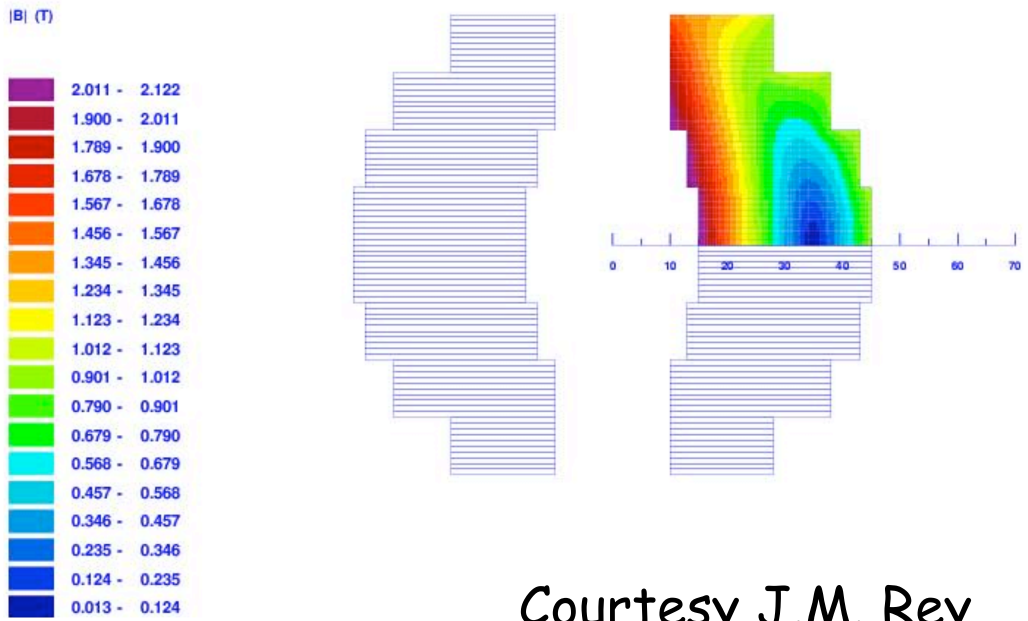


- 4 double pancakes
- 2 flat one
- 2 with bent end
- $Ø_e$: 98 mm

Inner bore diameter: 30 mm

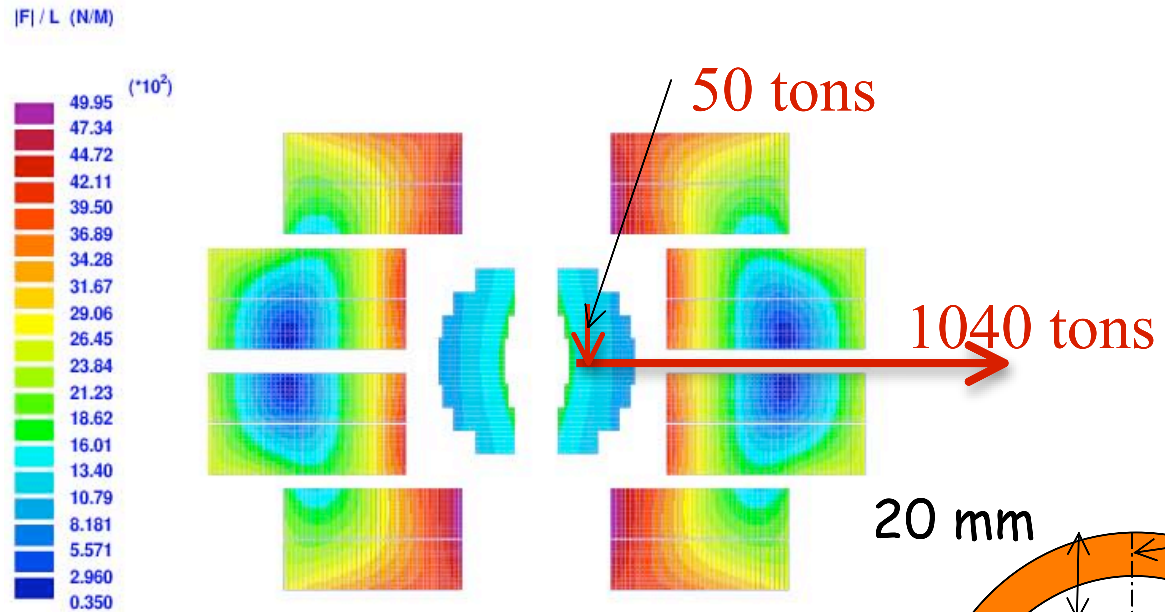
287 A/mm^2 needed to reach 6T

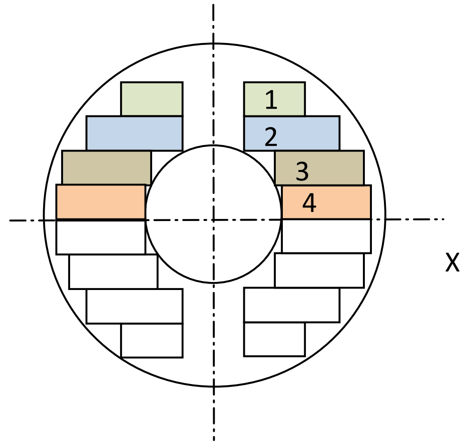
Peak field 6.1T

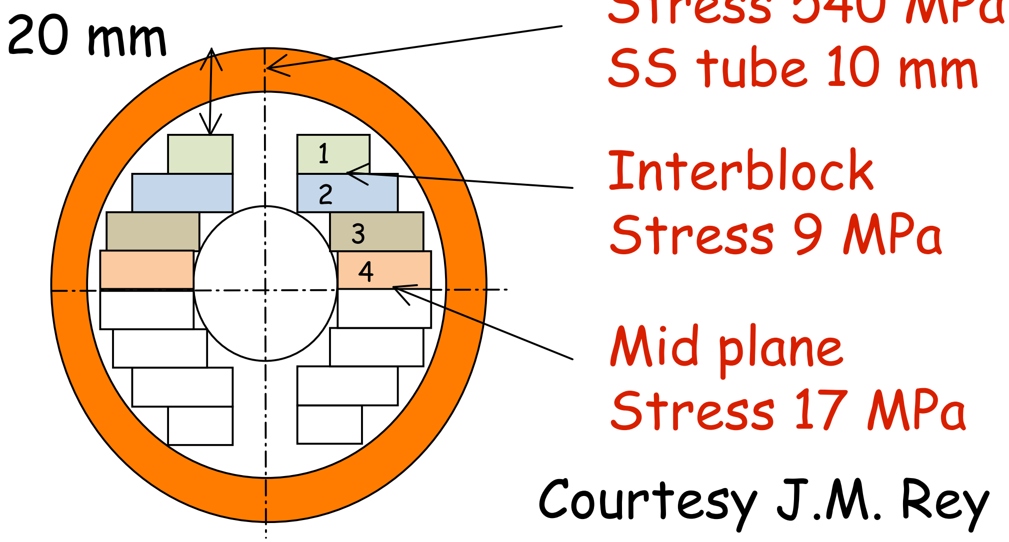


Courtesy J.M. Rey

Rough mechanical approach







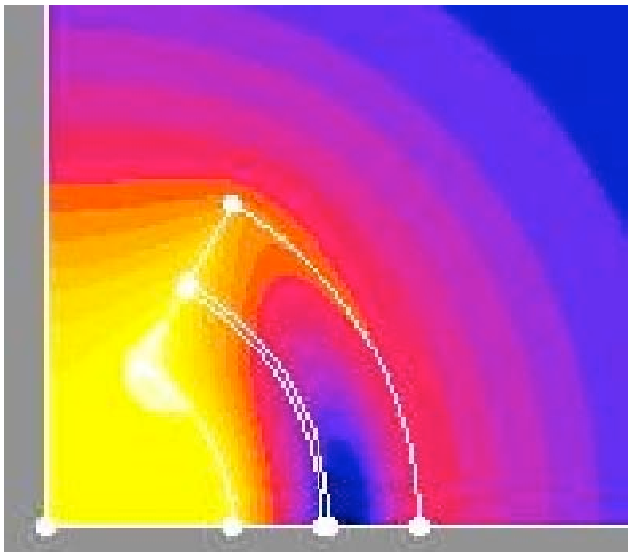
Courtesy J.M. Rey

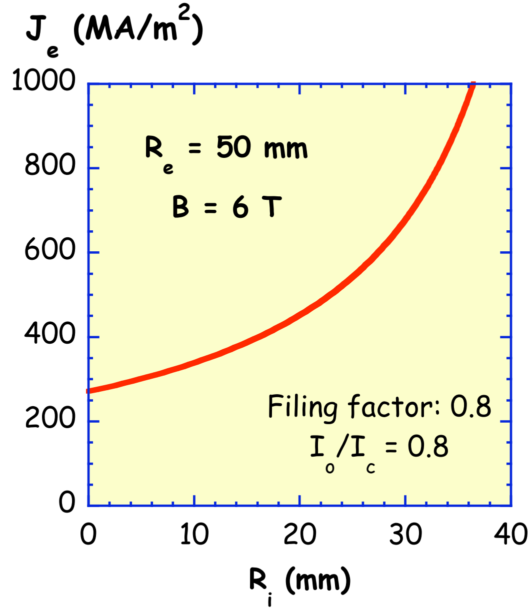
Preliminary insert design

Magnetic flux density for an ideal cosine coil:

$$B \approx \frac{2}{\pi}\mu_o \sin\left(\frac{\beta}{2}\right) J_e \left(R_e - R_i\right)$$

(no mag. shield)





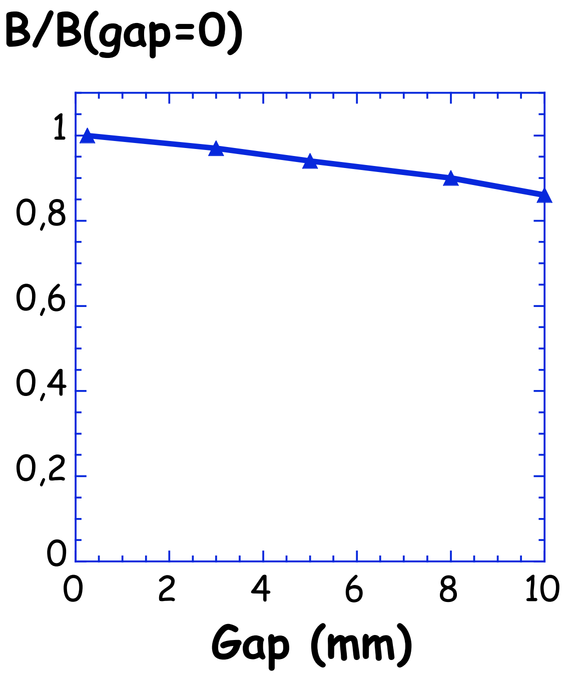
J_e > 400 MA/m² (20 T)

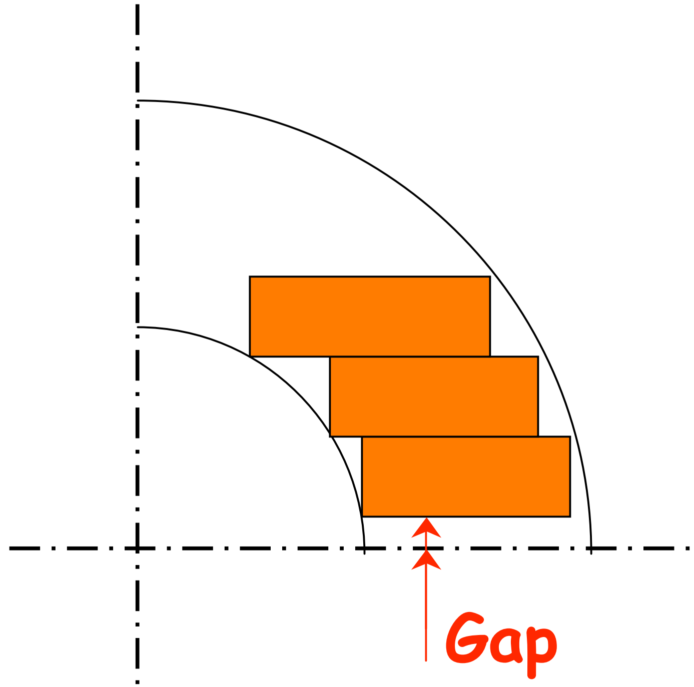
Similar result J.M. Rey

Insert with YBaCuO

Coil end issue:

influence of central airgap for the beam for flat coils

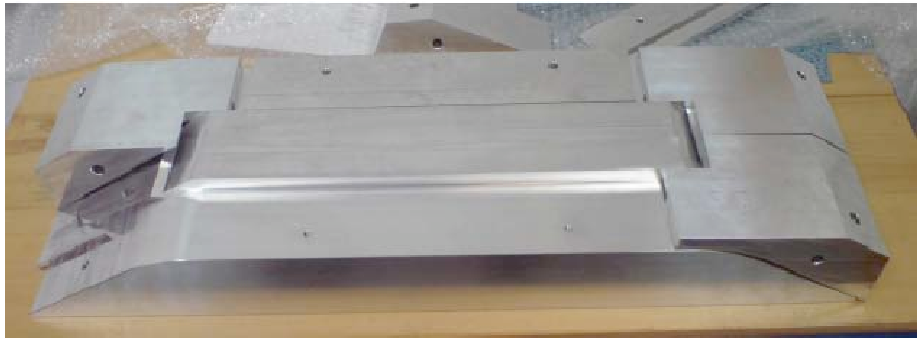




J.M. Rey configuration

Very promising way

Danish Technological Institute
InnovAcc



Courtesy N. Zangenberg

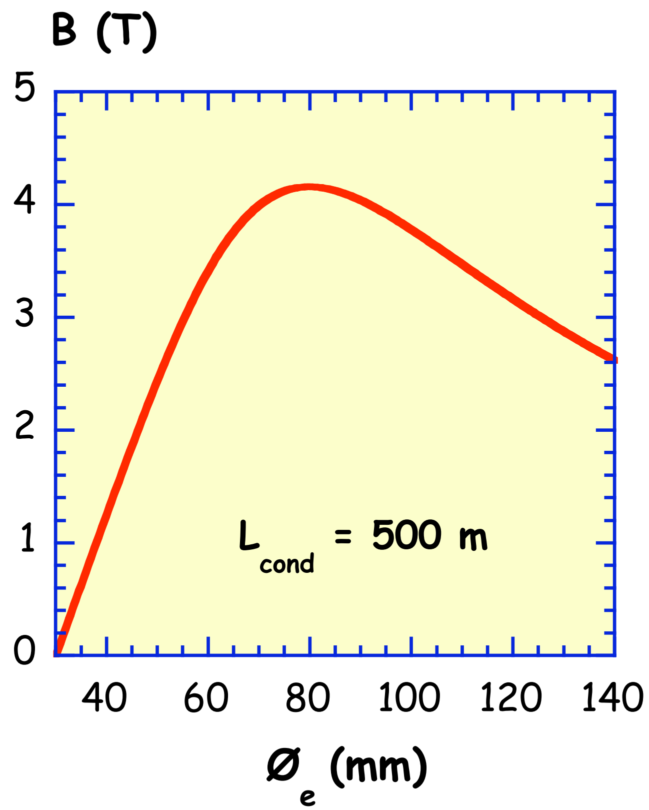
No (little) I_c degradation

Solenoids, preliminary works

- Optimization (B_{max}) from given conductor length

$$B = \frac{\mu_o J_e h}{2} \ln \frac{D_e + \sqrt{D_e^2 + h^2}}{D_i + \sqrt{D_i^2 + h^2}}$$

$$vol = c_f \frac{\pi}{4}\left(D_e^2 - D_i^2\right) h = S\, L$$

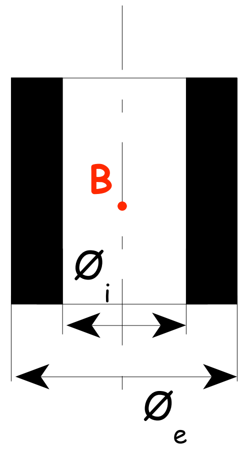


$Ø_i$ = 30 mm

J_e = 250 MA/m^2

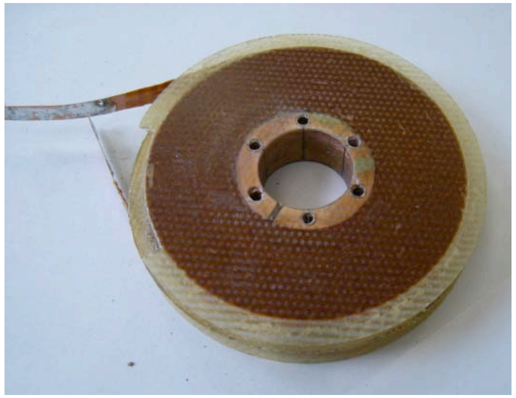
c_f = 0.8

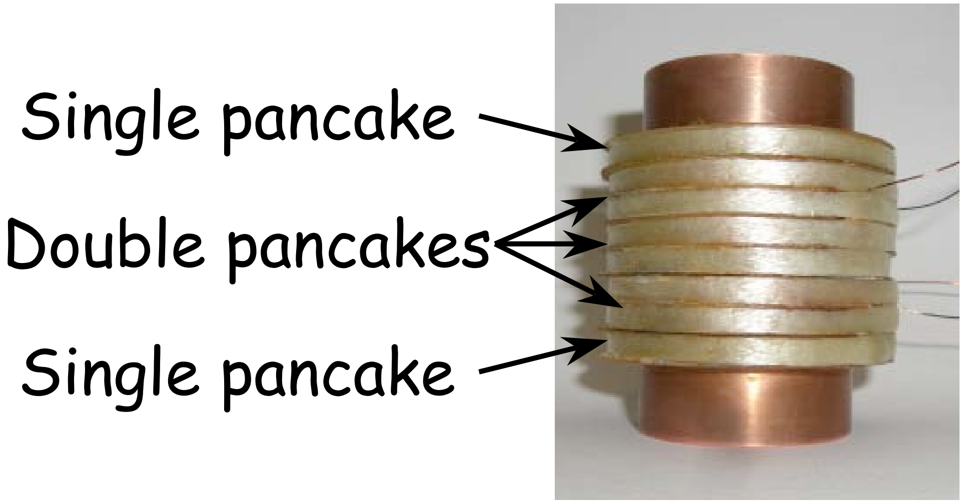
Tape : 4 mm x 0.1 mm



Solenoids, first realization (40 m YBCO)

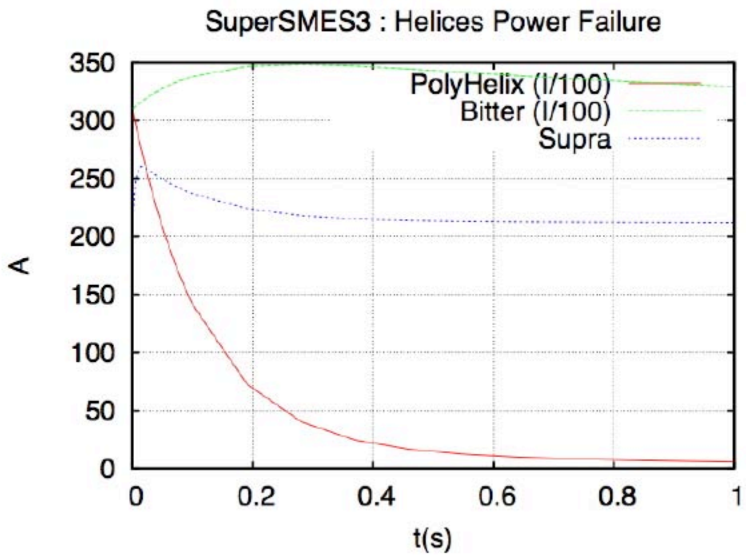
Pancakes	8
Turn number	8 x 44
$Ø_i$ - $Ø_e$ (mm)	22 /52
h_{tot} (mm)	37
B (100 A)	0.9 T

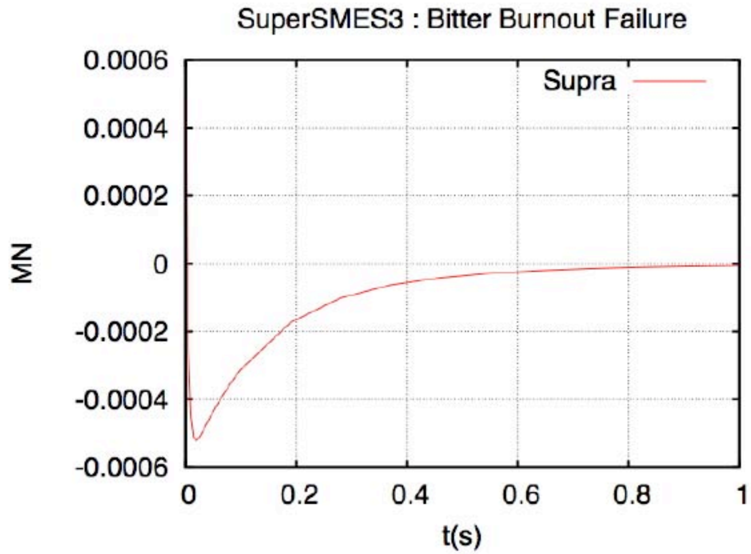




Fault scenari

- Consequences of failures (overcurrent, forces)
  - Poly-helix magnet failure
  - Bitter magnet burnout





Conclusions

&

Future works

Main conclusions

- 6 T HTS insert dipole in 100 mm: real challenge!
- High J_e (400 MA/m^2) for 6 T in Ø 100 mm
  - **Issue to protect (stabilize) the insert**
- Bi-2212 and YBCO possible options
  - **Heat treatment: BSSCO main issue**
  - I_c perf. on long lengths: another issue for BSSCO
  - **High current cable: YBCO main issue**
- Quench code validated for NbTi solenoids

Future works

- Carry on the characterization works
- Two YBCO tape conductor
  - Realization & mechanical characterizations
- Protection of the insert (with main dipole)
- First solenoid test
- Working group with main dipole
- Carry on the two quench models for solenoids
  - Data for HTS and model between T_{cs} and T_c
  - Define the required instrumentation

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Thank you!