Structural design of EuCARD2 magnets

Second Workshop on Accelerator Magnets in HTS (WAMHTS-2)
13/11/2014

Maria DURANTE
In behalf of EuCARD2 Task 10.3 members

WAMHTS-2 presentations on EuCARD2 magnets

- Structural design of EuCARD2 magnets

  by Maria Durante
- Considerations during the development of a HTS research accelerator magnet

  by Glyn Kirby
- Electrical Network Model for ReBCO Cables and Coils

  by Jeroen Van Nugteren
- Design of alternative cos-theta magnet with Roebel cable

  by Clément Lorin
- Modeling thermal propagation and quench behavior in a protection heater covered YBCO coil

  by Tiina Salmi (tomorrow afternoon)

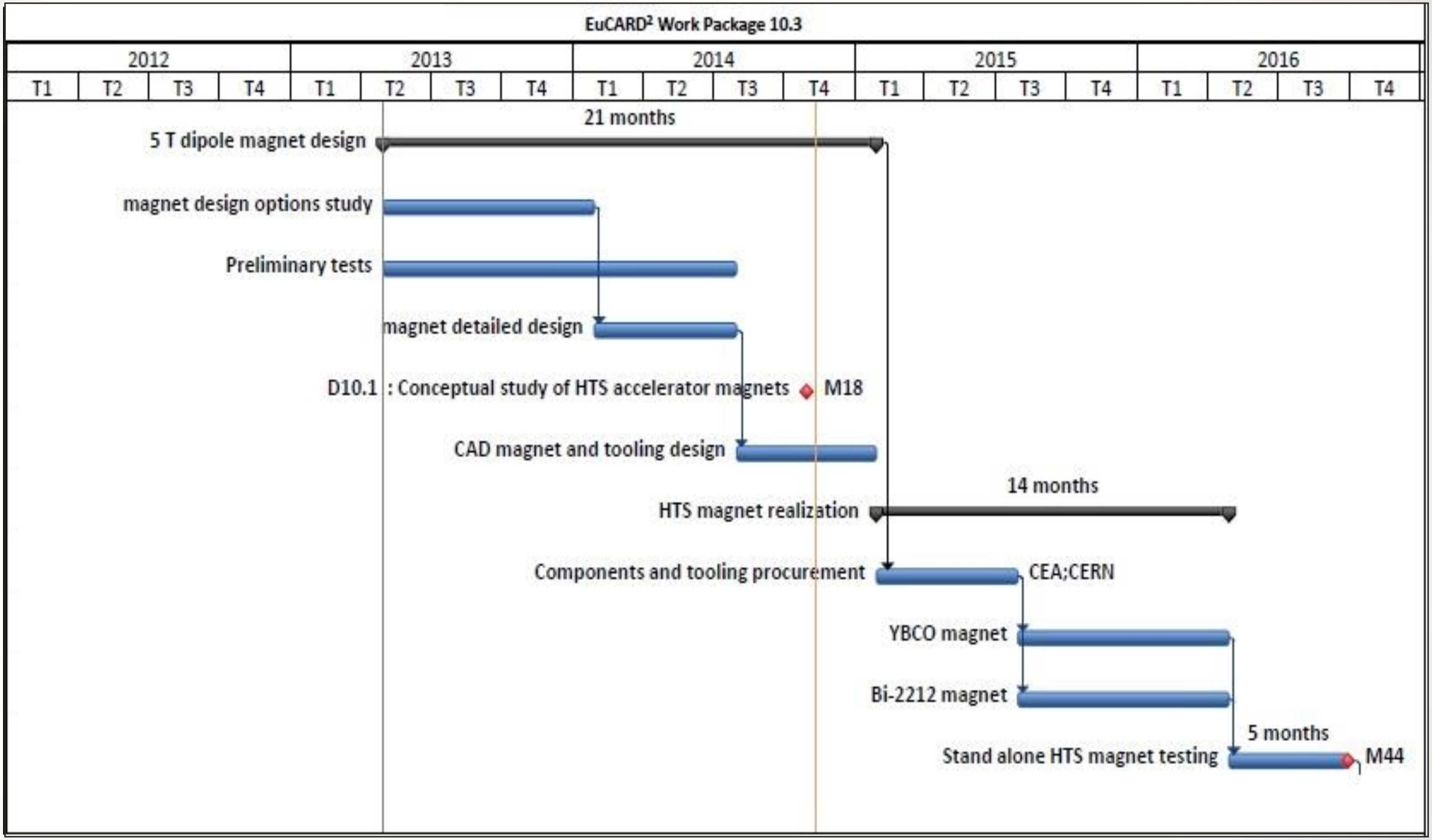
EuCARD2 Magnets Task 10.3 - Objectives

- Subtask 10.3.1 HTS accelerator magnet design
  - Explore magnet concepts suitable for HTS cable and ribbon based conductors providing magnetic field of accelerator quality in view of the 20 T HE-LHC dipole.
  - Compare saddle winding design with block winding design.
  - Adapt the protection scheme of superconducting magnet to the use of HTS conductor.
- Subtask 10.3.2 Bi-2212 magnet developments
  - Design and manufacture a prototype magnet using Bi2212 cable.
  - Bi-2212 dipole prototype must be designed to achieve 5T alone, or 20T as an insert, or to measure the limiting stresses on this material.
- Subtask 10.3.3 YBCO magnet developments
  - Design and manufacture an accelerator like prototype magnet using YBCO tape based conductor carrying at least 5kA at 4.2 K and 20 T.
  - Study field homogeneity and current redistribution in the ribbon based conductor.

EuCARD2 Magnets Task 10.3 - Contributions

Institute	**CEA**	**CERN**	**INPG**	**TUT**	**DTI**	**INFN**
	Maria Durante Clément Lorin	Glyn Kirby Jeroen van Nugteren Jaakko Murtomäki	Pascal Tixador Arnaud Badel John Himbele	Antti Stenvall Erkki Härö Tiina Salmi	Nikolaj Zangenberg	Giovanni Volpini Massimo Sorbi
Activities	Design and construction of YBCO made coil, development of proper technology Participation to design of Bi-2212 coil	Design and support to construction of the YBCO Design and construction of Bi-2212 coil in the collaboration with USA, development of proper technologies System for magnetic measurement evaluation	Design of HTS coils Analysis of e.m. behavior Development of technology (small coils for investigation, tests under high fields)	Modeling of HTS coils both YBCO and Bi-2212 Quench analysis and protection evaluation	Development of insulation technology for YBCO conductor Fabrication and test of samples and then of all tapes/cables Study of extension to Bi-2212	Quench computation Link to test boundary conditions

Magnet Task 10.3 Schedule

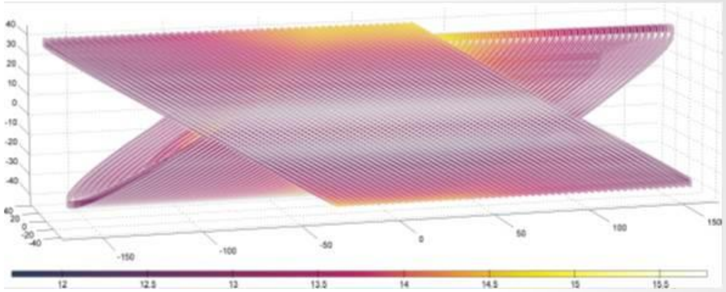


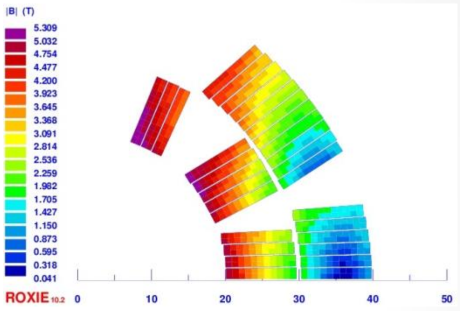
Magnet specifications

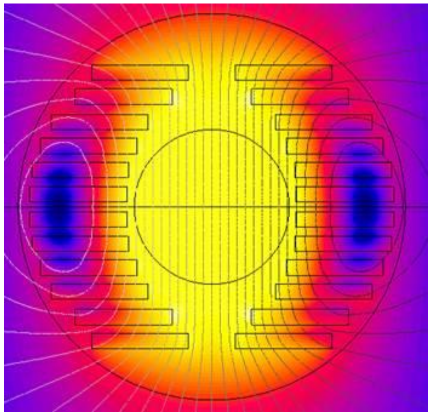
	Parameter name	Symbol	Value YBCO Magnet	Value Bi-2212 Magnet	Remarks
MAGNET	Central field	B_0	5 T	Up to 5	at 4.2 K (20% margin on loadline)
	Clear bore aperture	Φ_b	40 mm		High energy LHC dipole magnet (beam size 25-28 mm)
	Operational temperature	T	4.2 K	4.2	1.9 K also possible 77 K tests during magnet realization
	Current at 20 T	I	5 to 10 kA	5 to 10	
	Stray magnetic field	B_{out}	≤ 0.2 T		At border of cryostat
	Magnetic multipoles at 2/3 Φ_b	b_n	$5\ 10^{-4}$	-	Geometric
	Magnetic multipoles at 2/3 Φ_b	b_n	$30\ 10^{-4}$	-	Including magnetization and persistent current (best effort)
	Magnetization	M	300 mT	300	Allowing fast ramping up
	Straight section length	L	≥200 mm	≥200	As short as possible while remaining compatible with field quality for YBCO
	Magnet length	L_M	< 1500 mm		700 mm uniform field (Fresca2) Grenoble test facility
	Magnet outer diameter	Φ_M	< 99 mm (∅) < 140 mm x 90 mm (rect)		Without iron yoke – FRESCA2 (100 mm) or EDIPO (143 mm x 93 mm)

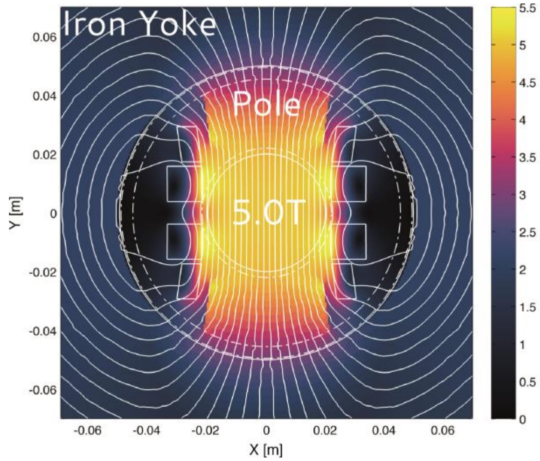
Magnet design concepts under study

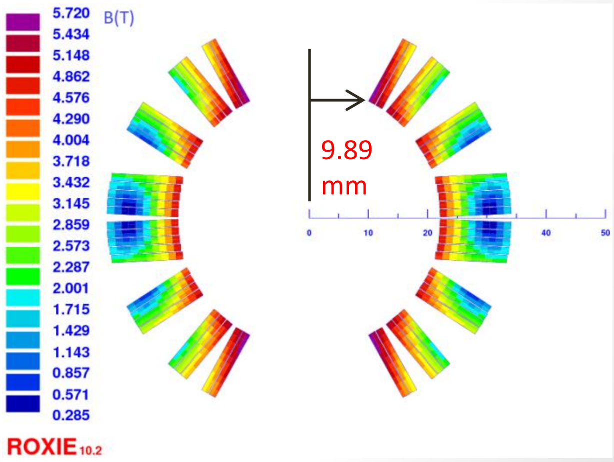
- BSCCO Rutherford cable CCT design
- BSCCO Rutherford cable Cosine-theta design
- YBCO Stacked tapes cable Block design
- YBCO Roebel cable Aligned Block design
- YBCO Roebel cable Cosine theta design







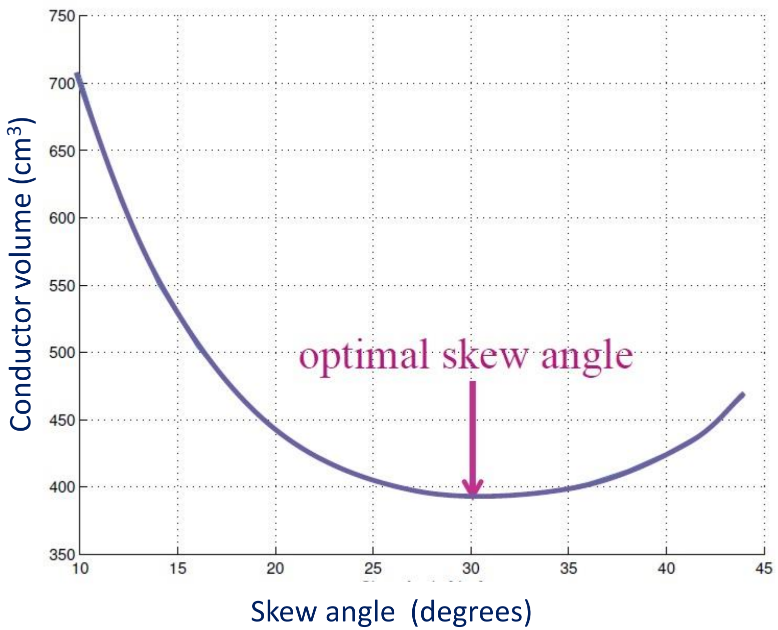




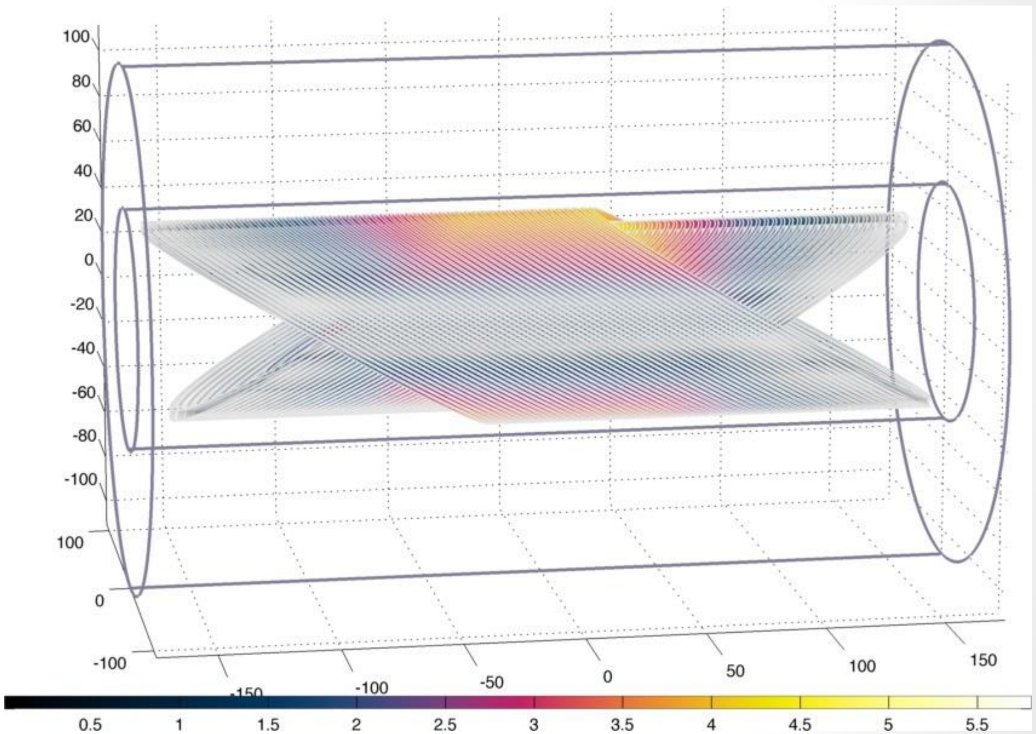
BSCCO Rutherford cable CCT Design

Jeroen van Nugteren,
Shlomo Caspi

- BSCCO Rutherford cable, 1.4 mm x 4.2 mm (2x 6 strands, ∅ 0.7 mm)
- Skew angle optimization to attain 5T with the minimal amount of conductor



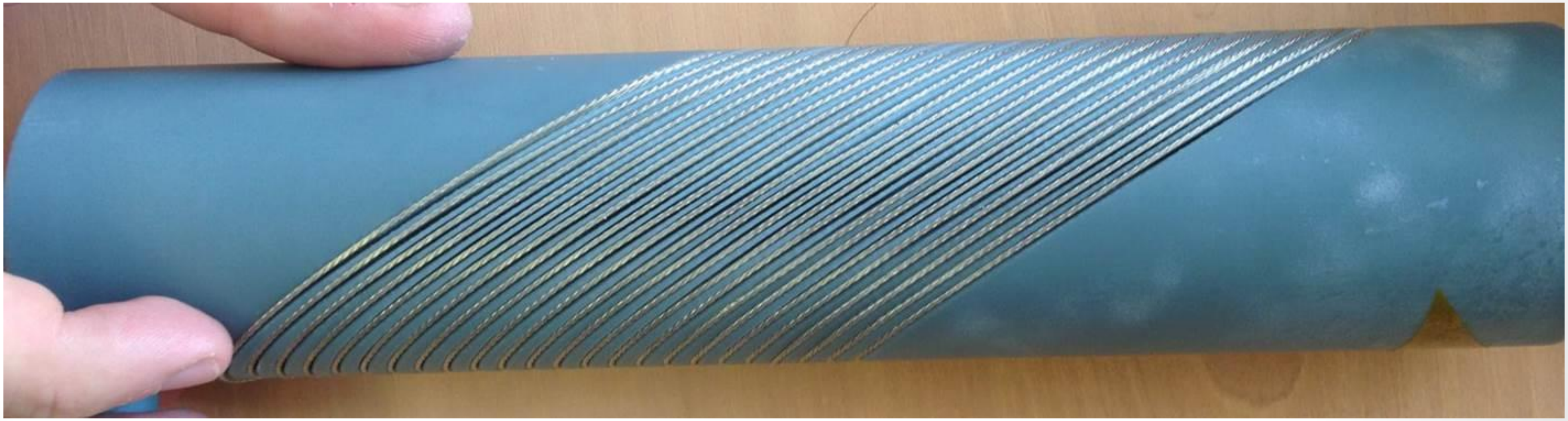
- 30 deg skew angle
- 4 layers
- Je = 510 A/mm² (80% Jc)
- Operating current = 3 kA
- Cable length : 65 m



BSCCO Rutherford cable CCT Design

Jeroen van Nugteren
Glyn Kirby

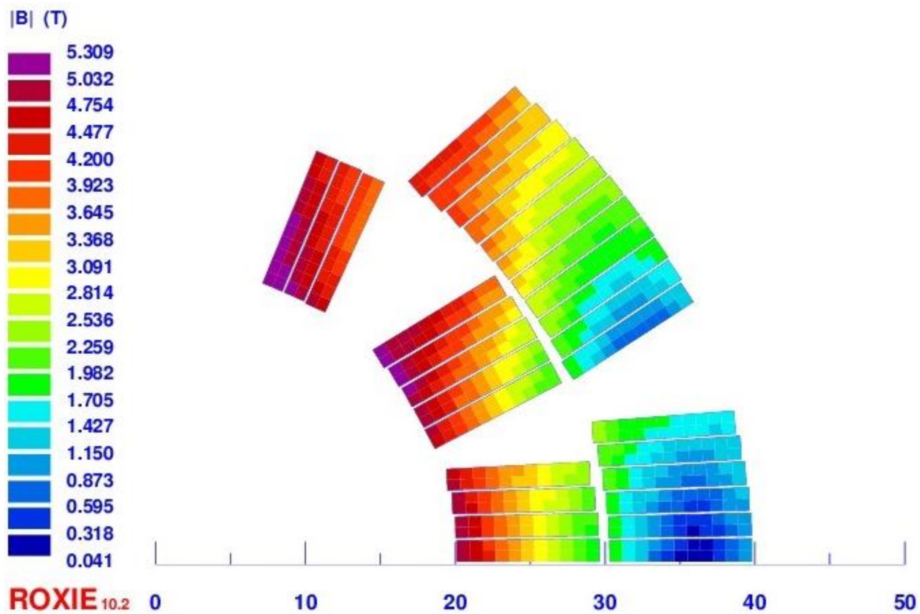
- CERN CCT demonstrator: 3D printed blue-stone coil former, NbTi cable

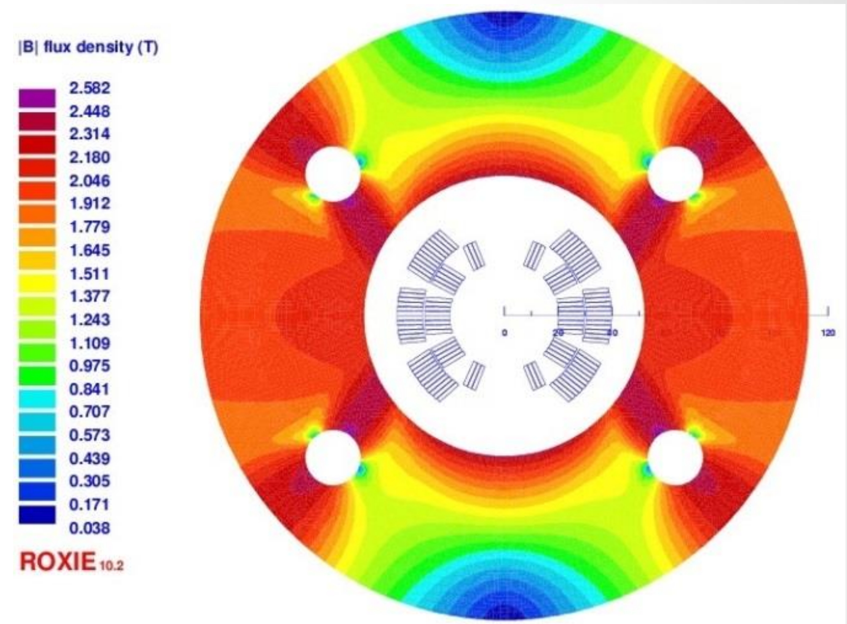


BSCCO Rutherford cable Cosine theta Design

Clément Lorin

- BSCCO Rutherford cable, 1.39/1.52 mm x 9.5 mm (15 strands, ∅ 0.8 mm)

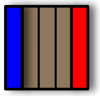


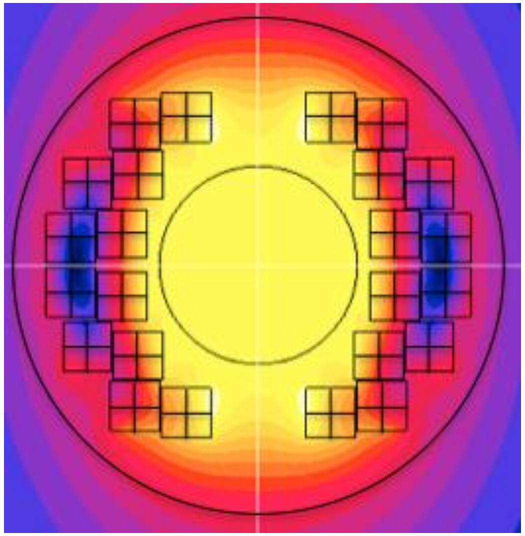


- 5T central field with required field quality
- Je = 434 A/mm² (72% Jc)
- In stand-by.
- Mechanical design : we expect similar results than for YBCO Roebel designs → if the mechanical structure has to fit inside FRESCA2 inner diameter, it will not be strong enough to avoid non-acceptable stress in the coils.

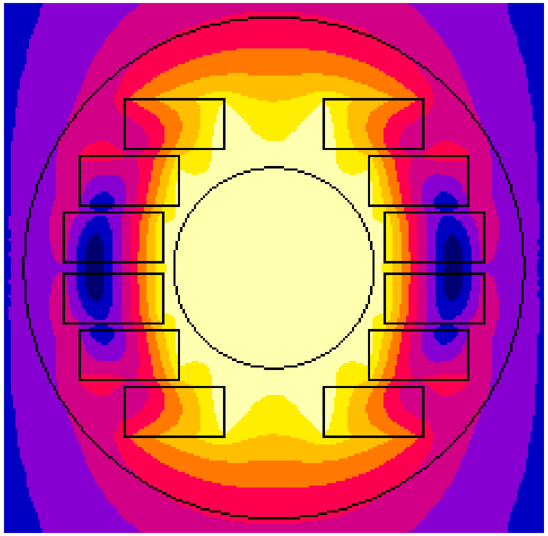
YBCO stacked tapes cable Block Design

John Himbele
Arnaud Badel

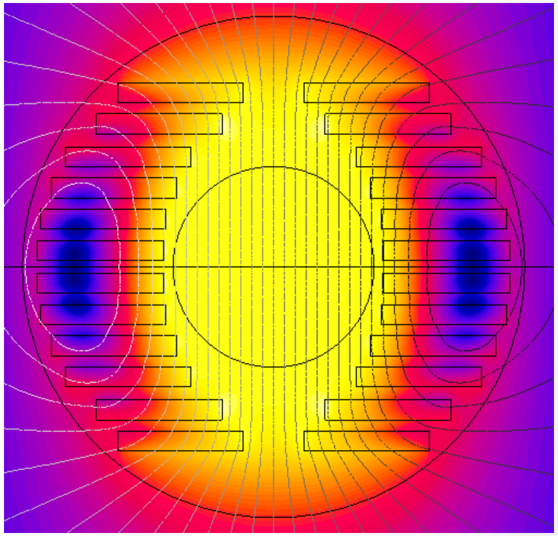
- YBCO tape 4 mm x 0.13 mm
-  4 x 4 mm stack cable of 28 insulated tapes (vertical)
- Transposition by twisting in coil ends : 1 twist per turn
- Studies on twisting efficiency is ogoing.
- Design optimization using hand made code.



- "EuCARD2 requirements"
- $J_{overall}$ = 397 A/mm²



- +"Blocks on same line"
- $J_{overall}$ = 391 A/mm²

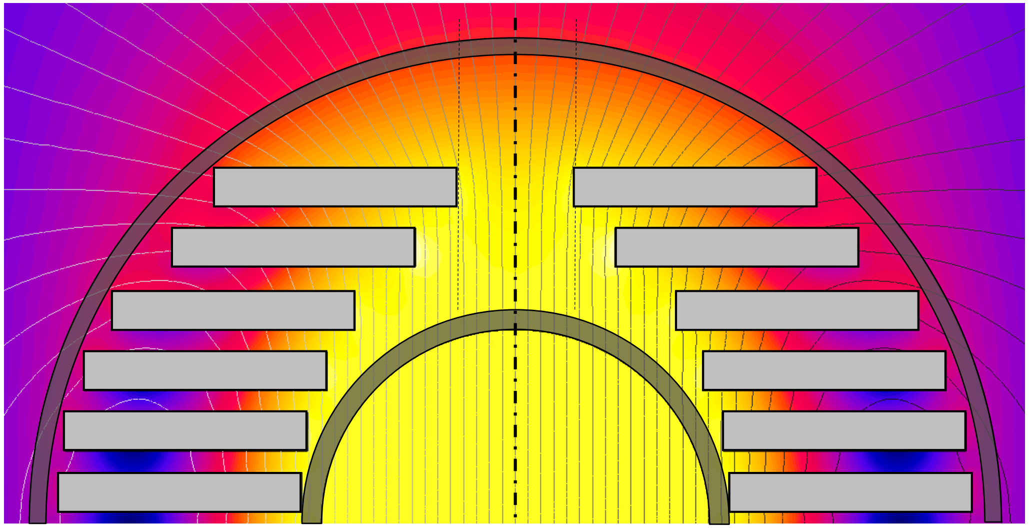


- +"twist and support"
- $J_{overall}$ = 415 A/mm²

YBCO stacked tapes cable Block Design

John Himbele
Arnaud Badel

- Mechanical support and twisting

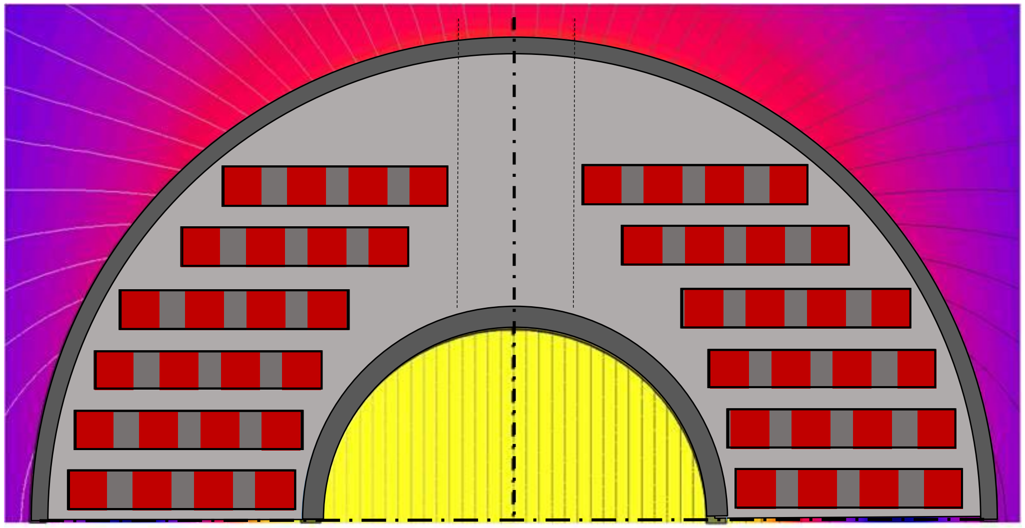


- Minimum bending radius : 6 mm (easy way bending)
- Inner and outer bore : 2 mm margin
- Between pancakes : 2.2 mm

YBCO stacked tapes cable Block Design

John Himbele
Arnaud Badel

- Mechanical support and twisting

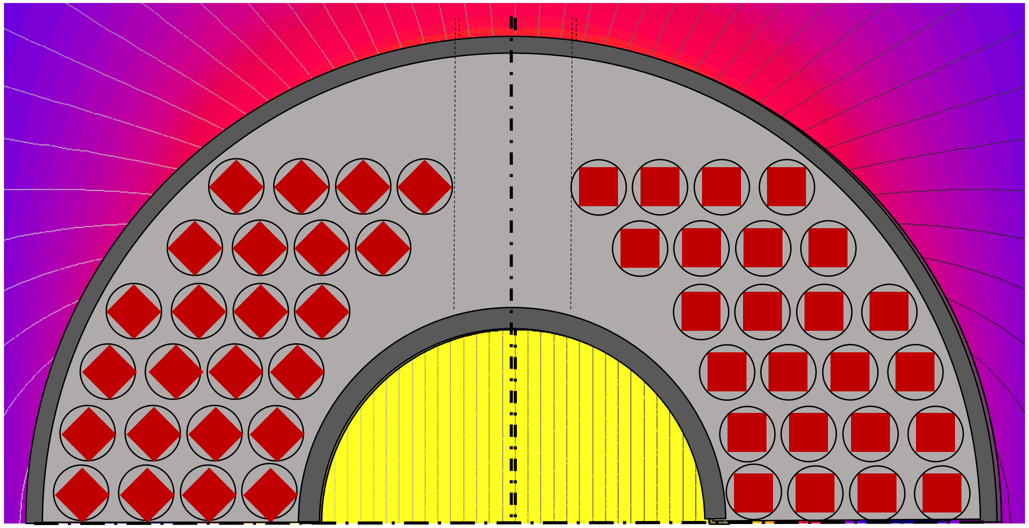


- Minimum bending radius : 6 mm (easy way bending)
- Inner and outer bore : 2 mm margin
- Between pancakes : 2.2 mm
- Distribution of the 4 turns to allow reinforcement and twisting

YBCO stacked tapes cable Block Design

John Himbele
Arnaud Badel

- Mechanical support and twisting

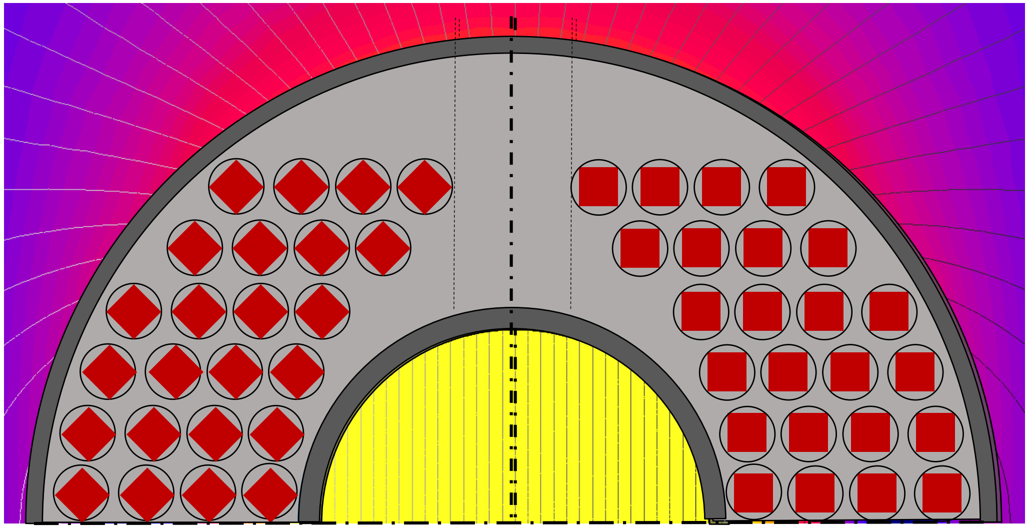


- Minimum bending radius : 6 mm (easy way bending)
- Inner and outer bore : 2 mm margin
- Between pancakes : 2.2 mm
- Distribution of the 4 turns to allow reinforcement and twisting
- All turns can be twisted at the same position

YBCO stacked tapes cable Block Design

John Himbele
Arnaud Badel

- Mechanical support and twisting

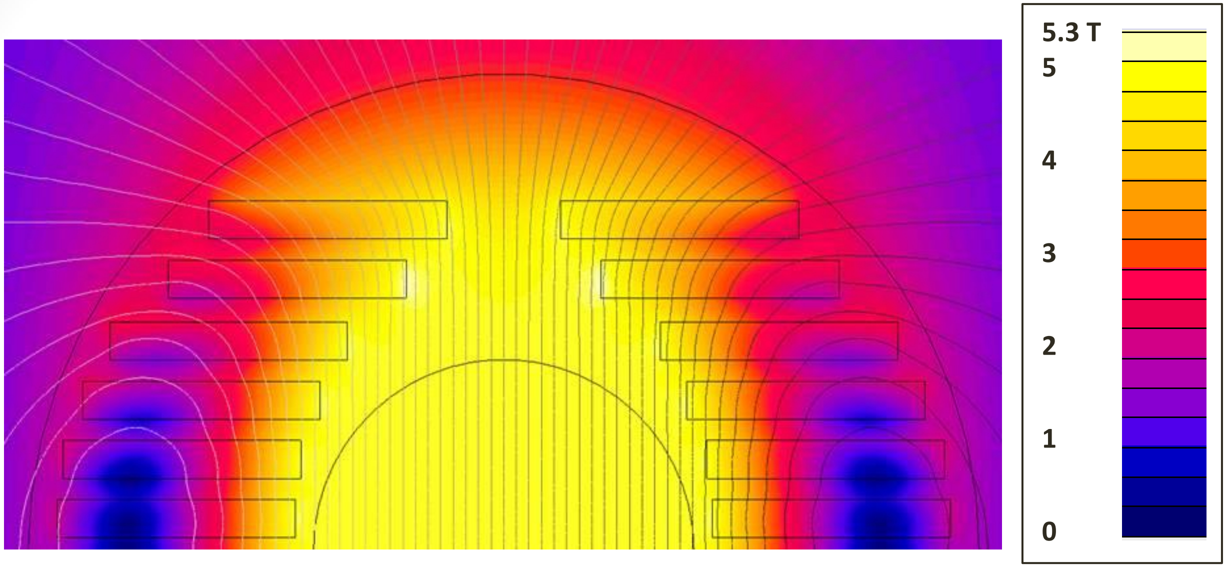


- Minimum bending radius : 6 mm (easy way bending)
- Inner and outer bore : 2 mm margin
- Between pancakes : 2.2 mm
- Distribution of the 4 turns to allow reinforcement and twisting
- All turns can be twisted at the same position

- 3 pancakes are flat :
  - 180° twist one side, 0° on the other
- 3 pancakes have twist-and-bend heads :
  - 180° twist one side,
    and 360° on the other side

John Himbele
Arnaud Badel

YBCO stacked tapes cable Block Design

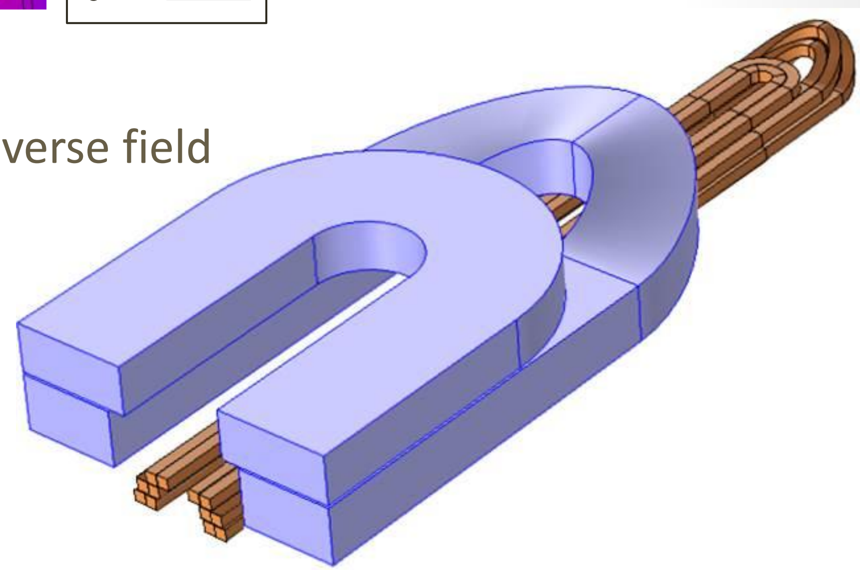


- B_{center} = 5 T
- $J_{overall}$ = 415 A/mm²
- Each block : 4 turns

  → J_e = 648 A/mm²

- Tapes aligned to main field direction → OK
- But in the twist region sthe tapes are in transverse field
  - Operation at lower Je < 600 A/mm²

    → B0 < 4.6 T
  - Twist outside the background field
    Need to do short coil heads !

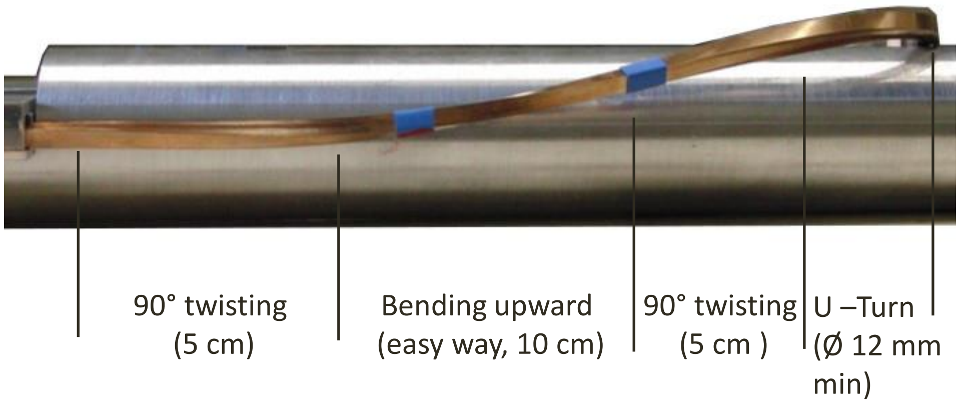


YBCO stacked tapes cable Block Design

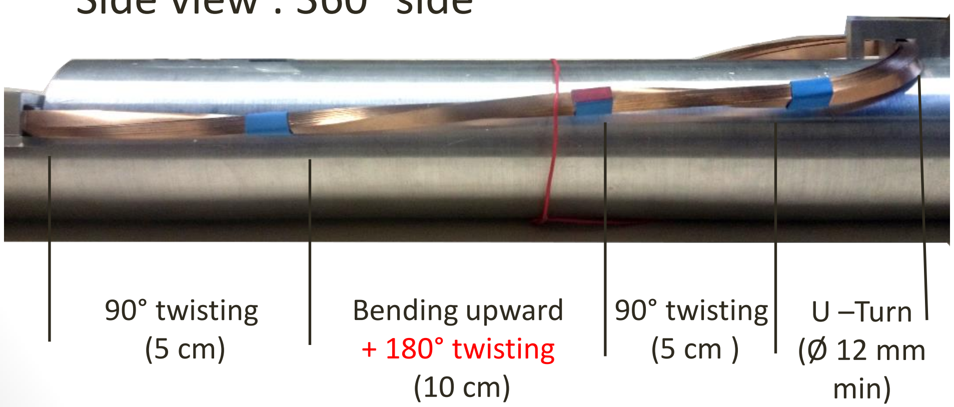
John Himbele
Arnaud Badel

- End geometry under study
- "Twist and bend" test on dummy cable

Side view : 180° side



Side view : 360° side



- Coil end length for lower pancake, inner turn : 22 cm
- Need to spread the turns in the heads : 10 cm additional length for 1 pancake
- Flat pancakes heads are shorter : 10 cm for 180° twisting + 4 cm for U-turn
- Expected complete coil head length : 30-40 cm

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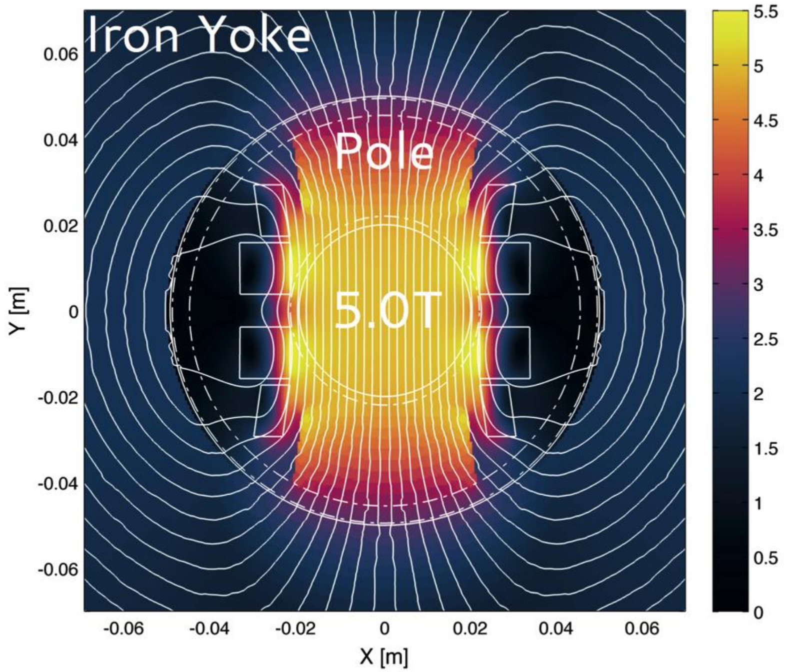
Roebel cable Aligned Block Design - 2D

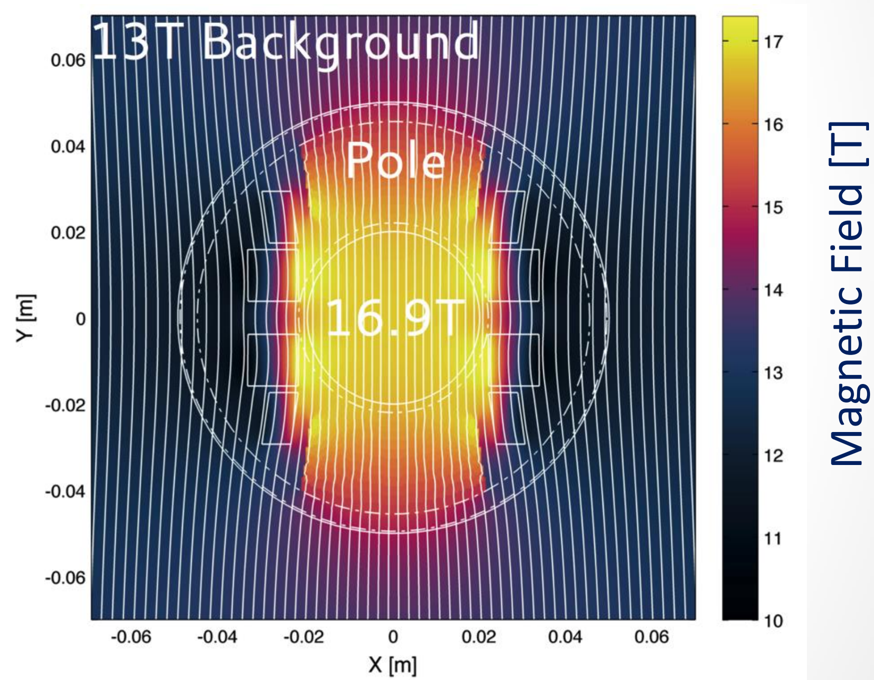
Jeroen van Nugteren
Glyn Kirby

- Baseline Roebel YBCO cable, 12 mm x 1.2 mm

- Tapes oriented in the direction of the field lines (in 13 T background field) → Critical current of the cable is maximized
- Je = 650 A/mm²



Stand-alone mode

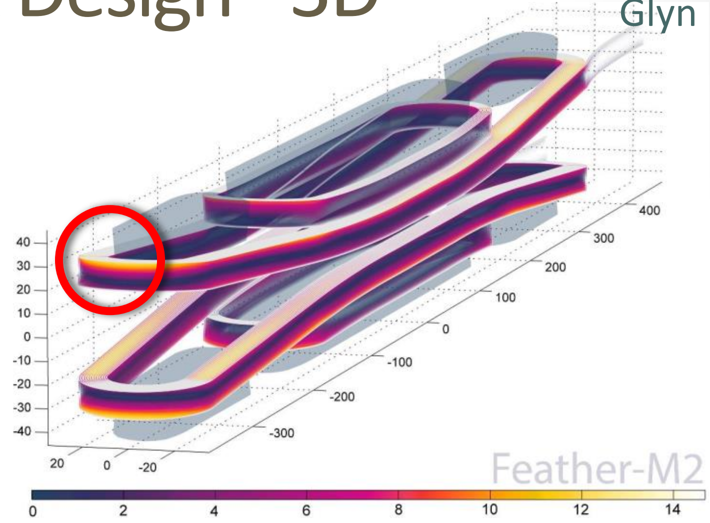


In 13T ideal background field

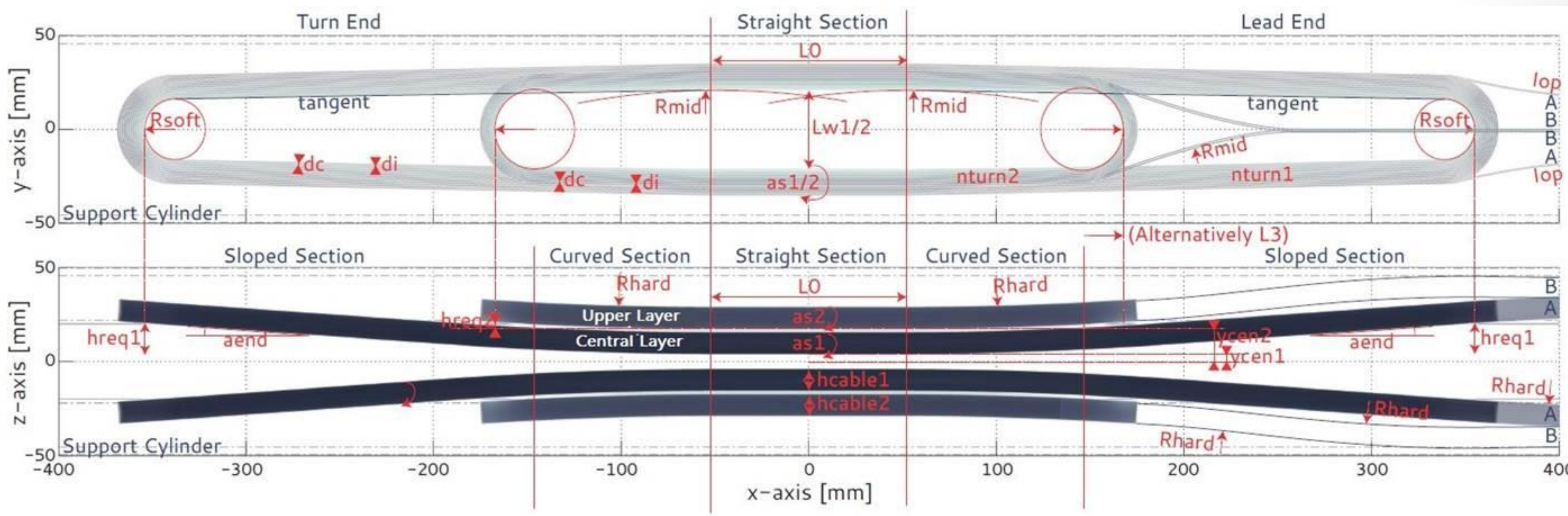
Roebel cable Aligned Block Design - 3D

Jeroen van Nugteren
Glyn Kirby

- Tracking along each strand there is always a low angle, high Jc volume.
- Lower limit expected on coil ends
- Minimum bending radius :
  - Soft way : 11 mm
  - Hard way : 2 m

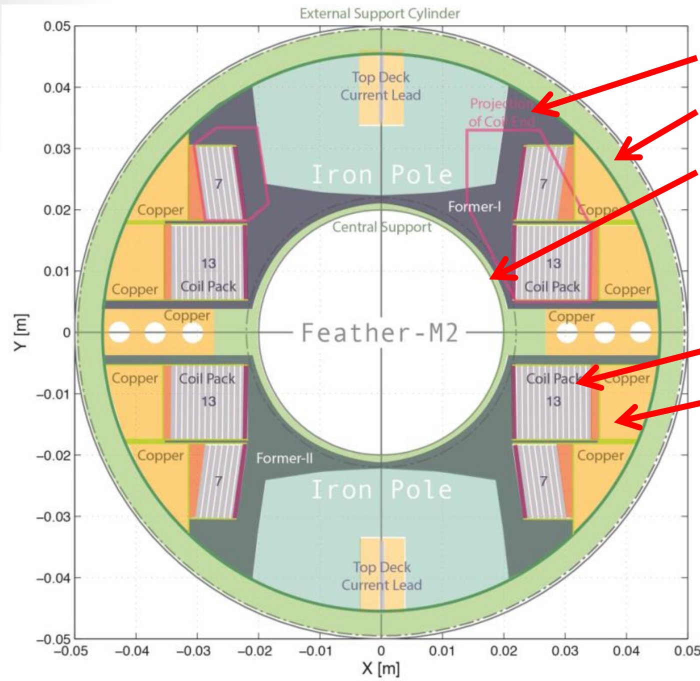


Field Angle in 13T Background Field



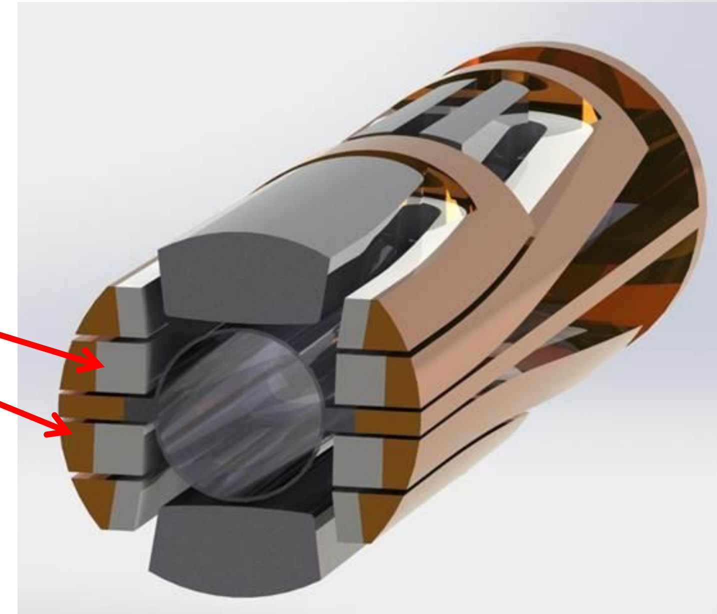
Roebel cable Aligned Block Design - Structure

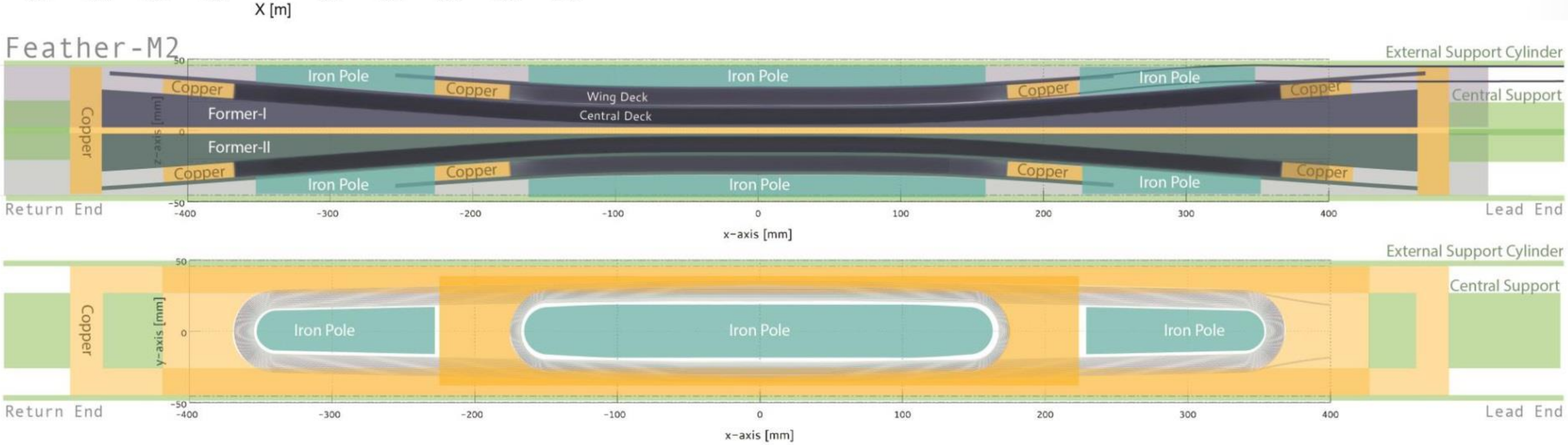
Jeroen van Nugteren
Glyn Kirby



Former
External support
Central support tube

YBCO Coils
ICEE (copper)

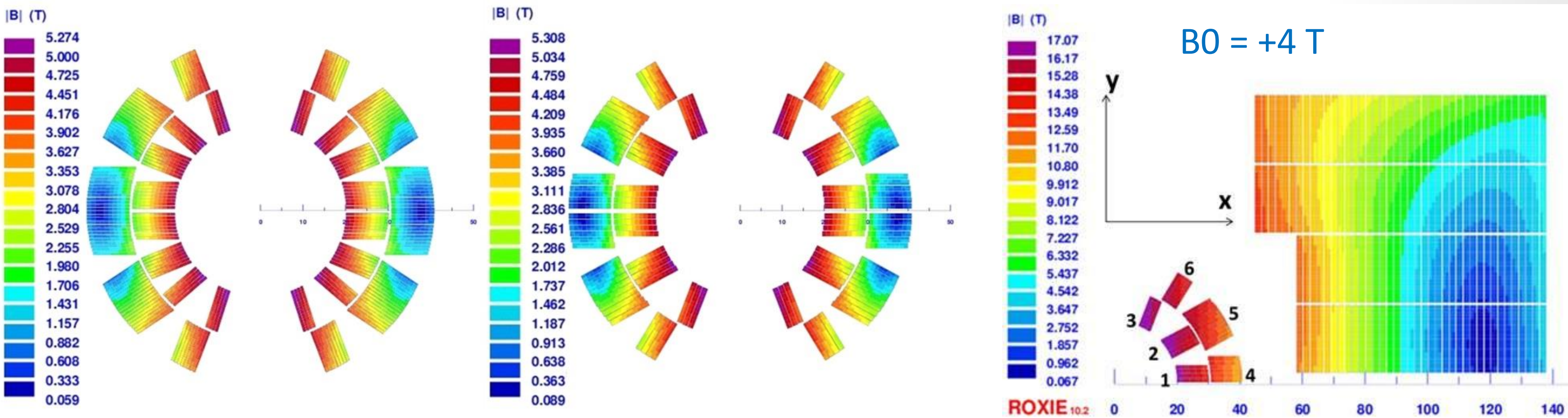




YBCO Roebel Cosine-Theta Designs

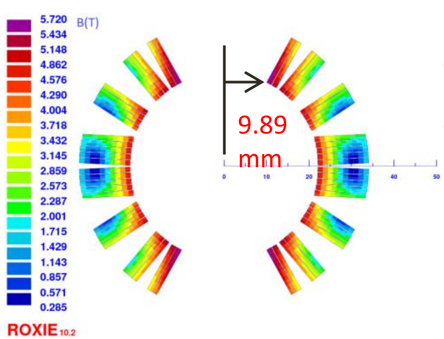
Clément Lorin

-  Narrower Roebel YBCO cables, 10 mm x 0.8/1.2 mm



  - B0 stand-alone = 5T with Je < 470 A/mm²

-  Baseline Roebel YBCO cable, 12 mm x 1.2 mm



  - B0 = 5T stand-alone in iron yoke, Je = 684 A/mm²
  - B0 = 2 T in 15 T background field, Je = 363 A/mm²

→ see Clément presentation

Studies : Roebel Cable Insulation

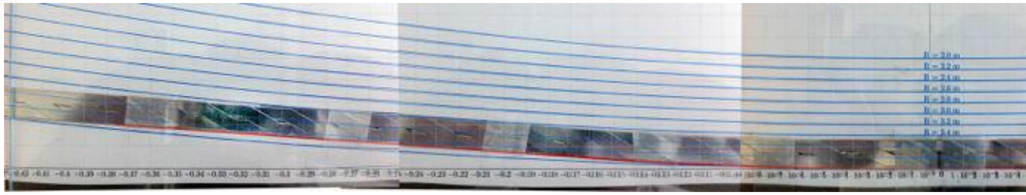

Adhesive Kapton tape , “C" wrap and 49% overlap. Problem with cable width.


Glass fibers sock over cable, impregnated with resin. Tested > 5KV insulation turn-to-turn.
Baseline insulation for Roebel cable

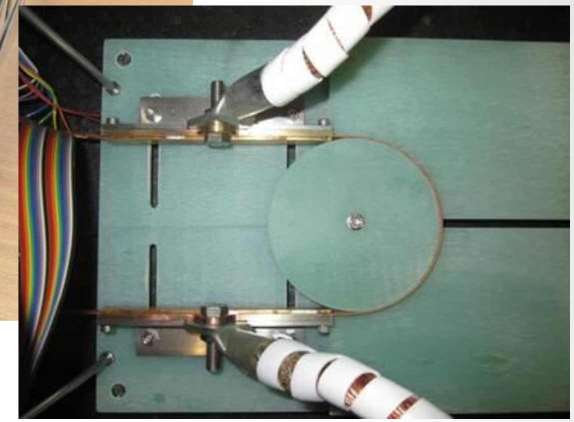
- In parallel, DTI is developing insulation techniques for REBCO tapes based on sol-gel approach.

Studies : Roebel Cable mechanical behavior

- Roebel cable characterization



Easy way and hard way bending

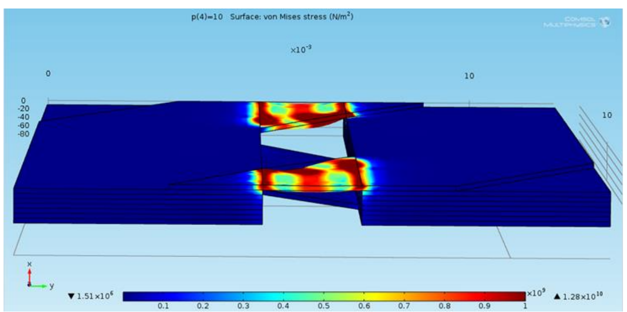


Easy way bending set-up at KIT

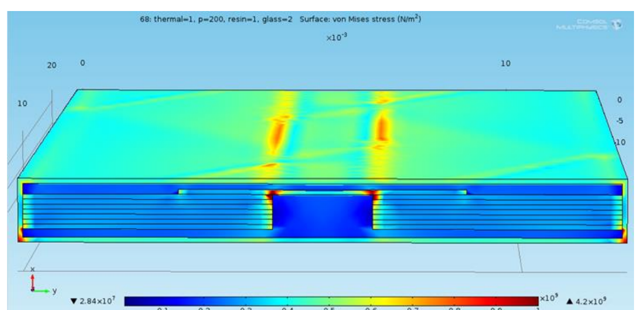
Not impregnated - Pressure on top

- Roebel cable modeling

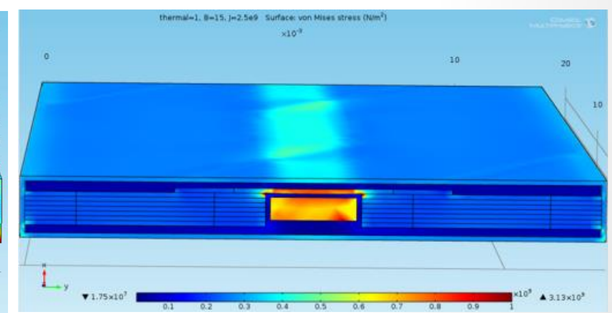
Nabil Chouika



Not impregnated - Pressure on top

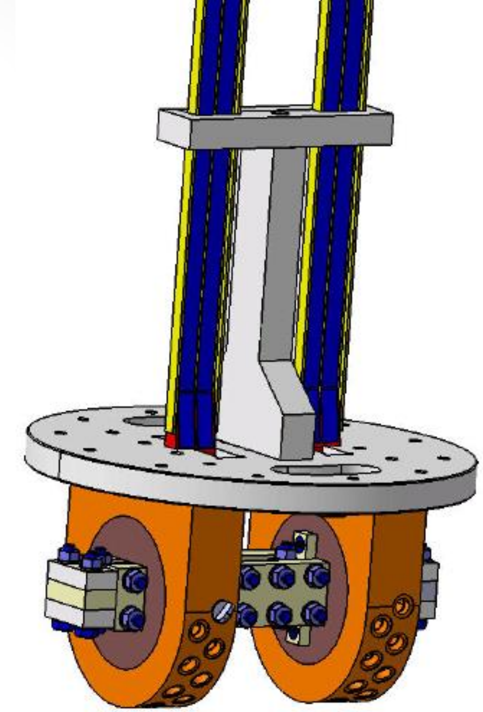


Glass sock + Impregnation
Cooled to 4K + Pressure applied on top surface

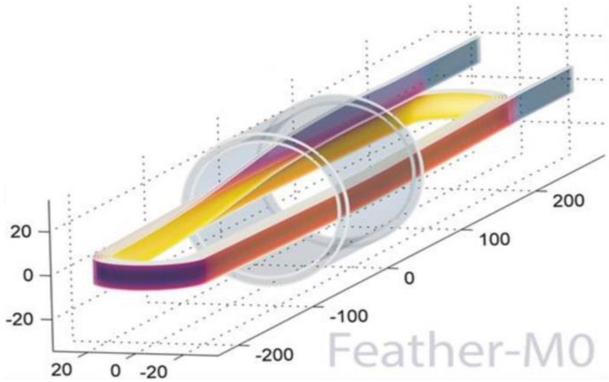


Impregnated + Copper insert
Cooled to 4K + Magnetic forces on the edges of the tapes

Studies : YBCO Cable electrical behavior

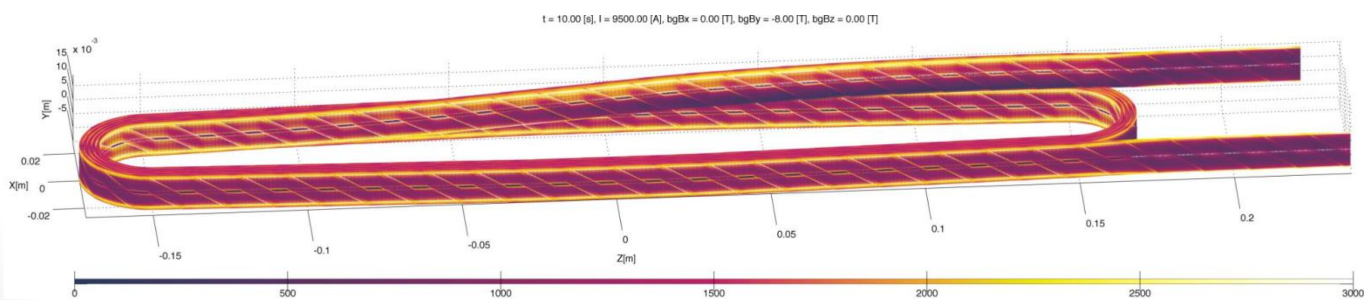


- Current distribution, magnetization measurements
  - Single layer single tape coils in LNCMI varying field angle facility
    - New instrumentation and modified coil geometry under study
  - Subscale models manufacturing and test



→ see Glyn and Clément presentations

- Current distribution modeling



→ see Jeroen presentation

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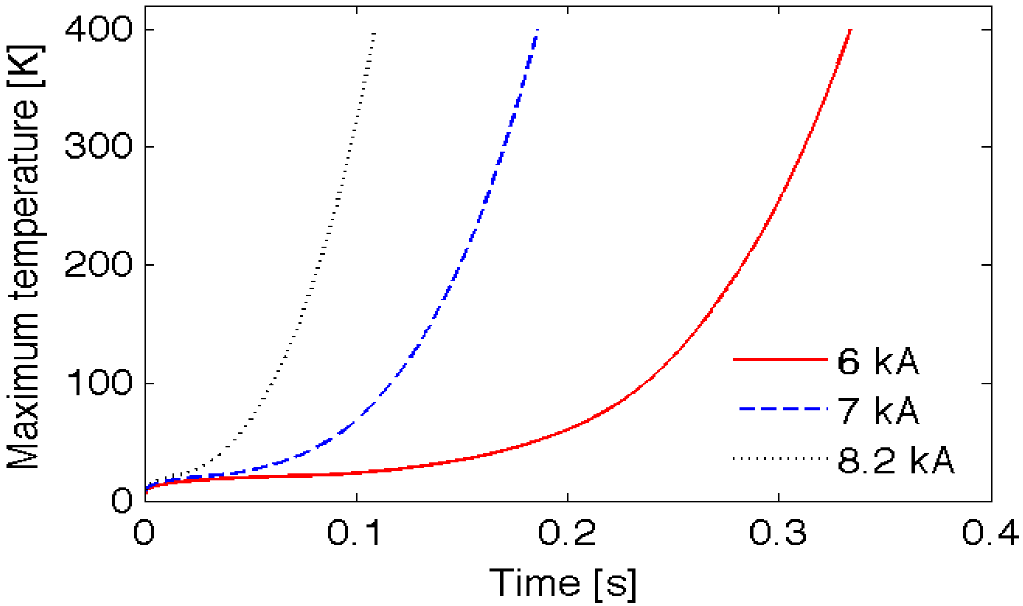
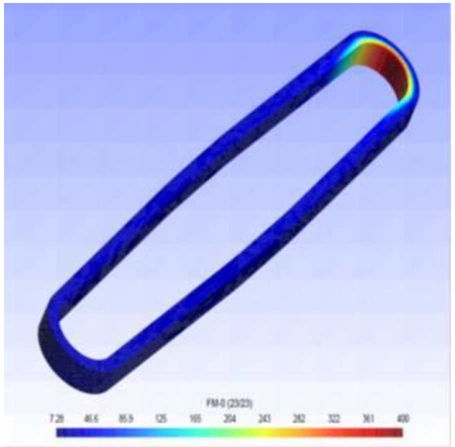
Studies : Quench protection

Antti Stenvall Tiina Salmi
Erkki Härö

- Quench protection studies started on subscale models

→ see Glyn presentation





- Quench heaters for HTS coils → see Tiina presentation tomorrow afternoon

Thanks for your attention

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